Final Report

CARE

Coordinated Accelerator Research in Europe

Integrating Activity
implemented as
Integrated Infrastructure Initiative

Contract number: *RII3-CT-2003-506395*

Project coordinator: *Roy Aleksan – Commissariat Energie Atomique*

Project website: *http://care.lal.in2p3.fr/*

Project Duration : 60 *months from 01/01/2004 to 31/12/2008*

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under the "Structuring the European Research Area" specific programme
Research Infrastructures Action

CARE Final Report

A. Activity Report

I. Introduction

The study of the sub-nuclear structure of matter, the study and the search of the elementary particles as well as understanding the origin of their mass and the fundamental forces governing their interactions require the most advanced particle accelerators. In many areas, the techniques involved for the development of these accelerators are innovative and necessitate significant progress beyond the state-of-the-art, which often leads to important breakthroughs in other fields of science.

The improvement of the existing infrastructures by upgrading their performances and/or by furthering their reliability and efficiency on the one hand and the realization of new accelerators on the other hand rely crucially on strong and steady RTD programs, the magnitude and diversity of which surpasses the intellectual, technical and financial resources of a single laboratory or institution, and thus necessitate a large international effort.

Finally, the size of these accelerators generally requires the industrialization of the developed techniques and hence ensuring an efficient technological transfer by promoting industrial partnerships is very important.

II. Fundamental CARE objectives

The main objective of the **CARE** project was to generate **a structured and integrated European area in the field of accelerator research and related R&D**.

A set of integrating activities involving the **largest European infrastructure** laboratories and their **user communities** “active in accelerator R&D”, including **industrial partners** was established with the following general objectives:

1) To optimise the use of existing infrastructures for improving the European knowledge on accelerator physics
    - By promoting a coherent and coordinated utilization and development of infrastructures and to facilitate the access to accelerators and test facilities for carrying accelerator studies
    - By understanding accelerator operation and reliability issues
2) To tackle new or state-of-the-art technologies in a more co-ordinated and collaborative approach
    - By developing a coherent and coordinated accelerator R&D program in Europe and carrying out joint R&D projects allowing one to enhance the existing (or in construction) facilities provided by the research infrastructures. These facilities could also be used as test beds for future projects either
        - by developing and testing advanced accelerator components
        - by exploring and testing new ideas and concepts. More generally, by establishing a closer interaction between a large number of scientist
3) To enhance the collaboration amongst accelerator physicists on the one hand and to develop the synergy between particle physicists and accelerator physicists on the other hand.
    - By promoting inter-disciplinary collaboration including industry

- By developing further and reinforcing the European expertise for the conception, design, development, construction and operation of new particle accelerators for High Energy Physics.

The framework of CARE has successfully integrated the subjects, the infrastructures and the expertise.

- **The subjects**
  - On-going and new studies on several types of used and planned accelerator were integrated, in line with the recommendation and priorities set forward in the ECFA report on the "future of accelerator-based physics in Europe" (ECFA/01/213):
    - *Electron linear accelerator and collider*
    - *Neutrino (muon) beams*
    - *High-energy/high-intensity proton accelerators*
- **The infrastructures**
  - *CARE has included all the relevant infrastructures allowing one to develop an overall efficient R&D program for accelerators and establish the first step toward a pan-European distributed Technological Platform to carry research on accelerator. The proposed activities were articulated around:*
    - Large Scale Facilities, including the existing or in construction state-of-the-art accelerators (CERN accelerator complex including LHC, DESY accelerator complex as well as those from LNF, RAL, PSI, GSI),
    - Large-scale accelerator test facilities (CTF at CERN, FLASH at DESY)
    - Specialized large and medium size infrastructures allowing one to develop and test specific accelerator concepts and components (LNF, RAL, PSI, CEA/Saclay, CNRS-IN2P3/Orsay).

The following table shows the existing (or in construction) accelerator facilities located within the laboratories, which participated to the CARE project. The vast majority of these infrastructures is unique in Europe and a large number of them have been or will be improved using the outcome of the CARE research activities.

Laboratory	Accelerator	Description
STFC-RAL	**ISIS**	Accelerator complex for the neutron and muon facility
CERN	**Linac2, PS, SPS, LHC**	Proton accelerator complex
	CNGS	Neutrino Beam
	CTF3	Two beams electron linear accelerator test facility
DESY	**PETRA, HERA**	Electron and proton accelerator complex
	FLASH, X-FEL	Electron superconducting linear accelerator test facility and free electron laser
FZR	**ELBE**	Electron linear accelerator for free electron laser
GSI	**UNILAC. SIS, ESR**	Heavy ion accelerator complex
INFN-LNF	**DAPHNE**	Electron-Positron collider
	SPARC	Electron linear accelerator for free electron laser
PSI	**SINQ**	Accelerator complex for the neutron and muon facility

Similarly, the next table shows the existing (or in construction) specialized test facilities relevant for the CARE project

Laboratory	Facility	Description
STFC	**"Unnamed"**	Cryogenic facility for mechanical measurement
CEA	**IPHI**	3 MeV High Intensity Proton Injector
	RF stand	704 MHz RF test stand for pulsed SC cavity testing (1 MW)

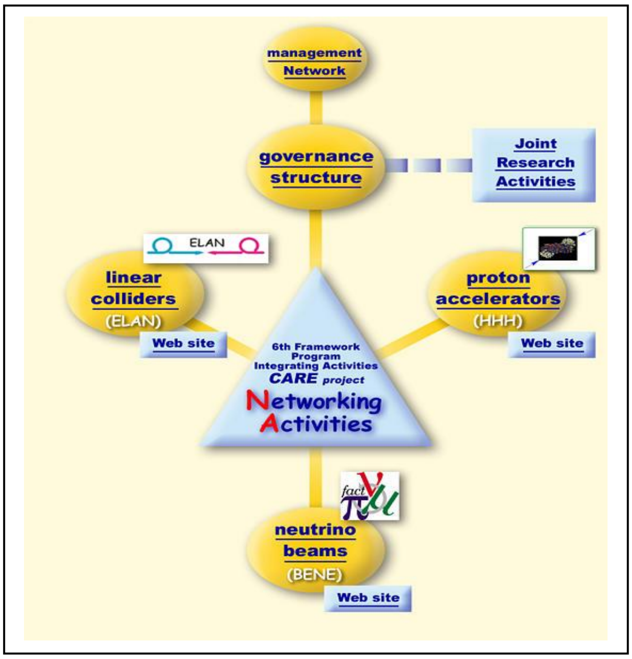
	Cryholab	Horizontal Cryogenic test stand
	W7X	Superconducting magnet test facility
	“Unnamed”	Cryogenic facilities for thermal, mechanical and electrical characterization
CERN	**Beqm chopping**	Test stand for beam chopping studies
	RF stand	352 MHz RF test stand for cavity testing (120 kW)
	FRESCA	Superconducting wire and cable test facility
CNRS-Orsay	**NEPAL** **“Unnamed”**	Test stand with photo-injector Coupler test laboratory
DESY	**CHECHIA**	Horizontal Cryogenic test stand
	“Unnamed”	Superconducting Magnet Test Facility
	PITZ	Photo-injector test facility
FZJ	**“Unnamed”**	Superconducting cavity test stand
GSI	**“Unnamed”**	Superconducting Magnet Test Facility
INFN-Ge	**“Unnamed”**	Superconducting wire test facility
INFN-Mi	**“Unnamed”**	High-Field Superconducting wire test facility

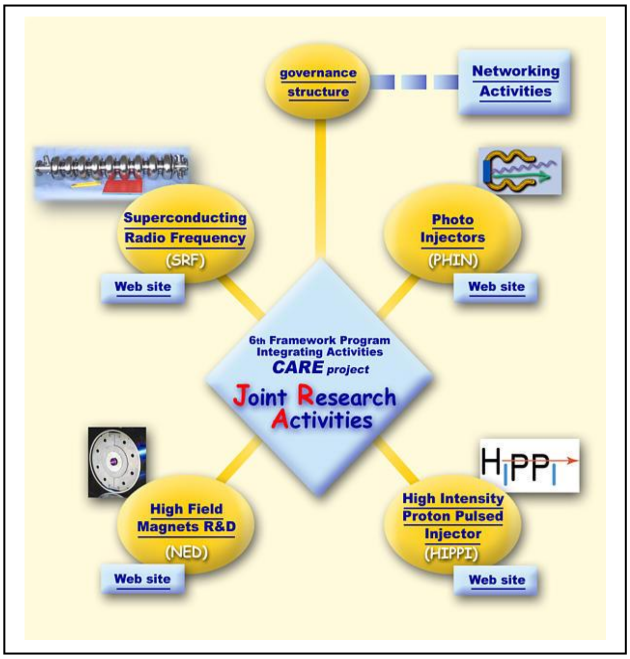
- **The expertise**
  - Most (if not all) European experts involved in the conception, design, development and construction of accelerator for particle physics (and to a large extend for nuclear physics and advanced light sources such as FEL) have participated to the CARE project.

Thus, the CARE project represented an innovative and unique opportunity in Europe as it involved almost all of the European expertise and know-how in accelerator physics and related technologies and has allowed one to address many of the issues relevant to particle accelerators. Futhermore, it has provided an integrated service to the entire European particle physics community and to some extends helped **other communities** (such as Nuclear Physics, FEL, Neutron Spallation) as well.

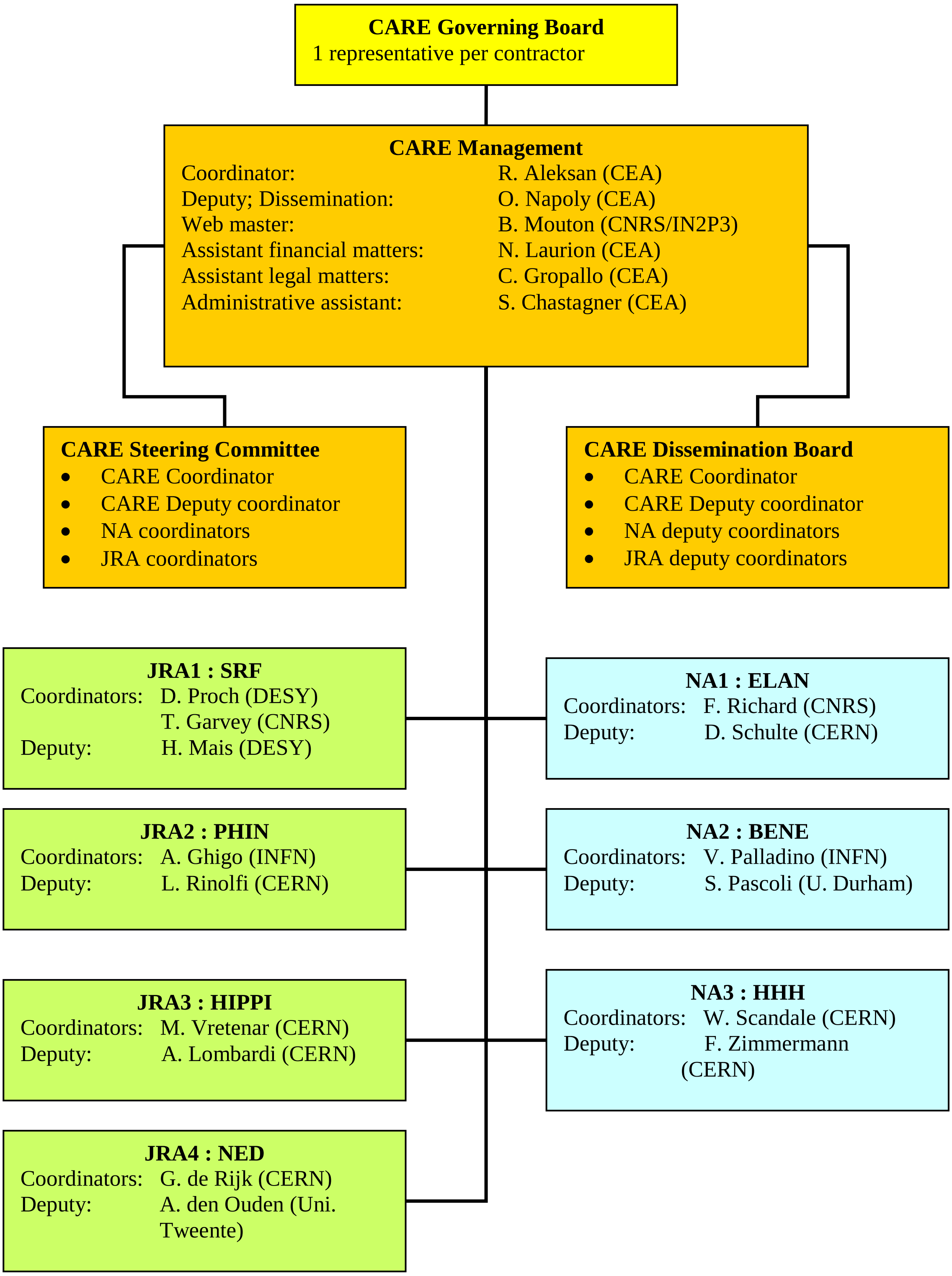
III. CARE Structure

CARE was articulated around **3 Networking Activities and 4 Joint Research Activities** including the most advanced scientific and technological developments relevant to accelerator research for Particle Physics, as can be seen from the figures below.





The overall management structure of CARE is displayed in the chart below



CARE Governing Board
1 representative per contractor

CARE Management

Coordinator:	R. Aleksan (CEA)
Deputy; Dissemination:	O. Napoly (CEA)
Web master:	B. Mouton (CNRS/IN2P3)
Assistant financial matters:	N. Laurion (CEA)
Assistant legal matters:	C. Gropallo (CEA)
Administrative assistant:	S. Chastagner (CEA)

CARE Steering Committee
- CARE Coordinator
- CARE Deputy coordinator
- NA coordinators
- JRA coordinators

CARE Dissemination Board
- CARE Coordinator
- CARE Deputy coordinator
- NA deputy coordinators
- JRA deputy coordinators

JRA1 : SRF
Coordinators: D. Proch (DESY)
T. Garvey (CNRS)
Deputy: H. Mais (DESY)

NA1 : ELAN
Coordinators: F. Richard (CNRS)
Deputy: D. Schulte (CERN)

JRA2 : PHIN
Coordinators: A. Ghigo (INFN)
Deputy: L. Rinolfi (CERN)

NA2 : BENE
Coordinators: V. Palladino (INFN)
Deputy: S. Pascoli (U. Durham)

JRA3 : HIPPI
Coordinators: M. Vretenar (CERN)
Deputy: A. Lombardi (CERN)

NA3 : HHH
Coordinators: W. Scandale (CERN)
Deputy: F. Zimmermann (CERN)

JRA4 : NED
Coordinators: G. de Rijk (CERN)
Deputy: A. den Ouden (Uni. Tweente)

The aim of the Networking Activities was to foster and strengthen the European knowledge to evaluate and develop efficient and cost effective methods to produce intense and high-energy electron, proton, muon and neutrino beams as recommended by the European Committee for Future Accelerator (ECFA). They have established

- comparative studies on the various techniques, established collaborative
- prioritised R&D programs aimed at improving the exiting infrastructures
- technical roadmaps toward their longer-term evolution and the construction of new facilities of worldwide interest.

The participants have integrated their infrastructures, establishing a European technological platform for accelerator research allowing one to develop joint R&D projects and to foster strong and effective collaborations.

The following table shows the different type of particle beams, infrastructures and projects and their relevance for the 3 Networking Activities (N1, N2, N3).

Networking Activities	Existing or in construction large scale accelerators	**Test facility or medium size facilities**	**Specialized test facilities**	**Accelerator Project**
N1: Electron Linear accelerator Network		**PHIL (LAL)** **FLASH(DESY)** **CTF(CERN)**	Photo-Injector test facilities (CNRS-Orsay,DESY) “Cryolabs” (CEA,CERN,DESY,FZJ) “Super conducting magnet test stations” (STFC,CEA,CERN,DESY,GSI,INFN-Ge,INFN-Mi)	ILC, CLIC
N2: Beams for European Neutrino Experiments (superBeam, βBeam, μ-beam)	CNGS(CERN)	ISIS(RAL) SINQ(PSI) IPHI(CEA)		Linac4,SPL, β-beams, ν-Fact
N3: High-Energy High-IntensityHadron Beams	LHC(CERN) HERA(DESY) SIS (GSI)	IPHI(CEA)		Linac4, SLHC, DLHC; FAIR

The ***four Joint Research Activities (JRA)*** aimed at developing critical or beyond the state-of-the-art components and systems allowing one to upgrade the infrastructures. They included

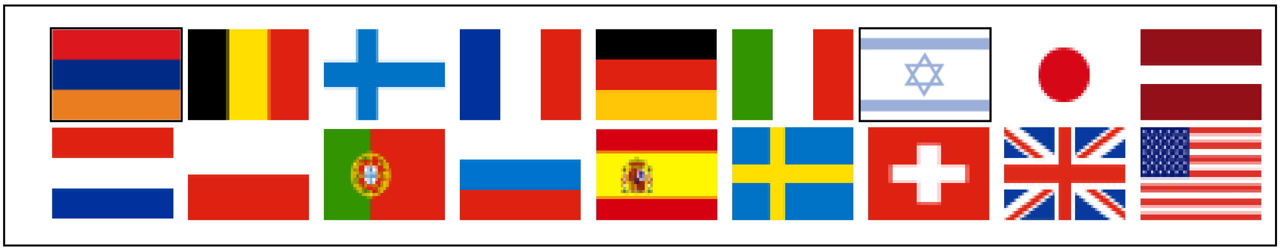
- **SRF**: The development of the superconducting cavity technology for the acceleration of electrons with gradient exceeding 35MV/m and the development of the subsequent necessary superconducting RF technology.
- **PHIN**: An R&D program for improving the technology of photo-injectors, in particular to match the severe requirements necessary for demonstrating the 2 beam acceleration concepts, new generation light sources and novel acceleration technique.
- **HIPPI**: The integrated developments of normal and superconducting structures for the acceleration of very high-intensity proton beams as well as challenging beam chopping magnets.
- **NED**: The development and mastering of the technology for reaching very high magnetic field (>15T) and high current densities (>1500A/mm^2).

The Joint Research Activities were closely connected and of extreme importance for the networking activities. The following table shows this relation and illustrates the overall integration of the CARE program.

NA JRA	***N1**: Electron Linear Accelerator Network (**ELAN**)*		***N2:** Beams for European Neutrino Experiments (**BENE**)*			***N3:** HE/HI Hadron Beams (**HEHIHB**)*
Existing accel. Future projects	*FLASH,ELBE* ILC, XFEL	*CTF,SPARC* CLIC	*CNGS* Super Beams	β–beams	*ISIS, SINQ* μ–beams	*SIS, LHC* FAIR,SLHC/DLHC
SRF	X				X	
PHIN	X	X				
HIPPI			X	X	X	X
NED	X	X			X	X

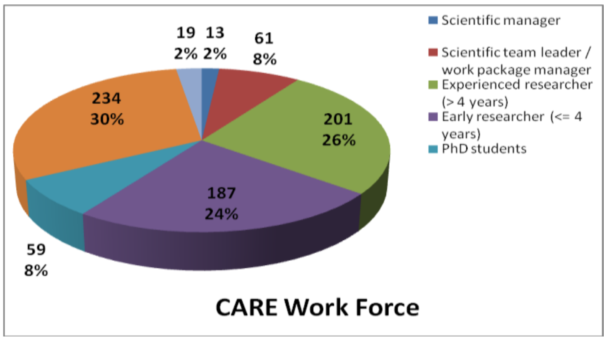
In fact the R&D projects were not only essential to the improvement of the existing infrastructures and the development of upgrade programs but have also established the foundation for new ones. Conversely the existing infrastructures were necessary to understand beam dynamics and properties, to validate ideas through dedicated machine developments and to test prototypes. The Research and Development carried in the JRAs have been presented and discussed in the networking activities. The achievements in the JRAs have influenced the studies in the Networking Activities, leading to new ideas, which in turn generated new research directions.

IV. CARE Collaboration

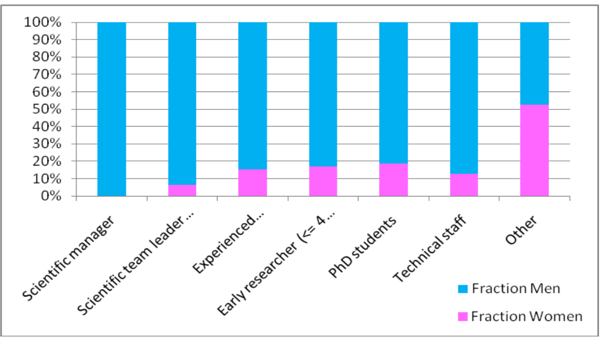


Twenty two contracting participants and a large number (62) of associated institutes (including 12 industrial partners and SMEs) participated in this unprecedented integrating effort, including accelerator physicists involved in Nuclear Physics accelerators, Free Electron Lasers and Neutron Spallation sources, see http://care.lal.in2p3.fr/Participants (the complete list is given in Annex 1).

In total, 774 persons have contributed to the CARE project. About 15% of the personnel were composed of women. The following diagrams show the distribution of the personnel according to various categories (scientific manager, scientific team leaders, experienced researchers, early researchers, PhD students and others) and their corresponding gender repartition.



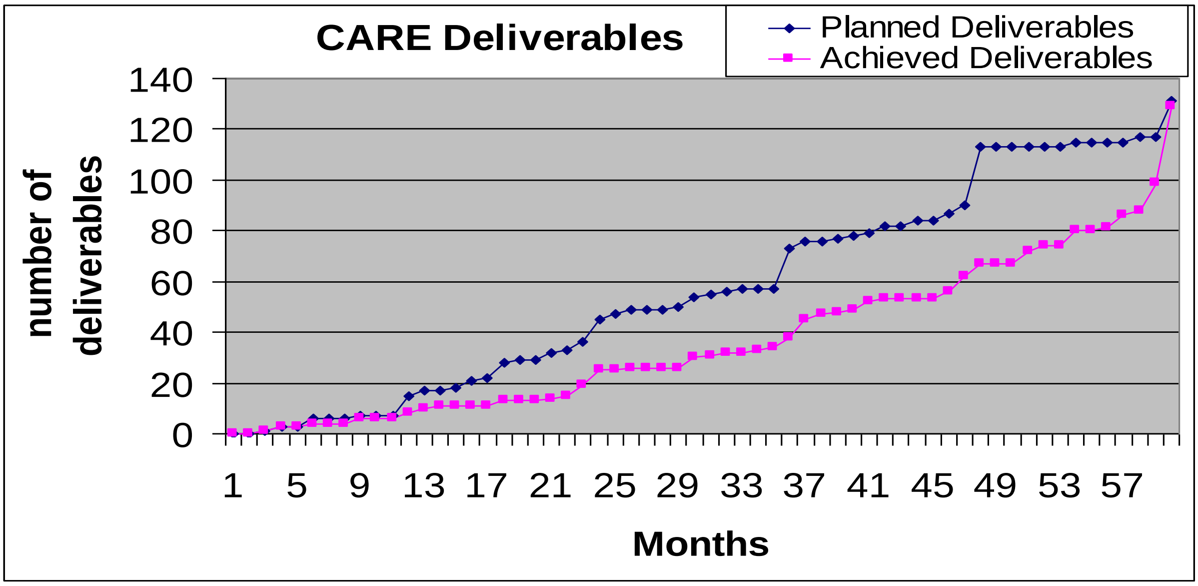
CARE Work Force



Finally, in order to implement a strong and efficient dissemination plan, a Web-based platform has been developed (http://care.lal.in2p3.fr), and was linked to the site of the European Steering Group for Accelerator R&D (http://esgard.lal.in2p3.fr).

V. Deliverables

CARE had an ambitious program including 131 deliverables as can be seen on the table below.



The complete list of the deliverables is shown in Annex 2. The JRAs had 99 deliverables, which have been all achieved within the duration of CARE, while the NAs had 32 deliverables, which have been all (but two) achieved. One of the missing deliverables was the submission of a proposal to the FP6 call on design study in 2004. This call has been cancelled by the EC. Fortunately, the planned activities have been integrated to a later proposal, which was approved by the EC. The second missing deliverable was the realization of a database for laser-plasma acceleration. However this activity has been integrated to a successful proposal initiated by the CARE NA-ELAN as a NEST project.

VI. Dissemination

The dissemination within CARE has been carried widely through several means: Web sites, CARE publications, presentations at conferences and organisations of workshops, conferences and general annual meetings. General meetings, common workshops and Dissemination Board activities have ensured an effective exchange of information while specialized joint workshops have been organized when several aspects of networking and joint research activities were common (ex. beams diagnostics and instrumentation, high field magnets needs for accelerators, etc...)

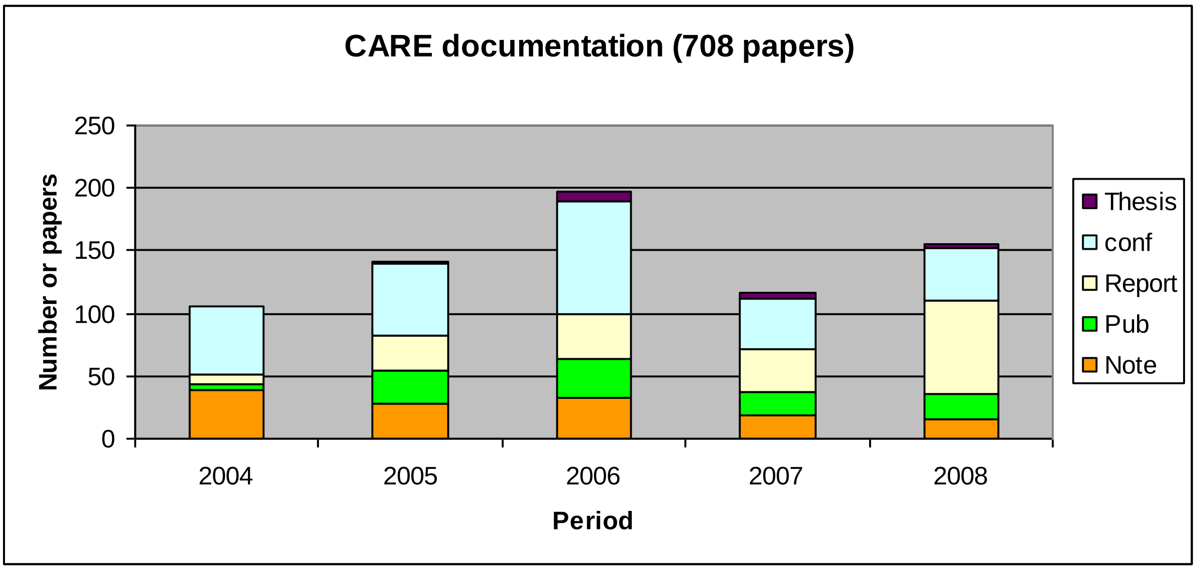
- ☐ The main Website of CARE

CARE has set up a main web site from which participants could access all relevant information as well as to secondary specialized web sites. The URL of the CARE site is: http://care.lal.in2p3.fr/

- CARE Documentations

A very large number (717) of documents (publications, reports, conferences contributions, notes and thesis) have been carries out by CARE. It is important to note that 18 theses were defended using the CARE work. The table and the figure below summarize this effort.

	All	2004	2005	2006	2007	2008
Note	133	39	28	32	19	15
Pub	102	4	26	32	19	21
Report	179	8	28	35	34	74
Conf. Contr.	285	54	58	91	40	42
Theses	18	0	2	7	5	4
Total	717	105	142	197	117	156



All these documents are accessible from the CARE publication database http://irfu.cea.fr/Documentation/Care/index.php.

- CARE Annual meetings and other events

Date	Location	Number of registered participants	Web site
Nov. 2–5, 2004	DESY (D)	191	http://care04.desy.de/
Nov. 23–25, 2005	CERN (CH)	164	http://indico.cern.ch/conferenceDisplay.py?confId=a059
Nov. 15–17, 2006	Frascati (I)	123	http://www.lnf.infn.it/conference/care06/index.htm
Oct. 29–31 2007	CERN (CH)	108	http://indico.cern.ch/conferenceDisplay.py?confId=15901
Dec. 2-5 2008	CERN (CH)	113	http://care08.web.cern.ch/care08/redir.do

In addition, each NA and JRA has participated to the organization of international conferences and have organized many internal meeting and workshops -see the NA/JRA sections for details.

VII. General CARE outcomes

The detailed outcomes of the CARE project are described in the NA/JRA sections. In general they have

- Considerably strengthened the European expertise and know-how in the field of accelerator R&D, far beyond the sole capacity of the largest research centres (such as CERN and DESY) to carry forefront accelerator R&D. **This can be considered as a major EU added value**.
- Helped many European Institutes and Universities for **developing their competences** on activities that are at (or beyond) the state-of-the-art technology in contact with the best experts in Europe. This collaborative effort can be viewed as a first step toward the long-term sustainability of accelerator R&D in Europe.
- Furthered the contact and the involvement of industry in R&D activities (12 companies have participated actively to the CARE activities).
- Established the basic development work allowing **the future strategic decisions** to be made on sound technological basis. CARE has provided several necessary technological inputs to ECFA and CERN Council.
- Identified the common issues relevant to other fields, contacted these communities and proposed common activities.

As already discussed, the CARE program has directly allowed one to raise the level of performance of the infrastructures, thanks to

- Networking Activities, that have compared and determined ways to upgrade the infrastructures both on the medium-term and on the long-term,
- Joint Research Activities, that have designed, constructed and tested prototypes for accelerator components, which are directly or indirectly used to improve the infrastructures.

In summary, the basic R&D for improving very significantly the performance of many European infrastructures for particle physics and for accelerator research in general has been successfully carried out, as acknowledged in the annex 3 by the letters of several laboratory directors. Some of these infrastructures have already benefited from the achievements of CARE and several others will benefit in the medium or long term. More details can be found below in the reports of each Networking and Joint Research Activity.

VIII. Long term sustainability and structuring effect

As shown above, one of the main objectives of the CARE project was to structure the European area on accelerator research. The prospects to achieve such an ambitious goal are rather brighter after CARE. This optimism is based on the fact that the entire particle physics community has adhered to and supported this initiative (even at the worldwide level with non-EU participation and ICFA support). Indeed,

1. All parties had a strong interest, motivation and commitment to CARE as it allowed them to both strengthen their individual and collective expertise on the long-term.
2. The structure set in place has permitted both extensive communication and wide dissemination of knowledge to take place, which will continue after the completion of the CARE program, as demonstrated for example by the FP7-IA EuCARD initiative.

3. A European Committee (ESGARD), which includes representatives from all major high-energy infrastructure laboratories, has been set up to oversee and monitor the European accelerator R&D activities relevant for particle physics. The foundation of this committee can be considered already as a first step toward ensuring the long-term sustainability of the collaborative effort put in place for CARE. It can be partly attributed to FP6. Discussions are underway to expand it to other fields such as Nuclear Physics, Free Electron Laser. This committee has already launched other initiatives such as Integrating Activities or Design Studies over the past years.
4. Most Joint Research Activities involves trans-field collaboration as well as industrial partnerships. They are the seed for extending or generating future collaborations.
5. CARE has offered an ideal framework for establishing specific collaborative arrangements. An unexpected example is a joint venture between industrial partners on the development of high performance superconductor cable. It is reasonable to expect that more such initiatives will be triggered, as people will collaborate more closely.
6. Several proposals for common European test platform have developed from the networking activities (for example: a Target Test Area or Superconducting Test facilities)
7. Most of the Joint Research Activities have contributed to lead to collaborative agreements to upgrade existing infrastructure (FLASH, CTF, CERN proton injector are good examples).They may even in some cases be the seed for the construction of new infrastructures.

Overall the CARE project has strongly contributed to establish a unique and durable interaction

- Amongst European accelerator physicist including connections with non-European partners
- Between accelerator and particle physicists
- Between different research field
- Between researchers and industrial partners

In conclusion, CARE has ensure the emergence of new ideas, new projects and new collaborations in a coordinated way and hence has provided all the ingredients for the long-term sustainability of the collaborative effort in the field of accelerator research, which it has initiated.

IX. Description of the Networking Activities

NA1: Coordination of studies and technical R&D for electron linear accelerators and colliders

Acronym: ELAN, **Coordinator**: *F. Richard (CNRS-IN2P3-Orsay)*

Deputy: *D. Schulte (CERN)*

Participants to the N2 Activities:

Country	Number of institutes	Number of persons
Finland	**1**	**3**
France	**8**	**70**
Germany	**12**	**130**
Italy	**5**	**45**
Netherlands	**2**	**7**
Poland	**3**	**20**
Portugal	**1**	**3**
Spain	**3**	**9**
Sweden	**1**	**2**
Switzerland	**2**	**3**
United Kingdom	**15**	**60**
CERN	**1**	**30**

Industrial Involvement:

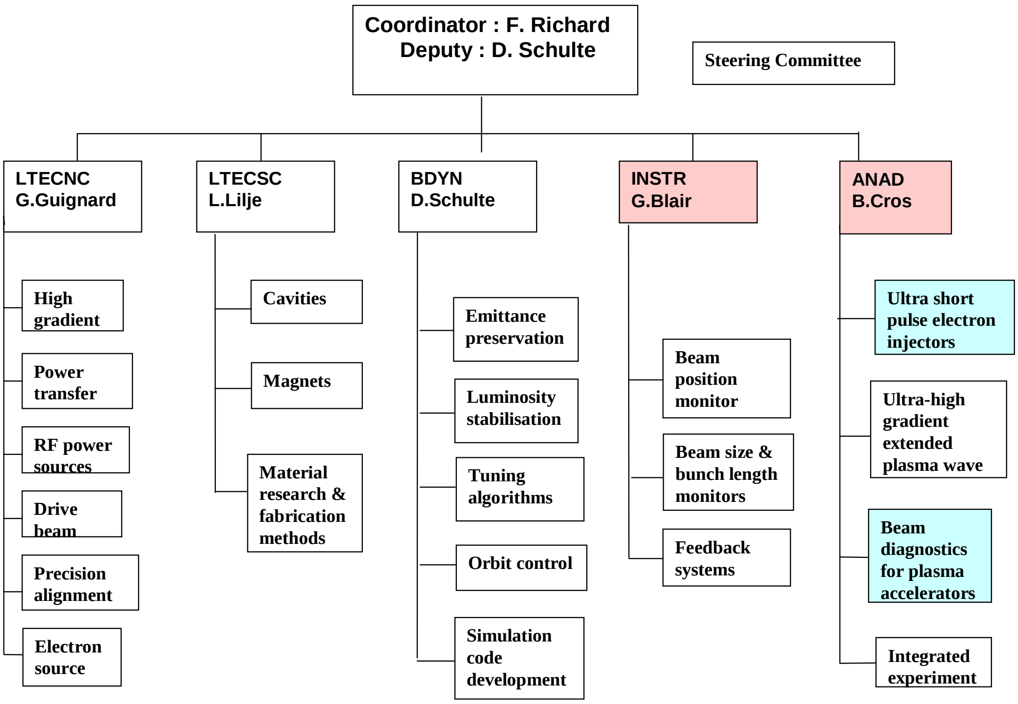
Country	Number of Company
Germany	**4**
Italy	**1**
UK	**4**

Main Objectives: Coordination of R&D on electron accelerators at the European level. Evaluating the various technologies for improving the present infrastructures and defining a roadmap for future electron accelerators and colliders, including new techniques of acceleration.

Introduction

ELAN organisation

ELAN was organised in 5 groups dealing with the various topics related to present and future electron linacs:



Tools

ELAN has the website:
http://esgard.lal.in2p3.fr/Project/Activities/Current/Networking/N2/ELAN/
with:

- Links to the activities and informations of the 5 WG
- List of workshops supported by ELAN
- List of ELAN Documents (these documents are stored under the responsibility of the Coordinator). Some of them, after agreement with the dissemination CARE coordinator, were published as CARE-ELAN Notes.

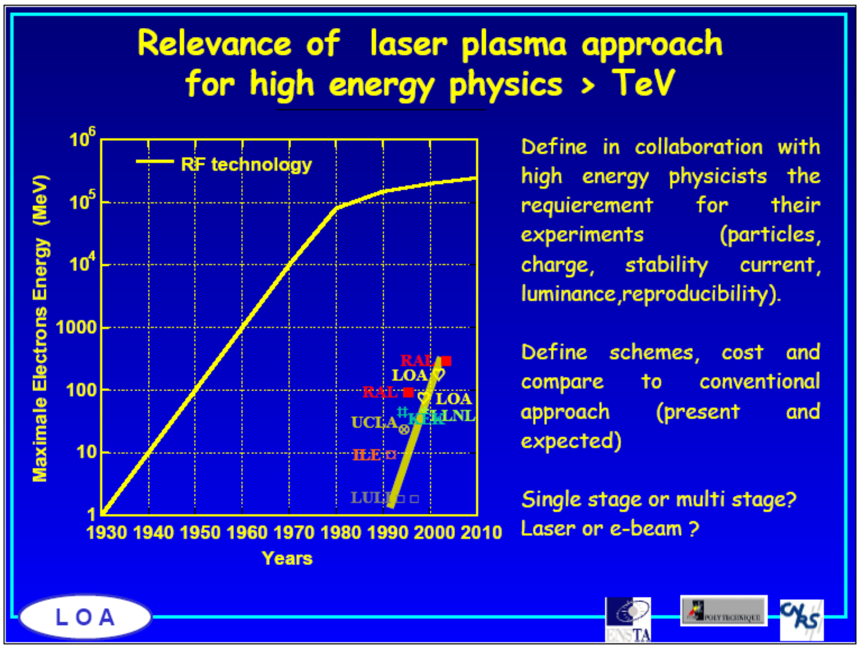
Main topics in ELAN

ELAN activities are connected to the two major efforts towards a worldwide Linear Collider

- ILC a project for a supraconducting Linear Collider LC with 0.5-1 TeV centre of mass energy. A costed project was delivered in 2007. This project is strongly connected to the ongoing construction of an XFEL in DESY.
- CLIC which has developed an R&D for a normal conducting high-gradient LC which aims at 3 TeV with a 1st step at 0.5 TeV

With the rapid development of the collider project organisations and the advent of the design study EUROTEV, ELAN became more and more embedded in these organisations. In particular, in the ILC organisation, LTECSC and INSTR where progressively integrated within the GDE.

ELAN was also set to design a strategy for more futuristic projects, in particular for plasma acceleration. This technique allows one to reach up to GeV/cm accelerating gradients given by excited plasma. This plasma is either excited by an auxiliary electron beam or by a very powerful laser. Both techniques have been tried with remarkable results recently achieved. The role of ELAN has been to help in connecting the accelerator community to this effort and to develop a NEST initiative called EUROLEAP which was approved in 2006. The following slide summarized the strategy of this activity.



Relevance of laser plasma approach
for high energy physics > TeV

Define in collaboration with high energy physicists the requierement for their experiments (particles, charge, stability current, luminance,reproducibility).

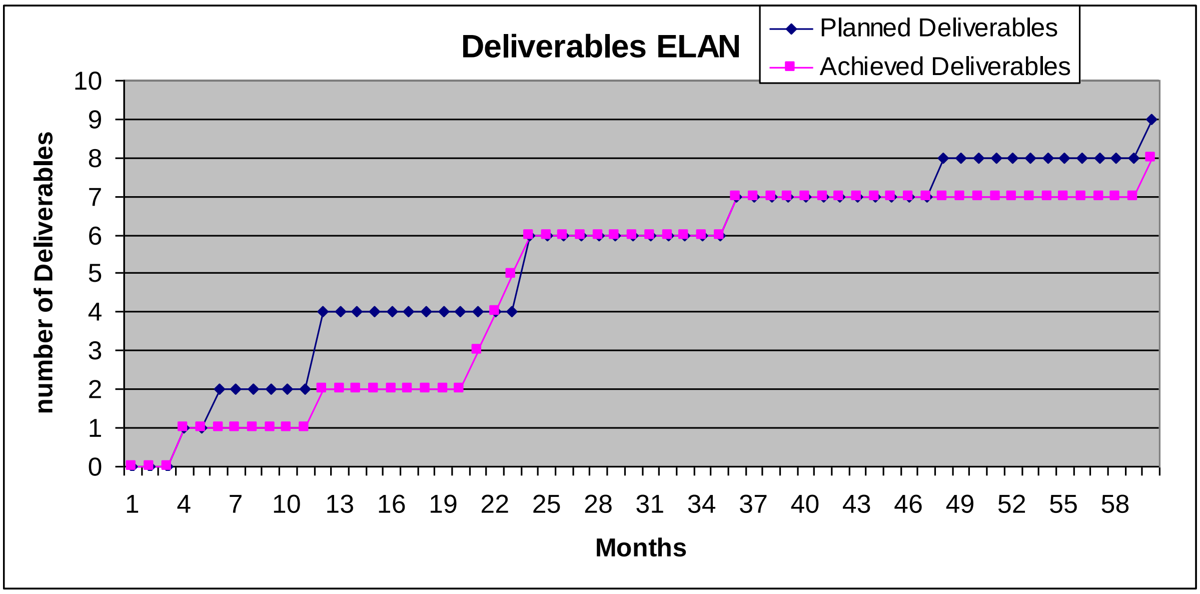
Define schemes, cost and compare to conventional approach (present and expected)

Single stage or multi stage?
Laser or e-beam ?

Highlights of ELAN

☐ Deliverables

Eight ELAN deliverables were planned within the 5 years of CARE as shown in the plot and the table below.



ELAN web site	Web site	All WPs	CNRS-Orsay
Beam Dynamics code repository site functional	Data base	WP3	CERN
Instrumentation web site	Web site	WP4	STFC, UMA
Instrumentation data base	Data base	WP4	STFC, UMA
Work plan and documentation data base	Data base	WP1	CERN
Data base on SRF documents	Data base	WP2	DESY
Data base on diagnostics performance	Data base	WP4	STFC, UMA
Data base on laser plasma acceleration	Data base	WP5	CRNS-LPGP
Final report of the ELAN network	Report	All WPs	CNRS-Orsay

These goals were fulfilled with the exception of the Database on laser plasma acceleration. Instead, thanks to the ANAD network, the community developed the ambitious R&D proposal EUROLEAP, which was approved as a NEST project by the EC. It was thus decided to redirect the effort toward this project.

☐ Dissemination

In total ELAN generated 104 documents. They correspond to presentations during workshops supported by ELAN, to studies and strategic aspects related to a future linear collider. The ELAN documents referenced in the CARE database include 10 CARE Reports, 4 CARE-Conference papers, 60 CARE Notes, as shown in the table below.

	2004	**2005**	**2006**	**2007**	**2008**	**sum**
CARE Notes	26	12	11	6	5	**60**
CARE Reports	1	3	2	1	3	**10**
CARE Conferences	0	2	2			**4**
Total	**27**	**17**	**15**	**7**	**8**	**74**

In terms of support to Workshops and internal publications:
(see http://esgard.lal.in2p3.fr/Project/Activities/Current/Networking/N2/ELAN/)

Year	2004	2005	2006	2007	2008
Documents	27	20	17	26	12
Workshops	2	16	12	11	10

A series of ELAN Meetings (see table below) was organized the 3 first years to foster the community around priority issues.

Date	**Title/subject**	**Location**	**Number of participants**
4-6 May 2004	1st ELAN workshop	Frascati (I)	79
20-24 June 2005	ILC European Regional Meeting with an ELAN session	Royal Holloway, (UK)	100
May 15 2006	ELAN workshop (followed by EUROLEAP and EUROTEV)	Orsay LAL (F)	85

ELAN has supported the International Accelerator School for Linear Colliders (70 students in 2008 see http://www.linearcollider.org/cms/?pid=1000490) which has allowed some financial support for some professors.

On top of the ELAN web site, several data bases were organized and maintained by ELAN conveners (see the table of deliverables in the ELAN final report).
ELAN has fostered CLIC-ILC synergies including detectors by supporting common workshops.

☐ Impact on European Research Landscape

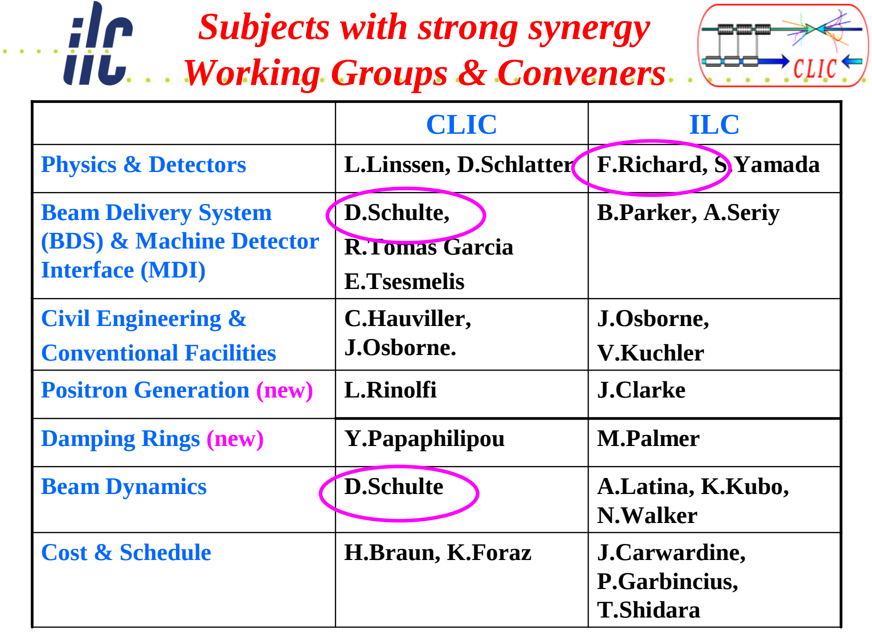
As will become clear in the following examples the role of ELAN has been to improve **communication** between the various actors working on R&D for colliders. This was naturally fostered by the ELAN management present in the activities around CLIC and ILC and for laser plasma projects. This communication was, in particular, insured by supporting some key workshops. What was achieved:

- Improved communication on R&D efforts was e.g. achieved on positron sources where different options were discussed both for CLIC and ILC (see for instance http://home.hiroshima-u.ac.jp/posipol/)
- Improved communication between CLIC and ILC experts on items common to both projects (site studies, costing, damping rings, emittance preservation, beam delivery systems, detectors). This resulted very recently in an MoU between ILC and CLIC involving 7 working groups (Chicago meeting http://www.linearcollider.org/lcws08/)
- Improved communication with the laser-plasma community which has resulted in the **International Workshp on High Energy Electron Acceleration Using Plasmas 2005** (http://polywww.in2p3.fr/actualites/congres/heeaup2005/)
- ELAN conveners were actively involved in the preparation of FP7 contracts, specifically EUCARD, the successor of CARE and ILC-Higrade which supports the European Preparatory Phase for ILC (which is acknowledged as one of the ~30 projects of the European Roadmap defined within the forum ESFRI).Through our connection to ESGARD it was possible to adjust to the reactions of our community to the severe limitation of the resources. We also encouraged a continued connection to the laser-plasma effort. Finally we actively participated to a common meeting at CERN with a large community to insure, again, good communication between the partners. The table below summarizes the various ELAN connections.

ELAN CONNEXIONS

ELAN WP	LINAC Test Beams TTF CTF	CARE JRA SRF PHIN	WW Collider ILC CLIC	Laser/Plasma Facilities ALPHA-X LOA….
NC	X	X	X	X
SC	X	X	X	
BDYN	X	X	X	X
INSTR	X	X	X	X
ANAD		X		X

This good communication between CLIC and ILC allows to prepare for a major step: decision on a future worldwide LC. As pointed out by the new CERN DG the final decision will be taken given the LHC results but we need to prepare, on comparable grounds (cost, schedule etc…), tangible elements for this decision. The table below summarizes the CLIC-ILC agreements.



Subjects with strong synergy
Working Groups & Conveners

	CLIC	ILC
Physics & Detectors	L.Linssen, D.Schlatter	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)	D.Schulte, R.Tomas Garcia E.Tsesmelis	B.Parker, A.Seriy
Civil Engineering & Conventional Facilities	C.Hauviller, J.Osborne.	J.Osborne, V.Kuchler
Positron Generation (new)	L.Rinolfi	J.Clarke
Damping Rings (new)	Y.Papaphilipou	M.Palmer
Beam Dynamics	D.Schulte	A.Latina, K.Kubo, N.Walker
Cost & Schedule	H.Braun, K.Foraz	J.Carwardine, P.Garbincius, T.Shidara

The table below summarizes selected achievements of ELAN

Selected Achievements	**Impacted Projects**	**Main improvement**	**Future impact**
R&D on Positrons	ILC CLIC	Comparison of the 3 techniques proposed	Optimal choice
ILC-CLIC Collaboration	ILC CLIC	Combined effort into 7 common working groups	Final decision on an LC after LHC results
Connection to plasma acceleration	EUROLEAP	Connection of the accelerator community to plasma techniques	Beyond present collider projects

Conclusion

The role of ELAN has been to improve **communication** between the various actors working on R&D for colliders. This was naturally fostered by the ELAN management present in the activities around CLIC and ILC and on laser plasma projects. This communication was, in particular, insured by supporting some key workshops. What was achieved:

- Improved communication on R&D efforts was e.g. achieved on positron sources where different options were discussed both for CLIC and ILC
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NA2: Beams for European Neutrino Experiments

Acronym: BENE **Coordinator**: *V. Palladino (INFN-Na)*

Deputy: *S. Pascoli (Durham University)*

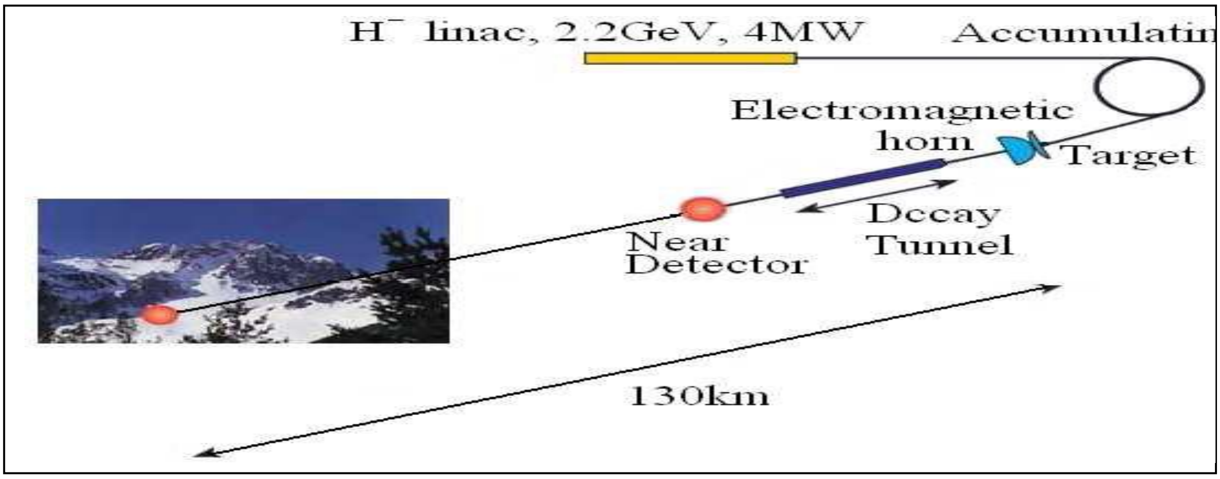
Participants to the N3 Activities:

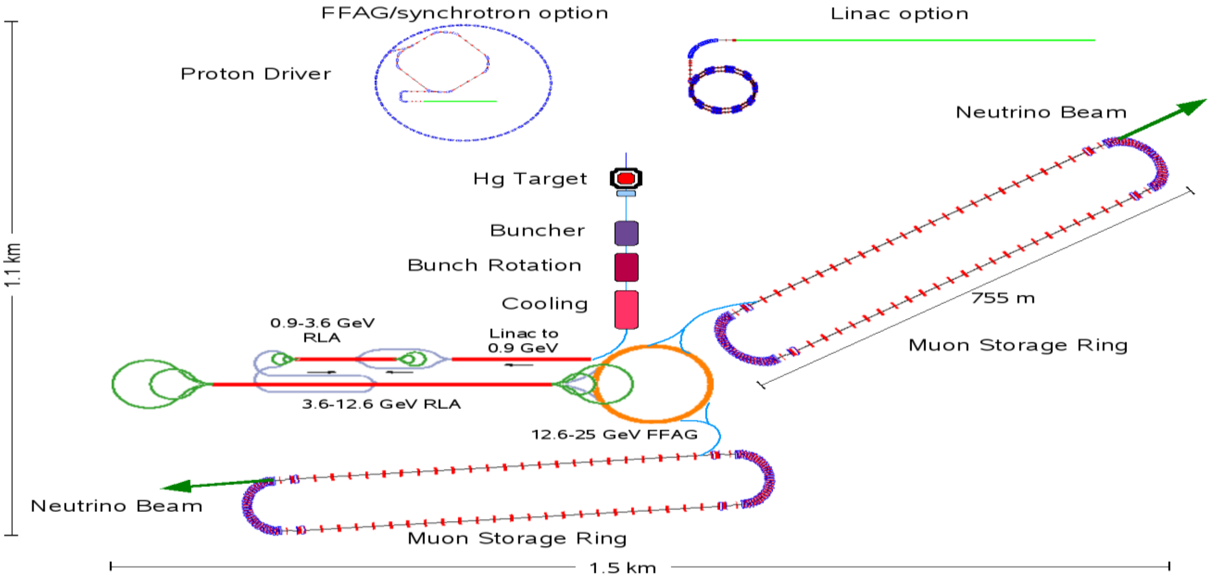
Country	Number of institutes	Number of persons
Belgium	**1**	**3**
CERN	**1**	**22**
France	**5**	**31**
Italy	**12**	**38**
Germany	**3**	**26**
Latvia	**1**	**3**
Netherlands	**1**	**1**
Spain	**3**	**18**
Sweden	**1**	**1**
Switzerland	**5**	**14**
United Kingdom	**14**	**47**
USA, Japan	**3 + 1**	**-**

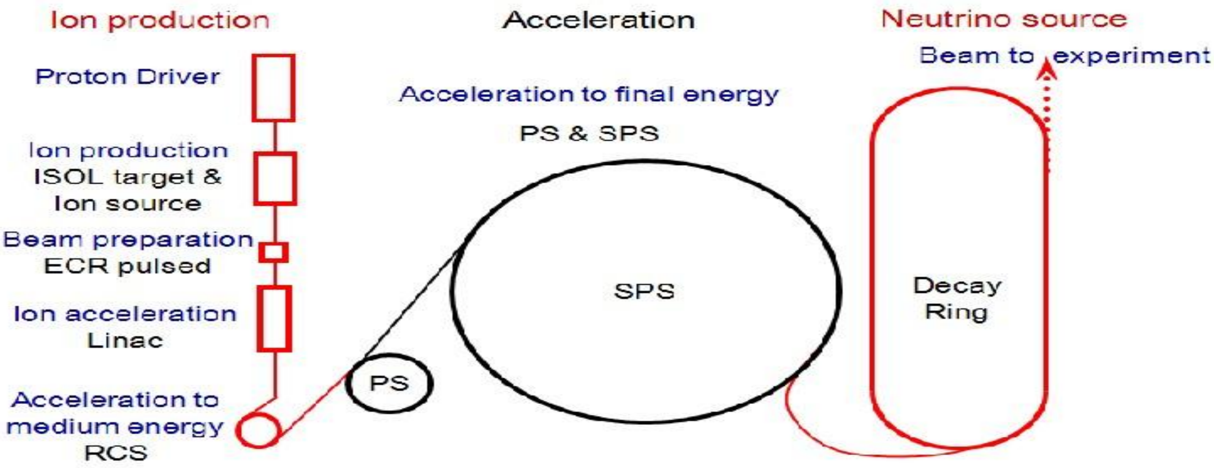
Main Objectives: The aim of this NA is to coordinate and integrate the activities of the accelerator and particle physics communities working together, in a worldwide context, towards achieving superior neutrino (ν) beam facilities for Europe. The final objectives are: 1) to establish a road map for upgrade of our present facility and the design and construction of new ones 2) to assemble a community capable of sustaining the technical realisation and scientific exploitation of these facilities and 3) to foster a sequence of carefully prioritized and coordinated initiatives capable to establish, propose and execute the R&D efforts necessary to achieve these goals.

Illustration of the Main Realisations of BENE

Baseline configurations of the three options of future neutrino facilities (CERN to Frejus Superbeam, Neutrino Factory, Betabeam) emerged during the lifetime of BENE and now object of the FP7 EUROnu Design Study.







Introduction and Executive Summary

The CARE-**BENE** network[1] has **kept alive** awareness of **the compelling physics case** of a Next accelerator Neutrino Facility (NNF), **the merits of a common European strategy** in this sector of particle physics, **the assets rooted in the 50 years of European know how** in neutrino (ν) beams and detectors. In more detail, it

- **promoted** a large number of international **R&D** and/or feasibility demonstration projects (MUSCAT, HARP, HIPPI, MICE, MERIT, EMMA, HPSPL and more) for multi megawatt proton drivers and targets and for capture, manipulation, acceleration and storage of ν parents.
- **prompted** a first decisive **endorsement** of its approach **by the CERN SPSC in** September **2004**, that first envisaged the notion a future "neutrino construction window" for Europe
- **reinforced international** collaborations and synergies with R&D and design work world wide, organized several of the key international yearly **NuFact and NNN workshops**
- **secured recognition,** for a next neutrino facility, **of the status of emerging facility of Eu interest** in the CERN Council Strategy Document of **Summer 2006**
- **promoted** the few preliminary Design Studies, the Betabeam WP in Eurisol DS and the ISS (Int. Scoping Study of Superbeam & Neutrino Factory), where European and International collaborations **assessed** available **R&D** results **and produced preliminary conceptual design baselines as well as comparative analysis of physics reach** for three most promising options: Superbeam, Betabeam, Neutrino Factory
- **managed the approval of** a complete Design Study **(EUROν)** of the three options and a new network (**EuCARD/NEu2012**). These two **FP7** initiatives will **continue** the path **towards** the final proposal of the optimal neutrino program, recommended by CERN Council for **2012 or so**.

In FP7 we will draw the road map to approval and construction. Our FP6 **road map was to be** instead **one of** steps in **R&D, baseline design work and peer recognition**. **Pan-European collaboration emerged much stronger**, composing sometimes different national interests and preserving a common intent. **Dissemination** effort **was given the necessary attention** throughout the 5-year programme, by means of publications, presentations and web site.

Highlights of BENE

☐ Deliverables

All deliverables, with the exception of a proposal to be submitted to a cancelled FP6 call, (organization and proceedings of workshops, reports of different size and scopes and last but most relevant, proposals to carry out R&D projects and design studies, both towards and independently of EC FP7 calls) have been delivered. Primary deliverables were, in addition to the BENE Web Site,

- *the Workshop PHYSICS WITH A MULTI-MW PROTON SOURCE*, CERN, Geneva, May 25-27 2004 and its Proceedings, that prompted a first positive response of the SPSC in Villars

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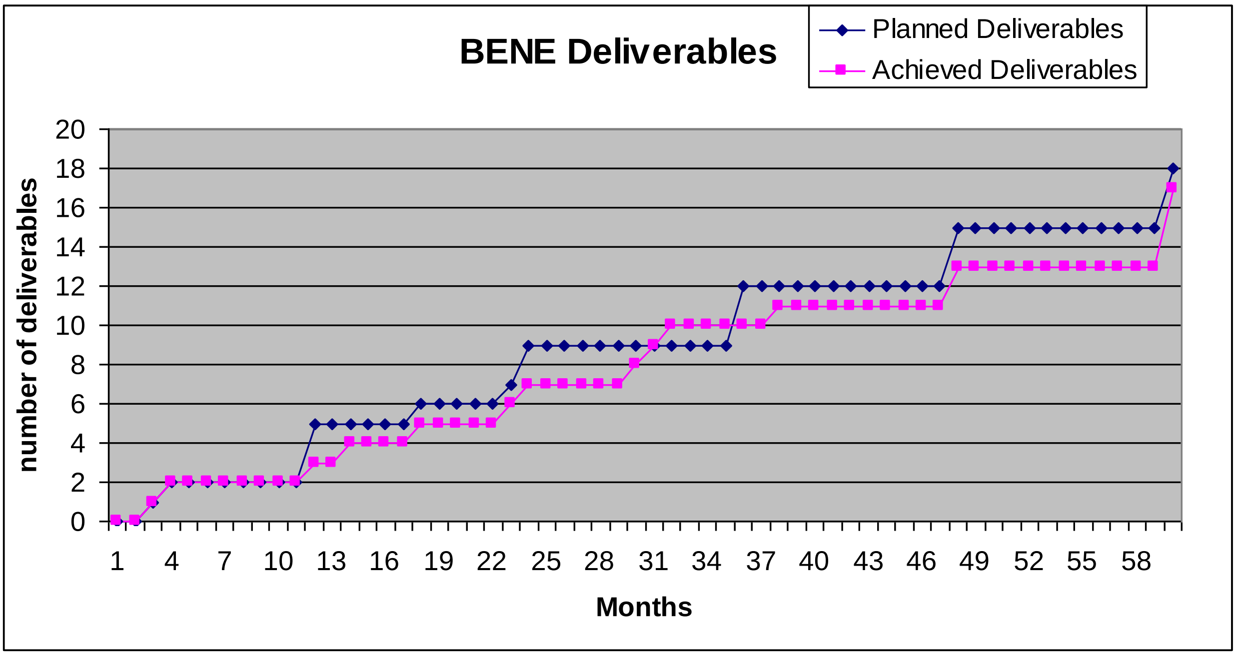
[1] approved "to integrate and coordinate the activities of the accelerator and particle physics community working together, in a worldwide context, towards achieving superior neutrino beam facilities for Europe, with the objectives to establish a first road map, to assemble a community capable of sustaining it, and to establish and propose the necessary R&D effort".

- *the comprehensive BENE Midterm scientific report*, 105 pages CERN Yellow Report number that was our successful input to the CERN Council Strategy process early in 2006
- *the two NuFact International Workshops* on Neutrino Factories, Super beams and Beta beams, NuFact05 in Frascati and NuFact08 in Valencia)
- *the two successful FP7 proposals for EUROnu and* the neutrino related aspects of *EuCARD*
- *this last BENE Final Report*



☐ Dissemination and Outreach

The Network relied on three major events per year, NNN, NuFact and the yearly BENE workshops during the days of the yearly CARE meeting

Date	Title/subject	Location	Number of participants
3 November 2004	BENE2004 Workshop	Hamburg (D)	60
23 November 2005	BENE2005 Workshop	CERN (CH)	40
17 November 2006	BENE2006 meeting	Frascati (I)	40
31 October 2007	BENE2007 meeting	CERN (CH)	40
2-3 December 2008	BENE2008 meeting	CERN (CH)	30

More topical workshops were organized in the first two years of BENE, replaced by strong support of ISS meetings later. Dissemination reached the other main yearly international ν events, whenever possible.

BENE generated a significant number of documents reflecting presentations or publications delivered within and outside the previously mentioned workshops, plus proceedings of the main workshops organized and the comprehensive BENE Interim Scientific Report. A complete list of documents, summarized in the table below, is appended to this report.

	2004	2005	2006	2007	2008	Sum
Notes	5	0	0			**5**
Publications	0	0	3	5	9	**17**
reports	0	4	5	2	3	**14**
Conf. contributions	1	0	0	3		**4**
Total	**6**	**4**	**8**	**10**	**12**	**40**

Two major comprehensive Reports, listed first among main deliverables below, were assembled in 2004 and 2006 having in mind students and colleagues new to the field. BENE supported largely scientist and student travel to the main events organized by BENE or of direct BENE interest. The BENE Web Site http://bene.web.cern.ch/bene/default.htm was given much CARE and will live beyond BENE as a summary of its five years initiative and a repository of references relevant for our future activities.

☐ The steps of BENE's impact on the European Research area

BENE and all the activities preceding and following it are driven by the implications[2] of the recently (1998) discovered fundamental phenomenon of spontaneous transitions in flight among ν's of three different species (flavours).

BENE was the CARE network for Beams for European Neutrino Experiments, comprising 13 participating nodes, summarized in Appendix 1 with their implication in the Work Packages, approaching the totality of the accelerator ν physics community.. The network grew out of ECFA Muon Groups (MUG), studying a muon decay ring as a novel and superior **Neutrino Factory** (NF), active since1998. One of its pillar, the CERN NF Working Group (NFWG) was however very painfully closed in 2002 by the LHC crisis, imposing years of deceleration of our initiative. Two workshop series had established, in 1999, two large, independent but connected, international coordination Workshop series, NuFact [3] on ν sources and NNN [4] on ν detectors.

The Muon Groups established soon the necessity of a new very high intensity, Multi Mega Watt (MMW) proton facility. The potential of a conventional pion decay tunnel ν **SuperBeam** (SB) at such a MMW proton facility was also explored as most natural reference for the novel muon decay ring option. Somewhat later, 2000 or so, a second very attractive novel concept, that of an ion beta decay ring, named **BetaBeam** (BB), also became object of much interest. After a few very difficult years, the growing recognition of the physics case of frontier accelerator ν facilities lead to approval of the BENE NA in 2004. The HIPPI JRA, R&D for high intensity proton drivers, was also approved then.

First initiative of BENE was a workshop at CERN in May 2004 on the general theme of the high intensity frontier of particle and nuclear physics, complementary to the high energy frontier of the large colliders. Very successful, this workshop on **Physics with a MultiMegaWatt Proton Source** was organized together with other particle physics and

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[2] Study of these phenomena promises insight into primordial physics questions ranging from mixing among lepton generations, to violation of charge-parity symmetry in lepton flavour transitions, to generation of the unexplained observed lepton and baryon asymmetries in the universe, to the extremely high energy phenomena responsible of the minute, but non zero, neutrino masses and more.

[3] NuFact Workshop series on Neutrino Factories, Superbeams and Betabeams

[4] NNN Workshop series on Next Neutrino and Nucleon decay detector

nuclear physics (Eurisol) communities interested in the opportunities open by a MMW proton driver.

The proceedings were then submitted to the special session of the CERN SPSC (Super Proton Synchrotron Program Committee) in September. Nine invited talks delivered by BENE to the SPSC resulted in renewed attention to a European ν accelerator program and to the R&D recognized as mandatory to make that conceivable. The SPSC suggested the possibility of a “construction window” for a ν facility between LHC and next CERN big collider.

A second result at the end of the 2004 was the approval of a first BetaBeam (BB) design study as a WP of the Eurisol FP6 DS. First data from the MUSCAT and HARP R&D experiments were made public.

In 2005, BENE consolidated its status on the European and the international scene, organizing both our two international workshops, **NNN05** in Aussois in April **and NuFact05** in June in Frascati, further establishing the compelling physics case of experimentation at high intensity ν facilities. NuFact05 **launched an International Scoping Study (ISS)** of Neutrino Factory and Superbeam, that BENE carried then out in collaboration with the US Neutrino Factory Collaboration, the Japanese NUFACTJ group, and teams from India and other countries. We kept thus momentum of R&D and studies, in spite of the postponement to FP7 of the next opportunity to propose a Design Study. The MICE and MERIT R&D experiment were approved this year.

The assembly of the proceedings of NuFact05 and NNN05 proved invaluable in preparing our **BENE Midterm scientific report**, comprehensive 105 pages CERN Yellow Report pre-**submitted**, in electronic form, **to the** open Symposium held in Orsay (Paris) on Jan 30 - Feb 1 2006, by the **CERN Council Strategy Group**. The CERN Council Strategy Document published in July, in Lisbon, raised **Next neutrino facility to the status of emerging facility of Eu interest** in the context of the ESFRI road map[5].

The last part of 2006 started an intense period of preparation of FP7 proposals. BENE contributed also to the approval of the EMMA electron prototype of non scaling Fixed Field Alternating Gradient (FFAG) accelerator in the Daresbury Laboratory in UK

In 2007, the Scoping Study (ISS) published three final reports (physics, accelerators, detectors) establishing the baseline configurations of Neutrino Factory and Superbeam that will be object of the Design Studies. A similar Betabeam baseline configuration had meanwhile emerged in the context of the Eurisol Design Study WP.

These three baselines defined the proposal of the **EUROnu Design Study** that was prepared and submitted by BENE late in May. EUROnu **was approved** in August to design, cost and compare the three options. It finally started only on Sep 1, 2008, with first funds yet later. Its design of a ν factory is being carried out in the larger international context of **the International Design Study** of a Neutrino Factory (IDS) that **was** meanwhile **established** as natural continuation of the ISS. The LAGUNA Design Study of ν detector sites was also approved.

In 2008, **several WPs or Tasks directly inspired by BENE, in the R&D program proposed by the EuCARD IA, were approved**: the new NEu2012 continuing BENE, the MICE-TA program, the HPSPL task of the SRF JRA and the EUROFFAG task of the ANAC JRA. So were other WPs of BENE interest for possible synergy with the R&D towards upgrade of LHC and towards ILC and CLIC. Like in 2005, again NuFact08 (July, Valencia)

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[5] It stated that a “*coordinated accelerator R&D program should be intensified to be able … to play a significant role in the study and development of a high intensity neutrino facility”* and that “*studies… and R&D are required … to be in a position to define the optimal neutrino program … in around 2012”*.

and NNN08 (October, Paris) returned both in Europe. BENE started following the progress of EUROnu and finally preparing its final meeting and final reports.

2012-3 is indeed the appropriate time to define the optimal next accelerator ν program: solid physics results will have come from LHC and from the current ν (T2K and Double-CHOOZ) experiments, financial resources liberated by the end of the payments for LHC and its detectors, major decisions mature, for ILC, for accelerator ν and for other sectors. The deadline must be met.

In order for that to be even conceivable, there is no doubt that **a CERN neutrino task force must be put again in place**. Discussions have been reopened by BENE with the new CERN Management and are being continued by EUROnu and NEu2012.

BENE established a first detailed roadmap for European high-intensity ν-beam facilities, defined baselines options and was constantly pushing and initiating the pertinent technical developments. Long term initiatives beyond BENE were established through new collaborations and projects, sometime with involvement of European industry. Significant ideas and concepts first originated in BENE workshops and its topical meetings that guided and stimulated progress. Networking activities included an intense dissemination effort of publications and presentations.

A significant last result, in the very last months, was the creation of institutional review bodies of the prospects of physics with accelerator ν’ s and of EUROnu and NEu2012 initiative: the CERN SPC ν panel in 2009 and, in the longer term, the CERN Council Strategy Secretariat.
The table below summarizes selected achievements of BENE

Selected Achievements	Impacted infrastructure	Main improvement	Future impacted infrastructure	Expected future impacts
confirmation of the 3*3 complex lepton flavour mixing matrix scenario	CNGS	one sole **and** measurable fundamental ChargeParityViolating phase exists	Any next ν facilities	Conclusive CPV statement possible
nearly complete design of a 4 and more MW proton driver (HPSPL)	CNGS	Higher beam power	Superbeam and Neutrino factory	Highly improved Eu proton complex
MERIT demonstration of feasibility of MMW target and collection	CNGS	Higher power production and collection of neutrino parents	Superbeam and Neutrino factory	Higher neutrino fluxes
MICE demonstration experiment started	RAL/ISIS muon beam	demonstration of muon ionization cooling	Neutrino factory	Higher neutrino fluxes
EMMA non scaling (NS) FFAG electron prototype in construction	Daresbury Laboratory	proof of principle of novel NS FFAG	Neutrino factory and Betabeam	Higher neutrino energies

Summary of BENE’s activities: Work packages and Networking dynamics

BENE was organized in five work packages: Physics, of general nature, Proton Driver, Target, Collector (focusing on issues common to conventional and novel beams and directly relevant for upgrades of our present conventional facilities to superbeams). and Novel Neutrino Beams (in turn subdivided in three sub-packages, two on ν factory, one on betabeam).

During the five years, all BENE WPs followed closely

- the progress of the CNGS, the present European accelerator ν facility, its initial radiation problems, its approach to full intensity, likely in 2009, fostering first estimates of the ultimate long term performance of the complex by the CERN/AB CNGS team and their re-visitation, in view a new round of experimentation with emerging detector options

- emerging plans emerging outside Europe, sometimes contributing to them, thus identifying a scenario that includes upgrade programs of the JPARC ν facility in Japan (somewhat limited in ultimate power reach), upgrade programs[6] of the Fermilab NuMi conventional pion decay ν facility, longer term studies[7], always at Fermilab, of a ν factory

All accelerator WPs contributed very significantly to the definition of the baseline Superbeam, and Neutrino Factory parameters documented in the final ISS accelerator report.

WP1 (PHYSICS) constantly monitored the physics results of the experiments and phenomenological work in progress from the largest ν community and their implications for the directions of the field.

The WP contributed its good share of the ISS reports on preliminary comparative analysis of the physics reach of the different options of ν beams and detectors. Close contacts were kept with the Eu accelerator ν teams busy in experiments in progress or preparation. In addition to the EU teams at the CNGS (OPERA, ICARUS) or in Double CHOOZ, also the large EU component of the T2K experiment in Japan and the smaller EU teams working in the US Fermilab ν beams.

Most important results were the unequivocal final evidence for solar ν transitions from the SNO experiments in 2004, the measurement of the mixing quantities governing them provided by the KAMLAND experiments, the null result of the MiniBoone experiment in 2007 strongly disfavouring the fourth light ν claimed by LSND and finally the recent much improved MINOS measurements of atmospheric transitions. The scenario provided by a 3*3 complex lepton flavour mixing matrix, with one sole and measurable CPV phase, is today much stronger as the leading candidate mechanism ruling ν transition and as a compelling motivation for the strategy proposed by BENE and its international collaborators. Last support came late in 2008, not from an experimental result, but from phenomenological hints of a non zero, order 1%, value of the so far undetected $\sin^2$ of the third mixing angle $\theta_{13,}$ essential for the 3*3 mixing matrix scenario.

WP2 (DRIVER) was faced with the definition of the optimal proton driver.

A high rep rate low energy (5-8 Gev) proton linac is maybe slowly proving most convenient both for most intense, MMW, proton beam technology and for optimal ν rates. Only final bunch accumulation and compression would use circular machines. The debate is still open among international experts, however. The choices being made for the LHC injectors will be decisive. The time scale of these decisions is likely to be 2010-1, mid-way in the life of our new FP7 initiatives.

It is being prepared by assessment of wide ranging items as design performance of the HP SPL and of realistic alternative designs in Europe and elsewhere, results from the HIPPI JRA and all R&D in progress in the sectors, the first steps in the construction of LINAC4, new data on energy dependence of pion production from HARP and, more in general, the wide context of the definition in progress of the new chain of LHC injectors.

WP3 (TARGET) area of interest was high power targets capable to sustain MMW proton beams, surviving mechanical, thermal and radiation shocks and fatigue.

A major demonstration experiment (MERIT) was proposed, fostered and carried out, with the decisive push of US collaborators, at the CERN PS. Analysis of these data seems to be validating the concept of a liquid metal jet target as baseline design for ν factories (as well as Eurisol, remarkably enough).

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[6] NuMi is Neutrino from the MI (the Main Injector). It is planned to add a new NuMI West line, towards the new big DUSEL deep underground national lab in S Dakota, to the present NuMI North line and to enhnce both by means of Project-X, a new 1 MW proton driver, a 8 GeV ILC like linac, that could bring about 2.3 MW in the MI

[7] coupled to even longer term plans for a high energy frontier Muon Collider, a muon based vision for the future of the Laboratory. The push for Project-X and its upgrade path to 4 MW is a decisive part of this too.

Solid (carbon) target technologies remain instead favoured for conventional ν beams. They have been adopted for the JPARK T2K beam in Japan, with decisive contributions from the RAL team of our WP3 coordinator. They remain also those favoured for future higher power superbeams. Work on solid tungsten targets at RAL shows that they could still be a viable alternative to mercury jets, standing the thermal shock from tens of millions of proton pulses and have clear advantages over liquids with regard to radiation hazard. Hybrid technologies, flowing powder targets among others, are also strongly pushed. The BENE WP3 team moved on very successfully to take large responsibilities in the relevant EUROnu WPs.

International co-ordination in this sector has developed into a new phase, with various strands of endeavour in high power targets for ν facilities being aligned with overlapping programmes, in view of maximal synergy, by means of regular yearly international meetings.

WP4(COLLECTOR) had as task evaluation of high power collection devices of ν parents (pions and muons) downstream of MMW targets.

Today's baselines are, for ν factories, a long high field tapered solenoidal collector surrounding the liquid metal jet, that MERIT is likely to validate also, while Superbeam applications, that have even more severe target-collector integration problems, keep a strong preference for toroidal devices like horns and reflectors. These studies will now continue in the framework of the EUROnu FP7 DS project; where the BENE WP4 team too has taken large responsibilities. The concept of multiple pairs of horn and (solid) target is emerging, so to divide up the power on each pair, mitigate the damage and increase lifetime of components and ancillary equipment. R&D is in addition being fostered also for the ancillary bulky electro-mechanic components that must pulse horns at high current and high repetition rate. Most of the expertise resides in the CERN CNGS team, that may hopefully soon be more available to contribute to more rapid progress.

WP5 focused on **Novel Neutrino Beam** options**:**

WP5a (MUFRONT) focused on the front end of a neutrino factory, downstream of the solenoidal collection device.

The WP contributed to the assessment of the various options that were considered to define the baseline muon front end in the ISS final accelerator report. This consists of an unprecedented arrangement of normal RF for bunching, phase rotation, ionization cooling and pre-acceleration, in large solenoidal magnetic fields. WP5a has been leading the effort to propose and have approved and funded the MICE muon ionization cooling demonstration experiment at the Rutherford Appleton Laboratory (RAL) and is currently leading the commissioning of its beam and the instrumentation. Results must be there before the conclusion of the EUROnu Design study and the 2012 decision point.

Field emission from RF cavity surfaces, in large magnetic fields, threatens fundamental limitations to achievable accelerating gradients. This is taking years of careful studies, mostly at the Fermilab Muon Test Area, from the MUCOOL project that WP5a has been closely following and contributing to. Key members of WP5a have meanwhile become leaders in the NF WP of EUROnu and in the larger context of the NF International Design Study. The development of the conceptual design for the muon front end is considering novel designs, with smaller magnetic fields to allow the desired accelerating gradient to be achieved. Cooling absorbing materials of easier use than the Li-H absorbers adopted in MICE are also very actively investigated

WP5b (MUEND) focused on the back end of a neutrino factory, acceleration and storage ring.

It contributed to the definition of the ISS acceleration baseline based on a muon linac, recirculating linear accelerators (RLAs) and a final muon FFAG. In the same years, it motivated, proposed and brought home approval of the EMMA electron prototype of non scaling Fixed Field Alternating Gradient (FFAG) accelerator in the UK laboratory in Daresbury and of the RACCAM FFAG Design Study in France and Belgium that has built and measured a S-FFAG magnet prototype in 2008, with significant industrial involvement. This generated recently also a new spiral scaling FFAG RACCAM++ activity.

Its key members have now taken responsibilities in the EURONu DS and the IDS, in collaboration with the US groups around Brookhaven, KEK and the KURR-Institute in Japan. Last, they also proposed successfully the EUROFFAG Task in the ANAC WP of the EuCARD FP7 IA. Funds will be dedicated to the EMMA upgrade (diagnostic systems). BENE WP5b has also been active in dissemination, bringing three times to Europe the FFAG workshop series initiated in Japan and running the European Accelerator School JUAS

WP5c (BETABEAM) was BENE link to the Betabeam R&D and Design work

The team secured approval of the betabeam WP within the FP6 design EURISOL DS late in 2004 and kept BENE and the ν community constantly aware of its developments. BENE provided in turn the proper forum to discuss performance of different pure electron (anti-)ν betabeam variants for ν oscillation physics and stimulate input from neutrino physicists to their design.

The FP6 DS WP concerns only the original first variant of betabeam, based on a new ion storage ring filled by the present PS and SPS with low Q value He (anti-ν) and Ne (ν) ions produced with the ISOL ion production technique. WP5c prepared the proposal of a betabeam WP in the FP7 EuroNu design study that will continue the Eurisol design study. and will also explore more recently proposed betabeam and detector arrangements and new, non ISOL, ion production techniques. Some of these variants are already compared to those achievable with superbeams and neutrino factories in the ISS physics report.

The final report of the Eurisol based DS is presently eagerly awaited. It will report on the entire set of studies, the comforting results of studies on radiation and heat deposition, the less comforting results on ion production, the demonstration at the PS of decay ring stacking, the benefits of an extra accumulator ring and more.

A monograph on beta-beams – theory, phenomenology and accelerator aspects − has been produced in 2008 and will be published as a single volume in spring 2009. Discussions on a beta-beam facility at DESY continues. The beta-beam concept was also presented to ICFA.

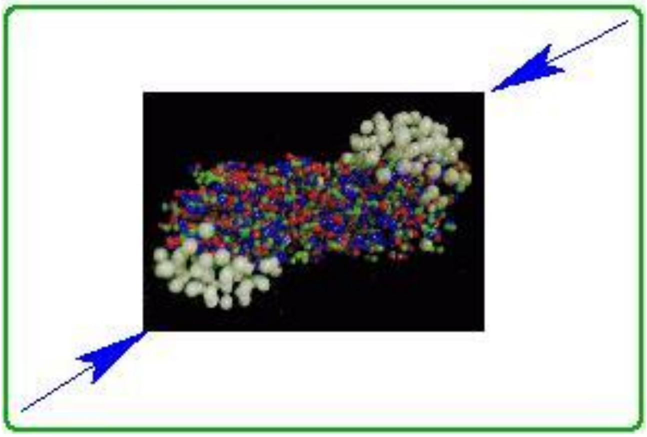
Conclusions

After 5 years of intense BENE Networking Activity, R&D and design study, a common strategic European involvement in a global accelerator ν program appears solidly on the agenda of CERN Council, for the year 2012 or so. Most of the tools necessary to match this challenge have been put in place during BENE’s term. A solid R&D program is in progress. A complete EURONeutrino Design Study has started, a new EUCARD Neu2012 NA is in place. Highlight scientific and technical achievements from this international community during the lifetime of BENE are summarized below

NA3: Coordination of studies and technical R&D for high-energy high-intensity hadron beams

Acronym: HEHIHB, **Coordinator:** *W. Scandale (CERN)*
Deputy: *F. Zimmermann (CERN)*

HEHIHB

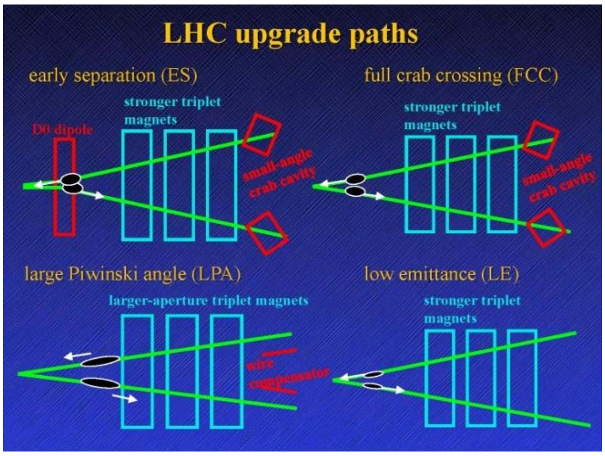


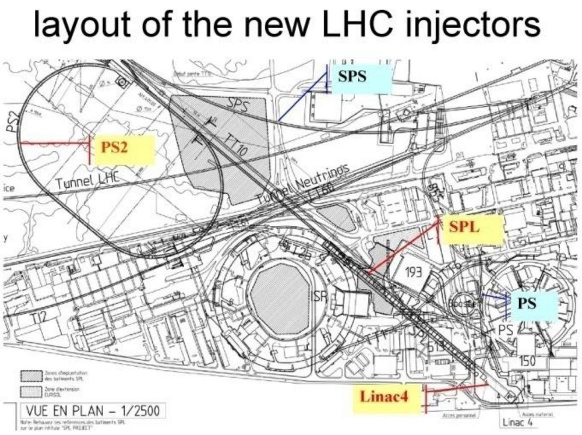
Participants to the N4 Activities:

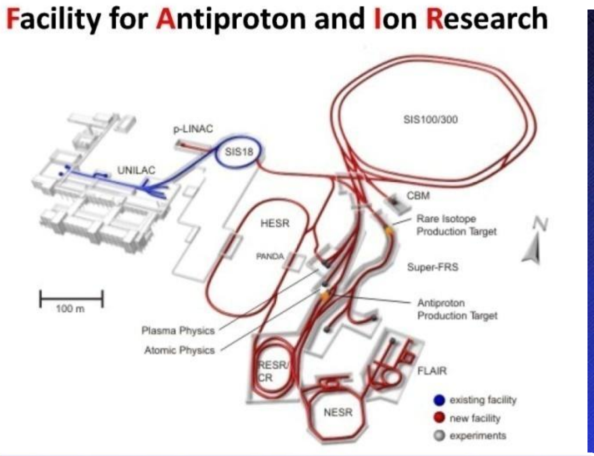
Country	Number of institutes	Number of persons
France	2	9
Germany	5	26
Italy	7	20
Japan	1	6
Netherlands	1	5
Poland	1	2
Spain	1	3
Sweden	1	3
Switzerland	2	4
United Kingdom	1	3
U.S.A.	3	25
Russia	2	4
CERN	1	33

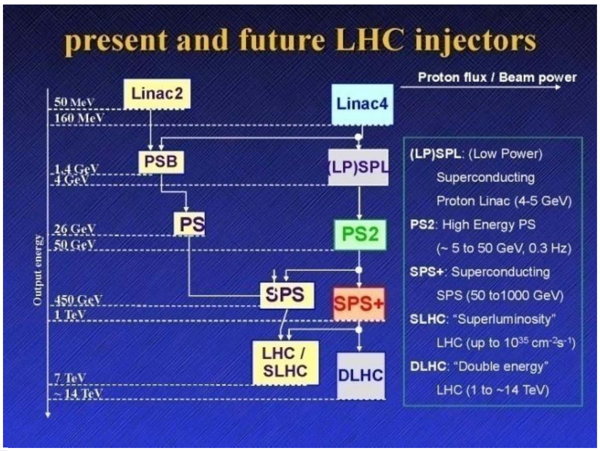
Main Objectives: Evaluating the various technologies for achieving hadron beams with energies and intensities above those currently at hand and defining a roadmap for the construction for a future hadron collider after the LHC.

Illustration of the Main Realisations of HHH

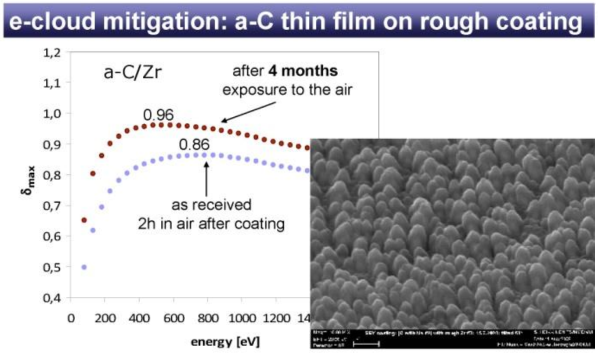


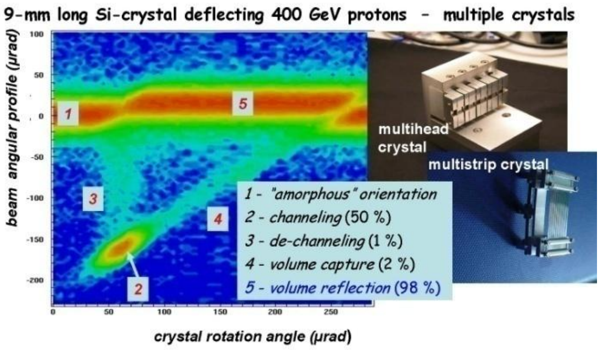




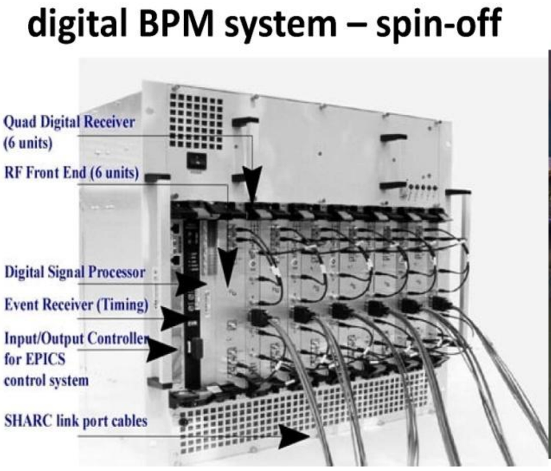


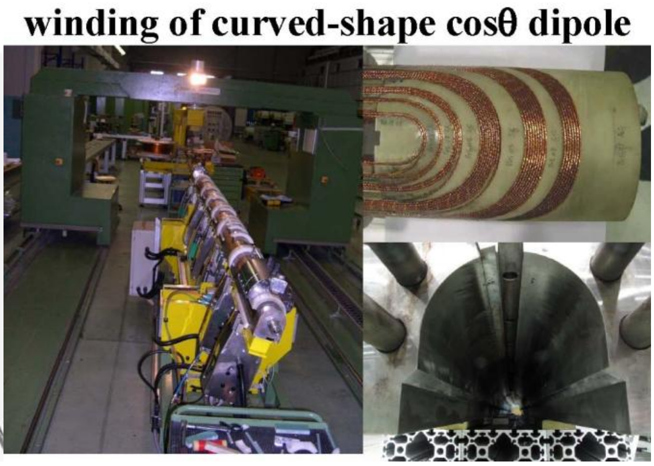
(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV, 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)





1 - "amorphous" orientation
2 - channeling (50 %)
3 - de-channeling (1 %)
4 - volume capture (2 %)
5 - volume reflection (98 %)





Introduction and Executive Summary

The CARE-HHH network gave birth to, and developed, many key ideas, concepts, strategies and technologies which have subsequently become integral components of the official upgrade plans for the CERN accelerator complex and of the GSI/FAIR project.

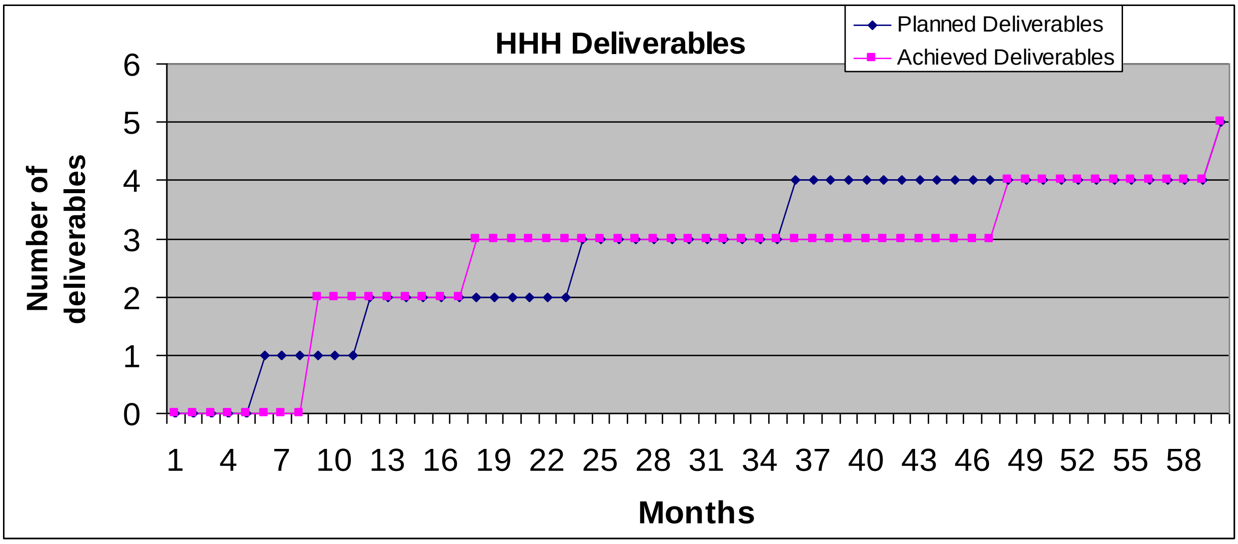
The innovations coming from HHH include detailed scenarios for the upgrade of the LHC and its injectors; the design of novel large-aperture, high-field or rapid-cycling superconducting (s.c.) dipole and quadrupole magnets; the identification of various bottlenecks in intensity or aperture, and the development of pertinent mitigation schemes, including a variety of remedies for the beam-beam interaction, for the electron-cloud effects, and for existing limitations on the collimation cleaning efficiency possibly overcome using crystals; advanced optics solutions for interaction regions and booster synchrotrons; and an improved understanding of high-intensity beam dynamics.

HHH established and strengthened pan-European and international collaborations, e.g., with European universities, with previously unconnected European organizations such as the European Fusion Development Agreement (EFDA) and the European Space Agency (ESA), as well as with overseas partners like US-LARP and KEK. Several open-access databases and web references were produced to the benefit of the worldwide accelerator community. An intense dissemination effort through publications and presentations was supported throughout the 5-year programme.

Highlights of HHH

☐ Deliverables

Five deliverables were planned within the 5 years of CARE as shown in the plot below. They had all been achieved.



The primary deliverables of HHH are a “web database for s.c. cables and magnets” which includes data from the LHC, Tevatron, RHIC and ITER, along with automatic tools for generating and importing these data from different projects, and the “accelerator-physics simulation codes web repository” containing no fewer than 53 programs. Another two deliverables were the generation and the continuous updating of the HHH and HHH-APD web sites. In addition, an LHC-upgrade IR optics and layout web repository, a booster synchrotron (PS2) optics web repository, and a structured list of intensity limits for the LHC and its injectors were also created, and represented important milestones. The last HHH deliverable is this final report.

☐ Dissemination and Outreach

In total HHH generated 156 documents reflecting presentations or publications delivered outside the previously mentioned workshops, plus (so far) 31 proceedings of workshops organized within HHH. The HHH documents include 11 CARE Reports, 70 CARE-Conference papers, 15 CARE Notes, 9 CARE journal articles, and 4 CARE theses (see table).

	2004	2005	2006	2007	2008	sum
CARE Notes	0	2	3	5	5	**15**
CARE Publications	0	1	3	3	2	**9**
CARE Reports	1	3	2	2	3	**11**
CARE Conferences	8	8	24	12	18	**70**
CARE Theses	0	0	1	1	2	**4**
Total	**9**	**14**	**32**	**23**	**30**	**109**

HHH also supported 44 scientist exchanges, as well as (partly) 15 master and PhD students. Also a total of 9 summer students were trained and contributed to HHH activities. Another important component of the HHH dissemination effort was the development and extension of the superconductor database and the accelerator-physics simulation codes web repository, as well as the maintenance and development of HHH web sites, plus several other web-based repositories. Presentations and discussions by HHH speakers at various experiment workshops and university seminars, as well as the reciprocal participation of the LHC experiments in HHH events, provided a valuable link to the particle-physics community, which aligned the accelerator upgrade plans with the detector requirements and with the upgrade plans of the experiments. In addition, many new contacts were established to communities outside particle physics, e.g. ORNL/SNS, and outside accelerator physics, e.g. the European Space Agency, on topics of common research interest.

Date	Title/subject	Location	Number of participants
22-24 March 2004	AMT workshop on Accelerator Magnet Superconductors (WAMS2004)	Archamps (F)	100
22-23 June 2004	ABI Workshop on Trajectory and Beam position measurements using digital techniques	Aumühle (D)	20
8-11 November 2004	APD Workshop on Beam Dynamics in Future Hadron Colliders and Rapidly Cycling High-Intensity Synchrotrons (HHH-2004)	CERN (CH)	90
1-2 December 2004	ABI Workshop on DC Current Transformers and Beam-Lifetime Evaluations	Lyon (F)	15
3-4 March 2005	AMT Workshop on Beam-Generated Heat Deposition and Quench Levels for LHC Magnets	CERN (CH)	80
31 August – 3 September 2005	APD Workshop on Scenarios for the LHC Luminosity Upgrade (LHC-LUMI-05)	Arcidosso (I)	40
26-28 October 2005	AMT Workshop on SC Pulsed Magnets for Accelerators (ECOMAG-05)	Frascati (I)	70
6-7 December 2005	ABI Workshop on Remote diagnostics and maintenance of beam instrumentation devices	Hirschberg (D)	20
3-6 April 2006	AMT Workshop on Accelerator Magnet Design and Optimization (WAMDO)	CERN (CH)	140
11-12 October 2006	AMT Workshop on the Low Energy Ring Study (LER)	CERN (CH)	50
16-20 October 2006	APD Workshop Towards a Roadmap for the Upgrade of the LHC and GSI Accelerator Complex (LHC-LUMI-06)	Valencia (E)	70

30 November -1 December 2006	ABI Workshop on Simulation of BPM Front-End Electronics and Special Mechanical Designs,	Lüneburg (D)	27
1-5 October 2007	APD Workshop on LHC Injectors Upgrade and LHC Beam Parameters Upgrade including Francesco Ruggiero Memorial Symposium and CERN-GSI Meeting (BEAM'07)	CERN (CH)	88
7-9 November 2007	APD Workshop on Interaction Regions for the LHC Upgrade, DAFNE and SuperB (IR'07)	Frascati (I)	39
19-20 November 2007	AMT Workshop on Heat Generation & Transfer in Superconducting Magnets (THERMOMAG)	Paris (F)	30
11-13 December 2007	ABI Workshop on Schottky, Tune and Chromaticity Diagnostics (with Real-Time Feedback)	Chamonix (F)	28
19-23 May 2008	AMT Workshop on Accelerator Magnet, Superconductor, Design and Optimization (WAMSDO 2008)	CERN (CH)	107
24-25 November 2008	HHH-2008 Workshop: Scenarios for the LHC upgrade and FAIR	Chavannes-de-Bogis (CH)	43
10-12 December 2008	ABI Workshop on Transverse and Longitudinal Emittance Measurement in Hadron (Pre-) Accelerators	Bad Kreuznach (D)	27

☐ Impact on European Research Landscape

HHH established a detailed roadmap for the European high-energy high-intensity hadron-beam facilities, formulating needed or desirable upgrade steps over the next decade, and initiating pertinent technical developments. In addition HHH made a further impact on the European research landscape via the launch of long-term activities, through new collaborations, and by the strategic involvement of European industry.

Significant ideas and concepts which originated in the frame of HHH include:

- the phasing of the LHC luminosity upgrade (“phase 1” and “phase 2”);
- an LHC “phase-1” interaction-region (IR) upgrade using larger-aperture NbTi magnets;
- the upgrade of the LHC injector complex involving higher energy and/or higher-intensity storage rings, as will be realized with Linac4, the SPL, PS2 and the upgraded SPS, with the goals of increasing beam intensity and reducing the effective LHC turnaround time;
- novel electron-cloud mitigation techniques such as carbon coating, black metals, mechanically or magnetically rough surfaces, enamel-based clearing electrodes, and wide-band beam feedback, most of which were qualified in beam tests at the SPS and PS, to suppress any electron-cloud build up for the SPS upgrade, PS2, and FAIR;
- the identification of several schemes for increasing the LHC luminosity by a factor of ten above nominal, and the development of four example scenarios for this LHC high-luminosity upgrade (“phase 2”), namely: “large Piwinski angle”, “early separation”, “full crab crossing”, and “low emittance”, each with its own distinct merits and challenges;
- the concept of LHC “luminosity leveling” to reduce the maximum event pile-up in the detector while providing a high integrated luminosity;
- the demonstration that, at the contemplated much higher luminosity, the new NbTi or Nb_3Sn interaction-region quadrupoles can efficiently be shielded against increased energy debris from the collision points, and that Nb_3Sn gains a factor 1.3-1.4 w.r.t. NbTi;
- the advancement of crystal collimation for higher-intensity operation and the qualification of novel and multiple crystals with SPS beams;
- the potential gains from crab cavities at an upgraded LHC, a staged crab-cavity implementation consisting of validation, a single global prototype, and, finally,

compact local cavities, as well as the establishment of a worldwide LHC crab-cavity collaboration;

- several refined schemes for LHC long-range beam-beam compensators, e.g. ones based on high-temperature superconductor or cold copper, and RF wire devices;
- the possible benefits from LHC “crab-waist” sextupoles including their use for long-range collisions and at collimators;
- pioneering contacts with European industries, e.g. enamel producers in Germany, beam instrumentation companies, manufacturers of s.c. cables and magnets, software developers for RF devices, as well as with other communities, e.g. ESA/ESTEC, the LHC experiments, SNS, EUROTeV, EPFL Lausanne, etc.;
- the design and optimization of high-field or fast cycling s.c. magnets, and particularly for FAIR the development, first proposed inside HHH, of a pulsed s.c. dipole with curved shape, which led to the procurement of a prototype from INFN; and
- improved hadron-beam diagnostics with several industrial spin-off products.

HHH guided and stimulated this progress by organizing numerous workshops, topical meetings, as well as targeted scientific exchanges, in which many of these ideas came to the surface. The pure networking activities were complemented by an intense dissemination effort in the form of publications and presentations.

The table below summarizes selected achievements of HHH

Selected Achievements	**Main impact**	**Impacted infrastructure**	**Expected future impact**
Plan for a phased LHC upgrade	Official CERN strategy for LHC upgrade	LHC	LHC luminosity increase
LHC “phase-1” interaction-region (IR) upgrade using larger-aperture NbTi magnets	Launch of LHC IR Phase-I upgrade project	LHC	More aperture, factor 2 reduction in beta*
Upgrade of the LHC injector complex	Linac-4 Project, design studies for SPL and PS2	CERN complex, Linac-4, SPL, PS2	More flexibility for LHC beam parameters, increased reliability, reduced LHC turnaround time
Novel electron-cloud mitigation techniques	Development of carbon coatings and black metals	SPS upgrade, PS2, FAIR	Suppression of electron cloud with improved accelerator performance, allowing full benefit of PS2 ; applications to ILC and CLIC
Phase-II LHC upgrade schemes	Development of four distinct upgrade scenarios	LHC injector complex and LHC interaction regions; LPA scheme for SuperB	Factor 10 luminosity increase beyond nominal for LHC

Concept of luminosity leveling	Reduced detector pile up	LHC Experiments and LHC interaction region	High quality physics data together with high integrated luminosity
Handling of collision debris	Shielding development and simulations for new Nb-Ti and Nb3Sn triplets	LHC interaction region quadrupoles	Quench avoidance and improved lifetime of IR magnets; applications to future hadron colliders like DLHC or VLHC
Advancement of crystal collimation and crystal qualification	Option for improved collimation	LHC collimation system	Beam operation and high-intensity beam handling for LHC and FAIR
LHC crab cavities	Worldwide collaboration; staged prototyping and implementation plan	LHC	Increased luminosity, easy luminosity leveling for LHC
Novel LHC long-range beam-beam compensators	Compensators based on high-Tc, cold copper, or RF wires	LHC	LHC beam performance
LHC crab-waist sextupoles	Main collisions, long-range collisions or collimation	LHC	Higher luminosity, higher beam-beam tune shift limit, improved cleaning efficiency, SuperB
Pioneering contacts with European industry, e.g. enamel producers in Germany, beam instrumentation companies, manufacturers of SC cables and magnets, software developers for RF devices, as well as with other communities, e.g. LHC Experiments, ESA/ESTEC, SNS, EUROTeV, EPFL Lausanne	Design, prototyping, production and in some cases commercialization; common development of new simulation codes; beam experiments; laboratory studies	LHC, SPS, PS, PS2	Better simulation tools, product delivery and commercialization; improved accelerator performance
Design and optimization of high-field or fast cycling s.c. magnets, and particularly for FAIR the development of a pulsed s.c. dipole with curved shape, which led to the	Procurement of a prototype pulsed SC dipole with curved shape from INFN	GSI FAIR	PS2, SPS2
Improved hadron-beam diagnostics	Industrial spin offs	DESY, GSI, CERN, US-LARP laboratories	All accelerators worldwide will profit from the beam diagnostics development

Summary of HHH activities: Workshops and Collaboration Dynamics

HHH was organized in three work packages: Advancements in Accelerator Magnet Technologies (AMT), Novel Methods for Accelerator Beam Instrumentation (ABI), and Accelerator Physics and synchrotron Design (APD). Each work package organized its own series of workshops. At least one workshop was held per work package per year. In addition, a number of topical mini-workshops were organized to make progress on specific issues, and several joint workshops on topics of common interest were co-organized with European or international partners. In total 39 primary HHH workshops were organized, 8 of which by AMT, 6 by ABI, and 17 by APD. The remaining 8 were co-organized by APD together with other institutions

The workshop participants came from numerous European laboratories (CEA, CERN, CI, CIEMAT, DESY, EFDA, ENEA, FZJ, GSI, IFJ-Krakow, INFN, IN2P3, ITEP-Moscow, JINR-Dubna, PSI, RAL, STFC,…), from European organizations (e.g. ESA), from European universities (in France, Germany, Italy, Spain, Switzerland, UK, etc.), from international organizations (e.g. IFMIF), from the US-LARP (BNL, LBNL, FNAL, SLAC), from other US laboratories (JLAB, NHMFL, ORNL), from US universities (e.g. Cornell, MIT, Texas A&M), from Asia (IHEP in China, KEK in Japan), and from European industry (Alstom, Accell, NBB, Bruker BioSpin, Outokumpu, Ansaldo, Eisenwerke Düker, AUROSAT, Bergoz, Globes Electronics, Kyocera, Wendel Email, Siemens). The number of participants varied between a minimum of 15 and a maximum of around 200. The workshops assumed a key role in determining the HHH collaboration dynamics.

In the frame of the AMT work package, 8 workshops were held on superconducting magnets and cables, and on applications of s.c. magnets to high-energy accelerators. Numerous industrial companies were involved in the AMT events. Many of the workshop topics were aligned with the superconductor development activities in the CARE-NED activity progressing in parallel. The early AMT workshops reviewed the capabilities of European industries and laboratories, and defined the needs and development directions for high-field and large-aperture as well as for fast-ramping s.c. magnets. Three workshops addressed the particular aspect of heat generation - by beam loss, by collision debris, or by the ramping of the magnet - as well as improved insulation and cooling schemes. The outcome of these workshops has been taken into account in the magnet design for the LHC interaction-region upgrade and in the fast-cycling pulsed magnet designs proposed for FAIR, the PS2 and an eventual SPS2. Other, later and larger AMT workshops considered the magnet requirements imposed by the beam optics solutions and by the interaction-region layouts developed within the APD work package, as well as magnet-specific issues like design and costing tools, novel design concepts, and magnet optimization. One special AMT workshop looked at the proposal to install an s.c. injector ring based on transmission-line magnets in the LHC tunnel. This proposal was rejected as a result of the workshop discussion. In summary, the AMT workshops have generated a strong European and international R&D community capable to develop the next generation of s.c. accelerator magnets, and to support both FAIR and the various phases of the CERN upgrades.

The ABI work package organized one workshop per year. The workshops were loosely connected, each time addressing a different type of beam diagnostics or beam control. Taken together they provided a complete survey of hadron beam instrumentation: trajectory and beam position measurements using digital techniques; DC current transformers and beam-lifetime evaluations; remote diagnostics and maintenance of beam instrumentation devices; simulation of BPM front-end electronics and special mechanical designs, Schottky, tune and chromaticity diagnostics (with real-time feedback); and transverse and longitudinal emittance measurements in hadron (pre-)accelerators. Numerous inter-laboratory collaborations and partnerships with industry resulted from this activity.

APD organized one major workshop per year, strongly involving the four LHC experiments, and other CERN non-accelerator departments, like TS, in addition to the participating institutes listed above. The APD workshops covered future hadron colliders (LHC upgrade scenarios) and rapidly cycling high-intensity synchrotrons (CERN injector complex upgrade and FAIR design), including closely related themes, e.g. high-intensity beam-dynamics issues, optics solutions for the upgraded LHC interaction region and for booster synchrotrons, machine protection, collimation, energy deposition, accelerator-physics simulation code web repository, and simulation code benchmarking efforts. The first APD workshop in 2004 brought the entire community together. Its primary focus was the review of upgrade issues and of inherited upgrade scenarios. The workshop endorsed a staged upgrade scenario, distinguishing an initial “phase 1” with changes only in the LHC interaction region, and a subsequent “phase 2” with major hardware modifications. Various joint activities were triggered at this workshop, e.g. the CERN-GSI collaboration on incoherent electron-cloud effects. A secondary goal was surveying the state-of-the-art in hadron-beam dynamics simulations, aided by an expert panel discussion. This first workshop already eliminated the so-called superbunch scheme for the LHC in view of unacceptable event pile up. The following workshop considered some revised upgrade scenarios with less pile up, especially a derivate of the former superbunch scheme - the large-Piwinski angle upgrade scenario with initially 75-ns bunch spacing. For the first time IR upgrade solutions were presented which reached β^* values of 0.25 m using large-aperture NbTi quadrupoles rather than Nb_3Sn. At this workshop also the idea of an “early-separation scheme” with further reduced β^* values, below 0.25 m, was first proposed. Large-angle crab-cavities were abandoned. The third workshop rejected the so-called dipole-first schemes, but added the novel concept of slim s.c. magnets (dipole or quadrupoles) embedded deep inside the detector, and it brought up the idea of small-angle crab crossing. Options with 12.5-ns bunch spacing were shown to lead to unacceptable heat load and were subsequently abandoned. Two new LHC upgrade scenarios were constructed that compromise between arc heat load and detector pile-up, one with 25-ns spacing, the smallest possible β^* and early beam separation, the other with 50-ns spacing, longer flat bunches, β^* of 0.25 m, and a large Piwinski angle. The fourth workshop in 2007 focused on the CERN injector upgrade, and on the production of the beams required for various LHC upgrade scenarios by the new injector complex, as well as on the possibility of luminosity leveling to reduce the peak pile up. Bolstered by KEKB progress, “full crab crossing” became a third option for the LHC upgrade. For PS2, arguments were invoked in favor of either conventional magnets or fast cycling s.c./superferric magnets. The last workshop, in 2008, synthesized the results of 5 years of HHH networking activity. It established 4 different scenarios for the LHC high-luminosity upgrade. The fourth, new scenario makes use of the low-emittance higher-brightness beam available from the SPL and PS2.

In addition to these primary workshops, APD organized a number of mini-workshops and working meetings. One mini-workshop, organized jointly with CARE-ELAN and EUROTeV in 2007, was devoted to technological consequences of electron-cloud effects. This workshop launched collaborative efforts for the development of novel coatings (black metals, carbon) and enamel-based clearing electrodes in view of the SPS upgrade and PS2. A follow-up workshop, in 2008, reviewed the achievements, and it fostered a pertinent collaboration with the European Space Agency and its partners on coatings and computer modeling. At this workshop also another electron-cloud remedy based on a static spatially modulated weak magnetic field was discussed. Further two mini-workshops advanced the idea of LHC crab cavities. The first of these, arranged jointly with the US-LARP and BNL, established a global collaboration on LHC crab cavities. The second crab-cavity mini-workshop discussed the validation requirements prior to installing a crab cavity in the LHC. Another three mini-workshops looked at the LHC interaction region upgrades, including the related magnet development in Europe and the US, or at beam-beam effects and beam-beam compensation, respectively. An HHH-APD networking support for crystal channeling, reflection and collimation, provided a forum of discussion to which many associated institutes in Russia and US, such as IHEP, PNPI, JINR and FNAL, have contributed. APD organized no less than 5 mini-workshops on crystal collimation in hadron colliders, to prepare, conduct and analyze a series of experiments with SPS proton and ion beams, and some complementary experiments at FNAL. As part of the crystal activity, the international conferences “Channeling’06” and “Channeling’08” were co-organized and sponsored by HHH. HHH-APD also supported participation in beam experiments on crystals or beam-beam compensation studies at the SPS, the FNAL Tevatron, and BNL RHIC. In addition, HHH-APD organized two CERN-GSI bilateral working meetings on “collective effects – theory and experiments”, which allowed an exchange of ideas and approaches in high-intensity beam dynamics, encouraged a common planning of future experiments and simulations at GSI and CERN, and, overall, fostered a much closer collaboration between the CERN upgrade study groups and the GSI FAIR design team.

In addition to workshops, exchanges of key scientists between member laboratories or associated institutes, over typical periods of 1 to 4 weeks, helped to make progress on crucial issues, for example energy deposition, high-field magnet design, crystal modeling, beam-beam interaction, or electron-cloud simulations.

Conclusions

After 5 years of intense HHH networking activity, the LHC luminosity upgrade has assumed a realistic shape. Meanwhile concrete efforts are underway for implementing the first upgrade phase around 2012/13. Hitherto considered baseline upgrade scenarios (e.g. 12.5-ns spacing, or superbunches) had to be completely abandoned. In their place, HHH has put 4 alternative scenarios, all with comparable luminosity - 10 times above nominal - , with similar event pile up rates, and with acceptable arc heat loads. HHH networking has also introduced the concepts of luminosity leveling and of a phased upgrade, both highly appreciated by the experiments. At the same time the CERN injector complex upgrade, first proposed in the frame of HHH, was advanced dramatically. HHH networking has also initiated an important fast-pulse s.c. magnet design for FAIR, as well as a collaboration on electron-cloud mitigation for the SPS upgrade which resulted in an impressive set of “solutions”, that promise to fully eliminate the occurrence of an electron cloud in future accelerators. Strong support by HHH has also pushed forward the development and manipulation of crystals for collimation applications, which may overcome one of the most important intensity limitations of the LHC.

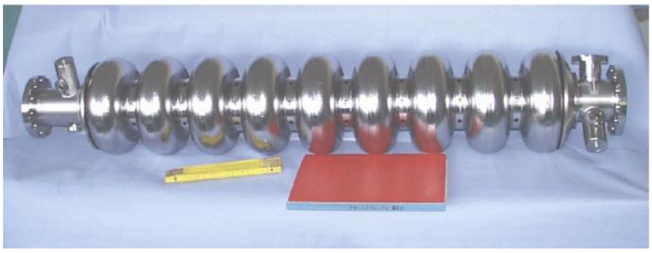
X. Description of the Joint Research Activities

JRA1: Research and Development on Superconducting Radio-Frequency Technology for Accelerator Application

Acronym: **SRF**

Co-Coordinators: ***D. Proch (DESY), T.Garvey (CNRS-Orsay)***

Deputy: ***H. Mais (DESY)***



Participating Laboratories and Institutes:

Institute (Participating number)	**Acronym**	**Country**	**SRF Scientific Contact**
DESY (6)	DESY	D	D. Proch
CEA/DSM/DAPNIA (1)	CEA	F	O. Napoly
CNRS-IN2P3-Orsay (3)	CNRS-Orsay	F	T.Garvey
INFN Legnaro (10)	INFN-LNL	I	E. Palmieri
INFN Milano (10)	INFN-Mi	I	C. Pagani
INFN Roma2 (10)	INFN-Ro2	I	S. Tazzari
INFN Frascati (10)	INFN-LNF	I	M. Castellano
Paul Scherrer Institute (19)	PSI	CH	V. Schlott
Technical University of Lodz (12)	TUL	PL	M. Grecki
Warsaw University of Technology (14)	WUT-ISE	PL	R. Romaniuk
IPJ Swierk (13)	IPJ	PL	M. Sadowski

Industrial Involvement:

Company Name	**Country**	**Contact Person**
ACCEL Instruments GmbH	D	M. Peiniger
WSK Mess- und Datentechnik GmbH	D	F. Schölz
E. ZANON SPA	I	G. Corniani
Henkel Lohnpoliertechnik GmbH	D	B. Henkel

Main Objectives: Carrying Research and Development of the technique allowing the realization of superconducting cavities reaching high accelerating gradient (>35 MV/m) and lower RF losses (higher quality factor), including the realization and tests of prototype cavities leading to the improvement of the FLASH facility for accelerator R&D. Conducting the Research and Development on radio-frequency systems and components to improve the technical performance and reliability of superconducting RF linear accelerators while reducing cost, including the verification of design improvements on FLASH with high gradient cavities and beam.

Illustration of the Main Hardware Realisations of SRF


EP at DESY


Rough EP at ACCEL (courtesy of M. Pekeler)

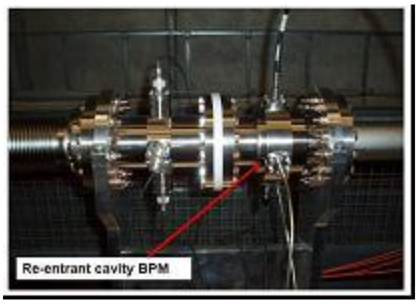

Hydroforming machine

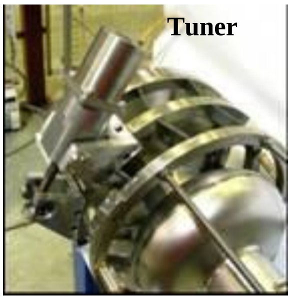

TiN coating device


Cry-Ho-Lab


SQUID SCANNER


CO_2 cleaning


Re-entrant cavity BPM


Tuner

Aims of SRF

The JRA-SRF has been active from 1.1.2004 until 31.12.2008. The purpose was to enhance the performance of superconducting cavities and related auxiliaries for the operation of a superconducting electron linac. Also innovative and promising technologies were investigated. A direct impact is expected for the operation and performance of FLASH. But new (e.g. XFEL) or future superconducting accelerators (e.g. ILC or energy recovery linacs) will benefit from the R&D efforts in JRA-SRF.

In total 8 partners were involved in the JRA-SRF: CEA, CNRS-Orsay, DESY, INFN (INFN-LNL, INFN-Mi and INFN.Ro2), TUL (Technical University of Lodz), IPJ (Swierk), WUT-ISE (Warsaw University of Technology) and PSI. In addition four industrial partners were attached to JRA-SRF (ACCEL, WSK, ZANON and Henkel).

The development of superconducting electron linacs has been pushed in Europe for more than 10 years. A major milestone of this activity was the foundation of the TESLA collaboration. The aim of this collaboration was to prepare the technical competence for the construction of a possible high energy physics collider with an energy reach of 500 GeV with possible extension to 1 GeV. This collaboration joined laboratories from Europe, USA and Asia. The central R&D superconducting linac installation was the TESLA TEST Facility TTF at DESY.

In 2004 the International Technical Recommendation Panel ITRP has recommended the superconducting solution for the linac technology for a future High Energy Physics linear collider. As a direct consequence the International Linear Collider effort ILC was founded. Based on the technical expertise of TESLA ILC initiated a global design effort for a 1 GeV collider.

Although the TTF linac at DESY has become a FEL user facility, it also serves as test bed to gain operating experience for new linac components. The TTF test infrastructure is a unique installation for preparation and testing of superconducting 1.3 GHz cavities. In the last years the main activity at DESY was devoted to prepare the technical knowledge for the construction of XFEL, a superconducting based new light source. The construction of XFEL started in 2008.

It is important to note that the success of SFR-JRA is based on a very active and fruitful collaboration between all partners from laboratories, universities and industries. The advancements of JRA-SRF further strengthen the European leadership in the field of superconducting electron linacs. Synergetic benefits of the partners will continue even after JRA-SRF ended.

Highlights for the JRA-SRF Project

☐ Summary of main achievements

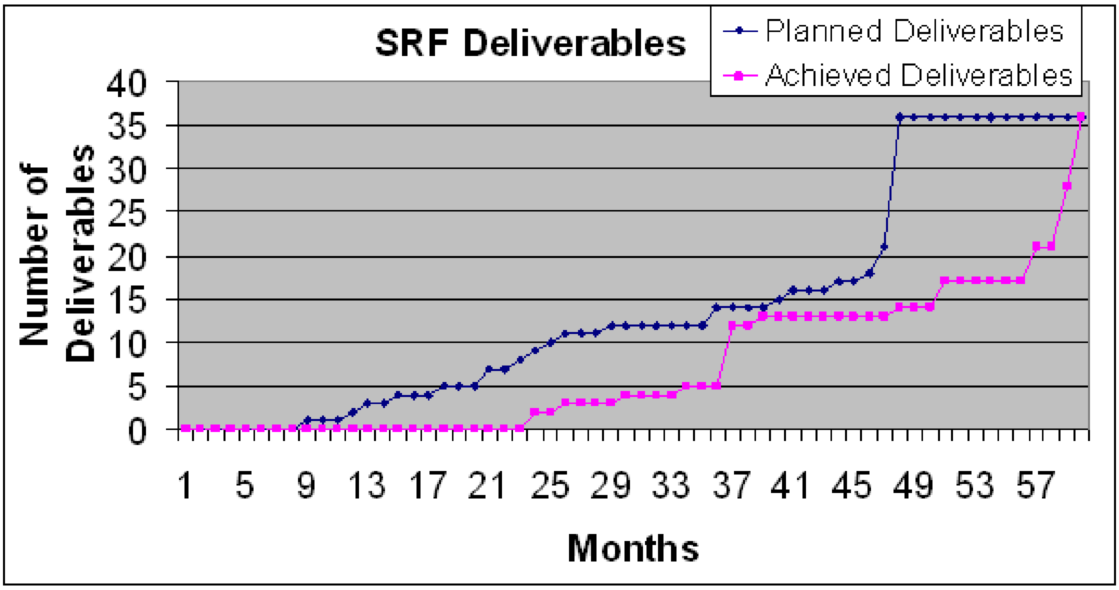
JRA-SRF activities covered a large field of R&D areas for design and performance improvements of superconducting cavities as well as upgrades of additional components related to the operation of superconducting RF accelerating systems. The main advancements are

- An electropolishing (EP) system for processing of 9-cell cavities has been designed, built and operated at DESY

- The technology of EP has been successfully transferred to industry (two companies in Germany)
- Two different tuning systems for SC cavities have been optimized and have been completed by adding fast tuner mechanisms
- A new beam position monitor for operation at cryogenic temperatures was designed, built and successfully tested in Flash
- A new non intercepting beam emittance monitor, based on Optical Diffraction Radiation ODR, was designed, built and successfully tested at FLASH
- New strategies for high power coupler conditioning were developed which dramatically reduce the effort of coupler training
- Several new hard and software components for the low level RF control (LLRF) were developed, built and successfully implemented in FLASH
- A superconducting SQUID scanner for quality control of Niobium sheets was built and demonstrated superior sensitivity as compared to the standard normal conducting Eddy current device.
- The Technology of seamless cavity fabrication was developed and a first 9-cell prototype could be built and was successfully tested
- The technology of large grain and single crystal cavities has been advanced and several prototypes were built and tested
- Dry ice cleaning was applied to cavities and RF guns as a novel method to purify surfaces without the need to use water
- An novel electrolyte for electropolishing without use of hydrofluoric acid has been proposed and was successfully explored on samples

☐ Deliverables

In JRA-SRF 36 deliverables were scheduled. They were aimed at improving existing design, components, software or procedures. Also innovative materials or treatments were investigated. One important component was to transfer expertise from laboratories to industry. All deliverables have been achieved, as shown in the table below.



☐ Dissemination

Members of JRA-SRF have attended and contributed to large accelerator conferences such as Linac06, Linac08, EPAC06, EPAC08, PAC07, TTC meetings and SRF workshops. Also at specialized conferences like SPIE (Polen) JRA-SRF members gave invited and/or contributed talks. Ten PhD reports have been finished and 30 refereed papers have been produced. In total 194 CARE documents were written (see table below). In addition 2 German patents have been granted (hydroforming of cavities and single crystal cavities).

	2004	**2005**	**2006**	**2007**	**2008**	**sum**
CARE Notes	6	6	4	3	0	**19**
CARE Publications	1	13	10	5	1	**30**
CARE Reports	1	3	10	8	22	**44**
CARE Conferences	18	26	35	10	2	**91**
CARE Thesis	0	0	5	3	2	**10**
Total	**26**	**48**	**64**	**29**	**27**	**194**

The Activity has organized every year a series of Meetings. The Table below reports the SRF Annual Meetings.

Date	**Title/Subject**	**Location**	**Participants**
02.-03. Nov.2004	Annual SRF meeting	DESY	43
19.-21. Oct. 2005	Annual SRF meeting	Legnaro	45
28.-31. March 2006	Thin film meeting	INFN, University Roma	8
14-15. Nov. 2006	Annual SRF meeting	Frascati	45
17.-19. Sept. 2007	Annual SRF meeting	Warsaw	15
26.-28. May 2008	Seamless, thin film meeting	Legnaro	15
02.-03. Dec.2008	Annual SRF meeting	CERN	18

☐ Main impacts of the JRA-SRF achievements

The impact of the JRA-SRF achievements can be grouped in two categories:

A. ***The design, functionality, treatment and performance of hardware or software have reached a mature state. In these cases components or treatments can directly be used or applied for infrastructures which are operating (such as FLASH), are under construction (such as XFEL) or are under planning (such as ILC). Examples are:***

- The cavity / helium vessel design was optimized with respect to cost effective fabrication and for high mechanical stiffness (in order to minimize the effect of Lorentz detuning). This design will be used for a possible upgrade of FLASH and also partially for the fabrication of XFEL cavities and for the design of ILC modules. For any new pulsed superconducting electron linac this design will be first choice.
- The standard electro polishing (EP) procedure for multi-cell cavities was finalized and is in operation at DESY for more than 150 cavities. This technology was successfully transferred to industry and can be "ordered" now by any present or future project. The European industry now is leader in the industrial EP technology.
- Niobium sheets are scanned for material defects by Eddy current devices. A superconducting SQUID detector should result in a higher sensitivity as compared to

the normal conducting pick up coil presently under use. In cooperation with the company WSK a novel SQUID scanner was designed, built and tested. The sensitivity of the SQUID scanner is about a factor of 4 higher when comparing the depth of detection of a 50 µm size calibration defect in the Niobium sheet.

- The design and optimization of slow and fast cold tuning systems for cavities is finalized and was approved by prototypes. Two versions are available: tuning mechanism is placed at the end or at the middle of the helium vessel. The first one is the standard solution for FLASH and XFEL type accelerators. The second one is first choice for accelerators where the absolute length is critical, e.g. ILC.
- A new type of beam position (re-entrant type of cavity) was designed, built and successfully tested at FLASH. This monitor complies with the requirements of class 100 clean-room assembly conditions and also meets the resolution specification of the XFEL. It was decided to use this monitor in FLASH. At present this monitor is the only choice for use in superconducting accelerators similar to XFEL.
- The technology for production of seamless cavities has been finalized. A patent has been granted for this new fabrication technology. Seamless tubes are fabricated by a combination of back extrusion and flow turning. A computer controlled hydraulic machine forms cavity cells from these tubes. The material properties, specification and the forming parameters are well understood and defined. A first 9-cell hydroformed cavity has been successfully tested at a high accelerating gradient of 30 MV/m. This fabrication method is ready to be used in cases where welding defects limit the performance of superconducting cavities. Europe is definitely the leader of this technology.
- The objective of the Low Level RF Control (LLRF) has been to advance RF Control Technology in the areas of hardware and software to meet the requirements for linear colliders and linac based free electron lasers (FEL and XFEL). The work has been focused on the following topics:
    - Pushing the technical performance such as field regulation close to the operational limits of the cavities and high power systems
    - Compatibility with tunnel installation including low maintenance and radiation tolerance
    - High degree of automation for large scale systems for adequate operability of large scale systems
    - Reliability and availability optimization in connection with cost reduction Overall the LLRF hardware and software currently implemented at the RF Gun and at the first cryomodule at FLASH as the result of the LLRF work in FP6 are considered pioneering work in this field. While several other labs and industry just started to follow the hardware development in this area, the software developed and evaluated in this framework has not only improved the field regulation but also paved the way to high availability, simplicity of operation, and exploration of operation close to the performance limits of cavities and high power systems.
- Input coupler conditioning can be time consuming and has the risk of breaking the RF window. New strategies have been developed and resulted in considerable reduction of conditioning time. This achievement is based on three components: stringent quality control during fabrication, applying clean-room technology during assembly and elaborate setting of interlock signals. This procedure will be applied during XFEL coupler procurement and is available for use at any construction project for SC linacs.

B. ***There are interesting and promising achievements which need additional R&D effort beyond CARE or cooperation with new partners or industry. Examples are:***

- The standard fabrication technology of Nb cavities is to form and weld sheet material of small grain structure. The intrinsic superconducting material parameters of Niobium might be reduced by the many intermediate steps of forging, baking and etching. Large grain or even single crystal cavities are formed by starting with Nb sheets being cut from the highly purified ingot raw material. JRA-SRF has fabricated and tested very successfully several large grain 9-cell resonators and also single cell single crystal cavities. A patent has been granted to the fabrication technology of single crystal single cell cavities. The breakthrough of this novel technology requires R&D effort by the Niobium industry for large scale production of appropriate ingot raw material. This would revolutionize the Niobium cavity fabrication with respect to fabrication cost and cavity performance. JRA-SRF has created one of the world leading centers of excellence in this field.
- Dry ice cleaning is an alternative method to high pressure water cleaning. An experimental set up for dry ice cleaning has been built and was operated in order to determine the optimum parameter set. Sample investigations demonstrated that the dry ice cleaning effect is superior to the high pressure water process. But this benefit could not be verified with Niobium cavities. However dry ice should be an optimum choice where the use of water is not recommended. This is the case for the normal conducting copper RF gun cavity where the water jet would oxidize the copper surface. As a first experiment the RF gun of FLASH has been cleaned by the dry ice method. The dark current of the RF gun could be substantially reduced by this procedure. This positive proof of principle experiment will initiate an activity to optimize the dry ice cleaning apparatus for RF gun cleaning. This effort will be beyond CARE but is an example of spin off technology from CARE activities.
- The standard electropolishing electrolyte is based on hydrofluoric acid (HF) which is very toxic. JRA-SRF has investigated HF free electrolytes. The most promising alternative is based on Chocline which forms an ionic liquid. Intensive studies with samples explored the parameter space of this solution (one PhD work). The surface of samples is very shiny, which is considered to be a necessary condition for good RF performance. The transfer of this technology to cavity application is rather complex and could not be finished within the scope of CARE. TTC (TESLA Technology Collaboration) has recently started a global activity to further investigate this novel EP technology. This is another example of global impact of the R&D work in CARE.
- The characterization of the transverse phase space for high charge density and high energy electron beams is demanding for the successful development of the next generation light sources and linear colliders. The interest in a non-invasive and non-intercepting beam diagnostics is increasing due to the stringent features of such beams. Optical Diffraction Radiation (ODR) is considered as one of the most promising candidates to measure the transverse beam size and angular divergence, i.e. the transverse emittance. JRA-SRF has developed a prototype of such a monitor. An experiment has been set up at the DESY FLASH Facility to measure the electron beam transverse parameters based on the detection of the ODR angular distribution. The experiment confirmed that ODR can be used as a non intercepting beam size diagnostics, allowing also the simultaneous measurement of the beam angular spread. The remaining difficulty is to lower the background of synchrotron radiation from bending and quadrupole magnets.

Summary Table of the main JRA-SRF Achievements and their impact on the Scientific Infrastructure

Selected Achievements	Main improvement	Direct impacted infrastructure	Future impacted infrastructures	Industrialisation
Helium vessel / cavity design	low cost, high mechanical stiffness	FLASH, XFEL	any pulsed SC linac for electrons	
Standard electro-polishing, EP	Industrialisation finished	XFEL	all SC linacs world wide	Tranfered to industry
Tuner design	two designs completed	XFEL	ILC, ALICE, RIB,ERL linacs	
Beam position monitor	high resolution	FLASH, XFEL	ILC, ALICE,ERLs	
SQUID scanner	Higher sensitivity than EDDY current device			Built by industry
Seamless cavity design	no performance limitations by welds	FLASH,	ERLs	Patent granted
Low level RF, LLRF	Advanced design	FLASH, XFEL	ILC, ALICE, RIB,ERL linacs	
Input coupler	Short conditioning time	FLASH, XFEL	ILC, ALIC, ERLs	
Large grain / single crystal cavity	Cost reduction & performance upgrade	FLASH	XFEL,	Patent granted
Dry ice cleaning	New cleaning method without water	FLASH	XFEL, ERLs	
Electro polishing without Hf acid	Avoids chemical hazard	FLASH	all SC linacs world wide	
Beam emittance monitor	Non intersepting monitor	FLASH	ILC, XFEL,	
Cry-Ho-Lab	New SCRF test facility	FLASH	ILC, XFEL, any SCRF project	

Summary of the JRA1 activities

Workpackage 2: "Improved standard cavity fabrication"

The main task in this workpackage was to find critical issues in the present cavity ancillaries, to improve the reliability of the existing components, to propose new cheaper solutions for the accelerator components of future large SC linacs. Taking into account the experiences with SC cavity auxiliaries in several laboratories this work concentrated on specific items, namely the cold joint system (cold flanges), the He-tank with the tuning system, and in particular its connection to the cavity. The He-tank and its connections to the cavity (end dishes) has been concretized both in a full dressed cavity prototype with modified He tank and in the realization of two simplified end groups with a new geometry. The experimental research activity has been supported by a thorough study of the stiffness behavior of the dressed cavity defining a spring model that was experimentally validated during tests in CHECHIA and at BESSY. This effort resulted in a simplification of the construction and welding procedures so that a considerable reduction of fabrication costs could be reached.

Workpackage 3: "Seamless cavity production"

Seamless cavity fabrication technology was investigated in order to avoid e-beam welds. The promise of this technology is cost and risk saving (no weld defects). Several single and multi-cell cavities were fabricated by hydro-forming and spinning. Hydro-forming is most advanced and could be transferred to industry. A German patent was granted for this new technology. This is an available and interesting alternative fabrication technology for new projects, especially those which require a large number of resonators.

Workpackage 4: “Thin film cavity production”

The main aim of this workpackage was to develop a new method of thin film coating by means of arc discharges under ultra-high vacuum (UHV) conditions. Instead of RF cavities made of bulk Nb one could apply Cu-cavities coated with thin Nb-layers.

Two different coating methods were investigated: Linear-Arc Cathode Coating and Planar-Arc Cathode Coating. Those tasks were based on different geometries of the cathode and they used different experimental facilities, but they explored the same principle and they applied identical measuring techniques. One common problem was to filter the micro-droplets which are produced by the arc process. Magnetic and electric bending was successfully applied to separate the stream of ionized Niobium atoms from the droplets. Several Cu cavities were coated by vacuum arc but adhesion problems of the thin Niobium film deteriorated the RF properties.

Workpackage 5: “Surface preparation”

Electropolishing is considered to be an important and critical step in the preparation chain of superconducting Niobium cavities. Several activities were conducted to optimize and industrialize this technology:

- the parameter space of electropolishing was investigated to define the best operating parameters
- computer simulations were used to determine the best cathode geometry
- a complete 9-cell cavity electropolishing installation was designed, built and operated
- an automated control system for the electropolishing installation was developed and will be used at the DESY system
- quality control methods were developed in cooperation with industry
- the technology of electropolishing was transferred to industry (Henkel, ACCEL) in preparation for the XFEL production.
- an alternative electrolyte without use of the dangerous HF acid was proposed and used for sample treatments.

These activities pushed the electropolishing technique from the state of experimental laboratory installation to complete industrialized standard. The chemical processing of the cavities for XFEL will be based on this industrialized process. Furthermore this industrial competence is now available for any new accelerator project using superconducting cavity technology.

Workpackage 6: “Materials Analysis”

Material analysis is an important QA step to assure a high quality of the Niobium sheets. Eddy current scanning was developed at DESY and is under regular for quality test of Niobium sheets. A superconducting SQUID element as detector of the EDDY currents should considerable increase the sensitivity as compared to the normal conducting coil. In cooperation with the company WSK such a SQUID scanner was designed, built and tested. Compared to the conventional normal conducting pick up coil the sensitivity could be increased by a factor 4.

As an alternative to the SQUID detector a flux gate magnetometer was tested for Niobium sheet scanning. But the sensitivity of this device was only comparable to the standard coil pick up system. However, an interesting new application for the flux gate magnetometer was explored: this device allows to measure the electropolishing current outside of the cavity and is thus an in situ check of the EP removal rate.

An apparatus for DC scanning of NB sample surfaces was designed, built and operated. Particles on the surface were characterized by their size, composition and field emission current. Also the cleaning efficiency of NB surfaces by high pressure water and dry ice jets were compared. One interesting result was that single crystal surfaces after dry ice cleaning were nearly free from foreign particles.

Workpackage 7: "Input couplers"

In the framework of this work package LAL-Orsay developed two new prototypes of power couplers for superconductive cavities, the TTF5 (TTF version 5) and the TW60 (Traveling Wave with coax outer diameter of 60 mm). The TTF5 is based on a modification of the TTF3. It is conceived to reduce the multipactor activity which depends on the coupler diameter and impedance. For this a larger cold part (the part that is in contact with the cavity) has been adopted passing from 40mm to 62mm.

The alumina ceramic of the window exhibits a high secondary emission yield (SEY) which might initiate RF breakdown by the multipactor effect. TiN coating is a well known remedy against multipacting. It was very important to grow this thin TiN film with constant thickness over the whole window surface. The stochiometry of the TiN film was measured at samples and stayed within 2% of the ideal value.

An important activity has been dedicated to the conditioning procedure of an existing and operating coupler model (the TTF3). The goal was to reduce its time duration and to provide a standard automatic procedure that can act as a reference for the new designs. In this framework excellent results were obtained by decreasing the average conditioning time from around hundred hours to twenty hours.

Workpackage 8: "Tuners"

The main aim of the work package was to develop an electromechanical tuner for superconducting cavities (SC). The development of active tuner systems is imperative for operation of SC cavities at high gradient especially the one which operates in pulse mode like the TESLA type one.

Slow tuners are required to tune the cavities to the correct frequency at cryogenic temperatures. Two different types of these tuners were developed: the end group tuner (CEA tuner) as foreseen for FLASH and the coaxial liquid Helium tank tuner as planned for ILC.

Fast tuners are required to counteract the so-called Lorentz de-tuning effect when the cavities are pulsed at high field so as to maintain the phase and amplitude constant during the RF pulse. Four of the participating laboratories were investigating innovative tuner systems as well as developing the electronic drive circuitry necessary for them. The active elements were investigated to assure proper operation. The research was focused on the piezoelectric elements. The optional magneto-strictive tuners were also investigated.

Workpackage 9: "Low Level RF (LLRF)"

The objective of the WP09 (LLRF) has been to advance RF Control Technology in the areas of hardware and software to meet the requirements for linear colliders and linacs based free electron lasers (FEL and XFEL). The work has been focused on the following topics:

- Pushing the technical performance such as field regulation close to the operational limits of the cavities and high power systems
- Compatibility with tunnel installation including low maintenance and radiation tolerance
- High degree of automation for large scale systems for adequate operability of large scale systems
- Reliability and availability optimization in connection with cost reduction

Several tasks had been defined to achieve these goals. For RF field control a new generation of hardware for down-converters, analog to digital conversion and fast signal processing with low latency communication links had been developed and successfully tested at FLASH. The field stability has been improved by a factor of three (up to 0.01 deg. in phase) by lowering the noise in the analog section and reduction of the latency in the feedback loop therefore allowing for higher feedback gain. Also a better stability of the master oscillator and frequency distribution system in terms of phase noise and phase drifts helped to support better short term and long term stability. The cavity field of the RF gun has been estimated from forward and reflected power because here no field probe is available. For the required precise calibration of these signals a procedure based on beam diagnostics has been developed and successfully applied at FLASH. This calibration ensures a long term field stability of 0.2 deg. over a wide range of cavity detuning.

Radiation tolerance for neutron induced single event set-up (SEU) has been achieved by triple redundant implementation of some critical algorithms. A start-up of a large accelerator requires initial phasing with a few electron bunches to minimize beam loss. With dedicated electronics the phase of individual 1nC bunches can be measured with an accuracy of 3 degrees. Operability has been improved by implementation of an automation scheme in the control system for FLASH. Some fundamental exception handling capability such as quench detection and recovery have improved the availability at FLASH significantly during high gradient operation. Piezo-control with low power drivers and resonant excitation support high gradient operation with up to 1 kHz of detuning compensation while ensuring low stress and therefore long lifetime of the piezo actuators.

Overall the LLRF hardware and software currently implemented at the RF Gun and at the first cryomodule at FLASH as the result of the LLRF work in FP6 are considered pioneering work in this field. While several other labs and industry just started to follow the hardware development in this area, the software developed and evaluated in this framework has not only improved the field regulation but also paved the way to high availability, simplicity of operation, and exploration of operation close to the performance limits of cavities and high power systems.

Workpackage 10: “Horizontal cryostat integration Tests”

The horizontal cryostat facility Cry-Ho-Lab was installed at Saclay to serve as infrastructure for testing superconducting 1.3 GHz cavities including auxiliary components such as input couplers and tuners. Concerning SRF-JRA, new “high power couplers” and a “cold tuning system” equipped with different fast tuners previously designed in work packages WP7 and WP8, were planned to be tested at high RF power (1.5 MW pulsed – 1 ms – 10 Hz) on a fully equipped 9cell cavity (1300 MHz). Moreover, synergy with CARE HIPPI gives now the possibility to test easily in this RF facility different sizes of multi-cell cavities at 700 and 1300 MHz. Two separate waveguide lines are installed with different high power coupler ports on the cryostat. A common modulator connected to 1.3 GHz Thales and 700 MHz CPI klystrons complete the RF platform as a power supply.
CryHoLab at CEA, CHECCHIA at DESY and HoBiCaT at BESSY are infrastructures to test multi-cell superconducting cavities in similar conditions as in accelerator cryomodules.

Workpackage 11: “Beam diagnostics”

- **Beam position monitor.**

  The reentrant cavity BPM is specially designed to be connected to superconducting cavities which are particularly sensitive to dust particle contamination, and care must be taken to avoid introducing any source of such contamination. This monitor is composed of a radio-frequency reentrant cavity with a beam pipe diameter of 78 mm, four feedthroughs, and electronics which perform signal processing. Its response is linear and accurate; further it can also measure the beam charge. A first prototype of a reentrant BPM has delivered measurements at a temperature of 2 K inside a cryomodule in the FLASH linac. Linearity around ± 1.5 mm was shown and a resolution of about 20 µm was achieved. The performance of this BPM was analyzed and the limitations of this existing system clearly identified. The second prototype showed a sensitivity about a factor of 5 higher than comparable monitors. It was decided that 50 of these beam monitor will be built and installed in XFEL as standard beam position monitors. This monitor will be an excellent diagnostics tool for any present or future superconducting electron linac.

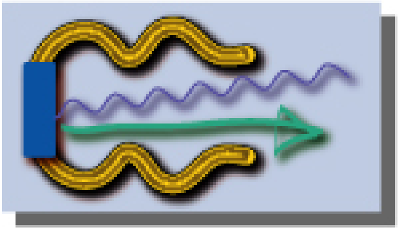
- **Beam emittance monitor.**

  The characterization of the transverse phase space for high charge density and high energy electron beams is a big challenge for the successful development of the next generation light sources and linear colliders. The interest in a non-invasive and non-intercepting beam diagnostics is increasing due to the stringent features of such beams. Optical Diffraction Radiation (ODR) is considered as one of the most promising candidates to measure the transverse beam size and angular divergence, i.e. the transverse emittance. This was our goal. An experiment, based on the detection of the ODR angular distribution, has been set up at DESY FLASH Facility to measure the electron beam transverse parameters, in order to retrieve the normalized transverse emittance. We could confirm that ODR can be used as a non intercepting beam size diagnostics, allowing also the simultaneous measurement of the beam angular spread. The main drawback, i.e. the background of synchrotron radiation from bending and quadrupole magnets, was strongly reduced by means of a stainless-steel shield with a larger cut in front of the screen.

JRA2: Charge production with Photo-injectors

Acronym: **PHIN** **Coordinator**: ***A. Ghigo (INFN-LNF)***

Deputy: ***L. Rinolfi (CERN)***



Participating Laboratories and Institutes:

Institute	Acronym	Country	PHIN Scientific Contact
STFC Rutheford Appletone Lab. (22)	STFC-RAL	UK	G. Hirst
CERN Geneva (19)	CERN	CH	K. Elsener
CNRS-IN2P3 Orsay (3)	CNRS-Orsay	F	G. Bienvenu
CNRS Lab. Optique Appl. Palaiseau (3)	CNRS-LOA	F	V. Malka
ForschungsZentrum ELBE (10)	FZR-ELBE	D	J. Teichert
INFN-Lab. Nazionali di Frascati (11)	INFN-LNF	I	A. Ghigo
INFN- Milan (11)	INFN-MI	I	I. Boscolo
Twente University- Enschede (13)	TEU	NL	P. van der Slot

Main Objectives: Perform Research and Development on charge-production by interaction of laser pulse with material within RF field and improve or extend the existing infrastructures in order to fulfil the objectives. Coordinate the efforts done at various Institutes on photo-injectors.

Illustration of the Main Hardware Realisations of PHIN

Figure 1: Layout of the PHIN CTF3 line

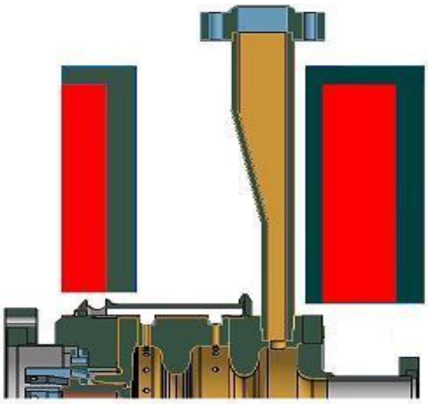


Figure 2: RF gun that LAL build for CERN and for NEPAL.

Figure 3: Accelerator in the NEPAL test room.

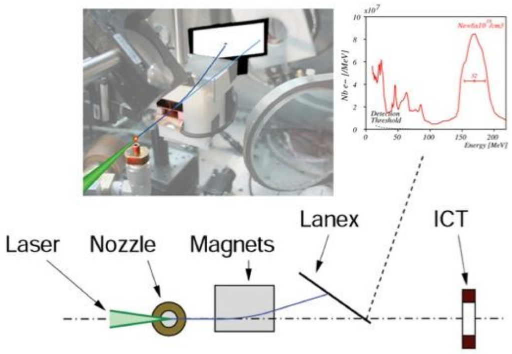


Figure 4: Experimental set-up and spectra obtained in the bubble regime.

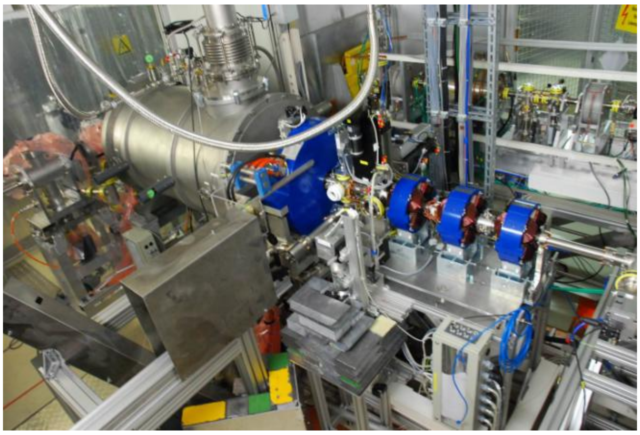


Figure 5: SRF photoinjector in the ELBE accelerator hall.

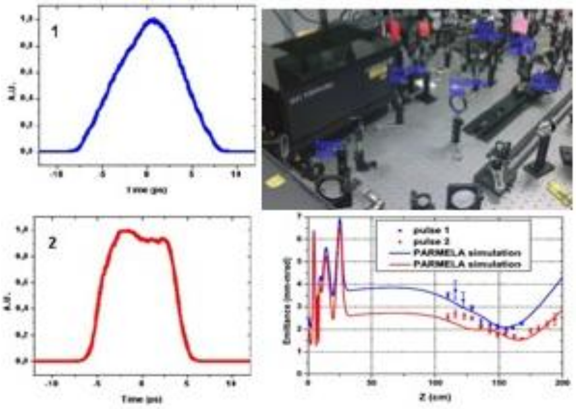


Figure 6: Simulated and measured emittance oscillation for Gaussian and square laser pulse shape

Aims of PHIN

The PHoto-INjectors (PHIN) JRA of CARE has held its kick off meeting in November 2003 at CERN and has been active from 1 January 2004 until 31 December 2008, with the goal of performing Research and Development on charge-production by interaction of laser pulse with material within RF field and improving or extending the existing infrastructures in order to fulfil the objectives.

It originally involved eight Institutes (RAL from UK, CNRS-LAL-Orsay and CNRS-LOA from France, FZR from Germany, INFN-LNF and INFN-Milan from Italy, Twente University from Nederland and CERN), later reduced to seven when RAL quit the PHIN collaboration in 2006.

The PHIN activities were focused at developing the technology for upgrading the accelerator infrastructure of five European Laboratories: LAL in France, FZR in Germany, LNF in Italy, TEU in Nederland and CERN.

The PHIN work was mainly devoted for:

- the development of future e^+e^- colliders. In particular, the high charge e^- beam for the RF power source of the two-beam linear collider CLIC (CERN).
- the realisation of the first photoinjector that uses a photocathode, laser driven, in a superconducting RF gun for application in ELBE (Rossendorf).
- the realisation of new electron source for NEPAL (Orsay) test stand.
- the realisation of a new laser profile for SPARC (Frascati).
- the development of laser-plasma acceleration in LOA (Palaiseau).
- the realisation of the new injector for TEU-FEL (Twente) including methods to improve the stability and durability of the cathodes under various modes of operation.

Highlights for the PHIN projects

☐ Summary of main achievements

1) CTF3

The PHIN photo-injector foreseen for the CTF3 Drive Beam has been completed on a dedicated stand-alone test bench. The photo-injector operates with a 2.5 cell RF gun working at 3 GHz. A 30 MW modulator-klystron has provided the necessary power to the RF gun and an accelerating field of 85 MV/m was obtained. A UV laser beam at 262 nm has been sent to the Cs_2Te photocathode. The Nd:YLF laser system consists of an oscillator, a preamplifier operating at 1.5 GHz and two powerful amplifier stages. The infrared radiation (1047 nm) produced at the source had its frequency quadrupled in two stages to obtain the UV light (262 nm). The synchronization between the RF and the laser was better than 1 ps. The train length was 1300 ns composed of 1908 bunches in the train.

2) NEPAL

The present RF gun is called AlphaX gun and is temporarily installed waiting for the third PHIN gun which is under construction. The laser routinely produced 100 µJ at 262 nm which are enough to get more than 1 nC electron bunch with Cs_2Te photocathode. The commissioning of the new modulator has started. The complete NEPAL beamline was completed in June 2008.

3) ELBE

The first accelerated beam of the superconducting RF gun was produced in November 2007 using a copper photo cathode. In 2008, the cathode transfer system was completed and the SRF gun was operated with Cs_2Te photo cathodes. The gun was operated in parallel to the user operation of the ELBE accelerator. The average current was mostly about 1 µA. During the beam time the acceleration gradient was always 5 MeV/m which belongs to 13.5 MV/m peak field in the cavity and about 4.5 MV/m at the photo cathode. In the operation period of the SRF gun in 2008, optimization and measurements were carried out concerning the photo cathodes, the driver laser system, the cryogenic system, the RF system and the cavity parameters and the electron beam production and characterization.

4) SPARC

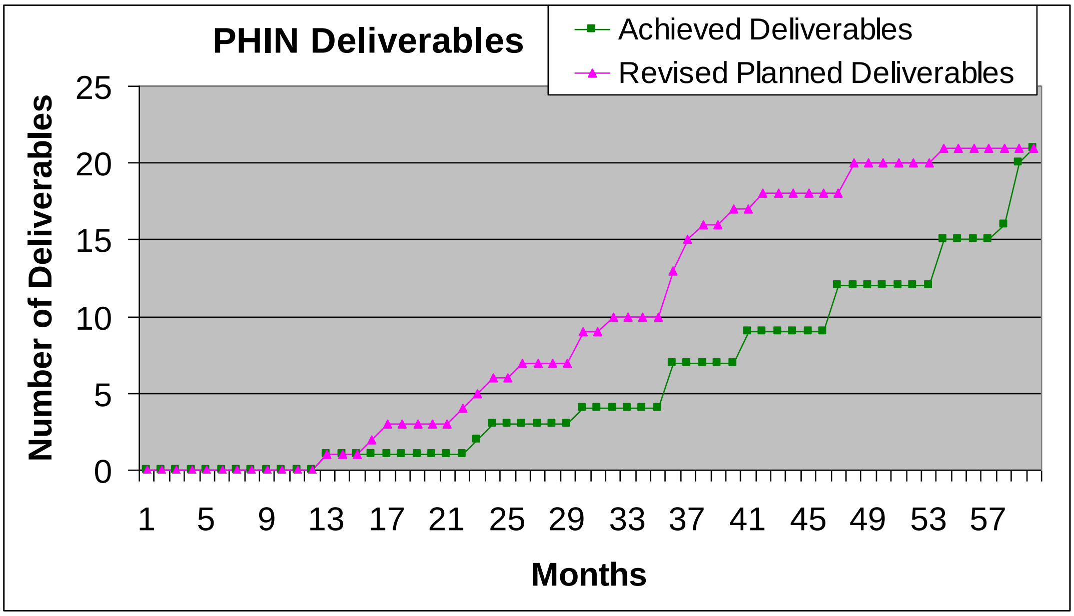
In the SPARC photoinjector the emittance evolution of the electron beam has been measured with Gaussian and square laser pulse longitudinal distribution. The comparison of the results, with the same photoinjector parameters, shows that the square pulse improves the beam emittance and the project value, 1.5 mm mrad, has been achieved. The two laser pulse-shaping system, the DAZZLER and liquid crystal mask, proposed in PHIN JRA have been tested with very good results.

5) PHOTOCATHODE DEVELOPMENT AT TEU

Based on literature and own work, a model for Cs:Te photocathodes has been formulated that may explain the observed differences in performance. To validate this model and enhance the in-situ diagnostics for Cs:Te photocathodes, ellipsometery study has been performed.
Ellipsometery is a complementary in-line diagnostic that can be used to help understand the physics of Cs:Te photocathodes that will eventually lead to better photocathodes.

☐ Deliverables

PHIN had scheduled 21 deliverables. They have been all achieved within the 5 years of CARE as can be seen on the table below.



☐ Dissemination

Dissemination of PHIN results took place mostly at Conferences, as it is custom in the linear accelerator community. PHIN was represented at the large accelerator conferences EPAC04, PAC05, FEL05, SPIE-Congress 2005, Advanced IFCA Beam Dynamics Nanobeams05 workshop, EPAC06, FEL06, Advanced IFCA Beam Dynamics ERL07 workshop, SRF07 Workshop on RF superconductivity, EPAC08, FEL08, as well as at a variety of smaller conferences dedicated to more specific subjects. Altogether, PHIN has made 30 contributed papers at major Accelerator Conferences during the duration of the Activity and 50 invited conference-talks. In addition, 25 refereed papers have been produced as well as 3 PhD theses. The CARE reports and notes were generally written in support of a specific deliverable or achievements. In total PHIN has produced 93 CARE referenced documents, as show in the table below.

	2004	**2005**	**2006**	**2007**	**2008**	**sum**
CARE Notes	2	1	1	0	1	**5**
CARE Publications	2	5	10	2	6	**25**
CARE Reports	1	6	5	8	10	**30**
CARE Conferences	6	5	8	5	6	**30**
CARE Thesis	0	2	0	1	0	**3**
Total	**11**	**19**	**24**	**16**	**23**	**93**

The Activity has organized every year a series of Meetings. The Table below reports the PHIN Annual Meetings.

Date	**Title/subject**	**Location**	**Number of participants**
19 November 2003	Kick off PHIN meeting	CERN(CH)	20
5 May 2004	First PHIN meeting In parallel with ELAN meeting	Frascati (I)	15
3 November 2004	Second PHIN meeting	Hamburg (D)	15
23 November 2005	Third PHIN Meeting	CERN (CH)	15
17 November 2006	Fourth PHIN Meeting	Frascati (I)	15
31 October 2007	Fifth PHIN Meeting	CERN (CH)	15
17-18 July 2008	Sixth PHIN Meeting	Lecce (I)	10
2-3 December 2008	Seventh PHIN Meeting	CERN (CH)	10

Several meetings took place as Video-conferences between different institutes over the 5 years.

☐ Main impacts of the PHIN achievements

1) A first photoelectron beam for the CTF3 has been produced in November 2008, validating the design of the photo-injector. The construction of the 3 sub-system (laser by RAL, RF gun by LAL and photo-cathodes by CERN) was crucial. This achievement for the CTF3 Drive Beam will contribute to the development of the future CLIC linear collider.

2) The upgrade of the NEPAL beamline will allow French and European community in accelerator technology to test accelerating structures. Moreover the electron beam produced will be available for users in chemistry, solid science and laser-plasma acceleration. Such test accelerator infrastructures are very useful.

3) New injection schemes, which allow the production of stable electron beam with tunable parameters, have been demonstrated by LOA using one or several laser pulses. The properties of the electron beam are promising for future applications and will open new collaborations with French and European community in accelerator technology. This laser plasma accelerator will be used to test new diagnostics for emittance measurement and beam transport. It will allow coupling with undulators for FEL studies and the exploration of applications in medicine and material science.

4) The new superconducting RF photoelectron injector, which is the worldwide first operating injector of its kind, essentially improves the ELBE accelerator facility since it combines high beam brightness and high average current (CW operation). Providing beam for regular user operation in 2009, it will impact the scientific output with respect to parameter range and quality and will open a new experimental field combining high-brightness electron beams and high-power lasers. In the long term the developed SRF gun will be applied for the proposed BERLINPRO high-current ERL.

5) The study and application of the laser pulse shaping in the SPARC photo-injector improve the knowledge in the laser pulse manipulation technique with acousto-optic modulators and liquid crystal masks. These activities have a strong impact in the laser community that work in the short pulse (pico-femtosecond) regime. The comparison of the emittance measurements with different longitudinal distributions at the exit of the RF gun has shown the better value with uniform electron extraction.

These achievements will contribute to the future high brightness photo-injector with special benefit for the Free Electron Laser.

6) Ellipsometery can be used both for the manufacturing of the cathodes and monitoring of cathode performance in accelerators. In the long term this may lead to longer lifetimes, as damage mechanisms under operational conditions, becomes better understood.

Summary Table of the main PHIN Achievements and their impact on the Scientific Infrastructure.

Selected Achievements	Impacted infrastructure	Main improvement	Future impacted infrastructure	Expected future impacts
Drive beam injector development	CTF3 at CERN	Production of the nominal electron beam	CLIC Drive Beam injector	High beam performance for future linear colliders
RF gun development	NEPAL at LAL	Excellent performance for RF guns working at high current	PHIL test stand	Chemistry, solid science for European community
New injection schemes for laser and plasmas	LOA at CNRS	Production of stable electron beam with tunable parameters	Future undulators and FEL	Applications in medicine and material sciences

First operating superconducting RF photo-injector	ELBA at FZR	High brightness and high average current	BERLINPRO high current ERL	Large parameter range for high average current (CW operation)
Pulse shaping for very short laser pulse	SPARC at LNF	Improvements of knowledge in laser pulse manipulation techniques	SPARX and future FEL	High brightness photo-injectors
Ellipsometry development	FEL at TEU	Monitoring the fabrication of photo-cathodes with great accurary	Future FEL	Reliable photocathodes with longer lifetime and high performance

Summary of the PHIN projects

CTF3 project

The CLIC project has many novel concepts which have never been used before and some parameters are approaching the limit of available technology. The main R&D effort within the CLIC study is aimed at answering these major feasibility issues. One line of this R&D goes into the development of a photo-injector to be implemented into the CLIC Test Facility CTF3. The aim is to demonstrate the key feasibilities by the year 2010.

After the 5 years of R&D with PHIN, the installation of the new photo-injector foreseen for the CTF3 Drive Beam has been completed on a dedicated stand-alone test bench (figure 1). The photo-injector operates with a 2.5 cell RF gun working at 3 GHz.

LAL delivered the RF gun with very demanding specifications: an average current of 3.5 A in the RF pulse, more than 2000 bunches. Figure 2 illustrates all the complexity of this photo-injector which includes also all the mechanical supports, vacuum systems and magnetic coils. A prototype of the RF gun has been ordered in 2005 and the definitive RF gun was ordered in 2006. RF measurements and mechanical adjustments on the gun were finished in 2007. Then the NEG chamber was welded in the end of April 2008. Finally the gun was tested for RF parameters and vacuum, no leak was detected. The RF gun was installed in the CTF2 experimental area at CERN with the help of the LAL staff in June 2008.

A 30 MW modulator-klystron provides the necessary power to the RF gun in order to get an accelerating field of 85 MV/m. A UV laser beam at 262 nm illuminates the Cs_2Te photocathode. The Nd:YLF laser system consists of an oscillator, a preamplifier operating at 1.5 GHz and two powerful amplifier stages. The infrared radiation (1047 nm) produced at the source has its frequency quadrupled in two stages to obtain the UV light (262 nm). The synchronization between the RF and the laser is better than 1 ps. The train length for CTF3 is 1.272 μs. There are 1908 bunches in the train. Assuming a quantum efficiency of the photo-cathode of 3 % and laser energy of 370 nJ/pulse on the photo-cathode, the requested charge of 2.3 nC per bunch could be obtained.

Concerning the laser system, the oscillator, the preamplifier and the two powerful amplifiers have been tested. The crystals for the second and fourth harmonic conversion process have converted the infrared to green (523 nm) and then to UV with high efficiency. The laser chain has been optimized to yield the best performance for the present configuration. Improvements of the performance of the second amplifier are ongoing. As a consequence the harmonic generation scheme will be changed to better match the full amplified beam yielding the highest conversion efficiency for the all process.

Measurements of the stability and losses at the sections (fiber launch, modulator, fiber beam splitter, fiber-fiber junctions) have been made for the Phase-Coding system. The test of the principle of operation of the entire Phase-Coding system was also successfully performed.

The expected and nominal quantum efficiency of the photocathode is 3%. A much higher value has been measured, at the beginning of the operation. After a one year of storage time this efficiency was reduced. All measured RF parameters of the RF gun correspond to the ones expected.

Although many difficulties were encountered for the PHIN CTF3 photo-injector, during the 5 years of design, construction and tests, a first photoelectron beam has been produced in November 2008, validating the design of this photo-injector.

NEPAL project

LAL received 210 k€ to build a photo-cathode preparation chamber. This device is indispensable in order to get photo-cathodes with a coating of Cesium Telluride (CsTe) which needs an ultra-high-vacuum (UHV) environment. Technical drawings of the vacuum chamber have been done in 2004. Then, in 2005, the vacuum tank designed to make alkaline deposits on photocathode substrate has been machined in the LAL workshop.

LAL received 225 k€ to buy a UV picosecond laser which will be used to produce a bunch of electrons from a photo-cathode in the radiofrequency (RF) gun. A ND:YLF picosecond mode locked laser, produced by the HighQ company delivers one single pulse at 5 Hz repetition rate, but it is possible to increase it up to 100 Hz. It is used on the fourth harmonic, at 262 nm wavelengths. The pulse energy at the exit of the laser box is 90 µJ in UV light. The pulse length duration is 8 ps (FWHM). The optical path length between the laser hutch and the photocathode of the gun is about 17 m. The RF guns and beam dynamics work package represented the largest amount of work for LAL.

The objectives were an upgrade of the NEPAL station in order to host a copy of the RF gun designed for the drive beam linac of CTF3. In addition LAL should proceed to systematic measurements of the electron beam produced by this photo-injector in the NEPAL station. The beamline was completed in June 2008 with delay due to the safety requirement: the ceiling has been shielded with 1.4 m thickness of concrete and the experimental area was available for the installation of the components at the end of 2007. The fabrication of a third PHIN gun has begun at the LAL workshop. This new gun will be not available before June 2009. Waiting for the PHIN gun it was decided to install in the NEPAL station another 3 GHz RF gun built by LAL called AlphaX RF gun. All the other components have been installed since June 2008 as one can see on the picture of the accelerator (Figure 3).

Plasma laser project

The purpose of our contribution in the project was the development of a compact and efficient “photo-injector” which produces directly an energetic electron beam by lasers and plasmas. Compact single shot electron spectrometers were designed, build and tested to optimise the coupling of the laser beam into the electron beam and especially to control the electron distribution energy. This development has allowed us to understand specific features of the interaction, to demonstrate new schemes of injection (bubble and colliding), and to explore new applications.

Experiments done at LOA facility with the compact 10 Hz, 40 TW powerful laser system of the “salle jaune” have produced quasi monoenergetic electron beams in the bubble or in the colliding laser pulses regime. Figure 4 shows the experimental set-up and typical electron beam produced in the bubble regime. The 6 cm diameter laser beam was focused using a 1 m focal length off axis parabolic mirror, producing a laser intensity of $I=3.2\times10^{18}W/cm^2$. The focal position and its value with respect to the sharp gas jet gradient have been measured and varied in order to optimise the electron beam parameter. This optimum position is found when focusing the laser beam on the edge of the plateau of the gas jet.

A second approach to generate quasi monoenergetic electron beams is based on the use of two laser pulses. The first laser pulse, the “pump” pulse, creates a wakefield whereas the second laser, the “injection” pulse is only used for injecting electrons. The laser pulses collide in the plasma and their interference creates an electromagnetic beatwave pattern which pre-accelerates some electrons. A fraction of these has enough energy to be trapped in the wakefield driven by the pump pulse and further accelerated to relativistic energies. This scheme offers more flexibility: experiments have shown that the electron beam energy can be tuned continuously from 10 to 250 MeV.

The electron beam has a quasi-monoenergetic distribution with energy spread in the 5-10 % range, charges in the 10-100 pC range and its parameters are stable within 5-10%. This approach is promising for the control of the electron beam parameters, and might allow changing both the charge and the energy spread.

In collaboration with the LLR laboratory, we have developed a 1% energy resolution spectrometer using three quadrupoles and shown that the energy spread of about 1% can be produced with laser plasma accelerators.

These electrons beam have been shown to be relevant for many applications such as radiotherapy and γ radiography.

ELBE project

Many of the most exciting and demanding applications for electron accelerators require electron beams with an unprecedented combination of high-brightness, low emittance and high average current. One very promising approach is the superconducting radio frequency photoinjector (SRF gun). State-of-the-art conventional photoelectron injectors (using normal conducting RF) can deliver electron beams of the highest brightness, but with low average current only. Superconducting acceleration technology is the most suitable for high average currents because of the very low RF losses and the straightforward continuous wave operation. The new SRF gun at the ELBE facility combines these two advantages. Even though proposed about twenty years ago, this gun is the first operating injector of this type installed at an accelerator worldwide. The greatest challenges have been the development of a suitable acceleration cavity and the difficulties associated with the photo cathode.

In 2004 the R&D project for the ELBE SRF gun was launched within the PHIN Joint Research Activity of CARE. The new photo cathode preparation equipment for Cs_2Te was built. The niobium cavity, the helium cryostat and the other subsystems of the gun were designed and constructed. Within a German collaboration (BESSY, DESY, MBI) the laser system and the diagnostic beam line were built. The SRF gun cryomodule was installed in July and the first cool-down was performed in August 2007. A photograph of the SRF gun after completed installation is shown in Figure 5. The first accelerated beam was produced on November 12, 2007 using a copper photo cathode. In 2008, the cathode transfer system was completed and the SRF gun was operated with Cs_2Te photo cathodes. The beam time was used for parameter optimization, RF parameter studies, and electron beam characterization.

In 2009 the SRF gun will deliver the first beam for user experiments at ELBE. The SRF gun will improve the beam quality in several respects, and is a center piece of the future developments in advanced radiation and particle sources: The experiments with neutrons and positrons can be carried out at high bunch charges. For the FEL operation at ELBE a higher stability, higher infrared power, and an extended parameter range can be expected. Also, better electron beam quality is an essential ingredient for future experiments which will combine the ELBE electron beam with the new ultra high-intensity laser system, “Draco”.

SPARC project

The electron beam emittance produced by the high field RF photoinjector is one of the most important characteristics for the new generation of high brightness accelerator devoted to the free electron laser. In order to reduce the emittance, the electrons have to be extracted with uniform density along the RF accelerating field. Since there is an optimal RF phase for electrons emission, stringent requirements are imposed on the laser to RF synchronization. The aim of the second task of the Work Package 3 of JRA2-PHIN was to produce a flat top longitudinal photon pulse distribution of the laser used to extract photoinjector and to verify the synchronization between the laser pulse and the RF accelerating field.

The two technologies quoted in the CARE program, LCP-SLM liquid crystal programmable spatial light modulator and AOM-PSLM/DAZZLER the acoustic-optic programmable dispersive filter, have been studied, compared, developed and implemented in the Frascati-SPARC facility for the generation of UV-rectangular laser pulses driving the radiofrequency electron gun.

Its features of simplicity, robustness and rise-time better than the two up-to-now proposed optical systems led to its adoption as laser shaping system at the SPARC facility.

A scheme for shaping a laser pulse into trains of sub-picosecond pulses for the generation of patterned sub-picosecond electron trains in a radiofrequency electron gun has been proposed and studied together with start-to-end simulations in the Frascati-SPARC accelerator.

The measurements have been performed with the frequency tripled Ti:Sa laser system used to drive the SPARC photoinjector at LNF-INFN. In order to produce a square laser pulse with rise and fall time of 1 ps and a 10 ps flat top an acousto-optics modulator, namely the DAZZLER, and a liquid crystal spatial modulator have been installed in the photoinjector laser.

Since these shapers are installed before the amplification and the third harmonic generator, the resulted UV pulse is suffered strong distortions due to the non-linearity of the amplification and harmonic conversion crystals. To improve the rise time of the flat top pulse we specifically designed an optical system based on the UV stretcher in which the tails of the frequency spectrum are cut away. The system reported in Figure 6, is now installed and routinely in operation.

The activity on the laser pulse temporal shaping has been completed measuring the electron beam emittance downstream the RF electron gun of the SPARC photoinjector. The electron beam has been characterized by a movable emittance meter, able to follow the emittance evolution from 1 to 2 meters from the photocathode. The Gaussian and flat top laser have been set for a FWHM of 10 ps and an electron beam charge of 1 nC.

The synchronization between the laser pulse and RF Phase in the gun has been measured with an innovative method in which the signal of the laser pulse detected by a fast photodiode is injected in a RF cavity. By mixing the ringing signal produced in the RF cavity and the local oscillator a synchronization measurement has been performed. A value of synchronization of 200 fs rms (long term) between the laser pulse and RF field has been measured, that is better than what we need in SPARC. The measured phase noise is used for active control of the RF phase and compensation of long term drifts.

The measured and the simulated normalized projected emittance are shown in Figure 6. It is clear that for the flat top pulse, reported on the red curve, the minimum of the emittance is lower than the one recorded starting from a Gaussian pulse (blue curve). The experimental measurement for the emittance (points) is in good agreement with PARMELA simulation (solid curve). Moreover the measured normalized emittance 1.5 mm*mrad is better than the nominal value specified for the SPARC experiments.

Photo-cathodes development project

Within this work package we have mainly focused on photocathodes based on Cs:Te. Based on own experiments, the data provided by partners and a literature study we have made an extensive survey on Cs:Te photocathodes. This survey resulted in the postulation of a physical model that may explain the large variation observed in the performance of Cs:Te photocathodes, both under rather ideal circumstances (i.e., evaluated in the preparation chamber) as under normal operating conditions (i.e., when used in RF accelerators). Our main assumption is that differences in stoichiometric composition of the various layers of the photocathode is responsible for the different quantum efficiencies, sensitivity to poisoning and therefore different life times observed.

To test this hypothesis and increase our knowledge on the composition of the photocathode, we have built a rotating compensator ellipsometer that allows us to measure the ellipsometric variables Ψ and Δ that can be converted to the index of refraction and layer thickness, allowing us to follow the evolution of these parameters when the cathode is grown. In a separate analyses (e.g., through XPS) we have to correlate the index of refraction to a specific stoichiometric compound of Cs:Te.

As the RF-accelerator and preparation chamber were scheduled to be used for a laser wakefield experiment, we then focused on improving the ellipsometer for measurements on photocathodes. A simpler rotating analyzer ellipsometer was build and characterized. This setup showed a dramatic improvement in intrinsic resolution by proper selection of components and improved readout accuracy. As a last improvement we started working on a novel, fibre based ellipsometer that avoids several drawbacks of standard ellipsometers and that may be ideally suited for use with the preparation chambers required to grow photocathodes. Research on this novel photocathode will continue in the near future and, depending on available manpower we want to implement one of the ellipsometers on an existing preparation chamber either at CERN or FZD.

This research has resulted in two master thesis, several conference presentations and a publication that is under preparation.

JRA3: High Intensity Pulsed Proton Injector

Acronym: HIPPI **Coordinator**: *M. Vretenar (CERN)*

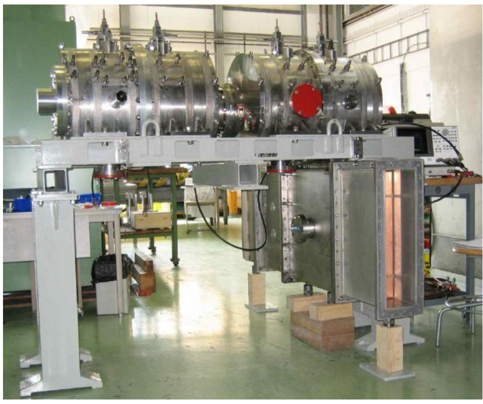
Deputy: *A. Lombardi (CERN)*

Participating Laboratories and Institutes:

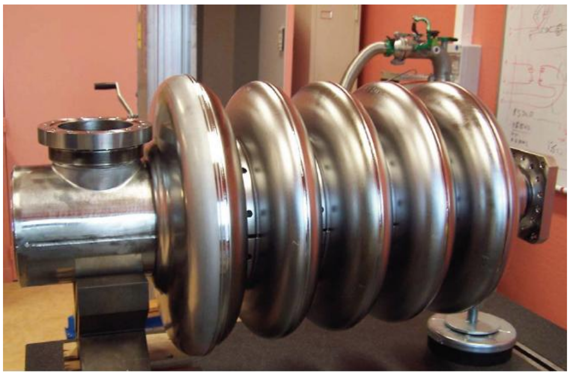
Institute (participant number)	Acronym	Country	Scientific Contact
STFC - Rutherford Appleton Laboratory (20)	STFC	UK	C. Prior
Commissariat à l'Energie Atomique (1)	CEA	F	A. Mosnier
CERN (17)	CERN	CH	R. Garoby
Forschungszentrum Jülich (7)	FZJ	D	R. Tölle
Gesellschaft für Schwerionenforschung, Darmstadt (4)	GSI	D	L. Groening
Institut für Angewandte Physik - Frankfurt University (5)	IAP-FU	D	U. Ratzinger
INFN-Milano (10)	INFN-Mi	I	C. Pagani
CNRS Institut de Physique Nucléaire d'Orsay (3)	CNRS-IN2P3-Orsay	F	T. Junquera
CNRS Laboratoire de Physique Subatomique et de Cosmologie (3)	CNRS-LPSC	F	J.M. De Conto

Main Objectives: Research and Development of the technology for high intensity pulsed proton linear accelerators up to an energy of 200 MeV.

Illustration of the Main Hardware Realisations of HIPPI



Prototypes of normal-conducting accelerating structures. From left: CH, CCDTL, and DTL.



Prototypes of superconducting accelerating structures and components. From left, elliptical cavity B, spoke cavity, prototype coupler.

From left, clockwise: the chopper beam line installed at CERN, the 1 MW test stand for superconducting cavities at CEA Saclay, a chopper structure

Aims of HIPPI

The High Intensity Pulsed Proton Injectors (HIPPI) JRA of CARE has been active from 1.1.2004 until 31.12.2008, with the goal of promoting research and development of the technology for high intensity pulsed proton linear accelerators (linacs) up to an energy of 200 MeV. It originally involved nine Institutes (RAL from UK, CEA, LPSC and IPNO from France, FZJ, GSI and IAP-Frankfurt from Germany, INFN-Milan from Italy, and CERN), later joined by a tenth one that agreed to coordinate its R&D activities in the field without financial contributions (INFN-Naples). The HIPPI work was specifically focused at developing the technology for upgrading the accelerator infrastructure of three European Laboratories, RAL in the UK, GSI in Germany, and CERN.

The main motivation for the HIPPI programme was the fact that whereas three scientific Laboratories in Europe had upgrade plans requiring modern linear accelerators, the last proton linac design developed in Europe dated back to the end of the 70s, and since then linac technology was not addressed anywhere in Europe at a level allowing the start of a construction project. In the last 30 years the main developments in the field of linear accelerators were based in the US and in Japan, where they resulted in the recent construction of the state-of-the-art SNS and JPARC accelerator facilities.

In view of their upgrade programmes, in the years before HIPPI some Laboratories had already started R&D programmes focused on linacs, which were limited by the amount of available resources and for this reason had problems going from the design to the hardware prototyping stage. The HIPPI JRA has integrated and coordinated these R&D efforts, allowing optimizing the use of resources and providing useful synergies, attracting other Laboratories that had competent resources but were missing a project to foster them and finally providing a welcome boost to the development effort from the EU funds. Another additional benefit of HIPPI was the constant follow-up of an External Scientific Advisory Committee that provided guidance and support together with an extremely useful link with the US and Japanese programmes.

The main achievement of this JRA has indubitably been the fact that the supported linac upgrade projects have gone via HIPPI from the basic design stage to the advance prototyping stage. HIPPI has allowed detailed development, testing and validating of technical solutions that are now pushing the technology beyond the US and Japanese projects, and have moved to Europe the center of linacs developments. The HIPPI technologies have been the basic building blocks for the preparation of the Technical Designs of two new facilities, Linac4 at CERN and the FAIR linac at GSI, which resulted in the approval of Linac4 and allowed the FAIR linac to go to the final phase of negotiations prior to construction. Linac4 was officially approved in June 2007 and the project phase started at beginning 2008. The civil engineering is progressing rapidly, and completion of the linac is foreseen at end 2012. The proposal for the construction of the FAIR linac by GSI, IAP and CEA has been presented in June 2008, and negotiations for the construction of the linac are presently in progress. It is mainly thanks to HIPPI that these projects are now bringing again Europe in the forefront of linac technology.

Highlights of the HIPPI projects

☐ Summary of main achievements

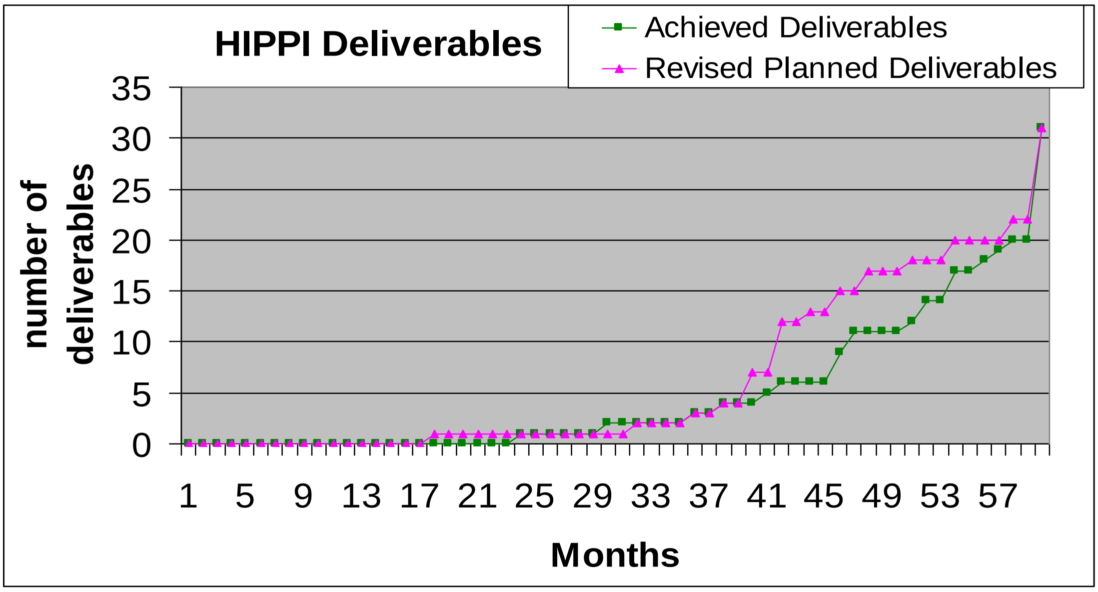
The HIPPI JRA has developed the technology for the construction of high-intensity pulsed linear accelerators that will be adopted by the future European projects in this domain.

In particular,

- HIPPI has developed and prototyped high-efficiency and high-reliability normal conducting structures for the energy range 3-160 MeV,
- HIPPI has developed and built prototype chopper deflectors for high-intensity linacs integrated in dedicated beam lines,
- HIPPI has developed and built superconducting linac structures at high gradient and with the stiffness required for pulsed operation that will be adopted by all future pulsed linac projects in Europe
- HIPPI has optimized and benchmarked between themselves and with a real machine the beam dynamics simulation codes that will be used for the design of the future generation of linac machines.
- Moreover, HIPPI has built and commissioned a modern high-power test stand for accelerating cavities at 704 MHz, which will be an essential tool for testing the next generation of cavities developed in Europe.

☐ Deliverables

HIPPI had scheduled 31 deliverables, consisting for a large majority in realizing and testing prototypes. Such hardware deliverables necessarily depend on several external factors (laboratory workshop workload and priority, fabrication problems, availability of testing equipment) and the activity had to constantly follow closely the deliverable schedule and adapt the schedule and the precise content of the deliverable to the evolving conditions. Nevertheless the deliverables have been all achieved within the duration of CARE as can be seen on the table below.



☐ Dissemination

Dissemination of HIPPI results took place mostly at Conferences, as it is custom in the linear accelerator community. HIPPI was represented at the large accelerator conferences LINAC06, LINAC08, APAC07, PAC07, EPAC06, EPAC08, as well as at a variety of smaller conferences dedicated to more specific subjects. Altogether, HIPPI had eight invited talks at major Accelerator Conferences during the duration of the Activity, corresponding to an average of 1.3 per conference. Four refereed papers have been produced as well as 29 notes. The CARE reports were generally written in support of a specific deliverable. In total HIPPI has produced 152 CARE documents as show in the table below.

	2004	**2005**	**2006**	**2007**	**2008**	**sum**
CARE Note		7	13	5	4	**29**
Publication	1	1	0	1	1	**4**
CARE Report	1	4	5	9	25	**44**
Contribution to conferences	19	14	19	7	16	**75**
Total	**21**	**26**	**37**	**22**	**46**	**152**

The Activity has organized every year a series of Workpackage Meetings in spring, and a general Annual Activity Meeting in autumn. The first Table below reports the Annual Meetings, whereas the second one lists the Workpackage Meetings.

Date	**Title/subject**	**Location**	**Number of participants**	**Web site**
Sept. 29-Oct.1, 2004	HIPPI Annual Meeting	Frankfurt (D)	38	http://hippi04.web.cern.ch/hippi04/index.htm
Sept. 28 – 30, 2005	HIPPI annual meeting	Abingdon (UK)	43	http://mgt-hippi.web.cern.ch/mgt-hippi/programme_HIPPI05.html
Sept. 27 – 29, 2006	HIPPI annual meeting	Jülich (D)	37	http://www.fz-juelich.de/ikp/hippi/autumn2006/
26-28 Sept. 2007	HIPPI Annual Meeting	Orsay (F)	32	http://www.fz-juelich.de/ikp/hippi/autumn2007/
29-31 October 2008	HIPPI Annual Meeting	Geneva (CH)	38	http://indico.cern.ch/conferenceDisplay.py?confId=39839

Date	**Workpackage**	**Location**	**Number of participants**
May 3-4, 2004	WP2	Grenoble (F)	~10
May 10 -11, 2004	WP4	CERN (CH)	~10
June 4, 2004	WP5	Darmstadt (D)	18
June 6-7, 2004	WP3	Saclay (F)	17
March 13-14, 2005	WP3	INFN-MI (Italy)	~20
April 13 -14, 2005	WP4	Abingdon (UK)	~10

April 14 – 15, 2005	WP5	Abingdon (UK)	~10
June 2 – 3, 2005	WP2	CERN (CH)	~8
May 4 – 5, 2006	WP4	CERN (CH)	10
April 27 – 28, 2006	WP3	FZJ Jülich (DE)	~20
April 27 – 28, 2006	WP5	FZJ Jülich (DE)	~20
May 18 – 19, 2006	WP2	Grenoble (FR)	8
28 April 2007	WP3	Orsay (F)	10
24-25 May 2007	WP2	Geneva (CH)	15
13 June 2007	WP4	Geneva (CH)	13
May 21 2007	WP5	Saclay (F)	7
19 May 2008	WP5	Darmstadt (D)	~8
10-11 June 2008	WP2	Grenoble (F)	10
20 June 2008	WP4	Geneva (CH)	5

A web site for HIPPI has been maintained at the URL: http://mgt-hippi.web.cern.ch/mgt-hippi/). It has stored all information concerning meetings, publications, job openings, etc. and will remain available after the completion of the JRA, maintained by CERN.

☐ Main impacts of the HIPPI achievements

The HIPPI achievements can be summarized in three main categories:

a. improvements on the short term, providing a better understanding and use of existing infrastructures, like the UNILAC machine at GSI, where the HIPPI benchmarking studies have allowed in increase in beam brilliance by a factor of 3.

b. Improvements on the medium term, providing the background in terms of analysis tools, hardware prototypes and scientific know-how for the construction of the linear accelerator upgrades to two major European Laboratories. The Linac4 project at CERN has started construction in 2008 and is foreseen to end in 2013. The FAIR linac at GSI is foreseen to start the construction phase at end of 2009. Both projects are based on the results of HIPPI. Moreover, other ongoing projects as the SPIRAL2 project at GANIL have adopted some technical solutions developed in the frame of HIPPI.

c. Improvements on the long term: several linac projects in Europe are seeking approval, and they are all in a different extent profiting of the HIPPI results. The European Spallation Source project (ESS), in the recent revision made in Spain, adopts some of the technical solutions developed in HIPPI, like the DTL and the spoke cavities. The EUROTRANS and EURISOL linear accelerators are based on different designs, because of the different applications, but have profited from the exchange of data and information with the HIPPI community. The upgrades proposed for the ISIS proton source at RAL (UK) are directly based on the HIPPI results.

The best summary of the HIPPI achievements has been probably made by the External Scientific Advisory Committee of HIPPI, which has written in its last report, intended to assess to overall results and achievements of HIPPI: “The prototype accelerating structures developed under HIPPI are now the alphabet with which new and different projects can be written. (…) The motivation for HIPPI was to develop a common European technology base for high intensity linacs. To a large extent this has been achieved.”

Summary Table of the main HIPPI Achievements and their impact on the Scientific Infrastructure.

Selected Achievements	Impacted infrastructure	Main improvement	Future impacted infrastructure	Expected future impacts
DTL, CCDTL, PIMS development	CERN LHC	Improvement in luminosity after Linac4 construction	All future proton linacs	High-efficiency and high-reliability structures available
CH development	GSI accelerator complex	New physics programme	FAIR and other proton linacs	Very high efficiency compact structure available
Superconducting structures development	CERN injector complex	Development of accelerating cavities for low beta in pulsed mode	SPL, ESS and other future proton linacs	Reliable structures available at high gradients
High-power test stand	CEA accelerator test infrastructure	Availability of a test stand for future linac projects	SPL, ESS and other future proton linacs	Makes possible testing of accelerator components
Chopper developments	CERN injector complex	Reduction of activation losses when injecting in a ring	Linac4, SPL, SPIRAL2 and other future proton linacs	Fast compact choppers available
WP5 Code benchmarking	GSI and CERN accelerator complex	Factor 3 improvement on brilliance of UNILAC	Linac4, SPL, FAIR, ESS and all future proton linacs	Reliable simulation codes available

Summary of the HIPPI activities

Normal Conducting Structures (WP 2)

The Normal Conducting Structures Workpackage concentrated in the advanced design and prototyping of accelerating structures that would push the technology beyond what achieved in the US and Japanese projects. The programme of this Workpackage was centred on two lines, the analysis and the improvement to the design of standard linac structures like the Drift Tube Linac (DTL) and the Side Coupled Linac (SCL), and in parallel the development of new more performing structures like the Cell-Coupled Drift Tube Linac (CCDTL), the CH structure, and finally the PI-Mode Structure (PIMS).

The development of the DTL had a difficult start, the original idea being to base the analysis on the test results of a prototype to be made by an external (non-HIPPI) Institute that was never able to deliver the promised prototype structure. After consulting the HIPPI partners, it was decided to launch a crash programme for the mechanical design of a prototype at CERN, which was eventually built on a separate funding thanks to the interest of a member of the HIPPI External Advisory Committee. The prototype was finally tested at CERN in 2008, confirming the soundness of this innovative DTL design that will be eventually adopted for Linac4. The prototype DTL coupler built by CEA and LPSC will be also adopted for Linac4. The HIPPI Side Coupled prototype suffered as well from some delays, but was finally completed in time to get hands-on experience with the tuning of this structure. The conclusion of the HIPPI team has been that the advantages of this structure did not compensate for the high cost and the long and difficult tuning, and more efforts went instead to the PIMS structure, which constitutes a valid alternative to the SCL.

The most important HIPPI achievements in WP2 were the development of several novel accelerating structures. Two prototypes of CCDTL were successfully built and tested, indicating that this structure can easily achieve the specifications of Linac4 and similar projects, being at the same time simpler and less expensive than other structures in the same energy range. The CH structure has been extensively studied and optimised for use in the FAIR linac at GSI. This structure is extremely innovative because it operates in an RF mode providing extremely high power efficiency that has never been used before for proton linacs. Following the interactions between teams inside HIPPI, the CH design was modified to include a coupling cell similar to what used on the CCDTL. A prototype CH was extensively studied, allowing a detailed engineering of the structure that now allows starting the construction of a first CH module for the FAIR linac. The PIMS structure was added to the list of HIPPI structure only in the last years of the programme, as a possible replacement for the SCL structure. A detailed design and engineering has taken place, resulting in the design of a prototype of the first PIMS module of Linac4, which will be now built at CERN and possibly used at Linac4.

Superconducting Structures Achievements (WP 3)

Work package 3 addressed the development of superconducting (SC) linac structures in the intermediate energy range (~5-200 MeV), to be operated in pulsed high-duty-cycle mode. Thanks to their main characteristics as high power efficiency and large apertures, these SC structures are well suited for acceleration of high intensity beams of protons and ions. The performance goals were fixed at the best international level (with Eacc>7 MV/m and Q > 1e10) and the main challenge was the mastering the Lorenz-force detuning (LFD) in pulsed operation.

Five European laboratories involved in the development of SC structures for proton and ion beams participated in this work package (CEA, CNRS, FZJ, IAP-Fu, INFN). The way from design to test of fully equipped structures goes through fabrication, surface preparation, clean assembly and RF tests. Thus, many types of equipments were used in this program among which clean rooms, chemical polishing cabinets, high pressure rinsing stations, vertical and horizontal cryostats, cryogenic systems and high power RF amplifiers. Some of these equipments were not available in participating laboratories (for chemical preparation or test at cold, for example) and push to strong inter-lab collaborations ; other equipments, not available at all, were developed in the program time (700 MHz high power test stand, RF measurements at cold, …). Moreover, the specific studies of LFD in pulsed mode asked for the development of other critical components as power couplers, frequency tuning systems and piezo actuators. For these reasons, the laboratories involved in HIPPI have been able to exhibit, at the end of the program, not only prototypes of various superconducting structures but also critical SCRF components and new equipments for R&D in the field.

IAP-Fu has developed a 19-gap prototype CH superconducting structure, which reached and accelerating field of 5.6 MV (peak surface field of 36 MV/m) after some efforts in surface preparation. The surface field is now consistent with the best cavities in this frequency range, while the accelerating field attained is clearly unique. Operability of this cavity with a frequency tuner in a cryogenic environment was validated.

FZ-J and IPN-O worked together on the study and prototyping of a 352 MHz triple spoke (or 4-gaps) cavity. In order to address the specific problems inherent to this kind of cavities, they performed intensive tests of different cavities already fabricated in projects that predated HIPPI (1-spoke at 352 MHz and β=0.35, 1-spoke at 352 MHz and β=0.15, 3-spokes at 760 MHz and β=0.20). Moreover, a complete parameterization of the critical EB welds was undertaken at FZ-Juelich (for large Niobium thickness and to keep a high RRR), as well as stiffening techniques like thick Cu coating. The development of this cavity was quite important in the HIPPI contest.

CEA-Saclay and INFN-Mi have developed β=0.50 elliptical cavities operating at 704 MHz. After the surface preparation and vertical tests performed at CEA-Saclay, these elliptical cavities have surpassed their design accelerating fields (> 12MV/m with Qo of 1e10). Frequency tuners with piezo of different types (coaxial and lateral) have been developed and fabricated, as well as magnetic shielding and high-power couplers.

In order to process the high-power couplers and to perform the tests of fully equipped cavities, a dedicated test facility, unique in Europe, has been built in the former Saturne Hall at CEA Saclay. It includes a multi-purpose horizontal cryostat (Cryolab) and a klystron having peak power of 1.2 MW and operating at 50 Hz with a 2-ms pulse width. With this power range higher than strictly necessary for HIPPI cavity development, testing of high-energy accelerating structure couplers is possible too.

Considering the pulse operation mode of the SC proton linacs, study of the Lorentz Forces Detuning factor (frequency detuning over accelerating field squared) was specifically important for HIPPI. Many measurements were performed with the different SCRF structures but first attempts were sometime deceiving because of the values obtained and the lack of reproducibility. With the efforts put by the participating laboratories to calculate and improve the mechanical systems used for the tests, the final results agreed with simulations.

Finally, the HIPPI program has proven that SCRF structures can achieve are able to compete with NC structures even in the low energy part of high intensity linacs in pulsed operation. Two different sets of structures are needed to cover the full energy range: CH or low-beta spoke structures in the 5-100 MeV range, followed by intermediate spoke or elliptical structures are good candidates in the upper energy range.

Chopper Achievements (WP 4)

WP4 within HIPPI addressed two different approaches to chopping which have been proposed for two upcoming facilities: CERN Linac4 and RAL FETS as well as for CERN SPL and the ISIS upgrade. Proton driver specifications for future facilities call for more than an order of magnitude increase in beam power. Beam loss injection and extraction into the circular accelerator, and the consequent activation of components, can be minimized by a programmed population of longitudinal phase space, produced by ‘chopping’ the linac beam at low energy. The ‘chopper’ produces precisely defined gaps in the bunched linac beam, and the chopping field must therefore rise and fall within, and be synchronous with, bunch intervals that are typically just a few nanoseconds in duration.

The work towards the demonstration of such a challenging device started in a collaborative fashion from the very beginning. Frequent exchange of information, mutual constructive criticism and tight interaction with beam dynamics designers have allowed to solve problems and find solutions which could be used by other groups. In the last years of HIPPI some accelerator scientists from the Spiral2 project at GANIL (Caen, France) have followed closely the chopper work and used the HIPPI results for the choice and realisation of their own chopper system.

The chopping scheme envisaged at STFC (UK) includes a slow pulse generator (SPG) and a fast pulse generator (FPG). A SPG has been realised and thoroughly tested during HIPPI. It is a DC coupled high voltage pulse generator, based on an ‘off the shelf’, ‘push-pull’ high voltage MOSFET switch module. Measured parameters and output waveforms show that the switch performance is generally compliant with the STFC specification at a burst repetition frequency (BRF) of 25 Hz. A power supply and cooling upgrade should enable testing at the full BRF of 50 Hz. The FPG is a high voltage pulse generator, designed and manufactured in the UK, to meet the specification for the previous ESS fast chopper. Measured performance parameters show the results of the measurements done at RAL. The results indicate that the design is generally compliant with the RAL FETS requirements.

The chopping scheme envisaged at CERN includes chopper electrodes made of a meander line structure printed on a high permittivity substrate which could be into the existing quadrupoles. Alumina (Al_2O_3, $\varepsilon_r \approx 9.8$) was chosen for the support because of its good radiation resistance (in particular compared to organic materials), good vacuum properties, good heat resistance and conduction and finally because a high ε implies small transverse meander size. For sufficient mechanical robustness, the substrate thickness of 3 mm was chosen. First prototypes were manufactured at CERN but the final ceramic plates were produced in the industry by Kyocera. The manufacturing process went through many revisions and was adapted to the available technology. The plates produced in industry were measured at CERN. Electrical, vacuum, and heat-conduction tests gave full satisfaction and confirmed the expectations.

A first approach to the chopper driver was a modular system based on MOSFET. This system has been designed, built and tested. Construction has been limited to a half scale prototype (±250 V), and coupling of four such modules would give the required ±500 V. 128 MOSFETs are used to achieve the nominal voltage and individual adjustment of the delay is required in order to minimize the transition fronts. This driver represents a sound solution to the problem of generating the signals for the chopper deflectors. Nevertheless its operation is more complicated when compared to that of a DC coupled amplifier. For this reason, an additional market survey was carried out and a potential industrial solution came from FID GmbH, the German branch of FID Technology located in St. Petersburg. It consists in high voltage pulse generators based on a proprietary high voltage, high current device (Fast Ionization Dynistor). Tests to prove the reliability of the semiconductor devices were made on a preliminary unit that was continuously operated during two weeks producing 1 MHz, 300 ns pulses in 1 ms bursts repeated at 50 Hz. The configuration of the unit was based on a single serial switch that got close to the required transition times but unfortunately could not quite reach the specification. The reached performance is well in excess of what needed for Linac4.

Another important achievement of the working group includes the use of a special optics layout which allows amplifying the chopper kick. This feature allows reducing the requirement on the chopper voltage for the same beam separation. Initially proposed by CERN, it has been finally adapted by both laboratories involved.

The charge of WP4 included a measurement campaign on the 3 MeV test stand at CERN, which turned out to be impossible during the HIPPI time frame. The IPHI-RFQ, which was initially foreseen to be operational in 2007, is still in production and will be ready only in 2010.

Beam Dynamics and Diagnostics Achievements (WP 5)

The development of most recent high intensity linacs has shown that phenomena associated with space charge and beam loss play a significant role in the design of high power proton accelerators. In particular, losses are mainly associated with mechanical and RF tolerances together with the appearance of beam halo. Those effects need to be modelled in terms of theory and simulations in order to minimize the risk of particles loss during high intensity operation. On the other side, a dedicated diagnostics system is required to protect the structure and to avoid activation beyond tolerated limits. The acceleration and transport of high power beams also presents new challenges for beam diagnostics. While conventional methods continue to be needed, operating conditions at high intensity require a remarkable

R&D effort. New measurement techniques are needed to diagnose the small fractional beam losses, which could cause serious damage to components and produce unacceptable levels of activation. Dedicated monitors for direct beam halo measurements are strongly required and needed to be designed, constructed and validated in existing machines. The activity of this work package combined infrastructures and resources from accelerator laboratories and universities and has been focused on three main topics: the validation and benchmarking of simulation codes, Experiments on Beam Halo and Emittance Growth and diagnostics.

The development of adequate 3D computer codes and the proper modelling of self-interaction by space charge is a crucial issue. Codes must be fast enough to allow large ensembles of particles in order to resolve very small loss fractions. Including the effect of errors jointly with space charge requires a significant enhancement of simulation capabilities. Benchmarking of computer simulation codes against each other and against analytical models represents the most effective way to increase the level of confidence in their predictions. In a first step major codes used in the linac community were compared one against each other and, in a second step, their predictions were compared with experimental campaigns performed at the GSI UNILAC. In parallel, codes developed by the participating laboratories were updated with new features dedicated to the evaluation of beam loss and space charge evaluation with numbers of particles up to 10^6.

At the starting point of the HIPPI collaboration, no satisfactory experiments on beam halo in high intensity linacs were performed in Europe; hence this topic was considered as a priority in the frame of the WP5. Beam experiments were performed at the UNILAC at GSI, where operational conditions, available intensities and diagnostics allowed performing relevant and reliable measurements. At the same time several codes were used to interpret the out-coming results. As an additional result, the measurement campaigns done in the frame of HIPPI on the UNILAC allowed a retuning of the machine elements that led to an increase of the UNILAC brilliance by a factor 3.

Three diagnostics devices were developed and successfully tested during HIPPI: the chopping and Halo detector at CERN, the Beam Induced Fluorescence monitor at GSI and the Beam Induced Fluorescence monitor at Forschungszentrum Jülich. These devices have shown how the parameters of intense proton beams can be measured at the level of detail required by the modern facilities.

JRA4: Next European Dipole

__Acronym:__ NED __Coordinator:__ G. De Rijk (CERN)

__Deputy:__ A. Den Ouden (Tweente University)

Participating Laboratories and Institutes

Institute (Participant Number)	Acronym	Country	Scientific Contact
STFC-RAL (20)	STFC	GB	D.E. Baynham
CEA/DSM/DAPNIA (1)	CEA	F	A. Devred
CERN (19)	CERN	CH	D. Leroy
INFN/Milano-LASA (10)	INFN-Mi	I	G. Volpini
INFN/Genova (10)	INFN-Ge	I	P. Fabbricatore
Twente University (13)	TEU	NL	A. den Ouden
Wroclaw University (17)	WUT	PL	M. Chorowski

Additional Industrial Involvement

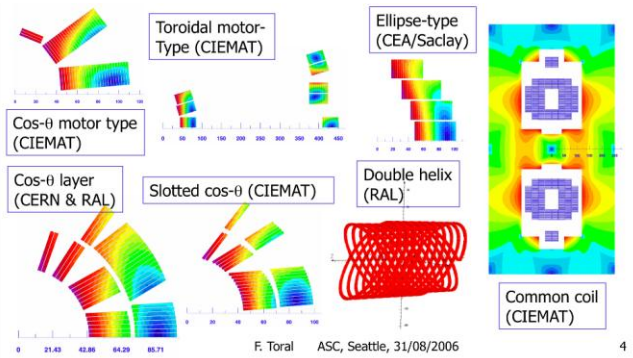
Company Name	Acronym	Country	Contact Person
Kriosystem (112)	KRIO	PL	B. Adamowicz
Alstom/MSA (105)	ALS	F	G. Grunblatt
European Advanced Superconductors (108)	EAS	D	H. Krauth

__Main Objectives:__ This program is a first unique step towards integration and coordination of superconducting Nb_3Sn accelerator magnet R&D in Europe by the involvement of most interested parties, with 3 main objectives: (1) to promote the development of high performance Nb_3Sn wire in collaboration with European industry (2) to develop a parametric design of a large-aperture (up to 88 mm), high-field (up to 15 T) Nb_3Sn dipole magnet, and (3) to execute a limited scientific program on heat transfer studies and insulation development, both directly related to Nb_3Sn conductor technology. The program should lay the ground to the realisation of a Nb_3Sn dipole magnet model that could push the technology well beyond present LHC limits.

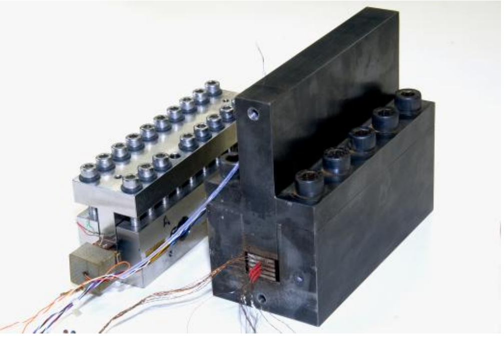
Illustration of the Main Hardware Realisations of NED

Heat transfer studies cryostat and controls electronics

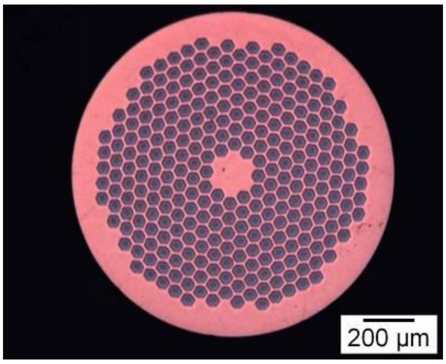
Cable stack with ceramic insulation



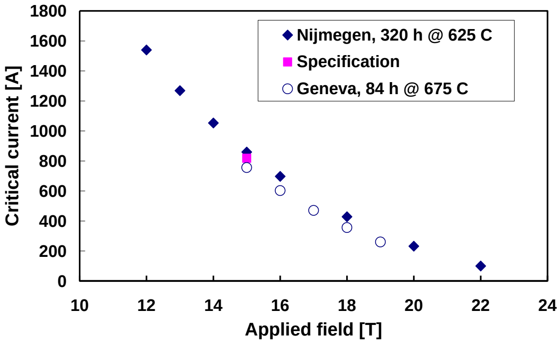
Examples of coil concept studies for high field dipole magnets



Coils stack jigs for heat transfer measurements



PIT strand cross section



High field performance of PIT strand after special heat treatment

Aims of NED

This NED program was a first unique step towards integration and coordination of superconducting Nb_3Sn accelerator magnet R&D in Europe by the involvement of most interested parties, with three main objectives: (1) to promote the development of high performance Nb_3Sn wire in collaboration with European industry (2) to develop a parametric design of a large-aperture (up to 88 mm), high-field (up to 15 T) Nb_3Sn dipole magnet, and (3) to execute a limited scientific program on heat transfer studies and insulation development, both directly related to Nb_3Sn conductor technology. The program was intended to prepare the ground for the realisation of a Nb_3Sn dipole magnet model that could push the technology well beyond present LHC limits.

NED was foreseen to provide the following three direct benefits to the European accelerator magnet community: (1) to integrate all European efforts on Nb_3Sn superconducting accelerator magnet R&D and to establish a long-lasting collaboration to prepare for the future of this field, (2) to promote a concrete support for the European Nb_3Sn wire manufacturers to bridge the gap with their American counterparts.

Besides these, four long term benefits were intended: (1) Relying upon the existing collaboration of European laboratories and European industries NED should try to convince various funding agencies to complement the budget to secure the development of a large-aperture, high-field dipole magnet model. (2) A high field large aperture dipole model magnet would serve to assess the feasibility of a new and promising optics layout for the LHC Insertion Regions that may boost the machine luminosity and could also be used to upgrade the CERN/MFRESCA cable test facility, thereby providing unique services to the entire applied superconductivity community. (3) The R&D program on high-performance wires is intended to support manufacturers to improve the quality and performance of other commercial Nb_3Sn products (such as high-field NMR wires). (4) The problems encountered with High Temperature Superconductors (HTS) are similar to those encountered with Nb_3Sn; lessons learned from Nb_3Sn should help future applications of HTS.

Highlights of the NED projects

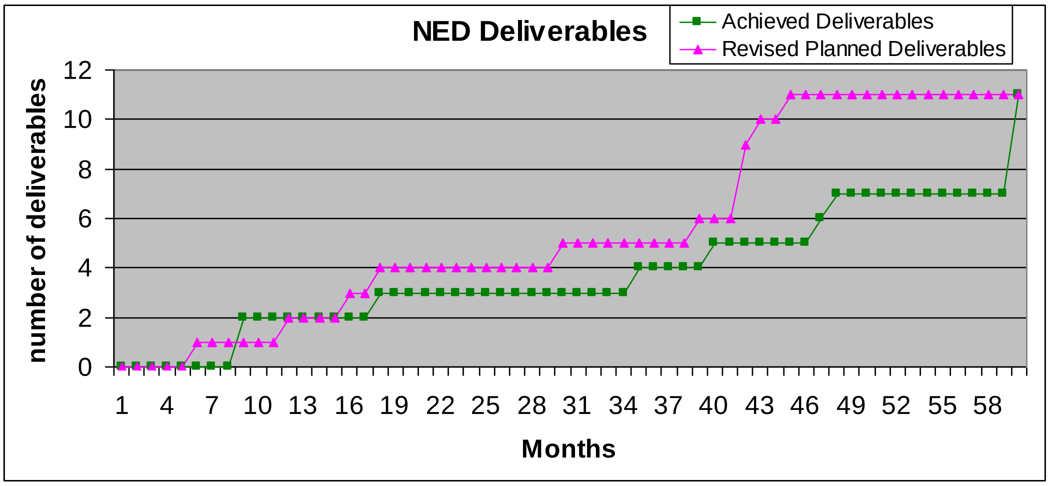
☐ Summary of NED main achievements

The main NED achievements are:

1. Establishment of a European vendor who can deliver medium large amounts of Nb_3Sn conductor for high field accelerator magnets
2. Conductor which reaches the goal of J_c(non--Cu) = 1500 A/mm^2 @ 15 T and 4.2 K with thin (0.050 mm) filaments. This represents a world record.
3. A conventional glassfibre-epoxy insulation scheme for Nb_3Sn magnets
4. An infrastructure to measure thermal flow properties on coil block samples and material samples
5. A better understanding of the heat removal properties of the various insulation schemes used for accelerator magnets
6. A first conceptual overview on the design options for 15 T accelerator magnets

☐ Deliverables

NED had scheduled 11 deliverables. They have been all achieved within the 5 years of CARE as can be seen on the figure and table below.



Deliverable name	Delivered by Contractor (s)	Achieved (month)
Final report on wire and cable specifications	CERN	6
Design report on 15 T dipole magnet	CERN	13
Commissioning of heat transfer facility	CEA, WUT	35
Final report on Quench Protection	INFN-Milano	23
Report on conventional insulation	STFC-RAL	40
Report on innovative insulation	CEA	48
Final Report on Heat Transfer Measurements	CEA	47
Final wire production	CERN	60
Final report on wire characterization	CERN	60
Final cable production	CERN	60
Final report on cable performances	CERN	60

☐ Dissemination

All publications and reports from the NED collaboration can be found on the CARE database (http://irfu.cea.fr/Documentation/Care/index.php) which can be freely accessed on the web. The international conferences on which NED results were presented are:

- MT; The Magnet Technology conference (2005, 2007)
- ASC: The Applied Superconductivity Conference (2004, 2006)
- EPAC: The European Particle accelerator conference. (2004, 2006)

Additionally, NED work was reported upon in the workshops of the CARE-HHH networks: WAMS, WAMDO, WAMSDO, Insulation & Impregnation Techniques, Beam heat & quench in LHC magnets and ECOMAG 2005.
NED has produced 47 CARE documents, including 16 refereed publications and one thesis, as show in the table below.

	2004	2005	2006	2007	2008	sum
CARE Note						**0**
Publication		5	6	3	2	**16**
CARE Report	2	4	5	3	6	**20**
Contribution to conferences	2	2	3	3		**10**
Theses			1			**1**
Total	**4**	**11**	**15**	**9**	**8**	**47**

☐ Main impacts of the NED achievements

The potential impacts of the NED program are listed in the table below. Before the NED program started only very limited experience with Nb_3Sn magnets existed in Europe. The Nb_3Sn conductors which were available would not allow for the construction of magnets much above 10 T, the critical current density was too low at high field, the filaments in the conductors were too thick for accelerator magnets and the design ideas were limited to an extrapolation from the LHC Nb-Ti magnets resulting in a too large stress on the cable. The conductor developed within NED in collaboration with European industry reached the world breaking characteristics of J_c(non--Cu) = 1500 A/mm^2 @ 15 T and 4.2 K with thin (0.050 mm) filaments. Clearly this opens many possibilities for the improvement of existing particles accelerators and the realisation of new ones. It is also essential for several other fields of science such as the ones using NMR and MRI technologies.

For the LHC phase 2 luminosity upgrade (SLHC) quadrupole magnets will be needed with maximum fields of the > 12 T range, which will be possible with the developed conductor. For constructing such magnets, the Fresca cable test station at CERN will have to be upgraded to 15 T by building very a high field dipole using Nb3Sn technology to be able to properly characterize the conductor. Similar high field quadrupoles are probably needed for CLIC as well.
The NED program has now put the partners into the situation that they can start building a 13 T dipole magnet and this program is about to start in the FP7-EuCARD framework.

Selected achievement	**Impacted infra-structure**	**Future impacted infra-structure**	**Expected impact**	**Industry transfer**
EU vendor for high performance Nb_3Sn strand		SLHC, DLHC, CLIC, Fresca2, MRI	higher fields, Luminosity or energy	EAS/SMI
Conductor with J_c(non--Cu) = 1500 A/mm^2 @ 15 T		SLHC, DLHC, CLIC, Fresca2, MRI	higher fields, Luminosity or energy	
conventional glassfibre-epoxy insulation scheme for Nb_3Sn magnets		SLHC, DLHC, Fresca2, CLIC	higher fields, Luminosity or energy	
infrastructure to measure thermal flow properties	LHC	SLHC	higher luminosity	
better understanding of the heat removal properties of insulation schemes	LHC	SLHC	higher luminosity	
first conceptual overview on the design options for 15 T accelerator magnets		SLHC, Fresca2	higher energy	

Summary of the NED activities

NED organization

To achieve the aims NED was laid-out around three work packages and one study group.

Work package: Thermal studies and quench protection.

In an accelerator the thermal properties and the quench protection of a superconducting magnet are of vital interest. The heat generated in the coil by ionizing particles, from beam losses or produced by the interactions, has to be evacuated in an efficient manner. The heat evacuation properties will be a limiting factor for the beam intensity and the luminosity in machines like the LHC. A systematic study of the heat evacuation properties of various insulation schemes and coil impregnation systems was conducted in this work-package. The quench properties of a magnet are very much intertwined with the heat removal properties in the coil. The ability to protect a magnet against burnout during a quench is a vital issue in magnet design. A comprehensive model calculation for the start and development of a quench was made for large aperture high field magnets to provide feasibility estimates for such constructions.

Work package: Conductor development.

The heart of a superconducting magnet is the conductor. It is also the most expensive component of the magnet. In order to successfully build a high field large aperture magnet, conductor is needed which has a sufficient critical current density at high field in small diameter Nb_3Sn filaments. The work-package first specified what to make and then placed two industrial development contracts for the conductor. The characterization of the conductor was an integral part of the work.

Work package: Insulation development.

The insulation schemes for Nb_3Sn coils need further development to meet all the requirements of the reaction around 800°C, the electrical properties and the thermal properties. Two schemes were developed in NED, one based on classical glass fibre wrapping and epoxy impregnation and one with an innovative ceramic compound.

Study group: Magnet design and optimization

The options for the coil layout for a high field large aperture magnet were studied and a comprehensive comparison was made of their magnetic and mechanical feasibility.

Thermal studies and quench protection

To perform heat transfer studies the NED partners designed and constructed a cryostat for the measurements. The Polytechnic of Wroclaw did the design and construction and the commissioning was done at CEA where the cryostat is now installed. With this the community now has a infrastructure for studying heat transfer properties which will be used well after the NED era for other projects.

Two types of measurements were performed in the new cryostat:

1. Stack experiments

For this type a stack of insulated cables is made such that the situation in a real coil is best simulated. The stack can be put under pressure, like in a real magnet coil, and the helium cooling can be chosen to happen from selected sides. The properties for the classical LHC style insulation employed for Nb-Ti coils could thus be compared to the innovative ceramic insulation intended for Nb_3Sn coils. This work also gave an important confirmation for the existing LHC insulation scheme where different cooling scenarios could be studied which at the design phase of the LHC were not experimentally accessible. The ceramic insulation showed to have a potentially tenfold larger cooling potential than the existing LHC scheme, compatible with the large heat influx in the coils of new insertion magnets needed for luminosity upgrades.

2. Drum experiments

In the drum experiments the heat conduction through materials and Kapiza resistance to the helium can be measured in a drum shaped device. With these measurements the properties of various insulating materials can be determined. Although coil sample measurements are done in the “stack” individual material properties are needed to do the basic selection and optimization and to get the input parameters for heat evacuation models. The properties of various insulation materials were mapped, which was used to steer the development of the classical Nb_3Sn insulation scheme. The results on the Kapiza resistance on insulation materials were for several materials first measurements.

Conductor development

As a first step for the conductor work a conceptual magnet design was done for a 88 mm aperture 12 T dipole model magnet. Two types of coils were considered, pure cos□ design and the cos□ slot design. From these conceptual designs the requirements for the conductor were derived. For this type of magnet the conductor should be a Rutherford cable made out of 40 strands with a strand diameter of 1.25 mm, a high $Jc \geq 1500$ A/mm^2 at 15 T and 4.2 K, a small effective filament diameter ≤ 50 μm, a Cu : non-Cu ratio of 1.25, a high copper residual resistivity ratio (RRR) ≥ 200, and wire which can be formed into cable with only modest degradation

The program has been successful in developing two European vendors for advanced Nb_3Sn conductor suitable for high-energy accelerator magnets. One vendor (SMI-EAS) has delivered a substantial quantity of wire, made by the powder-in-tube (PIT) method, which meets the targets. A second vendor (Altsom) has made good progress in developing the internal tin (IT) method.

SMI-EAS has delivered R&D strand made by the powder-in-tube (PIT) method that, with an optimized heat treatment, reaches $Jc = 1500$ A/mm^2 at 15 T and 4.2 K. The wire has an effective filament diameter of 50 μm and a RRR of more than 200. They have delivered a production quantity of 6.4 km of wire with similar properties, and the remaining 6.3 km of strand will be delivered by the end of December 2008. The delivered strand has a diameter of 1.25 mm, as specified for NED. Short sections cable, made according to the NED specifications with 40 strands, were made at the cabling machine in LBNL. Characterization of extracted strands has proven that cable degradation in terms of critical current is about 8%, which is less than the specified 10%. This strand and cable production was successful and met the challenging NED specification in full.

Alstom has followed two “roads” for the production of wire by the internal tin (IT) method. The first is an “innovative” method in which the sub-elements are cold drawn, while the second is a “conventional” method in which they are extruded. The results from road 1 have been disappointing so far, in terms of piece length, Jc, and RRR. This is similar to the experience of others in the past, who have tried the cold-drawing method. This road is unlikely to yield good results and this road should be dropped. The results from road 2 are more promising, but the Jc is still well below the target. The wire made has used a binary alloy. Higher Jc is expected by using a ternary alloy, in which either Ta or Ti is added to the Nb rods, or Ti is added to the Sn core. The fabrication of new sub-elements with NbTa filaments is in progress and is planned to yield 20 km-30 km of wire in spring 2009.

Besides the standard characterization measurements (Jc, and RRR) on strands and cables special measurements were performed to better understand the metallurgical processes which are taking place during the reaction treatment of the conductor to form the Nb_3Sn inter-metallic compound out of the separate niobium and tin components of the filaments. Two synchrotron techniques, notably synchrotron powder diffraction and synchrotron microtomography, have been used for the first time for the study of Nb_3Sn strands. A high flux of high energy monochromatic x-rays provided at the high-energy scattering beam line ID15 of ESRF has allowed performing powder diffraction measurements during in-situ Nb_3Sn strand reaction heat treatments. It was possible to detect for the first time all phases that are formed during the reaction heat treatment of Nb_3Sn strands of the PIT design. With the help of Scanning Electron Microscopy the grain sizes inside the filaments could be studied to understand the detailed build-up of Nb_3Sn grains.

Using the characterization techniques a heat treatment optimization was done on the PIT strand. With a longer heat treatment time at a slightly lower temperature (625°C) a J_c(non--Cu) = 1500 A/mm^2 @ 15 T and 4.2 K was reached. This result is a major step to render the construction of 15 T magnets feasible. It also means the fulfillment of the basic NED objective.

Insulation development

Conventional insulation

A program of materials technology work has been carried out in order to economically address the particular problems of insulation materials for niobium-tin, wind and react accelerator magnets. The program has been able to add to the body of knowledge by strategically targeting particular problem areas. The problem has been approached by performing screening tests on candidate materials. The three test methods chosen are: (1) Electrical breakdown, (2) Short beam shear, (3) Interlaminar fracture toughness. An extensive literature survey was also performed. In addition thermo-gravimetric analysis have been used to measure the very small weight loss arising from degradation of organic fibre coatings in the same environment as niobium-tin magnet insulation during the reaction cycle. The problem of industrializing the manufacturing process of niobium tin magnets has been addressed. Niobium tin magnets are currently produced using labour-intensive methods. Such magnets are relatively small and are usually solenoids. Scaling this technology to produce 10 m long accelerator-quality, high field dipole magnets represents a number of challenges. The challenge for this work package is to: (1) produce an insulation system that can be applied in the industrial coil manufacturing setting, (2) is compatible with the heat treatment, (2) meets the agreed Insulation Specification, (3) develop test techniques and samples which allow quantitative comparison of insulation mechanical properties.

The result of the work is the selection of an insulation system which will be tested on the Short Model Coil, a common project between RAL, CEA, CERN and LBNL to produce a 40 cm long double pan cake race track coil. The insulation system consist of :

- Matrix. The test magnets will not be exposed to a high radiation dose, therefore a established, tough epoxy widely used for cryogenic applications was chosen (RAL # 71A). The only disadvantage of such a system is the relatively short pot life compared to anhydride-cured epoxies. The impregnation tool needs to be carefully designed to allow good access for the resin. The tool should be qualified with a low cost “dummy coil” prior to committing a reacted niobium-tin magnet pole.
- Fibreglass tape. The S-glass fibreglass tape chosen for the model magnets is an S-glass tape from JPS Composites, woven with 18 ends and 26 double picks with a small amount of high temperature sizing.

Innovative ceramic insulation.

The innovative insulation program concentrated on a technique using glass-fibre tape impregnated with a viscous liquid that becomes a ceramic when subjected to a heat treatment around 800°C. The temperature used for this being the same as the reaction temperature for Nb_3Sn so that both processes, the Nb_3Sn reaction and the ceramic reaction, can occur in one heat treatment. In the thermal studies work-package the heat removal properties of coil stacks with this ceramic insulation proved to be an order of magnitude better than observed for the LHC insulation scheme. The test program was focused on the characterization and the improvement of the mechanical properties of insulated cable stacks representative of magnet coils. Two issues have been investigated: (1) foaming of ceramic samples during heat treatment, which has been eliminated by modification of the preparation method of the ceramic powder and (2) degradation of the rheological behaviour of ceramic suspensions, attributed to variations in the clay properties. Three heat treatment moulds to produce insulated cable stacks have been designed and manufactured. The moulds were used to prepare various insulated cable stacks relying on different pre-compressions during heat treatment so as to study the effect of this pre-compression on mechanical properties. The test program was focused on the mechanical characterization of insulated cable stacks representative of magnet coils. The used method is derivate from the classical technique used to qualify the quadrupoles: perform compression tests on stacks of conductors prepared with electrical insulation. At the a maximum pressure of 200 MPa some fissure lines have been observed on the sides on the samples. In fact, some of these fissures had been already observed when the samples are extracted from the reaction mould before the mechanical test itself. At this moment, the compression stress imposed during the heat treatment is released and what is observed is the relaxation and rearrangement of the cables. If the compression tests are performed on stacks of cables without insulation, a similar behaviour can be observed.

The ceramic insulation program has shown large potential for a thermal point of view. The mechanical behaviour under large loads, as they occur inside a coil, is though not yet sufficiently good to already apply this in a magnet. The program is being continued by CEA.

Magnet design and optimization

A number of alternative dipole magnet designs for very high fields and large apertures have been studied by the Working Group on Magnet Design and Optimization. Common starting parameters and figures of merit for a fair comparison have been identified. For the 88 mm aperture, the conventional layered cos-□ design is still the best one. However, for large apertures (130 mm160 mm), the coil mid-plane stresses become too high for this topology. The most promising configuration for large apertures is the slotted cos-□ design, as the others are less efficient and have obvious fabrication issues. The next step of the analysis, that is, the 2- D mechanical calculation, becomes very crucial, since the Lorentz forces are huge in all cases. A first estimate of the stresses has been done by averaging the forces on the broad cable face, but numerical computations are necessary to determine the actual local pressure, and the feasibility of the clamping structure. Finally, graded designs have been also studied whenever possible, as they allow a superconductor saving by the use of a low critical current density cable in the low field areas of the coil.

Annex 1

The legal entities of the participants, the associated institutes and the associated industrial partners are listed in the following tables

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)
1	**Commissariat à l'Energie Atomique, Paris, France**	**CEA**	*start of project*	*end of project*	***Fields of excellence***: High Energy and Nuclear Physics, Research, Development, Construction and operation of Particle Accelerator (Beam dynamics, Superconducting RF Technologies, High Magnetic Field technologies), Computing, remote operation systems ***Specific participation in***: **N1*, N2*, N3, JRA1*, JRA3*, JRA4*** ***Specific Responsibilities***: **General coordinator, coordinator for management of CARE and JRA4**
2	Uni. Catholique, Louvain la neuve, Belgium	**UCLN**	*start of project*	*end of project*	***Fields of excellence:*** High Energy and Nuclear Physics, Research, Development, Construction and operation of Particle Accelerator (ECR ion sources, cyclotrons, radioactive targets and radioactive beams) ***Specific participation in: N2***
3	Centre National de Recherche Scientifique **Paris, France**	**CNRS**	*start of project*	*end of project*	***Fields of excellence***: High Energy and Nuclear Physics Accelerators and Experiments, Construction and operation of Particle Accelerators and electron sources, Superconducting accelerators (cavities, couplers), neutrino horns, computing. Lasers and Plasmas for new techniques of acceleration ***Specific participation*** in: **N1*, N2, JRA1*, JRA2*, JRA3*** Specific Responsibilities: **coordinator for N1 and JRA1**
	CNRS/PNC/LAPP, Laboratoire d'Annecy le Vieux de physique des particules, Annecy leVieux, France	**CNRS-LAPP**	*start of project*	*end of project*	***Fields of excellence***: Active alignment, instrumentation and simulation ***Specific participation*** in: **N1**
	CNRS/PNC/CENBG, Centre d'Etudes Nucléaires de Bordeaux Gradignan, Bordeaux, France	**CNRS-CENBG**	*start of project*	*end of project*	***Fields of excellence***: Neutrino experiments ***Specific participation*** in: **N2**
	CNRS/PNC/LPSC, Laboratoire de Physique Subatomique et de Cosmologie, Grenoble, France	**CNRS-LPSC**	*start of project*	*end of project*	***Fields of excellence***: Ions sources. Accelerator design, construction and operation (GENEPI accelerator, IPHI collaboration). ***Specific participation*** in: **N2, JRA3***

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)
	CNRS/PNC/IPNL, Institut de Physique Nucléaire de Lyon, Lyon, France	**CNRS-IPNL**	*start of project*	*end of project*	***Fields of excellence***: Neutrino Physics and experiments ***Specific participation*** in: **N2**
	CNRS/PNC/LAL **Laboratoire de l'Acceleraeur Lineaire,** **Orsay, France**	**CNRS-LAL**	*start of project*	*end of project*	***Fields of excellence***: RF guns, accelerator construction, room temperature and super-conducting cavities, RF power couplers, beam simulations, analytic modelling, and electromagnetic simulations. ***Specific participation*** in: **N1*, JRA1*, JRA2***
	CNRS/PNC/IPNO **Institut de physique Nucleaire,** **Orsay, France**	**CNRS-IPNO**	*start of project*	*end of project*	***Fields of excellence***: Accelerator construction, room temperature and super-conducting cavities, beam simulations, analytic modelling, and electromagnetic simulations. ***Specific participation*** in: **JRA3**
	CNRS/SPI/LPGP, **Laboratoire de Physique des Gaz et des Plasmas,** **Orsay, France**	**CNRS-LPGP**	*start of project*	*end of project*	***Fields of excellence***: Laser beat-wave, wake-field for accelerating electrons. Beam plasma interaction at high currents. ***Specific participation*** in: **N1***
	CNRS/SCH/LCP, **Laboratoire de Chimie Physique d'Orsay,** **Orsay, France**	**CNRS-LCP**	*start of project*	*end of project*	***Fields of excellence***: Photo-cathode production and preparation, lasers, RF source, high-charge and short pulse photo-injector ***Specific participation*** in: **N1**
	CNRS/SPM/CPHT, **Centre de Physique Théorique de l'Ecole Polytechnique,** **Palaiseau, France**	**CNRS-CPHT**	*start of project*	*end of project*	***Fields of excellence***: Simulation of laser-plasma interaction ***Specific participation*** in: **N1**
	CNRS/SPM/LOA, **Laboratoire d'optique appliquée,** **Palaiseau, France**	**CNRS-LOA**	*start of project*	*end of project*	***Fields of excellence***: lasers, plasmas, plasma-acceleration, charged-particle production ***Specific participation*** in: **N1, JRA2**
	CNRS/SPI/LULI, **Laboratoire pour l'Utilisation des Lasers Intenses,** **Palaiseau, France**	**CNRS-LULI**	*start of project*	*end of project*	***Fields of excellence***: Generation of very intense laser beat-wave, wake field. Particle generation and acceleration of electrons. ***Specific participation*** in: **N1**

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)
	CNRS/PNC/LPNHE, Laboratoire Physique Nucléaire et Hautes Energies Paris, France	**CNRS-LPNHE**	*start of project*	*end of project*	***Fields of excellence***: neutrino physics ***Specific participation*** in: **N2**
4	**Gesellschaft fur Schwerionenforschung, Darmstadt, Germany**	**GSI**	*start of project*	*end of project*	***Fields of excellence***: Nuclear, atomic, plasma, and applied physics experiments with heavy ion beams, dynamics of high current beam transport and acceleration, development, design, construction and operation of heavy ion sources, linear and circular accelerators, storage rings, stochastic and electron cooling of stored beams, remote accelerator controls, computing, networking. ***Specific participation*** in: **N2, N3, JRA3***
5	**Institut fuer Angewandte Physik Frankfurt University Frankfurt, Germany**	**IAP-FU**	*start of project*	*end of project*	***Fields of excellence***: Linear Ion Accelerators, Volume Ion Sources, Low Energy Beam Transport, RFQ Development, Room Temperature and Superconducting Drift Tube Linac Development, Beam Optics and Beam Dynamics Computations ***Specific participation*** in: **JRA3**
6	Deutsches Eletronen Synchrotron **Hamburg, Germany**	**DESY**	*start of project*	*end of project*	***Fields of excellence***: Development, construction and operation of Particle Accelerators (linear accelerators, synchrotrons and storage rings for electrons, positrons and protons) for High Energy Physics and Synchrotron radiation sources, Superconducting Cavities, Superconducting Magnets, R&D on Linear colliders and Free Electron Lasers, Accelerator Controls, Computing, Networking, Video Communication Tools, Experience with far remote operations of the Tesla Test Facility and the Fermilab Photo-injector ***Specific participation*** in: **N1*, N3, JRA1*** Specific Responsibilities: **coordinator for JRA1**
7	***Forschungszentrum Jülich*** **Jülich, Germany**	**FZJ**	*start of project*	*end of project*	***Fields of excellence***: Medium energy physics accelerators and experiments, reliability of operation; polarized protons; stochastic cooling, electron cooling; electron beam welding; remote accelerator control and automation, design of superconducting accelerating structures, design of high intensity and high energy accelerators ***Specific participation*** in: **N1, N2, JRA3**
8	**Technical University München, Germany**	**TUM**	*start of project*	*end of project*	***Fields of excellence***: Long term expertise in the field of neutrino *and muon physics* and experiments. It will contribute to the general steering and studies of the PHYSICS potential of future long baseline experiments. The studies aim at guiding the exploration, planning and construction of conceivable set-ups by identifying the capabilities and the crucial components and limitations. ***Specific participation*** in: **N2**

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)
9	**Forschungszentrum Rossendorf, Germany**	**FZR**	*start of project*	*end of project*	***Fields of excellence***: Design and construction of intermediate energy accelerator, photo-injectors, photocathode for SC RF gun, synchrotron radiation source, Free Electron Laser, ELBE accelerator infrastructure. ***Specific participation*** in: **N1, JRA2***
10	**Istituto Nazionale di Fisica Nucleare Frascati, Italy**	**INFN**	*start of project*	*end of project*	***Fields of excellence***: High Energy and Nuclear Physics Accelerators and Experiments, Construction and operation of Particle Accelerators and Colliders, Accelerator Controls, Computing, Networking, Synchrotron Radiation Sources and Experiments, Astroparticle physics. ***Specific participation*** in: **N1*, N2*, N3, JRA1*, JRA2*, JRA3*, JRA4*** Specific Responsibilities: **coordinator for N2 and JRA2**
	INFN Bari Bari, Italy	**INFN-Ba**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics, hadroproduction data, muon cooling studies ***Specific participation*** in: **N2**
	INFN Frascati, Frascati, Italy	**INFN-LNF**	*start of project*	*end of project*	***Fields of excellence***: High Energy and Nuclear Physics Experiments, Construction and operation of electron and positron Particle Accelerators and Colliders, Beam Dynamics, Accelerator Diagnostics and Controls, Computing, Networking, Synchrotron Radiation Sources, FEL. ***Specific participation*** in: **N1*, N2, N3, JRA1*, JRA2*** Specific Responsibilities: **coordinator for JRA2**
	INFN Genoa, Genoa, Italy	**INFN-Ge**	*start of project*	*end of project*	***Fields of excellence***: Design of superconducting magnets. Finite element analyses. Electrical transport measurements on superconducting wires and cables. AC loss measurements on superconducting devices. ***Specific participation*** in**: N2, N3, JRA4**
	INFN Gran Sasso, L'Aquila, Italy	**INFN-GS**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics, main exploitation laboratory of the CNGS and of future facilities. ***Specific participation*** in: **N2**
	INFN Legnaro, Legnaro, Italy	**INFN-LNL**	*start of project*	*end of project*	***Fields of excellence***: SRF accelerator design and construction (ALPI). Chemistry and Electrochemistry Material surface treatments; Plastic deformation of materials and forming technology; Clean room (HPR and mounting); Thin film technology and PVD machine construction; Non destructive evaluation techniques, in particular flux gate magnetometry. ***Specific participation*** in: **N1, N2, JRA1***

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	**Short description (i.e. fields of excellence) and specific roles in the consortium** (* indicates work package responsibilities)
	INFN Milano, Milano, Italy	**INFN-Mi**	*start of project*	*end of project*	***Fields of excellence***: Design, construction and test of superconducting (SC) cavities for electrons and protons and of SC magnets for accelerators and detectors. High current proton beam dynamics; cryostat and cryomodule design and construction; photocathode and laser for high brightness photoinjector; SC cable and material low temperature characterization; SC magnet protection system design, and test; accelerator remote operation (GAN). Robust electron sources and laser pulse shaping. ***Specific participation*** in: **N1, N2, N3, JRA1*, JRA2, JRA3*, JRA4***
	INFN Napoli, Napoli, Italy	**INFN-Na**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics and beams, hadroproduction data, cooling studies. Long term expertise in theoretical and experimental accelerator physics. ***Specific participation*** in: **N2, N3** Specific Responsibilities: **coordinator for N3**
	INFN Padova, Padova, Italy	**INFN-Pa**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics and beams, hadroproduction data, muon cooling studies ***Specific participation*** in: **N2***
	INFN Pisa, Pisa, Italy	**INFN-Pi**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics, phenomenology and theory ***Specific participation*** in: **N2**
	INFN Roma 2, Roma, Italy	**INFN-Ro2**	*start of project*	*end of project*	***Fields of excellence***: SC Cavity fabrication R&D, accelerator instrumentation and controls, computing and networking. ***Specific participation*** in: **N1, JRA1**
	INFN Roma Tre, Roma, Italy	**INFN-Ro3**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics, hadroproduction data, muon cooling studies ***Specific participation*** in: **N2**
	University of Salerno, Salerno, Italy	**INFN-Sal**	*start of project*	*end of project*	***Fields of excellence***: Relevant beam dynamics expertise: Impedance estimates in accelerator structures. Single- and multi-bunch beam instabilities. Further developments and application of analytic estimates and simulation codes will be used to characterise the impedance, and to study intensity limitations and ultimate performance of future High-Energy/High-Intensity Proton Accelerators, such as the LHC and its injectors, including beam dynamics with barrier buckets. ***Specific participation*** in: **N3**
	INFN Torino, Torino, Italy	**INFN-To**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics, phenomenology and theory ***Specific participation*** in: **N2**
	INFN Trieste, Triestre, Italy	**INFN-Tr**	*start of project*	*end of project*	***Fields of excellence***: Neutrino physics, hadroproduction data, muon cooling studies ***Specific participation*** in: **N2**

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)
11	Twente University Enschede, Netherlands	**TEU**	*start of project*	*end of project*	***Fields of excellence***: Theoretical and experimental research on superconducting wire and cable, development of superconducting demonstration devices (NbTi, Nb3Sn and HTS), experience on design and manufacture of Nb3Sn dipole magnet models. Development for photo-cathodes and photo-injectors. ***Specific participation*** in: **N1, N3, JRA2, JRA4***
12	Technical University Lodz, Poland	**TUL**	*start of project*	*end of project*	***Fields of excellence***: Full-custom design and HDL synthesis of modern ASIC-VLSI circuits, Data acquisition and processing systems, Control systems, power electronics, hardware-software code design of digital systems, software tools for system design and simulation. ***Specific participation*** in: **N1, JRA1**
13	The Andrzej Soltan Institute for Nuclear Studies Otwock-Swierk, Poland	**IPJ**	*start of project*	*end of project*	***Fields of excellence***: High Energy and Nuclear Physics, Accelerator Physics and Technology (modelling of beam dynamics, bunching etc., design of accelerator parts, power supplies etc.), Plasma Physics and Technology (plasma diagnostics and techniques for material engineering, e.g. UHV-arc deposition of superconductor layers etc.) ***Specific participation*** in: **N1, JRA1**
14	Politechnika Warszawska, University of Technology, Institute of Electronic Systems Warsaw, Poland	**WUT-ISE**	*start of project*	*end of project*	***Fields of excellence***: Analog digital and mixed electronic systems and instrumentation, microwave and optical/photonic circuits and systems, microprocessor and computer and software engineering, distributed large and multichannel measurement systems, multi-gigabit optical links and networks, FPGA/DSP systems design, Internet engineering, image processing systems, neural networks and fuzzy systems ***Specific participation*** in: **N1, JRA1**
15	University of Technology Wroclaw, Poland	**WUT**	*start of project*	*end of project*	***Fields of excellence***: Mechanical Engineering, Refrigeration and Cryogenics, Research, Development, Construction and Commissioning of Cryogenic Systems (modeling of cooling systems and refrigerators, heat transfer and material thermal properties, flow calculations, modeling of magnet resistive transition thermo hydraulics etc.) ***Specific participation*** in: **N3, JRA4**
16	**Consejo Superior de Investigaciones Cientificas, Madrid, Spain**	**CSIC**	*start of project*	*end of project*	***Fields of excellence***: High energy experiments, accelerator studies, superconducting magnets, power supplies ***Specific participation*** in: **N1, N2, N3**
	Univ. of Barcelona, Barcelona, Spain	**UBa**	*start of project*	*end of project*	***Fields of excellence***: Experimental neutrino physics ***Specific participation*** in: **N2**

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)
	CIEMAT, Madrid, Spain	**CIEMAT**	*start of project*	*end of project*	***Fields of excellence***: Design and fabrication of superconducting magnets ***Specific participation*** in: **N1, N3**
	Universidad Autonoma de Madrid Madrid, Spain	**UAM**	*start of project*	*end of project*	***Fields of excellence***: Recognized leadership in the field of theory and phenomenology of neutrinos. ***Specific participation*** in: **N2**
	Lab. of Industr. Electron. & Instrum. Uni. Valencia, Valencia, Spain	**LEII**	*start of project*	*end of project*	***Fields of excellence***: Design of power supplies ***Specific participation*** in: **N1**
	University of Valencia Valencia, Spain	**IFIC**	*start of project*	*end of project*	***Fields of excellence***: Design optics, modelling of machine imperfections and beam based measurements ***Specific participation*** in: **N1, N2, N3**
17	**European Organization for Nuclear Research Geneva, Switzerland**	**CERN**	*start of project*	*end of project*	***Fields of excellence***: High energy Physics Accelerators and Experiments, Nuclear Physics accelerators including heavy ions and antiproton decelerator, Superconducting Cavities, Superconducting Magnets, Accelerator Controls, Computing, Networking, Video Communication Tools, Linear colliders, Photocathodes, Neutrino Factories, High Intensity Proton Machines, Ion Sources ***Specific participation*** in: **N1*, N2*, N3*, JRA2, JRA3, JRA4*** Specific Responsibilities: **coordinator for N3, JRA3**
18	**Université de Genève, Genève, Switzerland**	**UNI-GE**	*start of project*	*end of project*	***Fields of excellence***: A consortium of physicists from Swiss Universities contributing long-term expertise in the field of neutrino physics, experiments & beams (design, detailed simulation, operation and analysis of their data), expertise in horn technology and in the field of intense low energy muon beams and leadership in the experimental studies of muon ionisation cooling. It will contribute to the general steering and to the PHYSICS, TARGET, HORN, COOLING WPs. ***Specific participation*** in: **N2**
19	**Paul Scherrer Institute Villingen, Switzerland**	**PSI**	*start of project*	*end of project*	***Fields of excellence***: Development, construction and operation of electron and proton accelerators (linear accelerators, synchrotrons, storage rings and cyclotrons) for synchrotron radiation, nuclear, atomic and applied physics experiments. Development and operation of (digital) feedback systems for particle beam stabilization and RF-control. Research and development of accelerator instrumentation and data processing electronics. ***Specific participation*** in: **N1, N2, N3, JRA1**

Participant number	Organisation (name, city, country)	Short name	Date enter project	Date exit project	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)
20	**Council for the Central Laboratory of the Research Councils Oxfordshire & Daresbury,United Kingdom**	**STFC**	*start of project*	*end of project*	***Fields of excellence:*** High Energy Physics Accelerators and Experiments, proton accelerators, beam dynamics, targets for proton beams, synchrotron radiation sources and experiments, photo-injectors, free electron lasers, accelerator controls, superconducting magnets, computing. ***Specific participation in:*** **N1*, N2*, N3, JRA2*, JRA3, JRA4***
	Daresbury Laboratory Daresbury, UK	**STFC-DL**	*start of project*	*end of project*	***Fields of excellence: RF design.*** Small emittance electron sources. Laser acceleration. SC cavity design. RF coupler design. Machine simulation. Laser-plasma acceleration. Design and construction of linear accelerator components. High brightness gun design. Beam diagnostics and instrumentation (DL provides the coordinator for WP4). General coordination of many UK network activities. ***Specific participation in:*** **N1***
	Rutherford Appleton Laboratory Oxfordshire, UK	**STFC-RAL**	*start of project*	*end of project*	***Fields of excellence:*** High Energy Physics Accelerators and Experiments, accelerator physics and technology, lasers for photoinjectors, high brightness gun design, beam diagnostics using laser devices. laser-plasma acceleration, instrumentation, pulsed proton accelerators, high power target , ion sources, RFQs, chopper development, beam dynamics, superconducting magnets. ***Specific participation in:*** **N1, N2*, N3, JRA2*, JRA3, JRA4***
21	**Imperial College London, United Kingdom**	**ICL**	*start of project*	*end of project*	***Fields of excellence:*** Particle Physics experimentation, machine-experiment interface in experiments, electronics, muon cooling design, high gradient electron and ion acceleration techniques using laser-produced plasmas, diagnostic techniques, theoretical modelling of laser-plasma interactions. ***Specific participation in:*** **N1, N2, N3**
22	**Manchester University Manchester, United Kingdom**	**UMA**	*start of project*	*end of project*	***Fields of excellence:*** Particle Physics experimentation, simulation of beam delivery systems at linear colliders, beam diagnostics. ***Specific participation in:*** **N1**

Participant number	**Organisation (name, city, country)**	**Short name**	**Short description (i.e. fields of excellence) and specific roles in the consortium** (* indicates work package responsibilities)	**Associated to**
Associated Institutes				
1	**Center for the Advancement of Natural Discoveries using Light Emission, Yerevan , Armenia**	**CANDLE**	***Fields of excellence***: Beam dynamics in the main linac, optic optimization, emittance preservation, trajectory correction, wake fields and impedances, beam dynamics in damping ring, non-linear and fringe field effects. ***Specific participation in***: **N1**	CERN
2	**Helsinki Institute of Physics,** **Helsinki, Finland**	**HIP**	***Fields of excellence***: Beam diagnostics tools and instrumentation. HEPH is assisted by a consortium of Finnish institutes and industry with expertise in RF measurements, automation and vacuum related mechanics and welding. ***Specific participation*** in: **N1**	CERN
3	**European Synchrotron Radiation Facility, Grenoble, France**	**ESRF**	***Fields of excellence***: Beam dynamics and beam instrumentation expertise ***Specific participation*** in: **N3**	CERN
4	**RWTH,** **Aachen, Germany**	**RWTH**	***Fields of excellence***: High energy experiments, beam instrumentation ***Specific participation*** in: **N1**	DESY
5	**Max Born Inst** **Berlin, Germany**	**MBI**	***Fields of excellence***: Laser, RF gun ***Specific participation*** in: **N1**	DESY
6	**Technical Univ. Berlin** **Berlin, Germany**	**TUBE**	***Fields of excellence***: High frequency planar RF cavities, beam position monitors, wake field calculations ***Specific participation*** in: **N1, N3**	CERN
7	**TEMF/ Tech. Univ. Darmstadt,** **Darmstadt, Germany**	**TEMF**	***Fields of excellence***: Simulation code for machine modelling, RF gun ***Specific participation*** in: **N1, N3**	DESY
8	**Institiut für Theoretische Physik Düsseldorf, Germany**	**UDUSS**	***Fields of excellence***: Novel methods of acceleration, simulation of particle acceleration in plasma using PIC (particle in cell) codes ***Specific participation*** in: **N1**	CERN
9	Max-Planck-Institut für Quantumnoptik, **Garching, Germany**	**MPQ**	***Fields of excellence***: High intensity laser technology, relativistic plasma and electron generation and acceleration with laser-produced plasma, associated diagnostics ***Specific participation*** in: **N1**	CERN
10	**Forschungszentrum, Karlsruhe,** **Karlsruhe, Germany**	**FZK**	***Fields of excellence***: SMES, modulator, pulsed power sources ***Specific participation*** in: **N1, N3**	DESY

Participant number	Organisation (name, city, country)	Short name	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)	Associated to
Associated Institutes				
11	**University of Rostock, Rostock, Germany**	**UROS**	***Fields of excellence***: Space charge simulation, code development, HOMs ***Specific participation*** in: **N1**	DESY
12	**University of Wuppertal, Wuppertal, Germany**	**UWUP**	***Fields of excellence***: High gradient cavities, field emission control ***Specific participation*** in: **N1**	DESY
13	**Technion – Israel Institute of Technology, Tel-Aviv, Israel**	**Technion-IIT**	***Fields of excellence*****:** Beam Dynamics simulation, control system development and the integration of the two. ***Specific participation in***: **N1**	CERN
14	**Ente per le Nuove Tecnologie l'Energia e l'Ambiente** Roma, Italy	**ENEA**	***Fields of excellence***: Long experience in using tools capable to determine the nuclear responses in different components of magnetic fusion reactors. Those has been used (Monte Carlo methods mainly) to optimise the shields necessary to protect from the nuclear radiation the Superconducting Coils used to sustain the plasma in magnetic fusion reactors. Relevant work and contracts for ITER (International Thermonuclear Experimental Reactor). ***Specific participation*** in: **N3**	CERN
15	University of Osaka**,** **Osaka, Japan**	**UnO**	***Fields of excellence***: Neutrino and muon physics, accelerators, experiments, theory. Leading institution in the NuFACTJ Collaboration ***Specific participation*** in: **N2**	CERN
16	**KEK, High Energy Accelerator Research Organization Tsukuba, Japan**	**KEK**	***Fields of excellence***: Expertise in Sc magnets for Accelerators and detectors and SC accelerator integration. Development of design and constructing techniques for super conducting magnets, development of special conductors. Experience in the operation of storage rings with electron cloud effects and development of electron cloud simulation tools, design studies on linear colliders, development of klystrons, modulators and normal conducting RF cavities. ***Specific participation*** in: **N3**	CERN
17	**Institute of Physics, University of Latvia, Latvia,**	**IPUL**	***Fields of excellence***: IPUL has many years of expertise in designing and operating liquid metal loops and in developing necessary equipment and technologies. ***Specific participation*** in: **N2**	FZJ
18	**NRG** **Petten Netherlands**	**NRG**	***Fields of excellence***: NRG is experienced in fluid dynamics, structural mechanics and thermal hydraulics calculations and in developing suitable computer software. ***Specific participation*** in: **N2**	FZJ

Participant number	**Organisation (name, city, country)**	**Short name**	**Short description (i.e. fields of excellence) and specific roles in the consortium** (* indicates work package responsibilities)	**Associated to**
Associated Institutes				
19	**Eindhoven University of Technology Eindhoven, Eindhoven, Netherlands**	**TUE**	***Fields of excellence***: Photo--injectors and photo-guns. High brightness electron beams for FEL, colliders and laser wakefield accelerators ***Specific participation*** in: **N1**	CERN
20	**Cracow University of Technology, (Institute of Applied Mechanics), Krakow, Poland**	**CUT**	***Fields of excellence***: Vibration and stabilization issues, measurement and control; numerical analysis of vibration. ***Specific participation*** in: **N1**	CERN
21	**Group of Lasers & Plasmas of the Inst Sup Tecnico Lisboa,** **Lisboa, Portugal**	**GOLP**	***Fields of excellence***: Simulation and experiments on laser-plasma interactions and accelerators ***Specific participation*** in: **N1**	CERN
22	**Joint Institute of Nuclear Research, Dubna, Russia**	**JINR**	***Fields of excellence*: ** Expertise in accelerator magnets and integration. Design capability and studies on synchrotron radiation effect. Very special expertise in fast cycled magnets at low temperature. FEM produced power pulses and cavity-cell heating-tests. ***Specific participation*** in: **N3**	CERN
23	**Institute for High Energy Physics, Moscow, Russia**	**IHEP**	***Fields of excellence*** Radiation and shower calculations ***Specific participation*** in: **N3**	CERN
24	**University of Uppsala, Uppsala, Sweden**	**UPSA**	***Fields of excellence***: CTF3 commissioning. Tests of optics, modelling, and development of beam monitoring equipment. ***Specific participation*** in: **N1**	CERN
25	**Université Bern, Bern, Switzerland**	**UNI-Bern**	***Fields of excellence*: ** Experimental neutrino physics. ***Specific participation*** in: **N2**	UNI-GE
26	**Université de Neuchâtel, Neutchâtel, Switzerland**	**UNI-Neuchatel**	***Fields of excellence*: ** Experimental neutrino physics. ***Specific participation*** in: **N2**	UNI-GE

Participant number	Organisation (name, city, country)	Short name	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)	Associated to
Associated Institutes				
27	***Ecole Polytechnique Fédérale de Lausanne Centre de Recherches en Physique des Plasma*** **Lausanne, Switzerland**	**CRPP**	***Fields of excellence***: Design and characterization of high current carrying superconductors (both low and high Tc). Experiments and analyses in the field of ac losses, quench and stability. Fusion magnets. World largest test facility for low temperature, short length superconductors (SULTAN). ***Specific participation*** in: **N3**	CERN
28	**Eidgenossiche Technische Hochscule, Zurich, Switzerland**	**ETHZ**	***Fields of excellence***: Very high frequency oscillators with applications to CTF3, fast optics, short pulse and survey and detector alignment ***Specific participation*** in: **N1, N3**	CERN
29	**Physik-Institut Universitat Zurich Zurick, Switzerland**	**PIUZ**	***Fields of excellence***: Muon beams and muon experiments. High power beams and targets. ***Specific participation*** in: **N2**	UNI-GE
30	**University of Bath, Bath, U.K.**	**BAT**	***Fields of excellence***: Electromagnetic levitation. ***Specific participation*** in: **N2**	ICL
31	**Brunel University, Uxbridge, U.K.**	**BRU**	***Fields of excellence***: Particle Physics experiments, computing and software, ionisation cooling studies. ***Specific participation*** in: **N2**	ICL
32	**University of Cambridge, Cambridge, U.K.**	**CAM**	***Fields of excellence***: Particle Physics experiments, neutrino physics studies. ***Specific participation*** in: **N2**	ICL
33	**University of Abertay, Dundee, U.K.**	**UAD**	***Fields of excellence***: Ultra short electron bunch measurements with ultra fast lasers for LC ***Specific participation*** in: **N1**	UMA
34	**University of Durham, Durham, UK**	**DUR**	***Fields of excellence***: Neutrino physics studies ***Specific participation*** in: **N2**	ICL
35	**University of Edinburgh, Edinburgh, U.K.**	**EDIN**	***Fields of excellence*:** Particle Physics experiments, computing and software, ionisation-cooling studies. ***Specific participation*** in: **N2**	ICL
36	**University of Glasgow, Glasgow, U.K.**	**GLA**	***Fields of excellence***: Particle Physics experiments, computing and software, ionisation cooling studies ***Specific participation*** in: **N2**	ICL

Participant number	**Organisation (name, city, country)**	**Short name**	**Short description (i.e. fields of excellence) and specific roles in the consortium** (* indicates work package responsibilities)	**Associated to**
Associated Institutes				
37	**University of Lancaster, Lancaster, UK**	**LANC**	***Fields of excellence***: RF component design and simulation. ***Specific participation*** in: **N1**	UMA
38	**Queen Mary, Univ. of London, London, U.K.**	**QMUL**	***Fields of excellence***: Luminosity optimisation, simulation of beam transportation, prototype for fast feedback, neutrino physics studies. ***Specific participation*** in: **N1, N2**	UMA
39	**Royal Holloway, Univ. of London, London, U.K.**	**RHUL**	***Fields of excellence***: Geant4 simulation of beam line, laserwire R&D, collimation, luminosity spectrum ***Specific participation*** in: **N1**	UMA
40	**University College London, London, U.K.**	**UCL**	***Fields of excellence***: Laserwire R&D, Shintake monitor, luminosity spectrum ***Specific participation*** in: **N1**	UMA
41	**University of Liverpool, Liverpool, U.K.**	**ULI**	***Fields of excellence***: Simulation of beam delivery spectrum, positron undulator source, neutrino physics studies, ionisation muon cooling studies. ***Specific participation*** in: **N1, N2**	UMA
42	**University of Oxford Oxford, U.K.**	**UOX**	***Fields of excellence***: Particle Physics experimentation, neutrino physics studies, ionisation cooling studies, instrumentation for beam alignment, diagnostics, beam profile, beam delivery. Plasma for novel acceleration**.** RF power supply technology. ***Specific participation*** in: **N1, N2**	ICL
43	**University of Sheffield, Sheffield, U.K.**	**SHEF**	***Fields of excellence***: Particle physics experimentation, neutrino physics studies, mechanical aspects of targetry, ionisation muon cooling studies. ***Specific participation*** in: **N2**	ICL
44	**University of Southampton, Southampton, U.K.**	**SOTON**	***Fields of excellence***: Neutrino physics studies ***Specific participation*** in: **N2**	ICL
45	**Univ. of Strathclyde Glasgow, U.K.**	**USTRAT**	***Fields of excellence***: Laser plasma interactions and FEL, RF engineering for accelerators. ***Specific participation*** in: **N1**	UMA
46	**University of Sussex, Sussex, U.K.**	**SUSS**	***Fields of excellence***: Particle Physics experimentation, neutrino physics studies. ***Specific participation*** in: **N2**	ICL

Participant number	Organisation (name, city, country)	Short name	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)	Associated to
Associated Institutes				
47	Fermi National Accelerator Laboratory **Batavia**, **U.S.A.**	**FNAL**	***Fields of excellence***: Expertise in SC hadron collider integration and operation. Design and construction of accelerator magnets, test of magnets. Specific experience in high field A15 accelerator magnets R&D, design of innovative solution of VLHC (like the handling of synchrotron radiation). Radiation shielding calculations. Design work on linear colliders of SC and NC technology ***Specific participation*** in: **N3**	CERN
48	**Lawrence Berkeley National Laboratory, Berkeley, U.S.A.**	**LBNL**	***Fields of excellence***: Expertise in SC magnets for accelerators and wide experience in very high field design and construction technique. Test of SC magnets. Reference centre for cabling of Rutherford cable and of A15 and HTS development and test for accelerators ***Specific participation*** in **N3**	CERN
49	**Brookhaven National Laboratory Brookhaven, U.S.A.**	**BNL**	***Fields of excellence***: Expertise in SC hadron collider integration and operation, Accelerator Magnets design and construction, cable design, and test; recent development for cycling SC magnets and HTS special designed magnets ***Specific participation*** in: **N3**	CERN
50	**Stanford Linear Accelerator Center, Stanford, USA**	**SLAC**	***Fields of excellence*****:** Beam Dynamics for the linear collider, including all subsystems from the source to the beam delivery, high power microwave generation, delivery and accelerating structures, controls for accelerators including low level RF, beam feedback and machine protection, instrumentation for precision electron beams, measurement and stabilization of component vibration, High power beam collimation ***Specific participation*** in: **N1**	CERN
Associated industrial partners				
51	**Alsthom MSA Belford, France**	**ALS**	***Fields of excellence***: Design and manufacture of superconducting wire and cable, design and manufacture of superconducting magnet. ***Specific participation*** in: **JRA4**	CERN
52	**ACCEL Instruments GmbH, Bergisch-Gladbach Germany**	**ACCEL**	***Fields of excellence***: Design and fabrication of complete accelerating systems (normal- and superconducting), design and fabrication of superconducting cavities, infrastructure for chemistry and clean-room work, EB welding facility ***Specific participation*** in: **N1, JRA1**	DESY
53	***WSK Messtechnik GmbH,*** **Hanau, Germany**	**WSK**	***Fields of excellence***: Design and fabrication of analytic equipment for material analysis, development of a SQUID scanner for examination of sputter targets ***Specific participation*** in: **N1, JRA1**	DESY

Participant number	Organisation (name, city, country)	Short name	Short description (i.e. fields of excellence) and specific roles in the consortium (* indicates work package responsibilities)	Associated to
Associated industrial partners				
54	**European Advanced Superconductors GmbH, Hanau, Germany**	**EAS**	***Fields of excellence***: Design and manufacture of superconducting wires. ***Specific participation*** in: **JRA4**	CERN
55	**Henkel Lohnpoliertechnik GmbH Neustadt-Glewe, Germany**	**HLT**	***Fields of excellence***: chemical and electrochemical surface treatment of steel and special alloys for pharma, biotech. and semiconductor industry ***Specific participation*** in: **JRA1**	DESY
56	**E. Zanon S.P.A., Schio, Italy**	**ZANON**	***Fields of excellence***: Design and fabrication of Nb cavities, infrastructure for chemistry, EB welding facility ***Specific participation*** in: **N1**, **JRA1**	DESY
57	***ShapeMetal Innovation BV,*** **Enschede, Netherlands**	**SMI**	***Fields of excellence***: Design and manufacture of Nb3Sn wires by the powder-in-tube technique. ***Specific participation*** in: **JRA4**	CERN
58	**Kriosystem Ltd. Poland**	**KRIO**	***Fields of excellence***: Design and manufacture of helium cryostats. ***Specific participation*** in: **JRA4**	WUT
59	**e2v Technologies Ltd, Chelmsford, UK**	**E2V**	***Fields of excellence***: Design and manufacture of RF, microwave and switching devices, sensors, power supplies, etc. ***Specific participation*** in: **N1**	STFC
60	**TMD Technologies Ltd, Hayes, UK**	**TMD**	***Fields of excellence***: Design and manufacture of microwave tubes, high voltage power supplies, transmitters and receivers. ***Specific participation*** in: **N1**	STFC
61	**Oxford Danfysik Ltd, Oxford, UK**	**DAN**	***Fields of excellence***: Design, production and installation of synchrotron beam lines. ***Specific participation*** in: **N1**	STFC
62	**Technical Systems Ltd, Reading, UK**	**TECUK**	***Fields of excellence***: Design and manufacture of electron beam linear accelerators for industrial and scientific uses. ***Specific participation*** in: **N1**	STFC

Annex 2

The complete list of the deliverables is shown in the following tables for the 5 year period of CARE.

2004

Activity	Deliverable N°	Deliverable Name	Deliverable Type	Workpackage/ Task N°	Delivered by Contractor (s)	Planned (in months)	Achieved (in months)
ELAN	1	ELAN web site	Web site	All WPs	CNRS-Orsay	4	4
ELAN	2	Beam Dynamics code repository site functional	Data base	WP3	CERN	12	12
ELAN	3	Instrumentation web site	Web site	WP4	STFC, UMA	6	21
ELAN	4	Instrumentation data base	Data base	WP4	STFC, UMA	12	23
BENE	5	BENE web site	Web site	All WPs	INFN-Na	4	4
BENE	6	Annual report of the BENE network	Report	All WPs	INFN-Na	12	12
BENE	7	Proposal for FP6 Design Study of a new neutrino facility	Report	All WPs	INFN-Na	12	delayed to FP7
BENE	8	Proceedings of Multi-MW workshop	Report	All WPs	INFN-Na	12	14
BENE	9	BENE Physics web site	Web site	WP1	INFN-Pa, CERN	3	3
HHH	10	HHH web site	Web site	All WPs	CERN	12	9
HHH	11	APD web site	Web site	WP3	CERN	6	9
SRF	12	Final report on reliability issues	Report	WP2	DESY	9	30
SRF	13	EP on samples: best EP parameters	Report	WP5	CEA	12	26
NED	14	Final report on wire and cable specifications	Report	WP3	CERN	6	6
NED	15	Design report on 15 T dipole magnet	Report	WP3	CERN	12	13

2005

Activity	Deliverable N°	Deliverable Name	Deliverable Type	Workpackage/ Task N°	Delivered by Contractor (s)	Planned (in months)	Achieved (in months)
ELAN	1	Work plan and documentation data base	Data base	WP1	CERN	24	22
ELAN	2	Data base on SRF documents	Data base	WP2	DESY	24	24
BENE	3	18-month interim report	Report	All WPs	INFN-Na	23	23
BENE	4	Annual report of the BENE network	Report	All WPs	INFN-Na	24	24
BENE	5	Proceedings of NuFact'05 workshop	Report	All WPs	INFN-Na	24	30
BENE	6	Launch of scoping study of a new neutrino facility	Web site Report	All WPs	INFN-Na	18	18
HHH	7	Beam Dynamics code repository	Data base	WP3	CERN	24	18
SRF	8	EP on multi-cells: parameters fixed	Report	WP5	DESY	13	37
SRF	9	Automated EP is defined	Report	WP5	INFN-Legnaro	21	37
SRF	10	Dry ice cleaning: parameters fixed	Report	WP5	DESY	18	37
SRF	11	CEA tuner: start of integrated experiments	Prototype	WP8	CEA	15	24
SRF	12	Report on IN2P3 tuner activities	Report	WP8	CNRS-Orsay	24	39
SRF	13	Report on data management developments	Report	WP9	DESY	21	24
SRF	14	Report on RF gun control tests	Report	WP9	DESY	23	37
PHIN	15	High efficiency photocathode comparison	Report	WP2	FZR	24	24
PHIN	16	High power laser oscillator	Report	WP3	STFC-RAL	13	13
PHIN	17	Amplifier construction	Prototype	WP3	CERN, INFN	19	54
PHIN	18	Oscillator + amplifier test	Report	WP3	STFC-RAL	23	30
PHIN	19	Pulse shaping system: phase mask acquisition and test	Report	WP3	INFN-Milano	16	23
PHIN	20	Pulse shaping system: Dazzler acquisition and test	Report	WP3	INFN-LNF	17	41
PHIN	21	Pulse shaping comparison	Prototype	WP3	INFN-LNF, INFN-Milano	22	47
PHIN	22	UV harmonic generator test	Prototype	WP3	CERN, CEA	16	54
PHIN	23	Laser RF feedback development	Report	WP3	CERN	21	59
PHIN	24	Two 3 GHz RF guns construction	Prototype	WP4	CNRS-Orsay	18	54
PHIN	25	1-50 MeV spectrometer construction	Prototype	WP4	CNRS-LOA	24	36

HIPPI	26	Halo measurement device design and construction	Report	WP5	CERN	18	24
NED	27	Commissioning of heat transfer facility	Prototype	WP2	CEA, WUT	16	35
NED	28	Final report on Quench Protection	Report	WP2	INFN-Milano	18	23
NED	29	Report on conventional insulation	Report	WP4	STFC-RAL	24	40
NED	30	Report on innovative insulation	Report	WP4	CEA	18	48

2006

Activity	Deliverable N°	Deliverable Name	Deliverable Type	Workpackage/ Task N°	Delivered by Contractor (s)	Planned (in months)	Achieved (in months)
ELAN	1	Data base on diagnostics performance	Data base	WP4	STFC, UMA	36	36
BENE	2	Annual report of the BENE network	Report	All WPs	INFN-Na	36	38
BENE	3	Proposal for design studies and R&D	Report	All WPs	INFN-Na, STFC	36	31
BENE	4	Summary of NuFact'06 workshop Strategy document	Web site Report	All WPs	INFN-Na	36	32
HHH	5	Data base on SC magnets and cables	Data base	WP1	CERN	36	48
SRF	6	Evaluation of spinning parameters	Report	WP3	INFN-Legnaro	29	37
SRF	7	1-cell spinning parameters defined	Report	WP3	INFN-Legnaro	36	57
SRF	8	Report on new LLRF hardware components	Report	WP9	DESY	26	37
SRF	9	New BPM ready for installation	Prototype	WP11	CEA	25	34
SRF	10	Evaluation of HOM-BPM operation	Report	WP11	CEA	36	37
PHIN	11	Photocathode ready for 3 GHz RF guns	Prototype	WP2	CERN	25	41
PHIN	12	UV generation and feedback: overall system assembly and tests	Prototype	WP3	CERN	30	58
PHIN	13	SC RF gun realisation	Prototype	WP4	FZR	26	36
PHIN	14	SC RF gun test	Report Report	WP4	FZR	36	part 1: 39 final : 59
PHIN	15	CTF3 3 GHz RF gun test at CERN	Report	WP4	CNRS-Orsay, CERN	33	60
HIPPI	16	H-mode DTL prototype ready	Prototype	WP2	IAP-FU	36	54
HIPPI	17	CCDTL prototype tested	Report	WP2	CERN	36	47
HIPPI	18	Elliptical cavities: cavity B ready	Prototype	WP3	CEA	30	41
HIPPI	19	Chopping structure A: prototype ready	Prototype	WP4	CERN	32	36
HIPPI	20	Beam Dynamics: simulations and experiments at UNILAC	Report	WP5	GSI	36	46
HIPPI	21	Profile measurements by fluorescence	Report	WP5	GSI	31	38
HIPPI	22	Non interceptive bunch measurement	Report	WP5	GSI	36	42
HIPPI	23	Collimators design	Report	WP5	CERN	36	30
NED	24	Final Report on Heat Transfer Measurements	Report	WP2	CEA	36	47

NED	25	Final wire production	Prototype Report	WP3	CERN	30	60
NED	26	Final report on wire characterization	Prototype Report	WP3	CERN	30	60
NED	27	Final cable production	Prototype	WP3	CERN	36	60
NED	28	Final report on cable performances	Report	WP3	CERN	36	60

2007

Activity	Deliverable N°	Deliverable Name	Deliverable Type	Workpackage/ Task N°	Delivered by Contractor (s)	Planned (in months)	Achieved (in months)
ELAN	1	Data base on laser plasma acceleration	Data base	WP5	CRNS-LPGP	48	cancelled
BENE	2	Annual report of the BENE network	Report	All WPs	INFN-Na	48	48
BENE	3	Proposal for design studies and R&D	Report	All WPs	INFN-Na	48	48
BENE	4	Proceedings of NuFact'07 workshop	Web site Report	All WPs	INFN-Na	48	60
SRF	5	Fabrication of new cavity with improved components	Prototype	WP2	INFN	47	59
SRF	6	EB Welding of prototype components	Prototype	WP2	DESY	48	57
SRF	7	Fabrication Multi-cell cavities by spinning	Prototype	WP3	INFN-Legnaro	48	60
SRF	8	Fabrication of hydroformed 9-cell cavities	Prototype	WP3	DESY	47	60
SRF	9	First multicell coating with linear-arc cathode	Prototype	WP4	IPJ	48	60
SRF	10	First multicell coating with planar-arc cathode	Prototype	WP4	INFN-Roma2	41	60
SRF	11	Report on quality of HTc superconducting properties	Report	WP4	INFN-Roma2	48	59
SRF	12	EP on single cells: parameters fixed	Report	WP5	CEA	48	57
SRF	13	Evaluate oxipolishing experiments	Report	WP5	DESY	40	60
SRF	14	Final report on industrial electropolishing	Report	WP5	DESY	48	59
SRF	15	Automated EP: Conclude on best electrolyte	Report	WP5	INFN-Legnaro	44	59
SRF	16	VT cleaning of 9-cell cavities: evaluation of experimental results	Report	WP5	DESY	48	60
SRF	17	Dry ice cleaning of horizontal 9-cell cavities: evaluation of experimental results	Report	WP5	DESY	48	60
SRF	18	Final report on SQUID scanning	Report	WP6	DESY	48	57
SRF	19	Conclude on comparison of SQUID scanner vs. flux gate detector	Report	WP6	INFN-Legnaro	48	59
SRF	20	DC field emission: evaluation of scanning results	Report	WP6	DESY	48	51
SRF	21	DC field emission: evaluate strong emitter investigations	Report	WP6	DESY	48	51

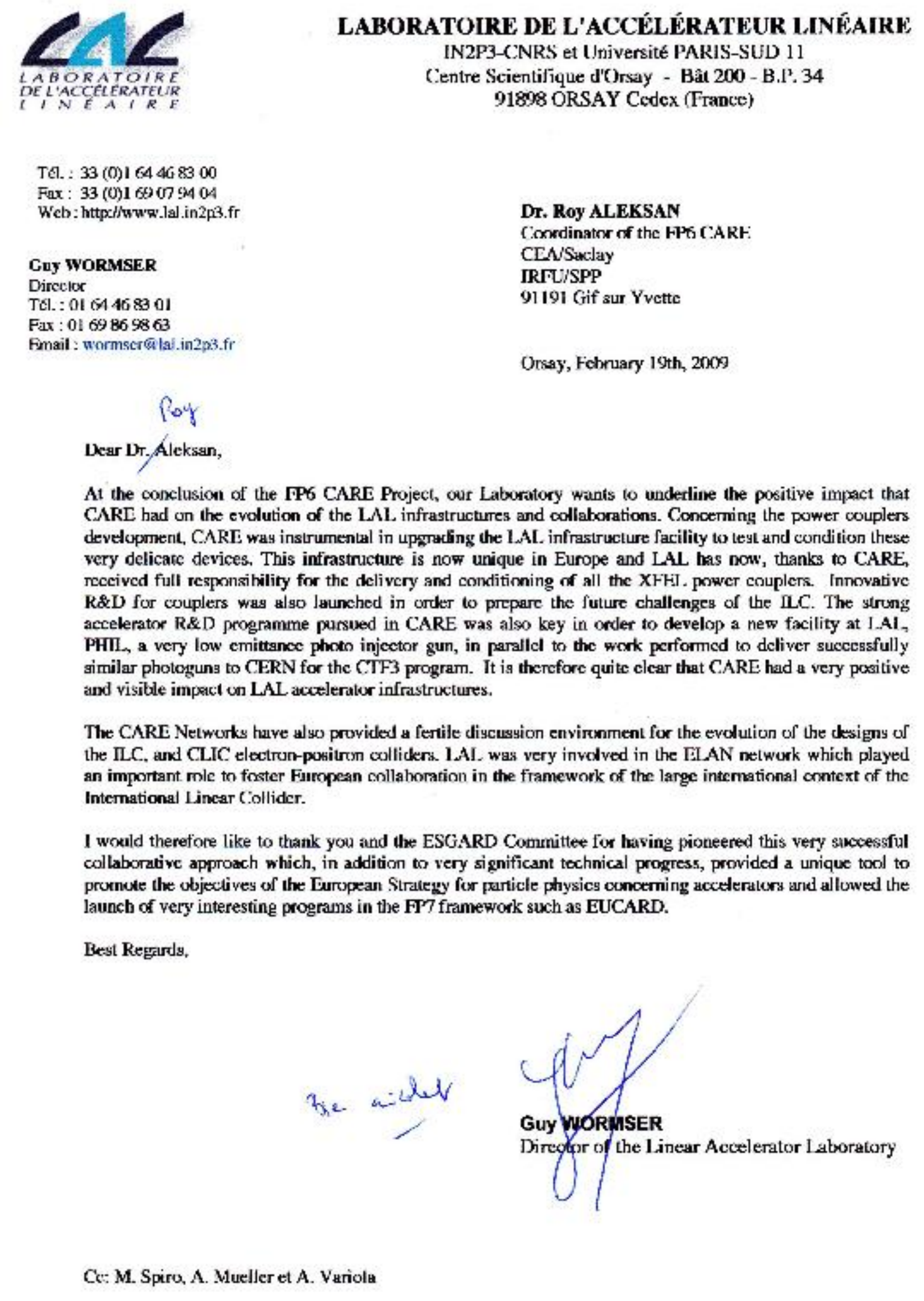
SRF	22	Prototype couplers: final report on conditioning	Report	WP7	CNRS-Orsay	47	59
SRF	23	Evaluation of INFN tuner operation	Report	WP8	INFN-Mi	48	51
SRF	24	Cryostat integration tests: final evaluation	Report	WP10	CEA	46	60
SRF	25	Evaluation of BPM operation	Report	WP11	CEA	48	48
SRF	26	Evaluation of beam emittance monitor operation	Report	WP11	INFN-Ro	48	59
PHIN	27	Superconducting cavity photocathode tests	Report	WP2	FZR	37	59
PHIN	28	Final report on 100 MeV laser driven plasma source R&D	Report	WP2	CNRS-LOA	48	47
PHIN	29	NEPAL 3 GHz RF gun test at Orsay	Report	WP4	CNRS-Orsay	37	59
PHIN	30	50 MeV (low energy) spectrometer test	Report	WP4	CNRS-LOA	42	36
PHIN	31	1 GeV spectrometer development	Report	WP4	CNRS-LOA	48	47
HIPPI	32	Drift Tube Linac: development of critical components	Report	WP2	CNRS-LPSC	37	46
HIPPI	33	Side Couple Linac: RF cold model prototype test	Report	WP2	CNRS-LPSC, CERN	48	52
HIPPI	34	Elliptical cavities: test stand ready	Test stand	WP3	CEA	39	47
HIPPI	35	Spoke cavities: prototype ready	Prototype	WP3	FZJ, CNRS-Orsay	46	54
HIPPI	36	Chopper structure A: prototype testing (w/o and with beam)	Report	WP4	CERN	44	57
HIPPI	37	Chopper line: Beam line assembly and measurements	Report	WP4	CERN	48	60
HIPPI	38	Chopper structure B: prototype ready	Prototype	WP4	STFC-RAL	42	54
HIPPI	39	Diagnostics and collimation: online transmission control	Report	WP5	GSI	46	52
HIPPI	40	Diagnostics and collimation: beam profile monitor for high intensity	Report	WP5	FZJ	42	46

2008

Activity	Deliverable N°	Deliverable Name	Deliverable Type	Workpackage/ Task N°	Delivered by Contractor (s)	Planned (in months)	Achieved (in months)
ELAN	1	Final report of the ELAN network	Report	All WPs	CNRS-Orsay	60	60
BENE	2	Final report of the BENE network	Report	All WPs	INFN-Na	60	60
BENE	3	Proposal for design studies and R&D	Report	All WPs	INFN-Na	60	60
BENE	4	Proceedings of NuFact'08 workshop	e-Proceedings	All WPs	INFN-Na	60	60
HHH	5	Final report of the HHH network	Report	All WPs	CERN	60	60
HIPPI	6	Drift Tube Linac: Optimised design	Report	WP2	CNRS-LPSC, CEA, CERN	60	60
HIPPI	7	H-mode Drift Tube Linac: design finished	Report	WP2	IAP-FU	60	60
HIPPI	8	Cell Coupled Drift Tube Linac: design finished	Report	WP2	CERN	54	56
HIPPI	9	Comparative assessment of Normal Conducting structures	Report	WP2	CNRS-LPSC, CEA, CERN, IAP-FU	60	60
HIPPI	10	Elliptical cavities: high power pulsed tests cavity A and B	Report	WP3	CEA, INFN-Mi	60	60
HIPPI	11	Spoke cavities: testing of prototype	Report	WP3	FZJ, CNRS-Orsay	60	60
HIPPI	12	CH resonator: measurements	Report	WP3	IAP-FU	60	60
HIPPI	13	Comparative assessment of superconducting structures	Report	WP3	CEA, INFN-Mi, FZJ, IAP-FU, CNRS-Orsay	60	60
HIPPI	14	Chopper structure B: prototype testing	Report	WP4	STFC-RAL	54	54
HIPPI	15	Comparative assessment of chopper designs	Report	WP4	CERN, STFC-RAL	58	60
HIPPI	16	Beam Dynamics: code benchmarking	Report	WP5	GSI et al.	58	58
HIPPI	17	Simulations and experiment at CERN	Report	WP5	CERN	60	60
HIPPI	18	Comparative assessment of dynamics and measurements	Report Report	WP5	GSI et al.	60	60

Annex 3

CNRS/IN2P3-LAL



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Dr. Roy ALEKSAN
Coordinator of the FP6 CARE
CEA/Saclay
IRFU/SPP
91191 Gif sur Yvette

Orsay, February 19th, 2009

Roy

Dear Dr. Aleksan,

At the conclusion of the FP6 CARE Project, our Laboratory wants to underline the positive impact that CARE had on the evolution of the LAL infrastructures and collaborations. Concerning the power couplers development, CARE was instrumental in upgrading the LAL infrastructure facility to test and condition these very delicate devices. This infrastructure is now unique in Europe and LAL has now, thanks to CARE, received full responsibility for the delivery and conditioning of all the XFEL power couplers. Innovative R&D for couplers was also launched in order to prepare the future challenges of the ILC. The strong accelerator R&D programme pursued in CARE was also key in order to develop a new facility at LAL, PHIL, a very low emittance photo injector gun, in parallel to the work performed to deliver successfully similar photoguns to CERN for the CTF3 program. It is therefore quite clear that CARE had a very positive and visible impact on LAL accelerator infrastructures.

The CARE Networks have also provided a fertile discussion environment for the evolution of the designs of the ILC, and CLIC electron-positron colliders. LAL was very involved in the ELAN network which played an important role to foster European collaboration in the framework of the large international context of the International Linear Collider.

I would therefore like to thank you and the ESGARD Committee for having pioneered this very successful collaborative approach which, in addition to very significant technical progress, provided a unique tool to promote the objectives of the European Strategy for particle physics concerning accelerators and allowed the launch of very interesting programs in the FP7 framework such as EUCARD.

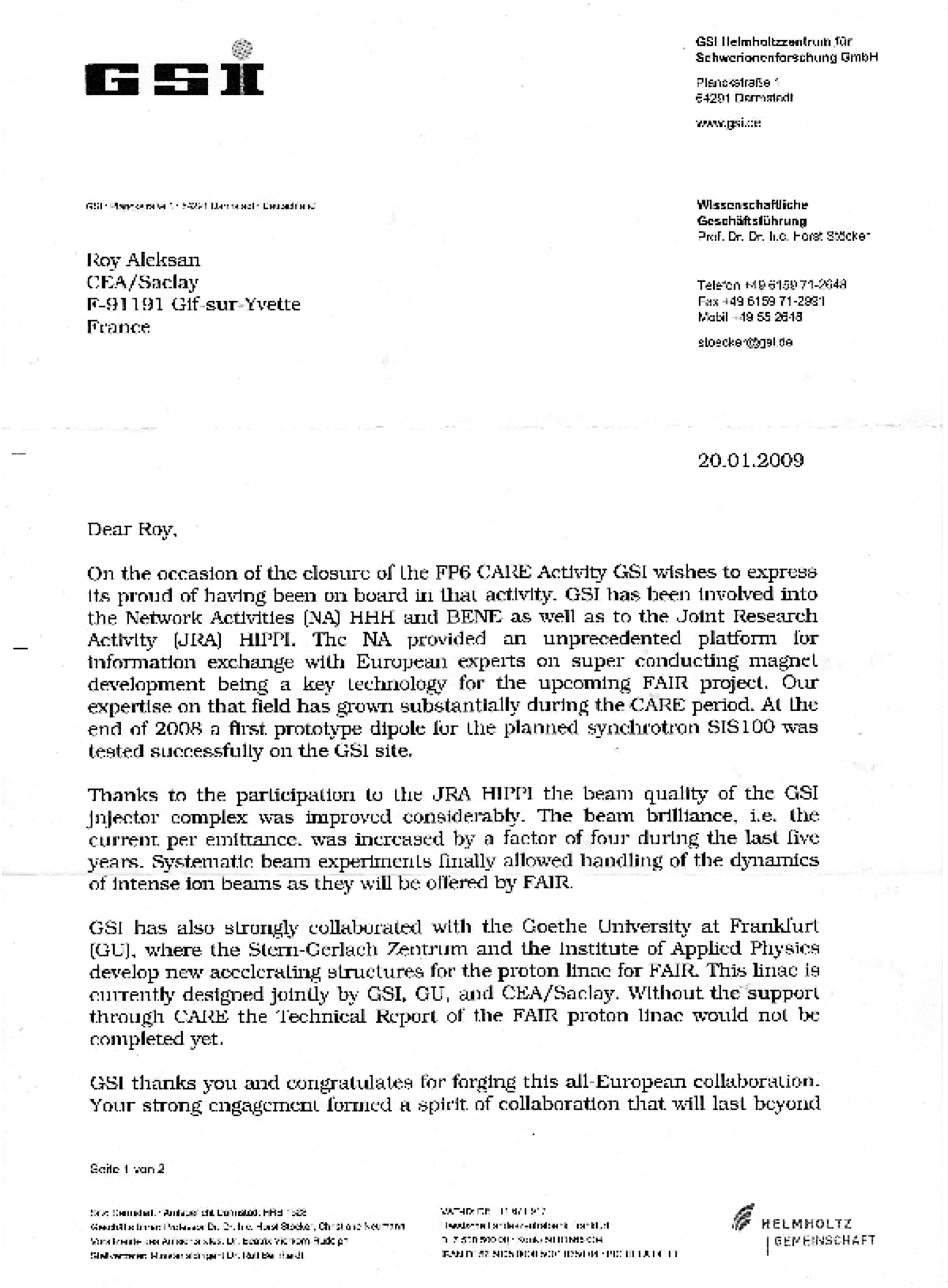
Best Regards,

Bien amicalement

Guy WORMSER
Director of the Linear Accelerator Laboratory

Cc: M. Spiro, A. Mueller et A. Variola

GSI



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Roy Aleksan
CEA/Saclay
F-91191 Gif-sur-Yvette
France

20.01.2009

Dear Roy,

On the occasion of the closure of the FP6 CARE Activity GSI wishes to express its proud of having been on board in that activity. GSI has been involved into the Network Activities (NA) HHH and BENE as well as to the Joint Research Activity (JRA) HIPPI. The NA provided an unprecedented platform for information exchange with European experts on super conducting magnet development being a key technology for the upcoming FAIR project. Our expertise on that field has grown substantially during the CARE period. At the end of 2008 a first prototype dipole for the planned synchrotron SIS100 was tested successfully on the GSI site.

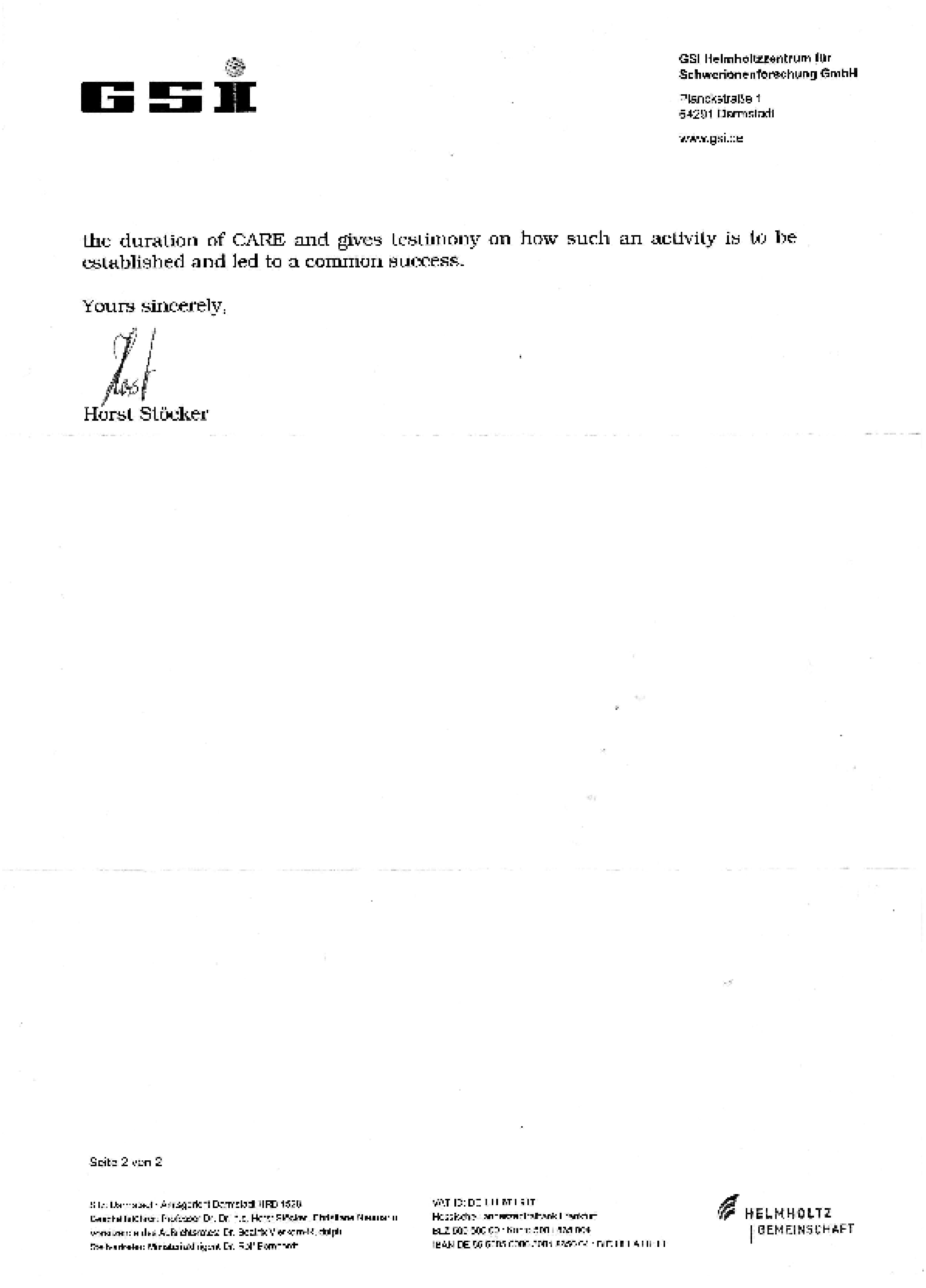
Thanks to the participation to the JRA HIPPI the beam quality of the GSI injector complex was improved considerably. The beam brilliance, i.e. the current per emittance, was increased by a factor of four during the last five years. Systematic beam experiments finally allowed handling of the dynamics of intense ion beams as they will be offered by FAIR.

GSI has also strongly collaborated with the Goethe University at Frankfurt (GU), where the Stern-Gerlach Zentrum and the Institute of Applied Physics develop new accelerating structures for the proton linac for FAIR. This linac is currently designed jointly by GSI, GU, and CEA/Saclay. Without the support through CARE the Technical Report of the FAIR proton linac would not be completed yet.

GSI thanks you and congratulates for forging this all-European collaboration. Your strong engagement formed a spirit of collaboration that will last beyond

Seite 1 von 2

HELMHOLTZ
GEMEINSCHAFT



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the duration of CARE and gives testimony on how such an activity is to be established and led to a common success.

Yours sincerely,

Horst

Horst Stöcker

Seite 2 von 2

IAP-FU

GOETHE
UNIVERSITÄT
FRANKFURT AM MAIN

Goethe-Universität Frankfurt am Main
Der Präsident • Präsidialabteilung •

Der Präsident

Mr. Roy Aleksan
CEA Saclay
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Datum: 16. März 2009

Dear Mr. Aleksan,

the European Accelerator Initiative CARE within FP6 was a very fruitful 5 year activity, which brought together working groups from large accelerator laboratories as well as from universities. In a phase, where new aims in particle intensities, beam quality and pulse structure are defined by basic research as well as by applied, beam driven facilities, it was a big chance for our university and the Applied Physics Institute to take part in the Joint Research Activity HIPPI, which allowed us intense exchange of ideas and collaboration in the field of high intensity, pulsed proton injectors with GSI Darmstadt, CERN Geneva and RAL Didcot, UK, mainly. These laboratories have actually projects in that field. Our research group was funded for contributions in beam dynamics as well as room temperature and superconducting rf cavity development.

During CARE we were able to demonstrate the potential of the room temperature CH structure. GSI has decided now to base their FAIR proton injector on that technology. We have some indications that other laboratories will also be attracted by this new development.

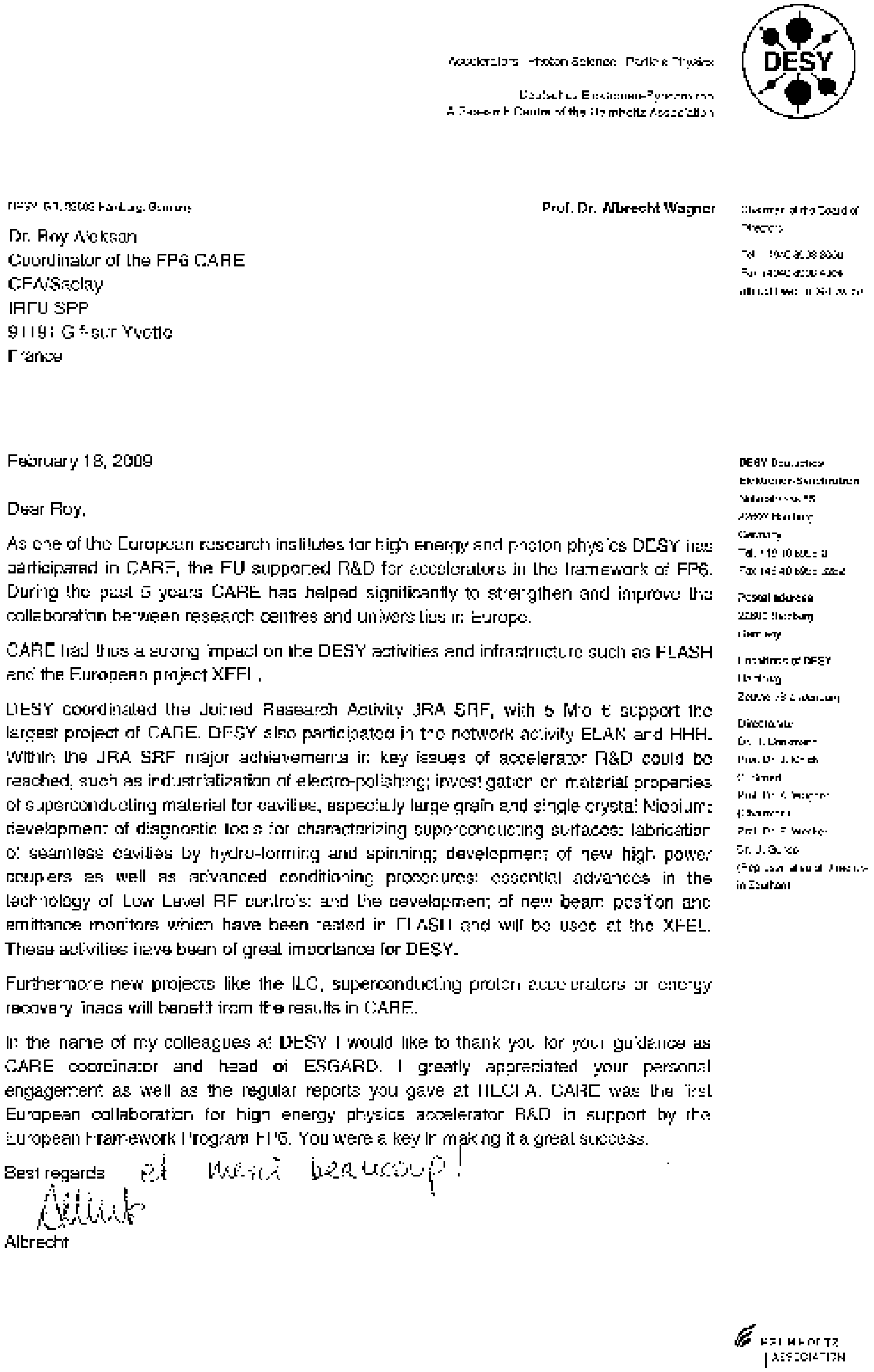
Moreover, we were able to demonstrate the feasibility of multicell, superconducting rf structures for low beam energies and to study resonance tuning concepts in detail. By this occasion we wish to thank you and the ESGARD committee for your intense support, which allowed this collaboration to become a great success.

Yours sincerely,

Prof. Dr. Werner Müller-Esterl
President

Campus Bockenheim • Senckenberganlage 31 • D-60325 Frankfurt am Main

DESY



Accelerators · Photon Science · Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

DESY · 22603 Hamburg · Germany

Prof. Dr. Albrecht Wagner

Chairman of the Board of Directors

[illegible]

Dr. Roy Aleksan
Coordinator of the FP6 CARE
CEA/Saclay
IRFU SPP
91191 Gif-sur-Yvette
France

February 18, 2009

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Locations of DESY
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Zeuthen/Brandenburg

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[illegible]

Dear Roy,

As one of the European research institutes for high energy and photon physics DESY has participated in CARE, the EU supported R&D for accelerators in the framework of FP6. During the past 5 years CARE has helped significantly to strengthen and improve the collaboration between research centres and universities in Europe.

CARE had thus a strong impact on the DESY activities and infrastructure such as FLASH and the European project XFEL.

DESY coordinated the Joined Research Activity JRA SRF, with 5 Mio € support the largest project of CARE. DESY also participated in the network activity ELAN and HHH. Within the JRA SRF major achievements in key issues of accelerator R&D could be reached, such as industrialization of electro-polishing; investigation on material properties of superconducting material for cavities, especially large grain and single crystal Niobium; development of diagnostic tools for characterizing superconducting surfaces; fabrication of seamless cavities by hydro-forming and spinning; development of new high power couplers as well as advanced conditioning procedures; essential advances in the technology of Low Level RF controls; and the development of new beam position and emittance monitors which have been tested in FLASH and will be used at the XFEL. These activities have been of great importance for DESY.

Furthermore new projects like the ILC, superconducting proton accelerators or energy recovery linacs will benefit from the results in CARE.

In the name of my colleagues at DESY I would like to thank you for your guidance as CARE coordinator and head of ESGARD. I greatly appreciated your personal engagement as well as the regular reports you gave at HLCIA. CARE was the first European collaboration for high energy physics accelerator R&D in support by the European Framework Program FP6. You were a key in making it a great success.

Best regards et merci beaucoup!

Albrecht

HELMHOLTZ
ASSOCIATION

FZJ

Dr. Sebastian M. Schmidt
Mitglied des Vorstandes

JÜLICH
FORSCHUNGSZENTRUM

Dr. Roy Aleksan
Coordinator of the FP6 CARE Project
CEA Saclay
F 91191 Gif sur Yvette
France

March 26, 2009

Dear Dr. Aleksan,

The FP6 CARE project has now come to a close and Forschungszentrum Jülich, as one of the beneficiaries of this project, would like to thank you, as the responsible coordinator, for continuously supporting our contribution to Coordinated Accelerator Research in Europe. Our institution was able to offer expertise in Hilbert spectroscopy, the modeling of second particle generation, and the design of superconducting accelerator cavities. We received not only financial support, but also - and at least equally important - we became part of a powerful European network. In our case, this was most evident in the production of the prototype of the HIPPI triple-spoke resonator. Tailored for use in high-intensity pulsed proton injectors, we designed, manufactured, and successfully tested the resonator in close collaboration with other European labs, for example CEA (Saclay), IPN (Orsay), CERN (Geneva), INFN (Milano), DESY (Hamburg), supported by CARE.

The HIPPI prototype resonator now has found its way to IPN (Orsay) where its properties will be investigated further. As our laboratory is now working hard in a joint effort with GSI for FAIR, we are currently not in a position to continue to pursue superconducting cavities in Jülich. However, the scientists and experts who were involved in the project are willing to respond to requests for assistance, and they will stay in contact with the community over the coming years to follow the developments in this exciting field.

We would like to thank you and the ESGARD committee for promoting the idea of strengthening European collaborative research, which finally resulted in Brussels attaining an excellent reputation in coordinated accelerator R&D.

Yours sincerely,

Dr. Sebastian M. Schmidt

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Dr. Ulrich Krafft (Stellv. Vorsitzender)
Prof. Dr. Harald Bolt
Dr. Sebastian M. Schmidt

Sitz der Gesellschaft: Jülich
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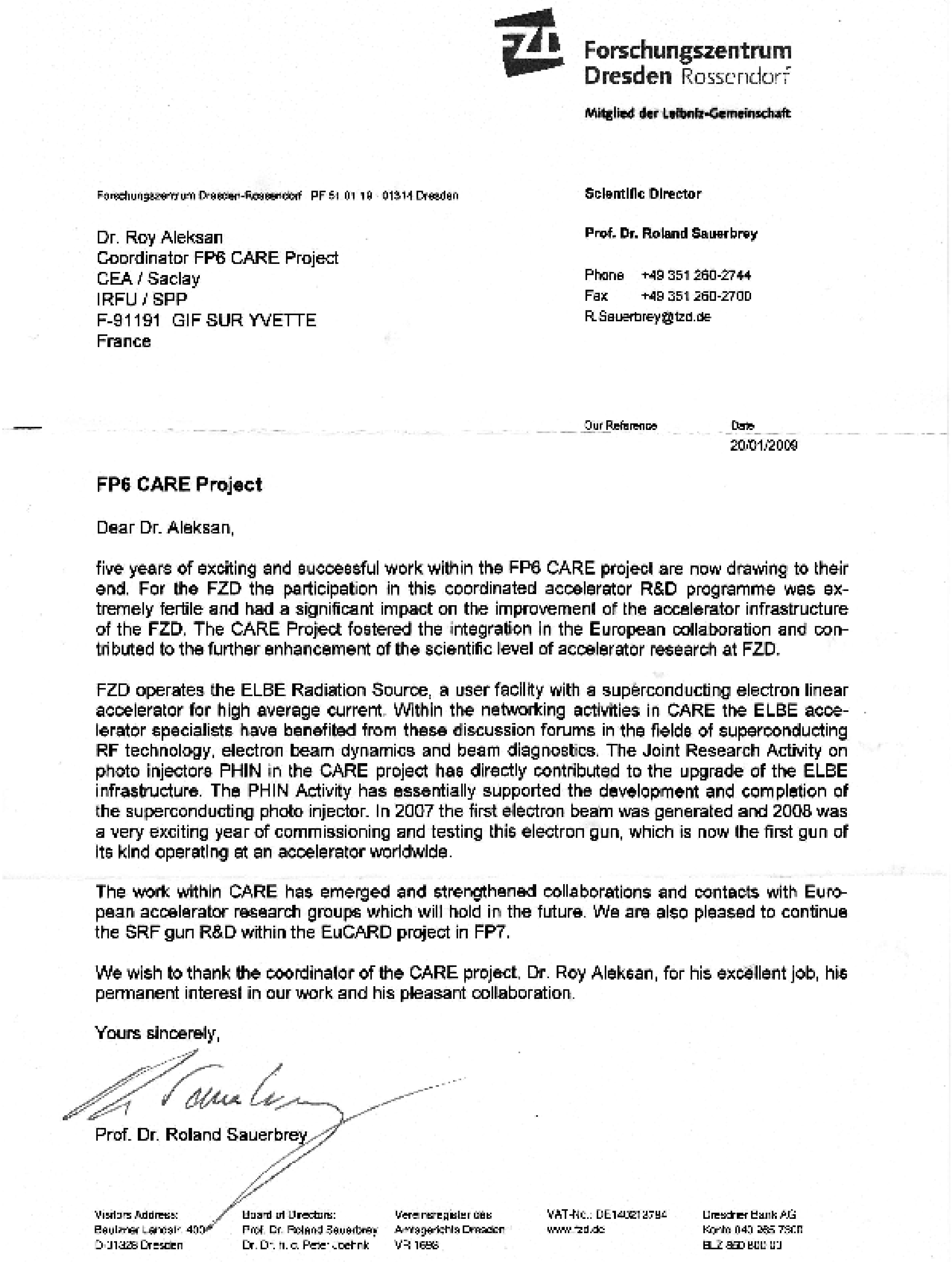
FZD-Rossendorf



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Dr. Roy Aleksan
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Scientific Director

Prof. Dr. Roland Sauerbrey

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R.Sauerbrey@fzd.de

Our Reference Date
20/01/2009

FP6 CARE Project

Dear Dr. Aleksan,

five years of exciting and successful work within the FP6 CARE project are now drawing to their end. For the FZD the participation in this coordinated accelerator R&D programme was extremely fertile and had a significant impact on the improvement of the accelerator infrastructure of the FZD. The CARE Project fostered the integration in the European collaboration and contributed to the further enhancement of the scientific level of accelerator research at FZD.

FZD operates the ELBE Radiation Source, a user facility with a superconducting electron linear accelerator for high average current. Within the networking activities in CARE the ELBE accelerator specialists have benefited from these discussion forums in the fields of superconducting RF technology, electron beam dynamics and beam diagnostics. The Joint Research Activity on photo injectors PHIN in the CARE project has directly contributed to the upgrade of the ELBE infrastructure. The PHIN Activity has essentially supported the development and completion of the superconducting photo injector. In 2007 the first electron beam was generated and 2008 was a very exciting year of commissioning and testing this electron gun, which is now the first gun of its kind operating at an accelerator worldwide.

The work within CARE has emerged and strengthened collaborations and contacts with European accelerator research groups which will hold in the future. We are also pleased to continue the SRF gun R&D within the EuCARD project in FP7.

We wish to thank the coordinator of the CARE project, Dr. Roy Aleksan, for his excellent job, his permanent interest in our work and his pleasant collaboration.

Yours sincerely,

Prof. Dr. Roland Sauerbrey

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Board of Directors:
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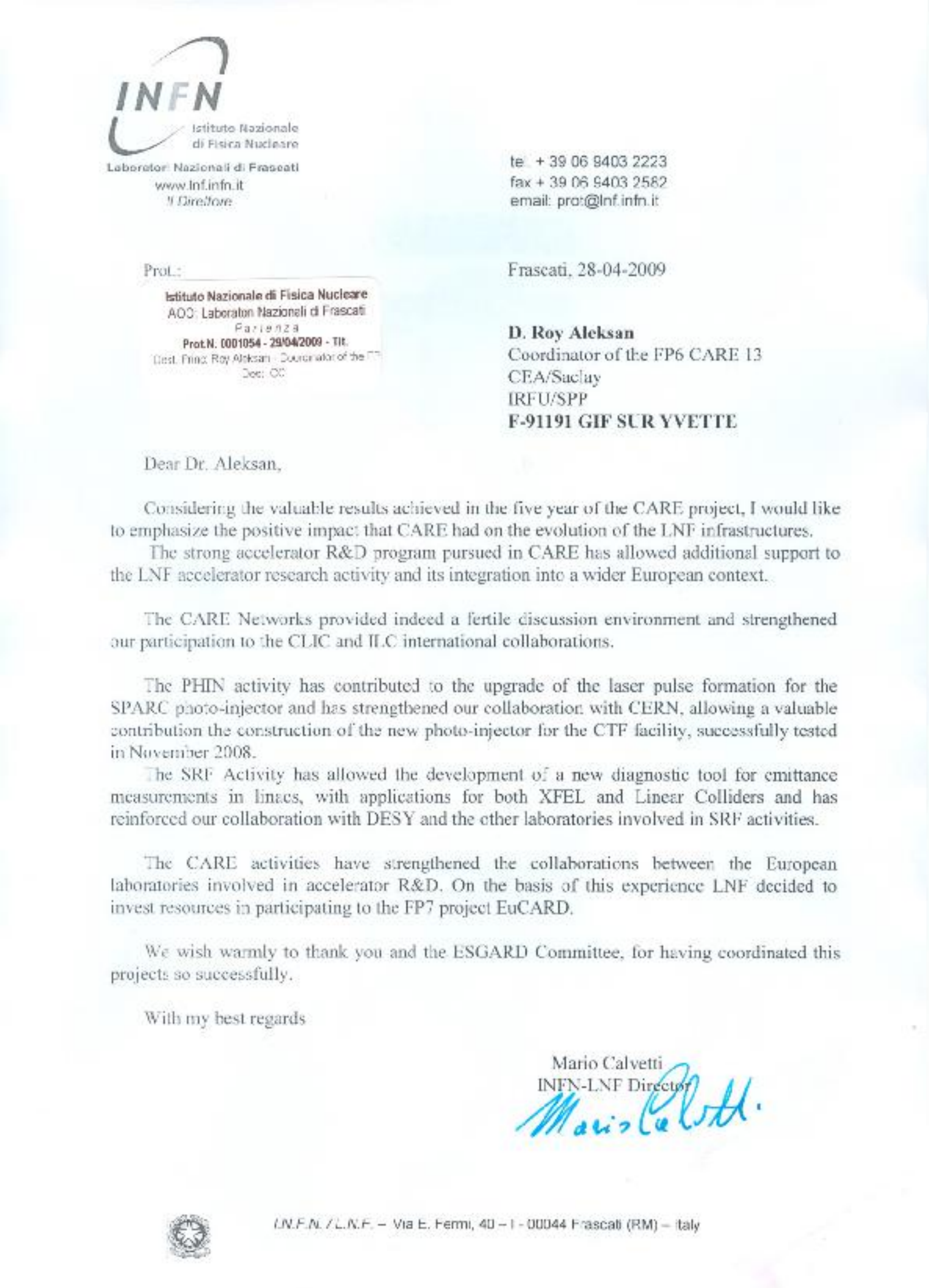

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Partenza
Prot.N. 0001054 - 29/04/2009 - Tit.
Dest. Princ: Roy Aleksan - Coordinator of the
Dest: CC

Frascati, 28-04-2009

D. Roy Aleksan
Coordinator of the FP6 CARE I3
CEA/Saclay
IRFU/SPP
F-91191 GIF SUR YVETTE

Dear Dr. Aleksan,

Considering the valuable results achieved in the five year of the CARE project, I would like to emphasize the positive impact that CARE had on the evolution of the LNF infrastructures.

The strong accelerator R&D program pursued in CARE has allowed additional support to the LNF accelerator research activity and its integration into a wider European context.

The CARE Networks provided indeed a fertile discussion environment and strengthened our participation to the CLIC and ILC international collaborations.

The PHIN activity has contributed to the upgrade of the laser pulse formation for the SPARC photo-injector and has strengthened our collaboration with CERN, allowing a valuable contribution the construction of the new photo-injector for the CTF facility, successfully tested in November 2008.

The SRF Activity has allowed the development of a new diagnostic tool for emittance measurements in linacs, with applications for both XFEL and Linear Colliders and has reinforced our collaboration with DESY and the other laboratories involved in SRF activities.

The CARE activities have strengthened the collaborations between the European laboratories involved in accelerator R&D. On the basis of this experience LNF decided to invest resources in participating to the FP7 project EuCARD.

We wish warmly to thank you and the ESGARD Committee, for having coordinated this projects so successfully.

With my best regards

Mario Calvetti
INFN-LNF Director
Mario Calvetti

IPJ

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2009.02.20.

Dr. Roy Aleksan
Coordinator of the FP6 CARE Project
CEA / Saclay, IRFU / SPP
F-91191 Gif sur Yvette, FRANCE

Dear Dr. Aleksan,

An experimental group from the Department of Plasma Physics & Technology (P-V) at the IPJ participated actively in the realization of the CARE/JRA1-SFR/Work-Package 4, which concerned the thin-film cavity production. Our efforts were concentrated mainly on the development of a new technology for the deposition of thin superconducting layers by means of ultra-high vacuum (UHV) arc discharges. The collaboration of the IPJ and the Tor-Vergata University in Rome was coordinated by Prof. M. J. Sadowski. Details of that activity were described in the Final Report on JRA1/WP4.1 sent to you in January 2009.

After the 5-years work I would like to indicate a very positive impact of the CARE project on the IPJ activity. We organized a modern laboratory equipped with two UHV facilities for the deposition of pure Nb or Pb layers. The IPJ team gained an extensive scientific and technological knowledge about the deposition of thin superconducting layers, e.g. those needed for the production of RF resonance cavities for liniacs. In the close collaboration with our Italian partners we presented many papers at international conferences, and the most important results were published in recognized scientific journals (see the Final Report).

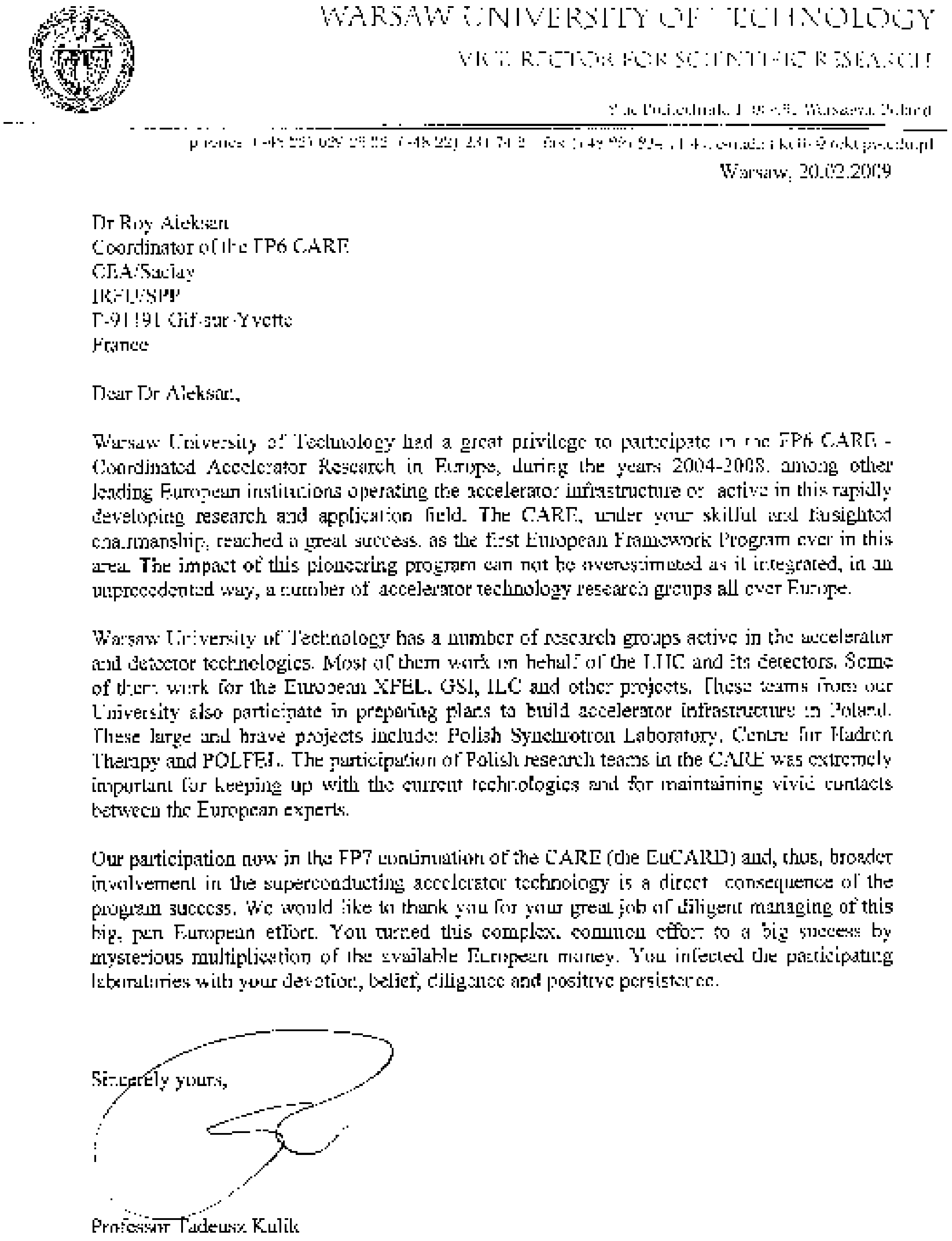
The experience gained during the CARE project will be very useful for future R&D activities at IPJ, and in particular it will be applied for the production of superconducting photo-cathodes for electron injectors, designed for modern FEL facilities. We intend to undertake new tasks in a frame of the FP7 EuCARD project, and we hope that such activities will also be helpful in a new POLFEL project.

At the very end of this letter, acting on behalf of my coworkers and myself, I would like to express our thanks for your continuous interest and effective coordination of the CARE project.

Yours sincerely,

Grzegorz Wrochna
Director General of IPJ

WUT-ISE



WARSAW UNIVERSITY OF TECHNOLOGY
VICE RECTOR FOR SCIENTIFIC RESEARCH

Plac Politechniki 1, [illegible] Warszawa, Poland
[illegible]

Warsaw, 20.02.2009

Dr Roy Aleksan
Coordinator of the FP6 CARE
CEA/Saclay
IRFU/SPP
F-91191 Gif-sur-Yvette
France

Dear Dr Aleksan,

Warsaw University of Technology had a great privilege to participate in the FP6 CARE - Coordinated Accelerator Research in Europe, during the years 2004-2008, among other leading European institutions operating the accelerator infrastructure or active in this rapidly developing research and application field. The CARE, under your skillful and farsighted chairmanship, reached a great success, as the first European Framework Program ever in this area. The impact of this pioneering program can not be overestimated as it integrated, in an unprecedented way, a number of accelerator technology research groups all over Europe.

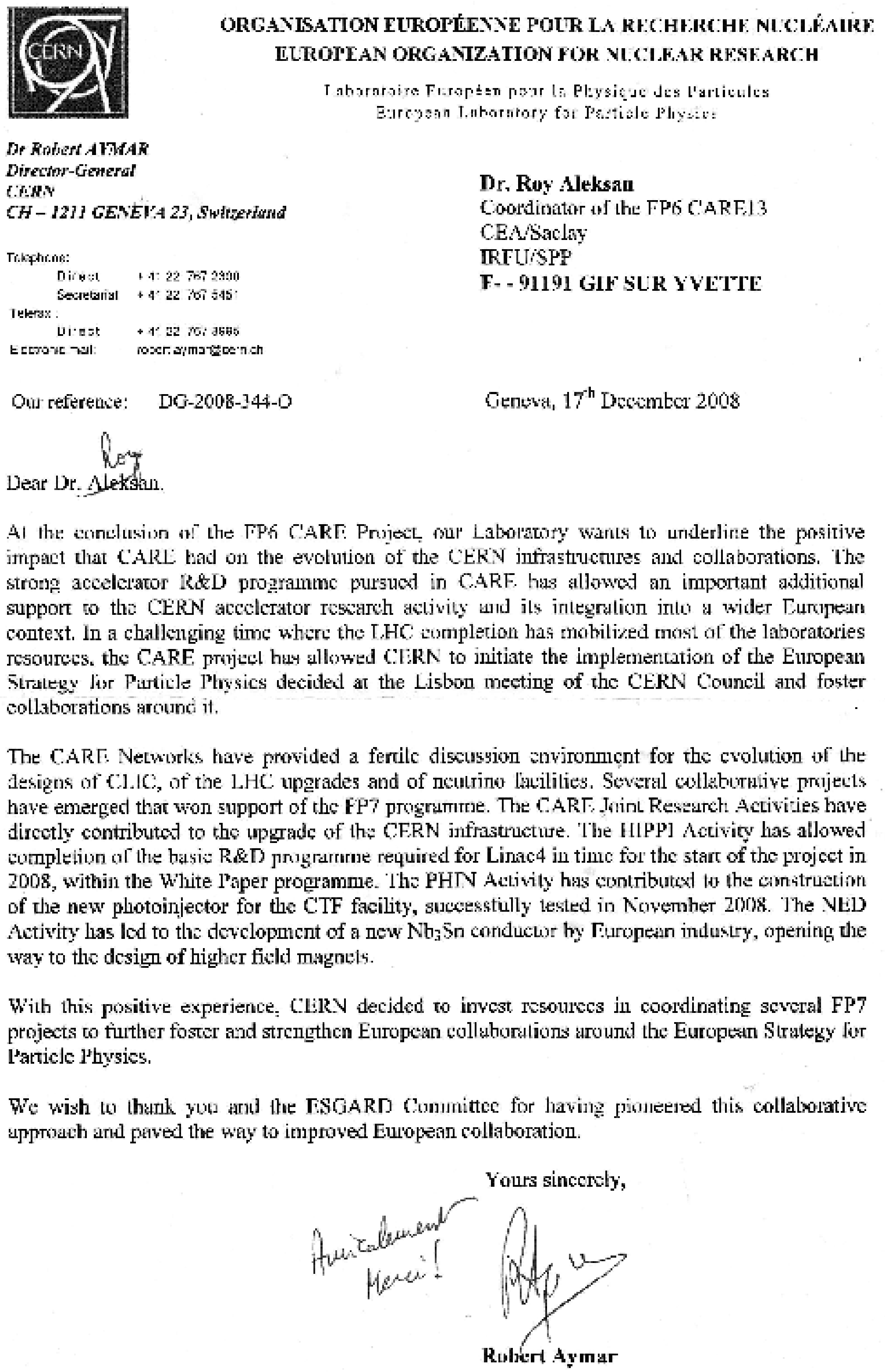
Warsaw University of Technology has a number of research groups active in the accelerator and detector technologies. Most of them work on behalf of the LHC and its detectors. Some of them work for the European XFEL, GSI, ILC and other projects. These teams from our University also participate in preparing plans to build accelerator infrastructure in Poland. These large and brave projects include: Polish Synchrotron Laboratory, Centre for Hadron Therapy and POLFEL. The participation of Polish research teams in the CARE was extremely important for keeping up with the current technologies and for maintaining vivid contacts between the European experts.

Our participation now in the FP7 continuation of the CARE (the EuCARD) and, thus, broader involvement in the superconducting accelerator technology is a direct consequence of the program success. We would like to thank you for your great job of diligent managing of this big, pan European effort. You turned this complex, common effort to a big success by mysterious multiplication of the available European money. You infected the participating laboratories with your devotion, belief, diligence and positive persistence.

Sincerely yours,

Professor Tadeusz Kulik

CERN



ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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Dr. Roy Aleksan
Coordinator of the FP6 CARE13
CEA/Saclay
IRFU/SPP
F- - 91191 GIF SUR YVETTE

Our reference: DG-2008-344-O

Geneva, 17th December 2008

Roy

Dear Dr. ~~Aleksan~~,

At the conclusion of the FP6 CARE Project, our Laboratory wants to underline the positive impact that CARE had on the evolution of the CERN infrastructures and collaborations. The strong accelerator R&D programme pursued in CARE has allowed an important additional support to the CERN accelerator research activity and its integration into a wider European context. In a challenging time where the LHC completion has mobilized most of the laboratories resources, the CARE project has allowed CERN to initiate the implementation of the European Strategy for Particle Physics decided at the Lisbon meeting of the CERN Council and foster collaborations around it.

The CARE Networks have provided a fertile discussion environment for the evolution of the designs of CLIC, of the LHC upgrades and of neutrino facilities. Several collaborative projects have emerged that won support of the FP7 programme. The CARE Joint Research Activities have directly contributed to the upgrade of the CERN infrastructure. The HIPPI Activity has allowed completion of the basic R&D programme required for Linac4 in time for the start of the project in 2008, within the White Paper programme. The PHIN Activity has contributed to the construction of the new photoinjector for the CTF facility, successfully tested in November 2008. The NED Activity has led to the development of a new Nb_3Sn conductor by European industry, opening the way to the design of higher field magnets.

With this positive experience, CERN decided to invest resources in coordinating several FP7 projects to further foster and strengthen European collaborations around the European Strategy for Particle Physics.

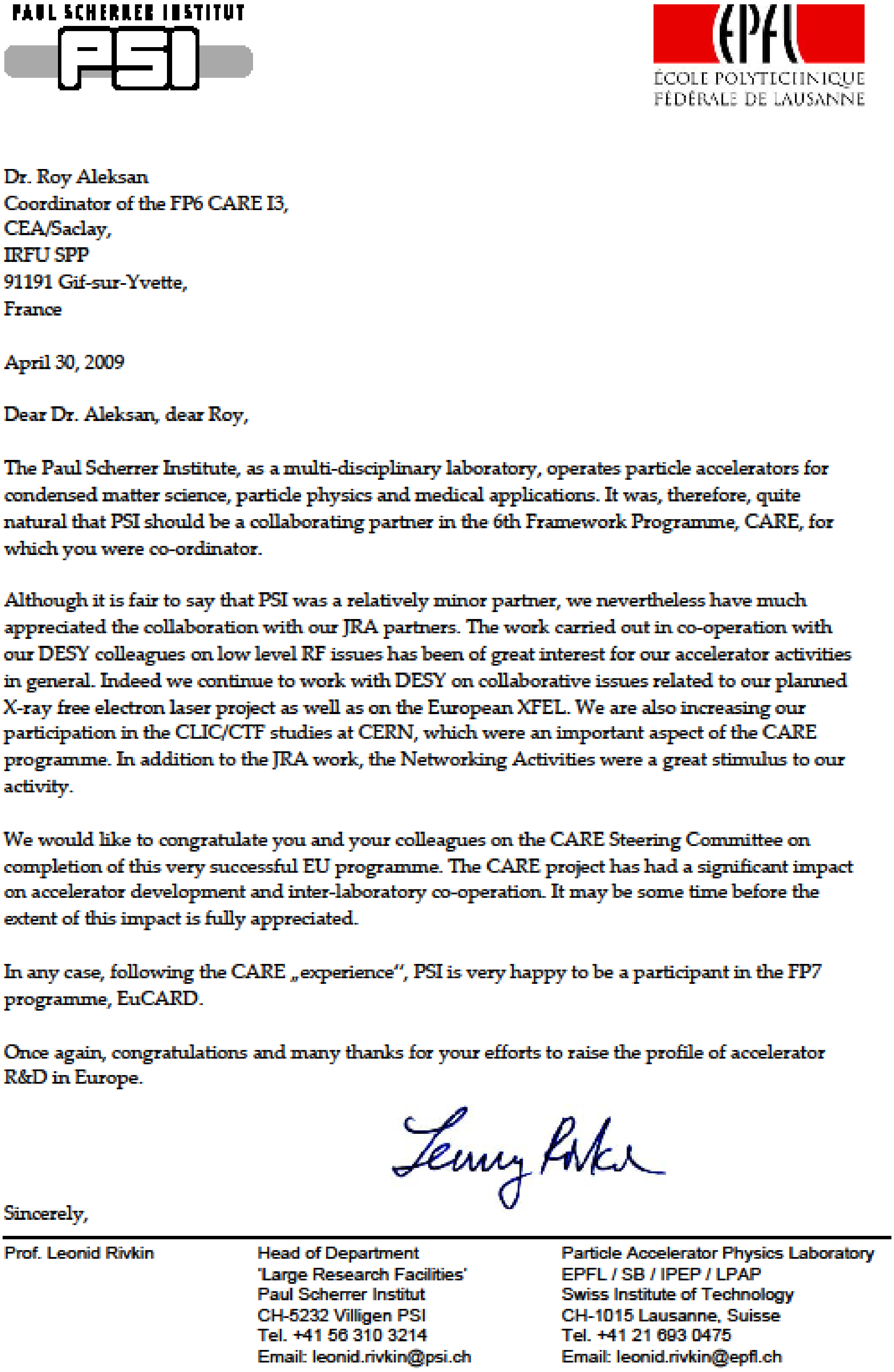
We wish to thank you and the ESGARD Committee for having pioneered this collaborative approach and paved the way to improved European collaboration.

Yours sincerely,

Amicalement
Merci!

Robert Aymar

PSI



Dr. Roy Aleksan
Coordinator of the FP6 CARE I3,
CEA/Saclay,
IRFU SPP
91191 Gif-sur-Yvette,
France

April 30, 2009

Dear Dr. Aleksan, dear Roy,

The Paul Scherrer Institute, as a multi-disciplinary laboratory, operates particle accelerators for condensed matter science, particle physics and medical applications. It was, therefore, quite natural that PSI should be a collaborating partner in the 6th Framework Programme, CARE, for which you were co-ordinator.

Although it is fair to say that PSI was a relatively minor partner, we nevertheless have much appreciated the collaboration with our JRA partners. The work carried out in co-operation with our DESY colleagues on low level RF issues has been of great interest for our accelerator activities in general. Indeed we continue to work with DESY on collaborative issues related to our planned X-ray free electron laser project as well as on the European XFEL. We are also increasing our participation in the CLIC/CTF studies at CERN, which were an important aspect of the CARE programme. In addition to the JRA work, the Networking Activities were a great stimulus to our activity.

We would like to congratulate you and your colleagues on the CARE Steering Committee on completion of this very successful EU programme. The CARE project has had a significant impact on accelerator development and inter-laboratory co-operation. It may be some time before the extent of this impact is fully appreciated.

In any case, following the CARE „experience“, PSI is very happy to be a participant in the FP7 programme, EuCARD.

Once again, congratulations and many thanks for your efforts to raise the profile of accelerator R&D in Europe.

Sincerely,

Prof. Leonid Rivkin

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Dr Roy Aleksan,
Coordinator of the CARE I3,
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France

Dear Dr. Aleksan,

As CARE draws to a close, I would like to express my appreciation for the benefits STFC has gained from being part of the project. We have participated in all three of the Networks and three out of the four Joint Research Activities, HIPPI, NED and PHIN. Staff from many of our departments have been involved in the work.

The main benefit we have received is improved collaboration with our European colleagues on accelerator R&D. This is particularly true of the Networks and our involvement in these has led to our participation in other FP6 and FP7 projects, in particular to our coordinating the FP7 EUROnu Design Study. The HIPPI JRA has made significant contributions to the design of our Front-End Test Stand, the first stage in an upgrade programme for the ISIS spallation neutron source. Our involvement in the NED JRA has allowed us to participate in studies of NB_3Sn superconductor and hence gain experience with this material. This is likely to lead to the design of higher field magnets. Through PHIN, we have developed a greater involvement in the CTF facility in CERN.

To summarise, CARE has been a positive experience for us and it is because of this that we are participating in the EuCARD FP7 project, the successor to CARE, at an increased level.

Yours sincerely,

Prof. John Womersley
Director of Science Programmes