European Coordination for Accelerator Research and Development

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EuCARD

European Coordination for Accelerator Research and Development

Seventh Framework Programme, Capacities Specific Programme, Research Infrastructures,
Combination of Collaborative Project and Coordination and Support Action

FINAL PROJECT REPORT

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1 EXECUTIVE SUMMARY

After four years of activity, EuCARD has most of its objectives fulfilled, with some new objectives added and a few others on excellent tracks while requiring additional time. The management has been active in reinforcing the collaborative links between partners and projects, contributing to the preparation of FP7-EuCARD2, initiating FP7-HiLumi-LHC Design Study, to favour sustained collaborations beyond EuCARD. An out-of-contract network has been successfully launched on laser plasma acceleration, to combine forces between accelerator, laser and plasma communities. Communication and dissemination activities have led to two highlights: Accelerating News, an accelerator R&D newsletter initiated by EuCARD and now common to all FP7 accelerator projects (over 1000 subscribers) and a series of monographs on accelerator sciences that is progressively finding its public.

The scientific networks have more than fulfilled their initial objectives: roadmaps are defined for neutrino facilities, submitted to the European HEP Strategy Session. The accelerator networks have so successfully become the international forum on accelerator sciences that their share and scope in EuCARD2 have been significantly expanded. With over 40 topical workshops organized on diverse scientific and technological topics, from innovative crab cavities to roadmaps towards novel frontier accelerators, their impact is largely acknowledged in the community.

The two open facilities (MICE@STFC, HiRadMat@SPS) delivered more access units than foreseen, with significant results.

The JRAs have the lion's share in EuCARD. They have had naturally tight links with networks and TA facilities, resulting in a coherent and coordinated approach.

The development of an innovative Nb_3Sn magnet with a YBCO insert, has made significant progress, confirmed by its international advisory committee, even though an extension of the study by 1.5 years turns out to be necessary: the mechanical structure of the magnet is completed and tested at cold, and a test coil with Cu conductor was manufactured. The Nb_3Sn cable shows excellent performance. The YBCO HTS insert solenoids were built and the dipole components are procured with completion of the insert by end 2013. The HTS electrical link demonstrator is fully operational. It will allow remote powering of magnets, avoiding risks of single event upset and easing maintenance.

The new collimation collaboration organized for EuCARD fully fulfilled its plans, including an optional crystal collimation experience. Novel more robust materials were characterized for collimator jaws. The smart collimator and cryo-catcher were designed, built and successfully tested.

The EuCARD contribution to linear colliders is deeply integrated in the CLIC/ILC studies. Significant progress was obtained in ultra-precise assembly and integration of RF modules, thermal stabilization, ultra-precise phase control to 20 fs and beam control. The active mechanical stabilization of magnets to a fraction of nanometer is especially impressive, as well as highly sophisticated simulations of RF break-downs, showing new microscopic mechanisms and giving directions for mitigation. The collaboration concurred to the record accelerating gradient obtained, exceeding 100 MV/m. The study of an innovative compact crab cavity gave momentum to this R&D line and went well beyond plans, with the fabrication of a bulk Nb sc unit. The progress in thin film deposition is slower, given the complexity of this highly promising technology. Better sputtering seems at hand. Progress is noted in chemical processing and cleaning strategies for sc cavities and their couplers. Two reference monographs were published. A new original RF control was built for FLASH and already showed improvement to operations.

Finally, the assessment of novel accelerator technologies out of the main stream (crab waist crossing, non-scaling FFAG and diagnostics for divergent beams from laser-plasma acceleration) all met the planned goals. In summary, EuCARD contributed to significant scientific progress beyond the state-of-the-art and to a marked expansion of the collaborative dimension.

2 PROJECT CONTEXT AND OBJECTIVES

2.1 CONTEXT

Particle physics, nuclear physics and light sources require more and more advanced accelerators to explore Nature. In particle physics, the LHC is primarily a discovery machine, with now the identification of the Higgs boson, and scope to discover the new physics necessary to answer fundamental questions in cosmology about antimatter, missing mass and energy. In nuclear physics, the FAIR complex will give to Europe a center of excellence equipped with a significant number of state-of-the-art facilities. The XFEL project - after FLASH- opens the door to ever decreasing size of observations using synchrotron light. All these sophisticated infrastructures need a strong R&D support prior to their design stage, but as well along their lifetime, to maintain the European facilities at the edge of the research, and thereby make best use of the significant investments of society.

Accelerator R&D has been mostly driven by the requirements of high-energy physics, but has rapidly found applications in other branches of science, such as superconducting accelerators for intense ion beams or a fourth generation of light sources (FEL), as well as important practical applications including non-invasive medical diagnostics, cancer therapy, biology, materials science and environmental monitoring.

The large research facilities in Europe, serving over 10,000 physicists from around the world, have made essential contributions to accelerator science throughout its history. These include the national laboratories and CERN, the largest particle physics laboratory in the world. The size, complexity and cost of their research infrastructures, coupled with the technological advances required to implement successful upgrades, clearly require that European efforts be further strengthened and integrated. This shall help facing the major international decisions to be made within the time scale of the FP7 program to choose and locate the next “world” accelerator.

2.2 CONCEPT

The EuCARD concept is to combine forces and competences to improve the performance of the European accelerator infrastructures. It builds on and consolidates the extensive collaboration successfully initiated by FP6-CARE. In so doing, EuCARD offers a forum to all accelerator experts, including those engaged in other FP7 topical initiatives. The relative importance of the IA components is tailored to accelerator R&D. Like in CARE, the emphasis is on Joint Research Activities (JRA) that are critical to the upgrade of the accelerators. Networking activities (NA) are an essential ingredient to exchange and strengthen collaborations. Experts from other communities, including those outside the IA, will as well be invited, providing coordination with other European actions. Accelerator laboratories have long established transnational access (TA) procedures for end users. In addition, two innovative accelerator test facilities will be opened for the first time to users from other fields.

2.3 OBJECTIVES

The EuCARD objectives follow closely the priorities defined by recognized European Associations and bodies:

- EuCARD has been launched by the European Steering Group for Accelerator R&D (ESGARD), set up by the directors of CERN, CEA-DSM-IRFU, DESY, INFN-LNF, CNRS-IN2P3, PSI and STFC, in consultation with the European Committee for Future Accelerators (ECFA), for the optimisation and enhancement of R&D in the field of accelerator physics in Europe;
- Concerning particle physics, the priorities are those of the CERN Council document "The European strategy for particle physics", Lisbon, 2006.
- Concerning nuclear physics and light sources, the priorities are consistent with the "roadmap of the European Strategy Forum on Research Infrastructures ESFRI", 2006.

2.3.1 Management and communication

Beyond running the project, maximize its S/T output and satisfy the EC requirements, an important objective of the management is to catalyse the collaborative aspects and take initiatives in this direction.

2.3.2 Networking activities

A first goal is the efficient dissemination of information and generated results: the publications shall be monitored and made easily accessible. Links shall be established between close scientific fields of research inside and outside the consortium. Attention to outreach shall be given.

The second domain of action is the scientific networks around three main scientific/technical themes: neutrino facilities, accelerators and colliders performance, and RF technologies. These networks shall be the backbone of the consortium, with, as their main tools, the organization of topical meetings and mini-workshops, and the capability of inviting or exchanging experts over periods of typically a week to a month. They shall contribute to the exchange of ideas and expertise between beneficiaries and between the consortium and external organizations, with the goal of identifying the most promising upgrade strategies and technologies. They shall be attractive beyond the Consortium, towards other related EU initiatives and towards large non-European partners like KEK in Japan and the US national accelerator laboratories. The resulting concentration of world expertise shall be a solid asset for the development of the infrastructures concerned by this project and for the development of a dynamical European Research Area.

2.3.3 Transnational access activities

The accelerator laboratories have been running their own Transnational access schemes for decades, with thousands of users. This is why EC TA's have a limited importance in EuCARD. Two test beam lines are open to EC-supported TA:

i) the MICE (STFC) facility for experimentalists wishing to investigate muon ionization cooling or to perform tests with high-quality low-energy beams of muons, electrons, protons or pions,

ii) an irradiation facility on the SPS accelerator at CERN allowing to send MJ proton beams with a pulse length of a few μs to a target, and to perform experiments that are in the interest of many researchers investigating the impact of pulsed irradiation.

These new facilities are also of primary importance for the beneficiaries of the Consortium within their joint research or network activities.

2.3.4 Joint research activities

- **High field magnets:**

The goal of this theme is the development of a new generation of accelerator quality magnets (dipoles, quadrupoles and undulators) able to exceed the capabilities of Nb-Ti magnets by a significant factor (potentially two or more with an HTS insert). The challenges are related to the brittleness of the Nb_3Sn material, its strain sensitivity, possible flux instabilities and practical implementation issues. No such magnet is presently installed in an accelerator. The increased performance will serve the accelerator upgrades in various ways. For the LHC luminosity upgrade, the quadrupole aperture can be increased for a given gradient, thereby allowing a stronger focusing at the interaction point to produce a higher collision rate. The larger margin in critical temperature obtained with Nb_3Sn will be used to mitigate the larger heat deposition from the secondary particles emerging from the collisions. Altogether the LHC peak and integrated performance and the operation efficiency will be significantly improved, up to a factor of 10 when combined with other upgrades under other themes. The same technology can be applied to the dipole magnets receiving a large heat deposition, such as dispersion suppressor dipoles in the LHC, exposed to particles diffracted by the collimators. In combination with High Temperature Superconducting (HTS) coils the magnetic field could be further boosted. A success in increasing significantly and in a cost-effective way the field of magnets opens the possibility of doubling or tripling the LHC energy with a large enhancement of its physics reach. The undulators share a similar requirement of increasing the magnetic field by mastering the Nb_3Sn technology. A neighbouring activity is the development of a superconducting electrical link to allow remote power accelerator magnets without losses.

- **Collimators and materials:**

The beam stored energy in hadron accelerators has to further increase to allow higher performance. Yet, the machines have to be efficiently protected. A specialized “collimator” community is building up in Europe and elsewhere in the world with so far independent research programs in individual laboratories. The joint research activity shall foster collaboration and further advances in this field. Important outcomes shall be i) a better modelling of the beam halo dynamics, a critical step in predicting the performance of collimators, ii) a selection of materials that at the same time can sustain the very high instantaneous energy deposition, are compatible with ultra-high vacuum and do not present to the beam a significant electro-magnetic impedance. These materials will also be characterized for their radiation resistance. Finally three technologies will be tested by prototyping and testing collimators: room-temperature, cryogenic and possibly crystal-based collimators, the latter being entirely innovative.

- **Normal Conducting Linacs:**

Normal Conducting accelerating structures presently achieve useable accelerating gradients of up to 80 MV/m; for higher gradients the breakdown rate becomes unacceptably high – an as yet unsolved issue. Contribution to the demonstration of high gradient acceleration is one of the main objectives of the purpose-built CTF3 facility at CERN and shall be supported by EuCARD studies. Both NC and SC linear colliders require extremely small (nanometre) beam sizes at collision, so common issues concern ultra-low emittance generation and conservation, and beam stability. The “NCLinac” work package shall focus on major issues in high-gradient acceleration and beam stabilisation, complementary to current research programs: from simulation and understanding of break-downs in high-gradient accelerating structures to global integration of accelerator modules, mechanical and alignment constraints to the µm-scale and very high accuracy synchronisation (20 fs). The investigations on emittance preservation methods and beam handling in the final focus (ATF2 at KEK) will provide strategies and beam diagnostics prone to improving the performance of accelerators handling beams of very small size.

- **Superconducting RF:**

Pioneering R&D work on Superconducting Radio Frequency (SRF) accelerator systems was started in the field of electron storage rings for high-energy physics as well as heavy ion accelerators. Meanwhile, SRF technology has matured and is in operation in many particle accelerators. In contrast to the ILC-HiGrade Preparatory activities in FP7, which are related to establish a high performance yield in industrial fabrication, the aim of EuCARD is to push the R&D towards improving fundamental issues of superconducting RF: improvements in cavity and coupler fabrication and processing for higher gradients, design and fabrication of new prototypes including a novel compact crab cavity demonstrator, progress in thin film technologies, assessment of the possibility of HOM-based beam and cavity diagnostics, and demonstration of an RF control based on telecommunication standards.

- **Assessment of novel accelerator concepts:**

This theme groups three important topics regarding novel accelerator concepts in three different fields: high luminosity colliders, technologies required by neutrino facilities and plasma wave accelerator techniques. The new collision scheme characterized by an innovative correction of higher-order optics aberrations combined with large angle beam crossing holds the promise of increasing the luminosity by more than two orders of magnitude beyond the current state-of-the-art in colliders. The planned instrumentation for the world's first so-called non-scaling FFAG (Fixed Field Alternate Gradient) (EMMA, STFC) shall allow a better understanding of the beam dynamics. Finally the measurement of ultra-short electron beams is instrumental to the assessment of laser plasma acceleration.

3 PROJECT ORGANIZATION

3.1 THE EUCARD COLLABORATION

The EuCARD collaboration includes 38 partners (beneficiaries): CERN, 9 national accelerator laboratories, 7 specialized institutes, 17 universities and 3 industrial partners:

Table 1: List of partners

European Organization for Nuclear Research RHP-Technology GmbH & Co. KG (AT) Helmholtz-Zentrum fur Materialien und Energie (DE) Budker Institute of Nuclear Physics (RU) Commissariat a l'Energie Atomique (FR) Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (ES) Centre National de la Recherche Scientifique (FR) Columbus Superconductors (IT) Instituto de Fisica Corpuscular (ES) Deutsches Elektronen-Synchrotron (DE) Bruker HTS GmbH (DE) Ecole Polytechnique Federale de Lausanne (FR) Forschungszentrum Dresden- Rossendorf (DE) Forschungszentrum Karlsruhe (DE) Gesellschaft fur Schwerionenforschung mbH (DE) The Henryk Niewodniczanski Institute of Nuclear Physics (PL) Istituto Nazionale di Fisica Nucleare (IT)	The A. Soltan Institute for Nuclear Studies in Swierk (PL) Politecnico di Torino (IT) Paul Scherrer Institut PSI (CH) Politechnika Wrocławska (PL) Royal Holloway University of London (UK) Russian Research Center 'Kurchatov Institute' (RU) University of Southampton (UK) Science and Technology Facilities Council (UK) Politechnika Lodzka (PL) Tampere University of Technology (FI) Helsingin Yliopisto (University of Helsinki) (FI) University of Huddersfield (UK) Universite Joseph Fourier (FR) University of Lancaster - Cockcroft Institute (UK) University of Malta (MT) Universite de Geneve (CH) University of Manchester - Cockcroft Institute (UK) University of Oxford (UK) Universitat Rostock (DE) Uppsala Universitet (SE) Politechnika Warszawska (PL)

The 37 national beneficiaries originate from 12 countries: Austria (1), Finland (2), France (3), Germany (7), Italy (3), Malta (1), Poland (5), Russia (2), Spain (2), Sweden (1), Switzerland (3), United Kingdom (7). For France, Italy and UK, the CNRS , INFN and STFC institutions actually cover several institutes or laboratories.

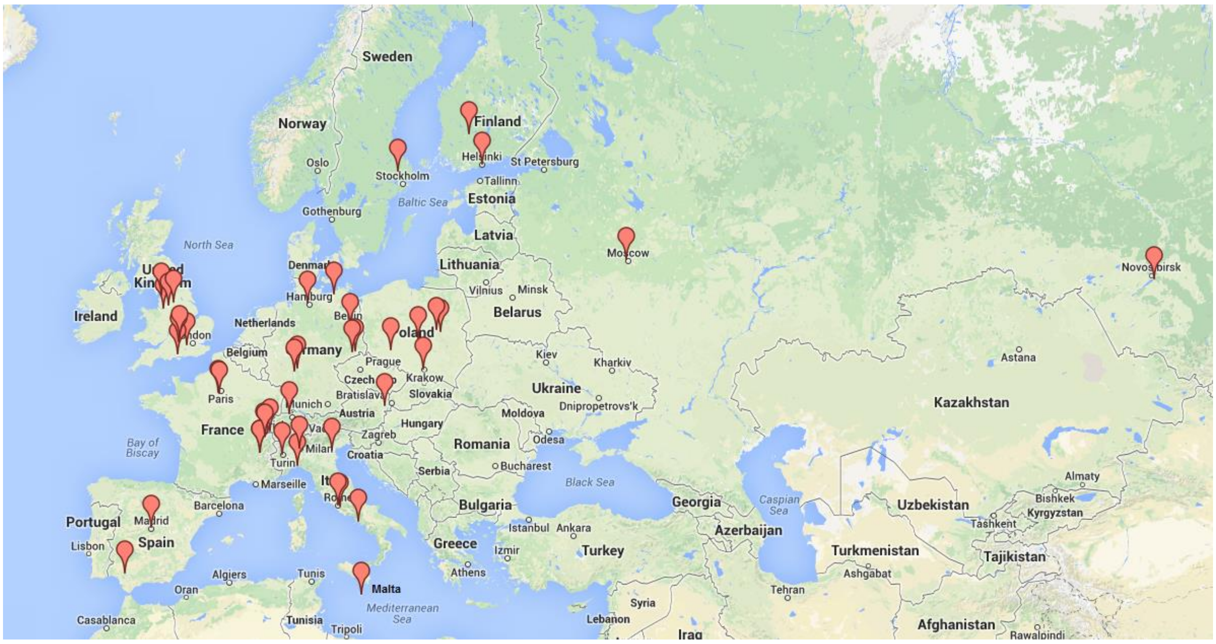


Figure 1: Map of partners

In addition, some 40 laboratories, institutes or universities declared interest in being informally associated, mostly via the activity of the networks. Among the latter major associated partners were the US DOE national laboratories and KEK in Japan.

3.2 THE EUCARD MANPOWER & THE PROJECT STRUCTURE

Close to 300 persons from the beneficiary institutions actively participated to the EuCARD activities, 10% of them being hired for this purpose.

The project is organized in 4 major activities implemented through 11 work packages:

- Management, communication and dissemination (WP1, WP2)
- Scientific networks (WP3, WP4)
- Facilities opened under transnational access (WP5, WP6)
- Joint research activities (WP7 to WP11)

The project organigram includes a Governing Board, meeting once a year, representing the project beneficiaries. It was chaired over the project duration by Prof. Tord Ekelof from Uppsala University, Sweden.

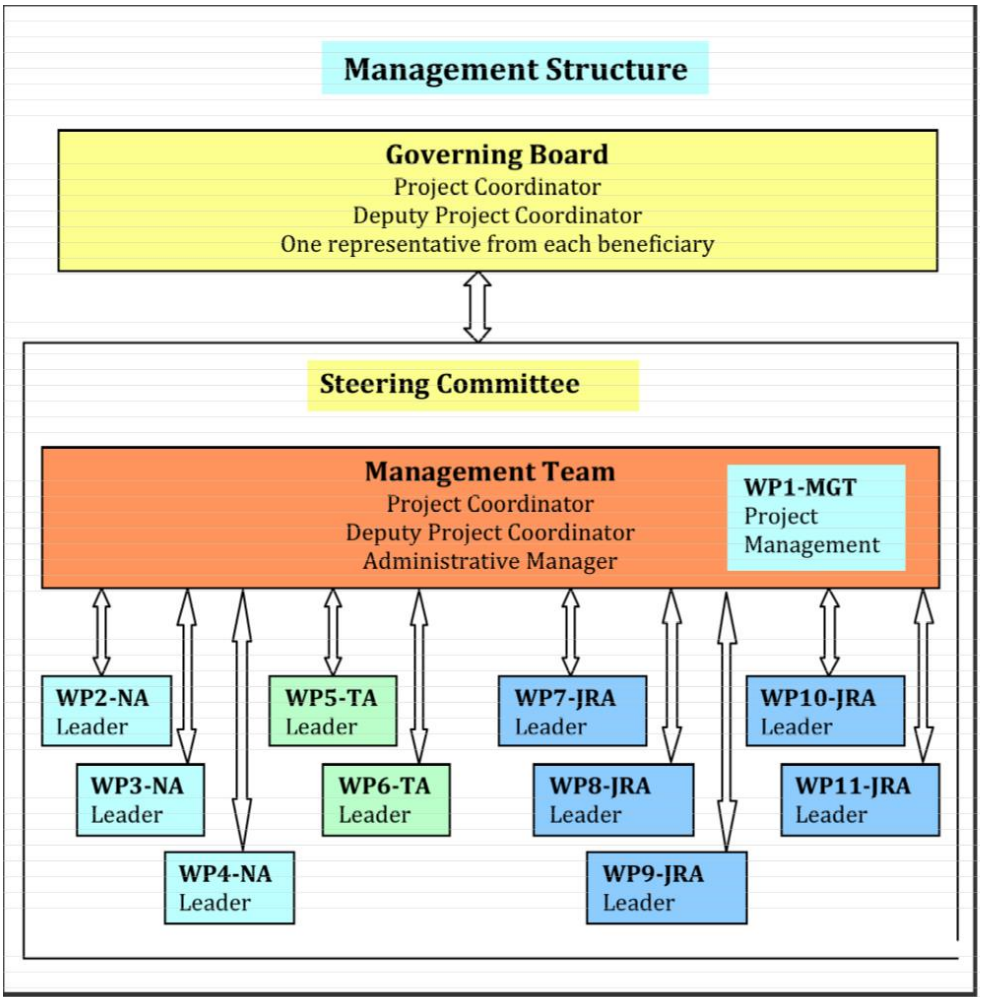


Figure 2: Project organisation chart

The coordinator is CERN and the project coordinated by Dr Jean-Pierre Koutchouk, DG Project and International Relations Offices, CERN. The deputies of the project coordinator were successively Dr Ralph Assmann, CERN and now DESY, and Dr Frank Zimmermann, CERN.

The Steering Committee met four times per year in the first year to launch the project, and subsequently twice a year, in addition to the Annual project meeting. Each of the workpackages was led by one or two coordinators, or one coordinator and a deputy. In most cases, all coordinators and deputies attended the Steering Committee meetings, ensuring a large representation of the consortium members:

WP	WP title	Coordinators and deputies
1-MGT	Management	Dr J.P. Koutchouk CERN, Dr R. Assmann CERN, Dr F. Zimmermann CERN, Dr S. Stavrev CERN
2-NA	Dissemination, Communication, Outreach	Prof. R. Romaniuk, WUT, K. Kahle CERN, A. Szeberenyi CERN

3-NA	Structuring the accelerator neutrino community	Prof. V. Palladino, INFN, Prof. S. Pascoli, Durham U.
4-NA	Accelerator Science networks	Dr. F. Zimmermann CERN, Dr W. Scandale CNRS, Dr P. Spiller GSI
5-TA	HiRadMat@SPS	Dr I. Efthymiopoulos CERN
6-TA	MICE@STFC	Prof. N. McCubbin STFC
7-JRA	High Field magnets	Dr G. de Rijk CERN, Dr F. Kircher CEA
8-JRA	Collimation and materials	Dr R. Assmann CERN, Dr J. Stadlmann GSI
9-JRA	Normal-conducting linacs	Dr E. Jensen CERN, Prof G. Blair RHUL, Dr S. Boogert RHUL & JAI
10-JRA	Superconducting RF	Dr O. Napoly CEA, Dr O. Brunner CERN
11-JRA	Assessment of novel accelerator concepts	Dr. M. Biagini INFN, Dr R. Edgecock STFC

In order to create focus and allow effective collaborations, the workpackages were themselves divided into tasks. In a total of 40 tasks, 12 tasks delt with management, communication and workpackage coordination, led by the project and workpackage coordinators and deputies. 29 tasks were dedicated to a wide range of accelerator R&D studies:

WP/task	Title	Task leader
3.2	Use of existing neutrino facilities	Dr I. Efthymiopoulos CERN
3.3	Neutrino: roadmap to the future	Prof A. Blondel UNIGE
4.2	Collider performance and projects	Dr F. Zimmermann CERN
4.3	RF technologies	Prof J.-M. de Conto UJF/CNRS
4.4	Plasma wakefield acceleration	Dr R. Assmann CERN, Prof H. Videau Paristech, Prof J. Osterhoff DESY
7.2	HFM support studies	Prof. M. Chorowski PWR
7.3	High field model	J.-M. Rifflet CEA
7.4	Very high field insert	Prof P. Tixador CNRS
7.5	Helical undulator	Prof J. Clarke STFC
8.2	Collimator modelling and materials	Dr A. Bertinelli CERN
8.3	Collimator prototyping	Dr R. Assmann CERN

9.2	NC high-gradient cavities	Dr G. Riddone CERN
9.3	Linac and FF stabilization	Dr A. Jeremy CNRS
9.4	Beam delivery system	Prof G. Blair, RHUL
9.5	Phase measurement	Dr F. Marcellini INFN
10.2	Sc cavities for proton linacs	Dr S. Chel CEA
10.3	LHC crab cavities	Dr P. MacIntosh STFC
10.4	Thin film cavities	Dr S. Calatroni CERN
10.5	HOM signals	Prof R. Jones UNIMAN
10.6	LLRF at FLASH	Dr M. Grecki DESY
10.7	SCRF gun at ELBE	Dr J. Teichert HZDR
10.8	RF coupler processing	Dr W. Kalabi CNRS
11.2	Crab waist	Dr C. Milardi INFN
11.3	EMMA diagnostics	Dr R. Edgecock STFC & HUD
11.4	Diagnostics for plasma wave accelerators	Dr V. Malka CNRS

The administration of the project was led by Dr Svetlomir Stavrev CERN and the financial aspects by Gregory Cavallo CERN. Agnes Szeberenyi CERN, deputy coordinator of WP2, actively participated to putting together this challenging final report to the EC.

The project assistant, and organizer of most project events was Merethe Olafsen CERN. Catherine Brandt, assistant in the CERN EU Project Office, dealt with the submission of reports to the EC.

3.3 THE DASHBOARD OF RESULTS

At the end of the project, almost all milestones have been met, not more than 10% had had to be rescheduled due to delays, some were fulfilled ahead of schedule and a minor number were either cancelled for lack of relevance, or combined with their respective deliverables. Milestones have played an important role in monitoring the progress towards deliverables, as most deliverables are by essence scheduled at the project end.

Out of 63 contractual deliverables,

- 59 are delivered as planned.
- one is delivered by another partner of the collaboration, after the resignation of a key person at the lead partner. This deliverable is as well published in the EuCARD monograph series.
- three important deliverables will be fully documented during the project but will reach full completion after the project end: one with about a one month delay (super-conducting proton cavities), another with a five month delay (HTS insert) and the third

one with a delay estimated at 1.5 years. In the first case, the delay is technical, while in the two other cases the delays are explained by the outstanding scientific challenges.

The two EuCARD Transnational-Access facilities have fully fulfilled their objectives and beyond. WP5 had suffered a delay of 2 years due to the LHC incident; its very efficient recovery has allowed fulfilling the contract. WP6 almost doubles its contractual commitment, by a strict control of expenses and the donation of the TA management time by STFC.

Finally the networks, beyond their contractual commitments, have systematically shown significant added value and visible impact, confirming the strategy of increasing their share and scope in EuCARD2.

Table 2: Status of progress towards deliverables. The HFM model magnet (WP7.3) will be late by 1.5 years. Its insert HTS coil (WP7.4) requires a few months for completion, while the sc cavities of WP10.2 have been delivered and will be tested in 2013.

WP	***1***	***2***	***3***			***4***			***5***	***6***	***7***					***8***		***9***				***10***							***11***		
task			***1***	***2***	***3***	***2***	***3***	***4***			***2***	***3***	***4***	***5***	***6***	***2***	***3***	***2***	***3***	***4***	***5***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***2***	***3***	***4***
Beyond contract	*	*					*			*				*			*						*								
On time			*	*	*	*		*	*		*				*	*		*	*	*	*			*	*	*	*	*	*	*	*
Minor delay													*									*		*			*	*			
Large delay												*																			

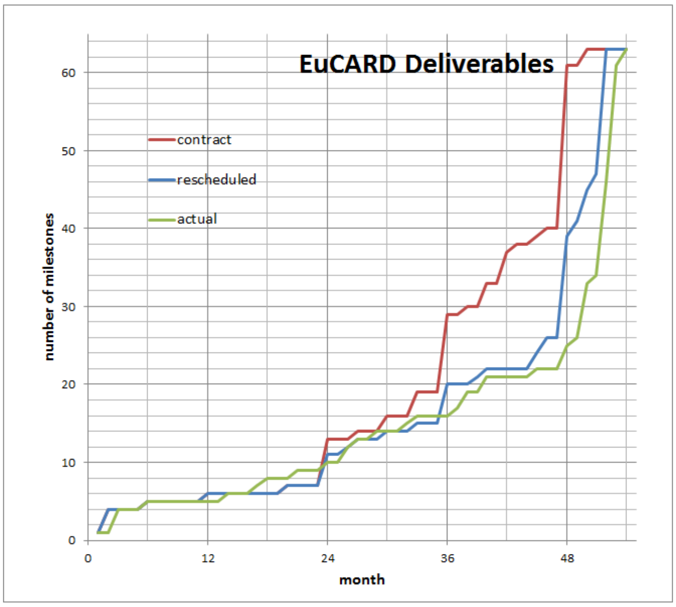


Figure 3: profile of delivery of Deliverables

3.4 THE PROJECT BUDGET

Figure 4 *below shows the relative use of resources and man-power per work-package:*

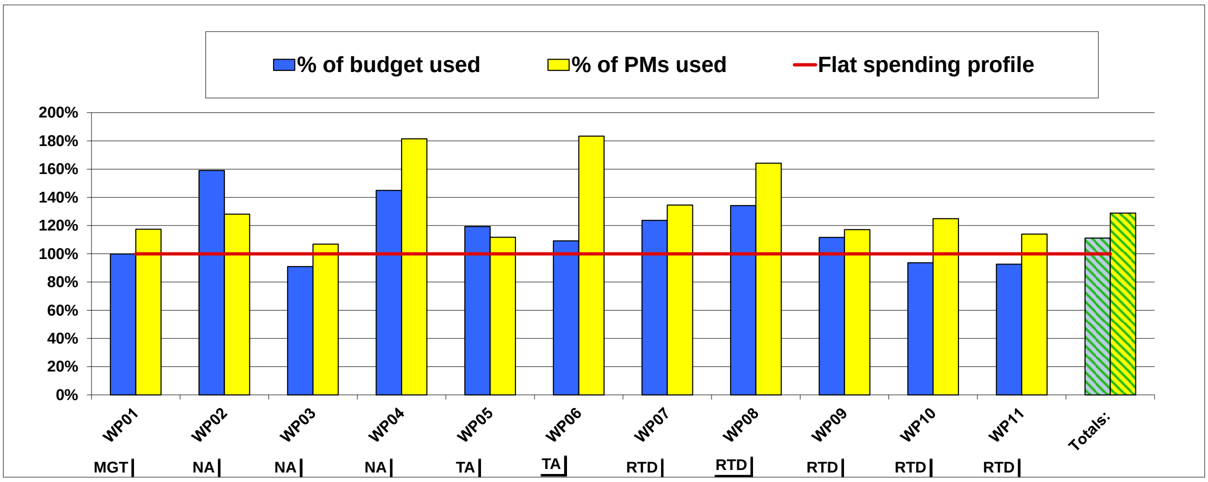


Figure 4: Utilization of man-power and budget resources for P1 + P2 + P3 expressed as percentage of the estimated totals for each Work Package over the full duration of the project (52 months)

Overall, the full costs of the EuCARD Consortium are 35.9 M€ and exceed by 3.6 M€ (11%) the budget commitments in Annex 1.

The overall use of man-power amounts to 3,040 person-months, which exceeds by 682 p-m (29%) the man-power commitments in Annex 1.

In summary, the EuCARD Consortium has used significantly more matching funds and man-power resources than foreseen in Annex 1, which demonstrates the full commitment of the beneficiaries to achieve the challenging objectives and deliverables of the project.

3.5 SOCIETAL IMPLICATIONS

At the end of each project the European Commission dedicates a separate section to obtain statistics and indicators on societal and socio-economic issues addressed by projects. These indicators are used also to evaluate the impact of the project. The following indicators are considered:

- Ethics: EuCARD was not confronted to any of the ethical issues monitored by the EC, mostly related to research on human beings and animals, protection of developing countries, as well as dual use potential for military applications.
- Gender balance: The project had about 300 members including experienced researchers, students and administrative staff. The gender balance was about 70% males and about 30% females. The project encouraged women in science; the Communication Officer attended several conferences on this topic.
- Additional researchers recruited specifically for the project: In total 27 researchers were recruited for the project, 1/3rd were women.
- Synergies with Science Education: The project strongly encouraged young people to be actively involved in EuCARD related activities. Several booklets were the republishing of PhD theses. One of the EuCARD theses has won the Springer Thesis Prize in 2013. The Transnational Access activities were promoted during the ESOF 2012 conference (EuroScience Open Forum). The project has developed educational resources for young people (including under 14, between 14 and 18 and above 18 years old) and created a collection of them on the website. Additionally, priority was given to students from networking activities' funds when supporting financially travels to networking events.
- Associated disciplines: The main discipline of the project was Physical science, but also mathematics and computer science, chemical sciences and other humanities were involved.
- Engaging with civil society and policy makers: The project also engaged with societal actors beyond the research community in framing the research agenda, implementing and communicating the research and its results. The output generated by the project in the fields of "external relations" and "research and innovation" could be used by policy makers. As a result, the place of Accelerator R&D was secured on the research agenda, the legacy will be taken over by EuCARD-2.
- Dissemination measures: As a result of the project, more than 500 publications were authored, out of which 70 were published in a peer-reviewed journal. During the lifetime of the project, 5 patent applications were filed. In total 58 FTE (full time equivalent= one person working fulltime for a year) resulted from the project. The website has been translated to several languages.

4 THE MAIN S&T RESULTS/FOREGROUNDS

We review in this chapter the main scientific and technical results, leaving the organizational and communications results for chapter 5.

4.1 EUCARD SCIENTIFIC NETWORKS

EuCARD ran four scientific networks grouped into two work packages:

- WP3 - Neu2012: Structuring the accelerator neutrino community
- WP4 - AccNet: coordination of the three Accelerator Networks, including
  - EuroLumi: LHC luminosity upgrade and synergies with FAIR
  - RFTech: Radio Frequency Technologies
  - EuroNNAc: European network on Novel Accelerators

4.1.1 Structuring the accelerator neutrino community (WP3 - Neu2012 - NA)

The mission of network NEu2012, coordinated by INFN, CERN and UniGe, was the consolidation of the European accelerator υ community and the enhancement of its collaborative work and exchanges in view of delivering in 2012 a strong consensual road map, an agreed programme of υ experiments, based on upgrades of existing infrastructures and/or on the proposal of a new one. This mission followed from the realization that the recent unequivocal evidence for massive neutrinos calls for a measurement of a new, possibly large, source of CP asymmetry, a fundamental phenomenon accessible only to accelerator neutrinos. The consolidation of the community, thriving on the legacy of the FP6 CARE/BENE network, progressed very well.

Figure 5: NuFACT 2011 workshop, organized by NEu2012

NEu2012 could submit to the European Strategy in Particle Physics (ESPP) 2012 Symposium, at the end of July 2012, its proposal of the next global accelerator neutrino facility for Europe to build or help build (NEu2012 D3.3.1). This proposal was drafted and agreed at the NEu2012 annual workshop in May 2012. The proposal of our community was the realization of a new giant European underground home for mega υ detectors, up to 10^6 m^3, in the Pyhasalmi mine in Finland, 2300 Km from CERN, served by CERN υ beams. This should ultimately be a 4 MW 10 GeV Neutrino Factory, and in the medium term similar, less powerful, conventional beams. This approach has important similarities to the US plans of Fermilab neutrino beams towards the SURF (Sanford Underground Research Facility) in South Dakota. Early in 2013, NEu2012 D3.2.1 documented further the analysis of performance and physics potential of the beams resulting from upgrades and/or of major additions to existing neutrino facilities as evaluated in the NEu2012 years, motivating in detail the choices behind our proposal. A smaller R&D and prototype neutrino detector home at CERN, on surface, was also identified as an essential and, in fact, most urgent part of the proposal. This multi-GeV, few thousand km option prevailed on a second option that was also thoroughly studied, intense sub-GeV beams travelling only few hundred km (CERN-Frejus), very similar, including its Water Cerenkov MEMPHYS detector technology, to the very successful approach that the Japanese neutrino community did and will further adopt. This option is recently being in part revived as an attractive option for the ESS MMW proton driver in Sweden and any EU/Japan future collaboration will greatly benefit of this effort.

The ESPP 2012 Strategy Upgrade Document in the spring of 2013 acknowledged the strong scientific case for a long-baseline (LBL) accelerator υ programme and the need to re-establish a CERN accelerator programme to pave the way for a substantial European role, possibly consisting of major participation in leading υ projects in the US and Japan. A major milestone achievement in this direction is the very recent establishment (mid-September 2013) by the CERN Directorate of a CERN Neutrino Project, with the aim "*to provide an effective platform for future activities at CERN and/or outside CERN. Meanwhile on-going discussions and R&D plans with US and Japanese colleagues should continue, in view of a plan towards a major Intensity Frontier Facility. The aim of the Project is to foster collaboration of all partners to create an effective research platform, supported by CERN, for a future research activity involving European partners"*. It is indeed possible that the very high costs of the facilities proposed will not permit to establish a program in Europe. The EUROnu costing report at the end of 2012 evaluated them as very similar to those of LHC. It is decisive that this program also includes the longer term effort towards a Neutrino Factory. Europeans have long been collaborating with the US on this project that requires, in a first step, MICE to be completed, while NuSTORM, a first simple muon decay ring for neutrinos, emerges as the natural next item of EU/US collaboration.

NEu2012 comes to its end confident to have reasonably approached the best progress possible. The precious EC support of many years of intense networking, in close connection to all world studies and, particularly, two FP7 Design Studies (LAGUNA and EUROnu) has made it possible. The tradition thus established of collaborative work and exchanges in the accelerator neutrino community will be invaluable, to face the challenges of costs and resources.

4.1.2 Hadron accelerators & colliders performance (WP4 - AccNet – EuroLumi - NA)

The EuroLumi network has primarily focused on hadron colliders and accelerators, namely the LHC and its synergies with FAIR. Given the success of its action, it gradually extended its scope to future frontier colliders. The main activity of the network has been the organization of topical workshops, complemented by exchange of experts between EuCARD partners and with associated institutes (60), representing the key accelerator centers in the world. Quantitatively, the EuroLumi network

Figure 6: LHCC2011 crab cavities workshop at CERN in the G. Charpak room organized or co-organized 27 topical workshops/meetings

- produced 78 documents, including 6 peer-reviewed publications, 2 PhD and 2 master dissertations and 1 EuCARD monograph,
- and sponsored 46 exchanges of experts.

A topical workshop typically gathers 20 to 50 scientists for one to three days (**Error! Reference source not found.**), with a strong nucleus of experts from EuCARD partners and a significant participation of the associated members, especially US and Japanese experts. Several workshops were co-organized with the host laboratories or other partners (e.g. USLARP, a consortium of US national accelerator laboratories). Most participants are self-supported, the network funding in priority the participation of PhD students, invited speakers and institutes in need of funding. This format of exchange platform is rather unique, complementary to existing larger conferences or events, and has demonstrated its efficiency by excellent attendance and creative output. This is illustrated by an "interactivity index", ratio of registrants over speakers of typically 2, as compared to about 12 in large conferences.
Major scientific results of EuroLumi are:

- **LHC crab cavities**: turned the disputed crab cavities into a realistic LHC upgrade scheme, now adopted by CERN and at the heart of the LHC upgrade plan. An

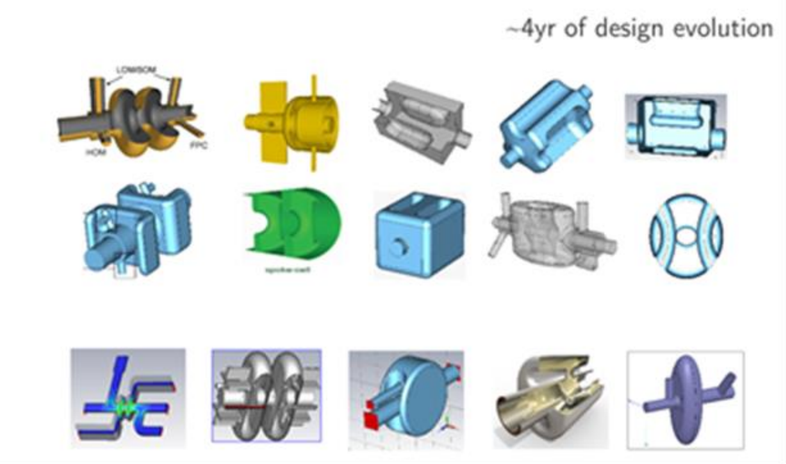


Figure 7: Various solutions of compact cavities studied in EuCARD and by US partners

  international collaboration has been initiated (Figure 7), now taken over by FP7 HiLumi-LHC DS.
- launched brainstorming on **higher-energy *pp* colliders (HE-LHC and VHE-LHC)**: an energy upgrade of the LHC with 20-T dipoles (Figure 8) (in relation with the EuCARD activity on high-field magnets) and a new concept (16-T to 20-T dipoles in ~100 km tunnel).

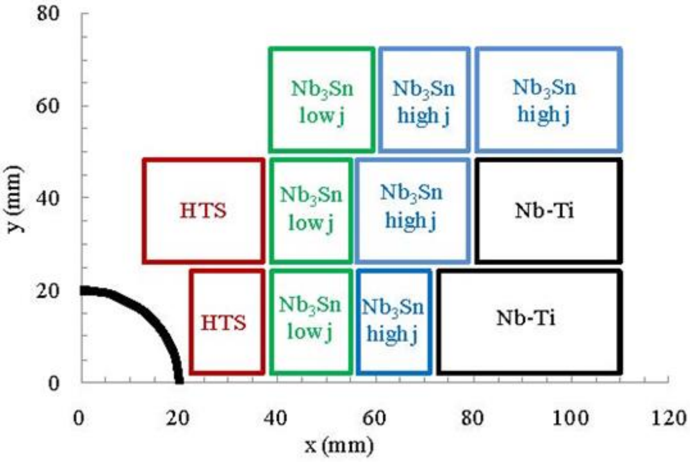


Figure 8: Block layout of a proposed Nb-Ti & Nb_3Sn & HTS 20-T HE-LHC dipole-magnet coil. Only one quarter of one aperture is shown (courtesy CERN)

- launched brainstorming on **circular e+e- collider Higgs factories (LEP3 and TLEP)** as a novel alternative to linear colliders, with the advantage of very high luminosity, robust technologies and sharing of existing or new tunnel with pp colliders, thereby offering a 50 year strategy for particle physics in Europe.
- launched brainstorming on **ERL based gamma-gamma colliders – SAPPHIRE.**

EuroLumi considered as well crystal-collimation, novel collider crossing schemes, electron-cloud and mitigations, space-charge codes, trapping by non-adiabatic resonance crossing, permanent magnets for boosting the LHC energy, higher performance collider optics,… In all cases, brainstorming was supported by exploratory studies, production of parameter lists and organization of collaborations for more detailed studies.

EuroLumi has served as an incubator for new or stronger collaborations, primarily between EU, US and Japan for the above-mentioned topics, with ESA on electron clouds, between CERN and GSI on electron-cloud and space-charge, with Japanese universities (Hiroshima and Kyoto) on the same topics and on higher-field magnets respectively, and with Mexico, where an initial seed funding by EuCARD to three CINVESTAV (Mexico) students in 2013 turned into an institutional regular support by CONACYT (Mexico) for Mexican PhD students at CERN.

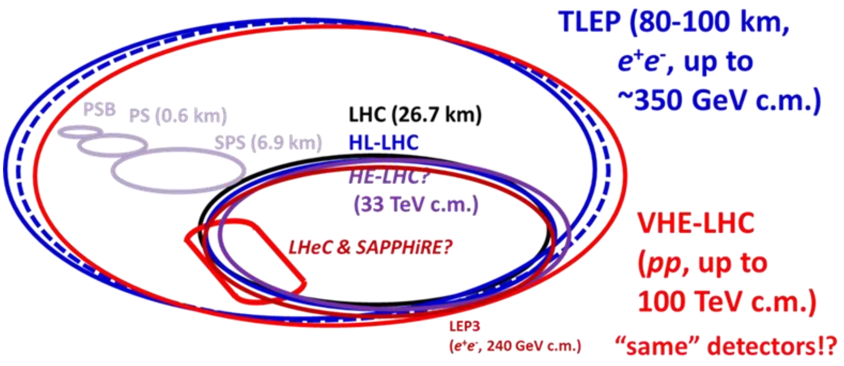


Figure 9: Vision for a European proton and leptons accelerator developments for HEP (courtesy EuCARD WP4 and CERN)

The EuroLumi workshop activity was concluded by the co-organization with the coordinators of EuCARD and EuCARD2 of an outstanding workshop "visions for the future of accelerators", imbedded in the final meeting of EuCARD and kick-off meeting of EuCARD2, with distinguished speakers from the major accelerator-based sciences. The final deliverable D4.1.2 provides a synthesis and proposes a perspective for frontier accelerators over the coming decades.

4.1.3 RF technologies (WP4 - AccNet - RFTech - NA)

The primary goal of the RFTech network was to bring together RF experts from different laboratories and communities, e.g. proton & electron accelerators, or storage rings & linacs, in order to exchange ideas and to promote innovation on all aspects of RF technology. Quantitatively, the RFTech network

- organized or co-organized 20 topical workshops/meetings,
- produced 30 documents, including 1 EuCARD monograph and 1 PhD thesis
- and sponsored 20 exchanges of experts.

The RFTech events gathered between 17 and 300 participants, mostly from the EuCARD consortium and as well from associated institutes, e.g. GANIL, ITER, BNL/USA, TRIUMF/CND.

The topics considered were:

- RF cavities: crab cavities, co-organized with EuroLumi, breakdowns,
- RF controls: xTCA, Integrated Circuits for Low Level RF, Advanced Low Level RF Control, Low Level RF for XFEL (Figure 10),

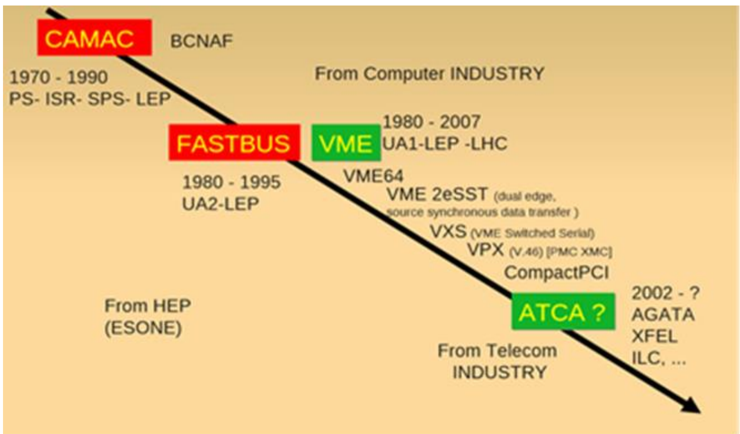


Figure 10: Trends in accelerator RF control (courtesy DESY)

- RF electro-magnetic field computations: computing in accelerator physics,
- RF power circuits: progress in solid-state amplifiers, klystron lifetime (Figure 11),

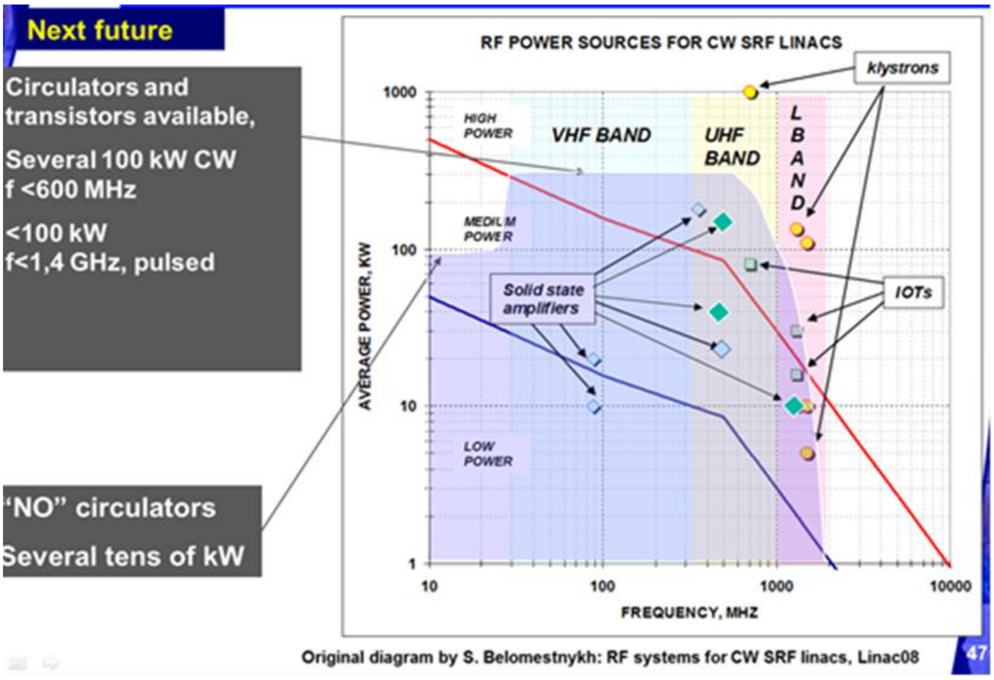


Figure 11 Trends in RF power sources (courtesy DESY)

- RF solutions for projects and studies: SPIRAL2, MYRRHA/MAX, CLIC, TESLA, ELI-NP, LHeC ERL, TLEP, LHC, FLASH, PS Booster, MedAustron, and SwissFEL,
- Global RF issues and strategies: strategy for SC technology and test stations (deliverable D4.3.2, published as a EuCARD monograph, Figure 12), reliability, efficiency, costing models.

RFTech also organized or co-organized special sessions at the MixDes 2010, 2011 and 2012 Conference on Mixed Design for Integrated Circuits and Systems with applications to accelerator RF systems, and at the ICAP'13 on accelerator RF related computing.

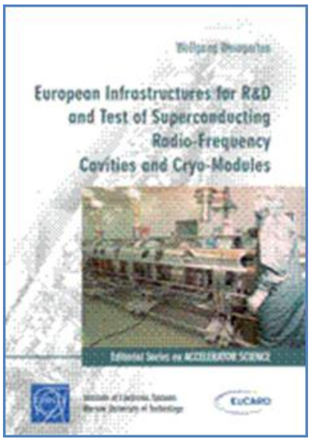


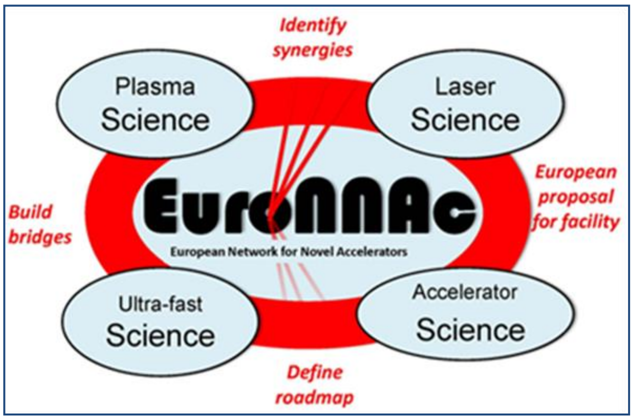
Figure 12: EuCARD monograph on sc RF test infrastructures

Globally, the network has fulfilled all its objectives: sharing experience, particularly important in a rapidly evolving field; defining priority topics common to a number of projects, and involving young scientists, essential to motivate new persons to this cutting-edge and demanding specialty. The monograph on sc technology provides the R&D directions to improve the RF gradients (especially the thin-film technology), as well as a summary of RF test stations with their capabilities. This is a typical input to FP7 TIARA-PP that integrates such information.

4.1.4 Novel acceleration schemes (WP4 – AccNet – EURRONAC - NA*)

** additional AccNet task*

The EuroNNAc network was launched in 2010 and added to Accnet with a minimal funding by the coordinator, its members being self-supported. Its motivation is to establish a bridge between communities so far weakly interacting: accelerators, lasers and plasmas. Indeed, plasma wakefield acceleration is getting results that are becoming closer to what would be necessary to be considered as a potential future technology for accelerators. The objectives of the laser and plasma communities are more fundamental and academic. It is believed that, by combining the achievements and competence of the laser and plasma experts with the technical expertise of the accelerator scientists and engineers, a roadmap can be defined to arrive at a demonstrator demonstrating the production of quality beams in a reliable and reproducible fashion.



EurroNac has organized three well-attended workshops in 2011, 2012 and 2013, and obtained strong support of the three communities. The network coordination is shared by CERN, DESY and Ecole Polytechnique. Working groups have been formed to study various aspects of a roadmap, from scientific to financial aspects. The first outcome has been a proposal sent to ESGARD to establish this network officially in EuCARD2 with a precise work plan. This was fully supported. A second was the preparation of a written report submitted to the CERN Council Session on the European Strategy for Particle Physics. An awareness of this venture by the funding agencies is indeed critical to the realization of a demonstrator. In parallel novel links and collaborations have been initiated either by the coordinator, AccNet or EuroNNac: contribution to and support of the AWAKE collaboration, proposing a proton-driven plasma wakefield acceleration experiment at the CERN-SPS, links to FP7 ICAN, IZEST. With the latter, EuroLumi entered discussions on the feasibility of a gamma-gamma collider (SAPPHIRE).

4.2 EUCARD FACILITIES OPEN UNDER TA

Two test facilities were open in EuCARD to transnational access: HiRadMat@SPS and MICE@STFC. The EC funding of these TA was mostly dedicated to the support of the users.

4.2.1 HiradMat@SPS (WP5 - TA)

In the new generation of accelerators, like LHC, the circulating beam has sufficient power well above the damage thresholds of the most robust materials. Damageswould clearly have important impact on operations and down-time for repair. Previous to HiRadMat, tests of robustness and damage effects were performed in ad-hoc installations in the transfer lines between SPS and LHC, however the difficulty in performing such important tests on temporary installations were the main motivations for the decision to build a new dedicated facility. HiRadMat (High Irradiation to Materials) is a new facility at CERN constructed in 2011 designed to provide high-intensity pulsed beams to an irradiation area where material samples as well as accelerator component assemblies can be tested (Figure 13). The facility uses a 440 GeV proton beam extracted from the CERN SPS with a pulse length of up to 7.2 μs, to a maximum pulse energy of 3.4 MJ. Annual proton budget to the facility is limited to about 10^{16} protons on target (p.o.t.) by environmental radiation protection aspects. Following the low-intensity commissioning in spring 2011, the full commissioning was completed with intensities up to 10^{13} protons/pulse in late summer 2011. Experiments in HiRadMat will contribute to the understanding of the behavior of materials under beam impact. t. It will thereby provide important feedback for tuning of mechanical multi-physics simulation codes thus enhancing their predictive power and impact on the design of the new high-power accelerators and spallation target stations. Beyond the needs of LHC, HiRadMat is, like all CERN beam facilities, open to other users and is also included in the EuCARD FP7 European Project as Transnational Access to facilitate its use by European teams. The online documentation for users is available at http://cern.ch/hiradmat.

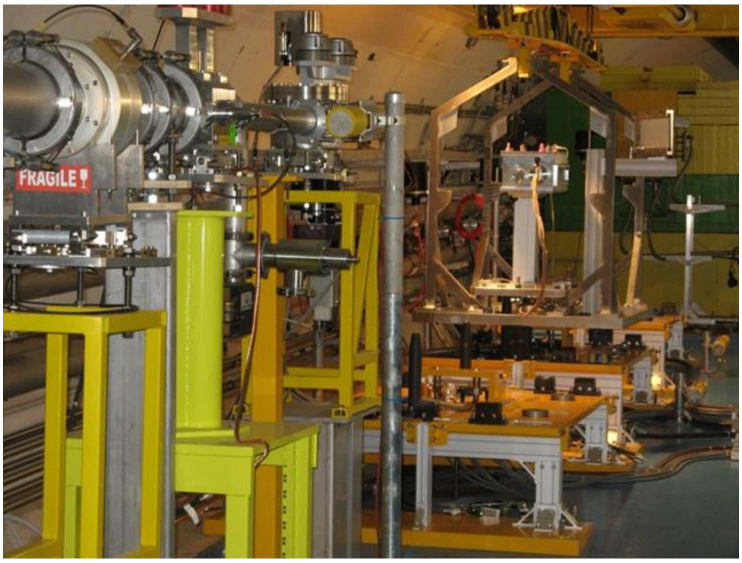


Figure 13: View of the experimental target area (courtesy CERN)

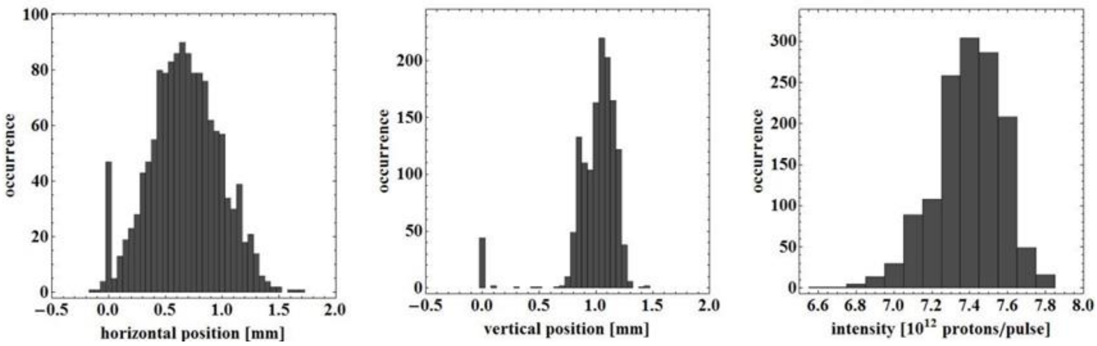


Figure 14: Beam positions and intensities over about 1500 SPS extractions to HiRadMat (courtesy CERN)

For 2012, the first year of operations of the facility, 15 applications for experiments in HiRadMat were received. Mainly due to the limited available beam time, the HiRadMat Scientific Board and the HiRadMat Technical Board approved 9 of them for running in 2012. All the experiments completed the irradiation time successfully. The safety precautions and procedures were followed resulting in no incident during HiRadMat operation. The experiments covered topics of collimation techniques, benchmarking of collimation material properties, targetry and particle detectors.

The integrated time of all SPS cycles for HiRadMat in 2012 sums up to 48 hours. The beam stability in terms of position and intensity is shown in Figure 14, as an example during the HRMT01 run. Also an SPS ion beam (lead) can be extracted to HiRadMat; so far only protons were requested by the users.

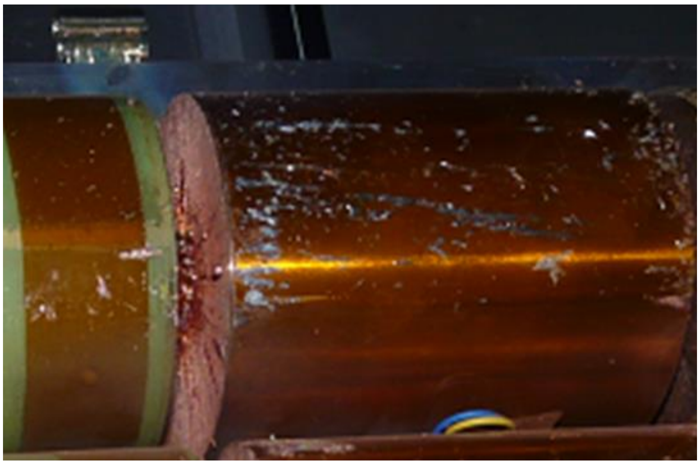


Figure 15: Measurement of hydro-dynamic tunnelling. Copper cylinders were exposed to the HiRadMat beam. The beam entered on the cylinder axis. On its front face one can recognize the beam impact point, where melt copper solidified again in a star pattern. Leading proton bunches generate a reduced matter density in the beam path, which allows trailing bunches reaching a greater penetration depth.

The LHC related experiments included the exposition of several different materials of interest for beam intercepting devices (collimators, etc.) to intense proton beams and robustness tests of a loss of the full LHC beam on solid materials. The collected experimental data are compared to advanced numerical models, also investigating the cavitation and beam effects (Figure 15 and Figure 26). Results of these experiments were presented in an oral presentation at IPAC13 and numerous (>15) scientific publications. Beyond LHC, two targetry experiments were performed along with a test using the produced pulsed neutron field to inter-compare and calibrate radiation monitors thus opening the use of the facility to a different user community, very interested in its use. HiRadMat is a unique facility and triggers the interest in all international workshops or conferences it is presented.

During the full duration of the EuCARD project, a total of 9 user projects and 19 users have been supported under the HiRadMat TA. 111 access units have been delivered, which exceeds significantly the 50 access units committed in the EuCARD Description of Work (Annex I).

The HiRadMat facility will be available again for future experiments with the SPS restart in autumn 2014. Several communities have already expressed their interest for beam time application. HiRadMat is participant of Transnational Access of EuCARD-2 and will provide EC funded support to users.

4.2.2 MICE@STFC (WP6 - TA)

The UK's Science and Technology Facilities Council (STFC) providec Transnational Access to a specialized beam line (Figure 16) developed for studies of ionisation cooling at its ISIS facility at the Rutherford Appleton Laboratory (RAL).

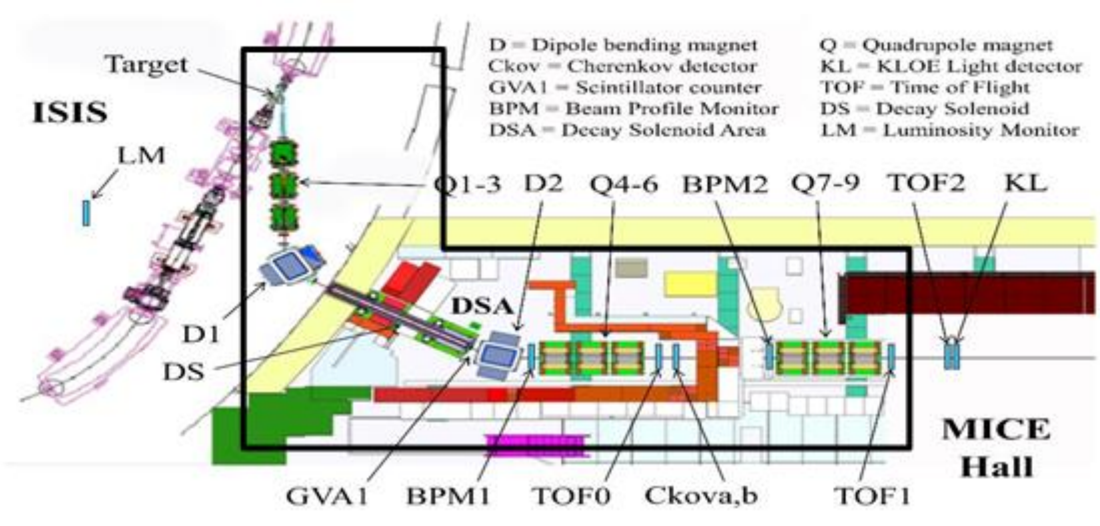


Figure 16: Schematic diagram of the ICTF beam line at STFC's ISIS facility. The major ICTF elements lie within the thick L-shaped border (courtesy STFC)

Transnational Access (TA) in EuCARD means support in terms of travel and expenses for EU researchers to visit and use the beam line. This beam line, together with its associated infrastructure, was originally referred to as the MICE facility, but, in order to distinguish the facility more clearly from the MICE experiment (see below and Figure 17), the facility is now designated the Ionisation Cooling Test Facility (ICTF).

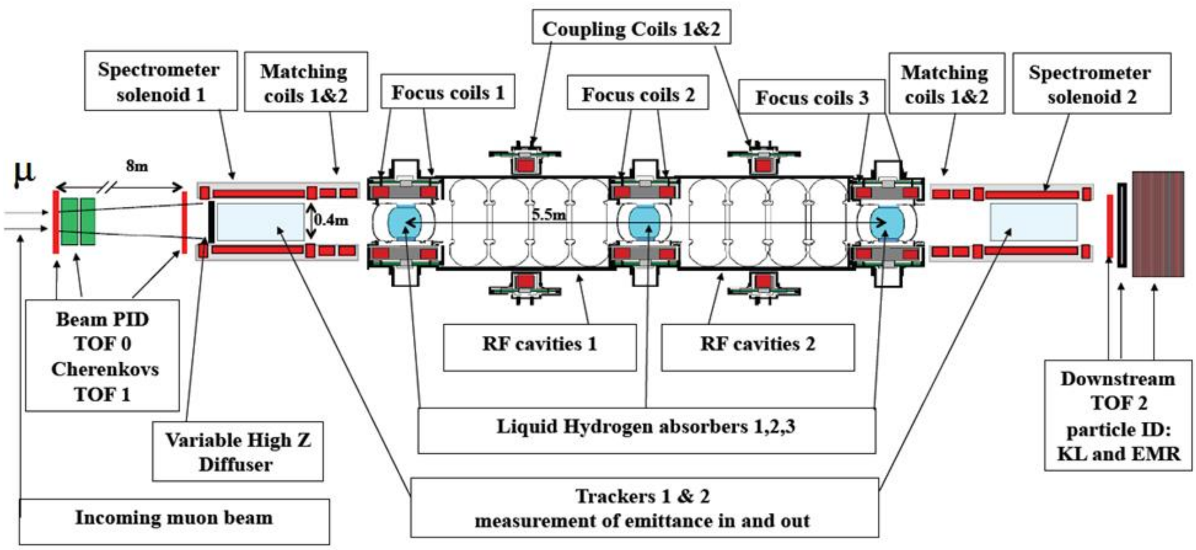


Figure 17: Final layout of MICE experiment at ICT, expected ~2018. Upstream particle-identification (PID) detectors are TOF0, TOF1 and Cherenkov counters, whilst downstream PID detectors are TOF2 and KL/EMR calorimeter. The cooling section and the magnetic spectrometers are situated between the upstream and downstream PID detectors.

The ICTF provides muon beams of either sign, pulsed at 1 Hz, in the momentum range 120 MeV/c to 350 MeV/c, as well as protons, pions and electrons from 100 MeV/c to 450 MeV/c. The intensity of the muon beam is up to ~250 particles per pulse. The facility also provides the radio-frequency (RF) and Liquid Hydrogen (LH) systems needed to carry out cooling tests.

The ICTF has been developed in the first instance for MICE (Muon Ionisation Cooling Experiment) http://mice.iit.edu/. Its collaboration comprises a large fraction of the international community of physicists and engineers working on ionisation cooling. The aims of the MICE experiment are (i) to show that it is possible to design, engineer and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory; ii) to place this channel in a muon beam and measure its performance, thereby investigating the limits and practicality of cooling. Cooling of a muon beam would be essential for a neutrino factory or muon collider, which are among the possible future facilities for particle physics. A key requirement for assessing the cooling efficiency is thus a high-accuracy measurement of the muon beam emittance, performed by measuring the phase-space parameters of each muon.

During the period of the EuCARD project, the TA has supported a total of 19 EU researchers from eight institutes. They have made a total of 131 visits to the ICTF, corresponding to ~4500 "access units", which exceeds by far the minimum of 3384 access units specified in the EuCARD Description of Work (Annex I). Details of the procedure used to select projects for TA support have been given before, in particular in the Period 2 (P2) report. The major contributions that have been facilitated, and in some cases made possible, by TA support are shown below, together with the main TA-supported contributors in each case:

- U. Geneva: Commissioning of the MICE Data Acquisition (DAQ) system and online resolution systems;
- INFN Milano and Pavia: Refurbishment of Time-of-flight (TOF) counters TOF0 and TOF1 to achieve resolution of ~50 picoseconds (ps);
- INFN Milano and Naples: First determination of full beam profiles and 6D emittance, exploiting the spatial and time resolution of the TOF counters;
- INFN Roma and U. Sofia: Determination of pion contamination in the muon beam;
- INFN Como and U. Geneva: Commissioning of first planes of the Electron-Muon Ranger

TOF resolution:

The TOF counters provide particle identification (PID), including rejection of pion contamination in the muon beam, and will in due course be used to determine the beam-particle timing with respect to the RF phase of the accelerating cavities. These aims require a timing resolution of ~50 ps for each TOF station. TOF performance from data-taking in 2010 was reasonably good, but it was realised that the performance of TOF0 and TOF1 could be improved by refurbishment and improved PMT performance. The performance of all three stations after this major rebuild meets the requirement, representing an improvement of ~10 ps in the resolutions of TOF0 and 1.

Beam emittance:

The scientific goals of ICTF and MICE depend on the measurement of the beam emittance, using a single particle method. The Time-of-Flight (TOF) counters have been essential both for identification of the beam particles and for momentum measurement, prior to the availability of the spectrometer solenoids and associated tracking in 2015. Thanks to their outstanding performance, it has proved possible to use these counters to measure the

Figure 18: Horizontal and vertical emittances after correction for measurement resolution and multiple scattering versus mean p_z of the seventeen measured beams. Solid circles μ- data, open black circles μ+ data, solid red triangles μ- simulation, open red triangles μ+ simulation. The nominal "p_z=140" MeV/c beams correspond to momenta in the range 170-190 MeV/c, "p_z=200" to 220-250 MeV/c, and "p_z=240" to 250-290 MeV/c (http://arxiv.org/pdf/1306.1509v1.pdf)

momentum of single muons with a resolution of better than 4 MeV/c and systematic error of < 3 MeV/c. The ability to measure the longitudinal momentum p_z to this precision will complement the momentum measurement of the magnetic spectrometers. For low transverse amplitude particles, the measurement of p_z in the TOF counters is expected to have better resolution than that of the spectrometers, which are primarily designed for measuring the transverse component of the momentum. Figure 18 shows the measured horizontal and vertical emittances, compared to simulations. These results demonstrate that the beam emittances are perfectly suitable for the MICE experiment.

Pion contamination:

The muon beam is obtained from the decay of pions produced in the ISIS target, and hence (undecayed) pions are a source of contamination in the muon beam. This contamination should be below a few per cent to avoid a detrimental effect on the emittance measurement. The broad momentum acceptance of the ICTF beam line means that the TOF distributions of pions and muons do overlap partially. The pions can, however, be distinguished from muons by their different signals in the KLOE Light (KL) calorimeter, and hence the level of pion contamination can be determined. Data were taken with TOF2 and KL placed ~2m downstream of TOF1 (see Figure 16) . Special calibration runs were performed to establish the KL response for pion and muon "templates", which are shown in Figure 19.

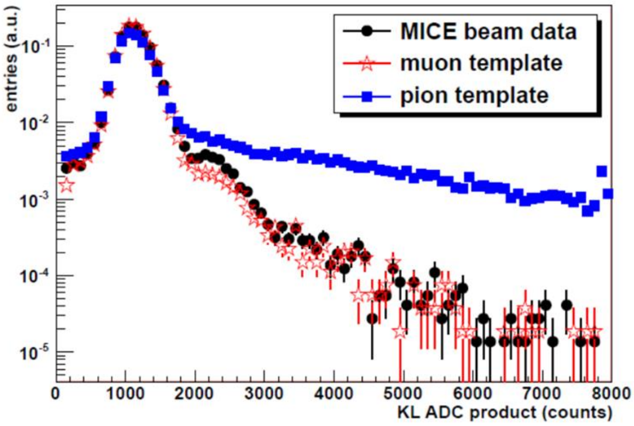


Figure 19: Signal in KL for muon (red stars) and pion (blue squares) templates from calibration runs, compared to MICE muon beam data (black dots). All distributions are normalised to unity (MICE Collaboration: paper in preparation).

The signal from the beam is also shown. It is clear that the beam can be described by the muon template with a small admixture of the pion template. This admixture is the contamination level. A complementary method, based on simple cuts on the KL distribution, gives similar results. Overall, the pion contamination is found to be less than 1%, which meets the requirement in order to demonstrate and characterise muon ionisation cooling.

4.3 EUCARD JOINED RESEARCH ACTIVITIES

4.3.1 Superconducting high field magnets (WP7 – HFM - JRA)

The high field magnet R&D workplan consists in two primary activities: support studies, design and construction of the Nb_3Sn magnet; study, design and construction of a HTS dipole insert. Two synergetic activities have been associated to the WP: the developments of an HTS electrical link and of a Nb_3Sn helical undulator.

The high field 13 Tesla Nb_3Sn magnet

The goal of this R&D is to design, construct and test a 13 T dipole magnet with a 100 mm diameter aperture. The expected LHC performance increase leads to higher irradiation, i.e. the materials must be especially robust. This first requirement led to the certification of the coil insulating materials to resist radiation at cold for an appropriate duration. Four materials maintained at 77 K were irradiated with 50 MGy by a 4 MeV electron beam. Electrical, mechanical and thermal tests of the materials before and after irradiation were performed in cryogenic conditions (LN2 environment). The whole procedure was quite challenging and brings data unavailable before. A second aspect deserved special attention and was interleaved with the magnet design: this is the magnet thermal model, needed, e.g. to define the cool-down speed. Two models were made, the second based on a two fluid model, being a breakthrough in modelling superfluid helium. The results of both models are being used for the thermal part of the design and the program of test of the magnet. After a thorough evaluation of design variants, a block coil layout with a structure using shell, bladder and keys was chosen. This layout is deviating from the classical cosine theta layout and opens the way for future high field magnets were these are not feasible anymore. The chosen PIT conductor is a derivative of the conductor developed for the FP6 CARE-NED project by a European vendor and a second option exists as the RRP conductor from a US vendor. A new 20-strand cable was developed which features low degradation at identical parameters for the two strand types. The design of the coil and the structure was done with attention to all details, leaving no open known issues. A study was done on the quench protection of the dipole and the magnet protection is well under control.

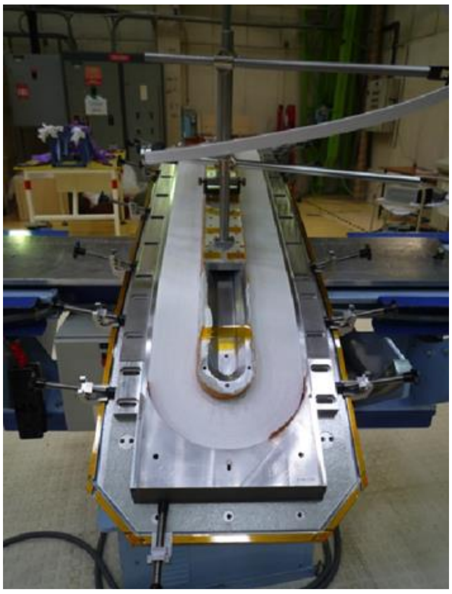


Figure 20: Coil manufacturing (courtesy CERN/CEA)

Nearly all of the components for the coils have been delivered and the magnet structure was assembled (**Error! Reference source not found.**). Conductor for one full set of coils has been delivered and spare conductor is on order. In order to verify the subtle game of pre-stress by differential shrinkage during cool-down, the structure was cooled down to LN2 temperature (77 K) in a specially built installation at CERN in the SM18 test facility and the stress effects on dummy coils were measured and verified to be in line with the finite element model predictions. To avoid costly progress by trial and errors, a systematic program of tests is carried out: winding, layer jump forming, cable reaction dilatation and 10-stack thickness under pressure. This has allowed for appropriate design of tooling, in particular for the high-temperature reaction for which the mould contains new features to allow for the axial shrinkage. In parallel, CERN is building a unique test station (4.2 and 1.9K) to be completed in summer 2014. The construction of the 4 coils passes via the construction of a Cu coil to test the full manufacturing process. One Cu coil was build. The magnets will be firstly tested with just 2 inner layer type coils by end 2014 and with the full layout of 4 coils a year later. During the design and construction, a panel of 7 international magnet experts reviewed the magnet project yearly. These reviews were used to verify the technical choices and strategies. Strong recommendations to add several intermediate construction and tests steps were made and followed. This has slowed down the project but is paying off as valuable information has been learnt, giving more confidence in the final success and the ability of reproducing high fields by a systematic approach.

The very high field dipole insert

This is a new concept, by which the field of the 13 Tesla Nb_3Sn magnet will be boosted by a 6 Tesla HTS insert to reach the 20 Tesla range. YBCO tape was selected as conductor, and the cable devised as two sets of two face-to-face soldered tapes. Substantial efforts were devoted to characterising the conductor.

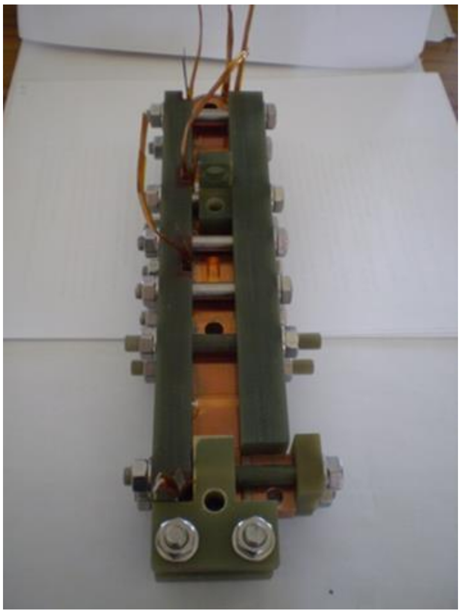


Figure 21: Test pancake coil for 10 T tests (courtesy CEA/CNRS)

The insert design was chosen to consist of 3 double pancake coils mounted in a novel concept structure of steel pads and a shrinking cylinder. The insert fits in the 100 mm dipole magnet aperture and does not have any mechanical interference with the magnet to avoid any damage to it. The quench behaviour of YBCO coils, being a major open issue for the design, was carefully studied with the help of several small solenoid coils that were tested in a 20 Tesla background field. The quench behaviour was studied by simulation and these models have steered the design of the insert and the design of a quench protection system. A small prototype racetrack coil with the double tape conductor was built (Figure 21) and tested in a 10 T background field to verify the coil concept and to measure the angular dependence of the critical current on the field inclination angle. All components of the final insert have been delivered and the conductor delivery is partially done in October 2013. The insert will be built in the last quarter of 2013. After a stand-alone test in 2014, the insert will be tested inside the high-field magnet when it will be available end 2015.

The high Tc superconducting link

This initially generic R&D study, gathering academics and industry, received a boost when the LHC luminosity upgrade project realized that this technology was required to transport DC currents in the kA range on typically 25 circuits/link and 100 m in a flexible cryostat. Three HTS conductor tapes were characterized (YCBO, Bi-2223 and MgB_2) and prototype short cables were built. Prototype short cables were assembled, characterized and tested in new test stations at various temperatures and under various operating conditions, leading to the fabrication of a five-meter long Superconducting Link containing 25 Twisted-Pair MgB_2 cables.

Figure 22: Completed 25 Twisted-Pair link cable (courtesy CERN)

Following its successful validation, two novel cabling machines were developed and assembled, enabling the controlled production of kilometre-long Twisted-Pair units, using MgB_2, YBCO or Bi-2223 conductors. The 25 Twisted-Pair cables were assembled together to form the 20 m long final multi-cable assembly, inserted in its flexible cryostat, i.e. the EuCARD deliverable (Figure 22). A new test station was designed, constructed and fully commissioned at CERN. This is a unique installation that enables the electrical characterization of up to 20 m long HTS cables and cable assemblies at any temperature from 5 K to 70 K. The 20 m long multi-cable assembly is integrated and ready to be tested in this test station.

The short period helical superconducting undulator

The goal was to increase the magnetic field level through the use of Nb_3Sn and new helical coil designs. The initially selected conductor showed instabilities at low field, specific to Nb_3Sn and this difficulty was overcome by using a wire from Supercon.

Figure 23: helical undulator in fabrication (courtesy STFC)

The mechanical design (Figure 23) was adapted from that of the Nb-Ti undulator with provisions to allow for the required Nb_3Sn heat treatment e.g the bore of this magnet was chosen stay of the same material as the helix. The design included an insulating plasma-sprayed alumina coating with an additional glass fibre epoxy layer in the groove base. After heat treatment, the undulators were vacuum impregnated with epoxy resin to provide mechanical support and electrical insulation. Winding trails were carried which highlighted some issues with the winding, splices and vacuum impregnation, that were resolved. Two 30 cm long undulators were built and tested at INFN-LASA in Milan, Italy. The results are disappointing: one undulator had a very high resistance (broken wire); the second one had quenches well below the nominal, identified as a break in the conductor. Also, the fractured macor winding posts indicate that significant tensile force was present in the windings at some stage of the realization, calling for a Nb_3Sn design departing from the Nb-Ti experience.

4.3.2 Collimation and Materials (WP8 – ColMat - JRA)

The large and complementary spectrum of competence and facilities of the partners involved in accelerator, radiation and material sciences and technologies has allowed a distinct progress in this field at the crossroad of specialties.

Support studies

Beam halo simulations and experimental studies were done for the LHC and the FAIR accelerator complex. A collimation system was designed for SIS100/FAIR offering 99% efficiency for proton beams. Extensive use and crosschecks are made of the MERLIN C++ library, used for collimation studies. A key result of the studies is the progress in understanding the phenomenology of extended damages induced by energetic particle beams hitting machine components (material phase transitions, extended density changes, shock waves propagation, explosions, material fragment projections etc.). Studies are done with hydro-codes: these are highly non-linear finite element tools, using explicit time integration schemes, developed to study very fast and intense loading on materials and structures. A considerable experience has been gathered by the EuCARD partners, using several different codes. The phenomenology of catastrophic LHC beam impacts has been clarified (Figure 24). By coupling hydro-codes with Monte-Carlo particle simulation, the hydrodynamic tunneling effect of multibunch beams has been evidenced: a beam can penetrate significantly deeper in materials (+50% or more) than previously expected, due to a progressive change of density seen by successive bunches (Figure 25).

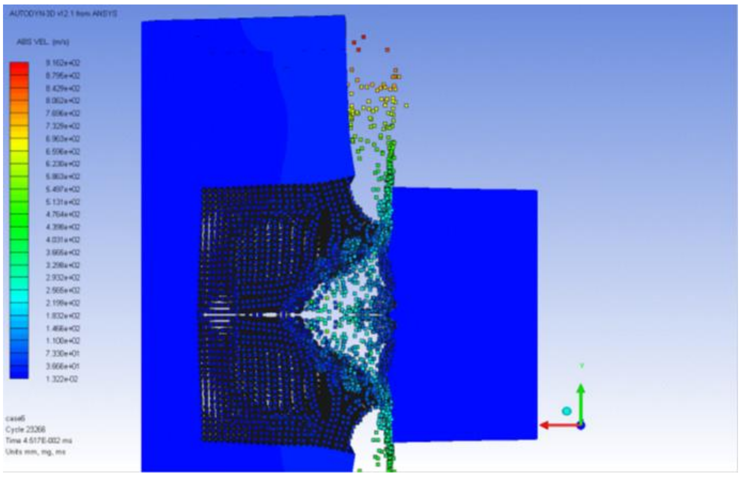


Figure 24: Projection of high velocity debris out of a tungsten jaw following the impact of 8 LHC bunches, each with 1.3e11 protons at 5 TeV. Opposite jaw is damaged by projected W particles, which are flying with velocities of up to 1000 m/s. (courtesy CERN)

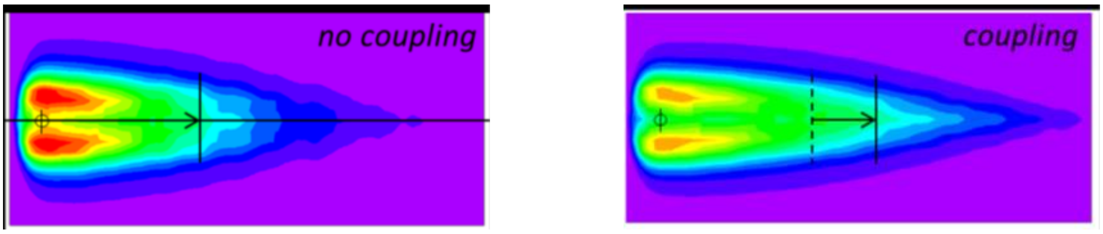


Figure 25: Differences in density between Fluka/Hydro-code coupled and non-coupled simulations for a copper target impacted by 30 LHC bunches. Note the significant difference in beam penetration (tunnelling effect) between the two cases (courtesy POLITO)

Novel materials for collimators

The requirements on collimators are numerous and challenging: high cleaning efficiency, high geometrical stability, high robustness in case of beam loss, high electrical and thermal conductivities and compatibility with ultra-high vacuum. Beyond classical materials (Cu, W, C-C), a new class of metal-matrix composites with diamond or graphite has been identified, produced and their characterization is in progress (Cu-CD, Ag-CD, Mo-CD, Mo-Graphite). To minimize brittleness, find appropriate sintering temperature and high-enough melting point, many combinations of a third phase or activating elements have been investigated. Cladding is also considered for increasing the electrical conductivity. Cu-CD represents an interesting candidate for future collimators, although Cu fairly low melting point somehow limits its application for highly energetic accidents. Its radiation hardness is currently being tested. Ag-CD has excellent properties but a low melting point and non-homogeneities. Optimized Mo-CD appears as a good candidate. A new material, MO-coated Mo-Gr, appears quite appealing due to the peculiar properties of graphite that are superior to diamond as reinforcement, and less expensive: low thermal expansion, low density, high thermal conductivity, high meting point, high shock wave damping, and high electrical conductivity by cladding.

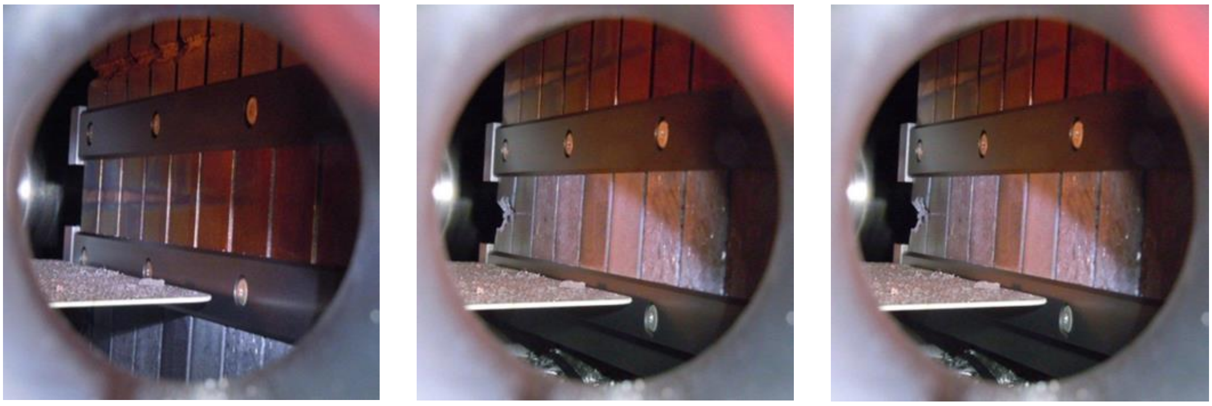


Figure 26: Beam impact on different novel materials: (left to right) Cu-CD, Mo-Cu-CD, Mo-Gr tested at HiRadMat (courtesy CERN)

It is being developed with a SME (small and medium enterprises). A key aspect of this material research is the experimental assessment of the radiation robustness (radiation bursts and long-term radiation doses). For the fast irradiation purpose, the HiRadMat@SPS facility (as well open as a TA) is invaluable and a number of tests have been carried out. For the second aspect, irradiation is carried out at other partners' facilities. It includes the study of residual activation of materials, with simulation and experimental studies already carried out on Carbon-composite and graphite. The post-irradiation tests requiring decay time for the samples, these studies will continue in EuCARD2, together with further improvements of Cu-CD, Mo-CD and Mo-Gr. Materials and techniques being developed may turn out to be very attractive for a number of sectors, including aerospace, electronics, nuclear and medical industries.

Smart collimators

Collimators need to be aligned on the beams within a fraction of the beam size. The alignment procedure is performed by touching the beam halo with the collimator jaws. Given the large number of collimators, the procedure can only be carried out in infrequent dedicated fills at low beam intensity. This procedure enforces rigid operation to guarantee reproducible collimation. To overcome these limitations, this task has investigated the possibility to include beam position monitors (BPM) in the collimator jaws, so as to make possible real-time optimization of collimators positions. Some of the challenges to overcome were the compatibility of sensitive electrometers (BPM's) with a device aimed at scattering particle, and the complexity of operation with BPM's where the distance between the electrodes varies, as being mounted on the moving jaws. A collimator with in-jaw BPM's was designed, constructed and installed in the SPS for beam tests (Figure 27).

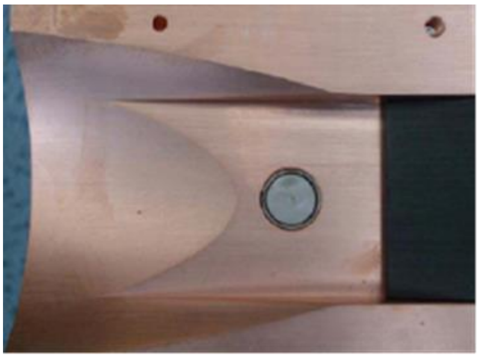


Figure 27: A second generation LHC collimator jaw with pickup button in copper support. (courtesy CERN)

The stainless steel electrodes were placed at each collimator end 10 mm below the surface of the graphite inserts above the Cu jaws. Simulations and experiments were carried out to verify the linearization of the BPM response, with good agreement. The 10 mm retraction of the

BPM's was shown to be sufficient to avoid disturbance by secondary protons from beam halo particles scattered by the jaws. The accuracy of the measured beam position was established by comparing the observations of the in-jaw BPM's with machine BPM's as the orbit is modified. The agreement found is satisfactory and better than 100 μm. The test having been positive, such smart collimators will be manufactured and installed in the LHC during the present machine stop. The expected impact is a reduction of the setting time of collimators by one order of magnitude, with a gain of integrated luminosity by up to 15%. Perhaps more importantly, it gives flexibility to operations, by a real-time adjustment for changing conditions, better machine protection and cleaning efficiency.

Cryo-catchers

In the main super-conducting accelerator SIS100 of the FAIR-complex, beam loss due to ionization is the most demanding loss mechanism at operation with high intensity, intermediate charge state heavy ions. A special synchrotron design has been developed for SIS100, aiming for hundred per cent control of ionization beam loss by means of a dedicated cryogenic ion catcher system at a peak of the loss distribution.

Figure 28: Cryo-catcher prototype (courtesy GSI)

To suppress dynamic vacuum effects, the cryo-catcher system shall provide a significantly reduced effective desorption yield. The construction and test of a prototype cryo-catcher was a EuCARD task (Figure 28). A prototype test setup, including cryostat has been designed, constructed, manufactured and tested under realistic conditions with beams from the heavy ion synchrotron SIS18. The cryo-catcher is a 25 cm long Ni-Au platted copper block, optimized by FLUKA simulations. Geometry and surrounding cold surfaces for pumping prevent the desorbed gases from reaching the beam axis. The cryo-catcher chamber is cooled via flexible copper straps, which are connected to a LHe pipe. Both are surrounded by a LN2 cooled thermal shield inside the cryostat chamber. Appropriate and compact warm-to-cold transitions minimize the heat load. The cryo-catcher is instrumented to measure its efficiency and the desorption rates under beam impact. During the experiments several parameters were investigated, e.g. cooling power, end-pressure, and heavy ion bombardment induced pressure rise as a function of the beam energy and cryo-catcher temperature. The results obtained in SIS18 and scaled to SIS100 show a stable operation of SIS100 even at highest heavy ion beam intensities. It could be shown that the design of the cryo-catcher prototype fulfils all requirements and it will be used for series production.

Crystal collimation

Over the last four years of UA9 collaboration, the deflection by bent crystal has made steady progress. The goal of this task has been to investigate the possibility of using bent crystals to assist LHC collimation by experimenting in the SPS.

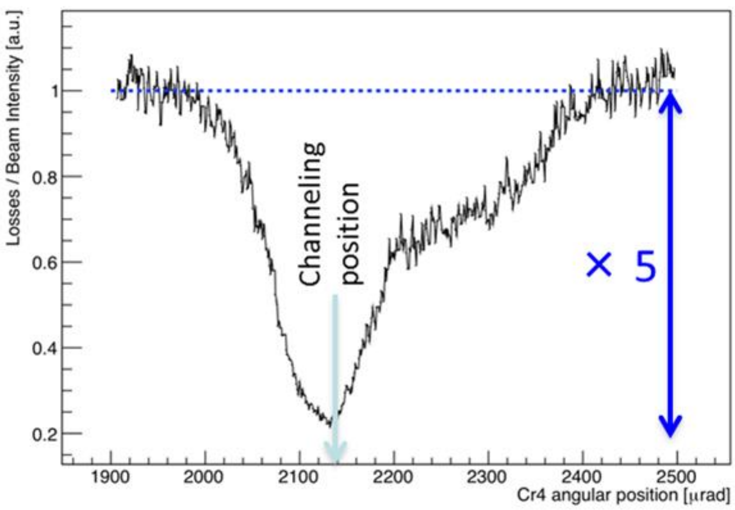


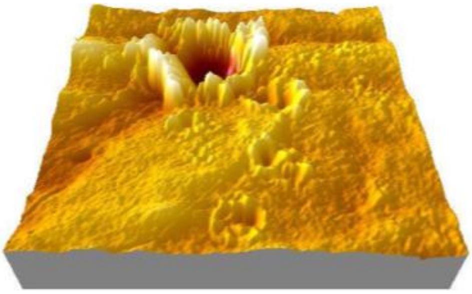
Figure 29: reduction of uncontrolled beam losses by optimal crystal orientation (courtesy UA9 collaboration)

A silicon crystal 2mm long, with a bending radius of 150 μrad is used as a “primary” collimator, to channel either protons or lead ions of the beam halo towards an absorber. Diagnostics of collimation efficiency is made by measuring beam losses around the accelerator, as a function of the orientation of the crystal. These uncontrolled beam losses should be reduced by successful collimation. Experiments show a reduction of losses by a factor between 4 and 10, demonstrating a significant channelling efficiency and potential of use (Figure 29).

4.3.3 Normal conducting linacs (WP9 - NCLinac - JRA)

Physics and diagnostics of RF break-downs

The very high gradient electromagnetic fields in metallic structures can result in frequent break-down events. The high currents densities (measured 2 10^8 A/cm^2) destroy the quality of the surface and of the material.



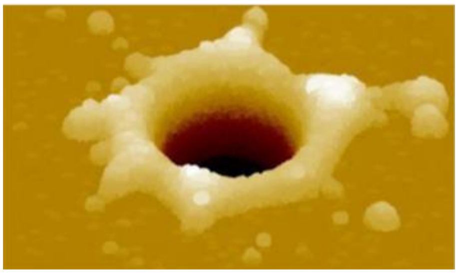


Figure 30: Observed and simulated breakdown craters (courtesy UH)

With the improvement of surface processing, it was observed (KEK) that the surface imperfections cannot explain all breakdown phenomena. In order to progress in the understanding, a multiscale/multiphysics numerical model was devised to simulate electrical breakdowns. It is used and continuously upgraded. To tackle the arcing effect, the model combines density functional theory, molecular dynamics, FME, kinetic Monte-Carlo and simulations of plasma-wall interactions.

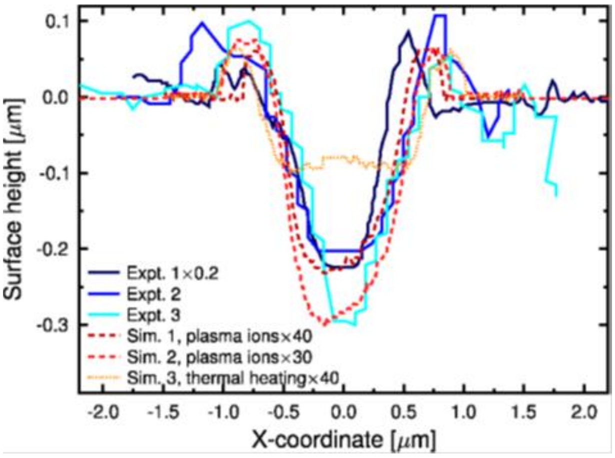


Figure 31: Self-similarity of breakdown crater dimensions (courtesy UH)

These simulations have shed light on the arcing phenomenology, not accessible via experiments: charging of surface, inducing tensile stress; irregularities in the surface concentrating the stresses, protrusions and intrusions initiating the formation of field emitters, leading to a plasma discharge and surface damage. An interesting result is the identification of the impact of voids and dislocations below the surface subject to tensile stresses and high field. They migrate and create protrusions which, in turn, will lead to catastrophic growth of tips. The importance of sub-surface characteristics is further consistent with the observed (in simulation) dependence of critical breakdown field with the base crystallographic structure of the material. Special instruments and diagnostics were developed to create controlled breakdowns, including in-situ inside an electron microscope, breakdown detectors (flashbox) and measurement of the surface and subsurface properties. These allowed comparing impacts of breakdowns in experiments and simulations. Figure 30 shows examples of breakdown craters simulated and created in experiments. They all exhibit the same depth to width ratio over several orders of magnitudes, identical in simulation and experiments (Figure 31). This research, which shall be continued, will help choosing materials (metals, alloys or composites) and surface treatments to minimize the onset of electrical breakdowns.

CLIC technologies

HOM damping

The goal of this research is the minimization of the wakefields starting from a linac consisting of 26-cell CLIC structures providing a 100 MV/m accelerating field and interleaving different structures. The design for a 6-fold interleaved structure is complete. It features improved overall wakefield suppression and exhibits a larger 1st dipole bandwidth. An improved HOM coupling from cell to manifolds is also proposed together with a reduced H-Field value on the cavity walls. Following validation with a pre-series phase, the production has been launched. The dimensional control of the disks and the preliminary RF results are satisfactory. Indeed, only few μm errors have been observed. The assembly consisting in bonding the disk stack and brazing the couplers and cooling circuits is completed. The RF measurements and tuning will follow, and high-power tests foreseen in 2014.

PETS (Power Extraction and Transmission System)

Figure 32: Assembled double-length PETS (courtesy CIEMAT)

The CLIC PETS has to extract RF power from the very rigid, high current CLIC drive beam. In order to extract the same amount of power from the less rigid, lower current CTF3 drive beam, the impedance of the PETS has to be artificially increased – this lead to the need of a double length version. The first double-length PETS for the CLIC module has been successfully designed, assembled and tested. The design comprises eight identical copper bars with damping material and two compact couplers placed at both ends of the bars to extract the generated power. The first PETS unit was fully assembled (Figure 32) and tested at low power. The compact couplers were then brazed and electro-beam welded. The geometrical control and RF characterisation demonstrated compliance with the requirements. A second PETS unit is currently under fabrication. New companies have been qualified for this production.

Precise assembly

The requirement for stability of the "CLIC module" as a whole (see next section) reflects evidently in the assembly and internal stability of the module, with in view a large scale production. Good practices have been defined and tested. In addition to the gravity, vacuum and RF loads, the environment conditions have been added to the FE model allowing thus to simulate the thermo-mechanical response (Figure 33) of the module following different ambient temperatures (from 20 °C to 40 °C) and air speed (from 0.2 m/s to 0.8 m/s). The experimental results are in good agreement with the model, e.g. thermal transients, and further comparisons will be made, to benchmark the model.

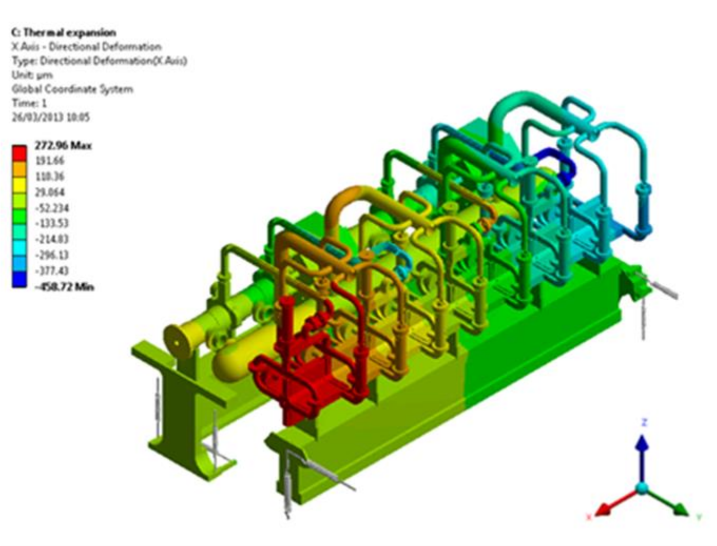


Figure 33: CLIC module FE model: Displacements (x) following an applied thermal load (courtesy CERN)

Nanometre mechanical stabilization

The CLIC collider requires stabilization of the linac to 1 nm at 1 Hz and stabilization of its Final Focus (FF) to 0.1 nm. A novelty in this task is the design, construction of a CLIC linac quadrupole and of its challenging stabilization equipment ((Figure 34). The effectiveness of stabilization components (such as tri-axial seismometers, displacement and strain gauges, piezoelectric actuators, triple-beam interferometers etc.) could then be studied in an environment close to that of a real accelerator (magnetic field, water cooling).

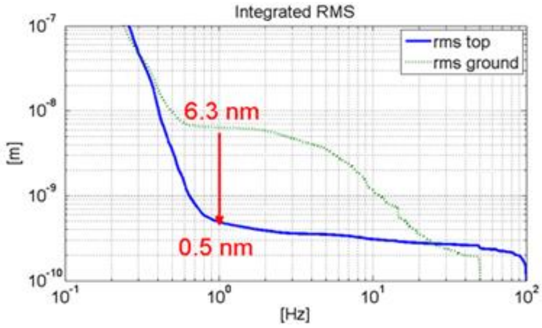


*Figure 34: **Left**: Powered quadrupole with water cooling*

***Right**: Vibration reduction obtained with stabilization system with magnetic field and water flow (courtesy CERN)*

The spectacular achievement of 0.5nm at 1Hz (Figure 34) validates the stabilization concept (stiff active stabilization, Stewart platform, inclined actuators,…) for the linac, including its diagnostic equipment. The limiting factor being the sensor noise, post-EuCARD developments with sensor manufacturers are considered. For the Final Focus, the extreme requirement of 0.1 nm above a few Hz can only be reached by a combination of mechanical stabilization and beam-based feedbacks. This FF study includes several sub-parts. First the "Annecy compact stabilization system" was developed (Figure 35).

Figure 35: Annecy compact stabilization system (courtesy CNRS-LAPP)

It is a stabilisation/isolation system with sensors and actuators stabilizing down to sub-nanometre level. It complies with the tight space and accelerator environment. The result obtained in Integrated RMS is 0.6 nm at 4 Hz, limited by the sensor noise level. Second the magnet itself needs to comply with very specific design constraints. A short prototype of the FF magnet was designed, built and measured showing excellent performances in terms of achieved gradient and field quality. Third, beam-based stabilization (equipment and control strategies) were developed and tested on different accelerator facilities showing nanosecond responses at ATF2, in relation with the next task. Global integrated beam-based feedbacks have been studied and show that the tools exist to mitigate ground motion when the final site characteristics will be known.

Beam-based stabilization

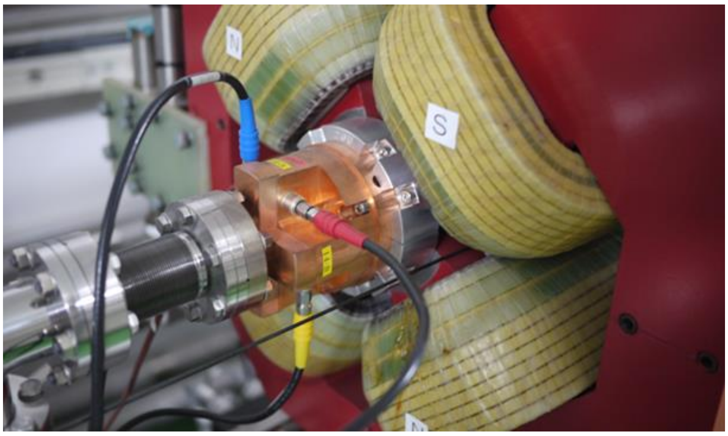


Figure 36: Cavity BPM cavities in ATF2 (courtesy RHUL)

As already mentioned, mechanical stabilization is necessary, but not sufficient to guarantee precise head-on collisions for the two sub-μm beams of linear colliders. Beam diagnostics and appropriate procedures for correction of fast and slow deviations are essential. The task has visited these aspects, and experimented procedures in ATF2 in Japan. It as well included improvements to CLIC/ILC beam crossing regions. With the support of EuCARD, the cavity BPM (CBPM, Figure 36) readout, control code, operational support and R&D was provided to the ATF2 linear collider test station. Resolution down to 30 nm has been demonstrated and much lessons learned. Various tuning procedures using the CBPM's were developed and tested, contributing to a reduction of the ATF2 beam size down to 70 nm. A laserwire monitor was designed, built and tested in ATF2, to measure the beam size. The laserwire has achieved its technical goal measuring one micrometre vertical beam sizes, from 5 to 10 micrometres at the start of the project, thanks to a refined understanding of the signal components and appropriate processing (Figure 37).

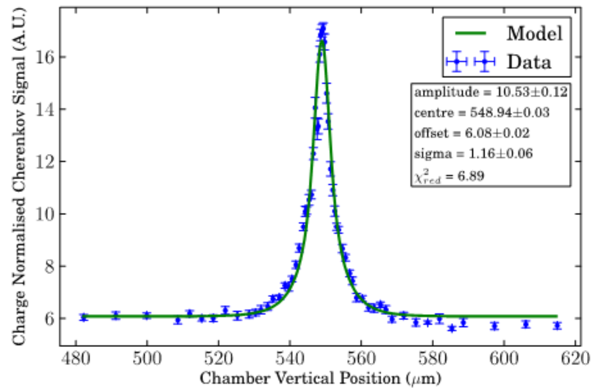
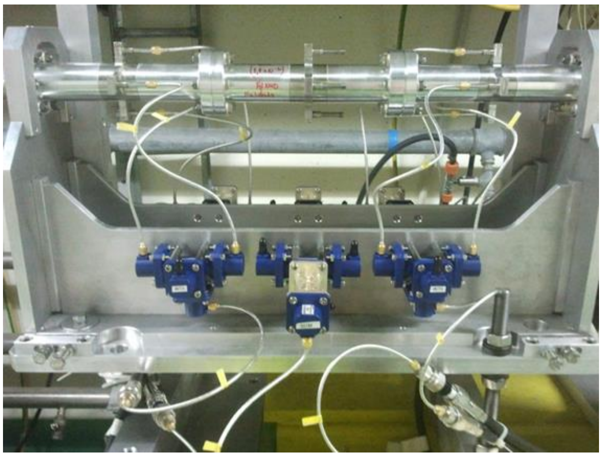


Figure 37: Beam size measurement by the ATF2 wirescanner: the rms beam size is 1.2 μm (courtesy RHUL)

Another laserwire based on a fiber laser was developed for PETRA3 where it can measure the beam size of individual bunches. Finally, the diagnostics were defined and optimized in simulation for monitoring the CLIC luminosity using the post-collision disrupted beams. Both for ILC and CLIC, lattice design and optics studies allowed minimizing the impact of aberrations blowing up the beam size at the interaction point.

Very precise RF phase control

The CLIC two-beam acceleration scheme requires precise synchronization between the "drive beam" that provides the RF power to the "main" beam. The requirement is 0.1° at the CLIC frequency of 12 GHz, requiring a resolution of ~ 20 fs. This signal shall be used to adjust a chicane controlling the beam time of flight. This time scale is that of ultra-fast physics, e.g. lasers, XFEL's, etc. This task explored two possible solutions for the detection of the beam arrival: electromagnetic (EMM) or electro-optical (EOM) detection (Figure 38).



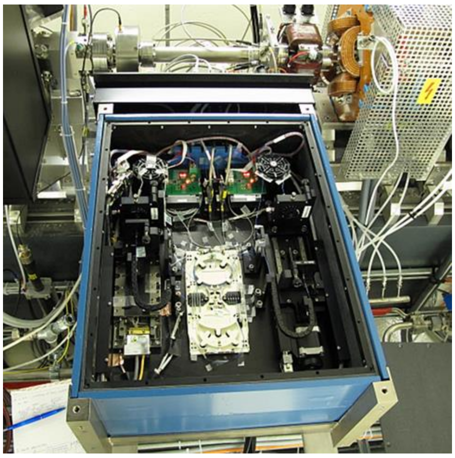


*Figure 38: Beam arrival time monitors: **Left**: EMM installed in CTF3 (courtesy CERN/INFN; **Right**: EOM optical cross-correlator (courtesy PSI)*

Several prototypes were designed, built and tested in RF laboratories. The EMM pick-up consists in a straight beam pipe provided with four slots to couple the beam induced signal out. Notch filters provide a resonant volume for the beam signal and reject RF noise and wake field. Special consideration was given to minimize the coupling impedance. The EOM consists of a master laser oscillator distributing a train of optical pulses over a system of stabilized fibre links. Electrical pulses from ultra-wide bandwidth pickups are mixed with the optical signals using electro-optical monitors to obtain the phase reference. Special care was given to noise and drift reduction and thermal stabilization. Both systems were tested with beam in the CLIC test station CTF3 and satisfy the CLIC requirements. Further improvements are on-going for application in the PSI injector and future SwissFEL.

4.3.4 Superconducting radiofrequency technologies (WP10 - SCRF - JRA)

RF cavities for compact proton linacs

This study aimed at designing, producing and processing high gradient 704 MHz cavities able to reach the challenging gradient of 25 MV/m (beta=1) and 19 MV/m (beta=0.65) for proton linacs, suitable for the SPL study at CERN, and preparing for the ESS project. The RF design requires sophisticated simulations to reach such gradients, with optimizations over about 30 parameters. The mechanical design and definition of the production process is critical to keep the RF parameters at their nominal values. The challenge turns then to the production and processing. The strategy followed was, after design, to interleave fabrication of half-cells and dumbbells in industry, intermediate mechanical and RF checks, cavity assembly in industry, chemical processing at the partner's laboratories and final integration and cryostat welding in industry. For this purpose, an electro-polishing set-up was designed and fabricated, with, for the first time, an unconventional vertical axis for a more uniform flow of electrolyte, following exploratory work made in Cornell (Figure 39). All tests were especially rigorous, and simulations were, e.g. done to find the best combination of dumbbells for maximum field flatness, taking into account the future equator welding shrinkage. The obtained flatness before tuning is 80% (beta=1), quite satisfactory, and reaches 92% or above after tuning for the two cavity types. Electro-polishing was done in two or three passes, with in-depth controls between passes (surface quality, field profile, Nb thickness). Special modifications of the process were made when some limited non-uniformities were detected and explained by a difficult evacuation of gazes and some retention of acid. For the beta=0.65 cavity, the welding of the Ti vessel in industry caused a severe degradation of the field flatness. To conclude, this project allowed improving significantly the technical follow-up and in particular the RF tuning procedure of 704 MHz elliptical cavities during manufacturing. The electro-polishing process has also been applied for the first time with very promising preliminary results. The cavities are being finalized and their performance will be measured at the end of 2013.

Figure 39: 704 MHz beta=1 5-cell cavity installed in the vertical electro-polishing set-up (courtesy CEA)

RF crab cavities

Crab cavities are novel transverse-field RF cavities used to rotate bunches from opposing beams to achieve effective head-on collisions in case of a crossing angle. They will find applications in LHC, CLIC and ILC. The LHC has a very long bunch length (8 cm) hence a low frequency cavity of less than 400 MHz is required to avoid non-linear crabbing. This leads to extreme size constraints as the separation between incoming and outgoing beams close to the LHC interaction points is smaller than the size of a suitable pillbox cavity at 400 MHz. A novel four rod deflecting cavity was studied, consisting of four parallel quarter wavelength rods. The structure has been optimised for low surface fields and low sextupole components to the deflecting field. Input Power and HOM couplers have been designed and a prototype aluminium cavity was produced and characterised in terms of its electro-magnetic field performance. Based upon these results, an aluminium cavity prototype has also been fabricated, which has been used to verify

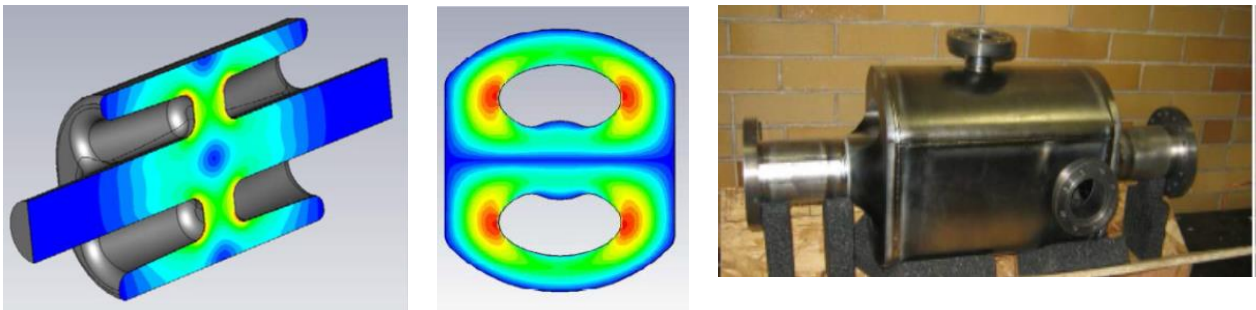


Figure 40: Geometry of the LHC 4RCC with electric field amplitude and Nb cavity (courtesy ULANC)

simulation results. In addition, further funding has been secured which has enabled a niobium high-power cavity prototype to be fabricated (Figure 40). It will be tested at CERN.

The challenge for CLIC crab cavities is the large beam loading, varying with the transverse beam position. As beam offsets are random, beam loading can randomly modify the deflecting fields, resulting in luminosity loss. Phase stability of the order of 20 mdeg and amplitude stability of 2 % has been targeted for the CLIC crab cavity. Thus the primary RF requirement on the CLIC crab cavity is to minimise dipole beam loading. The studied technology choice is a normal conducting, travelling wave structure. A high group velocity is required to have a high power flow to stored energy ratio helping fast field propagation. A frequency choice of 12 GHz allows the use of existing high power, X-band infrastructure. A conventional dual-feed coupler is proposed to transversely symmetrise the deflecting field; however single-feed couplers with beam loading compensation and those without any field asymmetry were also evaluated. Waveguide dampers are included, with the most threatening SOM requiring a damping of the order of Q ~ 100. Two prototypes have been manufactured (1-2 μm tolerances) for high gradient testing.

Low-level RF was designed for both CLIC and LHC: The focus for CLIC is accurate phase synchronisation of the cavities on the two opposing beams (to 5 fs), adequate damping of wakefields and modest amplitude stability. A prototype intelligent LLRF system addressing these issues has been studied in detail and successfully developed and tested. For the LHC, the main LLRF issues are related to imperfections: beam offsets in cavities, RF noise, measurement noise in feedback loops, failure modes and mitigations. Requirements have been defined.

RF coupler processing

Experience shows that the preparation of the RF couplers determines their conditioning time. For large machines like the XFEL with as much as 800 RF couplers, defining an optimal automated coupler processing process and machine would have significant impact. The goals of this study were to define the process of the automatic couplers cleaning, to have a full review of the different phases and to establish the necessary hardware components (Figure 41). The study analyzed the hand-made process in 6 steps applied to the XFEL couplers, starting from outside the clean rooms. It lasts 72 hours and includes 8 moves in clean rooms, with as many possibilities of contamination. This allowed defining 4 phases for the automatic process, including the transition between the external environment and the clean room in the first phase. The efficiency of the four-phase process machine, as far as the large mass production is concerned, is undoubted, especially after ultrasounds benchmarking. Some industrial machines already exist but none offers an integrated service as required. The cost is estimated at 119 ± 27.5 k€.

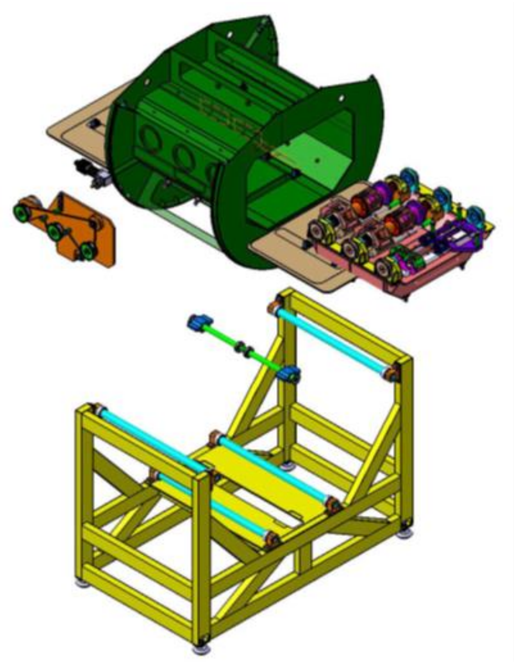


Figure 41: The automatic coupler preparation machine ALICEv2 (courtesy LAL-CNRS)

Thin film technologies – cavities & photocathodes

Thin film technologies were investigated both for photocathodes, with the prospect of increasing their quantum efficiency, and for accelerating cavities, where the prospect is to exceed significantly the gradients of bulb Nb cavities. In both cases, the goals are extremely ambitious as requiring break-throughs in physics, technologies and engineering. EuCARD activities aimed at contributing/stimulating this challenging line of research (Figure 42).

Photocathodes: Arc deposition was used to coat Pb onto Nb. Iterations on the set-up and procedures were needed to overcome oxidation. Progress was obtained as well on deposition rate, layer thickness and laser cleaning, resulting in QE of $3.3x10^{-3}$. Photo-injector cavities were in turn coated, reaching 39 MV/m in a first campaign, and eventually 54 MV/m. The embedded photocathodes however did not survive the chemical etching, leading to a change of design simplifying substantially the integration of the cathode in the clean superconducting structure. Beyond the scope of the task, the set-up has been installed on the HZB injector test stand to get more detailed information on the beam properties, on uniformity of the Pb photocathode and on its quantum efficiency.

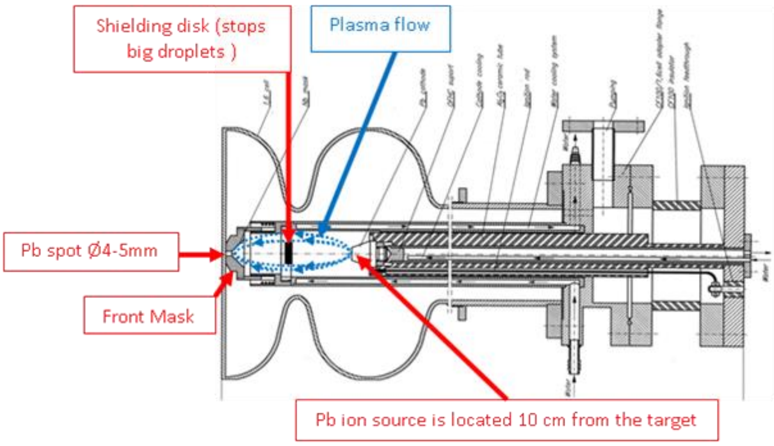


Figure 42: New arc-deposition setup installed inside 1.6-cell SRF gun cavity (courtesy DESY/NCNR)

Thin-film cavity coating:

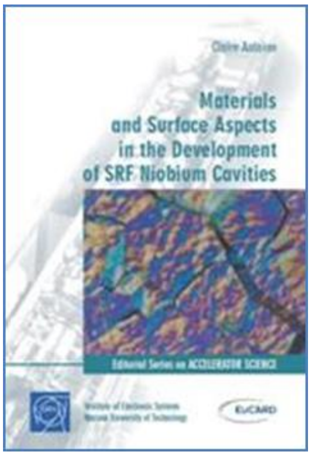


Figure 43: EuCARD monograph on sc RF physics (courtesy CEA)

Set-ups and developments are conducted in several collaborating institutes. Coating has been realized on different types of samples (Nb, Si, NbN/Mgo, Cu) as well as on full size cavities (stainless steel, copper). The results have helped studying different effects (e.g. RRR, inter-diffusion, proximity effects, and evolution of Hc1) as well as optimizing important parameters like the deposition rate, the film thickness and uniformity. The development of the magnetron sputtering technique at Legnaro has reached maturity with prospects for a patent application. The RRR of the Nb sputtered samples was increasing when increasing the power of sputtering. RRR values as high as 22 were obtained. In addition the Nb film is uniform all over within the cavity. The deposition rate is also very promising: 1 micron in about 15 minutes is more than 10 times faster than the biased diode technique. The final assessment requires a cavity to be delivered by CERN. A reference monograph on SRF cavities was prepared and published (Figure 43): Claire Antoine (CEA) “Materials and Surface Aspects in the Development of SRF Niobium Cavities” (Vol. XII of EuCARD Editorial Series on Accelerator Science), which constitutes the groundwork for the new Thin Films task of EuCARD2 which will address Hc1 improvements, ALD multilayers and Nb_3Sn thin film production, as well as new thin films test facilities (3rd harmonic Hc1 measurement).

Bulk GaAs photocathodes

The SRF gun with Cs_2Te photocathode and UV laser has been developed and operated. Tests were performed on bulk GaAs wafer cleanroom wet treatment and the vacuum heating cleaning. The inactivated GaAs was installed into the SRF gun cavity, and the dark current /field emission, rf power loss on crystal were measured with positive results. The cathode plugs to hold GaAs wafer have been designed, modified and proofed in clean room and in SRF gun, and the transportation for the plugs has been designed. However the first GaAs activation failed, while GaN(Cs) cathodes were successfully activated. This is attributed to an insufficient vacuum. A new preparation chamber with extreme high vacuum ($1x10^{-11}$ mbar) has been designed and built. National funding was granted to complete the research.

Advanced low-level RF controls

The goal of the upgrade of the FLASH LLRF was to assure the system suitability to the constantly developing FLASH needs: performance, reliability, availability, operability, maintainability, extensibility, flexibility, on a medium term scale (next 3 to 10 years). The existing DSP-based system was showing limits that could only be overcome by a novel design. The main fields requiring upgrade were:

- Field regulation (to improve long and short term stabilities by drift compensation and various calibrations)
- Availability (to reduce or eliminate the downtime through built-in diagnostics)
- Maintenance (to reduce the effort and required expertise to maintain the system)
- Operability (to automate the operators tasks)

A major choice of the new system is the use of telecommunication standards. Initially based on ATCA, the design was re-oriented to µTCA for its better suitability to small and medium size systems. The new system consists in a specialized crate, backplanes for digital and RF signals, and a number of functional modules (management unit, microprocessor board, timing, vector modulator, interlocks, klystron controller, digitizer, downconverter, e.g. Figure 44).

Figure 44: µTCA RadFETs dosimeters for FLASH, (courtesy DESY)

The tests of µTCA-based system were divided into functional tests and performance tests. Both kinds of tests were successful, pointing to several issues related to system integration that had to be solved during testing. The best regulation precision achieved with the new system so far is $\Delta A/A<9x10^{-5}$ for amplitude and $\Delta Ph<0.008$ deg. for the phase, with scope for further improvements. It has become possible to observe the influence of single bunches. Already after the first period of tests, the beam energy stabilization is improved by a factor of 2. The new µTCA system allows also implementing many new software applications that were impossible to implement in the old system due to limited resources and performance. One example is the investigation of the frequency characteristics of the 8/9pi mode of superconducting cavities.

Beam diagnostics based on RF HOM signals

Beam-excited wakefields in the third harmonic 3.9 GHz cavities of FLASH are significantly larger than those in the regular 1.3 GHz cavities and increase with beam offsets. To prevent adverse effects on the beam, they are minimized by extracting energy through special HOM couplers. For suitably small offsets the dominant components of the transverse wakefield are dipole modes, with a linear dependence on the transverse beam offset. This fact enables the transverse beam position inside the cavity to be determined by measuring the dipole modes extracted from the couplers. The challenge at high frequency (3.9 GHz) is to disentangle modes and cavities.

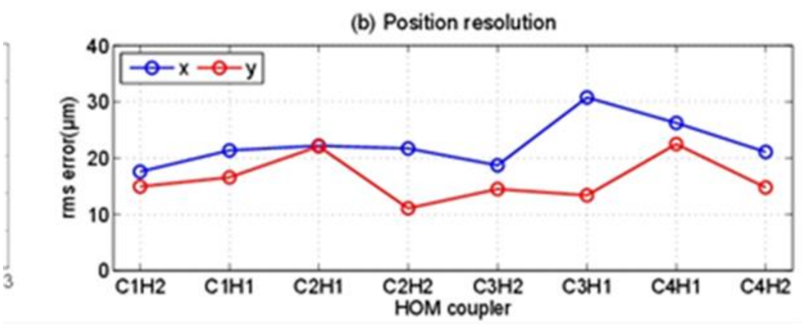


Figure 45: Measured resolution of beam position for coupled cavity dipole modes and various HOM couplers

Beam-pipe modes and trapped cavity modes in the fifth dipole band, and propagating cavity modes in the first two dipoles bands have been identified as appropriate frequency bands to measure the beam position in single cavities and four-cavity module. Dedicated test electronics was built and allowed measured resolutions of the order of 50 μm for single cavity and 20 μm for a four-cavity module (Figure 45), developing optimal algorithmic methods based on SVD. Advanced computationally intensive packages were used or developed to simulate a 4 cavity module and evaluate the impact on the modes of the cavity coupling, cavity location, fabrication and misalignment errors. Various strategies were tested (global scattering matrix, coupled-S-parameters calculations…). The simulations helped to understand the modal spectrum of the RF module and provided useful modal candidates for the HOM beam position monitor system, leading to a successful beam position measurement. The mode coupling and frequency shifts due to the above-mentioned imperfections however were shown to create a complexity that makes it difficult for HOM signals to be used for the identification of imperfections.

4.3.5 Assessment of Novel Accelerator Concepts (WP11 - ANAC - JRA)

Upgrade of the DAΦNE-KLOE **interaction region with crab waist**

A novel collision concept (crab-waist crossing) was tested in 2007 in the DAΦNE 2-rings collider at LNF Frascati in the non-magnetic detector SIDDHARTA. It proved to boost up the peak luminosity by about a factor of 3. This new scheme implies a large horizontal crossing angle, strongly focused beams at the IP and the use of a pair of sextupoles at a specific betatron phase to suppress synchro-betatron resonances arising from the crossing angle.

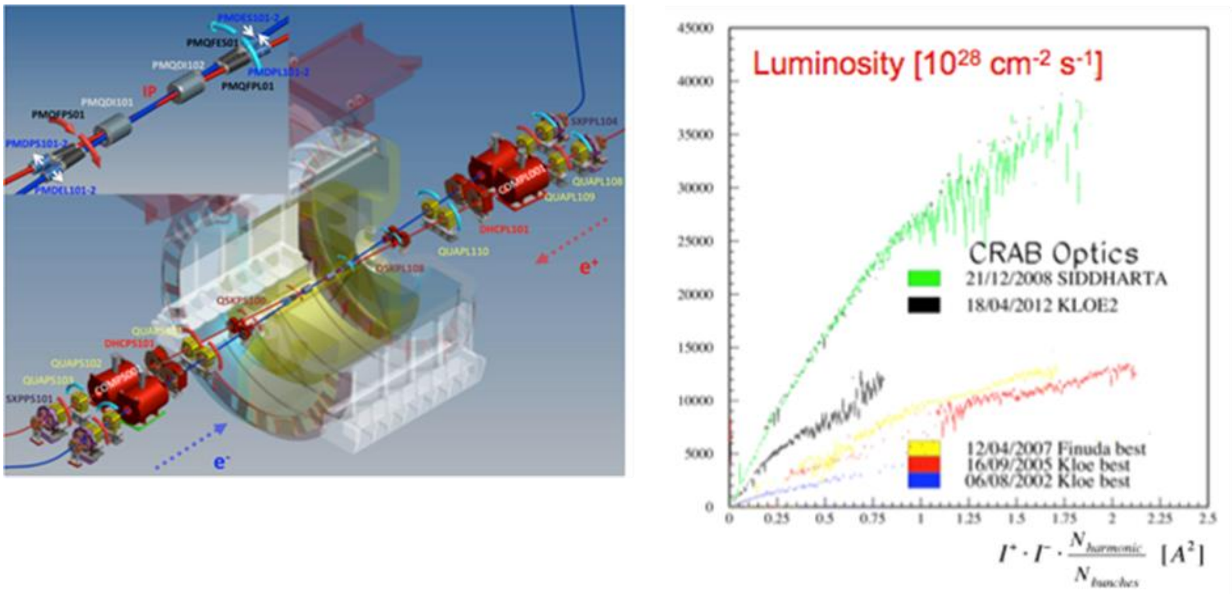


Figure 46: KLOE2 upgraded IR and new performance (courtesy INFN)

The potential of this new concept is such as to open a new approach for increasing the collider luminosity; it will be applied in SuperKEKB upgraded B-Factory in Japan. The aim of this EuCARD task was to apply this concept in the significantly more challenging situation of the KLOE insertion that includes an experimental solenoid and its coupling compensation, interfering with crab waist optics requirements and beam dynamics. The task started with the required theoretical studies (coupling and beam trajectories in the IR, e-cloud instability in the positron ring and Touschek effect) up to the IR construction (Figure 46). Actually not just the IR but the whole two rings were modified, with the introduction of diagnostics and devices to reduce beam instabilities.

The challenge of the IR mechanical design was to allow for a large beam crossing angle and an early vacuum pipe separation after IP. New very small permanent magnets, providing the necessary focusing, were built to be installed near the IP, inside the detector. A massive campaign of hardware upgrades were done to further improve performance. Among these, the installation of “clearing electrodes” in the dipole and wiggler vacuum chambers of the positron ring to capture the emitted photo-electrons in the e-cloud instability formation, allowing higher injected positron current. KLOE is now equipped with this new IR concept promising higher luminosity. This upgrade work will continue after the end of the EuCARD project.

Investigation of a crab-waist interaction region for the LHC luminosity upgrade

The goal of this task was to explore the applicability of the crab-waist principle to a proton collider, where the beam is naturally round at the IP. Unconventional magnetic optics were developed for various LHC upgrade scenarios (luminosity upgrade HL-LHC, e-p option

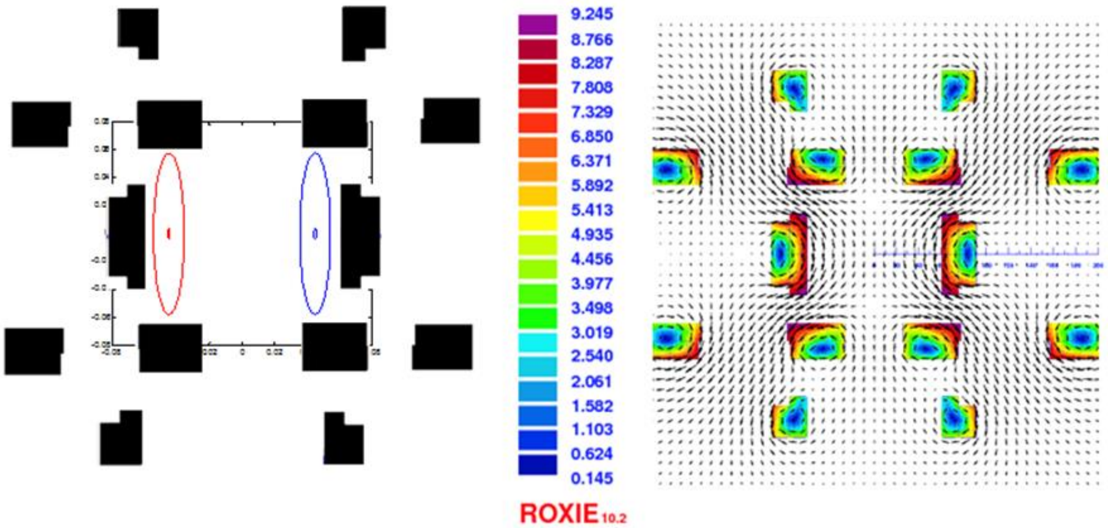


Figure 47: Cross section of the double half quadrupole DHQ. The coils are wound from simple racetracks in order to facility the production in case Nb_3Sn superconductor technology would be required.(courtesy CERN)

LHeC, energy upgrade HE-LHC), combining provisions for flat beams, large Piwinski angle, partial local chromatic correction, and a crab-waist scheme with sextupole pairs. The study included experimental beam tests in DAΦNE and LHC, as well as beam-beam simulations of achievable luminosity gains. Various local and non-local chromatic corrections schemes were initially designed and compared for the conceptually simpler LHeC case with a single low-energy electron beam. A beam-beam study together with frequency-map analysis was used to identify the beam parameter range for which crab-waist collisions would be beneficial at the LHC, and guided the optics design. In particular the minimum beam flatness σ_x^*/σ_y^* required for a successful crab-waist application was inferred from this study. For the LHC luminosity upgrade two specific optics configurations were developed and qualified. The most ambitious however did not allow a sufficient dynamic aperture so far. The second optics is more relaxed and acceptable, with a combined local/global chromatic correction. A key hardware ingredient of either optics is a novel “double half quadrupole” (DHQ) which focuses either beam in the vertical plane in a common aperture. Magnetic design (Figure 47) has shown the need to go for a combined function magnet consisting of eight racetrack coils that produce a combined dipole and sextupole field in a common aperture, without any mirror plate. This unconventional upgrade solution has shown no show-stopper and is now documented. It has entered the list of potential solutions for LHC upgrades.

Design and construction of the EMMA diagnostic devices and commissioning of the EMMA ring

EMMA is the first non-scaling Fixed Field Alternating Gradient accelerator built in the world. The project had two main goals. The first was to demonstrate that such an accelerator could be built and work as expected. It was not obvious at the outset that these would be achieved. However, with the aid of EuCARD, this has been done (Deliverable 11.3.1). The second goal was to learn as much as possible about this type of accelerator both for the acceleration of relativistic particles such as muons for particle and for the acceleration of non-relativistic particles such as protons for medical, energy and other applications.

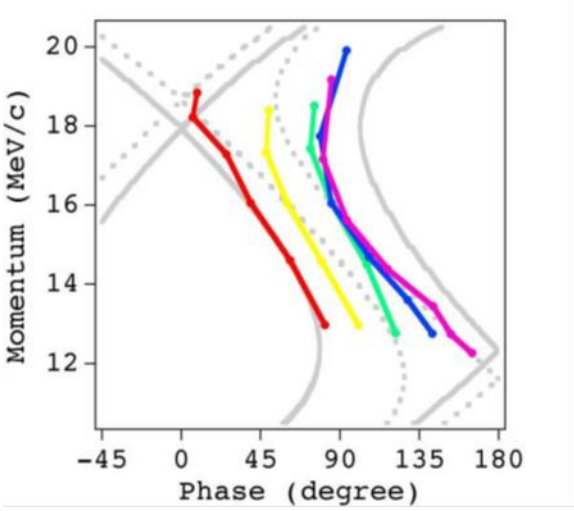


Figure 48: measurement of serpentine acceleration (courtesy STFC)

The second goal has been successfully achieved for relativistic particles. It has been shown that the unique features of serpentine acceleration (Figure 48), a parabolic variation of the time of flight of the beam around the accelerator and multiple integer tune crossings all work. This work has also allowed the testing and development of accelerator tracking codes. For the acceleration of non-relativistic particles, experiments are currently taking place. The successful EMMA proof of principle and the availability of numerical models tested in the field are already allowing machine designs for medical applications to be made. The first was the PAMELA accelerator for providing proton and carbon ion beams for cancer therapy. A detailed design report has been written and published. Further studies aim at reducing its size from 18 m to ~10 m diameter for Computed Tomography, proton and carbon therapy. The design and construction of EMMA has been published in R.Barlow et al, Nucl Instrum Meth A 624 (1) 1-19 (2010) and the results from commissioning in S.Machida et al, Nature Physics 8 243-247 (2012). A further 8 papers are in preparation with the results of the experimental programme and a total of 63 papers have been published in the proceedings of the PAC series of conferences.

Emittance measurement in laser-plasma accelerators

Electron beams produced by laser plasma acceleration have very small size and large divergence. The classical emittance measurement methods used in accelerators are not well suited. To solve the critical requirement of assessing the quality of a beam generated by laser-plasma acceleration, a new method of emittance measurement was proposed and investigated: measure the spectrum and transverse profile of the X-rays emitted by the electrons oscillating in the transverse plasma field. After setting-up the instrument (Figure 49), it was observed that electrons unexpectedly carry some angular momentum, modifying the X-ray properties. The growth of the angular momentum was explained by the fact that the laser pulse creates an asymmetric plasma cavity (because it is itself asymmetric). Electrons which are accelerated in this cavity oscillate with different frequencies along the two transverse directions, inducing an evolution of the electrons' angular momentum during the acceleration. This explanation for the origin of the angular momentum is supported by experimental results and simulations, where the X-ray transverse profiles evolve from elliptical and peaked to square and flat, as the angular momentum increases. Thanks to the good agreement, simulations could be used to correct the experimental results and estimate the emittance using both the spatial and spectral measurements.

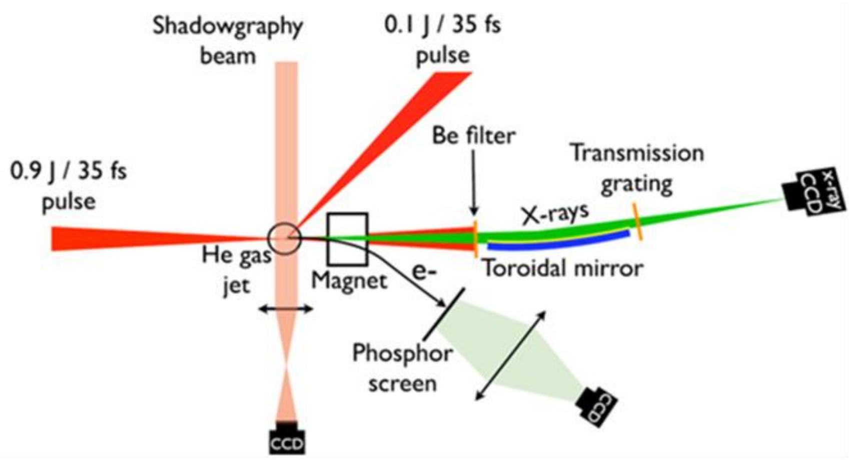


Figure 49: Schematic diagram of the experimental setup.(courtesy CNRS-LOA)

Doing so we found an emittance of 1 π.mm.mrad, consistent with our previous estimates and particle-in-cell simulations. The measurements of the X-ray spectra and divergence were published in Physical Review Letter in December 2011 (Phys. Rev. Lett. 107, 255003). The results regarding the variation of the angular momentum and the estimate of the emittance have been submitted to Physical Review Letter in June 2013.

5 POTENTIAL IMPACTS AND DISSEMINATION AND EXPLOITATION

5.1 STRATEGIC IMPACT

5.1.1 Contribution to policy developments

The EuCARD participants, representing the major European laboratories, research institutes and universities active in the field of accelerator R&D, have quite naturally an impact at several levels, from policy developments to scientific and technological implementations. While EuCARD, via its JRA's has been largely focused on the latter, the large collaborative dimension of EuCARD JRA's and the collaboration with major international partners, such as the US DOE laboratories and KEK in Japan naturally involve policy considerations. The activity of the EuCARD networks has directly impacted policies via the production of major roadmaps. The coordinator, taking due account of the EuCARD negotiation mandate, has given a specific importance to contributions to the development of the ERA. This activity has been facilitated by its status of international (intergovernmental) organization.

5.1.1.1 Definition of strategic European goals

While nuclear physics infrastructures, spallation sources and next generation of synchrotron light sources, all priorities of the ESFRI roadmap, are at an early implementation stage, high-energy physics has been exploiting its main infrastructures (LHC, CNGS, etc.) and needed a European strategy and a roadmap to prepare the after-LHC era. This is specifically the responsibility of the CERN Council via its Strategy Session, acknowledged by the European Strategy Forum on Research Infrastructures. After a consultation process, the CERN Council adopted on 30 May 2013[1] the first update of the European Strategy for Particle Physics initially defined in 2006. EuCARD had several potential impacts on this update process: a roadmap for neutrino physics facilities prepared by a network and submitted to the Strategy Session, pro-active accelerator networks, which proposed and/or analysed upgrades of the LHC or alternative accelerators, including non-conventional ones. Most of the recommendations of the CERN Council Strategy Session,

- Exploit its current world-leading facility for particle physics, the LHC, to its full potential over a period of many years, with a series of planned upgrades;
- Continue to develop novel techniques leading to ambitious future accelerator projects on a global scale;
- Be open to engagement in a range of unique basic physics research projects alongside the LHC;
- Be open to collaboration in particle physics projects beyond the European region;
- Maintain a healthy base in fundamental physics research, with universities and national laboratories contributing to a strong European focus through CERN;
- Continue to invest substantial effort in communication, education and outreach to engage global publics with science.

are in tune with what were key EuCARD objectives.

EuCARD participated in the “Consultation on possible topics for future activities for integrating and opening existing national research infrastructures”, a survey conducted by the EC. It informed the community (board of lab directors and TIARA-PP) and proposed the basis for a coherent answer. Based on the Assessment report of this survey, Accelerator R&D has been selected to be one of the topics on the “List of topics with high potential and with merit for future Horizon 2020 actions for integrating and opening existing national research infrastructures”.

5.1.1.2 European projects

Synergies with other related accelerator projects were developed from Period 2.

Fruitful outcomes of these synergies led to the evolution of the EuCARD Newsletter into a common publication “Accelerating News[2]”, a joined accelerator newsletter combining efforts from EuCARD, TIARA, HiLumi LHC, EUROnu and CRISP. This newsletter features also stories from other European projects, related to accelerator R&D but on different application fields, such as medical fields. The newsletter is taken over by TIARA and EuCARD2, with the objective of finding a sustainable editing support.

The fragmented community of wake-field acceleration (laser and plasma physics) was invited to form, together with the accelerator community, a voluntary network under the umbrella of EuCARD/Accelerator networks. This EuCARD initiative acknowledges the significant progress made in laser plasma acceleration by the laser and plasma communities, and the need to unite efforts with the accelerator community to make a convincing demonstrator satisfying requirements of reproducibility, availability… The network successfully started its activity

[1] http://press.web.cern.ch/press-releases/2013/05/cern-council-updates-european-strategy-particle-physics

[2] http://www.acceleratingnews.eu/

with well attended workshops and the definition of a roadmap. It is now integrated in EuCARD2, and will eventually need an IA of its own to build a demonstrator.

Strong links by cross-participation have been established with TIARA-PP, HiLumi-LHC and finally with ICAN. The EuCARD management and partners contributed to the emergence and work plans of HiLumi-LHC and EuCARD2. Thanks to a long history of collaboration between CERN, KEK and the US DOE, and to the tight links further woven in the EuCARD network topical workshops, the US and KEK play a special role in HiLumi-LHC, the latter being a full partner.

5.1.1.3 European R&D Studies

The EuCARD project (like its predecessor FP6-CARE) had been prepared under the auspices of the European Steering Group for Research and Technical Development on Particle Accelerators (ESGARD). The EC funding was highly leveraged, focused on concrete R&D collaborations between the participants to reach common S&T goals. The joint efforts under EuCARD have maintained a culture of collaboration creating the conditions for a more coherent and effective sharing of the work on very large projects far exceeding the possibilities of any partner. Quantitative indicators of success of this collaborative dimension appear in the large number of beneficiaries (38) and in the evolution of the budget of the project: overall, the full costs of EuCARD exceed by 11% (36 M€) the budget commitments in Annex 1, and the man-power used exceeds by 29% (680 p-m) the estimated person-months at the start of the project, with seven partners above 50%. EuCARD has shown that the high number of partners is very beneficiary for the dynamism of the research and for strengthening the ERA, and that its coordination can be smoothly managed by the coordinator. Due to justified technical requirements, the high risk/high gain high field Nb_3Sn magnet model requires an extension in time with unchanged deliverables. With the momentum provided by EuCARD, the major partners in this task have confirmed their commitment to finalize this key area for the future of accelerators and are negotiating the terms of their collaboration.

A significant number of non-European Institutes or Organizations participated actively to the EuCARD activities, mostly but not only via the networks (USA, Japan, Mexico, etc. mostly funded by their own national agencies). The participation of their world experts has been an invaluable contribution to the European R&D, especially in the most high gain/high risk R&D lines, such as the high field magnets, the crab cavities, the plasma wakefield acceleration,…

The last EuCARD Annual meeting (EuCARD'13) was combined with the EuCARD2 kick-off meeting and with the workshop on the "Visions for the future of Particle Accelerators"[3]. For the latter, experts from all over the world were invited to present prospective thinking for the next 50 years[4] for infrastructures serving HEP, nuclear physics, spallation and light sources. Such a brainstorming had never been done to our knowledge. Its primary goals were to identify synergies, common goals and discuss the merits of potential emerging concepts or technologies to prepare the future R&D programmes.

[3] https://espace.cern.ch/EuCARD/2013/annual-and-KickOff-meeting/Visit/Forms/AllItems.aspx?PageView=Shared

[4] http://home.web.cern.ch/about/updates/2013/06/accelerator-physicists-take-long-view-eucard13

It was quite a natural impact for EuCARD to contribute to the TIARA-PP project, and more specifically to the identification of the key accelerator research areas, one of the important deliverables of TIARA. The EuCARD experience allowed defining in ESGARD the concept for EuCARD2, leaving significantly more resources for networking in a much larger number of domains. The EuCARD2 JRA activities were selected from a bottom-up call for proposals carried out thru the EuCARD community.

The success of collaborations relies significantly on personal relations. EuCARD took special care in tightening links via attractive and efficient community events (meetings, topical workshops, associated to visits,..) rotating thru the partners' facilities to build a team spirit. The continuation with EuCARD2 will further strengthen these links. The activity of TIARA at an institutional level complements the EuCARD/EuCARD2 impact in the field.

5.1.2 Development of world-class infrastructures

Several world-class level accelerators were involved in EuCARD and have drawn a benefit from the EuCARD activities: the upgrade of the LHC, the upgrade of DAΦNE (electron-positron collider), with a potential very large luminosity increase, the upgrade of MICE (Muon ionization and cooling experiment), the implementation or commissioning studies of SIS and FAIR (heavy ion accelerators and project), of EMMA (a world first implementation of non-scaling FFAG principle), as well as many others such as SPS, CNGS, ...

In addition to accelerators, the goal of EuCARD was to improve and strengthen world-class test facilities for investigating the technologies needed for future accelerators. The facilities concerned were mainly the CLIC test facility CTF3, regarded as a key element in deciding the future world accelerator, ATF2, as a test-bed for the ILC and CLIC final focus, the ensemble of SC RF test stations of highest importance for all machines and projects based on superconducting RF acceleration, and aspects of laser-driven plasma wakefield accelerators.

Besides particle and nuclear physics, FLASH, central in EuCARD WP11, stands as a pioneering fourth generation light source (superconducting electron linac) in the VUV and soft X-ray domain. It is the test bed of a unique XFEL project producing high intensity ultra-short X-ray coherent flashes and opening up a whole range of new perspectives for the natural sciences and industry. It will benefit from a new versatile and open RF control system. Altogether, the accelerator infrastructures involved in this project, serve a large community of well over 10,000 physicists from all over the world.

New developments from studies included in EuCARD may have potential relevance for application of accelerators (industry and nuclear medicine). A specialized network was on purpose included in EuCARD2 to follow up on this point and ensure optimal impact.

EuCARD, by establishing win-win bridges between large and small players in accelerator sciences, has open larger the doors for the participation of universities and specialized institutes in the development of major world-class infrastructures. The combination of centralized leading laboratories with smaller but sharp and creative institutions distributed all over Europe appears as a potential model to strengthen the scientific creativity and potential of Europe.

5.1.3 Impact of the scientific and technological results

The EuCARD scientific and technological activities have produced results with important potential impacts on the upgrades of major accelerator infrastructures and on future projects and scientific roadmaps. These potential impacts are described in Part B Tables B2 and following, and the essentials are briefly summarized below.

- The workshops and roadmap for neutrino physics facilities were timely submitted to the European HEP Strategy session; they contributed to a new momentum to this branch of physics (WP3).
- The studies and topical workshop on crab cavities have definitely impacted the LHC luminosity upgrade project, having been adopted as a key component to allow a minimal ratio of peak/average performance (WP4). The performance increase by a factor of ten was inconceivable at the time of the LHC design. Design and fabrication (WP10) demonstrated feasibility of compact cavities.
- An ambitious roadmap for future accelerator facilities, visiting the most advanced concepts and thereby defining key R&D areas for the coming 50 years or more, has the potential to guide the debates on the future of frontier accelerators at a European level (WP4).
- The progress in implementing a high-field Nb_3Sn magnet (a first in Europe) with a high-temperature superconducting YBCO insert (another first) has been very significant and requires two more years of advanced and systematic engineering activities before the harvest. Its expected success will open the door to a new generation of energy-frontier accelerators, including the energy upgrade of the LHC. In a closer future, it will upgrade the FRESCA test station for super-conducting cables, used e.g. as well by ITER (WP7). NMR and MRI could benefit (higher magnetic fields).
- The success of the development of a high-temperature superconducting electrical link will impact on a short timescale the LHC upgrade, allowing efficient remote powering away from radiation areas. This principle, studied in collaboration with industry, may find applications in the energy domain (WP7).
- The studies of new robust materials for beam collimation have pointed to metal-diamond or graphite composites that offer very promising solutions when increasing the energy or power of accelerator beams (WP8). The new TA HiRadMat@SPS (pulsed irradiation) is a key infrastructure to experiment on samples and validate advanced simulations of beam impact on materials (WP5).
- The new LHC and FAIR collimators and cryo-catchers will have on short or medium term direct impact on the machine performance (WP8).
- The progress in the understanding of electrical breakdowns, ultra-precise mechanical assembly, nm stabilization by mechanical and beam-based methods and finally of ultra-precise phasing (20 fs) concur, together with the international CLIC and ILC collaborations, in preparing learned decisions on the choice of the next lepton collider (WP9). Indeed all results obtained are well beyond the state-of-the-art, showing that

quite extreme requirements of linear lepton colliders can, in fact, be satisfied. Impacts in other fields of science and technology are to be expected.

- In the field of superconducting RF, it is expected that the strategy of fabrication and processing of cavities for proton linacs will set a new higher standard for the accelerating gradient. This is of relevance for all proton linacs, e.g. ESS, SPL, accelerator-driven systems. Progress has been made on the delicate process of sputtering thin film of Nb onto a Copper RF cavity. Full validation remains to be done. The conclusions of experts (EuCARD monographs on superconducting RF test stations and technology) indeed show that this concept pioneered for LEP2, with gradients of about 4 MV/m is liable to reach much higher gradients, well in excess of the performance of the bulk Nb technology, which has reached close to its theoretical limit (WP4, WP10). High performance cavities require higher-performance RF couplers to feed them. The R&D on an automatic cleaning machine is a step forward, needing a demonstrator, to significantly decrease the cost and duration of coupler processing for large accelerators.

- In the field of diagnostics and control, FLASH inherits from an upgraded modular LLRF, with the originality that it is based on a commercial telecommunication standard. Already at commissioning, the gain in field stability is significant. This control system is liable to be used by XFEL and could be adapted to ILC. (WP10)

- Innovative concepts were pushed, such as operational crab-waist crossing in DAΦNE, beam diagnostics and commissioning of EMMA, the first non-scaling FFAG demonstrator, and the emittance measurement adapted to highly divergent beams produced by laser-plasma acceleration. In all cases, these activities have brought contributions that have already impacted their domains. (WP10)

5.1.4 Impact on European industry

The impact of EuCARD on European industry follows three channels:

- Direct collaborations: three SME's were beneficiaries participating to two tasks: Columbus Superconductors SpA and Bruker HTS GmbH were involved in the design and fabrication of a novel superconducting electrical link for dc currents, and RHP-Technology GmbH was involved in advanced metal-diamond materials for beam collimation. In both cases, the collaborations went swiftly without IPR issues and the foreground generated during the R&D studies has a potential of use outside the accelerator domain: the superconducting link can find applications for the transport of high intensity dc currents; the extensive characterization of metal-diamond composites and their brazing capabilities significantly extends the catalogue data available. Two of the three companies – Bruker HTS and RHP-Technology- have become beneficiaries in EuCARD2.
- Project expenditures in industry: EuCARD purchased equipment for about 6 M€ (direct cost) from industry. At the end of the project a survey was conducted to gather basic information on business relations between EuCARD partners (concerning purchase of equipment only) that resulted in additional R&D at the company, directly related to EuCARD. As a result of a partial survey at least 10 industrial purchases have triggered R&D at 9 different companies. Amongst the most costly orders were the

LHC 400 MHz SC Crab Cavity Structure, energy spectrometer and the CLIC X-Band NC Crab Cavity Structure.

- Finally, an intermediate situation is found for the fabrication of super-conducting elliptical cavities (two companies involved): their fabrication requires intermediate steps carried out in the research laboratories (TF tests of main components, chemical processing of cavities), before the final assembly in the companies. This approach requires tight collaborations between academics and industry for achievements beyond the state-of-the-art.

5.2 DISSEMINATION AND EXPLOITATION

The WP2-DCO identified the most appropriate dissemination tools and activities for each targeted audiences: the general public, the industry, scientific policy makers and the scientific community at large.

Dissemination results in numbers

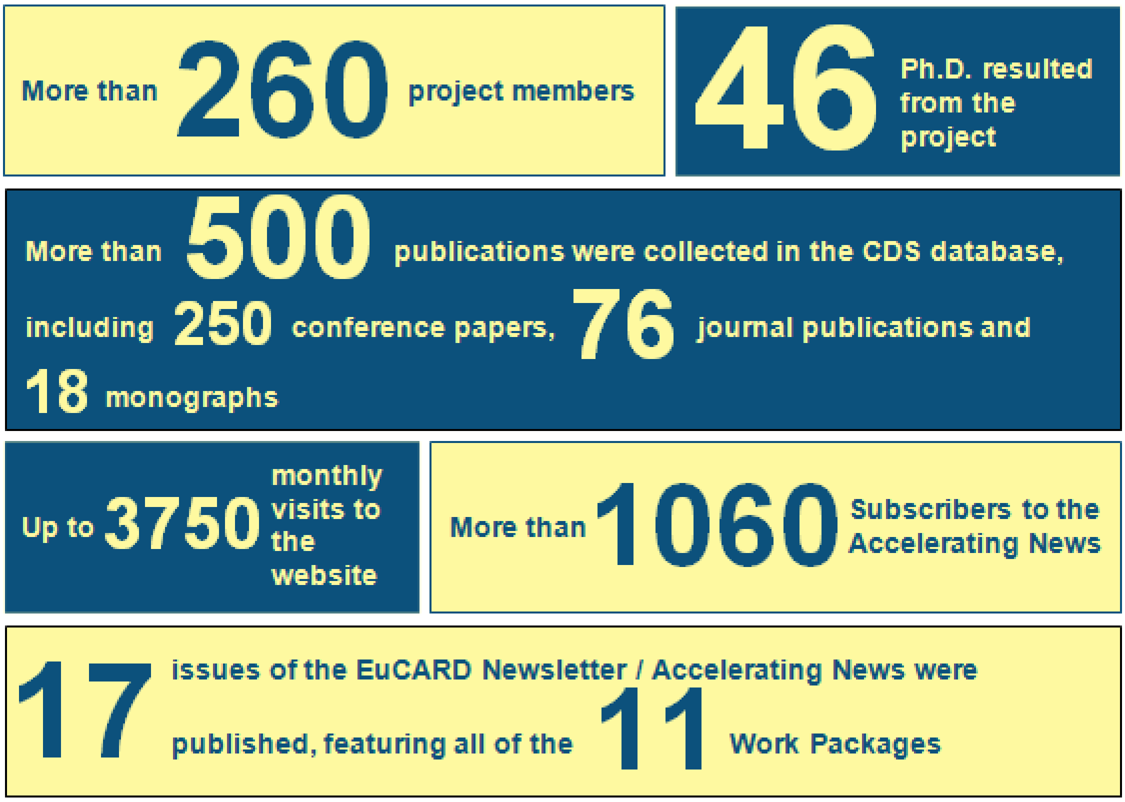


Figure 50 Key results in numbers

5.2.1 Dissemination tools

Website

The EuCARD website was one of the most important communication tools of the project. It was made ready for day 1 and was completely redesigned during P2 and P3 in order to make the web site more user-friendly. Soft colours matching the logo of EuCARD were used, pictures were put on almost every pages and the text was kept short so that the user would not need to scroll down. To reach the widest possible audience, a description of the project was made available online in 15 different languages thanks to translations from project members. This number exceeded the 10 languages of the project partners themselves. The content of the website was enhanced with an outreach section devoted to the general public that provided with definitions about accelerators using simple phrasing. Analysis of web site traffic showed that the number of visitors exceeded the number of EuCARD members by about a factor of 3.

Newsletter

The EuCARD Newsletter was published on a quarterly basis during Period 1 and 2, featuring all work packages: 7 issues were published in P1 and 4 others in P2. It showcased news and results from EuCARD as well as relevant events and links to external articles of interest to the accelerator community. Subscribers rose from initially 200 to 800 people, and the archive http://cern.ch/EuCARD/news/newsletters/archive/ was regularly accessed. As mentioned before, EuCARD took initiative to upgrade the project newsletter in April 2012 to a collaborative newsletter, resulting from synergies between EuCARD and other accelerator projects co-funded by EC FP7. The newly created Accelerating News initially combined efforts of 4 projects: EuCARD, HiLumi LHC, TIARA and EUROnu. When the EUROnu project finished in September 2012, the CRISP project was added to the newsletter. The scope of the Accelerating News was further extended: it covered a larger variety of fields and targeted a wider audience, also in some cases covering accelerator related topics from life sciences. The number of subscribers rose from 800 to 1066, attesting to the success of the new format of the newsletter. In order to further improve the Accelerating News, a survey[5] was conducted online and it received positive answers. The newsletter was also used to advertise the EuCARD monographs, which led to a dramatic increase in orders from all around the world. The Accelerating news will be taken over by TIARA and EuCARD-2.

Flyers and brochures

A **factsheet** for the European Commission**,** presenting the main project objectives and characteristics, was provided in P1 and updated in April 2013 based on the proposal of Intrasoft-intl. Additionally, a new **CERN brochure**, 'Particle Physics, a key driver for innovation', involved contributions from EuCARD members, particularly the Project Coordinator in P2. A EuCARD web page was opened on Wikipedia in 8 different languages as well.

5.2.2 Dissemination activities

Publications

Scientific publications and conferences are another important way to draw the attention of researchers working in accelerator-related fields on the project. As of 4 September 2013, the publications logged in the CERN Documentation System (CDS) database amounted to:

[5] http://www.surveymonkey.com/s/SFJNCJH

Conference papers	*Books*	*Journal publications*	*Academic dissertations*	*Notes & reports*	*Misc. publications*	*Oral presentations*	***Total***
250	18	76	8	50	35	76	513

This large number of publications (around two per EuCARD member on average, or 10 per full-time equivalent) and oral presentations shows the dynamism of the project members. The detailed table of the dissemination activities can be found in the Annex. Open access publications and journals were continuously favoured, and WP leaders were encouraged to open WP owned web sites with their key results.

Conferences and events

EuCARD information and Accelerator Technology sessions were organized by the DCO coordinator during professional conferences in Poland. The 6 WILGA Symposia also played a special role in dissemination of accelerator science and technology among young researchers in this and neighbouring countries. WILGA Special Sessions on EuCARD and Accelerator Science and Technology, a continuation from CARE Project, usually last one day with around 20 presentations related to experiments associated with LHC. They contain around 100 papers. All WILGA Symposium Proceeding volumes have covers and introduction with EuCARD logos and references.

EuCARD members were involved in didactic and teaching activities targeting young students or researchers from all around the world:

- Within the framework of CERN Local Communications, the Project Coordinator conducted a school visit to explain to young students HEP and accelerators in a talk: ‘A day in the life of a scientist’. He presented as well an open evening seminar on accelerators in everyday life at the Geneva Faculty of Physics and a lecture on trends in accelerator R&D at the Indian Institute of Technology, Bombay.
- The deputy WP8 coordinator opened the **university for children in Darmstadt** in 2011 with a talk "Accelerators, racetracks for atoms", well received in the media.
- Within the Polish EuCARD partners, a number of outreach initiatives were organised to reach Polish schoolchildren, e.g. NCBJ-organised video conferences
- Lecture by Pr. Romaniuk on CARE, TIARA and EuCARD projects during the advanced University Course, for Ph.D. students at Faculty of E&IT WUT on “Distributed Measurement and Control Systems for HEP Experiemnts, Accelerator Technology, FELs and Atronomical Experiments”
- Workshops by Dr. M. Linczuk with students at Faculty of E&IT WUT specializing in Electronics for HEP experiments on European HEP, accelerator, and FEL technology related projects: CARE, EuCARD, TIARA, E-XFEL, EuroNu.
- HEP Experiments and Accelerator Technology Weekly Seminars with Ph.D. students at Faculty of E&IT WUT (R.Romaniuk, K.Pozniak, W.Zabolotny). Extensive information about EuCARD, TIARA and EXFEL projects, with review of periodic advances and continuation perspectives to EuCARD-2. Encouragement for Ph.D. students to get involved via their work laboratories in CERN, PSI, DESY, Bessy, INFN, etc.

- Presentations of the achievements of modern accelerator technology at booths of WUT and NCBJ at the Annual Science Festival in Warsaw and Museums' Night (May 2012, May 2013), targeting a wide public.

EuCARD members also promoted the project at scientific conferences and outreach events, targeting the scientific community at large:

- The AccNet network contributed to numerous external workshops e.g. 'Outlook for PWA experiments' at KET strategy workshop.
- The WP4 coordinator presented to Japanese audiences "Large Hadron Collider - Status & Future" at KEK, Hiroshima U. and Kyoto U. on behalf of AccNet.
- EuCARD WP11 activities were represented at the EC Innovation Convention, December 2011 at a stand entitled "Novel Accelerators for our Future", based around the novel accelerator EMMA and its real world applications.
- Within the UK EuCARD partners, a number of accelerator outreach resources were developed such as Suzie Sheehy's "Accelerated Dreams" public talk.
- Periodic reports on EuCARD and TIARA work developments were presented by the DCO coordinator during the annual autumn meetings of the Polish Academy of Sciences, Department of Technical Sciences and Committee of Electronics and Telecommunications (October 2008, 2009, 2010, 2012, scheduled for October 2013).
- Information about the involvement of national research communities (physicists and engineers) in European Infrastructural Projects, including HEP, FEL, Fusion: EuCARD, TIARA and EXFEL, ITER, was spread during IEEE events (e.g. September 2012, 150 people) and SEP events (e.g. November 2012, 50 people from the industry and academia decision makers).
- The DCO coordinator presented information about European projects, including EuCARD, to Professional Learned Associations (Polish Physical Society and Photonics Society of Poland) during their annual meetings (December 2008, 2009, 2010, 2011, 2012, scheduled for December 2013).
- The project and Transnational Access opportunities were promoted with leaflets during the ESOF event (Euroscience Open Forum 2012, Dublin, 11-15th July) by the Eurorisnet + Network.

Finally, the Project Coordinator and administrative manager attended several meetings with EC officials to discuss project related accelerator R&D topics, strategy in Horizon2020. The Coordinator also attended and represented the project at the International Conference on Research Infrastructure (ICRI 2012) conference. He also contributed to the "Consultation on possible topics for future activities for integrating and opening existing national research infrastructures", a survey issued by the EC. The assessment of this survey[6] (published in February 2013) placed the topic of Accelerator R&D in a privileged position.

[6] http://ec.europa.eu/research/infrastructures/pdf/final-report-CEI-2013.pdf

Monographs

The EuCARD monograph series, a scientific editorial series of peer-reviewed monographs, was started a few months before the beginning of the EuCARD. Combining a kind of strictly research publisher with a transient project was a completely new initiative which turned out to be a big success. 18 booklets (all peer-reviewed) were published in total, some of them taken from the 46 PhDs theses resulting from the project: 8 volumes in P1, 3 volumes in P2 and 7 volumes in P3. They were made openly available via the CDS database and the publisher website as well as distributed to the partner libraries worldwide. DCO coordinator distributed approximately 250 copies of the monographs, separately from the number of copies managed at CERN. The series will be continued within EuCARD-2. The editor sent a few copies of full sets of these monographs to science and technology financial decision makers and received a very positive answer.

6 USE AND DISSEMINATION OF FOREGROUND

6.1 SECTION A: DISSEMINATION MEASURES (PUBLIC)

6.1.1 List of scientific (peer reviewed) publications

Table A1: List of scientific (peer reviewed) publications

NO	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[7] (if available)	Is open access[8] provided to this publication?
1	Development of accelerator technology in Poland, Impact of European CARE and EuCARD projects	Romaniuk, R	International Journal of Electronics and Telecommunications	Volume 54, No 3	Polish Academy of Science	Poland	2008	pp.239-251	CDS link	Yes
2	EuCARD and CARE - development of accelerator technology in Poland	Romaniuk, R	Elektronika	Volume 49, No 10	Association of Polish Electrical Engineers	Poland	2008	pp.12-17	CDS link	Yes

[7] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[8] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

3	Development of laser technology in Poland	Gajda, J et al	International Journal of Electronics and Telecommunications	Volume 55, No 3	Polish Academy of Science	Poland	2009	pp.135-144	CDS link	Yes
4	Photonics and Web Engineering: WILGA 2009	Romaniuk, R	International Journal of Electronics and Telecommunications	Volume 55, No 3	Polish Academy of Science	Poland	2009	pp.405-418	CDS link	Yes
5	Realization of CARE and EuCARD Projects in ISE-WUT, Accelerator and FEL Research, Development and Applications in Europe	Romaniuk, R	International Journal of Electronics and Telecommunications	Volume 55, No 3	Polish Academy of Science	Poland	2009	pp. 419–431	CDS link	yes
6	Free Electron Laser in Poland	Romaniuk, R	Photonics Letters of Poland	Volume 1, No 3	Photonics Society of Poland	Poland	2009	pp.103-105	Link	yes
7	Large Hadron Collider at CERN: Beams generating high-energy-density matter	Tahir, N A et al	Physical Review E	Volume 79, No 4	American Physical Society	USA	Apr 2009	n/a	Link	yes
8	ISE WUT in CARE and EuCARD Projects	Romaniuk, R	Elektronika	Volume 50, No 8	Association of Polish Electrical Engineers	Poland	Aug 2009	pp.157-162	CDS link	yes
9	Test stand with copper TESLA structure	Glowka, J et al	Elektronika	Volume 50, No 8	Association of Polish Electrical Engineers	Poland	Aug 2009	pp.176-182	CDS link	yes
10	Object oriented programming environment for reconfigurable applications implemented in FPGA chips	Drabik, P et al	Elektronika	Volume 50, No 8	Association of Polish Electrical Engineers	Poland	Aug 2009	pp.183-187	CDS link	yes
11	Conditioning of complex envelope signal from FLASH accelerator cavities	Stanislawski, T et al	Elektronika	Volume 50, No 8	Association of Polish Electrical Engineers	Poland	Aug 2009	pp.187-192	CDS link	yes
12	Indirect method of measuring	Pozniak, K	Elektronika	Volume 50, No	Association of	Poland	Aug	pp.193-	CDS link	yes

	changes of EM field in RF-gun cavity for XFEL accelerator	et al		8	Polish Electrical Engineers		2009	199		
13	A project of universal computing platform - cluster of floating point DSP processors	Dymanowsk, L et al	Elektronika	Volume 50, No 8	Association of Polish Electrical Engineers	Poland	Aug 2009	pp.206-208	CDS link	yes
14	Electronic system of the RPC Muon Trigger in CMS experiment at LHC accelerator	Bialkowski, H et al	Elektronika	Volume 50, No 8	Association of Polish Electrical Engineers	Poland	Aug 2009	pp.240-256	CDS link	yes
15	New editorial series on Accelerator Science and Technology by EuCARD Project	Romaniuk, R	Elektronika	Volume 50, No 8	Association of Polish Electrical Engineers	Poland	Aug 2009	pp.306-307	CDS link	Yes
16	Generation of warm dense matter and strongly coupled plasmas using the High Radiation on Materials facility at the CERN Super Proton Synchrotron	Tahir, N A et al	Physics of Plasmas	Volume 16, No 8	American Institute of Physics	USA	Aug 2009	n/a	Link	yes
17	Simulations of Full Impact of the LHC Beam With a Solid Graphite Target	Tahir, N A et al	Laser and Particle Beams	Volume 27, No 3	Cambridge University Press	UK	Sept 2009	pp. 475-483	Link	yes
18	Wake field suppression in high gradient linacs for lepton linear colliders	Jones, R	Physical Review Special Topics - Accelerators and Beams	Volume 12, No 10	American Physical Society	USA	Oct 2009	n/a	Link	yes
19	Interfaces and Communication Protocols in ATCA-Based LLRF Control Systems	Makowski, D et al	IEEE Transactions on Nuclear Science	Volume 56, No 5	IEEE Nuclear and Plasma Sciences Society	USA	Oct 2009	pp.2814-2820	Link	yes
20	Beam dynamics aspects of crab cavities in the CERN Large Hadron Collider	Sun, Y P et al	Physical Review Special Topics - Accelerators and Beams	Volume 12, No 10	American Physical Society	USA	Oct 2009	n/a	Link	yes

21	The design and commissioning of the MICE upstream time-of-flight system	Bertoni, R et al	Nuclear Instruments and Methods in Physics Research Section A	Volume 615, No 1	Elsevier	Netherlands	Mar 2010	pp.14-26	Link	yes
22	Crab dispersion and its impact on the CERN Large Hadron Collider collimation	Sun, Y P et al	Physical Review Special Topics - Accelerators and Beams	Volume 13, No 3	American Physical Society	USA	Mar 2010	n/a	Link	yes
23	Cs2Te normal conducting photocathodes in the superconducting rf gun	Xiang, R et al	Physical Review Special Topics - Accelerators and Beams	Volume 13, No 4	American Physical Society	USA	Apr 2010	n/a	Link	yes
24	Advanced Electronics and Photonics for High Energy Physics Experiments	Linczuk, M et al	International Journal of Electronics and Telecommunications	Volume 56, No 2	Polish Academy of Science	Poland	Apr 2010	pp.100-101	CDS link	yes
25	Present status and first results of the final focus beam line at the KEK Accelerator Test Facility	Bambade, P et al	Physical Review Special Topics - Accelerators and Beams	Volume 13, No 4	American Physical Society	USA	Apr 2010	n/a	Link	yes
26	Mechanism of surface modification in the plasma-surface interaction in electrical arcs	Timko, H et al	Physical review B	Volume 81, No 18	American Physical Society	USA	May 2010	n/a	Link	yes
27	Magnetic Design and Code Benchmarking of the SMC (Short Model Coil) Dipole Magnet	Manil, P et al	IEEE Transactions on Applied Superconductivity	Volume 20, No 3	IEEE Council on Superconductivity	USA	June 2010	pp.184-187	Link	yes
28	Mechanical Design of the SMC (Short Model Coil)	Manil, P et al	IEEE Transactions	Volume 20, No 3	IEEE Council on Superconductivity	USA	June 2010	pp. 204-	Link	yes

	Dipole Magnet		on Applied Superconductivity					207		
29	Seismic response of linear accelerators	Collette, C et al	Physical Review Special Topics - Accelerators and Beams	Volume 13, No 7	American Physical Society	USA	July 2010	n/a	Link	yes
30	Electronics and telecommunications in Poland - issues and perspectives	Modelski, J et al	Electronics and Telecommunications	Volume 1, No 3	Polish Academy of Science	Poland	Sept 2010	pp. 1-34	CDS link	yes
31	Active quadrupole stabilization for future linear particle colliders	Collette, C et al	Nuclear Instruments and Methods in Physics Research Section A	Volume 621, No1-3	Elsevier	Netherlands	Sept 2010	pp.71-78	Link	yes
32	EuCARD 2010 Accelerator Technology in Europe	Romaniuk, R	International Journal of Electronics and Telecommunications	Volume 56, No 4	Polish Academy of Science	Poland	Dec 2010	pp. 485-488	Link	yes
33	Advanced Photonic and Electronic Systems WILGA 2010	Romaniuk, R	International Journal of Electronics and Telecommunications	Volume 56, No 4	Polish Academy of Science	Poland	Dec 2010	pp. 479-484	Link	yes
34	Modelling of synchronous data streams processing in the RPC Muon Tribgger system of the CMS experiment	Pozniak, K T	International Journal of Electronics and Telecommunications	Volume 56, No 4	Polish Academy of Science	Poland	Dec 2010	pp. 489-502	Link	yes

35	Characterization of superconducting nanometric multilayer samples for SRF applications: first evidence of magnetic screening effect	Antoine, C Z et al	Physical Review Special Topics - Accelerators and Beams	Volume 13 No 12	American Physical Society	USA	Dec 2010	n/a	Link	yes
36	Accelerator infrastructure in Europe - EuCARD 2011	Romaniuk, R	Elektronika	Volume 52, No 8	Association of Polish Electrical Engineers	Poland	2011	pp.117-120	CDS link	yes
37	Shock loads induced on metal structures by LHC proton beams: modelling of thermo-mechanical effects	Peroni, L et al	Applied Mechanics and Materials	Volume 82	Trans Tech Publications	Switzerland	2011	pp 338-343	CDS link	yes
38	Overview on superconducting photoinjectors	Arnold, A et al	Physical Review Special Topics - Accelerators and Beams	Volume 14 No 2	American Physical Society	USA	Feb 2011	n/a	Link	yes
39	Temperature Stability of Coaxial Cables	Czuba, K et al	Acta Physica Polonica A	Volume 119, No 4	Polish Academy of Science	Poland	Apr 2011	pp. 333-337	Link	yes
40	The Large Hadron Collider and the Super Proton Synchrotron at CERN as Tools to Generate Warm Dense Matter and Non–Ideal Plasmas	Tahir, N A et al	Contributions to Plasma Physics	Volume 51, No 4	Wiley	Germany	May 2011	pp.299-308	Link	yes
41	Nano-motion control of heavy quadrupoles for future particle colliders: An experimental validation	Collette, C et al	Nuclear Instruments and Methods in Physics Research Section A	Volume 643, No 1	Elsevier	Netherlands	July 2011	pp.95-101	Link	yes
42	Development of Optical Fiber Technology in Poland	Dorosz, J et al	International Journal of Electronics and Telecommunications	Volume 57, No 2	Polish Academy of Science	Poland	July 2011	pp.191-197	Link	yes

43	Accelerator Infrastructure in Europe EuCARD 2011	Romaniuk, R	International Journal of Electronics and Telecommunications	Volume 57, No 3	Polish Academy of Science	Poland	Sept 2011	pp.413-419	Link	yes
44	Photonics and Web Engineering	Romaniuk, R	International Journal of Electronics and Telecommunications	Volume 57, No 3	Polish Academy of Science	Poland	Sept 2011	pp.421-428	Link	yes
45	Instrumental Developments for In-situ Breakdown Experiments inside a Scanning Electron Microscope	Muranaka, T et al	Nuclear Instruments and Methods in Physics Research Section A	Volume 657, No 1	Elsevier	Netherlands	Nov 2011	pp.122-125	Link	yes
46	Response of colliding beam-beam system to harmonic excitation due to crab-cavity rf phase modulation	Ohmi, K et al	Physical Review Special Topics - Accelerators and Beams	Volume 14, No 11	American Physical Society	USA	Nov 2011	n/a	Link	yes
47	Controlled Betatron X-Ray Radiation from Tunable Optically Injected Electrons	Corde, S et al	Physical Review Letters	Volume 107, No25	American Physical Society	USA	Dec 2011	n/a	Link	yes
48	WILGA Photonics and Web Engineering; EuCARD Sessions on HEP and Accelerator Technology	Romaniuk, R	SPIE-IEEE WILGA Symposium on Photonics and Web Engineering	n/a	n/a	Poland	Jan 2012	n/a	CDS link	yes
49	Effects induced by LHC high energy beam in copper structures	Peroni, L et al	Journal of Nuclear Materials	Volume 420, No 1-3	Elsevier	Netherlands	Jan 2012	pp.463-472	Link	yes
50	Thermal conductivity and Kapitza resistance of cyanate ester epoxy mix and	Pietrowicz, S et al	Cryogenics	Volume 52, No2-3	Elsevier	Netherlands	Feb 2012	pp.100-104	Link	yes

	tri-functional epoxy electrical insulations at superfluid helium temperature									
51	Parameters identification in strain-rate and thermal sensitive visco-plastic material model for an alumina dispersion strengthened copper	M. Scapin et al	International Journal of Impact Engineering	Volume 40-41	Elsevier	Netherlands	Feb-Mar 2012	pp.58-67	Link	yes
52	Accelerators for Society - TIARA 2012 Test Infrastructure and Accelerator Research Area (in Polish)	Romaniuk, R	Elektronika	Volume 54, No 3	Association of Polish Electrical Engineers	Poland	Mar 2012	pp.108-112	CDS link	yes
53	Astronomy and Space Technologies, WILGA 2012; EuCARD Sessions	Romaniuk, R	SPIE-IEEE WILGA Symposium on Photonics and Web Engineering	n/a	n/a	Poland	May 2012	n/a	CDS link	yes
54	Accelerator Technology and High Energy Physic Experiments, WILGA 2012; EuCARD Sessions	Romaniuk, R	SPIE-IEEE WILGA Symposium on Photonics and Web Engineering	n/a	n/a	Poland	May 2012	n/a	CDS link	yes
55	Photon Physics and Plasma Research, WILGA 2012; EuCARD Sessions	Romaniuk, R	SPIE-IEEE WILGA Symposium on Photonics and Web Engineering	n/a	n/a	Poland	May 2012	n/a	CDS link	yes
56	Simulations of electron-cloud heat load for the cold arcs of the CERN Large Hadron Collider and its high-luminosity upgrade scenarios	Maury Cuna, H et al	Physical Review Special Topics - Accelerators and Beams	Volume 15, No 5	American Physical Society	USA	May 2012	n/a	Link	yes
57	Impact of high energy high	Tahir, N A et	Physical	Volume 15, No	American Physical	USA	May	n/a	Link	yes

	intensity proton beams on targets: Case studies for Super Proton Synchrotron and Large Hadron Collider	al	Review Special Topics - Accelerators and Beams	5	Society		2012			
58	Design and Manufacture of a Main Beam Quadrupole Model for CLIC	Vorozhtsov, A et al	IEEE Transactions on Applied Superconductivity	Volume 22, No 3	IEEE Council on Superconductivity	USA	June 2012	n/a	Link	yes
59	Design and Manufacture of a Hybrid Final Focus Quadrupole Model for CLIC	Vorozhtsov, A et al	IEEE Transactions on Applied Superconductivity	Volume 22, No 3	IEEE Council on Superconductivity	USA	June 2012	n/a	Link	yes
60	A study of beam position diagnostics using beam-excited dipole modes in third harmonic superconducting accelerating cavities at a free-electron laser	Zhang, P et al	Review of scientific instruments	Volume 83, No 8	American Institute of Physics	USA	Aug 2012	n/a	Link	yes
61	Resolution study of higher-order-mode-based beam position diagnostics using custom-built electronics in strongly coupled 3.9 GHz multi-cavity accelerating module	Zhang, P et al	Journal of Instrumentation	Volume 7, No 11	IOP Publishing	UK	Nov 2012	n/a	Link	yes
62	Statistical methods for transverse beam position diagnostics with higher order modes in third harmonic 3.9 GHz superconducting accelerating cavities at FLASH	Zhang, P et al	Nuclear Instruments and Methods in Physics Research Section A	November 2012	Elsevier	Netherlands	Nov 2012	n/a	Link	yes
63	New Approach to Resonance Crossing	Franchetti, G et al	Physical Review Letters	Volume 109, No23	American Physical Society	USA	Dec 2012	n/a	Link	yes
64	Advanced Electronic Systems for HEP	Romaniuk, R	Elektronika	Volume 55, No 3	Association of Polish Electrical	Poland	Mar 2013	pp.99-122	CDS link	yes

	Experiments, Astroparticle Physics, Accelerator Technology, FELs and Fusion; 2013 WILGA January Symposium				Engineers					
65	European XFEL	Romaniuk, R	Elektronika	Volume 55, No 4	Association of Polish Electrical Engineers	Poland	Apr 2013	pp.149-154	CDS link	yes
66	LCLS Laser	Romaniuk, R	Elektronika	Volume 55, No 5	Association of Polish Electrical Engineers	Poland	May 2013	pp.66-69	CDS link	yes
67	Fusion - 2050 perspective	Romaniuk, R	Elektronika	Volume 55, No 6	Association of Polish Electrical Engineers	Poland	June 2013	p.73	CDS link	yes
68	Prospects of warm dense matter research at HiRadMat facility at CERN using 440 MeV SPS proton beam	Tahir, N A et al	High Energy Density Physics	Volume 9, No 2	Elsevier	Netherlands	June 2013	pp.269-276	Link	yes
69	An experiment to test advanced materials impacted by intense proton pulses at CERN HiRadMat facility	Bertarelli, A et al	Nuclear Instruments and Methods in Physics Research Section B	Volume 308, Aug 2013	Elsevier	Netherlands	Aug 2013	pp. 88-99	Link	yes
70	First electron-cloud studies at the Large Hadron Collider	Dominguez, O et al	Physical Review Special Topics - Accelerators and Beams	Volume 16, No 1	American Physical Society	USA	Jan 2013	n/a	Link	yes

6.1.2 Dissemination activities

Brief summary + web link of table

6.2 SECTION B: EXPLOITABLE FOREGROUND

6.2.1 List of applications for patents

Table B1: List of applications for patents, trademarks, registered designs, etc.

Type of IP Rights: Patents,	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patents	EP1729149B1	Solid state neutron detector system	Deutsches Elektronen-Synchrotron DESY Notkestrasse 85 22603 Hamburg / DE Technical University of Lodz Department of Microelectronics and Computer Science Al. Politechniki 11 90-924 Lodz / PL
Patents	DE102009028182B3 24.02.2011	Hochfrequenz-Fotoelektronenquelle mit supraleitendem Hohlraumresonatorsystem stabilisierter Eigenfrequenz	Forschungszentrum Dresden - Rossendorf e.V., 01328 Dresden, DE
Patents	DE 102009046463 A1 - 4.8.2011	Koaxialer schlitzgekopplter Resonatordiplexer	Helmholtz-Zentrum Dresden - Rossendorf e.V., 01328
Patents	n/a	Metodo per depositare film superconduttivi di Niobio e composti di niovio in cavità acceleratrici a quarto donda in unica soluzione tramite magnetron sputtering e sistema utilizzante tale metodo	Istituto Nazionale di Fisica Nucleare
Patents	SHOCK 2010611610	Computer program for numerical calculations of shock waves in irradiated materials	National Research Centre Kurchatov Institute

6.2.2 Exploitable foreground

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Owner & Other Beneficiary(s) involved
EUP	1.1 Consolidation of sustainable European collaborations in the field of frontier accelerators	No	European networking	Scientific policies and sc. community	Now	EuCARD2, TIARA, HiLumi-LHC, ESGARD + all EuCARD beneficiaries
EUP	1.2 International collaborations in the field of frontier accelerators	No	International networking	Scientific policies and community	Now	HiLumi-LHC, CERN, USLARP, KEK/Japan
EUP	1.3 Novel link between accelerator and plasma wake field acceleration	No	Inter-disciplinary networking	Scientific policies and community	Now	EuCARD, EuCARD2, plasma wake-field community, ICAN
EUP	1.4 Brochure on “Particle Physics, a key driver for innovation”	No	brochure	Scientific policies	Now	Scientific and political communities, TIARA
GAK	2.1 Accelerating news	No	Newsletter on accelerators	Scientific community	Now	EuCARD, TIARA, EuCARD2, accelerator community
GAK	2.2 Monographs in accelerator sciences	No	Book series	Scientific community	Now	EuCARD, EuCARD2, accelerator community
EXS TD	2.3 Publication portal and database	No	Web/CDS tool Open publications	publications	Now	EuCARD, AIDA, EuCARD2, HiLumi-LHC,…

[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

EXIN V	2.4 Outreach material	No	Web product	Grand public	Now	EuCARD, EuCARD2
GAK	2.6 Conference series for young researchers (WILGA)	No	Conference/workshop	Scientific community	Now	CARE, EuCARD, EuCARD2
EUP	3.1 Roadmap for neutrino infrastructures	No	roadmap	Scientific policies	Medium & Long	EuCARD, LAGUNA-LBNO, EUROnu, IDS-NF, CENF, ESS neutrinos,…
GAK	4.1 Active collaboration on compact crab cavities EU-US-JP	No	Feasibility assessed	Colliders, LHC	M	CERN, US, JP
EUP	4.2 Extended collaborations	No	New collaboration members : Mexico, ESA,…	Accelerators, electron cloud mitigation	N	
GAK	4.3 Roadmap for future frontier accelerators: TLEP, SAPPHIRE, HE-LHC, VHE-LHC,…	No	roadmap	EU HEP & NP	M,L	CERN, FAIR/GSI, …
EUP	4.4 Active collaboration on novel acceleration methods	No	New cross-linked community	Accelerators: frontier and application, including medical.	S,M,L	CERN, DESY, ParisTech
EXS TD	7.1 Certification of the radiation resistance of coil insulation material	No	Report of results	High radiation environment: accelerators, reactors	S	PWR

GAK	7.2 Development of a Nb_3Sn accelerator magnet	No	A mechanical model, the Nb_3Sn cable, the coil assembly and reaction, on the road to demonstrate practical feasibility and performance	Accelerators, with potential spin-off to advance application including cryogenics	M	CERN, CEA
GAK	7.3 Development of a high-temperature super-conducting insert magnet	No	A model magnet, on the road to demonstrate practical feasibility and performance	Colliders as first goal. Potential applications in many fields of science and technology	M	CEA, CNRS
GAK	7.4 Development of a high temperature superconducting electrical link	No	A multi-conductor dc link for high currents and low voltage	Accelerators, and all infrastructures where the powering shall be remote for safety or maintenance reasons	S	CERN
GAK	7.5 Development of a Nb_3Sn undulator	No	The assessment of a failure to implement this technology and of the necessary steps for a successful other attempt	Colliders and 5th generation light sources	S,M	STFC

GAK	8.1 Study of the robustness of new metal-diamond materials	No	report	High-energy and high power accelerators for research and applications	M	ARC, CERN, GSI, EPFL, RRC KI, POLITO
GAK	8.2 Integrate beam position measurement inside moving collimators	No	Smart collimators	accelerators	N	CERN
GAK	8.3 Design and build the first “cryocatcher” for machine protection in all cryogenic accelerators	No	cryocatcher	Cryogenic accelerators	N	GSI
EUP	8.4 Creation of a new multidisciplinary collaboration	No	Collaborative research	accelerators	S,M	Accelerator and material communities, industry
GAK	9.1 Electrical breakdown model	No	Software suite	Very high gradient RF cavities and components	N	UH
GAK	9.2 Two-beam acceleration RF technologies	No	RF couplers, thermal models, high precision engineering and integration	CLIC accelerator	L	CERN
GAK	9.3 nm-level mechanical stabilization	No	Nm-level active stabilization set-ups	Linear colliders	S	CERN, CNRS,…
GAK	9.4 Ultra-precise beam monitoring	No	Diagnostics equipment, experience and procedures	Linear colliders	M	RHUL

GAK	9.5 20 fs scale synchronization	No	Fast opto-electronics devices	Linear colliders, FELs	S,M,L	CERN, INFN
GAK	10.1 Design, fabrication and tests of high gradient RF cavities for proton linacs	No	Design, fabrication and processing process	RF systems for proton linacs: research and applications (energy)	S	CEA, CNRS
GAK	10.2 Design, fabrication and tests of crab cavities and associated LLRF	No	Fabrication process	Colliders at the energy frontier	M	ULANC
GAK	10.3 High accuracy sputtering of RF cavities	No	Fabrication process; patent to be applied for	RF cavities for accelerators	S,M	INFN
GAK	10.4 μTCA based LLRF	No	LLRF modules; patent application deposited	FEL's, LC's	N,S	DESY
GAK	10.5 Industrial strategy for RF coupler preparation	No	Design of the automatic processing machine	FEL's and linear colliders	S,M	CNRS
GAK	11.1 New DAFNE IR design	No	DAFNE upgrade	Basic physics	N	INFN
GAK	11.2 Study of crab waist crossing for LHC	No	study	Frontier colliders	L	CERN
GAK	11.3 Support to EMMA instrumentation and commissioning	No	Instrument line	Accelerator R&D	N	STFC
GAK	11.4 Emittance monitor for laser driven plasma wake field accelerator	No	Instrument and study	Plasma wake field accelerators	M,L	CNRS

Globally, the EuCARD project has produced significant S/T foreground in the key areas of accelerator R&D and in specialized areas selected for originality and higher gain/risk potential. With the exception of five patents, the results are open to public use. Further research is in most cases necessary, as the R&D time constants in the key areas of accelerator R&D are in decades. A special effort has been invested in networking the accelerator community and linking it to other synergetic communities with the goal of cross-fertilization and sustainability of the efforts, in an answer to the EuCARD reviewers corresponding to the needs of the accelerator community. In the following table, we summarize for a selection of major foreground topics, relevant information under the headings requested by the Commission. This table and Table B2 are indexed by a foreground number [“WP#.#”].

#	*Its purpose*	*How the foreground might be exploited, when and by whom*	*IPR exploitable measures taken or intended*	*Further research necessary, if any*	*Potential/expected impact (quantify where possible)*
1.1	Consolidate and expand the collaboration initiated by CARE and create new ones, with the objective of sustainable collaboration throughout EU	The momentum acquired is transferred to EuCARD2 directly and via ESGARD; ESGARD, TIARA and the accelerator lab directors to exploit these collaborations	open	An integration will require decades and a continuous effort from ESGARD/TIARA and the lab directors	A coherent European accelerator community operating a “distributed” laboratory, including CERN, the national labs, universities and specialized institutes
1.2	Extend informal or adhoc international collaborations into a more sustainable effort	Already exploited by FP7 HiLumi-LHC	open	At an institutional level, coherence between EC, US and Japanese collaborative instruments to be developed	Given the technical and financial challenges of frontier accelerators, efficient international collaborations are required
1.3	Create a strong link between two formerly separate disciplines and communities: accelerators, and plasma wake field acceleration	Already exploited in EuCARD2	-	Eventually a separate IA for this topic	Transition from proof of acceleration to accelerators. A success would produce a quantum jump in accelerator technology, both for research instruments and applications,

					e.g. medical.
1.4	Publicize the strong technological impact of basic research	Distributed to policy makers, to be exploited by them in support of basic science	-	Already further refined by TIARA; needs regular updates	Make it clear for the policy makers and the public that basic research relies on technologies beyond the state-of-the-art, with very significant spin-off to society.
2.1	Create a common information channel for the accelerator community, consolidate the synergies between EuCARD and other related accelerator projects	The information disseminated by the Accelerating News is exploited by its readers, members of the accelerator community	Open with proper referencing	To further expand the scope, apply for ISSN number to raise impact factor.	Strengthen the synergies between accelerator projects, consolidate the accelerator community by creating a common reading platform
2.2	Feature and disseminate achievements from EuCARD in a new initiative	Exploited by EuCARD members. A few copies were sent to decision makers within the accelerator community	open	The monograph series will be continued under EuCARD-2 with new topics	Stress the achievements of EuCARD to policy makers, with possible infrastructural consequences in the future
2.3	To collect and archive the project related contractual reports and additional technical reports, as well as the dissemination materials	The documented know-how will be taken over by EuCARD-2 and will be further available for other accelerator projects.	open	-	Know-how to be taken over
2.4	To give an introduction to a layman/young people on accelerators and related technologies, to show how public funding is spent for the benefit of the EU community	Public	Open	-	Public awareness on how accelerators work and what they can do for the common purpose
2.5	To play a special role in dissemination of accelerator science and technology among young researchers on	Young researchers	open	To further reach out to other Easter European countries.	A platform for young researchers to discuss and learn about each other's' works. Over 100 papers

	Polish national level. Special sessions on EuCARD and Accelerator Science and Technology feature presentations related to experiments associated with LHC, accelerator components like high field magnets, precision magnets, fast magnets, etc				documenting the conference presentations.
3.1	The physics of massive neutrinos is one of the major unresolved issues in HEP today, In contrast, the neutrino community is relatively less concentrated and organized than the High energy frontier (LHC, ILC) communities, while in need of major infrastructures. A roadmap meeting the adhesion of a large part of the community is thus of prime importance	It was submitted as an input to the HEP EU Strategy Upgrade in 2012, and is exploited, among other documents, by the CERN management.	open	Continuous research on ways and means to reduce the costs and effectively stage the infrastructures and on a world-wide organization and quality evaluation is a requirement for this branch of HEP.	This foreground, other contributions, including from other related FP7 projects and timely scientific findings, have been giving a new momentum to this branch of HEP, now acknowledged in the EU HEP strategy.
4.1	Creates a novel and credible approach to the LHC luminosity upgrade	Already exploited in a EuCARD JRA and by owners from US and JP and now CERN	-	Engineering developments, selection and test of final solution	Allows levelled luminosity, putting the physics detectors in optimal situation. Gain by ~*2
4.2	Associate new work force, exploit synergies	Collaborations continue under EuCARD2			Enhanced efficiency by exploiting synergies
4.3	Creates a vision for the challenging development of frontier accelerators	Create discussions in the HEP and NP communities, to be exploited by CERN and FAIR managements, R&D priorities to	-	Requires periodic updates	Provides a basis for expert discussion and a reference for selecting priority accelerator R&D areas and

		be exploited as well by TIARA.			infrastructures, including novel ones such as PWFA, crystal bending, anti-electron-cloud, etc…
4.4	Identify and develop new acceleration techniques well beyond the state of the art (plasma wake field acceleration)	To be exploited within EuCARD2, and by the major accelerator laboratories		The results obtained show the potential, but the feasibility of a real useful and productive accelerator remains fully to be established	
7.1	Few data existed so far on the radiation resistance of electrical insulation at cryogenic temperatures for a 50 MGy radiation level	Selection of insulation for magnet coils or other electrical components; to be used in the coming year by CEA and CERN	-	Some mechanical and thermal tests remain to be done	Can be of relevance for any equipment faced to severe irradiation, like frontier accelerators, nuclear reactors, tokamaks…
7.2	The energy of circular accelerators is limited by the maximum magnetic field; the purpose is to offer an improvement by a factor close to 2	CERN and CEA will finalize the magnet model to demonstrate its performance reach. CERN will install it in the sc cable test station where, e.g. ITER cables are tested. EuCARD2 will take over to demonstrate field quality in addition to field level.		Two more years to demonstrate performance	A success opens the way to a major step forward in the energy of frontier accelerators, by a factor close to 2. In the same range, NMR, MRI would benefit from this technology.
7.3	The above Nb_3Sn magnet will be limited by its superconductor to 13 to 15 Tesla. A 6 Tesla YBCO insert can both brings this sc technology to the wanted 20 Tesla range and resist to the extreme forces.	CEA, CNRS-Grenoble and CERN will insert this HTS magnet in the Nb_3Sn magnet under construction. If demonstrated, this technology of more compact and higher critical temperature cryomagnet could find multiple applications, e.g. MRI.		The final tests remain to be done.	Boost by 40% the accelerator energy. Offers 6 T magnets for applications, e.g. medical with reduced cryogenics requirements.
7.4	Allow remote electrical powering without losses	CERN will exploit the technology for remote powering			Allows remote dc powering in situations where safety, space

		of the upgraded LHC			or maintenance is an issue. Could find applications in the energy domain, for the transport of dc currents.
7.5	Increase the magnetic field in undulators	STFC to continue this development		Another iteration is needed	If successful, would allow more efficient production of positrons for collider sources and wider wavelength range for FELs.
8.1	Identify materials that can resist high level pulsed radiation (beam impacts) while showing appropriate characteristics as collimator jaws in ultra-high vacuum	EuCARD2 will take over the R&D		R&D until collimators are built with the new materials and tested with beam	Will allow an increase of beam power for the LHC upgrade, through a reduction by 90% of the collimator impedance to the beam
8.2	Allow a minimization of the complexity of accelerator operations and gain in integrated luminosity	Already implemented in the SPS accelerator, will be installed in the LHC			Reduced complexity of operation by a large factor; improve integrated luminosity by up to 15%
8.1	Identify materials that can resist high level pulsed radiation (beam impacts) while showing appropriate characteristics as collimator jaws in ultra-high vacuum	EuCARD2 will take over the R&D		R&D until collimators are built with the new materials and tested with beam	Will allow an increase of beam power for the LHC upgrade, with a goal of a factor of 10 increase in LHC performance.
8.2	Allow a minimization of the complexity of accelerator operations and gain in integrated luminosity	Already implemented in the SPS accelerator, will be installed in the LHC			Reduced complexity of operation by a large factor; improve integrated luminosity by ~ 10%
8.3	Allow the collection of halo particles at a higher temperature to minimize	To be installed in the FAIR project machines by GSI			Concept and device required to allow the SIS 100 project

	cryogenic losses and stabilize the vacuum.				
8.4	Tackle problems at the border of accelerator sciences and material sciences	Exploited in EuCARD2		R&D until collimators are built with the new materials and tested with beam	Cross-discipline fertilization
9.1	Macro and micro model of electrical breakdown under high RF fields	Actively exploited by the CLIC project for optimal cavity design and minimum breakdown rate; potentially relevant for all applications involving high RF fields		Improvement of the model and R&D on mitigation strategies: optimal substrate, surface and near-surface processing ,..	Liable to improve the predictability of RF cavities, wave guides and couplers performance; possibly a few 10% saving on cavity fabrication by reducing the non-conformities
9.2	Contribute to the development of an industrial approach to the fabrication of the CLIC module	Actively exploited by the CLIC project		R&D to further decrease costs for this highly challenging module that needs to be fabricated in over 10,000 copies	Cost reduction critical for the acceptance of the project.
9.3	Any future frontier linear collider needs to stabilize the beam at the nm scale to guaranty performance	The advancement on nm stabilization is exploited by the CLIC project and is of high relevance to the ILC project. Further developments of sensors with industry expected		The performance being reached or close-by, R&D is needed to reduce costs and further decrease the noise level of sensors	A successful stabilization to the nm is a critical requirement for linear collider projects. Possible impact on sensor manufacturers.
9.3	Any future frontier linear collider needs to stabilize the beam at the nm scale to guaranty performance	The advancement on nm stabilization is exploited by the CLIC project and is of high relevance to the ILC project		The performance being reached or close-by, R&D is needed to reduce costs	A successful stabilization to the nm is a critical requirement for linear collider projects.
9.4	To monitor the beam at the final focus (position and size) and make appropriate corrections	Exploited at ATF2 (Japan), as a test bench for linear colliders by international teams		Final precision goal in ATF2 not reached yet	A successful stabilization below the nm at the interaction point is a critical requirement for linear collider projects and more specifically CLIC

9.5	Measure beam arrival to 20 fs	Developed for the synchronization of the two-beam acceleration concept (CLIC), exploited by CERN and the CLIC collaboration			For CLIC, maximize the energy transfer between drive and main beam. Further developments launched for applications in the PSI injector and SwissFEL
10.1	High gradient sc RF cavities allow more compactness and lower power consumption for proton linacs	To be exploited for injector upgrade by CERN, for system optimization by ESS and possibly by other high-power linac projects, synergy with TESLA/XFEL		Finalize the tests and iterate, depending on performance achieved	Reach about 20 MV/m while normal conducting system in the same frequency range only offers a few MV/m
10.2	Recover the luminosity loss caused by the beam crossing angle in colliders	Being exploited for the LHC luminosity upgrade and the CLIC project. Similar need in the ILC project		Assessment of the performance in terms of deflecting field and of RF amplitude and phase noise	Allows head-on collisions and/or levelled luminosity, putting the physics detectors in optimal situation. Gain by ~*2 in performance or more.
10.3	Develop a new generation of sc Nb thin film cavities	For ISOLDE by CERN, and more generally for all sc cavity uses if the performance goal is reached	Patent application in preparation	It is generally agreed that thin film sc cavities have the potential to supersede bulk Nb cavities	More compact accelerating systems, and cost reduction (thin superconductor film deposited on a Cu cavity)
10.4	Modular and flexible LLRF system based on a telecommunication standard	Being exploited by DESY for FLASH, candidate for XFEL, ILC	Patent application made		Adaptability to changing environment of research accelerators, easier maintenance; follows progress of telecom electronics; in final better beam control
10.5	Make systematic the very delicate preparation of RF couplers	In preparation for XFEL and LC projects, where large quantities of couplers need to be processed		demonstrator	Significant time and cost savings for large projects
11.1	Combine the new concept of	Now, by INFN		Machine studies until the	Improvement of performance

	beam crossing with crab waist together with an experimental detector			performance goal is reached	by a factor of 3
11.2	Investigate the potential of crab waist crossing for the LHC upgrades	By CERN in the framework of the LHC upgrade studies		Improvement of dynamic aperture, feasibility of double-half quadrupole	possibly a novel unconventional alternative for the LHC luminosity upgrade or higher-energy proton colliders if further research has positive yield.
11.3	Support to the diagnostics and commissioning of a new type of accelerator	Further understanding of this type of accelerator		From proof of principle to operational machine	Potentially opens new possibilities for muon acceleration for research and applications to medicine and energy; medical application studies on-going: PAMELA…
11.4	Single-shot emittance measurement of point-like/large divergence beam from a laser-plasma wakefield accelerator	Approach can be used in plasma wakefield accelerators in many laboratories, especially LOA		Progress in accuracy by improved disentangling of the discovered effect of angular momentum	An element of a new toolkit adapted to the measurement of beams from plasma wakefield accelerator.