PROJECT FINAL REPORT

Grant Agreement number: 261905

Project acronym: TIARA

Project title: Test Infrastructure and Accelerator Research Area

Funding Scheme: INFRA-2010-2.2.11

Period covered: from Month 1 (January 2011) to Month 48 (December 2014)

Project co-ordinator: Roy Aleksan, CEA
Tel: +331 69 08 33 47
Fax: +33 1 69 08 64 28
E-mail: roy.aleksan@cea.fr

Project website address: http://www.eu-tiara.eu

TIARA final publishable summary

1 Executive summary

The TIARA preparatory Phase aims at establishing a sustainable structure enabling the implementation and the development of a long-term accelerator R&D strategy and programme in Europe through the creation of a Consortium of European research institutes, which operates significant accelerator R&D infrastructures. Through this Consortium, the integration of the crucial large-scale national and international R&D infrastructures will be facilitated.

TIARA-PP was divided into 9 Work Packages (WP), covering both organisational and technical aspects. All the objectives of the project were fulfilled, mostly during the first three years of the project (2011-2013). A one year extension (2014) was used to finalise the establishment of the future governance structure of TIARA within WP2 and TIARA-PP Governing Council. This included the definition of the consortium's organization, the constitution of the statutes and the required means and methods for its management, as well as the related administrative, legal and financial aspects. This work led to the development of a Memorandum of Understanding (MoU), which is expected to be signed by all TIARA partners.

WP3 (Accelerator R&D Infrastructures) was devoted to the integration and optimization of the European R&D infrastructures. Based on a survey of those that already exist, its objective was to determine present and future needs and to propose ways for developing, sharing and accessing these infrastructures among different users. This work package also investigated how to strengthen the collaboration with industry and define a technology roadmap for the development of future accelerator components in industry. The main objective of WP4 (Joint R&D Programming) was to develop a common methodology and procedure for initiating, costing and implementing collaborative R&D projects in a sustainable way. Using these procedures, WP4 proposed a coherent and comprehensive joint R&D programme in accelerator science and technology, which will be carried out by a broad community using the distributed TIARA infrastructures. The development of structures and mechanisms that allow efficient education and training of human resources and encourage their exchange among the partner facilities was the goal of WP5 (Education and Training for Accelerator Sciences). The main tasks were to survey the human and training resources and the market for accelerator scientists, as well as to establish a plan of action for promoting accelerator science.

Scientific and technological aspects of the project were addressed in Work Packages 6 to 9 with the aim of improving collaboratively specific existing infrastructures (or developing new ones). The selected showcases included: the conversion of the Swiss Light Source into an R&D infrastructure for reaching and measuring ultra-small emittances (within WP6), the upgrade of the RF power infrastructure of the Ionisation Cooling Test Facility (ICTF) at the UK's Rutherford Appleton Laboratory (within WP7), the energy upgrade of the Frascati SPARC test-facility Linac (within WP8) and the design (within WP9) of two test benches aimed at the development of large future accelerators (e.g. European isotope-separation on-line facility, EURISOL).

Communication and dissemination activities (within WP1 – Consortium Management) have led to two highlights: the newsletter Accelerating News, edited in collaboration with the EuCARD FP7 project, involving presently additional FP7 accelerator projects, and the Accelerators for Society project. A 3-fold brochure and a dedicated website were produced to promote accelerator S&T through its applications for research and development, health and medicine, energy and environment, industry, security and cultural heritage.

2 Project context and objectives

2.1 TIARA-PP organisational aspects: coordination of accelerator R&D in Europe

This section addresses the context and objective of the organisational aspects of TIARA-PP.

The realization of current and planned state-of-the-art accelerator-based research infrastructures, such as LHC, XFEL, FAIR, SPIRAL2, ESS, IFMIF, etc. which serve the needs of a vast range of research communities, is only made possible by continuous progress in accelerator science and technology supported by strong and sustainable R&D activities. It is thus logical that strengthening Europe's capability in accelerator R&D has been identified as a very high priority issue within many of the communities using accelerator based research infrastructures. This is, in particular, the case for Particle Physics, for which the CERN Council has ranked accelerator R&D as a top priority in its European Strategy for Particle Physics and subsequent updates documents, and also applies to a large number of projects included in the ESFRI roadmap.

To carry out a viable and state-of-the-art accelerator R&D programme requires the use of a wide variety of R&D infrastructures, ranging in scale from high-tech equipment and large size accelerator component test stands up to state-of-the-art test accelerator infrastructures costing several tens of millions of Euros.

A first estimate of the scale of total investment in these infrastructures is in the range from 900 million to 1.1 billion Euros, with maintenance and operating yearly costs estimated to be about 10% of the total cost. No single institute or laboratory, nor even a single country, has the expertise and the resources to develop and operate such a wide and diverse set of infrastructures. It has become increasingly clear that establishing an efficient, structured and sustainable coordination of activities in this area is crucial for the optimal use and development (upgrades and construction of new facilities) of this large variety of large scale test infrastructures. Thus, the idea of establishing Consortium of European research institutes, which operates significant accelerator R&D infrastructures to facilitate their integration and their access, has progressively emerged with the goal of creating in Europe the Test Infrastructure and Accelerator Research Area (TIARA).

The main objective of TIARA is thus evolved to the establishment a Consortium of European Research Institutions operating significant R&D Infrastructures in the European Particle Accelerator Research Area and to create a dedicated structure to exchange expertise and to facilitate and support the setting-up of joint R&D programmes and education and training activities in the field of Accelerator Science and Technology in Europe.

TIARA will enable full exploitation of the complementary features and expertise of the individual member infrastructures and will maximize the benefits for both the member infrastructures and the users. This includes the agreement and implementation of organisational structures and methods that will enable integration of existing individual infrastructures, their efficient operation and upgrades, and the construction of new infrastructures as part of the TIARA facility, thus ensuring the competitiveness and sustainability of accelerator R&D in Europe. Such a Consortium will enable Europe to maintain its leadership in accelerator science and technology through the development of an integrated R&D program embracing the needs of many different fields, as well as medical and industrial sectors, both for technical and human resource aspects.

Besides the preparation and realization of critical technological improvements to ensure that the TIARA distributed facilities will remain at the state-of-the-art and will be exploited with highest efficiency, taking advantage of the structure that will be established, TIARA will also aim to:
1) develop a joint European accelerator R&D programme, in particular by defining the structure and mechanism allowing to identify the user needs, to enable the formation of collaborative projects and to implement them as part of a coherent programme;
2) help the promotion of educating and training of accelerator scientists, through the establishment and implementation of a coherent European plan of action in this area;
3) offer economically efficient ways to develop collaboration on accelerator R&D with the industrial sector for the development of products for research facilities, as well as medical and industrial applications of accelerators.

The TIARA Preparatory Phase project, through its organizational WPs, aimed to develop the means and structures required to bring about the objectives of TIARA.

2.2 TIARA-PP technical aspects

This section addresses the context and objective of the technical aspects of TIARA-PP.

Upgrade of SLS vertical emittance tuning system (WP6 – SVET)

The Swiss Light Source (SLS) has achieved a vertical geometric emittance of around 3 pm at 2.4 GeV, one of the smallest vertical emittances ever obtained and only a factor 5 larger than the ultimate vertical emittance limit given by the quantum nature of synchrotron radiation. In this respect, SLS represents the ideal test-bed for deploying diagnostics and testing experimental approaches with a goal of reaching sub-pm vertical emittance beams. Recognizing this unique opportunity, PSI has agreed to allocate machine time to this important R&D program, making the SLS - a user facility by nature - an important R&D infrastructure.

In order to enable the SLS to perform the above mentioned dedicated R&D program, an upgrade of some of its key elements is however crucial. To identify these key elements and to implement this necessary upgrade of SLS is the objective of work package 6 (SVET). If successful, SLS will - after this upgrade - be an R&D infrastructure suitable to investigate ultra-low vertical emittance tuning and control, in particular also in the regime of strong IBS. This is relevant for damping rings of future linear colliders and for next generation light sources.

Ionization Cooling Test Facility (WP7 – ICTF)

The principal objective of this work package is to deliver detailed design reports of the RF power infrastructure upgrades that the Ionisation Cooling Test Facility at the Rutherford Appleton Laboratory requires for it to become the world's laboratory for ionization cooling R&D.

Muon storage rings have been proposed for use as sources of intense high-energy neutrino beams at the Neutrino Factory and as the basis for multi-TeV lepton-antilepton collisions at the Muon Collider. To optimize the performance of such facilities requires the phase-space compression (cooling) of the muon beam prior to acceleration and storage. The short muon-lifetime makes it impossible to employ traditional techniques to cool the beam while maintaining the muon-beam intensity. Ionization cooling, a process in which the muon beam is passed through a series of liquid-hydrogen absorbers followed by accelerating RF-cavities, is the technique proposed to cool the muon beam. A globally unique Ionisation Cooling Test Facility (ICTF) is under construction at the Rutherford Appleton Laboratory to provide the infrastructure required to allow the first steps in an ionization-cooling R&D programme to be carried out.

The ICTF presently serves the international Muon Ionisation Cooling Experiment (MICE) collaboration by providing a muon beam and the necessary infrastructure to carry out the first steps of the MICE programme. It is planned that the MICE experiment will be built up in six ‘Steps’. Step I will perform a detailed characterization of the ICTF muon beam to establish that it can deliver the range of emittance and momentum required by the experiment. The muon spectrometer system will be implemented in Step II and Step III and the first liquid-hydrogen absorber and focus-coil (AFC) system will be implemented in Step IV. Step V will add a first section of linac and a second AFC module and is expected to be complete in the second quarter of 2012/13. The work within TIARA-PP is required to allow the detailed design and specification of the RF power distribution system by which the ICTF can support Step V of MICE. In addition, by carrying out the design work required to further upgrade the RF power infrastructure, the ICTF will be able to support Step VI of MICE as part of the TIARA distributed network of European infrastructures for accelerator R&D.

High Gradient Acceleration (WP8 – HGA)

WP8 objective is the upgrade of the existing S-band Linac of the SPARC Test Facility at LNF-Frascati with high gradient C-band accelerating structures, in order to reach 250 MeV at the end of the structure. The upgrade will be done with state-of-the art technology, setting up a facility unique in Europe made of S-band and C-band Linacs (a new “hybrid” configuration, never implemented up to now).

The upgrade design proposed here is based on a S-Band photo-injector operating in a RF compression mode followed by a C-band Linac. This scheme seems very promising from the beam dynamics point of view in terms of preservation of the low emittance of the electron beam and reachable photon beam brilliance. It is also much more compact with respect to a full S-band Linac, since with relatively short (1.5 m) C-band accelerating sections it will be possible to reach an accelerating gradient of the order of 35 MV/m. Finally, this compact design will allow for performing the design and realization of the accelerating structures at LNF with the present facilities.

After the upgrade SPARC will facilitate R&D on low emittance beams, photo-emission processes with novel cathodes, generation of polarized electrons, acceleration and synchronization of a bi-frequency Linac, efficiency and reliability of the system. In particular, a velocity bunching R&D test, providing both a substantial pulse compression with a reduction of the compressed beam energy spread, due to the higher SPARC beam energy, will allow for opening a number of possible future FEL experiments.

The SPARC upgrade will be crucial for at least two future FEL projects in Europe (SwissFEL and SPARX), for which the use of C-band accelerators for the main Linac is being considered, since they can greatly profit from the high accelerating gradients the compactness of the system and lower energy consumption in comparison to S-band linacs.

Test Infrastructures for High Power Accelerator Components (WP9 – TIHPAC)

Before launching the construction of EURISOL, the next-generation facility for the production of very intense radioactive ion beams, two major technical issues need to be addressed; the development of high power target and low beta superconducting accelerating structures. The objective of WP9 is to coordinate the design of the corresponding test infrastructures: an irradiation test facility for the high power target developments and a test cryostat for testing fully-equipped low beta superconducting cavities (SC).

These installations are key infrastructures, not only for the accomplishment of the R&D programme that is required to enable the construction of EURISOL, but also for other projects, such as the European Spallation Source (ESS) or the development of Accelerator Driven Systems (ADS), in particular with the MYRRHA project, as part of the EUROTRANS programme.

The EURISOL facility is aiming at the production of very intense radioactive ion beams (RIB) using the ISOL (Isotope Separation On Line) technique. It would provide unique world-class research opportunities in nuclear physics, nuclear astrophysics and material science, and supply new radiopharmaceutical radioisotopes.

The facility is based on a 5 MW driver accelerator, capable of accelerating protons up to 1 GeV, and also some other species, such as deuterons and He3 (2+) to 250 MeV and 2 GeV respectively at a reduced current. The beam is then directed to one multi-MW target and several low power target stations for the neutron conversion and the RIB production. The produced RIBs produced are then prepared and sent to the post-accelerator, which can accelerate up to 150 MeV/u, depending on the physics case requirements.

Achieving the required performance on the EURISOL facility necessitates an important R&D on several key components to assess the technological choices. Several components are today at the technological limit, and the difficulties will be overcome only with an intense R&D effort which includes an important test and qualification programme. The opportunity to test these components in conditions as close as possible to the final operation of the machine is mandatory to achieve a reliable design, which can meet the specifications.

3 Description of the main S&T results/foregrounds

This section focuses on Work Packages 6 to 9 which include the scientific and technological aspects of the PP project.

3.1 Upgrade of SLS vertical emittance tuning system (WP6 – SVET)

All the work within WP6 and the corresponding deliverables were achieved in period one and two. In 2014, WP6 contributed to finalization of the second period report (provided in February 2014) and to the preparation of the final report.

The main objective of the WP6 was to upgrade the Swiss Light Source (SLS) at PSI to enable R&D on ultra-low emittances. These included the following three tasks:
i) Minimization of vertical emittance (VE), through the development and application of methods for suppression of betatron coupling and vertical dispersion in the SLS storage
ii) Construction of a high resolution (a few micron) beam size monitor, by building and commissioning a new beamline named X08DA at the SLS, for evaluation of visible and UV light images in order to determine a vertical beam size of a few micron
iii) Measurements on 3D beam size evolution due to Intra-Beam Scattering (IBS) by tuning the ring to low VE and to lower beam energy.

3.1.1 Vertical emittance minimization

Regarding the first task, methods had to be developed and were applied to minimize the Vertical emittance (VE) using the existing instrumentation. Pre-TIARA work at PSI already had achieved a VE of 3 pm and was further extended. Knowledge of BPM roll errors turned out to be essential for the measurement of vertical dispersion. Steps between magnet girders were identified as main sources of vertical dispersion, so several MD-shifts in 2011 were spent on beam assisted girder alignment. Reduction of rms vertical corrector strength by more than 60% confirmed success of girder alignment and resulted in a VE of 1.3 pm by November 2011. An alternative and more general algorithm was established, which performs suppression of vertical dispersion and coupled response matrix simultaneously with correction of linear optics and determination of BPM roll errors. Not only the 36 skew quadrupoles are used but also orbit manipulations in order to sample regular and skew quadrupole down feeds in the storage ring sextupoles. Only three MD shifts with INFN/LNF, PSI and CERN colleagues were spent on this method in March and August 2011 and in March 2012. Nevertheless a VE of 1.3 pm could be reached, and a VE of 3.6 pm was achieved by orbit manipulation alone, with all skew quadrupoles off. A model independent method was established too, which performs a minimization of the beam size at the beam size monitor by random variation of the skew quadrupoles in very small steps. This method was applied after a VE of 1.3 pm had been reached by the first method, and finally resulted in the world record low VE value of 0.9 ± 0.4 pm in December 2011, which also meets the requirements for the CLIC damping ring and it is only 5 times larger than the fundamental quantum limit of vertical emittance at SLS. Confirmation of a similar VE of 1.3 pm by the second methods was achieved in March 2012.

3.1.2 Hardware upgrade

Regarding hardware upgraded, it became soon clear that the performance of the BPM system did not limit the lowest possible VE, but rather the limited resolution of the beam size. Thus considerations on an improved monitor started early and the concept for the new monitor was established: like the existing one, it is based on an image of vertical polarized synchrotron light. But in order to improve the resolution, a lower wavelength of 266 nm is used, and the magnification is almost doubled, which required elongation of the monitor beam line out of the SLS ring tunnel. The measurement method can continuously vary between an imaging and an interferometric method, which provides redundancy and may further extend the resolution. Extensive simulations were done to establish the quality requirements for the critical optical elements.

The monitor became a complete beam line on its own, named X08DA and all work was executed according to schedule during the year 2012 and early 2013, thus the first synchrotron light could be seen in the hutch at Jan. 29, 2013. The toroidal mirror, required detailed studies, so it was ordered not earlier than December 2012. Delivery was scheduled by the company for October 2013 but further delayed, until it finally arrived in November 2013. The monitor was first realized in an intermediate configuration using a plano-convex lens and a flat mirror in place of the toroidal mirror. In January 2014, the toroidal mirror was installed and the beam line was commissioned in its final configuration.

The monitor commissioning at the intermediate configuration took place during 2013. A thorough alignment of the optical components was done with the intermediate lens configuration aligned in December 2013 to very high quality.

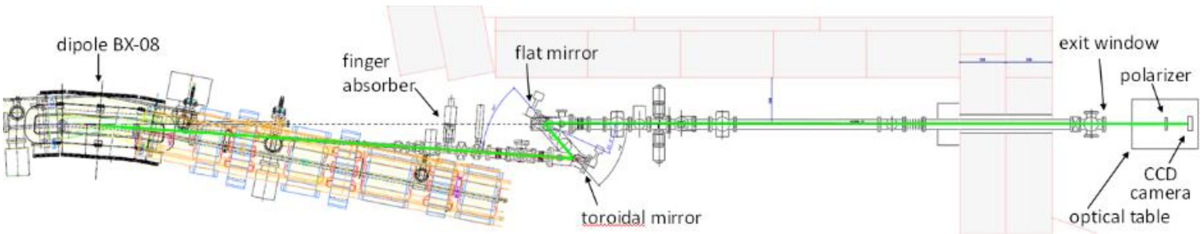

Figure 6.1: Layout of the new high resolution beam size monitor

3.1.3 Research on Intra-Beam Scattering

Measurements were in two wavelengths (325 nm and 266 nm). Imaging and interference methods using obstacles of three different sizes were applied and showed excellent agreement, well within the statistical error band of the beam size measurement. Lowest beam size values down to 4 µm have been observed using the new monitor corresponding to emittances of $\varepsilon y = 1.3 \pm 0.2$ pm·rad

Two items of the toroidal mirror were delivered and tested in a lab setup by the end of 2013. Lens and planar mirror were exchanged for one of the toroidal mirrors in the winter 2013/14 shutdown, while the other one stayed in the test setup for cross-check. First synchrotron light in the beam line in its final configuration was seen at January 2014. Alignment and fine tuning is still in progress.

In conclusion, the new monitor was built within schedule and performs as expected. However, a beam size near its expected limit of resolution near 2 µm could not yet be provided, but beam sizes down to 4 µm are easily resolved. Due to late delivery of the toroidal mirror the commissioning of the monitor beam line in its final configuration is still in progress now. The systematic error of the monitor is presently obscured by the statistical error from the beam size measurement due to image blur, presumably caused by mechanical vibrations of beamline components. This is subject to further investigations.

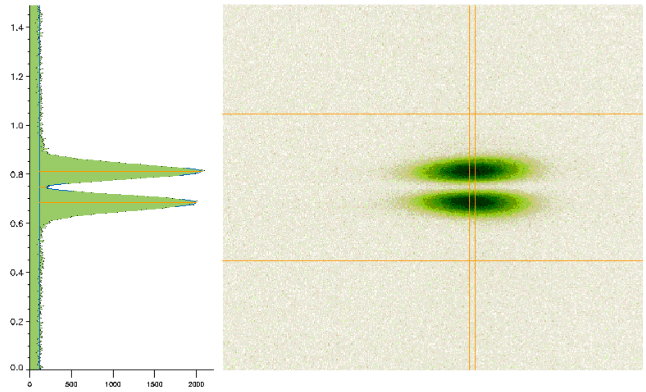

Figure 6.2: Image of vertical polarized synchrotron light: for an ideal beam of zero emittance, the image would show complete extinction of light in the midplane. Finite midplane intensity allows one to determine the beam size from the "valley to peak" intensity ratio of the image profile.

The main objective of WP6 was to upgrade the SLS to enable R&D on ultra-low emittance. Studies on bunch blow-up due to intra-beam scattering (IBS) were included as a first application, because this problem is most relevant for future light sources, colliders and damping rings. Simulations indicated that IBS effects are hardly visible at the nominal SLS beam energy of 2.4 GeV, therefore a mode of operation at a lower energy of 1.57 GeV was established, were IBS effects are more pronounced. Identification of IBS effects and disentanglement from other effects also increasing bunch dimensions (e.g. turbulent bunch lengthening) requires a precise 6-dimensional measurement of the bunch size over a wide range of bunch current. Beam emittances were obtained from beam size measurements using the old vertically polarized light monitor for vertical beam size and x-ray pinhole cameras for horizontal beam size. Bunch length was measured using a streak camera, and for determination of energy spread several methods were tried but yet without success. Some measurements could be done in 2012 and allowed comparison to IBS simulations.

In conclusion, the goal of WP6 was reached: methods to realize ultra-low vertical emittance have been established and a high-resolution monitor was built and successfully put into operation, which allows verification of ultra-low emittance. A very low vertical emittance of 1.5 pm can be set routinely, whereas tuning to the lowest emittance yet achieved of about 1 pm requires dedicated machine development time. The operating conditions are 2.4 GeV beam energy, 400 mA stored current and zero orbit (i.e. no bumps for beam lines). Measurements of intra beam scattering were performed as a first application of R&D at ultra-low emittance, but suffered from difficulties in tuning the SLS to lower energy and to measure the energy spread. The WP6 activities were to some extent limited by the fact that the SLS is a user facility and not a test accelerator. The machine is highly optimized to its standard mode of user operation. Tuning to alternative modes requires much manpower and machine development time and is also hampered by rather low radiation limits in the SLS building.

All three tasks of WP6 will be pursued further in 2014: The realisation of ultra-low vertical emittance will continue by further alignment campaigns, also automated coupling control still has to be implemented for user operation. The monitor commissioning is in progress and is expected to be completed during February/March 2014. A low energy mode of operation will be set-up thoroughly for the IBS measurements, and further research is planned to establish a reliable method of energy spread measurement.

3.2 Ionization Cooling Test Facility (WP7 – ICTF)

All the work within WP7 and the corresponding deliverables were achieved in period one and two. In 2014, WP7 contributed to finalization of the second period report (provided in February 2014) and to the preparation of the final report.

The objectives of work package 7 in the TIARA preparatory phase was to design, build, demonstrate and install the prototype high power radio frequency driver and power supply for the RF accelerators of the muon Ionisation Cooling Test Facility (ICTF). The project also intended to design the distribution network to provide 500 kW into 16 separate couplers (two each per cavity) with the correct phase relationships and controls from the four amplifier stations. The creation of this facility will enable the community to perform the Muon Ionisation Cooling Experiment (MICE). The MICE experiment will measure the emittance reduction caused by transporting a muon beam through a sequence of low Z 'absorber' cells followed by reacceleration in short accelerator modules. This will test the principles proposed to reduce the phase space footprint of a muon beam generated by a high power proton beam impacted into a target prior to acceleration for either a neutrino factory or a muon collider. The third objective of the project was to design a higher power amplifier for future upgrades to either the peak gradient or duty cycle for the ICTF and to ensure sustainability of the ICTF RF infrastructure. The general layout of the MICE experiment at the ICTF beam channel in its final configuration is shown in figure 7.1.

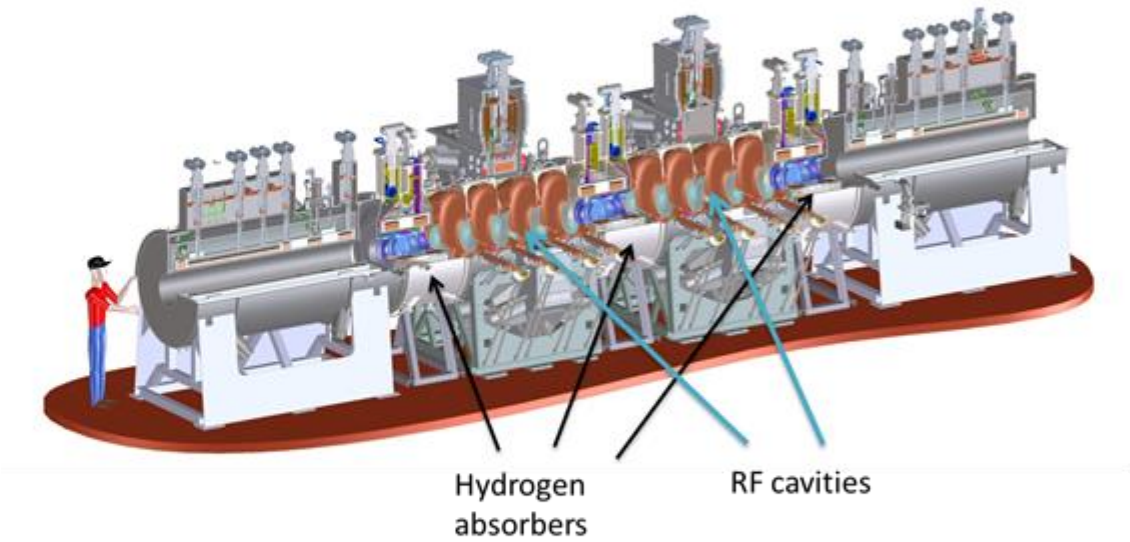

Figure 7.1: The MICE experiment at the ICTF, highlighting the two separate accelerator units and three absorber cells. The solenoids at each end surround scintillating particle trackers that form the momentum spectrometers.

3.2.1 ICTF RF power infrastructure

3.2.1.1 Development of the Power Amplifiers for the ICTF

The RF power infrastructure for the Ionisation Cooling Test Facility has been successfully developed under the preparatory phase of TIARA. The design, build and initial experimental work was undertaken at Daresbury Laboratory, with support from staff from the Rutherford Appleton Laboratory (RAL), Imperial College and the University of Strathclyde. The final installation and demonstration was undertaken by the same team at the ICTF at RAL.

The power required to maintain the required 8 MV/m, gradient in the High Q copper cavities is 1 MW (delivered as 500 kW each to two couplers). The design envisioned each pair of cavities being driven at a fixed phase offset of 124^{o}, by a single RF amplifier chain, each rated at 2 MW peak output power. The pulse duration would be 1 ms at a repetition frequency of 1 Hz. The frequency required was 201.25 MHz. The design process showed that this specification could be met using triode amplifiers based around the Thales TH116 valve with a gain of some 10-11 dB with a bias voltage of around 33-37 kV with an efficiency of around 50%. This defined the specification of the power supplies and the type of intermediate stage amplifier. A tetrode amplifier based around the Burle 4616 valve could be expected to achieve ~250 kW at a gain of nearly 20 dB at a bias voltage of some 19-20 kV. In turn this defined the initial SSPA to require an output power of up to 4 kW with a gain of ~60 dB.

To demonstrate that this amplifier system could meet the needs of the ICTF, a prototype amplifier was built. This encompassed either new build or major modernisation of large and complex amplifier systems and the associated HT and auxiliary power supplies. The long pulse durations demanded particular attention to protecting the amplifiers and the installed valves from the risk of breakdown, due to the energy stored in the power supplies. Arc detection systems were developed to trigger crowbar circuits to limit the energy which could be dissipated into the valve amplifiers in the event of such a fault circumstance. The crowbar switch for the triode system represents a particularly severe specification in charge switching and voltage hold-off requirements, which was successfully addressed by developing a system based on a modern thyratron valve.

Figure 7.2 illustrates general layout of the experimental facility built at Darebury to allow the testing and development of the amplifiers. It also shows the prototype tetrode and triode amplifiers. The tests culminated with successful sustained operation at the required power levels of 2 MW as illustrated in Figure 7.3.

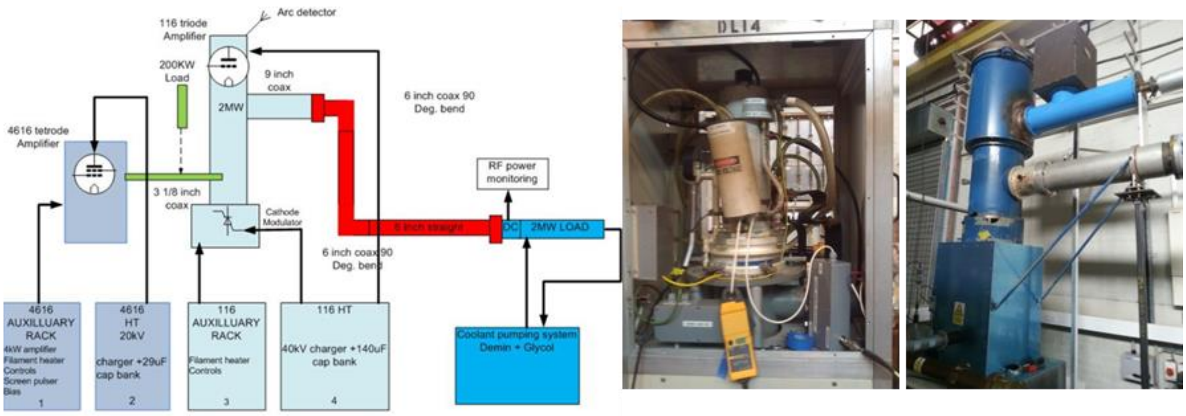

Figure 7.2: The diagram on the LHS illustrates the layout of the test system at Daresbury, the middle and right hand images show the intermediate and final stage prototype amplifiers.

As shown in figure 7.3, the triode achieved the required output signal at a bias voltage of 34 kV drawing 129 A of current with an efficiency of 46% (electronic) at a gain of 10.8 dB and presenting an input port return loss of -12.5 dB. The intermediate stage was operating at 170 kW at 18 kV of bias voltage with 15.5 A current at an efficiency of 61% and a gain of 19 dB demanding an input of 2.27 kW from the SSPA. The tetrode was separately tested to ensure it had the desired performance in hand and was found to be able to develop an output power in excess of 240 kW. These tests have therefore validated the design for the ICTF.

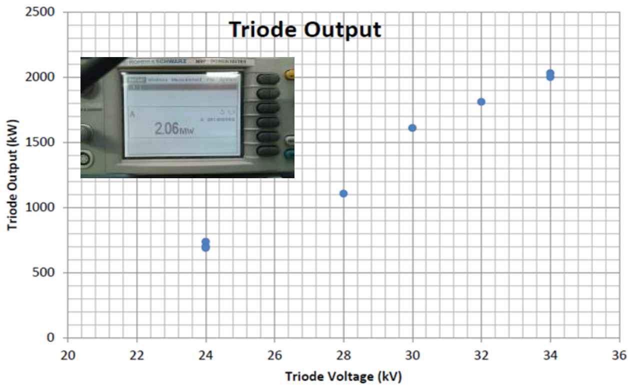

Figure 7.3: Demonstration of required peak output power, showing triode output versus bias voltage, and power measured by gated power meter

Following the successful demonstration of the prototype amplifier chain, the system was installed in the first amplifier position in the ICTF RF power station and the integration of the auxiliary systems verified by operating the amplifier chain into RF loads. The installation arrangements are shown in figure 7.4.

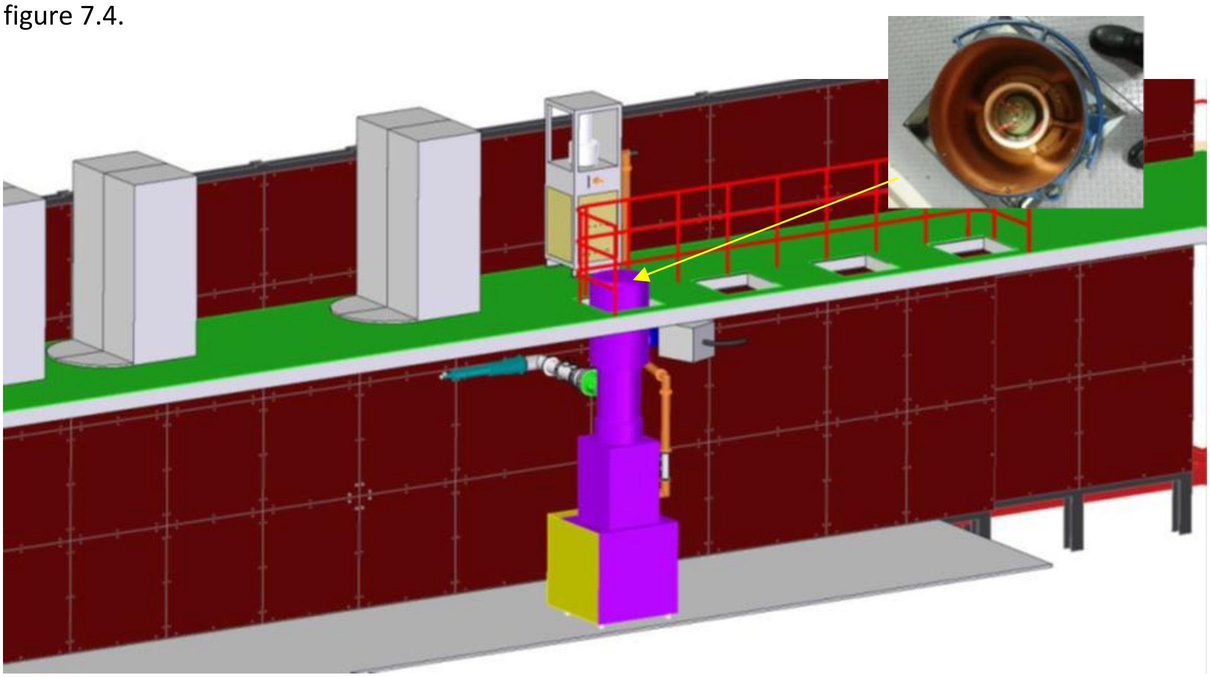

Figure 7.4: Illustration of the prototype amplifier installed in the 1st berth in the RF Power station at the ICTF, inset showing the valve seated in the amplifier top cap and viewed through the mezzanine floor, visible are the water cooling lines and HT bias feed to the anode. The intermediate amplifier can be seen on the mezzanine beside the triode with the power supply racks arrayed behind.

In addition to the completion and testing of the first amplifier system, the second tetrode amplifier has been tested at the required pulse duty cycle, 250kW, with 1ms at 1Hz duty. The two tetrode amplifiers and three triode amplifiers have all been brought to an advanced state of preparation (all mechanical work complete). This represents a change in the original workplan due to a change in the priorities of the MICE project. Due to a revision in the magnetic shield installation it is now envisioned that all four amplifiers will be needed at the same time, rather than being operated in an intermediate configuration as a pair (for a single 4 cavity linac module) then as a quad for the full ICTF.

3.2.1.2 RF distribution network

The RF distribution system has been evolved, by the team at Daresbury laboratory working with colleagues at RAL, Imperial College and the University of Strathclyde to allow the power from the four RF amplifiers, situated at one edge of the ICTF to the eight RF cavities (each with two input couplers) located in the centre of the shielded hall along lines with accurately known electrical lengths. This is essential since four separate lines feeding two adjacent cavities will all be referenced back to a single power amplifier chain, and only at this point will it be possible to regulate the phase dynamically. The phase shift between adjacent cavities is defined by the centre momentum for the MICE experiment 200 MeV/c at 124^{o} between adjacent cavities. Adjacent 'paired' cavities will be electronically tuned by the LLRF for the specific momentum in use at any time (the experiment can be tuned to work with muons between 140 MeV/c to 240 MeV/c).

The routing is complicated by the strong magnetic fields used in the 'cooling channel', shown in grey in figure 7.5 and the requirement to move large items of equipment into the service location between the amplifiers (against the bottom wall in figure 7.5) and the main beam line.

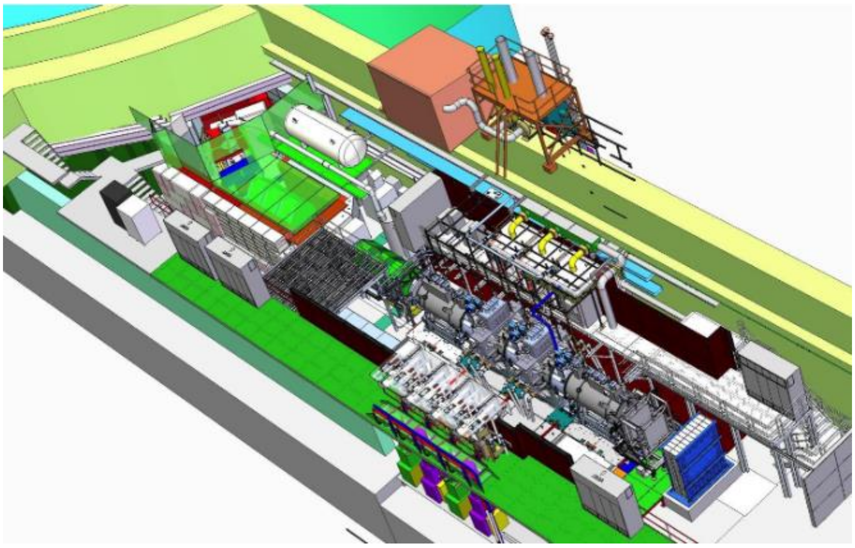

Figure 7.5: Overview showing major features of the ICTF, including the RF power stations on the bottom edge and the beamline components in grey in the centre (including the accelerator modules).

The high power co-axial lines were routed to avoid equipment conflicts whilst maintaining the correct electrical lengths by exploiting full 3D modelling linked to the RF component specification. Relatively small diameter coaxial lines were specified exploiting pressurisation with nitrogen and a novel feedforward control system to allow slow ramp of the drive amplifiers during the cavity charge cycle to prevent excessive standing wave amplitudes on the RF lines (SF_6 filling is reserved for any possible future power upgrades). These relatively small coaxial lines can be routed under the floorplates in the experimental hall to ensure relatively unobstructed access to one side of the beamline at all times. Key features of the distribution network are outlined in figure 7.6.

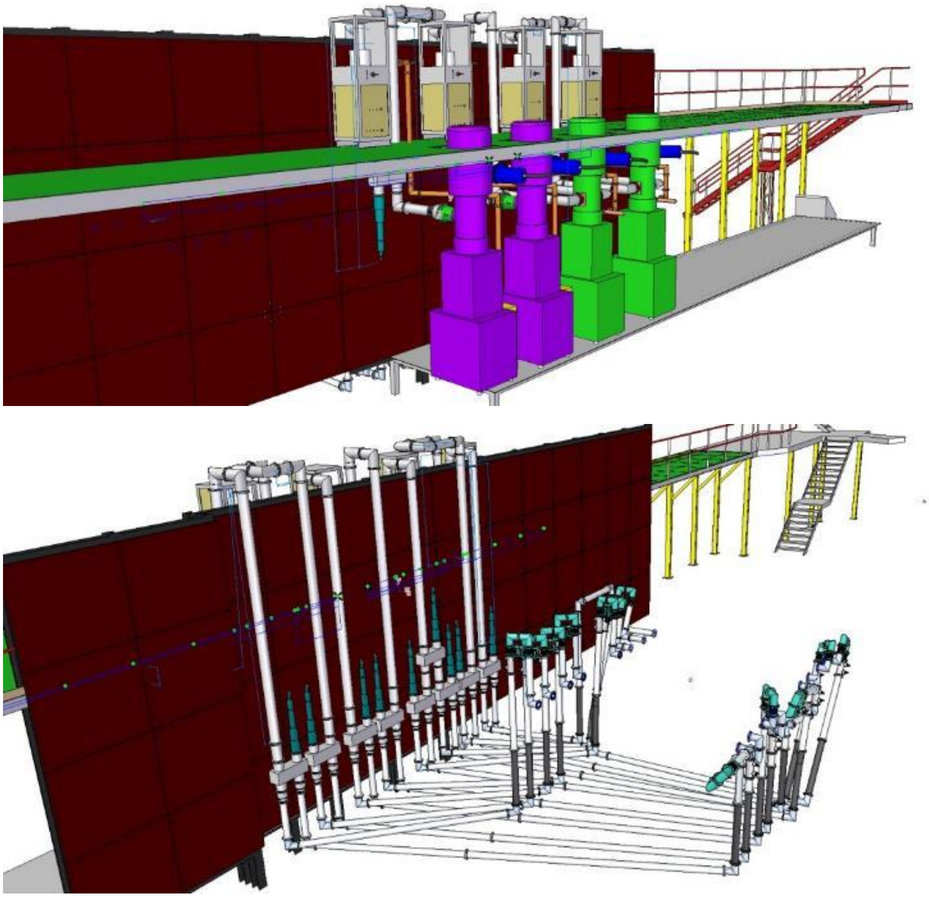

Figure 7.6: Illustrates the distribution network to deliver the RF power from the four amplifiers in the RF power station to the cavities, with the power lines running under the false floor of the experimental hall

Exploiting these 3D models and design tools, it was possible to draw up a detailed inventory of components required to build the system designed under the TIARA-PP programme and as a result the project was able to exploit a synergy with a US NSF MRI project which went beyond the design of the RF network and has resulted in the procurement of the vast majority of the equipment required to complete the installation, in addition to components to support the next R&D steps for the ICTF, including the development of the LLRF system and completion of the RF power system, this includes energy storage capacitors, charging power supplies, RF power valves and loads. This has resulted in the delivery to the ICTF of over $1M US in equipment and components required for implementation of the designs and prototypes developed in the preparatory phase.

3.2.2 Novel pulsed RF power amplifier design

Design of a 3 MW, 201.25 MHz, high duty capable RF power amplifier has been led by CERN working with staff at Los Alamos National Laboratory (LANL) in the US and with Daresbury Laboratory. The intention here is to ensure the scalability and long term sustainability of the ICTF infrastructure and simultaneously to develop an RF amplifier system that would enable the large scale future deployment of the ICTF technology for future muon colliders and/or neutrino factories. This objective has been surpassed and resulted in extensive testing of a prototype amplifier and industrialisation of the design.

3.2.2.1 Demonstration of a novel 3 MW capable RF amplifier

The new amplifier design exploits a modern advanced ‘tetrode’ valve technology, specifically the Thales Diacrode, which offers higher power for a given maximum frequency of operation compared to a conventional tetrode configuration. These modern valves ensure the long term sustainability of the amplifiers designed to use them. Working together CERN and LANL have undertaken extensive tests of a prototype 3 MW amplifier (at LANL), with drawings illustrating how the amplifiers could be integrated into the ICTF shown in Figure 7.7.

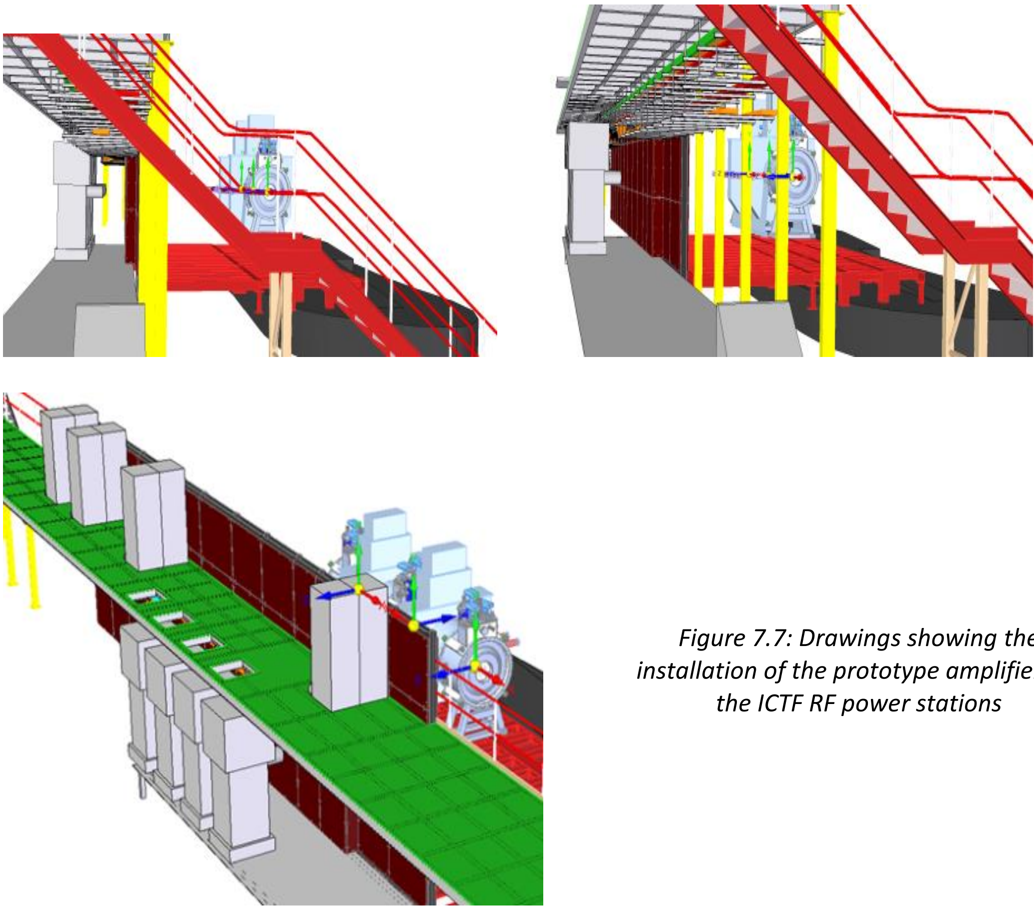

Figure 7.7: Drawings showing the installation of the prototype amplifiers at the ICTF RF power stations

The amplifier was tested with several valves in a range of duty configurations. Operation at 201 MHz with 2 MW pulses 1 ms in duration at 1 Hz PRF, see figure 7.8, demonstrated the amplifier could guarantee the sustainability of the ICTF infrastructure as it is currently defined for as long as the scientific community would require it. The amplifier was also tested in a range of alternative duty cycles to prove its flexibility for a future upgrade of the ICTF specification, as a driver for a neutrino factory or muon collider cooling channel, or for a range of other accelerator application. These included 2.75 MW at 1 ms and at a PRF of 120 Hz (this indicates a duty cycle would be available of up to 0.12 compared to the current duty of 0.001 and at higher power). The maximum achievable power of 3 MW was confirmed at shorter pulses, on the order of a few hundred microseconds in duration at a PRF of 30 Hz. Figure 7.8 also shows a 200 microseconds pulse with a 3 MW peak output power.

Figure 7.8: Illustration of the pulse envelopes achieved with the diacrode based power amplifier, on the LHS demonstrating the current ICTF specification pulses at 1Hz PRF and on the RHS showing the peak performance of the amplifier at 3MW.

The successful tests of the amplifier led to the industrialisation of the designs, with the first commercially manufactured units now being successfully tested.

3.3 High Gradient Acceleration (WP8 – HGA)

All the work within WP8 and the corresponding deliverables were achieved in period one and two. In 2014, WP8 contributed to finalization of the second period report (provided in February 2014) and to the preparation of the final report.

The goal of the Work Package 8 is the energy upgrade of the Frascati SPARC test-facility Linac by designing, constructing and commissioning two C-band (f=5712 MHz) TW high-gradient accelerating structures. The new C-band structures are fed by a 50 MW klystron Toshiba ET37202. The high voltage pulsed modulator and the 400 W solid state driver for the klystron have been manufactured respectively by ScandiNova (S) and MitecTelecom (CDN). The new system will also include a pulse compressor provided by the Institute of High Energy Physics (IHEP, Beijing).

The construction of the two accelerating sections was accomplished as Deliverable D8.1 of WP8. The installation, commissioning and test of the C-band Linac at SPARC (Deliverable 8.2) was also accomplished and a report published.

3.3.1 Construction of the two accelerating sections

Fabrication of all the RF cells of the accelerating structure was performed at LNF and in local private companies; the critical issues of the fabrication phase are the mechanical tolerances and the internal surface finishing. The cells of the first structure have been joined in two stacks and brazed in two halves at LNF, since the dimensions of the LNF oven do not allow for brazing the whole accelerating cavity (Figs. 8.1 and 8.2). Also IN-OUT couplers of the structure were fabricated and brazing of stainless steel flanges was performed. Then brazing of the stacks of cells with the in/out couplers for the first structure was done.

Figure 8.1: Preparation of the cells. Stacking the cells (left), inserting alloy rings for brazing (right).

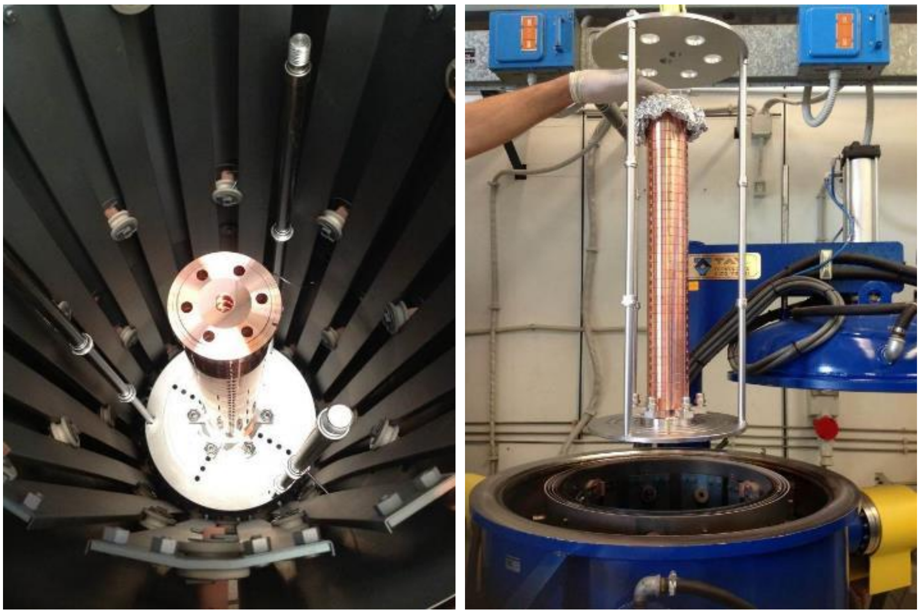

Figure 8.2: First stack in the oven for brazing

The procedure for brazing together the two stacks of cells was very delicate, since a problem occurred in the final brazing between the two halves of the structure that caused a field reflection and a consequent reduction of the accelerating field. The mechanical drawing of the central junction has been then modified and this new design was implemented also in the second structure. Fig. 8.3 shows the prototype of the two central cells of the new junction successfully realized, brazed and tested.

Figure 8.3: Prototype of the new junction between the two half structures (left), the two new central cells ready for brazing (right).

A special support was built to be able to horizontally braze the final structure with the new cells for the central junction. This time the brazing was successful, and the same procedure was then repeated for the second accelerating structure. On bench RF measurements were done on both structures and tuning of the electrical field was successfully performed. Similar results have been obtained for the second realized structure.

3.3.2 Low Level RF (LLRF) Electronics

Goal of this task was to provide a stable and flexible digital low level RF system to control the input to the RF amplifiers and monitor the RF signals of the high gradient C-band accelerating structures at SPARC test facility.

During the first phase of the design process, a modular approach has been pursued to separate the developments into two main blocks, the analogue front-end and digital backend part with well-defined interface specifications. The concept has been fixed to down-convert all C-band RF signals to an IF frequency. Commercially available FMC A/D modules then digitize those signals, the data is digitally demodulated on several VME64x FPGA/PowerPC processing boards to provide I/Q data and amplitude/phase information which is then transferred to the SPARC control system. Amplitude and phase correction waveforms are subsequently downloaded from the control system to the LLRF processing board again, converted to analogue baseband signals by a high-speed FMC D/A module to drive the input of a vector modulator. The focus of the design work has been put on acquiring commercially available FPGA/PowerPC processing boards and implementing the basic software and firmware framework on it which consist of:

- implementation of a real-time capable Linux kernel (PREEMPT_RT patched Linux kernel)
- driver developments to access on-board resources from standalone applications and from the control system
- implementation of the EPICS control system
- integration of several commercially available FMC A/D and D/A prototypes into a generic firmware structure and testing their performance
- implementation of the demodulation algorithm into firmware
- implementation of statistical calculations on PowerPC level within a real-time application

In parallel, the design of the baseband vector modulator, a 16-channel RF receiver front-end and the local oscillator (LO) generation unit to provide the required LO signals as well as all A/D and D/A converter clocks were carried out. All design steps have been described in more detail in milestone report MS31 (RF-LLE-D). Prototypes of all units have been developed and evaluated individually. The complete system has been setup in the lab at PSI and its overall performance has been characterized and documented (achievement of MS32, RF-LLE-P). The LLRF prototype system is shown in Fig. 8.4.

After shipping the LLRF system to LNF-Frascati, it has been successfully integrated into the SPARC controls system by implementing an EPICS/LabVIEW interface. In a first step the new LLRF system has been used to monitor all C-band RF signals during the conditioning phase. INFN has then developed a custom console, using the EPICS CA drivers in LabVIEW programming environment that is fully compatible with the SPARC_LAB control system. The conditioning of the second C band accelerating structure was performed by means of that interface, integrated in a "conditioning console" application that also includes vacuum reading and RF power station control. Fig. 8.5 shows the initial PSI GUI (on the right side) running together with the SPARC_LAB console application (left) that is controlling the LLRF during the conditioning (read signals from linac, control amplitude and phase of the RF driving pulse).

The system meets the specifications which are required for the successful operation of the new high gradient C-band accelerating structures with a SLED pulse compressor at the SPARC Test Facility at LNF-Frascati.

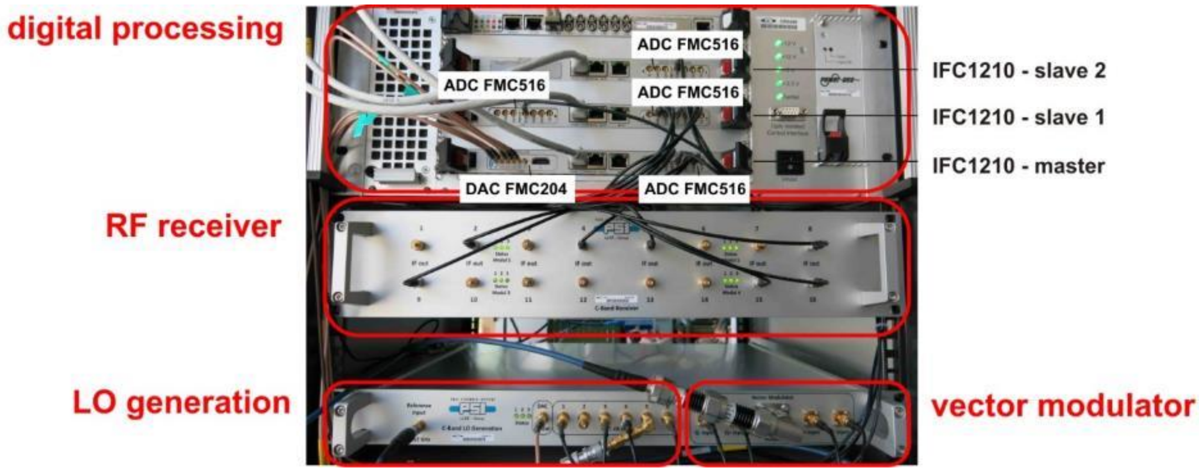

Figure 8.4: C-band LLRF prototype system for the SPARC test facility. The VME64x crate contains three digital processing cards (IFC1210) with one D/A FMC and several A/D FMC modules (on top of the picture). All C-band signals are down-converted to IF signals in the RF receiver module (middle part of the picture). A local oscillator (LO) generation unit provides the necessary LO signals for the RF receiver as well as all A/D and D/A clock signals for the FMC modules (on bottom of the picture). The unit also contains the baseband vector modulator to control the drive signal to the pre-amplifier and klystron.

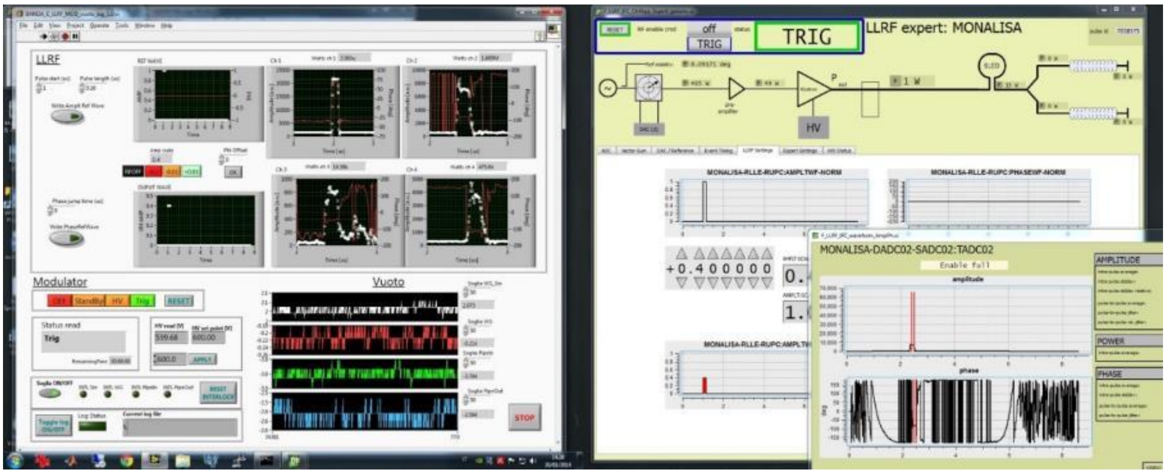

Figure 8.5: Initial PSI GUI (on the right side) running together with the SPARC_LAB console application (left) that is controlling the LLRF during the conditioning.

3.3.3 Installation, commissioning and test of the C-band Linac at SPARC

The first structure has been installed in the SPARC hall for high power test on October 2013 (see Fig. 8.6). The waveguide line from the klystron to the structure (including T-pumping units and RF pickups) has been connected and RF tested.

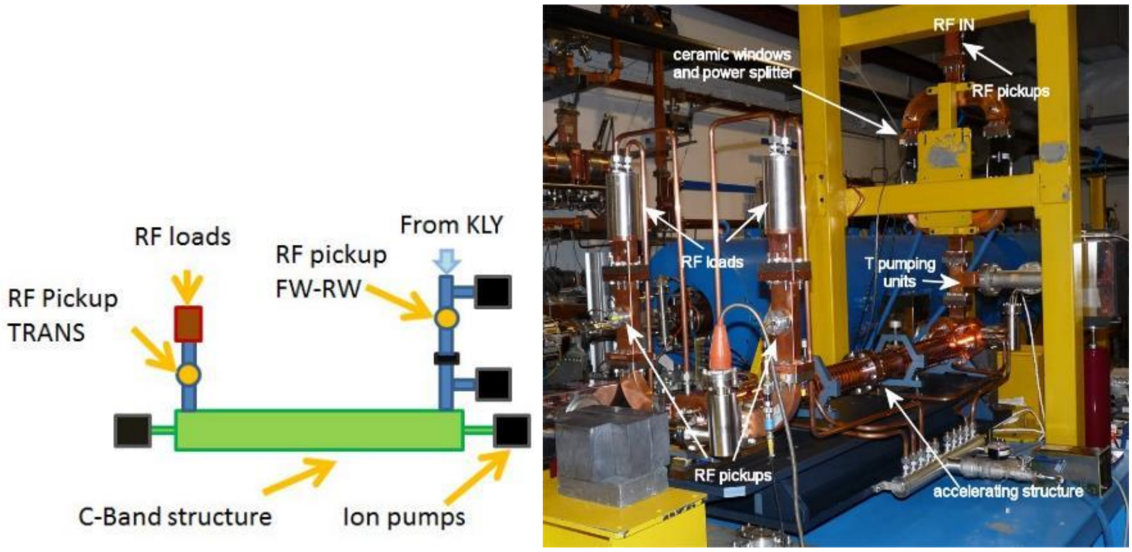

Figure 8.6: C-Band structure installed in SPARC for high power tests.

The high power test on the first C-band structure started on November 2013. Operation was at 10 Hz with the nominal pulse width of 165 ns (slightly longer than the filling time of the structure). The power from the klystron was progressively increased (by increasing the HV of the modulator) at the same time monitoring the current absorption of the 4 ion pumps (3 connected to the structure and 1 to the waveguide before the splitter) and the RF signals from pickups.

A picture of the control panel is given in Fig. 8.7. A typical event of discharge monitored by the increase in vacuum pressure is given in Fig. 8.8 while the picture of the RF monitored signals is given in Fig 8.9. Normal operation conditions were a vacuum level in the structure between 5 10^{-10} mbar and 2 10^{-9} mbar.

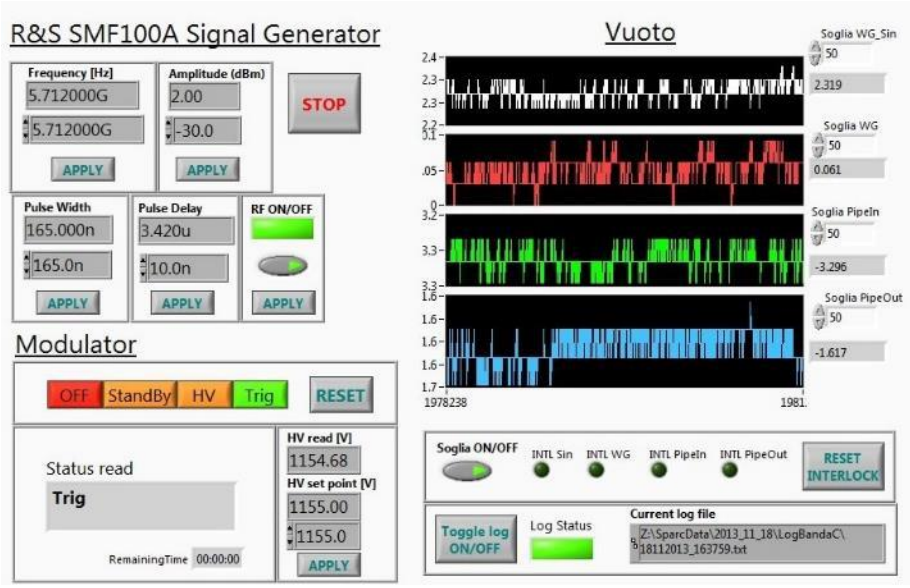

Figure 8.7: Control panel for high power test.

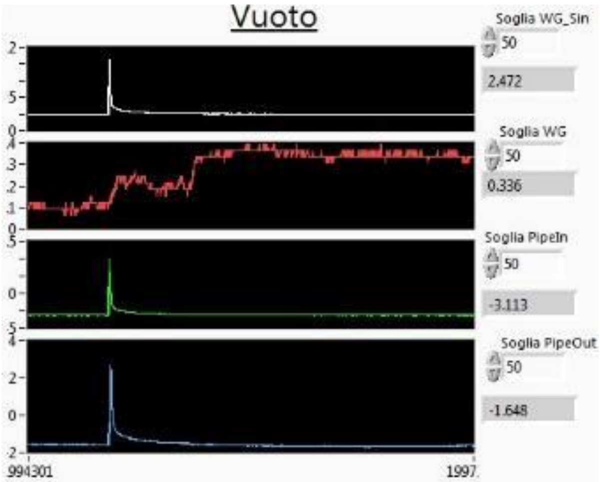

Figure 8.8: Typical event of discharge monitored by the increase in vacuum pressure.

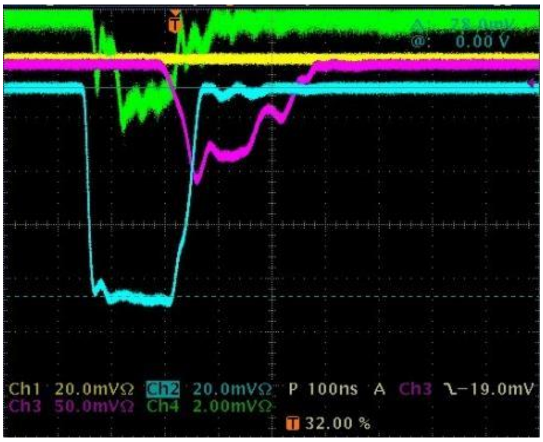

Figure 8.9: Picture of the RF monitored signals: cyan is forward input power, green is reflected power, magenta is transmitted power.

The duration of the RF conditioning for the first RF structure was about 10-15 full equivalent days. As a result, a 38 MW input power was reached in the structure (44 MW from the klystron), nominal repetition rate and pulse length with a corresponding accelerating field of 36 MV/m peak and 32 MV/m average with a breakdown rate BDR $<10^{-5}$ or less, not measured yet since a correct measurement of the BDR requires a long time.

A picture of the C-band modulator control panel at the maximum input power is given in Fig. 8.10.

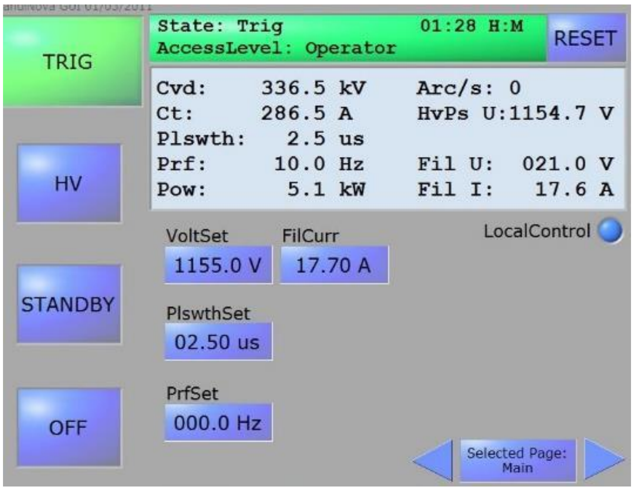

Figure 8.10: Picture of the C-band modulator control panel.

The RF conditioning of the second RF structure started on late December 2013 and was concluded on February 2014. Similar results have been obtained, confirming the achievement of the WP8 Deliverable 8.2 and the success of WP8.

3.4 Test Infrastructures for High Power Accelerator Components (WP9 – TIHPAC)

All the work within WP9 and the corresponding deliverables were achieved in period one and two. In 2014, WP9 contributed to finalization of the second period report (provided in February 2014) and to the preparation of the final report. Furthermore, the partners in WP9 have used the opportunity of the one year extension to improve and update the work in some of the Work Packages beyond the achievements agreed in the Annex “Description of Work”. Contacts were established with other communities which could be interested in the realization of the infrastructures designed in WP9, such as ESS or MYRRHA.

3.4.1 Definition and design of the irradiation test facilities for multi MW target complex tests

The main objective of this task was to design a versatile material testing station to provide a versatile facility for materials characterization under proton and neutron irradiation, Liquid-Metal (LM) corrosion and constant or cyclical stress. Such a test facility is very important to be able to conduct R&D programmes necessary to further develop high power spallation targets for future projects implementing such devices (Eurisol, ESS, Myrrha,…).
The engineering design of this test station is now fully achieved. The overall layout is presented in figure 9.1.

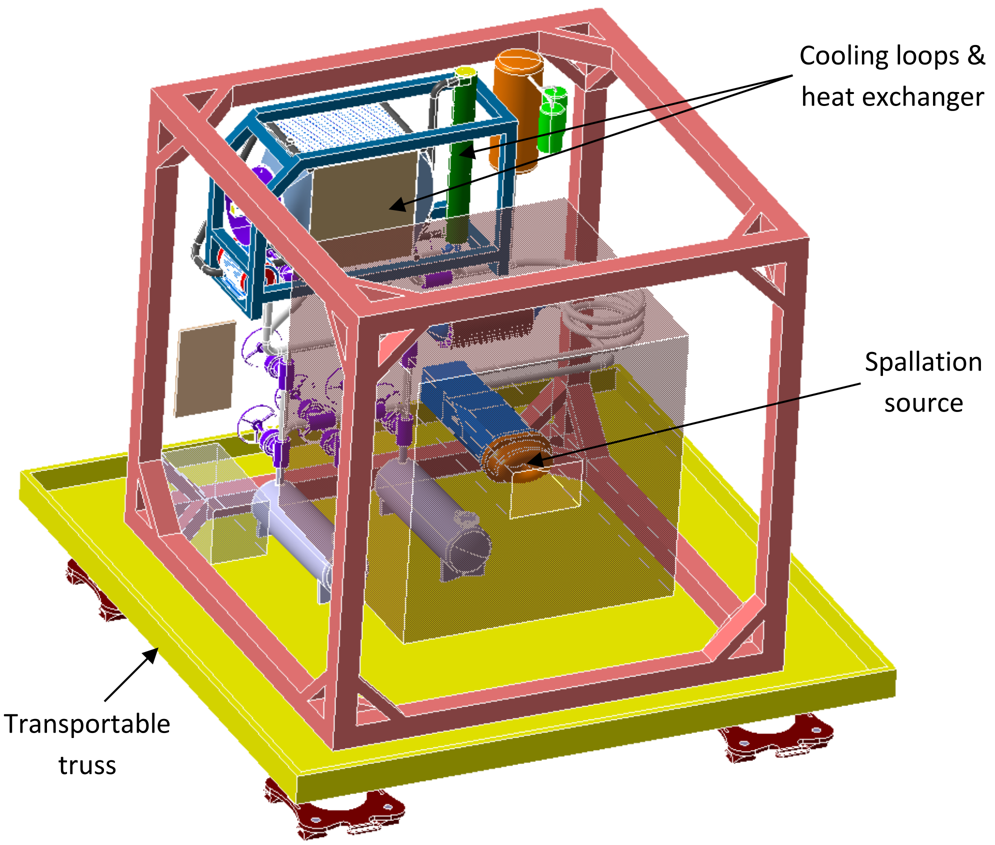

Figure 9.1: Layout of the versatile target test station

The entire facility is laying on an easily transportable truss with rollers or airpads, containing irradiation area and all ancillaries, barriers and shielding. In the center of the facility rests the neutron spallation source where the material samples are positioned for testing. The spallation source contains liquid lead which, when hitted by a proton beam, emits neutrons by the spallation reaction. These neutrons are inducing damages in the tests samples (displacements per atom, or dpa) that we want to characterize. A primary loop interfaces with a secondary loop containing gallium for evacuating the heat to an air-cooled heat exchanger.

The engineering design of the spallation source itself is also achieved (Fig. 9.2), based on neutronic calculations, computational fluid dynamics (CFD) and mechanical analysis to be able to integrate the sample holder (Fig 9.3) where the test material are installed, submitted to the neutron flux.

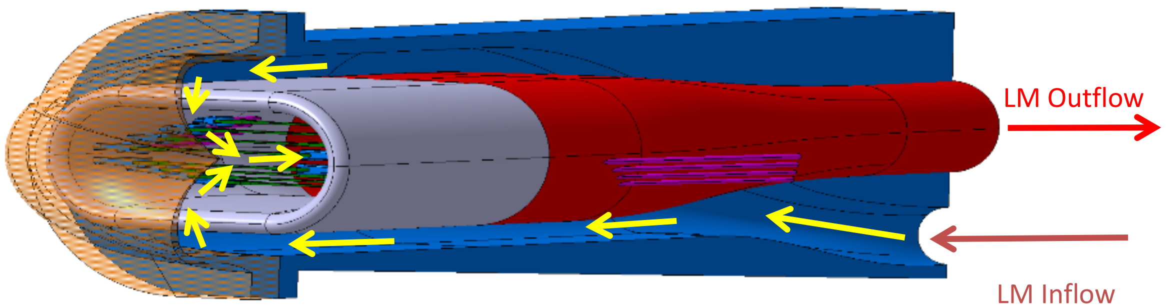

Figure 9.2: Cut-view of the spallation target integrating the Liquid -Metal loop

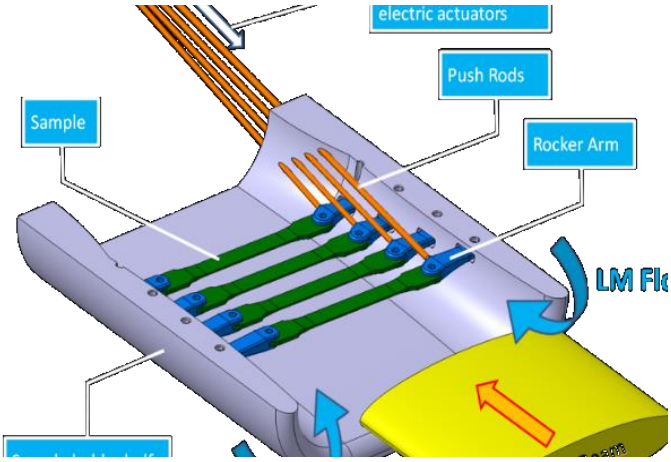

Figure 9.3: Internal view of the spallation target: the sample holder

The main achievement during the last months of the project, besides finalizing the complete engineering design of the test station, was in particular to assess that the dpas (displacement per atom) and the energy deposition from the beam are high enough to fulfill the user requirements. This was performed during the last 2 months, by calculating into details the power deposition by a careful neutronic analysis.

3.4.2 Design of a fully equipped low beta cavities test cryostat

The objective of this sub-task was to perform an engineering design of a versatile test cryostat, capable to host any kind of low beta superconducting cavities (quarter-wave, half-wave, spoke,…), equiped with their ancillaries system (power coupler, cold tuner) and to provide all the required cryogenic environment to perform RF tests at the nominal operating temperature.

After analyzing the user requirements for such an equipment, and after studing several potential cryostat configurations, the design work focused on the most adapted cryostat configuration: a top loaded configuration, which, despite a higher cost compared to a rounded-shaped horizontal cryostat, is much more adapted to provide the required versatility.
As shown on figure 9.5 & 9.6, the cryostat is about 2.7 meter long, 1.5 meter wide and 3.4 meter height. It has the capacity to host a cavity and a superconducting solenoid for specific tests.

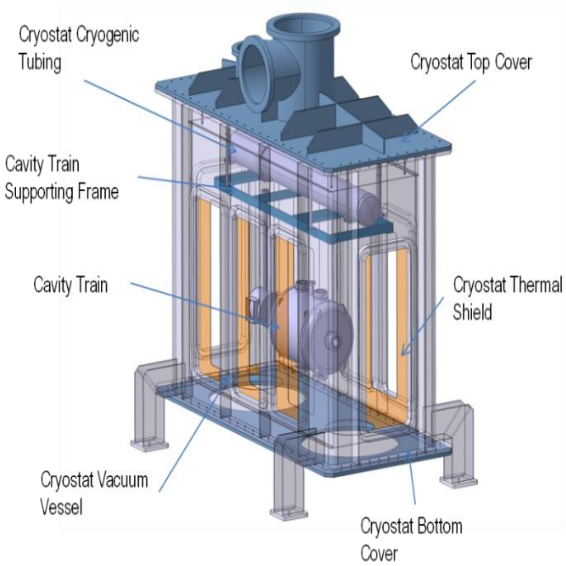

Figure 9.5: Overall view of the low beta test cryostat

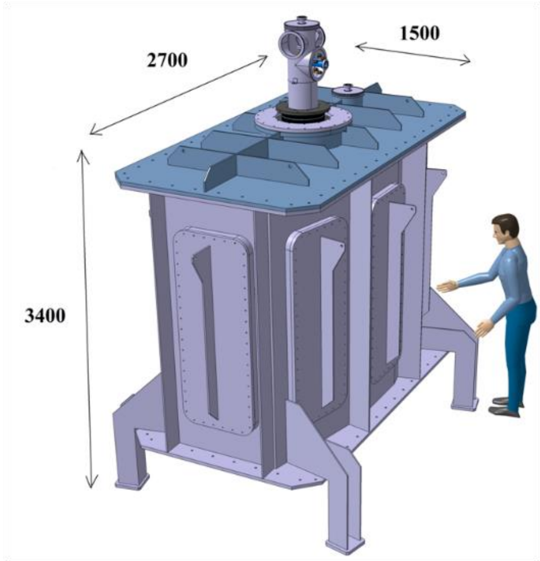

Figure 9.6: Main dimensions of the low beta test cryostat

Mechanical analysis was performed in order to determine and compute the required vacuum vessel shape, wall thicknesses and necessary stiffeners in order to sustain the isolation vacuum. FEM mechanical simulations for static and buckling load cases have been done and these calculations lead to the final choice: a polygonal shape, as shown on Fig. 9.7.

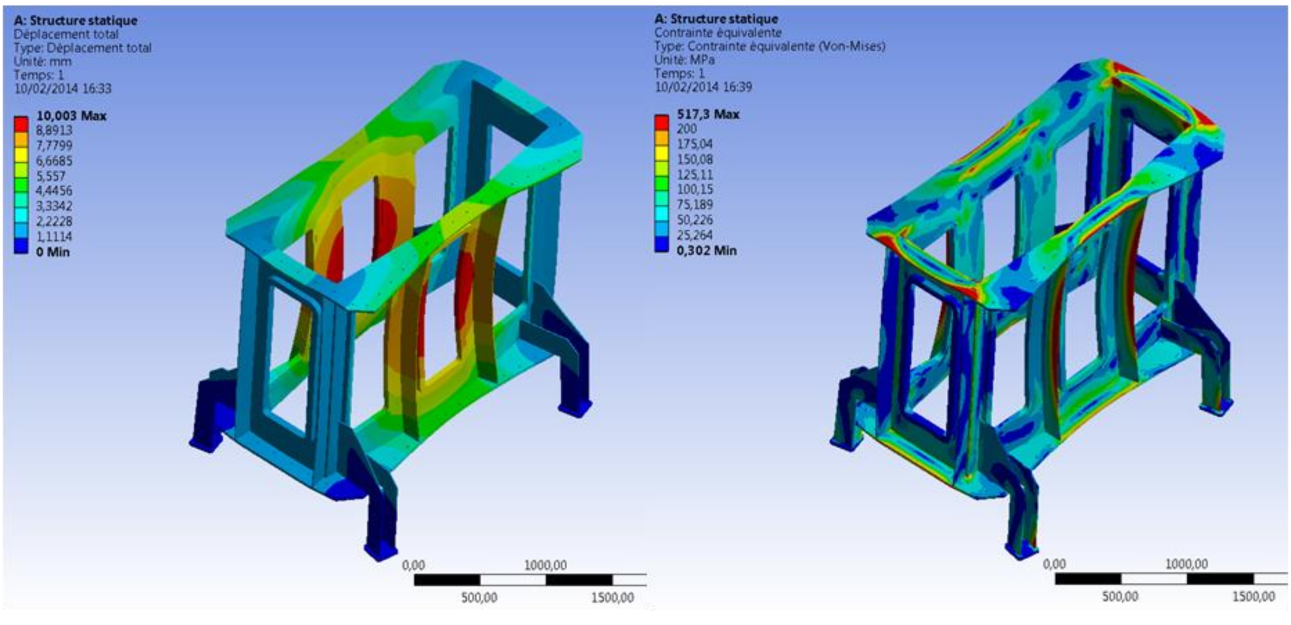

Figure 9.7: FEM analysis (deformation and induces Von Mises stress) of the cryostat under a 1 bar pressure load.

The other main achievement on this sub-task is concerning the valve box for the versatile cryomodule. A conceptual design of this valve box has been achieved. Its main purpose is to feed and evacuate the cryostat with the different cryogenic fluids, under different temperature and state (helium and nitrogen, under liquid or gazeous state).

The cryostat assembly conceptual sequences (together with first thoughts on the required assembly toolings) were also studied in order to check the feasability of the assembly process (Figure 9.8).

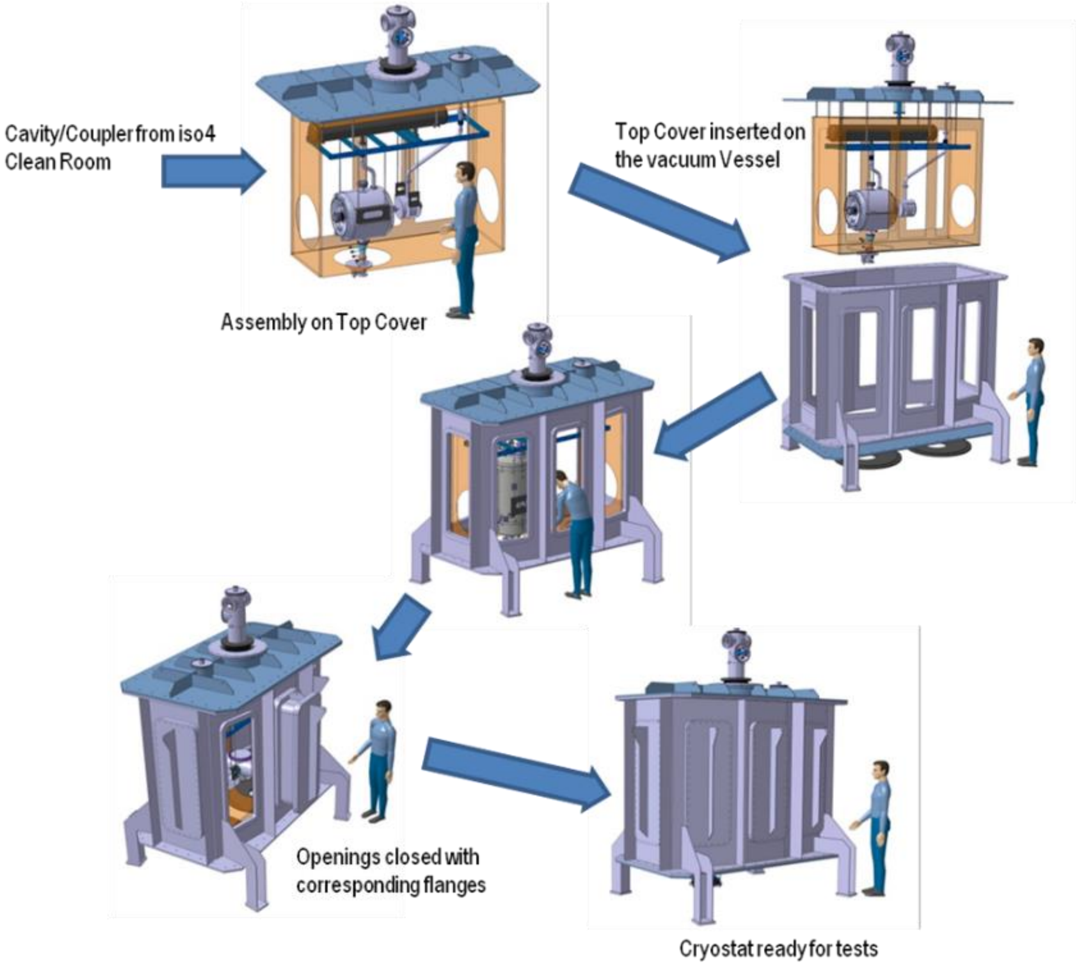

Figure 9.8: Cryostat assembly sequences

The engineering design of low beta cryostat was performed during TIARA-PP, with a solution based on a top loaded cryostat which fulfill the main requirements specifed by the future potential users of such a facility.

4 Potential impact and main dissemination activities and exploitation results

4.1 Potential impact

TIARA-PP aims at establishing a sustainable structure enabling the implementation and the development of a long-term accelerator R&D strategy and programme in Europe through the creation of a Consortium of European research institutes, which operates significant accelerator R&D infrastructures. For such a large-scale project, the implementation phase needs a number of critical organizational, financial, coordination, technical, and legal issues to be solved beforehand, all contributing towards the expected impacts. TIARA-PP tackled all these critical issues directly and will thus directly contribute towards the expected impacts.

4.1.1 Coordination issues (addressed in the Work Packages 2 to 5):

a) Joint Strategic programming and joint R&D programming:

The setting up of a distributed network of European infrastructures for accelerator R&D will be an essential tool for enabling a consistent accelerator R&D programme. An important impact of TIARA-PP is the development of appropriate and recognized structures allowing the communities and policy makers to reach consensus on the strategic areas and the related joint R&D programme. The planning and organization of the work carried out in WP3 and WP4 are important inputs to these expected impacts. WP2 has integrated these inputs and has included these important aspects in the TIARA governance.

b) Promotion of education and training:

In order to establish a sustainable R&D facility and the structure for carrying out accelerator R&D, one needs to address the issues for education and training of accelerator scientists and engineers. Indeed, the shortage of qualified human resources is identified as a critical issue, not only for the research sector but also for industry. WP5 was dedicated to establishing the appropriate plan of action to mitigate this situation, after setting up a large Europe-wide dynamic survey of the relevant education and training programmes available in parallel with a “market” study.

c) Strengthening the collaboration with the industrial sector:

The industrial sector is both the main provider of accelerator components and the user of particle beams for industrial applications. It is important to note that the latter point contributes also to technological development capacity in the European Research Area and to European competitiveness in the global market. The consortium addressed the means to establish the appropriate liaison to the industrial sector and involve industrial partners in the accelerator R&D programme, as well as the development and sharing of the distributed TIARA facilities. Addressing the appropriate mechanisms will result from a large consultation with the medical and industrial sector with the goal to strengthen the global competitiveness of Europe.

4.1.2 Technical issues (addressed in the Work Packages 6 to 9):

One of the reasons for creating the distributed TIARA facilities is to enable the European scientific community to develop world-leading accelerator facilities such as LHC upgrades, CLIC, the Neutrino Factory or EURISOL. The preparation of the corresponding critical technologies necessitates specific R&D projects that already require dedicated R&D infrastructures. It is thus natural to use the opportunity of the Preparatory Phase to accelerate their realization or upgrade in a collaborative way, anticipating partly the implementation of TIARA’s objectives. A first immediate achievement of the expected impacts of TIARA has thus been visible for the first 3 years of the Preparatory Phase.

Indirectly, the user communities will also benefit from a strong consortium combining world-class technical expertise and the timely forefront technical developments it can realize. Finally, the experience gained in developing jointly R&D infrastructures will be extremely useful to identify and solve specific practical issues for establishing the structure of TIARA.

4.2 Main dissemination activities and exploitation results

Appropriate measures ensuring optimum dissemination and use of major results from the project have been foreseen in the project structure. The following table summarizes the envisaged measures and the audience that will be targeted primarily.

The identified targeted audience is 4-fold.

- Research communities
- Medical and Industrial sectors
- Policy makers and government officials
- Public at large

Dissemination and outreach support		Primary targeted audiences: Research communities	Medical and industrial sector	Policy makers and Government officials	Public at large
Scientific and management documentation	Publication, reports	X	X		
	Survey results	X	X	X	
	MoU, MoA	X	X	X	
Meetings	General TIARA meetings	X	X	X	
	Conference/workshops, industry days	X	X	X	
Web-based tools	Internal website	X	X		
	External website	X	X	X	X
	Web-based publication repository	X	X		
	Web-based databases	X	X	X	
Advertising means	Flyers, leaflets and other advertising means		X	X	X
	Press releases			X	X

Four categories of dissemination and outreach means will be used to address these various audiences

- ***Scientific and management documentation***

The scientific and technical results of the projects will be disseminated through publications in journals, TIARA-PP reports, notes and conference papers. The main management documentation will be based on Memoranda of Understanding and Agreement. Several surveys will be used as groundwork to develop consensus and disseminate findings. Other than the formal reporting vis-à-vis the European Commission, specified in the contract, summary reports on the TIARA-PP project will be submitted to the ministries and government agencies of the CERN Member and Observer states, including the EC, through the normal status reports to the European Strategy Sessions of the CERN Council. The reports to the CERN Council will be prepared under the responsibility of the Project Coordinator. The reports to the TIARA-PP Governing Council will also represent an efficient mean of communication with the ministries and government agencies.

- ***Meetings***

The scientific results were also disseminated via attendance at various international and topical conferences and workshops in the field of accelerator science, which account for several thousand engineers and physicists worldwide. The three general TIARA-PP Meetings were a major dissemination event. Active discussions concerning the TIARA Implementation Phase also took place during these meetings, within the accelerator communities. Three TIARA industry workshops were also organised in coordination with WP3:
Superconducting Technologies for Next Generation of Accelerators" in collaboration with CERN
RF Power Generation for Accelerators, in collaboration with Uppsala University
Cryogenics, in collaboration with GSI.

- ***Web-based tools***

A dedicated web-site www.eu-tiara.eu, hosted on a CEA server and managed by the management team, is the main showcase and permanent dissemination tool of the TIARA-PP project. It serves to inform the scientific community at large, as well as any other interested parties, of the activities and results of the PP project. The TIARA website is the access point to various databases as deliverables of Work Packages 3, 4, and 5, as well as the repository for TIARA publications, documentation, and overall supporting material. In particular, a database of the existing R&D infrastructures with their specification and availability was generated and should increase the impact of the project. The TIARA website also provides impact indicators such as the number of publications/preprints/reports, presentations at conferences… as well as the status of the achievement of deliverables and milestones.

A quarterly newsletter, www.acceleratingnews.eu, set up in collaboration with EuCARD (now replaced by EuCARD2), EUROnu and HiLUmi LHC projects for the accelerator R&D community. This newsletter is presently distributed to around 1000 persons.

A public website www.accelerators-for-society.org has been set up and is in operation since July 2013. It demonstrates the impact of particle accelerators on Society through their applications in various domains: R&D but also health and medicine, industry, energy and environment, security and cultural heritage. Its home page is available not only in English but also in French, German, Italian, Polish, Spanish and Swedish.

- ***Advertising means***

Advertising the achievements and results of TIARA-PP is a crucial aspect of dissemination and outreach. The members of TIARA-PP presented the objectives and outcomes of TIARA-PP in wide audience presentations during general wide audience conferences, specific meetings with industries and/or with posters at policy maker meetings, such as ECRI conference. To support further dissemination and outreach, specific communication tools, as for example flyers/leaflets (including the 'Accelerators for Society' 3-fold brochure as well the corresponding Website http://www.accelerators-for-society.org/) and factsheets were developed. For significant highlights the TIARA Project office issued press releases.

Contribution to policy development

Finally, it is worthwhile repeating that the TIARA-PP project has resulted from the longstanding development of a coordinated set of accelerator R&D projects promoted and overseen by ESGARD. The experience gained from TIARA-PP may also have a significant impact on policy development at a European level to help develop practical models for integrated distributed facilities.