DEVELOPMENT OF BEYOND STATE-OF-THE-ART DIAGNOSTIC TECHNIQUES WITHIN THE EUROPEAN NETWORK DITANET

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Abstract

The development of new particle accelerators with unprecedented beam characteristics has always driven the need for an intense R&D program in diagnostic techniques. The successful operation of these machines is finally only possible with an adequate set of beam instrumentation.

DITANET is a large European network between several research centers, Universities, and partners from industry that aims for the development of beyond-state-of-the-art diagnostic techniques for future accelerator facilities. This includes research projects focusing on beam profile, current, and position measurements, as well as on particle detection techniques and related electronics. A particular focus of the consortium is the training of young researchers in this multi-disciplinary field and to thus prepare them for their future careers in academia or industry.

This contribution will introduce the network participants, present the general structure of DITANET, and give an overview of its research and training activities.

INTRODUCTION

Beam diagnostics is a rich field in which a great variety of physical effects are made use of and consequently provides a wide and solid base for the training of young researchers. Moreover, the principles that are used in any beam monitor or detector enter readily into industrial applications or the medical sector, which guarantees that training of young researchers in this field is of relevance far beyond the pure field of particle accelerators. Beam diagnostics systems are essential constituents of any particle accelerator; they reveal the properties of a beam and how it behaves in a machine. Without an appropriate set of diagnostic elements, it would simply be impossible to operate any accelerator complex let alone optimize its performance.

Future accelerator projects will require innovative approaches in particle detection and imaging techniques to provide a full set of information about the beam characteristics. Since a long time, Europe has played a major role in this field and the declared goal of this network is to pave the way for world-class research with particle accelerators. This will only be possible by a joint training effort, where knowledge and technology transfer are encouraged, where close collaboration with industry is an integral part of the network, and where leading research centers and major universities work closely together.

Marie Curie Initial Training Networks (ITN) are aimed at improving the career perspectives of researchers who are in the first five years of their career by offering structured training in well defined scientific and/or technological areas as well as providing complementary skills and exposing the researchers to other sectors including private companies.

DITANET - "**DI**agnostic **T**echniques for particle **A**ccelerators - an initial training **NET**work" - covers the development of advanced beam diagnostic methods for a wide range of existing or future accelerators, both for electrons and ions. The proposed developments in profile, current, and position measurement techniques clearly stretch beyond present technology and will mark the future state of the art.

The network comprises almost all of the European expertise in this field, either in the form of the network members themselves or as associate partners, having well-proven expertise in finding solutions to the technological challenges related to the development of cutting edge diagnostic techniques. This stimulates on one hand the search for the most advanced methods and technologies and ensures at the same time a comprehensive training of young researchers who will get the unique possibility to become experts not only in their main research field, but also in related techniques.

DITANET consists of the following network participants: University of Heidelberg (coordinator, Germany), CEA (France), CERN (Switzerland), DESY (Germany), GSI (Germany), HIT GmbH (Germany), IFIN-HH (Romania), Stockholm University (Sweden), Royal Holloway University of London (UK), and the University of Seville/Centro Nacional de Aceleradores (Spain).

It is complemented by twelve associated partners from all over the world: ESRF (France), idQuantique (Switzerland), INFN-LNF (Italy), Instrumentation Technologies (Slovenia), MPI for Nuclear Physics (MPI-K), PSI (Switzerland), THALES (France), Thermo Fisher

Scientific (USA), TMD Technologies Limited (UK), TU Prague (Czech Republic), ViALUX (Germany), and WZW Optics (Switzerland).

NETWORK STRUCTURE

The DITANET Marie Curie Initial Training Network forms a consortium which comprises the ten participants and a roughly equal number of associated partners. It is the goal of the governance structure to profit from the individual expertise of the parties involved while maintaining an effective decision making and controlling process.

The governance structure is sketched in the following figure 2. Its key bodies are the Supervisory Board, the Coordinator assisted by the Management Office in scientific, management and financial matters, and the DITANET Steering Committee.

Whenever required, a spin-off board will complement this structure.

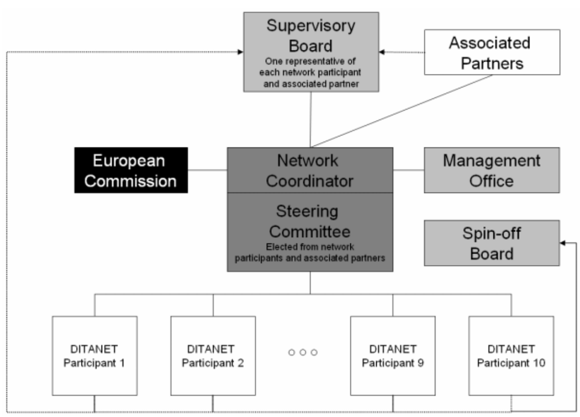

Figure 1: DITANET structure

A Consortium Agreement is presently being concluded between the partners. It regulates the management and organizational structure of the network and the demarcation of responsibilities between its different entities. It also regulates intellectual property issues such as pre-existing know-how, patents and accession rights.

RESEARCH

DITANET covers the development of advanced beam diagnostic methods for a wide range of existing or future accelerators, both for electrons and ions.

The DITANET projects can be split into six thematic packages as depicted in figure 2.

All projects within DITANET involve an extremely wide spectrum of technologies in various fields, including optics, mechanics, cryogenics, electronics, as well as data acquisition and processing, and thus require a multi-disciplinary approach. The aim of this network is thus to set up the frame for a truly inter-European network with the objective of strengthening interdisciplinary communication between the participating laboratories, partners from industry and university groups.

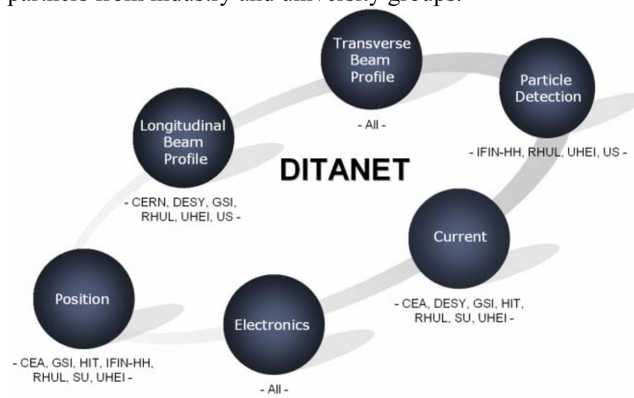

Figure 2: Overview of DITANET work packages

The accelerator projects that will be covered within DITANET range from the next generation of linear colliders (ILC, CLIC) and the most advanced high energy accelerators (LHC, FAIR), to innovative light sources (X-FEL) and novel low-energy storage ring projects (DESIREE, USR).

Some examples of the research projects within DITANET are outlined in the following sections.

The Large Hadron Collider (LHC)

The Large Hadron Collider [1] will boost protons and heavy ions to very high energies and bring them in collision. The particles will be grouped in bunches separated by empty spaces. The distance between two consecutive bunches is 25ns and their total number is 2 x 2808 . The particles that for a reason or another escape from the bunches will eventually be lost potentially quenching a magnet, or even damaging the machine. For this reason it is very important to monitor and study the distribution of the particles in the rings, and in particular to monitor the protons drifting out of the RF buckets or drifting into what is called the abort gap.

The monitor that will be developed by an Early Stage Researcher (ESR) must have a large dynamic range (10^6) and a fast time resolution (50ps). The solution proposed consists of a two-parts system, one with the required dynamic range but smaller time resolution (100ns) used to monitor the protons population in the mentioned abort gap, the other with a lower dynamic range (10^4) and full time resolution for the measurement of the protons population inside the bunches and in the empty spaces between them.

Both systems are based on the detection of single photons of synchrotron radiation emitted by the beam. In the first case the high dynamic range is achieved by using gated photomultipliers that are gated on the abort gap interval. In the second case the fast response is achieved by using state-of-the-art Avalanche Photo Diodes (APD) and time-to-digital converters.

Fast Wire Scanners for the XFEL Project

The performance of future projects based on (superconducting) Linacs like the ILC [2] and XFEL [3] depends critically on the correct matching of the phase space in the different parts of the machine. Even slight changes, e.g. in the injector region, might result in loss of performance by orders of magnitude. Therefore, a precise control of the beam sizes at different locations in the machine is required.

Due to the high load of their beams and the requirement of non destructive measurements screens cannot be used to determine the beam sizes during standard operation. Also the currently used types of wire scanners [see e.g. 4, 5] are not suitable. Due to the low speed of the existing types, the wire would burn within a bunch train. Scanner speeds of 10-20 m/s with a position resolution of 1 micron are necessary to get the required endurance. In the frame of a project for an Early Stage Researcher (ESR) a novel, continuously rotating wire scanner that is synchronized to the beam will be developed. High demands are put on synchronization and vacuum technology together with the requirement of a roughly 1 μm resolution.

Beam Diagnostics for CLIC

One of the major decisions in particle physics over the next 3 years will be to decide on the next major accelerator to access the multi-TeV energy scale. The CLIC two-beam acceleration scheme [6] is one of the candidates for the next accelerator for the high-energy frontier, and the CLIC Test Facility (CTF3) at CERN [7] is the unique facility to test the CLIC acceleration principle and to prove the feasibility of associated RF systems.

In addition to the RF accelerating systems themselves, a host of beam diagnostics will need to be developed to cope with the challenging environment of CLIC. There exists space at the CLEX area of the CTF3 facility to build a new Instrumentation Test Beam (ITB). One of the first tasks of the trainee will be to design the machine optics for the ITB in collaboration with the CERN experts and to work with the CLIC diagnostics team to optimize the layout and functionality for future key diagnostics projects.

In addition to the ITB design, the Early Stage Researcher (ESR) with work with TMD technologies to assess the opportunities for RF system development and to identify a fruitful new line of R&D where the expertise of TMD can be combined with the expertise at RHUL and CERN to develop a new product of use to the CTF3/CLIC project.

The system design work will be complemented by frequent data taking and machine operation at CTF3. This combination of practical experience, beam-line design, and industrial collaboration, will provide a unique training opportunity.

The Ultra-Low Energy Storage Ring (USR)

To enable the efficient investigation of some very essential questions regarding the physics with low-energy antiprotons and possibly exotic highly charged ions, a novel electrostatic cooler synchrotron, the ultra-low energy storage ring (USR) [8,9], and a state-of-the-art in-ring spectrometer [10] will be developed in the QUASAR group at the Kirchhoff Institute for Physics/Max-Planck Institute for Nuclear Physics in close collaboration with the GSI Atomic Physics Division, and other groups from the University of Heidelberg.

The aim of the USR will be to slow down antiprotons as well as possibly highly charged ions (up to bare uranium) to very low energies between 300 and 20 keV/q. This will provide world-wide unique conditions for both in-ring studies with an intensity of up to 10^{12} cooled and stored antiprotons or highly charged ions per second, as well as for experiments requiring extracted slow beams. In the frame of an Early Stage Researcher (ESR) project, the beam diagnostic elements as they are required for a successful operation of such a machine will be developed.

The boundary conditions of the USR project put very high demands on the machine's instrumentation: In order to ensure reasonable life times in the ring, ultimate vacuum pressures have to be realized extending to below 10^{-14} mbar if highly charged ions shall be stored and slowed down. Hence, an approach considered in the present study is to cryogenically cool the vacuum chambers of the USR to a temperature of only a few Kelvin. The extremely low vacuum pressure of the (cooled) USR together with a beam energy of only 20 keV and low currents of singly charged antiprotons between 1 nA and 1 uA require the development of new diagnostic methods as most of the standard techniques will no longer work.

Beam Tracking for FAIR

In order to study the nuclear structure of weakly-bound nuclei, knowledge about reactions induced by them should be improved. The existing Radioactive Ion Beam (RIB) facilities and the new ones (SPIRAL II, FAIR) provide an ideal environment to study such nuclides. From an experimental viewpoint, the detection and reconstruction of the particle trajectories is a key parameter to obtain good experimental resolution. In particular, the low energy branch of the FAIR facility will produce exotic beams, with large emittance and low energy resolution. These beams need to be tracked by detectors that allow obtaining the velocity and direction of each particle of the beam. Secondary emission detectors (SeD) have been proved to be adequate for this purpose [11], for very low beam intensity (10^3 pps). However, new developments are required to use SeD detectors to track the intensities expected at the low energy branch at FAIR [12].

The 3 MV tandem accelerator at the Centro Nacional de Aceleradores (CNA) at the University of Seville, along with a specifically designed tracking chamber offers an excellent opportunity to test the position and time signals of the tracking detectors, and correlate them with the known properties of the low energy beams.

This project will focus on the operation of different types of beam detectors (Diamond Detectors, Secondary Emission Detectors, Multi-wire Chambers) to track ion beams produced at the CNA, and to design prototypes of detectors to be used in the HISPEC-DESPEC experiment at the FAIR facility.

TRAINING

Young researchers participating in the network program will not only get the possibility to perform state-of-the-art research, they will also get a much wider training in the domain of beam diagnostics by interaction with other network participants and close collaboration with associated partners from the industrial sector. This includes regular exchanges of trainees between the partners that will thus get the possibility to participate in ongoing R&D work at linked institutes and universities.

This way, DITANET will provide a cohesive, flexible framework for the training and professional development of researchers in beam diagnostic techniques for particle accelerators, with a strong focus on possible applications of these principles in industry. The network will thus contribute to overcoming institutional and disciplinary boundaries and add value to the training of the researchers over and above that which could be provided by a single network partner.

The network members have a long record of successfully training young researchers and the necessary capacities to ensure a high-level training and close supervision. Mutual recognition of the training acquired at the different participating institutes is a core element of the DITANET joint training scheme.

While helping young researchers to put together their individual training plan at each of the institutes, DITANET will also promote a multidisciplinary training in the wider field of beam diagnostic techniques. This means that all young researchers within the network will have the opportunity to learn enough about other involved disciplines to be able to design, install and operate most of the key detectors used in accelerator physics. This responds to the need for strong interdisciplinary skills and expert knowledge in a range of different diagnostic techniques.

DITANET will organize one week courses on beam diagnostic techniques in spring 2009 and fall 2010 that will be open to all network participants as well as to external participants. Details on these courses will be published on the DITANET web site [13].

RECRUITMENT

DITANET's focus is the training of early stage researchers, i.e. PhD candidates, in next-generation diagnostic techniques for particle accelerators. Thus the main fraction of the researchers to be recruited (91%) is early-stage researchers.

High priority will be given to a recruitment strategy based on international competition. All positions are presently published in both online resources and relevant international journals, ensuring open access for interested applicants. Appointments will be made on the basis of direct comparison between the applications and qualification for the respective topic. The ultimate goal will be to ensure a multicultural network composition with the possibility for each trainee to experience the benefits of cultural diversity.

Particular attention is paid to promote gender issues by addressing this point in all position openings and explicitly encouraging women to apply. The participating institutions support this attempt by family-friendly policies, including flexible approaches to career breaks and support for return from career breaks. The possibility of part-time work and child minding services close to the working place is already established at many of the network partners and shall be offered wherever possible.

Furthermore, a special mentorship program will be established in the context of this network to accompany and promote female doctoral students and young Post-docs throughout their work in the network. The main objectives are to strengthen understanding, extend networking both laterally and vertically, and to develop effective strategies for the advancement of women, i.e., bottom up and top down.

INVOLVEMENT OF INDUSTRY

The participation of industry is an integral part of DITANET. As shown in the beginning of this article, a number of private companies are included as associated partners to the network. They are members of the supervisory board to ensure that industry-relevant aspects are covered in the different projects carried out within the network and to enhance knowledge transfer. In addition, one third of the DITANET Steering Committee members come from industry.

From the beginning, the DITANET management encouraged the involvement of these partners in the training program at the highest possible level. This led to the participation of HIT GmbH as a full network member with a PhD project that will be hosted by this company. In addition, the associated partner THALES, who is considered as a world-wide leader in the development of klystron technology, will host the trainee from CEA during up to 25% of the PhD project, thus taking over a considerable part of the training.

WZW Optics , Vialux, Thermo Fisher and idQuantique are among the leading companies in the field of optics, scientific cameras and detector systems. Instrumentation Technologies from Slovenia and TMD technologies from the UK have long-standing links to accelerator laboratories and have pushed the development of beam diagnostic techniques on various occasions in the past.

All companies as well as the other associated partners from academia (TU Prague, MPI for Nuclear Physics) and research (PSI, INFN, ESRF) have agreed to host the DITANET trainees during some weeks up to several months. This ensures that every trainee will get the possibility to realize an extended research stay at a leading partner institute from industry and to take part in its R&D efforts.

Thereby it is guaranteed that all trainees will be provided with a true multi-disciplinary and inter-sectorial training, where they will not only work on their main project, but learn about neighboring fields and get a view of possible applications and of the impact of their work in the industrial sector.

These measures will complement the scientific training and actively bridge between the academic and the industrial sectors within DITANET.

CONCLUSION

The largest ever coordinated EU education action for young researchers in the field of beam diagnostic techniques for particle accelerators has been awarded to a consortium of ten groups from all over Europe within the EU-Marie Curie program for initial training networks. The joint effort in setting up DITANET and the corresponding administrative and training-related boundary conditions will guarantee a continuous training of young researchers in this field. Close collaboration between the network participants and the associated partners with a very prominent role of industry, will ensure that the basis for DITANET is laid in a true international approach with a clear long term perspective.

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