DITANET CONTRIBUTING TO STATE-OF-THE-ART DIAGNOSTICS DEVELOPMENTS

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on behalf of the DITANET consortium

Abstract

DITANET is the largest-ever EU funded training network in beam diagnostics. The network members - universities, research centers and industry partners - are developing diagnostics methods for a wide range of existing or future particle accelerators, both for electron and ion beams. This is achieved through a cohesive approach that allows for the exploitation of synergies, whilst promoting knowledge exchange between partners. In addition to its broad research program, the network organizes schools and topical workshops for the beam instrumentation community.

This contribution gives an overview of the Network's research portfolio, summarizes the main research results from the first two years of DITANET and presents past and future training activities.

INTRODUCTION

The DITANET project officially started on 1.6.2008 and consists of ten network beneficiary partners and presently 17 associated and adjunct partners. The training network brings together Universities, research centres, and the industry sector with the aim to jointly train the next generation of young scientists in beam instrumentation.

A core idea of DITANET is that all network members interact and collaborate closely, promote the exchange of trainees and staff within the network, and jointly organize training events, workshops and conferences open also to external participants.

The participation of industry is an integral part of the training within DITANET and all partners from industry are included as 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, they offer internships to the students from the network to complement the scientific training and thus actively contribute to building the bridge between the academic and the industrial sector.

RESEARCH

DITANET covers the development of diagnostic methods for a wide range of existing and future accelerators. The developments target beam profile, current, and position measurement. This section presents some of the research outcomes to date.

The Ultra-low Energy Storage Ring

The international Facility for Antiproton and Ion Research (FAIR), to be located at the site of the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany comprises a series of rings to provide intense beams of antiprotons, unstable exotic nuclei and highly charged ions.

The Facility for Low-energy Antiproton and Ion Research (FLAIR) is based on the need for high-brightness high-intensity low-energy antiproton beams. Antiprotons from the new experimental storage ring (NESR) will be injected into the Low energy Storage Ring (LSR) at an energy of 30 MeV. They will then be cooled and further decelerated to 300 keV energy. The Ultra-Low energy Storage Ring (USR) [1], presently being developed by the QUASAR Group, will provide electron-cooled beams of antiprotons in the energy range between 300 and 20 keV.

These boundary conditions put challenging demands on the USR beam instrumentation. Some important beam parameters are summarized in Table 1.

Table 1: USR beam parameters

Energy	300 keV → 20 keV
Relativistic β	0.025 → 0.006
Revolution frequency	178 kHz → 46 kHz
Revolution time	5.6 µs → 21.8 µs
Intensity	1 µA → tens of fA
RF frequency (h = 10)	1.78 MHz → 459 kHz
Bunch repetition time (h = 10)	560 ns → 2.2 µs
RF bucket length (h = 10)	4.4 m
Charge per bunch (h = 10)	0.3 pC ($2\cdot10^6$ pbars)

Depending on whether slow or fast extraction will be applied, the beam intensity and the time structure of the extracted beam will vary in a wide range.

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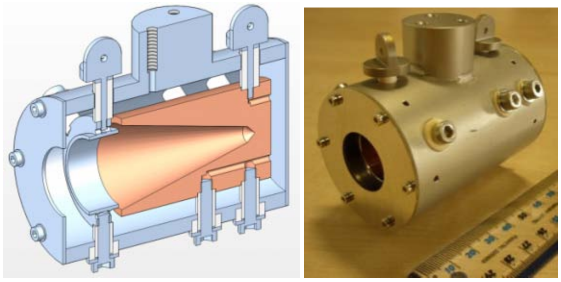

Figure 1: Faraday Cup for the USR

A Faraday cup was designed, based on an existing layout at the MPI-K, Heidelberg. It was optimized for the energy region of interest and allows for the measurement of beams with a maximum diameter of 20 mm, Fig 1.

The shape of the beam stopper was chosen in order to optimise the secondary electrons collection efficiency. The shape of the stopper as well as of the suppressing electrode that shall contain the emitted charges inside the cup was optimized with CST Studio and more detailed results are presented elsewhere in this workshop [2]. The cup will be used for first tests with beam at the Clatterbridge Centre for Oncology this summer.

Additional parts of this ESR project cover the design and optimization of a capacitive beam position monitor [3] and investigations into different screen materials for beam profile monitoring of low energy, low intensity beams [4]. For the latter, measurements were already realized in close collaboration with INFN, Italy.

Emittance Measurement at HIT

The transverse emittance of the ion beam at the Heidelberg Ion Therapy Center (HIT) will be measured within the Low Energy Beam Transport (LEBT) using a pepper-pot measurement system. At HIT, two ECR sources produce ions (H, He, C and O) at an energy of 8keV/u with different beam currents from about 80 µA to 2mA.

The mechanical design of the pepper–pot system is the result from collaboration between DITANET partners GSI and HIT and is shown in figure 2.

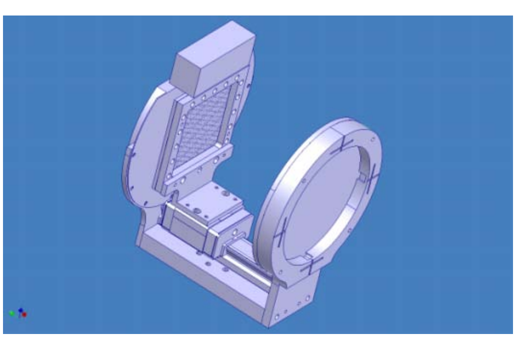

Figure 2: Illustration of the pepper-pot scintillator bench.

Critical to the performance of the emittance measurement is the performance of the scintillating screen. To enable high spatial resolution, the screen material should interact with the impinging particle beam in a similar way across the entire screen surface. For most materials that also satisfy the necessary vacuum and light yield conditions, this is not the case.

Detailed studies into different materials, aiming at identifying the optimum solution for the energy and intensities in question, were carried out at the MPI-K in Heidelberg. In these tests, the following materials were studied: (1) Inorganic Doped Crystal (YAG:Ce, YAP:Ce, Caf2:Eu), (2) Inorganic Undoped Crystal (Sapphire, YAG), Quartz and Borosilicate glass (Herasil 3 & 102, Infrasil 301 & 302, Suprasil 1 & 300), and Borosilicate Glass D 263 T.

During these runs, the scintillator was placed in the beam path at a 45 degree angle. The images were recorded with a conventional CCD camera. It was possible to place three scintillators on a common support and to test them under the same operating conditions. The detailed results of this study are presented in [5].

Longitudinal Beam Profile Measurements at the Large Hardron Collider

The Large Hadron Collider at CERN will accelerate protons up to an energy of 7 TeV. An optical arrangement has been made which focuses synchrotron light from two LHC magnets to image the cross-section of the beam. It is also planned to use this setup to produce a longitudinal profile of the beam by use of fast Single Photon Counting. This is complicated by the bunched nature of the beam which needs to be measured with a very large dynamic range.

The primary source of the synchrotron light is a 9 m long superconducting bending magnet with a uniform vertical magnetic field. In order to keep the beam trajectory constant, the magnetic field strength is increased in proportion to the beam energy. The field strength in this magnet is varied from 0.25 T to a maximum of 3.9 T. The nature of the synchrotron light emitted in the bending magnet can be calculated analytically [6] or computed using a simulation code such as Synchrotron Radiation Workshop (SRW) [7]. Not only the power emitted by each proton but also the spectrum and angular distribution of the light depend on the γ of the protons i.e. on their energy. The light will therefore change during the LHC's accelerating cycle. The total light emitted is simply the sum of the light from individual protons. Thus the light intensity can be used as a proxy for proton density at different points along the beam.

In order to allow the monitor to be used at lower beam energies, an additional undulator magnet has been installed just upstream of the bending magnet. It increases the emission of synchrotron light drastically without negative impact on the motion of the stored beam. In this case the emitted spectrum is dominated not by the critical frequency but by interference effects arising from the periodic structure of the undulator. This particular undulator has been designed to emit visible synchrotron light at proton energies below those at which the radiation from the bending magnet can be used.

In order to monitor not only the transverse beam profile, but also the longitudinal density profile of the LHC beam, the detector should allow for a detection of time structures with a resolution of 50ps. In addition, two functionalities are requested. Firstly, there should be a fast integration mode which can measure the bunch parameters (bunch length, density distribution) with an integration time of 1 ms. Secondly, there should be a high-sensitivity mode which can produce a full longitudinal profile showing all the bunches with a sensitivity of $5x10^5$ protons per 50ps bin. This implies a dynamic range of more than 30,000 compared to the maximum density at the centre of the bunch. Of particular importance is to measure the tails of the bunches and the nominally empty spaces between bunches. Given the small amount of light available and the fast time resolution required, time-correlated single photon counting will be used to construct the profile. An avalanche photo diode (APD) operated in the Geiger mode is suitable for detecting single photons with such high time resolution. Different detectors were already characterized in an optical lab at CERN [8] and will be used for tests with beam in the near future.

Intensity Modulated Radiation Therapy

Within a collaboration between the national accelerators center (CNA), the department of atomic, molecular and nuclear physics of the University of Seville, Virgen Macarena Hospital of Seville, the engineering school of the University of Seville and the private company INABENSA (ABENGOA), an active research is ongoing on a project dedicated to radiotherapy with high-energy photon beams.

This collaboration exploits the knowledge and expertise of these groups on nuclear instrumentation, electronic and mechanical design, theoretical calculations, Monte Carlo simulations and analysis of nuclear reactions, and transfers it to the medical field and in particular to radiotherapy treatments.

The aim of the project is to validate a novel method to obtain a map of doses in the pre-treatment of patients with Intensity Modulated Radiation Therapy (IMRT). The method uses a mathematical algorithm and Geant4 Monte Carlo simulations. Measurements are performed at Virgen Macarena Hospital using the 6-MV photon beam produced by a Siemens Primus accelerator.

The detector used for dose measurements is a commercial single-sided silicon strip detector of 500 μm thickness, Fig. 3. Its active area of 50x50 mm^2 is divided into 16 narrow strips (3 mm width each) and a separation of 0.1 mm between strips. This type of detector is widely used in nuclear physics experiments for time of flight measurement and particle or fragments identification.

Figure 3: Picture of the silicon strip detector inside the phantom for the characterization of its dosimetric response.

Preliminary tests with the detector and with a dedicated electronics have been carried out irradiating the device with 6 MV photon beams in order to study the response of the device and of the electronics with different radiation fields at different doses. The device showed a good linearity with respect to the dose accumulated, a good uniformity in the response of the strips and a good percent depth dose profile. These preliminary tests with this detector are very encouraging and it is planned to use it in further measurements for obtaining a dose map during a dedicated treatment.

Finally, in order to improve the actual spatial resolution, it is planned to investigate into the possible use of 2D silicon detectors.

Beam Halo Measurements at UMER

A thorough understanding of halo formation and its possible control is highly desirable for essentially all particle accelerators. Particles outside the beam core are not only lost for further experiments, they are also likely to hit the beam pipe, and activate this, as well as accelerator and experimental components in close proximity, which makes work on the accelerator costly and time consuming. Well established techniques for transverse beam profile measurements of electron or high energy hadron beams are the observation of synchrotron radiation, optical transition radiation or the like. A particular challenge, however, is the detection of particles in the tail regions of the beam distribution in close proximity of the very intense beam core. A flexible core masking technique based on a DMD micro mirror array which allows for a fast mask generation to blank out the central core and to focus the measurement on the tails of the distribution was developed in close collaboration between the University of Liverpool, the MPIK, CERN, ViALUX and the University of Maryland [9,10]. An example of a measurement with the adaptive mask is shown in the following Fig. 4.

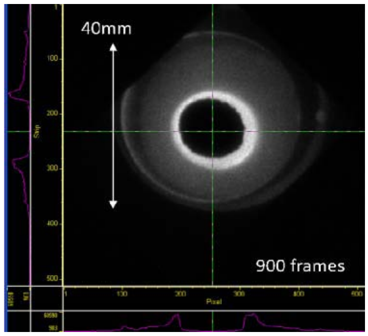

Figure 4: Beam profile measurement with core deflected by DMD at UMER.

This research project was not part of the original DITANET research program, but illustrates nicely how the structures and links created by the network can help paving the way for new developments.

TRAINING

Although training within DITANET is mainly by training through research, all network partners also provide an extensive local training to their Marie Curie Fellows. This is mostly realized in the frame of a structured PhD program and in collaboration with partners from different sectors. In addition, DITANET organizes network-wide events, such as Schools, Topical Workshops, and conferences that have to be attended by the network trainees, but are also open to the wider diagnostics community. This section provides a short summary of past events.

DITANET School on Beam Diagnostics

From March, 30th - April, 3rd 2009 the first DITANET School on Beam Diagnostics took place at Royal Holloway, University of London. The School was combined with the first DITANET annual meeting and brought together more than 70 researchers from major Research Centers, Universities and private industry from all over the world.

The School started with an introduction to accelerator physics and the definition of particle beams, before basic beam instrumentation, for example beam energy, beam current and transverse beam profile measurement were covered. Later in the week more advanced topics, e.g. the monitoring of the machine tune and electron cloud diagnostics were presented. An excursion to Rutherford Appleton Laboratory including visits to ISIS and DIAMOND on Wednesday, April 1st as well as two tutorials and one poster session complemented the broad program.

A particular highlight was a dedicated industry session on the last day where lecturers from Thermo Fisher Scientific, TMD, Thales, ViALUX, and Instrumentation Technologies gave an insight into cutting edge R&D activities in the industry sector with a focus on differences as compared to research in academia.

School on Complementary Skills

DITANET organized a Complementary Skills School at the University of Liverpool from 15th-19th March 2010. This course aimed at providing the network's early stage and experienced researchers with the necessary skills base for a future career in both, the academic and industry sectors.

After an introduction session, the participants focused on different presentation techniques and discussed best practice as well as common mistakes. Day two started with an introduction to project management, before putting a focus on individual presentations. All participants had to give a 5 minute presentation on their research projects that was recorded and then assessed individually. On Wednesday, the school triggered discussions about the benefits from and challenges in international networking. Representatives from Tech-X UK and Inventya reported on their personal experiences, before a session on time management concluded the morning. On Thursday, time and self management, a session on work/life balance as well as two hours on intellectual property rights and patent law confronted the trainees with a number of important skills and triggered many discussions. Finally, an extended session on scientific writing completed the week.

Topical Workshop Series

The first DITANET topical workshop took place on November, 24th and 25th in Hirschberg-Großsachsen, near Heidelberg, in Germany. It focused on the diagnostics of low energy and low intensity ion beams and brought together around 40 scientists and engineers from all over the world. Its particular aim was to join early stage researchers both from within the network and from the wider community with renowned experts to allow for establishing important contacts for their careers and for reviewing the status of the different R&D activities.

The first day started with an introduction to the future Facility of Antiproton and Ion Research, where many of the monitors presently under development in different groups will be used to monitor all beam characteristics with a high precession. It then stretched to the beam instrumentation used at different storage ring and cyclotron facilities around the world.

The second day concentrated on electrostatic storage rings which are the ideal tool for lowest beam energies down to a few tens of keV and intensities as low as 10^4 pps. Presentations were given on the ELISA (ISA, Arhus), DESIREE (MSL, Stockholm), CSR (MPI-K, Heidelberg), and USR (FAIR, Darmstadt) facilities and triggered interesting discussions on these challenging developments.

This workshop marked the beginning of a workshop series that will be organized by the network. A workshop on "longitudinal beam profile measurements in high accelerators and light sources" will be organized on July 12th and 13th at the Cockcroft Institute, UK.

Detailed information on all past and future events is accessible via the network's homepage [11].

NETWORK STRUCTURE

DITANET initially consisted of the following network beneficiaries: University of Liverpool (coordinator, UK), 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 (Italy), Instrumentation Technologies (Slovenia), MPI for Nuclear Physics (Germany), PSI (Switzerland), THALES (France), Thermo Fisher Scientific (USA), TMD Technologies Limited (UK), TU Prague (Czech Republic), ViALUX (Germany), and WZW Optics (Switzerland).

In addition, the network introduced *adjunct partnerships* for institutions that are active in R&D fields closely related to the network and that share the network's training visions. These partners agreed to contribute to the training and joined the consortium after the official project start. They are an important part of DITANET's long term strategy in establishing lasting bonds and partnerships across institutes and disciplines in Europe. So far Diamond Detectors Ltd. (UK), the University of Dundee (UK), the University of Uppsala (SE), the University of Maryland (USA) and Lawrence Berkeley National Lab (USA) joined DITANET as adjunct partners.

DISSEMINATION

The DITANET web site is hosted by the University of Liverpool and can be found at www.liv.ac.uk/ditanet. It is a central point for all information regarding the network and includes information about each of our partners, their trainees and the projects in which they are involved.

In addition, it provides information on events and is a collection point for all presentations and papers within the Network by providing external links in addition to uploaded documents.

The network issues a newsletter quarterly by e-mail to partners and colleagues in beam diagnostics and accelerator science across the world. Its aim is to inform and disseminate, providing information on members of the DITANET project, its partners, trainees and its scientific work.

Copies of the newsletter are freely accessible via the DITANET website which also provides a facility for on-line subscription.

An annual prize is part of the network's wider dissemination strategy. It is awarded for an outstanding contribution to the field of beam instrumentation for particle accelerators and presented to a researcher in the first five years of his/her professional career.

The 2010 prize was awarded to Frank Becker (GSI) for his research on beam induced fluorescence (BIF). The prize was awarded in March 2010 in Brussels as part of the annual meeting. On this occasion, the award winner gave a presentation of his prize winning work.

CONCLUSION

Two years after the start of DITANET, first results from its broad research program become visible and were summarized in this contribution. In close collaboration between the network beneficiaries and the partners from across the world, with a very prominent role of industry, accelerator instrumentation is pushed beyond existing limits. In addition, the network offers a wide training program to its trainees as well as to the wider community and past events were briefly described.

The newly introduced adjunct partnership status allows additional institutions that share the network's ideas and visions to join the DITANET frame and participate to its research and training program.

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