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LOW ENERGY BEAM DIAGNOSTICS DEVELOPMENTS WITHIN DITANET

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on behalf of the DITANET Consortium

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Abstract

Low energetic ion beam are very attractive for a large number of fundamental physics experiments. The development of beam instrumentation for such beams poses many challenges due to the very low currents down to only a few thousands of particles per second and the resulting very low signal levels.

Within DITANET, several institutions aim at pushing low energy, low intensity diagnostics beyond the present state-of-the-art. This contribution gives examples from the progress across the DITANET network in this research area.

INTRODUCTION

The DITANET project started on 1.6.2008. It is a Marie Curie Initial Training Network that brings together ten network beneficiary partners and presently 18 associated and adjunct partners. The main aim of the network is to provide research training to its internationally recruited early stage (ESR) and experienced researchers (ER). Participation of industry partners is an integral part of this training with smooth integration of industry not only in the individual research projects, but also in the overall training of the DITANET trainees. The network thereby strives to improve the career perspectives of the next generation of researchers in this field.

RESEARCH RESULTS

Many DITANET partners are carrying out research into low energy beam diagnostics. This includes for example the University of Maryland, the GSI Helmholtz Centre for Heavy Ion Research or the Heidelberg Ion Therapy facility (HIT). The following sections summarize some of the network's recent research outcomes. Full details can be found on the network's homepage [1].

Low Energy Storage Rings

At very low beam energies of only a few tens of keV, electrostatic storage rings offer significant advantages over their magnetic counterparts because of the mass independence of the electrostatic rigidity. Within DITANET, the University of Liverpool (UoL), the Manne Siegbahn Laboratory (MSL)/Stockholm University and the Max Planck Institute for Nuclear Physics in Heidelberg all carry out R&D into this rather new type of storage ring. Whilst work in Liverpool and at the MPIK within the QUASAR Group target an Ultra-low energy Storage Ring (USR) [2] at the future Facility for Antiproton and Ion Research (FAIR), MSL is in the process of building up and commissioning a cryogenic electrostatic double ring, DESIREE [3].

The USR is based on the need for beams of cooled low-energy antiprotons for beyond state-of-the-art experiments with these exotic particles. At FAIR, it is planned to inject antiproton beams from the New Experimental Storage Ring (NESR) into a Low energy Storage Ring (LSR) at an energy of 30 MeV, to then cool and further decelerated them to 300 keV energy. The USR will finally provide electron-cooled beams of antiprotons in the energy range between 300 down to only 20 keV. The beam intensity and time structure of both, stored and extracted beams, can be varied over a wide range.

The ESR project of J. Harasimowicz at UoL covers R&D into the 'basic' diagnostics of the USR, in particular into the design and optimization of a capacitive beam position monitor [4], a Faraday cup for sub-pA current measurements [5], as well as investigations into different screen materials for beam profile monitoring of low energy, low intensity beams [6].

For the latter, measurements were realized in close collaboration with INFN-LNS, Italy. CsI:Tl, YAG:Ce, and a Tb glass-based scintillating fiber optic plate (SFOP) were tested. The screens' response to 200 and 50 keV proton beams with intensities ranging from a few picoampere down to subfemtoamperes was studied, see Fig. 1. It was found that CsI:Tl can be used to monitor beam intensities of down to only $5\cdot10^3$ pps at 200 keV.

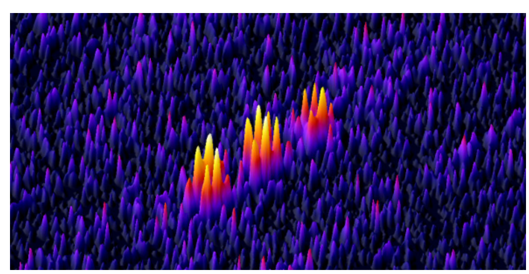

Figure 1: Example profile measured at INFN-LNS in Catania. A resolution of 0.3 mm was achieved in this measurement.

In addition, a secondary emission monitor for beam profile measurements was studied at MSL, Sweden by the ER S. Das with emphasis on the spatial resolution of the device. The monitor was successfully tested with protons down to 0.5 keV without any significant degradation in performance. It will be part of DESIREE and is also being considered for use in the USR.

It consists of an Aluminium plate, a grid placed in front of this screen, a microchannel plate (MCP), a fluorescent

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screen and a CCD camera [7]. Different collimators were used to study the spatial resolution of the system. Three holes of 1 mm diameter each, separated by 3 and 2 mm were used for measurements with a 10 keV proton beam. A spatial resolution of better than 2 mm was demonstrated, see Fig. 2 [8].

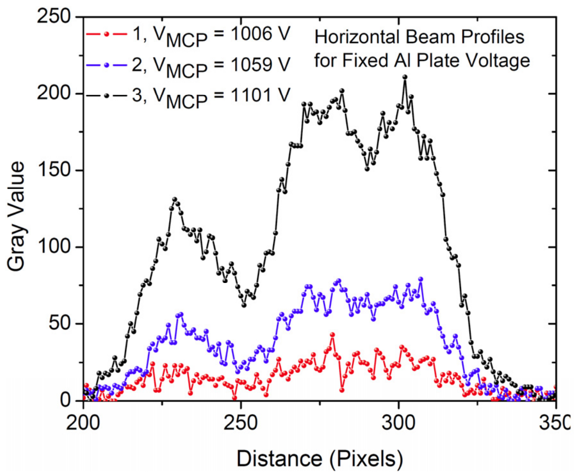

Figure 2: Measured beam profiles with different MCP voltages, but fixed Al plate voltage of 6.4 kV.

For beam profile monitoring applications where low beam perturbation together with bi-dimensional imaging is required, ionization monitors based on neutral gas-jet targets shaped into a thin curtain are an interesting option [9]. When integrated in an UHV environment, where local vacuum preservation is a primary concern, such system presents a number of difficulties linked to the generation, proper shaping and containment of the jet. The jet characteristics is strongly influenced by the geometry of the nozzle and skimmer used to generate it and by the values of the thermodynamic variables, such as for example pressure and temperature at both, the high pressure gas reservoir and in the vacuum chamber, where the jet is expanded.

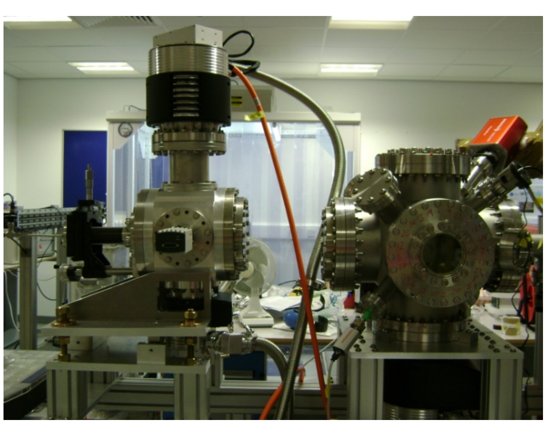

Figure 3: Photograph of the experimental setup. The jet is expanded in the left chamber, skimmed and finally collimated at a variable distance in the right chamber.

Such jet monitor has been assembled by the ESR M. Putignano at the Cockcroft Institute, UK. It is composed of an *expansion chamber* where the jet is created and expanded through nozzle and skimmers, shown on the left hand side in Fig. 3. The expansion chamber is kept at a vacuum pressure of 10^{-6} mbar, which rises to 10^{-3} or 10^{-4} mbar when the jet is in operation, the higher pressure level being dictated by the large gas load resulting from the skimming of the jet. The expansion chamber is followed by a *detection chamber*, which is kept at a lower vacuum pressure of 10^{-8} mbar, even when the jet is in operation, made possible by the directionality and reduced dimensions of the skimmed jet. The detection chamber incorporates an ion extraction system to attract the positive gas ions, terminating with an MCP detector imaged on an ITO coated phosphor screen that also acts as collecting electrode. Jet density profile measurements will be taken shortly on this setup and a full experimental analysis will be completed in 2011.

From Particle Detection to Medical Applications

In order to detect and reconstruct particle trajectories, detectors with good characteristics are required. Silicon detectors are widely used in nuclear physics and particle detection. In addition to their consolidated technology, they present very good time, position (angular), and also energy resolution. They can be coupled to commercial dedicated electronics.

The ESR Z. Abou Haidar and the ER A. Bocci at DITANET partner University of Seville/Centro Nacional de Aceleradores (CNA) used a commercial 50x50 mm² active area, double sided silicon strip detector (DSSSD), see Fig. 4. It is segmented into 16 horizontal strips on one side, and 16 vertical strips on the other. Each strip has its own electronics chain, hence allowing pixelizing the detector into 256 pixels.

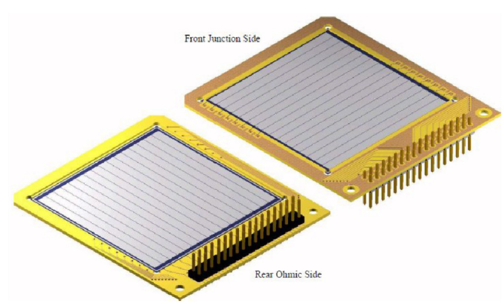

Figure 4: The two sides of a Double Sided Silicon Strip Detector (DSSSD).

In October 2009 the elastic and inelastic proton scattering on heavy ions around the coulomb barrier was measured at the Technological and Nuclear institute in Lisbon. In this setup, a low energy proton beam, hitting a certain target, was surrounded by detectors. The DSSSDs were mounted in a “telescope” structure pointing towards the target. The “telescope” consists of a thin (~40 µm) DSSSD mounted together with a non segmented thick (~500 µm) silicon detector so called “Pad” that has the same active area as the DSSSD. The particle, after interacting with the target, goes through the DSSSD depositing part of its energy, and then deposits its remaining energy in the Pad. By using a similar setup and pixelizing the detector, the fragments of the reaction can be detected and the hitmap be reconstructed.

Based on the promising results of the previous experiment, to optimize the Basic Nuclear Physics line at the 3 MV accelerator at CNA and to establish a permanent experimental and data analysis protocol, another experiment was carried out at CNA in July 2010. Moreover, following the group's experience in nuclear instrumentation, a research program in radiotherapy with high-energy photon beams was established between the Department of Atomic, Molecular and Nuclear Physics of the University of Seville, the National Accelerators Center (CNA) of Seville, the Virgen Macarena University Hospital in Seville, the Engineering School of the University of Seville and the private company Inabensa S.A. (Abengoa).".

This collaboration exploits the knowledge of the different groups in nuclear instrumentation, silicon detectors, electronic and mechanical design, theoretical calculations and Monte Carlo simulations, transferring these expertises to the medical field and to radiotherapy treatments.

The aim of the project is to benchmark a novel method to obtain a map of doses in the pre-treatment of patients with Intensity Modulated Radiation Therapy (IMRT). Two prototypes of phantoms have been designed and built in order to characterize the dosimetric properties of the detector and its angular response. The material of the phantoms is tissue-equivalent and suitable for dosimetry measurements.

The detector used for dose measurements is similar to the DSSSD described. Monte Carlo simulations of the experimental set-up with Geant4 were carried out to simulate the detector characteristics with both phantoms [11]. In addition, measurements were performed at Virgen Macarena University Hospital using the 6 MV photon beams produced by a Siemens Primus linac accelerator. A final characterization of the detector, including a comparison between Geant4 simulations and the Treatment Planning System (TPS) calculations has been performed. Dedicated treatment plan verification will be realized within short.

DITANET WORKSHOP

A DITANET topical workshop on low energy and low intensity beam diagnostics took place on November, 24th and 25th in Hirschberg-Großsachsen near Heidelberg in Germany. The workshop 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 to allow for establishing important contacts and for reviewing the status of the different R&D activities.

The event started with an introduction to the future Facility of Antiproton and Ion Research, where many of the diagnostics devices presently under development in different groups within DITANET will be used to monitor different beam parameters with 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 low energy storage rings and presentations were given on the ELISA (ISA, Arhus), DESIREE (MSL, Stockholm), CSR (MPI-K, Heidelberg), and USR (FAIR, Darmstadt) facilities, which triggered interesting discussions on these challenging developments. This workshop marked the beginning of the DITANET workshop series. All presentation from the workshop and the proceedings can be found at [12].

SUMMARY

Within the DITANET network, many partners are carrying out research into the development of novel instrumentation for low energy, low intensity beams. Low signal levels pose significant challenges to the monitor design. Prototypes of all monitors are now available across the network and have been tested with beam. It is expected that these monitors will become the future standard instrumentation for a number of low energy accelerators. In addition, the network has been promoting knowledge exchange in this important area through secondments and its Topical Workshop in 2009.

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