SCINTILLATING SCREEN STUDIES FOR LOW ENERGY, LOW INTENSITY BEAMS*

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Abstract

Future atomic and nuclear physics experiments put challenging demands on the required beam instrumentation. Low energy (< 1 MeV), low intensity ($< 10^7$ pps) beams will require highly sensitive monitors. This is especially true for the Facility for Low-energy Antiproton and Ion Research (FLAIR) where antiproton beams will be decelerated down to 20 keV and as few as $5 \cdot 10^5$ particles per second will be slowly extracted for external experiments. In order to investigate the limits of scintillating screens for beam profile monitoring in the low energy, low intensity regime, a systematic analysis of CsI:Tl and a scintillating fibre optic plate (SFOP) were done under different irradiation conditions with keV proton beams. This contribution presents the experimental setup and summarizes the results of this study.

INTRODUCTION

Recently, an increasing interest has come out around many applications of particle beams sharing a common feature, namely the low intensity of the produced ion beams [1]. Examples of such applications are the production of radioactive ion beams (RIB), facilities for low energy ion storage/trapping, low energy antiproton facilities, cancer therapy by means of protons and ions. Sometimes one might also wish to handle very low energy beams, thus complicating the already difficult task of a reliable beam diagnostics.

One of the main requests for low intensity beam diagnostic tools comes from the RIB facilities. Unfortunately the produced beams may have a weak intensity, due to the small cross section for the production of several interesting nuclear species and to the obvious limitations in the primary beam current. A general recipe cannot be formulated since each particular species has a different cross section and lifetime: the final beam current can span several orders of magnitude, becoming critical when reaching below 10^7 particles per second (pps).

Further challenges are imposed by low energy antiproton facilities like FLAIR (Facility for Low-energy Antiproton and Ion Research) [2]. Its central machine, the Ultra-low energy Storage Ring (USR), will offer world-wide unique conditions for both in-ring studies as well as for experiments requiring extracted beams below 300 keV [3, 4, 5]. With a slow extraction scheme, as few as $5 \cdot 10^5$ - 10^6 pps, corresponding to beam currents of approximately 100 fA, are expected. Whilst antiprotons are of the main interest at the USR, other particles, like protons or H^- ions, will be used for the initial commissioning of the machine. A sensitive yet easy-to-use and cost-effective diagnostic solution is preferred for this storage ring and its transfer lines. Ideally, all beams would be monitored with the same diagnostic devices, but interaction of particles and antiparticles with components of the beam monitor can differ significantly, thus limiting its usage.

In the frame of this study, the lowest detection limits of the scintillation imaging techniques in the low energy regime were studied. In terms of simplicity, cheapness and effectiveness, scintillators are amongst the best suited instruments for beam profile monitoring. Although they are not as sensitive as devices equipped with microchannel plates (MCPs) and other amplification stages, their ultimate detection limits have not been investigated in great detail. The lack of comprehensive data for few-particle beams in the keV range was the main motivation for the here-presented experiments with low velocity protons.

EXPERIMENTAL SETUP

In order to produce low energy proton beams, the 450 kV injector of the Tandem accelerator at the National Institute of Nuclear Physics INFN-LNS in Catania was employed [6]. Figure 1 shows the experimental setup. Downstream the 90° analyzing magnet, a conventional electrostatic Faraday cup (FC1) was installed that is normally used for ion source mass analysis. After the cup, a pair of X and Y variable slits was used as collimators, followed by two removable pepper-pot grids for intensity reduction. The size of a single hole in such a grid was of the order of 0.2 mm. Following the beam attenuators, a scintillating screen was used for the tests. Finally, the second electrostatic Faraday cup (FC2) was located at some distance behind the screen. All measurements were made under 10^{-6} mbar vacuum.

For the here-presented measurements, the ion source was operated with settings much different from the conditions it had been designed for. It was possible to lower the energy to 200 keV and 50 keV as well as to keep the beam intensity at the pA level. Thereby the limits in energy and current of the injector were reached. With decreasing operating values, the beam became unstable and its emittance

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* Work supported by the EU under contract PITN-GA-2008-215080, by the Helmholtz Association of National Research Centers (HGF) under contract number VH-NG-328, and GSI Helmholtz Centre for Heavy Ion Research.

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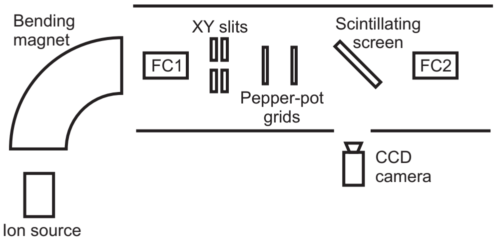

Figure 1: Experimental setup at INFN-LNS.

could not be controlled in a reasonable manner, resulting in a wide beam spread. No tests below 50 keV were possible and pepper-pot attenuators had to be used to study the response of the screens in the sub-pA region.

Three different scintillating screens were chosen: a 1 mm thick Cesium Iodide doped with Thallium (CsI:Tl); a 2 mm thick Terbium-doped glass Scintillating Fiber Optic Plate (SFOP) consisting of 10 μm diameter fibers; and a 0.05 mm thick YAG crystal doped with Cerium (YAG:Ce) deposited onto a 4 mm thick glass base. Unfortunately, a mechanical mishap and limited beam time prevented the collection of representative and systematic data for the YAG screen. Therefore only general comments can be made on its response to low energy proton beams.

The beam images were recorded with a high performance 14-bit CHROMA CX3 still camera produced by DTA, featuring a KAF1603 charge coupled device (CCD), manufactured by Kodak. The CCD was cooled down to $5°$C, in order to reduce its noise.

RESULTS WITH PROTONS

Recorded images of scintillation light emitted by the screens under different irradiation condition were analyzed off-line, yet real-time observation was also possible. For image handling, the public-domain image processing program IMAGEJ [7] was used. Sample images of the 200 keV proton beam taken with the CsI:Tl screen are shown in Fig. 2. With the pepper-pot grids fully retracted, a beam of elliptical cross-section was observed as shown in Fig. 2a. The attenuators introduced later resulted in a multi-peak structure of the beam presented in Fig. 2b.

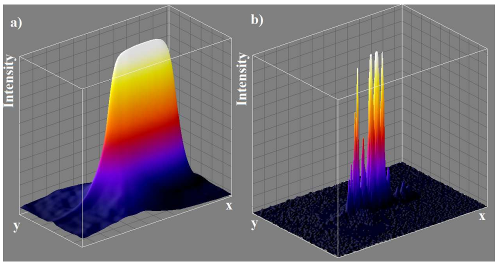

Figure 2: Beam image taken with the CsI:Tl screen for 200 keV protons with 1 s acquisition time and (a) no pepper-pot grids, (b) one pepper-pot grid.

Protons hitting the attenuator were removed from the beam, thus the total number of particles reaching the scintillating screen was reduced. This led also to modulation of the beam intensity and the multi-peak distribution of the particles could be observed. Narrow peaks were clearly visible and their full width at half maximum (FWHM) varied between 0.3 mm and 0.8 mm.

With the known number of acquired photoelectrons and the corresponding beam currents, it was possible to investigate the sensitivity in terms of the absolute values. However, a systematic indetermination not larger than one order of magnitude was introduced by the calibration procedure used in order to investigate the sub-pA region [8]. As a result, every following consideration about the absolute beam current is bound to the effective value of the light yield and can thus scale up/down accordingly.

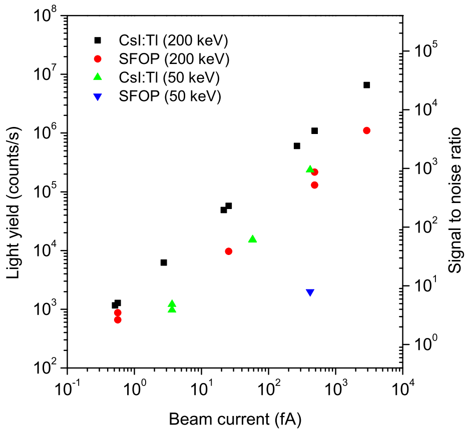

Figure 3: Calibrated light output and signal-to-noise ratio for CsI:Tl and SFOP irradiated with 200 keV and 50 keV proton beams. Note that the beam current was estimated, thus the results may shift “left” or “right” within the uncertainty of one order of magnitude [8].

As can be seen in Fig. 3, the CsI:Tl plate produced a higher light yield as compared to the SFOP and beam images were obtained even at intensities below 1 fA. The results were strongly dependent on the incident beam energy and for 50 keV it was impossible to produce reasonable images in the same current range as for 200 keV. The limiting factor was the noise which could have been lowered by longer irradiation times. The acquisition time, however, was limited and between 1 s to 60 s depending on the proton beam energy and attenuators used. The right hand side Y-axis of the plot shown in Fig. 3 presents the signal-to-noise ratio. The light emitted from CsI:Tl at 50 keV was lost in the noise with both pepper-pot grids placed in the beam path, while for the SFOP there was already not enough signal with one of the grids used. This dramatic change in the sensitivity was due to lower energy transferred to the scintillator which produced less light. When going from 200 keV to 50 keV, the decrease in light output for CsI:Tl was of a factor of about 4, which is in agreement with the rough assumption that the light yield scales with energy. The response of the SFOP was affected much stronger and it was decreased by almost two orders of magnitude.

As already mentioned, it was not possible to collect representative data for the YAG:Ce plate, thus it cannot be compared with the previous scintillators in a more systematic manner. However, the measurements indicated that it was significantly less sensitive than both, CsI:Tl and the SFOP. This is in agreement with the results obtained by other groups [9].

CONSIDERATIONS FOR ANTIPROTONS

Due to the nature of the processes following the annihilation, the response of a scintillator to keV antiprotons is much different than to the corresponding protons [8]. The amount of energy released in a scintillator due to annihilation will be several orders of magnitude higher and may lead to saturation of the monitor. Most of the nuclear fragments will be in the sub-MeV region and stop within a few mm of the annihilation point, producing most of the scintillation light. The variety and range of secondary particles can result in an increase of the observed beam size as well as in additional hot spots and tracks. Moreover, the time scale of the occurring atomic and sub-atomic events will be long enough to make the bunch-by-bunch observations difficult, if not impossible.

A profile monitor for low energy, low intensity antiproton beams should be optimized with the physical phenomena not present in the case of proton beams carefully taken into account. Important parameters to be considered include the number of antiprotons per burst, number of bursts per second, beam energy and the spatial resolution needed. This means a proper choice of material and its thickness in order to minimize the influence of particles emerging in random directions. A scintillator suitable for ultra-low intensity proton beams, like CsI:Tl, is expected to be too sensitive to highly ionizing annihilation products. It needs to be tested whether a suitable screen can be prepared for the difficult task of measuring keV antiprotons. If so, a beam profile monitor would have to incorporate two separate screens for the particles and the antiparticles available in the USR. Otherwise, a more expensive and complex technique will be used for antiproton beam profile monitoring.

CONCLUSIONS AND PERSPECTIVES

It was shown that CsI:Tl and the SFOP are sensitive enough for proton beam profile monitoring in the ultra-low energy, ultra-low intensity regime. With 200 keV beams, it is possible to measure currents even in the sub-fA range corresponding to about $5 \cdot 10^3$ pps [8]. For 50 keV beams, the sensitivity of both screens drops down and is about 4 times lower for CsI:Tl and approximately two orders of magnitude lower for the SFOP, respectively. The results obtained with YAG:Ce indicated that this screen is less sensitive than the two other materials under investigation.

A resolution of 0.3 mm was observed, but could be decreased by improving the setup and beam geometry as well as the granularity of the digital read-out. In addition, it should be kept in mind that two dimensional intensity maps can reveal complex structures present in images produced with pepper-pot grids, thus a simple projection onto one axis may not give sufficient information on the response of the system and degrade the resolution.

A sensitive scintillator will be very important during the initial commissioning stage of the USR with proton beams. In fact, both CsI:Tl and the SFOP, are under consideration for beam profile monitoring at this storage ring. Further investigations should include tests under ultra-high vacuum as well as detailed reproducibility studies.

Antiprotons add further challenges and complicate the already difficult task of ultra-low energy, ultra-low intensity beam diagnostics. The problem of highly ionizing particles created in the annihilation process and their influence on the beam profile monitoring will be investigated in detail in the near future.

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