SECONDARY EMISSION MONITOR FOR keV ION AND ANTIPROTON BEAMS*

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Abstract

Beam profile monitoring of low intensity keV ion and antiproton beams remains a challenging task. A Secondary electron Emission Monitor (SEM) has been designed to measure profiles of beams with intensities below 10^7 and energies as low as 20 keV. The monitor is based on a two stage microchannel plate (MCP) and a phosphor screen facing a CCD camera. Its modular design allows two different operational setups. In this contribution we present the design of a prototype and discuss results from measurements with antiprotons at the AE$\bar{g}$IS experiment at CERN. This is then used for a characterization of the monitor with regard to its possible future use at different facilities.

INTRODUCTION

Low-energy beams, both matter and antimatter are very interesting for various fundamental research studies. A world-class facility for low-energy antiproton and ion research (FLAIR)[1] will provide low-energy (300 keV/u) beams, which can be further decelerated using the ultralow-energy storage ring (USR), allowing energies down to 20 keV/u. Profile measurements of these beams are only part of the challenging diagnostic systems required in these accelerator facilities in order to monitor and tune the beam. Although the Secondary Emission Monitor (SEM) is a destructive one, it is a very helpful tool as a first diagnostic system in beam transfer lines when properly optimized for minimal image distortion due to strong electric fields and annihilation dose[2].

This monitor has been succesfully tested at INFN using protons[2] and also at the AE$\bar{g}$IS experiment (Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy)[3] located at the Antiproton Decelerator[4] facility at CERN, using a low-energy antiproton beam.

PRINCIPLE

The monitoring of antiproton beams with electron multiplier microchannel plates (MCP) has already been demonstrated[5][6]. This foil-based SEM consists of a metallic foil biased to a negative potential, a grounded metallic mesh, a two-stage MCP stacked in chevron configuration with a phosphor screen, and a CCD camera. The primary beam goes through the mesh at an angle of 45° and produces eV-range secondary electrons from the surface of the foil. These secondary electrons are accelerated by the negative foil potential and fly through the mesh towards the beam imaging system. When the electrons reach the MCP, they travel through it generating many more electrons that will eventually hit the phosphor screen, producing visible light that is finally registered by the CCD camera. A sketch showing the working principle of this monitor is presented in Fig. 1.

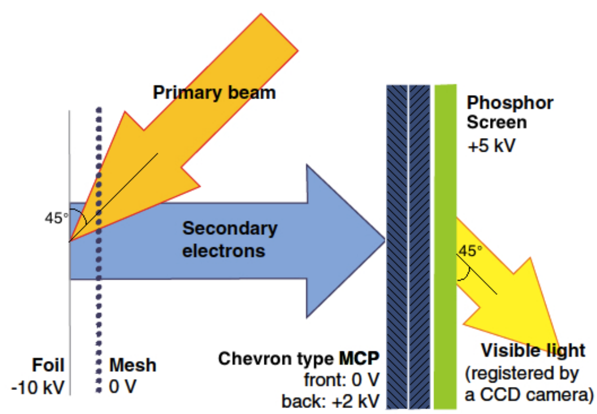

Figure 1: Working principle of the Secondary Emission Monitor.

In this system, only the secondary electrons generated at the foil reach the surface of the MCP placed at a certain distance, due to the fact that the direction of the strong electric field between the foil and the mesh will accelerate only the negative charged particles towards the MCP. The limitations of the device are that such an electric field ($2{\cdot}10^5$V/m) could affect the response of the monitor for keV energy beams, while posing no risk for high-energy or heavy-ion applications. In Fig. 2, a very simple model of the SEM is simulated with SIMION[7]. The influence of the SEM on primary beams is simulated for various beam energies and foil voltages. The MCP at 2 kV and the phosphor screen at 5 kV were present in all simulations but are shown only in the last figure.

* Work supported by the EU within the DITANET and CATHI projects under contracts 215080 and 264330, HGF and GSI under contract VH-NG-328 and STFC under the Cockcroft Institute core grant ST/G008248/1.
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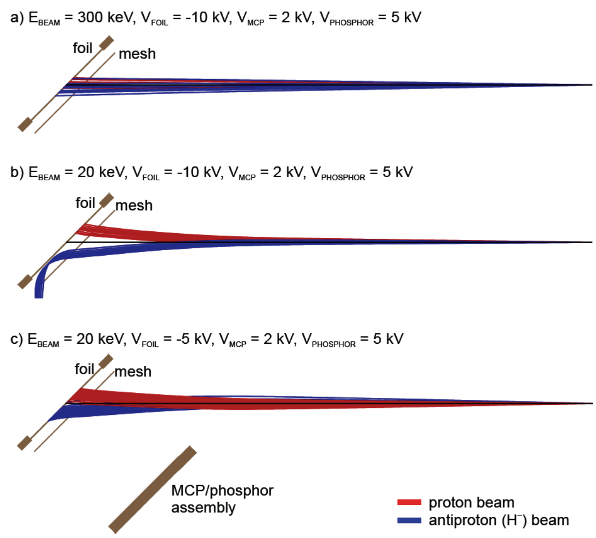

Figure 2: SEM influence on primary beams.

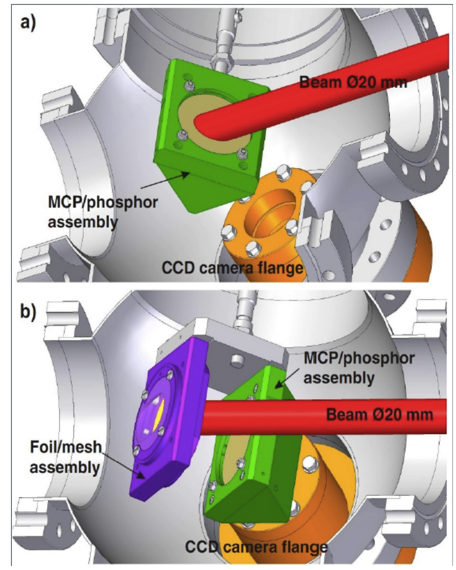

Figure 4: Two possible configurations of the monitor: (a) a foil-based SEM, and (b) MCPs placed directly in the beam path.

EXPERIMENTAL SETUP

This experimental monitor was installed downstream of the 1T magnet, at the end of the AE$\bar{g}$IS line in the AD Hall at CERN[4], as shown in Fig. 3; The monitor is mounted inside a CF 6-way cross vacuum vessel. Inside this chamber two possible configurations of the monitor are possible: A foil-based SEM and a stand-alone MCP-based SEM placed directly in the beam path. A sketch of both settings is shown in Fig.4.

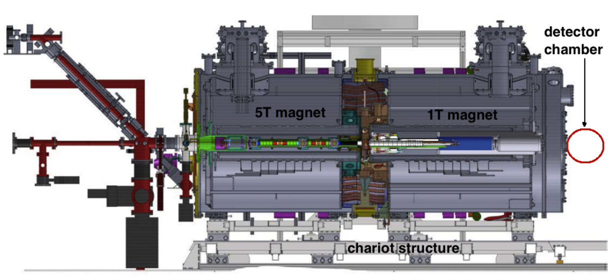

Figure 3: Cross-section through the 5T and 1T magnets showing details of the cryostats, transfer section and electrodes. The SEM was located downstream of the 1T magnet.

Equipment

The SEM can be retracted from the beam by means of a pneumatic actuator when not in use. In the foil+mesh assembly, a 200 μm thick UHV clean aluminium foil is used together with a nickel mesh with 80 lines per inch (3 wires per mm approx.) being each wire 25 μm thick. This means around 85% beam transmission.

The stack comprises two MCP 50-15 from TOPAG[8]. Each MCP has a channel angle of 8 $^\circ$ and gain of 10^4 at 1100V. The phosphor screen is a P-43 from ProxiVision[9] with a 42mm active diameter and phosphor layer of 4μm. The CCD Camera is DCU223C with C-mount lens MVL5WA from Thorlabs[10].

Electrical Design

A 3-channel HV power supply 19” THQ from ISEG[11] is used to supply voltages to the MCP, phosphor and foil. Two DPS series modules with a switchable polarity and 5 kV SHV output connectors can supply up to 3 kV/4 mA and 5 kV/2mA to the MCP and the phosphor screen respectively. Peak-to-peak ripple and noise for DPS modules are typically less than 2 mV and 7 mV maximum. A single CPS module with a fixed polarity and 16 kV LEMO output connector can supply up to -10 kV/1mA to the foil (the mesh is connected to ground). Peak-to-peak ripple and noise for the CPS modules is typically less than 200 mV and 500 mV maximum.

For the interface between air and vacuum, four 5 kV SHV feedthroughs and one 10 kV SHV feedthrough were welded to the actuator flange. The first three feedthroughs supply voltage to the front, middle and rear of the MCP assembly, the fourth 5 kV SHV is used for the phosphor screen, while the 10 kV SHV is used to bias the foil.

The chevron type MCP can be supplied with a maximum of 2 kV, giving a signal gain of approximately 10^6. No more than 1 kV should be applied to a single microchannel plate. The MCP and phosphor assembly is stacked in a sandwich with metal rings placed between the components, as shown in Fig. 5. Kapton insulated wires rated up to 5 kV were soldered to the contact rings. For the foil, a more stiff Kapton insulated wire rated up to 10 kV was used.

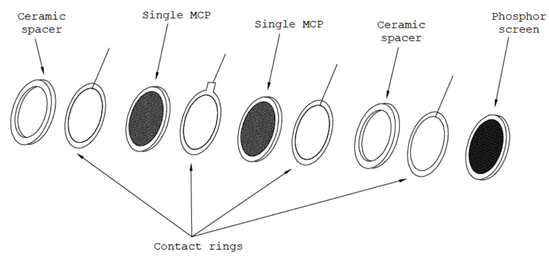

Figure 5: Sketch showing the order and connections of the two-stage MCP and the phosphor screen that form the SEM's main piece.

RESULTS

A dedicated detector and beam instrumentation test chamber was installed behind the AEgIS 5T and 1T magnets in order to carry out a series of detector tests with 300 keV antiprotons to characterize detector performance and to identify suitable technologies for a permanent installation in AE$\bar{g}$IS. The SEM shared the chamber with nuclear emulsions[12]. The nuclear emulsion detector confirmed that approximately 0.4 $\bar{p}$ /mm^2 per shot reached the end of the line. Unlike other detectors, the SEM was the only beam monitor working online, therefore proving to be crucial for the commissioning of all other detectors in that run.

Background and Alpha Source Checks

Prior to the beam run, the leakage current of each MCP was measured at increasing voltages, to check their resistance. The trigger of the camera was adjusted to take shots synchronously with the $\bar{p}$ beam, which delivered one shot every 110 s. Being the SEM in vacuum, the background of the camera was checked and an alpha source was installed inside the chamber facing directly the MCP stack. When the vacuum reached the working level of 10^{-7} mbar helium nuclei from the alpha source could be seen with the SEM, confirming that the monitor was ready to start monitoring the antiproton beam in AE$\bar{g}$IS. The alpha source was removed and measurements began with the first configuration (i.e. MCP stack directly hit by the beam).

Stand-Alone MCP Configuration

During the first $\bar{p}$ shots the gain and brightness of the MCPs and phosphor were adjusted respectively, reaching the following nominal settings:

- MCP stack biased at +1.95 kV
- Phosphor screen biased at +4.75 kV
- Camera exposure time between 2 and 10 ms

In this configuration, the two-stage MCP is tilted at 45° with respect to the beam, together with the phosphor screen stacked right behind them. This stack is also at 45° with respect to the camera, as shown in Fig. 4. This 90° configuration allows the profile of the beam to remain undistorted, as the camera is facing the MCP stack at 45°, thus correcting the first 45° distortion.

In this run the $\bar{p}$-beam and several traces of antiproton annihilations were observed, as well as evidence of other particles. These secondary particles that appeared in the monitor are pions, kaons and other particles coming from annihilations. Thanks to a gate valve just upstream of the SEM, the image seen on the SEM could be switched between measuring only secondary particles going through the gate valve or measuring the $\bar{p}$-beam together with some secondaries. Further analysis from those pictures confirmed that about 90% of the beam reaching the SEM was composed of antiprotons. A superimposed image composed of 8 beam pictures (to increase visibility) taken with the SEM is shown in Fig. 6.

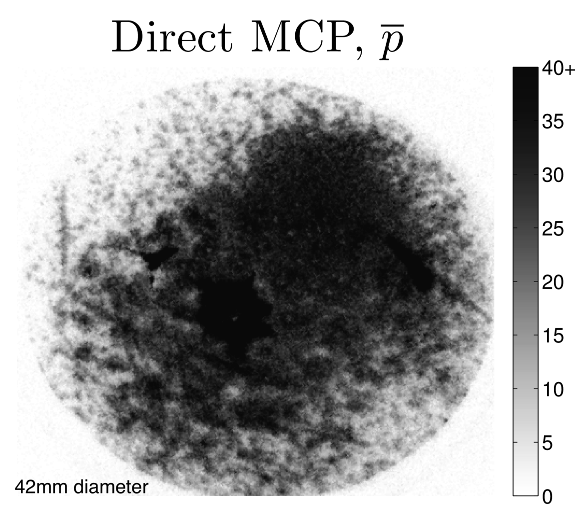

Figure 6: Antiproton beam detected by the SEM in the MCP stand-alone configuration. Scale in 8-bit grayscale palette.

The black saturated stains present in the image correspond to damage on the surface of the phosphor screen, probably due to some high-voltage sparks under vacuum. In Fig.6 the magnets' B-field was off, the beam degrader was in, as well as the beam counter, the gate valve was open, and the Faraday cup was out of the beam path. All these devices are located upstream of our chamber.

Some antiproton annihilation traces are visible on the far left of the picture. Further image correction algorithms were applied using MATLAB[13] in order to substract the background coming from other particles, as well as trying to isolate the $\bar{p}$ beam to estimate beam size. Eventually this was not possible due to the fact that the beam was very blown up after the 1T magnet and very difficult to steer into the SEM aperture in a stable fashion.

Foil-Based SEM Configuration

In this second configuration, the foil+mesh assembly is put in front of the SEM, at a distance of 52 mm. This distance is a compromise between the spatial resolution and the maximum beam diameter that can be observed. With this assembly, a beam as large as 20 mm in diameter can be monitored. The thin foil of the assembly was biased to -9 kV to allow all electrons produced in the foil to accelerate past the mesh towards the MCPs with minimum divergence. In Fig. 7 a superimposed picture of the antiproton beam in this configuration is presented. It is clear that the image intensity is weaker and the resolution worse compared to the previous configuration. The advantage of this configuration is an extended operational life of the monitor as the MCP will not get degraded as quickly as in the stand-alone configuration.

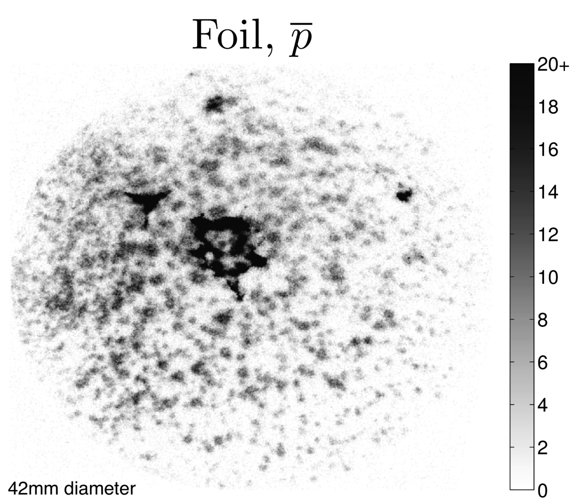

Figure 7: Antiproton beam detected by the SEM in the foil configuration (gate valve open). Scale in 8-bit grayscale palette.

CONCLUSIONS

Although single annihilation events were detected with both configurations of the device, the $\bar{p}$ beam was not intense enough to extract a beam profile. The beam was also blown-up and quite defocused after the 1 T magnet so the whole active diameter was iluminated by the $\bar{p}$ beam. The image diameter shown in Figs.6,7 is 42mm, from which the beam size could have been extracted eventually. Note that these measurements are destructive for either configuration of the device.

No significant differences in beam image brightness were observed between 1.6 and 2 kV in MCP gain for this test. No collimator tests were performed, but previous studies account for <2 mm spatial resolution for the foil-based configuration[2]. For the first time, the stand-alone MCP configuration was succesfully tested, showing clearer beam images, but introducing a little background noise from high energy secondary particles.

The SEM was the only online monitor in the latest AE$\bar{g}$IS run and the only one sensitive enough for the initial (low intensity) beam steering. This monitor has proven to work both with protons and antiprotons, yielding promising results as a detector for future installations such as the accelerator FLAIR at GSI, Darmstadt[1]. More studies are needed in order to fully characterize the SEM capabilities as a permanent monitor for low energy ion and $\bar{p}$ beams.

ACKNOWLEDGEMENTS

The author acknowledges the receipt of a Marie Curie fellowship under the CATHI ITN contracts number 264330.

REFERENCES

[1] Welsch, C. P., *et al.*, Nuclear Instruments & Methods in Physics Research A, 405-417, (2005)

[2] Harasimowicz, J., Welsch, C. P., Cosentino, L., Pappalardo, A., and Finocchiaro, P. Physical Review Special Topics-Accelerators and Beams, 15(12), 122801, (2012)

[3] Krasnicky, D., *et al.*, AIP Conf. Proc. 1521,144-153, (2013)

[4] Baird, S., *et al.*, Nuclear Instruments and Methods in Physics Research A, 391, (1997) 210-215.

[5] Andresen, G.B., *et al.* (ALPHA Collaboration), Rev. Sci. Instrum. 80, 123701, (2009)

[6] Imao, H., Torii, H. A., et al. Observation of Ultra-Slow antiprotons using microchannel plate. AIP Conference Proceedings, 1037(1):311-317, (2008)

[7] Inc. Scientific Instrument Services. SIMION: ion and electron optics simulator. http://simion.com/, (2009)

[8] TOPAG Lasertechnik GmbH, Nieder-Ramstdter Str. 247 64285 Darmstadt, Germany. http://www.topag.de/en/

[9] ProxiVision GmbH, Robert-Bosch-Str. 34 D-64625 Bensheim, Germany. http://www.proxivision.de

[10] Thorlabs Inc, 56 Sparta Avenue Newton, New Jersey 07860 USA. www.thorlabs.com

[11] ISEG Spezialelektronik GmbH, Bautzner Landstrasse 23 D-01454 Radeberg / OT Rossendorf, Germany. http://www.iseg-hv.com

[12] S Aghion *et al.* JINST 8 P08013 (2013)

[13] MathWorks, 3 Apple Hill Drive Natick, MA 01760-2098 USA. www.mathworks.com