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Investigations into beam monitors at the AE$\bar{g}$IS experiment

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Abstract Detailed diagnostic of antiproton beams at low energies is required for essentially all experiments at the Antiproton Decelerator (AD), but will be particularly important for the future Extra Low ENergy Antiproton ring (ELENA) and its keV beam lines to the different experiments. Many monitors have been successfully developed and operated at the AD, but in particular beam profile monitoring remains a challenge. A dedicated beam instrumentation and detector test stand has recently been setup at the AE$\bar{g}$IS experiment (Antimatter Experiment: Gravity, Interferometry, Spectroscopy). Located behind the actual experiment, it allows for parasitic use of the antiproton beam at different energies for testing and calibration. With the aim to explore and validate different candidate technologies for future low energy beam lines, as well as the downstream antihydrogen detector in AE$\bar{g}$IS, measurements have been carried out using Silicon strip and pixel detectors, a purpose-built secondary emission monitor and emulsions. Here, results from measurements and characterization of the different detector types with regard to their future use at the AD complex are presented.

Keywords Beam diagnostics · Beam monitors · Antiprotons · Secondary electron emission

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1 Introduction

Low-energy antiproton beams are very interesting for a large number of fundamental research studies. The Extra-Low ENergy Antiproton ring (ELENA) at CERN [1, 2] and the Ultra-low energy Storage Ring (USR) [3] at the future Facility for Low-energy Antiproton and Ion Research (FLAIR)[4] shall provide cooled beams of antiprotons at energies down to 100 and 20 keV/q, respectively. This creates challenges for beam instrumentation that need to be taken into account, such as the quasi-DC state of the beam in slow extraction mode or the fact that the RF frequency decreases during deceleration while the harmonic number h remains constant [5].

In order to test different detector types a dedicated instrumentation test chamber was installed behind the AE$\bar{g}$IS experiment at CERN[6]. There, a number of different detectors were tested in late 2012 prior to the first long shutdown at CERN using a 300 keV beam of antiprotons from the Antiproton Decelerator (AD)[7]. Measurements were carried out with nuclear emulsion detectors, several types of silicon detectors, as well as a purpose-built secondary electron emission monitor (SEM). The latter had already been tested using proton beams at INFN-LNS[8].

2 Secondary emission monitor

The SEM consists of a metallic foil biased to negative potential, a grounded metallic mesh, a two-stage Micro Channel Plate (MCP) stacked in Chevron configuration with a phosphor screen, and a CCD camera. Two different configurations of the monitor are possible, as shown in Fig. 1. First, the two-stage MCP together with a phosphor screen can be placed directly into them beam path at 45° with respect to the beam with a CCD camera monitoring the light coming from the back of the phosphor screen. Second, an additional metallic foil, biased up to −10 kV and a mesh connected to ground, can be introduced to generate secondary particles that are then accelerated through the mesh and towards the MCP and phosphor screen which are installed parallel to the foil plane. Note that the 45° orientation preserves the beam aspect ratio as seen by the camera. After background substraction and superimposition of consecutive images for statistics, measurements showed that annihilation events can be identified when the detector is exposed directly to the antiproton beam, as shown in Fig. 2. Additionally, measurements in the foil/mesh configuration in Fig. 3 show that closing the gate valve upstream of the monitor only allows high-energy particles (pions) to reach the monitor. These results confirm that the beam seen on the foil/mesh setup is mostly antiprotons.

The aim of testing this monitor at AE$\bar{g}$IS was to examine its sensitivity to pions and proton-antiproton annihilations, and to measure beam profiles. Although single annihilation events were detected with both configurations of the device, the antiproton beam was not intense enough to extract a clear beam profile. This was mainly because the beam was strongly defocused after passing the 1 T magnet, illuminating the whole active diameter of the MCP. After earlier tests with protons, this was the first time this monitor was tested using antiprotons and it has proven to work in this environment, yielding promising results for future installations. It should be noted that the SEM was the only online monitor in the here-presented detector tests and the only one sensitive enough for initial (low intensity) beam steering. Extensive numerical studies into the effect of different voltage settings were carried out in parallel, providing important information for optimum voltage settings [9].

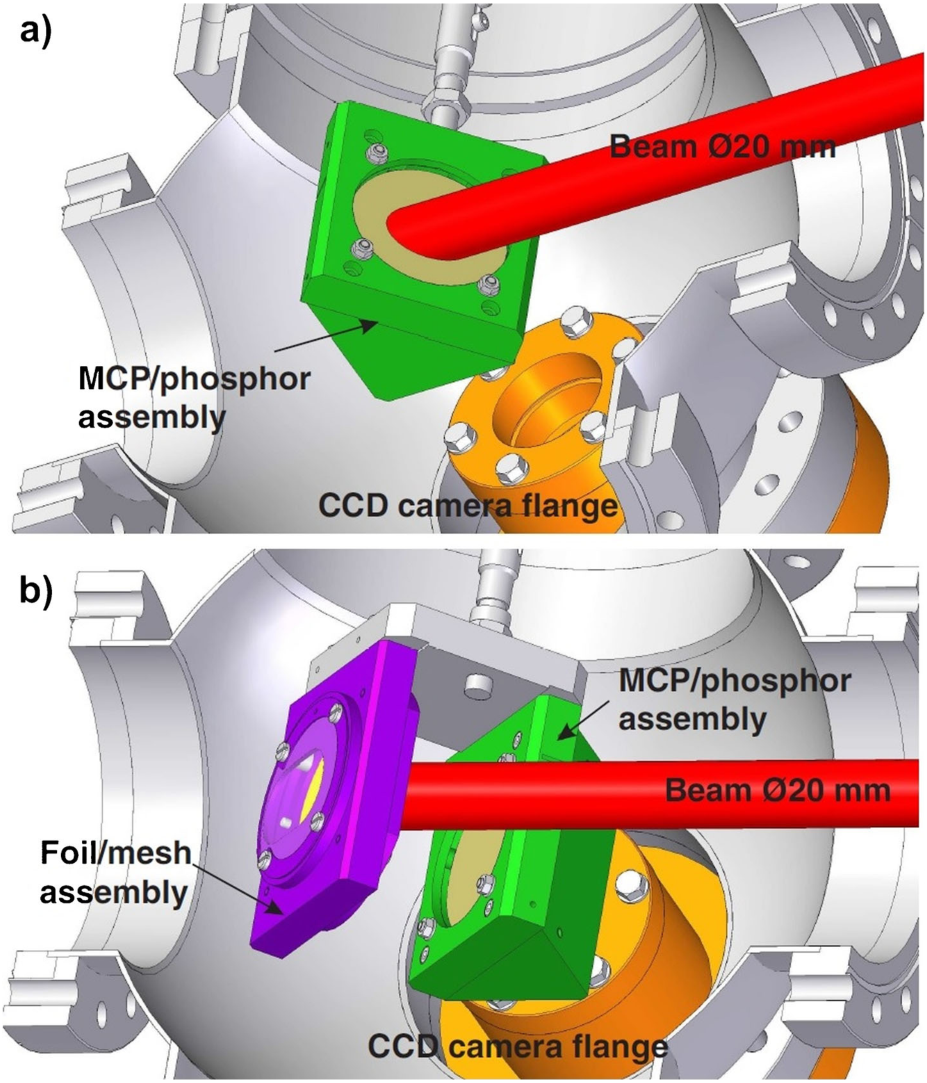

Fig. 1 Experimental setup of the Secondary Emission Monitor with two possible configurations

3 Emulsion detectors

Part of the AE$\bar{g}$IS detector system is a vertex detector made of a thin annihilation foil followed by nuclear emulsions and a time of flight detector to measure the velocities of the antihydrogen atoms. A thin vacuum window limits the position resolution due to multiple scattering, but is needed to separate the ultra-high vacuum part from the outer vacuum region containing the emulsion films. Measurements showed that emulsion detectors can measure the annihilation vertex of antihydrogen atoms in the AE$\bar{g}$IS experiment with very high precision. Vertex resolutions in the range of 1 to 2 μm were obtained which,

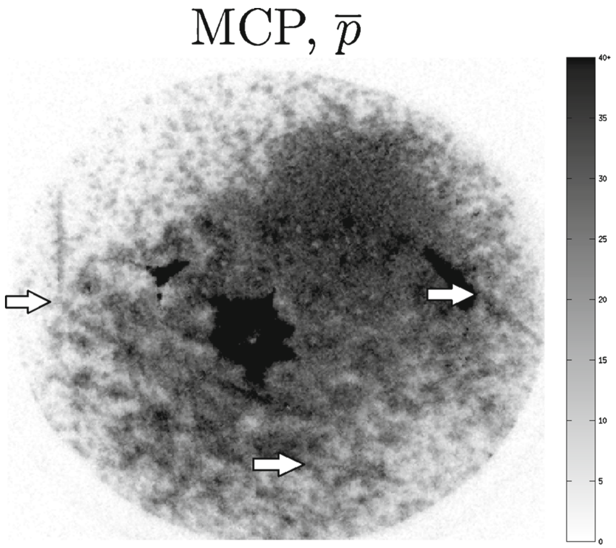

Fig. 2 Antiproton beam detected by the SEM in the MCP stand-alone configuration. Arrows highlight annihilation events in the detector. Scale in 8-bit grayscale palette

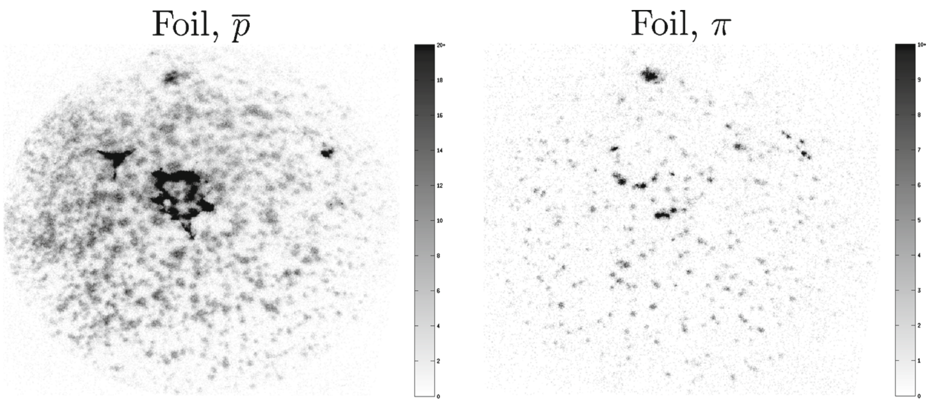

Fig. 3 Antiproton beam detected by the SEM in the foil/mesh configuration. When the gate valve upstream of the SEM is open (*left*) the monitor receives the full particle beam, and only high-energy pions otherwise (*right*). Scale in 8-bit grayscale palette

when combined with time of flight data, lead to an order of magnitude reduction of the data taking time originally foreseen to reach the goal of 1 % uncertainty in Δg/g [10] measurements. Figure 4 shows annihilation events with the vertex detector.

4 Silicon detectors

Finally, several different silicon detector technologies were also tested in this run. Among them, a Silicon strip detector, a 3D pixel detector and the MIMOTERA detector (ultra thin

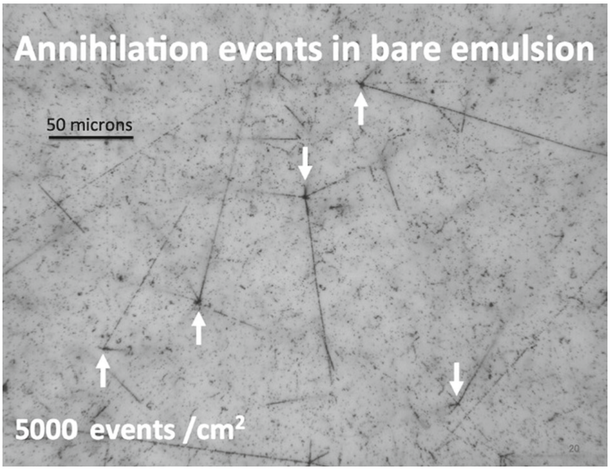

Fig. 4 Annihilation events in the vertex detector with nuclear emulsions

pixel detector). These detectors allowed for the first ever study of annihilation of low-energy antiprotons on silicon. Antiproton annihilations have been identified using the 3D pixel detector. Extensive amounts of valuable data have been acquired and are currently being compared with simulation results [11].

5 Conclusions

A dedicated beam instrumentation and detector test stand has been installed behind the AE$\bar{g}$IS experiment at CERN. Several antiproton detector technologies were successfully tested in the last 2012 run. It was shown that using improved emulsions data can now be taken much faster than before and annihilation vertices can be measured very precisely. Three different Silicon detector technologies were also tested and gave promising first results; data is currently compared against simulation results. Finally, the low-energy antiproton beam as well as single annihilation events were detected with two different configurations of a purpose-built SEM. The stand-alone MCP configuration yielded clearer beam images, but introduced some additional background noise from high energy secondary particles in comparison to the foil-based SEM configuration. In this run the SEM was the only online monitor and the only one sensitive enough for initial (low intensity) beam steering.

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