Operational experience with profile monitors for MeV and keV antiproton beams at CERN's Antiproton Decelerator

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Abstract

In this talk we briefly overview some beam profile monitors used in CERN's Antiproton Decelerator to measure the profile of antiproton beams with keV and MeV-scale energies.

The ASACUSA (Atomic Spectroscopy and Collisions Using Slow Antiprotons) collaboration is currently carrying out various atomic physics experiments involving antimatter at the Antiproton Decelerator (AD) [1] facility of CERN. The AD delivers a 100-ns-long pulsed beam containing $N_{\overline{p}} = (3-4)\times 10^7$ antiprotons of kinetic energy $K = 5.3$ MeV, at a repetition rate $f \sim 0.01$ Hz. A radiofrequency quadrupole decelerator (RFQD) [2,3] is then used to further reduce the beam energy to $K \sim 10$–100 keV. This beam is used to synthesize antiprotonic helium atoms ($\overline{p}\mathrm{He}^+ \equiv \overline{p} + \mathrm{He}^{2+} + e^-$) [2,4–6] and ions ($\overline{p}\mathrm{He}^{2+} \equiv \overline{p} + \mathrm{He}^{2+}$) [7], and carry out precision laser spectroscopy [4,5,8] on them. In this paper, we describe several kinds of detectors [9–11] with position-sensitive electrodes which were used for this purpose.

A parallel plate ionization chamber (PPIC) [9] was constructed to monitor an antiproton beam of $K = 21$ MeV. It contained three parallel polyester foils of 1.5-μm thickness – an anode foil and two position-sensitive cathodes mounted at a distance 2 mm on either side of it. The foils were placed in a vacuum chamber filled with a mixture of 90% argon and 10% methane (P10 gas), at a low gas pressure $P = 6.5$ kPa which helped to minimize space-charge and recombination effects [12,13]. The antiproton beam was allowed to travel through the foils in a direction perpendicular to their surfaces.

The electron-ion pairs produced in the gas were accelerated between the foil electrodes. The position-sensitive cathodes consisted of 20 segmented strips of width 0.92 mm in each plane. The X- and Y- projections of the antiproton beam were obtained by using 40 charge sensitive preamplifiers to measure the charge induced in each strip. The electrodes were manufactured by sputtering gold layers of thickness $t_d = 20$ nm onto the polyester foils The strip patterns were cut by focusing the output of a Q-switched neodymium-doped yttrium-aluminium garnet laser of wavelength $\lambda = 1064$ nm on the foil. By slowly scanning this spot along the foil surface, 80-μm-wide lines were drawn where the gold was vaporized and the underlying polyester exposed. The polyester, being highly transparent at 1064 nm, was undamaged by the laser.

The PPIC was irradiated with 300-ns-long beam pulses containing $N_{\overline{p}} = 5\times 10^7 - 1.4\times 10^9$ antiprotons at the Low Energy Antiproton Ring (LEAR) facility of CERN. The number of antiprotons $N_{\overline{p}}$ in each pulse was roughly deduced from the anode signal, under the assumptions that, i): a 21-MeV antiproton produced ~ 30 ion pairs [14,9] in the PPIC, ii): the electrons were collected with unit efficiency by the anode. At fields of $E = 75V/\mathrm{mm}$ applied between the anode and cathode, the collected charge became roughly equal to the value estimated above for an ideal ionization chamber. The horizontal and vertical centroid positions of antiproton pulses where thus measured, and systematic drifts in the beam position were studied [9].

We next constructed a parallel plate secondary electron emission detector [9], which measured the profiles of 5.3-MeV antiproton beams without the use of detector gas. As before, the detector consisted of an anode foil and two position-sensitive cathode foils. The foils were coated with a 50-nm thick layer of oxidized aluminium, which had a relatively large yield γ_e for secondary electron emission. These foils were placed in the vacuum pipe of the AD beam line, and evacuated to a pressure $P \sim 10^{-8}$ Pa.

When an antiproton struck a strip electrode on a cathode foil, an estimated $\gamma_e \sim 0.5$–1 [15,16] secondary electron were emitted. These were accelerated toward the anode foil biased at 50–100 V. Charge sensitive preamplifiers measured the charge ejected from each strip. The spatial profile of the AD beam measured with the device was characterized by a dense core of cooled antiprotons of diameter $d = 5$ mm, surrounded by a large ($d > 20$ mm) halo. This result was in good agreement with emittance measurements of the antiproton beam circulating in the AD, which were carried out using a scraper detector [1].

The pulsed beam emerging from the RFQD [2,3] had an energy $K = 10$–100 keV, a large diameter $d \sim 30$ mm, and contained $(5 - 8) \times 10^6$ antiprotons. At such low energies, parallel plate monitors could no longer be used since the antiprotons would stop in it. We therefore developed a secondary electron emission detector [10] based on grid electrodes of wires with diameter $d \sim 5$–10 μm. This allowed most of the antiprotons to pass through without degradation, while a small portion (typically 1–2%) intercepted by the wires produced the signal. The monitor consisted of X and Y position-sensitive cathode grids, sandwiched between three anode grids with a distance $l = 2$ mm between them. Each grid consisted of 32 gold-coated tungsten wires stretched over a ceramic frame, with a pitch $\Delta x = 0.25$–1 mm between neighboring wires. They were manufactured by first printing a pattern of gold readout microstrips with thickness $t_r = 30$ μm along the edges of the frame. An electrode tip made of tungsten pressed the microwire ends onto the corresponding microstrips. The wires were then embedded and fused into the microstrips by applying a pulsed current on the tip.

Due to the very small number of antiprotons intercepted by each wire, only $\sim$ 1000 signal electrons were emitted from it per antiproton pulse. Of particular importance to achieving a high sensitivity in the charge-sensitive preamplifier [10] was the use of junction field-effect transistors with a low $1/f$ noise coefficient $K_f \sim 10^{-27}$ J, and a high transconductance gain $g_m \sim 50$ mS. The output voltage signal V_0 of the preamplifier was converted into a differential current one I_d using a transconductance amplifier. This signal was then transmitted from the preamplifiers to an active filter amplifier housed in a nearby electronic rack, over several meters of shielded twisted-pair cable [10,17]. The differential nature and low impedance of the signal ensured that any external interference picked up on the cable would not degrade the signal-to-noise ratio. This was essential because the monitor was used next to the RFQD, which was excited with MW-scale RF powers at frequency $f \sim 202.5$ MHz. The detector achieved an equivalent noise charge of $\varepsilon \sim 200$ electrons. This is within a factor 2 of the best values reported for any room-temperature detector of comparable capacitance $C_{\mathrm{det}} \sim 10$ pF.

The monitor could also be used to measure the profiles of UV laser pulses, by employing the wires as photocathodes. Four such monitors were constructed, and operated in ultrahigh vacuum ($p \sim 10^8$ Pa), low temperatures ($T < 100$ K), and strong magnetic fields ($B > 0.1$ T) near an antiproton Penning trap [18]. A similar detector based on photon imaging of secondary electrons will be used in the Linac4 testbench facility now under construction at CERN [19].

This work was supported by the European Young Investigator Awards (EURYI) of the European Science Foundation and the Deutsche Forschungsgemeinschaft, and the Grant-in-Aid for Creative Basic Research of Monbukagakusho.

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