Production of ultra-slow antiproton beams

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In the study of atomic physics, exotic particles with negative charge have played an important role in revealing atomic capture processes as well as structures of formed exotic atoms. Among them, antiprotons with its infinite lifetime can be a best-suited probe, especially if they can be cooled to (sub-)atomic energies and become available as a mono-energetic beam at 10–1000 eV. With the aim of decelerating and cooling the antiproton beams delivered from the AD facility (at 5.3 MeV), ASACUSA collaboration prepared a sequential combination of an RFQD (Radio-Frequency Quadrupole Decelerator; down to 50–120 keV), degrader foils (to less than 10 keV) and a Multi-Ring electrode Trap (MRT) installed in a superconducting magnet of 2.5 T. Here the antiprotons were cooled by preloaded electrons to energies less than an electronvolt.

In order to extract the antiprotons out of the strong magnetic field and transport them to a field-free region for atomic physics experiments, a 3 m beamline was designed [1], where the antiproton beam was refocused three times by sets of Einzel lenses at the position of apertures. These variable apertures of diameter 4–10 mm allow differential pumping of 6 orders of magnitude along the beamline, which was necessary to keep the trap region at an ultra-high vacuum better than 10^{-12} Torr so as to avoid antiproton annihilation, while the end of the beamline will be exposed to atomic or molecular gas jets of upto 10^{-6} Torr in our near-future experiments.

We have so far achieved efficient confinement of millions of antiprotons in the MRT [2], and recently succeeded in producing an ultra-slow monoenergetic antiproton beam by extracting the trapped antiprotons and transporting them at a typical energy of 250 eV.

The MRT, the superconducting solenoid and the eV-beam transport line are jointly known as "MUSASHI", or the Monoenergetic Ultra-Slow Antiproton Source for High-precision Investigations. A variety of physics experiments will become possible using the unique beam from MUSASHI, ranging from atomic physics to nuclear physics [3]. The ultra-low energy of the beam allows single collision experiment with atomic targets, while the continuous aspect of the slowly extracted beam of 10 s duration per each spill allows event-by-event data acquisition associated with each single antiproton extracted.

Especially, we are preparing a supersonic gas-jet target to study atomic formation and ionization processes under single collision conditions. The target is aimed to achieve a density of 3×10^{13} cm^{-3} with a gas-jet cross section of 5 mm × 1 cm [4], which will be crossed with the beam of 10^5 antiprotons to produce 10^2 antiprotonic atoms per spill.

The overview of the project will be presented with an enphasis on the key points for efficient extraction from the strong magnetic field.

References

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