# AN ANTIPROTON RECYCLER FOR ATOM-ANTIPROTON COLLISION EXPERIMENTS*

M.R.F. Siggel-King, C.P. Welsch#, Cockcroft Institute and University of Liverpool, UK
O. Karamyshev, A.I. Papash, Max Planck Institute for Nuclear Physics, Heidelberg, Germany and
Joint Institute for Nuclear Research, Dubna, Russia (on leave)

*Abstract*

Collision experiments with low energy antiprotons and gas jet targets such as He, Ar, or H·, aimed at measuring differential cross sections, would be a very interesting way to elucidate the details of this interesting collision process. At present, such experiments are, however, not feasible, since the only source of antiprotons in the world, the AD at CERN, cannot provide beams of the required energy and quality. The design of a small electrostatic ring, which would enable such experiments, has been developed. This ring is also a prototype for the future ultra-low energy storage ring (USR), which will be integrated at the facility for low-energy antiproton and ion research (FLAIR). This small ring is unique due to its combination of size, electrostatic nature, and energy of the circulating particles. In this contribution, the design of the ring is described and possible scenarios for its use at the ASACUSA beam line and behind the ELENA ring are compared with each other.

## INTRODUCTION

Total cross section collision measurements with low energy antiprotons and gas jet targets such as He, Ar and H· have been measured [1,2] on the ASACUSA beamline [3] at the AD at CERN [4]; the results are interesting and not unambiguously interpretable. In order to further elucidate and understand the collision mechanism, it is desirable to make differential cross section measurements, which are presently not feasible due to the limitation of the available flux of low energy antiprotons.

At the present time, the antiproton decelerator (AD) at CERN is the only facility providing low energy antiprotons for physics experiments. Work is underway on two new low energy antiproton facilities. At the GSI in Germany, the Facility for Antiproton and Ion Research (FAIR) [5] will include the Facility for Low Energy Antiproton and Ion Research (FLAIR) [6]; FLAIR will include the Ultra-Low-energy Storage Ring (USR) [7], which has been designed to provide low energy antiprotons for a variety of physics experiments, including in-ring partial differential cross section measurements. It is, however, unlikely that the USR will be operational this decade. Meanwhile, at CERN, construction has begun on the ELENA ring [8], which is due to be completed in 2016. ELENA will be placed after the AD and will provide low energy antiprotons with greater efficiency than the present AD set-up. The ELENA ring includes two beamlines; the first one to be built will provide antiprotons mainly to the existing groups who currently use the AD. Whilst the ELENA ring will provide an enhancement in the flux of antiprotons available for experiments, it has not been designed for in-ring experiments of the type that would enable partial cross section experiments. It does, however, provide an opportunity for a small low-energy electrostatic ring [9,10], that could be placed on the ASACUSA beamline [3] or on an ELENA beamline.

## THE RECYCLER RING

A 3-D model of the recycler ring [9,10] is shown in Fig. 1 and includes the vacuum system and ion pumps, supports and ring alignment mechanisms. A cross sectional scale drawing of the injection beam line and recycling ring is also shown in Fig. 1. The ring optics are all electrostatic and comprise 90° cylindrical deflectors and quadrupole triplets and singlets. The ring has been designed to be a prototype for the USR and to meet the needs of the crossed beam studies. The latter includes a small antiproton beam spot size at the collision location, which is the reason for the relatively large number of quadrupole elements. In addition, the size of the whole setup was made as small as possible. The ring has a periodicity of two. An advantage of using electrostatic elements is that the voltages required on the elements are dependent only on the charge and energy of the ion; they are independent of the mass (whereas magnetic focussing and deflecting devices also have a mass dependence). The main parameters of the facility are presented in Table 1.

The ring and injector have been designed as relatively compact mobile facilities to enable them to be moved worldwide and used on a variety of different types of sources, including different charged projectiles; they can be used for a wide variety of applications and experiments. In this publication we will concentrate on two main scenarios, both of which provide antiproton projectiles to the ring for differential cross section studies.

---

[#] c.p.welsch@liverpool.ac.uk

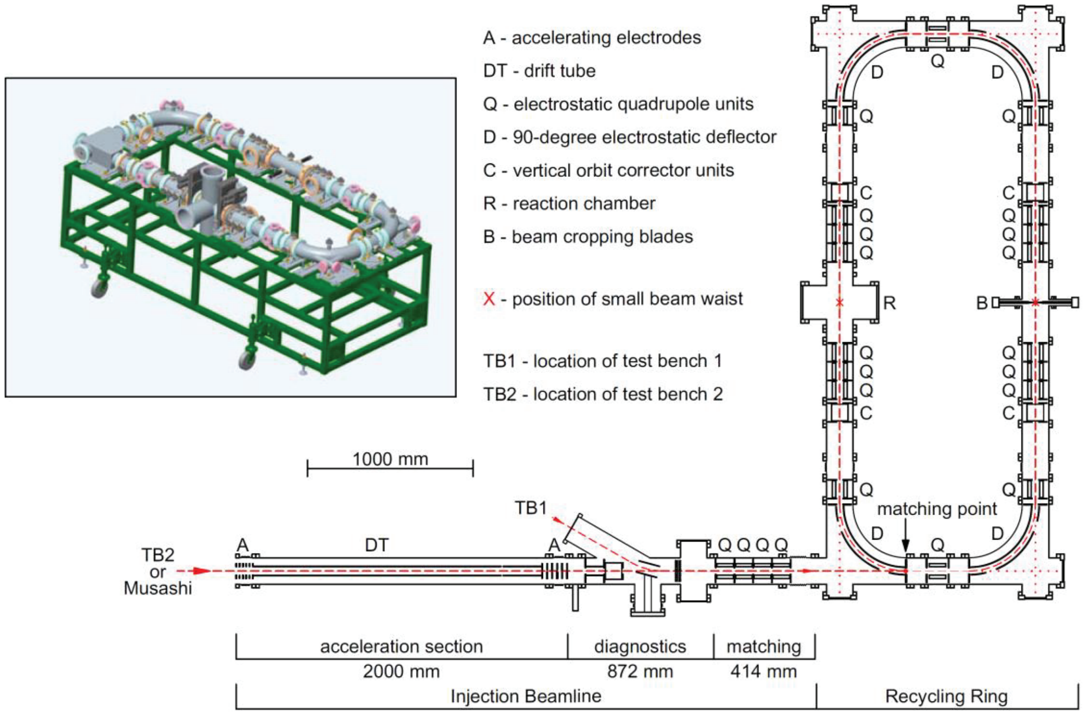

Figure 1: Scale drawing of the injection beamline and the recycling ring. TB1 denotes the location of a test beamline for setting up the ring when it is attached to the Musashi beamline. TB2 denotes the location of a test beamline for testing the injection beamline.

Table 1: Ring, Beam and Injection Parameters

| Parameter | Value(s) | |
|---|---|---|
| Energy range | 3 to 30 keV | |
| Circumference | 8.165 m | |
| Length of free straight for experiment | 324 mm | |
| Ring acceptance | 15 π mm·mrad | |
| Ion rotation frequency | 294 to93 kHz | |
| Vacuum | $10^{-10}$ mbar | |
| Operation time for 3000 turns | 10 to 32 ms | |
| $\beta$ (v/c) | $2.5 \times 10^{-3}$ to | $7.8 \times 10^{-3}$ |
| $\beta$-functions, min | $\beta_x = 0.02$ m | $\beta_y = 0.11$ m |

## RECYCLER ON THE MUSASHI TRAP

The first scenario is to use antiprotons from the MUSASHI trap [11] for the recycler ring. The trap is presently located on the ASACUSA beamline on the CERN-AD but it will eventually move onto the first ELENA beamline, once it is operational. The recycler ring accelerating injector [12] has been designed to transport antiprotons from the MUSASHI trap to the recycler ring.

Whilst the trap is in its present position, the antiproton beam that will be injected into the recycling ring will comprise 5 shots of antiprotons from the AD; these will be collected and cooled in the MUSASHI trap, then extracted with an energy between 150 and 500 eV kinetic energy and with a bunch length of 1-2 μs.

### *Accelerating Injector (for Use on the MUSASHI Trap)*

The accelerating injector [12] will transport antiprotons from the MUSASHI trap to the recycler ring. It will provide focusing and beam shaping and it will use electrostatic fields to adjust the energy of the particles to match the recycling energy of the ring whilst the trap and ring remain at ground potential; this is achieved without the expense of an RF accelerator.

The injector has three main parts. The first part is the acceleration section, where the energy of the antiprotons is increased from the extraction energy of the trap to the re-circulating energy of the ring (3-30 keV). The second part of the injection line is the diagnostics block. The third part is the matching section, which comprises four electrostatic quadrupoles that match the shape and divergence of the beam to the ring parameters.

The acceleration section comprises two sets of accelerating electrodes, which are separated by a long drift tube. When the beam pulse is inside of the drift tube the voltage applied to the central section of the pipe is switched to the required negative value, between -3 and -30kV. The acceleration is then realized using a series of apertures to which increasing positive voltages are applied (see Fig. 2). The choice of a pulsed electrostatic acceleration section avoids the necessity of floating the entire ring to high voltages.

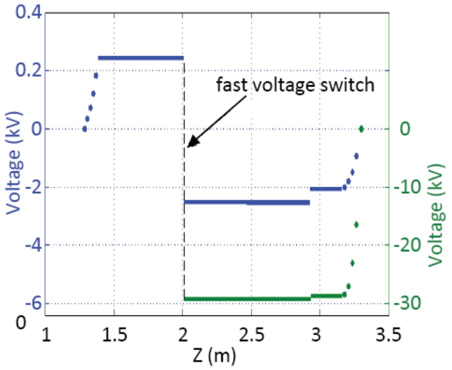

Figure 2: Electrode voltages for the acceleration section. The blue points and line corresponds to the voltages required for an initial energy of 150 eV and a final energy of 3 keV. The green points and line shows the voltages required for final acceleration to 30 keV.

### *Advantages of Using the MUSASHI Trap*

The main advantage of using the MUSASHI trip as a source for the recycling ring is that is exists at the present time and would enable measurement of partial cross sections to begin almost immediately. Extensive modelling and theoretical studies have provided an appropriate coupling injector design and evidence of the feasibility of such studies using this source. Typical real-time count rates for the total cross section data given in ref [1] were on the order of 100's of counts per hour. Using the MUSASHI trap in its current location with the above described injector and ring would yield an increase in the count-rate of about an order of magnitude (~a few thousand counts/hour) [9]. If, however, the antiprotons for the MUSASHI trap were to come from the ELENA ring, then an increase of another order of magnitude (to ~a few tens of thousands counts/hour) would be realised.

## RECYCLER ON THE ELENA RING

Another possibility of realising an improvement in the flux of antiprotons for the partial cross section experiments is to place the recycler ring directly onto an ELENA beamline. ELENA will provide cooled antiprotons at energies as low as 100 keV both in the form of a coasting beam and of bunches of several 100 ns duration. These beams can then be extracted by a fast extraction system and be delivered to up to four external experiments in parallel via a fast electrostatic beam switch.

An interesting option is to setup a purpose-built decelerating injection beamline to transport the antiprotons between ELENA and the small recycling ring at a very early phase of the ELENA project, i.e. when the ELENA ring is still being commissioned. This way, measurements of cross sections of antiproton-atom collisions could be done in parasitic mode and at a time when the other experiments would not yet be ready to take measurements. The ring could then be moved into one of the experiment zones at a later stage for measurements with different types of target gases.

## CONCLUSION

The design of a small recycling ring for low energy antiproton beams and an injection line to transport and accelerate antiprotons from the MUSASHI trap at the AD at CERN to the ring has been described. The option to install the ring in the ELENA extraction beam line has also been presented. The ring has been designed to enable differential ionization cross section measurements of antiproton-atom collisions by incorporating a very compact reaction microscope into the ring.

## ACKNOWLEDGEMENTS

The generous support of the Helmholtz Association of National Research Centers and GSI Helmholtz Centre for Heavy Ion Research under contract VH-NG-328, the EU under contract PITN-GA-2008-215080, the Max Planck Institute for Nuclear Physics and the STFC Cockcroft Institute Core Grant No. ST/G008248/1 is acknowledged.

## REFERENCES

[1] H. Knudsen et al., Phys. Rev. Lett. 101 (2008) 043201.
[2] H. Knudsen et al., Phys. Rev. Lett. 105 (2010) 213201.
[3] R.S. Hayano et al., ASACUSA Status Report, Jan. 2011, CERN-SPSC-2011-005, SPSC-SR-075.
[4] S. Baird et al., "The Antiproton Decelerator: AD," Proc. Part. Acc. Conf., Vancouver, Canada (1997).
[5] http://www.gsi.de/fair/
[6] C.P. Welsch et al., Hyperfine Interact. 172 (2007) 71.
[7] C.P. Welsch et al., Nucl. Instrum. Meth. A. 546 (2005) 405.
[8] J. Alsner et al., ELENA: An Upgrade to the Antiproton Decelerator, CERN-SPSC-2009-026 (2009).
[9] A.I. Papash et al., "Design of an Antiproton Recycling Ring", Proc. IPAC, JACOW, San Sebastian, Spain 2011, WEP205.
[10] M.R.F. Siggel-King et al., Hyperfine Interactions 199 (2011) 311-319.
[11] N. Kuroda et al., "Development of MUSASHI, a mono-energetic ultra-slow antiproton beam source," Proc. of IPAC'10, Kyoto. Japan, (2010) THPEC058, 4188-4190.
[12] O. Karamyshev et al., "Design of the Injector for a small Recycling Ring on the CERN-AD," Nucl. Instrum. Meth. A (2012), *in press*.