Cockcroft-11-33

DESIGN OF A LOW ENERGY ION BEAM FACILITY

M.R.F. Siggel-King, C.P. Welsch, Cockcroft Institute
and the University of Liverpool, UK
O. Karamyshev, G. Karamysheva, A.I. Papash, MPI-K, Heidelberg,
Germany and JINR, Dubna, Russia (on leave)

DESIGN OF A LOW ENERGY ION BEAM FACILITY*

M.R.F. Siggel-King#, C.P. Welsch, Cockcroft Institute and the University of Liverpool, UK
O. Karamyshev, G. Karamysheva, A.I. Papash, MPI-K, Heidelberg, Germany and JINR, Dubna, Russia (on leave)

Abstract

A small electrostatic ring, and associated electrostatic injection beamlines, are being designed and developed. The ring will make possible a variety of experiments using a choice of many types of recirculating ions (e.g., from protons, H^-, and antiprotons up to and including large charged biomolecules). A reaction microscope will be incorporated into the ring to enable differential ionization experiments between the recirculating ion beam and gas jet targets. Two injection sections have been designed to cover a variety of ion sources. The facility will be portable to enable it to be moved between facilities and beamlines and it will be unique due to its combination of design elements, flexible beam properties, energy (ca 3-30 keV) and type of circulating particles. In this paper, we give an update on this project.

INTRODUCTION

The measurement of ionization cross sections in collisions between low energy beams of antiprotons and different target gases, such as for example Helium, directly addresses the few-body Coulomb problem – one of the most fundamental problems in physics. Several experimental studies at CERN have been carried out over the past two decades, but have been limited to the level of total cross sections due to the single pass setup of the experiments and the very limited availability of high quality low energy antiproton beams.

A compact recycling ring that would capture a beam of antiprotons and store it for several thousands of turns, combined with an internal gas jet target and reaction microscope, would overcome the present limitations and enable, for the first time, measurements on the level of differential cross sections. Such ring and associated injector has been designed over the past two years [1,2] by the QUASAR Group in close collaboration with the ASACUSA collaboration and experts from the Max Planck Institute for Nuclear Physics in Heidelberg.

ION BEAM FACILITY

The initial design has now been extended into a general ion beam facility to accommodate a wider range of applications. The ring has been designed to circulate ions with an energy between 3 and 30 keV. A model of the ring, coupled to the non-accelerating ion injector, is shown in Fig. 1. This figure shows the vacuum system and includes ion pumps, supports and ring alignment mechanisms. In subsequent figures, many of the elements outside the main ring vacuum vessel have been removed.

The ring and injectors have been designed as relatively compact mobile facilities to enable them to be moved and used on sources world-wide as well as off-line in laboratories. 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).

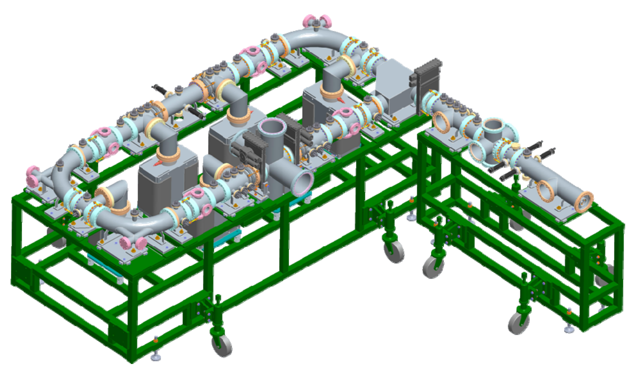

Figure 1: The recycling ring and non-accelerating injector.

RECYCLING RING

The electrostatic elements of the ring are shown in Fig. 2; the ions are injected into the ring from the lower right corner. The electrostatic elements comprise four 90° deflectors (D), four quadrupole (Q) triplets, six quadrupole (Q) singlets and four vertical orbit correctors (Cv). The horizontal orbit correction is effected using the 90° deflectors. The relatively large number of quadrupole elements enables the beam to be controlled and shaped to match the requirements of various in-ring experiments that occur at the centre (marked with a red ×) of the reaction chamber (R). These experiments will utilise an in-ring reaction microscope [3] for which the optimum diameter of the beam is ~1 mm. To confine the beam to a given size, four orthogonal retractable beam cropping blades (B) have been included on the side opposite the reaction chamber.

A good vacuum is required to optimise the number of turns the beam will make around the ring. The vacuum will be maintained using four ion pumps (shown in Fig. 1) together with three turbomolecular pumps placed under, and adjacent to, the reaction chamber.

All materials used for the vacuum housing or inside the vacuum housing will be non-magnetic UHV compatible

*Work supported by the Helmholtz Association and GSI under VH-NG-328, the EU under GA-PITN-215080, and STFC.
m.r.f.siggel-king@liverpool.ac.uk

(*e.g.* stainless steel, ceramic, copper, titanium, gold, etc.). All electrodes close to the beam will be gold coated to minimise oxide layers and the related patch potentials. The beam pipes and non-electrode stainless steel parts will be processed prior to assembly by polishing and by vacuum annealing to 900°C to minimise out-gassing. The assembled ring will be baked, under vacuum, by enclosing it in an insulated box with a heating element placed centrally and with fans used to circulate the heat.

The ring will be shielded from external magnetic fields by enclosing it in a box comprised of suitable shielding material (e.g. mu-metal or Co-netic). The magnetic shielding will be integrated with the bake-out box.

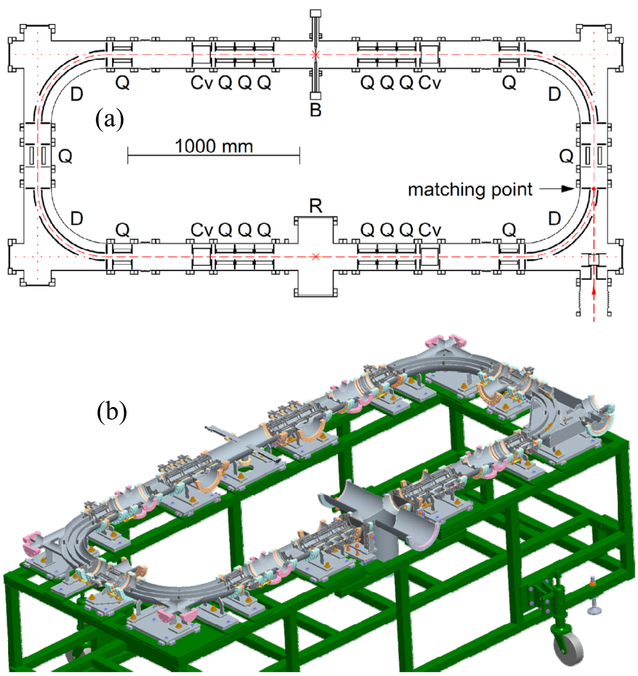

Figure 2: The ring. (a) Cross-sectional scale drawing of the ring; horizontal cut including the mean path of the ion beam (dashed red line). (b) 3-D model with horizontal cut through the mean beam path to show internal details.

The result of a MAD-X simulation for the ring is shown in Fig. 3. The x-axis gives the distance from the centre of the reaction vessel (s=0) the beam has travelled and covers one-half of the ring. Across the top of the figure are shown the locations of the quadrupole (blue vertical lines) and deflector (red horizontal lines) elements. The x and y components of the β functions are shown by the black and red curves, respectively (and correspond to the black vertical axis on the left side. The dispersion is shown by the green curve. The red vertical axis on the far left side corresponds to the two β curves and shows the relation between the beta values and the actual size of a beam of emittance of 17 π·mm·mrad, which just fills the ring at its limiting element. The centre of the in-ring reaction region is at s=0. These results show that it is possible to have a beam of β_x by β_y of 0.02 m × 0.11 m at the interaction region, which corresponds to a spot size (2σ) of 1.1 mm × 2.8 mm for a 3 keV beam and of 0.7 mm × 1.6 mm for a 30 keV beam. These values are appropriate for the reaction microscope.

A detailed discussion of the ring dynamics is given in [2]. Table 1 gives some of the ring parameters.

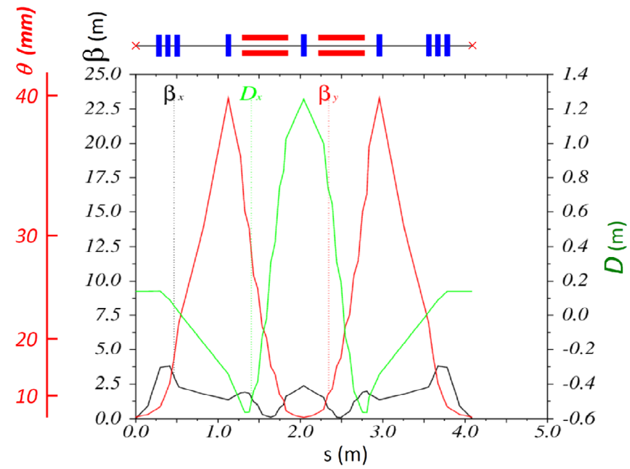

Figure 3: MAD-X simulation results for the ring.

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
Ion rotation period	3.4 to 10.7 µs
Vacuum	10^{-10} mbar
Operation time for 3,000 turns	10 to 32 ms
β (v/c)	2.5×10^{-3} to 7.8×10^{-3}
β-functions, min	$\beta_x = 0.02$ m $\beta_y = 0.11$ m

NON-ACCELERATING INJECTOR

The non-accelerating ion injector enables charged particles that are matched to the recirculating energy of the ring to be injected, and is, therefore, appropriate for many various types of ion sources including bolt-on proton, H^- and electro-spray sources and accelerator and decelerator rings.

This injector is shown in Fig. 4, where the ions travel from the source (on the right, not shown) to the ring (on the left). The ions first encounter a three-element Einzel lens (L), which focuses and guides the ions. The first element of the Einzel lens is fitted with pairs of vertical and horizontal correctors (Cv, Ch) and is installed with two rings (V) between the lens and the vacuum housing to provide differential pumping. An inflector/chopper (IC) is used to chop the beam into bunches to provide a pulsed beam for injection into the ring. A graphite collimator (GC) defines the beam that is injected. In the centre of the injector is a diagnostics chamber (DC) to enable various types of beam diagnostics to be inserted. Horizontal and vertical correctors are placed before the quadrupole (Q) quartet; the latter enables the beam to be shaped to match the phase of the ring.

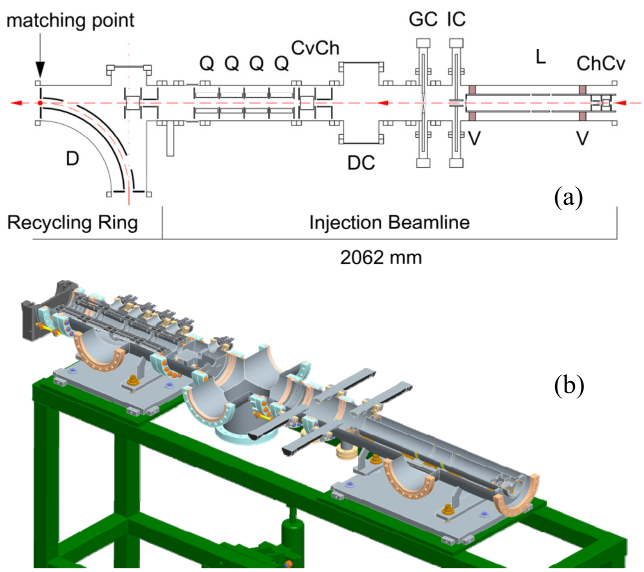

Figure 4: Ion injector for ions of energies that match the recirculating energy of the ring. (a) Cross-sectional drawing of the ion injector; horizontal cut including the mean path of the ion beam (short dashed line). (b) 3-D model with horizontal cut through the mean beam path to show internal details.

ACCELERATING INJECTOR

The accelerating injector is designed for very low energy ions. It enables a bunch of ions, having an energy of less than the desired recirculating ring energy, to be accelerated and matched to the ring. This injector was optimised for use on traps, where the ions are cooled to zero eV and are then extracted at an energy of less than 1 keV. Although this injector was designed with a particular source in mind, the MUSASHI trap at the CERN Antiproton Decelerator (AD) [4], it could be used on a variety of similar ion traps. A detailed description of the injector is given in [5] and [6].

A scale drawing of this injector is shown in Fig. 5, where the ions travel from right to left. The ions (B1) first encounter a short accelerating section (A) comprised of a set of ring electrodes which are sequentially biased with increasing voltages (positively for negative ions and negatively for positive ions). These electrodes accelerate and focus the ions towards the drift tube (DT). When the bunch is inside the drift tube, the voltage on the drift tube is rapidly switched to change the local earth reference for the bunch. The ions then encounter a second short accelerating section which accelerates the ions to the desired ring energy. This type of electrostatic accelerating section avoids the necessity of floating the ring to high voltages and enables more control over the beam; it also avoids the expense and complications associated with a traditional RF accelerating system.

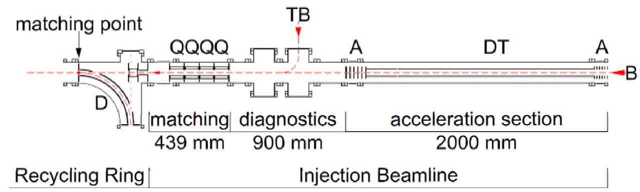

Figure 5: Accelerating injector for ions of energies less than the recirculating energy of the ring (a) Cross-sectional drawing of the low energy ion injector; horizontal cut including the mean path of the ion beam (short dashed line). (b) 3-D model with horizontal cut through the mean beam path to show internal details.

SUMMARY AND OUTLOOK

The design of a compact low energy ion beam facility, consisting of a compact recycling ring and associated injector(s), was presented in this paper. All important parameters were summarized with emphasis on the final (mechanical) design. Whilst this facility was initially developed with the aim of enabling beyond state-of-the-art atomic physics collision experiments with low energy antiprotons at CERN, the work summarized in this paper has transformed it into a true multi-purpose experimental facility for use with most different ions and molecules.

ACKNOWLEDGEMENTS

The authors are grateful to Søren Pape Møller, Helge Knudsen, Yasunori Yamazaki, Hiroyuki Torii, Naofuni Kuroda, Oleg Malyshev, Joachim Ullrich and Robert Moshammer for helpful discussions and to Michael Cordwell and Clive Hill for the mechanical design of the ring and ion injector.

REFERENCES

[1] M.R.F. Siggel-King, *et. al.*, “Electrostatic Low-energy Antiproton Recycling Ring”, Hyperfine Interact. 199 (2011) and references therein.

[2] A.I. Papash, *et al.*, “Design of an Antiproton Recycler Ring”, Proc. Part. Acc. Conf., New York, USA (2011) and references therein.

[3] R. Dörner, *et al.*, “Kinematically complete experiments using cold target recoil ion momentum spectroscopy”, Nucl. Instr. Meth. B (1997) 225.

[4] H.A. Torii, *et. al.*, “Production of ultra-slow antiproton beams” AIP Conf. Proc. 793 (2005) 293.

[5] O. Karamyshev, *et. al.*, "Design of an Antiproton Injection Beam Line for the AD Recycler Ring", Proc. IPAC, San Sebastian, Spain (2011).

[6] O. Karamyshev, *et. al.*, "Investigations into Efficient Extraction and Acceleration of Beams from Ion Traps", Proc. IPAC, San Sebastian, Spain (2011).