Electrostatic Low-Energy Antiproton Recycling Ring

Michele Siggel-King

on behalf of the Recycling Ring Design Group (Quasar, Musashi & Ullrich groups)
Motivation

Now

Low-Energy Antiproton Research

CERN Antiproton Decelerator

One possible future:

Facility for Antiproton and Ion Research

Facility for Low energy Antiproton and Ion Research

Ultra low energy Storage Ring

TCP 2010 Conference 12 April 2010

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Motivation

“ring of the future”
to enable
atomic physics experiments

Papash & Welsch, NIM A, (2010) accepted
Motivation

Low Energy Antiproton Research

Electrostatic Low-Energy Antiproton Recycling Ring
- Prototype for USR
- Enable atomic physics crossed-beam studies

antiprotons available from

FAIR delayed

FAIR delayed

USR delayed

2019, 2020?
Installation Configuration

ASACUSA Collaboration
http://cern.ch/ASACUSA

Electrostatic Low-Energy Antiproton Recycling Ring

CERN AD: S. Baird et al, PAC 97 Conf. Proc. 979
Antiprotons from Musashi Beamline

5 AD shots collected in trap
⇒ 250 eV (1µs) pulse
“beam” defined by 2 apertures

8 mm φ apertures
500 000 antiprotons
5 AD shots

ring emittance of 50 π·mm·mrad (@3 keV)

variable φ apertures
208 mm
detector

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Helium single ionisation cross section

fundamental atomic physics experiment

He \rightarrow_{\text{anti-proton}} \text{He}^+ + e^{-}

100's counts/hour

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Helium single ionisation cross section

\[ \text{He} + \text{p\_bar} \rightarrow \text{He}^+ + e^- + \text{p\_bar} \]

\[ KE_i \quad KE_i \quad KE \quad KE \quad KE_f \]
\[ \Omega \quad (\Omega=0) \quad \Omega \quad \Omega \quad \Omega \]

USR → fully differential cross sections
\[ \sigma(KE, \theta, \phi) \] for each particle

Recycling Ring → partial differential cross sections
\[ \sigma(p) \text{ or } \sigma(\Omega) \text{ or } \sigma(KE) \]

figures from M. McGovern et al., accepted for publication

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Differential Cross Section Measurements

Helmholtz coils

positive ion detector

electrostatic field

He^+

cold gas jet

antiproton beam

electron detector

Reaction Microscope
Resolution is a function of many parameters including:

- **Size of interaction region**: union of target gas jet & projectile antiproton beam.
- **Divergence of projectile beam**:

  - Beam cross sectional area at interaction point: ≤ 3 mm diameter
  - Beam divergence at interaction point: ≤ ±1° (±17 mrad)

\[ \Rightarrow \text{Experimental upper limit on the beam emittance of } \sim 26 \pi \text{-mm-mrad} \]
Experimental Set-up

most cross-beam experiments:

- single-pass (use beam only once)

Why not incorporate the experiment into the ring?

- Use beam many times (improvement in luminosity)
- USR and this ring
Electrostatic Antiproton Recycling Ring

Fixed-Energy Ring

circumference = 7.2 m

antiproton injection

quad singlet

quad triplet

90° deflector (250 mm radius)

y-corrector

x-corrector
## Ring and Injection Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum available intensity</td>
<td>$5 \times 10^5$ particles</td>
</tr>
<tr>
<td>Energy of injected particles</td>
<td>10 - 30 keV</td>
</tr>
<tr>
<td>Antiproton rotation frequency</td>
<td>193 - 335 kHz</td>
</tr>
<tr>
<td>Antiproton rotation period</td>
<td>5.2 - 3.0 $\mu$s</td>
</tr>
</tbody>
</table>

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Preliminary Simulation Results

MAD-X Simulation
A. Papash

\[ \beta_x = 10 \text{ cm} \]
\[ \beta_y = 27 \text{ cm} \]

at \( s = 0 \)

for an emittance of \( 10 \pi \text{ mm}\cdot\text{mr} \)

beam diameter = \( 2.0 \times 3.3 \text{ mm} \)

beam divergence = \( \pm 10 \times \pm 6 \text{ mrad} = (\pm 0.5^\circ \times \pm 0.3^\circ) \)
Electrostatic Acceleration Section

Lens

Drift tube

-20 kV pulse-on

0 V

-20 kV

Antiproton energy → 250 eV

Acceleration 20 keV

H. Knudsen
## Estimated Experimental Count rates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>energy of antiprotons (keV)</td>
<td>20</td>
</tr>
<tr>
<td>emittance of beam in ring (π·mm·mrad)</td>
<td>10</td>
</tr>
<tr>
<td>number of antiprotons/fill</td>
<td>~155 000</td>
</tr>
<tr>
<td>% of 300 000 beam</td>
<td>52%</td>
</tr>
<tr>
<td>average number of P_bar in ring</td>
<td>58 000</td>
</tr>
<tr>
<td>target density (cm⁻³)</td>
<td>5.0 x 10¹¹</td>
</tr>
<tr>
<td>average target length (cm)</td>
<td>0.079</td>
</tr>
<tr>
<td>ionisation cross section (cm⁻³)</td>
<td>4.8 x 10⁻¹⁷</td>
</tr>
<tr>
<td>detection efficiency</td>
<td>0.4</td>
</tr>
<tr>
<td>number of times bunch revolves around ring</td>
<td>6000</td>
</tr>
<tr>
<td>number of fills per hour</td>
<td>7</td>
</tr>
<tr>
<td>number ionisation events detected per hour</td>
<td>1828 (conservative value)</td>
</tr>
</tbody>
</table>
Beam Diagnostics

a challenging part of the USR and Recycling Ring project
beam diagnostics expertise in Quasar group

ultra-short bunches → DC beams
variable-energy beams low-energy beams
ultra-low currents
Beam Diagnostics

Beam Position Monitor

Capacitive Pick-up

Beam Profile

Scintillating screens

Beam Current Monitor

Faraday Cup

Gas Curtain
Beam Profile Monitor

supersonic expansion to a “gas curtain”

positive ion detector

electrostatic field

ion+

CCD

tion

reaction microscope

antiproton beam

gas curtain

Massimiliano Putignano

Hyperfine Interact (2009)
194:189-193

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Summary and Outlook

Electrostatic Low-Energy Antiproton Recycling Ring

to bridge the gap between now and until a new low-energy antiproton facility is operational

Capacitive Pick-up

Faraday Cup

Scintillating screen
Summary and Outlook

Electrostatic Low-Energy Antiproton Recycling Ring

to bridge the gap between now and
until a new low-energy antiproton facility is operational

- Prototype for USR
testing and development

- Enable progress in atomic physics crossed-beam studies
  partial cross section measurements

Presently determining overall feasibility.
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