

DESIGN STUDY FOR AN ANTIPROTON POLARIZER RING (APR)

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Abstract

In the framework of the FAIR [1] project, the PAX collaboration (Polarized Antiproton eXperiments) has suggested new experiments using polarized antiprotons [2], in particular the study of the transverse spin structure of the proton. In order to reach a high degree of polarization of the antiprotons, the spin filtering method is proposed using an optimally designed dedicated Antiproton Polarizer Ring (APR).

In this contribution the design of such a storage ring is described. The basic parameters follow from the requirements to have a large ring acceptance at an energy, where the spin-dependence of the antiproton-proton interaction leads to a large antiproton beam polarization: This suggests to operate the APR at an antiproton beam energy of 250 MeV with an emittance in both planes of 250 pi mm mrad. The APR consists of two 180 degree arcs and two straight sections. One straight section houses the elements needed for injection and extraction, and the polarized internal target. In the other straight section, the electron cooler and a Siberian snake are located. Different optical conditions have to be fulfilled in the straight sections: (1) The target cell requires a beta function of less than 0.3 m. (2) The beam has to be circular and upright in the phase space ellipse at the target, at the electron cooler, and at the snake. (3) The antiproton beam should have a size of 10 mm for an emittance of 250 pi mm mrad at the target. (4) The momentum dispersion has to be zero in both straight sections.

PHYSICS AT PAX

The polarized antiproton-proton interaction at the High Energy Storage Ring (HESR) will allow a unique access to a number of new fundamental physics observables.

The transversity distribution is the last leading-twist missing piece of the QCD description of the partonic structure of the nucleon. It is directly accessible uniquely via the double transverse spin asymmetry A_{TT} in the Drell-Yan production of lepton pairs. The theoretical expectations for A_{TT} are in the 30-40 percent range. With the expected antiproton spin filtering rate and luminosity of HESR the PAX experiment is uniquely suited for the

definitive observation of $h_1^q(x, Q^2)$ of the proton for the valence quarks.

At the core of the PAX proposal [2] is to polarize antiprotons by spin filtering of stored antiproton beam via multiple passage through an internal polarized storage cell hydrogen target. The spin dependent total cross section is given by

$$\sigma_{tot} = \sigma_0 + \sigma_{\perp} \cdot \vec{P} \cdot \vec{Q} + \sigma_{\parallel} \cdot \left(\vec{P} \cdot \vec{k} \right) \left(\vec{Q} \cdot \vec{k} \right) \quad (1)$$

where σ_0 denotes the unpolarized total cross section, $\sigma_{\perp}$ and $\sigma_{\parallel}$ are the spin-dependent transverse and longitudinal cross sections, $\vec{P}$ is the polarization of the beam, $\vec{Q}$ the polarization of the target and $\vec{k}$ is a unit vector pointing along the beam direction. For the initial case when the both spin states are equally populated $\uparrow (m = +\frac{1}{2})$ and $\downarrow (m = -\frac{1}{2})$ equation 1 is generated into equation 2 and

equation 3. For the transverse case $\vec{P} \cdot \vec{Q} = \pm Q$ and $\left(\vec{Q} \cdot \vec{k} \right) = 0$, and total cross section is given by

$$\sigma_{tot\pm} = \sigma_0 \pm \sigma_{\perp} \cdot Q, \quad (2)$$

For the longitudinal case again $\vec{P} \cdot \vec{Q} = \pm Q$ and $\left(\vec{P} \cdot \vec{k} \right) \left(\vec{Q} \cdot \vec{k} \right) = \pm Q$, and the total cross section reads

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_{\perp} + \sigma_{\parallel}) \cdot Q. \quad (3)$$

In Fig. (1) a schematic view of the complete accelerator system is shown. An Antiproton Polarize Ring (APR) built inside the HESR area with the aim of polarizing antiprotons at kinetic energies around 250 MeV to be accelerated and injected into the other rings.

HESR, CSR AND APR

A Cooler Synchrotron Ring (CSR, COSY – like) in which protons or antiprotons can be stored with a momentum up to 3.5 GeV/c. This ring shall have a straight

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section, where the PAX detector could be installed, running parallel to the experimental straight section of the HESR, where the PANDA detector is installed.

Unpolarized antiproton beam injected from the **pbar** source into the CSR with a momentum of 3.5 GeV/c is decelerated down to 250 MeV and cooled (by e-cooler), and after it is transferred into the APR, where the polarization build-up takes place. After the polarization buildup is completed, the beam is transferred back to the CSR, accelerated up to 3.5 GeV/c and then transferred into the HESR ring. By deflection of the HESR beam into the straight section of the CSR, either the collider or the fixed-target mode becomes feasible.

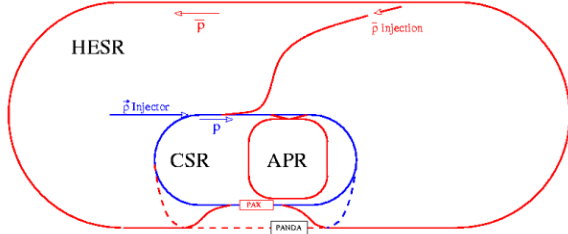


Figure 1: PAX accelerator configuration, comprising the High Energy Storage Ring (HESR), a Cooler Synchrotron Ring (CSR) and the APR.

ANTIPROTON POLARIZER RING

A storage ring is ideal to efficiently achieve a high degree of beam polarization [3]. Therefore, the ultimate goal of the PAX collaboration aims at providing a high degree of polarization, e.g. using a dedicated Antiproton Polarizer Ring (APR). The preliminary results of the lattice design study for such type of ring is presented. In Fig. 1, a floor plan of the suggested APR is shown. Following the known requirements [2], 4 straight sections are required for the insertions:

(a) injection and extraction of the antiproton beam, (b) a low β -section for the gas target, (c) the opposite section reserved for the Siberian snake (to longitudinally align the antiproton spin), and (d) electron cooling in the straight section opposite to the injection. Various ion optical conditions have to be met in the four straight sections: (i) in the target, e-cooler, and Siberian snake sections the beam cross section has to be circular and the beams phase space ellipse has to be upright, (ii) in all straight sections the dispersion should be zero, (iii) the antiproton beam in the e-cooling should be parallel and variable in order to match the size of the electron beam, (iv) and the radius of the beam spot at the target should be around 10 mm.

During a first study, we chose the following main parameters: beam energy of 250 MeV, beam emittance of $250 \pi \text{ mm mrad}$, and a magnetic rigidity of 2.4 Tm. The quadrupole arrangements in the straight sections enable tuning of the beam within a wide choice of optical conditions. The total circumference of the APR is 86.5 m,

which consisting of two 24 m long straight sections. Each of the two straight sections is divided into 12 m long straights. In addition, APR contains two 180° symmetrical arcs and the length of each arc is about 19 m. In the current design of the APR, 46 quadrupole magnets have been used with a length of 30 cm and 4 bending magnets with the length of 25cm.

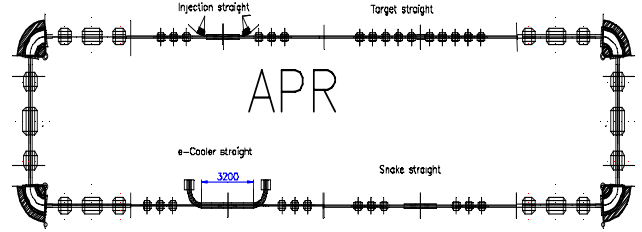


Figure 2: Floor plan of the APR

In the target straight section, a free space of 1 m is provided, for design of which a situation using three and five quadrupole was compared. The distribution for the beta function ($\beta_{x,y}$) was calculated using

$$\beta_{x,y}(s) = \beta_{x,y}(0) \left(1 + \frac{s_{x,y}^2}{\beta_{x,y}^2(0)} \right), \quad (4)$$

and the beam radius ($R_{x,y}$) using

$$R_{x,y}(s) = \sqrt{\mathcal{E}_{x,y} \times \beta_{x,y}(s)}, \quad (5)$$

where $\mathcal{E}_{x,y}$ denotes the beam emittance.

The minimum beta function for three quadrupole case is 0.21m and the beam radius is 7.25 mm in the center of the cell. However, in this case we the spikes for beta function along the quadrupole section are too large (dashed line in figure 3).

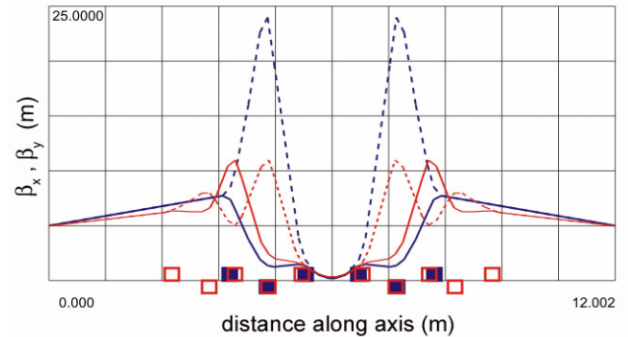


Figure 3: Beta functions of APR (β_x - solid, β_y - dashed) along the target section. Blue and red colors correspond to 3 and 5 quadrupole cases, respectively.

For the five quadrupole case, the beta function is much flatter (solid line) in the target cell region, compared to the situation with three quadrupoles. The minimum beta function is 0.31 m and the beam radius is 8.8 mm in the

center (Fig. 3). These numbers are still acceptable for the APR optics. This was a reason to choose design with five quadrupoles.

Since the antiprotons should be also longitudinally polarized [2], the ring has to contain a Siberian snake which is located in the opposite side of the target (Fig. 2).

To provide longitudinally polarized beam at the position of the storage cell, the integrated field strength should be roughly 2.74 Tm. This can be done with a 1.1 T solenoid of 2.5 m length. The space between the quadrupole triplets in this straight section is 4.1 m which is sufficient for this solution. To calculate the necessary solenoid field strength, the Thomas BMT equation [4] has been used

$$\chi = (1 + G) / B\rho \cdot \int B dL$$

where χ is the precession angle in solenoid, G is the anomalous magnetic moment $G=(g-2)/2$, where g is the gyromagnetic ratio.

The beam degradation, the geometrical blow-up and the subsequent smearing of the beam energy needs to be corrected by phase-space cooling, preferably by electron cooling. For the electron cooling (located next to the Snake straight section), a free space of 6.2 m is reserved. The antiproton beam in the electron cooling section should be parallel and its cross section should be variable in order to match the size of the electron beam.

An efficient system for injection and extraction of the antiproton beam has to be provided in the ring as well. For the injection and extraction of antiproton beam (located in the opposite side to the electron cooling section), a free space of 4.1m is foreseen. In this straight section two septa and one kicker are placed.

Finally in the APR we have two symmetrical arcs. In each arc two bending magnets and a triplet of quadrupole magnets have been used. Triplets were chosen because of smaller aberrational errors. The large acceptance requires multipole correctors, and the dispersion in such a design is zero by symmetry. In more detail, the other characteristics of this ring can be found in the talk [5].

TIMETABLE

2006 - 2007	Technical Design Reports finished; overall design of all PAX components
2008	Polarization buildup studies with the new low beta section, with the HERMES PIT at COSY.
2009	Installation of all components at the AD.
2009	2 months of beam time at the AD, plus extra weeks of machine commissioning prior to the run.
2010	2 months of beam time at the AD, plus

extra weeks of machine commissioning prior to the run.

2010	Spin filtering with protons in the APR tested, Fabrication of detector components finished.
2011	CSR operational with protons at FAIR.
2012	Installation of PAX detector finished.
2013	Commissioning of PAX detector with protons/antiprotons done, polarized antiproton facility (CSR & APR) ready for experiments
> 2015	Commissioning of HESR in the double - polarized collider mode.

REFERENCES

- [1] Conceptual Design Report for An International Accelerator Facility for Research with Ions and Antiprotons, available from <http://www.gsi.de/GSI-future/cdr>.
- [2] Proposal for *Antiproton-Proton Scattering Experiments with Polarization*, **PAX Collaboration**, arXiv:hep-ex/0505054(2005). available from <http://www.fz-juelich.de/ikp/pax>
- [3] A. Lehrach, S. Martin, F. Rathmann, P. Lenisa, I.N. Meshkov, A. Sidorin, A. Smirnov, C. Montag, E. Steffens, C.-A. Wiedner - A Method to Polarize Stored Antiprotons to A High Degree, Proceedings of the 2005 Particle Accelerator Conference (PAC2005), Knoxville, Tennessee (USA), ISBN 0-7803-8860-7, p. 2158 (2005)
- [4] V. Bargmann et al., PRL, 435 (1959)
- [5] A. Garishvili and S. Martin, CANU meeting, 2005, available from <http://www.fz-juelich.de/ikp/pax>