Storage Ring Section for a Polarized Gas Target with High Angular Acceptance

A. Garishvili[a,b], B. Lorentz[c], A. Nass[a], A. Lehrach[c], P. Lenisa[d], R. Maier[c], S. Martin[e], F. Rathmann[c], E. Steffens[a], and H. Ströher[c]

[a] Physikalisches Institut II, Universität Erlangen-Nürnberg, Erlangen, Germany
[b] High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[c] Institut für Kernphysik, Forschungszentrum Jülich, Jülich, Germany
[d] Universita' di Ferrara and INFN, Ferrara, Italy
[e] UGS Gerlinde Schulteis & Partner, 08428 Langenbernsdorf, Germany

Keywords: Particle beam focusing, superconducting magnets, polarized targets
PACS: 41.85.Lc, 84.71Ba, 29.25.Pj

Abstract. In the framework of the FAIR project [1], the PAX collaboration [2] has suggested new experiments using polarized protons and antiprotons. In order to provide polarized antiprotons, the polarization build-up by spin-dependent attenuation due to nuclear interaction (spin-filtering) must be studied. The goal of these investigations is to understand the physics of the spin-filtering process with stored protons at COSY, and to shed light on the role of polarized electrons for the polarization buildup. Later on, the spin-dependence of the proton-antiproton interaction will be investigated at the Antiproton Decelerator ring (AD) of CERN. In order to carry out these investigations, a storage ring section has to be developed which minimizes the spin-independent losses due to single Coulomb scattering.

Introduction

The central issue of the PAX collaboration is to polarize antiprotons via spin filtering by multiple passages through an internal polarized gas target. In order to provide this, the controversial interpretation of the FILTEX experiment has to be resolved [3], [4], [5]. In particular, we have to understand the kinetics of the spin-filtering process, and clarify which role electrons play in the polarization build-up process through a series if experiments with proton beam at COSY. Since there exist no experimental data to reliably predict the polarization build-up from spin filtering with antiprotons, experimental tests with antiprotons necessary. These can be carried out at the AD (Antiproton Decelerator) of CERN. The COSY measurements will also allow us to commission the experimental setup for the studies at the AD (see also ref. [6]).

Spin-Filtering studies require long beam lifetimes and long polarization lifetimes. In early summer of 2007 we began to study the beam lifetimes at injection energy of COSY. The obtained results (see ref. [7]) indicate that the observed beam lifetimes of the electron-cooled beam are dominated by single Coulomb scattering. The beam lifetime is given by $\tau_{\mathrm{beam}} = (\Delta\sigma_C \cdot d_t \cdot f)^{-1}$, d_t denotes the gas target thickness, and f the revolution frequency. The Coulomb-loss cross section $\Delta\sigma_C = 2\pi \int_{\theta_{acc}}^{\pi} \left(\frac{d\sigma}{d\Omega}\right)_C \sin\theta \cdot d\theta = 4\pi \frac{Z_1^2 Z_2^2 r_p^2}{\beta_{rel}{}^4 \gamma_{rel}{}^2 \theta_{acc}^2}$, where Z_1 and Z_2 are the atomic numbers of the gas particles and the ion beam, respectively. β_{rel} and γ_{rel} denote the relativistic variables for the given beam energy, r_p=1.535·10^{-16} cm is the classical proton radius, and θ_{acc} denotes the machine acceptance angle. Since θ_{acc} is proportional to the square root of the betatron amplitude, the beam lifetime is inversely proportional to the β-function at the target. For this reason, a low-β section needs to be implemented both at COSY and at the AD.

The Low-Beta section at COSY

The COSY ring has an acceptance of 30 π mm mrad and a magnetic rigidity of 12.34 Tm, which implies a maximum momentum of 3.7 GeV/c for the stored protons. After cooling, the beam emittance amounts to about 3 π mm mrad. The smallest achievable β-functions with the present COSY lattice are about 2 m. The spin-filtering tests require the use of a small cross section storage cell to produce a high-density polarized target. For this reason a new low-β section has to be implemented in the ring at TP1. The total available space at that position is 3.4 m.

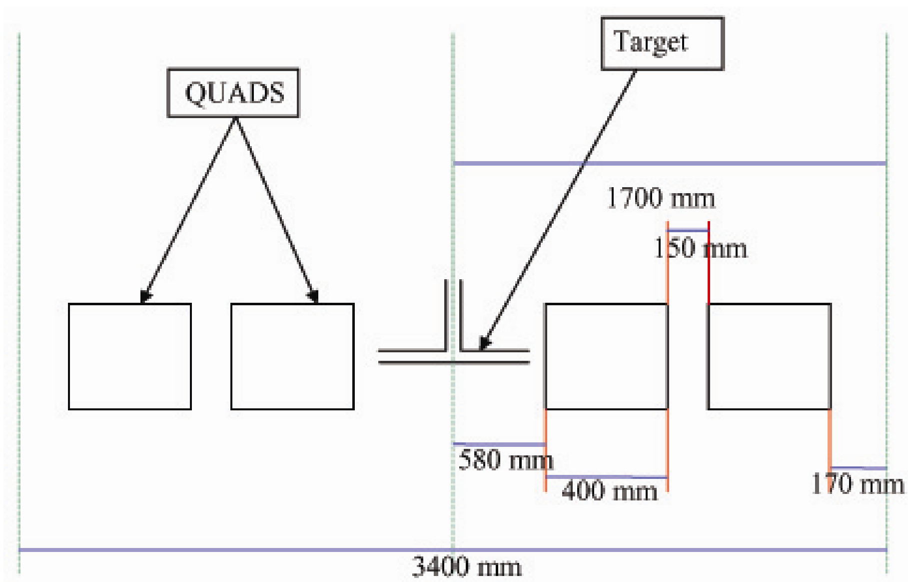

FIGURE 1: The sketch of the low-beta section at COSY. The effective length of the quadrupoles is 400 mm.

A sketch of the new low-beta section is shown in Fig. 1. The section is composed of two superconducting quadrupole magnets on each side of the target with a length of 400 mm. The drift space between the magnets is 150 mm, and for the target itself, 1160 mm are reserved.

The betatron amplitude function in the low-beta section has been calculated by fixing the original lattice parameters (α_x, α_y, β_x, and β_y) at the entrance and exit of the section and matching them to the original parameters. The highest focusing strength for the quadrupoles is 5.5 m^{-2}. The minimum values of the beta functions at the center of the target are β_x=0.46 m and β_y=0.52 m (Fig. 2).

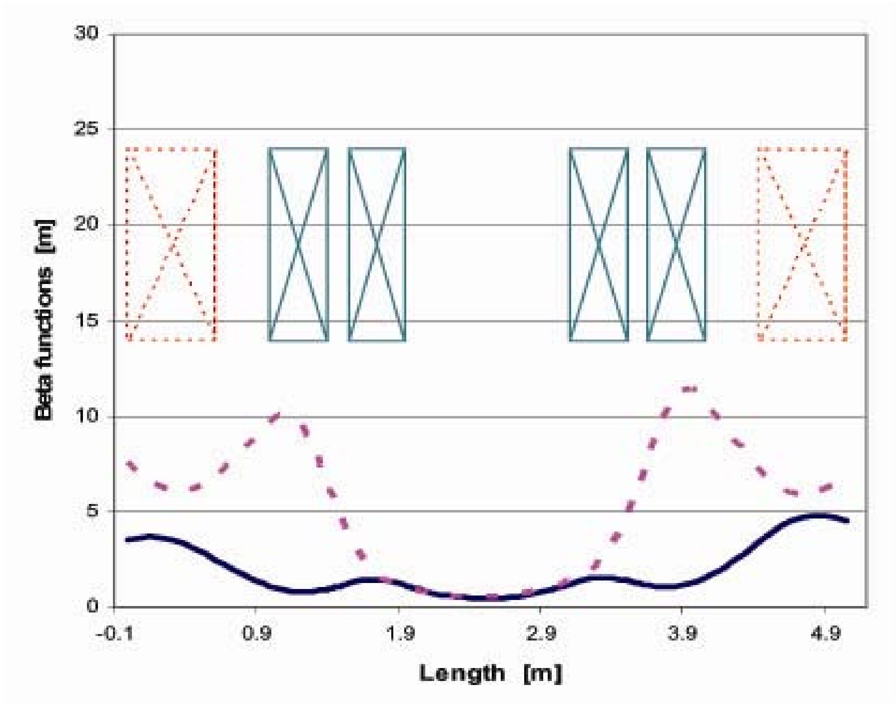

FIGURE 2: Distribution of the βfunctions along the low beta section at COSY. The magnets shown with dashed lines are the existing COSY quadrupoles; solid lines indicate the new low βquadrupoles. Solid lines denote the horizontal β-function β_x, and dashed lines the vertical β_y.

The maxima of the beta functions in the low-β section are around 10 m, which will allow the injecting of the uncooled beam into the closed target cell (Fig. 3).

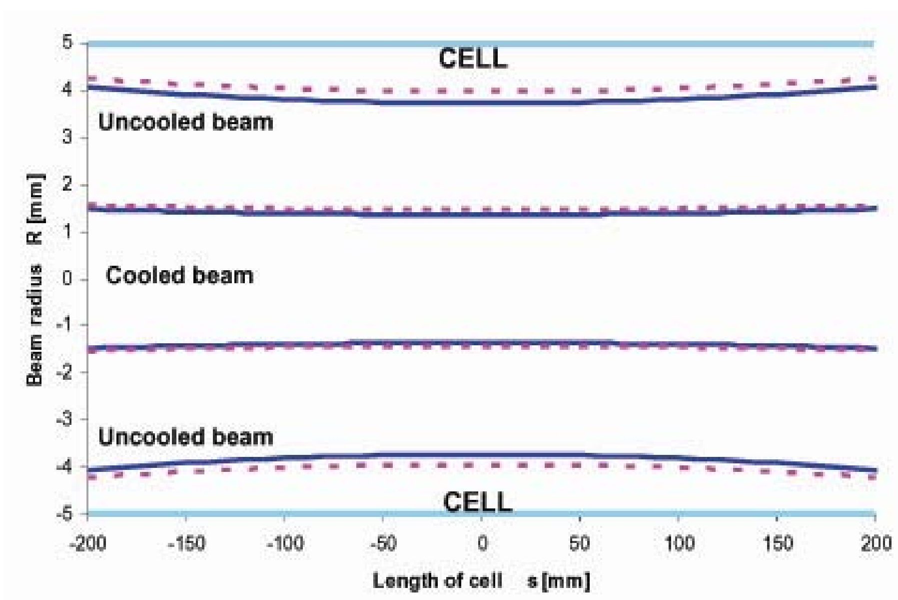

FIGURE 3: Beam envelope inside the storage cell at COSY. Solid lines indicate R_x, dashed lines R_y. As shown, the storage cell is 400 mm long and has a diameter of 10 mm.

At COSY, due to the ring telescopic mode of operation of the straight sections, it will be possible to turn on and off the low-β section by compensating the phase advance with the regular COSY quadrupoles.

The Low-Beta section at the AD

The AD ring at CERN presents a magnetic rigidity of 12.07 Tm, which implies a maximum momentum of 3.57 GeV/c. The horizontal acceptance of the AD is 220 π mm mrad, the vertical one 190 π mm mrad. At the lowest anticipated beam energy of 50 MeV, the beam emittance in both planes amounts to about 5 π mm mrad. Also at the AD, the present β-functions are larger than 2 m; therefore a new low-β section has to be installed here as well. The available space for the low-β section is 5.67 m, the central AD quadrupoles at the center of the straight section has to be removed and its functionality needs to be taken over by the new low-β magnets. A preliminary design of the low-β section at the AD is shown at Fig. 4.

At the AD on each side of the target an additional superconducting quadrupole (identical to the other four) needs to be implemented. In the design, the space foreseen for the target area is longer than at COSY (1.67 m). The gap between the additional and the quadrupoles used at COSY is 350 mm. The distribution of the β-function has been calculated in an analogous way as for the COSY lattice, and is shown in Fig. 5.

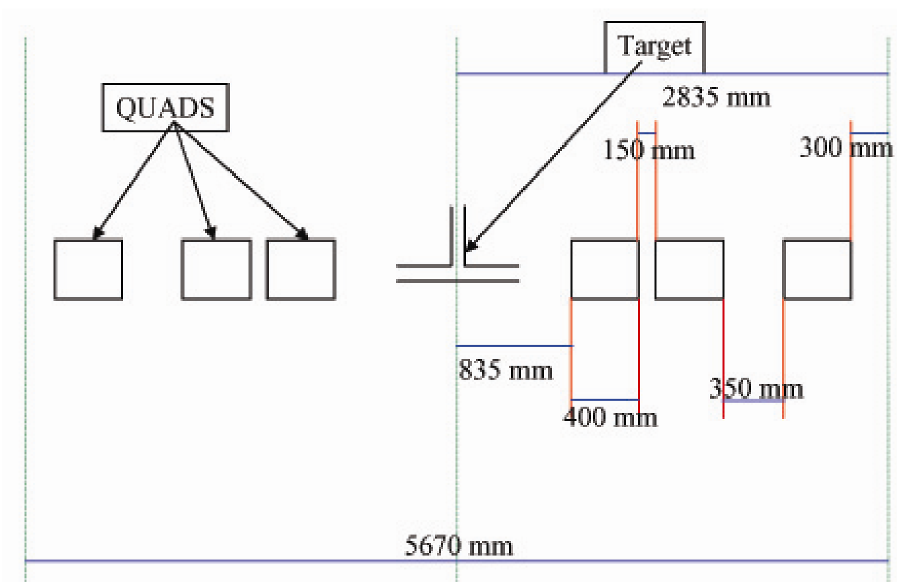

FIGURE 4: The sketch of the low-beta section for the AD.

The highest focusing strength for corresponding quadrupoles is 4.66 m^{-2}. The minimum β-functions at the center of the target are β_x=0.39 m and β_y=0.60 m. The maximum β-functions in the low-beta section are around 12.4 m.

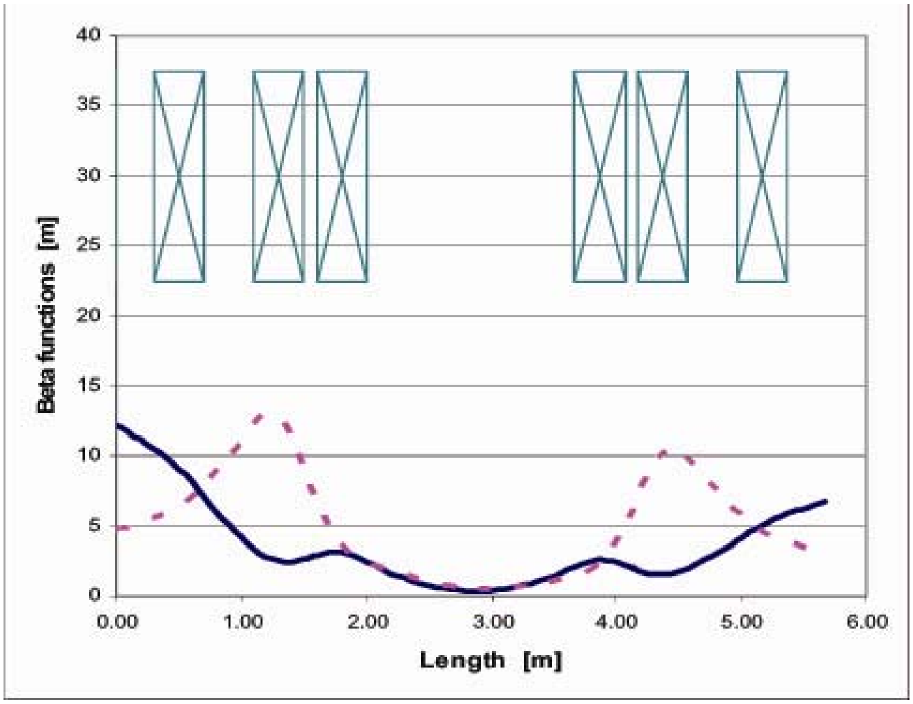

FIGURE 5: The distribution of the β-functions at the low-β section at the AD. Solid lines denote the horizontal β-function β_x, and dashed lines the vertical β_y.

As it can be deduced from Fig. 6, the uncooled antiproton beam cannot be injected through the closed storage cell. For this reason, at the AD, we have to open the cell at injection until the beam is cooled. At the AD, the low β-section has to be turned on during the whole deceleration cycle.

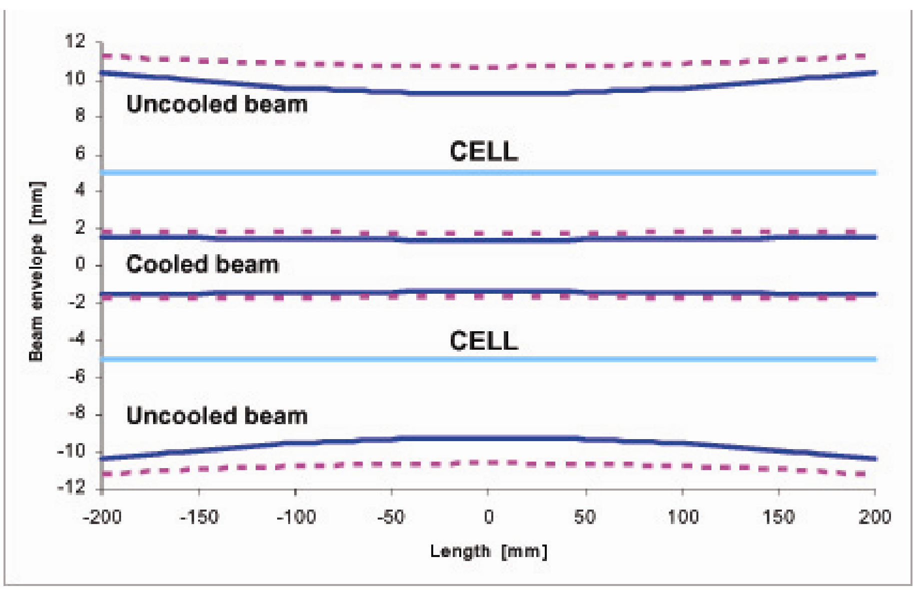

FIGURE 6: Beam envelope inside the storage cell for the AD (same line styles as in Fig. 3).

Superconducting quadrupoles

In total, the low-β section will require the production of six new superconducting quadrupoles. The possible gradient of the magnets is given by $g = B_P / R_1$, where B denotes the pole tip field and R_1 is the inner radius of current. The requirement for R_1 is $R_1 = r_1 + r_2 + r_3$, where r_1 is the radius of the beam envelope determined from the lattice calculation, plus a 10 mm safety margin for closed orbit deviation, r_2 is the space required for the vacuum chamber (2 mm), and r_3 is the required gap between vacuum chamber and the inner radius of current (5 mm), necessary to implement beam position monitors. With the calculated maximum β-function in the target region of 12.4 m, the corresponding beam envelope $R_1 = \sqrt{\varepsilon \times \beta} = 67\,\mathrm{mm}$. Field calculations for a quadrupole magnet design yield for this R_1 a pole tip field B_P=5.6 T. Hence, the achievable field gradient amounts to about 83 T/m. The necessary field gradient is given by $g = B\rho \cdot K$ where $B\rho$ is the magnetic rigidity and K denotes the maximum of the required focusing strength. For the situation at COSY, the highest required gradient g_{COSY}=68 T/m, while for the AD g_{AD}=57 T/m. More details about the characteristics of the superconducting quadrupole magnets can be found in ref. [8].

Spin-filtering studies with longitudinal beam spin

For experiments with longitudinal beam polarization of (anti)protons, both rings have to contain a Siberian snake. At the COSY injection energy of 45 MeV, the WASA solenoid operated together with the electron cooler solenoids can be used to provide a stable longitudinal spin direction at the target. At the AD, the existing electron cooler solenoids are not strong enough and not located on the opposite side of the target section, therefore a dedicated Siberian snake has to be implemented. The integrated field strength of such a Siberian snake amounts to roughly 2 Tm at an antiproton beam energy of 500 MeV. At present, we are working on the design of the Siberian snake section for the AD and explore possible options for its implementation.

References:

[1] Conceptual Design Report for an International Facility for Antiproton and Ion Research, *http://www.gsi.de/GSI-future/cdr*.

[2] PAX Technical Proposal, *http://www.fz-juelich.de/ikp/pax.*

[3] C. J. Horowitz and H.O. Meyer, *Phys. Rev. Lett.* **72,** 3981 (1994).

[4] A. Milstein and V. Strakhovenko, *Phys. Rev.* **E 72,** 066503 (2005).

[5] N.N. Nikolaev and F. Pavlov, *Spin Filtering of Stored (Anti)Protons: from FILTEX to COSY to AD to FAIR* (2007), e-Print Archive: hep-ph/0701175.

[6] A. Nass for the PAX Collaboration, contribution to these proceedings.

[7] *Measurement of the depolarizing $\vec{p}e$ cross section using co-moving electrons.* Proposal to COSY, (Submitted 2007 October), *http://www.fz-juelich.de/ikp/pax.*

[8] M. Statera et al. The cryogenic system for a Low Beta Section at COSY and AD: Particle Accelerator Conference (PAC'07), 1451.