LATTICE STUDIES FOR SPIN-FILTERING EXPERIMENTS AT COSY AND AD

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Abstract

In the framework of the FAIR [1] project, the PAX collaboration [2] has proposed a research program based on polarized antiprotons. Polarized antiprotons are to be produced by spin-dependent attenuation on a polarized hydrogen target. For a better understanding of this mechanism it is planned to perform Spin-Filtering studies with protons at COSY (Jülich). In a second phase, it is envisioned to study Spin-Filtering with antiprotons at the AD (CERN). Which will allow for the determination of the total spin-dependent transverse and longitudinal cross sections. In order to achieve the required long storage times, a storage ring section has to be developed which minimizes the spin-independent losses due to Coulomb scattering. The Coulomb-loss cross section for single scattering losses at fixed energy is proportional to the acceptance angle. Therefore, at the target point the beta functions should be as small as possible. For the low-beta section, superconducting quadrupole magnets are utilized. It is composed of two (COSY) and three (AD) SC quadrupoles on each side of the target. Results of the lattice studies and requirements for the superconducting quadrupole magnets will be discussed.

INTRODUCTION

The central issue of the PAX experiment 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 of experiments with a proton beam at COSY. Since no experimental data exists to reliably predict the polarization build-up from spin filtering with antiprotons, additional experimental tests with antiprotons are 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.

Spin-Filtering studies require long beam lifetimes and long polarization lifetimes. In early summer 2007 we began to study the beam lifetimes at injection energy of COSY. The obtained results (see ref. [6]) indicate that the observed beam lifetimes of the electron-cooled beam are dominated by single Coulomb scattering. The beam lifetime is given by $\tau_{beam} = (\Delta\sigma_C \cdot d_t \cdot f)^{-1}$ where d_t denotes the gas target thickness, and f the revolution frequency. The Coulomb-loss cross section is $\Delta\sigma_C = 2\pi\int_{\theta_{acc}}^{\pi}\left(\frac{d\sigma}{d\Omega}\right)_C \sin\theta \cdot d\theta = 4\pi\frac{Z_1^2 Z_2^2 r_p^2}{\beta_{rel}{}^4 \gamma_{rel}{}^2 \theta_{acc}^2}$, with Z_1 and Z_2 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 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 betatron amplitude 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 is 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 the position TP1. The total available space at that position is 3.6 m.

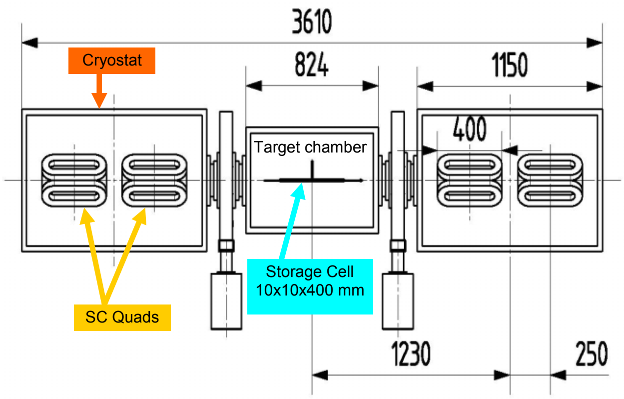

Figure 1: The sketch of the low beta section at COSY.

A sketch of the new low-beta section is shown in Fig. 1. The section is composed of a pair of superconducting quadrupole magnets on each side of the target with a length of 400 mm. The drift space between the magnets is 100 mm, and for the target itself, 824 mm are reserved.

The focusing strength for corresponding quadrupoles are -4.27 m^{-2} and 4.49 m^{-2}. The β-functions at the center of the target are 0.3 m in both planes.

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 is 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 5.4 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. 2.

At the AD on each side of the target an additional superconducting quadrupole (identical to the others) needs to be implemented. The gap between the additional and the quadrupoles used at COSY is 300 mm. The distribution of the β-function has been calculated in an analogous way as for the COSY lattice.

The highest focusing strength for corresponding quadrupoles is -5.1 m^{-2}. The minimum β-functions at the center of the target are β_x=0.42 m and β_y=0.44 m. The maximum values of the β-functions in the low-beta section are around 13.9 m.

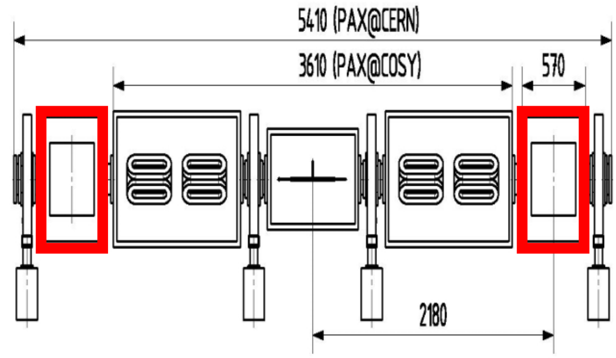

Figure 2: The sketch of the low beta section at the AD.

As it can be deduced from Fig. 3, the uncooled antiproton beam cannot be injected through the closed storage cell. For this reason, we have to open the cell at injection until the beam is cooled. The low β-section has to be turned on during the whole deceleration cycle.

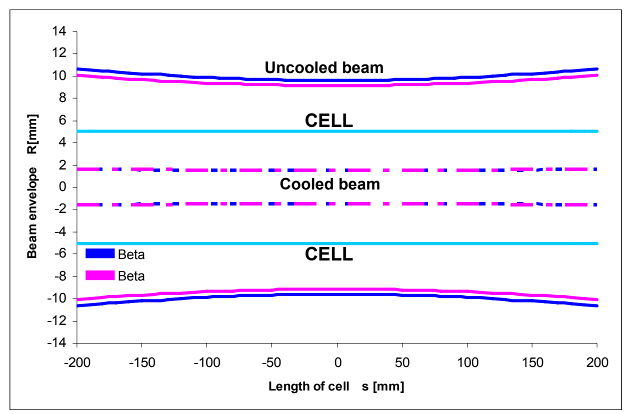

Figure 3: Beam envelope inside the storage cell for the AD. Blue solid and pink solid lines indicate R_x and R_y before cooling, respectively. Blue dashed and pink dashed lines indicate R_x and R_y after cooling, respectively.

SUPERCONDUCTING QUADRUPOLE

In total, the low-β section will require the production of six dedicated superconducting quadrupoles. The possible gradient of the magnets is given by $g=B_p/R_1$, where B_P denotes the pole tip field and R_1 is the inner radius of coil. 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 coil (5 mm), necessary to implement beam position monitors. With the calculated maximum β-function in the target region of 13.9 m, the corresponding beam envelope $R = \sqrt{\varepsilon \times \beta} = 50\,\mathrm{mm}$. Field calculations for a quadrupole magnet design give a pole tip field of B_P=5.1 T, for corresponding inner radius of coil. Hence, the achievable field gradient is about 75 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}=55 T/m, while for the AD g_{AD}=61 T/m. More details about the characteristics of the superconducting quadrupole magnets can be found in ref. [7].

SPIN-FILTERING STUDIES FOR 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 4 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.

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