A LOW BETA SECTION FOR POLARIZATION STUDIES OF ANTIPROTONS BY SPIN FILTERING

Paolo Lenisa, Giulio Stancari, Marco Statera (INFN-Ferrara, Ferrara, Italy),
Archil Garishvili, Bernd Lorentz, Siegfried Arno Martin, Frank Rathmann (FZJ, Julich, Germany)

Abstract

In the framework of the FAIR [1] project, the PAX collaboration has suggested new experiments using polarized antiprotons [2]. The central physics issue is now to study the polarization build-up by spin filtering of antiprotons via multiple passages through an internal polarized gas target. The goals for spin-filtering experiments with protons at COSY are to test our understanding of the spin-filtering processes and to commission the setup for the AD experiments with antiprotons at the AD (CERN). Spin-filtering experiments with antiprotons at the AD will allow us to determine the total spin-dependent transversal and longitudinal cross sections. The low-beta section at COSY is composed of two superconducting quadrupole magnets on each side of the target, while at the AD, we will use three quadrupoles on each side. Accelerator technical problems and details for COSY and AD to carry out the planned spin-filtering studies together with the technical problems and details of the superconducting quadrupoles will be discussed in this paper.

SECTION AT COSY

The COSY ring has an acceptance of 30 π mm mrad and magnetic rigidity of 12.34 Tm which implies a maximum momentum of 3.7 GeV/c for the stored protons. After cooling, the beam has an emittance of 3 π mm mrad. The lowest beta function reachable with the present lattice settings is about 2 m. The spin-filtering tests request the use of a small squared cross section (10x10 mm^2) 400 mm long storage cell to produce a high-density polarized target. For this reason a new low beta section has to be implemented. The total available space at the chosen position is 3.4 m.

The scheme of the new low beta section is presented in figures 1 and 2. The section is composed of two superconducting quadrupole magnets on each side of the target with a length of 0.4 m. Drift space between the magnets is 0.15 m. 1.3 m space is reserved for the target,.

The betatron amplitude function (beta function) in the low-beta section has been calculated by fixing the original input lattice parameters (α_x, α_y, β_x and β_y) at the beginning of the available space and matching them to the original input parameters at the end of the available space.

The highest focusing strength for corresponding quadrupoles is 5.16 m^{-2}. The minimum beta functions at the centre of the target are β_x=0.46 m and β_y=0.52 m.

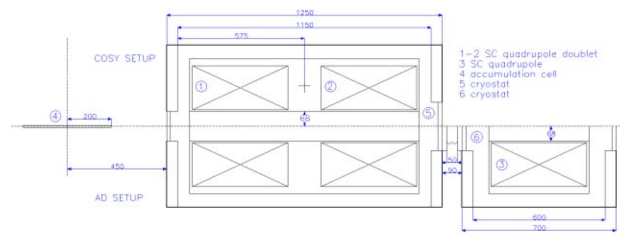

Figure 1: Scheme of the low beta section at COSY and AD. Dimensions in mm.

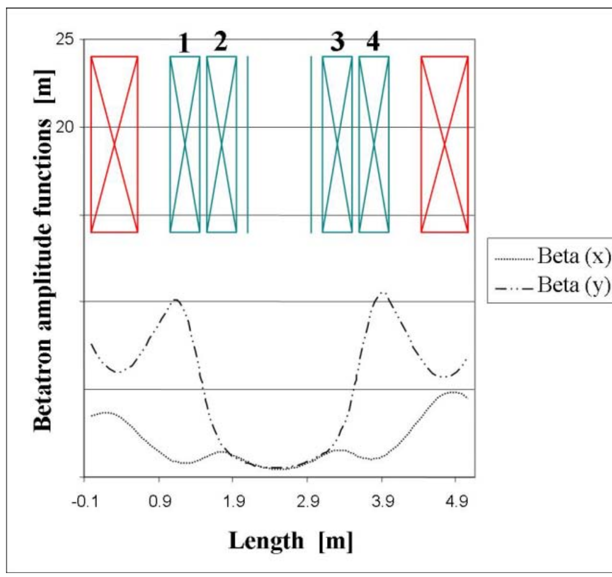

Figure 2: Distribution of the beta functions along the low beta section at COSY. The outer magnets are existing COSY quadrupoles, 1-4 are the new low beta quadrupoles.

The maxima of the beta functions in the low-beta section are around 10 m, which will allow to inject in the target cell also an uncooled beam (see figure 3).

At COSY, thanks to the ring telescopic mode in the straight sections, it will be possible to turn on and off the low-beta section during the running by compensating the phase advance with the regular COSY quadrupoles.

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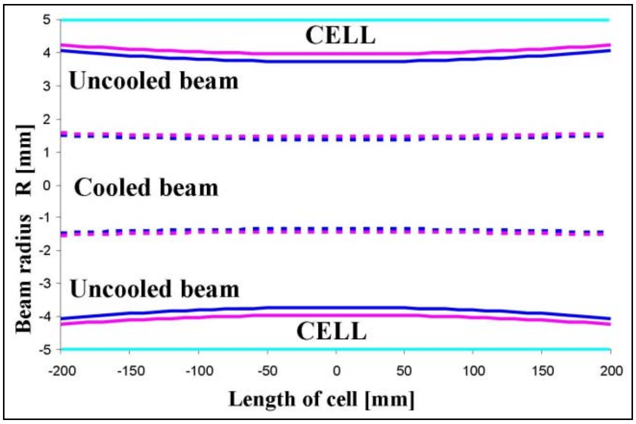

Figure 3: The beam envelope in the accumulation cell region at COSY is shown.

SECTION AT AD

The AD ring at CERN presents a magnetic rigidity of 12.07 Tm which implies maximum momentum of 3.57 GeV/c. The horizontal acceptance of the machine 220 π mm mrad and the vertical 190 π mm mrad. At the lowest

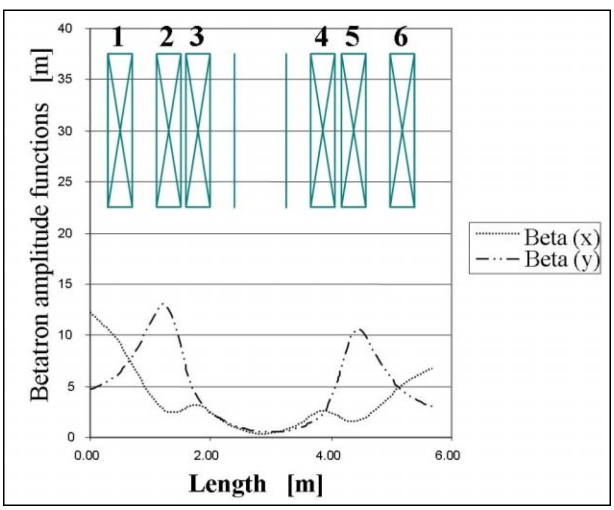

Figure 4: Distribution of the beta functions along the low beta section at AD.

energy (50 MeV) the beam emittance in both planes goes down to around 5 π mm mrad. The present beta functions are higher than 2 m, therefore a new low-beta section has to be installed here as well. The available space for the low-beta section is 5.67 m, provided that one of the existing AD quadrupoles at the center of the straight section at the AD has to be removed. A preliminary design of the low-beta section at the AD is shown in figure 1.

At the AD an additional superconducting quadrupole (identical to the others) is requested on each side of the target. In the design the space foreseen of the target is longer than at COSY (1.67 m). The gap between the additional and the quadrupoles used at COSY is 0.4 m.

The distribution of the low beta function has been calculated in an analogous way as in COSY and is shown in figure 4.

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

As it can be deduced from figure 5, the uncooled beam cannot be injected through the target cell. For this reason, at the AD, we have to open the cell [3] by about 2cm, before beam will be cooled.

At the AD the low beta section has to be turn on during the whole deceleration cycle

CONCEPTUAL DESIGN OF THE MAGNETS

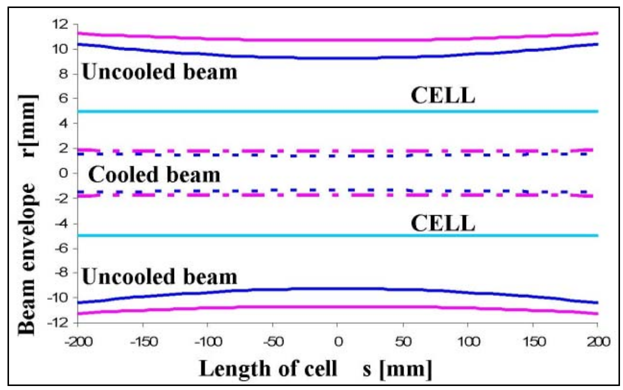

Figure 5: The beam envelope in the accumulation cell region at AD is shown.

In total, the low-beta section requires the production of six new superconducting quadrupoles, the 4 quadrupoles that will be used at COSY, will be moved to AD and installed together with the others. The magnets must be designed for the most demanding conditions. High flexibility is required for the cryostat and the main features have to be taken in account in the design of the low beta section.

The strictest constraint is the longitudinal space. The thermal insulation of the cryostat and valves on the beam line to insulate the magnets are of primary importance.

The beam envelope is $R = \sqrt{\varepsilon \cdot \beta}$, where β is the betatron amplitude function, ε is the beam emittance.

With the calculated maximum beta function in the target region of 12.4 m, the beam envelope radius is 52 mm; considering 10 mm for the uncertainties and some more safety the reference radius for the field region is R_b= 68 mm.

The gradient of the magnet g is given by: $g=B_b/R_b$, where B_b is the field at the reference radius R_b. The focusing strength of the magnet is K=g/bρ, where Bρ is the magnetic rigidity.

The minimum radius for the windings of the quadrupoles is the reference radius plus the space for the cryostat and vacuum chamber (2 mm) and 5 mm of liquid helium.

The target field for the magnet is 75 T/m radial gradient for a box shaped (ideal) magnetic field, the field at the reference radius in that case is 5.1 T.

The main constraint for the quadrupole is the available longitudinal space (see figure 1): the magnets must be superconducting to fulfil the field requirements so that both the thermal insulation and the vacuum connections (and valves) have been taken in account in the scheme used to calculate the maximum longitudinal dimension of the magnets.

The latter is about 520 mm and thus the designed coils have that total length. The coils are simple racetrack to maximise the integrated field in such short magnets. The goal of the design is to reach an integrated field corresponding to a 75 T/m (radial gradient) box (ideal) quadrupole 400 mm long. The integrated field at the reference radius along the z axis is 2.040 Tm.

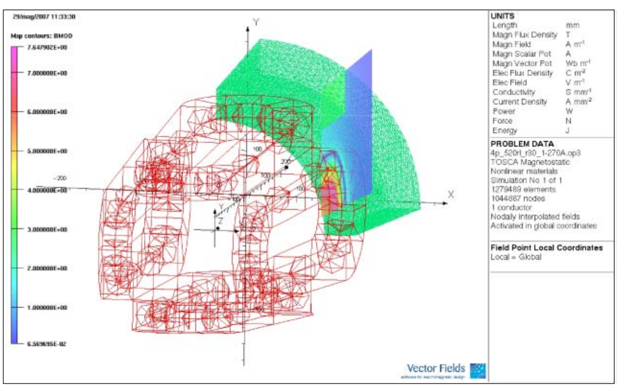

Figure 6: The coils of the designed racetrack coils quadrupole. Part of the iron shielding is also plotted; the shielding cylinder is attained using four fold and longitudinal symmetry. A field calculation into the coil is shown. the field is in Tesla.

The presented coils are 75 mm far from the z axis, have a 45x40 mm^2 cross section and the minimum bending radius is 30 mm (half of the 'pole' transverse dimension). An iron shielding 20 mm thick and with a minimum radius of 140 mm is used.

The geometry of the coils and a part of the iron shield is plotted in figure 6. It can be noticed that the geometry allows winding the coils using ribbon wires and thus reducing the inductance of the winding at a lower cost with respect to Rutherford cables.

The engineering current density in the coil is 270 A/mm^2 and the maximum field in the superconductor is

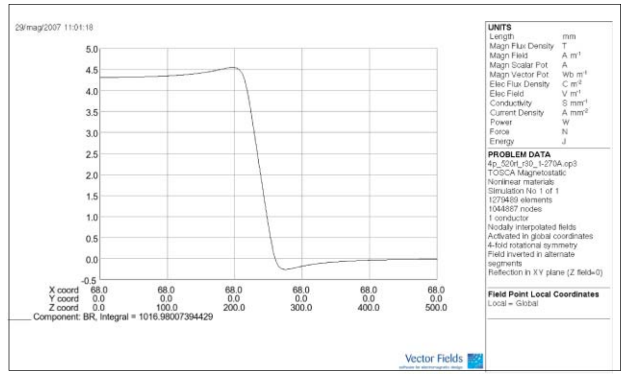

Figure 7: Longitudinal field at the reference radius from the centre of the quadrupole to 500 mm. The coils limit is 260 mm, the integrated field is also shown.

7.64 T. The safety margin is about 21% for a square cross section NbTi wire [4]. The integrated radial field at 68 mm is 2.034 Tm along the magnet (evaluating the contribution of the fringing field); the plot of the calculated field is reported in figure 7. The energy stored is about 225kJ.

The simulated ratio B_3/B_2 is below 10^{-4} at the beam envelope limit even in the fringing field. These values must be directly measured in each magnet.

REFERENCES

[1] Conceptual Design Report for an International Facility for Antiproton and Ion Research, www.gsi.de/GSIfuture/cdr.

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[3] Openable cell for PAX, G. Ciullo, at ANKE-PAX Workshop on SPIN PHYSICS, http://web.fe.infn.it/spinwiki/index.php/29-05-2007_ANKE-PAX_Workshop_on_SPIN_PHYSICS

[4] http://www.oxinst.com/wps/wcm/resources/file/ebcb4f0df052d24/Cu_Matrix_NbTi.pdf