Spin-filtering at COSY

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Abstract. The Spin Filtering experiments at COSY and AD at CERN within the framework of the Polarized Antiproton EXperiments (PAX) are proposed to determine the spin-dependent cross sections in $\bar{p}p$ scattering by observation of the buildup of polarization of an initially unpolarized stored antiproton beam after multiple passage through an internal polarized gas target. In order to commission the experimental setup for the AD and to understand the relevant machine parameters spin-filtering will first be done with protons at COSY. A first major step toward this goal has been achieved with the installation of the required mini-β section in summer 2009 and it’s commissioning in January 2010. The target chamber together with the atomic beam source and the so-called Breit-Rabi polarimeter have been installed and commissioned in summer 2010. In addition an openable storage cell has been used. It provides a target thickness of $5 \cdot 10^{13}$ atoms/cm$^2$. We report on the status of spin-filtering experiments at COSY and the outcome of a recent beam time including studies on beam lifetime limitations like intra-beam scattering and the electron-cooling performance as well as machine acceptance studies.

1. Introduction
The need for polarized antiproton beams is well recognized as a prerequisite to address several important topics in particle physics, including a first direct measurement of the transversity distribution of the valence quarks in the proton, a test of the predicted opposite sign of the Sivers-function, related to the quark distribution inside a transversely polarized nucleon, and a first measurement of the moduli and the relative phase of the time-like electric and magnetic form factors of the proton. The collaboration for Polarized Antiproton Experiments (PAX) has proposed a physics program that would be possible with a double-polarized proton-antiproton collider at the new Facility for AntiProton and Ion Research (FAIR), which is to be built at GSI in Darmstadt [1]. Even though a number of methods to provide polarized antiproton beams have been proposed at a workshop more than 20 years ago [2], no polarized antiproton beams have yet been produced, with the exception of a low-quality, secondary beam from the decay of anti-hyperons that has been realized at Fermilab [3].

Currently spin-filtering is the only proven method to polarize a stored beam in situ, a technique that exploits the spin-dependence of the strong interaction using a polarized internal target [4]. The PAX collaboration aims to use stored protons in COSY for high-precision polarization build-up studies with transverse and longitudinal polarization. Under these circumstances, the build-up process itself can be studied in detail because the spin-dependence of the proton-proton interaction around 50 MeV is completely known. In addition further investigations on beam lifetime limitations and machine parameters are in progress. For the measurement of the spin-dependence of the $\bar{p}p$ interaction at the AD-ring a proposal has been submitted by the PAX collaboration in 2009. The determination of the two total
spin-dependent \( \bar{p}p \) cross sections \( \sigma_1 \) and \( \sigma_2 \) at antiproton beam energies in the range from 50 to 450 MeV will provide a first experimental constraint of the spin-spin dependence of the nucleon-antinucleon potential [5]. Furthermore spin-filtering an antiproton beam with a vector polarized deuterium target may well prove more efficient than using hydrogen. In addition, measurements of the antiproton polarization buildup are required to define the optimum parameters of a future, dedicated Antiproton Polarizer Ring (APR), intended to feed a double-polarized asymmetric \( \bar{p}p \) collider with polarized antiprotons. Such a machine has recently been proposed by the PAX collaboration for FAIR.

2. Experimental setup
One crucial component of the experimental setup for spin-filtering experiments at COSY is the low-\( \beta \) section which consists of 8 COSY quadrupoles and 4 additional CELCIUS quadrupoles (see Fig. 1). An atomic beam source (ABS) together with an openable storage cell provides a dense polarized gas target, whose polarization will be measured by a Breit-Rabi polarimeter (BRP). The polarization of the proton beam after filtering will be measured by a \( \phi \)-symmetric detection system based on double-sided silicon-strip detectors.

![Figure 1](image.png)

**Figure 1.** \textit{PAX installation at the Cooler Synchrotron. Shown in yellow are the existing COSY straight section quadrupole magnets. 4 additional quadrupoles (blue) have been recuperated from the CELSIUS ring. The atomic beam source is mounted above the target chamber that houses the detector system and the storage cell. Three sets of Helmholtz coils providing magnetic holding fields along \( x, y, \) and \( z \) are mounted on the edges of the target chamber (brown). The Breit-Rabi target polarimeter and the target-gas analyzer are mounted outwards of the ring. The complete section can be sealed off from the rest of the COSY by valves.}

2.1. Low-\( \beta \) section
The installation of 4 former CELCIUS quadrupoles and additional steerers on the existing COSY quads in the straight section opposite to ANKE and WASA has been installed in summer 2009. The commissioning has shown that the PAX optics caused no additional acceptance restriction and therewith no shorter lifetimes [6]. But recent measurements indicate that the beam lifetime with PAX optics is smaller due to a change of the orbit. A measurement of the \( \beta \)-functions at the positions of the new quadrupoles coincides well with the calculated values and indicate that \( \beta_{x,y} \) reach about 0.3 m at the center of the target.
2.2. Target section
The target section provides a polarized hydrogen or deuterium gas target for the PAX spin-filtering experiments.

It is composed of the following main components: the ABS [7], the target chamber with the storage cell, the target gas analyzer (TGA) and the BRP [8]. A schematic view of the components is shown in Fig. 3. High areal target densities of $5 \times 10^{13}$ atoms/cm$^2$ are achieved by injecting nuclear spin polarized hydrogen or deuterium atoms produced by the ABS into a storage cell. The BRP measures the polarization of an effusive beam extracted from that cell. In order to maximize the target density an openable cell is used. It is open during injection of the beam and closes after the beam is cooled to a size of $\sigma \approx 0.4 \text{mm}$. This procedure avoids beam losses during injection, which is of particular importance for the AD measurements; in addition, it provides high target densities.

2.3. Detection system
One essential point for the planned spin-filtering experiments is the determination of the beam and target polarization by measuring the polarization observables in $p\bar{p}$-elastic scattering. Since the spin-correlation coefficients $C_{xx}$ and $C_{yy}$ are quite large in the energy region where sizeable buildup can be obtained, the beam polarization can be measured with $p\bar{p}$-elastic scattering and a $\phi$-symmetric detector system (Fig. 4) consisting of double-sided silicon strip detectors. The design follows closely the one recently developed at IKP for the ANKE experiment [9] at Jülich. A detailed description of the ANKE detector system can be found in [10]. The PAX detection system is currently under construction.
3. Machine development and commissioning

As approved by the Program Advisory Committee of COSY, the PAX collaboration has accomplished preparatory measurements in the second half of 2010 in order to enable a first spin-filtering measurement at COSY in the fall of 2011. An improvement of the beam lifetime has been achieved which is essential to allow for long filtering times. In addition, the beam size and position at the target place have been measured and optimized. And finally the experimental setup, described in Sec. 2, has been commissioned.

3.1. Beam lifetime

As explained in the COSY beam request #199.1 [11], the presently reached beam lifetime ($\tau \approx 4500$ s) will lead to polarizations of 0.5% after filtering for two lifetimes. Instead of filtering for a longer period of time and therewith loose beam intensity the lifetime of the proton beam has to be increased in order to provide reasonable measurement time. With the beam is stored at injection energy, all the typical actions aiming at the improvement of the beam lifetime have been tried. Those included an orbit correction procedure, supported by a beam position monitor installed in the low- section, and the search for the optimal working point ($Q_x$, $Q_y$) of the machine. According to the proposal single intra-beam scattering outside the longitudinal machine acceptance (Touschek effect) may be expected to be the main particle loss mechanism besides single Coulomb scattering outside the transverse machine acceptance. The Touschek lifetime is given by [12, 13]:

$$\tau = \frac{4\gamma^3 \cdot \beta^3 \cdot \langle \sqrt{\beta} \rangle \cdot C \cdot e^{3/2} \cdot \delta^2}{\sqrt{\pi} \cdot N \cdot c \cdot r^2}.$$  \hspace{1cm} (1)

An increase of the beam emittance has been induced by tilting the electron cooler beam and thereby reducing the cooling force, which was controlled by measurements with an ionization profile monitor [14]. Both measurements (see Fig. 5) have shown an increase of the beam lifetime with increasing beam emittance up to a certain maximum, but with different dependencies. Additional measurements with smaller beam intensities but constant emittance have shown no significant change of the beam lifetime. Further investigations are needed for a quantitative understanding of this effect.
Figure 5. Change of the beam lifetime over the beam emittance. The left-hand side shows a maximum lifetime of $\tau \approx 9100$ s. The best fit gives $\tau \sim \epsilon^2$, which is close to the touschek value. On the right-hand side the measurement has been done at smaller lifetimes ($\tau \sim \sqrt{\epsilon}$), which might be limited by other effects.

3.2. Machine acceptance and beam positioning

By the help of a movable frame system (see Fig. 6) the beam positions and machine acceptances have been measured at 3 different positions along the target. Especially the adjustment of the position at injection allows one to inject and store $8 \times 10^9$ particles even through a fixed tube of 9.6 mm diameter. The measured acceptance angles at the position of the target are $\Theta_{\text{Acc}} \approx 3.8 \pm 0.19$ mrad ($\beta_x = 0.549$ m, $\beta_y = 0.376$ m) and therewith smaller as the expected 5-6 mrad.

Figure 6. Left-hand side: Movable frame system with 3 frames and one fixed tube. Right-hand side: Acceptance measurement as described in [15].

3.3. Holding field commissioning

The holding field defines the direction of the target polarization during filtering. During the subsequent measurement of the beampolarization, the holding field is reversed. For a compensated holding field in $y$-direction ($\int B_y dl = 0$) the displacement of the beam at the center of the target has been calculated and measured with a result of $\pm 0.15$ mm. For the compensated case no change of the beam position around the ring has been observed. Whereas for the uncompensated case ($\pm x$-direction) the changes of beam positions could be calculated assuming one angle kick of 1.7 mrad.
3.4. Target commissioning
Besides a mechanical problem with the openable storage cell during a later phase of the commissioning period, the target including atomic beam source and Breit-Rabi polarimeter has worked as expected. For different vacuum conditions the pressures and lifetime contributions of the target chamber and the adjacent sections have been measured in order to fix the needs for lifetimes in order of 10,000 s. These measurements show that the planned pumping assembly with ten NEG pumps in the target chamber, additional flow limiters at the entrance and exit of the chamber and the NEG-coated tubes up- and downstream should lead to reasonable beam lifetimes. This means that finally the beam lifetime is limited by the ring lifetime without target.

4. Summary
Taking the results of the machine development the PAX collaboration is looking forward to realize a first spin-filtering measurement in 2011.

References
[1] Barone V et al. Antiproton-proton scattering experiments with polarization PAX Collaboration (2005) arXiv:hep-ex/0505054
[2] Proc. of the Workshop on Polarized Antiprotons, AIP Conf. Proc. vol 145 ed Krisch A Lin A and Chamberlain O (New York 1986) Bodega Bay CA 1985
[3] Grosnick D P et al. 1990 Nucl. Instrum. Methods A 290 269
[4] Rathmann F et al. 1993 Phys. Rev. Lett. 71 1379
[5] Barschel C et al. Measurement of the Spin-Dependence of the $p\bar{p}$ Interaction at the AD-Ring PAX Collaboration (2009) arXiv:0904.2325 [nucl-ex]
[6] Nekipelov M 2010 Outcome of the pax beam time in January 2010 PAX website http://www.fz-juelich.de/ikp/pax
[7] Nass A et al. 2003 Nucl. Instrum. and Methods Res. A 505 633–644
[8] Barschel C 2010 Calibration of the Breit-Rabi Polarimeter for the PAX Spin-Filtering Experiment at COSY/Juelich and AD/CERN diploma thesis University of Aachen website http://www.fz-juelich.de/ikp/pax
[9] Barsov S et al. 2001 Nucl. Instrum. and Methods Res. A 462 364 – 381
[10] Musgiller A 2006 Identification and tracking of low energy spectator protons Ph.D. thesis University of Cologne
[11] Nekipelov M and Weidemann C 2010 Status report and beam-time request for cosy experiment 199 PAX website http://www.fz-juelich.de/ikp/pax
[12] Piwinski A 1998 DESY 98-179
[13] Lehrach A et al. 2006 Nucl. Instrum. Methods A 561 289
[14] Kamerdzhiev V 2003 Ionization Beam Profile Monitor At The Cooler Synchrotron COSY-Juelich DIPAC 2003 Mainz Germany
[15] Grigoryev K et al. 2009 Nucl. Instrum. Methods A 599 130