Spin-Filtering studies at COSY and AD

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Abstract. An overview on the present understanding of the methods to polarize an antiproton beam is given and the planned measurements on spin filtering at COSY and AD rings with protons and antiprotons are described. The experimental setup which is being prepared for these measurements is described and focus is given on the polarized internal target.

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INTRODUCTION

The high physics potential of experiments with stored high-energy polarized antiprotons led to the PAX proposal[1] [1] for the High Energy Storage Ring (HESR) of the FAIR facility (Facility for Antiproton and Ion Research) at GSI (Darmstadt/Germany). It is proposed to polarize a stored antiproton beam by spin filtering with a polarized hydrogen (deuterium) gas target. The feasibility of spin filtering has been demonstrated in the FILTEX experiment [2]. The theoretical understanding of the collision of an (anti)proton beam with a polarized hydrogen (deuterium) target is crucial for the success of the spin-filtering technique. However, there exist two competing theoretical interpretations: one with substantial spin filtering of (anti)protons by polarized electrons [3], while the second one suggests a self-cancellation of the electron contribution to spin filtering [4] [5] leaving only the hadronic contribution. In order to clarify this situation several experimental studies with protons (at COSY/Jülich) as well as with antiprotons (at AD/CERN) have to be carried out. These investigations require an experimental set-up of a polarized internal gas target (PIT) with a system of Silicon detectors implemented into a large acceptance section of the magnetic lattice.

HOW TO POLARIZE ANTIPROTONS

Several methods to polarize antiprotons were reviewed on workhops held in Bodega Bay, April 18-21, 1985 [6] and in Daresbury, UK, August 29-31, 2007. All the possible methods are based on two mechanisms: selective flip and selective loss (Fig. 1) [7].

The first mechanism includes *spin transfer by co-moving polarized electrons or positrons* [8][9]. It is not yet shown if the relevant cross section is substantial. This needs further theoretical evaluation and will be tested at COSY soon. Another method

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[1] PAX - Polarized Antiproton eXperiment: http://www.fz-juelich.de/ikp/pax/

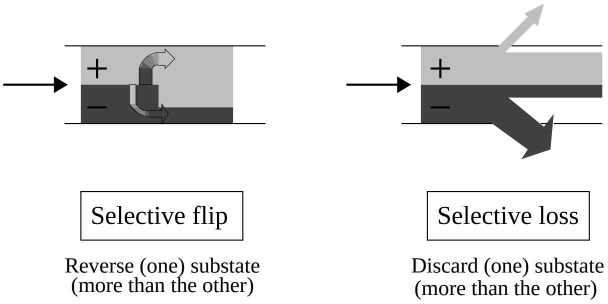

FIGURE 1. Two principles to polarize an (anti)proton beam [7].

is *Dynamic Nuclear Polarization (DNP)* in flight with co-moving polarized electrons or positrons. Antiprotons and positrons remain unbound and it is not clear if a double spin flip occurs at a sufficient rate.

The second mechanism includes polarization of an antiproton beam via *Stern-Gerlach separation*. Theoretically this seems to be impossible due to averaging effects in a stored beam [10]. Another method is polarization by *channelling trough bent crystals* [11]. Although unpolarized channelling works [12] it is not clear if polarization can be achieved with this method. Experimental tests are needed. The only successfully tested method is spin filtering.

PRINCIPLE OF SPIN FILTERING

Spin filtering is based on the effect of selective removal of (anti)protons of a stored beam by a polarized target. The total cross section

$$\sigma_{tot} = \sigma_0 + \sigma_\perp \vec{P}\cdot\vec{Q} + \sigma_{\|}(\vec{P}\cdot\vec{k})(\vec{Q}\cdot\vec{k}) \qquad (1)$$

consists of a transverse and longitudinal part, where $\vec{P}$ is the proton beam polarization, $\vec{Q}$ the target polarization and $\vec{k}$ the proton beam direction. For initially equally populated states $\uparrow$ ($m = +\frac{1}{2}$) and $\downarrow$ ($m = -\frac{1}{2}$) the total cross sections for the transverse and longitudinal cases are

$$\sigma^{\perp}_{tot\pm} = \sigma_0 \pm \sigma_\perp \vec{Q} \quad \text{and} \quad \sigma^{\|}_{tot\pm} = \sigma_0 \pm (\sigma_\perp + \sigma_{\|})\cdot\vec{Q}\,, \qquad (2)$$

respectively. Therefore an initially unpolarized (anti)proton beam will become polarized.

Experiments at the Test Storage Ring (TSR) at Heidelberg in 1993 (Fig. 2) showed that spin-filtering technique works in principle [2]. Although a polarization buildup was observed (Fig. 2, right panel), the interpretation of this result is ambiguous. The observed cross section is $\sigma_\perp = 72.5 \pm 5.8$ mb. In 1994 Horowitz and Meyer explained this result by three effects [3]:

- Selective scattering of protons out of the acceptance of the storage ring
- Scattering of target protons into the acceptance of the storage ring
- Spin transfer from polarized target electrons

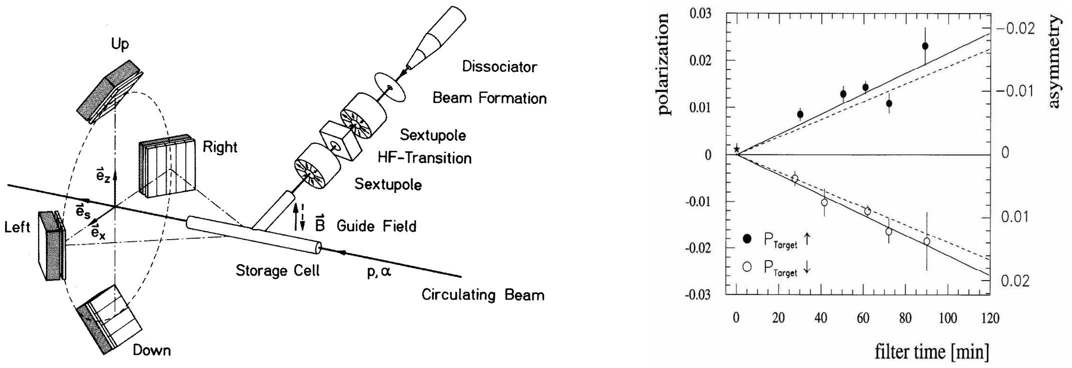

FIGURE 2. The setup of the test experiment at TSR and the results [2].

The combined cross section calculated by Meyer and Horowitz is $\sigma_\perp = 65$mb. In contrast to this, Milstein and Strakhovenko [4], as well as Nikolaev and Pavlov [5] showed recently that by considering pp-scattering only, a total cross section of $\sigma_\perp = 85.6$ mb is obtained. Both values are compatible with the experimental result.

The conclusion is that there are further experimental tests necessary to disentangle the effects of electrons and nucleons for the polarization buildup process. Depolarization [13] [14] as well as spin-filtering experiments [15] will be carried out at COSY (Jülich) with protons, followed by spin-filtering experiments with antiprotons at the Antiproton Decelerator Ring (AD/CERN) [16].

Required for the spin-filtering experiments is a highly polarized internal gas target with areal densities of up to $10^{15}\text{atoms}/\text{cm}^2$ using a storage cell. A low-β section is necessary to be able to pass the stored (anti)proton beam through the storage cell and to reduce the coulomb losses in order to achieve long storage times of several hours. It is expected that nuclear polarized deuterium could be equally effective for spin filtering as hydrogen. Therefore the target should run with hydrogen and deuterium with electron and nuclear polarization in variable target holding fields. Because no analyzing power measurement for $\vec{\bar{p}}\vec{d}$ scattering exists at this energy range, the target gas has to be exchanged with hydrogen in order to measure the antiproton beam polarization. For longitudinal spin filtering a Siberian snake has to be implemented in order to preserve the polarization of the beam.

EXPERIMENTAL OVERVIEW

The setup of the spin-filtering experiments consists of an Atomic Beam Source (ABS) to produce polarized target gas, a target chamber with storage cell and detector system to detect forward and recoil (anti)protons. A so-called Breit-Rabi Polarimeter (BRP) is used to measure the polarization of the target gas. A low-β section consisting of 4(6) magnets is necessary for the measurements at COSY(AD) [17], in order to decrease the transverse size of the (anti)proton beam. This is designed for the interaction point TP 1 at COSY (Fig. 3), and for one of the straight sections at AD. For longitudinal spin filtering at COSY the solenoids of WASA and the electron cooler located in the opposite straight

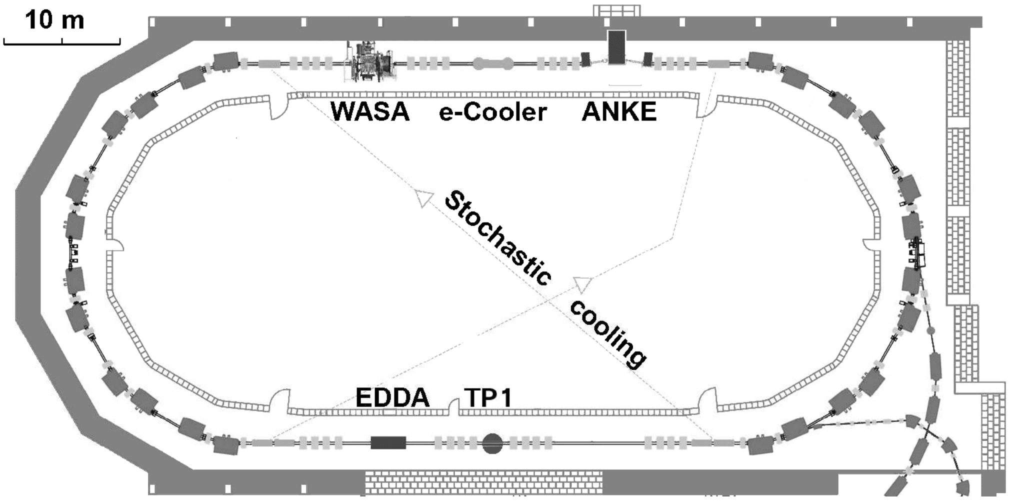

FIGURE 3. The Cooler Sychrotron (COSY) at Forschungszentrum Jülich.

section can be used as a Siberian snake, but for AD, an additional snake is required.

The Atomic Beam Source

The former HERMES-ABS [20] (schematic view in Fig. 4) was set up in Jülich with a modified vacuum system, mounted on a new support. The cryogenic pumps were replaced by turbo molecular pumps and an oil-free forevacuum system. It was completely recabled to allow a fast assembly and disassembly at COSY and AD, and the control system was renewed to allow for a full remote control via computer. The vacuum system with the microwave dissociator is operating well. The achieved pressures (Table 1) show that the new vacuum system is functioning as anticipated. None of the big turbo pumps run into their compression limit. After construction of a new analysis chamber with QMS and a calibrated compression tube the first intensity measurements were carried out. The measurements showed intensities of up to $6 \cdot 10^{16}$atoms/s for hydrogen in two hyperfine states. The ABS will be able to produce nuclear polarized hydrogen **or** deuterium beams in short sequence (5 min) without mechanical changes of components.

TABLE 1. Pressures in mbar in the ABS after a few days of pumping (IG - Ion Gauge). The pressures in line 3 and 4 are H_2 partial pressures for 90 sccm (1.5 mbarl/s) hydrogen gas flow.

	Pirani 1	**Pirani 2**	**IG 1**	**IG 2**	**IG 3**	**IG 4**	**IG CT**
base pressure	$5 \cdot 10^{-4}$	$1 \cdot 10^{-3}$	$1.8 \cdot 10^{-7}$	$3.9 \cdot 10^{-8}$	$2.6 \cdot 10^{-7}$	$3.3 \cdot 10^{-7}$	$1.9 \cdot 10^{-6}$
with gasinlet	$2 \cdot 10^{-2}$	$3 \cdot 10^{-2}$	$3.6 \cdot 10^{-4}$	$4.0 \cdot 10^{-5}$	$1.9 \cdot 10^{-6}$	$7.2 \cdot 10^{-7}$	$9.6 \cdot 10^{-6}$
Dissociator running	$2 \cdot 10^{-2}$	$3 \cdot 10^{-2}$	$4.0 \cdot 10^{-4}$	$9.5 \cdot 10^{-5}$	$2.7 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$1.2 \cdot 10^{-4}$

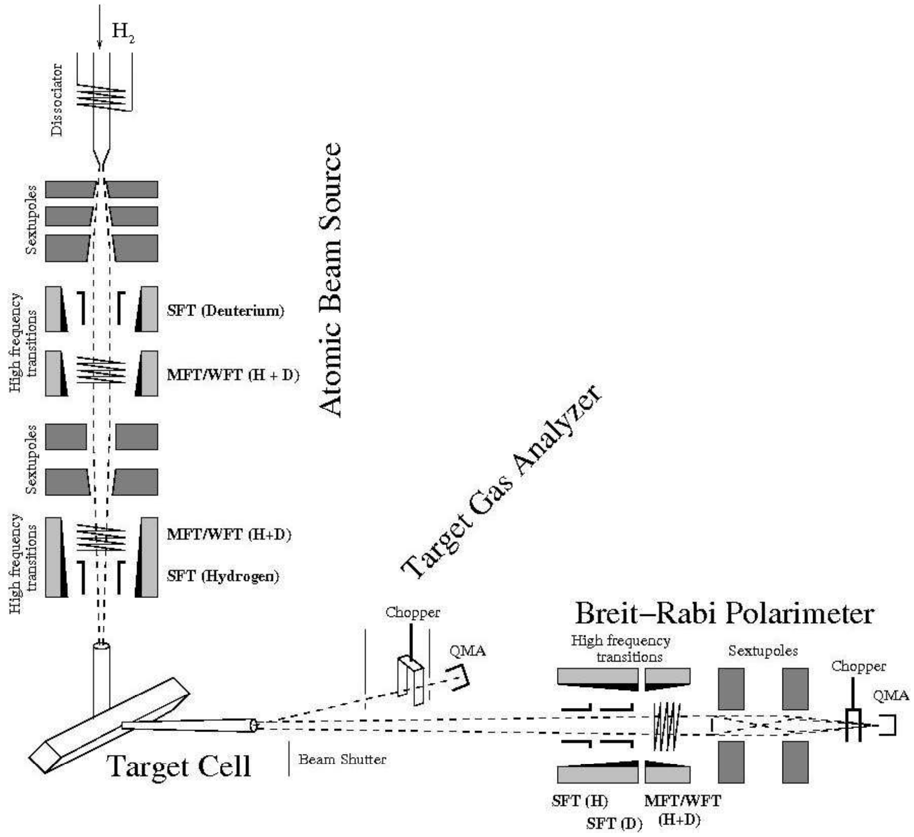

FIGURE 4. A schematic view of the setup of the polarized internal target.

Storage Cell and Silicon Detectors

Since spin filtering requires areal densities in excess of $10^{14}\mathrm{atoms}/\mathrm{cm}^2$, the use of a storage cell is mandatory. The present cell design consists of 5 μm Teflon walls supported by an aluminum frame (Fig. 5), similar to the cell design of PINTEX [18] [19]. Thin walls allow low energy recoil particles to pass through and be detected by the Silicon Tracking Telescopes (STT's). Teflon also suppresses depolarization and recombination of the target gas inside the cell. The cell has to be openable to provide enough space for the beam during injection at AD. The cell will be closed after the beam is decelerated and cooled. Subsequently the target gas is injected. Longitudinal and transverse weak holding field coils, included in the design of the cell provide the quantization axis for the polarized atoms. A strong holding field is necessary to produce pure electronic or nuclear polarization of the target gas in order to disentangle the effect of polarized electrons and nucleons. For these measurements an additional superconducting Helmholtz coil ($B \sim 3$ kG) will be installed.

The beam polarization will be measured by using pp $(p\bar{p})$-elastic scattering. To this aim a detector system consisting of 12 STT's will be implemented around the target cell (Fig. 5). The telescopes will detect both the low energy recoil particles (< 8 MeV) as well as the forward scattered particle with a large angular coverage and high resolution.

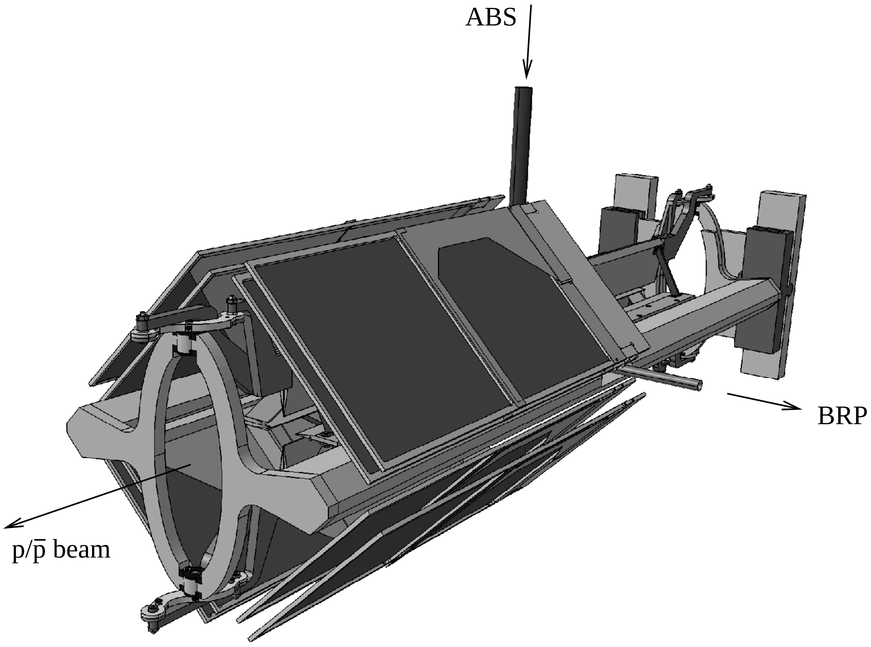

FIGURE 5. Preliminary design of the openable storage cell with surrounding detectors.

In addition the proton polarization of the target can be measured with the initially unpolarized (anti)proton beam. This allows for the calibration of the target polarimeter.

The Breit-Rabi Polarimeter

A BRP is required because of the inability of the detector system to measure the electron polarization of the target gas. It is also necessary to determine the nuclear polarization of deuterium at the AD because of the unknown analyzing power for $\bar{p}$d scattering.

The former HERMES-BRP [21] (schematic view in Fig. 4) was rebuilt on a new support stucture with modifications due to the new configuration with the ABS. Tracking calculations lead to a modified sextupole magnet configuration to adjust for the higher temperature of 300 K of the effusive hydrogen/deuterium beam out of the uncooled storage cell; at HERMES the cell was at 100 K. In addition a new strong field transition “Dual Cavity” was designed in order to induce transitions between hyperfine levels of hydrogen and deuterium. For this purpose two different frequencies are used, one for hydrogen and one for deuterium, respectively. Since the strong field transition cavity is mechanically tuned to these frequencies two different pairs of rods were installed to operate the transition unit with both frequencies in sequence. The cavity was constructed and tested with a spectrum analyzer. A test with an atomic beam will be carried out in the spring of 2008.

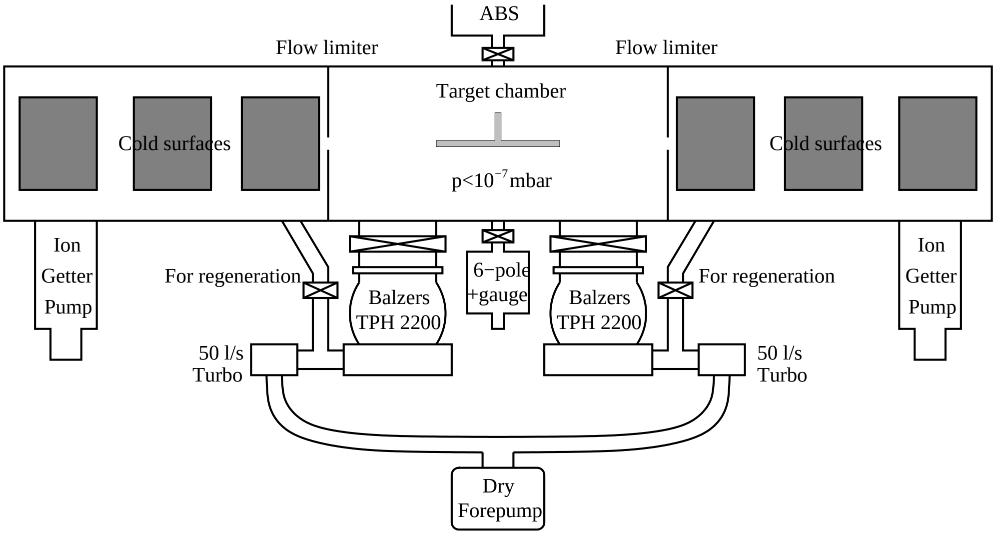

FIGURE 6. A schematic view of the target section including the chambers with the magnets of the low-β section and the target chamber.

Vacuum at the Target section

A schematic view of the target section is shown in Fig. 6. The vacuum system of the target section comprises two turbo molecular pumps, backed with smaller turbo molecular pumps and a dry forevacuum pump. This will ensure that most of the target gas exiting the storage cell is pumped away in the target chamber. The adjacent chambers containing the magnets of the low-β section will be pumped by ion getter pumps. In addition, the cold surfaces of the superconducting magnets are covered with charcoal to use them as cryogenic pumps. The cryopumps have to be regenerated using bypass lines to the turbomolecular pumps of the target chamber vacuum. In order to reduce the gas load on these cold surfaces, flow limiters will be installed between the target chamber and the magnet chambers. These flow limiters have to be adjustable to match the different beam diameters during injection and after cooling.

PLANNED MEASUREMENTS

A first set of measurements is planned to be carried out at COSY/Jülich. They include depolarization measurements with an initially polarized proton beam interacting with the electrons in the cooler. The aim of these measurements is to determine the spin transfer cross section at different energies [13] [14]. Subsequently to these depolarization studies, spin-filtering measurements with an initially unpolarized proton beam and a pure electron polarized hydrogen target or a pure nuclear polarized target in a strong holding field to determine the individual polarization buildup effect due to the electrons and nuclei will be carried out [15].

A second set of measurements is planned at AD/CERN. These will directly investigate the mechanism of the spin filtering process with an antiproton beam [16].

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