The polarised internal target for the PAX experiment

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The polarised internal target for the PAX experiment

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Abstract. The PAX (Polarized Antiproton eXperiment) collaboration aims to polarise antiproton beams stored in ring by means of spin–filtering. The experimental setup is based on a polarised internal gas target, surrounded by a detection system for the measurement of spin observables. In this report, we present results from the commission of the PAX target (atomic beam source, openable cell, and polarimeter).

1. Introduction

The high physics potential of experiments with stored polarised antiproton is well recognized [1]. The PAX–collaboration proposed [2] to produce a beam of polarised antiprotons by means of spin–filtering an initially unpolarised antiproton beam with a polarised hydrogen (deuterium) gas target, which as of now, constitutes the only experimentally proven method [3]. In order to determine the spin–dependent total cross section in $\bar{\mathrm{p}}$–p scattering, which will eventually be used to define the parameters of a dedicated Antiproton Polarizer Ring (APR) [4], the PAX–collaboration is presently devoting its efforts towards the development of a dedicated experimental setup

- for COSY [5] with the goal to perform a spin–filtering experiment with protons, and to commission the experimental setup for
- the Antiproton Decelerator ring at CERN [6], in order to carry out spin–filtering experiment with antiprotons.

This contribution deals with the target and its requirements in the framework of the foreseen experimental investigations. For spin–filtering experiments, a highly polarized internal gas target with an integrated thickness of 10^{14} atoms/cm^2 is required, which will be achieved by employing a storage cell. A low–β section is also needed in order to allow for the unperturbed passage of the stored beams through the narrow opening of the storage cell. Since at the AD, the injected beam is large, an openable storage cell has been developed. To verify the theoretical predictions that polarized deuterons in the target may provide larger polarisations after spin–filtering [7], the target should be operated with either hydrogen or deuterium, and with different orientations of the target holding field.

2. The target setup

In figure 1, a scheme of the experimental setup is shown, indicating the main components: a polarized Atomic Beam Source (pABS), a storage cell, and an analysing system, which consists of a Target Gas Analyser (TGA), and a Breit Rabi Polarimeter (BRP). The complete system was upgraded and all cables and connectors were renewed, in order to provide fast assembling and disassembling and quick transport and installation at COSY and AD.

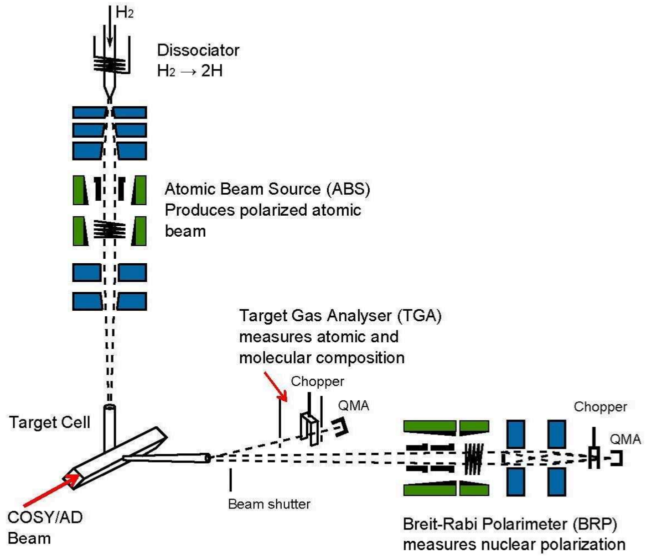

Figure 1. Scheme of the target with the atomic beam source in vertical position, the openable storage cell on the ring axis, and the Breit-Rabi polarimeter (BRP) in the horizontal position. The Target Gas Analyzer (TGA) determines the atomic to molecular fraction of the effusive beam from the storage cell.

2.1. The atomic beam source

The ABS, employed for the experimental investigations, is the former HERMES-ABS [8], which has been relocated from DESY to the Institut für Kernphysik (IKP) of Forschungszentrum–Jülich. The target is presently installed on a new support and in vertical position. Its four vacuum chambers were equipped with a new pumping systems, seven turbo pumps with a total pumping speed of about 10000 l/s have been implemented, and a new interlock system has been installed [9]. All cables and connectors are distributed from a patch panel on the ABS support to the electronics cabinets.

The atomic beam is produced by expansion of a dissociated beam of hydrogen (or deuterium) through a nozzle. A skimmer and a collimator are used to form a beam, which matches the acceptance of first sextupole magnet. The sextupole magnets are used to focus the atoms with electron spin aligned along the beam path (hyperfine states $|1\rangle$ and $|2\rangle$ for H), atoms with opposite electron spin are defocused. From this electron polarised beam, nuclear spin states are obtained by applying appropriate high frequency transitions (HFT), which exchange the population of two involved hyperfine states, and by a second set of sextupole magnets, located downstream along the atomic beam path, which defocuses the unwanted states.

A motorized beam shutter has been installed between the two sets of sextupole magnets, in order to block the atomic beam during the injection of the (anti)proton beam in the ring. After the commissioning of the ABS, the measured atomic beam intensity of two injected hyperfine states of hydrogen has reached the expected value of $6.6 \cdot 10^{16}$ atoms s^{-1}.

2.2. The openable cell

In order to be compatible with the $\bar{\mathrm{p}}$ beam operation at AD, a prototype of an openable cell has been designed and realised. The walls of the cell are made from a thin PTFE foil of 5 μm thickness, in order to be transparent to low momentum particles. The teflon foil walls were already employed in many experiments at the Indiana Cooler (IUCF [10]). The foils are fixed on a support made from aluminum, which defines the shape and houses the tubes required for feeding and sampling of the atoms. The cell opens in two halves; the geometry was designed to avoid trapping and depolarization of atoms. The opening of the cell, which provides a free space of 100 mm diameter during the injection of $\bar{p}$ in the AD, is precisely controlled by a stepper motor. The whole support of the PTFE foil and any piece of aluminum which can be hit by the atomic beam have been coated by PTFE as well. The storage cell for the PAX experiment is designed to work at room temperature. The cell has a square cross section of 10×10 mm^2 and a length of 400 mm. The feeding tube, along the direction of the beam from the ABS, is 10 mm in diameter and 100 mm long. The BRP sampling tube is 6 mm in diameter and 26 mm long, and on the aluminum support of the cell, at the end of this tube, an extension tube of 10 mm diameter and 328 mm length is mounted, for the effusion of the gas from the cell into the analysing systems of the BRP and the TGA. The calculated integrated target thickness for two injected hyperfine states of hydrogen at a cell temperature of 300 K is expected to be $8.6 \cdot 10^{14}$ atoms cm^{-2}.

The chamber, which houses the target, provides also the space for the installation of the system of silicon detectors around the cell, with a large angular coverage for the measurements of polarisation observables [5, 6].

The vacuum system of the target section will be equipped with a set of NEG pumps for a total pumping speed in the order of about 10000 l/s, to ensure that most of the target gas exiting the storage cell is pumped away. Turbopumps with a pumping speed of about 1000 l/s backed by small turbopumps and dry forevacuum pumps are installed, in order to evacuate the system during the bakeout of the target chamber and the regeneration of the NEG pumps. Flow limiters are installed between the target chamber and the adjacent up– and down–stream beam pipes to further reduce the gas load into the machine during operation of the target. The target chamber is also equipped with an unpolarised gas feeding system, to allow the injection of unpolarized gas into the cell, required for calibration measurements. Outside the target chamber, three pairs of Helmholtz coils provide magnetic guide fields of about ten gauss magnitude along x, y, and z as quantisation axis for the polarised atoms under the low field running condition.

2.3. The Breit-Rabi polarimeter and the target gas analyser

The sampling and extension tubes guide less than 10 % of the gas, injected into the cell, towards the analysing system, which allows one to measure the atomic fraction and the polarization.

The former HERMES diagnostics system was moved to Jülich and upgraded to fullfill the PAX experiment requirements. A new support was built in order to mount the BRP and TGA in horizontal orientation and to match the installation in COSY and AD. The vacuum system of the BRP was upgraded by dry backpumps and Ti-ball pumps with standard cryopanels, cooled by water. Also for the analysing system, cables and connectors were renewed and patch panels on the support were provided in order to allow for fast assembling and disassembling of the system.

The analysing system consists of a Target Gas Analyser (TGA) [11] and a Breit-Rabi Polarimeter (BRP) [12]. The former allows one to measure the atomic and molecular fraction, the latter the population of hyperfine states. The TGA is mounted at 7° off-axis with respect to the BRP, in order to not interfere with the sampled gas entering the polarimeter. The BRP, as indicated in figure 1, consists of HFT and sextupole magnets. The gas effuses from the cell at room temperature, therefore the sextupole magnets were optimized for optimum transmission of the velocity distribution of a 300 K effusive atomic beam.

The detector used to measure beam intensity for both TGA and BRP is a Quadrupole Mass Analyser (QMA), consisting of a cross–beam ion source, a quadrupole mass filter and a channeltron electron multiplier. The resolution and the mass selection are controlled by a LabView program. The data acquisition records two types of signals, pulses from the two QMAs by two fast counters, and analog voltages with ADCs. The data acquisition and slow control software are programmed with LabView running on a standard PC.

A fork shaped chopper placed in front of each QMA, periodically interrupts the incoming beam and rotates at a low frequency of $\sim$ 4–5 Hz. The signal is averaged over many cycles, depending on the required statistical error. The signal difference between closed and open position allows one to subtract the background.

The signal processing boards and the software for the control of the QMA and HF transition have been upgraded. The offline calibration programs have been rewritten as well. The software for the control of the spin selection of the ABS and the cycling of all states of the BRP have been written by Labview.

3. Working plan for the PAX target

The plans for measurements at COSY and AD require particular settings and flexibility of the target.

- The requirement for the first spin–filtering experiment at COSY [5] is to use the polarised target in order to spin–filter the circulating beam in the ring. After the filtering process is completed, the beam polarisation will be measured with elastic scattering $p_\uparrow d$, using the silicon tracking telescopes and a deuterium cluster target at the ANKE location, at a proton kinetic energy $T_{p_\uparrow}$=49.3 MeV, where analysing powers are available.
  The target density can be obtained from the observed deceleration, of the beam when electron cooling is switched off. The target polarisation is continuously monitored by the BRP, which has to be calibrated both for hydrogen and for deuterium. The calibration of the BRP for the hydrogen target will be carried out using the full PAX detector system. The most efficient way is to determine the target polarisation, using the spin correlation parameters in pp scattering with a polarised beam, whose polarisation will be measured with the system of silicon tracking telescopes at ANKE [13].
- For the spin–filtering experiment at AD [6] with hydrogen, the polarisation of the target can be determined from the known $\bar{p}p$ analysing power. The BRP will provide the calibrated polarisation at antiproton beam energies where data are not yet available. In addition, the BRP will operate anyhow as a monitor for the target polarisation.
  For deuterium target, only the BRP will provide the calibration standard to convert measured asymmmetries into polarisation, since there are no measured $\bar{p}d$ polarisation observables. Another option consists of feeding polarised deuterium in the target in order to polarise the stored $\bar{p}$ beam and then, after the spin–filtering process is completed, inject unpolarised hydrogen into the storage cell to make use of the well know $\bar{p}p$ analysing powers.

The flexibility of the cell will allow us to investigate and measure different spin observables.

4. Commissioning of the PAX target

The complete system, consisting of the ABS, the openable cell and the TGA/BRP was installed in a test area at Jülich for commissioning.

The ABS provided the expected intensity and stability. The BRP was calibrated in order to determine the transition efficiencies of the HFT and the transmission probability of the sextupole magnets. The behavior of the complete system follows in stability and reproducibility very well the performance obtained at HERMES [14]; it fulfills the requirements for the test experiment outlined in the COSY proposal [5] and those proposed for the AD [6]. The nozzle cycle was about four days, before the need of a regeneration which requires few hours. Along a cycle the

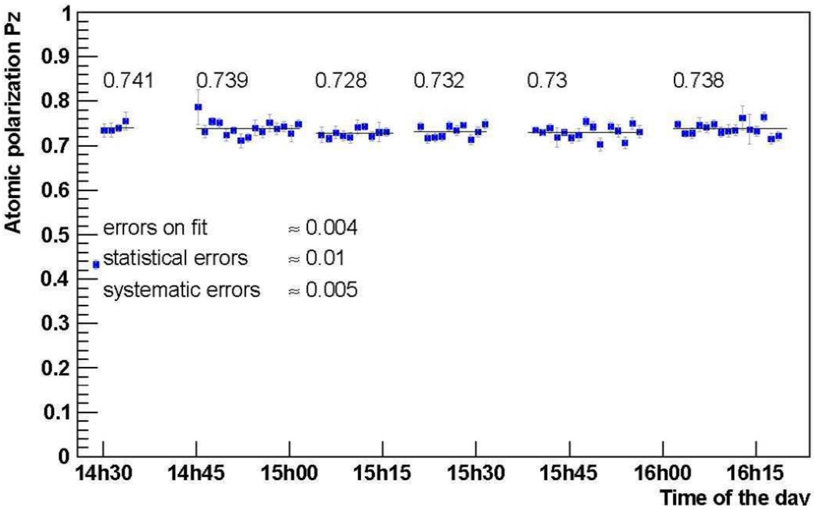

Figure 2. Results on the measured polarisation of the gas sampled from the openable cell. In the time period between the measurements, the cell was open.

polarisation measured by the BRP remained constant. The most delicate problem, the opening of the cell, showed an ideal behavior as reported in figure 2, which shows the stability of the polarisation for successive operations of opening and closing. The test also proved that for one state injected the polarisation of the target can be maintained already at a magnetic field of five gauss.

In the summer of 2010, the PAX target was installed in the COSY ring.

5. Conclusion

The PAX target was commissioned: all components, atomic beam source, openable cell and analysing system, provided good performance, as required for the spin–filtering experiments at the COSY ring. The calibration procedures were performed and the polarisation measurements showed stable conditions in the low field, few gauss region, of one state feeding the storage cell. The BRP allows us to continously monitor the status of the target, providing polarisation measurements of a gas sample extracted from the center of the cell.

References

[1] Rathmann F and *et al* 2011 Polarized Sources, Targets and Polarimetry *Proceedings of the 13th International Workshop* (Singapore: Word Scientific Publishing) p 282 , and *these proceedings*
[2] Rathmann F 2005 *Phys. Rev. Lett.* **94** 014801
[3] Rathmann F 1993 *Phys. Rev. Lett.* **71** 1379
[4] Lorenz B *these proceedings*
[5] PAX-Collaboration 2009 COSY Proposal # 199, Spin–Filtering Studies at COSY **http://www.fz.juelich.de/ikp/pax**
[6] PAX-Collaboration 2009 AD Proposal SPSC-P-337, Measurement of the Spin–Dependence of the $p\bar{p}$ Interaction at the AD-Ring **http://www.fz.juelich.de/ikp/pax**
[7] Rouba A *these proceedings*
[8] Airapetian C and *et al* 2005 *NIM* A **540** 68
[9] Nass A 2009 *SPIN PHYSICS 18th Intern. Spin Phys. Symp.* vol 1149 (AIP Conf. Proc.)
[10] Ross M and *et al* 1994 *NIM* A **344** 307
[11] Baumgarten C and *et al* 2003 *NIM* A **508** 268
[12] Baumgarten C and *et al* 2002 *NIM* A **482** 606
[13] PAX-Collaboration 2009 Status Report and Beam–Time Request for COSY experiment # 199, Spin–Filtering Studies at COSY **http://www2.fz-juelich.de/ikp//pax/portal/documents/proposals/files/beamrequest20100519.pdf**
[14] Barschel C and *et al* 2011 Polarized Sources, Targets and Polarimetry *Proceedings of the 13th International Workshop* (Singapore: Word Scientific Publishing) p 200