First Experiments with the Polarized Internal Gas Target (PIT) at ANKE/COSY

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Abstract. For future few-nucleon interaction studies with polarized beams and targets at COSY-Jülich, a polarized internal storage-cell gas target was implemented at the magnet spectrometer ANKE. First commissioning of the polarized Atomic Beam Source (ABS) at ANKE was carried out and several improvements of the system have been done. Storage-cell tests to determine the COSY beam dimensions have been performed. Electron cooling combined with stacking and stochastic cooling has been studied. Experiments with N_2 gas in the storage cell to simulate the background, produced by beam interaction with the aluminum cell walls, were performed to investigate the beam heating by the target gas. The analysis of the $\vec{d}\vec{p} \rightarrow dp$ and $\vec{d}\vec{p} \rightarrow (dp_{sp})\pi^0$ reactions showed that events from different vertex positions within the extended target can be clearly identified in the ANKE detector system. The polarization of the atomic beam of the ABS, positioned close to the dipole magnet $D2$ of ANKE, was tuned with a Lamb-shift polarimeter (LSP) installed beneath the target chamber. With use of the known analyzing powers of the quasi-free $np \rightarrow d\pi^0$ reaction, the polarization in the storage cell was measured to be $Q_y = 0.79 \pm 0.07$ in the vertical stray field of the $D2$ magnet, acting as a holding field. The target thickness achieved was 2×10^{13} atoms/cm^2 for one hyperfine state injected into the cell. With 6×10^9 polarized deuterons stored in the COSY ring, the luminosity for double polarized experiments was 1×10^{29} cm^{-2} s^{-1}.

Keywords: Atomic beam source, ANKE, Polarized target, Internal target, Polarimeter, Detection of atomic beams; Spin polarized hydrogen, Deuterium.
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INTRODUCTION

In 2004 the Atomic Beam Source (ABS) [1] and the Lamb-shift polarimeter (LSP) [2] were transferred from the laboratory to the COSY building outside the accelerator tunnel. The necessary test measurements led to the parameters of Tab. 1. In the summer of 2005, the source was ready for installation at the spectrometer ANKE and further commissioning. Measurements to determine the COSY-beam dimensions at the ANKE-target position and first tests with storage-cell prototypes were carried out in parallel to these studies.

Gas Type	Intensity, at/s	P_z	P_{zz}
Hydrogen	$(7.8 \pm 0.2) \times 10^{16}$	$+0.89 \pm 0.01$	-
		-0.96 ± 0.01	-
Deuterium	$(3.9 \pm 0.1) \times 10^{16}$	$+0.73$	$+0.77$
		-0.82	-1.17

Table 1: The esential parameters of the polarized atomic beam source of ANKE/COSY.

PIT AT ANKE

In order to achieve the maximum luminosity in the experiments with the internal gas target, one task was to determine the optimum size of the storage-cell tube. During the first test in February 2004, the diameter of the COSY beam at injection and after acceleration at the ANKE target position had to be measured. For this, a frame carrying various diaphragms was constructed. The diaphragm, which was mainly used, had dimensions of $50_{hor.} \times 25_{vert.}$ mm^2, i.e. larger than the expected beam size. During the tests, the supporting frame was moved across the beam by stepper motors. First, the center of the diaphragm was placed at the expected center of the COSY beam. By moving the diaphragm, the COSY beam is gradually destroyed and its full size can be measured[1]. At injection, the beam had elliptical shape and its full size was $38_{hor.} \times 17_{vert.}$ mm^2. The accelerated beam without target had a size of $9_{hor.} \times 14_{vert.}$ mm^2. With the cluster-target beam (density: 10^{12} atoms/cm^2), used to simulate the cell gas, it increased to $17_{hor.} \times 17_{vert.}$ mm^2 due to beam heating by the target.
To operate the ABS in the strong magnetic stray field of the D2 magnet required shielding of several components. For example, most of the turbo pumps and all the cryo-pumps had to be shielded by soft iron. In addition, the weak-field transition (WFT) unit behind the last sextupole magnet of the ABS, could only be operated with a strong shielding.

POLARIZED INTERNAL TARGET COMMISSIONING

Based on the measured results, two storage-cell prototypes were built from a 25 μm thick aluminum foil (99.95 Al). With acceleration of an unpolarized deuteron beam through the large cell ($30_{hor.} \times 20_{vert.}$ mm^2) to an energy of about 2.1 GeV, it was possible to store and accelerate more than 2/3 of the injected deuterons ($\sim 9 \times 10^9$) in the COSY ring [3]. Using beam scrapers in the opposite section of the accelerator ring, the dimensions of the stored beam in the cell were decreased to $13_{hor.} \times 11_{vert.}$ mm^2. With a small cell of $15_{hor.} \times 15_{vert.}$ mm^2, 1.7×10^9 deuterons, i.e. about 15% of the injected deuterons, were successfully stored in the COSY ring. The length of both cells

[1] These measurements were done with a 2.1 GeV proton beam without using any cooling procedures (electron cooling at injection, stochastic cooling after acceleration) nor any stacking procedure at injection.

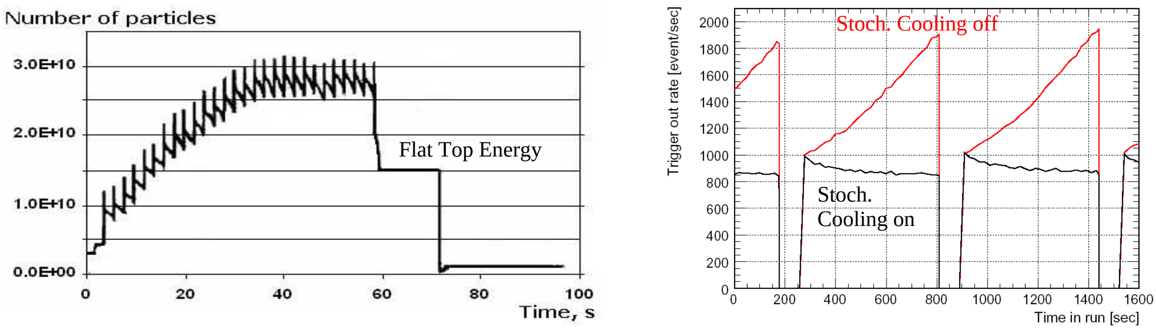

FIGURE 1. **Left hand:** The beam-current transformer signal and the number of the stored protons in the COSY ring during stacking (28 stacks) through a storage cell followed by 2 s of electron cooling and accelerating to flat top energy. **Right hand:** The trigger rate during data tacking with stochastic cooling switched on and off during a set of cycles. The strong increase of the trigger rate at the flat top energy after acceleration with stochastic cooling off occurs due to the increase of beam-cell walls interactions, caused by beam heating.

was 220 mm.

For the first beamtime an aluminum foil, covered with PTFE to minimize depolarization on the surface, was used. The beam tube of this prototype was 380 mm long and had a cross section of $20_{hor.} \times 20_{vert.}$ mm^2. During the run, stacking injection [4] and electron cooling were employed to increase the number of stored and accelerated protons with the storage cell in place (see left hand of Fig. 1). As a last step, the ANKE spectrometer magnet D2 was moved to a deflecting angle of 9.2°. At this configuration, 6.4×10^9 protons could be stored and accelerated in the ring. This corresponds to about 50% of the number of particles which can be accelerated without cell and without stacking at injection. This number yields an appreciable luminosity of about 10^{29} cm^{-2}s^{-1} for double polarization experiments.

For beam energies higher than 831 MeV stochastic cooling can be used at COSY. This compensates the beam heating by the target. At the right hand side of Fig. 1 the full trigger rate during data acquisition is shown as a function of time during different beam cycles. When stochastic cooling is switched off and the beam is heated, the rate of beam hits on the cell walls is increased and the background is growing significantly. With stochastic cooling, the beam heating could be compensated and the trigger rate remained constant during a cycle.

In addition to the storage cell tests, the ABS beam was used as a jet target. In a first experiment the target position along the COSY beam direction could not be identified by the ANKE detector system. The background gas pressure was too large. For a second experiment a cryo catcher was installed below the interaction point with the COSY beam to adsorb the ABS-beam atoms and to suppress backscattering into the target chamber. With this additional pumping power, the pressure in the target chamber decreased by about one order of magnitude to 3.7×10^{-8} mbar. Now, with vertex reconstruction, the jet-target position could be clearly identified. The integral jet-target thickness of 1.5×10^{11} cm^{-2} matches well with the predicted value.

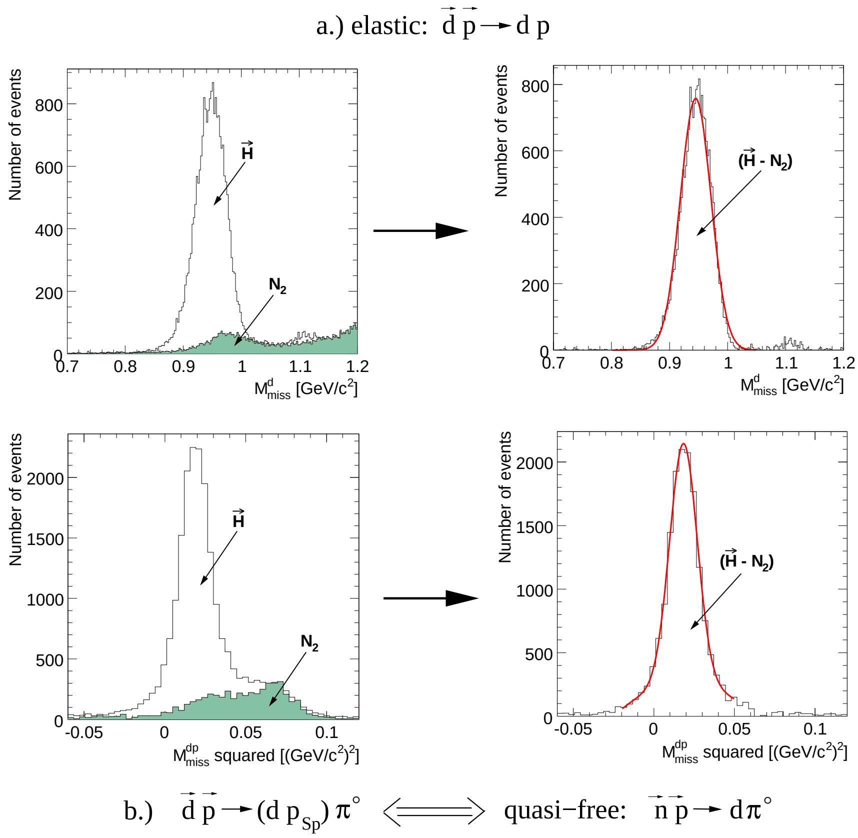

FIGURE 2. Missing-mass spectra for the proton from elastic $\vec{d}\vec{p}$ scattering (a.) and the π^0 from the quasi-free $np \to d\pi^0$ reaction (b.) before (figures at the left hand side) and after background substraction (figures at the right hand side). The background substraction is based on the additional measurement with N_2 gas in the target cell.

RESULTS OF THE COMMISSIONING

In early 2007, the LSP was used to tune and to control the polarization of the ABS beam. However, the magnetic stray field of the spectrometer magnet $D2$ caused a number of problems:

- The slow protons behind the Glavish-type ionizer of the LSP were partially deflected and, therefore, the sensitivity of the LSP was decreased.
- The quantization axis of the polarization, defined in the longitudinal solenoid field of the ionizer, was deflected, too. The LSP measures the projection of the polarization on the horizontal beam line only. The measured polarization was about 22% of the expected value only and, furthermore, it had the wrong sign.

Nevertheless, the transition units could be tuned and the polarization, which was measured once per day, could be controlled to be stable within 5% during one week of operation.
During this beam time a storage cell ($15_{ver.} \times 20_{hor.} \times 380$ mm^3) was used. In addition,

unpolarized H_2 or N_2 could be injected into the cell by two separate gas feeding tubes. A first silicon tracking telescope (STT) was mounted near to the cell. Polarized or unpolarized deuterons were accelerated to the flat-top energy of T_d = 1.2 GeV through the storage-cell tube filled with polarized hydrogen from the ABS or with unpolarized H_2 or N_2 gas from the calibrated gas supply system.

Fig. 2 shows sample spectra from the elastic scattering $\vec{d}\vec{p}$ (upper part) and the $\vec{d}\vec{p} \rightarrow (dp_{sp})\pi^0$ reaction (lower part). Both missing-mass spectra could be corrected for events, which are produced at the cell walls. For this reason data were taken with N_2 in the storage cell, of a pressure chosen to simulate the heating of the COSY beam by the hydrogen target gas [5]. The event distributions of these runs were subtracted from the original measured spectra with hydrogen in the cell and the results are shown on the right hand side of Fig. 2. The analyzing powers for the reaction $d\vec{p} \rightarrow (dp_{sp})\pi^0$ for different scattering angles are known with a good precision [6]. Therefore, the total target polarization in the cell was determined with an unpolarized deuteron beam at COSY as $\sim 0.79 \pm 0.07$ based on the measured asymmetries. Vice versa, the polarization of the COSY beam can be observed with unpolarized hydrogen gas in the storage cell as well.

OUTLOOK

In the fall of 2009, a long beam time at ANKE on double-polarized $\vec{p}\vec{d}$ breakup is planned at flat top energies $T_d = 1.2$ and $T_d = 2.23$ GeV [7]. At this time a modified LSP with a rotatable Wien filter will be available to compensate for the deflection of the quantization axis by the magnetic stray fields of the ANKE spectrometer magnet $D2$.

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