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 in summer 2005. First commissioning of the polarized Atomic Beam Source (ABS) at ANKE was carried out and some 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 have 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 $\vec{d}\vec{p} \to dp$ and $\vec{d}\vec{p} \to (dp_{sp})\pi^0$ reactions showed that events from 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 strong dipole magnet $D2$ of ANKE, was tuned with a Lamb-shift polarimeter (LSP) beneath the target chamber. With use of the known analyzing powers of the quasi-free $np \to d\pi^0$ 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 achieved target thickness was 2×10^{13} atoms/cm^2 for one hyperfine state populated in the ABS beam only. With a COSY beam intensity of 6×10^9 stored polarized deuterons in the 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 late 2003, the development of the ANKE Atomic Beam Source (ABS) [1] was successfully finished. The source produces polarized hydrogen or deuterium beams, the main parameters like intensity and polarization are shown in Table 1.
In 2004 the ABS and the Lamb-shift polarimeter (LSP) [2] were transferred from the laboratory to the COSY building. There, the ABS was rebuilt on a support bridge between two columns, representing the first beam-bending magnet $D1$ and the spectrometer magnet $D2$ of ANKE (see Fig. 1). The figure also shows the platform for the trans-

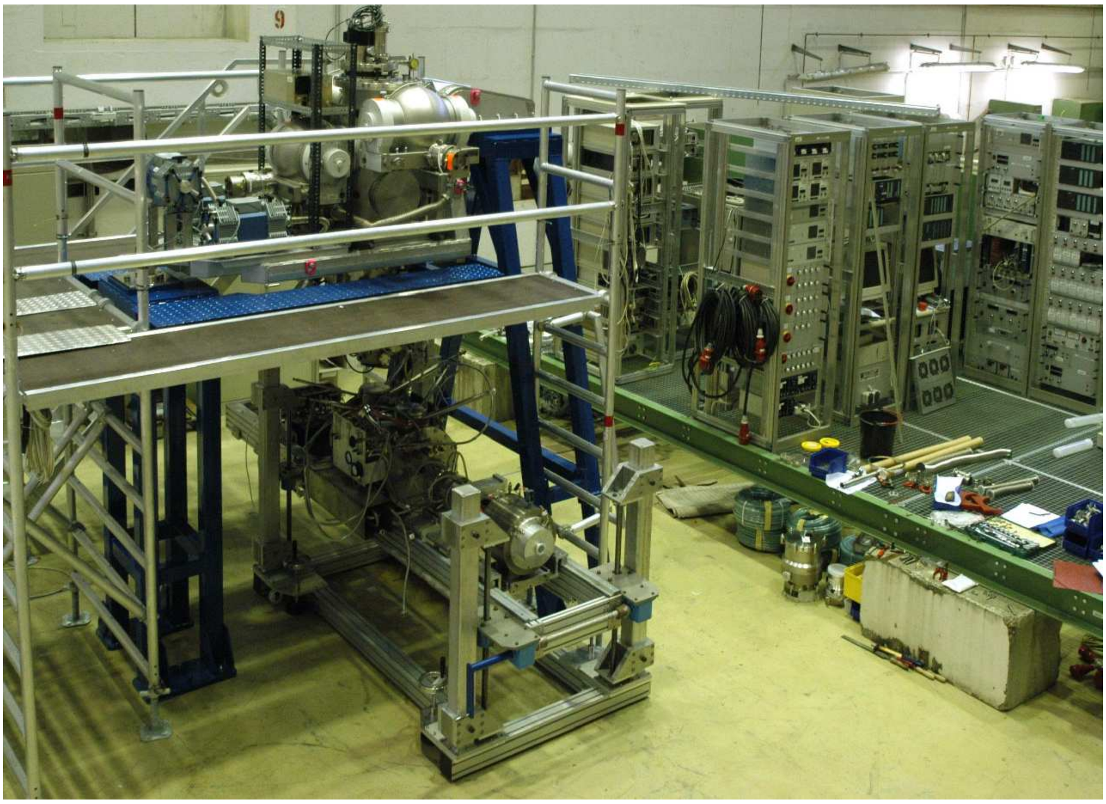


FIGURE 1. The ABS in the accelerator hall near the COSY tunnel.

portation of the electronic and power-supply modules from that place to ANKE. After all necessary tests, in summer 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 parallel to this 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: Main parameters of the polarized beam source of ANKE/COSY.

COSY BEAM STUDIES

To achieve the maximum luminosity in the experiments with the internal gas target one had to determine the least possible 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

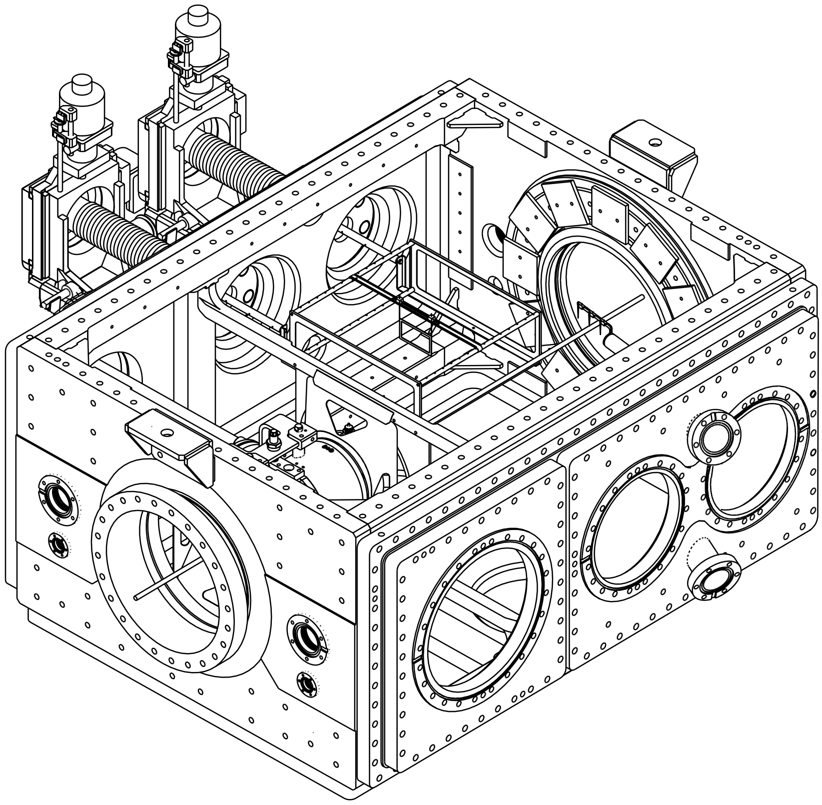


FIGURE 2. The moveable frame in the target chamber of ANKE.

diaphragms was constructed. The diaphragm, which was mainly used, had dimensions of $50_{hor.}\mathrm{x}25_{vert.}$ mm^2, i.e. larger than the expected beam size. In order to move the frame, a XY manipulator was mounted at the target chamber as is shown in Fig. 2. During the tests, the supporting frame was moved 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 $38_{hor.}\mathrm{x}17_{vert.}$ mm^2. The accelerated beam without target had a size of $9_{hor.}\mathrm{x}14_{vert.}$ mm^2. With the cluster-target beam (density: 10^{12} atoms/cm^2) it increased to $17_{hor.}\mathrm{x}17_{vert.}$ mm^2 due to beam heating by the target.

ABS AT ANKE

In the summer of 2005 the ABS was mounted between the ANKE bending magnet *D*1 and the spectrometer magnet *D*2 (see Fig. 3). To operate the ABS in the strong magnetic stray field of the *D*2 magnet requires shielding for several components. For example,

[1] This measurements were done with 2.1 GeV proton beam without using any cooling procedures (electron cooling at injection, stochastic cooling after acceleration) and stacking procedure at injection.

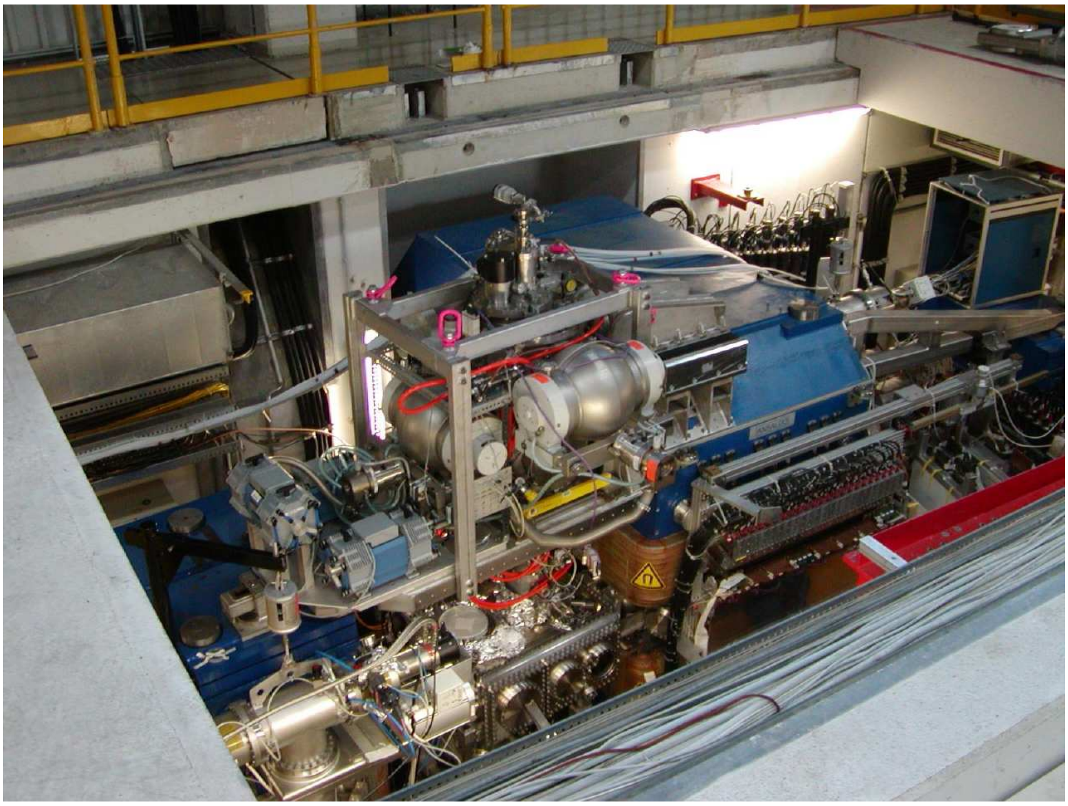
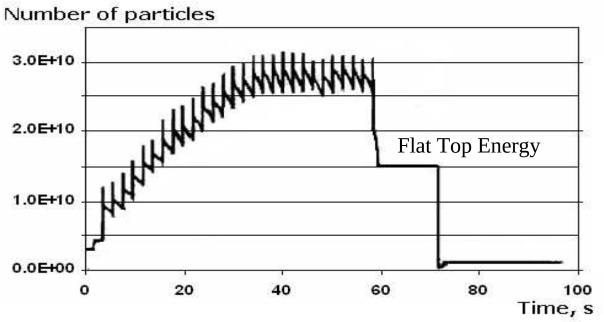


FIGURE 3. The ABS in the COSY tunnel, mounted on top of the target chamber in front of the spectrometer magnet *D*2. The COSY beam enters the setup from the left.

most of the turbo pumps and all of the cryo-pumps must be shielded by soft iron to avoid their destruction. In a first polarized run in autum 2005 we realized, that the weak field transition (WFT) unit, following the last sextupole magnets of the ABS, did not change the population of the hydrogen atoms in the beam from hyperfine state (HFS) 1 into HFS 3. During the measurement of the magnetic field along the ABS beam axis is was observed that the stray field in the region of the WFT was larger than expected and, therefore, the WFT was not induced. In a following beam time the shielding of the WFT unit was improved and the LSP was used to tune the WFT unit with the *D*2 magnet switched on.

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) for the February 2005 beamtime. With acceleration of an unpolarized deuteron beam through the large cell ($30_{hor.}\text{x}20_{vert.}$ 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 ($\sim 9\times10^9$) in the COSY ring. Using beam scrapers in the opposite section of the accelerator ring, the dimensions of the stored beam in the cell were decreased



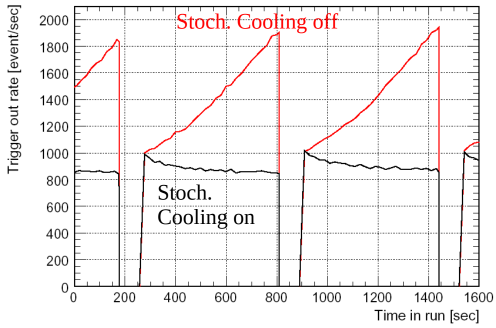


FIGURE 4. Left hand: The beam-current transformer signal and the number of the stored protons in the COSY ring during stacking (28 stacks) through a storage cell followed by 2 s of electron cooling and accelerating to flat top energy. **Right hand:** The trigger rate during data tacking with stochastic 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.

to $13_{hor.}$x$11_{vert.}$ 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 was 220 mm.

When the first cell test at ANKE was finished, preparation for the beamtime in the fall of 2005 started. An aluminum foil, covered with PTFE to minimize depolarization on the surface, was used for the new prototype of the storage cell. The beam tube of this prototype was 400 mm long and had a cross-section of $20_{hor.} \times 20_{vert.}$ mm^2. During the run, stacking injection [3] and electron cooling were used to increase the number of stored and accelerated protons with the storage cell in place (see left hand of Fig. 4). As a last step, the ANKE spectrometer magnet $D2$ was moved to the position which corresponds to a deflecting angle of 9.2° by the first beam bending magnet $D1$. At this configuration, 6.4×10^9 protons could be stored and accelerated in the ring. This is about 50% of the number of particles which can be accelerated without cell and stacking at injection. This number yields an appreciable luminosity of 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 allows to compensate for the beam heating by the target. At the right hand of Fig. 4 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 dramatically. With stochastic cooling, the beam heating is compensated and the trigger rate did not increase during the cycles.

Prior to these tests with the storage cell, calibration runs were made with a polyethylene strip target. The position of the strip target along the COSY beam was very close to the location of the maximum of the gas density along the storage-cell tube. Then, the reconstructed vertex distribution for the strip target (longitudinal and transversal widths are $\sigma_{\parallel} \sim 35 - 40$ mm and $\sigma_{\perp} \sim 8$ mm, respectively) allows to put the appropriate cuts in the distributions measured with the storage cell.

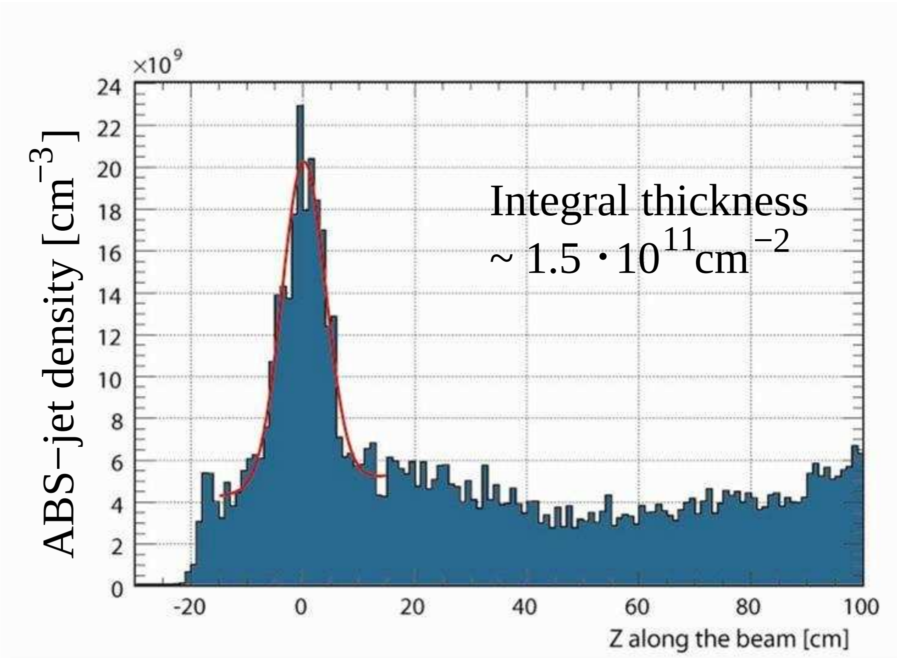


FIGURE 5. The reconstructed target density along the beam line. The jet-target position is clearly visible and the integral target thickness is 1.5×10^{11} cm^{-2}.

THE ABS AS A JET TARGET

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 (z) could not be identified by the ANKE detector system. The background pressure was too large. In a second experiment an ABS beam cryo catcher was built which was installed below the interaction point with the COSY beam. With this additional pumping power, the pressure in the target chamber was decreased by one order of magnitude down to 3.7×10^{-8} mbar. Now, with vertex reconstruction the jet-target position could be clearly identified (see Fig. 5). The integral jet-target thickness of 1.5×10^{11} cm^{-2} perfectly fits the predicted value.

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

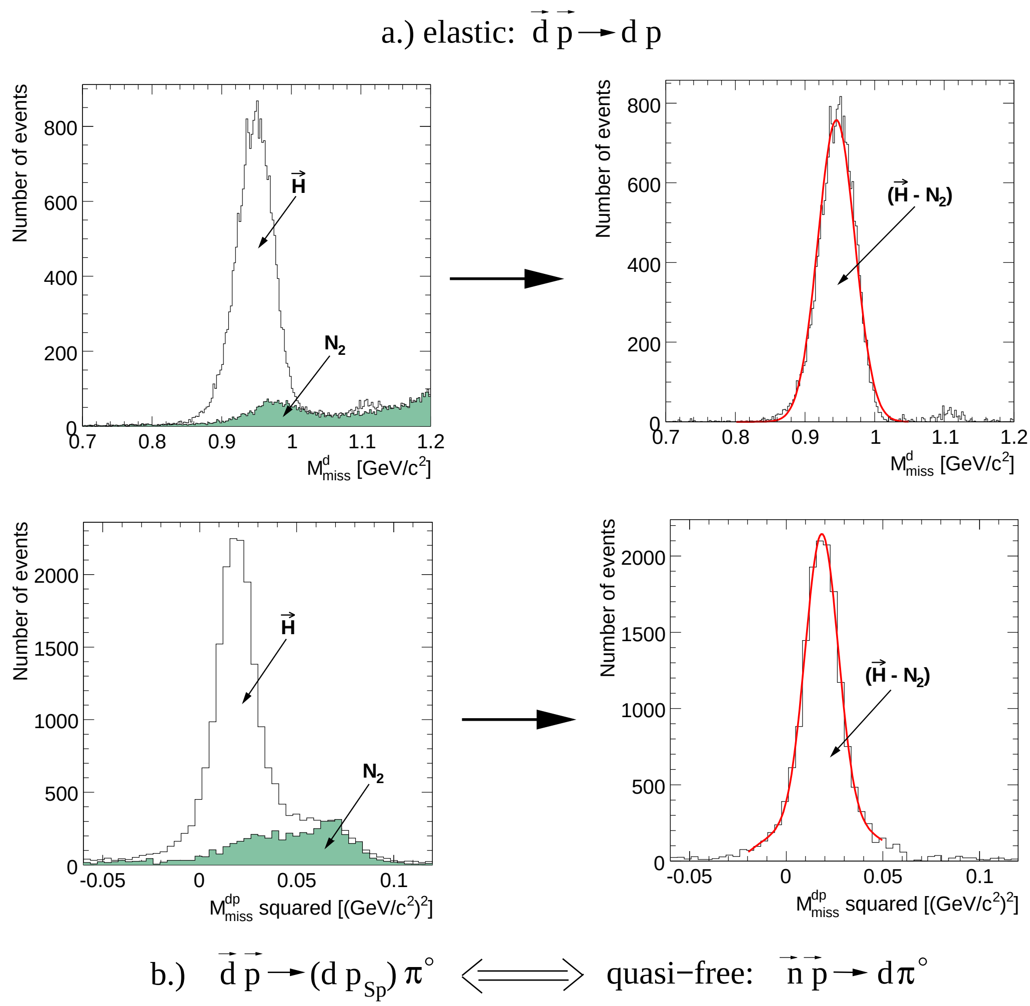


FIGURE 6. Missing-mass spectra for the proton from elastic $\vec{d}\vec{p}$ scattering (a.) and the π^0 from the quasi-free $np \rightarrow d\pi^0$ reaction (b.) before (figures at the left hand side) and after background substraction (figures at the right hand side). The background substraction is based on the additional measurement with N_2 gas in the target cell.

polarization on the horizontal beam line only. The measured polarization was about 22% of the expected value only and, furthermore, it had 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.
In this beam time a storage cell ($15_{ver.} \times 20_{hor.} \times 380$ mm) was used, made from 25 μm aluminum foil covered with 5 μm Teflon. In addition H_2 and N_2 could be injected into the cell by two separate gas feeding tubes. A first silicon tracking telescope was mounted around 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.

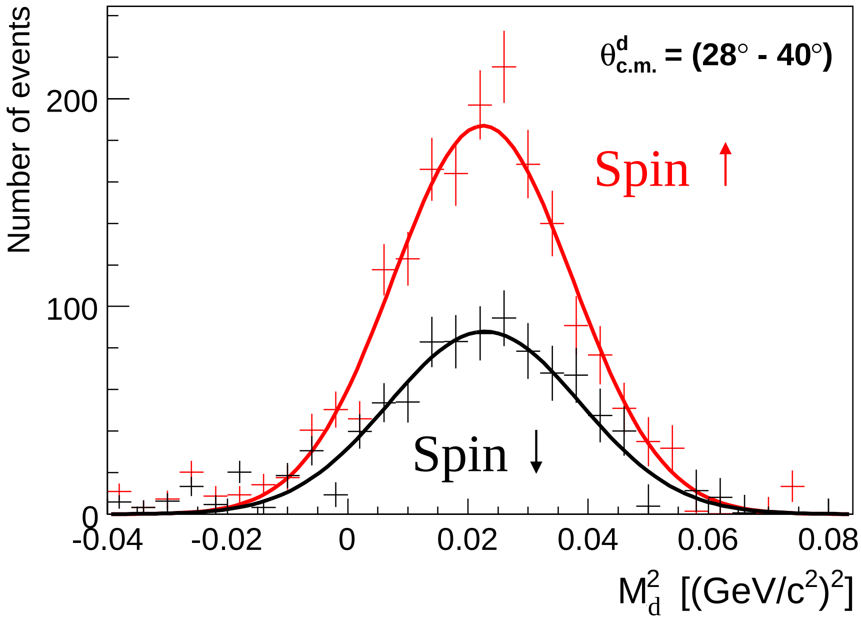


FIGURE 7. The missing mass spectra of the deuteron from the reaction $d\vec{p} \to (dp_{sp})\pi^0$ for two different runs with positive and negative nucleon polarization of the hydrogen atoms in the storage cell.

Fig. 6 shows sample spectra from the elastic scattering $\vec{d}\vec{p}$ (upper part) and the $\vec{d}\vec{p} \to (dp_{sp})\pi^0$ reaction (lower part). Both missing-mass spectras 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 [4]. The event distributions of these runs were substracted from the original measured spectra with hydrogen in the cell and the results are shown on the right hand side of Fig. 6.

The analyzing powers for the reaction $d\vec{p} \to (dp_{sp})\pi^0$ for different scattering angles are known with a good precision as given in ref. [5]. Therefore, the polarization of the hydrogen atoms in the cell was determined with an unpolarized deuteron beam at COSY as $\sim 0.79 \pm 0.07$ based on the measured asymmetries (Fig. 7). Vice versa, the polarization of the COSY beam can be observed with unpolarized hydrogen gas in the storage cell as well.

SUMMARY AND OUTLOOK

After implementation of the polarized internal target at ANKE/COSY double polarized $\vec{d}\vec{p}$ experiments were carried out in early 2007. With a cell-target density of 2×10^{13} hydrogen atoms/cm^2 in one hyperfine state (1 or 3) and a COSY beam intensity of more 6×10^9 stored polarized deuterons in the ring a luminosity of more than 10^{29} cm^{-2}s^{-1} has been achieved. The vector polarization of the hydrogen gas in the storage-cell target was measured by nuclear reactions to be about 0.79 ± 0.07.

In addition the ABS beam can be used as a jet target, too. In this case a target density of 1.5×10^{11} hydrogen atoms/cm^2 was measured which perfectly agrees with the predicted value based on the atomic flux of the ABS. An absolute measurement of the polarization could not be done with the LSP up to now. But tuning of the ABS transition units to optimize the polarization was possible. The expected polarization values according to earlier measurements in the laboratory are $+0.89 \pm 0.01$ for atoms in hyperfine state 1 and -0.96 ± 0.01 for hyperfine state 3.

In early 2008 a long beam time at ANKE on double-polarized $\vec{p}\vec{d}$ breakup is planned at flat top energies $T_d = 1.2$ or $T_d = 2.23$ GeV [6]. At this time a modified LSP with a rotatable Wien filter will be available to compensate the deflection of the quantization axis by the magnetic stray fields of the ANKE spectrometer magnet $D2$.

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