The Polarized Internal Gas Target for the Deuteron Break-up Experiment of ANKE at COSY-Jülich*)

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In order to provide the experimental tools necessary to carry out few-nucleon reaction studies with polarized beams *and* targets at the medium energy storage ring COSY at Jülich, our group is currently developing a polarized internal storage-cell gas target for first use at the magnetic spectrometer ANKE. In this paper we give an overview about currently relevant aspects of the polarized deuteron breakup experiment.

1 Physics Motivation

During the preceding decade the combination of stored cooled polarized beams incident on polarized internal gas targets has become a powerful tool in nuclear physics research [1]. In the near future on the medium energy sector two new facilities will be commissioned, BLAST[1]) at Bates, USA [2] and ANKE[2]) at the storage ring COSY[3]) in Jülich, Germany [3]. The unique potential of COSY [4] for polarization physics at proton and deuteron beam momenta ranging from 275 to 3650 MeV/c has been addressed by a recent workshop [5]. This year the funding for a new injector has been secured. It is envisioned with the upgrade to fill COSY up to the acceptance limit with polarized protons or deuterons.

The ANKE collaboration has recently begun to carry out a study of the *pd*

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[1]) **B**ates **L**arge **A**ngle **S**pectrometer **T**oroid
[2]) **A**pparatus for Studies of **N**ucleon and **K**aon **E**jectiles
[3]) **CO**oler **SY**nchrotron

breakup reaction $\vec{p}\vec{d} \to ppn$ [6], which is expected to provide new information on the NN interaction and the short-range structure of the deuteron. When a proton pair at small relative energy ($E_{pp} \leq 3$ MeV) is emitted in the forward direction, it appears predominantly in the $^1S_0$-state. This process constitutes a modification of proton deuteron backward elastic scattering $pd \to dp$ at almost the same kinematics. Therefore a model is applicable, which includes relativistic one-nucleon exchange (ONE), Δ-isobar excitation (Δ) and single pN scattering (SS) [7, 8]. In contrast to the $pd \to dp$ process, the iso-spin triplet nature of the pp pair from breakup results in a considerable suppression of the Δ contribution, thus the ONE mechanism dominates in the $pd \to pp(^1S_0)n$ reaction [9]. Furthermore, the ONE amplitude is modified since $l \neq 0$ states vanish in the forward pp pair. These two properties result in a dip of the unpolarized cross section at $T \sim 0.7$ GeV (Fig. 1, top left) and in a strong variation of spin observables (Fig. 1, bottom left) [10]. When rescatterings are taken into account in the distorted wave Born ap-

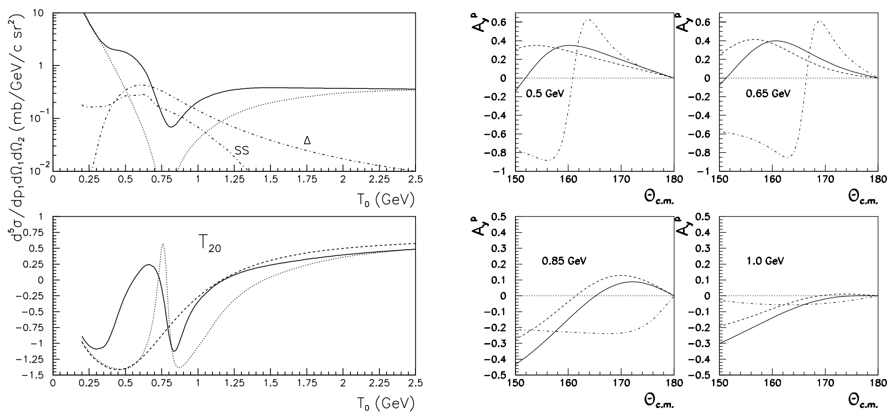

Fig. 1. Five-fold differential cross section (top left) and tensor analyzing power (bottom left) as function of kinetic beam energy for different mechanisms: ONE (DWBA) + Δ + SS (solid line), ONE (DWBA) (dotted), and ONE (dashed); vector analyzing power A_y^p of the proton (right) vs neutron scattering angle θ_{cm} in the $\vec{p}d \to (pp)_s n$ reaction at $E_{pp} = 3$ MeV at kinetic energies $T = 0.5$, 0.65, 0.85, and 1 GeV for different mechanisms: ONE (DWBA) (dash-dotted), ONE + Δ + SS (dashed), and ONE (DWBA) +Δ+ SS. The ANKE acceptance covers scattering angles above $\theta_{cm} \approx 166°$. (Graphs from Ref. [10].)

proximation (DWBA) approach within the ONE mechanism, the situation remains essentially unchanged [10]. The validity of the ONE +Δ+ SS model can be tested by polarization experiments (Fig. 1). The employed model does not contain any free parameters. Deviations of the experimental data from the model predictions would therefore indicate the presence of more exotic mechanisms like three-baryon resonances in the s-channel or N^*-exchanges in the u-channel [7].

2 Polarized Target for ANKE

The implementation of the polarized internal target into the COSY ring at ANKE comprises a major redesign of many components, because a powerful differential pumping system is needed to accommodate the high gas load from the polarized Atomic Beam Source (ABS). In addition, a new large target chamber is required in order to install the storage cell.

2.1 Atomic Beam Source and Setup at ANKE

The atomic beam source (Fig. 2, left) [11] will be utilized to feed a storage cell with vector and tensor polarized deuterium[4]). The production of vector polarized hydrogen will be possible as well. For two hyperfine states of hydrogen a flux of $(6.9 \pm 0.3) \times 10^{16}$ atoms/s has been injected into a compression tube located at the position of the future storage-cell feeding tube (diameter 10 mm, length 100 mm, 300 mm behind the exit of the last sextupole magnet).

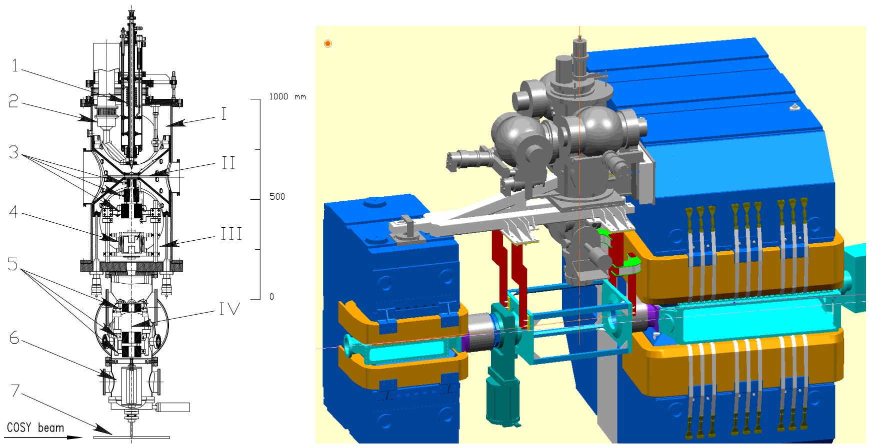

Fig. 2. **Left:** Layout of the ANKE Atomic Beam Source. The differential pumping system consists of four stages (I-IV). Arabic numbers denote dissociator (1), nozzle cooling (2), first set of sextupole magnets (3), medium field transition unit (4), second set of sextupole magnets (5), strong and weak field transition unit (6), and storage cell (7). **Right:** CAD drawing of the implementation of the ABS target at the magnetic spectrometer ANKE. Shown are the COSY beam deflection dipole magnet (left), the ABS above the new target chamber (center), and the main large gap spectrometer magnet with its chamber (right). A top view including the current detection system is shown in Fig. 4.

In particular a measurement of the polarization of the deuterium gas target poses difficulties, since nuclear reactions involving polarized deuterons have either

[4]) A detailed description of polarized internal targets can be found elsewhere in these proceedings [12].

not been measured well enough or not at all in the COSY energy range to allow for a precise determination of beam and target polarization. For this purpose a Lamb-Shift target polarimeter, currently installed for beam studies at the ABS, has been developed at the Universität zu Köln [13].

2.2 Aperture tests for storage cell development at ANKE

First tests with different apertures at the ANKE target location have been carried out in order to arrive at approximate design parameters for the future storage cell. Further studies aiming at the identification of cells suitable for the breakup experiment can be carried out only once new target chamber (Fig. 2) and differential pumping system have been installed. The dimensions of the apertures were based on beam optics considerations including an allowance for transverse beam motion during ramping. The calculated horizontal and vertical β-functions (in m) at injection (294 MeV/c) are $(\beta_x, \beta_y) = (3.11, 2.78)$, and $(2.88, 2.87)$ at 2.1 GeV/c ($T = 1362$ MeV).

The experimental setup (Fig. 3, left) included two aluminum apertures of 30 mm width (along x) and 10 mm height (along y). They were mounted on the solid strip

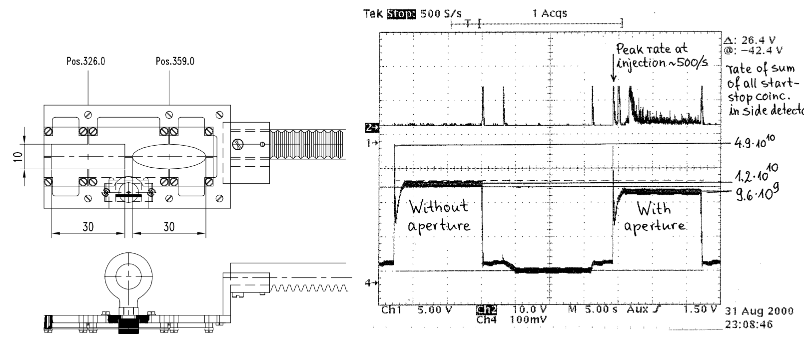

Fig. 3. **Left:** View along the beam direction (top) of the aperture support on the ANKE solid strip target holder. The unit can be moved along the horizontal (x) axis. The top view (bottom) shows the surface barrier detector, which had been installed as a monitor counter. **Right:** Beam current (bottom trace) and detector rate (top trace) for two cycles, one without aperture (left-hand side) and one with rectangular aperture at 2.1 GeV/c.

target support mechanism, whereby horizontal movement (along x) of the apertures in 0.1 mm steps perpendicular to the beam became possible.

Without aperture about 10^{11} protons could be stored at the injection energy of 45 MeV. With aperture in place, beam accumulation was observed only after a vertical beam bump was introduced, making use of two COSY steerers up- and downstream of ANKE ($\approx$ 50 m apart). Under these conditions $\approx 1.4 \cdot 10^{10}$ protons could be stored at 45 MeV, i.e. $\approx$ 14% of the number accumulated without the two-steerer bump and without restriction by the aperture. By moving the aperture in and out, it could be shown that the number of particles stored at injection is not adversely affected, thus acceptance limitation and associated loss of particles must take place elsewhere in the ring. The neutron monitor rate at COSY did show increased losses in the arc following ANKE, where the vertical aperture height inside the bending magnets is 6 cm only.

After a few hours of optimization the beam could be ramped to 2.1 GeV/c in the presence of the rectangular aperture. At that time, Fig. 3 (right) was taken from the scope. The lower trace shows the beam current during injection and ramping with and without rectangular aperture in place. The highest measured beam currents without aperture corresponded to $1.2 \cdot 10^{10}$ stored protons and with aperture to $9.6 \cdot 10^{9}$. During injection the rate corresponding to the sum of all triggered start-stop combinations in the ANKE side detector system (Fig. 4) peaked around 500 s^{-1} (top trace in Fig. 3, right).

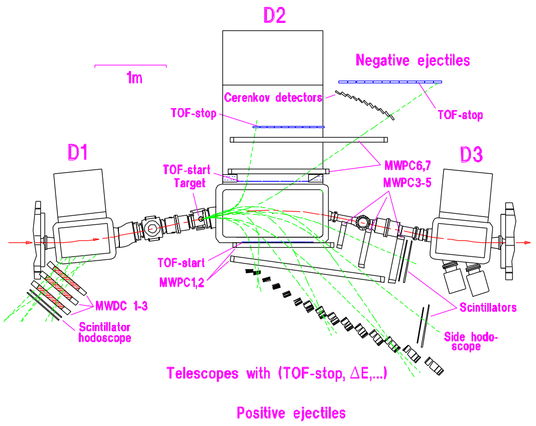

Fig. 4. Top view of the ANKE spectrometer and the detector system. The Forward Detector (FD), used for the measurements described in Sec. 3), consists of three multi-wire proportional chambers (MWPC), labeled 3, 4 and 5, and a two layer scintillation hodoscope located behind them.

3 Identification of the process

Recently, first measurements of the differential cross section of the deuteron breakup reaction $pd \to ppn$ in collinear kinematics with proton pairs near 0° were carried out [14]. For the first time proton pairs from the breakup reaction at relative energies $E_{pp} < 3$ MeV have been detected.

The total flux of charged particles recorded by the Forward Detector (FD, Fig. 4) at ANKE exceeds the flux of proton pairs with small relative energy ($E_{pp} < 3$ MeV) by factors between $0.2 \cdot 10^6$ and $5.3 \cdot 10^6$ for beam energies near the dip in the cross section between 0.5 and 1 GeV (Fig. 1).

In order to separate the process under consideration from other processes, a subset of events with two tracks in the FD MWPC's was selected. For these events it was verified that the tracks cross the corresponding hodoscope counters, and that measured energy losses and time-of-flight differences correspond to what is expected for protons. The reconstruction of the momenta of the individual tracks enables to calculate the missing mass M_X for the process $pd \to p_1 p_2 X$, where p_1 and p_2 are the protons with measured momenta $\vec{P}_1$ and $\vec{P}_2$, respectively. The missing-mass distributions obtained at all measured beam energies ($T = 0.5$, 0.6, 0.7, 0.8, 0.95, 1.35, and 1.9 GeV) exhibit the expected peak near the neutron mass (Fig. 5, left). These events must stem from the process $pd \to ppn$. The measured relative energy distribution (E_{pp}) of the events in the neutron missing mass peak is shown in the right panel of Fig. 5. The enhancement for events with $E_{pp} < 3$ MeV is pronounced.

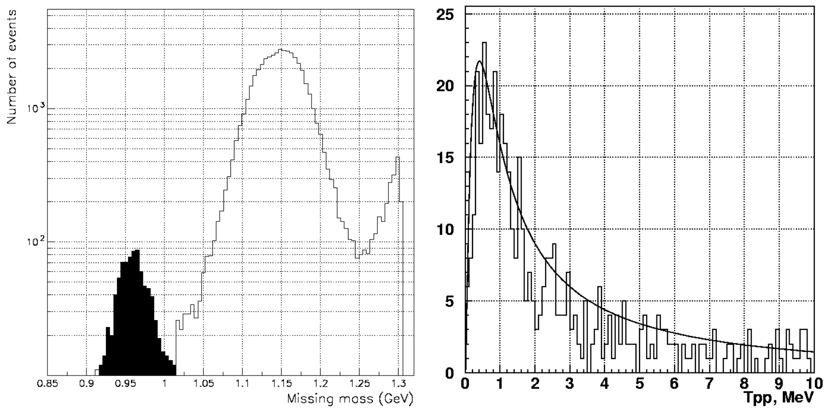

Fig. 5. **Left:** The missing mass distribution of the deuteron breakup reaction with two forward protons at a beam energy of 0.6 GeV yields a peak near the neutron mass. The large peak at 1.15 GeV is caused by quasi-free pion production. **Right:** Distribution of relative energies E_{pp} for the events in the neutron missing mass peak. The curve is obtained from Migdal-Watson final-state pp interaction, including Coulomb interaction [15].

4 Outlook

In order to proceed with beam optics studies for storage cell development at ANKE, a differential pumping system, a new target chamber, and a new set of small aperture beam position monitors before and behind the target are currently prepared together with a new beam line between magnets D2 and D3 (Fig. 4).

The analysis of the differential cross section data (Fig. 1) is near completion [14]. The primary goal of our future activities lies in the implementation and commissioning of the storage cell gas target at ANKE. Although in the fall of 2001 for the first time at ANKE data with a polarized proton beam incident on an unpolarized deuterium cluster target [16] have been accumulated, whereby the analyzing power A_y^p (Fig. 1) should be accessible, the scattering angles detectable at ANKE are small, hence the effect itself is small. Much larger effects should be observed in tensor analyzing power T_{20} and spin-spin correlation parameters C_{yy}, for which the polarized target is required. The first, polarized measurements will be limited to vertical orientation of polarization, by employing the vertical stray field of ANKE as a holding field for the polarized atoms in the storage cell. Later it is envisioned to install a holding field system that will allow for sideways and longitudinal orientation on the cell axis as well.

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