PROCEEDINGS OF SCIENCE

Polarimetry for the polarized deuterium target at ANKE/COSY

Boxing Gou* **for the ANKE collaboration**
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China
University of Chinese Academy of Sciences, Beijing 100049, China
Institute für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany
E-mail: b.gou@fz-juelich.de

The understanding of the NN interaction is fundamental to the whole of nuclear and hadronic physics. The scattering amplitudes for the complete description of NN interactions can be reconstructed from phase-shift analyses (PSA), which require measurements with polarized beam and polarized target. Very little is known about the np system above 800 MeV nucleon energy. The ANKE collaboration at COSY-Jülich has proposed to extract np scattering amplitudes using deuterons as a source of quasi-free neutrons. The first part of the program with a polarized deuteron beam and a hydrogen target allowed successful determination of np amplitudes up to 1.15 GeV nucleon energy. Use of a polarized deuterium target and a proton beam will allow to increase np studies up to 2.8 GeV, the highest energy available at COSY. In order to compensate the low density of the atomic beam source (ABS), polarized deuterium gas will be injected into a storage cell, placed along the COSY beam direction. Commissioning of the polarized deuterium target at ANKE was carried out in June 2012. Nuclear reactions with large and well-known cross sections and analyzing powers were selected to measure the target vector and tensor polarizations (Q_y and Q_{yy}).

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*Speaker.

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PoS(PSTP2013)020

1. Introduction

Nucleon-nucleon scattering is an ideal probe to study the nuclear interaction. Using the observables measured in scattering experiments, it is possible to determine NN amplitudes from phase-shift analyses (PSA). In order to fully investigate the spin dependence of nuclear forces, polarized beams and targets are indispensable. Due to the lack of free neutrons, experimental data on np scattering are very few, especially at high energies. It is argued that phase-shift analyses allows to extract np scattering amplitudes from spin observables of charge-exchange reaction $pd \to \{pp\}_{^1S_0}n$ [1]. This has already been proved [2] at ANKE. During the first phase of the np programme at ANKE [3], polarized deuteron beams incident on hydrogen targets were used, yielding important results [4, 5]. However, at COSY the maximum momentum of the beam is 3.7 GeV/c, thus the maximum energy per nucleon in the case of deuteron beam is 1.15 GeV. In the second phase, it is planned to extend the np study up to the highest nucleon energy available at COSY, which requires a polarized deuterium target. The polarized internal target (PIT), which was used to provide the polarized hydrogen target in the first phase of the np study, has been commissioned as a polarized deuterium target.

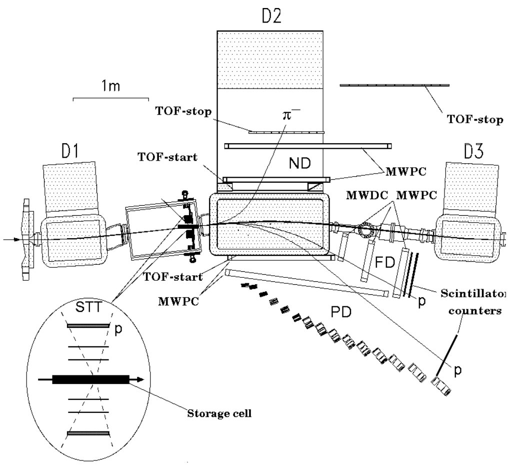


Figure 1: Schematic plot of ANKE.

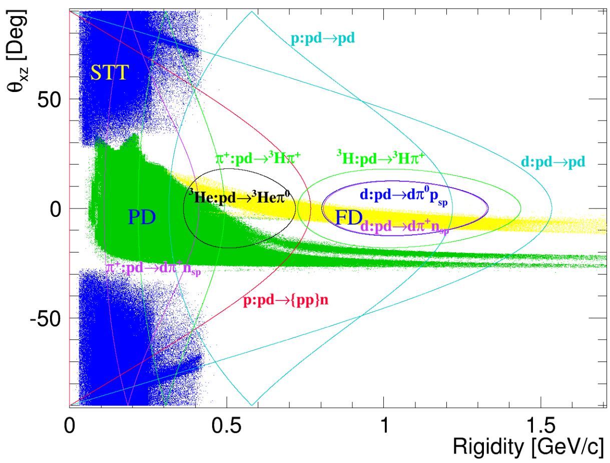


Figure 2: Acceptance of the FD, PD and STT.

2. Experimental Setup

The polarized internal target consists of three major parts: atomic beam source (ABS) [6], storage cell (SC) and Lamb-shift polarimeter (LSP) [7]. The ABS is able to provide deuterium beams with different combinations of vector (Q_y) and tensor (Q_{yy}) polarization. In this experiment four different states were used: (+1, +1), (-1, +1), (0, -2) and (0, +1). The atomic beams from the ABS go into the T-shaped storage cell via the feeding tube and diffuse along the beam direction, which substantially increases the target thickness. Since the Lamb-shift polarimeter can measure the polarization of the atomic beam from the ABS with an absolute precision better than 1% within several seconds, it is used for tuning the setting of the ABS before the experiments.

The polarized deuterium target was commissioned at the ANKE spectrometer [8] (Figure 1), using an unpolarized proton beam of 600 MeV provided by the COoler SYnchrotron (COSY) [9]

PoS(PSTP2013)020

in the Forschungszentrum Jülich. The forward detector (FD), positive detector (PD) and silicon tracking telescope (STT) were exploited to detect the scattered particles; the corresponding acceptances are shown in Figure 2. For polarimetry the $p\vec{d} \to pd$ reaction was used due to its high cross section and well measured analyzing powers: most of the deuterons from this reaction are detected in two STTs placed closely on the left and right sides of the storage cell in the target chamber. Each of the STTs is composed of three layers of double-sided silicon strip detectors (Figure 3), whose good spatial resolution enables excellent track reconstruction. The particle identification is performed by using the energy deposition information in different layers, see Figure 4.

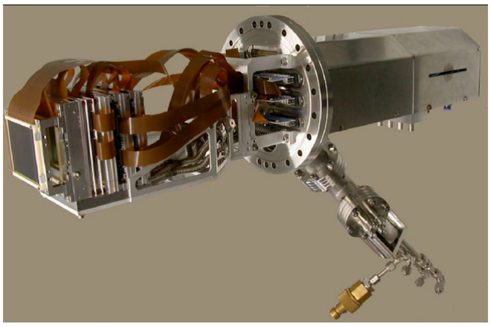


Figure 3: Silicon Tracking Telescope

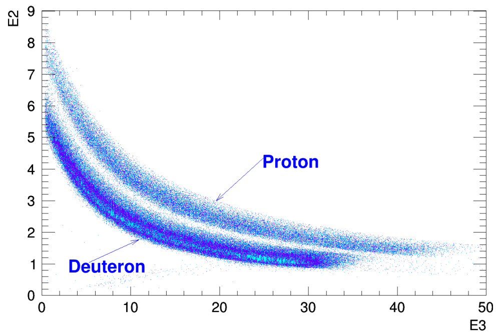


Figure 4: Particle Identification

3. Polarimetry

Any nuclear reaction within ANKE acceptance with large and well-known analyzing powers and sufficient cross section is suitable for the polarimetry. A large number of deuterons from $p\vec{d} \to pd$ are registered in STT, which is confirmed by the reconstructed missing mass spectrum showing a peak at the proton mass (Figure 5). Both vector (A_y) and tensor (A_{yy}) analyzing powers of this reaction in the acceptance of STT have been well measured by several laboratories at our energy (Figure 6).

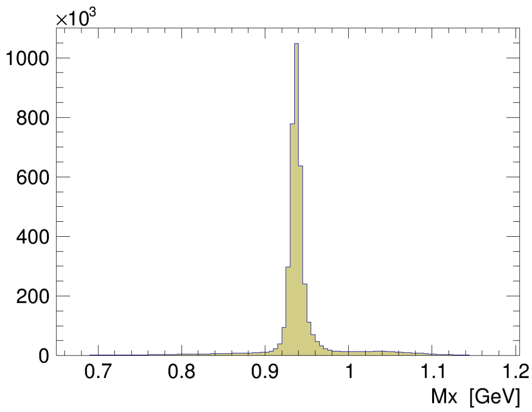


Figure 5: Missing mass of $p\vec{d} \to dX$

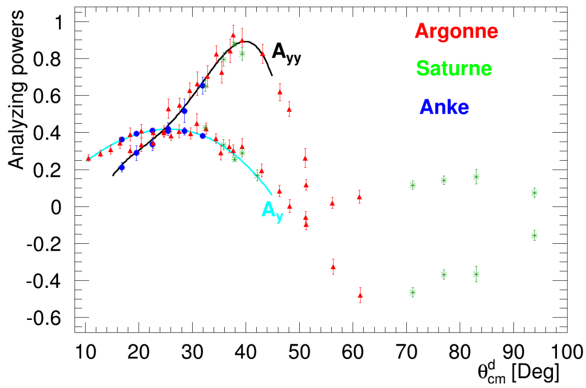


Figure 6: Deuteron analyzing powers of $p\vec{d} \to pd$

PoS(PSTP2013)020

With the target polarization axis pointing perpendicular to the accelerator plane, the polarized ϕ-dependent differential cross section of $p\vec{d} \to pd$ in the c.m. frame is given by [10]

$$\frac{d\sigma}{d\Omega}^P(\theta,\phi) = \frac{d\sigma}{d\Omega}^0(\theta)\{1+\frac{3}{2}Q_yA_y(\theta)\cos\phi + \frac{1}{4}Q_{yy}[A_{yy}(\theta)(1+\cos 2\phi)+A_{xx}(\theta)(1-\cos 2\phi)]\} \quad (3.1)$$

where $\frac{d\sigma}{d\Omega}^0(\theta)$ is the unpolarized differential cross section, $A_y(\theta)$ and $A_{yy}(\theta)$ are the vector and tensor analyzing power respectively. The polarizations are extracted through the azimuthal asymmetries between polarized and unpolarized target states. A cross ratio is defined:

$$CR = \frac{N_L^P N_R^0 - N_R^P N_L^0}{N_L^P N_R^0 + N_R^P N_L^0} \quad (3.2)$$

where $N_{L/R}^{P/0}$ is the number of events with polarized/unpolarized target and with deuterons detected in the left/right STT. The major advantage of this method is that the luminosities and the consequent systematic errors are canceled. In addition, it is observed that the ratio of the left and right STT efficiency $\frac{\varepsilon_L}{\varepsilon_R}$ does not change over the time. Therefore, it can be derived that

$$CR(\theta) = \frac{-\frac{3}{2}Q_yA_y(\theta)\cos\phi}{1+\frac{1}{4}Q_{yy}[A_{yy}(\theta)(1+\cos 2\phi)+A_{xx}(\theta)(1-\cos 2\phi)]} \quad (3.3)$$

By restricting ϕ close to 0 and π, the cross ratio is further simplified as

$$CR(\theta) \approx \frac{-\frac{3}{2}Q_yA_y(\theta)}{1+\frac{1}{2}Q_{yy}A_{yy}(\theta)} \qquad \phi \to 0,\pi \quad (3.4)$$

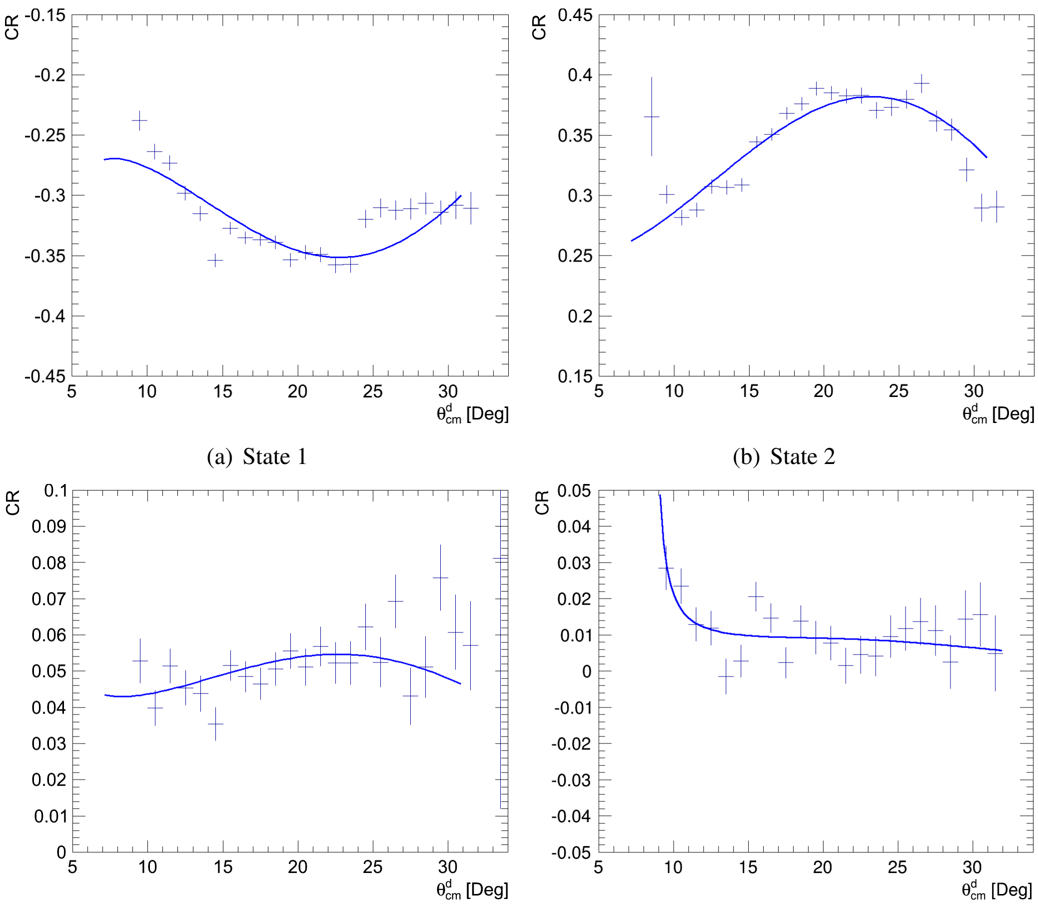
Based on the above discussion, both vector (Q_y) and tensor (Q_{yy}) polarizations can be extracted in one step by fitting the cross ratio (CR) with eq. (3.4) unless the vector analyzing power is too small. Figure 7 shows the results of these fits.

The polarizations (Q_y and Q_{yy}) of the state 1 (+1, +1) and state 2 (-1, +1) were measured to be Q_y^1=0.719 $\pm$ 0.005 , Q_{yy}^1=0.951$\pm$0.054 and Q_y^2=-0.716$\pm$0.007, Q_{yy}^2=0.738$\pm$0.068 respectively, however for state 3 (0, -2) and state 4 (0, +1) the tensor polarization (Q_{yy}) can not be determined due to reduced signals caused by the small vector polarization (Q_y). On the other hand the smallness of the vector polarization allows to determine the tensor polarization (Q_{yy}) via a counting rate ratio between polarized and unpolarized states.

$$\frac{N^P(\theta,\phi)}{N^0(\theta)} \approx R_{Lum.}[1+\frac{1}{4}Q_{yy}A_{yy}(\theta)(1+<\cos 2\phi>)] \qquad \phi \to 0,\pi \quad (3.5)$$

Here $R_{Lum.} = \frac{Lum.^P}{Lum.^0}$ is luminosity ratio between polarized and unpolarized states. By fitting counting rate ratio with eq. (3.5), following results were obtained: $R_{Lum.}^3$=0.697$\pm$0.003, Q_{yy}^3=-1.24$\pm$0.023 and $R_{Lum.}^4$=0.702$\pm$0.004, Q_{yy}^4=0.3032$\pm$0.026 (Figure 8).

PoS(PSTP2013)020



(a) State 1 (b) State 2

(c) State 3 (d) State 4

Figure 7: Preliminary results of cross ratio (CR) as a function of deuteron scattering angle for all the four states. To extract vector (Q_y) and tensor (Q_{yy}) polarizations, data points are fitted by eq. (3.4).

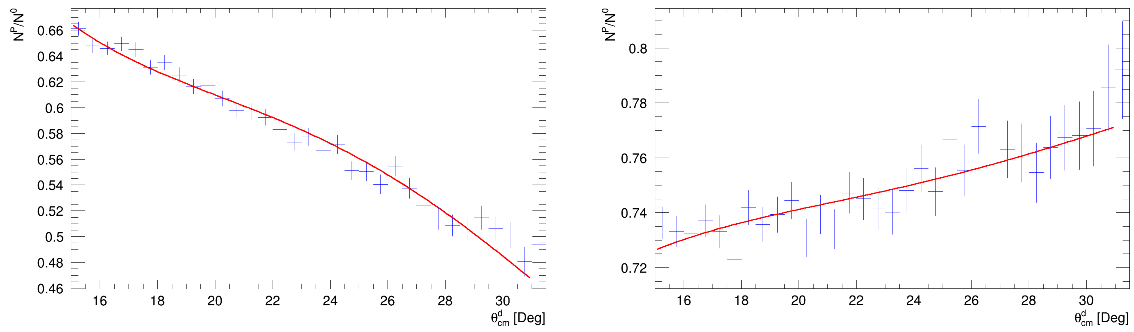
4. Preliminary Result of Charge-Exchange Reaction

To check the applicability of charge-exchange reaction for np studies, the $p\vec{d} \to \{pp\}n$ process at T_p = 600 MeV was investigated. It was identified by the missing mass spectrum of 2-proton events detected in STT (Figure 9). To select the diprotons in $^1S_0$ state, the excitation energy of the proton pair was restricted below 3 MeV. In this condition, the cross section of $p\vec{d} \to \{pp\}n$ is only sensitive to tensor polarization, hence:

$$\frac{N^P(\theta,q)}{N^0(\theta)} \approx R_{Lum.}[1+\frac{1}{4}Q_{yy}A_{yy}(q)(1+<\cos 2\phi>)] \qquad \phi \to 0,\pi \tag{4.1}$$

where q is the momentum transfer between deuteron and diproton. Using the measured values of $R_{Lum.}$ and Q_{yy} it is possible to determine A_{yy} using eq. (4.1). Due to complexity of the experiment up to now this procedure was only applied to state 3. Using the measured values: $R^3_{Lum.}$=0.697±0.003 and Q^3_{yy}=-1.24±0.023, first preliminary result was obtained (Figure 10). It is very reasonable compared to theoretical prediction, which gives a hope that our method of np study can be extended to higher energies.

PoS(PSTP2013)020



(a) State 3 (b) State 4

Figure 8: Preliminary results of counting rate ratio (N^P/N^0) as a function of deuteron scattering angle for state 3 and 4. To extract luminosity ratio ($R_{Lum.}$) and tensor polarization (Q_{yy}), data points are fitted by eq. (3.5).

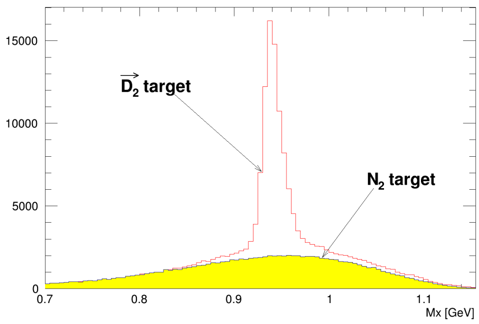


Figure 9: Missing mass of $p\vec{d} \to \{pp\}X$. The background under the peak produced by the beam interaction with the cell is simulated using a nitrogen target.

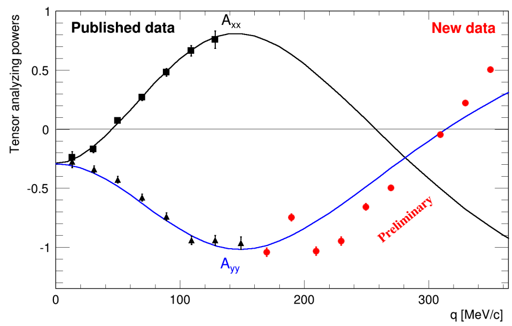


Figure 10: A_{xx} and A_{yy} of $p\vec{d} \to \{pp\}_{^1S_0}n$. The squares and triangles are the published data [5] while the dots represent the preliminary results from the current experiment. The curves indicate the theoretical predictions.

5. Summary and Outlook

Commissioning of the polarized deuterium target was successful, ANKE is able to perform target polarimetry with nuclear reactions and extract analyzing powers for the charge-exchange process. Measurements at higher energies are scheduled in beam time 2014, also with polarized proton beams to measure the spin correlation coefficients. After the installation of a Siberian snake, it will be possible to further extend the np study at ANKE with a longitudinally polarized beam.

Acknowledgments

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PoS(PSTP2013)020

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PoS(PSTP2013)020