COSY Proposal / Letter of Intent / Beam Request

For Lab. use

Exp. No.:	Session No.
201	37

Title of Experiment

Commissioning and initial research with the Polarized Internal deuterium gas Target at ANKE

Collaborators:

ANKE Collaboration

Spokesperson for collaboration: Name: **Kirill Grigoryev**

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Is support from the LSF program of the EC requested?
No

Date: **24.07.2009**

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Total number of particles and type of beam (p,d,polarization)	Momentum range (MeV/c)	Intensity or internal reaction rate (particles per second) minimum needed	maximum useful
unpolarized protons	519 MeV/c 887 MeV/c	$1 \cdot 10^{10}$	$5 \cdot 10^{11}$
Type of target	**Safety aspects (if any)**	**Earliest date of installation**	**Total beam time (weeks)**
ANKE PIT D_2 polarized target	-	01.10.2009	2 weeks

What equipment, floorspace etc. is expected from Forschungszentrum Jülich/IKP?

Summary of experiment (do not exceed this space):

The proposal concerns the commissioning of the Polarized Internal Target (PIT) with deuterium gas at ANKE and the initial research phase. It will include the measurements of vector and tensor polarizations of the deuterium gas target. The dependence of the polarization along the storage cell should be determined as well. The anticipated physics program of single- and double-polarization measurements with the deuterium gas target and unpolarized proton beam is briefly outlined, as well as the results of the commissioning of the polarized hydrogen gas target carried out previously. The status of the different PIT components is discussed, and the time schedule for the commissioning of the polarized deuterium target is presented.

The first phase of the commissioning is planned without COSY beam. This time is required for changing the ABS operation from the hydrogen to deuterium gas, tuning up the performance of the ABS transition units and measuring the polarization of the deuterium atomic jet with the Lamb-shift polarimeter. The second part of the commissioning with unpolarized proton COSY beam is requested to determine the deuterium target polarization, the target thickness and polarization dependence along the storage cell using the $p\vec{d}$-elastic at $T_p = 135$ MeV and quasi-free $p\vec{n} \rightarrow d\pi^0$ reaction at $T_p = 353$ MeV.

For the activities outlined in the proposal, **two weeks** of beam time are requested.

Attach scientific justification and a description of the experiment providing the following information:

For proposals:

Total beam time (or number of particles) needed; specification of all necessary resources

For beam requests:

Remaining beam time (allocations minus time already taken)

Scientific justification:

What are you trying to learn?
What is the relation to theory?
Why is this experiment unique?

Details of experiment:

Description of apparatus.
What is the status of the apparatus?
What targets will be used and who will supply them?
What parameters are to be measured and how are they measured?
Estimates of solid angle, counting rate, background, etc., and assumptions used to make these estimates.
Details which determine the time requested.
How will the analysis be performed and where?

General information:

Status of data taken in previous studies.
What makes COSY suitable for the experiment?
Other considerations relevant to the review of the proposal by the PAC.

EC-Support:

The European Commission supports access of new users from member and associated states to COSY. Travel and subsistence costs can be granted in the frame of the program Access to Large Scale Facilities (LSF).

COSY Proposal and Beam Request

Commissioning and Initial Research with the Polarized Internal Deuterium Gas Target at ANKE

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Jülich, 28 July 2009

Abstract

The proposal concerns the commissioning of the Polarized Internal Target (PIT) with deuterium gas at ANKE and the initial research phase. It will include the measurements of vector and tensor polarizations of the deuterium gas target. The dependence of the polarization along the storage cell should be determined as well. The anticipated physics program of single- and double-polarization measurements with the deuterium gas target and unpolarized proton beam is briefly outlined, as well as the results of the commissioning of the polarized hydrogen gas target carried out previously. The status of the different PIT components is discussed, and the time schedule for the commissioning of the polarized deuterium target is presented.

The first phase of the commissioning is planned without COSY beam. This time is required for changing the ABS operation from the hydrogen to deuterium gas, tuning up the performance of the ABS transition units and measuring the polarization of the deuterium atomic jet with the Lamb-shift polarimeter. The second part of the commissioning with unpolarized proton COSY beam is requested to determine the deuterium target polarization, the target thickness and polarization dependence along the storage cell using the $p\vec{d}$-elastic at T_p = 135 MeV and quasi-free $p\vec{n} \to d\pi^0$ reaction at T_p = 353 MeV.

For the activities outlined in the proposal, **two weeks** of beam time are requested.

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1 Introduction

A key feature of the ongoing and planned experiments at ANKE is the use of polarized beams and targets which allow us to perform double-polarization measurements [1]. The first experiment at ANKE that requires the polarized deuterium target is planned to be the measurement of the spin correlation parameters A_{xx} and A_{yy} in the $\vec{p}\,\vec{n} \to \{pp\}_s\pi^-$ process, where $\{pp\}_s$ is a proton pair in $^1S_0$ state. This measurement is a part of the experimental program at ANKE aiming at the extraction of the four nucleon-pion contact term in ChPT, corresponding to an effective $NN \to NN\pi$ vertex [1, 2]. Therefore, we propose to focus on the conditions of this experiment during commissioning of the polarized deuterium target.

Since 2005 ANKE is equipped with a Polarized Internal gas Target (PIT) [3] (shown in Fig. 1), which consists of an Atomic Beam Source (ABS) [4] feeding a storage cell (SC) and a Lamb-shift polarimeter (LSP) [5]. The equipment is mounted on a special bridge located between the beam bending magnet D1 (shown in Fig. 1) and the spectrometer magnet D2. The large-volume target chamber is supporting the storage cell together with the Silicon Tracking Telescopes (STT) [6]. The Lamb-shift polarimeter, installed below the chamber, is used for online tuning of the transition units of the ABS and is capable to monitor the atomic polarization of the ABS beam during experiments.

The polarized hydrogen internal gas target has been already commissioned at ANKE, as described in Sec.2, and a first physics experiment is scheduled for October 2009 [7]. The aim of this proposal is to commission and study the performance of the polarized deuterium gas target.

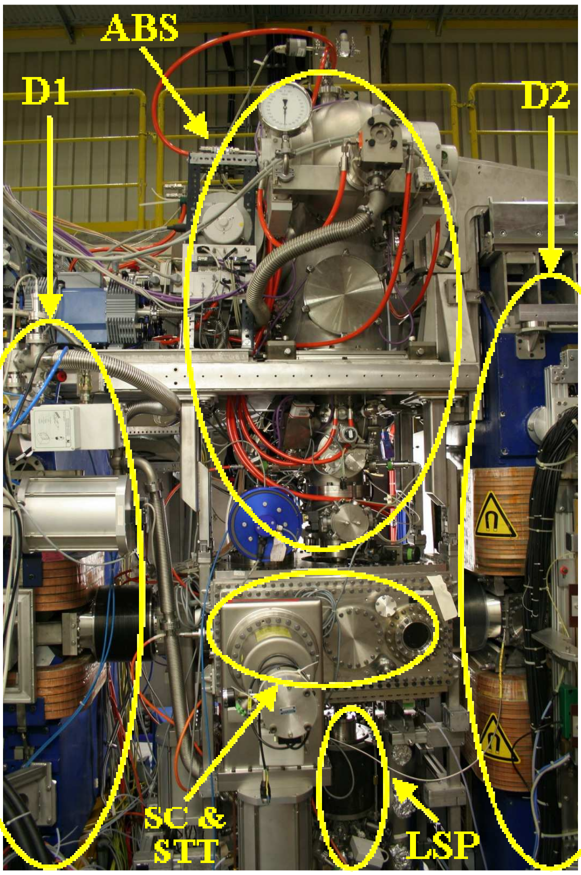


Fig. 1. Photo of ANKE with the Polarized Internal Target (PIT) installed between the beam bending magnet D1 and the spectrometer dipole magnet D2. The main components of the PIT system are: Atomic Beam Source (ABS), Lamb-shift Polarimeter (LSP), and the target chamber supporting the Storage Cell (SC) together with Silicon Tracking Telescope (STT) system. The COSY beam enters the setup from the left.

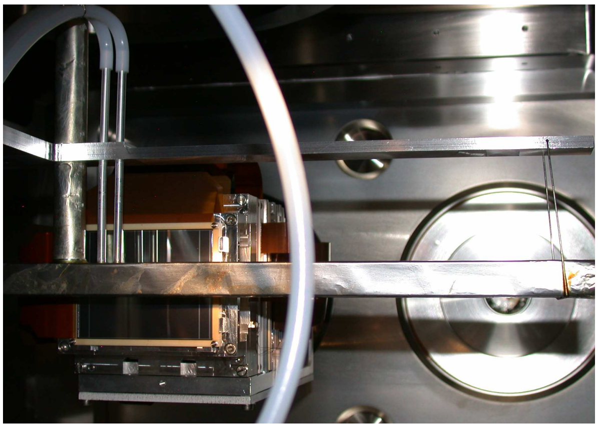
2 Results of the polarized internal target commissioning with hydrogen gas

During initial commissioning of the ABS in summer 2005 (allocated to the proposal #146 [8]), it has been shown that the source can be operated in a strong magnetic stray field of the spectrometer magnet D2 with an additional shielding of some components. In order to increase the flux of polarized atoms into the polarimeter and thereby to increase the sensitivity of the direct measurement of the target gas polarization the LSP was mounted below the target chamber. A separate bench to support components of the polarimeter was designed taking into account the spatial boundary conditions in the ANKE target region and the movement of the D2 magnet together with the target chamber. All power supply units for the ABS and the LSP, as well as their slow-control system [9], were mounted on a common transport platform.

The final commissioning of the polarized internal hydrogen gas target was successfully completed in November 2006 / January 2007 [10-13]. During this time all available COSY-techniques at like electron cooling, scraping at injection, stacking injection and stochastic cooling have been used. The Unpolarized Gas Supply System (UGSS) [14], a large number of ANKE detection subsystems, and the silicon tracking telescopes have been employed during the measurements.

In preparatory to these studies the storage cell and its support mechanism were upgraded. This allows installation of the silicon tracking telescopes near the storage cell and using of various unpolarized gas targets (hydrogen, nitrogen, etc.) with calibrated target thickness. The body of the storage cell was produced from 25 μm thick aluminum foil, with the inner surface covered by ~5 μm Teflon. The beam tube had a cross section of $20 \times 15\ \text{mm}^2$ and length of 390 mm [15].

For the first time studies with the COSY polarized deuteron beam at a flat top energy of T_d = 1.2 GeV were performed using the storage cell (Fig. 2a), fed with polarized hydrogen gas. The results are presented in the following subsections.

a) 

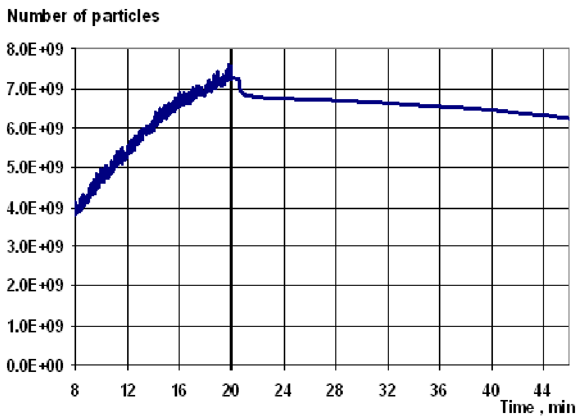
b) 

Fig. 2. a) The storage cell installed in the target chamber together with the Silicon Tracking Telescope (STT) system behind the cell. Two Teflon tubes, coming from the top, are used for the unpolarized gas feeding. **b)** The number of stored protons in the ring during stacking (120 stacks) through the storage cell followed by 10 s of electron cooling and accelerating to the flat top energy.

2.1 Results of the COSY-beam development

To compensate beam losses on the storage-cell walls during injection, a long cooler-stacking injection was implemented. Even without stochastic cooling (this is not available at the beam energy of $T_d = 1.2$ GeV), the achieved beam quality generally allowed the deuterons to pass through the cell without touching it. The procedure of scraping the accelerated beam using the COSY-scraper system before data taking minimizes the background coming from interactions of the beam halo with the cell wall.

Switching off the feeding of the storage cell during cooler-stacking and electron cooling prior to the injection helps to store and accelerate more deuterons in COSY. After optimization of the acceleration procedure almost 99% of the particles (at this time it was about $7 \cdot 10^9$ polarized deuterons) were accelerated to the flat top energy (see Fig. 2b). This value, together with the polarized hydrogen target thickness of $d_t = 1.34 \cdot 10^{13}$cm^{-2}, led to a luminosity of $L \sim 1.0 \cdot 10^{29}$ cm^{-2}s^{-1}.

Prior to the data taking, Low Energy Polarimetry (LEP) was carried out with eight different polarization states. Based on these results, the five spin modes with the highest intensity and polarization were selected for the experiment (see Table 1).

Table 1. Polarization value measured with LEP and ANKE for five deuteron vector polarization states.

	intensity	theoretical maximum polarization		measured vector polarization	
		vector (P_z)	tensor (P_{zz})	LEP	ANKE
1	1	0	0	+0.008 ± 0.008	compatible with zero
2	1	–⅔	0	–0.545 ± 0.006	–0.33 ± 0.08
3	1	+⅓	–1	+0.257 ± 0.008	+0.15 ± 0.08
4	⅔	–1	+1	–0.723 ± 0.006	–0.66 ± 0.09
5	⅔	+1	+1	+0.597 ± 0.004	+0.63 ± 0.09

2.2 *Studies with the PIT*

After the installation of the ABS at ANKE the target polarization has been maximized and the equality of positive and negative polarizations has been verified by the online measurements with the Lamb-shift polarimeter.

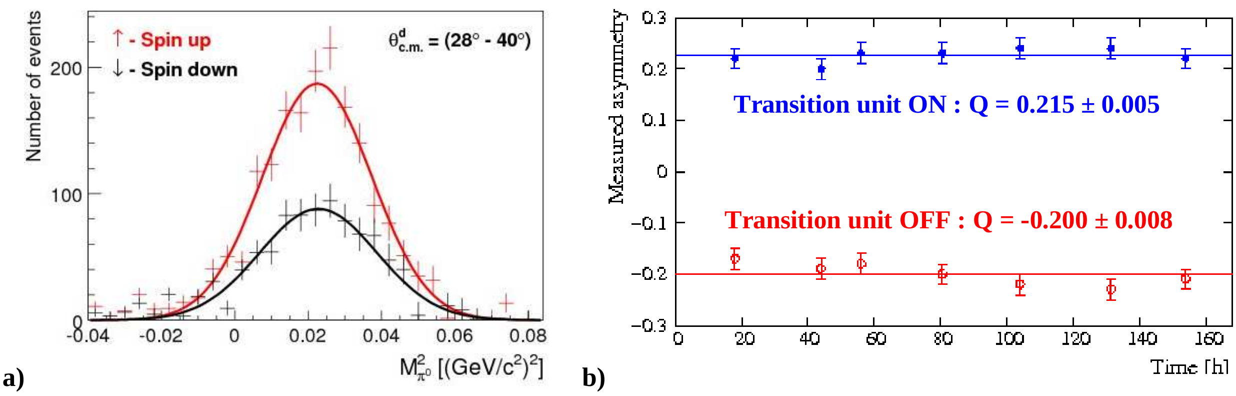


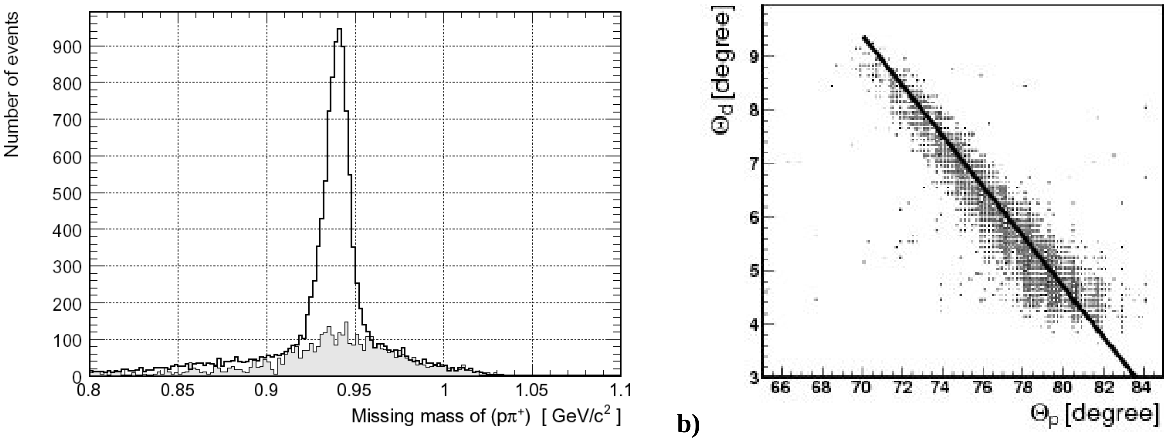
Fig. 3. a) The missing-mass squared distribution for the $d\vec{p} \to dp_{sp}X$ reaction, measured with the storage cell and the 1.2 GeV deuteron beam. Red (black) histograms show target polarization with "spin-up" ("spin-down") after background subtraction using nitrogen. **b)** The target polarization measurements with the Lamb-shift polarimeter carried out every 24 hours during the beam time in January 2007.

Switching of the polarization states of the target every five seconds between the maximum positive ("spin-up") and negative ("spin-down") values allows for the online monitoring of the polarization values, extracted from $d\vec{p} \to dp_{sp}X$ reaction (see Fig. 3a). In parallel to data taking, the count rate asymmetry of the different target polarization was measured every 24 hours (see Fig. 3b) using the Lamb-shift polarimeter and stability of the source has been confirmed.

Unfortunately, the Lamb-shift polarimeter measures the projection of the ABS beam polarization on the horizontal line only. Stray fields of the D2 magnet deflect the quantization axis of the polarization, defined by the longitudinal solenoidal field of the ionizer [5]. Thus, the measured polarization value was lower than the extracted value from $n\vec{p}\to d\pi^0$ reaction of $Q_y = 0.75 \pm 0.06$ and, furthermore, had the wrong sign (see Fig. 3b). Use of a rotatable spinfilter [5] and a better shielding after the ionizer can help to overcome this problem in the future.

2.3 Data analysis

The achieved value of the target polarization extracted from the analysis of the quasi-free $n\vec{p}\to d\pi^0$ reaction was measured to be $Q_y = 0.75 \pm 0.06$. It was higher than in the first measurements which took place in 2006 (COSY proposal #125.2 [10]). The clean identification of events for the exclusive $\vec{d}\vec{p}$-reactions with a long storage-cell target has been demonstrated. This was done on the basis of experimental information, obtained from the polarized hydrogen gas target, and the known shape of the background from the cell walls, determined experimentally by injecting nitrogen gas in the cell (see Fig. 4a).



a) b)

Fig. 4. a) Missing-mass distribution from the $pp \to pn\pi^+$ reaction, measured with the storage cell. The open histogram represents the results from the hydrogen target, the background distribution, measured with nitrogen is shown in grey. **b)** Angular correlation between the protons and deuterons detected in the STT and forward detector, respectively. The expected kinematical correlation for the *dp*-elastic reaction is shown by the black line.

A clean identification of the following processes ($\vec{d}\vec{p}\to dp_{sp}\pi^0$, $\vec{d}\vec{p}\to(pp)n$, $\vec{d}\vec{p}\to{}^3He\pi^0$, and $\vec{d}\vec{p}\to dp$) with one final particle undetected at ANKE has been achieved with the missing-mass technique. The last channel was identified almost background-free (see Fig. 4b) by using the silicon tracking detectors in coincidence with the ANKE forward detector system. The value of the vector polarization P_z of the deuteron beam was extracted from the quasi-free $n\vec{p}\to d\pi^0$ reaction using known analyzing power of the $\vec{p}p\to d\pi^+$ reaction [18]. The same process was used to determine the target polarization. The result, $\left\langle P_z^{ANKE}\right\rangle = 0.60 \pm 0.10$, is compatible with the value of $\left\langle P_z^{LEP}\right\rangle = 0.660 \pm 0.003$, obtained from the LEP measurements.

3 Polarized internal deuterium gas target commissioning

Nearly all necessary equipment for the commissioning of the polarized internal deuterium gas target will be installed at ANKE in the beginning of October 2009. All PIT components and one STT will be used in the double-polarized experiment with polarized hydrogen target and polarized deuteron COSY beam (see proposal #172.1 [7]). The time for commissioning with deuterium is desired to be allocated in the next two weeks (calendar weeks #48 and #49) because it will tremendously reduce the manpower and the installation time. Since the target is installed, there is no need in dedicated maintenance week for exchanging of the cluster target to the atomic beam source and installation of the Lamb-sift polarimeter.

The first commissioning phase does not require the COSY beam. The first task should be to change the ABS operation from the hydrogen to deuterium gas and optimize the performance of the transition units of the source. The commissioning with deuterium gas is more delicate than with hydrogen, because only two out of six deuterium states (|1> and |4>) are pure. Other four states are mixed. Switching on the spectrometer magnet D2 will influence on the magnetic field in the region of the storage cell. Thus, the polarization value of the deuterium atoms will strongly depend on the ratio of the external magnetic field to the critical field (see Fig. 5). In case of deuterium, the critical field is equal to 117 G. The measurements of the 3D magnetic field map at the ANKE target chamber near the storage-cell region with different settings of the D2 magnet are obligatory. It can be done afterwards, while the ANKE chamber is open for mounting of the STT.

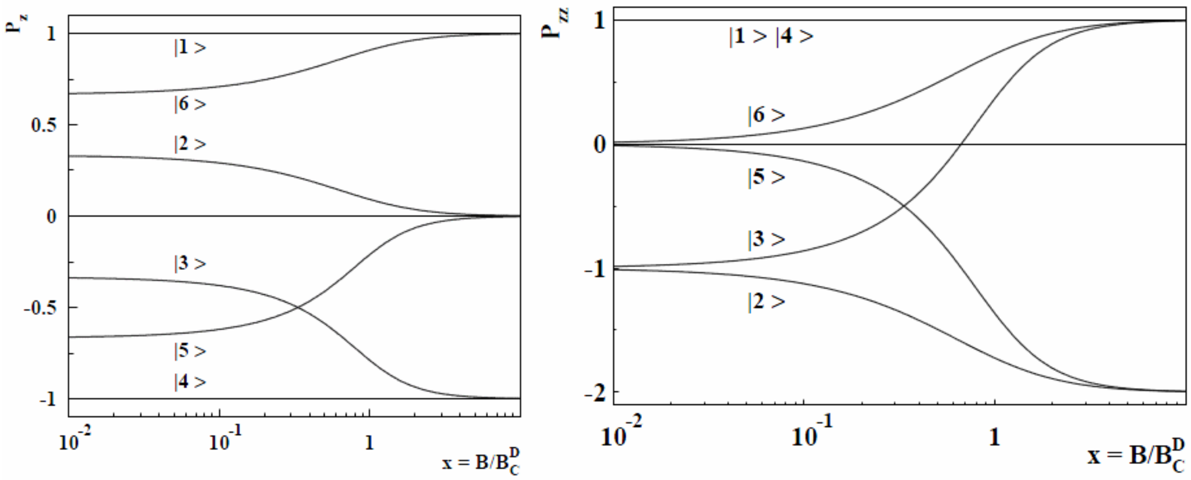


Fig. 5. The expectation values of the vector (left) and tensor (right) polarization of the hyperfine states of the deuterium as a function of an external magnetic field. B_c = 117 G – is the critical field.

All possible polarizations of the atoms coming from the source (see Table 2 and Fig. 6) should be measured with the direct feeding of the Lamb-shift polarimeter at different settings of the ANKE magnets:

- ANKE magnets turned off – I_{D2} = 0 A; B_{D2} = 0T;
- ANKE magnets in "stand-by" mode – I_{D2} ~ 44 A;
- At the first requested energy – 135MeV – I_{D2} = 272.63 A; B_{D2} = 0.4113 T;
- At the second requested energy – 353MeV – I_{D2} = 473.9 A; B_{D2} = 0.7026 T;
- One intermediate field – B_{D2} = 1.3 T;
- D2 magnet at the maximum field – B_{D2} = 1.58 T.

The ANKE magnets can be switched on only when the transition units of the atomic beam source have demonstrated proper polarization values without magnetic field. These values should not be lower than the ones obtained in the laboratory (see Table 2) [16].

Table 2. Possible configuration of the target polarization in the storage cell fed with different gases.

	Hydrogen		Deuterium			
P_z	+1	–1	+1	–1	0	0
P_{zz}	–	–	+1	+1	+1	–2
Transition Unit #1	MFT 2→3	MFT 2→3	MFT 3→4	MFT 3→4	MFT 1→4	MFT 1→4
Transition Unit #2	–	WFT 1→3	–	WFT 1→4, 2→3	–	–
Transition Unit #3	–	–	SFT 2→6	–	SFT 2→6	SFT 3→5
Atomic states injected	1	3	1+6	3+4	3+6	2+5
Laboratory ABS results	vector 0.89±0.01	vector -0.96±0.01	vector 0.73±0.05	vector -0.82±0.06	tensor 0.77±0.06	tensor -1.17±0.08

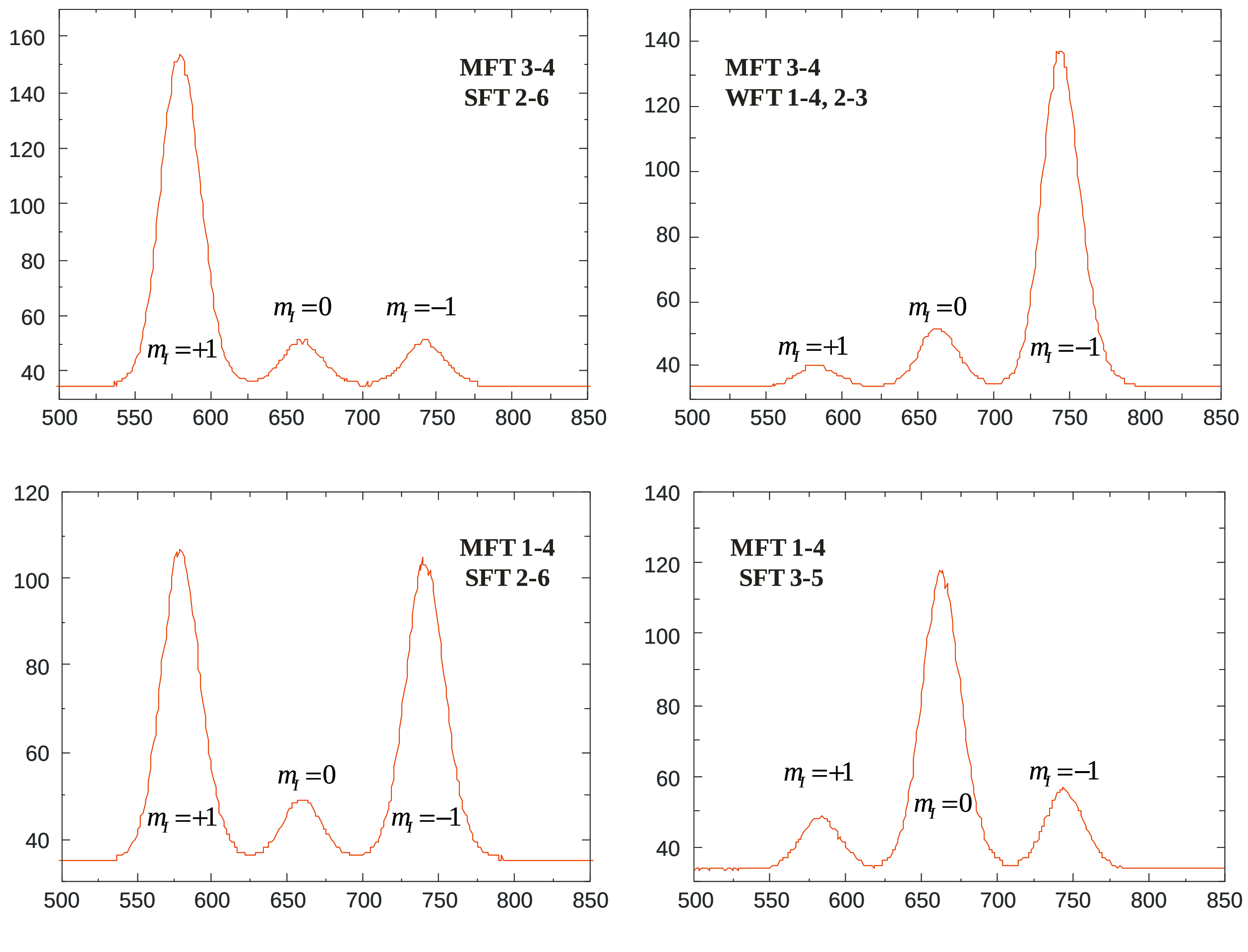


Fig. 6. Lyman -α spectra of deuterium ABS beam measured with Lamb-shift polarimeter in the IKP laboratory. The two top pictures shows vector and tensor polarized, the bottom ones – only tensor polarized deuterium beam.

When the first part of the commissioning with the Lamb-shift polarimeter will be completed, the machine development can be initiated. For safety reasons, the STT-detectors should be installed in the target chamber only if the beam orbit is optimized and the losses on the storage-cell walls at injection and during acceleration are small. Two telescopes should be mounted on the left side of the ANKE target chamber (as shown in Fig. 7) and installed as close as possible to each other. It means that the first STT should be shifted from its nominal position downstream by 30 mm and the second one - 30 mm upstream with respect to the COSY beam direction.

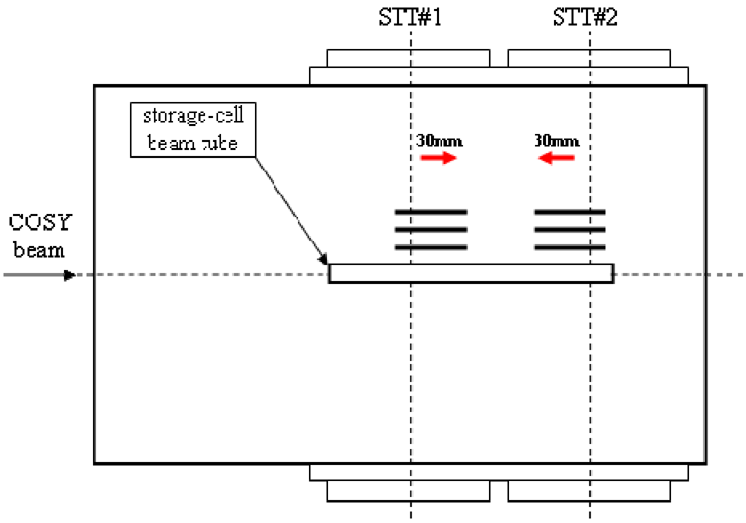


Fig. 7. Position of the STT at the ANKE target chamber.

The second commissioning phase with unpolarized proton COSY beam is requested for determination of the deuterium target polarization in the storage cell using the $p\vec{d}$-elastic at T_p = 135 MeV and quasi-free $p\vec{n} \rightarrow d\pi^0$ reaction at T_p = 353 MeV.

3.1 Target polarization from $p\vec{d}$-elastic scattering at 135 MeV

The deuteron target polarization can be determined from $p\vec{d}$-elastic scattering at a beam energy of T_p = 135 MeV where the differential cross section and analyzing powers are known and relatively large [17]. The simulations show that with the third layer of the STT detector one can clearly identify deuterons, stopped in the second or third detection layer (see Fig. 8a). The first telescope will cover the central region of the storage cell with the highest target density. The second telescope will give more information about polarization dependence along the cell.

Assuming the target thickness of $1 \cdot 10^{13}$ polarized deuterium atoms in 2 HFS and an unpolarized COSY proton beam intensity of 10^{10} protons, which leads to a luminosity of $L \sim 8 \cdot 10^{28}$ $s^{-1}cm^{-2}$, we expect that 4 hours of data taking for each polarization state are sufficient to reach accuracy of 1% in the target polarization. Taking into account time for changing the polarization state, we are confident that the $p\vec{d}$-elastic measurement can be done in 1 day.

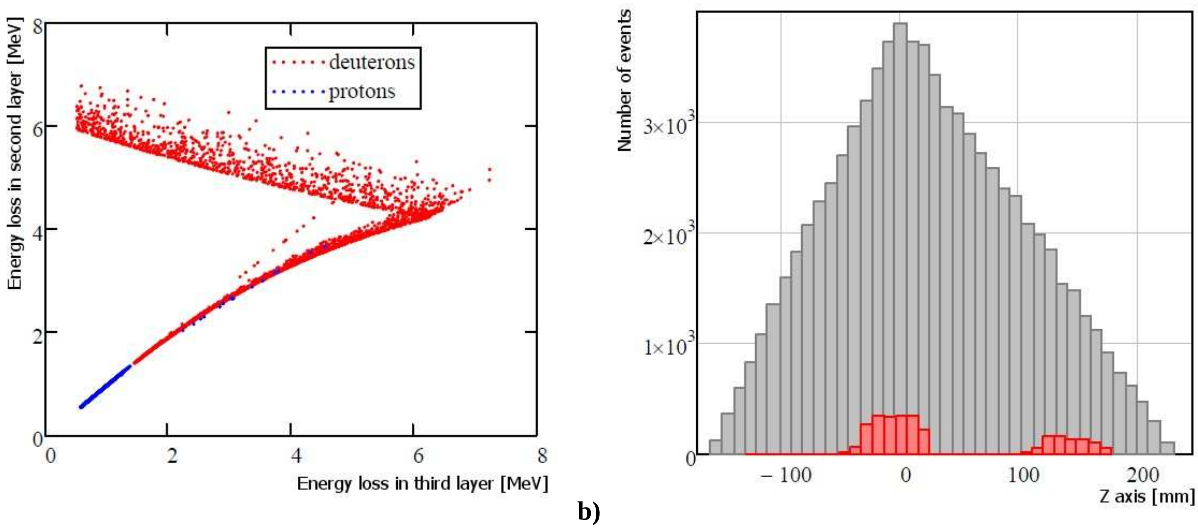


Fig. 8. a) Energy loss in second versus third STT detector layer. **b)** Reconstructed $p\vec{d}$ events (red color) with two STT detectors. Grey color triangular shape is the target density distribution along the cell (the ABS axis at zero).

3.2 Target polarization from quasi-free $p\vec{n}\to d\pi^0$ reaction at 353 MeV

The measurement of A_{xx} and A_{yy} observables in the $\vec{p}\vec{n}\to\{pp\}_s\pi^-$ process is planned to be the next experiment of the ANKE double polarization program [1]. This measurement is of relevance for the ChPT and is proposed to be carried out at a near threshold beam energy. Only vector polarization of the deuterium target is needed for this experiment. We propose to determine the polarization value using the quasi-free $p\vec{n}\to d\pi^0$ reaction since the analyzing power in this process is rather large at 353 MeV (see Fig. 9a), and is available [18].

The missing-mass-squared distribution for the $\vec{p}d\to p_{sp}dX$ reaction, where p_{sp} is the spectator proton, is shown in Fig. 9b. This distribution was obtained in a measurement with the polarized proton COSY beam and the deuterium cluster target, carried out in April 2009 [2].

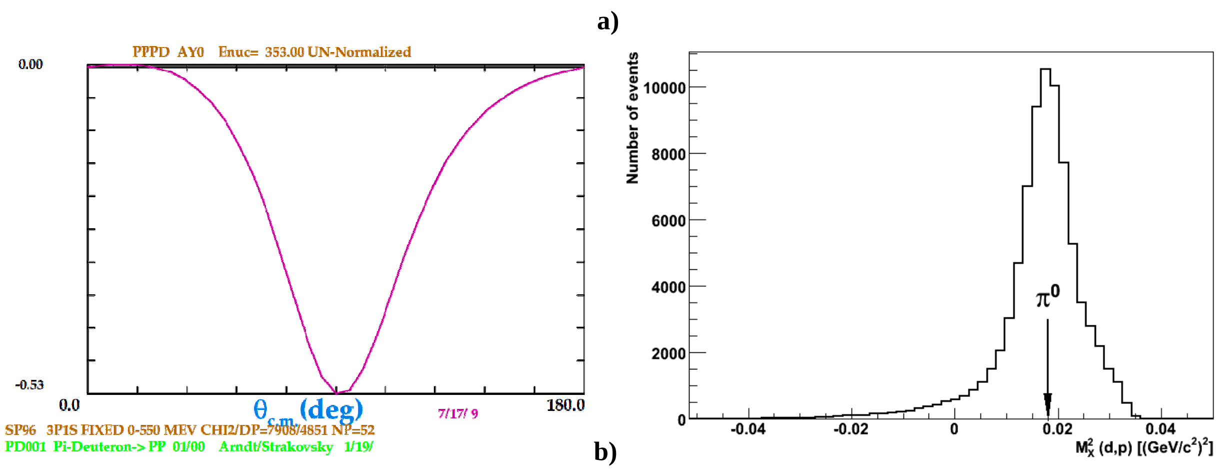


Fig. 9. a) Analyzing power A_y^d at 353 MeV from SAID [18]. **b)** The pion missing mass spectra at 353MeV.

Assuming the target thickness of $1\cdot 10^{13}$ polarized deuterium atoms in 2 HFS and unpolarized COSY proton beam intensity of 10^{10} protons, which lead to a luminosity of $L\sim 10^{29}\ s^{-1}cm^{-2}$, it is anticipated that 9 days of the measurements are sufficient to reach 5% uncertainty in the vector polarization.

3.3 Target thickness and background determination

The mean frequency shift of the circulating particles in the storage ring during the cycle is used to determine the internal target thickness [19]. The Schottky spectrum of the individual cycle shows deceleration of the beam after passing through the target, which gives a shift in the revolution frequency of the beam. This shift depends on the target density and the type of gas in the target.

For determination of the background, generated from the COSY beam interaction with the cell walls, the UGSS will be used. The background from aluminum walls could be removed from the obtained data by using data, taken with unpolarized nitrogen (see Fig. 4a) [20]. This method was successfully used with polarized hydrogen internal gas target and can be applied to the polarized deuterium gas target as well.

4 Time schedule and beam time request

The proposal requires IN TOTAL **two weeks**. This time will split in two phases for the activities listed above as follows:

1. **The first phase** for commissioning of the deuterium polarized internal gas target with the Lamb-shift polarimeter should directly follow the 4 week production run with the polarized hydrogen target, scheduled for calendar weeks 42-46. It is planned to change the ABS operation from hydrogen to deuterium gas. The source will be commissioned with use of the polarimeter, radio-frequency transition units will be optimized for deuterium beam, and the polarization of the atoms feeding the storage cell will be measured. The commissioning and tuning work necessitates different magnetic fields of the ANKE dipole magnets. This task can be fulfilled in **4 days**.

2. **The second phase** will consist of the data taking at two desired energies. **One day** should be foreseen for the measurements of $p\vec{d}$-elastic scattering at a beam energy of T_p = 135 MeV. The measurement above should be followed by **9 days** of data taking with proton beam at the energy of T_p = 353 MeV, where later the (A_{xx}, A_{yy}) measurements of the $\vec{p}\vec{n} \rightarrow \{pp\}_s\pi^-$ reaction will take place.

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[2] S. Dymov, *Measurement of the cross section and analyzing power of the quasi-free* $\vec{p}n \to (pp)\pi^-$ *reaction at ANKE*, COSY Proposal **#192** (2008), available from http://www.fz-juelich.de/ikp/anke.

[3] K. Grigoryev *et al.*, *The polarized internal gas target of ANKE at COSY*, International Journal of Modern Physics E (IJMPE) vol. 18 issue: 2 (February 2009), page: 511 – 517.

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