# Commissioning and Initial Research with the Polarized Internal Target (PIT) at ANKE

## Results from COSY experiment No. 146.1

and

## Beam request for COSY experiment No. 146.2

L. Barion[1], D. Chiladze[2], S. Dymov[3], R. Engels[4], K. Grigoriev[5], D. Gusev[6], A. Kacharava[7], F. Klehr[8], A. Kulikov[3], P. Lenisa[9], B. Lorentz[4], M. Mikirtytchiants[10], S. Mikirtytchiants[10], A. Nass[7], D. Prasuhn[4], F. Rathmann[4], J. Sarkadi[4], R. Schleichert[4], H. Seyfarth[4], E. Steffens[7], H. Straatmann[8], H. Ströher[4], and A. Vassiliev[10]

[1] PhD student from University of Ferrara, 44100 Ferrara, Italy
[2] PhD student from High Energy Physics Institute, Tbilisi State University, 0186 Tbilisi, Georgia
[3] Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, 141980 Dubna, Russia
[4] Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany
[5] PhD student from High Energy Physics Department, Petersburg Nuclear Physics Institute, 188350 Gatchina, Russia
[6] PhD student from Laboratory of Nuclear problems, Joint Institute for Nuclear Research, 141980 Dubna, Russia
[7] Physikalisches Institut II, Universität Erlangen–Nürnberg, 91058 Erlangen, Germany
[8] Zentralabteilung Technologie, Forschungszentrum Jülich, 52425 Jülich, Germany
[9] University of Ferrara and Istituto Nazionale di Fisica Nucleare (INFN), 44100 Ferrara, Italy
[10] High Energy Physics Department, Petersburg Nuclear Physics Institute, 188350 Gatchina, Russia

for the ANKE Collaboration

Jülich, April 11, 2006

# 1 Status

For commissioning of the PIT and first experiments, two weeks of beam time towards the end of 2005 had been granted by the PAC No. 29 (COSY experiment No. 146). These two weeks have been used for the activities described in Sec. 2 under beam–time session **1** (November 21 to December 2, 2005) and **2** (February 9 to 12, 2006). Further two weeks of beam time have been given by the PAC No. 30 (COSY experiment No. 146.1). One of the two weeks has covered the activities of the beam-time session **3**. During sessions 1 - 3, substantial progress has been made towards the operation of PIT and COSY with the storage cell at the ANKE target position. **This beam request concerns the allocation of the one week left, which we would like to use in November 2006, to further proceed and finalize the commissioning.**

# 2 Schedule of the PIT commissioning activities

Earlier, preparatory beam times in 2000, 2001, and 2002 had aimed at studies of the COSY-beam intensity, life time, and the beam dimensions at the ANKE target position with use of displaceable diaphragms. Based on the obtained data of the beam cross section, thin walled storage cells have been produced from 25 $\mu$m Al foil with the inner surface covered by Teflon. The storage–cell tubes with an inlet and an extraction tube are suspended in a lightweight frame, supported and positioned within the ANKE target chamber by means of two remote-controlled [1] XY manipulators, as shown in our earlier proposal and beam request [2].

The performed commissioning efforts since the past meeting of the PAC were distributed over three beam time sessions:

1. **November 21 to December 2, 2005**: COSY beam studies were performed using a storage cell of $20 \times 20$ mm$^2$ cross section, 400 mm length (in the following given as ($20 \times 20 \times 400$ mm$^3$)) and a $40_{\text{hor}} \times 25_{\text{vert}}$ mm$^2$ diaphragm to investigate the achievable beam intensity at injection and at 600 MeV with single injection, stacking injection, and electron cooling at injection for ANKE positioned at 0° (beam straight through) and at 9.2° with the atomic beam source (ABS) installed at the ANKE target chamber.

   On **December 2, 2005**, the support frame with the cell was dismounted and a cryogenic catcher for the ABS beam (Fig. 1) was installed to reduce the hydrogen pressure in the target chamber during measurements when the direct polarized ABS beam is used as a gas–jet target (i.e. without a storage cell). Due to a failure of the cyclotron, however, these studies had to be postponed to the supplementary beam time of session 2.

2. **February 9 to February 12, 2006**: Data were taken by the ANKE forward detector and side detector system with the polarized hydrogen jet from the ABS, the unpolarized COSY proton beam of 600 MeV, and ANKE set to 9.2 °.

   On **February 12, 2006**, the ABS had to be dismounted to allow for preparation of subsequent measurements with the cluster target. At its position outside the COSY tunnel, the ABS will be used for experiments in the framework of an ISTC project [3] until its re–installation at ANKE.

3. **March 22 to March 29, 2006**: dismounting of the cryogenic catcher and re-mounting of the target–support frame with the diaphragm and two storage cells

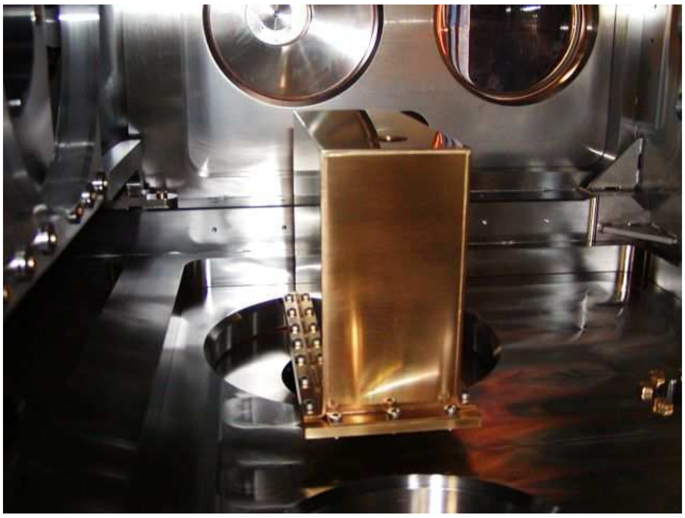

Figure 1: Side view into the ANKE target chamber with the cryogenic catcher (dimensions of the shielding box: 138 mm height, 189.5 mm depth, and 72 mm width; the 20 mm diameter of the circular hole in the upper wall is adapted to the diameter of the vertically incoming ABS beam). The outer surface is polished and gold–plated to reduce the radiation–heat load. By a Cu heat bridge the catcher is connected to a cold head, mounted below the target chamber. Two cryogenic pannels from Leybold COOLVAC 800 cryogenic pumps are installed inside the shielding box.

($20 \times 20 \times 380$ mm$^3$ and $10 \times 10 \times 380$ mm$^3$). With this setup, studies of stochastic cooling of the COSY beam at 831 MeV proton energy (1500 MeV/c) were carried out. Well–defined gas flows of unpolarized $H_2$ and $N_2$ into the ($20 \times 20 \times 380$ mm$^3$) cell were made available by a dedicated unpolarized calibrated gas–supply system [4]. In a first attempt of using the cell tube of smaller cross section ($10 \times 10$ mm$^2$), aiming at a higher target density, $2.5 \cdot 10^9$ protons could be stored at injection, but the beam was completely lost, when the COSY rf was switched on at the beginning of the acceleration process.

The use the Lamb-shift polarimeter (LSP) at the ANKE target position for tuning of the rf transition units and measuring the polarization of the target gas by extraction of a gas sample from the storage cell had to be postponed. Preliminary results of nuclear polarization measurements in the laboratory have demonstrated the feasibility of the method [5]. The sensitivity, however, has to be substantially enhanced to achieve the envisaged accuracy. Therefore, in the forthcoming beam times the LSP will be used in a modified geometry, which allows polarization measurements of the direct ABS beam and thus enables tuning of the rf transition units at the ANKE target position as performed earlier in the laboratory [6].

# 3 Achieved results

## 3.1 COSY-beam intensities with storage cells

In the first beam–time session, with stacking injection and electron cooling at injection (about 30 stacks separated by 2 s for cooling), with the ($20 \times 20 \times 400$ mm$^3$) cell, and ANKE positioned at $0°$, $2.5 \cdot 10^{10}$ protons could be stored at injection, $1.5 \cdot 10^{10}$ of which could be accelerated to the flat top energy at 600 MeV. Such a cycle is shown in Fig. 2. With careful beam tuning, comparable values are believed to be achievable also for ANKE

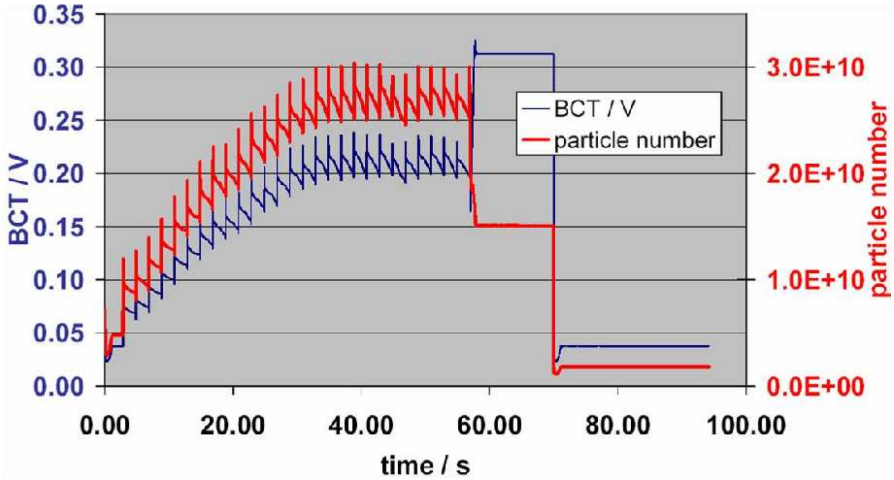


Figure 2: Charateristic cycle with 28 injected stacks, each followed by 2 s electron cooling, acceleration after 58 s to the 600 MeV flat top, and end of the cycle after 70 s. The number of stored protons is deduced from the voltage signal of the Beam-Current-Transformer (BCT).

set off the 0° position. Preliminary attempts for 9.2° gave $6.4 \cdot 10^9$ accelerated protons in the 600 MeV flat top.
In the third beam–time session, with ANKE set to 8.0° and with the ($20 \times 20 \times 380$ mm$^3$) cell tube, $1.6 \cdot 10^{10}$ protons could be accelerated to the flat top energy of 831 MeV, thus reaching the value achieved in the first beam–time session only at the 0° position. Furthermore, the Fig. 3 demonstrates, how by stochastic cooling the trigger rate from the

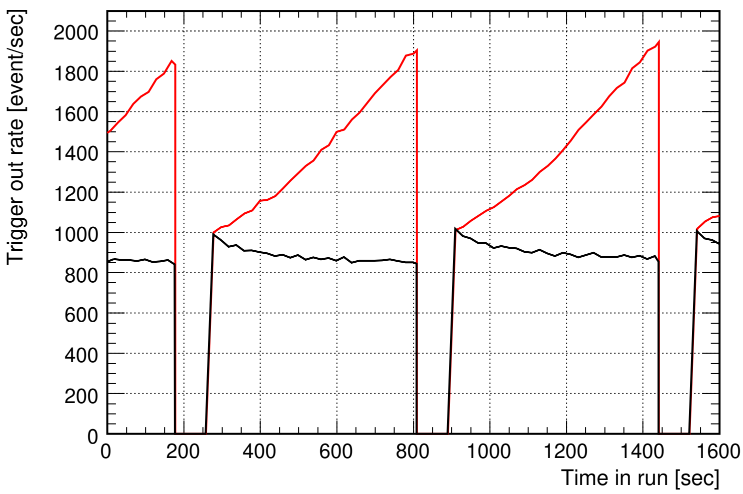


Figure 3: Time dependence of the trigger rate of the ANKE Forward-Detector system in the 831 MeV flat top without (red) and with stochastic cooling.

ANKE forward detector system is kept rather constant during the flat top contrary to the increase without cooling, where beam heating, i.e. emmittance growth, leads to a rate increase caused by increasing interactions of the beam with the storage–cell wall.

### 3.2 Event identification

The Fig. 4 contains events, for which two charged particles were detected in the double–layer forward scintillation hodoscope during the beam–time session 3 with unpolarized $H_2$ gas in the ($20 \times 20 \times 380$ mm$^3$) cell and 831 MeV protons. The figure shows the arrival–time differences for the two particles in the hodoscope, calculated after momentum and trajectory reconstruction under the assumption that both particles were protons, versus the measured difference of the two time signals from the scintillators. Thus, the two protons from the pp $\rightarrow$ pp$\pi^0$ reaction come to lie on the diagonal, whereas other pairs are found elsewhere (e.g., the d$\pi^+$ events with a $\pi^+$ and a slower deuteron are found to the right of the pp diagonal. The same holds for the p$\pi^+$ events, which are smeared out due to the momentum carried by the undetected neutron from the pp $\rightarrow$ pn$\pi^+$ reaction. The mirror events, lying to the left of the diagonal exist due to the fact that an event with a positive $\pi^+$-to-d(or p) time difference also are regarded as such with a negative d(or p)-to-$\pi^+$ time difference. The Fig. 5 shows the same plot as that of Fig. 4, but

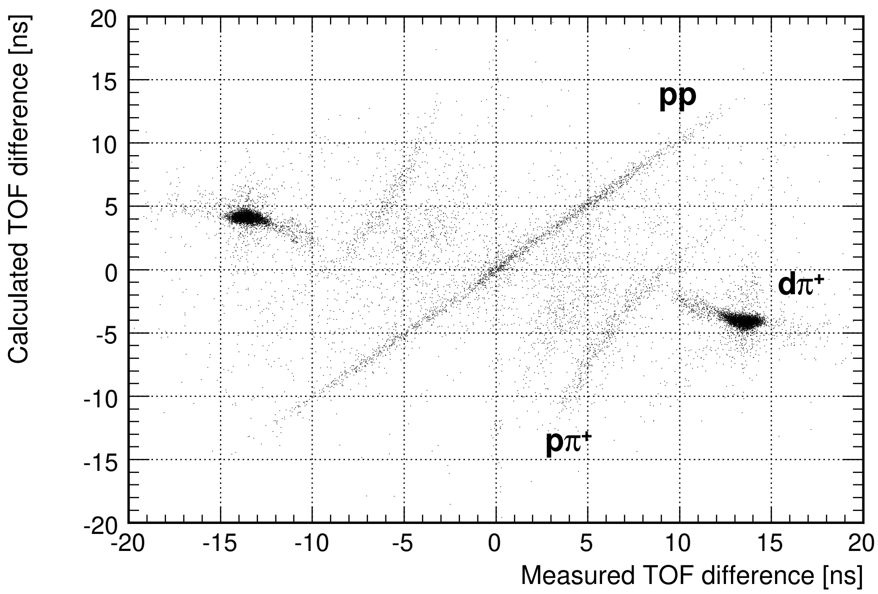


Figure 4: Time difference of the two detected charged particles, calculated under the assumption of both particles being protons, versus the measured time difference for events from 831 MeV protons and $H_2$ gas in the storage cell of 20x20 mm$^2$ cross section and 380 mm length measured during beam–time session 3.

with the $H_2$ in the cell replaced by $N_2$. Based on the idea behind earlier measurements, performed at IUCF [10], these data have been taken to study the admixture of events in the target-cell Al wall. Reactions in the $N_2$ gas in the cell are expected to show the same smearing of the ejectile momenta as reactions in the Al cell-wall material due the Fermi motion of the nucleons. In fact, the comparison of Fig. 4 and Fig. 5 shows this effect for the d$\pi^+$ and p$\pi^+$ events, which should allow discrimination of reactions in the $\vec{\mathrm{H}}$ (and later also $\vec{\mathrm{D}}$) gas in the storage cell from wall events due to the different width in the

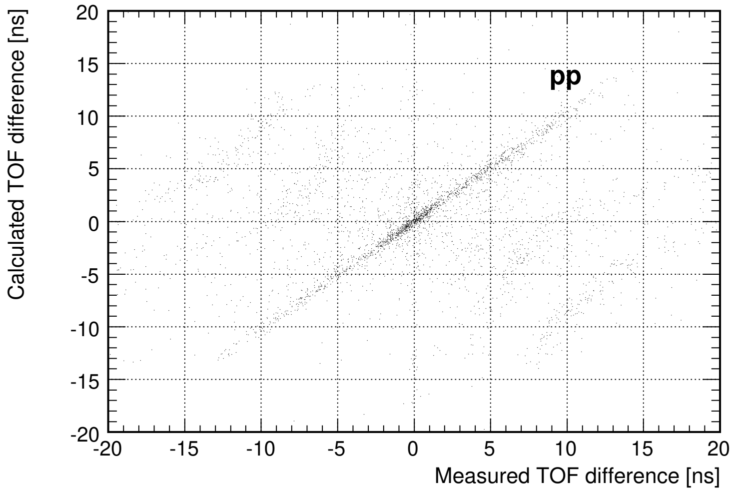


Figure 5: As Fig. 4, but with $N_2$ gas in the cell.

momentum distribution. The narrow band of the pp events contains events from $H_2$ and $N_2$ as well as those from the cell wall.

### 3.3 Target-gas thickness

The ABS beam intensity, measured with a compression tube, is $I_{\vec{H}}=(3.4 \pm 0.1) \cdot 10^{16}$ H atoms/s, when one of the two hyperfine (HF) state populations is removed with the use of the medium-field rf transition unit. For the ABS-nozzle temperature of 60 K, the average H atom velocity in the beam is $\bar{v}=1.5{\cdot}10^5$ cm/s [7]. The ABS jet diameter $d_{jet}=(1.8 \pm 0.1)$ cm at the height of the COSY beam is comparable with that of the 600 MeV COSY beam, as measured with the displaceable diaphragm. With these numbers, the effective jet-target thickness is calculated as

$$t_{\vec{H}\ jet} = \frac{4 \cdot I_{\vec{H}}}{\pi \cdot \bar{v}} \cdot d_{jet} = (1.6 \pm 0.1) \cdot 10^{11} \text{ H atoms/cm}^2. \quad (1)$$

The given error might be slightly increased by a not perfect overlap of the jet and the COSY beam.
The storage cell, installed during the beam-time section 3, has a $20 \times 20$ mm$^2$ cross section and a total length L=380 mm. A molecular flux of $I_{H_2}=(3.4 \pm 0.1) \cdot 10^{16}$ $H_2$ molecules from the unpolarized gas-supply system was feeding the cell via a 1 mm diameter hole, positioned 110 mm from the beam-up and 270 mm from the beam-down end of the storage tube. Here the atomic target thickness results as

$$t_{H\ cell} = \frac{I_{H_2} \cdot L}{C_{tot}} = (1.9 \pm 0.1) \cdot 10^{13} \text{ H atoms/cm}^2, \quad (2)$$

where $C_{tot}= 6.92{\cdot}10^4$ cm$^3$/s is the total conductance of the quadratic tube, calculated with use of the formulae given in Ref. [8].
The calculated values of (1) and (2) are to be compared with the target-density distributions, derived from the pp$\rightarrow$d$\pi^+$ reaction data, taken in the beam-time sessions 2 and 3. For the direct ABS jet the density distribution of the left-hand side of Fig. 6 yield the effective target density as $t_{\vec{H}\ jet}=(1.5 \pm 0.1) \cdot 10^{11}$ H atoms/cm$^2$. The data for the cell

(right-had side of the figure) give $t_{\mathrm{H\ cell}}=(2.1 \pm 0.1) \cdot 10^{13}$ H atoms/cm$^2$. Both measured results show excellent agreement with the calculated values of (1) and (2). The gain in target thickness confirms the early estimates of two orders of magnitude, suggesting the use of gas-storage cells for storage-ring experiments [9].

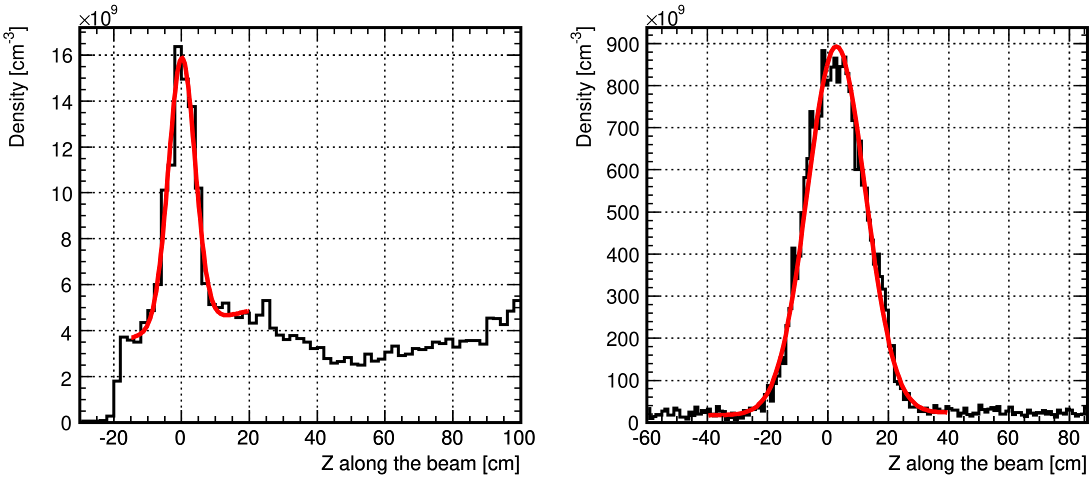


Figure 6: Target density distributions along the COSY beam direction. They result from the trajectories of the pp $\rightarrow$ d$\pi^+$ reaction with both charged particles detected in the ANKE forward detector system, accounting for luminosity, detector acceptance, and reaction-cross section. The target densities, given in the text, result from the summation over the peaks. Left–hand side: Measurement with the jet of H–atoms and 600 MeV protons (beam- time session 2). The width of the distribution reflects the uncertainty in the trajectory determination. Right–hand side: Measurement with $H_2$ gas in the storage cell of $20 \times 20$ mm$^2$ cross section, 380 mm length, and 831 MeV protons (beam–time session 3). The width of the distribution reflects the length of the storage cell.

### 3.4 Polarization of the $\vec{\mathrm{H}}$ jet target

In the laboratory the polarization of the $\vec{\mathrm{H}}$ beam from the ABS had been measured as $P_+ = +0.898 \pm 0.004$ [12] and $P_- = -0.960 \pm 0.005$ [13]. With the use of both medium and weak field rf transition units it had been planned to populate either the pure $m_I = m_J = +1/2$ hyperfine (HF) state for positive polarization or the pure $m_I = m_J = -1/2$ state for negative polarization. A failure of the weak field rf transition unit, probably caused by insufficient magnetic shielding, forced us to populate the mixed HF state with $m_I = \pm 1/2$ and $m_J = \mp 1/2$ to produce negative polarization by switching the sign of the magnetic gradient field in the medium field rf transition unit. The magnetic field in the jet axis at the height of the COSY beam has been measured as 165 G for the current of 563 A, applied during the experiment to produce the field in the D2 gap. The full positive polarization is maintained with the population of the pure HF state. For the negative polarization, however, one expects a reduction by a factor 0.32 in the field of 165 G, which lies appreciably lower than the critical field of 507 G for hydrogen (e.g., [14]). Thus, the measured value of –0.96 for the negative polarization in the jet target is expected to be reduced to –0.31.

The $p\vec{p}$ elastic scattering reaction has been used to measure the polarization of the $\vec{\mathrm{H}}$ jet. To minimize systematic errors, the polarization of the jet within the runs was changed every 5 s by switching the sign of the gradient field in the medium field rf transition unit.

The data were taken in the beam-time session 2 with the proton beam of 831 MeV. The missing-mass spectra of Fig. 7 were deduced from single-proton events in the forward

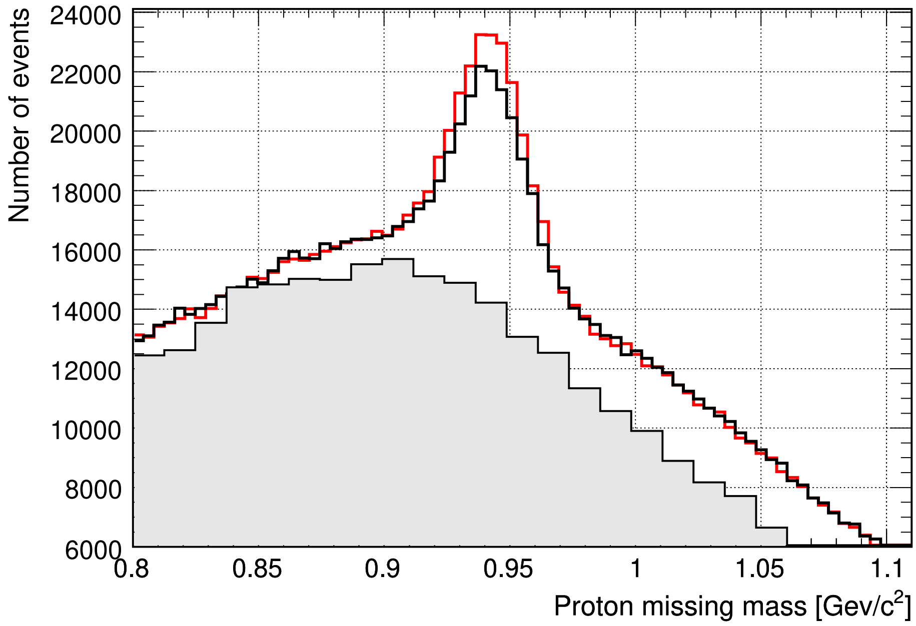


Figure 7: Missing mass spectra from p$\vec{p}$ elastic scattering, measured with the polarized jet $\vec{\mathrm{H}}$ target and the 600 MeV proton beam in beam-time session 2. Open red (black) histograms: data, taken with negative (positive) jet polarization, achieved by switching the sign of the magnetic gradient field in the medium field rf transition unit of the ABS each 5 s during the runs. Grey-shaded histogram: data, taken with the jet closed.

detector system, taken with the two jet polarizations. The normalized difference between the two proton-peak areas $N_+$ and $N_-$ is related to the two jet polarizations $P_+$ and $P_-$ by

$$\frac{N_+ - N_-}{N_+ + N_-} = \frac{(P_+ - P_-) \cdot \langle A_y \rangle}{2 + (P_+ + P_-) \cdot \langle A_y \rangle}. \tag{3}$$

Here

$$\langle A_y \rangle = \frac{\int_{10}^{20} A_y(\theta) \cdot d\sigma(\theta) \cdot \varepsilon_{acc} \cdot \langle \cos\ \phi \rangle_\theta \ d\Omega}{\int_{10}^{20} d\sigma(\theta) \cdot \varepsilon_{acc} \cdot \langle \cos\ \phi \rangle_\theta \ d\Omega} \tag{4}$$

is the average analyzing power, calculated with data for the analyzing powers and the differential cross sections from Ref. [11], and the detector acceptance $\varepsilon_{acc}$. The integration runs over the proton c.m. polar angle $\theta$=10$^\circ$ to 20$^\circ$. In the calculation of the average value of cos $\phi$, the limits of integration depend on the polar angle $\theta$. The values of $\phi$ lie near 180$^\circ$.
The average value $\langle A_y \rangle$ results as –0.314 with an estimated error of 5%. With the above mentioned expected polarization values $P_+$=0.90 and $P_-$=–0.31 one obtains for the normalized peak ratio an expected value of $-(0.22\pm0.01)$. The value of $-(0.12\pm0.02)$, resulting from the distributions of Fig. 7, results with the right sign. Its absolute value, however, lies significantly lower than expected. The reduction probably is caused by the effect of the magnetic stray field from the dipole magnet D2 on the medium field rf transition unit. In this first measurements we did not have the possibilty to perform fine tuning of the

transition units with the LSP under influence by the D2 stray field. By a modification of the setup, which is under preparation, this will be facilitated in the next beam-time session, applied for in section 5.

# 4 Missing-mass distributions from the pp→pn$\pi^+$ and pp→pp$\pi^0$ reactions

Time-of-flight cuts according the distributions of the Figs. 4 and 5 on the p$\pi^+$ and pp twofold-charged particle events allow to derive the missing-mass distributions of the reactions pp → pn$\pi^+$ (Fig. 8) and pp → pp$\pi^0$ (Fig. 9). Both distributions from data, taken with the (20 × 20 × 380 mm$^3$) cell fed by the unpolarized gas-supply system with $H_2$ or $N_2$, and the 831 MeV proton beam in the beam-time session 3, show a well-distinguished peak on a smooth backgound.

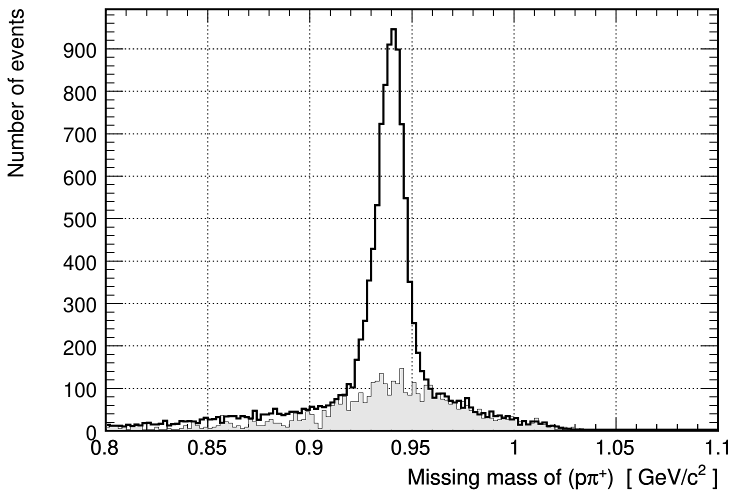


Figure 8: Missing-mass distribution for the reaction pp→pn$\pi^+$, measured with $H_2$ in the (20 × 20 × 380 mm$^3$) storage cell and the 831 MeV proton beam (open histogram). The background distribution (grey shaded) was measured with $N_2$ in the cell. This distribution has been normalized to the distribution, measured with $H_2$ at the right-hand side of the peak region.

# 5 Beam-time request

Based on the experiences, described above, we ask to allocate the **ONE WEEK of beam time**, already granted in the PAC meeting No. 30 (see section 1) in late 2006. Favourable would be

- One week Machine Development (MD) before that requested beam time with:
  - 2 days for installation of the Polarized Internal Target (PIT) at ANKE,
  - 2 days for installation and commissioning of the Lamb-shift Polarimeter (LSP), followed by fine-tuning of the rf transition units of the polarized atomic beam source with the magnetic field of D2 on,

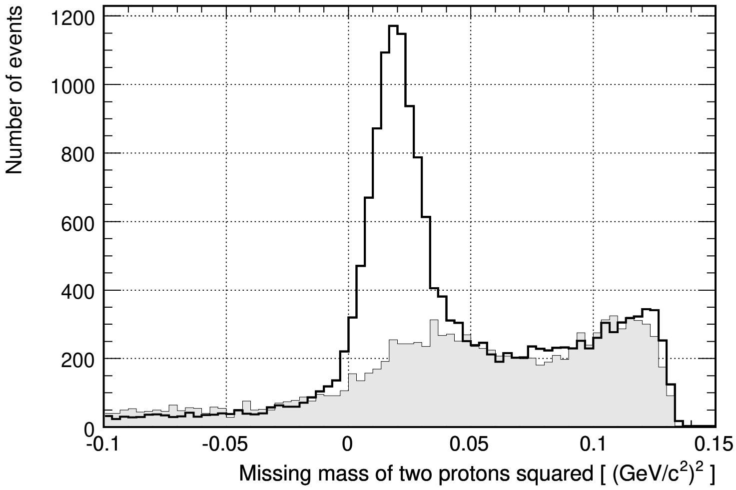


Figure 9: As Fig. 8, but for the reaction $pp \rightarrow pp\pi^0$.

  - 2 days COSY beam development with polarized deuterons of momentum higher than 3 GeV/c and stacking injection, electron cooling, and stochastic cooling at the flat top.

- Followed by the **ONE WEEK** of beam time, requested here to start the double-polarized experiment $\vec{d}\vec{p} \rightarrow (pp)n$ by measuring with a $\vec{H}$ storage-cell gas target.

- The following week is asked for the installation of the Silicon Tracking Telescopes (STT) close the the storage cell to test it under the optimized beam conditions, developed earlier. These activities are covered by a separate COSY Proposal (R. Scheichert).


The members of the PIT group highly acknowledge the great efforts of B. Lorentz and D. Prasuhn in optimizing the COSY beam tune to achieve the mentioned beam intensities with the "annoying" storage cell.


# References


[1] H. Kleines et al., Nucl. Instr. and Methods A (in press, 2006).

[2] COSY experiment No 146.0 Proposal and Beam Request, presented at PAC meeting No. 29; COSY experiment No 146.1 Beam Request, presented at PAC meeting No. 30.

[3] **I**nternational **S**cience and **T**echnology **C**enter project No. 1861.

[4] M. Nekipelov, Diploma Thesis, St. Petersburg State Technical University (1999).

[5] R. Engels et al., Proc. $10^{th}$ Workshop on Polarized Sources and Targets, Novosibirsk, Russia, September 22-26, 2003 (PST 2003). Eds. A.S. Terekhov, I.A. Rachek, and D.K. Toporkov, Nucl. Instr. and Methods A **536** (2005) 334.

[6] R. Engels et al., Rev. Sci. Instr. **74** (2003) 4607.

[7] B. Lorentz, Diploma Thesis, MPI Heidelberg (1993).

[8] A. Roth, Vacuum Technology (Elsevier Science B.V., 1990).

[9] Proc. $2^{\text{nd}}$ Int. Symp. on Polarization Phenomena, eds.P. Huber and H. Schopper, Experientia Suppl.**12** (Birkhäuser, Basel, 1966), P. 64.

[10] W. Haeberli et al., Phys. Rev C **55** (1997) 597; F. Rathmann et al., Phys. Rev C **58** (1998) 658, H.O. Meyer et al., Phys. Rev C **63** (2001) 064002.

[11] SAID Nucleon-Nucleon Scattering Database, Center for Nuclear Studies, Department of Physics, George Washington University, USA, *gwdac.phys.gwu.edu/analysis/nnanalysis.html.*

[12] R. Engels et al., Rev. Sci. Instr. **76** (2005) 053305.

[13] R. Engels et al., $6^{\text{th}}$ Int. Conf. on Nuclear Physics at Storage Rings, Jülich–Bonn, Germany, 2005. Eds. D. Chiladze, A. Kacharava, and H. Ströher, Matter and Materials **30** (FZ Jülich, 2005), P. 381.

[14] W. Haeberli, Ann. Rev. Nucl. Sci. **17** (1967) 373.