Beam Time Request for Machine Studies and First Measurements of the $\vec{p}d$ break-up reaction

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Contents

1 Introduction

The *Exclusive Deuteron Break-up Study with Polarized Protons and Deuterons at COSY* was approved by COSY PAC#4 in 1992 [1]. An extension of the proposal for unpolarized studies was presented to COSY PAC #19 (November 1999) [2]. One week of beamtime was granted by PAC for detector tuning using H_2 and D_2 cluster targets and to begin unpolarized studies of $p + d \to (pp)_{0^\circ}n$. At PAC #20 (May 2000) following a request from the previous session a preliminary time schedule [3] for the total beam time required to complete the pd break-up studies [1, 2] was presented. One week was granted by PAC #20 for exploratory studies of count rates and background conditions. The scheduled beamtime (January 22-28, 2001) will also be used for studies on ω/ϕ production [4] and a_0 production [5].

The present beamtime request details the next steps required in order to implement the polarized storage cell target of ANKE into COSY, thereby reacting to the recommendation of COSY PAC #20 "to pursue more swiftly and vigorously the goal of installing a polarized deuterium target at ANKE" and to revise the data taking schedule. Furthermore, new theoretical results concerning the mechanisms of the pd break-up are employed here.

The collaboration asks for two weeks of beam time in the second half of 2001.

1. The first week will be devoted primarily to machine studies with unpolarized beam to achieve beam storage in the presence of a prototype storage cell at ANKE concurrent with background studies.

2. In the second week with polarized beam a first measurement of the proton vector analyzing power A_y^p of the pd break-up reaction will be carried out for the special case that two protons are emitted in the forward direction in a $^1S_0$ state with a small relative energy $E_{pp} \leq 3$ MeV [2].
   For this measurement with unpolarized deuterium gas a storage cell will be utilized at ANKE. A suitable silicon microstrip detector setup will be available near the cell to facilitate background studies, to allow for luminosity monitoring and to measure the beam polarization at ANKE.

2 Recent Aperture Tests at ANKE

2.1 Experimental Setup and Results

In order to arrive at approximate design parameters for a storage cell, a few simple tests with apertures were carried out[1]. The dimensions of the apertures used during these tests were based on beam optics considerations which included a certain allowance for the transverse beam motion during ramping. The calculated horizontal and vertical β-functions at injection (294 MeV/c) and at 2.1 GeV/c (T = 1362 MeV) are listed in Table 1. The experimental setup shown in Fig. 1 included two aluminum apertures of 30 mm width (along x) and 10 mm height (along y). They were mounted on the solid-strip target support mechanism at ANKE, whereby horizontal movement of the apertures in 0.1 mm steps perpendicular to the beam was 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

[1] August 31 and September 14, 2000

	β_x	β_y
Injection	3.11	2.78
2.1 GeV/c	2.88	2.87

Table 1: Calculated β-functions at injection and at 2.1 GeV/c [6].

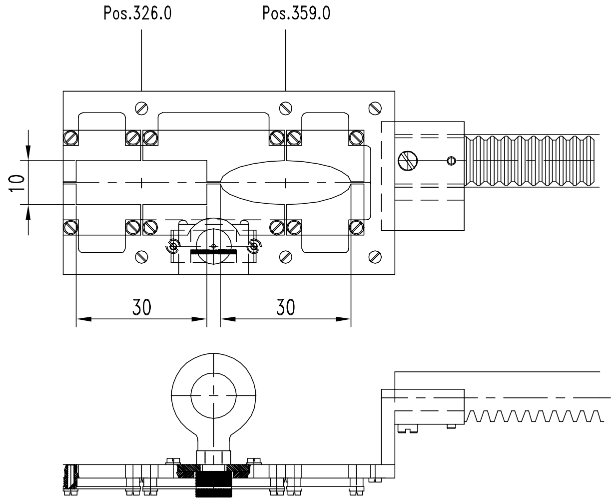

Figure 1: View along the beam direction (top) of the aperture support on the ANKE solid strip target holder. The unit can be moved along the x axis. (The indicated positions are the nominal center positions of the Labview Target Box.) The birds view (bottom) shows the surface barrier detector which had been installed as a monitor counter.

using the two steerers SV24 and SV34 up- and downstream of ANKE $\approx$ 50 m apart was introduced. In Fig. 2 the vertical beam positions around the ring are shown. It was possible to store about $1.4 \cdot 10^{10}$ protons at 45 MeV, i.e. $\approx$ 14% of the number accumulated without the two steerer bump and without the restriction due to the aperture. It could be shown by moving the aperture in and out, that the number of particles stored at injection is not adversely affected by the aperture, thus one must conclude that a limitation of the acceptance and the associated loss of stored particles takes 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 only 6 cm.

After a few hours of optimization the beam could be ramped up to 2.1 GeV/c through the rectangular aperture. At that time Fig. 3 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 $9.6 \cdot 10^9$. The top trace in Fig. 3 indicates the detector rate as the sum of all triggered start-stop combinations, which showed a peak rate around 500 s^{-1} during injection. It was tried with some success to reduce the detector rate by varying the position of the scrapers in the target section opposite to ANKE. The scrapers in the straight section upstream of ANKE did not show any positive effect on the measured detector rate.

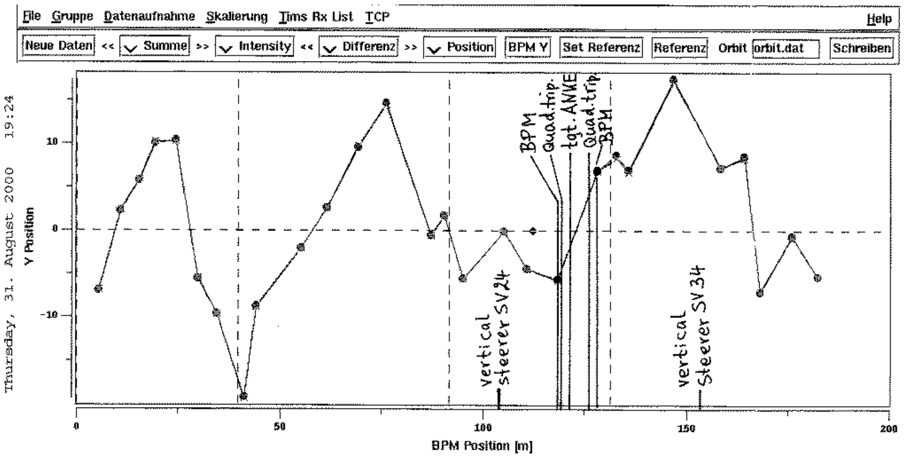

Figure 2: Vertical beam positions (in mm) along COSY with the available vertical steering capabilities. The positions of ANKE target, the two steerers and the two quadrupole triplets adjacent to ANKE are indicated.

2.2 Conclusions

From these tests two essential requirements follow that have to be met before further studies involving a storage cell at ANKE can be carried out:

1. The present capabilities of COSY to measure the position of the stored beam at ANKE up- and downstream of the target are inadequate[2]. The standard COSY beam position monitors (BPM's) with a diameter of 150 mm are too large to allow for position determination of x and y beam centroids upstream of the storage cell. The machine group of COSY was approached to develop a set of smaller vertical and horizonal BPM's (diameter $\approx 50 \ldots 80$ mm) for the upstream side. Downstream of the D2 magnet at ANKE the diameter of the beam pipe reduces to 90 mm. Thus between D2 and D3 a set of BPM's of only 90 mm diameter would be suitable, whereby the capabilities of ANKE to detect ejectiles at small scattering angles near the beam pipe would be enhanced.

2. The beam steering capabilities at ANKE need to be improved. The machine group of COSY is presently studying suitable scenarios, which should allow for four-steerer bumps at ANKE. We are intending to continue the aperture tests as soon as additional steerers become available.

3 Storage Cell Tests (Week 1)

3.1 The New ANKE Target Chamber

In order to perform any tests with storage cells at ANKE, a new target chamber is required. Since ANKE in the future will be utilized by different users utilizing different targets, the

[2]The two vertical BPM's between D1-D2 and D2-D3, respectively, were removed after additional valves in the ANKE region had to be installed.

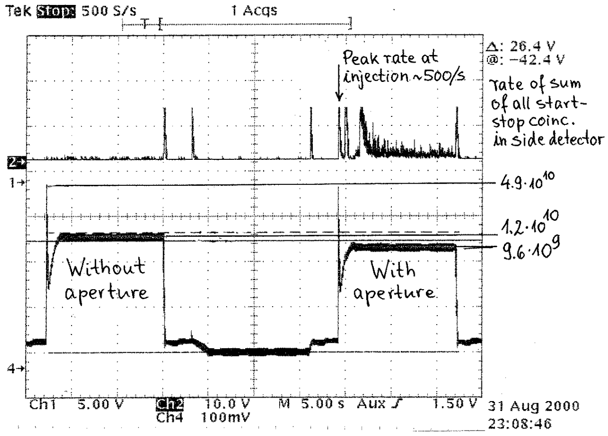

Figure 3: Beam current (bottom trace) and detector rate (top trace) for two cycles, one without aperture (left-hand side) and one with rectangular aperture at a beam momentum of 2.1 GeV/c.

new target chamber should be able to accommodate the existing cluster jet target, the strip target, a storage cell target fed by the ABS and possibly also a pellet target. In Fig. 4 a picture of the chamber design between the D1 and D2 magnets is shown. The target chamber consists of a frame structure onto which rectangular flanges can be attached that are tailored to the experimenters special requirements. The chamber itself is connected to the bellows at D2 and D1 with a shut-off valve at D1. The chamber is large enough to allow for the installation of a new pair of small BPM's upstream of the storage cell. The design of the new target chamber is anticipated to be completed by the end of this year. Thus with chamber production in early 2001, an installation will be not possible before week 21 (May 21-27) of 2001.

3.2 ANKE Vacuum System

The gas load at ANKE requires a powerful differential pumping system along COSY. The production of such a system has been started and components will be installed step by step at the new target chamber (Leybold Coolvac 1500), at D1 (2× Coolvac 1500), on the downstream end of D2 (2× Coolvac 1500) and between D2 and D3 (2× Coolvac 800).

3.3 Storage cells

Attached to *xyz* manipulators several prototype storage cells differing in length and diameter will be available for testing.

3.4 Unpolarized gas flow system

As a result of the diploma work of a student from St. Petersburg (M. Nekipelov) an unpolarized gas supply system is available. Using this system it is possible to admit calibrated amounts of any gas species into the various storage cells during the tests.

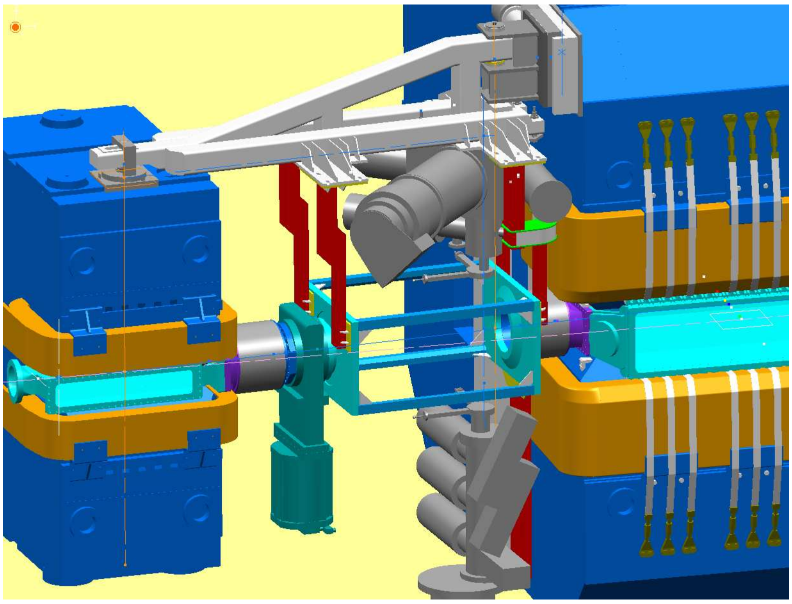

Figure 4: Design of a new target chamber for ANKE. The chamber consists of a frame onto which suitable plates according to the experimenters requirements can be attached. The present bridge between magnets D1 (left-hand side) and D2 supports the cluster jet target and the catcher. The COSY beam comes from the left.

3.5 Requested Time

In view of the difficulties to operate COSY with a storage cell target, we feel inclined to ask for **one week** of dedicated machine development time to practice storage and ramping of the beam in the presence of a storage cell. During this test we will provide several cells inside the target chamber, differing in length and transverse dimensions. The main task will be to identify suitable cell dimensions (length, diameter) for the *pd* break-up experiment, which permit tolerable background conditions. Thus data taking with the *pd* break-up detector setup must take place concurrently to these machine studies. Investigations of the background conditions with a heavy gas (e.g. N) are possible through feeding lines from the unpolarized gas supply system to any of the installed storage cells.

Previous experience shows that a fixed one week schedule to accomplish the goals outlined above might turn out to be inefficient, if for instance unforeseen difficulties are encountered. We thus would like to ask for a rather flexible approach, the details of which will be worked out in close collaboration with the machine group.

4 Measurement of A_y^p in $\vec{p}d$ break-up (Week 2)

4.1 Theoretical background

Supplementing the earlier proposal [1] to study $\vec{p}\vec{d} \to p(0°)p(180°)n$ it is shown in Ref. [2] that valuable information on the NN interaction can be obtained in a special situation, when a proton pair with a small relative energy $E_{pp} \leq 3$ MeV is emitted in the forward direction predominantly in the $^1S_0$-state. This process constitutes a modification of the proton deuteron backward elastic scattering $pd \to dp$ at almost the same kinematics. Therefore a model is applicable [7, 8], which includes the relativistic one-nucleon exchange (ONE), Δ-isobar excitation (Δ) and single pN scattering (SS). In contrast to the $pd \to dp$ process the iso-spin triplet nature of the pp pair results in a considerable suppression of the Δ contribution and provides a dominance of the ONE mechanism in the $pd \to pp(^1S_0)n$ reaction [9]. Furthermore, the ONE amplitude is modified essentially due to the vanishing of $l \neq 0$ states in the forward pp pair. These two properties result in a dip of the unpolarized cross section at $T \sim 0.7$ GeV and in a strong variation of spin observables in the dip region [10]. When rescatterings are taken into account in the DWBA approach within the ONE mechanism, the situation remains essentially unchanged [10]. The validity of the ONE $+\Delta+$ SS model can be tested by polarization experiments. The employed model does not contain any free parameters. Thus deviations of the experimental data from the model predictions would indicate the presence of more exotic mechanisms like three-baryon resonances in the s-channel or N^*-exchanges in the u-channel [7].

We suggest to measure the vector analyzing power A_y^p of the proton in the break-up of unpolarized deuterons induced by transversely polarized protons. The A_y^p value is determined by the coherent sum ONE+Δ+SS at energies $T \leq 1$ GeV and predominantly by the ONE at higher energies. Each of these mechanisms alone yields $A_y^p = 0$, but their interference provides for non-vanishing values of A_y^p at polar angles of the pp pair ejection even close to $\theta_{pp} \sim 0°$ [10] (Fig. 5). Therefore, nonzero values for A_y^p in the energy range of 0.5 to 1 GeV should be observed.

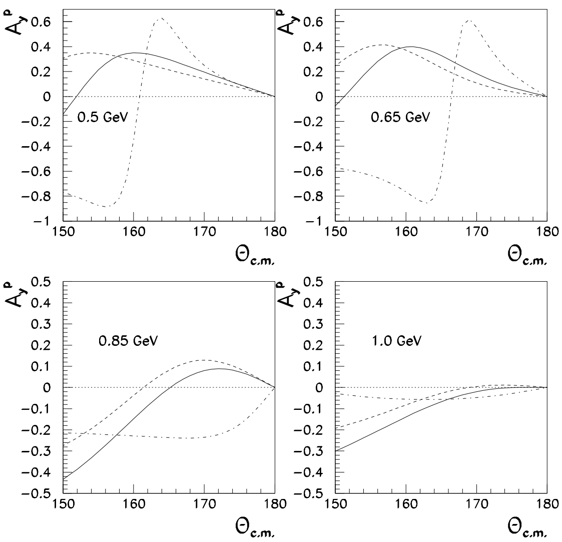

Figure 5: Vector analyzing power A_y^p of the proton versus the neutron scattering angle θ_{cm} in the $\vec{p} + d \to (pp)_s + n$ reaction at $E_{pp} = 3$ MeV for the different mechanisms at kinetic energies $T = 0.5$, 0.65, 0.85, and 1 GeV: ONE (DWBA) (dashed-dotted), Δ (dotted), ONE $+\Delta+$ SS (dashed) and ONE (DWBA) $+\Delta+$ SS (full).

The proton pairs will be detected by the Forward Detector (FD) system of ANKE. The FD angular acceptance covers polar angles up to 3°, which corresponds to neutron emission angles $\theta_{\rm cm} = 180^\circ \ldots 173.5^\circ$. Table 2 lists the expected values for A_y^p, averaged over the FD acceptance, and the uncertainties at the different energies, where a beam of

Beam energy [GeV]	N_{pp} events [s^{-1}]	Time [h]	$\bar{A}_y^p$
0.5	0.34	20	0.10 ± 0.01
0.6	0.20	30	0.06 ± 0.01
0.7	0.062	30	0.07 ± 0.02
1.0	0.047	60	0.0 ± 0.02

Table 2: Expected rates, uncertainties and measuring time estimates for a measurement of the proton analyzing power A_y^p averaged over $\pm 3^\circ$ acceptance of the forward detector at the requested beam energies for a luminosity of 10^{30} s^{-1}cm^{-2}.

$2 \cdot 10^9$ protons of polarization $P = 1$ and a deuteron target thickness of $5 \cdot 10^{14}$ cm^{-2} is assumed. Additional input to the estimation comes from *i)* the calculated cross section from Ref. [10], *ii)* the FD-acceptance at ANKE found from a Monte-Carlo simulation, and *iii)* the proton pair detection efficiency of 50%, including the six MWPC planes, the efficiency of the track reconstruction procedure, and amplitude and time cuts in the trigger counters.

4.2 Vertex Detection

A vertex detector setup consisting of four double sided silicon detectors of about 50×50 mm^2 area will be available for the measurements. This system will be utilized to carry out background studies. Also possible will be a first measurement of the beam polarization at ANKE. In addition, the detectors provide a good luminosity monitor through detection of elastic *pd* events.

4.3 Requested Time

Independent of the goals outlined above (Sec. 3), we would like to ask for **one week** of polarized beam for first *pd* break-up studies. The goal of this request is to carry out a measurement of the proton vector analyzing power A_y^p for break-up events with $E_{pp} \leq 3$ MeV. As a target we will use a a storage cell fed with unpolarized deuterium. As a backup, we will be prepared to use the Münster cluster jet target (presently installed at ANKE). Although the polarized beam intensity is lower than for unpolarized beam, the thickness of the unpolarized storage cell target can be adjusted to make up for that to a certain extent. The existing polarimeter in COSY will be used to determine the beam polarization.

5 Status of other components

5.1 Atomic Beam Source

5.1.1 Intensity

The set of sextupole magnets has been installed at the source [11]. A systematic optimization of the source output is currently underway. At the moment a flux of hydrogen atoms in two hyperfine states of $6.4 \cdot 10^{16}$ atoms/cm^2 is measured with a compression tube of 10 mm diameter and 100 mm length located about 300 mm behind the exit of the last sextupole magnet. Operation of Running the source with deuterium gas does not involve modifications of the sextupole magnet system.

5.1.2 Hyperfine Transitions

In order to carry out the deuteron break-up experiment hyperfine transitions have to be utilized, because the target is operated in a strong vertical guide field, which is generated by the fringe field of the D2 magnet. The necessary hyperfine transition units for Deuterium have to be built.

5.2 Lamb-Shift Target Polarimeter

Because of a scarcity of suitable deuteron target polarimeter reactions a target polarimeter is needed. At the University of Cologne a Lamb-shift polarimeter is currently being developed. The polarimeter will be moved to Jülich in December 2000 for first tests at the ABS beam.

5.3 Bridge for Atomic Beam Source

The ABS has to move when the D2 magnet is set to a different deflection angle. Therefore a special bridge is needed to mount the ABS above the beam pipe. Design work for this bridge will begin beginning of 2001.

5.4 Time plan for complete installation

One of the major milestones of the current installation of the target setup for the deuteron break-up experiment at ANKE is the installation of the new target chamber. We believe that the chamber will be properly equipped, tested and ready for installation before June 2000. The production of the differential pumping system for ANKE has been started. Design and construction of the ABS bridge should be completed middle of 2001. We anticipate to assemble the ABS, the new target chamber, the Lamb-Shift Polarimeter and the new bridge for further tests during a period of a few months in the Bermuda triangle in the COSY hall at the end of 2001. The complete polarized target assembly could be ready for installation at COSY in early 2002.

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