Beam Time Request for the Measurement of the Spin-averaged Cross Section and the Vector Analyzing Power A_y^p of the $\vec{p}d \to ppn$ Reaction at ANKE

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Contents

1 Introduction

At the COSY PAC session #22 (Spring 2001) the masterplan for the study of the deuteron breakup at high–momentum transfer (COSY experiment #20) was positively received. In accordance with this plan, the experiment consists of two main phases:

1. Measurements with unpolarized deuterium target to obtain spin–averaged differential cross sections, angular distributions, and the vector analyzing power.

2. Measurements with polarized deuterium target to obtain the other polarization observables (tensor analyzing power, spin–spin and spin–tensor correlation parameters).

The final goal of both phases is the measurement of a complete set of observables. It should be noted that this goal cannot be achieved in one step, because of the significant difference in the experimental conditions. The well defined event vertex of the point–like unpolarized cluster–jet target in phase 1 makes possible a precise determination of the angular dependence of the differential cross section. On the other hand, in phase 2, the storage cell target provides an extended vertex distribution only along the proton beam direction. Therefore, for a comparison with theory and in order to extract angular distributions of polarization observables, the angular distribution of the differential cross section must be obtained during phase 1.

The first week of beam time granted for unpolarized measurements in 2001 year was used to obtain first results for the cross section, which have been recently submitted to Phys. Lett. B [1]. The second week of polarized beam, allocated in 2001, allowed us to develop mainly the beam polarimetry. A first measurement of the vector analyzing power at a beam energy of 0.5 GeV could be achieved as well.

The polarized gas target and the relevant devices to utilize it at the COSY beam will be available at ANKE end of next year. It is our intention to complete the data taking for phase 1 during 2003 with the present request. After that, the activities concerning COSY proposal #20 are considered as finished. The further investigations of the deuteron breakup at high–momentum transfer with polarized target shall be performed in the framework of a new proposal, the preparation of which is in progress for the next PAC meeting. The new proposal will detail the measurement of polarization observables for the deuteron breakup study. It will also contain a suitable commissioning experiment for the polarized target. The proposal will be presented to the PAC after the cell tests at the COSY beam, approved already, and the differential cross section measurements, requested here, have been performed.

The COSY proposal #20 was approved as a first priority experiment by the COSY PAC in 1992. At that time neither the ANKE setup nor COSY itself existed. The proposal to study the deuteron breakup had the character of a wide physical program. At that time, a reasonable estimation of the total beam time could not be supplied. The cross sections had to be measured and the experimental conditions had to be studied first. A reasonable planning of a study for a non-explored process can be only done step by step, taking into account new information from the experiment. This approach is described in the following sections.

2 Measurement of the spin–averaged cross section

The breakup process

$$p + d \to (pp) + n \tag{1}$$

with forward emission of a fast proton pair with small excitation energy $E_{pp} < 3$ MeV was studied at ANKE at six beam energies from 0.6 to 1.9 GeV. The process (1) has never been explored under these conditions. The experiment allows a complete kinematical reconstruction of the events, whereby the five–fold differential cross sections can be determined. Examples of the obtained distributions are shown in Fig. 1.

The statistics taken at $T_p > 1$ GeV is insufficient even for the determination of the three–

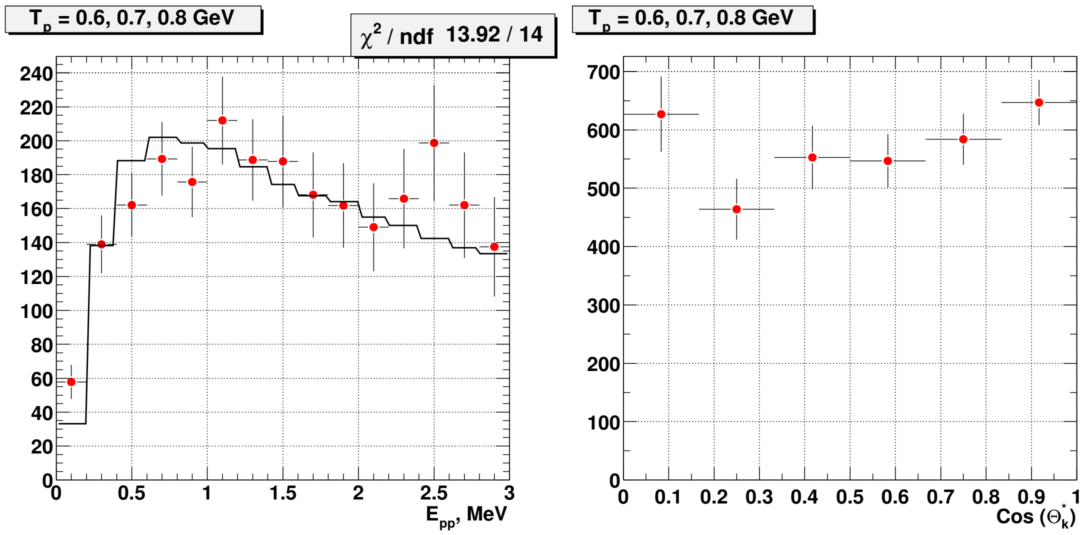

Figure 1: Excitation energy E_{pp} distribution in comparison with the theoretical expectation from final–state interaction (fsi) (left), and the distribution over the cosine of the angle between the relative momentum of the protons in the pair and their total momentum for $E_{pp} < 3$ MeV (right). The distributions contain the data taken at three beam energies.

fold differential cross section. Therefore, in order to compare the energy dependence of the cross section with the theoretical prediction (ONE+Δ+SS model [1]), the cross section was integrated over the interval $0 < E_{pp} < 3$ MeV and averaged over the pair emission angle in the range $0 < \theta_{pp}^{\rm cm} < 8°$. The results are shown in Fig. 2 [1]. The model reproduces the cross section at low energy where the Δ mechanism dominates, but fails at higher energies (left panel in Fig. 2). There is no evidence for the expected dip and the experimental cross section at $T_p > 1$ GeV is overestimated by the model using the RSC and Paris NN potentials. The model implies the ONE mechanism dominance in this energy region, and therefore the short–range properties of the potentials strongly affect the theoretical predictions. When the full Bonn potential is used (right panel in Fig. 2), the calculations are almost consistent with the experimental data. With such a "soft" deuteron, the dip should be filled almost completely by contributions of the Δ mechanism. The comparison of the obtained cross section with the $pd \to dp$ data, taken from literature, allows one to obtain, for the first time, the ratio of the spin–singlet to spin–triplet amplitudes of the breakup process at high–momentum transfer [2]. This ratio also depends on the individual contribution of the considered mechanisms.

In this situation, the first task lies in a clarification of the role of the ONE mechanism at high energies. If this mechanism is really dominant, process (1) may provide an interesting tool to directly probe the short–range structure of the NN interaction. If not, other approaches for dynamics studies in high–momentum transfer processes in few–nucleon systems should be developed.

There are several ways how the situation can be clarified:

1. The spin–averaged cross sections should be compared to model predictions of

   – the measured angular distributions of the total momentum of the proton pair.

   – the angular distributions of the relative momentum in the pair with respect to the

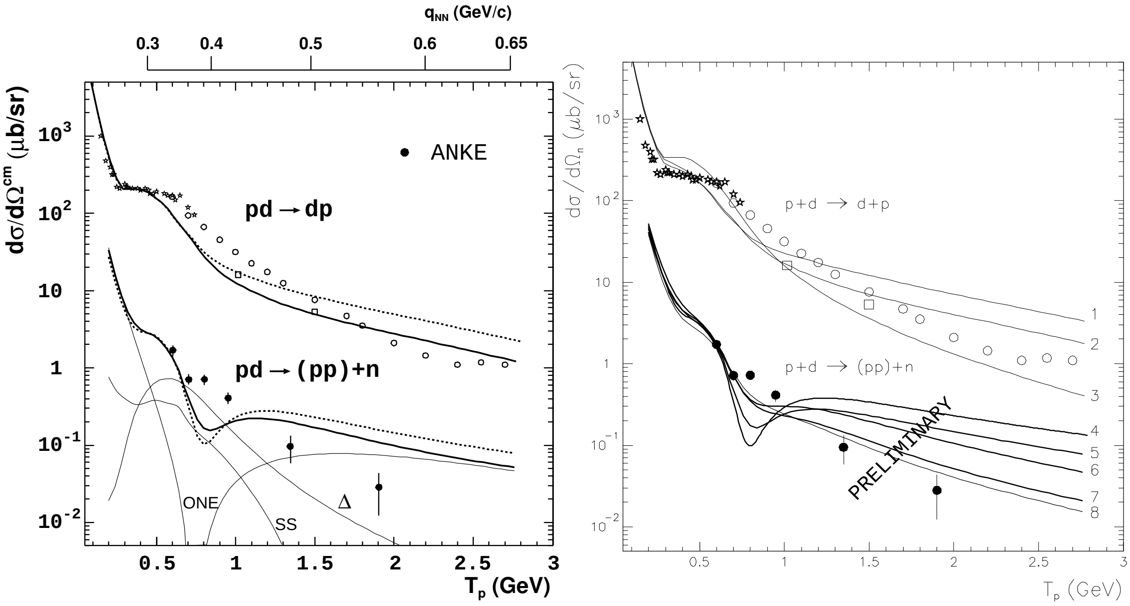

Figure 2: Left panel: Measured cross section of the process (1) in the interval $E_{pp} < 3$ MeV. The calculations with ONE+Δ+SS model are performed using the NN potentials RSC (dotted line) and Paris (solid). The individual contributions with the Paris potential are shown by thin full lines [1]. Right panel: The ONE+Δ+SS model calculations are performed for the $pd \to dp$ (1–3) and $pd \to (pp)n$ (4–8) processes using the RSC (1,4), Paris (2,5), CD Bonn (3,6,7), and full Bonn (8) NN potentials.

total momentum. This provides a test of the $^1S_0$ state dominance in the pair for $E_{pp} < 3$ MeV (first results shown in Fig. 1, right panel).

- the excitation energy E_{pp} distribution to check manifestation of the fsi enhancement. The obtained data point towards relaxation at higher energies, which is incompatible with the ONE mechanism.
- the energy dependence of the differential cross section with higher accuracy than obtained earlier. That allows one to obtain the energy dependence of the spin–singlet to spin–triplet ratio in the range $T_p = 0.5$ to 2.0 GeV.

2. In Born approximation the vector analyzing power A_y^p is zero for each of the mechanisms (ONE, Δ, and SS) individually and deviates from zero only by interference of the mechanisms. Therefore, vanishing of A_y^p at about 1 GeV would be an indication for the dominance of the ONE mechanism.

3. The most crucial test of the validity of the model is a comparison to a measurement of the tensor analyzing power and the spin–spin and spin–tensor correlation parameters, which will be carried out in the second phase of the experimental study. Moreover, the measurement of the polarization observables aim at a model–independent amplitude analysis of the breakup process. In this respect, process(1) has a significant advantage compared to the $pd \to pd$ process, since in collinear kinematics only two spin–dependent amplitudes contribute.

The experimental information we intend to obtain through measurements with unpolarized beam are summarized in Table 1. The differential cross sections at lower energies ($T_p < 1$ GeV) will be obtained by spin–averaging the data with polarized beam (see Sect. 4). We would like to emphasize again, that the differential cross section data are a crucial requirement for the future measurements of polarization observables, utilizing the polarized target.

Table 1: Estimate of the required beam time for a measurement of the spin–averaged differential cross section at the indicated beam energies, assuming a luminosity of $1.0 \cdot 10^{30}$ s^{-1}cm^{-2} (approx. $2 \cdot 10^{10}$ stored protons, $f_{\rm rev} = 1.6$ MHz, $d_t = 5 \cdot 10^{13}$ cm^{-2}). N_{pp} corresponds to the number of exptected events with $E_{pp} < 3$ MeV.

Beam energy [GeV]	Aim	Target	N_{pp} events	Time [h]
0.5, 2.0	FD calibration	H_2	–	20
1.2	$d^5\sigma/dp_1 d\Omega_1 d\Omega_2$	D_2	600	80
1.4	$d^5\sigma/dp_1 d\Omega_1 d\Omega_2$	D_2	400	120
2.0	$d^5\sigma/dp_1 d\Omega_1 d\Omega_2$	D_2	100	60
				in total $\approx$ **2 weeks**

3 Beam polarimetry at ANKE and first glance at A_y^p

One week of beam time granted by PAC for first measurements with polarized beam at ANKE (September 2001) was mainly used to develop a method to determine the beam polarization at ANKE. The intensity of the beam was unstable and during the week decreased from initially $2 \cdot 10^9$ stored protons to $5 \cdot 10^8$. Nevertheless, a preliminary value of the analyzing power could be obtained.

A measurement of the beam polarization at EDDA is possible only at energies above $\approx$ 0.7 GeV (1343 MeV/c). In addition, the employed polyethylene targets at EDDA do not tolerate beam intensities exceeding about $5 \cdot 10^8$ stored protons. According to the previous beam time request, we wanted to perform a measurement of A_y^p at 0.5 and at 1.0 GeV, therefore a macro cycle was realized, which consisted of two flattops at 0.5 and 1.0 GeV (Fig. 3, left panel). The beam polarization was measured in separate cycles with appropriately reduced intensity (micro–pulsing), but otherwise identical to the data–taking cycles. At 0.5 GeV data were taken for 10 min, subsequently the beam was ramped to a very short 1 GeV flattop. The beam spin was alternated from cycle to cycle. Polarization data with EDDA were recorded once or twice per day, *a)* during flattop at 1 GeV to monitor the polarization and *b)* during the ramp at 0.7 GeV, with modified flattop durations. Since between 0.5 and 0.7 GeV the depolarizing resonances in COSY are understood and compensated, this procedure provides the beam polarization at 0.5 and at 1.0 GeV.

Since the polarization data recorded with EDDA did not provide a continuous monitoring of the beam polarization, the up/down ($\uparrow$, $\downarrow$) beam spin asymmetry of protons scattered off the deuterium target was measured with ANKE. Elastically and quasi-elastically scattered protons between $\theta_{\rm lab} = 5°$ to $11°$ were registered in the FD. At the same time proton pairs from the breakup process under study were recorded. The relative luminosity $\mathcal{L}_\uparrow/\mathcal{L}_\downarrow$ was determined from inelastically scattered protons near zero degree, simultaneously detected in the FD. Online track reconstruction provided information (angle and momentum) to select the scattered protons. Both proton count rates and observed asymmetry were sufficiently large to monitor the beam polarization during the run. The resulting polarizations from EDDA and asymmetries from ANKE $\varepsilon(\uparrow,\downarrow) = \frac{N_\uparrow/\mathcal{L}_\uparrow - N_\downarrow/\mathcal{L}_\downarrow}{N_\uparrow/\mathcal{L}_\uparrow + N_\downarrow/\mathcal{L}_\downarrow}$ are shown in Fig. 3. The asymmetries from ANKE were obtained for 2 h runs carried out right after the EDDA polarization measurements. The data are quite stable in time, thus averaging was justified. At $T_p = 0.7$ GeV, $P_{beam}^{\rm EDDA} = 0.645 \pm 0.009$, while at $T_p = 1.0$ GeV, $P_{beam}^{\rm EDDA} = 0.577 \pm 0.001$. The measured asymmetries at ANKE at $T_p =$ 0.5 GeV correspond to $\varepsilon(\uparrow,\downarrow) = 0.294 \pm 0.006$. The false asymmetries $\varepsilon(\uparrow,\uparrow)$ and $\varepsilon(\downarrow,\downarrow)$ were obtained by analyzing cycles with the same polarization direction, yielding $[\varepsilon(\uparrow,\uparrow)+\varepsilon(\downarrow,\downarrow)]/2 = -0.002 \pm 0.009$. The effective analyzing power of ANKE, given by the ratio $\varepsilon(\uparrow,\downarrow)/P^{\mathrm{EDDA}}_{beam}$, is thus $A^{\mathrm{eff}}_y = 0.456 \pm 0.011$.

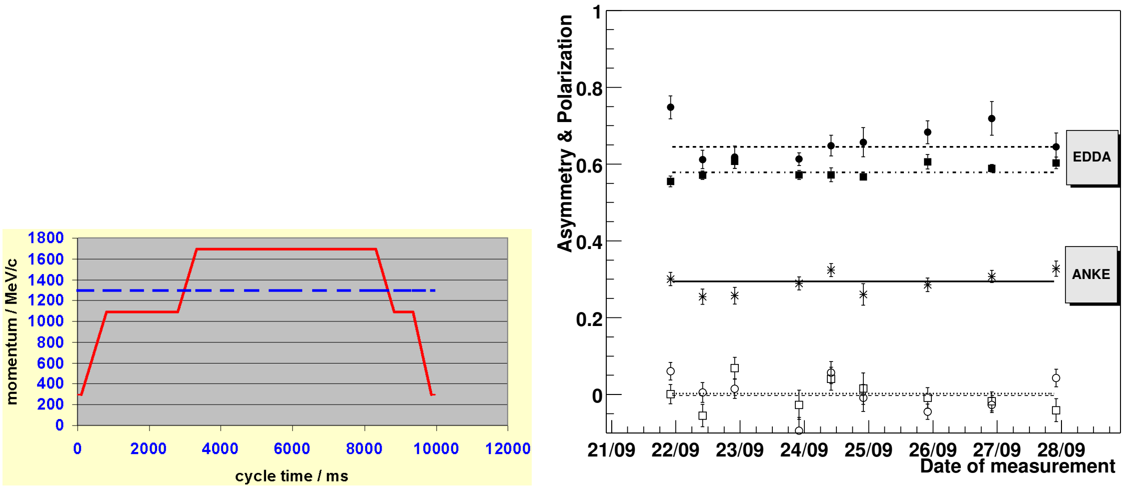

Figure 3: Left panel: Schematic picture of the cycle with two flattops, at $T_p = 0.5/1.0$ GeV (1.090/1.696 GeV/c). Right panel: EDDA beam polarization and asymmetry measured at ANKE. Filled circles denote the measured beam polarization at 0.7 GeV at EDDA, filled squares the 1 GeV flattop polarization. Stars indicate the asymmetry of small-angle scattered protons off the deuteron target, and the open symbols correspond to the measured false asymmetries.

A clean separation of the *pd* elastic scattering at small angles was achieved by detection of the scattered deuterons using the vertex spectator detector in coincidence with a fast proton detected in the FD (see Fig. 4a). A comparison of the obtained ANKE data at 500 MeV with other data available from literature is shown in Fig. 4b. Detection of *pd* elastic scattering events with the spectator counter can be directly applied to measure the beam polarization at ANKE at 796 MeV, utilizing the existing precise data from Irom et al. [5]. For ANKE, this is the method of choice to determine the beam polarization at present. It is possible to export a calibrated measurement of the beam polarization from 796 MeV to other energies, higher or lower, as shown in Ref. [8].

A first measurement of the vector analyzing power A^p_y for process (1) could be obtained. The analyzing power A^p_y is expected (Fig. 5 (left panel)) to follow a linear function of the neutron emission angle θ_n in the range from 180° to 165°: $A^p_y = \alpha^p_y \cdot (180^\circ - \theta_n)$. In Fig. 5 (right panel) the obtained angular dependence of the observed asymmetry for process (1) is shown. The dependence exhibits a linear behaviour and the obtained value of the slope parameter α^p_y is equal to (0.041 ± 0.011) deg^{-1}. Thus, the measured preliminary value differs by about two standard deviations from the theoretical value of 0.020 deg^{-1}.

4 Measurement of the vector analyzing power A^p_y

Our measurements at 0.5 GeV have shown that in spite of the vanishing analyzing power at $\theta_n = 180^\circ$, a substantial value can be obtained, because the angular acceptance of ANKE for process (1) ranges from 180° to 165°. Within the ONE+Δ+SS model, A^p_y exhibits a rather significant value in the energy range from 0.5 to 0.85 GeV, while near 1 GeV its value is close to zero (Fig. 5, left panel). The respective slope parameter α^p_y changes from $(2.0-1.7)\cdot 10^{-2}$ deg^{-1}

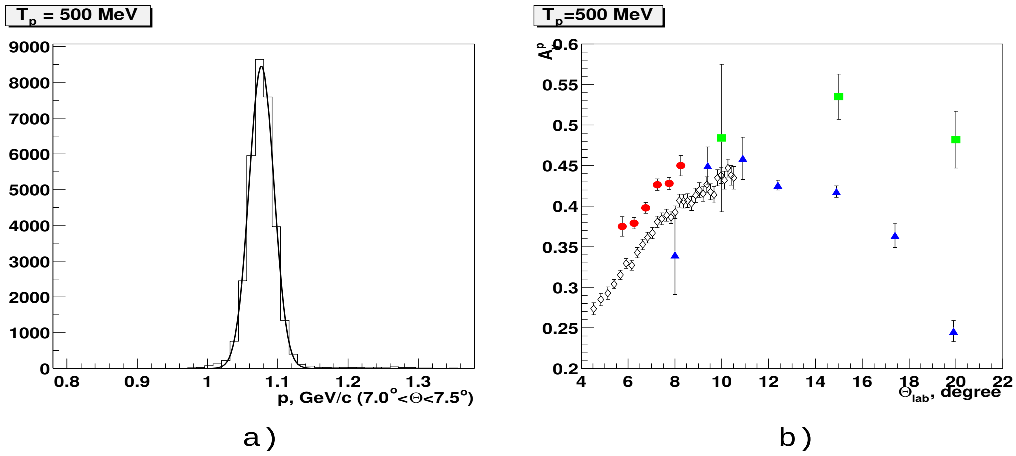

Figure 4: Beam polarimetry utilizing *pd* elastic scattering: a) Momentum of protons registered in the FD in coincidence with deuterons stopped in the second layer of spectator detector. b) Comparison of the angular dependence of the proton vector analyzing power measured at ANKE at 500 MeV (circles) and the data obtained at 544 MeV [4] (squares), 796 MeV [5] (rhombuses) and 800 MeV [6] (triangles).

to $1.0 \cdot 10^{-3}$ deg^{-1} at these energies. In order to test this prediction, we suggest to measure A_y^p at three energies 0.5, 0.796, and 1.0 GeV with good statistical accuracy $\sigma(\alpha_y^p)$. The polarization of the beam will be measured at 796 MeV using the spectator detector, as described in the previous section. We will employ a polarization export procedure, described in Ref. [8]. For that purpose, the macro cycle has to consist of three parts A, B and C, where $T_A = T_C = 796$ MeV, and T_B is either 500 or 1000 MeV. The difference between the beam polarizations of part A and part C can be made small (few percent) [7]. With that technique, the polarization measured at 796 MeV can be exported to 500 and 1000 MeV. Thereby, we would provide a new measurement of *pd* elastic scattering analyzing powers at 500 and 1000 MeV as well. In addition, we will find out, if there was a problem with the polarization normalization of the analyzing power during the previous run, and the data can be renormalized. For the estimate of the beam time, listed in Table 2, a luminosity of $4 \cdot 10^{29}$ s^{-1}cm^{-2} ($5 \cdot 10^9$ stored protons, $f_{\rm rev} = 1.6$ MHz, $d_t = 5 \cdot 10^{13}$ cm^{-2}) was assumed.

Table 2: Estimate of the beam time for the measurement of the vector analyzing power A_y^p of process (1) for a luminosity of $4 \cdot 10^{29}$ s^{-1}cm^{-2}. N_{pp} corresponds to the number events expected with $E_{pp} < 3$ MeV.

Beam energy [GeV]	Aim	Target	N_{pp}	$\sigma(\alpha_y^p)$ [deg$^-$1]	Time [h]
0.5, 1.0	FD calibration	H_2			20
	Spectator Installation, Polarimeter Setup	D_2			36
0.5	A_y^p	D_2	2000	$5.0 \cdot 10^{-3}$	30
0.796	A_y^p	D_2	2000	$5.0 \cdot 10^{-3}$	100
1.0	A_y^p	D_2	1000	$7.0 \cdot 10^{-3}$	110
					in total ≈ **2 weeks**

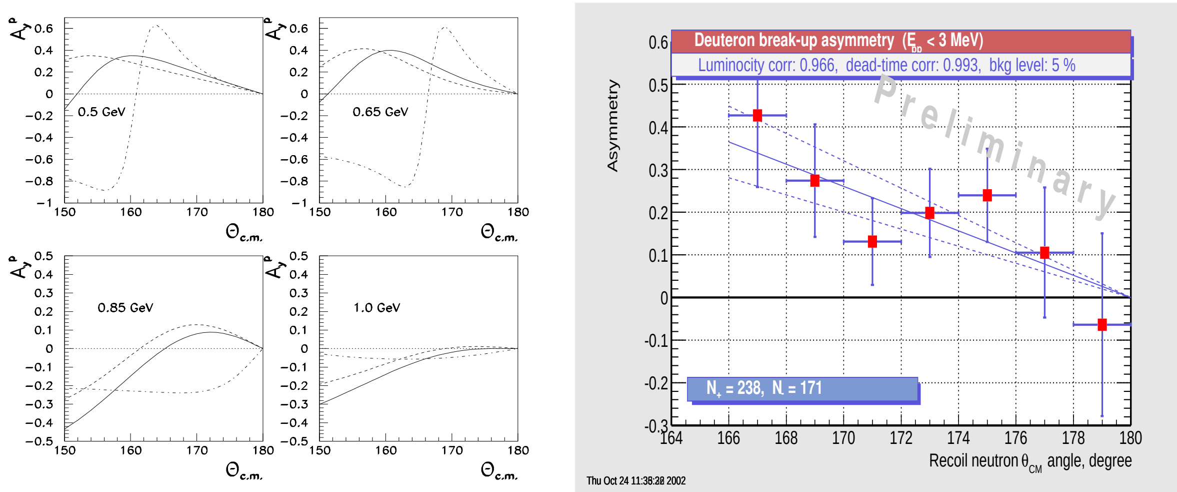

Figure 5: Left panel: Vector analyzing power A_y^p of the proton versus the neutron scattering angle θ_{cm} in the $\vec{p} + d \to (pp)_s + n$ reaction at $E_{pp} = 3$ MeV for the different mechanisms at kinetic energies $T = 0.5$, 0.65, 0.85, and 1 GeV: ONE (DWBA) (dashed–dotted), Δ (dotted), ONE $+\Delta+$ SS (dashed) and ONE (DWBA) $+\Delta+$ SS (full) [9]. Right panel: Measured asymmetry of the neutron emission at backward $\theta_{\rm cm}$ angle in the $\vec{p} + d \to (pp) + n$ reaction with excitation energy $E_{pp} < 3$ MeV. The solid line shows a linear fit to the data.

5 Apparative developments

Two essential improvements of the current setup will be utilized in the upcoming beam time:

– The deuterium cluster target operation allows one to run at least at target densities 5 times higher than in the Feb 2001 run.

– A new trigger electronics was developed with the aim to suppress single particle counting. It allows us to reduce dead–time losses significantly. The new trigger is already adjusted during previous runs.

Much effort, in tight collaboration with the Zentralabteilung für Technologie of the Forschungszentrum and with great support from there, has been given to prepare the installation of the polarized storage–cell gas target at ANKE. A large target chamber of 80 cm length, 60 cm width, and 40 cm height is under construction and will be installed at the target position during the Christmas shutdown 2002/2003. Its basic design feature is that of a frame structure, whereby flanges adapted to the various installations can be easily installed. A set of newly–developed movable horizontal and vertical beam–position monitors will be installed in front of the future storage cell. The cluster–beam source and its beam catcher, the strip–target manipulator will be mounted as well, while target–near Si–strip detectors on both sides of the target can be positioned in the more appropriate forward direction, thereby enhancing substantially the acceptance of the setup. Furthermore, the new chamber can be connected to the polarized atomic beam source and will accomodate two step–motor driven xyz manipulators to position the storage cells. These will be used to move a frame, carrying a number of prototype storage cells of different lengths and cross sections, for testing at the target position. These prototype cells will be installed to study the beam properties and interactions with the cell wall at the beginning of 2003. The goal is to find the most appropriate design parameters for the cells of the polarized target for the second phase of the deuteron breakup experiment. In view of the gas load from the open–ended storage cell (about $2 \cdot 10^{-3}$ mbar $\cdot$ l/s), a strong pumping system is being installed in addition in the ANKE section of the COSY ring.

6 Requested Beam Time

In accordance with the estimate given in Sects. 2 and 4, we request in total two weeks of unpolarized proton beam in July–August and two weeks of polarized beam, which shall take place only after installation and tuning of the new spectator detector, which is requested for the ω–production experiment in August 2003.

We would like to emphasize once more, that both measurements with unpolarized target constitute a necessary step of the study of the deuteron breakup reaction.

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