COSY Test Beam Time

For Lab. use

Exp. No.:	Session No.
E4	3

EDM Polarimeter Database for Deuterons and Protons

Collaboration JEDI

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Total number of particles and type of beam (p,d,polarization)	Energy range (MeV)	Intensity or internal reaction rate (particles per second)	
		minimum needed	maximum useful
Polarized d Polarized p	160 – 270 MeV 180 – 240 MeV	1×10^9	1×10^{10}
Experimental area	**Safety aspects (if any)**	**Earliest date of Installation**	**Total beam time (No.of shifts)**
WASA (Forward)	N/A	October 2016	2 × 2 weeks

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

WASA Forward Detector and new target station.

Description of request (motivation, milestone(s), goals; maximum 5 pages)

Proposal

EDM Polarimeter Database for Deuterons and Protons

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Abstract

This proposal asks for beam time in two separate blocks to create bases of deuteron and proton-induced reaction data from a carbon target (differential cross section and vector and tensor analyzing power). These data may be used to produce realistic Monte Carlo simulations of detector responses for a polarimeter designed for an electric dipole moment (EDM) search using a storage ring. The beams would be polarized, including both vector and tensor for the deuteron. The database would also form the basis for estimating systematic error effects in any EDM ring polarimeter. Normalization would be made to scattering from hydrogen in a $(CH_2)_N$ target. The database detectors would be taken from the forward cone of the WASA system. The experiment would run at the old WASA target location on the COSY ring.

Introduction

A storage ring search for an electric dipole moment (EDM) requires a way to measure very small changes (at the level of a microradian) in the vertical component of the beam polarization during its storage time. For this, the current design concept involves the slow extraction of particles from the beam onto a thick carbon target from which they scatter in the forward direction onto a set of detectors that favor the accumulation of elastic scattering events. Polarimeter systems [1,2] have been built based on this concept with efficiencies in the range of 1 – 4 % and sizable analyzing powers. As a part of Experiment 176, a thick carbon target scheme was implemented for the COSY ring using the EDDA scintillation detectors [3,4]. These detectors were chosen for easy availability and use since the original experiment with them was already completed. A study [5] demonstrated that a thick target mounted on the edge of the beam could be used successfully to sample the polarization of the beam with high efficiency (7×10^{-4}) and large analyzing power (A_Y = 0.45). (Efficiencies are smaller here due to the loss of angle coverage with EDDA at the most forward scattering angles.) With a suitable calibration, information from the detector rates could be used to correct for rate-dependent effects and for centroid shifts of the beam position and angle during the measurement to a level at or below 10^{-5}.

Internal discussions of the plan to construct such a storage ring have focused on the deuteron case because of it sensitivity to CP-violation in super-symmetric theories [6,7] and the possibility to construct an EDM storage ring of a size comparable to the present COSY machine. This would mean that a polarimeter would operate at momenta of about p = 1 GeV/c or less. This, along with the necessity to characterize the scattering as the projectile loses energy in a thick carbon target, suggests an energy range for study between about 160 and 270 MeV. New data is needed that goes beyond recording just the elastic scattering and documents the production of forward-going particles from deuteron breakup. A similar energy range is also applicable to the proton, in part because the "magic" momentum (p = 0.7007 GeV/c, T = 232.8 MeV) where the spin is frozen along the velocity is also an excellent place for proton-carbon polarimeter construction. In this case, the flux from non-elastic reactions is less and characterizing detector responses would be easier. Because of the polarized ion source setup time, the deuteron and proton runs should be separated into different running periods.

In preparation for this study, as much data as existed on deuteron-induced reactions on carbon for energies around 200 MeV was gathered, systematized, and used in a Monte Carlo simulation of the thick target and EDDA scintillator combination. From this, it was determined that a beam momentum of 0.97 GeV/c was optimal for the separation of elastically scattered deuteron events at forward angles in the EDDA scintillators. Beyond this conclusion, the analyzing power predictions of the model were not quantitatively accurate, and attempts to understand systematic errors were misleading. This was mainly due to the inadequate representation of deuteron breakup and other deuteron-induced reactions, which was based on a set of measurements made at the KVI at about half of the COSY beam energy.

Detector choice

The detector most nearly suited to the database task is the Forward Detector from WASA. The active range of the detector is between 3° and 18°. After the particles exit from the vacuum window through a thin wall, there is in succession a pair of plastic hodoscopes, a stack of straw tubes for tracking the direction of the particles, a trigger scintillator, and three 10-cm calorimeter detectors. Additional 15-cm detectors are available if needed. Without the final 15-cm detectors, the system can stop protons below about 230 MeV and deuterons below about 310 MeV. Higher energies may be deduced given the energy loss in the existing system.

Beginning in the latter part of 2015, the decommissioning of the WASA 4π crystal ball and pellet target system has begun. Once the target space is accessible, the target box will be replaced with a pair of crosses with large flanges suitable for mounting a variety of target configurations and tests equipment. Figure 1 shows a cross sectional view of how this part of the WASA detector might look in the new configuration. The trigger and data acquisition electronics will be retained for use with this system.

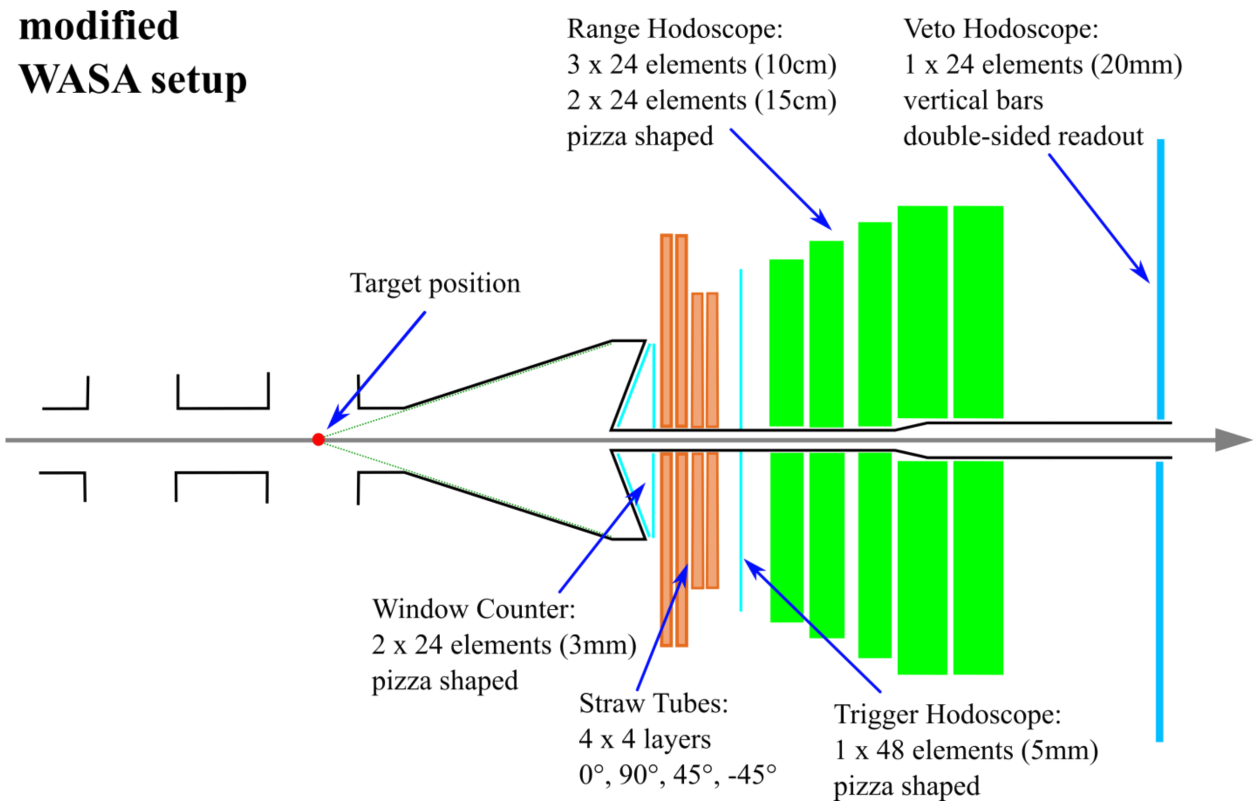

Figure 1: A cross-sectional view of the Forward 17° detector from WASA as it may be configured in 2016 for the database experiment. The target position and various detector components are indicated.

The target box is being reconstructed as a twin cross to provide a number of ports that may be used for various devices, as shown in Fig. 2.

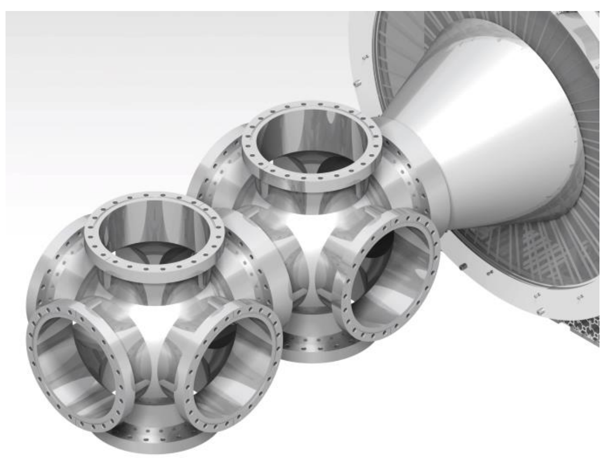

Figure 2. Crosses that will replace the current WASA target chamber with the right hand cross located at the old center of scattering.

We intend to use the ANKE target assembly, shown in Fig. 3, to hold thin conical targets of either carbon or polyethylene. These targets already exist. The polyethylene target has a thin aluminum coating to conduct away heat and prevent charge buildup.

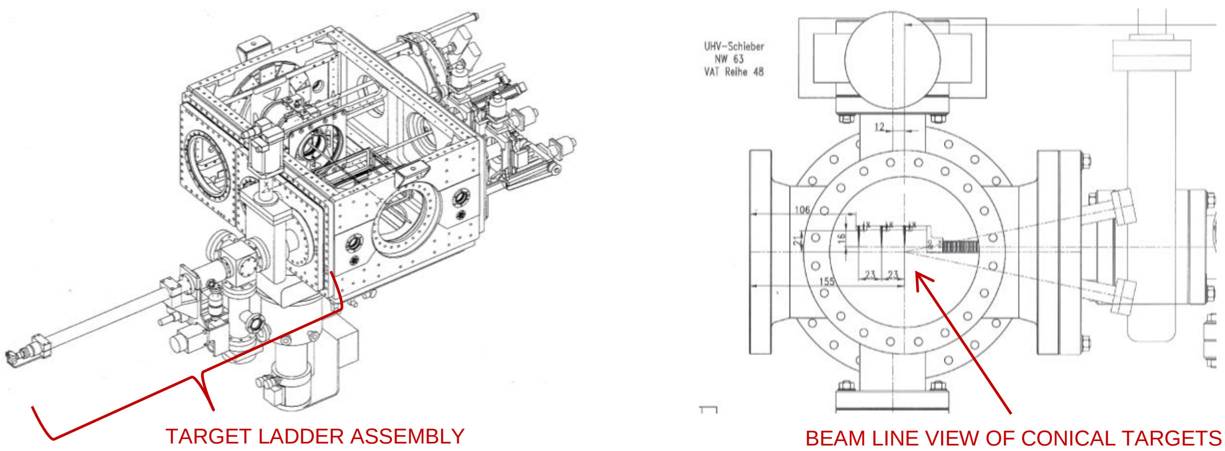

Figure 3. Two drawings showing the ANKE target assembly.

The horizontal motion is motor-driven, allowing continuous adjustment with an encoder readout. The target points are located at the center of scatter. Slow extraction onto the targets may be achieved by lowering the beam orbit a few millimeters, then driving the beam into the target by either ramping a local beam bump or applying electrical white noise to heat the beam's vertical phase space.

Deuteron data

The main problem for a deuteron-beam polarimeter is the presence of significant flux from breakup. This is illustrated in Fig. 4, which shows a particle identification spectrum from a KVI experiment at 110 MeV and 27° scattering angle.

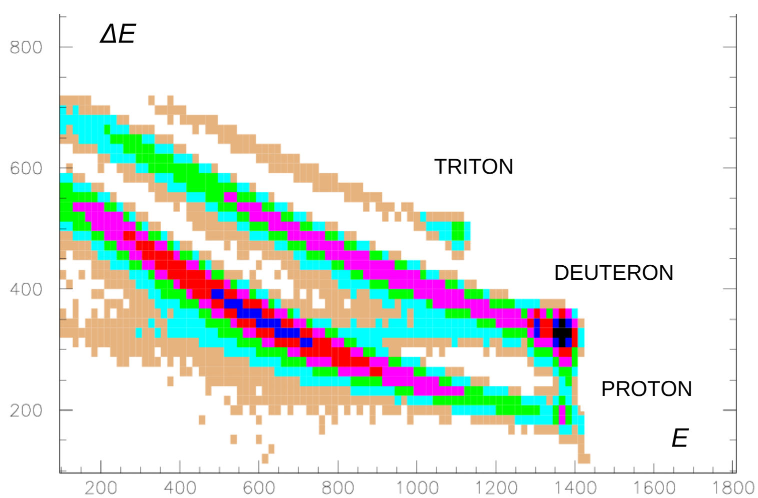

Figure 4: Particle identification spectrum of 110-MeV deuterons on a carbon target with a ΔE-E (plastic + NaI) detector telescope located at 27°. The bands represent tritons, deuterons, and protons going from top to bottom. Note the large flux of protons at roughly half of the beam energy. A reaction tail from the "energy" detector may be seen extending to the left of the elastic scattering peak at the end of the deuteron locus.

The analyzing power of the protons from deuteron breakup (much of which is Coulomb induced) is essentially zero with only a few percent effects appearing in the far tails. Any polarimeter must exclude this background. One way to do this is to place an absorber layer before the final detector. The protons will stop in such an absorber, and this approach will also reduce the overall count rate in the detectors. There may be other strategies for handling this situation. The clear conclusion is that data is needed in order to assess the effectiveness of various separation strategies in the design of a polarimeter.

Figure 5 shows two panels of elastic scattering data that were collected for the prior Monte Carlo study. There are laboratory cross section measurements (mb/sr) as a function of the laboratory angle (left panel) along with vector (A_y) analyzing powers. The data from successive energies (shown in the caption) are shifted by either a factor of 4 or an offset of 0.2 respectively. All cross sections are forward peaked. The curves represent empirical fits to the data. At the highest energies, all of the measurements are positive at angles beyond the Coulomb-nuclear interference point (about 5°). Thus a polarimeter that favors forward angles is well suited for the EDM ring. Starting around 150 MeV, a negative dip appears in the model. This feature grows as the energy goes down, finally showing as negative data points at 113 MeV. These angles would need to be excluded from any data sample, so in this energy range the minimum angle expands to at least 15°. The loss of efficiency at small angles can be replaced in part by including more large-angle scattering in the detector acceptance. Below about 70 MeV, the second interference minimum in the analyzing power also goes negative, pushing the minimum angle out to about 35°. These two changes reduce the figure of merit, making lower energies less desirable for polarimeter operation. At the same time, reducing the energy allows the ring to be built with smaller fields and a smaller radius, both of which are helpful in terms of operating characteristics and cost.

If we restrict the study to the region where the analyzing power is positive throughout the angular range, then a reasonable set of energies might be 270, 235, 200, and 160 MeV. More energies would be desirable. Before making the final choice for the deuteron case, it would be helpful to reanalyze these measurements with an optical model program in order to obtain a more physically reasonable set of curves. Lower energies might be needed if there is a decision made to pursue operation with a smaller ring.

Proton data

One choice for the momentum of the EDM experiment is the "magic" momentum at which the polarization precesses along with the velocity ("frozen spin") and the ring bending elements are entirely electrostatic (p = 0.7007 GeV/c, T = 0.2328 GeV). This energy range has been covered by several laboratories where thick target polarimeters were built for nuclear structure spectrometer experiments. Figure 6 is taken from a survey by McNaughton [8] in which he plots the analyzing power of these polarimeters.

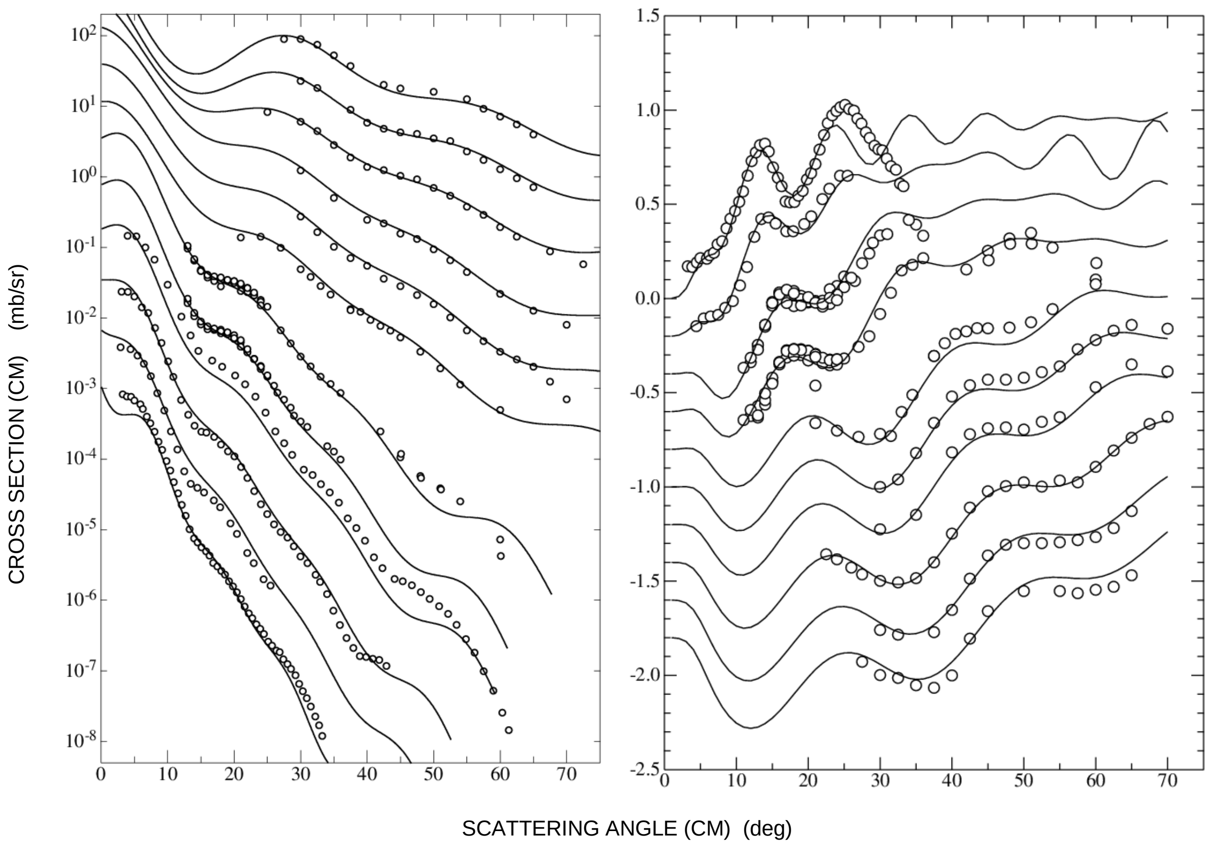

Figure 5: (Left panel) Measurement of the deuteron elastic scattering differential cross section in mb/sr at energies of 45, 49, 54, 65, 70, 76,113, 133, 140, 170, 200, and 270 MeV from top to bottom with subsequent plots lowered by factors of 4. The model curves are shown by solid lines. (Right panel) Measurements of the analyzing power A_Y for deuteron-carbon elastic scattering at energies of 270, 200, 133, 113, 76, 70, 65, 56, 49, and 45 MeV from top to bottom with each plot offset by −0.2 from the one above it.

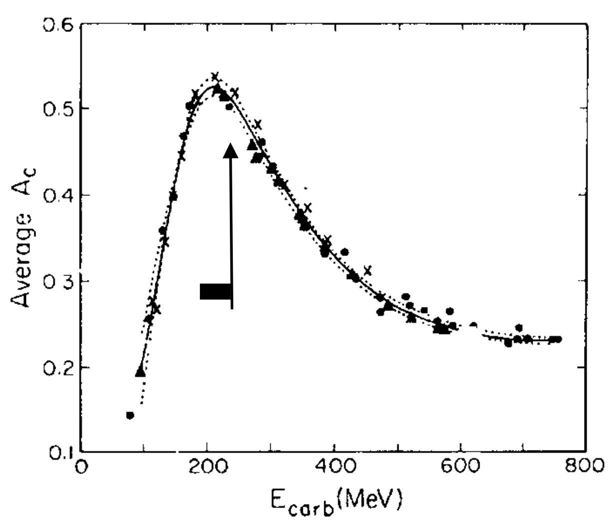

Figure 6: Values of the average analyzing power of a proton-carbon scattering polarimeter as a function of the proton energy. In general, passing scintillators were used in which the acceptance spanned the angles from the Coulomb-nuclear interference point (about 5°) to an angle where the cross section is small enough not to matter (>16°). The arrow indicates the magic energy of 232.8 MeV. The box spans the energy of such protons in traveling through 5 cm of carbon.

On Fig. 6 the arrow indicates the magic energy for operating at the frozen spin point. For a thick carbon target, there will be some energy loss over which the analyzing power of the polarimeter is averaged. The black box on the lower side of the arrow shows the range of energies spanned (about 40 MeV) in a 5-cm thick target of reactor grade graphite (2.22 g/cm^3). This span is almost exactly situated on the peak of the analyzing power. Below this the analyzing power starts to drop significantly, so there is little advantage in extending the thickness of the target. So long as the electrostatic ring is the preferred option for a proton EDM experiment, this is the range that is needed in the database experiment. The four energies for study would be 240, 220 200, and 180 MeV.

Polarization Calibration

A beam with a vertical quantization axis (established at the polarized ion source) may be characterized on target in COSY by two polarization parameters, p_Y (vector) and p_{YY} (tensor). These two polarizations create changes in the count rate at a finite scattering angle according to:

$$\sigma_{POL}(\theta) = \sigma_{UNPOL}(\theta)\left[1 + \tfrac{3}{2}\, p_Y A_Y(\theta) + \tfrac{1}{2}\, p_{YY} A_{YY}(\theta)\right] \qquad (1)$$

where A_Y and A_{YY} are respectively the vector and tensor analyzing powers. The sign of the vector term changes sign on either side of the beam, thus a left-right asymmetry is a useful measurement to isolate this term. The tensor term is the same on either side. It must be extracted with reference to an unpolarized run. This measurement then depends on knowing the relative luminosities of the polarization states with and without tensor polarization. In our case, there will be measurements across a range of angles. For deuteron elastic scattering on carbon, forward angles in the vicinity of 5° usually have a negligibly small tensor analyzing power and may be used to determine this relative luminosity. Scattering in the vertical direction has no vector analyzing power, but there is a tensor, A_{XX}, that is different from A_{YY}. This may be used as a check since values of A_{XX} exist for d+p elastic scattering. For the moment, we focus on the more abundant A_{YY} data.

Measurements have been made for d+p elastic scattering at deuteron energies of 140, 200, and 270 MeV [9]. Figure 7 shows the data for forward-going protons at small angles in d+p elastic scattering.

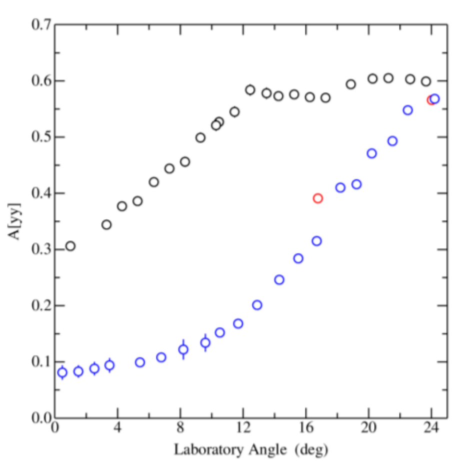

Figure 7: Measurements of the $A_{YY}(\theta)$ tensor analyzing power plotted in the laboratory system for the forward-going proton in d+p elastic scattering. The deuteron energies are 270 MeV (black), 200 MeV (red), and 140 MeV (blue). The theoretical angular distributions show a Gaussian shape [9] that corresponds well to the data at 140 MeV and the data up through 12° at 270 MeV. For the larger angles at 270 MeV, the smooth angular distributions breaks away from the Gaussian shape. This shape increases smoothly with increasing energy, also leaving behind the 200 MeV measurements. These discrepancies need to be considered when extracting a beam polarization. A_{XX} data is also available.

Measurements of $A_{YY}(\theta)$ are also available for d+Carbon elastic scattering at 270 MeV [10] and 200 MeV [11], as shown here in Figs. 8 and 9.

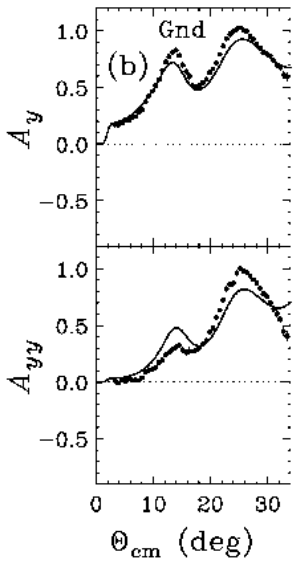

Figure 8 (left); Measurements of d+C analyzing powers at 270 MeV.

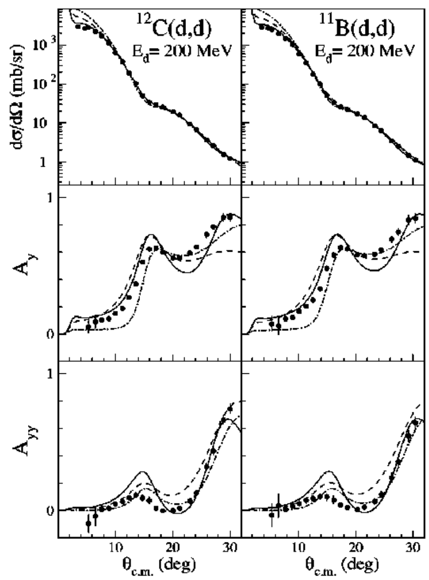

Figure 9 (right): Measurements of d+C and d+B cross section and analyzing powers at 200 MeV.

Note that in the angular range available for the WASA forward detector, the values of $A_{YY}(\theta)$ at 200 MeV are small (< 0.1) and will be difficult to use for a precise beam polarization calibration.

Operation at other energies will require that we either assume the polarization is unchanged with a change in beam energy or find another standard suitable for a check. The Low Energy Polarimeter usually operates by observing d+C elastic scattering at 40° in the lab and at the 76-MeV transfer beam line energy. For this configuration, the tensor analyzing power is very small and not useful as a standard. Some consideration is being given to observing d+p elastic scattering instead at a well-chosen angle pair where the p+d coincidence may be observed. This option is still under development.

The RF transition units in the polarized ion source offer a variety of polarization options. At present only the options of an RF transition following a single separation sextupole are usually used. These offer two vector polarized options, a weak field transition or the combination of the 2-6 and 3-5 strong field transitions. Neither is nominally tensor polarized. At an earlier time, the functions of the 2-6 and 3-5 transition units were operated separately (which requires a different transition field configuration). In this case the result of each transition alone is a vector polarization of 1/3 in both cases and tensor polarizations of magnitude 1 and opposite signs. These polarizations will be reduced depending on the efficiency of the transition units, but the 3-to-1 magnitude rule is generally well preserved. If the vector polarization may be determined from either the COSY experiment or the LEP, then this rule allows the tensor polarization to be inferred as well. This allows for another check of the calibration of the tensor polarization, and it may be employed at all deuteron beam energies.

The final calibration scheme will be determined in consultation with the COSY machine staff.

Beam time request

This beam time request asks for two weeks to study the deuteron beam and another two weeks on a separate occasion to study the proton beam. For each beam, at least four energies will be run. The optimum choice of detector is the Forward Detector from the WASA setup. A new target assembly will be installed at the old WASA location. It will contain thin, pointed rods of carbon and polyethylene (possibly coated for heat transport) mounted for separate insertion at the edge of the beam. The polyethylene sample will provide a calibration reference for the cross section and analyzing power using scattering from the hydrogen in the target.

Because of the time needed for the installation of the new twin cross target chambers, the running time should be scheduled for the last quarter of 2016 (after the fall shutdown in October 2016). The first beam time should be for deuterons. The proton run should be scheduled for some time in 2017. Two weeks of beam time are requested for each run to allow for triggers that emphasize different parts of the background and cycling through at least five polarization states (2 vector, 2 tensor, and 1 unpolarized). If time permits, additional energies below 160 MeV for deuterons will be included in the run.

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