The EDDA Experiment at COSY

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Abstract. Polarized and unpolarized proton-proton elastic scattering is investigated with the EDDA-experiment at the Cooler Synchrotron COSY at Jülich to significantly improve the world data base in the beam energy range 500-2500 MeV. Measurements during beam acceleration with thin internal targets and a large acceptance detector produce excitation functions over a broad angular and energy range with unprecedented internal consistency. Data taking with an unpolarized CH_2 fiber target and an unpolarized beam have been completed and the derived differential cross sections demonstrate the benefit of this technique. With a polarized atomic beam target recently installed in COSY and a polarized COSY beam – currently under development – the measurements will be extended to analyzing powers and spin correlation parameters.

INTRODUCTION

Nucleon-nucleon (NN) elastic scattering is fundamental to the understanding of the NN force, being the basis for many models in nuclear and heavy ion physics. Having been studied for decades, an enormous experimental database has been acquired. When compared to theoretical models of the NN force the experimental information generally enters through empirical phase shifts, which are fit to the data assuming a smooth energy dependence (e.g. [2]). Below about 1 GeV the phase shifts are well known owing to the many experiments performed in this region. Above 1 GeV the data points are less numerous – especially for polarization observables – and scatter considerably. Until recently global phase shifts did not extend beyond 1.6 GeV. For a substantial improvement of the NN database experiments are needed which provide internally consistent data over a wide kinematic range and/or with small uncertainties. Storage rings for nuclear physics offer novel experimental possibilities [3]: low background, easy changes of beam energy and the possibility to use pure polarized internal hydrogen targets in the recirculating beam.

These novel options are exploited by the EDDA experiment [4], designed to measure unpolarized cross sections, analyzing power and the spin correlation parameters A_{yy}, A_{xx}, and A_{xz} between 500 and 2500 MeV in narrow energy

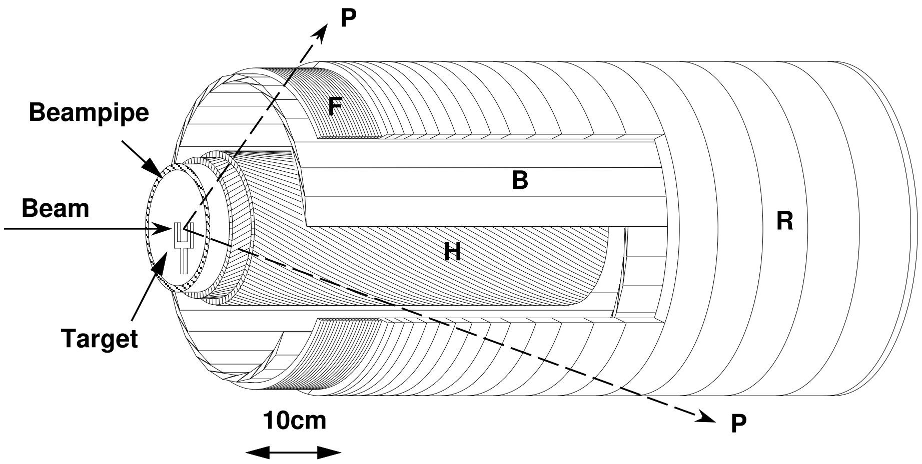

FIGURE 1. The EDDA detector (not to scale): **Target** fiber (CH_2) or a polarized atomic hydrogen beam; **B** scintillator bars ; **R** scintillator semi-rings; **F** semi-rings and **H** helix (4 layers) made from scintillating fibers.

steps and over a wide angular range ($35° < \theta_{\mathrm{c.m.}} < 90°$). It uses the internal proton beam of the Cooler Synchrotron COSY in Jülich on a thin 5x4 μm^2 CH_2 fiber target for unpolarized and an atomic beam target [5] for polarized measurements.

Data are taken **during synchrotron acceleration**, such that a low-statistics excitation function is acquired in a single machine cycle (injection, acceleration, deceleration, reset). Statistics is gained by repetition of this cycle. This technique was first used for fixed angle measurements of differential cross sections at SATURNE [6] and analyzing powers at KEK [7]. Because all beam energies are sampled within a few seconds, systematic errors due to drifts in luminosity monitors, target and beam performance are greatly reduced.

Excitation function data of this type, being quasi-continuous in beam energy, is ideally suited to look for energy-dependent structures in elastic scattering observables. Such structures have been proposed (e.g. [8]) as a signature of a coupling of dibaryons – genuine six quark states – to the NN channel but, despite large efforts, no experimental evidence has been found as yet. Searching a large energy range with many observables and good resolution will hopefully clarify if such states exist with an appreciable coupling to the NN channel.

DETECTOR

The EDDA detector is shown schematically in Fig. 1. Its design is based on a fast triggering of coplanar two–prong events of charged particles that fulfill the kinematic relation between the laboratory angles for elastic proton–proton scattering. The detector consists of a cylindrical double layer that surrounds the thin walled beampipe downstream from the internal target (In Fig. 1 a horizontally oriented fiber target) . The angular range covered extends from $\Theta_{lab} = 10°$ to $72°$ subtending 85% of the solid angle. The outer layer consists of 32 scintillator bars (B in Fig. 1) parallel to the beam axis, surrounded by scintillator semi–rings (R,F). The scintillators are in both layers partially overlapping; their cross sections have been designed such that each particle from the vertex traversing the outer layer deposits energy in two adjacent bars and two semi–rings. Analysis of the fractional light output is then used [9] to determine scattering angles with a resolution of 1.0° (1.9°) (FWHM) in $\Theta_{c.m.}(\Phi_{c.m.})$.

For unpolarized measurements the reaction vertex is well determined by the beam width and the size of the fiber target. Here, the outer layer suffices to measure scattering angles. Use of the atomic beam target requires vertex reconstruction. For this purpose an inner detector made from 4 layers of scintillating fibers (160 each) wound helically around the beam pipe in alternating directions has been installed. (H in Fig. 1).

UNPOLARIZED MEASUREMENTS

Measurements were performed with about 10^7 protons circulating in COSY, data were collected during beam acceleration (1.15 GeV/c/s) between 500 and 2500 MeV proton energy. A total of $4{\cdot}10^7$ elastic scattering events have been accumulated.

Background originating from the carbon content of the CH_2 target was measured with a pure carbon target and subtracted statistically. Contributions from inelastic pp reactions are small and were investigated with Monte-Carlo simulations.

The relative change of luminosity as a function of beam energy was monitored by concurrent measurements of the total yield of secondary electrons emanating from the target and the δ electron yield from e-p elastic scattering. They are described in [10]. Both methods agree within 2.5% for all energies. Absolute normalization of the whole data set was achieved with reference to data at 793 MeV from LAMPF [11] where an absolute normalization uncertainty of 1% was achieved.

Unpolarized differential cross sections based on $2{\cdot}10^7$ elastic pp events have been published [10] and are shown in Fig. 2. They add 2121 entries to the NN elastic scattering data base with typically 5% error (statistical and systematic). Two excitation functions are compared to previously published data in Fig. 3. The impact of the new EDDA data on phase shifts [2] is evinced in the difference of the dashed (solution SM94, without EDDA data) and solid (solution SM97, with EDDA data) lines. Note, that the phase shift analysis

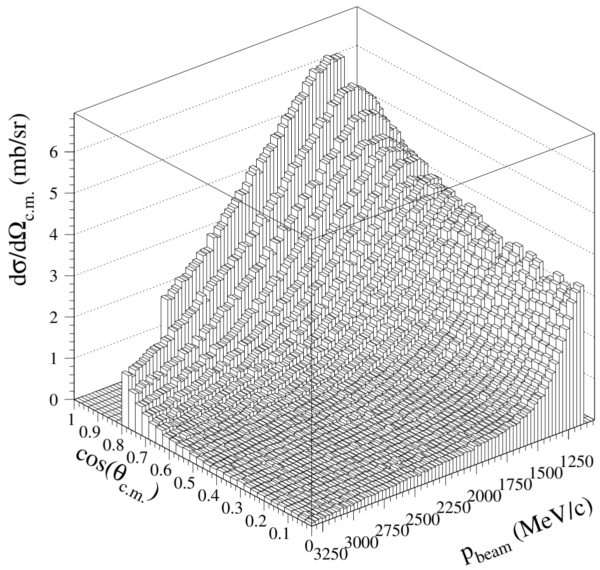

FIGURE 2. Differential proton-proton elastic scattering cross section as a function of c.m. scattering angle and proton beam momentum [10].

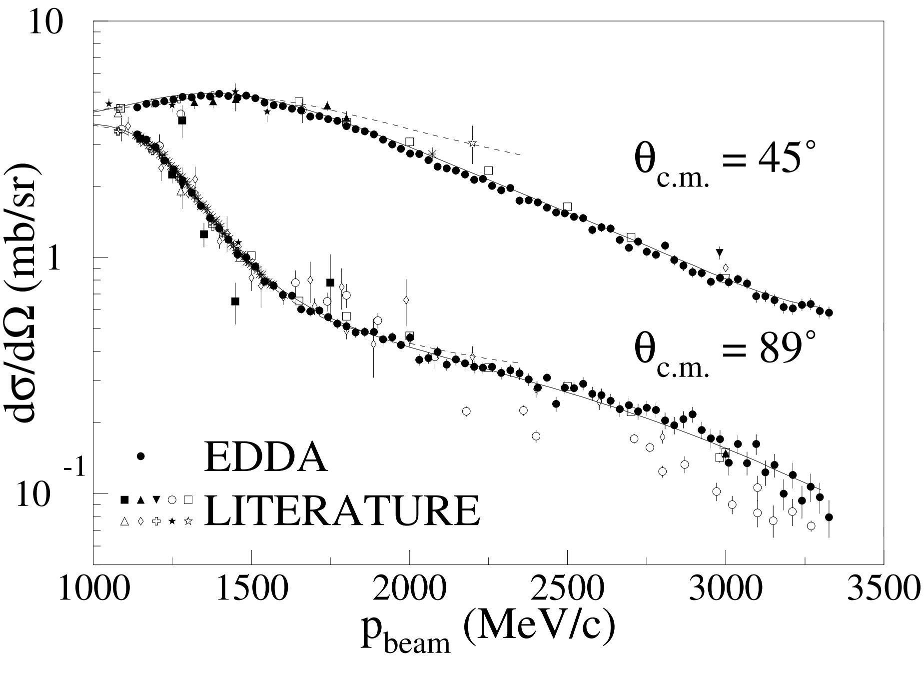

FIGURE 3. Excitation functions of unpolarized differential cross sections at two selected c.m. scattering angles. The EDDA data from [10] are compared to previously published data (extracted from the SAID [2] database) and two phase shift solutions [2] excluding (dashed) and including (solid line) this data.

could be extended to 2500 MeV. No indication for structures in the present data have been observed [10].

Currently, a refined analysis of all acquired data is underway in order to further reduce the error bars. Improvements are expected due to increased statistics, better background suppression by use of self-organizing maps for event classification and an additional luminosity monitor.

The quality of the unpolarized cross sections acquired by the EDDA experiment show the potential of the experimental technique. The EDDA collaboration now strives to achieve the same level of precision on polarization observables.

PREPARATIONS FOR POLARIZED MEASUREMENTS

For the experimental program of the EDDA experiment on polarization observables the detector has been upgraded by the inner helix detector (cf. Fig. 1) by the end of 1996. With the polarized atomic beam target – installed in May this year – and an unpolarized COSY beam, analyzing powers will be measured first. For spin correlation parameters both a polarized target and beam are needed and will commence when a polarized COSY beam over the full energy range and with sufficient intensity is available.

Polarized Target

The design of the atomic beam target [5] had to meet constraints imposed by the EDDA experiment. First, the space close to the interaction region is limited: target components must be outside the angular acceptance of the EDDA experiment. This allows only weak holding fields such that pure spin states must be used. Secondly, measurements during beam acceleration makes the use of a storage cell unfavorable. The reduction of the acceptance, and thus the injected current at 40 MeV beam energy, and possible beam movements during acceleration to 2500 MeV would at least partly offset the benefit of higher target densities. Since elastic scattering has a large cross section (2.5 -25 mb in the angular range covered by the EDDA detector) target densities of a few 10^{11} H/cm^2, as they are obtained by atomic beams, suffice. With a recirculating (1.5 MHz) COSY beam of $> 5 \cdot 10^{10}$ protons luminosities of $> 10^{28}$ cm^{-2}s^{-1} will produce rates of > 50 - 200 elastic events per second.

The atomic beam target as it was used in first tests during June 1997 is shown in Fig. 4. Hydrogen is dissociated in a 350 W RF discharge and passes through an aluminum nozzle cooled to 30 K. The low temperature of the nozzle leads to a decreased lower velocity (most probable velocity 1.1 km/s) and thus an increased target thickness. Hydrogen atoms in the $m_j = +1/2$

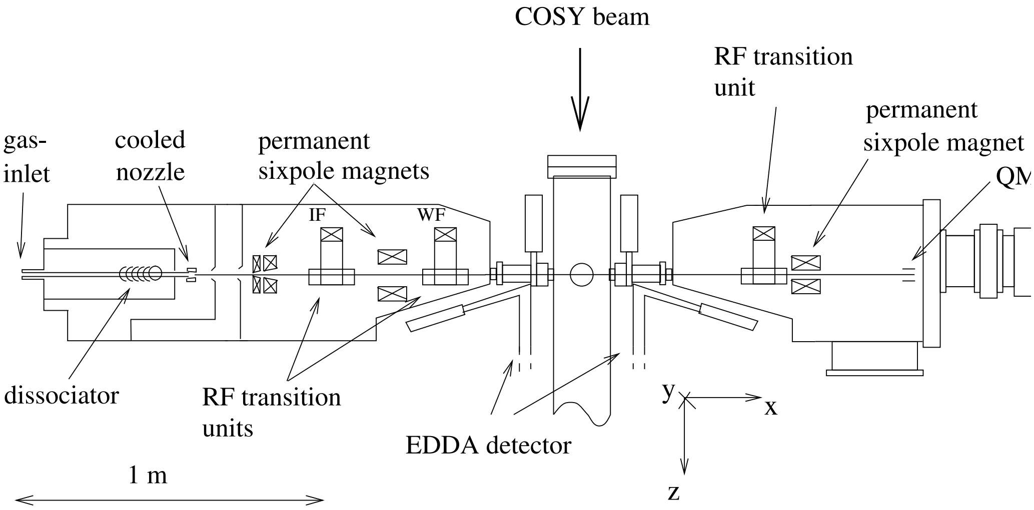

FIGURE 4. Simplified drawing of the atomic beam target [5]. Only the upstream light-guides and phototubes of the EDDA detector (cf. Fig. 1) are shown to show the space constraints imposed on the target chambers.

spin states are focused by a set of three permanent sixpole magnets into the interaction region while the $m_j = -1/2$ states are defocused.

The proton spin can be prepared by two RF-transition operating at intermediate (IF, 2→ 4) and weak fields (WF, 1→ 3). Nuclear polarization in a pure state is obtained when the IF transition is in operation. The proton spin is aligned by a 0.9 mT holding field in the interaction region and can be flipped by either the WF transition or by changing the sign of the holding field. In the beam dump (right side of Fig. 4) a sixpole magnet, RF transition and a QMS is installed for beam optimization and monitoring.

Right after installation the atomic beam target was tested with a 1455 MeV/c internal COSY beam, i.e. data were acquired after synchrotron acceleration. The preliminary result of this very first test is presented here, with the analysis still going on. It should be noted that due to limited time for optimization of the atomic beam, performance with the design values [5] is not yet to be expected.

The vertical beam profile of the atomic beam has been measured by sweeping the COSY beam through steerer magnets across the target and measuring the vertex distribution of elastic proton-proton scattering events. In Fig. 5 the movement of the COSY beam (top) and the distribution of the scattering vertex along the COSY beam (bottom) is shown as a function of cycle time. From the modulation of scattering rate from the atomic beam at z=0 with the vertical position of the COSY beam, an atomic beam width of 13 mm (FWHM) is derived. This is in agreement with the width extracted from the z-distribution of the scattering vertex when the resolution of vertex reconstruction of 2.5 mm is considered. Scattering rates from the atomic beam

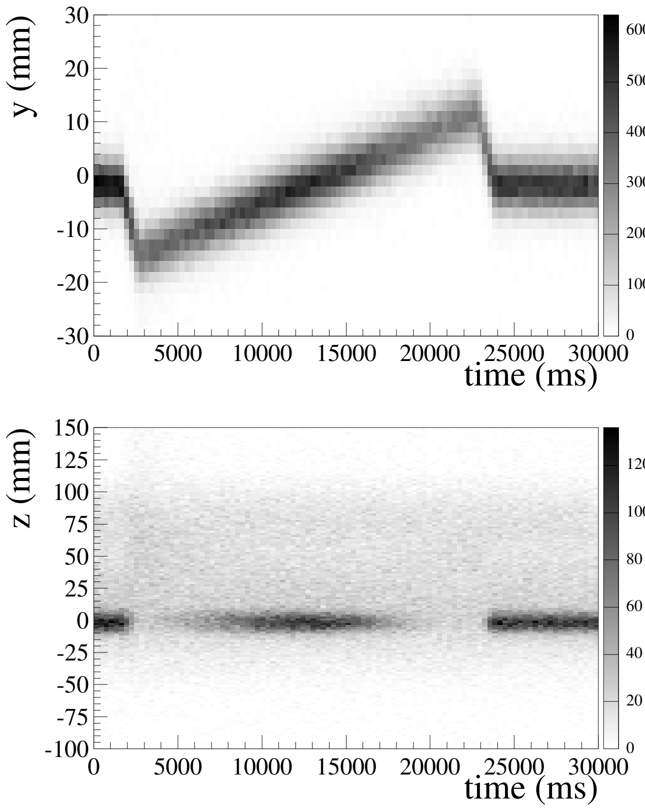

FIGURE 5. Top: Distribution of the reconstructed scattering vertex perpendicular to both the COSY and atomic hydrogen beam as a function of cycle time. The COSY beam is swept across the target beam by steerer magnets. **Bottom:** The resulting modulation of the scattering vertex distribution along the COSY beam (z). From the change of the scattering rate with time at the atomic beam location (z=0, bottom) the vertical atomic beam profile is deduced. For the choice of coordinates refer to Fig. 4.

part of the target thickness distribution are in line with densities of about 10^{11} H/cm^2.

In the tests only the IF transition was used to prepare a pure $m_j = +1/2$, $m_I = +1/2$ state. The spin was flipped by reversing the holding field. The target polarization was measured by observing the asymmetry of elastic proton-proton scattering events with known analyzing power [2]. The scattering rate to the left ($-70° < \phi < 70°$) and right ($-110° < \phi < 250°$) are plotted in Fig. 6 (a) and (c) as a function of the reconstructed scattering vertex position along the COSY beam axis. The derived polarizations are shown in (b) and (d). Apart from the polarized beam at z=0, a diffuse cloud of unpolarized hydrogen extends up and downstream. The decrease in rate below z<-20mm and z>80mm is due to the acceptance of the EDDA hardware trigger. Polarizations of about 60% (when the diffuse background is subtracted of around

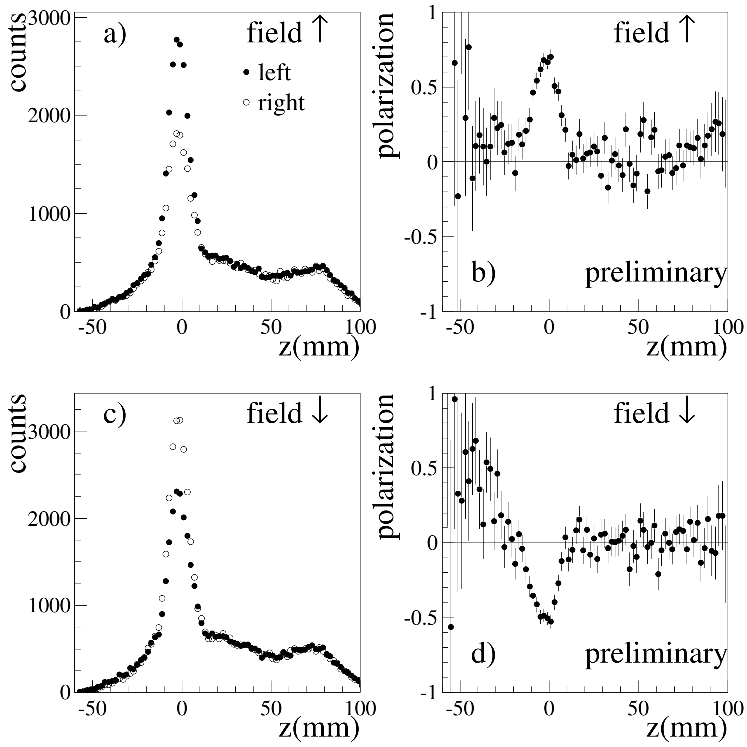

FIGURE 6. Elastic proton-proton scattering rate as a function of the position z along the unpolarized COSY beam to the left and right of the detector (left column) and the derived polarization (right column). The polarized atomic hydrogen beam stands out at z=0 on a unpolarized background. A holding field in the interaction region of 0.9 mT pointing up (top row) or down (bottom row) was used to align the target spins.

80%) have been reached in this first test. The difference in polarization between the two field directions – measured separated in time – may reflect true changes in polarization or be due to false asymmetries in this preliminary analysis and needs to be investigated. Technical improvements now focus on a reduction of the unpolarized hydrogen background by vacuum improvements and optimization of the atomic hydrogen beam transport and are discussed in [5].

Polarized Beam

Polarized beam development using the polarized source at COSY [12] has started [13]. Here, the EDDA detector serves as a fast polarimeter for beam development by acquiring continuously the asymmetry of scattering events from a CH_2 fiber target as a function of beam energy. Within a few minutes, relative changes of the beam polarization can be measured. Up to now the COSY team has successfully accelerated polarized protons up to 2200 MeV/c crossing 7 depolarizing resonances. This was achieved by dynamic changes of ion optics without recourse to fast quadrupoles. Polarized beam development will continue later this year.

CONCLUSION

The quality of the unpolarized cross section data produced by the EDDA experiment have demonstrated that the experimental method of data acquisition during synchrotron acceleration works well. Here, the main challenge has been and is the consistent normalization.

Preparations for continuing the experiment with a polarized atomic beam target and a polarized beam are well under way. A detector upgrade has been successfully completed and the target has produced both density and polarization not too far from its design values. However, unpolarized background observed in these first tests needs to be reduced, and first steps in this direction have been taken. Development of the polarized beam at COSY, i.e. preserving polarization when crossing depolarizing resonances, is under way and has led to promising results.

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REFERENCES

1. M. Altmeier[1], F. Bauer[2], J. Bisplinghoff[1], T. Bissel[1], R. Bollmann[2], M. Busch[1], K. Büßer[2], P. Cloth[3], R. Daniel[1], O. Diehl[1], F. Dohrmann[2], H.P. Engelhardt[1], J. Ernst[1], P.D. Eversheim[1], O. Felden[1], J. Flammer[2], M. Gasthuber[2], R. Gebel[3], J. Greiff[2], A. Groß[2], R. Groß-Hardt[1], K. Hebbel[2], F. Hinterberger[1], T. Hüskes[1], R. Jahn[1], I. Koch[2], R. Langkau[2], T. Lindemann[2], J. Lindlein[2], R. Maier[3], R. Maschuw[1], T. Mayer-Kuckuk[1], M. Pfuff[2], D. Prasuhn[3], H. Rohdjeß[1], D. Rosendaal[1], P. von Rossen[3], N. Schirm[2], M. Schulz-Rojahn[1], V. Schwarz[1], W. Scobel[2], S. Steinbeck[2], G. Sterzenbach[3], S. Thomas[1], H.J. Trelle[1], M. Walker[1], E. Weise[1], A. Wellinghausen[2], K. Woller[2], R. Ziegler[1]
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2. R. A.. Arndt et al., *Phys. Rev.* **C 50**, 2731 (1994) and preprint nucl-th/9706003 (1997); Program SAID solutions SM94 and SM97.
3. H. O. Meyer "Nuclear Physics with Light-Ion Beams" to be published in *Ann. Rev. Nucl. Part. Sci.*

4. J. Bisplinghoff and F. Hinterberger, AIP Conf. Proc. **221**,312 (1991); W. Scobel, Phys. Scripta **48**,92 (1993); H. Rohdjeß, Proc. Int. Conf. on Physics with GeV-Particle Beams (Jülich 1994), p.334.
5. P.-D. Eversheim, Contribution to this Conference
6. M. Garcon et al., *Nucl. Phys.* **A445**, 669 (1985)
7. H. Y. Yoshida et al., *Nucl. Phys.* **A541**, 443 (1992)
8. P. Gonzalez et al. *Phys. Rev.* **D35**, 2142 (1986) ; R. Vinh Mau et al. *Phys. Rev. Lett.* **67**, 1392 (1987)
9. J. Bisplinghoff et al. (EDDA Collaboration), Nucl. Instr. and Meth. **A329**,151 (1993);
10. D. Albers et al. (EDDA Collaboration), *Phys. Rev. Lett* **78**, 1652 (1997)
11. A. J. Simon et al. *Phys. Rev.* **C48**, 662 (1993) K. Ackerstaff et al., Nucl. Instr. and Meth. **A335**,113 (1993).
12. R. Gebel, Contribution to this Conference
13. A. Lehrach et al., *Proceedings of the 12th International Symposium on High-Energy Spin Physics*, Amsterdam 1996, World Scientific 1997, pp. 416-418.