Results from EDDA@COSY: Spinobservables in Proton-Proton Elastic Scattering[1]

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Abstract. Elastic proton-proton scattering as one of the fundamental hadronic reactions has been studied with the internal target experiment EDDA at the Cooler-Synchrotron COSY/Jülich. A precise measurement of differential cross section, analyzing power and three spin-correlation parameters over a large angular ($\theta_{\mathrm{c.m.}} \approx 35° - 90°$) and energy ($T_p \approx 0.5 - 2.5$ GeV) range has been carried out in the past years. By taking scattering data during the acceleration of the COSY beam, excitation functions were measured in small energy steps and consistent normalization with respect to luminosity and polarization. The experiment uses internal fiber targets and a polarized hydrogen atomic-beam target in conjunction with a double-layered, cylindrical scintillator hodoscope for particle detection. The results on differential cross sections and analyzing powers have been published and helped to improve phase shift solutions. Recently data taking with polarized beam and target has been completed. Preliminary results for the spin-correlation parameters A_{NN}, A_{SS}, and A_{SL} are presented. The observable A_{SS} has been measured the first time above 800 MeV and our results are in sharp contrast to phase-shift predictions at higher energies. Our analysis shows that some of the ambiguities in the direct reconstruction of scattering amplitudes which also show up as differences between available phase-shift solutions, will be reduced by these new measurements.

INTRODUCTION

The nucleon-nucleon (NN) interaction as one of the fundamental processes in nuclear physics has been studied over a broad energy range and its contribution to our understanding of the strong interaction cannot be overstated. NN elastic scattering data, parameterized by energy-dependent phase-shifts, are used as an important ingredient in theoretical calculations of inelastic processes, nucleon-nucleus and heavy-ion reactions. Below the pion production threshold at about 300 MeV elastic scattering is described to a high level of precision by a number of models [1], e.g. phenomenological and meson exchange. More recently, chiral perturbation theory [2] has also made significant progress in this energy domain. Meson exchange models have been pushed further and

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[1] supported by the BMBF and FZ Jülich

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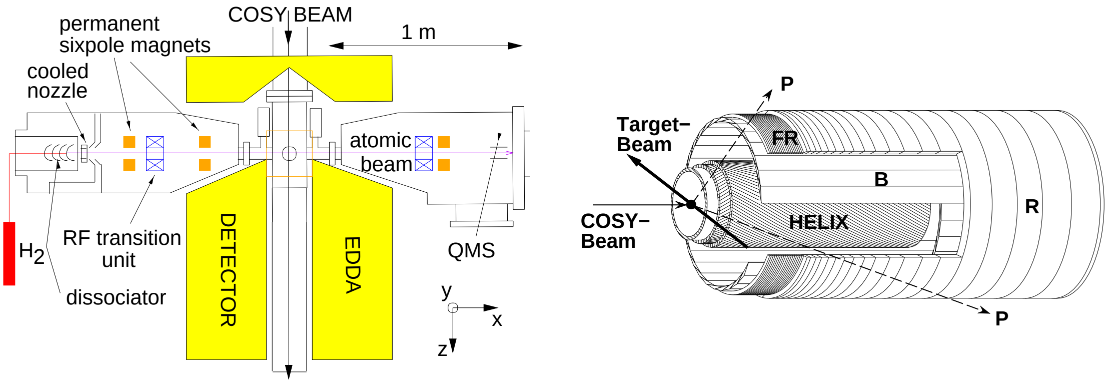

FIGURE 1. Schematic view of the atomic beam target (left) and the EDDA-detector (right).

roughly reproduce experimental data up to 1 GeV. However, at even higher energies, where details of the short-range interaction may become important, the limits of these models remains to be explored. An unambiguous determination of phase shift parameters has been achieved up to about 1 GeV[3, 4, 5, 6, 7]. With increasing energy, however, the number of partial waves to be determined grows, but the quality and density of the experimental data base diminishes. Recently, it has been pointed out that above about 1.2 GeV serious discrepancies between Phase-Shift Analysis (PSA) of different groups [7, 8] exist. An unambiguous, model-independent direct reconstruction of the 5 complex scattering Amplitudes, which could solve this puzzle, is as yet not possible, as it was shown by the Saclay-Geneva group [8]. Only new data, preferably on observables where little or no data exists, will pin down phase shift parameters and remove discrete ambiguities in amplitude reconstruction.

EXPERIMENT

The EDDA-experiment was conceived to provide high-precision elastic-scattering data in the COSY energy range (0.5-2.5 GeV). Unpolarized differential cross [9] and analyzing power excitation functions [10] have been measured in the first phases of the experiment and helped to extend PSA-analysis up to 2.5 GeV [7, 11]. These data have been used to impose strong upper bounds [12] on possible resonant contributions to pp-elastic scattering, as they might arise from coupling to isovector, strangeness zero dibaryonic resonances (e.g. [13, 14]).

Recently, data taking with a polarized beam on the polarized atomic beam target [15] (Fig. 1) has been completed. This allows to access spin correlation parameters A_{BT}, which describe the dependence of the cross section on the relative spin-orientation of the beam (B) and target (T) protons. By orienting the target-spin in different directions, normal (N) to or sideways (S) in the scattering plane, or longitudinal (L) to the beam, three such spin correlation parameters A_{NN}, A_{SS}, and A_{SL} can be measured with a detector of full azimuthal coverage. Here, a storage ring provides a unique experimental environment by combining pure polarized hydrogen targets with fast and easy spin-manipulation in order to minimize systematic errors, a technique pioneered by the

PINTEX [16, 17] collaboration at IUCF at lower energies.

The EDDA-detector [18, 19] (cf. Fig.1) is comprised of two cylindrical double-layered scintillator hodoscopes surrounding the COSY-beampipe downstream of the internal target. Protons from pp elastic scattering are detected in coincidence for scattering angles ranging from 30° to 90° in the center-of-mass. A beam of polarized hydrogen atoms crossing the COSY beam at right angle serves as an internal target with a typical area density of $2 \cdot 10^{11}$ atoms/cm^2 and polarization above 90%. The density of unpolarized hydrogen which builds up in the beam pipe when operating the target reduces the effective polarization to about 70% for accepted scattering events. To this end, the scattering vertex, reconstructed offline with 1 mm resolution, is used to select events originating in the overlap region of the atomic beam target with the COSY beam. The target polarization is aligned by applying a weak (1 mT) magnetic guiding field in either one of 6 possible directions $\pm$x,$\pm$y, and $\pm$z in the interaction region.

Data is acquired during acceleration of the COSY beam and for about 5s in the flattop at the desired beam momentum. Beam intensities ranged from $3 \cdot 10^9$ to $1.5 \cdot 10^{10}$ protons stored and accelerated in the ring and provided luminosities in the $1-5 \cdot 10^{27}$ 1/(cm^{2}s) range with beam polarizations between 50 and 75%. Due to the limited beam intensity, nine different flattop momenta were chosen to cover the energies above 2100 MeV/c with sufficient statistics in view of dropping cross-sections. Data in the lower energy range is obtained from data recorded during the ramp. For each COSY machine cycle the target and beam polarizations were held constant and then alternated between the twelve different combinations of the beam ($\pm$y) and target ($\pm$x,$\pm$y,$\pm$z) spin orientations.

ANALYSIS

Data analysis proceeds in two steps: First the elastic scattering rate for 5° wide bins in the c.m. polar angle $\theta_{\mathrm{c.m.}}$ is determined as a function of the azimuthal angle ϕ, by selecting events well within the detector acceptance, which originated at the desired target location and obey elastic scattering kinematics. Due to the analyzing power and the non-vanishing spin correlation coefficients, the scattering rate for each spin combination exhibits characteristic modulations with the azimuthal angle. Secondly, the spin correlation parameters as well as beam and target polarizations are extracted either by calculating certain asymmetries [20, 21] which cancel the influence of detector efficiencies to first order, or by standard χ_2-minimization techniques. Both methods yield consistent results. The overall normalization of the target and beam polarizations is fixed with reference to the EDDA analyzing power data [10] with an uncertainty ranging from 1.5-3% from lower to higher energies.

RESULTS

The results for the three spin correlation parameters were extracted for 12 angle bins between 30° and 90° in $\theta_{\mathrm{c.m.}}$ both for the data measured during the flattop and beam acceleration. An example of an excitation function and an angular distribution is shown

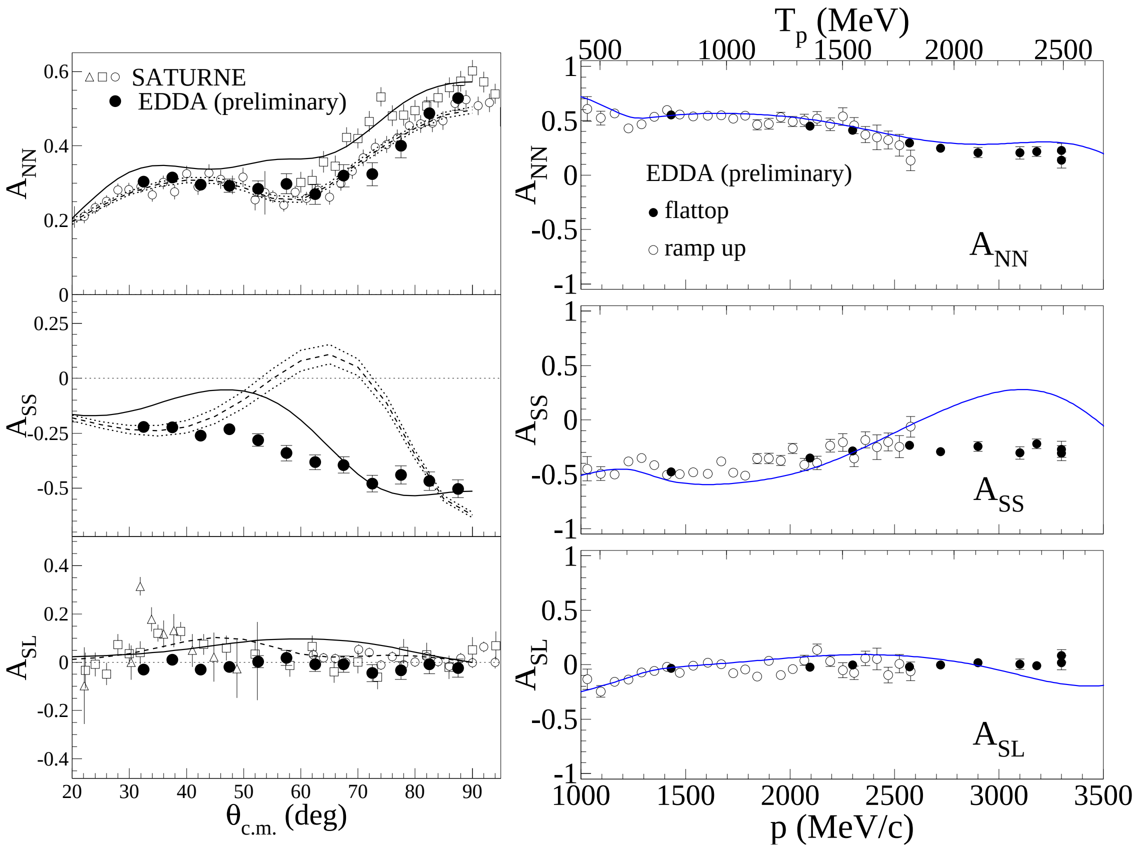

FIGURE 2. Angular distributions at 2572 MeV/c (left) and excitation functions at $\theta_{\text{c.m.}} = 47.5°$ (right) of spin correlation parameters A_{NN}, A_{SS}, and A_{SL} in comparison to phase shift predictions of SAID [7] (SM00, solid) and the Saclay-Geneva [8] (dashed line) analysis. On the left, data from SATURNE [22] are shown as open symbols. On the right, closed (open) symbols distinguish data points measured at the flattop (during acceleration) of the COSY machine cycle. All EDDA data are preliminary.

in Fig 2. The results obtained during beam acceleration nicely match those obtained at fixed momenta, and provide reasonably accurate data below 2100 MeV/c.

Previous measurements of spin correlation parameters at these energies were done mainly at SATURNE [22] on A_{NN}, A_{LL}, and A_{SL}. In comparison, our new data on A_{NN} is consistent at all energies, however, we find values for A_{SL} more or less compatible with zero at all angles and do not confirm excursions in the angular distributions (cf. Fig. 2) as evinced in the SATURNE data. In contrast the observable A_{SS} has not been measured before above 800 MeV. These data thus put the predictive power of existing parameterization by scattering phase shifts to a true test. In the figures our new data are compared to PSA solutions of the Virginia (SAID, solution SM00) and Saclay-Geneva groups. They fit our data on A_{NN} and A_{SL} reasonably well but are in striking disagreement with the new data on A_{SS} - and each other - in particular at higher energies. PSA solutions at these energies should therefore be used with caution.

This highlights that the world data base on proton-proton elastic scattering to date does not allow to unambiguously determine the scattering phase shifts or amplitudes at energies well above 1GeV. It will be interesting to see to what extent the new spin correlation data on A_{SS} will be a remedy. Since A_{SS} is sensitive to the interference of non-spinflip and double-spinflip helicity amplitudes [23], it provides important information on the spin-dependence of the NN-interaction. To explore this, we carried out a direct reconstruction of the scattering amplitudes along the lines of [8] and found that the addition of our data to the world database removes some – but not all – of the discrete ambiguities. Here, further, significant improvement, can only be obtained by accurate triple polarization observables, i.e. with detection of the polarization of one ejectile. To what extent the PSA variants on the market will converge towards a unique solution remains to be seen until the new EDDA data is included in the data base. First steps in this direction indicate sizable modification of the phase shifts in the central partial waves of the SAID solutions.

ACKNOWLEDGMENTS

The excellent beam support by the COSY accelerator team during all phases of the now completed experimental program of EDDA is warmly acknowledged.

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