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Cross-sections and spin observables in proton-proton elastic scattering: Results from EDDA at COSY

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Abstract. At the Cooler-Synchrotron COSY/Jülich polarized and unpolarized elastic proton-proton scattering has been investigated with the EDDA-Experiment in the energy range ($T_p \approx$ 0.5–2.5 GeV). By taking scattering data during the acceleration of the beam with a large-acceptance ($\theta_{\mathrm{c.m.}} \approx 30^\circ$–$90^\circ$) detector, precise excitation functions for differential cross-section and analyzing power have been measured in small energy steps with consistent normalization with respect to luminosity and polarization. These data have helped to improve the determination of phase-shifts at higher energies and impose tight quantitative upper bounds on possible resonant contributions to pp elastic scattering, as they might arise from exotic 6-quark configurations. Recently, with polarized beam and target, the spin-correlation parameters A_{NN}, A_{SS}, and A_{SL} have been determined at 10 energies between 0.8 and 2.5 GeV. 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.

PACS. 24.70.+s Polarization phenomena in reactions – 25.40.Cm Elastic proton scattering – 11.80.Et Partial-wave analysis – 13.75.Cs Nucleon-nucleon interactions (including antinucleons, deuterons, etc.)

1 Introduction

The nucleon-nucleon (NN) interaction is fundamental to nuclear physics and has been studied over a broad energy range. The contribution of extensive experimental and theoretical efforts to our understanding of the strong interaction cannot be overestimated. 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. While below the pion production threshold at about 300 MeV elastic scattering is described to a high level of precision [1] by a number of models, *e.g.* phenomenological, meson exchange, and more recently chiral perturbation theory [2], only meson exchange models have been pushed further to roughly reproduce experimental data up to 0.8 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. On the experimental side, available data allow to do a Phase-Shift Analysis (PSA) unambiguously up to about 1 GeV [3–7]. At higher energies, the increased number of partial waves to be determined is not yet met by experimental data of sufficient quality and density, leading to serious discrepancies between phase-shift solutions of different groups [7,8] above about 1.2 GeV.

To this end, the EDDA-experiment has been conceived to provide highly accurate data between 0.5 and 2.5 GeV. Being internal to the COSY ring it takes advantage of this unique experimental environment: data acquisition during beam acceleration to measure quasi-continuous excitation function, first done at SATURNE [9], and the use of pure polarized hydrogen targets for fast and easy spin-manipulation to minimize systematic errors, a technique pioneered by the PINTEX [10,11] Collaboration at IUCF at lower energies.

EDDA uses the recirculating proton beam of COSY in conjunction with thin internal targets, CH_2-fibers for unpolarized and a hydrogen atomic beam target [12] for polarized measurements. Elastically scattered protons are detected in coincidence by a cylindrical double-layered

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scintillator hodoscope [13,14] for scattering angles ranging from 30° to 90° in the center of mass. Excitation functions of unpolarized differential cross-sections [15] and analyzing power [16] have been measured in the first phases of the experiment and helped to extend the PSA up to 2.5 GeV [7,17].

Such excitation functions with small energy steps are ideally suited to search for resonant contributions, as they might arise by coupling of dibaryonic states B_2 [18,19] to the elastic channel. Although these states have been proposed in many different models (*e.g.*, [20–22]) they have not been established experimentally [23].

Here, we report on two recent achievements: preliminary results on spin correlation parameters, where data taking with polarized beam and target has been recently completed, and upper limits on resonant contributions to elastic scattering in the mass range $\sqrt{s} = 2.2 \ldots 2.8$ GeV based on the previously published data.

2 Spin correlation parameters

With a vertically polarized (50–75%) COSY-beam and a polarized atomic beam, spin-aligned in the interaction region by a weak (1 mT) magnetic guiding field to one of the 6 possible directions $\pm x$, $\pm y$, and $\pm z$, we have access to the spin correlation parameters A_{NN}, A_{SS}, and A_{SL}. A_{BT} describe the deviation of the cross-section from the spin-averaged value for the spin of beam (B) and target (T) protons oriented longitudinal to the beam (L) or normal (N) to or sideways (S) in the scattering plane. With beam intensities ranging from $3 \cdot 10^9$ to $1.5 \cdot 10^{10}$ protons stored we achieved luminosities in the $(1\text{–}5) \cdot 10^{27}/(\mathrm{cm}^2\mathrm{s})$ range. We took data during acceleration and at the flat-top momentum, where 9 about evenly spaced beam momenta between 2.1 and 3.3 GeV/c were selected. This allows to cover the low (acceleration) and high (flat-top) energy region with sufficient statistical accuracy. 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. A cut on the reconstructed vertex to select events from the beam-target overlap are applied as well as cuts selecting events which 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 [25,26] 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 [16]. An example of a preliminary angular distribution obtained at 2572 MeV/c ($T_p = 1.8$ GeV) is shown in fig. 1. The data analysis is almost finalized.

Previous measurements of spin correlation parameters at these energies were done mainly at SATURNE [24] 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 (see fig. 1) 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 fig. 1 the new data are compared to different PSA variants. They disagree strikingly with our data on A_{SS} and with each other. 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 1 GeV. It will be interesting to see to what extent the new spin correlation data on A_{SS} will be a remedy. As a first step we found [27] that the addition of our data to the world database removes some of the ambiguities in the reconstruction of the scattering amplitudes found in [8].

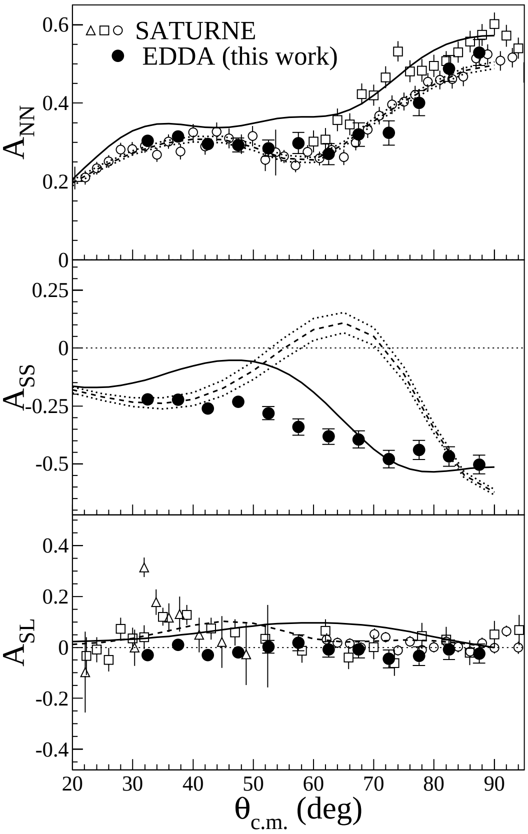

Fig. 1. Angular distribution of the spin correlation parameters A_{NN}, A_{SS}, and A_{SL} at $p = 2572$ MeV/c ($T_p = 1.8$ GeV) in comparison to phase shift predictions of SAID (SM00, solid line) [7] and the Saclay-Geneva (dashed line) analysis [8] and data from SATURNE [24]. The EDDA data are preliminary.

3 Upper limits on resonance contributions

The excitation functions of the differential cross-sections and analyzing powers have shown no apparent resonant

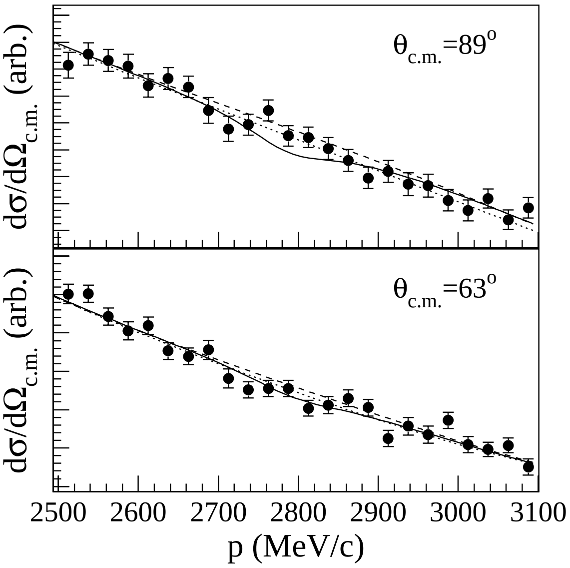

Fig. 2. Differential cross-sections at two out of 28 scattering angles in comparison to PSA solutions. The best fit, with (without) a $^1S_0$ resonance at $\sqrt{s} = 2.7$ GeV, $\Gamma_{\rm tot}$= 50 MeV and $\eta_{\rm el}$= 0.043, excluded with 99% CL by the data is shown as the solid (dashed) line. The dotted line shows the nonresonant background as described by the PSA in the presence of the resonance.

Table 1. Typical values for the partial elastic width $\Gamma_{\rm el}$ of resonances for $\sqrt{s} = 2.2 \ldots 2.8$ GeV and $\Gamma_{\rm tot} = 10 \ldots 100$ MeV excluded with 99% CL.

$^{2S+1}L_J$	$\eta_{\rm el}= \Gamma_{\rm el}/\Gamma_{\rm tot}$
$^1S_0$	0.08
$^1D_2$	0.04
$^3P_0$	0.10
$^3P_1$	0.03
$^3F_3$	0.05

structure. By using the PSA analysis as a model for the non-resonant background [28], the compatibility of a narrow (10–100 MeV) resonance in a particular partial wave with the data can be tested quantitatively, as long as the energy dependence assumed in the PSA is slowly varying with energy as compared to the resonance width to be tested. The hypothesis of the existence of a resonance in a partial wave with energy $\sqrt{s}$, total width $\Gamma_{\rm tot}$ and partial elastic width $\Gamma_{\rm el}$ was tested by the following procedure: An energy dependent PSA along ref. [17] was done on a database tailored to give the best fit to the EDDA data by excluding all data from other experiments for this observable in the same energy range and served as the null-hypothesis for comparison. Then a Breit-Wigner term representing the resonance was added to the S-matrix and the PSA parameters adjusted to yield the best fit to the data in the presence of the resonance to be tested. The partial elastic width $\Gamma_{\rm el}$ was then gradually increased until the resonance was excluded with 99% confidence level (CL) by a χ^2-test based on the EDDA data. For the unknown phase between the resonant and non-resonant amplitudes the value giving the largest $\Gamma_{\rm el}$ excluded was chosen. An example —corresponding to a $^1S_0$ resonance predicted in ref. [29]— is shown in fig. 2, and typical minimal values in $\eta_{\rm el} = \Gamma_{\rm el}/\Gamma_{\rm tot}$ for the five lowest uncoupled partial waves are listed in table 1. The EDDA data, in particular those on differential cross-sections, therefore exclude a sizeable coupling of isovector resonances, like dibaryons, to the elastic channel in the parameter space covered.

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