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Nucleon-nucleon scattering at small angles, measured at ANKE-COSY

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Abstract. The most accepted approach to describe nucleon-nucleon (NN) interaction is the partial wave analysis (PWA), which translates various experimental observables to the common language of the partial waves. The reliable analysis relies not only on the quality experimental data, but also on the measurements of scattering observables over preferably the full angular range. Small angle scattering has been measured for six beam energies between 0.8 and 2.4 GeV using polarized proton beam incident on both proton and deuteron unpolarized targets at COSY-ANKE. This proceeding will report on the published and preliminary results for both *pp* and *pn* scattering from this and other recent experiments at ANKE. This study aims to provide the valuable observables to the SAID group in order to improve the phenomenological understanding of the nucleon-nucleon interaction.

1 Introduction

The interactions between nucleons and their constituent quarks and gluons, are mainly governed by the strong interaction. However, Quantum Chromodynamics, the theory of strong interaction, which perfectly describes the phenomena at high energies, cannot give us quantitative description of the strong interaction at lower energies. Hence the only feasible approach to describe nucleon interaction at intermediate energies is phenomenological one. That is why, the partial wave decomposition of the proton-proton and proton-neutron scattering data is a very important issue in nuclear physics.

The SAID data base and analysis (Scattering Analysis Interactive Dialin) [1] have proved to be a truly invaluable tool over many years for researchers working in this area. Such an analysis is based on the measurements of various NN scattering observables at different energies over the full angular range. Many accelerators around the world included the NN study into their research program, however even after many years of studies, there are still many gaps in our knowledge. As one can see on the Fig. 1, even in the data base of the most basic reaction of proton-proton elastic scattering, there has been a significant gap at the small angles ($\theta_{cm} < 30^\circ$) above 1 GeV. The COSY-ANKE facility was designed for the investigation of the small angle region and is thus well suited to cover this significant gap in the database. The situation is far less advanced for the isoscalar channel where the much poorer neutron-proton data base only permits the I = 0 phase shifts to be evaluated up to at most 1.3 GeV but with significant ambiguity above about 800 MeV.

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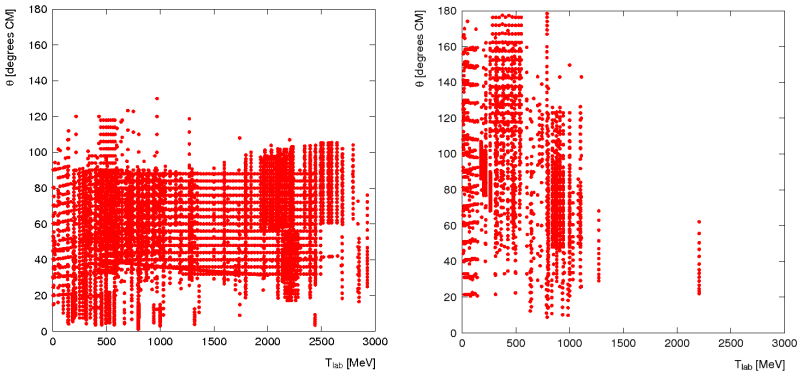

Figure 1. Abundance plot of c.m. scattering angle (θ_{cm}) versus beam energy (T_{lab}) for experiments on the analysing power for proton proton elastic scattering (left) and for proton neutron quasi-elastic scattering (right). *Source: nn-online.org*

2 Experiment

The experiment was carried out using the ANKE magnetic spectrometer positioned inside the storage ring of the COoler SYnchrotron (COSY) of the Forschungszentrum Jülich. The ANKE spectrometer can provide precise data on the differential cross section and spin observables in the energy range up to 2.8 GeV for center-of-mass angles $5° < \theta_{cm} < 30°$. The ANKE forward detector (FD) comprises a set of multiwire proportional and drift chambers (MWCs) and a two-plane scintillation hodoscope. The two silicon tracking telescopes (STT) were placed symmetrically inside the vacuum chamber, to the left and right of the beam near the unpolarised cluster-jet target. Each telescope consists of three double-sided silicon strip detectors of 70 μm, 300 μm, and 5 mm thickness.

The ANKE experiment used a vertically polarised beam incident on an unpolarised target so that the preparation and the measurement of the beam polarisation are critical. The H^- ions from the polarised ion source were accelerated to 45 MeV in the cyclotron JULIC before being stripped of their electrons and injected into COSY.

3 Results

3.1 Proton-proton scattering

The results of all the ANKE measurements of A_y for pp elastic scattering are shown for the six energies in Fig. 2 [3]. For the five of these energies the measurements have been performed for the first time in the angular range from 4° to 28°. The agreement between the STT and FD data, which involved completely independent measurements of the final state, is remarkably good. Although the analysing power results agree all with the many published data at 796 MeV, and also with the most recent partial wave solution (SP07) at this energy, the ANKE data at higher energies lie well above the predictions of this solution at small angles. An updated phase shift analysis that uses the ANKE results together with the World data leads to a much better description of these new measurements.

The experiment measuring the differential cross-sections $\frac{d\sigma}{d\Omega}$ has been performed using an unpolarized proton beam at eight different beam energies, T_p= 1.0, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, and 2.8 GeV, interacting with a hydrogen cluster-jet target. The preliminary results of this experiment are presented in Fig. 3.

3.2 Proton-neutron scattering

The detailed studies of $dp \to \{pp\}_s n$ were undertaken by the ANKE collaboration at energies per nucleon of $T_N = 0.6, 0.8, 0.9$, and 1.135 GeV [9][10]. At the three lower energies the predictions of

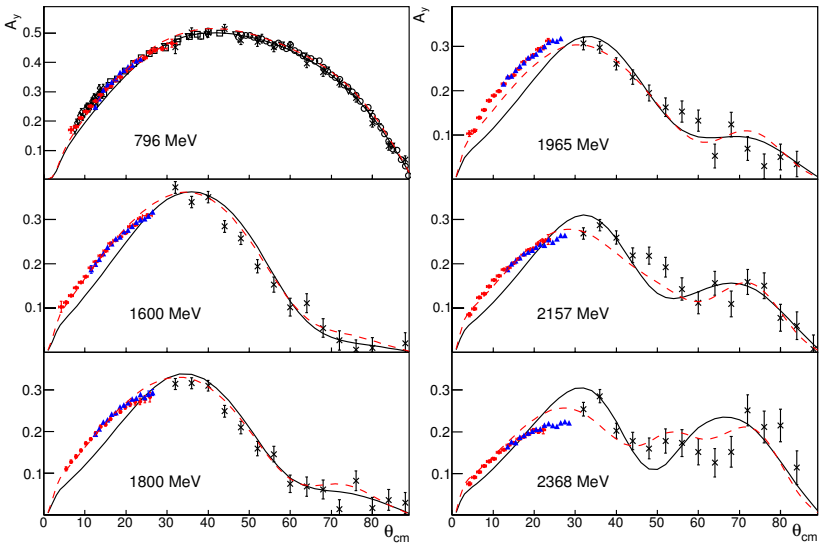

Figure 2. Comparison of the ANKE measurements of the proton analysing power in pp elastic scattering using the STT (red filled circles) and FD (blue filled triangles) systems with the curves corresponding to the SAID SP07 (solid black line) and the revised fit (dashed red) solutions [1]. Only statistical errors are shown so that the systematic uncertainties arising, for example, from the calibration of the EDDA polarimeter have not been included. Also shown are selected results from EDDA (black crosses) [2] at the energies different by no more than 7 MeV and, at 796 MeV, LAMPF [4–6], and SATURNE [7] (black open symbols).

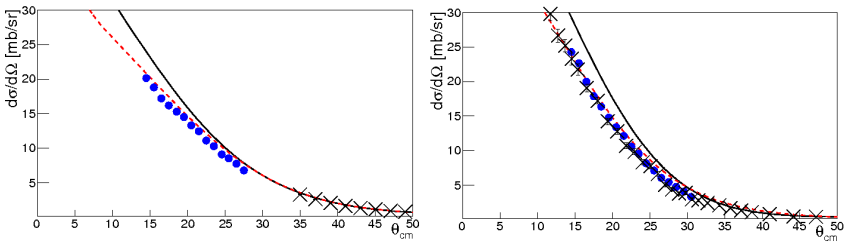

Figure 3. Comparison of the preliminary ANKE measurements of the differential cross section in pp elastic scattering (blue filled circles) systems with the curves corresponding to the SAID SP07 (solid black line) and the revised fit (dashed red) solutions [1] at 2.0 GeV (left) and 2.8 GeV (right).

the impulse approximation model describe the data very well on the basis of np input taken from the SAID SP07 partial wave solution [1]. Deviations were, however, noted in the 2.27 GeV data [10] that were ascribed to an overestimate of the strength of the np spin-longitudinal amplitude at 1135 MeV.

To continue the studies at COSY to higher energies, where there is great uncertainty in the neutron-proton amplitudes, the experiments had to be carried out in inverse kinematics, with a proton beam incident on a polarized deuterium target. The study of the charge exchange at low momentum transfers would then require the measurement of two low energy protons recoiling from the target. The results of the first measurement for the $pd \to n\{pp\}_s$ charge-exchange at 600 MeV that extends the earlier

deuteron beam data out to larger values of the momentum transfer q, are reported in [11]. The ANKE

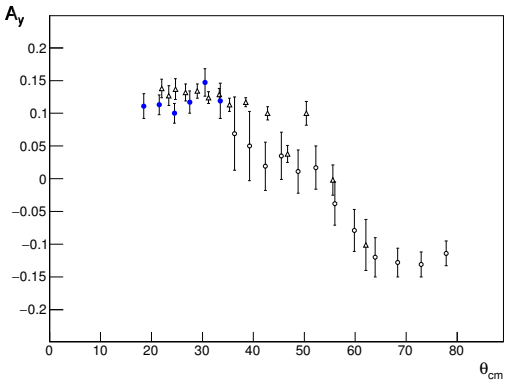

Figure 4. Comparison of the preliminary ANKE measurements of the analysing power in *pn* quasi-elastic scattering (blue filled circles) with the results from Argonne Narional Laboratory at 2.157 GeV [12] [13].

measurements of A_y for *pn* quasi-elastic scattering have been performed using polarised proton beam at the six energies and unpolarised deuterium target. The SAID SP07 solution [1] describes our results very well at the lowest energy of 796 MeV. The solution is valid, however, only up to 1.3 GeV kinetic energy The results at 2.157 GeV are shown in Fig. 4 in order to show how well our measurements agree with the existing data from Argonne National Laboratory. The measurements at other energies have been performed for the first time at small angles.

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