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Angular dependence of pp spin correlation and rescattering observables between 1.80 and 2.10 GeV

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Abstract. A polarized proton beam extracted from SATURNE II and the Saclay polarized proton target were used to determine the spin correlation parameter A_{oosk} and the rescattering observables $K_{os''so}$, $D_{os''ok}$, $N_{os''sn}$, and N_{onsk} at 1.80 and 2.10 GeV. The beam polarization was oriented perpendicular to the beam direction in the horizontal scattering plane and the target polarization was directed either along the vertical axis or longitudinally. Left-right and up-down asymmetries in the second scattering were measured. A check for the beam optimization with the beam and target polarizations oriented vertically provided other observables, of which results for D_{onon} and K_{onno} at 1.80, 1.85, 2.04, and 2.10 GeV are listed here. The new data at 2.10 GeV suggest a smooth energy dependence of spin triplet scattering amplitudes at fixed angles in the vicinity of this energy.

1 Introduction

The experiment is a part of the Nucleon-Nucleon program at SATURNE II devoted to a study of the energy and angular dependence of scattering amplitudes up to the highest energies of the accelerator. We present the data resulting from an experiment performed to resolve an observed ambiguity in the *pp* elastic scattering direct amplitude reconstruction at 2.1 GeV [1].

Most of the *pp* amplitude determinations, based on previously measured data at 11 energies between 0.8 and 2.7 GeV, have resulted in a unique type of solution [1]. However two solutions were obtained at 2.1 GeV. One of them is similar to the solutions found at other energies. The second one, more probable, is different and indicates the existence of a possible resonance in a spin-triplet amplitude in the vicinity of this energy. In contrast, the solution with the lower probability did not suggest a resonance. In order to compare the two solutions at 2.1 GeV, all measurable quantities were calculated using both sets of amplitudes. The predictions differ most for the observables $K_{os''so}$ and N_{onsk}; $K_{os''so}$ was determined in the original data with insufficient accuracy, while N_{onsk} was measured as a linear combination with other observables [2]. A comparison of the predictions with new experimental results may rule out one of the solutions. Measurements of these two observables were performed at 1.80 and 2.10 GeV. In addition, the quantities A_{oosk}, D_{onon}, K_{onno}, $D_{os''ok}$, and $N_{os''sn}$ were obtained as by-products. The tuning of the accelerator at 1.85 and 2.04 GeV for other purposes resulted in measurements of D_{onon} and K_{onno} at two additional energies.

The formulae for the measured observables in terms of event numbers are given in Sect. 2. In Sect. 3 the experimental set-up is described. The tuning of the beam polarization when oriented sideways in the presence of the longitudinal proton polarized target (PPT) magnetic holding field is described. The results are presented in Sect. 4. They are are compared with previous Saclay data from [2 to 7], with BNL Cosmotron data for D_{onon} and

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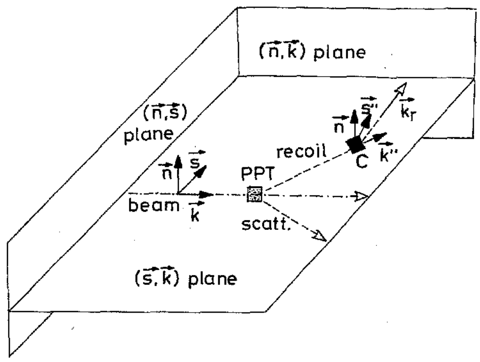

Fig. 1. The unit vectors $\vec{n}$, $\vec{s}$ and $\vec{k}$ for the beam and target laboratory frame, $\vec{n}$, $\vec{s}$" and $\vec{k}$" for the recoil particle frame and the $\vec{k}_r$ is the rescattered recoil particle direction

$D_{os"os}$ at 1.9 GeV [8], with ANL-ZGS data for D_{onon} at 2.205 GeV [9] and with predictions from a phase shift analysis [10]. Throughout the paper we use the NN formalism and the four-index notation for observables given in [11]. Between the notation of [11] and that of Halsen-Thomas [12,13] following relations hold for observables treated here : $A_{ooon} = A_{ooon} = P_{onoo} = P$, $A_{oosk} = C_{SL}$, $A_{oonn} = C_{NN}$, $K_{onno} = K_{NN}$, $K_{os"so} = K_{SS}$, $K_{ok"so} = K_{SL}$, $D_{onon} = D_{NN}$, $D_{os"os} = D_{SS}$, $D_{os"ok} = D_{LS}$, $D_{ok"ok} = D_{LL}$, $N_{onnn} = H_{NNN}$, $N_{os"sn} = H_{SNS}$ and $N_{onsk} = H_{SLN}$.

2 Nucleon-nucleon observables

The subscripts of any observable X_{oqij} refer to the polarization states of the scattered, recoil, beam, and target particles, respectively. For the so-called "pure experiments," the polarizations of the incident and target particles in the laboratory system are oriented along the basic unit vectors

$$\vec{k}, \qquad \vec{n}, \qquad \vec{s} = [\vec{n} \times \vec{k}]. \tag{2.1}$$

The recoil protons are analyzed in the directions

$$\vec{k}", \qquad \vec{n}, \qquad \vec{s}\," = [\vec{n} \times \vec{k}"], \tag{2.2}$$

where the unit vector $\vec{k}$" is oriented along the direction of the recoil particle momentum. The unit vectors for the first and second scattering are shown in Fig. 1.

The most general formula for the correlated nucleon-nucleon scattering cross section Σ is given in [11]. It assumes that both initial particles are polarized and that the polarization of scattered and recoil particles are analyzed. The formula contains all 256 possible experimental quantities and does not change whether the fundamental conservation laws are applied or not. It is valid in any reference frame, but we will next use it in the laboratory system, where the basis unit vectors are given by (2.1) and (2.2). The general formula can be simplified, when one or more of the four polarization states involved is not measured in an experiment. Here we give the formula valid for the polarized beam and target and for the analyzed recoil particle labeled "2".

$$\Sigma(P_B, P_T, P_2) = I_2(\frac{d\sigma}{d\Omega})_0 \Big((1 + A_{ooio}P_{Bi} + A_{oooj}P_{Tj} + A_{ooij}P_{Bi}P_{Tj}) + P_2(P_{oqoo} + K_{oqio}P_{Bi} + D_{oqoj}P_{Tj} + N_{oqij}P_{Bi}P_{Tj})n_{2q}\Big). \tag{2.3}$$

The summation is implicit over the indices o, q, i, j. Indices i, j correspond to the three basis vectors of (2.1), index q refers to the unit vectors of (2.2), index "o" denotes zero. $(d\sigma/d\Omega)_0$ is the differential cross section for single scattering of unpolarized incident and target particles. P_{Bi} and P_{Tj} are the beam and target polarization components, respectively. I_2 and P_2 denote the cross section and the analyzing power for the recoil particle analyzer "2", respectively. If there is no rescattering ($q = o$), we obtain the single scattering observables and $I_2 = 1$ and $P_2 = 0$. The unit vector $\vec{n}_2 = [\vec{k}" \times \vec{k}_r]$ is along the direction of the normal to the recoil particle analyzing plane. Here $\vec{k}_r$ is a unit vector in the direction of the rescattered particle (Fig. 1). The scalar product $(\vec{n}, \vec{n}_2)$ determines the components n_{2q} for different directions of $\vec{n}_2$.

In absence of a magnetic field between the first target and the analyzer the scalar product $n_{2k"}$ is zero, since the vectors $\vec{k}$" and $\vec{n}$ are perpendicular. Thus, all components of polarization tensors involving k" subscript vanish from the measured recoil particle distributions. A magnetic field, for example along the direction $\vec{s}$" will rotate the polarization of the recoil particle in the $(\vec{k}", \vec{n})$ plane.

The scalar products n_{2n} and n_{2k} are then to be understood as cosines of the angles between the normal $\vec{n}_2$ and the direction to which the $\vec{n}$ and $\vec{k}$" of the recoil particle polarization have been rotated by the magnetic field. Note that in any experiment, residual components of the beam and target polarizations in non-dominant directions might exist. The target magnetic field bends the charged particles and rotates spins of all incoming and outgoing particles. This may result in combinations of "pure observables".

Below we apply the conservation laws, which remove many observables [11]. Let us consider that $\vec{P}_B$ and $\vec{P}_T$ are oriented strictly along the basis vectors (2.1) and that we analyze the recoil particle polarization components along $\vec{n}$ and $\vec{s}$". Moreover, we assume no magnetic field after the first scattering.

a) For P_{Bs} and P_{Tk} (2.3) reduces to

$$\Sigma(P_B, P_T, P_2) = I_2(\frac{d\sigma}{d\Omega})_0 \Big((1 + A_{oosk}P_{Bs}P_{Tk}) + P_2(P_{onoo} + K_{os"so}P_{Bs} + D_{os"ok}P_{Tk} + N_{onsk}P_{Bs}P_{Tk})n_{2q}\Big). \tag{2.4}$$

From the single scattering we obtain A_{oosk}. From the Down-Up (D-U) asymmetry in the second scattering, if the central direction of $\vec{n}_2$ in the scalar product n_{2q} is oriented along $\pm\vec{s}$", we obtain $K_{os"so}$ and $D_{os"ok}$. The Left-Right(L-R) second scattering asymmetry (the central direction of $\vec{n}_2$ is oriented along $\pm\vec{n}$) , gives P_{onoo} and N_{onsk}. The PPT holding coil fringe field may rotate recoil proton spins from $\vec{k}$" toward $\vec{s}$" and contribute to (2.4) by a very small fraction $\epsilon(K_{ok"so}P_{Bs} + D_{ok"ok}P_{Tk})$. These second order contributions were treated in detail in [7, 14] and were mostly supressed in the present experiment (see below).

b) For P_{Bs} and P_{Tn}, under the same conditions as for item a) we obtain :

$$\Sigma(P_B, P_T, P_2) = I_2(\frac{d\sigma}{d\Omega})_0\Big((1 + A_{ooon}P_{Tn}) + P_2(P_{onoo} + K_{os"so}P_{Bs} + D_{onon}P_{Tn} + N_{os"sn}P_{Bs}P_{Tn})n_{2q}\Big). \qquad (2.5)$$

The single scattering gives the target analyzing power A_{ooon}. In the present paper it was imposed by interpolated results of [15]. P_{onoo}, D_{onon} are determined from the L-R asymmetry in the second scattering, the D-U one provides $K_{os"so}$ and $N_{os"sn}$. Small residual contribution $\epsilon(K_{ok"so} + N_{ok"sn})$ is almost suppressed.

c) For P_{Bn} and P_{Tn} (2.3) reduces to

$$\Sigma(P_B, P_T, P_2) = I_2(\frac{d\sigma}{d\Omega})_0\Big((1 + A_{oono}P_{Bn} + A_{ooon}P_{Tn} + A_{oonn}P_{Bn}P_{Tn}) + P_2(P_{onoo} + K_{onno}P_{Bn} + D_{onon}P_{Tn} + N_{onnn}P_{Bn}P_{Tn})n_{2q}\Big). \qquad (2.6)$$

The observables A_{oono} and A_{ooon} are equal due to Pauli principle [11]. They may be determined in the single scattering together with the spin correlation A_{oonn}. The analyzing scattering gives P_{onoo}, D_{onon}, K_{onno} and N_{onnn} from the L-R asymmetry. In order to determine D_{onon} and K_{onno} a knowledge of A_{oonn} and N_{onnn} is not needed. Observable K_{onno} is independent on the target polarization and D_{onon} is independent on the beam one. A normalized sum of events over the beam polarization represents an unpolarized beam and the terms containing A_{oonn}, K_{onon} and N_{onnn} cancel out. Similar consideration is valid for P_{Tn}, where only P_{onoo}, K_{onno} and A_{oono} survive. In this beam and target spin configuration possible residual observables are negligibly small.

The observable K_{onno} at the angle θ_{CM} is equal to D_{onon} at the angle $180° - \theta_{CM}$. The rescattering observables $P_{onoo} = N_{onnn}$ are equal to the single scattering quantities A_{oono} and A_{ooon}, which are known with better accuracy. We therefore fixed, in the calculations, P_{onoo} by the single scattering $A_{oono} = A_{ooon}$ data from [15].

All other observables are equal to zero due to conservation laws.

The observables $K_{os"so}$ and D_{onon} were each measured in the two different beam and target spin configurations.

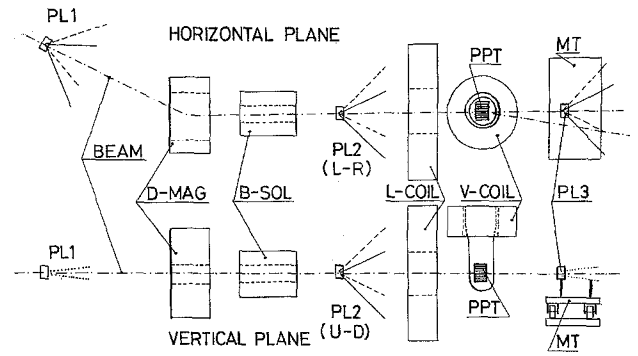

Fig. 2. The horizontal and vertical views of the proton beam line (not to scale). PL1, PL2 and PL3 are polarimeters, D-MAG is a bending dipole, B-SOL is the beam solenoid, L-COIL is the longitudinal holding coil, V-COIL is the vertical one. PPT is the polarized target and MT is the movable table

The configuration "a)" would have been sufficient to determine both the desired observables $K_{os"so}$ and N_{onsk}, but the additional measurement in the configuration "b)" removes many undesirable residual quantities and checked internal compatibility of the experiment. This procedure has been discussed in [2, 5–7].

3 Polarized beam and experimental set-up

The polarization of the extracted proton beam at SATURNE II was oriented vertically and its direction was flipped at each accelerator spill. We have measured the beam particle scattering asymmetry with three polarimeters. The beam polarization was monitored by a first beam polarimeter (PL1) [16], having two pairs of kinematically conjugate arms in the horizontal plane and beam intensity monitors in the vertical plane. It measured the L-R scattering asymmetry $\epsilon = P_B * A$, where A is the analyzing power. In the present experiment the $p - CH2$ asymmetry was measured at $13.9° lab$ and the pp elastic scattering asymmetry was deduced using the known ratio of the CH_2 and the pp asymmetries for this polarimeter [17]. The beam polarization was calculated using the energy dependence of $A_{oono} = A_{ooon}$ at fixed angles, listed in [18].

The vertical beam polarization could be rotated around the beam axis by a superconducting solenoid, with a maximum magnetic field integral of 12 Tm. The resulting beam polarization direction was checked by a second beam polarimeter (PL2), positioned ~ 2.7 m upstream of the PPT. This polarimeter measured L-R and D-U scattering asymmetries [16, 19], depending on the solenoid current IS. The beam line is shown in Fig. 2. The absence of a vertical beam polarization component resulted in a zero L-R asymmetry and a maximal value of the D-U asymmetry. This is shown in Fig. 3, where L-R and U-D asymmetries are plotted as functions of the current IS.

Downstream of the second polarimeter, and 60 cm upstream of the PPT, was situated the longitudinal superconducting holding coil, which provided the nominal holding field of 0.33 T at the target center. Particles passed

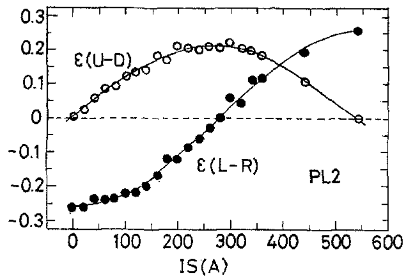

Fig. 3. Dependence of the L-R and U-D asymmetries (*open circles* and *black dots*, respectively) as functions of the beam solenoid current IS. Measured with the polarimeter PL2. The IS current corresponds to the zero crossing point of the *dashed curve* for P_{Bs}, P_{Tn} measurement and it is zero for P_{Bn}, P_{Tn} measurement. For the P_{Bs}, P_{Tk} configuration see Fig. 4

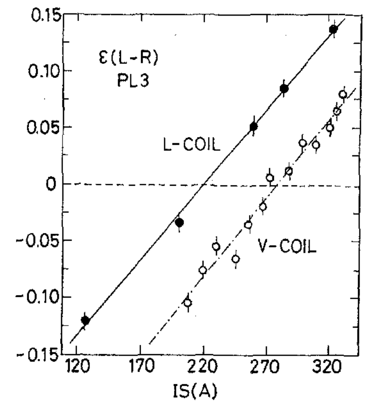

Fig. 4. Dependence of the L-R asymmetries measured with the polarimeter PL3 as functions of the beam solenoid current IS. Measurements were performed with the sideways oriented beam polarization. The *dot-dashed line* was measured with the nominal vertical PPT holding field (V-COIL) and the IS current setting corresponded to the zero crossing of this curve. It is equal to the IS current for the zero cross of *dashed line* in Fig. 3. The *solid curve* was measured with the nominal L-COIL holding field and its zero crossing point determine the IS current setting for the measurement in the P_{Bs}, P_{Tk} configuration

through this holding coil and sideways-oriented spins were rotated around the beam axis by a magnetic field integral of about 1 Tm. This corresponds to the proton spin rotation of $\sim 15°$ at 2 GeV. In order to obtain the sideways beam polarization in the PPT center, the beam solenoid current was adjusted to correct for the spin rotation due to the holding coil.

Since all relevant magnetic elements were superconducting and the field maps were accurately measured, the correction was calculable. This had already been done for previous measurements, for which a strictly sideways polarization was not obtainable for technical reasons. The beam line of the present experiment was improved. Moreover, a new polarimeter (PL3) was constructed and positioned 7 m downstream of the PPT on a remotely-controlled movable table. The PL3 array could move horizontally, perpendicular to the beam axis. The PL3 layout was similar to PL1, with a thicker, smaller CH_2 target and better angular resolution.

The procedure to obtain the correct compensation was as follows. The beam position at the PL3 target was first found without the longitudinal target holding field. Then the D-U asymmetry was measured with PL2, and L-R asymmetries were simultaneously obtained with PL2 and PL3. The solenoid current corresponding to the value where both of the L-R asymmetries crossed zero could be rapidly determined. At the nominal longitudinal holding coil current, the beam position was again checked. Then a new L-R zero crossing point for the PL3 asymmetry was found as a function of IS. This function is shown in Fig. 4 in the vicinity of the zero crossing point with and without the longitudinal holding field. The solenoid current for sideways beam polarization was found with an accuracy better than $\pm 1\%$. This procedure was used at both energies, and the stability of the asymmetries were monitored during the measurements.

When the PPT was polarized along the vertical axis, the vertical magnetic holding coil provided only a weak bending field for incident and outgoing charged particles. The bending of the beam particles could be easily determined by the difference of the beam spot positions, with and without the vertical holding field, measured by varying the PL3 location. A similar measurement without the vertical holding field determines a possible difference between the incident beam direction and the geometrical beam axis. This has been checked at all energies.

The sideways beam polarization in the vertical holding field rotated negligibly around the vertical axis. The polarization direction of the recoil particles may slightly rotate for any direction of the target field. This rotation was taken into account in the calculations of the observables as described in [19].

The Saclay frozen spin PPT, 35 mm thick, 40 mm long, and 49 mm high, contained pentanol-1 doped with paramagnetic centers [20]. The typical target polarization was $\sim +80\%$. The target worked in the frozen spin mode at a small magnetic holding field. The relaxation time of the target averaged around 25 days which was taken into account in the off-line data analysis. The longitudinal target polarization could be inverted either by a PPT repolarization using a different hyperfrequency, or by magnetic field inversion. In the two cases, the strictly sideways beam polarization corresponded to different IS values. Applying both methods, one considerably decreases the contributions of undesired observables [19].

The present measurements were carried out using the Nucleon-Nucleon experimental set-up. This apparatus and additional information on the data analysis is described in detail in [19]. It consisted of a two-arm spectrometer with an analyzing magnet in the forward arm (Fig. 5). Each arm was equipped with single scintillation counters and counter hodoscopes selecting events with pairs of charged particles. These signals triggered eight multi-wire proportional chambers (MWPC's) with three wire planes each. Recoil particles were rescattered on a 6 cm-thick carbon analyzer and L-R and D-U rescattering events were recorded. The *pp*-elastic events from the PPT were selected in the OFF-LINE analysis by kinematic conditions,

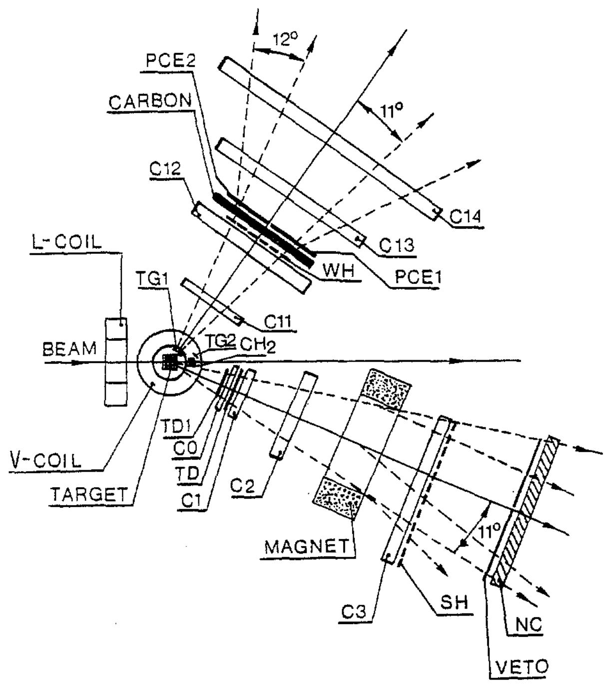

Fig. 5. The experimental set-up (not to scale). TD1, TD, TG1, TG2, PCE1, PCE2 were the single scintillation counters, SH, WH, "VETO" and NC were the counter hodoscopes, CARBON was the analyzer, CH_2 was a small target, C0, C1, C2, C3, C11, C12, C13 and C14 were MWPC's. Other symbols are as in Fig. 2

bending of scattered protons in the analyzing magnet, and by TOF information. Rescattering events with one outgoing particle from the carbon analyzer, and with a lab scattering angle in the carbon of 4° to 20°, were accepted in the OFF-LINE data analysis. They represented about 2% of the single scattering events. The $p-C$ analyzing power was interpolated from the results given in [8, 21-30].

Finally note that in the present experiment, only the two states of the ion source with large polarizations were used. The magnitudes of the polarizations were shown to be equal in [31].

4 Results and discussion

The results for the spin correlation parameter $A_{oosk}(pp)$ obtained with the beam polarization oriented in the $\pm\vec{s}$ direction and the target polarization along the $\pm\vec{k}$ axis at two energies are listed in Table 1 and are plotted in Fig. 6. Statistical and random-like uncertainties, added in quadrature, are listed for individual points. The relative random-like systematic error of ±5% was provided by time-dependent MWPC efficiency fluctuations in the measurements with two opposite PPT polarizations. The relative normalization systematic error in P_B was ±3% [18, 19], and the same error was attributed to the PPT polarization [20]. The global normalization errors Δ are listed in the tables.

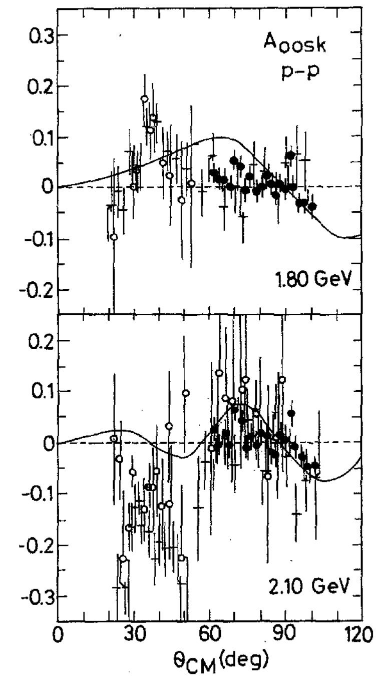

Fig. 6. Angular dependence of $A_{oosk}(pp)$ at 1.80 GeV and 2.10 GeV Solid curves are predictions of the energy dependent PSA [8]. The meaning of the symbols is: •....present results, ○.... [3], +.... [4]

Table 1. The spin correlation parameter $A_{oosk}(pp)$ measured with the beam polarization oriented in $\pm\vec{s}$ direction and the target polarization along the $\pm\vec{k}$ axis. The normalization systematic error is $\Delta = \pm 4.3\%$

θ_{CM} (deg)	A_{oosk} 1.80 GeV	A_{oosk} 2.10 GeV
62.2	$+0.031 \pm 0.024$	$+0.028 \pm 0.026$
64.0	$+0.018 \pm 0.020$	-0.004 ± 0.022
66.0	$+0.015 \pm 0.020$	$+0.017 \pm 0.022$
67.9	-0.001 ± 0.021	-0.007 ± 0.023
70.1	$+0.053 \pm 0.022$	$+0.063 \pm 0.020$
72.0	$+0.040 \pm 0.020$	$+0.042 \pm 0.022$
74.0	-0.012 ± 0.020	-0.010 ± 0.022
76.0	$+0.023 \pm 0.021$	$+0.013 \pm 0.023$
78.0	-0.010 ± 0.020	-0.010 ± 0.023
80.0	$+0.001 \pm 0.021$	$+0.019 \pm 0.024$
82.0	$+0.022 \pm 0.024$	$+0.014 \pm 0.026$
84.0	$+0.003 \pm 0.023$	-0.022 ± 0.025
86.0	-0.017 ± 0.021	-0.026 ± 0.024
88.0	$+0.016 \pm 0.022$	$+0.016 \pm 0.024$
90.0	-0.002 ± 0.022	$+0.003 \pm 0.024$
92.0	$+0.063 \pm 0.022$	$+0.061 \pm 0.025$
94.0	-0.001 ± 0.024	-0.008 ± 0.027
96.0	-0.033 ± 0.023	-0.028 ± 0.026
98.0	-0.030 ± 0.023	-0.049 ± 0.034
101.5	-0.040 ± 0.014	-0.047 ± 0.016

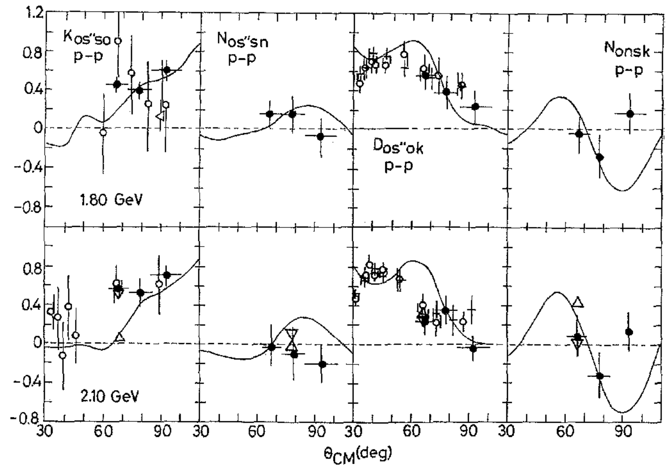

Fig. 7. Angular dependence of $K_{os"so}$, $D_{os"ok}$, $N_{os"sn}$ and N_{onsk} at 1.80 GeV and 2.10 GeV. *Solid curves* are predictions of the energy dependent PSA [10]. The meaning of the symbols is: •....present results, ○.... [2], +.... [7], ◁ ....[8], ▷ .... [9], ▽.... Sol. 1 (non-resonant), △.... Sol. 2 (amplitude analysis of [1])

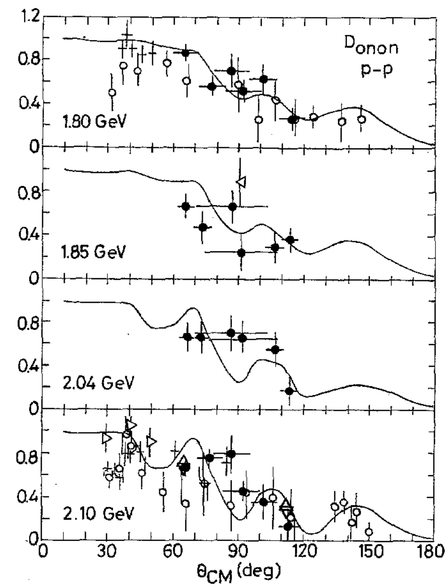

Fig. 8. Angular dependence of $D_{onon}(\theta_{CM})$ and $D_{onon}(180° - \theta_{CM}) = K_{onno}(\theta_{CM})$ at four energies. *Solid lines* are predictions of the PSA [10]. The meaning of the symbols is: •....present results, ○....[5], +....[6], ◁ ....[8], ▷ .... [9], ▽.... Sol. 1 [1], △.... Sol. 2 [1]

The results are compared with the previously-measured Saclay data from [3,4], and with the predictions of an energy-dependent PSA [10]. Previously-existing data were measured with the beam having nonzero polarization components in both the $\vec{s}$" and $\vec{k}$" directions, and had large statistical errors. At small angles, the angular distribution changes rapidly with energy [3,4]. Above $60° CM$, the new A_{oosk} data are consistent with zero at both 1.80 and 2.10 GeV.

In Table 2 are listed the rescattering observables with two and three spin indices measured with the beam polarized in the $\pm\vec{s}$ direction and with the target polarized either in the $\pm\vec{k}$ or $\pm\vec{n}$ directions. They are plotted in Fig. 7 together with previously-measured $K_{os"so}$ [2] and $D_{os"ok}$ [2, 7] Saclay data. The point $D_{os"os}(90°) = K_{os"so}(90°)$ measured at 1.9 GeV in a triple scattering experiment at the BNL Cosmotron [8] is plotted together with the data at 1.80 GeV. The PSA predictions [10] are also shown. The new data for $K_{os"so}$, which are independent of the PPT polarization, were averaged over measurements with two target spin configurations. Also shown in Fig. 7 are the amplitude analysis predictions at 2.10 GeV and $66° CM$ for both the non-resonant (Sol. 1) and the resonant solutions (Sol. 2) from [1]. The new results for the $K_{os"so}$ and N_{onsk} observables agree well with Sol. 1. Predictions for the other quantities are too close to each other to be distinguishable. An amplitude determination, including all the new results, will be performed in the near future.

The observables $D_{onon}(\theta_{CM})$ and $K_{onno}(\theta_{CM})$, measured as by-products of the experiment, are listed in Table 3. Since D_{onon} is independent of the beam polarization, the results from the two measurements at 1.80 and 2.1 GeV with the PPT oriented along the $\pm\vec{n}$ direction were averaged. The $D_{onon}(\theta_{CM})$ and $K_{onno}(\theta_{CM}) = D_{onon}$ $(180° - \theta_{CM})$ results are plotted in Fig. 8, together with the previously-existing data [5, 6], one point at 1.9 GeV from [8], three points at 2.2 GeV measured at the ANL-ZGS [9] and PSA predictions [10]. The present results were not included yet in the PSA database.

The normalization systematic errors of the rescattering observables in Tables 2 and 3 are mainly provided by a normalization uncertainty in the $p - C$ analyzing power. Using the two-dimensional fit to all existing data, this normalizing error is around ±6% for the recoil proton energy up to ~ 1 GeV.

Angular bins for rescattering observables are shown in Tables 2 and 3. They are larger, due to small statistics of events. The $p - C$ analyzing power was applied to each accepted event at its energy and angle and then the values were averaged over the bin-widths.

5 Conclusions

Previous measurements of A_{oosk} occur in [3, 4], of $K_{os"so}$ in [2,8], of $D_{os"ok}$ in [2, 7], of D_{onon} in [5, 6, 8, 9], and of K_{onno} in [5, 6]. Observables of $N_{os"sn}$ and N_{onsk} were not measured as the "pure observables" previously in 2 GeV region. All quantities treated here were determined at 6 GeV/c at the ANL-ZGS and used in the direct reconstruction of the scattering matrix at this beam momentum [13]. The observables $K_{os"so}$ and N_{onsk} behave alike at 1.80 and 2.10 GeV and support the validity of the amplitude solution with the non-resonant spin-triplet partial waves. All the present results improve the existing database for *pp* elastic scattering. A sideways-oriented polarized proton beam, with immeasurably-small residual polarization components at the target center, was achieved for the purposes of the present experiment.

Table 2. Rescattering data for the beam polarization in $\pm\vec{s}$ direction and the target polarization either in $\pm\vec{k}$ or in $\pm\vec{n}$ directions

T_{kin} = 1.80 GeV

θ_{CM}(deg)	$K_{os''so}$	$N_{os''sn}$	$D_{os''ok}$	N_{onsk}
66.0 ± 6.0	+0.43 ± 0.08	+0.15 ± 0.14	+0.54 ± 0.14	−0.04 ± 0.19
78.0 ± 6.0	+0.39 ± 0.10	+0.15 ± 0.20	+0.39 ± 0.18	−0.28 ± 0.23
92.6 ± 8.2	+0.60 ± 0.10	−0.09 ± 0.20	+0.22 ± 0.17	+0.18 ± 0.22
Δ	±6.7%	±7.4%	±6.7%	±7.4%

T_{kin} = 2.10 GeV

θ_{CM}(deg)	$K_{os''so}$	$N_{os''sn}$	$D_{os''ok}$	N_{onsk}
67.3 ± 4.7	+0.57 ± 0.11	−0.03 ± 0.21	+0.23 ± 0.14	+0.09 ± 0.22
78.0 ± 6.0	+0.51 ± 0.14	−0.10 ± 0.28	+0.36 ± 0.15	−0.33 ± 0.23
92.4 ± 8.4	+0.70 ± 0.11	−0.20 ± 0.20	−0.04 ± 0.12	+0.12 ± 0.19
Δ	±6.7%	±7.4%	±6.7%	±7.4%

Table 3. Rescattering data for the beam and target polarizations in $\pm\vec{n}$ direction. The normalization systematic error is $\Delta = \pm6.7\%$ for each data set

T_{kin}	1.80 GeV	1.80 GeV	T_{kin}	1.85 GeV	1.85 GeV
θ_{CM}(deg)	D_{onon}	K_{onno}	θ_{CM}(deg)	D_{onon}	K_{onno}
66.0 ± 6.0	0.86 ± 0.09	0.24 ± 0.11	66.0 ± 3.0	0.65 ± 0.11	0.35 ± 0.11
78.0 ± 6.0	0.54 ± 0.09	0.62 ± 0.14	72.5 ± 3.5	0.46 ± 0.15	0.29 ± 0.15
92.6 ± 8.6	0.52 ± 0.10	0.70 ± 0.15	92.6 ± 16.6	0.23 ± 0.16	0.68 ± 0.15

T_{kin}	*2.04 GeV	*2.04 GeV	T_{kin}	*2.10 GeV	*2.10 GeV
θ_{CM}(deg)	**D_{onon}	**K_{onno}	θ_{CM}(deg)	**D_{onon}	**K_{onno}
66.0 ± 3.0	0.66 ± 0.13	0.16 ± 0.15	67.3 ± 4.7	0.66 ± 0.08	0.12 ± 0.16
72.5 ± 3.5	0.66 ± 0.15	0.54 ± 0.17	78.0 ± 6.0	0.75 ± 0.10	0.34 ± 0.19
92.6 ± 16.6	0.64 ± 0.15	0.70 ± 0.17	92.4 ± 8.4	0.47 ± 0.09	0.79 ± 0.17

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