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pp elastic scattering polarization transfer K_{onno} and depolarization D_{onon} between 1.94 and 2.80 GeV

C.E. Allgower[1], J.Ball[2,3], L.S.Barabash[4], M.Beddo[1], Y.Bedfer[2], A.Boutefnouchet[5], J.Bystrický[3], P.-A. Chamouard[2], Ph. Demierre[6], J.-M.Fontaine[2,3], V.Ghazikhanian[5], D.Grosnick[1], R.Hess[6†], Z.Janout[4a], Z.F.Janout[6b], V.A.Kalinnikov[4], T.E.Kasprzyk[1], Yu.M.Kazarinov[4†], B.A.Khachaturov[4], R. Kunne[2,c], C.Lechanoine-LeLuc[6], F.Lehar[3], A. de Lesquen[3], D.Lopiano[1], M. de Mali[3†], V.N.Matafonov[4], I.L.Pisarev[4], A.A.Popov[4], A.N.Prokofiev[7], D.Rapin[6], J.-L.Sans[2,d], H.M.Spinka[1], Yu.A. Usov[4], V.V.Vikhrov[7], B.Vuaridel[6], C.A.Whitten[5], A.A.Zhdanov[7]

[1] Argonne National Laboratory, HEP Division, 9700 South Cass Avenue, Argonne, IL 60439, USA,
[2] Laboratoire National SATURNE, CNRS/IN2P3 and CEA/DSM, CEA/Saclay, 91191 Gif sur Yvette Cedex, France,
[3] DAPNIA, CEA/Saclay, 91191 Gif sur Yvette Cedex, France,
[4] Laboratory of Nuclear Problems, JINR, 141980 Dubna, Moscow Region, Russia,
[5] UCLA, 405 Hilgard Ave., Los Angeles, CA 90024, USA
[6] DPNC, University of Geneva, 24 quai Ernest-Ansermet, 1211 Geneva 4, Switzerland,
[7] Petersburg Nuclear Physics Institute, 188350, Gatchina, Russia

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Abstract. A polarized proton beam extracted from SATURNE II and the Saclay polarized proton target were used to measure the rescattering observables K_{onno} and D_{onon} at 26 energies from 1.94 to 2.80 GeV and at 0.80 GeV. The beam and target polarizations were oriented vertically and left-right as well as up-down asymmetries in the second scattering on carbon were measured. The present data, obtained in small energy steps, are practically constant as a function of energy at $90°CM$, where $K_{onno} = D_{onon}$. These data will bring about important modification to phase shifts and stabilize the solutions.

1 Introduction

The experiment was carried out within the Nucleon-Nucleon (NN) program at SATURNE II. The rescattering observables K_{onno} and D_{onon} were measured simultaneously with the single scattering observables A_{oono} and A_{ooon}, (beam and target analyzing powers respectively) and with the spin correlation coefficient A_{oonn}. Only the rescattering observables will be reported here: the single scattering parameters [1] will be published separately.

In this paper Sect. 2 details the method of the D_{onon} and K_{onno} extraction. In Sect. 3 the experimental set-up and off-line analysis are briefly described. The results are presented in Sect. 4. They are compared at three energies with the existing data and with the predictions of phase shift analyses (PSA) [2,3]. The energy dependence at $90°CM$ is also shown.

Present address:
a) Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Břehová 7, 11519 Prague 1, Czech Republic,
b) Computing Center of the Czech Technical University, Zikova 4, 16635 Prague 6, Czech Republic,
c) Institut de Physique Nucléaire IN2P3, 91400 Orsay, France,
d) Centrale Themis, F-66121 Targasonne, France.
†) Deceased.

Almost all existing depolarization and transfer polarization data in the energy region under discussion were measured at SATURNE II and are published in [4-7]. Concerning other results, one D_{onon} point was measured at the BNL Cosmotron at 1.9 GeV [8] and three D_{onon} points were obtained at the ANL-ZGS at 2.205 GeV [9].

Throughout the paper we use the NN formalism and the four-index notation for observables given in [10]. Between the notation of [10] and that of Halsen-Thomas [11,12] the following relations hold for dominant observables treated here [13]: $A_{oono} = A_{ooon} = P_{onoo} = P$, $A_{oonn} = C_{NN}$, $K_{onno} = K_{NN}$, $D_{onon} = D_{NN}$, $D_{os"os} = D_{SS}$ and $N_{onnn} = H_{NNN}$.

2 Determination of 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

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

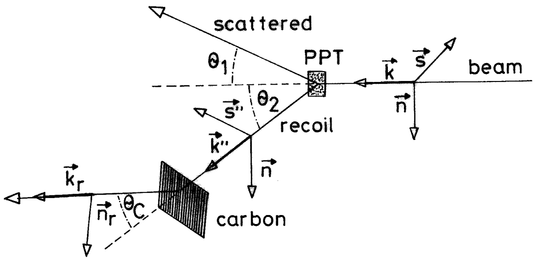

Fig. 1. The unit vectors $\vec{n}$, $\vec{s}$, and $\vec{k}$ for the beam and target laboratory frame, and $\vec{n}$, $\vec{s}\,$", and $\vec{k}$" for the recoil particle frame. The $\vec{k}_r$ is the rescattered recoil particle direction and $\vec{n}_r$ is the normal to the analyzing plane $(\vec{k}", \vec{k}_r)$. θ_1, θ_2 are the laboratory angles of the scattered and recoil particles, respectively, θ_C is the scattering angle of the recoil particle on carbon. The unusual orientation of the unit vectors reproduces the existing experimental set-up, described in [14]

where $\vec{k}$ and $\vec{k}'$ are the beam and scattered particle directions, respectively, and $\vec{n}$ is the normal to the first scattering plane.

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 unusual orientation of the unit vectors is due to existing experimental set-up described in [14].

The most general formula for the correlated nucleon-nucleon scattering cross section Σ is given in [10]. 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 rely on any of the conservation laws. It is valid in any reference frame, but we will apply it in the laboratory system, where the base unit vectors are given by (2.1) and (2.2). The general formula simplifies, if one or more of the four polarization states involved is not measured in the experiment. Here we give the formula valid for the polarized beam and target and for the analyzed recoil particle labeled "r", while the polarization of the scattered particle is not measured:

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

The summation is implicit over the indices q, i, j. Indices i, j correspond to the three unit vectors (2.1), the index q refers to the unit vectors (2.2), and the index "o" denotes zero or unmeasured polarization. $\vec{P}_B$ and $\vec{P}_T$ are the beam and target polarization vectors, P_{Bi} and P_{Tj} are their projections along the unit vectors (2.1) respectively. $(d\sigma/d\Omega)_0$ is the differential cross section for single scattering of unpolarized incident and target particles. It depends, as well as all observables, on the single scattering angle θ_{CM}. 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 ($q = 0$), we put $I_2 = 1$ and $P_2 = 0$ and we obtain the single scattering observables. The unit vector $\vec{n}_r = [\vec{k}" \times \vec{k}_r]$ 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 $(\vec{n}, \vec{n}_r)$ determines the components n_{rq} for different directions of $\vec{n}_r$.

In the absence of a magnetic field between the first target and the analyzer, the longitudinal component of the recoil particle polarization $\vec{P}$" cannot be analyzed and all observables containing the spin-index $q = k$" remain undetermined. 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_{rn} and n_{rk} are then to be understood as cosines of the angles between the normal $\vec{n}_r$ and the direction to which $\vec{n}$ or $\vec{k}$" of the recoil particle polarization have been rotated by the magnetic field.

In any experiment, residual components of the beam and target polarizations in the non-dominant directions might exist. The beam is usually convergent and the target magnetic field bends the charged particles and rotates spins of all incoming and outgoing charged particles. An acceptance of the apparatus is finite. This may result in combinations of "pure observables."

The application of the conservation laws implies that many observables in (2.3) are either equal to zero, or are equal, or dependent [10]. For example, due to parity conservation only observables with one spin-index $i = j = q = n$ remain, i.e. $A_{ooso} = A_{ooko} = A_{ooos} = A_{oook} = P_{osoo} = P_{okoo} = 0$. The non-zero two index observables must have an even number on n indices (0 or 2), whereas for independent three spin-index quantities a number of n indices must be odd. Time reversal invariance (TRI) and Pauli principle reduce again the number of independent observables:

$$A_{oono} = A_{ooon} = P_{onoo} = N_{onnn}, \quad A_{oosk} = A_{ooks}. \tag{2.4}$$

TRI and Pauli principle impose additional relations between the two and the three spin-index rescattering observables. E.g. only four from the five non-zero two spin-index rescattering quantities are independent.

We assume first no magnetic field around the target. The unit vectors (2.1) and beam or target polarization vectors in the first scattering frame may be expressed by azimuthal angle ϕ-functions. The unit vectors (2.1) in the reference frame $(\vec{h}, \vec{v}, \vec{k})$ (horizontal perpendicularly to the beam, vertical and beam direction) are:

$$\begin{aligned}\vec{s} &= (\cos\phi,\ \sin\phi,\ 0), \\ \vec{n} &= (-\sin\phi,\ \cos\phi,\ 0), \\ \vec{k} &= (0,\ 0,\ 1).\end{aligned} \tag{2.5}$$

The beam and target polarization vectors, arbitrarily oriented, are expressed by components in the reference frame:

$$\vec{P}_B = (P_{Bh},\ P_{Bv},\ P_{Bk}), \quad \vec{P}_T = (P_{Th},\ P_{Tv},\ P_{Tk}). \tag{2.6}$$

In the present experiment $\vec{P}_B$ and $\vec{P}_T$ are oriented along the vertical direction ($P_{Bv} = \pm|P_B|$, and ($P_{Tv} = \pm|P_T|$. In addition to the conditions discussed above, this remove all observables with indices $i = k$ and $j = k$. The single scattering term reduces to:

$$\frac{d\sigma}{d\Omega} = (\frac{d\sigma}{d\Omega})_0 \Bigg(1 + (A_{oono}P_B + A_{ooon}P_T)\ \cos\phi + A_{oonn}P_BP_T\ \cos^2\phi + A_{ooss}P_BP_T\ \sin^2\phi \Bigg). \tag{2.7}$$

A background is due to inelastic *pp* contributions and to scattering of polarized protons on unpolarized target nuclei. The *pp* inelastic part is strongly reduced by the elastic event selection. The latter part is dominant and depends on the beam polarization. The background can be considered as a dilution d of the proton spin contribution to the differential cross section:

$$(1-d)\ [pp \to pp] + d\ [background]. \tag{2.8}$$

It has been determined either by measurements with an unpolarized hydrogenless target or by a fit over wings of θ and ϕ distributions for each beam polarization direction. The background subtraction results in a multiplication of any *pp* single scattering observable by the factor $(1-d)$ and in an addition of the factor $d * A(back)$ to the corrected polarized beam analyzing power $(1-d)\ A_{oono}$. Here $A(back)$ is the background analyzing power.

For the second scattering on carbon nuclei the unknown recoil particle beam polarization $\vec{P}$" for a given first scattering angular bin depends on energy T_2. It is analyzed along the vectors $\vec{n}$ and $\vec{s}$" (2.2). The differential cross section is:

$$(d\sigma/d\Omega)_C = I_C(\theta_C,\ T_2)\Bigg(1 + |\vec{P}"(\theta_2,\ \phi,\ T_2)|A_C(\theta_C,\ T_2) \times[\ \cos\phi_C + \sin\phi_C\ ]\Bigg). \tag{2.9}$$

It has a symmetry period of 180° in ϕ_C. For thin PPT and carbon targets T_2 is a function of θ_2. The quantities $A_C\ (\theta_C,\ T_2) = P_2$ and $I_C(\theta_C,\ T_2) = I_2$ were defined in (2.3), ϕ_C is the azimuthal angle for the second scattering.

Under the conditions given above, only the non-zero components of $\vec{P}$" in $\vec{s}$" and $\vec{n}$ directions can be determined. The additive term R, corresponding to the spin-dependent second scattering reduces:

$$\begin{aligned} R = &+A_C\cos\phi_C\Bigg(P_{onoo} + (K_{onno}P_B + D_{onon}P_T) \\ &\times\cos\phi + N_{onnn}P_BP_T\cos^2\phi\Bigg) \\ &-A_C\sin\phi_C\Bigg((K_{os"so}P_B + D_{os"os}P_T)\sin\phi \\ &+N_{onss}P_BP_T\sin^2\phi \\ &+(N_{os"ns} + N_{os"sn})P_BP_T\sin\phi\cos\phi\Bigg) \end{aligned} \tag{2.10}$$

The ϕ acceptance of our apparatus was ±8°. whereas ϕ_C turned in the interval $0° - 360°$. The observables for which

$$\cos\phi\ \sim\ \cos^2\phi\ \sim\ 1, \tag{2.11}$$

i.e. A_{oono}, A_{ooon}, A_{oonn} in (2.7) and P_{onoo}, K_{onno}, D_{onon}, N_{onnn} in (2.10) are predominant. The mean value of $\sin^2\phi$ is around 0.007 and introduce a negligibly small amount of A_{ooss} into A_{oonn}. Due to the ϕ-symmetry of the acceptance, the mean value of $\sin\phi$ is zero and some of remaining undesired quantities cancel in measurements. They were checked in the data analysis and were found to be unmeasurably small.

A bending of particles in a weak vertical magnetic holding field (Sect. 3) conserves vertical polarization direction. A fringed field may rotate spins of beam, scattered and recoil particles. This provides P_{Bh} and P_{Bk} beam polarization components. Contribution of P_{Bh} was calculated using the target field map and was smaller than $0.02 \cdot P_B$. Since P_T remains in the vertical direction, the multiplicative term at A_{ooss} in (2.7) will be now $P_T\ sin\phi\ (\ P_B\sin\phi + P_{Bh}\ cos\phi)$. The P_{Bk} value was found to be zero and was neglected. Then any observable with the spin-index $i = k$ will not contribute.

The spin rotation of recoil particle in the fringe field provides the k" component ($\sim$ 2% relative) and may slightly change the n and s" components. This adds to (2.10) terms containing $K_{ok"so}$ and $N_{ok"sn}$, which cannot be analyzed in our experiment. Contributions of the spin rotation were taken into account in ϕ-functions. The dominant quantities are affected only little, due to (2.11).

The field may bend particles and disturb the ϕ-symmetry of the acceptance. A term $\epsilon(instr.) \cdot \sin\phi$, added in (2.7) checks this instrumental effect.

For a given energy, (2.7) provides four relations for the two opposite directions of $\vec{P}_B$ and $\vec{P}_T$, respectively. These polarizations are common to all scattering angles θ_{CM}.

The opposite proton beam polarizations at SATURNE II for the two ion source polarized states, were accurately measured in a dedicated experiment discussed in detail in [15]. It was found $P_B = |P_B^+| = |P_B^-|$. Only the two states of the ion source with large polarizations were used (the two "unpolarized" ion source states were polarized to ±6%).

On the other hand $|P_T^+| \neq |P_T^-|$, but any P_T was measured by the same apparatus and a possible normalization error results in a common factor F, which multiply both P_T^+ and P_T^-.

If the absolute value of P_B or F is unknown, we can solve four relations (2.7) with different beam and target polarizations for three quantities: P_B (or F), $A_{oono} = A_{ooon}$, and A_{oonn} (assuming $A_{ooss} = 0$ as a negligible contribution) and relate P_B and F. For this purpose one imposes the statistical equality of $A_{oono}(av)$ and $A_{ooon}(av)$ values, averaged over the same angular range. Either P_B or F varies, whereas the other quantity is fixed, until the equality $A_{oono}(av) = A_{ooon}(av)$ is obtained. Since the errors of the two averaged observables are small with respect to the beam or target polarizations, the errors of P_B and $F \cdot P_T$ will be of the same order. Comparison of the beam and target analyzing powers [14] was used to determine P_B at all high energies. Additionally a check of F was made at 0.80 GeV, where the *pp* analyzing power is well known. At this energy was also checked P_{onoo} which is independent on P_B and P_T and most affected by an instrumental asymmetry.

In order to determine D_{onon} and K_{onno} knowledge of dominant observables A_{oonn} and N_{onnn} is not needed, in principle. K_{onno} is independent of the target and D_{onon} of the beam polarization, Therefore, a normalized sum of events over the beam polarization represents an unpolarized beam as the terms containing A_{oono}, A_{oonn}, K_{onno}, $K_{os"so}$, and three-index observables cancel out. Similar considerations are valid for normalized sums of events over target polarizations P_T^+ and P_T^-, where only the same quantities and P_{onoo} survive. For $P_T = P_B = 0$ only $P_{onoo} \neq 0$ can be determined.

In this paper at all energies, (2.3) with terms (2.7) and (2.10), for the four beam and target polarization combinations was solved. In this case $A_{oono} = A_{ooon}$ and A_{oonn}, determined in the single scattering, as well as P_{ooon}, and N_{onnn} must be imposed, since double scattering statistics are relatively small.

From the Pauli principle it follows that the observable K_{onno} at the angle θ_{CM} is equal to D_{onon} at the angle $180° - \theta_{CM}$. This condition was not imposed in the data analysis. It was used for data presentations in figures only.

All dominant rescattering observables in (2.10) are determined from the left-right asymmetry in the second scattering. The up-down scattering provides mainly a check of undesired observables and of the internal consistency of the measurements. As mentionned above in this beam and target spin configuration any possible contributions of residual observables are small.

3 Polarized beam and experimental set-up

The polarization direction of the extracted proton beam at SATURNE II 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 left-right (L-R) scattering asymmetry $\epsilon = P_B \cdot A$, where A is the analyzing power. In the present experiment the $p - CH_2$ 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 [16,17]. The recorded data improve independent P_B measurements, described in Sect. 2.

The beam polarization was also checked by a second beam polarimeter (PL2), positioned $\sim$ 2.7 m upstream of the polarized proton target (PPT). This polarimeter measured L-R and up-down (U-D) scattering asymmetries [7,14]. The absence of a horizontal beam polarization component resulted in a zero U-D asymmetry.

A third polarimeter (PL3) was positioned 10 m downstream of PL2 on a remotely-controlled movable table. The PL3 array could move horizontally, perpendicular to the beam axis [7].

The Saclay frozen spin PPT, 35 mm thick, 40 mm wide, and 49 mm high, contained pentanol-1 doped with paramagnetic centers [18]. The typical target polarizations were $\sim +80\%$ and $\sim -85\%$. The PPT worked in frozen spin mode at 0.33 Tesla magnetic holding field in the target center, provided by a vertical superconducting holding coil [18]. The relaxation time of the target averaged around 25 days, which was taken into account in the off-line data analysis.

Since the PPT was polarized along the vertical axis, the vertical magnetic holding coil results in 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. Similarly a measurement without the vertical holding field determines a possible difference between the incident beam direction and the geometrical beam axis, which could induced a shift in the scattering angle. This has been checked at most energies. A comparison of asymmetries measured with and without the holding coil checks an effect of a beam particle spin rotation in the fringe field. The difference of both asymmetries was unmeasurably small.

The present measurements were carried out using the Nucleon-Nucleon experimental set-up. This apparatus is described in detail in [14]. It consisted of a two-arm spectrometer with an analyzing magnet in the forward arm. 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 U-D rescattering events were recorded. The acceptance of each arm in the laboratory frame was $\sim \pm 4.5°$ vertically and 23° horizontally. The ϕ acceptance of both arms together was limited to $\pm 8°$.

Reducing the ϕ limits one checks a contribution of $\sin^2 \phi$ term. A possible effect was always smaller than one fourth of A_{oonn} experimental errors. Another check of the A_{ooss} contribution was a selection of events with $\phi > 0$ and $\phi < 0$. This corresponds to the U-D asymmetry measurement at small ϕ. A contribution of A_{ooss} was found around 0.003 with a large error.

At any incident beam energy a complete tracking for each recorded event was performed. For the first scattering it provides vertex in PPT, scattering and azimuthal angles θ_1, ϕ_1, θ_2, ϕ_2, and momentum of the scattered particle. Cuts are applied for the vertex, particle momentum, kinematically conjugate angles θ_{CM} and coplanarity $\Delta\phi$. Remaining events represent a set for single scattering which is corrected for background.

From the set of single scattering events one selects those scattered on carbon, with one outgoing charged particle from the carbon analyzer. The vertex in carbon, and angles of rescattering particle θ_C, ϕ_C are determined.

From the first and second scattering vertices an energy loss in the PPT and carbon targets was calculated and gave a corrected recoil particle energy T_2 for any accepted event. T_2 and θ_C on the carbon analyzer determine corresponding A_C values.

Cuts are applied for the vertex in carbon, for θ_C, as well as for the ϕ_C and ϕ mirror symmetry conditions [14]. Remaining events at all high energies represented about 2% of the single scattering events. Their number varied between 8×10^3 and 10^5, depending on energy.

The $p - C$ analyzing power A_C was interpolated from the results given in [8,19-28]. Above 1 GeV the results from [29] were used. The Saclay measurements [30], the Gatchina and Protvino data [31], as well as the JINR-Dubna data [32], were also taken into account.

Within a given θ_{CM} bin, (2.7) together with (2.10) may be used to calculate terms at independent combinations of $\sin\phi$, $cos\phi$, $\sin\phi_C$ and $\cos\phi_C$ by the maximum likelihood method. It involves all events for any beam and target polarization configuration. It is the most accurate method in order to determine observables, but corresponding calculations are long due to convergence purposes. In principle, the maximum likelihood method needs no θ_{CM} binning at all [33].

The rescattering observables in this paper as well as in a majority of previous ones were determined using the method, first proposed by the Geneva group [20]. This method was derived from the maximum likelihood method and applied to a given θ_{CM} bin, separately for each beam and target polarization direction. We will not describe it here in detail and we refer to [20,34]. It was shown that independent sums over all single scattering events in [2.7]:

$$\Sigma \sin\phi, \quad \Sigma \cos\phi, \quad \Sigma \sin\phi \, \cos\phi, \quad \Sigma \sin^2\phi, \quad \Sigma \cos^2\phi, \tag{3.1}$$

determine multiplicative coefficients containing observables and known beam and target polarizations in the first and second scattering. The second scattering formula (2.9) contains unknown recoil particle polarization $\vec{P}$"$(\sin\phi, \, \cos\phi)$. The sums

$$\Sigma \, A_C(\theta_C, \, T_2) \cdot \sin\phi_C, \quad \Sigma \, A_C(\theta_C, \, T_2) \cdot \cos\phi_C. \tag{3.2}$$

determine the coefficients of the $\vec{P}$" components. Here $A_C(\theta_C, \, T_2)$ behaves as a weight for each event. The second scattering terms in (2.10) are multiplied by $A_C(\theta_C, T_2) \, \sin\phi_C$ and $A_C(\theta_C, T_2) \, \cos\phi_C$. The corresponding sums over all events for one bin of the first scattering angle:

$$\Sigma \, A_C^2 \, \cos^2\phi_C, \quad \Sigma \, A_C^2 \, \sin^2\phi_C, \quad \Sigma \, A_C^2 \, \sin\phi_C \, \cos\phi_C, \tag{3.3}$$

together with sums (3.2) determine n and s" component of $\vec{P}$" [20] for any ϕ-function. From these components, using (2.7) and (2.10) for different beam and target polarization configurations, one calculates the observables.

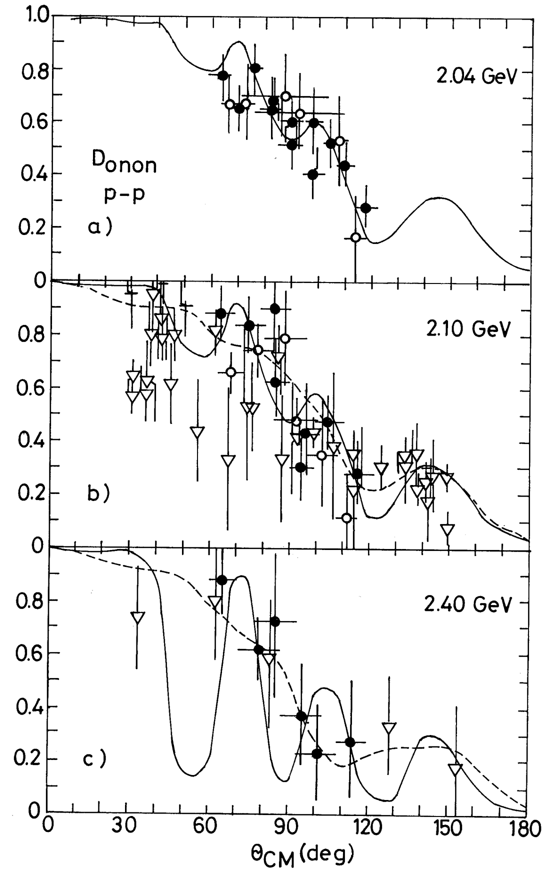

Fig. 2. a The present results for $D_{onon}(\theta_{CM})$ and for $K_{onno}(\theta_{CM}) = D_{onon}(180° - \theta_{CM})$ (black dots) at 2.035 GeV, **b** 2.115 GeV, and **c** at 2.395 GeV. They are compared with the previously-existing data of [4-6] (triangles), from [7] (open circles) and with ANL-ZGS data [9] (+). Solid curves are the predictions at 2.04, 2.10 and 2.40 of the energy dependent PSA [2], which contains the data [4–7,9] only, and dashed curves in **b,c** are predictions of the PSA [3], which also contains the present data and the results from [1]

Since each sum in (3.1) to (3.3) is calculated only once, the Geneva method is faster. A comparison with the maximum likelihood method showed an excellent agreement of results and errors.

4 Results and discussion

The rescattering observables K_{onno} and D_{onon} are given in Table 1 at 27 energies. The beam energy at the PPT center is given; the energy of the extracted beam was $\sim$ 5 MeV higher. Statistical and random-like uncertainties are listed for individual points. They are dominant with respect to other possible systematic errors, except at 0.8 GeV, where the rescattering data were measured with high statistical accuracy. The relative normalization systematic error in P_B was $\pm(3-5)$% and ±3% error was attributed to the PPT polarization.

P_{onoo} and N_{onnn} were calculated from recorded events at 0.80 and 2.04 GeV, where statistics was sufficient. They

Table 1. The observables K_{onno} and D_{onon} in pp elastic scattering. The beam kinetic energy, the central CM angles, and the angular bins for rescattering observables in degrees are listed. The statistical and random like systematic errors are quoted. The normalization systematic error in P_B was $\pm(3-5)\%$, in P_T $\pm3\%$ (relative). The systematic error provided by a normalization uncertainty in the $p-C$ analyzing power was $\pm6\%$ (relative)

θ_{CM}	θ_{CM} bin	K_{onno}	D_{onon}
	$T_{kin} = 0.795$ GeV		
55.2	51.0–57.3	0.486 ± 0.034	0.615 ± 0.039
59.9	57.3–63.0	0.576 ± 0.022	0.741 ± 0.028
65.3	63.0–68.0	0.589 ± 0.024	0.715 ± 0.032
72.4	68.0–77.0	0.678 ± 0.021	0.695 ± 0.027
80.0	77.0–83.0	0.711 ± 0.031	0.707 ± 0.040
85.2	83.0–89.0	0.694 ± 0.042	0.751 ± 0.052
	$T_{kin} = 1.935$ GeV		
60.4	56.0–64.0	0.321 ± 0.198	0.569 ± 0.185
70.0	64.0–76.1	0.375 ± 0.184	0.744 ± 0.170
86.0	76.1–96.0	0.322 ± 0.168	0.462 ± 0.155
	$T_{kin} = 1.955$ GeV		
60.7	56.0–64.0	0.427 ± 0.188	0.778 ± 0.153
70.0	64.0–75.7	0.450 ± 0.176	0.717 ± 0.142
86.0	75.7–97.0	0.472 ± 0.146	0.408 ± 0.120
	$T_{kin} = 1.975$ GeV		
62.0	56.0–65.2	0.293 ± 0.136	0.876 ± 0.116
69.3	65.2–72.8	0.640 ± 0.124	0.670 ± 0.105
76.0	72.8–79.2	0.430 ± 0.127	0.761 ± 0.124
85.0	79.2–91.0	0.335 ± 0.104	0.400 ± 0.100
95.0	91.0–100.0	0.739 ± 0.143	0.234 ± 0.134
	$T_{kin} = 2.015$ GeV		
60.5	56.0–63.9	0.522 ± 0.197	0.888 ± 0.243
70.0	63.9–76.0	0.142 ± 0.178	0.871 ± 0.221
86.0	76.0–97.0	0.370 ± 0.154	0.450 ± 0.194
	$T_{kin} = 2.035$ GeV		
63.4	57.0–66.0	0.284 ± 0.096	0.781 ± 0.089
70.0	66.0–73.2	0.438 ± 0.090	0.658 ± 0.084
75.9	73.2–78.6	0.534 ± 0.092	0.807 ± 0.098
82.0	78.6–85.3	0.401 ± 0.085	0.688 ± 0.093
90.0	85.3–94.8	0.508 ± 0.076	0.609 ± 0.081
98.1	94.8–101.0	0.652 ± 0.118	0.609 ± 0.126

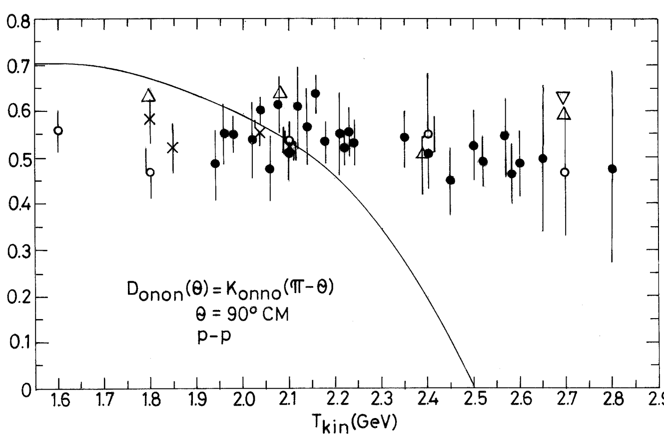

Fig. 3. The D_{onon} (K_{onno}) energy dependence at 90° CM. Black dots are the present data, open circles are from [4-6], and crosses from [7]. Solid line is the prediction of [2], triangles are predictions from [3]

Table 1. (cont.)

θ_{CM}	θ_{CM} bin	K_{onno}	D_{onon}
	$T_{kin} = 2.055$ GeV		
62.0	56.0–66.5	0.241 ± 0.155	0.970 ± 0.167
72.0	66.5–77.0	0.265 ± 0.180	0.647 ± 0.196
86.0	77.0–97.0	0.186 ± 0.147	0.414 ± 0.162
	$T_{kin} = 2.075$ GeV		
61.9	57.0–66.0	0.139 ± 0.145	1.175 ± 0.160
71.3	66.0–76.0	0.515 ± 0.160	1.002 ± 0.178
86.0	76.0–97.0	0.267 ± 0.129	0.590 ± 0.148
	$T_{kin} = 2.095$ GeV		
64.7	57.0–69.5	0.133 ± 0.141	0.598 ± 0.132
75.0	69.5–80.5	0.389 ± 0.147	0.751 ± 0.135
90.0	80.5–101.0	0.627 ± 0.128	0.385 ± 0.118
	$T_{kin} = 2.115$ GeV		
64.4	58.0–69.0	0.272 ± 0.124	0.878 ± 0.110
75.0	69.0–80.5	0.451 ± 0.106	0.840 ± 0.106
85.0	80.5–89.8	0.299 ± 0.127	0.620 ± 0.132
95.3	89.8–101.0	0.903 ± 0.157	0.424 ± 0.157
	$T_{kin} = 2.135$ GeV		
62.0	57.0–65.7	0.363 ± 0.223	0.854 ± 0.214
71.5	65.7–76.7	0.389 ± 0.226	0.891 ± 0.216
86.0	76.7–96.0	0.376 ± 0.182	0.517 ± 0.179
	$T_{kin} = 2.155$ GeV		
65.2	58.0–70.2	0.292 ± 0.105	0.984 ± 0.090
76.0	70.2–81.4	0.388 ± 0.092	0.870 ± 0.093
85.0	81.4–89.0	0.317 ± 0.120	0.635 ± 0.125
95.1	89.0–102.0	0.708 ± 0.124	0.509 ± 0.127
	$T_{kin} = 2.175$ GeV		
65.0	58.0–70.2	0.406 ± 0.104	0.802 ± 0.094
76.0	70.2–81.4	0.277 ± 0.097	0.625 ± 0.098
85.0	81.4–88.9	0.346 ± 0.131	0.844 ± 0.137
95.1	88.9–102.0	0.341 ± 0.138	0.485 ± 0.138

agree well with the known A_{oono} data. At the same energies were determined other "undesired" observables with large errors. They were used for a check of an internal compatibility and are not listed in Tables.

The normalization error of the rescattering observables is mainly due to the normalization uncertainty in the $p-C$ analyzing power. Using the two-dimensional fit in T_r and θ_C to all existing data, the additional normalization error is around $\pm6\%$ at all energies.

The $D_{onon}(\theta_{CM})$ and $K_{onno}(\theta_{CM}) = D_{onon}(180^\circ - \theta_{CM})$ results at 2.04, 2.10, and 2.40 GeV are plotted in Fig. 2 together with previously-existing data [4-7]. The predictions of the energy independent PSA [2] are plotted at three energies and those of the Saclay-Geneva fixed energy PSA [3] at the two higher energies, The present results and the preliminary data from [1] were not included in the database of the PSA [2], whereas the PSA [3] contains all the data. This lack of data probably induces considerable fluctuations in predictions [2], namely at 2.40 GeV, as can be seen in Fig. 2.

We have averaged the D_{onon} and K_{onno} data around 90° CM. The results at all high energies are plotted in Fig. 3 together with existing data [4-7] and PSA predictions. One observes a fairly constant values of the data within the errors over a large energy range. The predic-

Table 1. (cont.)

θ_{CM}	θ_{CM} bin	K_{onno}	D_{onon}
	$T_{kin} = 2.205$ GeV		
62.4	58.0–66.1	0.533 ± 0.233	0.739 ± 0.231
72.0	66.1–77.5	0.354 ± 0.217	0.807 ± 0.217
86.0	77.5–96.0	0.360 ± 0.187	0.578 ± 0.192
	$T_{kin} = 2.215$ GeV		
65.1	58.0–70.2	0.304 ± 0.095	0.710 ± 0.088
76.0	70.0–81.4	0.370 ± 0.082	0.658 ± 0.087
85.0	81.4–88.8	0.378 ± 0.107	0.586 ± 0.120
95.1	88.8–102.0	0.585 ± 0.111	0.378 ± 0.122
	$T_{kin} = 2.225$ GeV		
64.6	59.0–69.5	0.249 ± 0.125	0.763 ± 0.116
76.0	69.5–81.3	0.350 ± 0.109	0.765 ± 0.116
84.9	81.3–88.7	0.641 ± 0.134	0.541 ± 0.143
95.1	88.7–102.0	0.435 ± 0.143	0.492 ± 0.150
	$T_{kin} = 2.235$ GeV		
65.7	60.0– 0.7	0.201 ± 0.128	0.820 ± 0.113
76.0	70.7–80.9	0.302 ± 0.116	0.762 ± 0.124
85.0	80.9–89.1	0.298 ± 0.136	0.475 ± 0.149
95.0	89.1–102.0	0.563 ± 0.150	0.702 ± 0.157
	$T_{kin} = 2.345$ GeV		
64.5	60.0–68.7	0.124 ± 0.187	0.789 ± 0.153
76.0	68.7–81.3	0.397 ± 0.148	0.670 ± 0.149
86.0	81.3–91.0	0.515 ± 0.165	0.906 ± 0.172
97.0	91.0–103.0	0.313 ± 0.206	0.580 ± 0.204
	$T_{kin} = 2.395$ GeV		
65.6	60.0–71.2	0.275 ± 0.219	0.878 ± 0.127
79.0	71.2–87.3	0.224 ± 0.185	0.617 ± 0.121
95.0	87.3–103.0	0.713 ± 0.285	0.373 ± 0.188
	$T_{kin} = 2.445$ GeV		
65.5	60.0–71.4	0.193 ± 0.146	0.752 ± 0.138
80.0	71.4–87.1	0.271 ± 0.122	0.737 ± 0.137
95.0	87.1–103.0	0.416 ± 0.177	0.411 ± 0.202

tion of the PSA [2] shows a disagreement above 2.2 GeV. The predictions of the energy fixed PSA [3], caried out at four energies, are in good agreement.

5 Conclusions

The present results on D_{onon} and K_{onno} improve significantly our knowledge of these observables in the angular range around 90° CM and over a large energy interval. They will help to extend the PSA toward high energy and contribute as well to remove some ambiguities present in direct reconstructions of scattering amplitudes [35].

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Table 1. (cont.)

θ_{CM}	θ_{CM} bin	K_{onno}	D_{onon}
	$T_{kin} = 2.495$ GeV		
65.9	60.0–71.4	0.318 ± 0.189	0.833 ± 0.159
78.0	71.4–84.8	0.126 ± 0.169	0.946 ± 0.162
94.0	84.8–103.0	0.683 ± 0.235	0.221 ± 0.225
	$T_{kin} = 2.515$ GeV		
65.2	60.0–70.3	0.147 ± 0.153	0.706 ± 0.149
80.0	70.3–87.1	0.410 ± 0.121	0.609 ± 0.144
95.0	87.1–103.0	0.608 ± 0.178	0.388 ± 0.211
	$T_{kin} = 2.565$ GeV		
65.9	60.0–71.3	0.634 ± 0.208	0.990 ± 0.190
78.0	71.3–84.8	0.453 ± 0.191	0.522 ± 0.193
94.0	84.8–103.0	0.408 ± 0.256	0.335 ± 0.272
	$T_{kin} = 2.575$ GeV		
65.1	60.0–70.0	0.225 ± 0.168	0.695 ± 0.156
79.0	70.0–85.8	0.328 ± 0.140	0.530 ± 0.156
94.0	85.8–103.0	0.594 ± 0.188	0.453 ± 0.208
	$T_{kin} = 2.595$ GeV		
65.9	60.0–71.2	0.370 ± 0.162	0.709 ± 0.152
78.0	71.2–85.0	0.372 ± 0.149	0.640 ± 0.154
94.0	85.0–103.0	0.397 ± 0.206	0.313 ± 0.224
	$T_{kin} = 2.645$ GeV		
65.9	60.0–71.0	0.640 ± 0.187	0.818 ± 0.167
77.0	71.0–82.9	0.575 ± 0.188	0.975 ± 0.181
92.4	82.9–103.0	0.646 ± 0.251	0.675 ± 0.246
	$T_{kin} = 2.795$ GeV		
70.1	62.0–80.0	0.427 ± 0.341	0.849 ± 0.250
90.0	80.0–102.0	0.931 ± 0.400	0.233 ± 0.353

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