MEASUREMENTS OF THE D_{\pi\pi} AND K_{\pi\pi} OBSERVABLES
IN np ELASTIC SCATTERING BETWEEN 0.80 AND 1.10 GeV

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**ABSTRACT**

We present results of the rescattering observables $D_{\text{onon}}(np)$ and $K_{\text{onno}}(np)$ measurements at eight energies between 0.80 and 1.10 GeV. The SATURNE II polarized beam of free neutrons obtained from the break-up of polarized deuterons was scattered on the polarized Saclay frozen-spin proton target. Part of the data was obtained with a CH$_2$ target where only the polarization transfer parameter $K_{\text{onno}}$ was determined. The present results are the first existing measurements of these observables above 0.80 GeV. They provide an important contribution to any future theoretical or phenomenological analysis.

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1. INTRODUCTION

We present measurements of the depolarization $D_{\text{non}}$ and the polarization transfer parameter $K_{\text{non}}$ in np elastic scattering at 0.80, 0.84, 0.86, 0.88, 0.91, 0.94, 1.00 and 1.10 GeV. Results for these Wolfenstein parameters were obtained with the SATURNE II polarized beam of free quasi-monochromatic neutrons scattered in the Saclay frozen spin proton target. The beam and target polarizations were oriented vertically. Recoil protons were rescattered in a carbon analyzer and the $p-C$ asymmetry was measured. The single-scattering data from the experiment provided the analyzing power $A_{\text{non}}$ and spin correlation parameter $A_{\text{onn}}$, which were reported in refs[1,2,3]. All these data were taken simultaneously with the transmission measurement of the total cross section difference $\Delta \sigma_T(np)$[4]. The experiment is part of a systematic study of the nucleon-nucleon system at SATURNE II.

Throughout this paper we use the nucleon-nucleon formalism and the four-spin notation of observables developed in ref.[5].

2. POLARIZED BEAM AND TARGET

Polarized neutrons are produced by break-up of vector-polarized deuterons on a Be target. The production target was 20 cm thick and the neutron beam is defined by a total of 8 meters of collimators inserted in the 17.5 m long neutron beam line[6]. The neutron beam momentum spread of about ± 20 MeV is due to deuteron absorption in the production target and to the Fermi motion of the neutrons in the deuterons. The polarized deuteron beam with $2-3 \times 10^{11}$ deuterons/burst produced $\sim 6 \times 10^7$ neutrons/burst. The neutron beam intensity was monitored by a scintillation counter array inserted in the beam in front of the polarized target[4].

The deuteron beam polarization was flipped every burst of the accelerator by a change of the RF transitions in the ion source. The polarization of the break-up neutrons was determined by a dedicated experiment, as explained in refs[1,6]. The polarization of the neutrons is $P_n = 0.59$, independent of energy. The polarization of the protons in the accelerated deuterons was also checked by the beam polarimeter[7].

Page 1
The proton polarized target (PPT) was 35 mm thick, 40 mm wide and 49 mm high [8]. The target material was pentanol, with a typical proton polarization of 85%. The target polarization was held in a magnetic field of ~0.33 T produced by a vertical superconducting holding coil. The target polarization was inverted every few hours. The polarization direction was changed by a PPT repolarization at a different microfrequency. Part of data at 0.88 GeV was measured with a CH$_2$ target at the same position at the PPT.

In order to monitor correctly measurements with two opposite target polarization directions, for part of the data-taking a polyethylene "CH$_2$" target 3 to 10 mm thick was positioned downstream of the PPT and viewed by a dedicated scintillation counter. Particles scattered either of the PPT or of the CH$_2$ target produce independent triggers, but their tracks are detected by the same MWPC's. The number of events from the CH$_2$ target, is used to check the normalization of the data taken with opposite PPT polarizations.

3. EXPERIMENTAL SET-UP AND DATA ANALYSIS

The experimental set-up is described in ref.[6]. Outgoing particles are detected by a two-arm spectrometer which comprises single scintillation counters, counter hodoscopes, the neutron counter (NC) hodoscope with its VETO, an analyzing magnet and eight multiwire proportional chambers.

The NC hodoscope[6,9] consists of 15 scintillating bars and measures a particle's position from the time difference between the signals from the two PM's on either side of a bar, with a precision of $\pm$25 mm. Veto counters in front of the neutron counter hodoscope distinguish between neutral and charged particles.

The recoil protons from the PPT and from the additional CH$_2$ target may be rescattered in a carbon plate. The plate was 3 cm thick at small neutron scattering angles and 5 cm at large angles. The coordinates of rescattered protons are determined by hits in two MWPC's, behind the carbon plate. The rescattered events represent ~1% to 2% of the single scattering events. For this reason the rescattering data have considerably larger statistical errors.

The triggers and fast electronics are described in ref.[6].
Candidates for np events are determined and recognized by 2 different pretriggers. The following pretriggers are used:

1. Forward neutron, backward proton, np scattering in the PPT: pretrigger TND.
2. Forward neutron, backward proton, np scattering in the additional CH₂ target: pretrigger MND.

The sum of pretriggers enters in the NC logic, which determine charged or neutral NC events, and gives the Master Trigger. This trigger gives an event interrupt NIM signal to the CAC module (based on the MOTOROLA 68000 microprocessor) and to the on-line computer. The CAC module starts the acquisition of MWPC's, TDC's and the information of different memory units. Coincidences between the accepted master trigger signals and delayed pretriggers determine the final kind of triggers.

The data analysis is described in detail in ref.[6]. The forward neutron momentum is determined by neutron time-of-flight between the PPT and the NC hodoscope. The wings in the coplanarity distribution of the particles and their left-right angular correlation were used to subtract the carbon and inelastic background from the single scattering events. For events where the recoil charged particle is rescattered in the carbon block, the off line analysis applies all kinematic cuts for single scattering. Cuts on the position of the vertex of the recoil particle in the analyzer as well as on the rescattering angle (required to be larger than 4°) are added.

4. DETERMINATION OF D_{\text{nono}} AND K_{\text{onno}}

The general expression for the differential cross section of elastic scattering with polarized beam and polarized target is given in ref.[5]. In the present experiment the beam and target polarizations (P_B and P_T, respectively) are oriented vertically. The difference between the first scattering plane and the horizontal plane is given by the azimuthal angle $\phi$, which may reach $\pm 7^o$ at most. In this case only the normal component of the recoil particle polarization (spin-index n) provides non-zero observables and was measured in the second scattering. Under
these condition and assuming that the first scattering plane is the horizontal plane, the general formula reduces to:

$$
\Sigma(P_B,P_T) = I_C \sigma \left[ 1 + A_{oono} P_B + A_{oon} P_T + A_{oonn} P_B P_T \right]
$$

$$
+ P_C \left[ (P_{oono} + P_K' Konno + P_T Donon + P_{2T N onn}) \cos \phi_2 \right].
$$

where $I_C$ and $P_C$ are the differential cross section and analyzing power for the second scattering on the carbon analyzer, respectively. They depend on the angle of the second scattering $\theta_2$ and on the energy $T_2$ of the recoil proton incident on the analyzer. The symbol $\sigma = (d\sigma/dQ)$ denotes the np differential cross section, for unpolarized beam and target and $\phi_2$ is the angle between the normals of the first and the second scattering. The azimuthal angles $\phi$ and $\phi_2$, for each recorded event, were taken into account. The angular dependence of the observables $A_{oono}$, $A_{oon}$ and $A_{oonn}$ has been reported in refs[1,2,3]. Assuming the generalized Pauli principle (isospin invariance) and time-reversal invariance to hold as in ref.[5], it follows $P_{oono} = N_{onnn} = A_{oono} = A_{oonn}$. The result for $P_{oono}$, representing the average over beam and target polarization, is obtained with relatively large statistical errors and may be affected by a possible instrumental asymmetry which is not cancelled by beam or target-spin reversal. For this reason we fixed in the analysis the $P_{oono}$ and $N_{onnn}$ observables by the values of $A_{oono} = A_{oonn}$ obtained from refs[1,2]. The measured values of $P_{oono}$ and $N_{onnn}$ were used only as a check of internal consistency of the measurements. We have also fixed the spin correlation $A_{oon}$ by the accurately measured angular dependence of this observable from ref.[3]. The $(\theta_2,\phi_2)$ distribution in the second scattering with known $P_C(\theta_2,T_2)$ (see ref.[6]), measured with different combinations for the signs $P_B$ and $P_T'$ forms a redundant set which allows to remove a major part of the instrumental asymmetries. The observables $D_{onon}$ and $K_{onno}$ are obtained as "pure" observables, i.e. the corresponding asymmetries do not depend on other parameters.

For the measurements with an unpolarized target, all terms containing $P_T$ in Eq.(1) drop out and only the observables $A_{oono}$, $P_{oono}$ and $K_{onno}$ survive.

Eq.(1) may be used to determine the linearly independent observables $D_{onon}$ and $K_{onno}$ by the maximum-likelihood method. As mentioned in ref.[6], in the present
analysis we have applied the momentum method, used with success and described by
the Geneva University group [10,11]. This method, adapted to our experiments, is
treated in detail in ref.[12]. Several test show that the maximum-likelihood method
and the momentum method give the same results.

5. RESULTS

One part of the preliminary results of this experiment is given in ref.[13].
The final results are listed in Table 1. The statistical errors are dominant and
are given in the table. We estimate that an additional error due to uncontrolled
instrumental effects is negligible for the present experiment. The uncertainty
in the target polarization measurements is ± 3%, the errors in the p-C analyzing
power are of the same order. The systematic error due to the normalization of the
number of events obtained for opposite beam and target polarizations to the same
integrated beam intensity, was considerably reduced by the use of the additional
CH₂ target. The angles given in the table are the weighted averages over the
corresponding angular bins.

Fig. 1 shows our results for D_{onon} at 8 energies, K_{onno} data are given in Fig.
2. The prediction of the Saclay-Geneva phase shift analysis [14] are shown at 0.80
GeV in both figures. The observable D_{onon} reaches large values at all energies
and angles. The observable K_{onno} is small in the measured angular range and mostly
compatible with zero within errors.

6. CONCLUSIONS

The rescattering observables D_{onon}(np) and K_{onno}(np) were measured at eight
energies between 0.80 and 1.10 GeV using the SATURNE II vertically polarized beam
of free neutrons together with the Saclay frozen spin polarized proton target
polarized in the same direction.

At all energies and angles the measured angular dependence of D_{onon}(np) shows
large values. The K_{onno} data are mostly compatible with zero. Their values, in
general, slightly increase at large angles.
The results for both observables were measured for the first time above 0.8 GeV. They represent an important contribution to the np → np data base. They will be used for a direct reconstruction of np scattering amplitudes, will improve the existing PSA solutions and will contribute to the extension of the PSA towards higher energies.

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REFERENCES


TABLE CAPTION

TABLE 1 Results of the depolarization $D_{\mathrm{onon}}$ and the polarization transfer parameter $K_{\mathrm{onno}}$ in np elastic scattering at 0.80, 0.84, 0.86, 0.88, 0.91, 0.94, 1.00 and 1.10 GeV.
FIGURE CAPTIONS

Fig. 1 Angular dependence of the depolarization parameter D_{non} in np elastic scattering at 0.80, 0.84, 0.86, 0.88, 0.91, 0.94, 1.00 and 1.10 GeV. The dashed line at 0.80 GeV represents the prediction of the Saclay-Geneva phase shift analysis[14].

Fig. 2 Angular dependence of the polarization transfer parameter K_{onno} in np elastic scattering at 0.80, 0.84, 0.86, 0.88, 0.91, 0.94, 1.00 and 1.10 GeV. The dashed line at 0.80 GeV represents the prediction of the Saclay-Geneva phase shift analysis[14].
Table 1

<table>
<thead>
<tr>
<th>Angle</th>
<th>(-t)</th>
<th>Donon</th>
<th>Konno</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM deg.</td>
<td>(GeV/c)²</td>
<td>Donon</td>
<td>Konno</td>
</tr>
</tbody>
</table>

\(T_{\text{kin}} = 0.80\ \text{GeV},\ P_{\text{lab}} = 1.463\ \text{GeV/c}\)

<table>
<thead>
<tr>
<th>(\text{Angle (CM deg.)})</th>
<th>(-t)</th>
<th>(\text{Donon} \pm \text{Error})</th>
<th>(\text{Konno} \pm \text{Error})</th>
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<tbody>
<tr>
<td>48.2</td>
<td>0.251</td>
<td>0.801 ± 0.146</td>
<td>0.108 ± 0.221</td>
</tr>
<tr>
<td>64.1</td>
<td>0.423</td>
<td>1.113 ± 0.157</td>
<td>0.281 ± 0.215</td>
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</table>

\(T_{\text{kin}} = 0.84\ \text{GeV},\ P_{\text{lab}} = 1.511\ \text{GeV/c}\)

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<th>(\text{Konno} \pm \text{Error})</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.9</td>
<td>0.302</td>
<td>0.662 ± 0.103</td>
<td>-0.021 ± 0.111</td>
</tr>
<tr>
<td>58.7</td>
<td>0.379</td>
<td>0.834 ± 0.105</td>
<td>0.011 ± 0.118</td>
</tr>
<tr>
<td>65.6</td>
<td>0.463</td>
<td>0.886 ± 0.117</td>
<td>0.329 ± 0.135</td>
</tr>
<tr>
<td>76.7</td>
<td>0.608</td>
<td>0.581 ± 0.146</td>
<td>0.033 ± 0.167</td>
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\(T_{\text{kin}} = 0.86\ \text{GeV},\ P_{\text{lab}} = 1.535\ \text{GeV/c}\)

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<th>(\text{Konno} \pm \text{Error})</th>
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</thead>
<tbody>
<tr>
<td>53.0</td>
<td>0.322</td>
<td>0.675 ± 0.129</td>
<td>-0.079 ± 0.146</td>
</tr>
<tr>
<td>61.7</td>
<td>0.425</td>
<td>0.921 ± 0.128</td>
<td>-0.029 ± 0.146</td>
</tr>
<tr>
<td>76.3</td>
<td>0.580</td>
<td>0.785 ± 0.118</td>
<td>0.186 ± 0.135</td>
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### Table 1 - Cont.

#### $T_{\text{kin}} = 0.88$ GeV, $P_{\text{lab}} = 1.558$ GeV/c

<table>
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<tr>
<th>Angle CM deg. (GeV/c)$^2$</th>
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<th>$D_{\text{non}}$</th>
<th>$K_{\text{non}}$</th>
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<tr>
<td></td>
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<tr>
<td>49.5</td>
<td>0.289</td>
<td>0.619 ± 0.067</td>
<td>0.042 ± 0.089</td>
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<tr>
<td>55.8</td>
<td>0.362</td>
<td>0.994 ± 0.070</td>
<td>0.120 ± 0.078</td>
</tr>
<tr>
<td>60.8</td>
<td>0.423</td>
<td>0.810 ± 0.058</td>
<td>0.084 ± 0.065</td>
</tr>
<tr>
<td>77.1</td>
<td>0.642</td>
<td>0.909 ± 0.046</td>
<td>0.139 ± 0.050</td>
</tr>
</tbody>
</table>

#### $T_{\text{kin}} = 0.91$ GeV, $P_{\text{lab}} = 1.593$ GeV/c

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<th>Angle CM deg. (GeV/c)$^2$</th>
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<th>$D_{\text{non}}$</th>
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<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>51.7</td>
<td>0.324</td>
<td>0.875 ± 0.071</td>
<td>0.131 ± 0.079</td>
</tr>
<tr>
<td>53.8</td>
<td>0.416</td>
<td>0.881 ± 0.076</td>
<td>0.130 ± 0.085</td>
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<td>65.7</td>
<td>0.502</td>
<td>0.752 ± 0.087</td>
<td>0.081 ± 0.096</td>
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<td>75.5</td>
<td>0.640</td>
<td>0.772 ± 0.107</td>
<td>0.105 ± 0.117</td>
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<tr>
<td>96.4</td>
<td>0.800</td>
<td>0.579 ± 0.174</td>
<td>-0.032 ± 0.208</td>
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#### $T_{\text{kin}} = 0.94$ GeV, $P_{\text{lab}} = 1.628$ GeV/c

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<tr>
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<tr>
<td>47.6</td>
<td>0.288</td>
<td>0.696 ± 0.094</td>
<td>-0.054 ± 0.123</td>
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<tr>
<td>53.9</td>
<td>0.362</td>
<td>0.996 ± 0.104</td>
<td>0.210 ± 0.125</td>
</tr>
<tr>
<td>58.9</td>
<td>0.426</td>
<td>0.693 ± 0.099</td>
<td>0.077 ± 0.115</td>
</tr>
<tr>
<td>72.9</td>
<td>0.623</td>
<td>0.727 ± 0.083</td>
<td>0.240 ± 0.096</td>
</tr>
<tr>
<td>Angle (CM deg.)</td>
<td>(-t) (GeV/c)(^2)</td>
<td>Donon</td>
<td>Konno</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>47.6</td>
<td>0.306</td>
<td>0.749 ± 0.095</td>
<td>0.084 ± 0.130</td>
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<tr>
<td>56.3</td>
<td>0.418</td>
<td>0.823 ± 0.135</td>
<td>0.052 ± 0.165</td>
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<tr>
<td>62.3</td>
<td>0.503</td>
<td>0.736 ± 0.153</td>
<td>-0.051 ± 0.183</td>
</tr>
<tr>
<td>77.1</td>
<td>0.729</td>
<td>0.732 ± 0.182</td>
<td>0.198 ± 0.217</td>
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</table>

\(T_{\text{kin}} = 1.00\text{ GeV}, P_{\text{lab}} = 1.697\text{ GeV/c}\)

<table>
<thead>
<tr>
<th>Angle (CM deg.)</th>
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<th>Konno</th>
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<tbody>
<tr>
<td>42.8</td>
<td>0.275</td>
<td>1.015 ± 0.134</td>
<td>-0.003 ± 0.203</td>
</tr>
<tr>
<td>53.7</td>
<td>0.412</td>
<td>0.799 ± 0.101</td>
<td>0.024 ± 0.146</td>
</tr>
<tr>
<td>55.5</td>
<td>0.448</td>
<td>0.839 ± 0.099</td>
<td>0.051 ± 0.142</td>
</tr>
<tr>
<td>70.0</td>
<td>0.680</td>
<td>0.926 ± 0.093</td>
<td>-0.025 ± 0.138</td>
</tr>
</tbody>
</table>

\(T_{\text{kin}} = 1.10\text{ GeV}, P_{\text{lab}} = 1.810\text{ GeV/c}\)