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

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ABSTRACT

We present results of the rescattering observables $D_{onon}(np)$ and $K_{onno}(np)$ 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_{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_{onon} and 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. 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_{oono} and spin correlation parameter A_{oonn} , which were reported in refs[1,2,3]. All these data were taken simultaneously with the transmission measurement of the total cross section difference $\Delta\sigma_T(\text{np})$ [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 $2\text{--}3 \times 10^{11}$ deuterons/burst produced $\sim 6 \cdot 10^7$ 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 $P_B = 0.59$, independent of energy. The polarization of the protons in the accelerated deuterons was also checked by the beam polarimeter[7].

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 ± 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 $\sim 1\%$ 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
 CH_2 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_{onon} AND K_{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 ϕ , which may reach $\pm 7^\circ$ 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 :

$$\Sigma(P_B, P_T) = I_C \sigma \{ [1 + A_{oono} P_B + A_{oon} P_T + A_{oonn} P_B P_T] + P_C [(P_{onoo} + P_B K_{onno} + P_T D_{onon} + P_B P_T N_{onnn}) \cos \varphi_2] \} \quad (1)$$

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 θ_2 and on the energy T_2 of the recoil proton incident on the analyzer. The symbol $\sigma = (d\sigma/d\Omega)$ denotes the np differential cross section, for unpolarized beam and target and φ_2 is the angle between the normals of the first and the second scattering. The azimuthal angles φ and φ_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 $P_{onoo} = N_{onnn} = A_{oono} = A_{oon}$. The result for P_{onoo} , 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_{onoo} and N_{onnn} observables by the values of $A_{oono} = A_{oon}$ obtained from refs[1,2]. The measured values of P_{onoo} and N_{onnn} were used only as a check of internal consistency of the measurements. We have also fixed the spin correlation A_{oonn} by the accurately measured angular dependence of this observable from ref.[3]. The (θ_2, φ_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_{onoo} 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 $\pm 3\%$, 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 CH_2 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 $D_{\text{onon}}(\text{np})$ and $K_{\text{onno}}(\text{np})$ 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 $D_{\text{onon}}(\text{np})$ 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 $np \rightarrow np$ 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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TABLE CAPTION

TABLE 1 Results of the depolarization D_{onon} and 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.

FIGURE CAPTIONS

Fig. 1 Angular dependence of the depolarization parameter D_{onon} 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

$T_{\text{kin}} = 0.80 \text{ GeV} , P_{\text{lab}} = 1.463 \text{ GeV/c}$			
Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
48.2	0.251	0.801 ± 0.146	0.108 ± 0.221
64.1	0.423	1.113 ± 0.157	0.281 ± 0.215

$T_{\text{kin}} = 0.84 \text{ GeV} , P_{\text{lab}} = 1.511 \text{ GeV/c}$			
Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
51.9	0.302	0.662 ± 0.103	-0.021 ± 0.111
58.7	0.379	0.834 ± 0.105	0.011 ± 0.118
65.6	0.463	0.886 ± 0.117	0.329 ± 0.135
76.7	0.608	0.581 ± 0.146	0.033 ± 0.167

$T_{\text{kin}} = 0.86 \text{ GeV} , P_{\text{lab}} = 1.535 \text{ GeV/c}$			
Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
53.0	0.322	0.675 ± 0.129	-0.079 ± 0.146
61.7	0.425	0.921 ± 0.128	-0.029 ± 0.146
76.3	0.580	0.785 ± 0.118	0.186 ± 0.135

Table 1 - Cont.

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

Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
49.5	0.289	0.619 ± 0.067	0.042 ± 0.089
55.8	0.362	0.994 ± 0.070	0.120 ± 0.078
60.8	0.423	0.810 ± 0.058	0.084 ± 0.065
77.1	0.642	0.909 ± 0.046	0.139 ± 0.050

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

Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
51.7	0.324	0.875 ± 0.071	0.131 ± 0.079
58.8	0.416	0.881 ± 0.076	0.130 ± 0.085
65.7	0.502	0.752 ± 0.087	0.081 ± 0.096
75.5	0.640	0.772 ± 0.107	0.105 ± 0.117
96.4	0.800	0.679 ± 0.174	-0.032 ± 0.208

$$T_{\text{kin}} = 0.94 \text{ GeV} , \quad P_{\text{lab}} = 1.628 \text{ GeV/c}$$

Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
47.6	0.288	0.896 ± 0.094	-0.054 ± 0.123
53.8	0.362	0.996 ± 0.104	0.210 ± 0.125
58.8	0.426	0.693 ± 0.099	0.077 ± 0.115
72.9	0.623	0.727 ± 0.083	0.240 ± 0.096

Table 1 - Cont.

$$T_{\text{kin}} = 1.00 \text{ GeV} , \quad P_{\text{lab}} = 1.697 \text{ GeV/c}$$

Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
47.6	0.306	0.749 ± 0.095	0.084 ± 0.130
56.3	0.418	0.823 ± 0.135	0.052 ± 0.165
62.3	0.503	0.736 ± 0.153	-0.051 ± 0.183
77.1	0.729	0.732 ± 0.182	0.198 ± 0.217

$$T_{\text{kin}} = 1.10 \text{ GeV} , \quad P_{\text{lab}} = 1.810 \text{ GeV/c}$$

Angle CM deg. (GeV/c) ²	-t	D _{onon}	K _{onno}
42.8	0.275	1.015 ± 0.134	-0.003 ± 0.203
53.7	0.412	0.799 ± 0.101	0.024 ± 0.146
55.5	0.448	0.839 ± 0.099	0.051 ± 0.142
70.0	0.680	0.926 ± 0.093	-0.025 ± 0.138

FIG. 1

FIG. 2