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Abstract

Elastic pd backward scattering in the kinetic energy range $0.6 < T_p < 2.7$ GeV has been measured and is discussed in terms of the one nucleon exchange (ONE) and the one pion exchange (OPE) mechanisms. The experimental plateau appearing in the 180° excitation function for $T_p > 2.$ GeV could be explained as excitation of the $\Delta(1950)$ in the intermediate state.

Keyword Abstract

Nuclear Reaction : pd → pd elastic scattering at backward proton angles. Intermediate energy range 0.6-2.7 GeV.

In the last ten years, backward elastic pd scattering has been the subject of an extensive work, especially in the energy ranges 0.4 to 1.2 GeV (ref. 1, 2, 3) and 2 to 2.5 GeV (ref. 4). The motivation was essentially the search for high momentum components in the deuteron wave function, such as the deuteron D-state contribution or exotic (NN^*) configuration suggested by Kerman and Kisslinger (ref. 5). At the present time, three main models compete in the explanation of the plateau observed in the $\theta_p = 180°$ excitation function at proton kinetic energies around $T_p = 0.6$ GeV; these models explain the plateau as due to either :

i) a dominant one pion exchange mechanism (OPE) emphasizing the role of the $\Delta(1232)$ in intermediate states (ref. 6, 15).

ii) a shoulder in the deuteron body form factor in a multiple scattering expansion (ref. 7).

iii) a true 3N resonance in the s-channel (ref. 8).

The new SPES 4 facility (ref. 9) at the Saturne National Laboratory, has made it possible to measure the elastic pd scattering at very backward angles ($158 \leq \theta_p \leq 180°$ in the c.m.) in the energy range $0.6 \leq T_p \leq 2.7$ GeV in one single experiment. The main result of this work, aside the monotonous decrease of the cross-section with increasing energy till 2 GeV, is the observation of a second structure in the 180° excitation function starting at 2.2 GeV. After a brief description of the experimental set-up, an analysis and a discussion of our data is presented in terms of a one-nucleon exchange mechanism (ONE) and of a one-pion exchange mechanism (OPE).

The experimental set-up has been described elsewhere (ref. 10) and is summarized as follows. The Saturne synchrotron beam, the energy of which can be continuously changed from 0.2 to 2.7 GeV, hits a cryogenic liquid, ^2H target of thickness 600 mg.cm^{-2}. The SPES IV spectrometer yields an intermediate focal plane (IFP) at 16 meters from the target and a final focal plane (FFP) at 32 meters from the target. Using plastics scintillator detectors a time of flight measurement is performed between the IFP and the FFP. In the FFP, an hodoscope detector of 0.2 % momentum resolution over a 3.8 % momentum range is followed by three rows of plastic scintillators allowing energy loss measurements.

The combination of a 16 meters time of flight path, leading to a 0.8 ns time resolution, and of three energy loss measurements for each event, results in a very good separation from the background : in the worst case at 2.55 GeV incident kinetic energy and at $\theta_d = 2°$, the ratio between the elastic peak and the background under the peak is $\frac{100}{8}$. The beam current, of the order of 2 to 5.10^{11} protons per burst, was monitored by three telescopes each made up of 3 plastic scintillators, two of them viewing a very thin CH_2 film upstream and one viewing the liquid target. A secondary electron monitor was also used. Calibrations of these monitors were obtained at each energy by activity measurements from $^{12}C(p,pn)^{11}C$. The variation of the stability of the monitors during the experiment, the uncertainty in the absolute beam calibration and on the target thickness lead together to a systematic error of ± 8 %.

All the experimental data are presented in Table 1. The error on each datum is only statistical so the systematic uncertainty must be added. For each energy, the values measured at or extrapolated to $\theta_p = 180°$, are shown on Fig. 1 as a function of the incident proton kinetic energy. Apart the monotonous exponential decrease of this excitation function between 0.7 GeV and 2 GeV, a second shoulder appears between 2.2 GeV and 2.7 GeV, the maximum energy at which our measurements were done.

Only two different approaches will be used here to interprete the elastic backward cross-sections, (i) the ONE and (ii) the OPE, which we briefly discuss below.

i) The single-nucleon exchange mechanism (ONE) for backscattering leads to a differential cross-section which is proportional to the second power of the momentum-space deuteron density. Using expressions given by Noble and Weber (ref. 11) and a deuteron wave function calculated with the Paris nucleon-nucleon potential (PP) (ref. 12) yields the result shown as a dashed curve on Fig. 1. Compared to the data, this calculation gives too slow a decrease of the 180° excitation function with increasing proton energies, the ratio between the calculation and the experiment reaching a factor of about 15 at 2.5-3 GeV. Levitas and Noble (Ref. 13) have investigated the rescattering effects in a DWIA model using an exchange potential. Rescattering reduces the elastic pd backward cross-sections, the attenuation increasing with incident proton energies. The attenuation factor obtained in Ref. 13 is about 4 at 2.5-3 GeV, not enough to produce agreement with the data.

In figure 2, all the measured cross-sections between T_p = 1.7-2.7 GeV have been divided by the relativistic phase space invariant, and plotted versus the laboratory momentum of the final state proton, which is equivalent in this ONE model to the relative momentum of the proton or neutron in the rest frame of the deuteron. The dashed curve joins the 180° (or the points extrapolated to 180°) measurements, emphasizing a change of slope at around T_p = 2.2 GeV. The experimental data between 2.4 and 2.7 GeV seem to stand on an universal curve, and in this region the slope of the data is close with ONE of Ref. 11. The results of Ref. 13 are not compatible with the change of slope of the 180° excitation function observed starting at T_p = 2.2 GeV in Fig. 2.

Recently, Kondratyuk et al. (Ref. 14) have described the ONE mechanism in terms of light front dynamics (ONELFD). Using their formula with the Paris potential wave function to calculate the 180° excitation function, one obtains the dotted-dashed curve shown on Fig. 1. The main difference between the two ONE calculations comes from the value of the momentum q of the proton or neutron in the deuteron at which the Fourier transform of the wave functions is calculated : the Kondratyuk et al. formula requires higher q-values than the Noble and Weber formula. For instance, at T_p = 2 GeV and θ_p = 180°, q = 2.42 fm^{-1} in the first case, and q = 3.07 fm^{-1} in the second case, leading to a ratio of 6 to 1 between the two calculations. Although the ONELFD calculation is in better agreement with our experimental results in the 2.-2.7 GeV region, it is unable to explain the change of regime in this energy range ; furthermore, the ONELFD calculation does not include rescattering effects. Nevertheless, whatever the formula used, the ONE calculation indicates that the data are in the T_p = 0.6-2.7 GeV energy range are mainly sensitive to the D state component of the deuteron wave function, in the momentum range concerned here, the D-state contribution is never less than 90 % of the full ONE cross-sections.

ii) The one pion exchange mechanism describes rather satisfactorily the large bump near T_p = 0.6 GeV in the 180° excitation function, as had been shown by Craigie and Wilkin (Ref. 15) particularly when the cross-section is calculated in terms of the $\pi N \to \pi N$ subreaction and the loop integrals in the double pion exchange graph are explicity performed (Ref. 16). The enhancement at T_p = 0.6 GeV appears as a consequence of the $\Delta(1236)$ excitation exactly as it appears at the same laboratory kinetic energy in the $pp \to d\pi$ excitation for θ_π = 180°

We used the expression proposed by Barry (Ref. 18) to calculate the 180° excitation function in terms of the $pp \to d\pi$ cross-sections for θ_π = 180°. A polynomial fit was obtained based on a compilation of the available $pp \to d\pi$ data in the energy range considered here, $0.3 < T_p < 2.7$ GeV (Ref. 19). Some experimental ambiguities exist around 2 GeV. The result of the calculation is shown in Fig. 1 as a continuous line ; it yields a change of slope in the 180° excitation function around T_p = 1.4 GeV and a wide plateau from 1.7 to 3 GeV. This plateau comes from a wide bump in the $pp \to d\pi$ elementary interaction which shows the same structure. This wide bump in the $pp \to d\pi$ was explained by Cocconi et al. (Ref. 20) as due to the $\Delta(1950)$ excitation in the OPE model of Yao (Ref. 21).

A more sophisticated calculation should take into account the ONE diagram, the OPE diagram, and include rescattering terms coherently. In its absence, we cannot suggest a definitive explanation of the new plateau observed in the present work. Certainly the slow monotonous decrease of the corss-section between 1.2 GeV and 2 GeV is associated with the D-state component of the deuteron wave function. The second plateau observed for the first time in the present experiment could be associated with the $\Delta(1950)$ excitation in the intermediate state as suggested by the OPE model predictions. These experiments will have to be pursued to still higher energies to follow the behaviour of the structure observed.

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Table caption

Table 1 : Experimental results.

1) Excitation function at $\theta_p=180°$. The values quoted (E) are obtained by extrapolation of the very backward measurements.

2) Angular distributions.

An overall absolute uncertainty of ±8% has to be added to the statistical uncertainties given in this table.

Figure captions

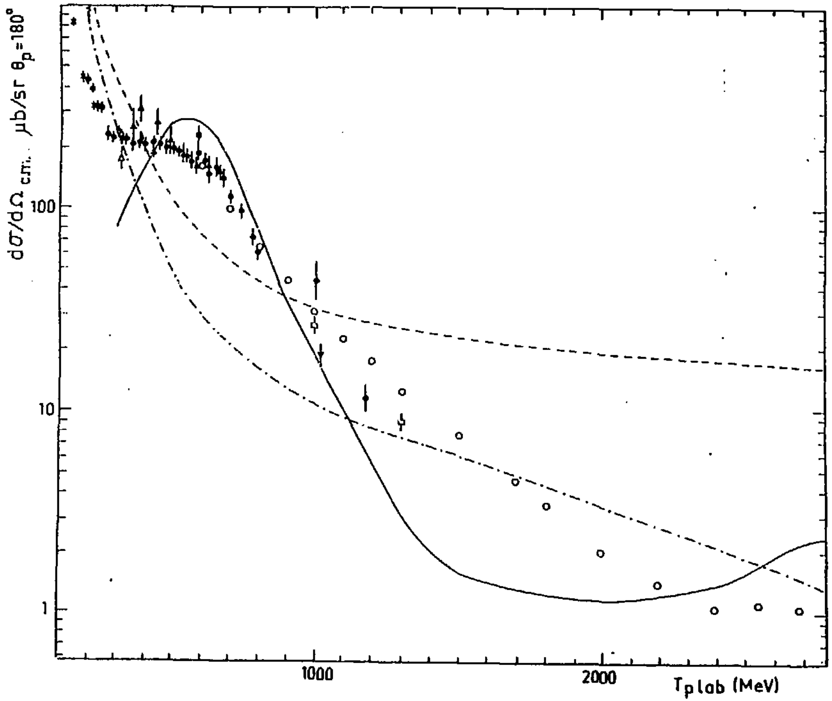
Fig.1. Experimental θ_p=180° excitation function compared to three calculations. The open circles are the data of this experiment, the other results come from ref.1), 2), 3), 4). The dashed line is the ONE calculation with the formula given by Noble and Weber [ref.11], the dashed-dotted line the ONELFD calculation with the Kondratyuk et al.[ref.14] formula. The continuous line is the OPE calculation with the formula given by Barry [ref.18].

Fig.2. Differential cross-sections divided by the relativistic phase space invariant of the ONE diagram of [ref.11] as a function of the relative momentum of the proton in the rest frame of the deuteron.

Table 1

1) Excitation function at $\theta_p = 180°$			2) Angular distributions			
T_{lab} GeV	θ_d(lab)	$(d\sigma/d\Omega)_{c.m.}$ μb/sr	T_{lab} GeV	θ_d(lab) deg.	$\theta_{c.m.}$ deg.	$(d\sigma/d\Omega)_{c.m.}$ μb/sr
.6	0	163 ±2	1.8	- 1	2.4	3.52 ±0.035
.7	0	94 ±3.5		4	9.7	2.99 ±0.030
.8	0	66.4 ±0.7		6	14.6	2.54 ±0.025
.9	0	45.4 ±0.5		8	19.4	2.08 ±0.021
1.0	0	31.5 ±0.4	2.2	- 1	2.5	1.440±0.029
1.1	0	22.6 ±0.3		2	5.0	1.339±0.027
1.2	0	17.4 ±0.2		4	10.0	1.243±0.017
1.3	0	12.5 ±0.9		6	14.9	1.116±0.015
1.5	-.5	7.62±0.10	2.4	4	10.1	0.943±0.013
1.7	-.5	4.78±0.06		6	15.2	0.763±0.010
1.8	(E)	3.52±0.07		8	20.2	0.635±0.009
2.0	-.5	2.10±0.03	2.55	- 1	2.6	1.183±0.020
2.2	(E)	1.45±0.04		2	5.1	1.07 ±0.11
2.4	(E)	1.10±0.10		4	10.3	0.861±0.016
2.55	(E)	1.18±0.03		6	15.4	0.645±0.014
2.7	(E)	1.10±0.05	2.7	- 2	5.2	1.019±0.021
				4	10.4	0.767±0.014
				6	15.5	0.564±0.012
				8	20.7	0.373±0.008

(E) : extrapolation to $\theta_d = 0°$


dσ/dΩ c.m. μb/sr θp=180°
100
10
1
1000
2000
Tp lab (MeV)

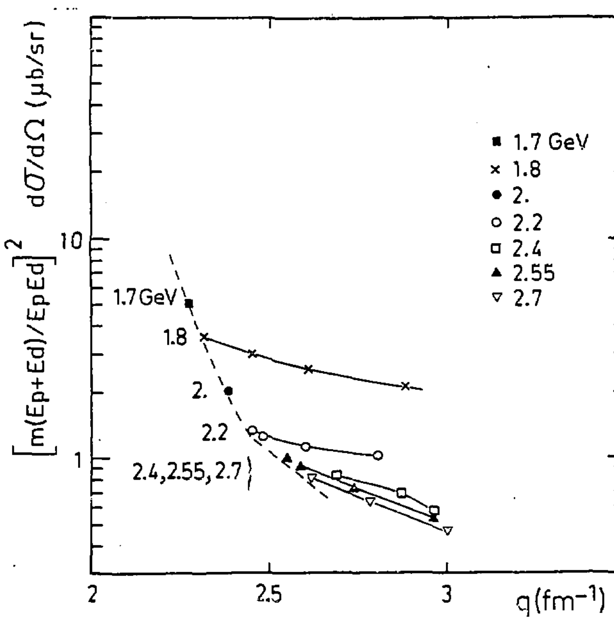

$d\sigma/d\Omega$ ($\mu b/sr$) $\left[m(E_p+E_d)/E_pE_d\right]^2$
10
1
2
2.5
3
q(fm^{-1})
1.7 GeV
1.8
2.
2.2
2.4
2.55
2.7
1.7GeV
1.8
2.
2.2
2.4,2.55,2.7

Fig. 2