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Abstract

The three particle reaction d + p $\rightarrow$ p + p + n has been studied at a deuteron energy of 51.5 MeV.

The measured correlation spectrum exhibits a pronounced effect due to the n-p final state interection and the analysis of the data shows that this interaction is dominated by the virtual singulet state of the deuteron.

The investigation and understanding of one of the simplest three particle reactions, namely the reaction p + d → p + p + n, is of basic importance in the large field of few nucleon problems. The existing experimental data [1-5] provide evidence for the contribution of three different reaction models:

1) The three nucleons are statistically emitted into the available phase space.
2) One nucleon acts only as a 'spectator' particle, its interaction with the two others can be neglected, this process can be treated as quasi-free scattering of two nucleons.
3) A final state interaction between two of the nucleons is characteristical for the reaction. The process might then be treated as a sequential reaction in two steps.

The reaction H(d,2p)n was first investigated by P.F. Donovan [2] using 21 MeV deuterons. His results provided the first conclusive evidence for a neutron-proton final state interaction at low relative energies between the neutron and the proton.

I.Šlaus, and co-workers [3] investigated the reaction D(p,2p)n induced with 46 MeV protons. The data which show effects due to quasi-free process and due to final state interaction have been analyzed in terms of three different spectator model calculations and the Chew-Low extrapolation procedure. However, since these experimental data predominantly show the spectator effect, the theoretical analysis concentrates on this quasi-free scattering.

The aim of our experiment was to investigate the H(d,2p)n reaction under conditions where mainly a n-p final state interaction might be studied. A collimated beam of 51.5 MeV deuterons from the Karlsruhe isochronous cyclotron was used to bombard a hydrogen filled gas target. The emitted protons were detected in coincidence with two scintillation counters situated at angles of Θ_3 and Θ_4 relative to the beam axis. In this case an event is kinematically completely defined, if the energies of both protons E_3 and E_4 are registered. The energy and the direction of the third particle (the neutron) as well as the relative energies between two of the outgoing particles are calculated. The requirement for the investigation of the final state interaction is that one wants E_{45} (the relative energy between one proton and the neutron) to become zero along the kinematically allowed curve. This condition fixed Θ_4 at 25^o after Θ_3 had been chosen to be 40^o in the laboratory system. The point where E_{45} is zero corresponds to the maximum allowed value of E_3. Large distances between the target and the detectors (L_4 = 92 cm, L_3 = 70 cm) allowed a particle discrimination between protons and elastically scattered deuterons using time-of-flight techniques [6] and taking advantage of the extremely short beam bursts of the Karlsruhe isochronous cyclotron. These large distances were also convenient for achieving the necessary small angular resolution of $\Delta\Theta_4 = \pm 0.5^o$ and $\Delta\Theta_3 = 0.75^o$.

The coincident events were registered in a two-dimensional 4096 channel analyzer. Fig. 1 on the left side shows a map display of the experimental data with E_3 as the abscissa and E_4 as the ordinate in an array of 32 x 128 channels. Most of the registered events populate the kinematically allowed curve $E_3 = f(E_4)$. The uniform distribution in the upper part of the curve seems to be proportional to the available phase space. However, a distinct peak appears in the region where E_3 reaches its maximum allowed value. This peak is assigned to a final state interaction between one outgoing proton and the neutron. The right-hand side of Fig. 1 shows the projection onto the E_4 axis. For comparison, the full line represents the normalized phase space.

The aim of the following interpretation of the experimental results is to extract information on the n-p system from the final state interaction in the three particle system. The analysis of these data should show directly the S-matrix pole of the deuteron singlet state. One should also be able to compare three particle results with values obtained from the corresponding two particle reaction, namely the free n-p scattering.

Generally the cross section for the 3 particle reaction may be written as

$$\frac{d^3\sigma}{d\Omega_3 \, d\Omega_4 \, dE_4} = \varrho(\Omega_3, \Omega_4, E_4) \sum_{SI} |M_{SI}|^2 \cdot g_{SI} \qquad (1)$$

where I is the channel spin and S the total spin of the two particles experiencing the final state interaction, and g_{SI} and $\varrho(\Omega_3, \Omega_4, E_4)$ are the statistical factors due to spin and space, respectively.

The contribution of the virtual singlet deuteron state to the final state interaction can now be described by writing $|M_{0\frac{1}{2}}|^2$ as

$$|M_{0\frac{1}{2}}|^2 = \left| A + \frac{B}{k + i\varkappa_s} \right|^2 \qquad (2)$$

Here k is the internal momentum within the n-p system and $-i\varkappa_s$ characterizes the position of the pole of the S-matrix (see, for instance, Watson [7]).

In order to check the pole character of the matrix element it is convenient to plot the quantity $\frac{1}{(N/PSF)-1}$ versus the relative energy E_{np} · N is the number of counts per dE_4 interval. The phase space factor PSF is proportional to $\varrho(\Omega_3, \Omega_4, E_4)$ and is normalized to the experimental data.

Fig. 2 shows such a plot for our experimental data. Within the statistical errors the plotted points are represented fairly well by a straight line intersecting the abscissa at

$$E_o = - \frac{\hbar^2 \varkappa_s^2}{2m} .$$

The value obtained for E_o is $E_o = -(120 \pm 30)$ KeV. This would correspond to a scattering length of $|a_s| = (19 \pm 2.5)$f. This value, obtained from the investigation of the n-p final state interaction, may be compared with the scattering length known from the n-p singlet cross section which is $a_s = -(23.73 \pm 0.007)$f.

The following conclusions can be drawn from our experiment:

1) The final state interaction as observed in our experiment is dominated by the virtual singlet state of the deuteron.

2) The extracted scattering length a_s appears to be smaller than the value known from the n-p cross section. If this result will be confirmed by an experiment with improved statistics it might be explained by an influence of the triplet bound state or by an interference effect. Only a part of this interference between the A and B term of equation (2) has the same E dependence as the pure B term.

References

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Captions of figures:

Fig. 1

Experimental data for the reaction $d + p \rightarrow p + p + n$. A map display for the two protons (with energies E_3 and E_4) which were registered in coincidence is shown on the left-hand side. The data projected onto the E_4 axis and the normalized phase space factor are shown on the right hand side.

Fig. 2

Analysis of the pole character of the final state interaction peak. The straight line is intersecting the abscissa at $E_{np} = -(120 \pm 30)$ KeV.

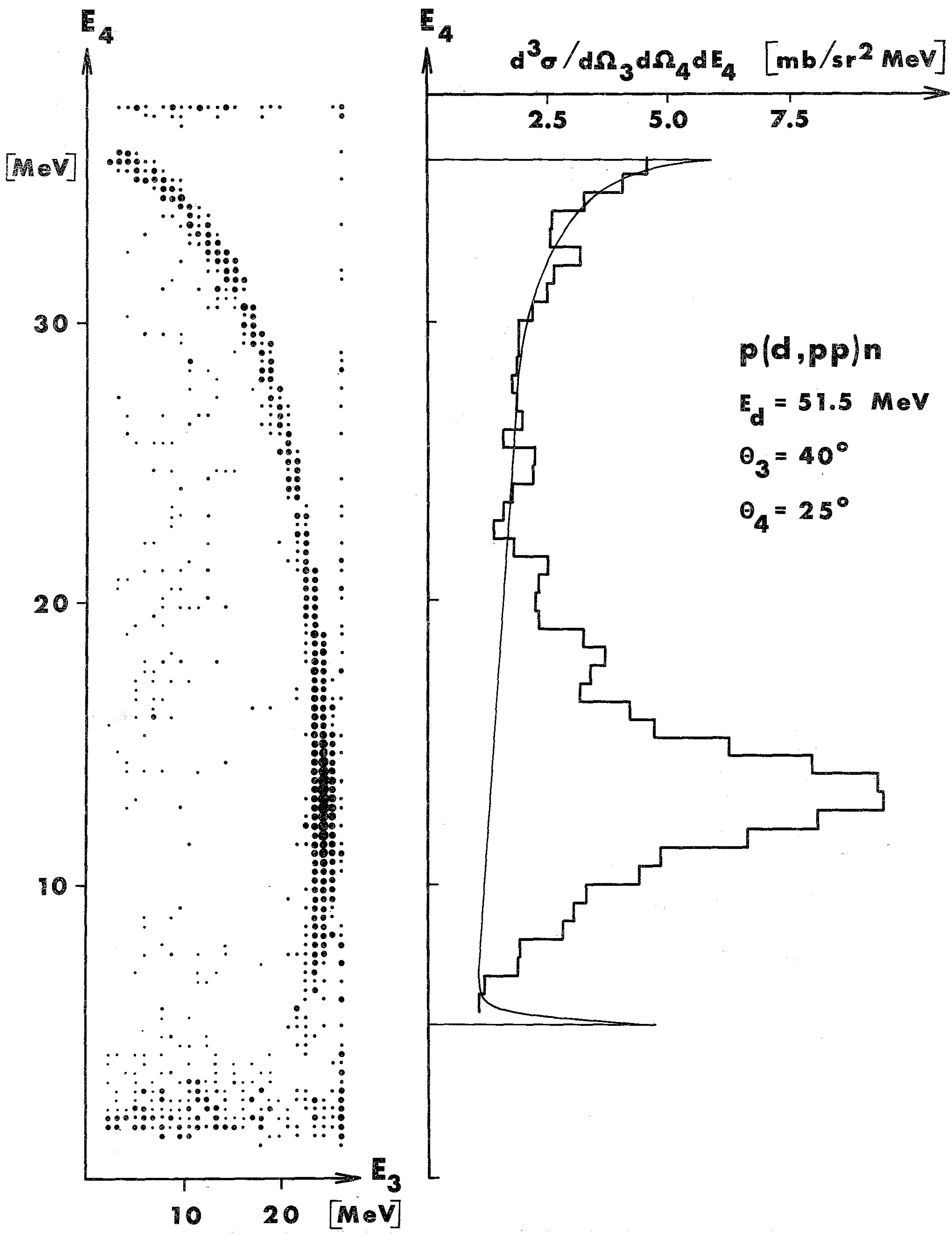
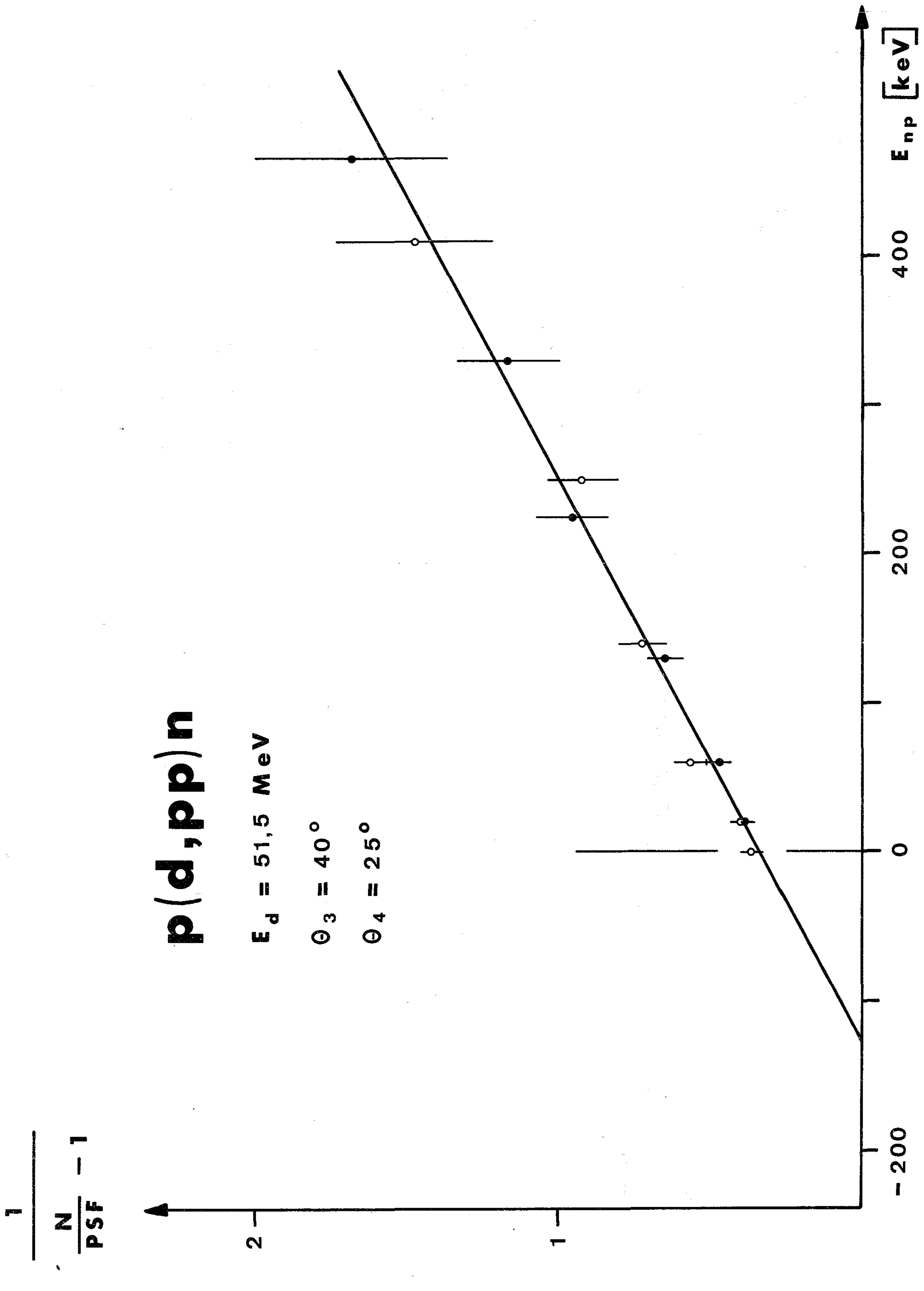

E4
[MeV]
30
20
10
E3
10
20
[MeV]
E4
d3σ/dΩ3dΩ4dE4 [mb/sr2 MeV]
2.5
5.0
7.5
p(d,pp)n
Ed = 51.5 MeV
Θ3 = 40°
Θ4 = 25°

Fig. 1



p(d,pp)n
E_d = 51,5 MeV
Θ_3 = 40°
Θ_4 = 25°
E_{np} [keV]
−200
0
200
400
1
2
$\frac{1}{\frac{N}{PSF} - 1}$

Fig. 2