Study of the Reaction D(p,π^+)T at T_p = 410, 605, and 809 MeV

E. Aslanides, R. Bertini, O. Bing, F. Brochard, Ph. Gorodetzky, and F. Hibou
Centre de Recherches Nucléaires and Université Louis Pasteur, 67037 Strasbourg Cedex, France

and

T. S. Bauer,[a] R. Beurtey, A. Boudard, G. Bruge, H. Catz, A. Chaumeaux, P. Couvert, H. H. Duhm,[b] D. Garreta, G. Igo,[c] J. C. Lugol, M. Matoba,[d] and Y. Terrien
Département de Physique Nucléaire /Moyennes Energies, Centre d'Etudes Nucléaires de Saclay, 91190 Gif-sur-Yvette, France

and

L. Bimbot, Y. Le Bornec, and B. Tatischeff
Institut de Physique Nucléaire, 91406 Orsay, France
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Pion production on a CD_2 target has been measured using the high-resolution magnetic spectrometer SPES I. Differential cross sections for the reaction D(p,π^+)T have been determed at T_p = 410, 605, and 809 MeV. The present data, together with previous results establish a complete angular distribution of the reaction D(p,π^+)T at ~ 600 MeV and the energy dependence of the differential cross section for this reaction at several constant momentum transfers.

The interest in the study of the (p,π) reaction on nuclei has been stressed by several authors in many theoretical and experimental reviews.[1] The underlying motivation is the extraction of useful information concerning the high-momentum components of nuclei, since such reactions involve high momentum transfers, of several hundreds of MeV/c. Recently[2] results were reported on the reactions ^{6}Li(p,π^+)^{7}Li and ^{3}He(p,π^+)^{4}He as part of a series of experiments on the two-body final-state pion production, undertaken at Saclay, aiming at the measurement of pion angular distributions well above threshold energies.

The particular interest in studying the reaction D(p,π^+)T is due to the small number of nucleons involved in the initial and final nuclei. The reaction can be considered close to the elementary process $NN \rightarrow NN\pi$ and its reaction mechanism.

TABLE I. Differential cross sections for the reaction $p + \text{D} \rightarrow \text{T} + \pi^+$ in μb sr^{-1}.[a]

T_p	θ_{LAB}	$\frac{d\sigma}{d\Omega}_{LAB}$	θ_{CM}	q_{CM} MeV/c	$\frac{d\sigma}{d\Omega}_{CM}$
410 MeV	5°	47.4 ± 3.0	7.1°	376	23.5 ± 1.5
	15°	30.6 ± 1.2	21.2°	396	15.6 ± 0.6
	25°	18.8 ± 0.8	35.1°	432	10.1 ± 0.4
	43°	4.5 ± 0.7	58.7°	513	2.8 ± 0.4
605 MeV	5°	27.8 ± 1.5	7.4°	390	12.6 ± 0.7
	15°	14.3 ± 1.6	22.2°	429	6.7 ± 0.7
	25°	6.0 ± 0.4	36.5°	493	3.0 ± 0.2
	32°	2.5 ± 0.3	46.3°	546	1.34 ± 0.14
	45°	0.90 ± 0.18	63.5°	645	0.56 ± 0.11
	65°	1.6 ± 0.35	87.3°	780	1.35 ± 0.29
809 MeV	5°	8.2 ± 0.5	7.8°	400	3.4 ± 0.2
	10.7°	6.0 ± 0.4	16.7°	429	2.5 ± 0.15
	19°	3.1 ± 0.55	29.3°	498	1.4 ± 0.25

[a]Errors represent statistical, dead time, and relative normalization uncertainties. The absolute normalization uncertainty is 20%.

The differences between the two reactions can then be expressed through a nuclear form factor and rescattering corrections (incoming proton and outgoing pion distortions) which can be calculated quite extensively, in contrast to those necessary for heavier targets. In the present work angular distributions have been measured for the reaction $D(p,\pi^+)T$ at 410, 605, and 809 MeV, with special emphasis on the 600-MeV region, where a 0° measurement[3] and extensive larger-angle measurements have been previously reported.[4,5] The energy dependence of the differential cross section at constant momentum transfer should yield information about the reaction mechanism involved, since most of the nuclear structure information, contained in the nuclear form factor, should be possibly separated out of the data. We thus measured differential cross sections at the most forward possible angle (5° lab) and at a few more angles at 410 and 809 MeV (see Table I) in order to "complete" earlier measurements.[4-9]

The experiment has been carried out with the proton beam of the SATURNE synchrotron. The pion spectra were measured with the high-resolution magnetic spectrometer, SPES I. Detailed information concerning the spectrometer is given elsewhere.[10] Particle trajectories were determined with four position-sensitive drift chambers with an accuracy of 0.7 to 1.2 mm. The pion identification was made by three lucite Čerenkov counters following four planes of plastic scintillators and the trigger was defined by the coincidence between all Čerenkov and scintillation counters. The total detection efficiency varied from 60% to 90% depending on the pion energy. The data have also been corrected for the pion losses through decay (31% to 66%), including pion counting through detection of the decay muon, and for the pion losses through interactions (14% to 21%), depending on the pion energy. The estimate of the latter correction has been experimentally checked for 300-MeV/c pions. The beam intensity was monitored with a secondary-emission counter downstream of the target. Two scintillator telescopes, pointing at the target at 40° and 140°, provided the relative normalization of the data. All monitors were calibrated, using the carbon activation method.

The overall absolute normalization uncertainty

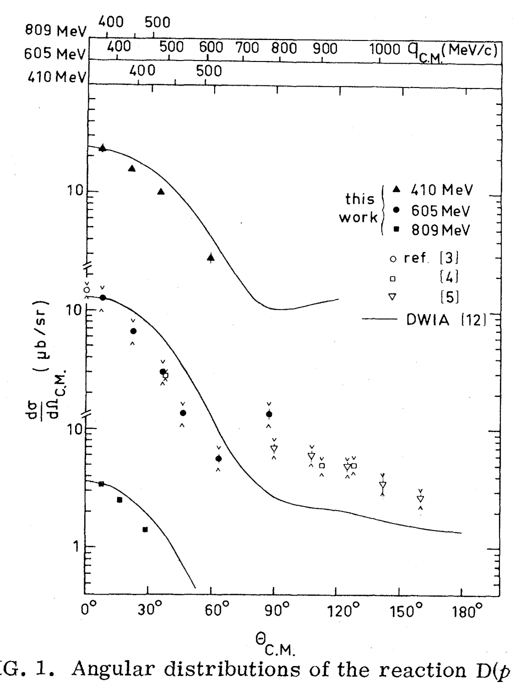

FIG. 1. Angular distributions of the reaction $D(p,\pi^+)T$ as established in the present experiment and previous results at ~600 MeV. In order to allow a better comparison of data due to different experiments we represent the limits of the absolute normalization uncertainty for each experimental point by carets and inverted carets. The vertical bar represents the statistical uncertainty of each point.

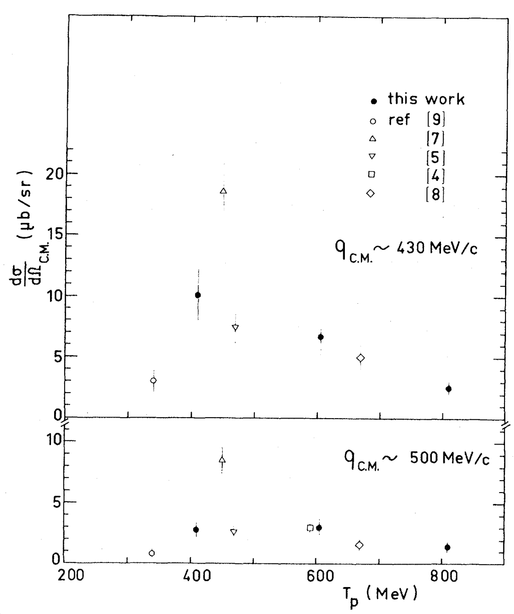

FIG. 2. Energy dependence of the reaction $D(p,\pi^+)T$ established with earlier data and the results of the present work at $q_{c.m.}$ ~ 430 MeV/c and at $q_{c.m.}$ ~ 500 MeV/c. The error bars include the absolute normalization uncertainty of the differential cross sections.

of the data was ± 20%. As an additional check on the absolute accuracy in the measured cross sections, we also measured cross sections for the reaction $pp \to d\pi^+$ at 410, 600, and 800 MeV, at laboratory angles between 5° and 15°. Our values are in good agreement with previous CERN data.[11]

Table I contains the differential cross sections determined in the present experiment. Figure 1 shows our results at 605 MeV and all the available information on the differential cross sections of the reaction $D(p,\pi^+)T$ around 600 MeV,[3-5] and our results at 410 and 809 MeV.

The present 600-MeV results are in good agreement with previously reported data[3-5] with the exception of the $\theta_{c.m.} = 87°$ point which is somewhat higher than the Dollhopf *et al.*[5] $90°_{c.m.}$ point. The full lines on Fig. 1 represent the results of a distorted-wave impulse-approximation (DWIA) calculation made by Fearing.[12] The calculation uses a D-state component in the deuteron's wave function and a realistic wave function for the three-body system, reproducing the dip in the electromagnetic form factor of the triton. It also includes the distortion of the incoming proton and the outgoing pion obtained in the Glauber approximation using experimental NN and πN cross sections. Changes in the wave functions or in the distorting-potential parameters and different ways of incorporating distortion effects each lead to a theoretical uncertainty in the normalization of the calculated cross sections, of about a factor 2 or 3. We arbitrarily chose to normalize the theoretical results to our $5°_{lab}$ experimental points.

The theory reproduces qualitatively the experimental angular distributions but fails to reproduce the forward angle slopes at all three energies.

Figure 2 represents the energy dependence of the reaction $D(p,\pi^+)T$ at the momentum-transfer values of ~430 and ~500 MeV/c. When necessary, interpolation of the data was made in the momentum-transfer q representation, to minimize systematic errors. The data tend to follow a common energy dependence, that is, a peak around 400 MeV. Such an energy dependence is in qualitative agreement with the hypothesis of the (3,3) resonance influence on the pion production mechanism.[12,13] The downward shift of this bump with respect to the energy of 450 MeV, expected from kinematic arguments, could be due to distortion and nuclear-form-factor effects.[12]

From Fig. 2 it can be seen that there is a large variation in the differential cross sections measured around 450 MeV. More experiments on this reaction in the presently reported energy region should help to clarify the situation. However, even at the present state of the experiment, extensive calculations of the reaction $D(p,\pi^+)T$ are desired in order to explain not only the complete angular distribution at ~600 MeV but also the energy dependence of this reaction at various momentum transfers.

[a]Present address: Clinton P. Anderson Meson Physics Facility, Los Alamos Scientific Laboratory, Los Alamos, N. Mex. 87545.

[b]Present address: Institut für Experimental Physik, Hamburg, West Germany.

[c]Present address: Department of Physics, University of California, Los Angeles, Calif. 90024.

[d]Present address: Kyushu University, Fukuoka, Japan.

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