Photoproduction of $\pi^{\pm}$ Mesons in Nitrogen

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In this paper we describe the results of the analysis of the photodisintegration and $\pi^{\pm}$ photoproduction processes in nitrogen obtained by exposing a diffusion cloud chamber in a magnetic field to the γ-ray beam of the Frascati synchrotron ($E_{\gamma\max}=1000$ MeV). The value of the cross section obtained per equivalent quantum and per nucleon for $\pi^{\pm}$ photoproduction is in agreement with that estimated per free nucleon.

INTRODUCTION

The photodisintegration of nitrogen has been studied, up to now, for energies below the threshold for π meson photoproduction.[1–3]

The measurements in nuclear emulsions with high-energy photons[4,5] show a great contribution to the photodisintegration processes of the light nuclei and confirm the hypothesis that the pion photoproduction takes place from single nucleons and that the principal difference between light and heavy nuclei is, therefore, the pion reabsorption probability. In particular, the optical model values[6] of the mean free path in nuclear matter are sufficiently small so that in light nuclei the reabsorption is significant even for low-energy pions. The aim of this experiment was to evaluate the pion producing part of the total photostar production in nitrogen and to compare the cross section per equivalent quantum and per nucleon for $\pi^{\pm}$ photoproduction with that estimated per free nucleon.

EXPERIMENTAL METHOD

The experimental apparatus consisted of a 60-cm-diam diffusion cloud chamber, filled with nitrogen at 1.3 absolute atmospheres in a magnetic field of 10 kG, exposed to the γ-ray beam of the Frascati electrosynchrotron ($E_{\gamma\max}=1000$ MeV). Figure 1 shows the outline of the experimental arrangement; it is the same as described previously.[7–9]

The photographic repetition rate was of one picture every 25 sec. For this reason we built a pulsed-internal thin target for the synchrotron which permitted the chamber to be operated simultaneously with experiments on other beams. In order to avoid the background caused by low-energy photons in the cloud chamber, the bremsstrahlung spectrum was hardened by 3.7 radiation lengths of LiH using the method described by Hart *et al.*[10,11]

The intensity of the γ-ray beam was that which produced four electron pairs per picture with a beam of cross section $(4\times8)\text{mm}^2$.

EXPERIMENTAL RESULTS

From earlier exposures, with the diffusion cloud chamber filled with hydrogen,[9] we deduced the spectrum of the γ-ray beam which crossed the cloud chamber. For this purpose we have employed for $100<E_\gamma<1000$ MeV the total cross section for electron pair production calculated by Wheeler and Lamb[12] and for E_γ below 100 MeV the data of Wapstra *et al.*[13] In Fig. 2 are shown the histograms which describe the hardened spectrum, obtained from the analysis of 1664 events, compared with the theoretical thin-target bremsstrahlung spectrum having the same intensity between 70 and 1000 MeV.

It can be seen that the hardened spectrum is in agreement with the theoretical bremsstrahlung spectrum for E_γ greater than 70 MeV and it is practically flat be-

Table I. Number of observed photostars in nitrogen having three or more charged prongs and relative abundance of charged π mesons of these events.

No. of prongs	3	4	5	6	7
No. of stars[a]	77	86	39	18	6
π^+	16	11	10	6	...
π^-	13	8	9	4	2
$\pi^+\pi^-$	1	4	2	3	3
$>2\pi^{\pm}$	...	...	...	1	1

[a] There are also four two-prong photostars with one $\pi^{\pm}$.

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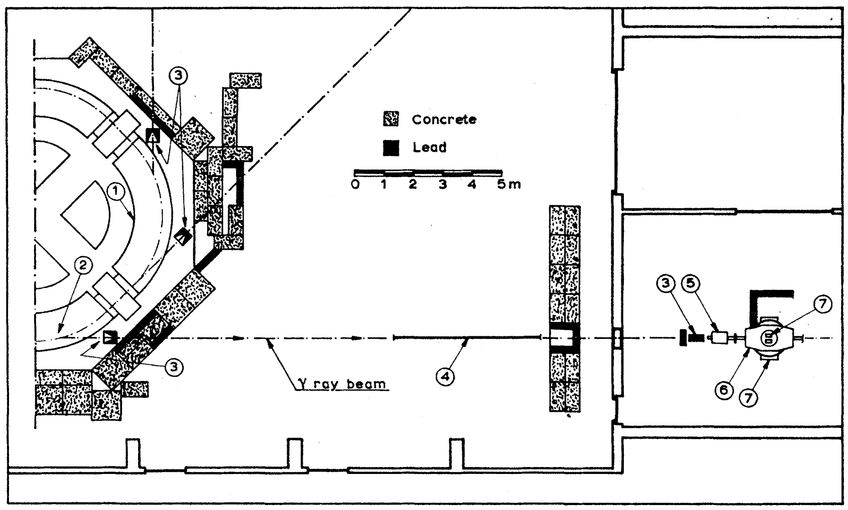

FIG. 1. Experimental arrangement. (1) Synchrotron, (2) pulsed target, (3) collimator, (4) LiH hardener, (5) broom magnet, (6) magnet, (7) cameras and flash units of the diffusion chamber.

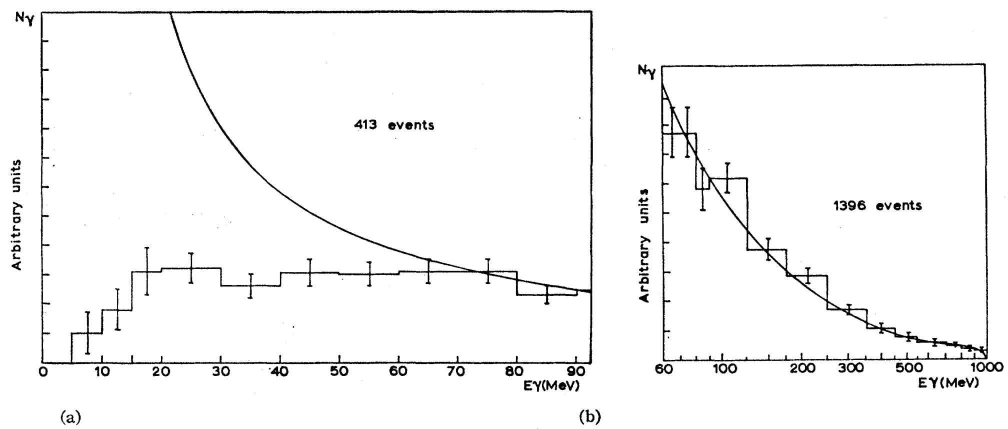

FIG. 2. The histogram describes the spectrum hardened by 3.7 radiation lengths of LiH, i.e., the spectrum crossing the diffusion cloud chamber. The solid line is the theoretical thin-target bremsstrahlung spectrum. The errors shown are statistical.

tween 15 and 70 MeV. The number of photons at energy less than 15 MeV is negligible. The number of equivalent quanta contained in the hardened spectrum turns out to be equal to 96% of those of a thin-target bremsstrahlung spectrum having the same intensity between 70 and 1000 MeV. The usual enhancement of degraded photons is hardly noticeable in our hardened spectrum because our collimator in front of the chamber subtended only $\sim 1\ \mu$sr at the end of the LiH rod.

Our data on the photodisintegration of nitrogen were obtained by analyzing about 6500 photographs with a total of about 400 photostars with two or more charged prongs. In Table I are listed all the photostars with a number of charged prongs $\geqslant 3$ and the photostars with one or more $\pi^{\pm}$ mesons. The pions were identified by curvature and ionization, the latter visually determined by comparison with nearby relativistic electrons. In the doubtful cases we used the photometric comparator described elsewhere.[14]

The average number of prongs per event is in our case $\bar{N}=4.1$ instead of the value $\bar{N}=3.6$ obtained by Gorbunov *et al.*[3] with $E_{\gamma\max}=170$ MeV. This difference is in agreement with the behavior of $\bar{N}$ as a function of $E_{\gamma\max}$ deduced by Castagnoli *et al.*[15] We measured the total number of events for the coplanar[16] reaction $N^{14}(\gamma,p)C^{13}$. Since we know the beam spectrum and the value of the cross section for this reaction as a function of E_{γ},[1,2] we have deduced the total number of equivalent quanta which have crossed the diffusion cloud chamber. Correcting the value 1.66 ± 0.35, found as the ratio between the yields of the reaction $N^{14}(\gamma,np)C^{12}$ and $N^{14}(\gamma,p)C^{13}$, by taking into account the difference between the bremsstrahlung and our hardened spectrum for $E_{\gamma}<70$ MeV,[17] we find that our result is in better agreement with the result of Balfour *et al.*[2] than with that of Gorbunov.[18]

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[16] The coplanarity of these events was evaluated for the particularly short recoil tracks between $\pm 3°$. The competing events involving α particles were identified by the very different track density. The events of the type $N^{14}(\gamma,d)C^{12}$, not easily distinguishable from the $N^{14}(\gamma,p)C^{13}$ events, were considered as the latter because they are much less probable from consideration of isotopic spin confirmed for helium (Ref. 18).

Making the same consideration as done by other authors[15,19] and considering the nitrogen nucleons as equally probable photopion sources for high-energy photons, we have deduced the total cross section per equivalent quantum for the $\pi^\pm$ photoproduction from free nucleons. In the case of the reaction $\gamma+n\rightarrow\pi^-+p$, we have considered also the ratio π^-/π^+ for free nucleons obtained by Pine and Bazin[20] from the photoproduction from deuterium. The total cross section calculated gives agreement within 15% with the experimental value $(388\pm65)\times10^{-30}$ cm^2.

The calculated values for the cross section per equivalent quantum and per nucleon for pion production gives the same agreement with the measured values of $(328\pm60)\times10^{-30}$ cm^2 for photostars with one charged pion and $(52\pm13)\times10^{-30}$ cm^2 for photostars with a pion pair.

These results confirm the considerable contribution of the light nuclei to the process of photodisintegration in nuclear emulsion, and confirm the hypothesis that at high energies, the photoproduction of real pions occurs on the individual nucleons also in the case of complex nuclei. The reabsorption of the real $\pi^\pm$ mesons photoproduced was found to be negligible with our experimental resolution.

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Model Three-Body Problem*

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Solutions are obtained for a three-dimensional model three-body problem involving a spinless D particle and a spinless n particle with coupling $D\rightleftarrows n+n$. D-n scattering and D-n bound states are studied. The model is soluble in the sense that one obtains a linear, one-dimensional Fredholm equation for each partial wave in n-D scattering. We have solved the equations numerically on a high-speed computer for different values of the interaction strength and for different values of a size parameter used in the interaction form factor. In particular, we have studied the interaction-strength limit which corresponds to making the D a bound state of the n's. In this limit there are two three-body bound s states. The n-D scattering phase shifts obey a Levinson's theorem and also show the expected kink at the threshold for $n+D\rightarrow 3n$. The angular distribution for n-D scattering has considerable variation and shows the backward peak characteristic of an exchange mechanism. When parameters are chosen in the model to make the D fit the deuteron, the major features of nucleon-deuteron scattering are reproduced except at very low energies when the three-particle bound states dominate and our neglect of spin is important.

I. INTRODUCTION

The theory of scattering beyond the two-body problem has recently been the subject of vigorous attack from many quarters. This is not surprising in view of the wide importance of the problem and the rudimentary state of the theory. Some of the recent efforts have been devoted to putting the formal situation in order for the full problem,[1] but these developments do not remove the essential difficulties associated with going beyond the two-body problem even in classical physics, namely the extra degrees of freedom. It may be that computers will soon enter a stage where the full three-body problem can be computed "exactly," but that stage has not yet arrived.

A more modest approach in which the three-body problem is simplified to the point where "exact" computation is possible has recently been introduced by one of us.[2] In this paper, we present calculations based

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