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PHOTOPRODUCTION OF THE ETA MESON ON DEUTERIUM

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The differential cross section at several c.m. angles for inelastic eta meson photoproduction on deuterium has been measured at an incident photon energy of about 850 MeV. Our results indicate that the photoproduction cross section on the neutron is quite similar to that on the proton. Both these c.m. angular distributions are consistent with isotropy. Remarks are made on the relative contribution of the isoscalar and isovector parts of the eta photoproduction amplitude.

In this paper we report on an experiment performed at the Frascati 1.1 GeV electron synchrotron on the inelastic photoproduction of the eta meson on deuterium

$$\gamma + d \rightarrow \eta + (p,n). \qquad (1)$$

The differential cross section for the process (1) has been measured for different c.m. angles, at two photon energies around 850 MeV. The overall energy resolution of the incident gamma beam was ±35 MeV.

The purpose of the experiment is to make a direct comparison of the eta photoproduction cross sections for deuterium and for hydrogen [1]. A study of these two reactions can lead to information on the relative properties of photoproduction from protons and neutrons from which the relative contribution of the isoscalar and isovector parts of the eta photoproduction amplitudes may be deduced.

Our results show that, within the accuracy of the measurements, the ratio of the cross section for the process (1) and the cross section for the photoproduction on free protons is about two and does not depend upon angle. This result indicates that the neutron and proton cross sections are quite similar and consistent with a center-of-mass angular distribution that is essentially isotropic.

The experimental set-up is shown schematically in fig. 1. It is the same that we have used in a previous measurement on eta photoproduction in hydrogen [1].

The γ-ray beam was incident on a cylindrical deuterium target, 7 cm in diameter. The η's from reaction (1) were detected by measuring the angles and energies of both photons of the two photon decay mode.

Two pairs of photon detectors (each composed of a lead-glass total-absorption Čerenkov counter preceded by a veto scintillation counter) were used in order to increase the collection rate and to reduce possible sources of systematic errors.

The kinematical definition of the events from reaction (1) is given by the opening angle between the photon detectors and the energy maximum of the bremsstrahlung spectrum.

For each kinematical condition the detection efficiency of the apparatus was determined by a

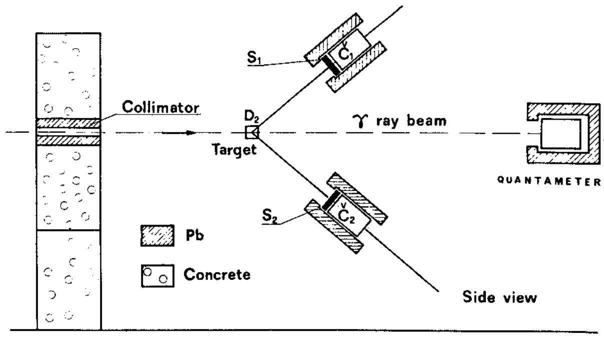

Fig. 1. Schematic drawing of the experimental set-up; C_1 and C_2 are two lead glass Čerenkov counters, S_1 and S_2 veto scintillation counters. Each photon detector covers a typical laboratory solid angle of 12 msr. A Wilson type quantameter [8] was used.

Monte Carlo calculation in which the measured energy resolution of the photon detectors and the Fermi motion of the target nucleons were properly taken into account.

The background, mainly due to multiple π^0 production, was measured by changing slightly the geometry of the apparatus in such a way as to exclude the detection of η-events, but at the same time maintaining the same angle of each photon detector with respect to the γ-ray beam line. Since a strong correlation between the energies of the two detected photons is not expected for the background, we believe that this procedure can be used directly for a proper background subtraction. This method was successfully applied in our previous experiment on eta photoproduction in hydrogen [1].

Our results on the differential cross section for deuterium are shown in fig. 2. In this same figure earlier results [1,2] on hydrogen at the same incident γ-rays energies are shown for comparison. The deuterium points refer to the γ-nucleon center-of-mass system.

The errors quoted are inclusive of the uncertainties in the background subtraction. In addition there are systematic errors due to uncertainties in the quantameter calibration, shape of the bremsstrahlung spectrum near the maximum energy etc., which are not included. This gives an overall systematic error of ±10%. Note that a better determination of the efficiency has resulted in some difference in the values reported for hydrogen in ref. 1. The angular resolution is shown by the horizontal error bars.

We observe from fig. 2 that the differential cross sections for hydrogen and for deuterium do not show a significant departure from isotropy. Furthermore, the photoproduction rate per nucleon for deuterium turns out to be equal to the rate for hydrogen.

The analysis of the experimental results has been carried out by making use of the impulse approximation, which states, essentially, that the transition amplitudes for each of the two nucleons in the deuteron target are linearly superposable [3].

In this approximation the differential cross section elastic plus inelastic is given approximately by [3]:

$$\left(\frac{d\sigma}{d\Omega^*}\right)_D \propto A_p^2 + A_n^2 + 2\,\mathrm{Re}(A_p A_n^*) I(2\Delta) \qquad (2)$$

where A_p (A_n) is the amplitude for η production on free proton (neutron) and $I(\Delta) = \int \psi^2{}_D \times \times \exp(2i\Delta \cdot \boldsymbol{R})\, d^3\boldsymbol{R}$ is the deuteron form factor ($\Delta = \frac{1}{2}(\boldsymbol{k}-\boldsymbol{q})$ and where $\boldsymbol{k},\boldsymbol{q}$ are the photon and

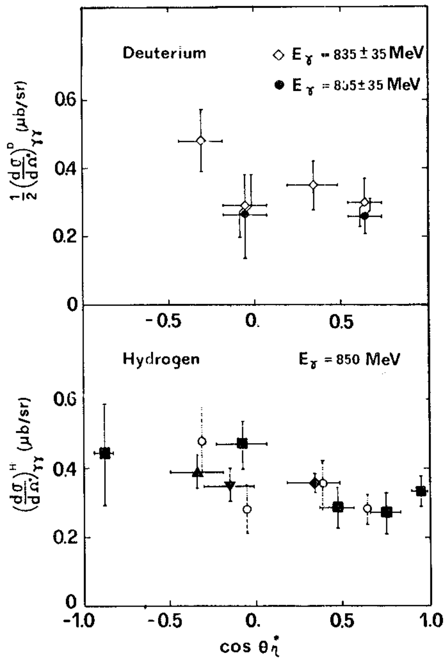

Fig. 2. Experimental results for $(d\sigma/d\Omega^*)$ $(\eta \to \gamma\gamma)$ per nucleon in deuterium (upper points) and in hydrogen (lower points) as function of θ^*_η (η angle in the γ-nucleon c.m.s.). E_γ is the average energy of the incident photons. In the lower part the points indicated with ■ are our results at E_γ = 850 ± 25 MeV (A better determination of the efficiency has produced some difference in our results on hydrogen reported in ref.(1)). The points indicated with ▲, ▼ and ◆ are from C. Bacci et al., R. Prepost et al., and E. D. Bloom et al. respectively [2], for which we have assumed the latest world average [9]:

$$\frac{\Gamma(\eta \to \text{all modes})}{\Gamma(\eta \to \gamma\gamma)} = 0.26.$$

For a comparison in the lower part of the figure we have plotted also an average of our experimental data on deuterium (open circles).

η meson laboratory momenta, respectively). Due to the magnitude of the form factor, the last term in (2) is small (< 10%) for all of our kinematical conditions. On the other hand the elastic part ($\gamma + d \to \eta + d$) of the cross section is given by $(d\sigma/d\Omega^*)_{el} \propto |A_p + A_n|^2 I^2(\Delta)$ and, as the form factor is squared it turns out to be negligible at our values of Δ. As a consequence, our measurement essentially determines the inelastic part of $(d\sigma/d\Omega^*)_D$ in which the interference term is negligible.

Now in order to interpret the observed cross section for deuterium in terms of those for free nucleons one has to consider η rescattering and absorption effects. On the basis of a measurement on inelastic η photoproduction on various nuclei that we have made using the same apparatus [4], we are led to the conclusion that this correction is small. Additional evidence for the assumption that rescattering and absorption effects at our energy are negligible comes from a comparison of pion-nucleon scattering on hydrogen and deuterium [5]. Then:

$$\left(\frac{d\sigma}{d\Omega^*}\right)_D \approx A_p^2 + A_n^2 = \left(\frac{d\sigma}{d\Omega^*}\right)_p^{free} + \left(\frac{d\sigma}{d\Omega^*}\right)_n^{free} .$$

In conclusion, our experimental result at $E_\gamma \approx 850$ MeV/i.e.:

$\left(\frac{d\sigma}{d\Omega^*}\right)_D / \left(\frac{d\sigma}{d\Omega^*}\right)_p^{free} \approx 2$ which is approximately independent of angle therefore indicates that:

$$\left(\frac{d\sigma}{d\Omega^*}\right)_p^{free} \approx \left(\frac{d\sigma}{d\Omega^*}\right)_n^{free} .$$

In terms of the isoscalar parts $T^{(o)}$ and $T^{(\frac{1}{2})}$ of the $T = \frac{1}{2}$ production amplitude $\langle \eta N | T | \gamma N \rangle$ this relation gives $|T^{(o)} + T^{(\frac{1}{2})}|^2 \approx |T^{(o)} - T^{(\frac{1}{2})}|^2$.

Now if we assume, according to several experimental indications [6], that the η-nucleon system, just above threshold, goes through a $T = \frac{1}{2}$, $J^P = \frac{1}{2}^-$ resonance state at a center of mass energy of about 1520 MeV ($\Gamma \approx 150$ MeV), then the principal multipole involved is the electric dipole E_{0+}. In this regard we are led to conclude that

$$|E_{0+}^{(o)} + E_{0+}^{(\frac{1}{2})}|^2 \approx |E_{0+}^{(o)} - E_{0+}^{(\frac{1}{2})}|^2 \qquad (3)$$

or that

$$\mathrm{Re}\left(E_{0+}^{(o)*} \cdot E_{0+}^{(\frac{1}{2})}\right) \approx 0 .$$

Assuming a resonant structure for both $E^{(o)}{}_{0+}$ and $E^{(\frac{1}{2})}{}_{0+}$, it follows from (3) that either the isovector or the isoscalar part of the photoproduction amplitude is small.

Supplementary information is necessary for a complete separation of the two isospin parts of the amplitude; fôr instance the isoscalar part of the amplitude could be isolated by elastic eta photoproduction on $T = 0$ nuclei [7].

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