Near Threshold Pion Photoproduction on Deuterons

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ABSTRACT

The study of photoproduction of mesons is a prime tool in understanding the properties of strong interactions. The only photoproduction reaction on deuteron with two-body final state is coherent pion photoproduction reaction. Several theoretical studies are being carried out on the pion photoproduction on deuterons since several decades. On the experimental side, the accelerator and detector technology has improved the developments.

In the recent years, measurements of tensor analyzing powers associated with coherent and incoherent pion photoproduction are also being carried out at the VEPP-3 electron storage ring. In one of the recent measurements, Rachek et al [1] have observed discrepancy between theory and experiment at higher photon energies and have suggested for improvement of the theoretical models. In a more recent analysis, [2] the role of D-wave component on spin asymmetries have been identified.

In view of these developments, the purpose of the present contribution is to study coherent pion photoproduction on deuterons using model independent irreducible tensor formalism developed earlier to study the photodisintegration of deuterons.[3]

An Introduction

- A nuclear reaction in which the absorption of high-energy electromagnetic radiation (a gamma-ray photon) causes the absorbing nucleus to change to another species by ejecting a subatomic particle, such as a proton, neutron, or alpha particle.
- As particles collide at high energy, the collision energy becomes available for the creation of subatomic particles such as mesons and sometimes hyperons.

- A measure of probability that a specific process will take place in a collision of two particles.
- When a cross section is specified as a function of some final-state variable, such as particle angle or energy, it is called a differential cross section.
- When a cross section is integrated over all scattering angles (and possibly other variables), it is called a total cross section.

- The measured reaction rate of a given process depends strongly on experimental variables such as the density of the target material, the intensity of the beam, the detection efficiency of the apparatus, or the angle setting of the detection apparatus.
- Polarisation of reactants in the initial state of the reaction.
- Polarisation of products in the final state of the reaction.

- The simplest nuclei with one proton, neutron and electron
- We choose deuteron.
- Photodisintegration, photoproduction and Electro-production.
- Photoproduction of mesons helps us to understand strong interactions in low energy region.
- Strong interactions are indirectly responsible for the transmission of the force between nucleons that hold the nucleus together.

- Possible pion photoproduction reaction on deuteron are:
  1. $\gamma + d \to d + \pi^0 -$ Coherent
  2. $\gamma + d \to n + p + \pi^0 -$ Incoherent
  3. $\gamma + d \to n + n + \pi^+ -$ Incoherent
  4. $\gamma + d \to p + p + \pi^- -$ Incoherent

Litrature Rewiew

- Theoretical studies since 1930's and Experimental studies since 1950's.
- Neutral pions can be produced coherently and are sensitive to the entire nuclear matter distribution and to the pion wavefunction in the nuclear interior.
- The coherent - nuclear photoproduction of pions, (γ, π^0), combined with elastic electron scattering, has been suggested to be a very accurate probe of density differences.

- Knowing the difference between the neutron and proton densities of nuclei is a significant topic because of its importance for understanding neutron star structures and cooling mechanisms.
- Measurement of vector analysing power of pion photoproduction reactions by polarised photons helps us to understand the proton spin structure.

- Studies using different potential and models have been done in the intervening years.
- ∗ Bonn potential [4]
- ∗ Statistical model [5],
- ∗ Impulse Approximation implying Chew - Goldbarger - Low - Nambu (CGLN) amplitudes [6],
- ∗ Radioactive Capture Method [7],
- ∗ Final State Interaction Model [8],
- ∗ Effective Lagrangian Approach [9],

* Maniz Unitary Isobar Model (MAID) partial wave analysis [10]
* Scattering Analysis Interactive Dial-In partial wave analysis and Bonn-Gotchina (Bn-Ga) Model [11],
* Argonne National Laboratory - Osaka University (ANL- Osaka) amplitudes [12]

- Experimental facilities - Jefferson lab, CLAS, ESRF, MAMI and many other help in collecting data[13]

Formalism

- Let $\mathbf{k} = k\hat{\mathbf{k}}$ denotes the photon momentum which is chosen along the $z-$axis.
- The polarization of photon is denoted by $\mu = \pm 1$ following Rose [14].
- Let $\hat{\mathbf{q}}$ denote the the $c.m.$ momentum of π^0 in the case of $d + \gamma \longrightarrow d + \pi^0$.
- We may conveniently choose a right-handed Cartesian coordinate system with $\mathbf{q}$ coming out with an angle θ in the $zx-$plane.

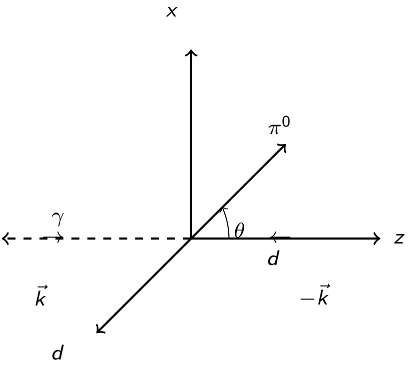

FIGURE: The reaction $\gamma + d \longrightarrow d + \pi^0$ in c.m frame in the $z - x$ plane

The reaction matrix for coherent pion photoproduction can be written in the form

$$M(\mu) = \sum_{\lambda=0}^{2} \left(S^{\lambda}(1,1) \cdot \mathcal{F}^{\lambda}(1,\mu) \right) \qquad (1)$$

$$\mathcal{F}_{\nu}^{\lambda}(1,\mu) = \sum_{L=1}^{\infty} \sum_{l=0}^{\infty} \sum_{j=L-1}^{j=L+1} (-1)^{j+L} (i)^{L-l} \, W(1L1l; j\lambda)$$

$$[j]^2 \, [L] \, g_{\nu}^{\lambda}(l, L, \mu) \qquad (2)$$

$$g_\nu^\lambda(l, L, \mu) = 4\pi\sqrt{2\pi} F_L^{lj} C(lL\lambda; m_l - \mu\nu)\; Y_{lm_l}(\hat{\mathbf{q}}) \quad (3)$$

$$F_L^{l\,j} = \frac{1}{2}\left[P_+\,\mathcal{M}_L^{lj} + i\mu\,P_-\,\mathcal{E}_L^{lj}\right] \quad (4)$$

$$P_\pm = \frac{1}{2}[1 \pm (-1)^{L-l}] \quad (5)$$

$S^{\lambda}_{\nu}(1,1)$ of rank λ are the spin transition tensors.
$\mathcal{F}^{\lambda}_{\nu}(1,\mu)$ are the irreducible tensor amplitudes of rank λ.
l is the orbital angular momentum.
L is the total angular momentum of the photon.
Short hand notation $[L]$ to represent $\sqrt{2L+1}$
j is the conserved total angular momentum of the reaction.
$W(1L1l;j\lambda)$ represents the racah coefficients.

$g_\nu^\lambda(l, L, \mu)$ is the angular dependence and the dependence on photon polarization.
F_L^{lj} are the partial multipole amplitudes.
Electric 2^L-pole amplitudes, $P^+ = 1$
Magnetic 2^L-pole amplitudes, $P^- = 1$.
$\mathcal{M}_L^{lj}$ and $\mathcal{E}_L^{lj}$ represent the magnetic and electric multipole amplitudes respectively.

Discussion

Since we are looking at only near threshold energies, we may restrict ourselves to only $L = 1, 2$ and to $l = 0, 1, 2$ partial waves.

It is pertinent to note that the reaction can be described by only 6 non-zero irreducible tensor amplitudes $\mathcal{F}_{\nu}^{\lambda}(1, \mu)$ with $\lambda = 0, 1, 2$ and $\mu = \pm 1$ at all energies.

In terms of these limited number of partial wave multipole amplitudes, the irreducible tensor amplitudes $\mathcal{F}_{\nu}^{\lambda}(1, \mu)$ may explicitly be written in terms of these multipole amplitudes.

For $\lambda = 0$

$$\mathcal{F}_0^0(1,1) = -3\sqrt{3}g_0^0(1,1,1) - 5\sqrt{3}g_0^0(2,2,1) \quad (6)$$

$$\mathcal{F}_0^0(1,-1) = -3\sqrt{3}g_0^0(1,1,-1) - 5\sqrt{3}g_0^0(2,2,-1) \, (7)$$

For $\lambda = 1$

$$\mathcal{F}_q^1(1,1) = i\sqrt{3}g_\nu^1(0,1,1) - \frac{5i}{2}g_\nu^1(1,2,1) - \frac{i\sqrt{5}}{2}g_\nu^1(1,2,1)$$

$$+\frac{i\sqrt{3}}{2}g_\nu^1(2,1,1) + \frac{i\sqrt{15}}{2}g_\nu^1(2,1,1) \qquad (8)$$

$$\mathcal{F}_q^1(1,-1) = i\sqrt{3}g_\nu^1(0,1,-1) - \frac{5i}{2}g_\nu^1(1,2,-1) - \frac{i\sqrt{5}}{2}$$

$$g_\nu^1(1,2,-1) + \frac{i\sqrt{3}}{2}g_\nu^1(2,1,-1) + \frac{i\sqrt{15}}{2}g_\nu^1(2,1,-1) \qquad (9)$$

For $\lambda = 2$

$$\mathcal{F}_q^2(1,1) = \sqrt{3} g_\nu^2(0,2,1) - \frac{i\sqrt{5}}{2} g_\nu^2(1,2,1) + \frac{3i}{2}$$

$$g_\nu^2(1,2,1) - \frac{i\sqrt{3}}{2} g_\nu^2(2,1,1) + \frac{3}{2}\sqrt{\frac{3}{5}} g_\nu^2(2,1,1) \quad (10)$$

$$\mathcal{F}_q^2(1,-1) = \sqrt{3} g_\nu^2(0,2,-1) - \left(\frac{i\sqrt{5}}{2} + \frac{3i}{2}\right) g_\nu^2(1,2,-1)$$

$$- \frac{i\sqrt{3}}{2} g_\nu^2(2,1,-1) + \frac{3}{2}\sqrt{\frac{3}{5}} g_\nu^2(2,1,-1) \quad (11)$$

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