PrimEx Note 44

Background contribution from ω photoproduction in the experiment Primex

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Abstract

We have identified the possible mechanisms of the ω photoproduction off complex nuclei contributing to the forward π^0 production yield in the Primex experiment. The differential cross sections vs. production angle (momentum transfer) are evaluated for the major processes and are ready to be used for the numerical estimation of the background contribution through the Monte Carlo simulations.

1 Introduction

In the Primex experiment the π^0 radiative decay width is being extracted from the differential cross section of pions on nuclei at the forward production angles.Therefore, any π^0 photoproduced off nuclei and satisfying the kinematical selection conditions of the experiment may potentially contribute in the experimental yields. In this paper we are evaluating the possible background contribution from the photoproduced ω mesons through the decay channels $\omega \to \pi^0\gamma$ and $\omega \to \pi^0\pi^+\pi^-$. The ω mesons in our experiment can be produced through the different mechanisms:
a) Coherent photoproduction off nuclei:

$$\gamma(k) + A \to \omega(p) + A \tag{1}$$

b) Incoherent photoproduction:

$$\gamma + A \to \omega + X \tag{2}$$

Here X is the final state of the target nuclei, including all possible exitations or its break up.

Two major elementary processes are contributing to the incoherent photoproduction:
1. The elastic ω production on nucleon: $\gamma + N \rightarrow \omega + N$
2. The ω production with an isobar in the final state: $\gamma N \rightarrow \omega\Delta(1232)$
We have found that the isobar production is essential to be included in the background simulations.

We adopt the following normalization for cross sections:

$$\frac{d\sigma}{d\Omega} = \frac{k^2}{\pi}\frac{d\sigma}{dt} = \mid F_S(E,q) \mid^2 \tag{3}$$

$F_S(k,q)$ is the amplitude of the process (1).The invariant momentum transfer $t = (k-p)^2 = m_\omega^2 - 2k(\sqrt{p^2+m^2} - p\cos\theta)$. Since at our energies $\frac{m^2}{p^2} \ll 1$ one can expand the square root in this relation and presented the invariant momenta t through the longitudinal q_L and transverse $\vec{q}$ momenta:

$$t = (k-p)^2 = -(\frac{m_\omega^2}{2E})^2 - 4kpsin^2\frac{\theta}{2} = -q_L^2 - q^2 \tag{4}$$

It is convenient to introduce the variable $t\prime = t - t_{min} = -q^2$,where $t_{min} = -\frac{m_\omega^4}{4k^2}$ is the minimum momentum transfer.

2 Coherent omega photoproduction off nuclei.

In the Glauber multiple scattering theory the amplitude for vector meson coherent photoproduction off nuclei(the nucleus remain in its ground state) is given by [1]:

$$\begin{aligned} F_S(q,q_L) &= A\frac{ik}{2\pi}\int e^{i\vec{q}\vec{b}+iq_L z}\Gamma_p(\vec{b}-\vec{s})\rho(\vec{s},z) \\ &\times [1 - \int \Gamma_s(\vec{b}-\vec{s}\prime)\rho(\vec{s}\prime,z\prime)d^2s\prime dz\prime]^{A-1}d^2bd^2sdz \end{aligned} \tag{5}$$

Here A is the atomic number of the target nuclei. The two dimensional vectors $\vec{b}$ and $\vec{s}$ are the impact parameter vector and the nucleon coordinate in the transverse to the photon momenta plane and $d^2b = bdbd\phi$; z is the longitudinal coordinate of nucleon in the nucleus and integration in this expression goes up to infinity, as real nuclear distributions have an infinite tail; $\rho(\vec{s},z)$ is the nuclear density distribution at the point $\vec{r}(\vec{s},z)$,normalized to

$$\int \rho(\vec{s},z)d^2sdz = 1 \tag{6}$$

The profile functions

$$
\begin{aligned}
\Gamma_p(\vec{b}-\vec{s}) &= \frac{1}{2\pi ik}\int e^{i\vec{q}(\vec{b}-\vec{s})}f_p(q)d^2q \\
\Gamma_s(\vec{b}-\vec{s}) &= \frac{1}{2\pi ik}\int e^{i\vec{q}(\vec{b}-\vec{s})}f_s(q)d^2q \qquad (7)
\end{aligned}
$$

are the two dimensional Fourier transformation of elementary amplitudes for the vector meson photoproduction off nucleon $f_p = f(\gamma N \to \omega N)$ and elastic scattering amplitude $f_s(q) = f(\omega N \to \omega N)$

Taking into account that distribution of nucleons in nuclei $\rho(r)$ is slowly varying function in comparing to profile functions[1],one can take out the nuclear distribution out from the integration in (5):

$$
\begin{aligned}
F_S(k,q) &= Af_N(0)F_A(q,q_L) \\
F_A(q,q_L) &= \int \exp(i\vec{q}\vec{b}+iq_Lz)\rho(\vec{b},z)d^2bdz[1-\frac{\sigma\prime}{2}\int_z^\infty \rho(\vec{b},z\prime)dz\prime)]^{A-1} \qquad (8)
\end{aligned}
$$

Here $F_A(q,q_L)$ is the nuclear formfactor;$\sigma\prime = \sigma(1-i\alpha)$ with $\sigma = \sigma^{tot}(\omega N)$ is the total omega-nucleon cross section and $\alpha = \frac{Ref(0)}{Imf(0)}$ is the ratio of real to imaginary parts of forward elastic ωN scattering amplitudes [2]

Replacing the binomial in (6) by an exponential function (this approximation is valid for middle and heavy nuclei ($A > 10$)) one immediately obtains the well known expression for the formfactor [1, 2, 3]:

$$
\begin{aligned}
F_A(q,q_L) &= \int \exp(i\vec{q}\vec{b}+iq_Lz)\rho(\vec{b},z)d^2bdz \\
&\times \exp(-\frac{\sigma\prime}{2}A\int_z^\infty \rho(\vec{b},z\prime)dz\prime) \qquad (9)
\end{aligned}
$$

Therefore,based on the normalization condition (3) and obtained above expression (6) the differential coherent cross section on nuclei can be expessed by the forward differential cross section on the nucleon and the nuclear formfactor:

$$
\frac{d\sigma}{dt} = A^2\frac{d\sigma_N(0)}{dt} \mid F_A(q_L,q) \mid^2 \qquad (10)
$$

Neglecting the longitudinal momentum transfer q_L in (6) we obtain the total cross section:

$$
\sigma(\gamma A \to \omega A) = \int \frac{d\sigma}{dt}dt = 16\pi A^2\frac{d\sigma_N}{dt}(0)\int \mid \frac{1-exp(-\frac{\sigma\prime}{2}\int \rho(\vec{b},z\prime)dz\prime)}{\sigma\prime} \mid^2 d^2b \qquad (11)
$$

[1]The slopes of elementary amplitudes f_s, f_p are much less than the square of nuclear radius for middle and heavy nuclei

[2]The total cross section $\sigma = 26mb$ and $\alpha = -0.2$ at our energies [1]

In the above expressions $f_N(0)$ and $\frac{d\sigma_N}{dt}(0)$ are the ω diffractive photoproduction amplitude on nucleon and corresponding cross section at zero angle (Pomeron or two gluon exchanges).
Besides the diffraction mechanism the ω mesons can be produced by exchange of pions (OPE-mechanism), and has an essential contribution at these energies.It is well known that isospin one exchange (OPE), leads to opposite signs for photoproduction amplitudes from neutron and proton. From the other hand in the coherent processes one has to sum the elementary amplitudes thus only the diffractive part of elementary amplitude f_N contributes to coherent production off isospin zero nuclei.
For the diffractive part of the elementary cross section at zero angle in (7), we use the parameterization from [4]:

$$\begin{aligned} \frac{d\sigma_N}{dt}(0) &= C(1+\frac{D}{E}); \\ C &= (9.3 \pm 1.7) \quad \mu b/GeV^2; \quad D = (1.4 \pm 1.2) GeV. \end{aligned} \tag{12}$$

For distribution of nucleons in nuclei $\rho(r)$ we adopt the Fermi parameterization:

$$\rho(r) = \rho_0 \frac{1 + w\frac{r^2}{R^2}}{1+\exp(\frac{r-R}{c})} \tag{13}$$

Carbon (A=12):w=-0.149;R=2.355f;c=0.5224f $\rho_0 = 0.01519 f^{-3}$
Lead (A=208):w=0;R=6.624f;c=0.549f $\rho_0 = 7.696 f^{-3}$
On the Fig.1 we plot the square of nuclear formfactor as a function of scattering angle for carbon nuclei, calculated by expression (9).The dotted line correspond to Born approximation (without absorption, i.e. $\sigma\prime = 0$).We see that absorption diminish the formfactors substantially.

3 Incoherent production $\gamma A \to \omega X$

Following the work [5] the incoherent ω production can be expressed as:

$$\begin{aligned} \frac{d\sigma^{inc}}{dt} &= N(0,\sigma(\omega N))[(\frac{d\sigma}{dt}(1-G(t)) + \frac{d\sigma}{dt}(\gamma N \to \omega\Delta(1232))] \\ G(t) &= (1+(\frac{q^2R^2}{15})^2) exp(-\frac{2q^2R^2}{15}) \end{aligned} \tag{14}$$

with $R = 14 GeV^{-1}$ The effective nucleon number $N(0,\sigma)$ is determined by the distribution of nucleons in nucleus and $\sigma(\omega N)$

$$N(0,\sigma) = \int \frac{1 - exp(-\sigma \int \rho(b,z)dz)}{\sigma} d^2b$$

Using the distribution (9) and $\sigma(\omega N) = 26mb$ we obtain $N(0,\sigma) = 7.36$ for the carbon nuclei.
The omega photoproduction cross section off nucleon was parameterizied according to SLAC data [4]:

$$\begin{aligned} \frac{d\sigma}{dt}(\gamma N \to \omega N) &= \frac{d\sigma}{dt}(0)e^{Bt} \\ \frac{d\sigma}{dt}(0) &= 20 \pm 3.2\frac{\mu b}{GeV^{-2}}; B = (7.9 \pm 0.9)GeV^{-2} \end{aligned} \tag{15}$$

For the omega photoproduction cross section with isobar in the final state, we use the parameterization from the experimental data presented in [7]:

$$\begin{aligned} \tfrac{d\sigma}{dt'} \quad &(\gamma N \to \omega\Delta(1232)) = \frac{d\sigma}{dt'}(0)exp(Bt') \\ \tfrac{d\sigma}{dt'}(0) \quad &= (14.9 \pm 1.8)\frac{\mu b}{GeV^{-2}}; \quad B = (20.6 \pm 2.8)GeV^{-2} \end{aligned} \tag{16}$$

On the Fig. 2 we depicted the differential cross sections for coherent production (solid curve) and incoherent cross section (dotted one).All calculations have been done for mean photon energy E=5.2GeV.

4 ω decays into π^0

For the $\omega \to \pi^0\gamma$ decay we suggest to use the angular distribution proportional to $(1 + cos^2\theta)$ in the ω rest frame [3]. $\omega \to \pi^0\pi^+\pi^-$ decays it is [5] $sin^2\theta$ in the helicity system.

References

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Figure 1: The square of nuclear form factor (expression (9)) for Carbon nuclei without absorption (red curve,$\sigma\prime = 0$) and with absorption.

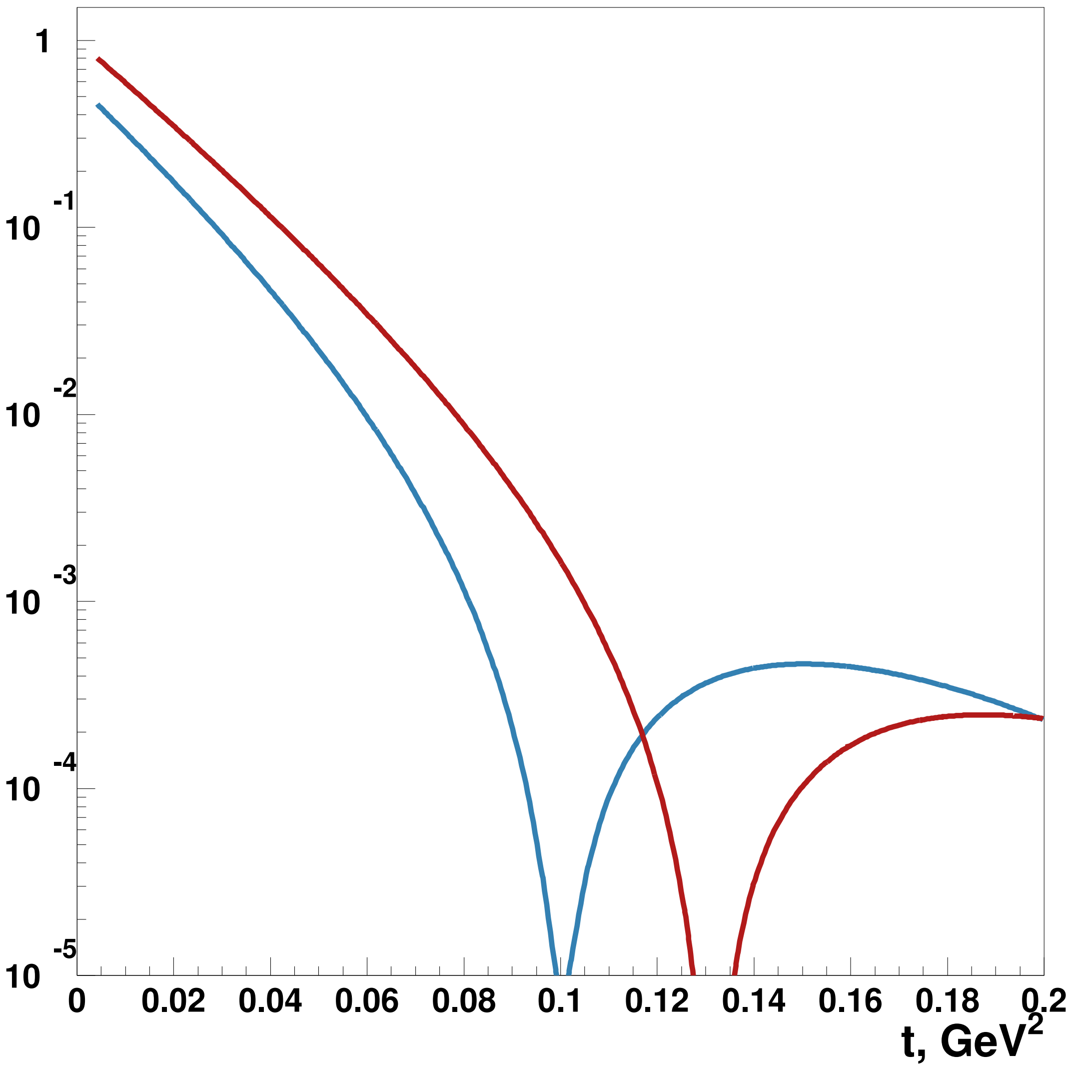

Figure 2: The differential cross sections dependence on momemtum transfer for Carbon. 1.Coherent production. 2. Incoherent production in quasielastic process 3 Incoherent production with isobar in the final state.