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Study photoproduction of ω mesons on nuclei with the GlueX detector.

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Abstract

We propose to study the photoproduction of ω mesons on complex nuclei with the GlueX detector in the photon beam energy range between 5 GeV and 9 GeV. Production of ω's in coherent photoproduction $\gamma A \to \omega A$ provides a possibility to measure the total cross section of transversely polarized ω mesons with nucleon $\sigma_T(\omega N)$. The investigation of incoherent photoproduction $\gamma A \to \omega A'$ (A' - nuclear excitation or its break-up products) allows one to extract the total cross section of the longitudinally polarized ω mesons with nucleon $\sigma_L(\omega N)$, which has not yet been measured. We plan to measure the spin density matrix elements of ω mesons on various nuclei, which also provides an opportunity to estimate the value of $\sigma_L(\omega N)$.

1 Introduction

Interactions of particles with nonzero spin with nucleons can be characterized by a set of amplitudes corresponding to different polarization states. For instance, a scattering amplitude of a vector meson $V_0(\rho, \omega, \varphi)$ on the nucleon at zero angle, averaged over the nucleon spin is determined by two quantities: $\sigma'_T = \sigma_T(1 - i\alpha_T)$ and $\sigma'_L = \sigma_T(1 - i\alpha_L)$, where $\sigma_{T(L)}$ is the total cross section for the interaction of a transversely (longitudinally) polarized vector meson with the nucleon and $\alpha_{T(L)} = Ref_{T(L)}(0)/Imf_{T(L)}(0)$ is the ratio of the real to imaginary part of the corresponding amplitudes at zero angle. Measurement of these quantities is crucial for different theoretical models.

Dependence of vector particle interactions on the particle's polarization is known for many years. This takes place especially if the vector particle constituents have nonzero orbital momenta; a vivid example of which is the deuteron interaction with matter [1, 2]. There are predictions that interactions of mesons with nonzero orbital momenta with nucleons are strongly correlated with the meson polarization [3, 4].

The first indications that interactions of vector mesons V_0 with nucleon may depend on its polarization came from the ρ electroproduction on protons. The ratio of production cross sections can be represented as $R = \frac{\sigma(\gamma_L p \to V_L p)}{\sigma(\gamma_T p \to V_T p)} = \xi \frac{Q^2}{m_\rho^2}$, where the parameter ξ corresponds to the ratio of longitudinal to transverse ρ^0 total cross sections $\xi = \frac{\sigma_L(\rho p)}{\sigma_T(\rho p)}$. The value of ξ obtained from measurements is $\xi \approx 0.5$ [5], while the naive quark model predicts equal cross sections $\sigma_L(\rho p) = \sigma_T(\rho p)$. As was shown in [6] the distribution of valence quarks in transversely and longitudinally polarized vector mesons is significantly different, that should lead to different interactions of polarized mesons with nucleons.

2 Photoproduction of ω mesons

Photoproduction of ω mesons on nuclear targets in the GlueX kinematic region is a unique way to obtain information on the possible dependence of the strong interaction on the polarization of vector mesons. The reasons are as follows:

- Photoproduction of ω mesons on nucleons $\gamma N \to \omega N$ at the photon energies of several GeVs is determined [7] by a t-channel Pomeron exchange (diffraction, natural parity exchange) and one-pion-exchange (OPE) (unnatural parity exchange). The pion exchange leads to a copious production of longitudinally polarized ω mesons, unlike the diffraction process, which results in the production of transversely polarized mesons due to the s-channel helicity conservation. Contributions from diffraction and pion exchange are almost equal at a photon energy of $E_\gamma = 5$ GeV [5]. Measuring ω meson production at different energies will provide data samples with different fractions of ω polarization.

- In the coherent photoproduction $\gamma(k)A \to \omega(p)A$ the unnatural exchange part of the elementary amplitude cancels out; in the coherent processes one has to sum amplitudes from different nucleons, and the pole exchange of particles with isospin one has different sign in production on protons and neutrons. Therefore, from coherent photoproduction one can extract only the total cross section of transversely polarized vector mesons off nucleons.

- Unlike the coherent production, in the incoherent photoproduction $\gamma A \to \omega A'$ the cross section on the nuclei is the sum of photoproduction cross sections on nucleons. As a result ω mesons with both polarizations can be produced in the incoherent process. This can be used to study interactions of longitudinally polarized vector mesons with matter.

In the late 60's and early 70's many experiments were carried out to study photoproduction of vector mesons on nuclei [5]. The photoproduction of ω mesons on nuclei in the GlueX energy range of interest[1] was measured by two seminal experiments [8, 9, 10]. The Rochester

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[1] Several experiments measured omega production on nuclei at low beam energies, E01-112 (at Jefferson Lab), KEK-E325, and CB-ELSA/TABS

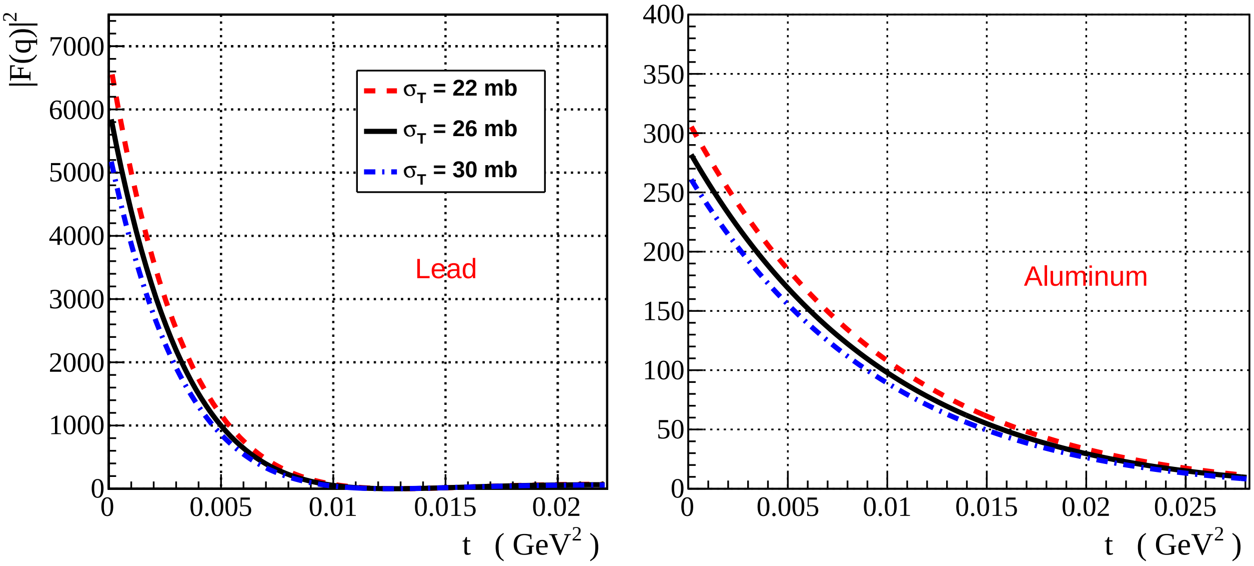

Figure 1: Form factor squared as a function of the momentum transfer for various values of the transverse ωN cross section.

group [8, 9] investigated ω photoproduction on different nuclei at a mean photon beam energy of $E_\gamma = 6.8$ GeV. Omega mesons were identified using the $\omega \to \pi^+\pi^-\pi^0$ decay channel. In the Bonn-Pisa experiment [10] (mean energy $E_\gamma = 5.7$ GeV) mesons were identified through the decay $\omega \to \pi^0\gamma$. The main goal of these experiments was the extraction of the ωN total cross section from the coherent photoproduction on a set of nuclei. The incoherent part was considered to be an undesirable background. Both experiments confirmed naive quark model predictions: $\sigma(\omega N) = \sigma(\rho N) = \frac{1}{2}(\sigma(\pi^+ N) + \sigma(\pi^- N))$, which is not strange as long as from the coherent part of the cross section one extracts only the transversely polarized mesons cross section $\sigma_T(\omega N)$. The coherent and incoherent photoproduction will be shortly described in Section 3 and Section 4.

3 Coherent photoproduction

The differential coherent cross section on nuclei is:

$$\frac{d\sigma}{dt} = \frac{d\sigma_N(0)}{dt} \mid F_A(q_L, q, \sigma_T) \mid^2, \tag{1}$$

where $\frac{d\sigma_N(0)}{dt}$ is the diffractive part of the forward cross section on the nucleon $\gamma(k) + N \to \omega(p) + N$, and $F_A(q_L, q, \sigma_T)$ is the nucleus form factor, which accounts for the absorption of

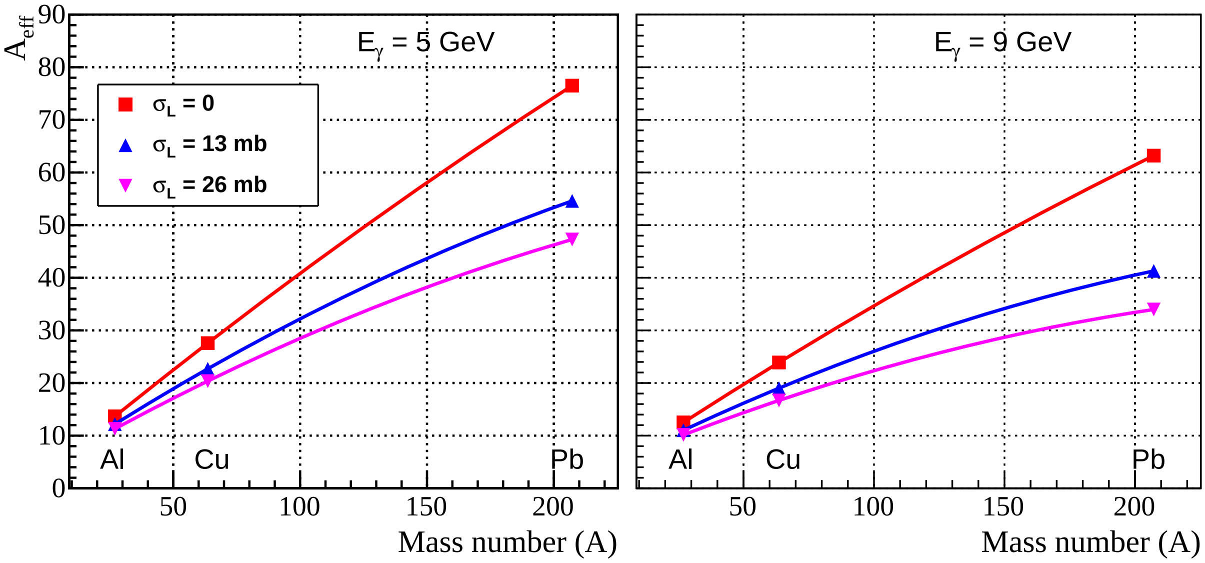

Figure 2: Ratio of ω meson yields on nuclei to nucleon A_{eff} for different nuclei. The ration is shown for three values of σ_L and two photon beam energies: $E_\gamma = 5$ GeV (left) and $E_\gamma = 9$ GeV (right).

ω in nucleus [5]. The form factor depends on the photon energy through the longitudinal momentum transferred $q_L = \frac{m_\omega^2}{2k}$. The transverse momentum is given by the standard relation $q^2 = -4kpsin^2\frac{\theta}{2}$. Figure 1 shows dependence of the coherent cross section on the transferred momentum for different values of $\sigma_T(\omega N)$. As it will be described in Section 5, GlueX will allow measurements of σ_T with a precision better than 5%.

4 Incoherent photoproduction

The incoherent part of the photoproduction cross section of ω mesons in the typical range of the momentum transfer $0.1\ \mathrm{GeV}^2 < t < 0.5\ \mathrm{GeV}^2$ can be presented in the following form [11]:

$$\begin{aligned}
\frac{d\sigma_A(q)}{dt} &= \frac{d\sigma_0(q)}{dt}(\rho_{00}N(0,\sigma_L) + (1-\rho_{00})N(k,\sigma_T)) \\
N(0,\sigma) &= \int \frac{1-\exp(-\sigma\int\rho(b,z)dz)}{\sigma} d^2b \\
N(k,\sigma) &= \int \rho(b,z) \mid E(b,z) \mid^2 dz d^2b \\
E(b,z) &= \exp(-\frac{\sigma}{2}\int_z \rho(b,z')dz') - \frac{\sigma}{2}\int^z \rho(b,z')dz' e^{iq_L(z'-z)} \exp(-\frac{\sigma}{2}\int_{z'}\rho(b,z'')dz'')
\end{aligned} \tag{2}$$

Here $\rho(r)$ is the nuclear density; $\frac{d\sigma_0(q)}{dt} = \frac{d\sigma_N(q)}{dt} + \frac{d\sigma_U(q)}{dt}$ is the differential cross section of ω meson photoproduction on nucleon, which accounts for diffraction and unnatural parity exchanges; ρ_{00} is the density matrix element in the helicity system, which corresponds to the fraction of longitudinally polarized mesons in photoproduction on nucleon. In the Fig.2 we present the ratio of ω's yield $A_{eff} = \frac{d\sigma_A}{dt} / \frac{d\sigma_0(q)}{dt}$ on nuclei to nucleon for different nuclei. The input values are [12] $\rho_{00} = 0.2$ and the total transverse ω-nucleon cross section [10] $\sigma_T(\omega N) = 26$ mb. Density matrix elements in photoproduction on nuclei and nucleons can be related according to the following relation [11]:

$$\rho^A_{00} = \frac{N(0,\sigma_L)}{\rho_{00}N(0,\sigma_L) + (1-\rho_{00})N(k,\sigma_T)}\rho_{00} \tag{3}$$

Dependence of the ρ^A_{00} on the atomic number for different values of σ_L is presented in Fig. 3.

5 Reconstruction of ω mesons

Photoproduction of ω mesons will be studied for the large photon beam energy range corresponding to $E_\gamma > 5$ GeV. The energy of a beam photon will be reconstructed using hits in the tagger hodoscope and microscope detectors. Reconstruction of the beam energy in the region around 5 GeV is complicated due to the relatively large rate of coincidental hits (hits originating from different events) in the tagger detectors. In order to reduce the coincidental rate to a level of a few percent, we are going to decrease the electron beam current to about 10 nA, by a factor of 220 from the originally proposed current for the GlueX of 2.2 μA. The probability to reconstruct events with multiple hits in the tagger hodoscope in the photon energy region of [4.5 - 6.5] GeV and the time window of 8 ns is about 3%.

Reduction of the photon beam flux is also required by the neutron background originating from nuclei. Another possible way to reduce neutron radiation is to use thinner target foils. At the moment we consider to use targets with thicknesses between 3% and 7% radiation lengths (the GlueX LH_2 target thickness is $3.5\%X_0$). Further optimization of the photon beam flux and target thicknesses will be performed in the future.

Target	σ_{Incoh} (μb)		$N_{\rm rec}$ per day	
	5 GeV	9 GeV	5 GeV	9 GeV
Pb	130	64	17300	16500
Al	31	19	15600	17600

Table 1: The incoherent cross section and the number of $\omega \to \pi^0\gamma$ decays reconstructed from the incoherent production of ω mesons. The yield is shown for one day of taking data on 5 $\%X_0$ thick *Pb* and *Al* targets. The photon beam is produced by a 10 nA electron beam in 10^{-4} X_0 radiator.

We performed a study of the reconstruction efficiency of the of $\omega \to \pi^0\gamma$ decays using Hall D detector simulation. $\gamma p \to \omega p$ events was selected from Pythia event generator and passed through the GlueX Geant simulation. The reconstruction efficiency for $\omega \to \pi^0\gamma$ decays was found to be about 42 %[2]. The expected number of reconstructed $\omega \to \pi^0\gamma$ decays produced in the incoherent process on different nuclei targets is listed in Table I. We expect to reconstruct about $60 \cdot 10^3$ $\omega \to \pi^0\gamma$ decays produced in the incoherent process in each photon energy bins after taking data for 4 days on a Pb target. Statistical errors on measurements of A_{eff} and ρ^A_{00} are expected to be on the level of a few percents. Possible sources of systematic errors for proposed measurements are being currently investigated. Errors on the the extraction of the transverse cross section σ_T from the coherent production is estimated to be better than 5 %.

The expected beam time is about 16 days of taking data on four nuclei targets sequentially (about 4 days per target). Using multiple targets in parallel is not desired due to the possible target misidentification in reconstruction of the multi-photon final state ($\pi^0\gamma$). We assume that properties of $\gamma p \to \omega p$ decays will be measured by GlueX and therefore focus on the program with nuclei targets.

6 Summary

We propose to measure photoproduction of ω mesons on various nuclei (C, Al, Cu, and Pb) using the GlueX detector in the photon beam energy range between 5 GeV and 9 GeV. The original goal of the experiment is to:

1. Extract the total transverse cross section $\sigma_T(\omega N)$ of ω mesons using coherent photoproduction $\gamma A \to \omega A$ on nuclei.

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[2] The efficiency for $\omega \to \pi^+\pi^-\pi^0$ decays is expected to be similar.

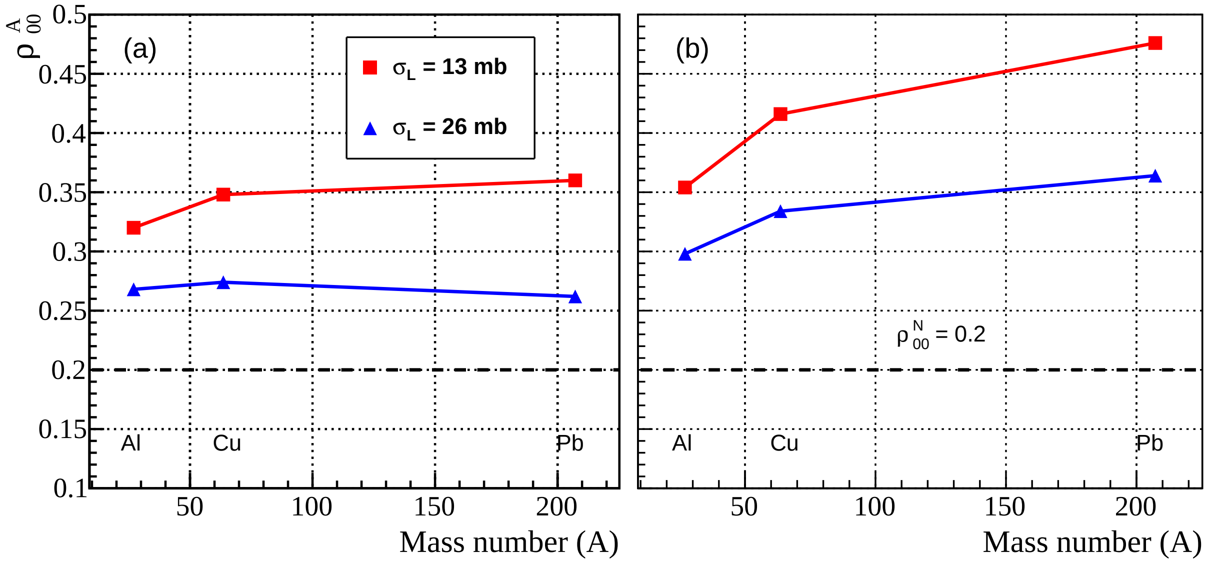

Figure 3: Density matrix element ρ^A_{00} predicted in omega photoproduction on nuclei for two values of σ_L and two photon beam energies: (a) $E_\gamma = 5$ GeV, (b) $E_\gamma = 9$ GeV.

2. Measure the ratio of ω's yield on nuclei to nucleon for different nuclei using incoherent photoproduction $\gamma A \to \omega A'$.
3. Measure density matrix elements for ω mesons on different nuclei using incoherent photoproduction.

Measurement results from (2) and (3) will be used for the first extraction of the cross section $\sigma_L(\omega N)$ of the longitudinally polarized ω mesons from their absorption in nuclei. Omega mesons will be identified using $\omega \to \pi^0\gamma$ and $\omega \to \pi^+\pi^-\pi^0$ decay channels[3]. Data sample acquired for omega photoproduction can be used for other studies of meson photoproduction on nuclei. The expected length of the experiment is less than 20 days of taking data. The detector will be operated at small luminosity in order to minimize neutron background in the experimental Hall D (to be studied). The feasibility to use linearly polarized photons to study photoproduction on nuclei is being investigated.

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