Polarization observables from the photoproduction of ω-mesons using linearly polarized photons

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Abstract. We report on the photon beam asymmetry, Σ, of the ω meson decaying into π^+, π^-, π^0 using a beam of linearly polarized photons in the photon energy region of $E_\gamma = 1.9$ GeV. These preliminary results are from the summer 2005 g8b dataset, which were collected with the CLAS detector in Hall B of Jefferson Lab.

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INTRODUCTION

The missing resonance problem states that there are far more predicted excited states of the nucleon, than the states already measured and catalogued with more or less accuracy. Constaints have been made to the theory, like the case of the diquark model, in which a bond between two quarks of the nucleon reduces the total number of degrees of freedom inside the so called nucleon and therefore its spectrum of resonances; but the problem remains, and what one model lacks, other one has in excess.

Polarization observables are necessary for delineating the underlying processes in the photoproduction of ω mesons. The angular distributions of the ω mesons and, in turn, the angular distributions of the daughter pions from ω decay give critical information on constraining the production mechanisms. By measuring the photon asymmetry parameter as functions of the Mandelstam variables s and t ($\Sigma = \Sigma(s,t)$), we can constrain the underlying production mechanisms. For example, in the forward or diffractive region, linear polarization provides a reference plane for describing the in- or out-of-plane distributions of the pions resulting from ω decay. And consequently serves as a parity filter for understanding the nature of the t-channel exchange, i.e. whether the exchange is from either pseudoscalar or scalar mesons or even perhaps a combination thereof. In the more central regions, other processes are expected to dominate. Since the ω is an isoscalar, it may only couple to N^* states, i.e. $I = \frac{1}{2}$. This eliminates Δ resonance production and makes for cleaner data samples. We expect that a precise measurement of the photon asymmetry parameter for $\vec{\gamma}p \rightarrow \omega p$ will shed light on the spin-parity of the underlying baryon resonances and will further help in disentangling the overlapping N*s.

The photon asymmetry parameter can be decomposed into several spin-density matrix elements (SDME's) and as such set constraints on these SDME's. SDME's are formed of bilinear combinations of the helicity amplitudes, which are the physics of the production

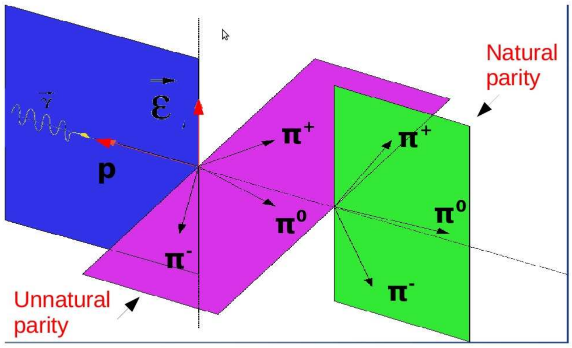

FIGURE 1. Representation of natural and unnatural parity for the process $\gamma p \to p\omega$.

mechanisms. These SDME's, therefore, are the matching point between theory and experiment. Our objective is to ultimately extract the SDME's, and measuring $\Sigma = \Sigma(s,t)$ is the necessary first step in the analysis chain for this reaction.

The goal here is to extract a clear signal, and analyze the channel $\gamma p \to p\omega$, with $\omega \to \pi^0\pi^+\pi^-$, in the photon energy range of 1.9 GeV from the data collected in 2005, using a coherent Linear Polarized Photon Beam at Hall B at Jefferson Lab facilities. This will provide useful information to elucidate and extend the discussion about the above mentioned topics, as well as clarify the mechanism of parity exchange in the t-channel [1], since all models agree that:

- π^0 exchange (unnatural parity) in the t-channel plays a significant role in the cross section of the electro- and photoproduction of ω mesons.
- Baryon resonances contribute significantly to both the total and differential cross section in ω electro- and photoproduction.

We need polarized observables to disentangle which resonances and by how much these resonances contribute to the cross section [1].

G8b experiment

The photoproduction of ω mesons off the proton was achieved by using CEBAF (Continuous Electron Beam Accelerator Facility) and the CLAS (CEBAF Large Acceptance Spectrometer) detector at Thomas Jefferson National Accelerator Facility during the g8b run period which took place in the summer of 2005. CEBAF produces an electron beam with end point energy: 4.544 GeV, that impinges upon a diamond radiator to produce linearly polarized photons by bremsstrahlung and by tuning the angle of the diamond radiator in such way that coherent light is obtained from a set of lattice vectors, taking advantage of the crystal structure of the diamond [2]. The remaining incoherent light is emitted at large angles compared to the polarized part, which is emitted very forward, thus making possible to remove this part from the coherent one, by using a collimator with a stacking arrangement of thirteen nickel diskettes with a small aperture ($r=$1mm) at the center (the distance from the goniometer is 23 meters, therefore it subtends an angle of 43 μrad) [3] that allow the polarized part of the photon spectrum to pass through, removing 80% of the background and enhancing the quality of the polarization.

CLAS

The CEBAF Large Acceptance Spectrometer, which is nearly a 4π detector, is used to detect particles in the final state, and is designed to measure the momentum, time of flight and path length of those particles. From these values, coupled with the curvature of the particle's trajectory can we extract the mass and charge, thereby providing a complete information of the specific event under study.

A set of six superconducting coils divide CLAS into six azimuthal sectors, create a magnetic field transverse to the particle's momentum, suitable to bend particles of a specific charge. A target cell near the center of CLAS contains liquid Hydrogen. A start counter gives the start time for TOF (Time of flight) measurements by identifying the beam bucket associated to an event. Situated between the coils, are a set of three separate regions of drift chambers, which track the particle's path and hence from the curvature, the momentum of the particle. A set of scintillators covering the polar coordinate from 8° to 142° measure the Time of Flight of the particles and along with the momentum obtained with the drift chambers, the mass of the particles is reconstructed.

Event Selection

We begin by requiring at least three particles in the final state, i.e. π^+,π^- and a proton, a track in the drift chambers, and a coincidence in the TOF system. We use mass, charge, beta, time, momentum, and TOF time to best identify good events. By using the missing mass technique we take events that contain a π^0, by performing a 3 to 5 sigma cut around the mean value of a Gaussian fit to the π^0 mass peak. The mass of the ω meson is obtained by using the 4-momentum of the detected pions π^+,π^- plus the reconstructed π^0. In the figure we can see the ω meson signal, as well as a small η meson peak around 5.4 GeV. We then fit the ω mass distribution with a Voigtian, which is a Breit-Wigner distribution convoluted with a Gaussian, and a 4th degree polynomial for the background. As a first approximation we let all the parameters float. Later, we will fix parameters, such as the Breit-Wigner width Γ in the Voigtian (Γ for the ω meson is 8.49 ± 0.08 MeV).

Beam Asymmetry Σ Extraction

For this calculation we need to study different angular regions of CLAS as well as different bins in energy around the coherent peak, where the maximum polarization

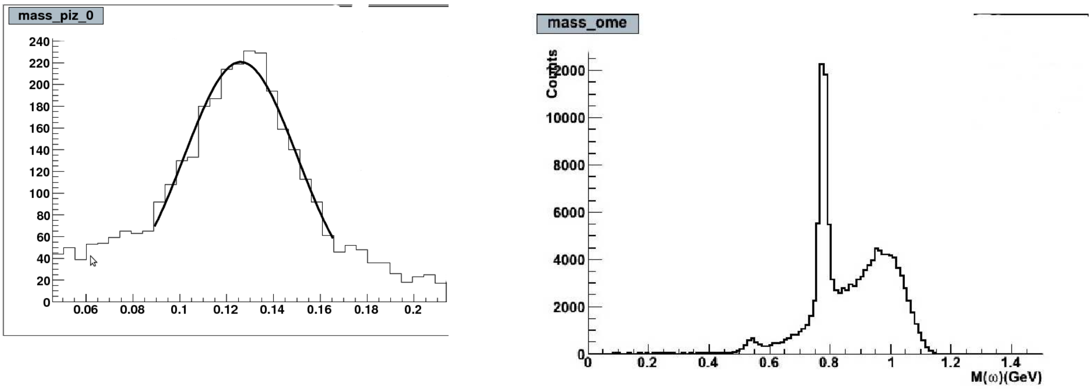

FIGURE 2. Left. Missing mass reconstruction and Gaussian fit to the π^0 peak. We take 3 to 5σ as accepted events. The image correspond to a sample from 1.9 GeV data set. Right. Three pion invariant mass reconstruction searching for ω meson signal. Note the η meson peak at around 0.54 GeV. The image correspond to 1.9 GeV data set.

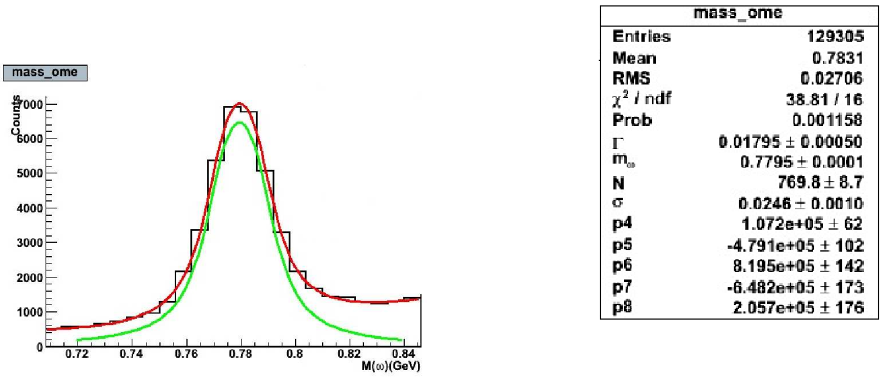

FIGURE 3. Fit for ω meson signal. Voigtian plus 4th-degree polynomial.

values are achieved. We separated CLAS into 10 $\cos\theta$ bins and 18 bins in ϕ, and checked the asymmetry parameter for three E_γ values of 27 MeV, to be compared with the values obtained by P. Collins in a separate analysis. The Beam Asymmetry parameter Σ is determined by fitting the ratio $\frac{PERP-PARA}{PERP+PARA}$ for each $\cos\theta$ bin and E_γ bin, to a $\cos 2\phi$ like function:

$$\begin{aligned}
\sigma_\perp &= \sigma_0(1+P_\perp\Sigma\cos 2\phi) \\
\sigma_\parallel &= \sigma_0(1+P_\parallel\Sigma\cos 2\phi+\pi) \\
\sigma_\parallel &= \sigma_0(1-P_\parallel\Sigma\cos 2\phi)
\end{aligned}$$

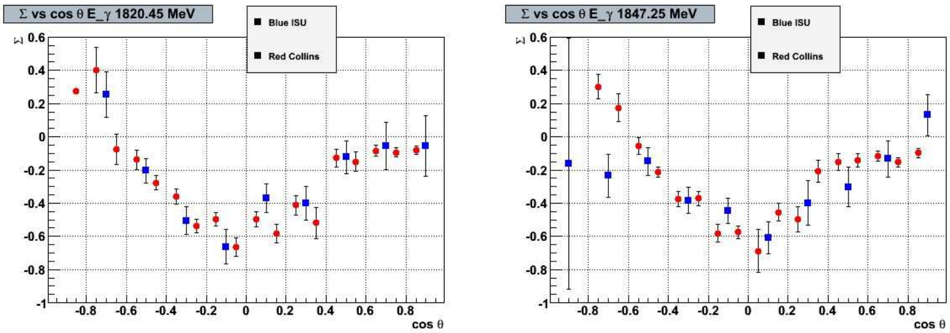

FIGURE 4. Beam Asymmetry Σ for 2σ around ω peak. The squares with bigger uncertainties correspond to the ϕ bin method -ISU-, and the dots correspond to method of moments -P. Collins data- [4, 5].

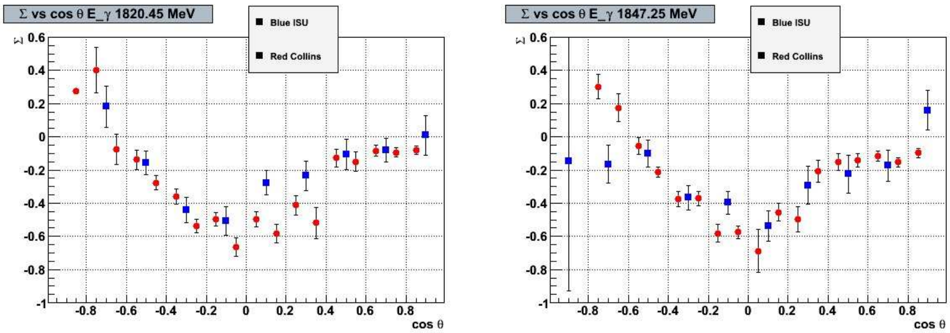

FIGURE 5. Beam Asymmetry Σ for 3σ around ω peak. The squares with bigger uncertainties correspond to the ϕ bin method -ISU-, and the dots correspond to method of moments -P. Collins data- [4, 5].

$$\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \frac{(\frac{N_\perp}{N_\parallel} - 1) - (\frac{N_\perp}{N_\parallel} P_\perp + P_\parallel)\Sigma\cos(2(\phi))}{(\frac{N_\perp}{N_\parallel} + 1) - (\frac{N_\perp}{N_\parallel} P_\perp - P_\parallel)\Sigma\cos(2(\phi))}$$

PATH FORWARD

We have determined Σ through the ϕ bin technique and cross compared to the method of moments used by P. Collins [4, 5]. They agree and we have a good handle on our systematics. Further studies on the binning for both $\cos\theta$ and ϕ are to be done, since the next step is to reduce the ω invariant mass background, meaning this that we have to study the mass distribution for each bin in $\cos\theta$ and ϕ. The other coherent energy sets have to be analized. The next step is the extraction of Spin Density Matrix Elements $\rho^{\alpha}_{i,j}$ -SDME's-, by checking the angular distribution of the decay pions, which in turn are parametrized in terms of the SDME's [8]:

$$W^L(\cos\theta, \phi, \Phi) = W^0(\cos\theta, \phi) - P_\gamma \cos 2\Phi W^1(\cos\theta, \phi) - P_\gamma \cos 2\Phi W^2(\cos\theta, \phi)$$

with,

$$
\begin{aligned}
W^0(\cos\theta,\phi) &= \frac{3}{4}\left[\frac{1}{2}\left(1-\rho^0_{00}\right)+\frac{1}{2}\left(3\rho^0_{00}-1\right)\cos^2\theta-\sqrt{2}Re\rho^0_{10}\sin 2\theta cos\phi \right.\\
&\left. -\rho^0_{1-1}\sin^2\theta cos2\phi\right]\\
W^1(\cos\theta,\phi) &= \frac{3}{4}\left[\rho^1_{11}\sin^2\theta+\rho^1_{00}\cos^2\theta-\sqrt{2}\rho^1_{10}\sin 2\theta cos\phi-\rho^1_{1-1}\sin^2\theta cos2\phi\right]\\
W^2(\cos\theta,\phi) &= \frac{3}{4}\left[\sqrt{2}Im\rho^2_{10}\sin 2\theta\sin\phi+Im\rho^2_{1-1}\sin^2\theta\sin 2\phi\right]
\end{aligned}
$$

Σ will be used as a constraint for these SDME's, since:

$$
\Sigma = P_\gamma \frac{2(\rho^1_{11}+\rho^1_{1-1})}{1-\rho^0_{00}+2\rho^0_{1-1}}
$$

If helicity is conserved in the *s*-channel, then, only two of the SDME's [6] are nonzero: $\rho^1_{11}=0.5$ and $Im\rho^2_{11}=-0.5$, hence $\Sigma=1$ when P_γ is 1 [7] (with θ and ϕ determined in the helicity frame). Any deviation from this value is an indication that non-diffractive processes are present. Assuming natural parity, $\rho^1_{11}=0.5$ and $\rho^1_{00}=0$. For unnatural parity, $\rho^1_{11}=-0.5$ and $\rho^1_{00}=0$.

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