ϕ-meson photoproduction off the protons by using linearly polarized photons in the mid- to higher-t regimes at threshold energies*

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Abstract Observables from vector meson photoproduction by linearly-polarized photons can be expressed in term of bilinear combinations of helicity amplitudes parameterized by the Spin Density Matrix Elements (SDMEs). These SDMEs give straightforward relations for understanding the nature of the parity exchange at threshold energies, as well as for extracting signatures of the Okubo-Zweig-Iizuka violation. This paper will show preliminary measurements of SDMEs for $\vec{\gamma}p \to \phi p$ in the photon energy range of 1.7 to 1.9 GeV (momentum transfer squared t range of -1.2 to -0.25 GeV^2) and 1.9 to 2.1 GeV (t range of -1.4 to -0.25 GeV^2) from the g8b experimental data collected in the summer of 2005 in the Hall B of Jefferson Lab.

Key words photoproduction of ϕ-mesons, linearly-polarized photons, polarization observables

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1 Introduction

In the baryon resonance regime (about 2.0 GeV), the photoproduction mechanism for ϕ-mesons is not completely explained by pure pomeron exchange. As put forth by T. Nakano, H. Toky and T.-S. H. Lee[1] other mechanisms must take place. Along similar logic, the observed 15.3% branching ratio of $\phi \to \rho\pi$ indicates the possibility of OZI rule violation, which would tend to allow for other mechanisms for ϕ-meson production like meson exchange[2].

An incisive tool for delineating this mix between natural parity exchange (pomeron) and unnatural parity exchange (pseudoscalar mesons) is by extracting the spin density matrix elements (SDMEs) as a function of momentum transfer squared t. At low t, or forward angles, the helicity nonconserving processes are found to be small[3] resulting from mostly two contributions: one from pomeron exchange and the other one from π, η exchange, where natural parity exchange contribution was dominant. In this paper we will show the behavior of the ϕ-meson decay angular distribution at mid- to higher-t (larger angles) and report on our measurement of the corresponding SDMEs.

2 Experiment

The g8b experiment took place in Hall B of Jefferson Laboratory in the summer of 2005[4]. The Coherent Bremsstrahlung Facility, CBF, provided the linearly-polarized photon beam from the Continuous Electron Beam Accelerator Facility (CEBAF), cf. Fig. 1, with average polarization, P_γ, which ranged from 60% to 70% for photon energies between 1.7 and 2.1 GeV.

Linearly-polarized photons are produced from coherent bremsstrahlung of electrons (CEBAF) from a thin-wafer diamond placed at the center of the goniometer3). This gives an enhancement from the incoherent Bethe-Heitler photon background as shown in Fig. 2. Tight collimation of one-half characteristic angle (or ∼ 50 μrad) by the Active Collimator allowed to enhance the coherent peak by reducing the

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3) The goniometer provides an accurate orientation of the diamond. Thus orientation is crucial to obtain a high linear polarization.

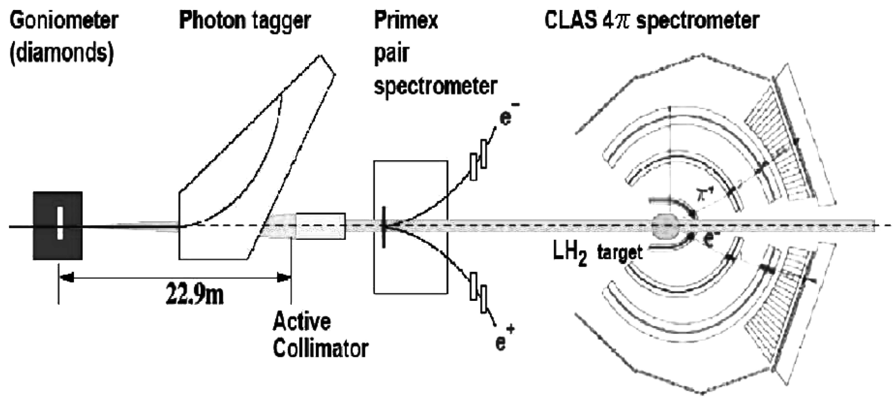
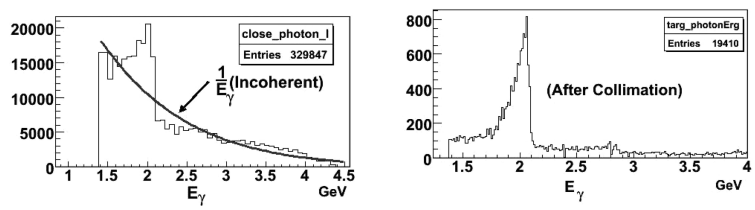


Fig. 1. CLAS with the Coherent Bremsstrahlung Facility Beamline.



(a) (b)

Fig. 2. (a) Photon spectrum from coherent bremsstrahlung before collimation. (b) Photon spectrum after collimation to 1/2 of a characteristic angle.

incoherent background and consequently increase the polarization as indicated in Fig. 2.

Downstream of the CBF, the tagged and collimated photon beam is directed onto a liquid hydrogen target, which was placed 20 cm upstream of the geometric center of the CEBAF Large Acceptance Spectrometer or CLAS. CLAS covers 70% of 4π and the sub-detectors inside CLAS, coupled with a toroidal magnetic field, allows to identify the final-state particles in high-multiplicity events.[5] In this case, the final state particles detected were p and K^+.1)

Measuring angular distribution of the ϕ-meson decay products, K^+ (directly) and K^- (by missing mass) in the helicity frame of the ϕ meson, will allow us to study various ϕ photoproduction mechanisms as discussed above.

3 ϕ-meson decay angular distribution

The decay angular distribution, $W(\cos\theta,\phi,\Phi)$, is a function of spin density matrix elements (SDMEs) where θ and ϕ are the polar and azimuthal angles of the K^+ (K^-) decay product in the helicity reference frame2) and Φ is the azimuthal angle of the photon polarization in the c.m. frame. In order to extract the SDMEs we use five one-dimensional distributions defined by[6]:

$$W(\cos\theta) = N\left[\frac{1}{2}(1-\rho^0_{00})\sin^2\theta+\rho^0_{00}\cos^2\theta\right]\to\rho^0_{00}=\rho^1, \tag{1}$$

$$W(\phi) = N[1-\rho^0_{1-1}\cos 2\phi]\to\rho^0_{1-1}=\rho^2, \tag{2}$$

$$W(\phi-\Phi) = N[1+2P_\gamma(\rho^1_{1-1}-\mathrm{Im}\rho^2_{1-1})\cos 2(\phi-\Phi)]\to\frac{1}{2}(\rho^1_{1-1}-\mathrm{Im}\rho^2_{1-1})=\rho^3, \tag{3}$$

$$W(\phi+\Phi) = N[1+2P_\gamma(\rho^1_{1-1}+\mathrm{Im}\rho^2_{1-1})\cos 2(\phi+\Phi)]\to\frac{1}{2}(\rho^1_{1-1}+\mathrm{Im}\rho^2_{1-1})=\rho^4, \tag{4}$$

$$W(\Phi) = N[1-P_\gamma(2\rho^1_{1-1}+\rho^1_{00})\cos 2\Phi]\to 2\rho^1_{1-1}+\rho^1_{00}=\rho^5\to P_\gamma\rho^5\cos 2\Phi=\frac{W(\Phi)_\parallel-W(\Phi)_\perp}{W(\Phi)_\parallel+W(\Phi)_\perp}, \tag{5}$$

1) This was due to a very small statistic from pKK, pK^- and KK topologies.

2) The z- or quantization-axis is defined as the direction opposite the proton in the total c.m. system.

where $\rho^{i=1,5}$ are used to fit these distributions to the data, extract SDMEs, and study the relative contribution of natural and unnatural parity exchange ($\rho^{3,4}$) as well as the photon beam asymmetry Σ (ρ^5).

4 Preliminary results

We wish to point out that these results are still under study and hence are not yet the final results, but are getting very close. Here we have two data sets featured by two energy ranges: $1.7 < E_\gamma < 1.9$ GeV and $1.9 < E_\gamma < 2.1$ GeV, and subsequently by two different photon polarization orientations: parallel (PARA) and perpendicular (PERP), 90° to each other. Fig. 3 and Fig. 4 (right) show the behavior of $W(\cos\theta)$ where ρ^1 was found to be small (see Table 1) consistent between orientations and in very good agreement with previous measurements from Spring-8 and SLAC.[3, 7] $W(\phi)$, for PARA and PERP $1.9 < E_\gamma < 2.1$ GeV data, exhibits an small oscillation as well as for PERP $1.9 < E_\gamma < 2.1$ data. However, for PARA $1.9 < E_\gamma < 2.1$ data, ρ^2 was found to be larger than the others. This issue has to do with the low yield around $\phi = 180°$, where there are few events in this azimuthal angle range. Nevertheless our acceptance calculation was good enough to correct data having such low statistics.

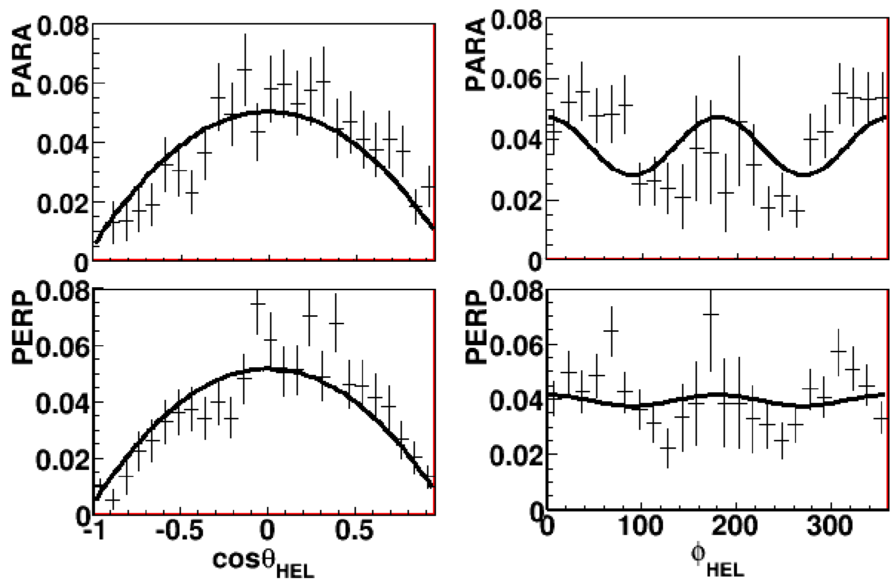


Fig. 3. $W(\cos\theta)$ (left) and $W(\phi)$ (right) for $1.7 < E_\gamma < 1.9$ GeV.

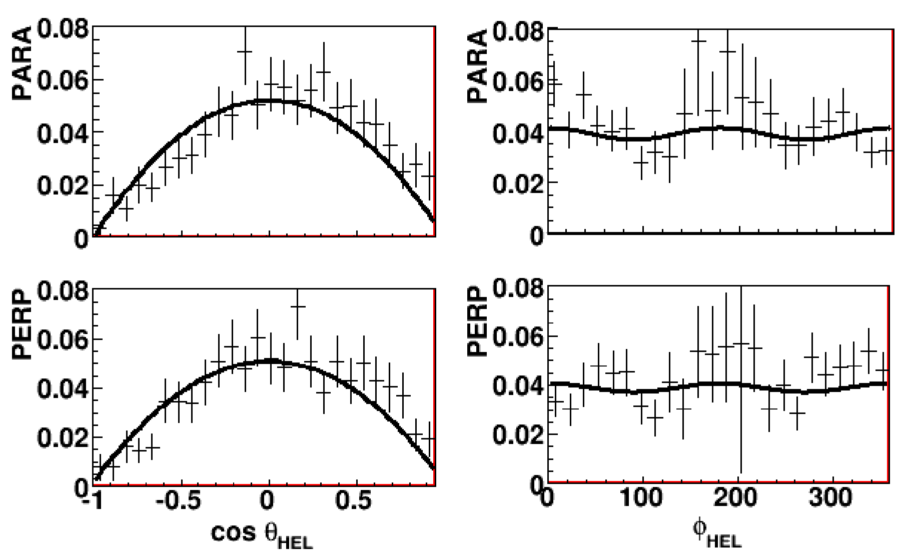


Fig. 4. $W(\cos\theta)$ (left) and $W(\phi)$ (right) for $1.9 < E_\gamma < 2.1$ GeV.

Table 1. Results for $\rho^{i=1,4}$.

orientation	ρ^1	ρ^2	ρ^3	ρ^4
data set		$1.7<E_\gamma<1.9$ GeV		
PARA	0.048±0.039	−0.128±0.032	0.144±0.051	−0.002±0.052
PERP	0.036±0.017	−0.024±0.028	0.149±0.043	0.003±0.043
data set		$1.9<E_\gamma<2.1$ GeV		
PARA	0.001±0.021	−0.074±0.03	0.206±0.043	0.065±0.044
PERP	0.013±0.031	−0.075±0.029	0.204±0.047	0.021±0.048

Figure 5 and Fig. 6 (right) shows $W(\phi-\Phi)$ where ρ^3 was found to have a positive value but definitely departs from 0.5 which indicates the reaction mechanism has more contribution from pomeron exchange than meson exchange. And as can be seen, our results for each orientation are similar to each other. Furthermore, $W(\phi+\Phi)$ shows an small oscillation (ρ^4 close to zero for both energy ranges), which implies that ρ^1_{1-1} and $\mathrm{Im}\rho^2_{1-1}$ are, in absolute value, close to each other. This behavior is well know at high energies and is predicted from the Vector Dominance Model (VDM).[8]

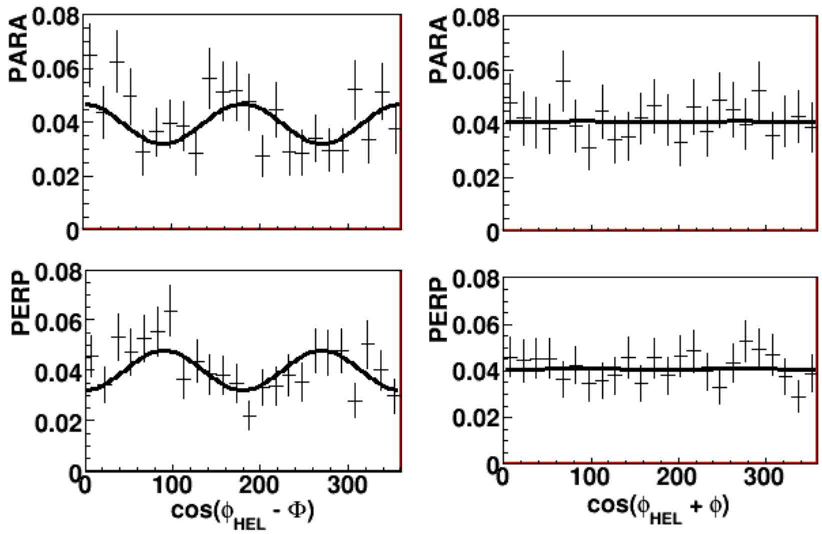


Fig. 5. $W(\phi-\Phi)$ (left) and $W(\phi+\Phi)$ (right) for $1.7<E_\gamma<1.9$ GeV.

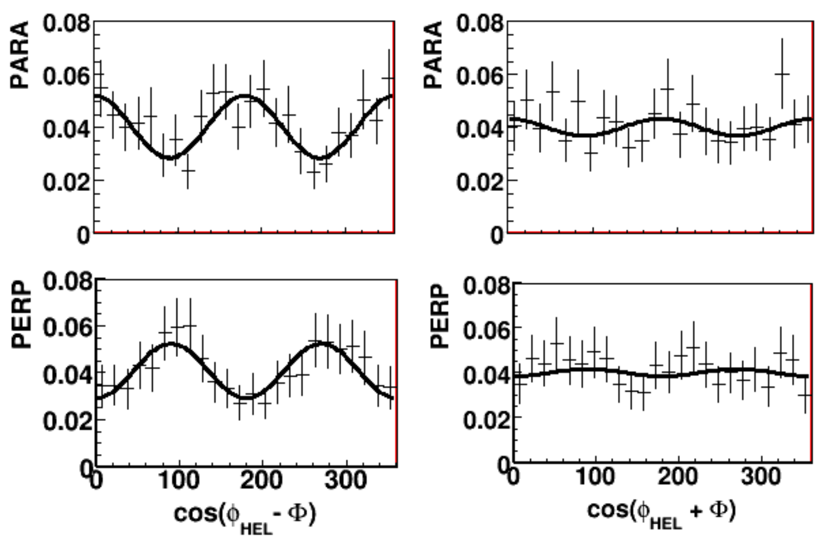


Fig. 6. $W(\phi-\Phi)$ (left) and $W(\phi+\Phi)$ (right) for $1.9<E_\gamma<2.1$ GeV.

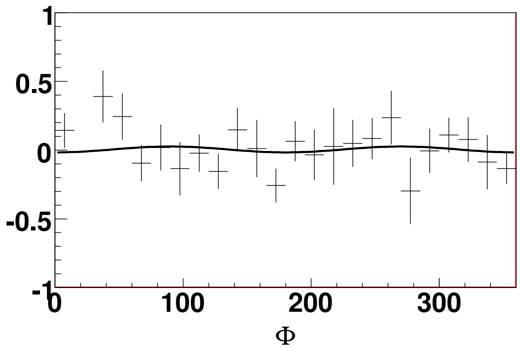


Fig. 7. $P_\gamma \rho^5 \cos 2\Phi$ for $1.7 < E_\gamma < 1.9$ GeV.

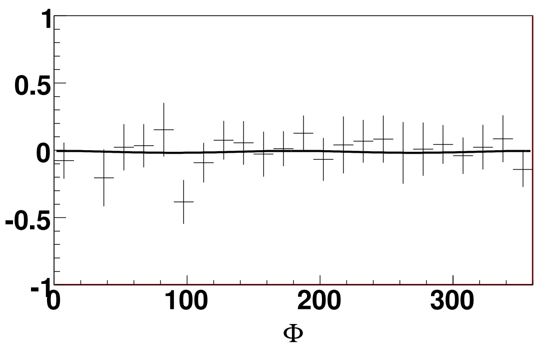


Fig. 8. $P_\gamma \rho^5 \cos 2\Phi$ for $1.9 < E_\gamma < 2.1$ GeV.

$P_\gamma \rho^5 \cos 2\Phi$ is shown in Figs. 7 and 8. This was extracted based on the photon beam asymmetry relationship (bottom of Eq. (1)) since the difference between PARA and PERP polarizations was less than 1.5%. For both energy ranges ρ^5 was found to be close to zero (see Table 2). It was expected in the framework of the VDM. Also results from Spring-8[3] and calculation from Ref. [6] agree with our result.

Table 2. Results for $\rho^{i=5}$.

data set	ρ^5
$1.7 < E_\gamma < 1.9$ GeV	0.018±0.036
$1.9 < E_\gamma < 2.1$ GeV	0.041±0.044

5 Future work

We are expected to finish our study of the systematic errors and refine the extraction of the SDMEs from $\rho^{i=1,5}$ soon. This work will be PhD thesis of the first author, JS.

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References

1 Nakano T et al. Nucl. Phys. A, 2001, **684**: 71—79
2 Titov A I, Oh Y, YANG S N, Morii T. Phys. Rev. C, 2001, **58**: 2429—2449
3 Mibe T et al. Phys. Rev. Lett., 2005, **95**: 182001
4 Cole P L, Tedeschi D J (spokespersons). Photoproduction of ϕ Mesons with Linearly Polarized Photons, JLab Experiment E-98-109
5 Mecking B A et al. Nucl. Instr. and Meth. A, 2003, **503/3**: 513—553
6 Titov A I, Lee T-S H. Phys. Rev. C, 2003, **67**: 065205
7 Ballam J et al. Phys. Rev. D, 1973, **7**: 3150—3177
8 Schilling K, Seyboth P, Wolf G. Nucl. Phys. B, 1970, **15**: 397—412