POLARIZATION OBSERVABLES FROM THE PHOTOPRODUCTION OF ω MESONS USING LINEARLY POLARIZED PHOTONS

NSTAR-2013
Peñiscola, Spain
29 May 2013

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Supported in part by the U.S. National Science Foundation under grant NSF-PHY-1206082

- N*s are broadly overlapping
- Hard to disentangle without polarization observables

“Missing” Resonances?

Problem: symmetric CQM predicts many more states than observed (in πN scattering)

Possible solutions:

1. diquark model

- fewer degrees-of-freedom
- open question: mechanism for q^2 formation?

2. not all states have been found

- possible reason: decouple from πN -channel
- model calculations: missing states couple to $\pi\pi N$ ($\pi\Delta$, ρN), ωN , KY

γ coupling not suppressed $\longrightarrow$ electromagnetic excitation is ideal

s-channel resonances

t-channel exchanges

Processes contributing
to the reaction
 $\gamma p \rightarrow \omega p$

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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 in the central t regime.

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

Coherent Bremsstrahlung Facility and The CEBAF* Large Acceptance Spectrometer (CLAS)

*CEBAF: Continuous Electron Beam Accelerator Facility

CLAS and JLab

Jefferson Lab
CLAS Detector

CEBAF Large Acceptance Spectrometer

Torus magnet

6 superconducting coils

Liquid D_2 (H_2) target +
 γ start counter; e minitorus

Drift chambers

argon/ CO_2 gas, 35,000 cells

Large angle calorimeters

Lead/scintillator, 512 PMTs

Gas Cherenkov counters

e/π separation, 216 PMTs

Electromagnetic calorimeters

Lead/scintillator, 1296 PMTs

Time-of-flight counters

plastic scintillators, 684 PMTs

G8b RUN

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Target type: Liquid H₂

Electron end-point energy: 4.544 GeV

E_γ at the coherent peak (GeV)	Events (billion)
1.3	1.5
1.5	1.5
1.7	1.5
1.9	1.0
2.1	1.0
Amorphous data	1.8

SELECTION PROCESS

We start by requiring three particles in the final state: proton, π^+ , and π^- .

The PID process encompasses cuts on the values for mass, beta, time, momentum, and TOF time to best identify good events.

A track in the drift chambers and a coincidence in the TOF detector are required to accept a candidate event.

SELECTION PROCESS

The mass distribution. Peaks correspond to pion, kaon and proton mass.

A comparison between π^+ and π^- cut is seen.

Zooming on proton mass cut.

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x1000

EXAMPLE

Cuts to the photon energy range are established for each data set.

The initial cuts for the data sets are:

1.3 GeV → 1.1 to 1.32 GeV

1.7 GeV → 1.3 to 1.52 GeV

1.7 GeV → 1.5 to 1.72 GeV

1.9 GeV → 1.7 to 1.92 GeV

2.1 GeV → 1.8 to 2.12 GeV

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π^0 RECONSTRUCTION

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A Gaussian fit to the π^0 mass peak (PDG value: 134.9 MeV), found by using missing mass technique, from which the 3 to 5 sigma cut is made.

ω RECONSTRUCTION

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The mass of the ω meson is obtained by using the 4-momentum of the detected π^+ and π^- , and also from the reconstructed π^0 .

ω RECONSTRUCTION

Fitting function:

- Voigtian function for the ω signal.
- 4th degree polynomial for the background.
- No constraints to the parameters.

BEAM ASYMMETRY EXTRACTION

The Beam Asymmetry is determined by fitting the ratio PERP-PARA/PERP+PARA for each $\text{Cos } \Theta_{cm}$ and E_y bin, to a cosine 2ϕ like function.

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

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

The ranges for the beam asymmetry
 $\cos \theta$ bins are

1. -0.9 to -0.6
2. -0.6 to -0.4
3. -0.4 to -0.2
4. -0.2 to 0.0
5. 0.0 to 0.2
6. 0.2 to 0.4
7. 0.4 to 0.6
8. 0.6 to 1.0

ω beam asymmetry ratio PERP-PARA/PERP+PARA, E. Set 1.3 GeV

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

ω beam asymmetry ratio PERP-PARA/PERP+PARA, E. Set 1.5 GeV

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

ω beam asymmetry ratio PERP-PARA/PERP+PARA, E. Set 1.7 GeV

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

The Decay Angular Distribution

The complete angular distribution $W(\cos\theta, \phi, \Phi)$ is given by,

$$W(\cos\theta, \phi, \Phi) = W^0(\cos\theta, \phi, \rho_{\alpha\beta}^0) - P_\gamma \cos 2\Phi W^1(\cos\theta, \phi, \rho_{\alpha\beta}^1) - P_\gamma \sin 2\Phi W^2(\cos\theta, \phi, \rho_{\alpha\beta}^2),$$

where

$$W^0(\cos\theta, \phi, \rho_{\alpha\beta}^0) = \frac{3}{4\pi} \left[\frac{1}{2} \sin^2 \theta + \frac{1}{2} (3 \cos^2 \theta - 1) \rho_{00}^0 - \sqrt{2} \operatorname{Re} \rho_{10}^0 \sin 2\theta \cos \phi - \rho_{1-1}^0 \sin^2 \theta \cos 2\phi \right]$$

$$W^1(\cos\theta, \phi, \rho_{\alpha\beta}^1) = \frac{3}{4\pi} \left[\rho_{11}^1 \sin^2 \theta + \rho_{00}^1 \cos^2 \theta - \sqrt{2} \operatorname{Re} \rho_{10}^1 \sin 2\theta \cos \phi + \rho_{1-1}^1 \sin^2 \theta \cos 2\phi \right]$$

$$W^2(\cos\theta, \phi, \rho_{\alpha\beta}^2) = \frac{3}{4\pi} \left[\sqrt{2} \operatorname{Im} \rho_{10}^2 \sin 2\theta \sin \phi + \operatorname{Im} \rho_{1-1}^2 \sin^2 \theta \sin 2\phi \right],$$

Linearly polarization gives access to six more density matrix elements

Those are calculated in ω -meson rest frame (e.g. Helicity Frame)

Density Matrix Elements

IF VDM:

All density matrix elements should be equal to **ZERO** except for two (ρ^1_{1-1} and $\text{Im}\{\rho^2_{1-1}\}$)

- $\rho^1_{1-1}, \text{Im}\{\rho^2_{1-1}\} = (1/2, -1/2 : \text{Pomeron})$
- $\rho^1_{1-1}, \text{Im}\{\rho^2_{1-1}\} = (-1/2, 1/2 : \text{Meson})$

If any of the other SDMEs are nonzero:

Interesting physics beyond VDM

Σ can be used as a constraint for several SDMEs, since:

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

If Helicity is conserved in the s-channel, then only two of the nine SDMEs are nonzero: $\rho_{1-1}^1 = 0.5$ and $Im\rho_{1-1}^2 = 0.5$, hence $\Sigma = 1$ when $P_{\gamma} = 1$ (with θ, ϕ determined in the helicity frame). Any deviation from this value is an indication that nondiffractive processes are present. If we assume natural parity as the production mechanism, then

$$\rho_{1-1}^1 = 0.5, \rho_{00}^1 = 0$$

If unnatural-parity exchange dominates, then

$$\rho_{1-1}^1 = -0.5, \rho_{00}^1 = 0$$

SDMEs parametrization

Acceptance

$$W(\cos\theta) = N[\frac{1}{2}(1 - \rho_{00}^0)\sin^2\theta + \rho_{00}^0\cos^2\theta] \quad \rho_{00}^0 = \rho^1$$

$$W(\phi) = N[1 - 2\rho_{1-1}^0\cos 2\phi] \quad \rho_{1-1}^0 = \rho^2$$

$$W(\phi - \Phi) = N[1 + 2P_\gamma(\rho_{1-1}^1 - \text{Im}\rho_{1-1}^2)\cos 2(\phi - \Phi)] \quad \frac{1}{2}(\rho_{1-1}^1 - \text{Im}\rho_{1-1}^2) = \rho^3$$

$$W(\phi + \Phi) = N[1 + 2P_\gamma(\rho_{1-1}^1 + \text{Im}\rho_{1-1}^2)\cos 2(\phi + \Phi)] \quad \frac{1}{2}(\rho_{1-1}^1 + \text{Im}\rho_{1-1}^2) = \rho^4$$

$$W(\Phi) = N[1 - P_\gamma(2\rho_{1-1}^0 + \rho_{00}^1)\cos 2\Phi] \quad 2\rho_{1-1}^1 + \rho_{00}^1 = \rho^5$$

Acceptance effects cancels out

$$P_\gamma \rho^5 \cos 2\Phi = \frac{W_{\text{PARA}} - W_{\text{PERP}}}{W_{\text{PARA}} + W_{\text{PERP}}}$$

From the Angular Distributions in the rest frame of the phi-meson we can extract:

SPIN DENSITY MATRIX ELEMENTS

$$\rho^1 = \rho_{00}^0$$

$$\rho^2 = \rho_{1-1}^0$$

$$\rho^3 = \frac{1}{2}(\rho_{1-1}^1 - \text{Im}\rho_{1-1}^2)$$

$$\rho^4 = \frac{1}{2}(\rho_{1-1}^1 + \text{Im}\rho_{1-1}^2)$$

$$\rho_{1-1}^1 = \rho^3 + \rho^4$$

$$\text{Im}\rho_{1-1}^2 = \rho^3 - \rho^4.$$

Those are calculated in ω -meson rest frame (e.g. Helicity Frame)

SPIN DENSITY MATRIX ELEMENTS EXTRACTION

We define the binning for the data:

- 5 bins in $(t - t_{\min})$
- 36 bins in ϕ_{hel} are used.
- 50 MeV wide E_{γ} bins.

The ranges for the SDME binning in $t-t_{\min}$:

1. -1.2 to -0.6
2. -0.6 to -0.45
3. -0.45 to -0.3
4. -0.3 to -0.2
5. -0.2 to 0.0

AZIMUTHAL DISTRIBUTIONS HELICITY FRAME

1.3 GeV, PARA

$$W(\phi) = N[1 - \rho^2 \cos 2\phi]$$

AZIMUTHAL DISTRIBUTIONS HELICITY FRAME

1.5 GeV, PARA

$$W(\phi) = N[1 - \rho^2 \cos 2\phi]$$

AZIMUTHAL DISTRIBUTIONS HELICITY FRAME 1.7 GeV, PARA

$$W(\phi) = N[1 - \rho^2 \cos 2\phi]$$

$(\phi - \Phi)$ DISTRIBUTIONS 1.3 GeV, PARA

$$W(\phi - \Phi) = N[1 + 2P_\gamma \rho^3 \cos 2(\phi - \Phi)]$$

$(\phi - \Phi)$ DISTRIBUTIONS 1.5 GeV, PARA

$$W(\phi - \Phi) = N[1 + 2P_\gamma \rho^3 \cos 2(\phi - \Phi)]$$

$(\phi - \Phi)$ DISTRIBUTIONS 1.7 GeV, PARA

$$W(\phi - \Phi) = N[1 + 2P_\gamma \rho^3 \cos 2(\phi - \Phi)]$$

$(\phi + \Phi)$ DISTRIBUTIONS 1.3 GeV, PARA

$$W(\phi + \Phi) = N[1 + 2P_\gamma \rho^4 \cos 2(\phi + \Phi)]$$

$(\phi + \Phi)$ DISTRIBUTIONS 1.5 GeV, PARA

$$W(\phi + \Phi) = N[1 + 2P_\gamma \rho^4 \cos 2(\phi + \Phi)]$$

($\phi + \Phi$) DISTRIBUTIONS 1.7 GeV, PARA

$$W(\phi + \Phi) = N[1 + 2P_\gamma \rho^4 \cos 2(\phi + \Phi)]$$

PATH FORWARD

- Extraction of beam asymmetry Σ . (*ϕ binning method*).
 - *acceptance independent*
 - *compare to the ASU/CUA Fourier Moment Method.*
 - *cross correlate with overlapping coherent peak regions, which are essentially different experiments having different polarizations.*
- Extraction of the spin density matrix elements SDMEs.
 - *as functions of the Mandelstam variables s and t*
 - *in the Helicity and Gottfried-Jackson frames*
- Constrain SDMEs via Σ and other “Schilling-Seybold-Wolf” identities.
- Compare azimuthal SDMEs with CMU PWA ones*
- Perform acceptance studies.
- “Pair-Spectrometer” clean-up of events.

- ASU: Arizona State University
- CUA: Catholic University of American
- CMU: Carnegie Mellon University *See B. Vernarsky (B1)

Gràies !!

The RF bucket timing structure.

Δt vs momentum

A loose cut between -1.5 and 1.5 ns is performed. The plot shows Δt vs momentum.

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$\Delta\beta$ vs momentum

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db_vs_mom_1

A cut for $\Delta\beta$ (as given by EVNT bank - calculated β) is performed between -0.05 and 0.05.

$$\beta = v/c$$

INITIAL CUTS/CORRECTIONS

- *Fiducial cuts (angular)*

*Energy loss corrections (by using **eloss** package written by Eugene Pasyuk)*

Momentum corrections are less than 1%, so for now they are neglected in the analysis.

The six sectors of CLAS are well distinguished and also are the coils (the spaces with no data).

EXTRA CUTS

- $\text{Cos } \Theta_{cm}$ cut for bad photons:

A cut of 0.01 for $\text{Cos } \Theta_{cm}$ distribution for π^0 is done to ensure non- π^0 misidentified events are ruled out of the analysis. Notice how at the most forward part there is an excess of events. These belong to the wrong photon assignment to a non- π^0 event.

- Vertex cuts

$\text{Cos } \Theta_{cm}$ distribution after a 3 sigma cut on the π^0 mass and the cut mentioned above.

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ω beam asymmetry ratio PERP-PARA/PERP+PARA, E. Set 1.3 GeV

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

ω beam asymmetry ratio PERP-PARA/PERP+PARA, E. Set 1.5 GeV

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

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