The high-energy photoproduction of light-quark pseudoscalar and scalar meson at GlueX

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OUTLINE

- Introduction
- 2 γ processes at GlueX
  - Photoproduction of pseudoscalar meson
- 4 γ processes at GlueX
  - Photoproduction of scalar meson
- Summary and outlook
Introduction

Meson photoproduction

- Almost 50 years at SLAC, DESY, and Cambridge
- Growing vigorously recently: JLab, ELSA, and MAMI
- In the low energy regime: provide constraints on “background” to baryon resonance extraction
- In high regime: provides insight into dominant production mechanism

The long-term aim at GlueX

- Understand quark-gluon interactions
- Search for exotic hybrid mesons

<table>
<thead>
<tr>
<th>Exchange particle</th>
<th>Final states</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho ) 0++</td>
<td>2^{+-}, 0^{+-} b^0, h, h'</td>
</tr>
<tr>
<td>( \pi^0 ) 0--</td>
<td>2^{+-} b_2^0, h_2, h'_2</td>
</tr>
<tr>
<td>( \pi^\pm ) 0--</td>
<td>1^{--} \pi_1^\pm</td>
</tr>
<tr>
<td>( \omega ) 1--</td>
<td>1^{--} \pi_1, \eta_1, \eta'_1</td>
</tr>
</tbody>
</table>

The high-energy photoproduction is a vital step to the final aim

Searching for Multiphoton final states is a component of a wide meson photoproduction project, among which we will focus on 2\( \gamma \) and 4\( \gamma \) photoproduction
Linearly polarised photon beam at GLUEX

Outline:

- Radiators of Interest
- X-ray Measurements at the Canadian Light Source
- Comparison of 50 micron vs. 20 micron diamond

Linearly polarized photons via coherent bremsstrahlung from diamond radiator off liquid hydrogen peaking at 9 GeV
2γ processes at GlueX
Pseudoscalar mesons π⁰/η Photoproduction

JPAC Regge Model

Mathieu et al. PRD 92, 074013 (2015)

Exchange J^{PC}
1^{--} : ω, ρ
1^{++} : b, h

\[ \frac{d\sigma}{dt} = \sigma_\perp + \sigma_\parallel = |\rho + \omega|^2 + |b + h|^2 \]

\[ \Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2} \]

There are no previous measurements of the Σ asymmetry for γp→ηp with E_γ > 3 GeV

SLAC: PRD 4, 1937 (1971)
**ω Backgrounds**

- **Continuum background** between $\pi^0$ and $\eta$ is negligible.
- **The largest background** is $\gamma p \rightarrow \omega p$, $\omega \rightarrow \pi^0 \gamma$ with a missing photon. To get the background shape, we simulated this reaction then normalized to the $\omega$ leakage peak.
- **Our exclusive measurements and cuts ensure very low backgrounds:** for the eta the dilution is only 0.38%, while for the $\pi^0$ it is negligible.
Final -t distributions

V. Mathieu (JPAC): PRD 92, 074013

SLAC Data
Beam Energies

Without acceptance correction
Beam Asymmetry: Method

\[
\frac{d\sigma}{d\phi_{\text{proton}}} \propto 1 - P\Sigma \cos 2(\phi_{\text{proton}} - \phi_\gamma)
\]

\[
Y_\perp \propto N_\perp (1 + P_\perp \Sigma \cos 2\phi_{\text{proton}}) \quad \phi_\gamma = 90^\circ
\]

\[
Y_\parallel \propto N_\parallel (1 - P_\parallel \Sigma \cos 2\phi_{\text{proton}}) \quad \phi_\gamma = 0^\circ
\]
Beam Asymmetry: Method

\[ Y_\perp \propto N_\perp (1 + P_\perp \sum \cos 2\phi_{\text{proton}}) \quad \phi_\gamma = 90^\circ \]
\[ Y_\parallel \propto N_\parallel (1 - P_\parallel \sum \cos 2\phi_{\text{proton}}) \quad \phi_\gamma = 0^\circ \]

\[ \frac{Y_\perp - F_R Y_\parallel}{Y_\perp + F_R Y_\parallel} = \frac{(P_\perp + P_\parallel) \sum \cos 2\phi_{\text{proton}}}{2 - (P_\perp - P_\parallel) \sum \cos 2\phi_{\text{proton}}} \]

Repeat in bins of -t for both π⁰ and η

\[ F_R = \frac{N_\perp}{N_\parallel} \]
Beam Asymmetry: Results

- Measured asymmetries consistent with previous SLAC data
- Our measured $\Sigma$ asymmetries are close to 1, with little evidence of $-t$ dependence
- Don’t observe prominent dip in beam asymmetry at $-t = 0.5$ (GeV/c)$^2$ as seen in the cross section
- Our data are consistent with the JPAC and Laget calculations

First Measurement

Greater Precision

PHYS REV C 95, 042201(R) (2017)
**4 γ processes at GlueX**

**Scalar mesons Photoproduction**

- The dominant channels:
  \[ \pi^0 \pi^0 \& \pi^0 \eta \]
- Light scalar mesons \( a_0(980) \) and \( f_0(980) \) photoproduction

Exploring the nature of Light scalar mesons \( a_0(980) \) and \( f_0(980) \) photoproduction

with \( \pi^0 \pi^0 / \pi^0 \eta \) as final states

can help to understand the chiral symmetry breaking mechanisms of QCD and the confinement of hadrons.
The status of the study of the scalar mesons Photoproduction

- Theoretical method: Regge-cut phenomenology, which is well understood in pion photoproduction.
  

- CB-ELSA and CLAS collaborations made some measurements for $a_0(980)$ and $f_0(980)$ photoproduction respectively at lower energies.

  Phys. Rev. Lett. 102, 102001 (2009)

- Published statistics for $a_0(980)$ and $f_0(980)$ photoproduction is low and in a limited energy range.
More challenge on the background study
The baryon backgrounds

1. Baryon Background cut is indicated by the black dashed line.

2. Reference: Jon Zarling, ππ Final States at GlueX

\[ \pi^0 \pi^0 \]

Counts / 10 MeV

\[ \Delta^+(1232) \]

\[ N(1520) \]

\[ \Delta^+(1700) ? \]

\[ M(\pi^0 \text{proton}) \ (\text{GeV}/c^2) \]
Moment analysis for di-pseudoscalar-meson photoproduction

The moments of the di-pion angular distribution defined as

\[ < Y_{LM} > (E_\gamma, t, M_{\pi\eta}) = \sqrt{4\pi} \int d\Omega_\pi \frac{d\sigma}{dtdM_{\pi\eta}d\Omega_\pi} Y_{LM}(\Omega_\pi) \]

\( \Omega_\pi \): the polar and azimuthal angles of the \( \pi^0 \) flight direction in the \( \pi^0\eta \) helicity rest frame

\( Y_{LM} \): is the spherical harmonic of degree \( L \) and order \( M \)

Measured angular distribution corrected by the detector acceptance

Extraction of the moments via likelihood fit of experimental data

Two approaches:
- parametrization with amplitudes/moments

Results can be used as the input of \( a_0(980) \) beam asymmetry analysis
Summary and Outlook

- A broad meson photoproduction project at GlueX is under way, including beam asymmetries, cross sections and spin density matrix elements analysis.

- The linearly polarized photon beam asymmetry $\Sigma$ for $\pi^0/\eta$ photoproduction have measured.

- A detailed survey of the multi-photon processes is performed deeply.

- The moment analysis for di-pseudoscalar-meson photoproduction and the beam asymmetry studies of scalar mesons are in progress.
Thanks!
Back up
Detector resolutions:

Photons: \( \sigma_E/E \sim 6\%/\sqrt{E} \pm 2\% \)

Tracks: \( \sigma_p/p \sim 1 - 3\% \)

Receptance: \( 1\degree - 120\degree \)
Search for exotic hybrids

Evidence exists for $J^{PC}=1^{-+}$ amplitudes, but interpretation clearly not conclusive

Search for a pattern of hybrid states in many final states

<table>
<thead>
<tr>
<th>Approximate Mass (MeV)</th>
<th>$J^{PC}$</th>
<th>Final States</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_1$ 1900</td>
<td>$1^{-+}$</td>
<td>$\omega \pi \pi^{\uparrow}$, $3 \pi^{\uparrow}$, $5 \pi$, $\eta 3 \pi^{\uparrow}$, $\eta' \pi^{\uparrow}$</td>
</tr>
<tr>
<td>$\eta_1$ 2100</td>
<td>$1^{-+}$</td>
<td>$4 \pi$, $\eta 4 \pi$, $\eta \eta \pi \pi^{\uparrow}$</td>
</tr>
<tr>
<td>$\eta_1'$ 2300</td>
<td>$1^{-+}$</td>
<td>$KK \pi \pi^{\uparrow}$, $KK \pi^{\uparrow}$, $KK \omega^{\uparrow}$</td>
</tr>
<tr>
<td>$b_0$ 2400</td>
<td>$0^{+-}$</td>
<td>$4 \pi$</td>
</tr>
<tr>
<td>$h_0$ 2400</td>
<td>$0^{+-}$</td>
<td>$\omega \pi \pi^{\uparrow}$, $3 \pi^{\uparrow}$, $KK \pi \pi$</td>
</tr>
<tr>
<td>$h_0'$ 2500</td>
<td>$0^{+-}$</td>
<td>$KK \pi \pi^{\uparrow}$, $\eta 3 \pi$</td>
</tr>
<tr>
<td>$b_2$ 2500</td>
<td>$2^{+-}$</td>
<td>$4 \pi$, $\eta \pi \pi^{\uparrow}$</td>
</tr>
<tr>
<td>$h_2$ 2500</td>
<td>$2^{+-}$</td>
<td>$\omega \pi \pi^{\uparrow}$, $3 \pi^{\uparrow}$</td>
</tr>
<tr>
<td>$h_2'$ 2600</td>
<td>$2^{+-}$</td>
<td>$KK \pi \pi^{\uparrow}$, $KK \pi^{\uparrow}$</td>
</tr>
</tbody>
</table>

Mass (MeV)

- $0^{+-}$
- $2^{+-}$
- $1^{-+}$
Spring 2016: Detector commissioning and engineering runs

Spring 2017: The first physics runs

GlueX-I [low-intensity]: 2017-18
Event Selection

- Loose timing cuts
- Proton requirements:
  - $p_{\text{proton}} > 250$ MeV
- Originates from target region
- CDC dE/dx contour
- $\gamma p \rightarrow p\gamma\gamma$ cuts
  - $\Delta\phi$, Missing Mass squared, Missing energy, beam energy ($E_\gamma > 4.0$ GeV), only two photons reconstructed, Missing mass off proton, coherent beam energy ($8.4 < E_\gamma < 9.0$ GeV)