Photoproduction of Excited $\eta$ Resonances

$\gamma p \rightarrow p\pi^+\pi^-\eta$ at CLAS

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Motivation

- Supernumerous resonance with $J^{PC} = 0^{-+}$
- $\eta(1295)$
  - Seen in $\pi^- p$ scattering experiments
  - Seen by DM2 in $J/\psi \rightarrow \gamma \pi^- \pi^+ \eta$
  - No further observation
  - Interference with $f_1(1285)$
  - Artifact of $f_1$?
- $\eta(1405)$
  - Only seen in gluon rich processes like $\bar{p}p$ annihilations and radiative $J/\psi$ decays
  - Not seen in photoproduction or $\gamma\gamma$ fusion
  - Decays to $K\overline{K}\pi$ and $\pi\pi\eta$
  - Glueball candidate
- $\eta(1475)$
  - Strong coupling to $K\overline{K}\pi$
  - Not yet seen in $\pi\pi\eta \rightarrow$ weak coupling
Event Selection

\[ \gamma p \rightarrow p\pi^+\pi^- (\eta) \]

- \( g_{12} : \approx 60\% \)
- Photon energy 1.5 to 5.5 GeV
- Trigger Conditions: 3 charged tracks in 3 different sectors
  or 2 charged tracks in 2 different sectors
  and photon energy > 3.2 GeV
- Require:
  - 3 charged particles
    (2 positive, 1 negative)
  - PID: \( p, \pi^+, \pi^- \)
  - \( \eta \) reconstruction via missing mass method
- Origin in target: \( r < 2 \text{ cm}, \)
  \(-110 < z < -70 \text{ cm}\)
- Timing: \( \Delta t = t_{\text{Tagger}} - t_{\text{StartCounter}}, \)
  \(|\Delta t| < 0.5 \text{ ns}\)
- Minimal momentum: \( p_p > 0.3 \text{ GeV/c}, \)
  \( p_{\pi^+, \pi^-} > 0.1 \text{ GeV/c}\)
- Fiducial volume cut
- PID: \( \beta_{\text{calc}} = \frac{p}{\sqrt{m_{\text{PDG}}^2 + p^2}} \)
  \( \Rightarrow d = \beta_{\text{calc}} - \beta_{\text{meas}} \Rightarrow |d| < 0.04 \)
- Cut on missing mass:
  \( 480 \text{ MeV/c}^2 < m_{\text{miss}} < 620 \text{ MeV/c}^2 \)
- Track Efficiency
  \( \Rightarrow \approx 18.6 \cdot 10^6 \text{ events} \)
Event-based Background Suppression

**Assumption:** Distribution of background events in a small cell of the phasespace is different compared to signal events.

→ **Event-by-event procedure:**

- **First step:** find $N$ nearest neighbours $B$ of seed event $A$ in phasespace
  - Define metric to calculate distances in phasespace
  - Choose $N$ events with smallest distance to seed event

- **Second step:** fit invariant mass spectrum $m(\eta)$ of nearest neighbours with appropriate functions for signal and background

**Metric contains:**
- Production angle $\eta'$
- $E_\gamma$
Event-based Background Suppression

- Third step: calculate signal to background ratio

\[ Q = \frac{f_s s}{f_s s + (1-f_s) b} \]
\[ s = S(m_{seed}) \]
\[ b = B(m_{seed}) \]

- Fourth step: normalize S/B and assign it as probabilistic weight for each event

- **Benefit:** No knowledge on the origin of background is needed!
Differential Cross Section of $\gamma p \rightarrow p \eta'$

Differential cross section of $\gamma p \rightarrow p \eta'$:

CLAS g11 run

This work (g12 run)
Excited $\eta$ states in $\gamma p \rightarrow p\pi^+\pi^- (\eta)$

- Broad $\eta$ peak
- Neutral kaon contribution
- Kinematic fit takes background events in as well as “real” $\eta$ events
  $\rightarrow$ Q-factor method on missing mass in $\eta$ region

Huge background contribution.
Weighted Missing $\eta$ Mass Spectrum

Metric:

- Angular Distributions
- $E_\gamma$
- $m^2(\pi^+\pi^-\eta)$

- Unweighted
- Q weighted
- 1-Q weighted
Weighted $\pi^+\pi^-\eta$ Invariant Mass Spectrum

Peaking background, e.g. $\eta' \rightarrow \pi^0\pi^0\eta(\pi^+\pi^-\pi^0)$
Weighted $\pi\pi\eta$ Invariant Mass Spectrum

Contribution of $\gamma p \rightarrow p\Phi \rightarrow pK_sK_L \rightarrow p\pi^+\pi^- m_{miss}$
Motivation

Data Reconstruction and Analysis

Summary

\[ M_x(p) \text{ Vs. } M_X(p\pi^+\pi^-) \]

Horizontal Band crossing under \( \eta' \) and \( \eta(1295)/f_1(1285) \)

Possible background channels:

- \( \Phi \rightarrow K_s(\pi^+\pi^-)K_L(m_{miss}) \)
- \( \eta' \rightarrow \pi^0\pi^0\eta(\pi^+\pi^-\pi^0) \)
- \( f_1(1285) \rightarrow 4\pi \)
- \( \eta(1295) \rightarrow \pi^0\pi^0\eta(\pi^+\pi^-\pi^0) \)
- ...
Motivation

Data Reconstruction and Analysis

Summary

$M_X(p) \text{ Vs. } M_X(p\pi^+\pi^-)$

Selecting a band with signal events and two bands for sideband each half the width of the signalband
$M_X(p)$ for Signalband and Sidebands in bins of $E_\gamma$
Weighted $\pi\pi\eta$ Invariant Mass Spectrum

1-C kinematic fit with $\eta$ mass constraint

$prob > 0.01$
Summary

- Study of excited $\eta$ mesons in $\gamma p \rightarrow p\pi^+\pi^-\eta$
  - Sample of $18.6 \cdot 10^6$ reconstructed events
  - Successfully applied event-based background suppression to $\eta'$ and missing $\eta$
  - Observed an enhancement at $\approx 1295$ MeV/c$^2$ and at $\approx 1417$ MeV/c$^2$
- Extracted $\gamma p \rightarrow p\eta'$ differential cross section from g12 data
  - Good agreement with previous study, for Q-factor method on $\eta'$
  - Small discrepancies for Q-factor method on $M_x(p\pi^+\pi^-)$ (under investigation)
- Next steps:
  - Further investigation of the nature of the enhancement at 1290 MeV/c$^2$
  - Extract (upper limit) of $\eta(1405)$ production cross section
Differential Cross Section of $\gamma p \rightarrow p\eta'$

**CLAS g11 run**

This work (g12 run)

Q-factor method for $\eta$