Analysis of the $\eta(548) \rightarrow \pi^+ \pi^- \pi^0$ and $\eta'(958) \rightarrow \pi^+ \pi^- \eta$ channels for the GlueX Experiment


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The GlueX Experiment

➢ GlueX detector:
  ➢ Nearly 4π-hermetic
  ➢ Sensitive to neutral and charged particles

➢ 12 GeV electron beam
➢ Linearly polarized photon beam
➢ High luminosity
➢ 9 GeV coherent Bremsstrahlung peak

GlueX Physics

➢ Search for evidence of exotic $J^{PC}$ hybrids
➢ Map light meson spectrum
  ➢ Specifically, the lightest hybrid multiplet (predicted by LQCD calculations)

➢ Provide validation for QCD model with gluonic degrees of freedom

$q\bar{q}$ pair w/ contributions from an excited gluon

See CC.00001 (M. Shepherd)
Establish robust analyses of simplest light mesons using 'Spring 2016' data set

η and η' mesons abundantly available at GlueX
- World η/η' photoproduction data is sparse at high energies
- Σ beam asymmetries not yet measured at high energies
- Provide rich arrays of resonances for study
- Many other light mesons decay through π and η mesons
- πη and πη' resonances high on list of possibly-accessible exotics/hybrids

Reconstructing pure samples of these simple mesons is the first step

This talk: most recent results for reconstruction of η and η'
- Results include ~ 1/4 of the Spring 2016 data set

\[
\begin{align*}
\eta &\rightarrow \pi^+ \pi^- \pi^0 \quad (BR \sim 22.9\%) \\
\pi^0 &\rightarrow 2 \gamma \\
\eta' &\rightarrow \pi^+ \pi^- \eta \quad (BR \sim 42.9\%) \\
\eta &\rightarrow 2 \gamma
\end{align*}
\]
Event Selection Cuts

- Select combinations of particles which match our topology
  - 2 pos. tracks (p, π+), 1 neg. track (π−), 2 neutral showers (π0 or η → 2γ)
- Loose dE/dx cut for Proton/Pion separation
- Missing mass cut to select out exclusive η or η' production
  - Ensure invariant mass of beam + target ≈ invariant mass of candidate particle
- Kinematic fit constrains 2γ mass and tests for conservation of E and P
- Vertex cuts remove candidates with decay vertices outside target volume

Cuts shown in RED
Event Selection Cuts

- Photon reconstruction around the beam hole and BCAL-FCAL gap less reliable
- Cut combos with a neutral shower close to either region
- Cut on $2\gamma$ mass to reject less-likely combos which passed kinematic fit

For particle combos which passed all cuts:
- Invariant mass spectra
- Beam asymmetries

Clean Events
\( \eta \rightarrow \pi^+ \pi^- \pi^0 \) Mass Spectrum

\[ \pi^+ \pi^- \pi^0 \text{ Mass Post-Cut} \]

**All Beam Energies**

Mean = 549.5 ± 0.1 MeV  
Sigma = 5.7 ± 0.1 MeV  
# Eta ~ 15771

8.4 < \( E_\eta \) (GeV) < 9.0

**All Beam Energies**

Mean = 548.1 ± 0.1 MeV  
Sigma = 5.8 ± 0.1 MeV  
# Eta ~ 2151

\( \eta' \rightarrow \pi^+ \pi^- \eta \) Mass Spectrum

\[ \pi^+ \pi^- \eta \text{ Mass Post-Cut} \]

**All Beam Energies**

Mean = 959.5 ± 0.1 MeV  
Sigma = 6.7 ± 0.1 MeV  
# Eta' ~ 9519

8.4 < \( E_\eta \) (GeV) < 9.0

**All Beam Energies**

Mean = 958.8 ± 0.2 MeV  
Sigma = 7.2 ± 0.2 MeV  
# Eta' ~ 1395

See DC.00001 (S. Taylor)
Beam Asymmetry

- Σ beam asymmetry: polarization observable
- Provides insight into helicity amplitudes of the interaction
- Use coherent peak data (8.4 – 9.0 GeV)
- Polarized yield as a function of ϕ is proportional to PΣ
- 2 polarization configurations: PARA, PERP
- Fit to ASYM eliminates possible ϕ-dependent acceptance effects
- F_R = PERP/PARA yield normalization factor

See CC.00004 (Z. Zhang)

\[
\text{PERP yield } \sim (1 + P_\Sigma \cos(2\phi))
\]

\[
\text{PARA yield } \sim (1 - P_\Sigma \cos(2\phi))
\]

\[
\text{ASYM} = \frac{Y_\perp - F_R Y_{\parallel}}{Y_\perp + F_R Y_{\parallel}} = \frac{(P_\perp + P_\parallel)\Sigma \cos(2\phi)}{2 - (P_\perp - P_\parallel)\Sigma \cos(2\phi)}
\]

\[
P_\perp \approx P_\parallel \rightarrow \text{ASYM} \approx P\Sigma \cos(2\phi)
\]
\[ \eta \rightarrow \pi^+ \pi^- \pi^0 \] Beam Asymmetry

\[ f(\varphi) = P\Sigma \cos(2\varphi) \]

- Clear sinusoidal behaviour
- Sensitive to \( \Sigma \) asymmetry!
$$\eta' \rightarrow \pi^+ \pi^- \eta$$ Beam Asymmetry

- Clear sinusoidal behaviour
- Sensitive to $\Sigma$ asymmetry!

$$f(\varphi) = P\Sigma \cos(2\varphi)$$
Summary and Outlook

➢ Our detector/analysis gives clean signals for both η and η' decays

➢ Able to see PΣ asymmetry for η and η' (using ~ 1/4 of the Spring 2016 data set)
   ➢ Similar sensitivity to t-averaged PΣ asymmetry
   ➢ More robust analysis (P/P considerations, phase shift correction) to come

➢ Upcoming physics production running
   ➢ Expect ~ 10x more data than Spring 2016 data set over the first year
   ➢ Will significantly improve errors in fits arising from current lack of statistics

➢ η' Σ asymmetry never before measured at GlueX energies
   ➢ More statistics → first accurate measurement?

➢ Theory group (JPAC) predictions of Σ vs mom. transfer (-t)
   ➢ Currently, sparse data at high t
   ➢ More statistics → bin data in t
   ➢ Investigate yield and Σ asymmetry as functions of t

Questions?