

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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**NSERC
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The GlueX Experiment at Jefferson Lab

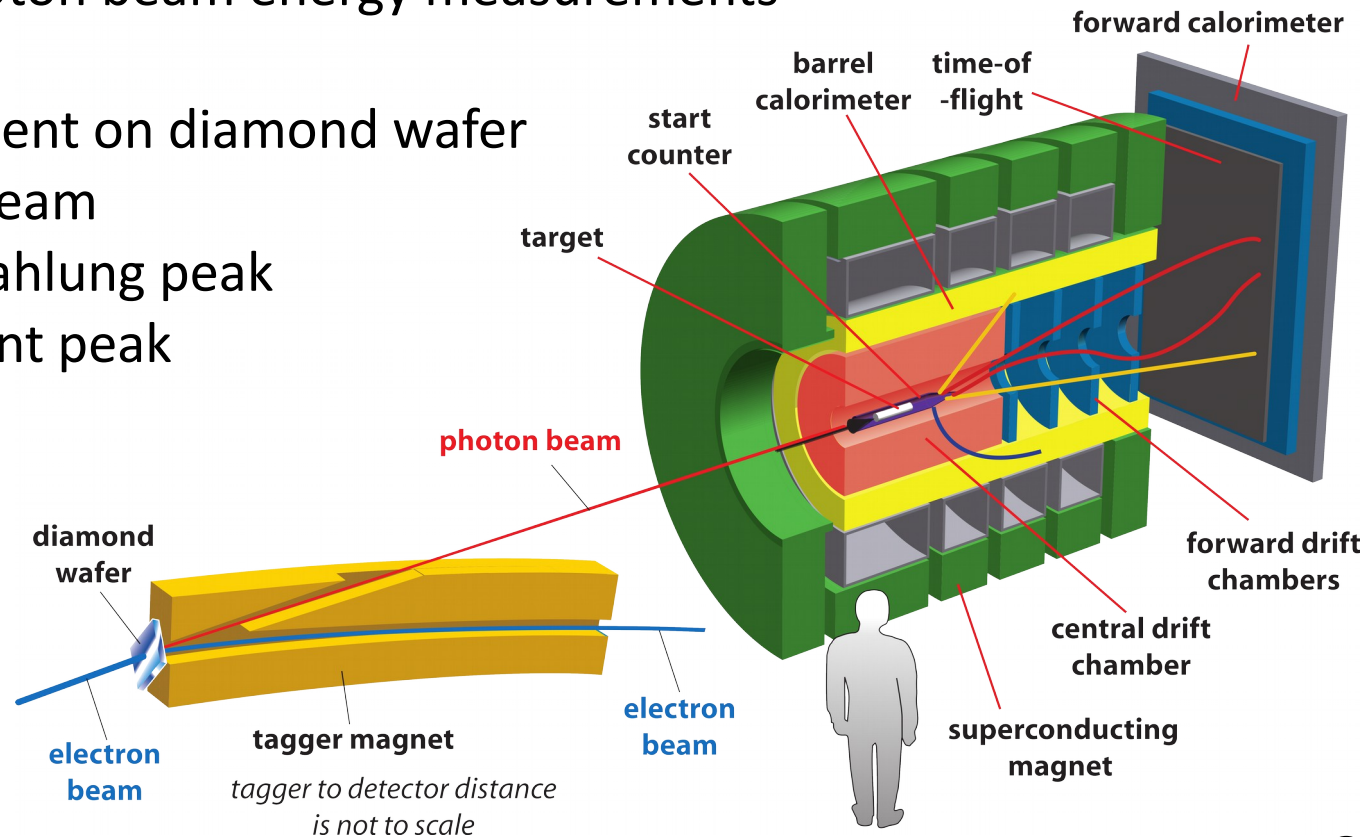
- GlueX detector:
 - Nearly 4π -hermetic
 - Liquid Hydrogen target
 - Two calorimeters for neutral energy deposition
 - Tracking chambers for charged particle tracking
 - Triplet Polarimeter for photon beam polarization measurements
 - Pair Spectrometer for photon beam energy measurements

- 12 GeV electron beam incident on diamond wafer
- Linearly polarized photon beam
 - 9 GeV coherent Bremsstrahlung peak
 - High luminosity in coherent peak
 - $10^7 \gamma/s$ on target

- Resolutions:

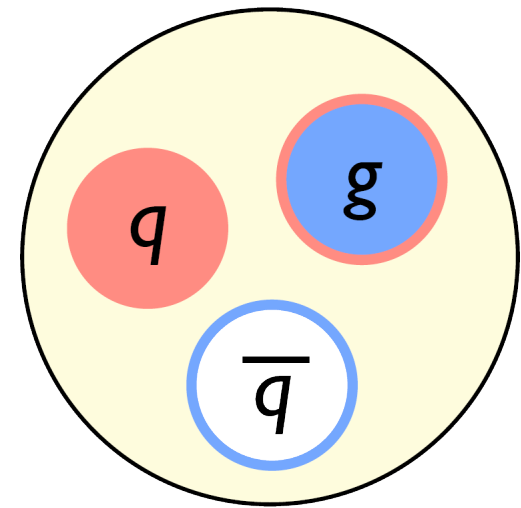
$$\gamma: \sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$$

$$q^\pm: \sigma_p/p \sim 2 - 5\%$$

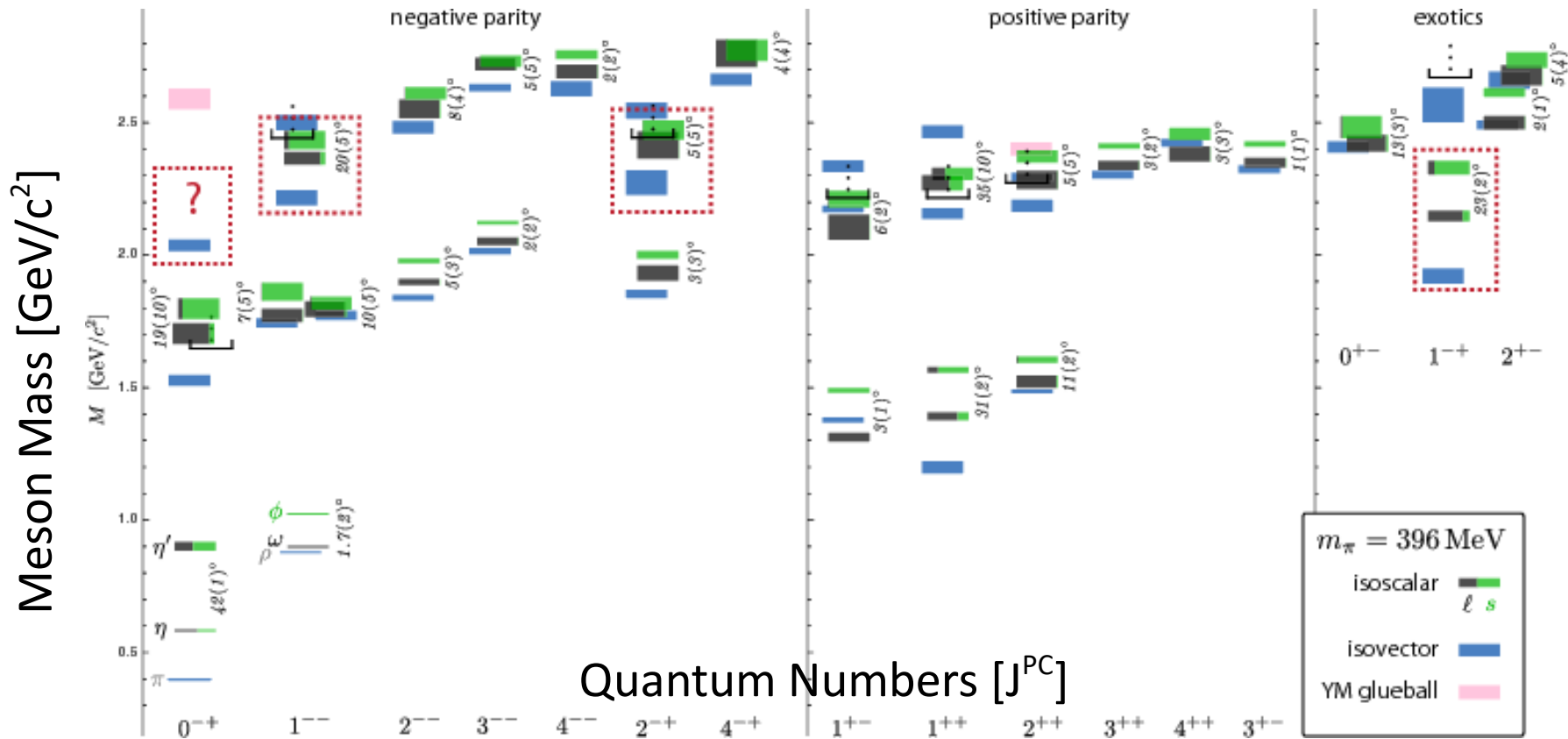


GlueX Physics

- 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

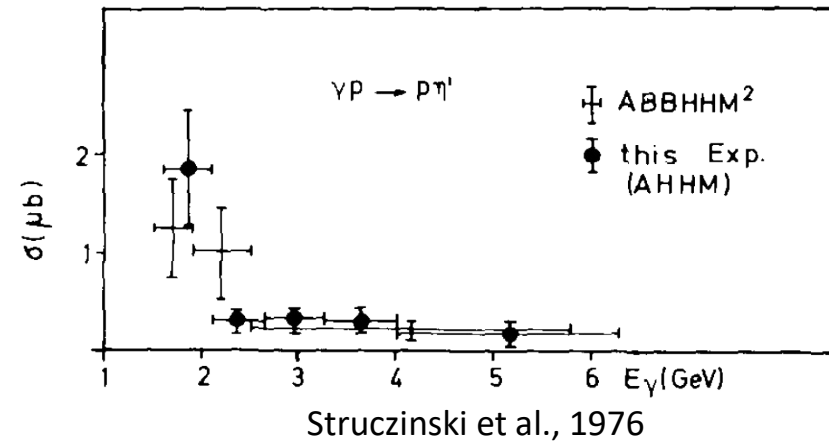
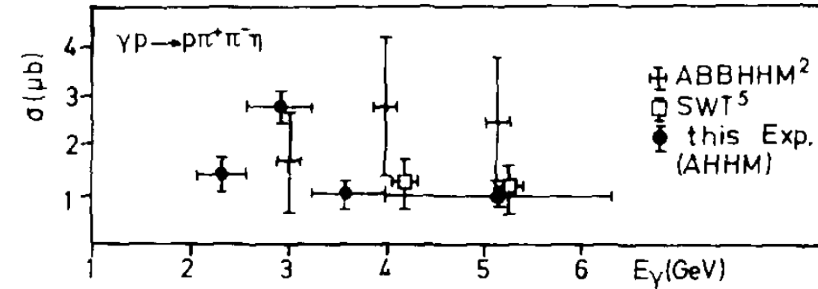


$q\bar{q}$ pair w/ contributions from an excited gluon

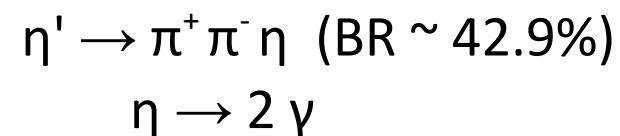
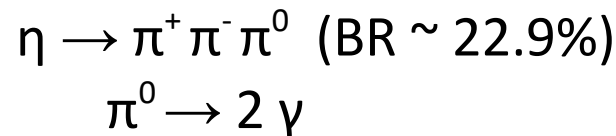


Purpose

- 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 GlueX energies (up to 12 GeV)
 - Σ beam asymmetries/cross sections not yet measured at GlueX energies
- Provide rich arrays of resonances for study
- Many other light mesons decay through π and η mesons
- $\pi\eta$ and $\pi\eta'$ resonances high on list of possibly-accessible exotics/hybrids
- Reconstructing pure samples of these simple mesons is the first step

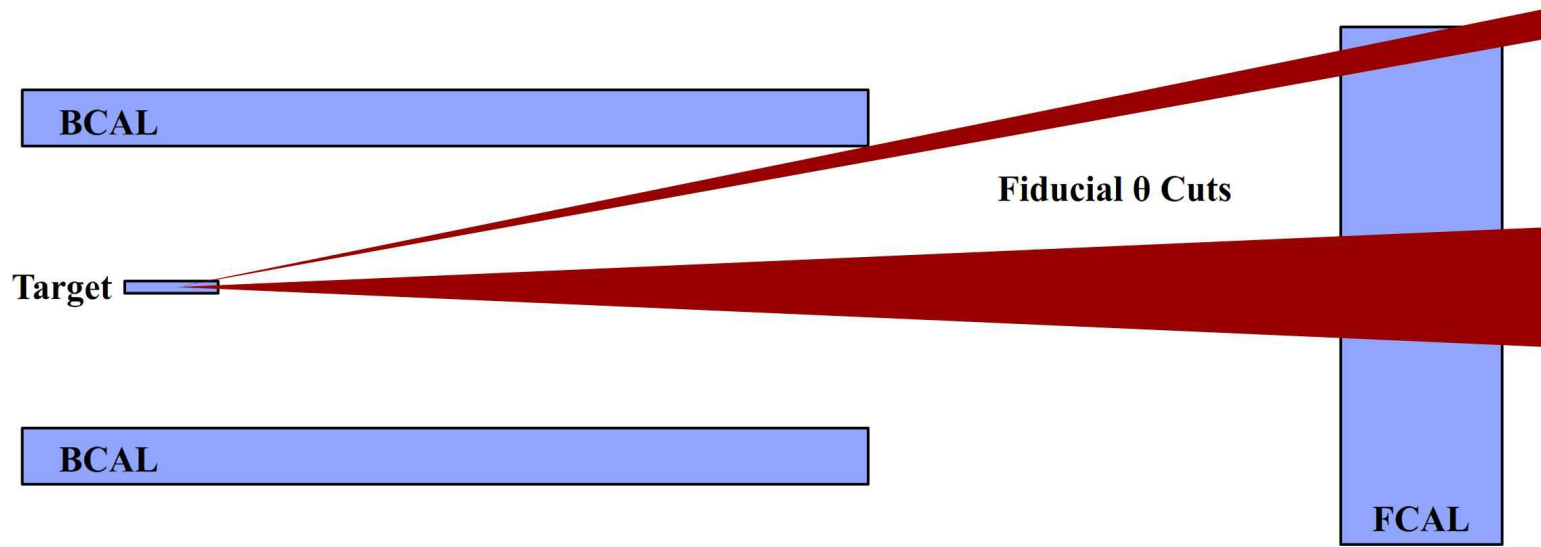


- This talk: most recent results for reconstruction of η and η'
 - Results include $\sim 1/4$ of the Spring 2016 data set



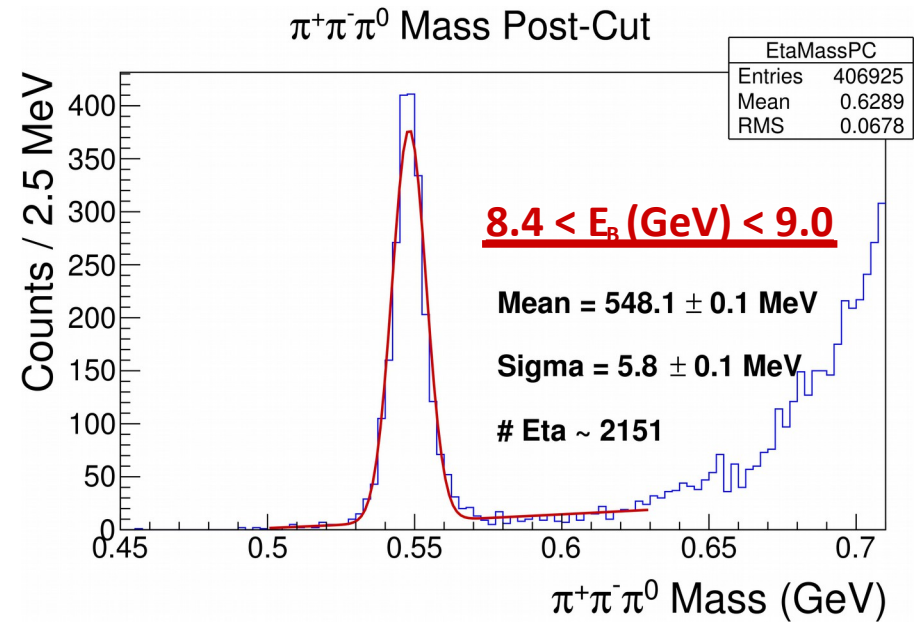
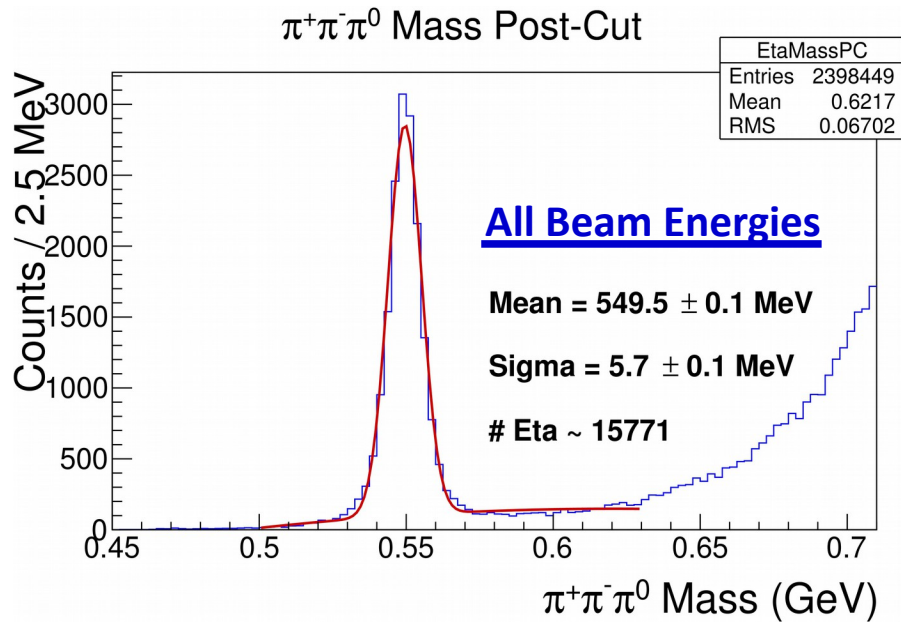
Event Selection Cuts

- Select combinations of particles which match our topology
 - 2 pos. tracks (p , π^+), 1 neg. track (π^-), 2 neutral showers (π^0 or $\eta \rightarrow 2\gamma$)
- Loose **dE/dx cut** for Proton/Pion separation (See next talk – A. Foda)
- **Missing mass cut** to select out exclusive η or η' production
 - Ensure invariant mass of beam + target \approx 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
- Photon reconstruction around the beam hole and BCAL-FCAL gap less reliable
 - **Fiducial cut** removes combos with neutral shower close to either region

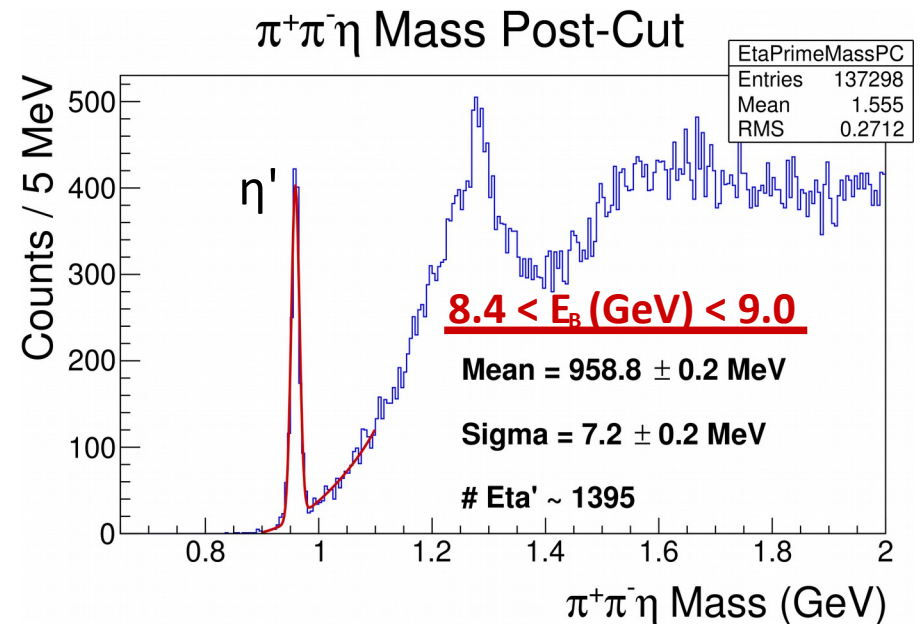
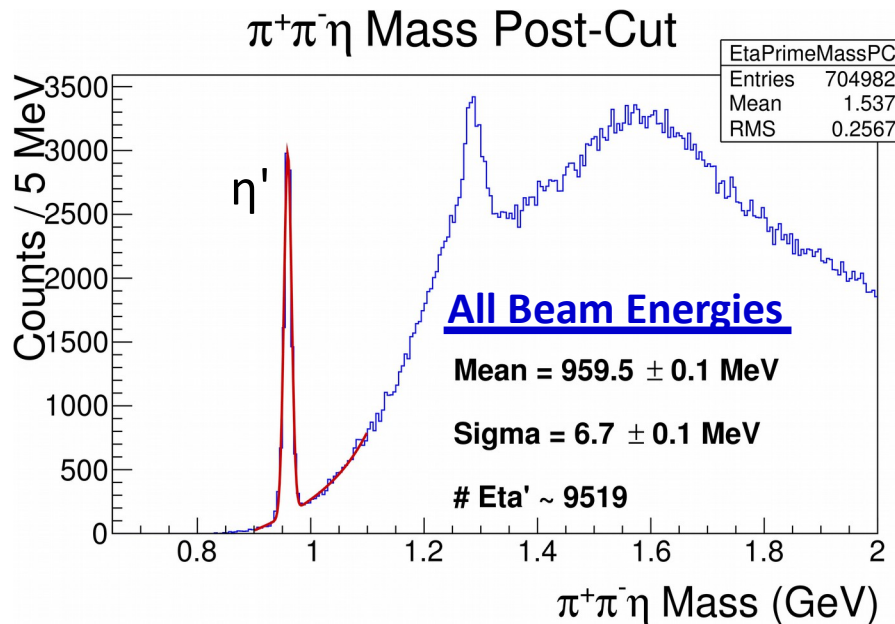


- **Clean events**: Mass spectra, beam asymmetries, acceptance studies

$\eta \rightarrow \pi^+ \pi^- \pi^0$ Mass Spectrum

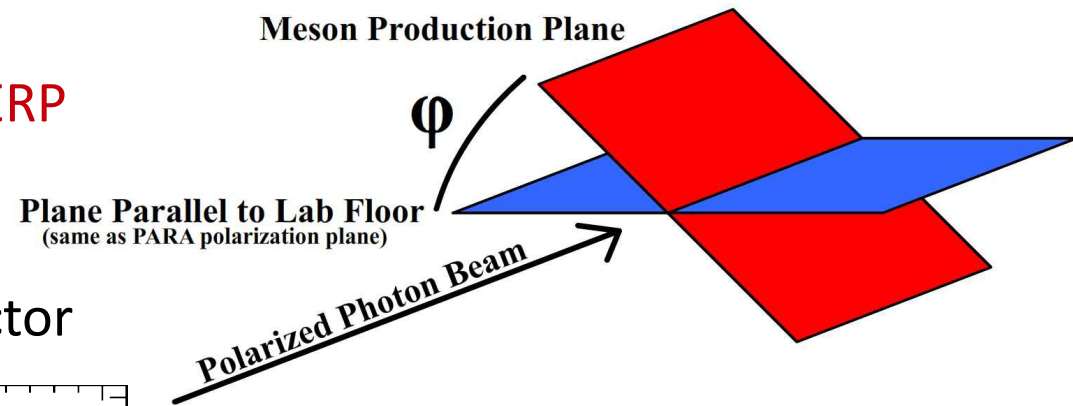
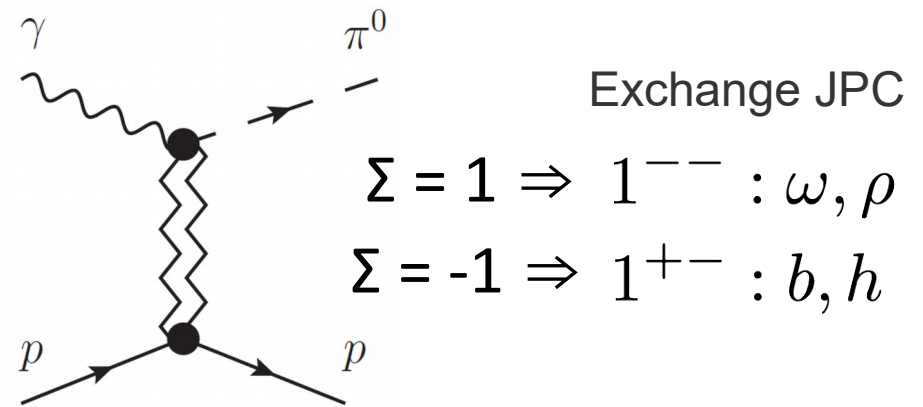
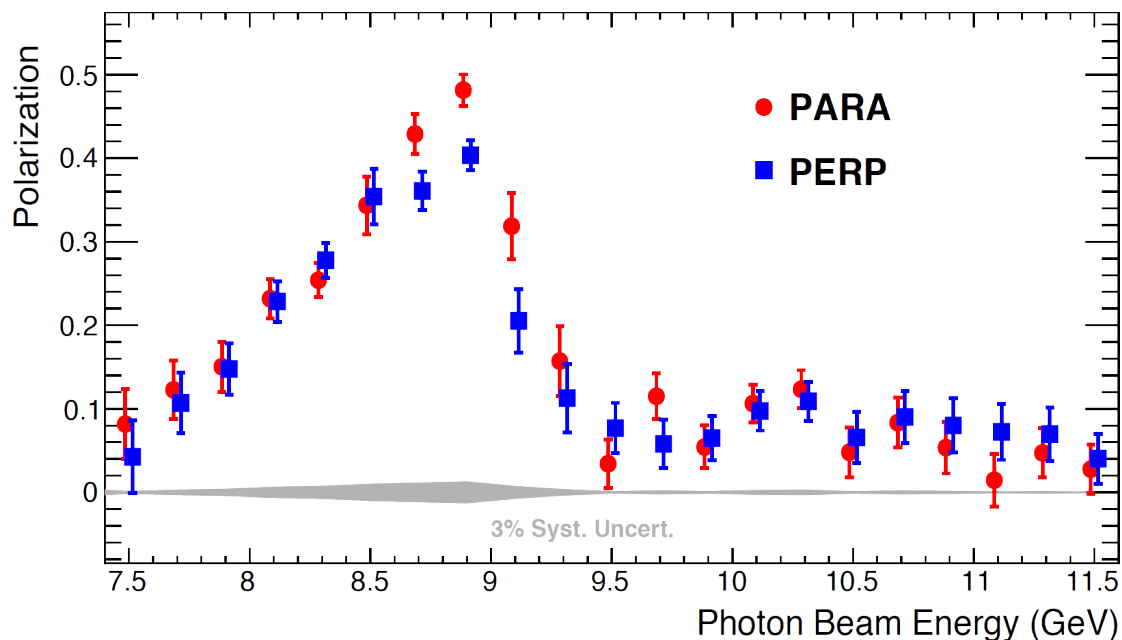


$\eta' \rightarrow \pi^+ \pi^- \eta$ Mass Spectrum



Beam Asymmetry

- Σ beam asymmetry: polarization observable
- Provides insight into **beam-target exchange**
 - $\Sigma = 1 \Rightarrow$ natural parity exchange (ω, ρ)
- Use coherent peak data (8.4 – 9.0 GeV)
- Polarized yield as a function of φ is proportional to $P\Sigma$
- 2 polarization configurations: **PARA, PERP**
- Fit to **ASYM** eliminates possible φ -dependent acceptance effects
- $F_R = \text{PERP/PARA yield normalization factor}$



PERP yield $\sim (1 + P_{\parallel} \Sigma \cos(2\varphi))$

PARA yield $\sim (1 - P_{\perp} \Sigma \cos(2\varphi))$

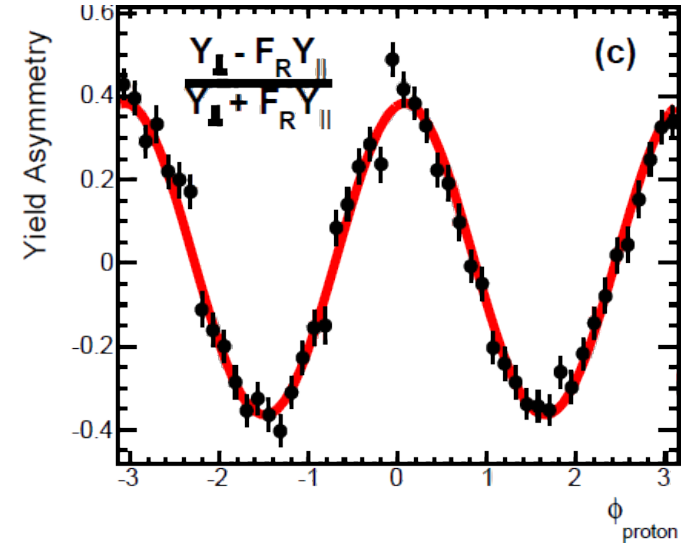
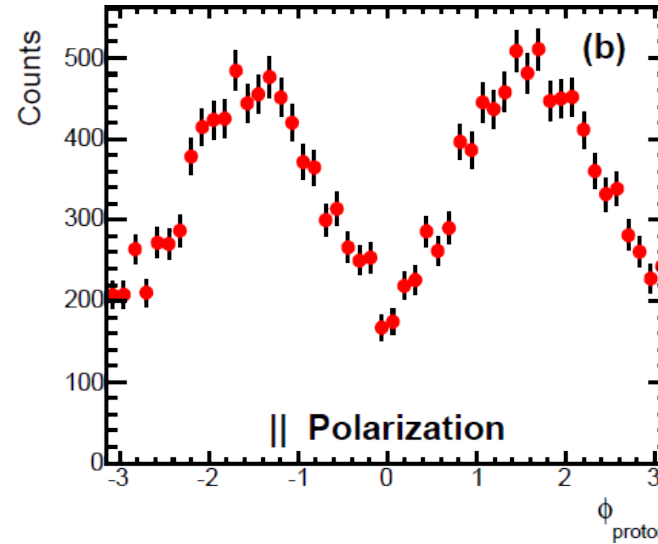
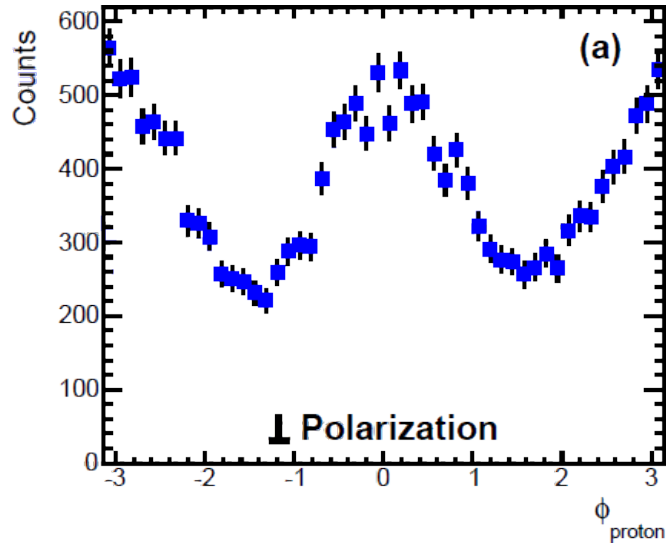
$$\text{ASYM} = \frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + F_R Y_{\parallel}} = \frac{(P_{\perp} + P_{\parallel}) \Sigma \cos(2\varphi)}{2 - (P_{\perp} - P_{\parallel}) \Sigma \cos(2\varphi)}$$

P_{\perp} and P_{\parallel} found from TPOL (left)

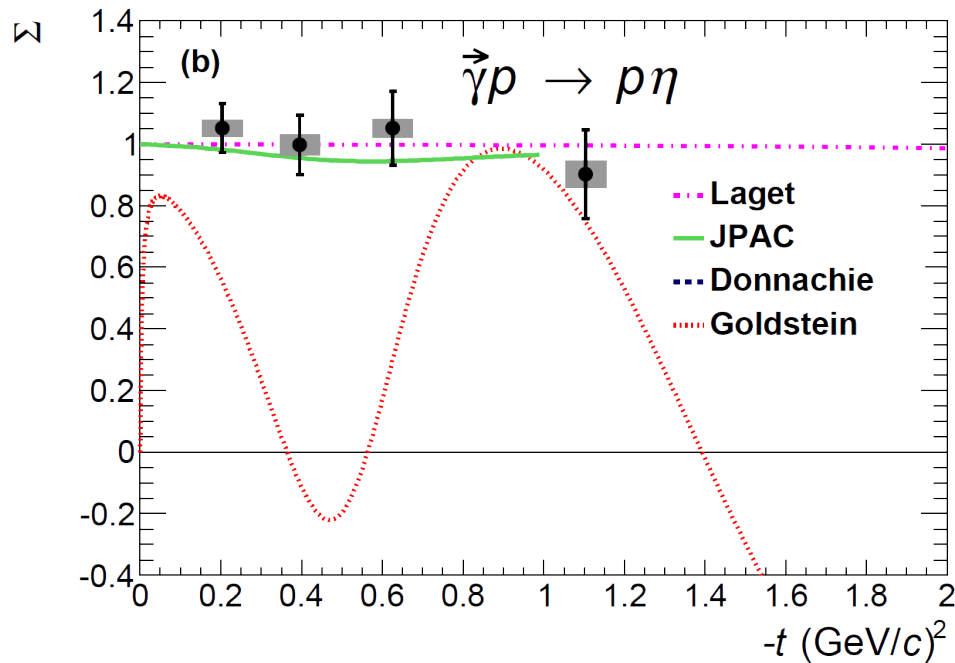
Fit data to this function to extract Σ

GlueX π^0/η Σ Asymmetry

PRL submission: arXiv:1701.08123 [nucl-ex]



$\pi^0 \rightarrow 2 \gamma$ Yield vs. ϕ (t-averaged)

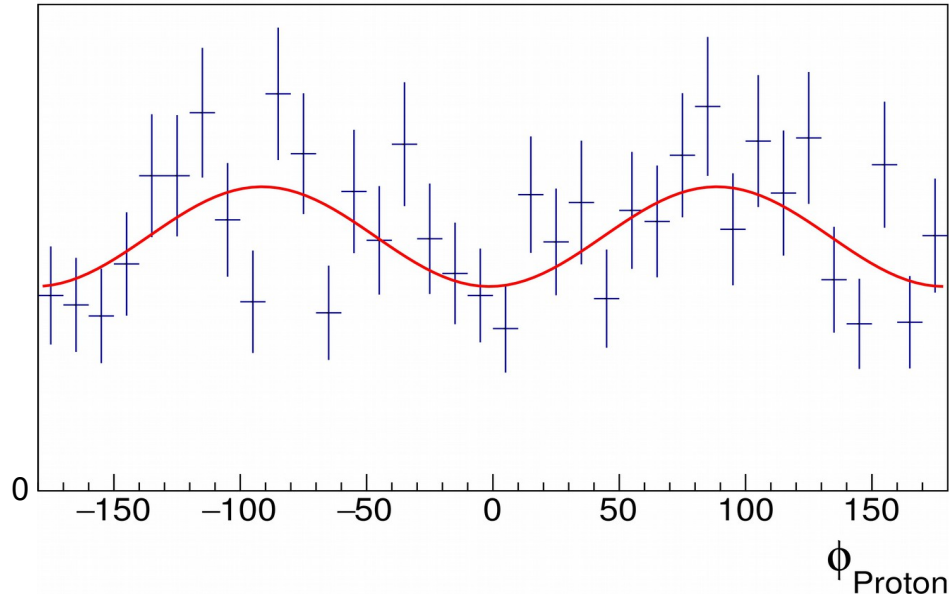


- Detailed analysis of π^0 and η asymmetry
- High statistics $\eta \rightarrow 2 \gamma$ channel
- Model predictions vs. momentum transfer
- Form yield asymmetry for ranges of $-t$
- Extract beam asymmetry for each range
- Compare to model predictions (left)

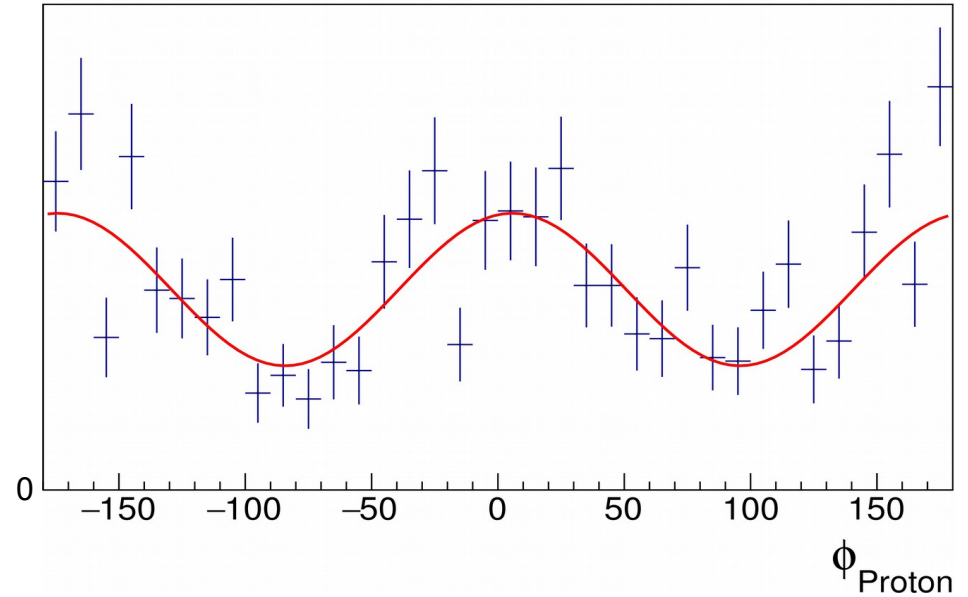
Goal: Confirm result with $\eta \rightarrow \pi^+ \pi^- \pi^0$
 Observe result with $\eta' \rightarrow \pi^+ \pi^- \eta$

$\eta \rightarrow \pi^+ \pi^- \pi^0$ Beam Asymmetry

PARA Proton ϕ

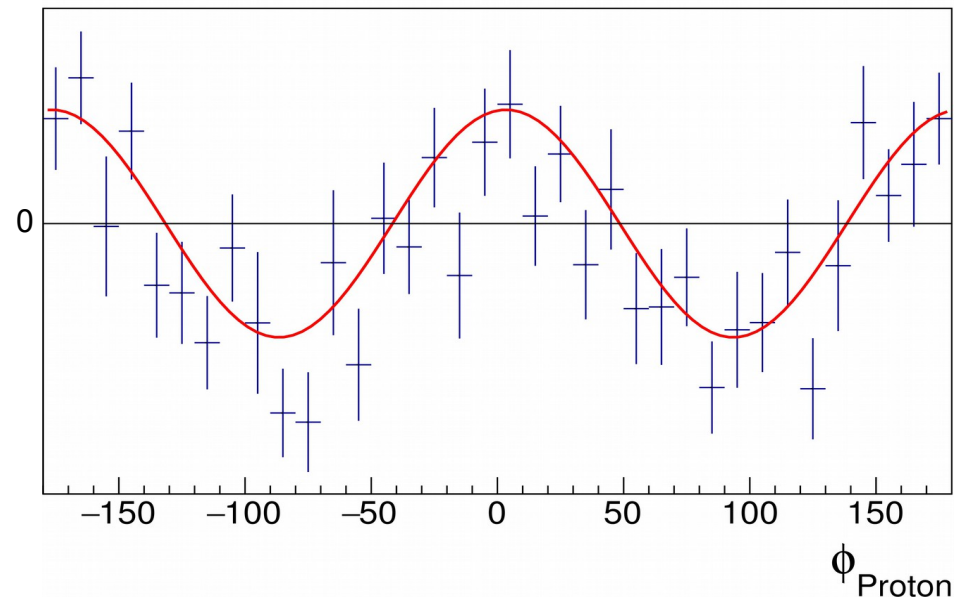


PERP Proton ϕ



$$f(\varphi) = \frac{(P_{\perp} + P_{\parallel})\Sigma \cos(2\varphi)}{2 - (P_{\perp} - P_{\parallel})\Sigma \cos(2\varphi)}$$

Asymmetry



- Low statistics: qualitative look
- Clear sinusoidal behaviour
- Sensitive to Σ asymmetry!
(t-averaged)

Quantitatively similar results for $\eta' \rightarrow \pi^+ \pi^- \eta$

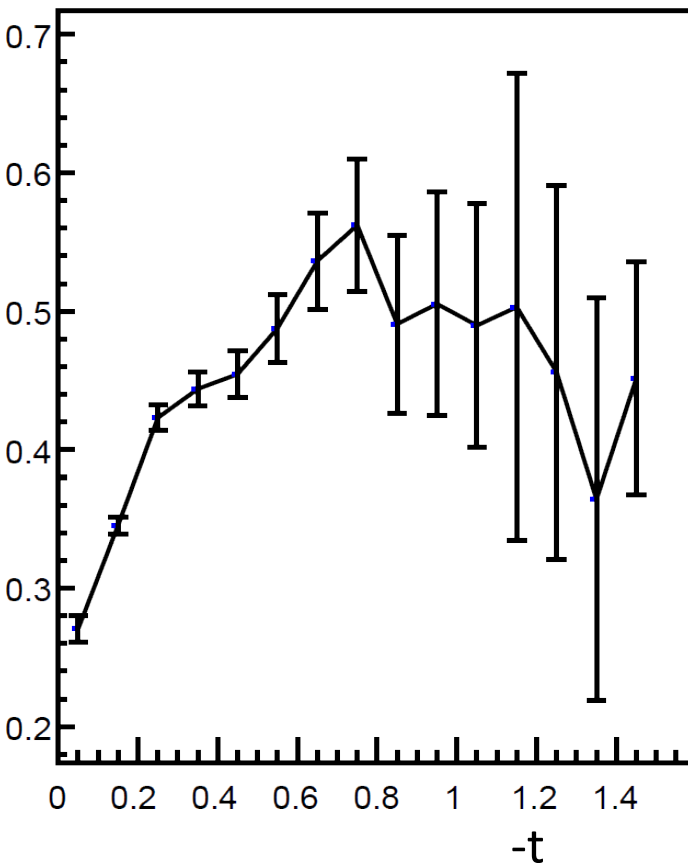
MC Acceptance Study: $\eta \rightarrow 2\gamma, 3\pi^0, \pi^+\pi^-\pi^0$

- Understand detector acceptance/efficiency for future cross-section extraction
- Simulate equal number of events for each decay channel in bins of beam E
- Pass events through detector simulation and reconstruction

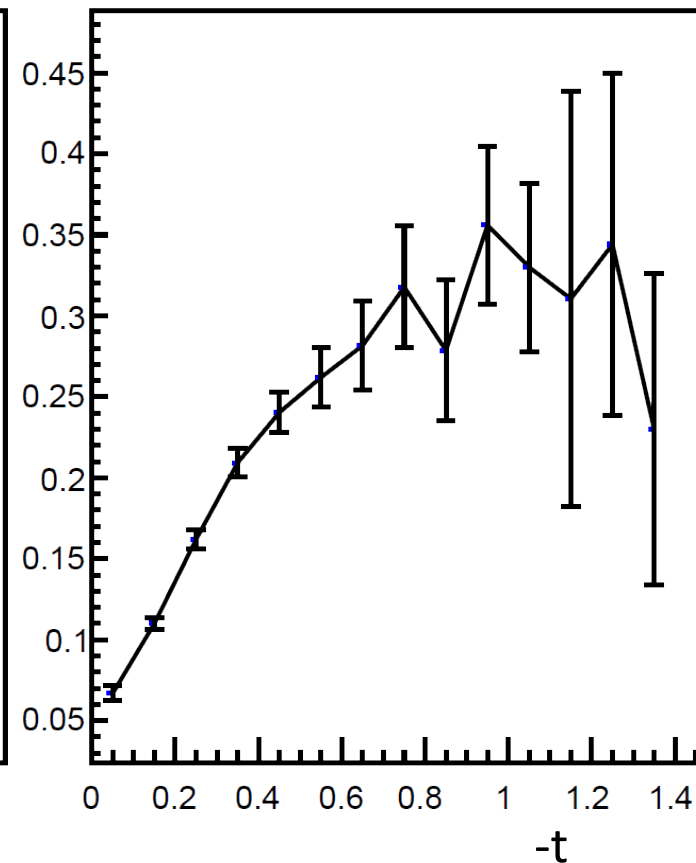
Ratios provide insight into detector acceptance/efficiency between topologies (ex: detecting charged vs. neutrals) vs. beam energy and $-t$

(Efficiency * Acceptance) Ratios for Beam Energy Between 8 and 10 GeV:

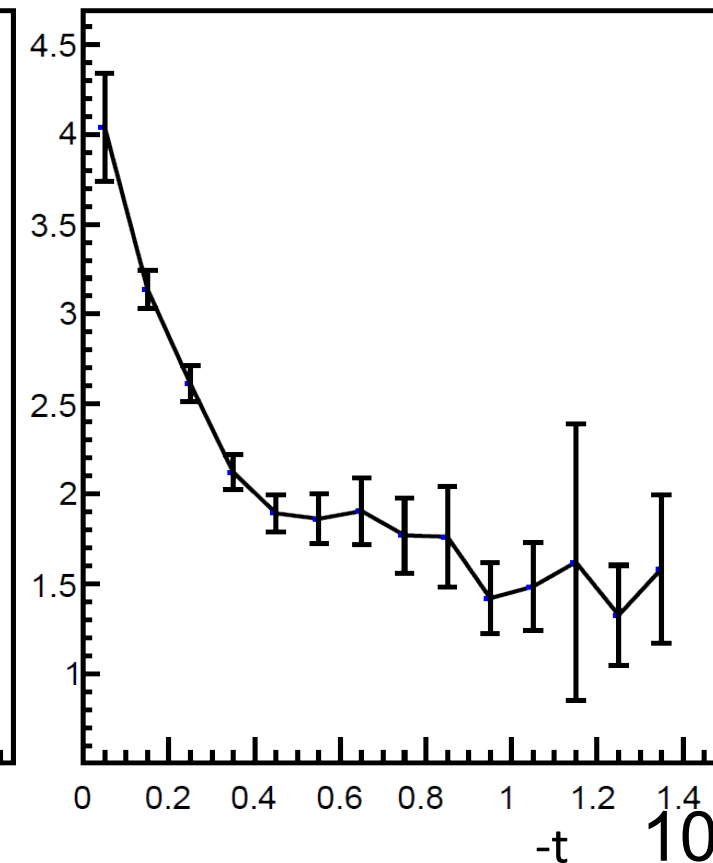
$\pi^+\pi^-\pi^0 / 2\gamma$ Ratio



$3\pi^0 / 2\gamma$ Ratio



$\pi^+\pi^-\pi^0 / 3\pi^0$ Ratio



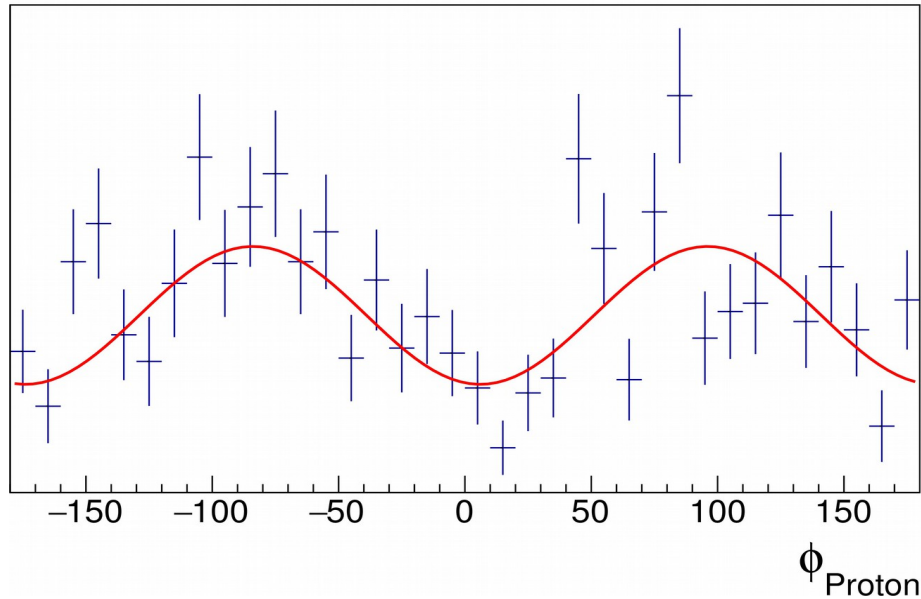
Summary and Outlook

- Our detector/analysis gives clean signals for both η and η' decays
- Able to see $P\Sigma$ asymmetry for η and η' (using $\sim 1/4$ of the Spring 2016 data set)
 - More robust analysis (with higher statistics) to come
- Physics production running has begun (Jan. 31, 2017)
 - Expect $\sim 10x$ more data than Spring 2016 data set over the first year
- Σ asymmetry for the η' never before measured at GlueX energies
 - More statistics \rightarrow first accurate measurement?
 - More statistics \rightarrow bin data in t
 - Investigate yield and Σ asymmetry as functions of t
- Continue with MC and data (work in progress) acceptance studies

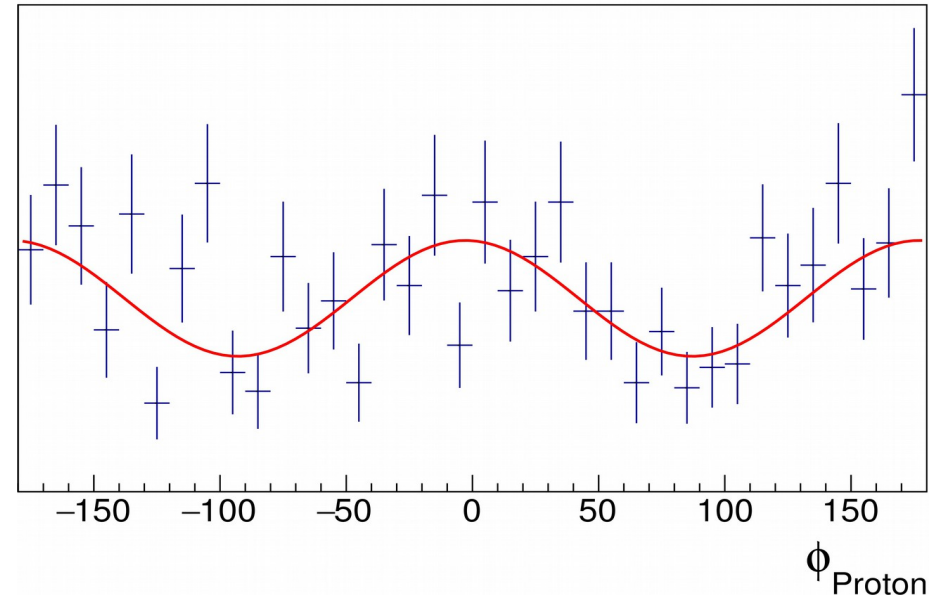
Questions?

$\eta' \rightarrow \pi^+ \pi^- \eta$ Beam Asymmetry

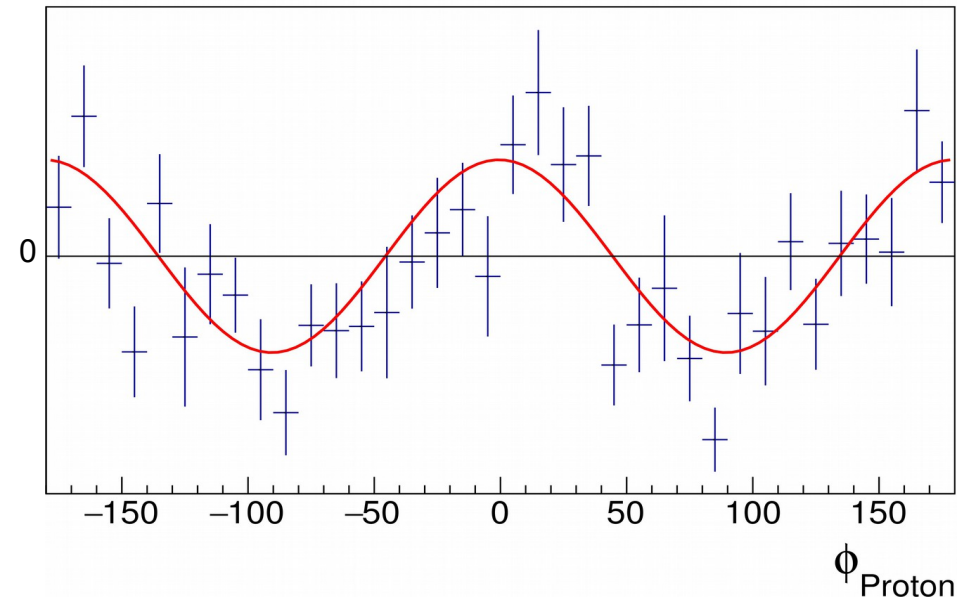
PARA Proton ϕ



PERP Proton ϕ



Asymmetry



$$f(\varphi) = \frac{(P_{\perp} + P_{\parallel})\Sigma \cos(2\varphi)}{2 - (P_{\perp} - P_{\parallel})\Sigma \cos(2\varphi)}$$

- Clear sinusoidal behaviour
- Sensitive to Σ asymmetry!

(t-averaged)

Beginning of Acceptance Studies

For $\eta \rightarrow 2\gamma, 3\pi^0, \pi^+\pi^-\pi^0$

- Understand acceptance for future cross-section extraction
- Investigating acceptance in bins of beam energy and momentum transfer (-t)
 - Simulate data in bins of beam energy
 - Form ratios of yields vs. -t
 - **Compare to same ratios in data**
 - Work in Progress
- Simulations:
 - 600,000 events per 2 GeV beam energy bin
 - Plotted η mass in bins of -t
 - Fit to Gaussian, extract abundance
 - Correct abundances for branching fractions
 - Plot yield ratios vs. -t

