Analysis of the η(548) → π+ π- π0 and η'(958) → π+ π- η channels for the GlueX Experiment

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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
    - ➤ 10^8 γ/s (Design)

- ➤ Resolutions:

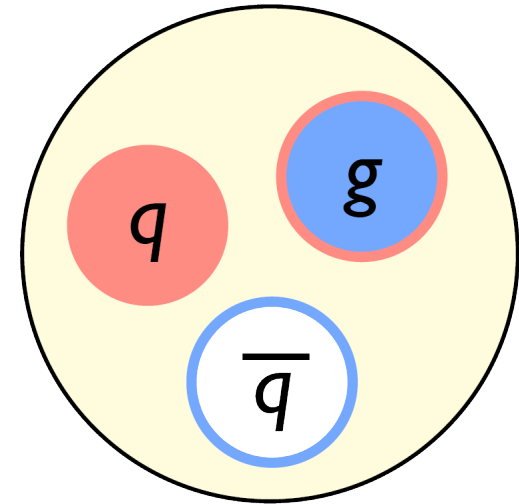 γ: $\sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$

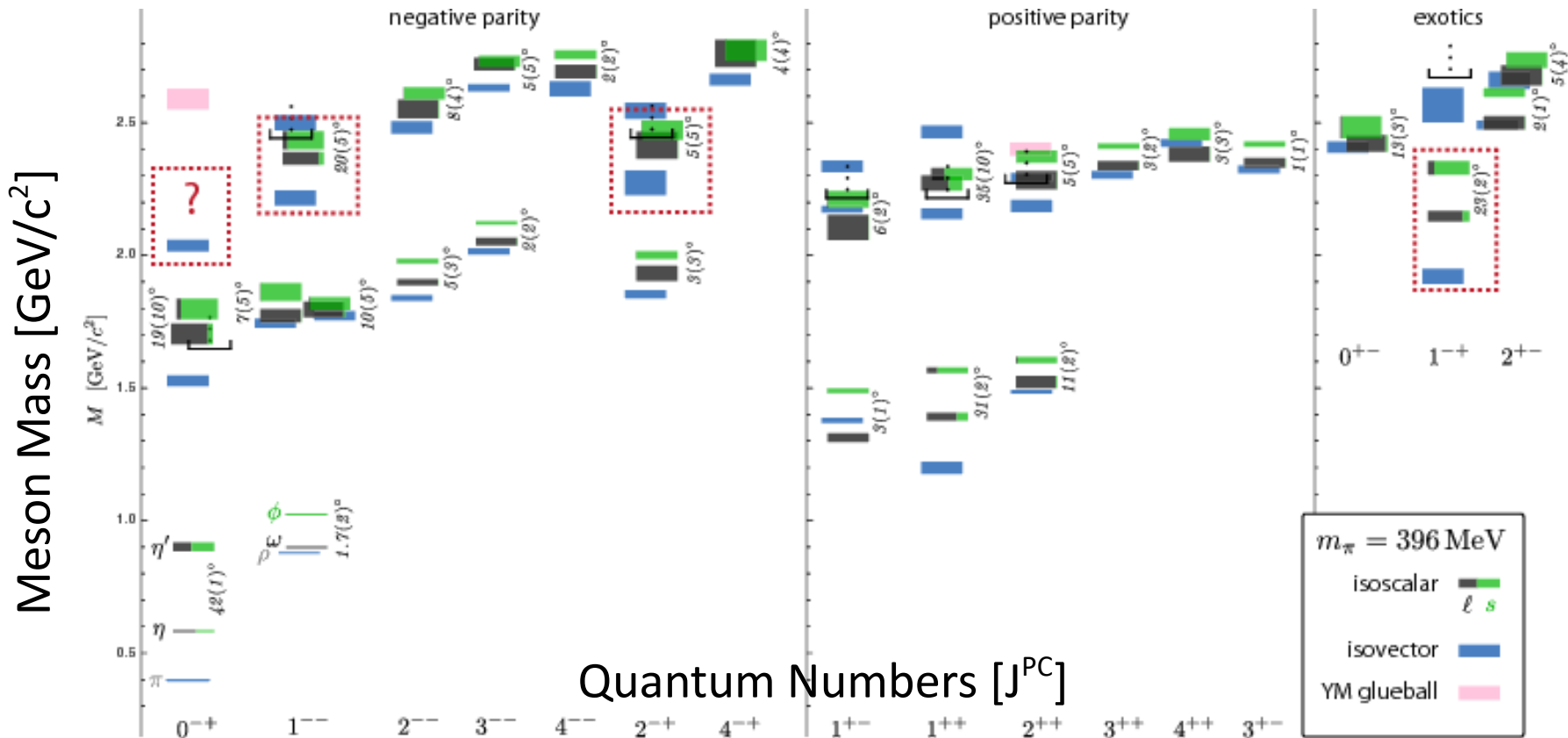 q$^{\pm}$: $\sigma_p/p \sim 2 - 5\%$
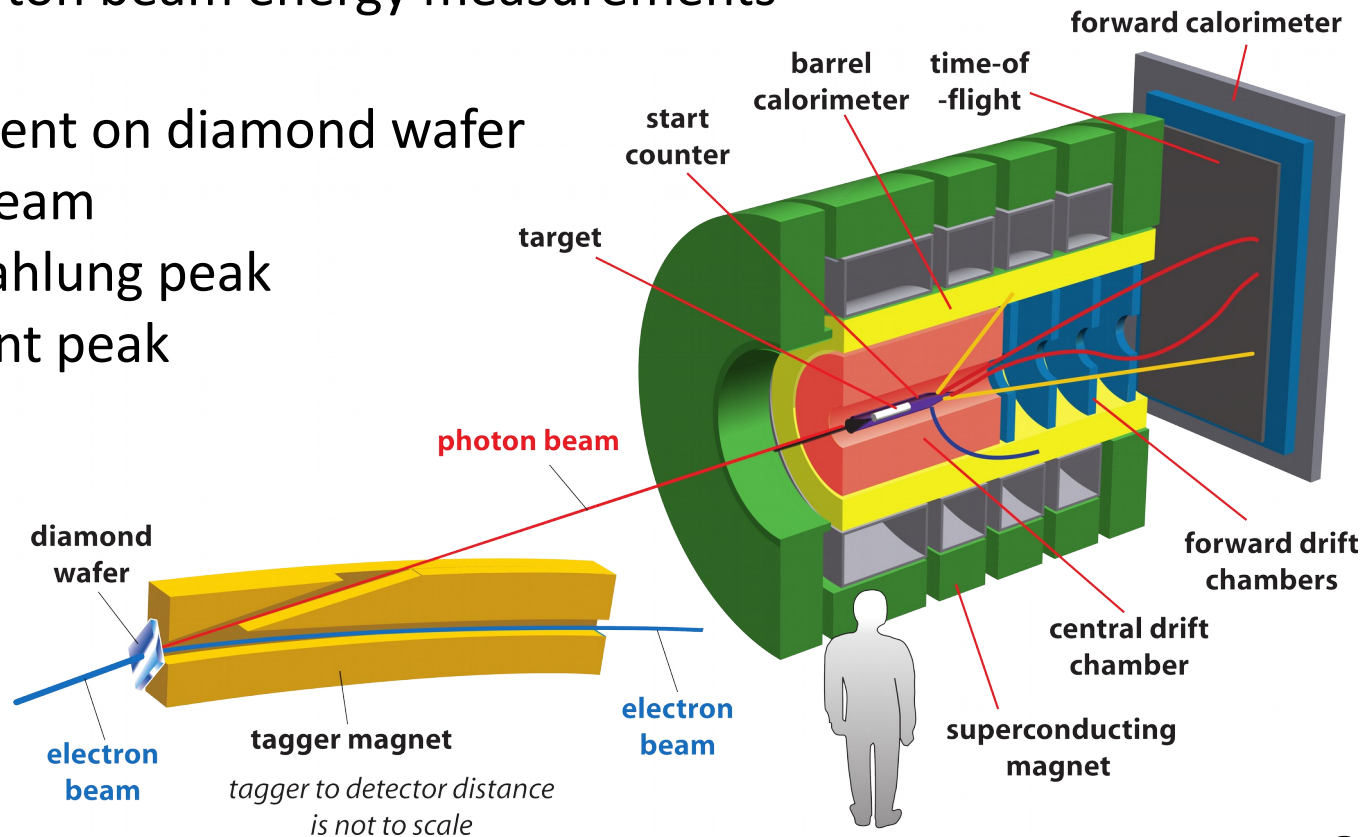
GlueX Physics

- 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

Meson Mass [GeV/c^2]

Quantum Numbers [J^{PC}]

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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 high energies
  ➢ Σ beam asymmetries/cross sections 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

Struczinski et al., 1976

➢ Reconstructing pure samples of these simple mesons is the first step
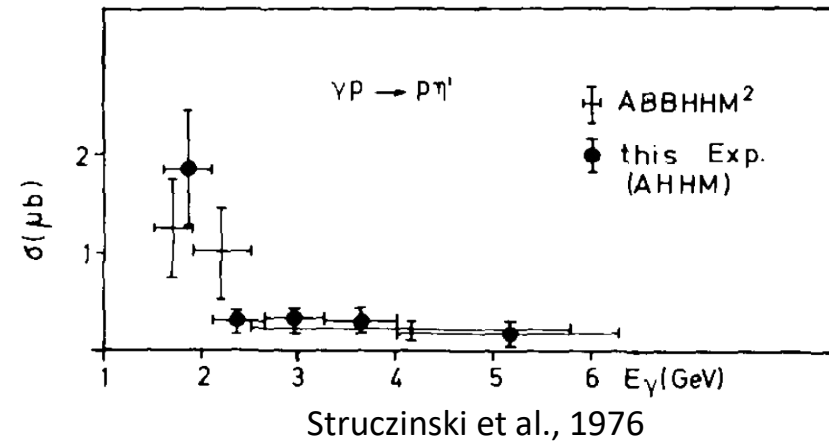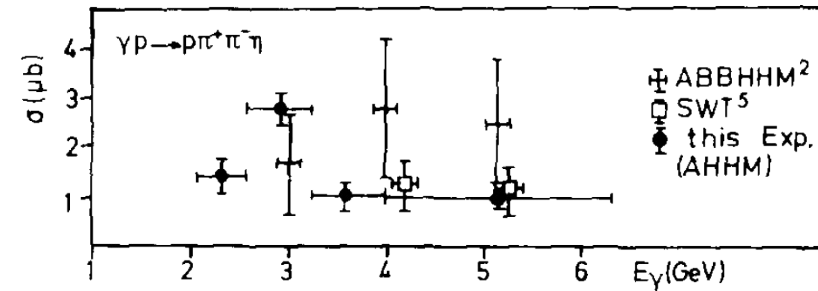
➢ This talk: most recent results for reconstruction of η and η'
  ➢ Results include ~ 1/4 of the Spring 2016 data set

$$\eta \to \pi^+ \pi^- \pi^0 \ (BR \sim 22.9\%)$$
$$\pi^0 \to 2\gamma$$

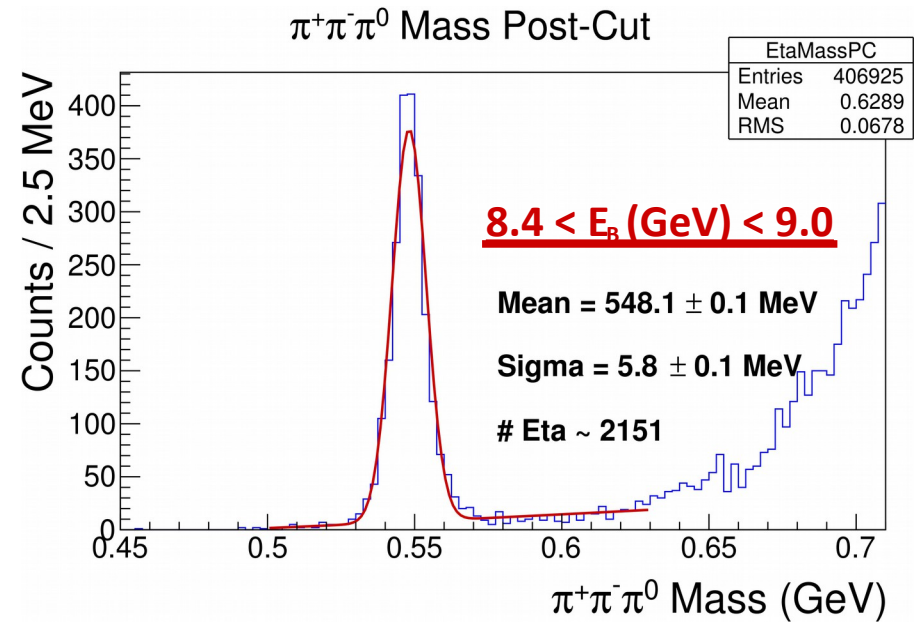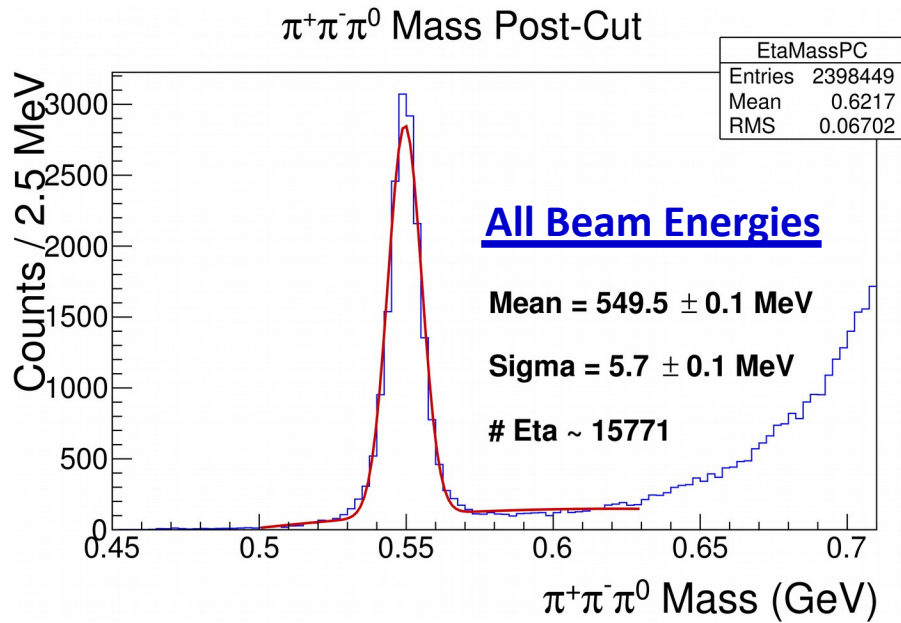$$\eta' \to \pi^+ \pi^- \eta \ (BR \sim 42.9\%)$$
$$\eta \to 2\gamma$$

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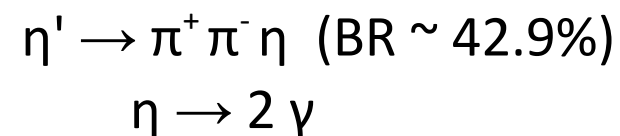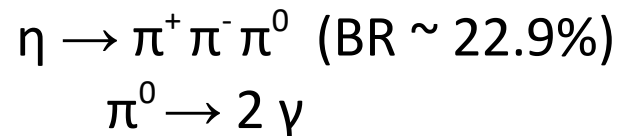
Event Selection Cuts

- 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 ≈ 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
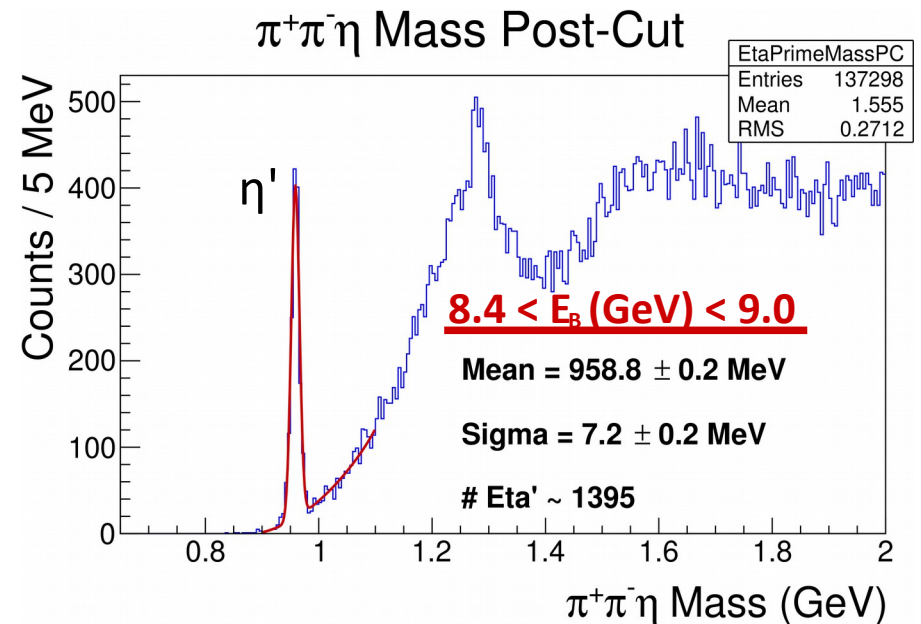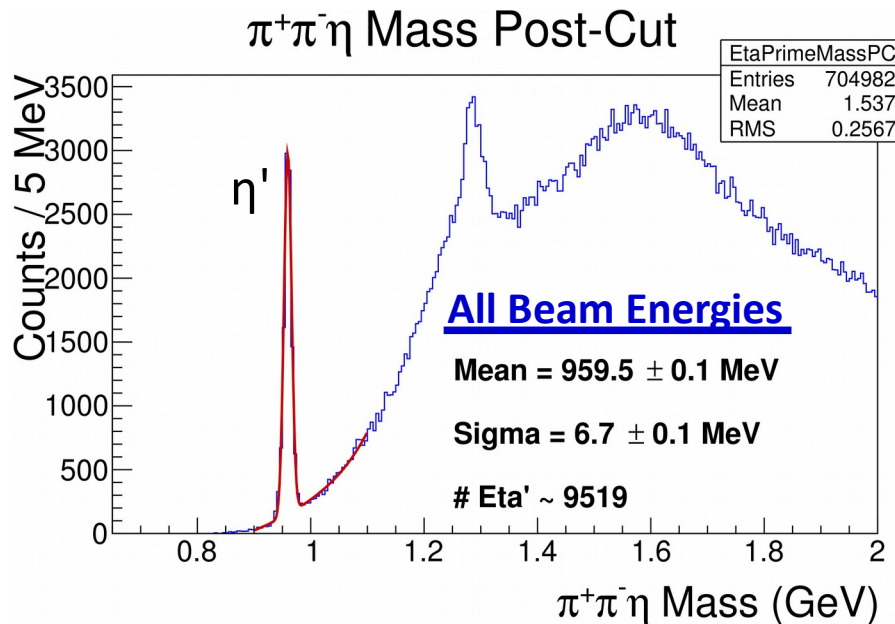 - Fiducial cut removes combos with neutral shower close to either region
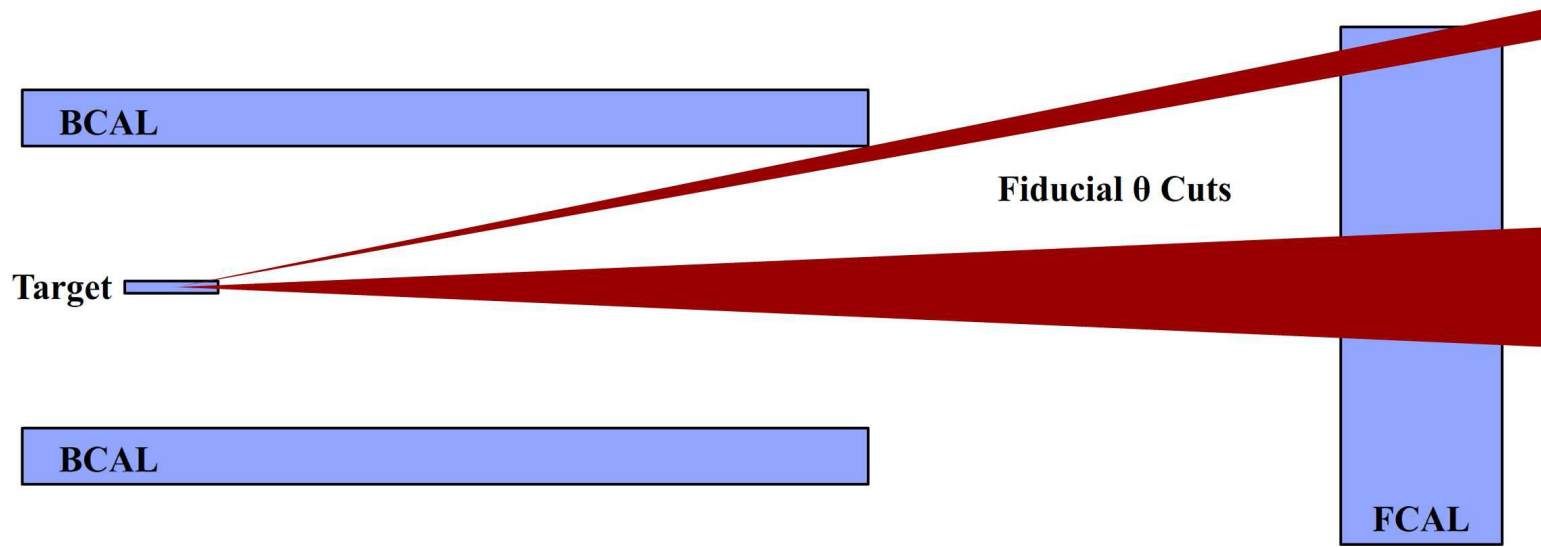
- Clean events: Mass spectra, beam asymmetries, acceptance studies

η → π⁺π⁻π⁰ Mass Spectrum

π⁺π⁻π⁰ Mass Post-Cut

EtaMassPC	
Entries	2398449
Mean	0.6217
RMS	0.06702

All Beam Energies

Mean = 549.5 ± 0.1 MeV

Sigma = 5.7 ± 0.1 MeV

 # Eta ~ 15771

π⁺π⁻π⁰ Mass Post-Cut

EtaMassPC	
Entries	406925
Mean	0.6289
RMS	0.0678

8.4 < E_B (GeV) < 9.0

Mean = 548.1 ± 0.1 MeV

Sigma = 5.8 ± 0.1 MeV

 # Eta ~ 2151

η' → π⁺π⁻η Mass Spectrum

π⁺π⁻η Mass Post-Cut

EtaPrimeMassPC	
Entries	704982
Mean	1.537
RMS	0.2567

η'

All Beam Energies

Mean = 959.5 ± 0.1 MeV

Sigma = 6.7 ± 0.1 MeV

 # Eta' ~ 9519

π⁺π⁻η Mass Post-Cut

EtaPrimeMassPC	
Entries	137298
Mean	1.555
RMS	0.2712

η'

8.4 < E_B (GeV) < 9.0

Mean = 958.8 ± 0.2 MeV

Sigma = 7.2 ± 0.2 MeV

 # Eta' ~ 1395

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

Meson Production Plane

φ

Plane Parallel to Lab Floor
(same as PARA polarization plane)

Polarized Photon Beam
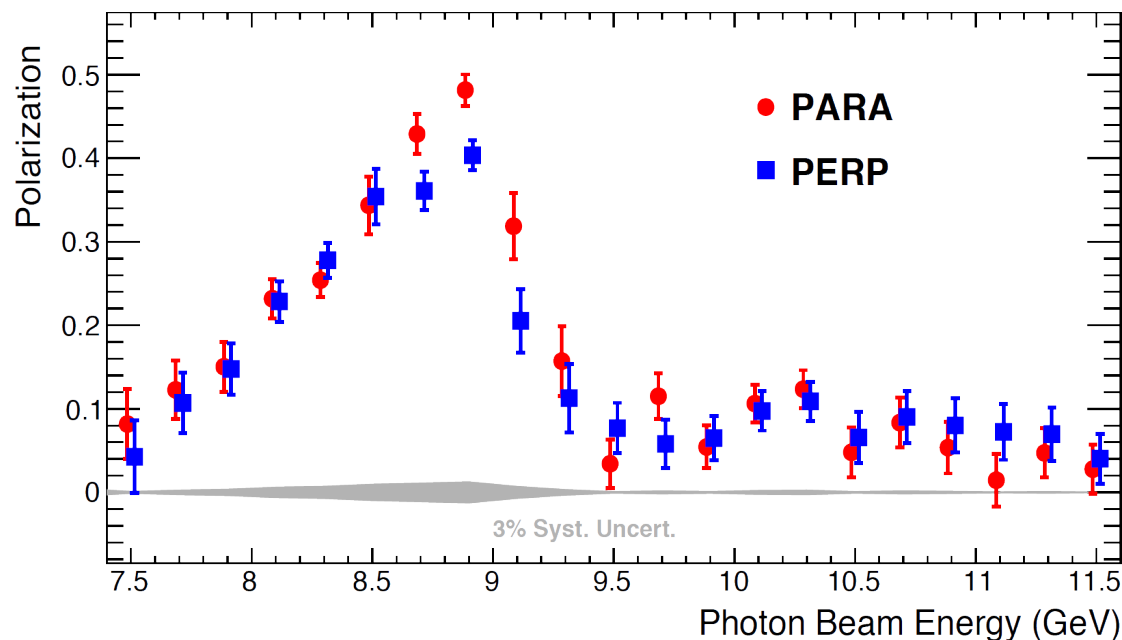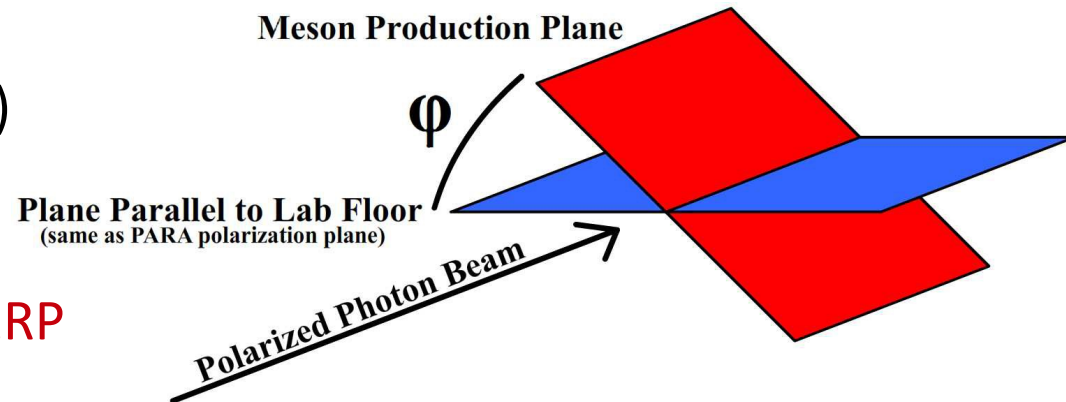
PERP yield ~ $(1 + P_{||}\Sigma \cos(2\varphi))$
PARA yield ~ $(1 - P_{\perp}\Sigma \cos(2\varphi))$

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

$P_{\perp}$ and $P_{||}$ found from TPOL (left)
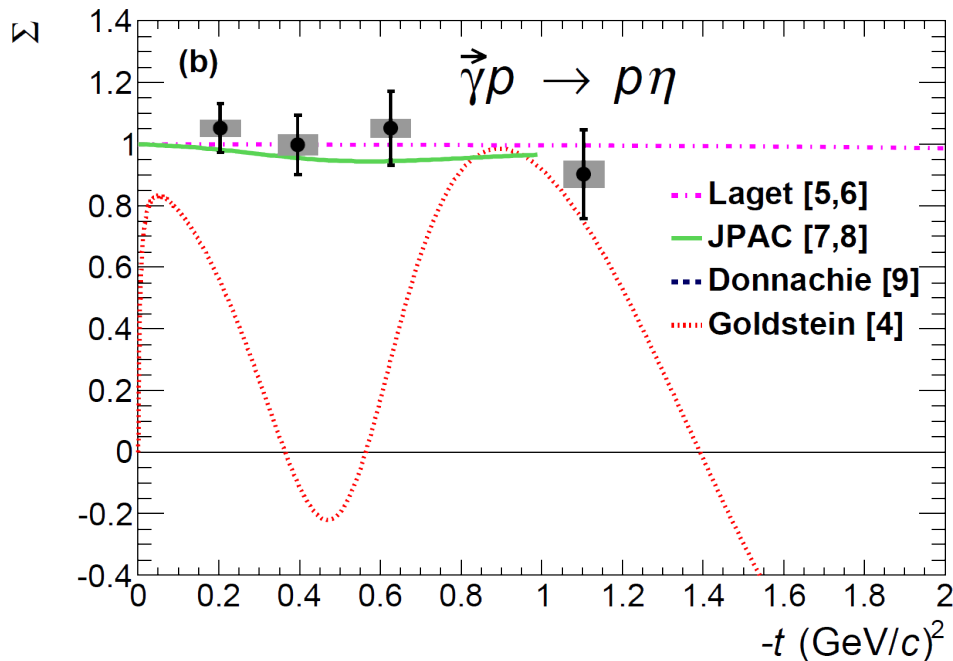
Fit data to this function to extract Σ

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GlueX PRL Submission: π^0/η Σ Asymmetry

arXiv:1701.08123 [nucl-ex]
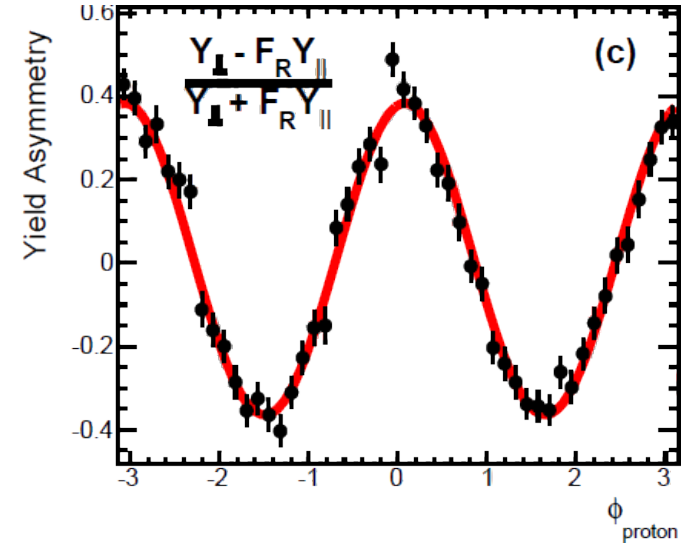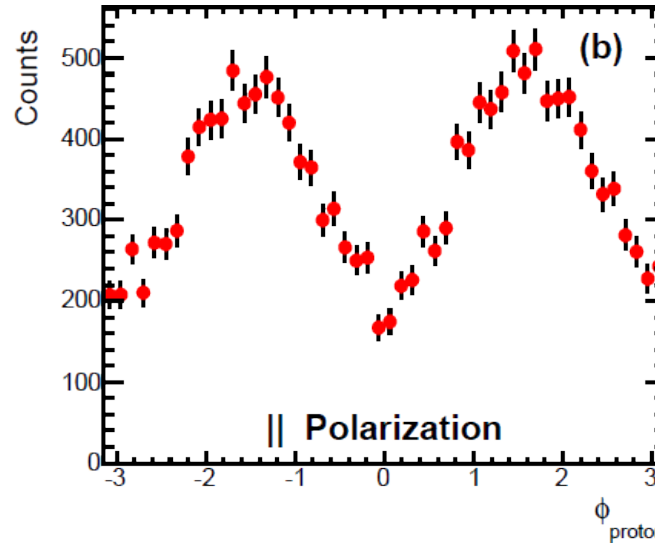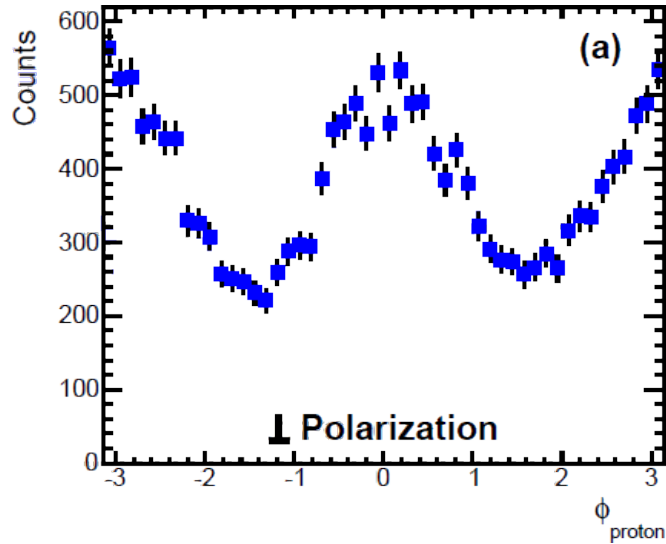
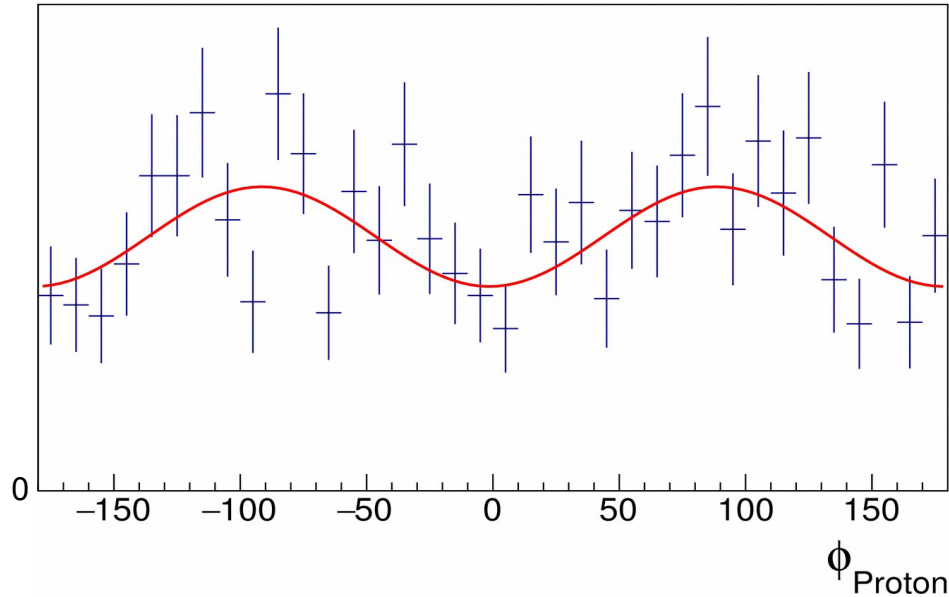$\pi^0 \rightarrow 2\,\gamma$ Yield vs. φ (t-averaged)

➤ Detailed analysis of π^0 and η asymmetry
➤ High statistics η → 2 γ 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 η → $\pi^+\pi^-\pi^0$
Observe result with η' → $\pi^+\pi^-\eta$

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η → π⁺π⁻π⁰ Beam Asymmetry

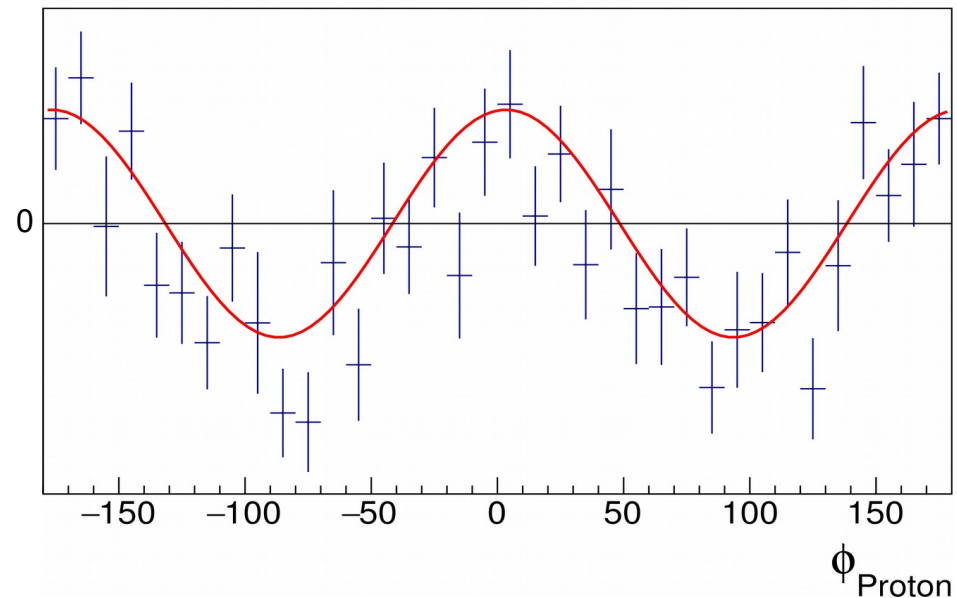$\eta \rightarrow \pi^+ \pi^- \pi^0$ Beam Asymmetry

PARA Proton φ

PERP Proton φ
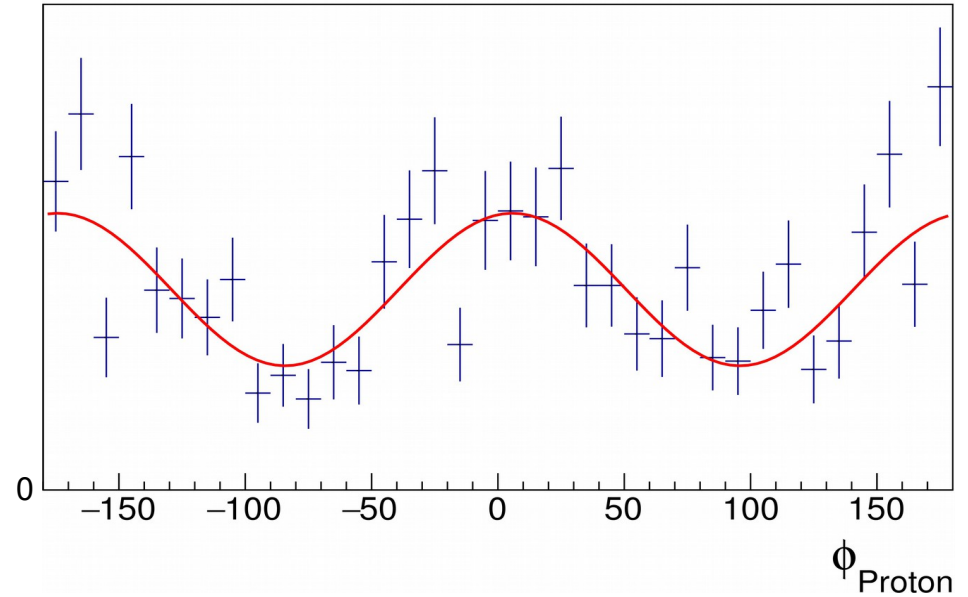
Asymmetry

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

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

Quantitatively similar results for η' → π⁺π⁻η

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MC Acceptance Study: η → 2γ, 3π⁰, π⁺π⁻π⁰

- Understand detector acceptance for future cross-section extraction
- Simulate signal events in bins of beam energy, extract yields, form ratios

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

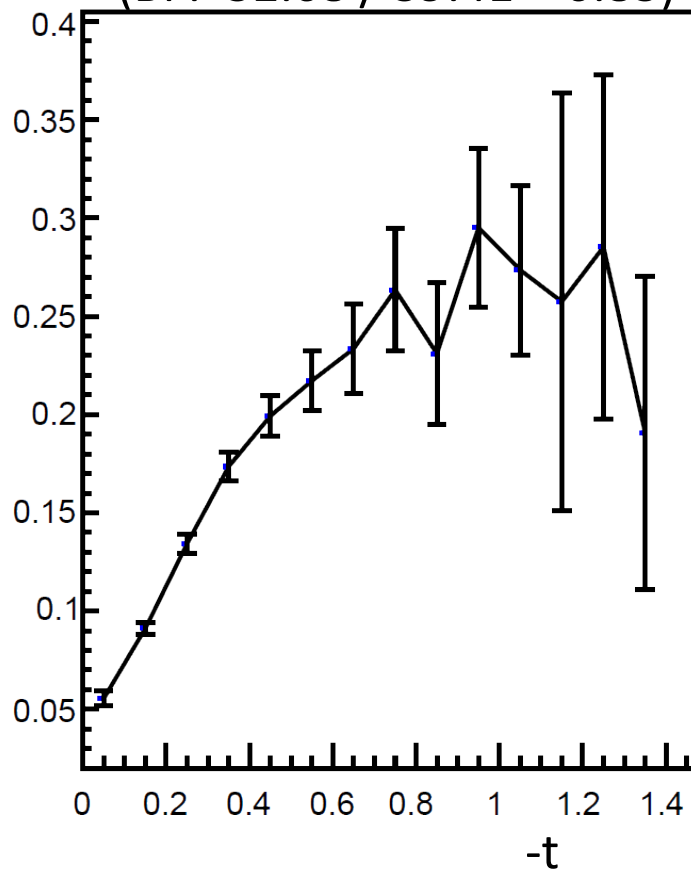## Branching Fraction Corrected Yield Ratios for Beam Energy Between 8 and 10 GeV:

π⁺π⁻π⁰ / 2γ Yield
(BF: 22.92 / 39.41 = 0.58)
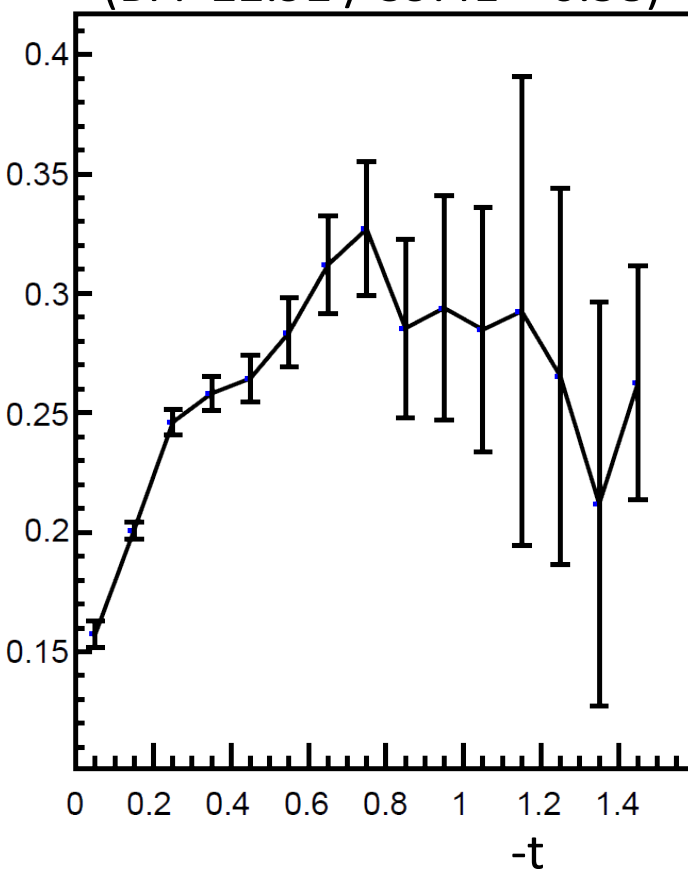
3π⁰ / 2γ Yield
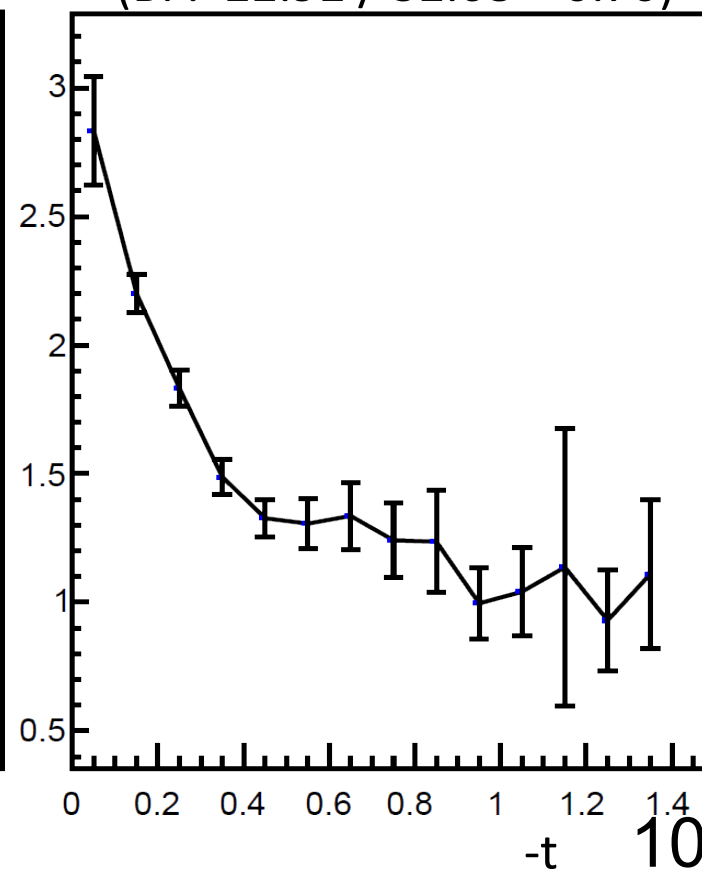(BF: 32.68 / 39.41 = 0.83)

π⁺π⁻π⁰ / 3π⁰ Yield
(BF: 22.92 / 32.68 = 0.70)

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 (with higher statistics) 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

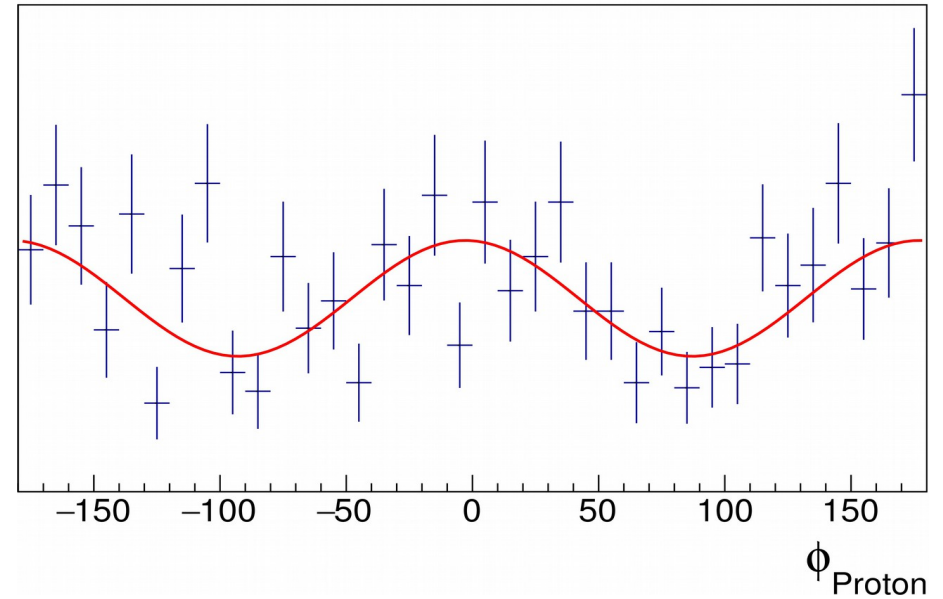➢ Continue with MC and data (work in progress) acceptance studies
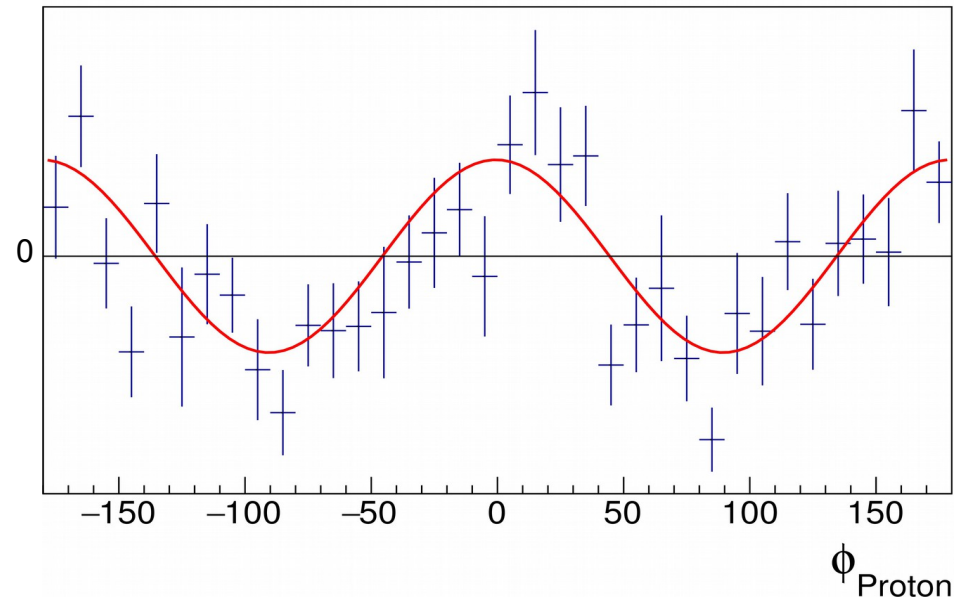
Questions?

η' → π⁺π⁻η Beam Asymmetry

PARA Proton φ
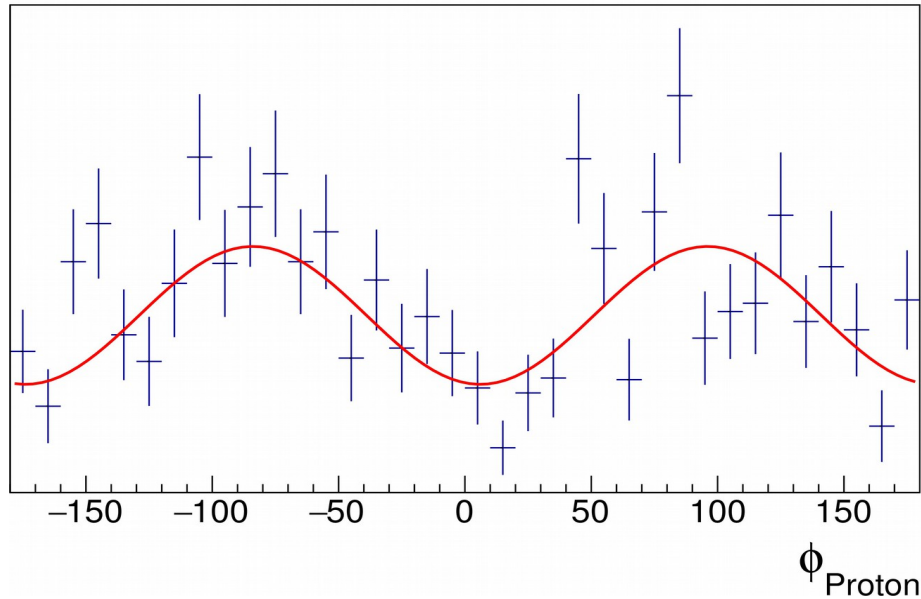
PERP Proton φ

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

9GeV $\eta \rightarrow 3\pi^0$ Mass (0.4 < |-t| < 0.5)

$\eta \rightarrow 3\pi^0$ Mass	
Entries	2239
Mean	0.5466
Std Dev	0.01456
χ^2 / ndf	281 / 41
Prob	1.581e−37

$3\pi^0$ Mass (GeV)