Beam Asymmetry in $\gamma\, p \rightarrow \eta\, \Delta^{+}$ at GlueX

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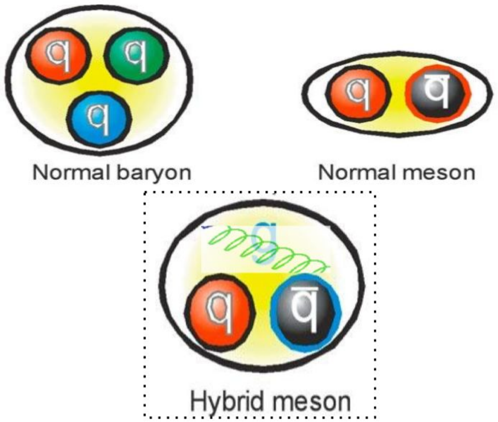
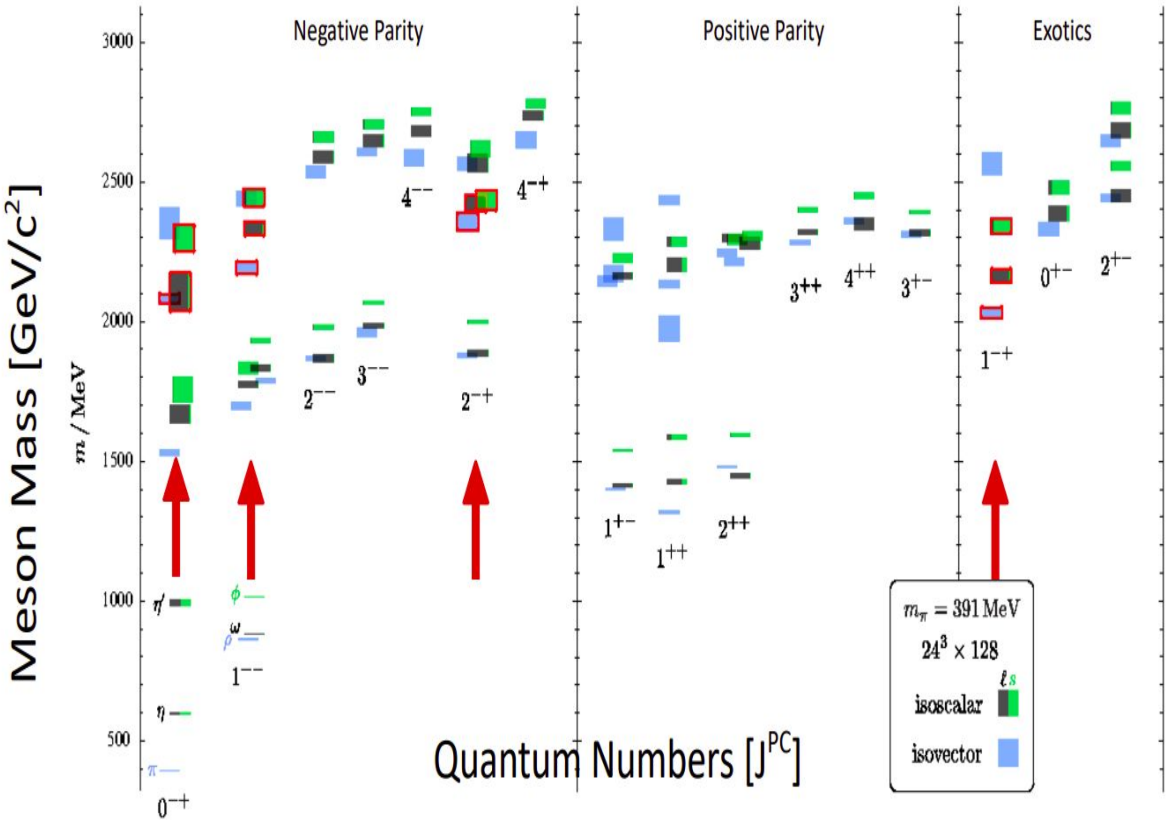
GLUEX Experiment (Motivation)

- Search for evidence of exotic J^{PC} hybrids
- Specifically, the lightest hybrid multiplet (predicted by LQCD calculations)



Ref: [IOP Publishing: Home]()



J.J. Dudek, R.G. Edwards, P. Guo, and C.E. Thomas, Phys. Rev. D88 094505 (2013)

Motivation (Physics) Σ beam asymmetry

- **Σ (-t)** provides insight into beam-target exchange(production mechanism)

Channel : $\gamma\, \mathbf{p} \rightarrow \boldsymbol{\eta}\, \Delta^{+}$

Where : $\eta \rightarrow \gamma\ \gamma$

$\Delta^{+} \rightarrow p\ \pi^{0}$

Exchange J^{PC}

1^{--} Vector

1^{+-} Pseudo Vector

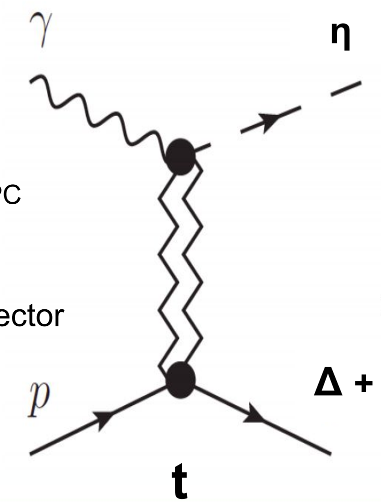


Fig. Exchange interaction

- From V.Mathieu (JPAC theory group)
  Exchanges similar to **γp** → **ηp** (ρ, b trajectories).
  The coupling at the lower vertex **p** and $\boldsymbol{\Delta^{+}}$ (instead of **p** and **p**)
  Expect Σ ≈ 1 natural parity exchange

- Experimentally, analysis tools from previously done **γp** → $\boldsymbol{\pi^{-}\ \Delta^{++}}$ beam asymmetry analysis in GlueX are adapted with very minor tweaks

Measurement of beam asymmetry for π−Δ++ photoproduction on the proton at Eγ=8.5 GeV
GlueX Collaboration https://arxiv.org/abs/2009.07326v1

GLUEX Experiment

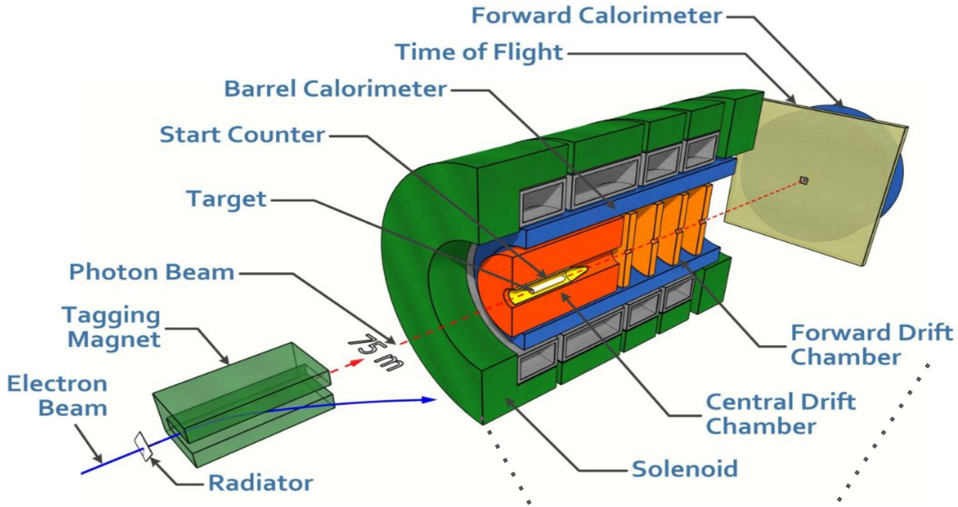


Fig. Illustration of GlueX Detector

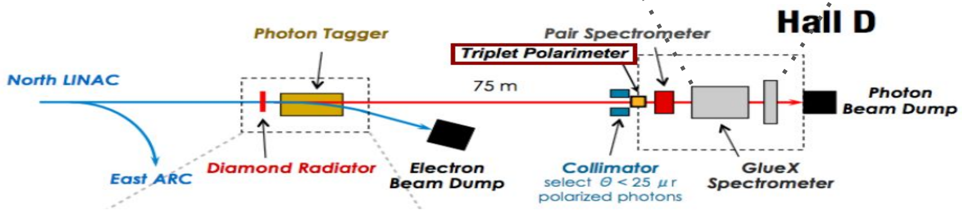


Fig. Schematic diagram of beamline

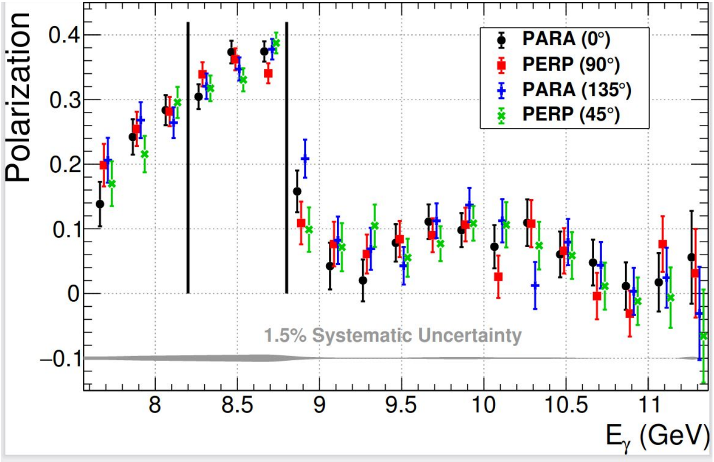


Fig. Polarization vs energy plot

Two Orthogonal polarizations:
PARA(||) PERP(⊥)
with two datasets
(0 , 90)
(-45 , 45)

Linearly polarized photon beam
Unpolarized target

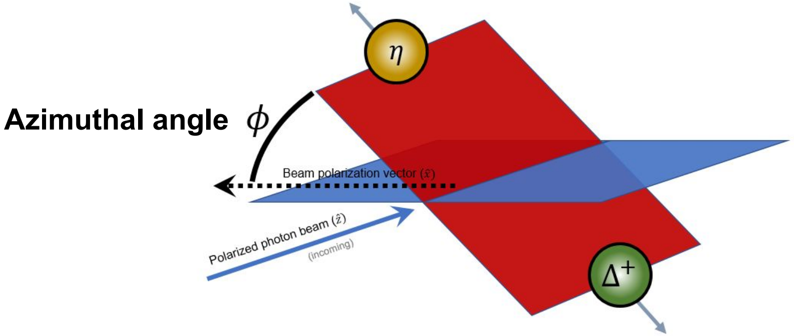
Beam asymmetry Σ (Method)

- Σ beam asymmetry: polarization observable

$$\sigma_{\mathrm{pol}}(\phi, \phi_\gamma) = \sigma_0\{1 - P_\gamma \Sigma \cos[2(\phi - \phi_\gamma)]\},$$

σ_{pol}, σ_0 are polarized, unpolarized cross sections

p_γ Photon beam polarization



$$\Sigma = \frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel}$$

In terms of yields which can be be directly measured from experiment

$$Y_\perp(\phi, \phi_\gamma = 90) \propto N_\perp[\sigma_0 A(\phi)(1 + P_\perp \Sigma \cos 2\phi)],$$

$$Y_\parallel(\phi, \phi_\gamma = 0) \propto N_\parallel[\sigma_0 A(\phi)(1 - P_\parallel \Sigma \cos 2\phi)],$$

$p_{/\!/,\perp}$ are polarization values

$N_{/\!/,\perp}$ are flux values

Beam asymmetry Σ (Method)

- Direct fit to **φ** distribution :

$$\text{Yield Asym} = \frac{Y_\perp - F_R Y_\parallel}{Y_\perp + F_R Y_\parallel} = \frac{(P_\perp + P_\parallel)\Sigma\cos(2(\phi - \phi_0))}{2 - (P_\perp - P_\parallel)\Sigma\cos(2(\phi - \phi_0))}$$

$p_{//,\perp}$ are polarization values

F_R Flux ratio

Σ Is the free parameter to fit

- "Moment-Yield " method: Implemented in GlueX for **γp** → **π⁻ Δ⁺⁺**

  Measurement of beam asymmetry for π−Δ++ photoproduction on the proton at Eγ=8.5 GeV

  GlueX Collaboration https://arxiv.org/abs/2009.07326v1

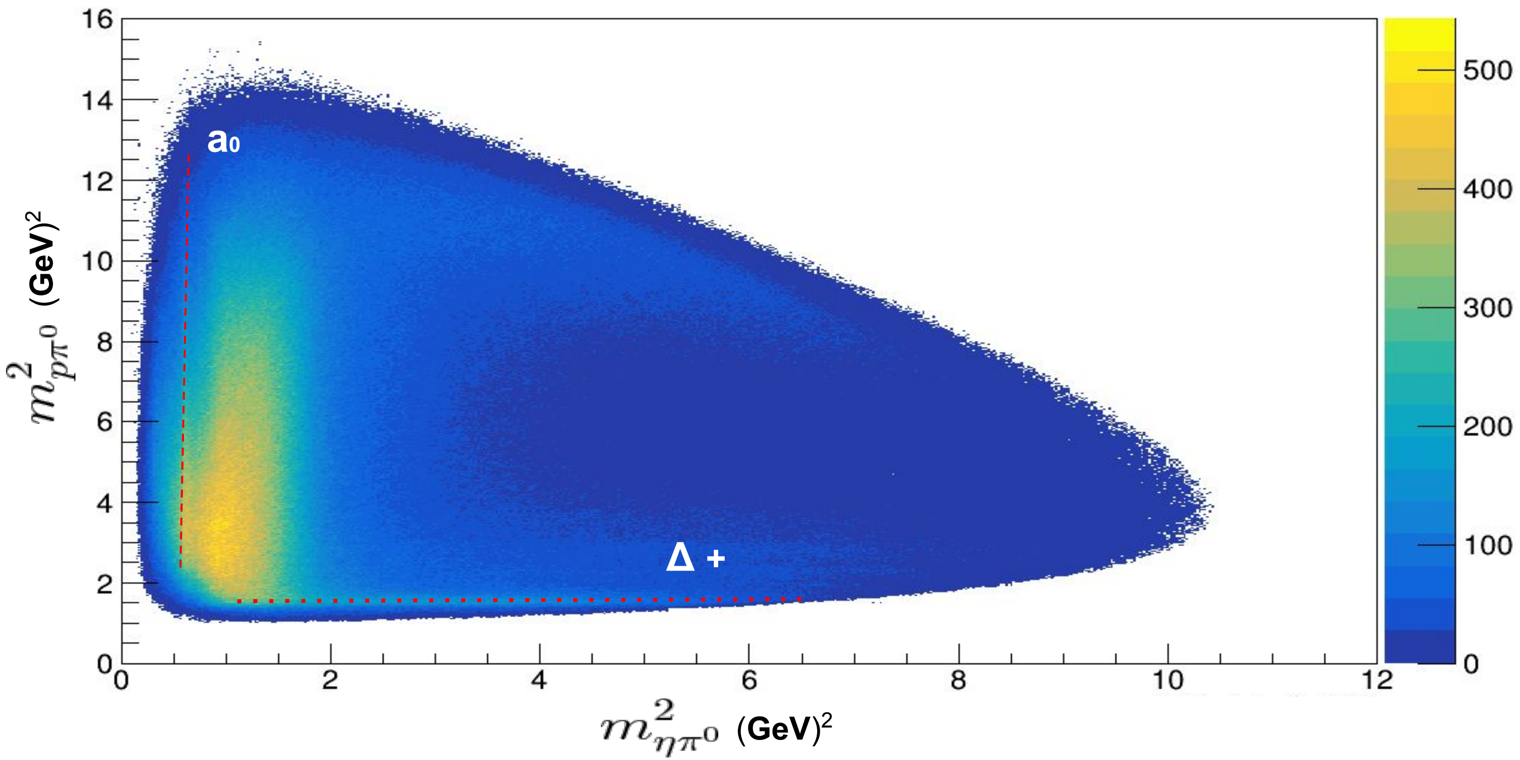
$$\Sigma = \frac{Y_2^\perp - Y_2^\parallel}{\frac{P_\parallel}{2}(Y_0^\perp + Y_4^\perp) + \frac{P_\perp}{2}(Y_0^\parallel + Y_4^\parallel)}$$

$Y_n^{\parallel,\perp}$ are yields from moment weighted (cos**nφ**) histograms. **n**=0,2,4,...
PARA and PERP combination helps cancellation of acceptance

M. Dugger et al.(CLAS Collaboration), Phys. Rev. C88, 065203 (2013)

- Present analysis done with 20 % of GlueX-I dataset

Dalitz plot

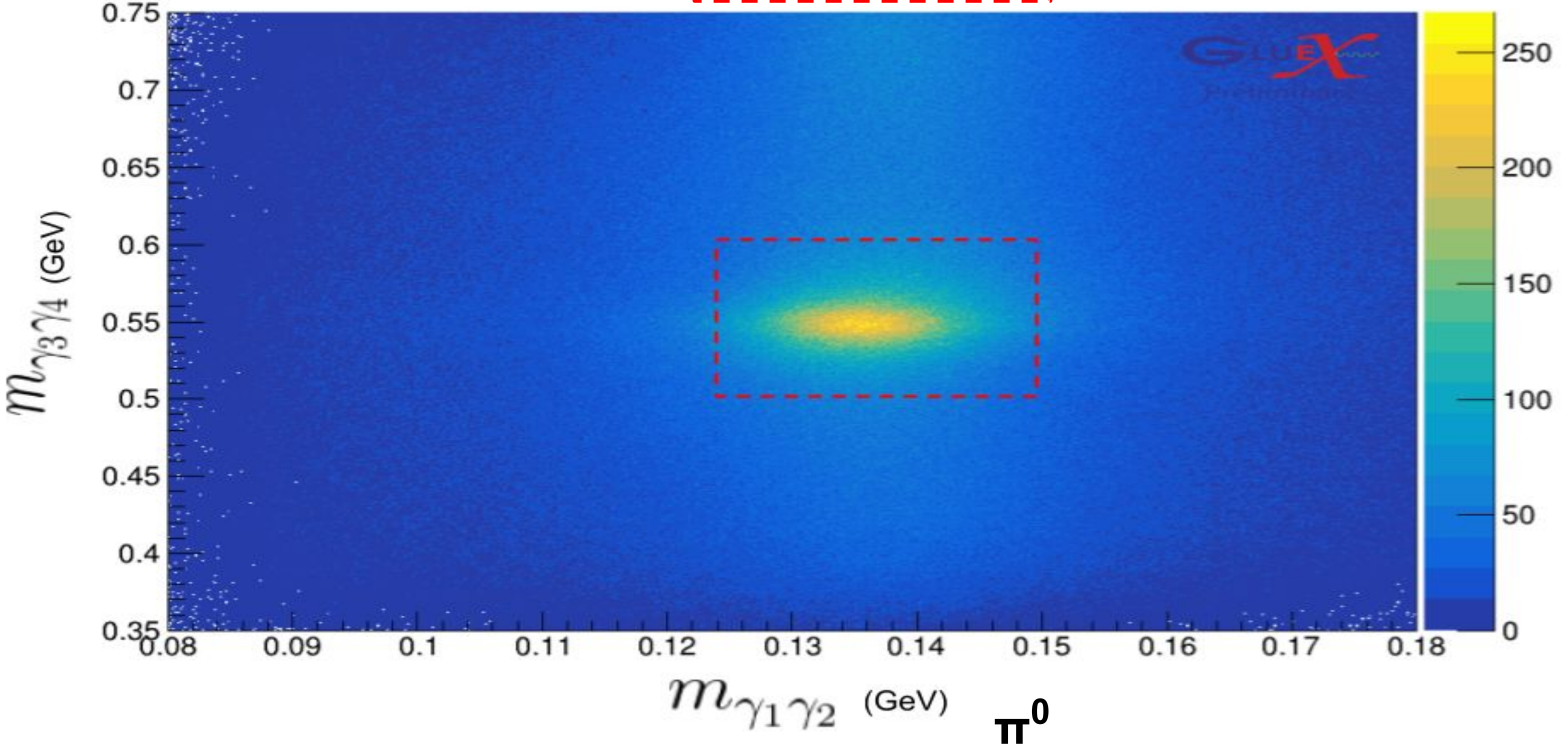


a0
Δ +
$m^2_{p\pi^0}$ (GeV)^2
$m^2_{\eta\pi^0}$ (GeV)^2
0
2
4
6
8
10
12
14
16
100
200
300
400
500

π^0, η Mass selection cuts

0.125 < π^0 < 0.150
0.50 < η < 0.60

η

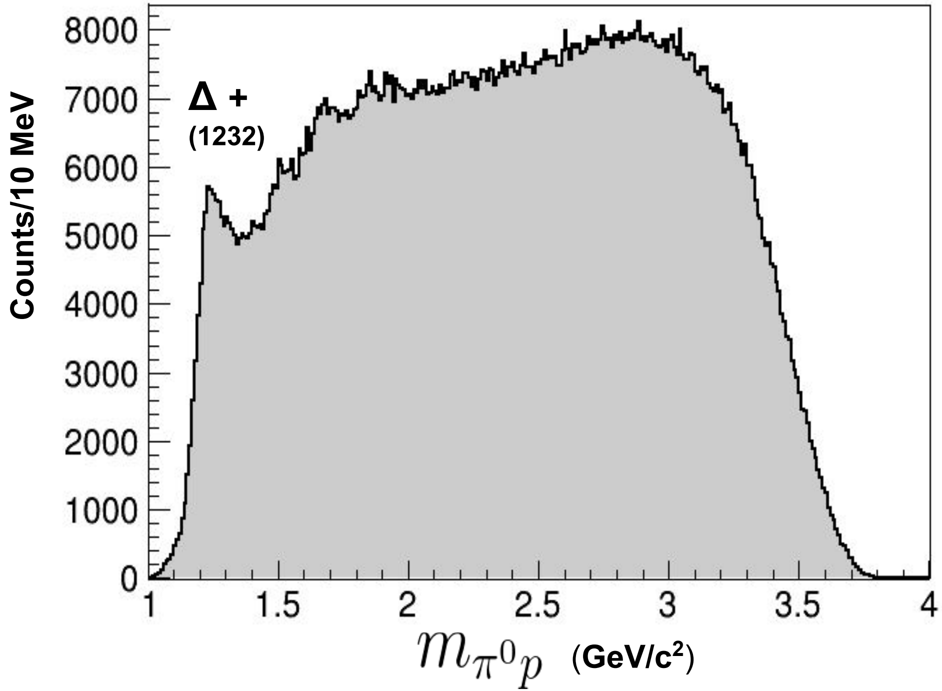


π^0

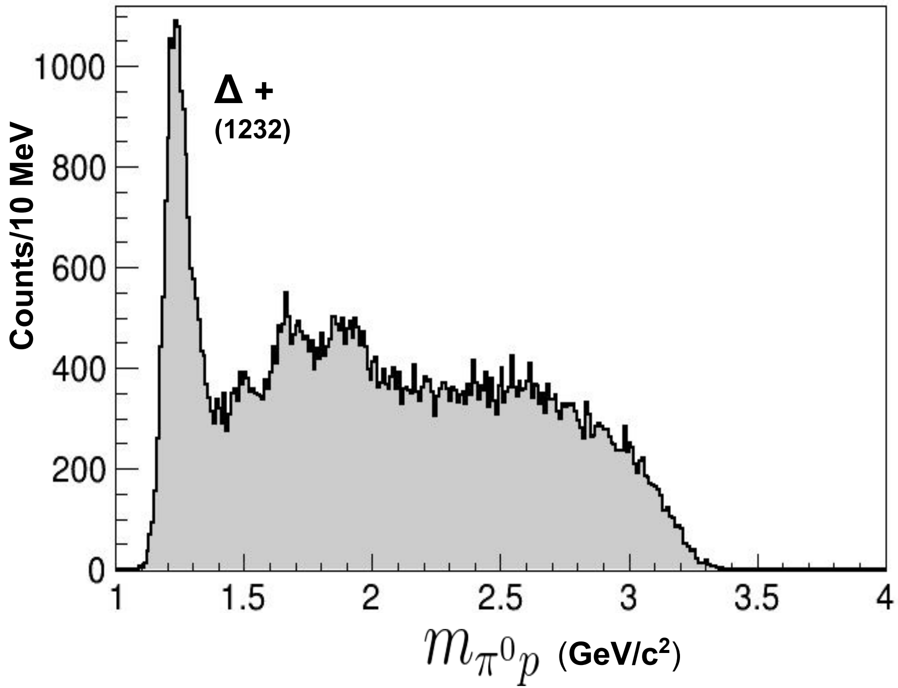
$\pi^0 p$ Mass Distribution

0.125 < π^0 < 0.150
0.50 < η < 0.60

Before π^0, η Mass selection cuts



After π^0, η Mass cuts



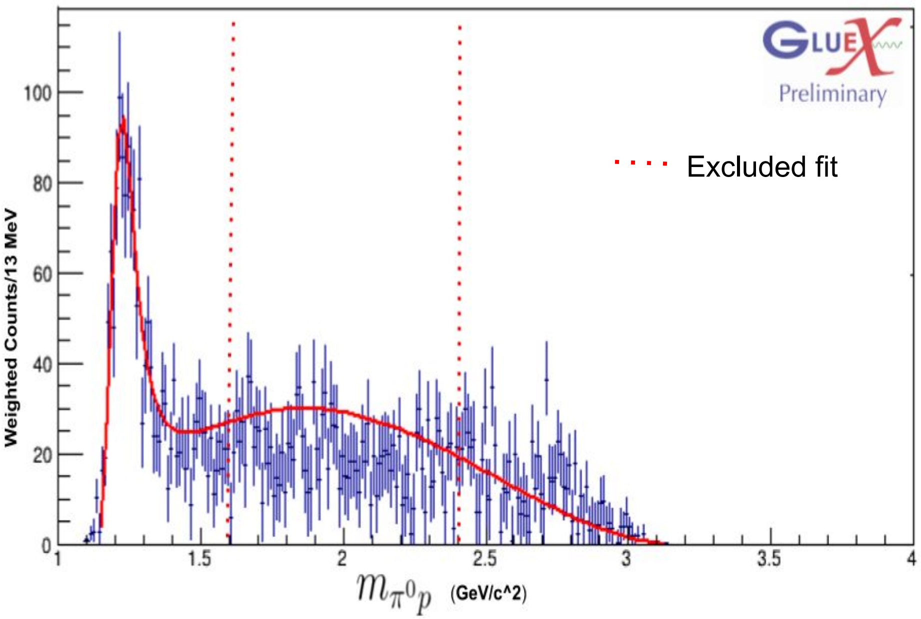
Extraction of Σ_η

$$\Sigma = \frac{N}{D} = \frac{Y_2^{\perp} - Y_2^{\parallel}}{\frac{P_{\parallel}}{2}(Y_0^{\perp} + Y_4^{\perp}) + \frac{P_{\perp}}{2}(Y_0^{\parallel} + Y_4^{\parallel})}$$

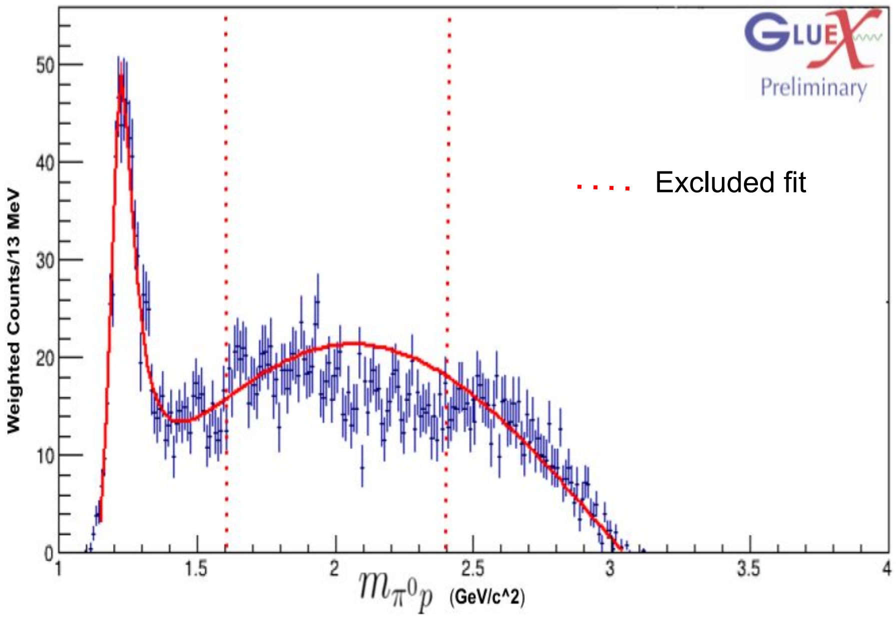
$Y_n^{\parallel,\perp}$ are yields from moment weighted (cos**nφ**) histograms. **n**=0,2,4,...

Signal -> Breitweigner (Dynamic)
Background-> bernstein polynomial

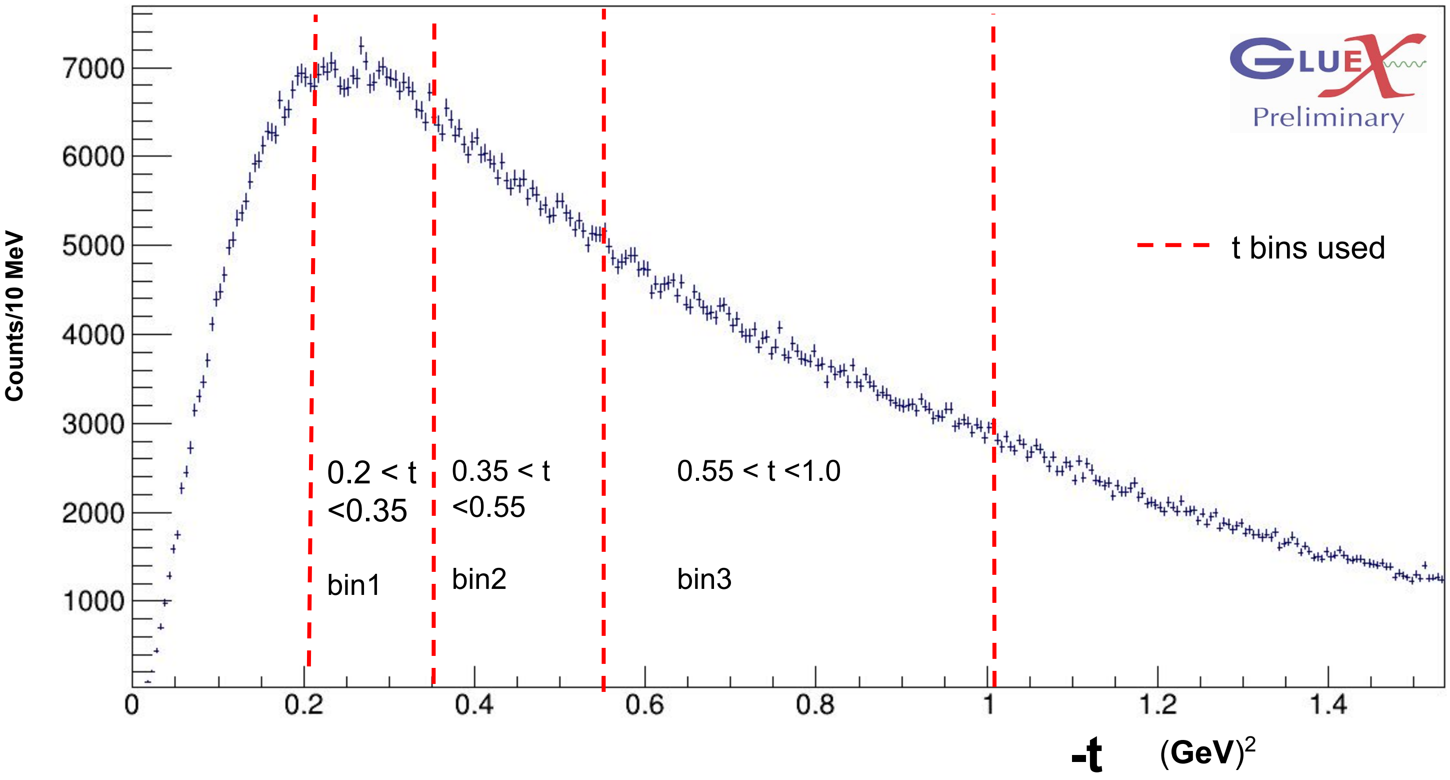
Numerator Histogram



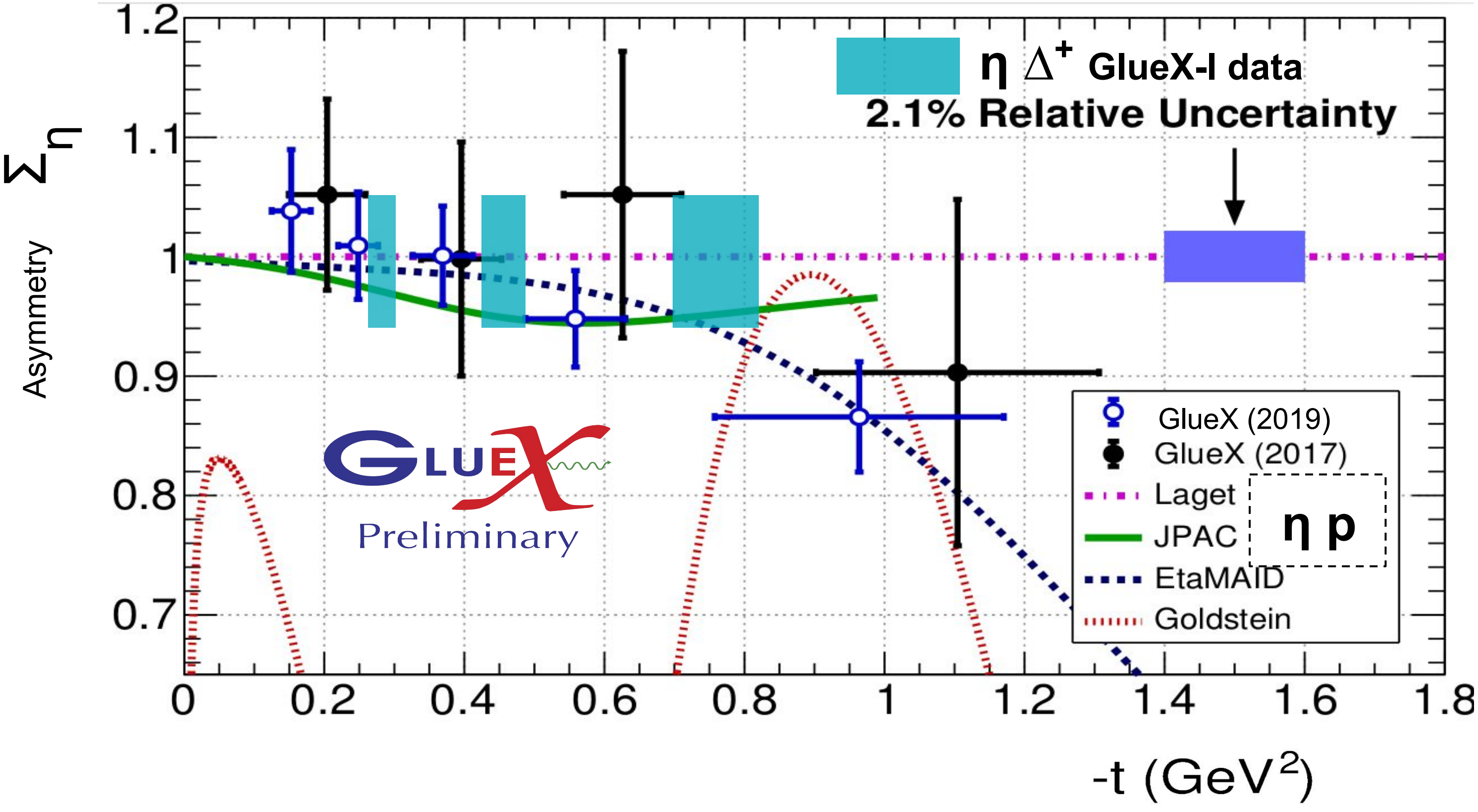
Denominator Histogram



Mandelstam t distribution



Projected Preliminary uncertainty in Σ_η



Summary

- Preliminary analysis is done with 20 % of GlueX-I dataset
- Demonstrated previously done “yield-moment” method in $\gamma\, p \rightarrow \pi^- \Delta^{++}$ can be applied to $\gamma\, p \rightarrow \eta\, \Delta^{+}$
- This analysis will be an external validation of $\gamma\, p \rightarrow \eta\, p$

Next..

- Will look into systematic and statistical uncertainties in detail with complete GlueX-I dataset

Thank You !!!

Backup Slides

Preliminary uncertainty in **Σ** (statistical)

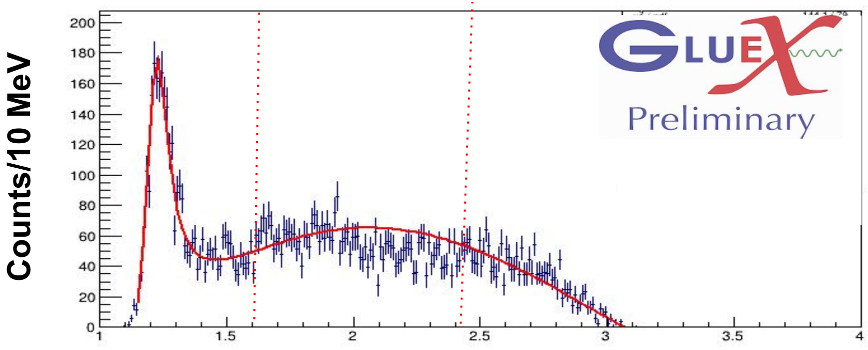
$$\sigma_\Sigma^2 = \frac{1}{2}\left(\frac{\sigma_N^2}{N^2} + \frac{\sigma_D^2}{D^2} - \frac{2Cov(N,D)}{ND}\right)$$

$$\sigma_N^2 = \frac{1}{2}(Y_{\perp 0} + Y_{\perp 4}) + \frac{1}{2}(Y_{\parallel 0} + Y_{\parallel 4})$$

$$\sigma_D^2 = \frac{P_\parallel^2}{4}(Y_{\perp 0} + \frac{1}{2}(Y_{\perp 0} + Y_{\perp 8}) + \frac{1}{2}(Y_{\parallel 0} + Y_{\parallel 4}) + (\perp \Leftrightarrow \parallel))$$

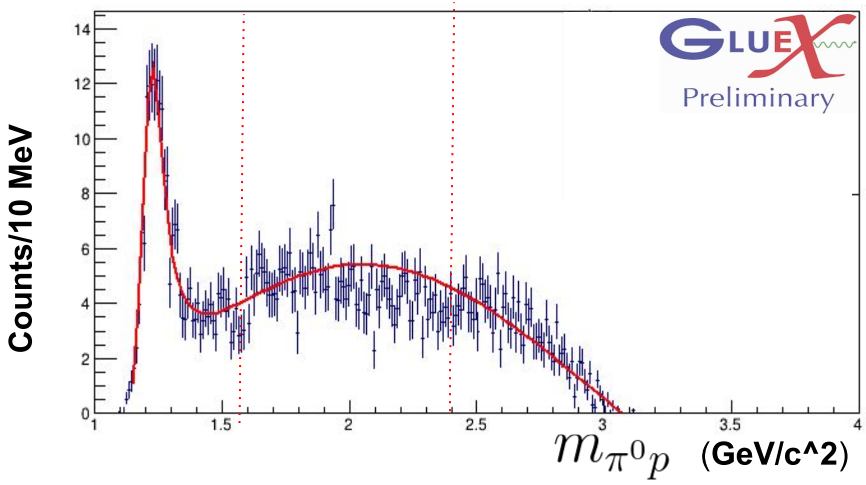
$$Cov(N,D) = \frac{P_\parallel}{4}(3Y_{\perp 2} + Y_{\perp 6}) - (\perp \Leftrightarrow \parallel)$$

Numerator Variance

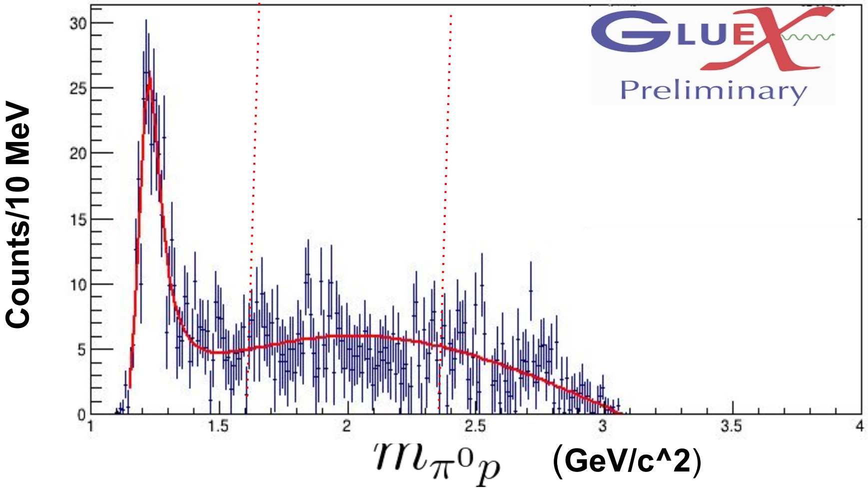


$m_{\pi^0 p}$ (GeV/c^2)

Denominator Variance



Covariance



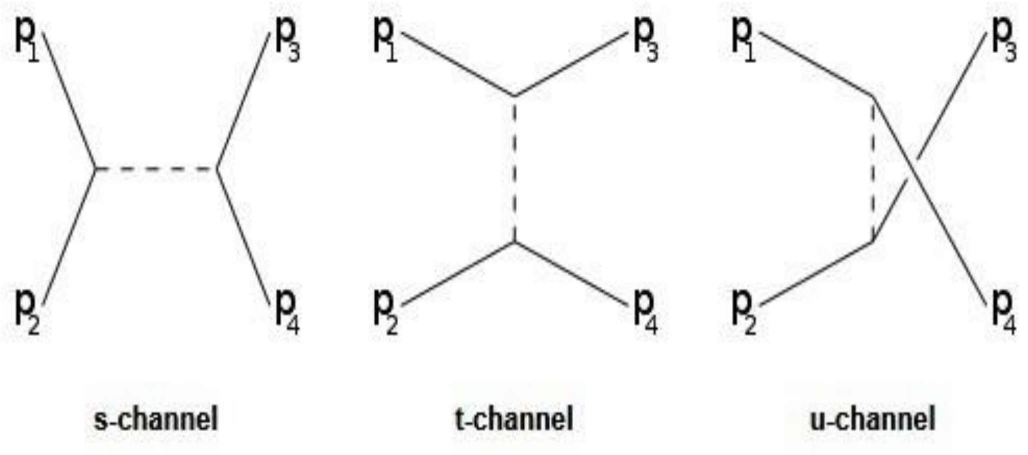
Mandelstam variables

- Lorentz invariant quantities involving Energy, Momentum and angles between them.

$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$

$$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$$

$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$



- **s** -> square of the center-of-mass energy (invariant mass)
- **t** -> square of the four-momentum transfer.

$$s + t + u = m_1^2 + m_2^2 + m_3^2 + m_4^2$$

Beam asymmetry Σ (Method)

Experiments can be run with polarized beam, target, and recoil baryon

- ➢ P^S , P^i , and P^b respectively

GlueX has **only beam polarization**

- ➢ $P^i = P^b = 0$

$$\sigma = \sigma_0[(1 + P^S_x P^i_y P^b_y) + P(P^b_y + P^S_x P^i_y) + \Sigma(P^S_x + P^i_y P^b_y) + T(P^i_y + P^S_x P^b_y)$$
$$+ E(P^S_z P^i_z + P^S_y P^i_x P^b_y) + F(P^S_z P^i_x - P^S_y P^i_z P^b_y) + G(-P^S_y P^i_z + P^S_x P^i_x P^b_y)$$
$$+ H(-P^S_y P^i_x - P^S_z P^i_z P^b_y) + C_x(P^S_z P^b_x + P^S_y P^i_y P^b_z) + C_z(P^S_z P^b_z - P^S_y P^i_y P^b_x)$$
$$+ O_x(-P^S_y P^b_x + P^S_z P^i_y P^b_z) + O_z(-P^S_y P^b_z - P^S_z P^i_y P^b_x) + T_x(P^i_x P^b_x + P^S_x P^i_z P^b_z)$$
$$+ T_z(P^i_x P^b_z - P^S_x P^i_z P^b_x) + L_x(P^i_z P^b_x - P^S_x P^i_x P^b_z) + L_z(P^i_z P^b_z - P^S_x P^i_x P^b_x)]$$

$$\sigma_{\text{pol}}(\phi, \phi_\gamma) = \sigma_0\{1 - P_\gamma \Sigma \cos[2(\phi - \phi_\gamma)]\},$$

σ_{pol} , σ_0 are polarized, unpolarized cross sections

p_γ Photon beam polarization