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Beam asymmetry Σ of the $a_0(980)^0$ photoproduction in the GlueX experiment

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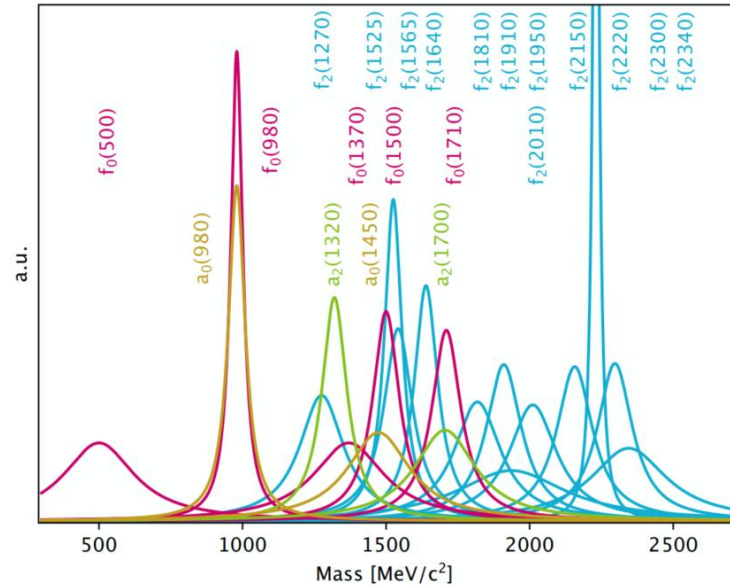


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SC0016583.



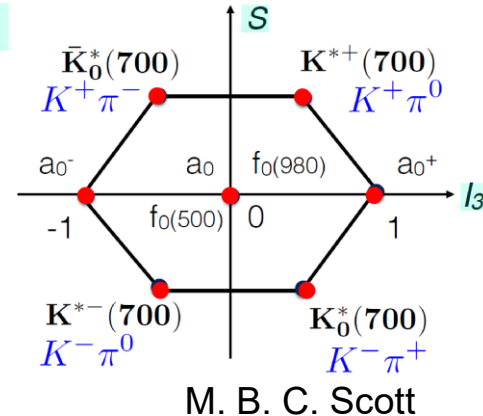
LIGHT SCALAR MESONS

- The structure and properties of light scalar mesons are not fully understood.
- This a consequence of the overlap of many meson resonances with wide widths
- Of these mesons, we are interested in the neutral member of the $a_0(980)$ triplet, the $a_0(980)^0$ meson, here after referred to as the $a_0(980)$.



Kulšner, Meike. <https://indico.jlab.org/event/960/>

$$J^{PC} = 0^{++}$$



Strakovsky, Igor.
<https://agenda.infn.it/event/20446/sessions/16002/#2020116>

$a_0(980)$ $J^{PC} = 0^{++}$

- The $a_0(980)$ is a scalar meson with a mass of 980 MeV that primarily decays into an $\eta\pi^0$, with a secondary decay into $K\bar{K}$.
- Branching ratio fraction: $\Gamma_{KK}/\Gamma_{\eta\pi} = 0.172$
- Studying photoproduction of the $a_0(980)$ through beam asymmetries (Σ)
 - $\eta\pi^0$ channel
 - Exclusive four photons and one proton final state

$$\gamma + p \rightarrow p + a_0$$

$$a_0 \rightarrow \pi^0 + \eta$$

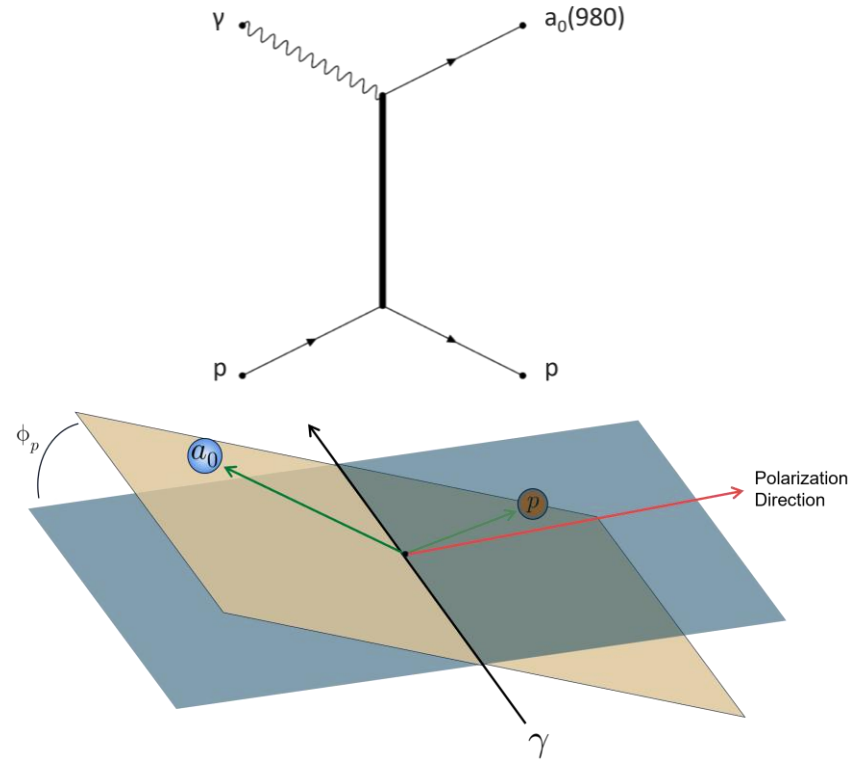
$$\pi^0 \rightarrow 2\gamma$$

$$\eta \rightarrow 2\gamma$$

MOTIVATION

- At high energies the $a_0(980)$ is produced through virtual meson exchange in Regge theory.
- Photon polarization // to the reaction plane $\rightarrow$ Unnatural exchange
- Photon polarization $\perp$ to the reaction plane $\rightarrow$ Natural exchange
- A photoproduction beam asymmetry is related to the differences in these exchanges

$$\Sigma = \frac{d\sigma_{\perp} - d\sigma_{\parallel}}{d\sigma_{\perp} + d\sigma_{\parallel}} \approx \frac{d\sigma_N - d\sigma_U}{d\sigma_N + d\sigma_U}$$



$$\begin{aligned} \text{Unnatural } \rightarrow P &= (-1)^{J+1}; \pi, \eta, b_1, h_1 \\ \text{Natural } \rightarrow P &= (-1)^J; \rho, \omega, a_2, f_2 \end{aligned}$$

PHOTOPRODUCTION AND BEAM ASYMMETRY

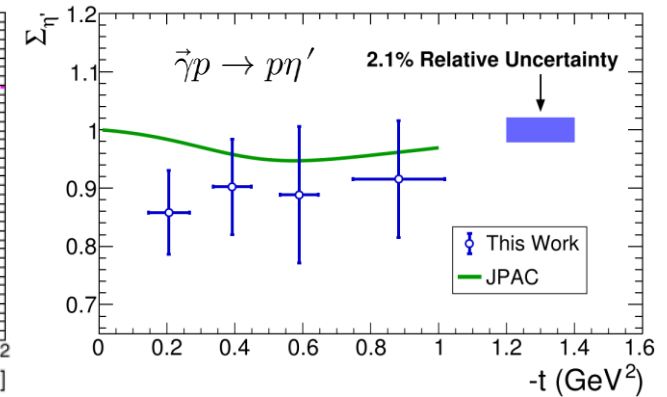
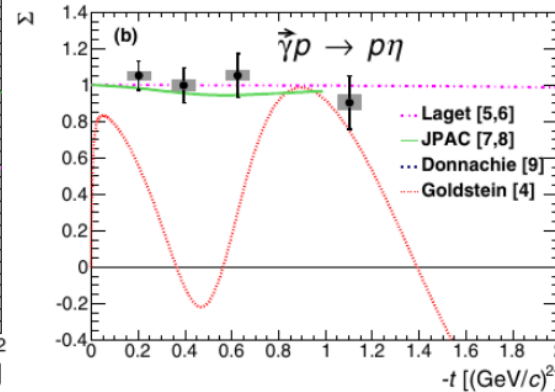
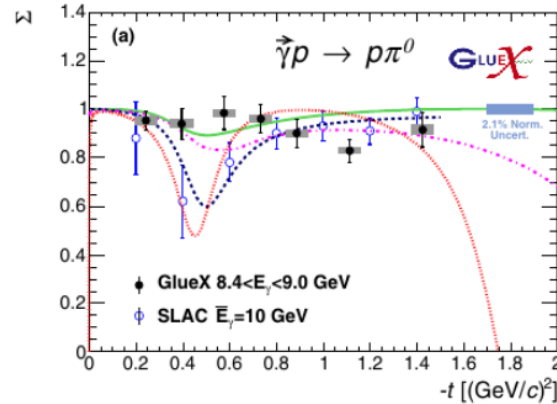
- Measure of the polarized yields of the $a_0(980)$.
- Take the difference between flux normalized the perpendicular and polarized yields and divide by their sum.
- Fit with a cosine function and extract the beam asymmetry.

$$Y_{\perp/\parallel} \approx N_{\perp/\parallel} \left(1 \pm P_{\perp/\parallel} \Sigma \cos(2\phi_p) \right)$$

$$Y_A = \frac{Y_{\perp}(\phi_p) - F_R Y_{\parallel}(\phi_p)}{Y_{\perp}(\phi_p) + F_R Y_{\parallel}(\phi_p)} = \frac{(\bar{P}_{\perp} + \bar{P}_{\parallel}) \Sigma \cos 2(\phi_p)}{2 + (\bar{P}_{\perp} - \bar{P}_{\parallel}) \Sigma \cos 2(\phi_p)}$$

PSEUDOSCALAR BEAM ASYMMETRY RESULTS

- The beam asymmetry is related to the parity of the generated particle
- Pseudoscalar mesons, like the η , π^0 , and η' have a negative parity and a $\Sigma \approx +1$ across $-t$
- Natural exchange dominated

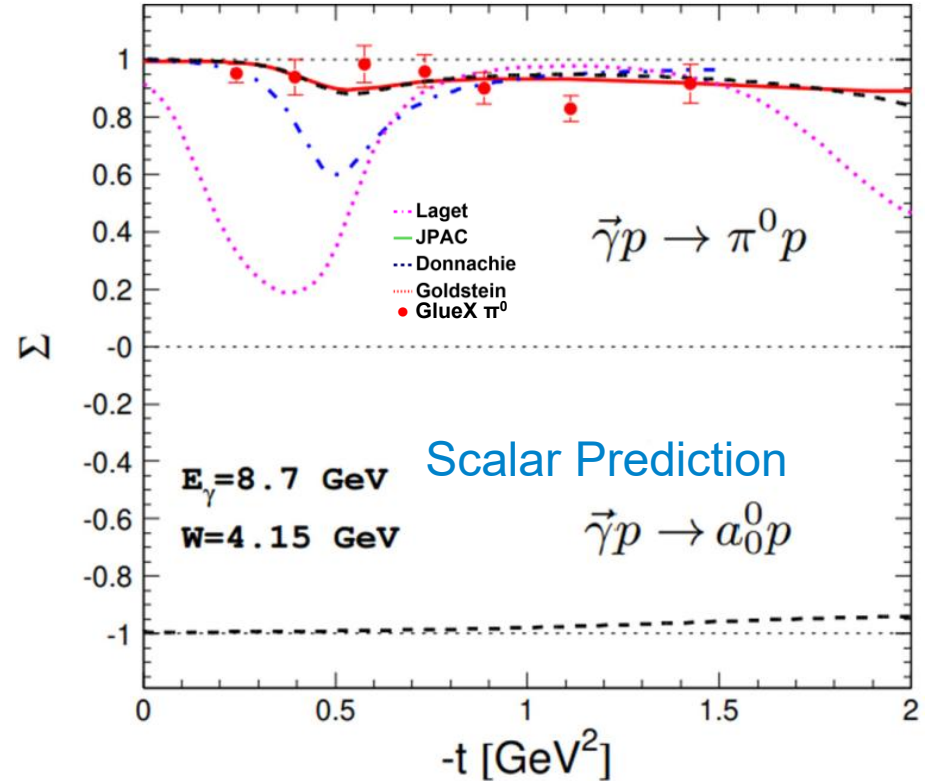


Ghoul et al. (GlueX Collaboration) <https://doi.org/10.1103/PhysRevC.95.042201>

S. Adhikari et al. [GlueX Collaboration], Phys. Rev. C 100, 052201 (2019).

SCALAR BEAM ASYMMETRY PREDICTIONS

- $a_0(980)$ has the opposite parity, *i.e.*, +1
- Expected $\Sigma \approx -1$ across $-t$
- Unnatural exchange dominated
- Predicted Σ for the $a_0(980)$ is shown as the black dashed line in the plot



JEFFERSON LABORATORY

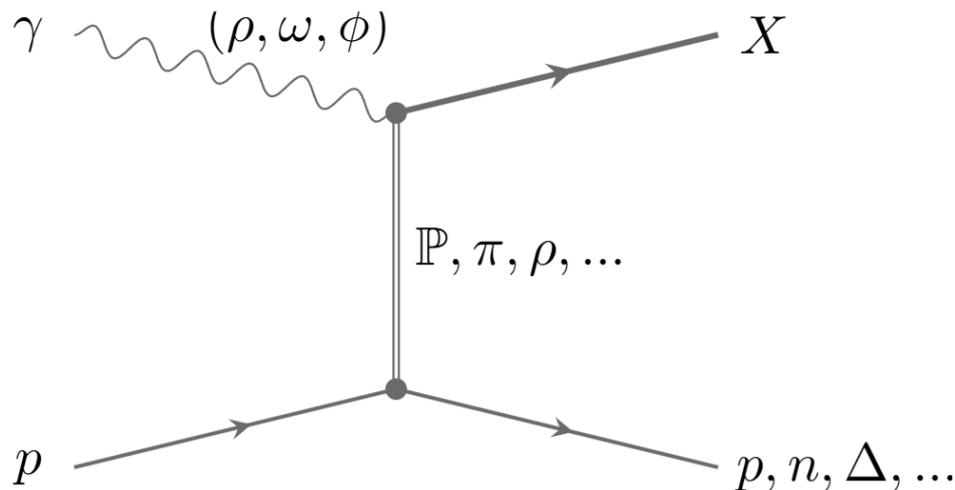
- National laboratory in Newport News, Virginia
- Continuous Electron Beam Facility (CEBAF) provides high energy polarized electrons with energies that can be 2.2, 4.4, 6.6, 8.8 or 11 GeV
- 4 experiment halls
 - Halls A, B, and C study electron scattering
 - Hall D studies photon scattering



P. Hurr https://indico.cern.ch/event/1250132/contributions/5361478/attachments/2674845/4638086/talk_IWHSS_PH.pdf

GLUEX

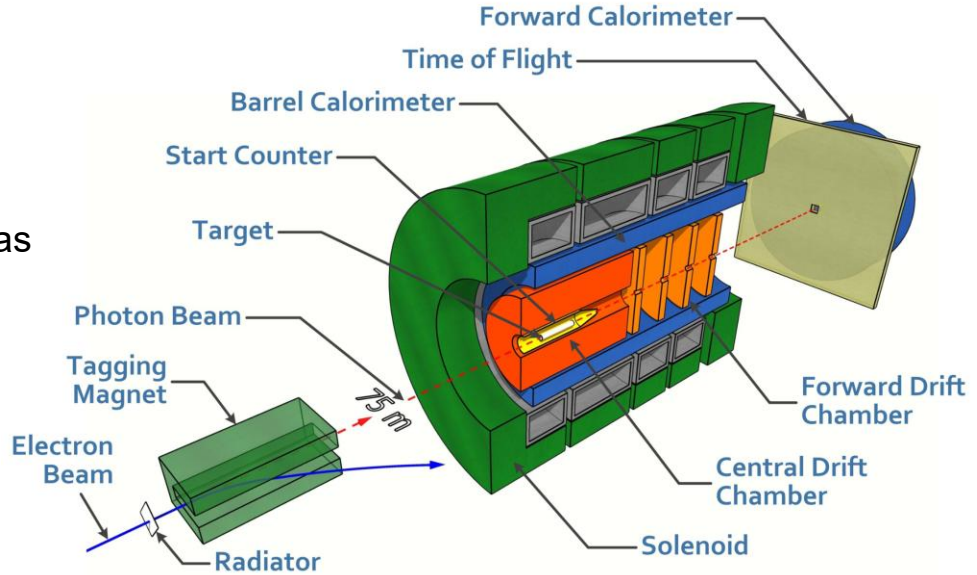
- Gluonic Excitation (GlueX) is a hermetic, fixed target experiment housed in Hall D
 - Light meson spectroscopy
 - Gluonic excitations in mesons, *i.e.*, hybrid mesons
 - Meson polarization measurements
 - Beam asymmetry meson photoproduction asymmetries
 - Short range correlations
- GlueX receives an electron beam from CEBAF which collides with a diamond radiator to produce a high energy linearly polarized photon beam to interact with a LH_2 target.
- Polarization angle of the photon beam is changed via diamond radiator rotations



A. Austregesilo https://indico.ihep.ac.cn/event/6329/contributions/83272/attachments/43252/49810/PANIC2017_Austregesilo.pdf

GLUEX

- 4 polarization directions broken into 2 orientation pairs for a reduction of acceptance effects
 - 0 and 90 degrees
 - 45 and 135 degrees
 - 90 and 45 degrees are designated as “perpendicular”, with 0 and 135 being assigned as “parallel” in the analysis
- **Central region**
 - Polar angle coverage : $11 - 126^\circ$
 - Solenoid, Central Drift Chamber, Start Counter, Barrel Calorimeter
- **Forward region**
 - Polar angle coverage : $1 - 11^\circ$
 - Forward Drift Chamber, Forward Calorimeter, Time of Flight



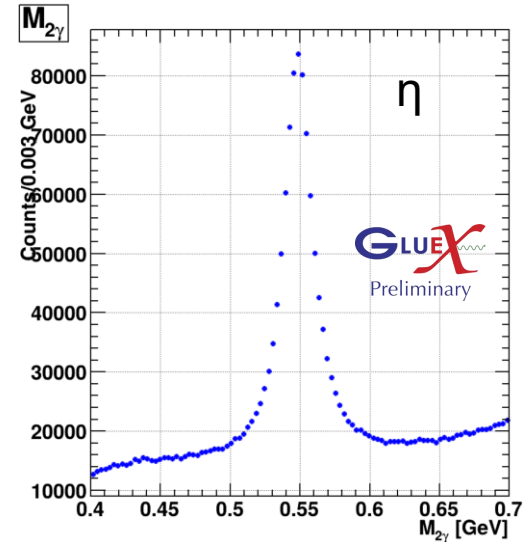
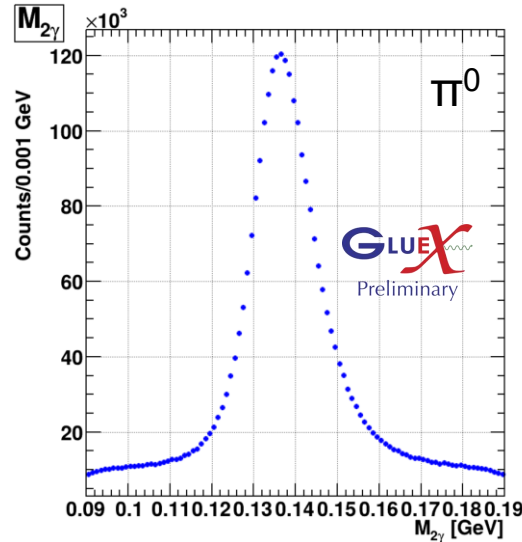
S. Adhikari *et al.* <https://doi.org/10.1016/j.nima.2020.164807>

GLUEX DATA

- All Phase 1 data is used in this work
 - Ran from Spring 2017 to Fall 2018
 - 439.6 pb⁻¹ with $E > 6$ GeV
- Phase 2 will be completed in 2027
- Phase 3 data taking is planned

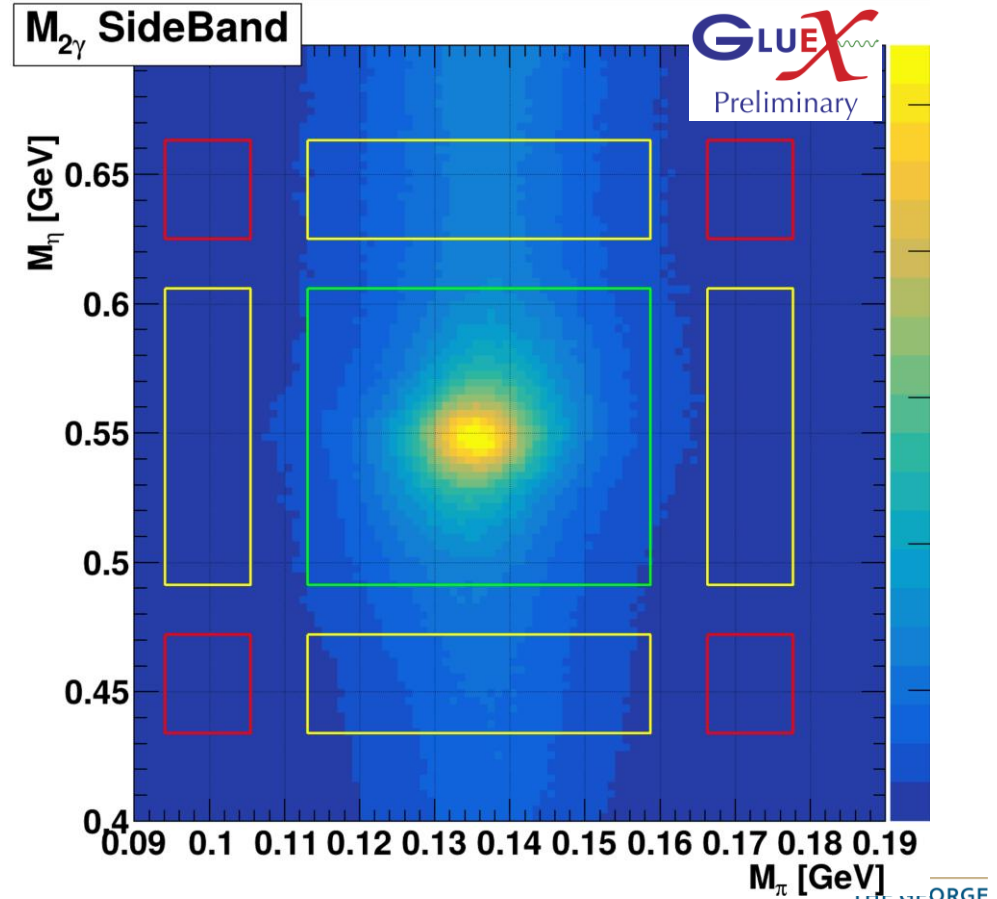
GOOD MESONS

- Software pairs photons into likely π^0 and η candidates.
- Good candidate pairs, are near the mass peaks of the π^0 and the η
- Ideally within each event, one photon pair has a $M_{2\gamma}$ near M_{π} and the other pair a near M_{η}



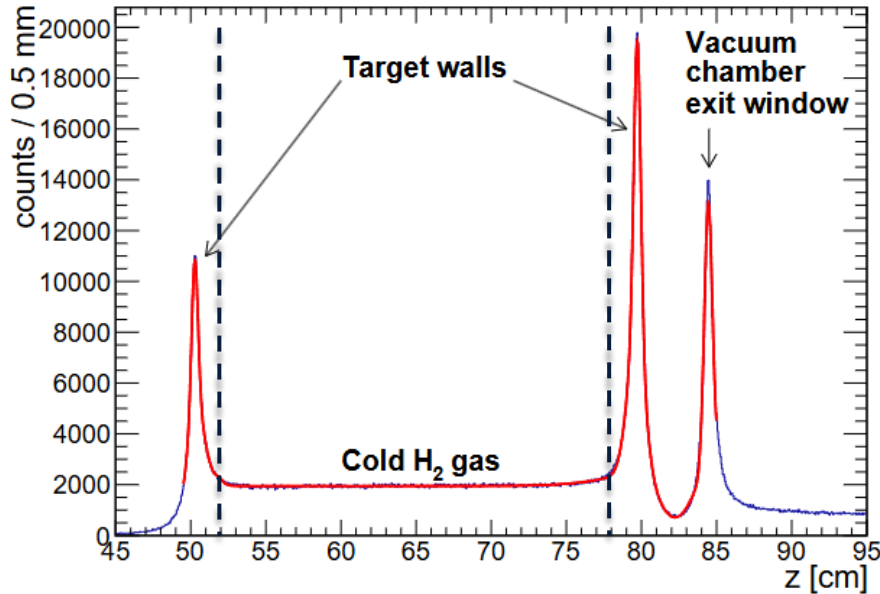
SIDEBAND SUBTRACTION

- Sideband method weighs events based upon the distance from the π^0 and η masses
- Signal region (green box) get a weight of unity
- Orange boxes, each have one “good” meson, possess a negative weight
- Red regions have a small positive weight.

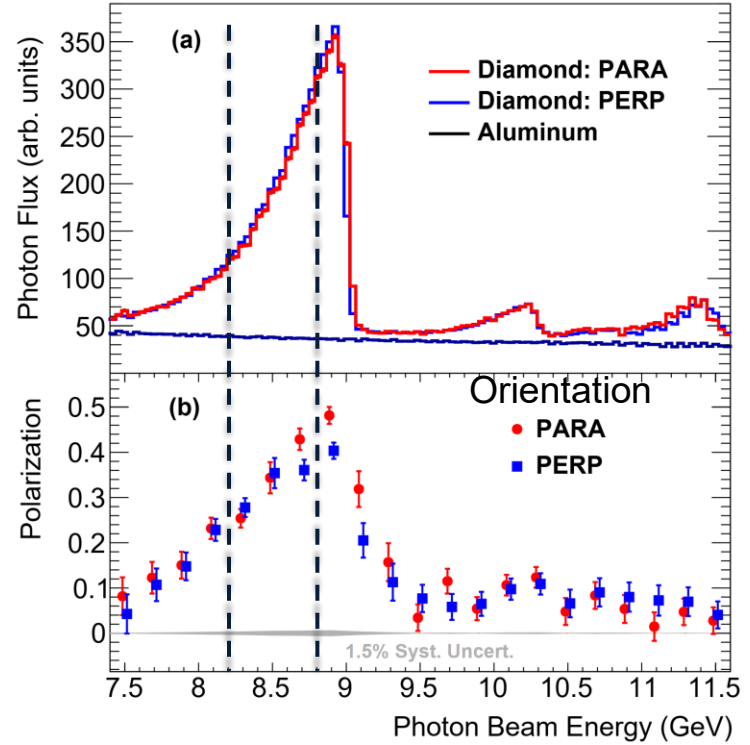


FIDUCIAL/VERTEX CUTS

- $8.2 < E_{\text{beam}} < 8.8 \text{ GeV}$ (coherent peak region)
- $52 < z < 78 \text{ cm}$



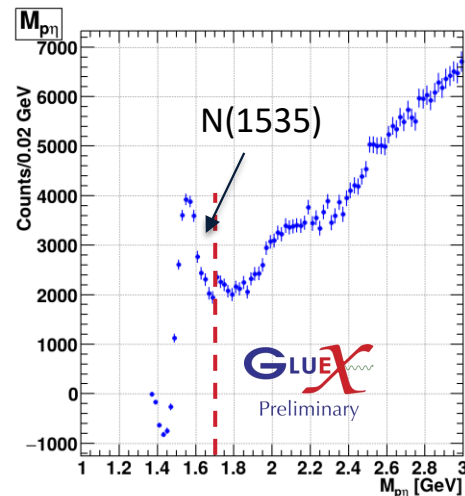
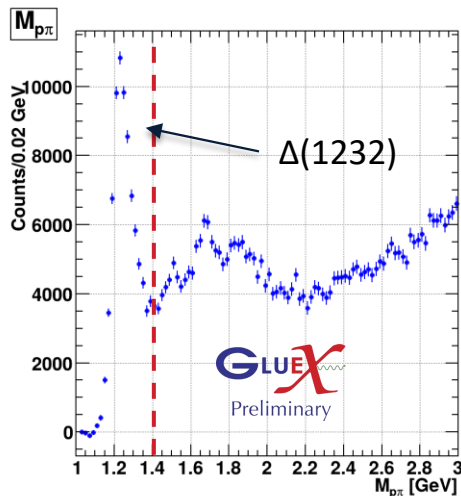
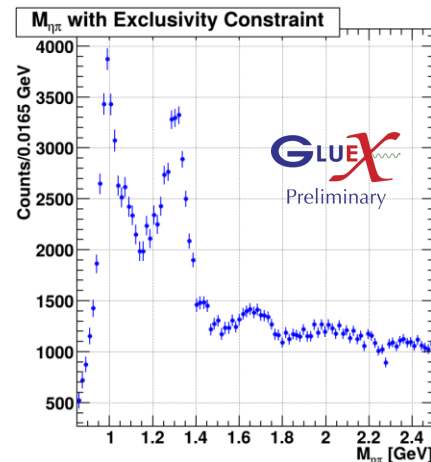
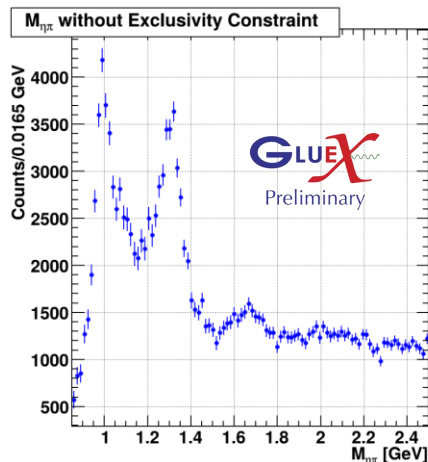
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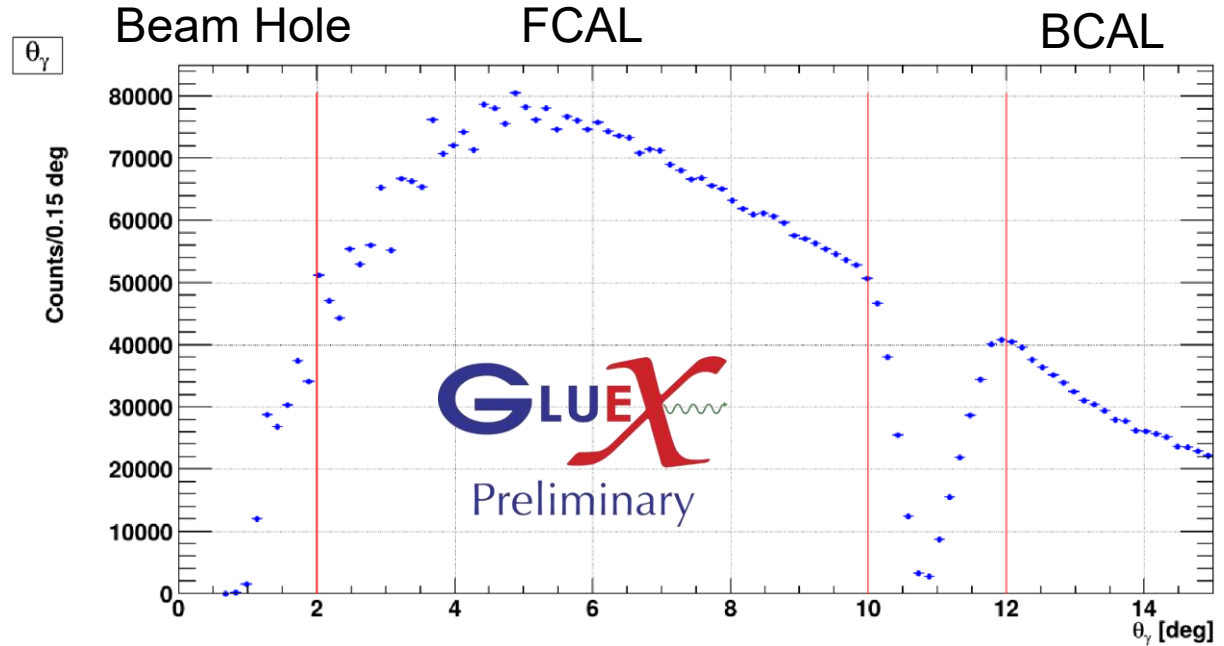
CONTAMINATION

- Other processes can mimic our 4 photons and 1 proton final state
- $b_1(1235) \rightarrow \omega + \pi^0 \rightarrow 5\gamma$
 - If we fail to detect one of the photons, we get the same final state
 - Fix this by removing events with any leftover energy after the kinematic fitting
- Baryonic resonances can contribute
 - Cut out regions in $M_{p\pi}$ and $M_{p\eta}$ near the resonances



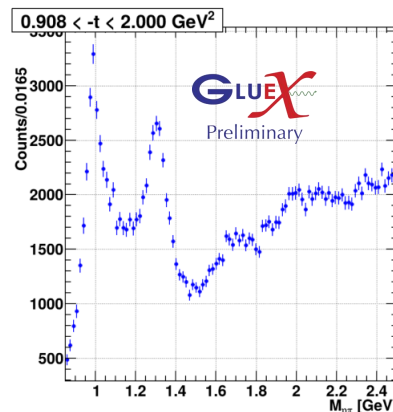
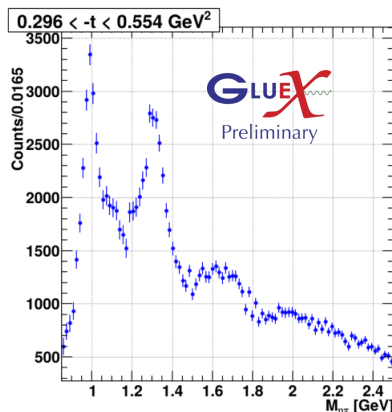
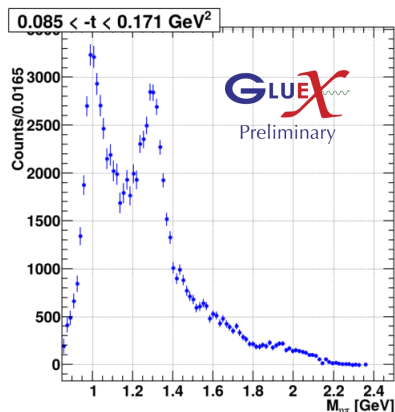
CALORIMETER FIDUCIAL VOLUME CUTS

- $\theta_Y > 2^\circ$; reject events near the beam line
- $\theta_Y < 10^\circ$ or $\theta_Y > 12^\circ$; reject events in the BCAL/FCAL overlap region
- Red lines denote the cut regions



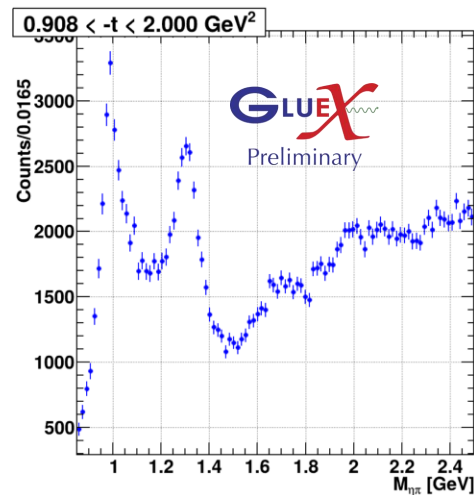
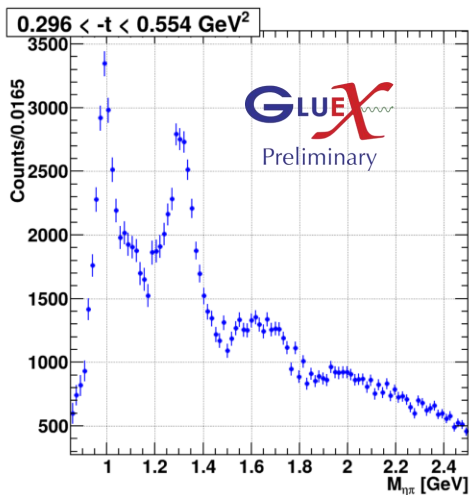
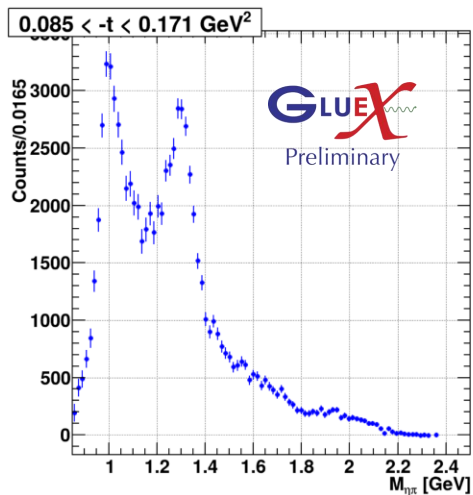
SELECTION SUMMARY BACKGROUND

- All GlueX Phase 1 data, with a $p + 4\gamma$ final state Kinematic fitter and unconstrained η and π^0 masses.
- Photon
 - $2^\circ < \theta_\gamma < 10^\circ$ or $\theta_\gamma > 12^\circ$
 - $E_\gamma > 0.1$ GeV
- Proton
 - $P_p > 0.3$ GeV
- Beam
 - $8.2 < E_{\text{beam}} < 8.8$ GeV
 - $52 < z < 78$ cm
- Baryon contamination
 - $M_{p\pi} > 1.4$ GeV
 - $M_{p\eta} > 1.7$ GeV
- Quality
 - Kinematic Fit $\chi^2 < 20$
 - Sideband Subtraction
 - Unused Energy = 0



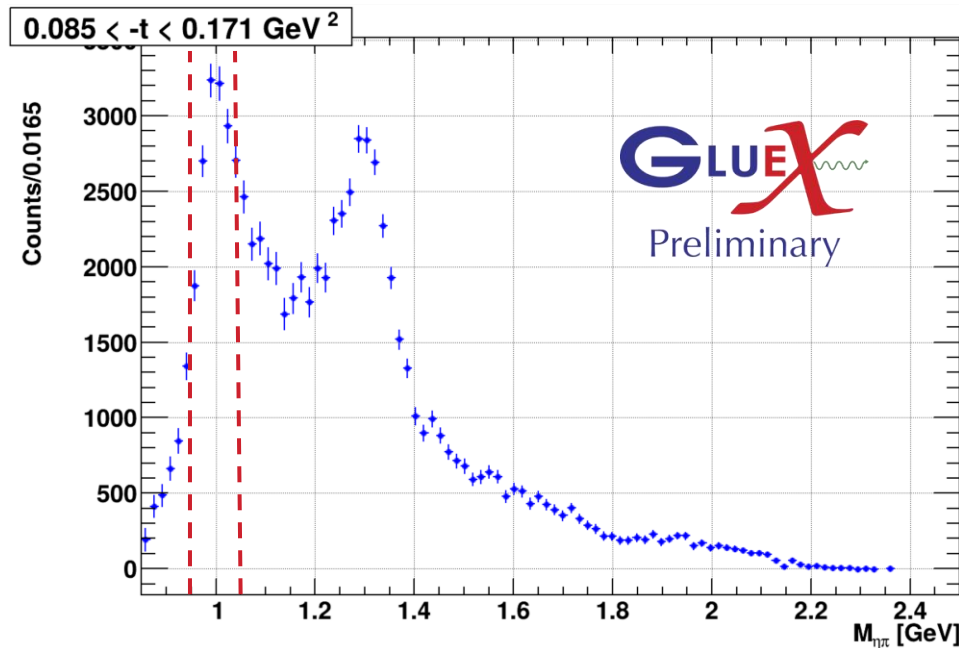
Non- $a_0(980)$ CONTRIBUTIONS

- Strongly t and mass dependent background
- Two sources
 - Non-resonant and baryonic
 - $a_2(1320)$ meson



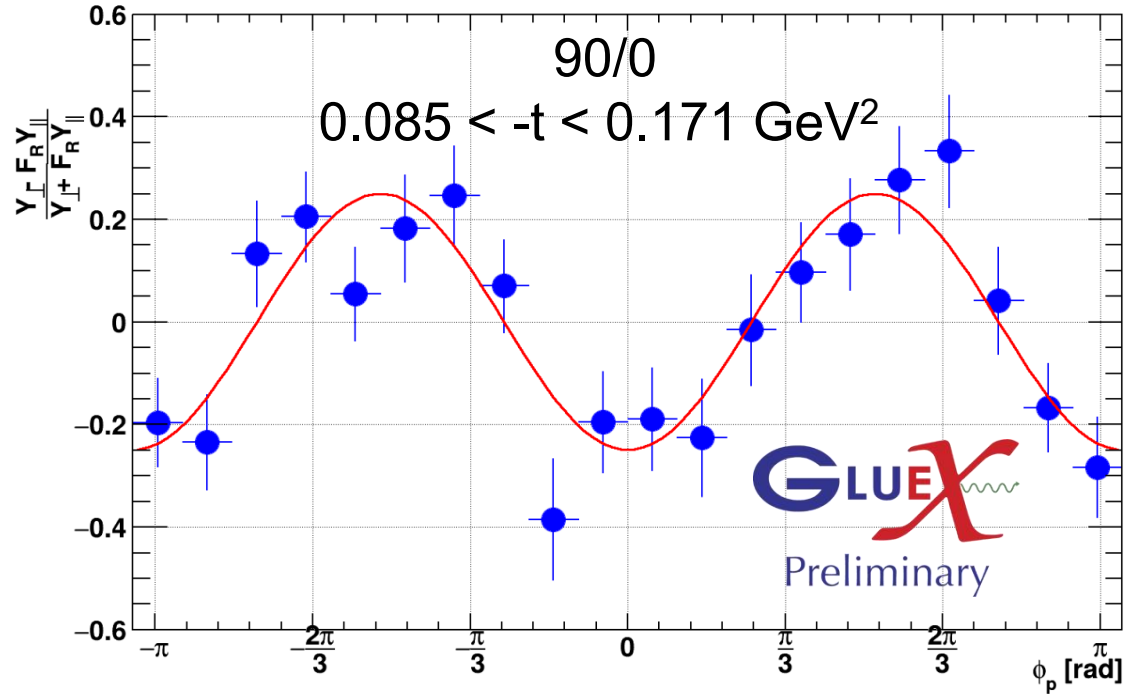
ASYMMETRY EXTRACTION

- Extracting the beam asymmetry under the $a_0(980)$ peak
- $M_{\eta\pi}$ range of 0.9 to 1.05 GeV
- Mass range depicted with the red dotted lines.
- No separation of a_0 -and non- a_0 contributions under mass peak



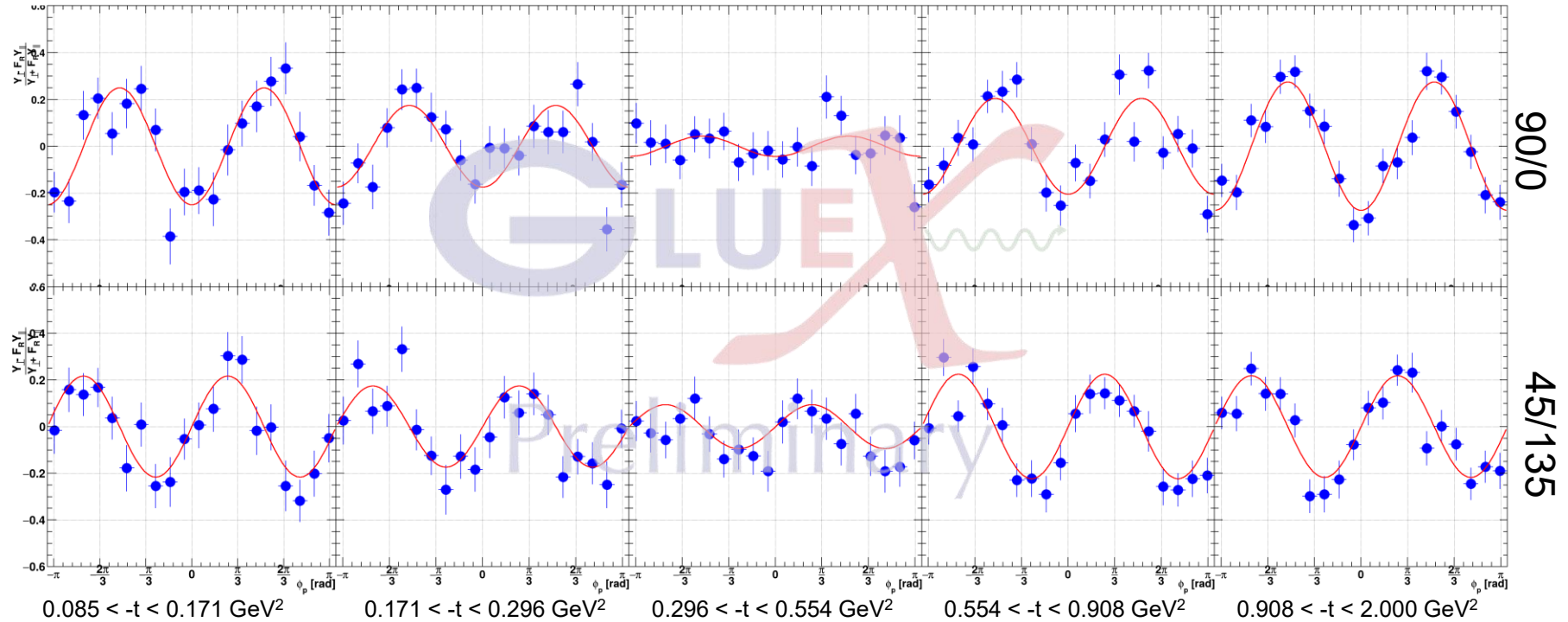
ASYMMETRY FIT

- $M_{\eta\pi}$ yield asymmetry as a function of ϕ_p
- 90/0 orientation in the first $-t$ bin
- Red curve is the $\cos 2\phi_p$ fit function with one free parameter (Σ).



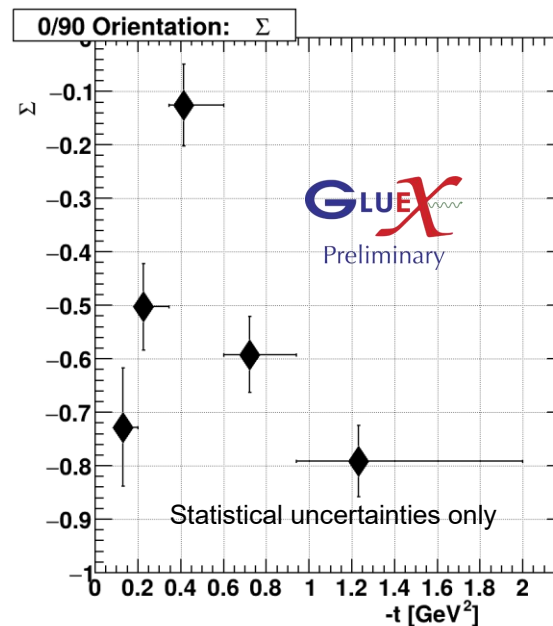
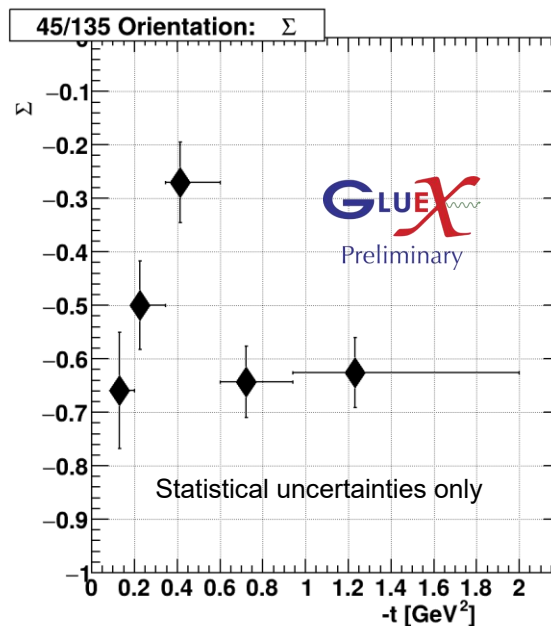
$$Y_A = \frac{Y_{\perp}(\phi_p) - F_R Y_{\parallel}(\phi_p)}{Y_{\perp}(\phi_p) + F_R Y_{\parallel}(\phi_p)} = \frac{(\bar{P}_{\perp} + \bar{P}_{\parallel})\Sigma \cos 2(\phi_p)}{2 + (\bar{P}_{\perp} - \bar{P}_{\parallel})\Sigma \cos 2(\phi_p)}$$

BEAM ASYMMETRY



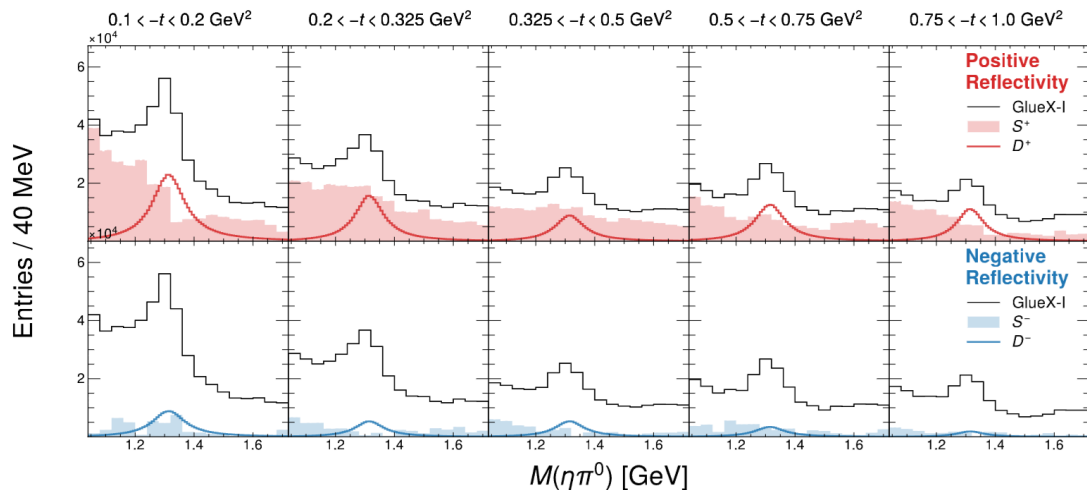
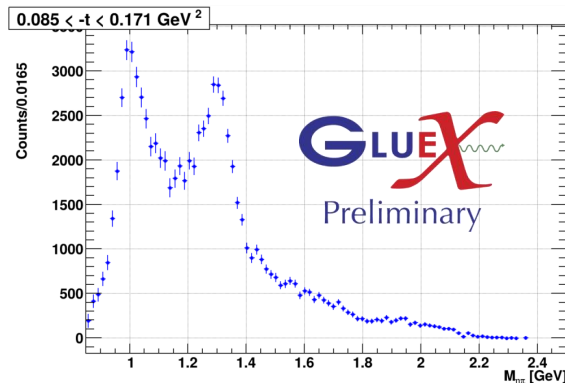
Σ RESULTS

- Σ for $0.9 < M_{\eta\pi} < 1.05$, is consistently **negative** across all $-t$
- The rise in the asymmetry in the middle bin, is consistent across all runs
- Unnatural exchange dominance
- Combining the two orientation pairs into one Σ is in progress



$a_0(980)$ ASYMMETRY EXTRACTION

- Extracting the $a_0(980)$ from the fit is challenging
 - Mass and $-t$ dependent background.
 - Hard to disentangle the a_0 , which is an s-wave and the non-resonant s-wave contributions in the same area
- Potential paths forward
 - Fix the a_2 yield to the published cross section.
 - Use a two-body phase-space background shape.
 - Use the published S-wave slope.



CONCLUSION AND FUTURE WORK

- The photoproduction beam asymmetry for the $0.9 < M_{\eta\pi} < 1.05$ mass region meson has been extracted, showing a consistent negative asymmetry across $-t$.
- This result is suggestive of significant unnatural exchanges, in contrast to the pseudoscalar results.
- Current work is centered around studying the behavior of the asymmetries in the mid $-t$ range and studying systematic error analyses.

GlueX Acknowledgements



Backup Slides



SIDEBAND

3. Separate weights are calculated for the pi0 part and the eta part of an event.
4. Final event weight =
 $\text{pi0_weight} * \text{eta_weight} * \text{accidentWeight}$
5. Calculations
 1. Pi0(eta) within their respective signal regions -> Weight = 1(1) respectively
 2. Pi0(eta) within their respective skip regions -> Weight = 0(0) respectively
 3. Pi0(eta) within their respective sideband regions -> Weight = $-1 * (\text{Mass width}) / (\text{Length of the total Sideband region})$
 4. Pi0(eta) outside their respective sideband regions -> Weight = 0(0)

π	η	Combined Weight
Signal	Signal	1
Signal	Side band	$-W_{\eta}/W_{b\eta}$
Side Band	Signal	$-W_{\pi}/W_{b\pi}$
Side Band	Side band	$W_{\pi} * W_{\eta} / (W_{b\pi} * W_{b\eta})$

- The table above has all the non-zero weights.
- W stands for the width(Standard Deviation) of the mass peak
- The subscript “b” refers to the side band, so the W_b terms is the width of the sidebands for the respective particles.

REGGE TRAJECTORIES OF INTEREST

- Regge trajectories of primary interest:
 - Vector exchanges : ρ and ω
 - Pseudovector exchanges : $h_1(1170)$ and $b_1(1235)$
- By vector dominance, the vector exchanges dominate