Polarization Observables in High Energy Photoproduction at GlueX

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USERS GROUP MEETING

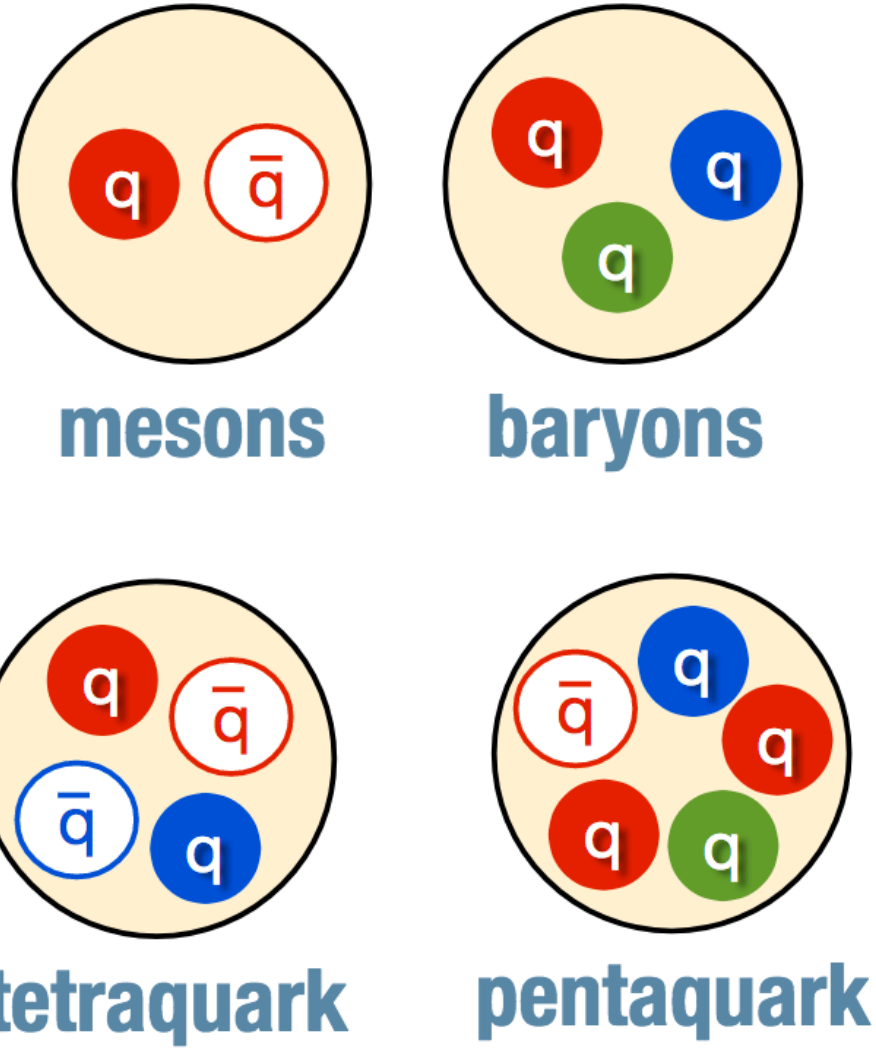
6/17/2018

Outline

- Motivation for GlueX
- Beam Asymmetries
- Spin Density Matrix Elements
- Summary

Quantum Chromo-Dynamics

- Interactions of quarks through the exchange of gluons.
- Single quarks are not observed
  - confined in hadrons.
- We detect combinations of quarks.
- States consisting of 2 or 3 quarks are well described by QCD
- Other states are allowed to exist.

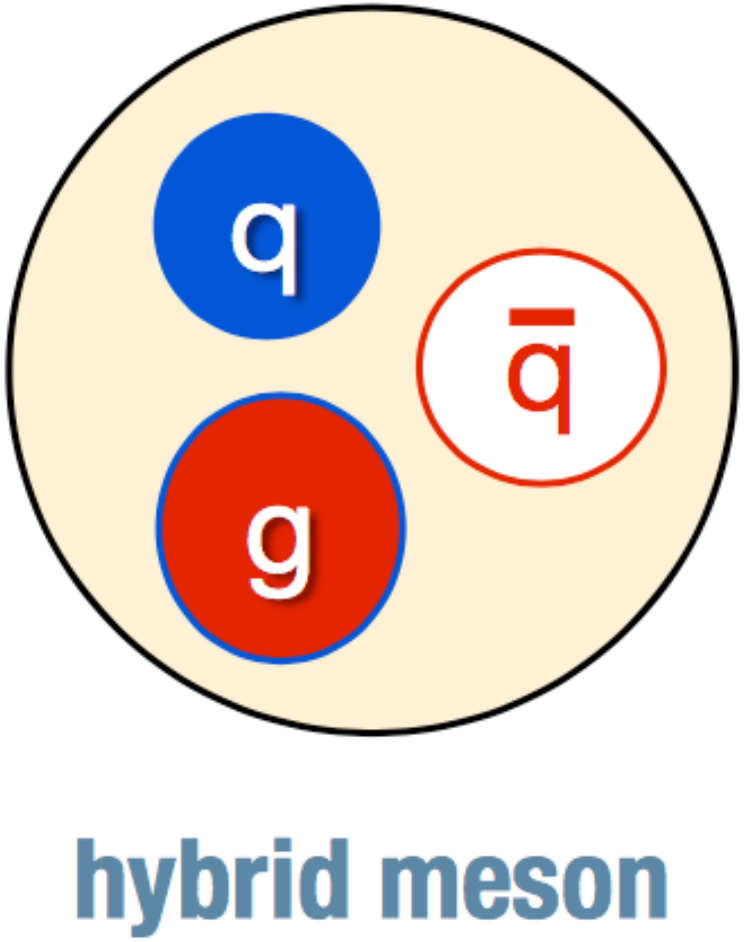


Quantum Chromo-Dynamics

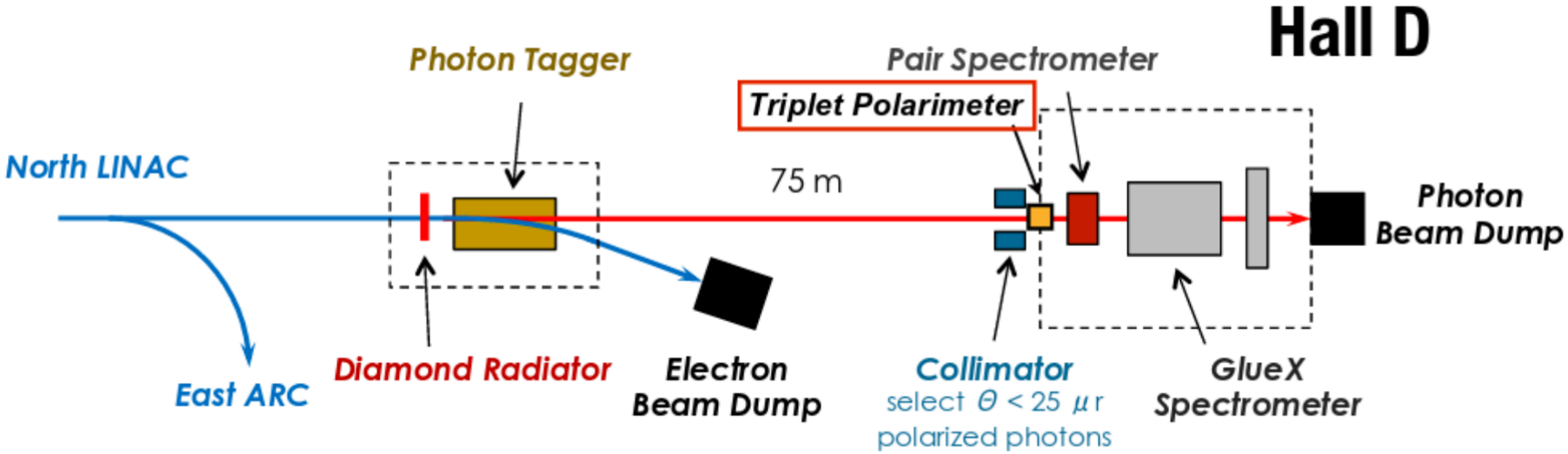
- Certain sets of quantum numbers cannot be formed from a quark and antiquark pair, such as:

$$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$$

- These quantum numbers can be reached if excitations of the gluonic fields contribute.
- These mesons are known as hybrid mesons.
- Lattice QCD predicts a rich spectrum of light hybrid mesons.

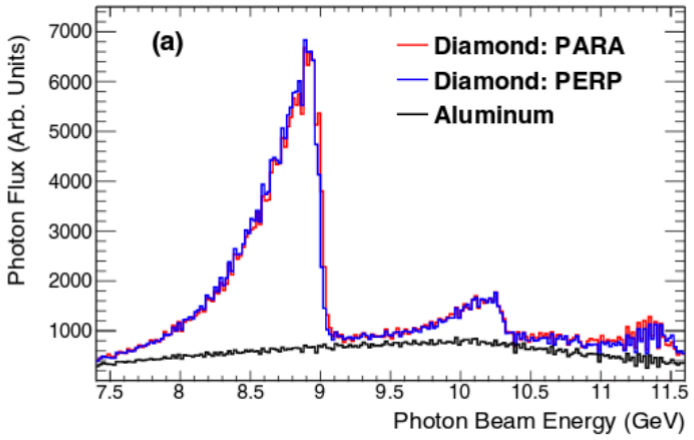


Beamline and Polarization

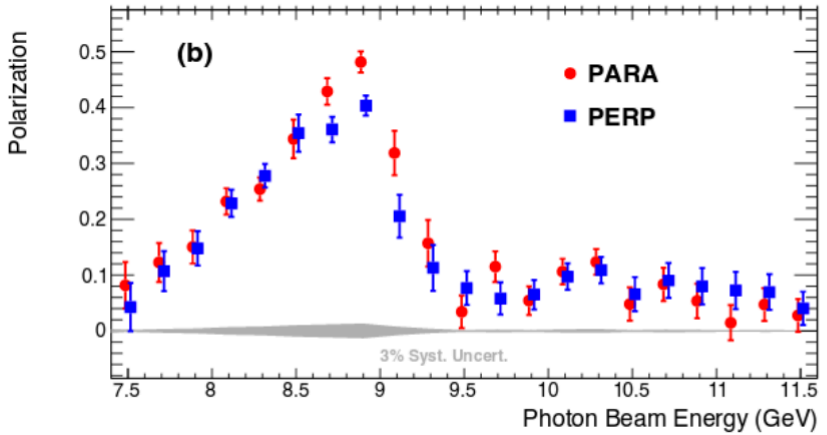


Coherent Bremsstrahlung

Observed Flux

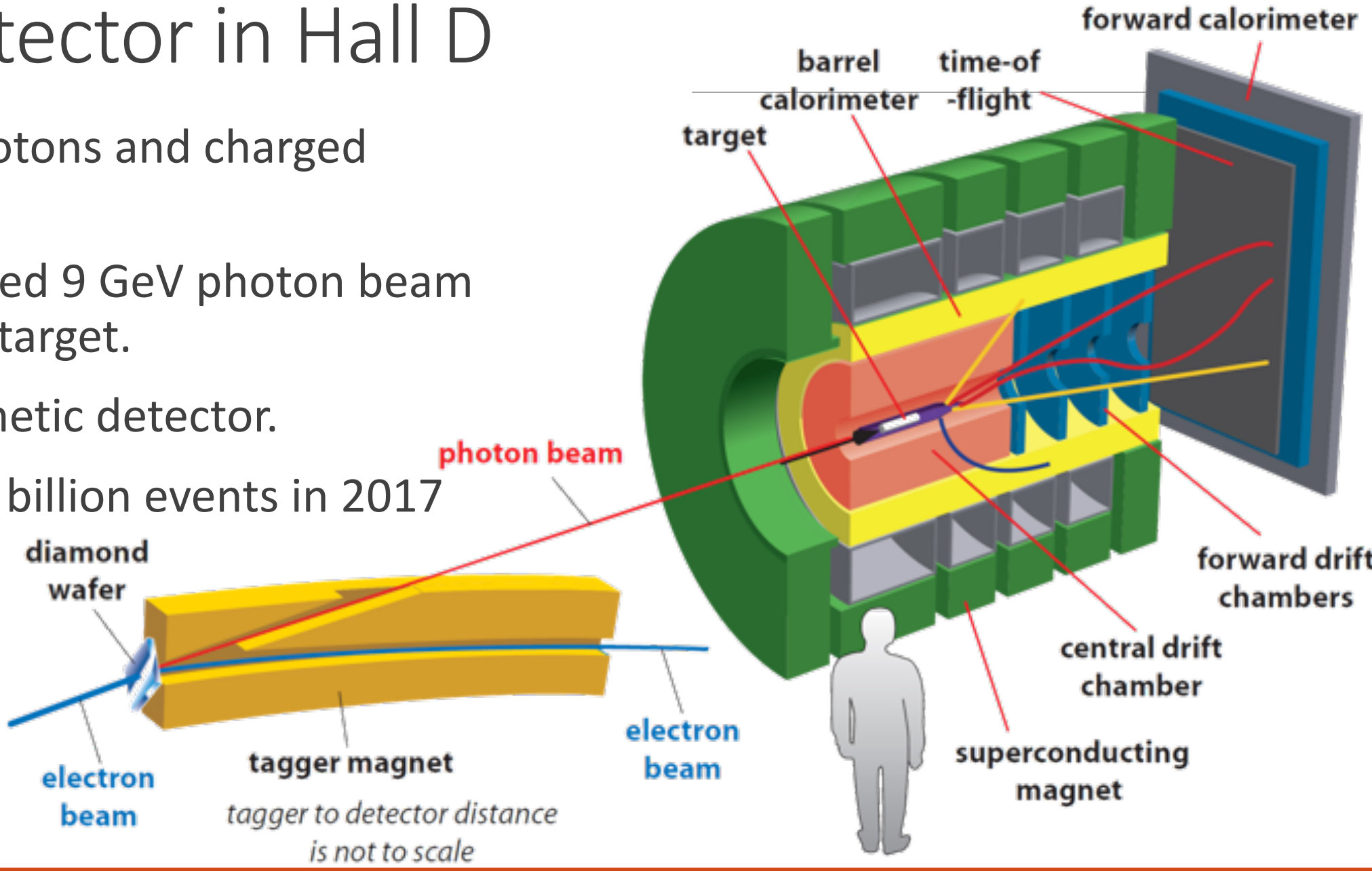


Measured Polarization



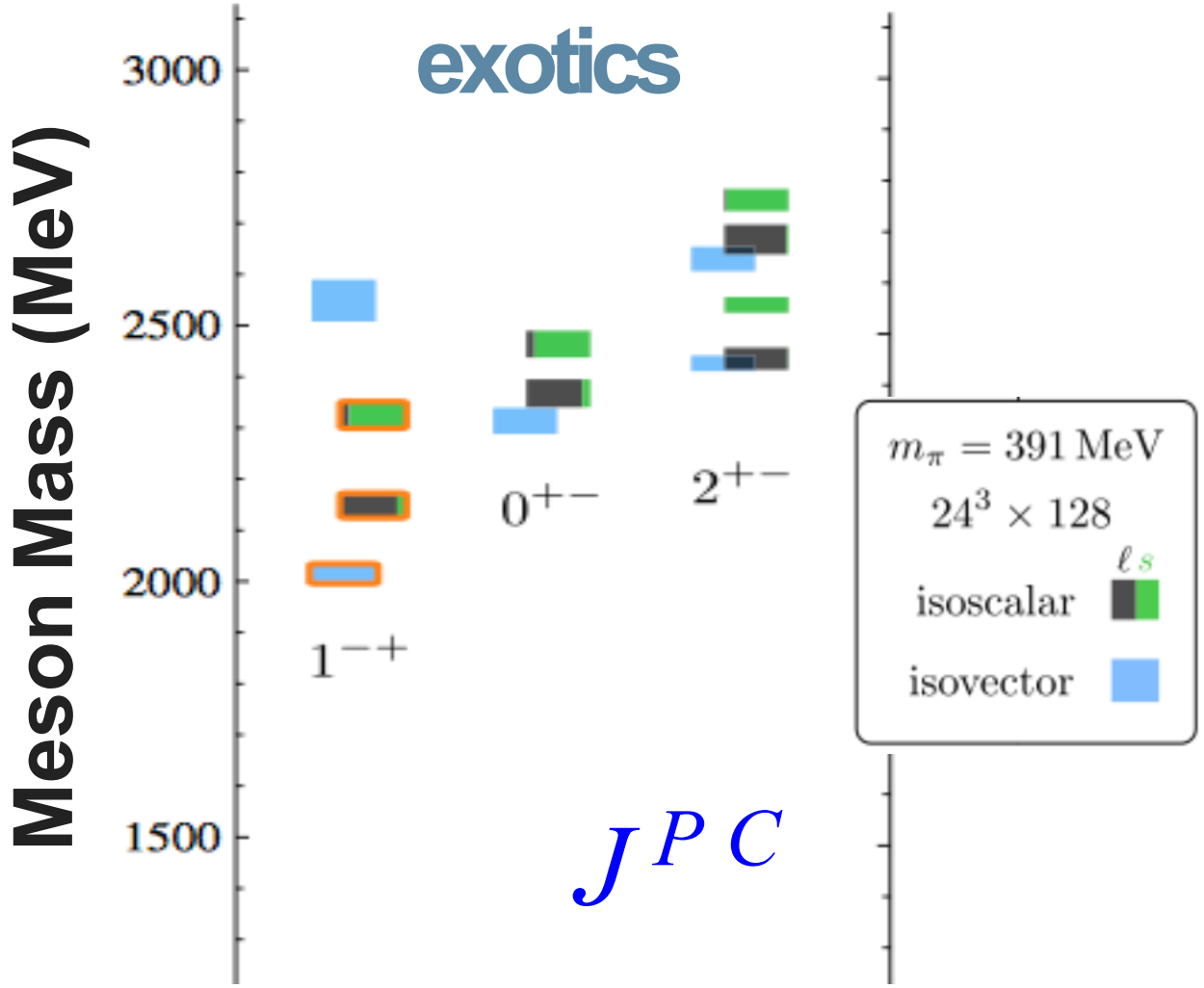
GlueX Detector in Hall D

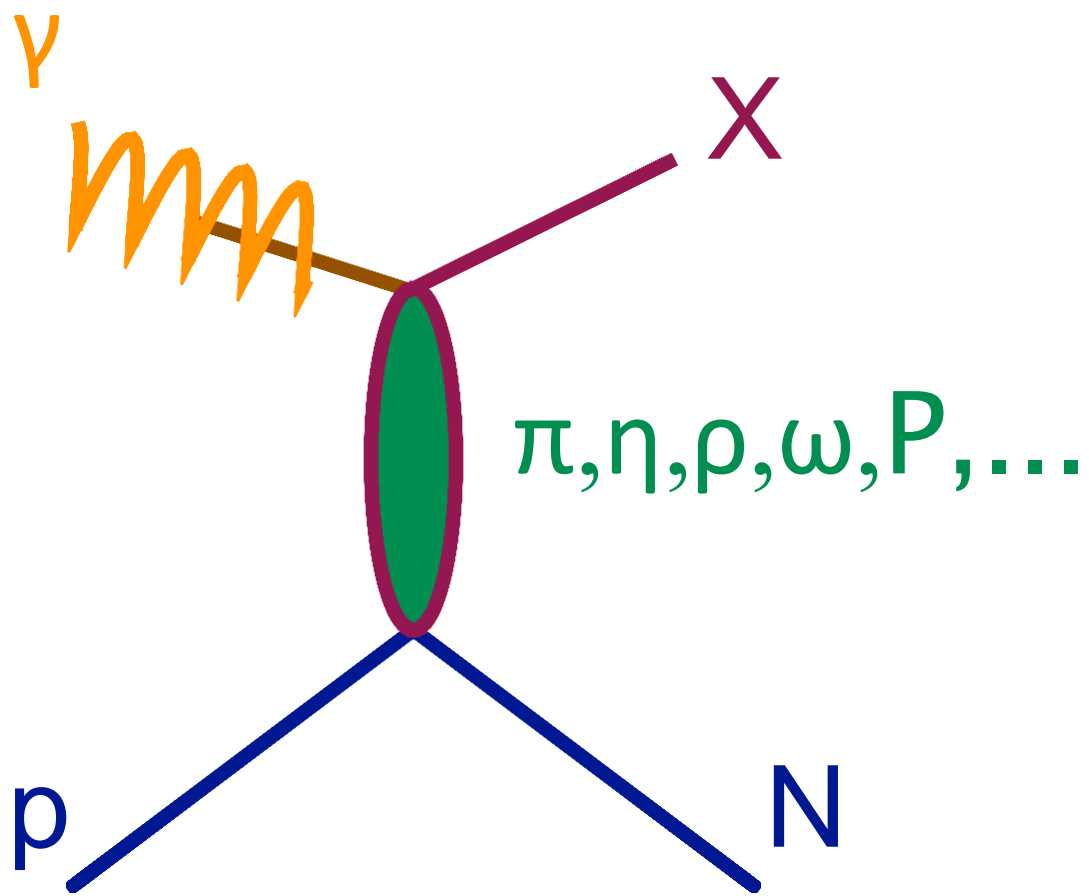
- Sensitive to photons and charged particles.
- Linearly polarized 9 GeV photon beam incident on LH_2 target.
- Nearly 4π hermetic detector.
- Collected ~200 billion events in 2017 and 2018.



Exotic J^{PC} in Photoproduction

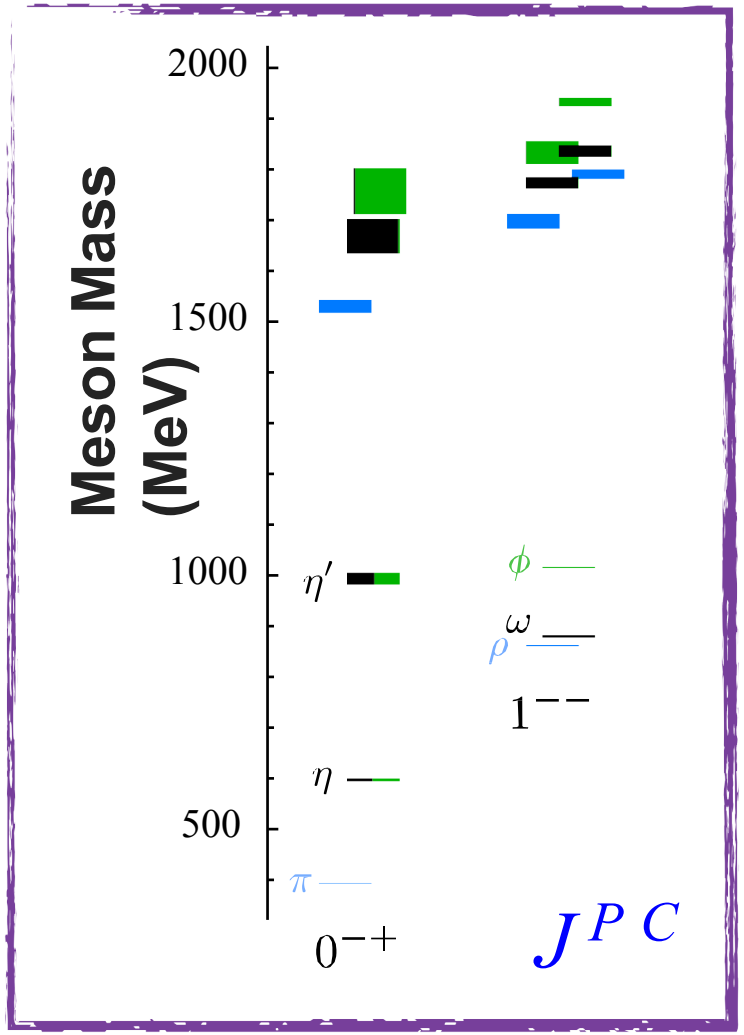
Meson X with particular J^{PC}

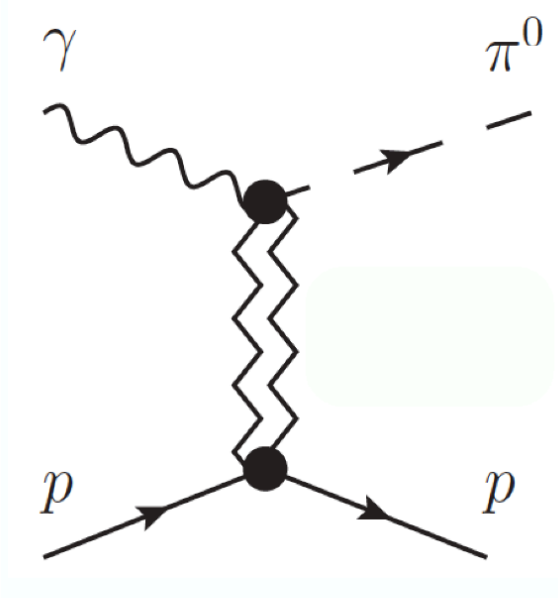




Dudek J J 2013 *Phys. Rev.* D 88 014501

Non-exotic J^{PC} in Photoproduction





Exchange J^{PC}

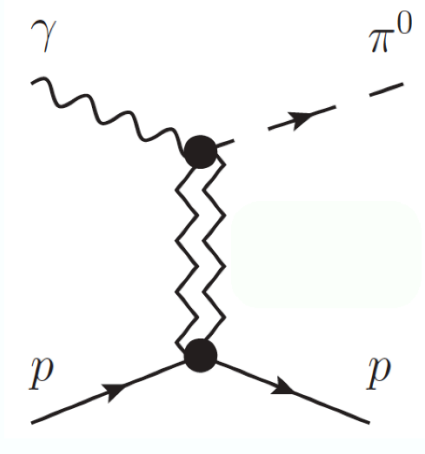
$1^{--} : \omega, \rho$

$1^{+-} : b, h$

- Begin by understanding simpler production mechanisms.
- Linear photon beam polarization critical to filter out J^{PC} of the exchange particle.

Beam Asymmetry Motivation

- Σ Beam asymmetry provides insight into the production mechanism for pseudoscalar mesons.
- GlueX asymmetry measurements will offer new constraints to Regge models.
- Only measurement of Σ for γp → ηp at $E_\gamma > 3$ GeV was made by GlueX.



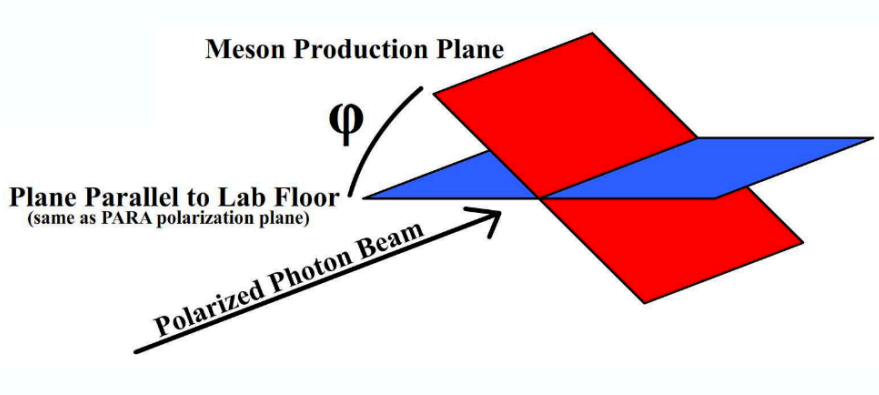
Exchange J^{PC}

$$1^{--} : \omega, \rho$$
$$1^{+-} : b, h$$

$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$

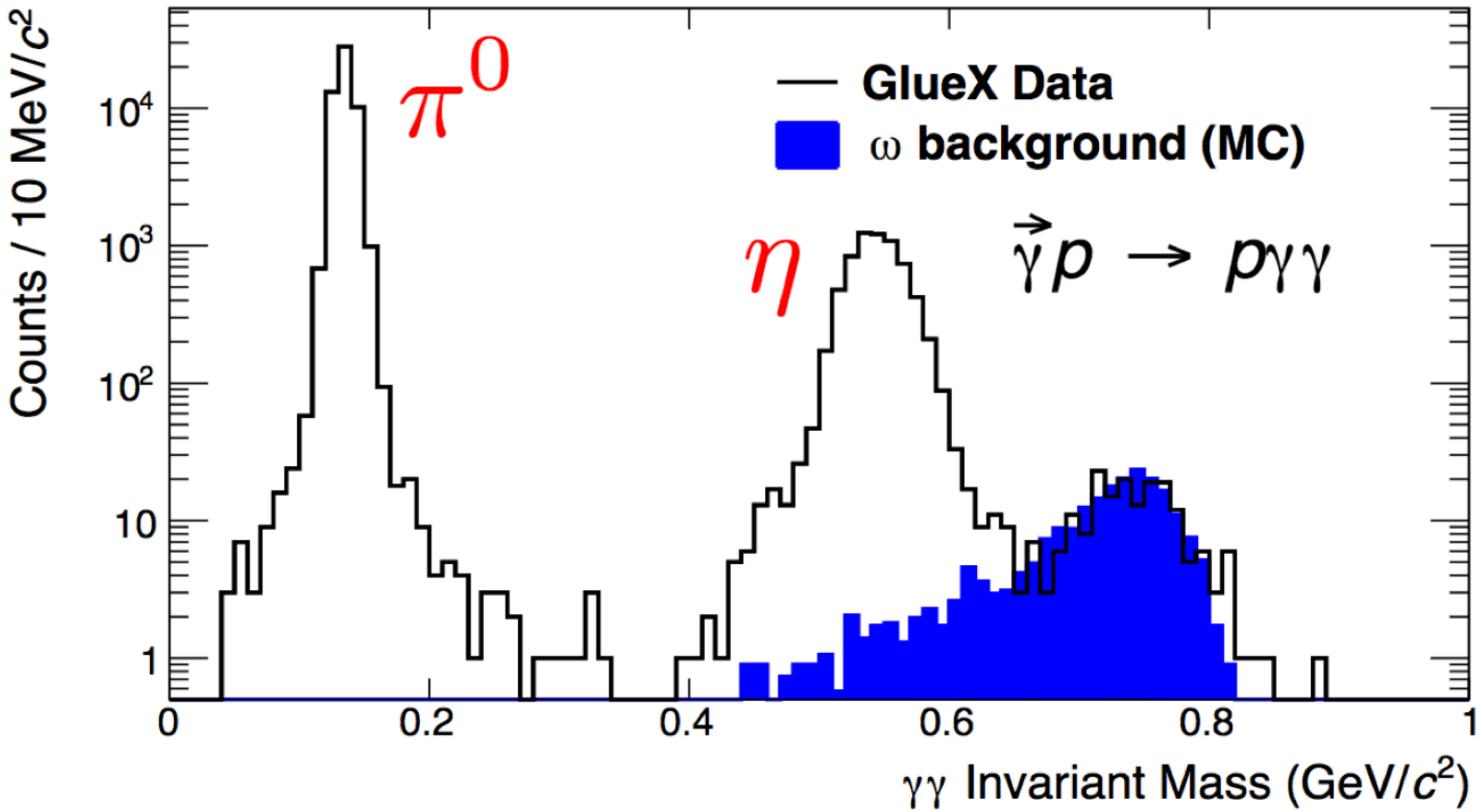
Mathieu et al. PRD 92, 074013 (2015)

- PARA yield: $Y_{\parallel} \propto (1 + P_{\parallel}\Sigma cos(2\phi))$
- PERP yield: $Y_{\perp} \propto (1 - P_{\perp}\Sigma cos(2\phi))$
- Asymmetry: $\frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + F_R Y_{\parallel}} = \frac{(P_{\perp} + P_{\parallel})\Sigma cos(2(\phi - \phi_0))}{2 - (P_{\perp} - P_{\parallel})\Sigma cos(2(\phi - \phi_0))}$

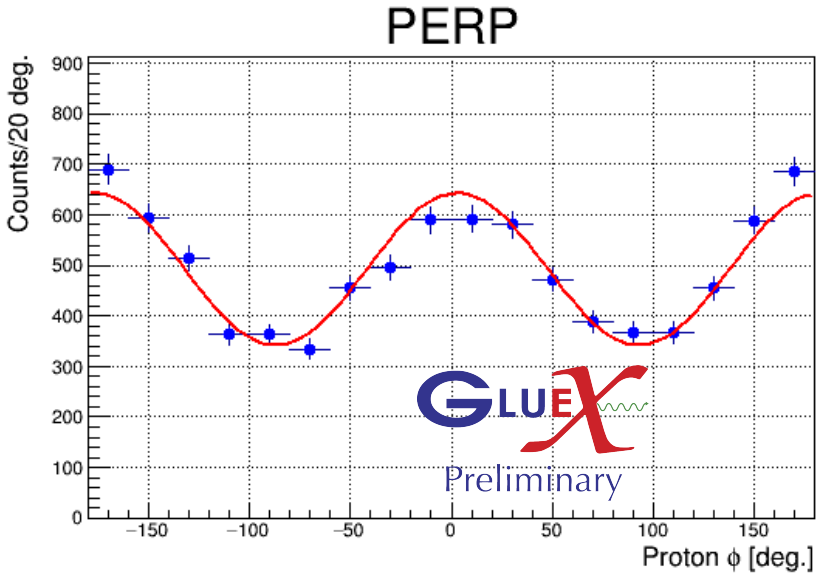


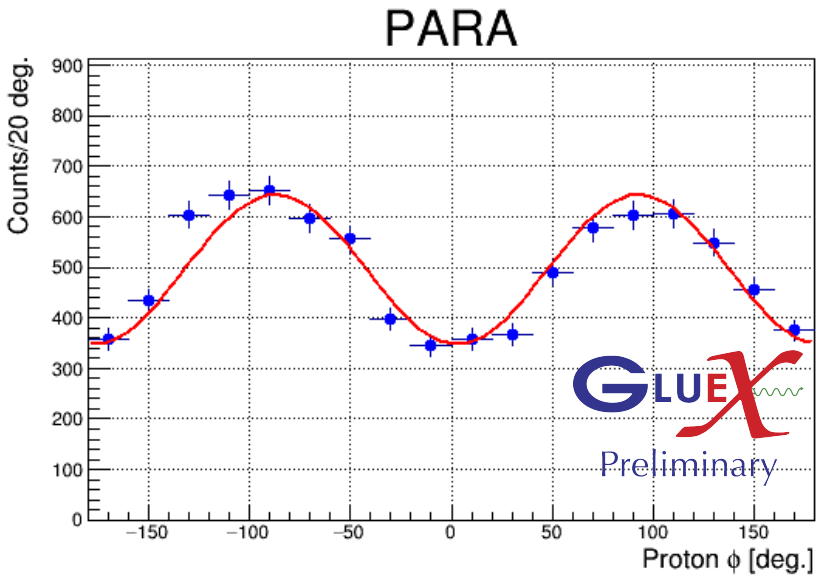
π^0 and η Beam Asymmetries

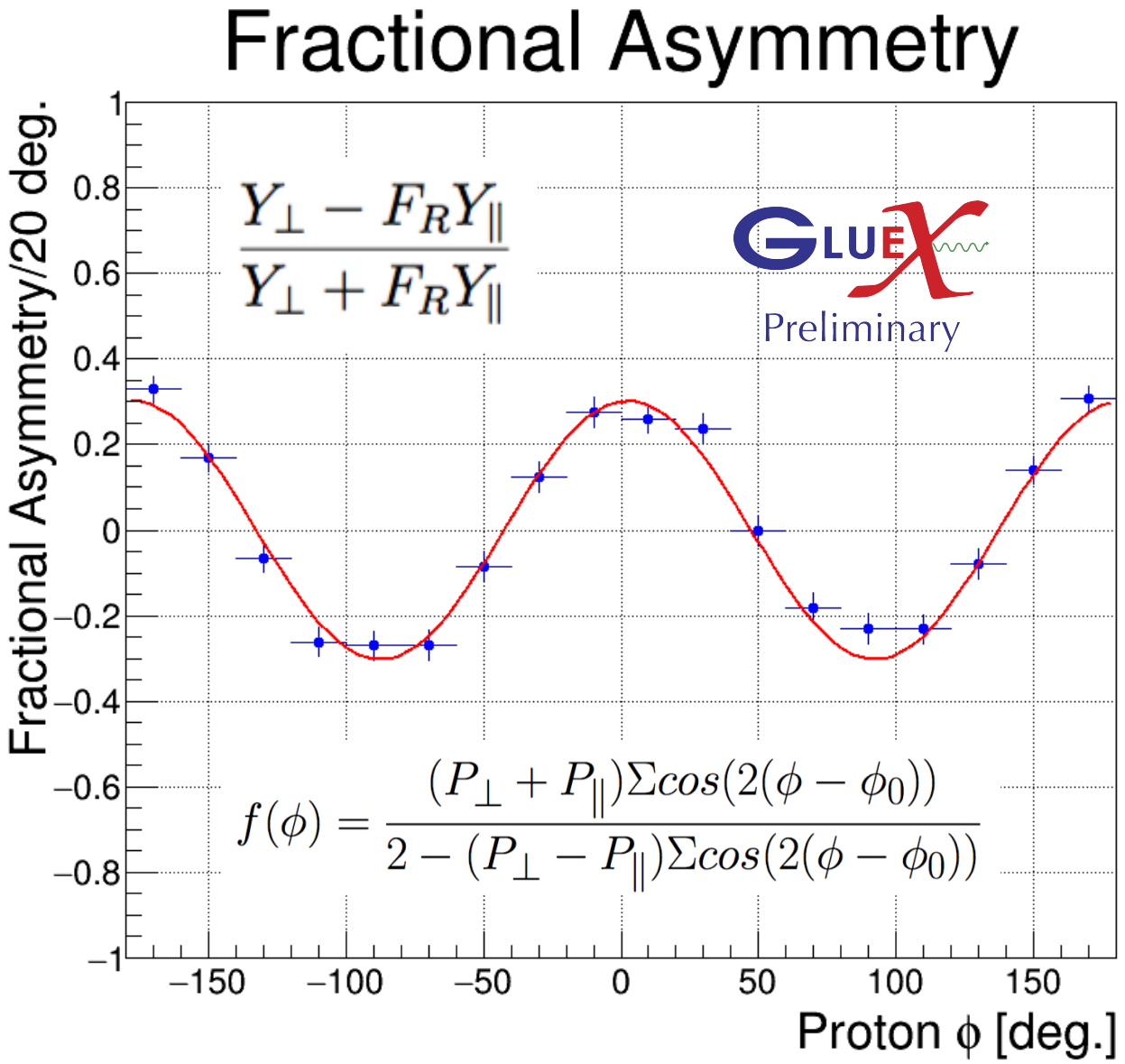
$$\gamma p \rightarrow p\gamma\gamma$$



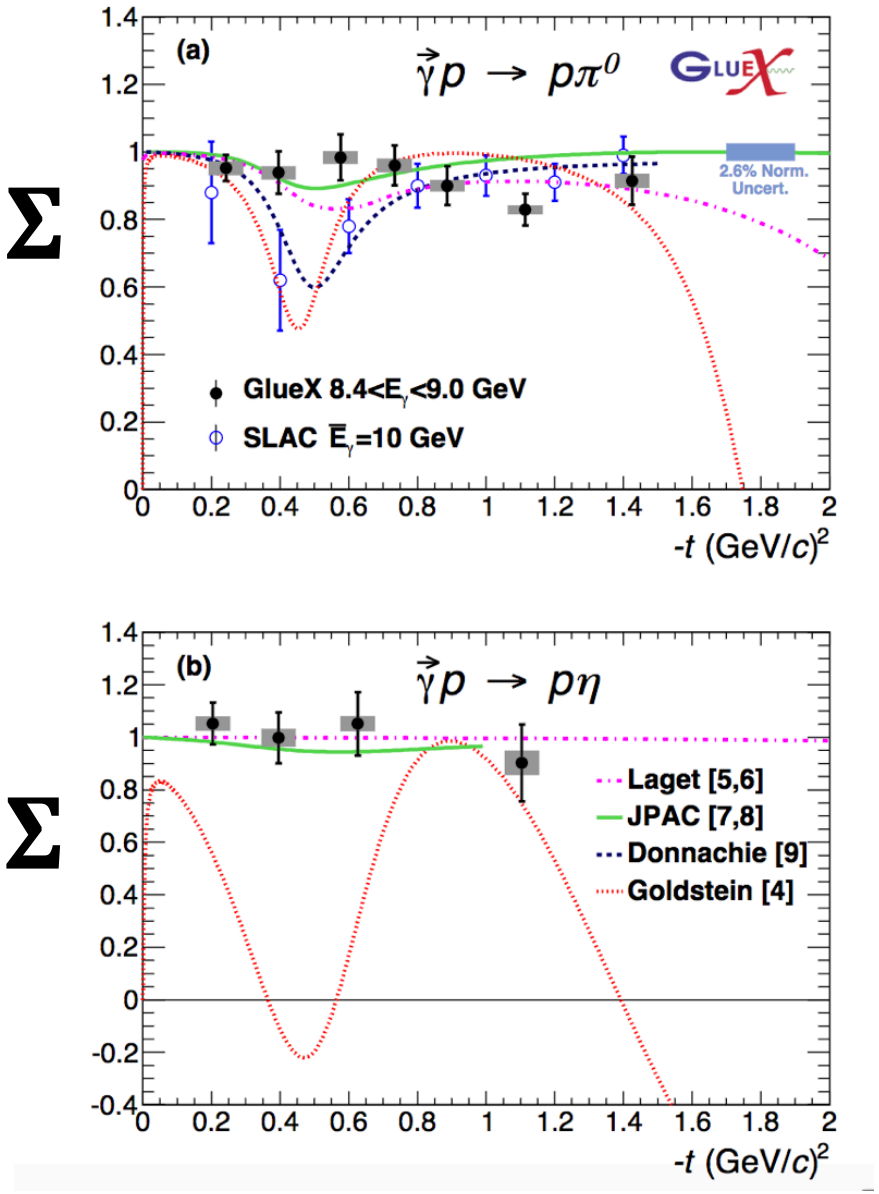
Fractional Asymmetry: $\eta \rightarrow 2\gamma$







π^0 and η beam asymmetries

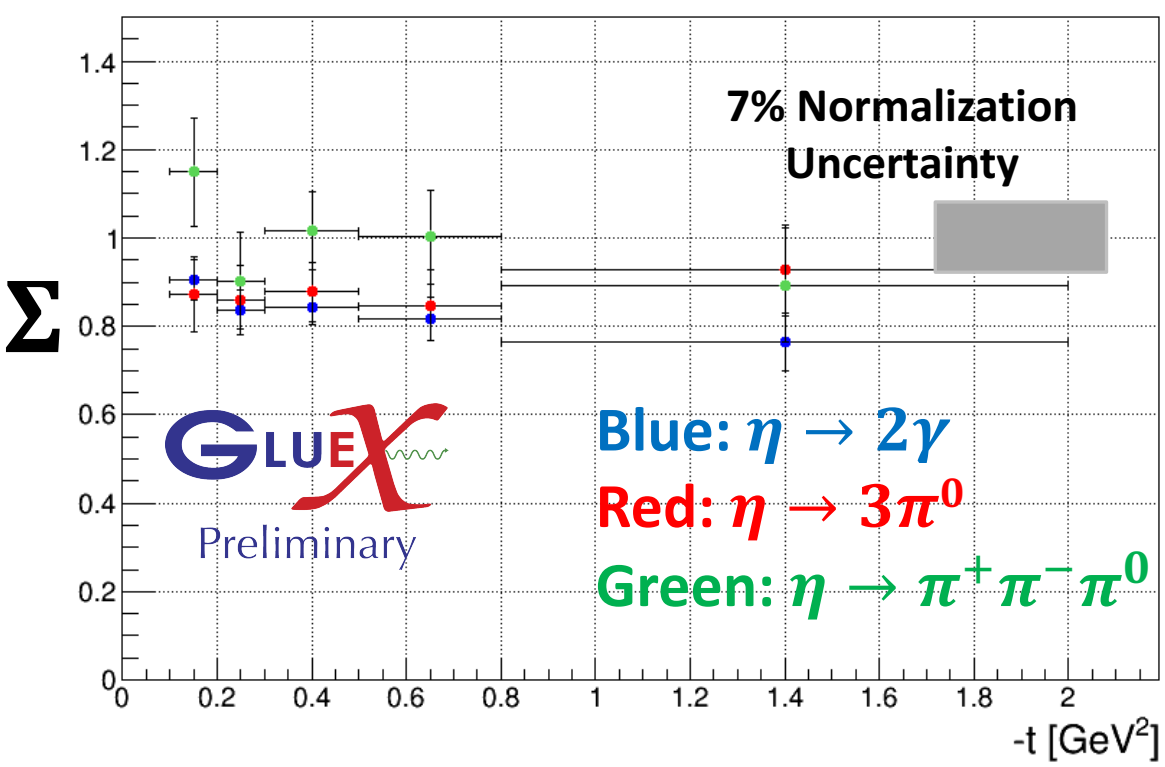


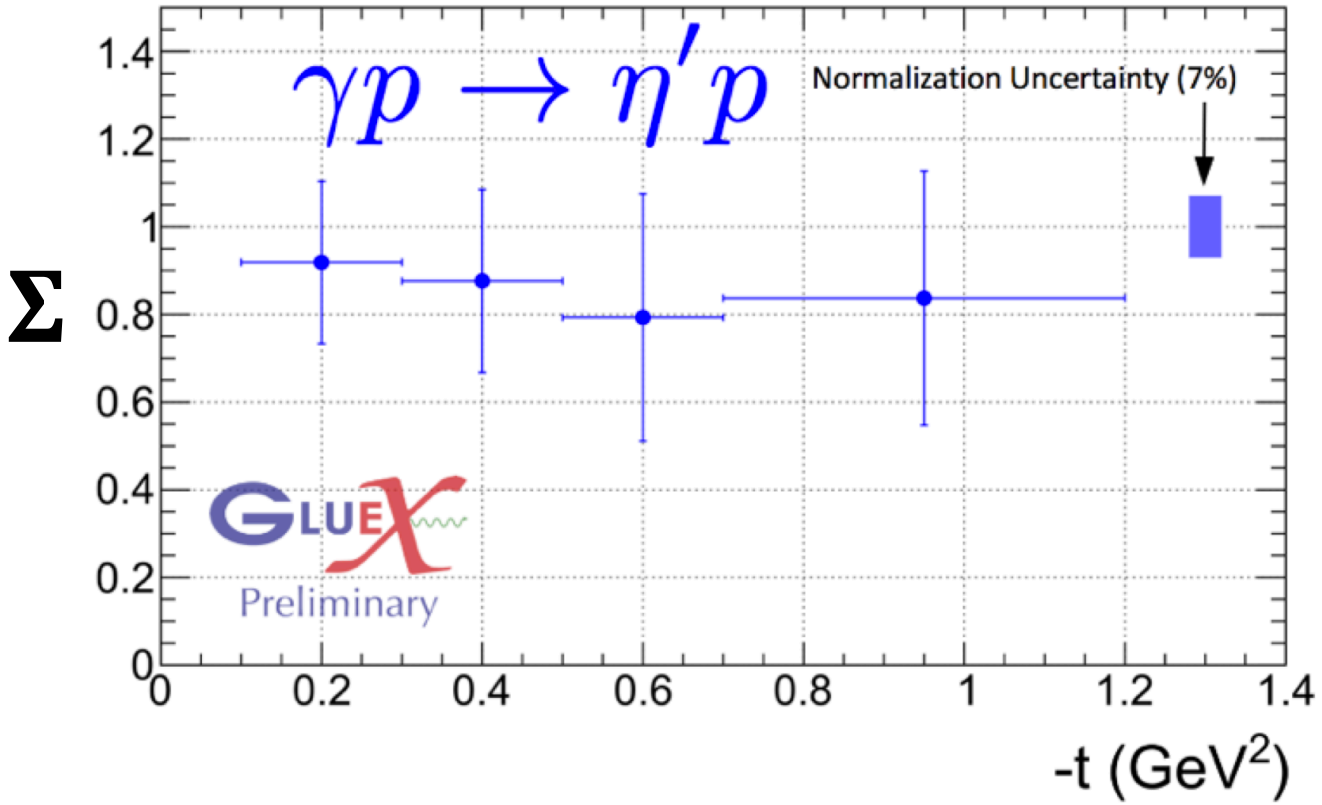
- Dip in multiple theory predictions not observed in the data
- Asymmetry consistent with 1 indicates the exchange is dominated by the vector mesons
- Additional asymmetry measurements ongoing with the current data set
- First 12 GeV publication!

Phys. Rev. C 95, 042201(R)

Pseudoscalar Asymmetries

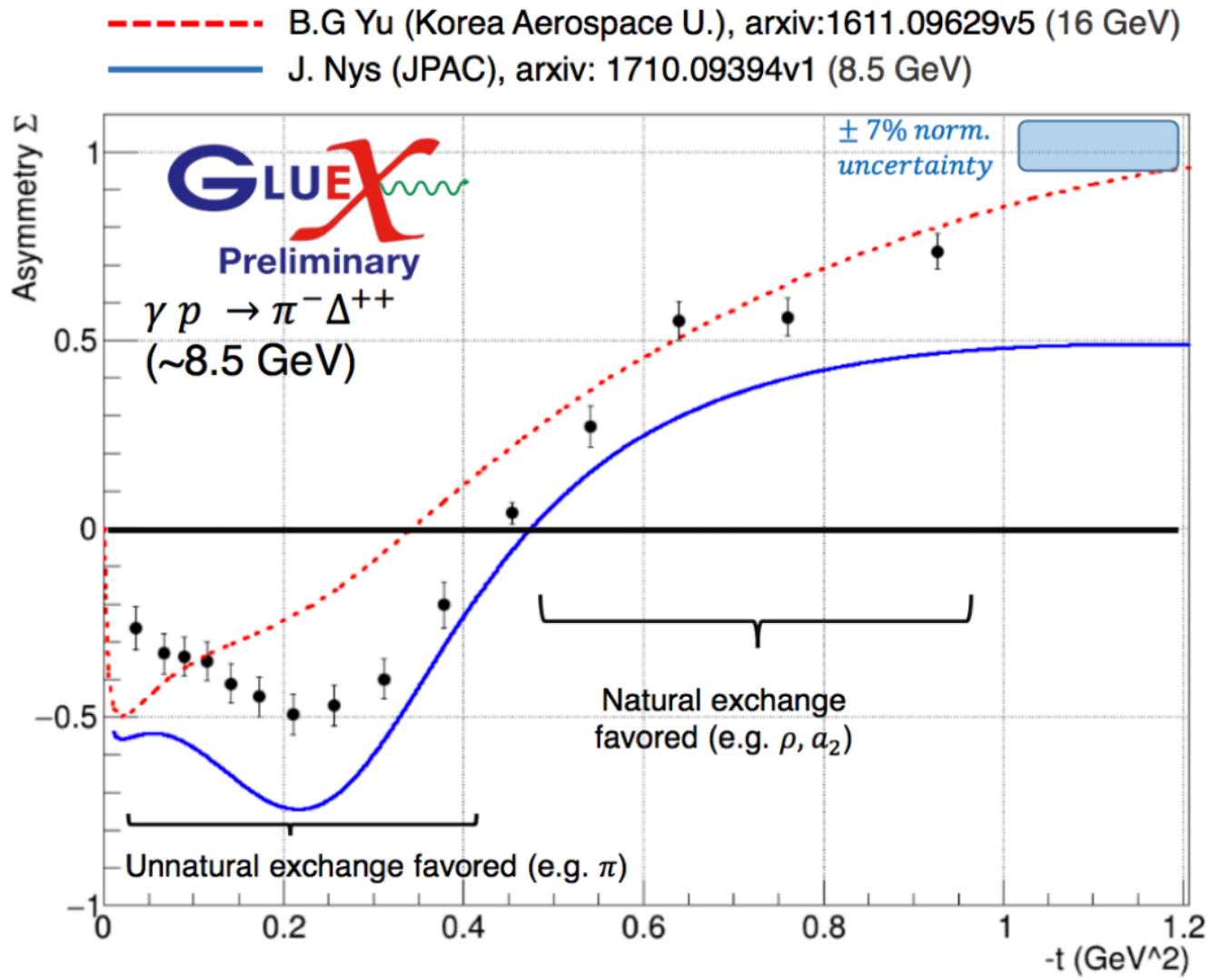
- Statistical Errors only

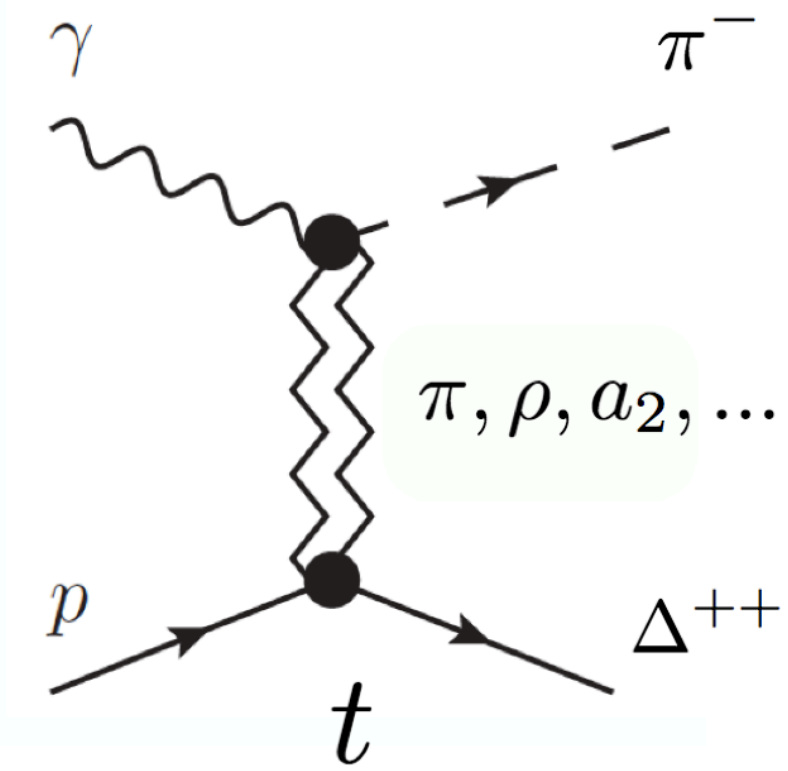




- Neutral pseudoscalars: Σ consisistent with 1, dominated by vector exchange.

Pseudoscalar Asymmetries





- Charged pseudoscalar: Σ more complicated t-dependence

Spin Density Matrix Elements

- SDMEs measure the transfer of polarization from the incoming photon to the vector meson.
- Describe the spin state of the vector meson
  - Related to the density matrix of the photon by the production amplitudes.
- There are ongoing analyses for the ρ, ϕ and ω mesons. I will focus on the hadronic decay of the ω meson: $\gamma p \rightarrow p\omega$, $\omega \rightarrow \pi^+\pi^-\pi^0$.

$$\rho(V) = T\rho(\gamma)T^\dagger$$

$$\rho(\gamma) = \frac{1}{2}I + \frac{1}{2}\mathbf{P}_\gamma \cdot \boldsymbol{\sigma}$$

- For linearly polarized beam:

$$\mathbf{P}_\gamma = P_\gamma(-\cos 2\Phi, -\sin 2\Phi, 0)$$

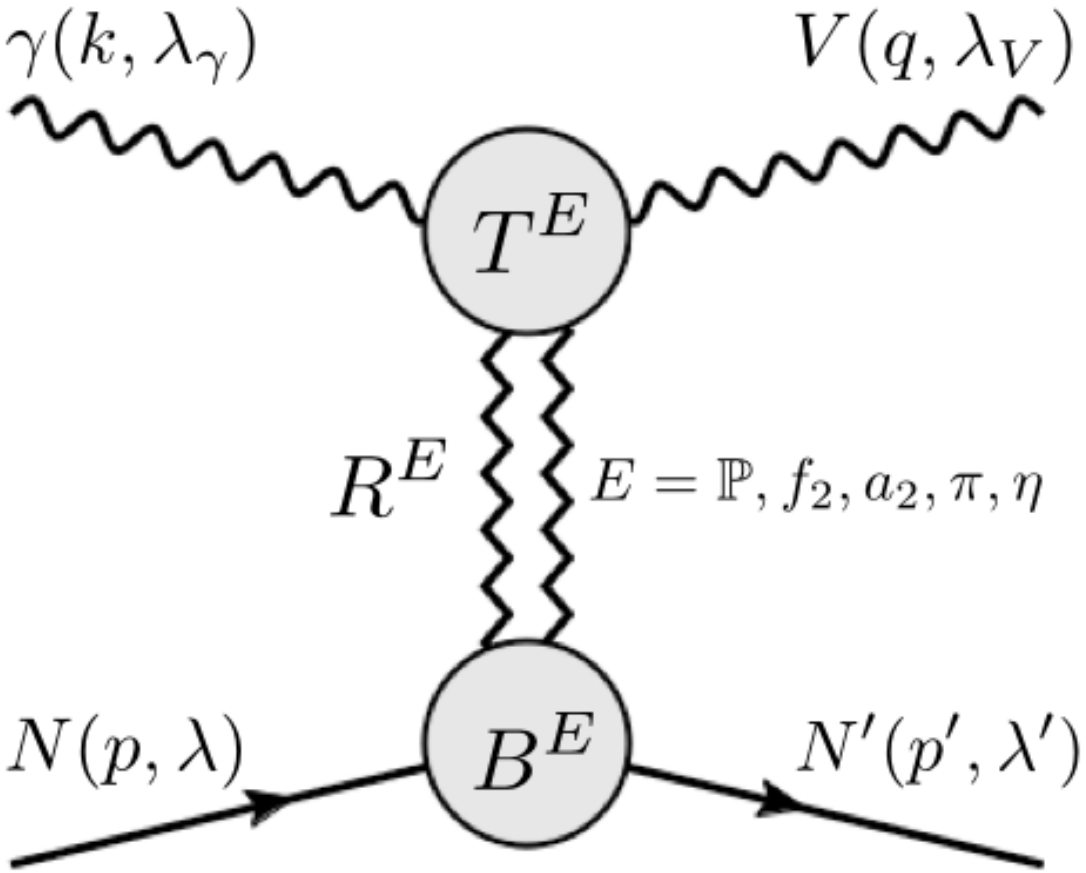
  - Φ is the angle between the polarization direction and the production plane.

Spin Density Matrix Elements

Model from JPAC

Phys.Rev. D97 (2018) no.9, 094003

- Model for photoproduction of a vector meson at our energy.
- Measuring the SDMEs offers feedback to theory on the strength of the contribution of each exchange particle.



Spin Density Matrix Elements

Angular Distribution

$$W(\cos\theta,\phi) \quad = \quad W^0(\cos\theta,\phi) + \sum_{i=1}^{3} \mathbf{P}_\gamma^i W^i(\cos\theta,\phi)$$

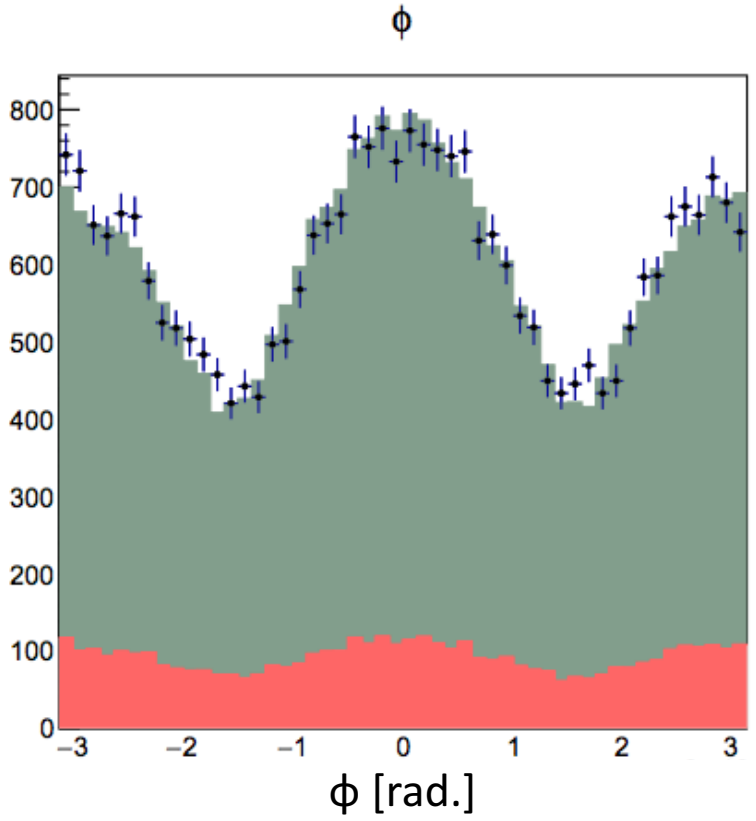
- Example angular distribution:

$$W_h^2(\cos\theta,\phi,\rho^2) \quad = \quad \frac{3}{4\pi}\left[\sqrt{2}\,\mathrm{Im}\rho_{10}^2 \sin 2\theta \sin\phi + \mathrm{Im}\rho_{1-1}^2 \sin^2\theta \sin 2\phi\right]$$

- Measured in the "Helicity Frame": In the ω c.m. frame, $\hat{z}$ opposite recoil proton, $\hat{y}$ normal to production plane.

$$\hat{x} = \hat{y}\times\hat{z}$$

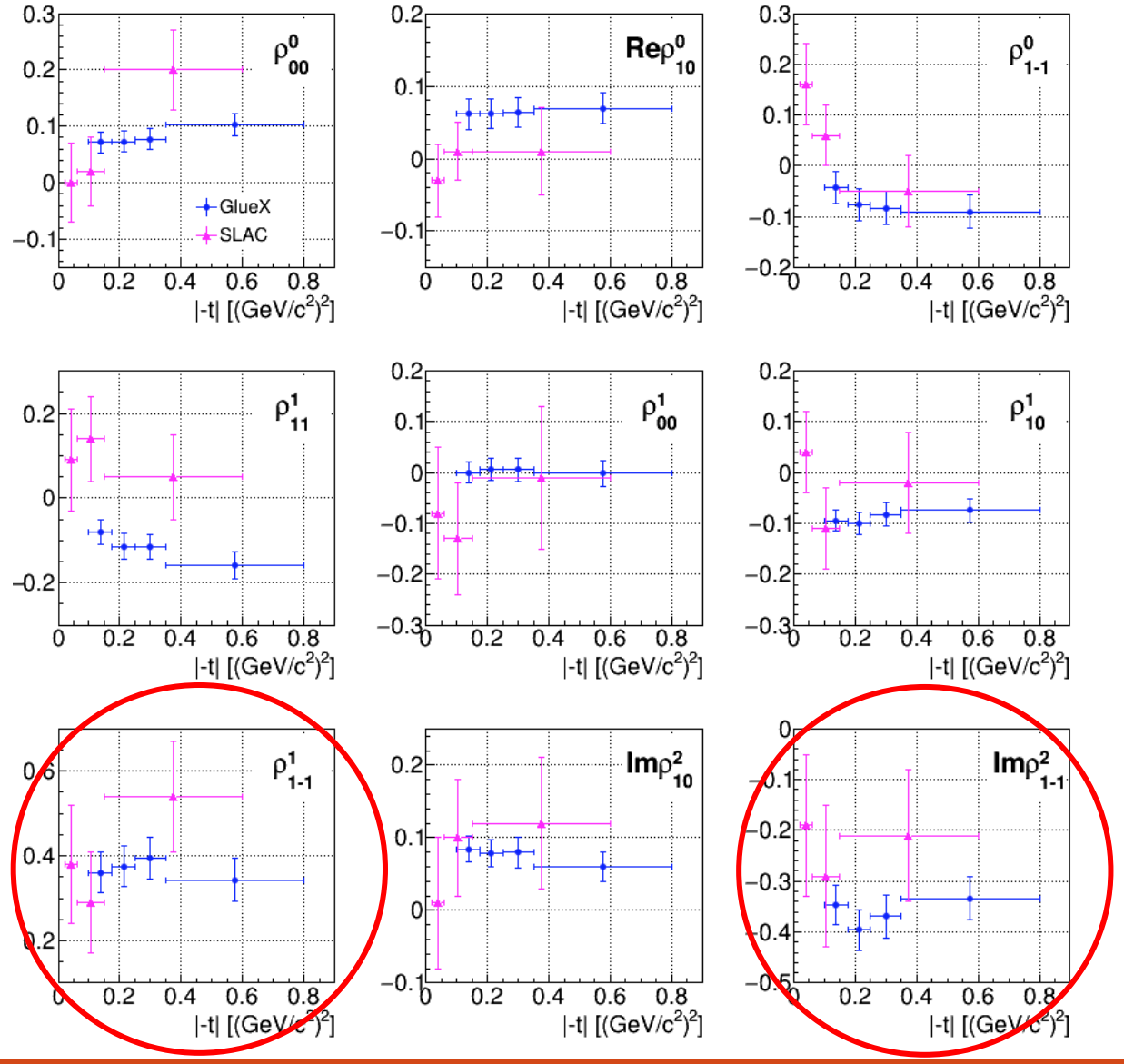
- With a linearly polarized beam we can measure 9 of the SDMEs



- Fit for one of the angles in the helicity frame.

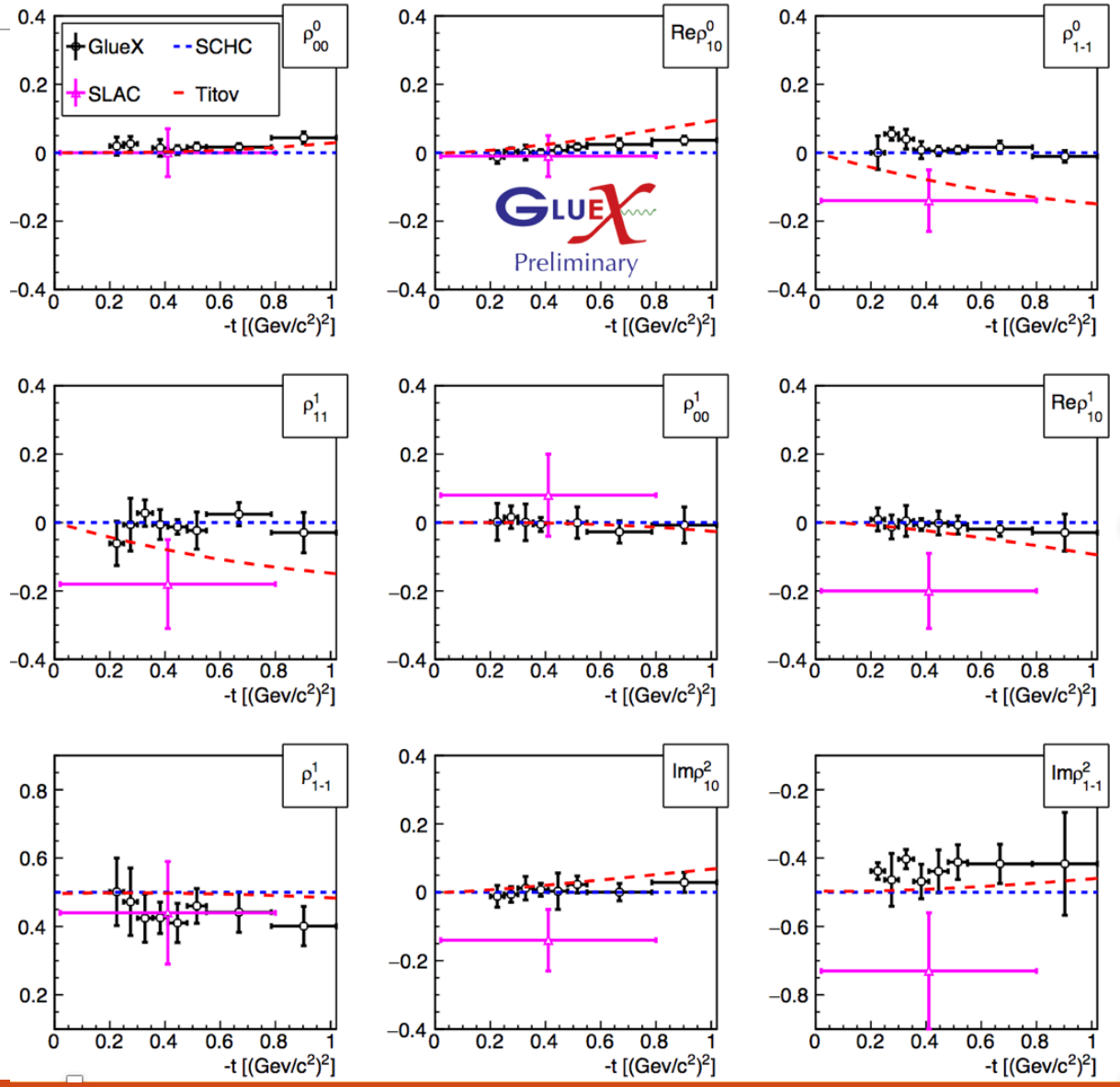
Results for γp → pω, $\omega \to \pi^+\pi^-\pi^0$

- Results are consistent with previous SLAC measurements, but of much higher statistics.
- Offers some insight into the relative strength between exchange particles.



Results for γp → pϕ, ϕ→K^+K^-

- Blue dashed line: s-channel helicity conservation
  - ρ^1_{1-1} = - Imρ^2_{1-1} = 0.5 in helicity frame
  - All other elements are zero.
- Red line: Titov model prediction
- Magenta triangle: Ballam et al.
- Data is consistent with s-channel helicity conservation.
- The production mechanism is dominated by Pomeron exchange with little contribution from the neutral pseudoscalars.



Summary

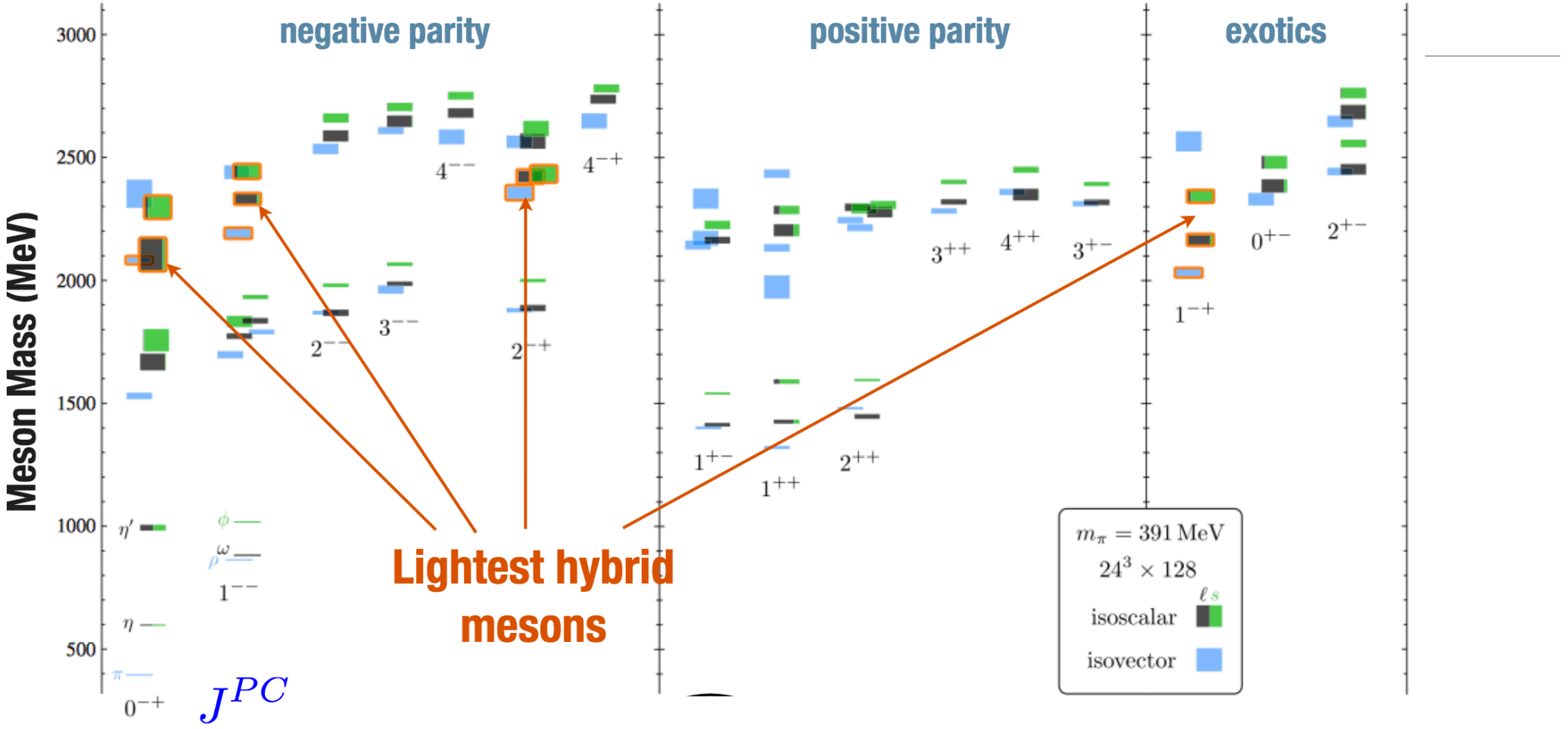
- The GlueX experiment is commissioned and the initial meson program is well underway.

- Early measurements of polarization observables to gain insight into production mechanisms
  - Sigma beam asymmetry for neutral and charged pseudoscalars
  - SDMEs for vector mesons

- Understanding the production mechanisms of these pseudoscalar and vector mesons will be important going forward with our search for the hybrid meson spectrum

backups

Lattice QCD Predictions



Dudek J J 2013 *Phys. Rev.* D 88 014501

- Rich spectrum of light hybrid mesons
- Primary goal of the GlueX experiment is to search for and ultimately map out the spectrum of light quark hybrid mesons