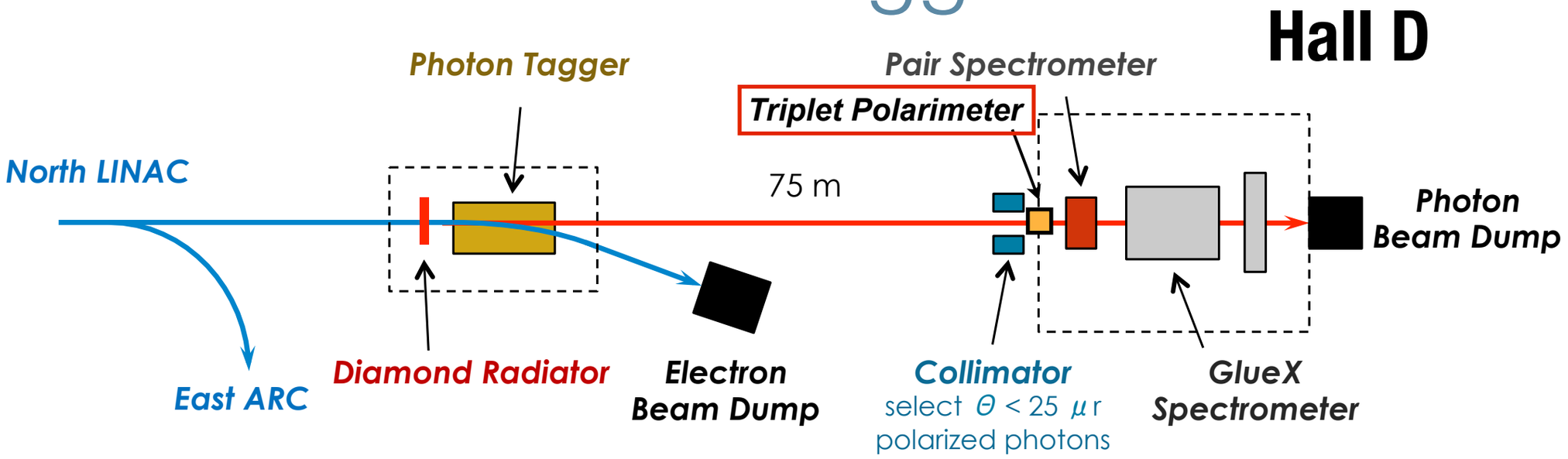
Backward angle meson photoproduction at GlueX

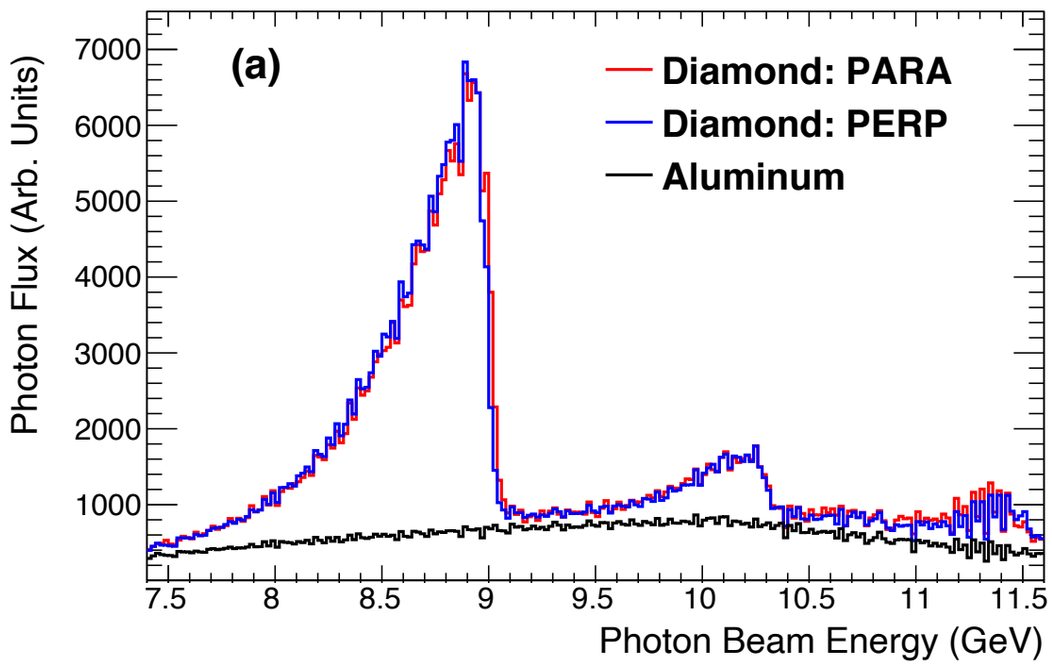
Justin Stevens

William & Mary
Chartered 1693

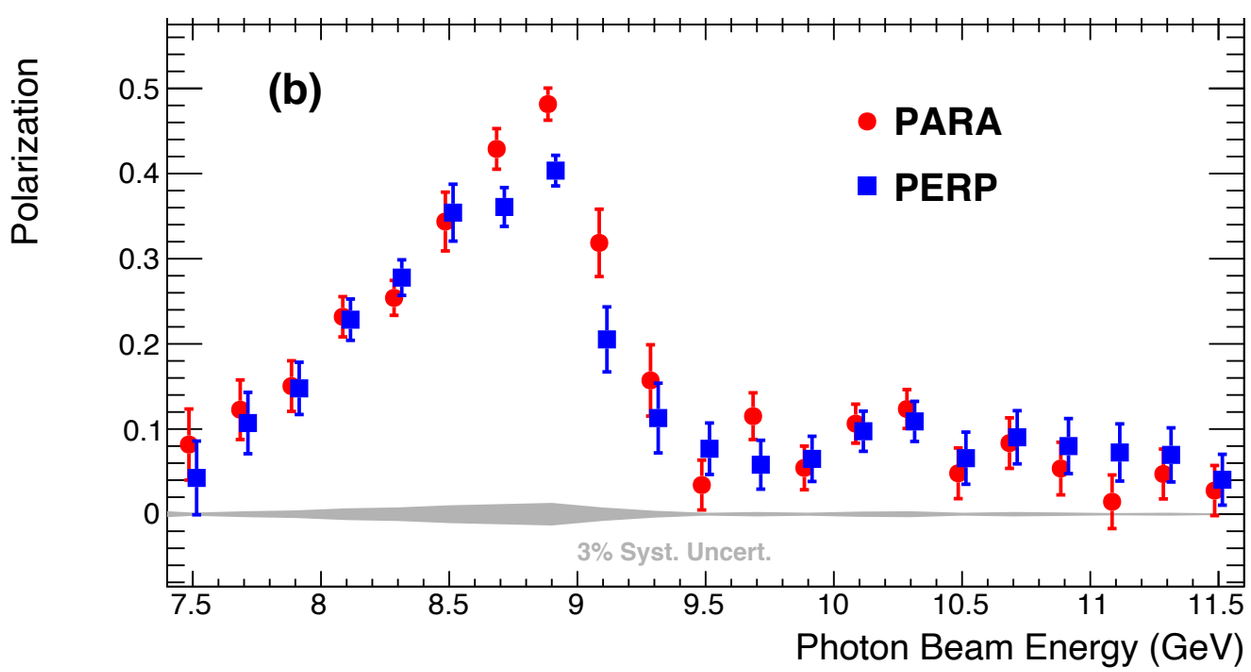
Photon Beam and Tagger



Measured Flux



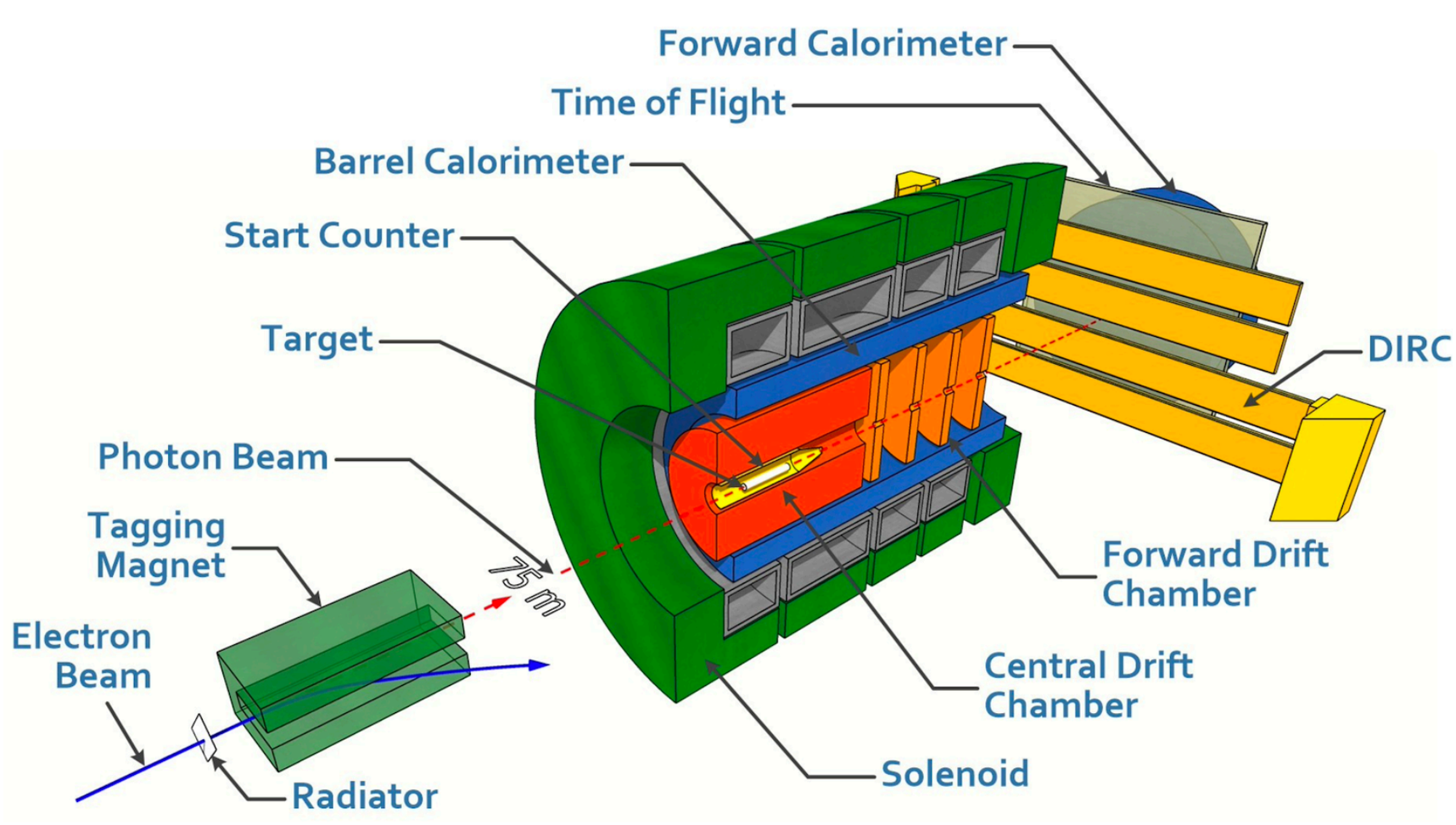
Measured Polarization



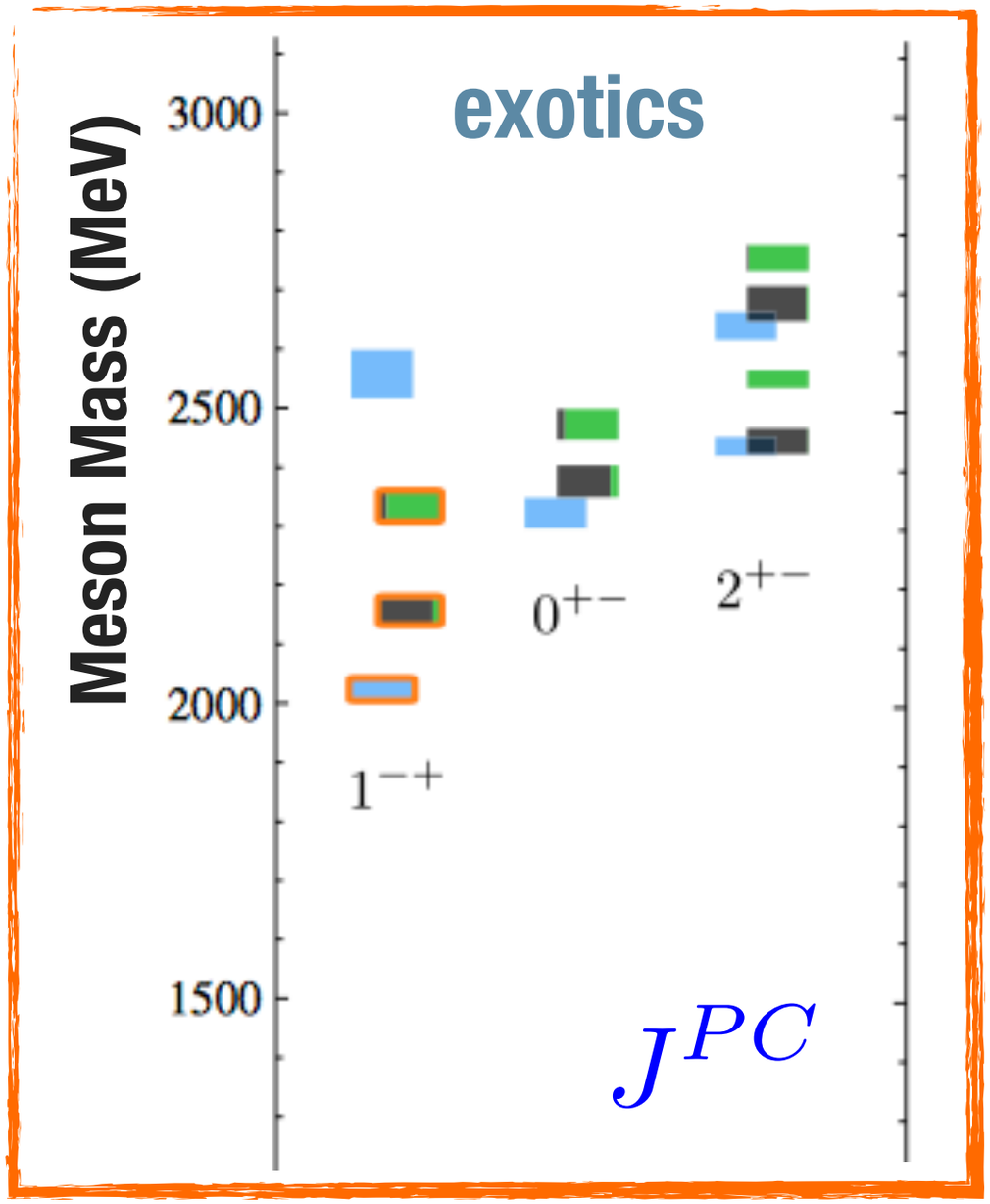
Filter on production mechanism

GlueX in Hall D

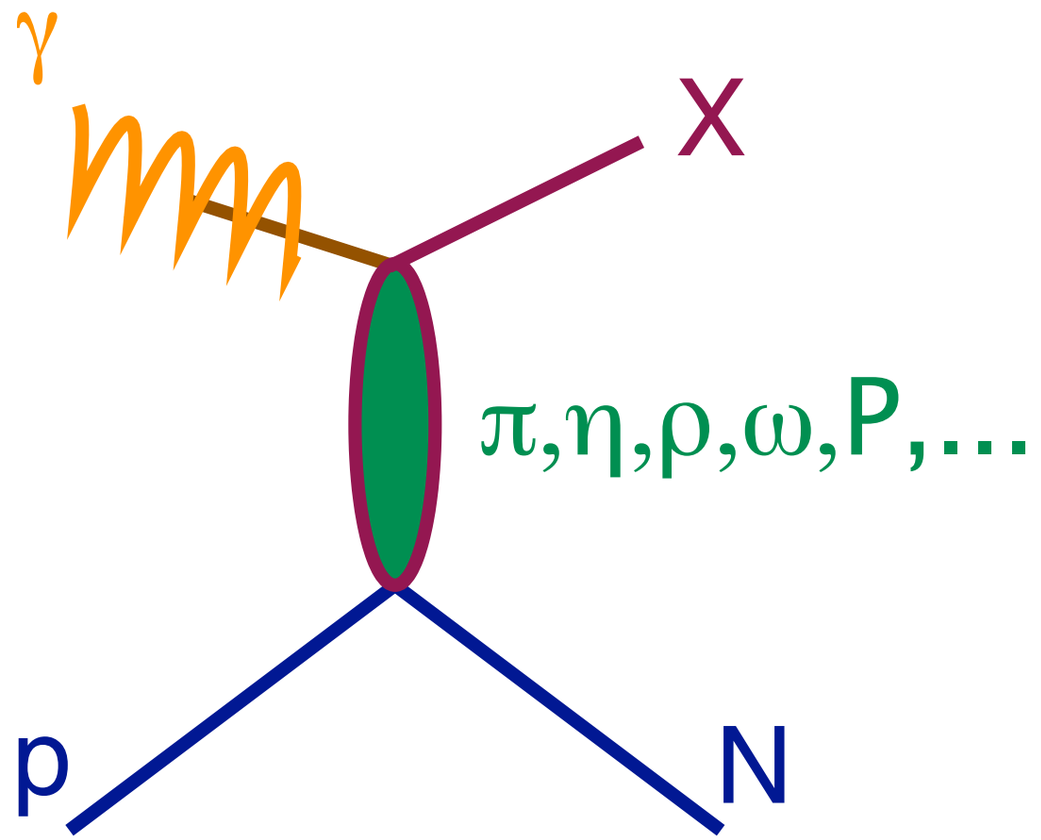
- Large acceptance detector for charged and neutral particles (many final states)
- Orders of magnitude higher statistics than previous photoproduction experiments



Exotic J^{PC}: t-channel photoproduction

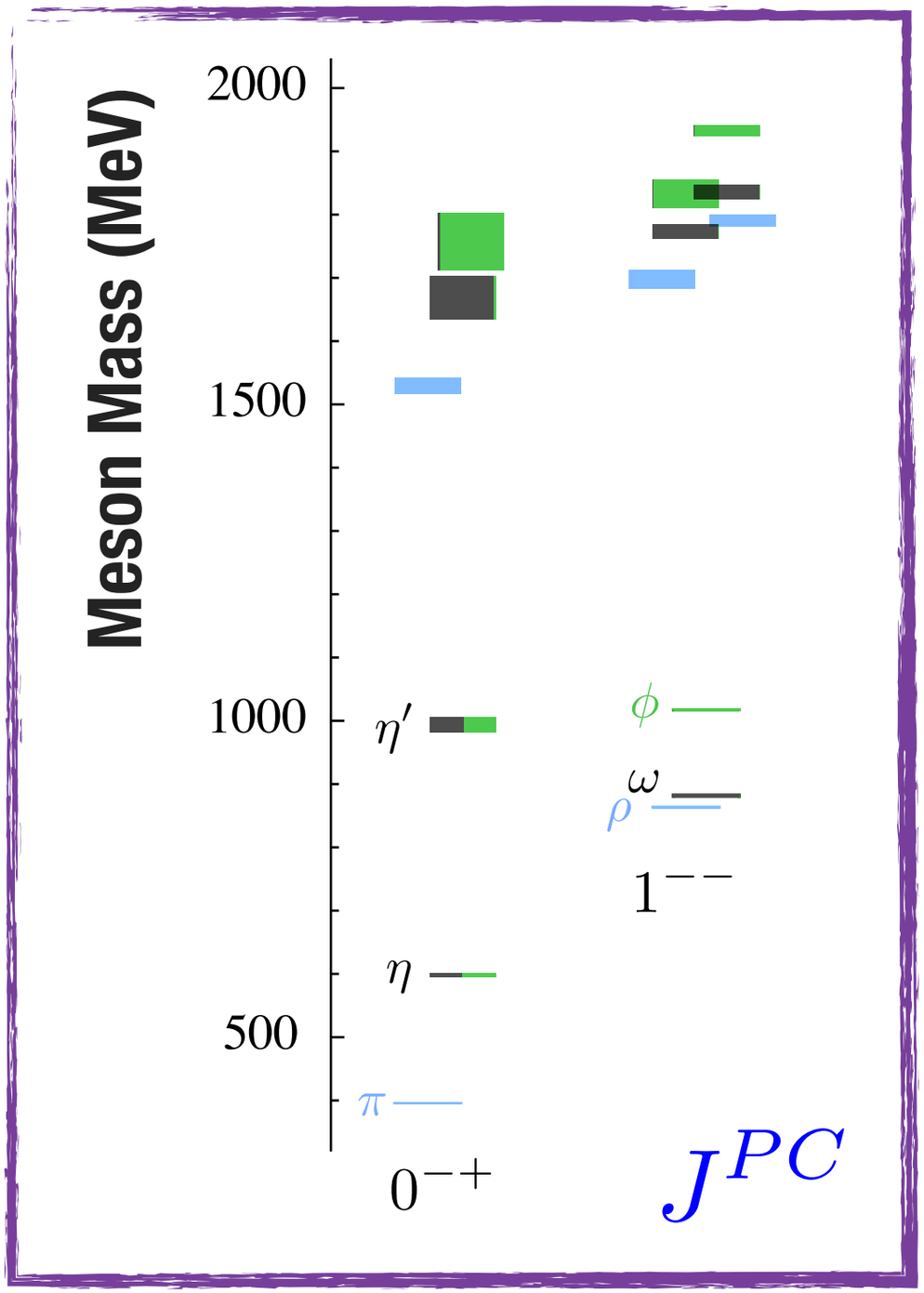


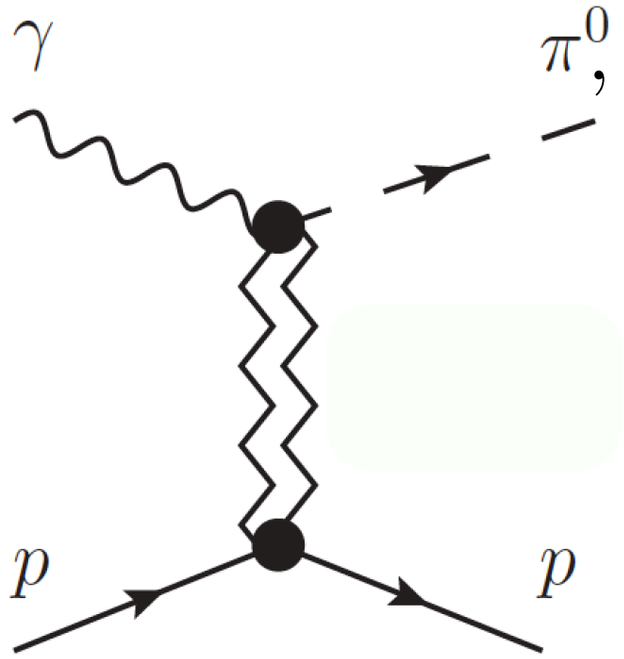
Meson X with particular J^{PC}



Production through t-channel meson exchange

Conventional: t-channel photoproduction





Exchange J^{PC}

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

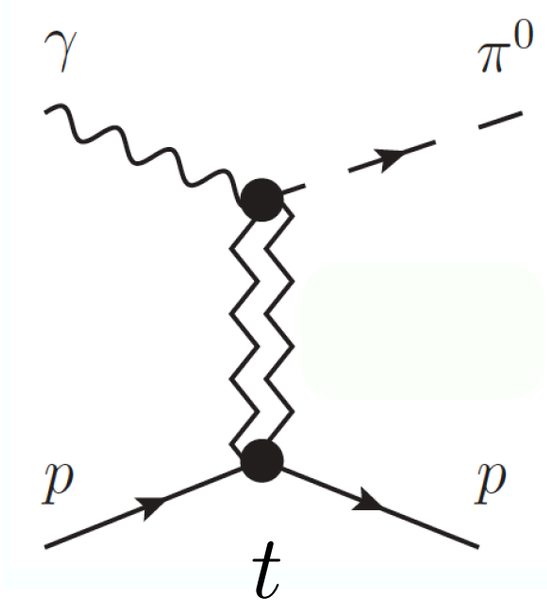
$1^{+-} : b, h$

- Begin by understanding non-exotic production mechanism
- Linear photon beam polarization critical to filter out “naturality” of the exchange particle

$\gamma p \to \pi^0 p$ beam asymmetry Σ

- Beam asymmetry Σ provides insight into dominant production mechanism

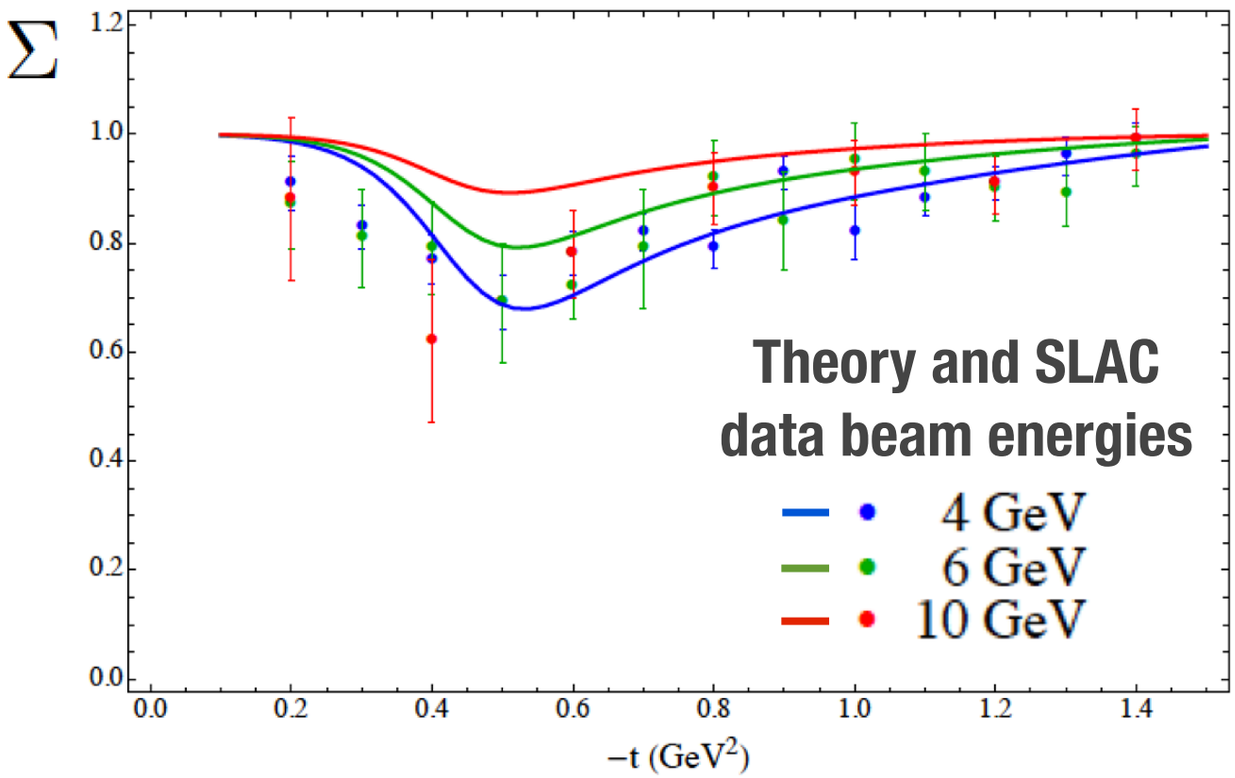
$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$



Exchange J^{PC}

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

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

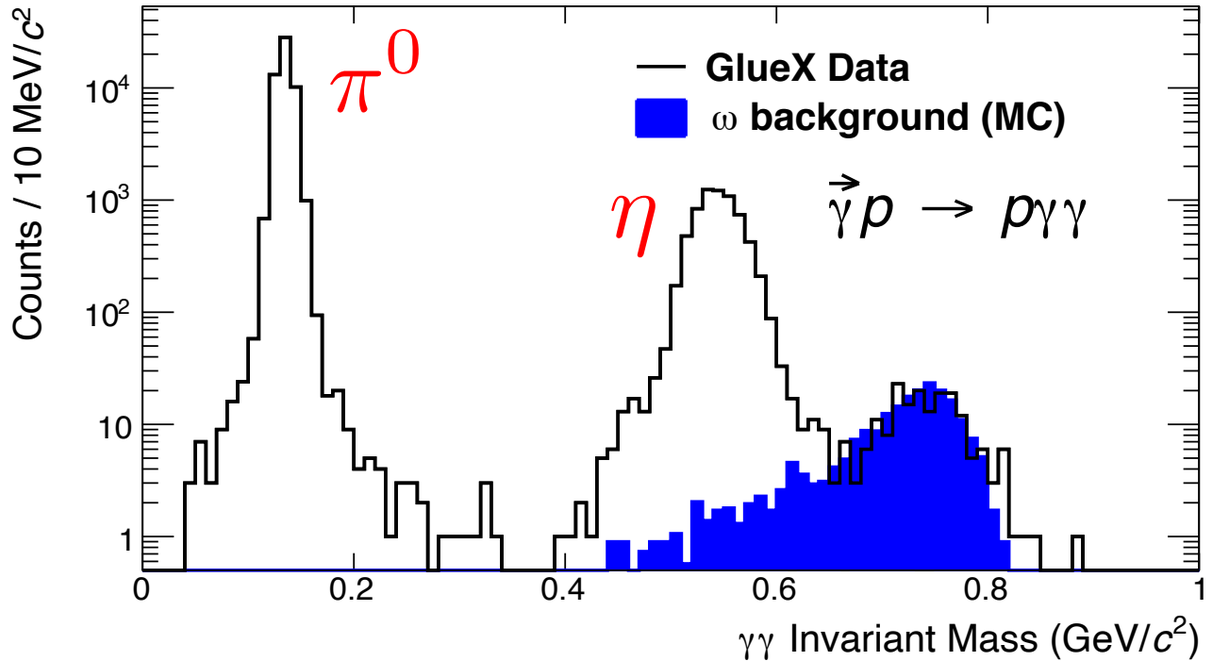


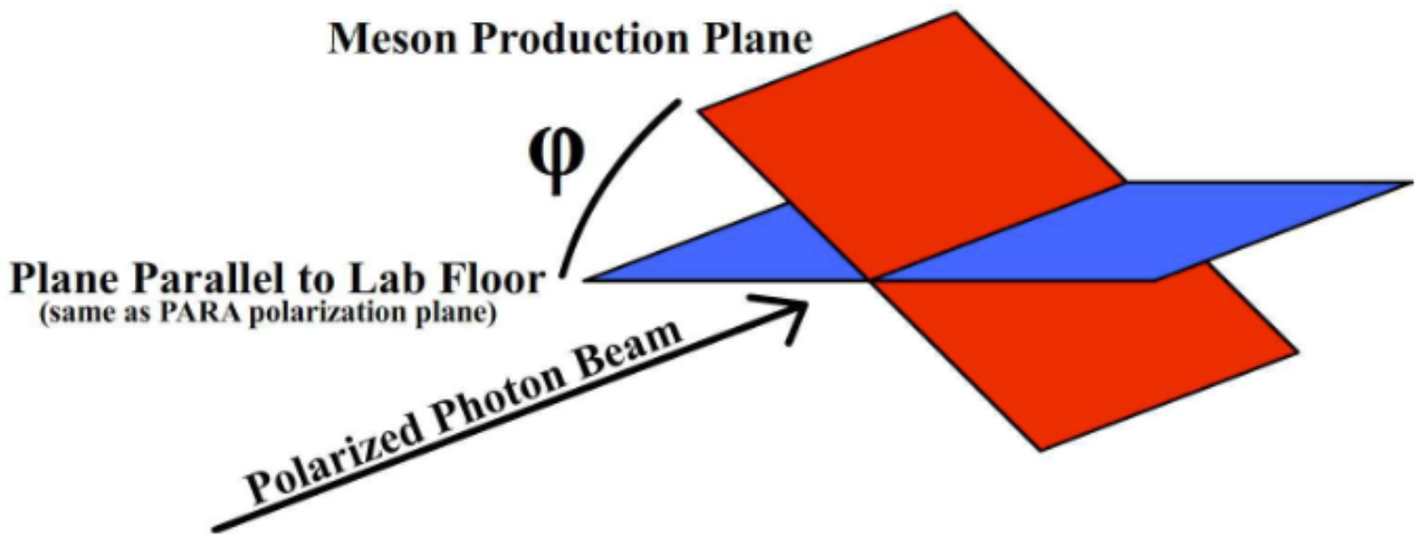
- From experimental standpoint it's easily extended to $\gamma p \to \eta p$
  - **No previous measurements!**

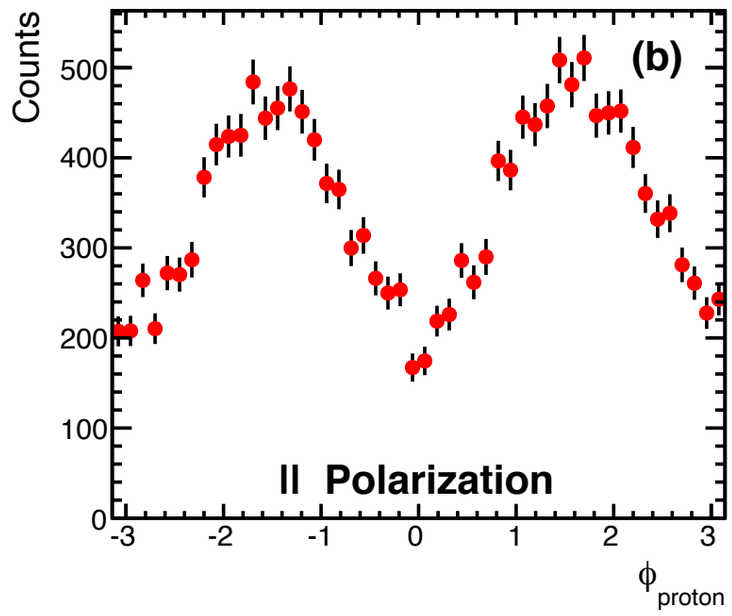
Mathieu et al. PRD 92, 074013

π^0 and η beam asymmetries

$$\gamma p \to p\gamma\gamma$$



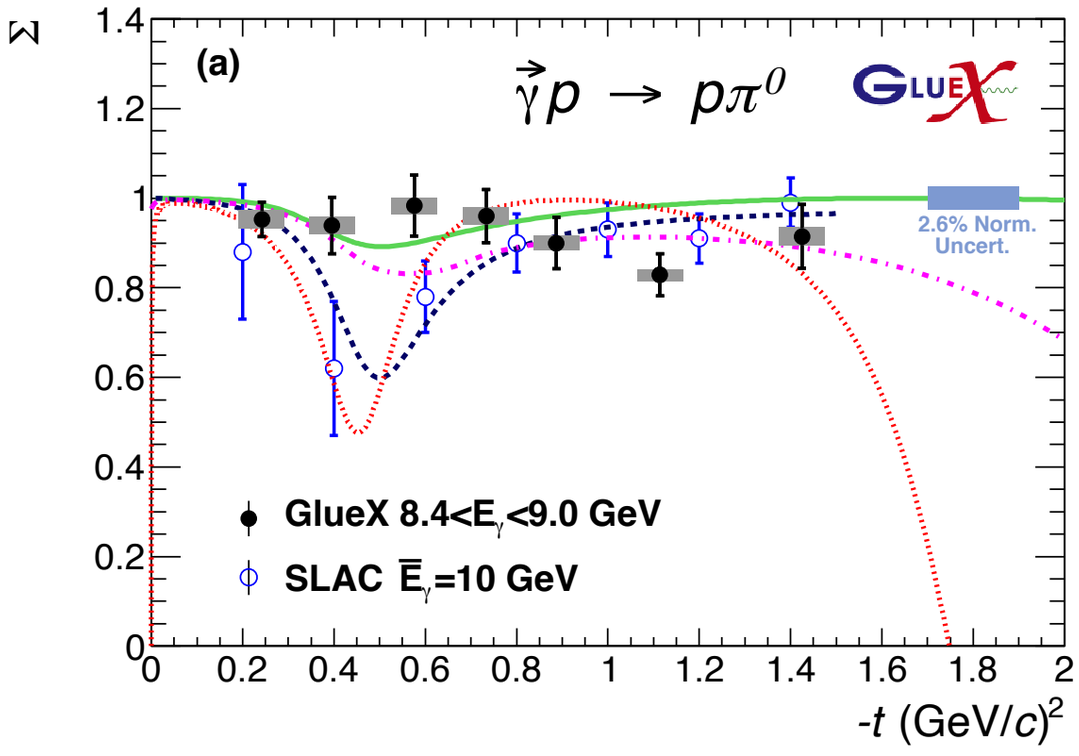


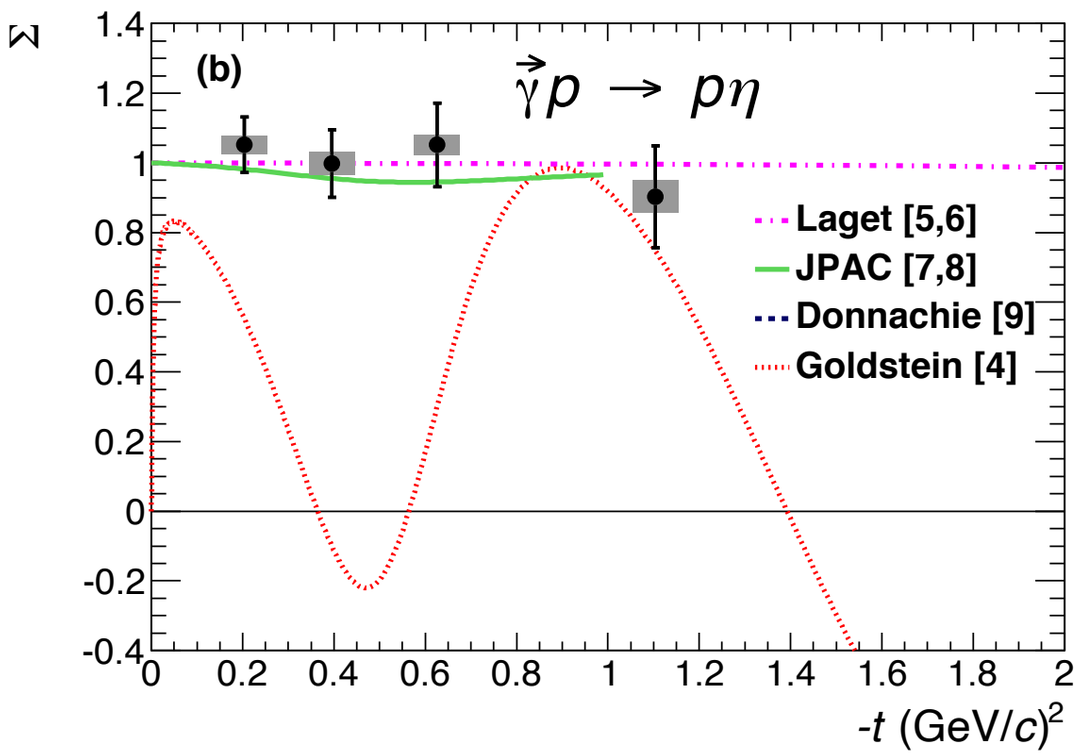


$$\sigma = \sigma_0 \left(1 - P_\gamma \Sigma \cos 2(\phi_p - \phi_\gamma^{\text{lin}})\right)$$

Phys. Rev. C 95, 042201(R)

π^0 and η beam asymmetries



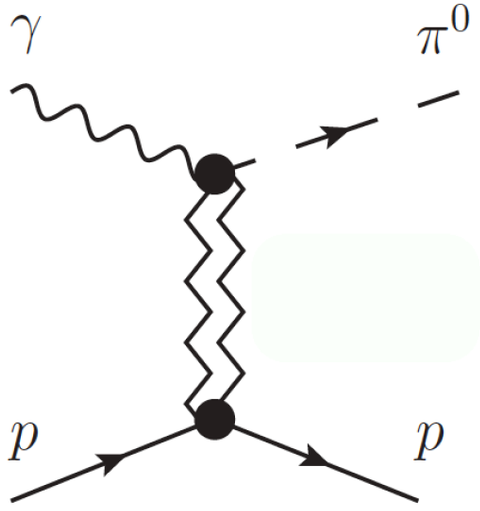


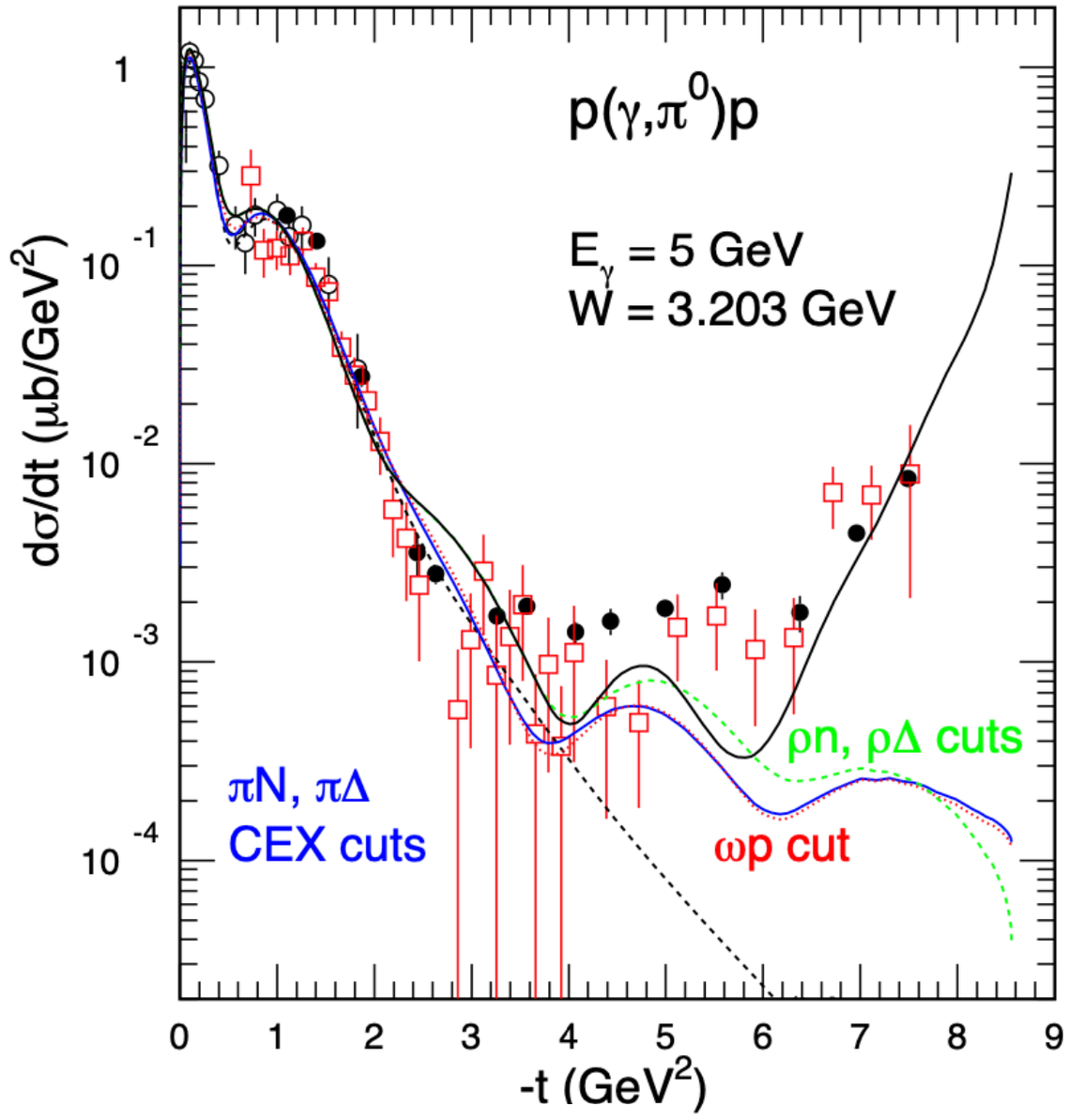
- Dip in multiple theory predictions not observed
- Vector exchange (Σ=1) dominance at this energy
- Additional asymmetry measurements for eta, eta'
- What about backward angles (u-channel)?

Phys. Rev. C 95, 042201(R)

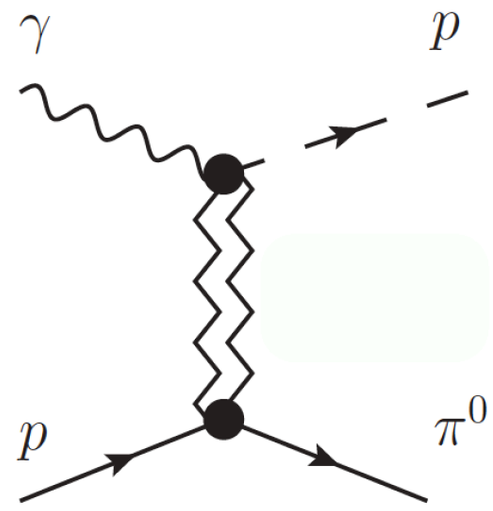
Previous backward π^0 measurements

Meson exchange

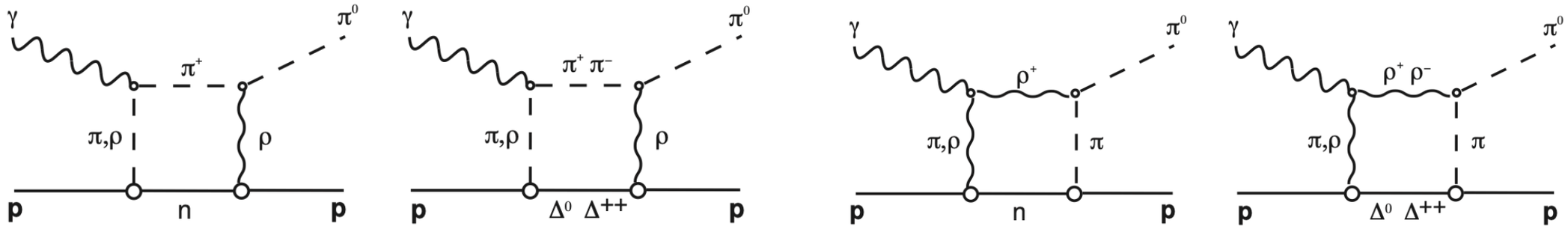




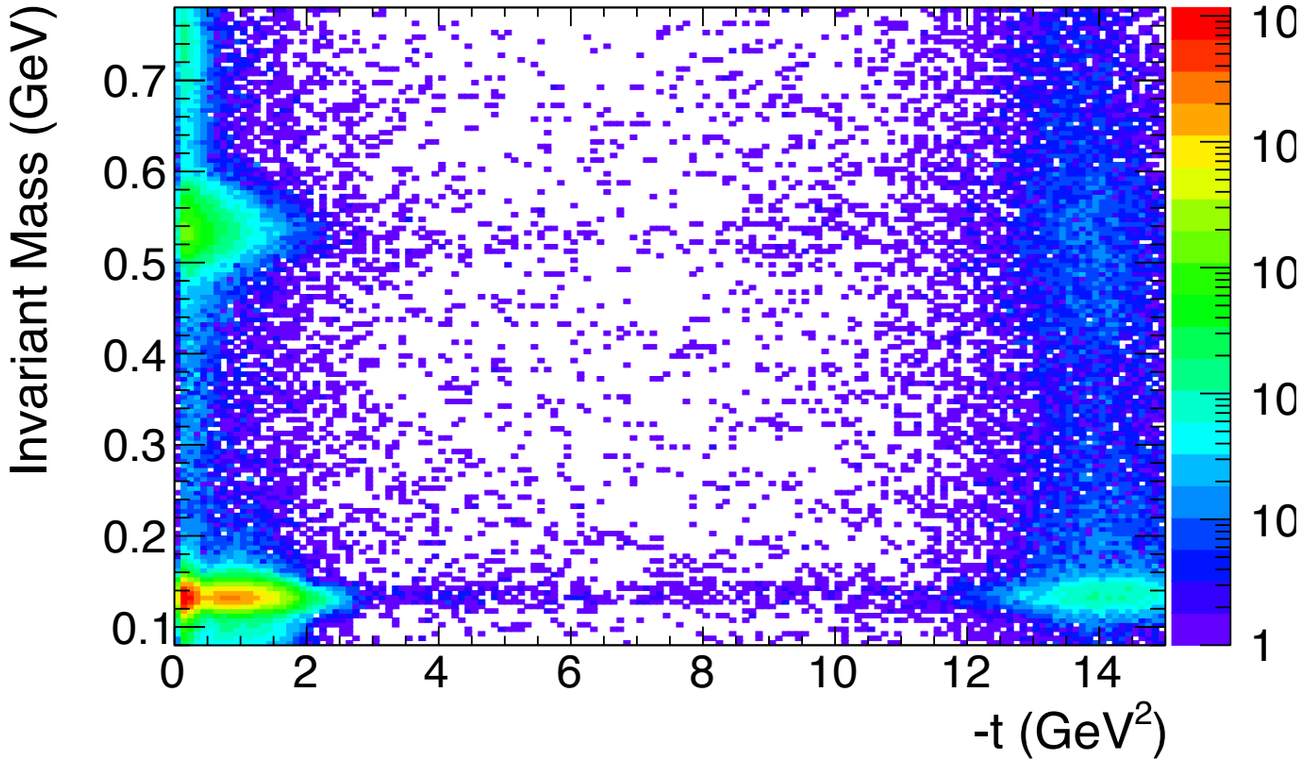
N/Δ exchange



Laget Review
arXiv:1911.04825

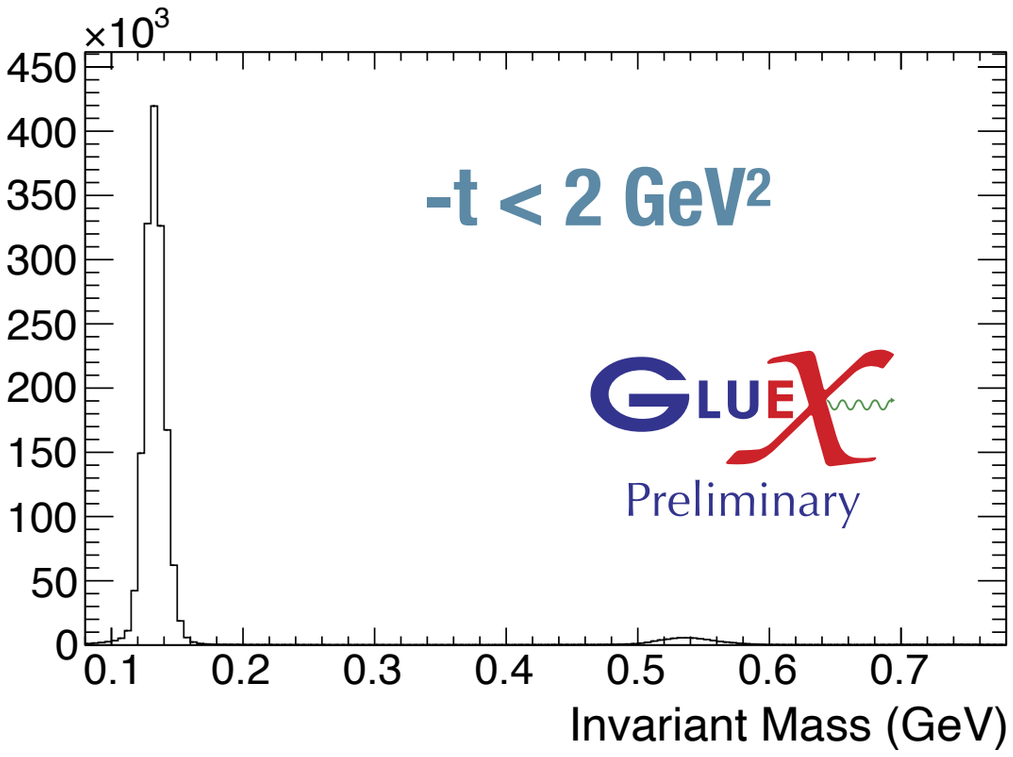


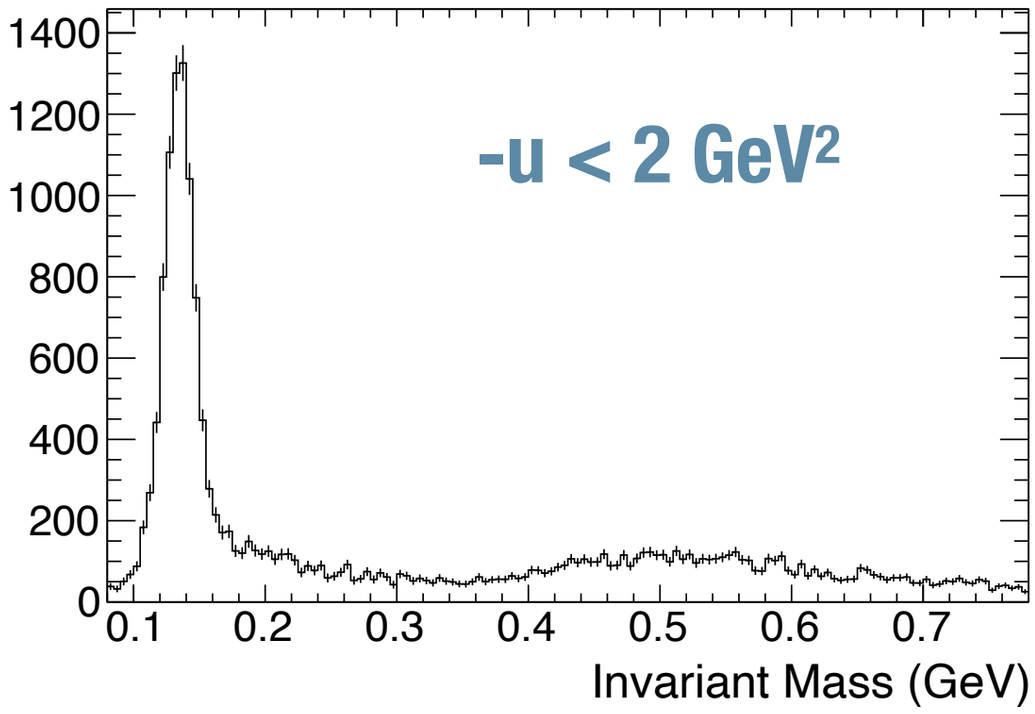
t and u dependence of exclusive π^0



$$\gamma p \to p\gamma\gamma$$

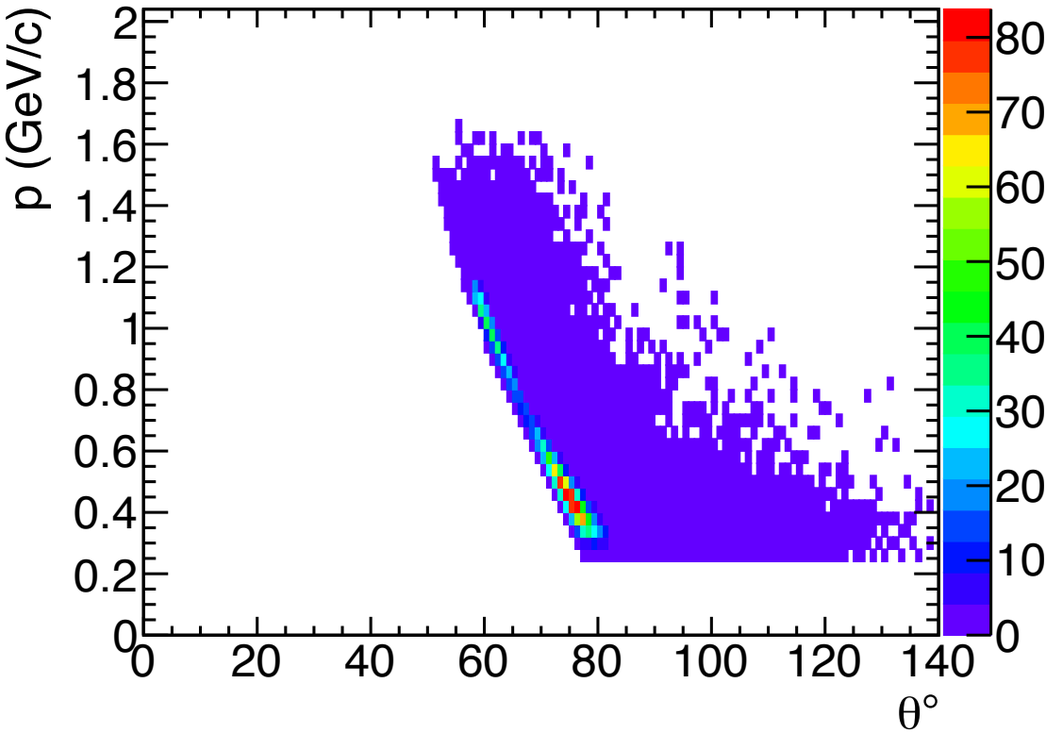
Fully reconstructed final state



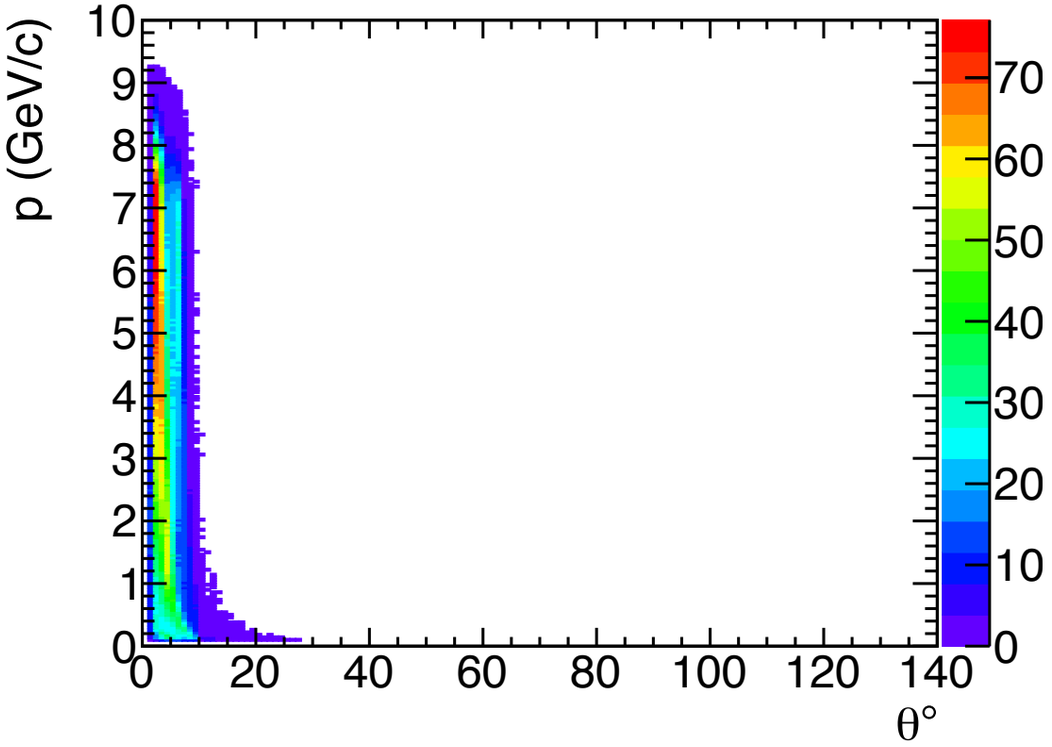


t-channel kinematics of exclusive π^0

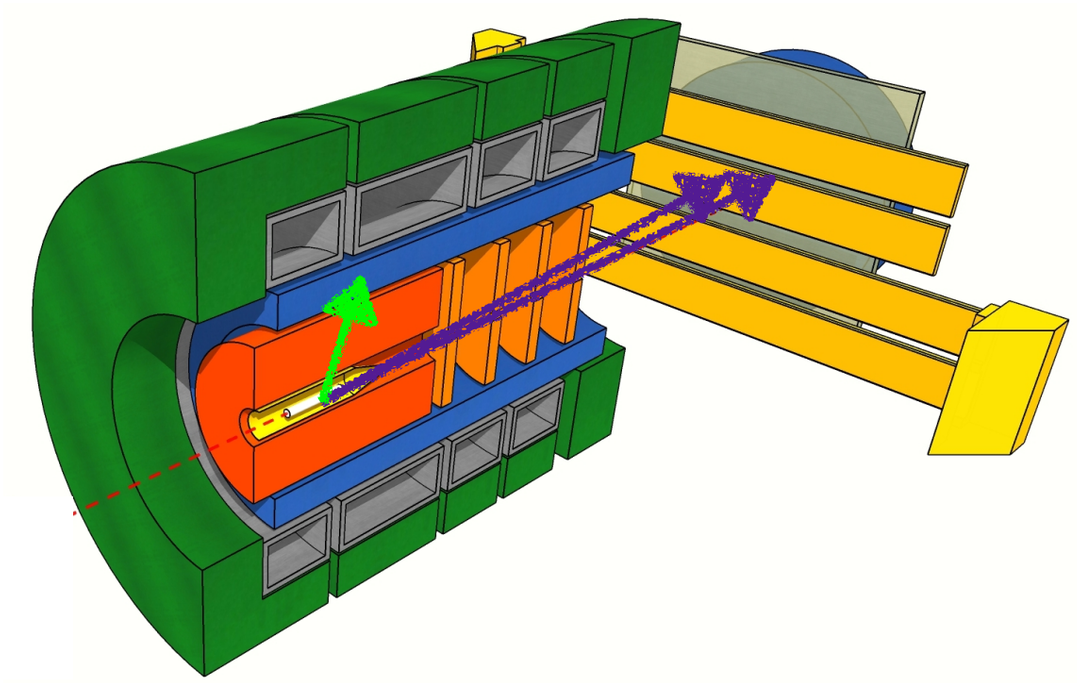
Detected protons



Detected photons

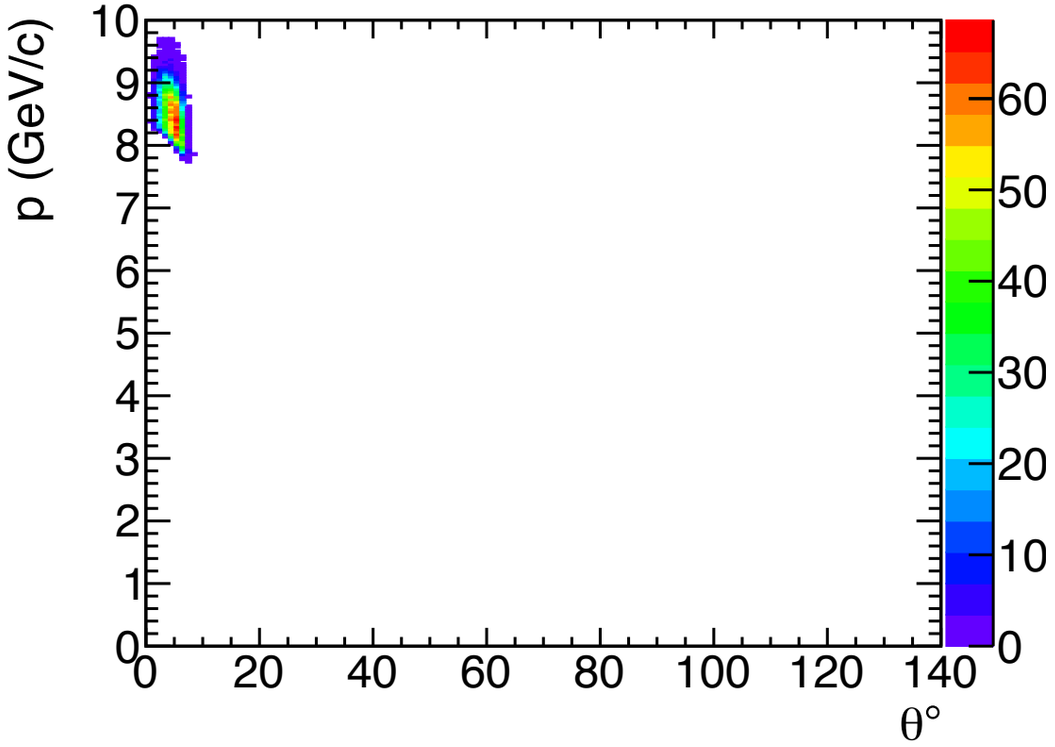


- For high energies $E_\gamma > 8$ GeV with $-t < 2$ GeV^2
- GlueX well suited for slow recoil protons and forward photons

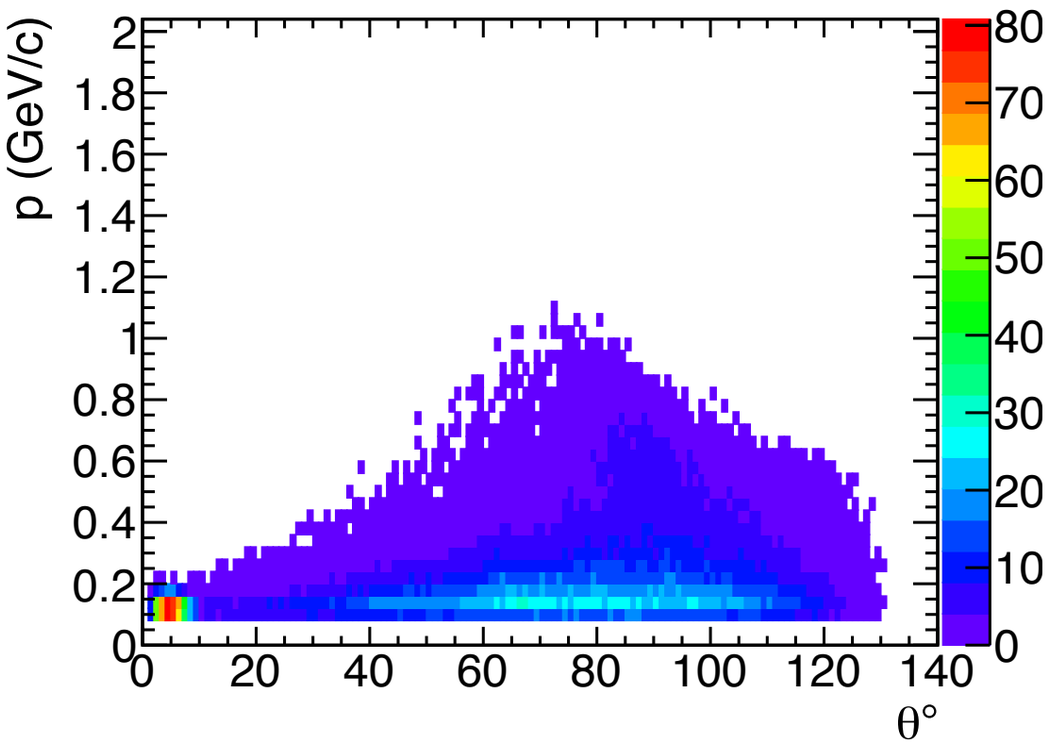


u-channel kinematics of exclusive π^0

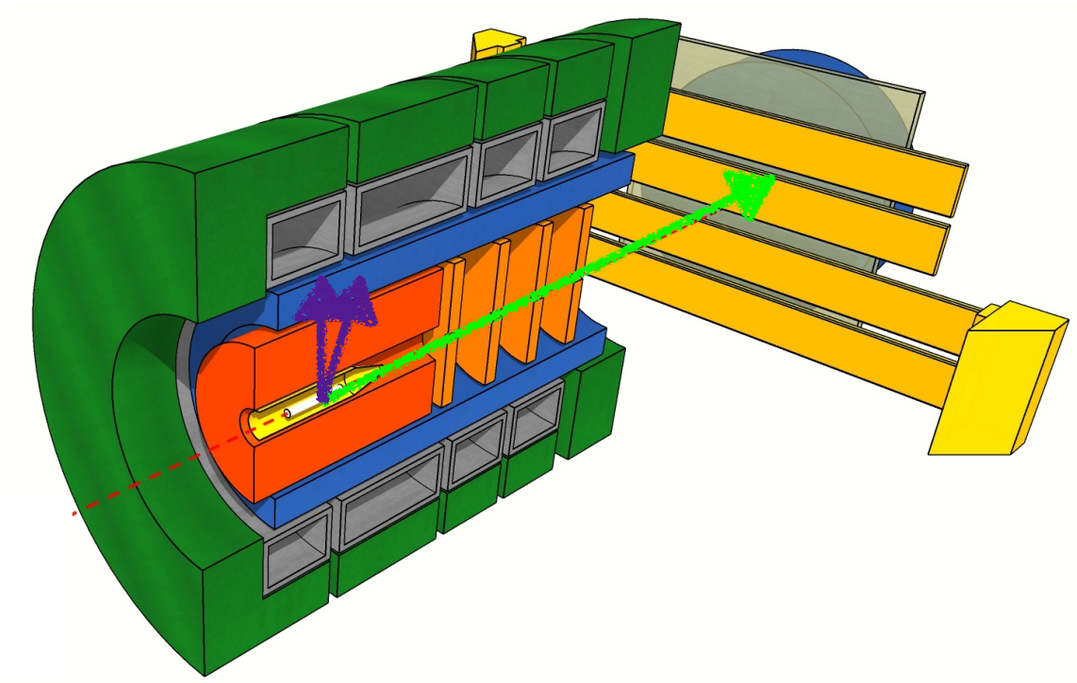
Detected protons



Detected photons

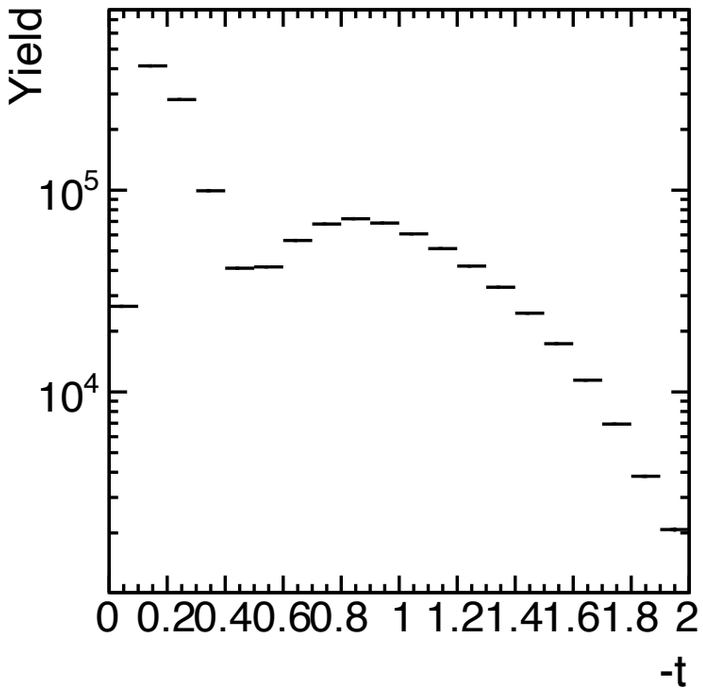


- For high energies $E_\gamma > 8$ GeV with $-u < 2$ GeV^2
- Fast forward protons and low energy photons in barrel calorimeter, still detectable

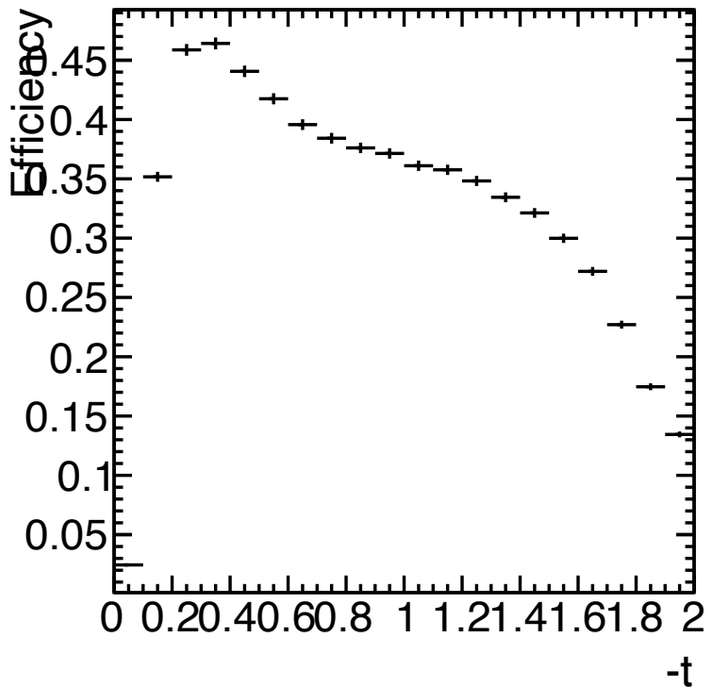


t-channel π^0

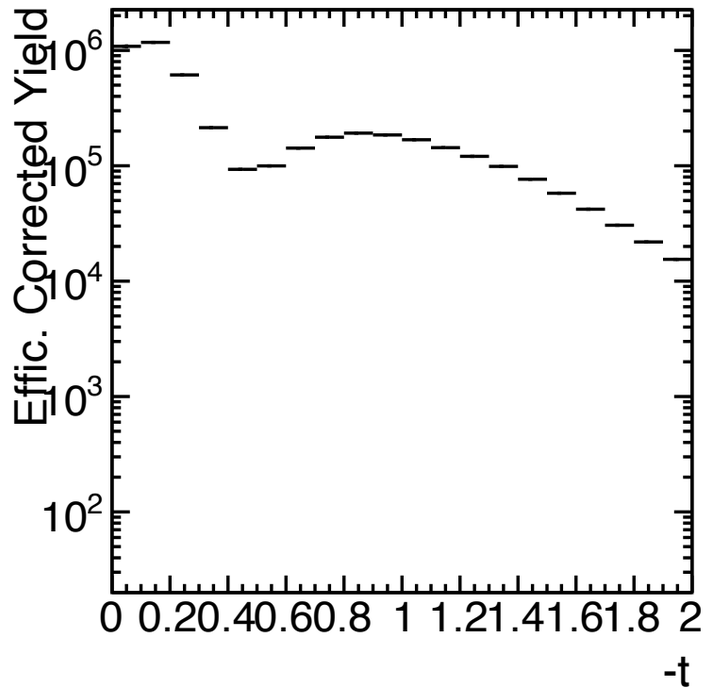
Yield



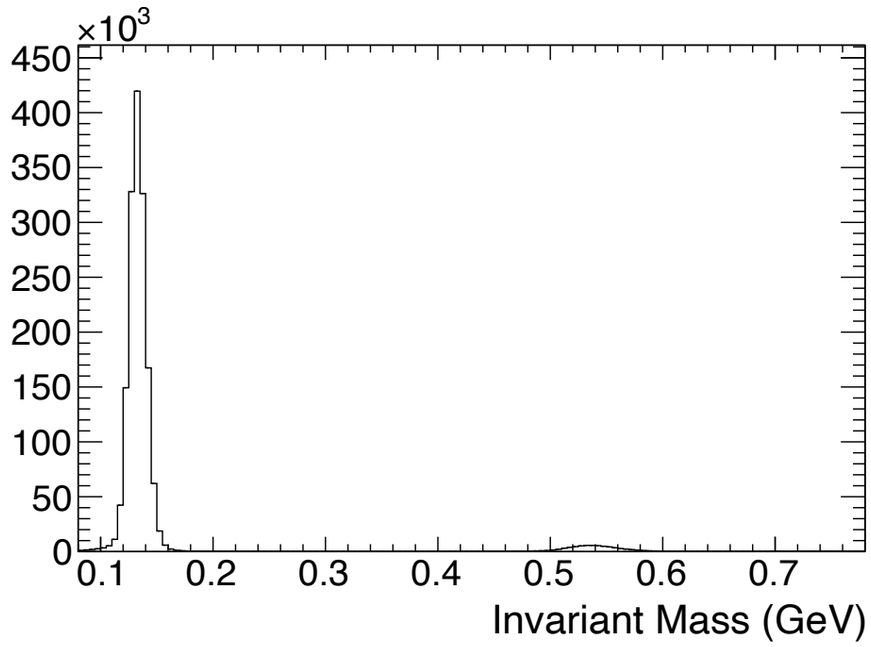
Efficiency



Efficiency corrected yield

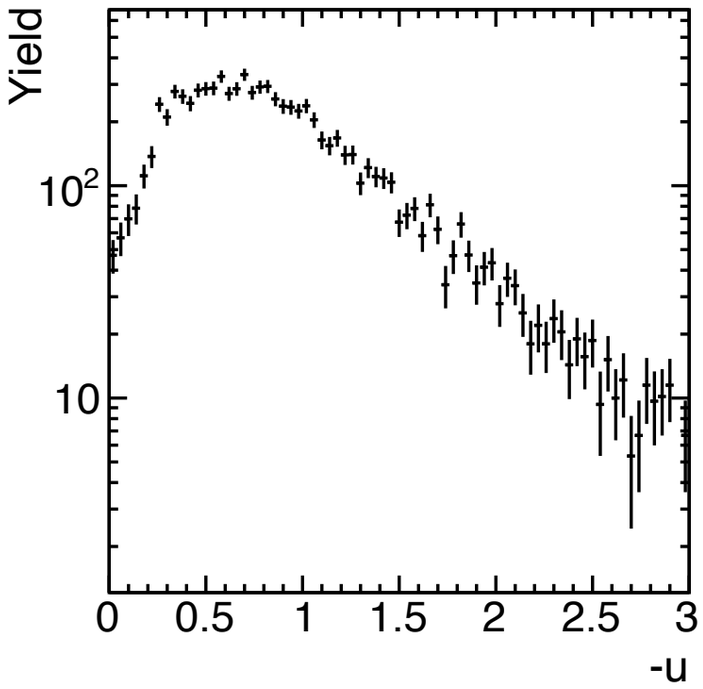


- For high energies $E_\gamma > 8$ GeV, expected dip at $-t = 0.5$ GeV^2 from zero in vector meson trajectory
- Smooth efficiency over range dominated by t-channel exchange

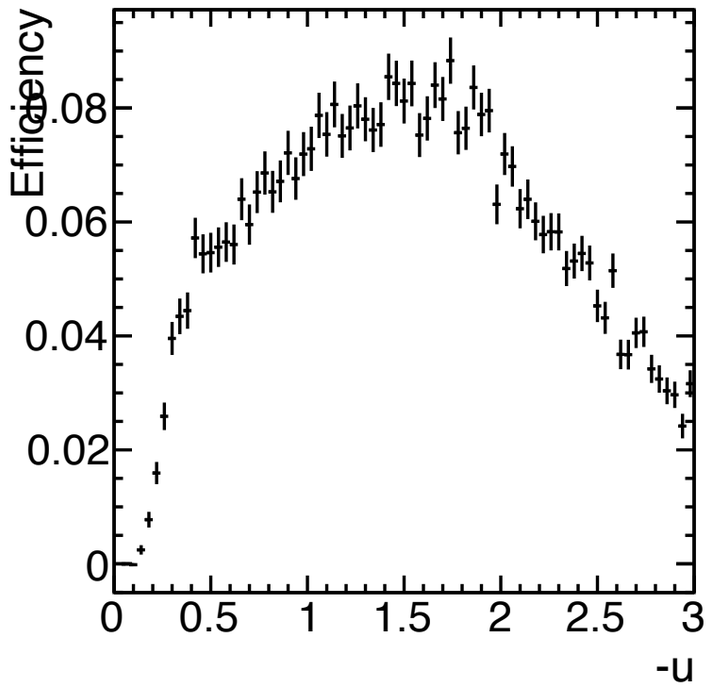


u-channel π^0

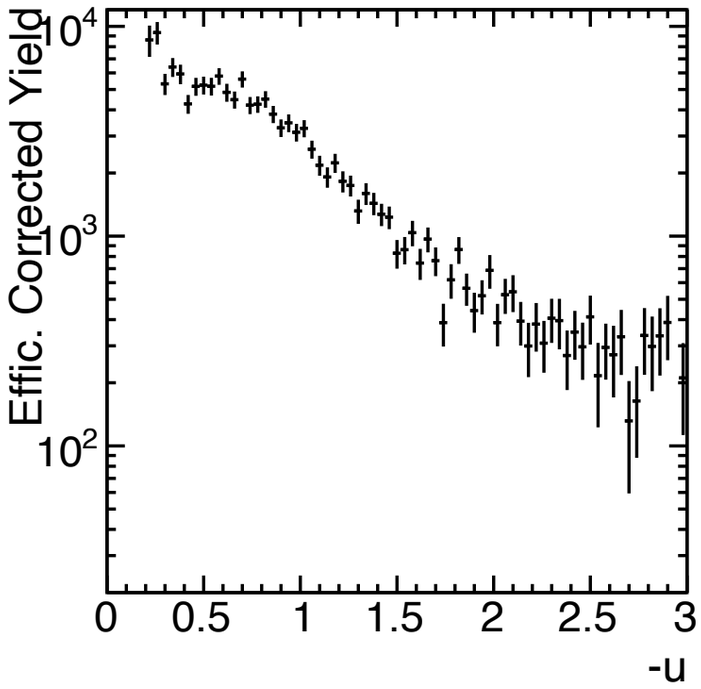
Yield



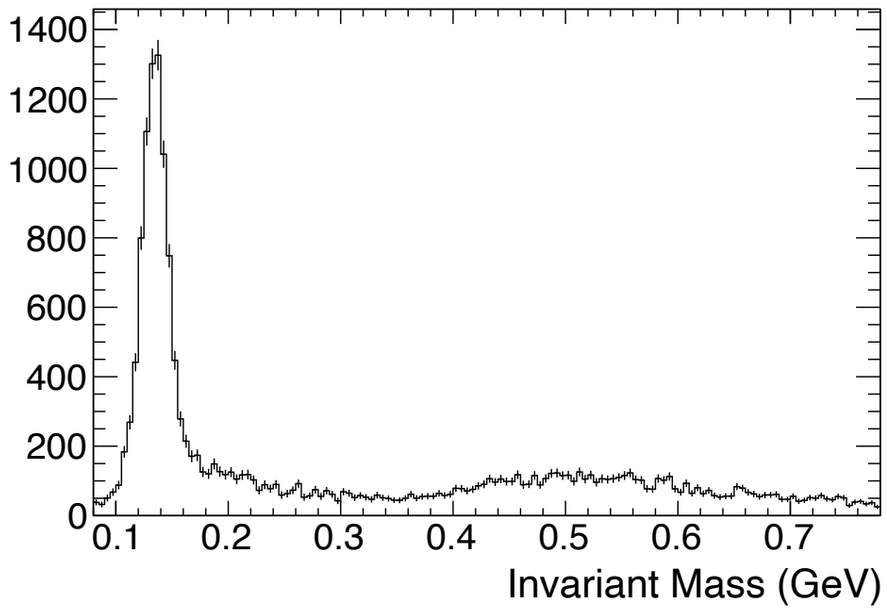
Efficiency



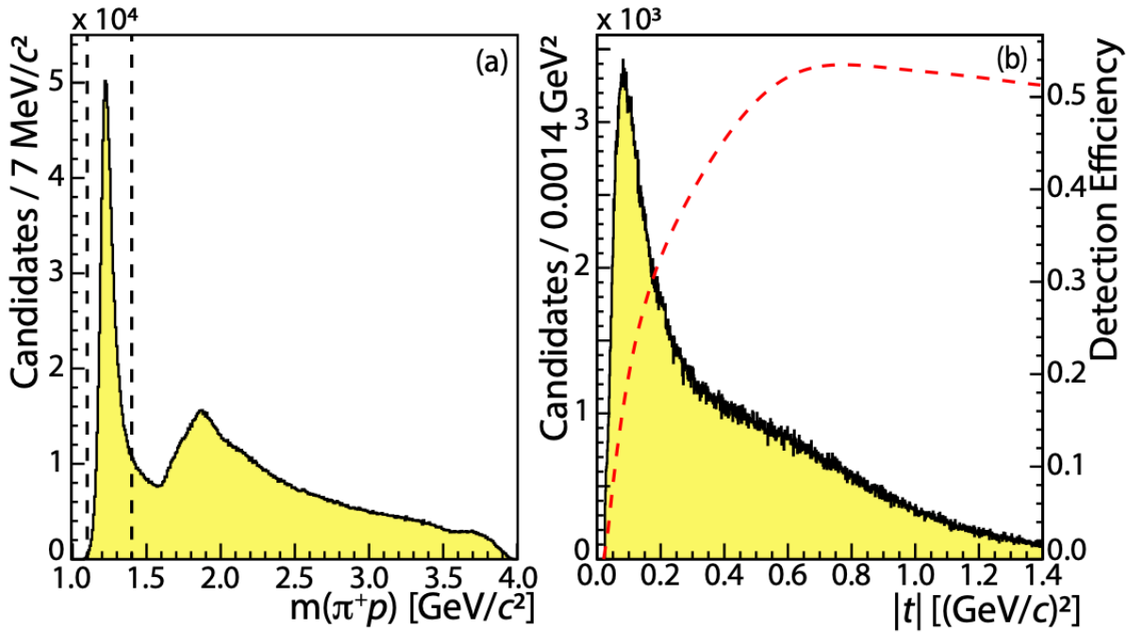
Efficiency-corrected yield

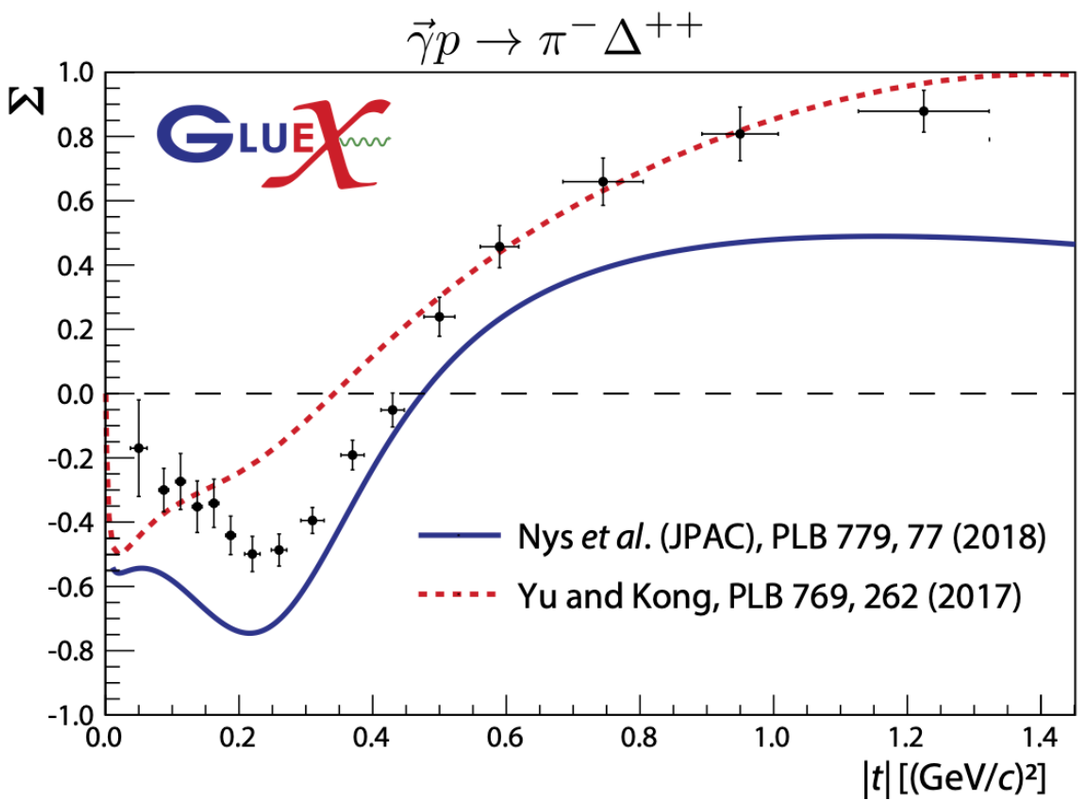


- For high energies $E_\gamma > 8$ GeV, smooth efficiency over range dominated by u-channel exchange
  - Low-u region needs further investigation of decreasing effic.
- Large u-channel exchange coverage with clean π^0 peak

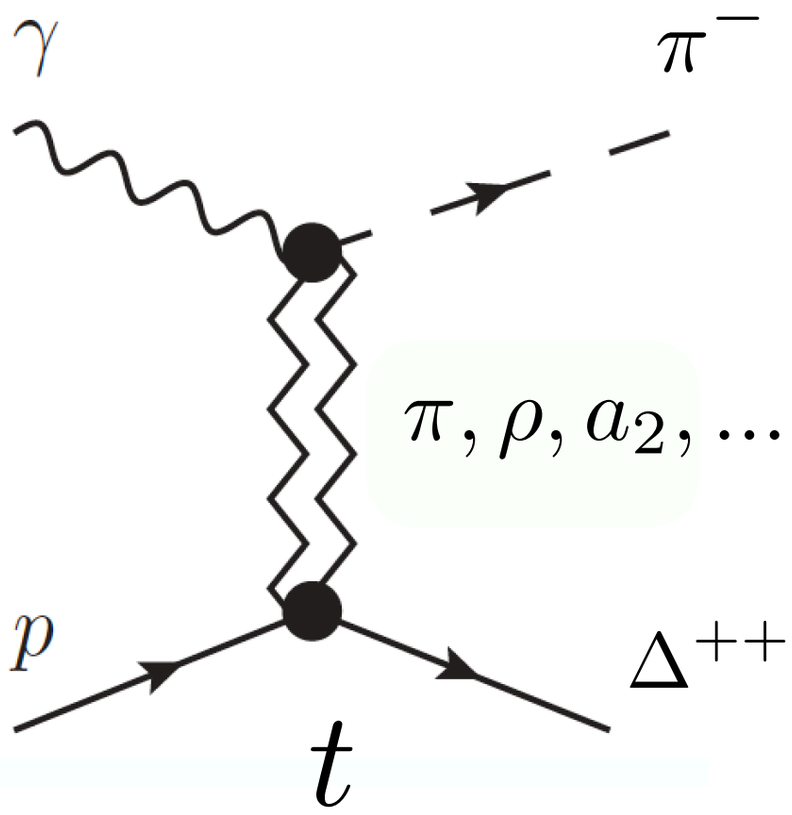


π- beam asymmetry: t-channel





arXiv:2009.07326

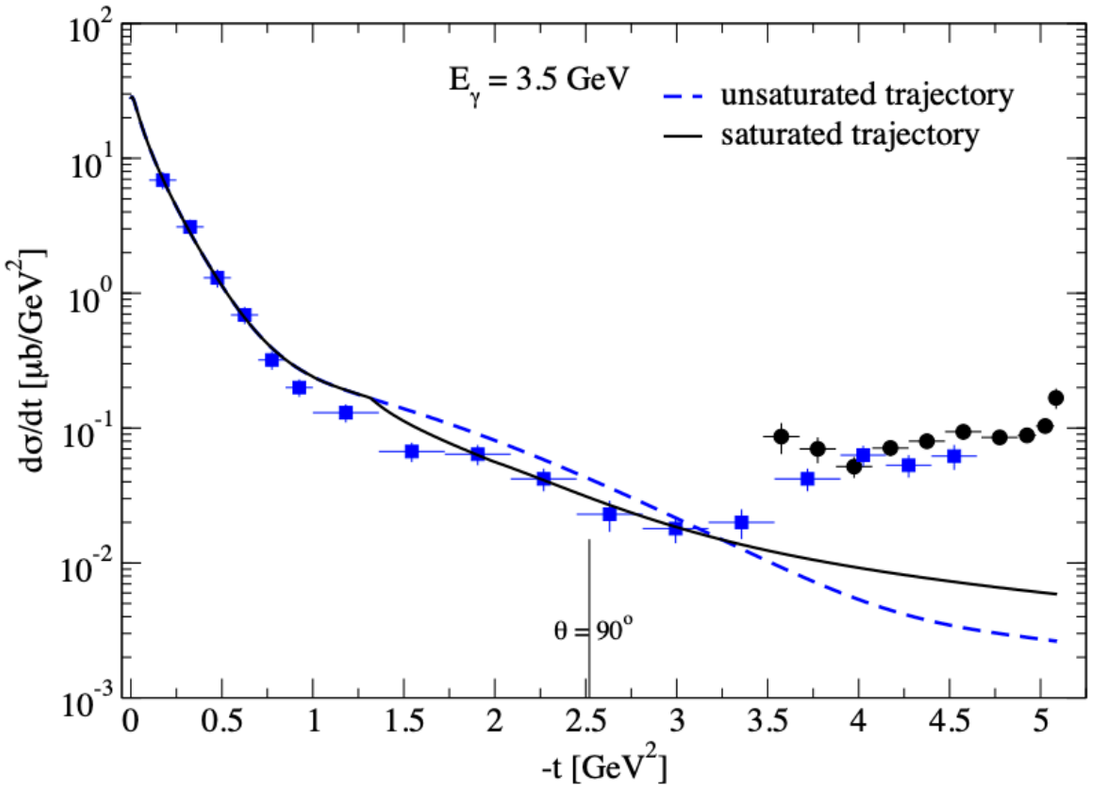


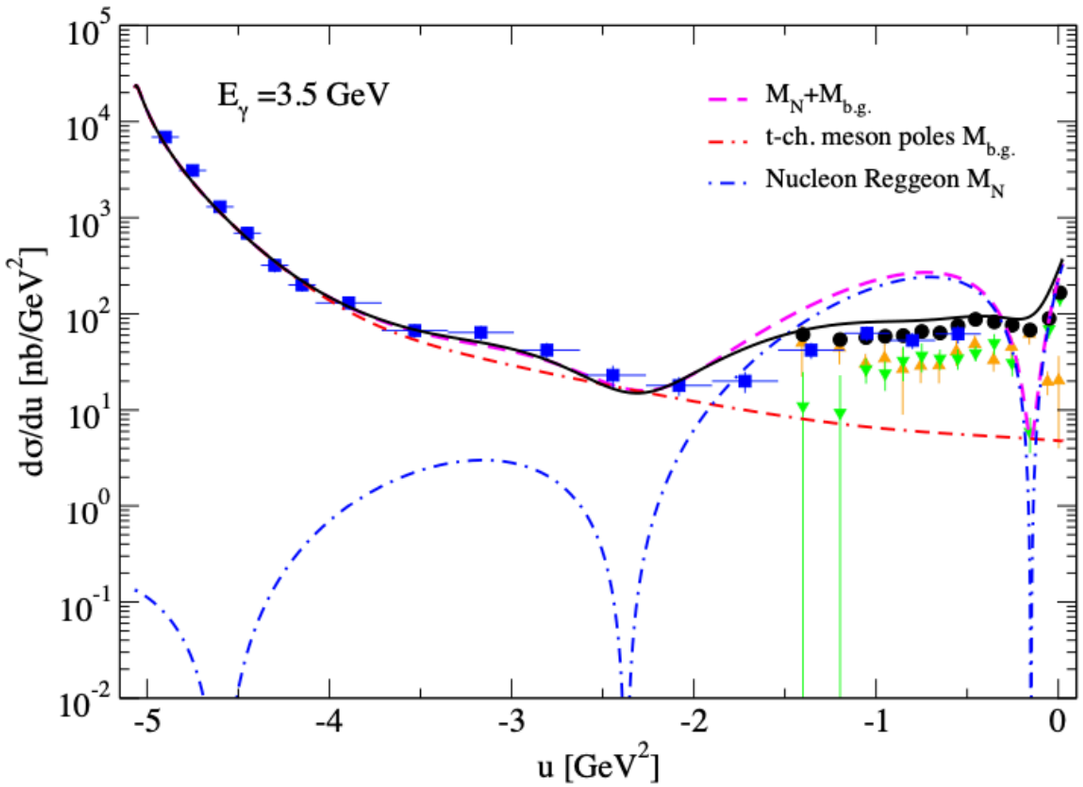
Charged pseudoscalars: more complicated *-t* dependence

Mark suggested the investigation of u-channel: beam asymmetry, dσ/du?

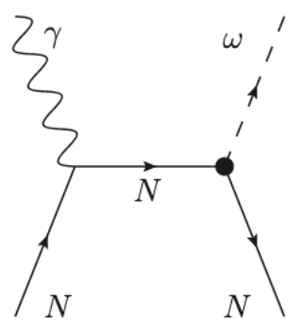
Backward vector mesons

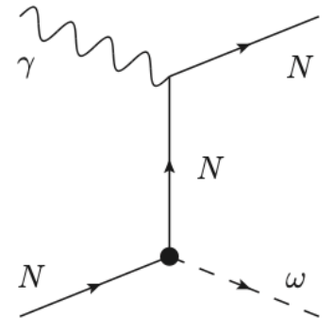
arXiv:1810.11645
arXiv:1710.04511





- Data on ω from CLAS6 and Clifft et. al.
- Models from Laget, B.-G. Yu, et. al. (see talk this morning's talk)
- Interest in pushing to higher energies for more complete s, t, u dependence?





t-channel: Spin Density Matrix Elements

- Intensity expressed as function of production and decay angles for vector mesons: $\gamma p \to \rho p$

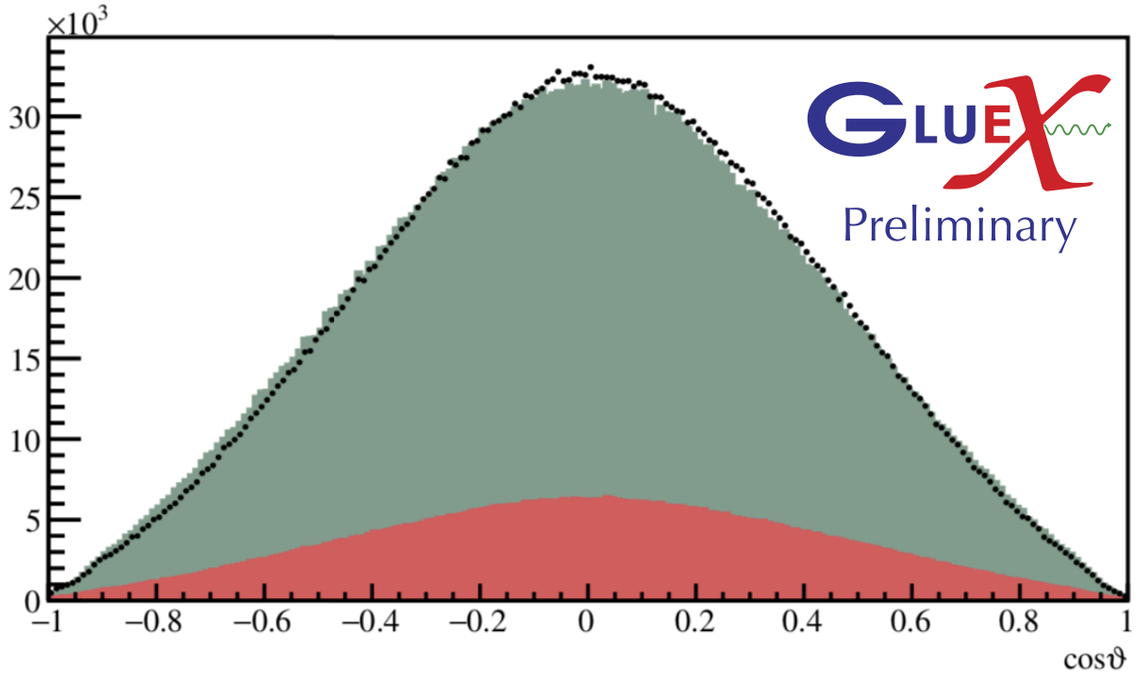
$$W^0(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^0_{10}\sin 2\vartheta\cos\varphi - \rho^0_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

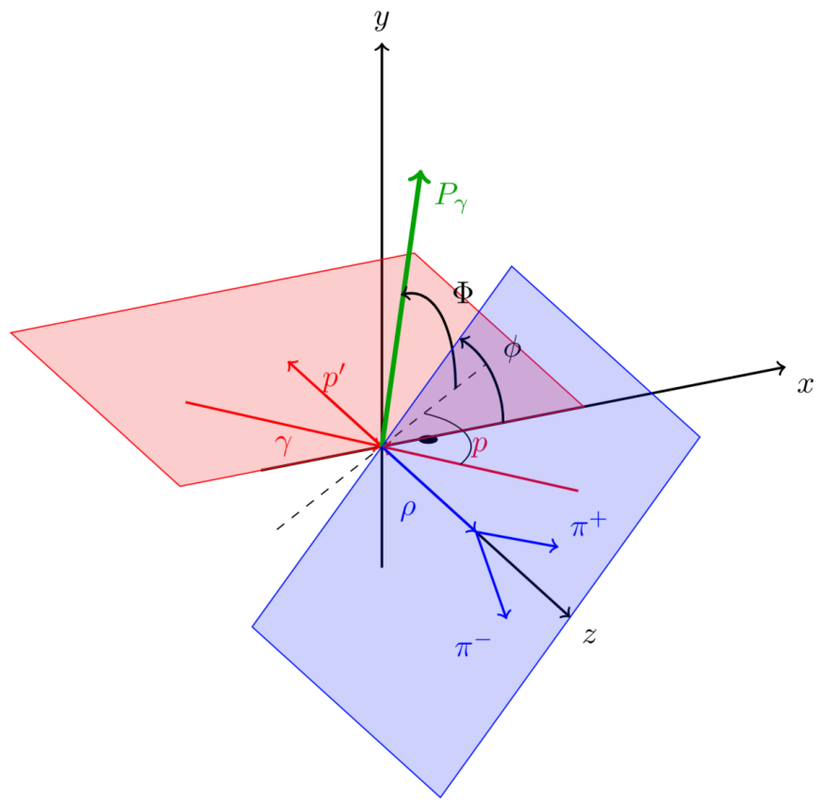
$$W^1(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\rho^1_{11}\sin^2\vartheta + \rho^1_{00}\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^1_{10}\sin 2\vartheta\cos\varphi - \rho^1_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

$$W^2(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\sqrt{2}\mathrm{Im}\rho^2_{10}\sin 2\vartheta\sin\varphi + \mathrm{Im}\rho^2_{1-1}\sin^2\vartheta\sin 2\varphi\right)$$

$$W(\cos\vartheta,\varphi,\Phi) = W^0(\cos\vartheta,\varphi) - P_\gamma\cos(2\Phi)W^1(\cos\vartheta,\varphi) - P_\gamma\sin(2\Phi)W^2(\cos\vartheta,\varphi)$$

Schilling [Nucl. Phy. B, 15 (1970) 397]





t-channel: Spin Density Matrix Elements

- Intensity expressed as function of production and decay angles for vector mesons: $\gamma p \to \rho p$

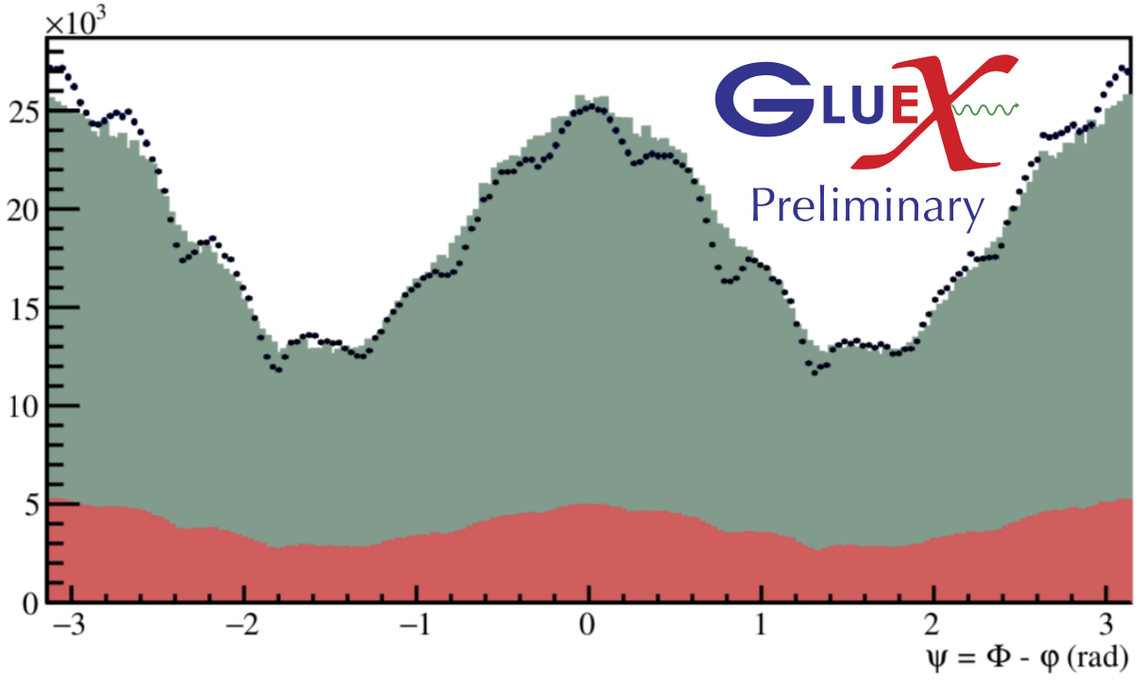
$$W^0(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^0_{10}\sin 2\vartheta\cos\varphi - \rho^0_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

$$W^1(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\rho^1_{11}\sin^2\vartheta + \rho^1_{00}\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^1_{10}\sin 2\vartheta\cos\varphi - \rho^1_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

$$W^2(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\sqrt{2}\mathrm{Im}\rho^2_{10}\sin 2\vartheta\sin\varphi + \mathrm{Im}\rho^2_{1-1}\sin^2\vartheta\sin 2\varphi\right)$$

$$W(\cos\vartheta,\varphi,\Phi) = W^0(\cos\vartheta,\varphi) - P_\gamma\cos(2\Phi)W^1(\cos\vartheta,\varphi) - P_\gamma\sin(2\Phi)W^2(\cos\vartheta,\varphi)$$

Schilling [Nucl. Phy. B, 15 (1970) 397]



- Requires control of angular acceptance distributions similar to PWA

$$\ln L = \sum_{i=1}^{N}\ln I(\Omega_i) - \sum_{j=1}^{M}\ln I(\Omega_j) - \int d\Omega\, I(\Omega)\,\eta(\Omega)$$

Signal **Bkgd.** **Accept.**

t-channel: Spin Density Matrix Elements

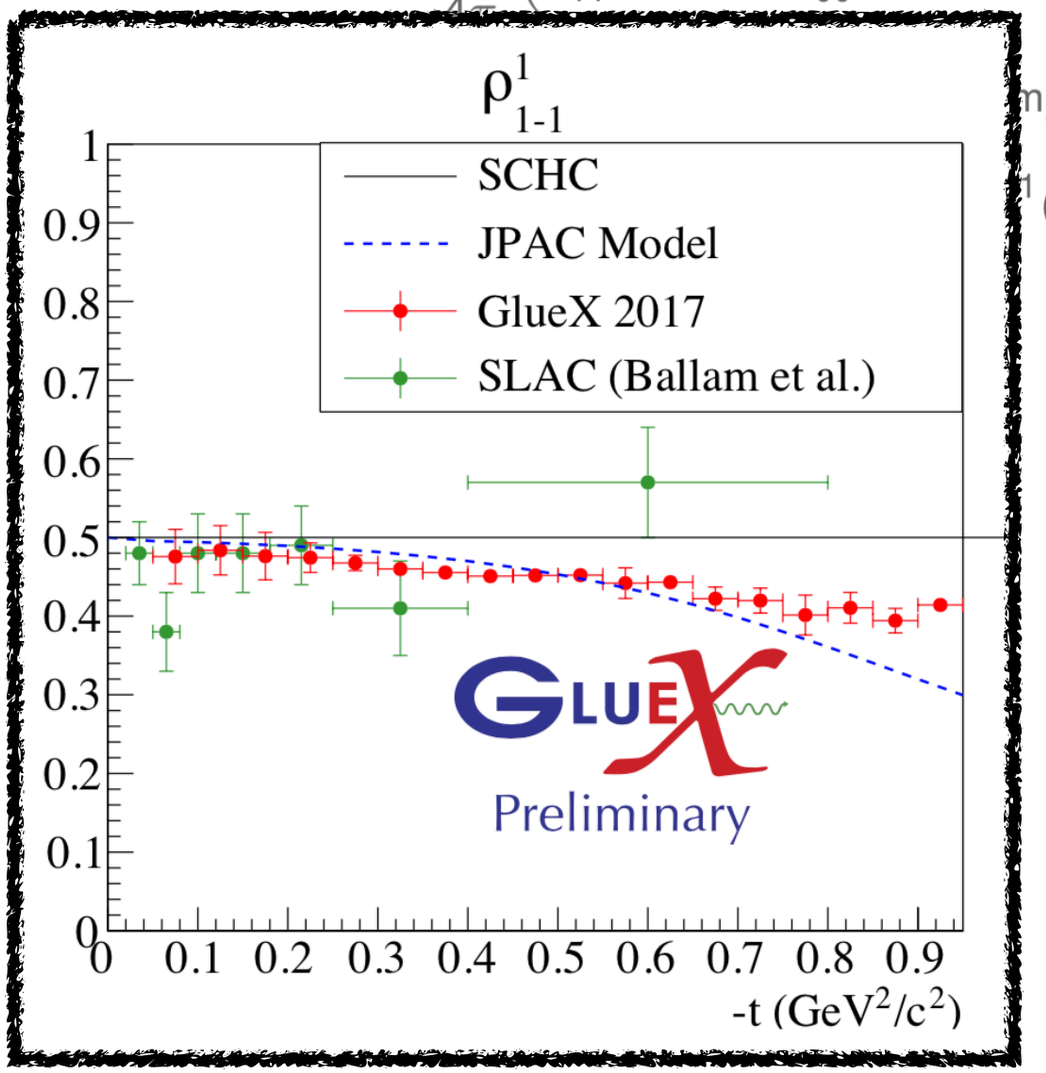
- Intensity expressed as function of production and decay angles for vector mesons: $\gamma p \to \rho p$

$$W^0(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^0_{10}\sin 2\vartheta\cos\varphi - \rho^0_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

$$W^1(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\rho^1_{11}\sin^2\vartheta + \rho^1_{00}\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^1_{10}\sin 2\vartheta\cos\varphi - \rho^1_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

$$\mathrm{m}\rho^2_{1-1}\sin^2\vartheta\sin 2\varphi\Big)$$

$$^1(\cos\vartheta,\varphi) - P_\gamma\sin(2\Phi)W^2(\cos\vartheta,\varphi)$$



- Good agreement with JPAC model in the low *-t* regime
- Natural parity exchange is dominant for ρ, ϕ, and ω

MENU2019 Proceedings arXiv:1908.07275

t-channel: Spin Density Matrix Elements

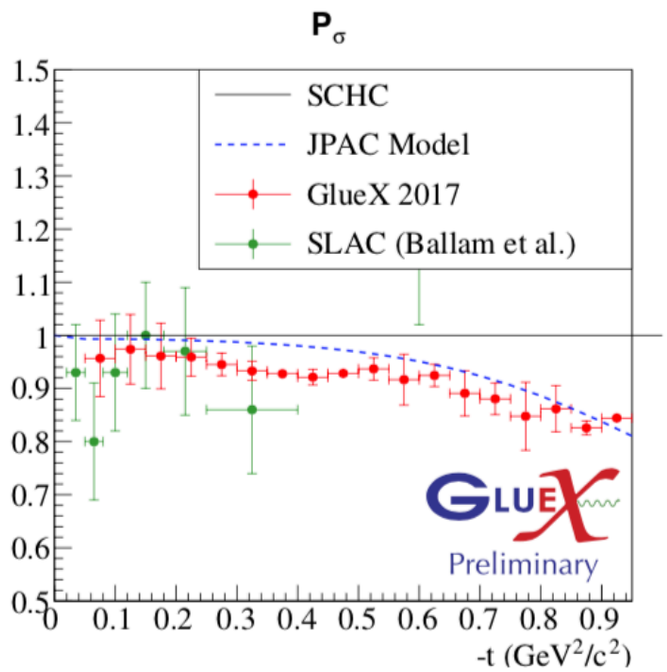
- Intensity expressed as function of production and decay angles for vector mesons: $\gamma p \to \rho p$

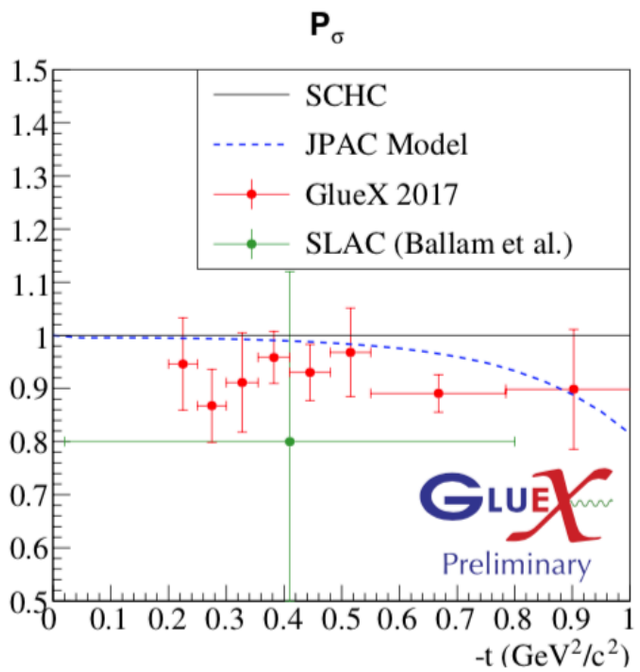
$$W^0(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^0_{10}\sin 2\vartheta\cos\varphi - \rho^0_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

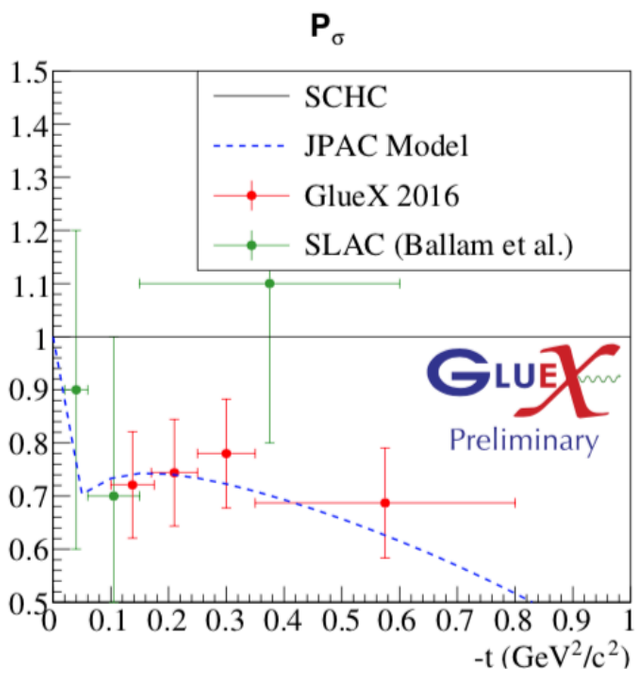
$$W^1(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\rho^1_{11}\sin^2\vartheta + \rho^1_{00}\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^1_{10}\sin 2\vartheta\cos\varphi - \rho^1_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

$$W^2(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\sqrt{2}\mathrm{Im}\rho^2_{10}\sin 2\vartheta\sin\varphi + \mathrm{Im}\rho^2_{1-1}\sin^2\vartheta\sin 2\varphi\right)$$

$\rho(770) \to \pi^+\pi^-$ | $\phi(1020) \to K^+K^-$ | $\omega(782) \to \pi^+\pi^-\pi^0$

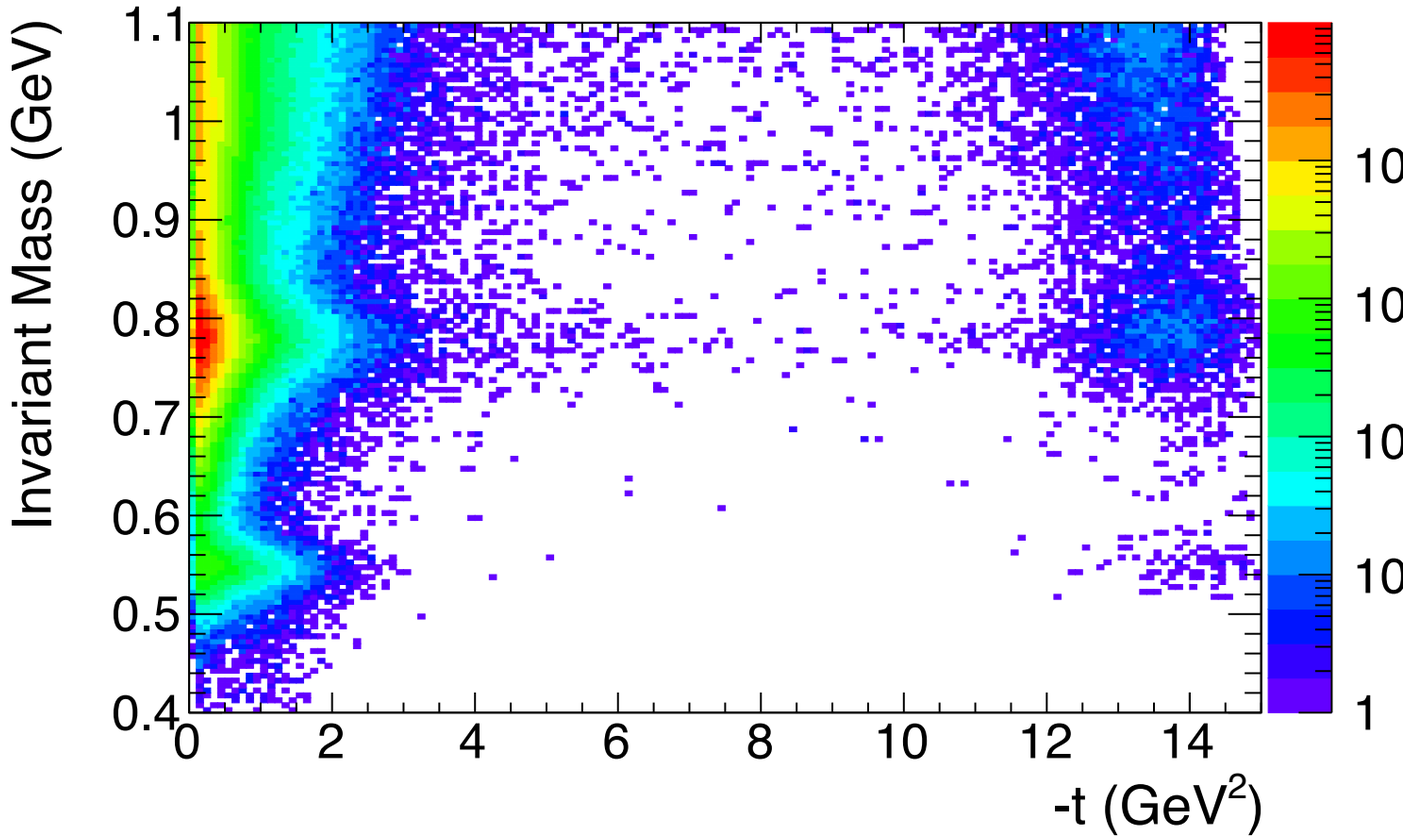






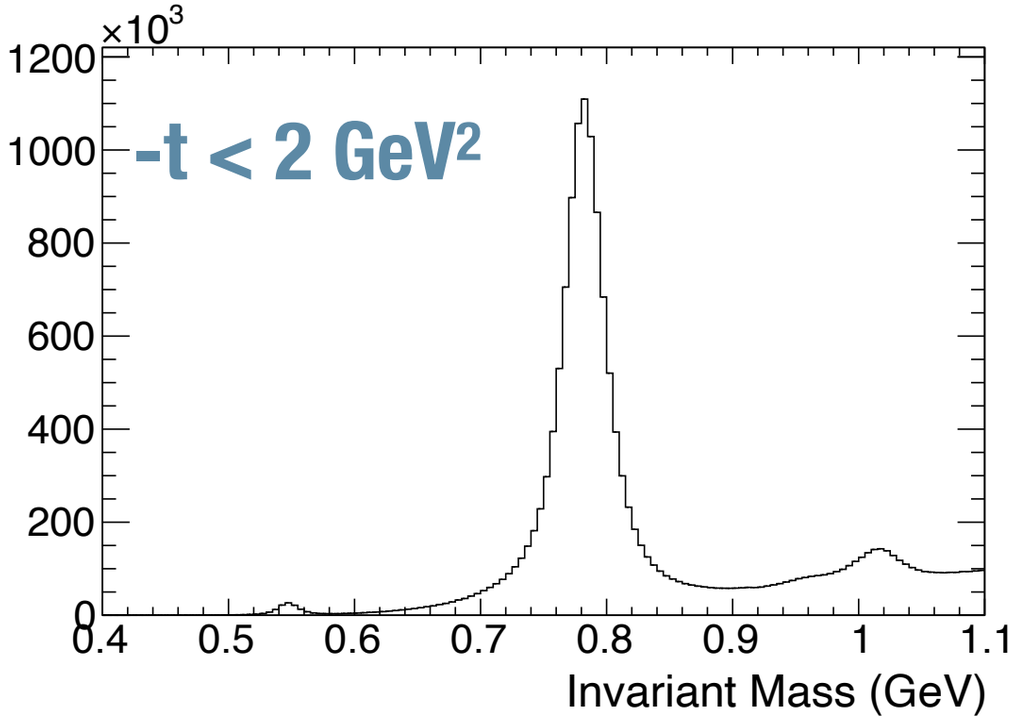
MENU2019 Proceedings arXiv:1908.07275

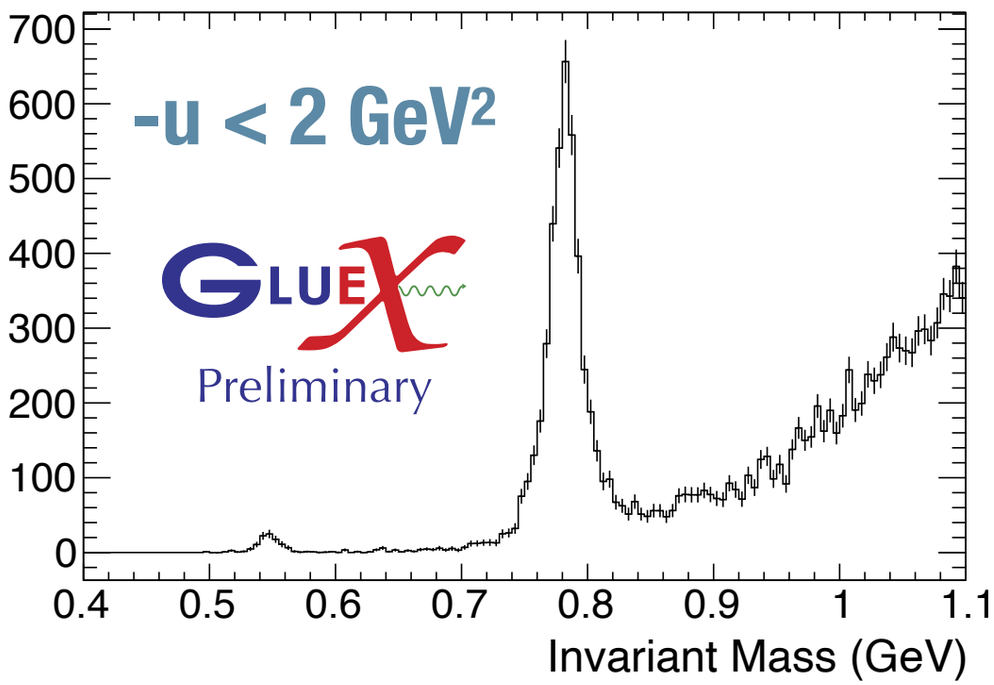
t and u dependence: exclusive $\omega \to \pi^0\pi^+\pi^-$



$$\gamma p \to \pi^0\pi^+\pi^- p$$

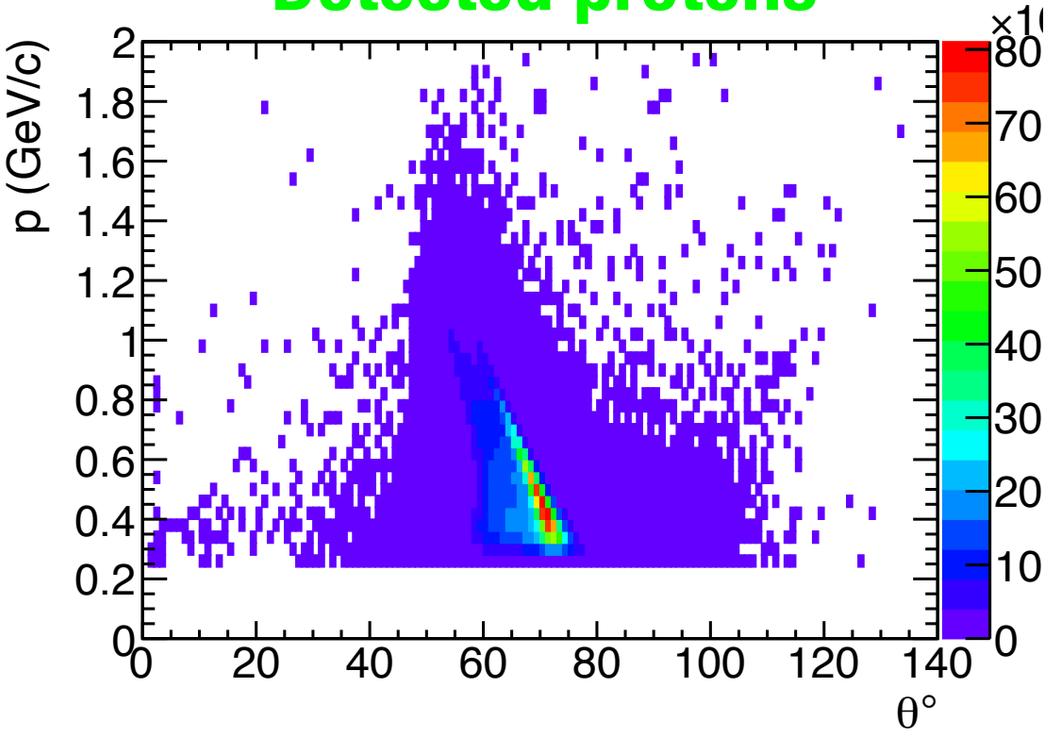
Fully reconstructed final state



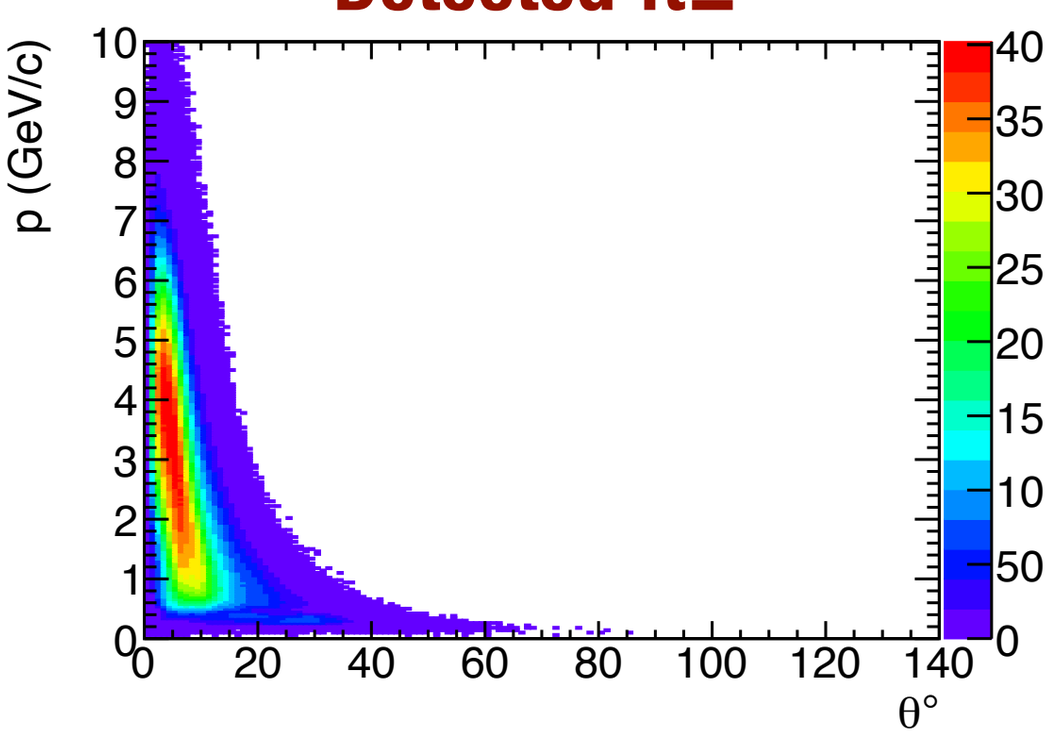


t-channel kinematics: exclusive $\omega \rightarrow \pi^0\pi^+\pi^-$

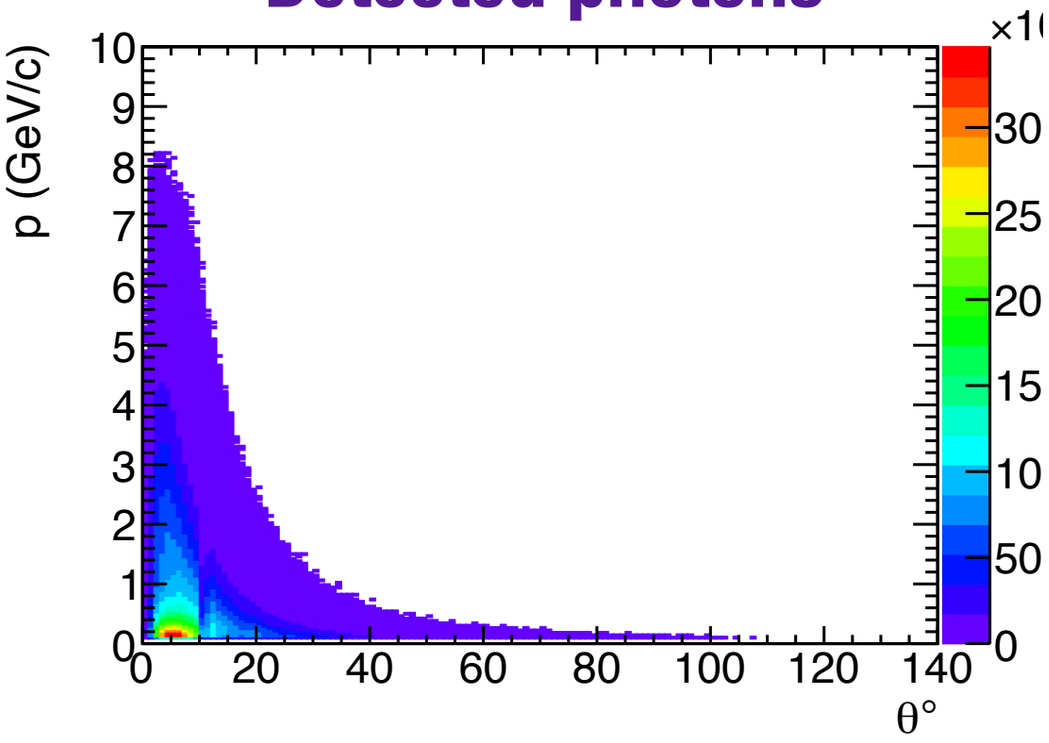
Detected protons

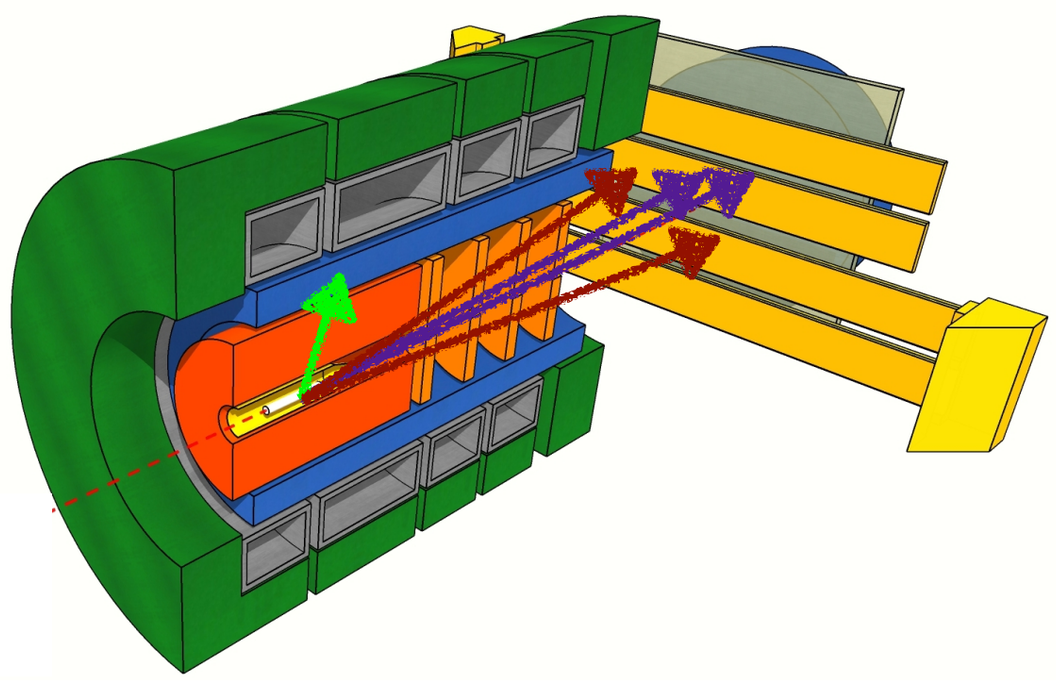


Detected π±



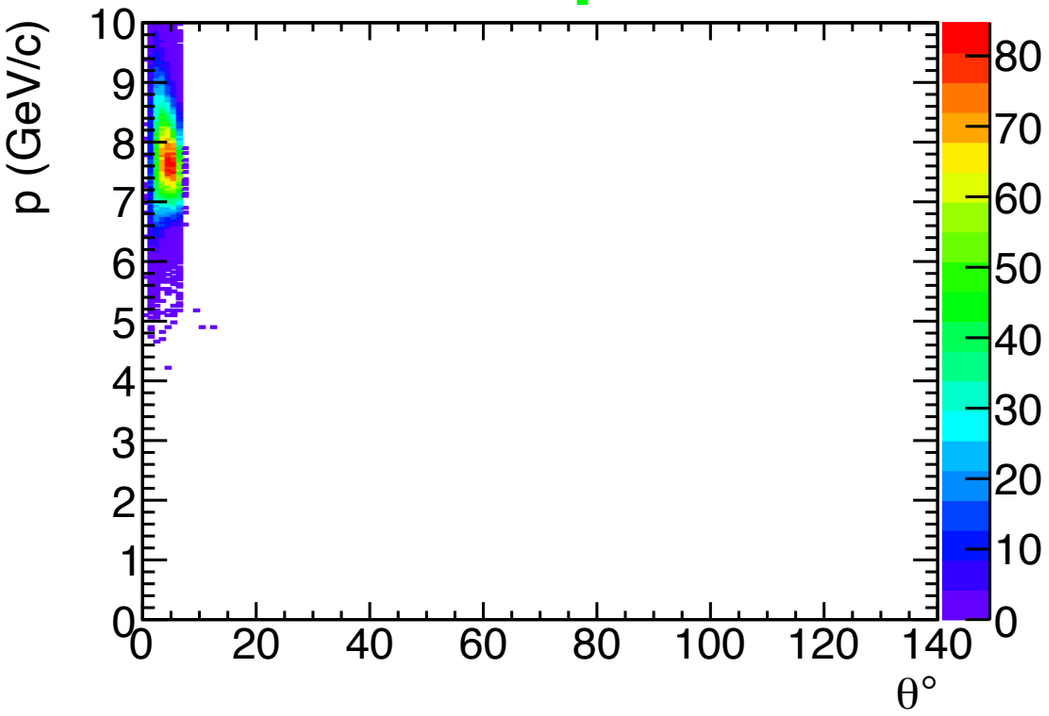
Detected photons



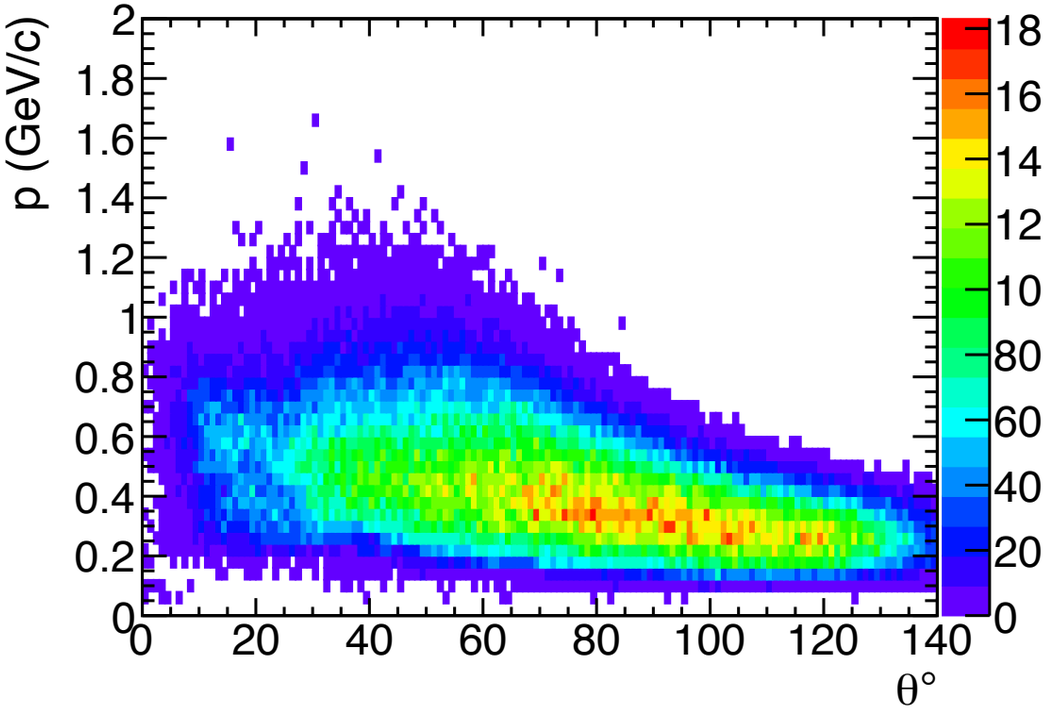


u-channel kinematics: exclusive $\omega \rightarrow \pi^0\pi^+\pi^-$

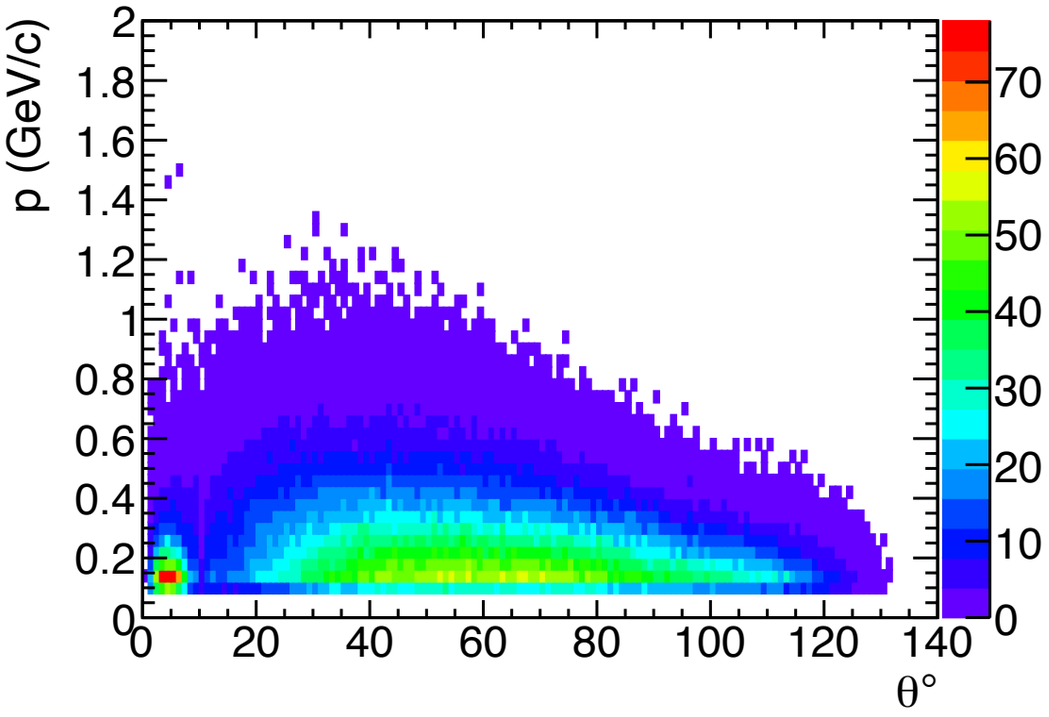
Detected protons

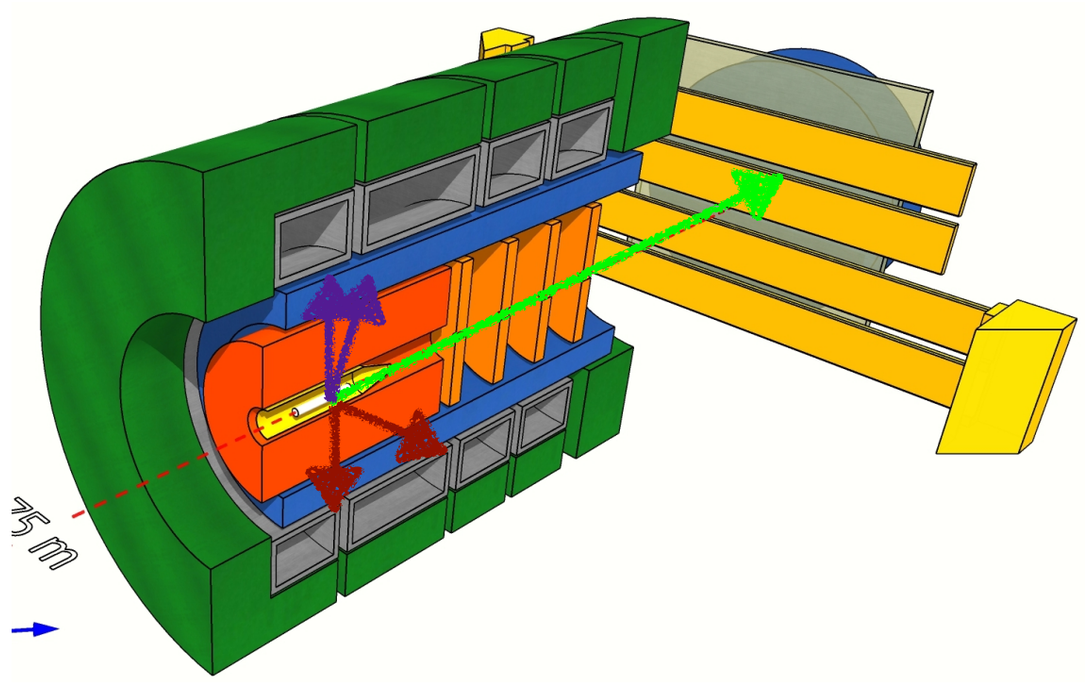


Detected π±



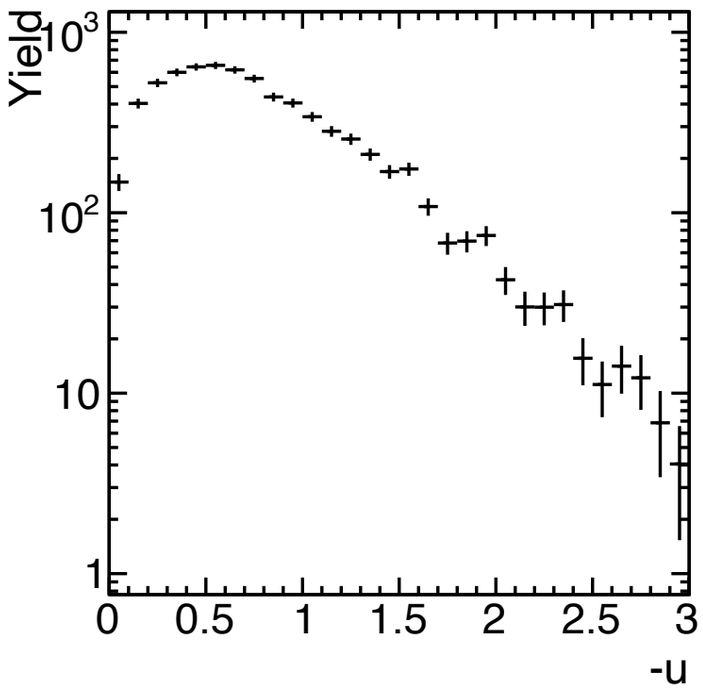
Detected photons



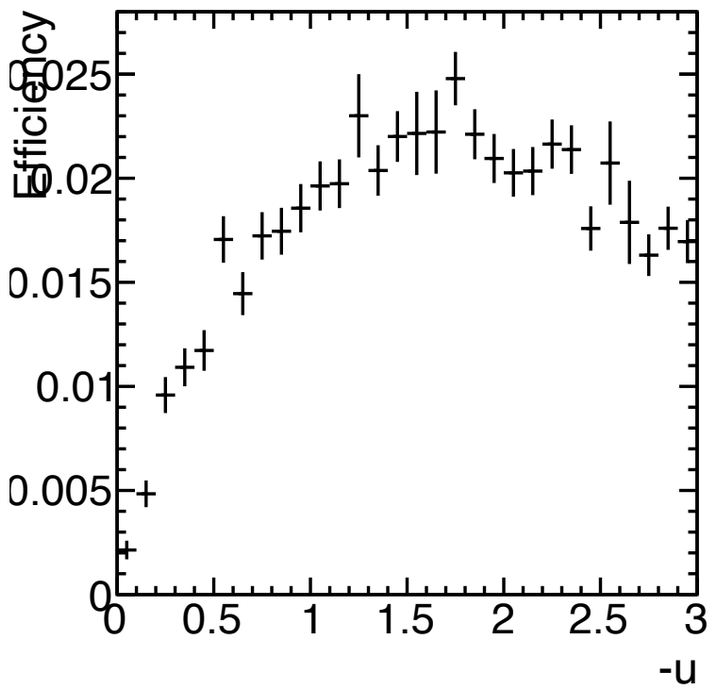


u-channel $\omega \rightarrow \pi^0\pi^+\pi^-$

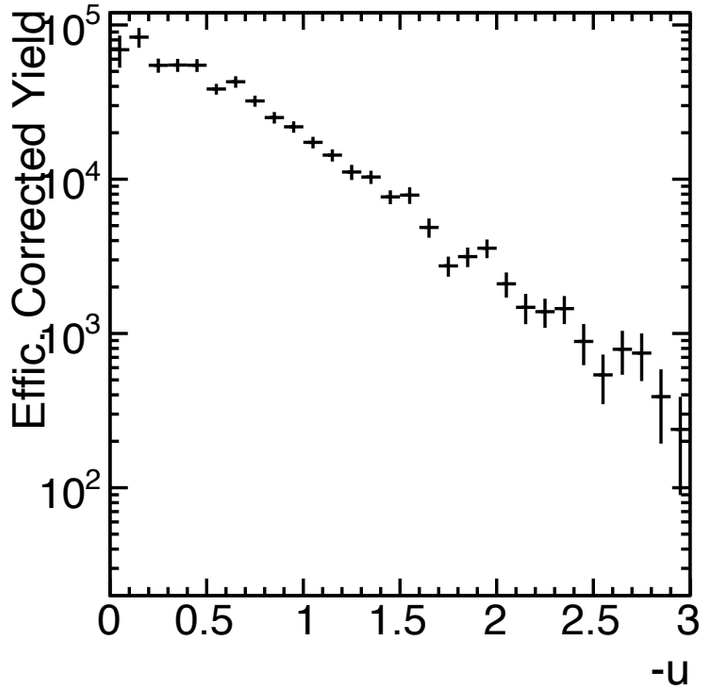
Yield



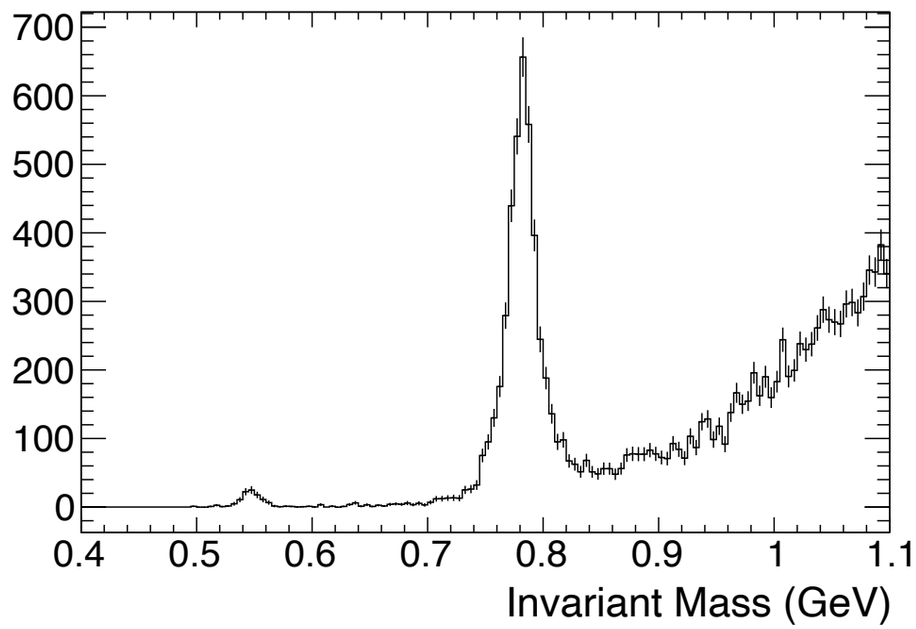
Efficiency



Efficiency-corrected yield



- For high energies $E_\gamma > 8$ GeV, smooth efficiency over range dominated by u-channel exchange
  - Low-u region needs further investigation of decreasing effic.
- Large u-channel exchange coverage with clean η, ω peak

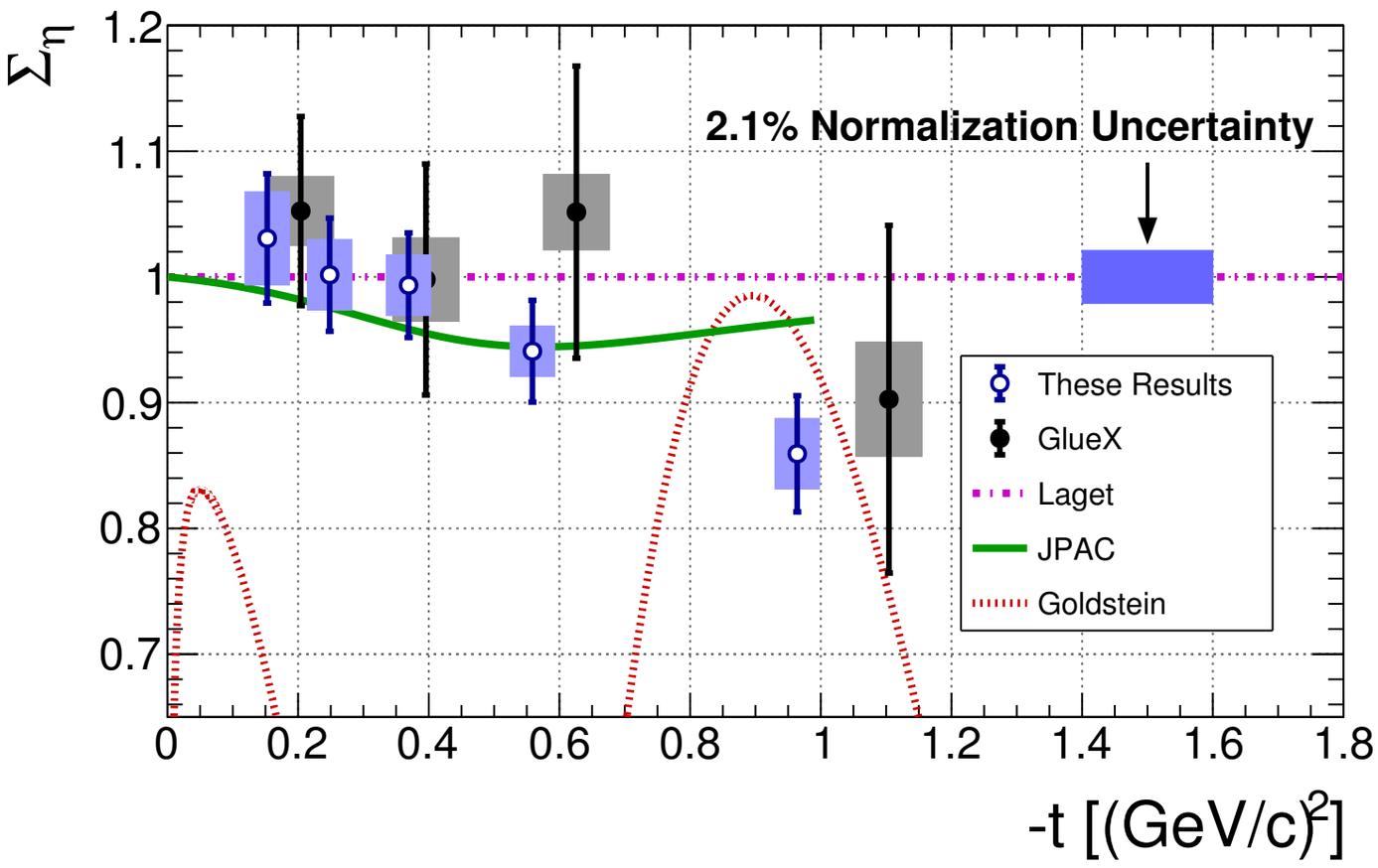


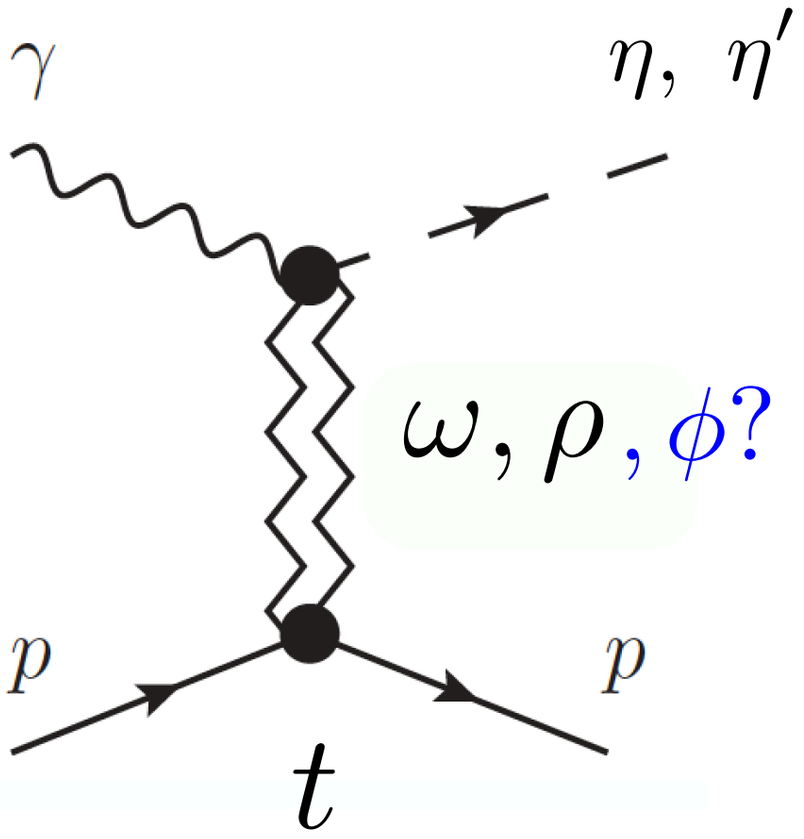
Summary

- "Backward" angle peaks observed for π^0, η, ω mesons, next talks show more interesting examples
- Large acceptance allows GlueX to fully reconstruct these final states in u- and t-channel production
- **Observables:**
  - $d\sigma/du$ for $3 < E_\gamma < 11.5$ GeV
  - polarization (Σ and SDMEs) for $8.2 < E_\gamma < 8.8$ GeV
- **Questions:**
  - Which final states are most interesting from theoretical perspective? And which are simplest to interpret/model?
  - Which observables are most important?

η/η' beam asymmetry

Recently submitted to PRC
arXiv:1908.05563



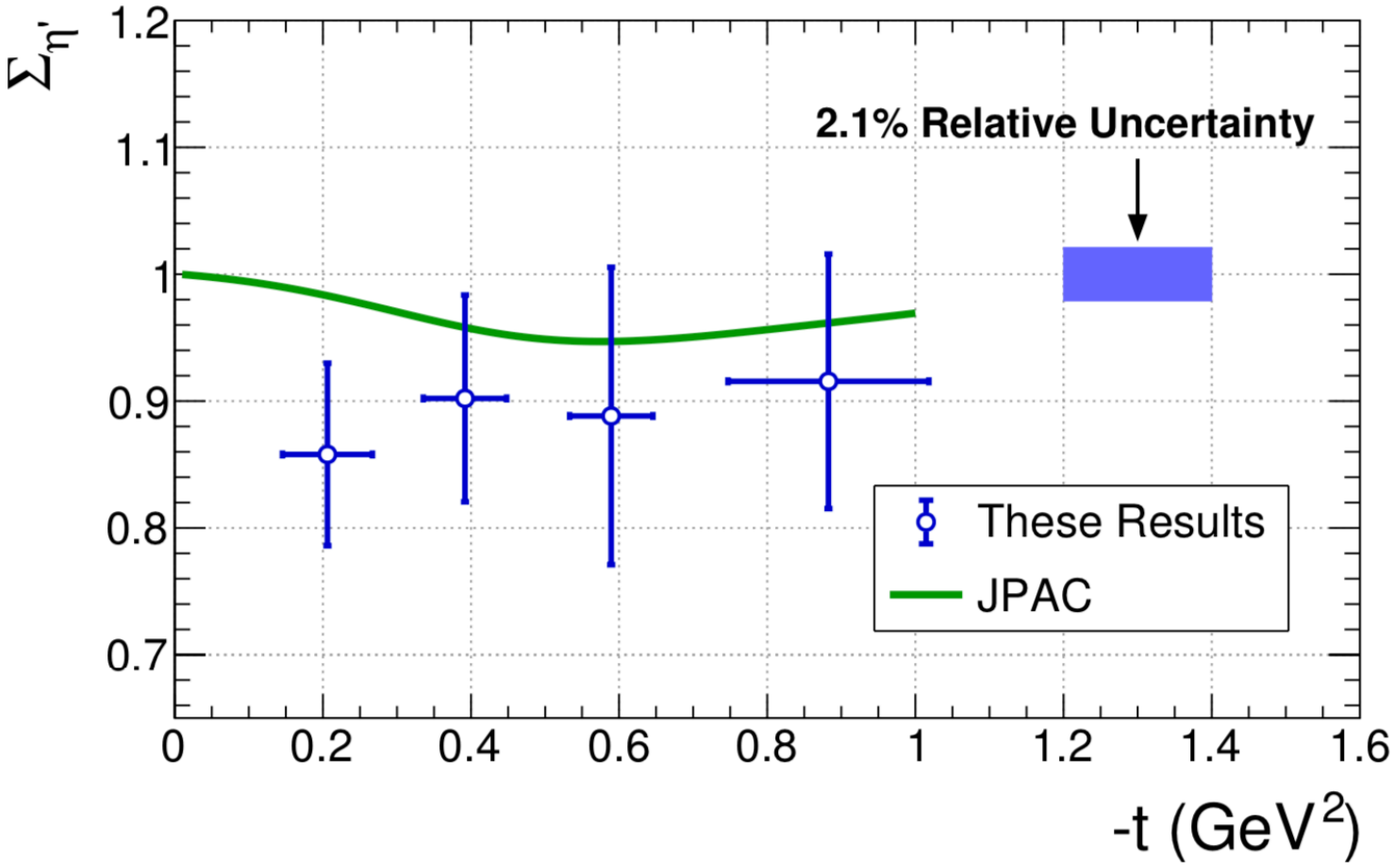


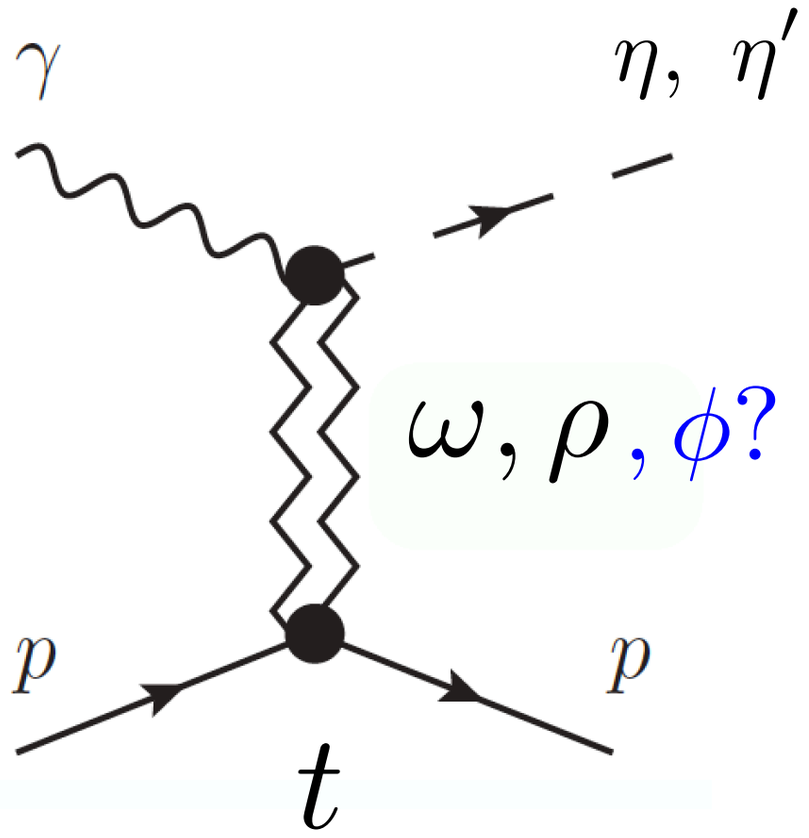
Consistent with prediction from JPAC: PLB 774 (2017) 362

Neutral pseudoscalars: Σ~1, dominated by vector exchange

η/η' beam asymmetry

Recently submitted to PRC
arXiv:1908.05563





Consistent with prediction from JPAC: PLB 774 (2017) 362

Neutral pseudoscalars: Σ~1, dominated by vector exchange