Measurement of the t-dependence of the beam asymmetry for the reaction $\vec{\gamma}p \rightarrow \eta p$

Tolga Erbora

Florida International University, Miami, FL

On behalf of the GlueX Collaboration

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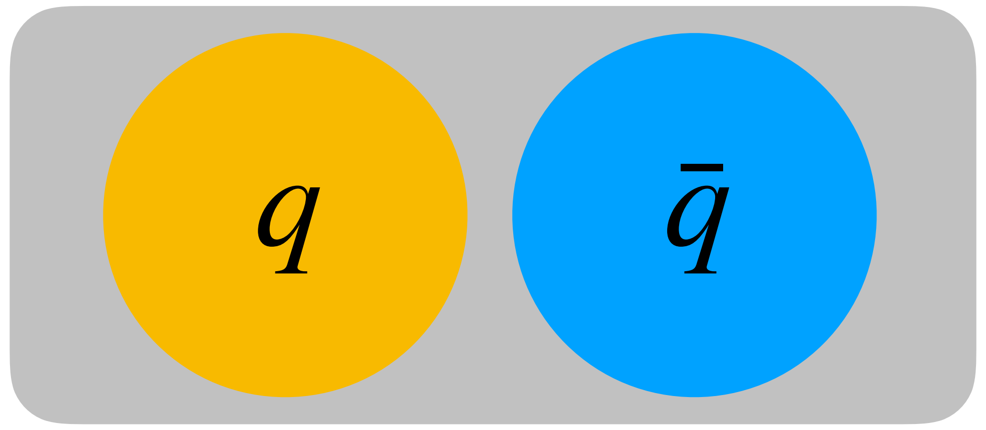
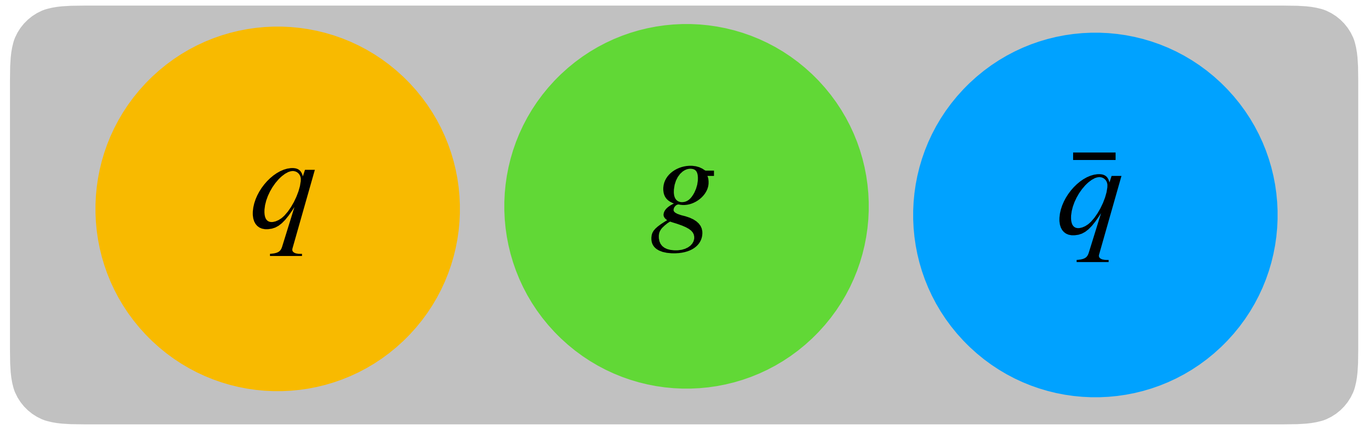
Motivations

- The GlueX experiment at Jefferson Lab is searching for hybrid mesons.
  - Hybrid meson: $q\bar{q}g$
  - Among those: Exotics: Quantum #s beyond simple quark model (e.g. $J^{PC} = 1^{-+}$)
  - Studying mass spectrum of hybrids with rel. to quantum #s
  - Several decay particles: $\rho, \eta, \omega, \pi, \ldots$
- **This work**: study η production mechanisms

Meson Constituents



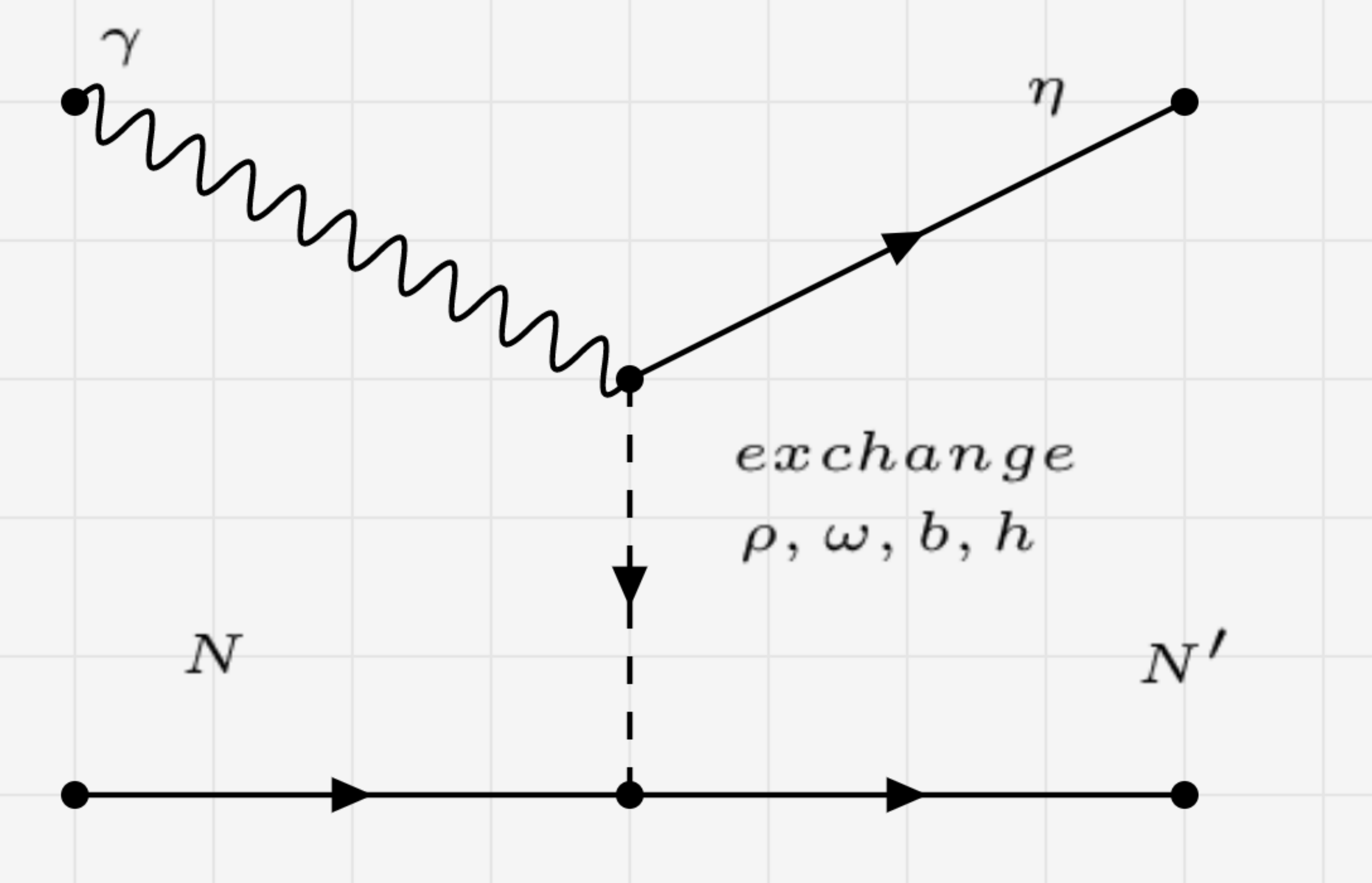
Hybrid Meson Constituents

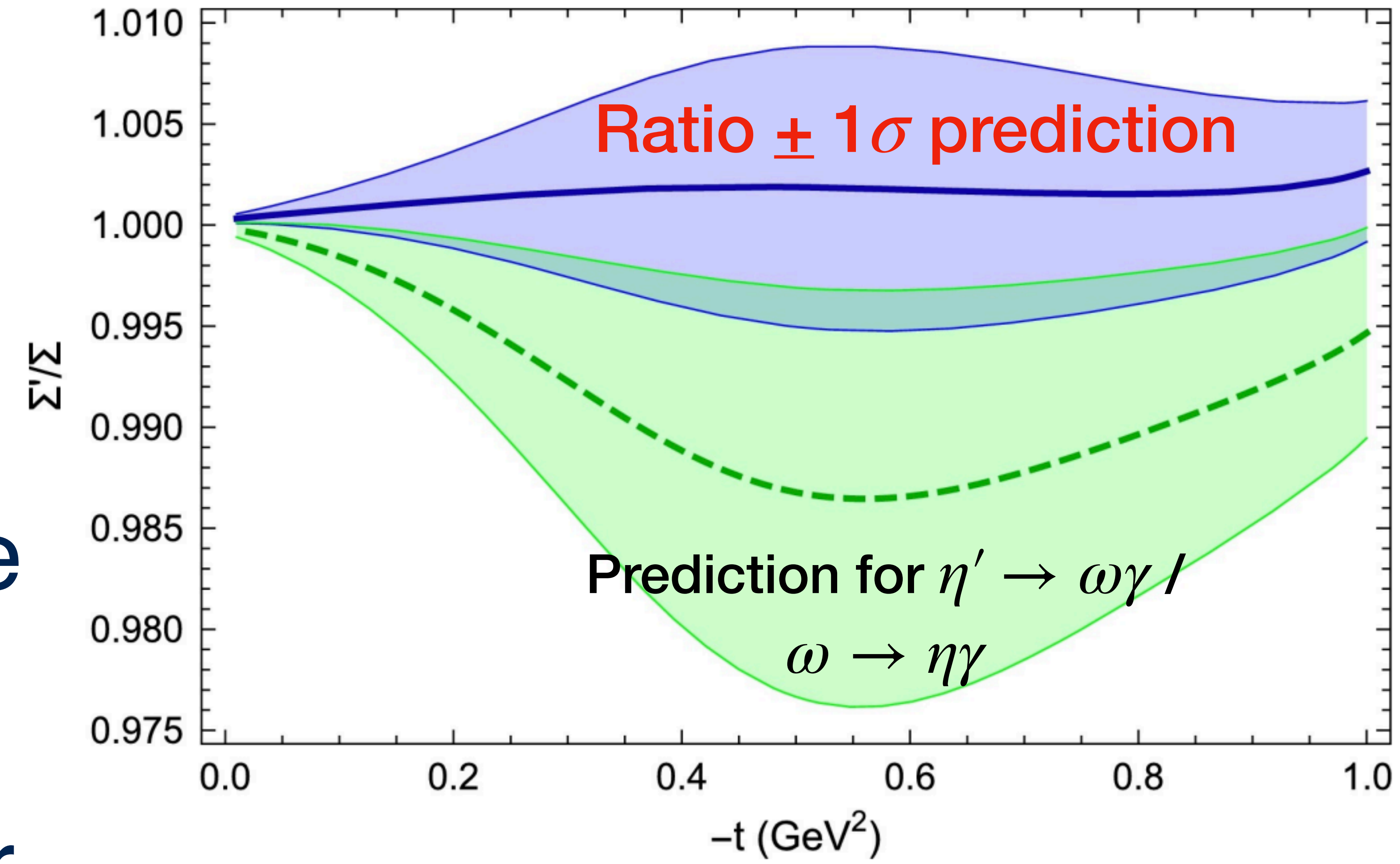


Motivations

- η mesons (547 MeV, $J^{PC} = 0^{-+}$)
  - Produced @ GlueX energies via Meson, Reggeon exchanges
- Mechanism: Photon beam asymmetry $\Sigma \in [-1,1]$
  - $\Sigma = 1$: **natural** parity exchange - $P = (-1)^J$ $(\rho, \omega$: $1^{--})$
  - $\Sigma = -1$: **unnatural** parity exchange $P = (-1)^{J+1}$ $(b, h$: $1^{+-})$
- What is the ratio of $\Sigma_{\eta'}/\Sigma_{\eta}$?
  - If $\Sigma_{\eta'}/\Sigma_{\eta} > 1$, we see hidden strangeness exchange contributions
    - JPAC prediction limited to low momentum transfer

Sample t-channel exchange diagram





JPAC Model comparison of $\Sigma_{\eta'}/\Sigma_{\eta}$ (PLB 774, 362 (2017))

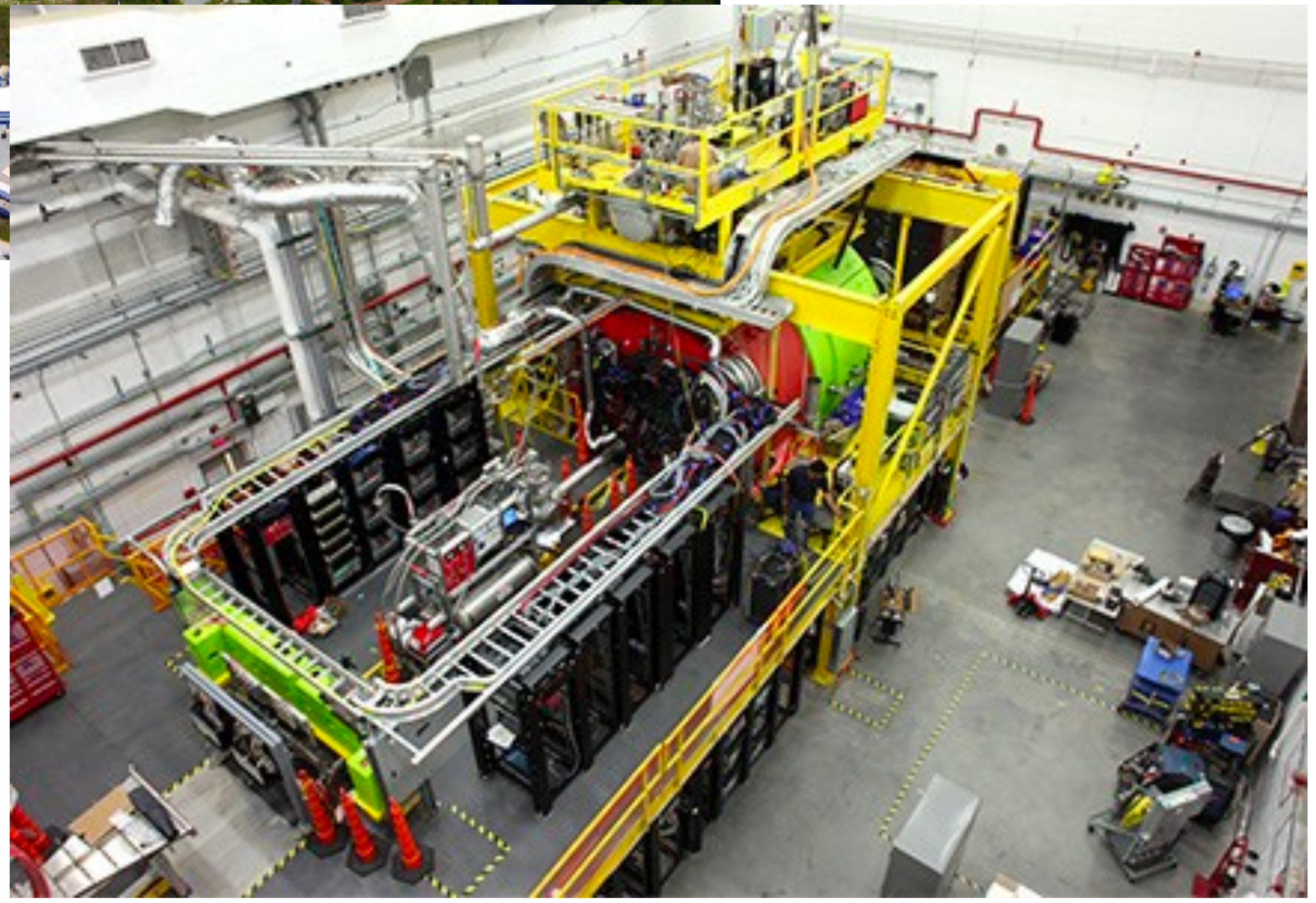
Channels Analyzed

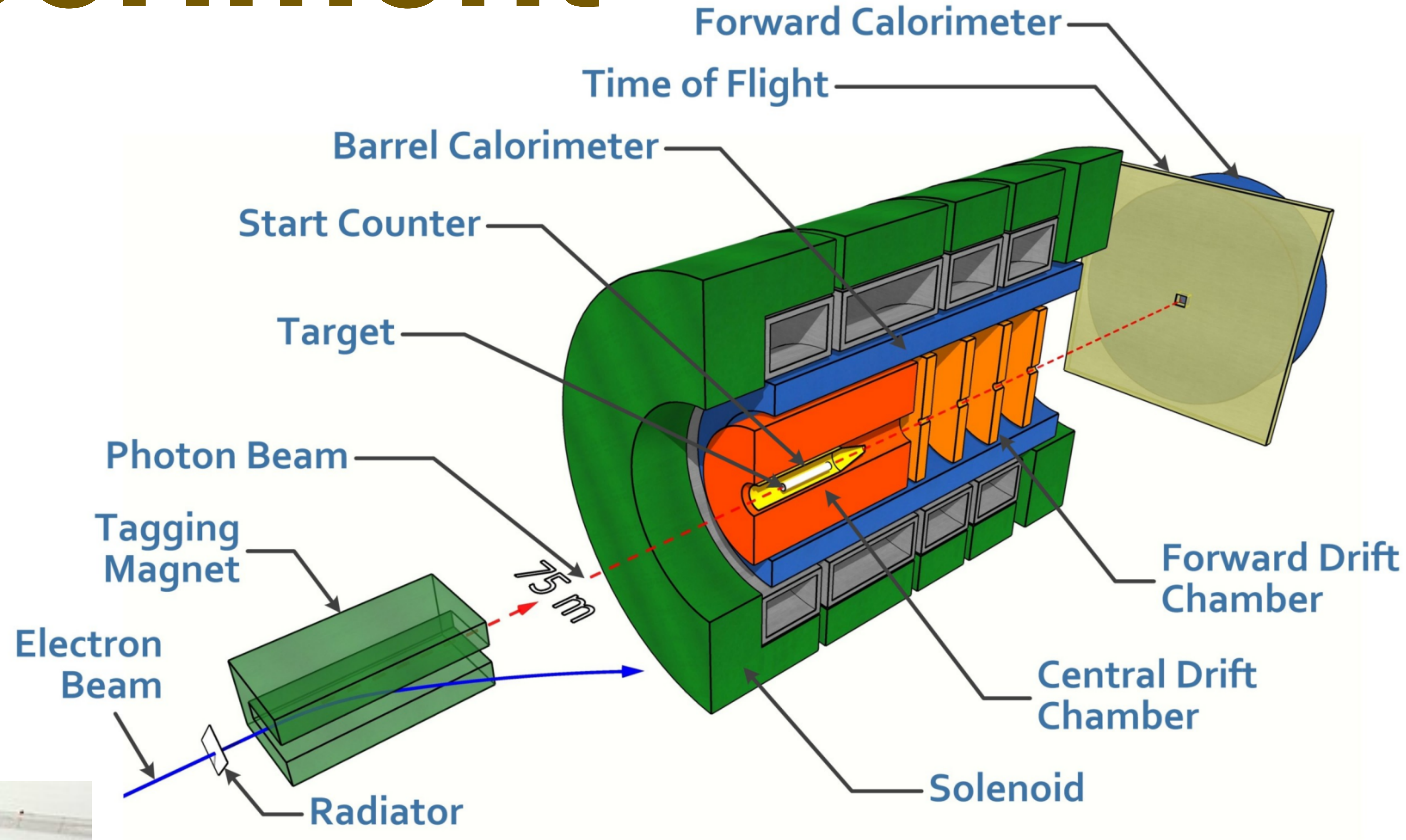
$\vec{\gamma}p \rightarrow \eta p$ Dominant η decay channels (PDG*):

1. $\eta \rightarrow \gamma\gamma$ **(42%) (Today's Talk)**
2. $\eta \rightarrow \pi^+\pi^-\pi^0$ **(21%) (shown previously/in progress)**
3. $\eta \rightarrow 3\pi^0$ (30%)
4. $\eta \rightarrow \pi^+\pi^-\gamma$ (4%)

*P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020).

Experiment





GlueX Tagger Hall (L) and Detector (R)

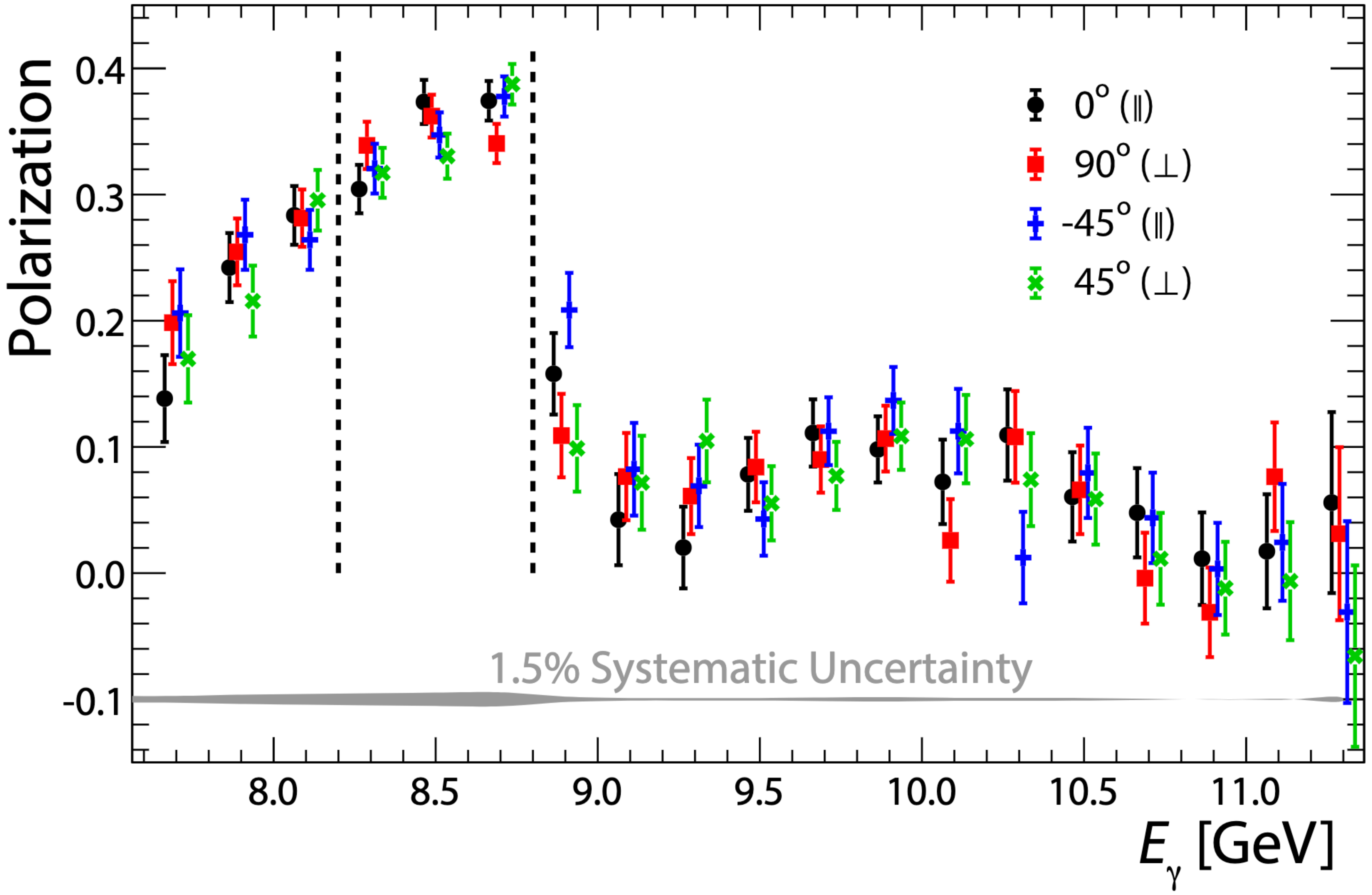
- Advantages of the GlueX Detector at Jefferson Lab:
  - Hermetic (full solid angle range accepted)
  - High energy polarized photon beam (> 8 GeV)
  - High Statistics for this analysis

Asymmetry Calculation

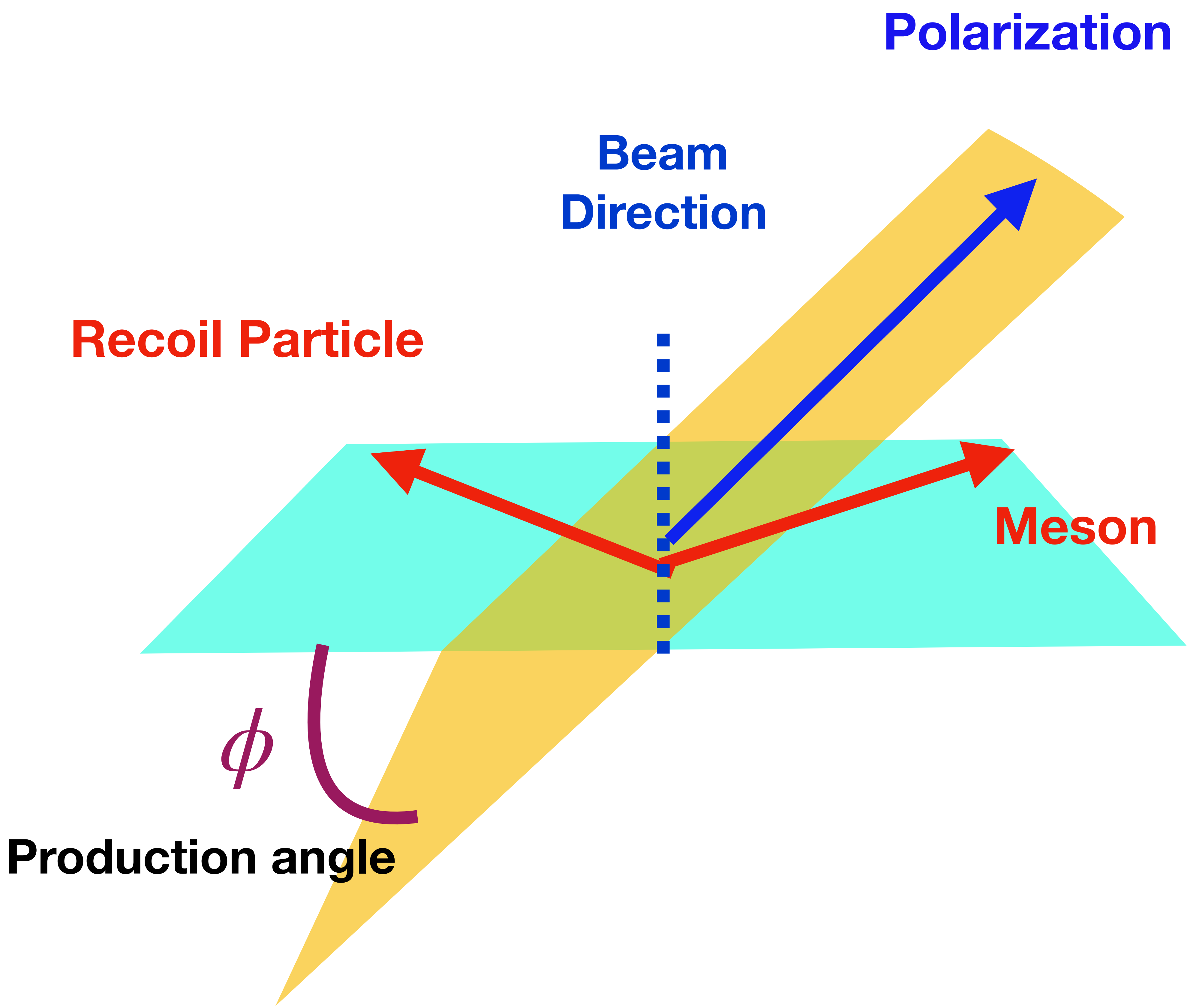
- By definition, $\Sigma = \dfrac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \dfrac{|\rho + \omega|^2 - |b + h|^2}{|\rho + \omega|^2 + |b + h|^2}$
- Yield: $Y \propto N_\gamma N_t A(\phi)[\sigma_0(1 + P_\gamma \Sigma cos(2\phi - 2\phi_0))]$
- With 2 orthogonal choices of ϕ_0, we can get:
- Yield asymmetry $f(\phi) = \dfrac{Y_\perp - F_R Y_\parallel}{Y_\perp + F_R Y_\parallel} = \dfrac{(P_\parallel + P_\perp)\Sigma cos(2\phi - 2\phi_0)}{2 + (P_\perp - P_\parallel)\Sigma cos(2\phi - 2\phi_0)}$
  - Where Flux Ratio $F_R = \dfrac{N_\perp}{N_\parallel}$, N - integrated photon flux
  - Beam asymmetry Σ is directly extracted via a fit!

Production

Ref: Polarization vs Beam Energy, 2017



Linearly polarized photon beam can be oriented by a goniometer in Tagger Hall to four possible angles, with order 1 deg accuracy

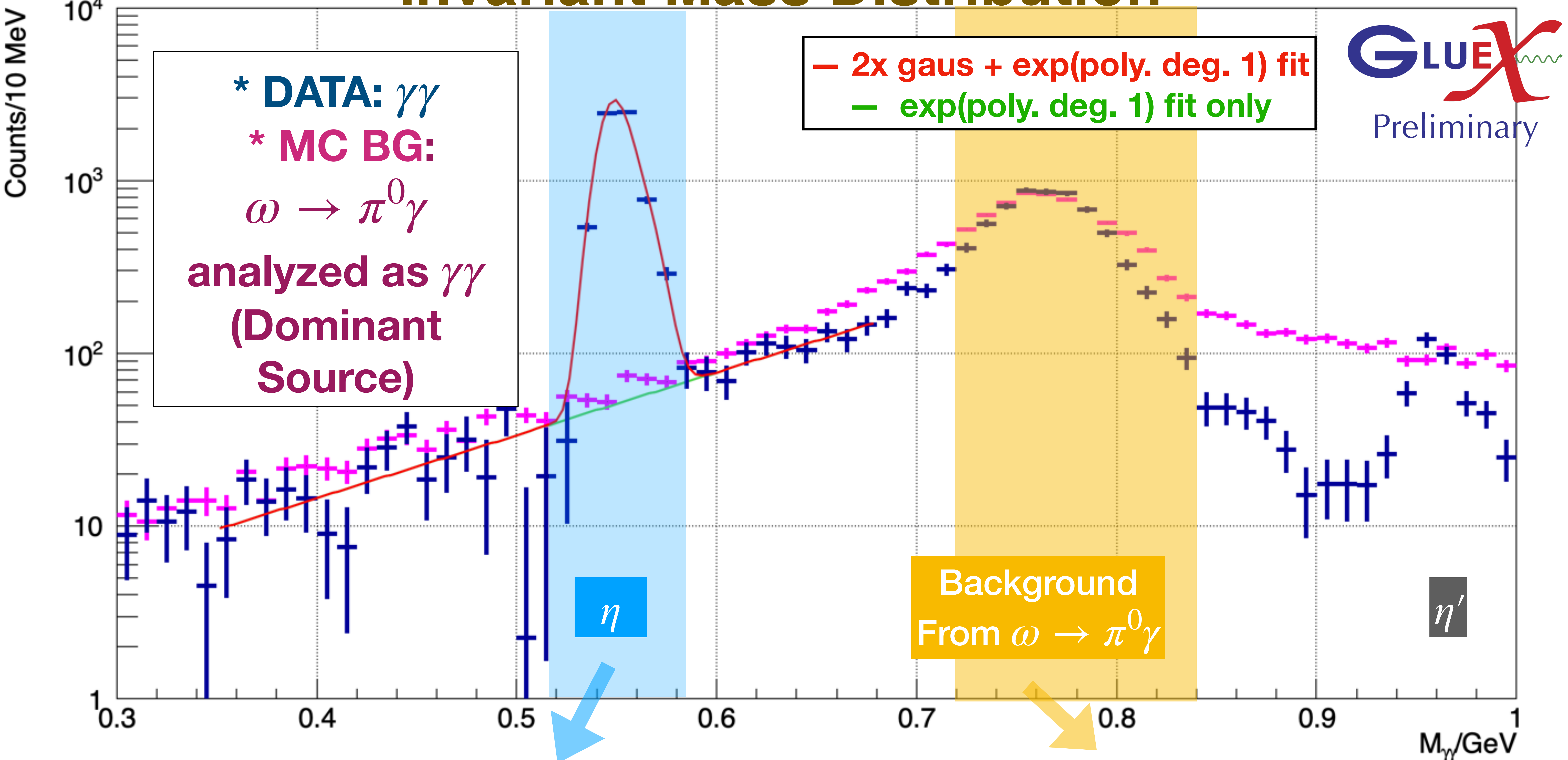


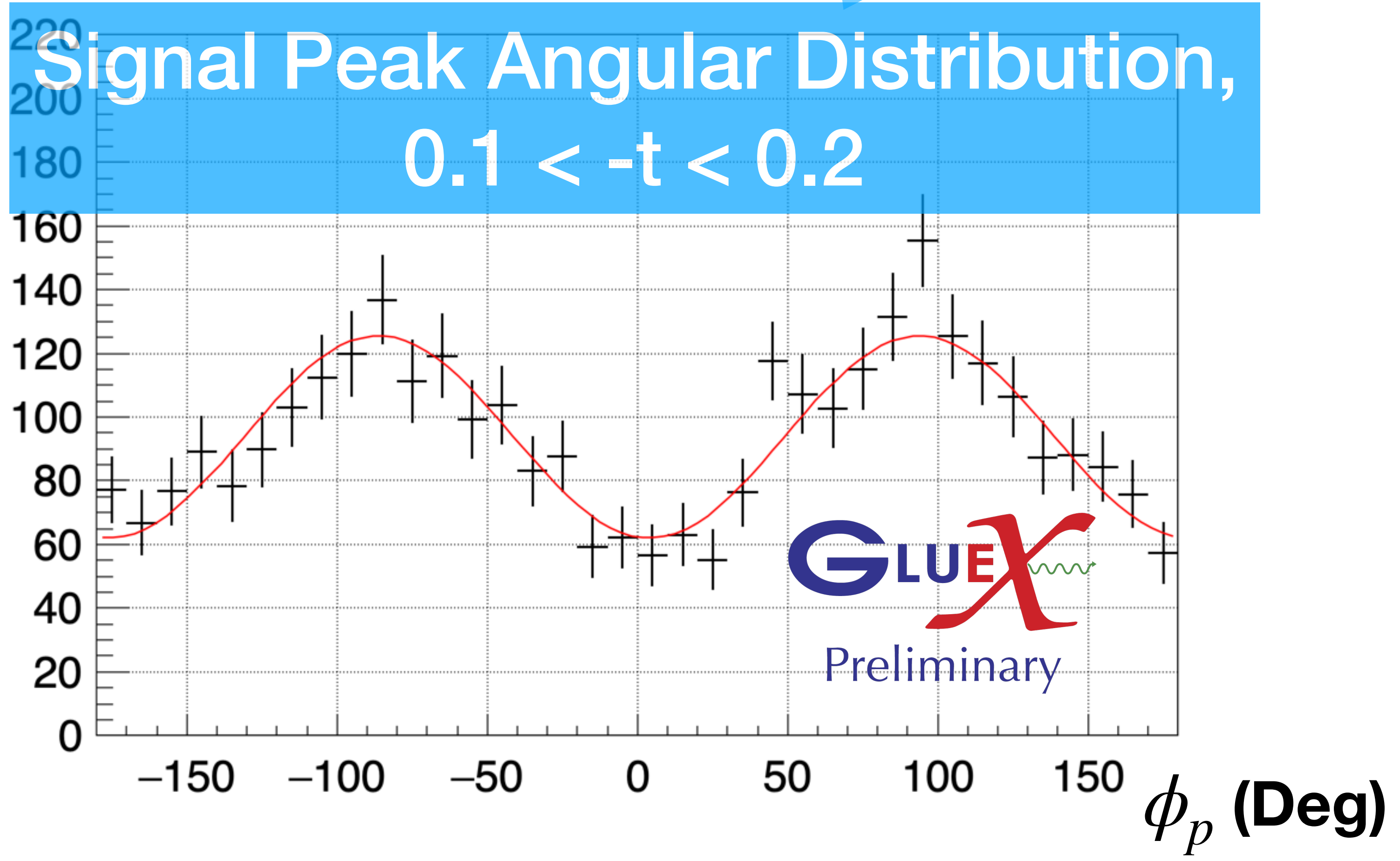
Production Schematic

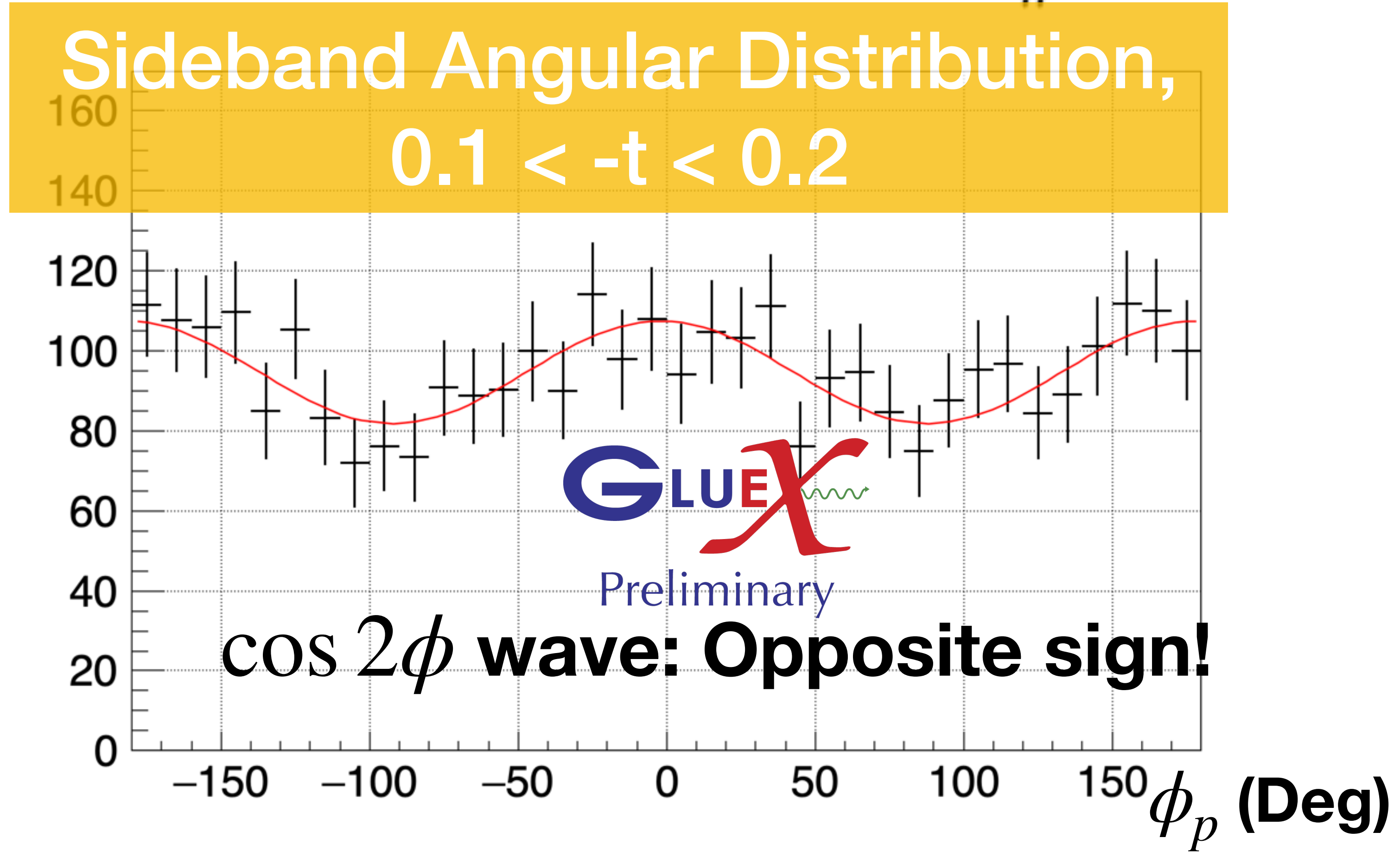
$$Y \propto N_\gamma N_t A(\phi)[\sigma_0(1 + P_\gamma \Sigma cos(2\phi - 2\phi_0))]$$

Polarization angle has a "phase offset" ϕ_0

Invariant Mass Distribution

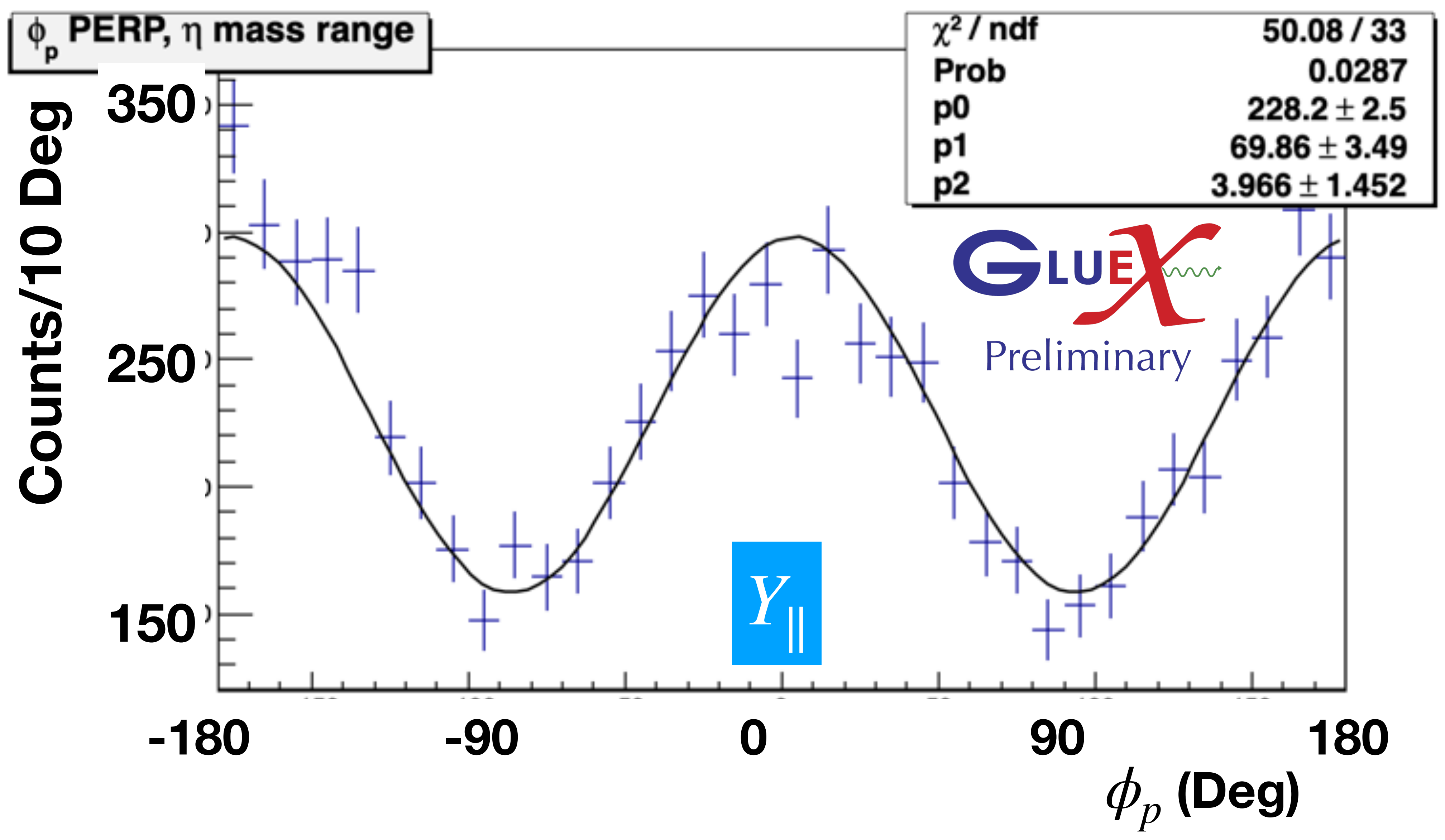


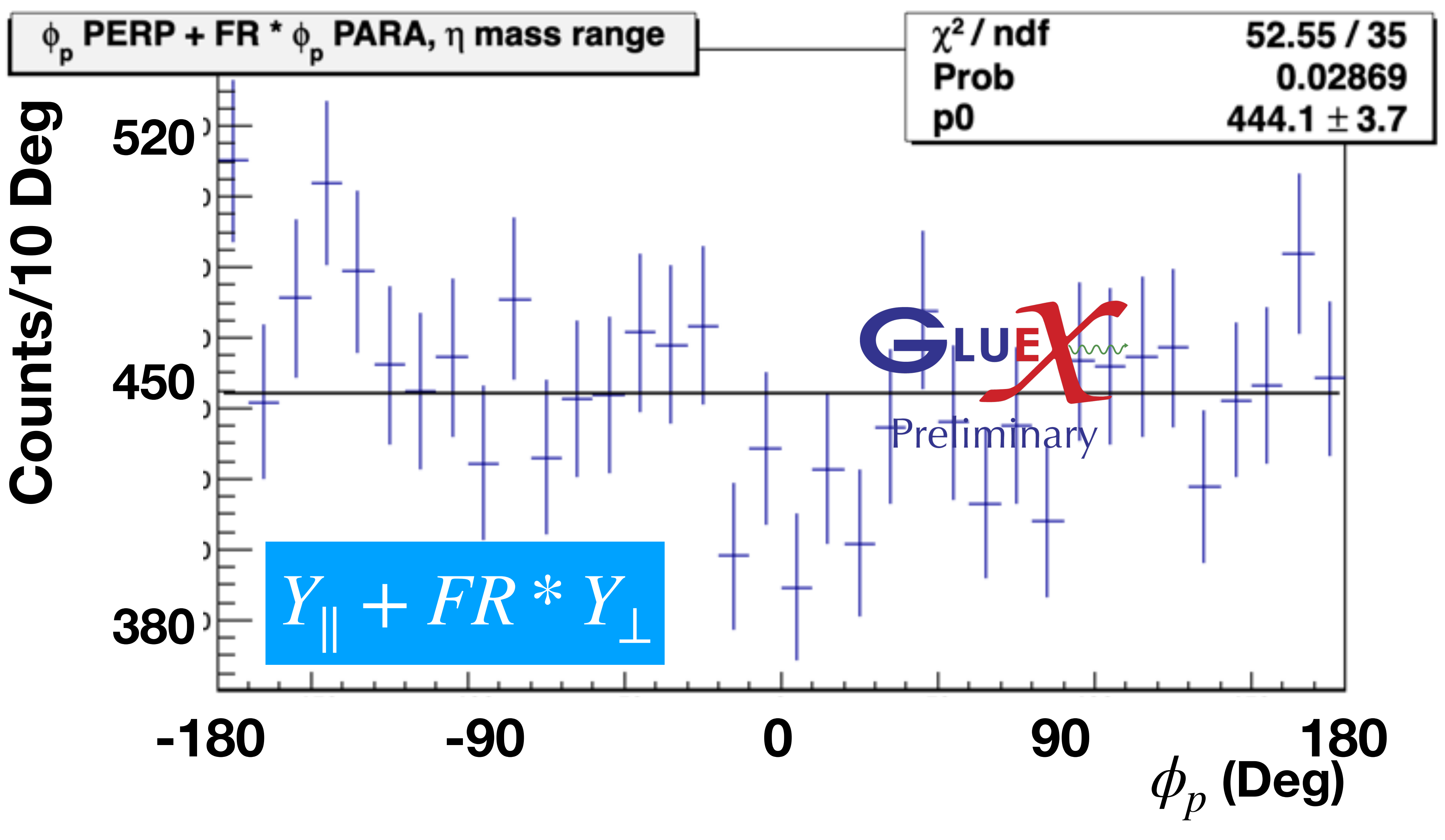


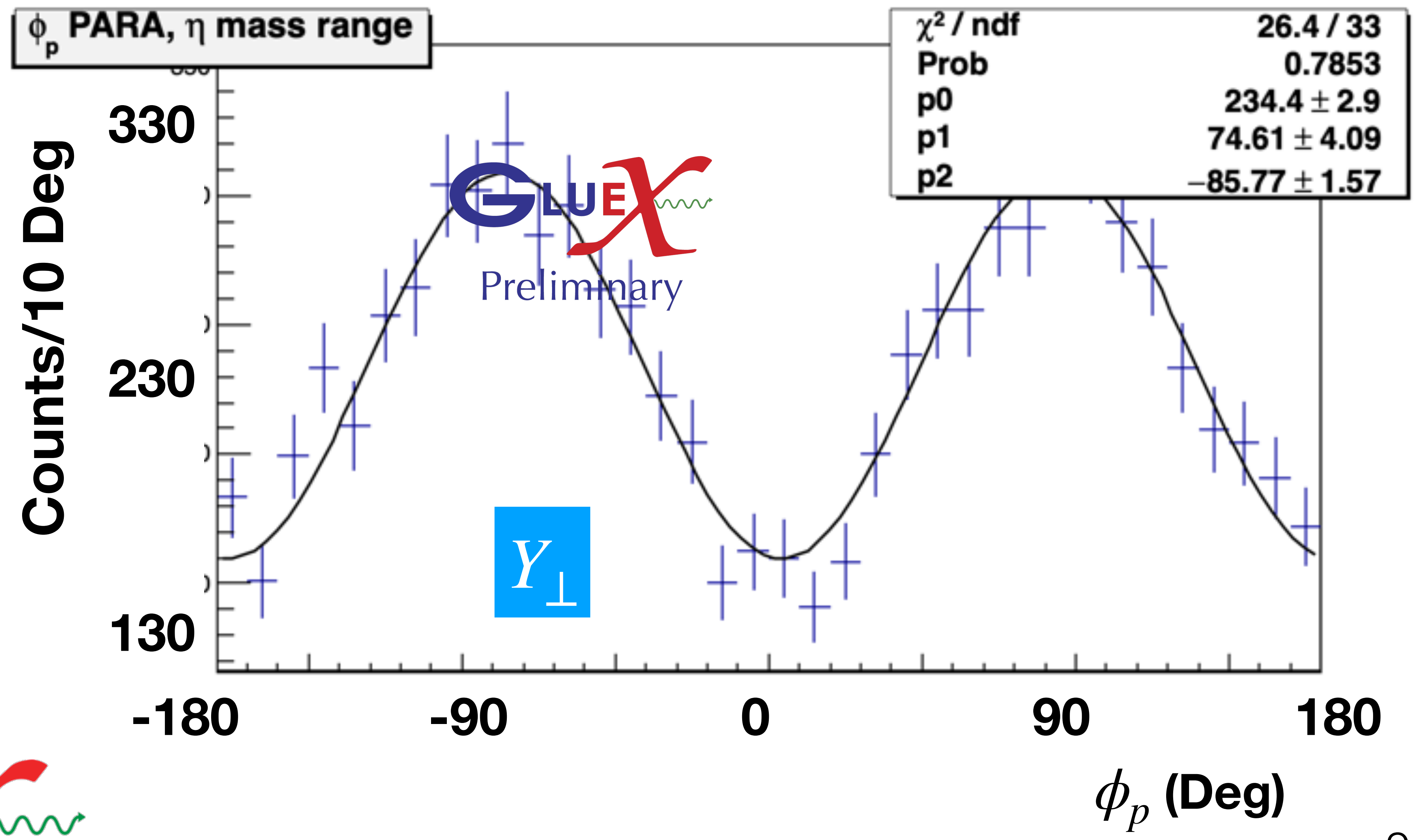


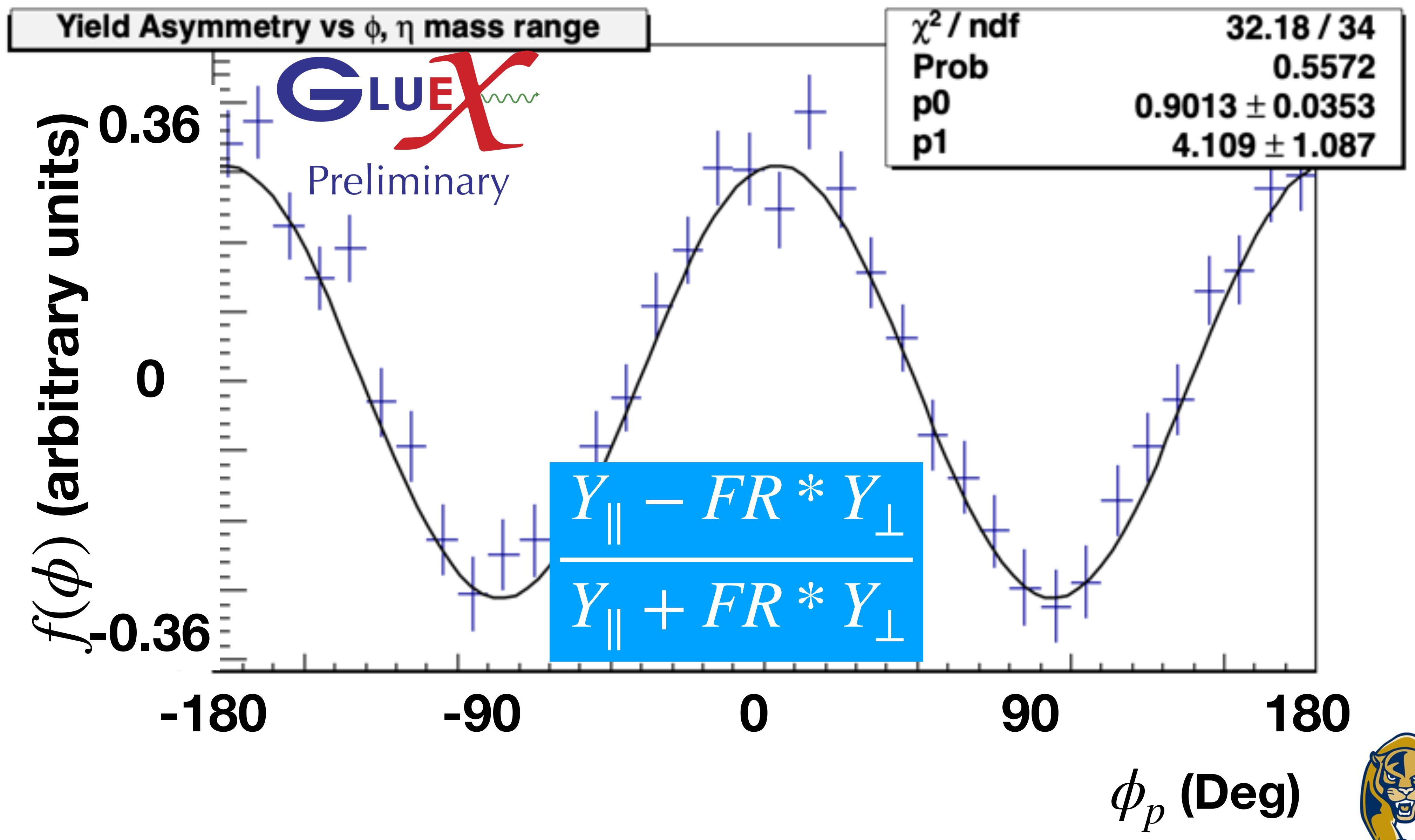
$\eta \to \gamma\gamma$ **Yields - Low -*t* example**

$0.1 < -t < 0.2$
50% GlueX-I







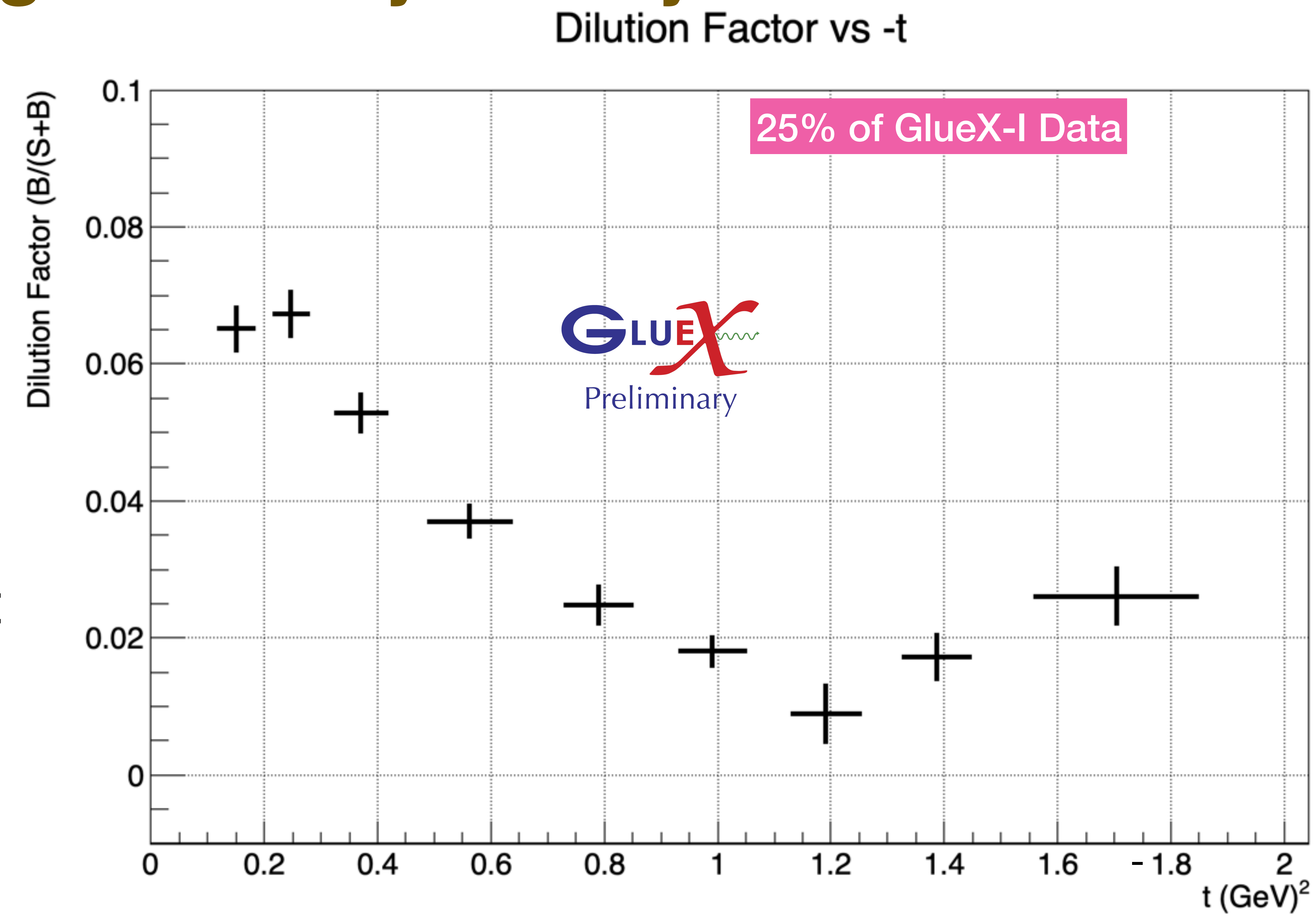


Correcting Beam Asymmetry

$$\Sigma = \frac{\Sigma_{peak} - f\Sigma_{sideband}}{1-f}$$

where dilution factor: $f = \dfrac{B}{S+B}$

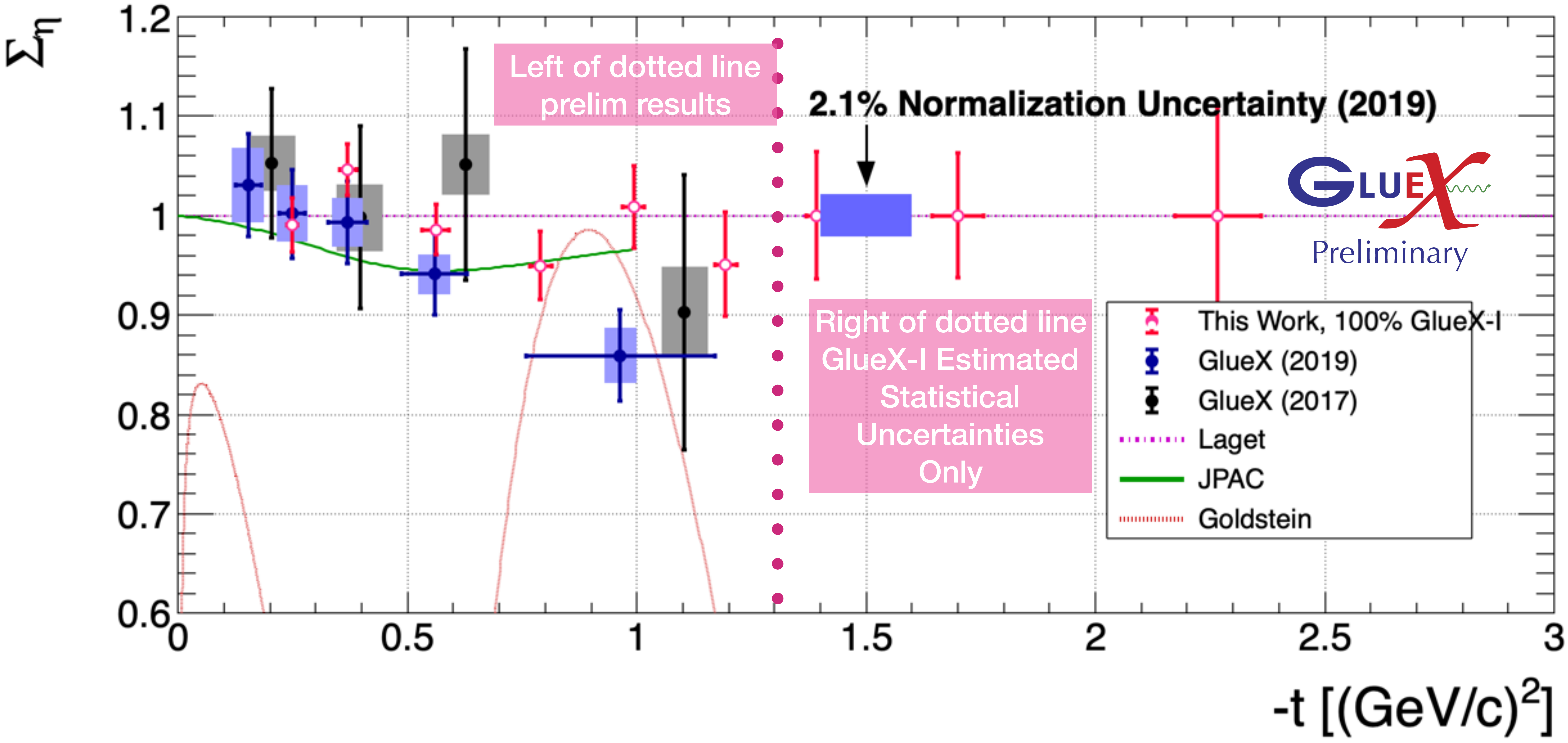
- "Peak" - 0.52-0.58 GeV range
- "Sideband"- 0.72-0.84 GeV range
- Fit on background used to extract dilution factor (order 1-10% depending on -t)
- **Higher-t: *f* sufficiently small & sideband sufficiently small to minimize contribution to Σ**



B: Calculated integral of estimated BG

S+B: Histogram Integral in η peak range

$\eta \to \gamma\gamma$ Σ Beam Asymmetry vs. -t



Summary and Next Work

- The GlueX Experiment is studying properties of exotic mesons including production and interaction of particles such as the η
- Showed mass distributions of the final state particle and azimuthal angular distributions for the recoil proton
- Prelim results for Σ up to |t| ~ 2.0 $(\mathrm{GeV})^2$
- Future:
  - Further Monte-Carlo Signal-Background analysis
  - Systematic uncertainties and various checks
  - $\eta \rightarrow \pi^+\pi^-\pi^0$ analysis and systematic corrections
- **ACKNOWLEDGEMENTS**

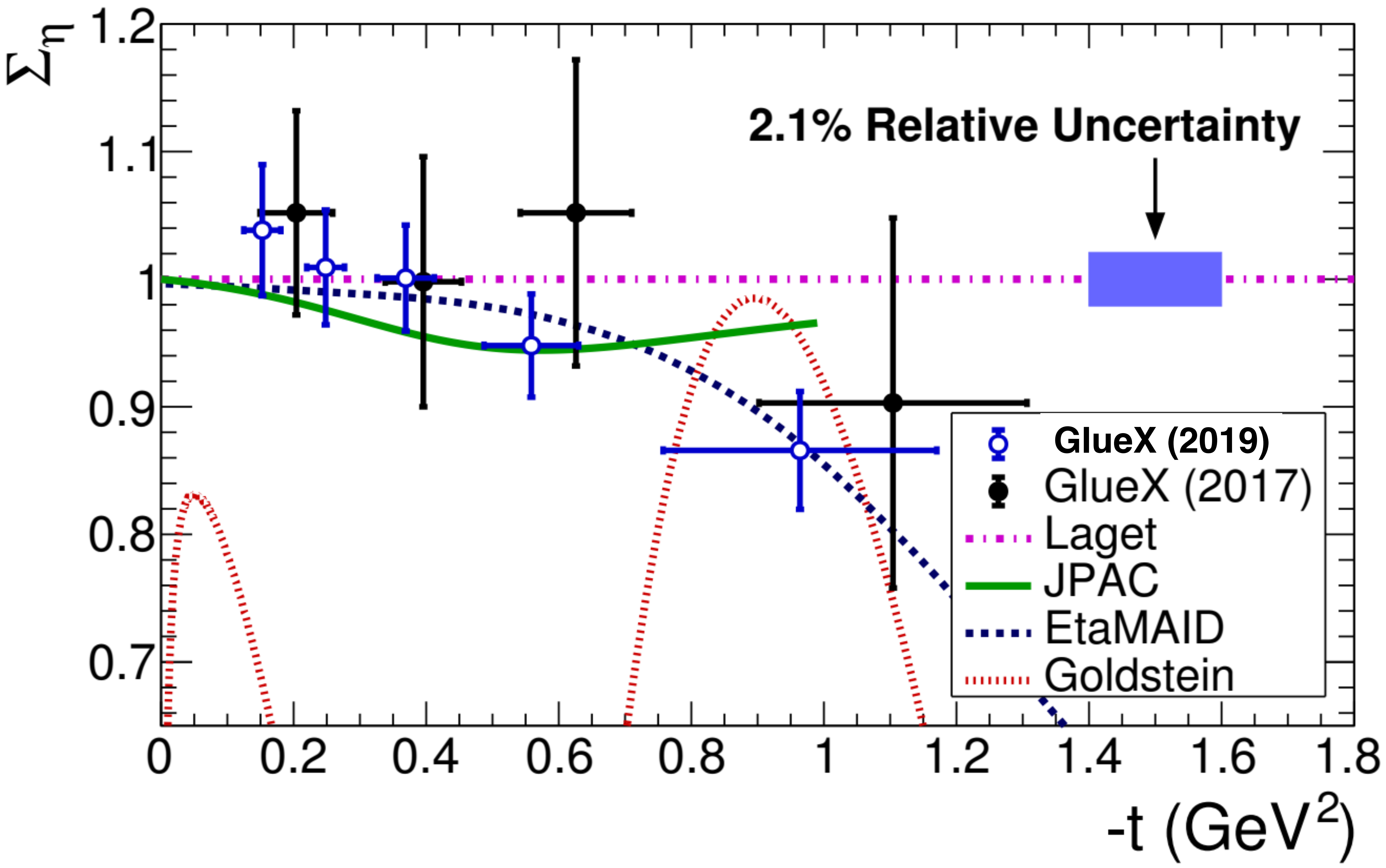
GlueX acknowledges the support of several funding agencies and computing facilities - www.gluex.org/thanks

Thank you!!

Backup

Past Results and Models

- Past results: 18% of the GlueX-I data (PRC 100(2019).052201) $E_\gamma \in (8.4,\ 9.0)$ GeV
- All other at $E_\gamma < 2$ GeV:
  - Experiment:
    - Phys. Rev. B771, 05.045, CLAS
  - Theory:
    - Phys. Lett. B695, 199 (Laget)
    - Phys. Rev. D95, 034014 (JPAC)
    - Phys. Rev. C96, 035207 (EtaMAID)
    - Phys. Rev. D7, 865 (Goldstein)



BACKUP - Dilution Factor Estimations - Error Propagation

Careful treatment of variables!

1. $f = \dfrac{B}{S+B}$**. Replace B with B'. Define** $B' = \alpha B$ **where** α **is the scale value to level the background (MC) counts with the signal counts.**
2. $\delta B' = \sqrt{\dfrac{\partial B'^2}{\partial B}(\delta B)^2 + \dfrac{\partial B'^2}{\partial \alpha}(\delta\alpha)^2} = \sqrt{\alpha^2 B + B^2(\delta\alpha)^2}$**. The scaling uncertainty is computed while figuring the ratio out. If we don't mess with a scaling value, the error term is dropped, and we just have** $\sqrt{B}$
3. $\delta f = \sqrt{\dfrac{\partial f}{\partial B'}^2(\delta B')^2 + \dfrac{\partial f}{\partial S}^2(\delta S)^2}$**. We can nicely plug in the result of #2 :**

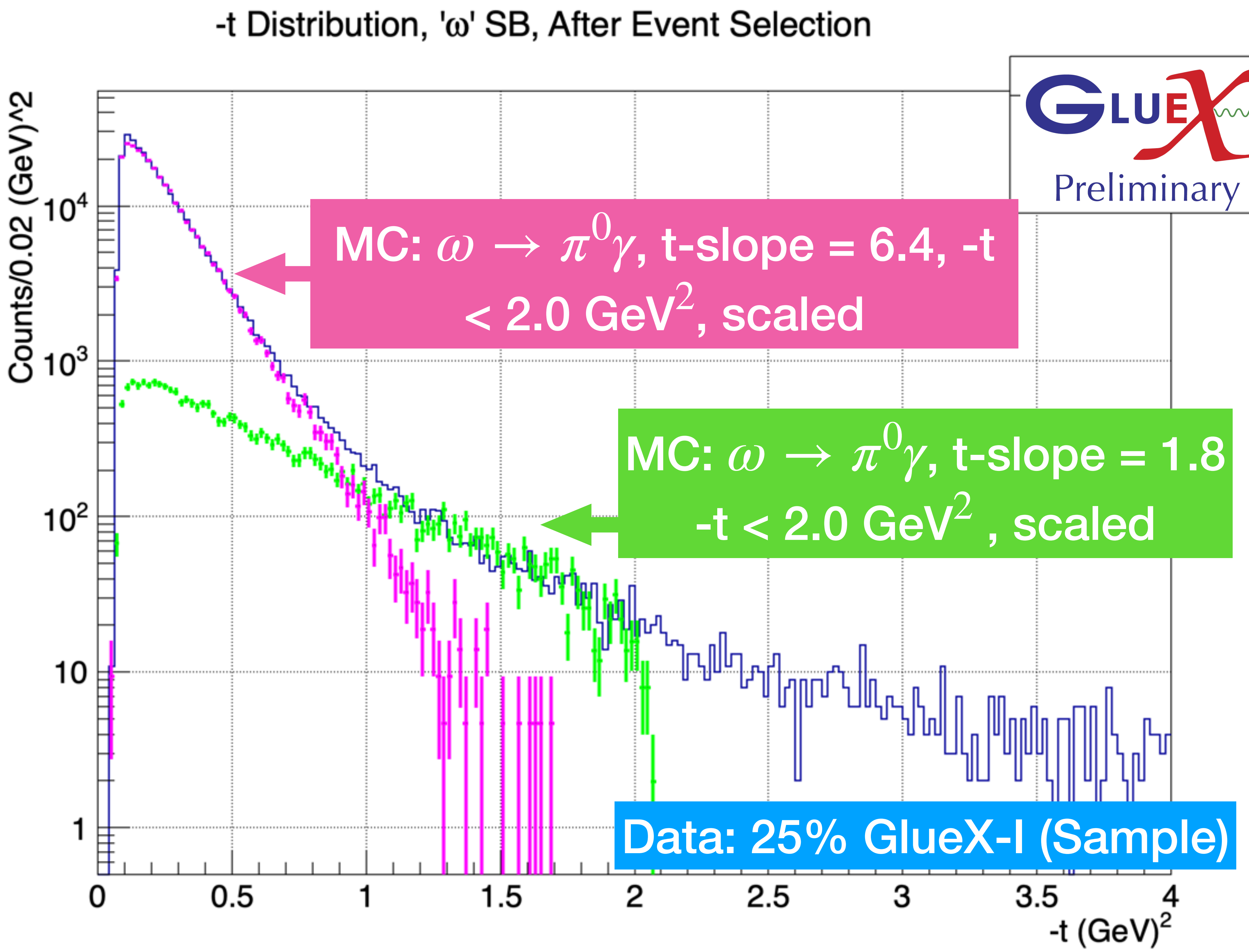
   $$\delta f = \sqrt{\frac{S^2}{(S+\alpha B)^4}(\alpha^2 B + B^2(\delta\alpha)^2) + \frac{S\alpha^2 B^2}{(S+\alpha B)^4}}$$

4. $\Sigma = \dfrac{\Sigma_{peak} - f\Sigma_{sb}}{1-f}$**. Using the propagating error method,**

   $$\delta\Sigma = \frac{1}{1-f}\sqrt{(\delta\Sigma_{peak})^2 + f^2(\delta\Sigma_{SB})^2 + (\Sigma_{peak} - \Sigma_{SB})^2(\delta f)^2}$$

(cross check, no bkgd and no dilution gives the identity relation $\delta\Sigma = \delta\Sigma_{peak}$**)**

Correcting Beam Asymmetry



The data, especially at the radiative ω region, agrees with two different t-slopes. Figuring out which areas on which to concentrate Monte Carlo effort.

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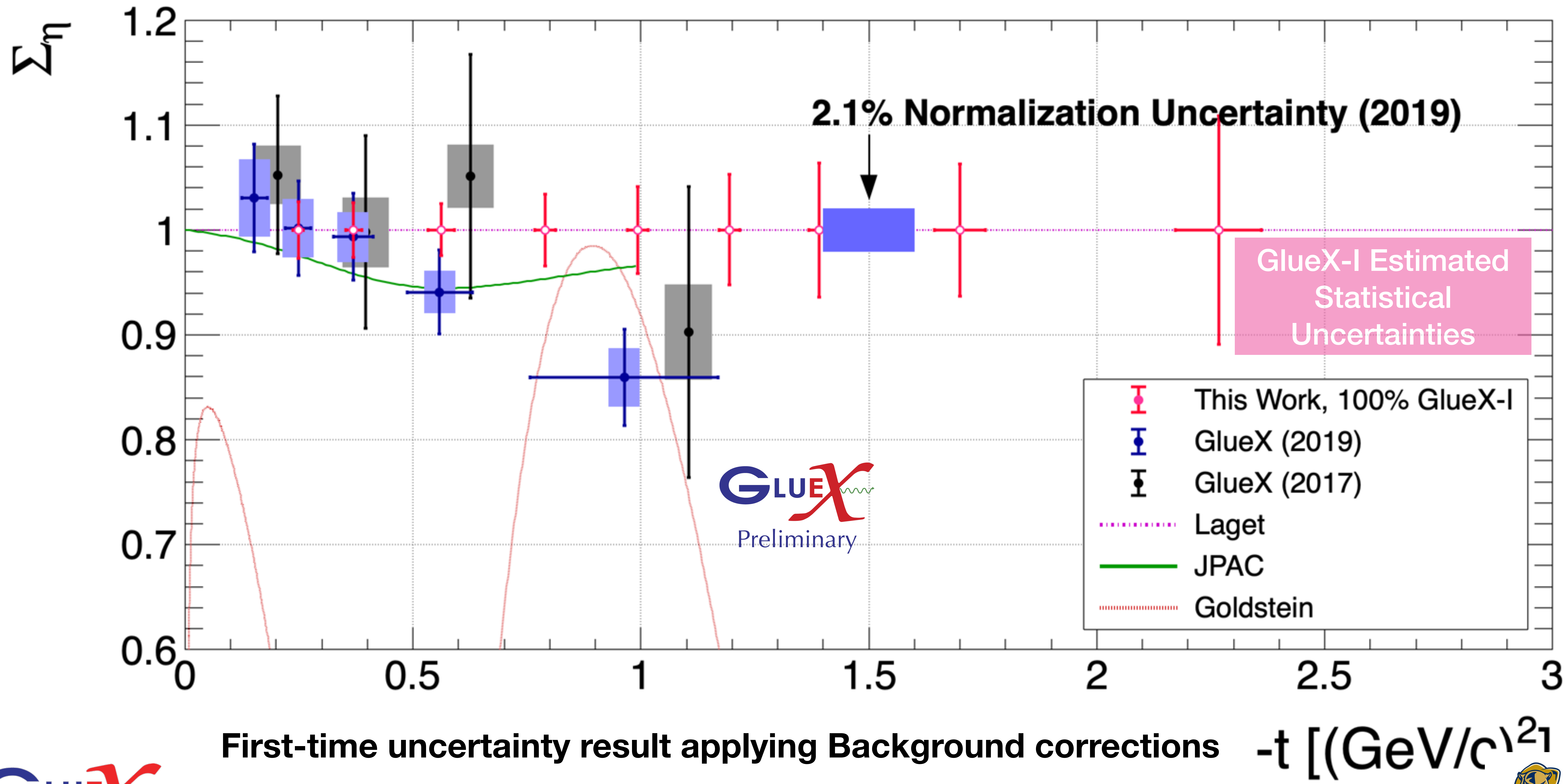
$\eta \to \gamma\gamma$ Σ Beam Asymmetry vs. -t



First-time uncertainty result applying Background corrections