Peter Pauli for the GlueX collaboration

Measurements of spin-density matrix elements at GlueX

University of Glasgow

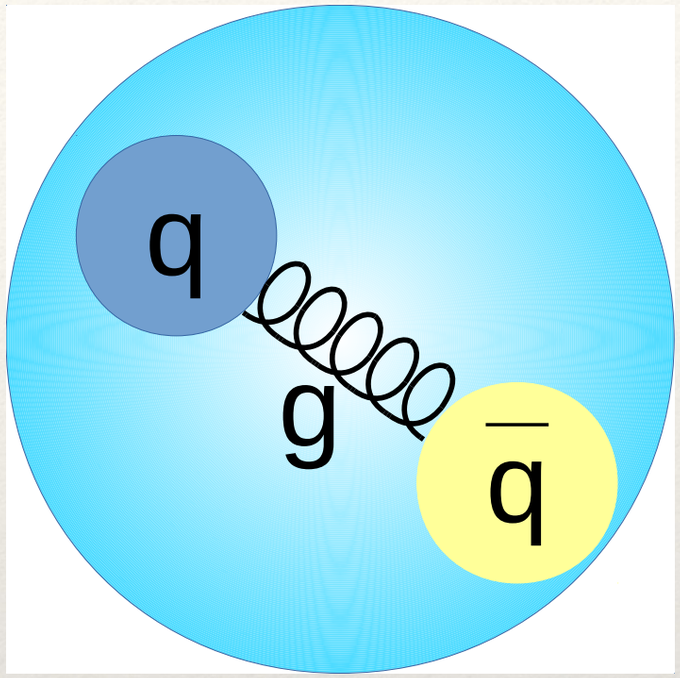
2021 JLUO ANNUAL MEETING

Hybrid mesons

- main objective for GlueX:
  Search and study of hybrid mesons

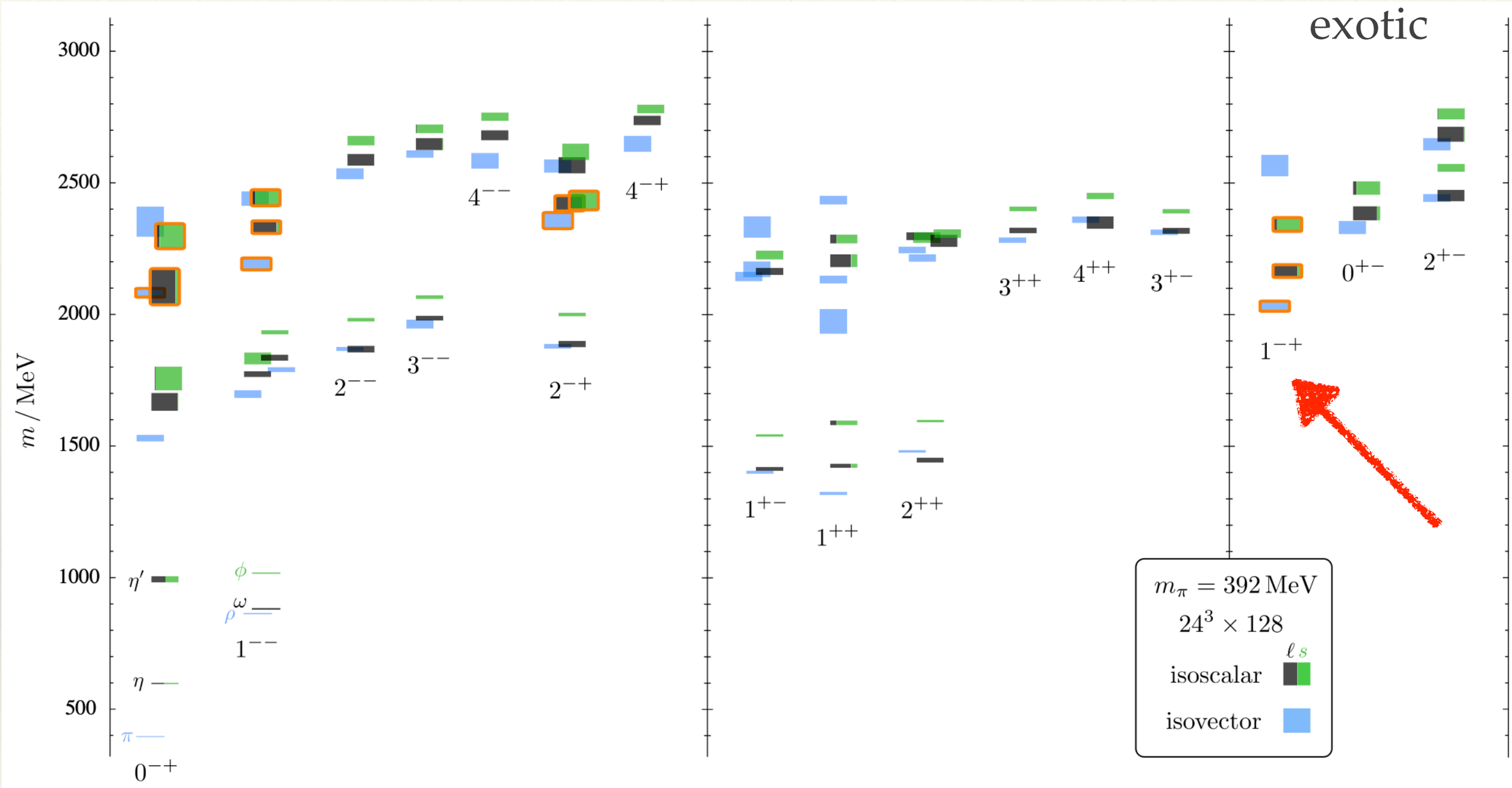
- In quark model:
  $\vec{J} = \vec{L} + \vec{S}$, $P = (-1)^{L+1}$, $C = (-1)^{L+S}$

  → <u>not</u> allowed:
  $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$



- "Exotic" quantum numbers are "smoking gun"

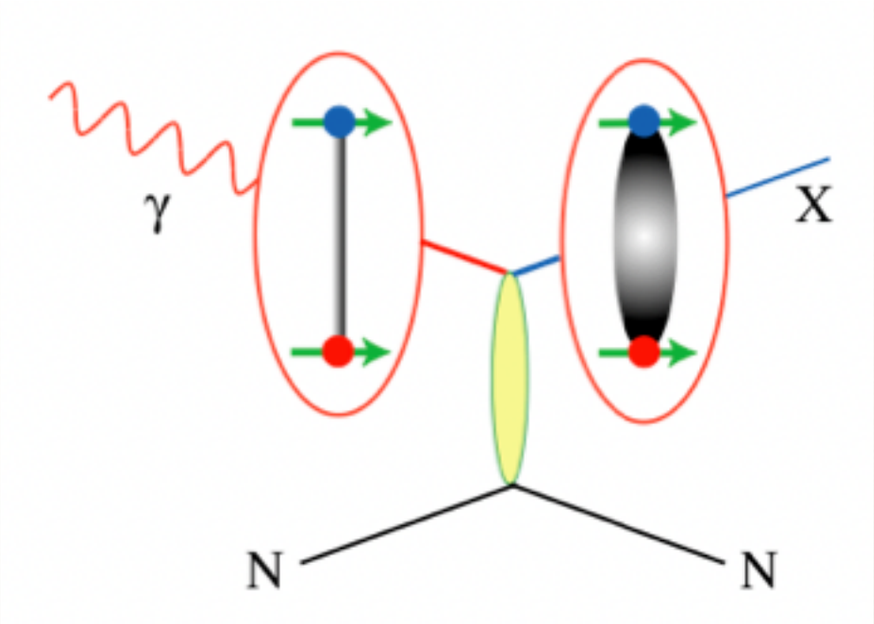
Light quark mesons from lattice QCD



Jozef J. Dudek, Robert G. Edwards, Peng Guo, and Christopher E. Thomas (for Hadron Spectrum Collaboration), Phys. Rev. D **88**, 094505

Towards hybrids at GlueX

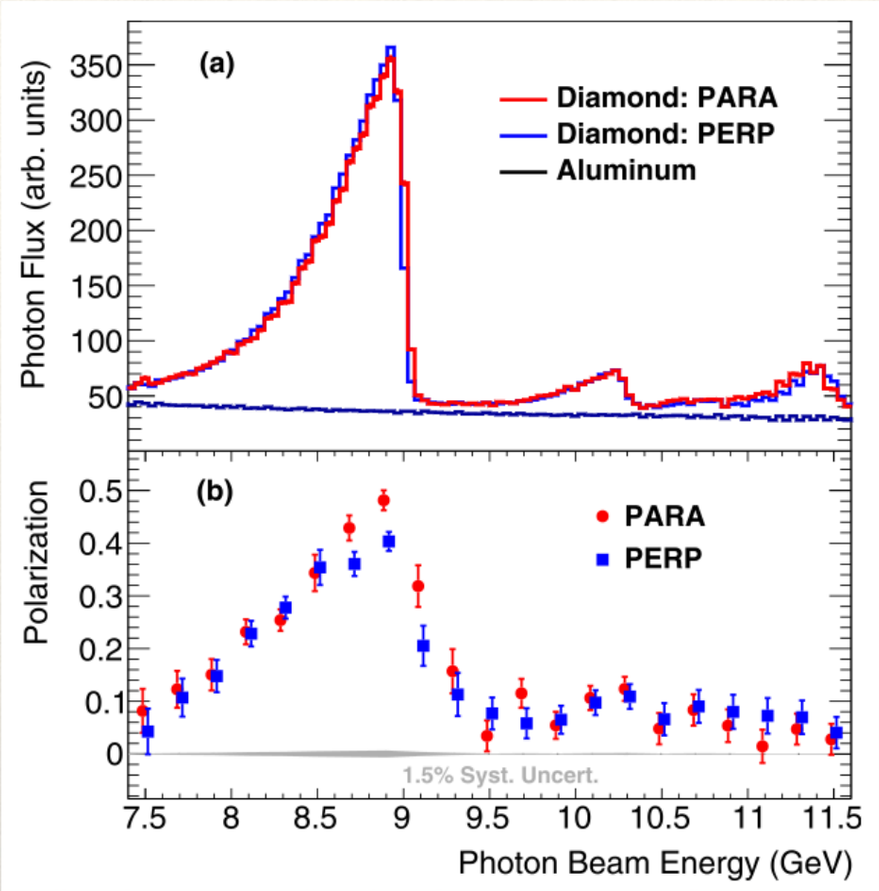
- Best evidence so far in pion production (COMPASS)
  - Photoproduction complementary



- Utilize polarization to understand production mechanisms

- First step: measure SDMEs
- Exercise PWA techniques for hybrid search

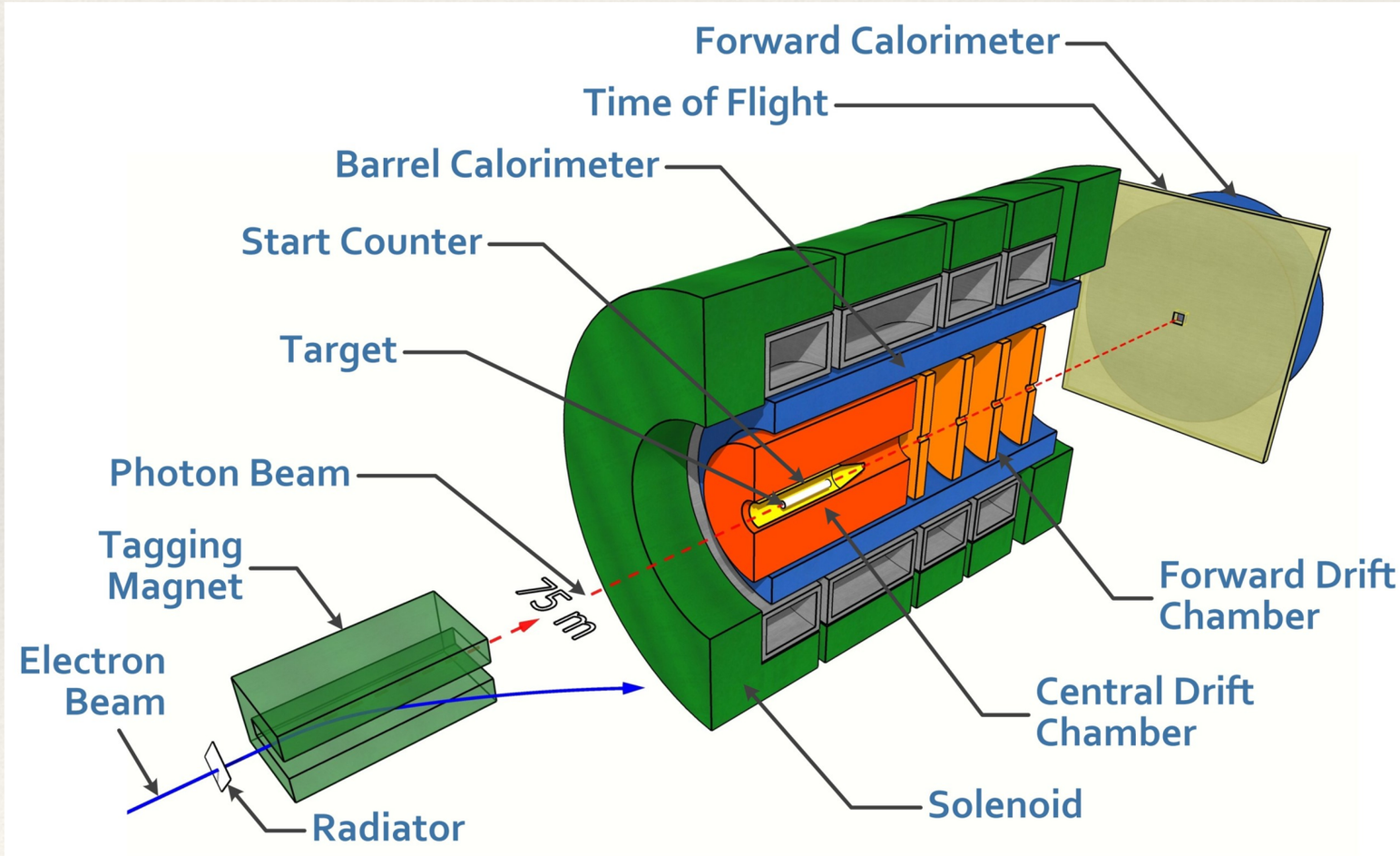
GlueX experiment in Hall D



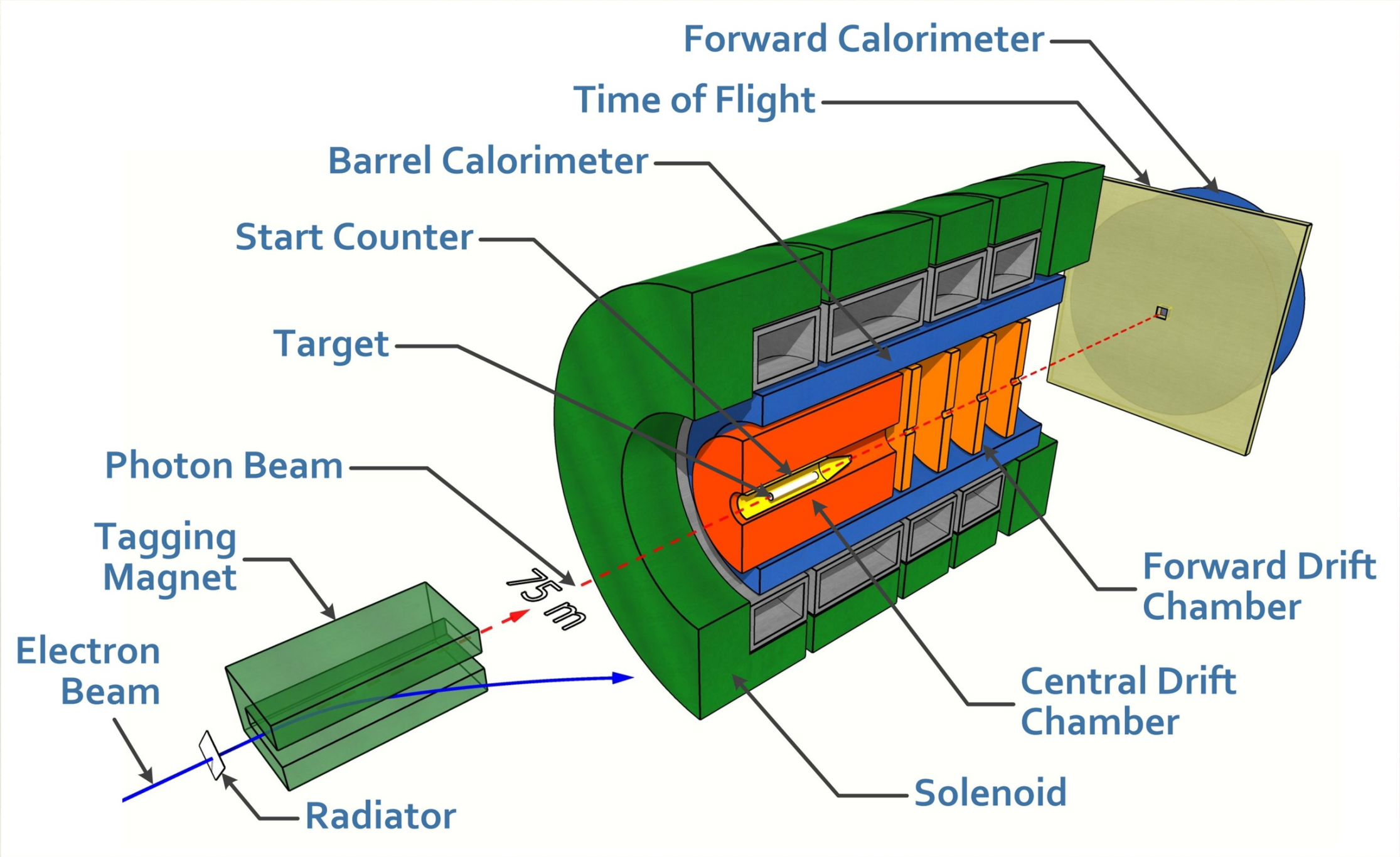
https://doi.org/10.1016/j.nima.2020.164807

- produce linearly polarized photon beam via coherent bremsstrahlung on thin diamond

- tag electrons to determine photon energy



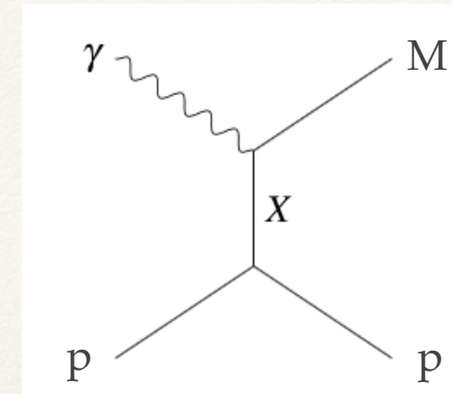
GlueX experiment in Hall D

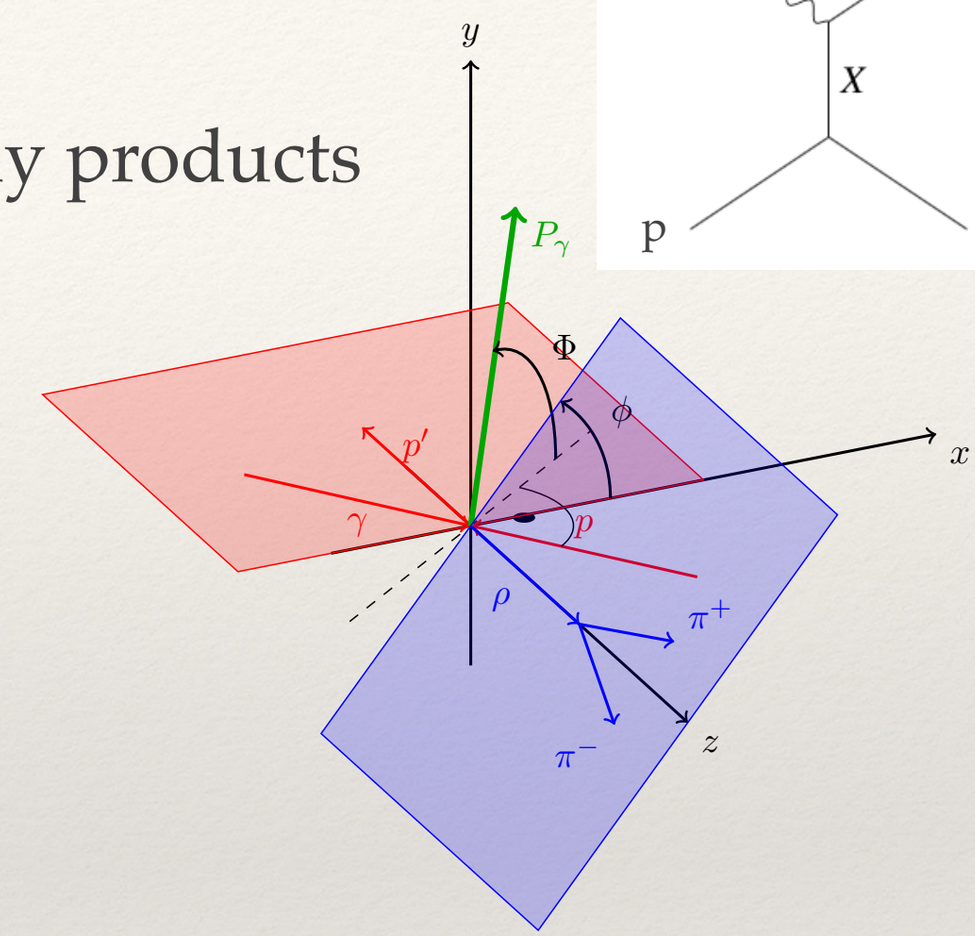


- Acceptance: $\theta_{lab} \approx 1^\circ - 120^\circ$
- Charged particles: $\sigma_p/p \approx 1\% - 3\,\%$ ($8\% - 9\,\%$ very-forward high-momentum tracks)
- Photons: $\sigma_E/E = 6\,\%/\sqrt{E} \oplus 2\,\%$

Spin-density matrix elements

- SDMEs contain information on the spin-polarization of the produced state
- Measure angular distribution of decay products
- Learn about production mechanism
  - Study the naturality $\eta = P(-1)^J$ of the exchanged particle X





For vector meson to pseudo-scalar decays:

$$W(\cos\theta,\phi,\Phi) = W^0(\cos\theta,\phi,\Phi) + P_\gamma \cos(2\Phi) W^1(\cos\theta,\phi,\Phi) + P_\gamma \sin(2\Phi) W^2(\cos\theta,\phi,\Phi)$$

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

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

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

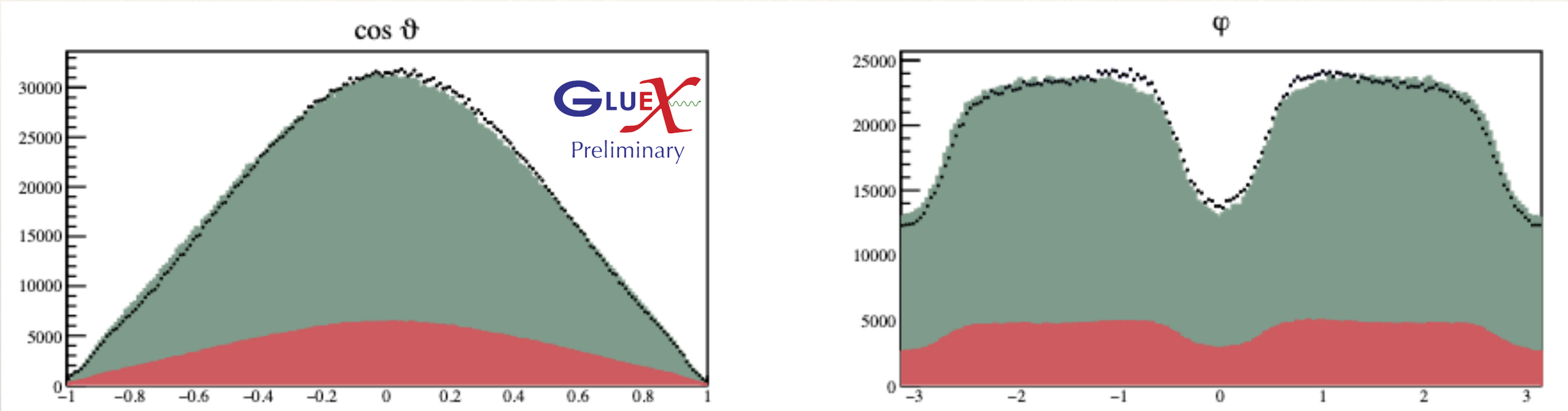
Schilling *et al.*, Nucl. Phys. B **15** (1970) 397-412

$\rho(770)$ SDMEs

Alex Austregesilo

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

Example fit:



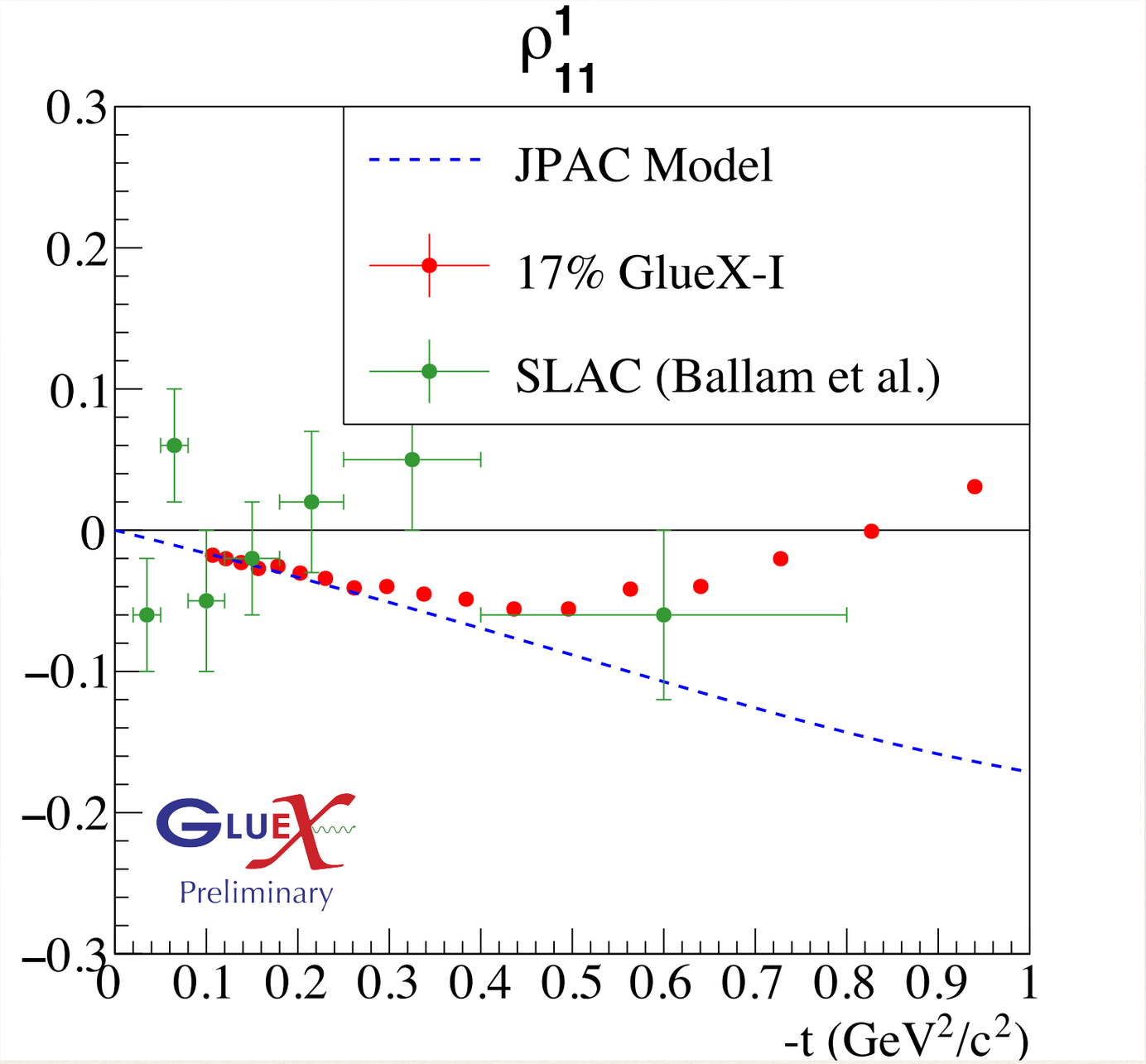
- black: measured
  green: accepted MC, weighted by fit results
  red: out-of-time background

- Good way to study small effects in our MC description of the detector

$\rho(770)$ SDMEs

Alex Austregesilo

- Uncertainties dominated by systematics
- s-channel helicity conservation: $\rho^1_{1-1} = -\,\mathrm{Im}\rho^2_{1-1} = 0.5$ valid for very small $-t$
- JPAC: Regge model (fit to SLAC data) →good agreement at low $-t$



Mathieu *et al.*, Phys. Rev. D **97**, 094003 (2018)

$\rho(770)$ SDMEs

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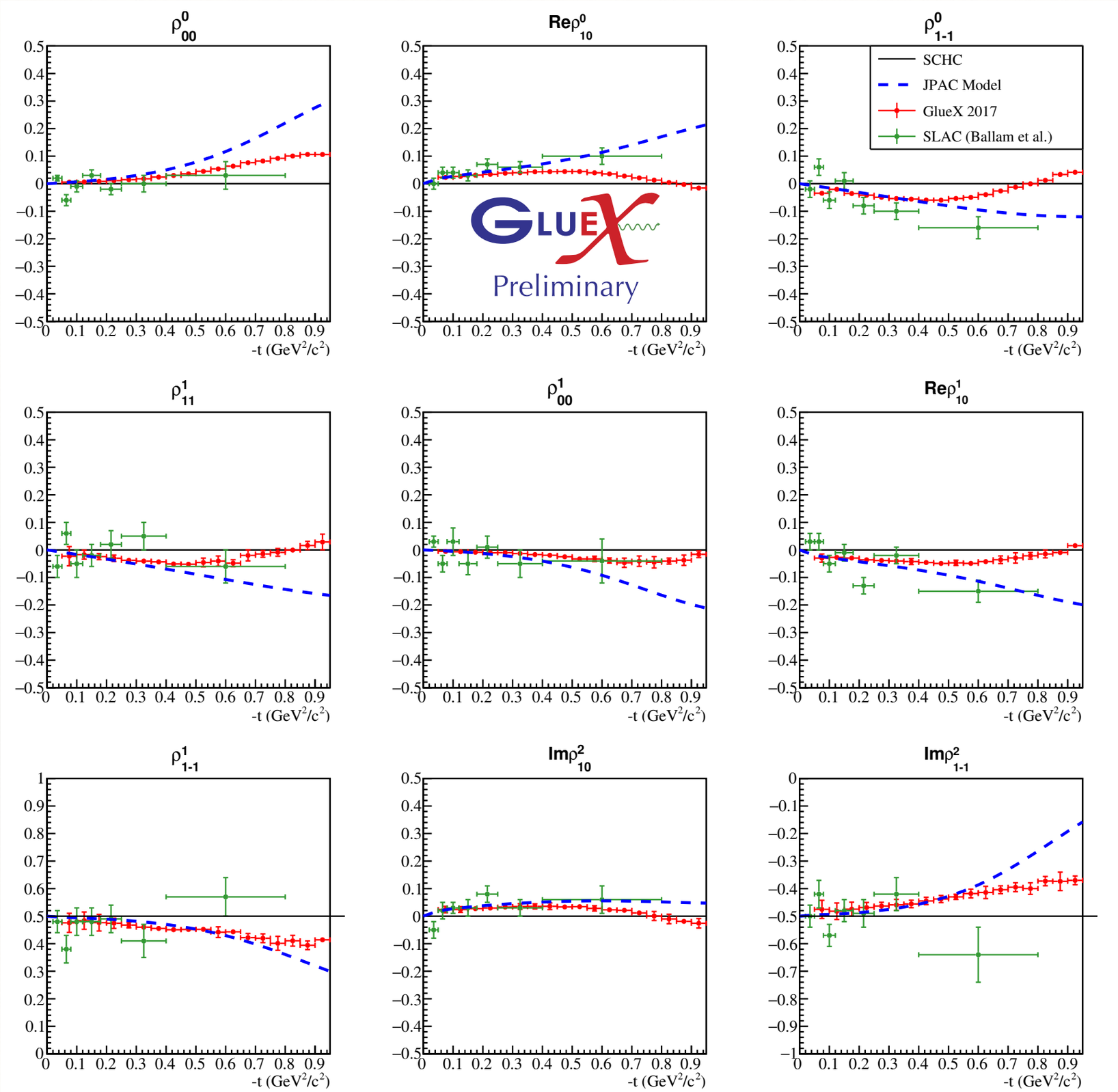


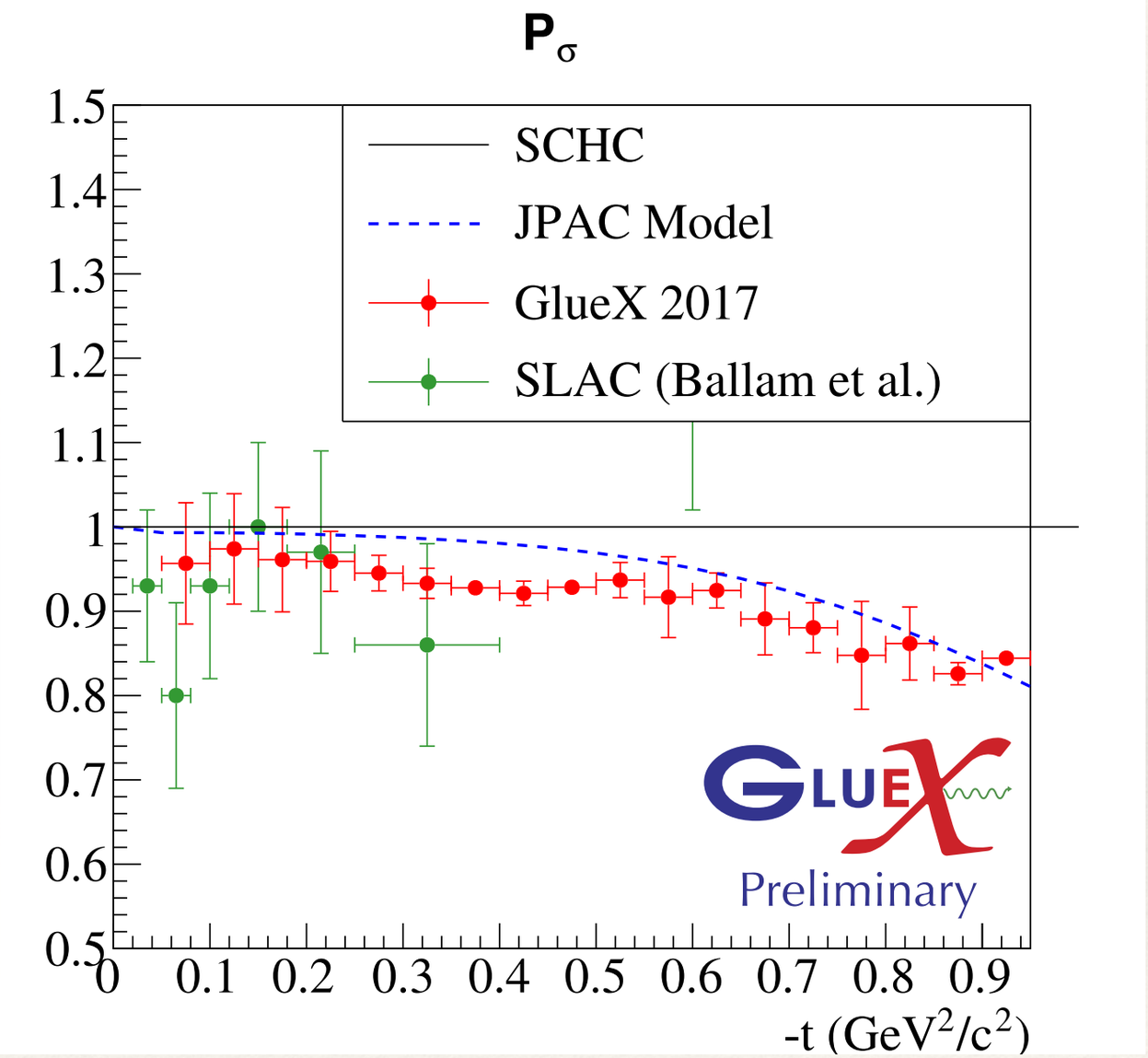
Mathieu *et al.*, Phys. Rev. D **97**, 094003 (2018)

$\rho(770)$ SDMEs

Alex Austregesilo

$$P_\sigma = \frac{\sigma^N - \sigma^U}{\sigma^N + \sigma^U} = 2\rho^1_{1-1} - \rho^1_{00}$$

- Study naturality of exchange through parity asymmetry
  $P_\sigma = 1$, purely natural
  $P_\sigma = -1$, purely unnatural
- Very good agreement with JPAC model
- Publication in preparation

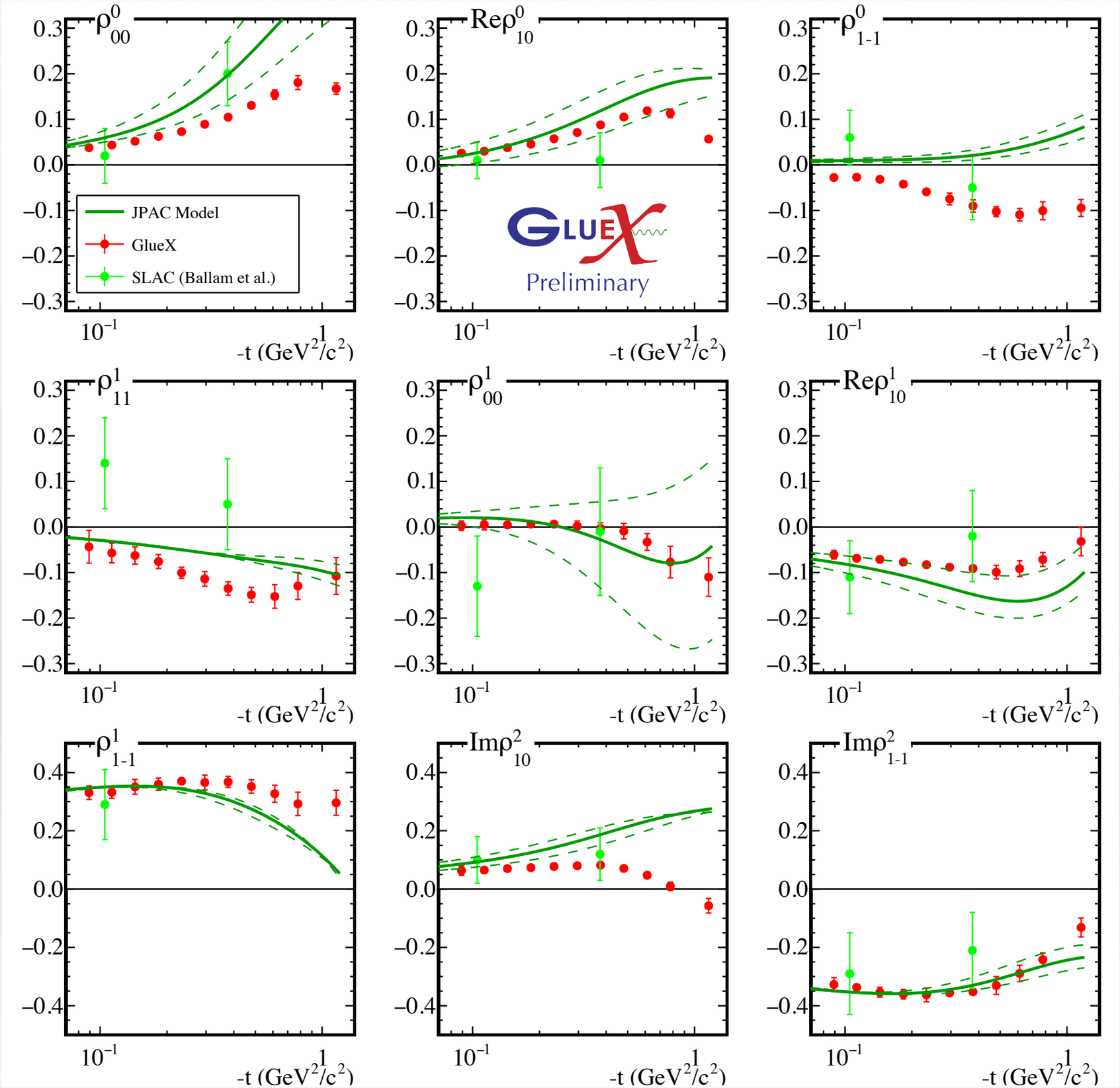


$\omega(782)$ SDMEs

Mark Dalton

$\gamma p \to \omega p$

- Results for $\omega \to \pi^+\pi^-\pi^0$
- Good agreement with JPAC model for low $-t$
- No SCHC at $-t \to 0$

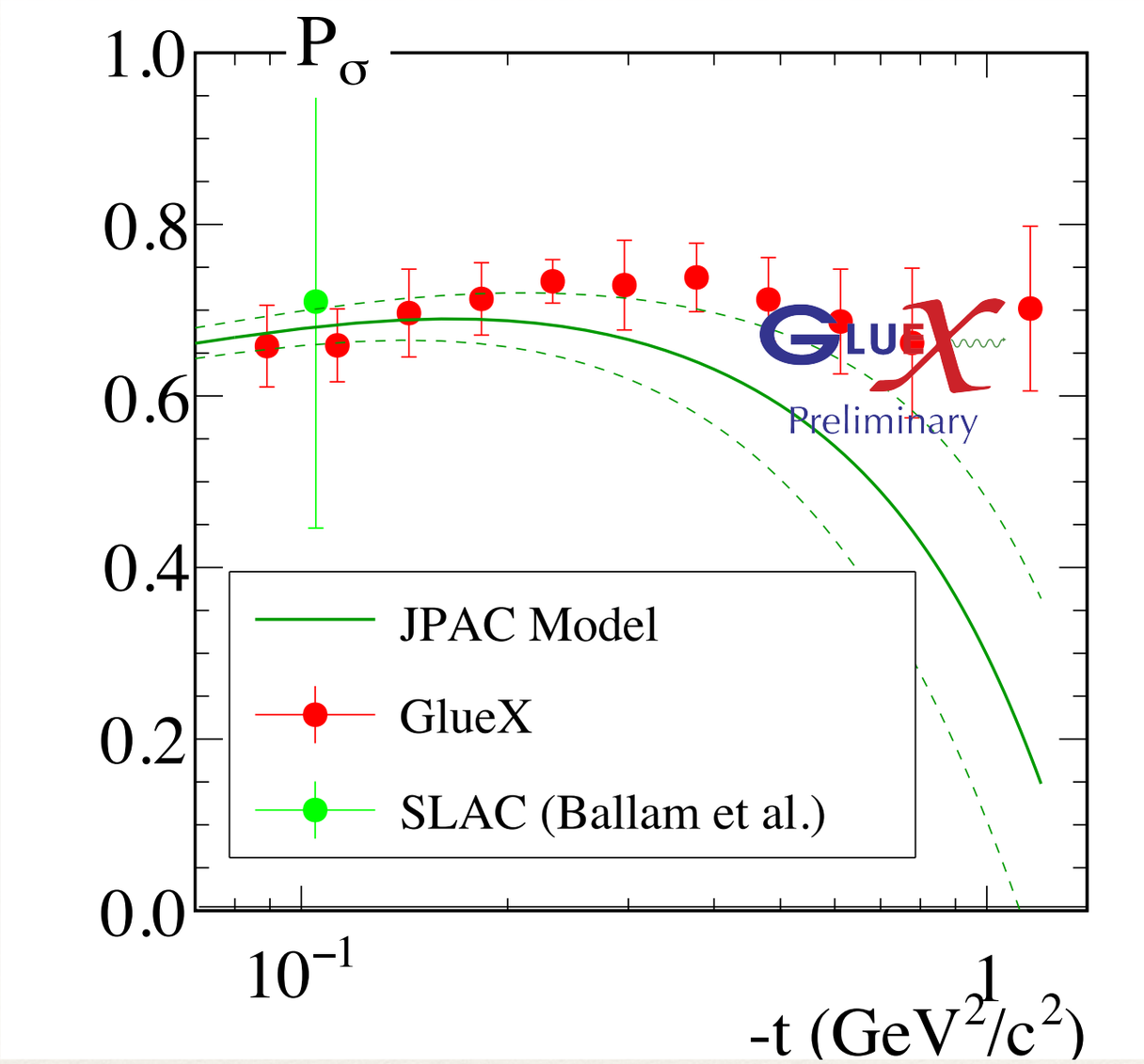


$\omega(782)$ SDMEs

Mark Dalton

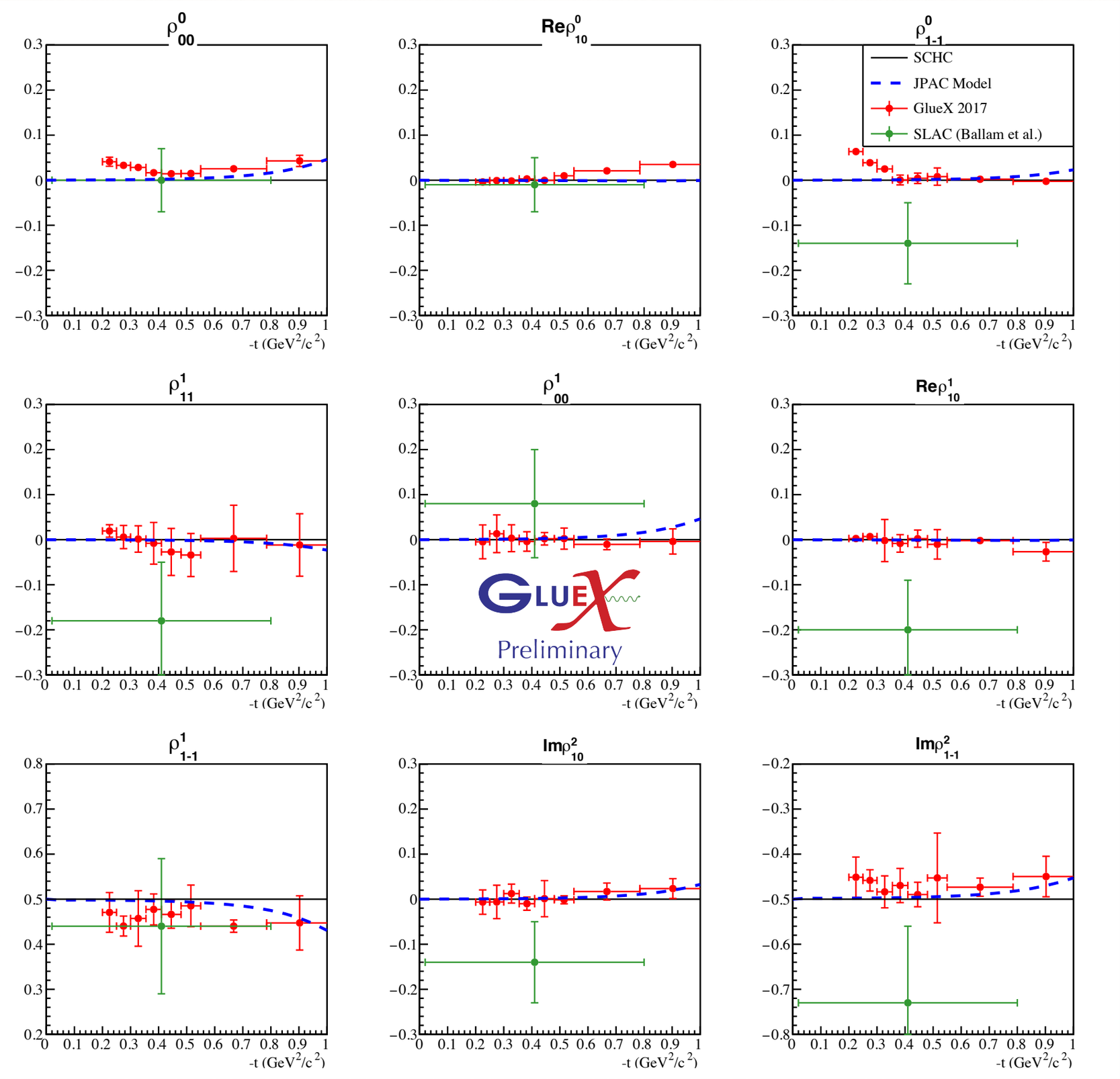
$$P_\sigma = \frac{\sigma^N - \sigma^U}{\sigma^N + \sigma^U} = 2\rho^1_{1-1} - \rho^1_{00}$$

- Clear unnatural component
  - Sign of π exchange
- Good agreement with model at small $-t$
- $\omega \to \gamma\pi^0$ also under analysis



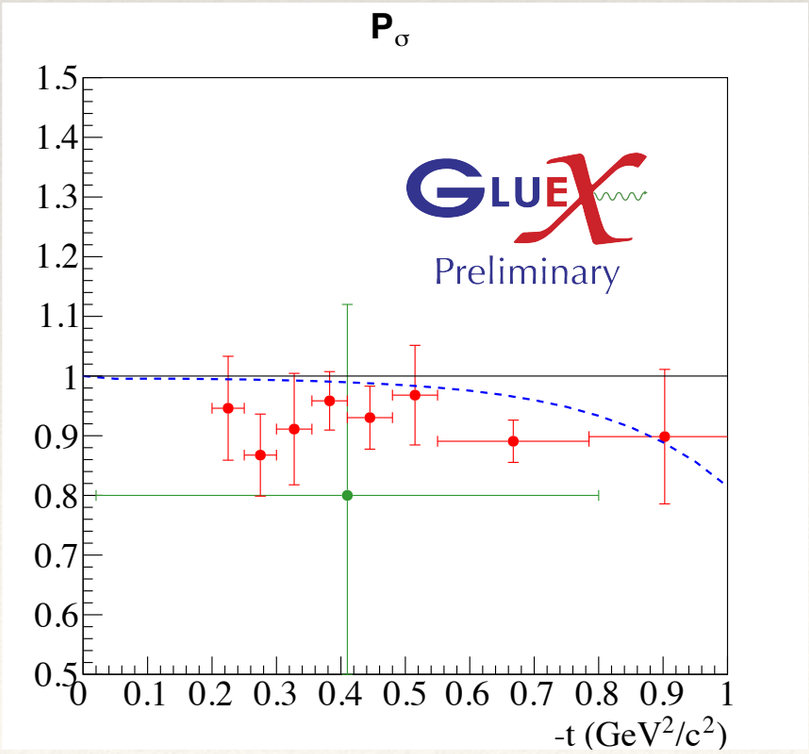
$\phi(1020)$ SDMEs

Alex Barnes



- $\phi \to K^+K^-$
- SCHC
- Agreement with model at small $-t$ (pomeron + PS exchange)

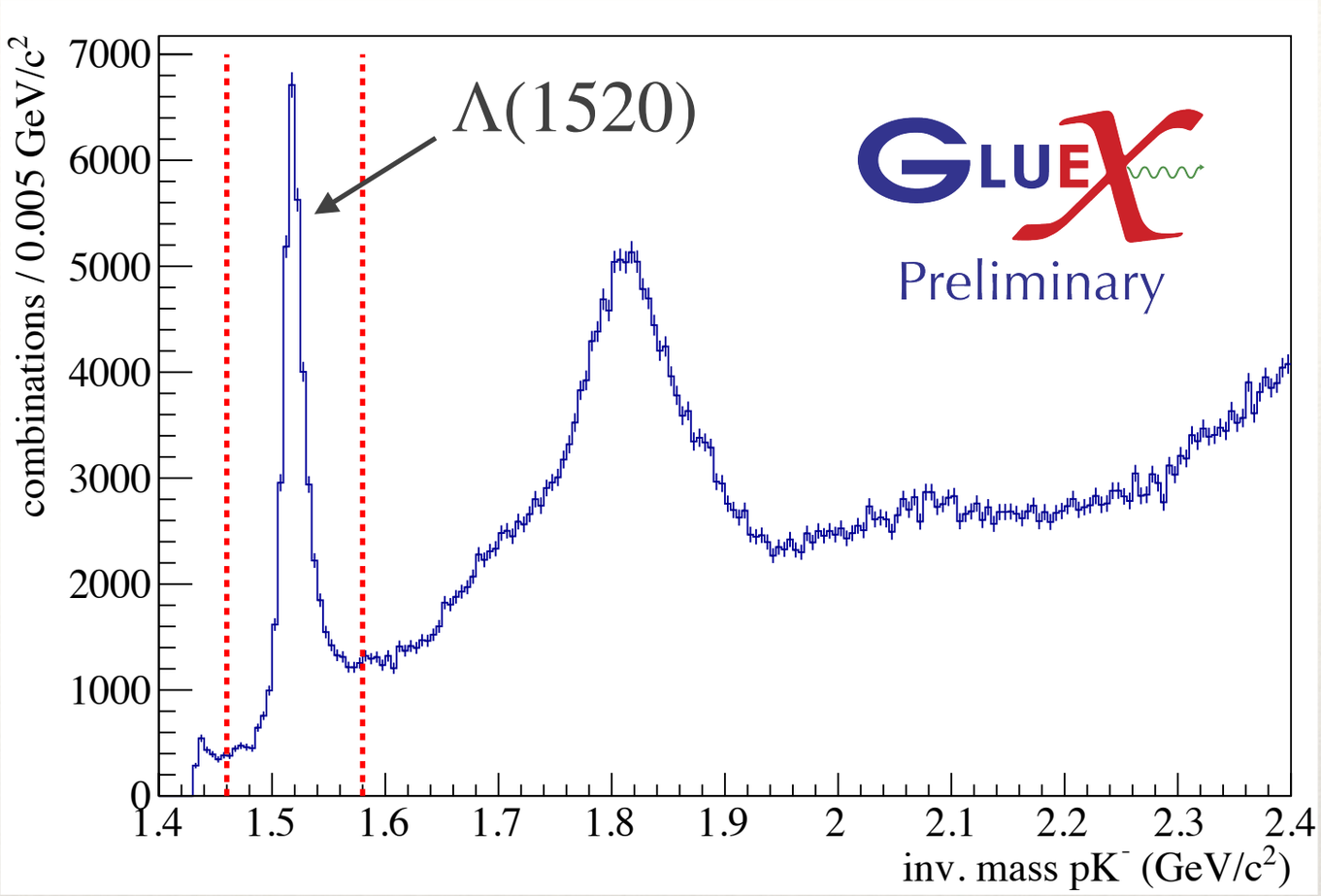
Titov *et al.*, Phys. Rev. C **60**, 035205 (1999)

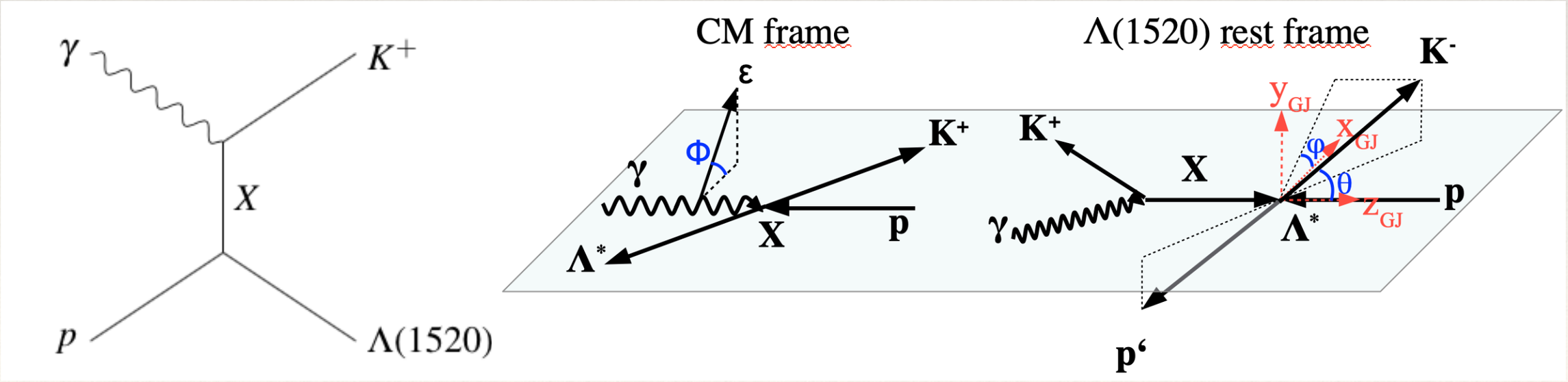


Λ(1520) SDMEs

PP

- Excited Λ hyperon with $J^P = \frac{3}{2}^-$
- $\Lambda(1520) \to K^- p$
- Very different mechanism
- Study in Gottfried-Jackson frame

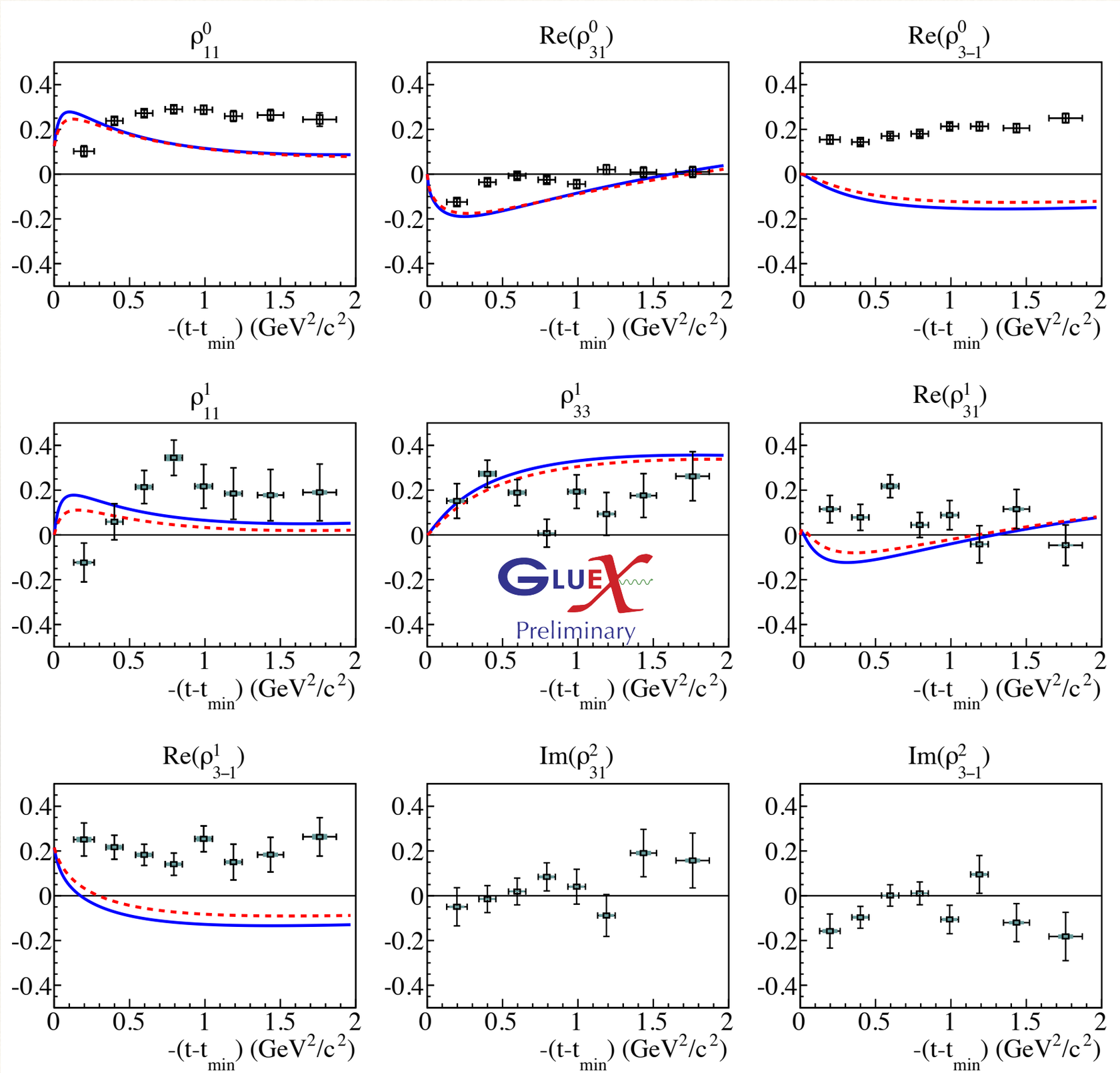




Λ(1520) SDMEs

PP

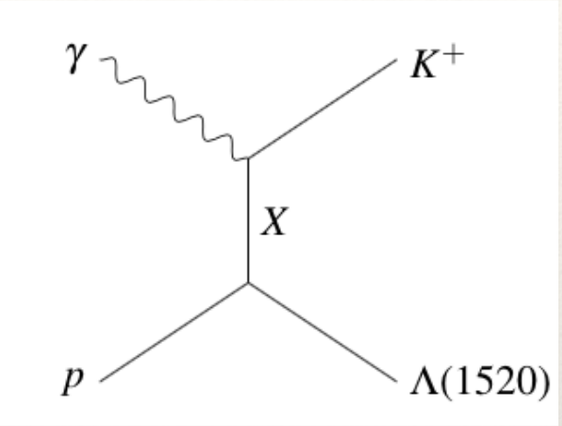
- red and blue show model predictions in Reggeized framework (priv. comm. based on [1])
- these measurements constrain models in the future



[1] Byung-Geel Yu and Kook-Jin Kong, Phys. Rev. C **96**, 025208 (2017)

Λ(1520) SDME Interpretation

- to help with interpretation form combinations of SDMEs which correspond to purely natural (N) and purely unnatural (U) exchange amplitudes



X is exchange particle with spin-parity quantum number J^P and naturality $\eta = P(-1)^J$

Natural: e.g. $K^*(892)$, $K_2^*(1430)$

Unnatural: e.g. $K(492)$, $K_1(1270)$

$$\rho^0_{11} + \rho^1_{11} = \frac{2}{N}(|N_0|^2 + |N_1|^2) \qquad \mathrm{Re}(\rho^0_{31} + \rho^1_{31}) = \frac{2}{N}(N_{-1}N_0^* - N_2N_1^*)$$

$$\rho^0_{11} - \rho^1_{11} = \frac{2}{N}(|U_0|^2 + |U_1|^2) \qquad \mathrm{Re}(\rho^0_{31} - \rho^1_{31}) = \frac{2}{N}(U_{-1}U_0^* - U_2U_1^*)$$

$$\rho^0_{33} + \rho^1_{33} = \frac{2}{N}(|N_{-1}|^2 + |N_2|^2) \qquad \mathrm{Re}(\rho^0_{3-1} + \rho^1_{3-1}) = \frac{2}{N}(N_{-1}N_1^* + N_2N_0^*)$$

$$\rho^0_{33} - \rho^1_{33} = \frac{2}{N}(|U_{-1}|^2 + |U_2|^2) \qquad \mathrm{Re}(\rho^0_{3-1} - \rho^1_{3-1}) = \frac{2}{N}(U_{-1}U_1^* + U_2U_0^*)$$

$$N = 2(|N_{-1}|^2 + |N_0|^2 + |N_1|^2 + |N_2|^2 + |U_{-1}|^2 + |U_0|^2 + |U_1|^2 + |U_2|^2)$$

work by V. Mathieu (JPAC)

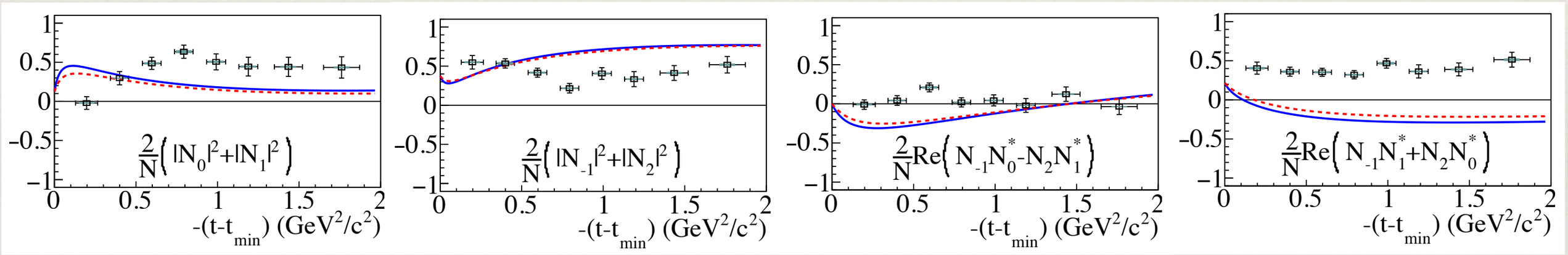
Λ(1520) SDME Interpretation

PP

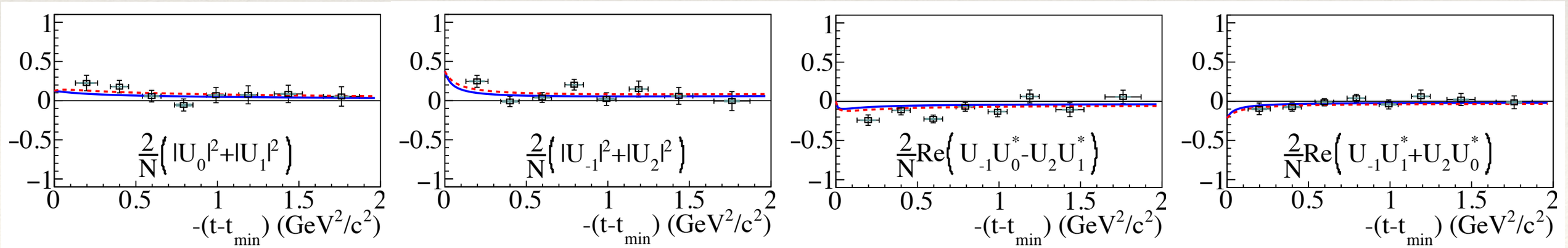
- red and blue show combinations of previous model [1]
- natural amplitudes dominate
- Publication in collaboration review

GlueX Preliminary

Natural



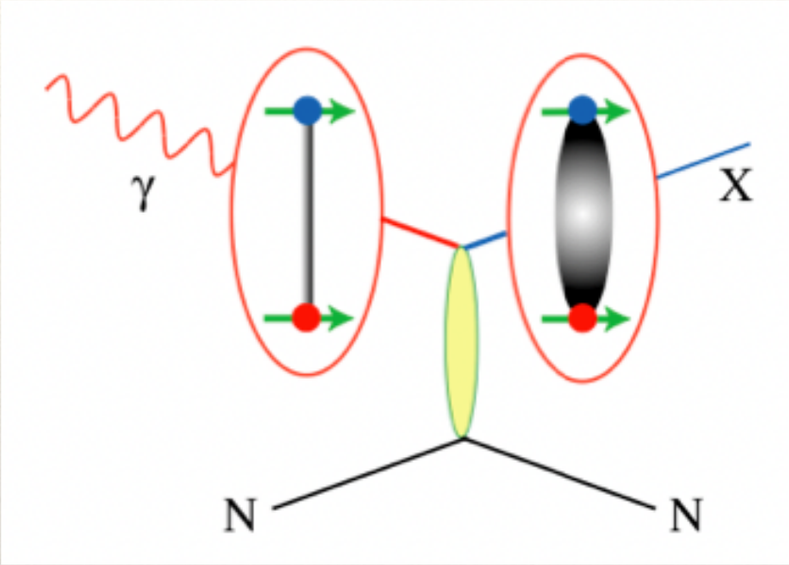
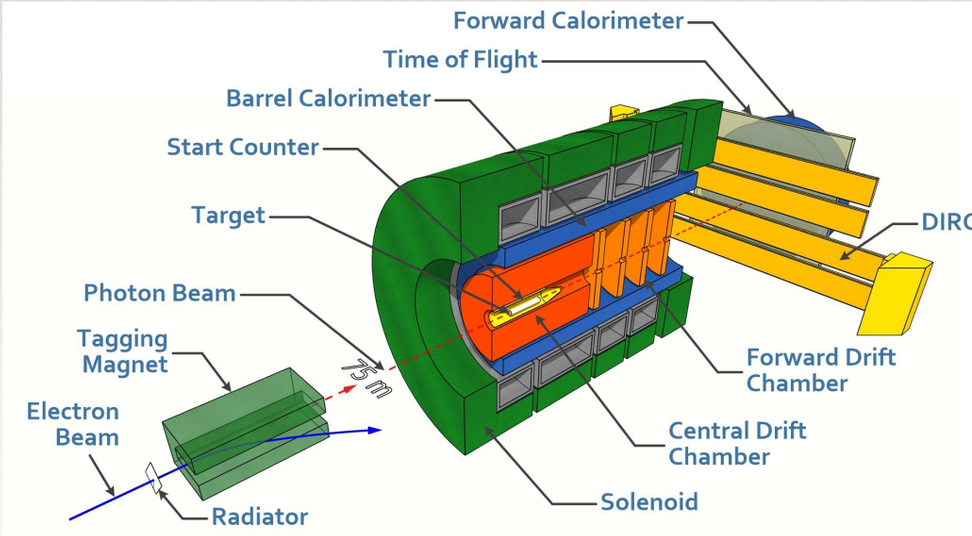
Unnatural



[1] Byung-Geel Yu and Kook-Jin Kong, Phys. Rev. C **96**, 025208 (2017)

Summary

Acknowledgments:

gluex.org/thanks

- SDMEs contain useful information on production processes
- So far measurements indicate dominance of natural exchanges at GlueX energies
- Publications in preparation/under collaboration review
- Practising PWA techniques, studying detector MC modelling
  →important work towards hybrid search
- GlueX has a unique data set with unprecedented statistical precision in its energy range
- Many more interesting analyses in the pipeline