Peter Pauli for the GlueX collaboration

Accessing glue through photoproduction measurements at GlueX

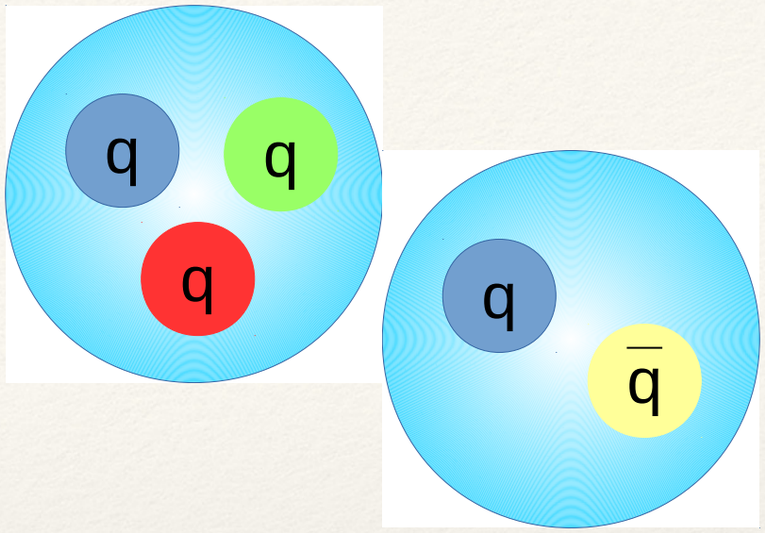
University of Glasgow

Hadron 2021

GlueX

Introduction

- QCD gives rise to spectrum of hadrons
  - Many $q\bar{q}$ and qqq states have been observed
  - $q\bar{q}q\bar{q}$, $qqqq\bar{q}$, … are not forbidden!



A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN

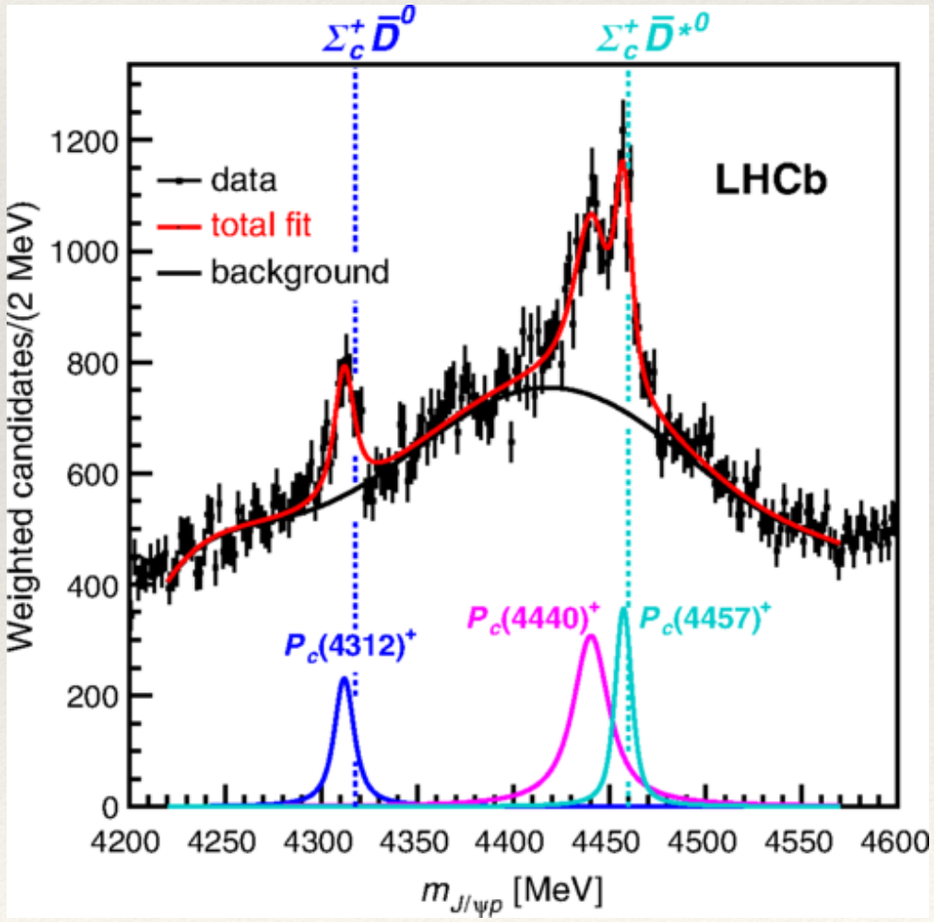
California Institute of Technology, Pasadena, California

Received 4 January 1964

. . . Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. . . .

Phys. Lett. 8 (1964) 214

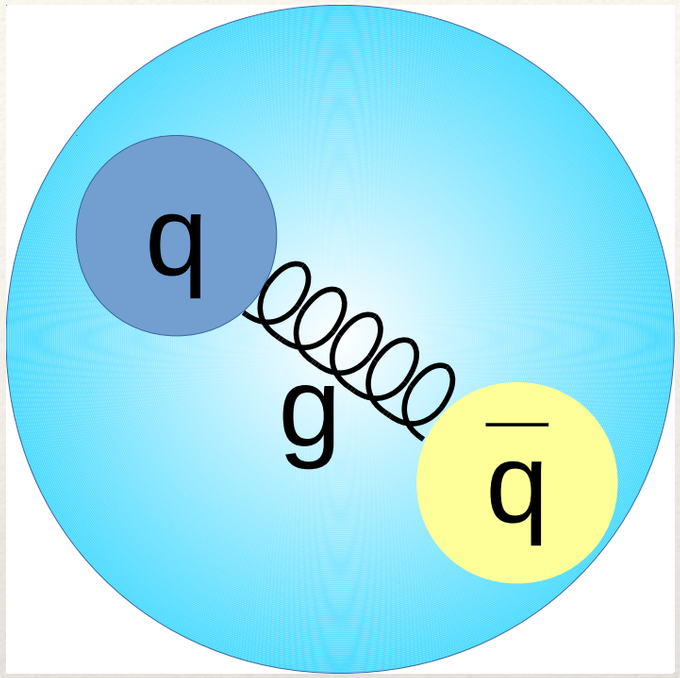
Evidence exists for pentaquark states:



LHCb, Phys. Rev. Lett. **122**, *222001*

Hybrid mesons

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



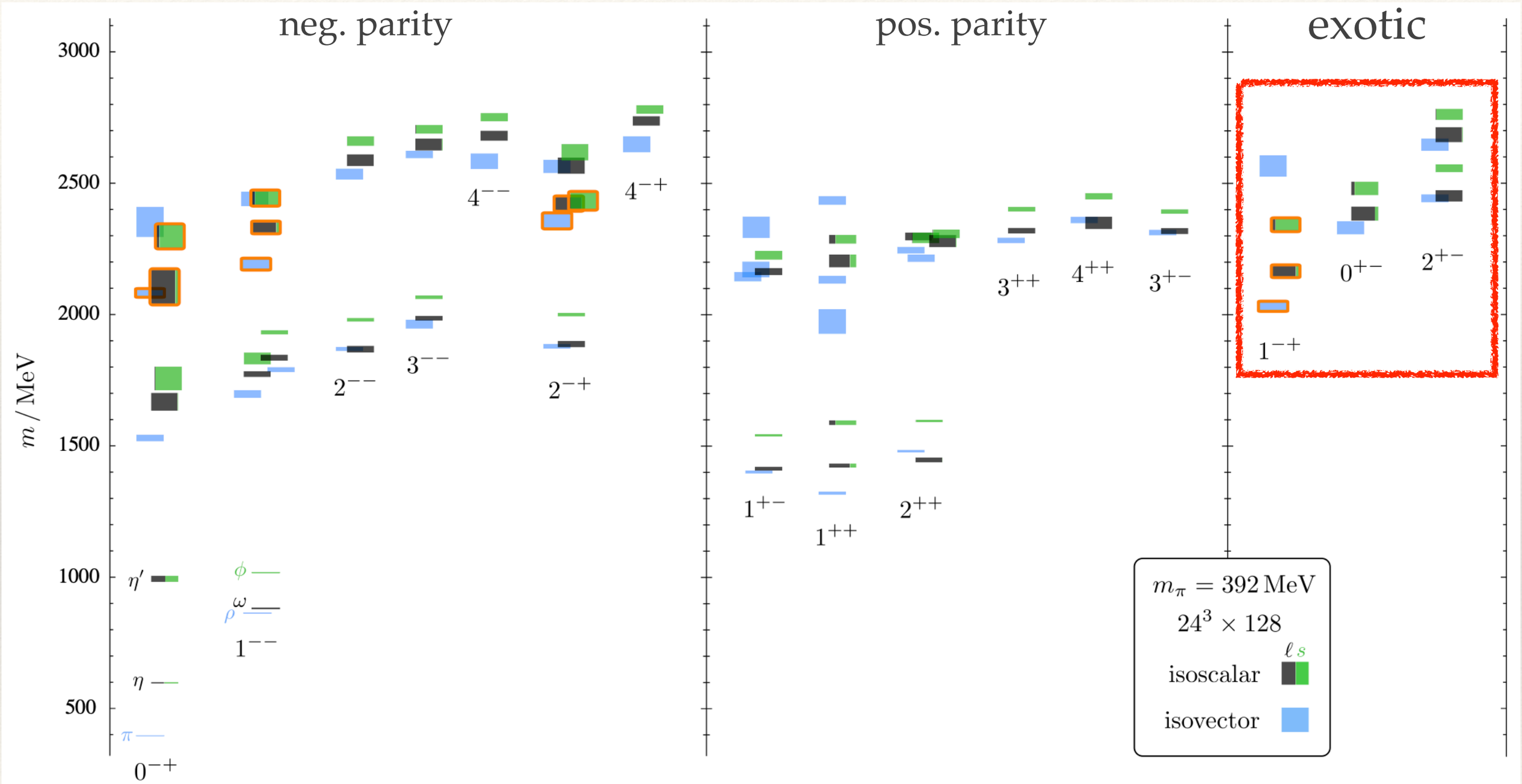
- In quark model:
  $\vec{J} = \vec{L} + \vec{S}$, $P = (-1)^{L+1}$, $C = (-1)^{L+S}$

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

- "Exotic" quantum numbers are "smoking gun" for something not being pure $q\bar{q}$

Light quark mesons from lattice QCD

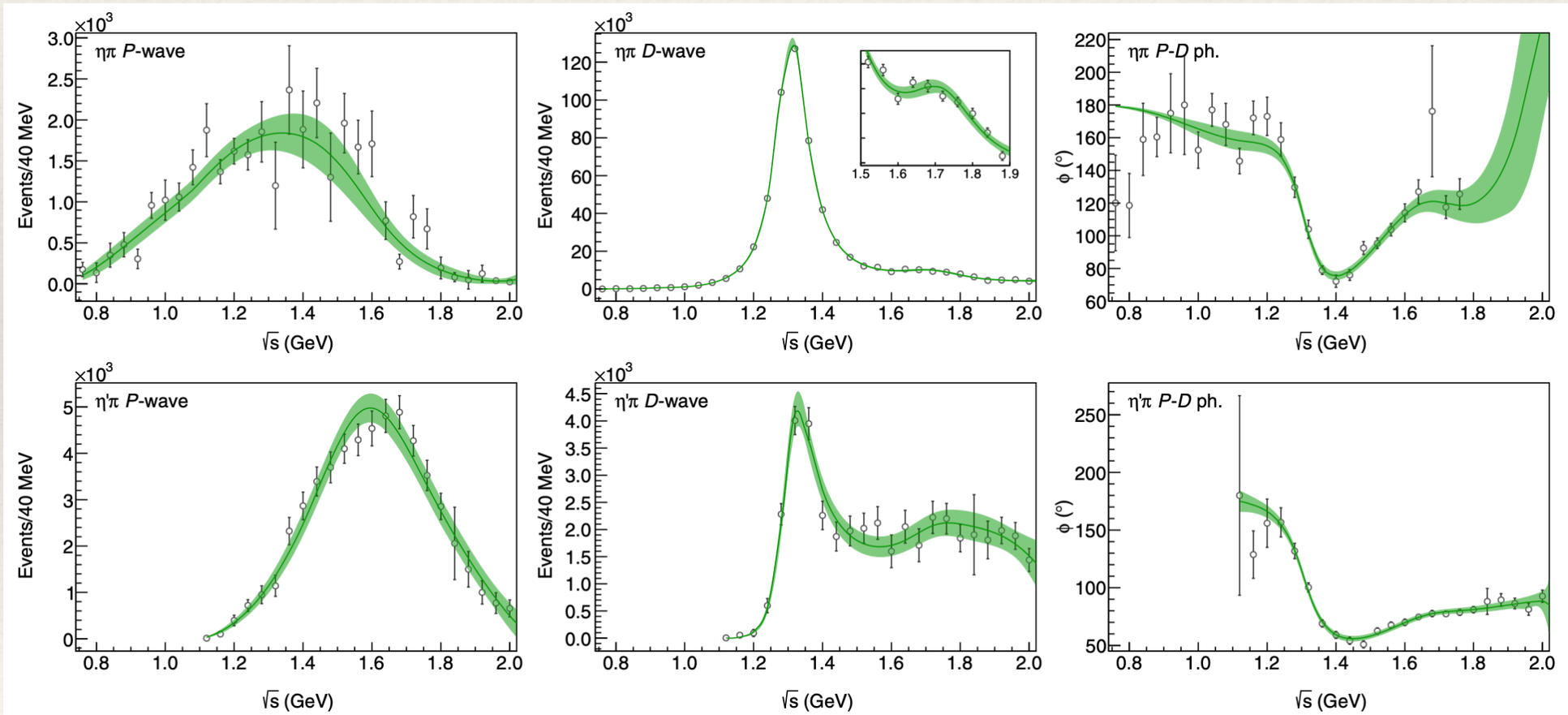
hadspec collaboration



*hadspec, Phys. Rev. D **88**, 094505*

Hybrid mesons - evidence

- Experimental evidence for a 1^{-+}:
  - $\pi_1(1400)$: GAMS, VES, E852, CBAR, COMPASS
  - $\pi_1(1600)$: VES, E852, COMPASS
- JPAC coupled channel fit to $\eta\pi$ and $\eta'\pi$ data from COMPASS



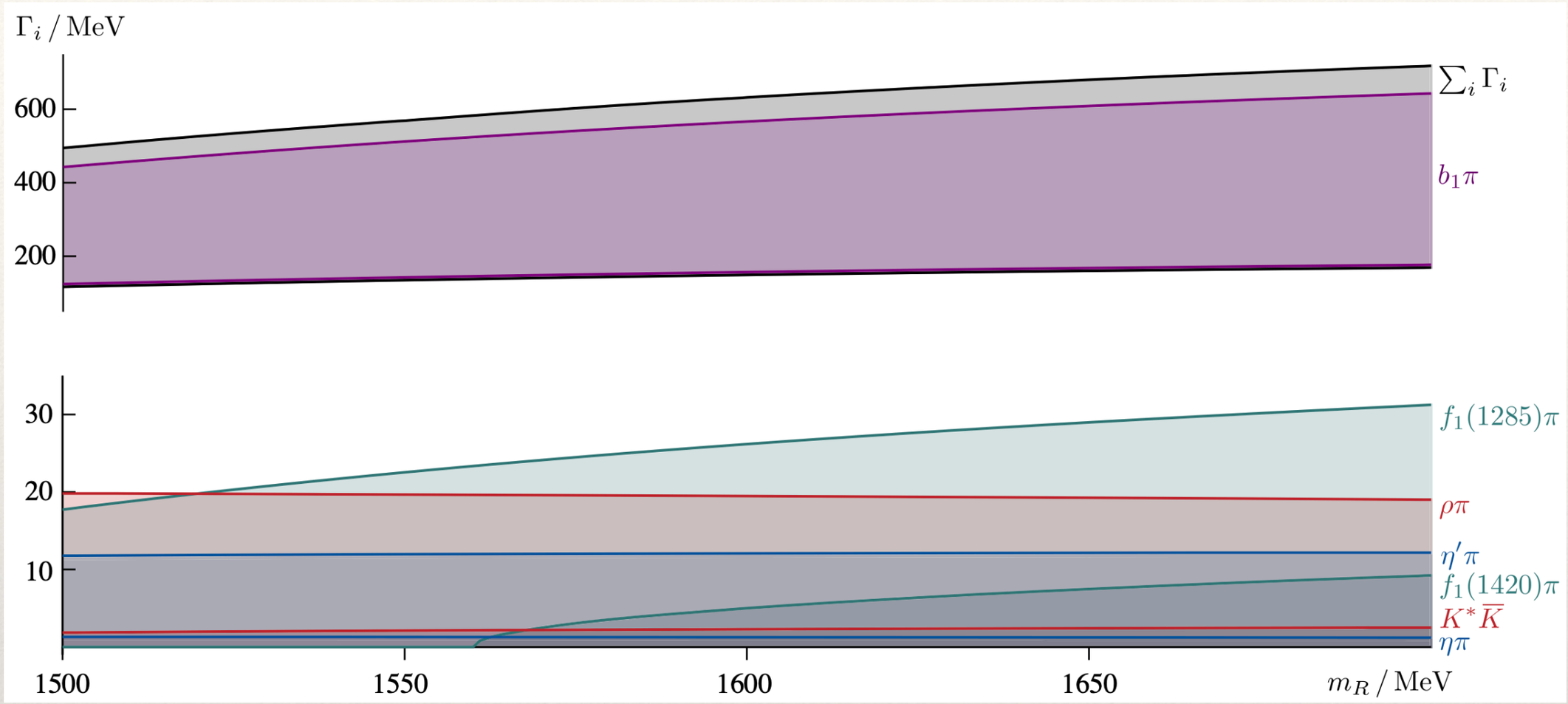
$$\text{mass} = 1564 \pm 24 \pm 86 \text{ MeV} \quad \text{width} = 492 \pm 54 \pm 102 \text{ MeV}$$

JPAC, Phys. Rev. Lett. ***122****, 042002*

1^{-+} hybrid from lattice QCD

hadspec collaboration

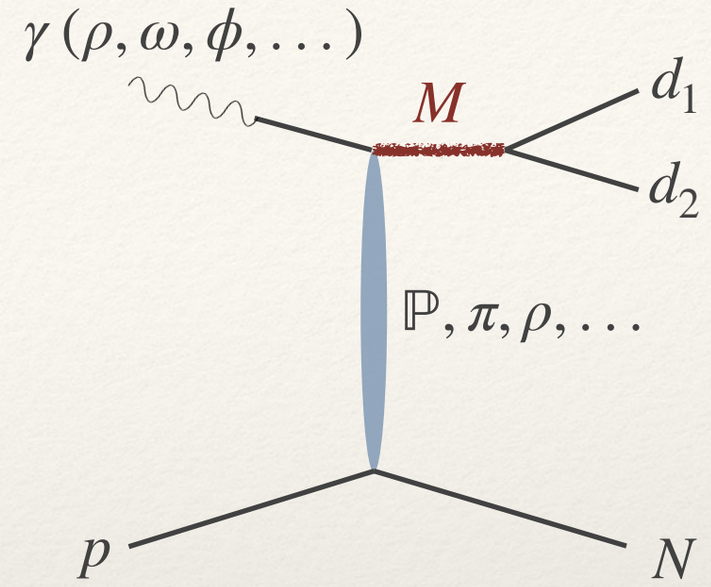
*hadspec, Phys. Rev. D **103**, 054502*



- LQCD indicates that $b_1\pi$ is the dominant decay mode
  - Experimentally challenging
- Start with $\eta\pi$, $\eta'\pi$
  - Smaller expected branching ratio but large statistics

Towards hybrids at GlueX

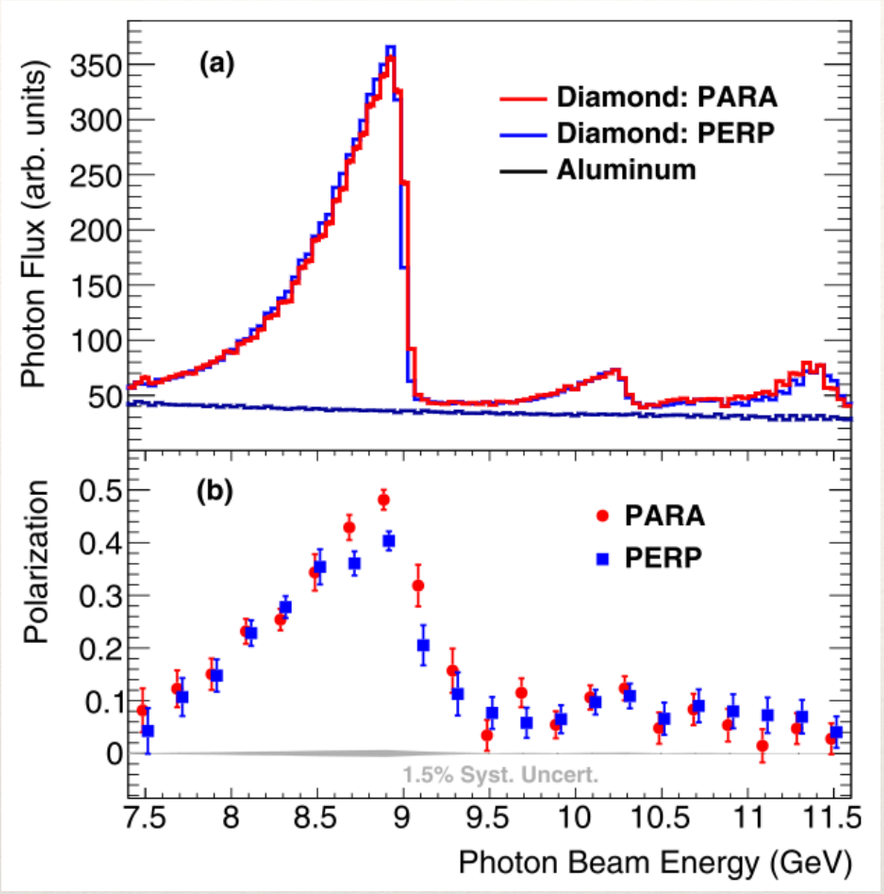
- Photoproduction complementary to pion production
  - Utilize polarization to understand production mechanisms



- Study production mechanisms to inform choice of wave sets for PWA (beam asymmetries, spin density matrix elements)
- Reproduce previous results by COMPASS
- Study $b_1 \to \omega\pi$ as first step towards $b_1\pi$ PWA
- Work closely with theory colleagues

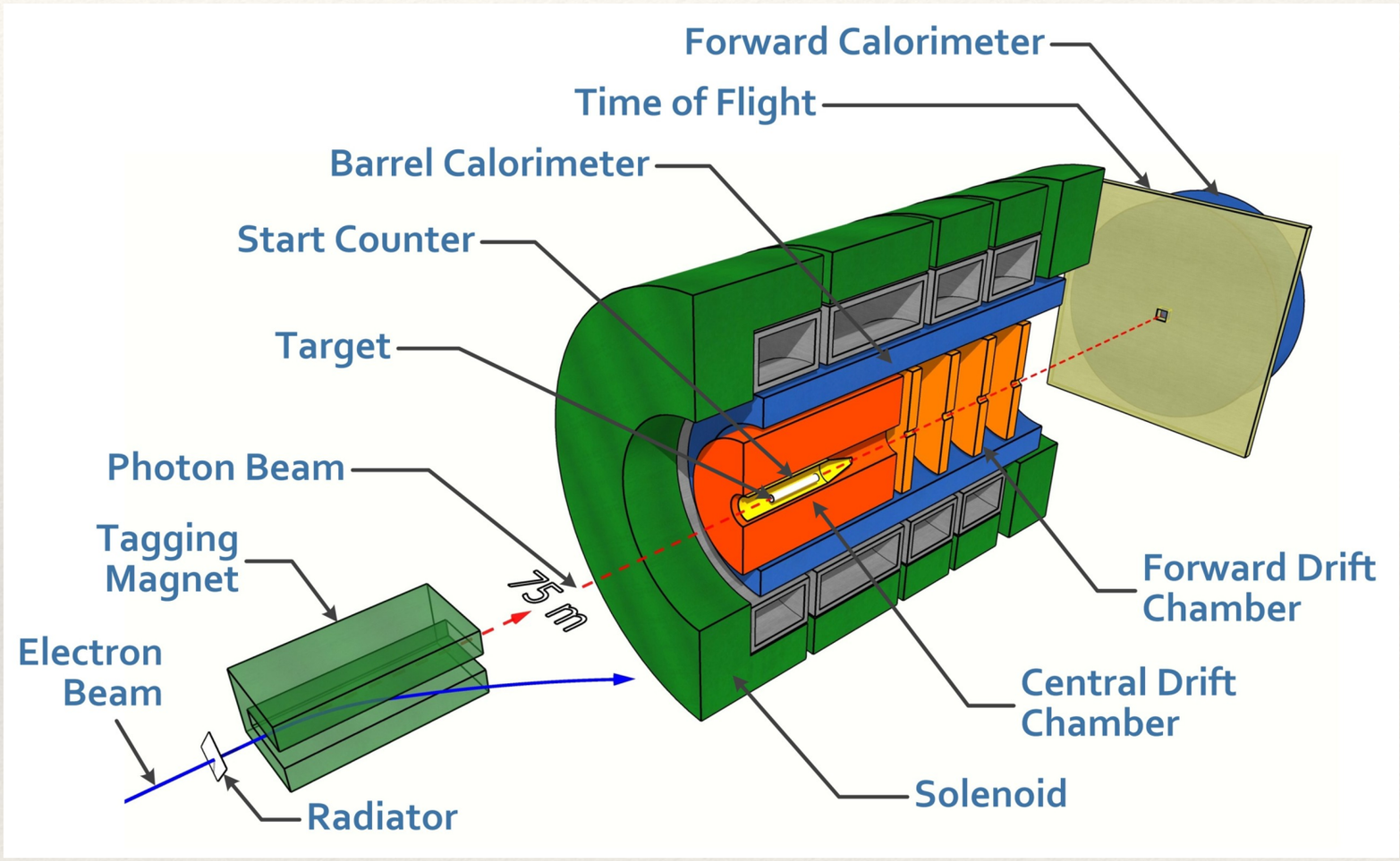
CEBAF at Jefferson Lab

GlueX experiment in Hall D



GlueX, Nucl. Instrum. Meth. A 987 (2021) 164807

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



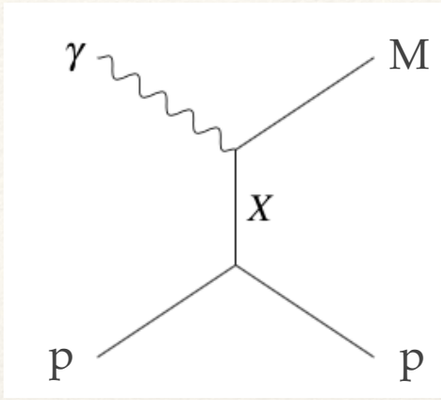
- tag electrons to determine photon energy

- 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

Talk by A. Austregesilo, Mon 12:40

- SDMEs ρ^i_{jk} 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:

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

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

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

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

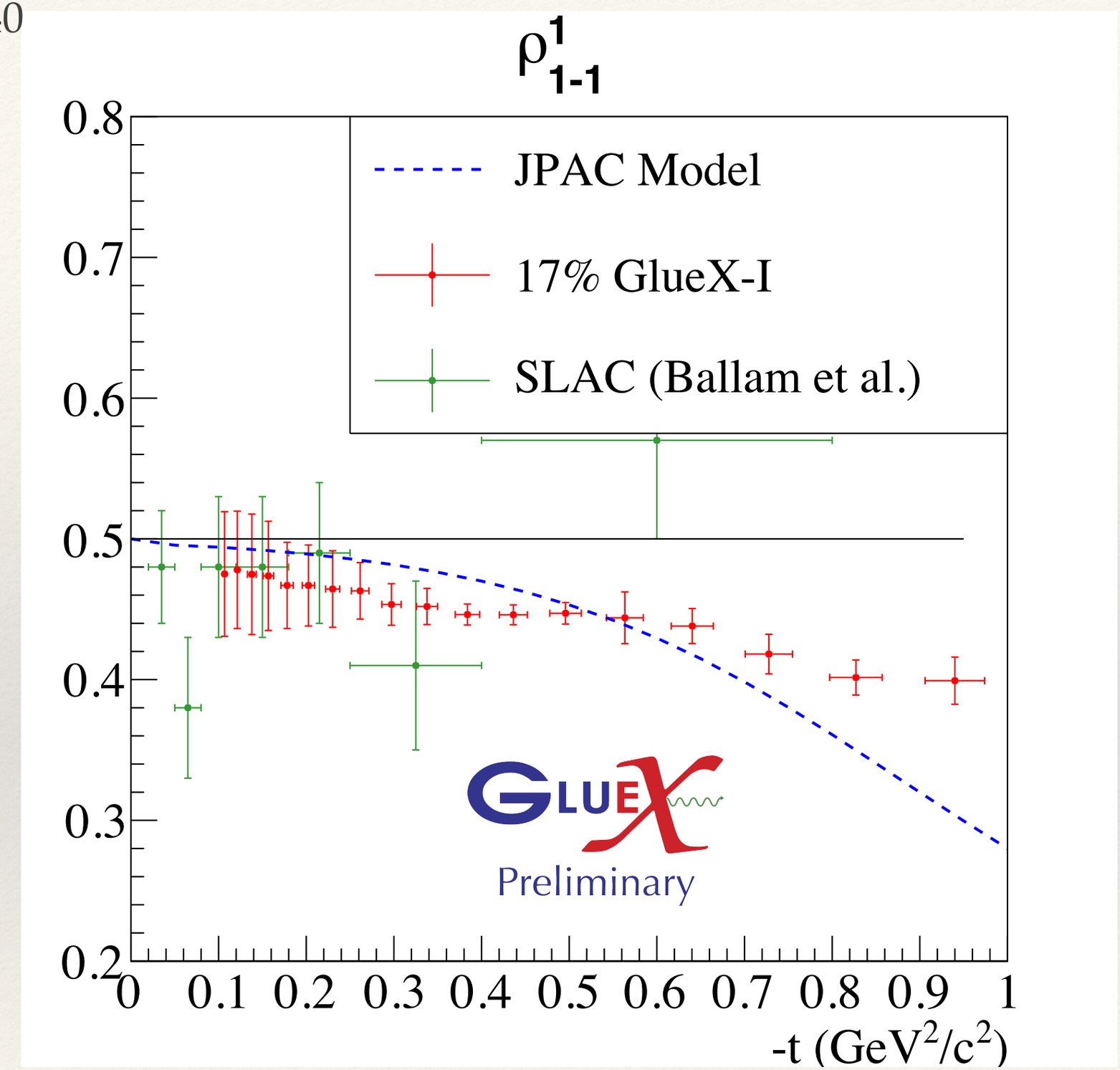
*Schilling et. al., Nucl. Phys. B **15** (1970) 397-412*

$\rho(770)$ SDMEs

Talk by A. Austregesilo, Mon 12:40

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

*JPAC, Phys. Rev. D **97**, 094003 (2018)*



$\rho(770)$ SDMEs

Talk by A. Austregesilo, Mon 12:40

- Study combinations of SDMEs which are purely natural or unnatural

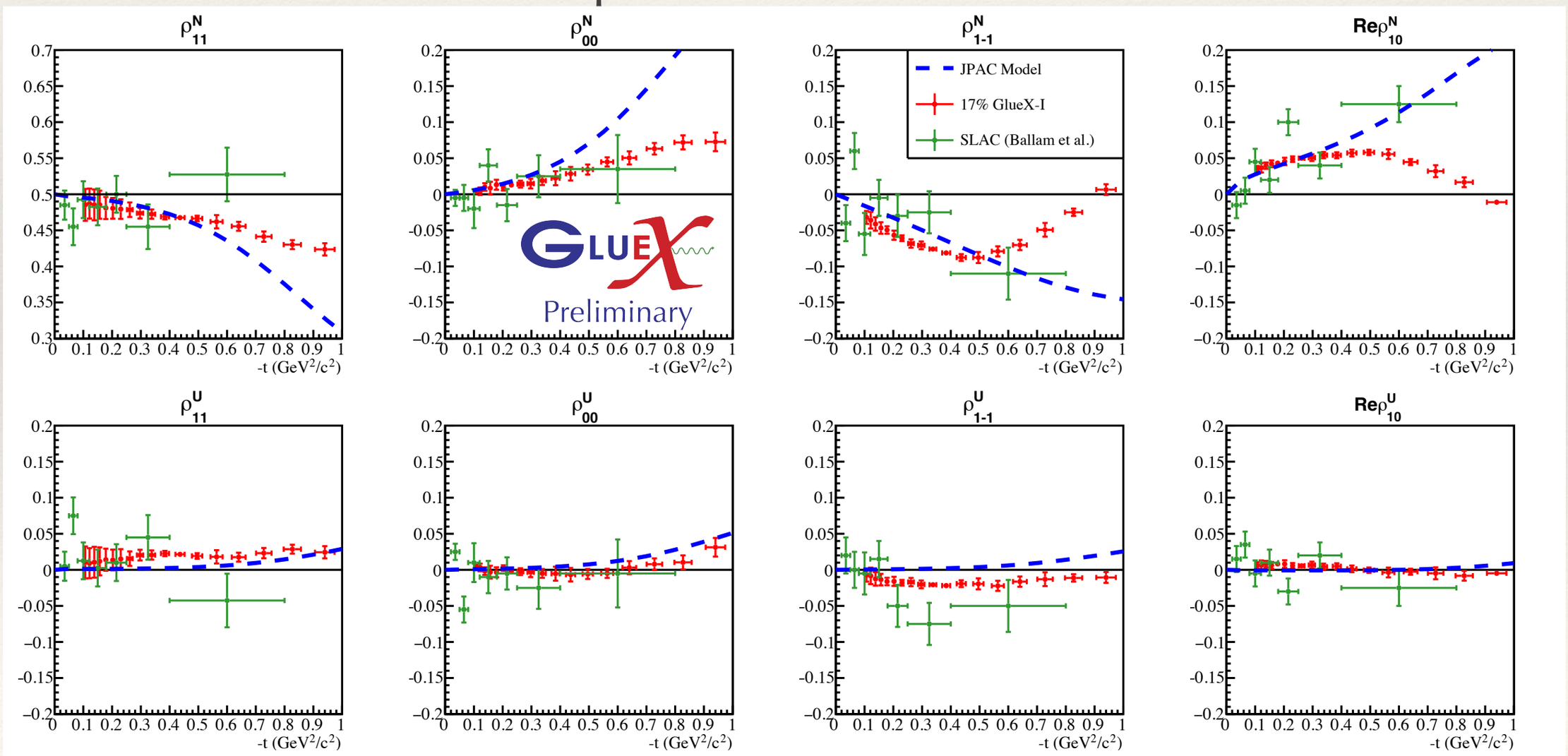
- $$\rho^{N,U}_{jk} = \frac{1}{2}\left(\rho^{0}_{jk} \mp (-1)^{i}\rho^{1}_{-jk}\right)$$

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

Natural: e.g. f_2, a_2

Unnatural: e.g. π, η

- Dominance of natural amplitudes



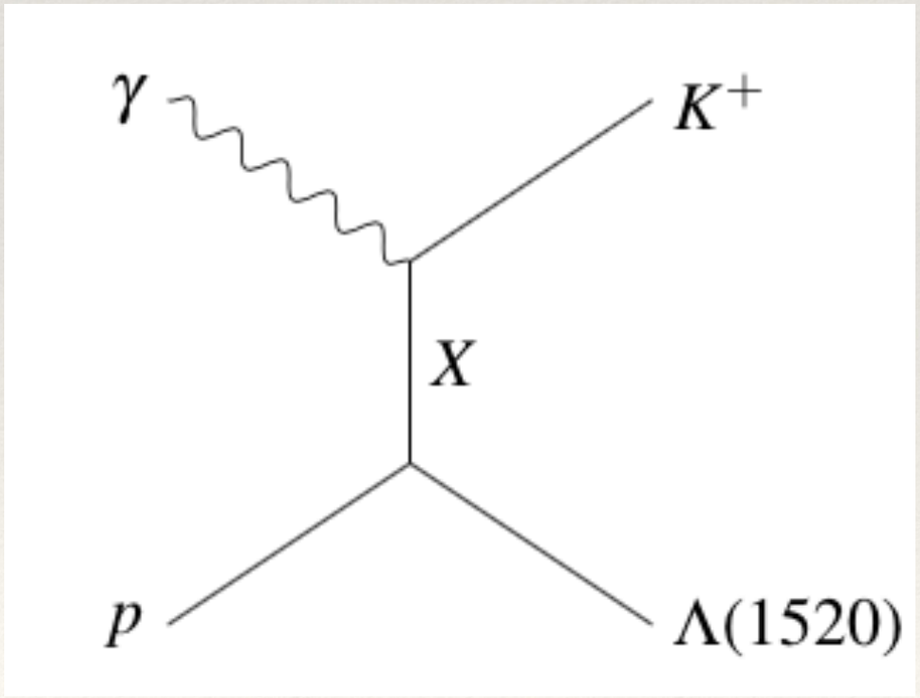
*JPAC, Phys. Rev. D **97**, 094003 (2018)*

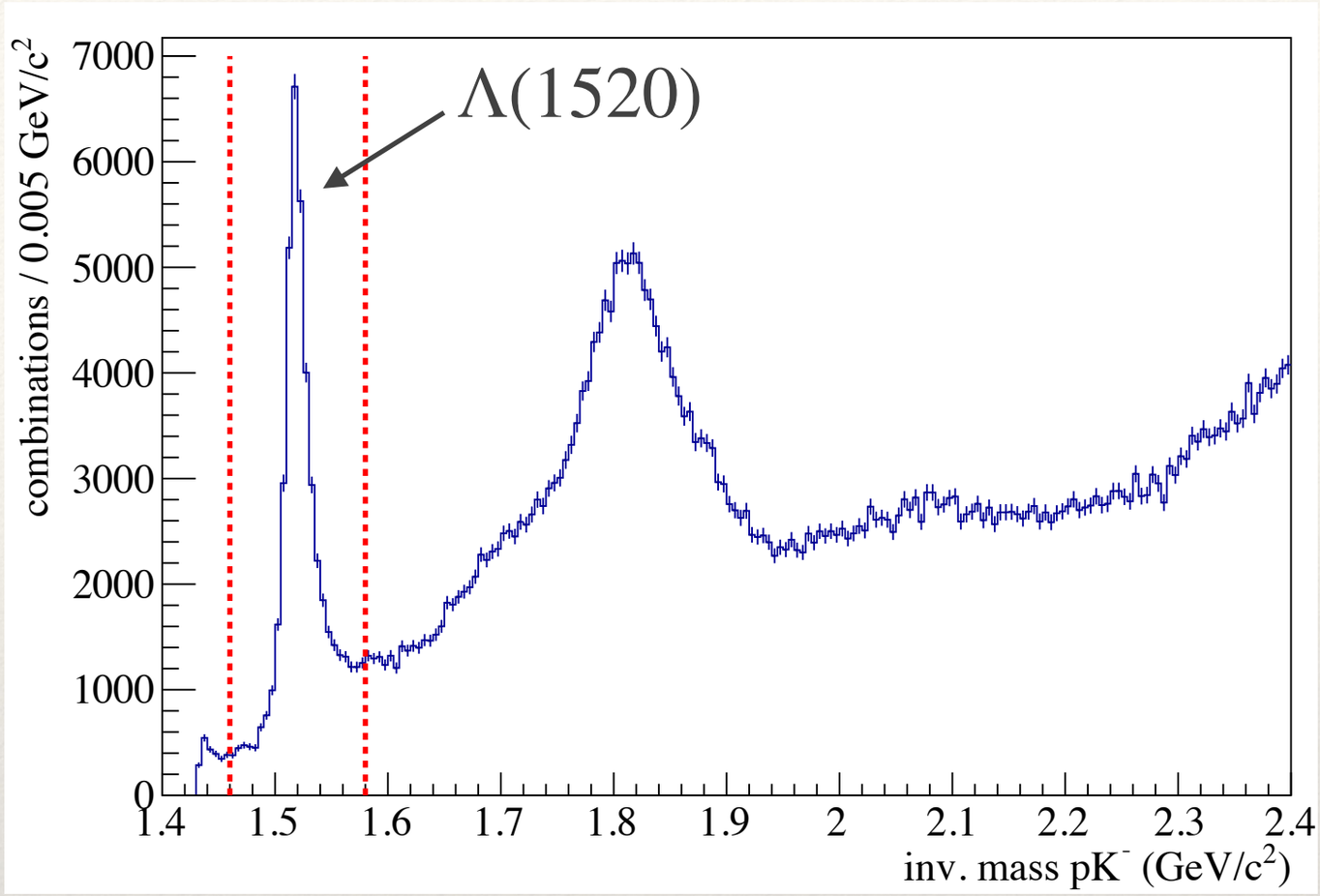
Λ(1520) SDMEs

PP

arxiv:2107.12314

- Excited Λ hyperon with $J^P = \frac{3}{2}^-$
- $\Lambda(1520) \rightarrow K^- p$





- Production mechanism via strangeness
- First measurement of polarised SDMEs for Λ(1520)

Λ(1520) SDME Interpretation

arxiv:2107.12314

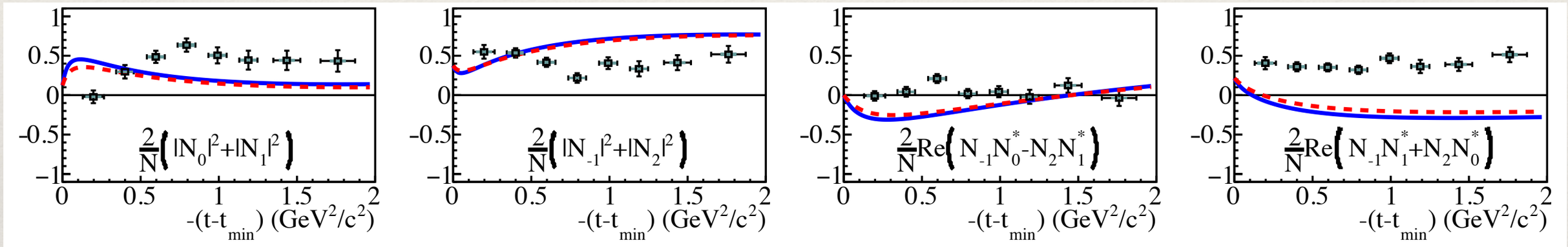
- Study combinations of SDMEs which are purely natural or unnatural
  - e.g. $\rho^0_{11} + \rho^1_{11} = \frac{2}{\mathcal{N}}\left(|N_0|^2 + |N_1|^2\right)$

Natural: e.g. $K^*(892)$, $K^*_2(1430)$

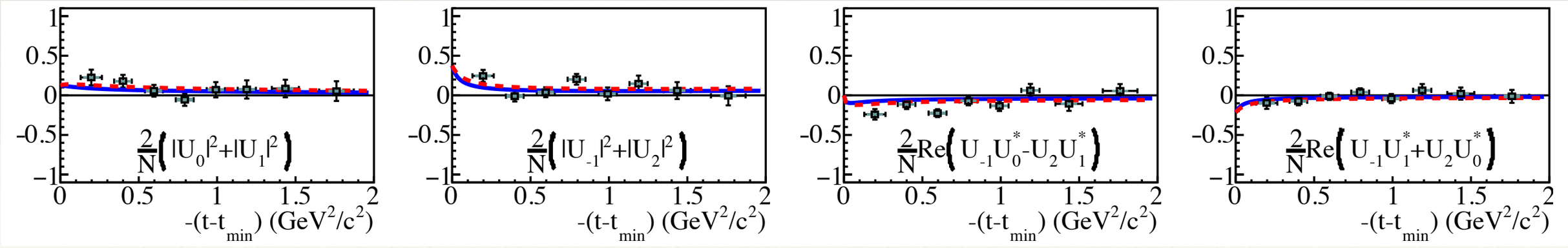
Unnatural: e.g. K, $K_1(1270)$

- Again, dominance of natural amplitudes

Natural



Unnatural

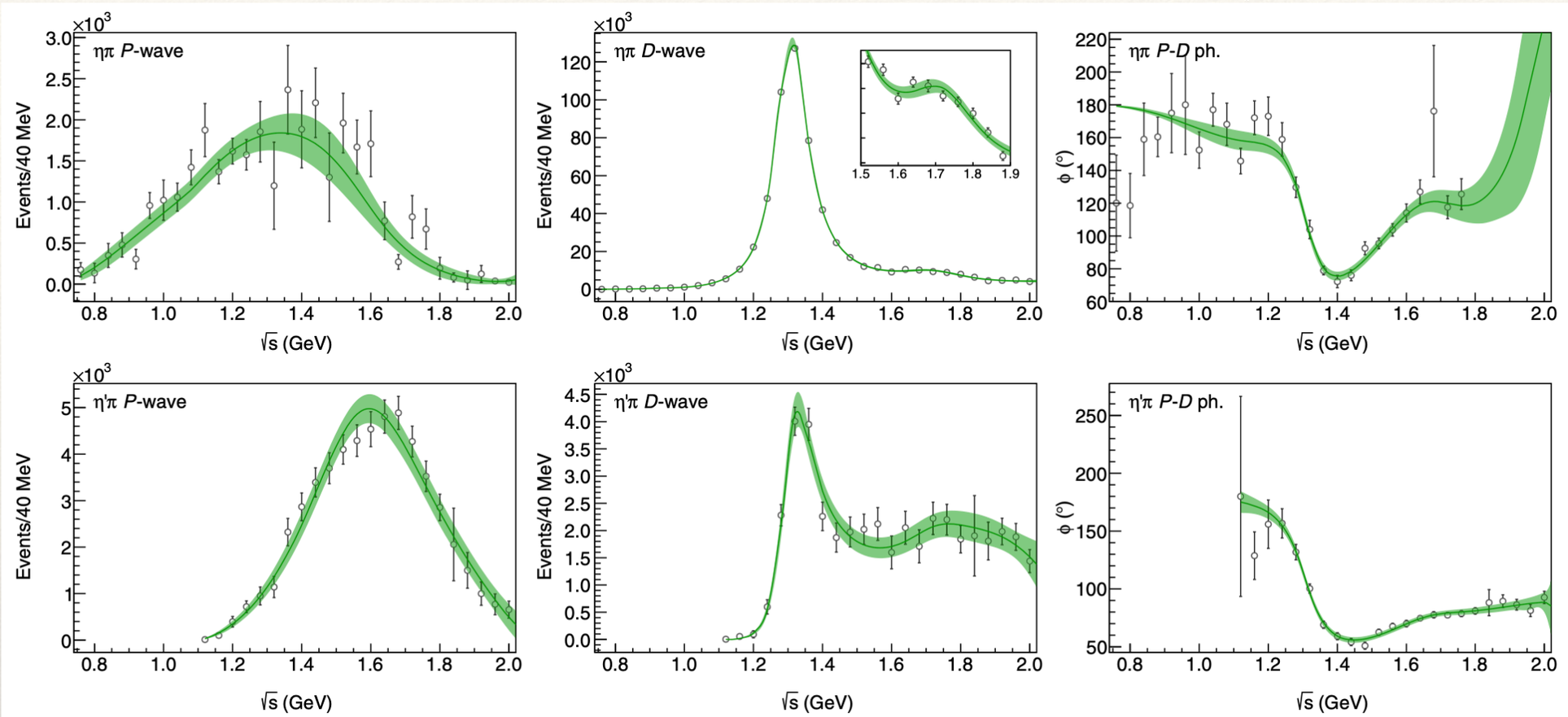


Model based on: B.-G. Yu, K.-J. Kong, *Phys. Rev. C* ***96****, 025208 (2017)*

Hybrid search in $\eta\pi$

Talk by C. Gleason, Wed 10:30

JPAC, Phys. Rev. Lett. ***122****, 042002*



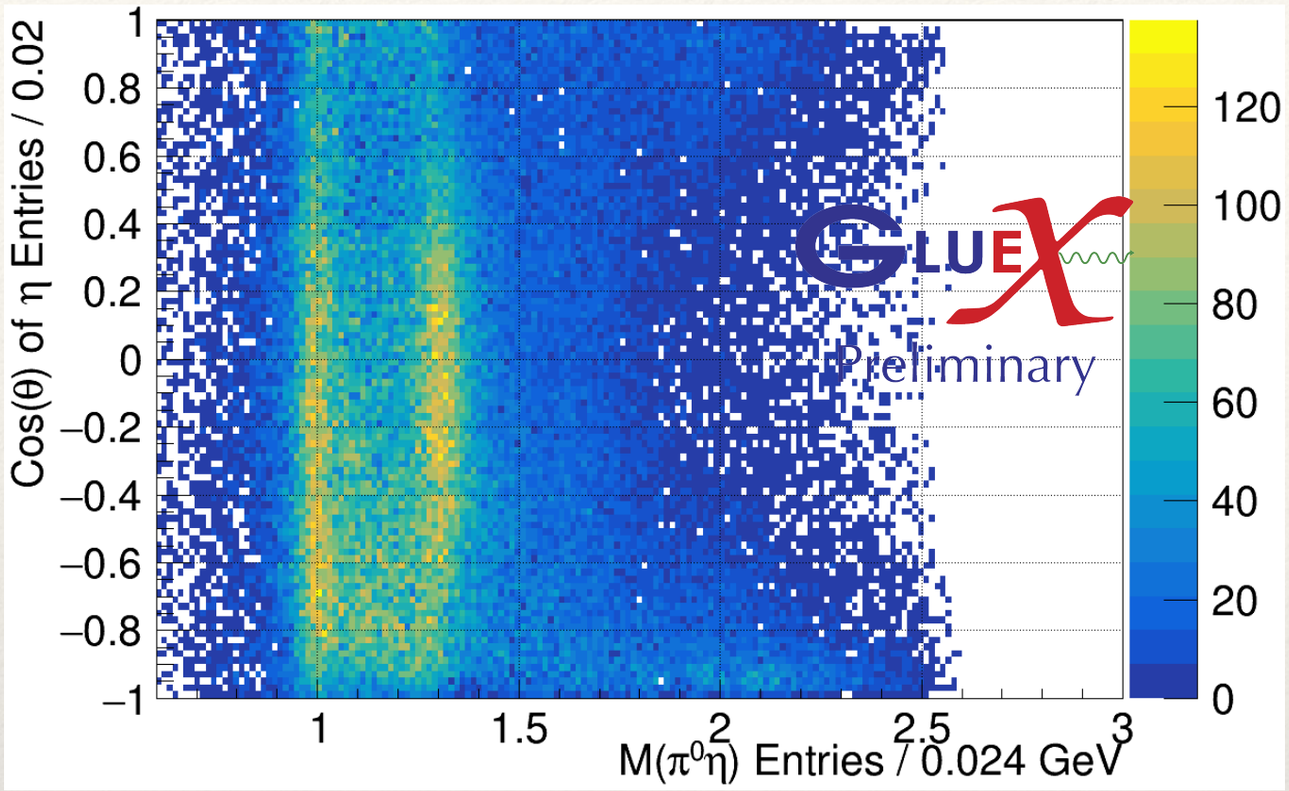
- JPAC coupled channel fit to $\eta\pi$ and $\eta'\pi$ data from COMPASS
- GlueX has access to different decay modes in multiple final states
- $\gamma p \to \eta\pi^0 p,\ \eta \to \gamma\gamma$
- $\gamma p \to \eta\pi^0 p,\ \eta \to \pi^+\pi^-\pi^0$
- $\gamma p \to \eta\pi^-\Delta^{++},\ \eta \to \gamma\gamma$
- $\gamma p \to \eta\pi^-\Delta^{++},\ \eta \to \pi^+\pi^-\pi^0$
- $\gamma p \to \eta'\pi^0 p,\ \eta' \to \pi^+\pi^-\eta,\ \eta \to \gamma\gamma$
- $\gamma p \to \eta'\pi^-\Delta^{++},\ \eta' \to \pi^+\pi^-\eta,\ \eta \to \gamma\gamma$

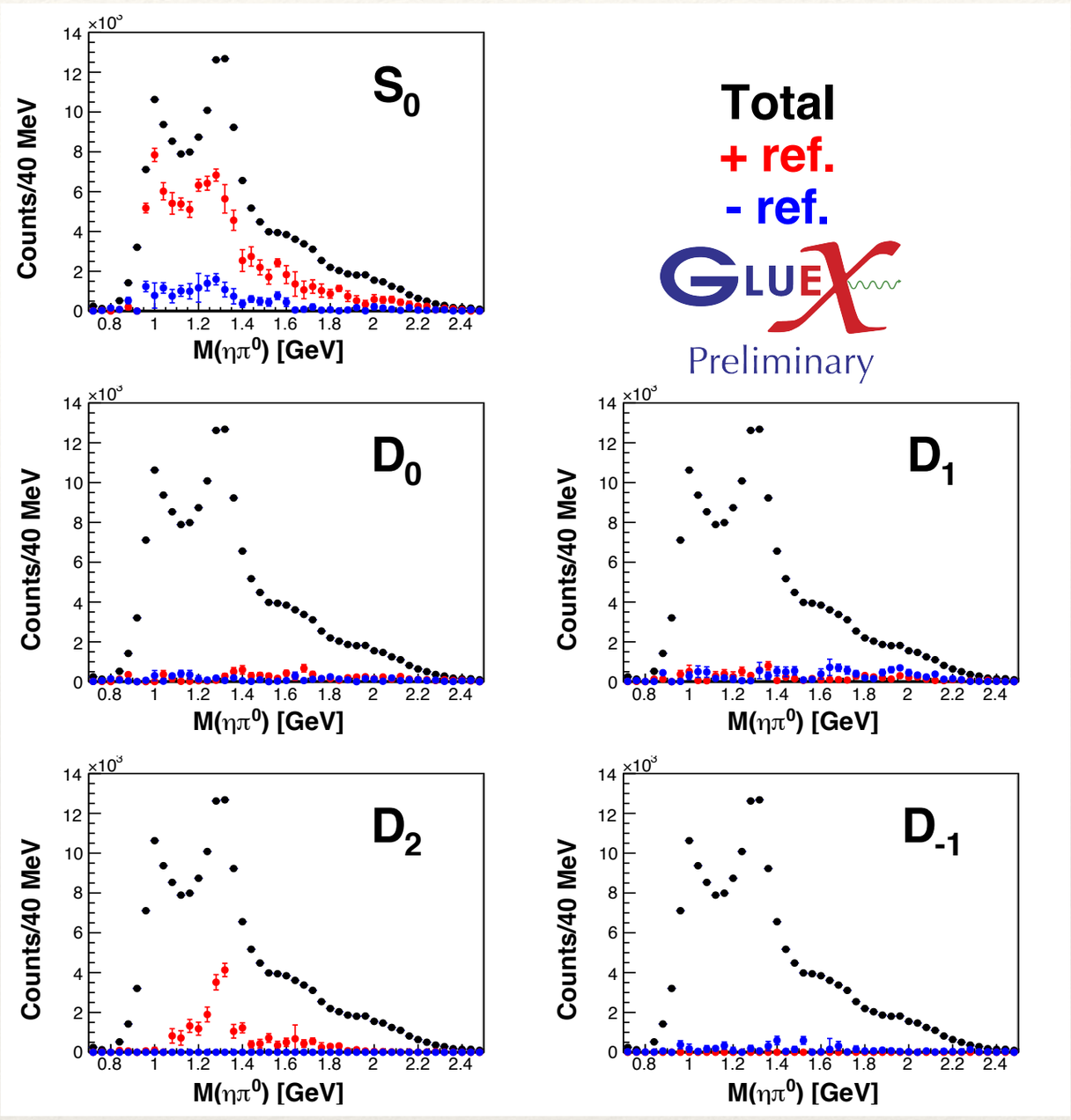
Towards a PWA in $\eta\pi^0$

M. Albrecht
L. Ng

Talk by C. Gleason, Wed 10:30

$0.1<t<0.3$





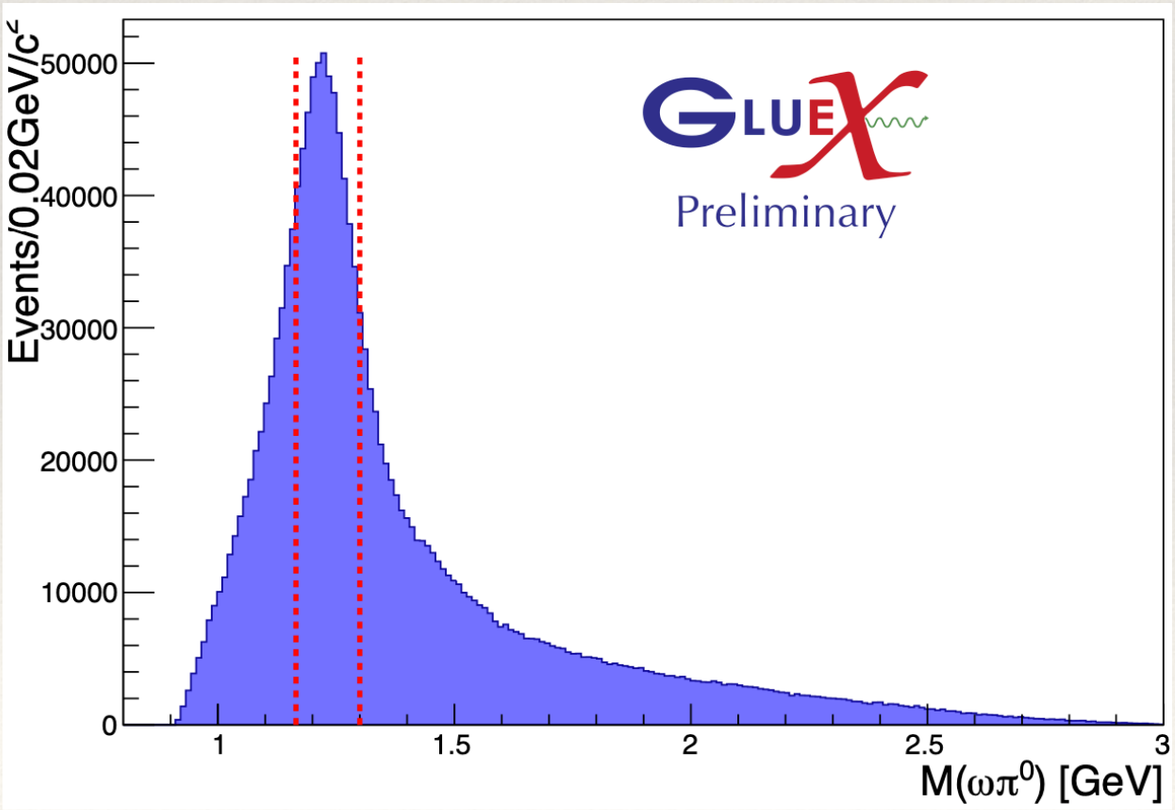
- First look at PWA in $\eta\pi^0$
- Study $a_0(980)$ and $a_2(1320)$
  - Positive helicity (natural exchange, e.g. ρ) dominates
  - a_2 predominantly D_2 wave, consistent with helicity=2 dominance at Belle ($\gamma\gamma \rightarrow \eta\pi^0$)

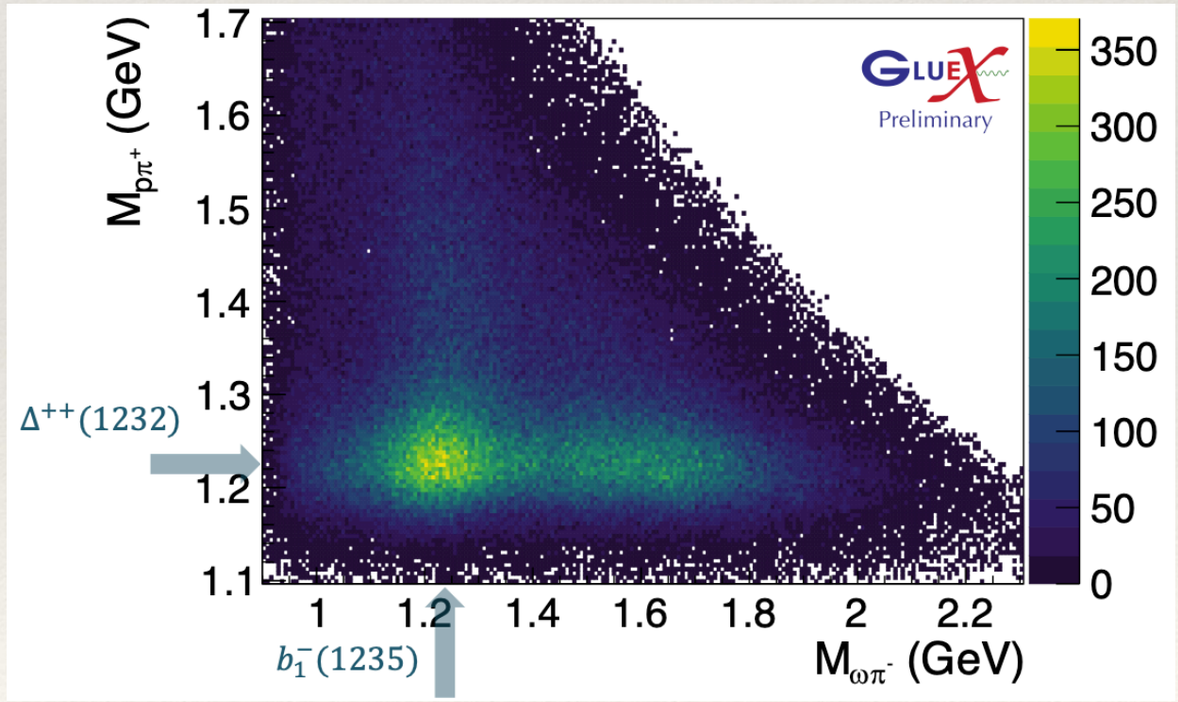
Belle, Phys. Rev. D ***80****, 032001*

b_1 decay

A. Schertz
K. Suresh

- LQCD: $b_1\pi$ is dominating decay mode of 1^{-+} exotic
- First step: study b_1
  - $\gamma p \to b_1 p \to \omega\pi^0 p \to \pi^+\pi^-\pi^0\pi^0 p$
  - $\gamma p \to b_1^-\Delta^{++} \to \omega\pi^-\Delta^{++} \to \pi^+\pi^-\pi^0\pi^-\pi^+ p$

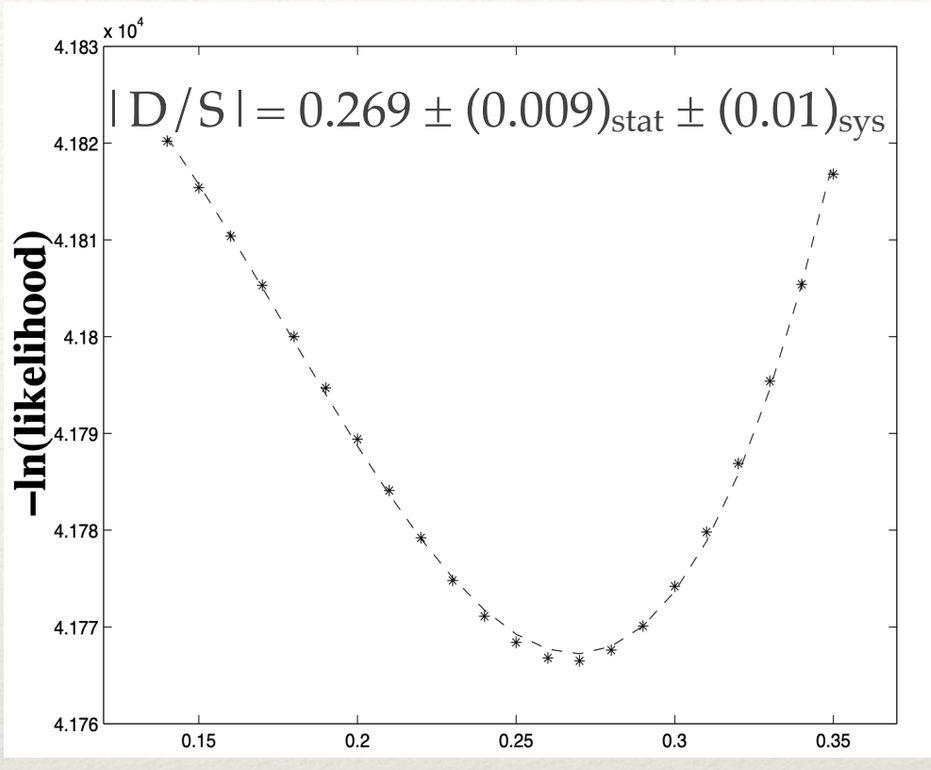




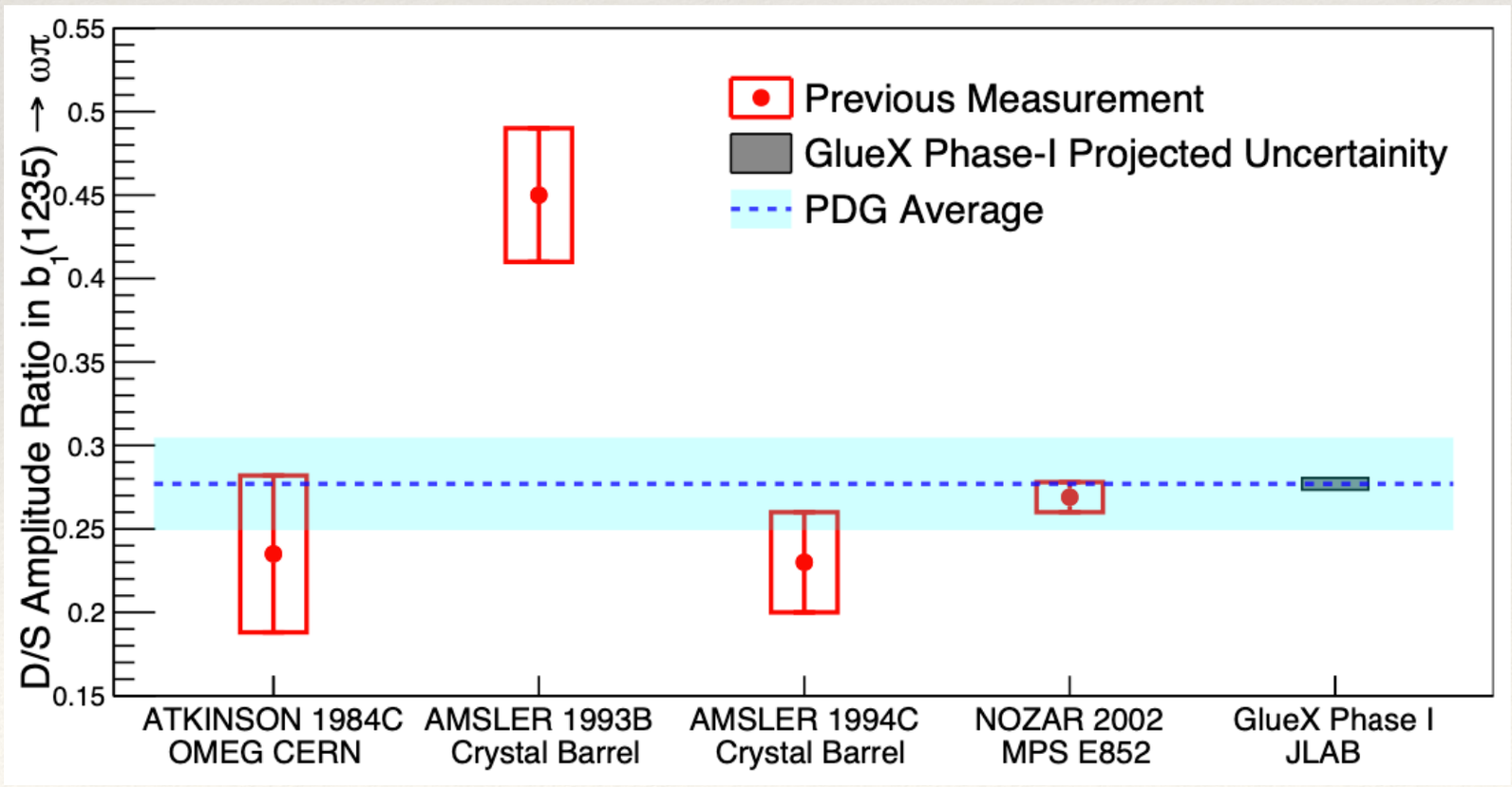
b_1 decay

A. Schertz
K. Suresh

- Start by measuring D/S amplitude ratio
- LQCD prediction by hadspec of
  $|D/S| = 0.27(20)$
  hadspec, Phys. Rev. D 100, 054506 (2019)



E852, Phys. Lett. B 541, 35 (2002)

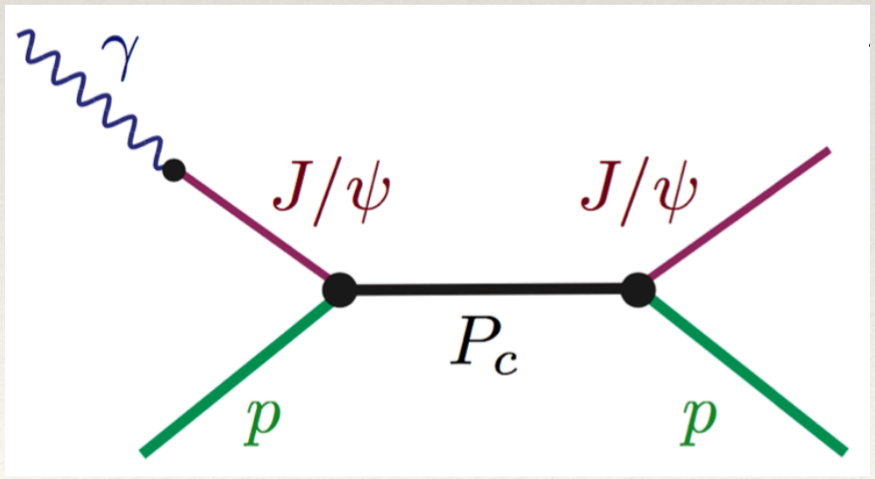


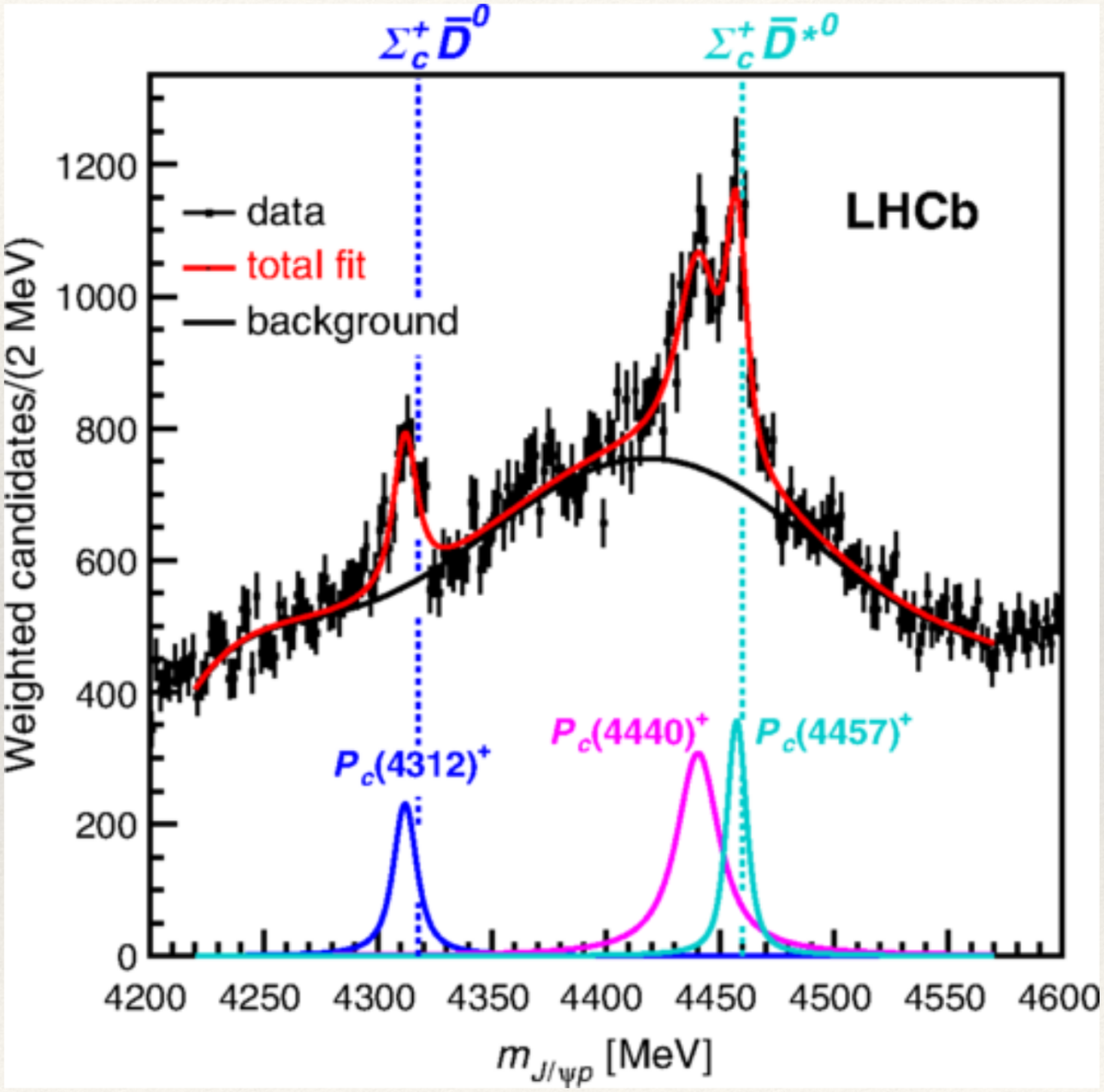
- Good first test of amplitude model
- Can be expanded to all vector-pseudoscalar systems ($\omega\eta$, $\phi\pi$, $\phi\eta$,…)

$J/\psi p$

- LHCb sees pentaquark signal in $\Lambda_b^0 \to J/\psi p K^-$
- GlueX can search for s-channel production

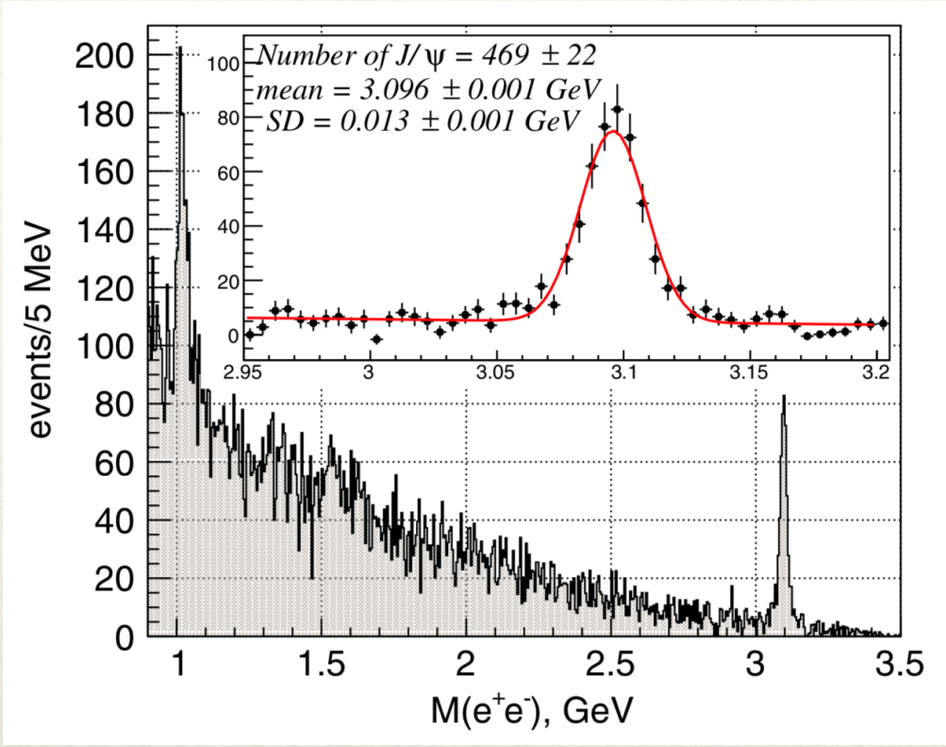
VMD





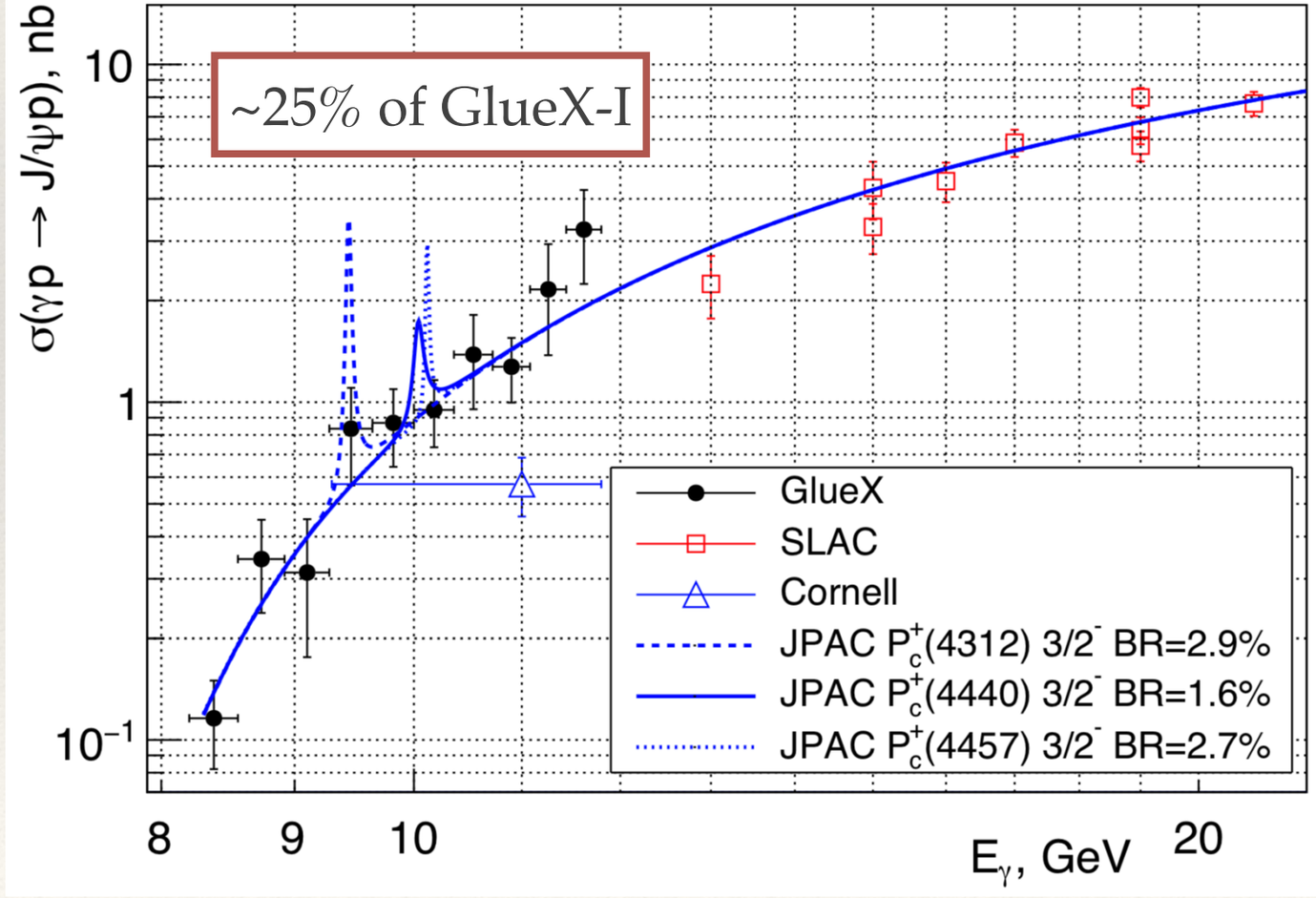
LHCb, Phys. Rev. Lett. ***122****, 222001*

$J/\psi p$



GlueX, Phys. Rev. Lett. **123**, 072001

- measure leptonic decay
  $\gamma p \to J\psi p \to e^+e^-p$
- exclusive reaction
- normalise cross-section to non-resonant e^+e^- production (Bethe-Heitler)



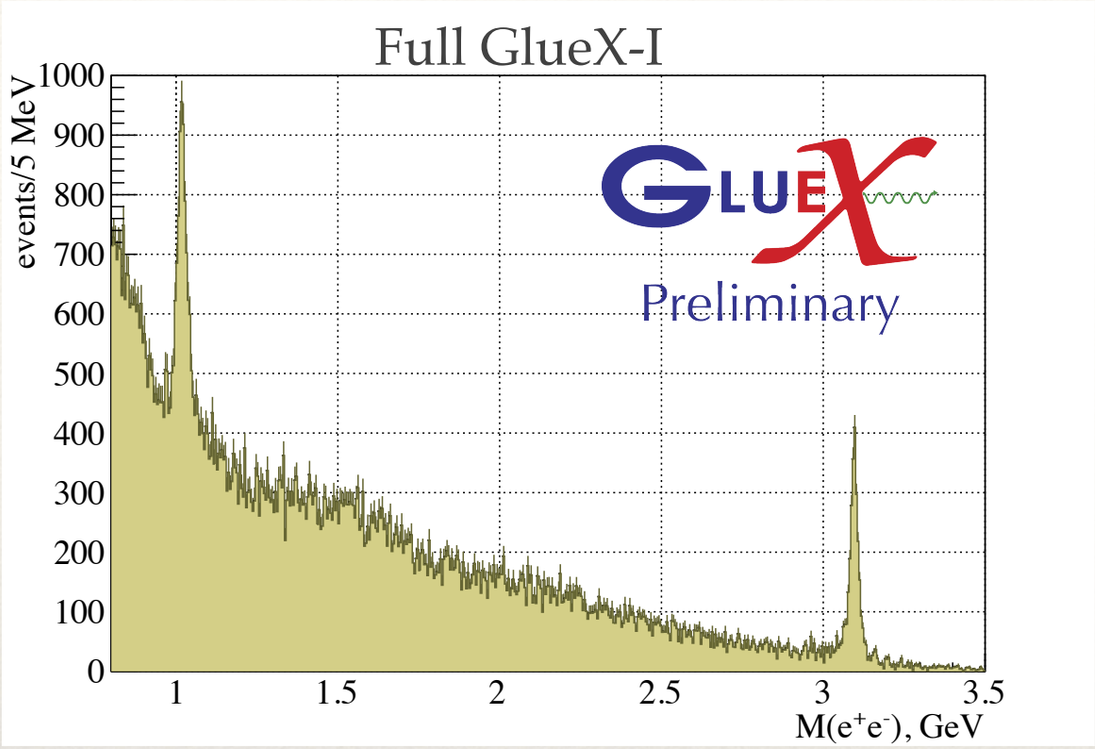
model dependent upper limits at 90% CL

$BR(P_c(4312) \to J/\psi p) < 4.6\,\%$

$BR(P_c(4440) \to J/\psi p) < 2.3\,\%$

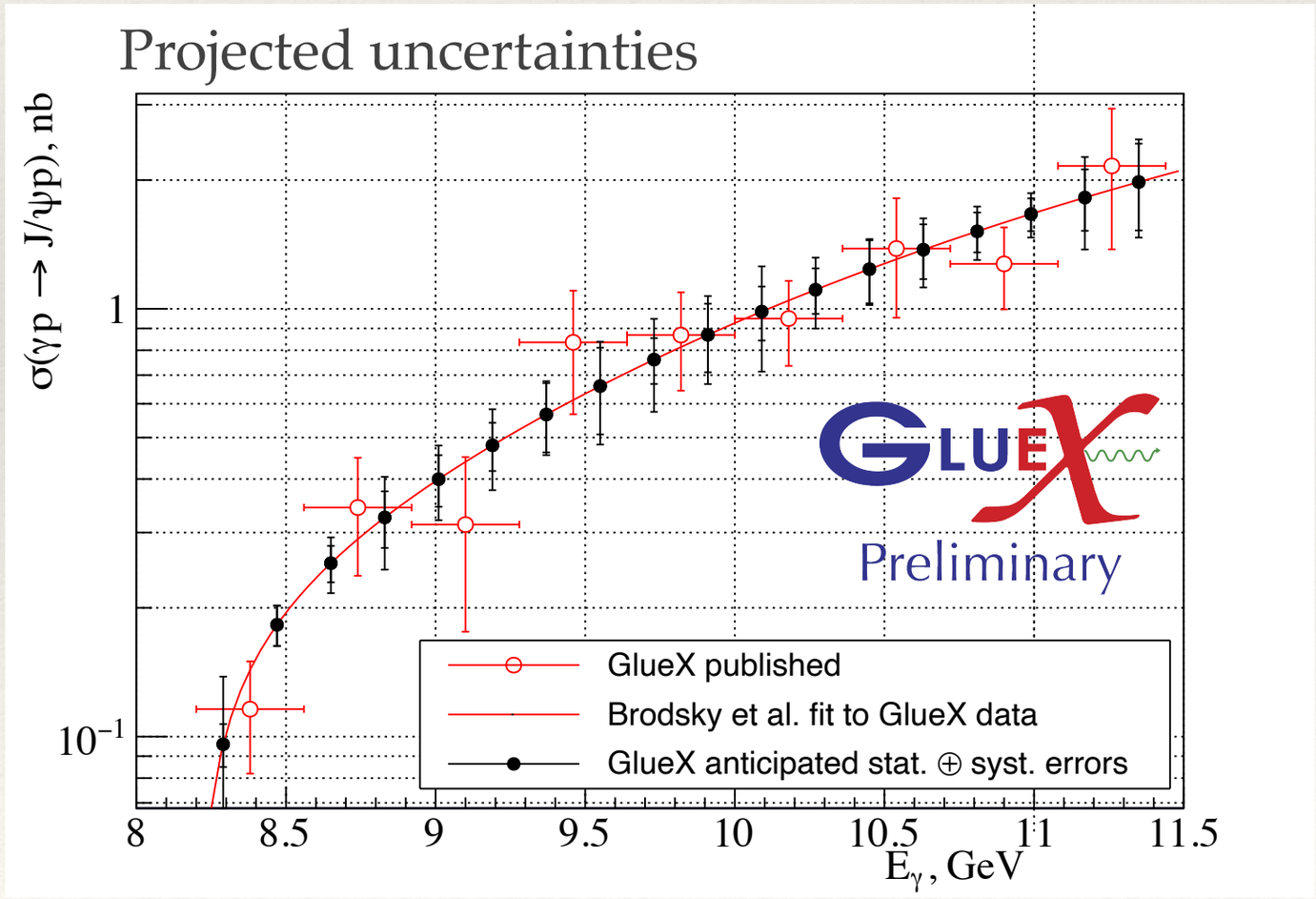
$BR(P_c(4457) \to J/\psi p) < 3.8\,\%$

$J/\psi p$ outlook



- Full GlueX-I data has about 5x more J/Ψ events than published
- Near publication

- Lots of interest in J/Ψ production near threshold from theory beyond spectroscopy



Summary

Acknowledgments:

gluex.org/thanks

- GlueX has a unique data set with unprecedented statistical precision in its energy range
- Start with studying production mechanisms and develop PWA in parallel
- J/Ψ near threshold
- Many more interesting analyses in the pipeline
- Room for other physics:
  - Hyperons, ALPs, …
  - Primex-Eta (I. Jaegle, Mon 12:20)
  - JEF (Z. Papandreou, Wed 16:15)