Peter Hurck for the GlueX collaboration

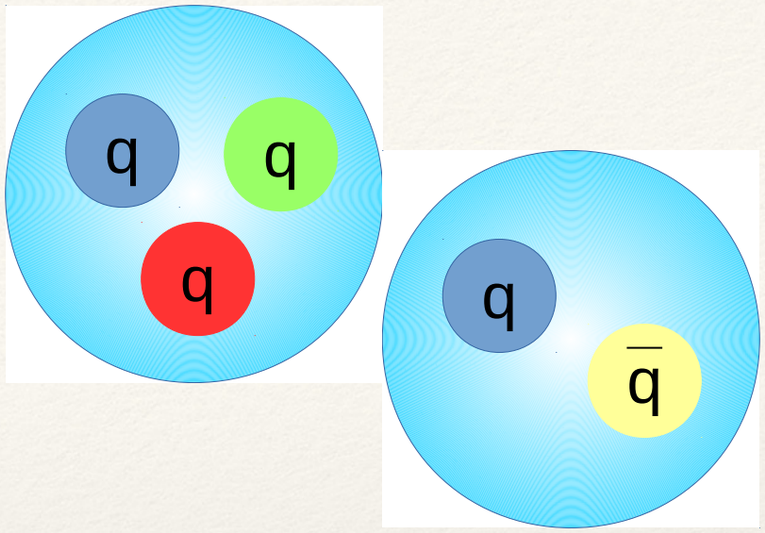
Hadron spectroscopy at GlueX

University of Glasgow

International Workshop on Hadron Structure and Spectroscopy 2023
Czech Technical University, Prague

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

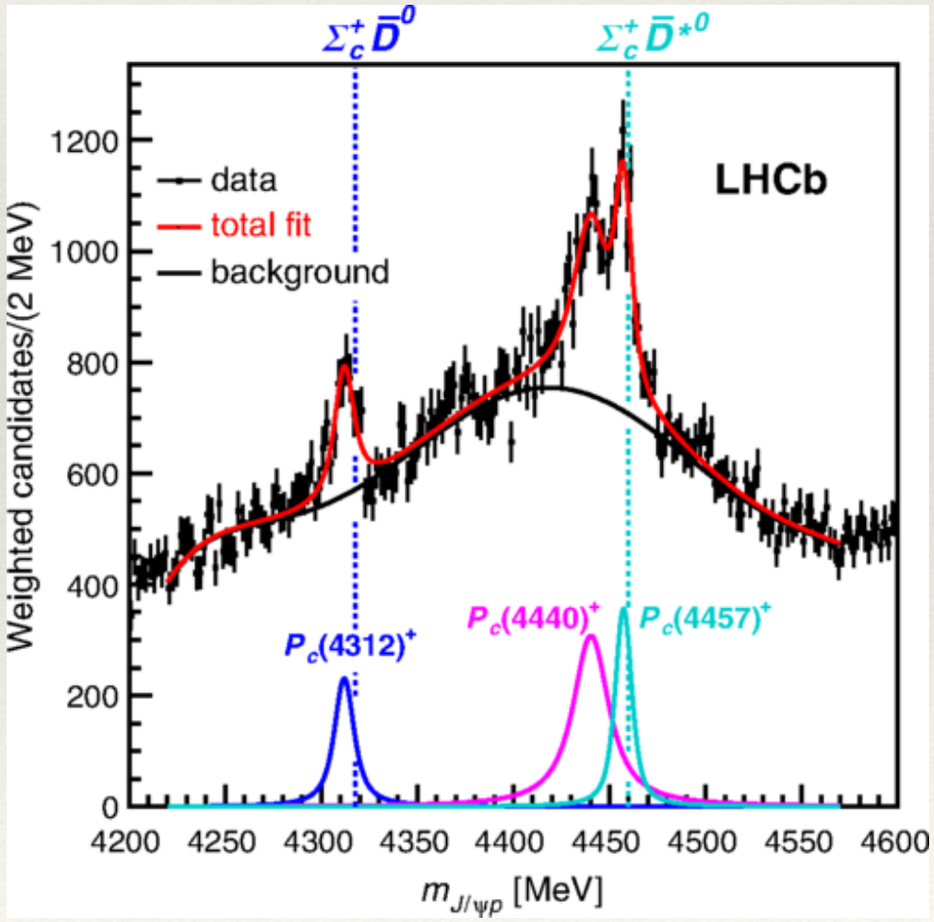
California Institute of Technology, Pasadena, California

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

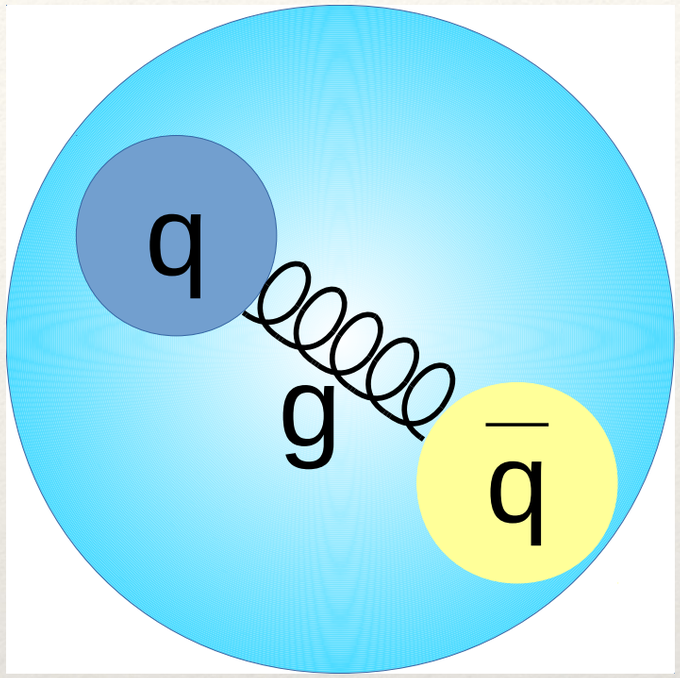
Evidence exists for pentaquark states:



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

Hybrid mesons

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



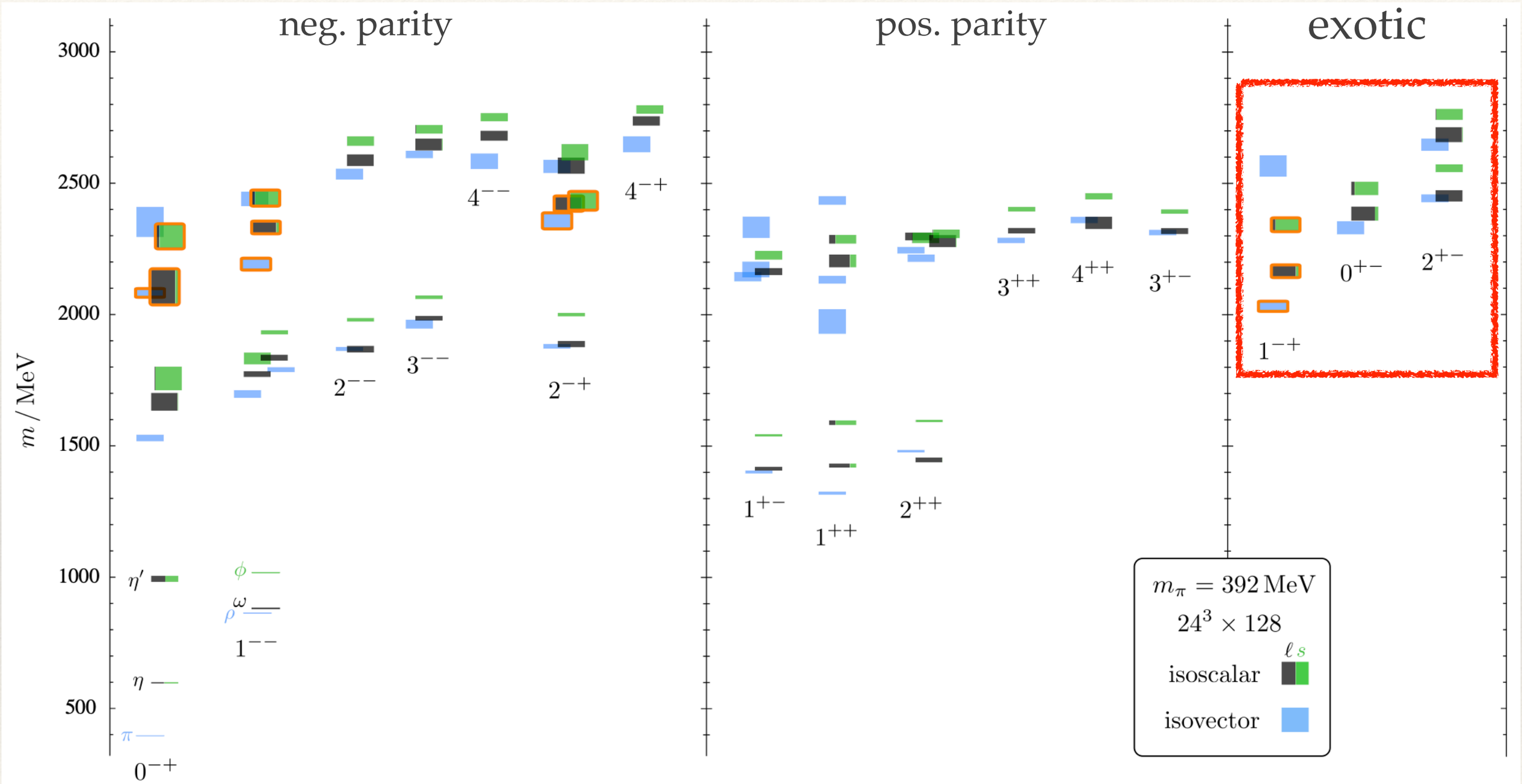
- In quark model:
  $\vec{J} = \vec{L} + \vec{S}$, $P = (-1)^{L+1}$, $C = (-1)^{L+S}$

  → <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

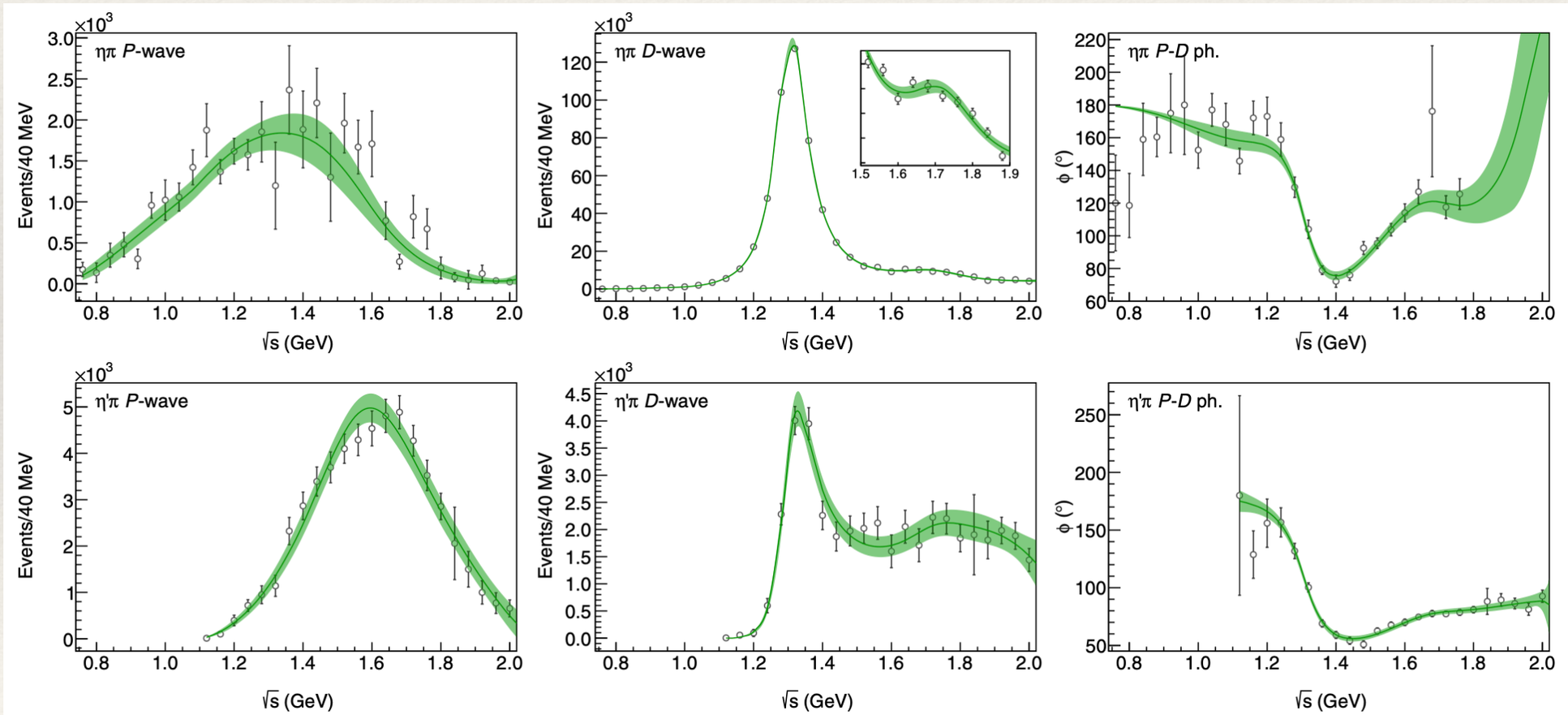
hadspec collaboration



*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



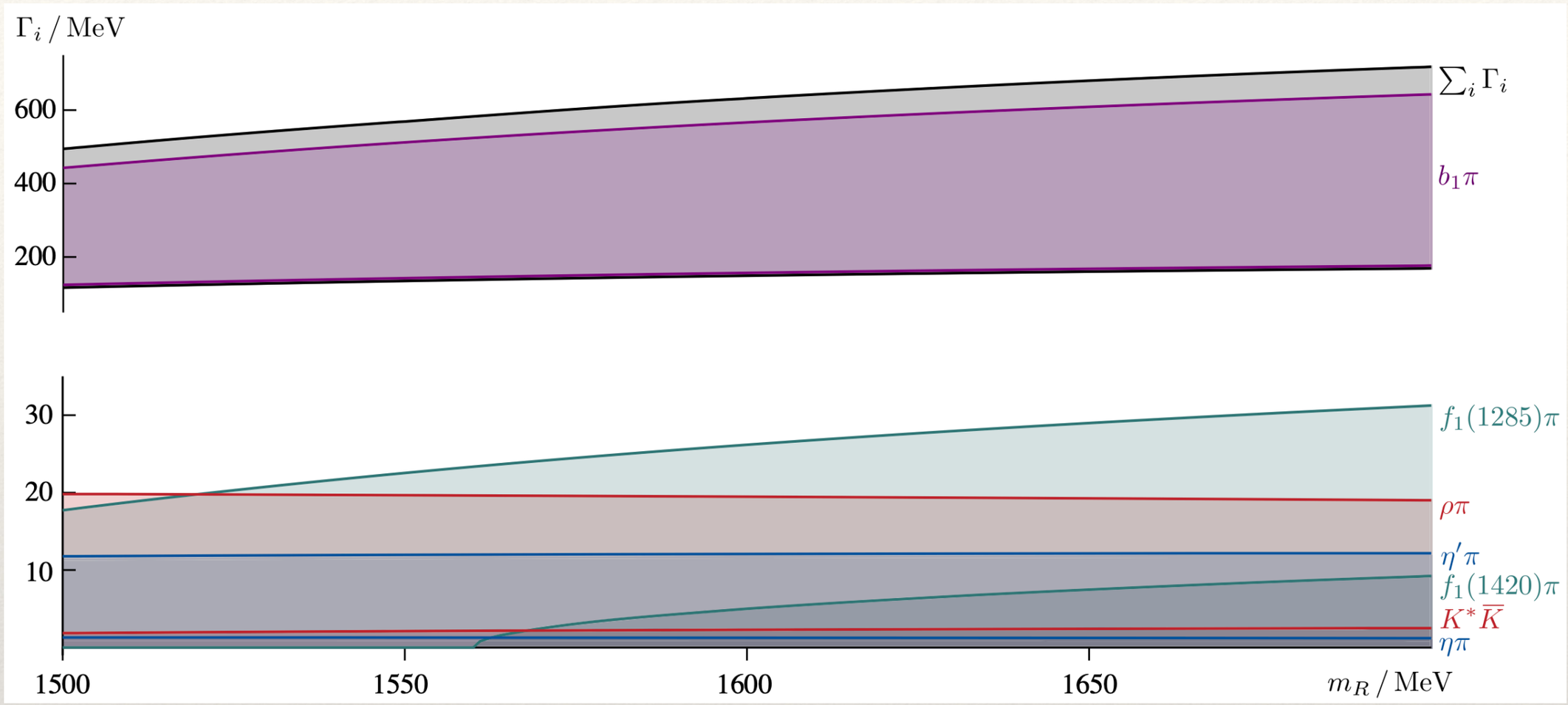
$$\text{mass} = 1564 \pm 24 \pm 86 \text{ MeV} \quad \text{width} = 492 \pm 54 \pm 102 \text{ MeV}$$

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

1^{-+} hybrid from lattice QCD

hadspec collaboration

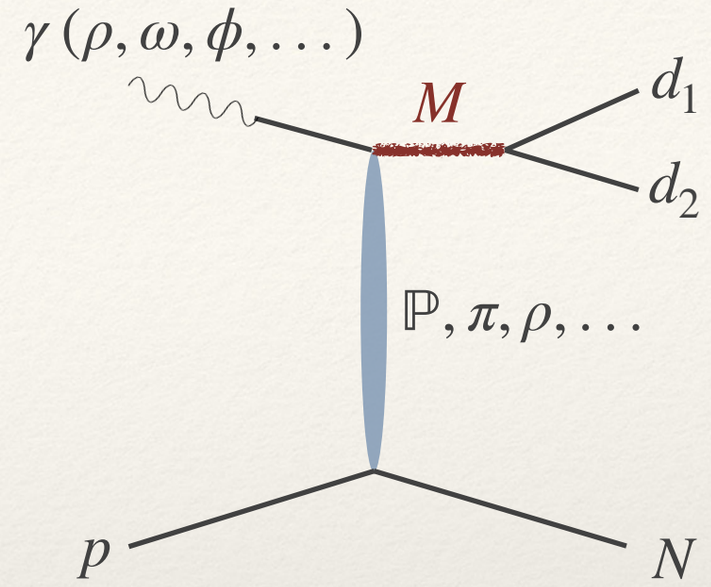
*hadspec, Phys. Rev. D **103**, 054502*



- 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
  - Narrow peaks and pseudo scalars

Towards hybrids at GlueX

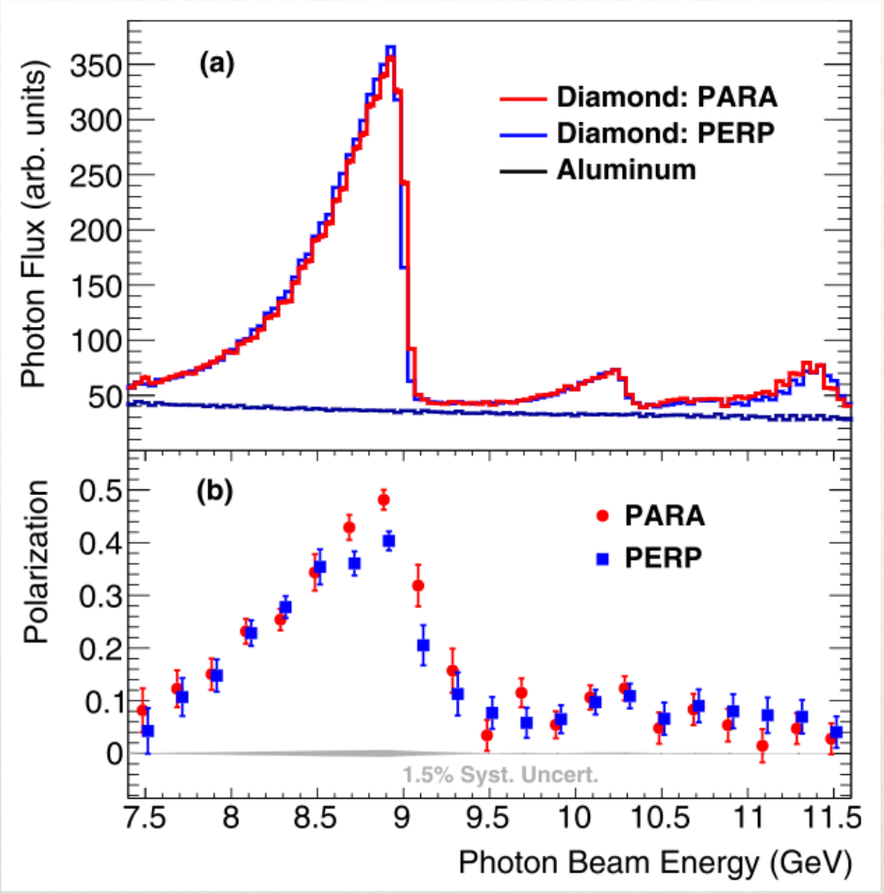
- Photoproduction complementary to pion production
  - Utilize polarization to understand production mechanisms



- Study production mechanisms to inform choice of wave sets for PWA (beam asymmetries, spin density matrix elements)
- Reproduce previous results by COMPASS
  - Focus on $\eta\pi$ and $\eta'\pi$
- Work closely with theory colleagues to tackle model complexity

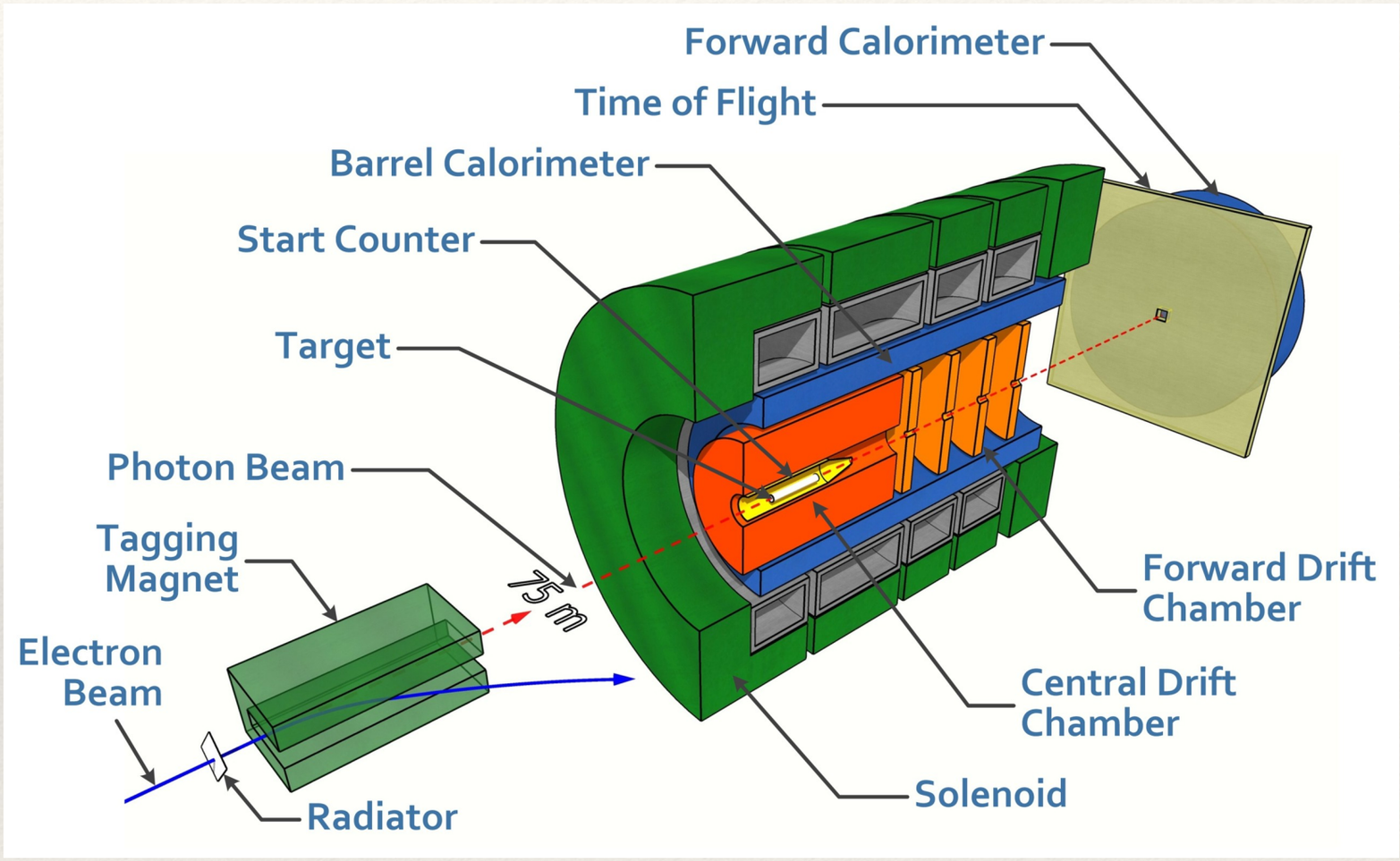
CEBAF at Jefferson Lab

GlueX experiment in Hall D



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

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



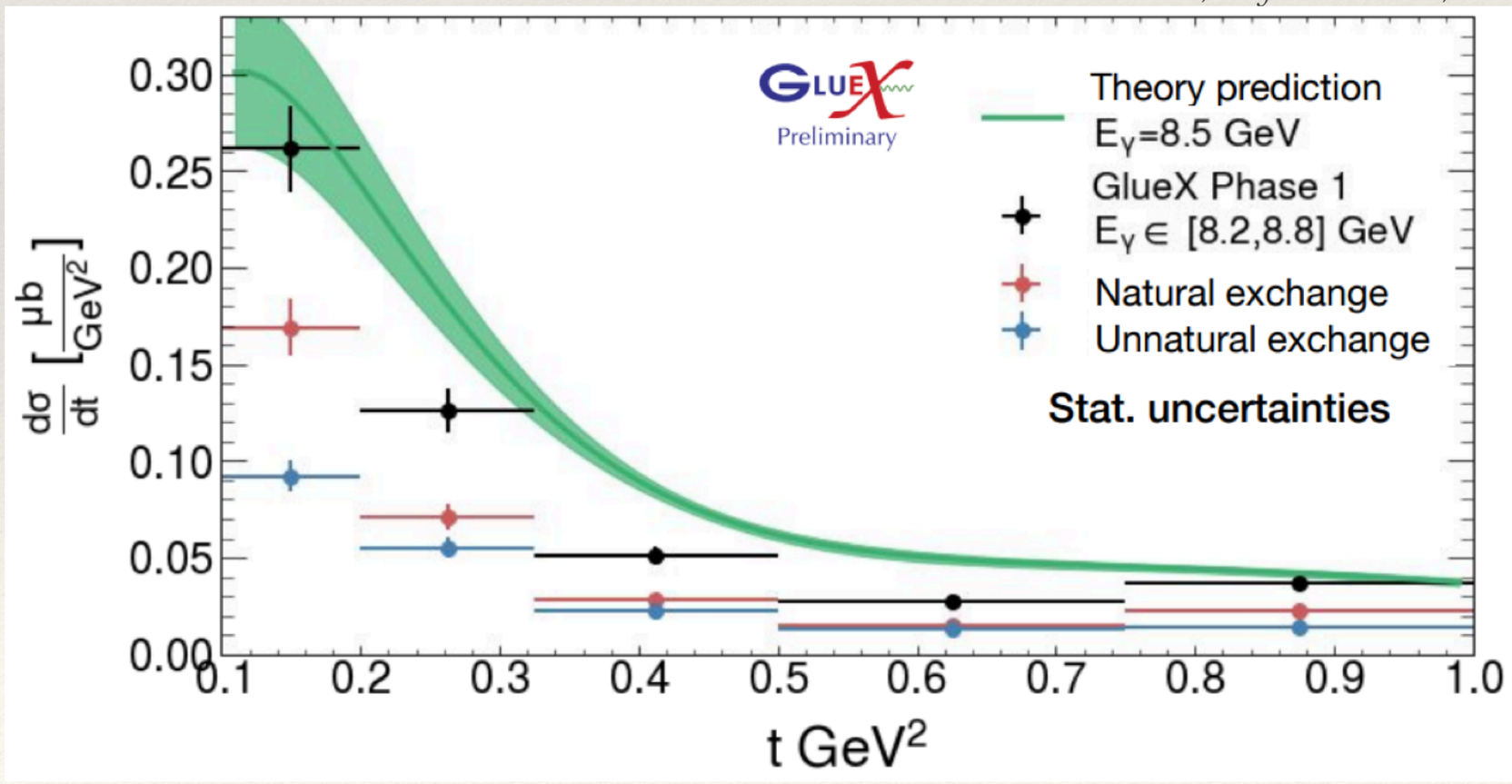
- tag electrons to determine photon energy

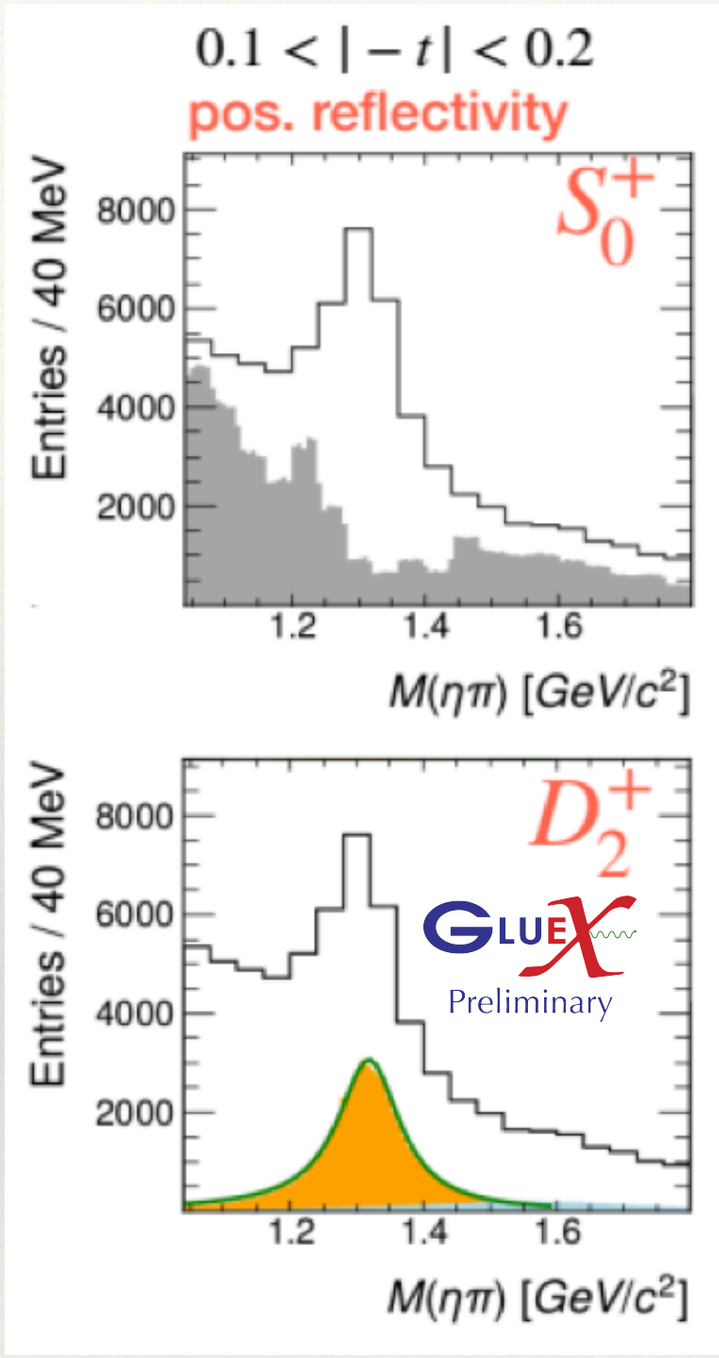
- Acceptance: $\theta_{lab} \approx 1^\circ - 120^\circ$
- Charged particles: $\sigma_p/p \approx 1\% - 3\,\%\,(8\% - 9\,\%$ very-forward high-momentum tracks)
- Photons: $\sigma_E/E = 6\,\%/\sqrt{E} \oplus 2\,\%$

Towards a PWA in $\eta\pi^0$ - $a_2(1320)$ cross-section

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

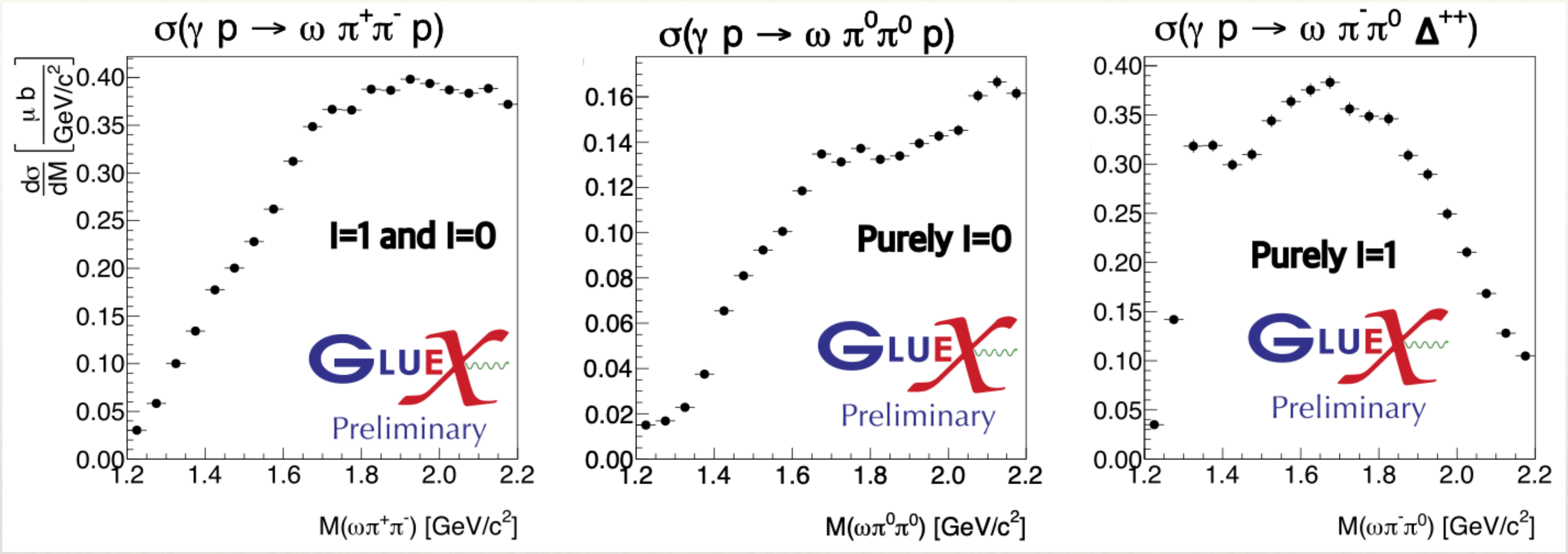
Belle, Phys. Rev. D ***80****, 032001*





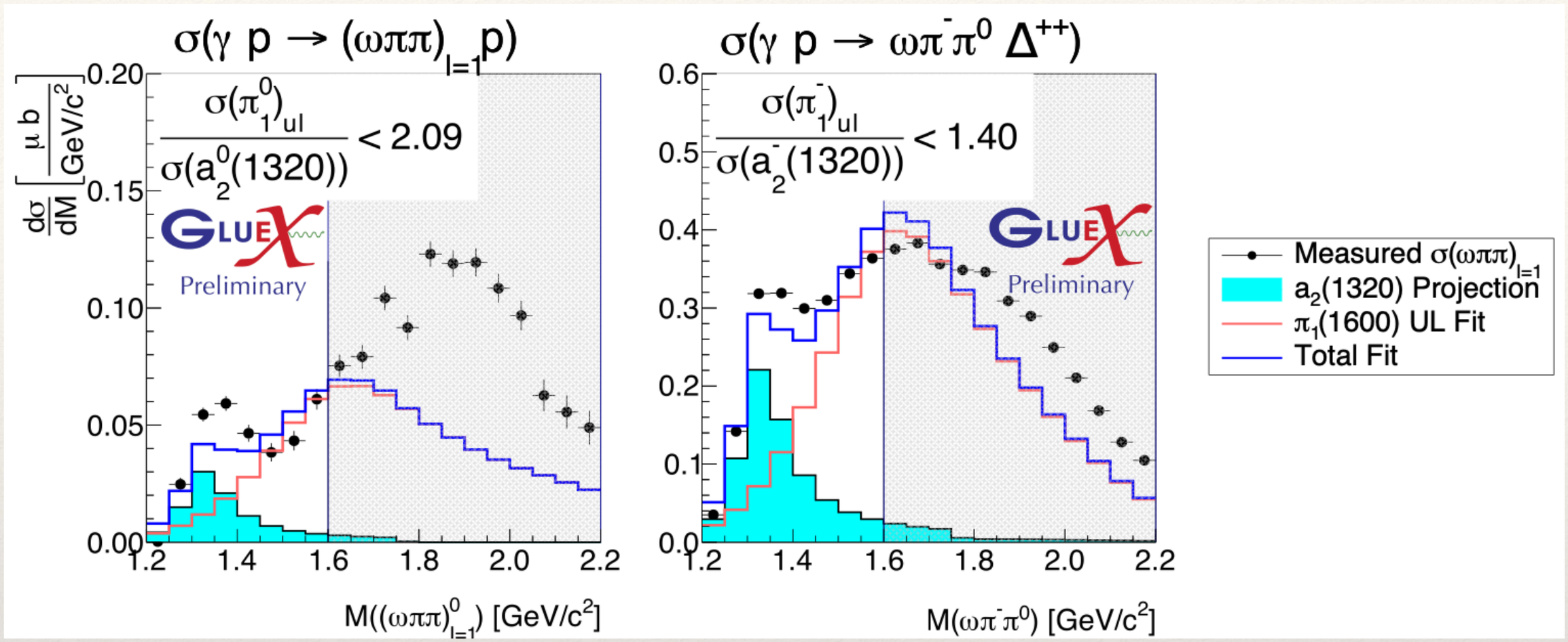
Mixed method: imposing BW shape on a_2 improves fit

$\pi_1(1600)$ upper limits



- Set upper limit on $\pi_1(1600)$ using isospin separation, assume no $I = 2$
  - $\sigma((\omega\pi\pi)^0)_{I=1} = \sigma(\omega\pi^+\pi^-) - 2\sigma(\omega\pi^0\pi^0)$
  - $\sigma((\omega\pi\pi)^-)_{I=1} = \sigma(\omega\pi^-\pi^0)$
- Fit $\sigma(\omega\pi\pi)_{I=1}$ using known shapes for a_2 (PDG) and π_1 (JPAC)

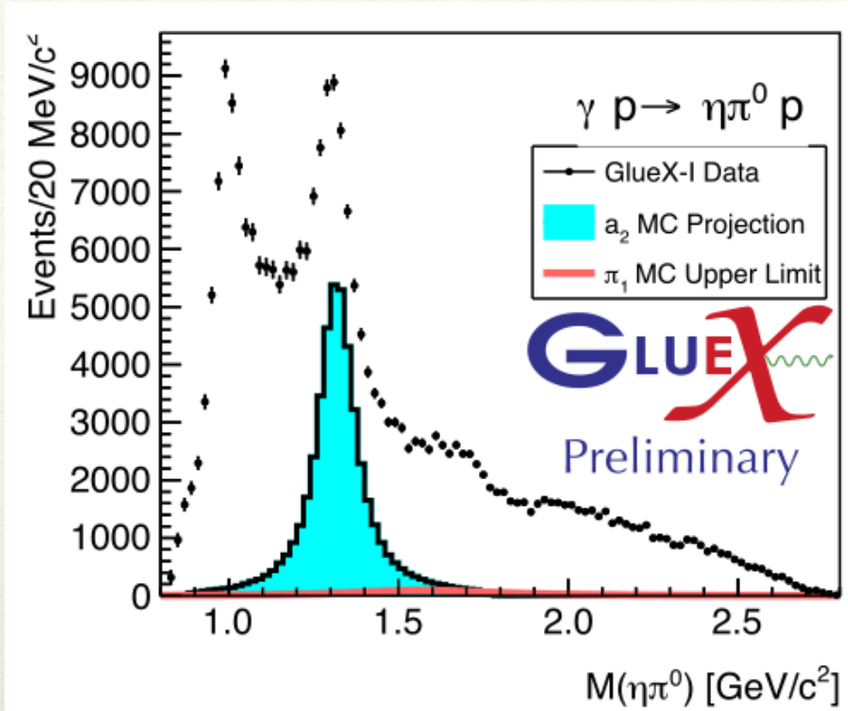
$\pi_1(1600)$ upper limits

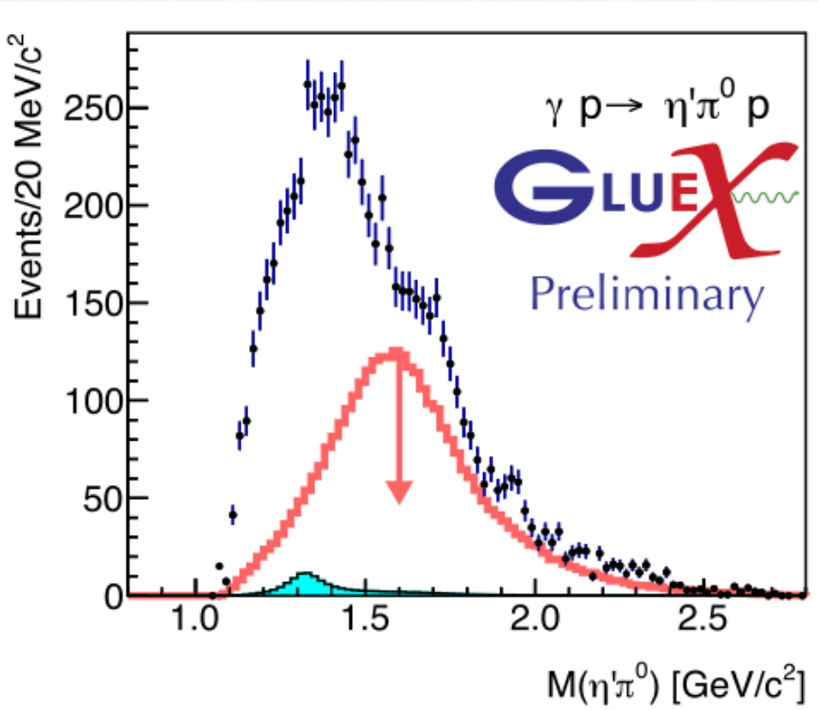


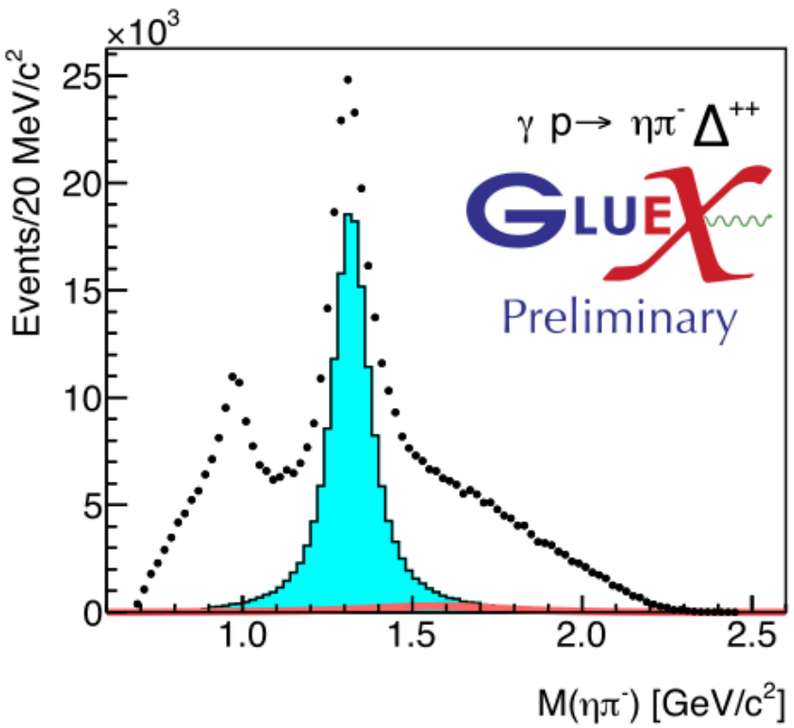
- Fit $M(\omega\pi\pi)_{I=1} < 1.6\,\mathrm{GeV}/c^2$
- Fix a_2 size to measured cross-section adjusted with known BR
- π_1 BR from lattice
- Only free parameter is π_1 normalisation!
- π_1 upper limits similar in size to a_2 cross-sections

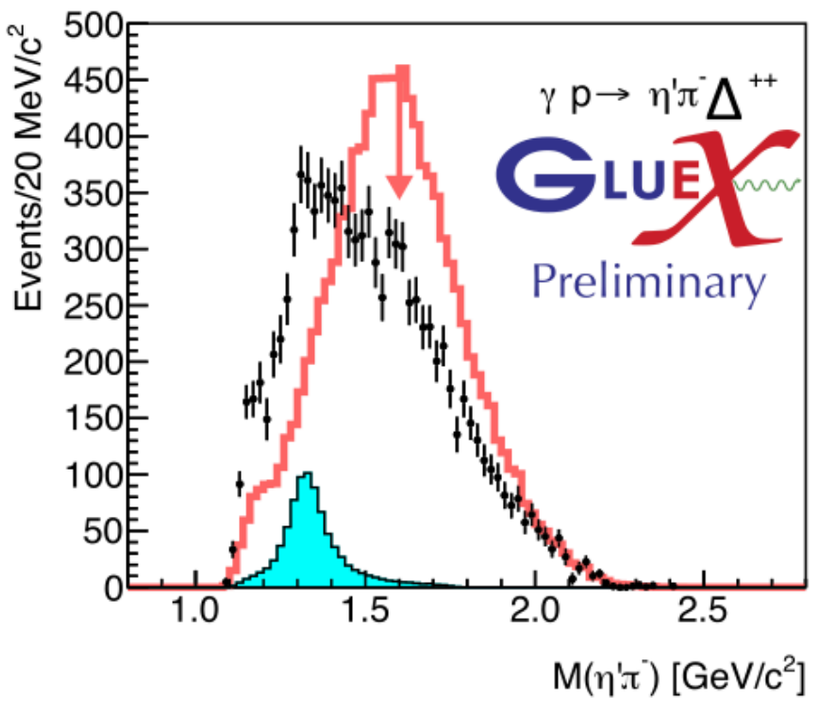
π_1 projections to $\eta\pi$ and $\eta'\pi$

- $\pi_1 \to \eta\pi$ expected to be very small
- $\pi_1 \to \eta'\pi$ potentially dominating the spectrum
- First limit on size of photoproduction cross-sections
- Guidance for amplitude analysis



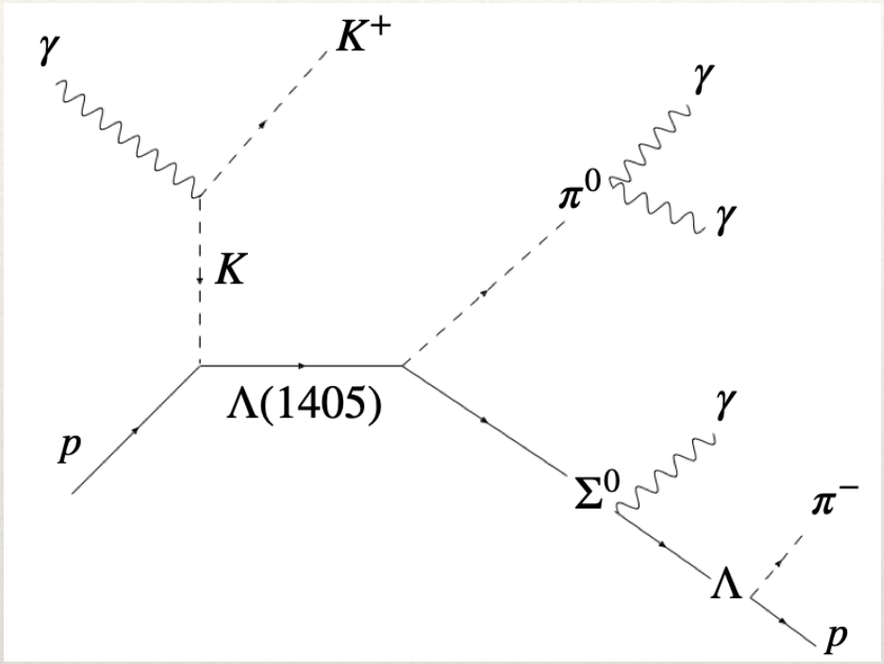






$\Lambda(1405)$ line shape measurement

N. Wickramaarachchi

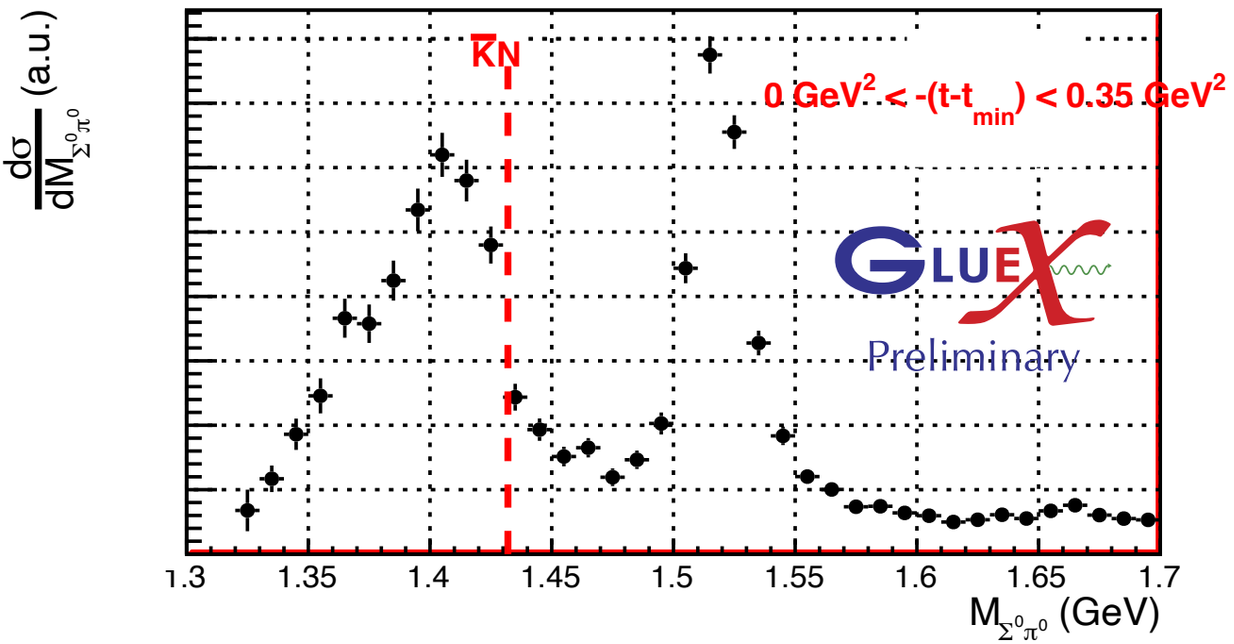


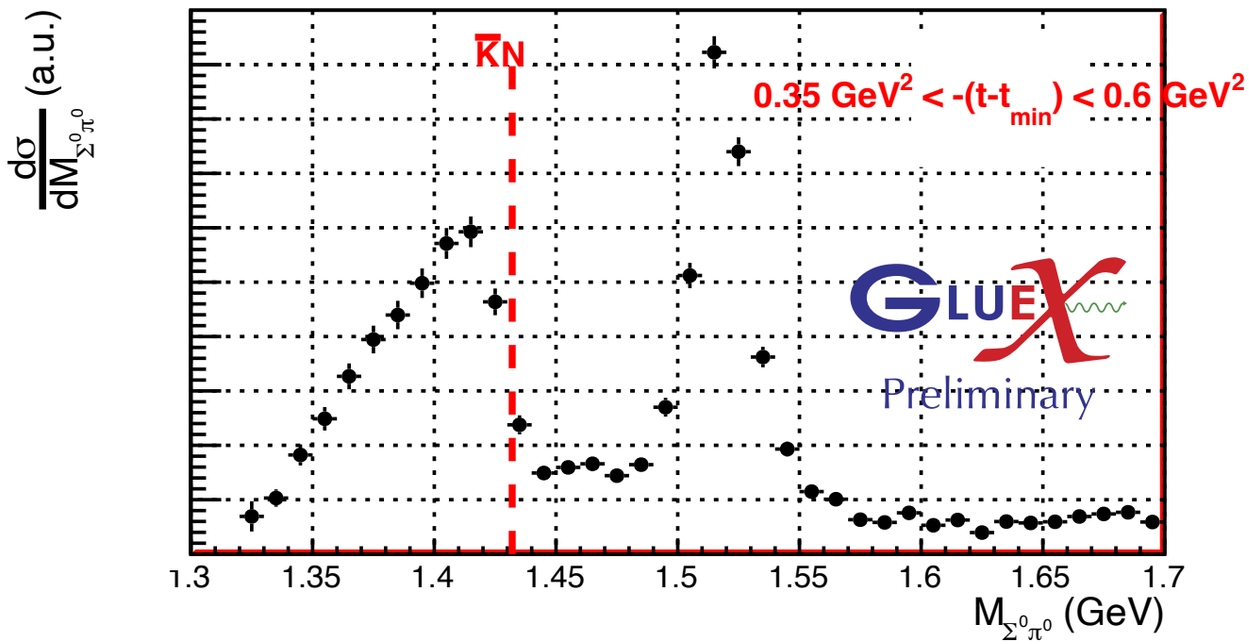
$\Lambda(1405) \to \Sigma^0\pi^0$ $(I = 0)$ is free from $\Sigma(1385)$ background

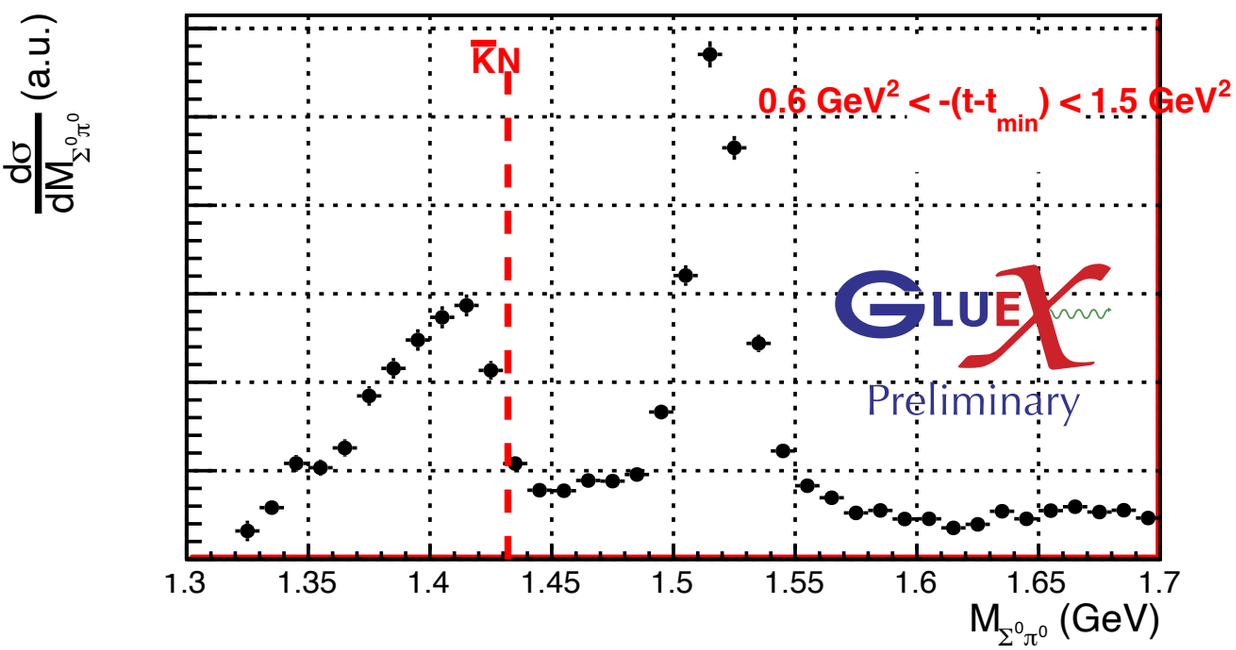
- Excited Λ with $J^P = \frac{1}{2}^-$
- $\Lambda(1405) \to \Sigma\pi$
- Previous measurements (e.g. COSY-Jülich or CLAS) show very clear non-Breit-Wigner line shape
- Interpretation under active investigation
- Many theory models find two-pole structure:
  not just one state
- Recent PDG addition: ** $\Lambda(1380)$

Λ(1405) line shape measurement

N. Wickramaarachchi
(HYP2022)



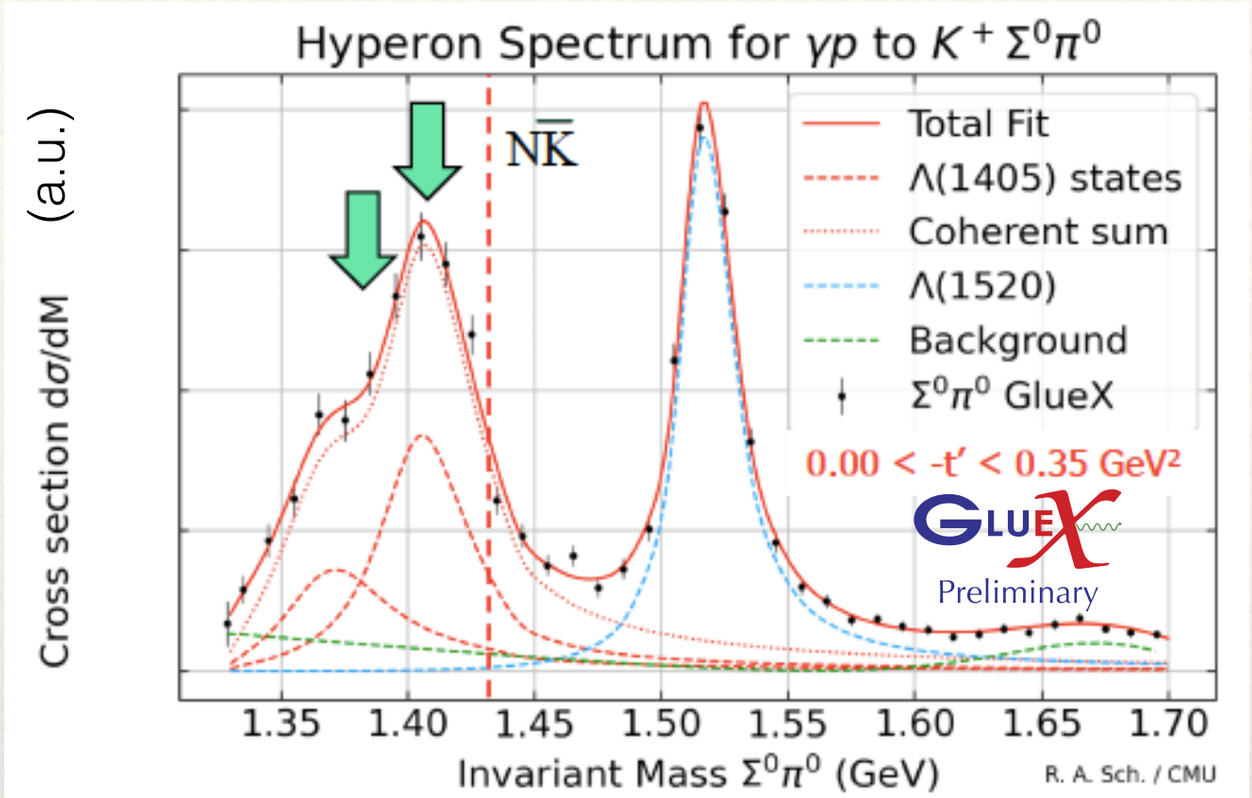


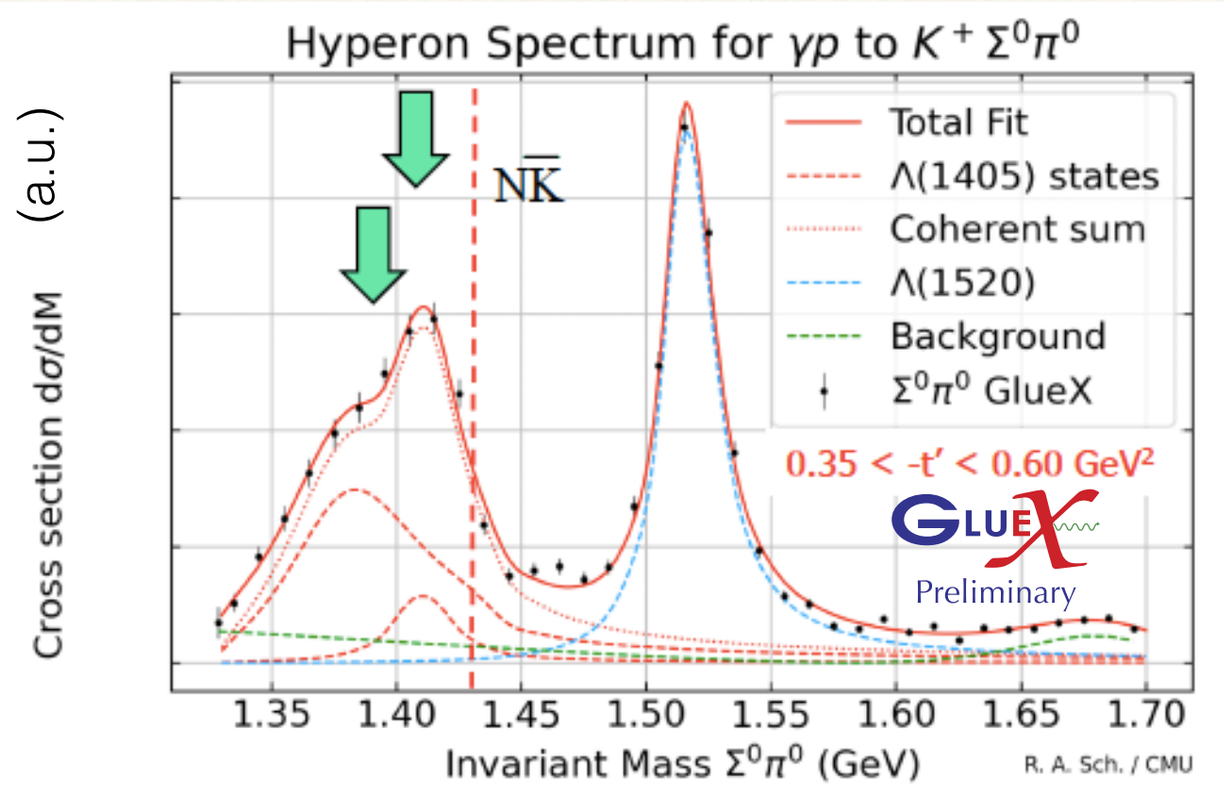


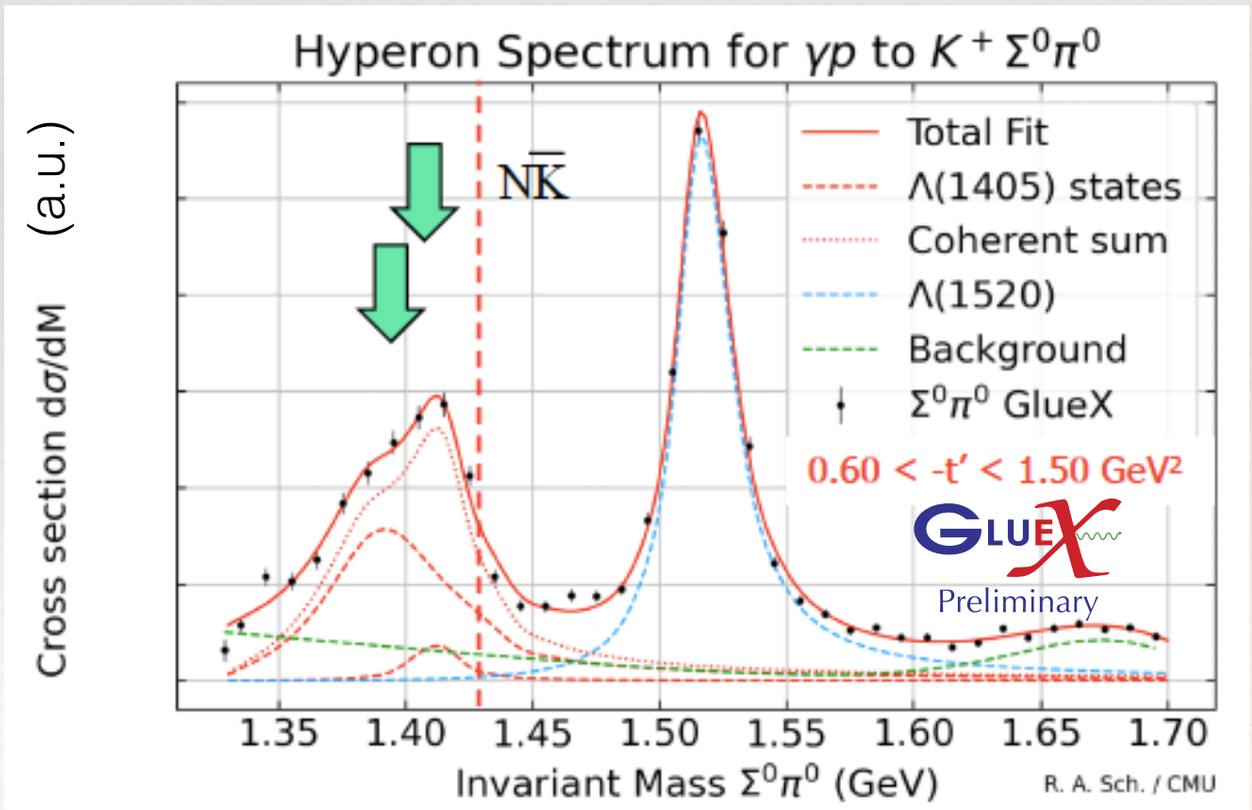
- Λ(1405) t-dependent line shape?
- Could support two-pole structure

Λ(1405) line shape measurement

N. Wickramaarachchi
(HYP2022)





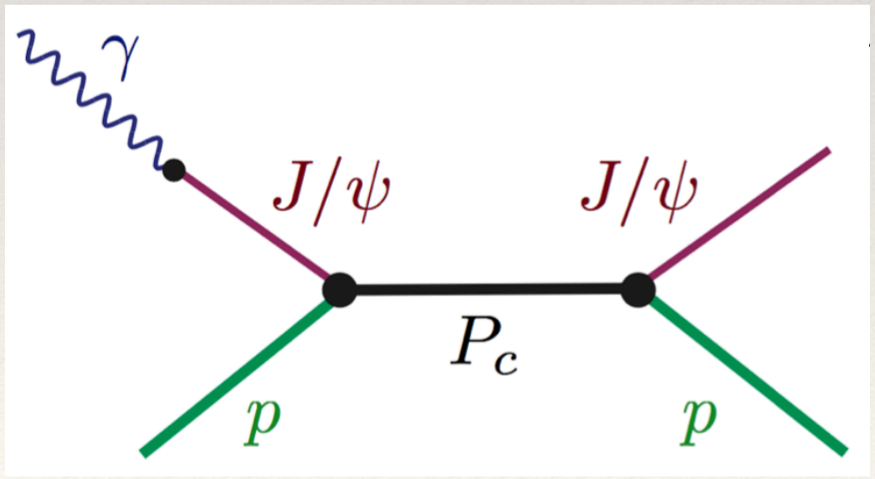


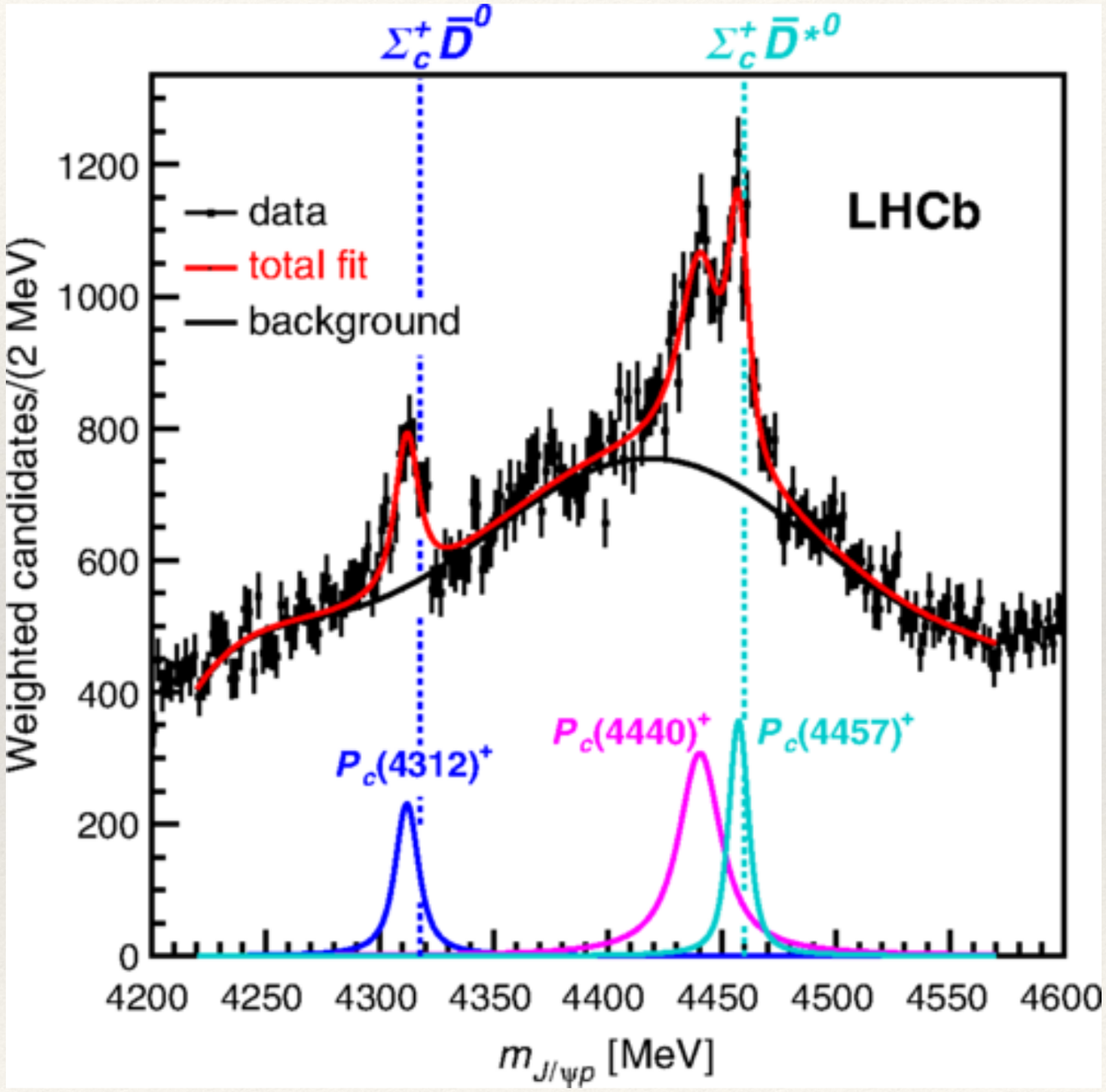
- Fit of two coherent Flatté amplitudes, incoherent Λ(1520) and backgrounds
- Preliminary fit results support two-pole structure

$J/\psi p$

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

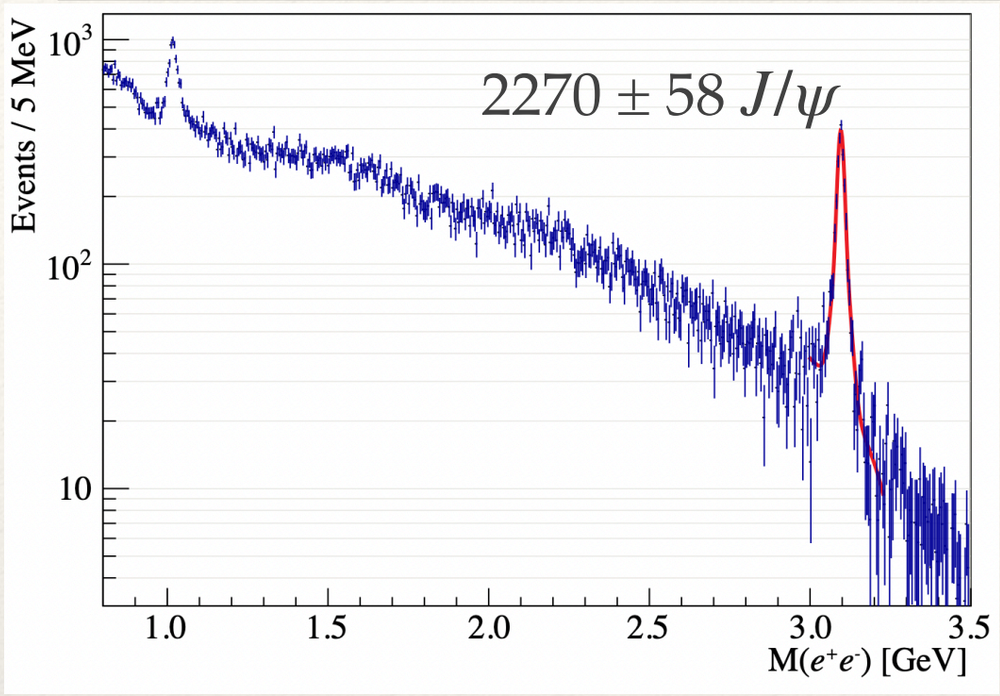
VMD





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

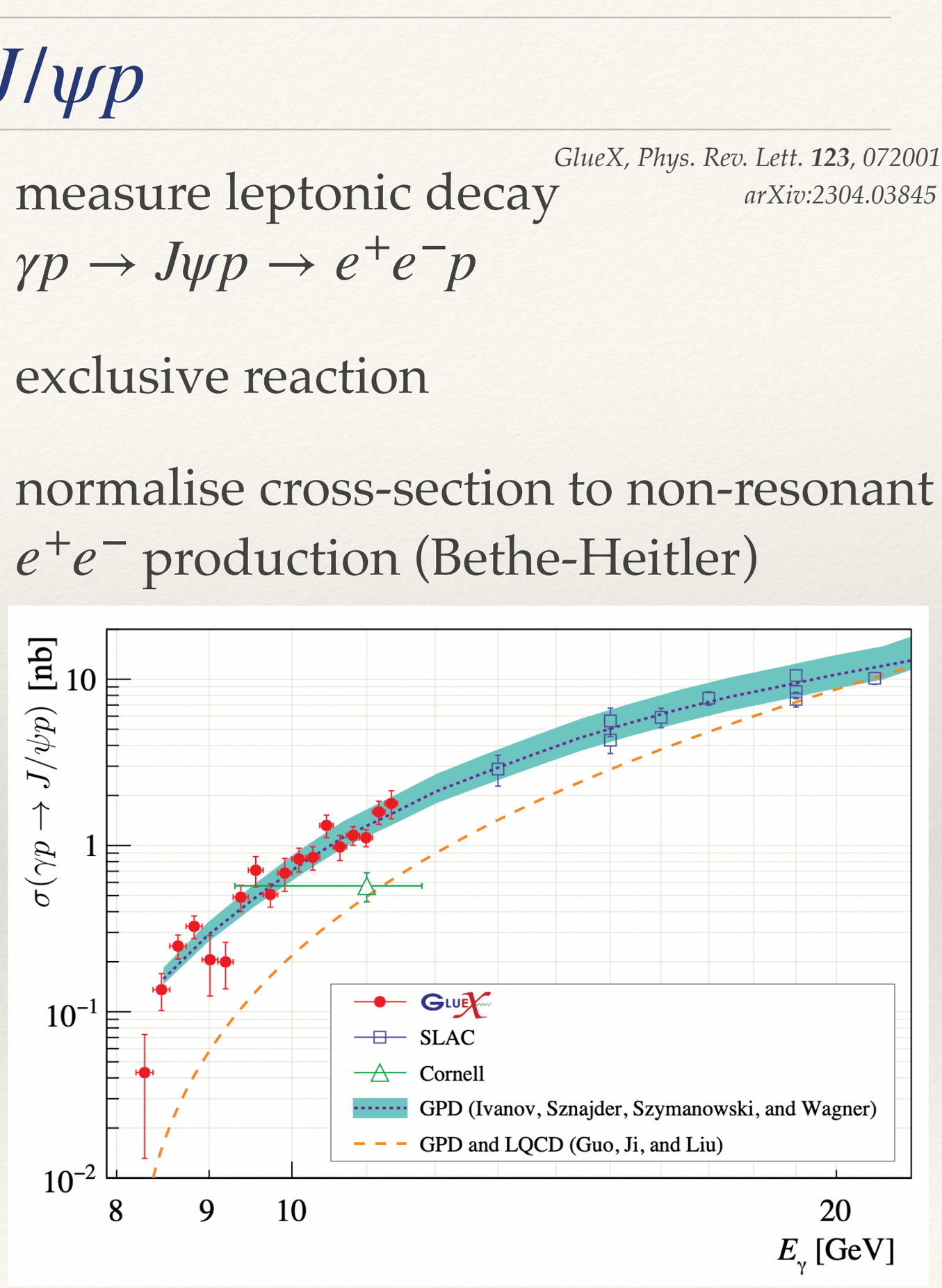
$J/\psi p$



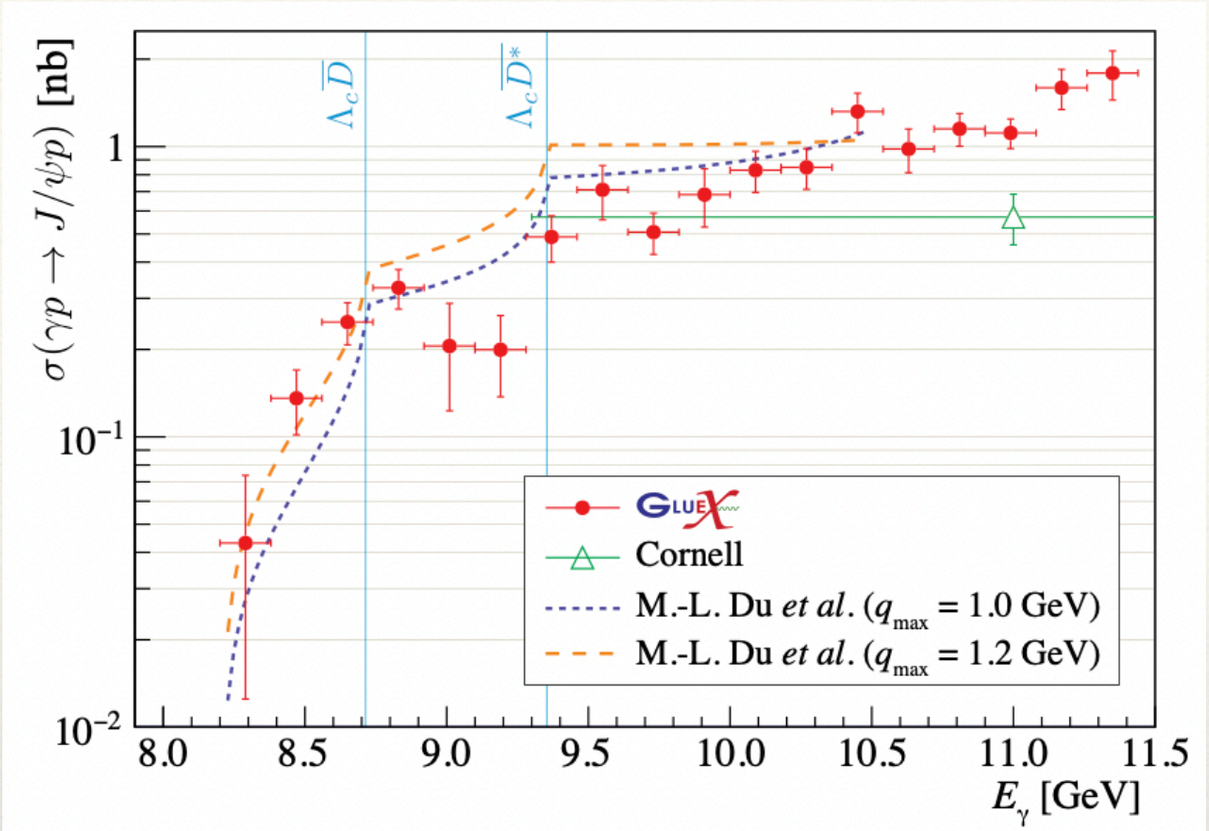
GlueX, Phys. Rev. Lett. ***123****, 072001*
arXiv:2304.03845

- 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)

- Updated measurement:
  4x more stats
- Dip at ~9 GeV has 2.6σ significance
  (with look-elsewhere-effect 1.4σ)
- Improved model dependent P_c
  upper limits by ~30%
  previous:
  $BR(P_c(4312) \to J/\psi p) < 4.6\,\%$
  $BR(P_c(4440) \to J/\psi p) < 2.3\,\%$
  $BR(P_c(4457) \to J/\psi p) < 3.8\,\%$



$J/\psi p$

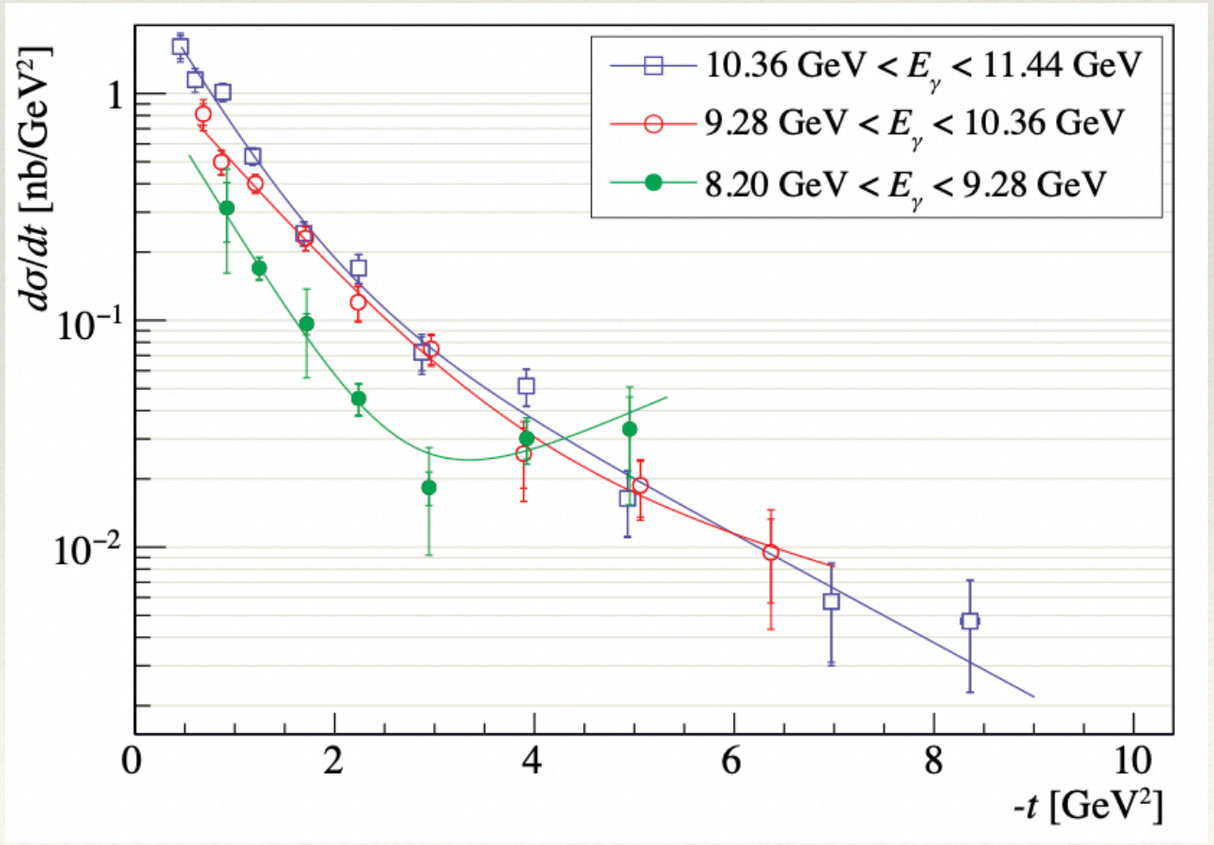


M.-L. Du et al. Deciphering the mechanism of near-threshold J/ψ photoproduction. Eur. Phys. J. C 80, 1053 (2020)

- Flattening of $d\sigma/dt$ in lowest energy range
- Indication of s- or u-channel contribution?
- Need better understanding of production mechanism

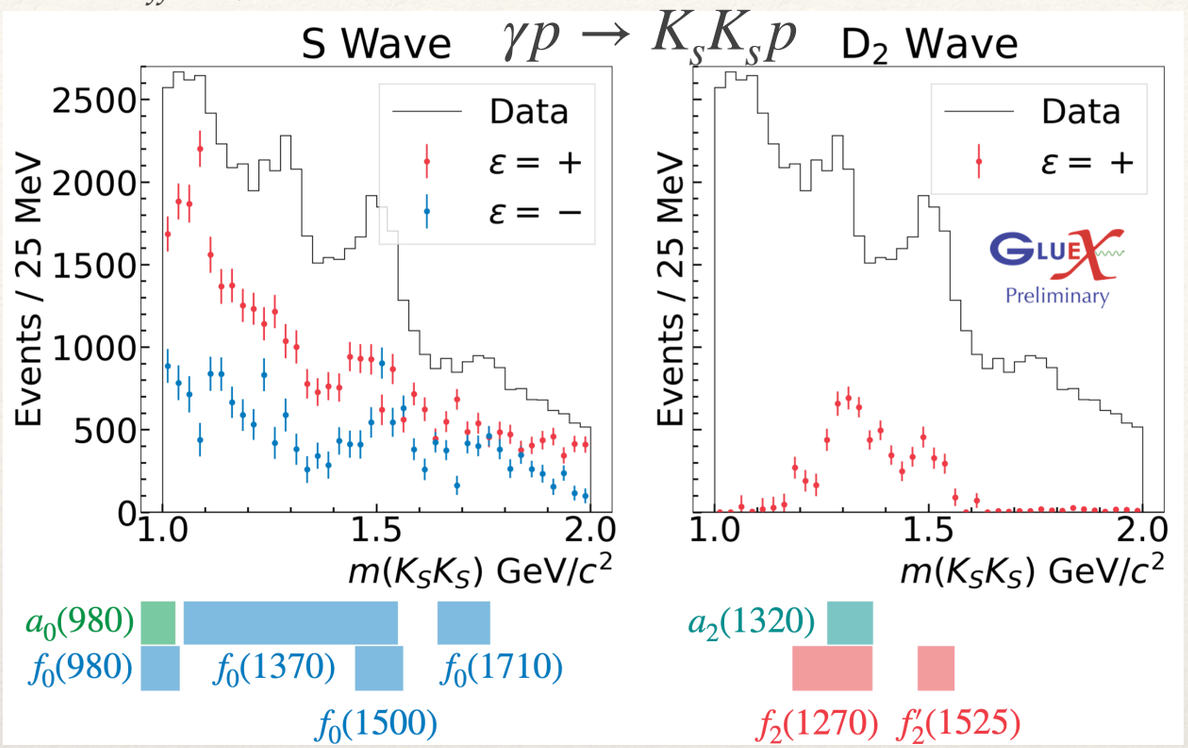
GlueX, Phys. Rev. Lett. ***123****, 072001*
arXiv:2304.03845

- Du et al. propose production through $\Lambda_c \bar{D}$ and $\Lambda_c \bar{D}^*$
- Generate cusp structures

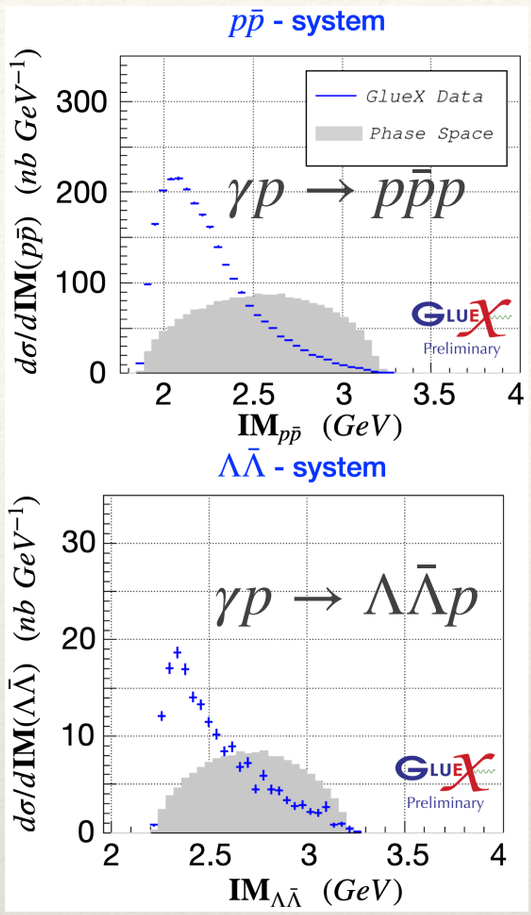


Further analyses

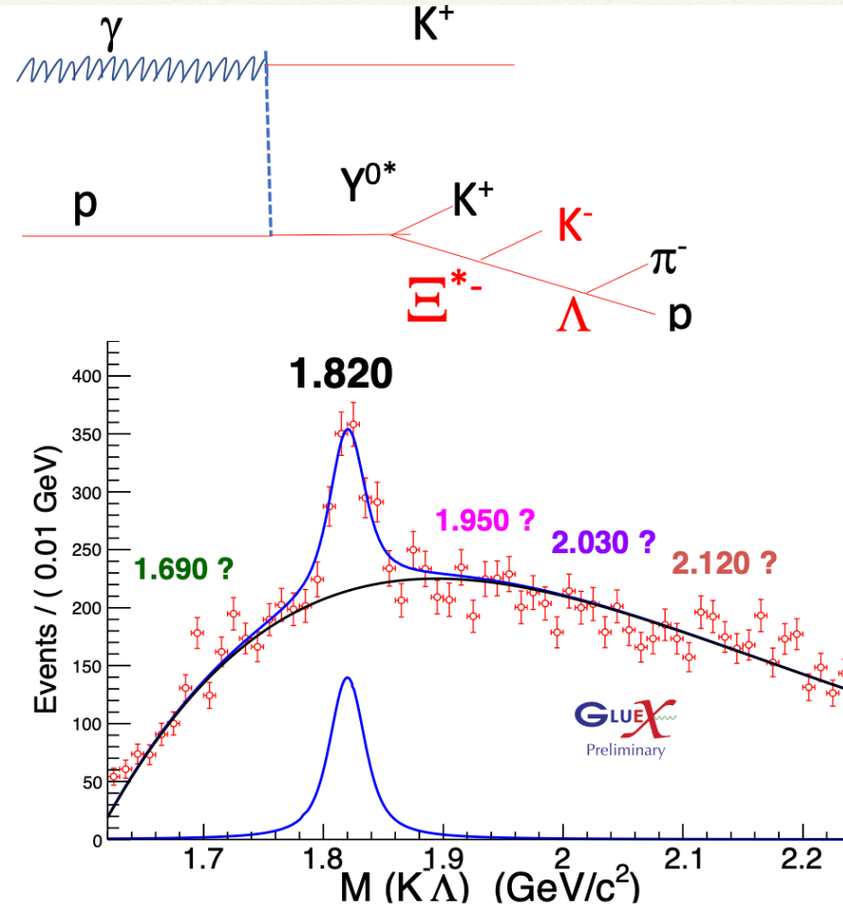
N. D. Hoffman, APS 4/2023



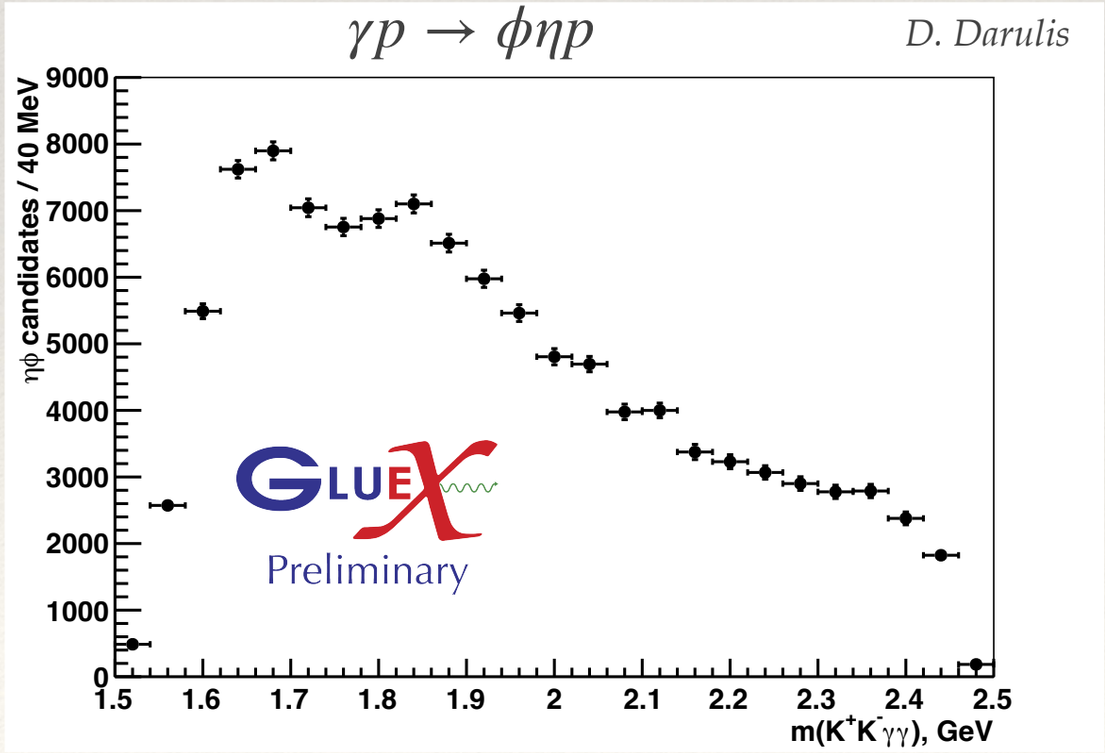
Hao Li, APS-DNP 2021



C. Akondi, GHP 2023



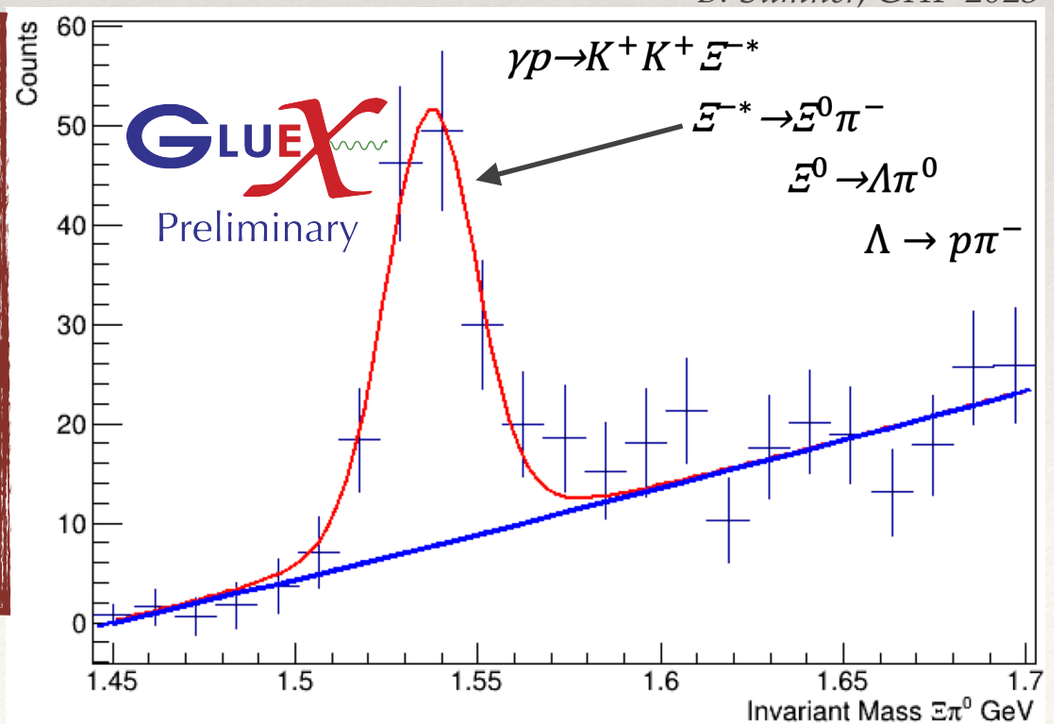
D. Darulis



A. Schertz, HADRON 2023

Just a glimpse of our ongoing physics program

B. Sumner, GHP 2023



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
- $\pi_1(1600)$ upper limits, guide for future searches
- J/Ψ near threshold extends understanding of production mechanism
- Many more interesting analyses in the pipeline and room for other physics:
  - Strangeonium, cascades, ALPs, …
- Future and outlook:
  - Ongoing GlueX-II
  - HI-GlueX, GlueX-24 (?)