Light Exotic Hadrons at GlueX

as part of the

Snowmass planning exercise for HEP

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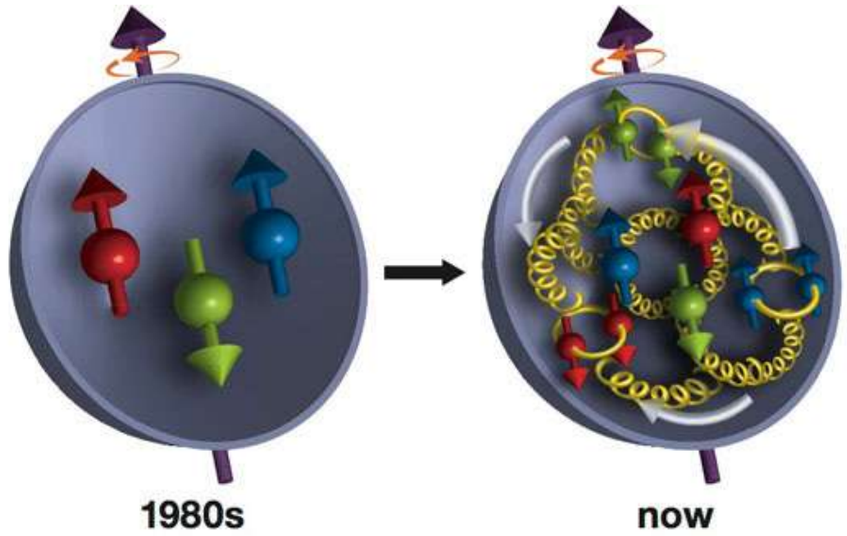
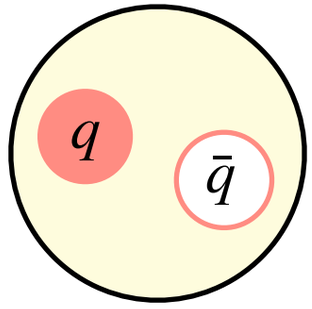
on behalf of

The GlueX Collaboration

Motivation: Mysterious Gluons

- Hadrons (and their properties) emerge from interaction of quarks and gluons as described by QCD.
- Role of gluons?
  - mass of hadrons
  - spin?
  - *allowable quantum numbers?*
- Key thing to search for: mesons with quantum numbers forbidden by $q\bar{q}$ configuration
- The "1980s picture" seems to work really well for describing the spectrum of mesons.
  - Why? Are there exceptions?





color singlet
quark anti-quark

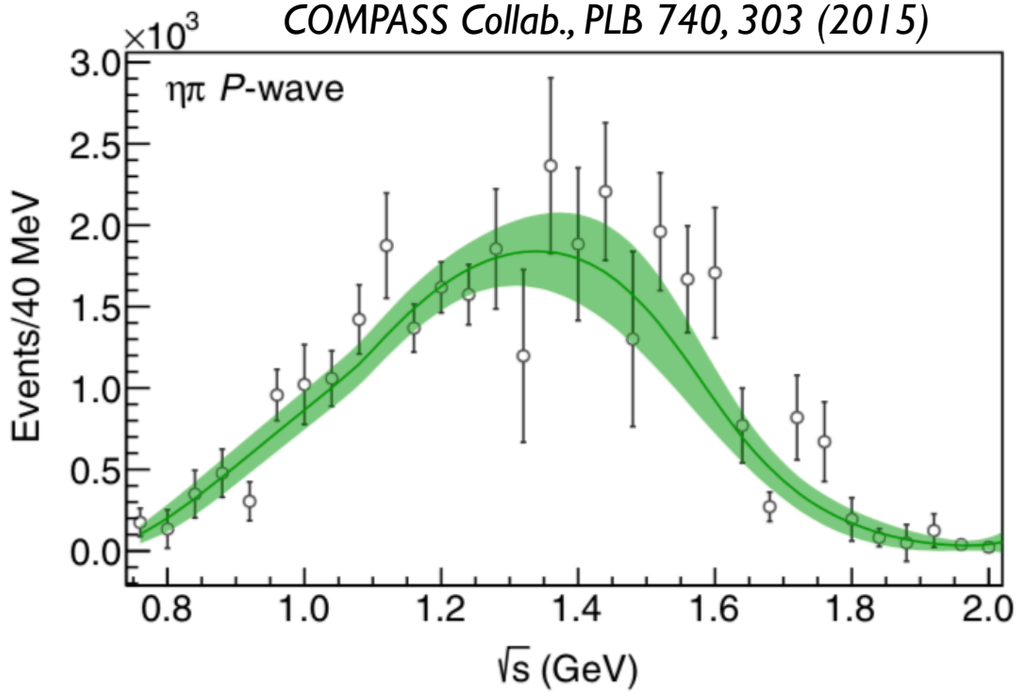
$$\vec{J} = \vec{L} + \vec{S} \quad P = (-1)^{L+1} \quad C = (-1)^{L+S}$$

Allowed J^{PC} : $0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, \ldots$
Forbidden J^{PC} : $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

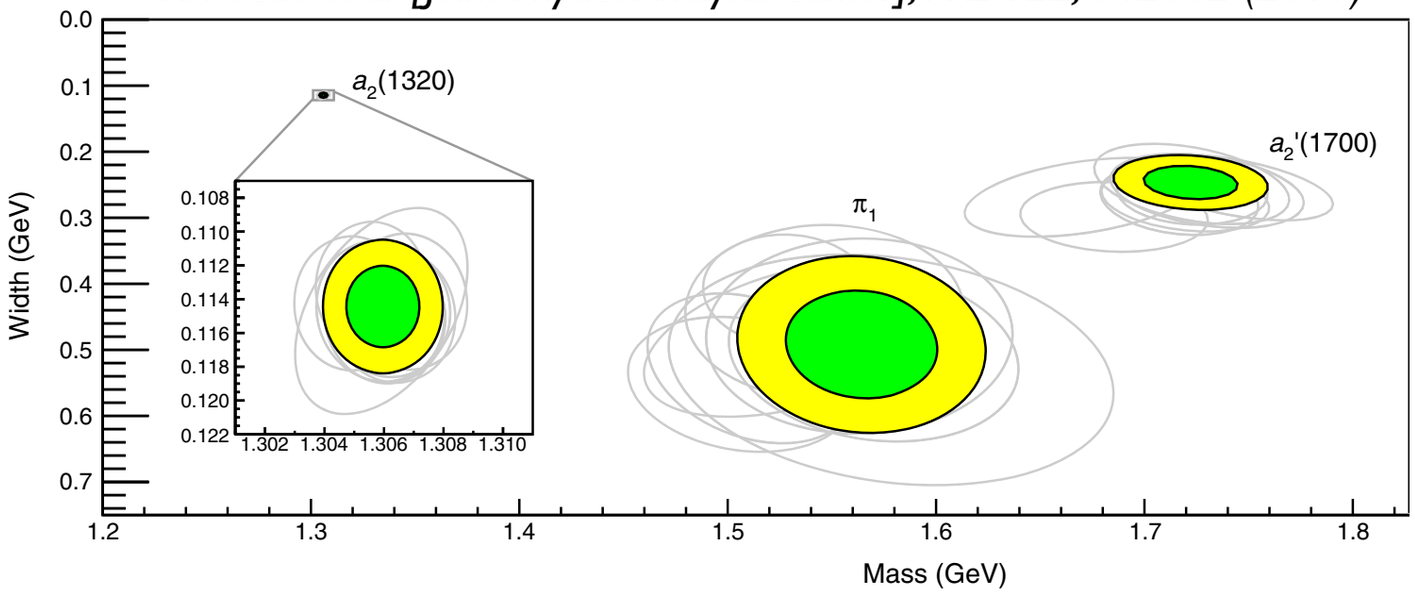
Context: GlueX and Light Exotic Hybrids

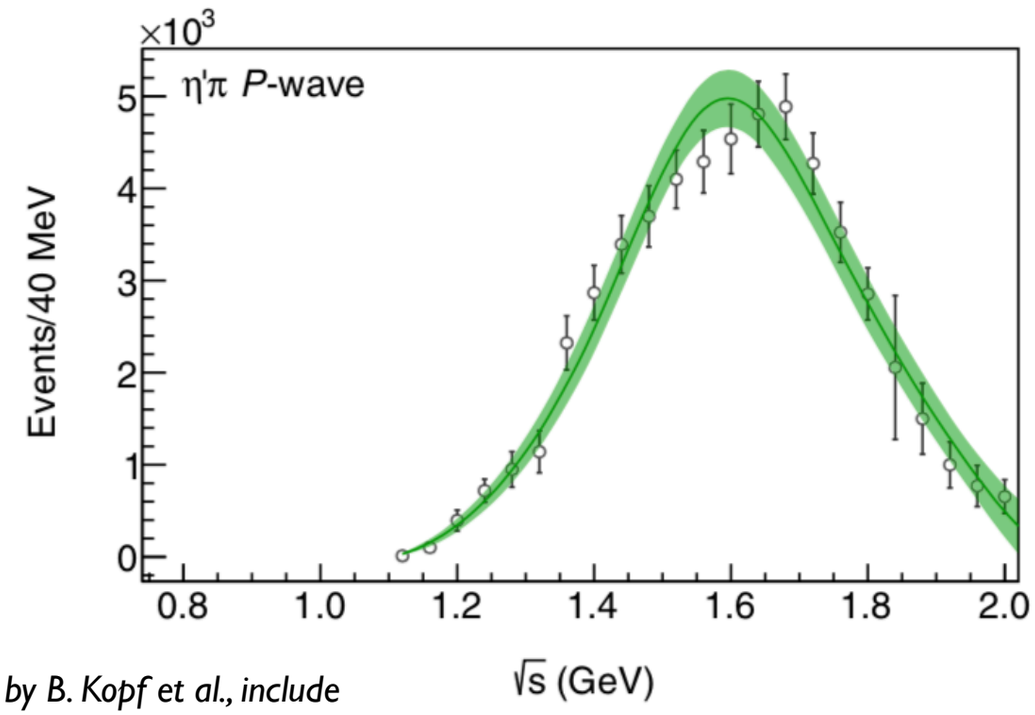
- Ongoing program of light exotic hybrid spectroscopy — GlueX unique in production mechanism
- Key tools
  - amplitude analysis
  - scattering phenomenology: extract resonance poles from amplitudes

exotic 1^{-+} amplitudes from COMPASS Collab., PLB 740, 303 (2015)



A. Rodas et al. [Joint Physics Analysis Center], PRL 122, 042002 (2019)

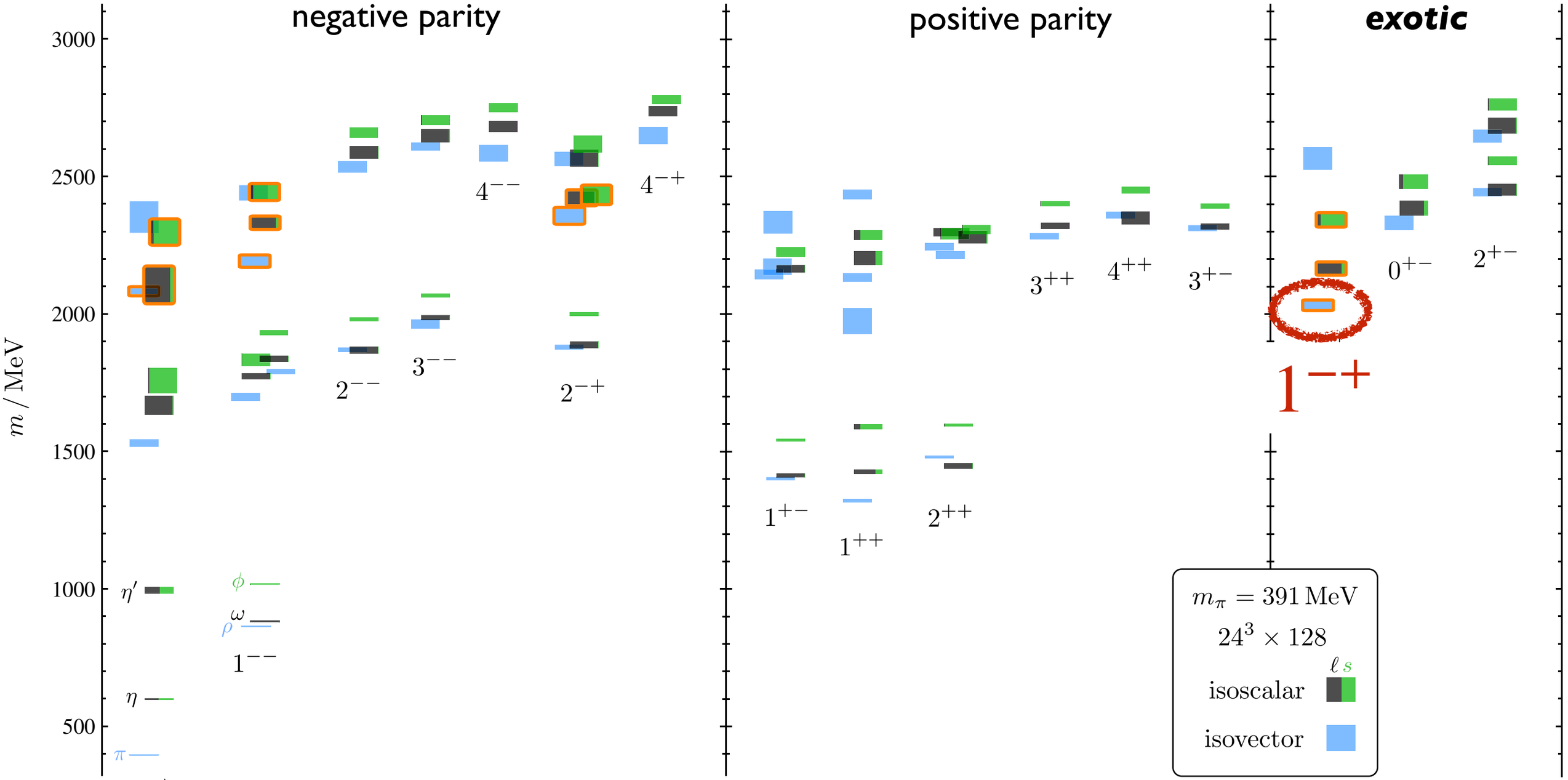




recent results by B. Kopf et al., include data from Crystal Barrel: arXiv:2008.11566

Light Quark Mesons from Lattice QCD

Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)

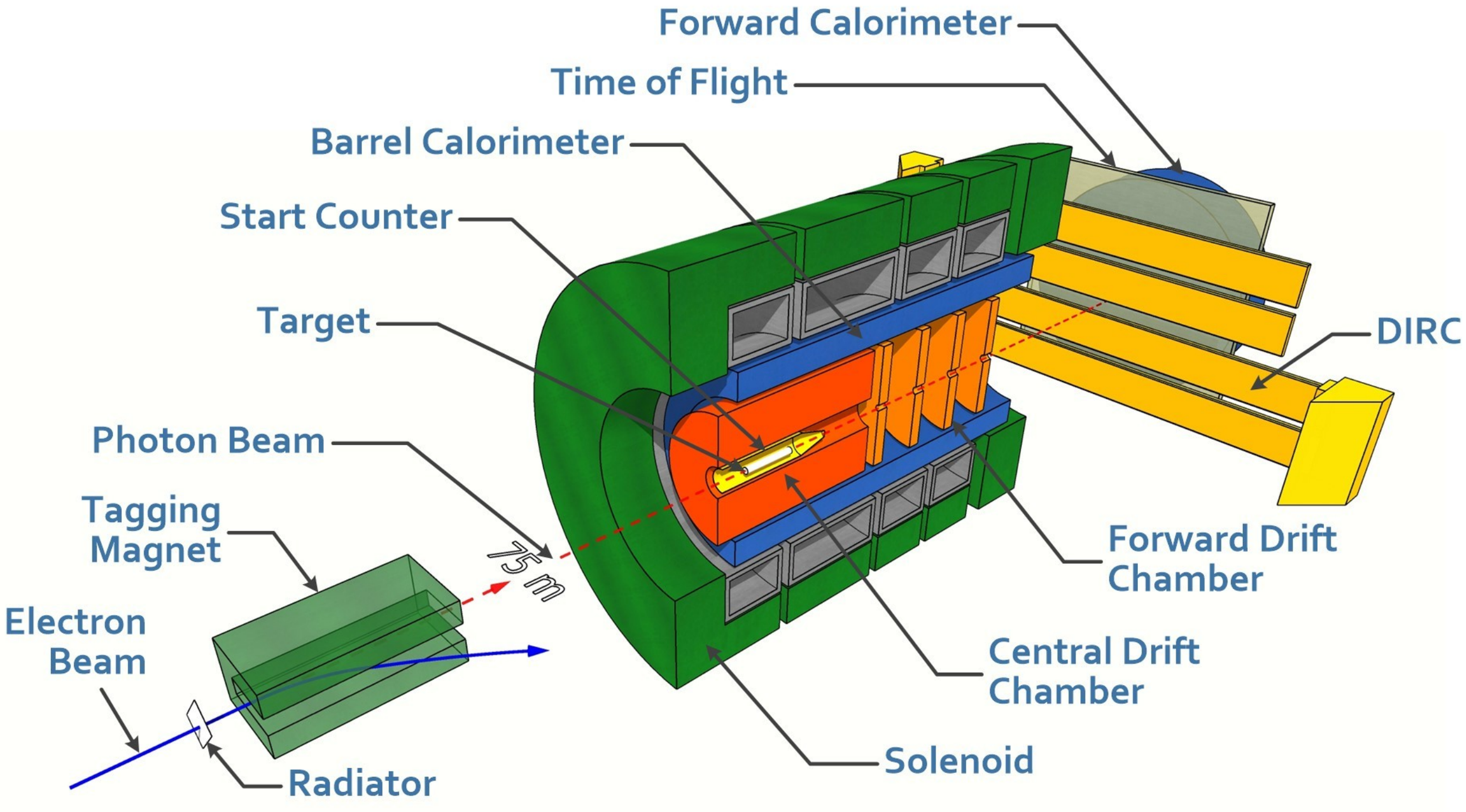


Coverage: $1^\circ < \theta < 120^\circ$, all ϕ

Tracking: $\sigma_p/p \approx 1\% - 5\,\%$

Calorimetry: $\sigma_E/E \approx 6\,\%/\sqrt{E} + 2\,\%$

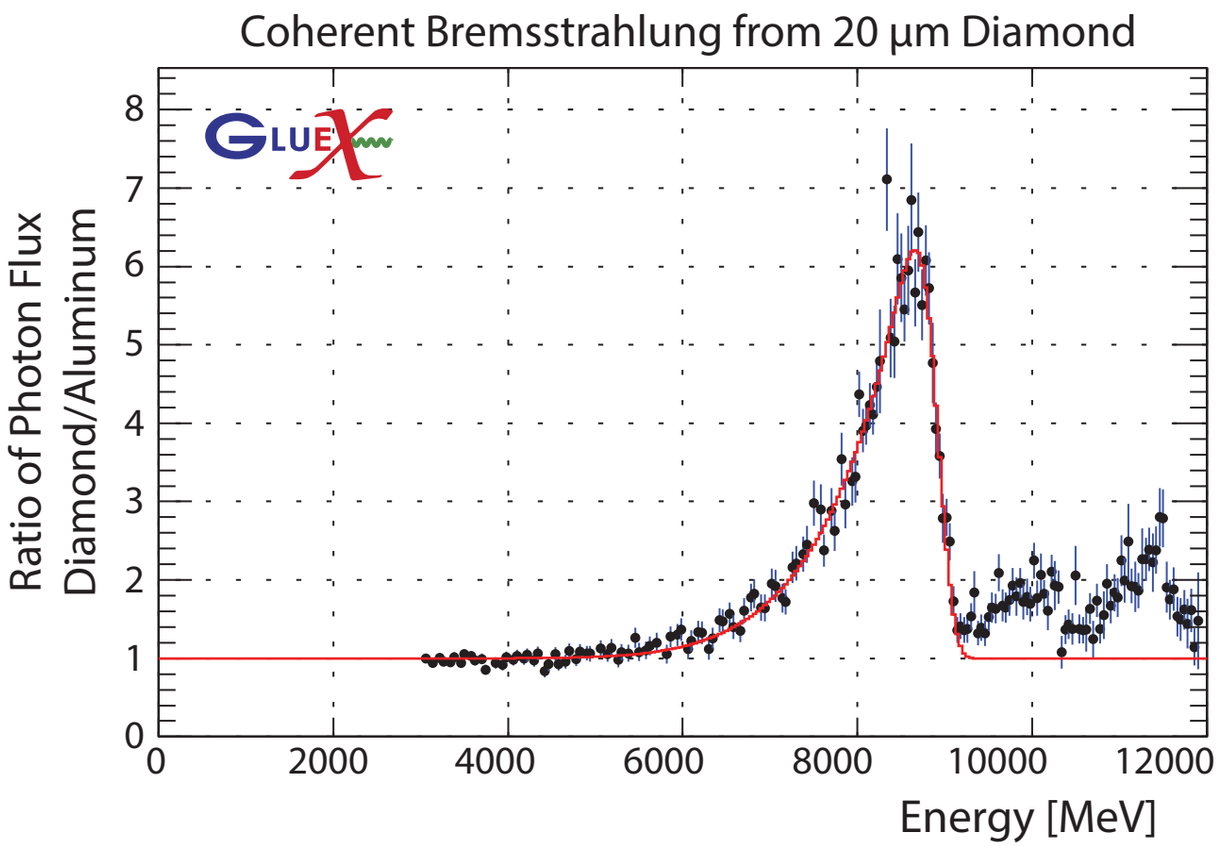
Liquid Hydrogen Target

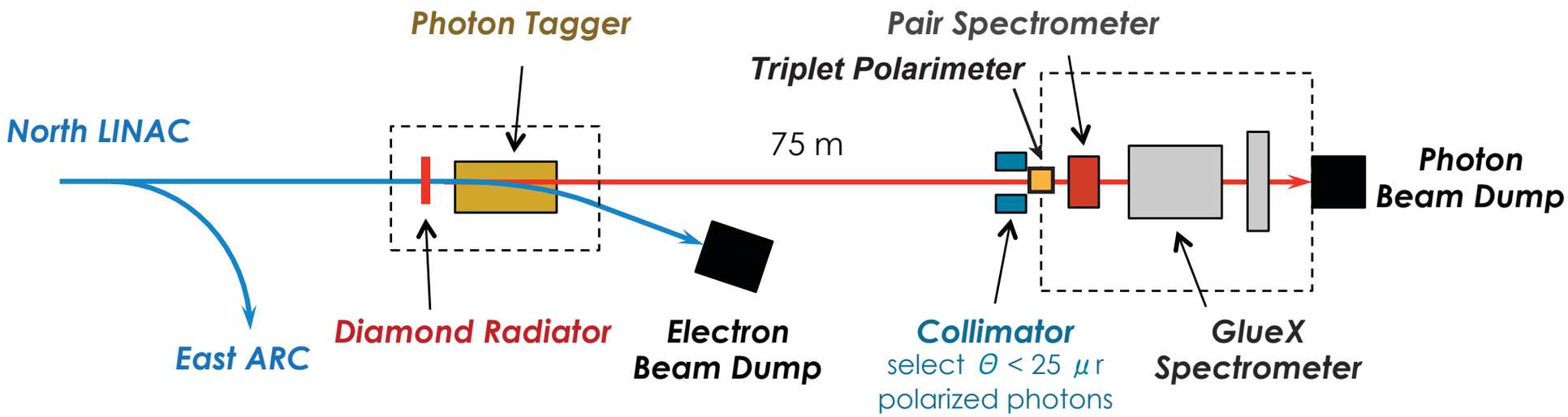


GLUEX

120+ members from 29 institutions

The Hall D Photon Beamline

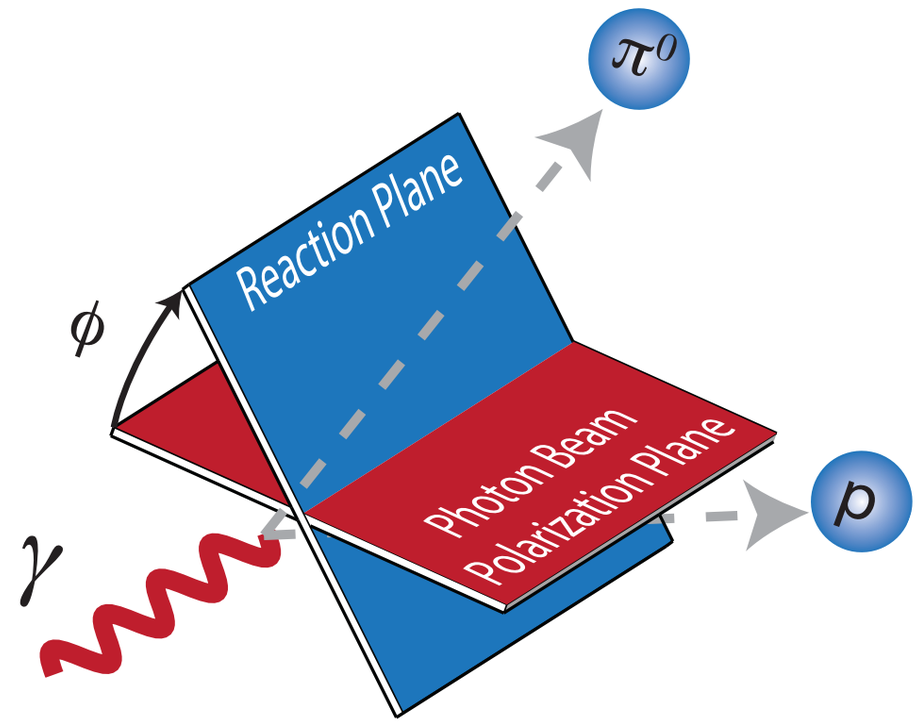


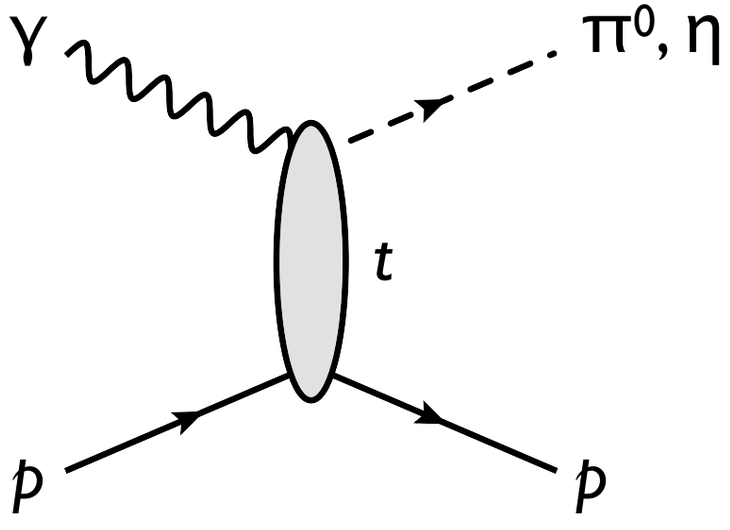


Hall D Experimental Complex
(April 2012)

Asymmetry of Pseudoscalar Production

- Angle between beam polarization plane and reaction plane ϕ is sensitive to J^P of exchange
  - $\sigma(\phi) = \sigma_0[1 - P_\gamma \Sigma \cos(2\phi)]$
  - $\Sigma = +1 \implies 0^+, 1^-, 2^+, \ldots$
  - $\Sigma = -1 \implies 0^-, 1^+, 2^-, \ldots$
- Asymmetry Σ depends on a t in general
- Goal: understand and develop models for photoproduction of known mesons
  - learn about available production mechanisms
  - leverage in search for hybrid mesons





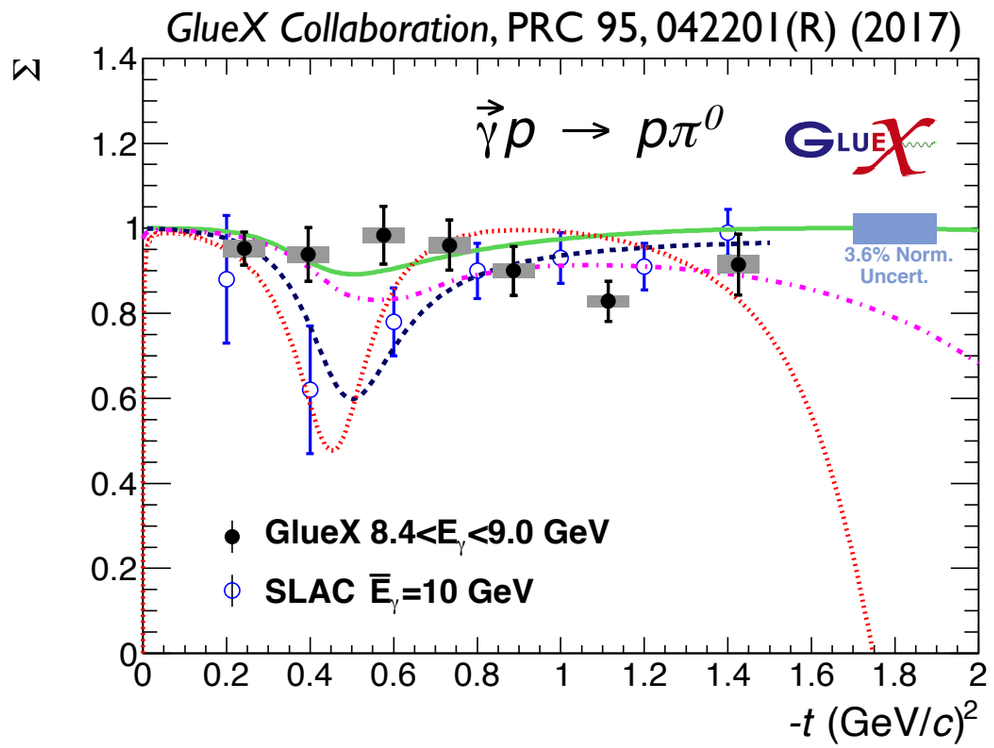
Exchange J^{PC}

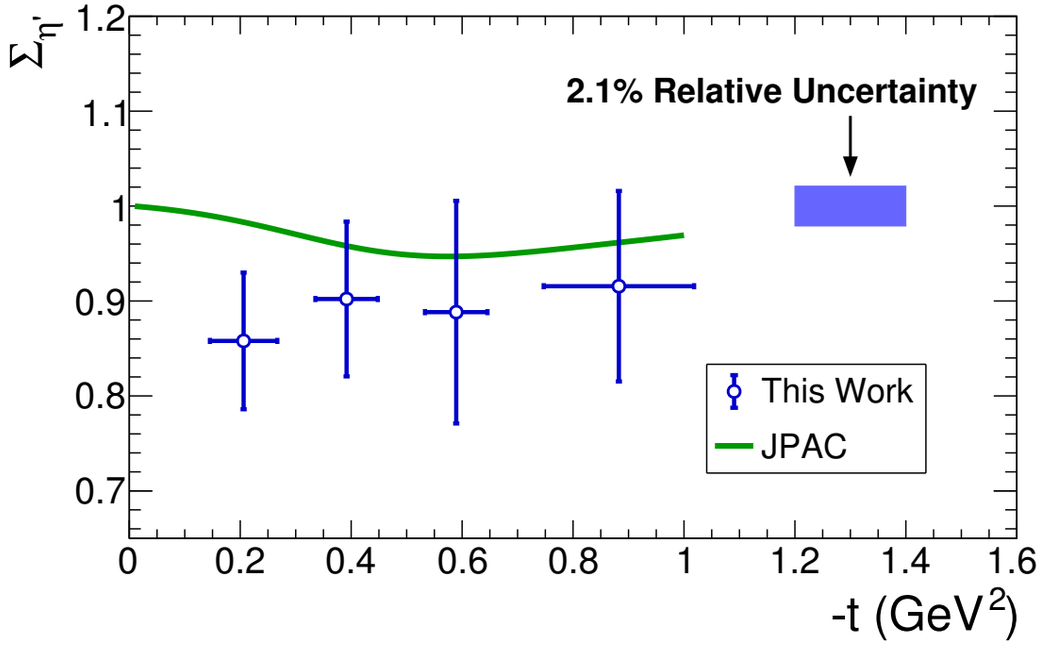
$1^{--}: \ \omega, \rho$

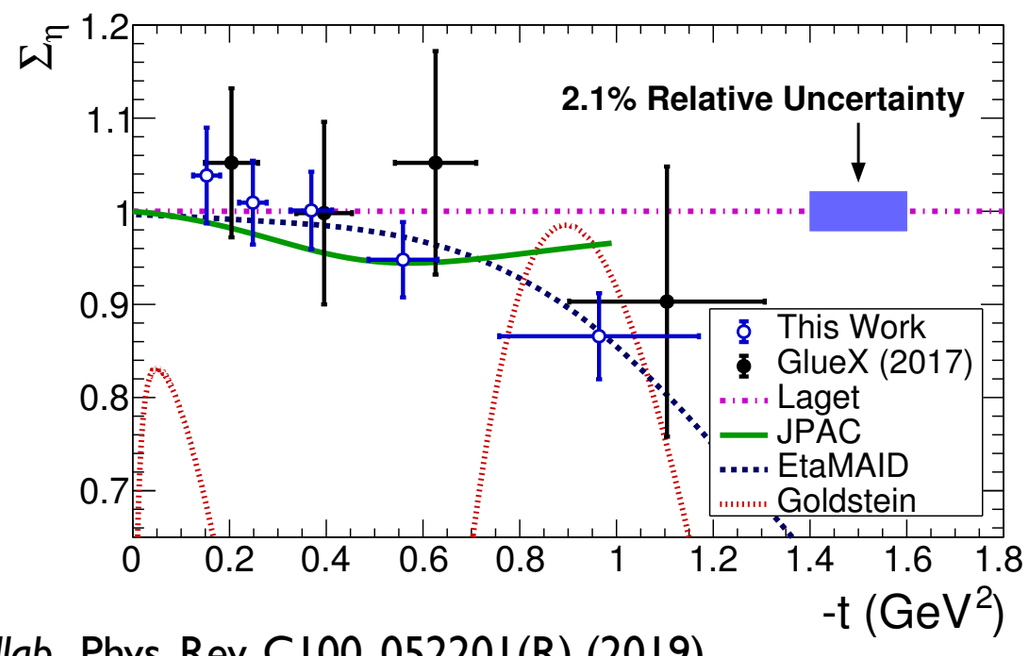
$1^{+-}: \ b, h$

Single Pseudoscalar Production Asymmetry

- GlueX π^0 production asymmetry
  - more precise than SLAC
  - no dip around t = 0.5 (GeV/c)^2
- First measurements of η and η' production asymmetry
- A test of high energy t-channel production models



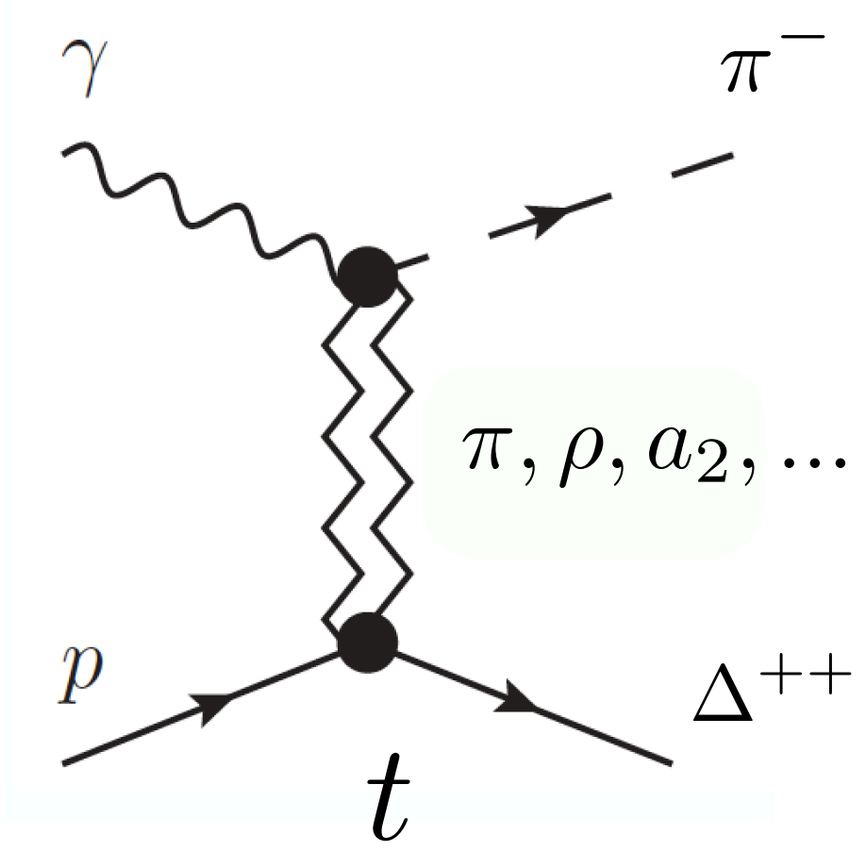


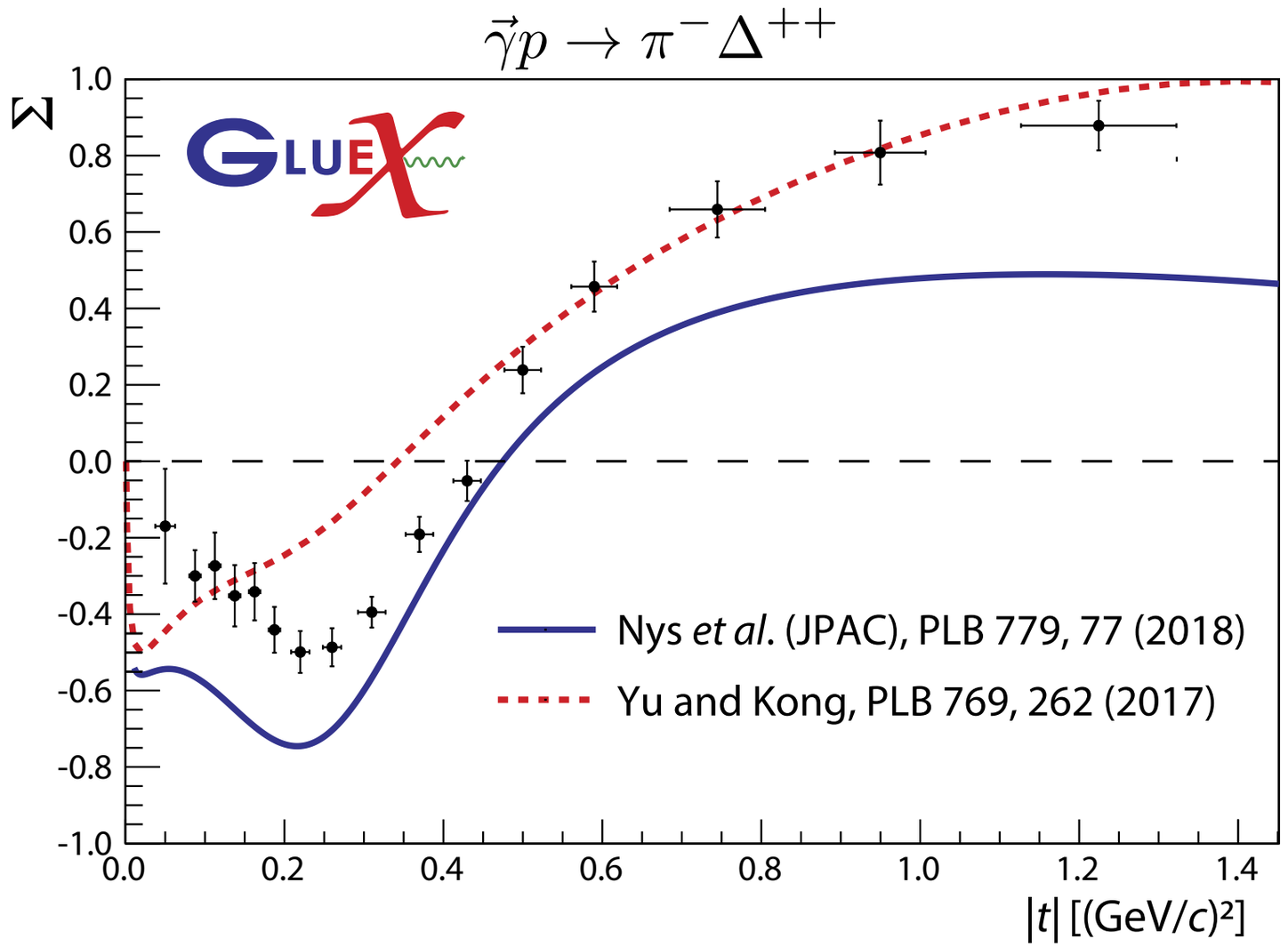


GlueX Collab., Phys. Rev. C100, 052201(R) (2019)

Photoproduction of π-

- Charge exchange process
- Dominated by π exchange at low *t*





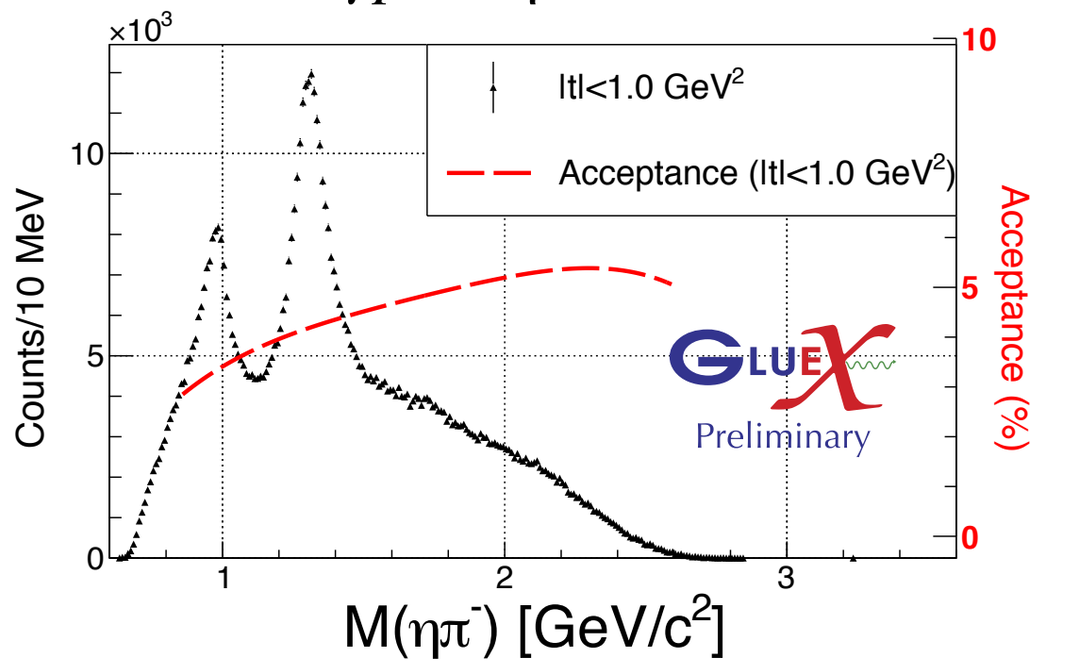
GlueX Collab., arXiv:2009.07326 (submitted to PRC)

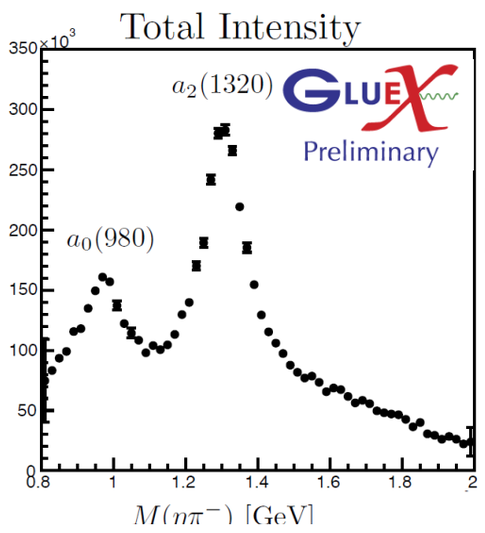
The $\eta^{(\prime)}\pi$ System

- Analysis of $\vec{\gamma}p \to \eta^{(\prime)}\pi p$ is a high priority for GlueX
  - Expect world-leading statistical precision
  - Multiple charge combinations and decay modes accessible
    - access different physics
    - systematic cross checks of acceptance
- Linear beam polarization provides additional observables with enhanced sensitivity
  - Collaboration with Joint Physics Analysis Center (JPAC) to develop analysis techniques, e.g., V. Mathieu *et al.* [JPAC Collaboration], PRD 100, 054017 (2019)

about 1/3 of collected data

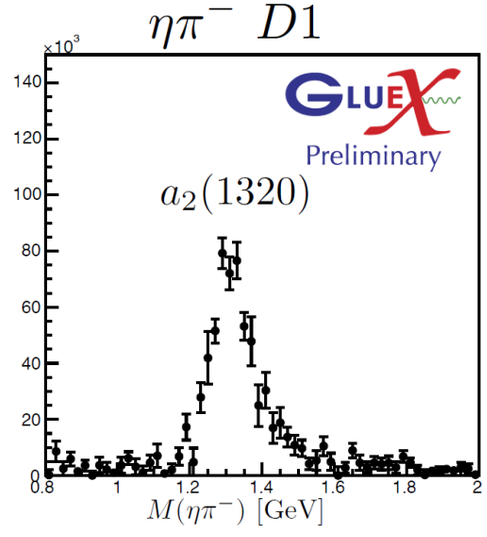
$\gamma p \to \eta\pi^-\Delta^{++}$





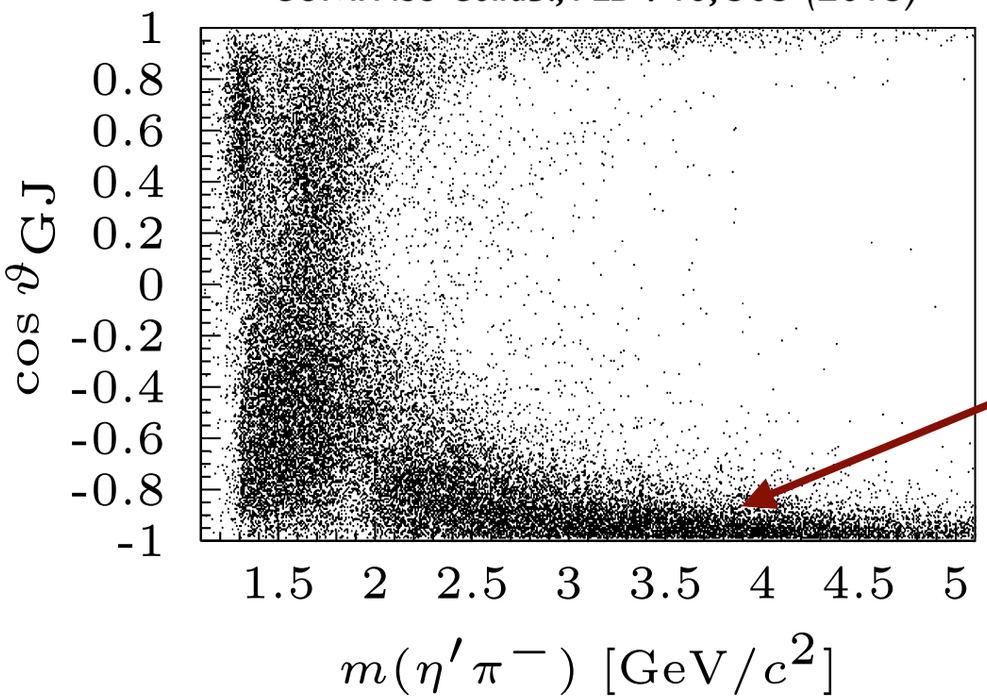
$\gamma p \to \eta\pi^-\Delta^{++}$

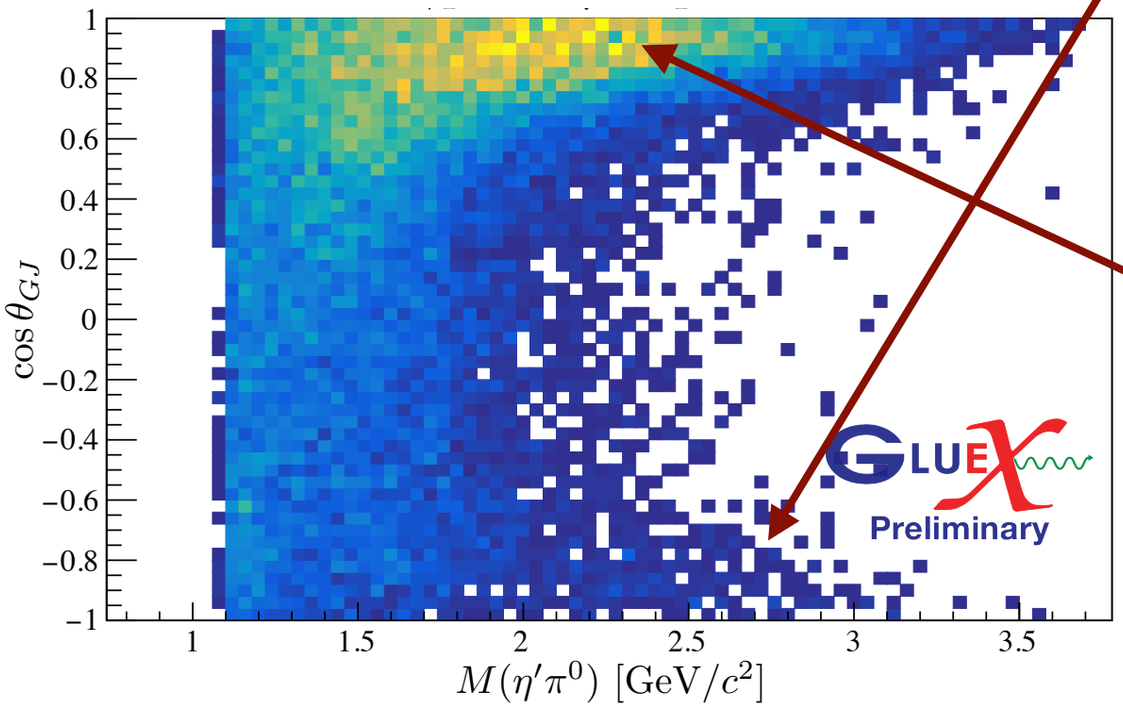
PWA



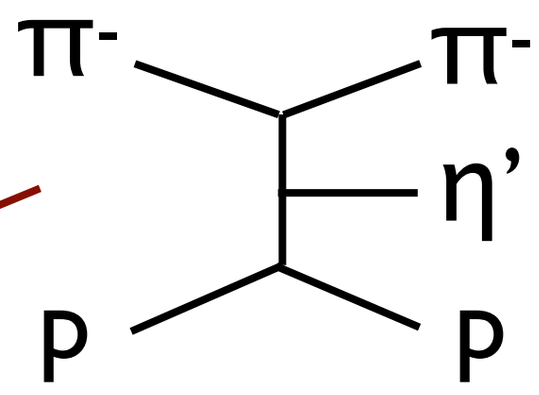
The $\eta^{(\prime)}\pi$ System

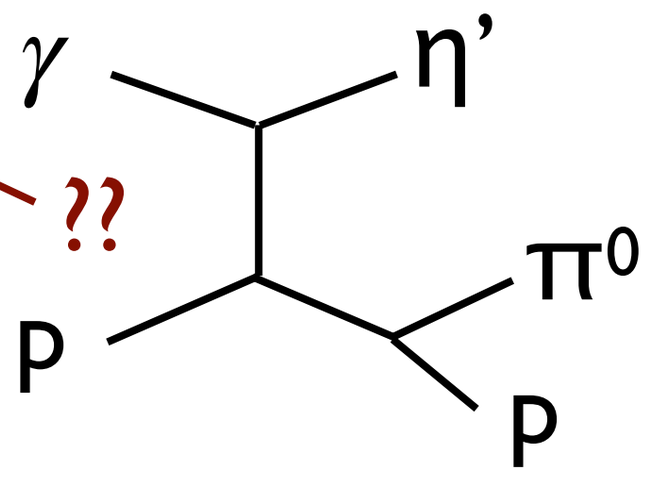
COMPASS Collab., PLB 740, 303 (2015)



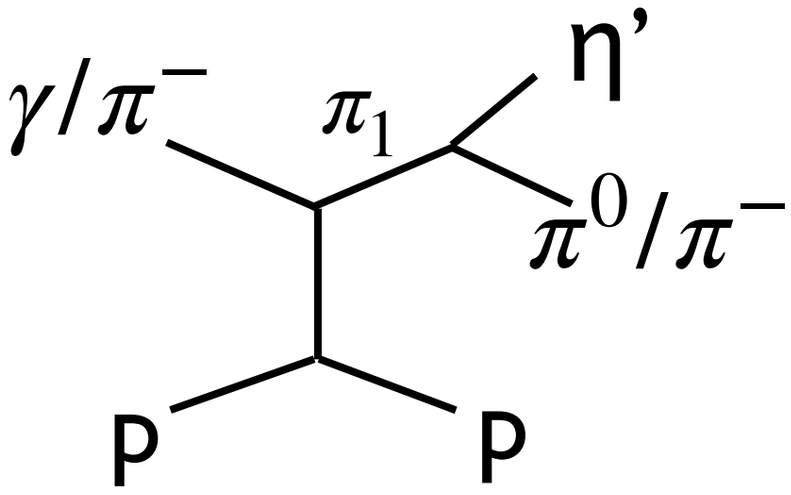


"Deck effect"





Exotic P-wave Signal

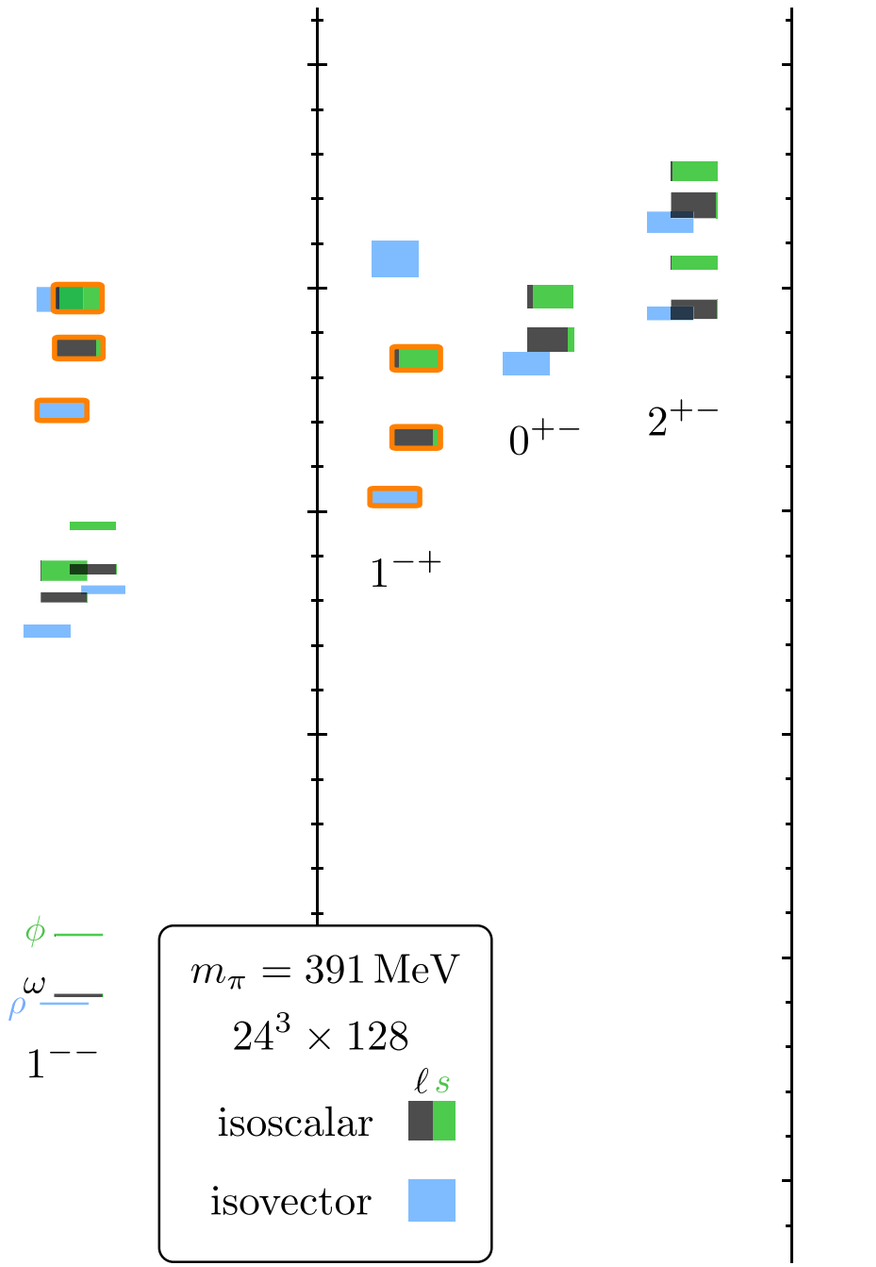


Do we observe consistent resonant P-wave signals in the presence of different physics backgrounds?

Summary: GlueX and Light Exotics

- Sufficient data in hand to explore the $\eta\pi$ and $\eta'\pi$ systems with comparable precision to other leading experiments
- In 2020 we doubled the data set and enhanced particle identification; expect another 2x - 3x more data in the coming years
- Extend exotic search beyond 1^{-+} π_1 candidates:
  - other exotic quantum numbers, e.g.: $b_2 \to a_2\pi$
  - probe flavor of isoscalar hybrids, e.g.: expect $\eta_1' \to K^*K$ but $\eta_1 \nrightarrow K^*K$
- We can do more than light exotic hybrids:
  - hybrids with conventional J^{PC}
  - light meson and baryon spectroscopy
  - explore strange analogues of XYZ states
  - a little bit of real charmonium production

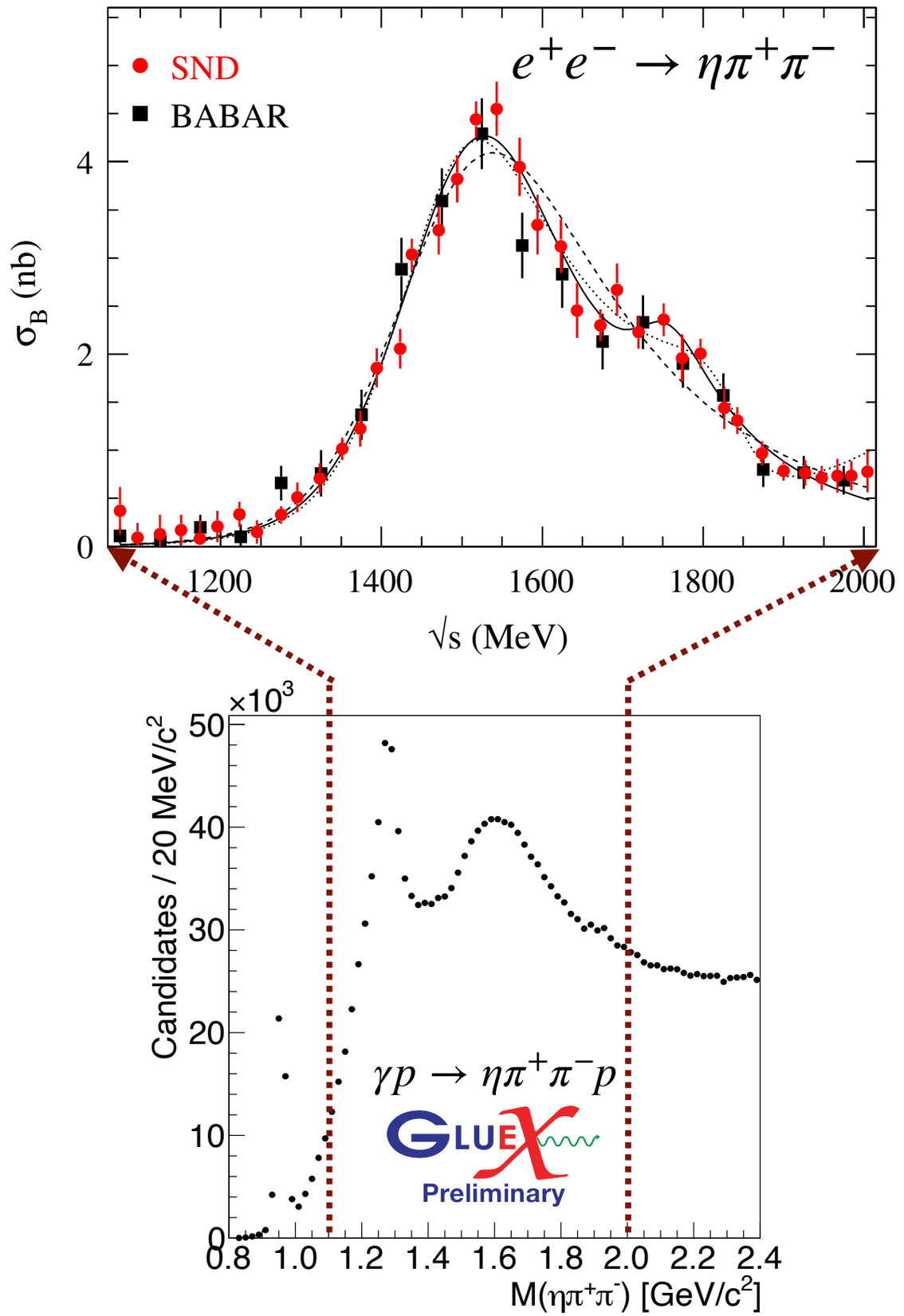
Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)



Complementary Production

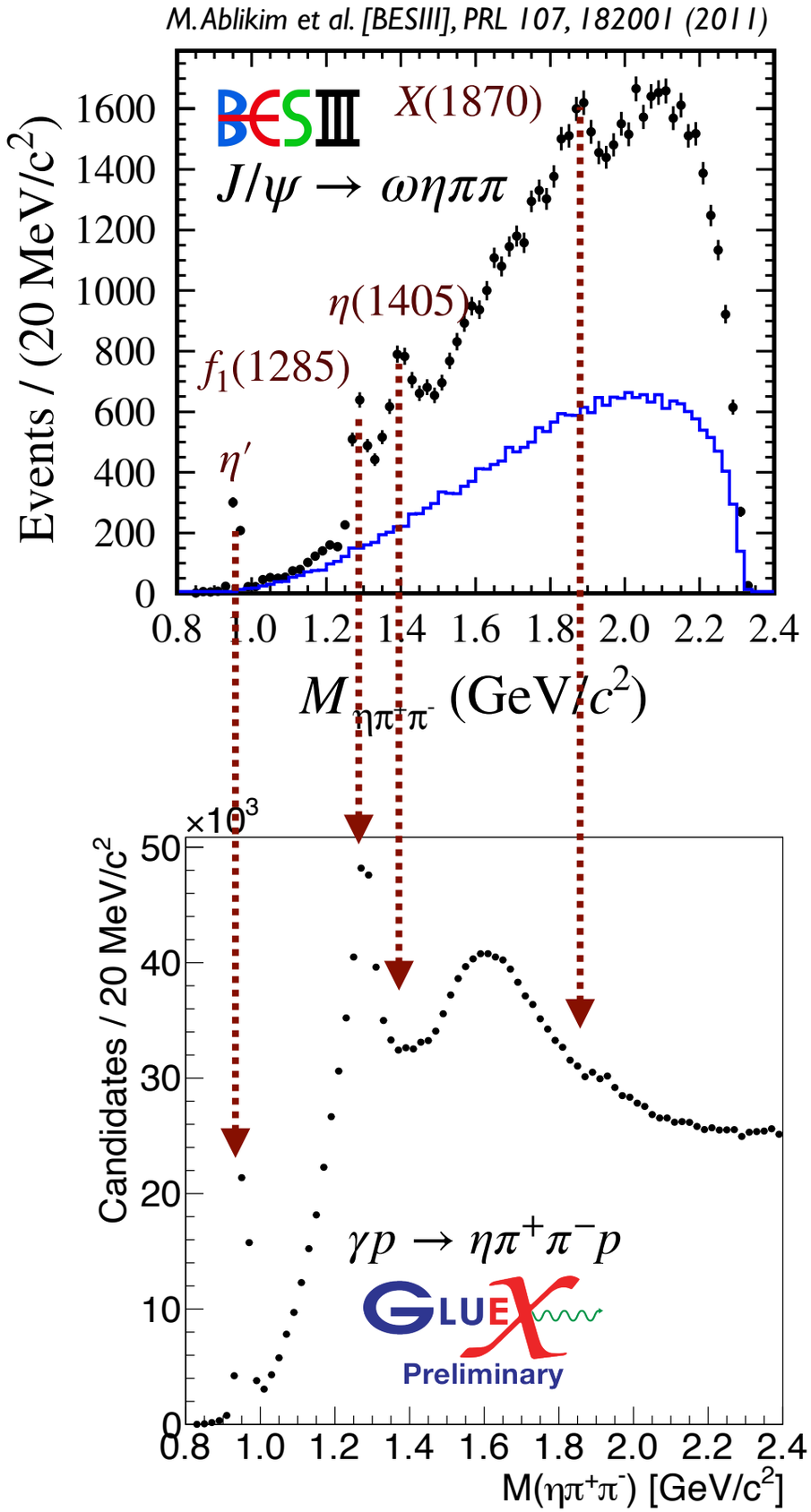
- Naively expect enhanced photoproduction of vector (1^{--}) mesons
  - vector meson dominance
- In e^+e^- collisions…
  - only 1^{--} states are produced
  - $\eta\pi^+\pi^-$ system described by interference of $\rho(1450)$ and $\rho(1700)$
- Do data from GlueX provide a consistent picture of these states?
- GlueX data should permit an exploration of the $\eta\pi\pi$ system with unprecedented statistical precision (including searches for η_1 and b_2 hybrids)

SND, PRD 97, 012008 (2018); BaBar PRD 76, 092005 (2007)



Complementary Production

- What do differences in production tell us about nature of hadrons?
- Consider $\eta\pi^+\pi^-$ produced against an ω in J/ψ decay
  - $C = +$
  - naively "glue rich"
- Compare with $\eta\pi^+\pi^-$ in photoproduction
  - any C allowed
- For 0^{-+} states, the $\eta(1405)$ appears to be suppressed with respect to the η' in photoproduction.
  - what does it mean?

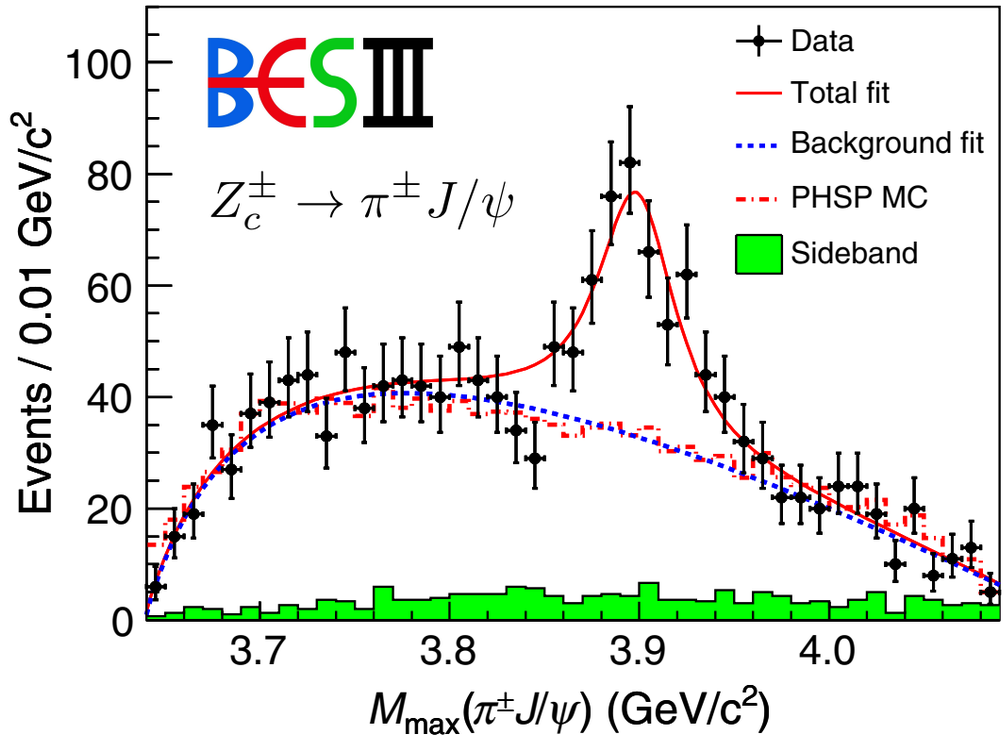


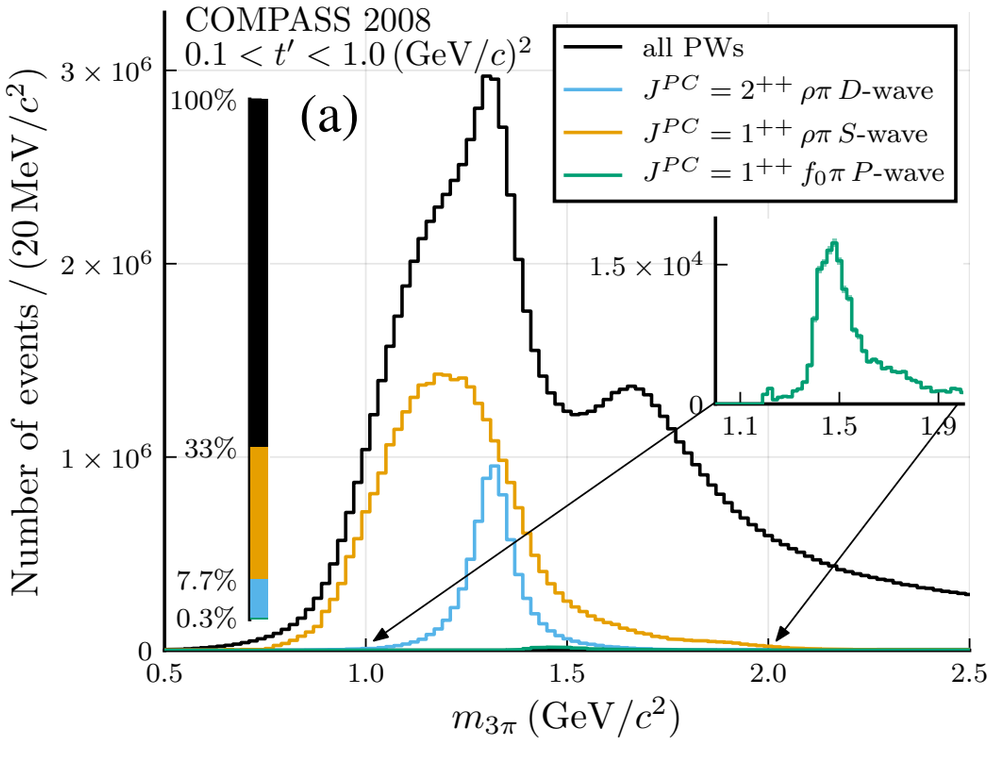
See also: R. Dickson et al. [CLAS Collaboration], PRC 93, 065202 (2016)

Connections to Heavy Quarks and HEP

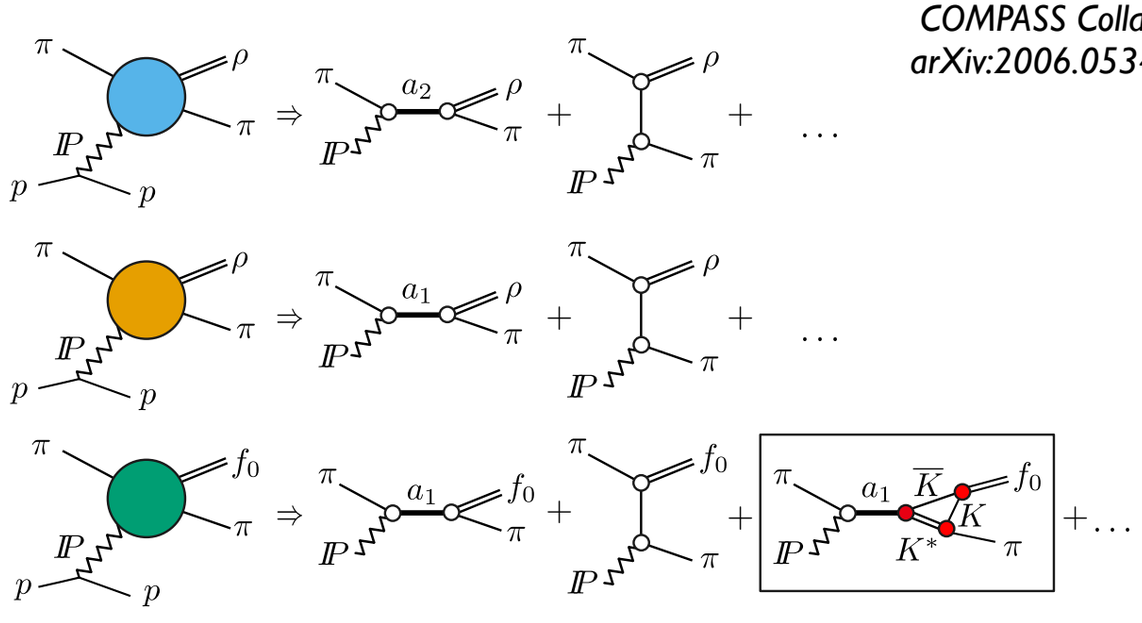
- What does all the *XYZ* physics imply for the strange quark sector?
- GlueX may be able to contribute through
  - searches for strange *XYZ*-like states, e.g., $\phi\pi\pi$ as an analogue to $J/\psi\pi\pi$
  - explore kinematic singularities with high statistical precision: $\gamma p \to K^*Kp \to \phi\pi^0 p$

BESIII Collaboration, PRL 110, 252001 (2013)



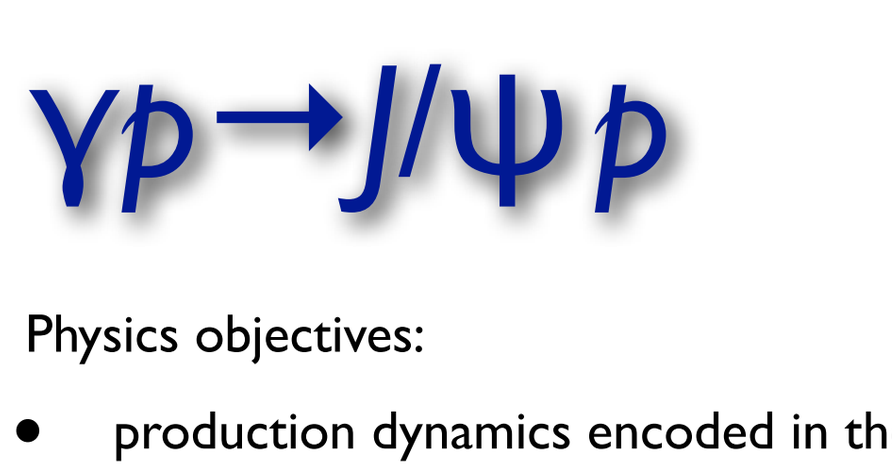


COMPASS Collab.
arXiv:2006.05347

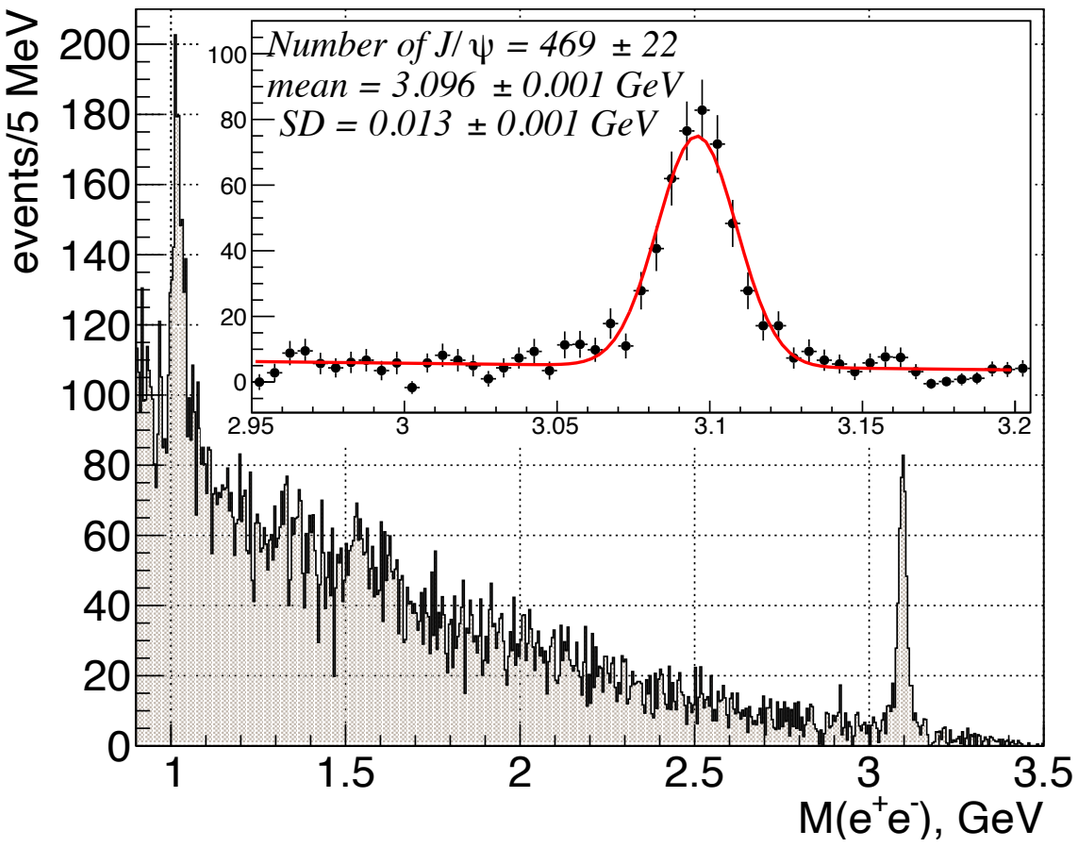


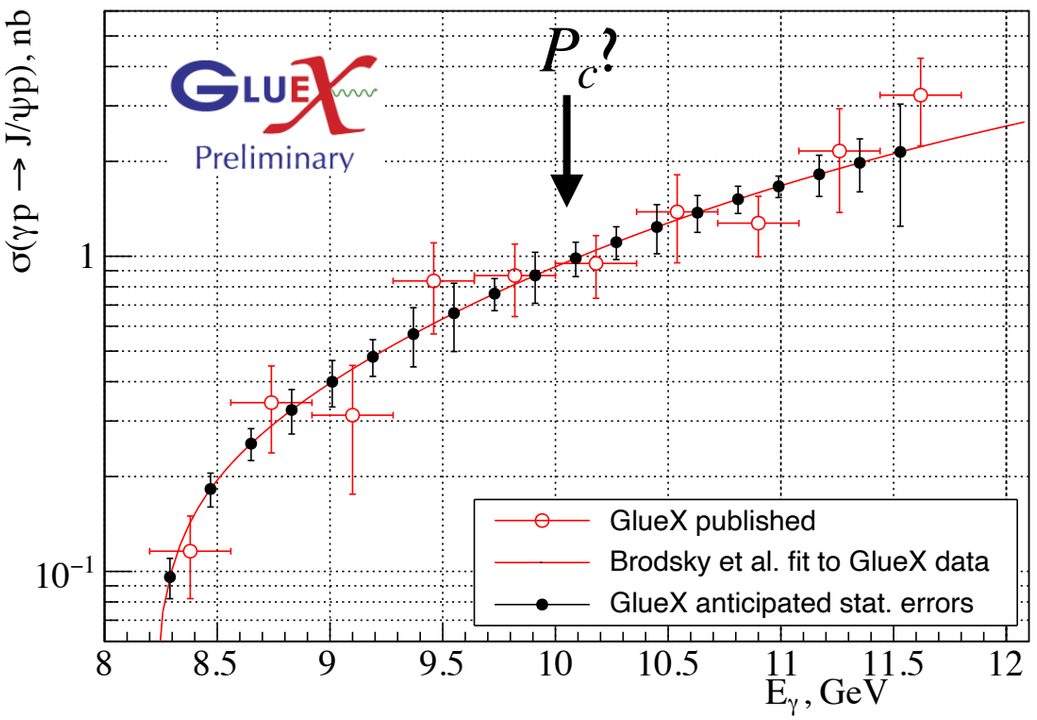
$\gamma p \rightarrow J/\psi p$

- Physics objectives:
  - production dynamics encoded in the shape of cross section at threshold
  - search for *s*-channel production of pentaquark candidates observed by LHCb



A. Ali et al. [GlueX Collab.], PRL 123, 072001 (2019)





Summary

- Understanding how QCD generates the properties of hadrons remains an interesting question
  - relies on studying hadrons of all flavors
  - requires complementary production mechanisms
  - spans particle and nuclear physics facilities around the world
- GlueX has a unique role to play in this effort
  - access to light exotic and conventional mesons through high-statistics photoproduction
  - a variety of connections to charmonium and *XYZ* physics
  - a multi-purpose physics program that will acquire new data and produce results through the next decade
- It is essential maintain free flow of results, people, analysis technology, *etc.* between the high-energy physics and nuclear physics communities
  - complementary approaches to the same underlying physics