An Overview of the GlueX Physics Program

presented at the

XVIII International Conference on Hadron Spectroscopy and Structure

Matthew Shepherd
Indiana University
on behalf of

The GlueX Collaboration

Outline

- Motivation: Gluons in QCD
  - global context
  - complementary capabilities of GlueX

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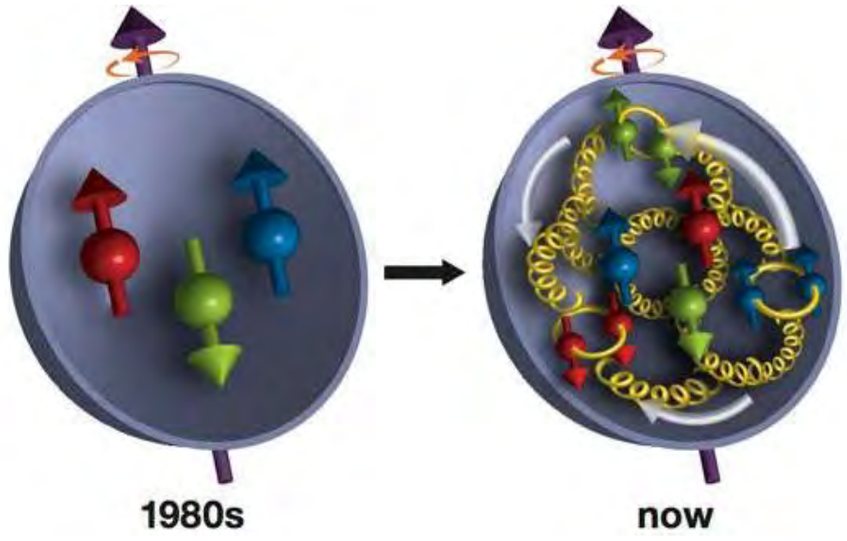
  - complementary capabilities of GlueX
- GlueX Status and Early Results
  - understanding photoproduction mechanisms
  - opportunistic searches for exotic states: $P_c \rightarrow J/\psi p$
- Looking Forward
  - towards searches for exotic hybrids
  - future data collection with enhanced particle identification capability

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?*



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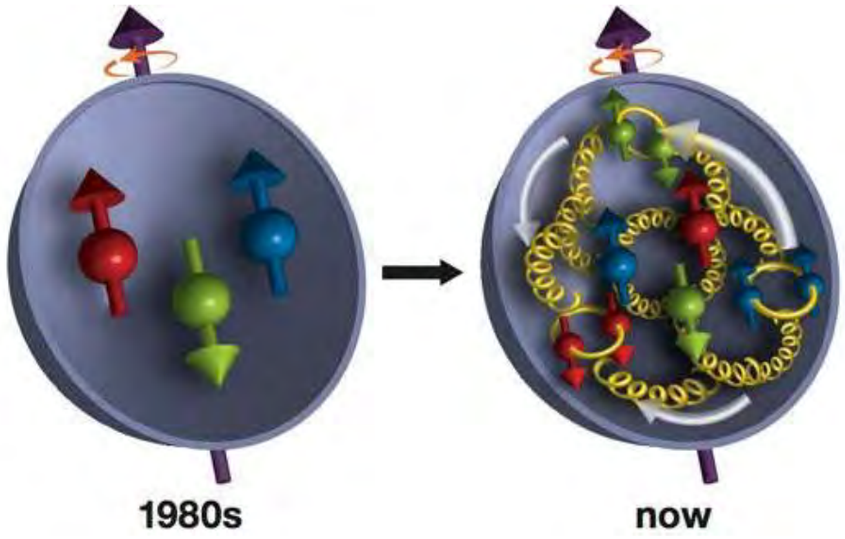

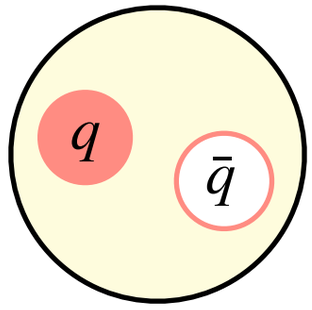

color singlet
quark anti-quark

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

Allowed J^{PC} : $0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, \ldots$
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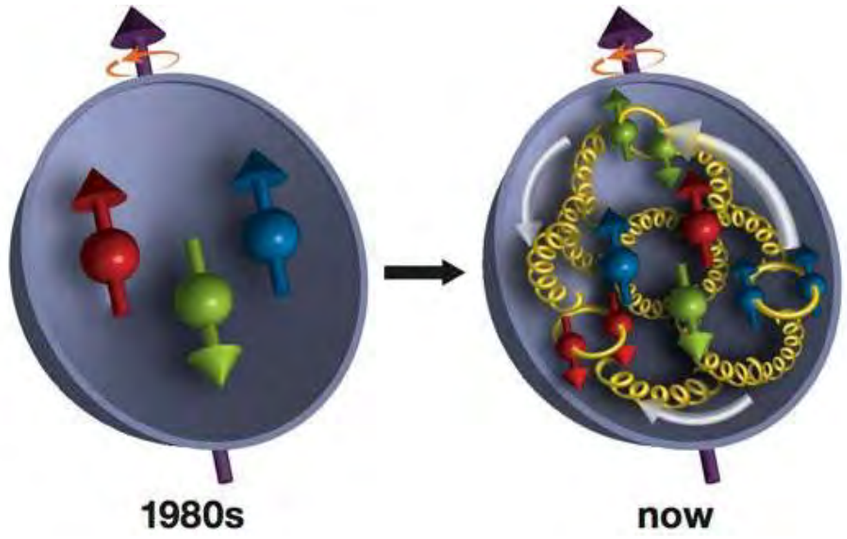
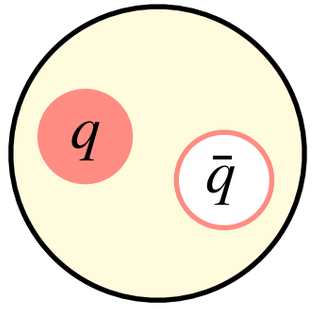
- The "1980s picture" seems to work really well for describing the spectrum of mesons.
  - Why? Are there exceptions?





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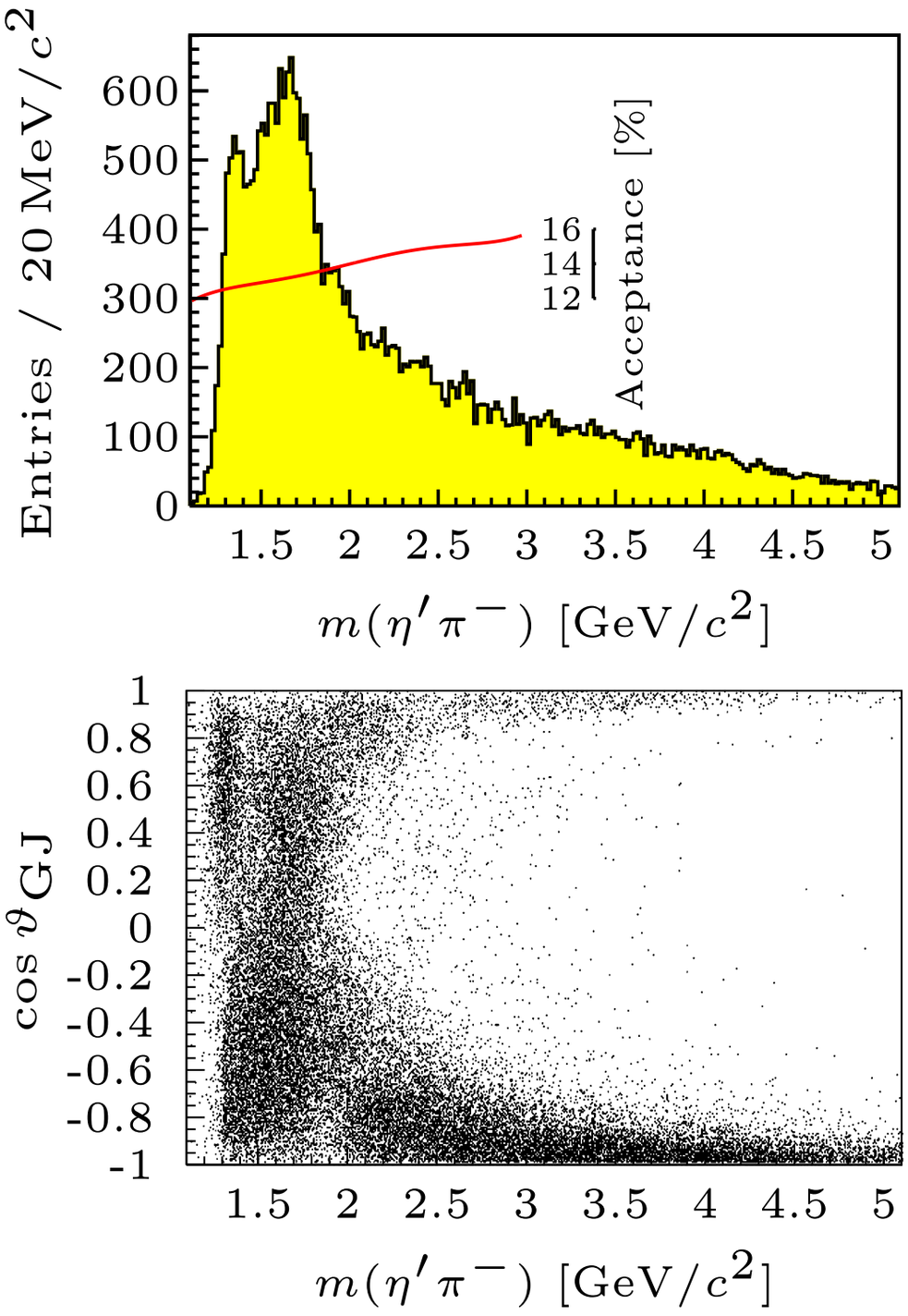
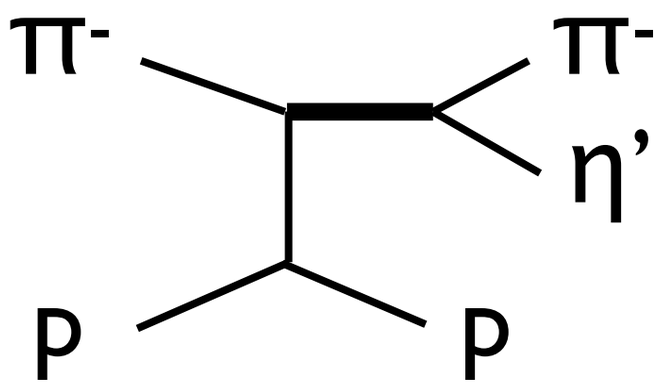
Searching for Exotic Mesons in Pion Production





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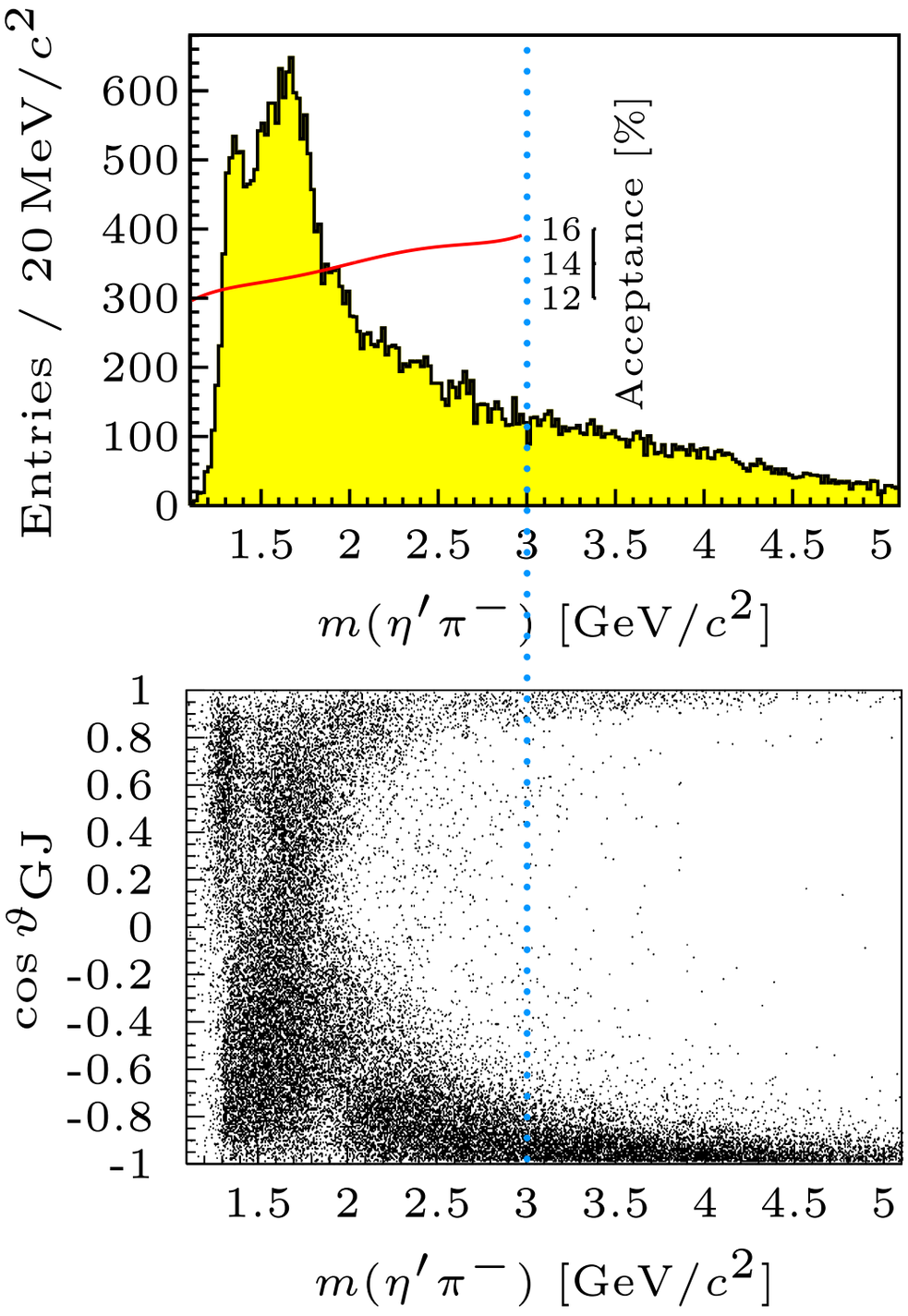
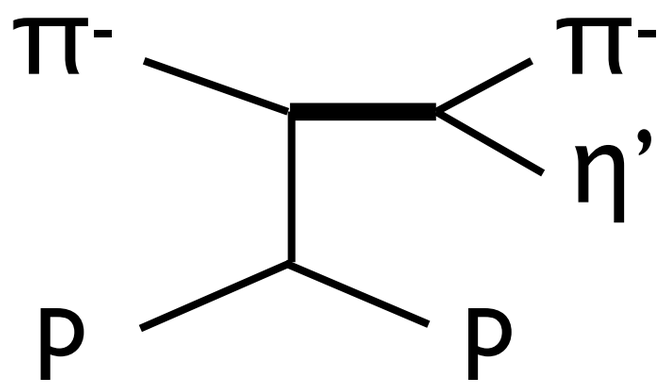
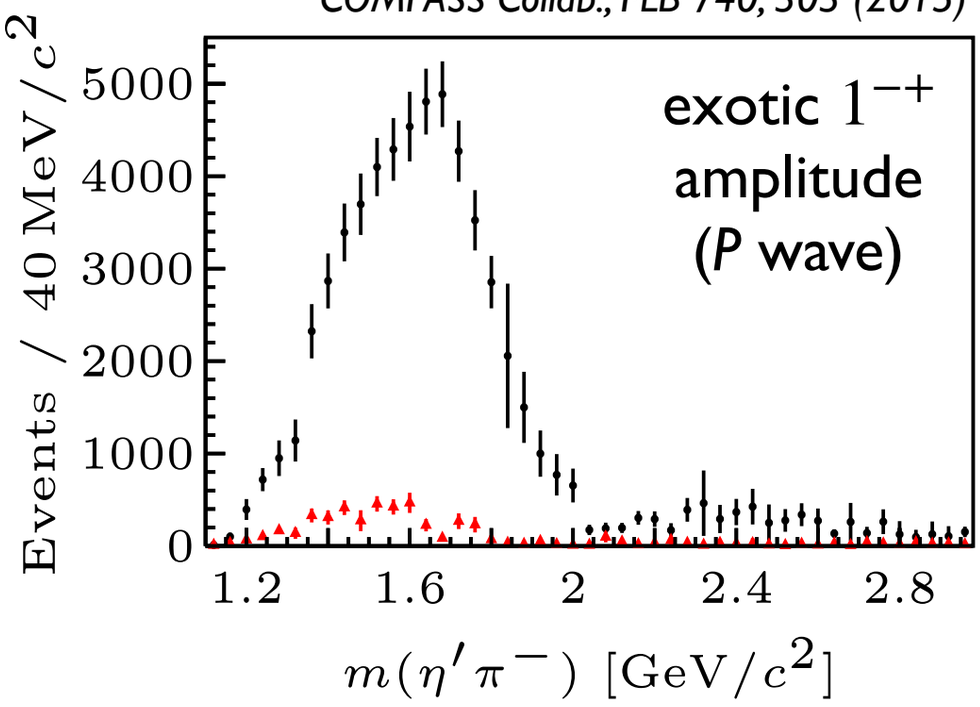




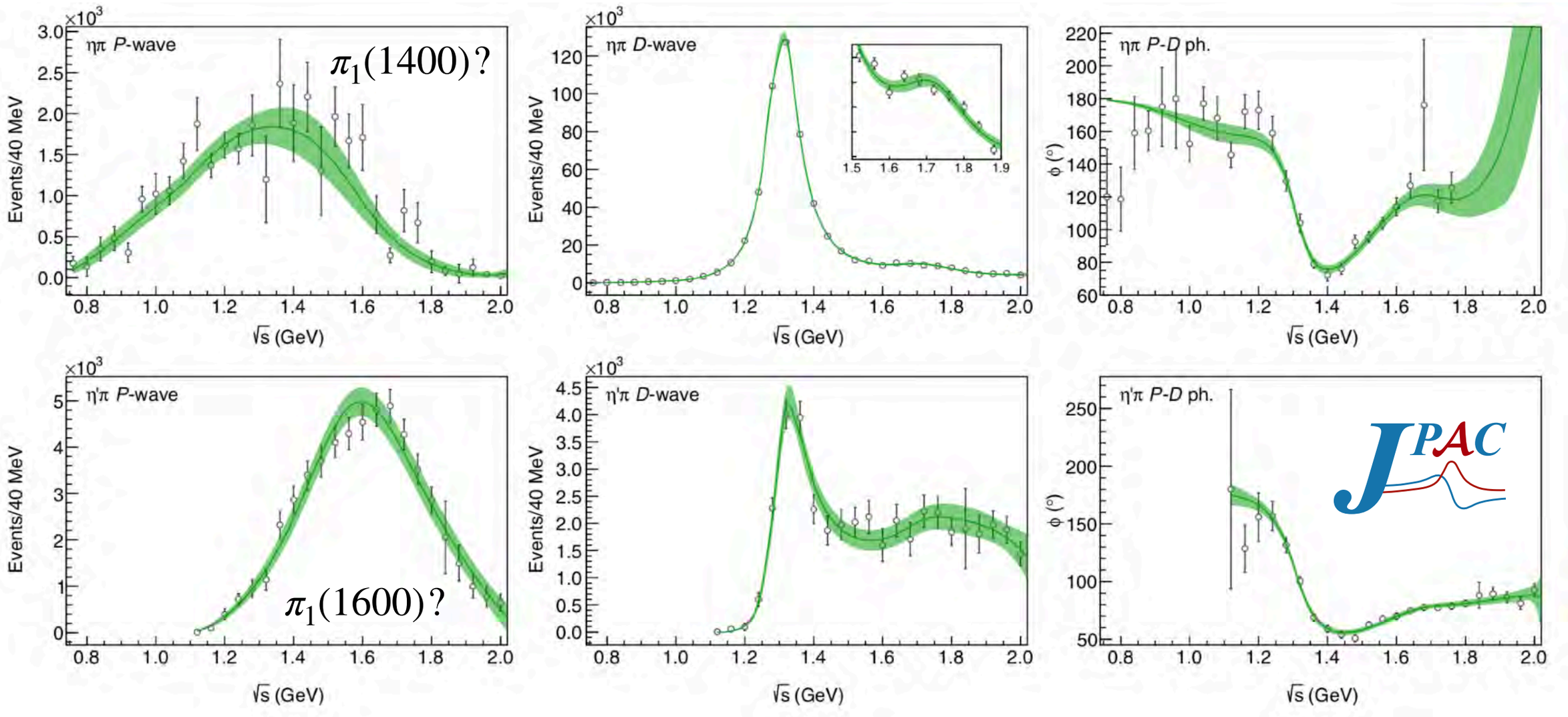
COMPASS Collab., PLB 740, 303 (2015)



Resonances in $\eta^{(\prime)}\pi$

Coupled-channel analysis that enforces unitarity and analyticity of the S matrix.

A. Rodas et al. [Joint Physics Analysis Center], PRL 122, 042002 (2019)
[using data from COMPASS Collab., PLB 740, 303 (2015)]



Two π_1 states are reported in the literature (see PDG review).

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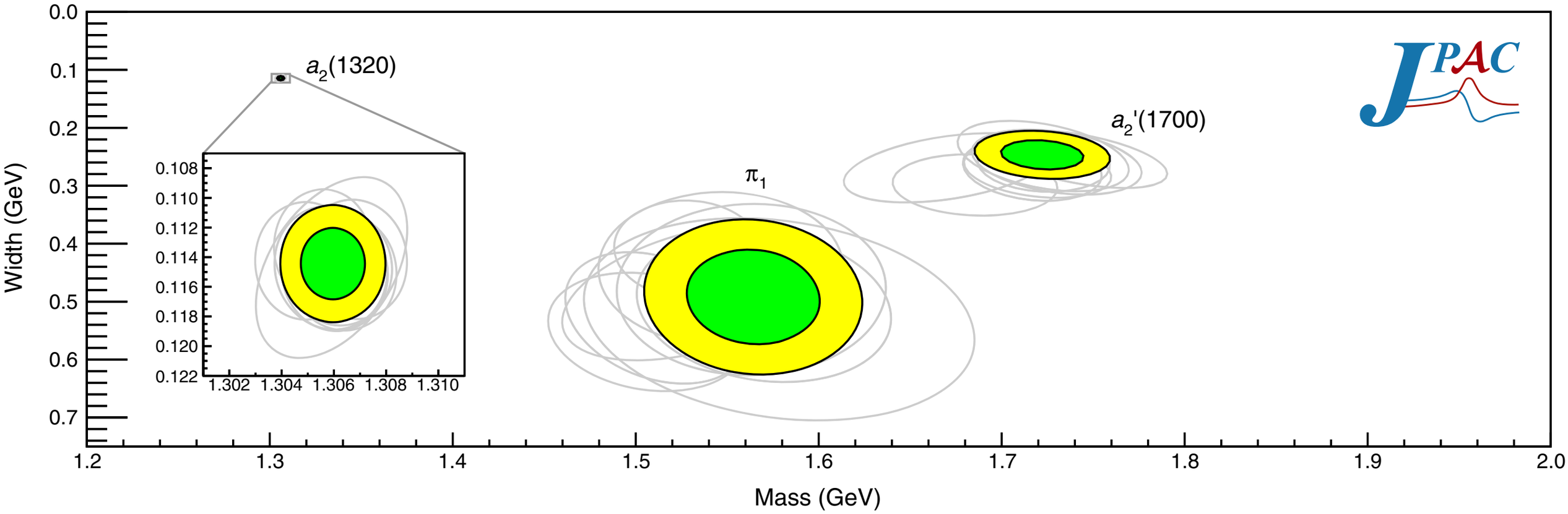
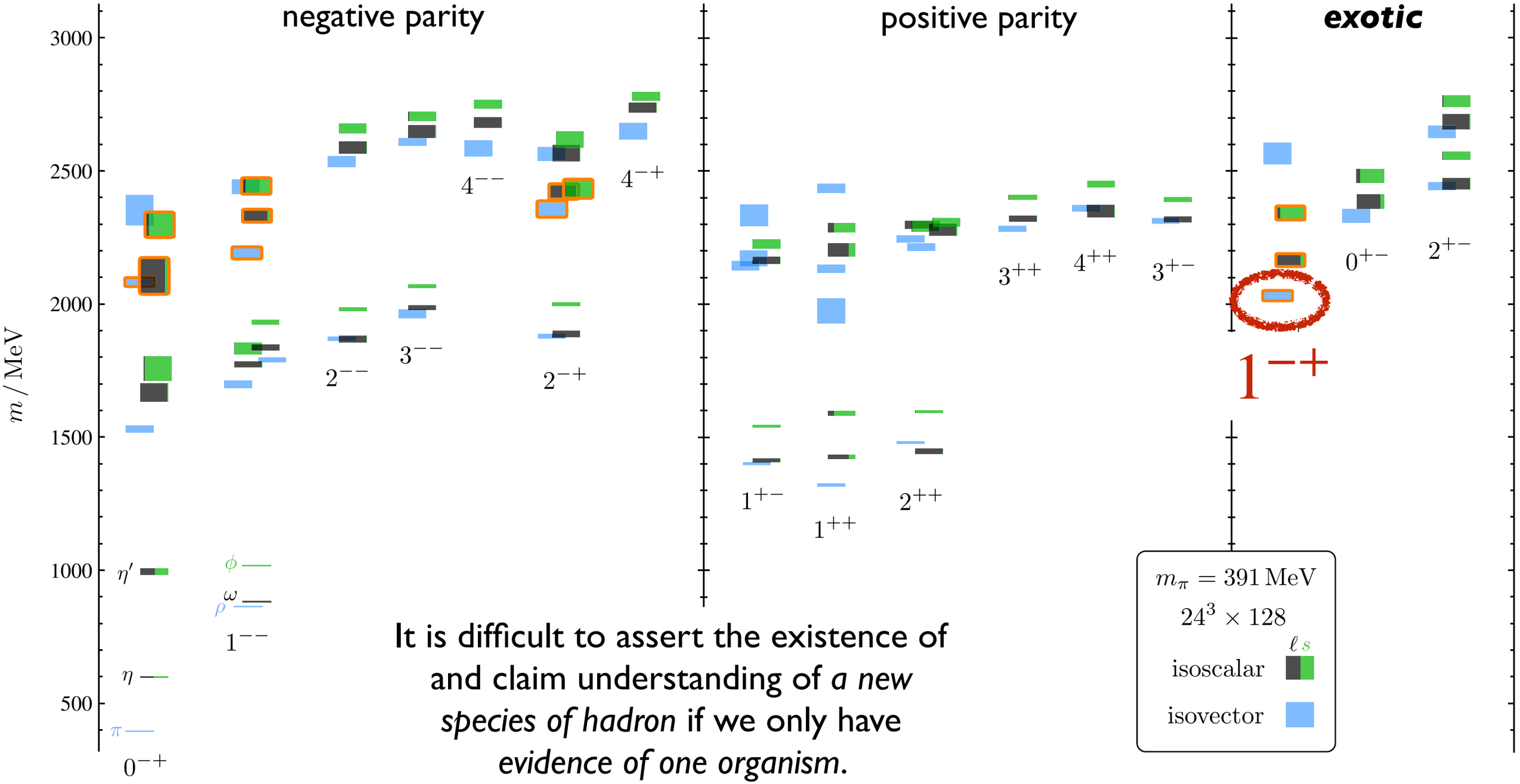


Are all existing observations consistent with a single pole associated with the lightest isovector exotic hybrid?

Poles	Mass (MeV)	Width (MeV)
$a_2(1320)$	$1306.0 \pm 0.8 \pm 1.3$	$114.4 \pm 1.6 \pm 0.0$
$a_2'(1700)$	$1722 \pm 15 \pm 67$	$247 \pm 17 \pm 63$
π_1	$1564 \pm 24 \pm 86$	$492 \pm 54 \pm 102$

Light Quark Mesons from Lattice QCD

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



It is difficult to assert the existence of and claim understanding of *a new species of hadron* if we only have *evidence of one organism*.

GLUEX

120+ members from 29 institutions

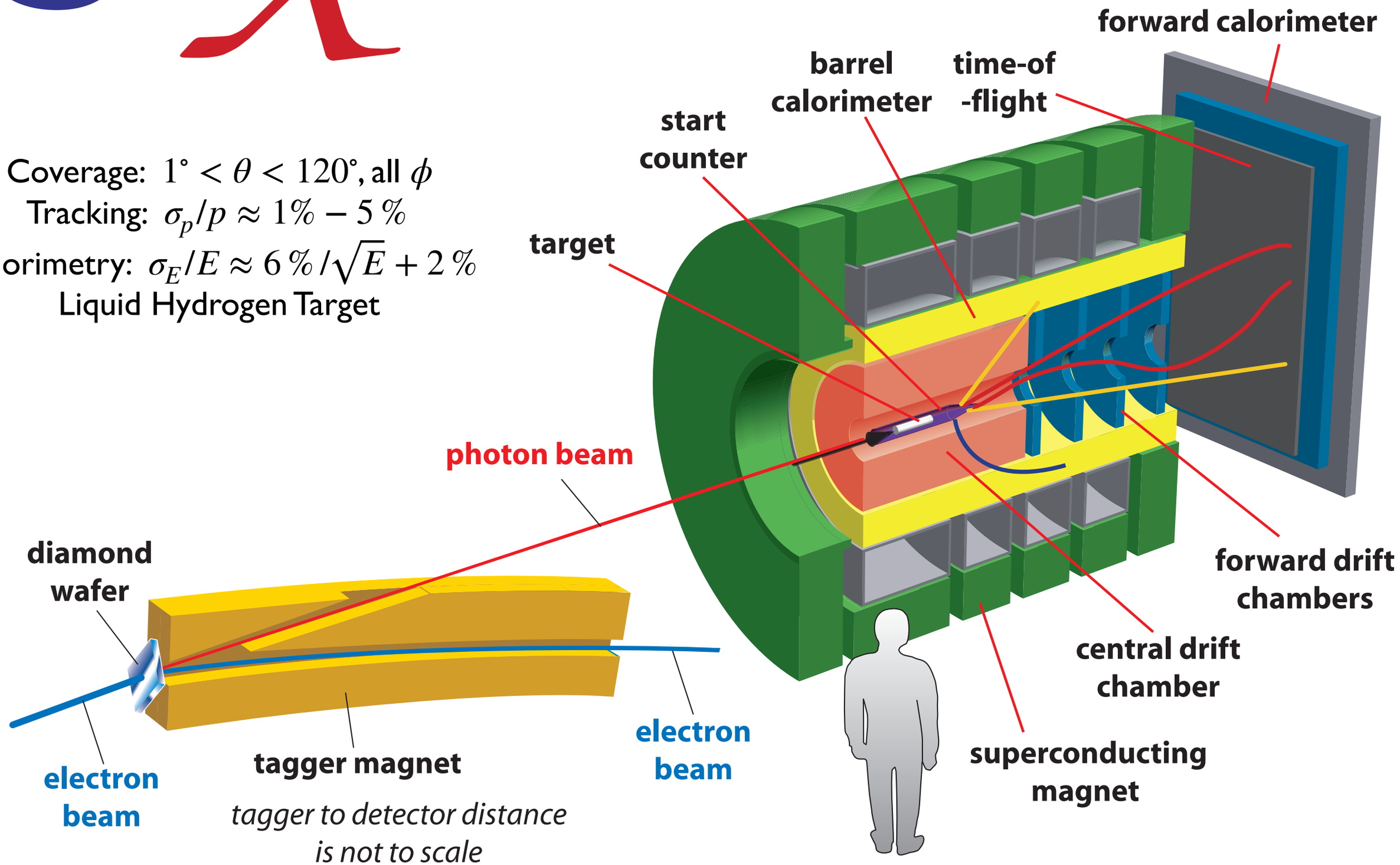
GlueX

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

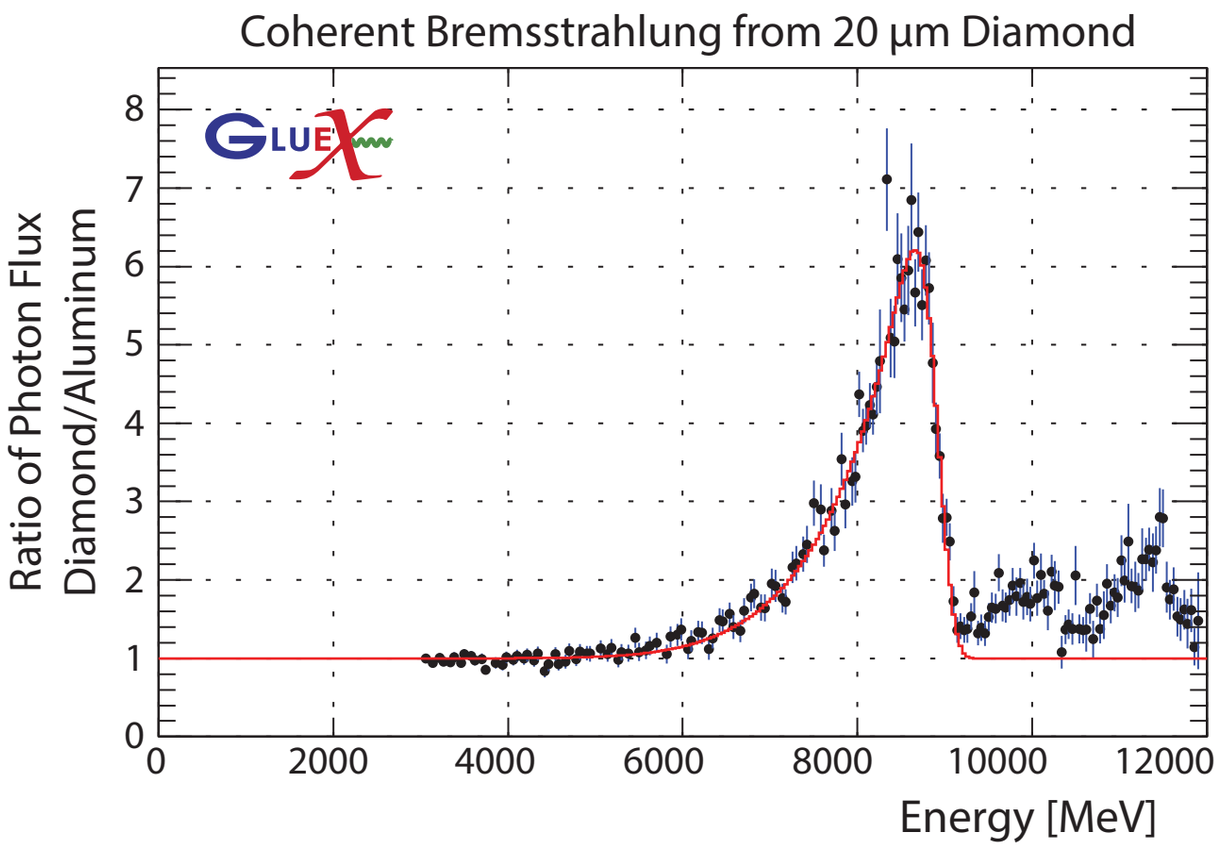
Tracking: $\sigma_p/p \approx 1\% - 5\,\%$

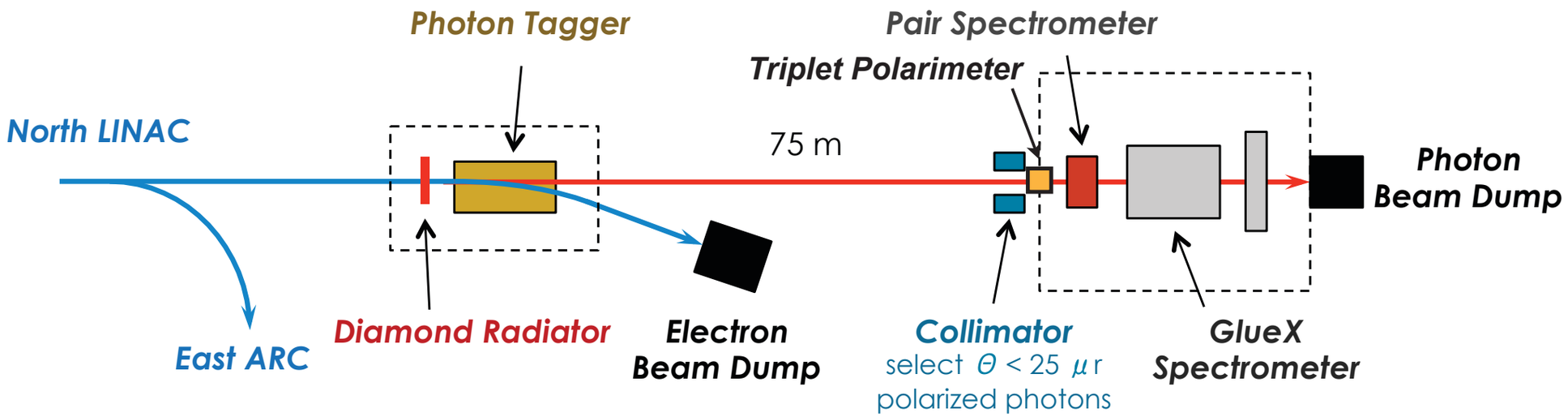
Calorimetry: $\sigma_E/E \approx 6\,\%/\sqrt{E} + 2\,\%$

Liquid Hydrogen Target



The Hall D Photon Beamline





Hall D Experimental Complex
(April 2012)

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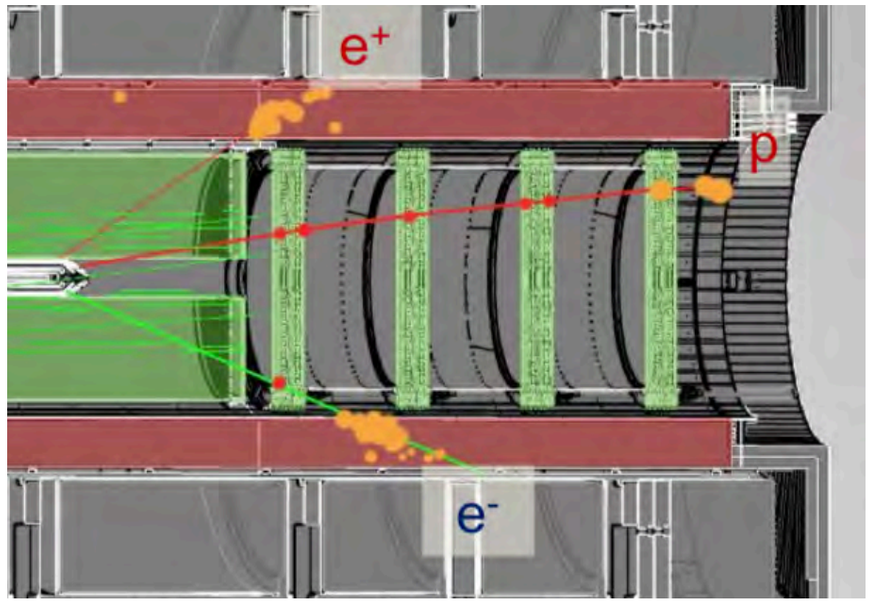
  - coherent peak luminosity: $21\ \mathrm{pb}^{-1}$
  - observation of $J/\psi \to e^+e^-$

$\gamma p \to J/\psi p$



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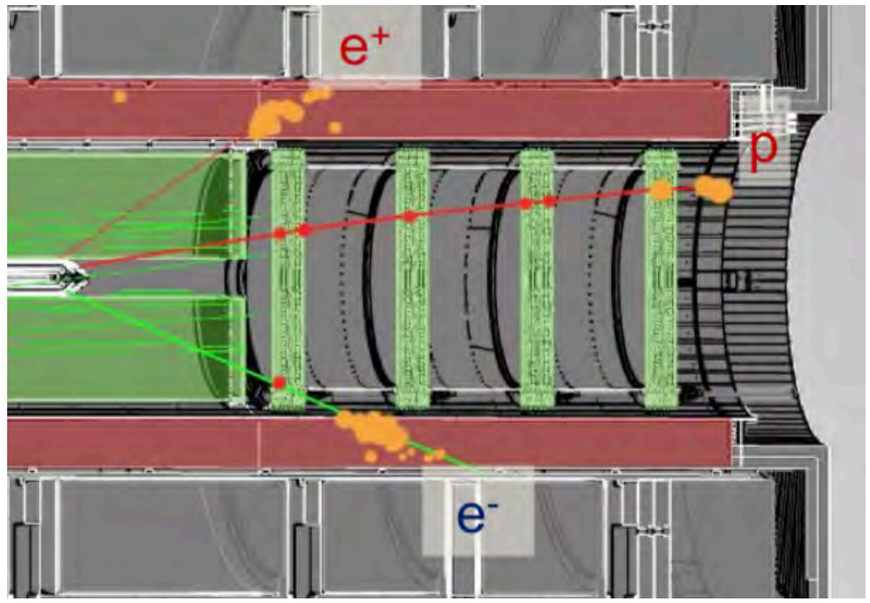

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- Spring 2019:
  - commissioning of DIRC particle ID system
  - dedicated Primakoff running: precision measurement of $\Gamma(\eta \to \gamma\gamma)$

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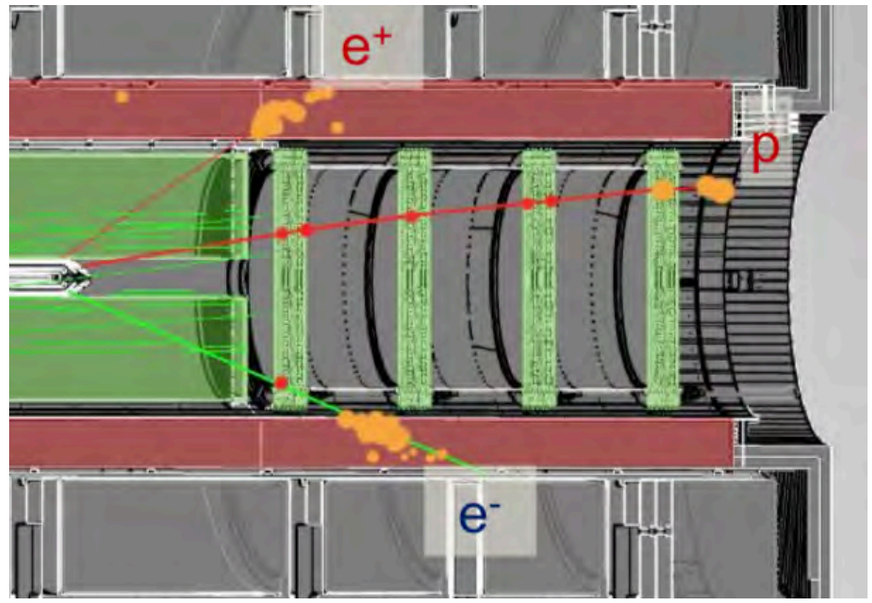

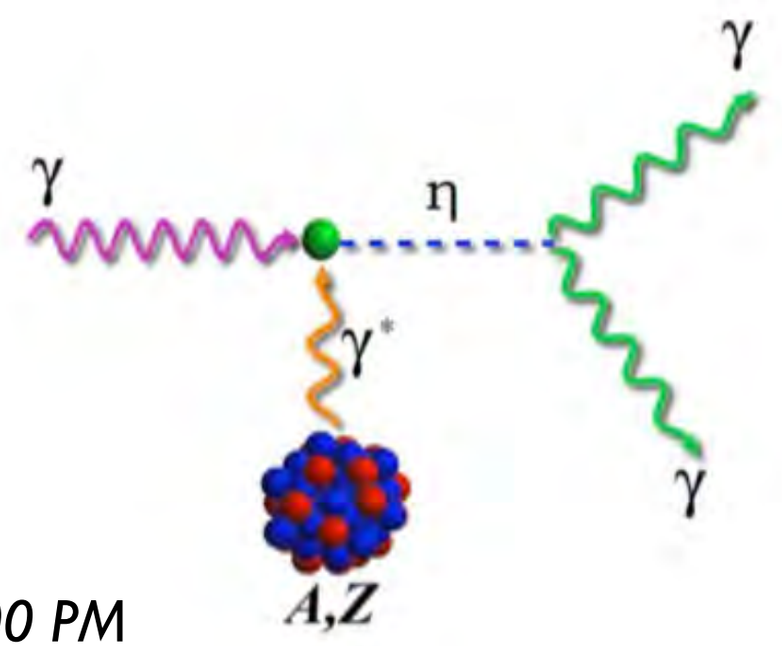

See talk by Alex Somov at 5:00 PM

Asymmetry of Pseudoscalar Production

- Angle between beam polarization plane and reaction plane ϕ is sensitive to J^P of exchange
  - $\sigma(\phi) = \sigma_0[1 - P_\gamma \Sigma \cos(2\phi)]$
  - $\Sigma = +1 \implies 0^+, 1^-, 2^+, \ldots$
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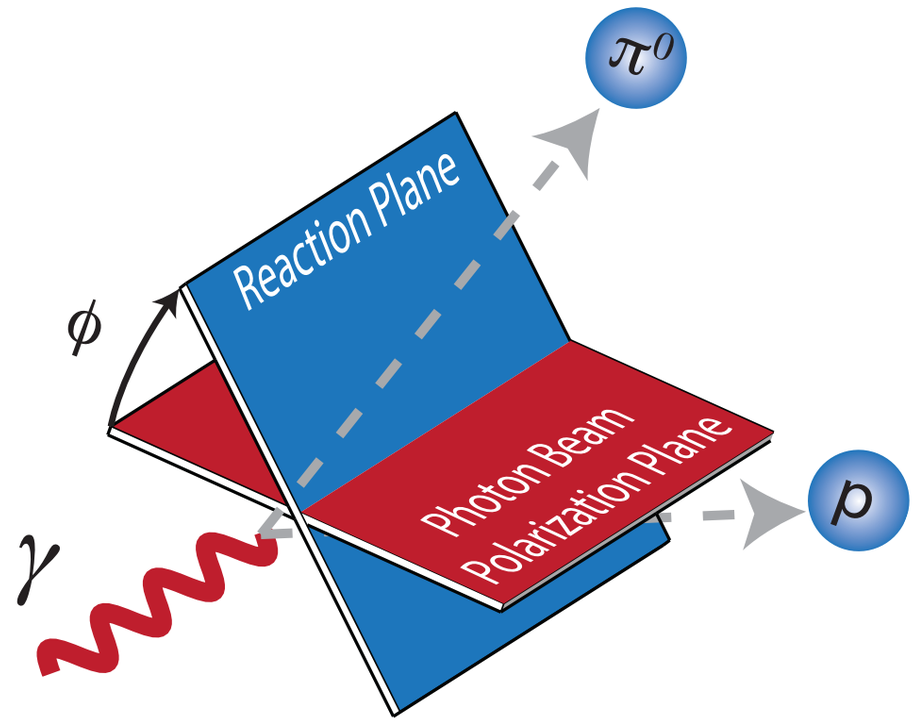

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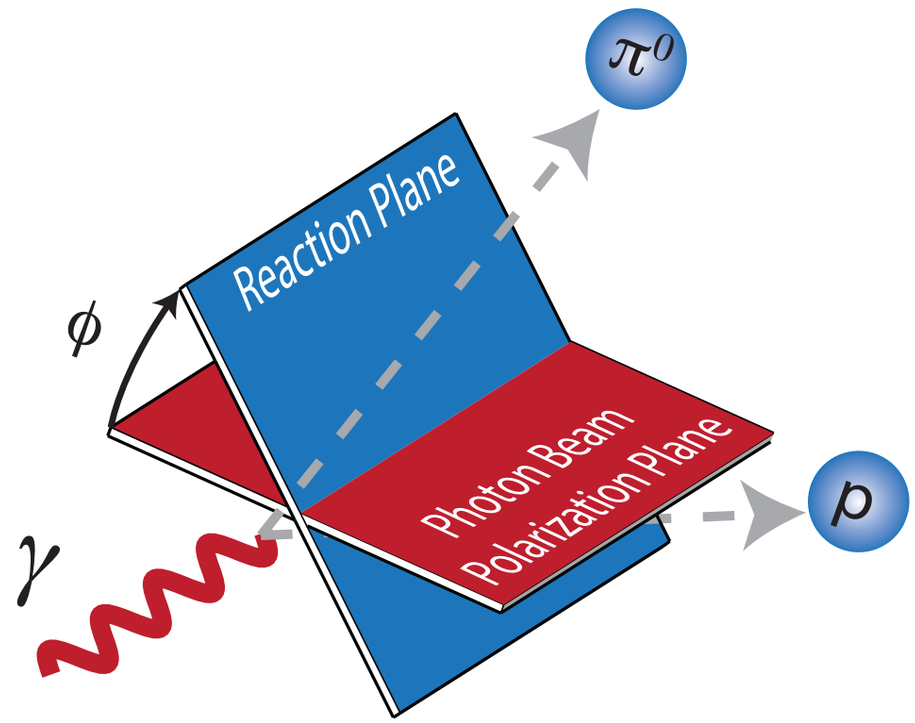

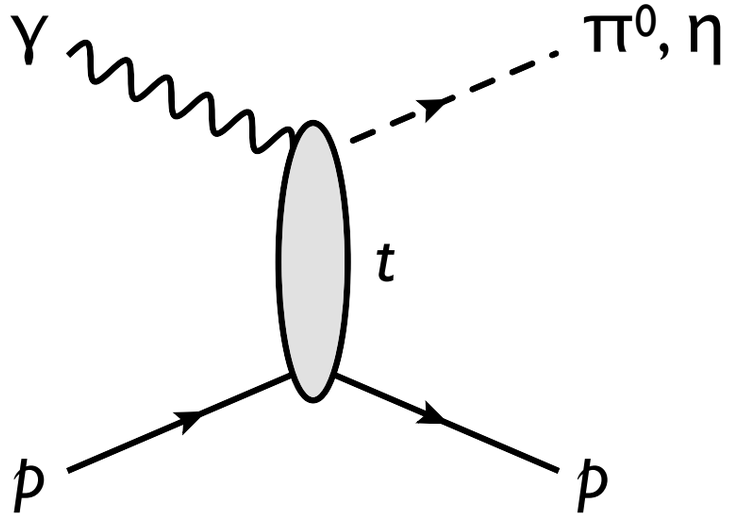

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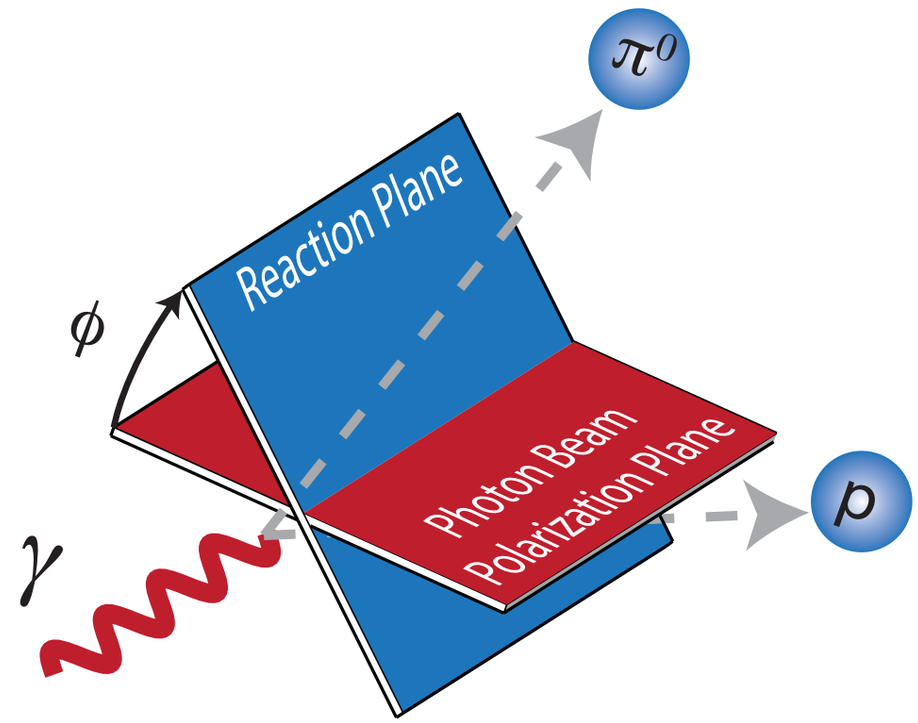
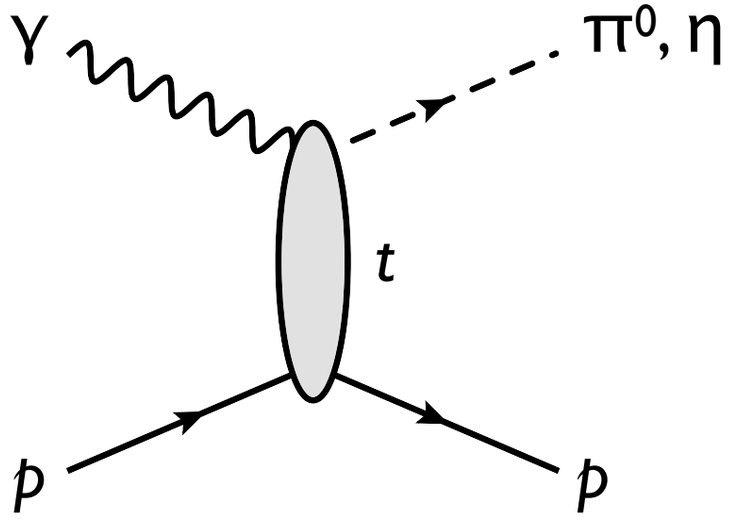
- Goal: understand and develop models for photoproduction of known mesons
  - learn about available production mechanisms
  - leverage in search for hybrid mesons





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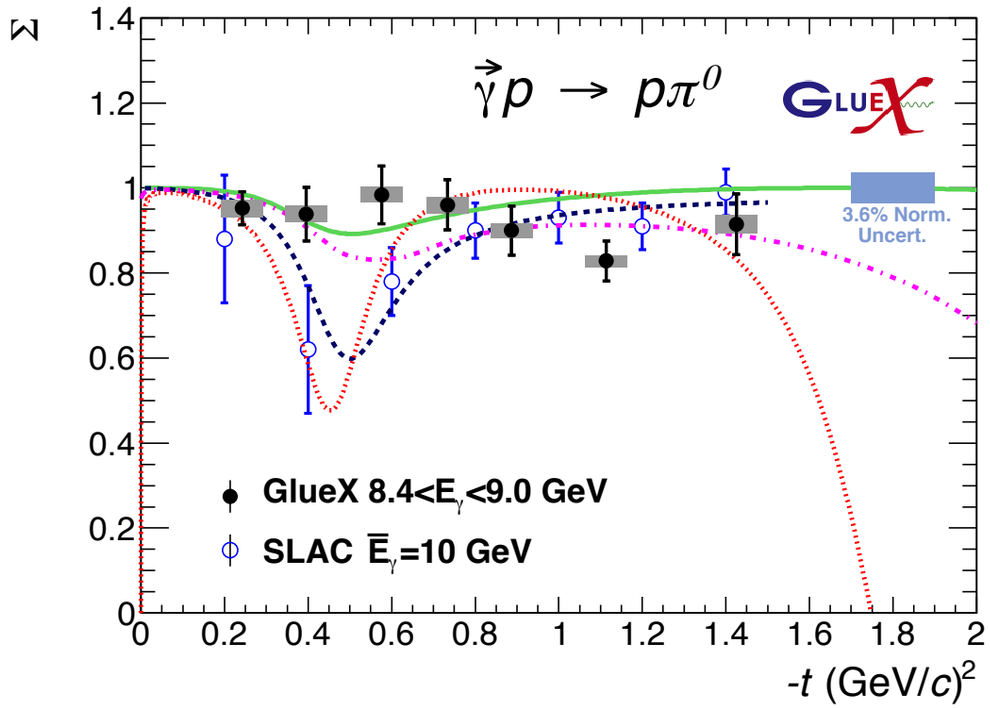
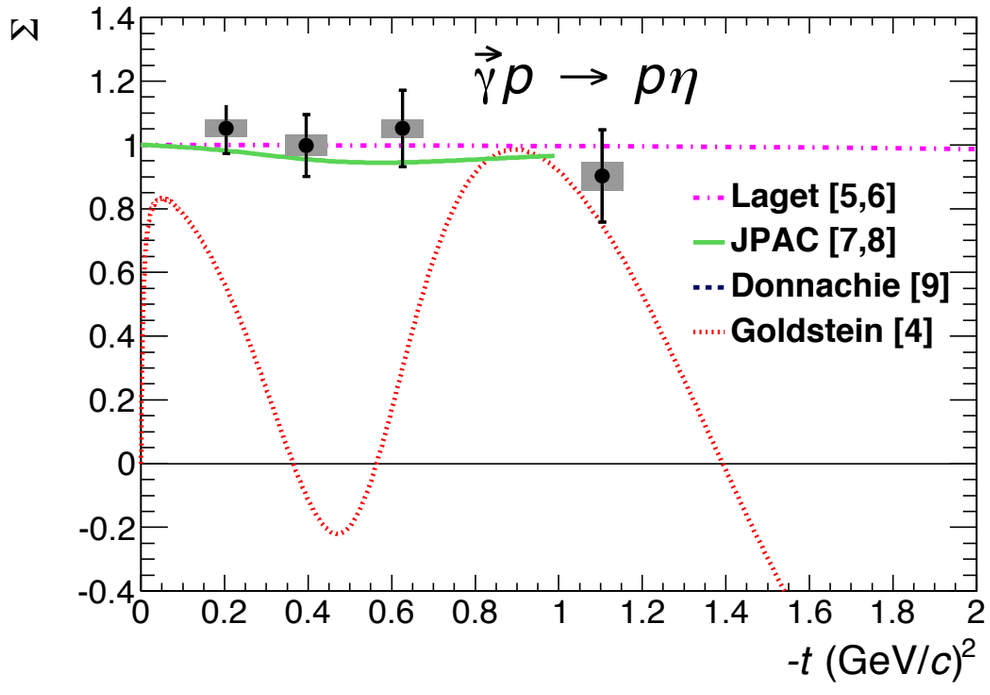
Single Pseudoscalar Production Asymmetry

- Correlated uncertainty due to polarization: < 5%
- GlueX π^0 production asymmetry
  - more precise than SLAC
  - no dip around t = 0.5 (GeV/c)^2
- First measurements of η production asymmetry
- A test of high energy t-channel production models

See new results for η and η' in talk by David Mack at 4:15 PM (arXiv: 1908:05563)

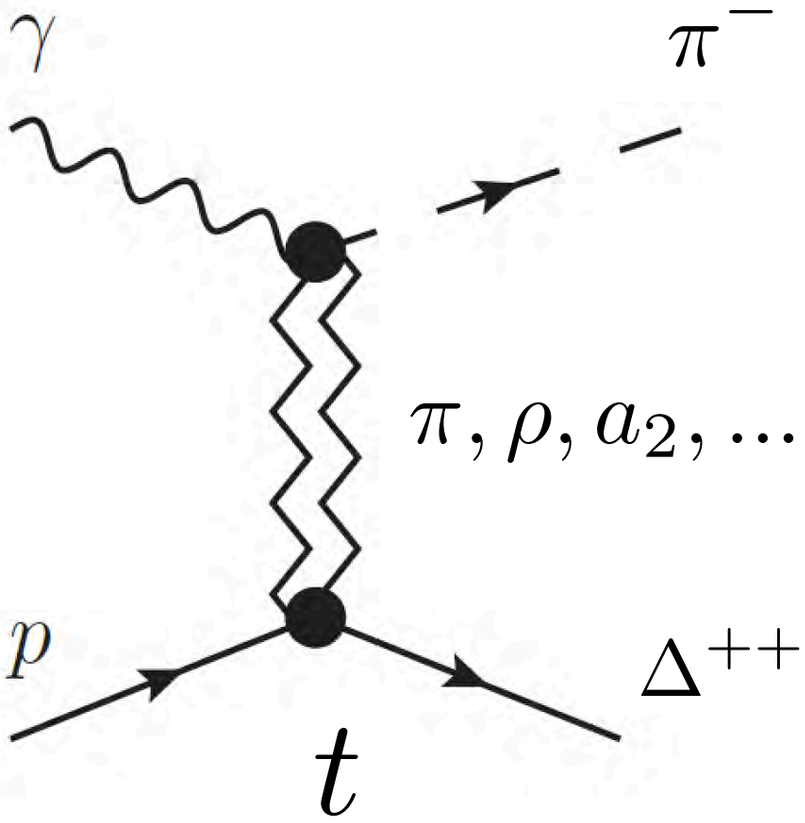


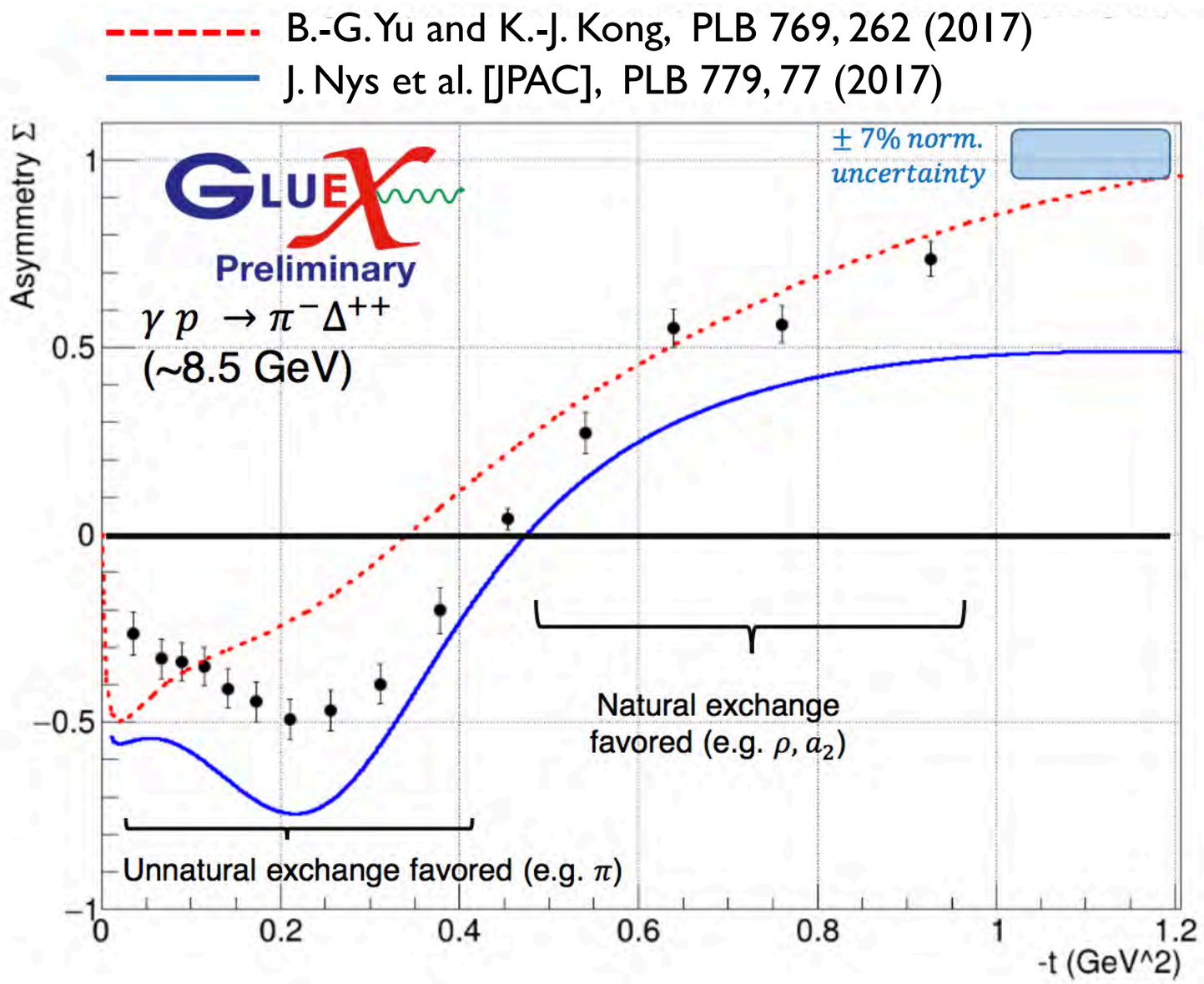


GlueX Collaboration, PRC 95, 042201(R) (2015)

Photoproduction of π^-

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





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

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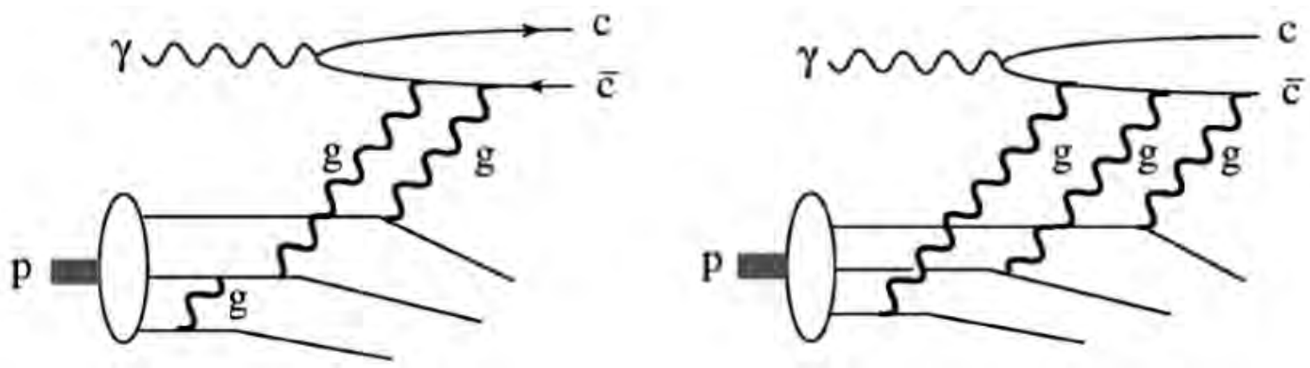
  - production dynamics encoded in the shape of cross section at threshold
  - differential cross section sensitive to gluonic content of proton



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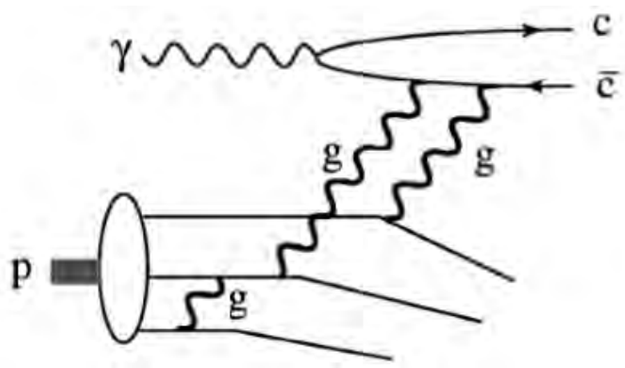

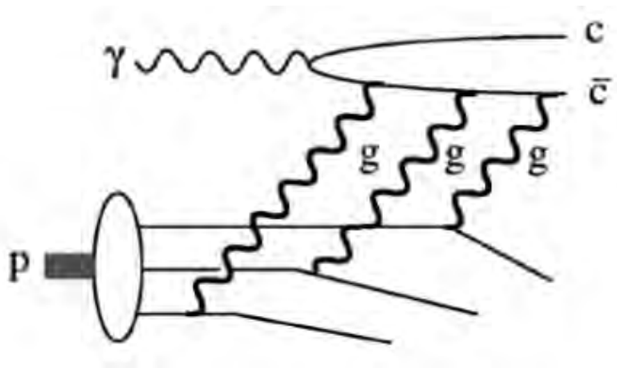

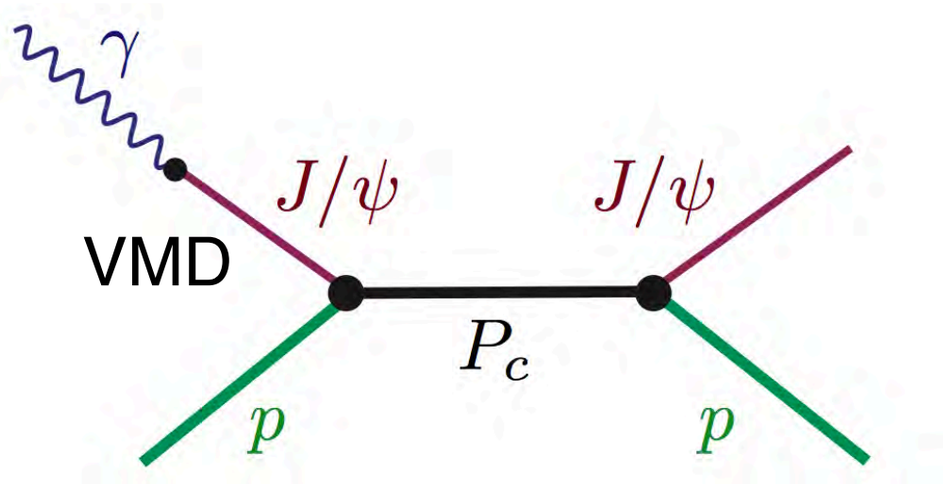

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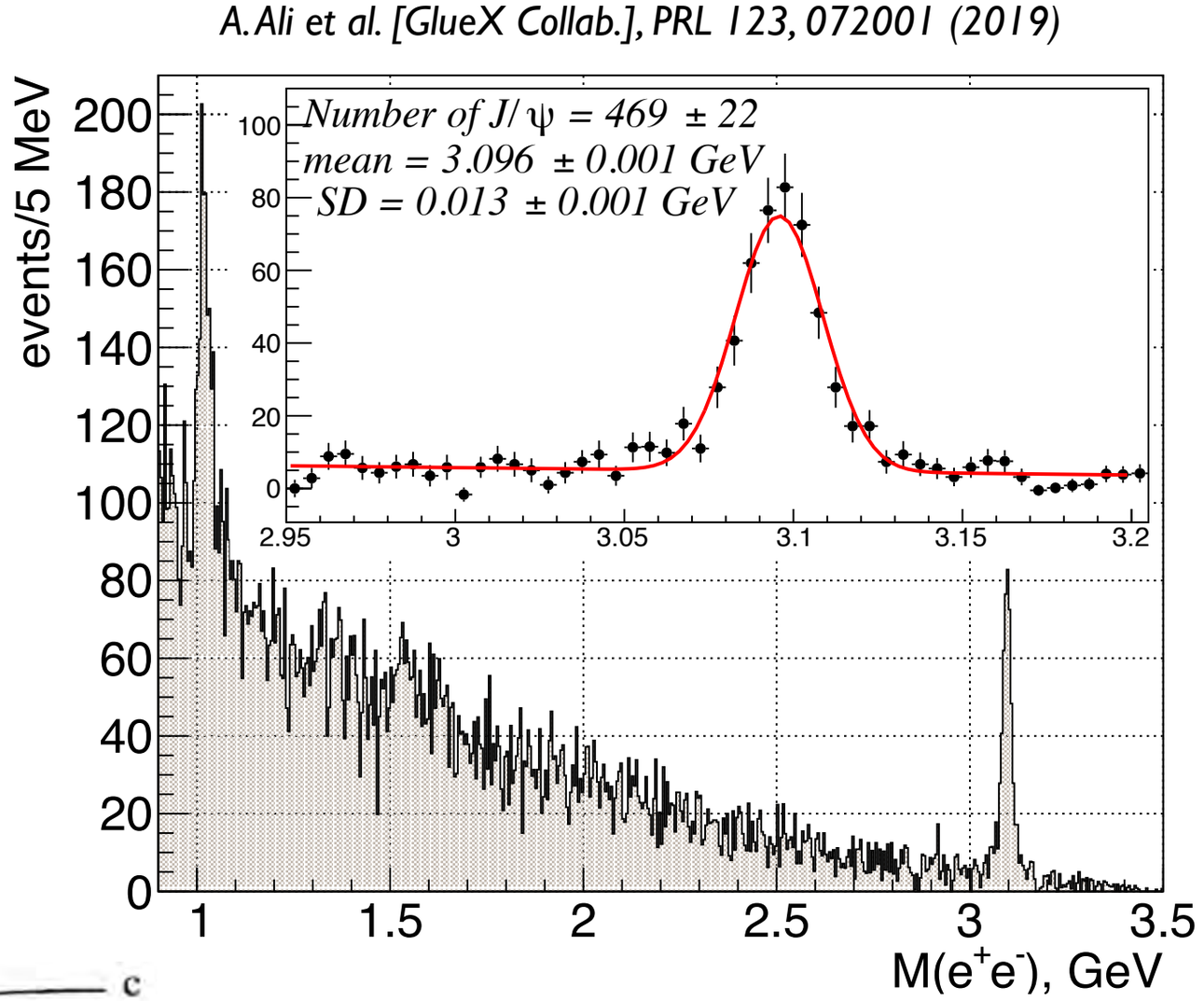
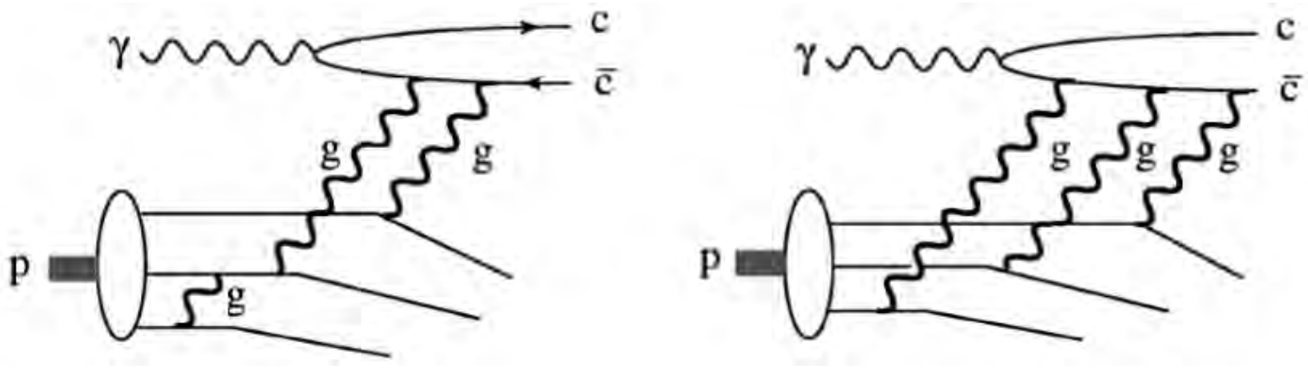
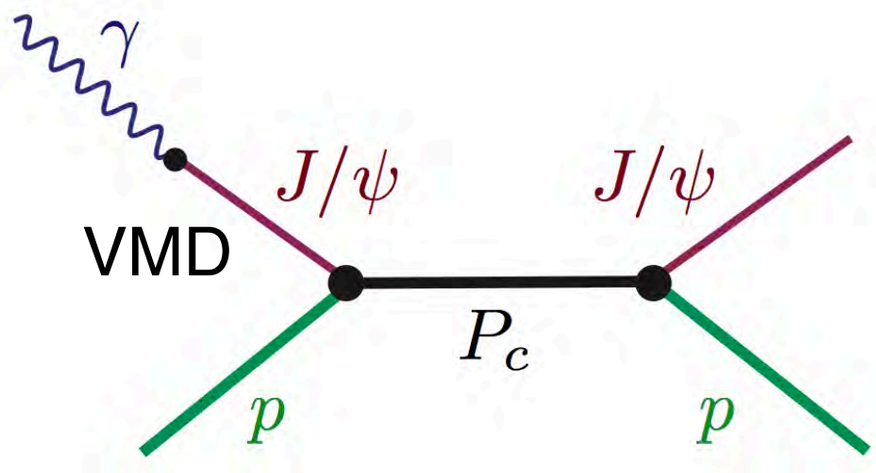
A. Ali et al. [GlueX Collab.], PRL 123, 072001 (2019)







See talk by Sean Dobbs at 4:15 PM

Looking Forward: The Road to Hybrid Searches

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Guizhou, China

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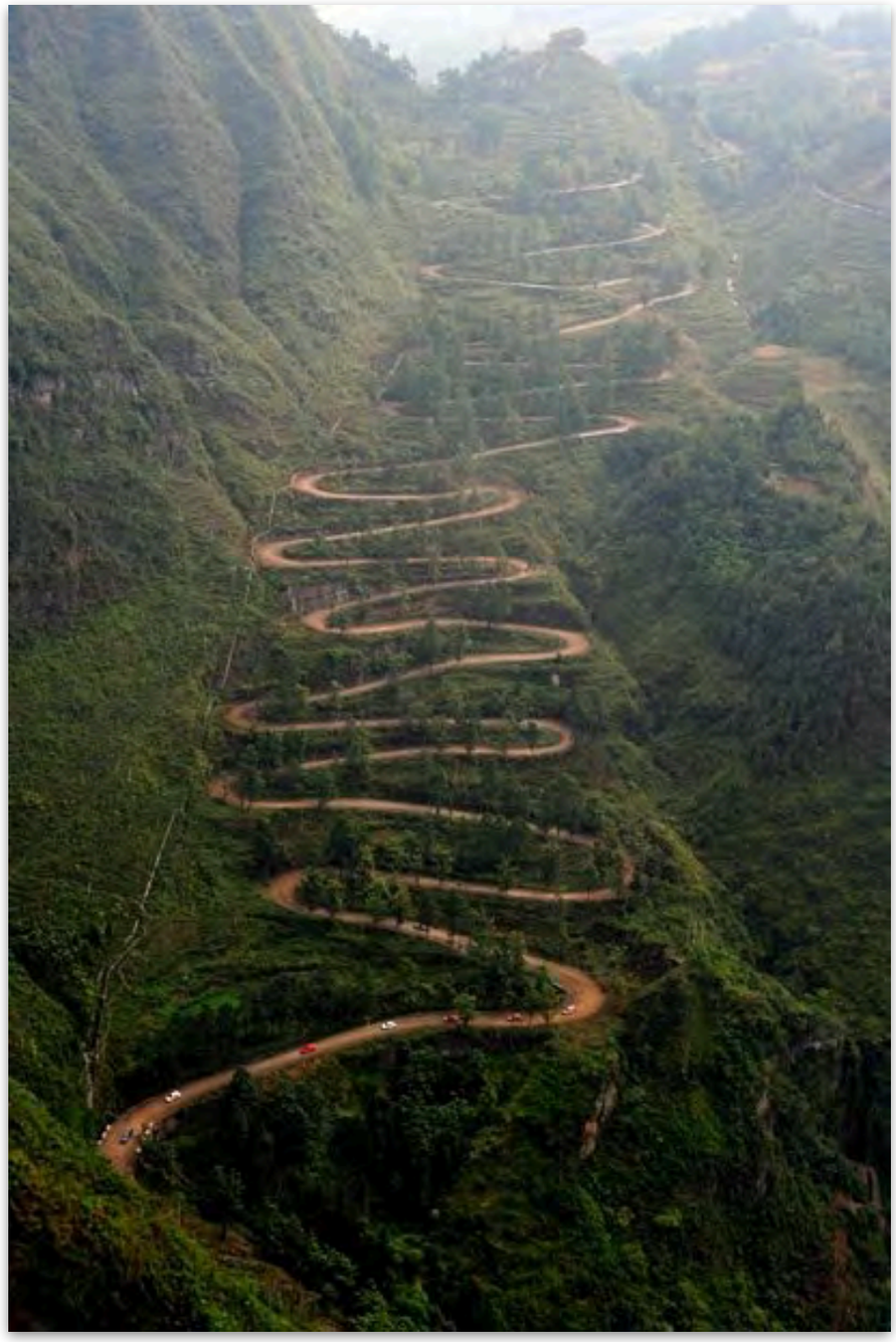
- Simultaneously collect additional data with improved detector capability and intensity



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

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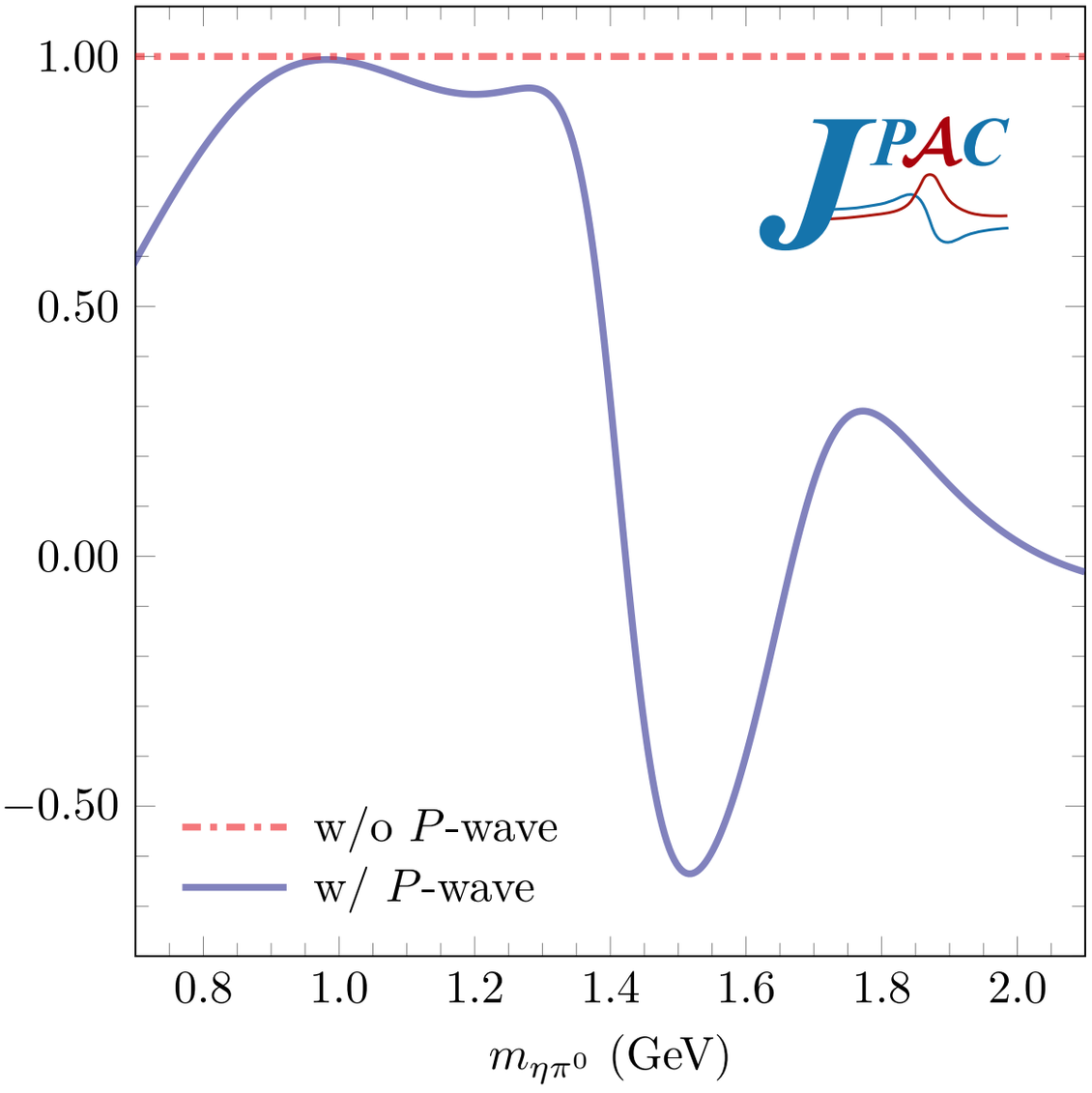
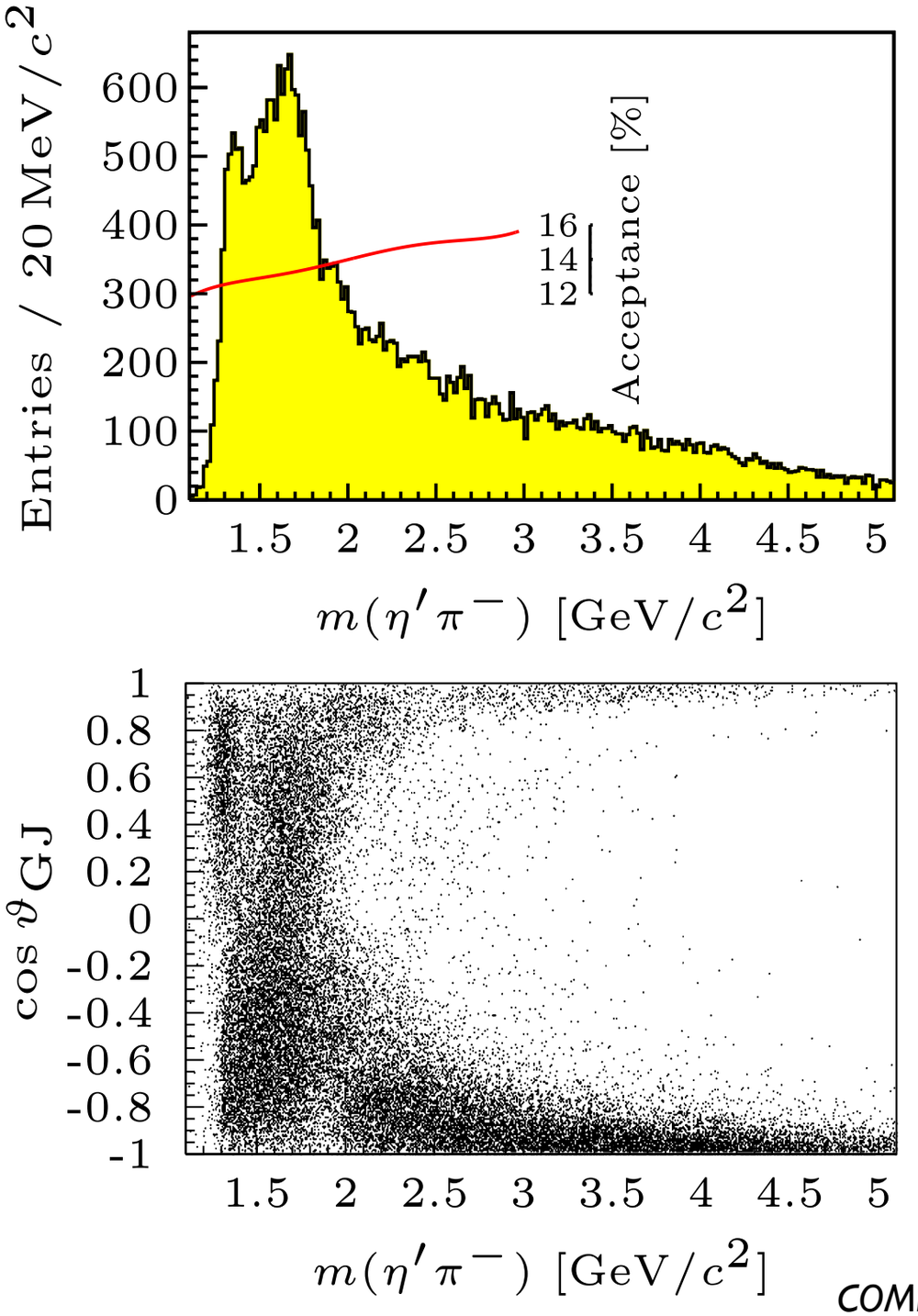
- Linear beam polarization provides additional observables with enhanced sensitivity
  - Collaboration with Joint Physics Analysis Center (JPAC) to develop analysis techniques

V. Mathieu *et al.* [JPAC], arXiv:1906.04841



See talk by Colin Gleason on Wednesday 21-Aug at 11:10 AM

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



COMPASS Collab., PLB 740, 303 (2015)

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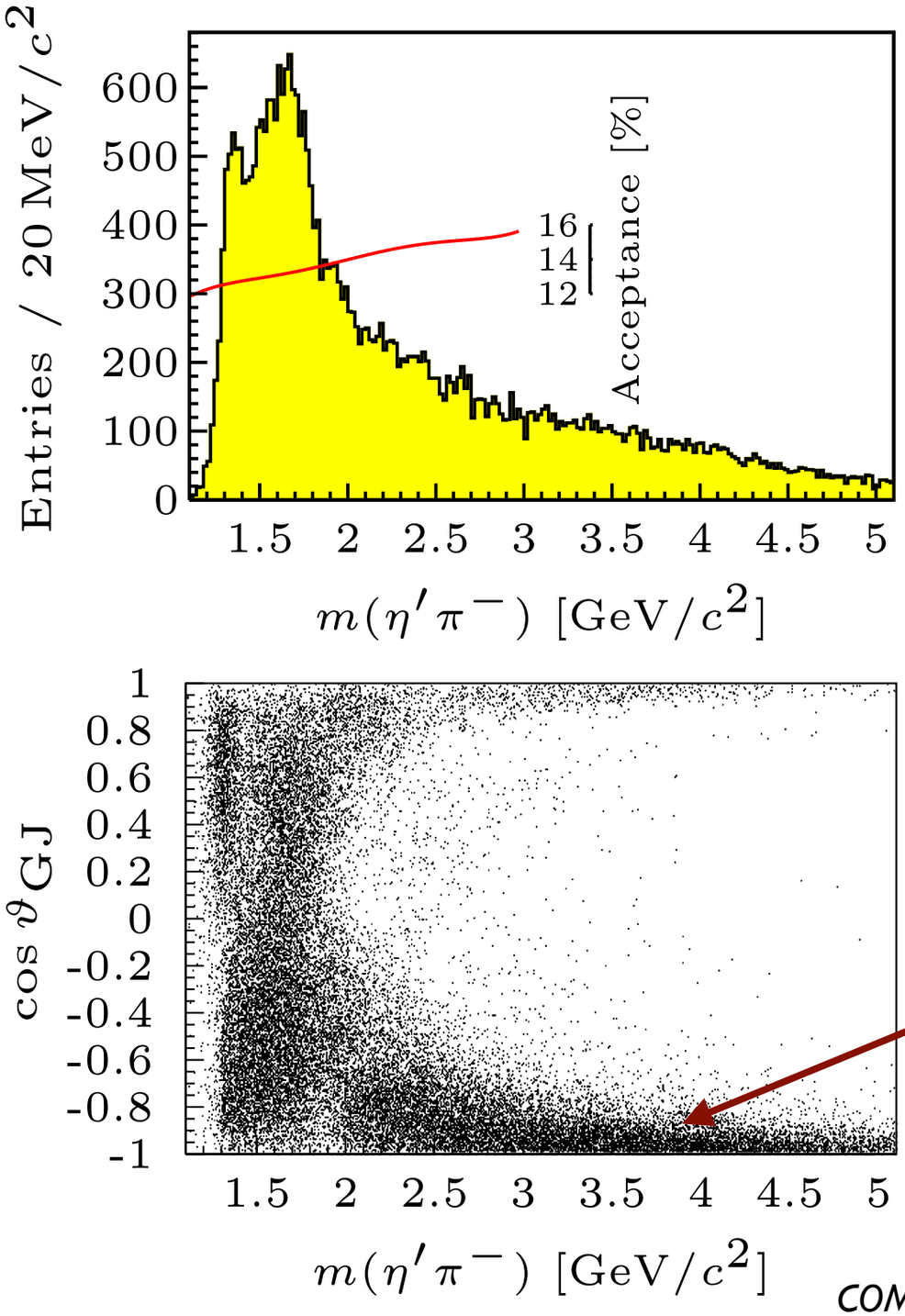
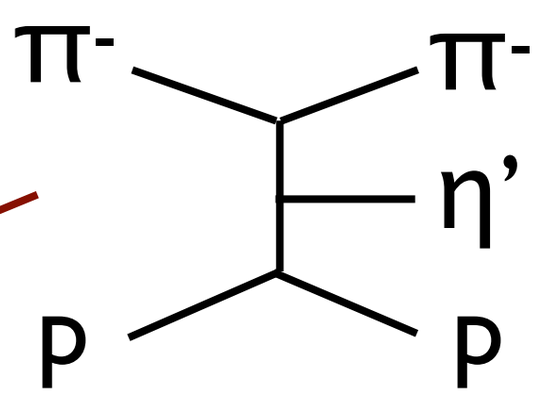
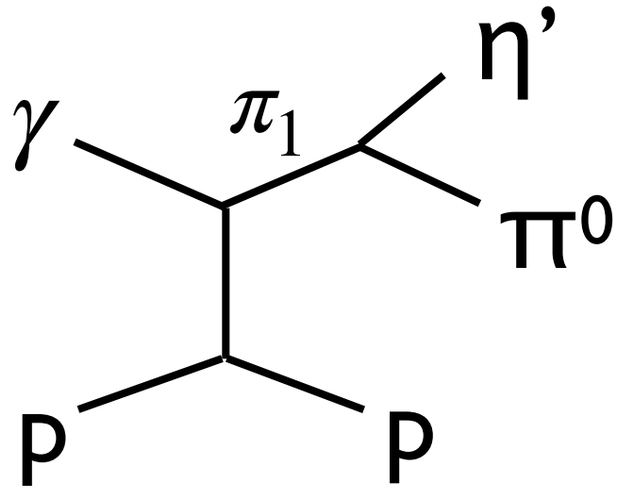


"Deck effect"



Exotic P-wave Signal



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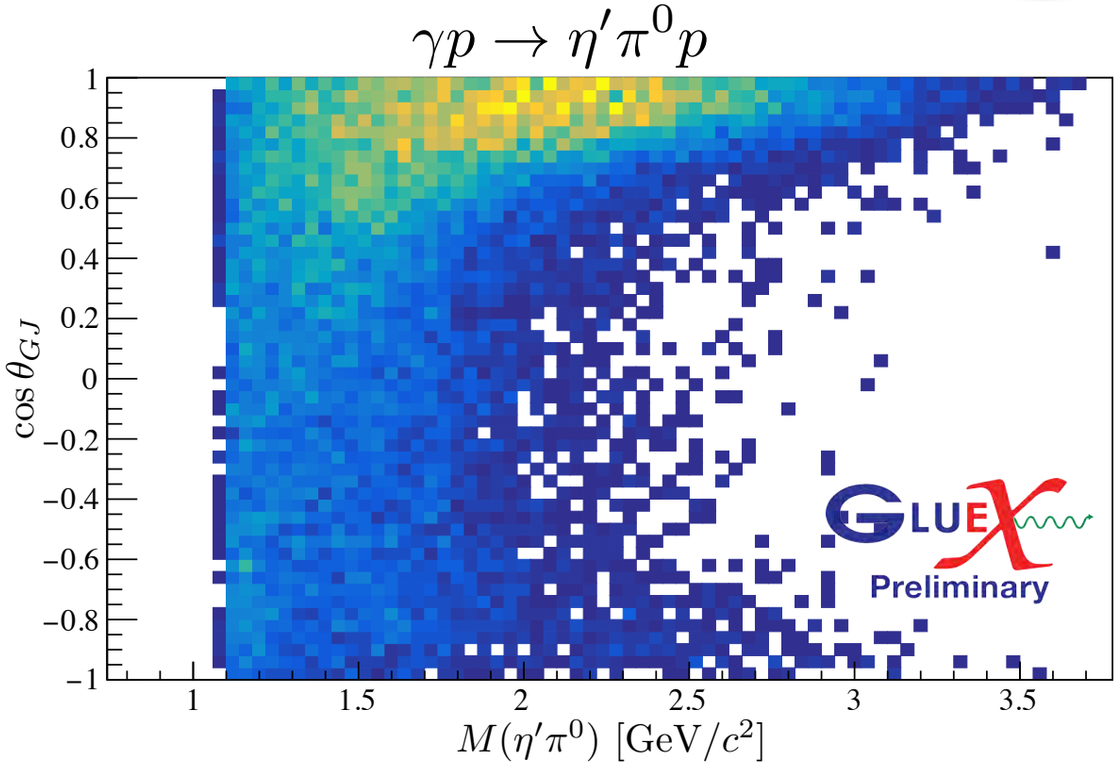

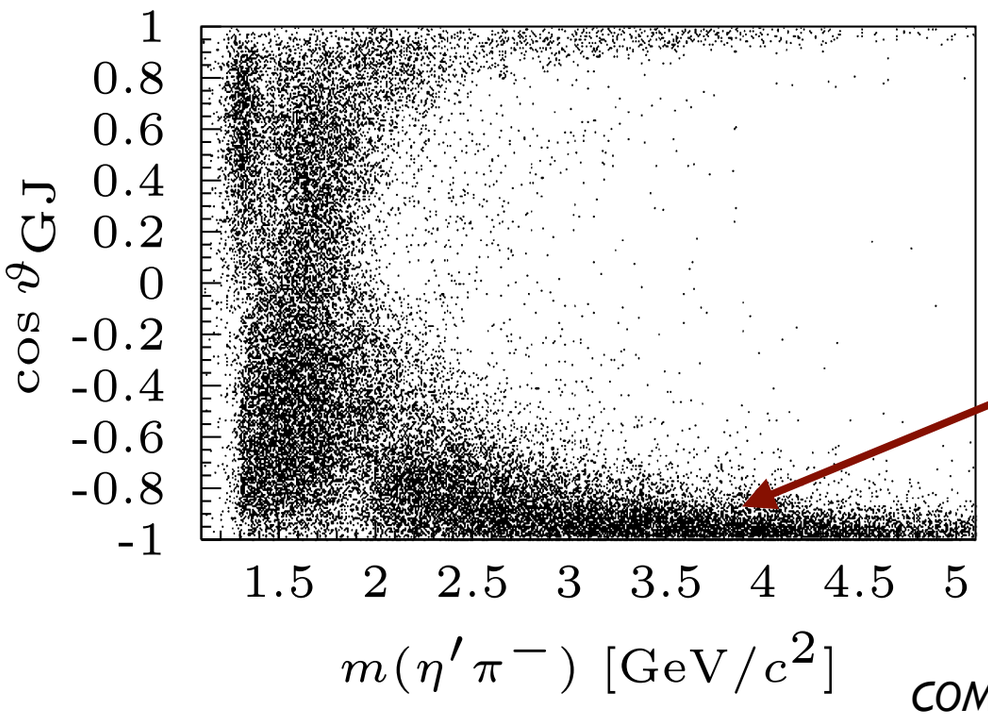

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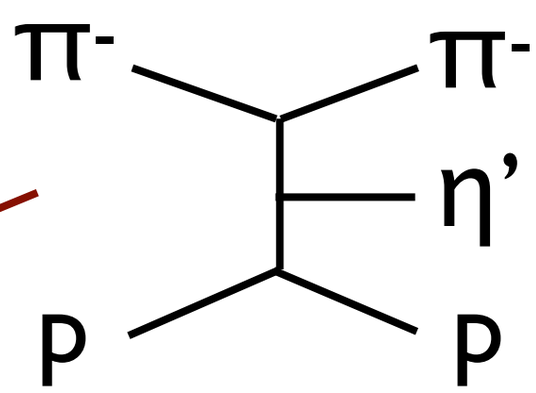

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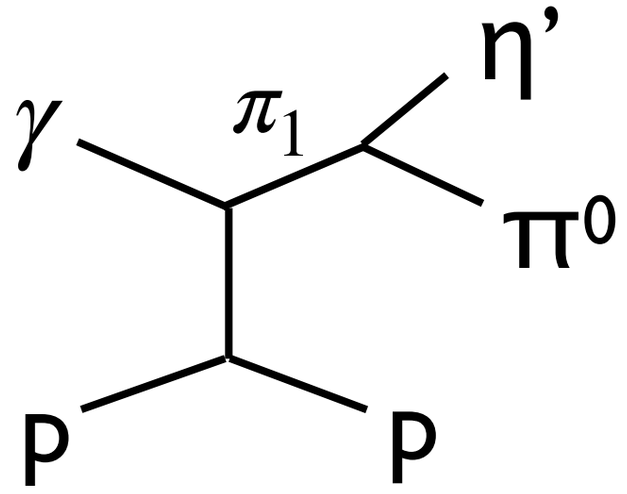

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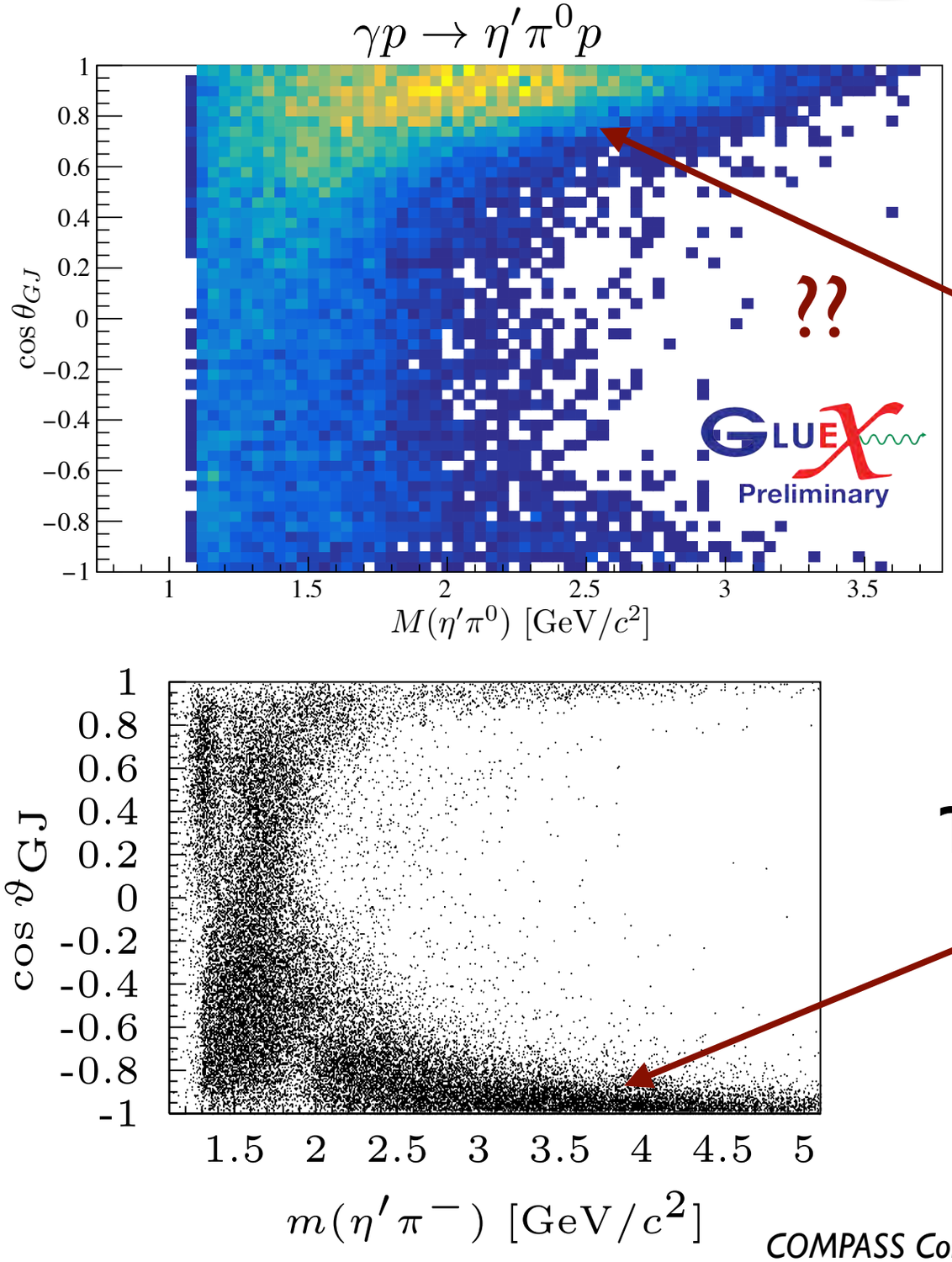
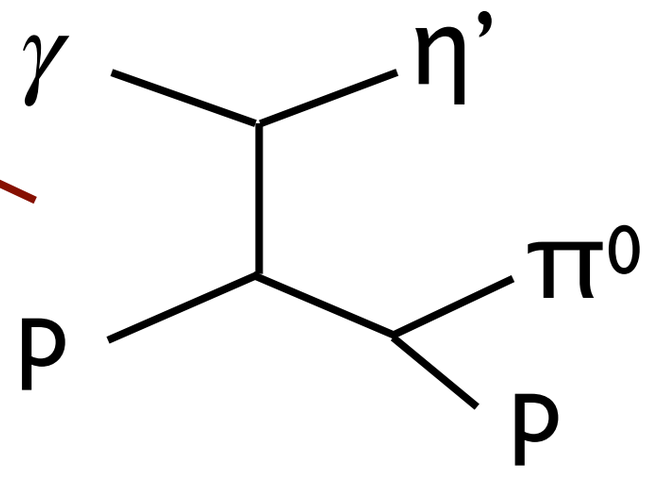
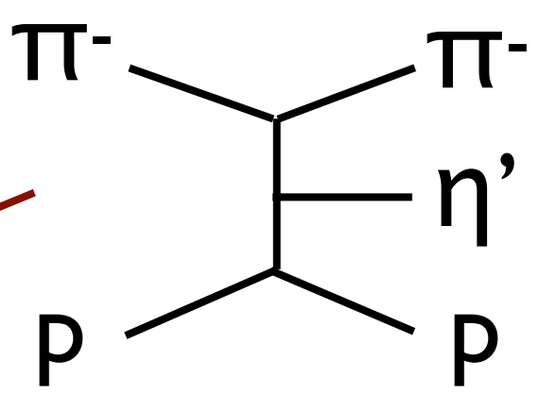




Do we observe consistent resonant P-wave signals in the presence of different physics backgrounds?

"Deck effect"



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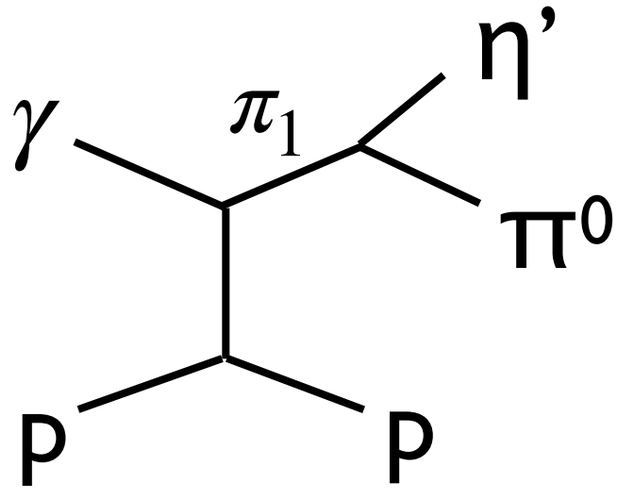
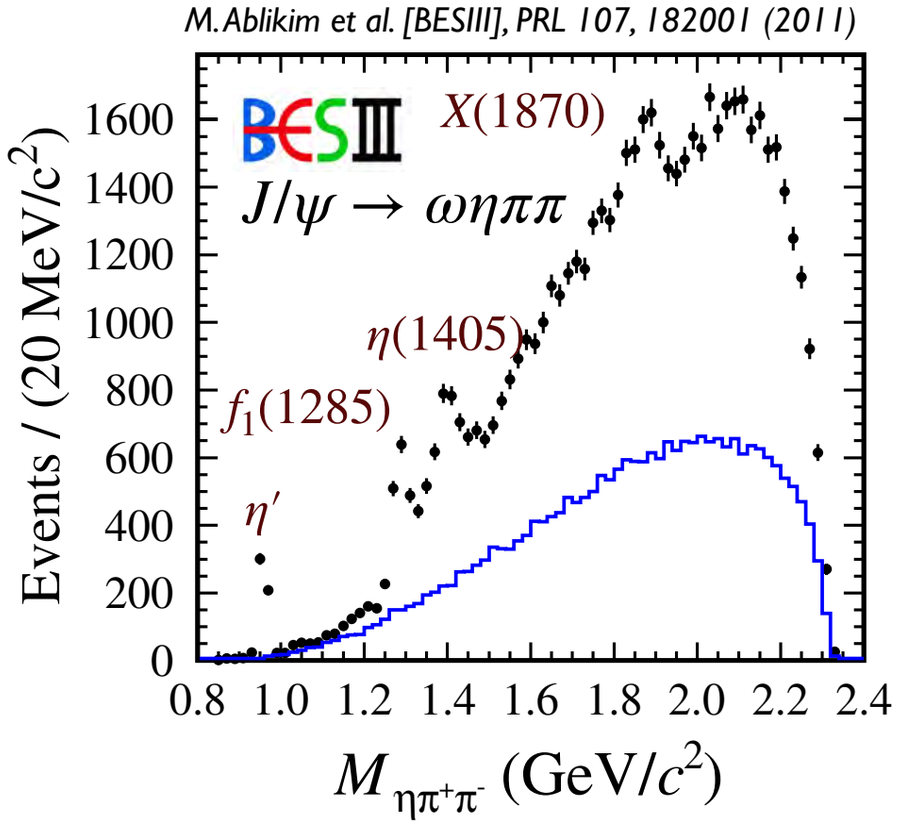


COMPASS Collab., PLB 740, 303 (2015)

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"



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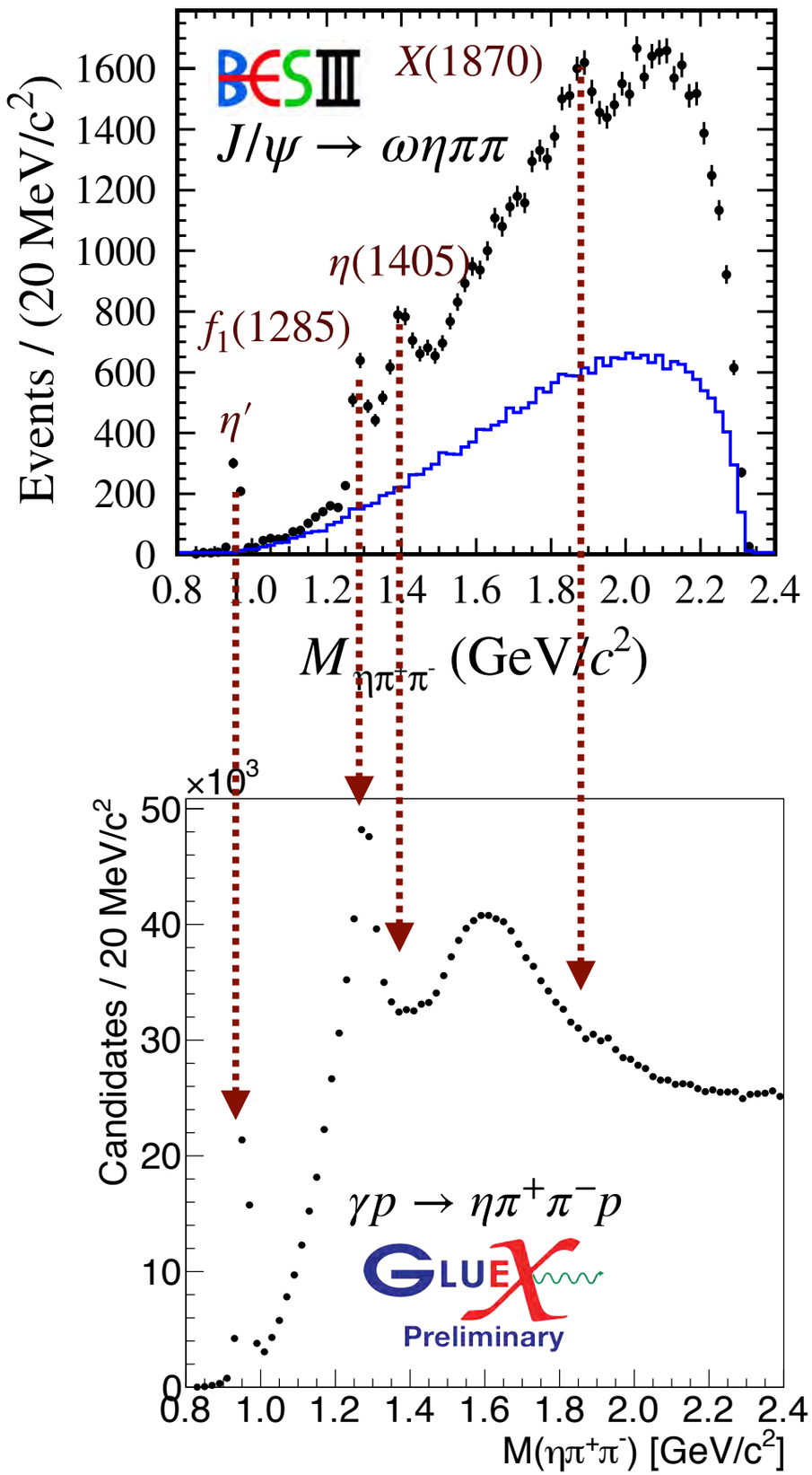
M. Ablikim et al. [BESIII], PRL 107, 182001 (2011)



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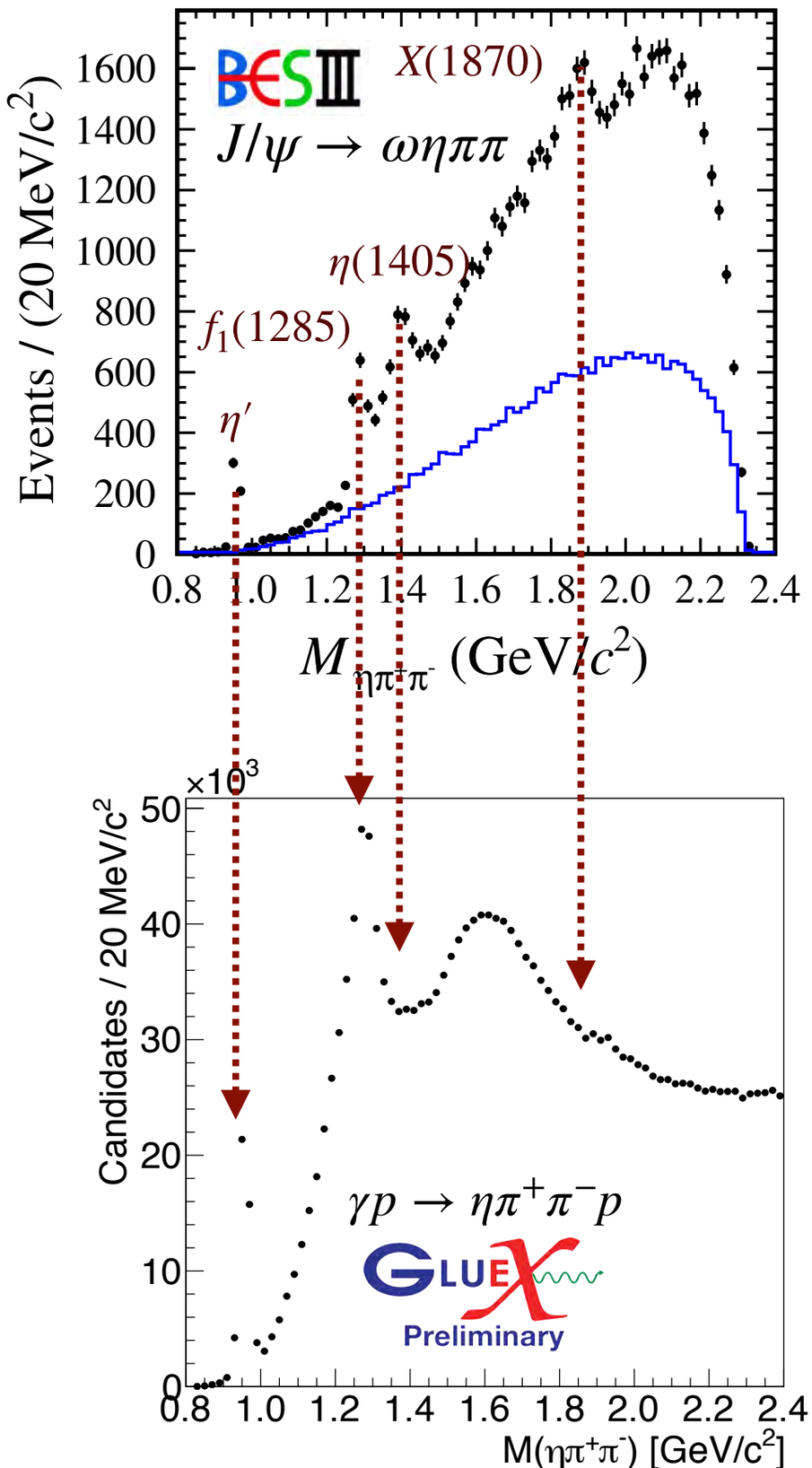
- For 0^{-+} states, the $\eta(1405)$ appears to be suppressed with respect to the η' in photoproduction.
  - what does it mean?

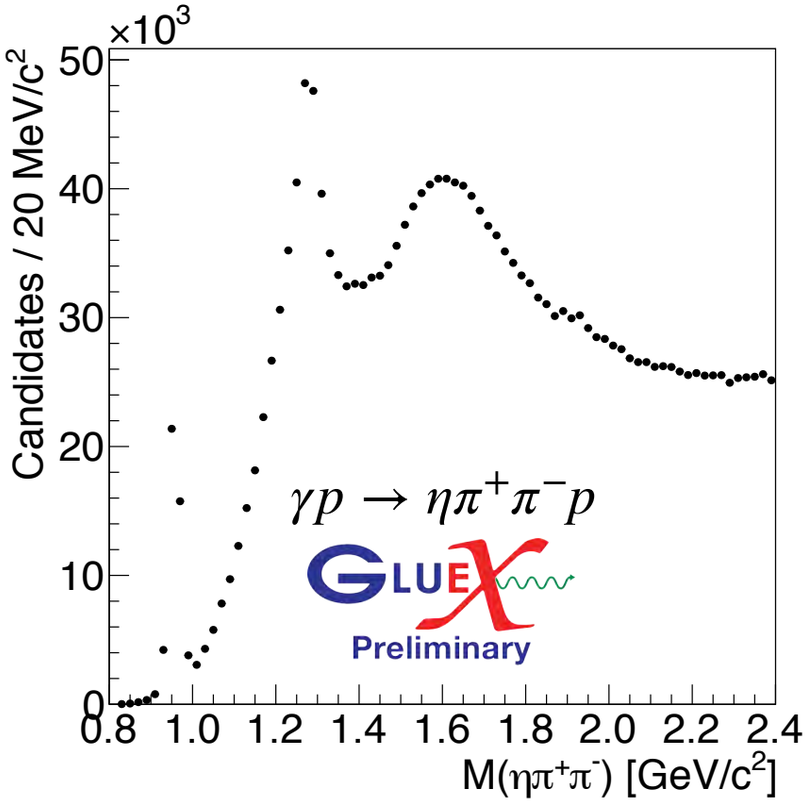
M. Ablikim et al. [BESIII], PRL 107, 182001 (2011)



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

Complementary Production

- Naively expect enhanced photoproductuction of vector (1^{--}) mesons
  - vector meson dominance



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- In e^+e^- collisions…
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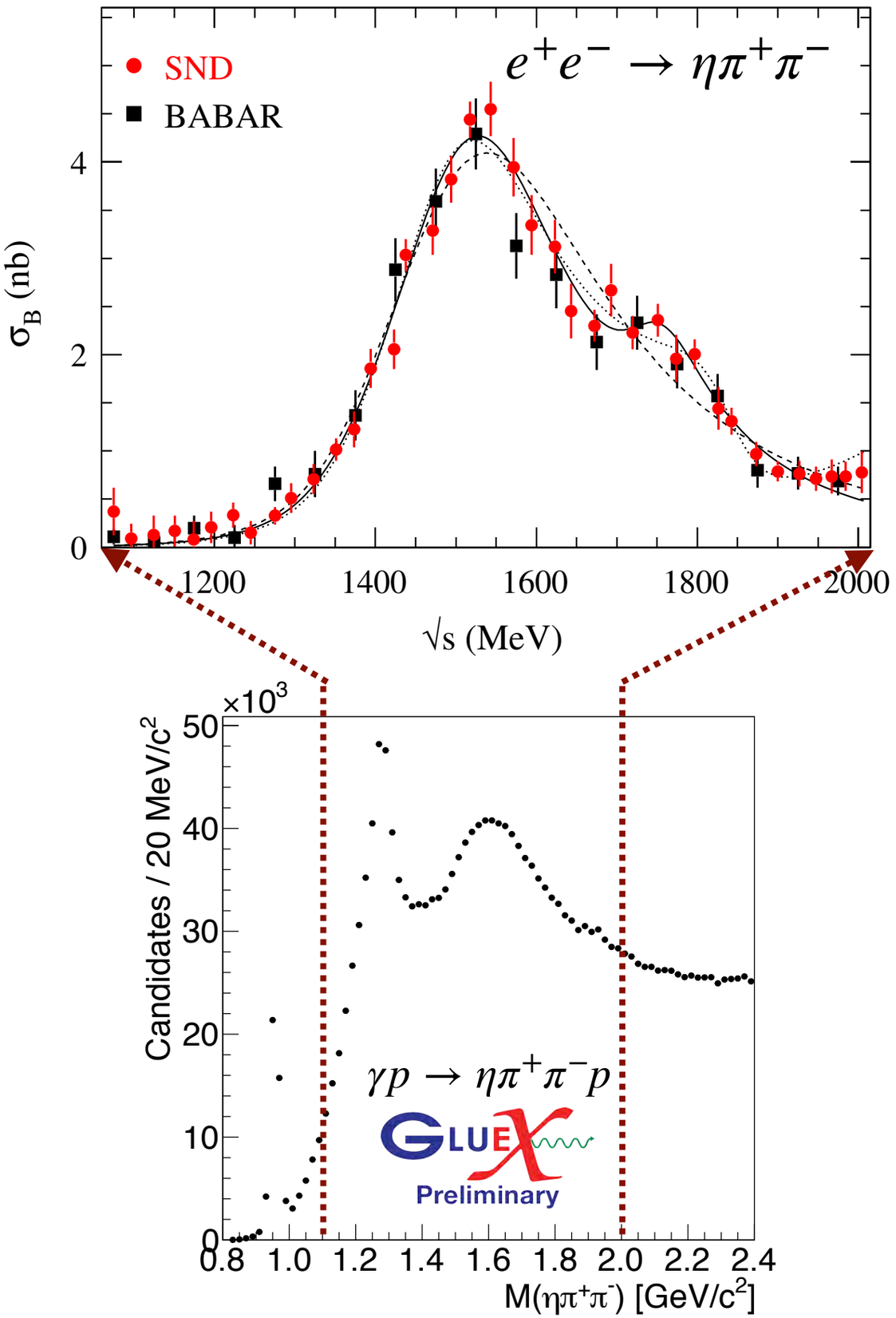
  - $\eta\pi^+\pi^-$ system described by interference of $\rho(1450)$ and $\rho(1700)$

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



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- In e^+e^- collisions…
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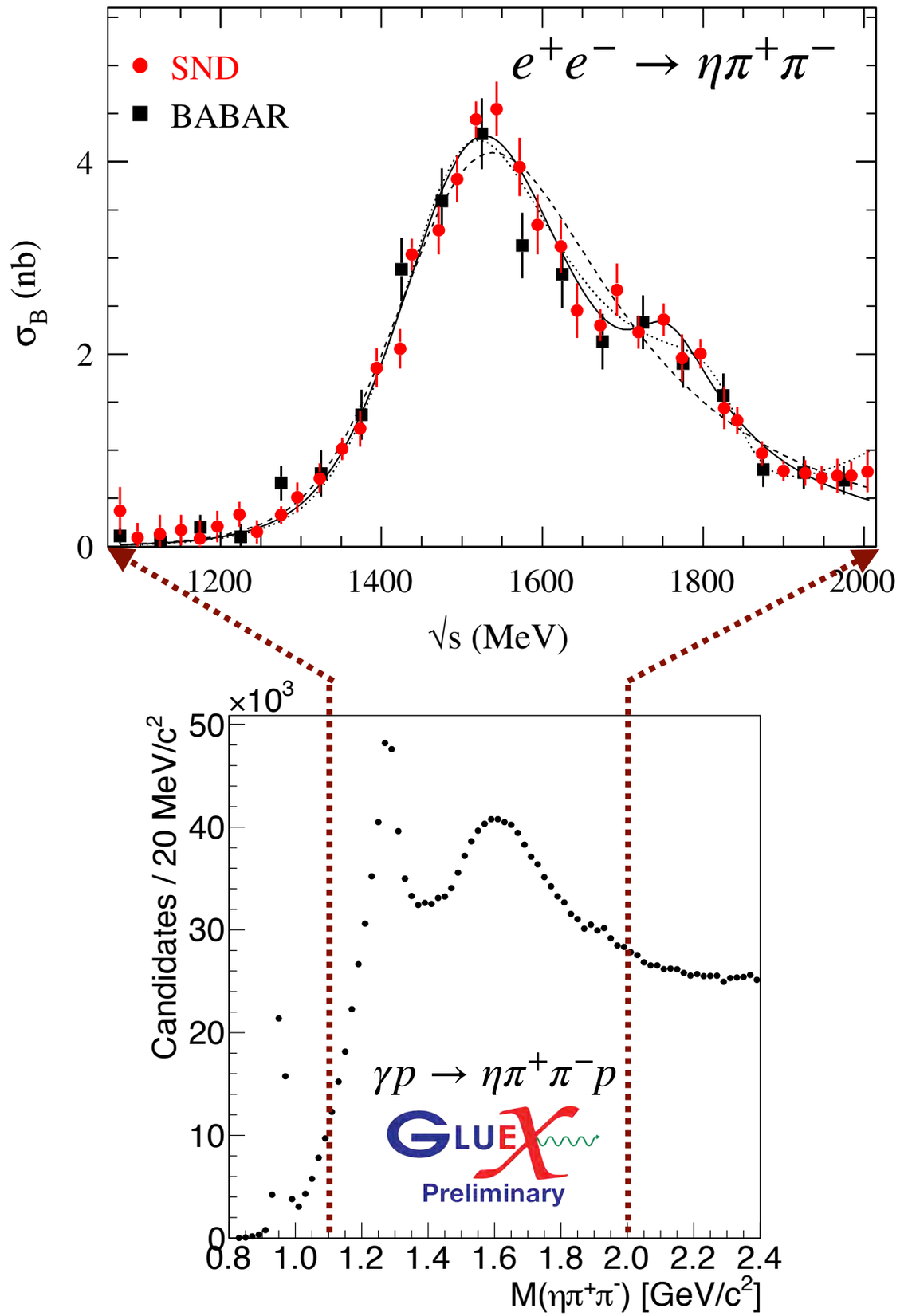
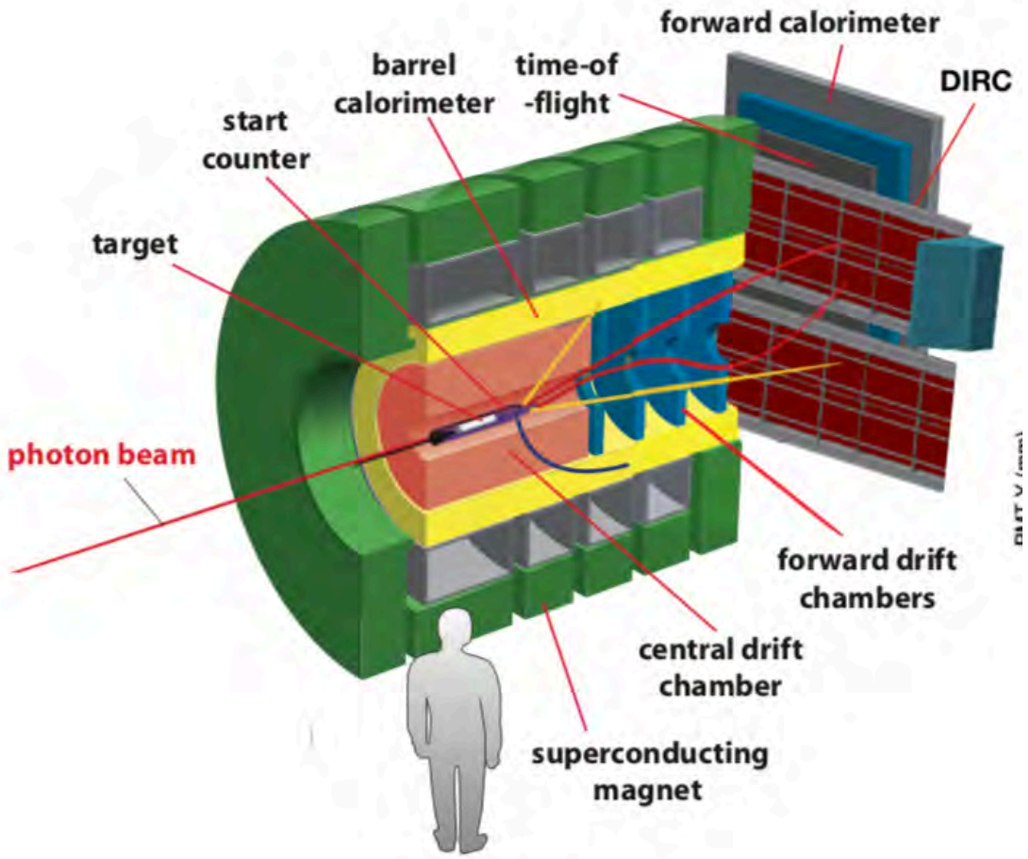
- Do data from GlueX provide a consistent picture of these states?
- GlueX data should permit an exploration of the $\eta\pi\pi$ system with unprecedented statistical precision (including searches for η_1 and b_2 hybrids)

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

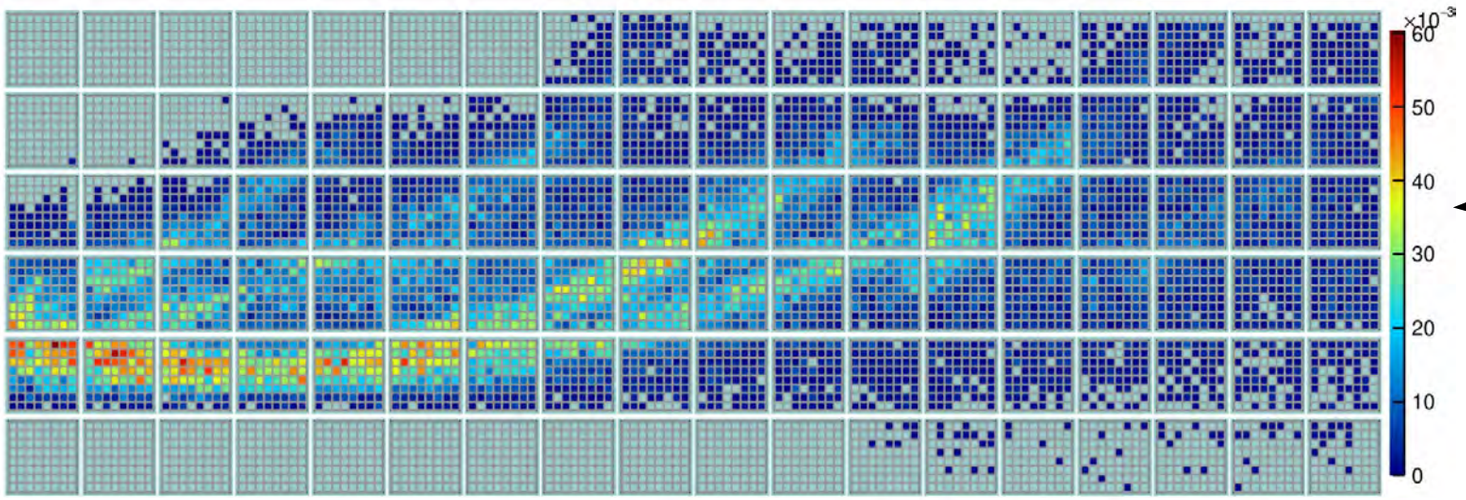


The Near Future

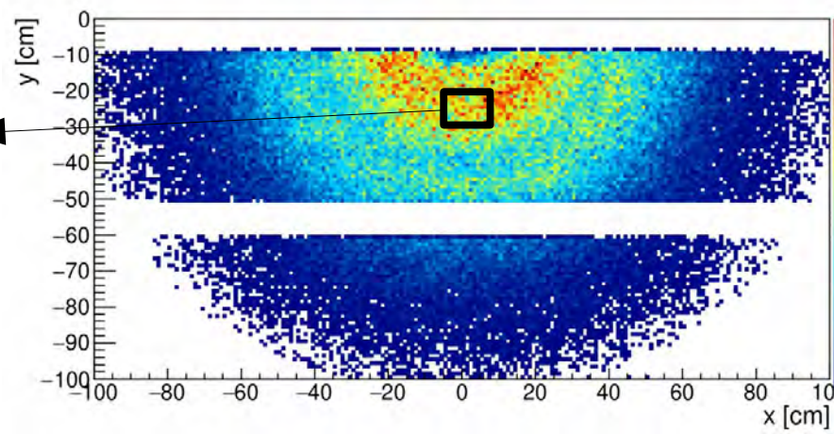
- Upgrade PID using synthetic quartz radiators from the BaBar DIRC
  - new multi-anode PMT photon camera
  - partially commissioned in 2019
- Start a new data taking campaign in fall 2019
  - factor of 4-5 more data
  - emphasis on $s\bar{s}$ states and strange baryons



[3.8,4.2] GeV/c pions



Hit positions on the radiator wall:



Summary

- The GlueX Collaboration has collected a unique data set for exploring the spectrum of light hadrons with high statistical precision.
  - What role do gluons play in determining the properties of hadrons?
  - complementary energy regime to *XYZ* spectroscopy: how do gluonic degrees of freedom evolve with quark mass?

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- The GlueX Collaboration has collected a unique data set for exploring the spectrum of light hadrons with high statistical precision.
  - What role do gluons play in determining the properties of hadrons?
  - complementary energy regime to *XYZ* spectroscopy: how do gluonic degrees of freedom evolve with quark mass?
- Key feature of the GlueX experiment: linearly polarized photon beam
  - access to production mechanisms (results: *PRC 95, 042201(2015); arXiv:1908.05563*)
  - enhanced sensitivity for hybrid searches
  - complementary production environment to existing data: π-beam, B decay, $c\bar{c}$ decay, $p\bar{p}$ annihilation, e^+e^- annihilation, *etc.* (results on P_c: *PRL 123, 072001 (2019)*)

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- A systematic approach to exotic searches is underway
  - new understanding of production of conventional states
  - building theoretical and experimental analysis framework
  - the data and environment are new, but many of the challenges are not: collaboration with other experiments and phenomenologists will be essential