



# Recent Results From the GlueX Experiment

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2018/11/13





# Outline

- Physics motivation
- Photoproduction and GlueX overview
- GlueX light spectroscopy program
  - Focus: studying production mechanisms
  - Final states of interest
- Additional physics
  - $J/\psi$  threshold production
  - Baryon sector



# Hadron Spectroscopy

- Many QCD states allowed beyond observed mesons and baryons
  - Theorized since 1960's

A SCHEMATIC MODEL OF BARYONS AND MESONS \*

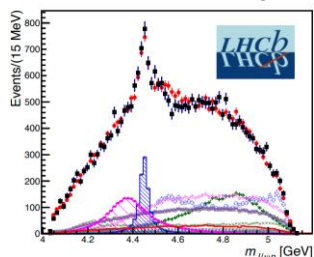
M. GELL-MANN

California Institute of Technology, Pasadena, California

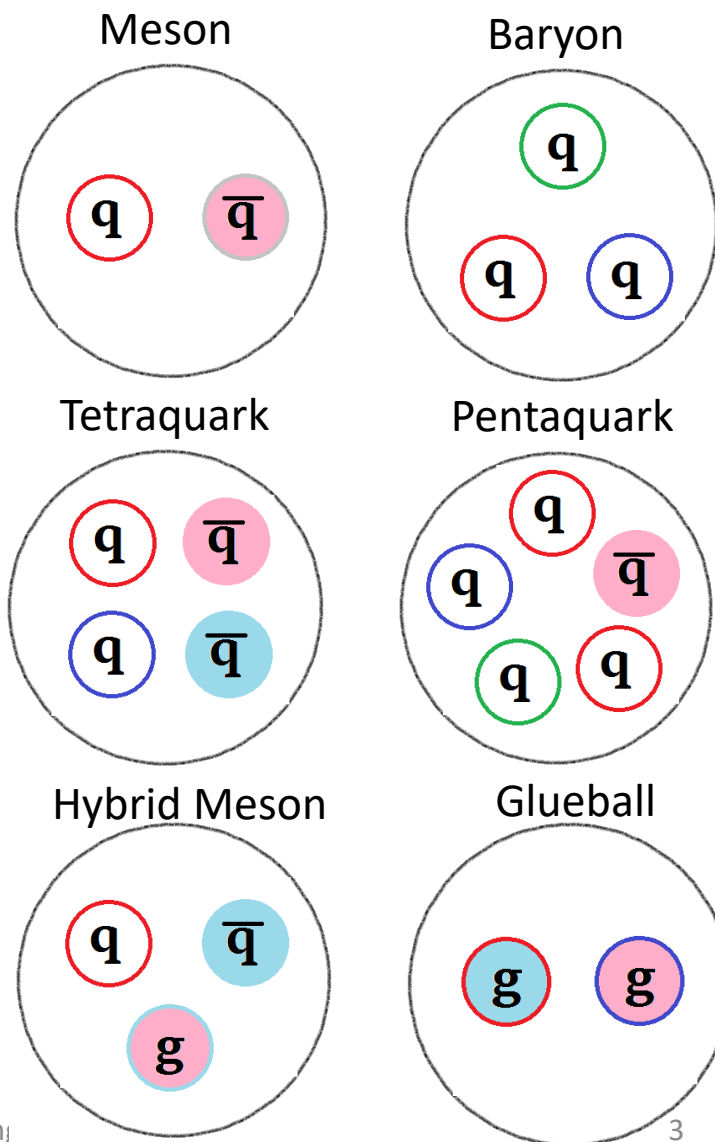
... Baryons can now be constructed from quarks by using the combinations (qqq), (qqqq $\bar{q}$ ), etc., while mesons are made out of (q $\bar{q}$ ), (qq $\bar{q}\bar{q}$ ), etc. ...

Phys. Lett. 8 (1964) 214

- Growing body of evidence for tetraquark, pentaquark candidates in recent years

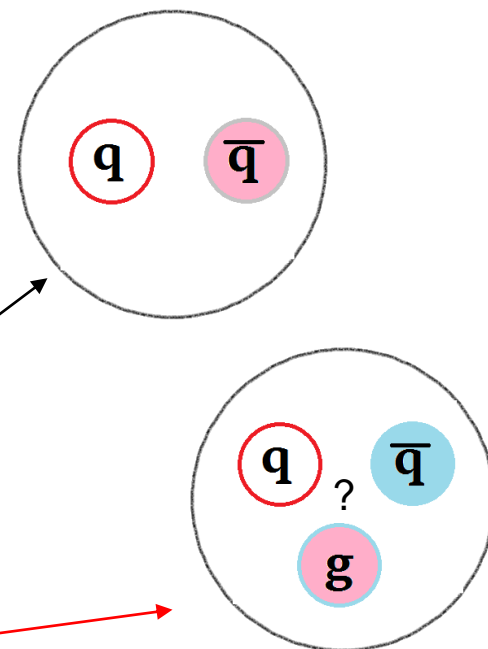


LHCb collab., PRL 115, 072001 (2015)



# Constructing Mesons

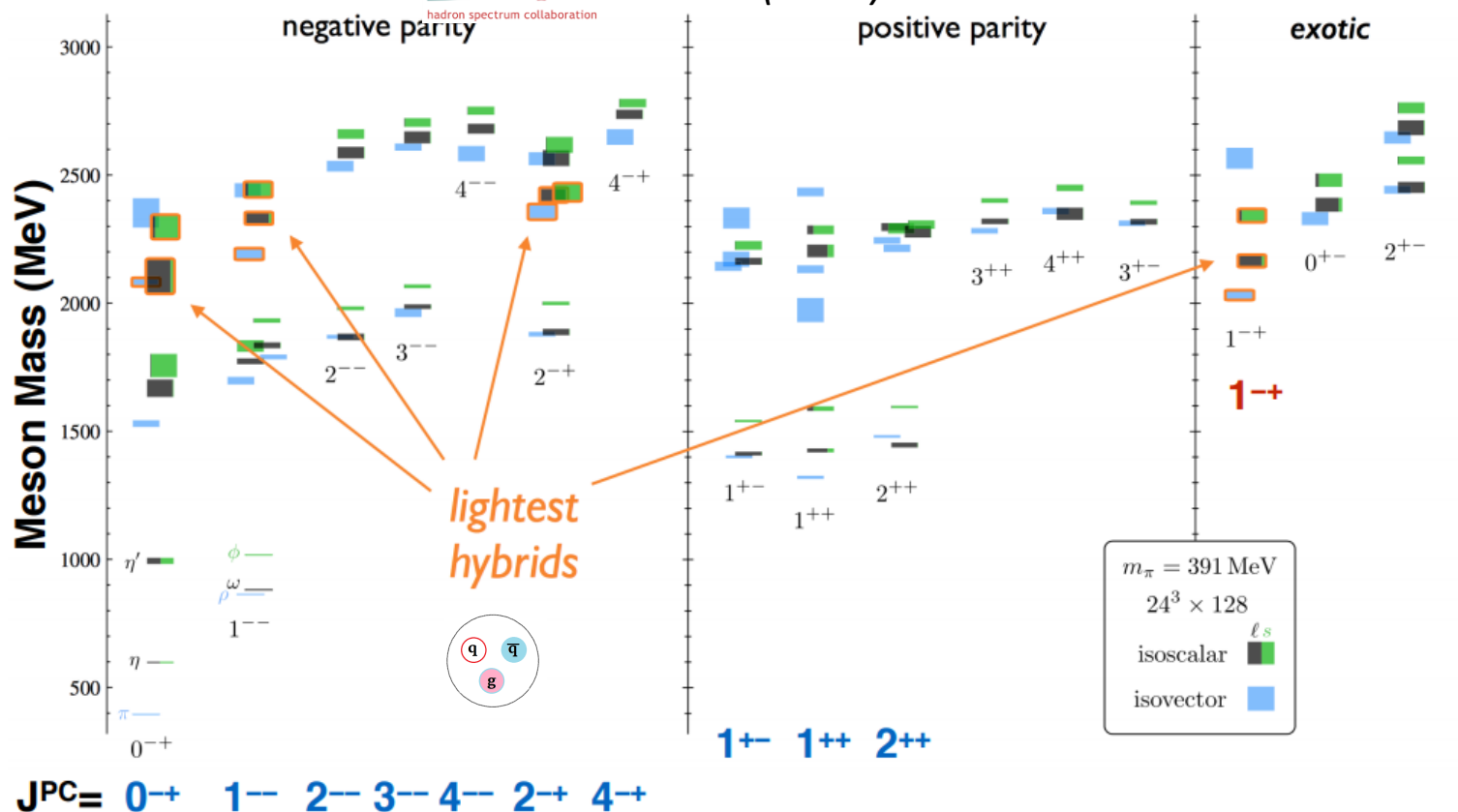
- States are classified by quantum numbers  $J^{PC}$
- Using only  $q\bar{q}$  constituents:
  - $J = L + S$
  - $P = (-1)^{L+1}$
  - $C = (-1)^{L+S}$
- $q\bar{q}$  allows for numbers:
  - $J^{PC} = 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, 2^{-+}, \dots$
- $q\bar{q}$  cannot form states:
  - $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \dots$
  - Detection of such  $J^{PC}$  implies non- $q\bar{q}$  structure!





# Lattice Predictions in the Light Spectrum

had spec PRD 88 (2013) 094505  
hadron spectrum collaboration

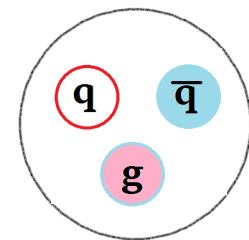


- Exotic states expected
- Ideally, would like to establish spectrum of states

# Candidates For Light Exotic States

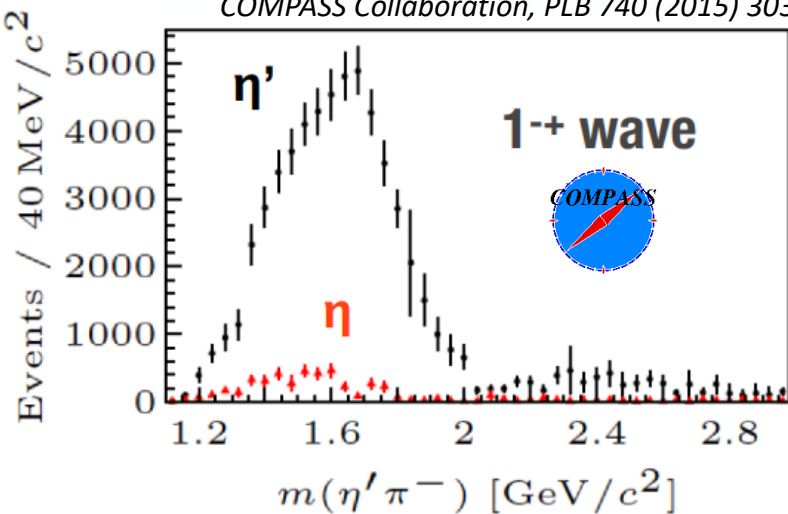
- Potential search channels?

- A state decaying to  $\pi \eta^{(\prime)}$  in a P-wave would be exotic

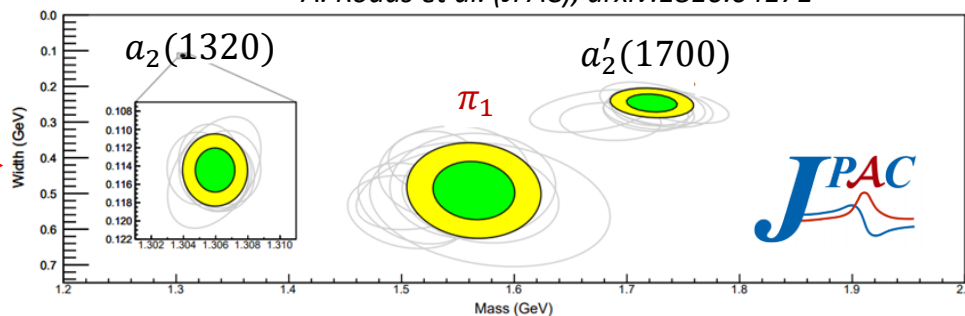


$$\pi^- p \rightarrow \pi^- \eta^{(\prime)} p$$

COMPASS Collaboration, PLB 740 (2015) 303



A. Rodas et al. (JPAC), arxiv:1810.04171



“New data from *GlueX* and CLAS12 experiments at Jefferson Lab in this and higher mass region will be valuable...”

Name	$J^{PC}$	Total Width MeV		Allowed Decay Modes
		PSS	IKP	
$\pi_1$	$1^{-+}$	81 – 168	117	$b_1\pi, \pi\rho, \pi f_1, \pi\eta, \pi\eta', \eta a_1, \pi\eta(1295)$
$\eta_1$	$1^{-+}$	59 – 158	107	$\pi a_1, \pi a_2, \eta f_1, \eta f_2, \pi\pi(1300), \eta\eta', KK_1^A, KK_1^B$
$\eta_1'$	$1^{-+}$	95 – 216	172	$KK_1^B, KK_1^A, KK^*, \eta\eta'$

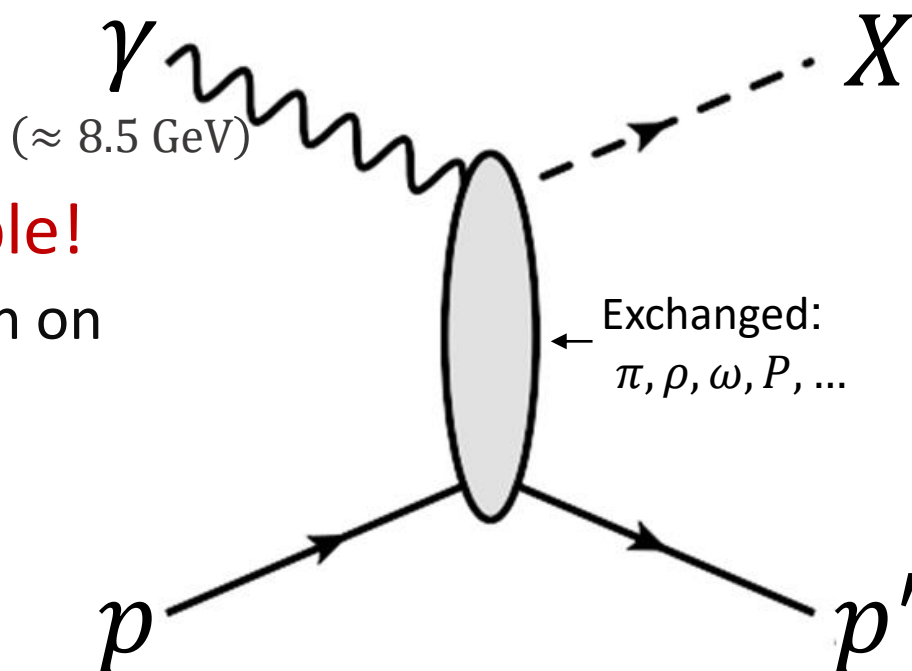


# Probes To Study Light Mesons

- $e^+e^-$  (BESIII, Belle)
- Hadroproduction (COMPASS)
- Photoproduction (GlueX, LEPS)
  - Little data above  $E_\gamma \approx 3$  GeV
  - To do:
    - Understand production mechanisms for well-established states at  $E_\gamma \approx 8.5$  GeV
    - Study potential final states of interest
  - Future: amplitude analysis of individual/coupled channels

# Features of Photoproduction

- Described by t-channel production at GlueX energies
    - Meson, pomeron exchange
  - **Polarization: unique observable!**
    - Provides additional information on exchanges (this talk's focus)
- ⇒ Useful probe in search for exotic states!

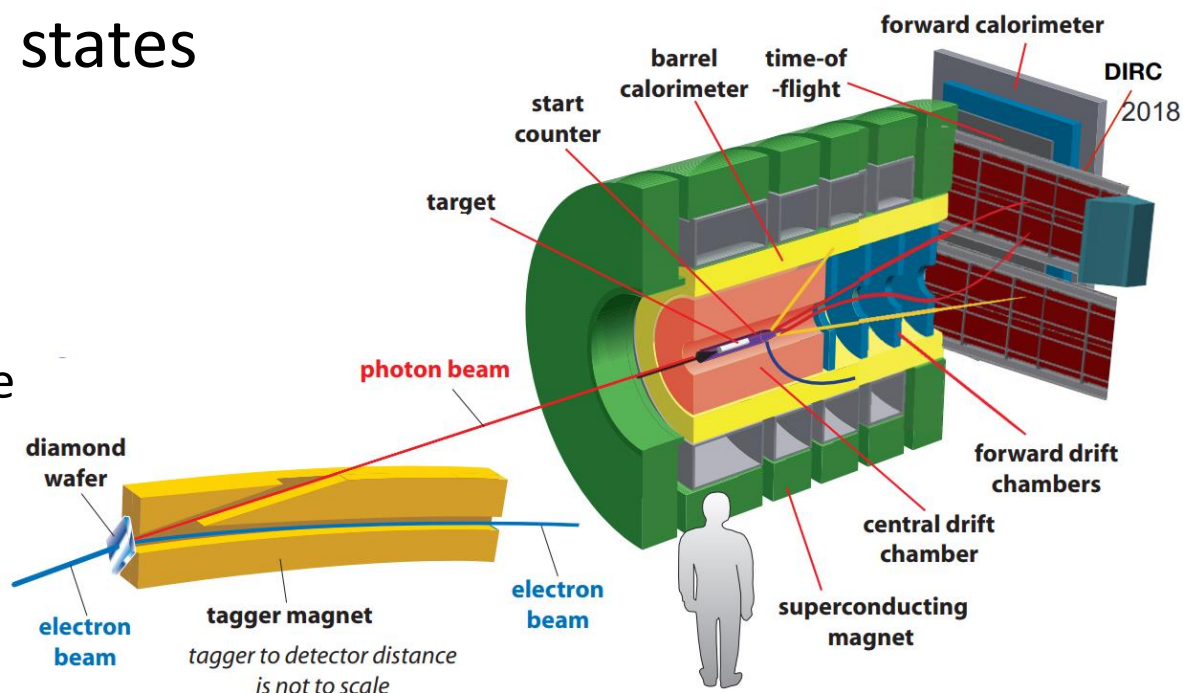






# GlueX Detector

- Large acceptance spectrometer for charged and neutral states
- Photon beam E:
  - 8-9 GeV polarized
  - Polarization  $P_\gamma \approx 0.35$
  - 3 GeV masses reachable



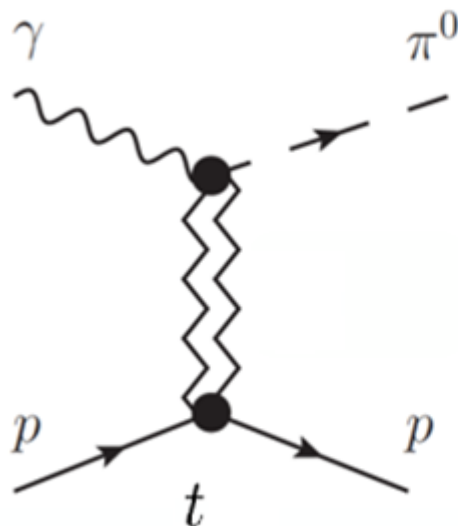
More than 200 billion events:

- 2016:  $\sim 10 \text{ pb}^{-1}$
- 2017:  $\sim 45 \text{ pb}^{-1}$
- 2018:  $\sim 100 \text{ pb}^{-1}$
- Total hadronic cross section  $\sim 120 \mu\text{b}$

Located at Jefferson Lab,  
Newport News, VA, USA

# Production Asymmetry: $\gamma p \rightarrow \pi^0 p$

What is exchanged in photoproduction to produce a  $\pi^0$ ?



Exchange  $J^{PC}$

$1^{--} : \omega, \rho$  positive “naturalness”

$1^{+-} : b, h$  negative “naturalness”

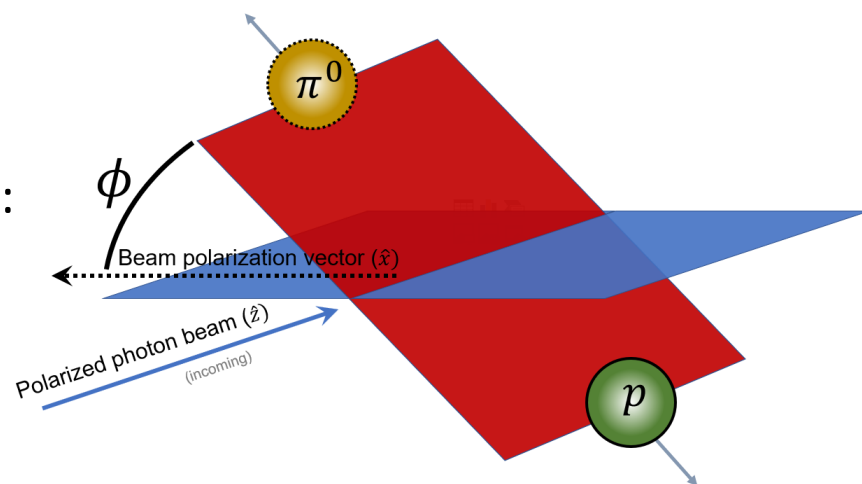
**Polarization allows us to distinguish positive and negative “naturalness” contributions**



# Experimental Measurement of Asymmetry $\Sigma$

Distribution of  $\pi^0$  events has  $\phi$ -dependence:

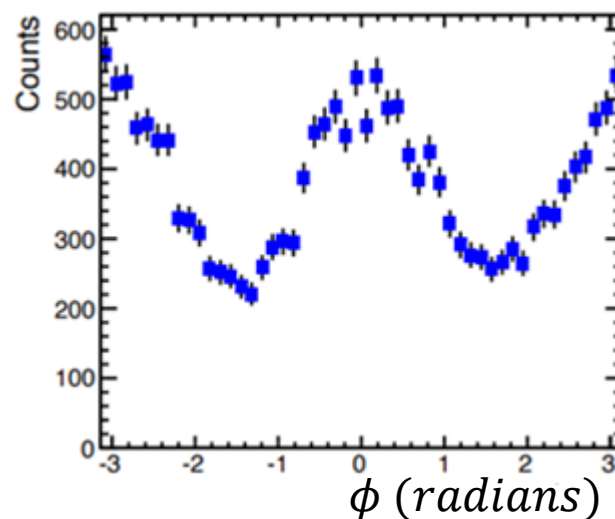
$$\sigma(\phi) = \sigma_0(1 - P_\gamma \Sigma \cos(2(\phi - \phi_{lin})))$$



$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$

If  $\Sigma = +1 \Rightarrow$  purely  $\omega, \rho$

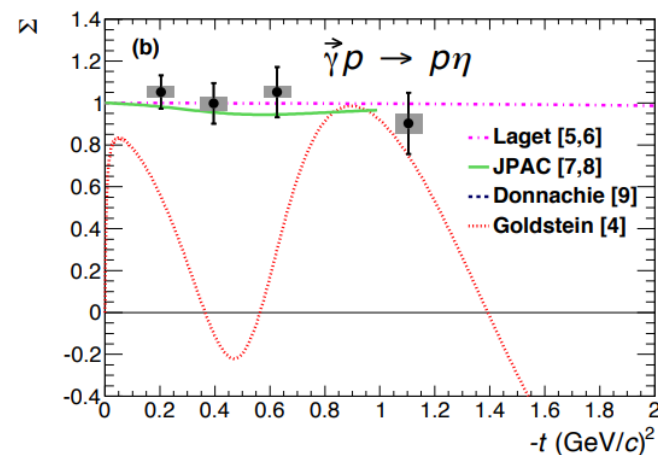
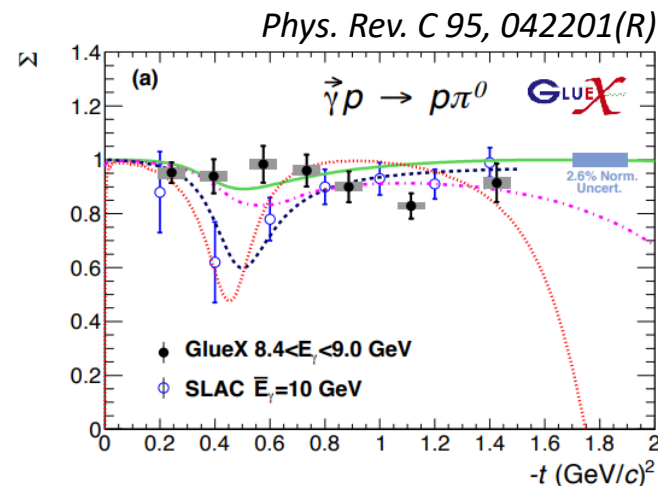
If  $\Sigma = -1 \Rightarrow$  purely  $h, b$





# $\pi^0$ and $\eta$ Photoproduction Asymmetries

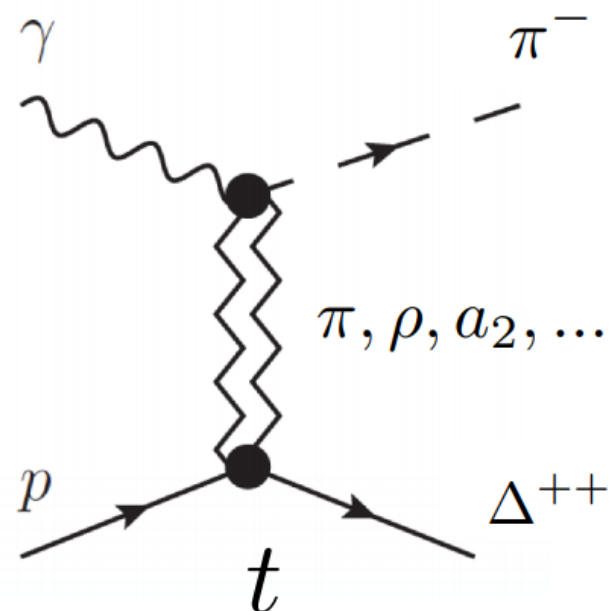
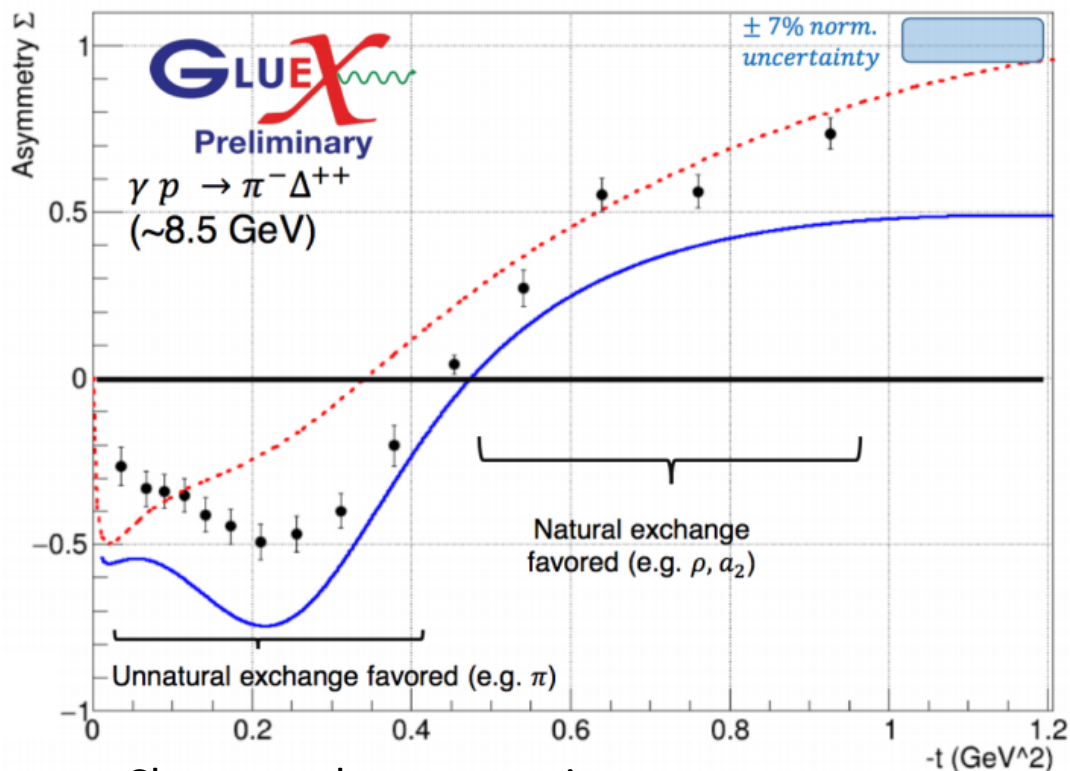
- Production mostly/all from natural exchange (e.g.  $\rho$  or  $\omega$ )
  - No strong  $t$  dependence
- First measurement for  $\eta$  meson
- First publication with data after Jefferson Lab 12 GeV upgrade!





# Asymmetry of $\pi^-$ Production

- B.G Yu (Korea Aerospace U.), PLB **769** 262 (16 GeV)
- J. Nys (JPAC), PLB **779**, 77 (8.5 GeV)



Charge exchange reaction:

- production changes with  $t$
- restricts allowed isospin of exchanges  
(my thesis analysis)

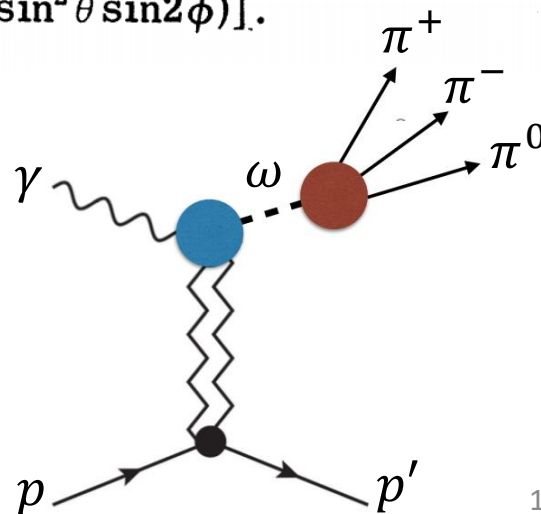
# Vector Meson Production

- Spin-1 kinematics are more complicated
- Additional decay angles  $\cos(\theta)$ ,  $\phi$ 
  - Physics encoded in “spin-density matrix elements”  $\rho_{jk}^i$

$$W(\cos\theta, \phi, \Phi) = \frac{3}{4\pi} \left[ \frac{1}{2}(1 - \rho_{00}^0) + \frac{1}{2}(3\rho_{00}^0 - 1)\cos^2\theta - \sqrt{2}\text{Re}\rho_{10}^0\sin 2\theta\cos\phi - \rho_{1-1}^0\sin^2\theta\cos 2\phi \right. \\ \left. - P_\gamma\cos 2\Phi(\rho_{11}^1\sin^2\theta + \rho_{00}^1\cos^2\theta - \sqrt{2}\text{Re}\rho_{10}^1\sin 2\theta\cos\phi - \rho_{1-1}^1\sin^2\theta\cos 2\phi) \right. \\ \left. - P_\gamma\sin 2\Phi(\sqrt{2}\text{Im}\rho_{10}^1\sin 2\theta\sin\phi + \text{Im}\rho_{1-1}^2\sin^2\theta\sin 2\phi) \right].$$

Simplest model:

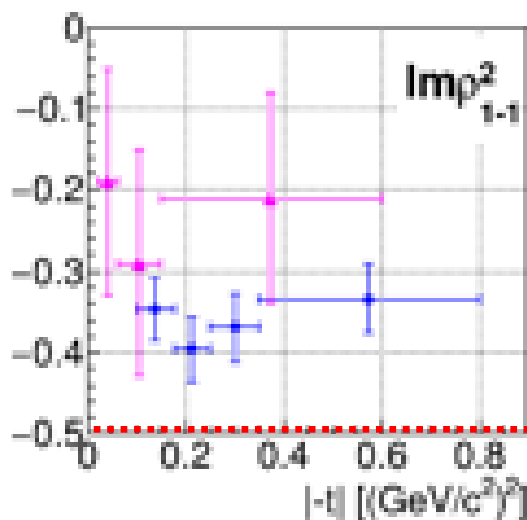
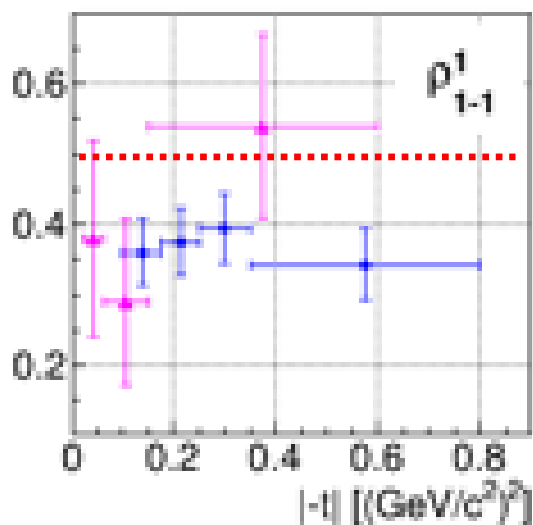
- Complete polarization transfer from photon
- Predicts  $\rho_{1-1}^1 = -\text{Im}\rho_{1-1}^2 = 0.5$   
(all other  $\rho_{jk}^i = 0$ )





# Production Dynamics: $\gamma p \rightarrow \omega p$

GLUEX  
Preliminary



Magenta: SLAC

J. Ballam *et al.*, Phys. Rev. D7 (1973)

Blue: GlueX

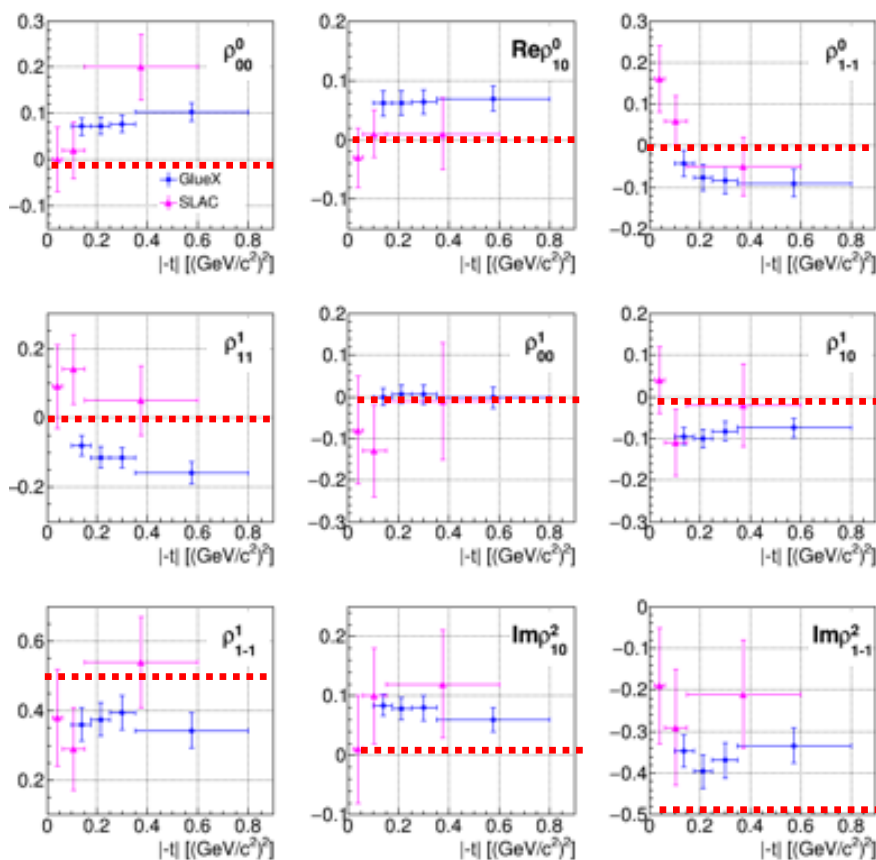
..... full polarization transfer





# More $\omega$ SDME's

- 9 measurements. 8 independent.



Magenta: SLAC

J. Ballam *et al.*, Phys. Rev. D7 (1973)

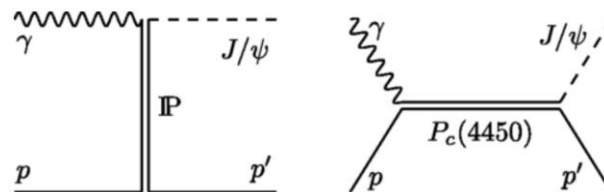
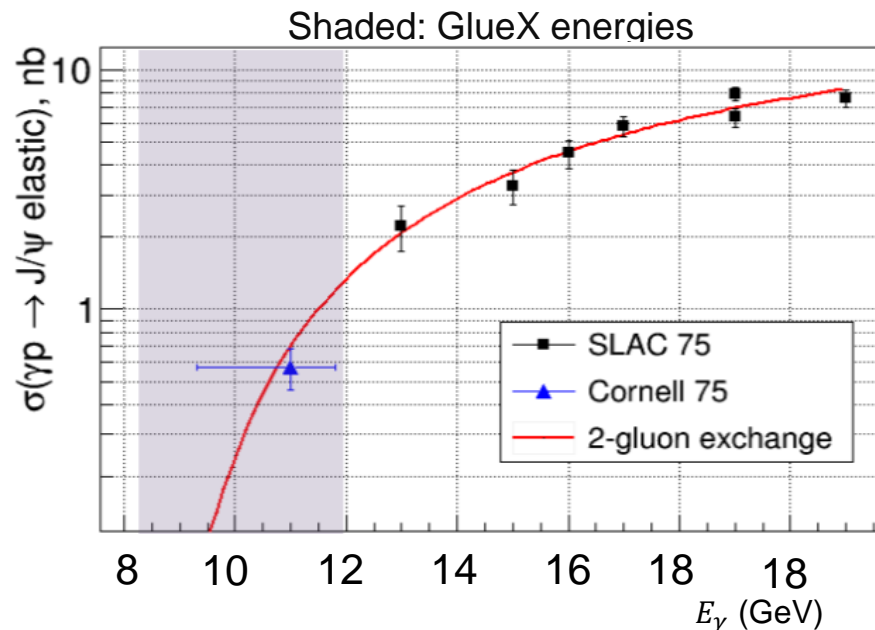
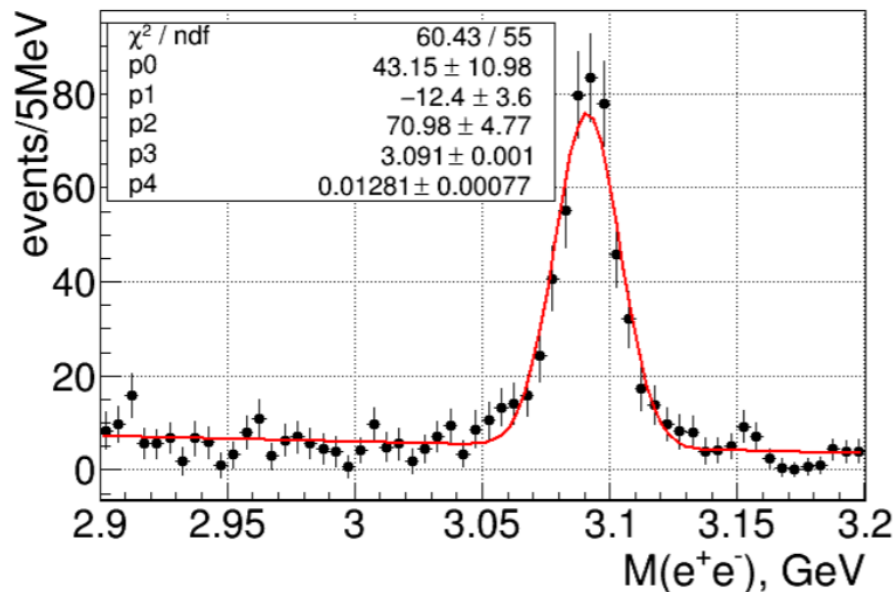
Blue: GlueX

..... full polarization transfer





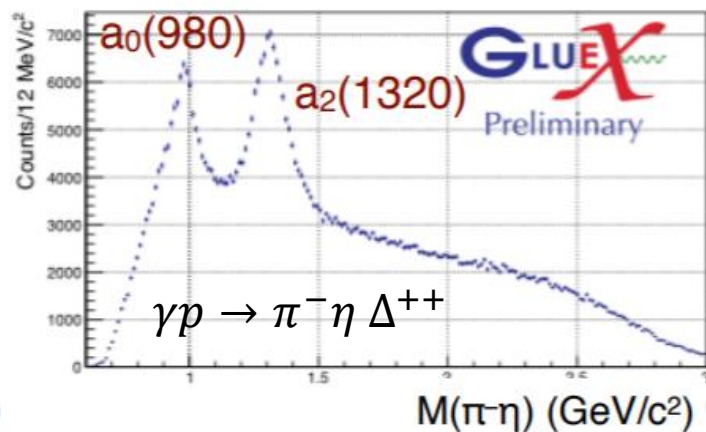
# Beyond Light Mesons: J/ψ Threshold Production



- Production also probes gluon distributions of proton and multiquark correlations
- See: L. Pentchev's talk Friday 16:30 room 402 for more
- GlueX: happens to cover s-channel threshold of pentaquark candidate  $P_c(4450)$ !

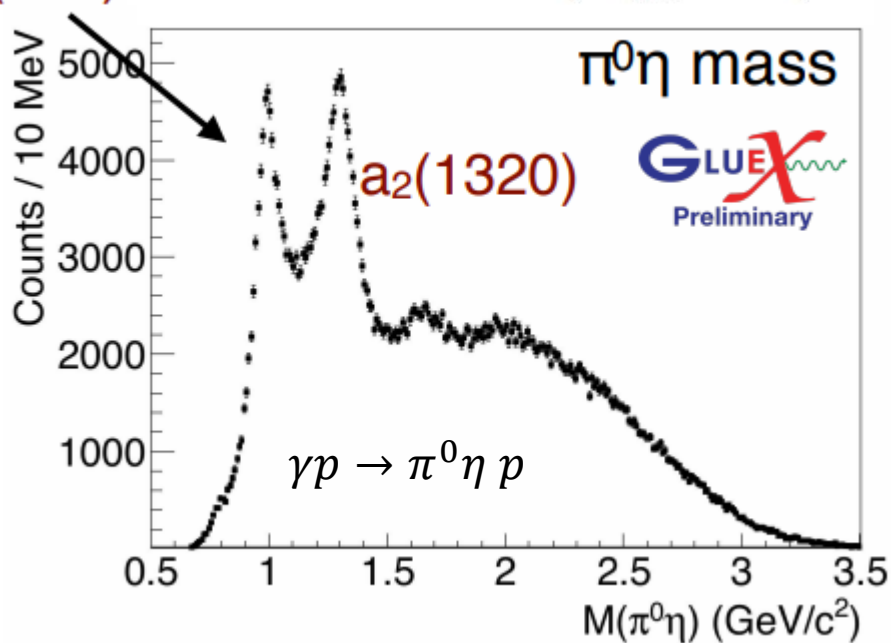


# $\pi\eta$ Final States



Reminder: a state decaying to  $\pi\eta$  in a P-wave is manifestly exotic!

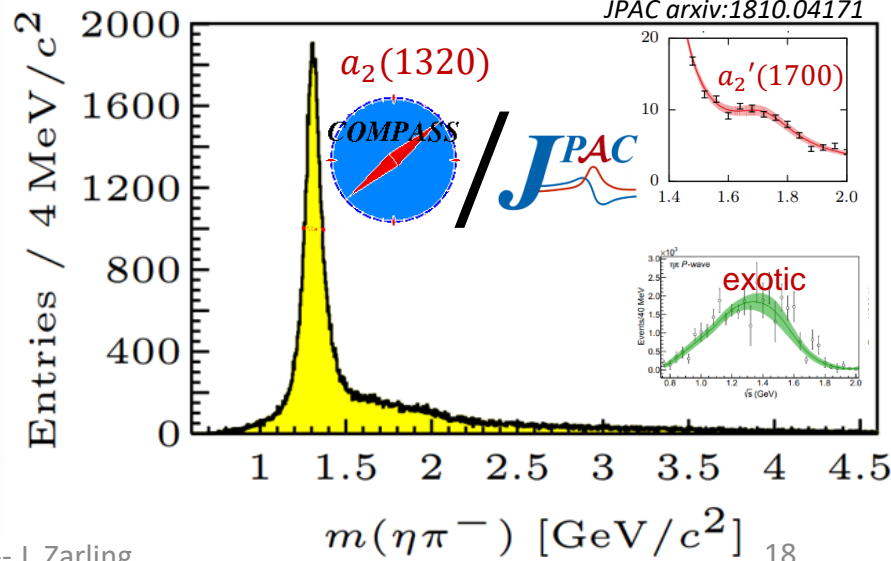
$a_0(980)$



COMPASS Collaboration, PLB 740 (2015) 303

PLB 779 (2015) 464

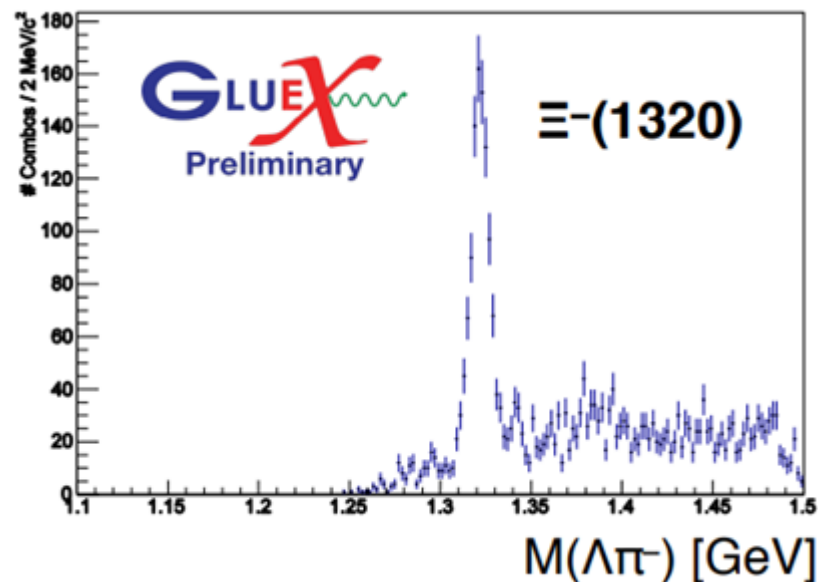
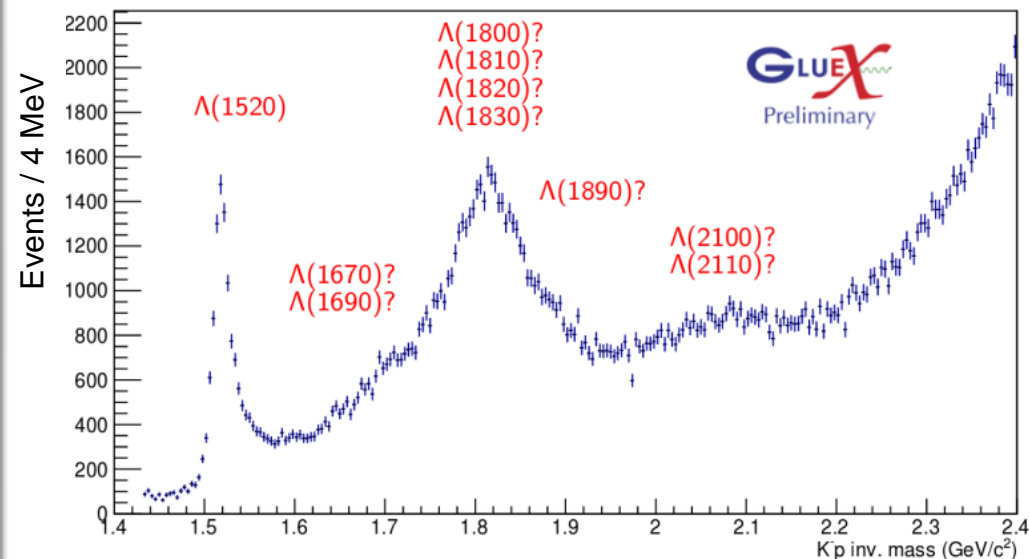
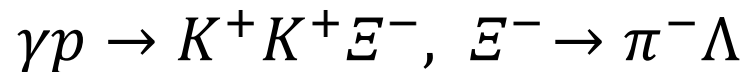
JPAC arxiv:1810.04171





# Baryon Spectroscopy

- Baryon spectroscopy opportunities also available at GlueX
- Example: hyperon spectra



# GlueX Summary

- Light spectroscopy program:
  - Orders of magnitude improvement in existing high energy photoproduction data
  - Pseudoscalar asymmetries and vector SDMEs: gaining insight into production mechanisms
  - Initial investigations of potential exotic channels underway
- Additional opportunities
  - $J/\psi$  threshold production
  - Baryon spectroscopy
  - ...and more!





# Thank You!

Questions?

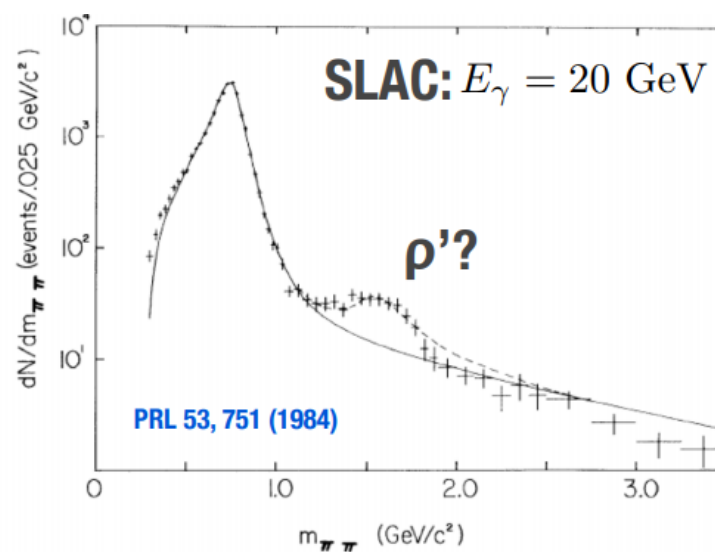
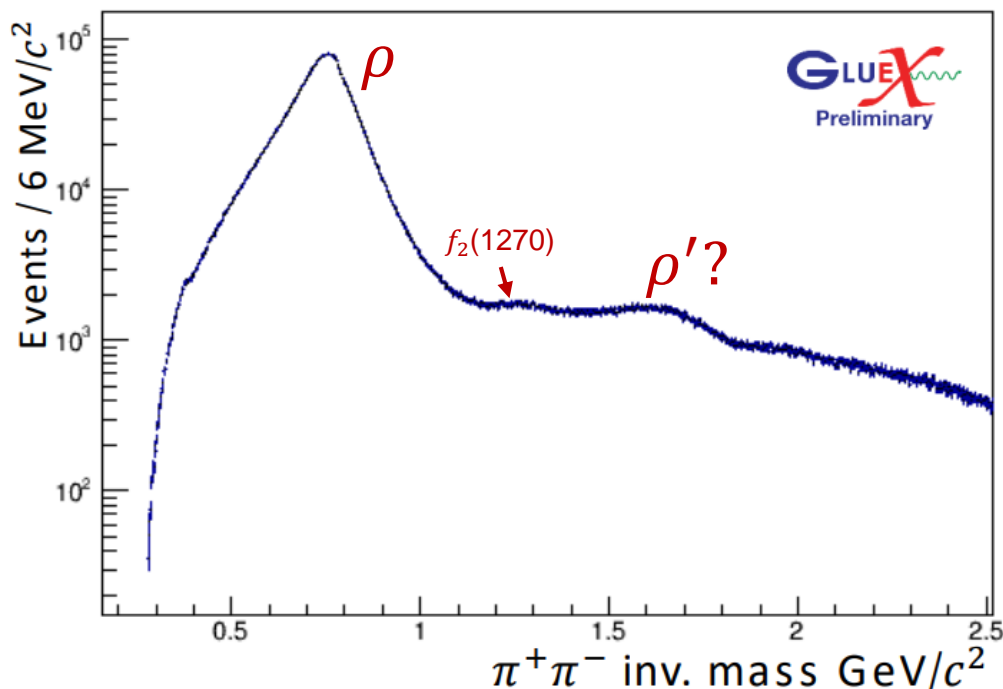


# Backup Slides



# Spectroscopy: $\gamma p \rightarrow \pi^+ \pi^- p$

- Factor 1,000 $\times$  more statistics than previous SLAC data
- Additional polarization observables at GlueX to exploit

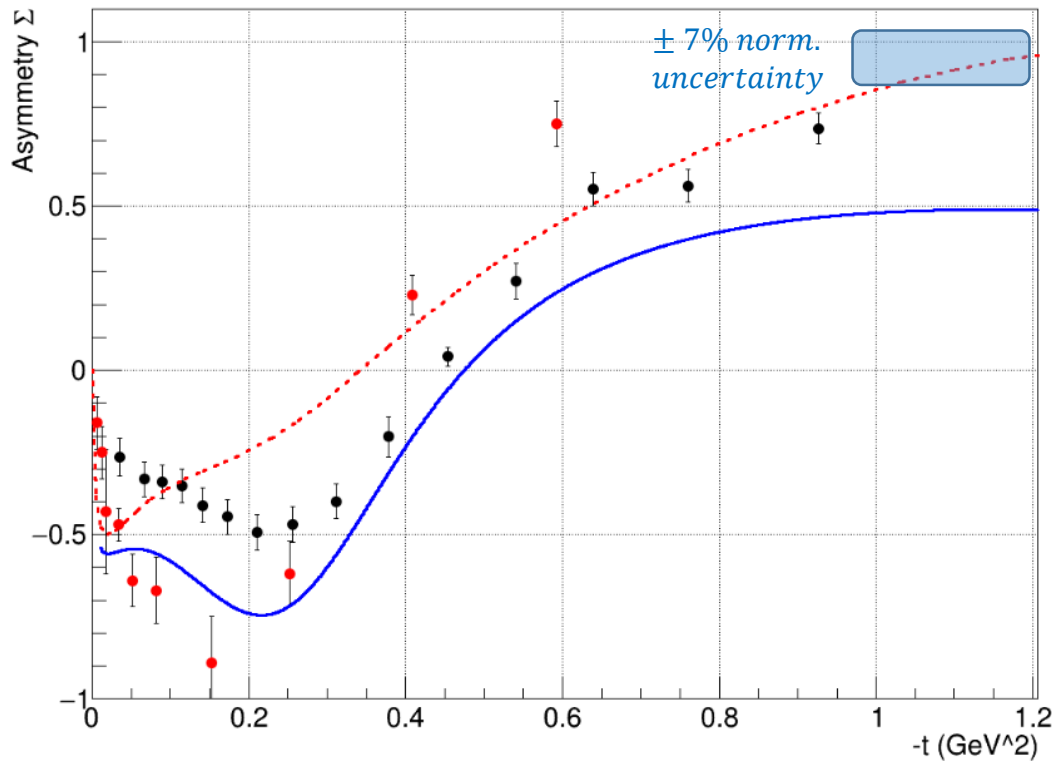




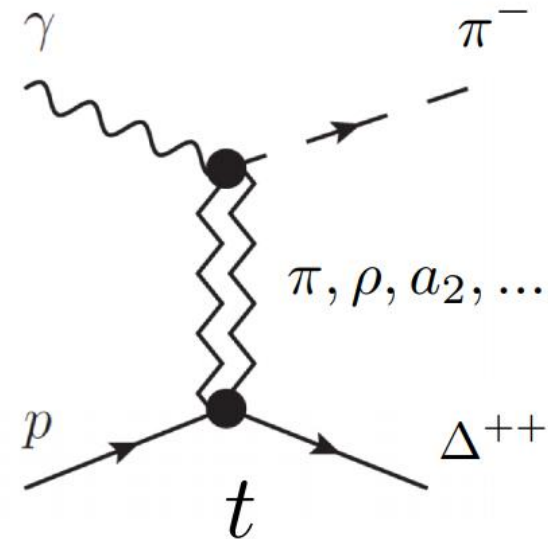


# Additional SLAC Data: Asymmetry of $\pi^-$ Production

----- B.G Yu (Korea Aerospace U.), PRC **96**, 025208 (16 GeV)  
————— J. Nys (JPAC), PLB **779**, 77 (8.5 GeV)



Black: GlueX data  
 Red: SLAC data (16 GeV)



- Charge exchange reactions: restricts allowed isospin of exchanges (my thesis analysis)