



Latest Results from GlueX

Thomas Britton

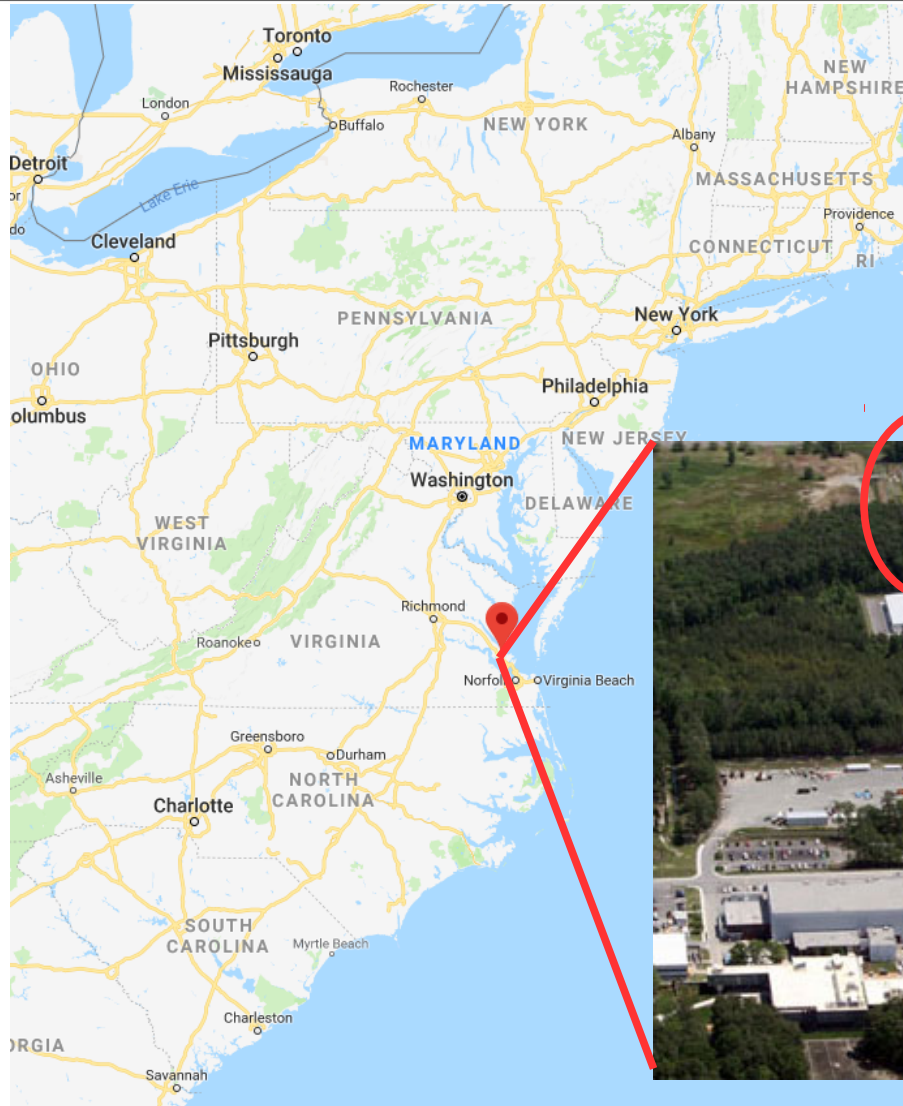
on behalf of the GlueX collaboration

**15th International Workshop on
Meson Physics**

KRAKÓW, POLAND

7th - 12th June 2018

Jefferson Lab

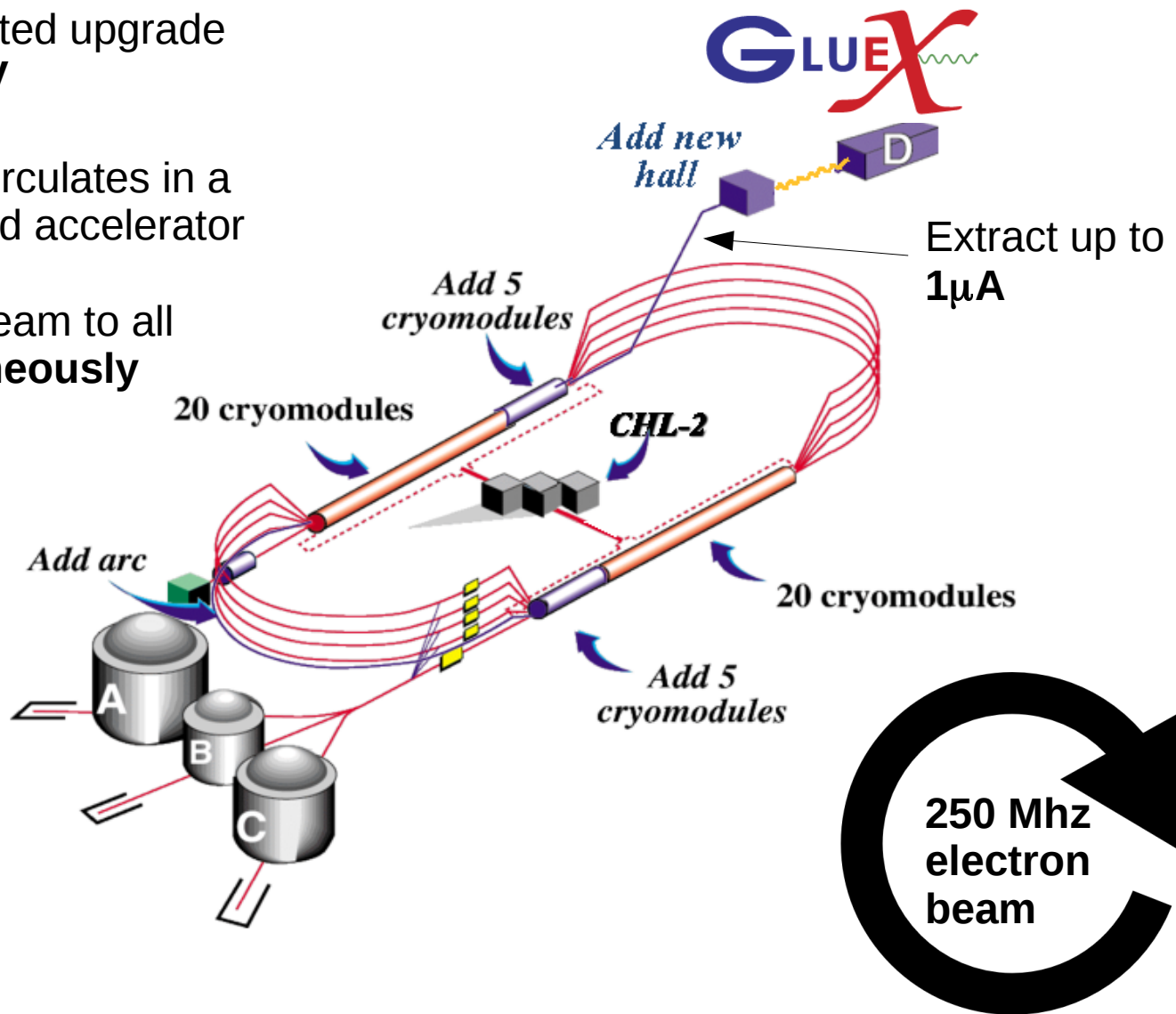


- Located in Newport News
- Continuous Electron Beam accelerator Facility (CEBAF)



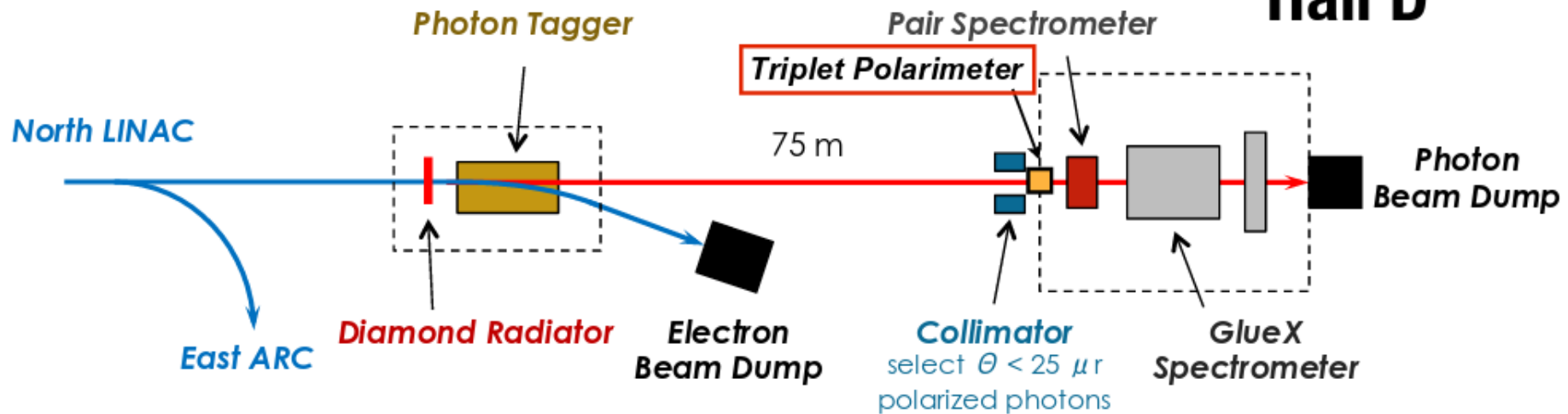
Jefferson Lab cont.

- Recently completed upgrade from 6 to **12 GeV**
- Electron beam circulates in a race track shaped accelerator
- Able to deliver beam to all **4 halls simultaneously**



GlueX

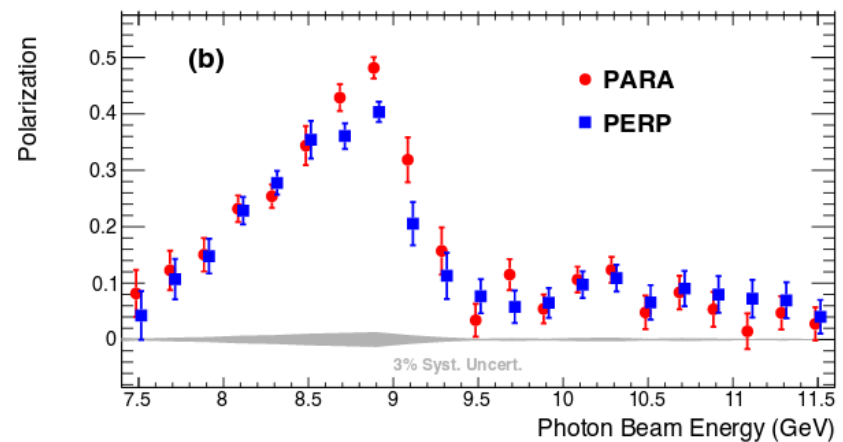
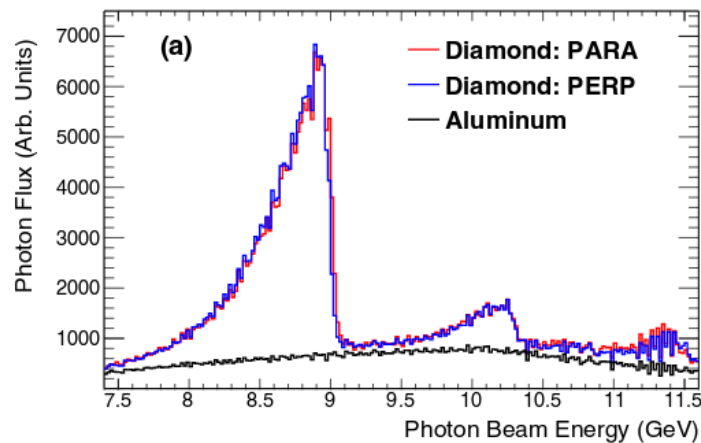
Hall D



Coherent
Bremsstrahlung

Measured Flux

Measured Polarization



GLUE X_{wavy}

- [illegible]



Purpose (preamble)

- QCD predicts bound states of constituent quarks

- Mesons, baryons
- Tetra/penta-quark

- But these aren't the only states QCD predicts!

A SCHEMATIC MODEL OF BARYONS AND MESONS *

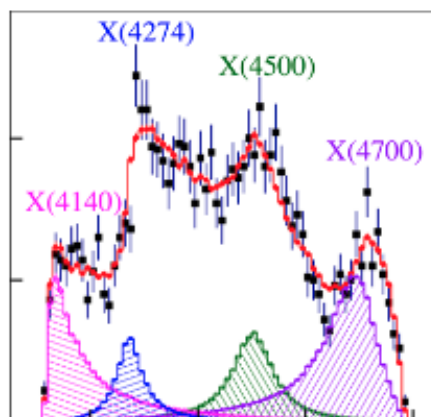
M. GELL-MANN

California Institute of Technology, Pasadena, California

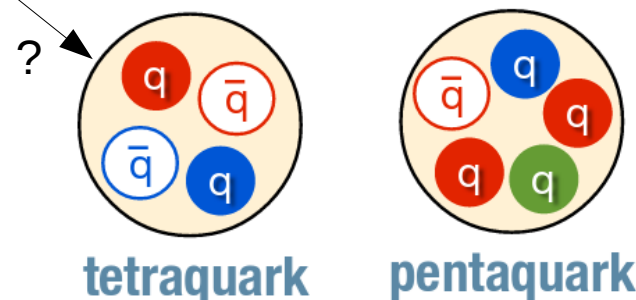
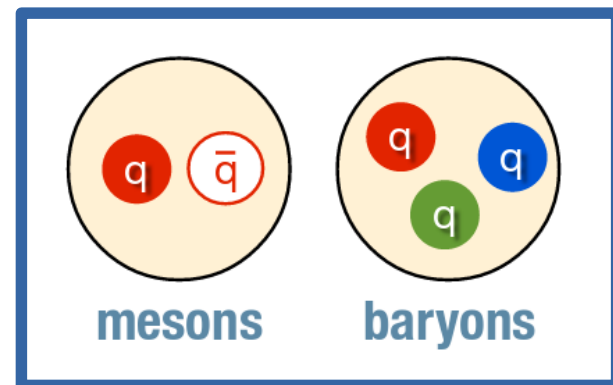
... Baryons can now be constructed from quarks by using the combinations (qqq) , $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. ...

Phys. Lett. 8 (1964) 214

$B \rightarrow J\psi\phi K$



LHCb 2016



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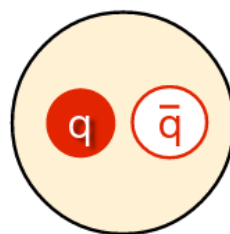
A SCHEMATIC MODEL OF BARYONS AND MESONS *

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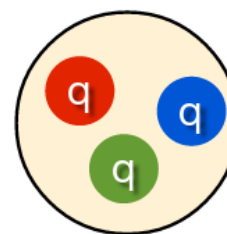
California Institute of Technology, Pasadena, California

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

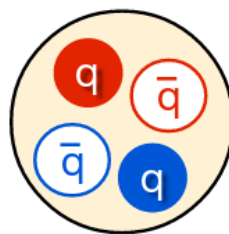
Phys. Lett. 8 (1964) 214



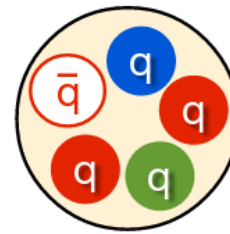
mesons



baryons

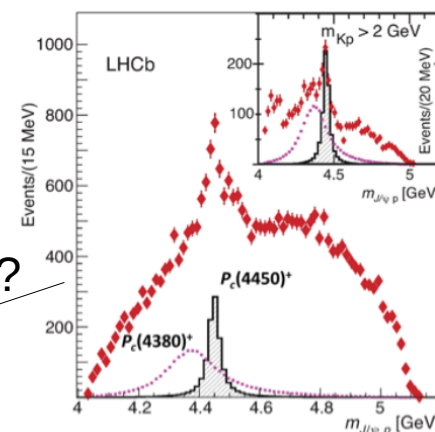


tetraquark



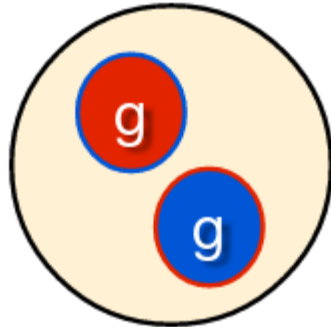
pentaquark

$$\Lambda_b \rightarrow J/\psi p K^-$$

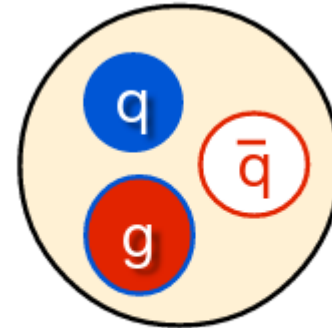


LHCb 2015

Purpose (preamble)



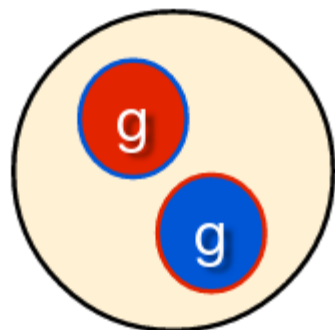
glueball



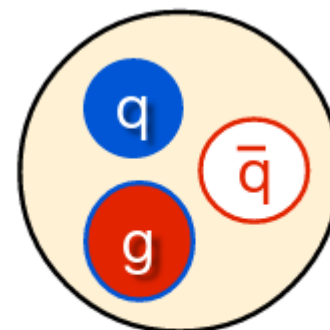
hybrid meson

- LQCD also predicts a spectrum of bound states beyond the constituent quark model

Purpose (preamble)



glueball



hybrid meson

- In the Non-Relativistic quark model:

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

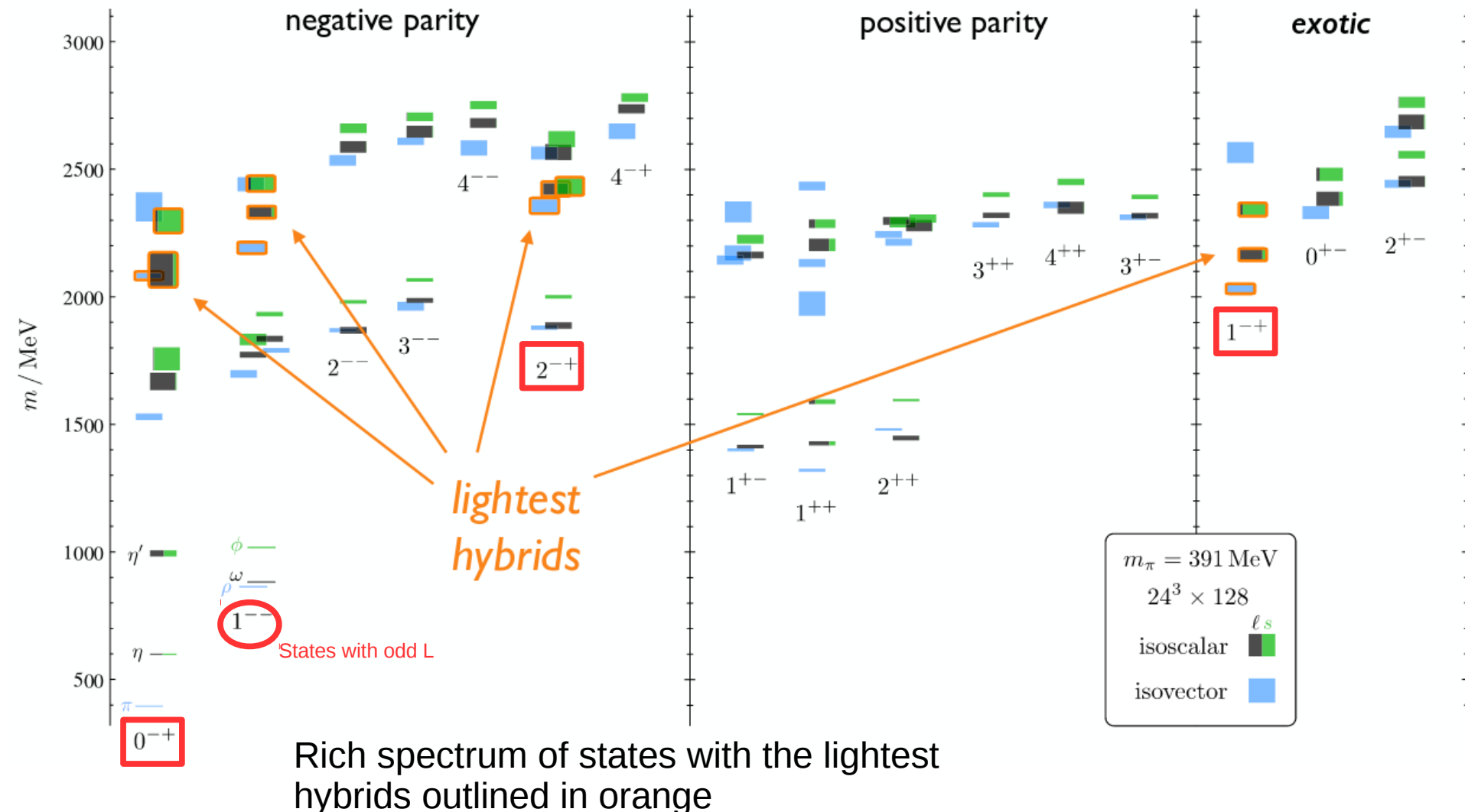


JPC sets forbidden by the
constituent quark model:
 $J^{PC}=0^{+-}, 1^{-+}, 2^{+-}, \text{etc...}$

Observation of states with “exotic” quantum numbers
would provide direct evidence for “exotic states”
beyond the constituent quark model

Predicted Spectrum

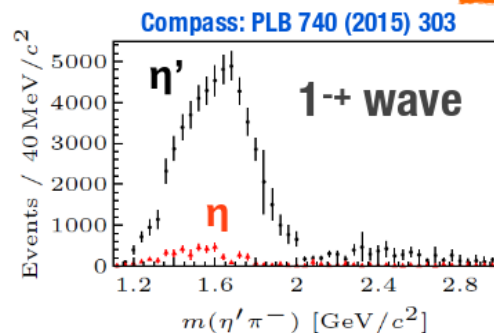
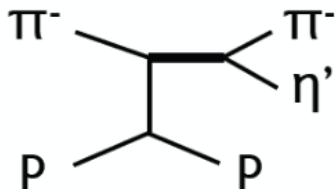
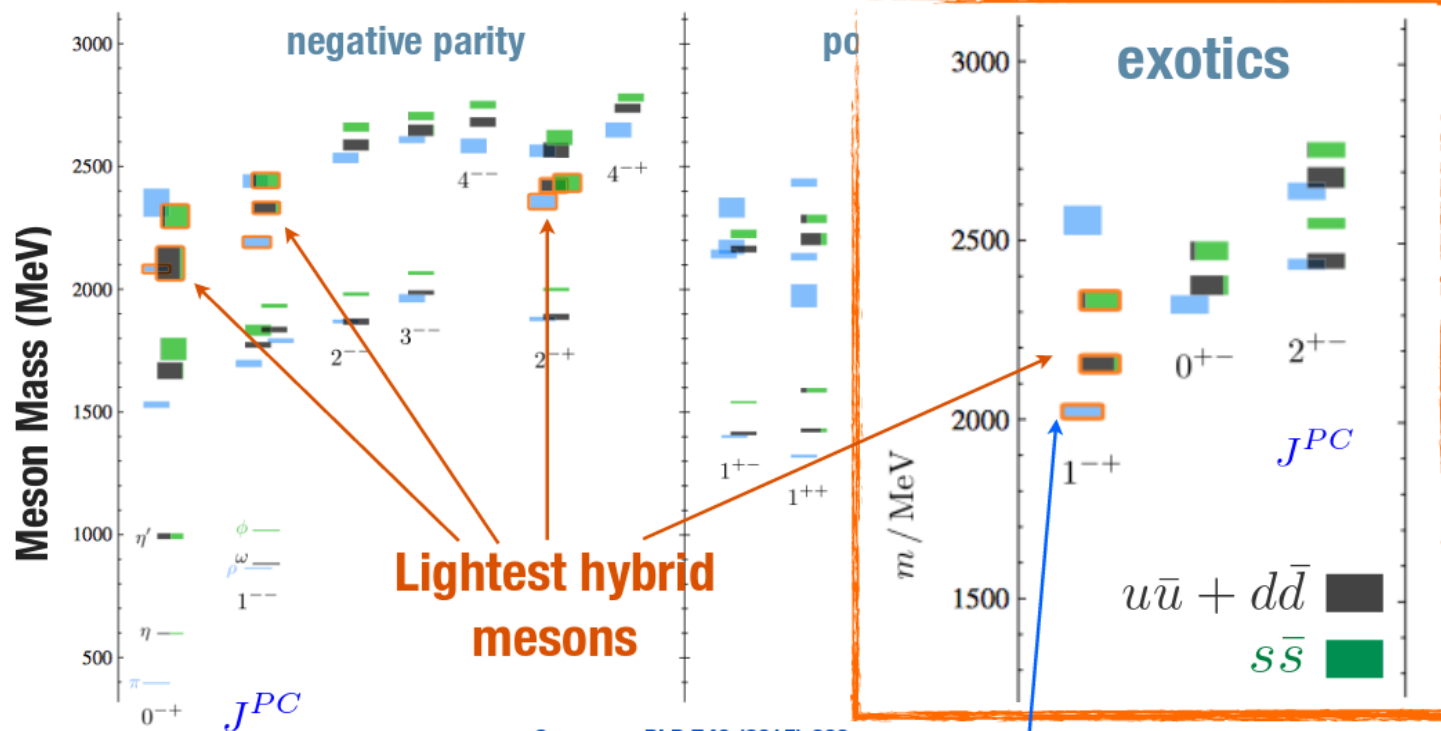
Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)



Past Searches

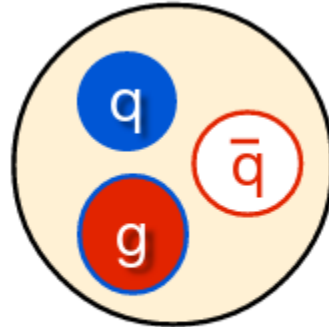
Lattice QCD

Dudek et al. PRD 88 (2013) 094505



Most experimental searches for hybrids limited to the π_1 state

An Interpretation



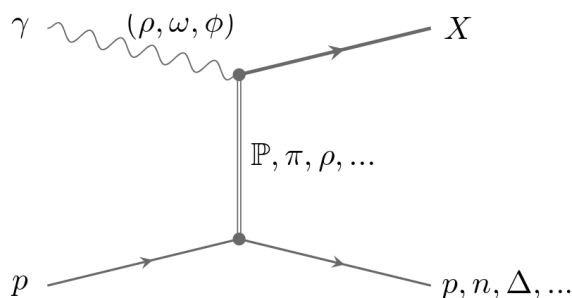
hybrid meson

- Observation of the predicted states with exotic J^{PC} could be interpreted as an excited gluonic field with $J^{PC}=1^{+-}$ and a mass of 1-1.5 GeV coupling to $q\bar{q}$

Photon Beam as Probe

- Why GlueX?

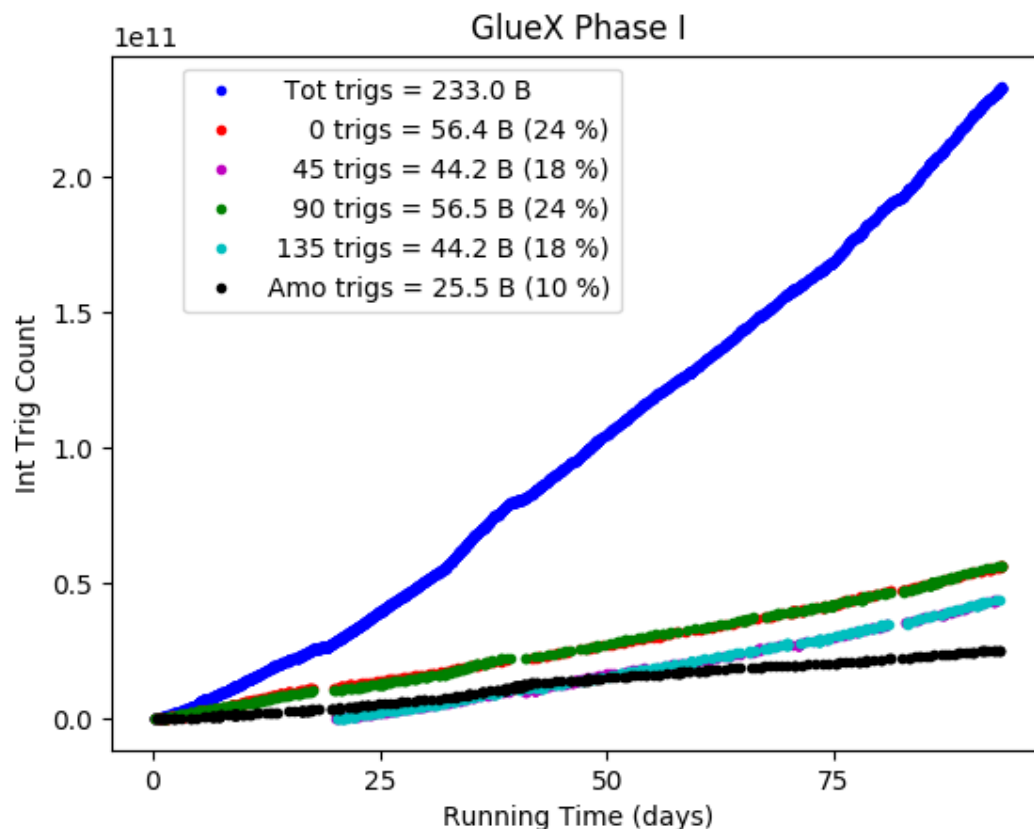
- Very few photo-production experiments looked at GlueX energy ranges
 - Ripe for discoveries
 - Exactly where we expect to find such hybrids
- The photon beam is linearly polarized
- γ coupling via vector meson dominance to wide variety of states (including exotic J^{PC})



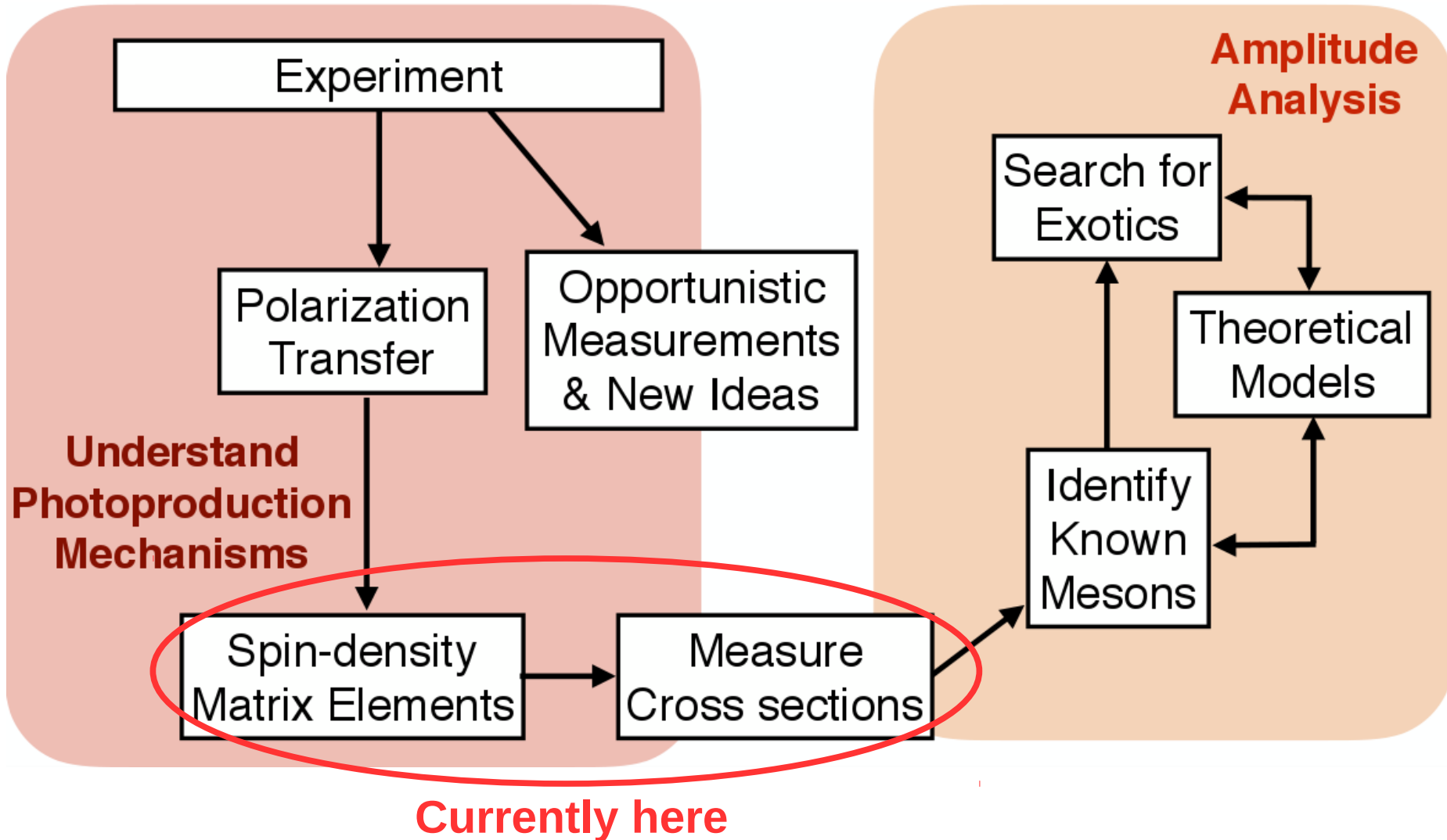
| Exchange | | Exotic Final States | |
|--------------|----------|--------------------------|------------------|
| \mathbb{P} | 0^{++} | b, h, h' | $2^{+-}, 0^{+-}$ |
| π^0 | 0^{-+} | b_2, h_2, h'_2 | 2^{+-} |
| π^\pm | 0^{-+} | π_1^\pm | 1^{-+} |
| ω | 1^{--} | π_1, η_1, η'_1 | 1^{-+} |

Data Collection

- Over 200 billion triggers in ~100 days of running
- ~75% GlueX-I data recorded
 - ~25% analyzed



Analysis Road-map

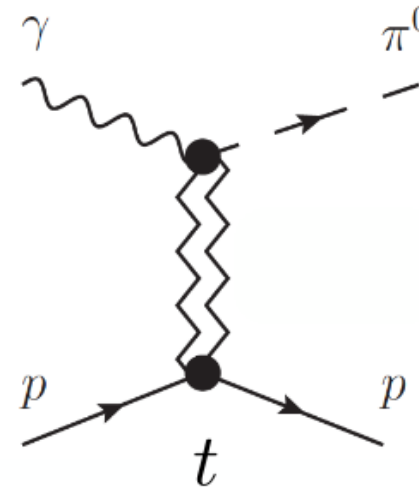


Beam Asymmetries (Σ) for $\gamma p \rightarrow \pi^0 p$

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

$$\frac{d\sigma}{dt} = \sigma_{\perp} + \sigma_{\parallel} = |\rho + \omega|^2 + |b + h|^2$$

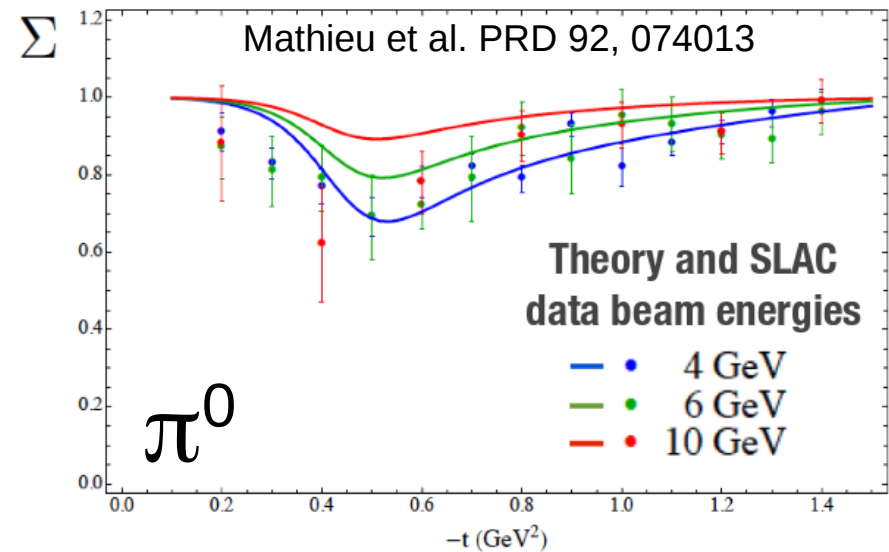
- Beam asymmetries provide insight into production mechanisms
- Experimentally easy to extend to η ($\gamma p \rightarrow \eta p$)
 - No previous beam asymmetry measurements for η



Exchange J^{PC}

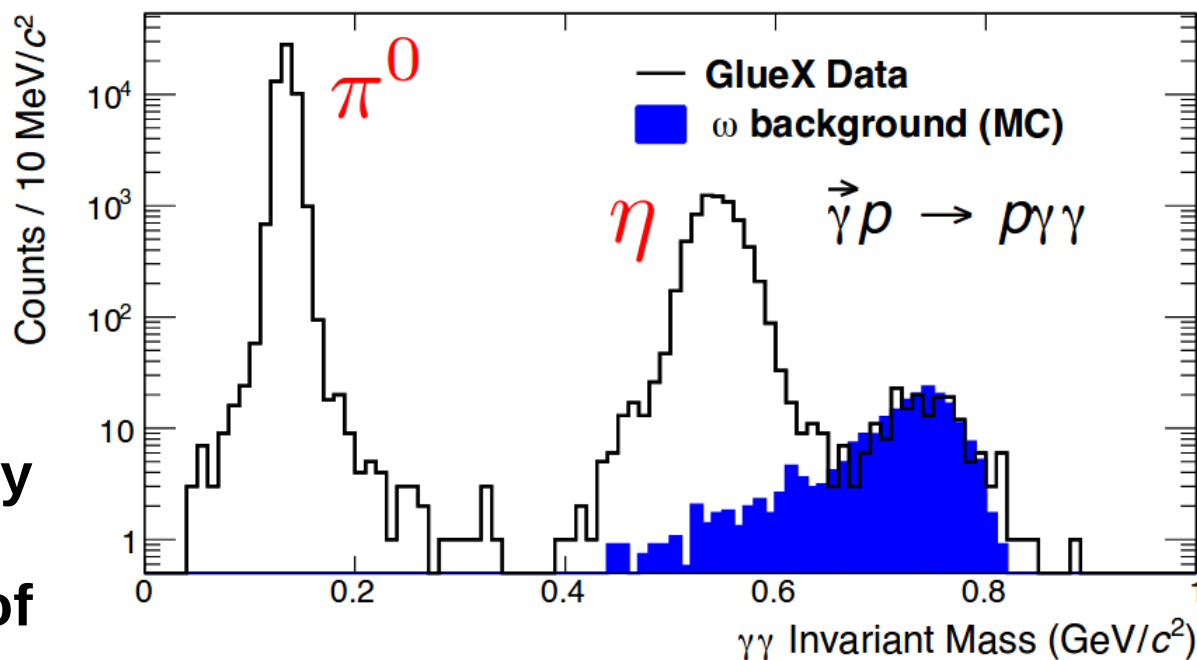
$1^{--} : \omega, \rho$

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



Beam Asymmetries (Σ) for π^0 and η

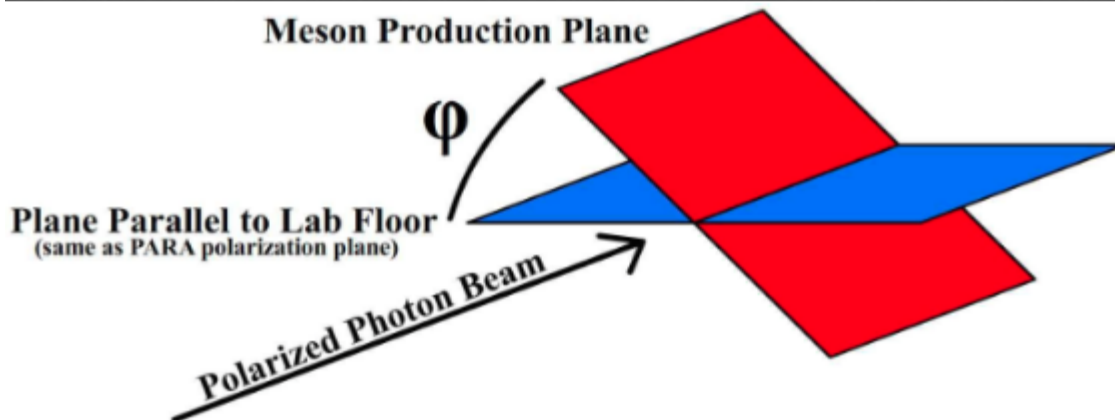
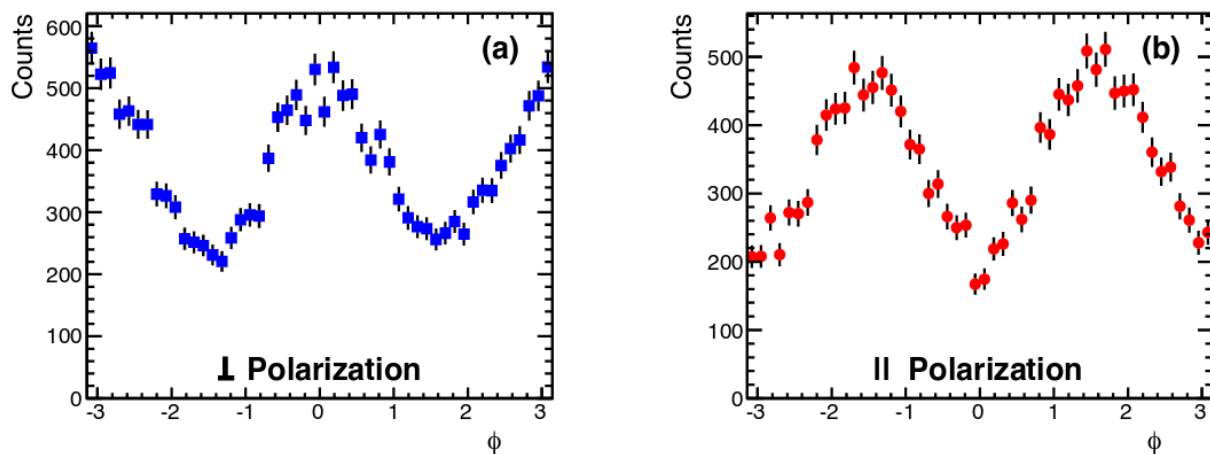
$$\gamma p \rightarrow p \gamma \gamma$$



Relatively
clean
sample of
both π^0
and η

Phys. Rev. C 95, 042201(R)

Beam Asymmetries (Σ)

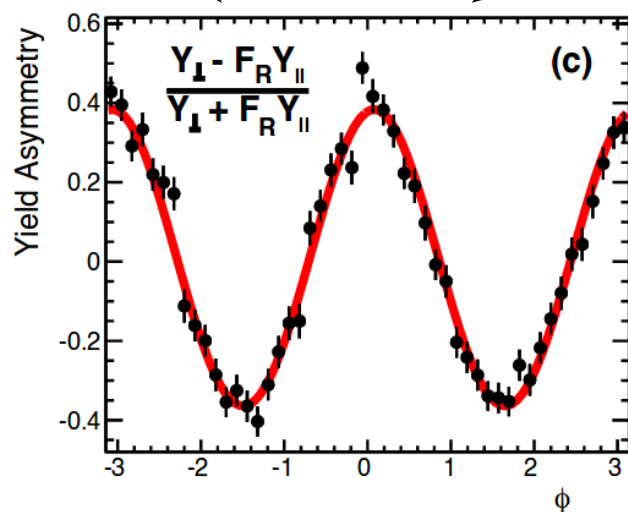
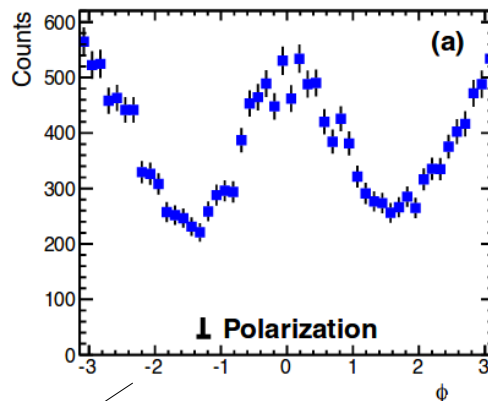
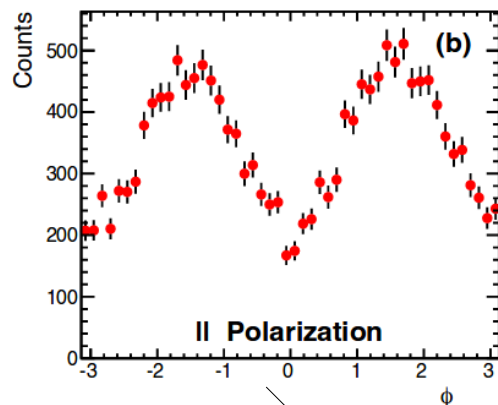


$$\sigma = \sigma_0 \left(1 - P_\gamma \Sigma \cos 2(\phi_p - \phi_\gamma^{\text{lin}}) \right)$$

\parallel
 ϕ

Phys. Rev. C 95, 042201(R)

Beam Asymmetries (Σ)



Yield
Asymmetry

Beam
Polarization

$$\frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + F_R Y_{\parallel}} = P_{\gamma} \Sigma \cos 2\phi \quad \text{Fitted}$$

*Efficiency cancels!

Phys. Rev. C 95, 042201(R)

Beam Asymmetries cont.

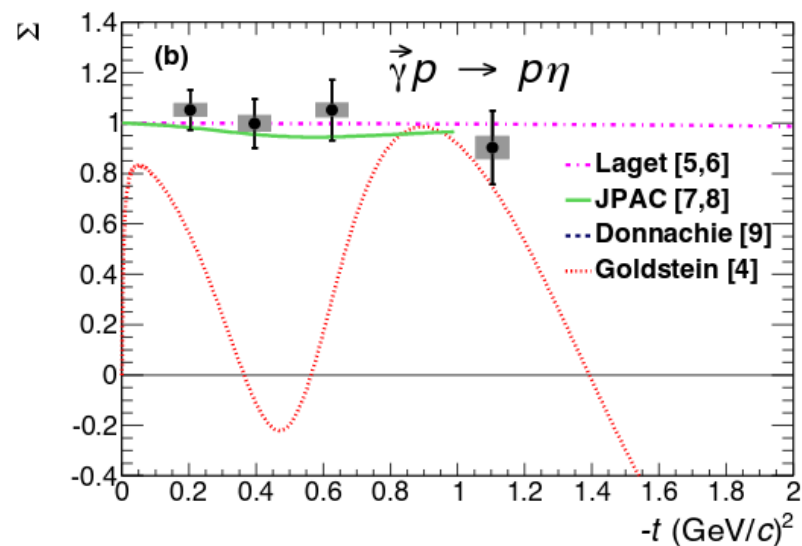
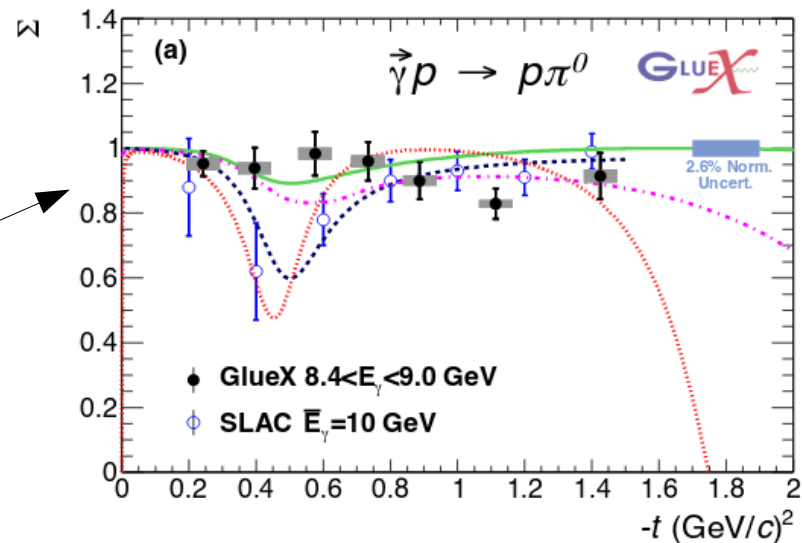
- We do not observe SLAC's dip in Σ of π^0 at $-t=0.4$

- Data are not consistent with Laget, Donnachie, Goldstein models
- Better agreement with JPAC predictions

- $\Sigma \sim 1 \Rightarrow$ vector exchange dominance

- GlueX first physics publication in 2017

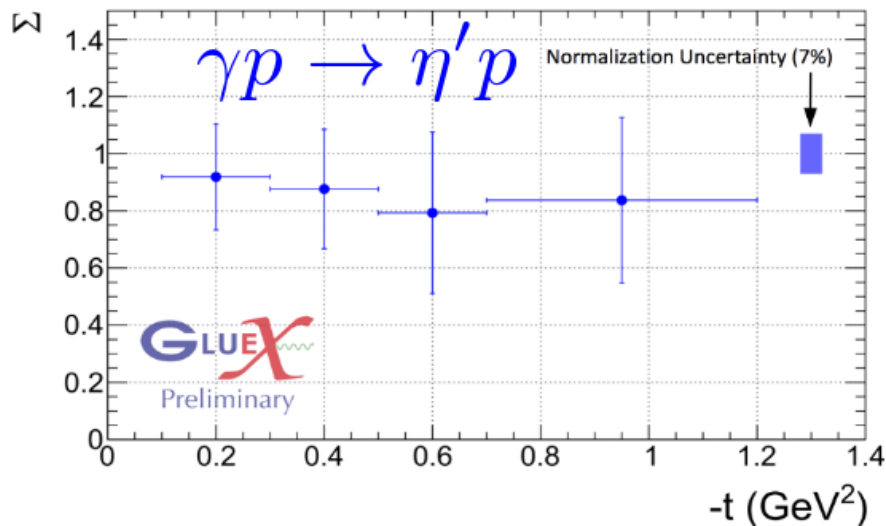
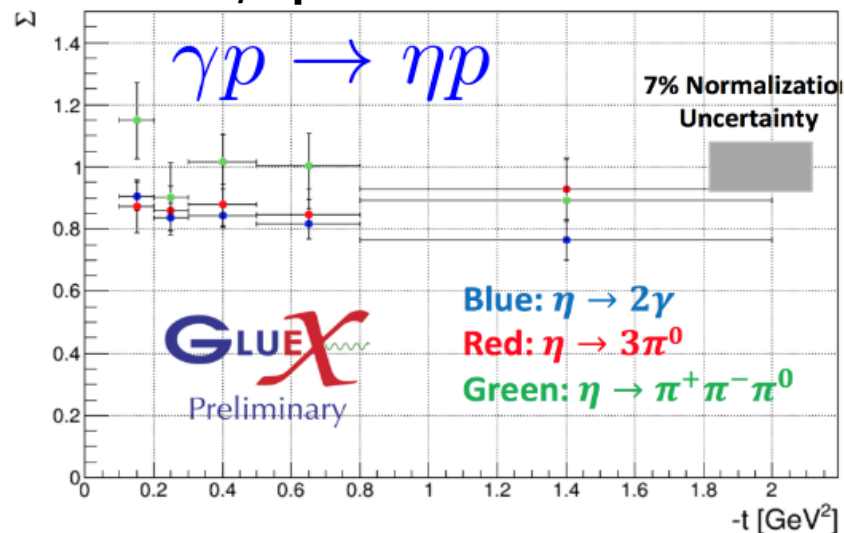
– [Phys. Rev. C 95, 042201\(R\)](#)



Beam Asymmetries cont.

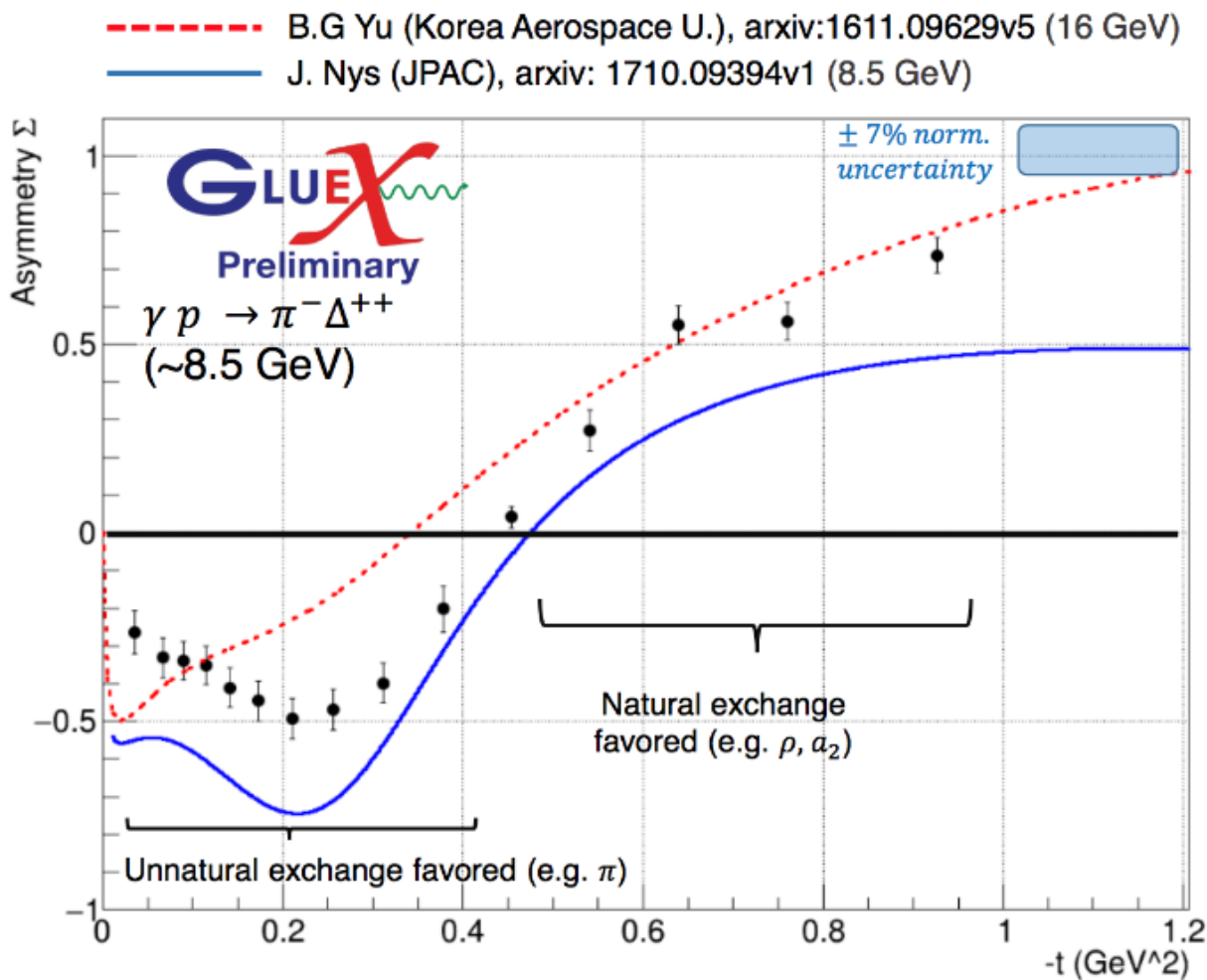
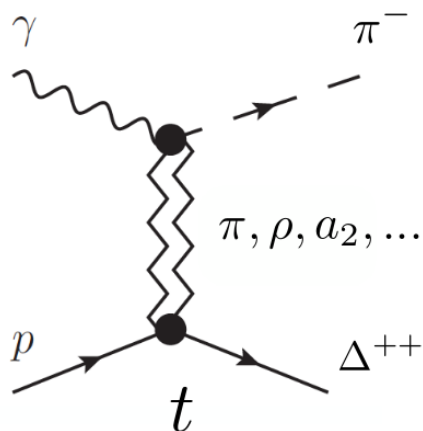
- Neutral pseudo-scalars η and η'
 - $\Sigma \sim 1 \Rightarrow$ vector exchange dominance

η update with 5x the data



Beam Asymmetries cont.

- Charged pseudo-scalars as in $\gamma p \rightarrow \pi^- \Delta^{++}$
 - More complicated t dependence



Other Analyses

- Leveraging GlueX's coverage of a wide variety of final states
 - More than 50 channels being actively analyzed
- Provides many opportunities for discovery

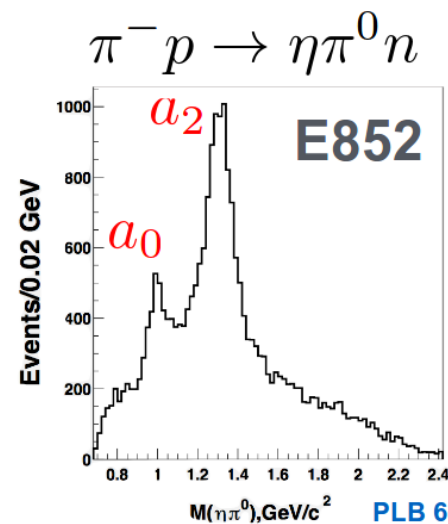
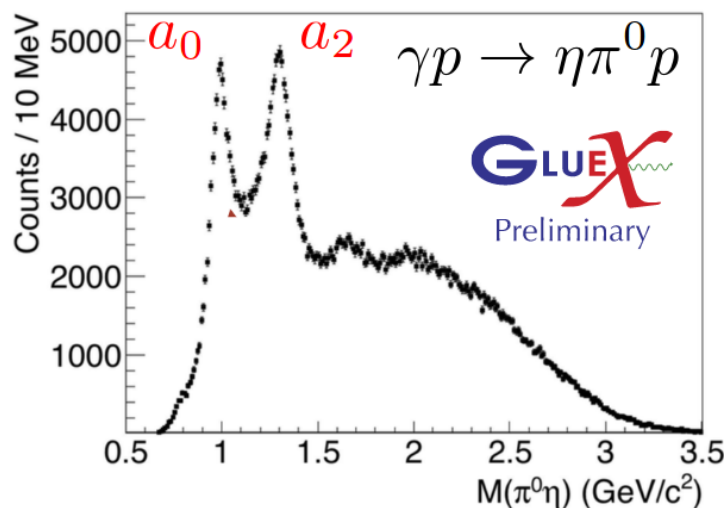
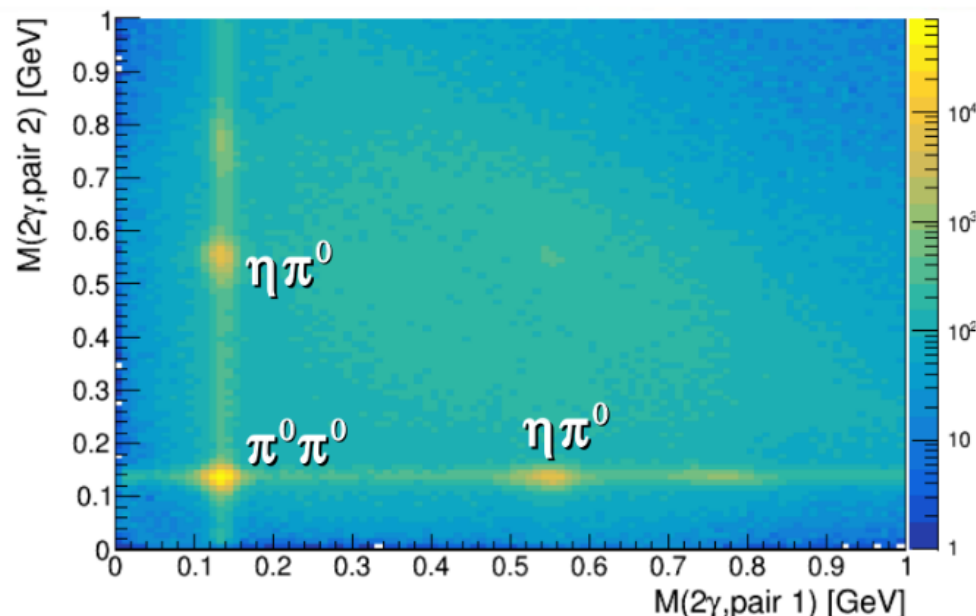
| Topology(ies) |
|--------------------------|
| $p\gamma\gamma$ |
| $p\pi^0\gamma$ |
| $p2\pi^0$ |
| $p\pi^+\pi^-$ |
| $p\pi^+\pi^-\gamma$ |
| $p\pi^+\pi^-\pi^0$ |
| $p3\pi^0$ |
| $p\pi^+\pi^-2\pi^0$ |
| $p2\pi^+2\pi^-$ |
| $p2\pi^+2\pi^-\pi^0$ |
| pK^+K^- |
| $pK^+K^-\pi^0$ |
| $pK^+K^-2\pi^0$ |
| $pK^+K^-\pi^+\pi^-$ |
| $p2K^+2K^-$ |
| $pK^+K^-\pi^+\pi^-\pi^0$ |
| $p\eta\pi^0$ |
| $p\eta2\pi^0$ |
| $p\eta\pi^+\pi^-$ |
| $p\eta K^+K^-$ |
| $p\eta\pi^+\pi^-\pi^0$ |
| $p\eta2\pi^+2\pi^-$ |
| $p2\eta$ |
| $p2\eta\pi^+\pi^-$ |

$p2K_S$
 $pK^-K_S\pi^+$
 $pK^-K_S\pi^+\pi^0$
 $pK^-K_S\pi^+2\pi^0$
 $pK^-K_S2\pi^+\pi^-$
 $pK^+K_S\pi^-$
 $pK^+K_S\pi^-\pi^0$
 $pK^+K_S\pi^-2\pi^0$
 $pK^+K_S\pi^+2\pi^-$
 $\Lambda2K^+K^-$
 $\Lambda K_S\pi^+\pi^0$
 $\Lambda K_S\pi^+$
 $\Lambda K^+\pi^+\pi^-$
 ΛK^+
 $\Lambda K^+\gamma$
 $\Lambda K^+2\gamma$
 $\Lambda K^+\pi^0\gamma$
 $K^+K^+\Xi^-$
 $K^+(K^+)\Xi^-$
 $K^+K^+(\Xi^-)$

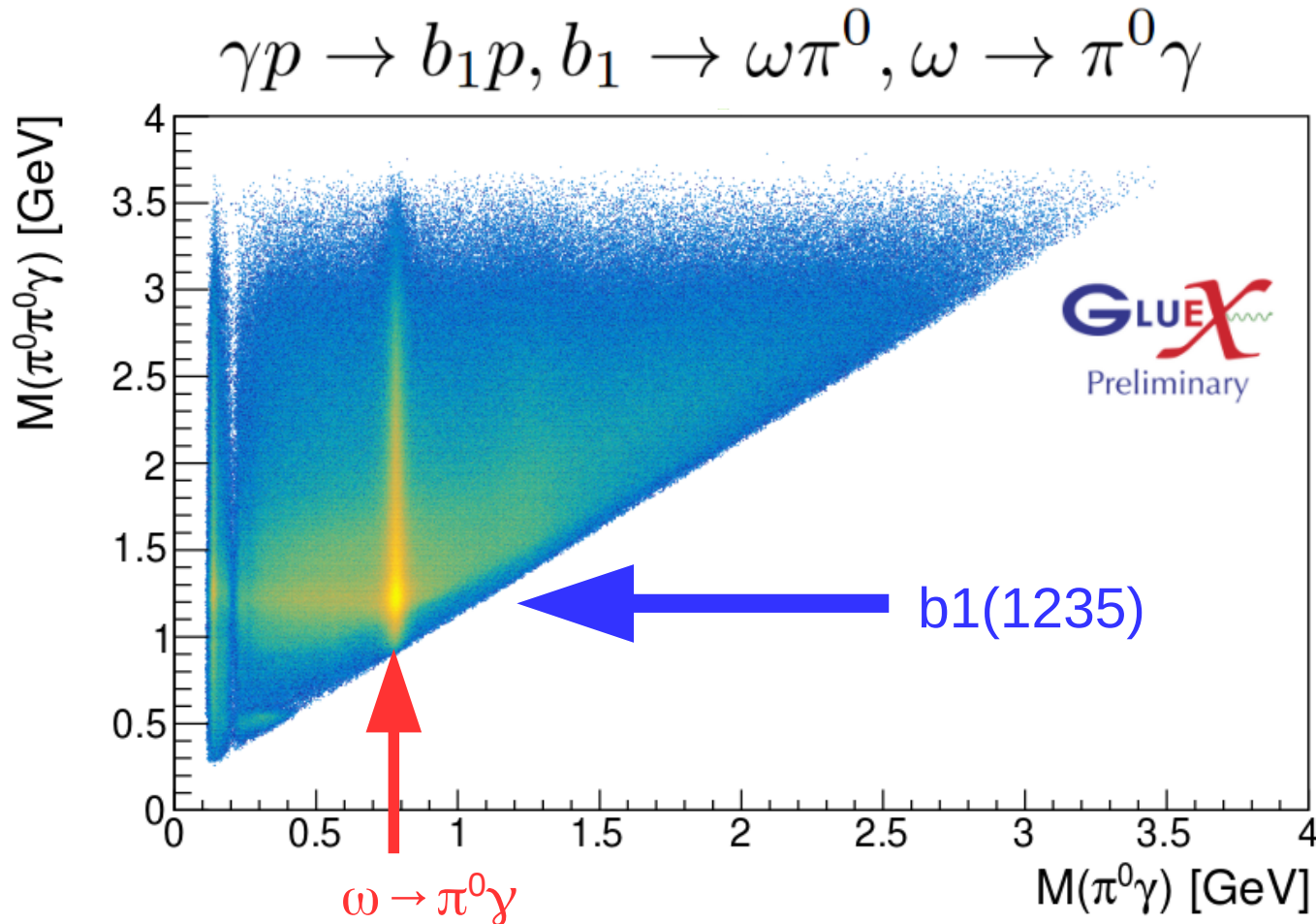
■ ■ ■

Spectroscopy Opportunities ($\gamma p \rightarrow \gamma \gamma \gamma \gamma p$)

- $\gamma p \rightarrow \gamma \gamma \gamma \gamma p$
 - Sparse prior data in channels with multiple neutral states
 - Already much more data than previous experiments
 - Interesting features emerging

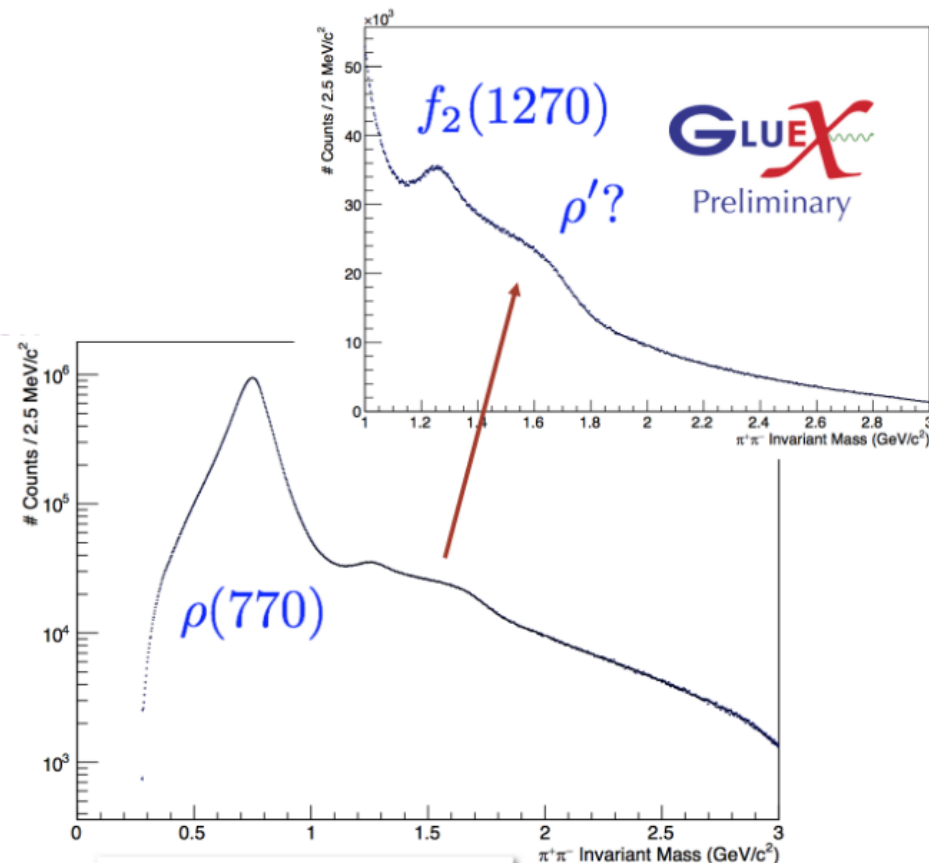
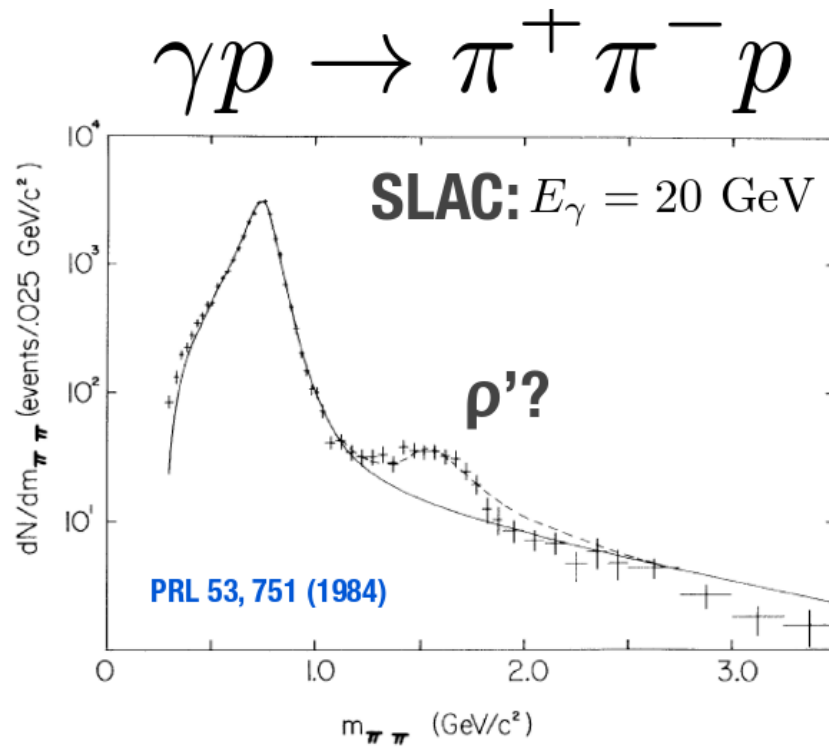


Spectroscopy Opportunities (5γ)



- **Able to reconstruct 5γ final states**
- **$b_1(1235)$ observed in its dominant decay mode**

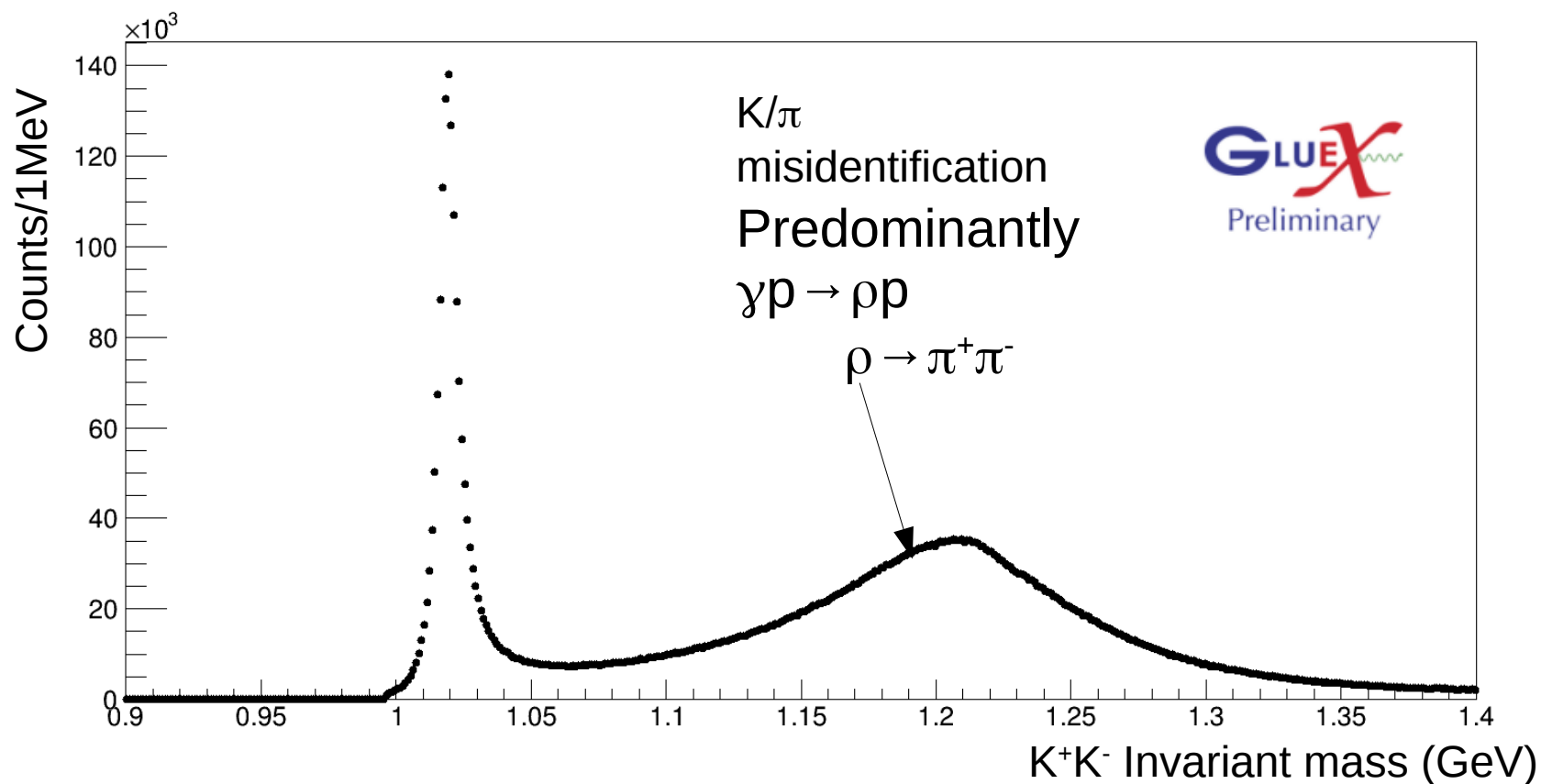
Spectroscopy Opportunities ($\gamma p \rightarrow \pi^+ \pi^- p$)



Distribution consistent with SLAC but already with 100x the statistics

Further analysis (e.g. polarization observables) needed to work out the nature of the enhancements

Spectroscopy Opportunities ($\gamma p \rightarrow K^+ K^- p$)

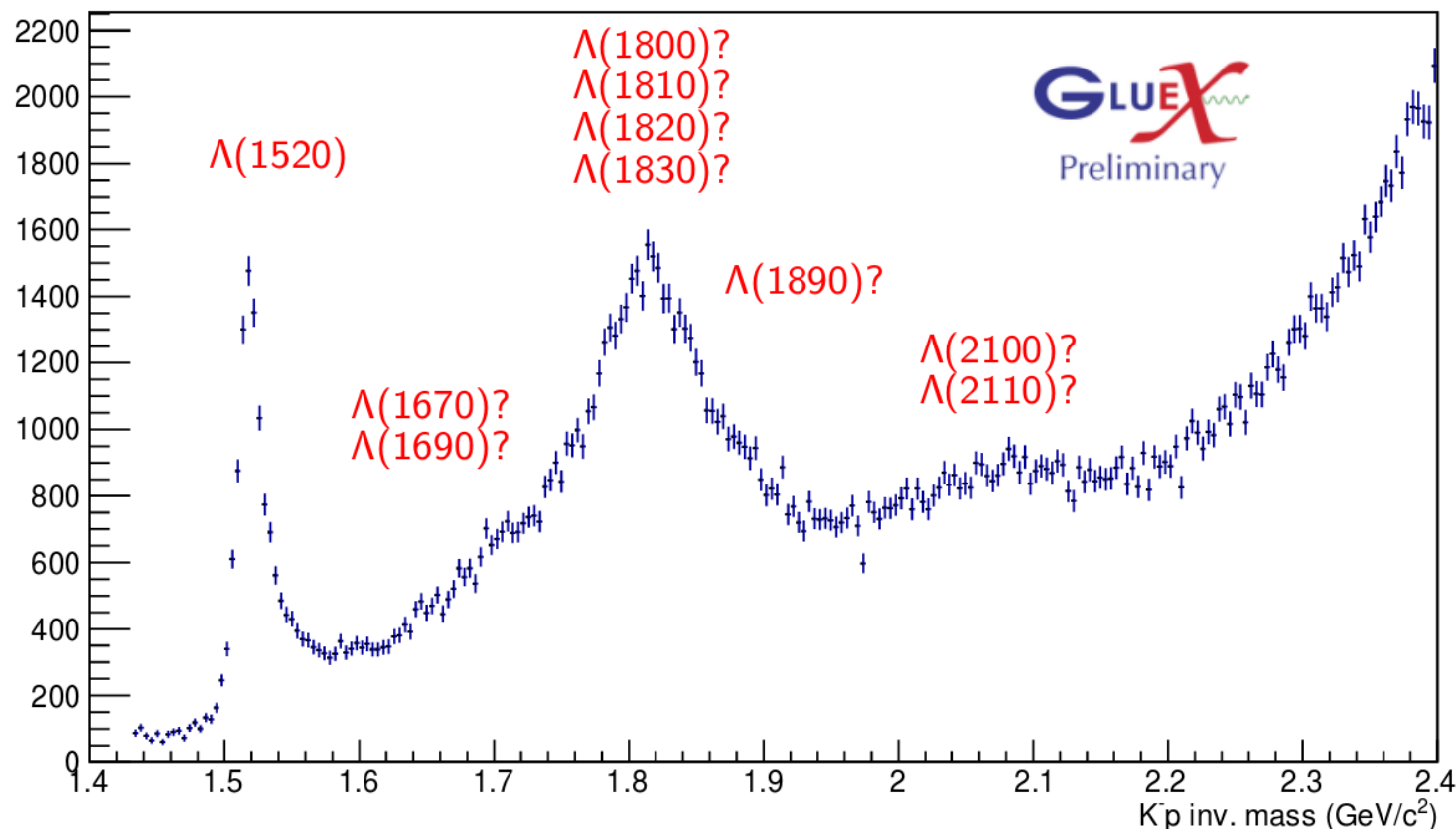


Looking at ~25% of data

Clear ϕ peak

Spectroscopy Opportunities ($\gamma p \rightarrow K^+ K^- p$)

$$\gamma p \rightarrow K^+ \Lambda, \Lambda \rightarrow K^- p$$

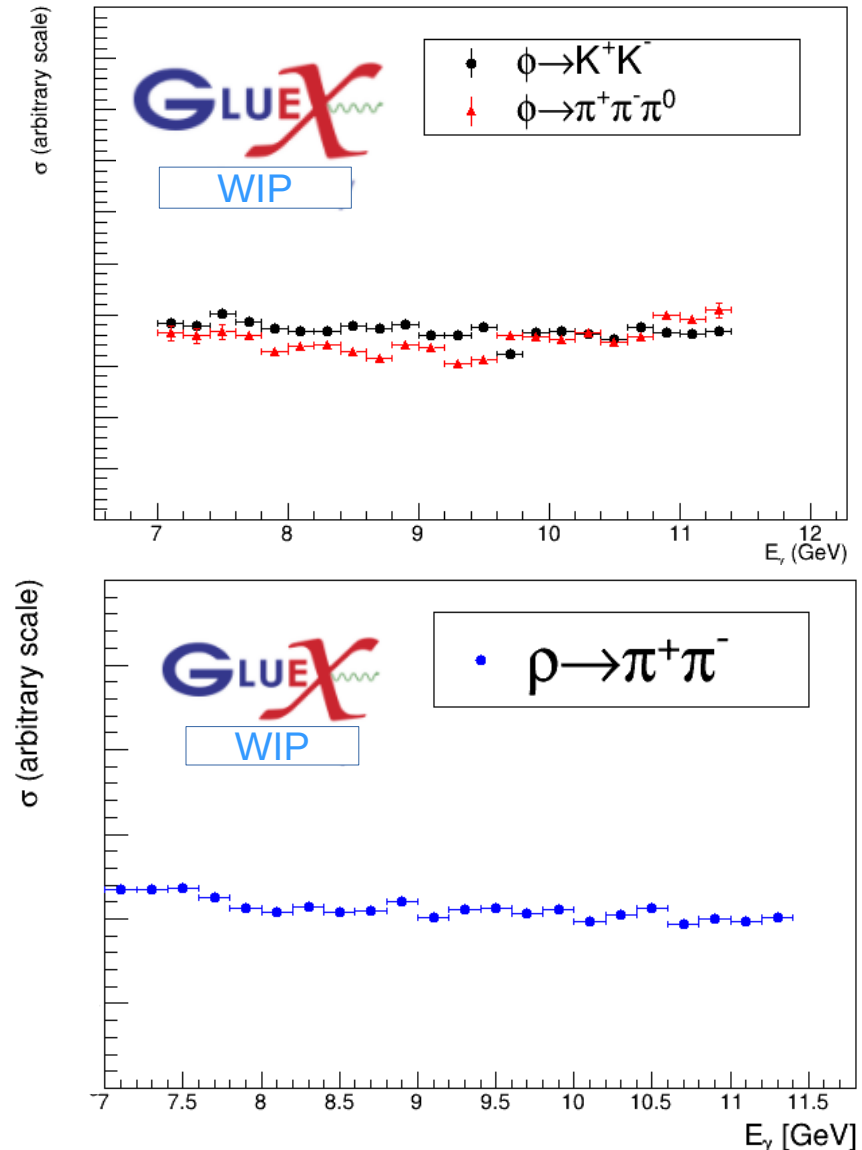


Many interesting features present in $K^- p$

A lot of higher mass Lambda states have poorly measured mass/widths

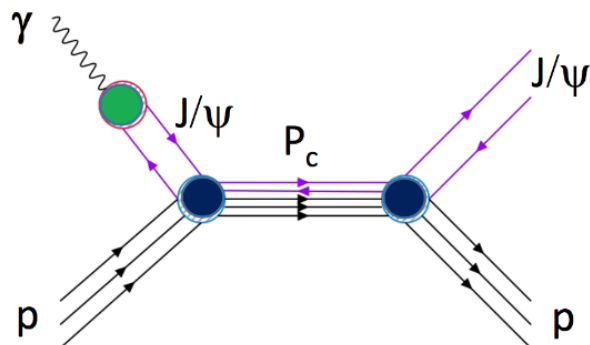
On the Road to Cross-Sections (**W**ork **I**n **P**rogress)

- Unlike beam asymmetry measurements cross-sections are sensitive to our understanding of the flux and efficiency
 - Useful to calibrate the experiment on known meson cross-sections
- Qualitatively trends agree with previous measurements as a function of energy
 - Analysis is ongoing



J/ψ Photo-Production

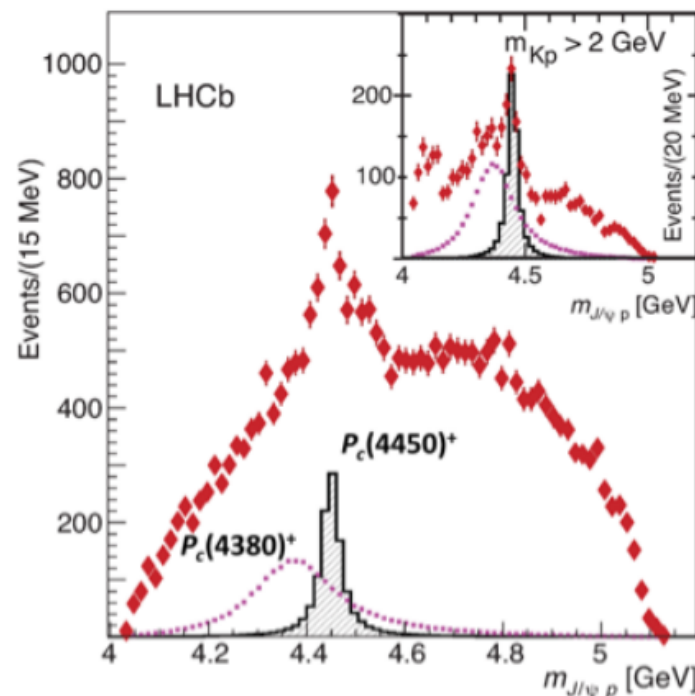
Photo-produced pentaquark



- LHCb's pentaquark candidates, found in decays to $J/\psi p$, should be accessible to GlueX thanks to the 12GeV upgrade
- States should appear as s-channel resonances at photon energies of $\sim 10\text{GeV}$

Phys. Rev. D 92 3, 031502, 2015
 arXiv:1508:0033
 arXiv:1508.01496

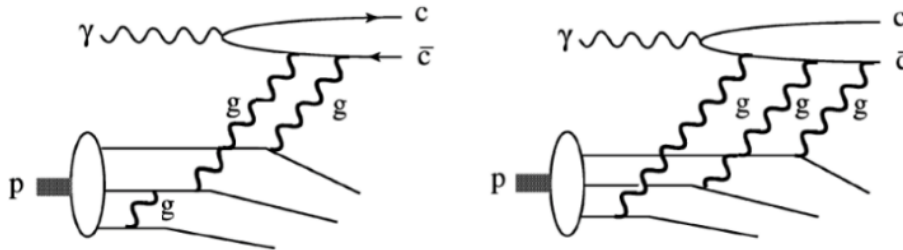
$$\Lambda_b \rightarrow J/\psi p K^-$$



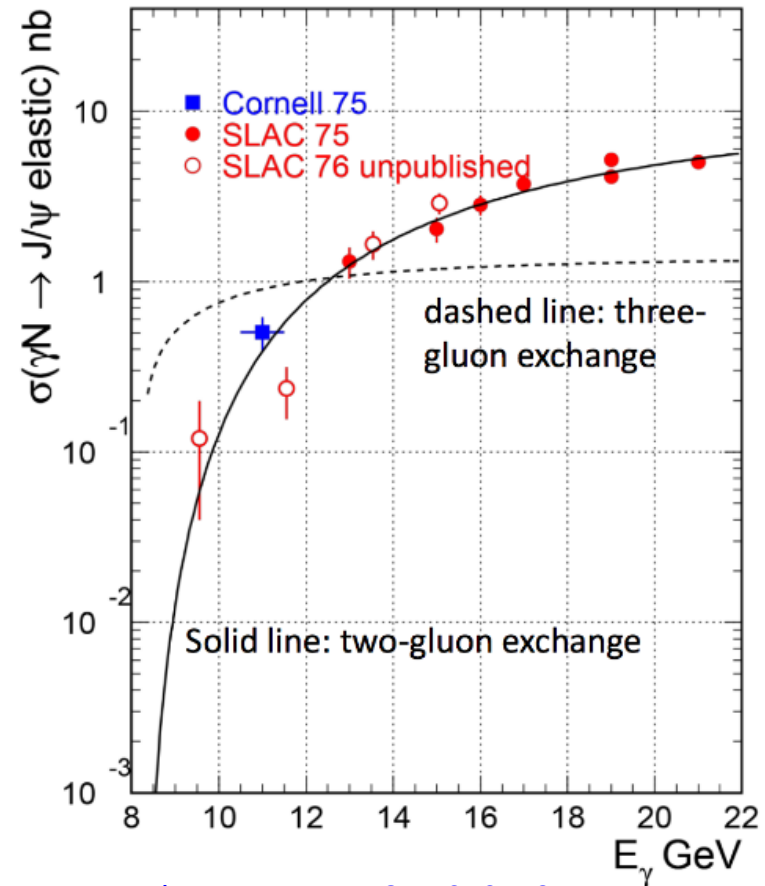
Phys. Rev. Lett. 115, 072001
 (2015) [LHCb]

J/ ψ Photo-Production cont.

- Studying J/ ψ near threshold gives nucleon distribution information



- Signals in $\gamma p \rightarrow J/\psi p$ would be an important confirmation of LHCb's states
 - Can measure branching ratio $P_c \rightarrow J/\psi p$ (or set limits)
 - Can measure cross-section
- Photo-production measurements would help distinguish the nature of the states



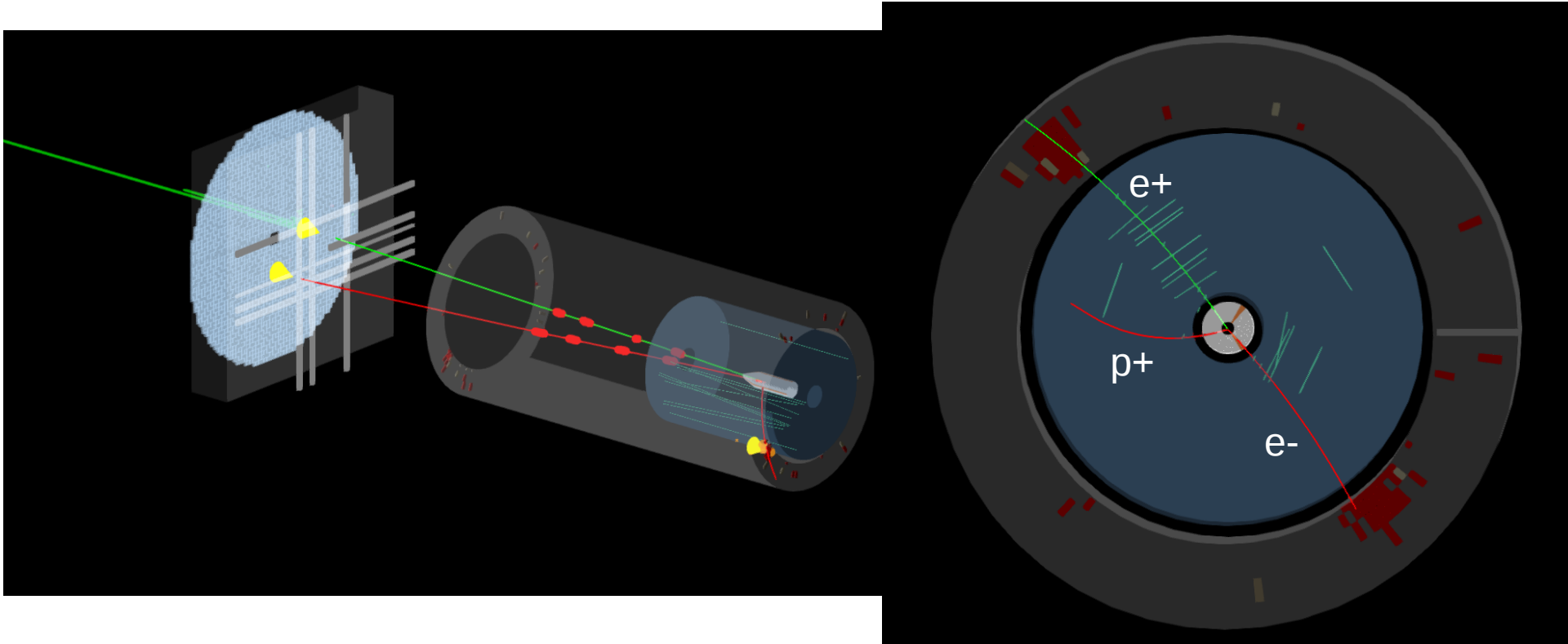
-Phys. Rev. Lett., 35:1616, 1975

-Phys. Rev. Lett., 35:483, 1975

-Excess Muons and New Results in ψ Photoproduction. 1976

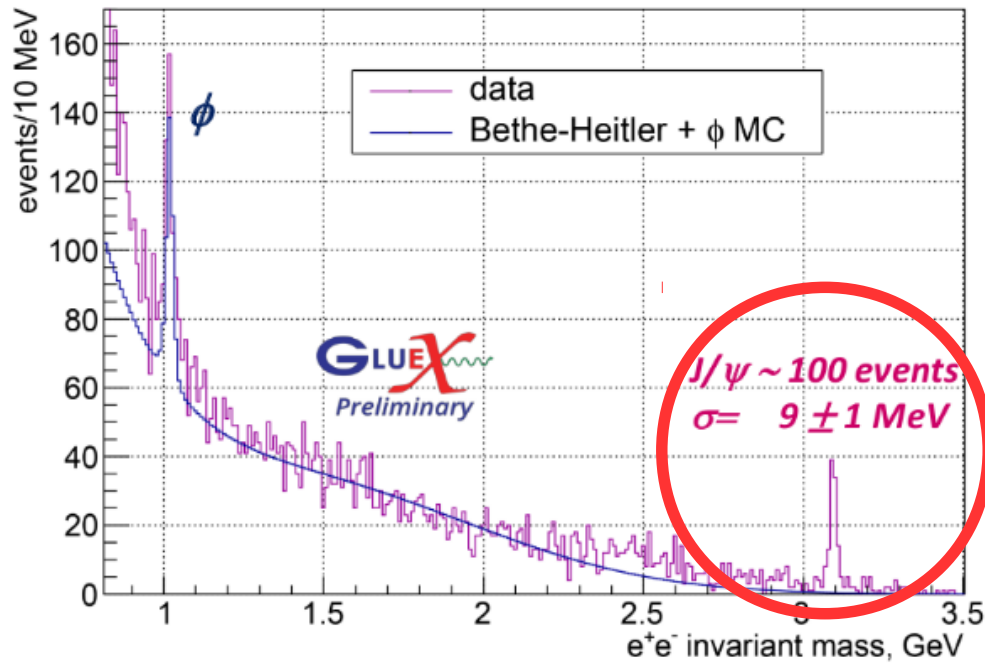
J/ψ in Hall-D

$$\gamma p \rightarrow J/\psi p, J/\psi \rightarrow e^+e^-$$



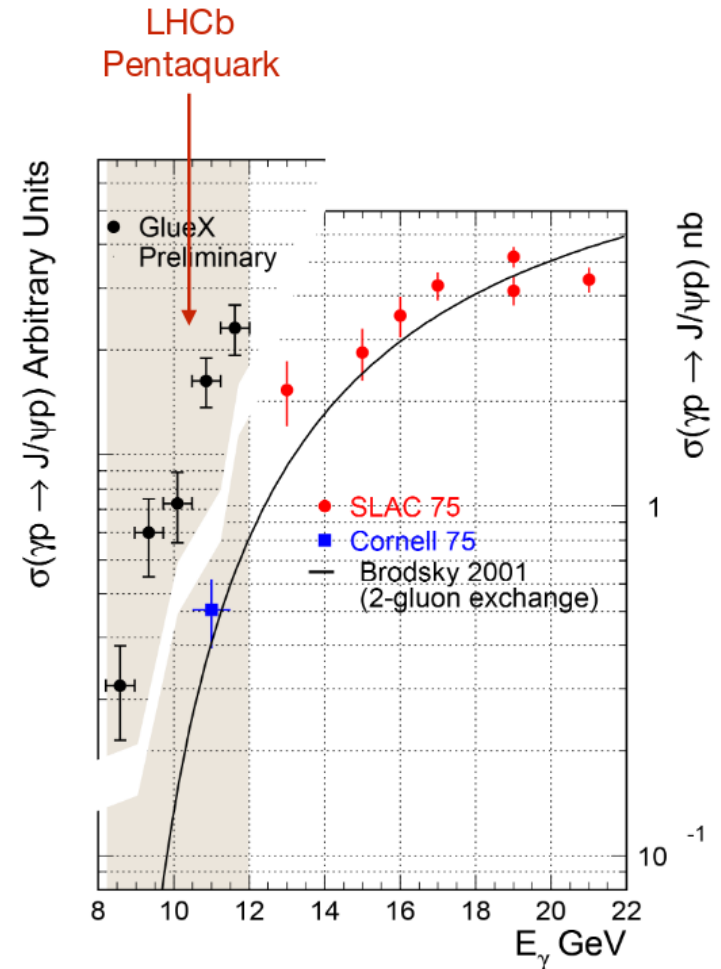
J/ψ in Hall-D cont.

MC normalized to ϕ x-sec. kin.fit $\chi^2 < 200$, $\theta_e > 2^\circ$



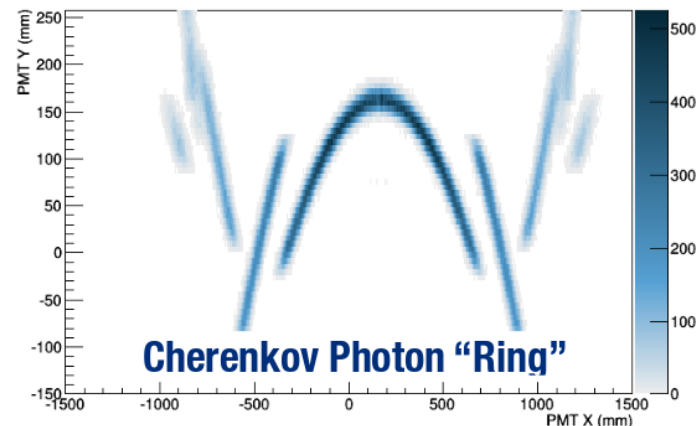
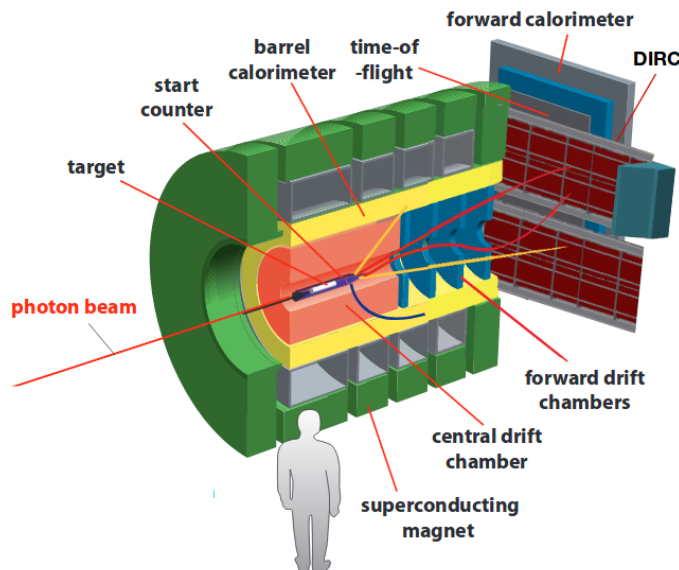
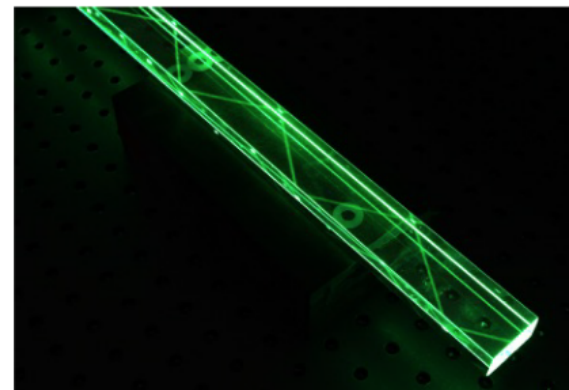
- Small fraction of data
 - Clear J/ψ signal
- Will be able to perform measurements related to LHCb Pc states

$$\gamma p \rightarrow p e^+ e^-$$



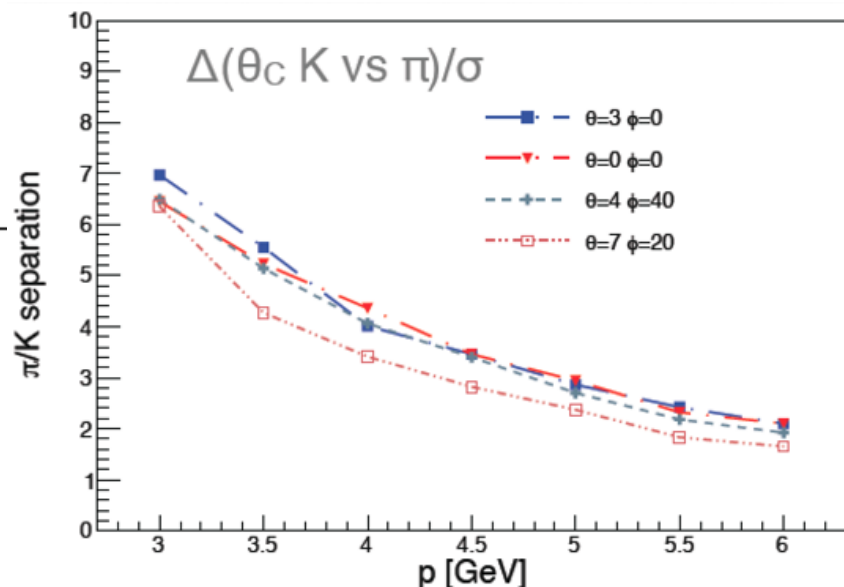
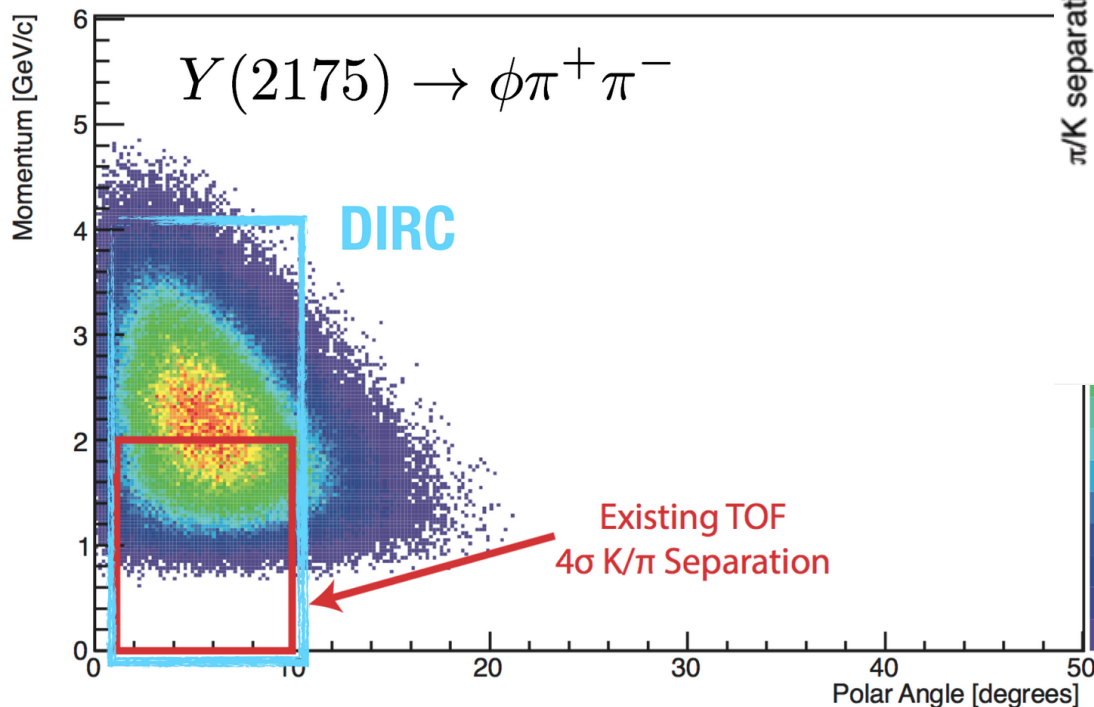
The DIRC

- The GlueX DIRC (**D**etection of **I**nternally **R**eflected **C**herenkov light) will enhance K/π particle identification
- The GlueX DIRC will be built using components from the **BaBar** DIRC
- Partial installation and commissioning in **2018**



DIRC Expectations

GLUEX Simulation



- Expect to extend the range by factor of 2
- More opportunities in spectroscopy with strangeness

Summary

- ~75% initial GlueX data taken
 - ~**25% analyzed**
- First physics paper on the beam asymmetries of π^0 and η published
Phys. Rev. C 95, 042201(R)
- Data Analysis underway
 - **Beam asymmetries for η , η' , and π^-**
 - Spin Density Matrix Elements for vector mesons
 - Cross-section measurements
 - **J/ ψ measurements**
 - BR $P_c \rightarrow J/\psi p$
 - cross-section
- **DIRC** detector to be installed this year to enhance π/K PID separation