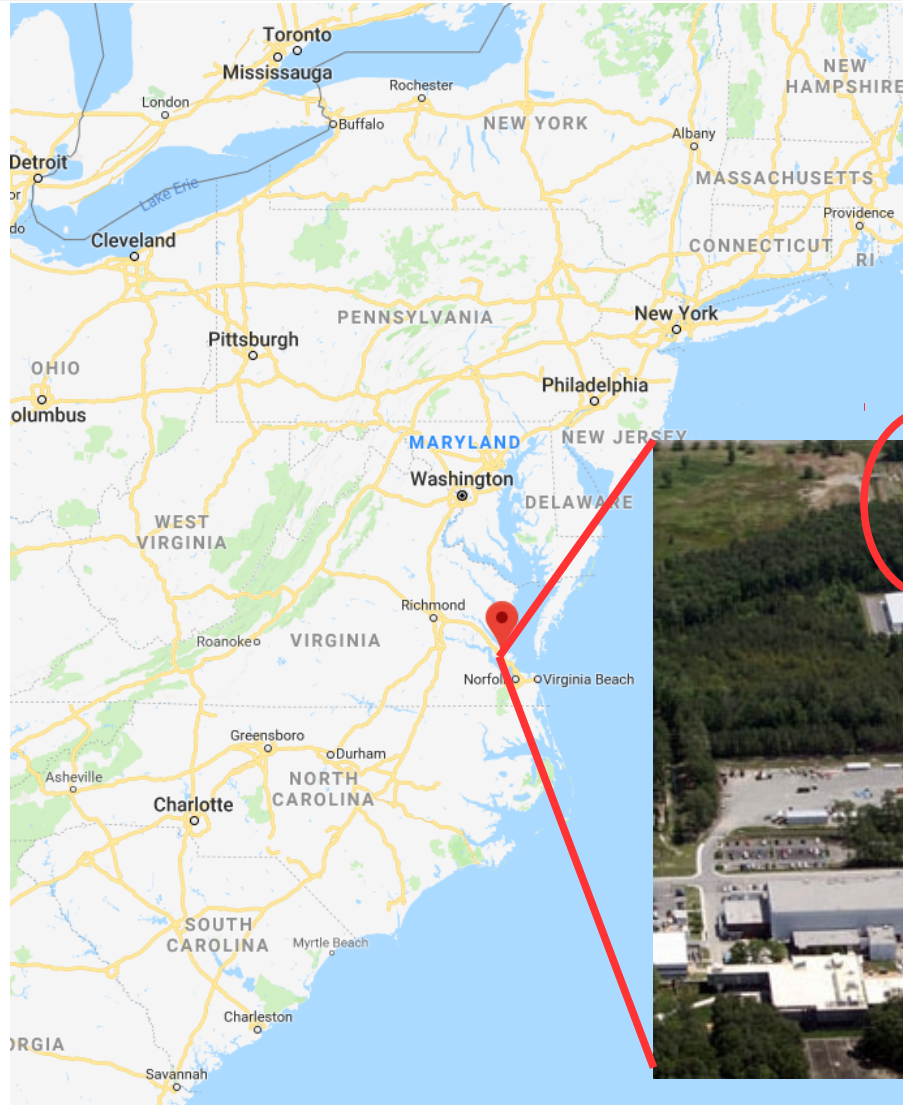# Latest Results from GlueX

Thomas Britton

on behalf of the GlueX collaboration

15th International Workshop on Meson Physics

KRAKÓW, POLAND
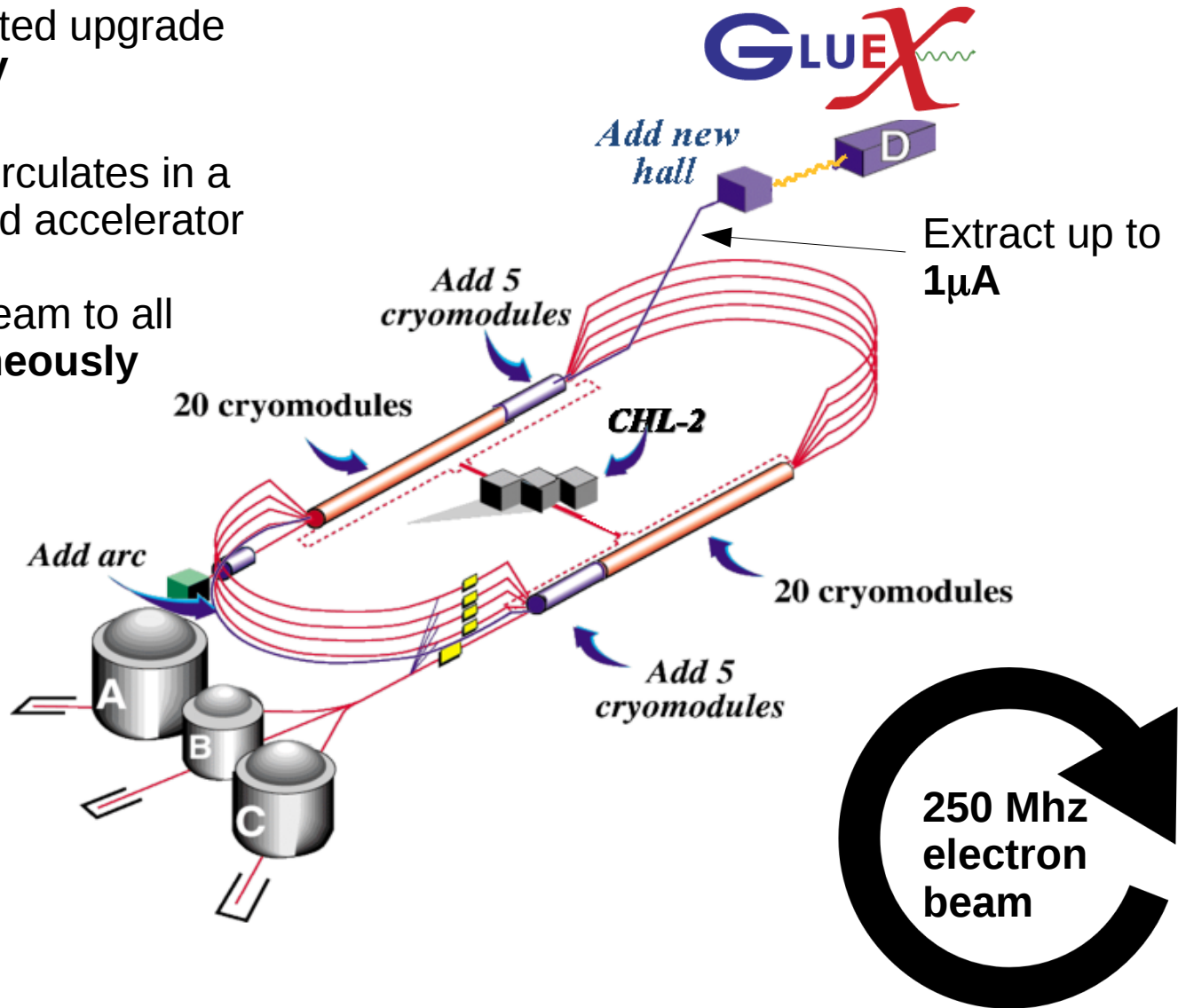
7th - 12th June 2018

Jefferson Lab

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

U.S. DEPARTMENT OF **ENERGY**   JSA
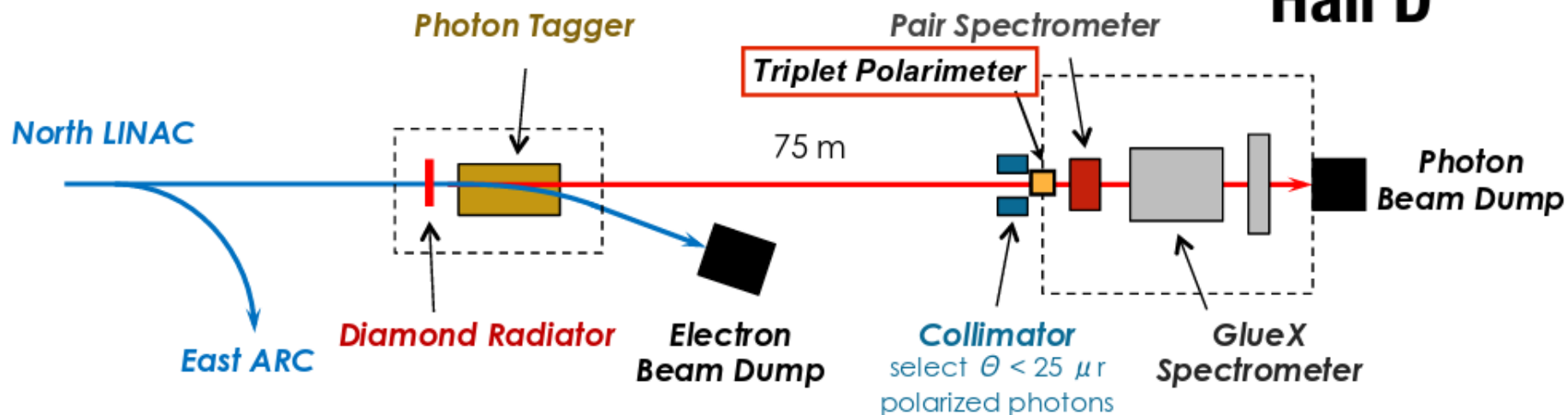
Jefferson Lab

Jefferson Lab cont.

- Recently completed upgrade from 6 to **12 GeV**

- Electron beam circulates in a race track shaped accelerator

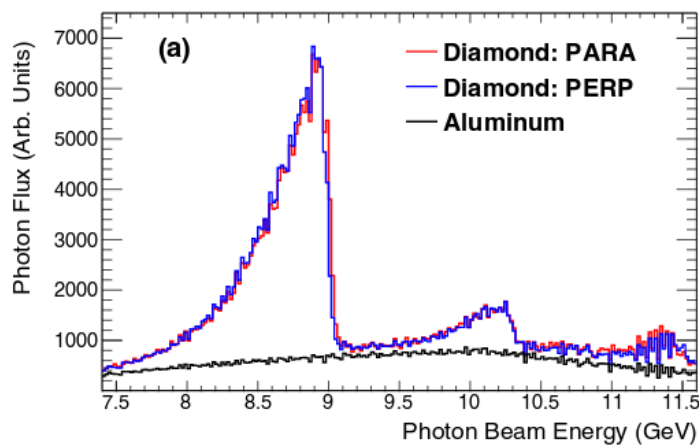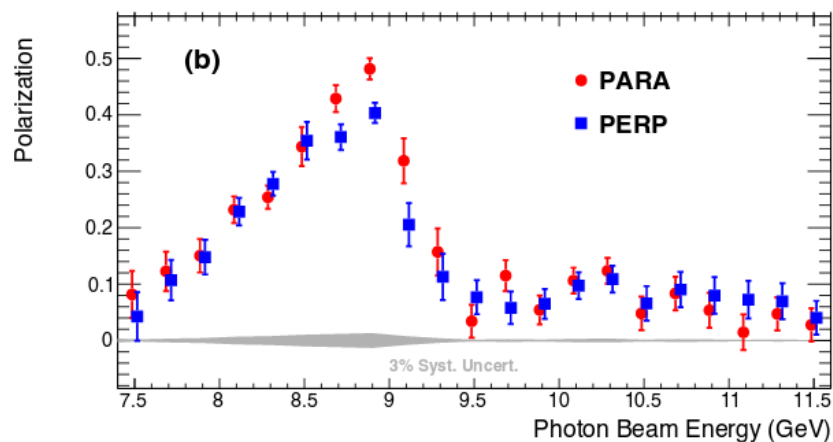- Able to deliver beam to all **4 halls simultaneously**

Extract up to **1μA**

250 Mhz electron beam

GlueX

GlueX cont.

- Beam resolution **~0.1%**
- Liquid hydrogen target
- Good coverage for detection of both neutral and charged final state particles
  – Resolutions of **1-5%**

50 nA to 1 μA extracted

(2 Tesla)

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

$B \rightarrow J\psi\phi K$

X(4274)
X(4500)
X(4700)
X(4140)

LHCb 2016

mesons   baryons

?

tetraquark   pentaquark

JSA   Jefferson Lab

Purpose (preamble)

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  - Mesons, baryons
  - Tetra/penta-quark
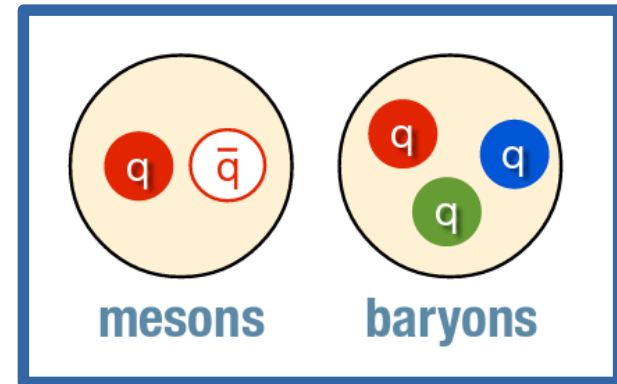
- But these aren't the only states QCD predicts!
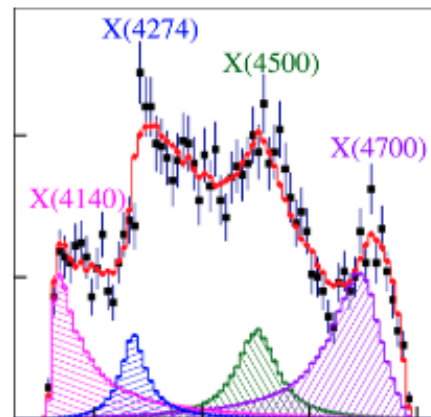
A SCHEMATIC MODEL OF BARYONS AND MESONS *

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… 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. …
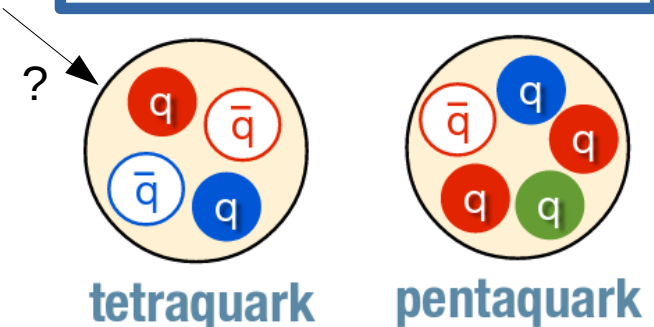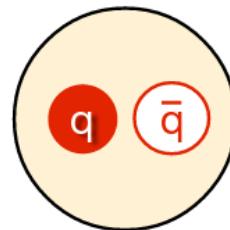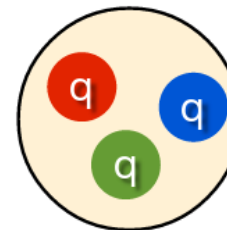
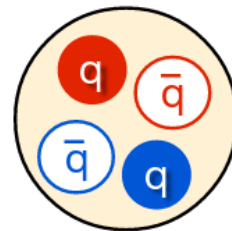**Phys. Lett. 8 (1964) 214**

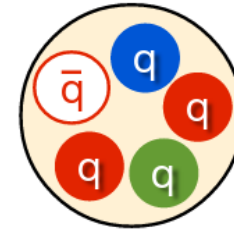$$\Lambda_b \to J/\psi p K^-$$
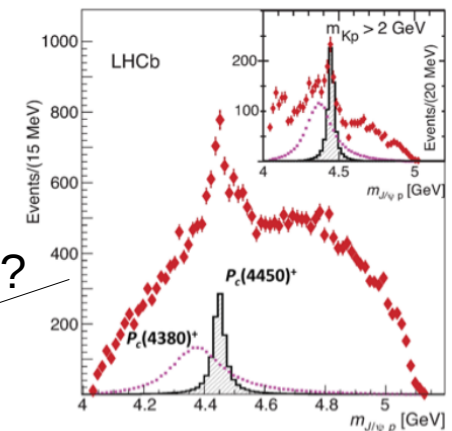
mesons   baryons

tetraquark   pentaquark

LHCb 2015

Jefferson Lab

Purpose (preamble)

glueball

hybrid meson

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

Purpose (preamble)
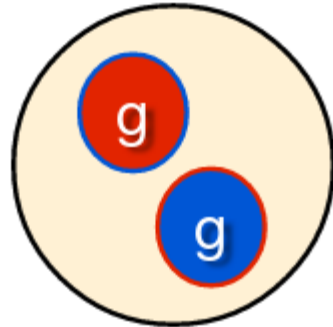
glueball
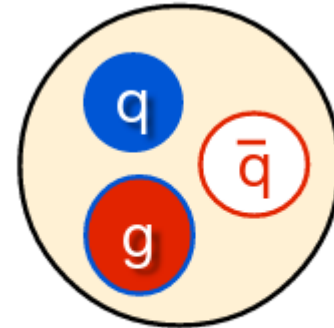
hybrid meson

- ## In the Non-Relativistic quark model:

  – $J = L + S$

  – $P = (-1)^{L+1}$ → JPC sets forbidden by the constituent quark model: $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$, etc...
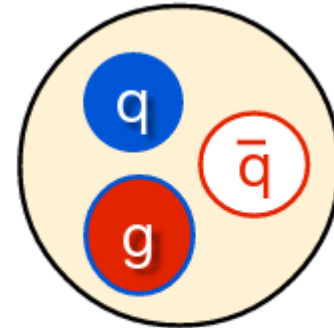
  – $C = (-1)^{L+S}$

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

Jefferson Lab

Predicted Spectrum

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

Rich spectrum of states with the lightest hybrids outlined in orange
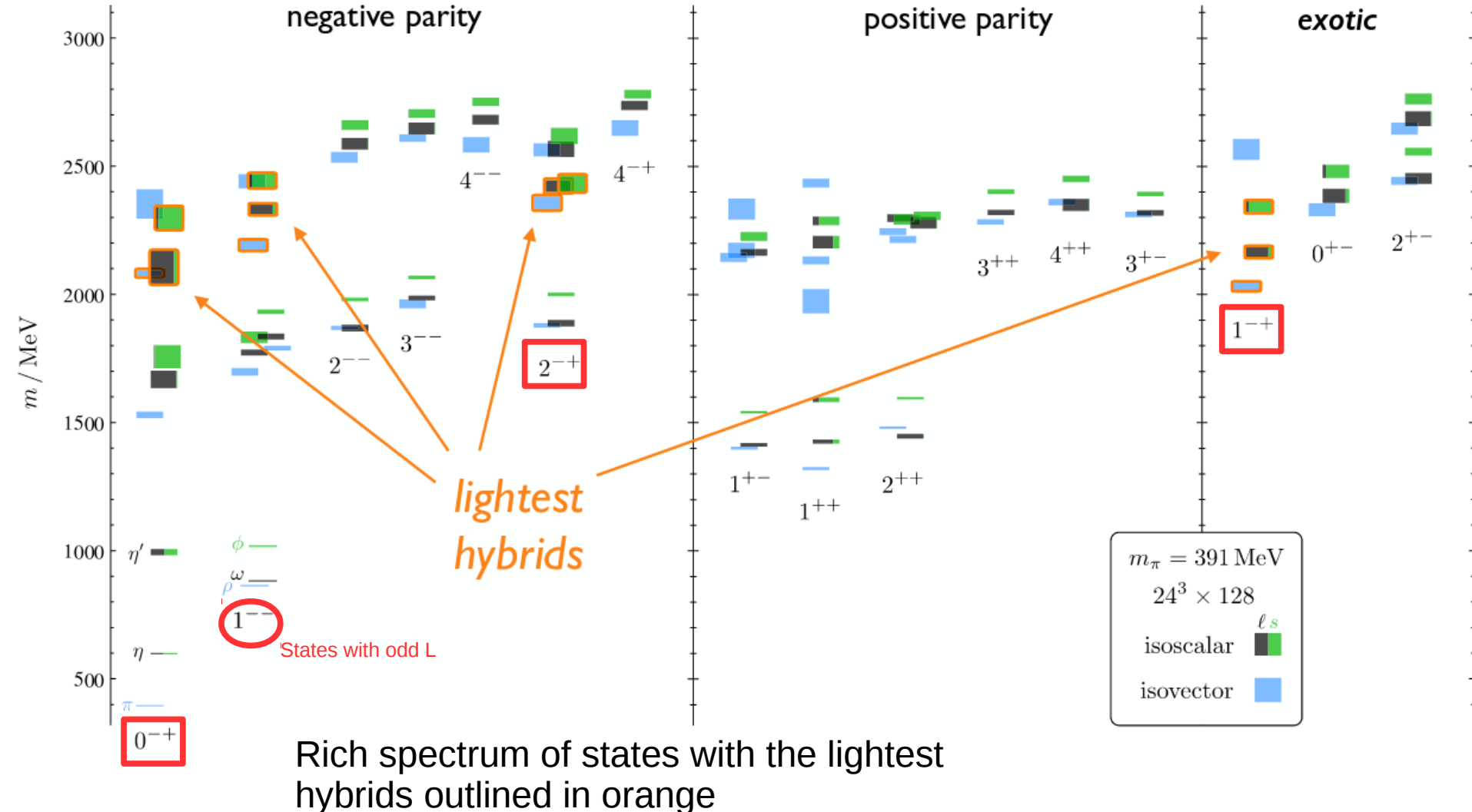
Lattice QCD

Dudek et al. PRD 88 (2013) 094505

Lightest hybrid mesons

Compass: PLB 740 (2015) 303
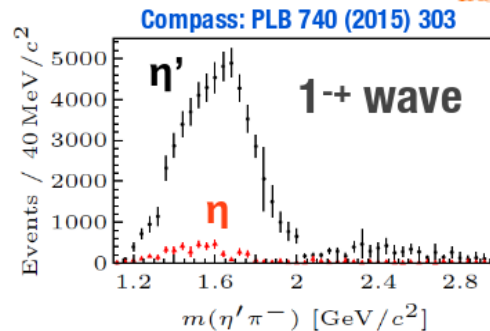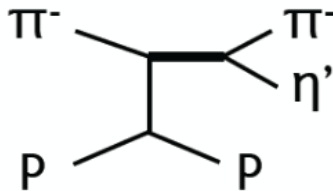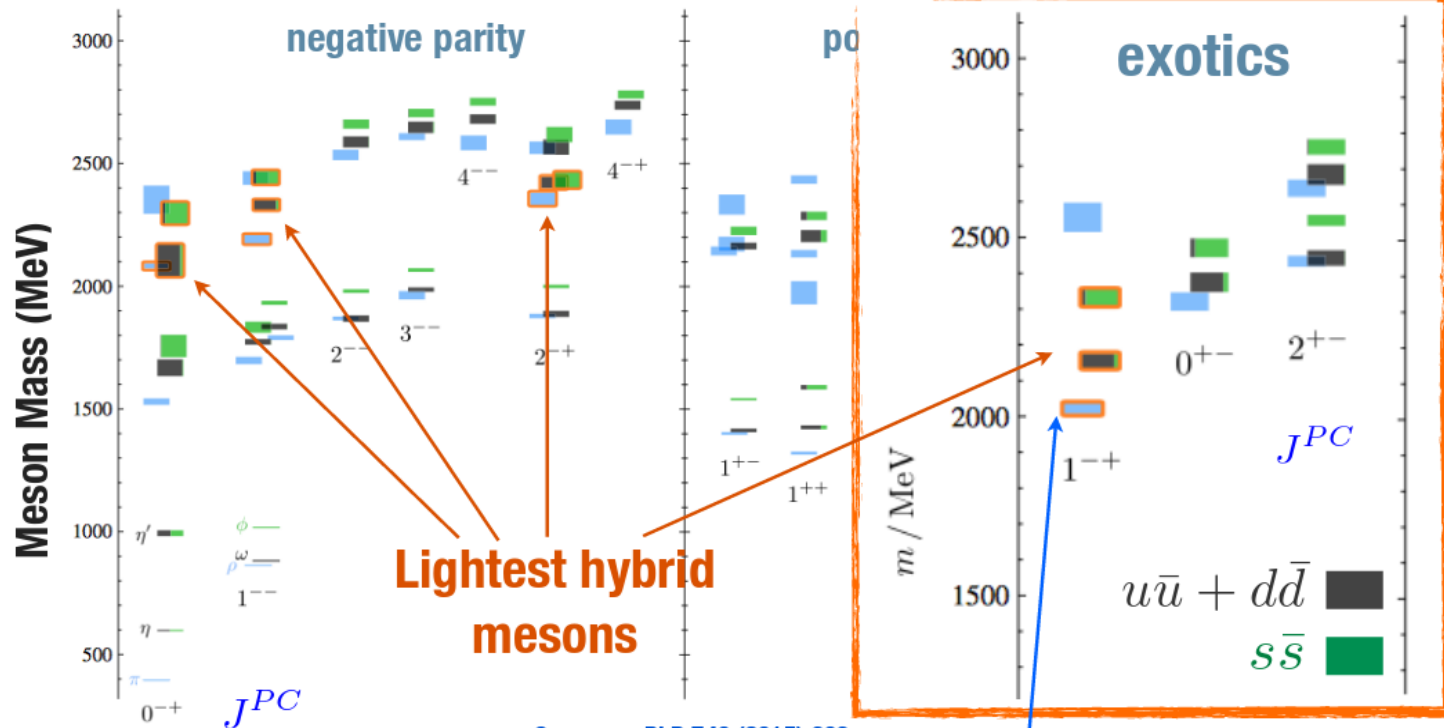
Most experimental searches for hybrids limited to the **π₁ state**

An Interpretation
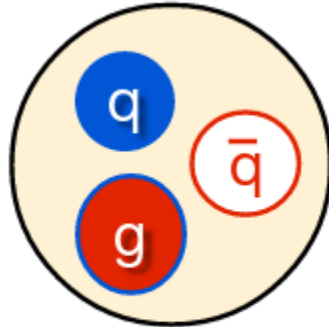
hybrid meson

- 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 $q\bar{q}$

Jefferson Lab

- ## 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
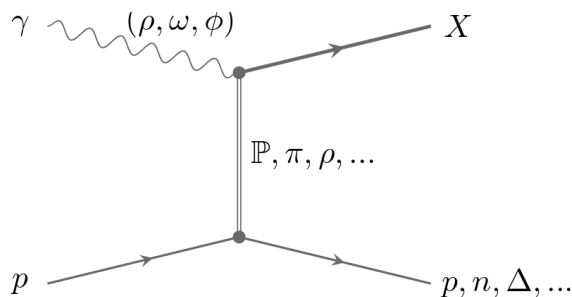 - γ coupling via vector meson dominance to wide variety of states (including exotic J^{PC})

Exchange		Exotic Final States	
$\mathbb{P}$	0^{++}	b, h, h'	$2^{+-}, 0^{+-}$
π^0	0^{-+}	b_2, h_2, h'_2	2^{+-}
$\pi^{\pm}$	0^{-+}	$\pi_1^{\pm}$	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
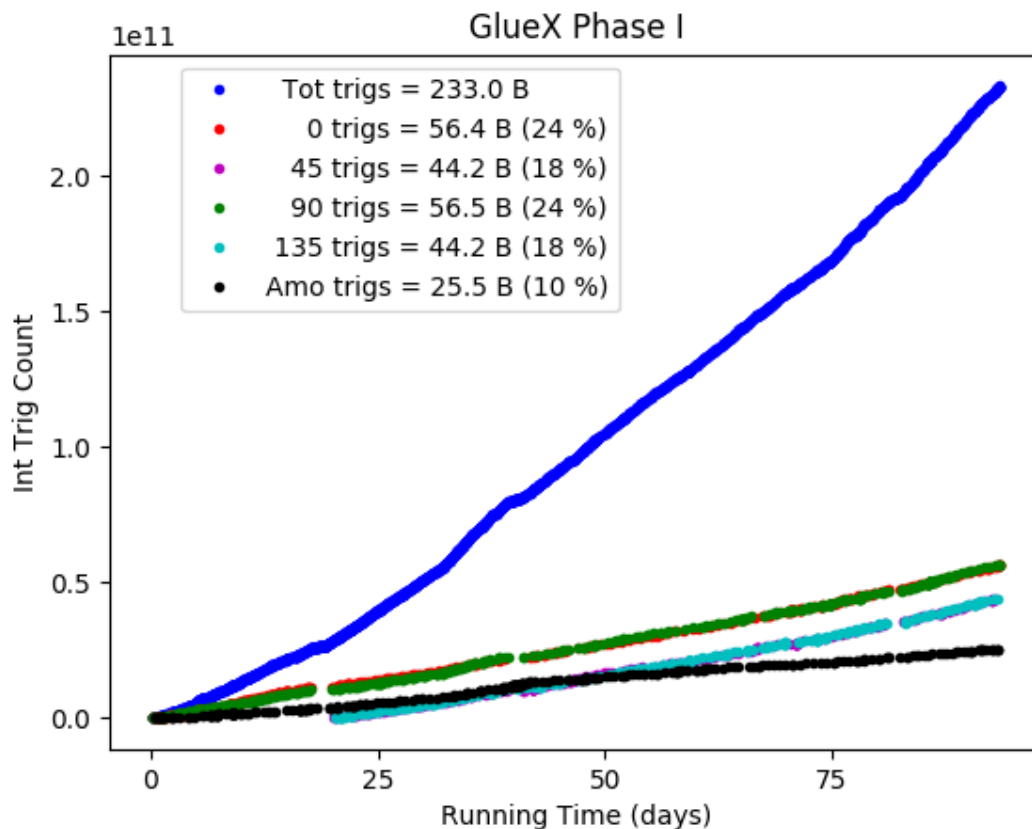
Analysis Road-map
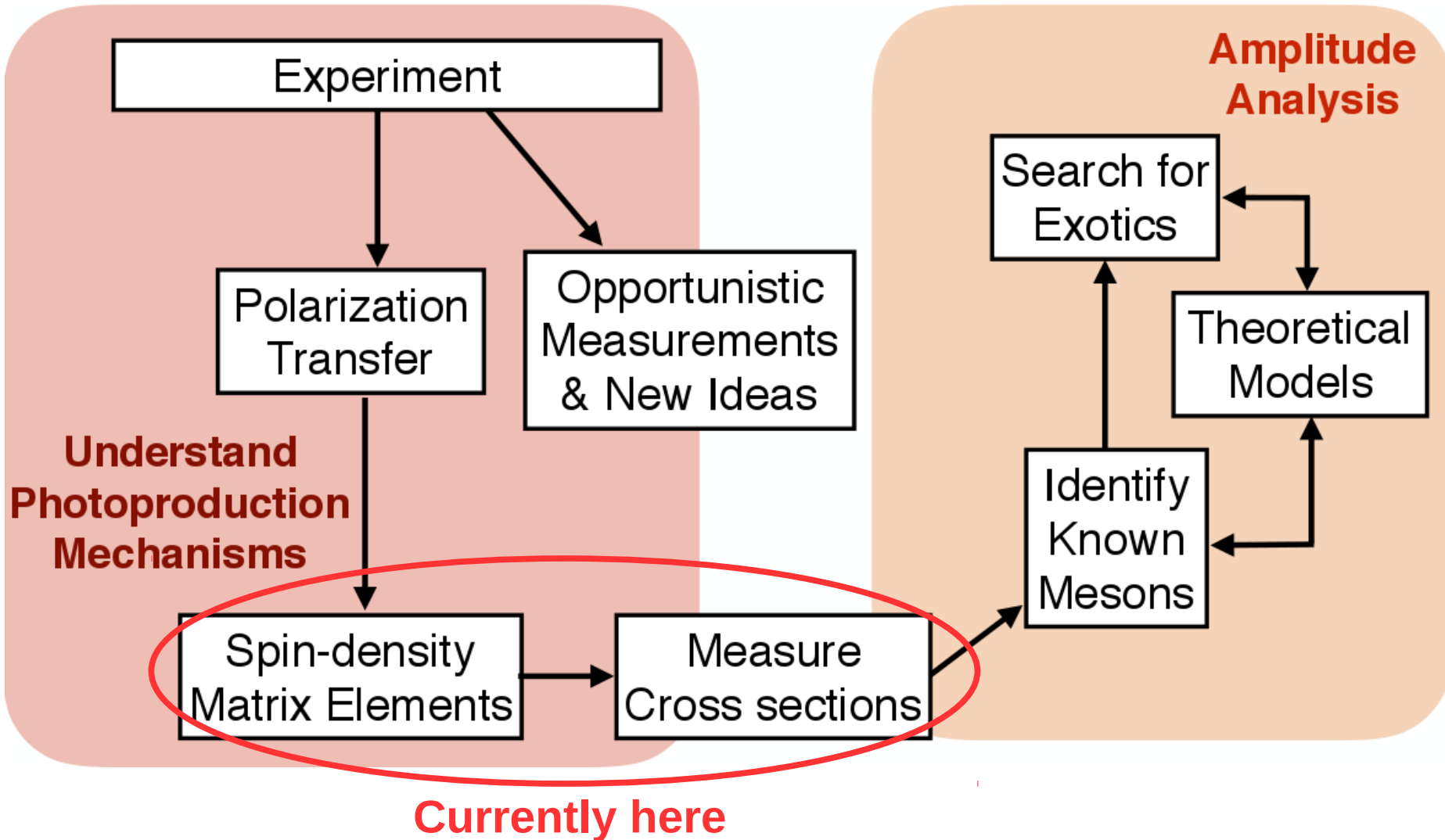
Beam Asymmetries (Σ) for $\gamma p \rightarrow \pi^0 p$
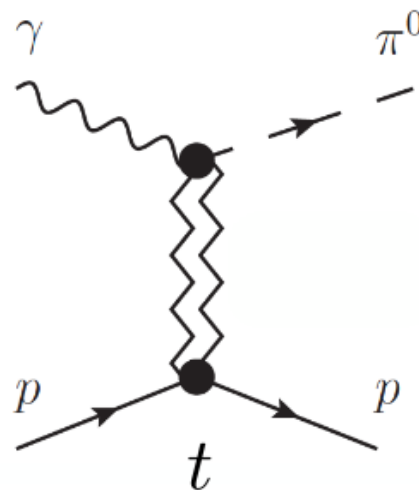
$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$

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

• 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}

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

Mathieu et al. PRD 92, 074013

Theory and SLAC data beam energies
— • 4 GeV
— • 6 GeV
— • 10 GeV

π^0

Beam Asymmetries (Σ) for π^0 and η
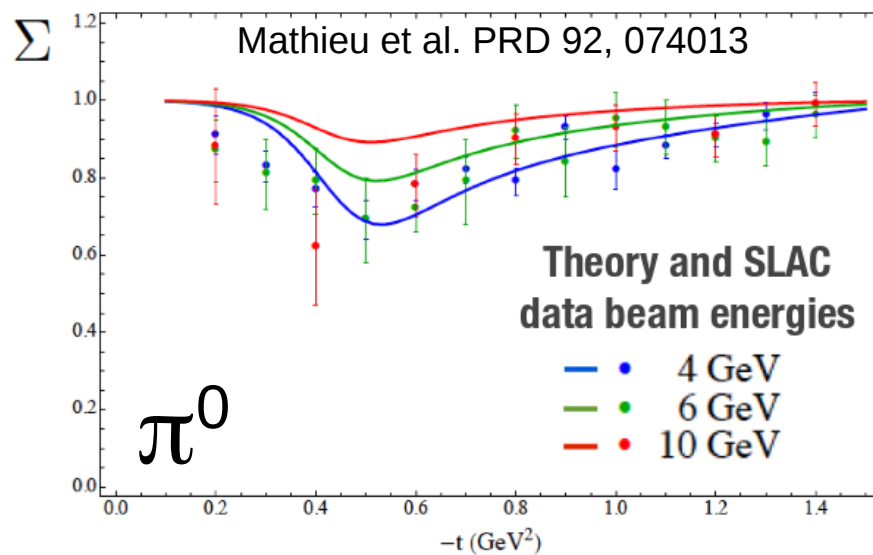
$$\gamma p \rightarrow p\gamma\gamma$$
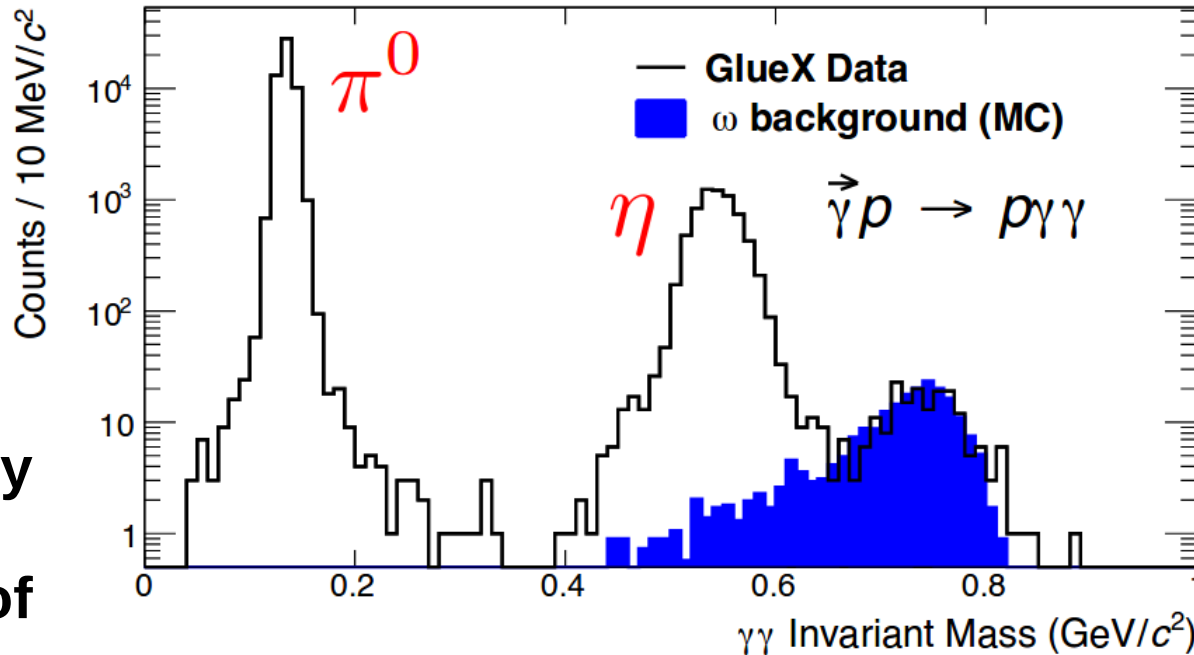
Relatively clean sample of both π^0 and η

Phys. Rev. C 95, 042201(R)

Beam Asymmetries (Σ)

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

Jefferson Lab
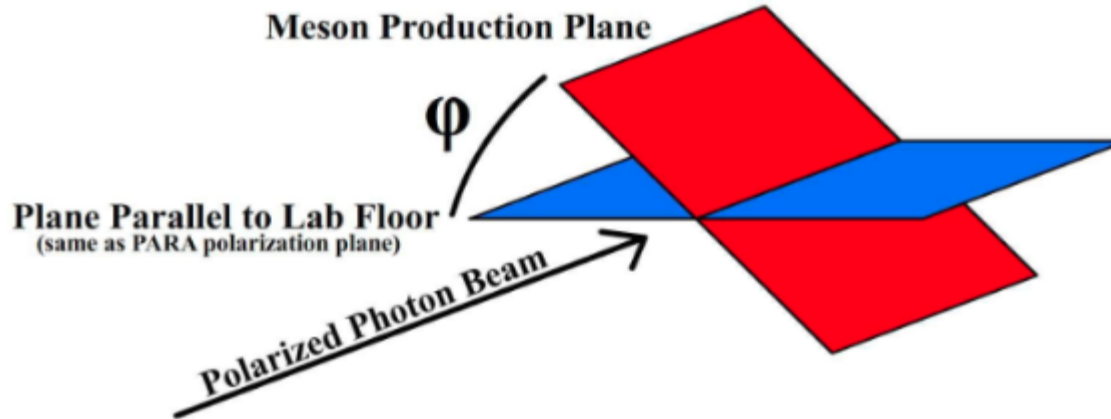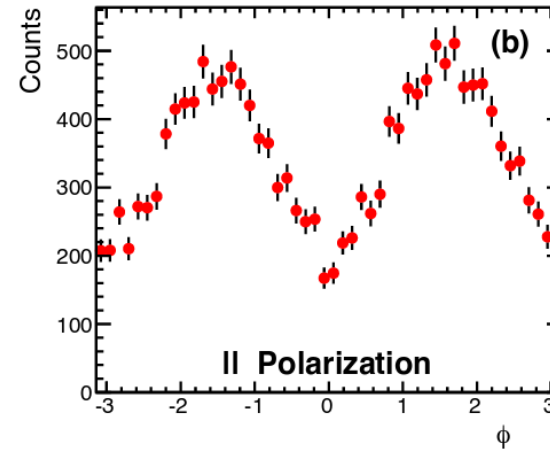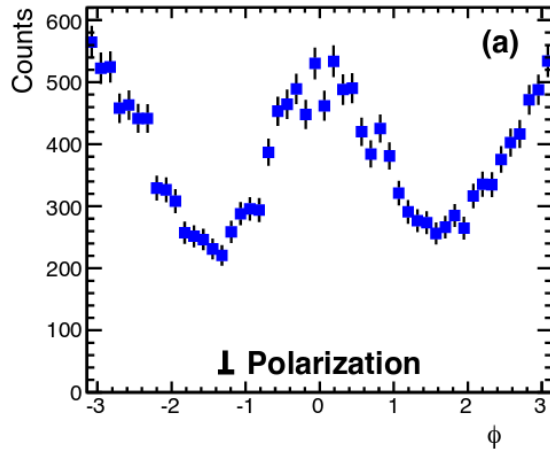
Beam Asymmetries (Σ)
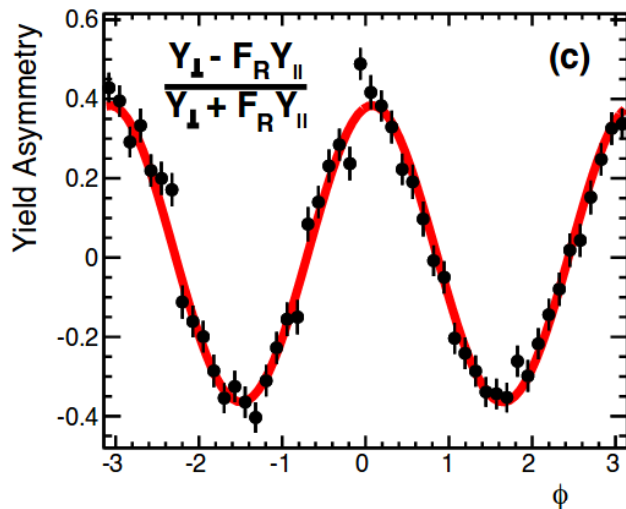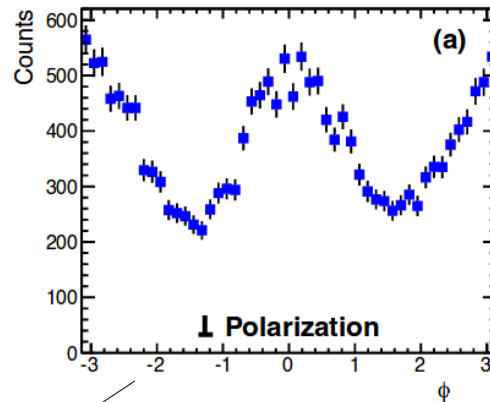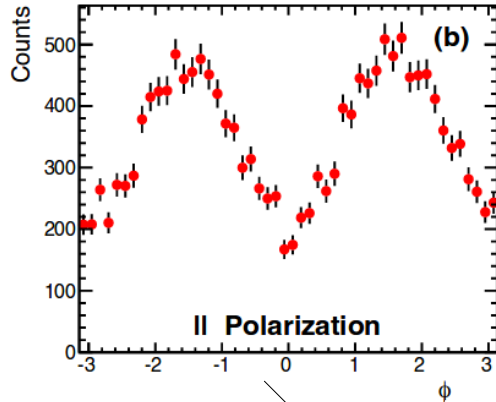
$$\frac{Y_\perp - F_R Y_\parallel}{Y_\perp + F_R Y_\parallel} = P_\gamma \Sigma \cos 2\phi$$

Yield Asymmetry

Beam Polarization

Fitted

Efficiency cancels!

Phys. Rev. C 95, 042201(R)

Jefferson Lab

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

- $\Sigma \sim 1 =>$ vector exchange dominance

- GlueX first physics publication in 2017
    - **Phys. Rev. C 95, 042201(R)**
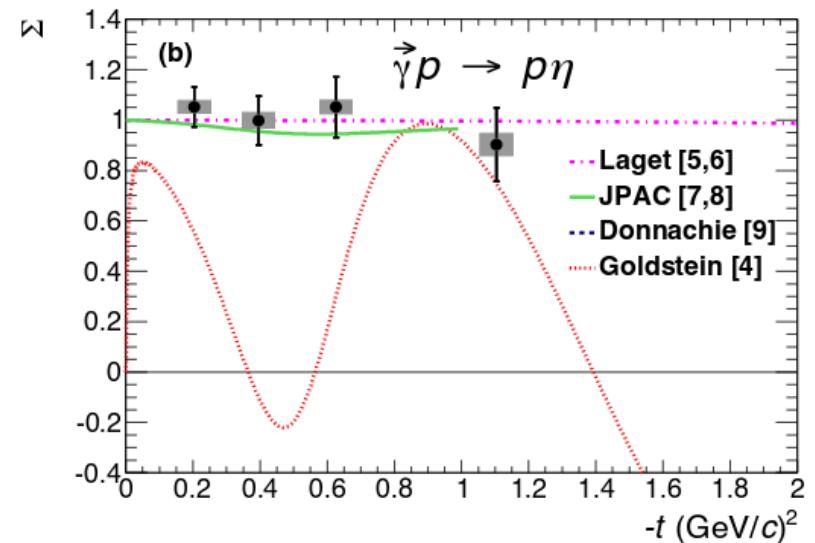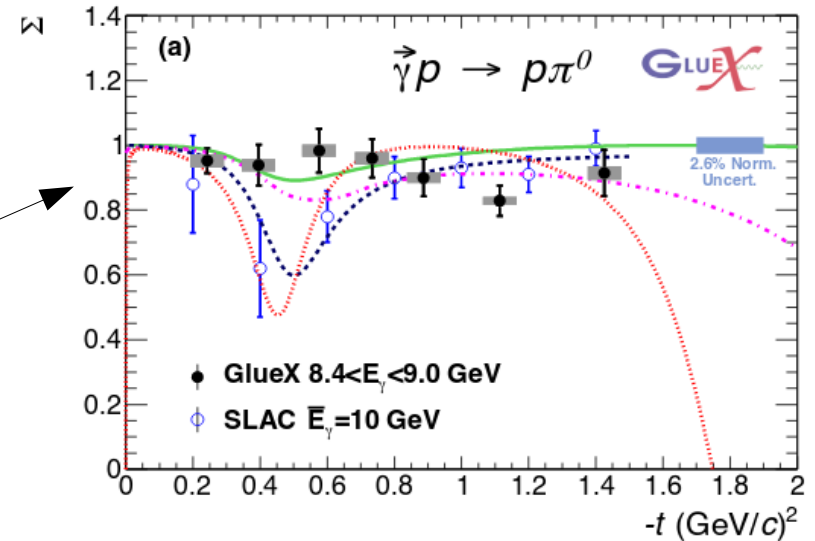
- **Neutral pseudo-scalars η and η′**
  - Σ ~1=> vector exchange dominance

η update with 5x the data

$\gamma p \rightarrow \eta p$

7% Normalization Uncertainty

Blue: $\eta \rightarrow 2\gamma$
Red: $\eta \rightarrow 3\pi^0$
Green: $\eta \rightarrow \pi^+ \pi^- \pi^0$

GlueX Preliminary

-t [GeV²]

$\gamma p \rightarrow \eta' p$

Normalization Uncertainty (7%)

GlueX Preliminary

-t (GeV²)

Jefferson Lab
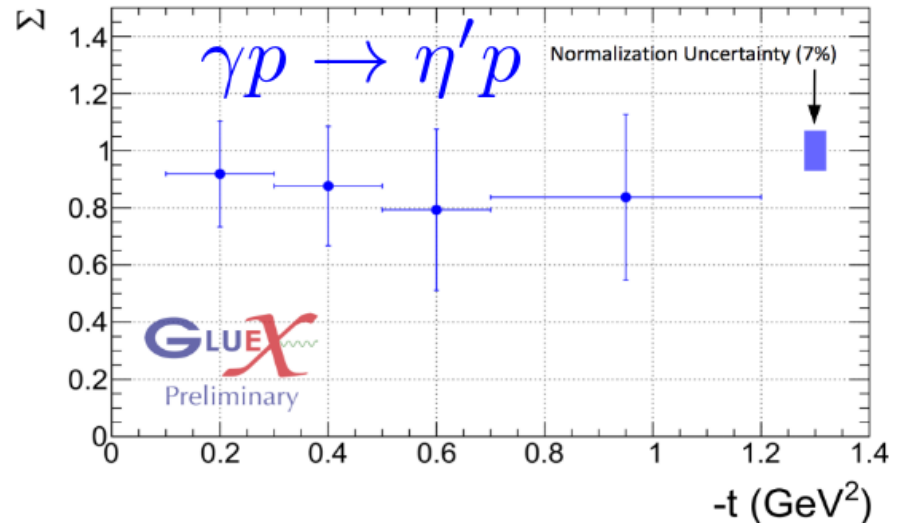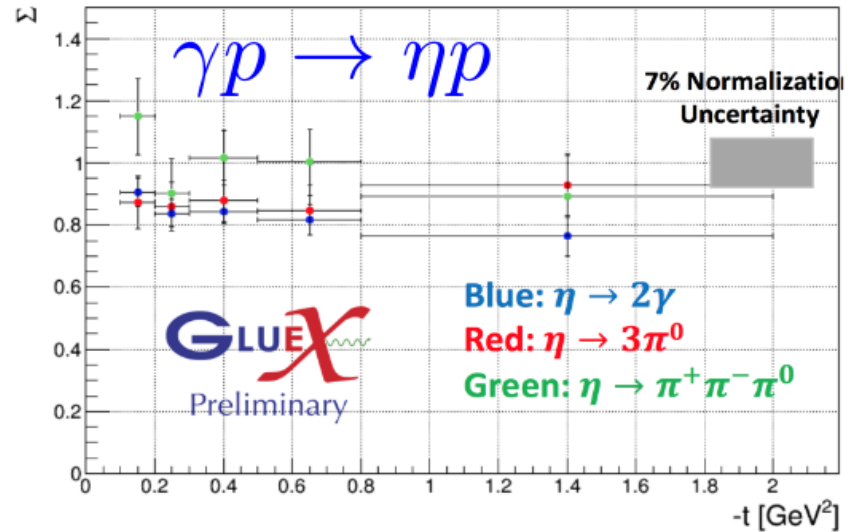
Beam Asymmetries cont.

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

  - More complicated t dependence

B.G Yu (Korea Aerospace U.), arxiv:1611.09629v5 (16 GeV)

J. Nys (JPAC), arxiv: 1710.09394v1 (8.5 GeV)

GlueX Preliminary

$\gamma p \rightarrow \pi^- \Delta^{++}$ (~8.5 GeV)

$\pm$ 7% norm. uncertainty

Natural exchange favored (e.g. ρ, a_2)

Unnatural exchange favored (e.g. π)
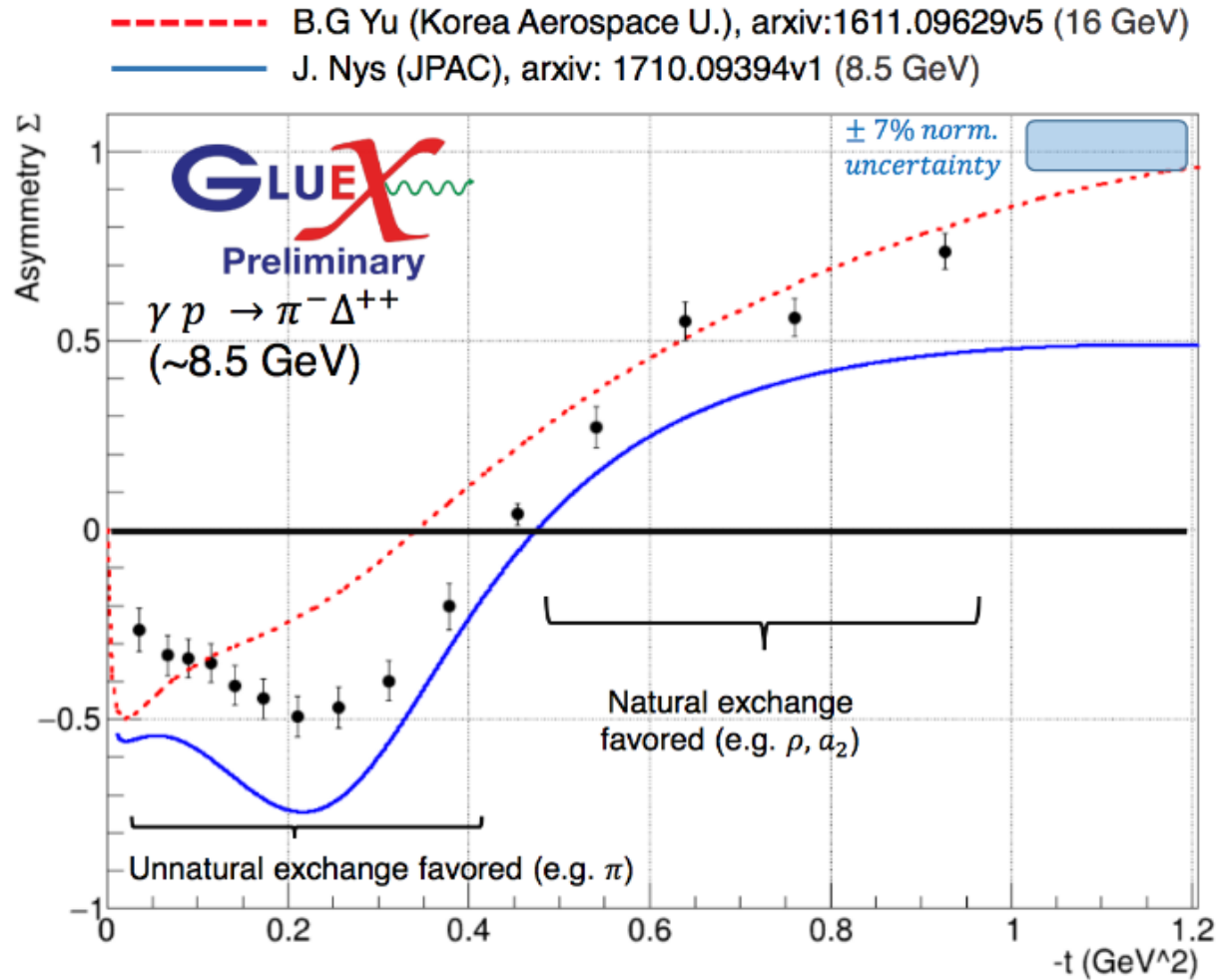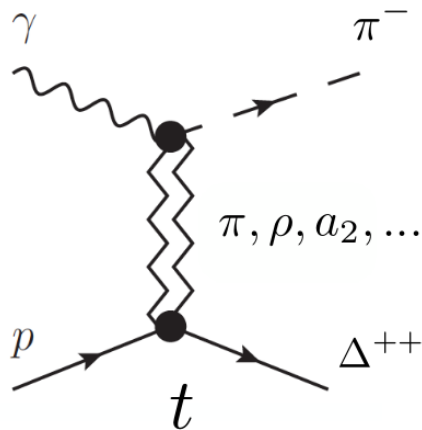
- **Leveraging GlueX's coverage of a wide variety of final states**
  - More than 50 channels being actively analyzed

- **Provides many opportunities for discovery**

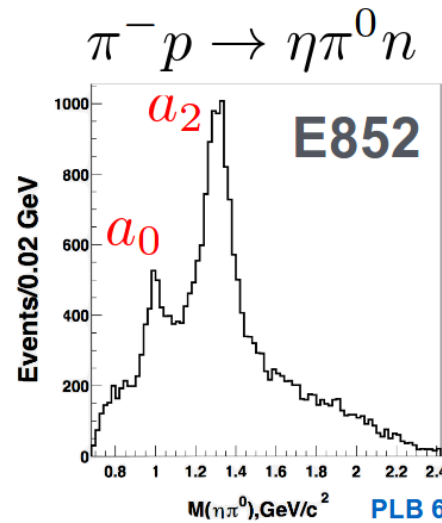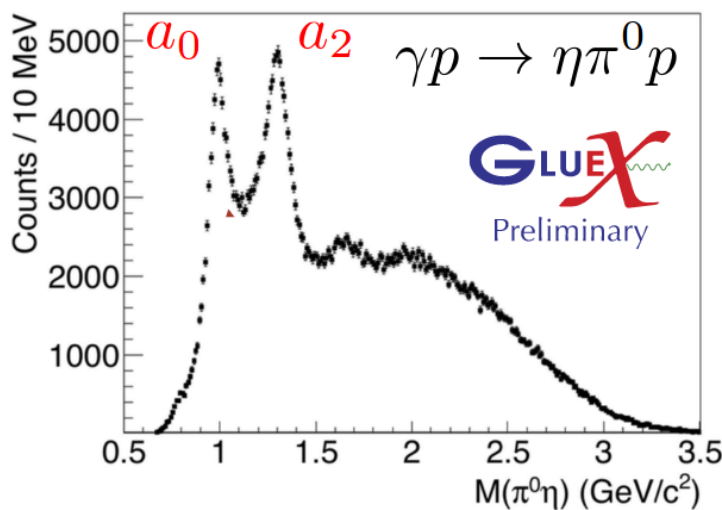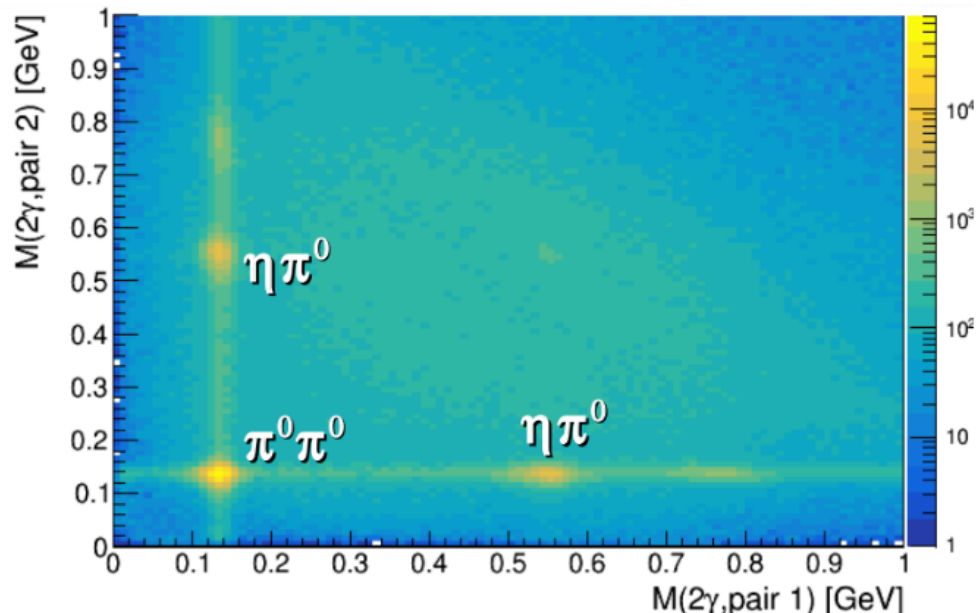| Topology(ies) |
| --- |
| $p\gamma\gamma$ |
| $p\pi^0\gamma$ |
| $p2\pi^0$ |
| $p\pi^+\pi^-$ |
| $p\pi^+\pi^-\gamma$ |
| $p\pi^+\pi^-\pi^0$ |
| $p3\pi^0$ |
| $p\pi^+\pi^-2\pi^0$ |
| $p2\pi^+2\pi^-$ |
| $p2\pi^+2\pi^-\pi^0$ |
| pK^+K^- |
| $pK^+K^-\pi^0$ |
| $pK^+K^-2\pi^0$ |
| $pK^+K^-\pi^+\pi^-$ |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

$p2K_s$
$pK^-K_s\pi^+$
$pK^-K_s\pi^+\pi^0$
$pK^-K_s\pi^+2\pi^0$
$pK^-K_s2\pi^+\pi^-$
$pK^+K_s\pi^-$
$pK^+K_s\pi^-\pi^0$
$pK^+K_s\pi^-2\pi^0$
$pK^+K_s\pi^+2\pi^-$
$\Lambda 2K^+K^-$
$\Lambda K_s\pi^+\pi^0$
$\Lambda K_s\pi^+$
$\Lambda K^+\pi^+\pi^-$
ΛK^+
$\Lambda K^+\gamma$
$\Lambda K^+2\gamma$
$\Lambda K^+\pi^0\gamma$
$K^+K^+\Xi^-$
$K^+(K^+)\Xi^-$
$K^+K^+(\Xi^-)$

. . .

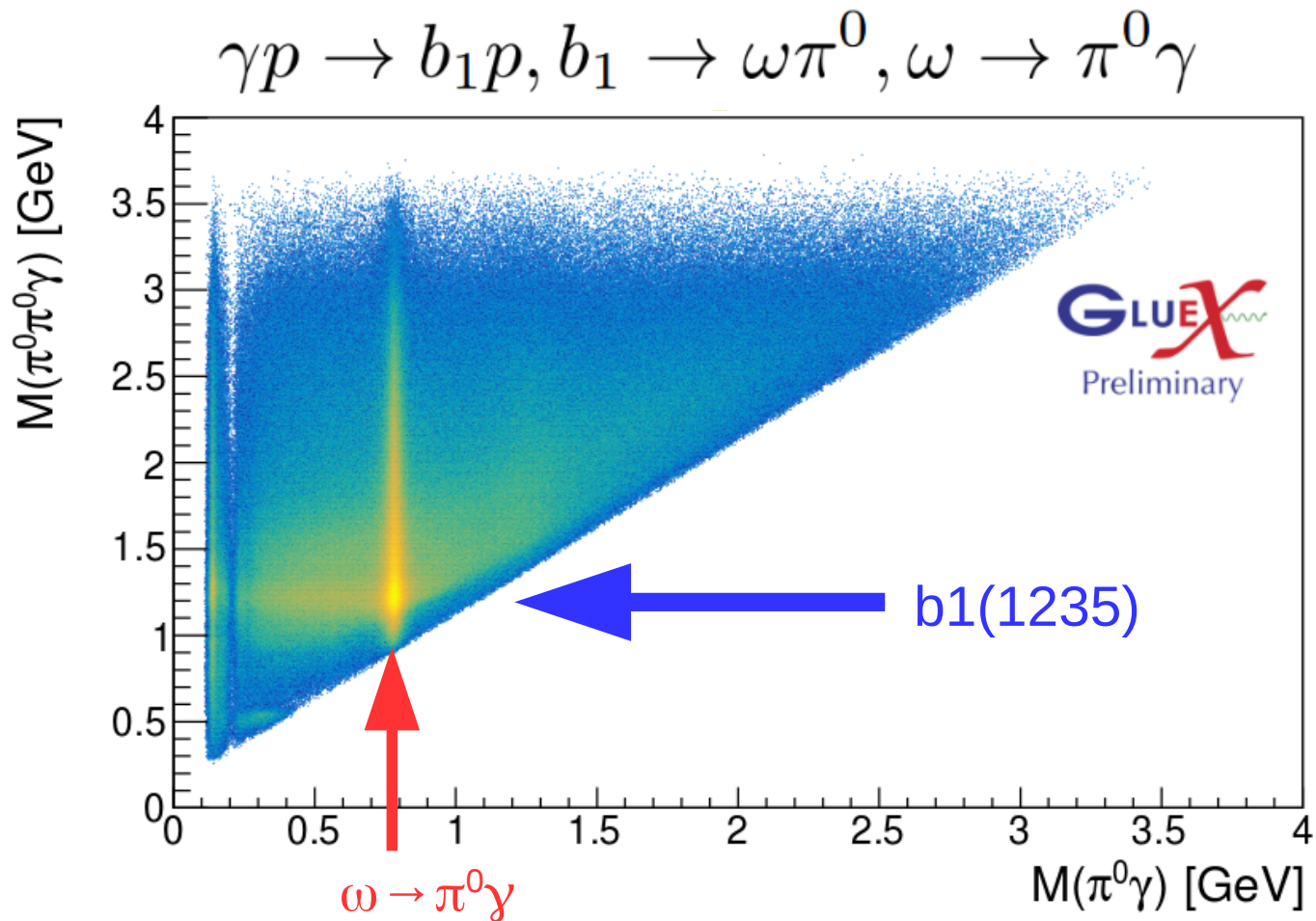# Spectroscopy Opportunities ($\gamma p \to \gamma\gamma\gamma\gamma p$)

- $\gamma p \to \gamma\gamma\gamma\gamma p$

  - Sparse prior data in channels with multiple neutral states

  - Already much more data than previous experiments

  - Interesting features emerging

Spectroscopy Opportunities (5γ)

$$\gamma p \to b_1 p, b_1 \to \omega \pi^0, \omega \to \pi^0 \gamma$$

Figure axes: $M(\pi^0 \pi^0 \gamma)$ [GeV] (vertical), $M(\pi^0 \gamma)$ [GeV] (horizontal). GlueX Preliminary. Blue arrow labeled b1(1235). Red arrow labeled $\omega \to \pi^0 \gamma$.
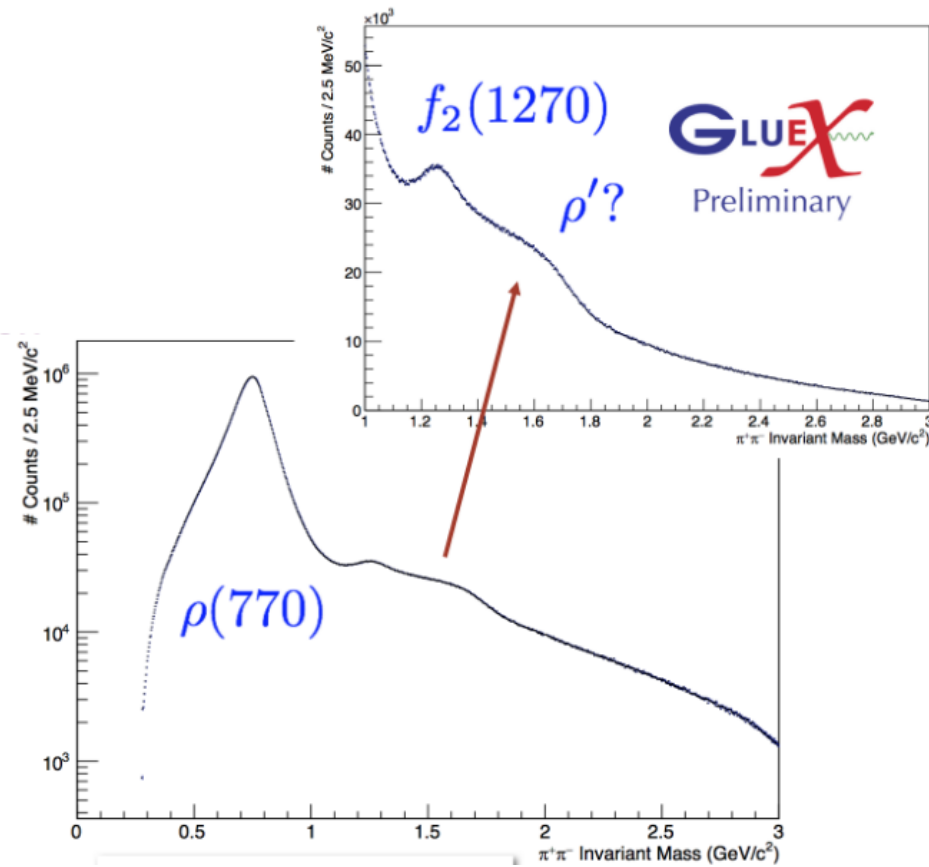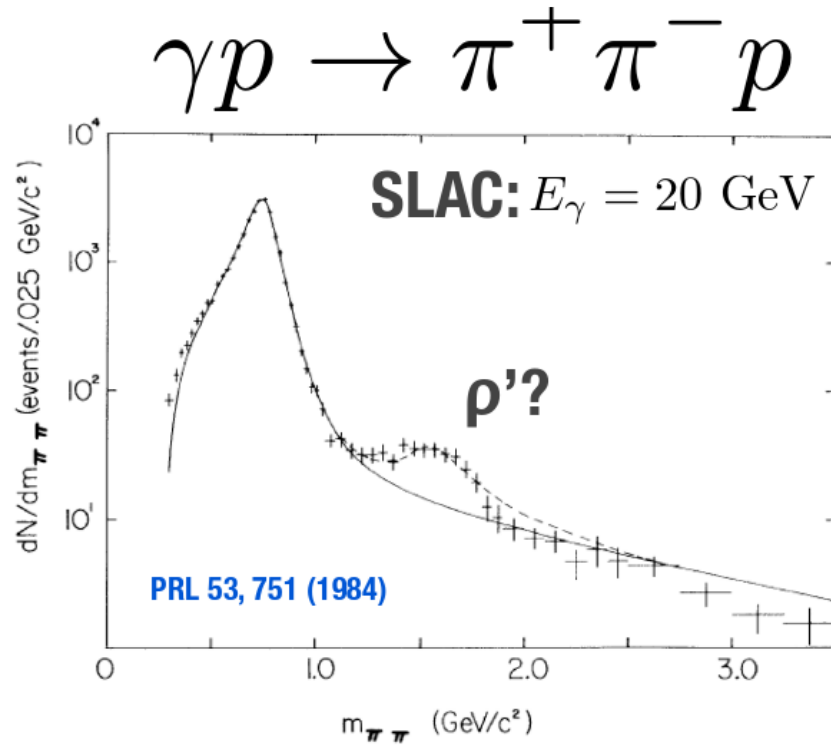
- **Able to reconstruct 5γ final states**

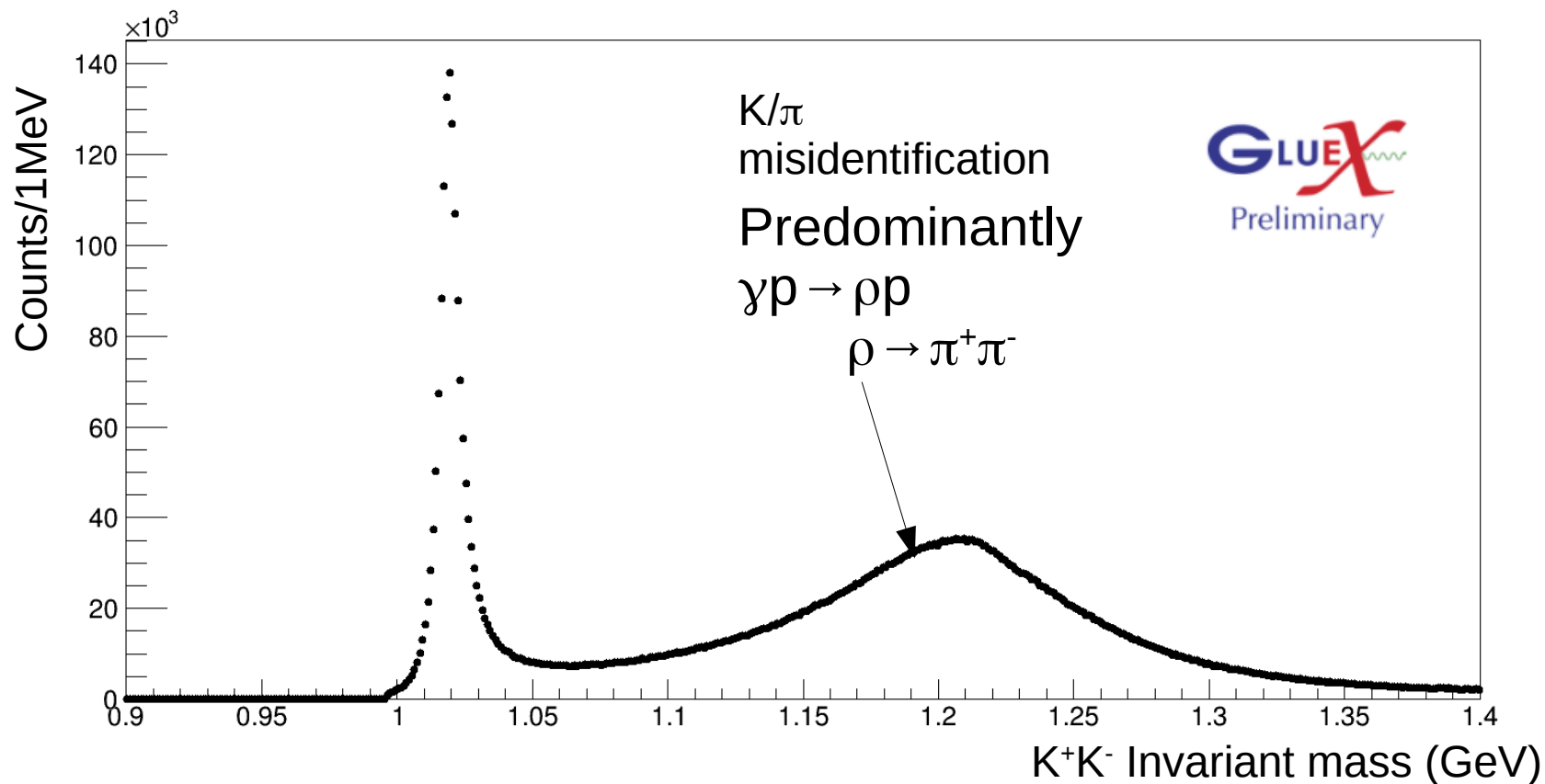- **b1(1235) observed in its dominant decay mode**

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

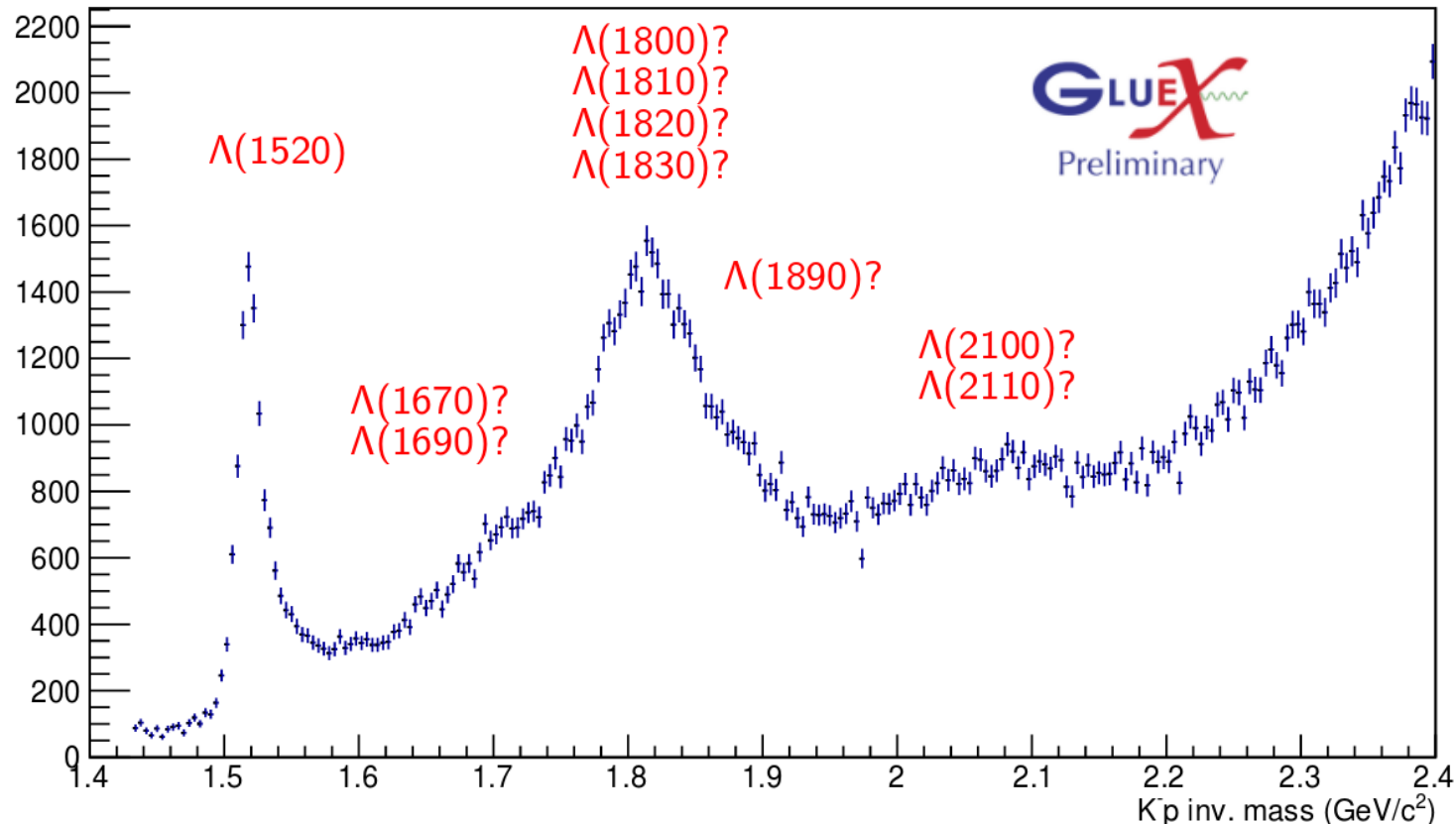# Spectroscopy Opportunities ($\gamma p \rightarrow K^+ K^- p$)

K/π misidentification

Predominantly

$\gamma p \rightarrow \rho p$

$\rho \rightarrow \pi^+ \pi^-$

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
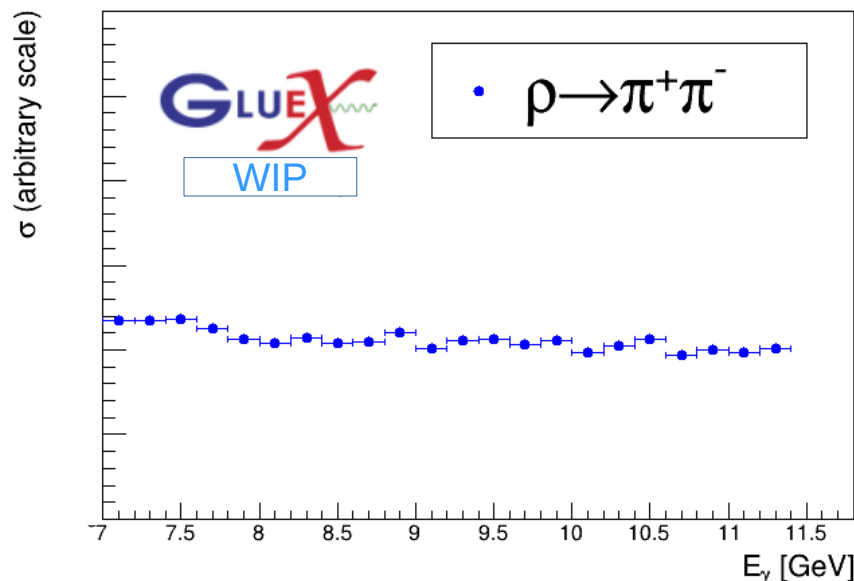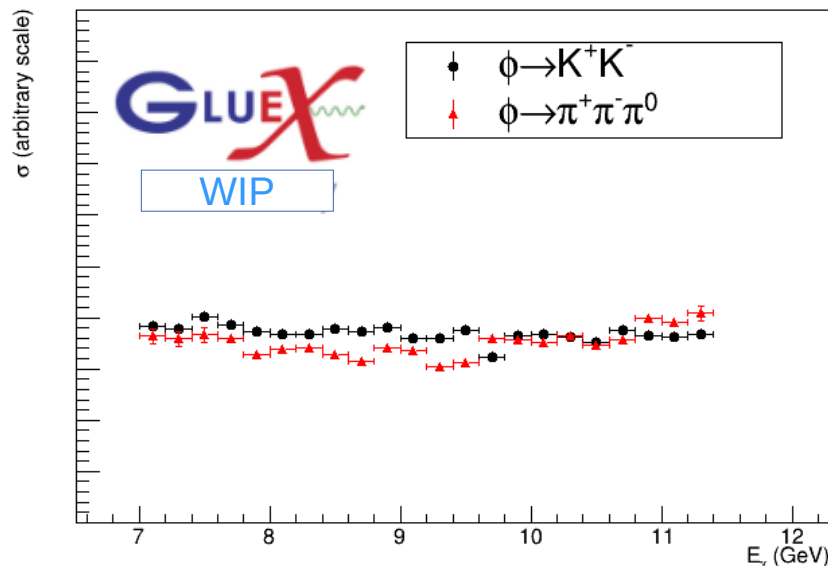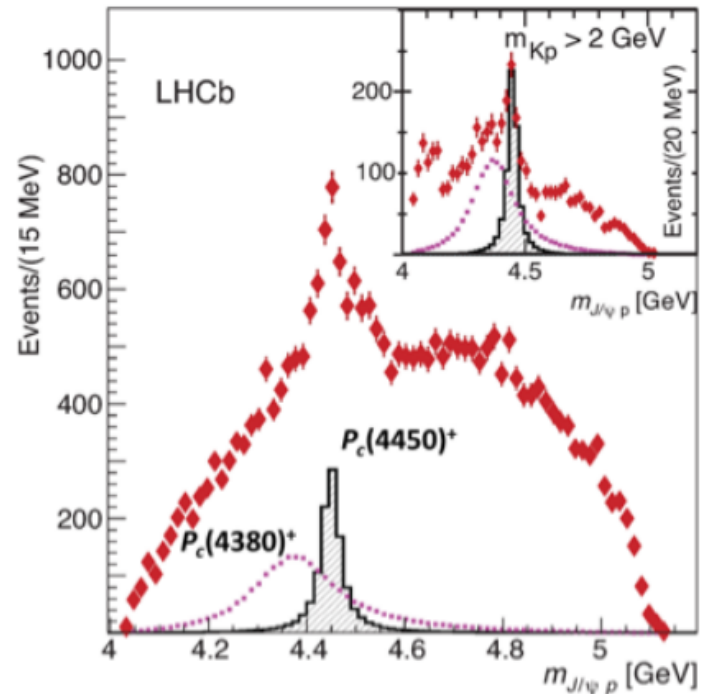
J/ψ Photo-Production

Photo-produced pentaquark

$$\Lambda_b \to J/\psi p K^-$$
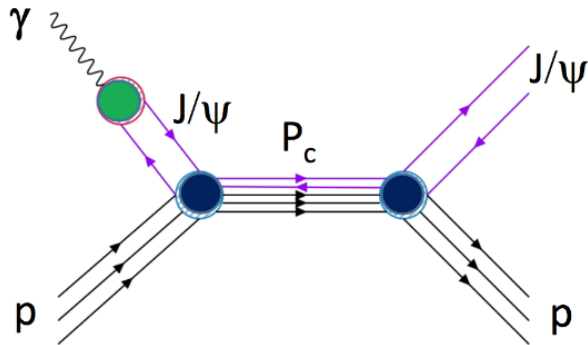
- LHCb's pentaquark candidates, found in decays to J/ψp, should be accessible to GlueX thanks to the 12GeV upgrade

- States should appear as s-channel resonances at photon energies of ~10GeV

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

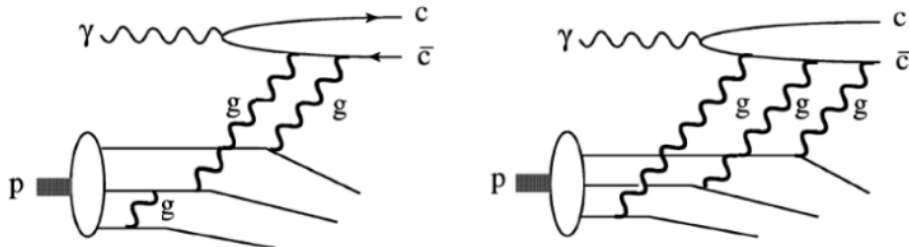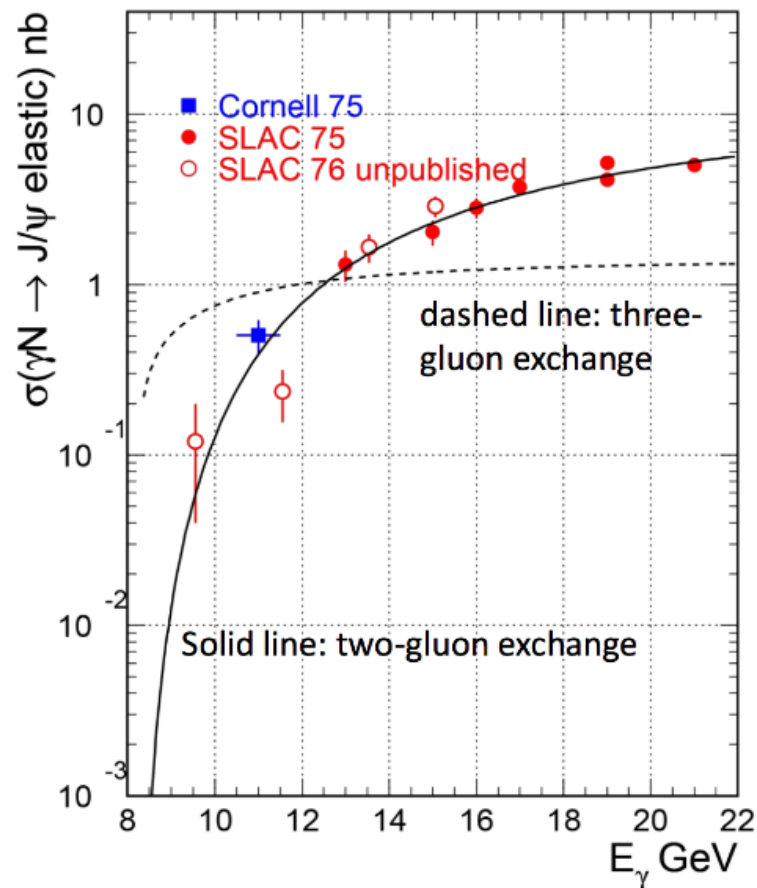**Phys. Rev. Lett. 11 5, 072001 (2015) [LHCb]**

J/ψ Photo-Production cont.

- Studying J/ψ near threshold gives nucleon distribution information

- Signals in γp→J/ψp would be an important confirmation of LHCb's states

  – Can measure branching ratio Pc→J/ψp (or set limits)

  – Can measure cross-section

- Photo-production measurements would help distinguish the nature of the states
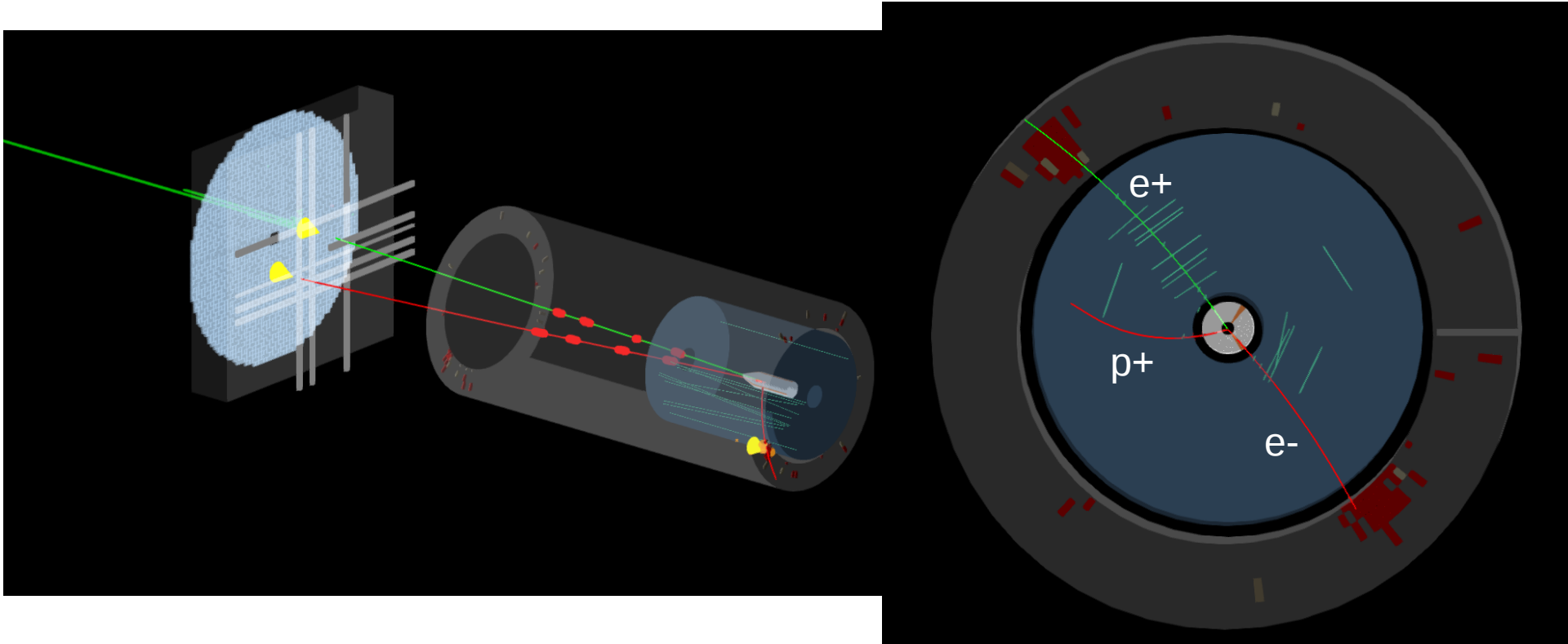

-Phys. Rev. Lett., 35:1616, 1975
-Phys. Rev. Lett., 35:483, 1975
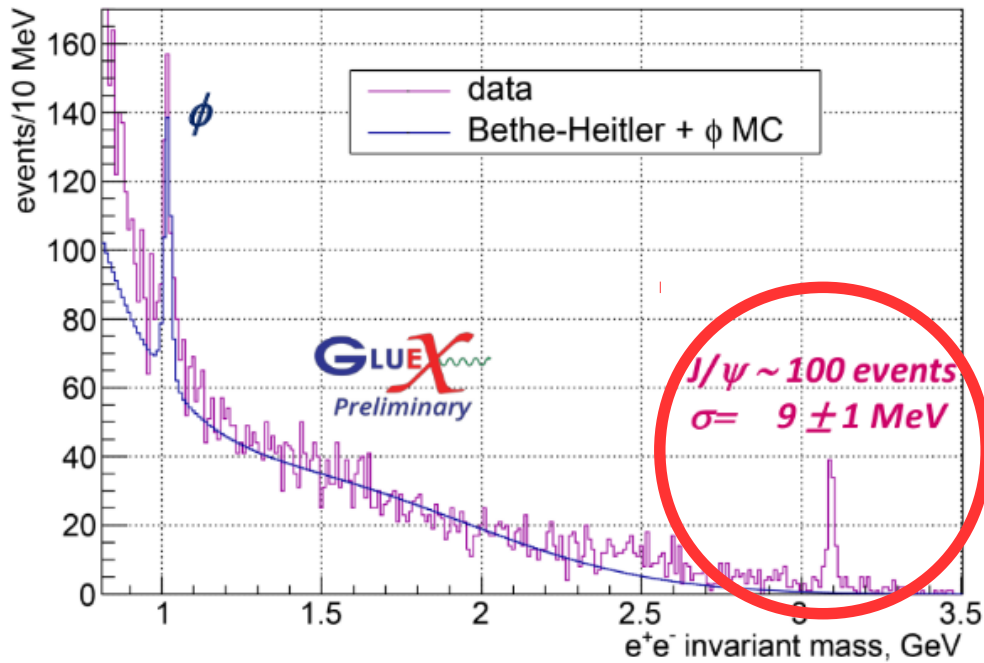-Excess Muons and New Results in psi Photoproduction. 1976

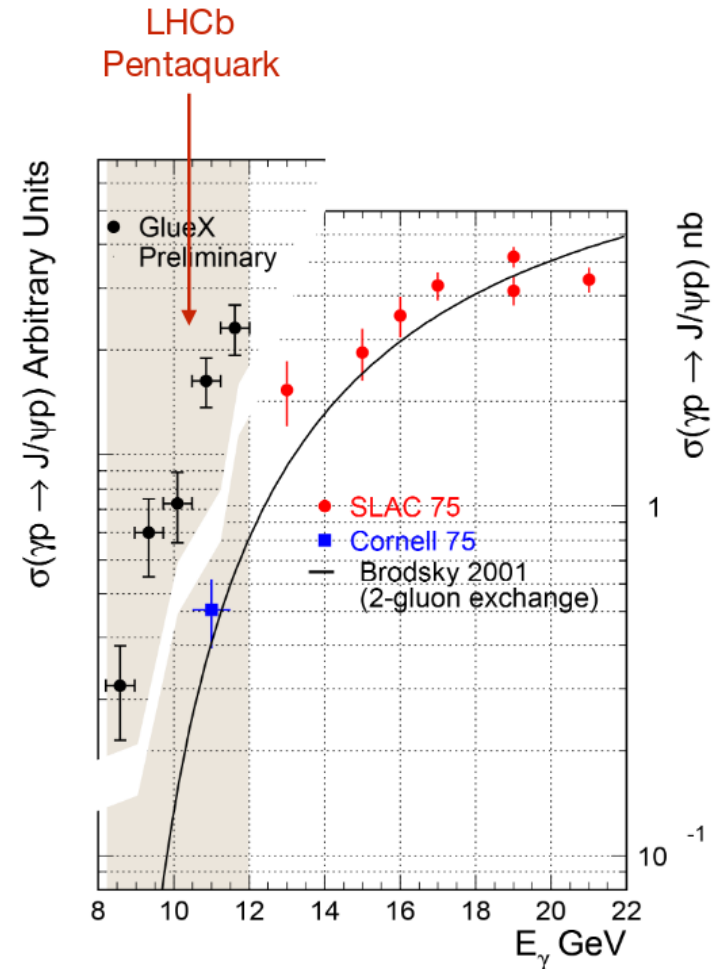$$\gamma p \rightarrow J/\psi p, \; J/\psi \rightarrow e^+ e^-$$

J/ψ in Hall-D cont.

MC normalized to φ x-sec.   kin.fit $\chi^2 < 200$, $\theta_e > 2^0$
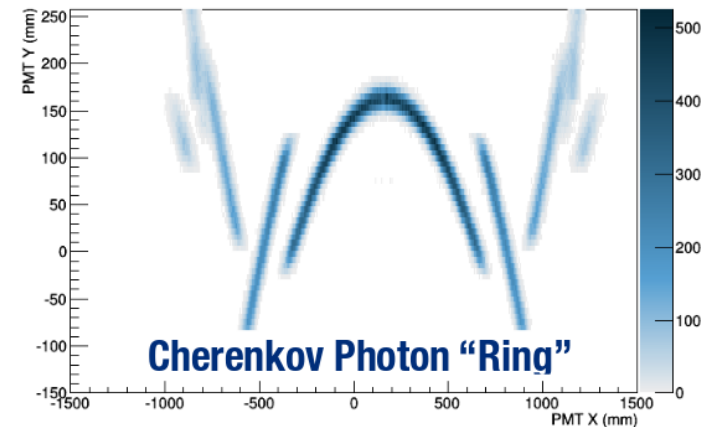
data
Bethe-Heitler + φ MC

φ

GLUE𝒳 Preliminary

J/ψ ~ 100 events
σ= 9 ±1 MeV

events/10 MeV — e^+e^- invariant mass, GeV

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

LHCb Pentaquark

GlueX Preliminary

SLAC 75
Cornell 75
Brodsky 2001
(2-gluon exchange)

$\sigma(\gamma p \rightarrow J/\psi p)$ Arbitrary Units
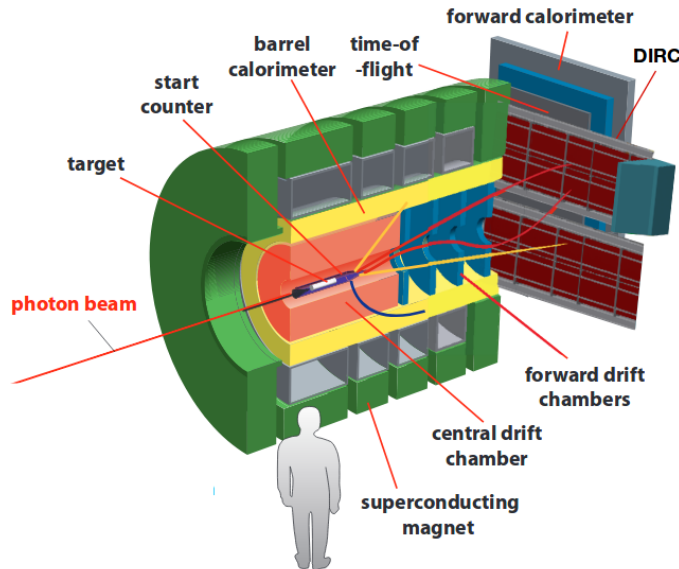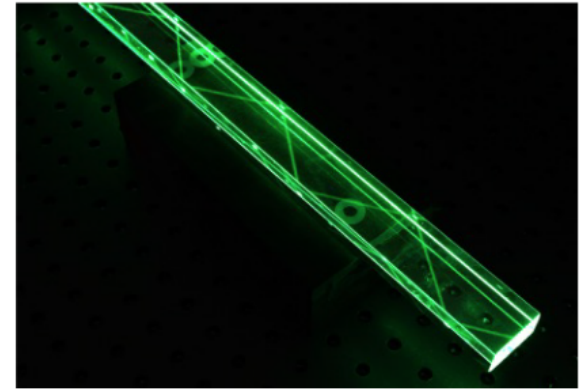
$\sigma(\gamma p \rightarrow J/\psi p)$ nb

E_γ GeV

- ## Small fraction of data
  - Clear J/ψ signal

- Will be able to perform measurements related to LHCb Pc states
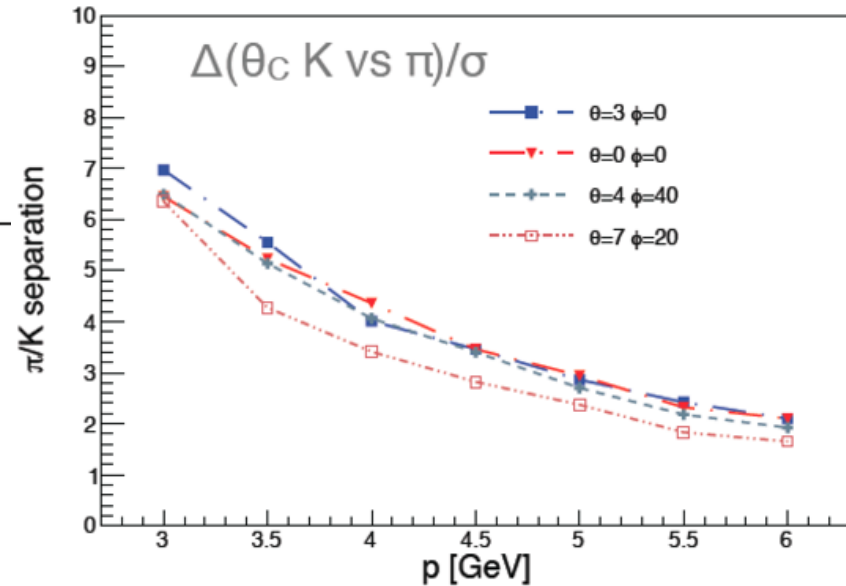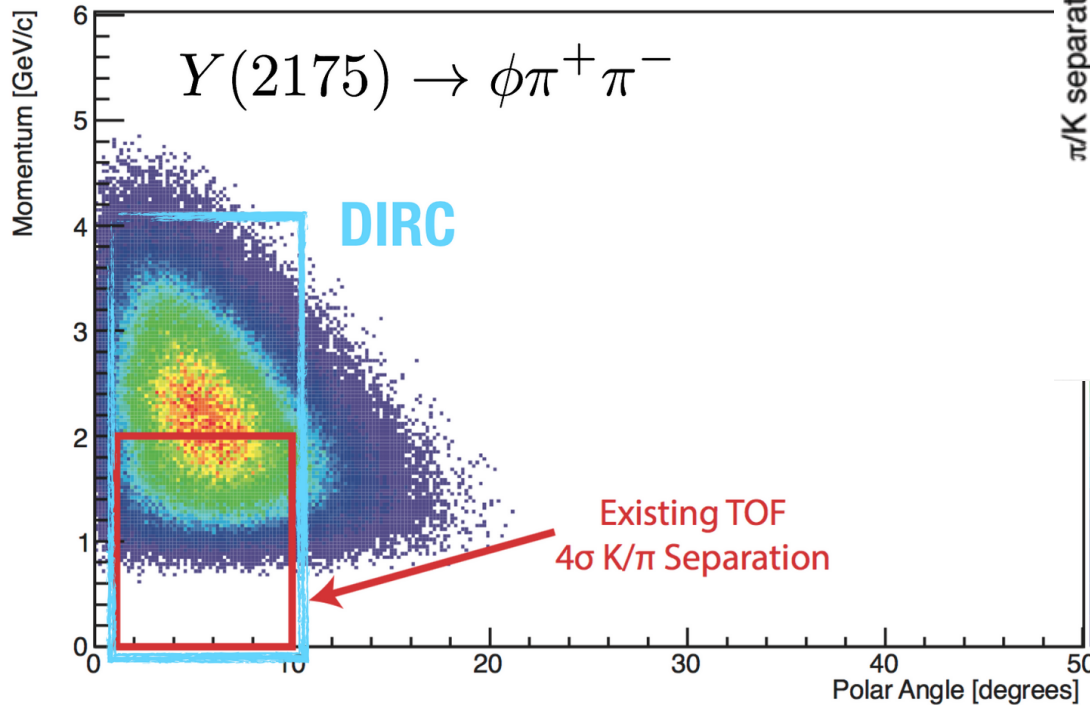
Jefferson Lab

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

$Y(2175) \to \phi\pi^+\pi^-$

DIRC

Existing TOF
4σ K/π Separation

$\Delta(\theta_C \text{ K vs } \pi)/\sigma$

- **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 Pc→J/ψp
    - cross-section

- **DIRC** detector to be installed this year to enhance π/K PID separation