
# Recent progress on GlueX program at JLab Hall D

Zhenyu Zhang  Wuhan University
For GlueX Collaboration

The 10th Workshop on Hadron physics in China and Opportunities Worldwide
Shandong University Academic Center in Weihai
2018. 7. 30

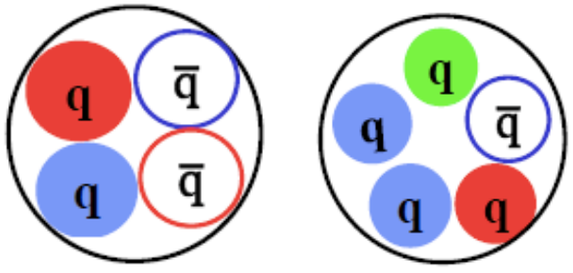
武漢大學 WUHAN UNIVERSITY

Jefferson Lab GLUEX

# OUTLINE

- Introduction
- GlueX experiment and performance
- Hadron photoproduction at GlueX
- Programs and upgrades
- Summary and outlook

# QCD Exotic States




Multi-quark states  Hadron molecular states

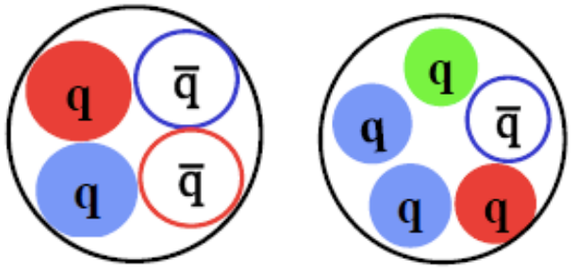
Phys. Letts. 8 (1964) 214

- In 1964, Gell-Mann's original paper alludes to the possibility of exotic hadrons.
- Exotic hadrons have structures that are more complex.

In 1984, Prof. Jueping Liu constructed baryon current operators composed of five-quark field to investigate the resonance Lambda(1405) in the framework of QCD sum rules.

Z. Phys. C 22 (1984) 171

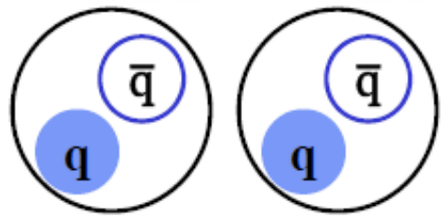
# QCD Exotic States



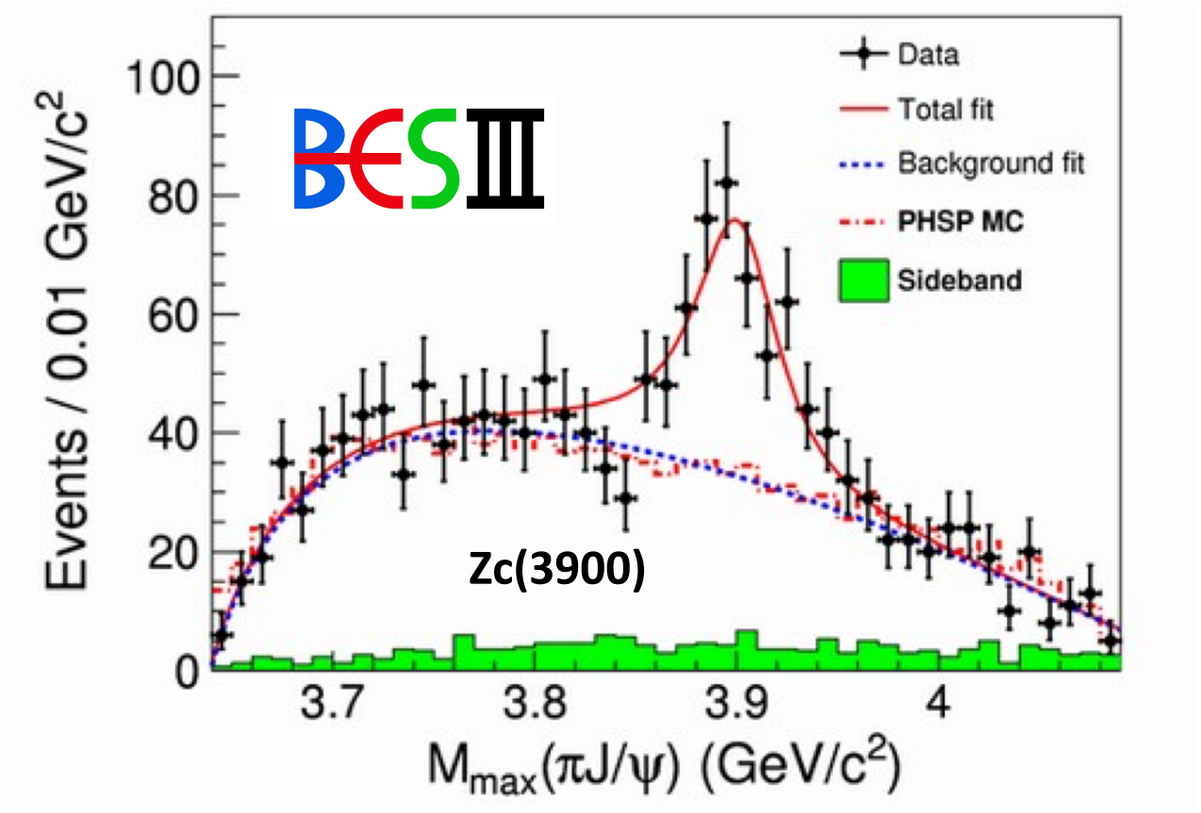




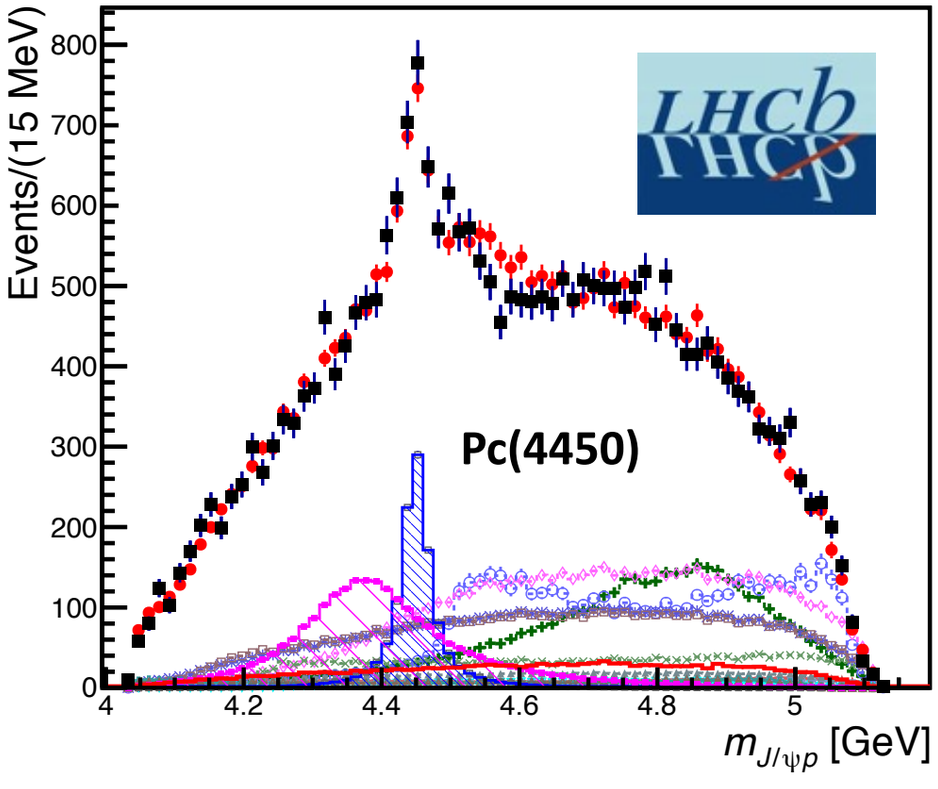
**Multi-quark states**




**Hadron molecular states**



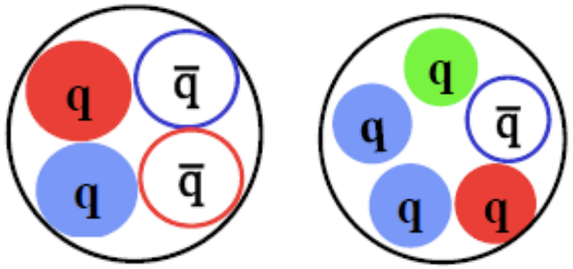

PRL 110, 252001 (2013)



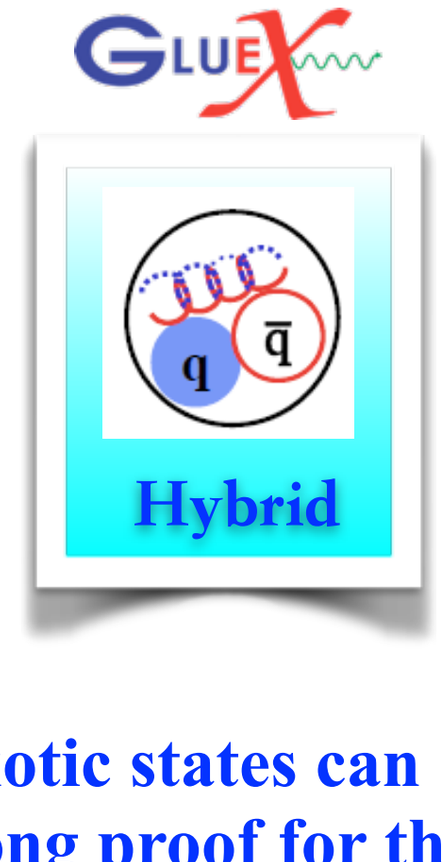

PRL 115, 072001 (2015)

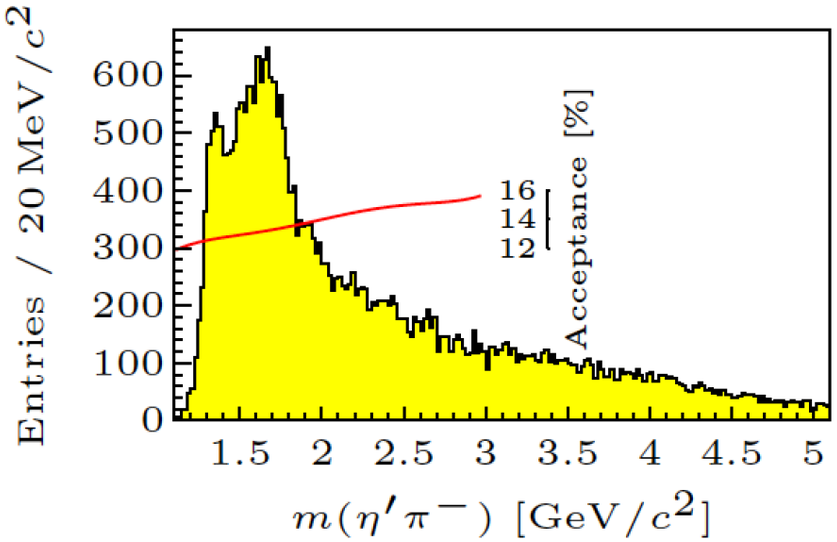
**A number of exotic states candidates are found in recent years.**

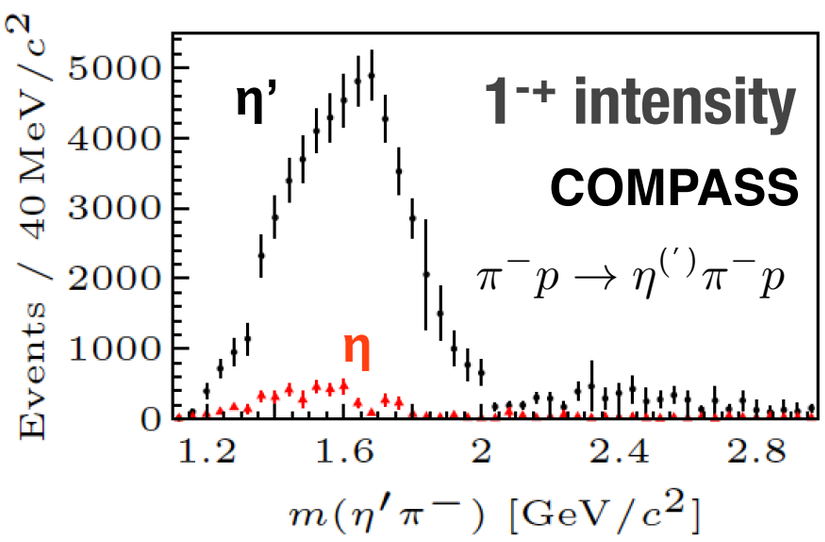
# QCD Exotic States




**Multi-quark states** **Hadron molecular states** **GlueBalls**



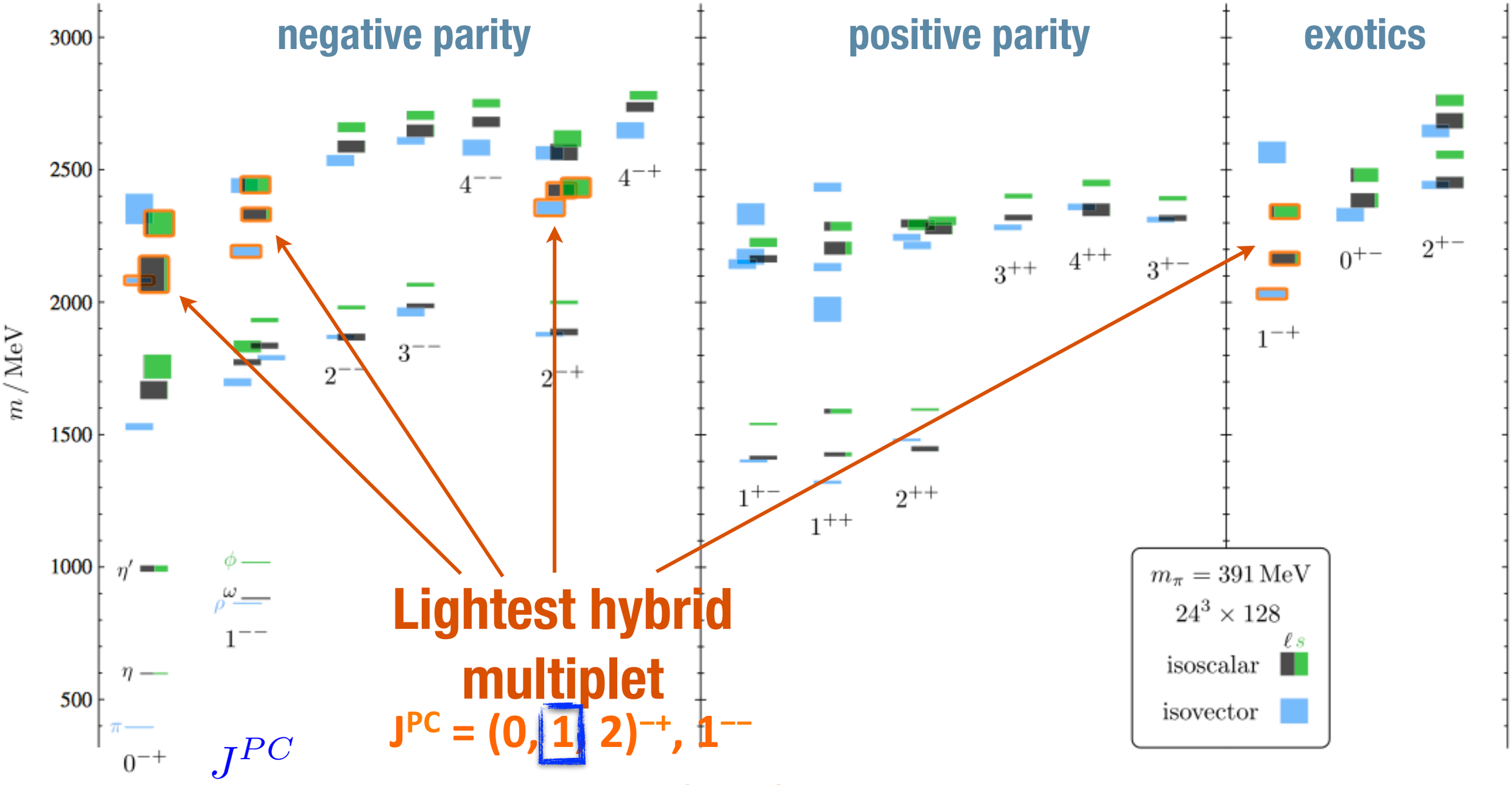




**PLB 740, 303 (2015)**

**The exotic states can be strong proof for the existence of hadrons with gluonic degrees of freedom, predicted by QCD as the strong interaction mediator.**

**Despite extensive experimental searches, no unambiguous candidates for any of these exotic configurations have yet to be identified.**

# LQCD Meson Spectrum for Light Quarks




**Lightest hybrid multiplet**

$J^{PC}$ = $(0, 1, 2)^{-+}$, $1^{--}$

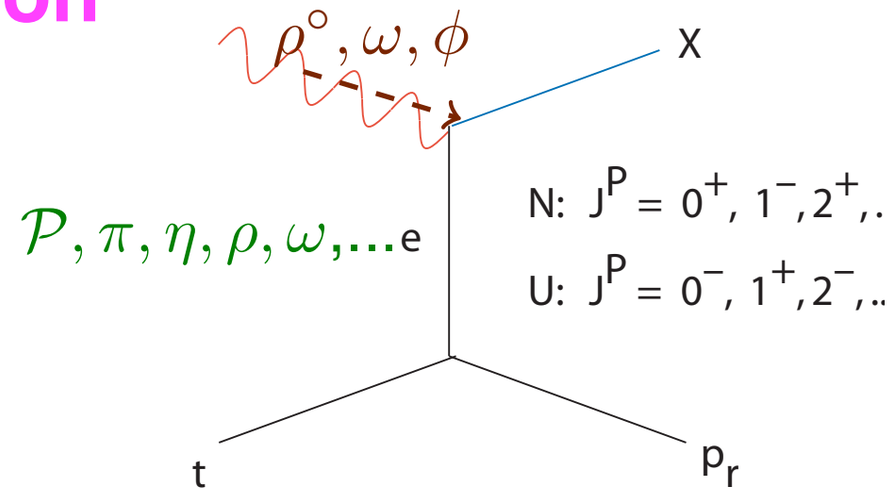
Dudek Phys.Rev. D84 (2011) 074023

# Hybrid Meson Search Strategy

## The High-Energy Photoproduction

GLUEX

- **Unique production mechanism with access to exotic $J^{PC}$**
- **Access to hybrid masses up to ~2.8 GeV**
- **Large acceptance for multi-particle final states**
- **Identification of exotic JPC through amplitude analyses**
- **Ability to study many final states simultaneously**




| Exchange particle | | Final states | |
|---|---|---|---|
| $\mathcal{P}$ | $0^{++}$ | $2^{+-}, 0^{+-}$ | $b^\circ, h, h'$ |
| $\pi^\circ$ | $0^{-+}$ | $2^{+-}$ | $b_2^\circ, h_2, h_2'$ |
| $\pi^\pm$ | $0^{-+}$ | $1^{-+}$ | $\pi_1^\pm$ |
| $\omega$ | $1^{--}$ | $1^{-+}$ | $\pi_1, \eta_1, \eta_1'$ |

Can couple to all 3 exotic nonets

$1^{-+}$ $\pi_1, \eta_1 \ldots$ $\sim$2.0 – 2.4 GeV/c$^2$
$0^{+-}$ $b_\circ, h_\circ \ldots$ $\sim$2.3 – 2.5 GeV/c$^2$
$2^{+-}$ $b_2, h_2 \ldots$ $\sim$2.4 – 2.6 GeV/c$^2$

# The 12-GeV upgrade at Jefferson Lab

- The 12-GeV upgrade is completed in Feb. 2016.
- The GlueX has been data taking at 12 GeV successfully since 2016 spring.
- The “Low intensity” program, GlueX I, expected to be completed in 2018.
- The “high intensity” program, GlueX II, will begin in 2019 fall with the new DIRC detector.
- Ten times more data and higher K-$\pi$ separation are expected.

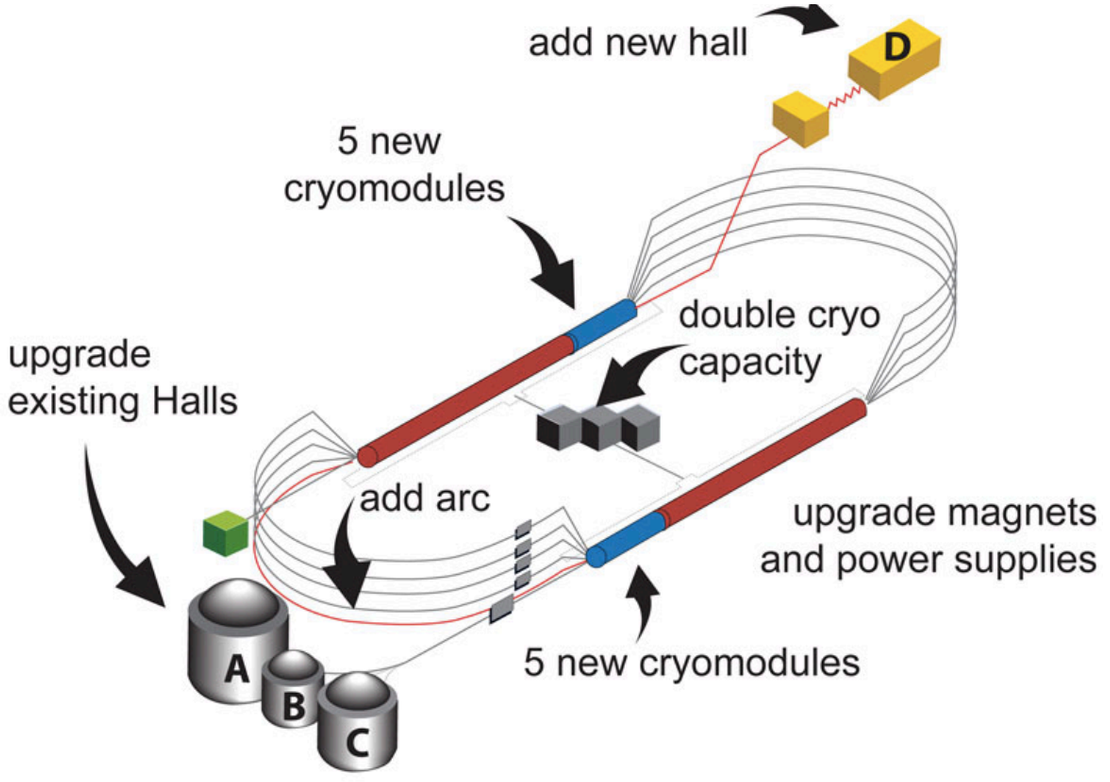
**Hall D: The new experiment hall at JLab**

**GlueX: The spectrometer in the Hall D**

**The long-term aim:**

**Understand quark-gluon interactions**

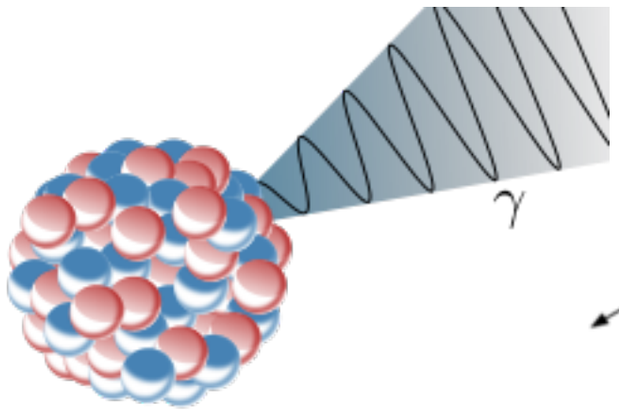
**search for exotic hybrid mesons**



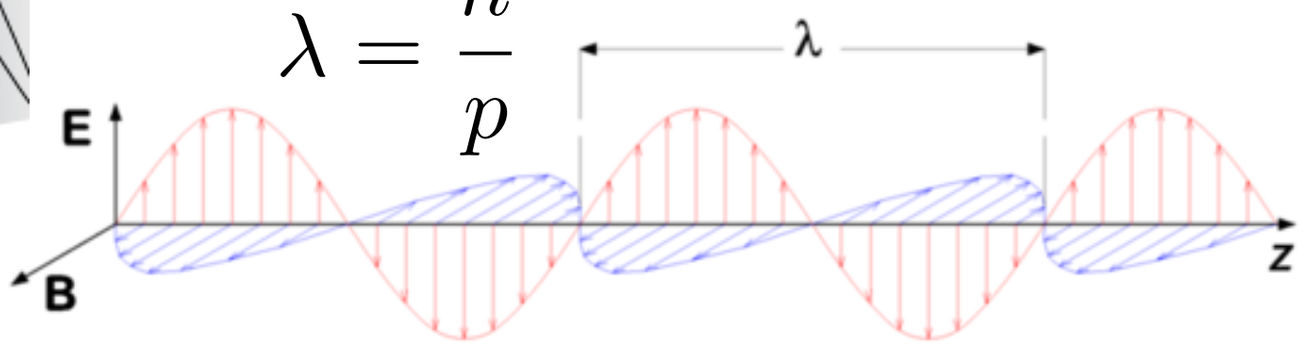
# GlueX Collaboration

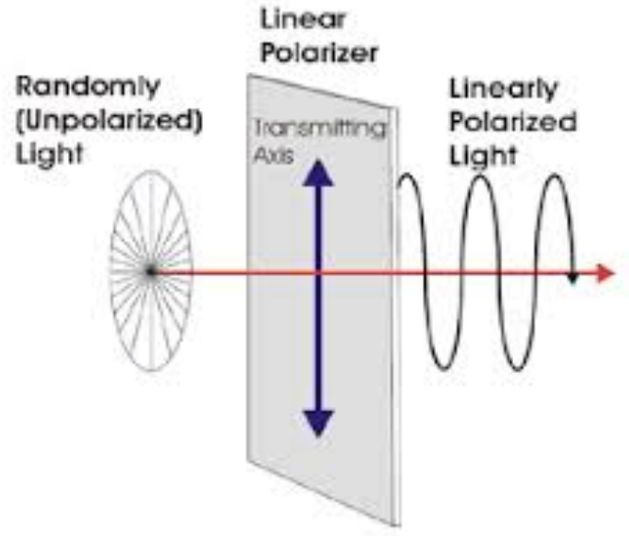
http://portal.gluex.org/GlueX/Home.html ~120 members from 28 institutions of 9 counties

# Linearly polarised photon beam

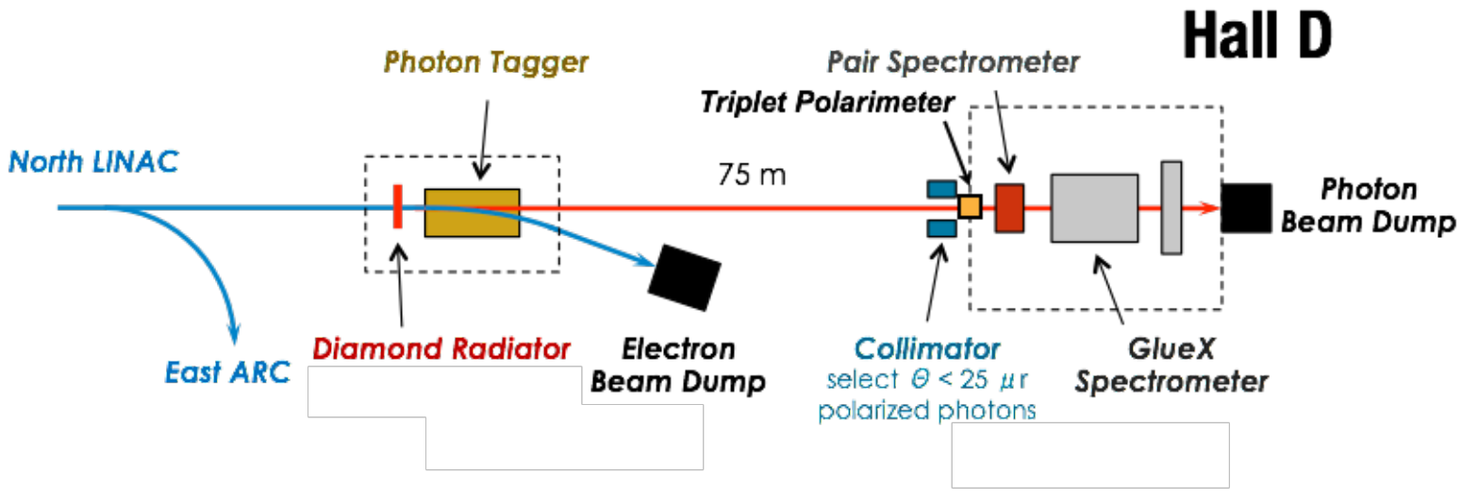


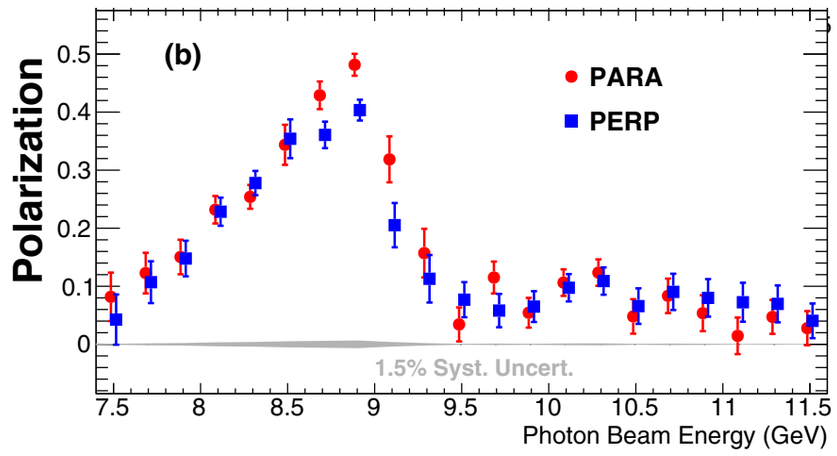

$$\lambda = \frac{h}{p}$$



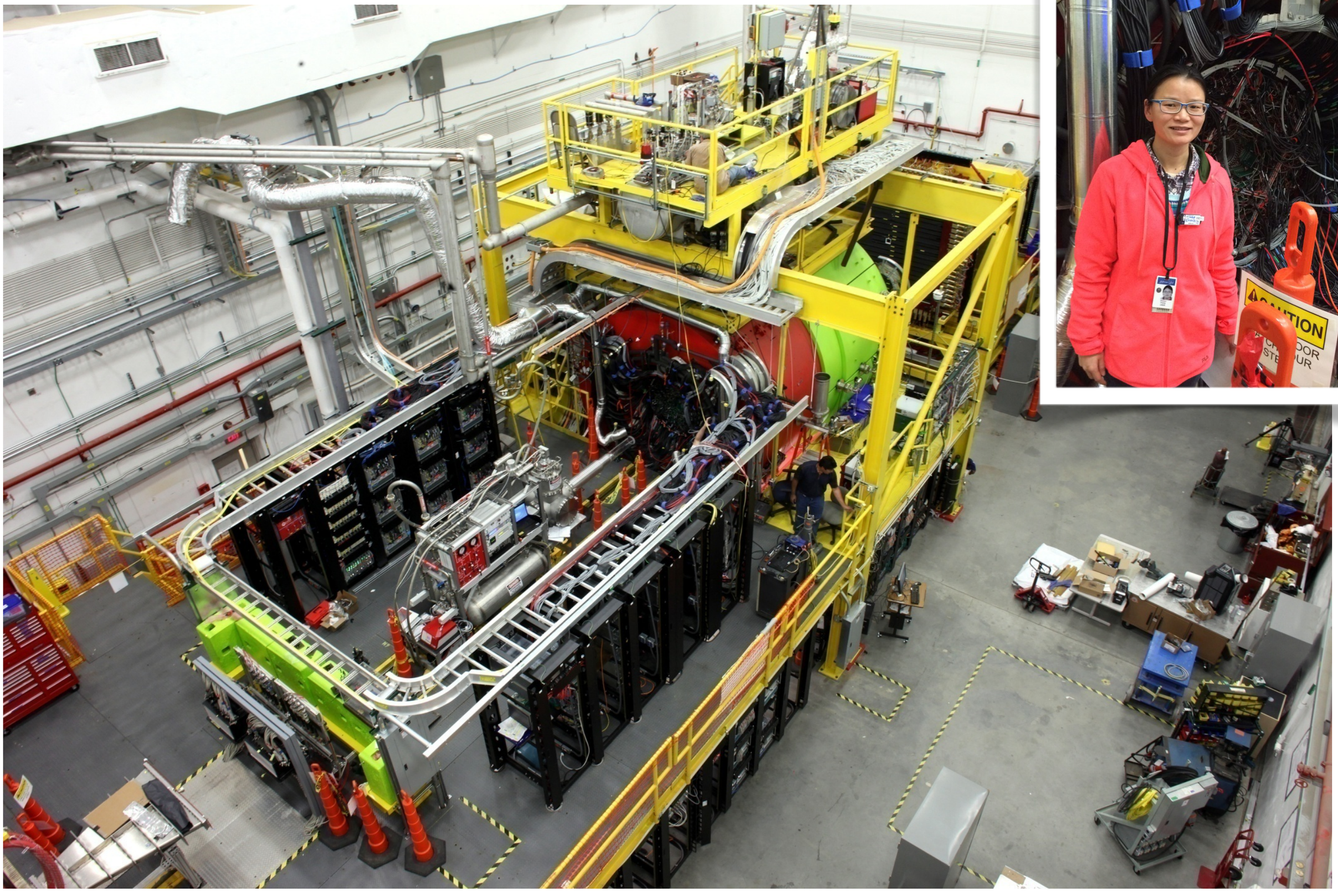

**Photon flux 10-100 MHz in the peak**




**Linearly polarized photons via coherent bremsstrahlung from diamond radiator off liquid hydrogen peaking at 9 GeV**

# GlueX Detector



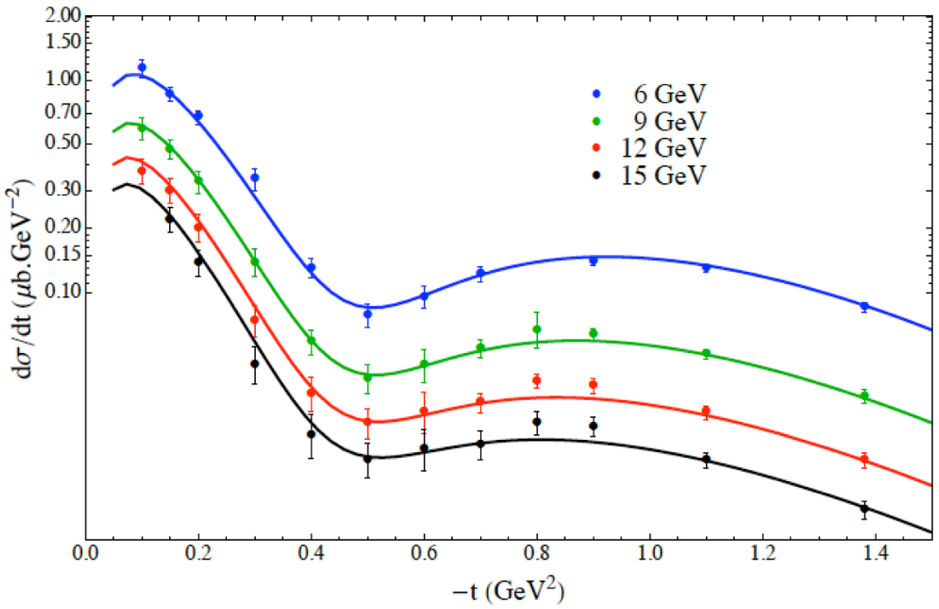
# Physics at GlueX

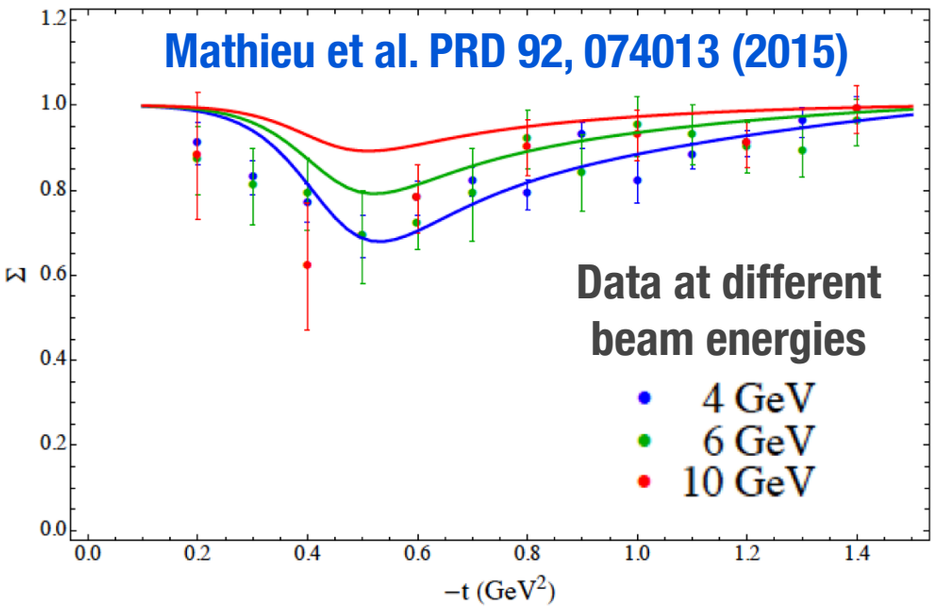
- **Early Physics:**
  - **Beam asymmetry and polarization transfer measurements in the meson/bayon photoproduction**

- **Long-term Physics:**
  - **Spin-density matrix elements to understand production mechanisms.**
  - **Cross section measurements**
  - **Search for exotic hybrids (PWA analysis)**

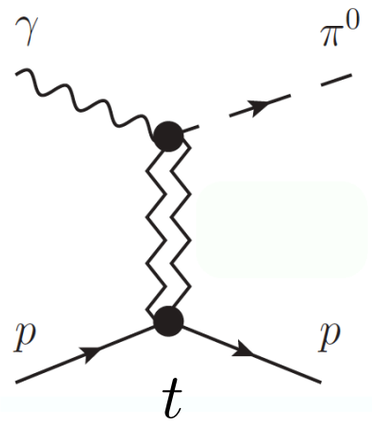
# Psuedoscalar mesons $\pi^0/\eta$ Photoproduction

## JPAC Regge Model




**SLAC: PRD 4, 1937 (1971)**




**Exchange $J^{PC}$**

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

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

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

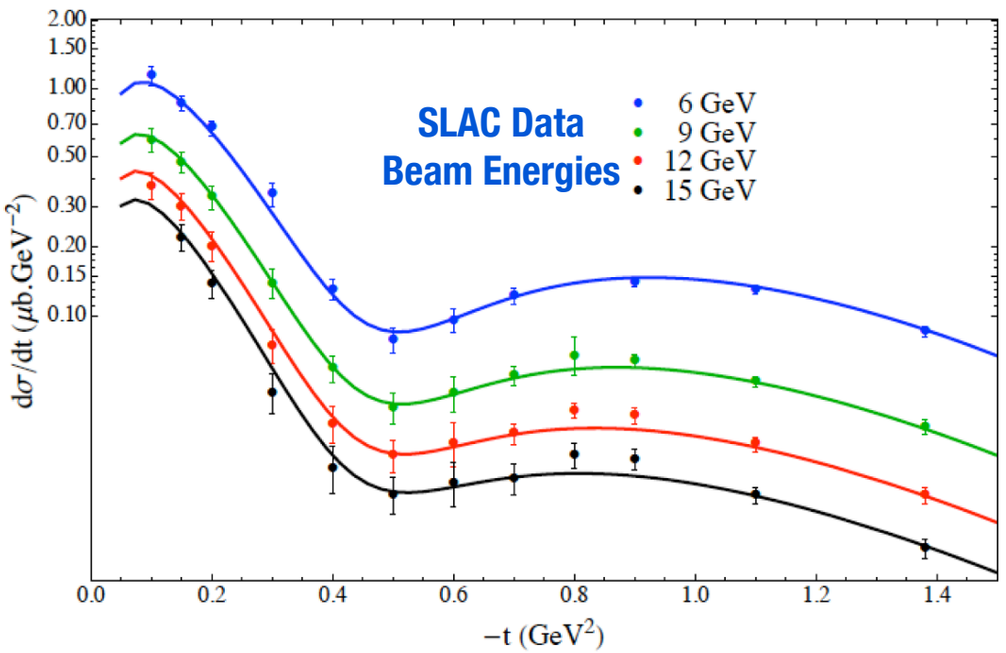
$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$

**The high intensity, linearly polarized photon beam of GlueX/Hall D can provide important new constraints on Regge models**

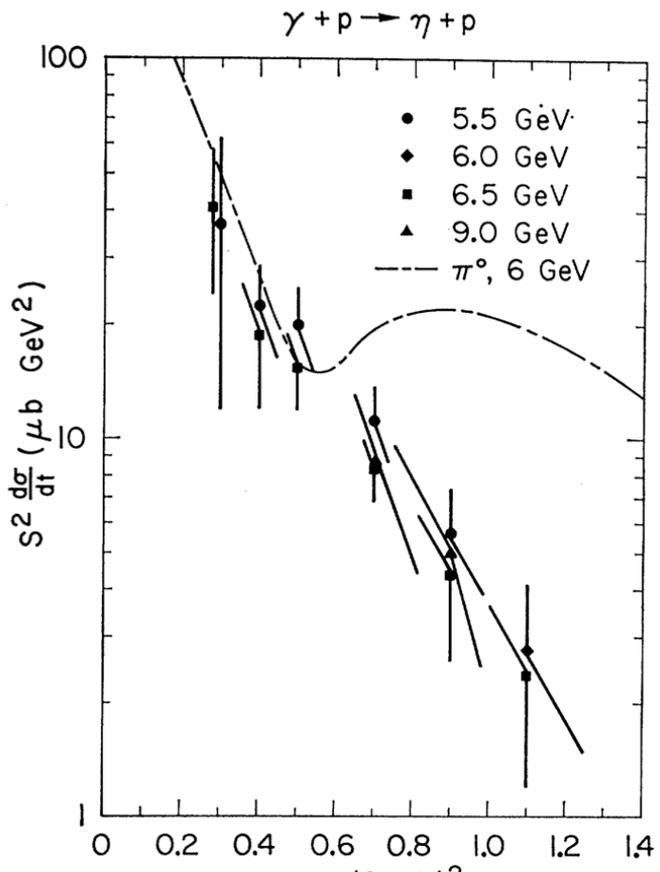
**There are no previous measurements of the Σ asymmetry for $\gamma p \to \eta p$ with $E_\gamma > 3$ GeV**

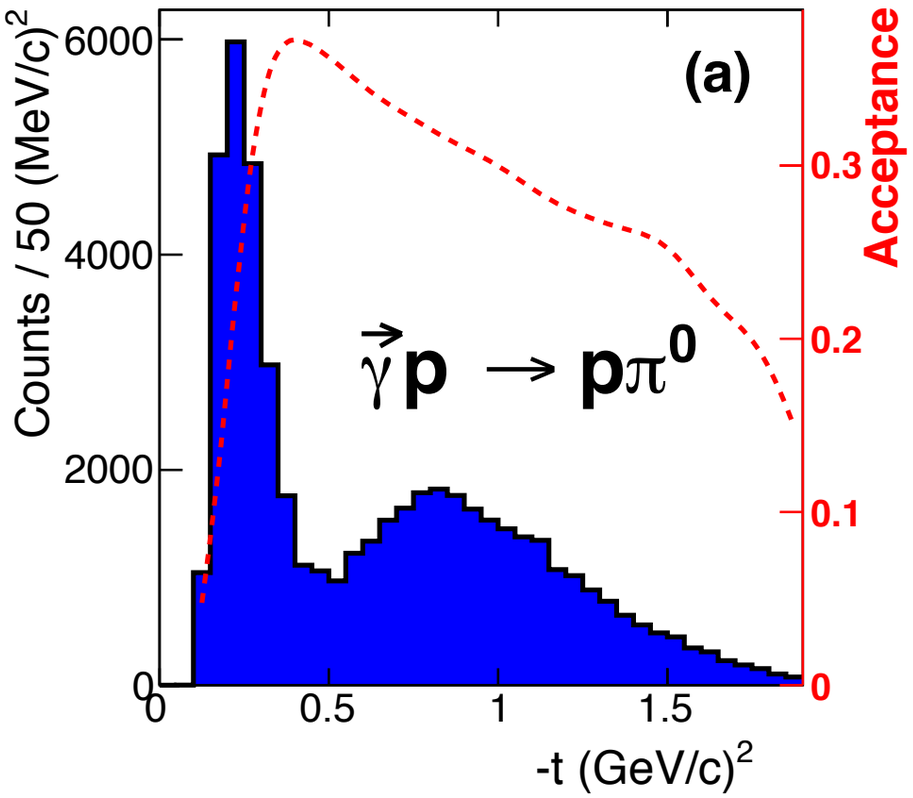
# Final -t distributions

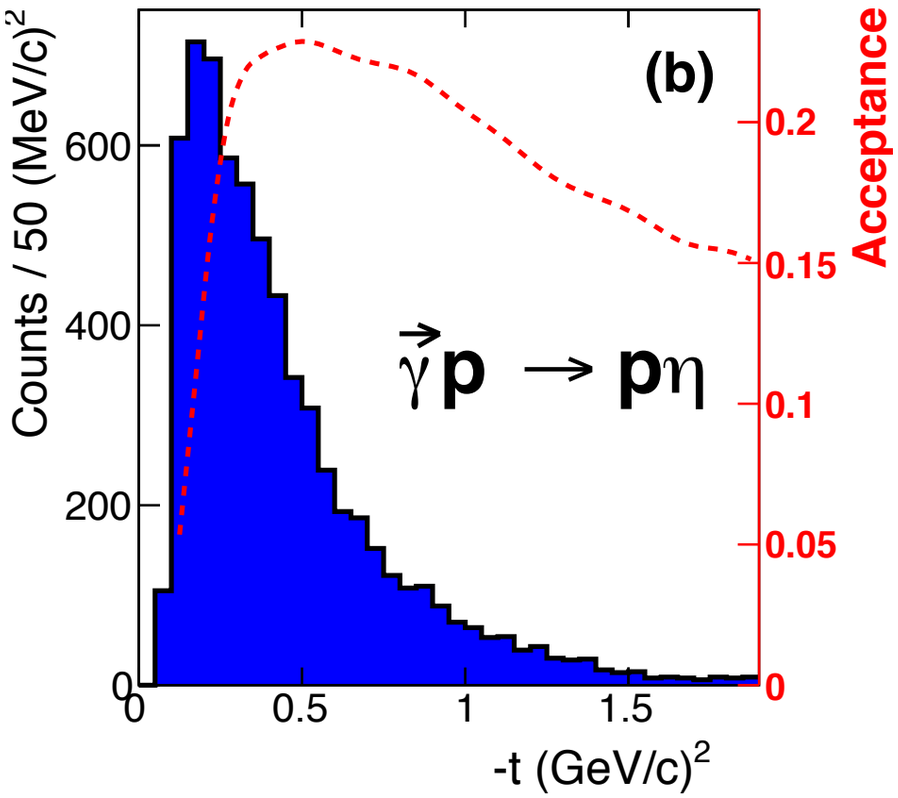
V. Mathieu (JPAC): PRD 92, 074013




SLAC: PRD 1, 27 (1970)



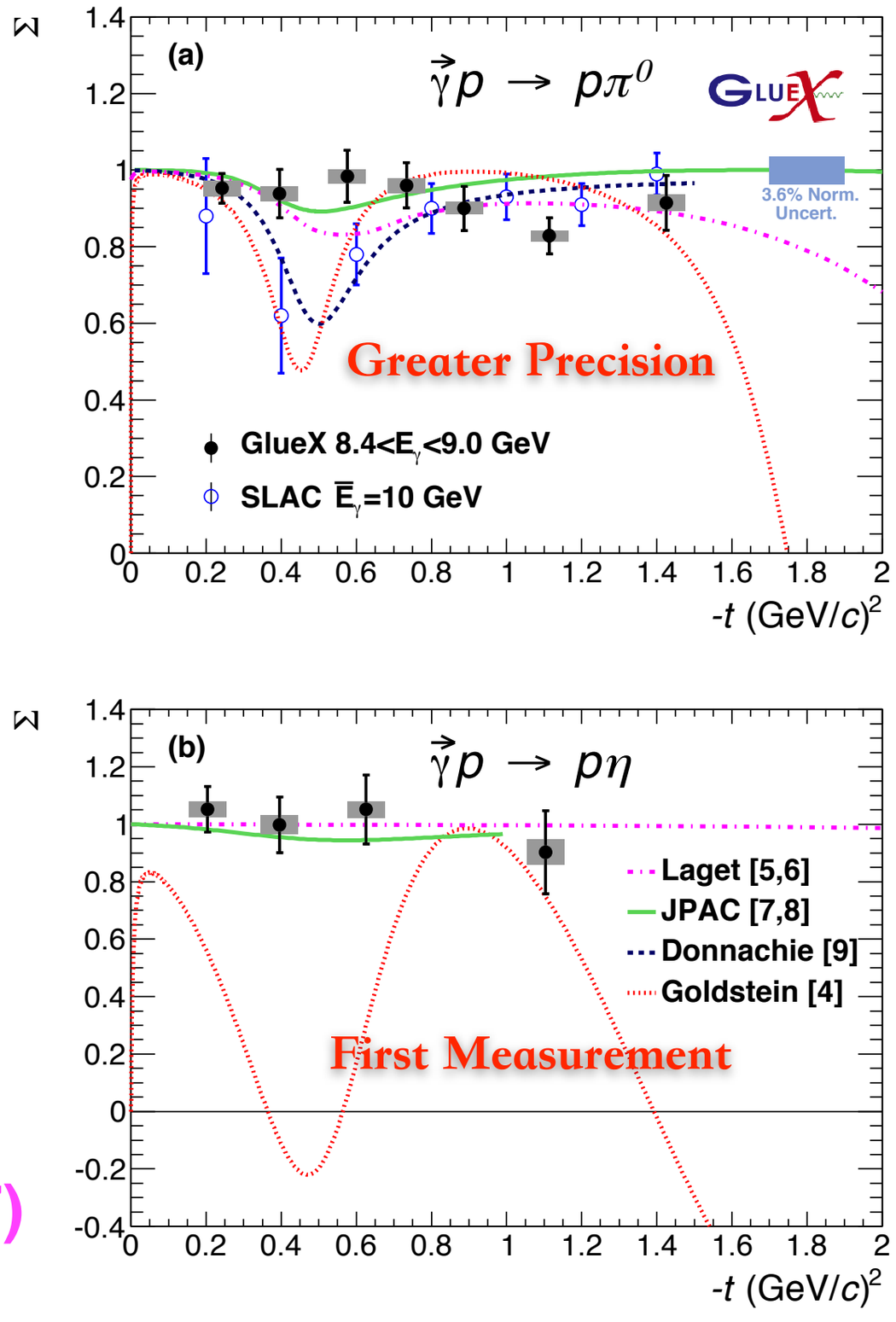




PHYS REV C 95, 042201(R) (2017)

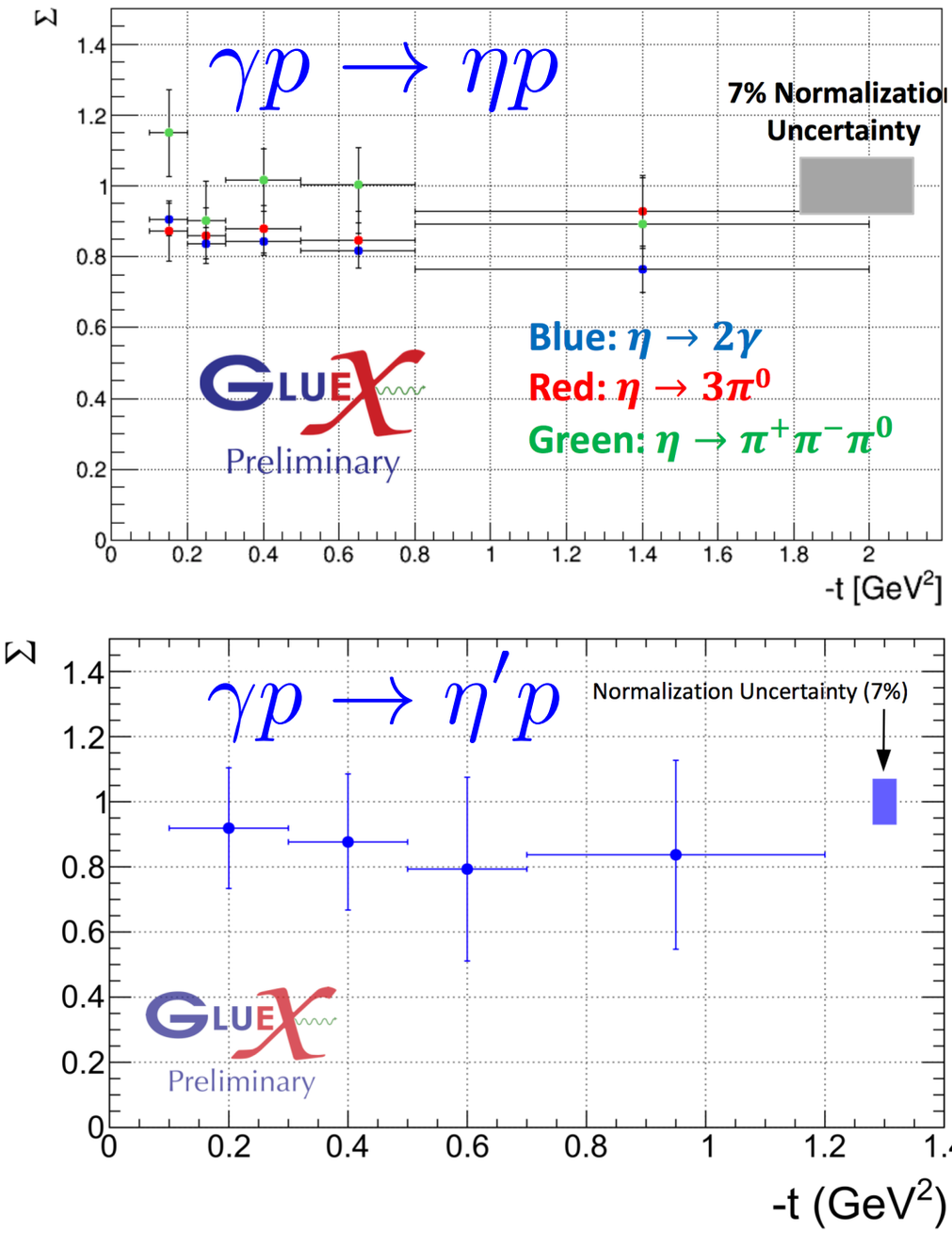
# Beam Asymmetry: Results

- **Measured asymmetries consistent with previous SLAC data**
- **Our measured Σ asymmetries are close to 1, with little evidence of -t dependence**
- **Don't observe prominent dip in beam asymmetry at -t = 0.5 (GeV/c)² in multiple theory predictions**




PHYS REV C 95, 042201(R) (2017)

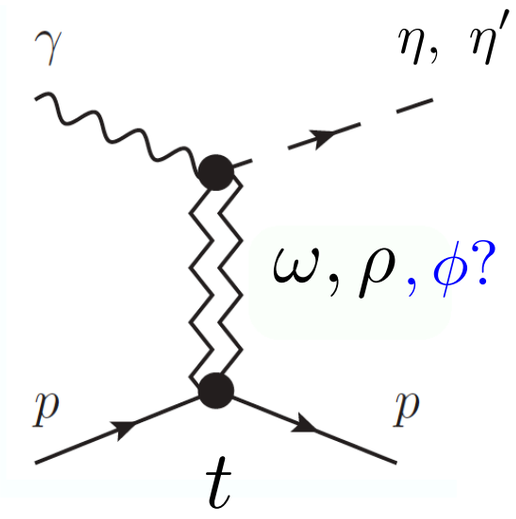
# Psuedoscalar mesons η/η′ Photoproduction







**Statistical uncertainties only**



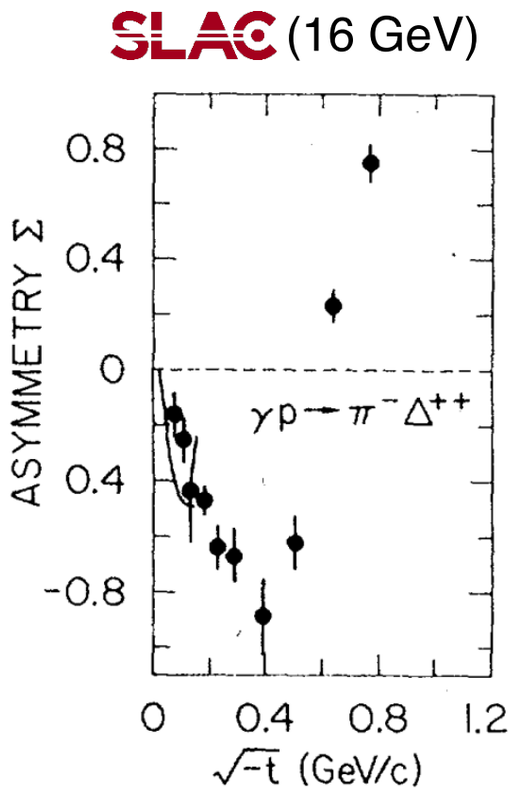

Sensitive to hidden strangeness components

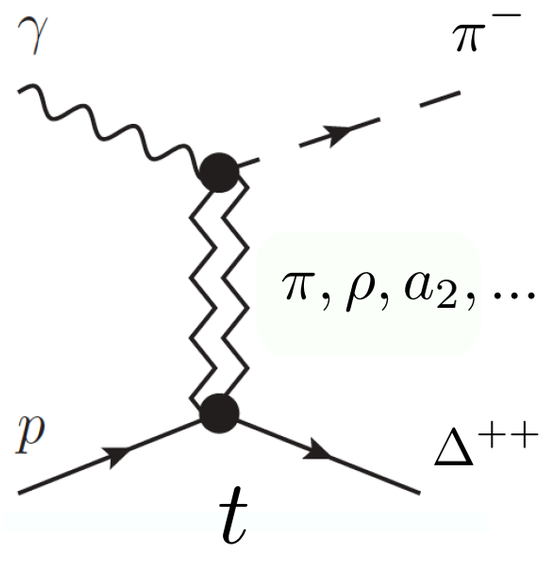
JPAC: PLB 774 (2017) 362

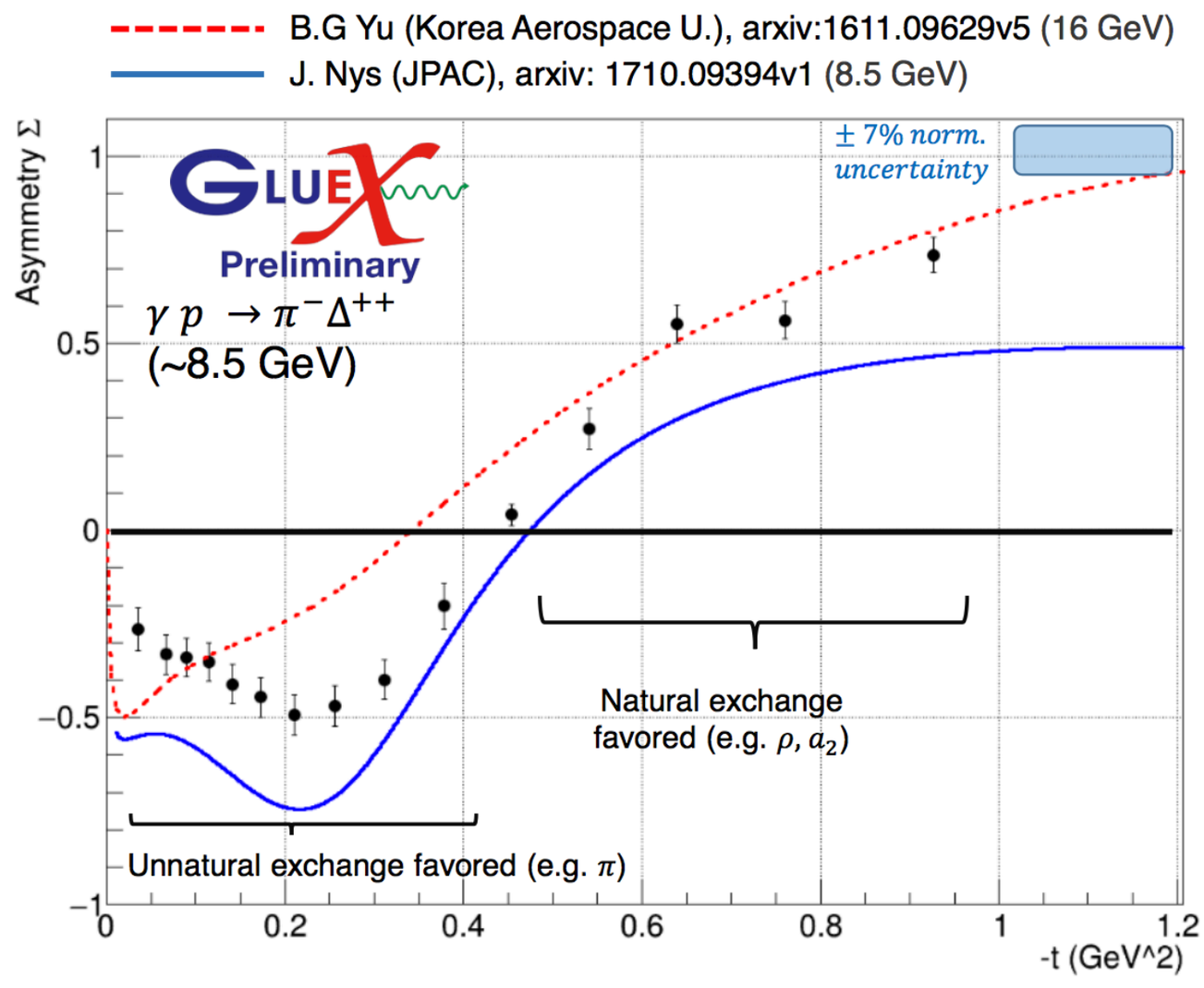
- **Additional decay modes are studied using 2017 data**
- **Consistent with vector exchange dominance**
- **The ratio of the asymmetries in η′ and η production is estimated to be close to unity as predicted by JPAC**

# Charged Psuedoscalar Meson Photoproduction

Phys. Rev. D **20**, 1553 (1979)

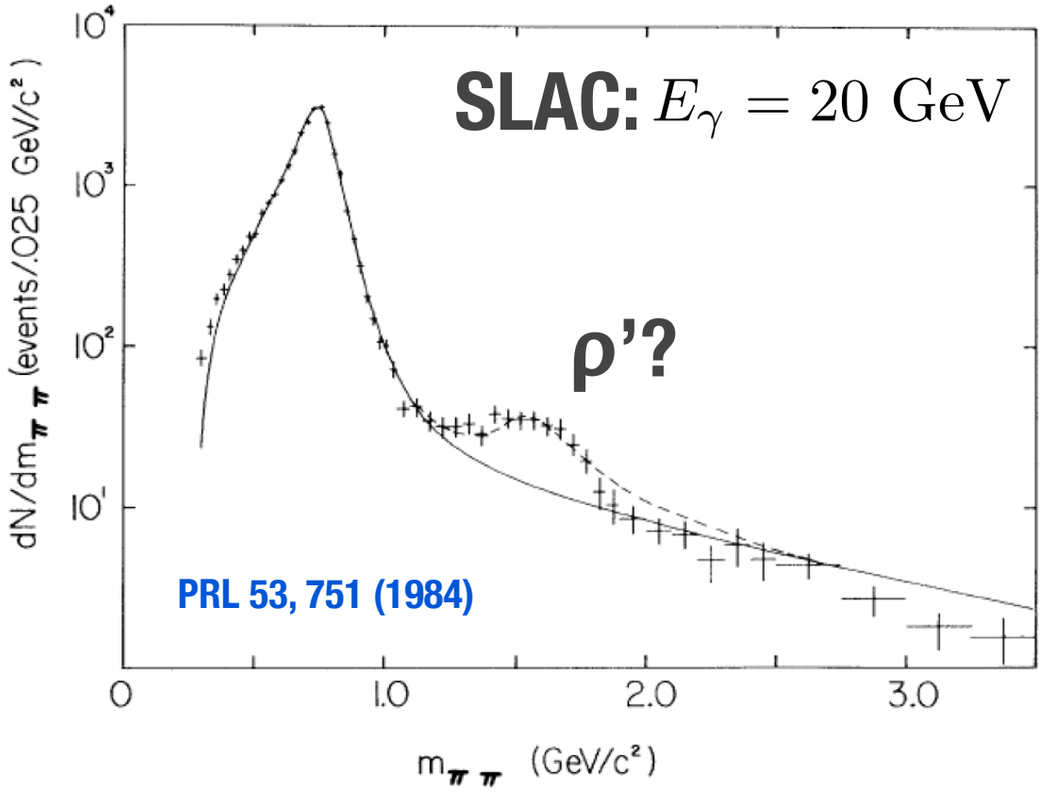


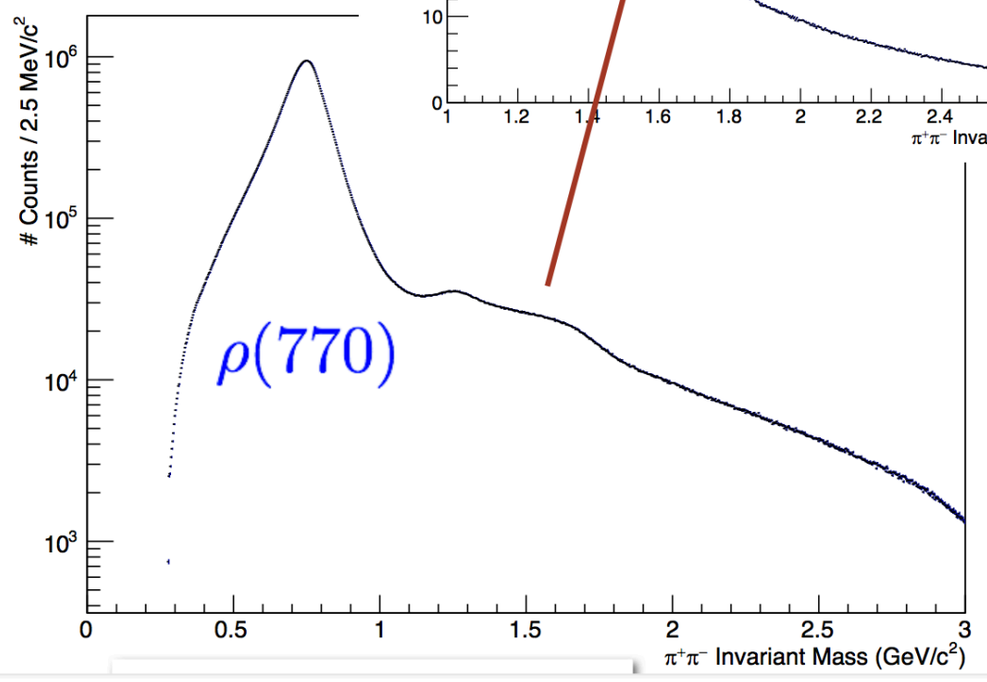



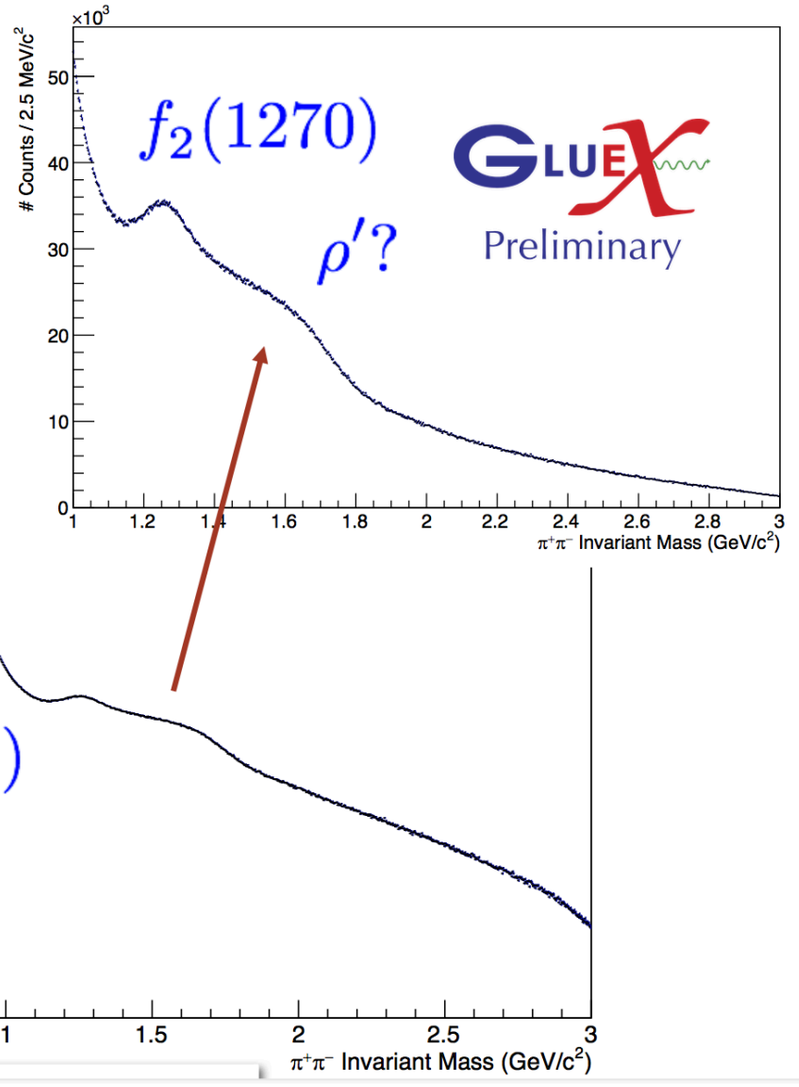




- **More complicated t-dependance**

# Early spectroscopy opportunities for $\gamma p \to \pi^+\pi^- p$

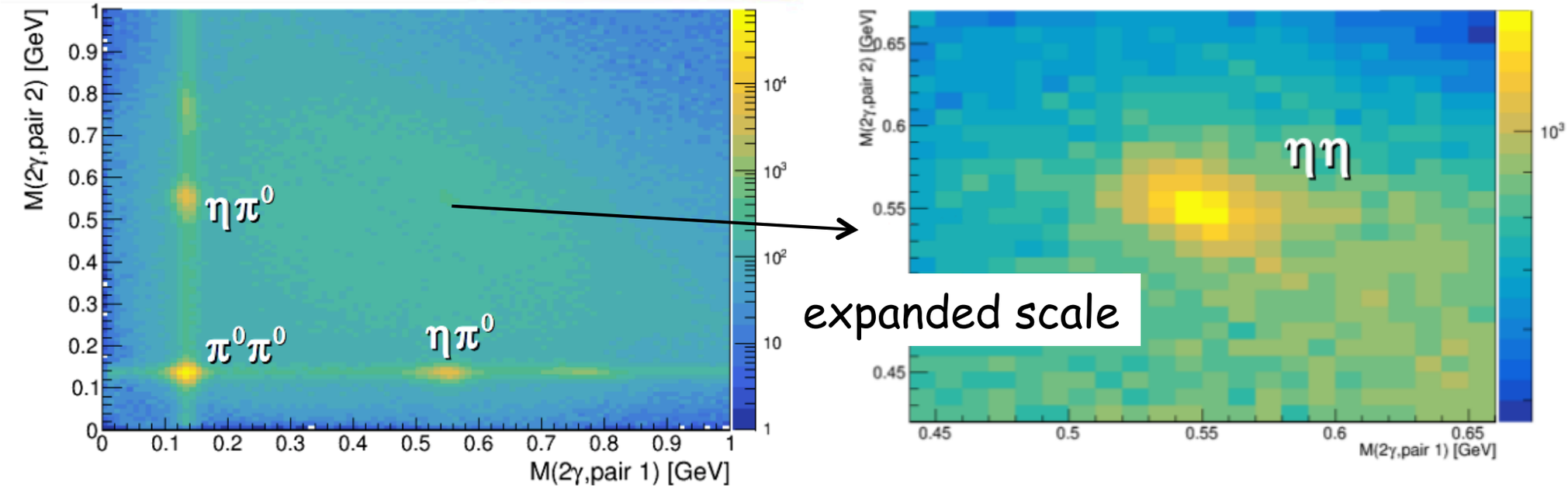


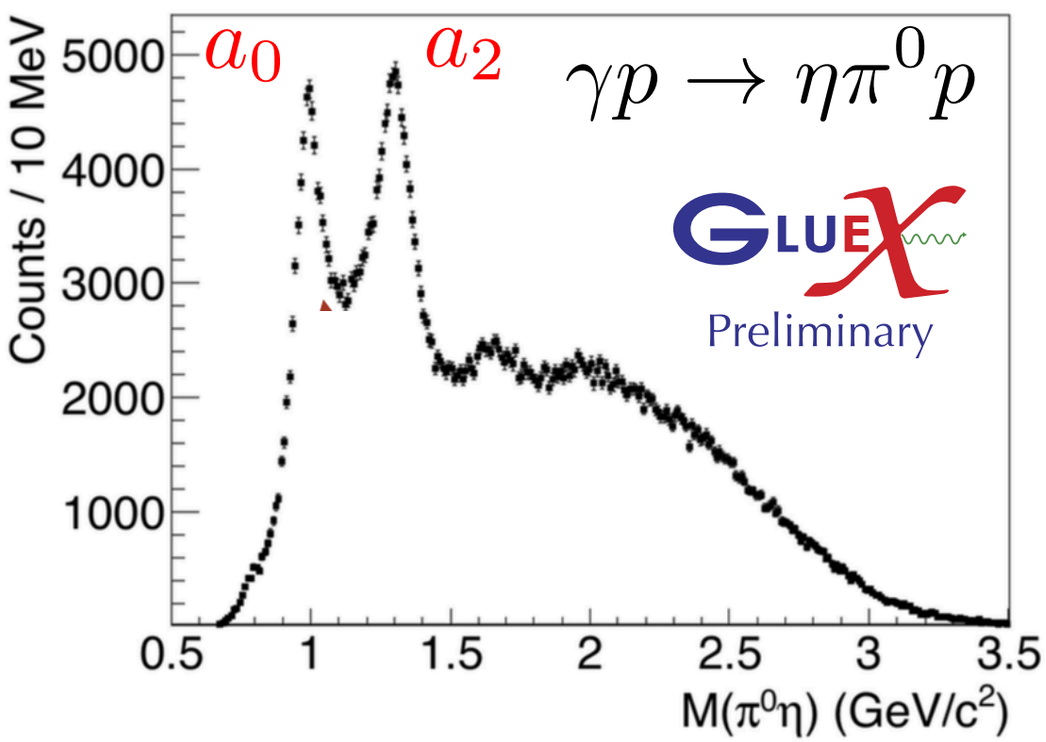



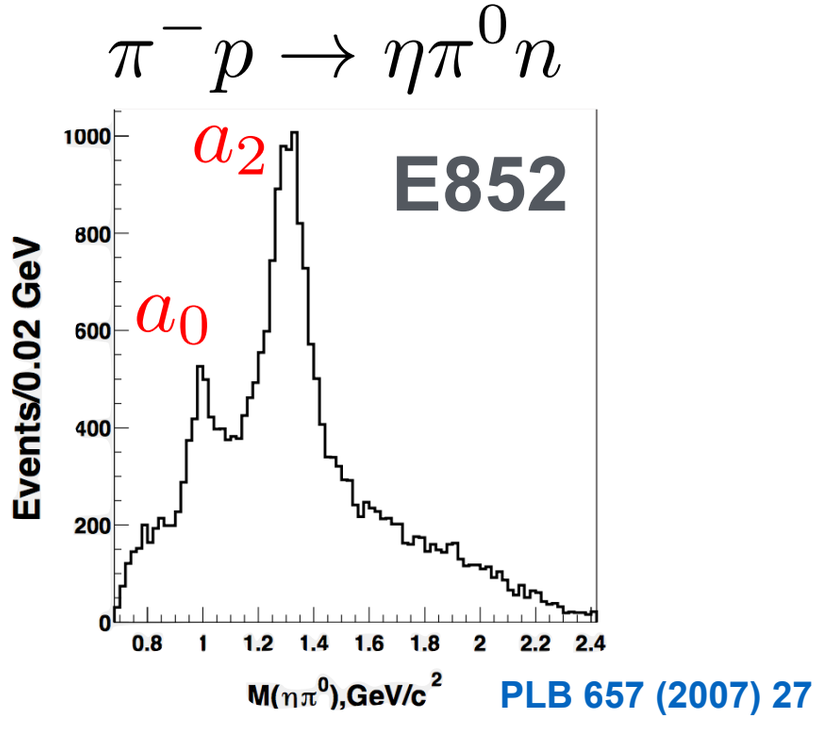




- **The enhancement around 1.5 GeV is consistent with previous SLAC data**
- ***K*$^+$*K*$^-$ spectroscopy is also under way**

# Four photon final states scalar and tensor mesons Photoproduction



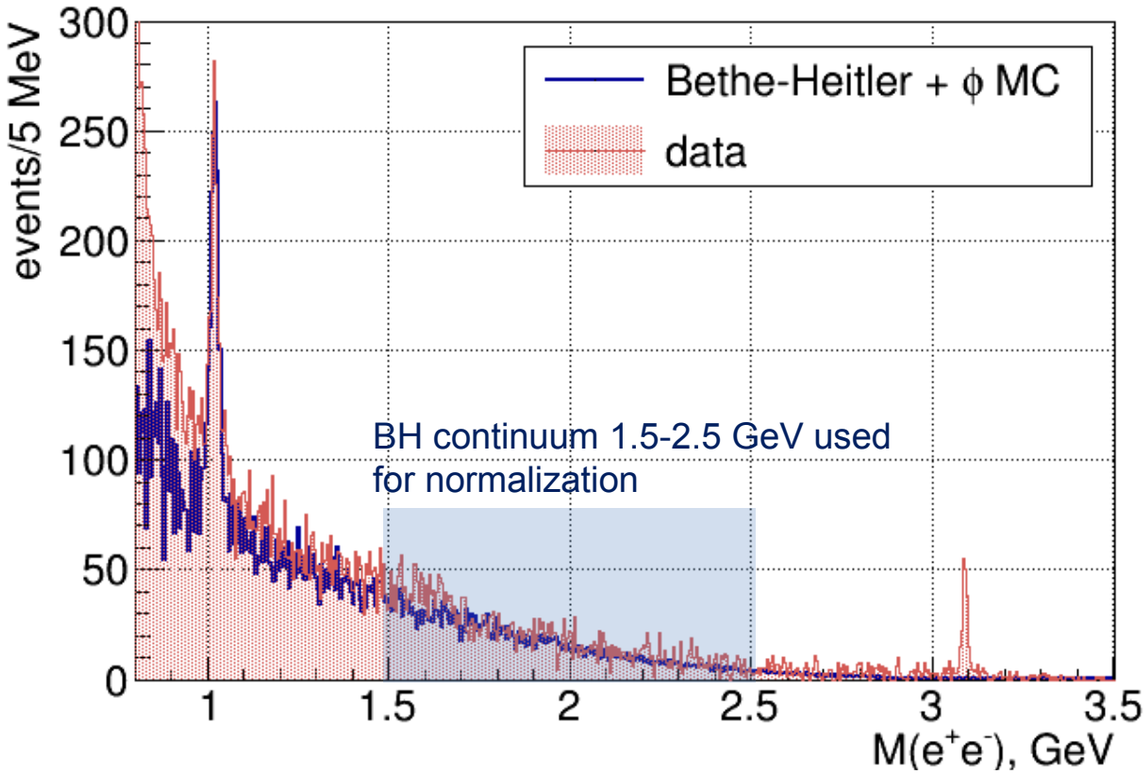



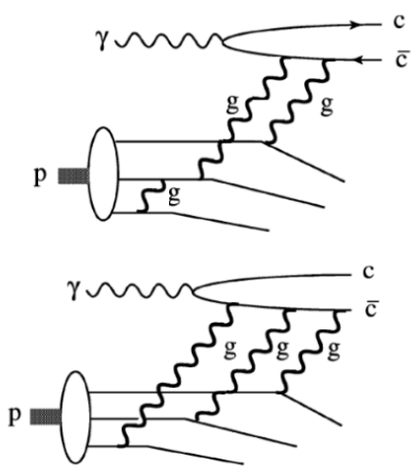




PLB 657 (2007) 27

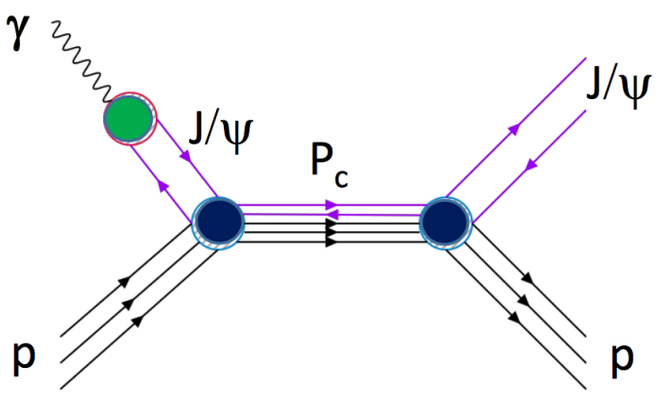
# J/Ψ Photoproduction near threshold

- BH simulations from R.Paremuzyan, based on:
- Berger, E., Diehl, M. & Pire, B. Eur. Phys. J. C (2002) 23: 675.



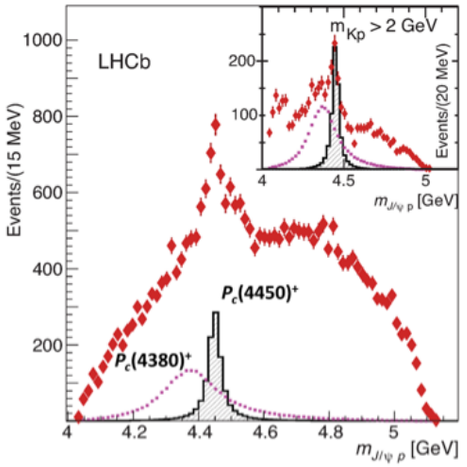

*PLB 498, 23 (2001)*



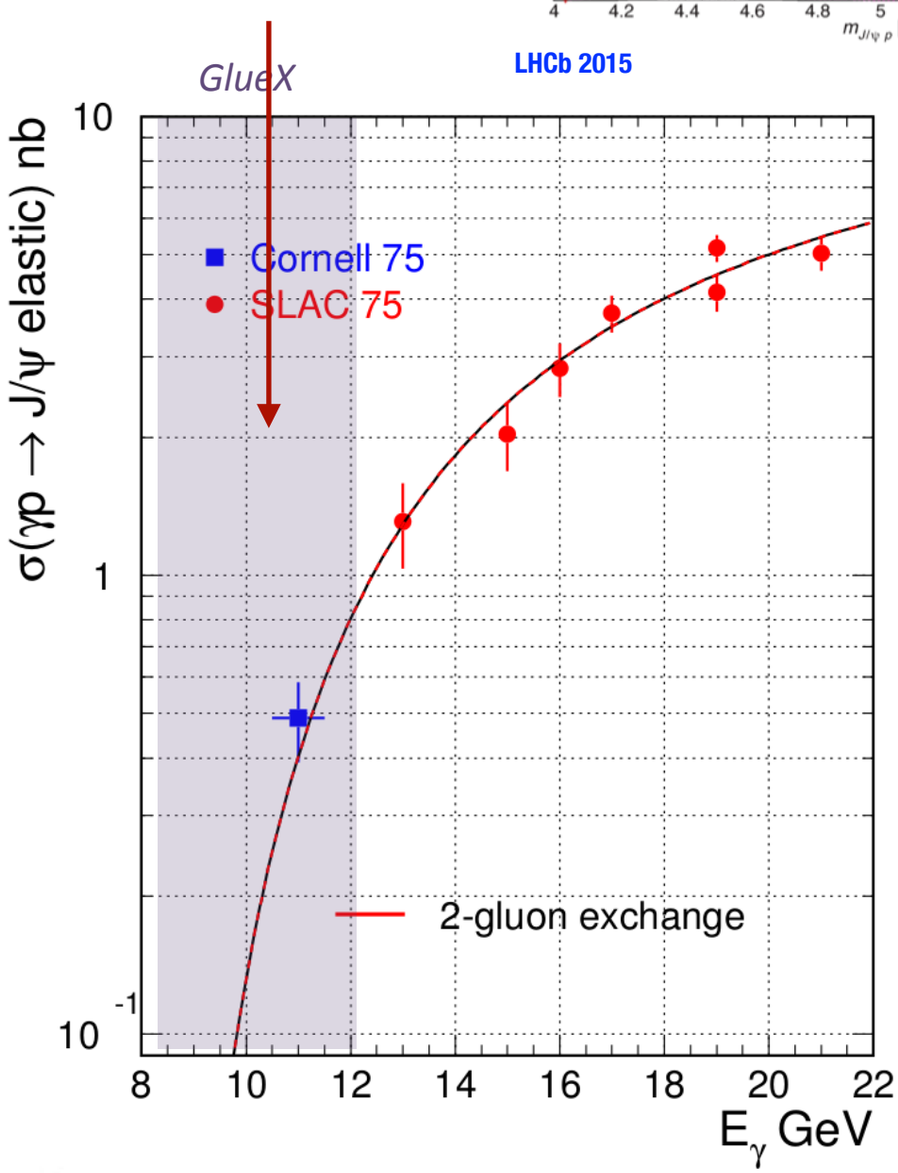

***JPG 41, 115004 (2014)***
***PRD 92,034022 (2015)***
***PRD 92.031502 (2015)***
***PLB 752, 329 (2016)***
***PRD 94,034002 (2016)***

***PRL 115, 072001 (2015)***

**LHCb Pentaquark**

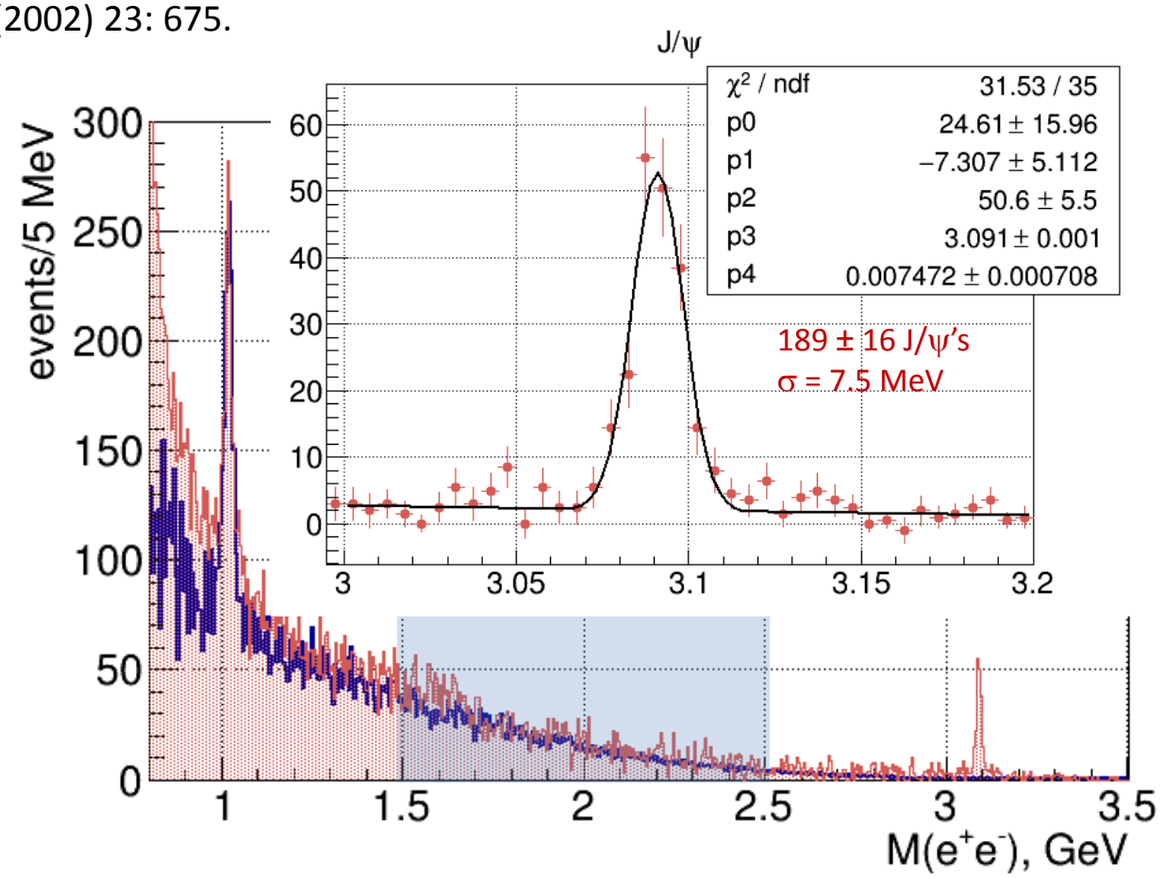


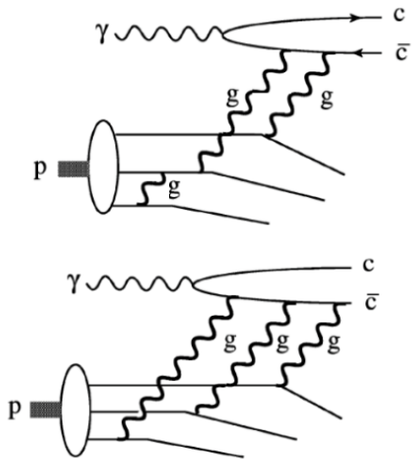

**LHCb 2015**



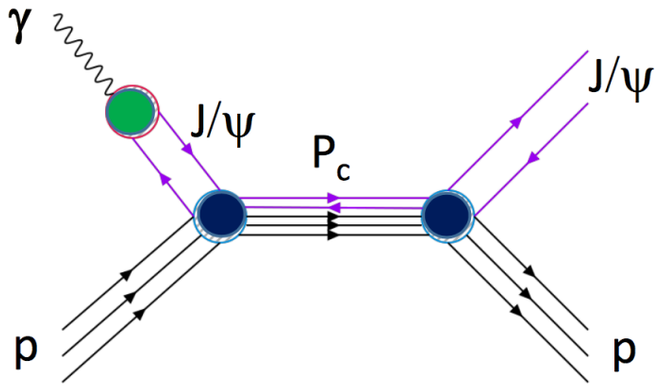
# J/Ψ Photoproduction near threshold

- BH simulations from R.Paremuzyan, based on:
- Berger, E., Diehl, M. & Pire, B. Eur. Phys. J. C (2002) 23: 675.



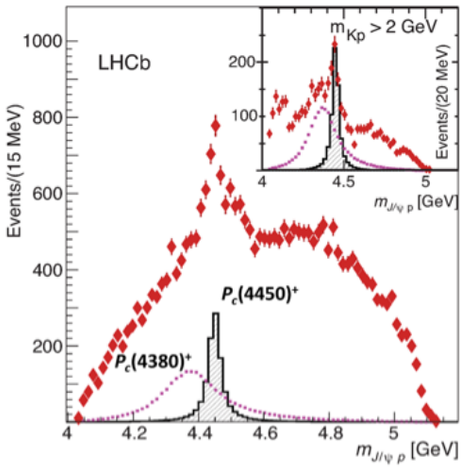

*PLB 498, 23 (2001)*



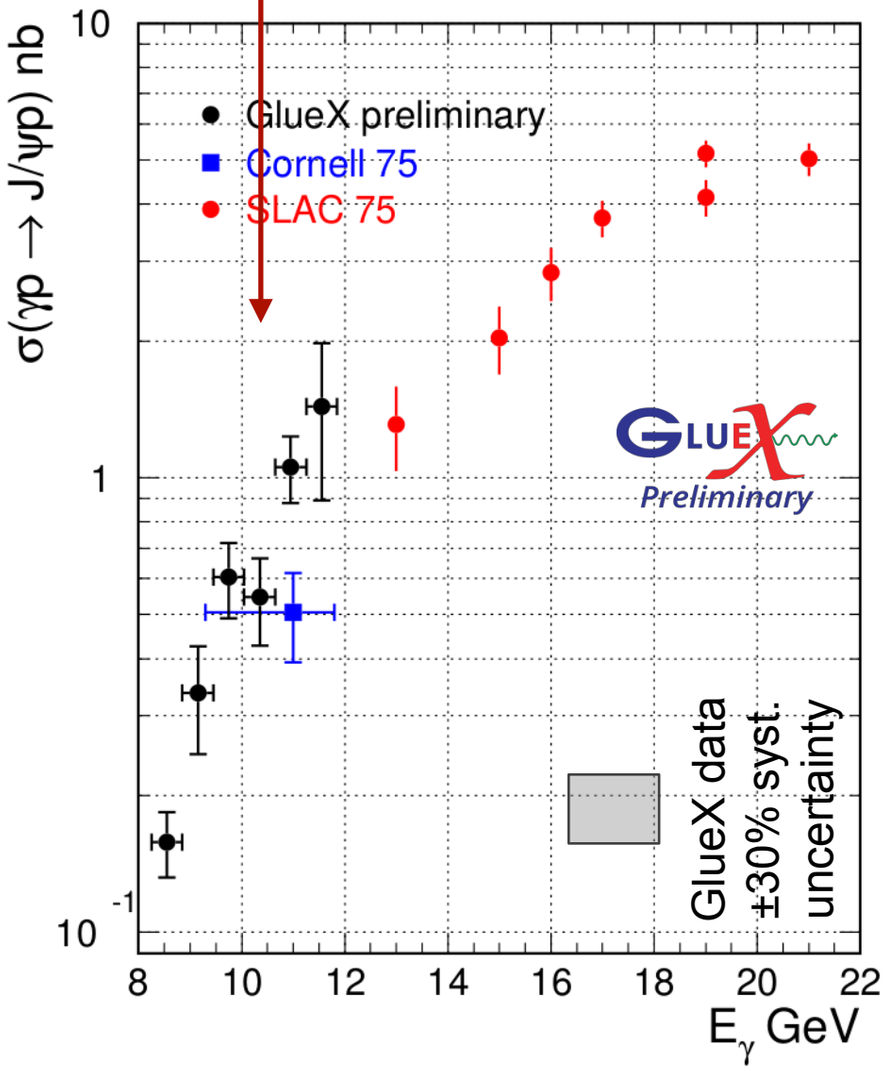

***JPG 41, 115004 (2014)***
***PRD 92,034022 (2015)***
***PRD 92.031502 (2015)***
***PLB 752, 329 (2016)***
***PRD 94,034002 (2016)***

***PRL 115, 072001 (2015)***

**LHCb**
**Pentaquark**




**LHCb 2015**



# Program and upgrades

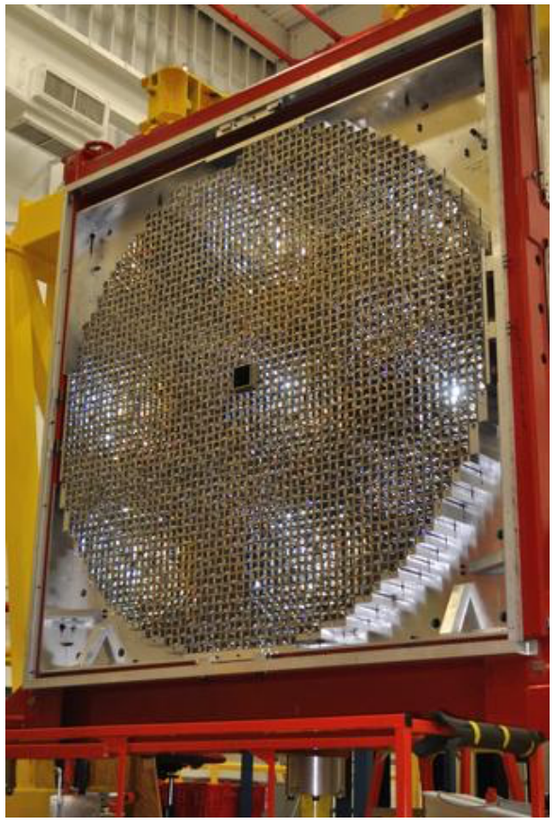
| Experiment | Description | Beam Time (days) |
|---|---|---|
| GlueX I | Study spectrum of light mesons and gluonic excitations (low intensity) | **120** |
| GlueX II | Study of hadron decays to strange final states (high intensity) | 200+220(*) |
| Primakoff eta | Eta radiative decay width | 79 |
| CPP | Charged pion polarizability measurement | 25 |
| Jlab Eta Factory | **Probe for QCD and BSM physics by rare η decays** | **130(*)** |

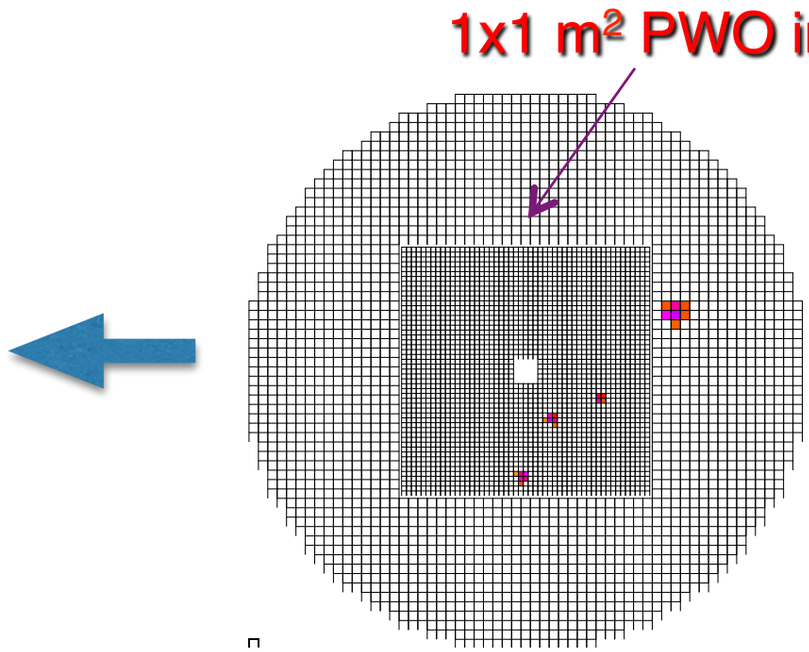
(*) May run concurrently

# JEF experiment

## Leptophobic B, CVPC, ChPT and the quark mass ratio

## New Equipment: FCAL-II






**2464 PWO crystal modules**

**PWO vs. lead glass**

| Property | Improvement factor |
|---|---|
| Energy σ | 2 |
| Position σ | 2 |
| Granularity | 4 |
| Radiation-resistance | 10 |

**PWO crystals may be bought from Shanghai Institute of Ceramics**

**QC of the PWO crystals can be performed in China**

Upgraded Forward Calorimeter with High resolution, high granularity PWO insertion (FCAL-II) to detect multi-photons from the η decays

# Summary and Outlook

- GlueX is installed, commissioned and all detector systems are exceed or near design specifications.

- The “Low intensity” program, GlueX I, is expected to be completed in 2018, then the Primakoff η and the high intensity GlueX (GlueX II with DIRC), will begin subsequently.

- The linearly polarized photon beam asymmetry Σ for $\pi^0$/η photoproduction have measured. A broad meson photoproduction project is under way, including beam asymmetries, cross sections and spin density matrix elements analysis. A upper limit can be set for LHCb Pentaquark.

- DIRC upgrade for enhanced π/K separation is ongoing. High resolution calorimeter is needed for parts of the JEF program.

- The broader program of exotic mesons is in sight. New ideas and new collaborators are welcome.

# Thanks!

武漢大學 WUHAN UNIVERSITY

Jefferson Lab GLUEX

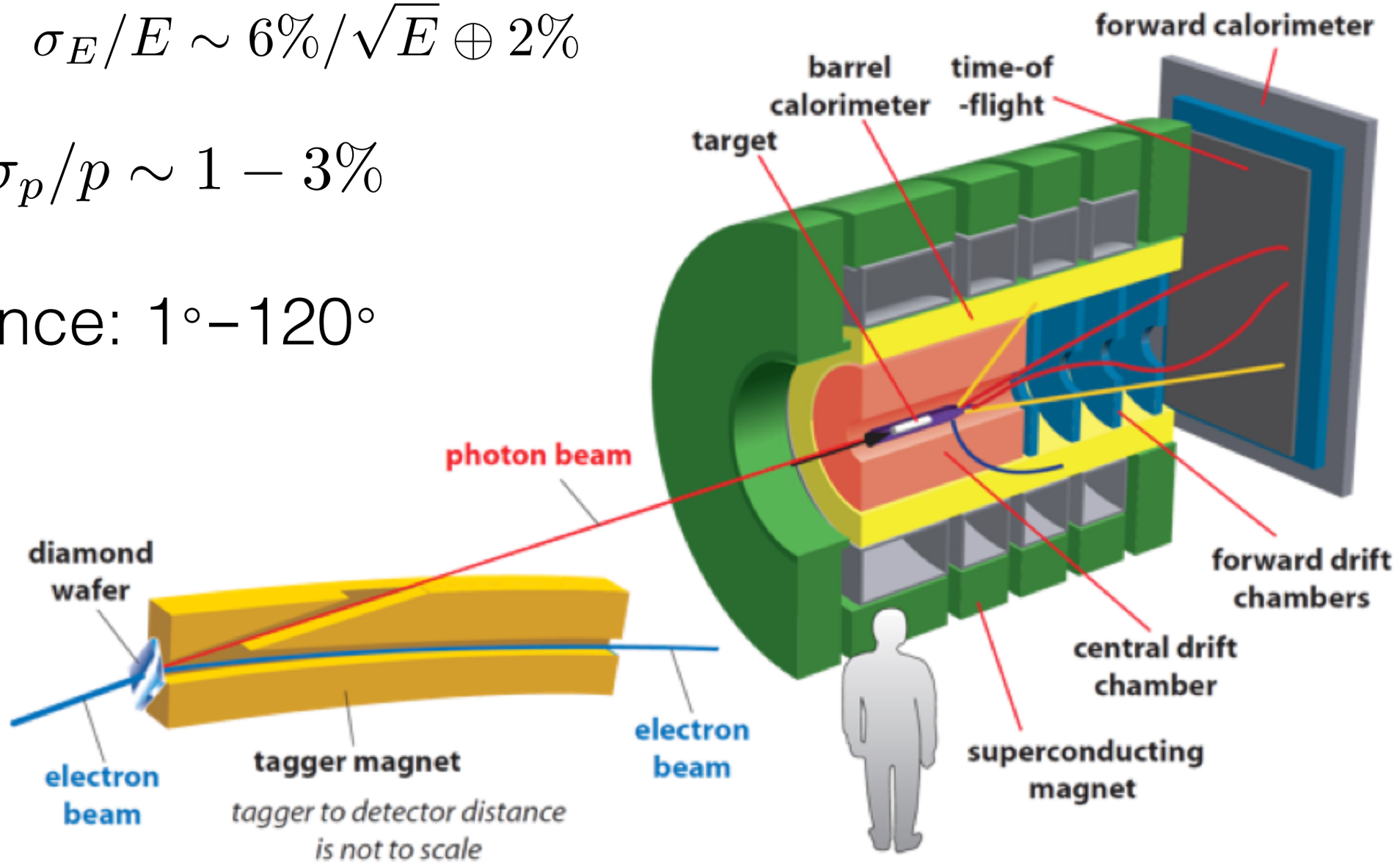
# GlueX Detector

**Detector resolutions:**

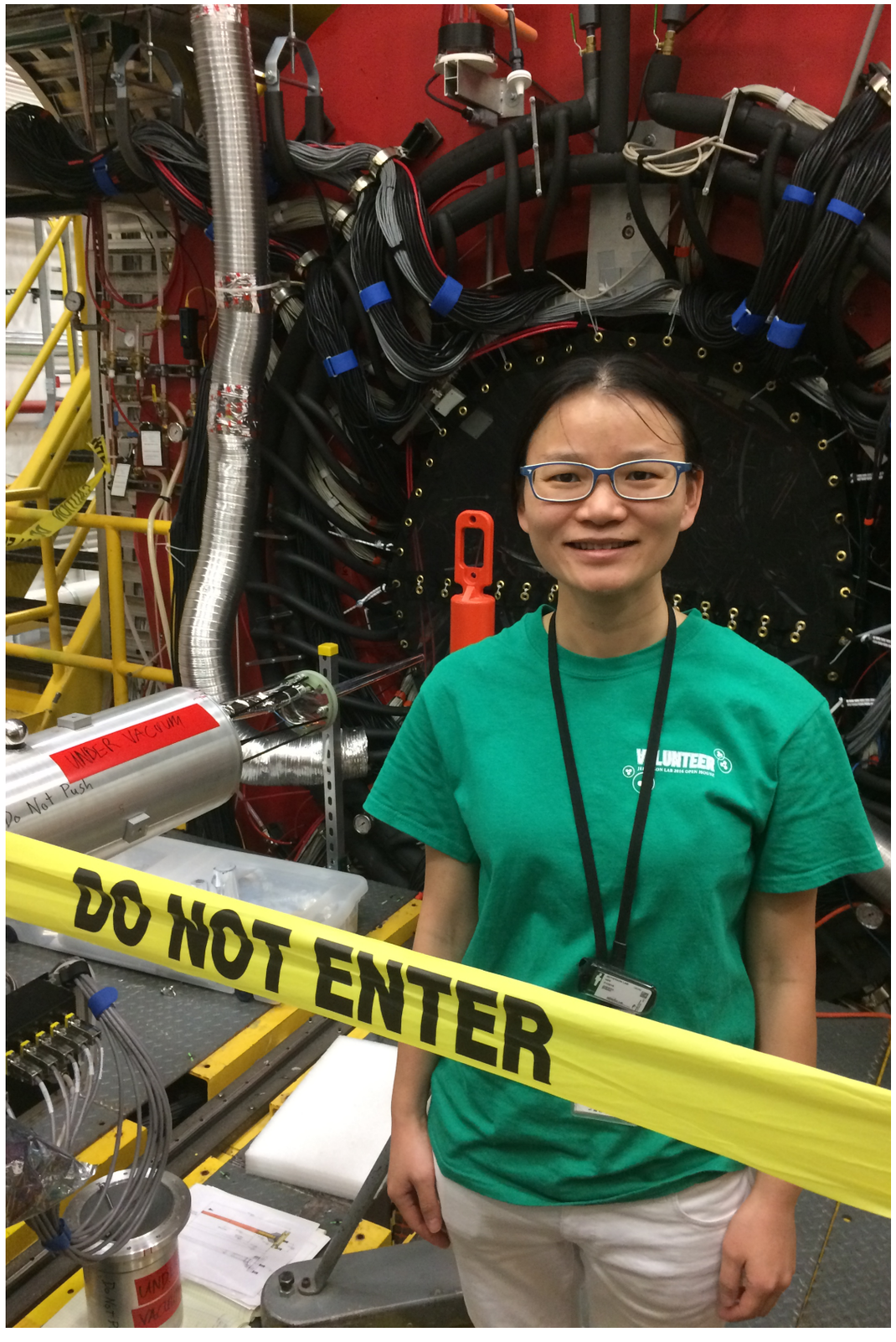
Photons: $\sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$

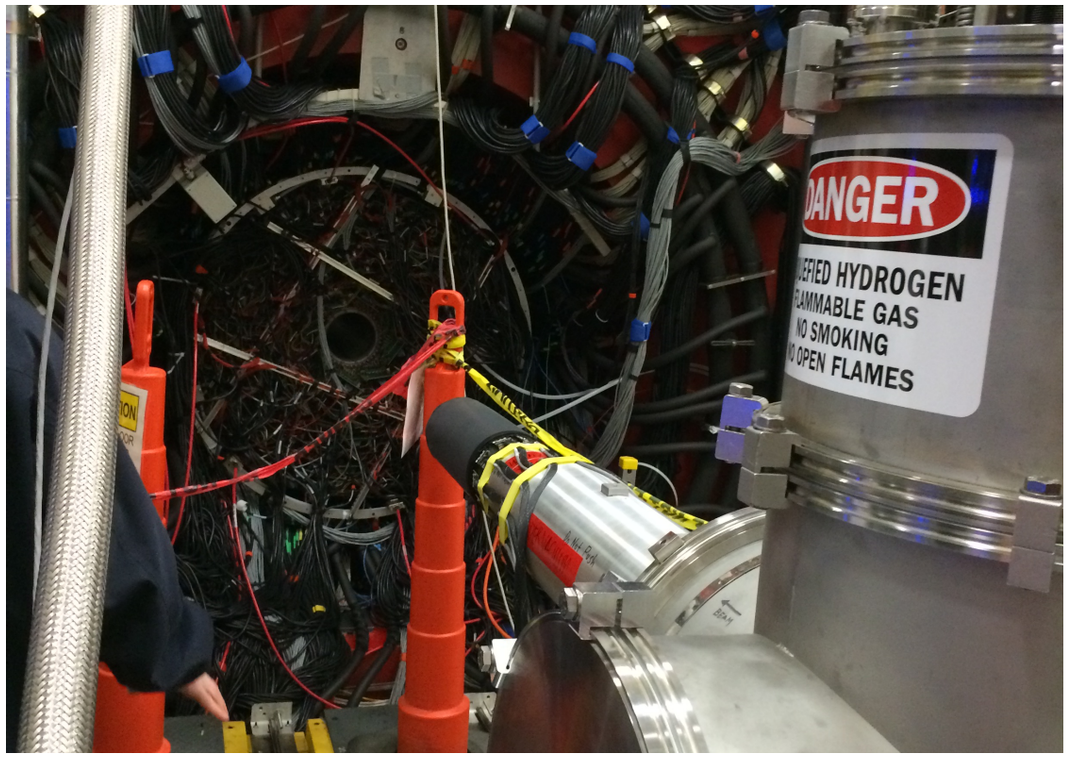
Tracks: $\sigma_p/p \sim 1 - 3\%$

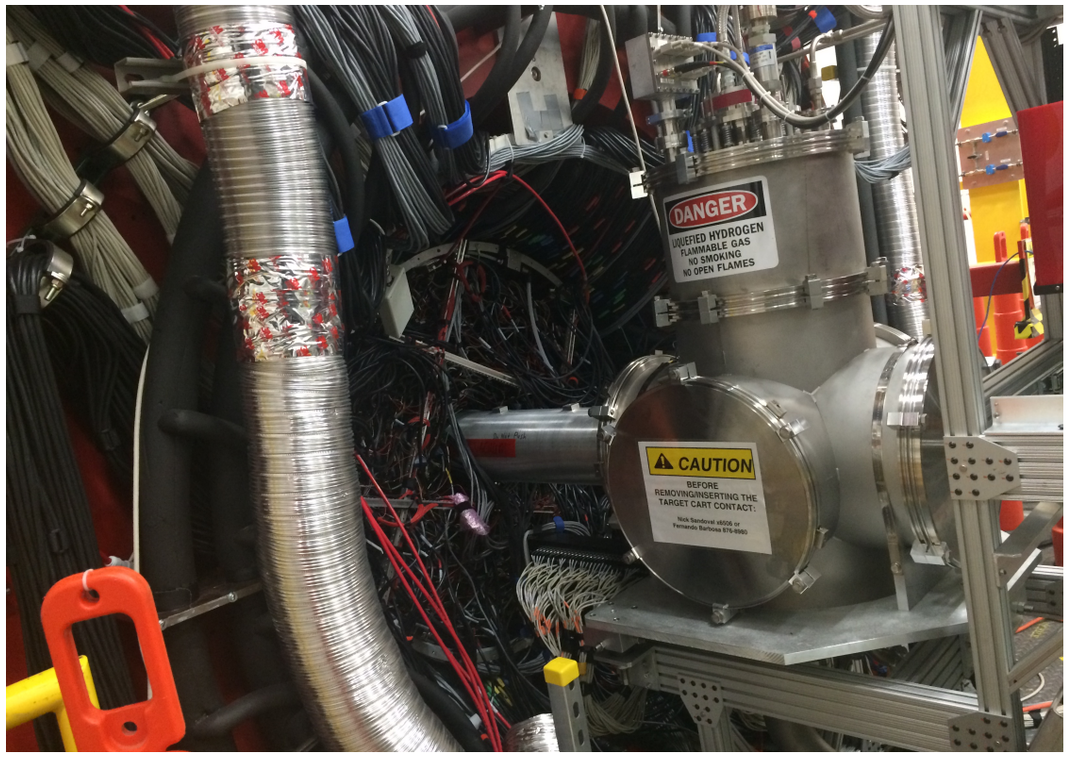
Receptance: 1°–120°



# Liquid hydrogen target and start counter

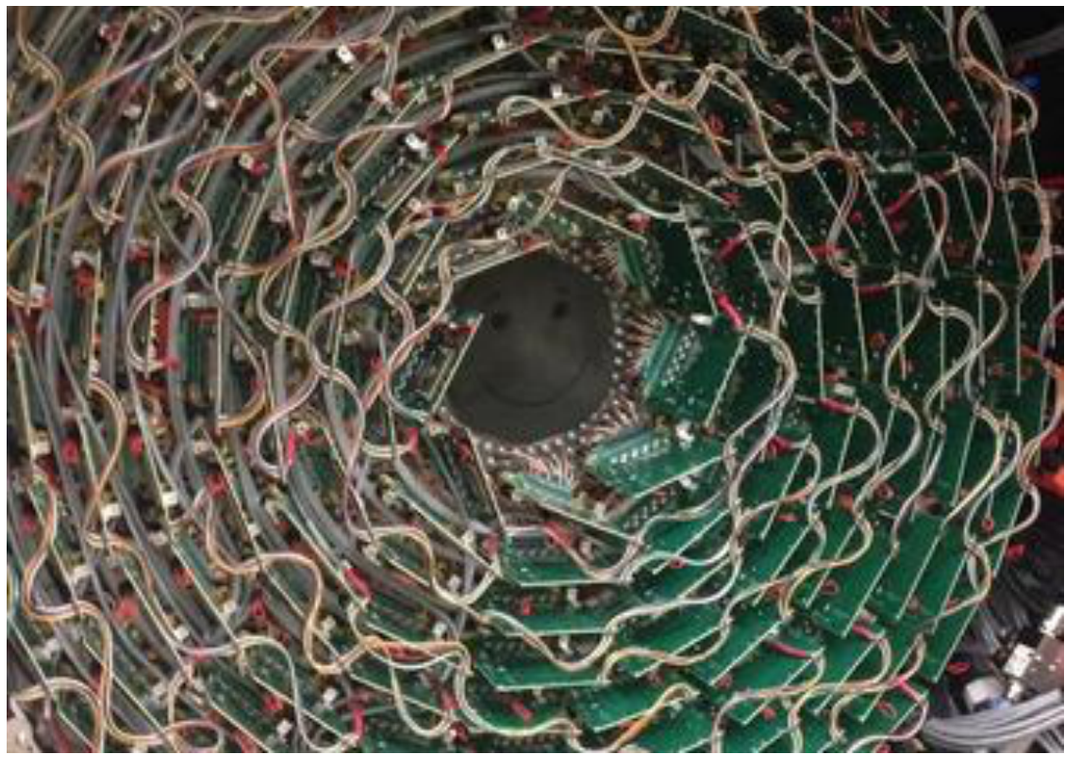


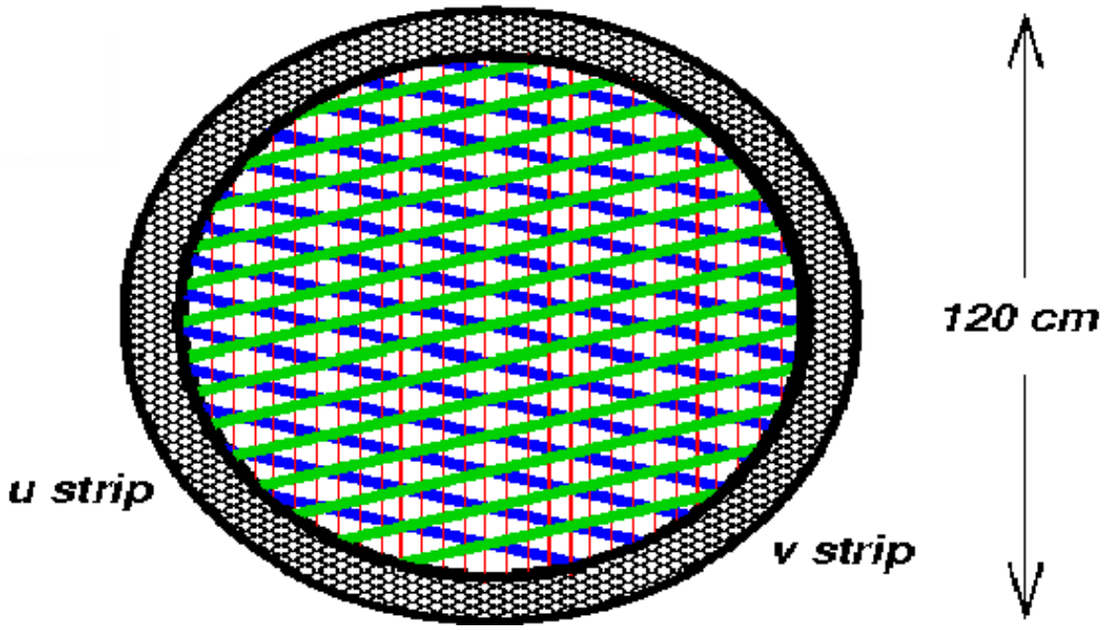



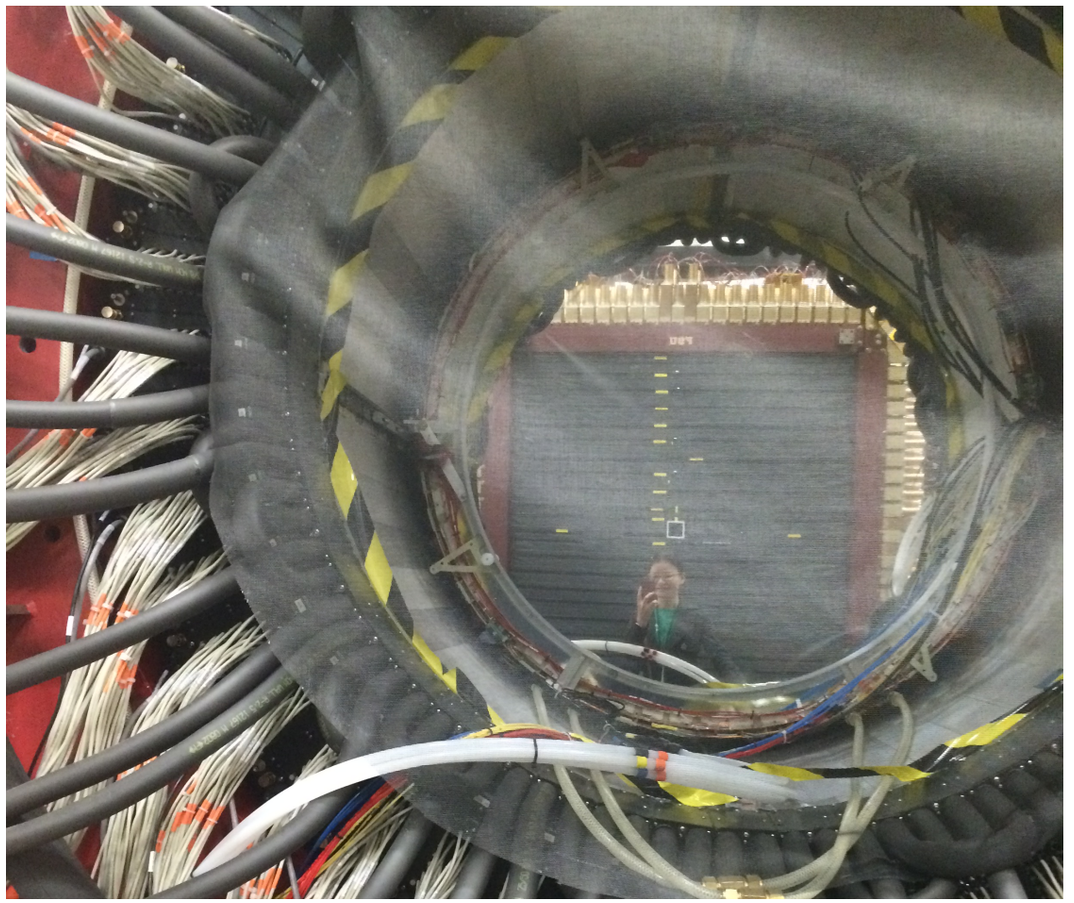
# CDC and FDC

**Straw tube drift chamber**



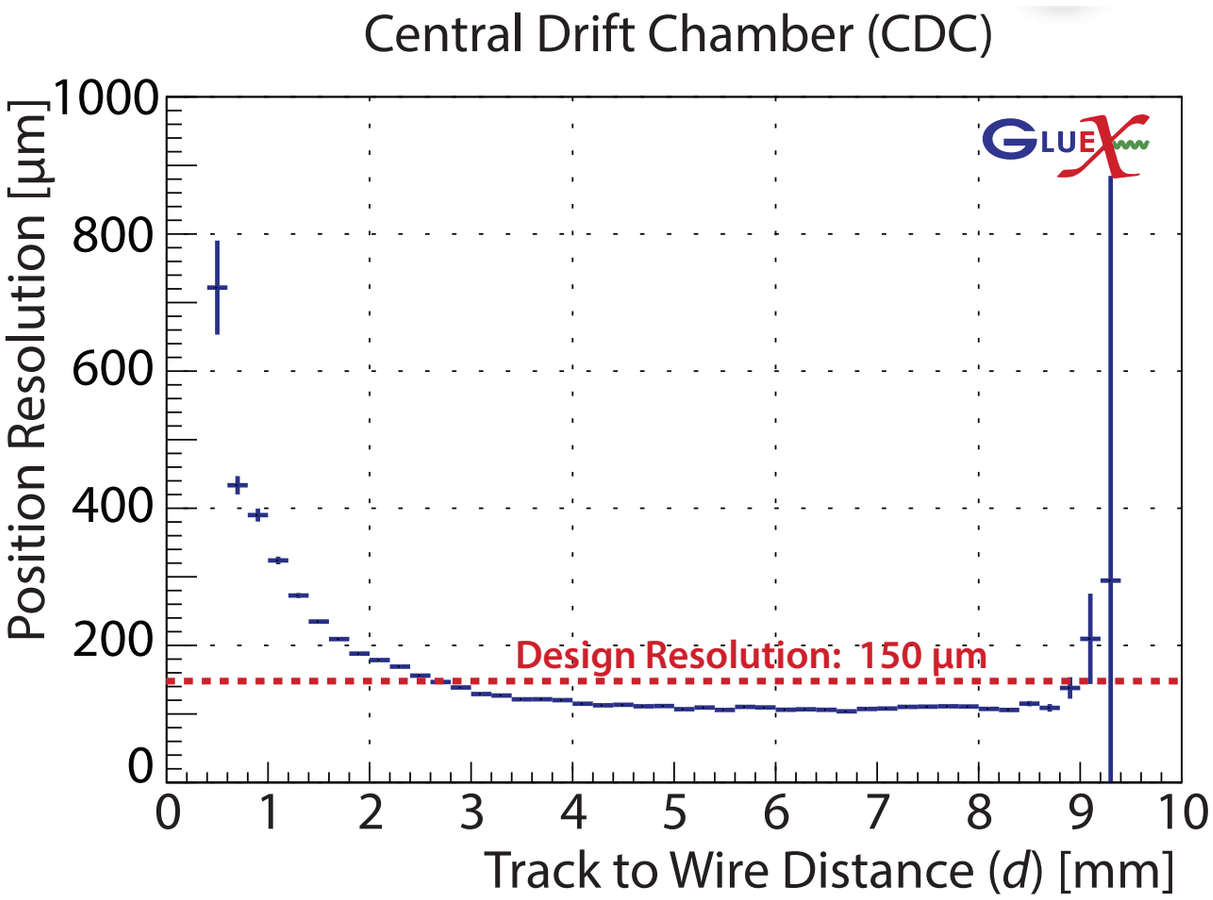
**Interleaved planes of field/sense wires and planes of cathode strips**

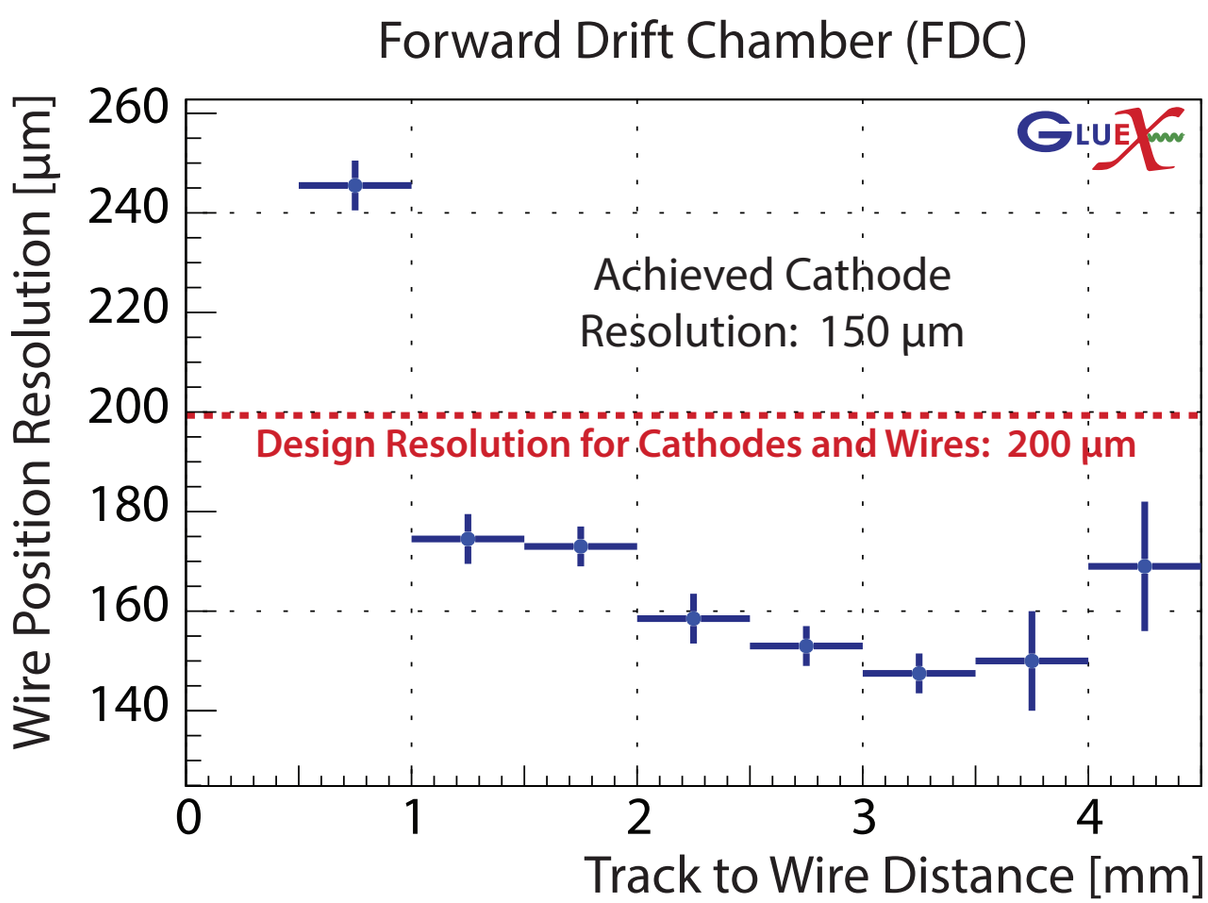


# Detector Performance

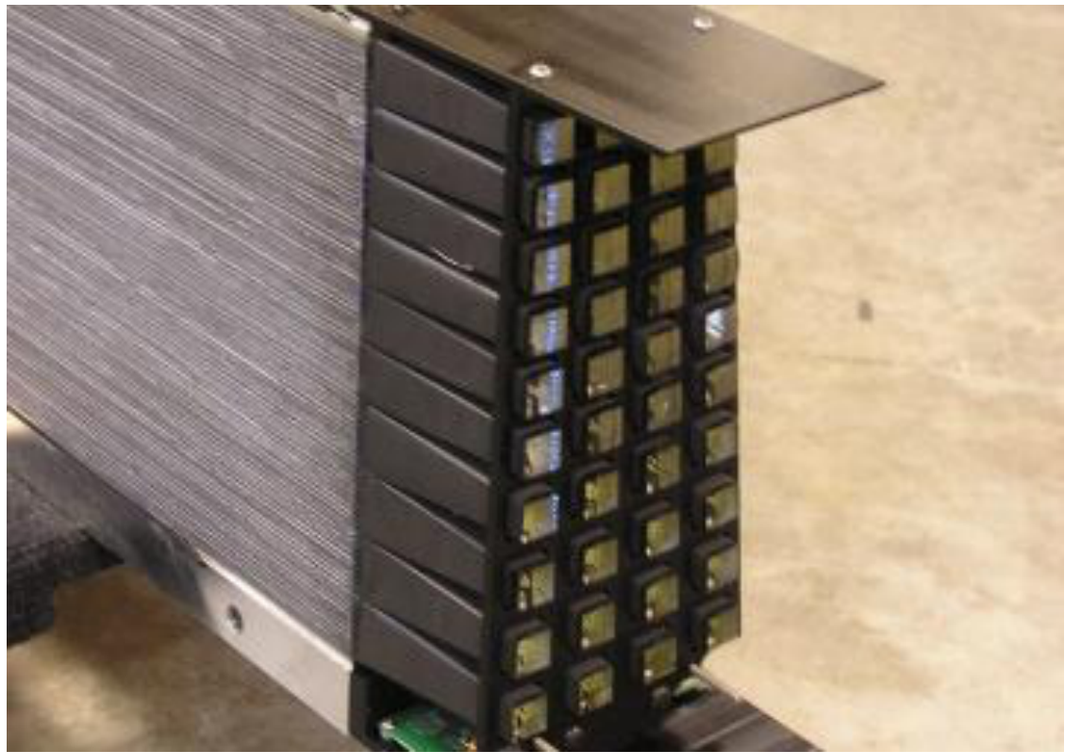
## Drift chambers exceed design position resolution



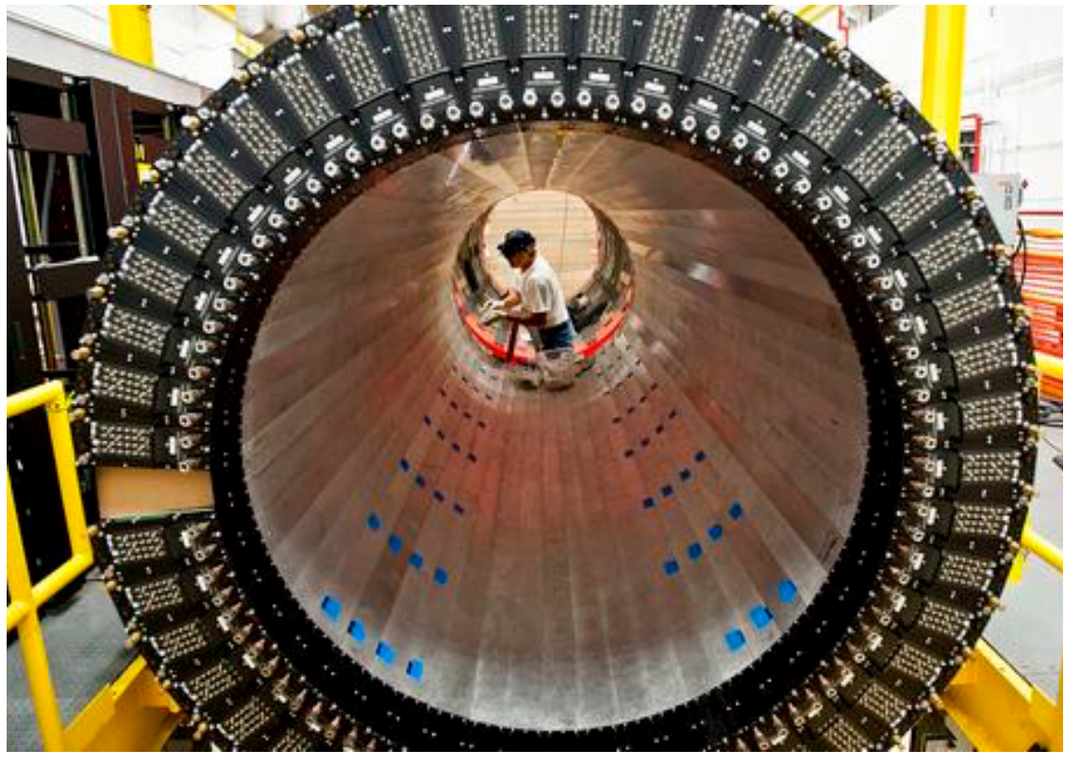



# BCAL and FCAL

**Scintillating fibers in the interstitial layers of lead**



**Fast silicon photomultipliers (SiPMs)**

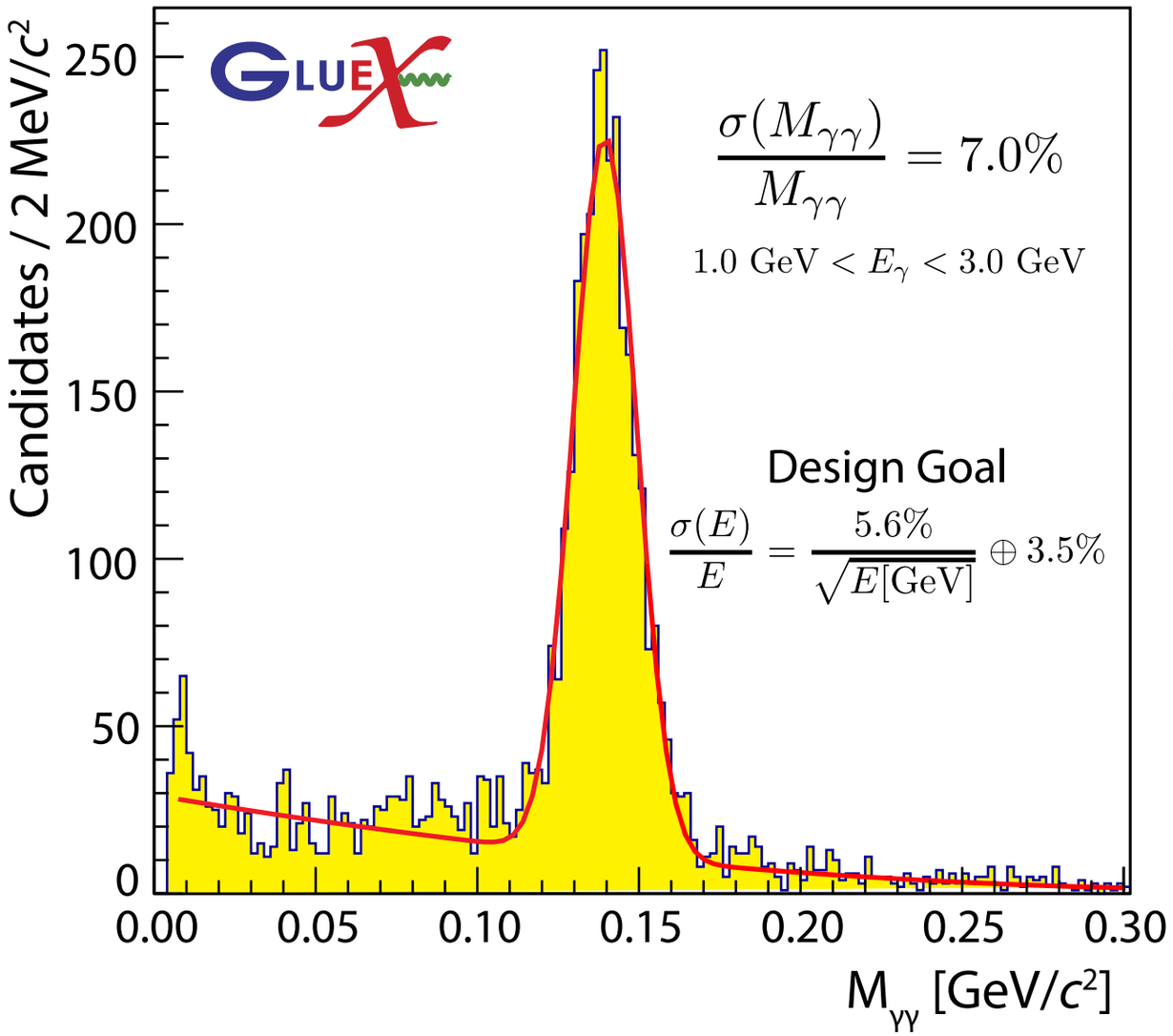


**F8-00 lead glass, 4 × 4 × 45 cm**

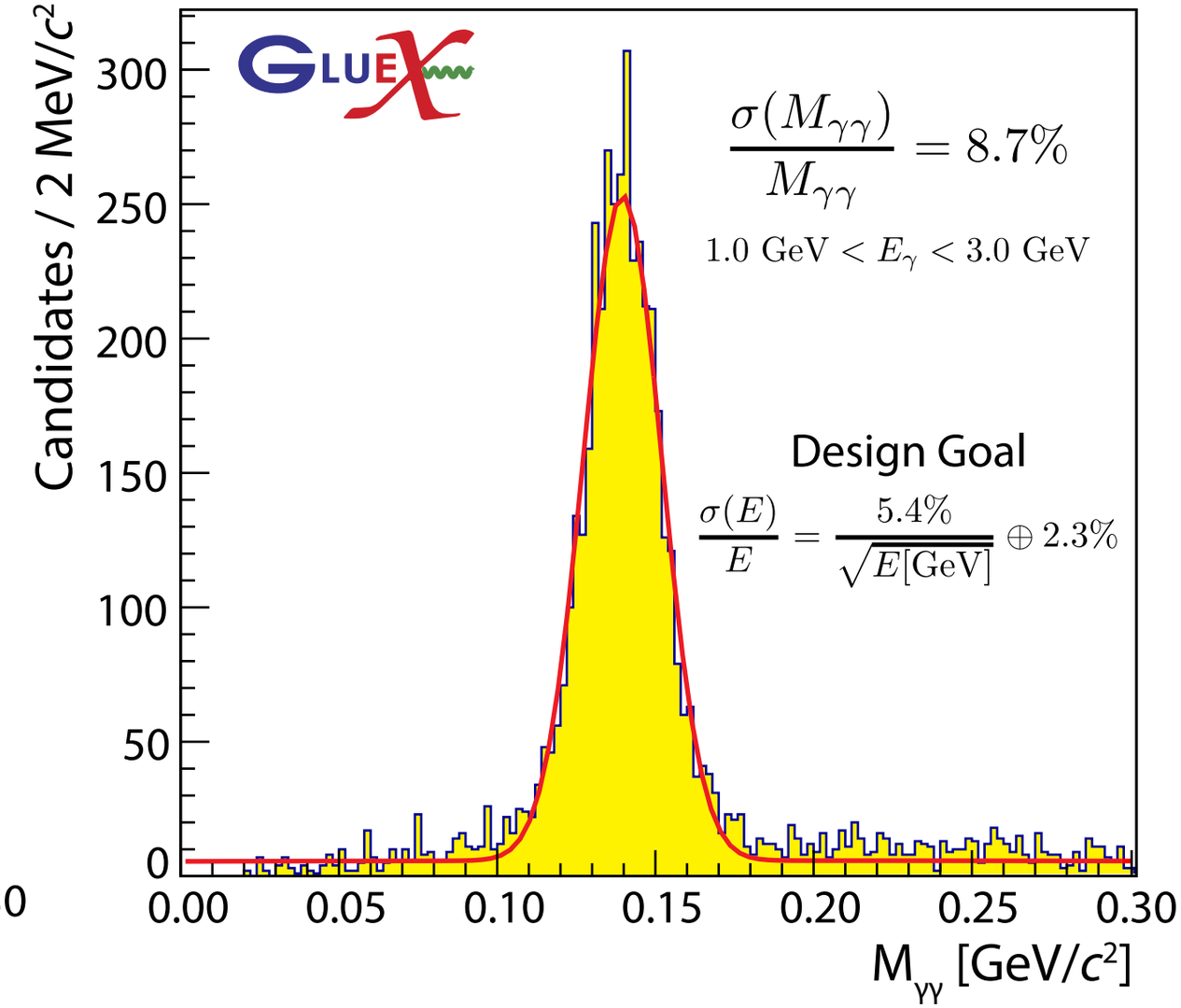
# Detector Performance

## Calorimeters approaching design energy resolution

Forward Lead Glass Calorimeter

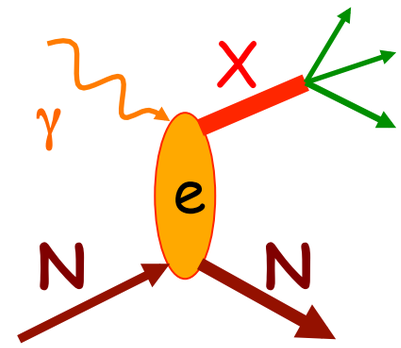



Barrel Lead-Scintillating Fiber Calorimeter



# Meson Photoproduction

- **Meson photoproduction: almost 50 years at SLAC, DESY, and Cambridge**
- **Growing vigorously recently： JLab, ELSA, and MAMI**
- **Understanding the properties of strong interaction in the nonperturbative regime**
- **Search for exotic hybrid mesons**
- **Provide constraints on “background” to baryon resonance extraction in the low energy regime**
- **Beam asymmetry Σ provides insight into dominant production mechanism**

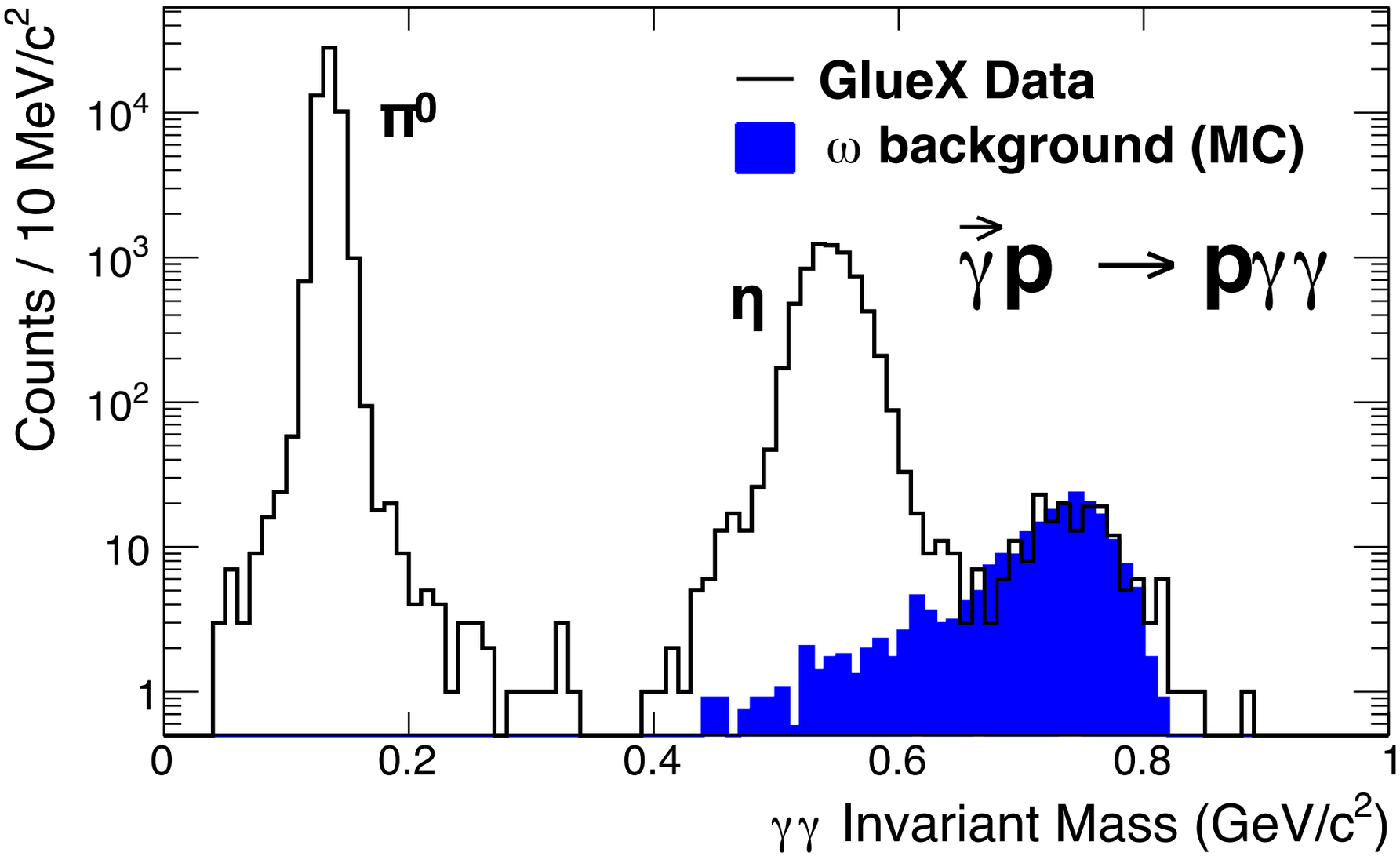



$\gamma \Leftrightarrow \rho, \omega, \phi$

## High-Energy Meson Photoproduction: VMD & Regge-cut phenomenology

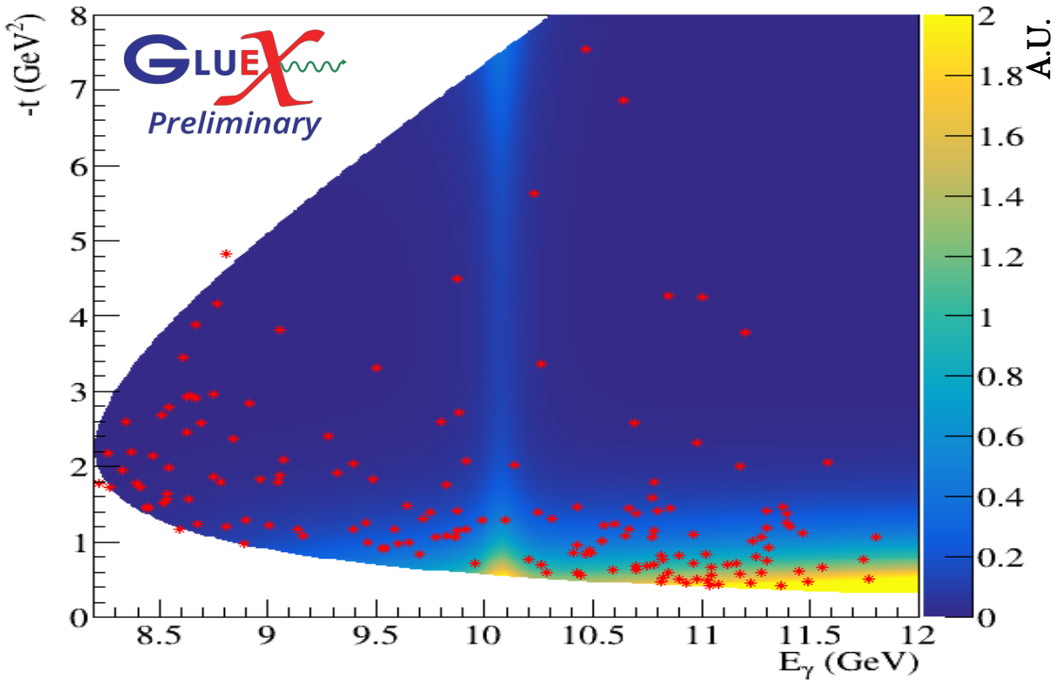
**GlueX & JPAC: Experiment & Theory**

# ω Backgrounds




- **Continuum background between $\pi^0$ and η is negligible.**
- **The largest background is $\gamma p \to \omega p$, $\omega \to \pi^0 \gamma$ with a missing photon. To get the background shape, we simulated this reaction then normalized to the ω leakage peak.**
- **Our exclusive measurements and cuts ensure very low backgrounds: for the eta the dilution is only 0.38%, while for the $\pi^0$ it is negligible.**

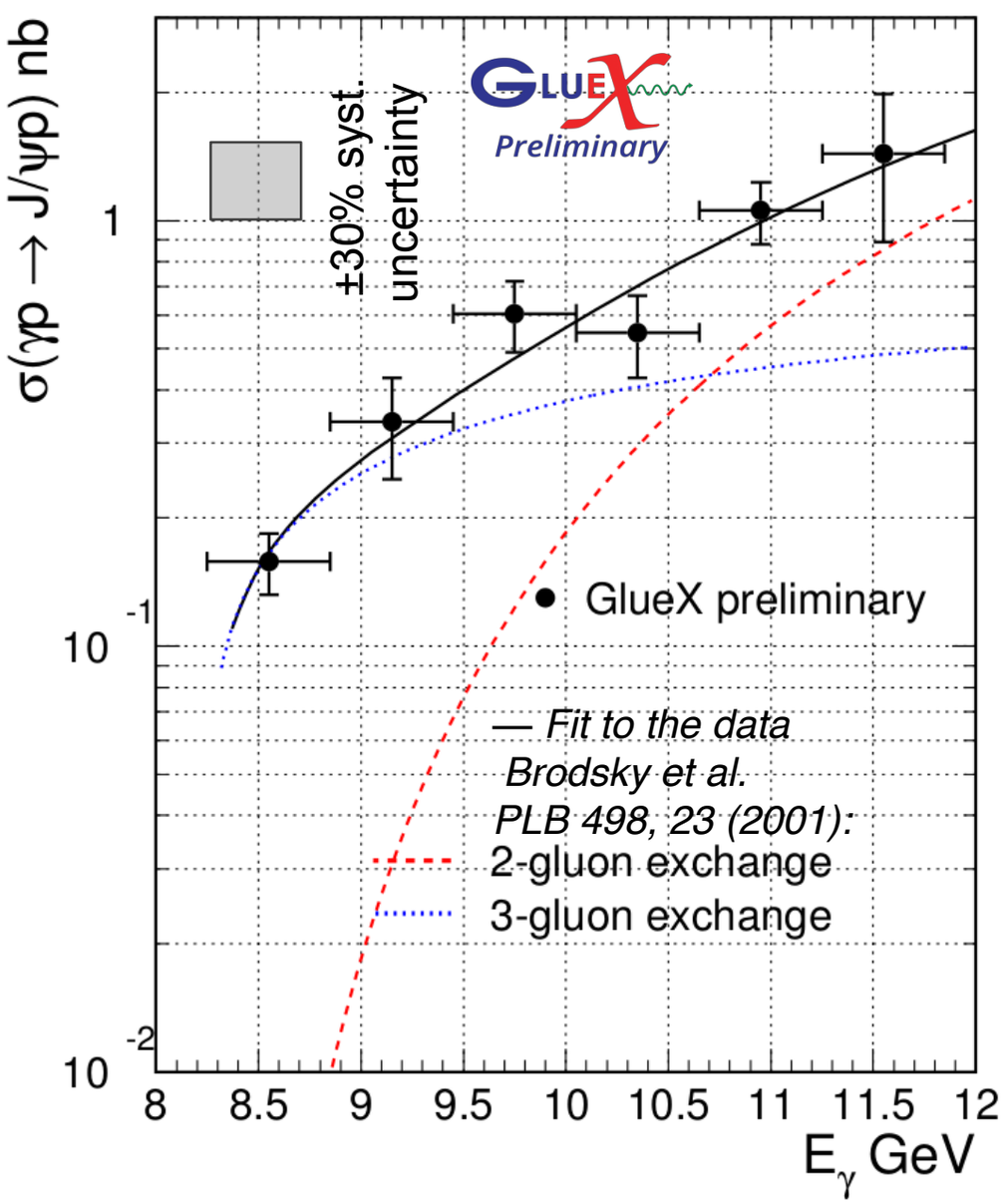
# Threshold J/Ψ production at GlueX



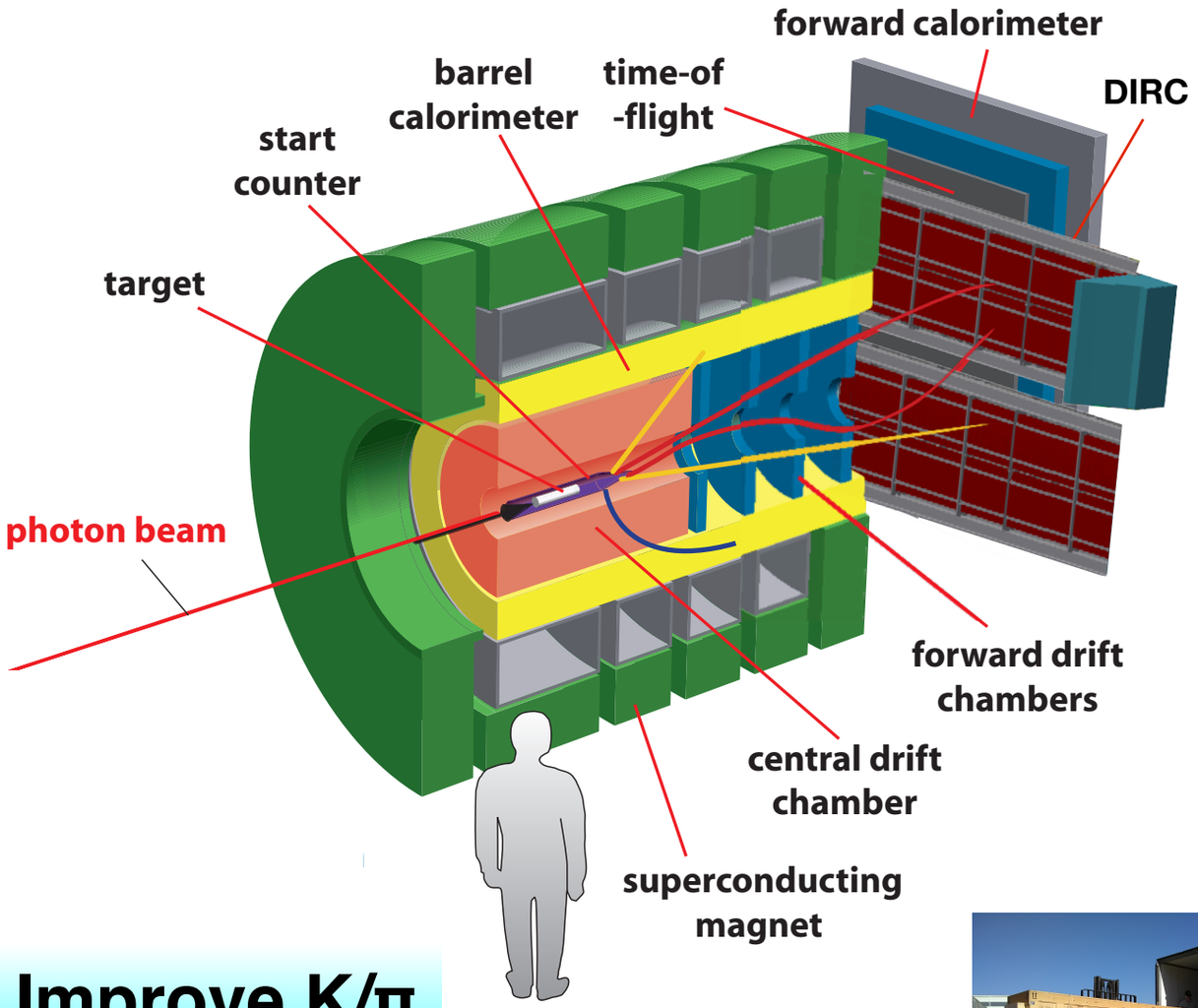

dots – GlueX data

color – prediction from JPAC for $P_c(4450)$ $5/2^+$

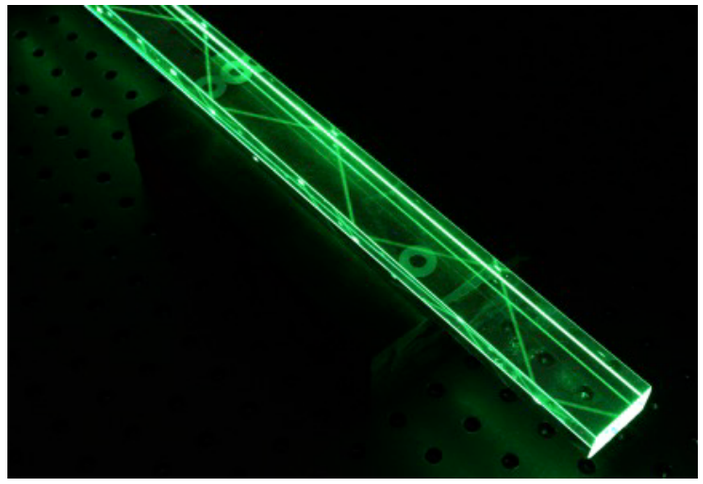
A.Blin, C.Fernandez-Ramirez, A.Jackura, V.Mathieu, V.Mokeev, A.Pilloni, and A.Szczepaniak, PRD 94,034002 (2016).

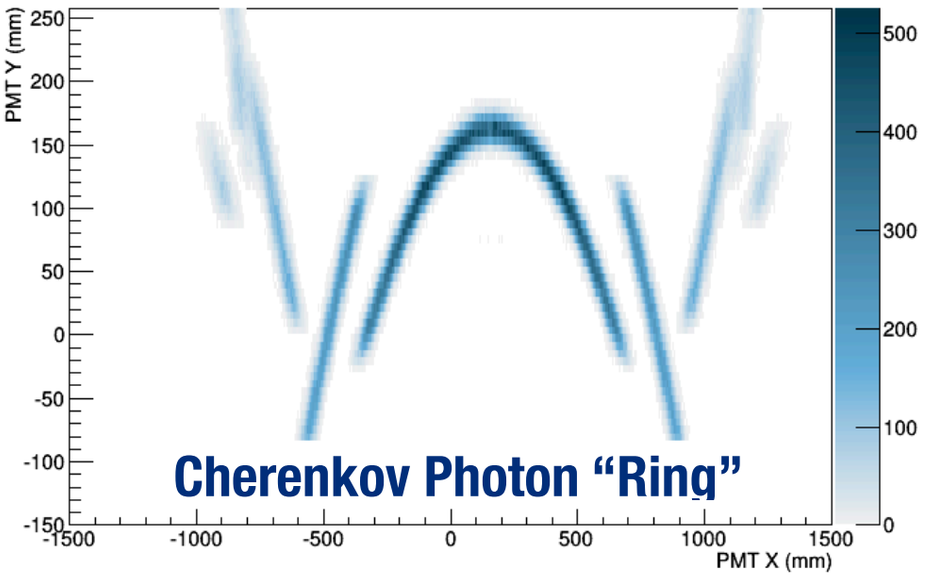


# DIRC upgrade




**Improve K/π separation**






**The BaBar bar boxes have been Delivered safely from SLAC to JLab.**

**First two (of four) the bar boxes have been installed in Hall D.**

**DIRC (D**etection of **I**nternally **R**eflected **C**herenkov light)