Hadron physics at GlueX

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For GlueX Collaboration

中国物理学会高能物理分会第十届全国会员代表大会暨学术年会
上海，上海交通大学
2018. 6. 22

武漢大學 WUHAN UNIVERSITY

Jefferson Lab GLUEX

OUTLINE

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

The Strong Force and QCD

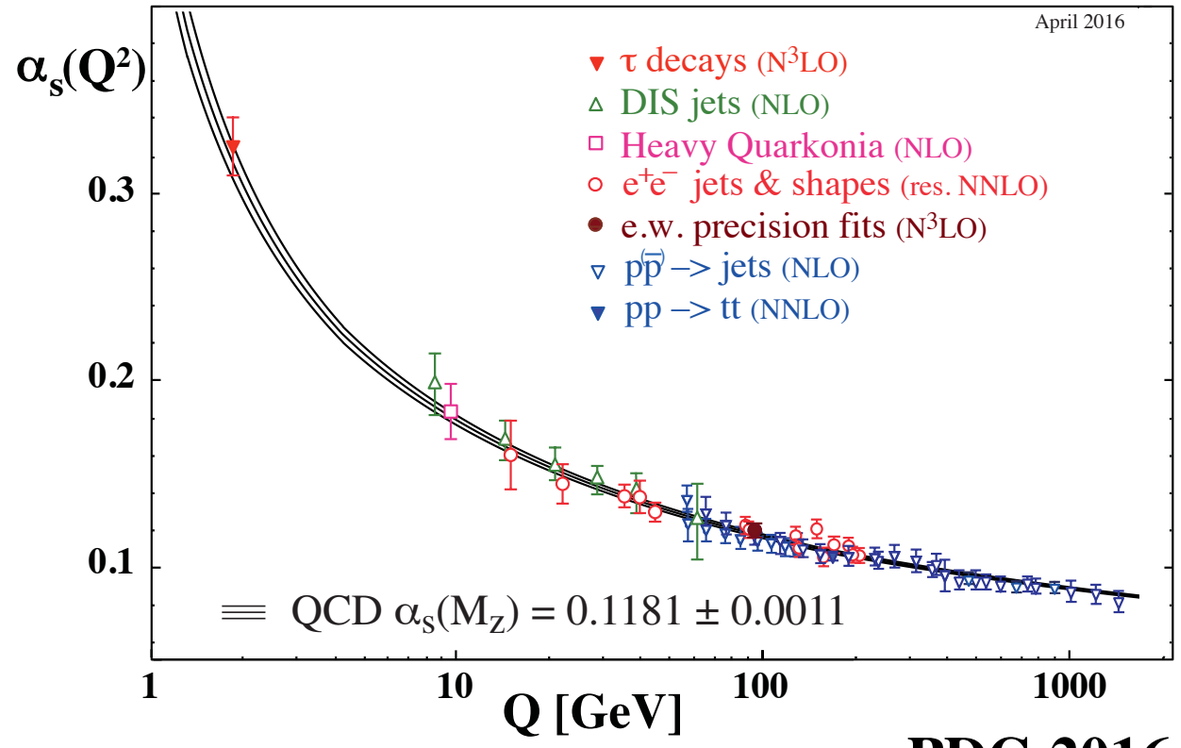
- **Quantum Chromodynamics (QCD) is a gauge theory describing the strong interaction between the coloured particles, quarks and gluons.**

- **High energy: asymptotic freedom, perturbation theory**

- **Low energy: confinement, nonperturbative theory**

- **Nonperturbative methods: QCD-inspired models, effective field theory, lattice, QCD sum rules**

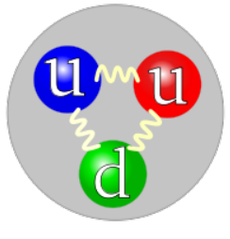
Running coupling

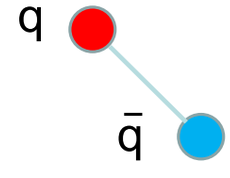


PDG 2016

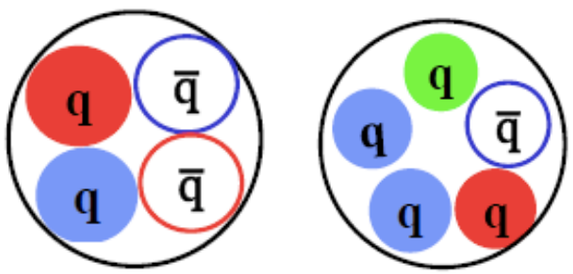
Strong coupling constant runs with momentum scale Q

Ordinary hadrons: mesons and baryons

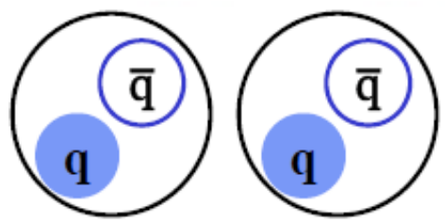




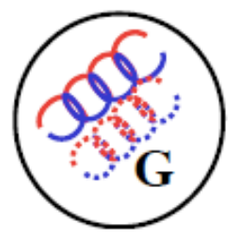
QCD Exotic States



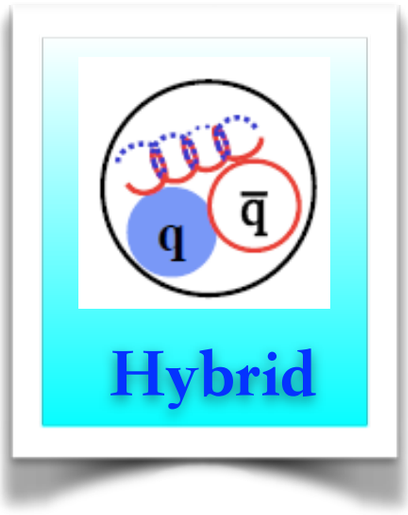
Multi-quark states



Hadron molecular states



GlueBalls



Hybrid

Phys. Letts. 8 (1964) 214

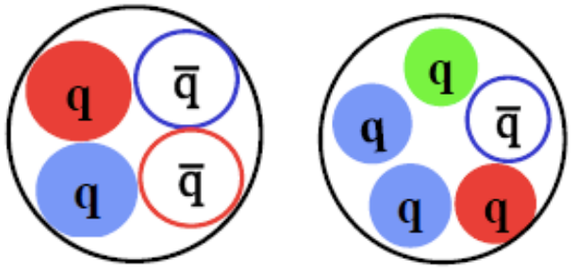
- **In 1964, Gell-Mann's original paper alludes to the possibility of exotic hadrons**
- **Exotic hadrons have structures that are more complex**
- **A number of exotic states candidates are found in recent years**

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.

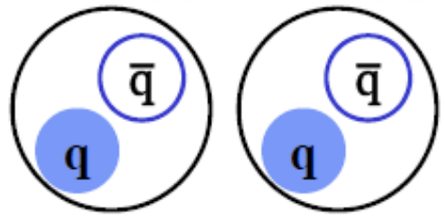
Z. Phys. C 22 (1984) 171

The exotic states can be strong proof for the existence of gluon predicted by QCD as the strong interaction mediator.

QCD Exotic States



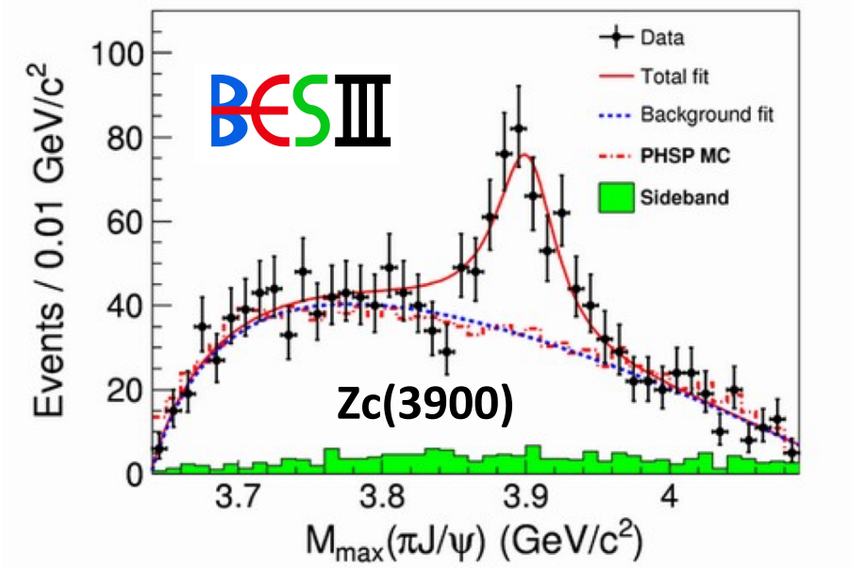
Multi-quark states

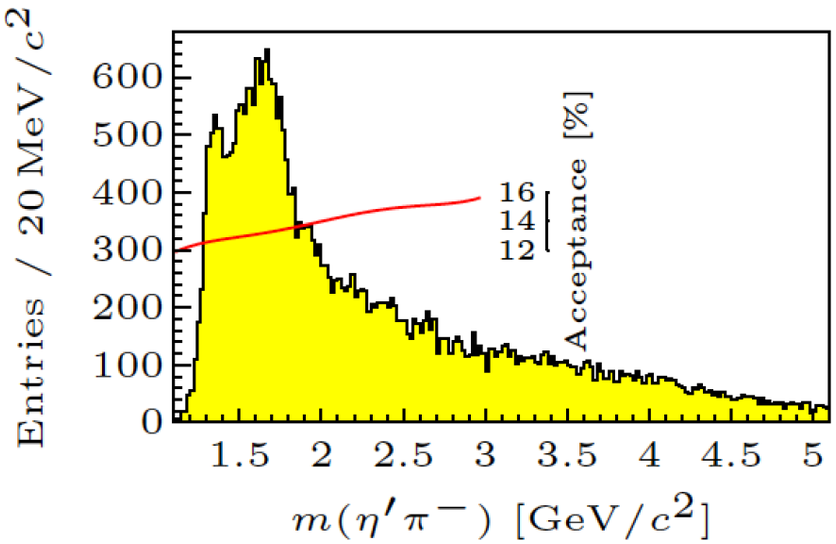


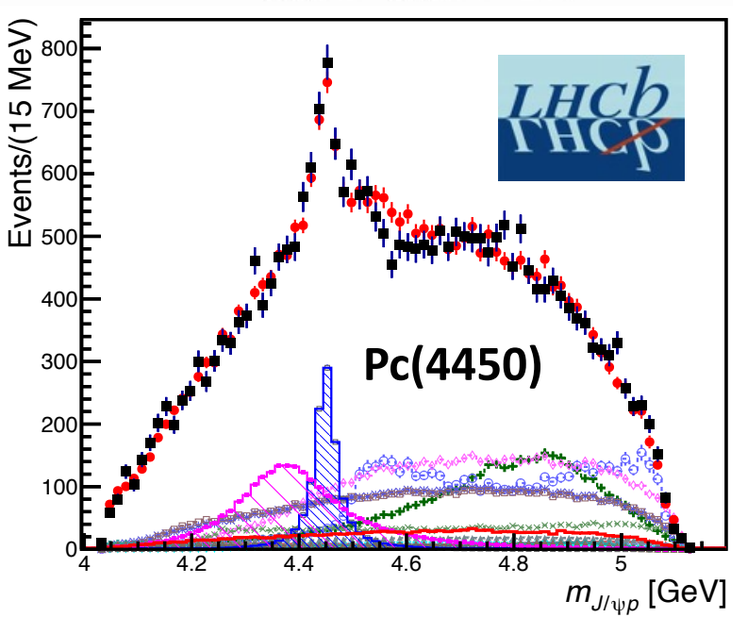
Hadron molecular states

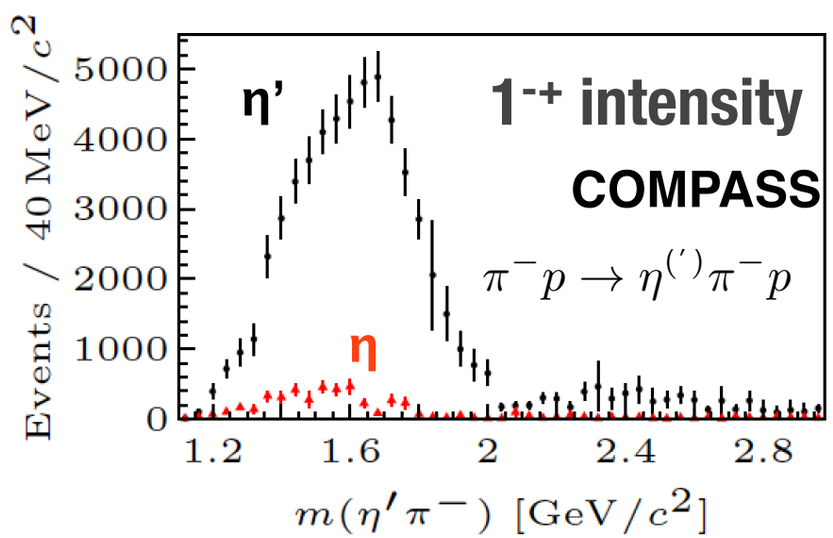
GlueBalls

Hybrid





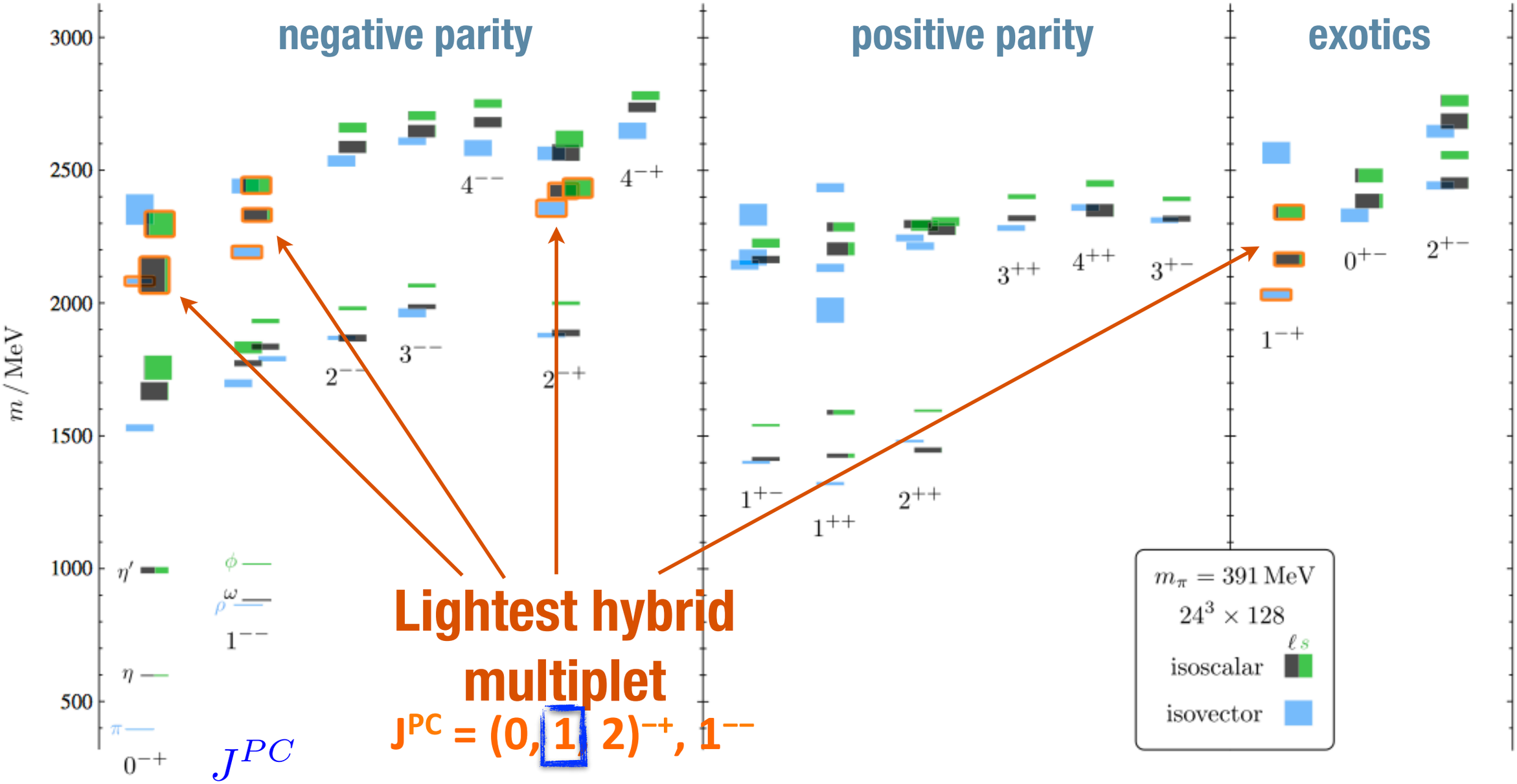




Despite extensive experimental searches, no unambiguous candidates for any of these exotic configurations have yet to be identified

PRL 110, 252001 (2013)
PRL 115, 072001 (2015)
PLB 740, 303 (2015)

LQCD Meson Spectrum for Light Quarks



Lightest hybrid multiplet

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

J^{PC}

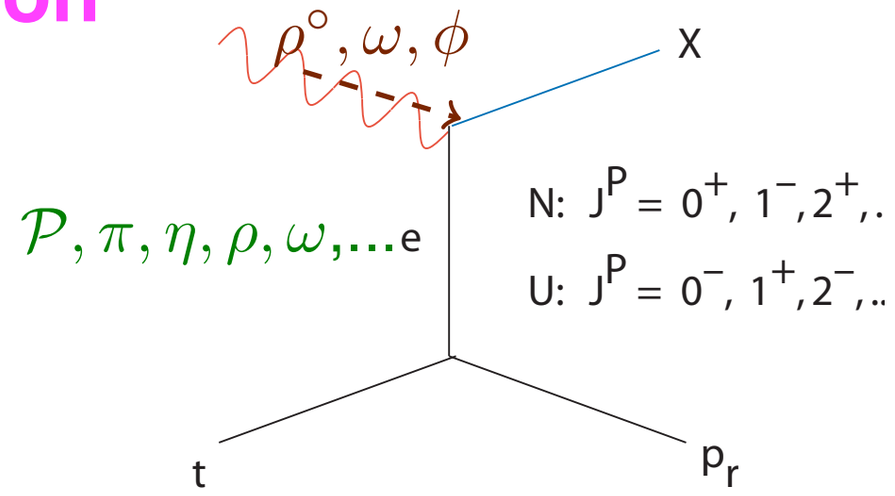
Dudek Phys.Rev. D84 (2011) 074023

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°, h, h'
π°	0^{-+}	2^{+-}	b_2°, h_2, h_2'
$\pi^\pm$	0^{-+}	1^{-+}	$\pi_1^\pm$
ω	1^{--}	1^{-+}	π_1, η_1, η_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

Hall D: The new experiment hall at JLab

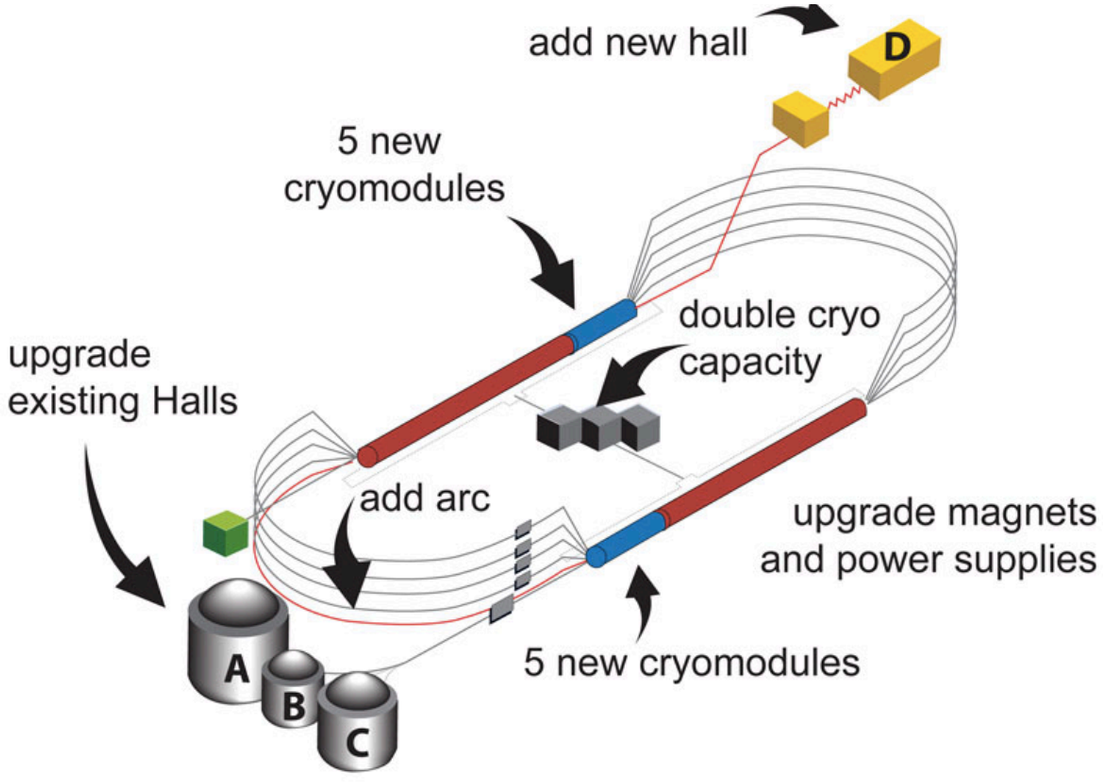
GlueX: The spectrometer in the Hall D

The long-term aim:

Understand quark-gluon interactions

search for exotic hybrid mesons

- 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 subsequently with the new DIRC detector.
- Ten times more data and higher K-π separation are expected.



The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

Here are the recommendations of the 2015 Long Range Plan.

RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

- *With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model must be realized.*

GlueX Collaboration

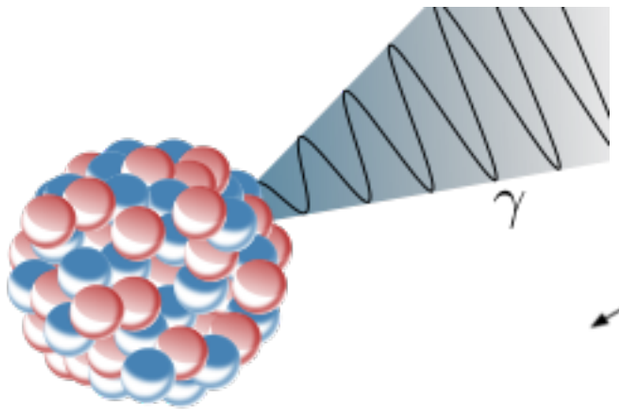
http://portal.gluex.org/GlueX/Home.html ~120 members from 28 institutions of 9 counties

Wuhan University and IHEP became the GlueX members from Asia;

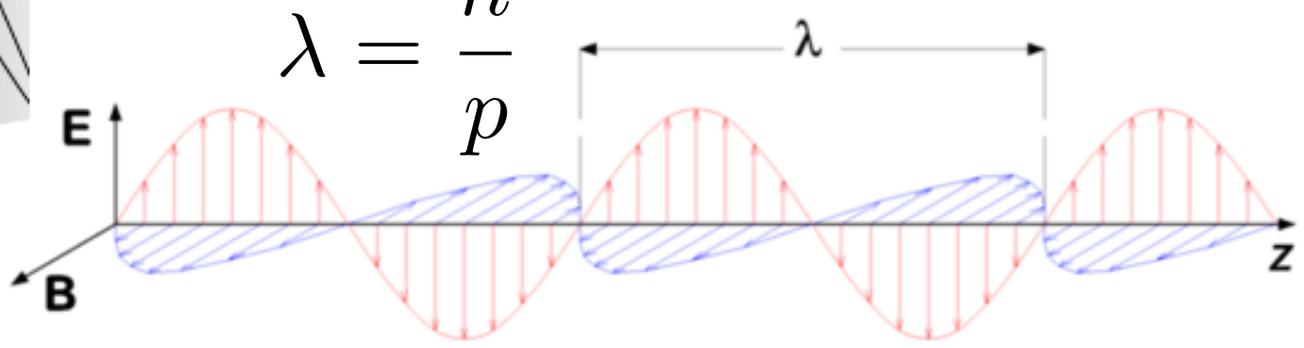
2017年8月，在北京召开GlueX/BESIII联合会议

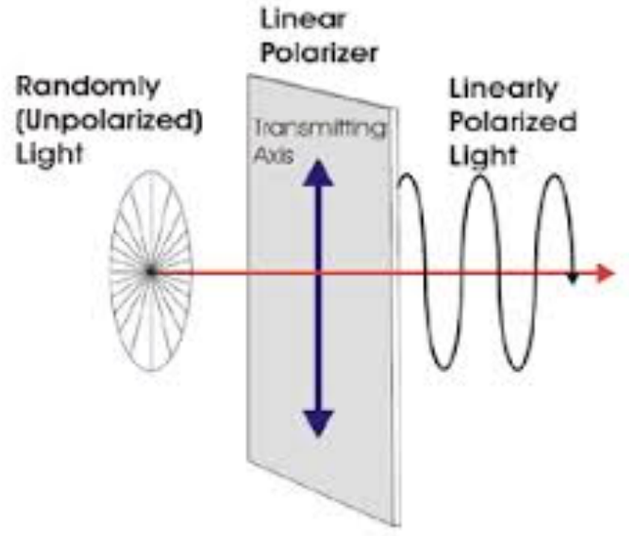
GlueX/BESIII: A Workshop on Common Topics

Linearly polarised photon beam

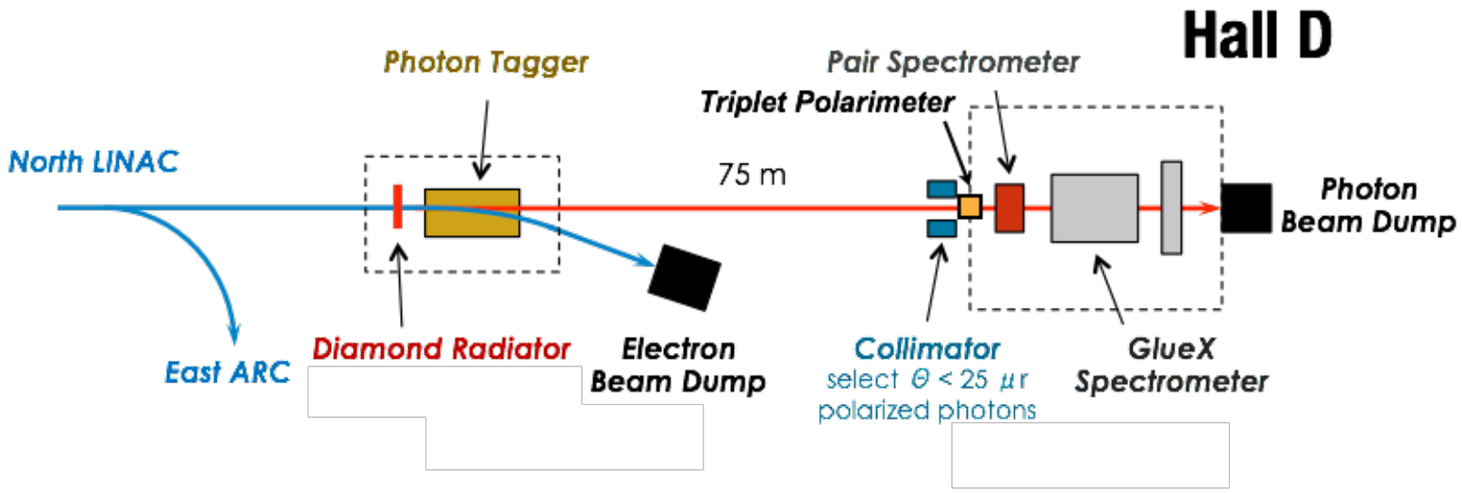


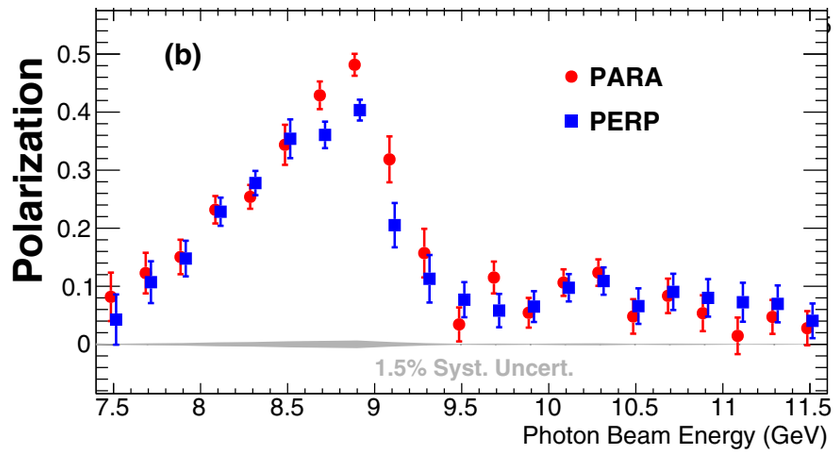
$$\lambda = \frac{h}{p}$$





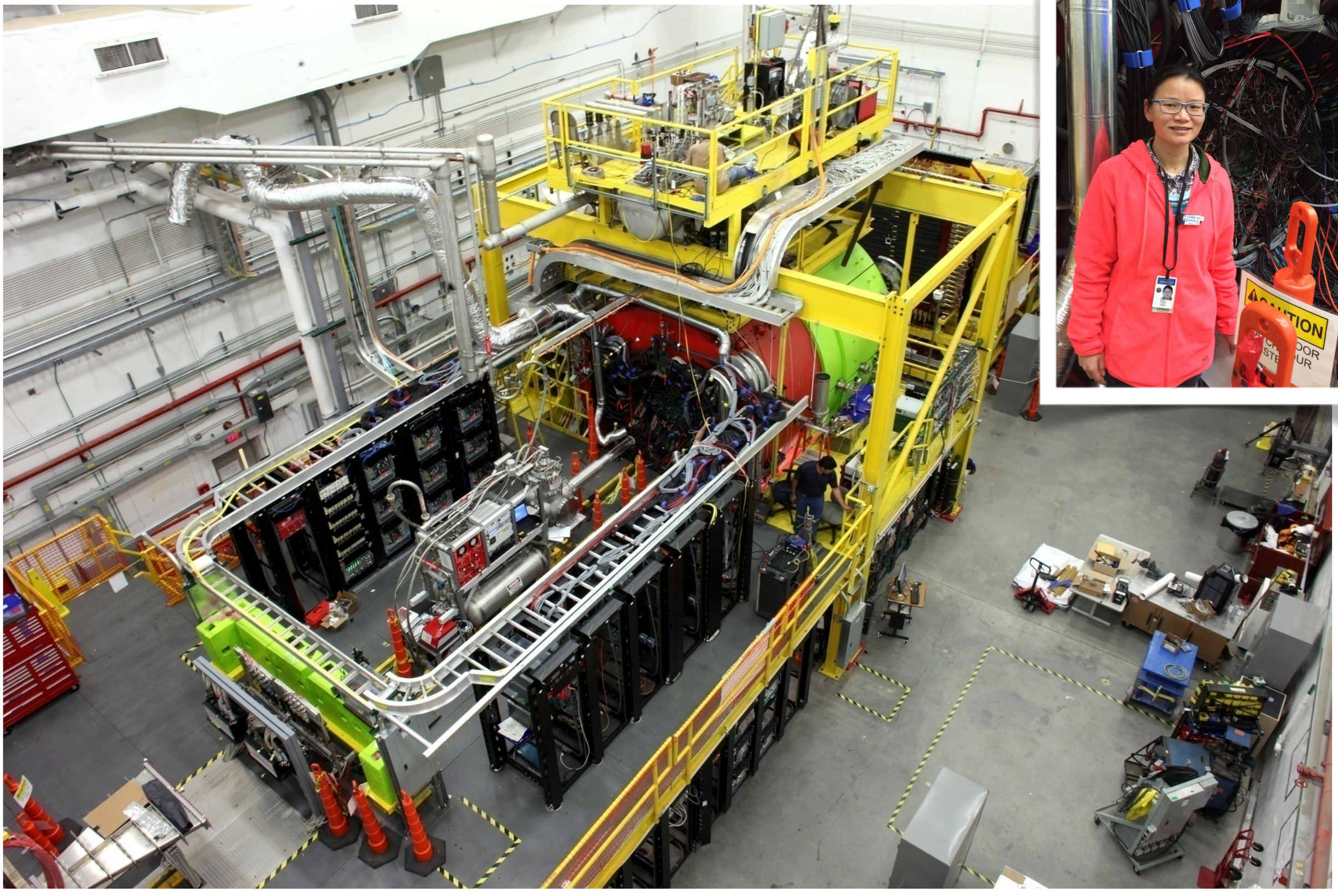
Photon flux 10-100 MHz in the peak





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

GlueX Detector

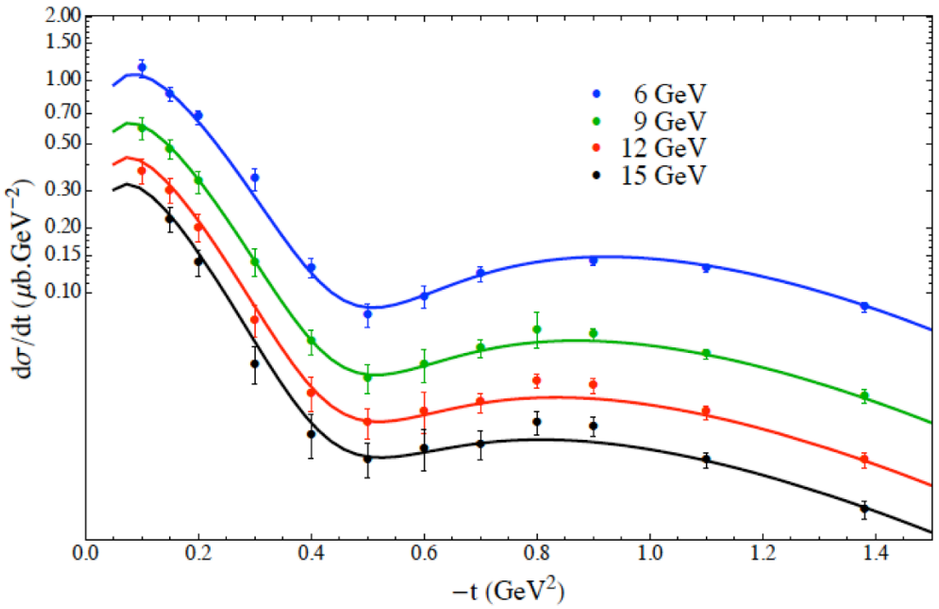


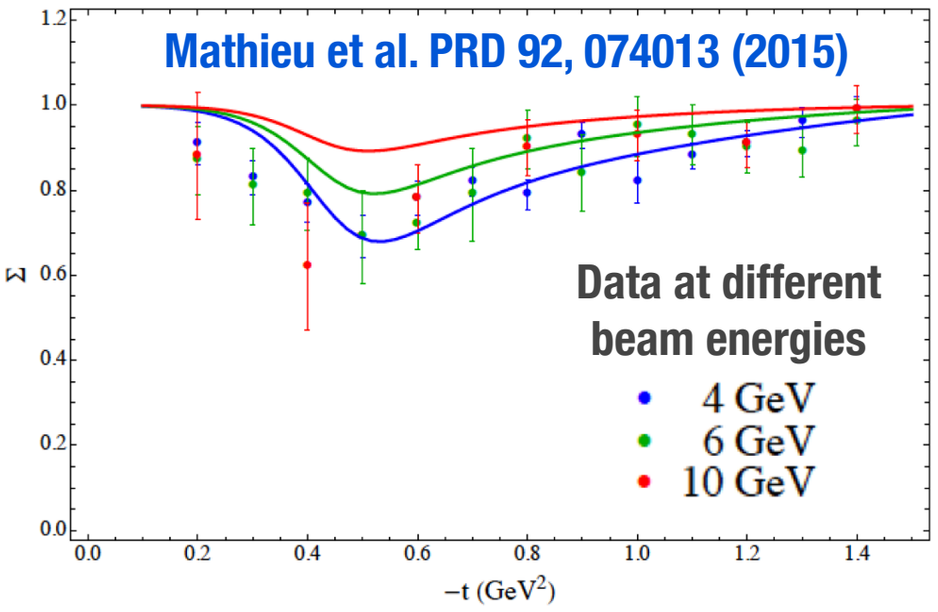
Physics at GlueX

- **Early Physics:**
  - **Beam asymmetry and polarization transfer measurements in the meson/bayon photoproduction**
- **Long-term Physics:**
  - **Search for exotic hybrids (PWA analysis)**
  - **Spin-density matrix elements to understand production mechanisms.**
  - **Cross section measurements**
  - **Generalized Parton Distributions measurement from time-like Compton scattering**

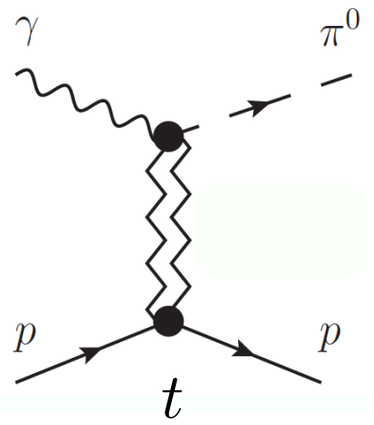
Psuedoscalar mesons π^0/η Photoproduction

JPAC Regge Model





SLAC: PRD 4, 1937 (1971)



Exchange J^{PC}

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

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

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

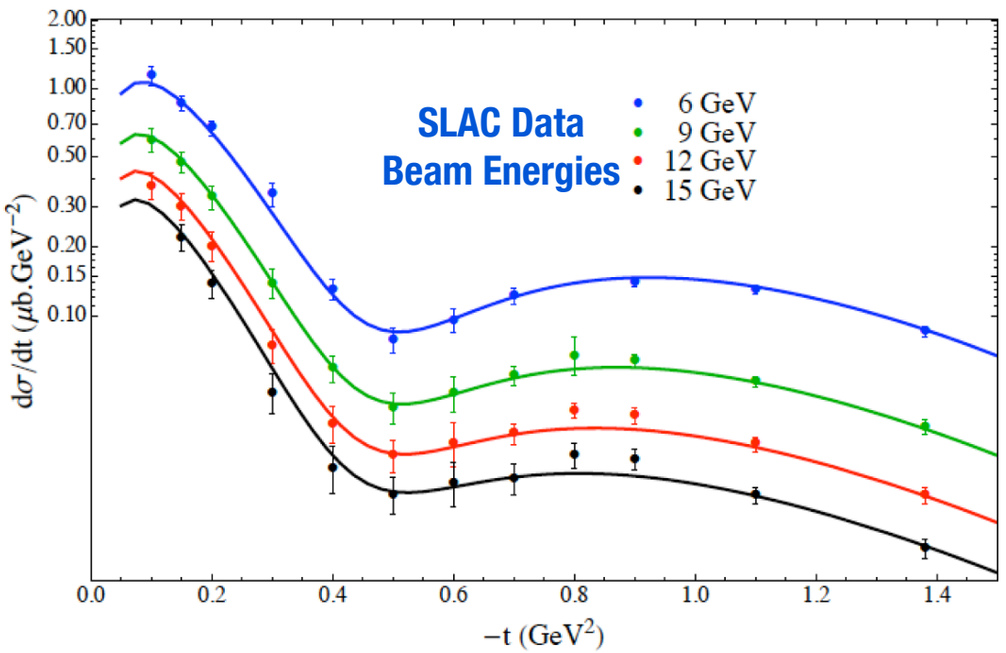
$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$

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

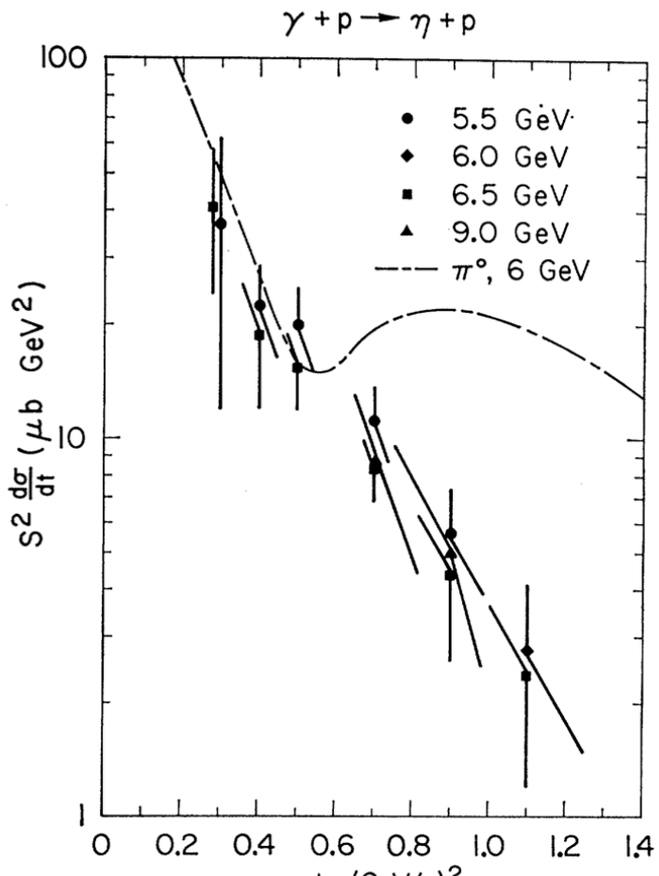
There are no previous measurements of the Σ asymmetry for $\gamma p \to \eta p$ with $E_\gamma > 3$ GeV

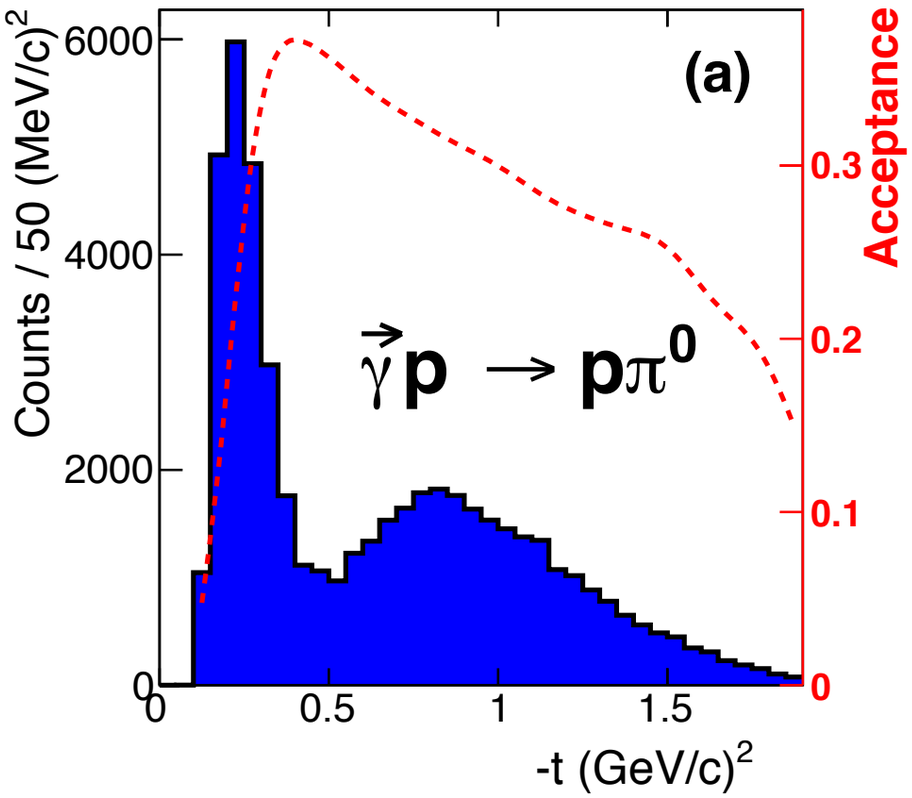
Final -t distributions

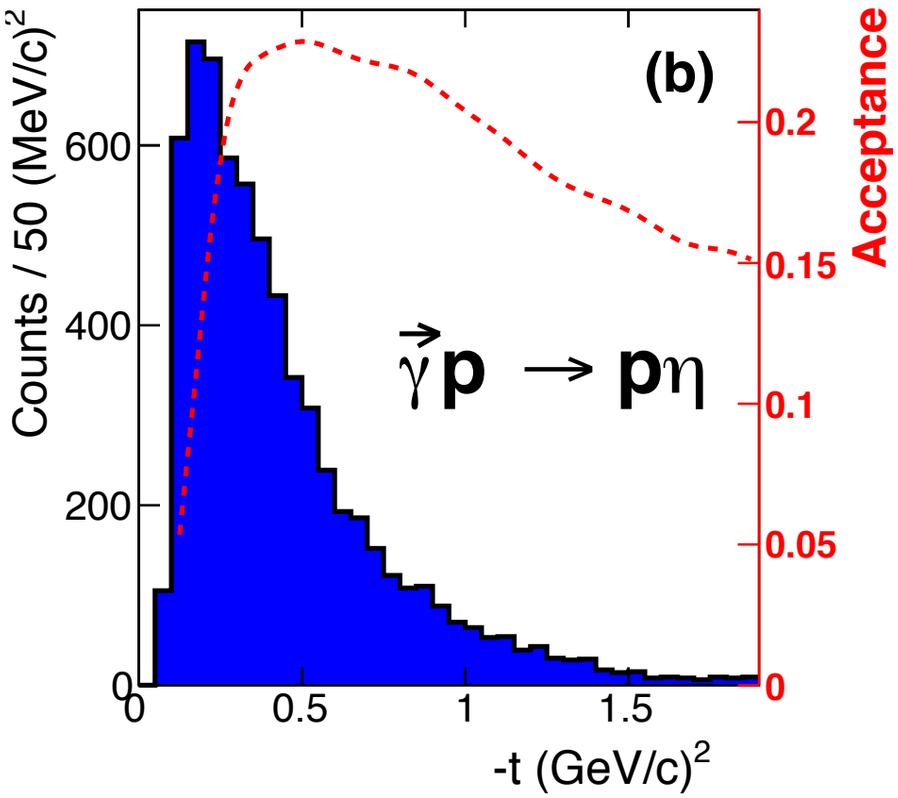
V. Mathieu (JPAC): PRD 92, 074013



SLAC: PRD 1, 27 (1970)





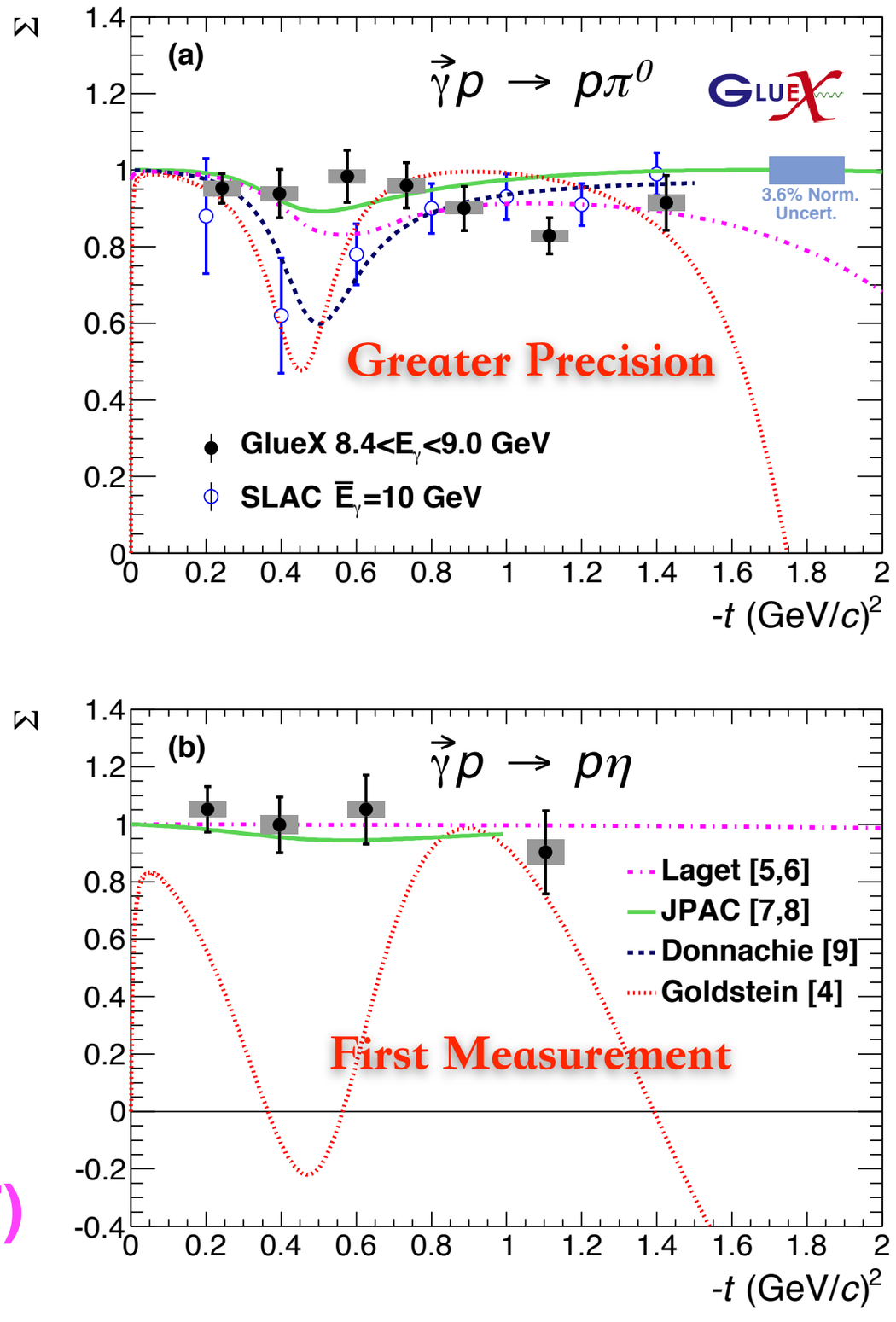


PHYS REV C 95, 042201(R) (2017)

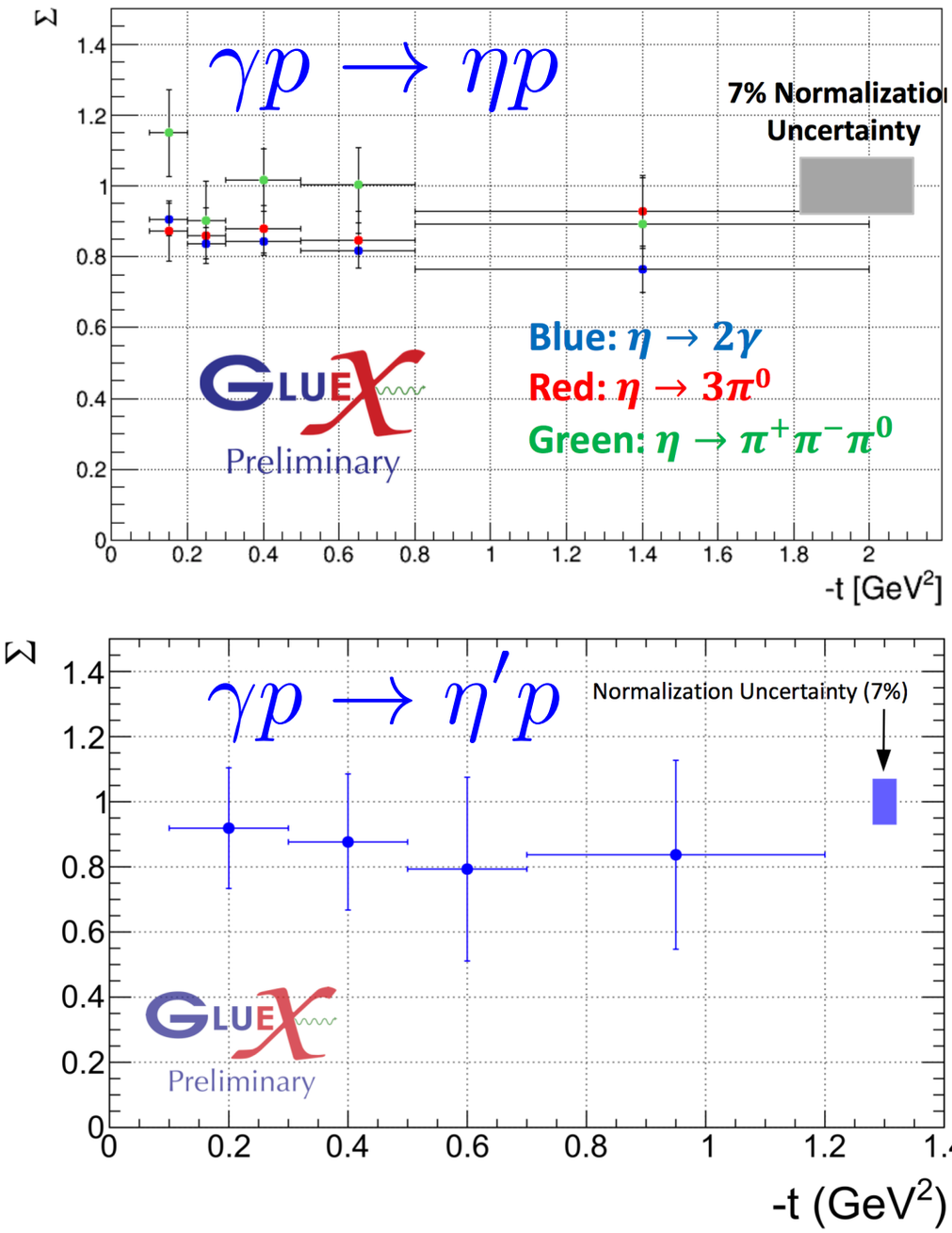
Beam Asymmetry: Results

- **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**

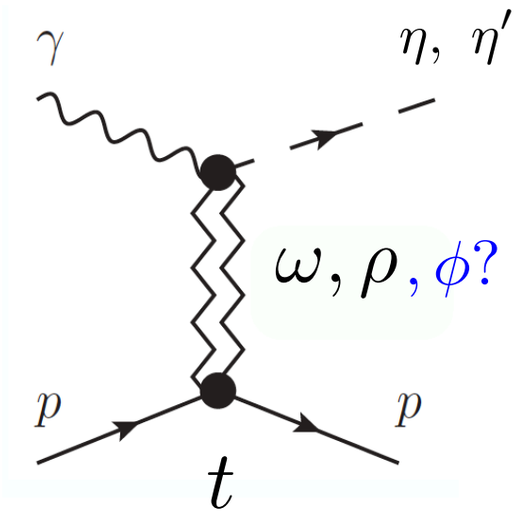
PHYS REV C 95, 042201(R) (2017)



Psuedoscalar mesons η/η′ Photoproduction



Statistical uncertainties only



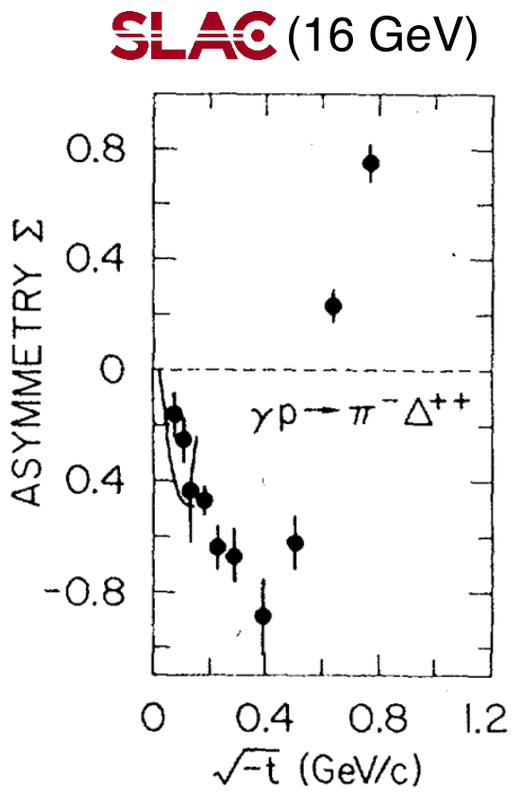
Sensitive to hidden strangeness components

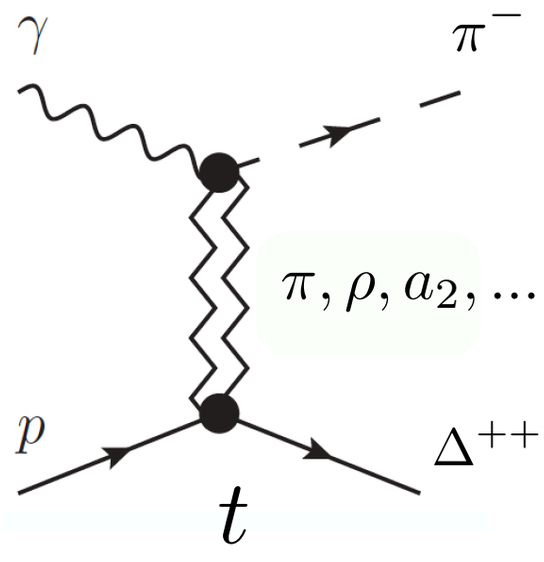
JPAC: PLB 774 (2017) 362

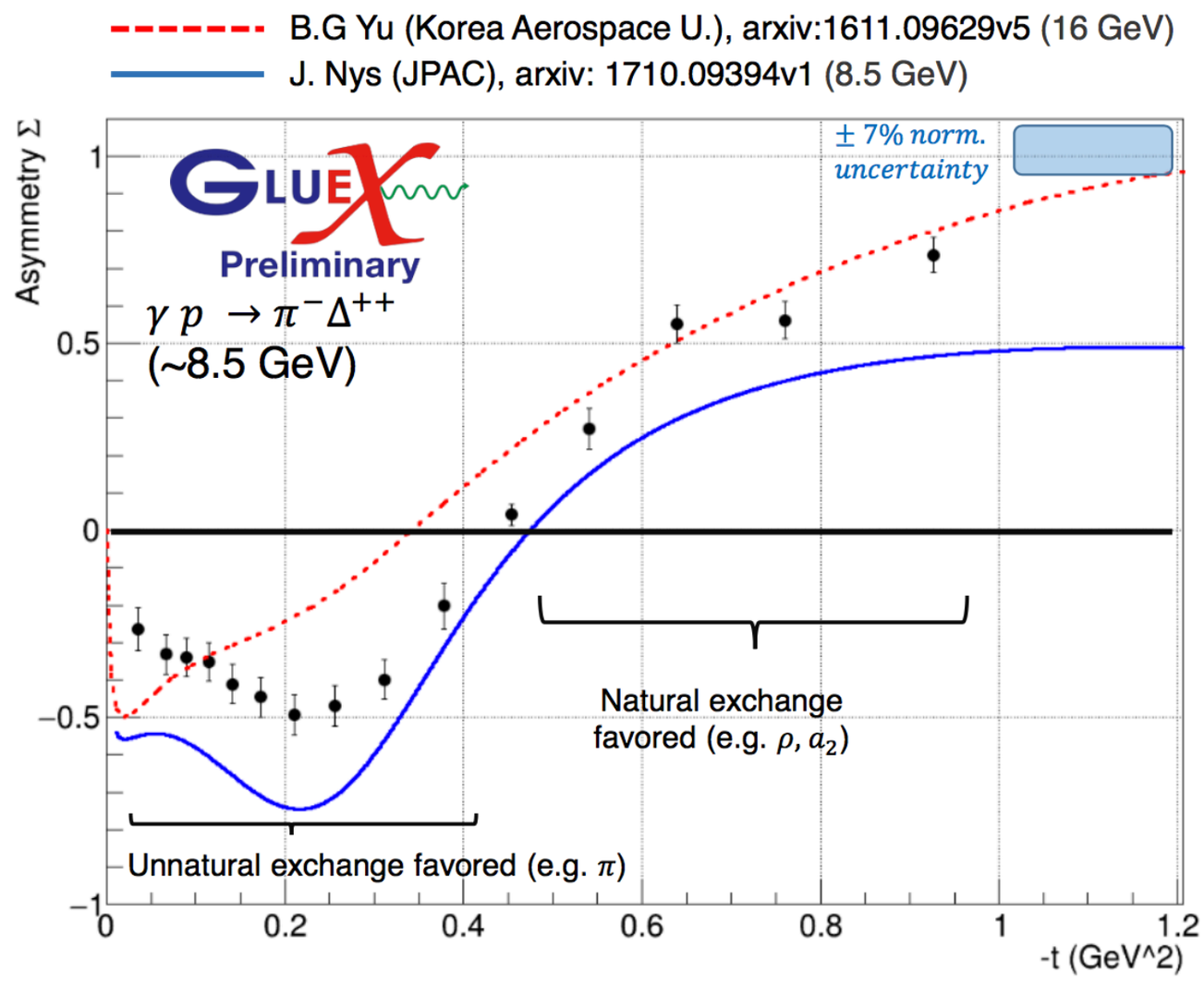
- Additional decay modes are studied using 2017 data
- Consistent with vector exchange dominance
- The ratio of the asymmetries in η′ and η production is estimated to be close to unity as predicted by JPAC

Charged Psuedoscalar Meson Photoproduction

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

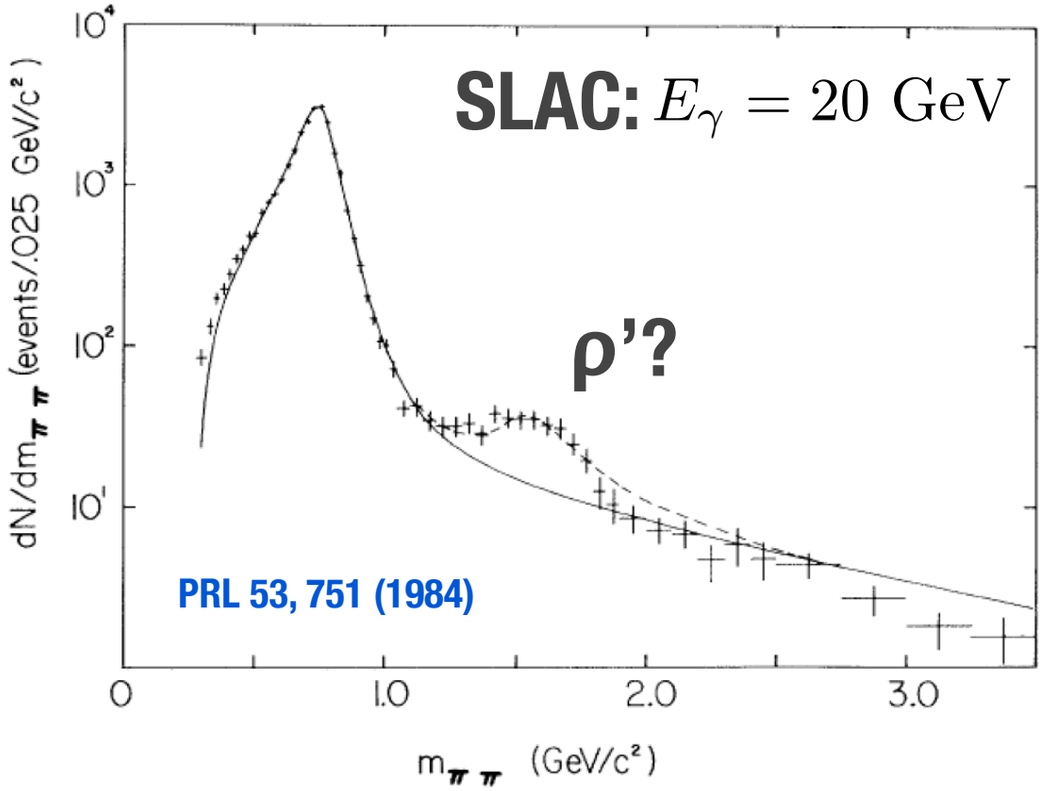


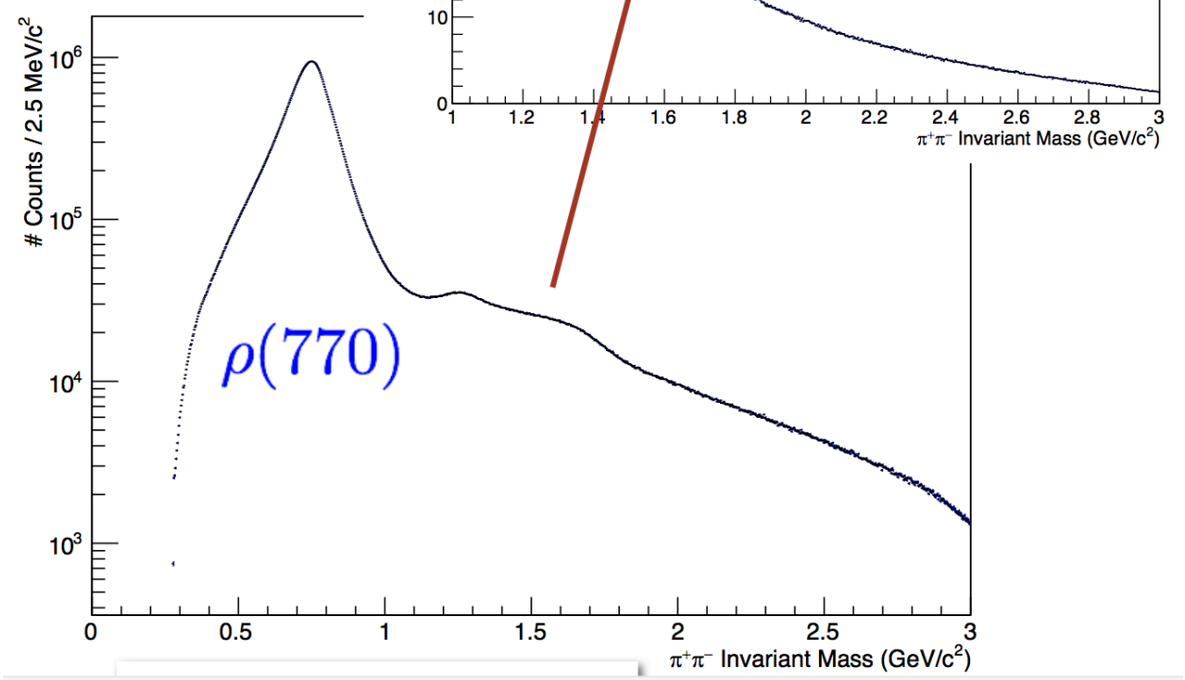




- **More complicated t-dependance**

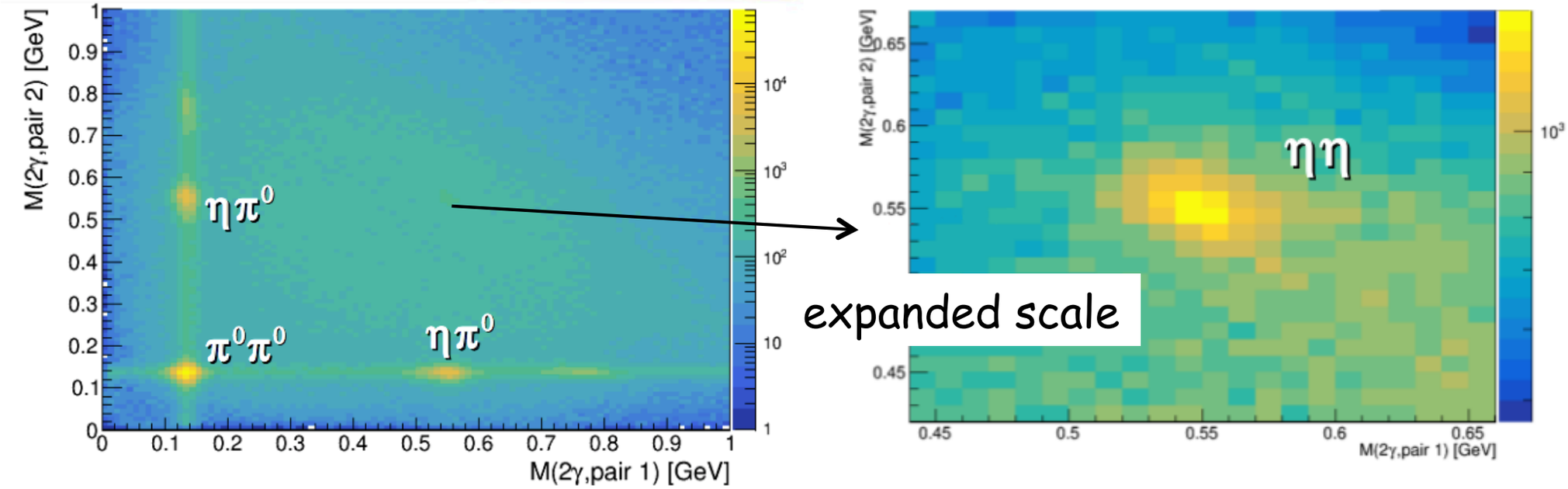
Early spectroscopy opportunities for $\gamma p \to \pi^+\pi^- p$

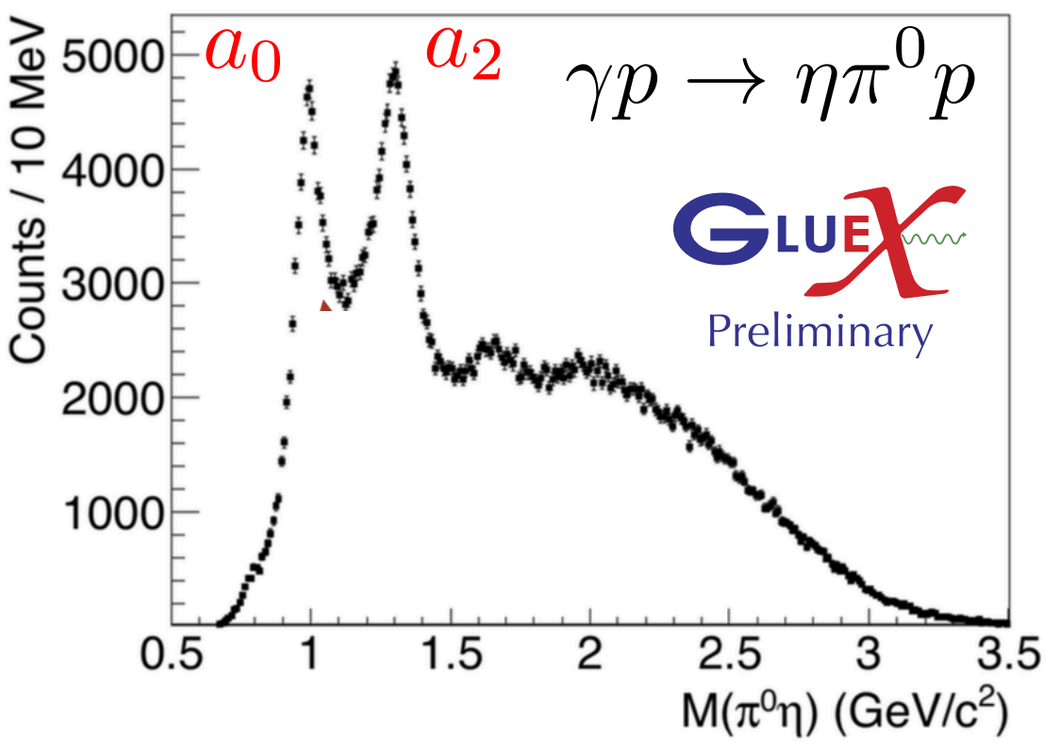


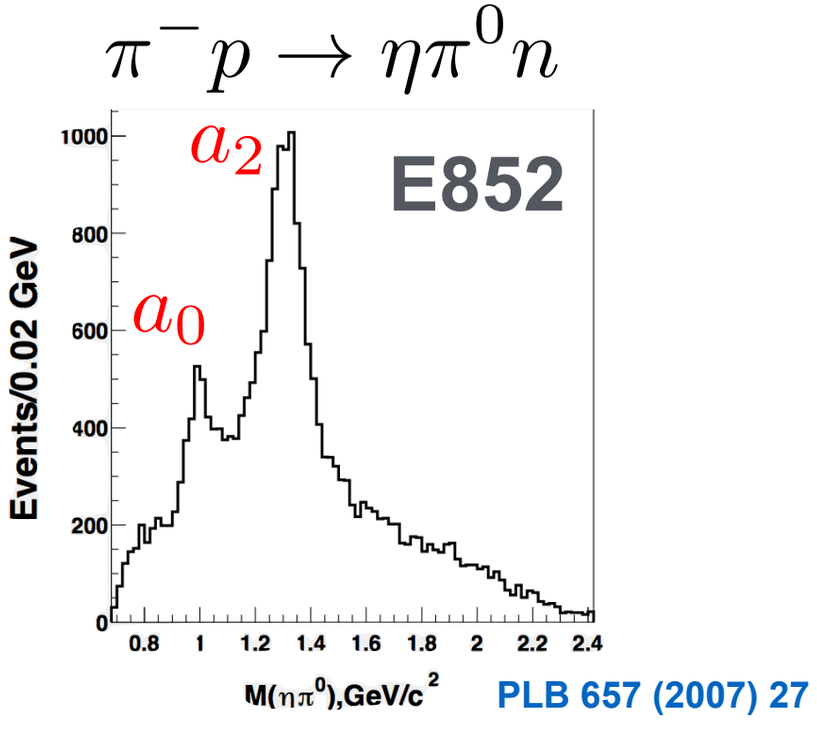


- **The enhancement around 1.5 GeV is consistent with previous SLAC data**
- ***K^+K^-* spectroscopy is also under way**

Four photon final states scalar and tensor mesons Photoproduction



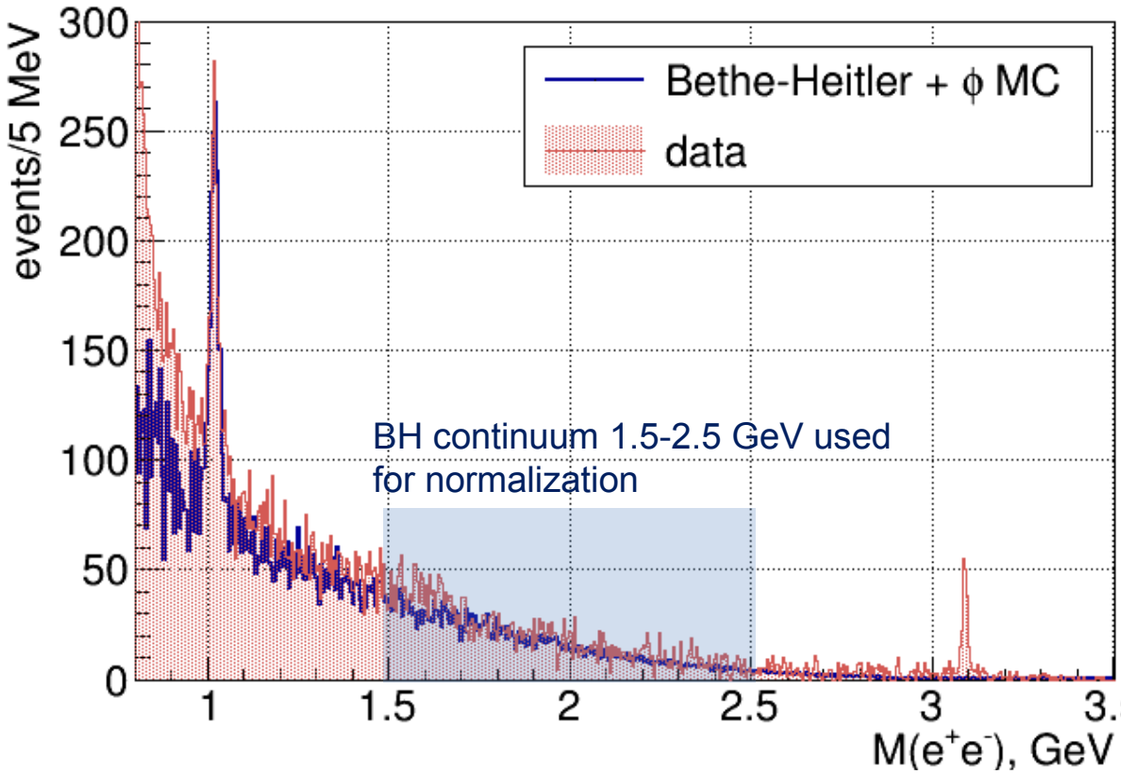


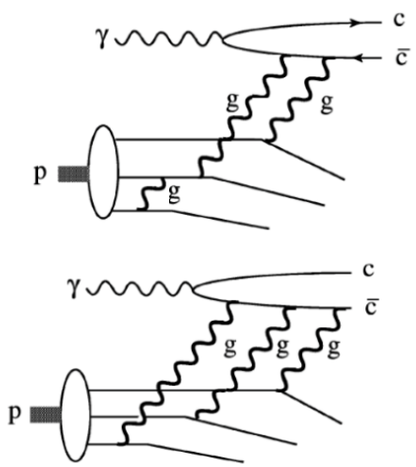


PLB 657 (2007) 27

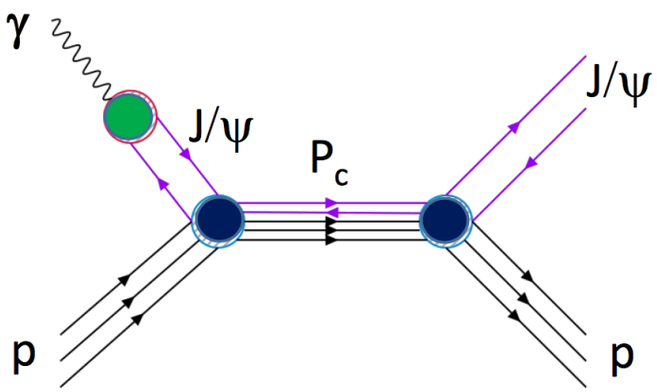
J/Ψ Photoproduction near threshold

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





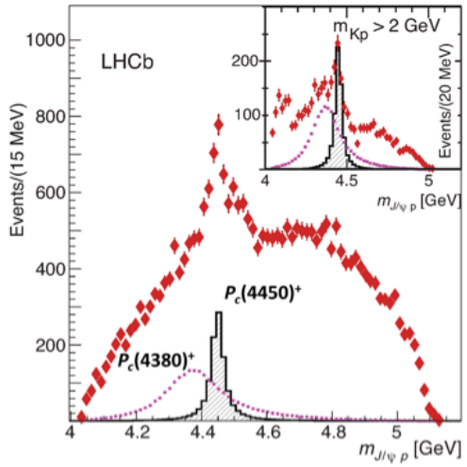
PLB 498, 23 (2001)



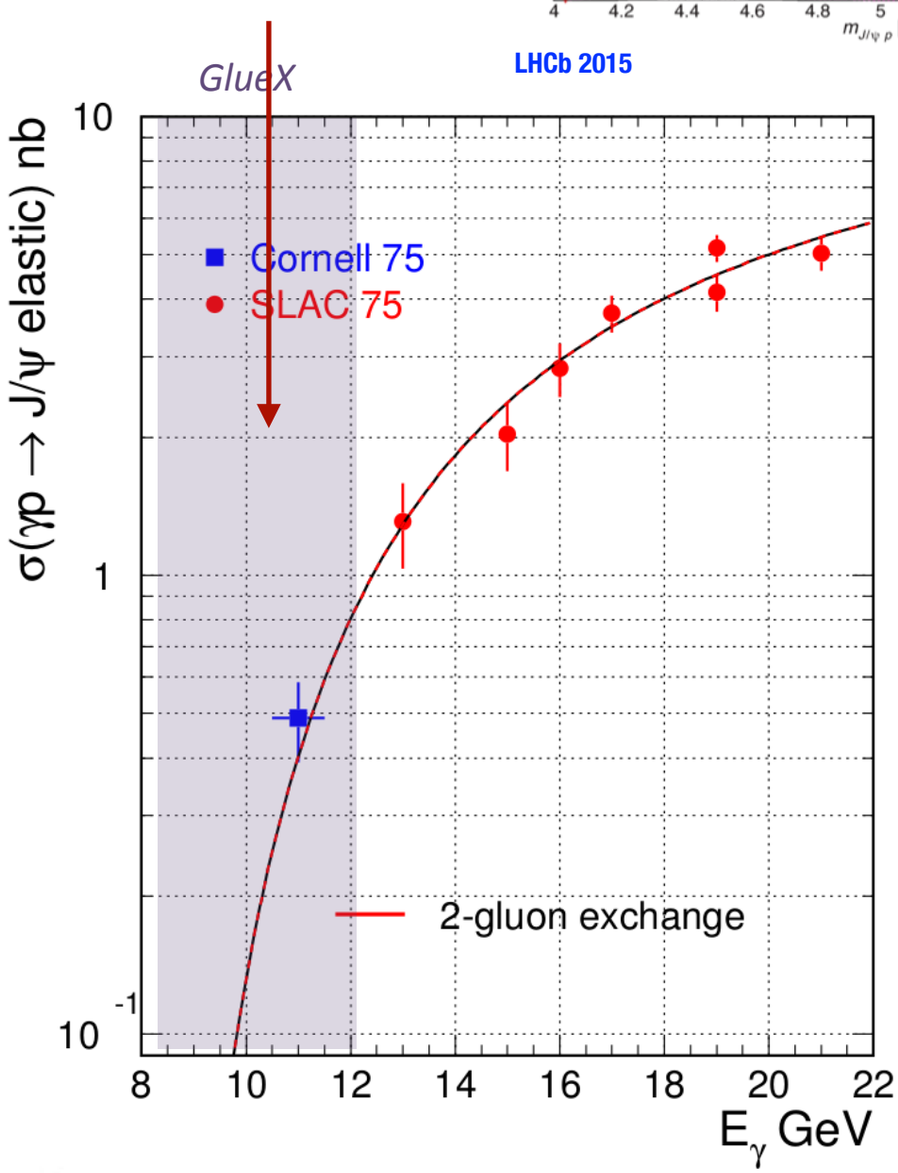
PRD 92,034022 (2015)
PRD 92.031502 (2015)
PLB 752, 329 (2016)
PRD 94,034002 (2016)

PRL 115, 072001 (2015)

LHCb
Pentaquark



LHCb 2015



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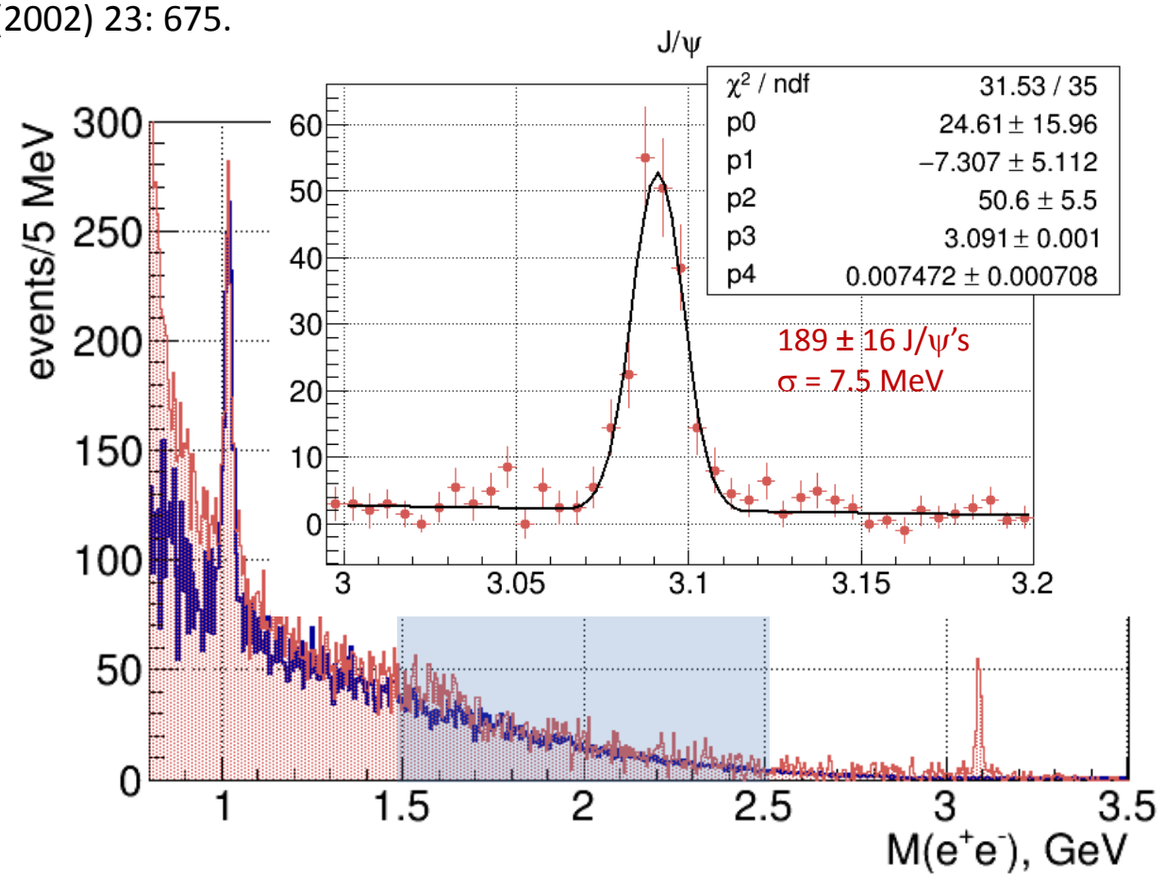
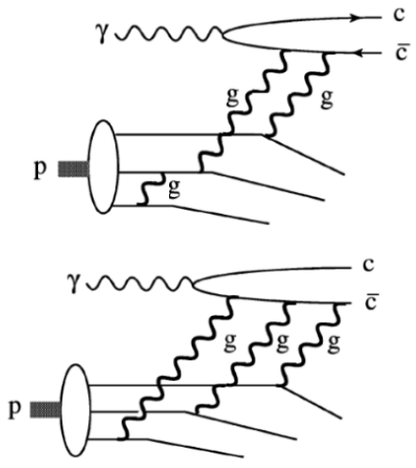
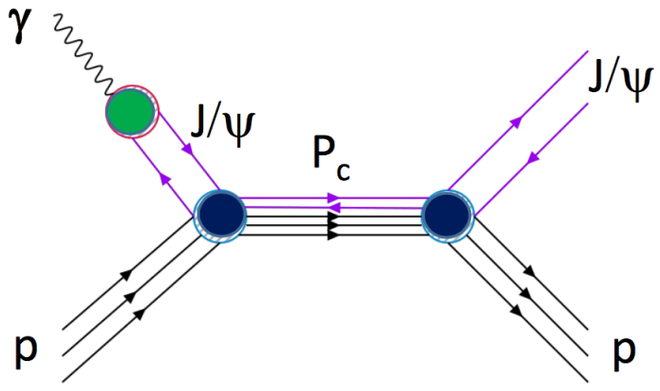
- Berger, E., Diehl, M. & Pire, B. Eur. Phys. J. C (2002) 23: 675.





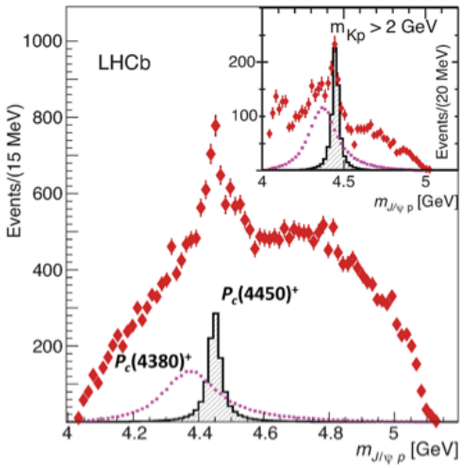
PLB 498, 23 (2001)



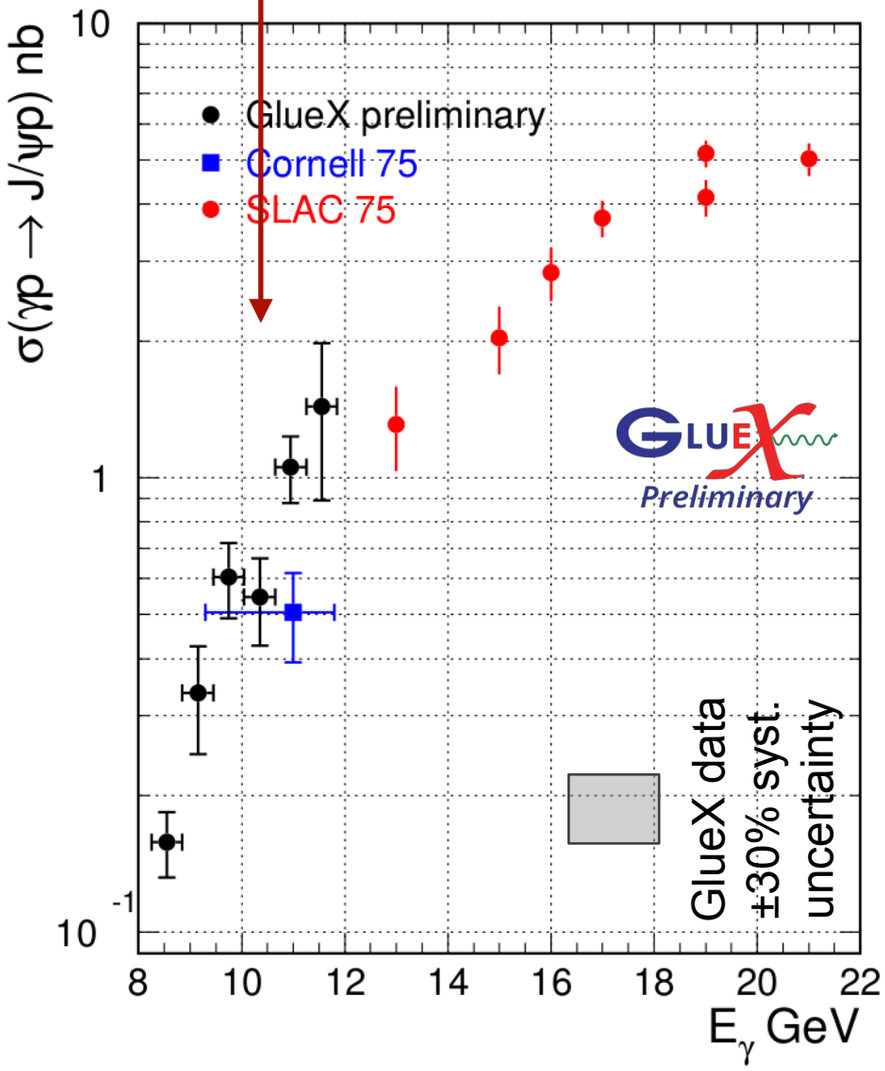
PRD 92,034022 (2015)
PRD 92.031502 (2015)
PLB 752, 329 (2016)
PRD 94,034002 (2016)

PRL 115, 072001 (2015)

LHCb
Pentaquark



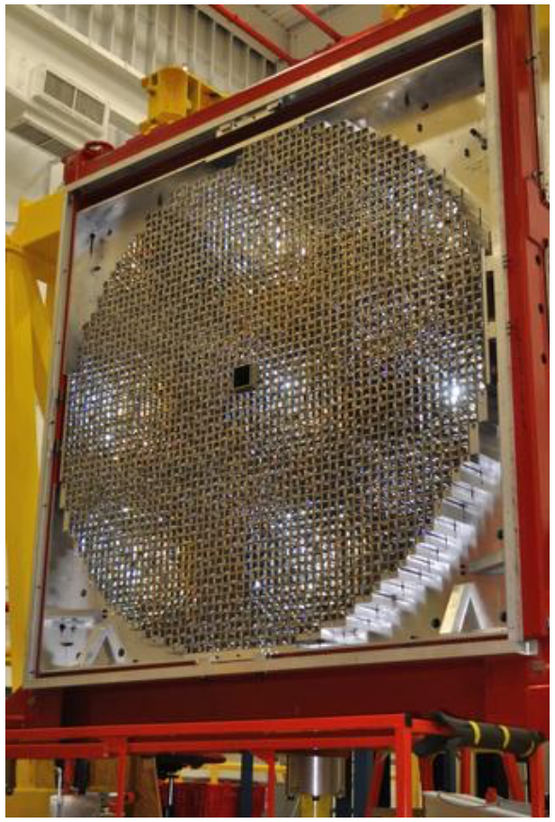
LHCb 2015

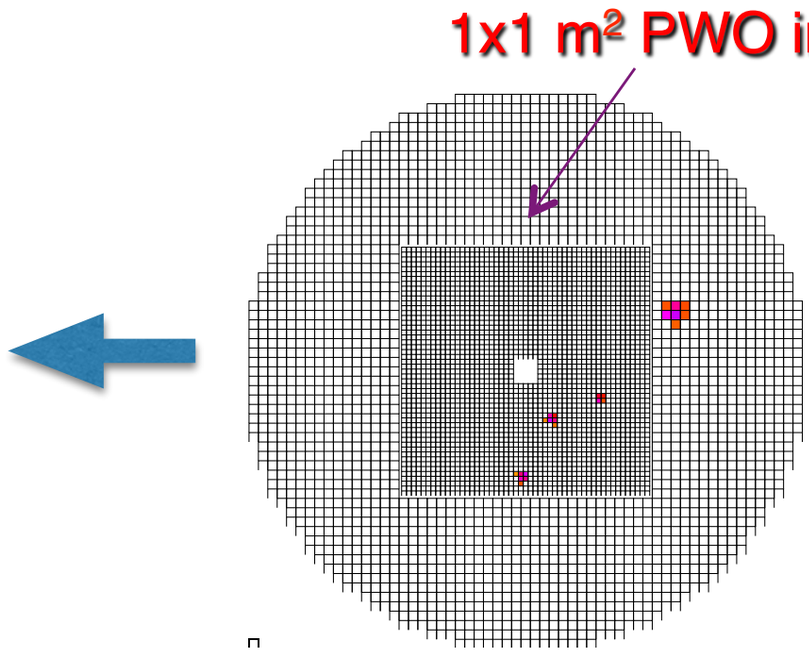


JEF experiment

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

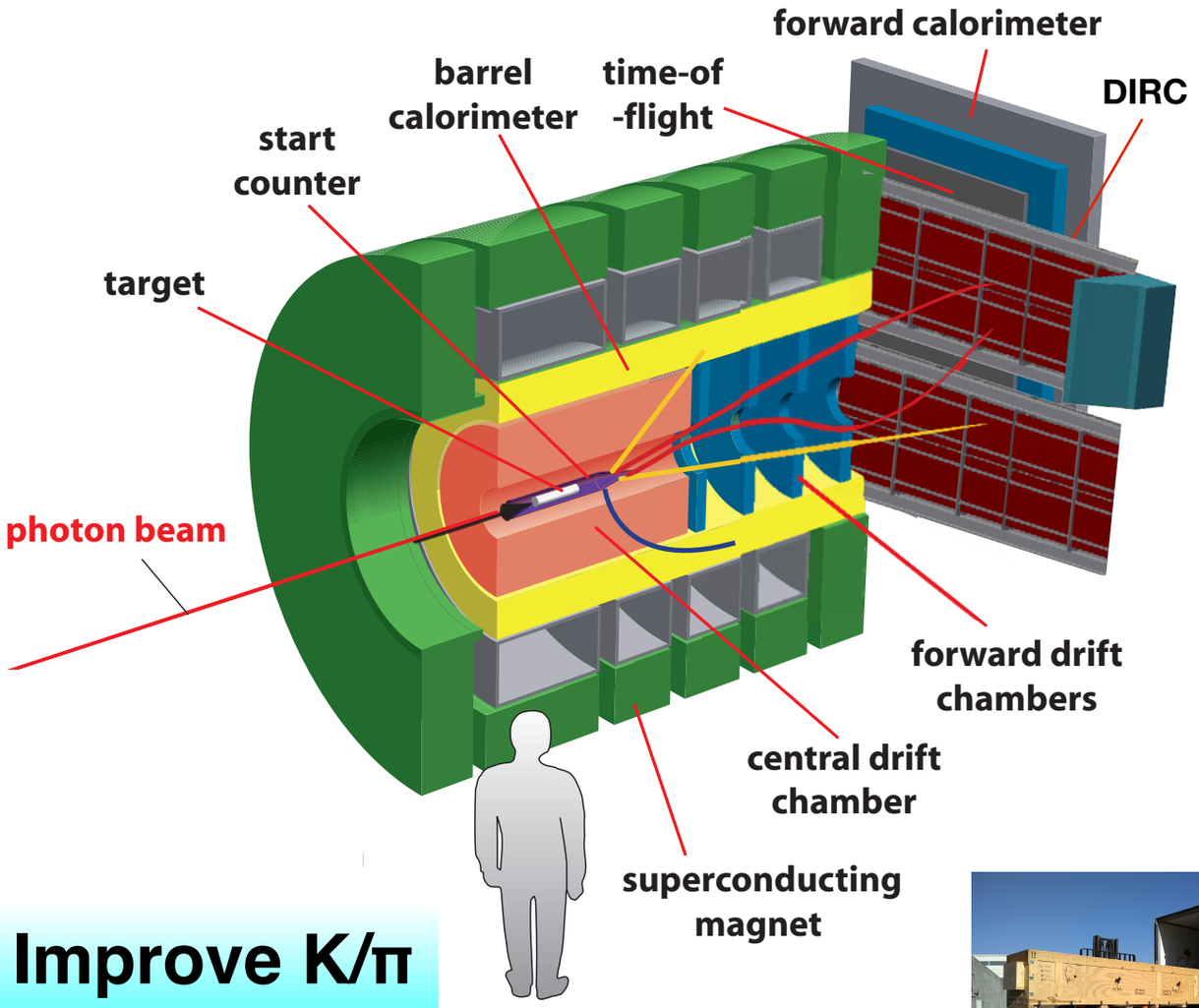
PWO crystals may be bought from Shanghai Institute of Ceramics

QC of the PWO crystals can be performed in China

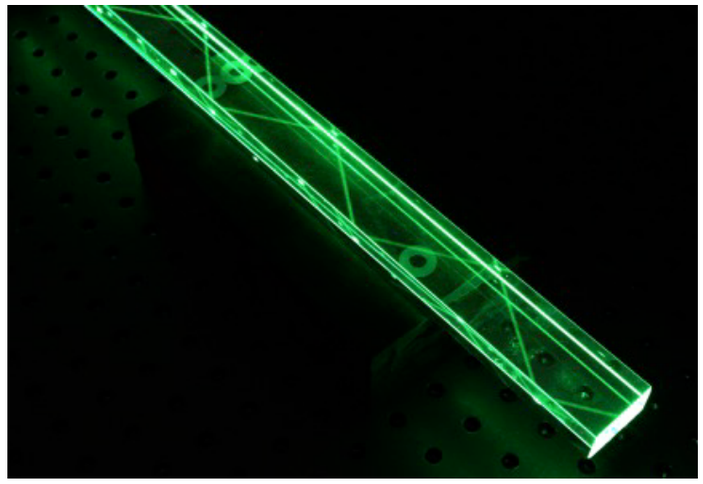
Upgraded Forward Calorimeter with High resolution, high granularity

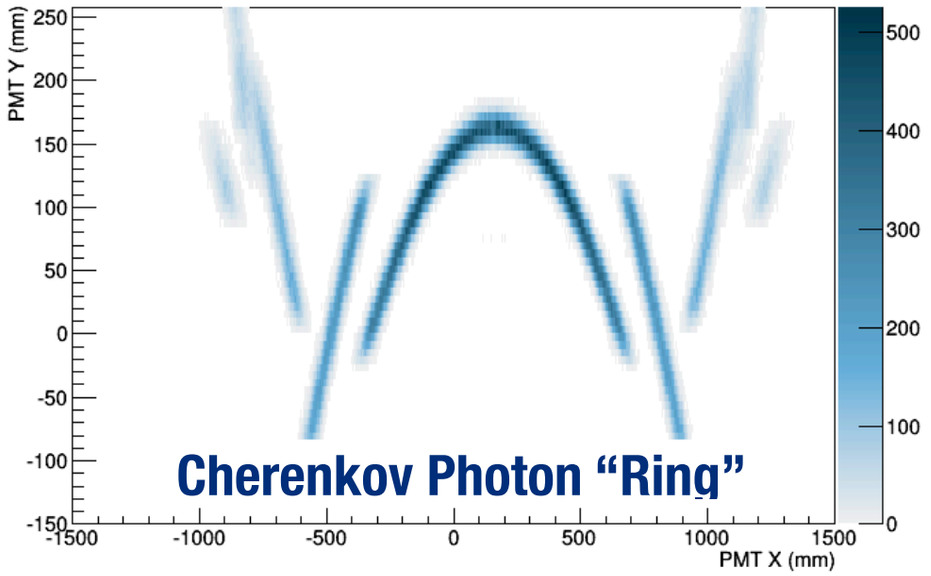
PWO insertion (FCAL-II) to detect multi-photons from the η decays

DIRC upgrade



Improve K/π separation





The BaBar bar boxes are Delivered safely from SLAC to JLab

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

[hep-ex] arXiv:1707.05284

Proposal for JLab PAC45

Strange Hadron Spectroscopy with a Secondary K_L Beam at GlueX

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, and the “high intensity” program, GlueX II, will begin subsequently.

- The linearly polarized photon beam asymmetry Σ for π^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

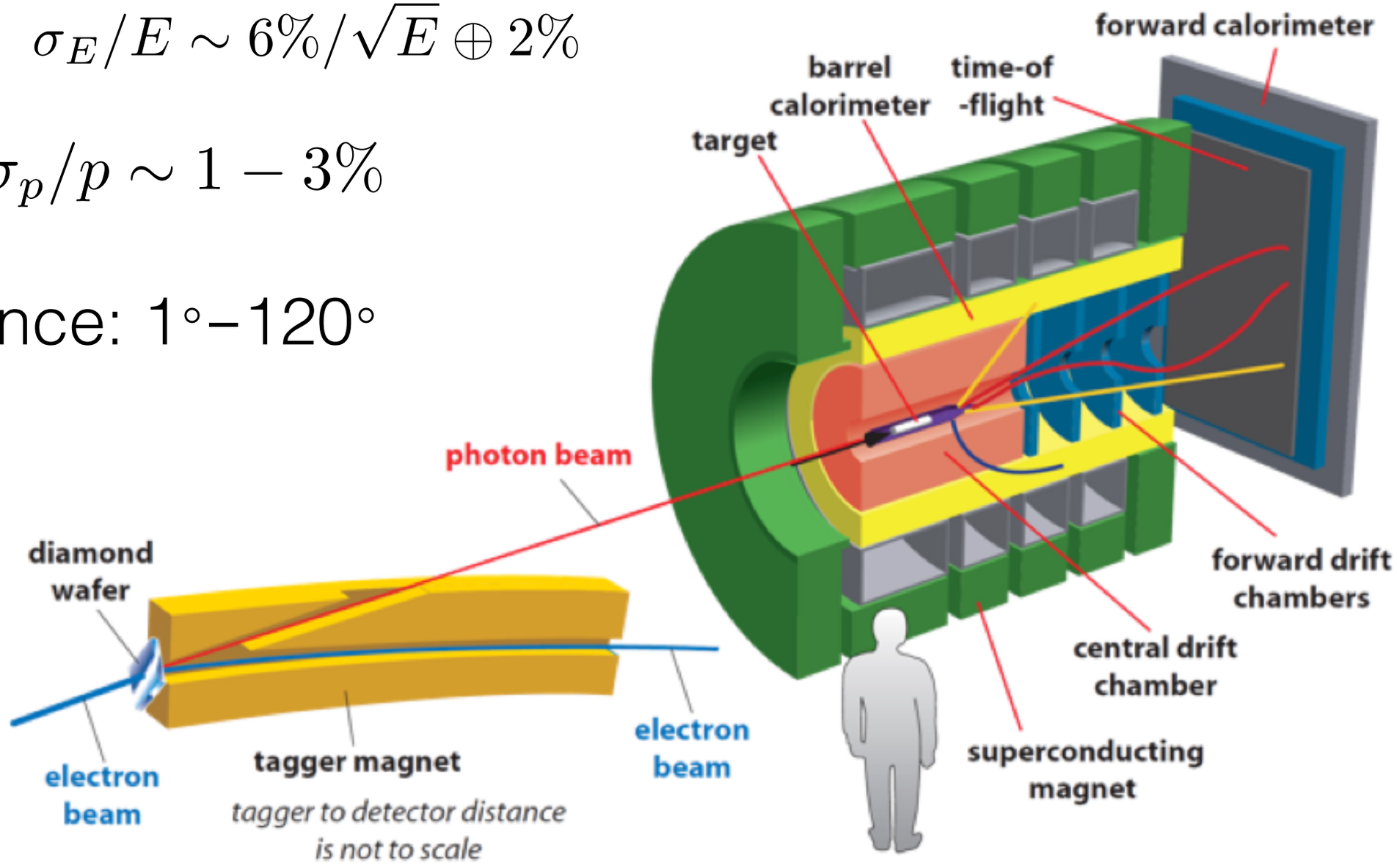
GlueX Detector

Detector resolutions:

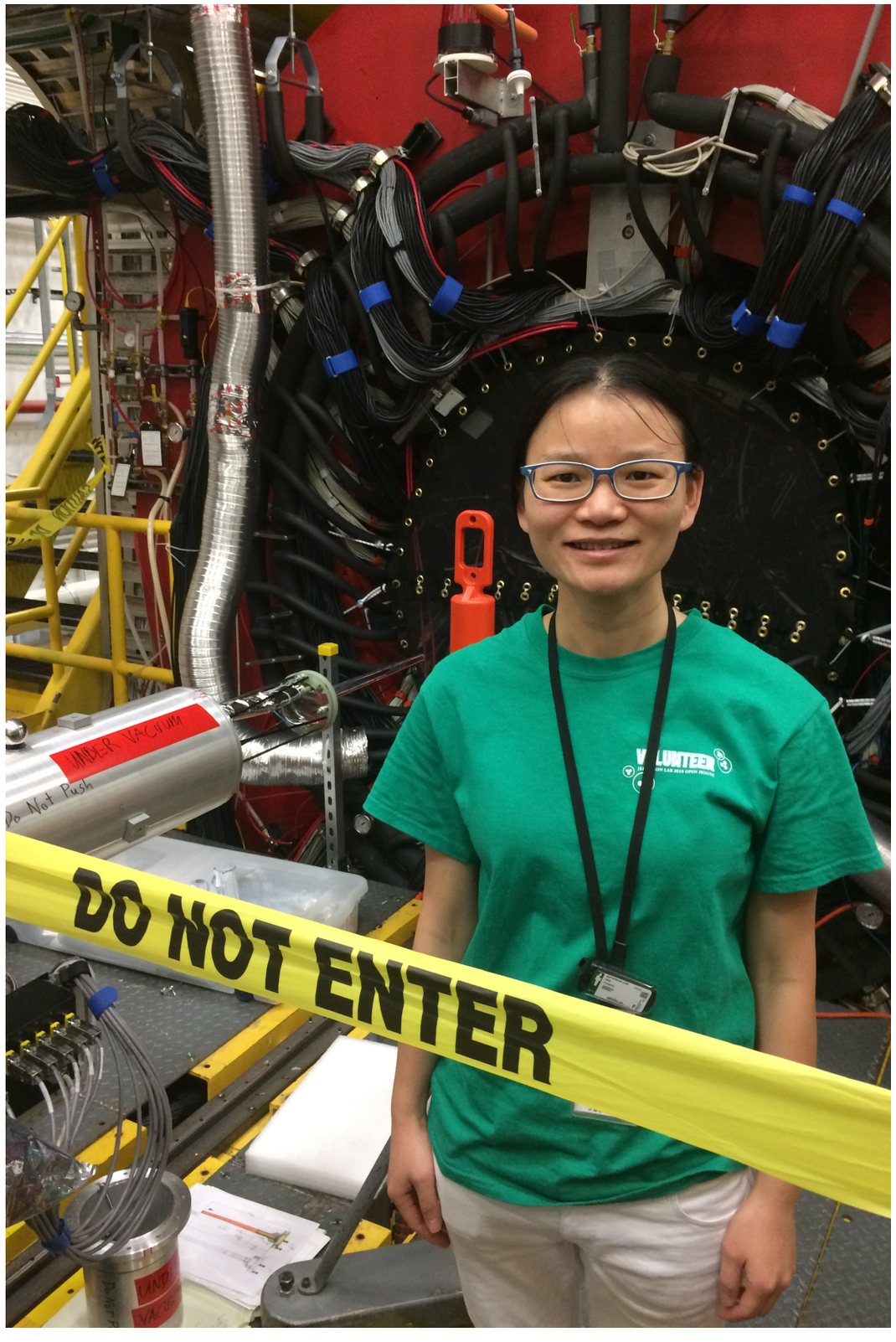
Photons: $\sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$

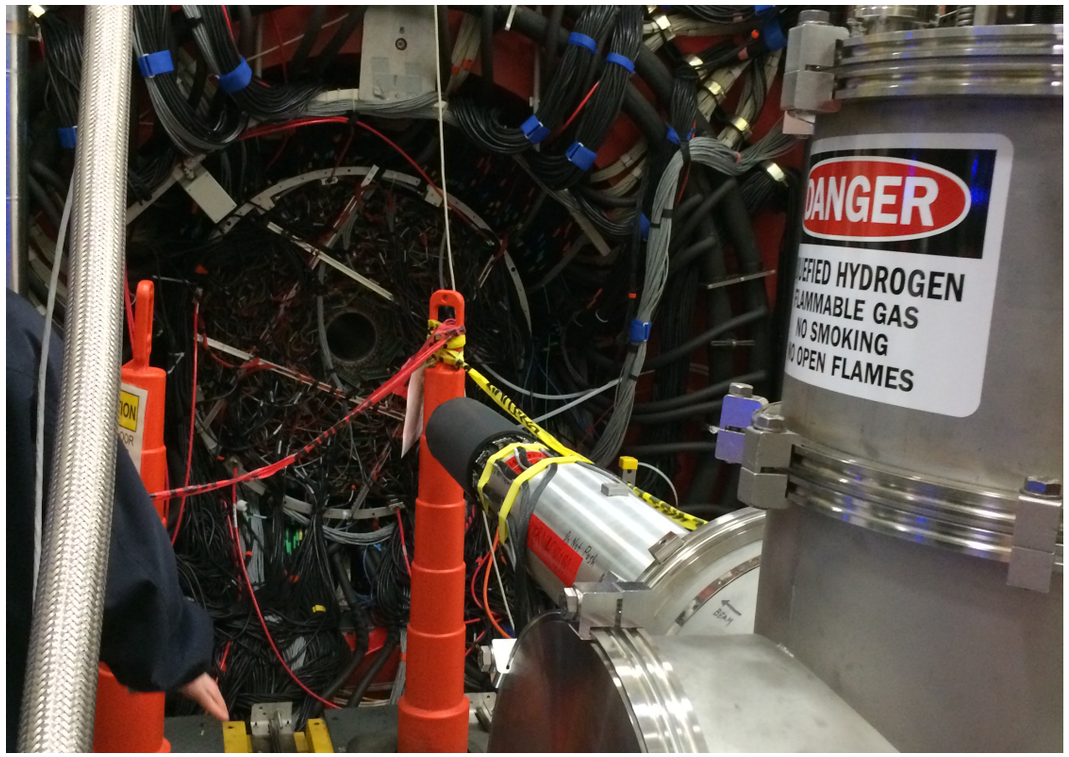
Tracks: $\sigma_p/p \sim 1 - 3\%$

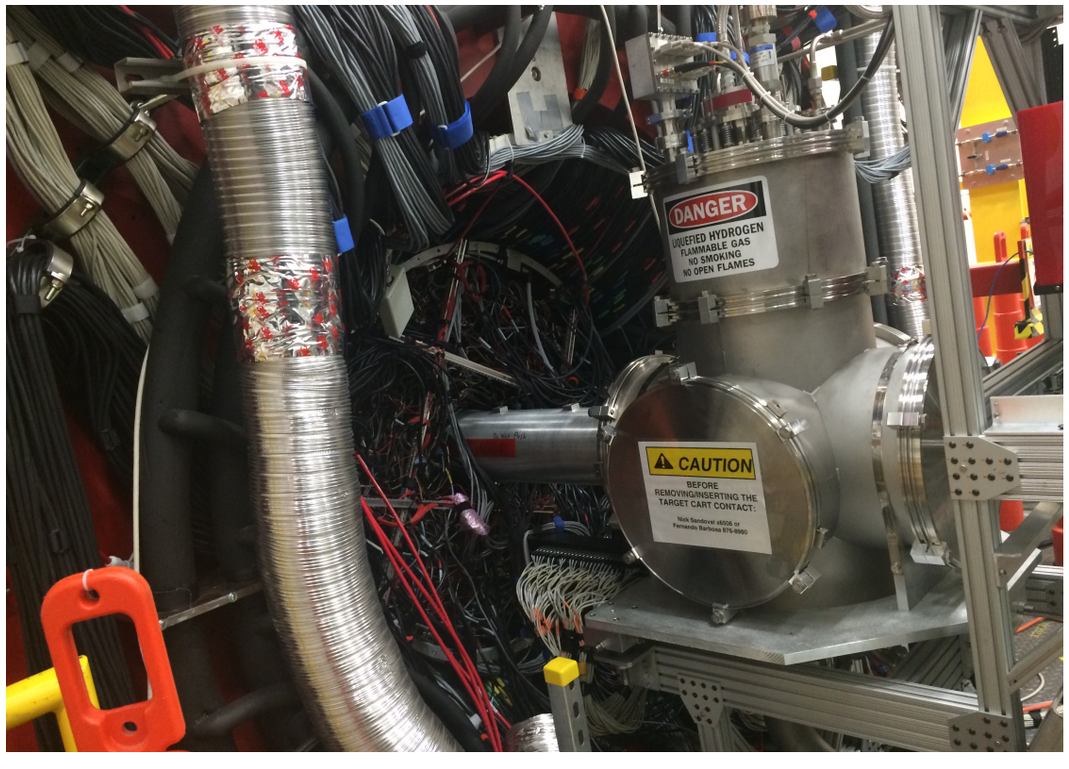
Receptance: 1°–120°



Liquid hydrogen target and start counter

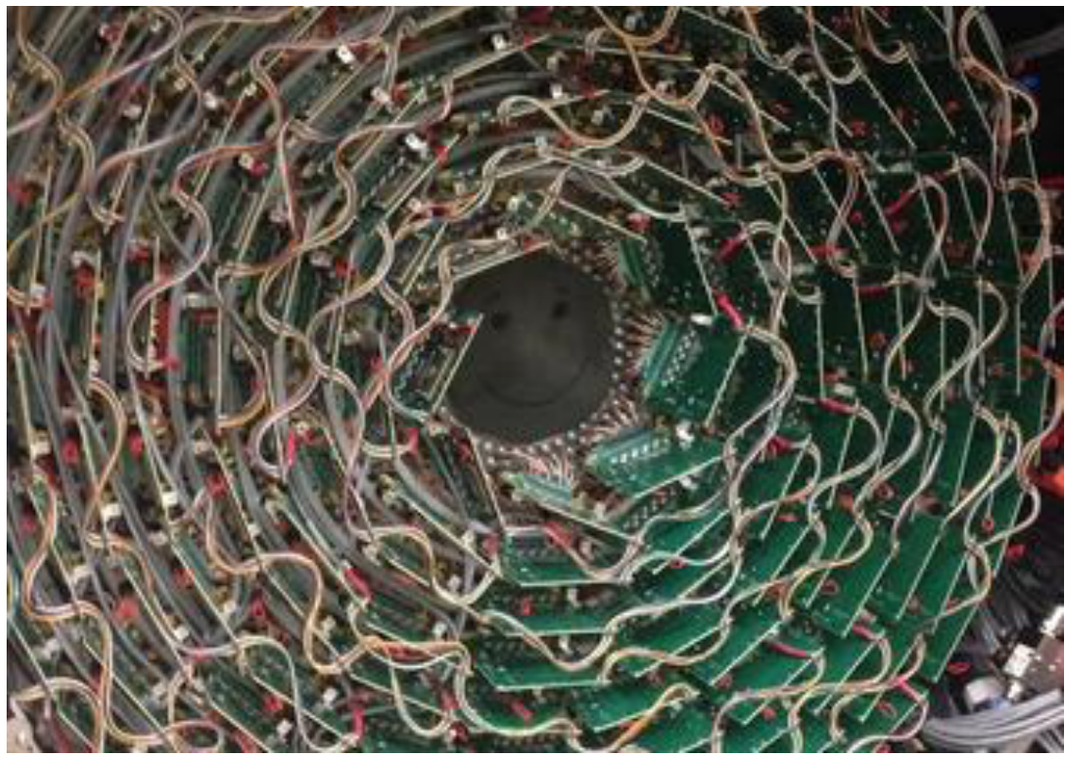




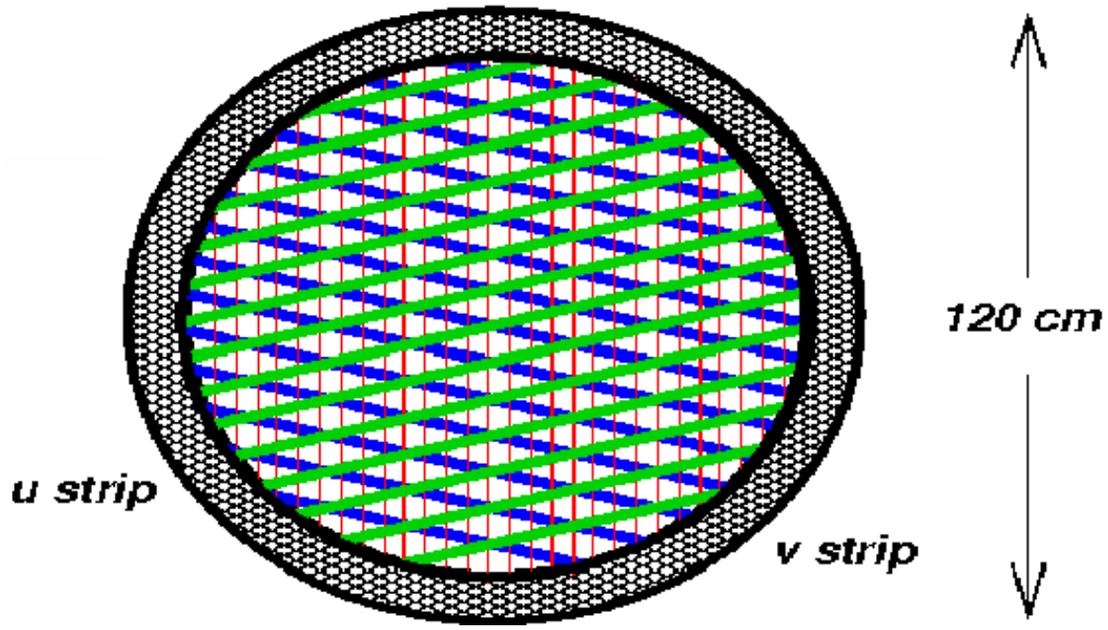


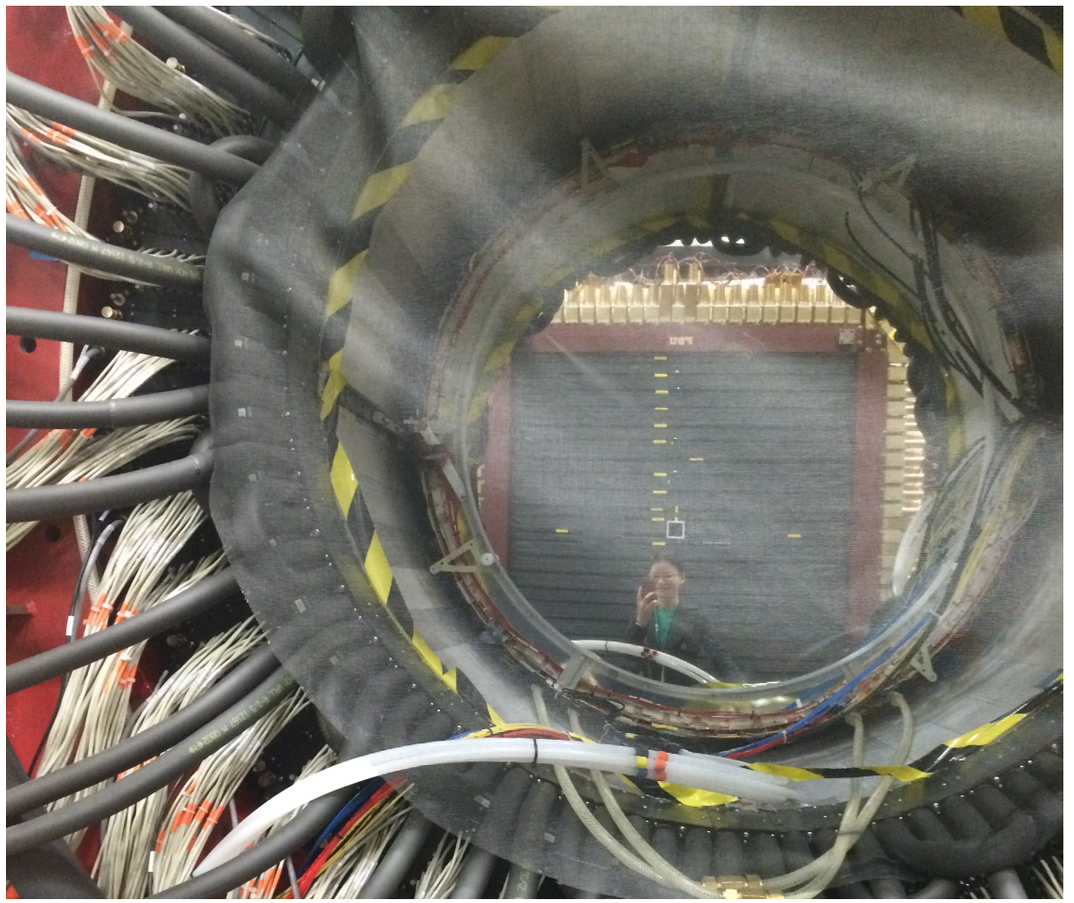
CDC and FDC

Straw tube drift chamber



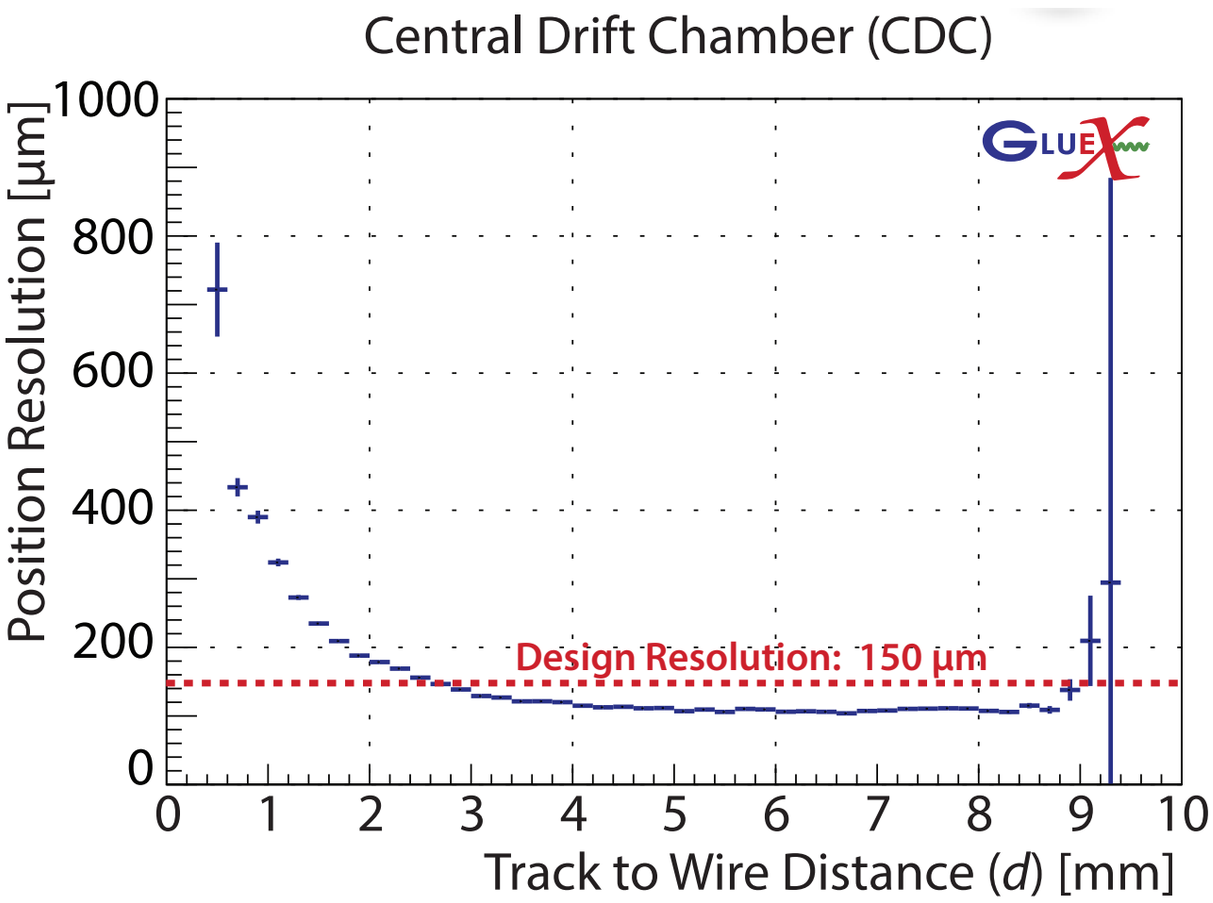
Interleaved planes of field/sense wires and planes of cathode strips

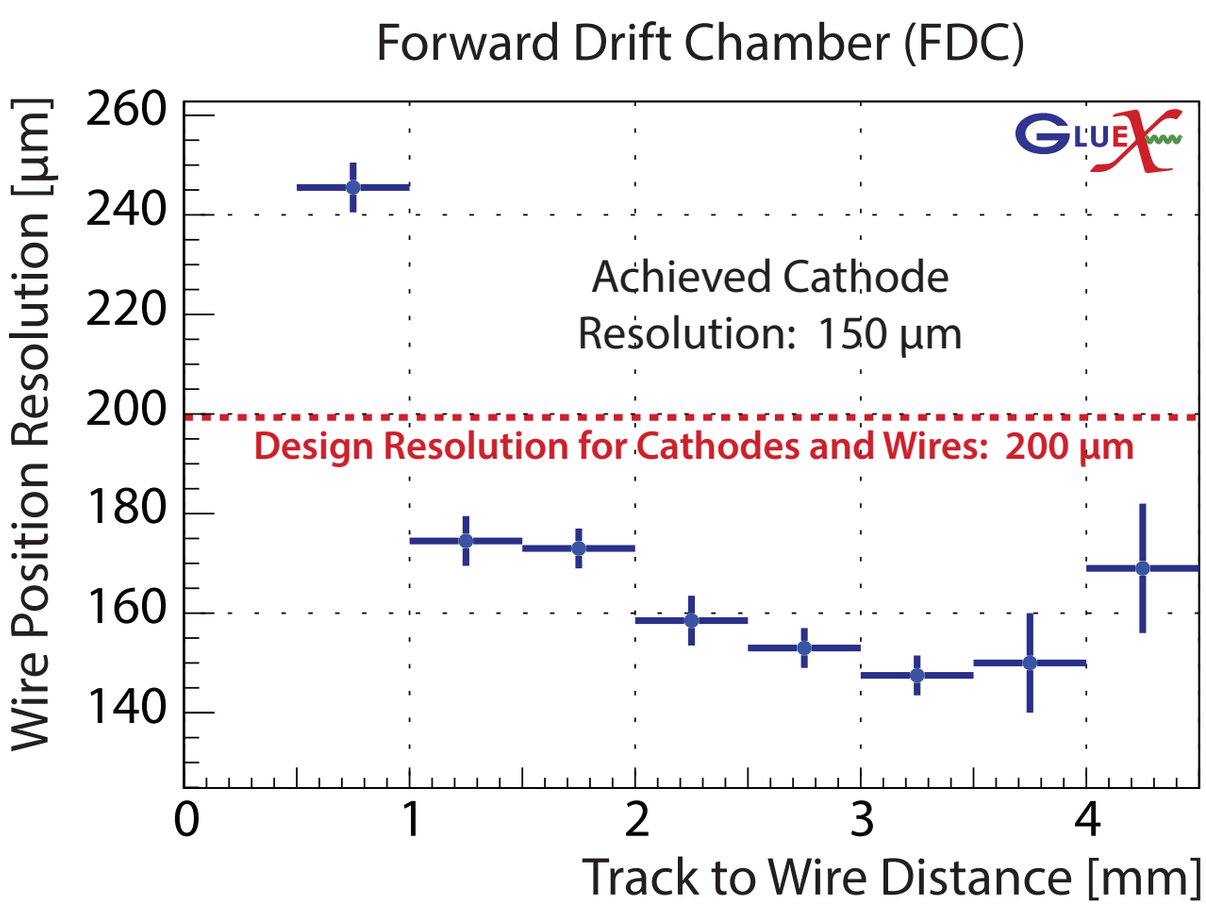




Detector Performance

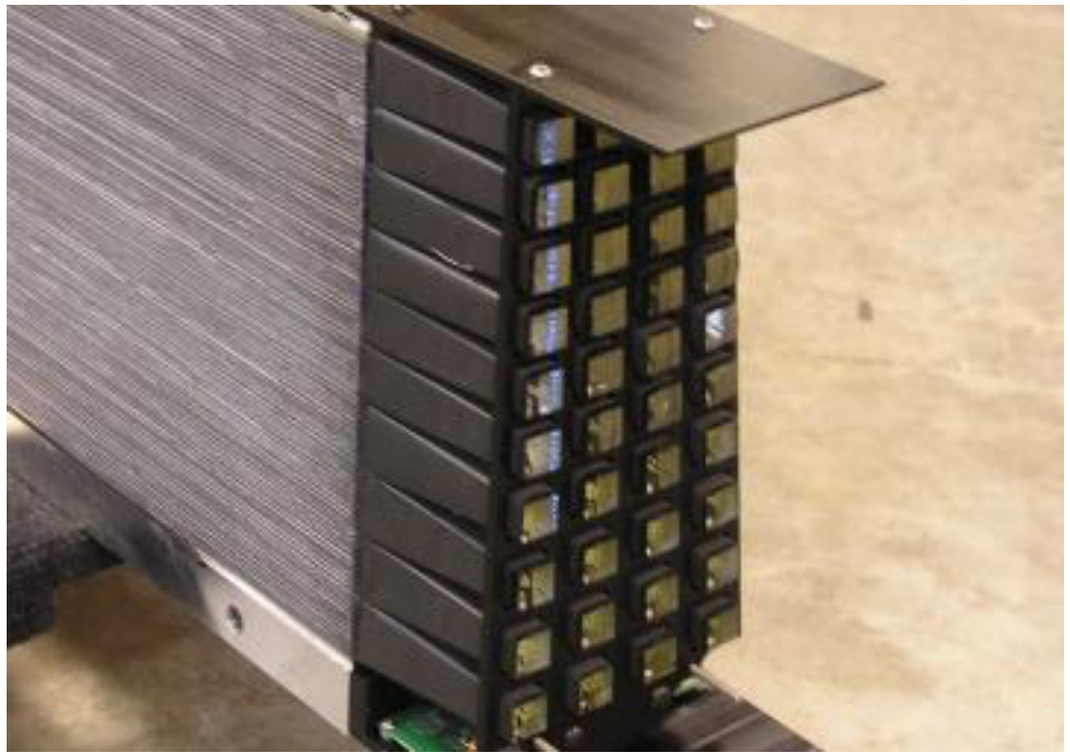
Drift chambers exceed design position resolution



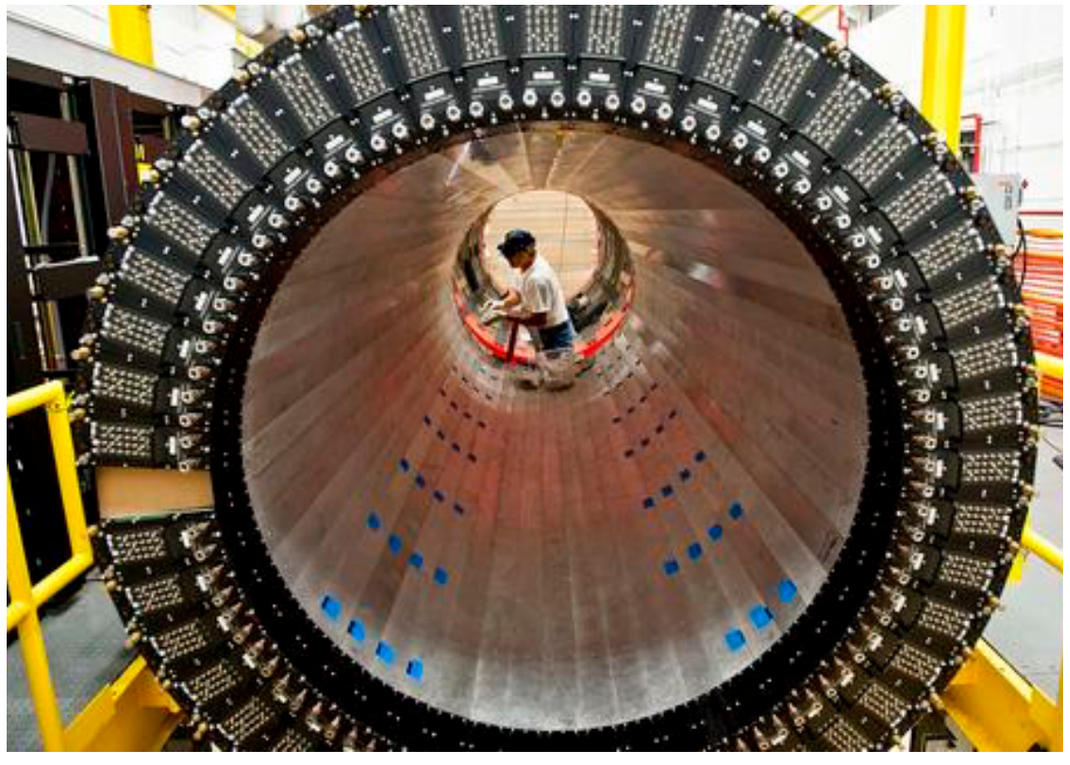


BCAL and FCAL

Scintillating fibers in the interstitial layers of lead



Fast silicon photomultipliers (SiPMs)

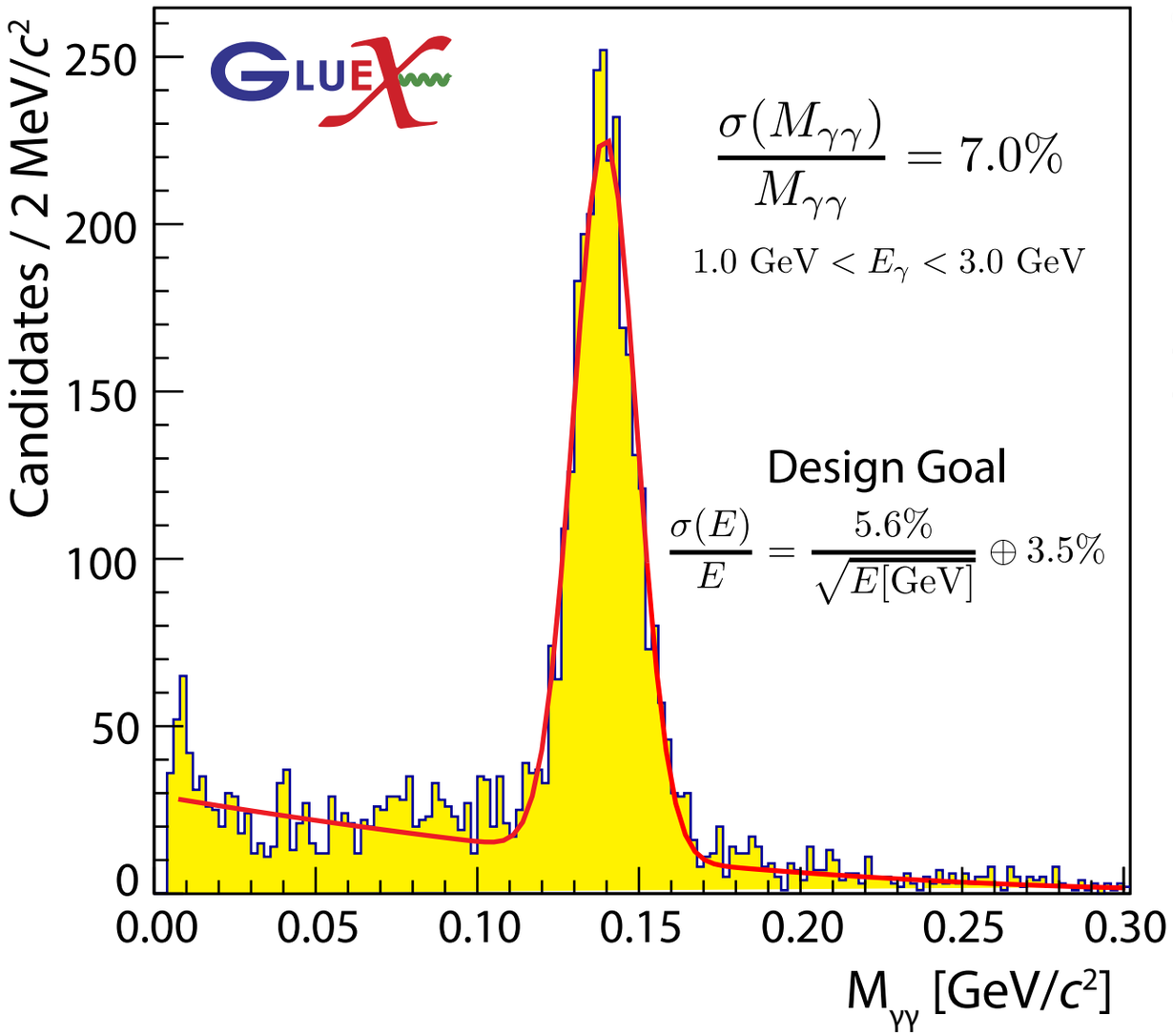


F8-00 lead glass, 4 × 4 × 45 cm

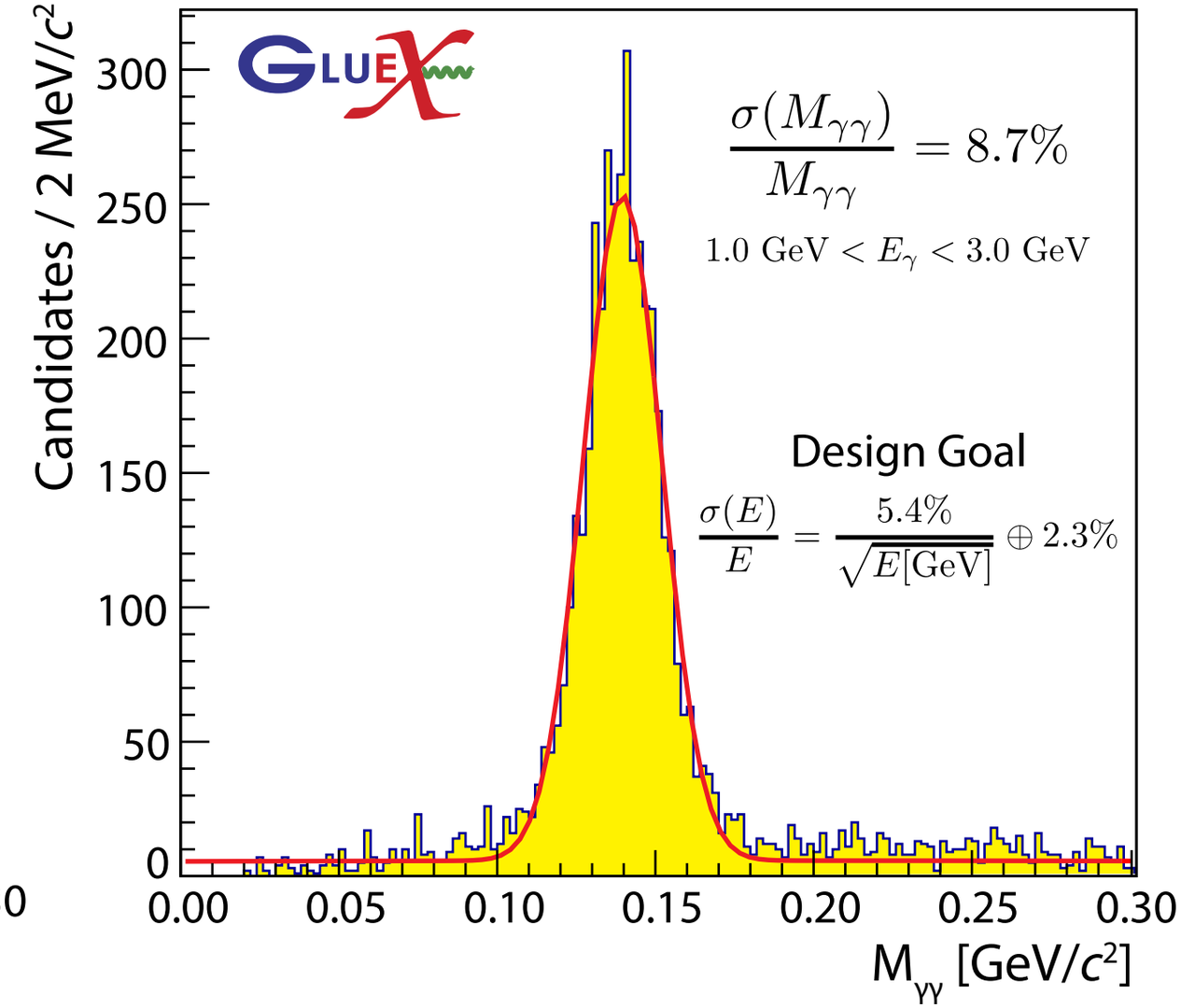
Detector Performance

Calorimeters approaching design energy resolution

Forward Lead Glass Calorimeter

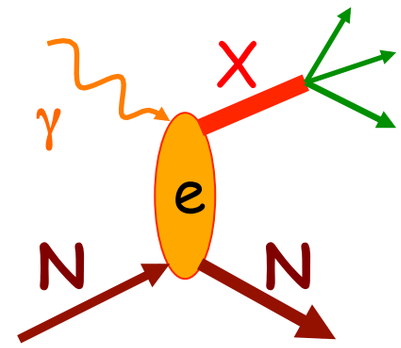


Barrel Lead-Scintillating Fiber Calorimeter



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

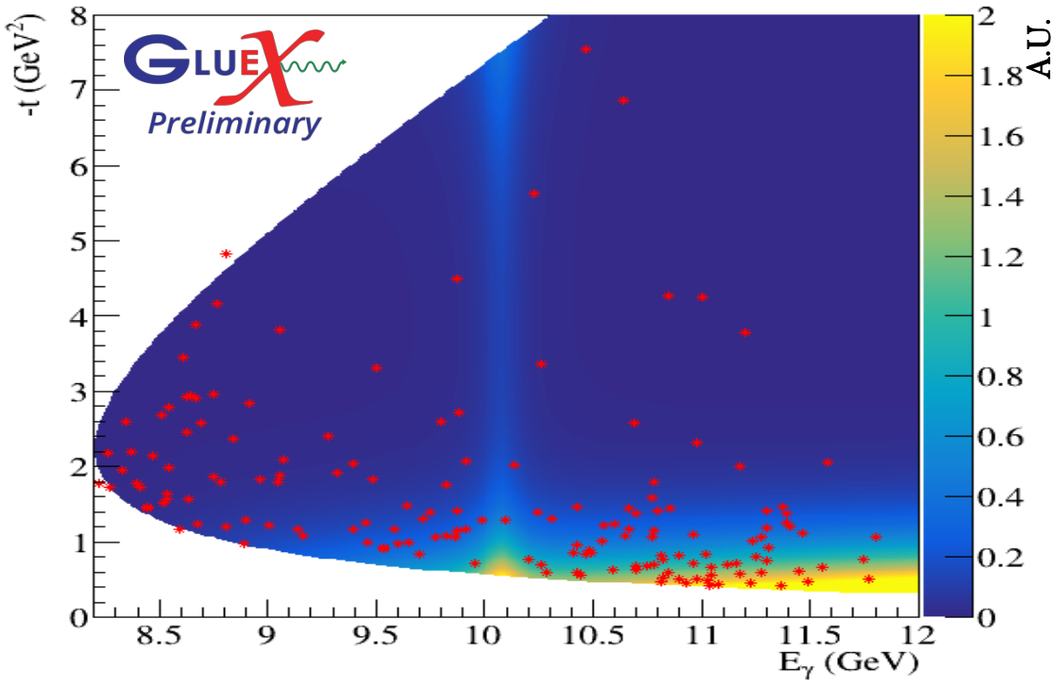
GlueX & JPAC: Experiment & Theory

Program and upgrades

Experiment	Description	Beam Time (days)
GlueX I	Study spectrum of light mesons and gluonic excitations (low intensity)	80
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

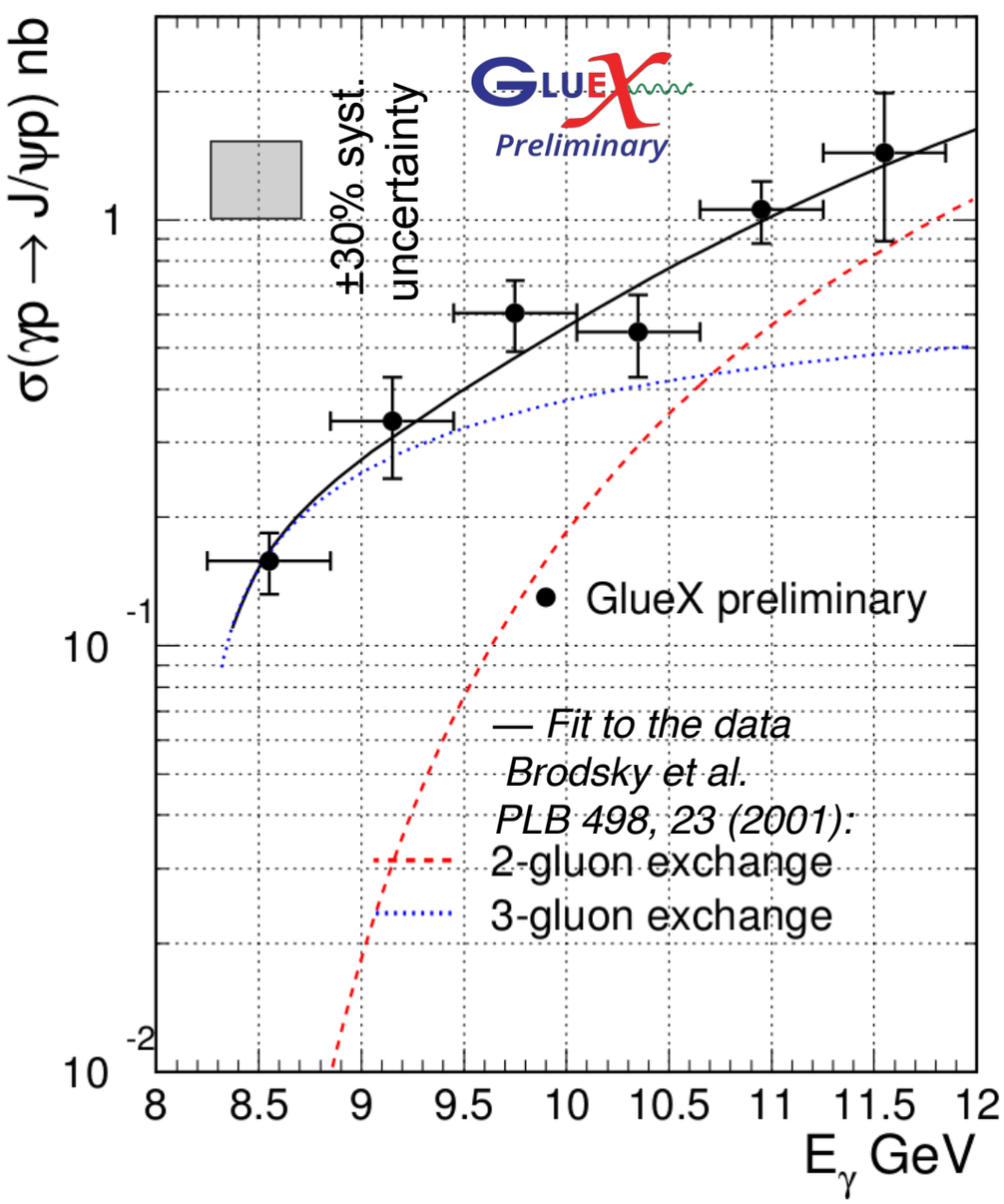
Threshold J/Ψ production at GlueX



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).



From Bingsong Zou's Report

Totally different predictions for $1/2^-$ hyperons:

	unquenched		quenched
Σ^*	[us][du] $\bar{d}$	~ 1400 MeV	uus (L=1) ~ 1650 MeV
Ξ^*	[us][ds] $\bar{d}$	~ 1550 MeV	uss (L=1) ~ 1760 MeV
Ω^*	[us] ss $\bar{u}$	~ 1800 MeV	sss (L=1) ~ 2000 MeV

Meson-Baryon states

	Y.S.Oh	K. P. Khemchandani et al.
Σ^*	~1475 MeV	~1426 MeV
Ξ^*	~ 1616 MeV	~1606 MeV
Ω^*	~ 1837 MeV	Ramos & Oset