

Hall D 12 GeV Overview

Mark Dalton, Jefferson Lab

For the GlueX Collaboration



[GlueXperiment](https://www.facebook.com/GlueXperiment)



[@Glue_X](https://twitter.com/@Glue_X)

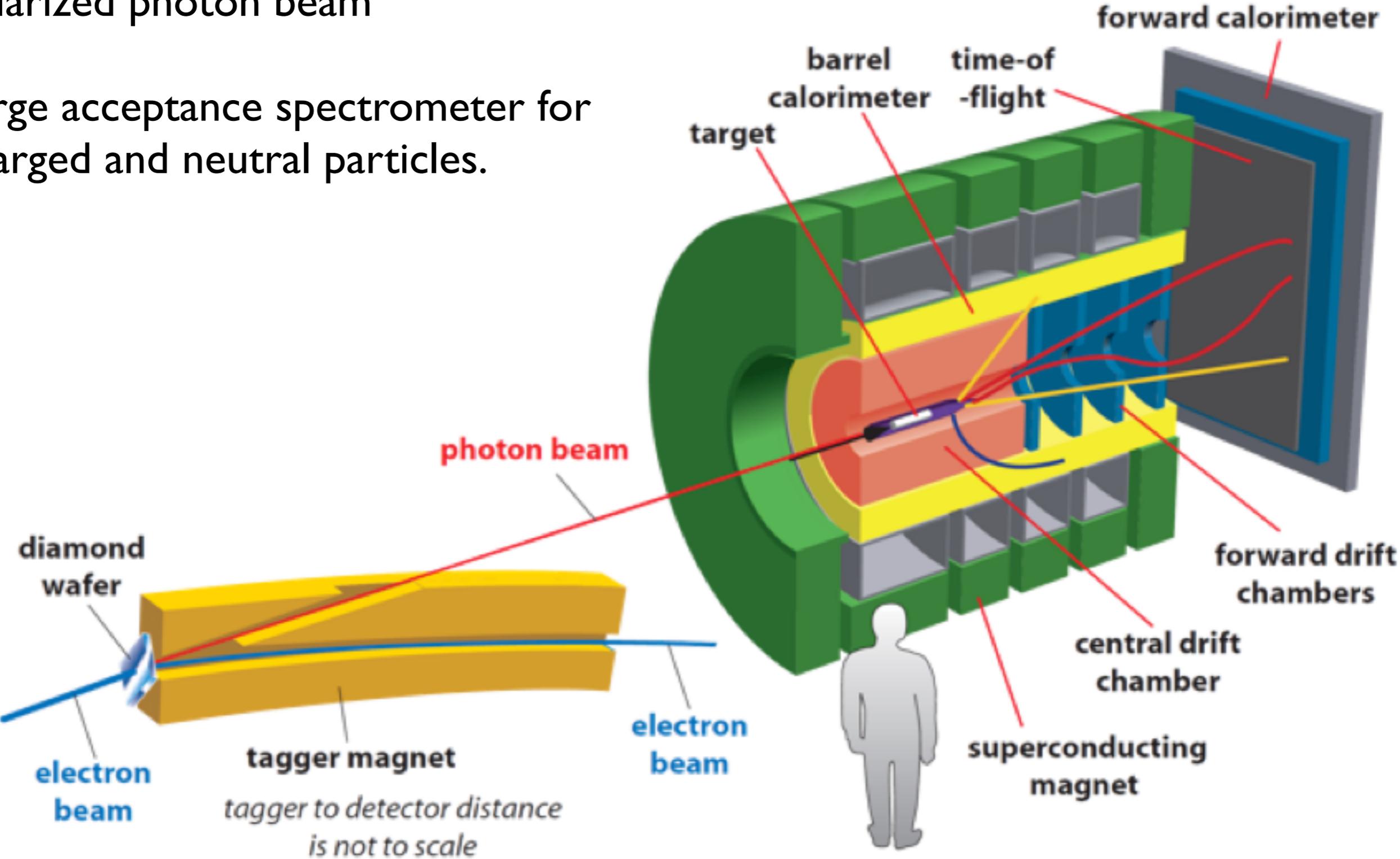


[@gluexperiment](https://www.instagram.com/@gluexperiment)

Hall D Apparatus

Polarized photon beam

Large acceptance spectrometer for charged and neutral particles.

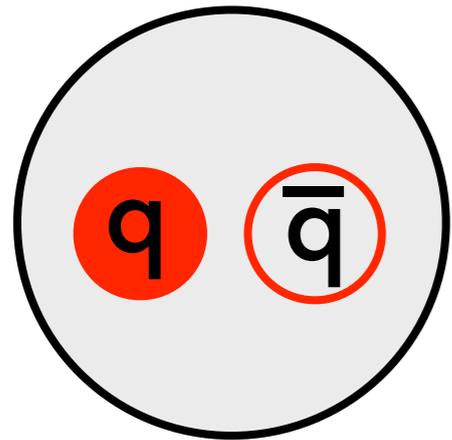


Hall D Approved Program

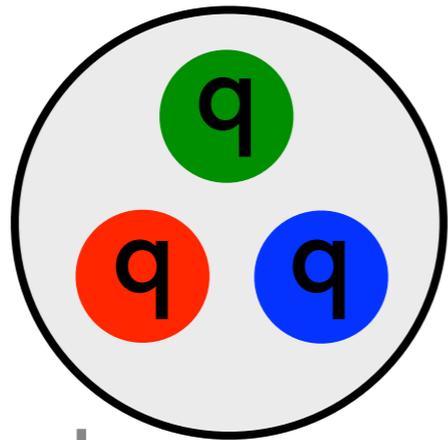
Experiment	Description	Beam Time (PAC days)
GlueX-I	Spectroscopy of light and hybrid mesons (low-intensity)	80
GlueX-II	Spectroscopy of hadrons with strange quark decays (high-intensity)	220+
PrimEx-eta	Eta radiative decay width	79
CPP	Charged pion polarizability	25
JEF	Rare eta decays	concurrent



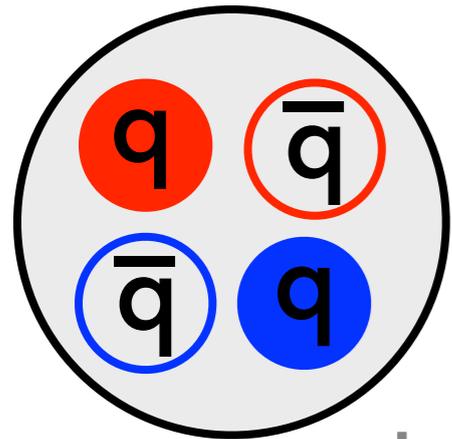
Hadron Spectroscopy



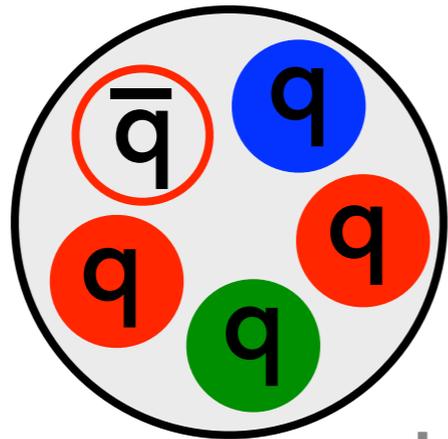
mesons



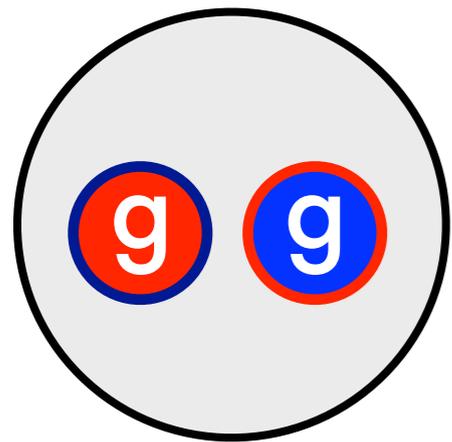
baryons



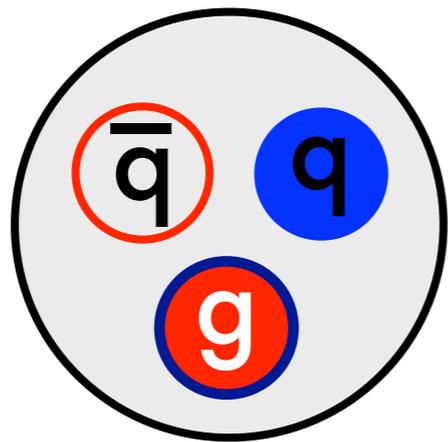
tetraquark



pentaquark



glueballs



hybrid meson

Motivated the Quark Model
“Constituent” quarks: flavor SU(3)

QCD: exact color SU(3) symmetry;
asymptotic freedom; confinement; mass
generated dynamically.

Recent progress in studying QCD through
spectrum of bound states

New high-intensity experiments
Renewed theoretical interest.

Which color-singlet states exist in nature?

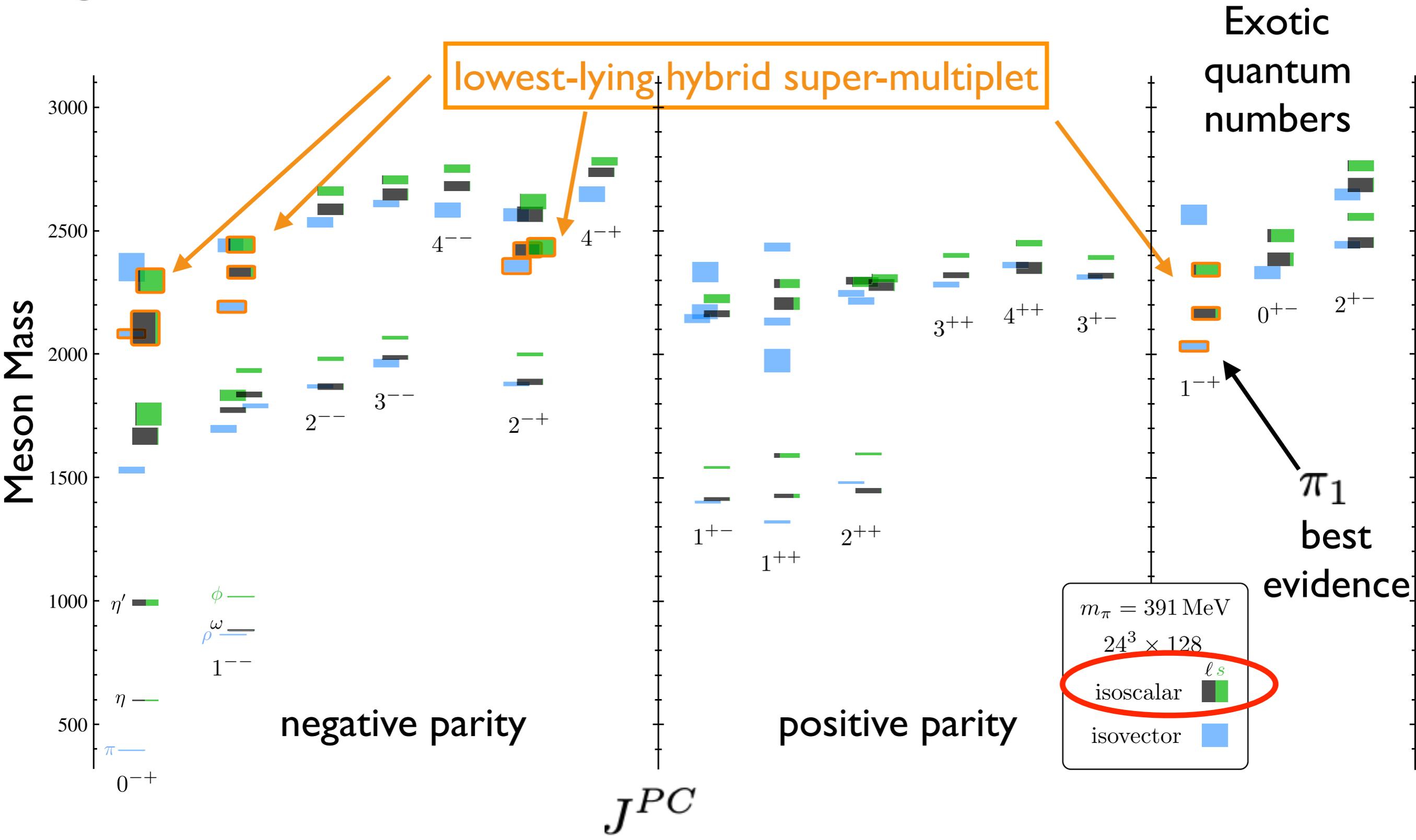
What are their properties?

Why are they so elusive?

Are gluonic degrees of freedom manifest?

Smoking gun for hybrid mesons are exotic
quantum numbers

Light Quark Mesons from Lattice

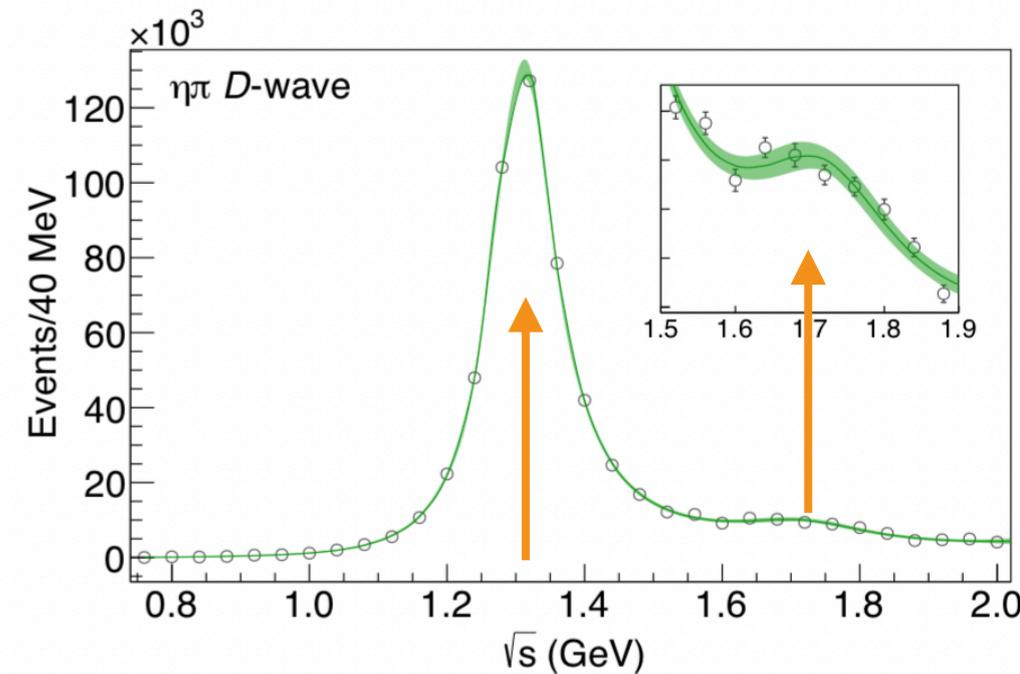
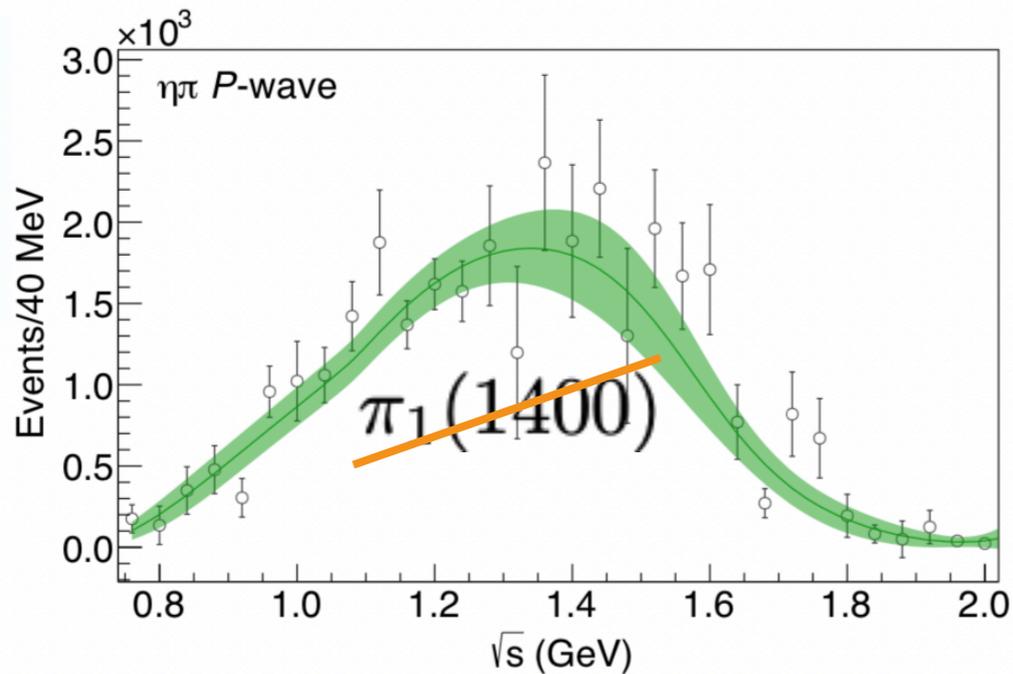
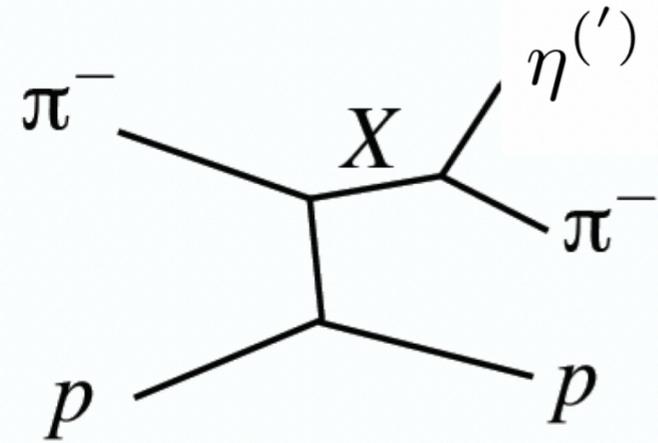


Pattern suggests 1^{+-} constituent gluon

Dudek et al. PRD 88 (2013) 094505

$\eta\pi/\eta'\pi$ spectroscopy

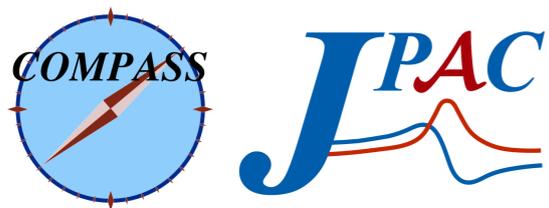
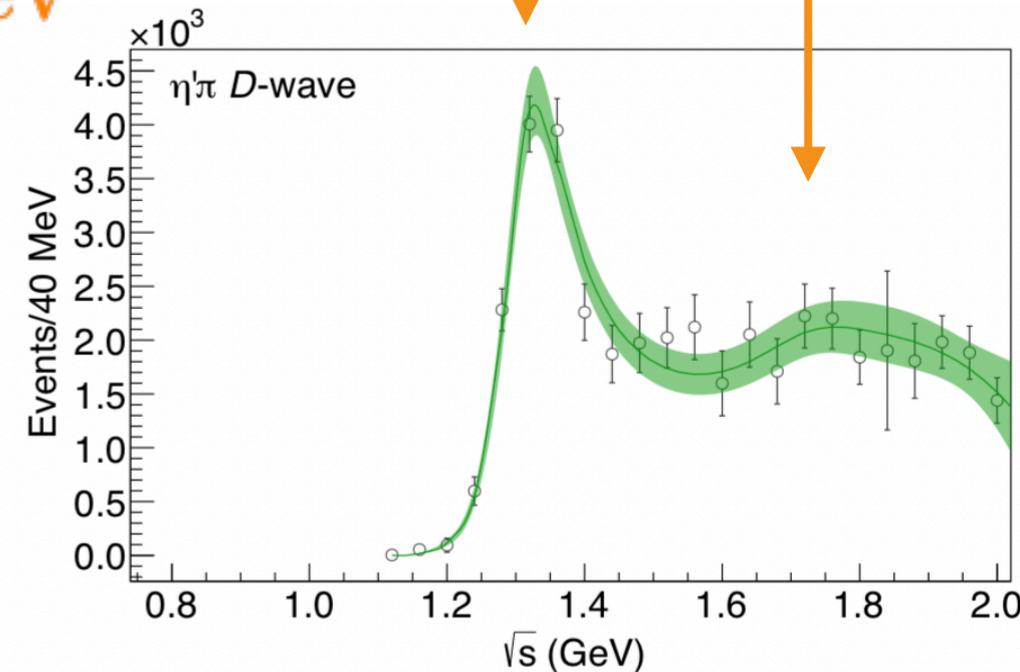
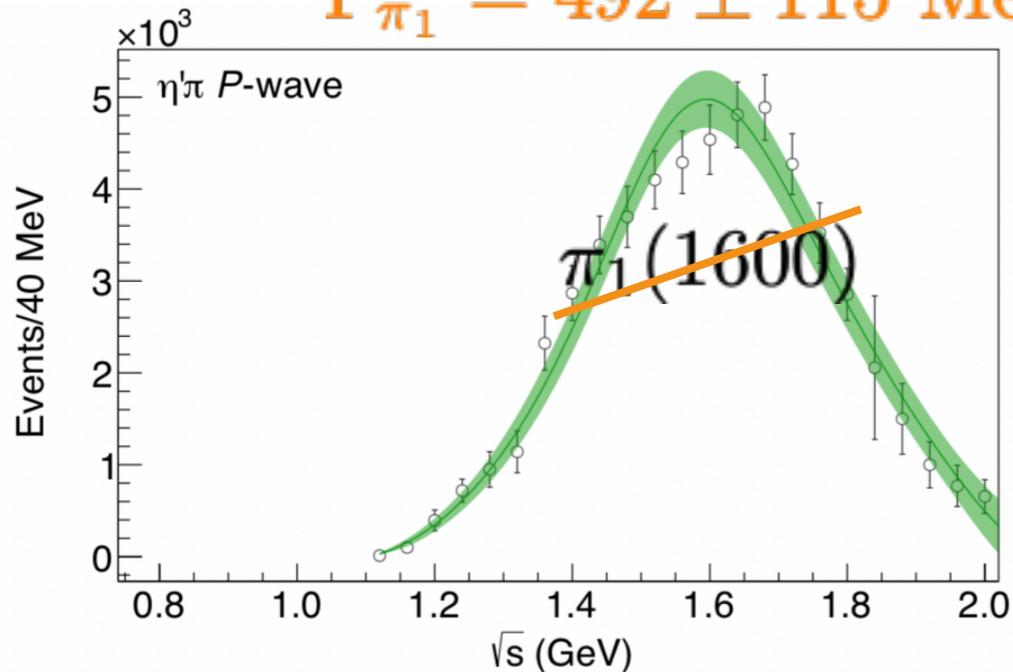
coupled channel fit to $\eta\pi$ and $\eta'\pi$ determine pole positions for a_2 , a_2' , and exotic π_1



$$M_{\pi_1} = 1564 \pm 89 \text{ MeV}$$

$$\Gamma_{\pi_1} = 492 \pm 115 \text{ MeV}$$

$$a_2(1320) \quad a_2'(1700)$$



COMPASS:
PLB 740 (2015) 303
JPAC:
PRL 122 (2019) 042002

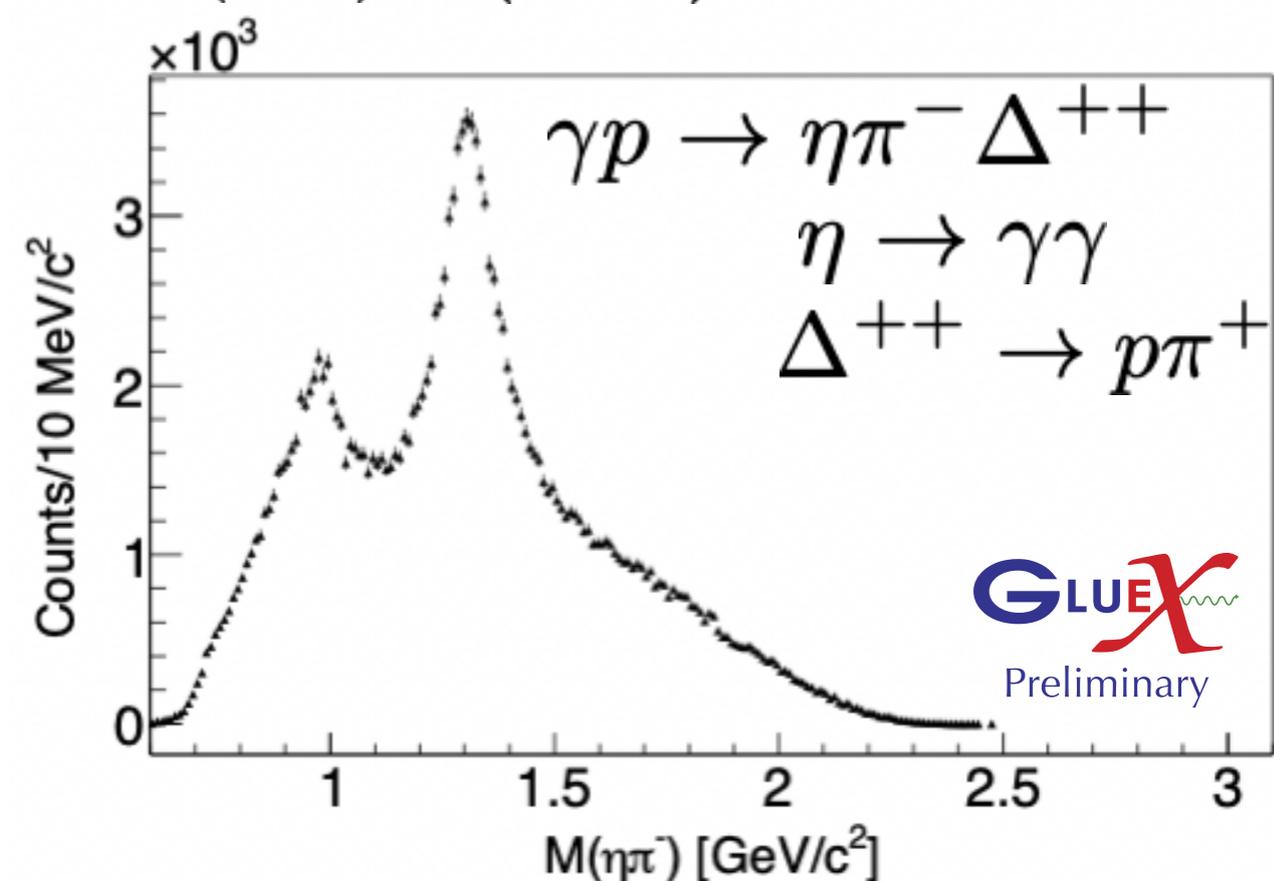
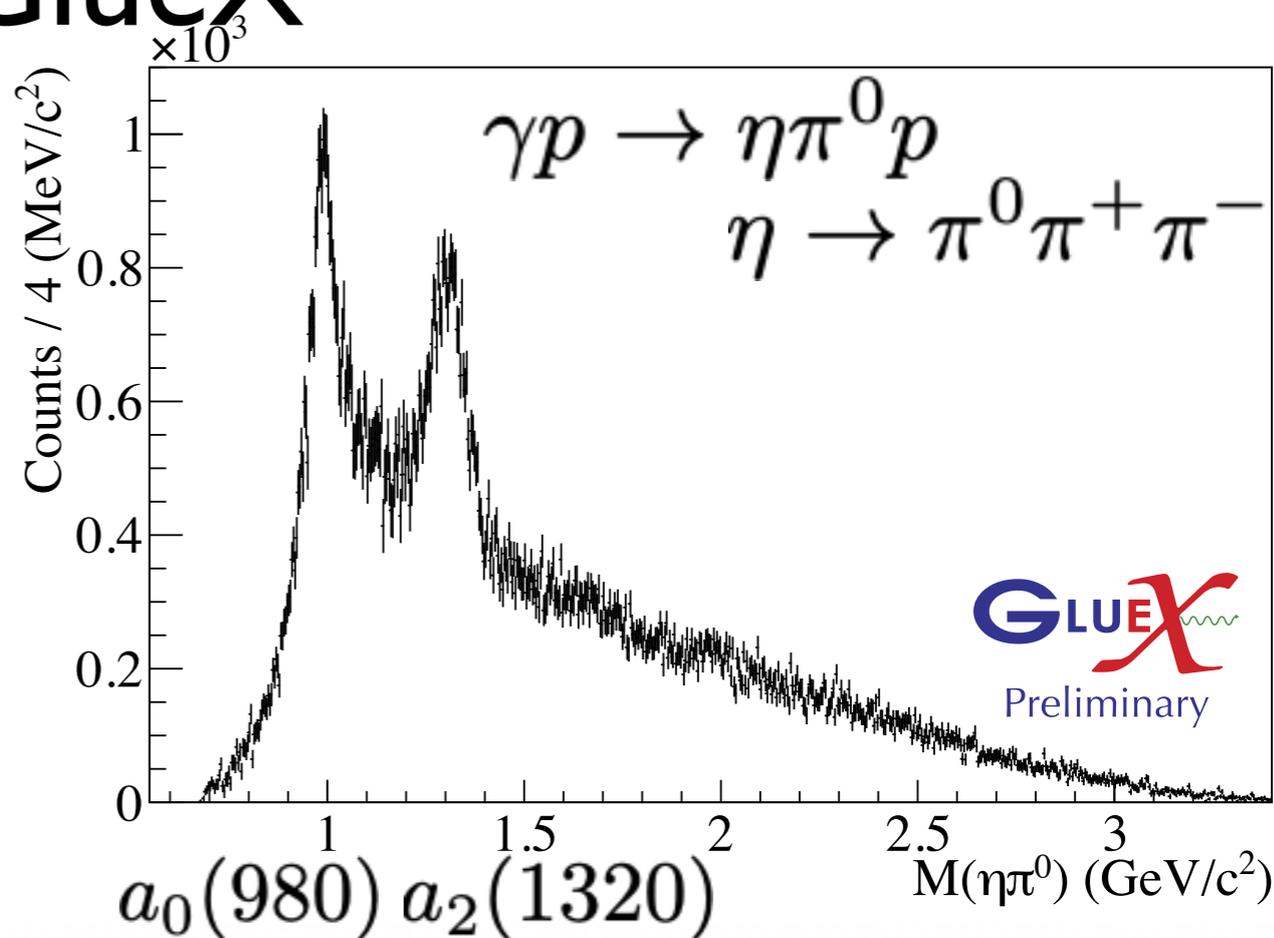
$\eta\pi/\eta'\pi$ spectroscopy at GlueX

Analysis of $\eta\pi$ and $\eta'\pi$ final states well underway

Several well-known mesons identified with 20% of GlueX Phase-I

GlueX-I dataset competitive with COMPASS statistics (different production mechanism)

Multiple final states available

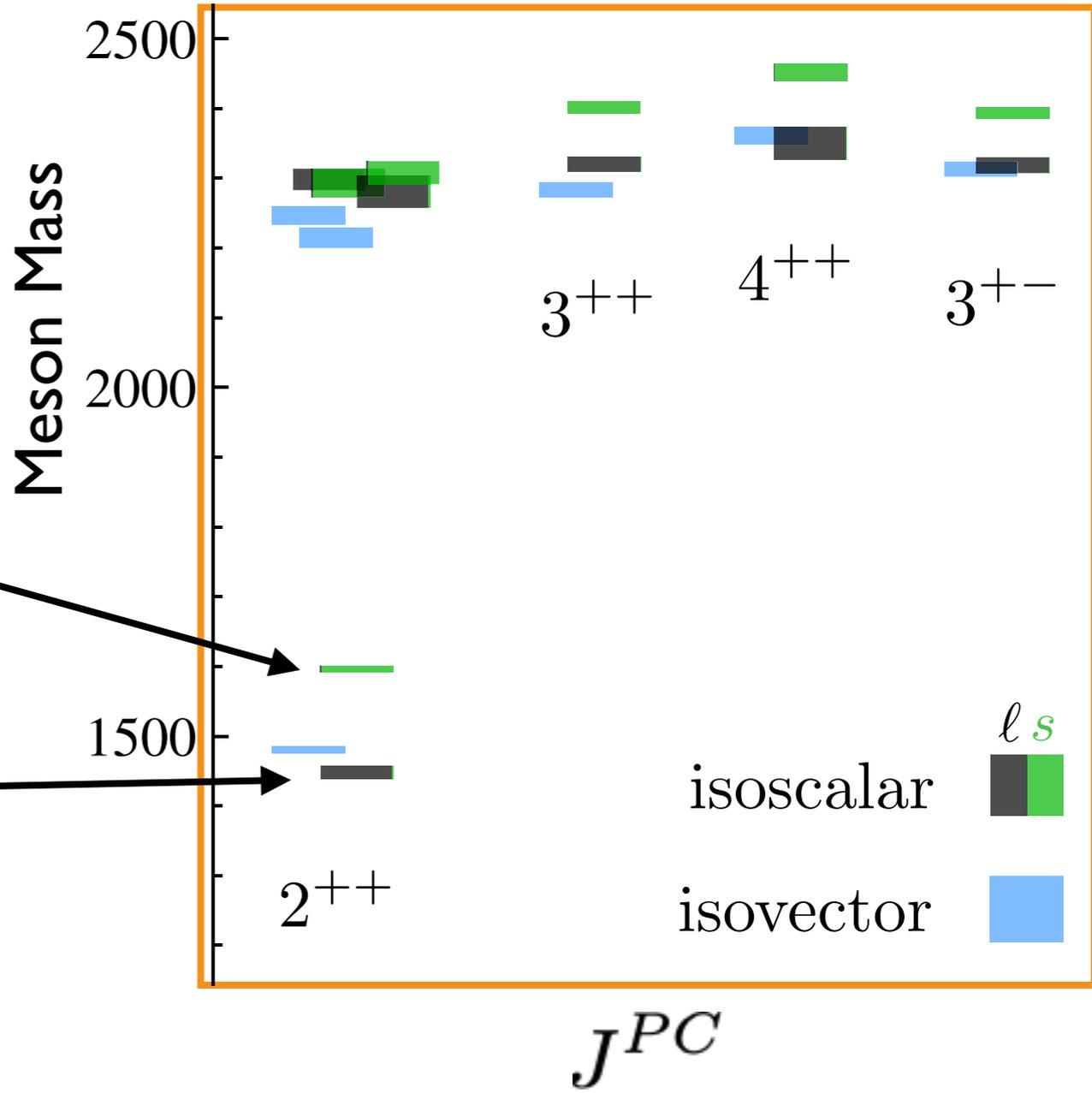


Strangeness program

Experimentally infer quark flavor composition through branching ratios to strange and non-strange decays

$$\frac{B(f'_2(1525) \rightarrow \pi\pi)}{B(f'_2(1525) \rightarrow KK)} \approx 0.009$$

$$\frac{B(f_2(1270) \rightarrow \pi\pi)}{B(f_2(1270) \rightarrow KK)} \approx 20$$



Consistent with lattice QCD mixing angle for 2⁺⁺

Strangeness Program

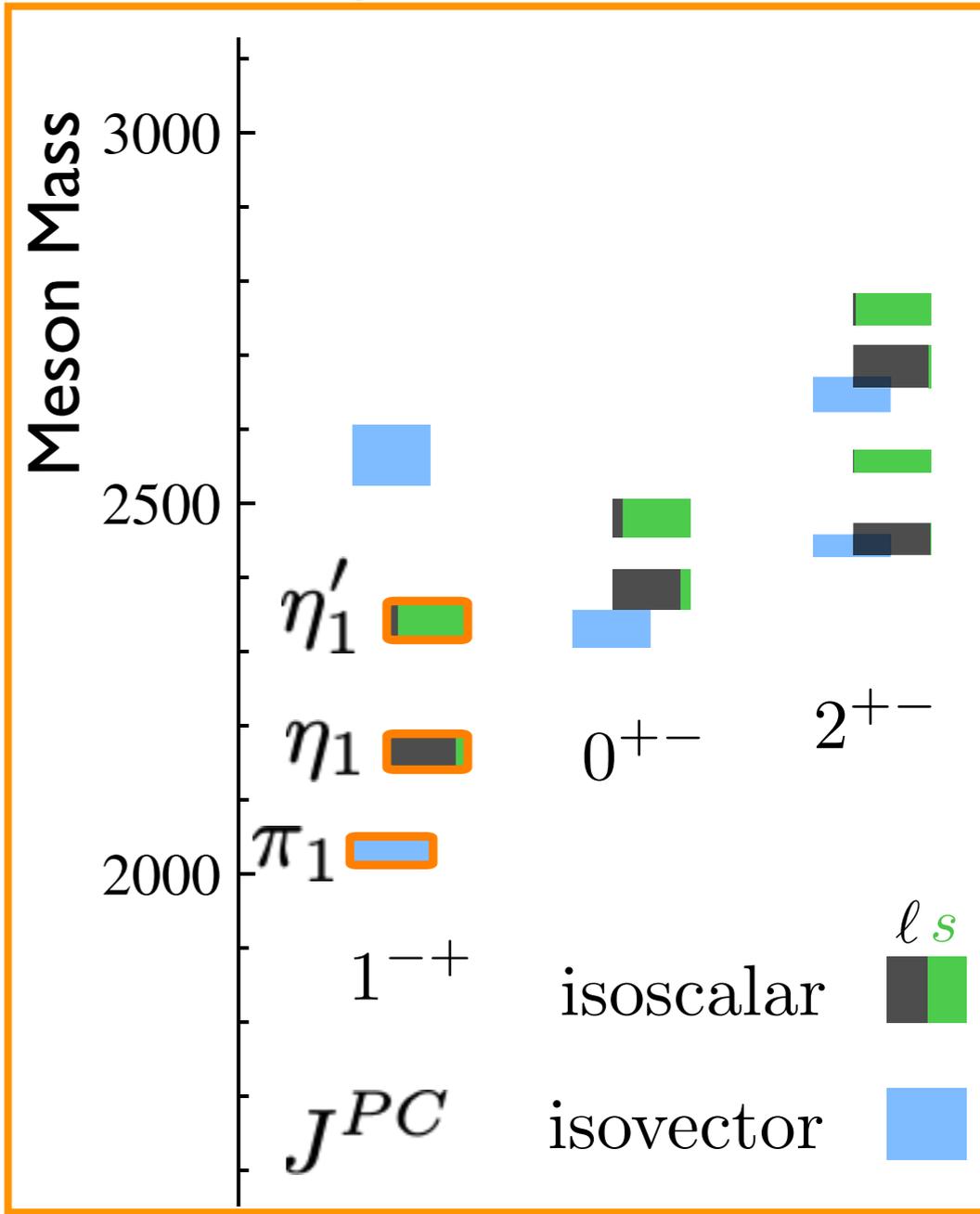
Lattice predicts strange and light quark content for mesons

Search for a pattern of hybrid states in many final states

Requires clean identification of charged pions and kaons

	Allowed decay modes
π_1	$\pi\rho, \pi b_1, \pi f_1, \pi\eta', \eta a_1$
η_1	$\eta f_2, a_2\pi, \eta f_1, \eta\eta', \pi(1300)\pi, a_1\pi$
η'_1	$K^*K, K_1(1270)K, K_1(1410)K, \eta\eta'$

Exotic quantum numbers

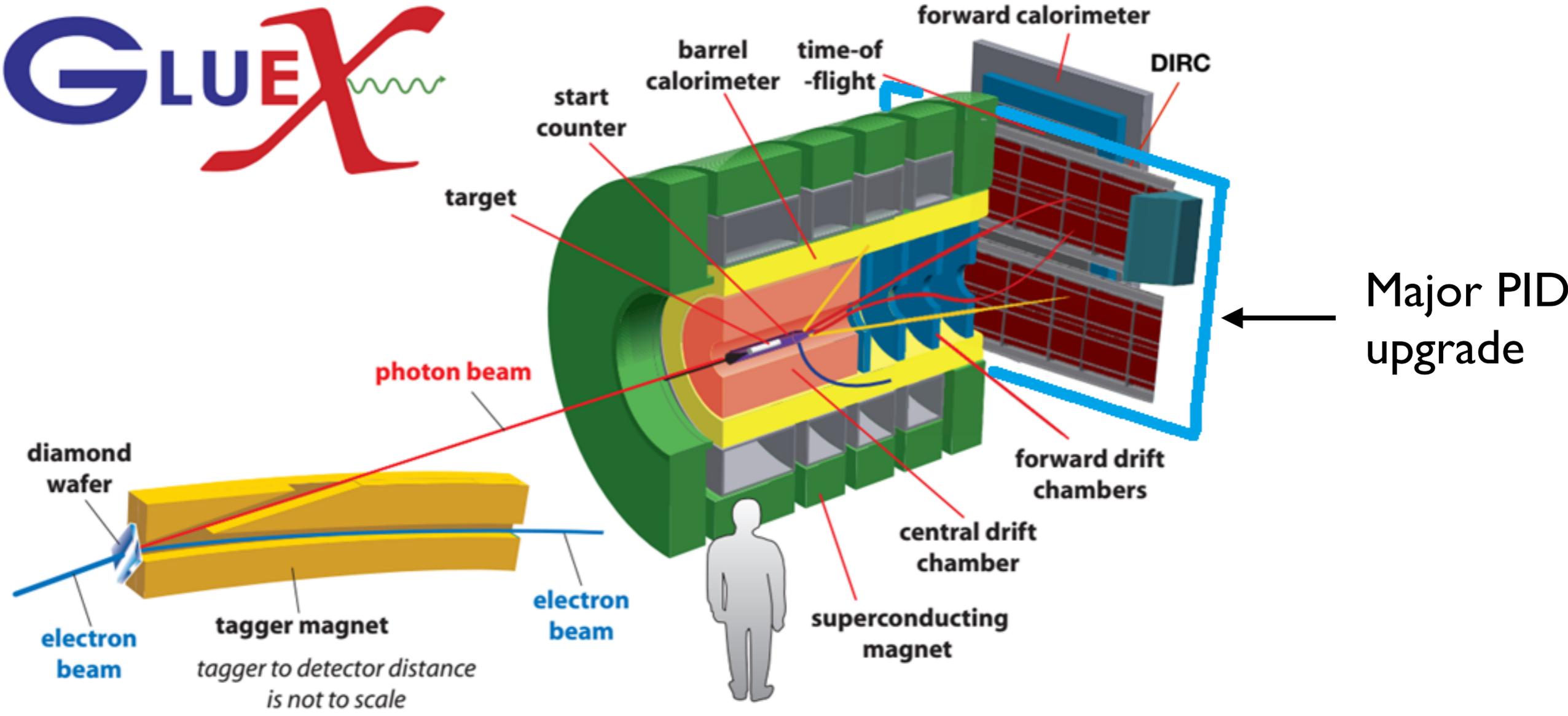


Strangeness Future

Flash Talk: Cascade Photoproduction (Ashley Ernst)

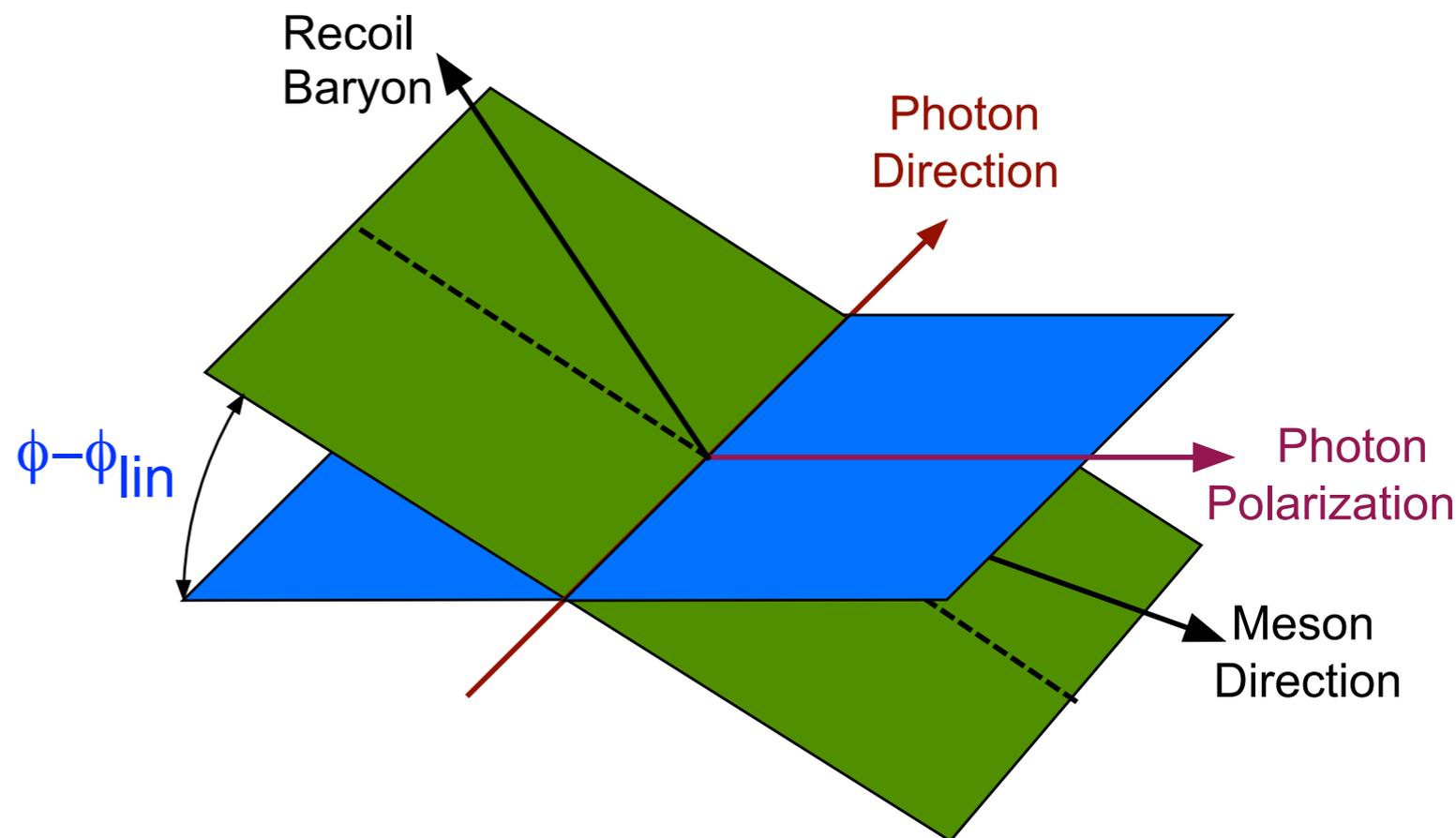
Flash Talk: GlueX DIRC upgrade (Yunjie Yang)

GlueX-II to start in Fall 2019.



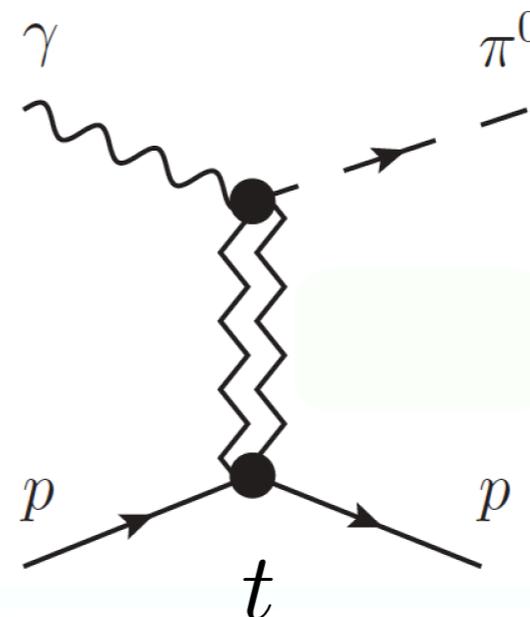
Σ Beam Asymmetry

$$\gamma p \rightarrow (\pi^0, \eta, \eta') p$$



Provides insight into production mechanism
Constrain Regge models

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



Exchange J^{PC}

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

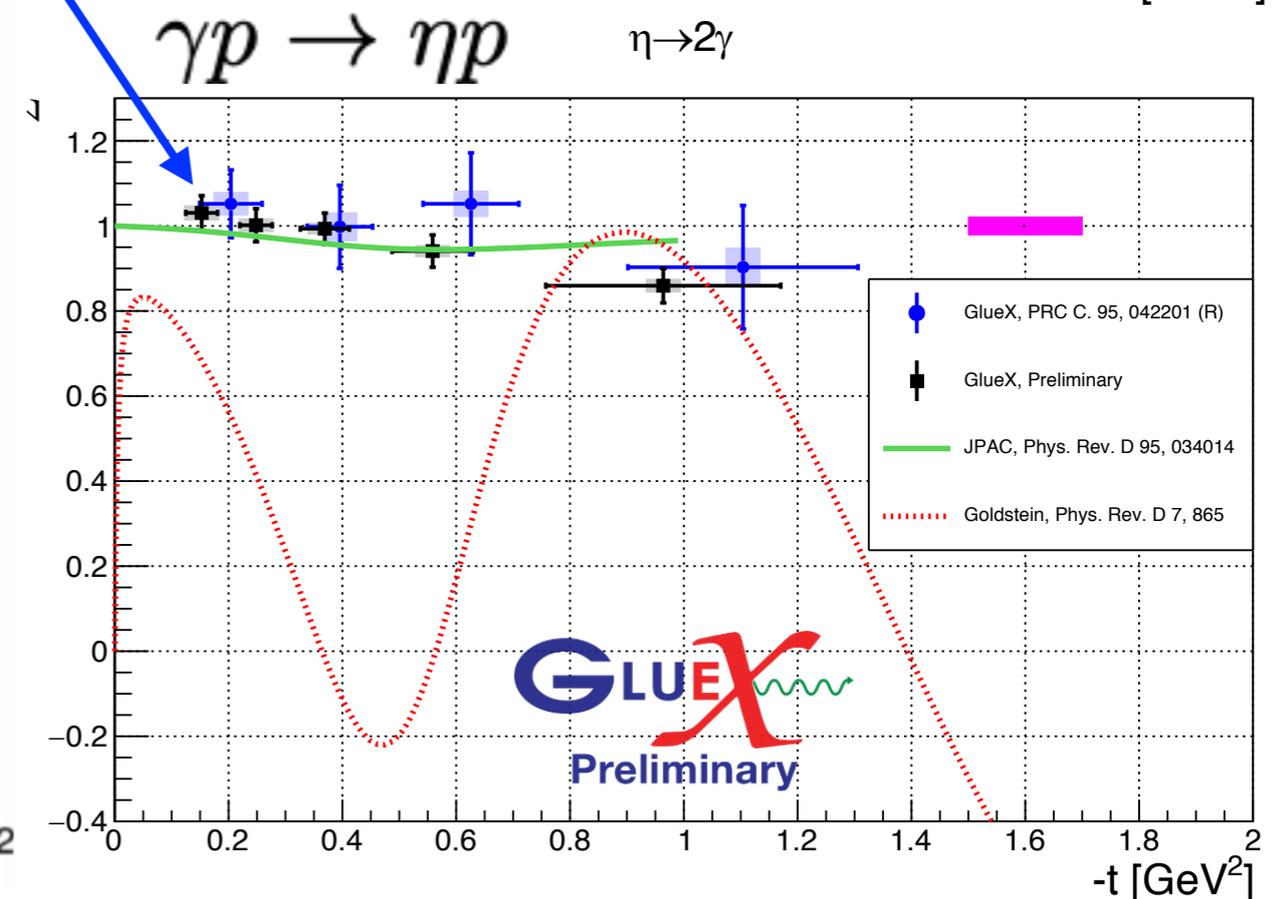
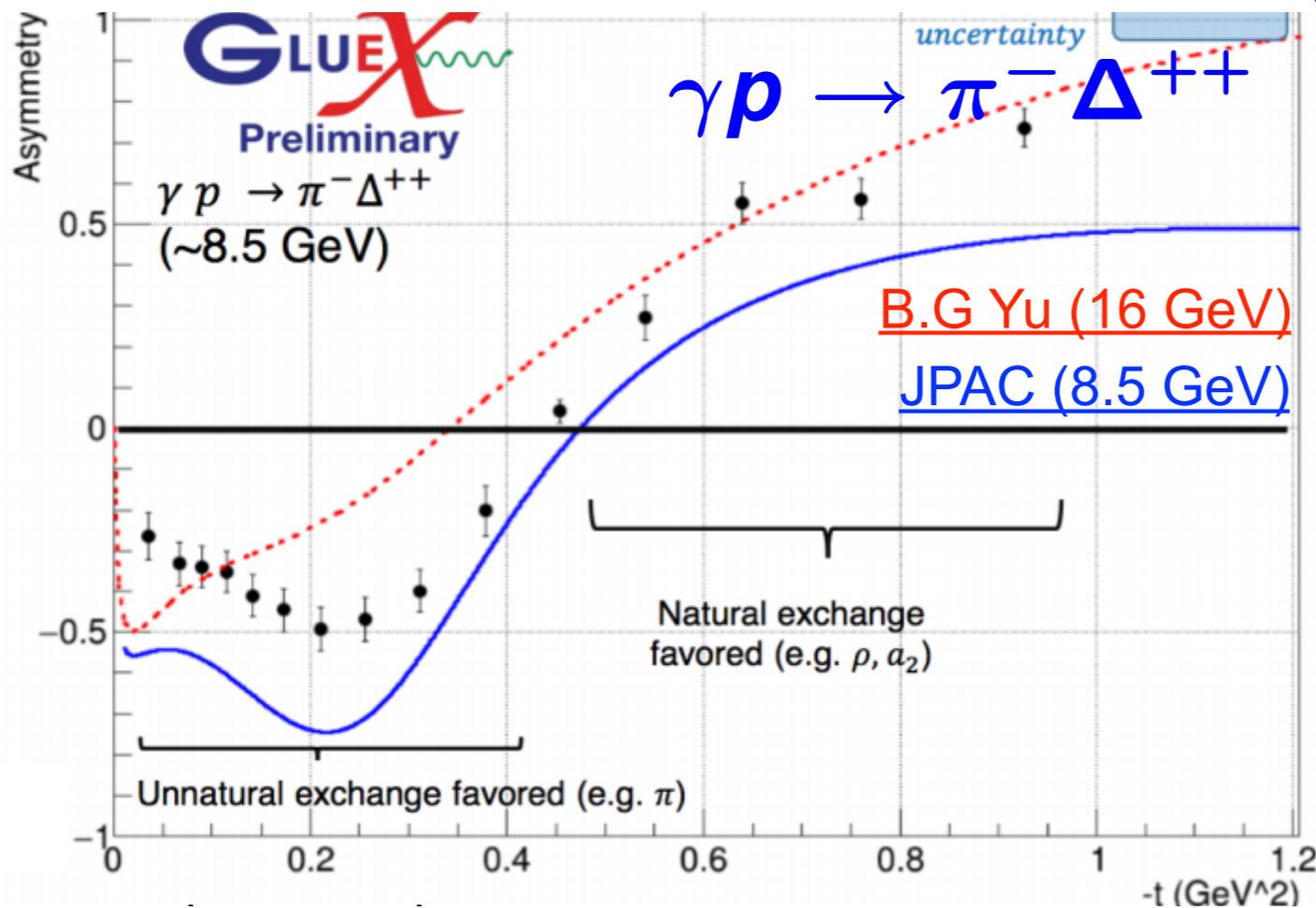
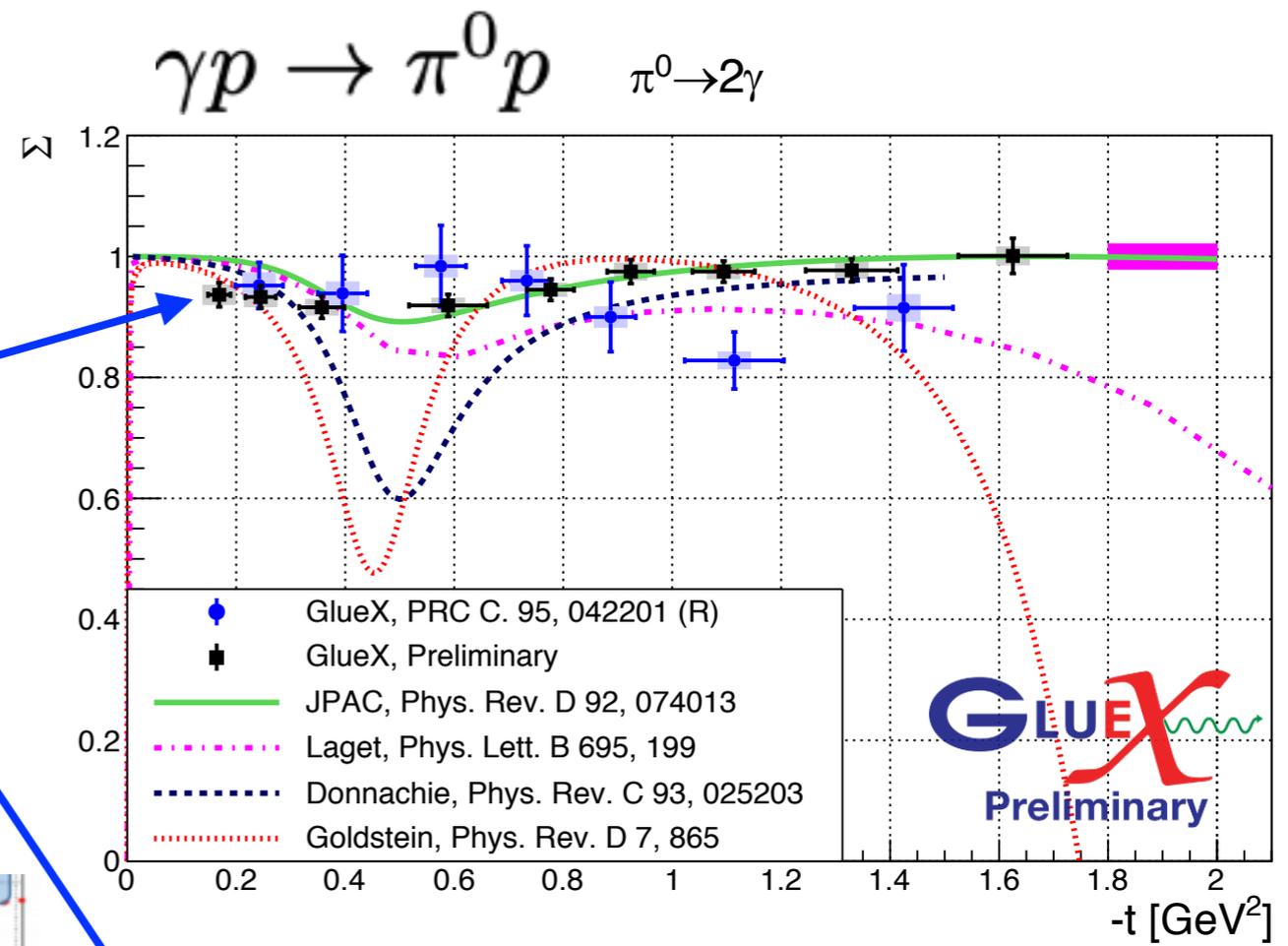
$$1^{+-} : b, h$$

Easy initial results: Need photon polarization, but most other factors cancel out.

Beam Asymmetry

First JLab 12 GeV paper
[Phys.Rev.C 95, 142201\(R\)](#)

Data under review,
 publication expected in 2019

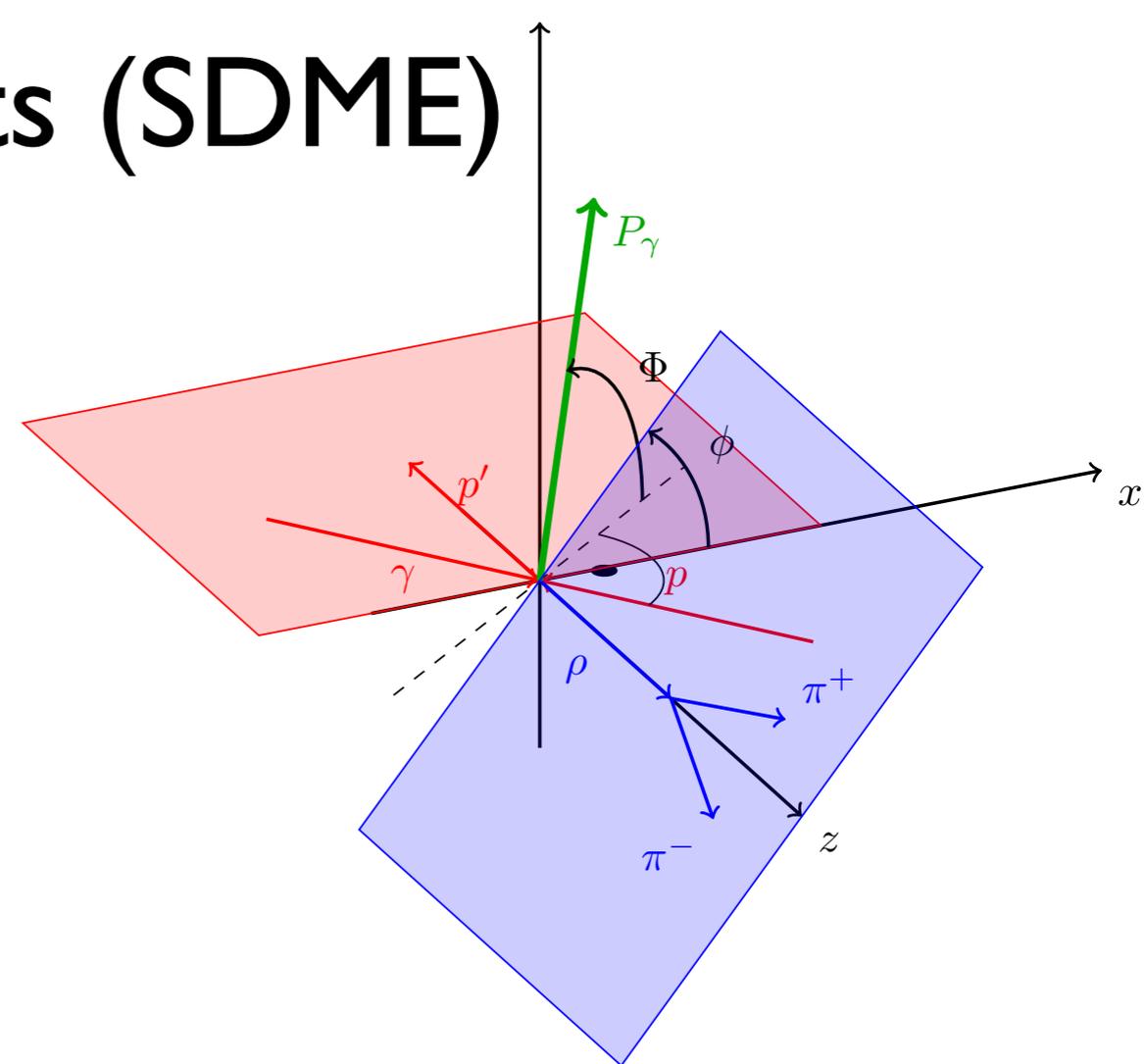


Spin Density Matrix Elements (SDME)

Measures spin transfer from linear polarized photon to vector meson

$$\gamma p \rightarrow (\rho^0, \omega, \phi) p$$

Sensitive to the production mechanism
(natural/unnatural exchange)



Linear beam polarization provides access to nine linearly independent SDMEs

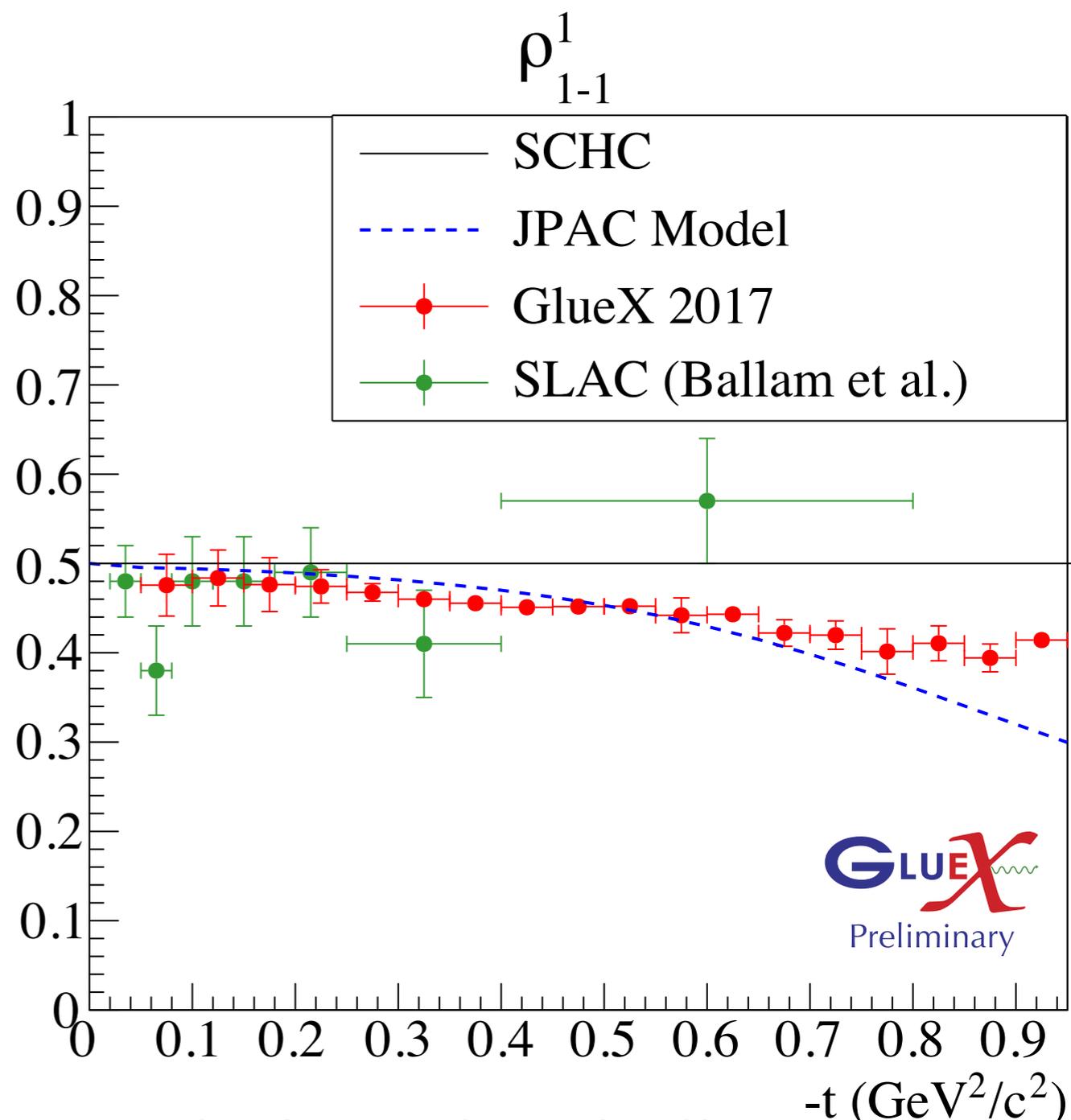
Obtained by fitting complex angular distributions

$$W_h^1(\cos \theta, \phi, \rho^1) = \frac{3}{4\pi} \left[\rho_{11}^1 \sin^2 \theta + \rho_{00}^1 \cos^2 \theta - \sqrt{2} \operatorname{Re} \rho_{10}^1 \sin 2\theta \cos \phi - \rho_{1-1}^1 \sin^2 \theta \cos 2\phi \right] \dots \text{etc.}$$

Requires good understanding of detector acceptance.

Spin Density Matrix Elements (SDME)

- Spin-density matrix elements extracted for $\rho(770)$, $\omega(782)$ and $\varphi(1020)$
- Statistical precision increased by orders of magnitude
- Natural parity exchange dominates at $E_\gamma = 9$ GeV for $t \rightarrow 0$
- General agreement with models for $t < 0.5$ GeV²/c²
- Analysis also used to tune and confirm MC simulation



Example of 1 SDME for $\rho(770)$.
Systematics dominated.

[JPAC \[Phy. Rev. D, 97 \(2018\) 094003\]](#)

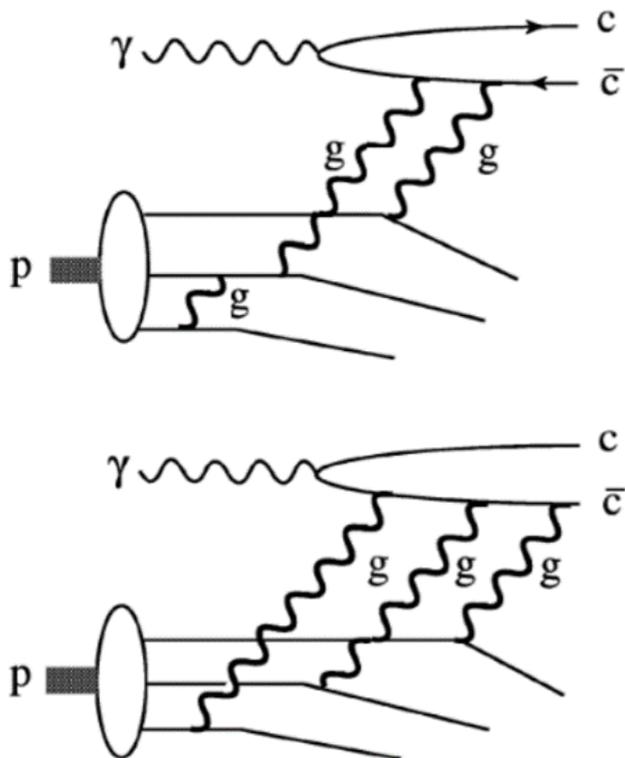
J/ψ Photoproduction at GlueX

Talk by Lubomir Pentchev yesterday

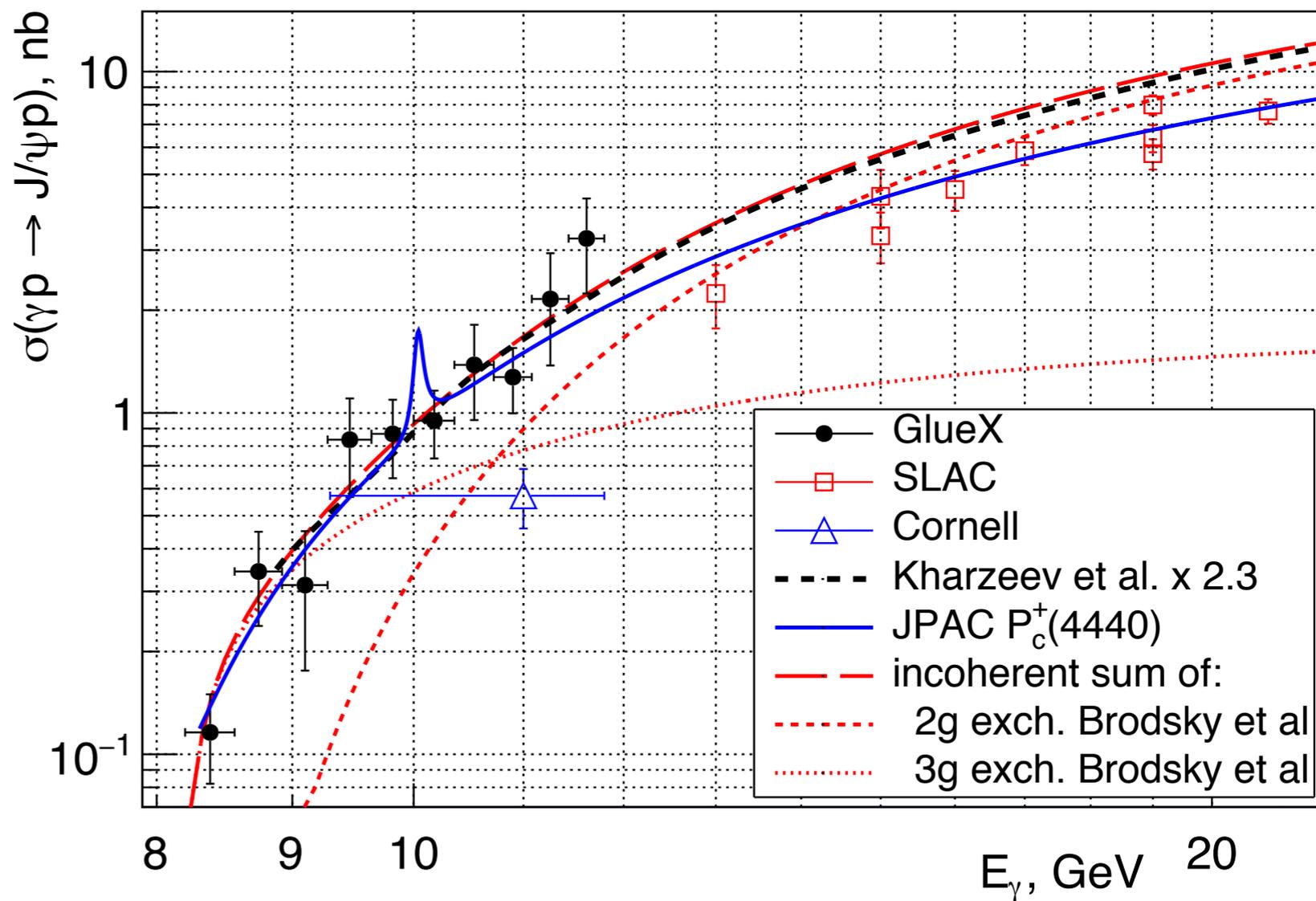
First J/ψ cross section measurement at threshold

27% normalization uncertainty

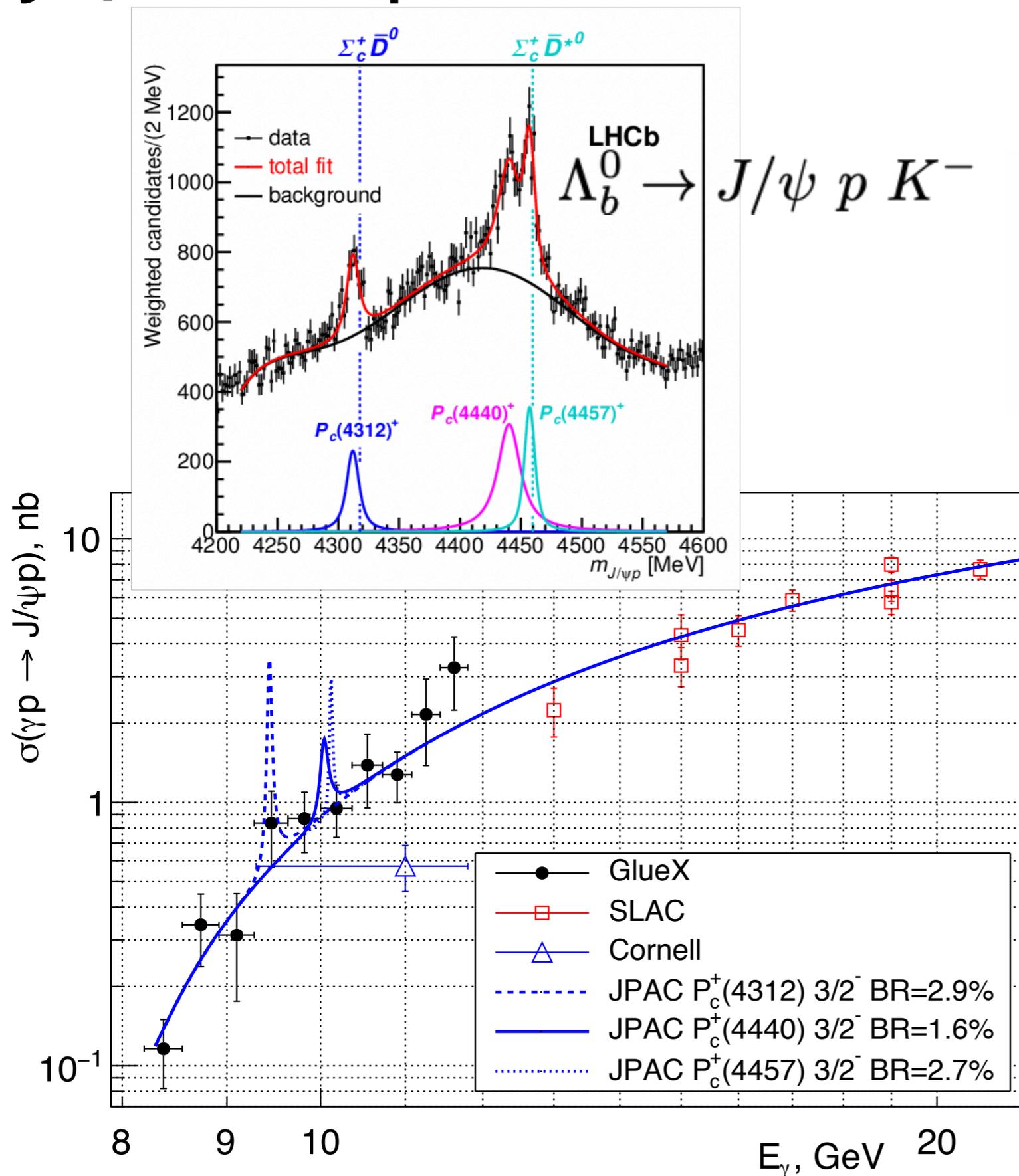
3-gluon exchange needed to describe cross section at threshold



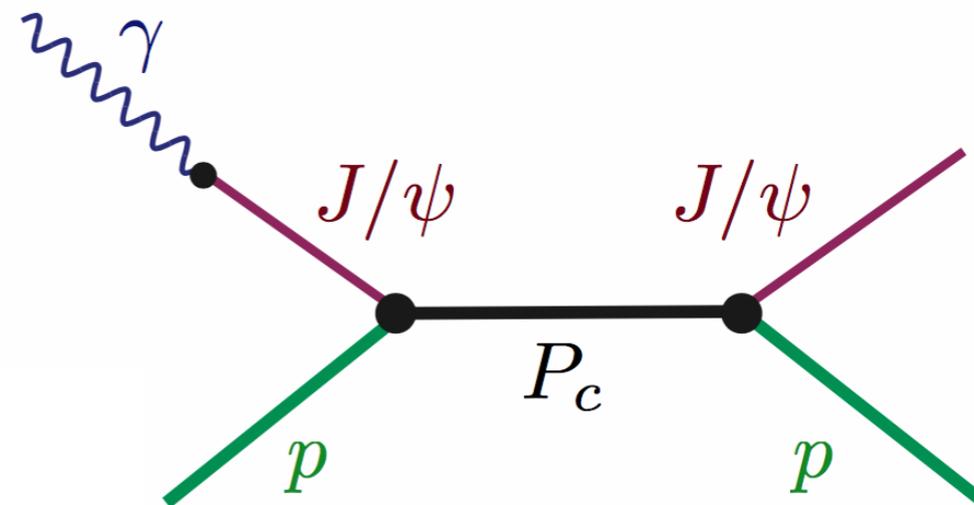
arXiv:1905.10811: Submitted to PRL



J/ψ Photoproduction at GlueX



s-channel photoproduction probes nature of 5-quark interaction!



Model-dependent upper limits at 90% CL:

$$\text{Br}(P_c(4312) \rightarrow J/\psi p) < 4.6\%$$

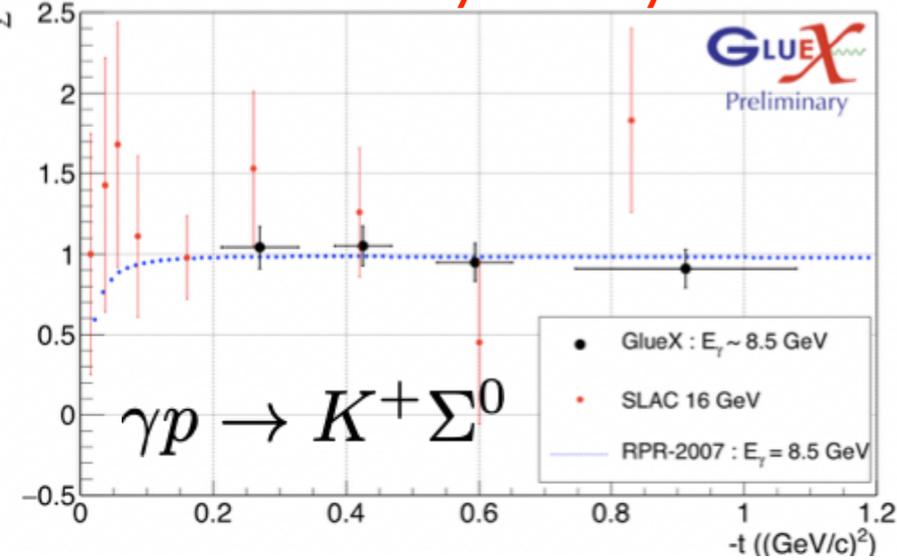
$$\text{Br}(P_c(4440) \rightarrow J/\psi p) < 2.3\%$$

$$\text{Br}(P_c(4457) \rightarrow J/\psi p) < 3.8\%$$

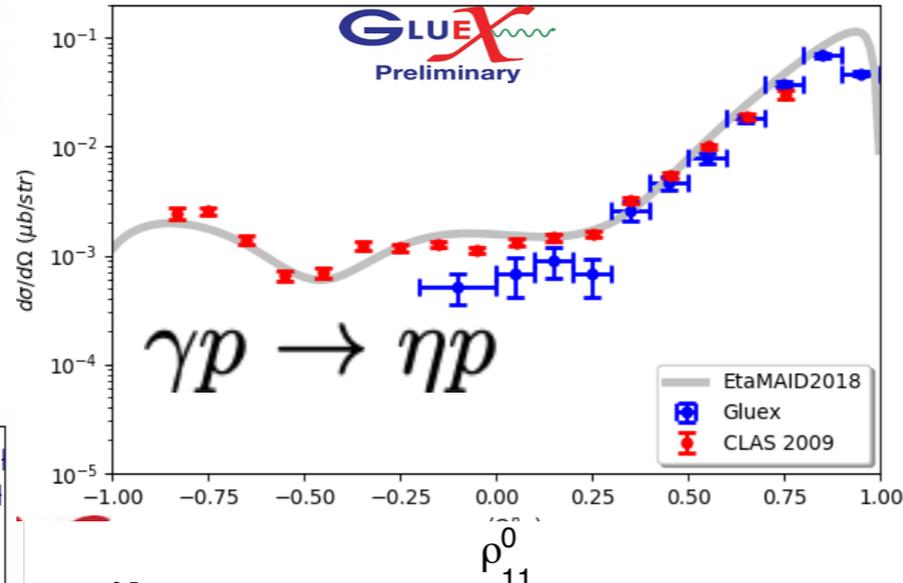
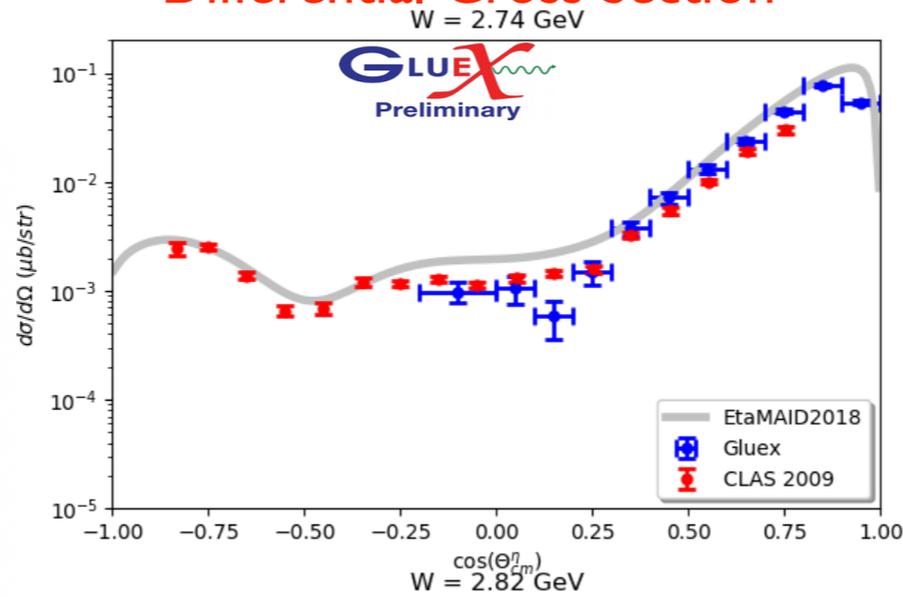
Full Phase-I under analysis:
additional 300% stats
unbinned analyses planned

Many Other Analyses Ongoing

Beam Asymmetry

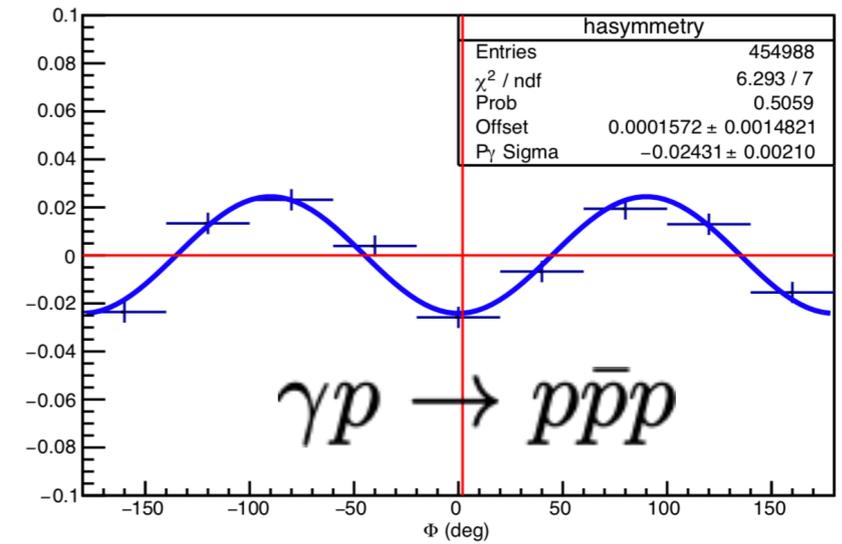


Differential Cross Section

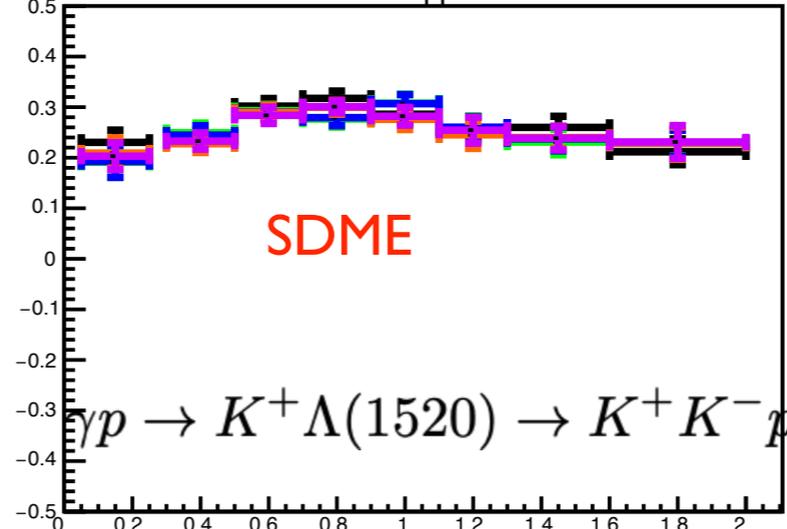
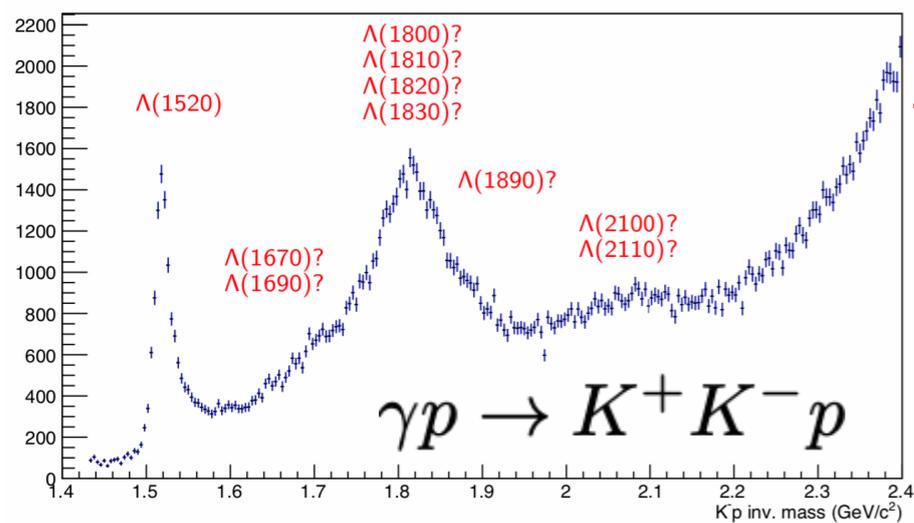


Di-baryon production

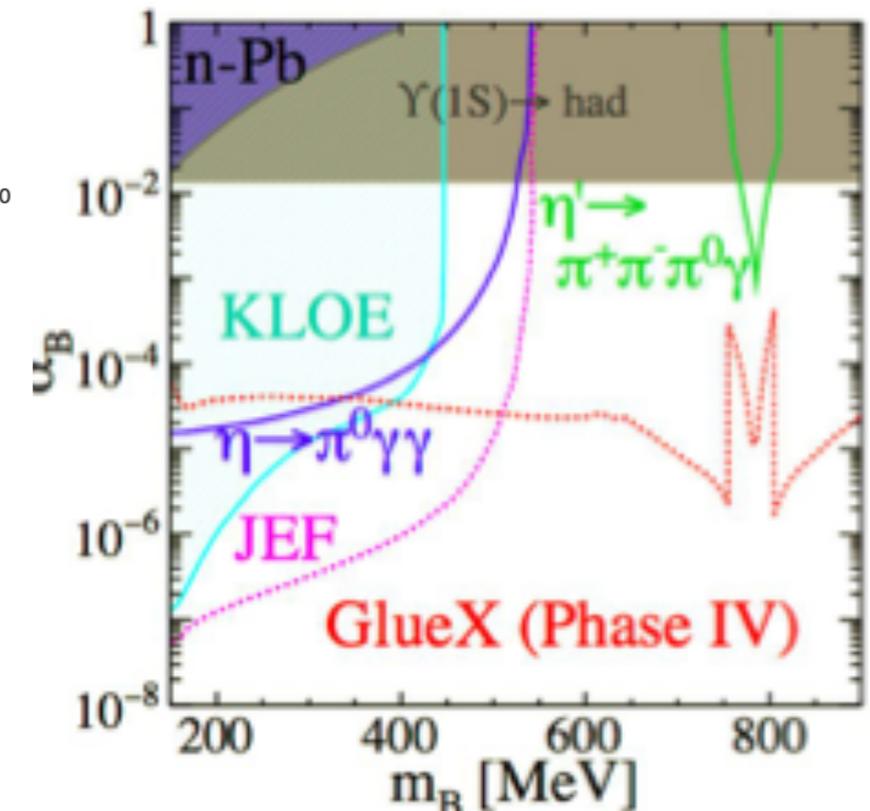
Proton-Antiproton Plane Asymmetry



Hyperon Spectroscopy

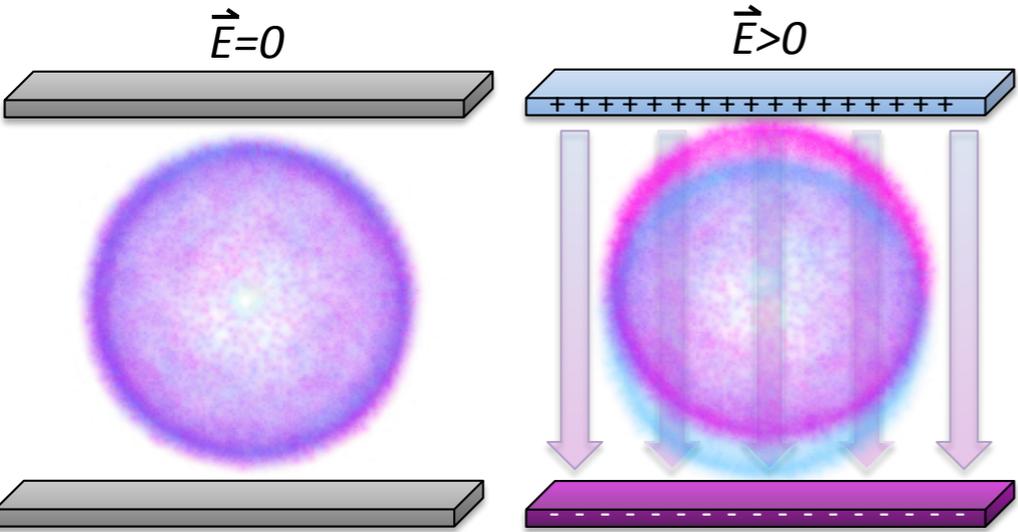
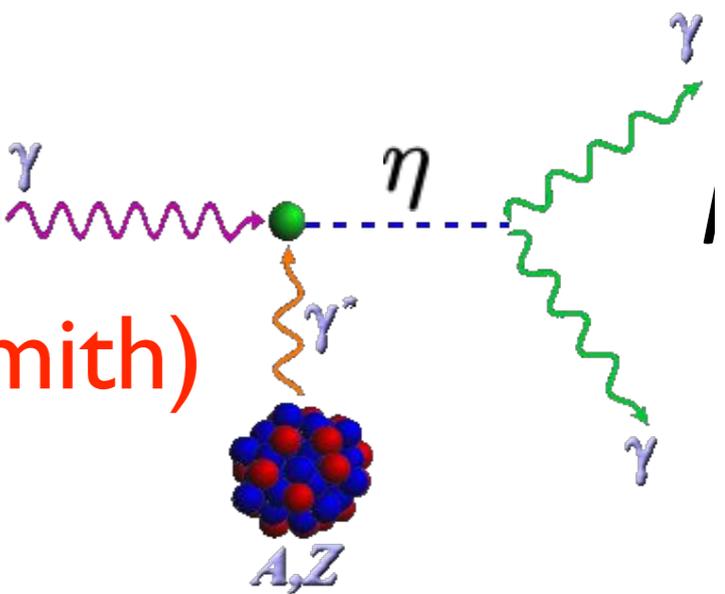


Beyond Standard Model



Primakov Effect

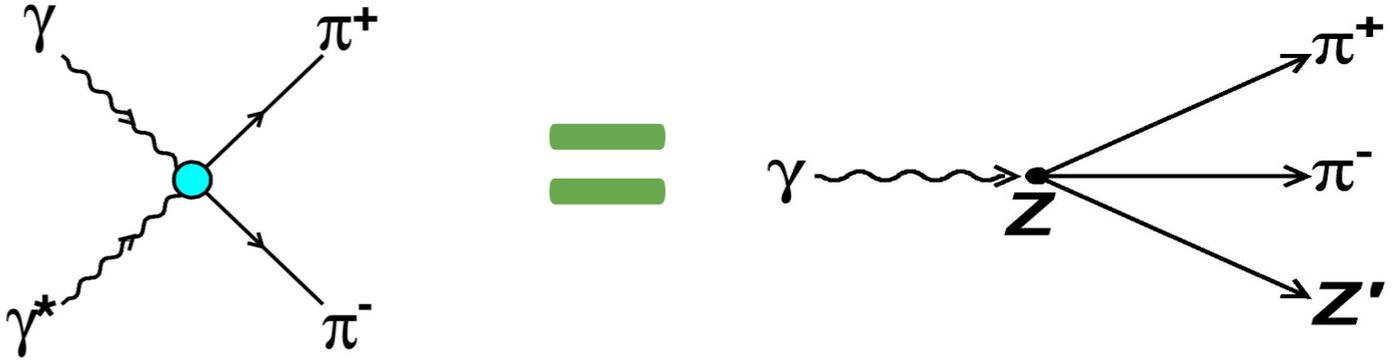
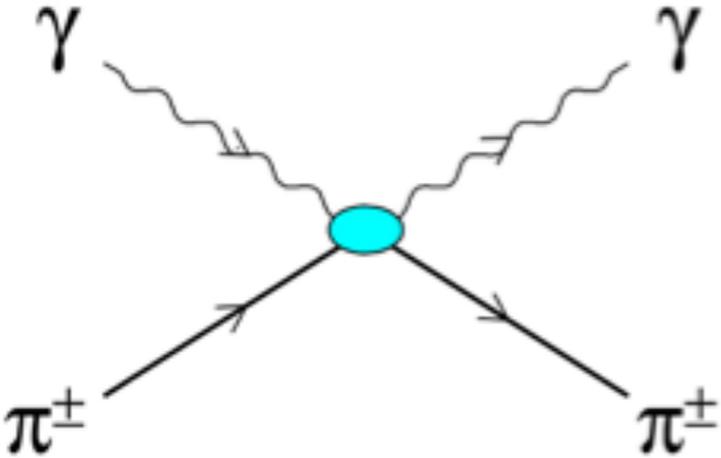
Flash Talk: PrimEx-D experiment (Andrew Smith)



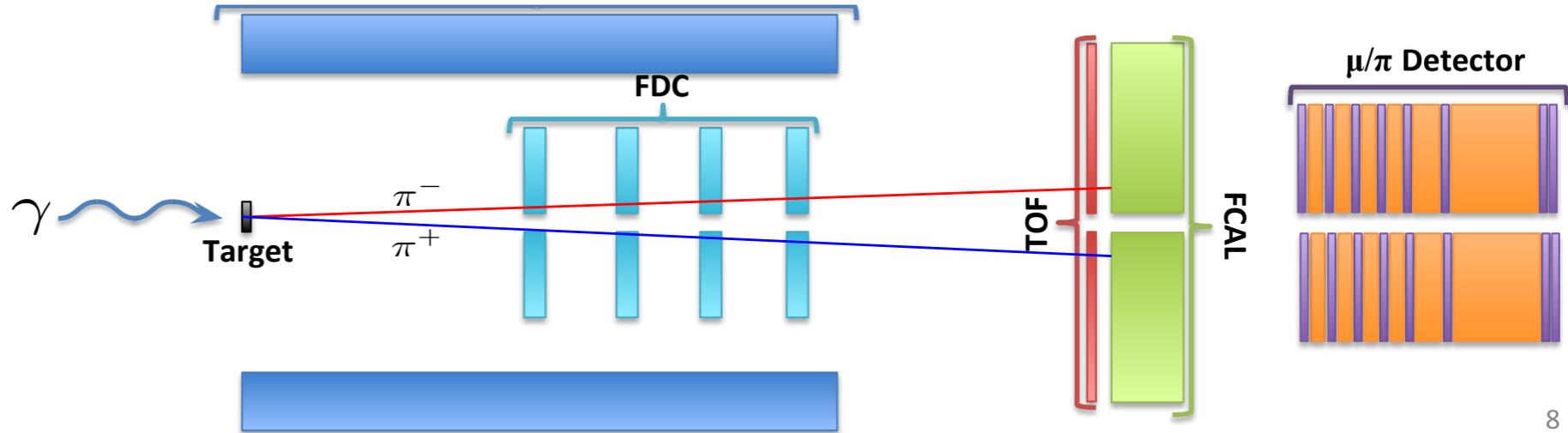
π^\pm polarizability is directly related to “chiral-even” part of the ChPT Lagrangian.

$$\alpha_\pi = -\beta_\pi = \frac{4\alpha}{m_\pi F_\pi^2} (L_9^r - L_{10}^r)$$

EM polarizability affects the Compton scattering cross section

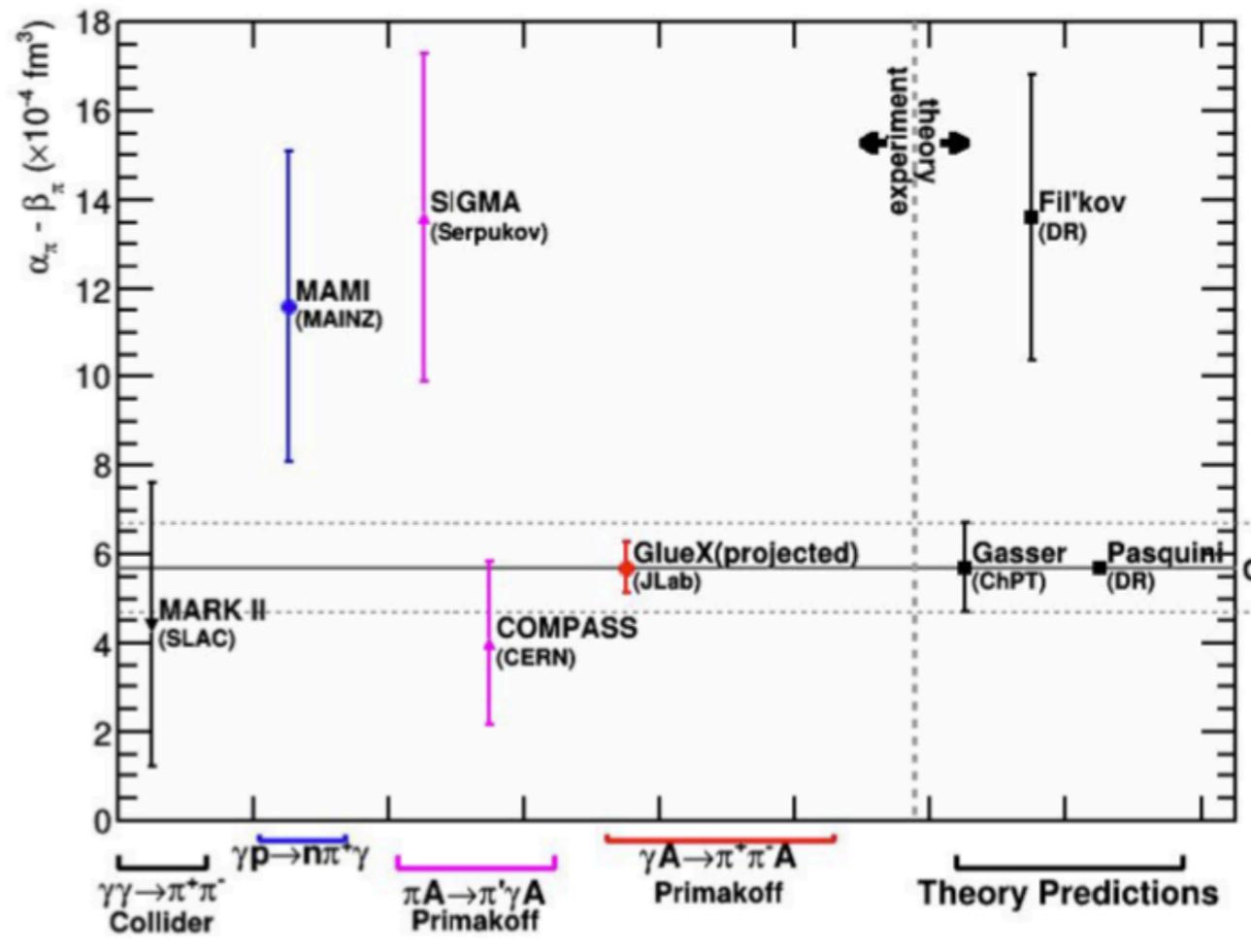
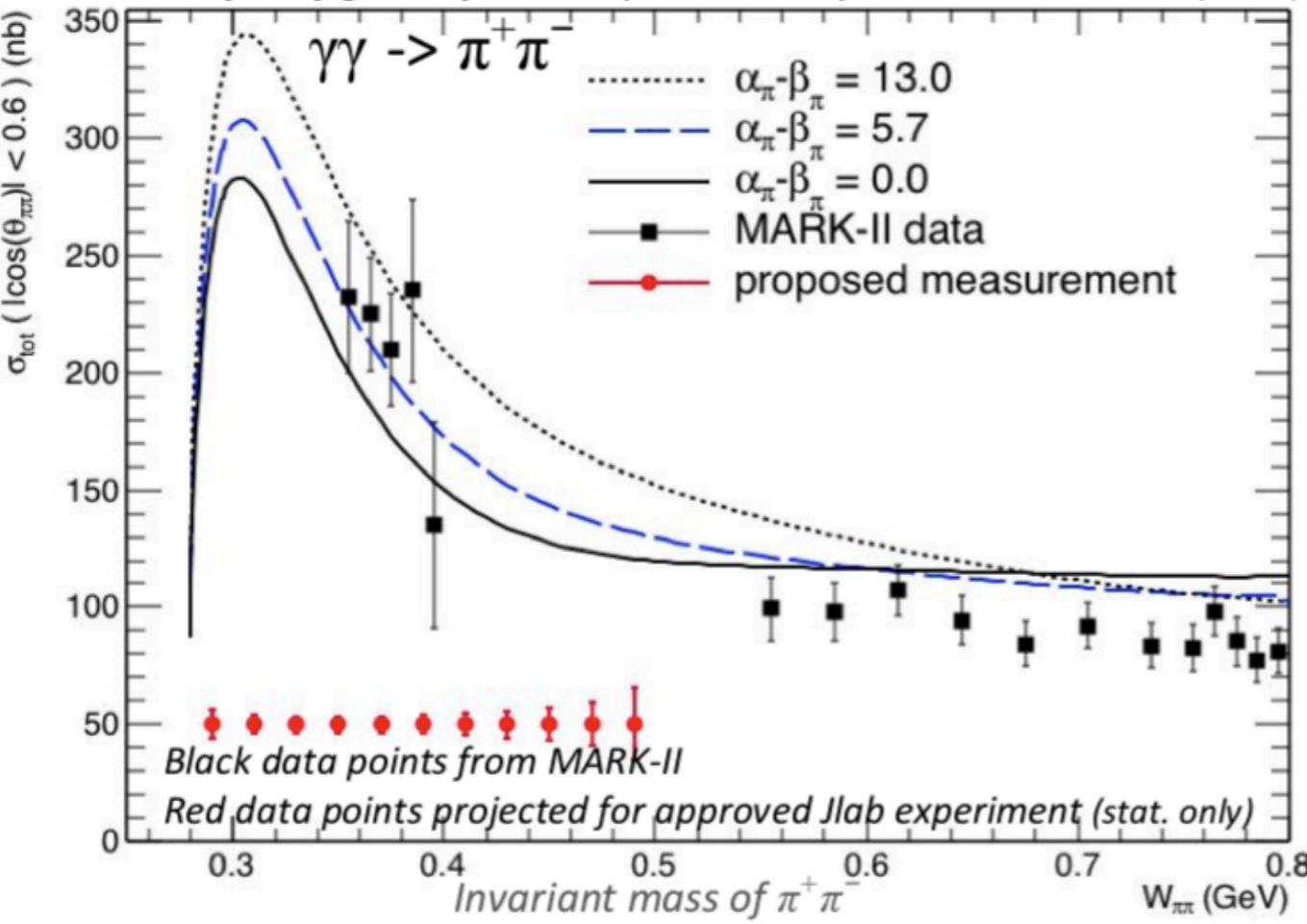


Charged Pion Polarizability Experiment (CPP)



PROJECTED RESULTS FOR $\alpha_{\pi} - \beta_{\pi}$

Curves from figure 5. from Pasquini et al. Phys. Rev. C 77, 065211 (2008)



The JLab Eta Factory (JEF) program

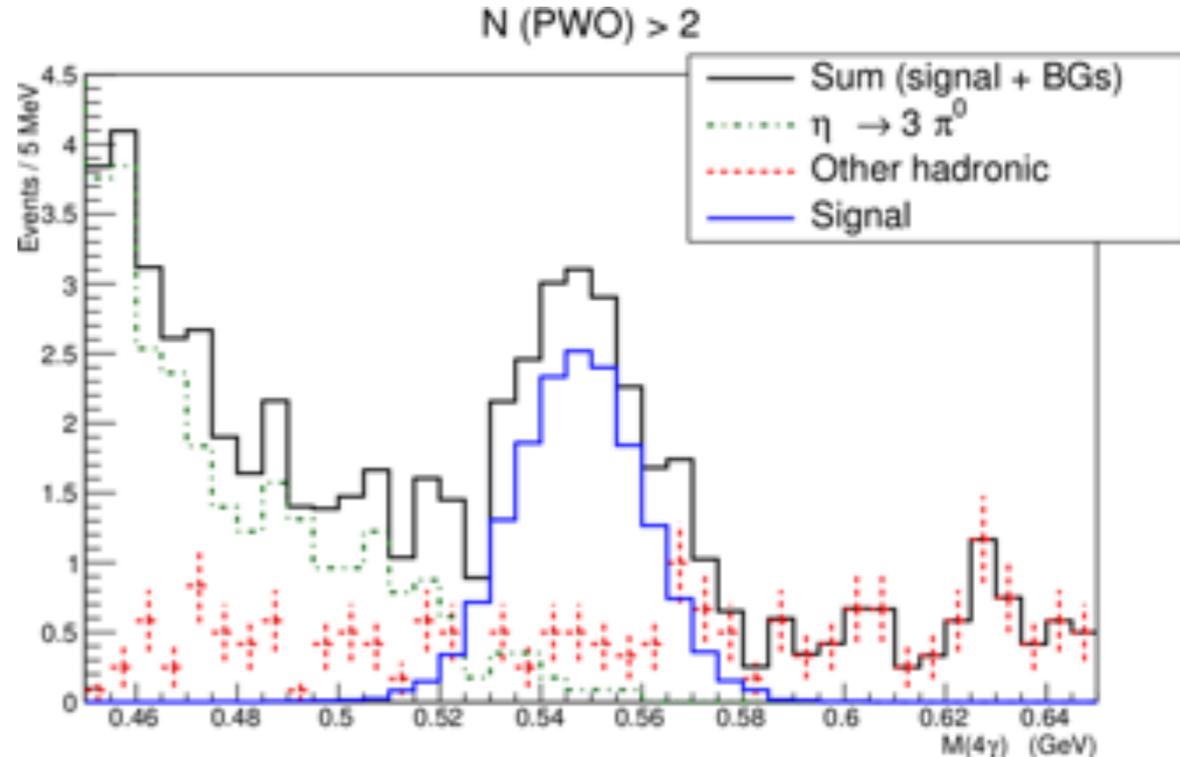
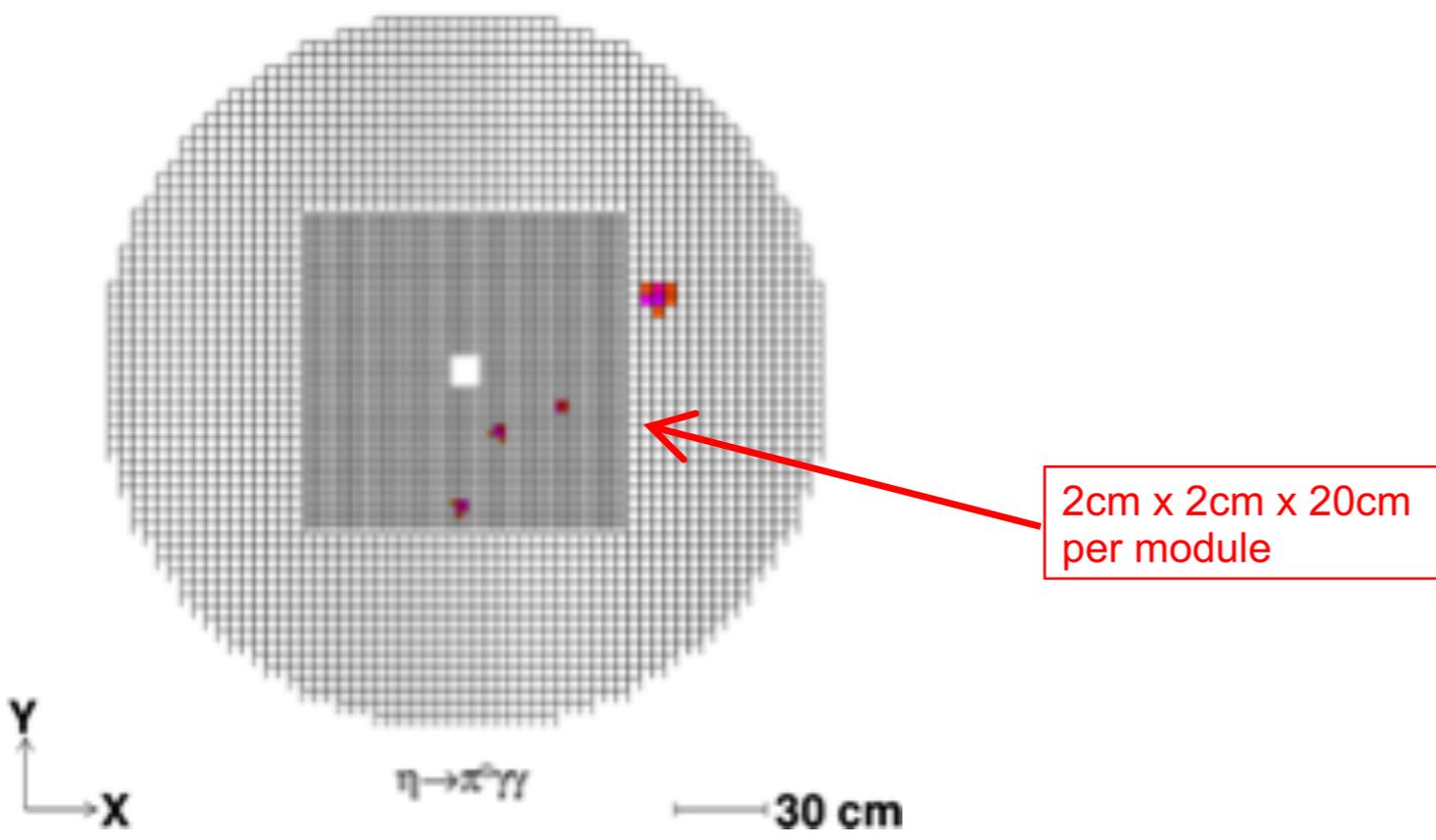
Study η decays
with emphasis
on rare channels

Mode	Branching Ratio	Physics Highlight	Photons
priority:			
$\gamma + B$	beyond SM	leptophobic vector boson	4
$\pi^0 2\gamma$	$(2.7 \pm 0.5) \times 10^{-4}$	χ PTh at $\mathcal{O}(p^6)$	4
$3\pi^0$	$(32.6 \pm 0.2)\%$	$m_u - m_d$	6
$\pi^+\pi^-\pi^0$	$(22.7 \pm 0.3)\%$	$m_u - m_d, CV$	2
3γ	$< 1.6 \times 10^{-5}$	CV, CPV	3

$\pi^0\gamma\gamma$ requires upgrade to FCAL
Replace inner blocks with PbWO₄ crystals

Simulation of $\gamma p \rightarrow p\eta, \eta \rightarrow \pi^0\gamma\gamma$
for 1 day of running
Beam energy: 8.4-11.7 GeV
intensity $N_\gamma \sim 1 \times 10^8/s$

FCAL view from downstream looking upstream



Summary

GlueX has started mapping the normal meson spectrum
First step towards establishing the hybrid meson spectrum.
Phase I run is complete, program of production & cross section
measurements well underway.

Flash Talk: Cascade Photoproduction (Ashley Ernst)

First limits on $\text{Br}(P_c \rightarrow J/\psi p)$ constrain nature of LHCb P_c states

Phase-II High-luminosity running will begin this Fall, extend reach
of strange-quark program

Flash Talk: GlueX DIRC upgrade (Yunjie Yang)

Future Experiments: PRIMEX, CPP, JEF are approved, preparations are
underway and some data has been taken.

Flash Talk: PrimEx-D experiment (Andrew Smith)