

Recent results from **GLUEX**

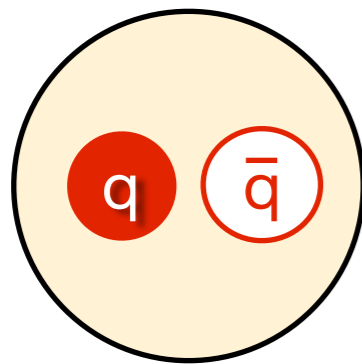
Justin Stevens



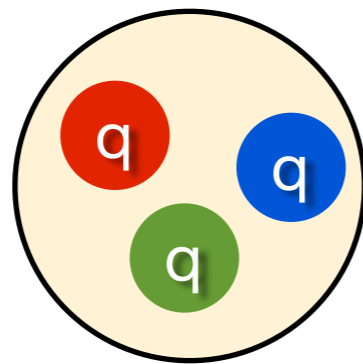
WILLIAM & MARY

CHARTERED 1693

Confined states of quarks and gluons



mesons

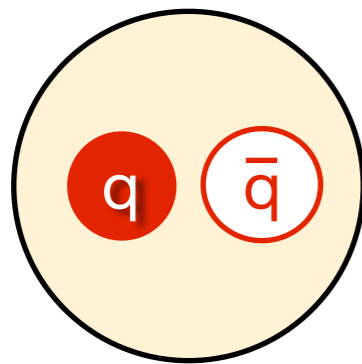


baryons

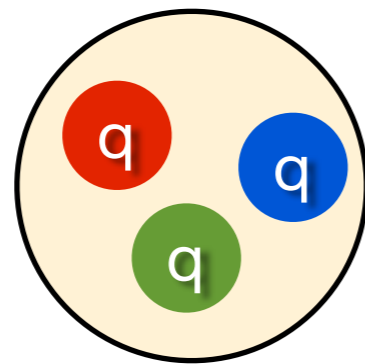
Observed mesons and baryons well described by 1st principles QCD

But these aren't the only states permitted by QCD

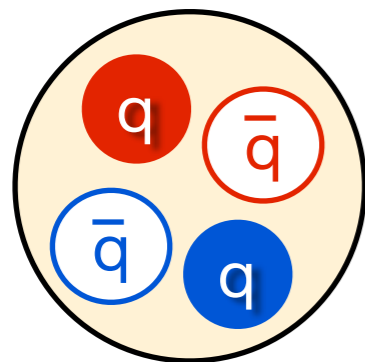
Confined states of quarks and gluons



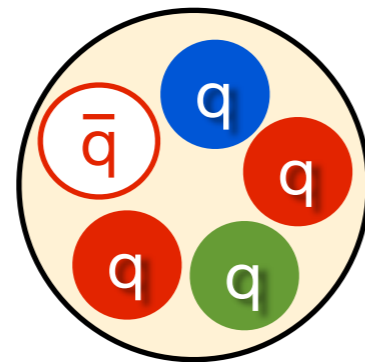
mesons



baryons



tetraquark



pentaquark

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A SCHEMATIC MODEL OF BARYONS AND MESONS *

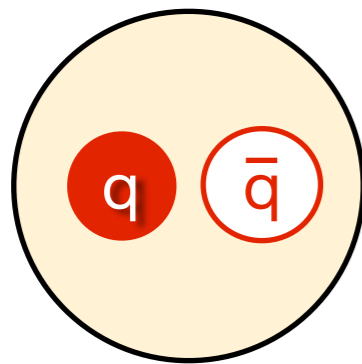
M. GELL-MANN

California Institute of Technology, Pasadena, California

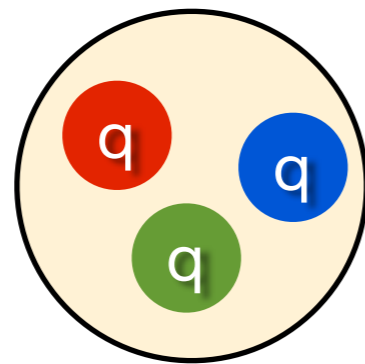
... Baryons can now be constructed from quarks by using the combinations (qqq) , $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. ...

[Phys. Lett. 8 \(1964\) 214](#)

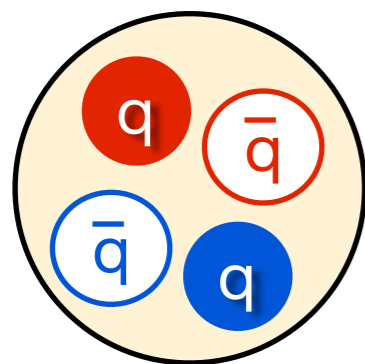
Confined states of quarks and gluons



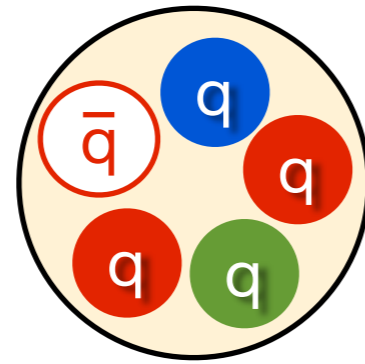
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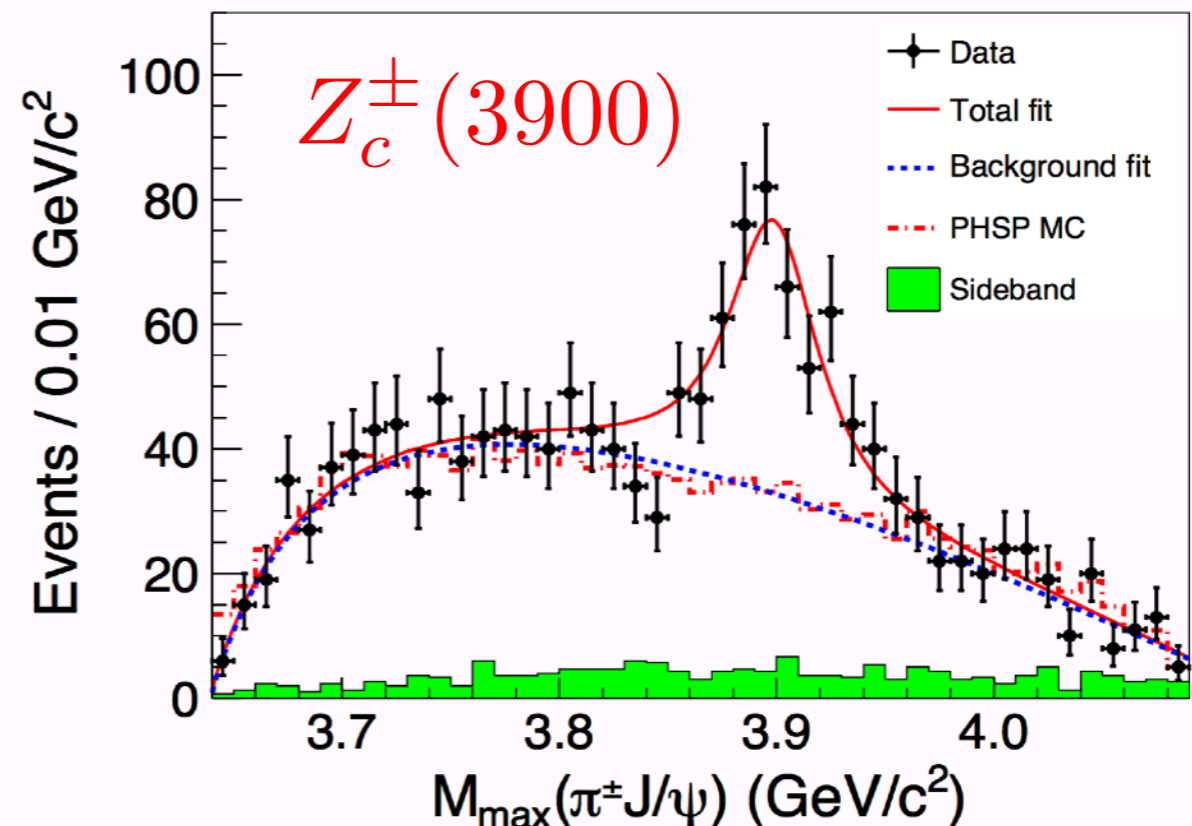


pentaquark

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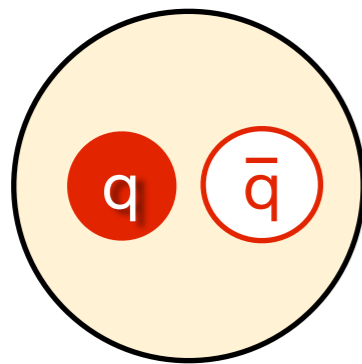
But these aren't the only states permitted by QCD

$$e^+ e^- \rightarrow J/\psi \pi^+ \pi^-$$

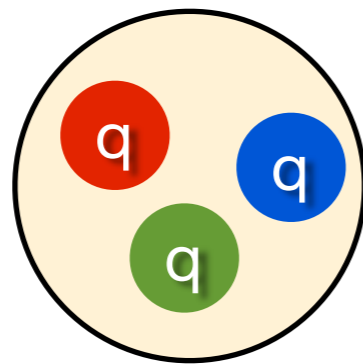


PRL 110, 252001 (2013) BES III

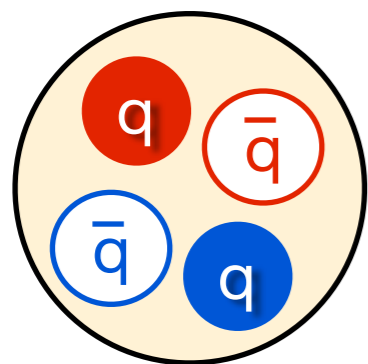
Confined states of quarks and gluons



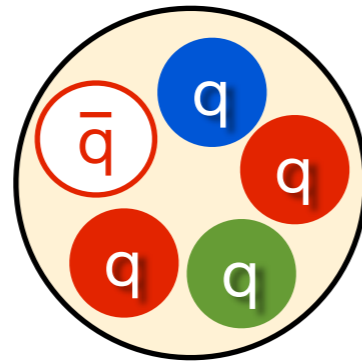
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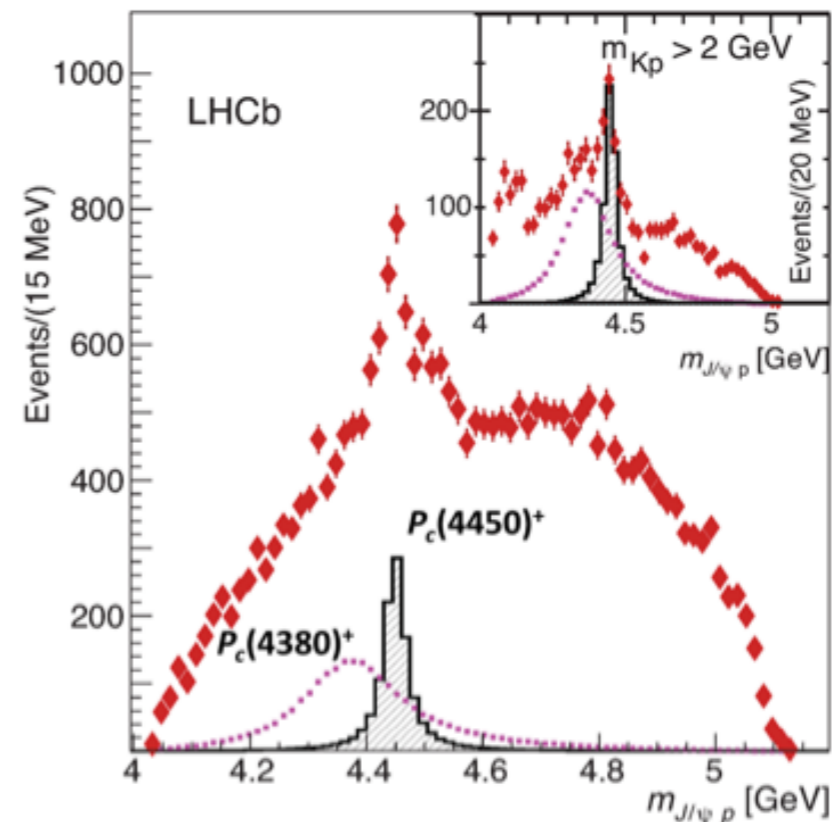


pentaquark

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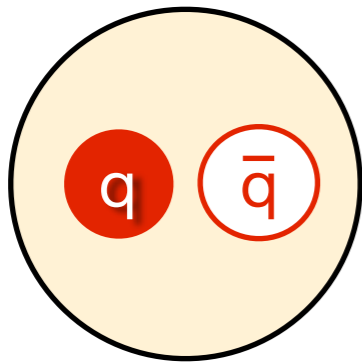
$$\Lambda_b \rightarrow J/\psi p K^-$$



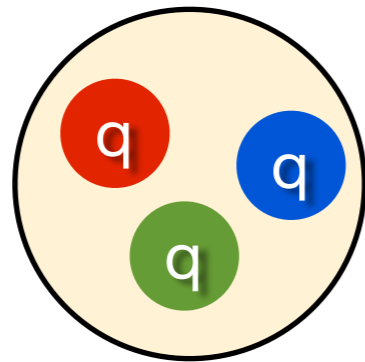
PRL 115, 072001 (2015)



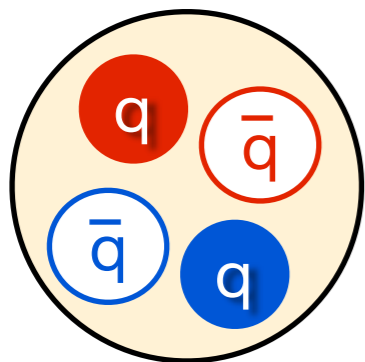
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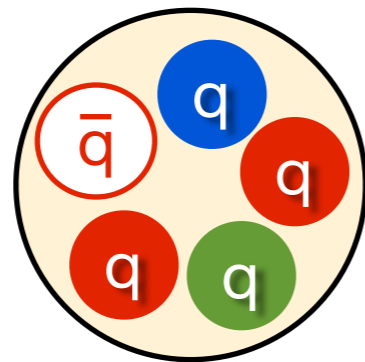
mesons



baryons



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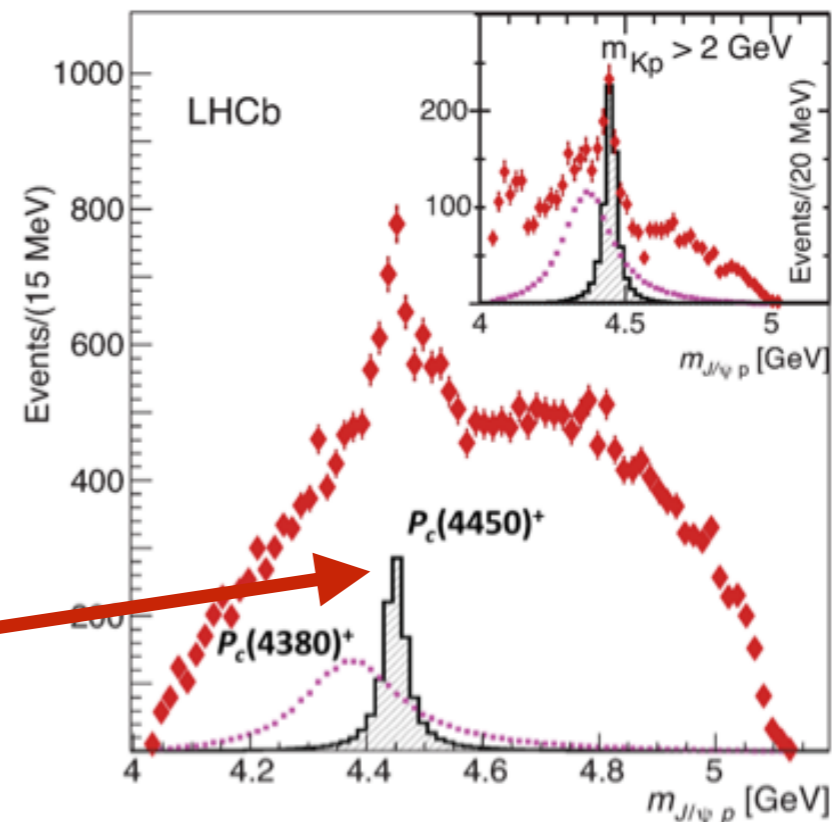


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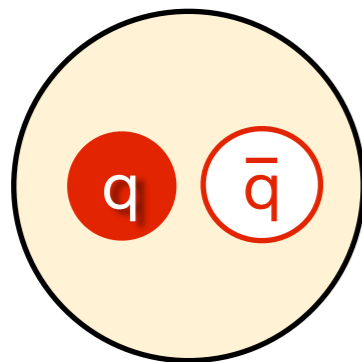
Accessible at

Jefferson Lab

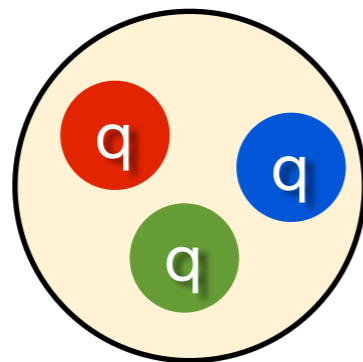
PRL 115, 072001 (2015)



Confined states of quarks and gluons



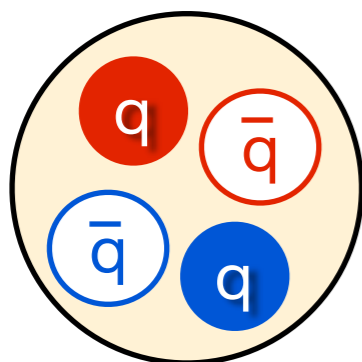
mesons



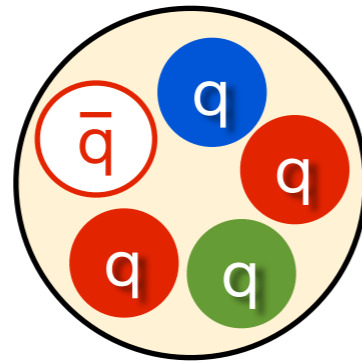
baryons

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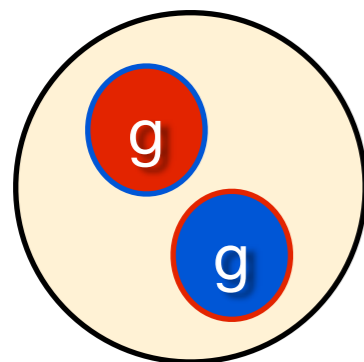
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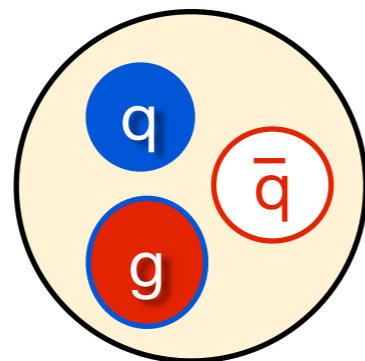
tetraquark



pentaquark



glueball

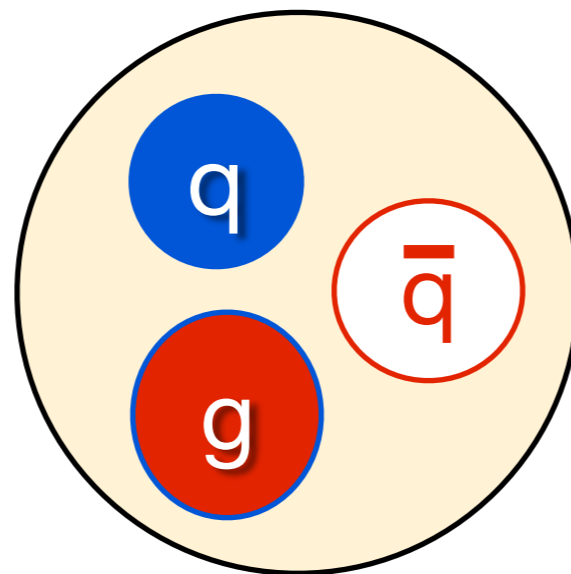


hybrid meson

Do gluonic degrees of freedom manifest themselves in the bound states we observe in nature?

Hybrid mesons and gluonic excitations

- * Excited gluonic field coupled to $q\bar{q}$ pair
- * Rich spectrum of hybrid mesons predicted by Lattice QCD
- * Gluonic field with $J^{PC} = 1^{+-}$ and mass = 1-1.5 GeV

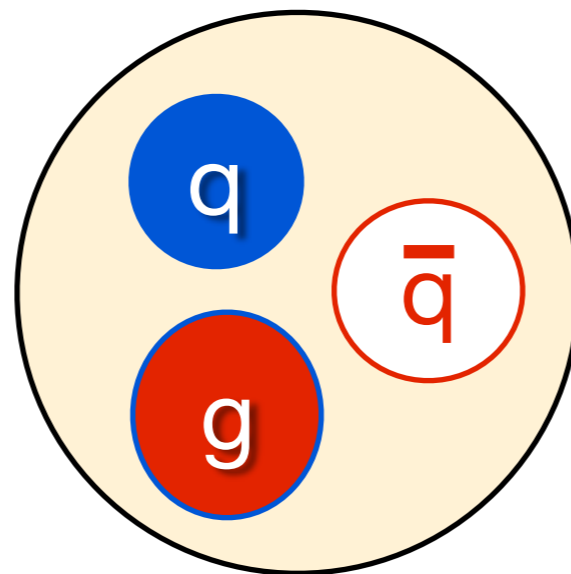


hybrid meson

Hybrid mesons and gluonic excitations

- * Excited gluonic field coupled to $q\bar{q}$ pair
- * Rich spectrum of hybrid mesons predicted by Lattice QCD
- * Gluonic field with $J^{PC} = 1^{+-}$ and mass = 1-1.5 GeV
- * “Exotic” J^{PC} : not simple $q\bar{q}$ from the non-rel. quark model

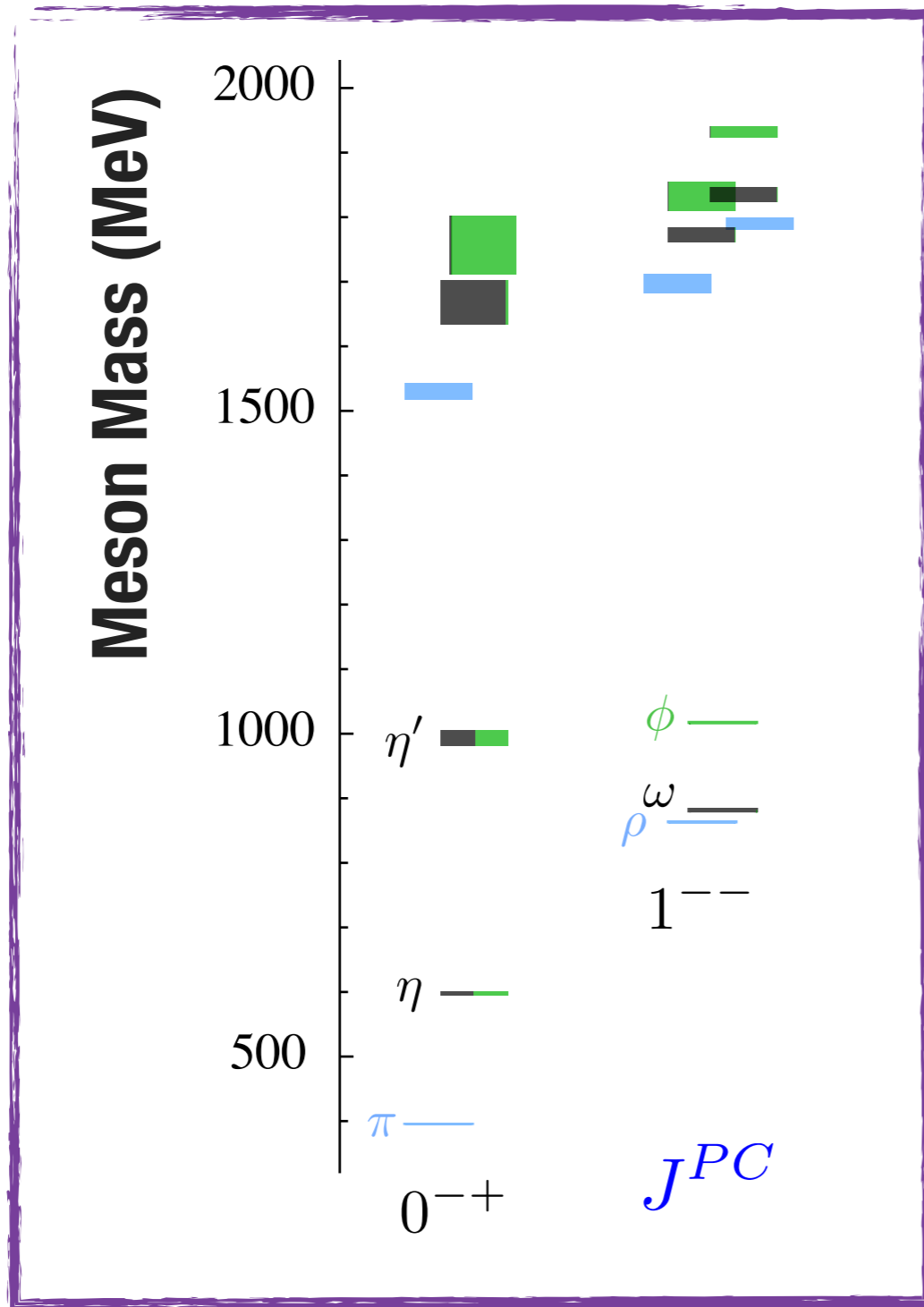
$$J^{PC} = 0^{+-}, 1^{-+}, 2^{+-} \dots$$



hybrid meson

$$\begin{aligned} \vec{J} &= \vec{L} + \vec{S} \\ P &= (-1)^{L+1} \\ C &= (-1)^{L+S} \end{aligned}$$

Lattice QCD



$$u\bar{u} + d\bar{d} \quad \blacksquare$$

$$s\bar{s} \quad \blacksquare$$

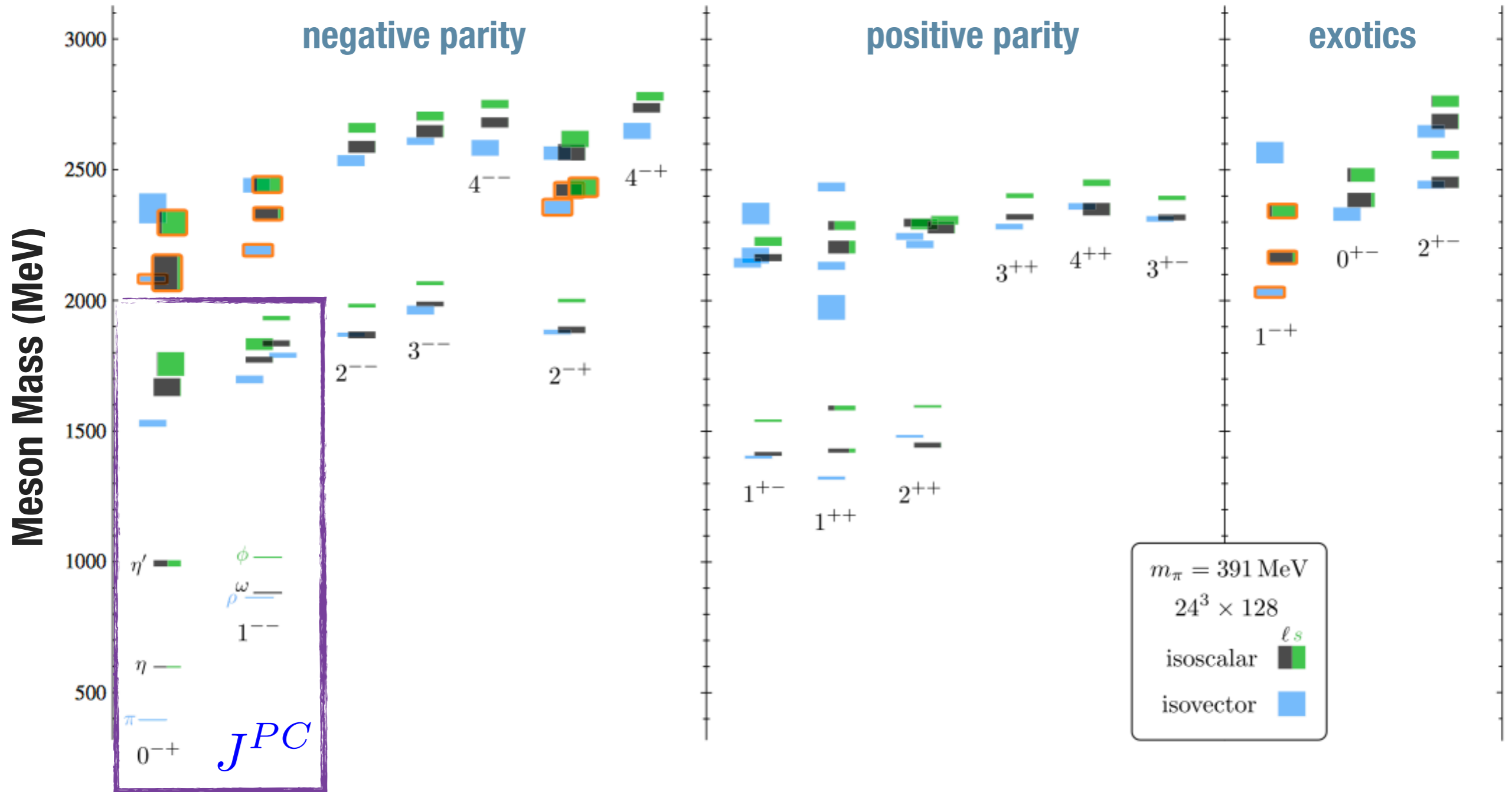
$$\phi = |s\bar{s}\rangle$$

$$\omega = |u\bar{u} + d\bar{d}\rangle$$

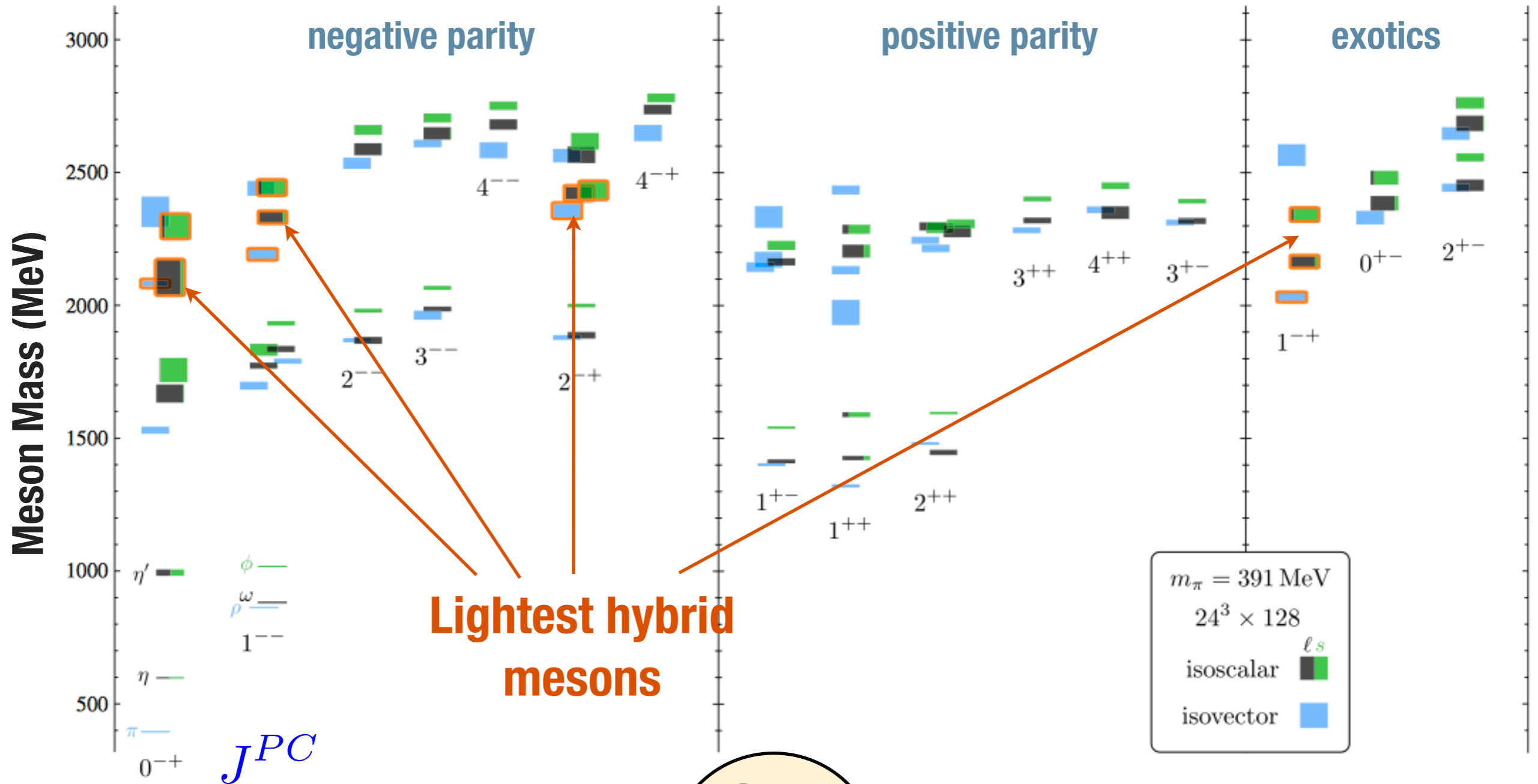
$$\pi^0 = |u\bar{u} - d\bar{d}\rangle$$

Note: $m_\pi = 392 \text{ MeV}$

Lattice QCD



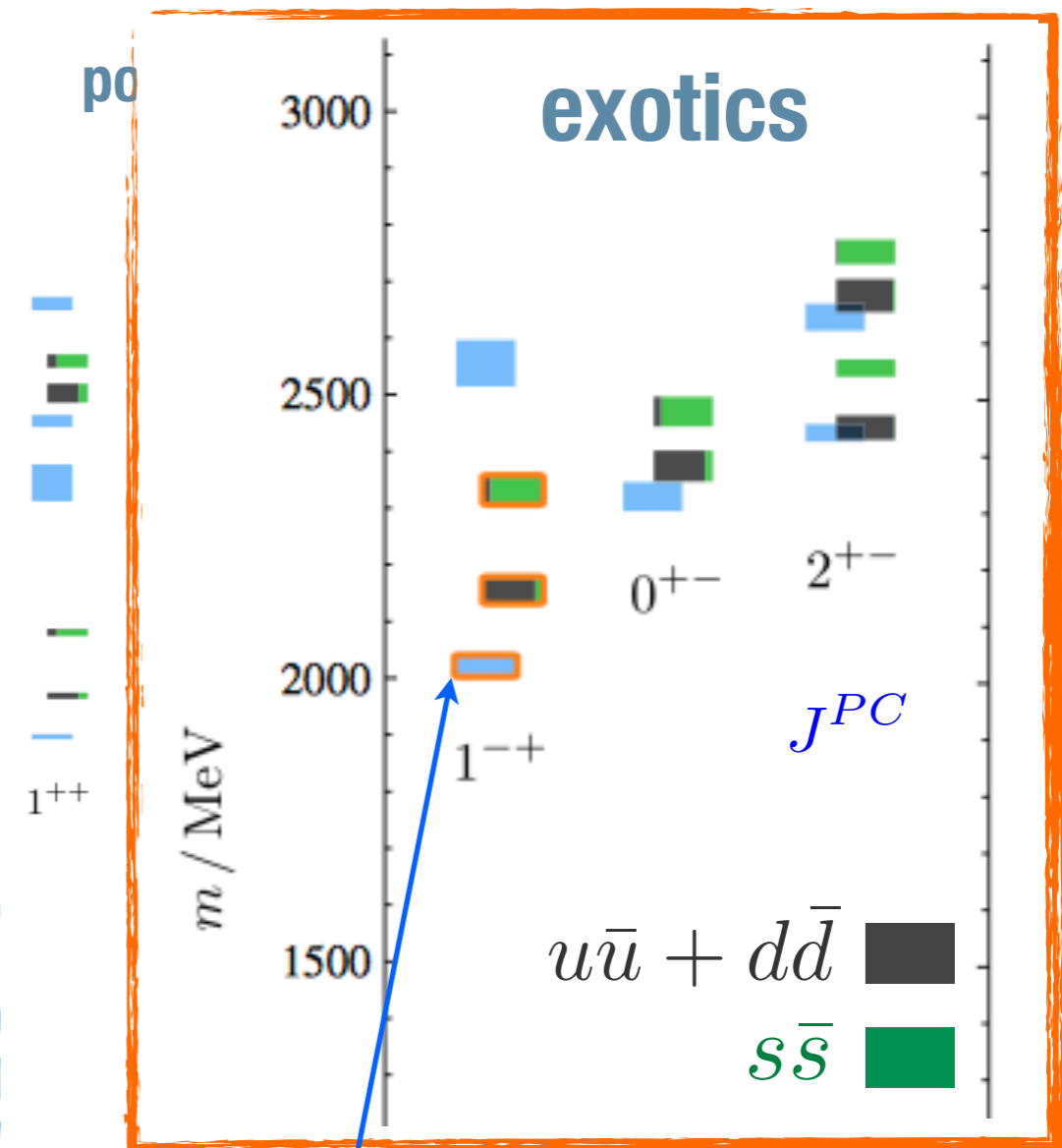
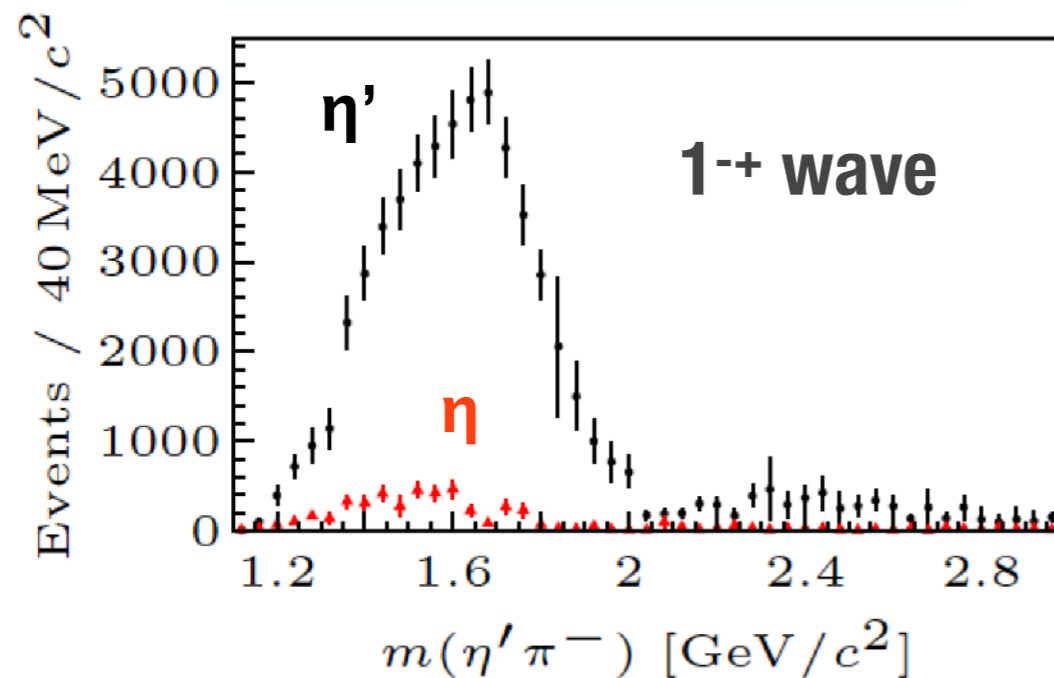
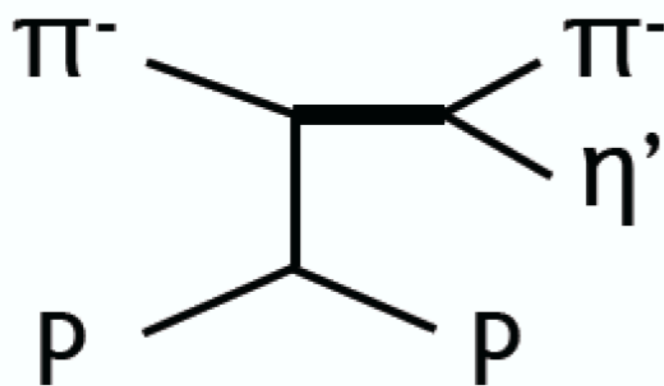
Lattice QCD



Lattice QCD

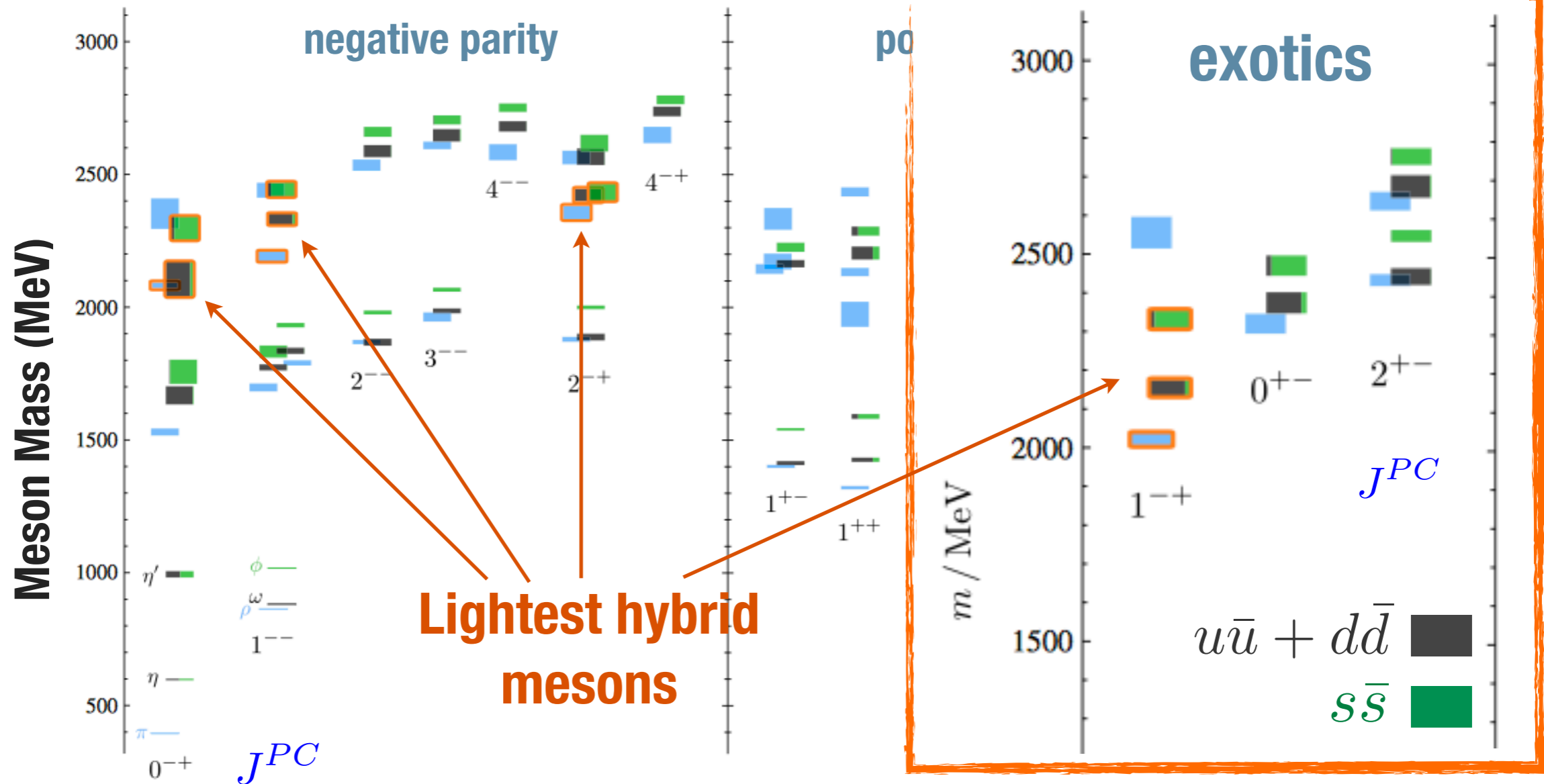


Compass: PLB 740 (2015) 303



Most experimental searches for hybrids limited to the π_1 state

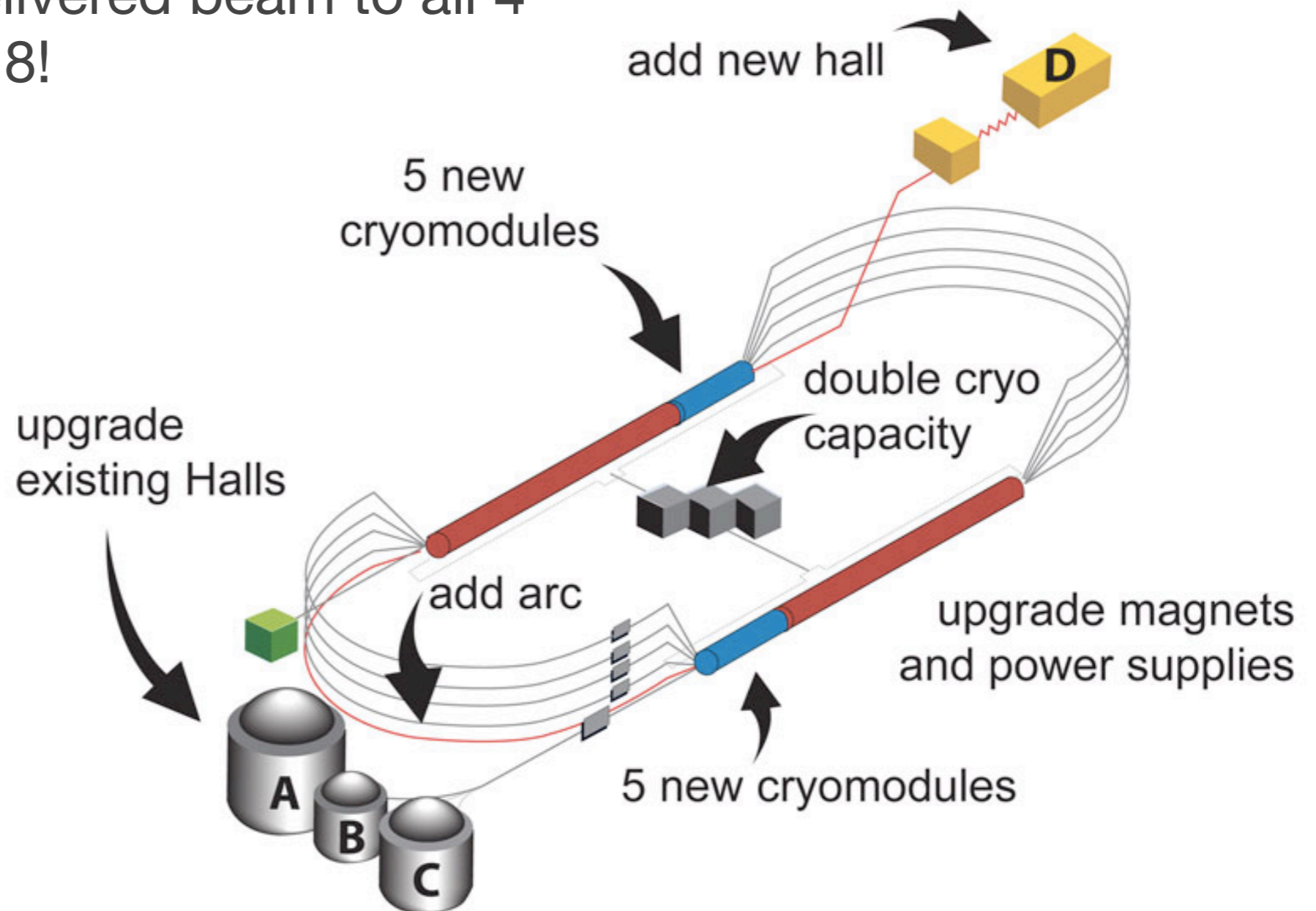
Lattice QCD



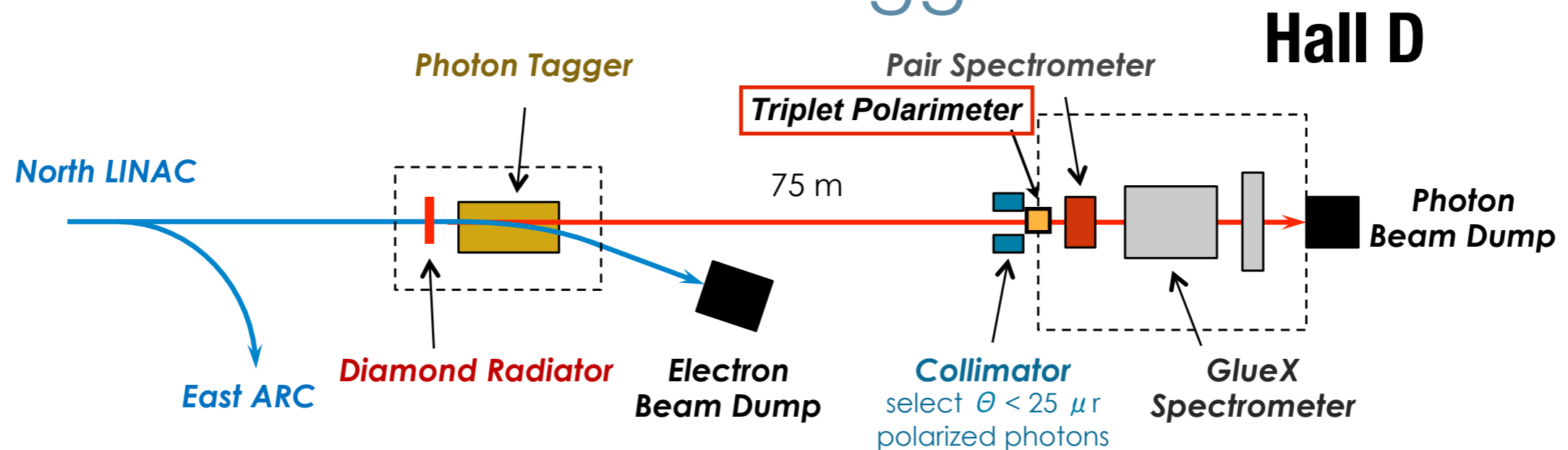
- * Ideally look for a pattern of hybrid states in multiple decay modes
- * Primary goal of the GlueX experiment is to search for and ultimately map out the spectrum of light quark hybrid mesons

Jefferson Lab 12 GeV Upgrade

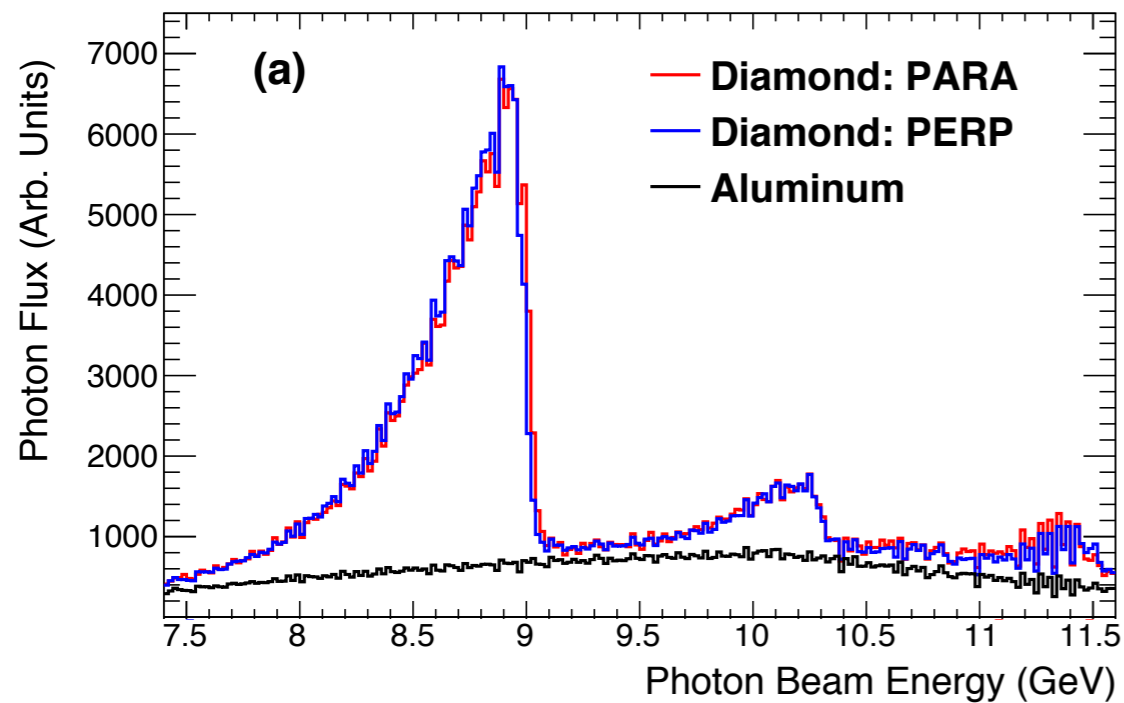
- * Completed upgrade of maximum electron beam energy from 6 to 12 GeV
- * Simultaneously delivered beam to all 4 halls in Spring 2018!



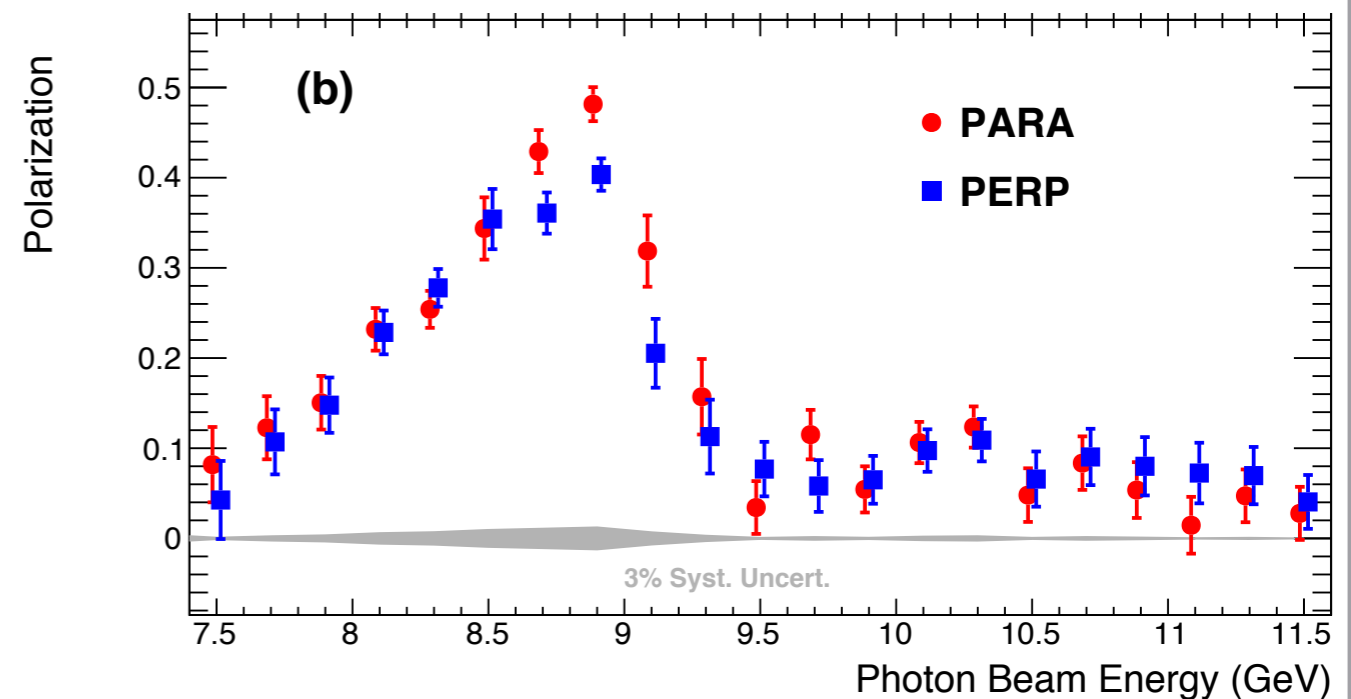
Photon Beam and Tagger



Measured Flux

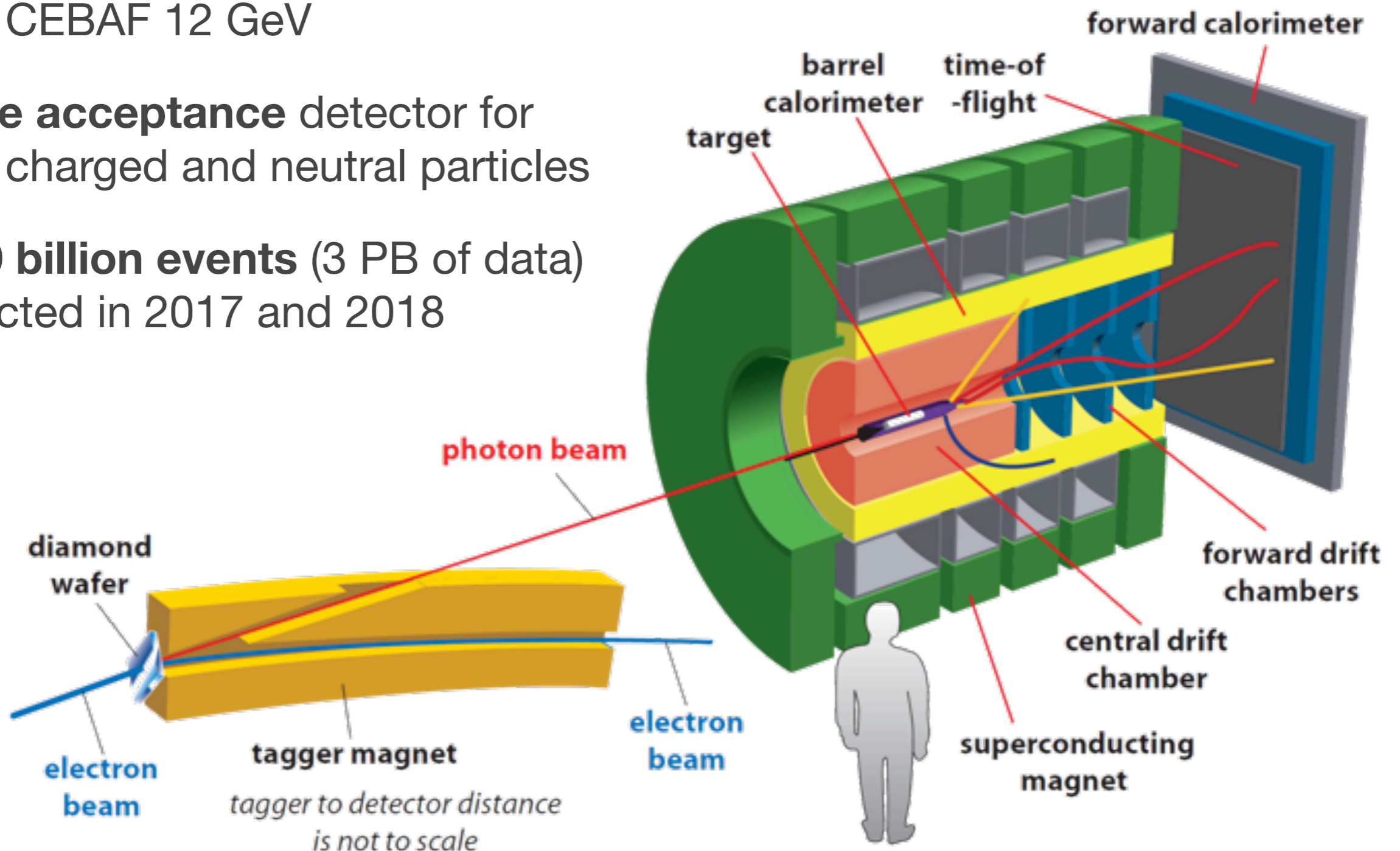


Measured Polarization

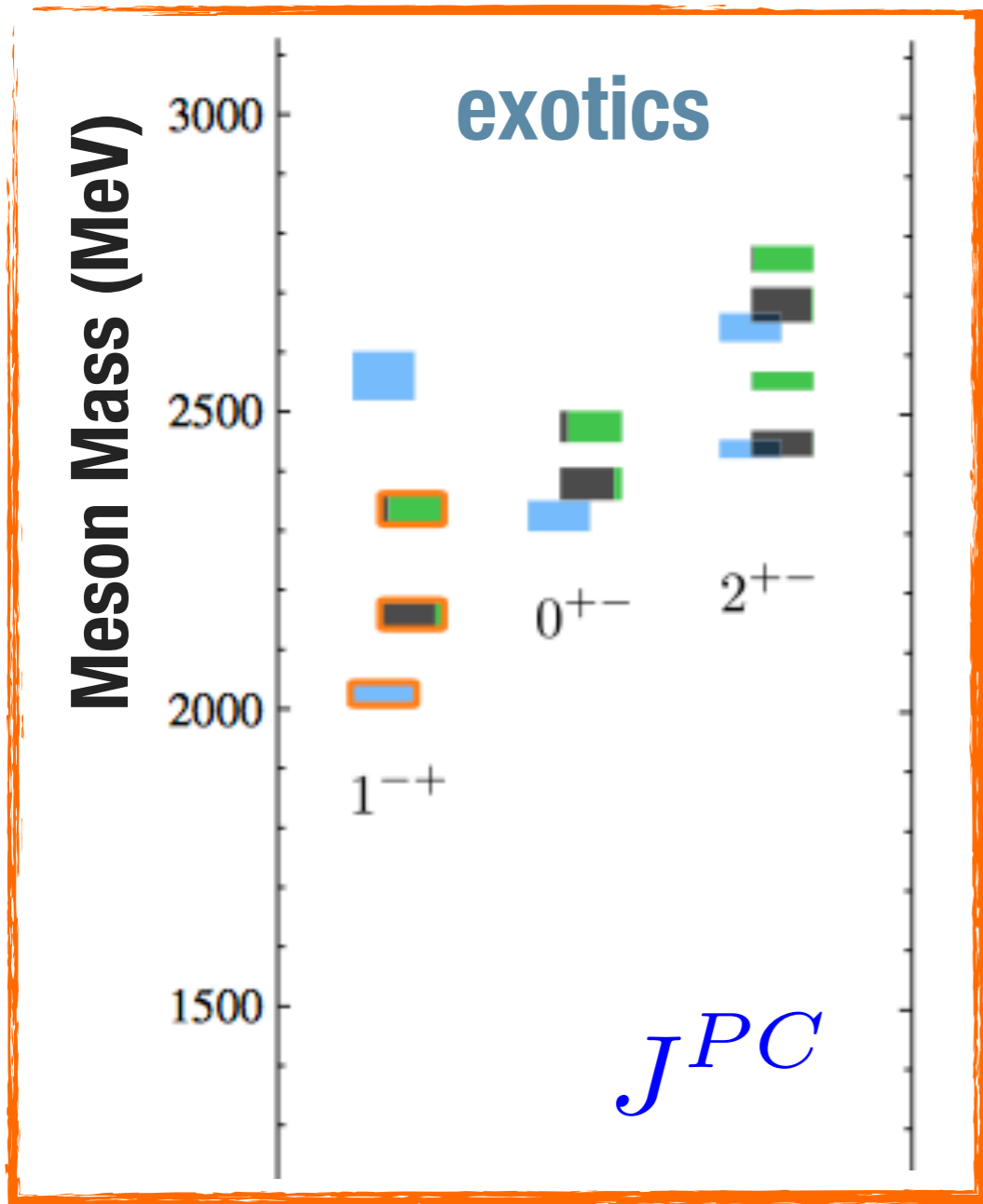


GLUEX in Hall D

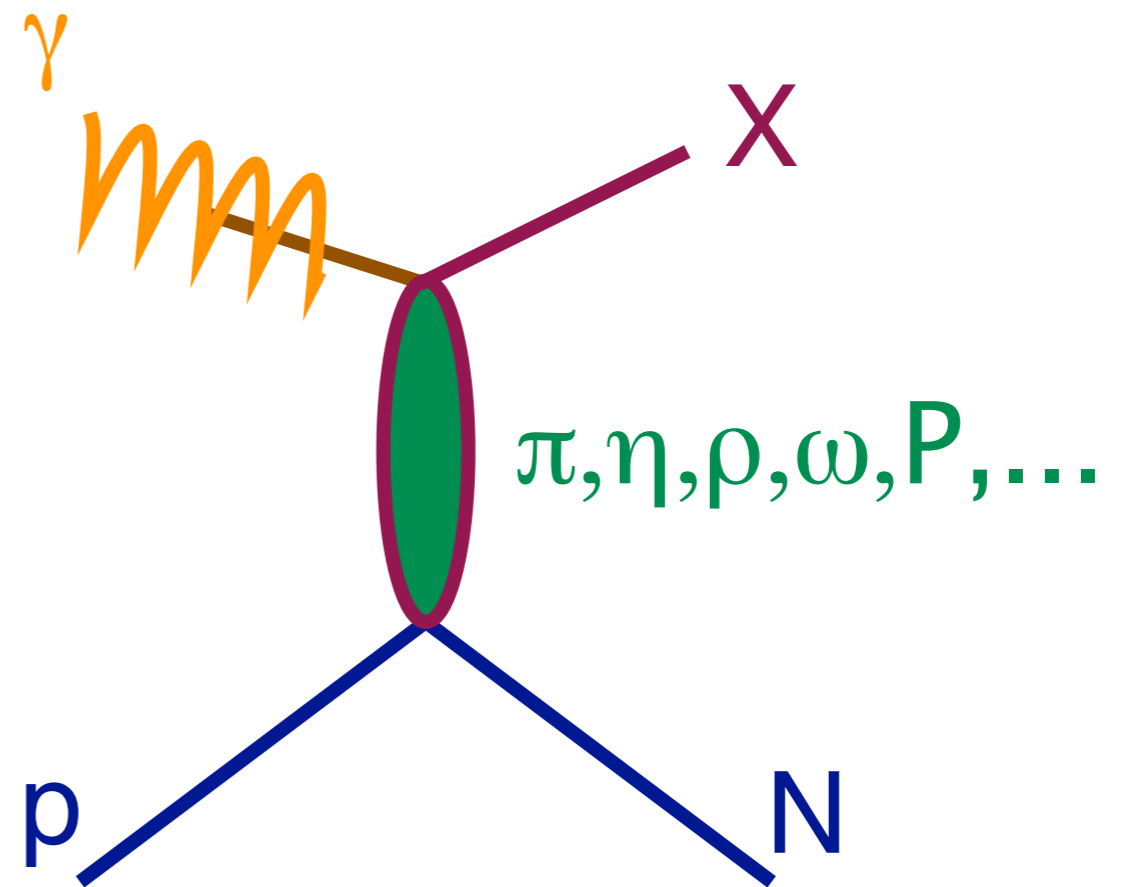
- * **Linearly polarized photon beam** from CEBAF 12 GeV
- * **Large acceptance** detector for both charged and neutral particles
- * **~200 billion events** (3 PB of data) collected in 2017 and 2018



Exotic J^{PC} in photoproduction

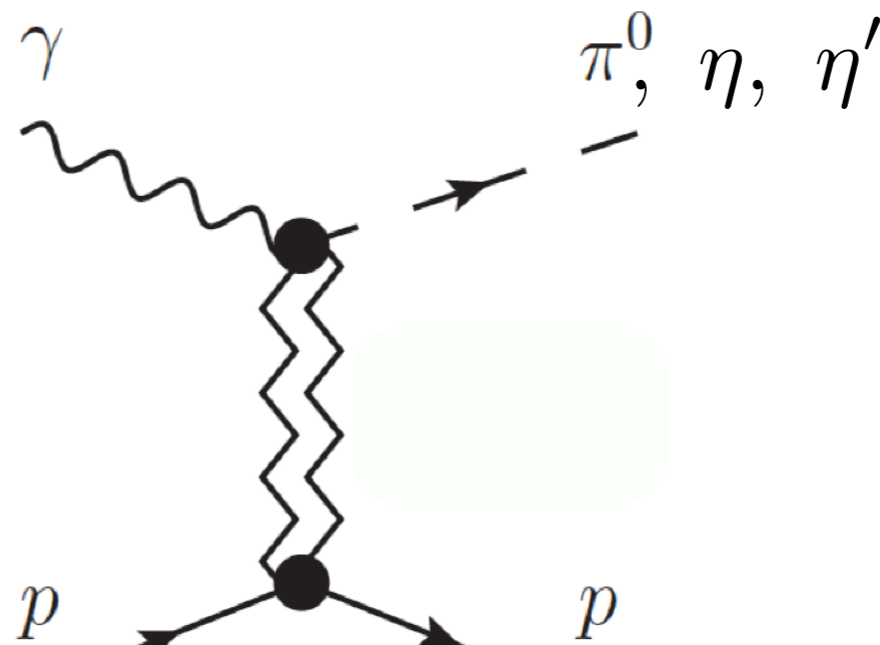
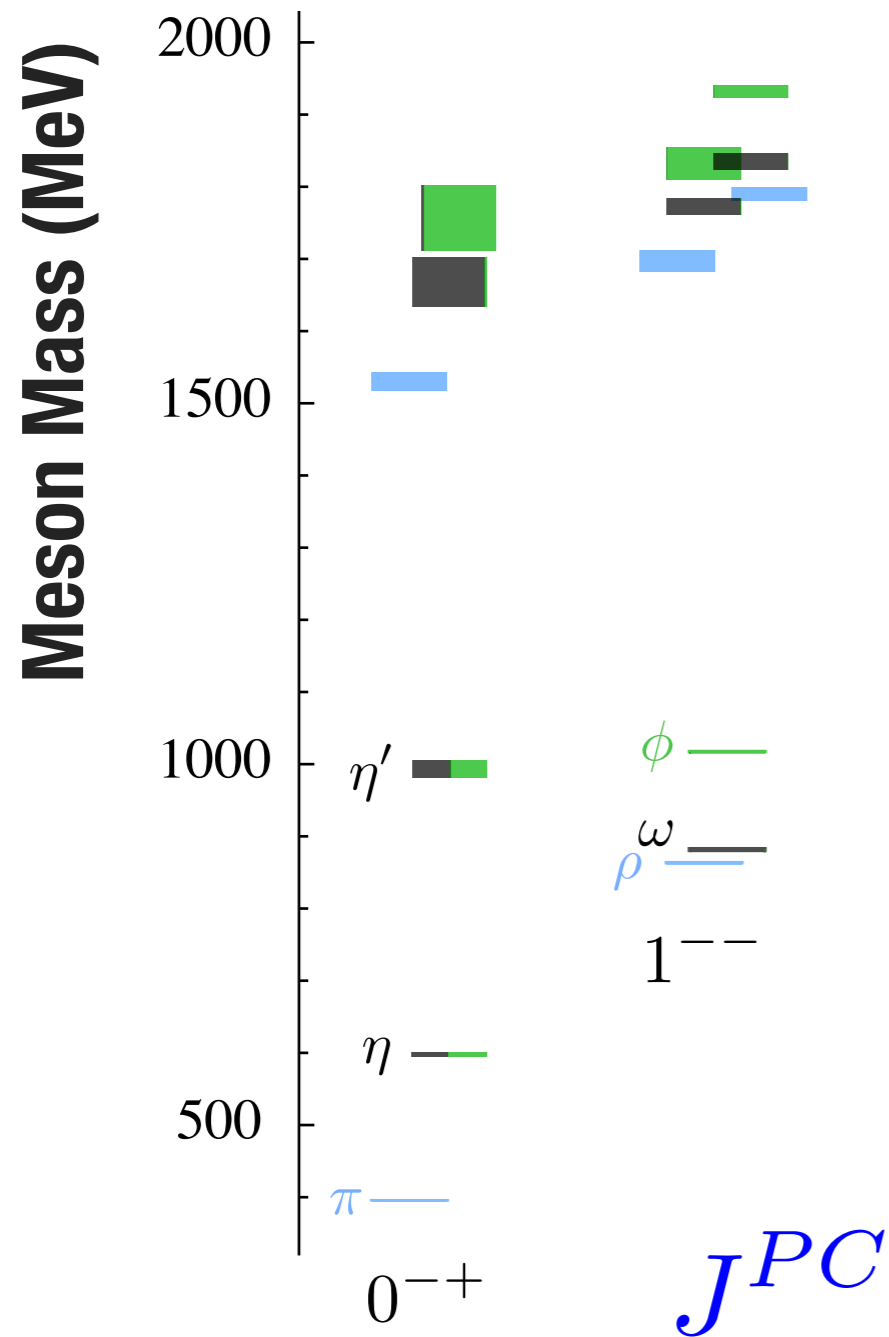


Meson X with particular J^{PC}



**Production through t-channel
“quasi-particle” exchange**

Non-exotic J^{PC} in photoproduction



Exchange J^{PC}

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

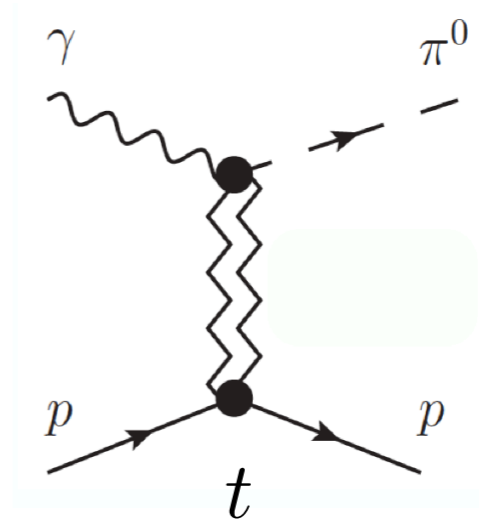
$1^{+-} : b, h$

- * Begin by understanding non-exotic production mechanism
- * Linear photon beam polarization critical to filter out “naturalness” of the exchange particle

Early **GLUEX** physics: $\gamma p \rightarrow \pi^0 p$

High-Energy π^0 Photoproduction from Hydrogen with Unpolarized and Linearly Polarized Photons*

R. L. Anderson, D. B. Gustavson, J. R. Johnson, I. D. Overman, D. M. Ritson, and B. H. Wiik
Stanford Linear Accelerator Center, Stanford, California 94305
 and
 D. Worcester†
Harvard University, Cambridge, Massachusetts 02138
 (Received 25 June 1971)

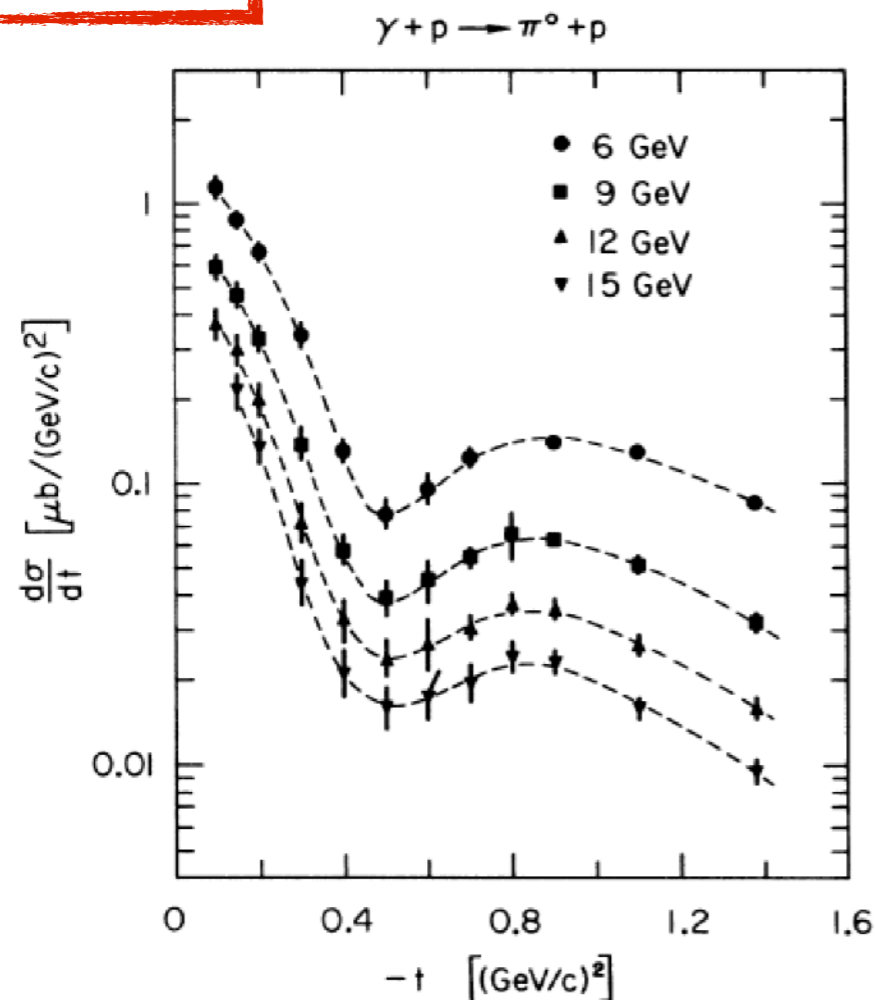


Exchange J^{PC}

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

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

1 OCTOBER 1971

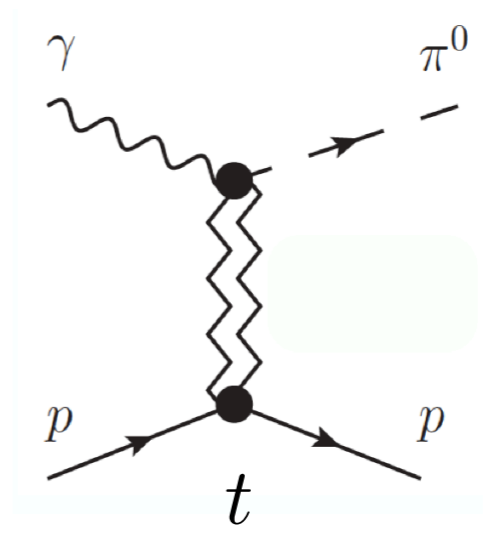


$$\frac{d\sigma}{dt} = \sigma_{\perp} + \sigma_{\parallel} = |\rho + \omega|^2 + |b + h|^2$$

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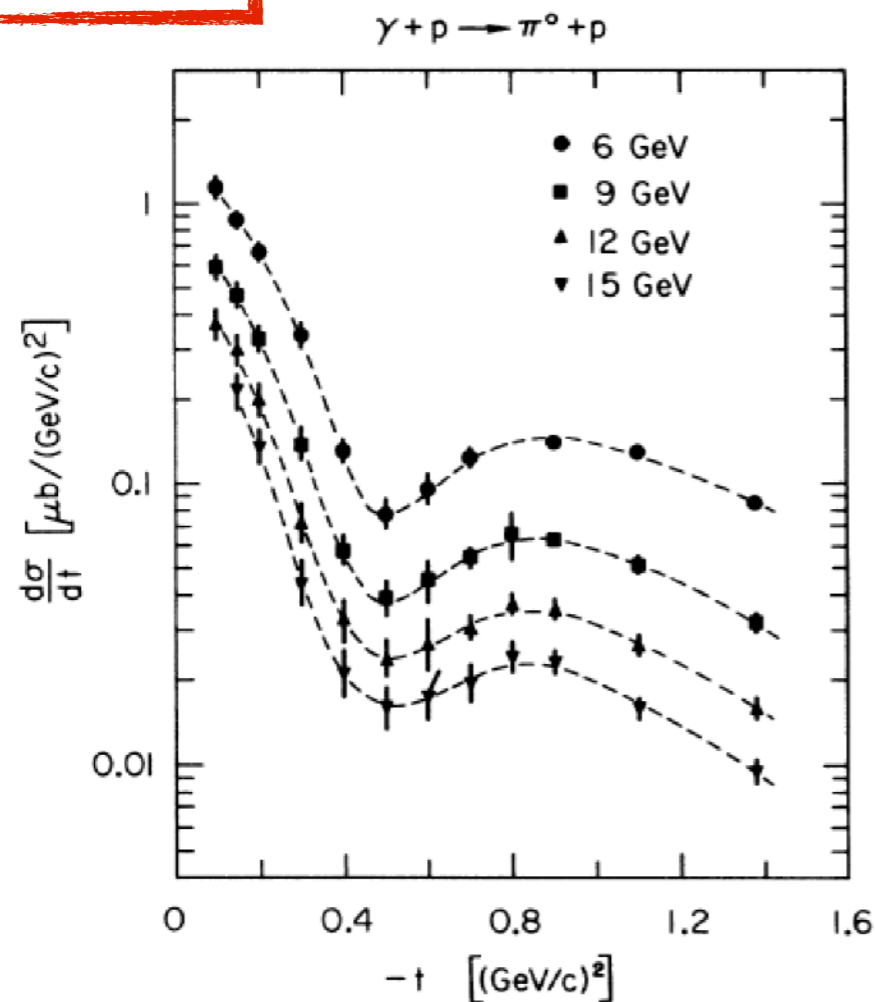


Exchange J^{PC}

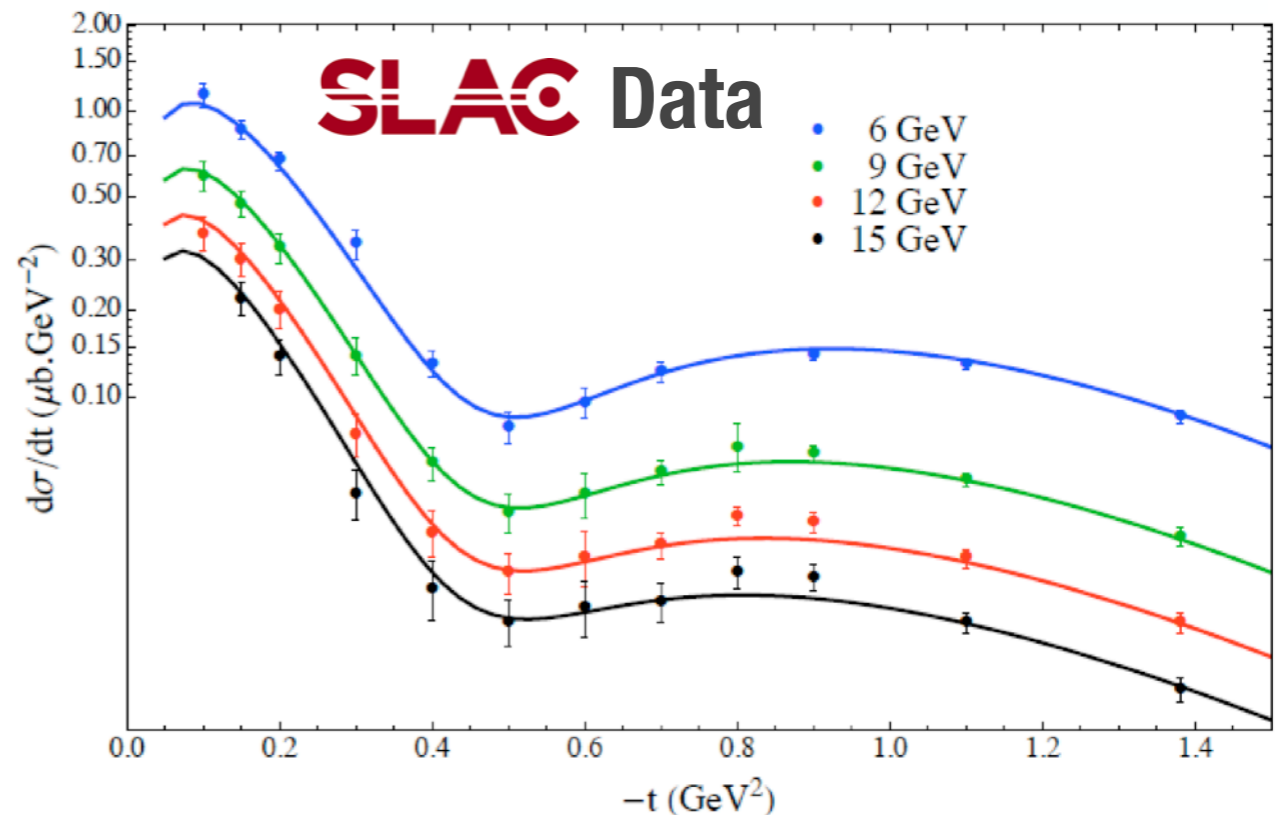
$1^{--} : \omega, \rho$

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

1 OCTOBER 1971



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



JPAC : Mathieu et al. PRD 92, 074013

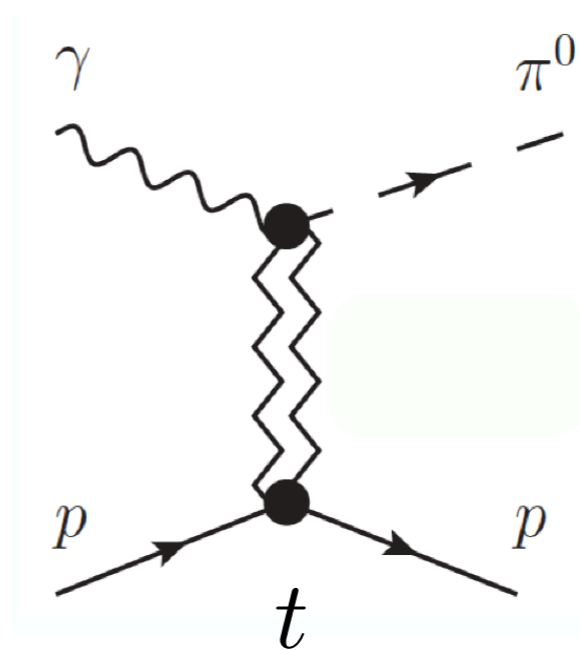
$\gamma p \rightarrow \pi^0 p$ beam asymmetry Σ

- * Beam asymmetry Σ provides insight into dominant production mechanism

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

- * From experimental standpoint it's easily extended to $\gamma p \rightarrow \eta p$

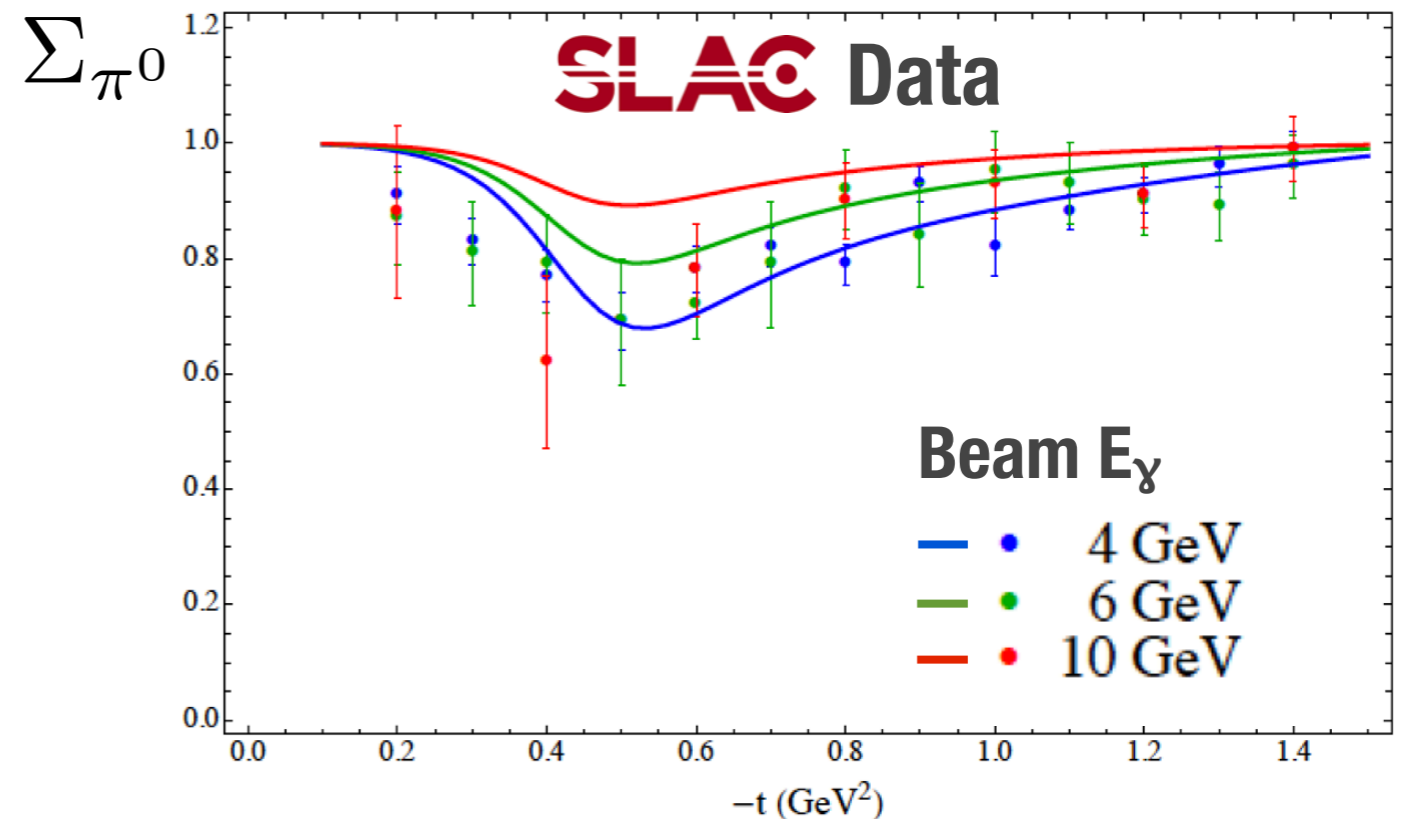
- * **No previous measurements!**



Exchange J^{PC}

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

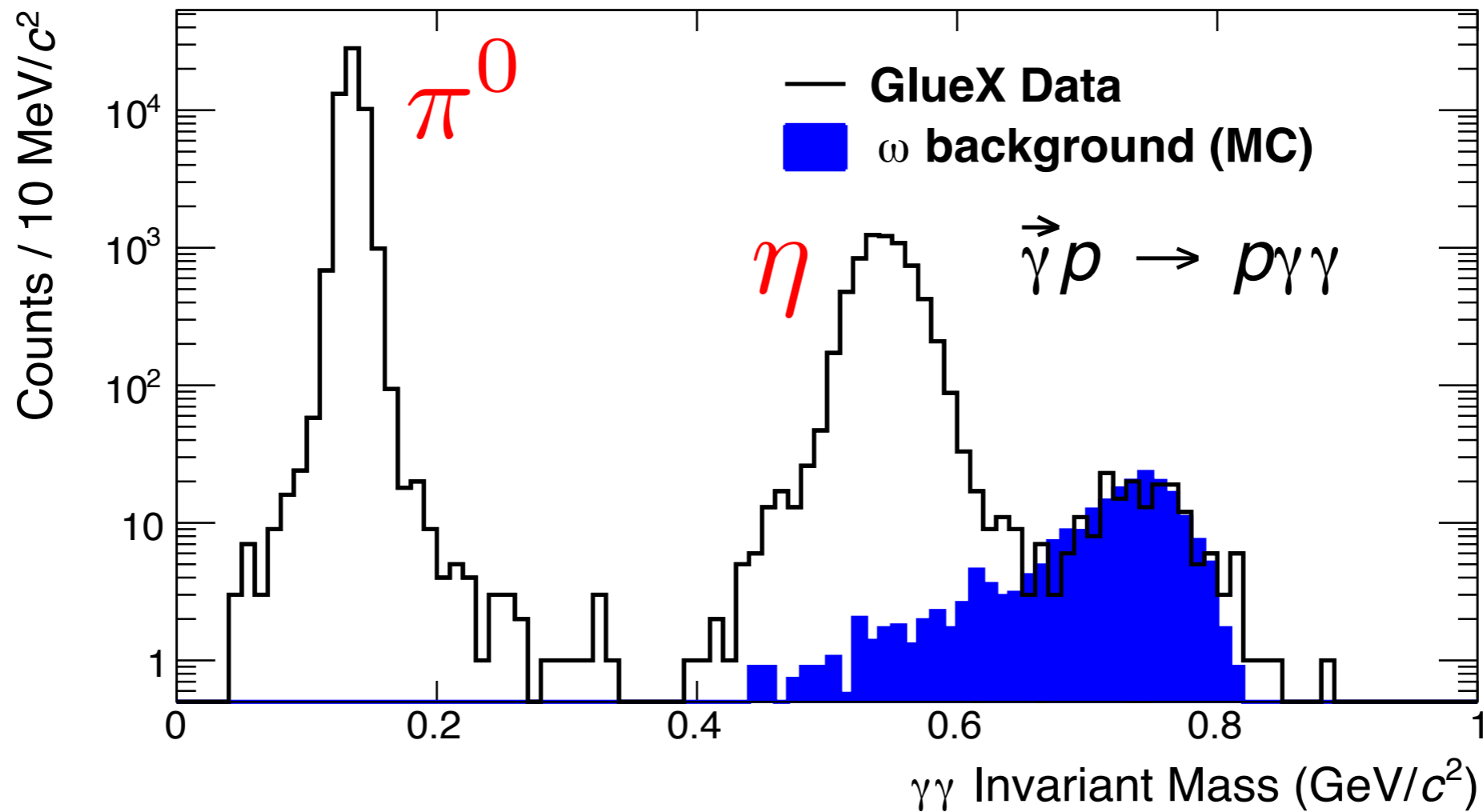
$1^{+-} : b, h$



JPAC : Mathieu et al. PRD 92, 074013

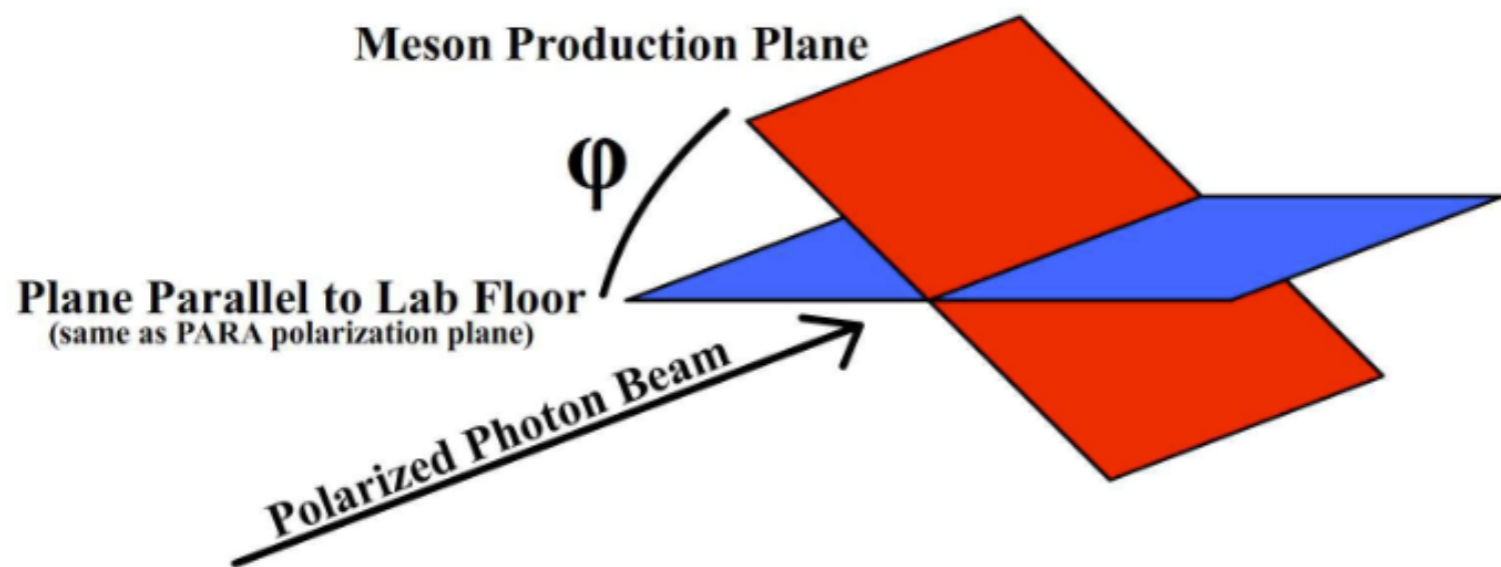
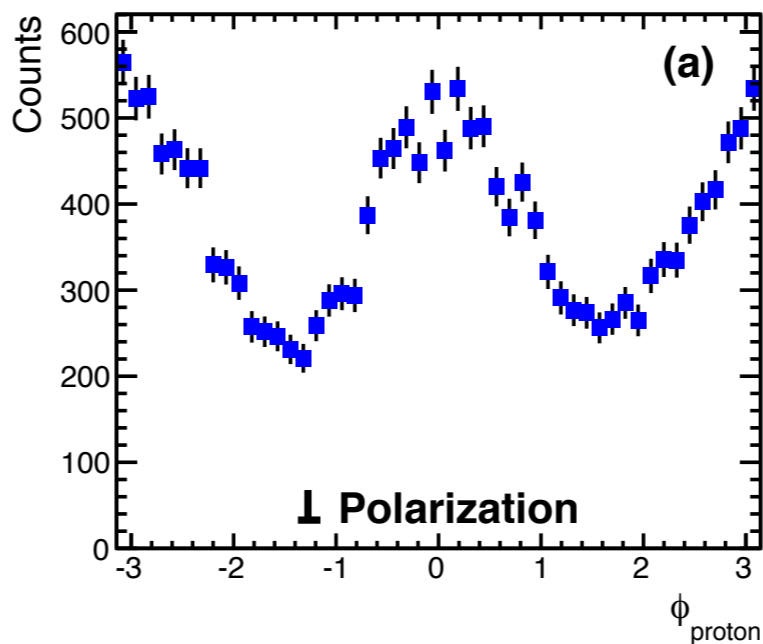
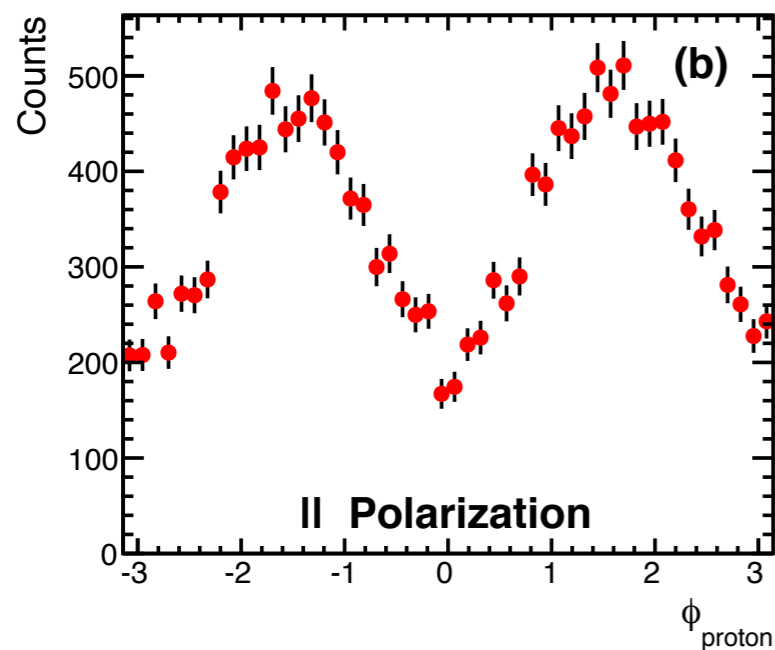
π^0 and η beam asymmetries

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



Phys. Rev. C 95, 042201(R)

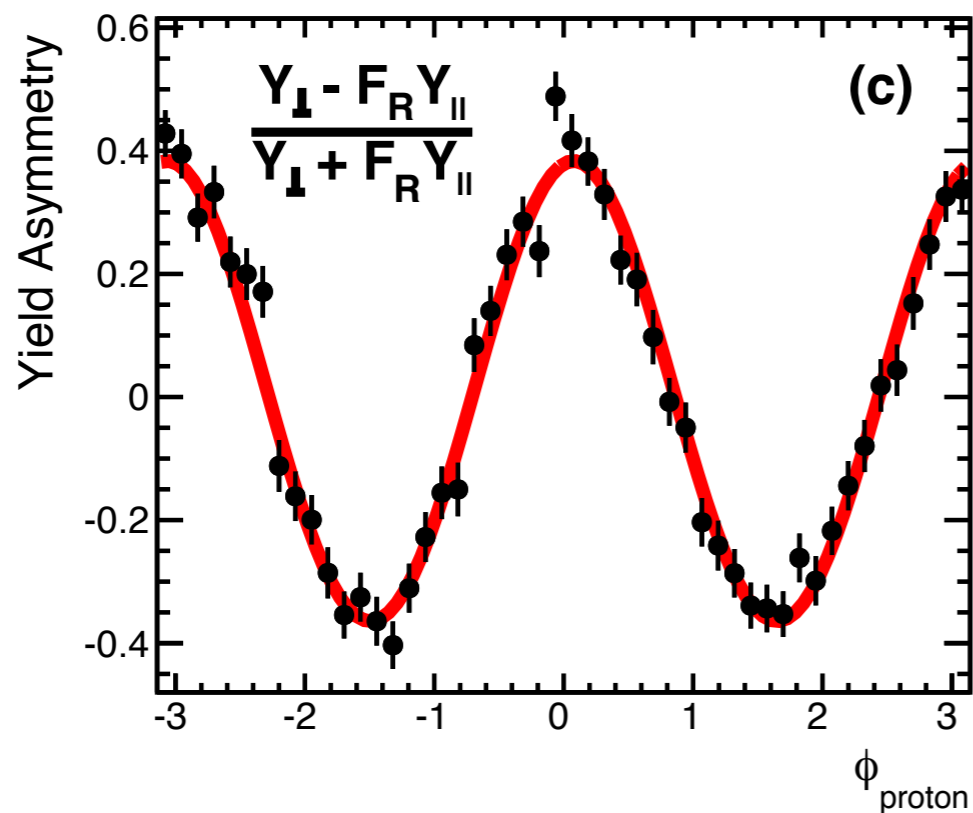
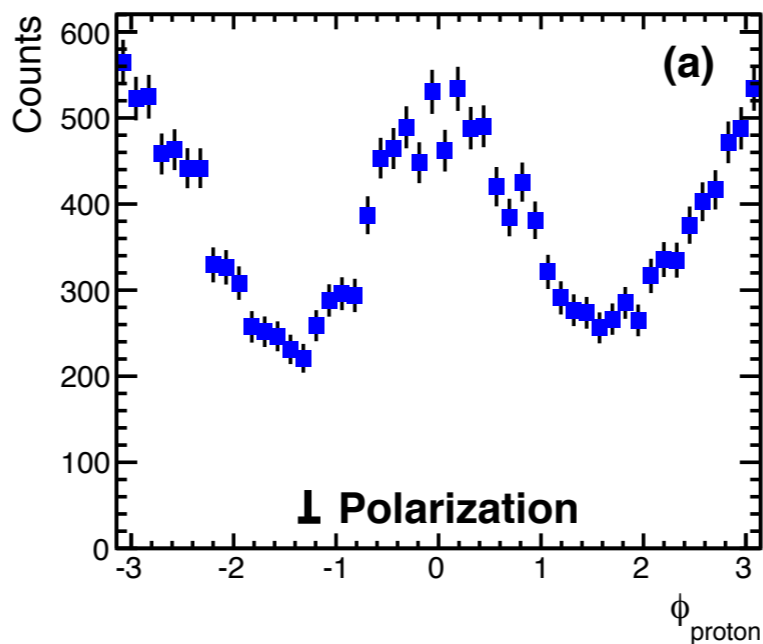
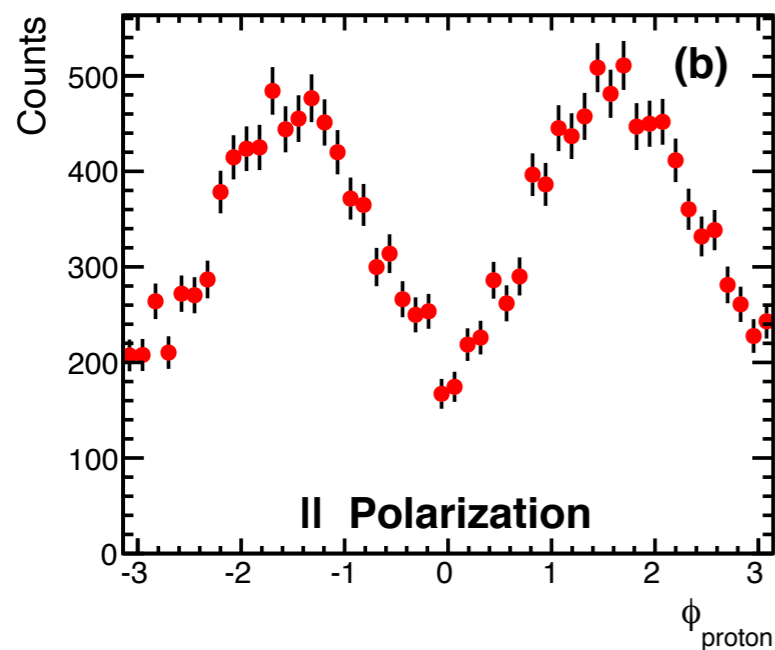
π^0 and η beam asymmetries



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

Phys. Rev. C 95, 042201(R)

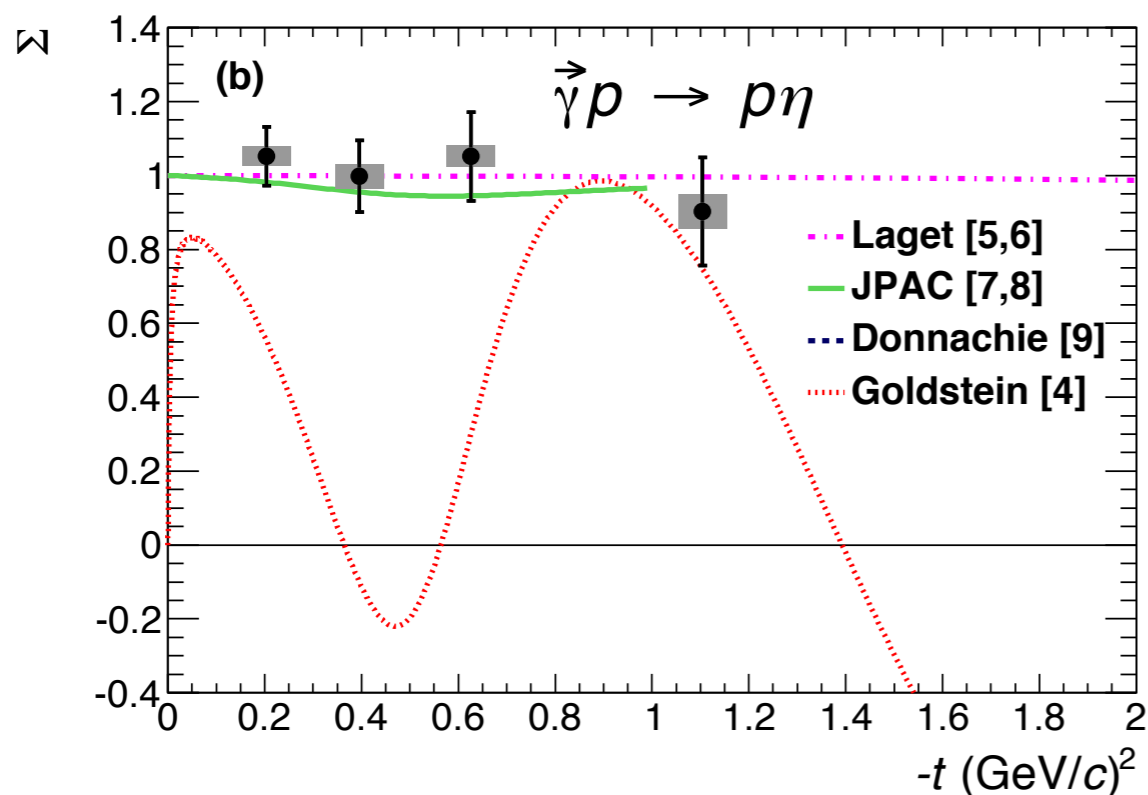
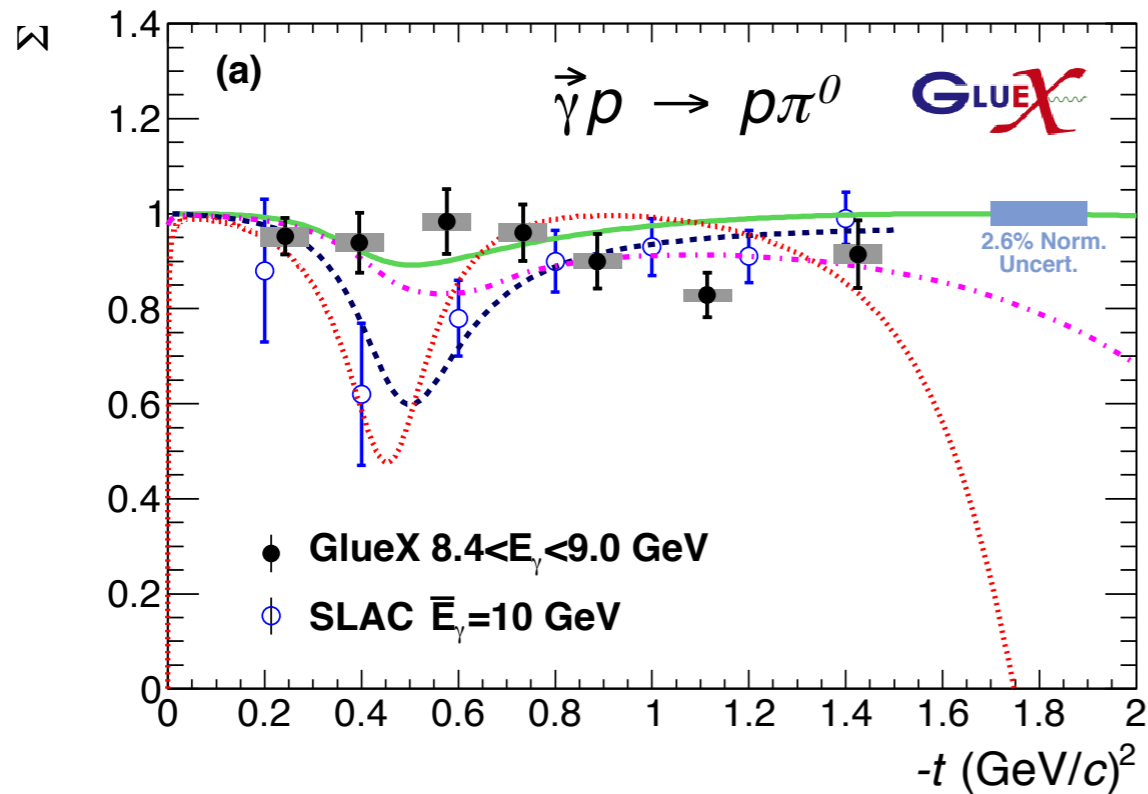
π^0 and η beam asymmetries



$$\frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + F_R Y_{\parallel}} = P_{\gamma} \Sigma \cos 2\phi_p$$

Phys. Rev. C 95, 042201(R)

π^0 and η beam asymmetries

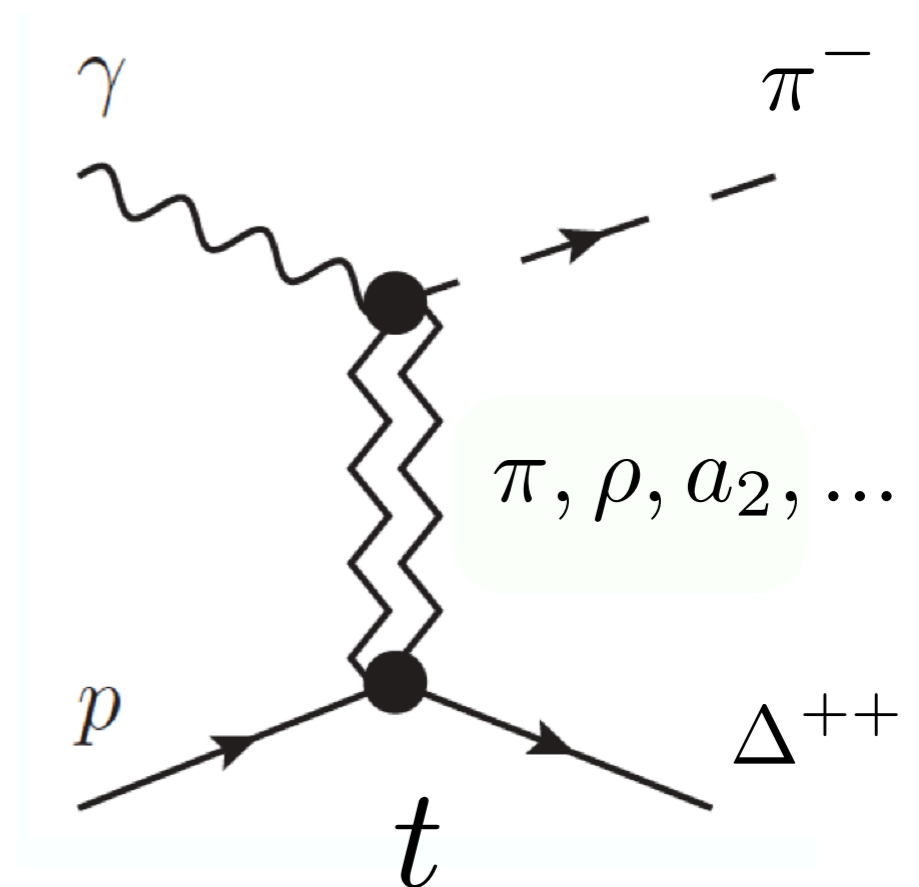
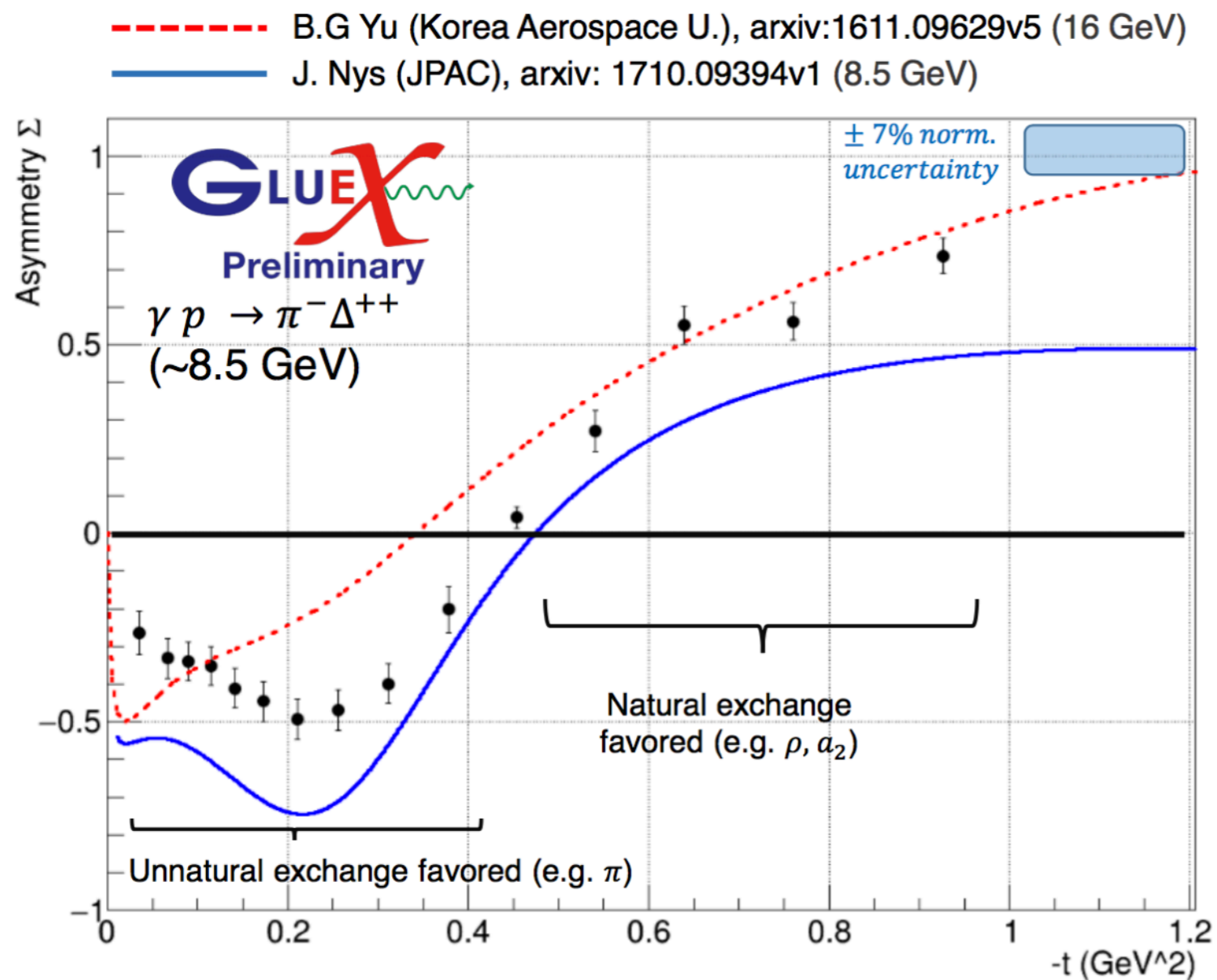


- ✱ Testing models for t -channel production at high energies
- ✱ No dip in t -dependence observed at 0.5 $(\text{GeV}/c)^2$
- ✱ Vector exchange mechanism dominant at these energies, expect similar mechanism for exotics

First JLab 12 GeV publication!

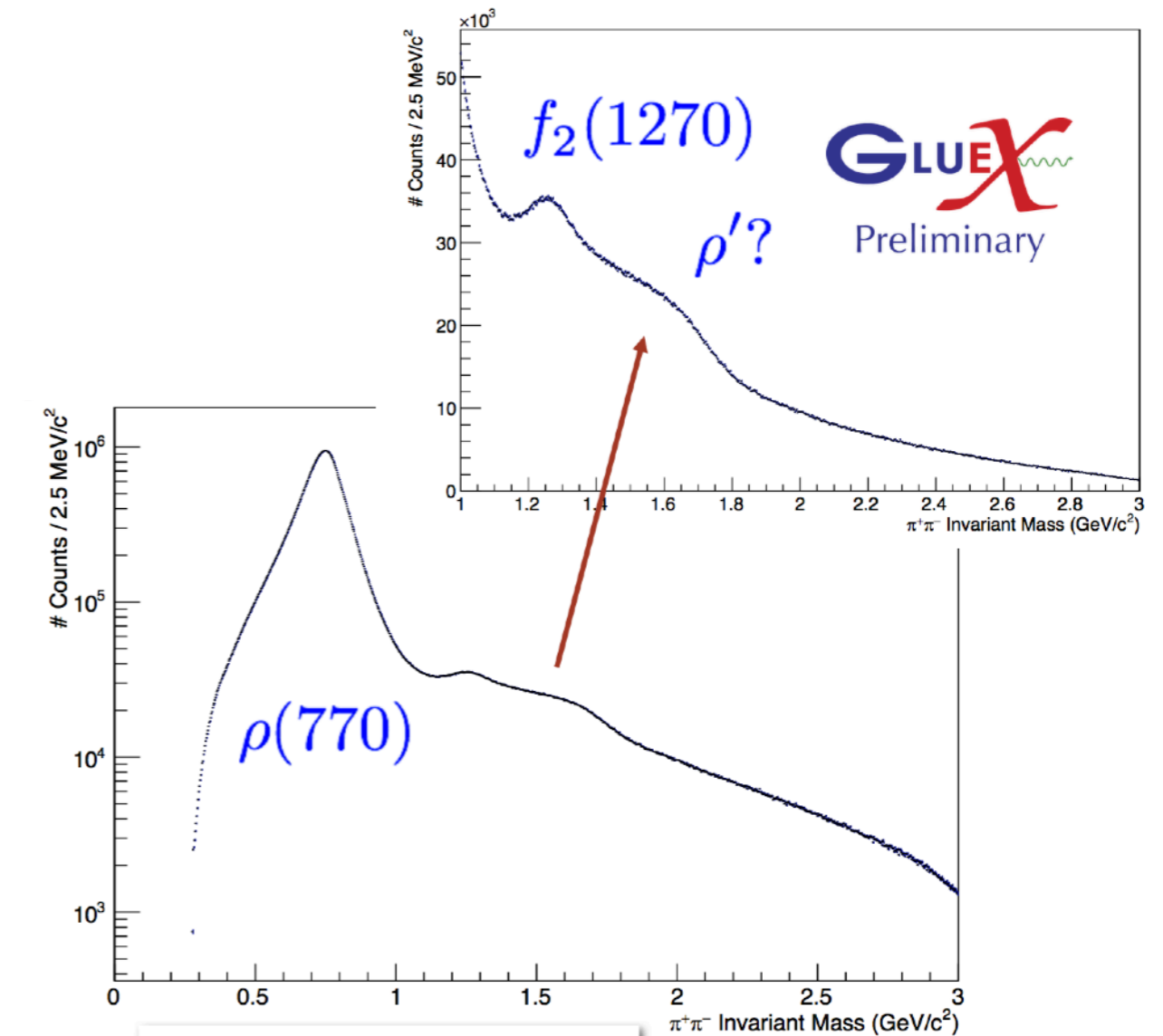
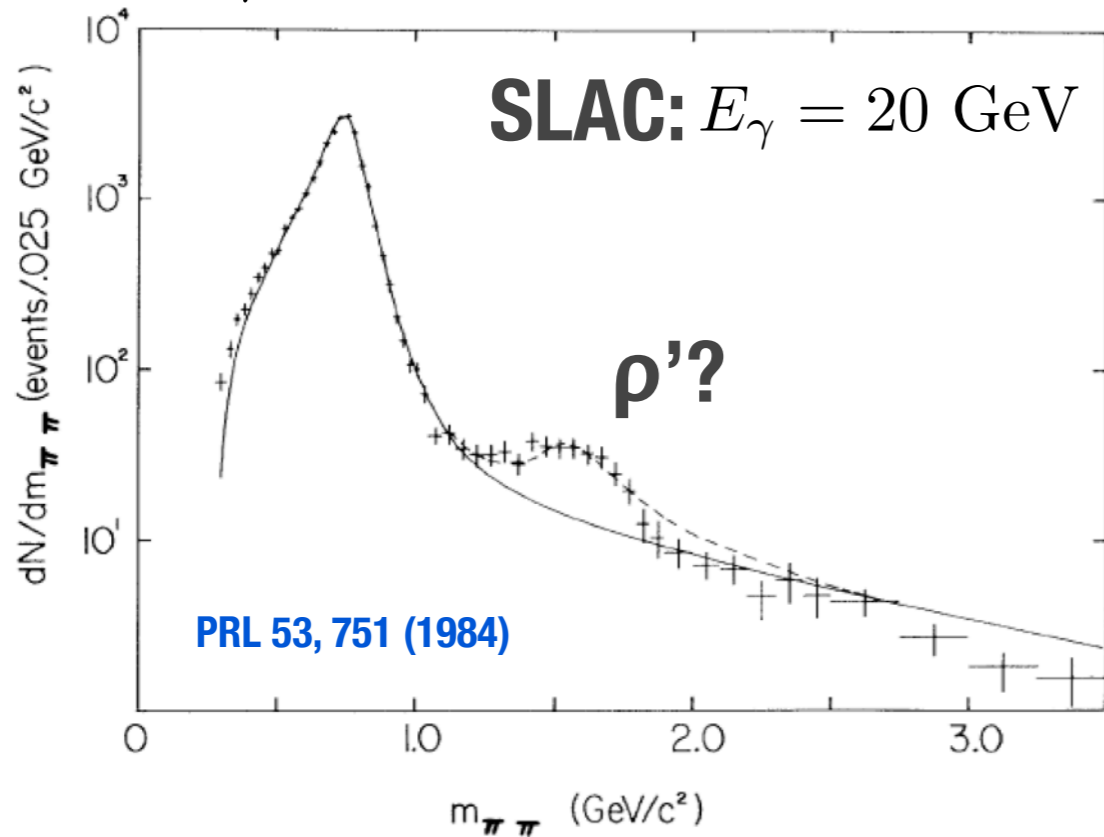
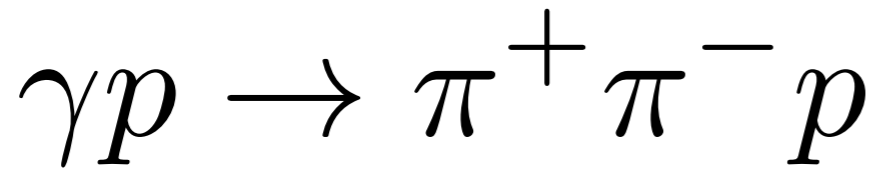
Phys. Rev. C 95, 042201(R)

Pseudoscalar beam asymmetries



Charged pseudoscalars: more complicated $-t$ dependence

Early spectroscopy opportunities



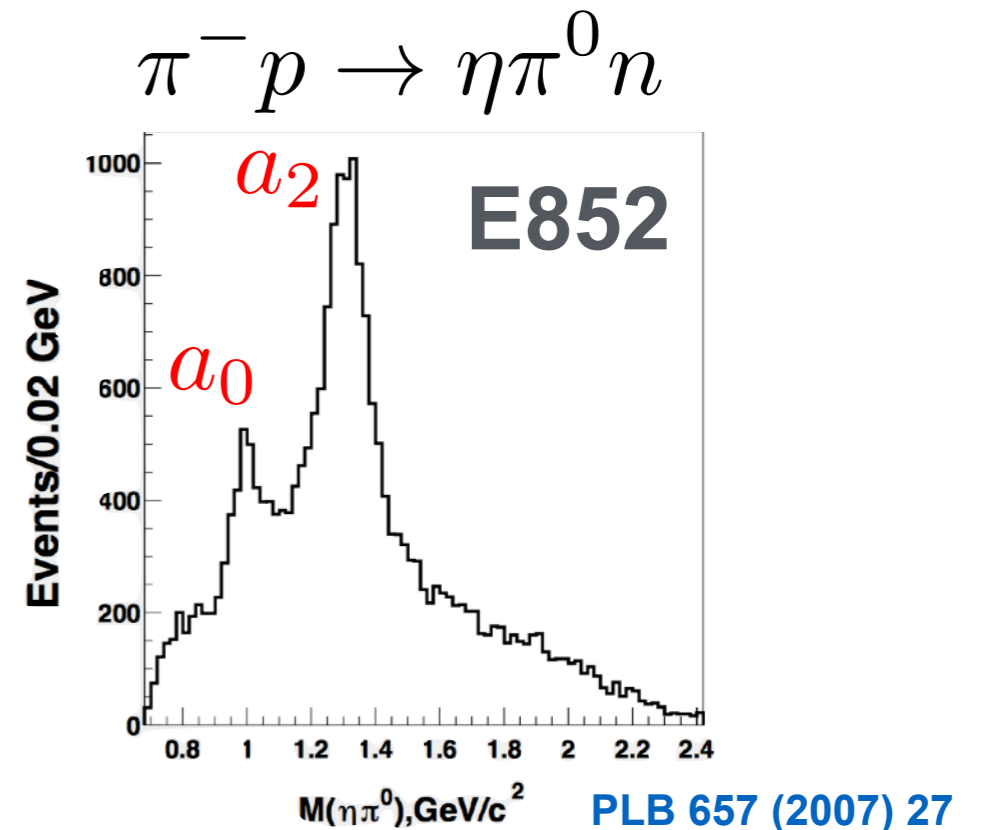
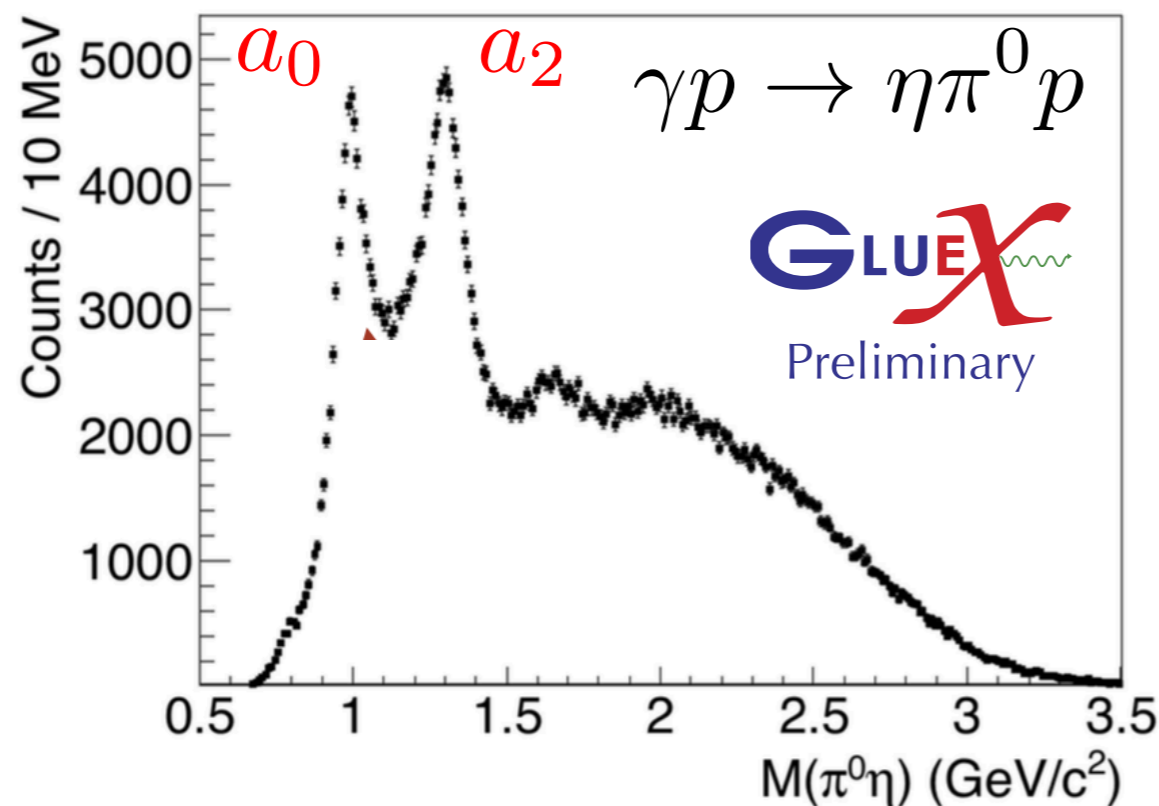
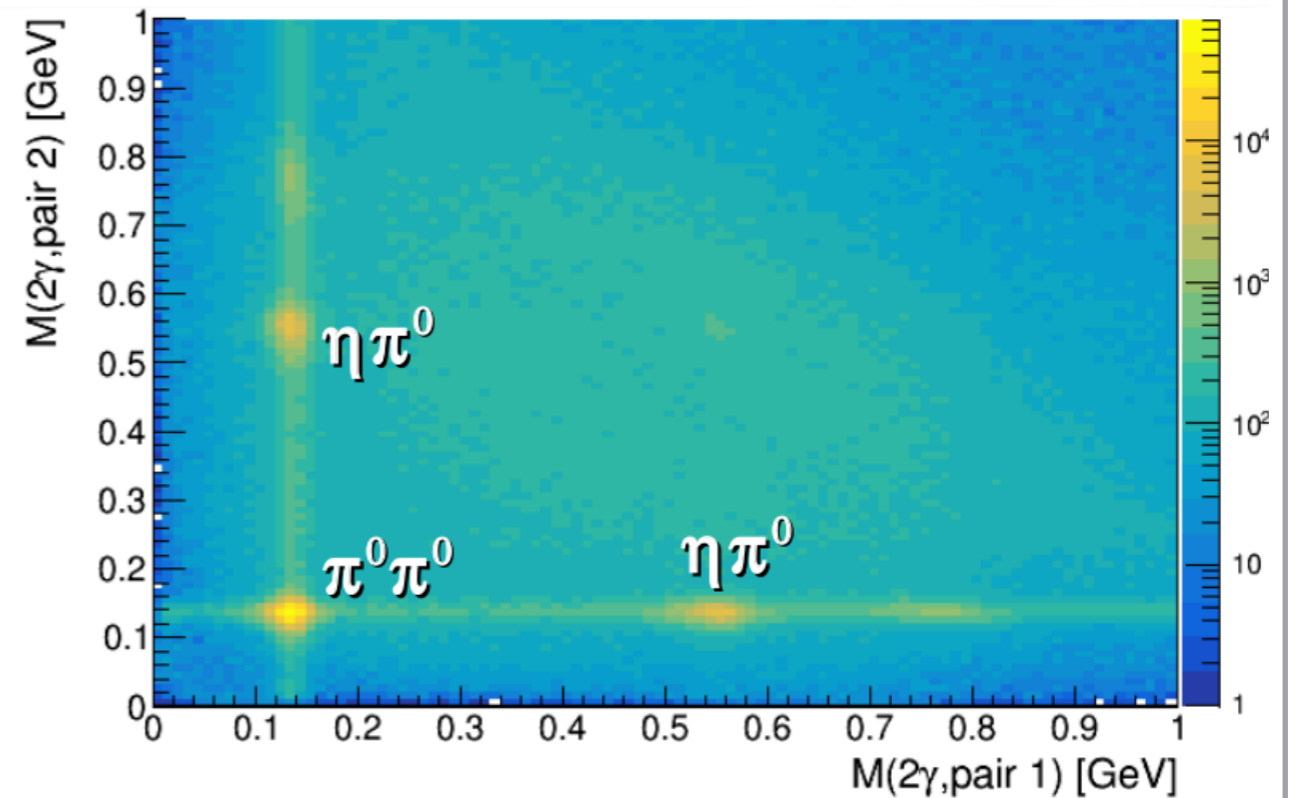
- * Enhancement consistent with earlier SLAC measurement, but $\sim 1000x$ more statistics with early GlueX data
- * Polarization observables will provide further insight into the nature of this enhancement

Early spectroscopy opportunities

$$\gamma p \rightarrow 4\gamma p$$

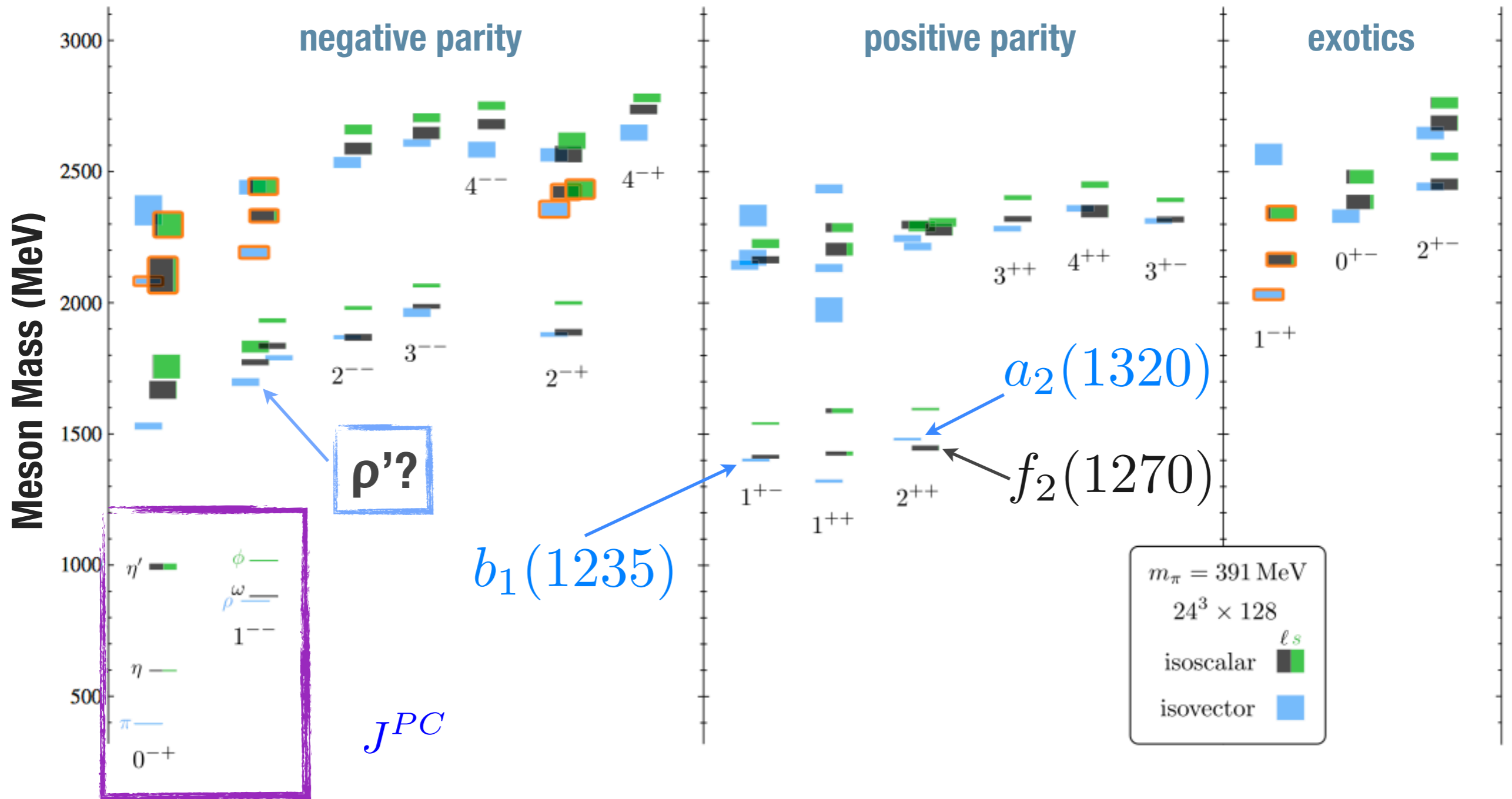
- ✱ Previous photoproduction data very sparse for channels with multiple neutrals particles
- ✱ Early opportunity in $\eta\pi/\eta'\pi$ since P-wave is exotic

A. Austregesilo: Friday, QCDHS @ 16:10



Mapping the meson spectrum

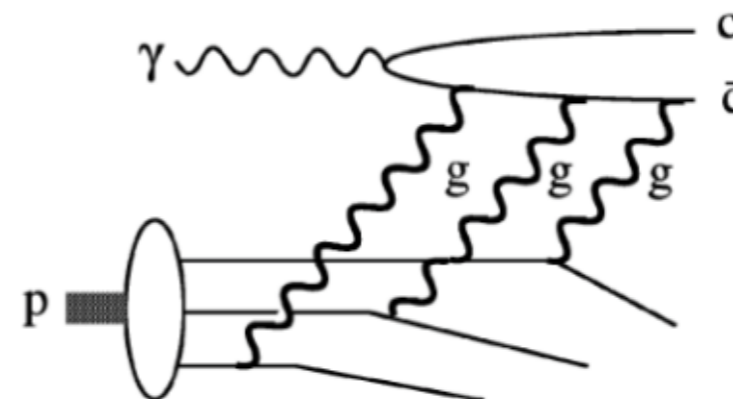
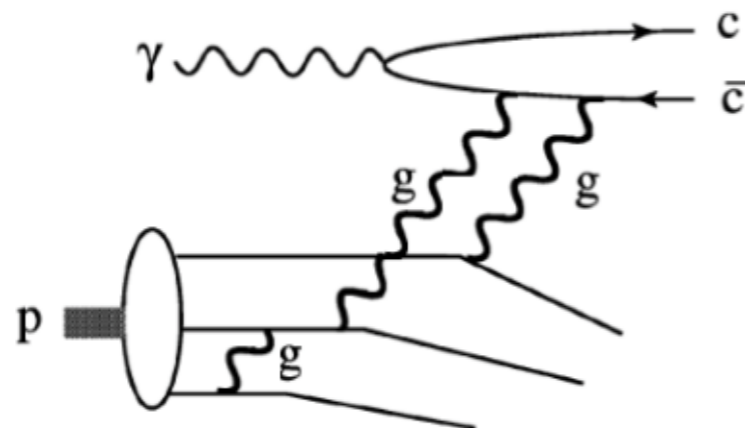
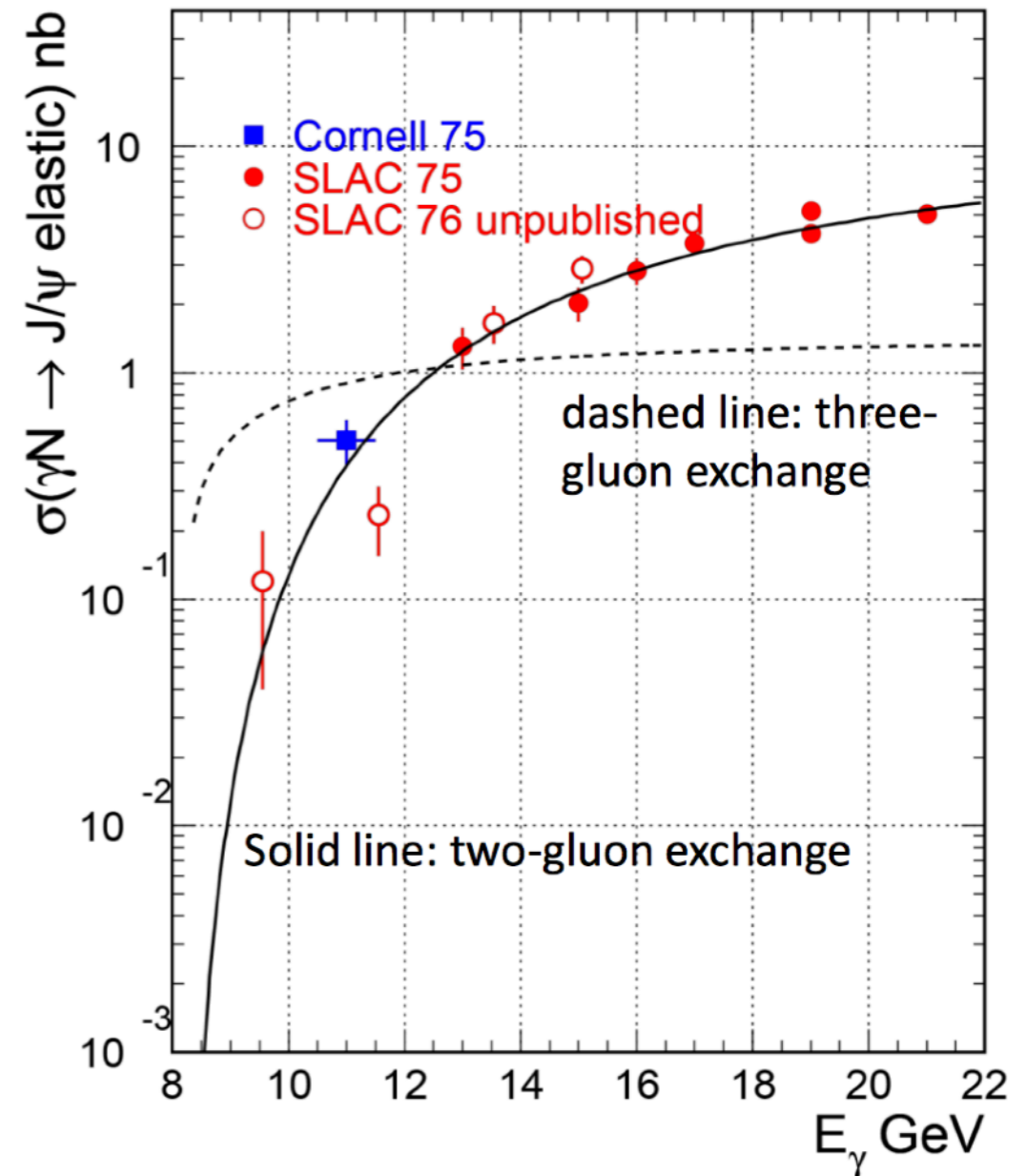
PRD 88 (2013) 094505



- * Already studying polarization observables for **“simple” final states**
- * Beginning to identify **known mesons** in multi-particle final states

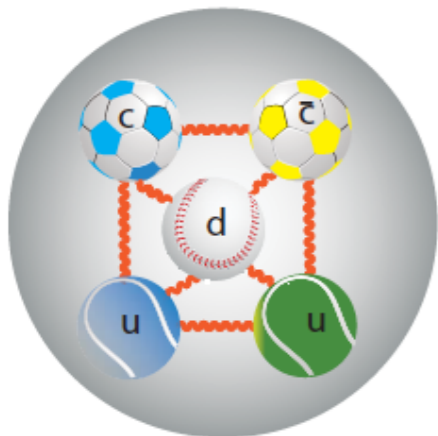
J/ψ photoproduction at JLab

- ✱ Threshold J/ψ provides information on the gluon distributions in the nucleon
- ✱ Planned measurements in Hall A, B and C
- ✱ First data from Hall D already under analysis

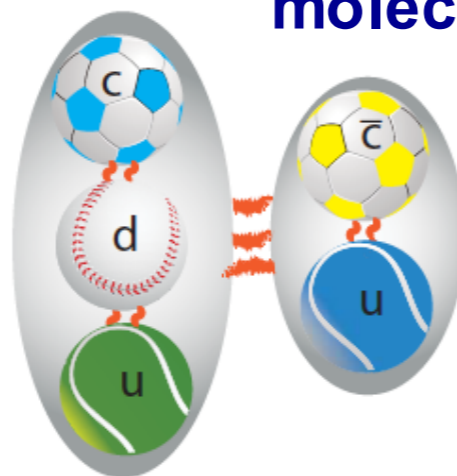


Pentaquark photoproduction at JLab

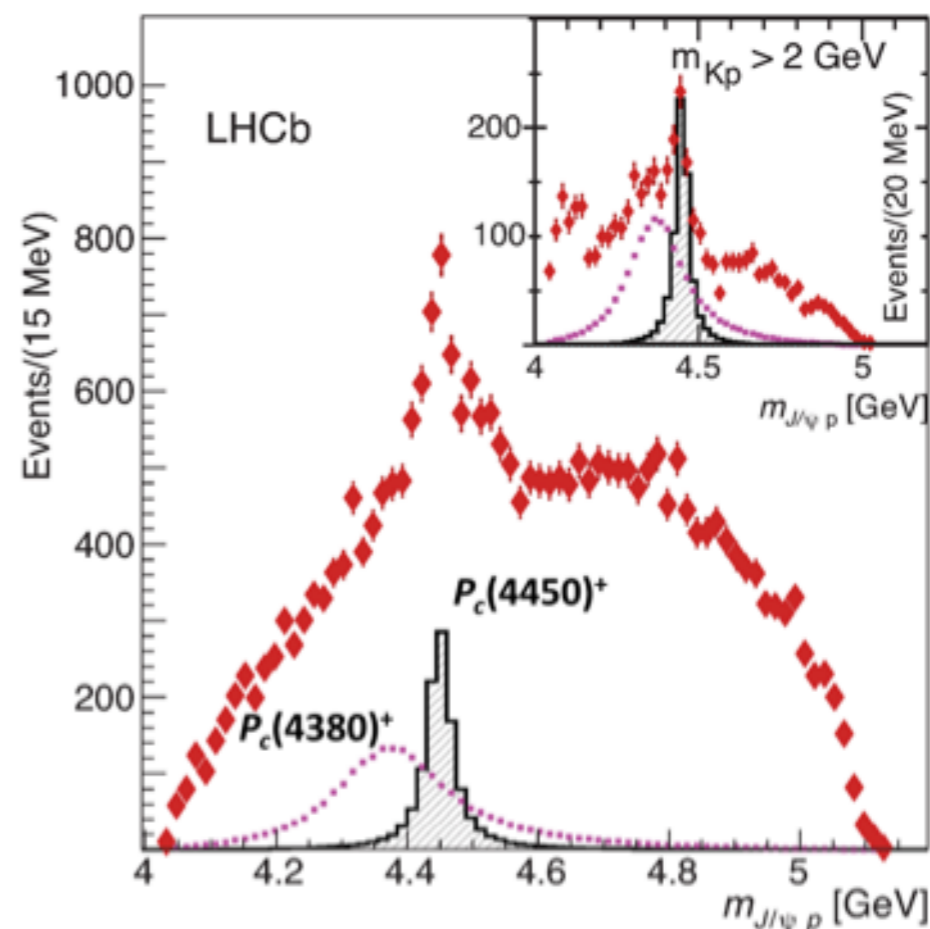
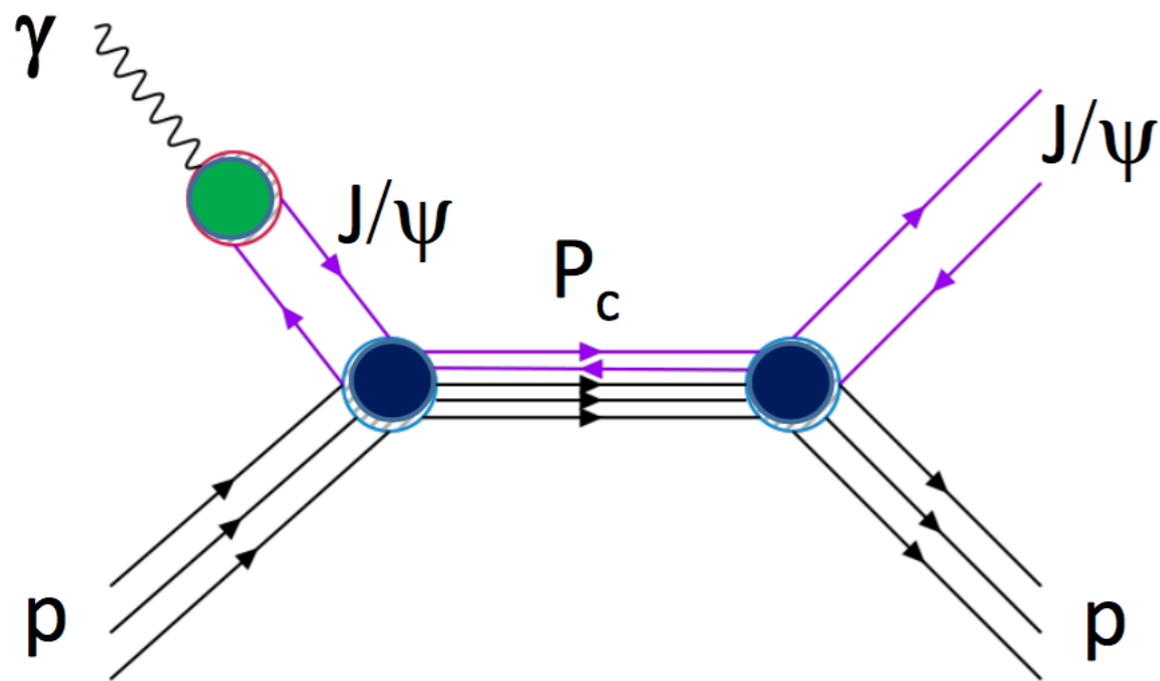
5-quark bound state



Hadronic molecule



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

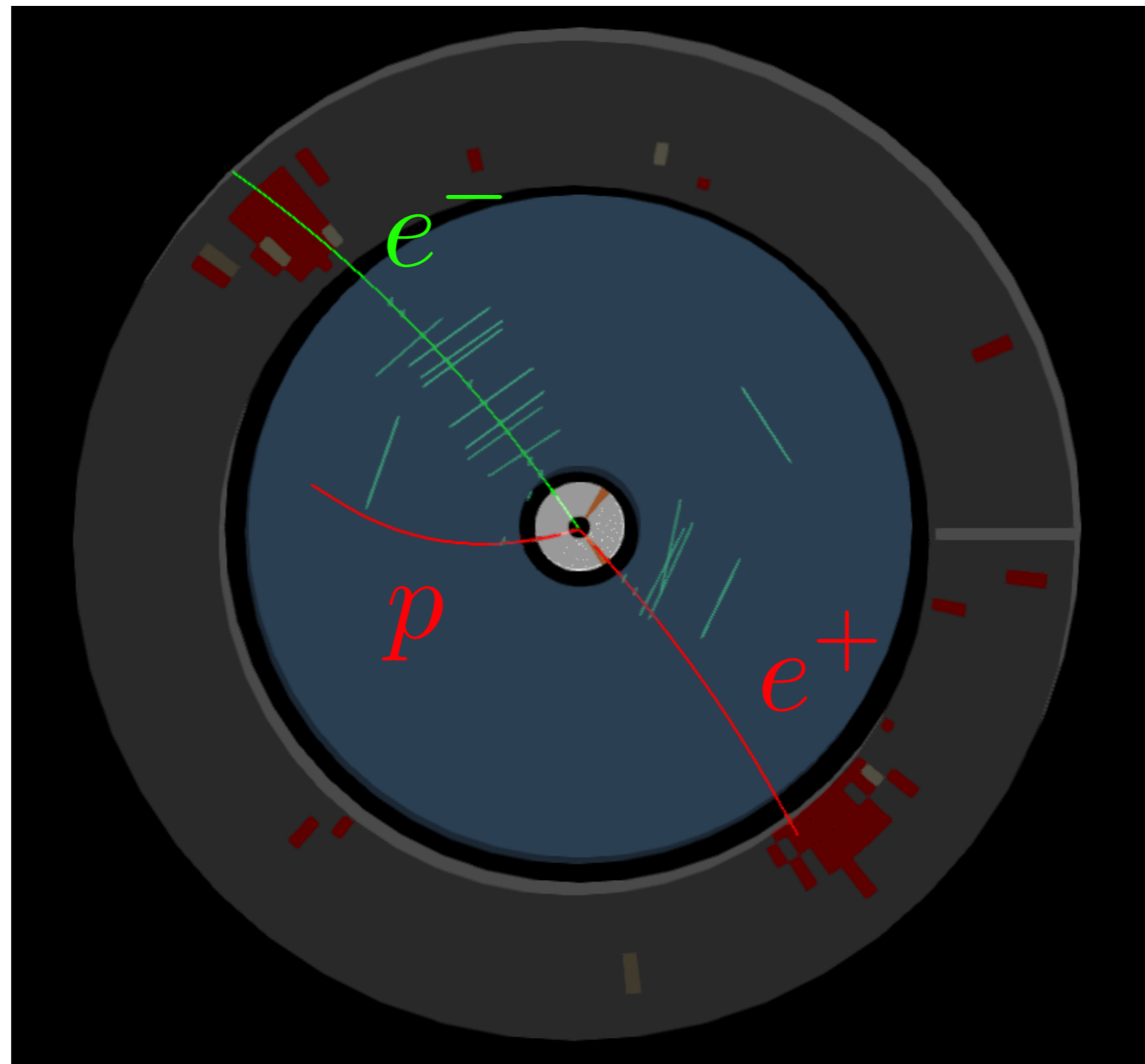


PRL 115, 072001 (2015)



Observation of charm at **GLUEX**

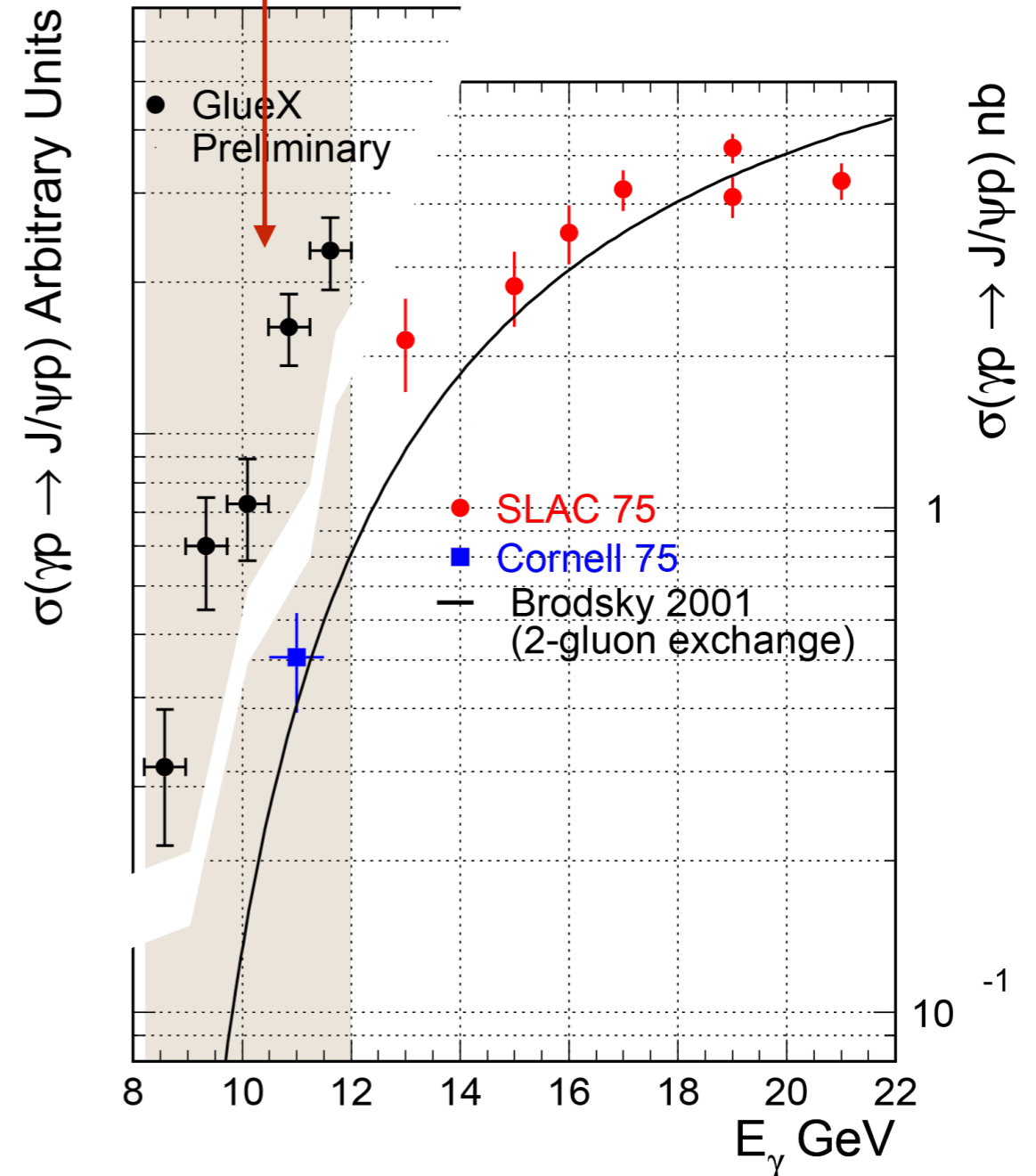
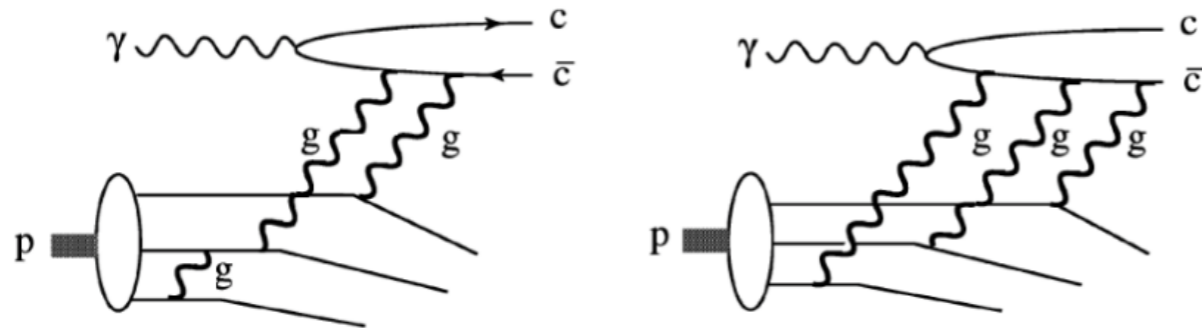
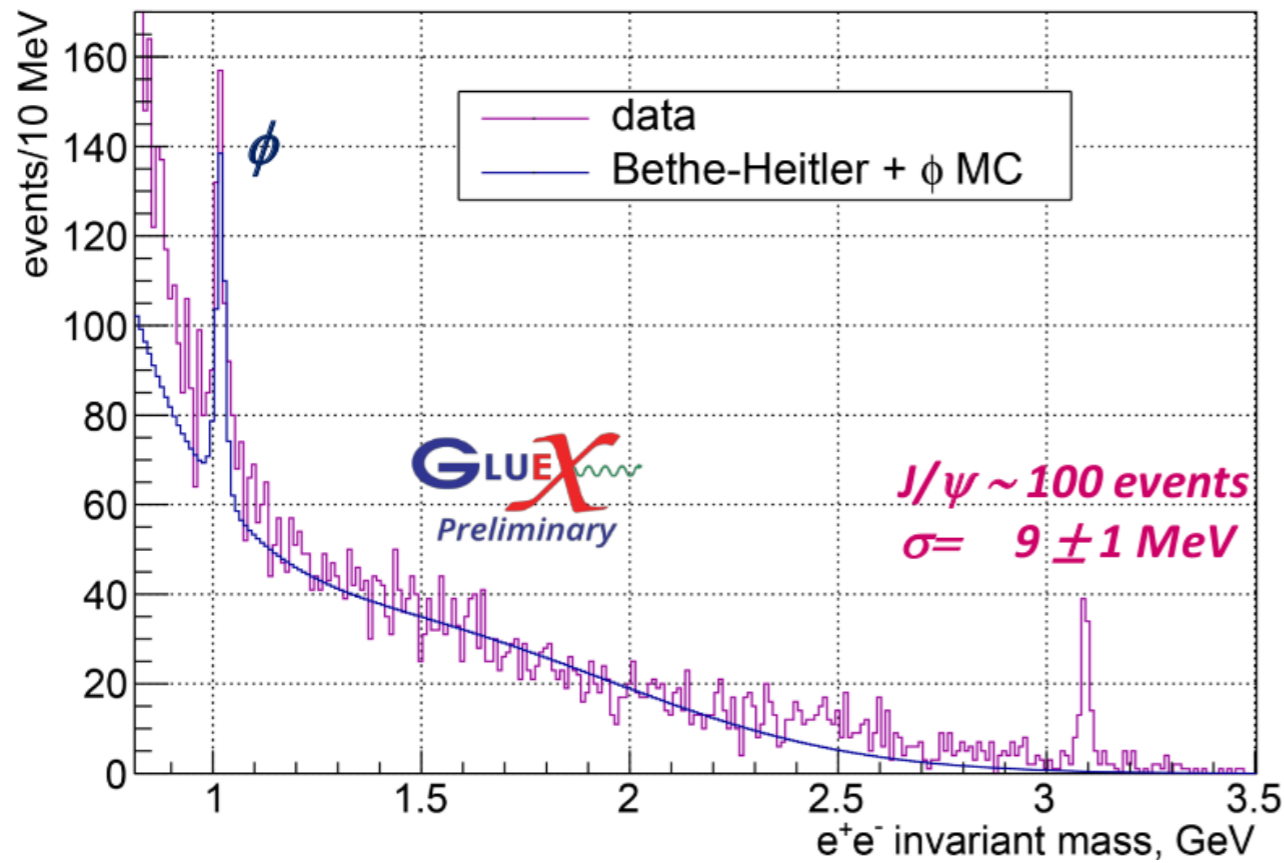
$$\gamma p \rightarrow p e^+ e^-$$



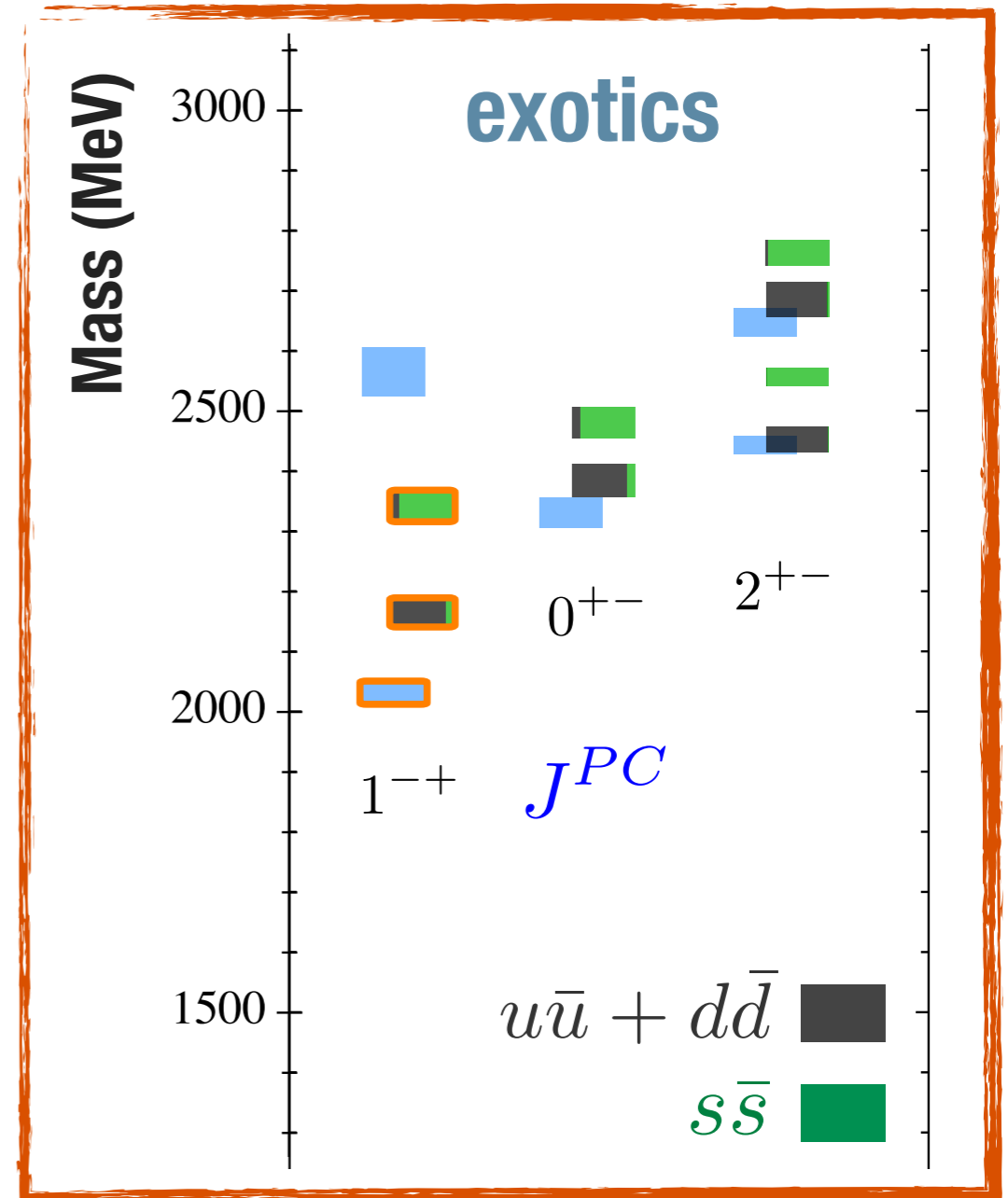
J/ ψ photoproduction at **GLUEX**

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

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



- * 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

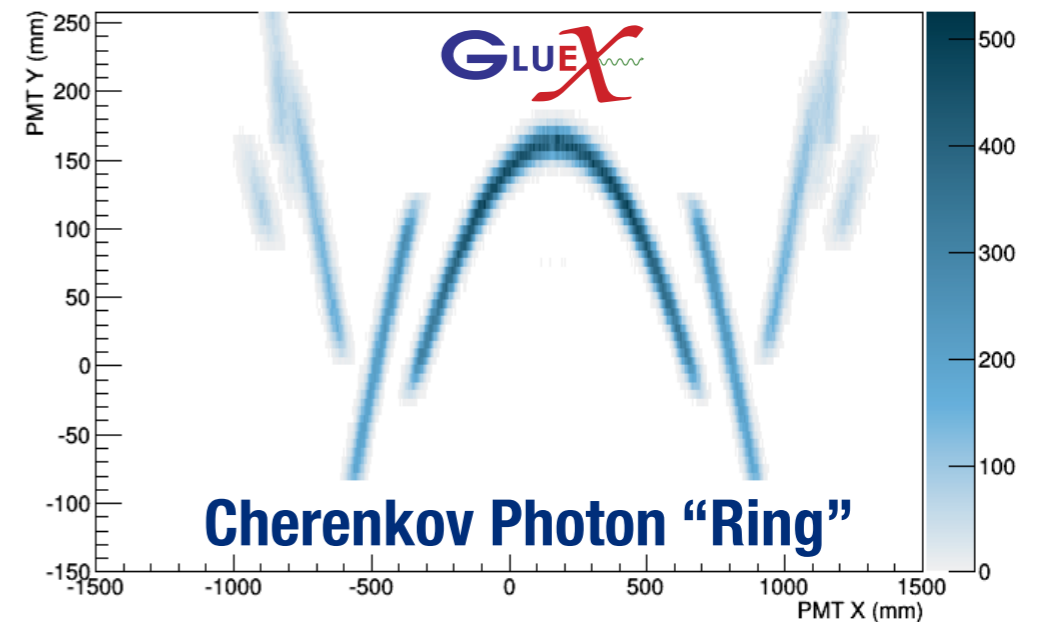
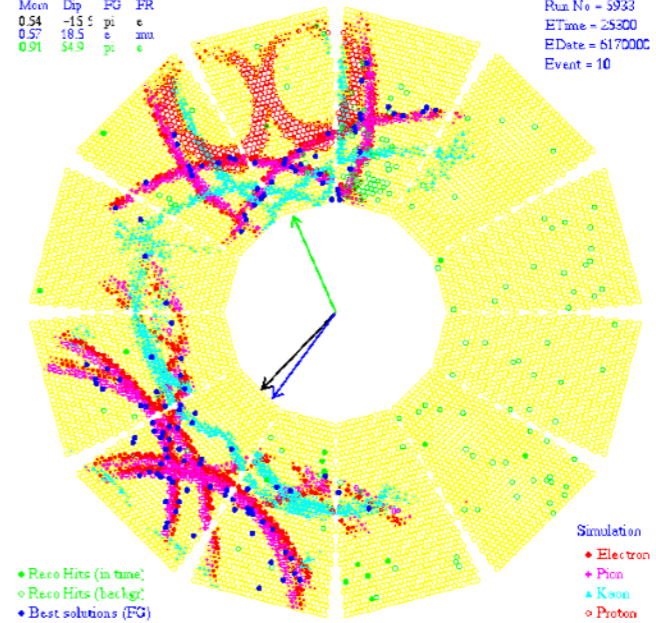
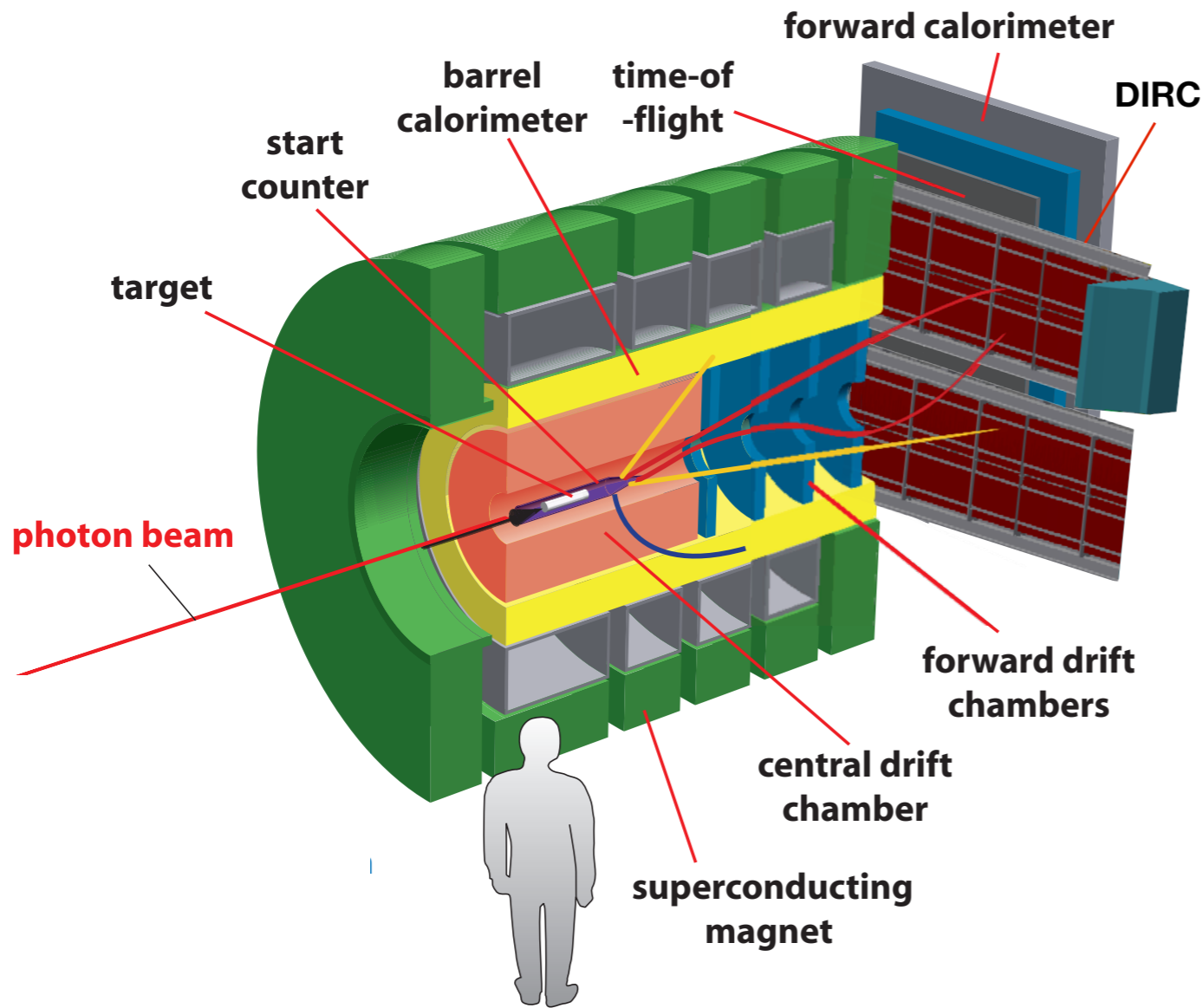


	Approximate Mass (MeV)	J^{PC}	Final States
π_1	1900	1^{-+}	$\omega\pi\pi^\dagger, 3\pi^\dagger, 5\pi, \eta 3\pi^\dagger, \eta'\pi^\dagger$
η_1	2100	1^{-+}	$4\pi, \eta 4\pi, \eta\eta\pi\pi^\dagger$
η'_1	2300	1^{-+}	$KK\pi\pi^\dagger, KK\pi^\dagger, KK\omega^\dagger$

GLUEX DIRC upgrade



Mean	Dip	FG	FR	Run No = 5933
0.54	-15.5	e	e	ETime = 25800
0.57	18.5	e	mu	EDate = 617000
0.91	54.9	pi	e	Event = 10

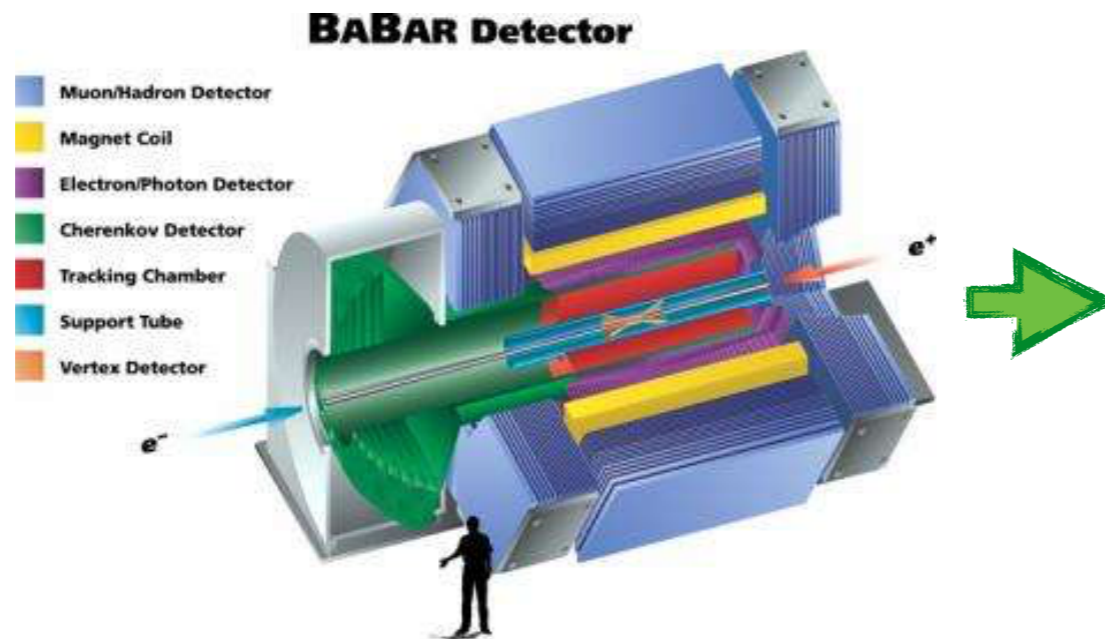


- * The GlueX **DIRC** (**D**etection of **I**nternally **R**eflected **C**herenkov light) provides new K/ π separation and will use components of the BaBar DIRC
- * Partial installation and commissioning in **2018**

GLUEX DIRC upgrade



Final shipment from SLAC to JLab this week!



Follow our trip: [twitter](https://twitter.com/GlueX_DIRC) @GlueX_DIRC

Summary

- ✦ The **GLUEX** experiment is commissioned and the initial meson program is well underway
- ✦ Early measurements aimed at understanding the meson production mechanism through polarization observables
- ✦ First observation of charm at Jefferson Lab, potential limits on pentaquark production

