



Meson spectroscopy: the **GLUEX** perspective

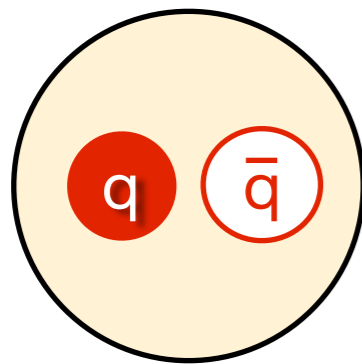
Justin Stevens



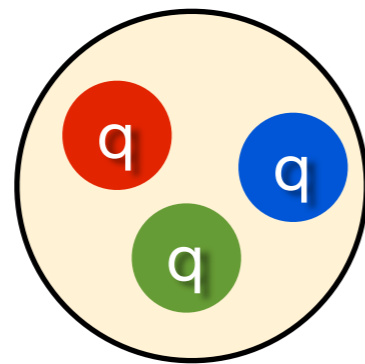
WILLIAM & MARY

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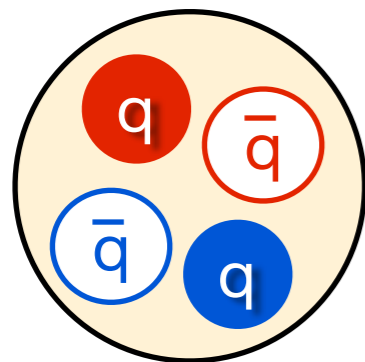
Confined states of quarks and gluons



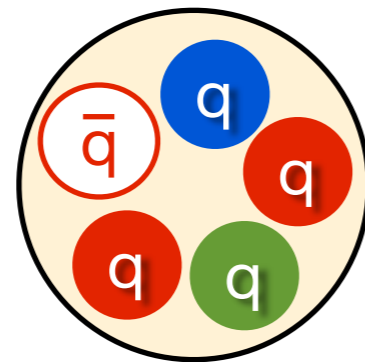
mesons



baryons



tetraquark



pentaquark

Observed mesons and baryons well described by 1st principles QCD

But these aren't the only states permitted by QCD

A SCHEMATIC MODEL OF BARYONS AND MESONS *

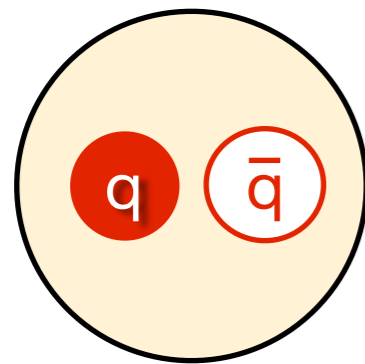
M. GELL-MANN

California Institute of Technology, Pasadena, California

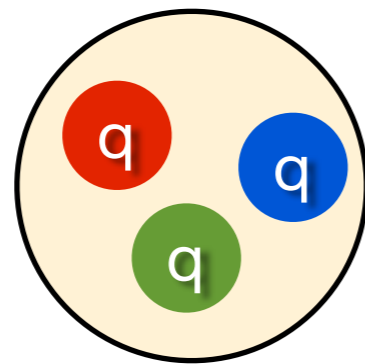
... Baryons can now be constructed from quarks by using the combinations (qqq) , $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. ...

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

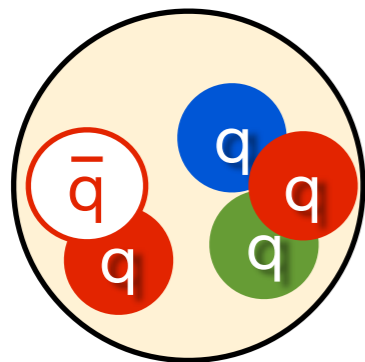
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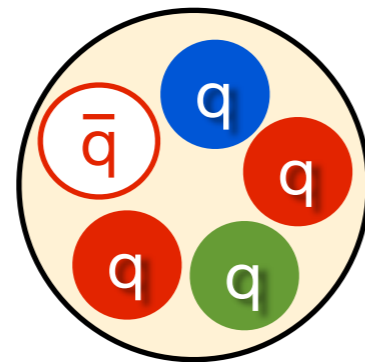
mesons



baryons



molecules

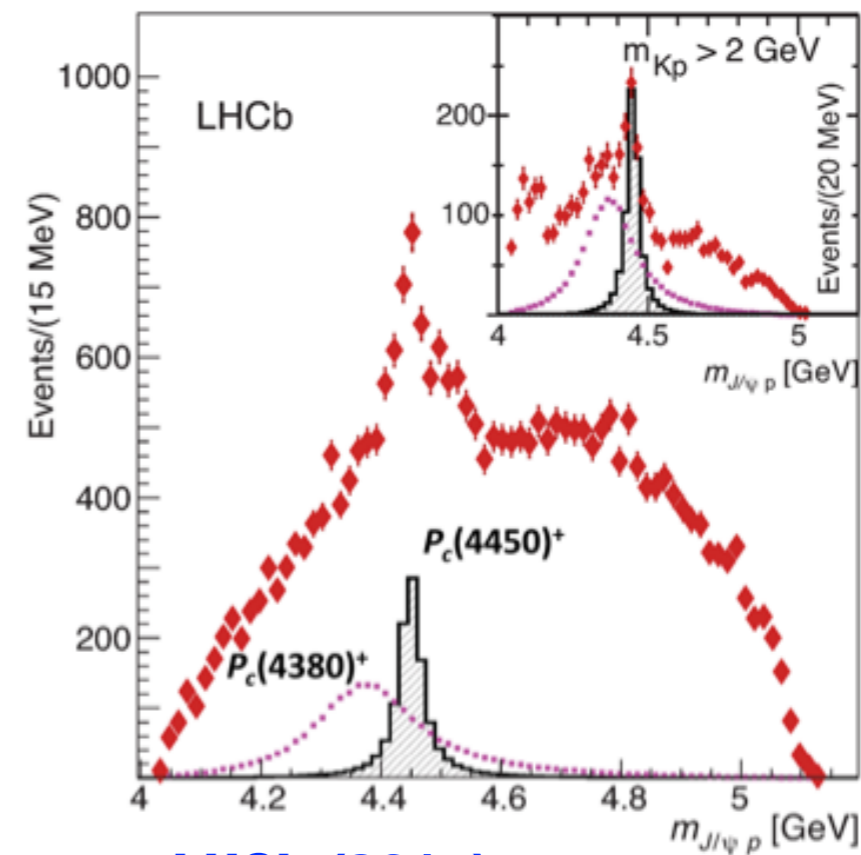


pentaquark

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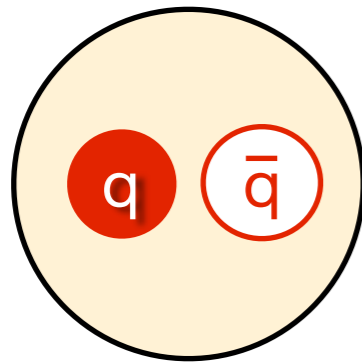
But these aren't the only states permitted by QCD

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

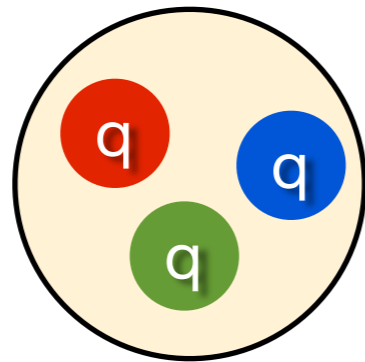


LHCb (2015)

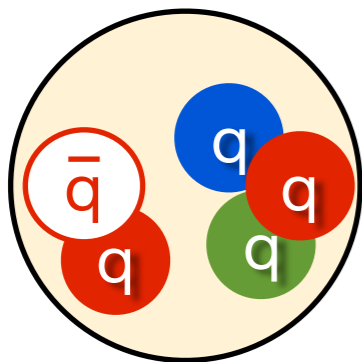
Confined states of quarks and gluons



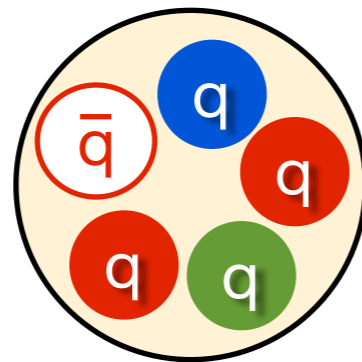
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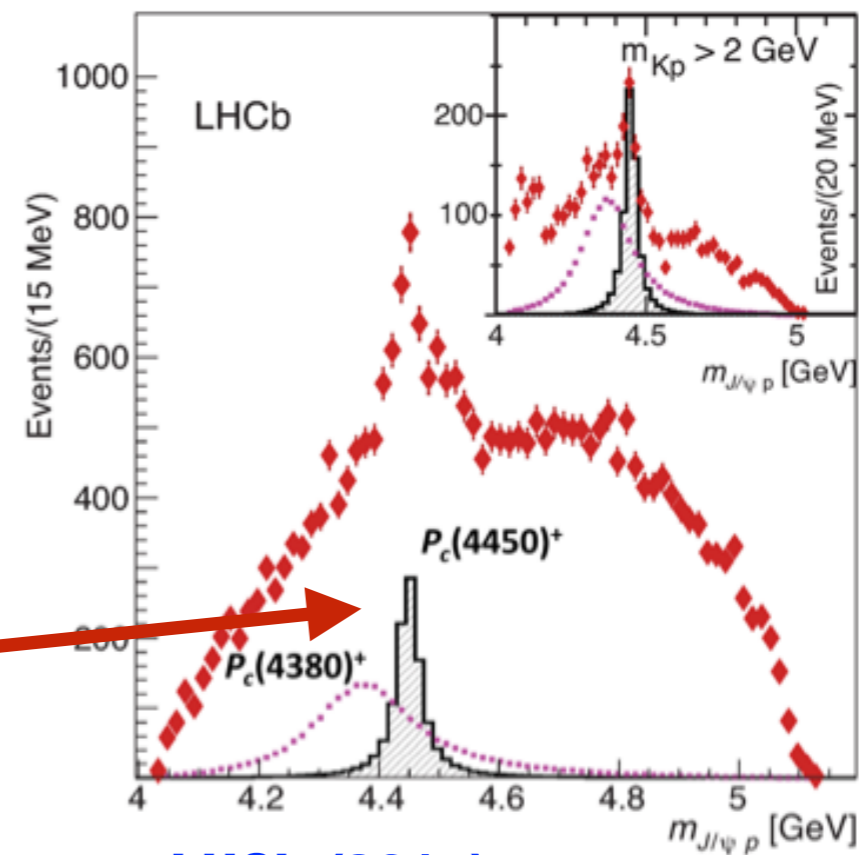


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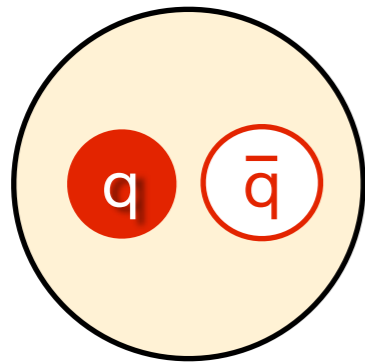


LHCb (2015)

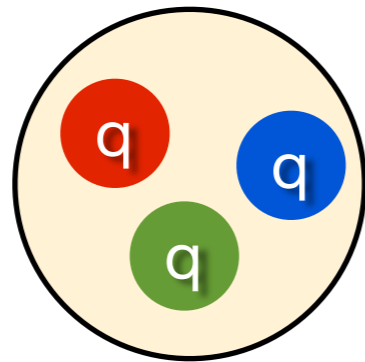
Accessible at

Jefferson Lab

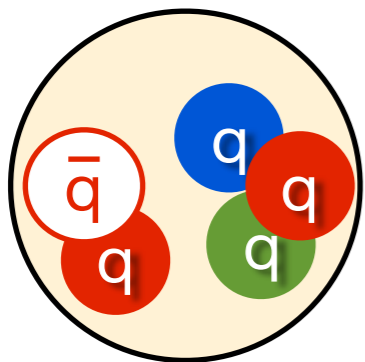
Confined states of quarks and gluons



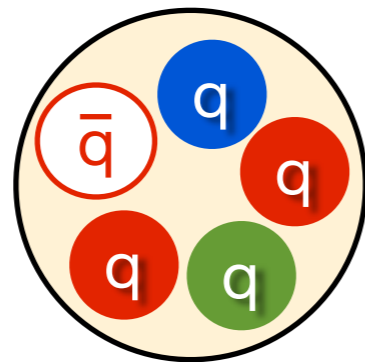
mesons



baryons



molecules

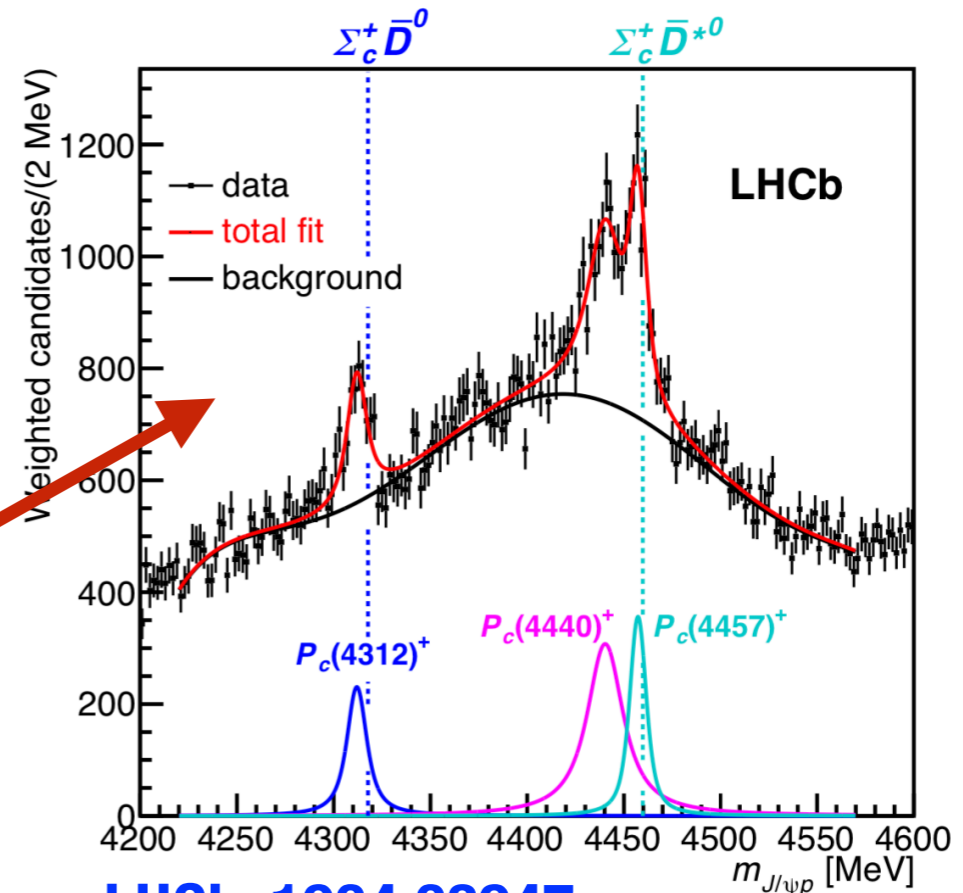


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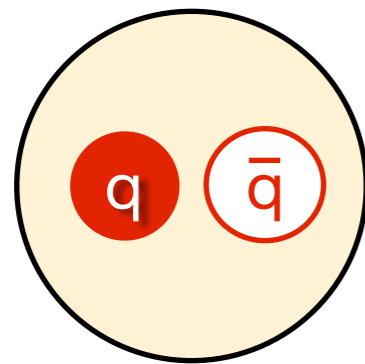
$$\Lambda_b \rightarrow J/\psi p K^-$$



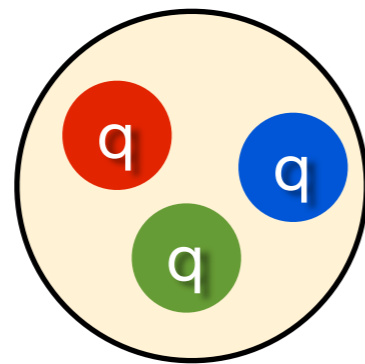
Accessible at

LHCb: 1904.03947

Confined states of quarks and gluons



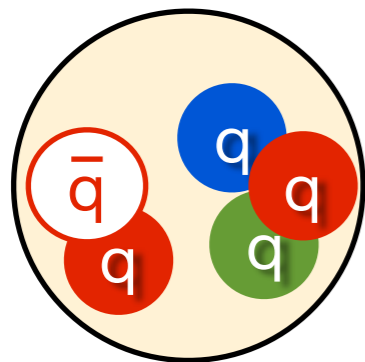
mesons



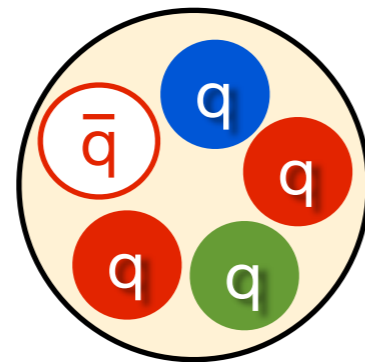
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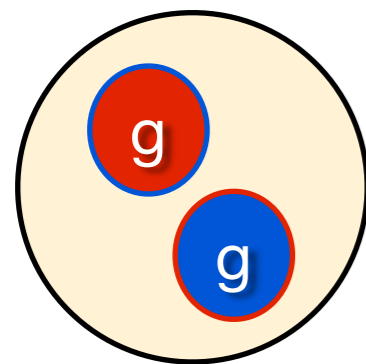
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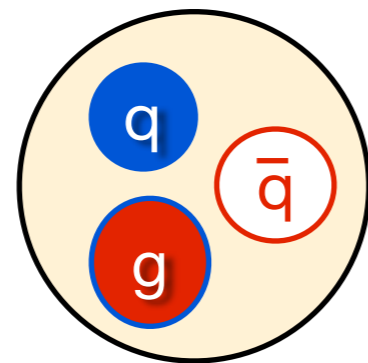
molecules



pentaquark



glueball



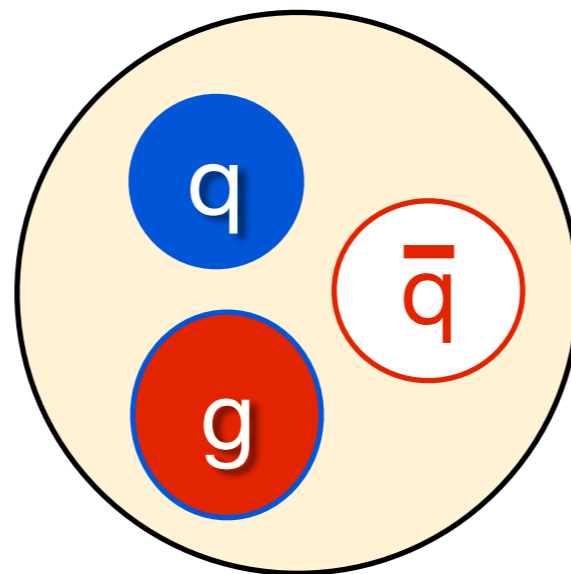
hybrid meson

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 scale $\approx 1-1.5$ GeV
- * “Exotic” J^{PC} : not simple $q\bar{q}$ from the non-rel. quark model

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

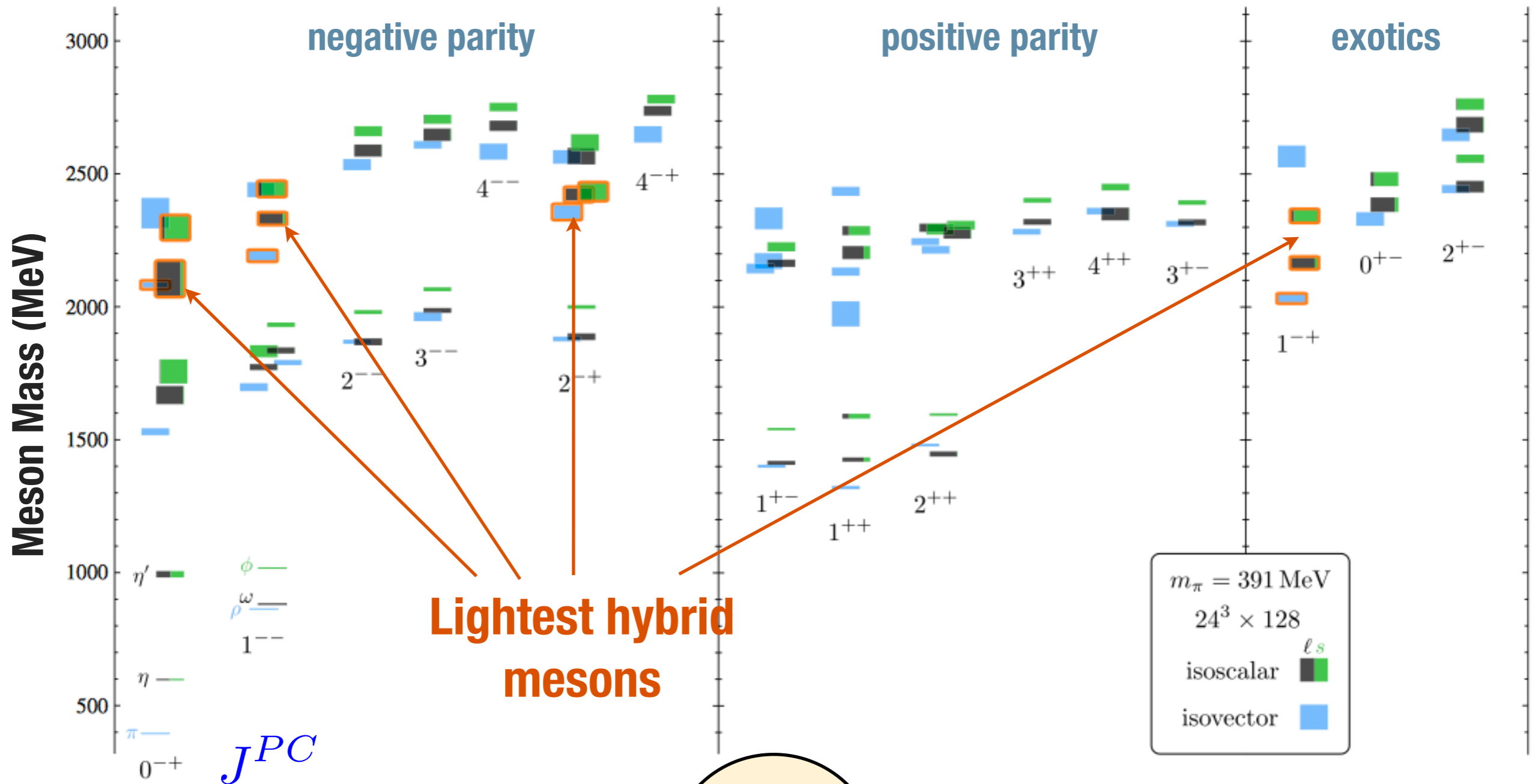


hybrid meson

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

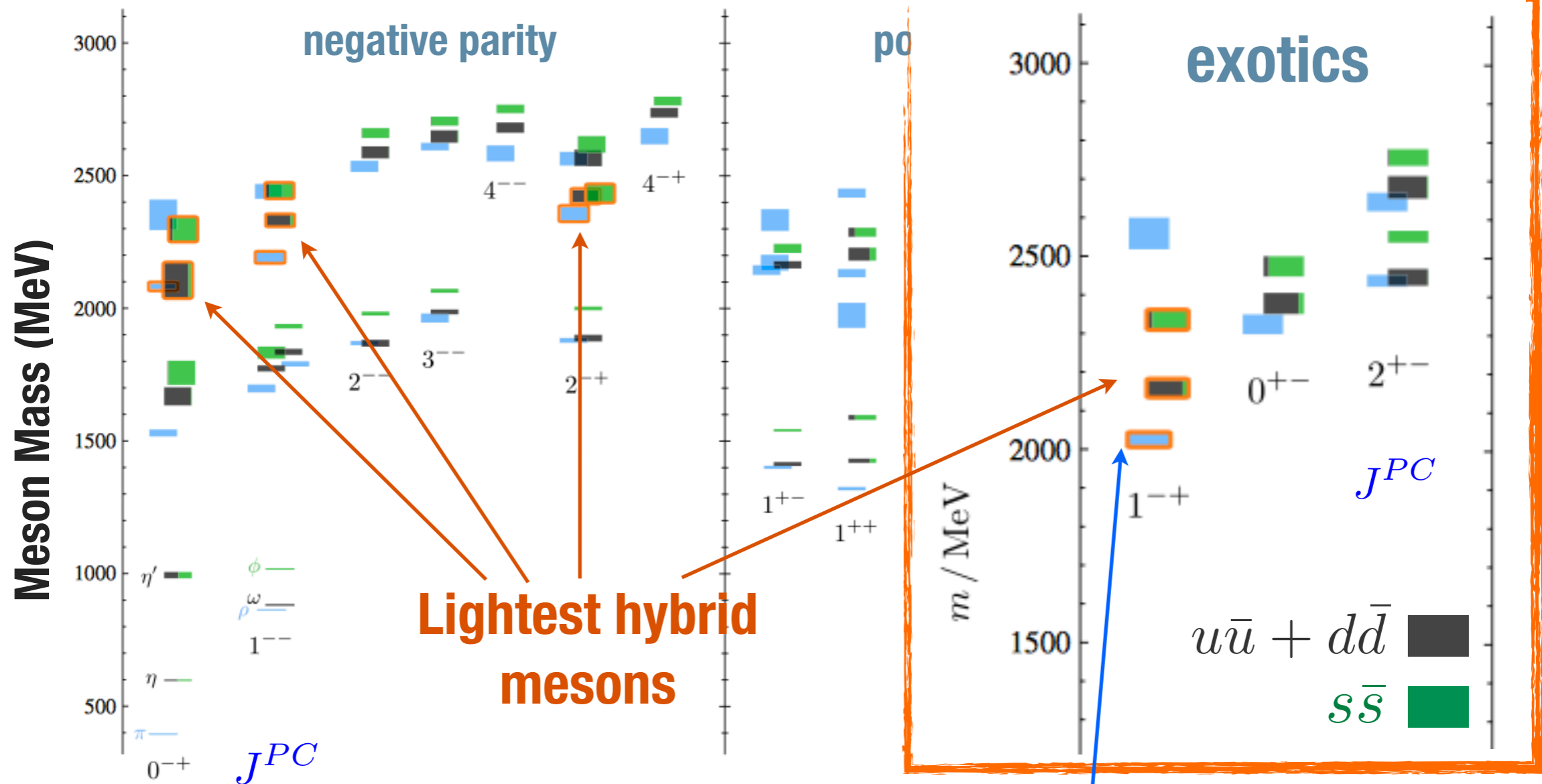
Lattice QCD

Dudek et al. PRD 88 (2013) 094505

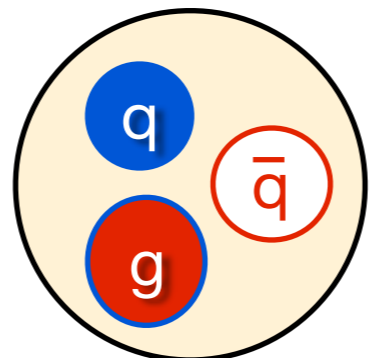


Lattice QCD

Dudek et al. PRD 88 (2013) 094505



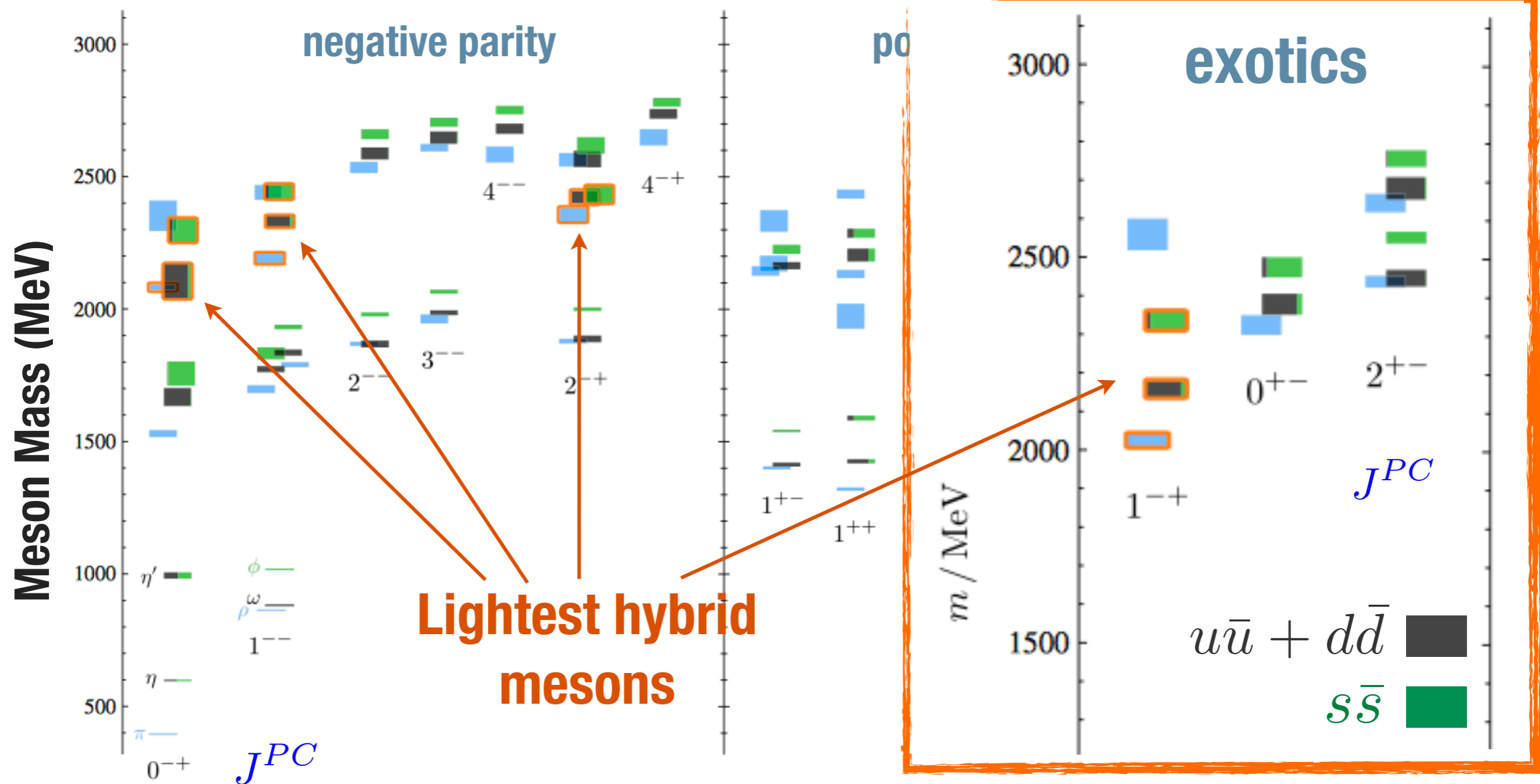
Lightest hybrid mesons



Most experimental searches for hybrids limited to the π_1 state

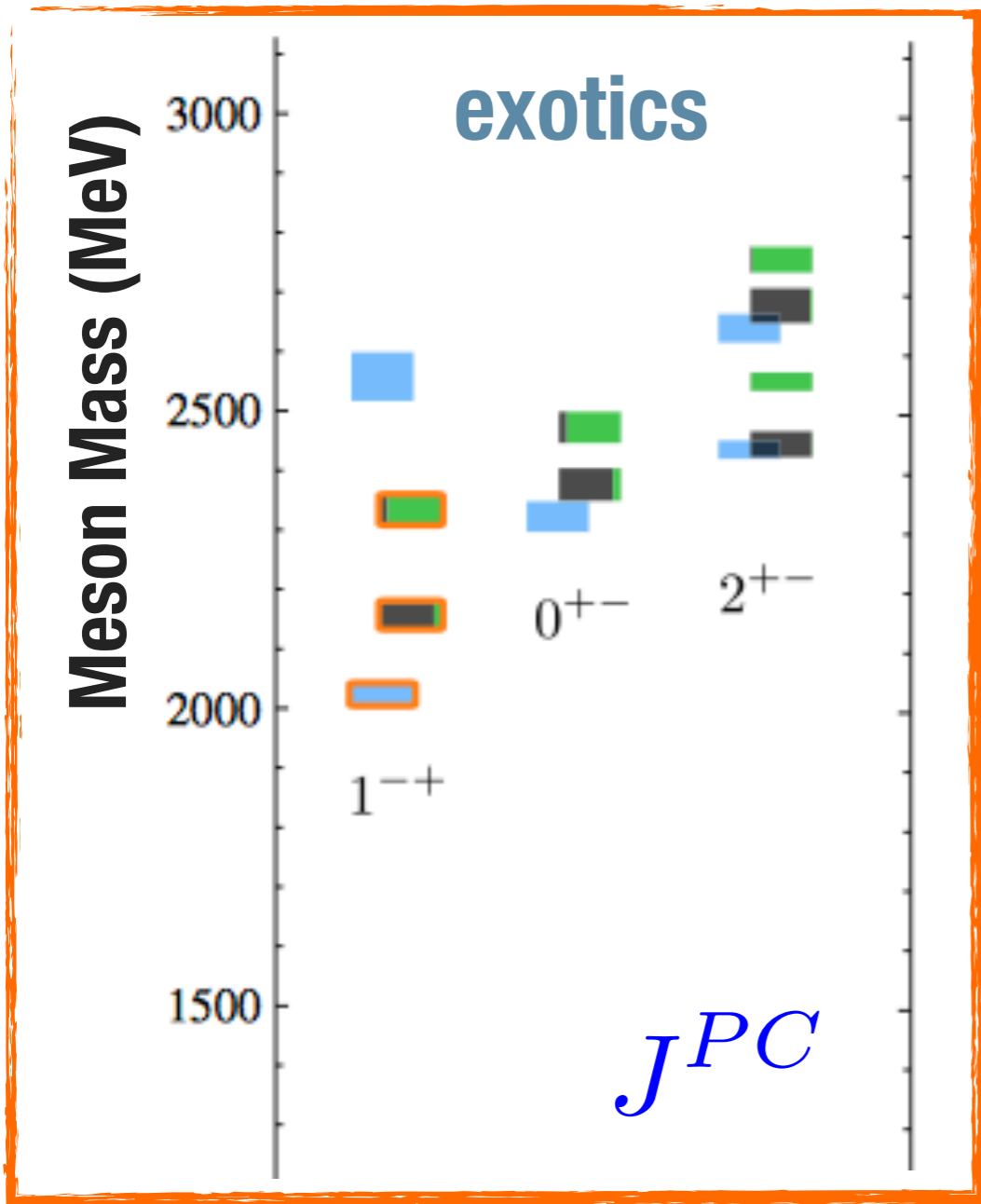
Lattice QCD: Mesons

Dudek et al. PRD 88 (2013) 094505

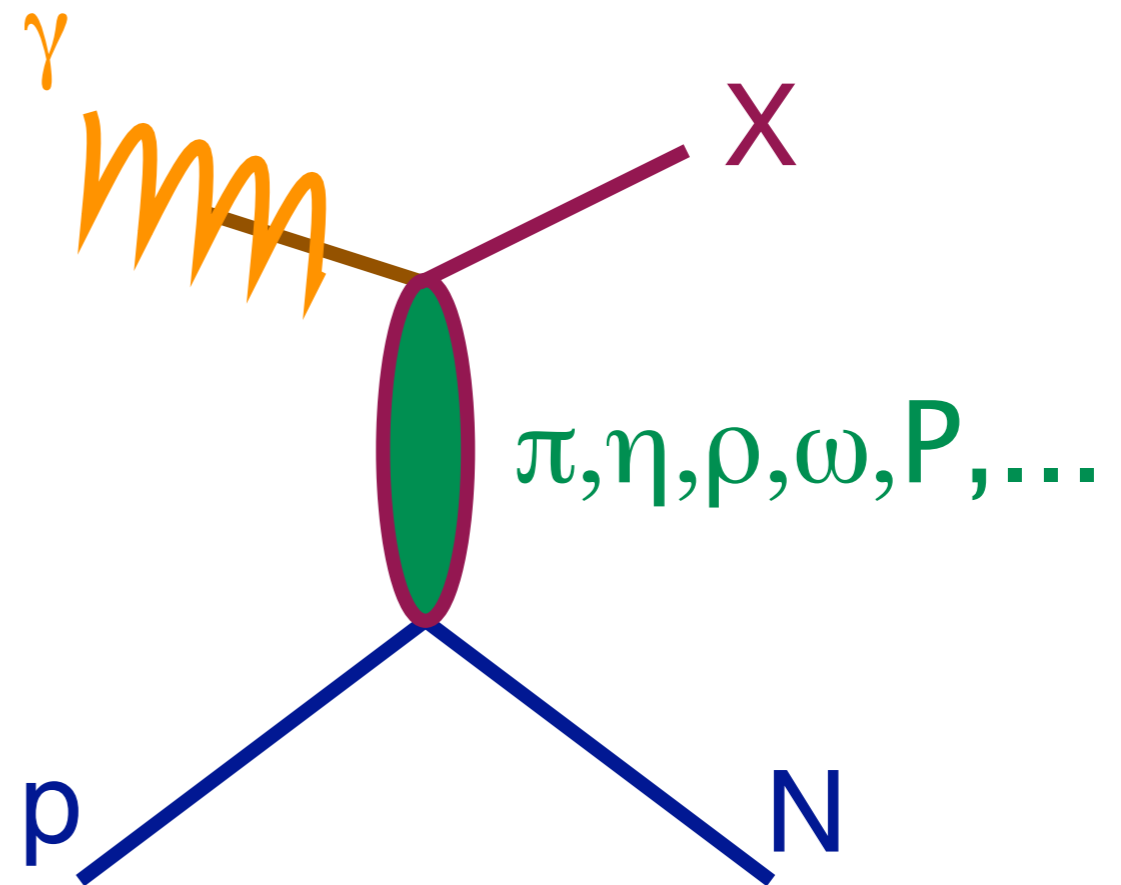


- * Ideally look for a pattern of hybrid states in multiple decay modes
- * Primary goal of the GlueX experiment is to search for and ultimately map out the spectrum of light quark hybrid mesons

Exotic J^{PC} in photoproduction



Meson X with particular J^{PC}

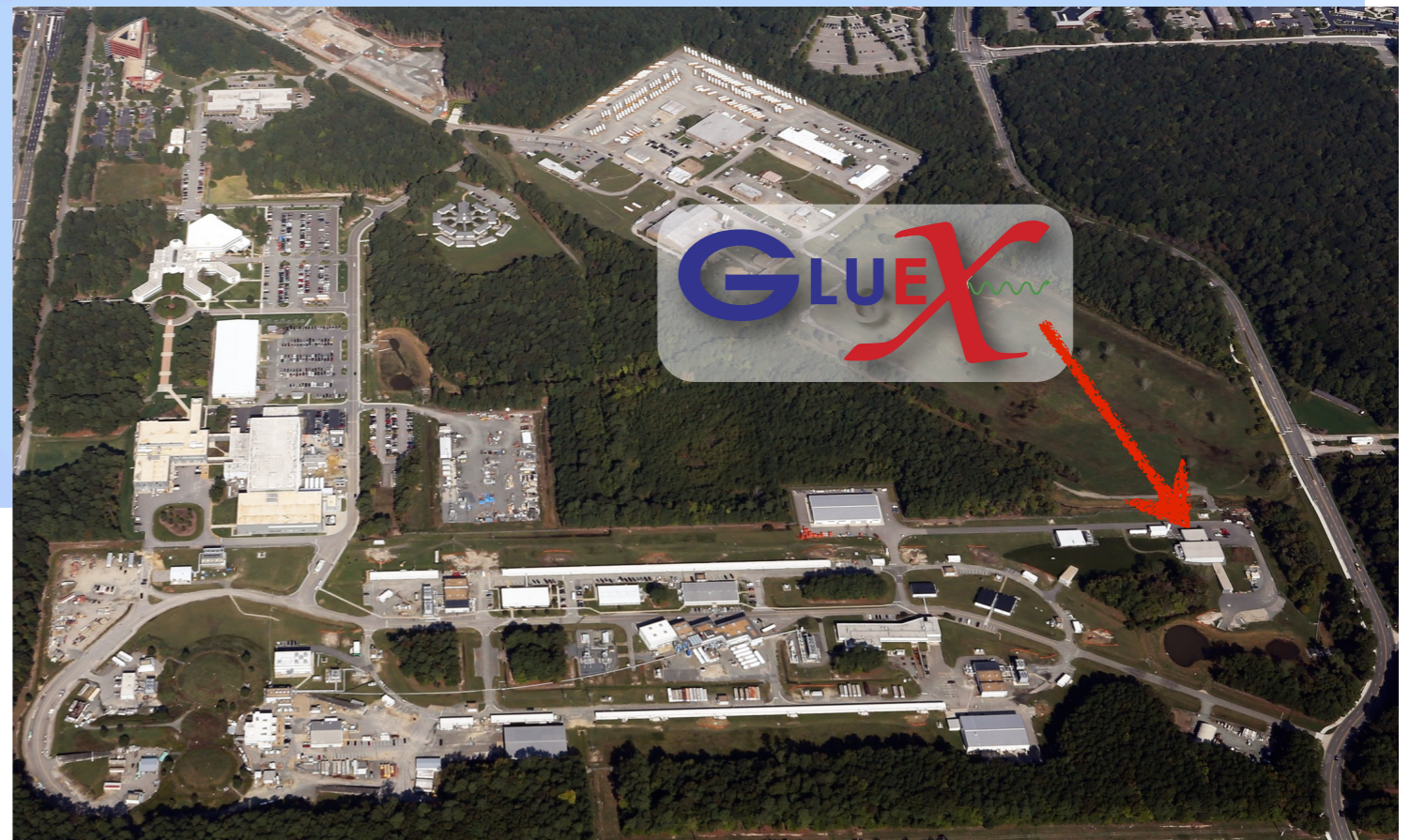


**Production through t-channel
“quasi-particle” exchange**

Jefferson Lab (JLab)

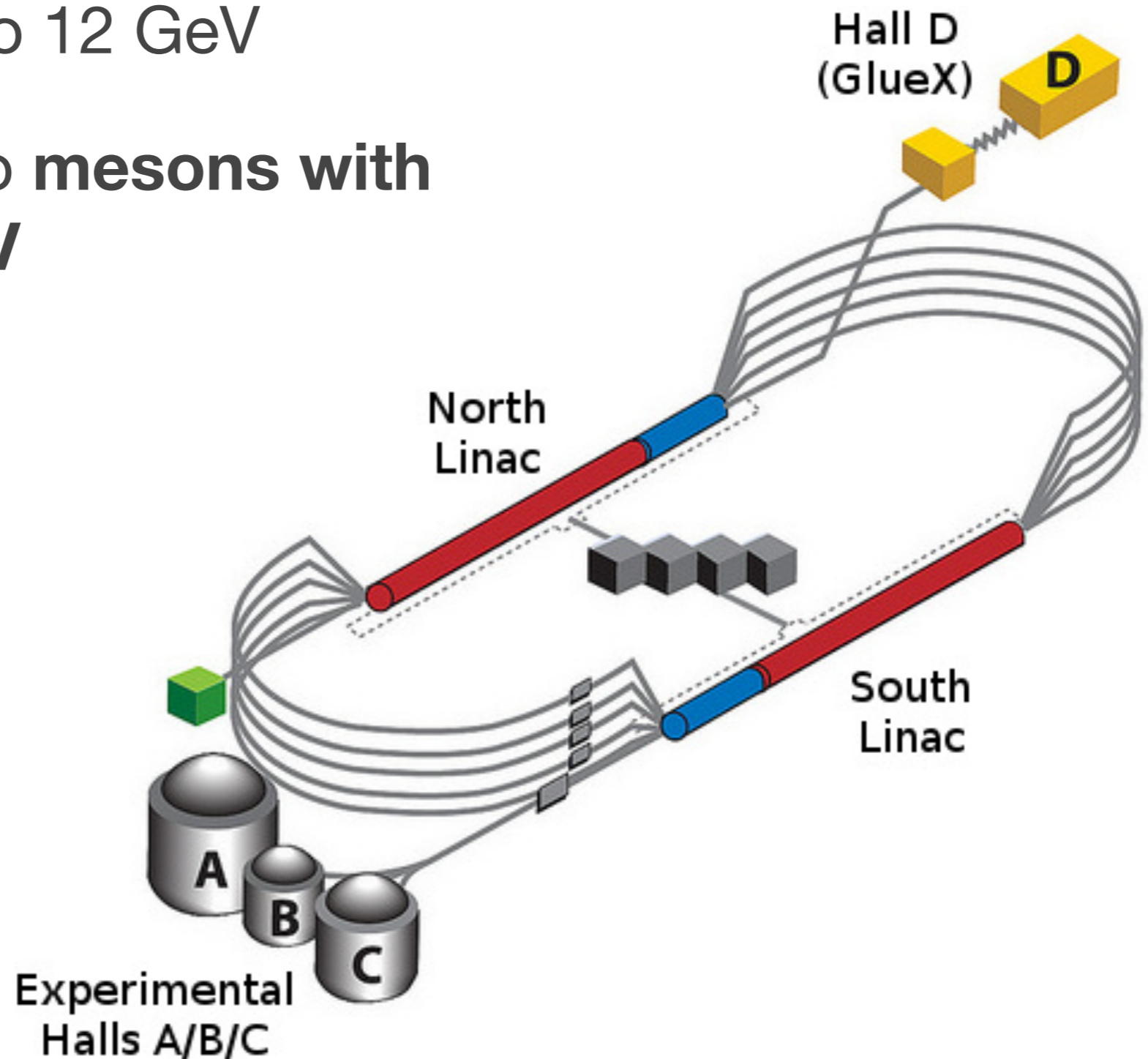


- ☀ Newport News, Virginia
- ☀ Home to the Continuous Electron Beam Accelerator Facility (CEBAF)

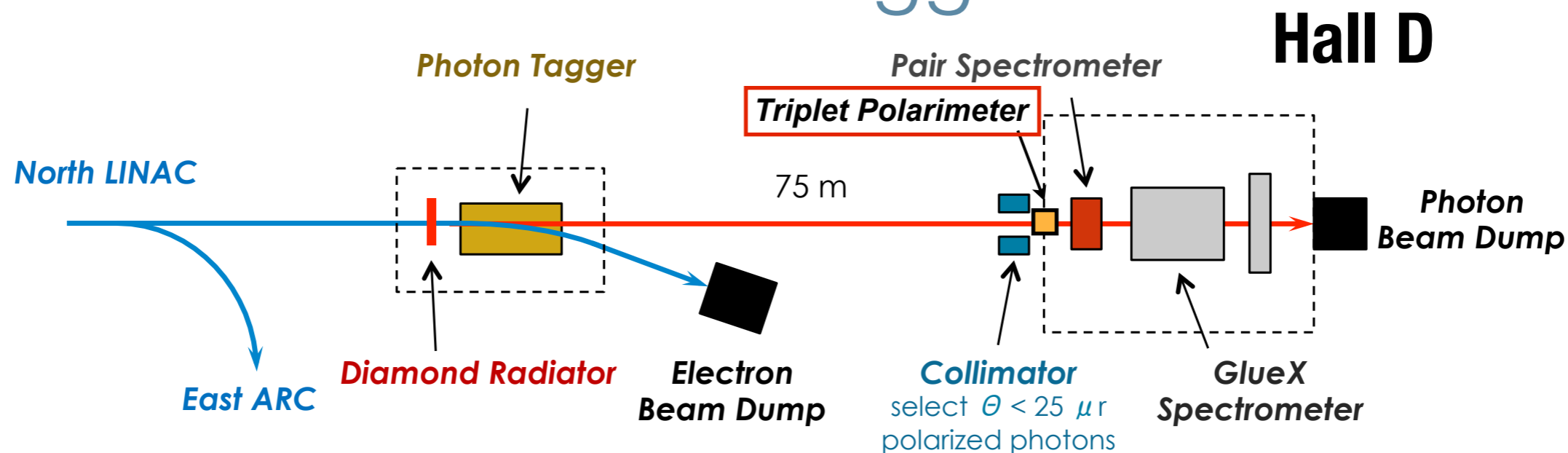


Jefferson Lab 12 GeV Upgrade

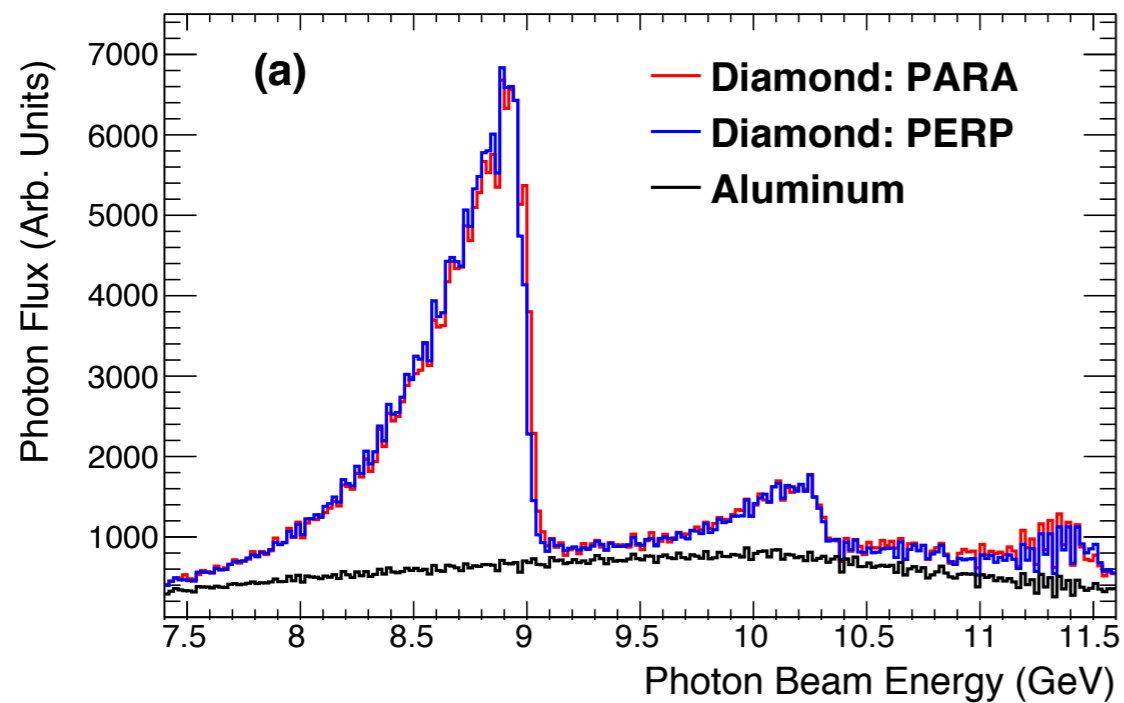
- * Maximum electron beam energy upgraded from 6 to 12 GeV
- * Provides access to **mesons with masses to ~3 GeV**



Photon Beam and Tagger

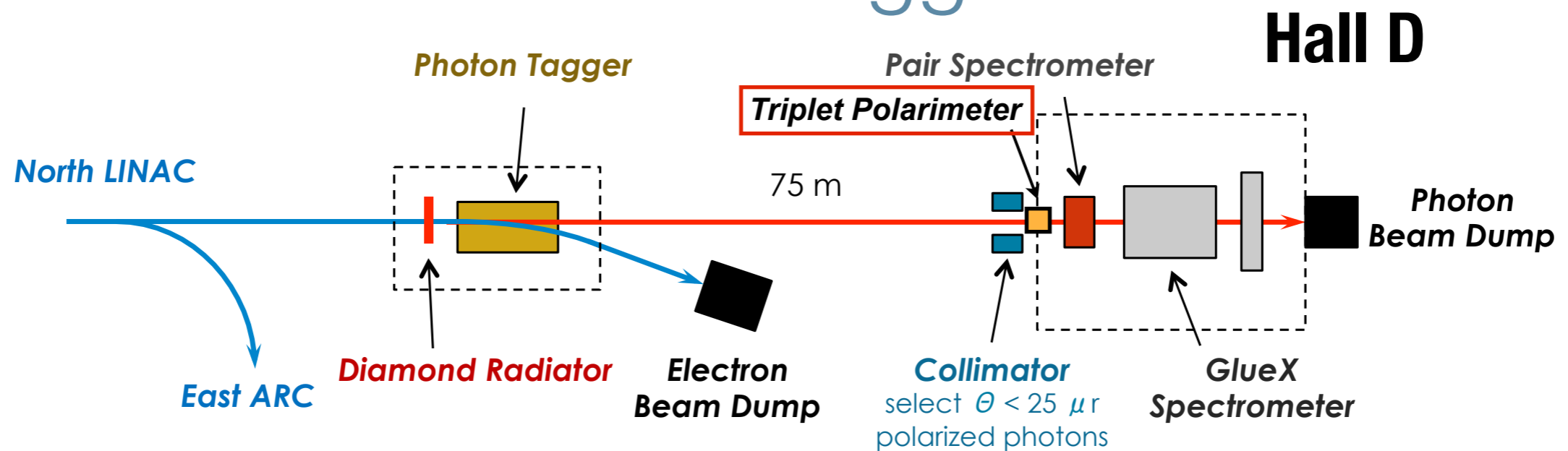


Measured Flux

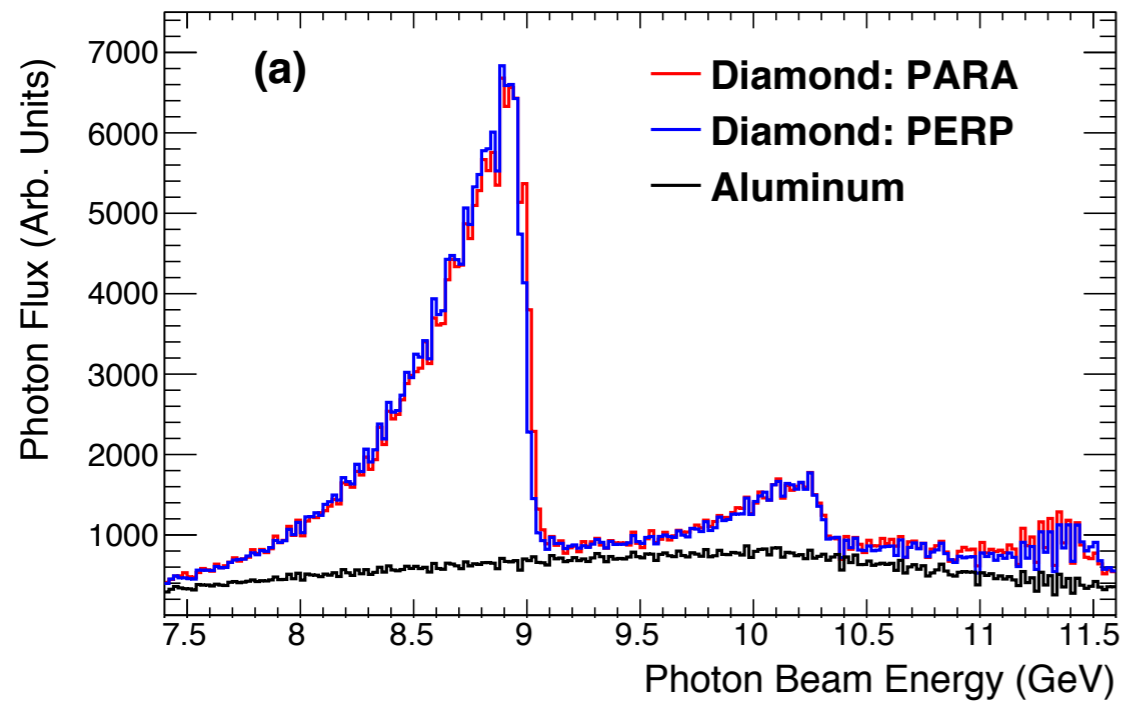


Mesons up to ~3 GeV

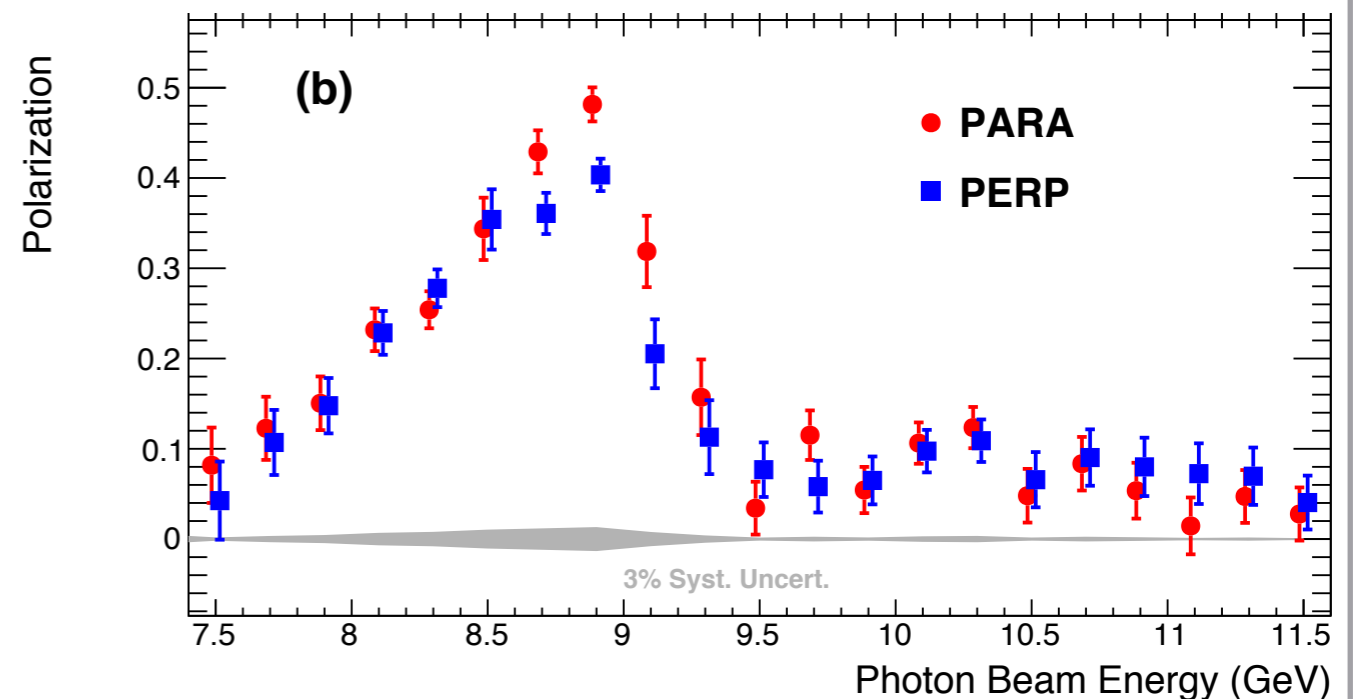
Photon Beam and Tagger



Measured Flux



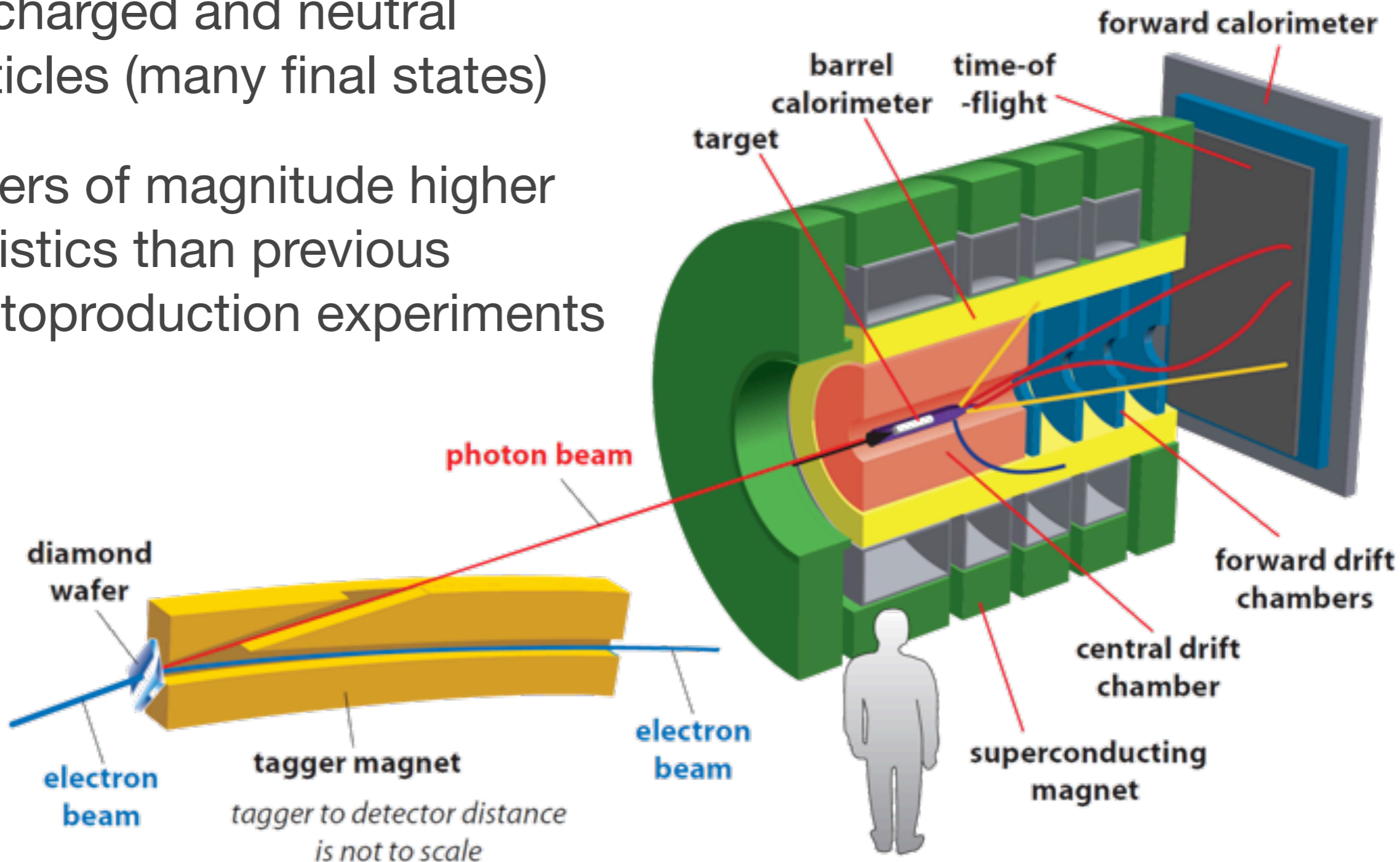
Measured Polarization



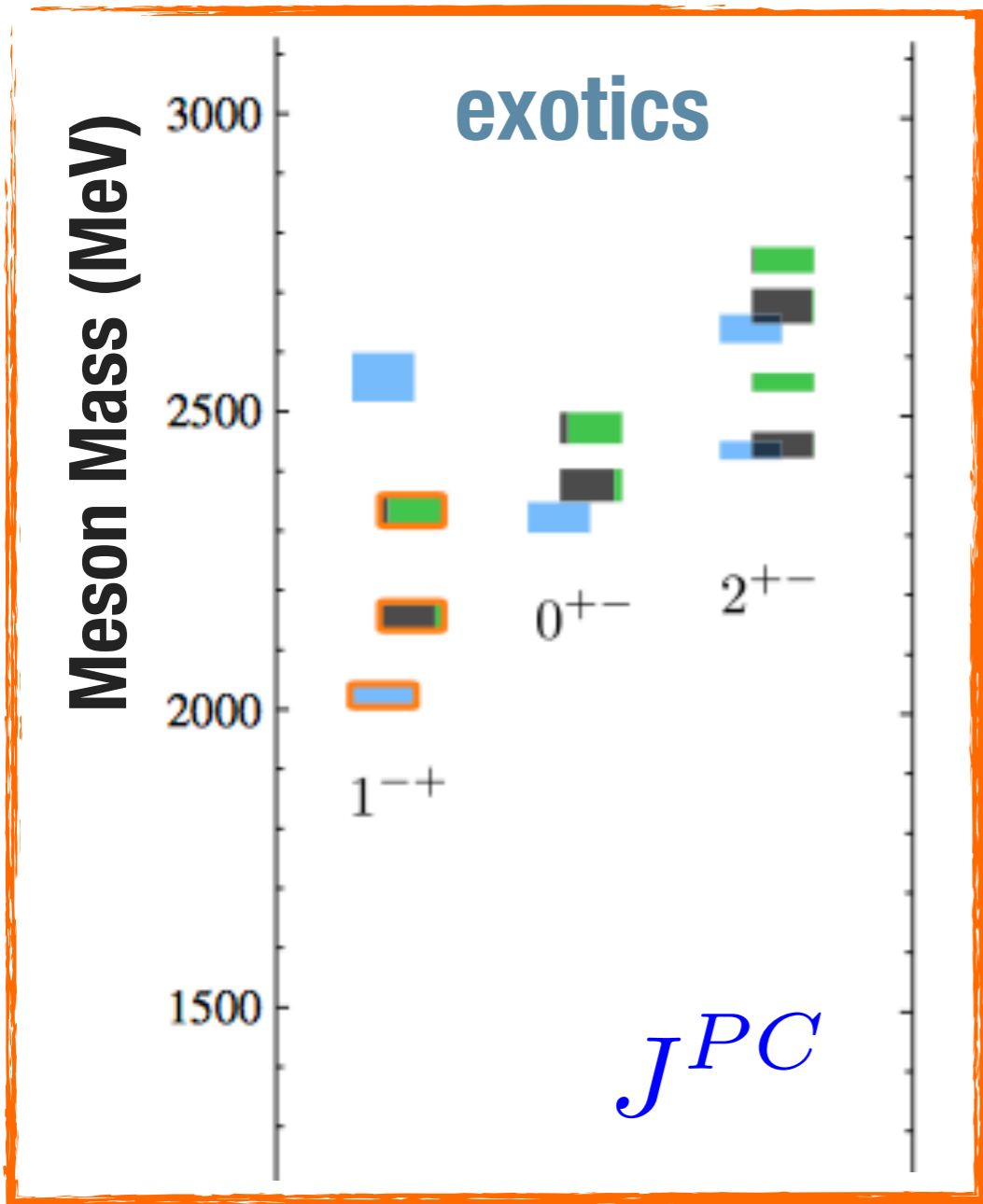
Filter on production mechanism

GLUEX in Hall D

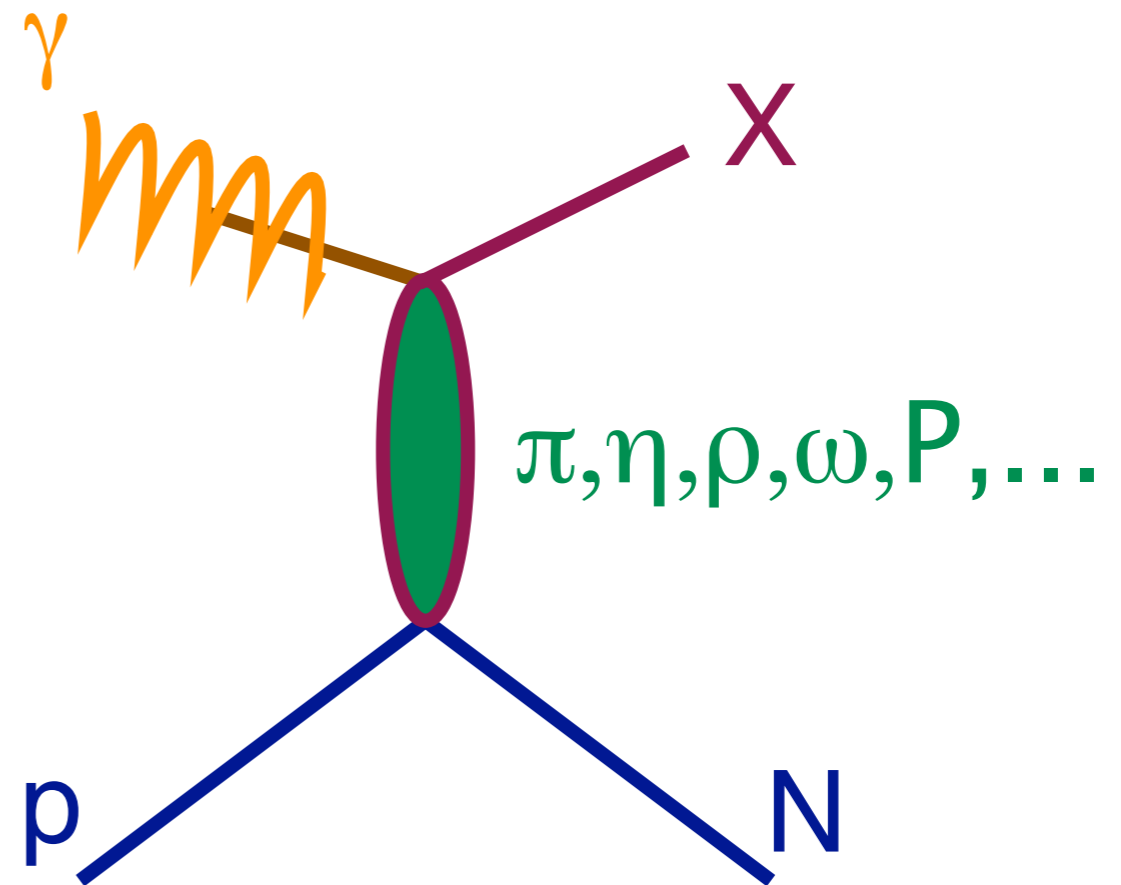
- * Large acceptance detector for charged and neutral particles (many final states)
- * Orders of magnitude higher statistics than previous photoproduction experiments



Exotic J^{PC} in photoproduction

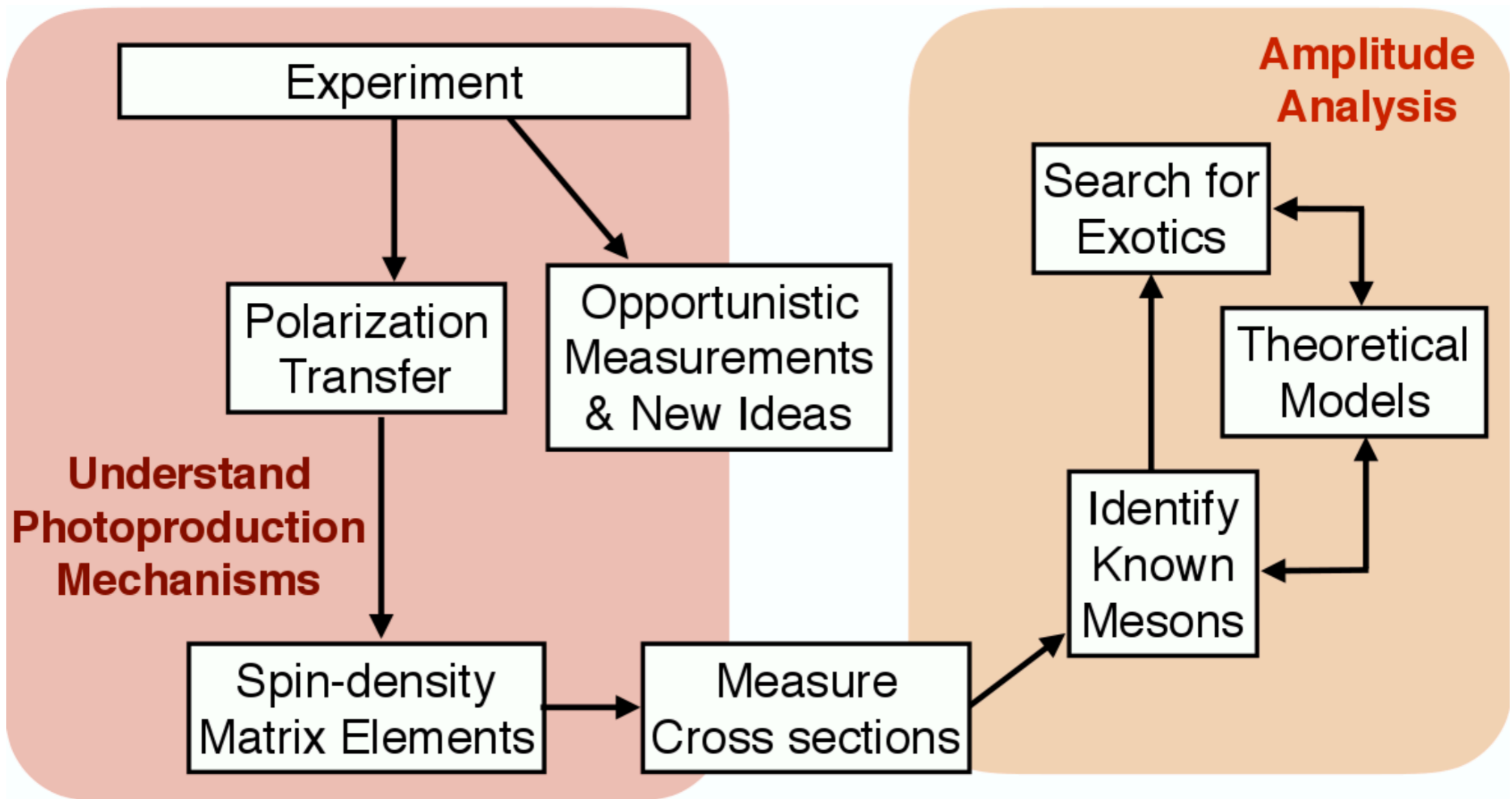


Meson X with particular J^{PC}



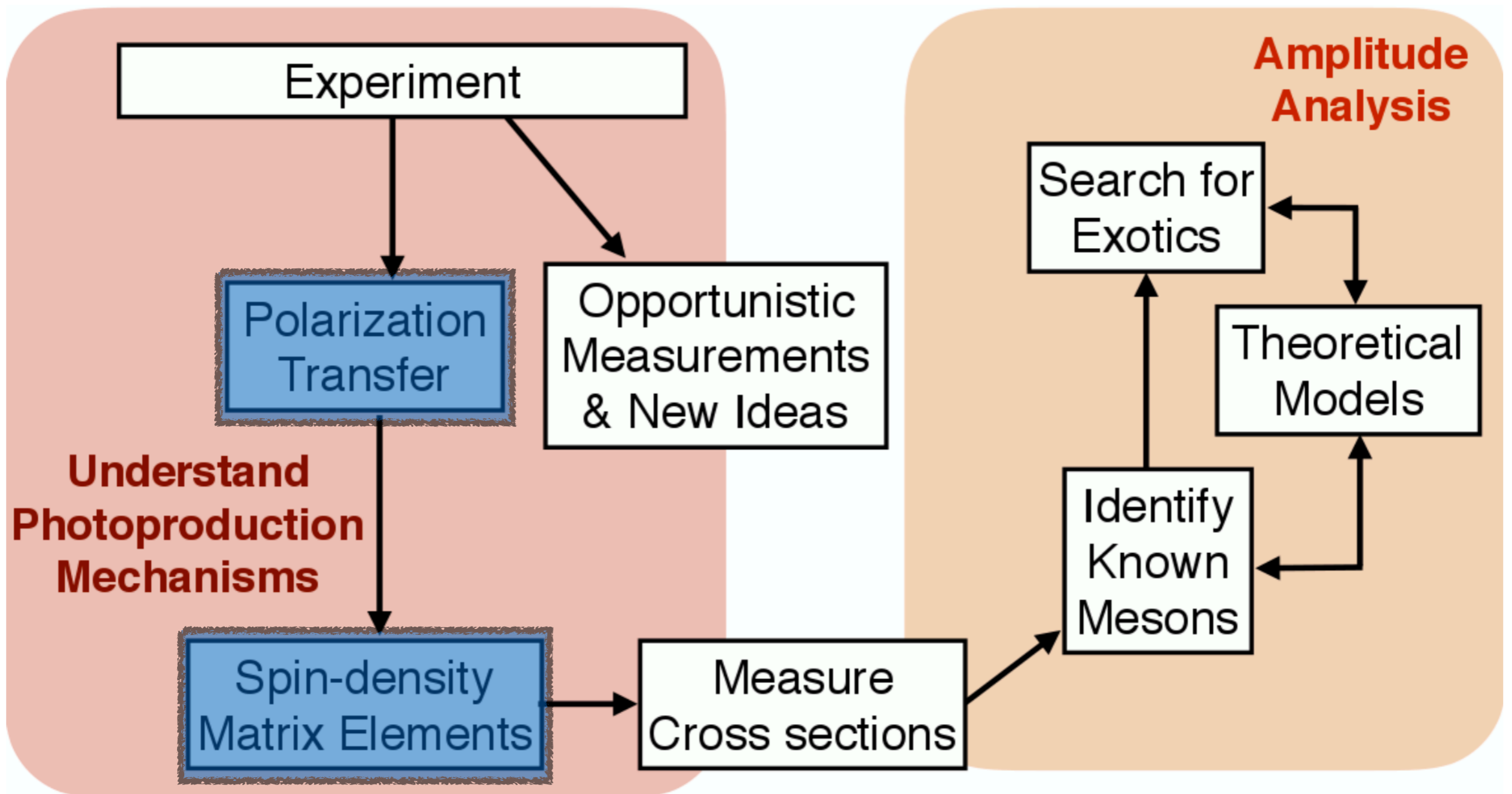
Production through t-channel “quasi-particle” exchange

GLUEX Physics Program



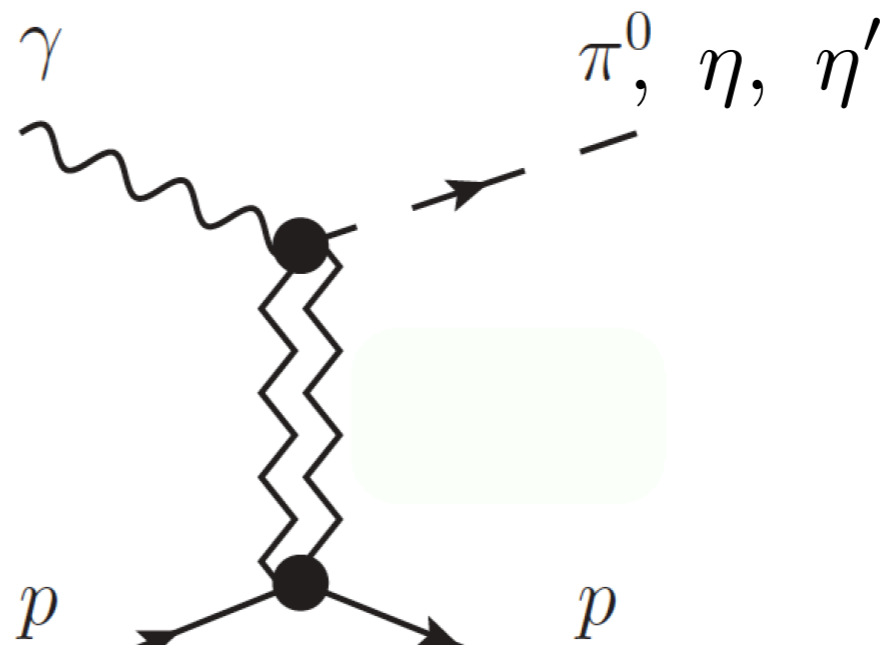
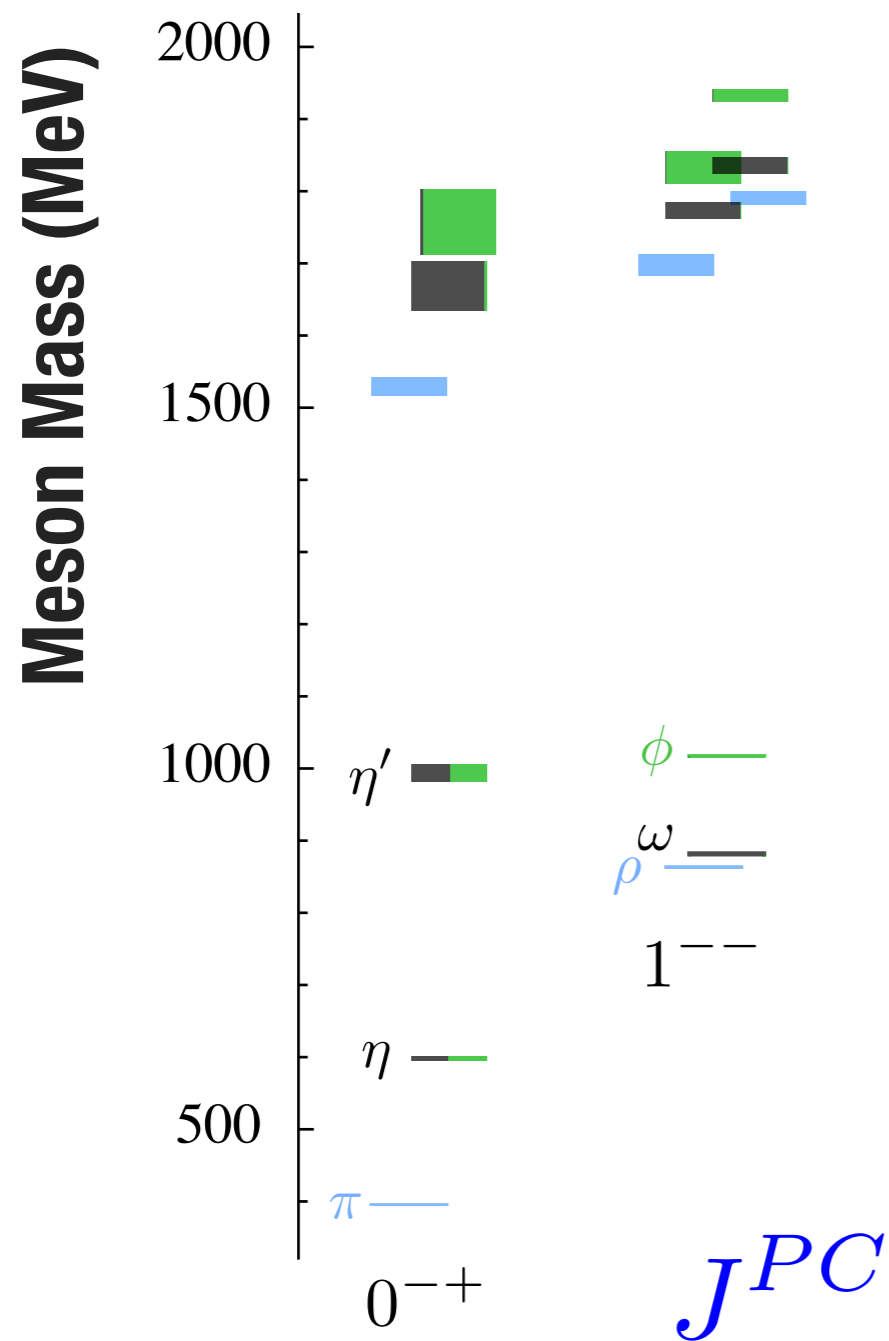
GLUEX Physics Program

Strong collaboration with theory required: e.g. *J*PAC



Welcome more collaboration with theory!

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 “naturality” of the exchange particle

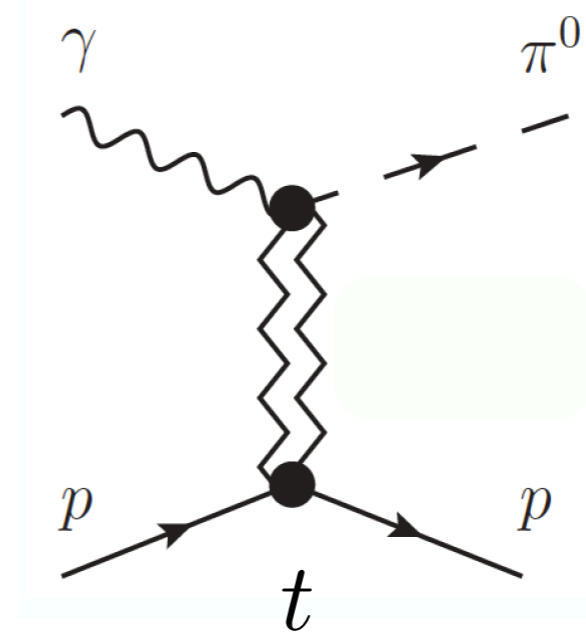
$\gamma p \rightarrow \pi^0 p$ beam asymmetry Σ

- * 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 $\gamma p \rightarrow \eta p$

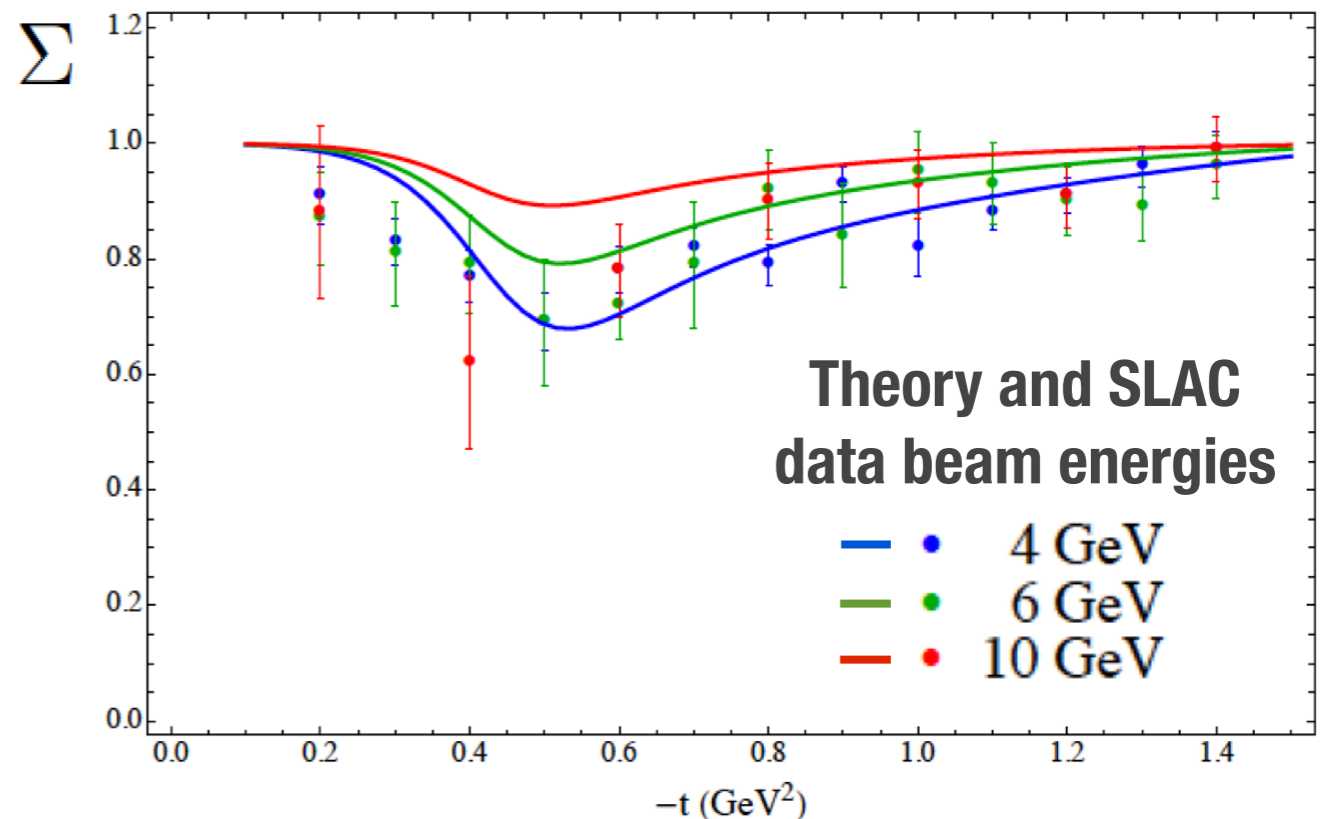
* **No previous measurements!**



Exchange J^{PC}

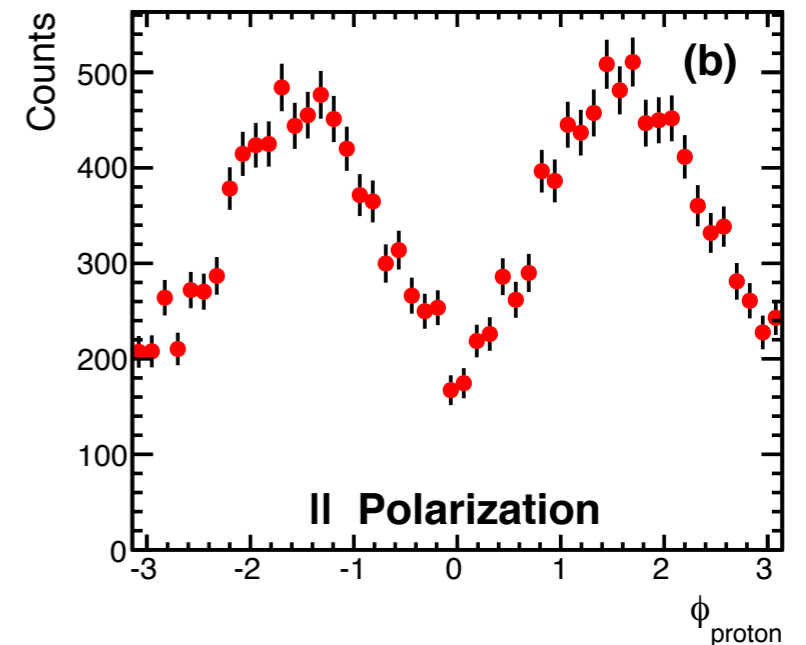
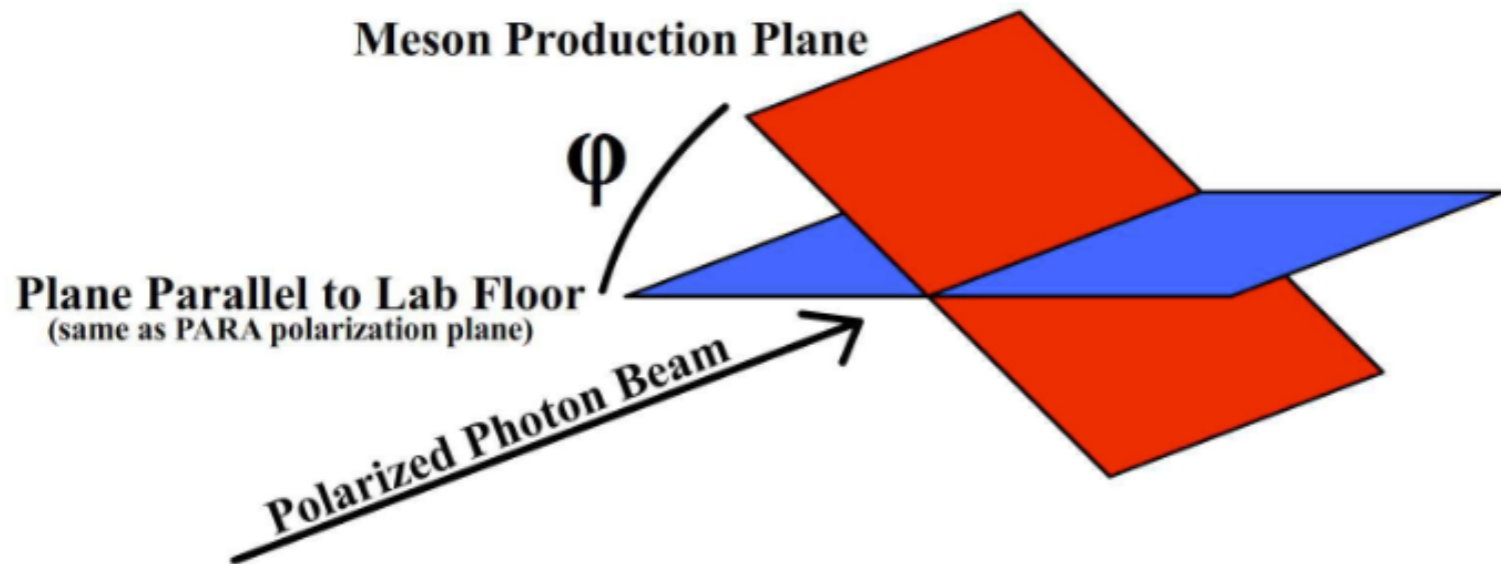
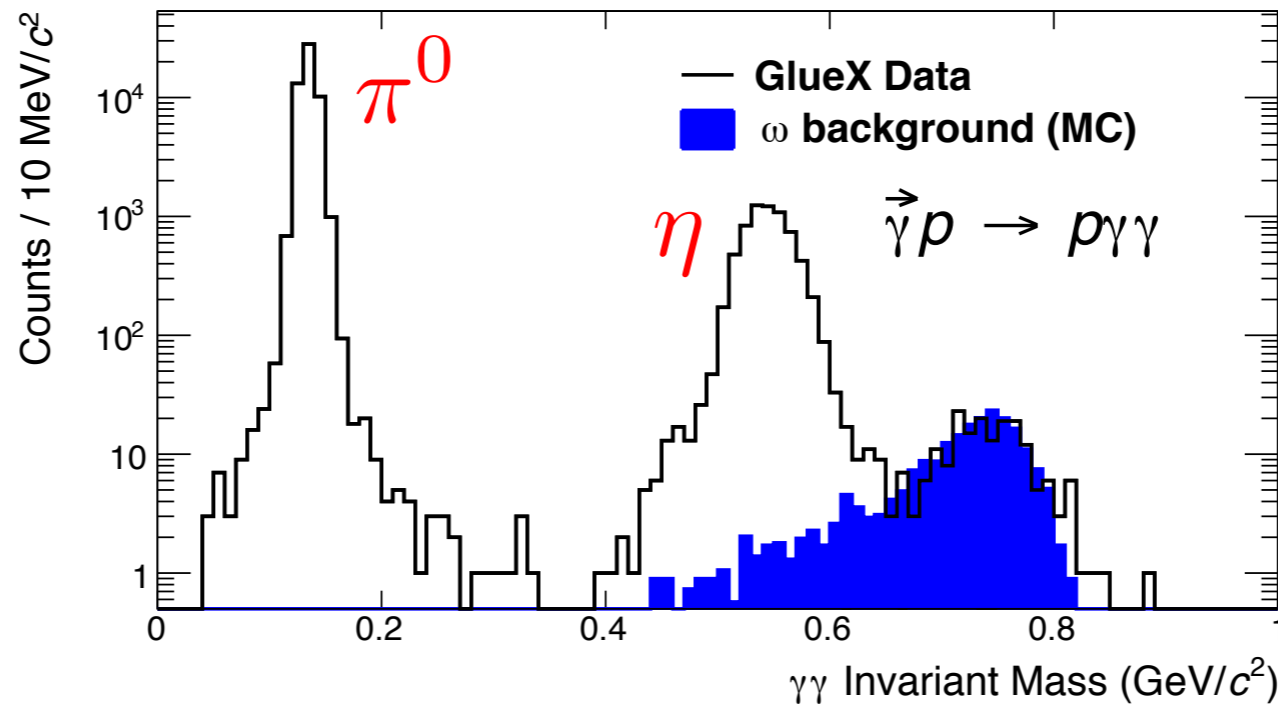
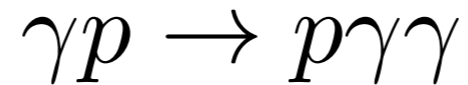
$1^{--} : \omega, \rho$

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



Mathieu et al. PRD 92, 074013

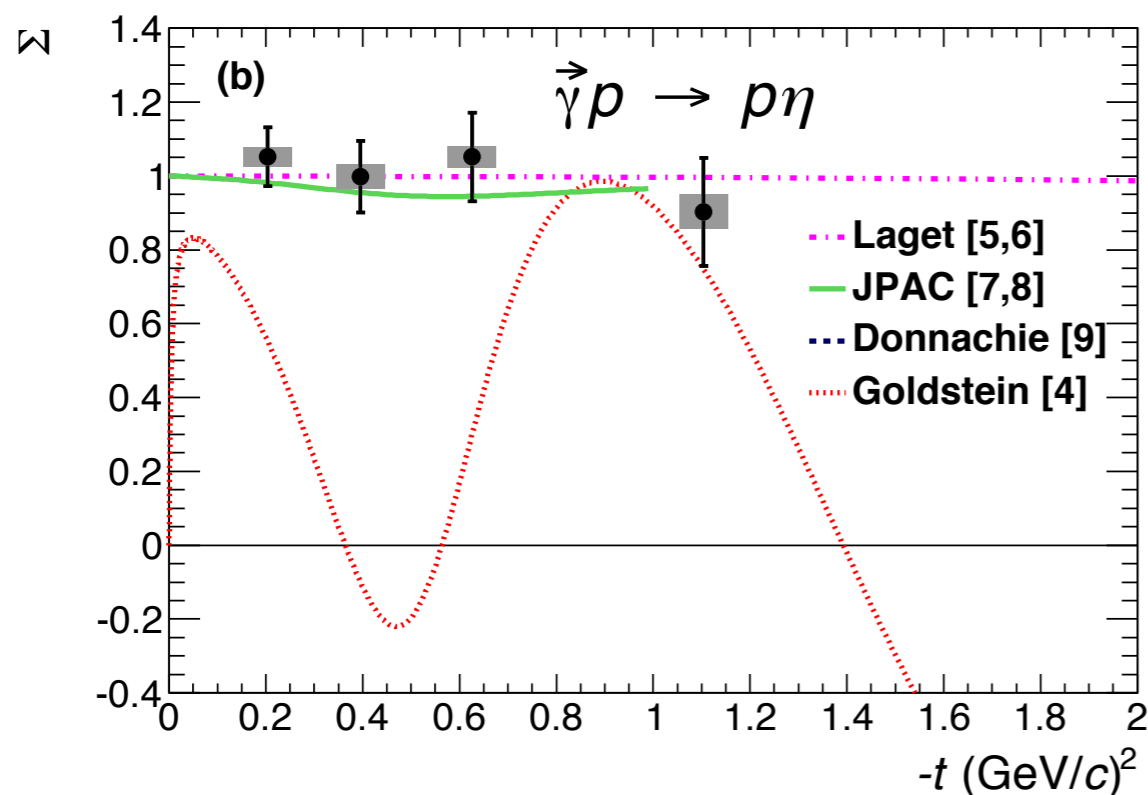
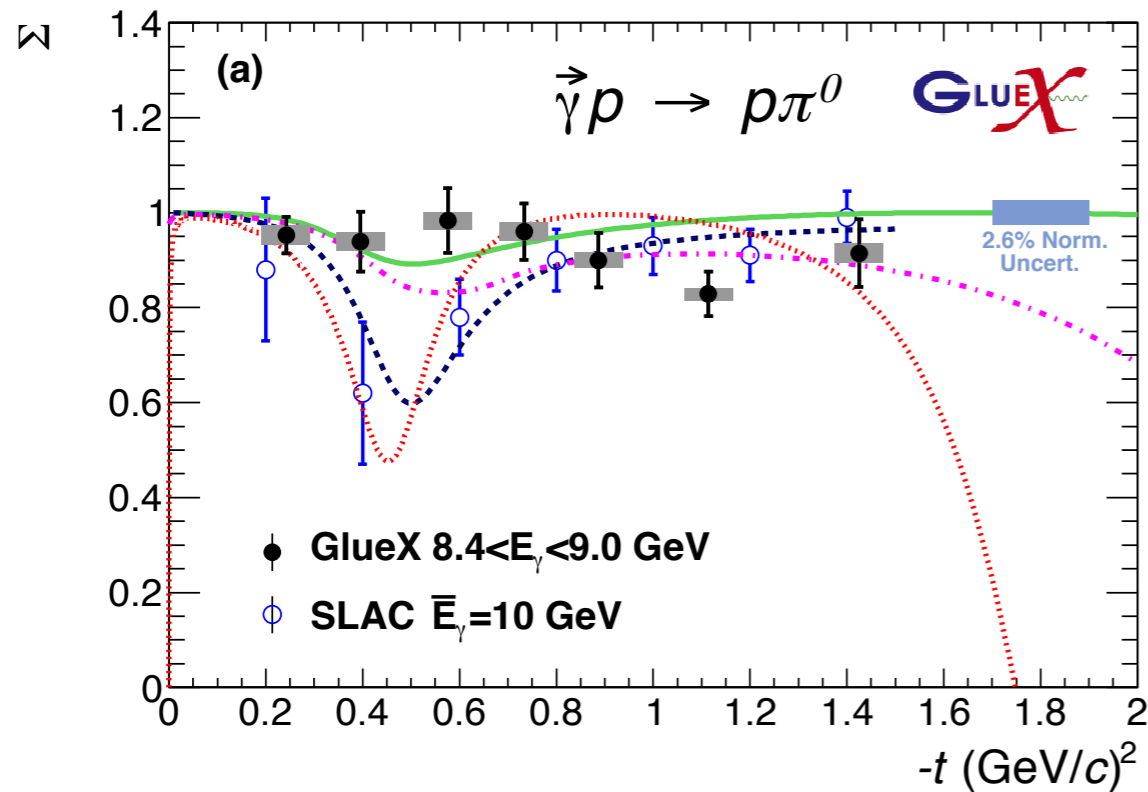
π^0 and η beam asymmetries



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

Phys. Rev. C 95, 042201(R)

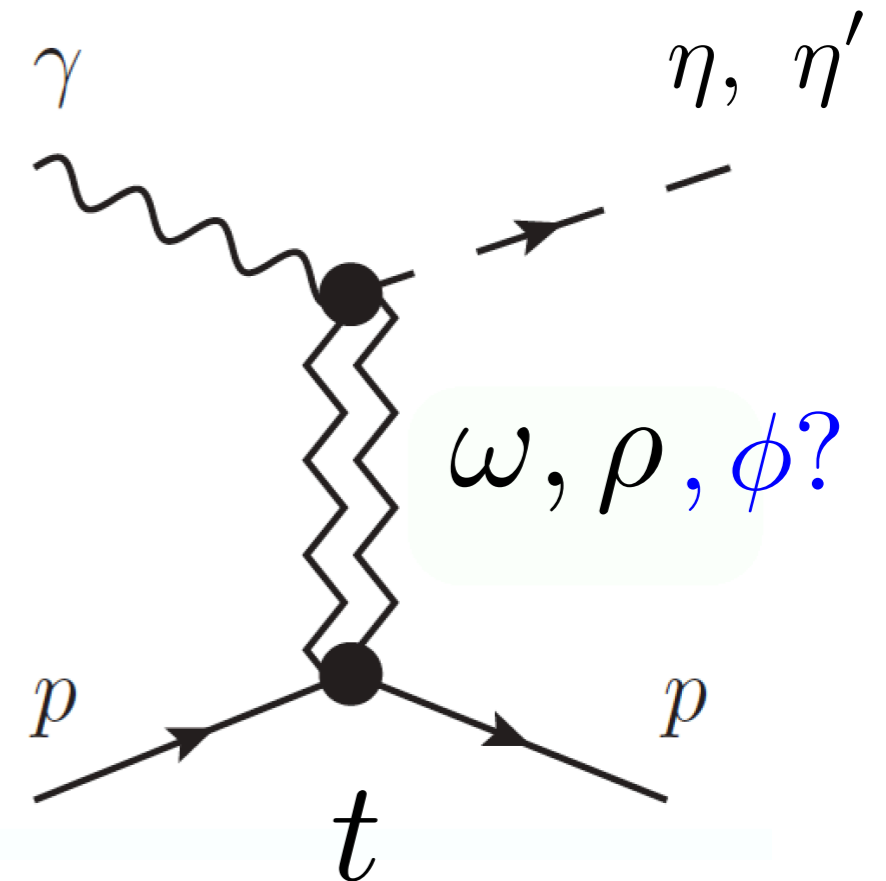
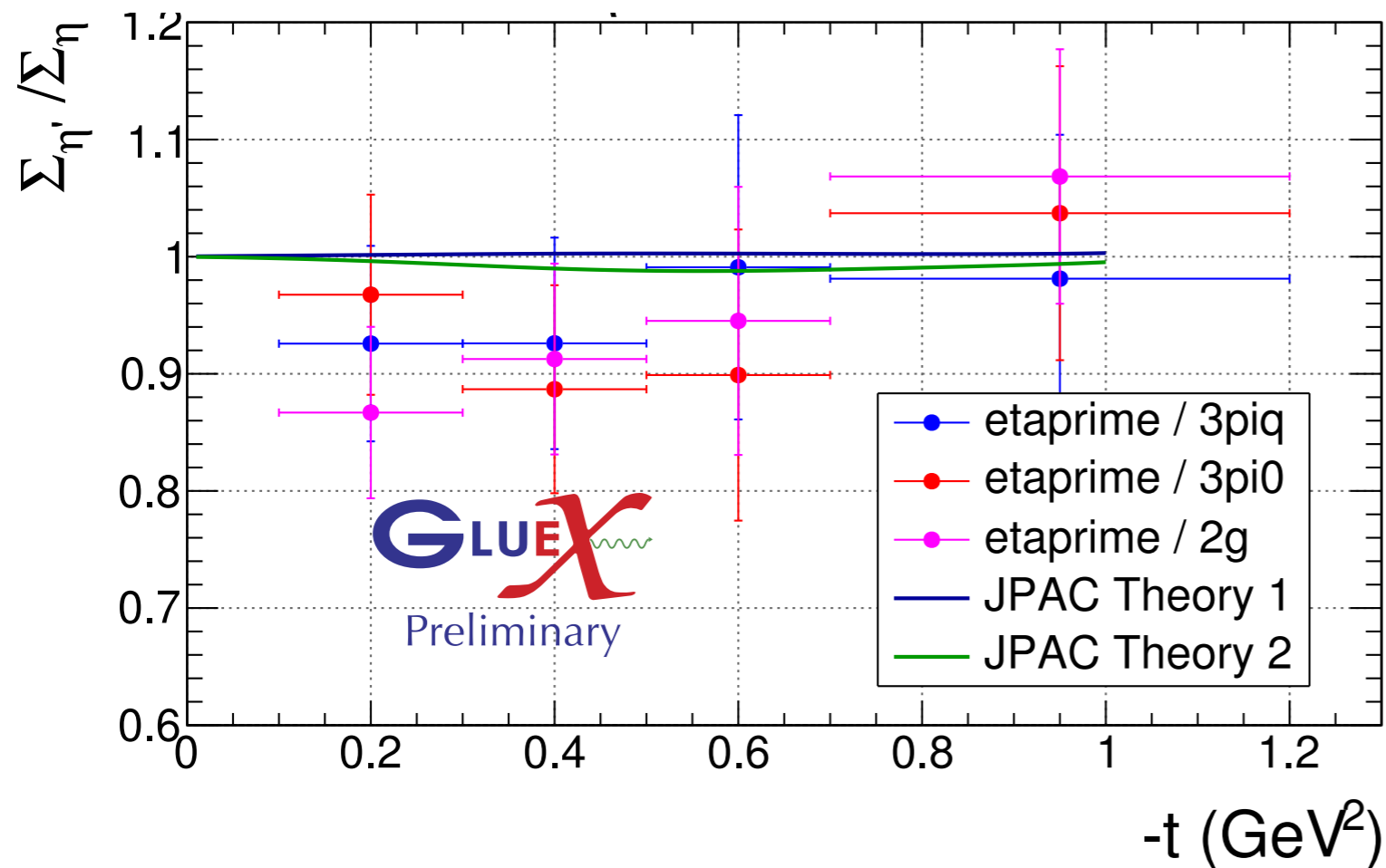
π^0 and η beam asymmetries



- * Dip in multiple theory predictions not observed
- * Indication of vector exchange dominance at this energy
- * Additional asymmetry measurements ongoing with this dataset

First 12 GeV publication!
Phys. Rev. C 95, 042201(R)

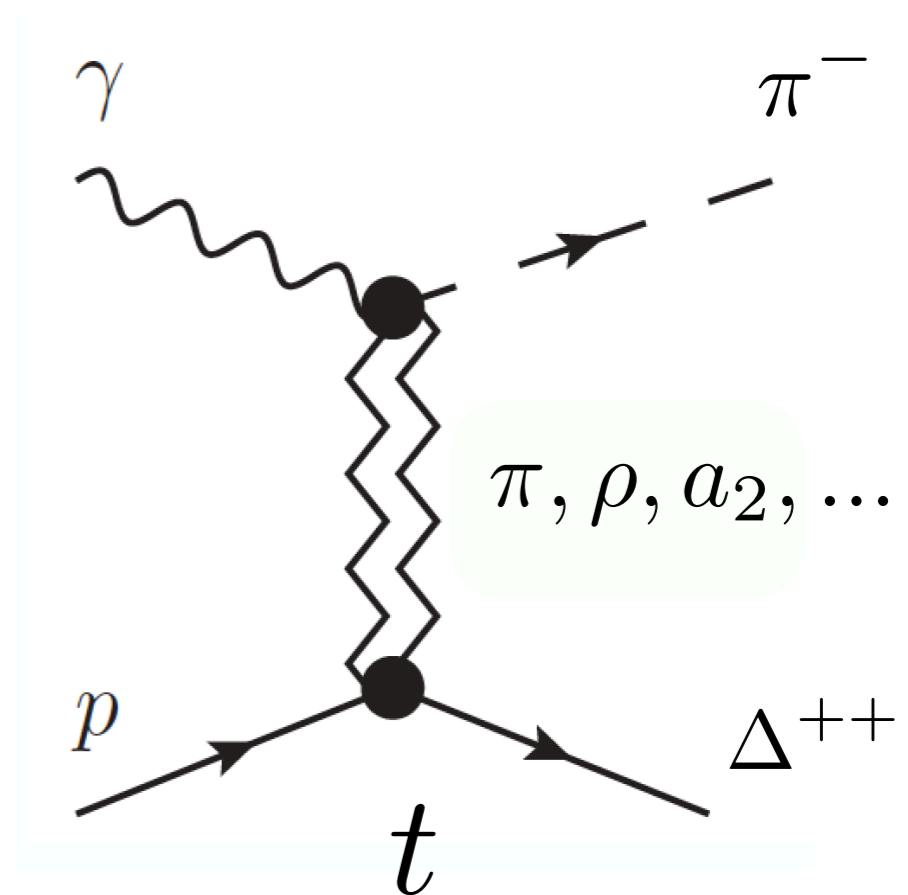
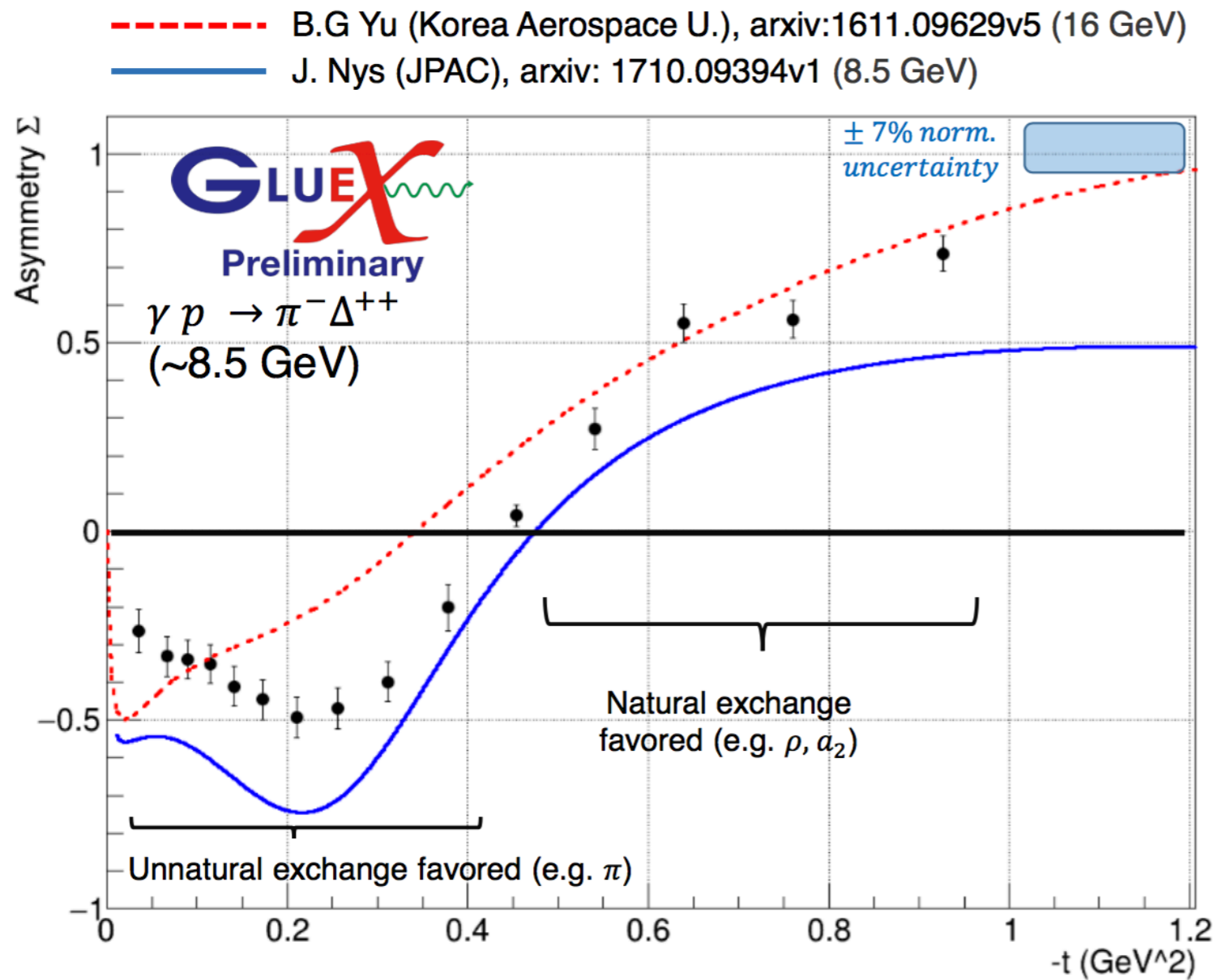
η/η' beam asymmetry ratio



Consistent with prediction
from JPAC: [PLB 774 \(2017\) 362](#)

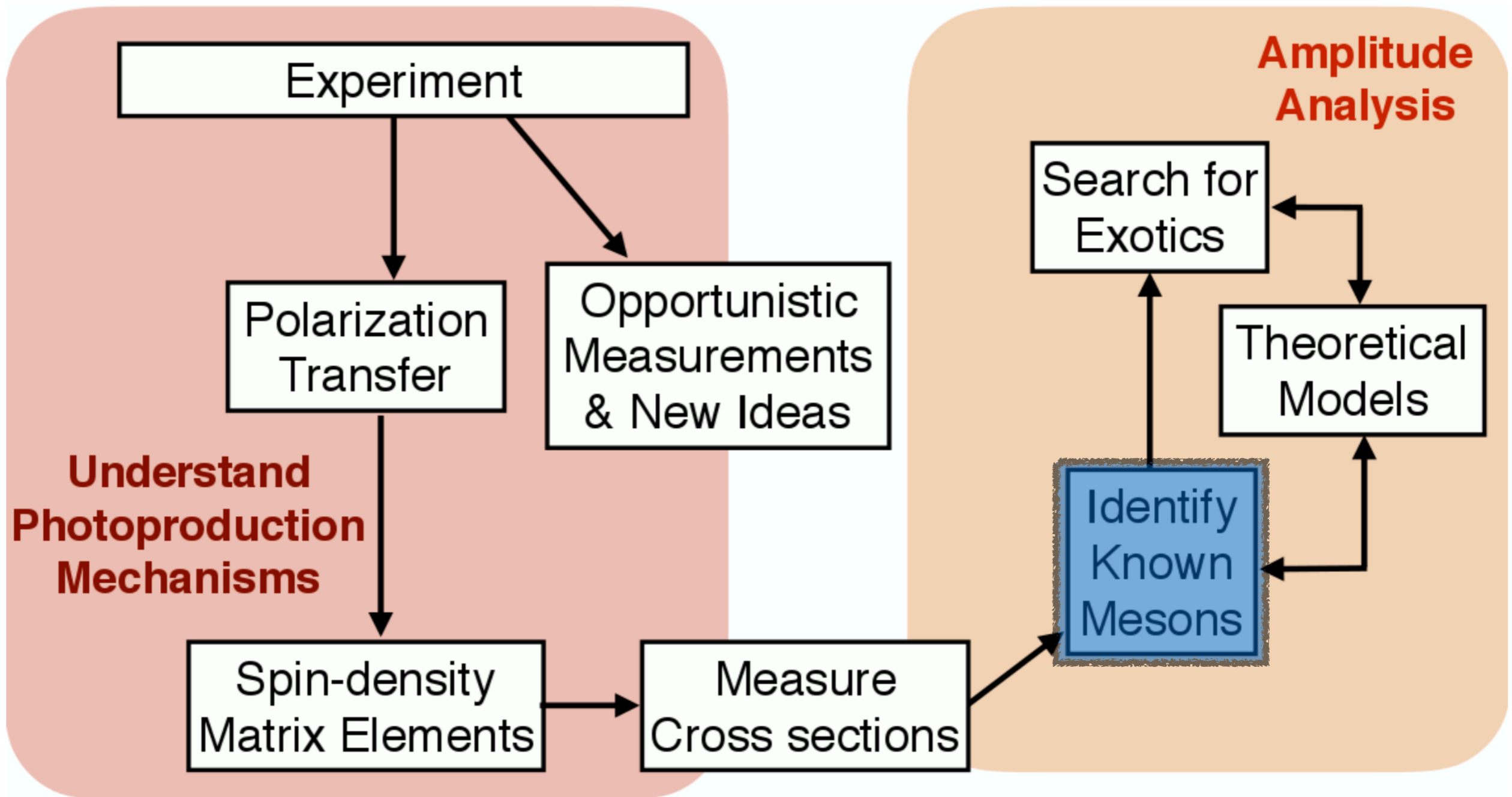
Neutral pseudoscalars: $\Sigma \sim 1$, dominated by vector exchange

π^- beam asymmetry

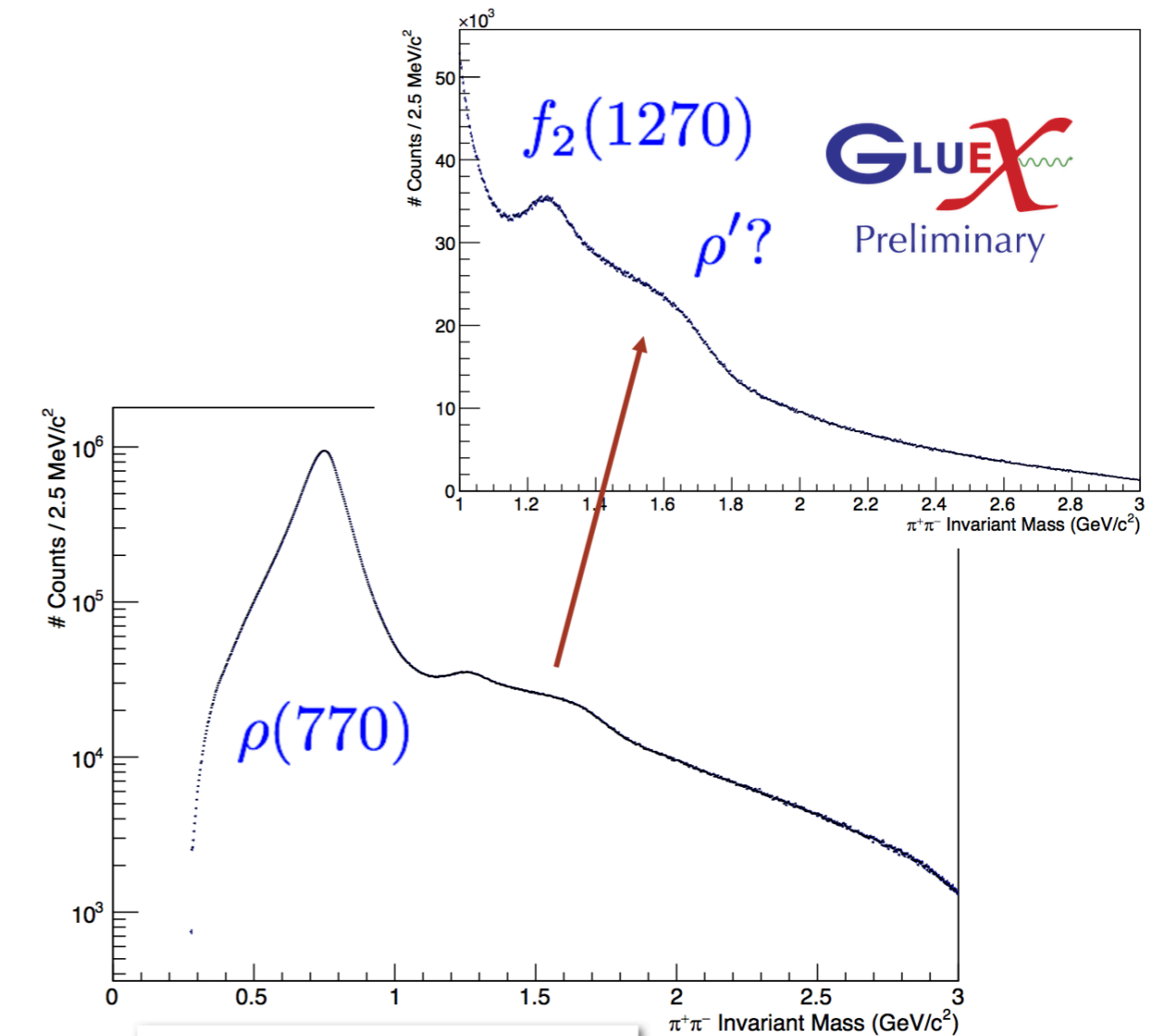
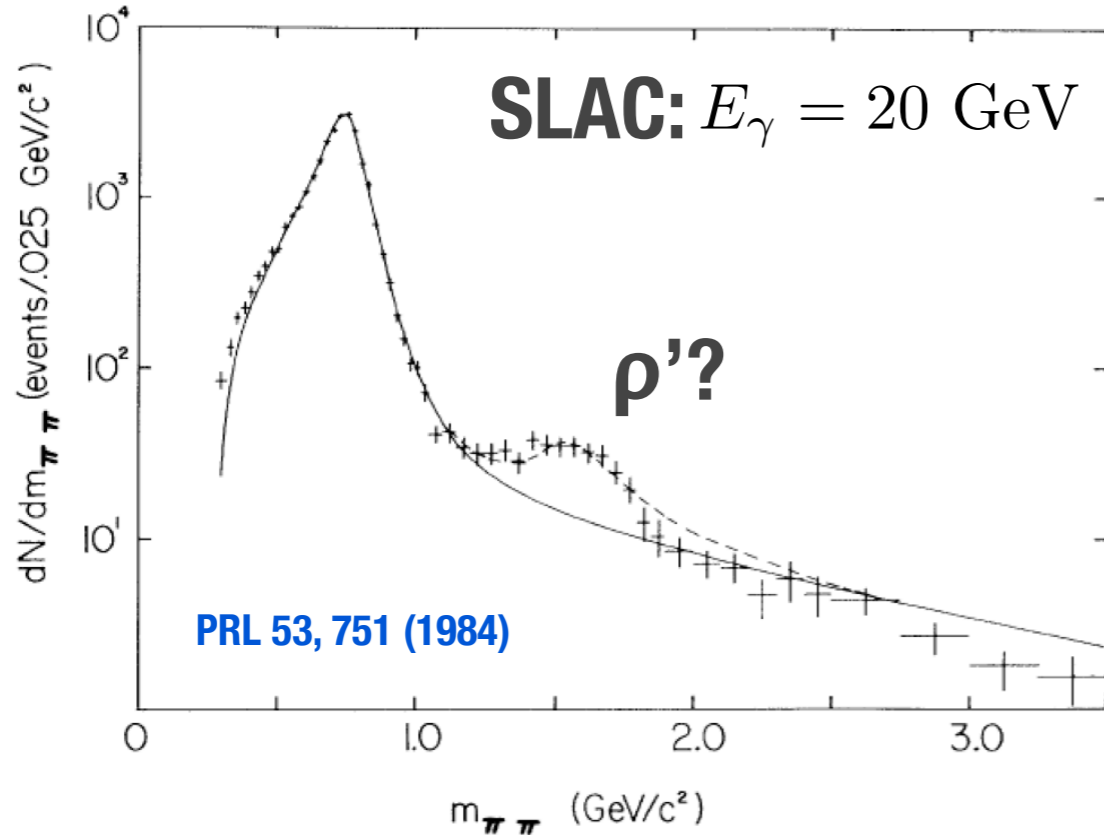
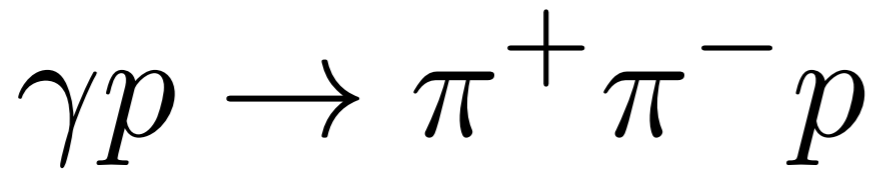


Charged pseudoscalars: more complicated $-t$ dependence

GLUEX Physics Program

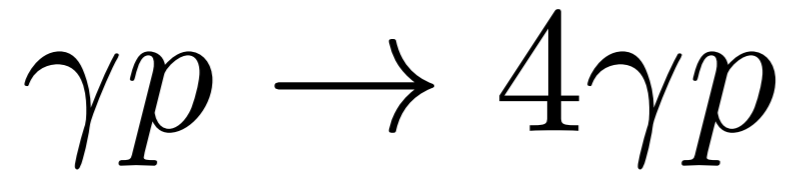


Early spectroscopy opportunities

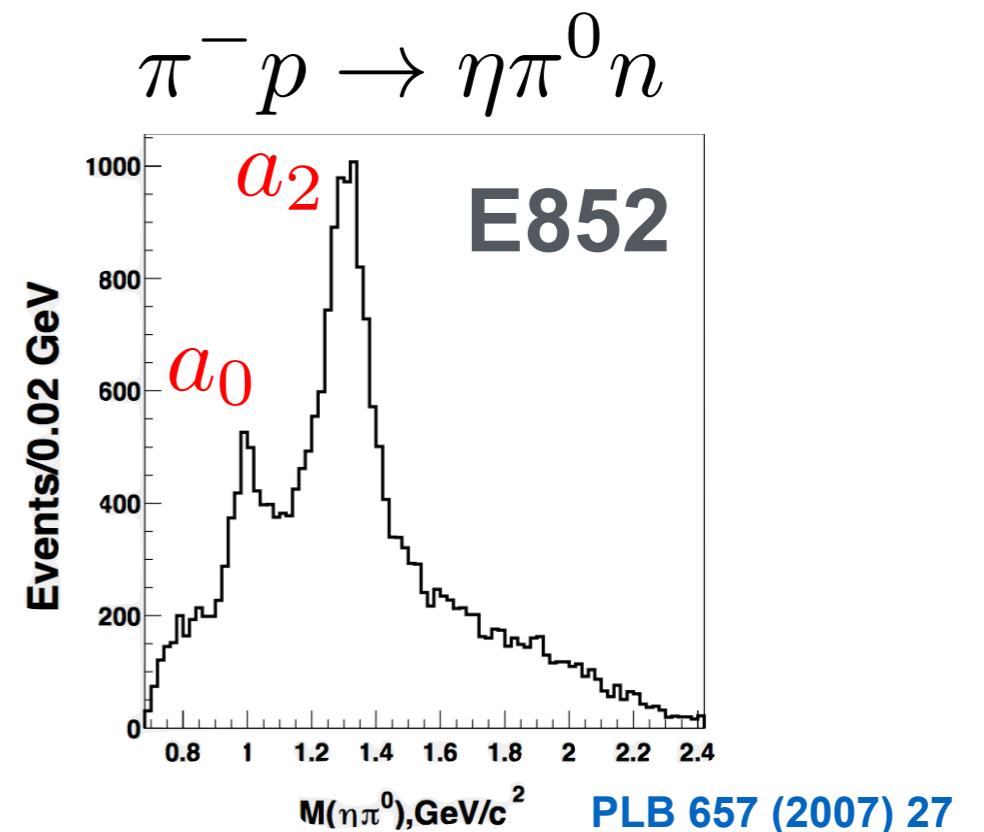
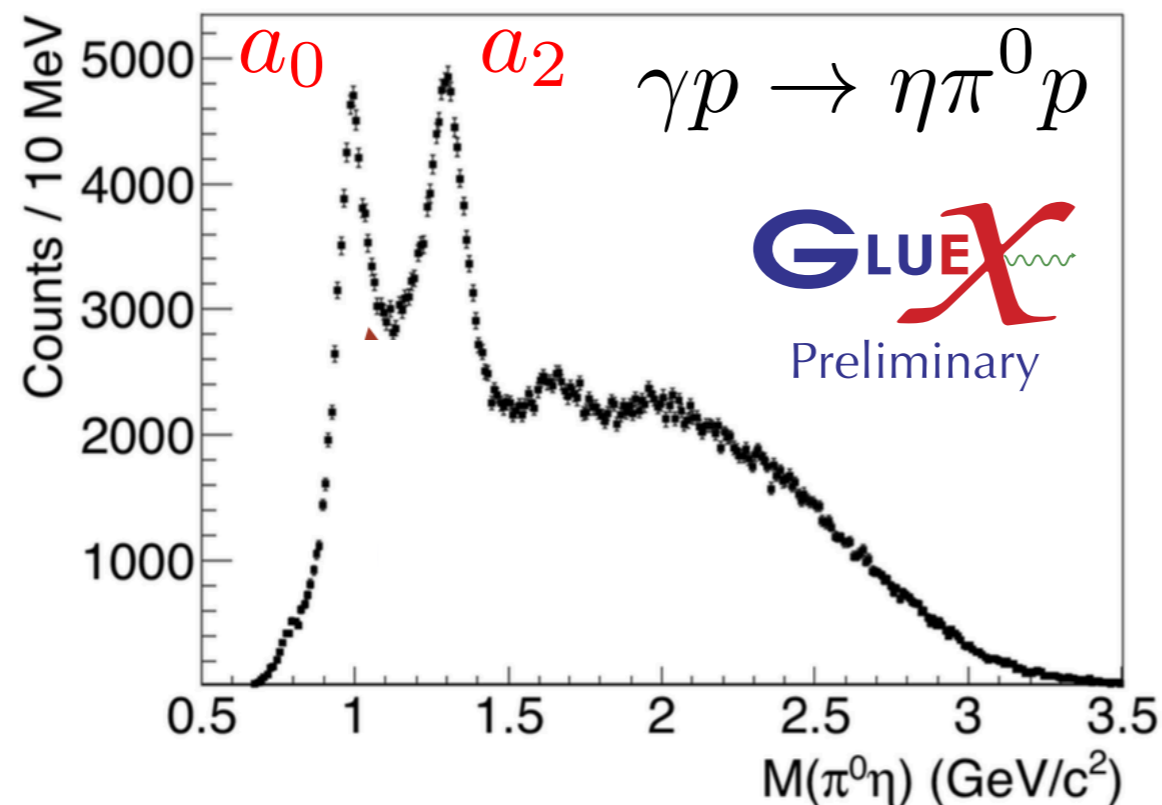
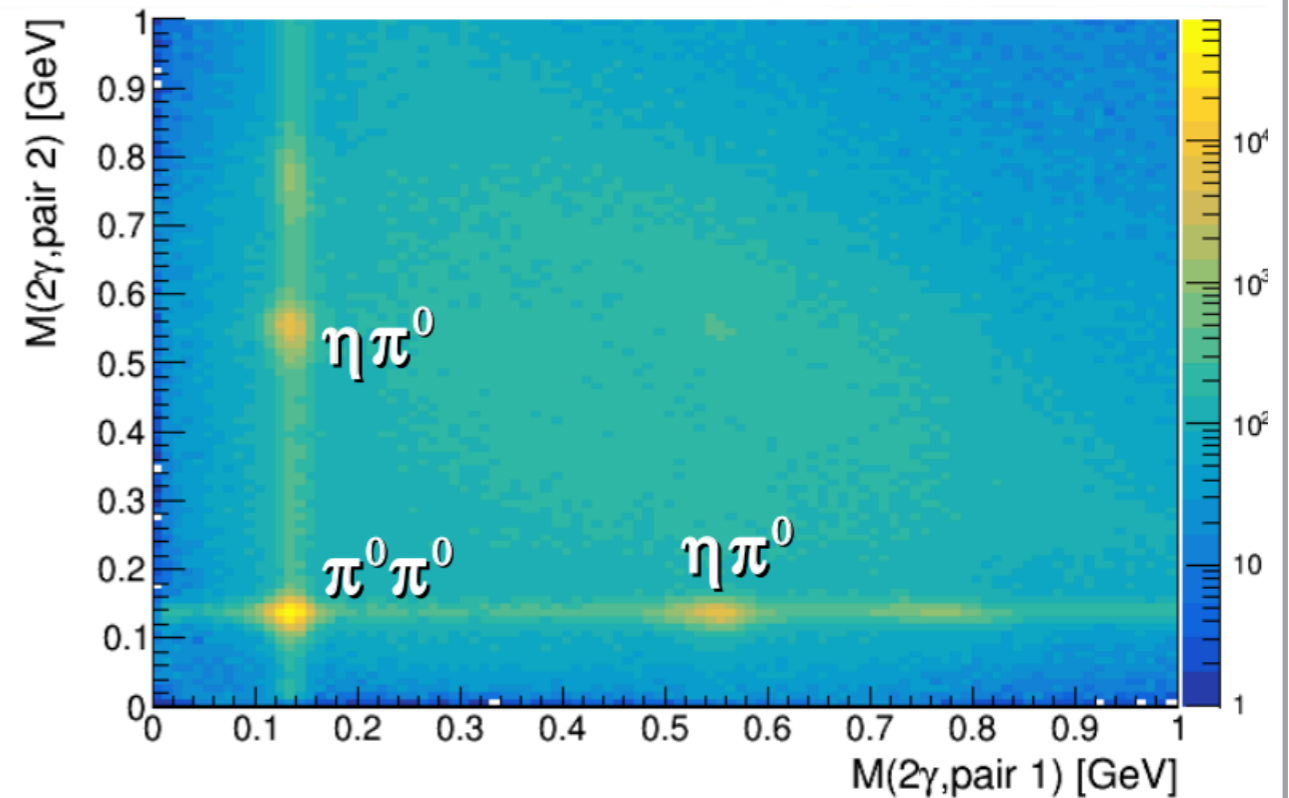


- * Enhancement consistent with earlier SLAC measurement, but $\sim 1000x$ more statistics with early GlueX data
- * Polarization observables will provide further insight into the nature of this enhancement

Early spectroscopy opportunities



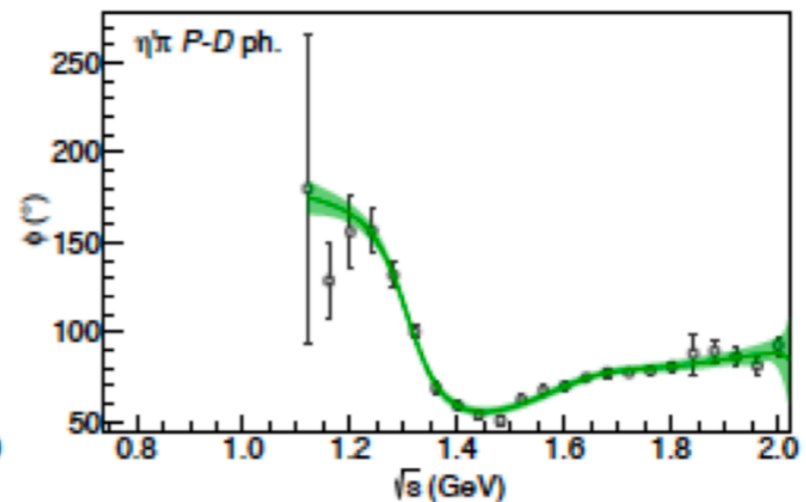
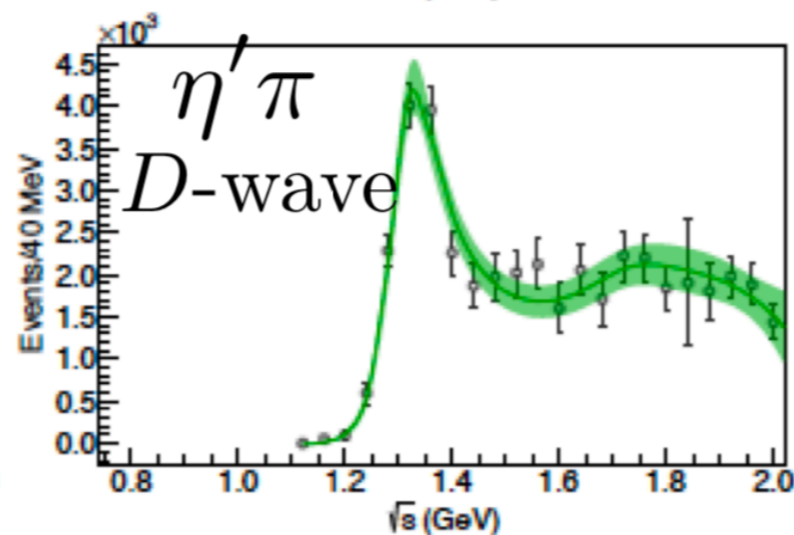
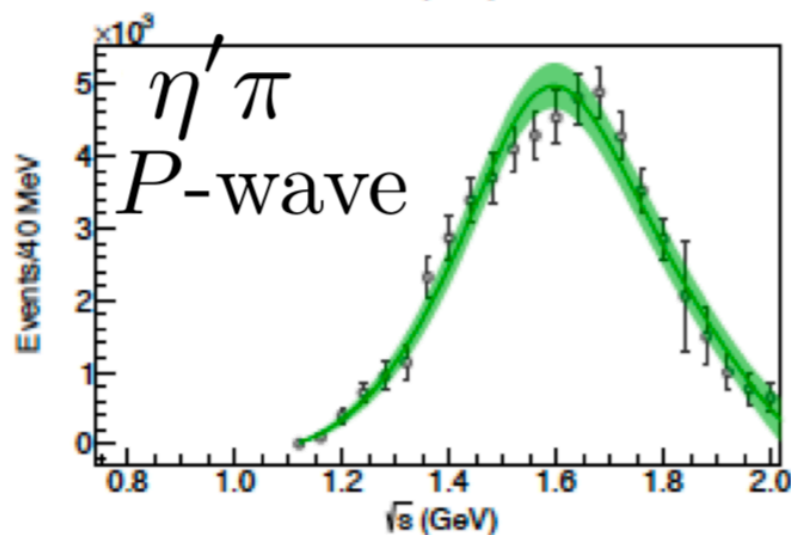
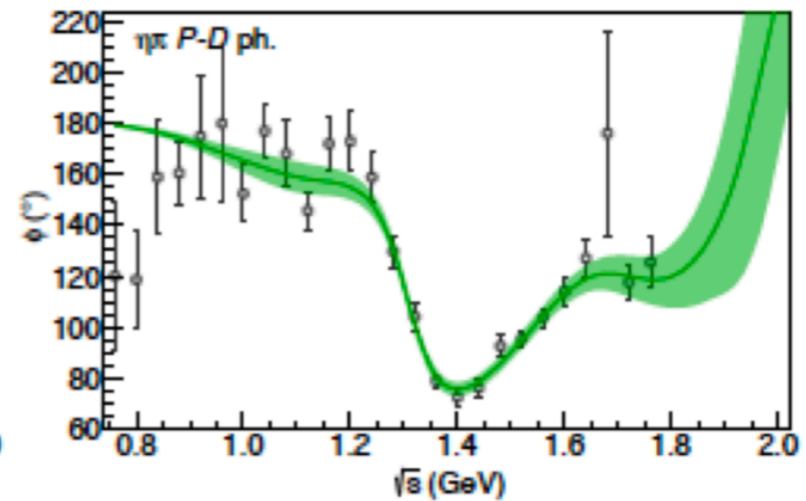
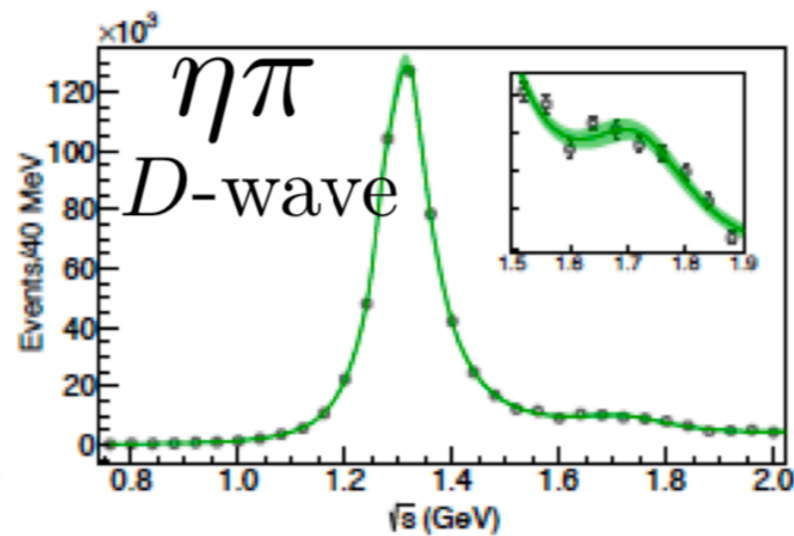
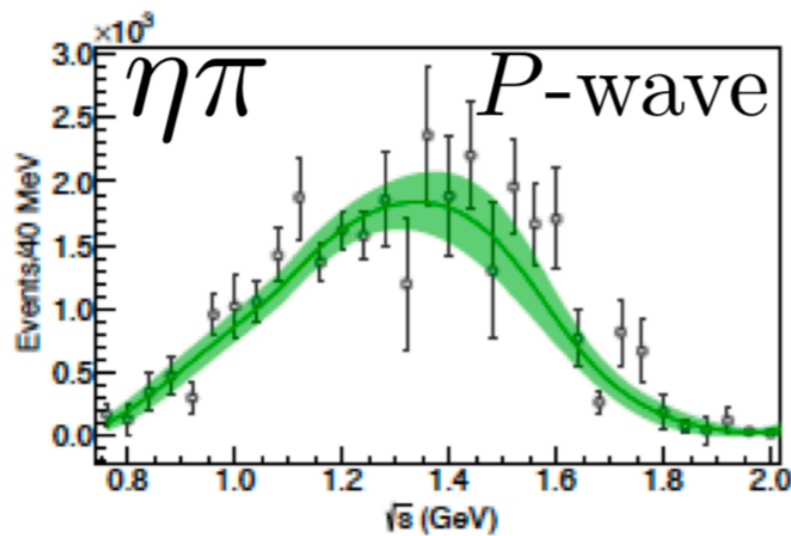
- * Previous photoproduction data very sparse for channels with multiple neutrals particles
- * Preliminary studies are already showing interesting features



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



with **JPAC**

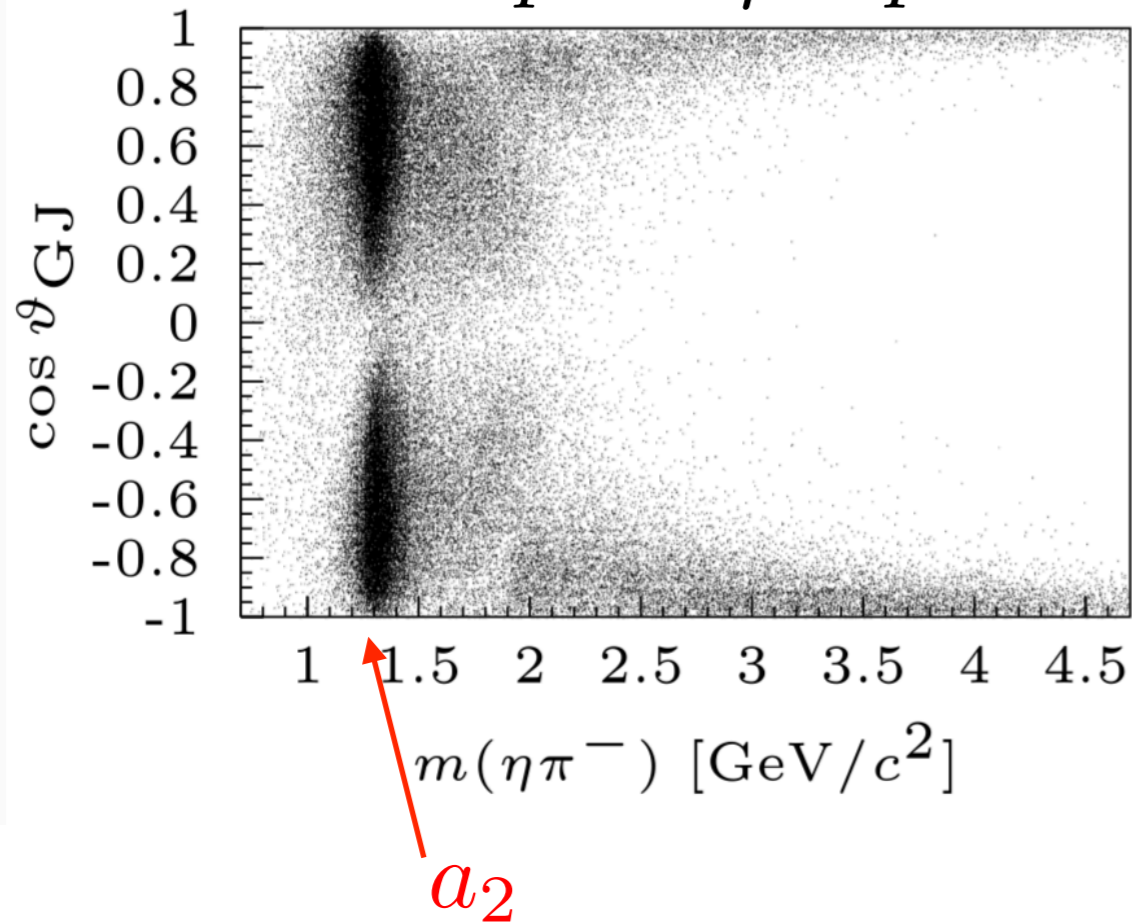
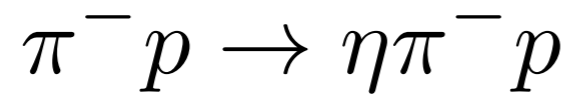


✱ Extraction of partial waves by Compass

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

COMPASS: Phys. Lett. B 740, 303 (2015).
JPAC: Phys. Rev. Lett. 122, 042002 (2019).

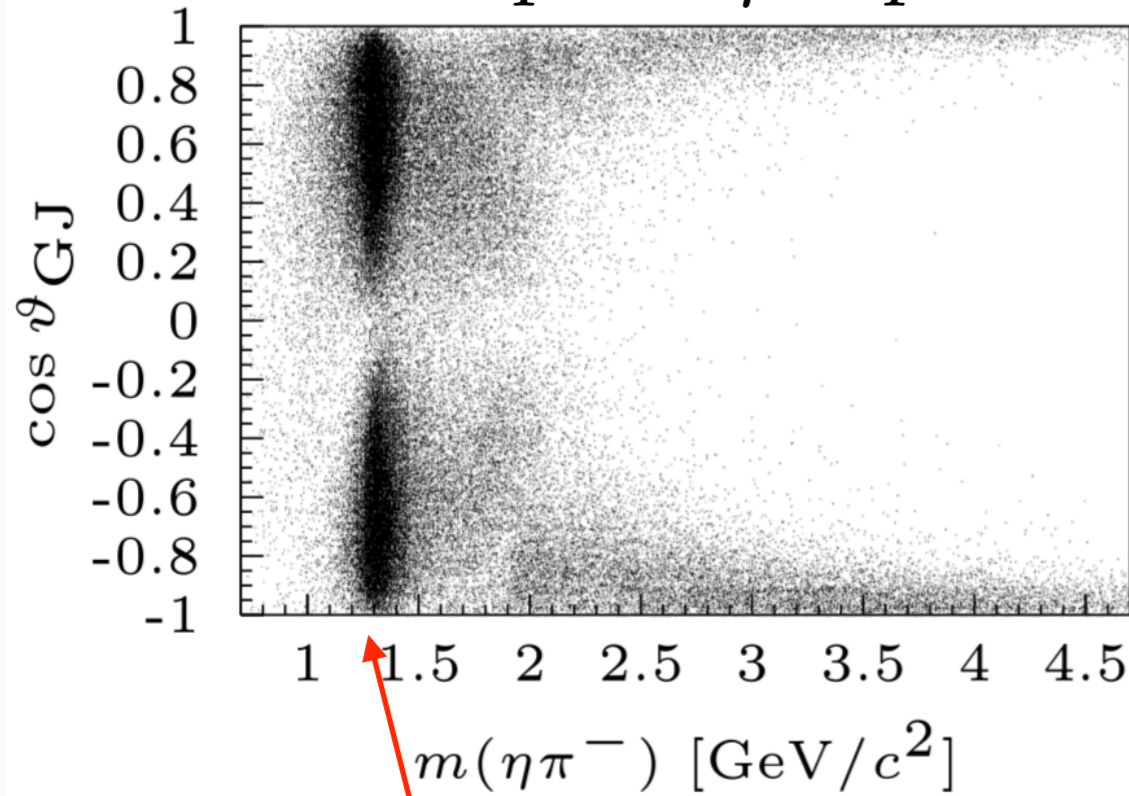
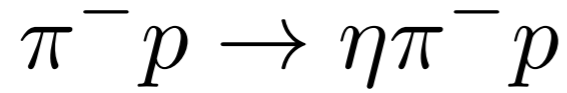
$\eta\pi$ spectroscopy at



- * **Compass** publication statistics 116k $\eta\pi$ and 39k $\eta'\pi$

$M(\eta\pi^-)$ GeV/c^2

$\eta\pi$ spectroscopy at

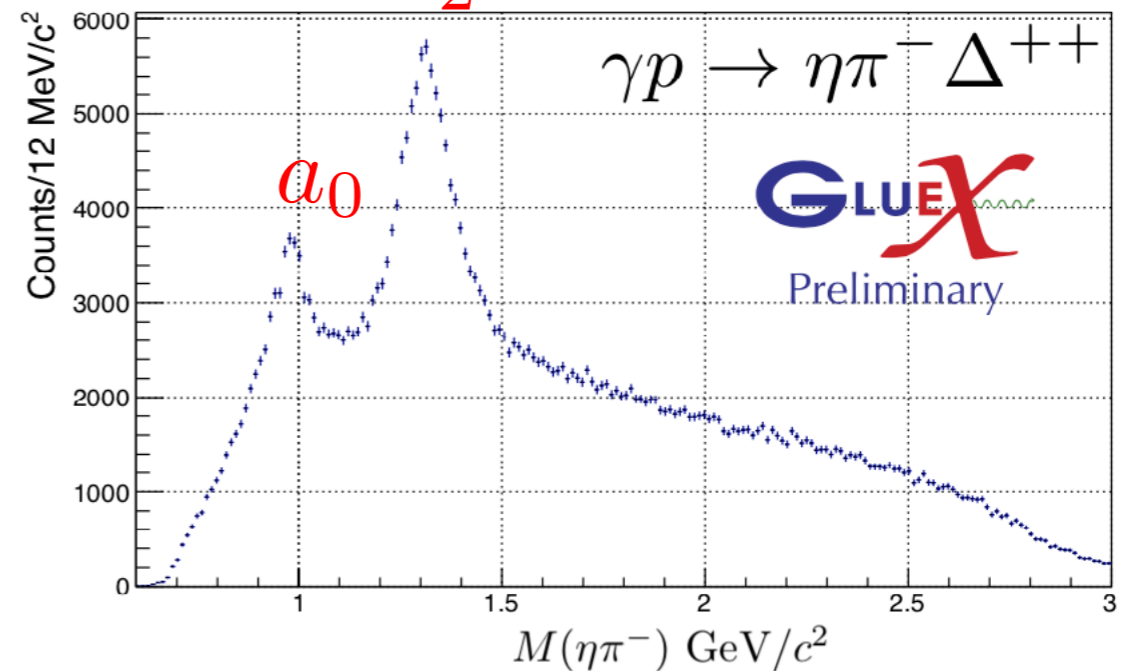
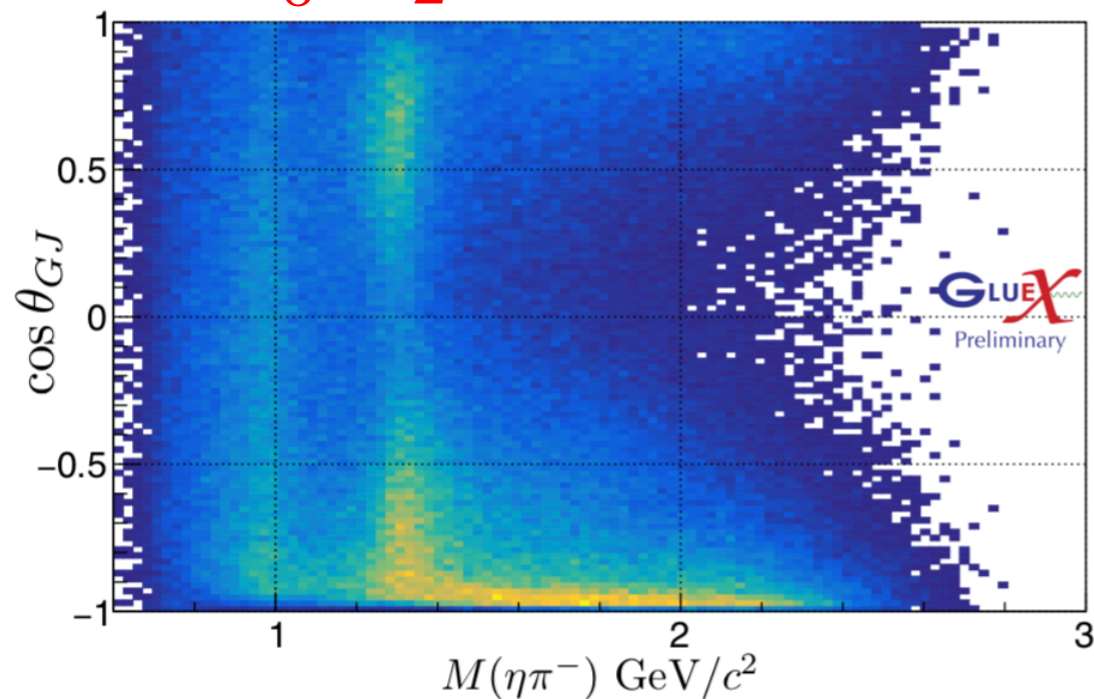


- * **Compass** publication statistics 116k $\eta\pi$ and 39k $\eta'\pi$
- * Expect 280k $\eta\pi$ and 52k $\eta'\pi$ from current **GlueX** dataset for a single decay mode

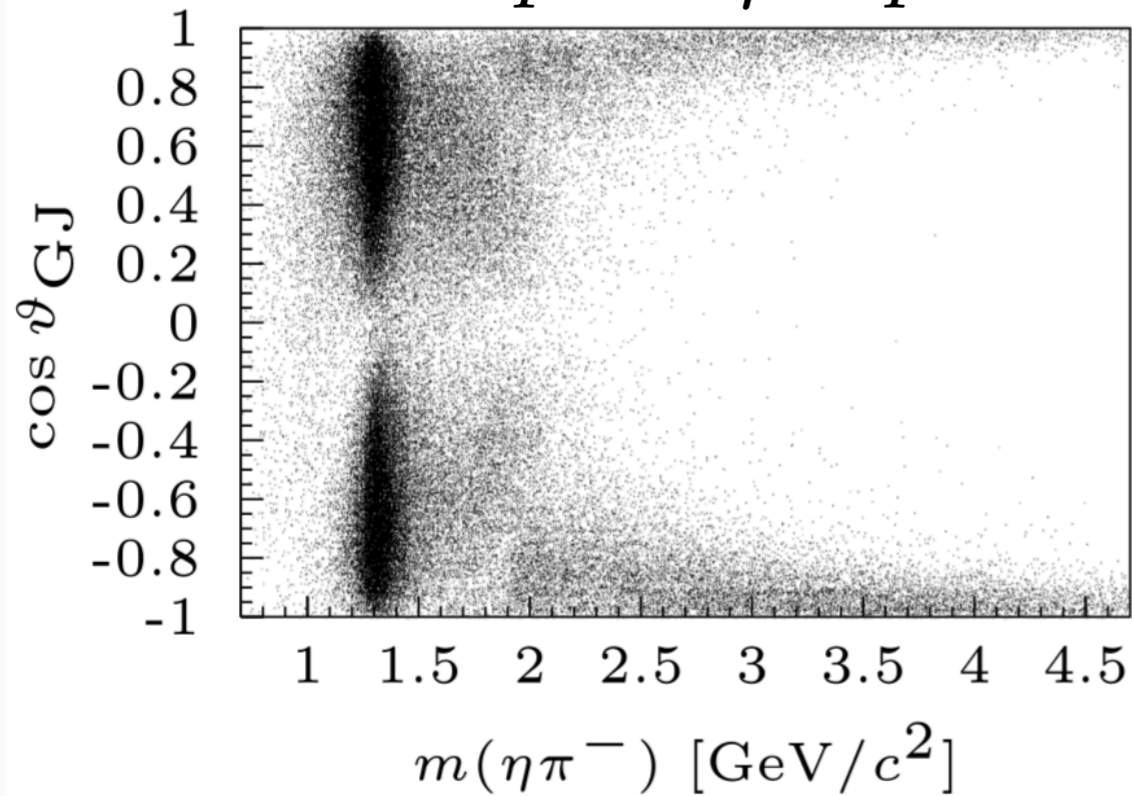
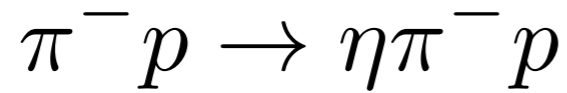
a_0 a_2



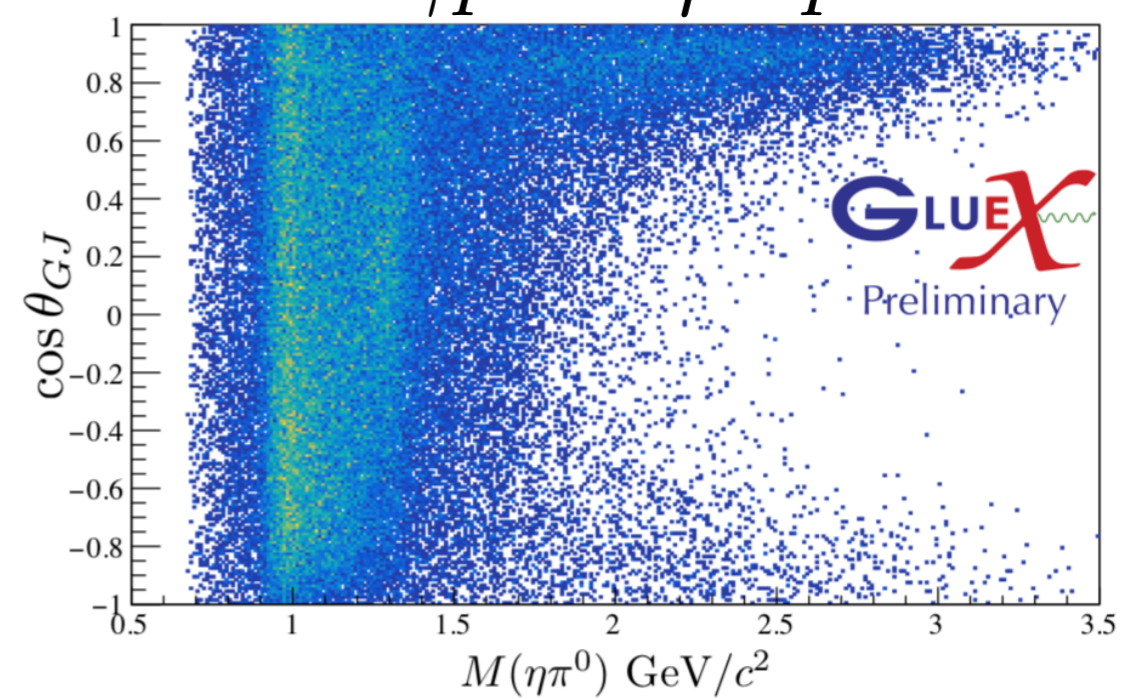
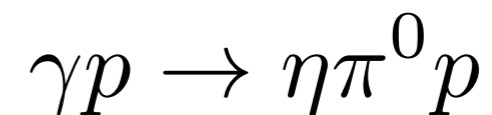
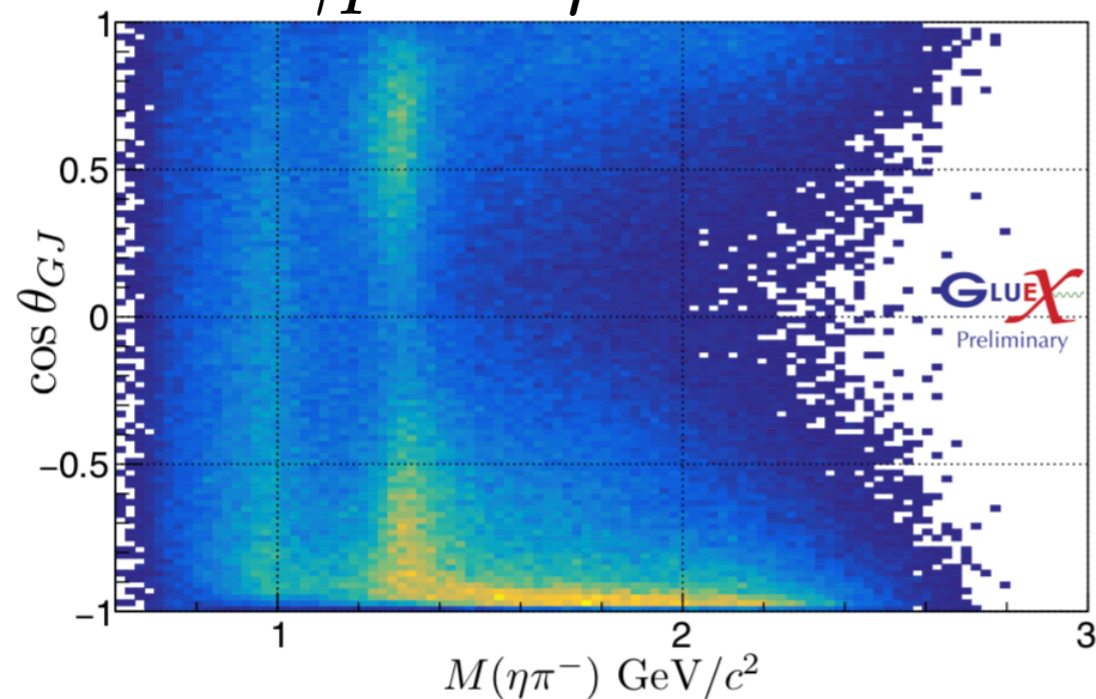
a_2



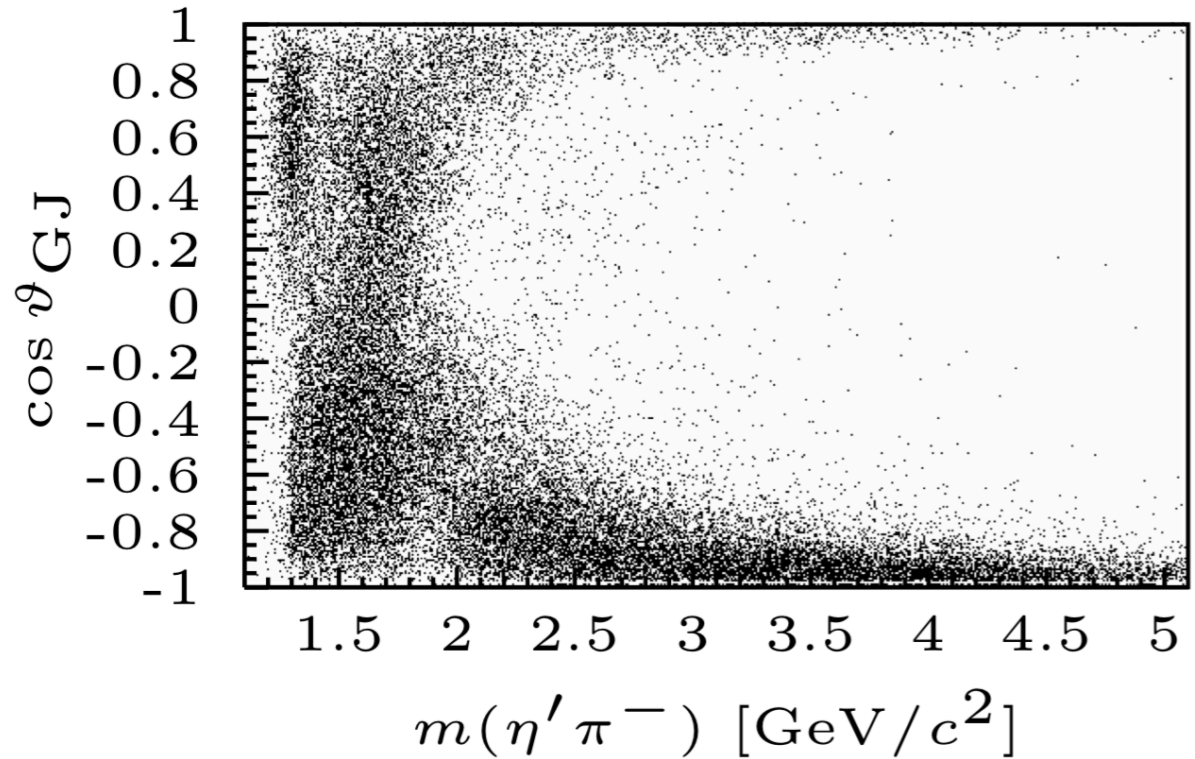
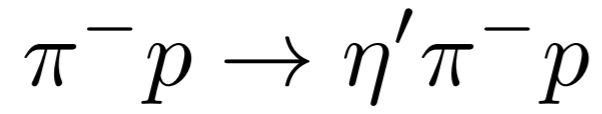
$\eta\pi$ spectroscopy at



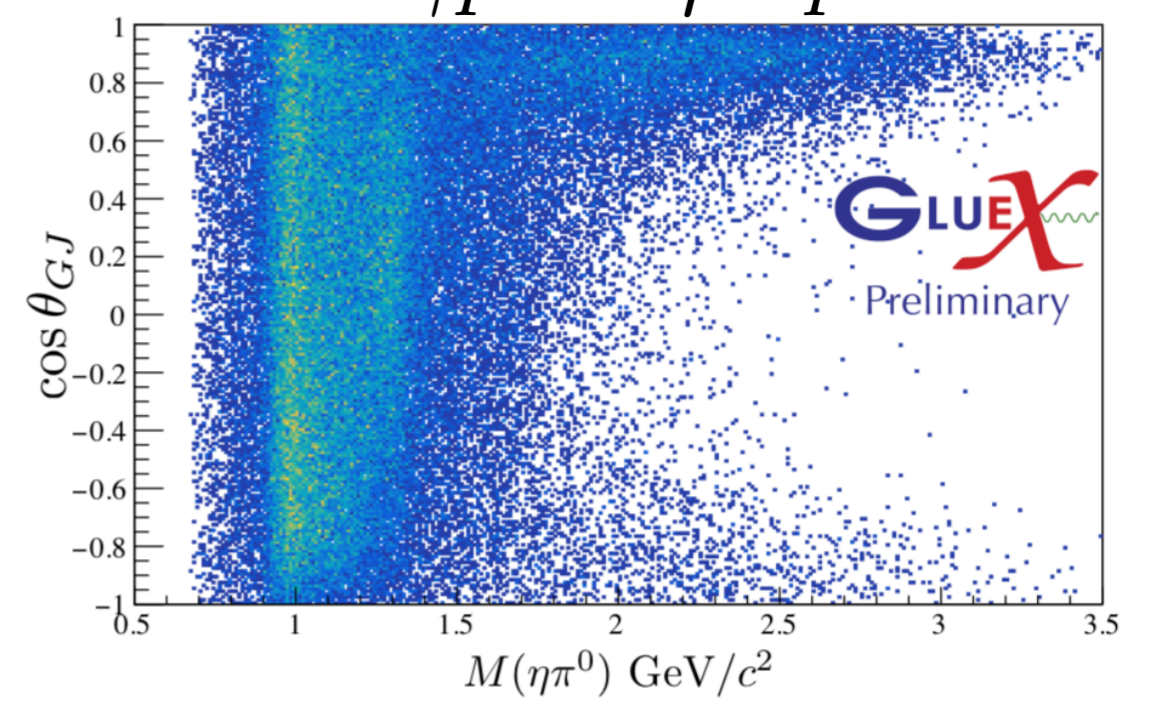
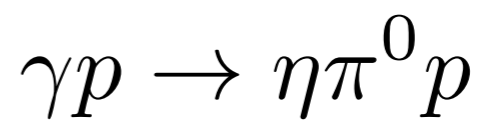
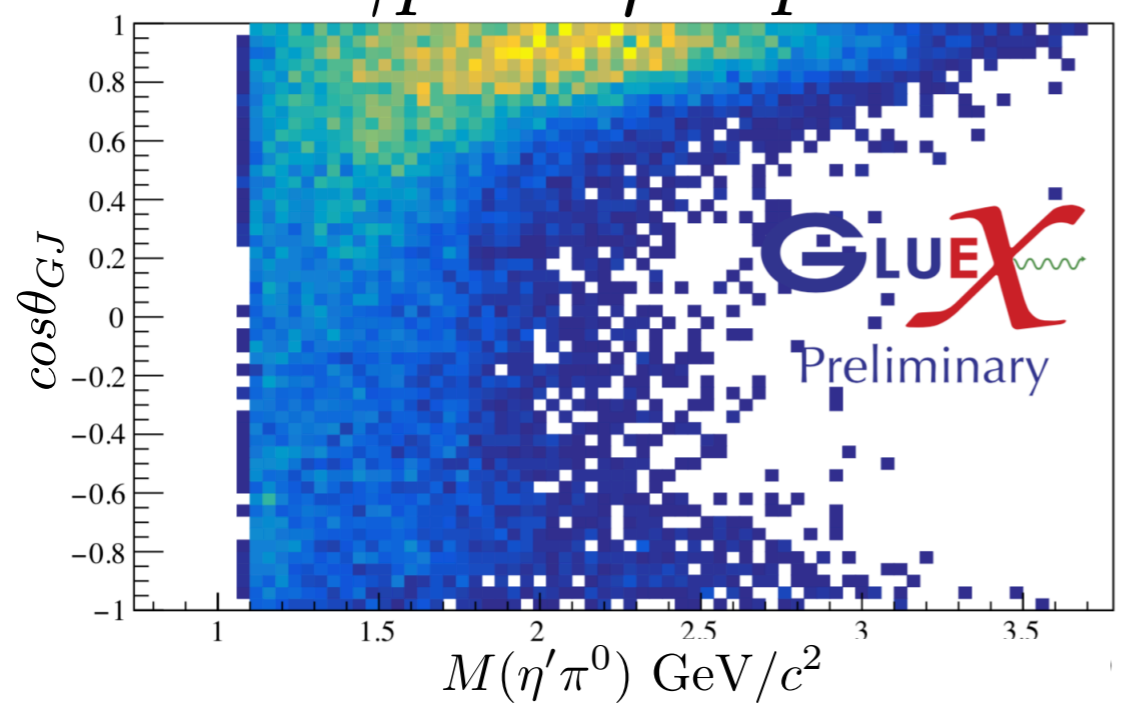
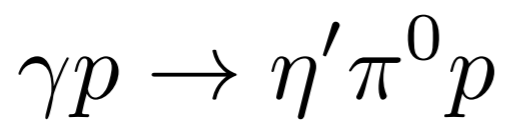
- * **Compass** publication statistics 116k $\eta\pi$ and 39k $\eta'\pi$
- * Expect 280k $\eta\pi$ and 52k $\eta'\pi$ from current **GlueX** dataset for a single decay mode



$\eta'\pi$ spectroscopy at **GLUEX**

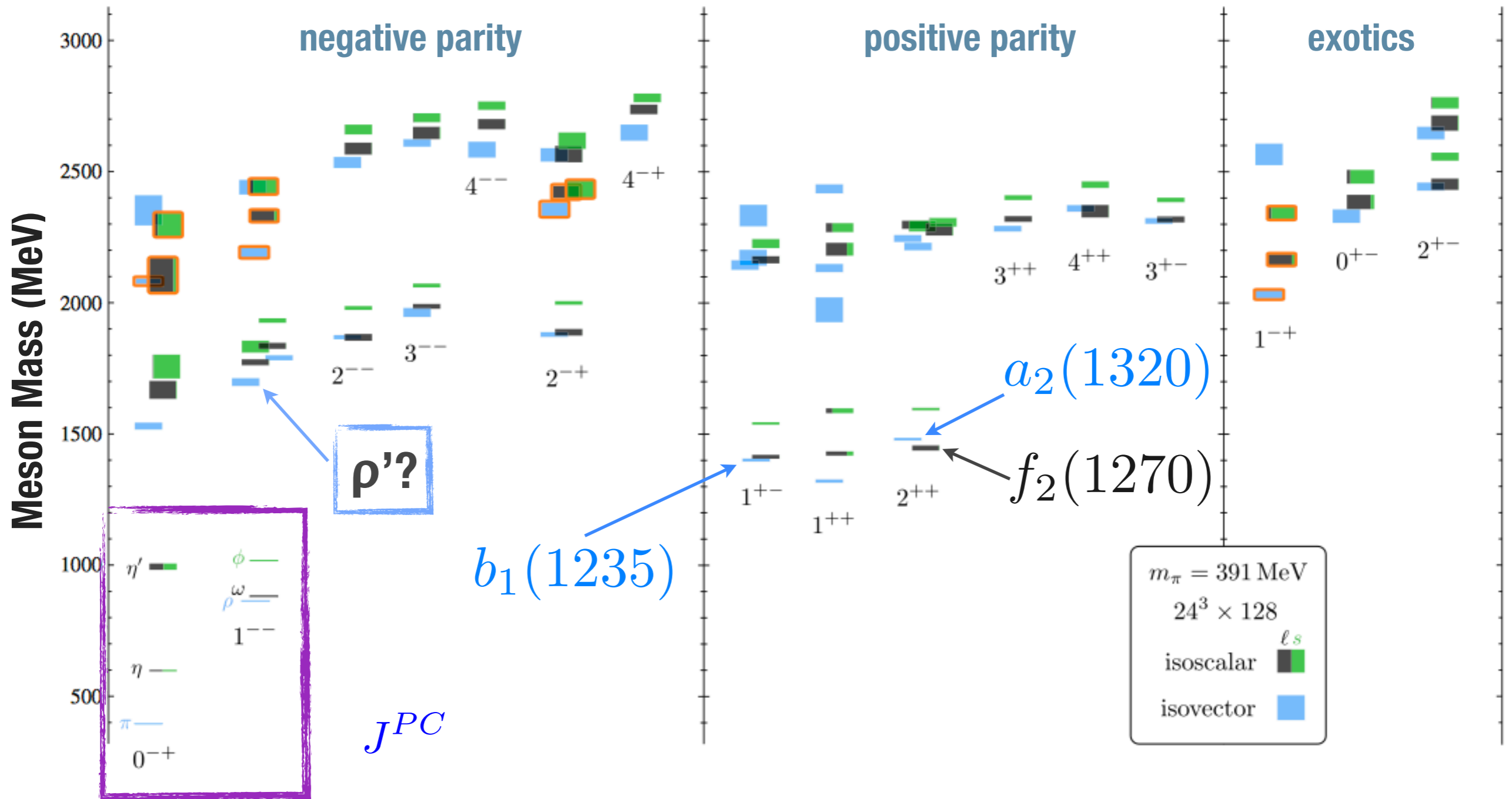


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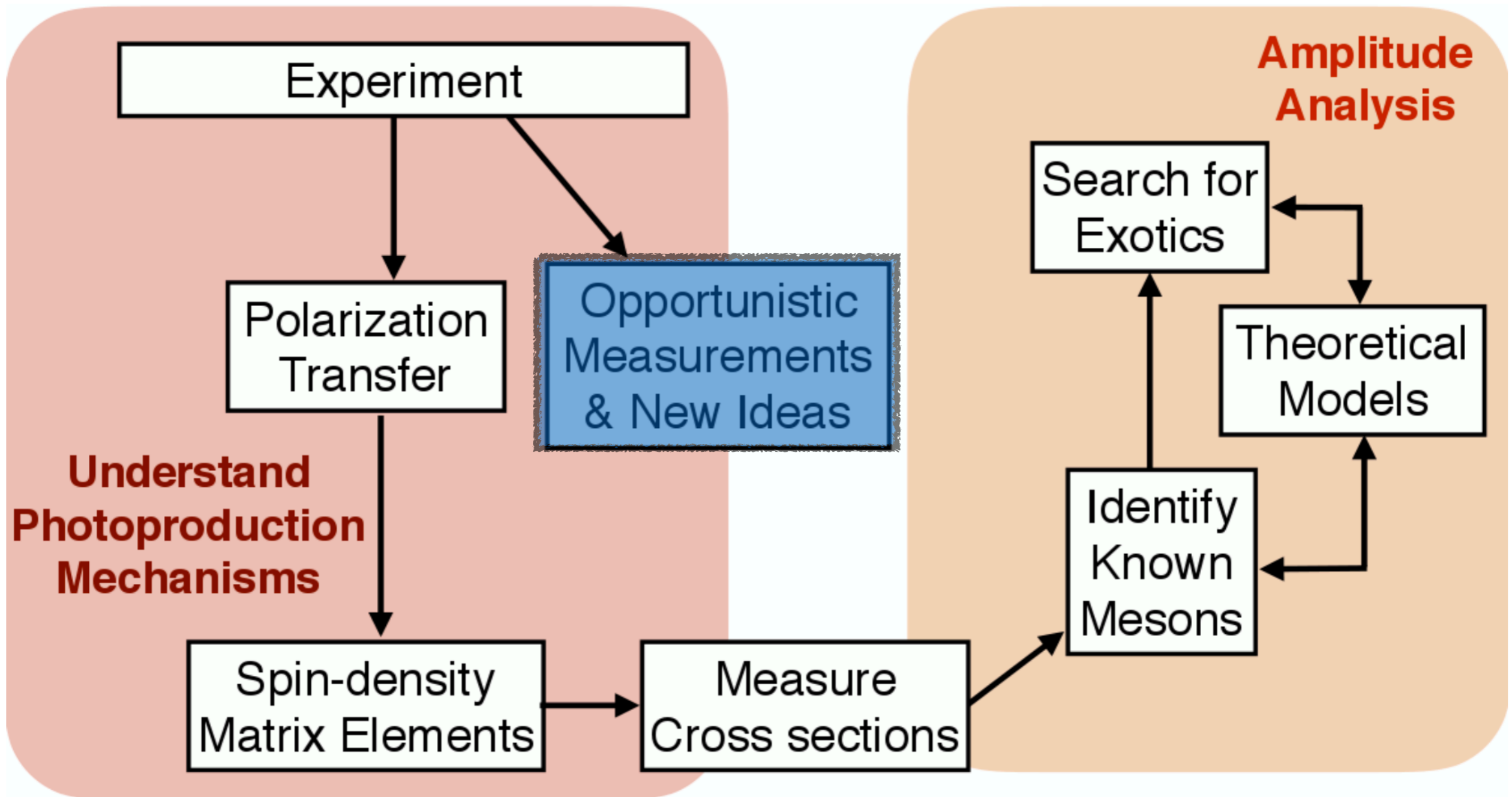
Mapping the meson spectrum

PRD 88 (2013) 094505

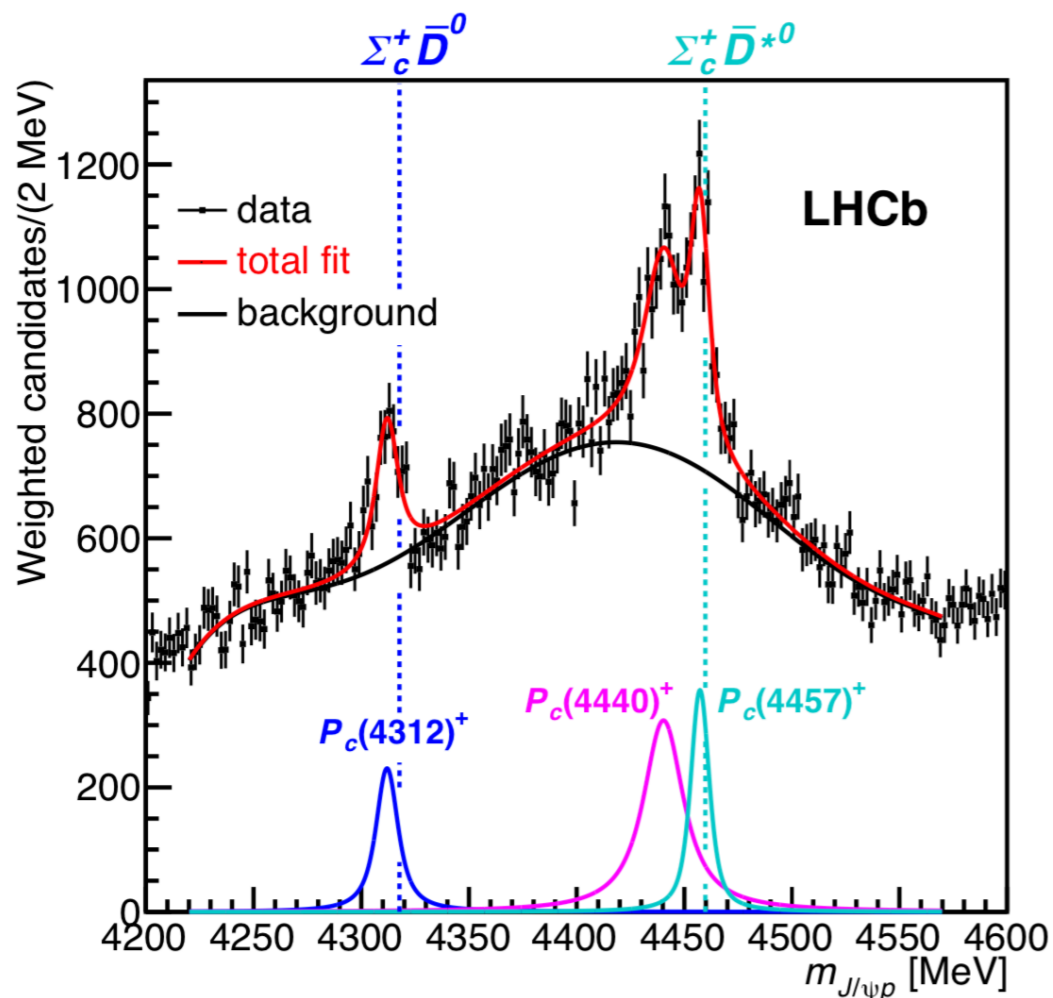


- * Already studying polarization observables for **“simple” final states**
- * Beginning to identify **known mesons** in multi-particle final states

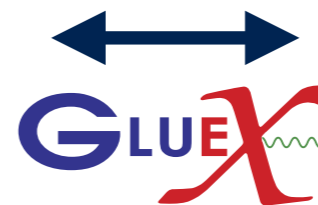
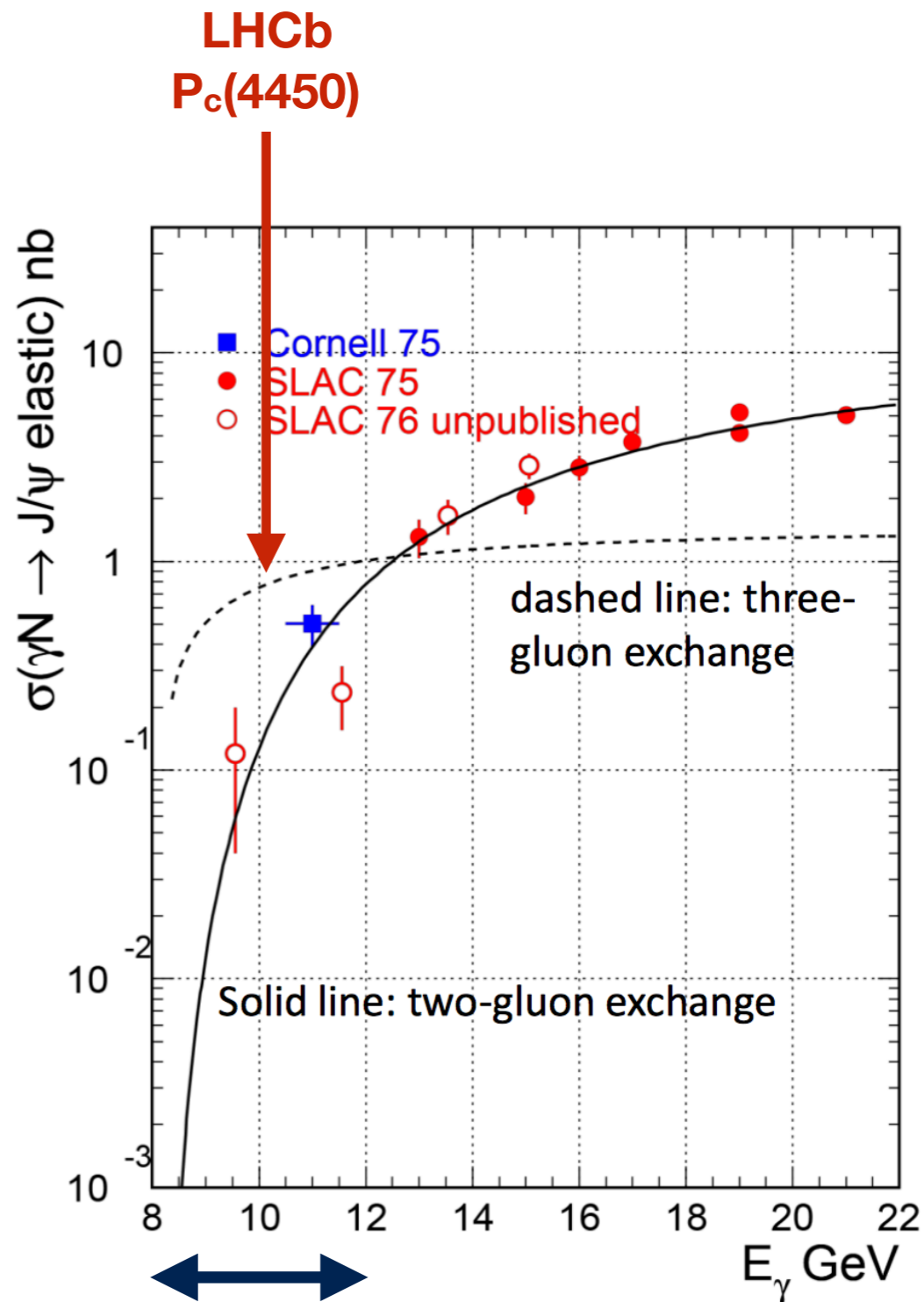
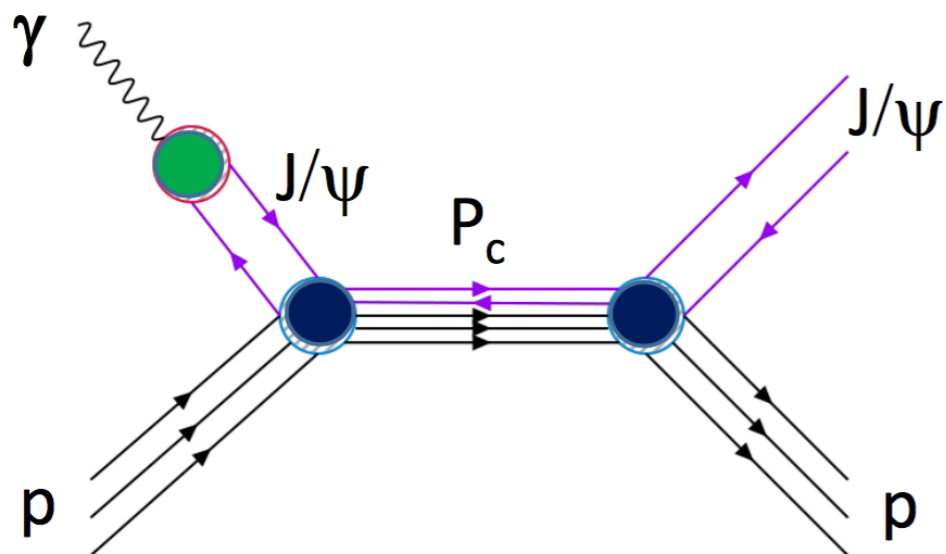
GLUEX Physics Program



Charmonium at JLab

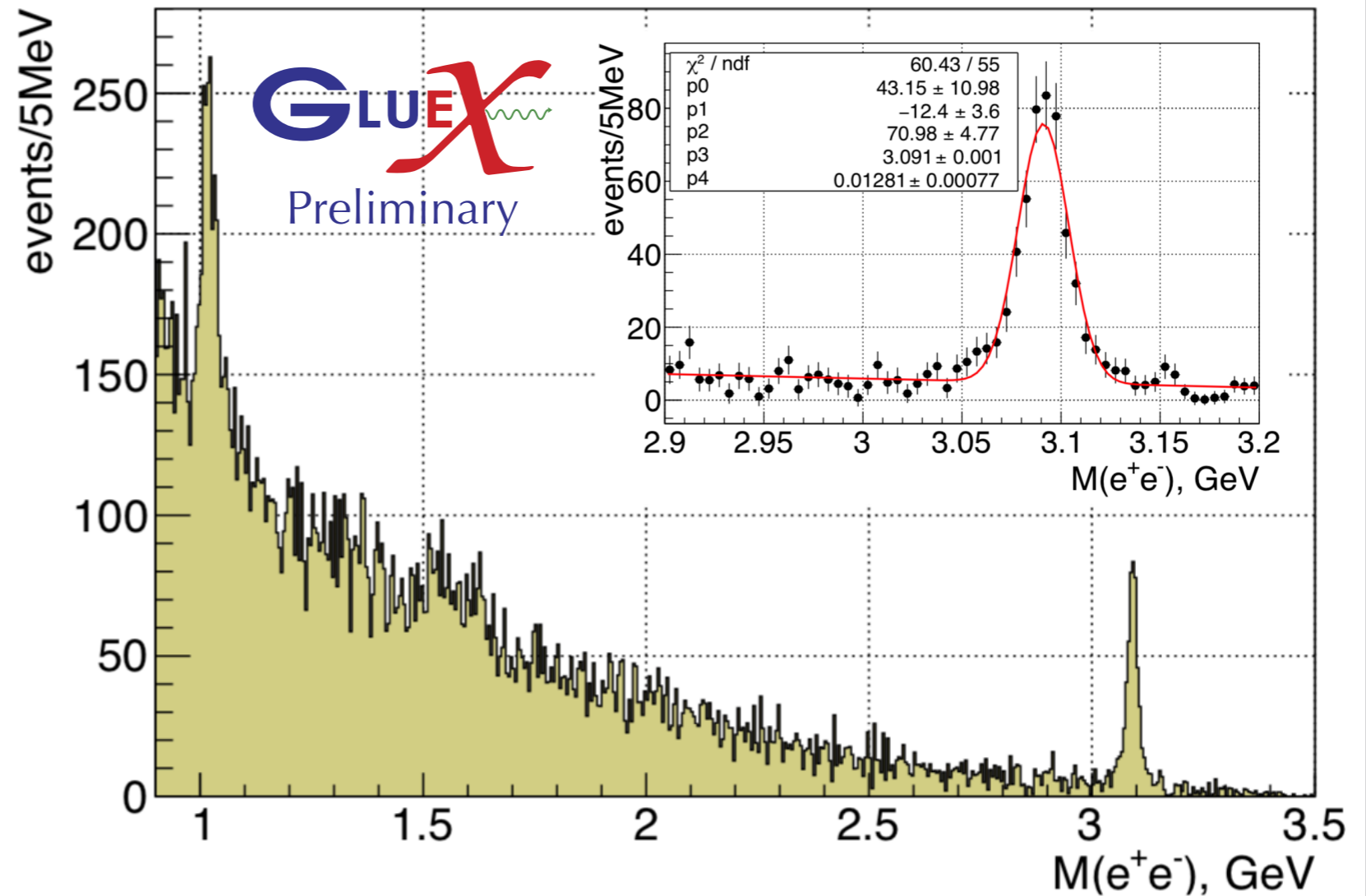


LHCb: 1904.03947



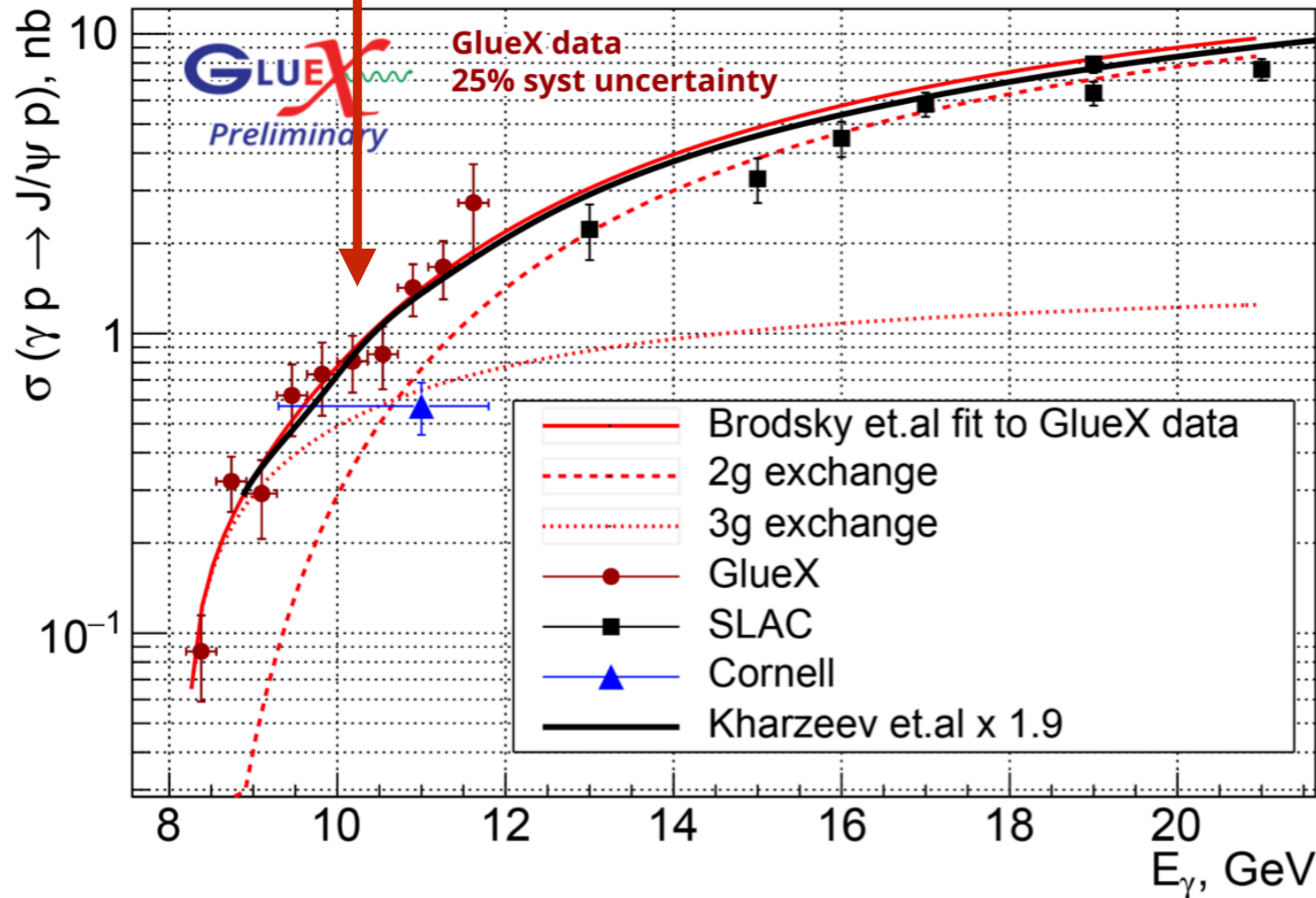
J/ ψ photoproduction at **GLUEX**

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

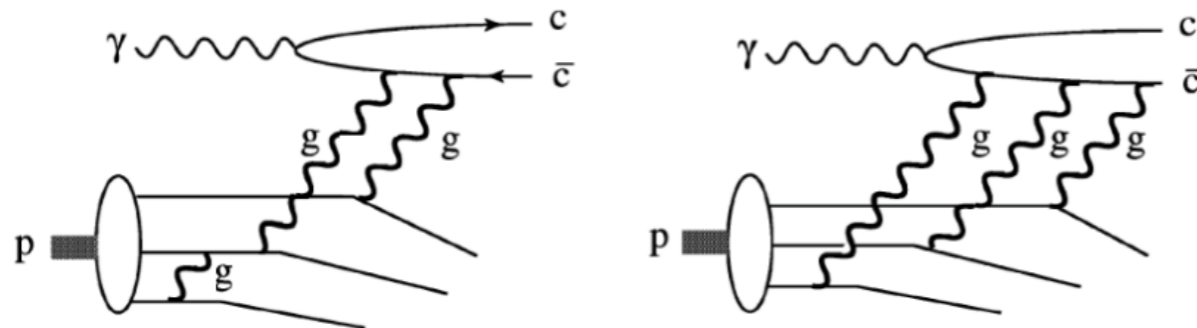
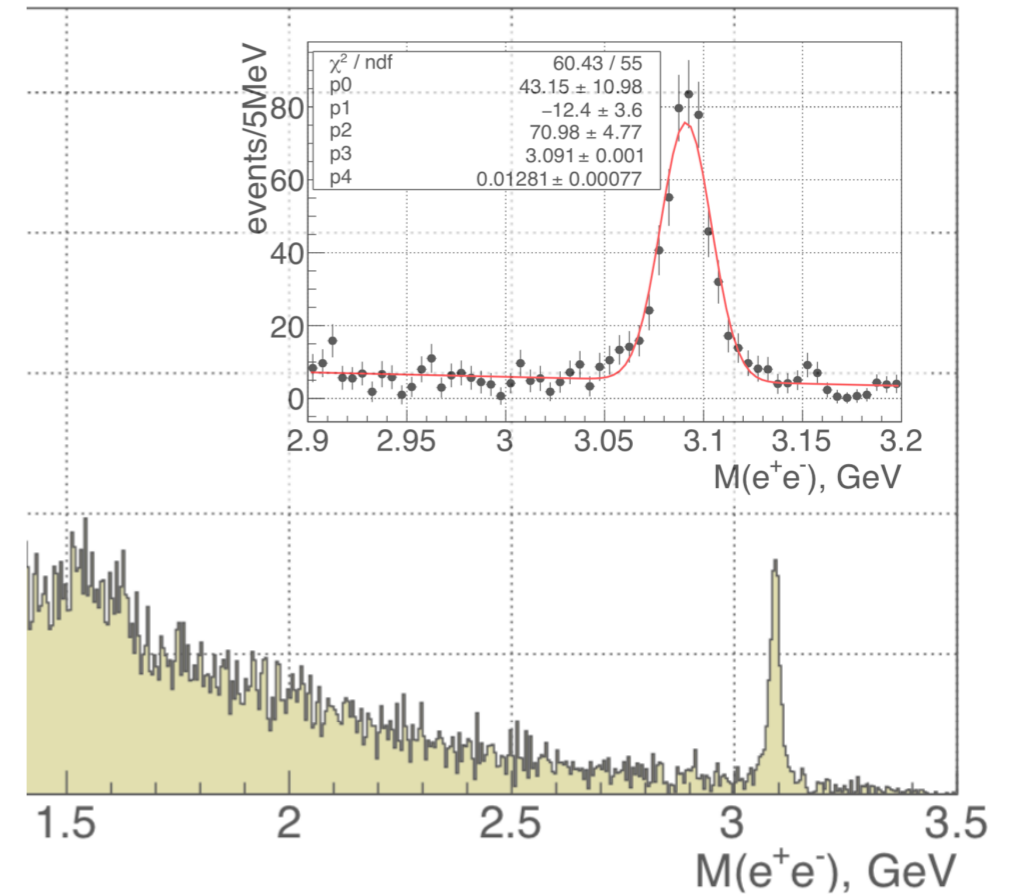


J/ ψ photoproduction at **GLUEX**

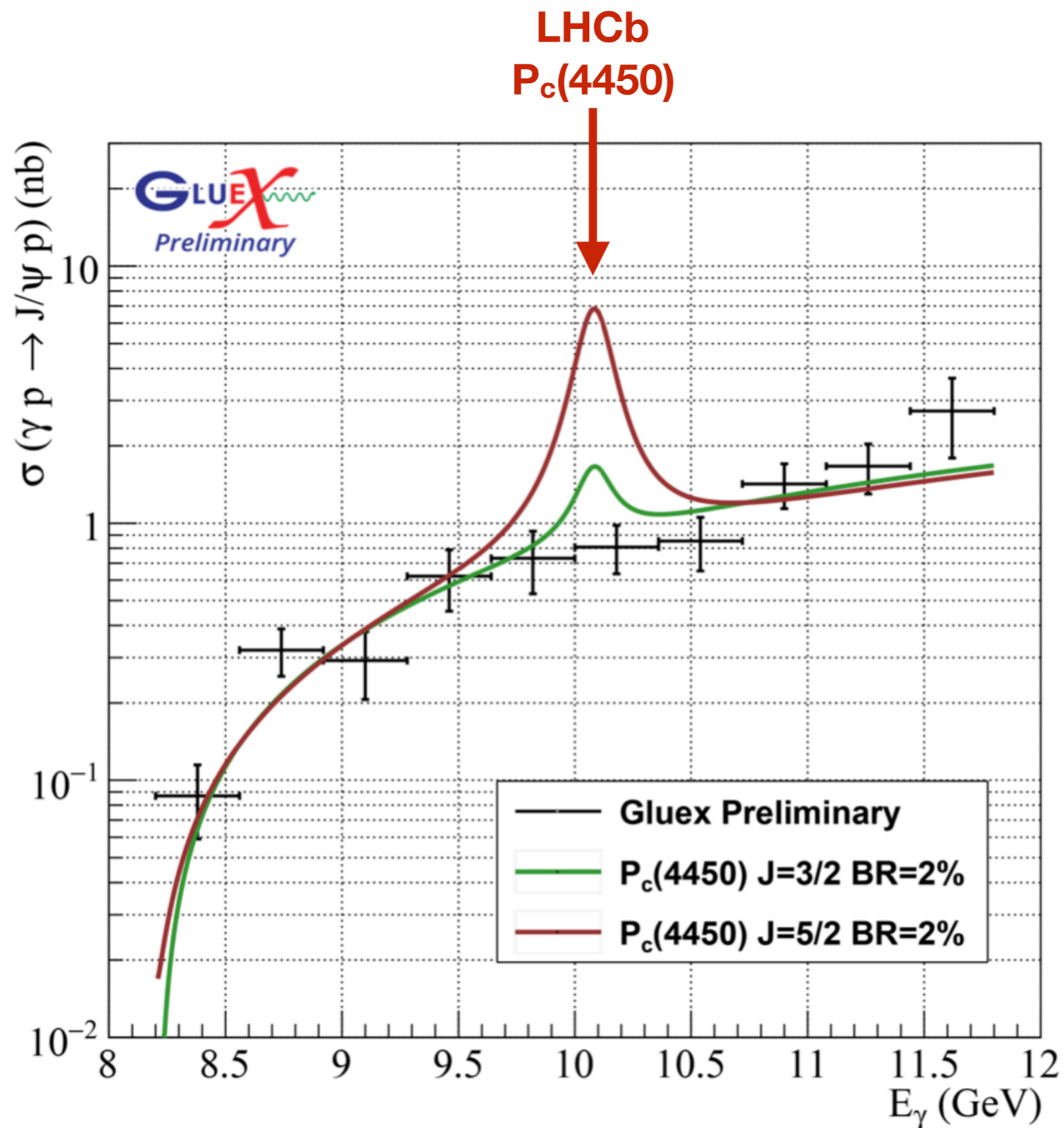
LHCb
 $P_c(4450)$



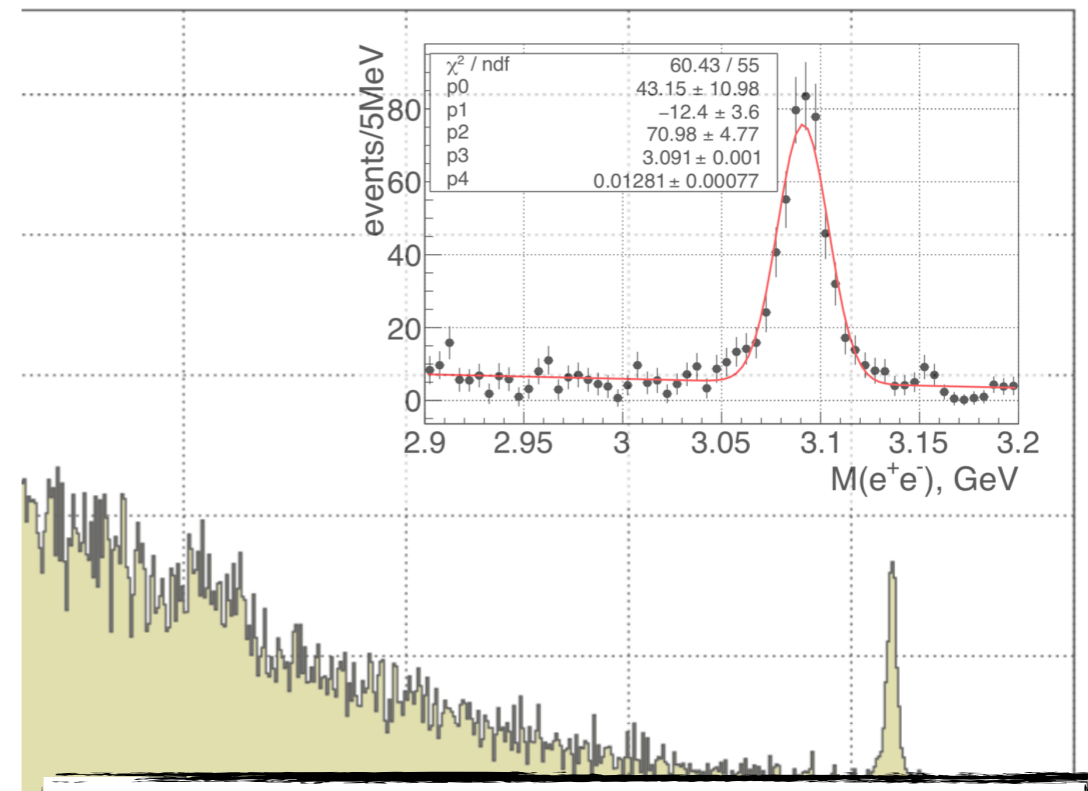
$$\gamma p \rightarrow p e^+ e^-$$



J/ ψ photoproduction at **GLUEX**



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



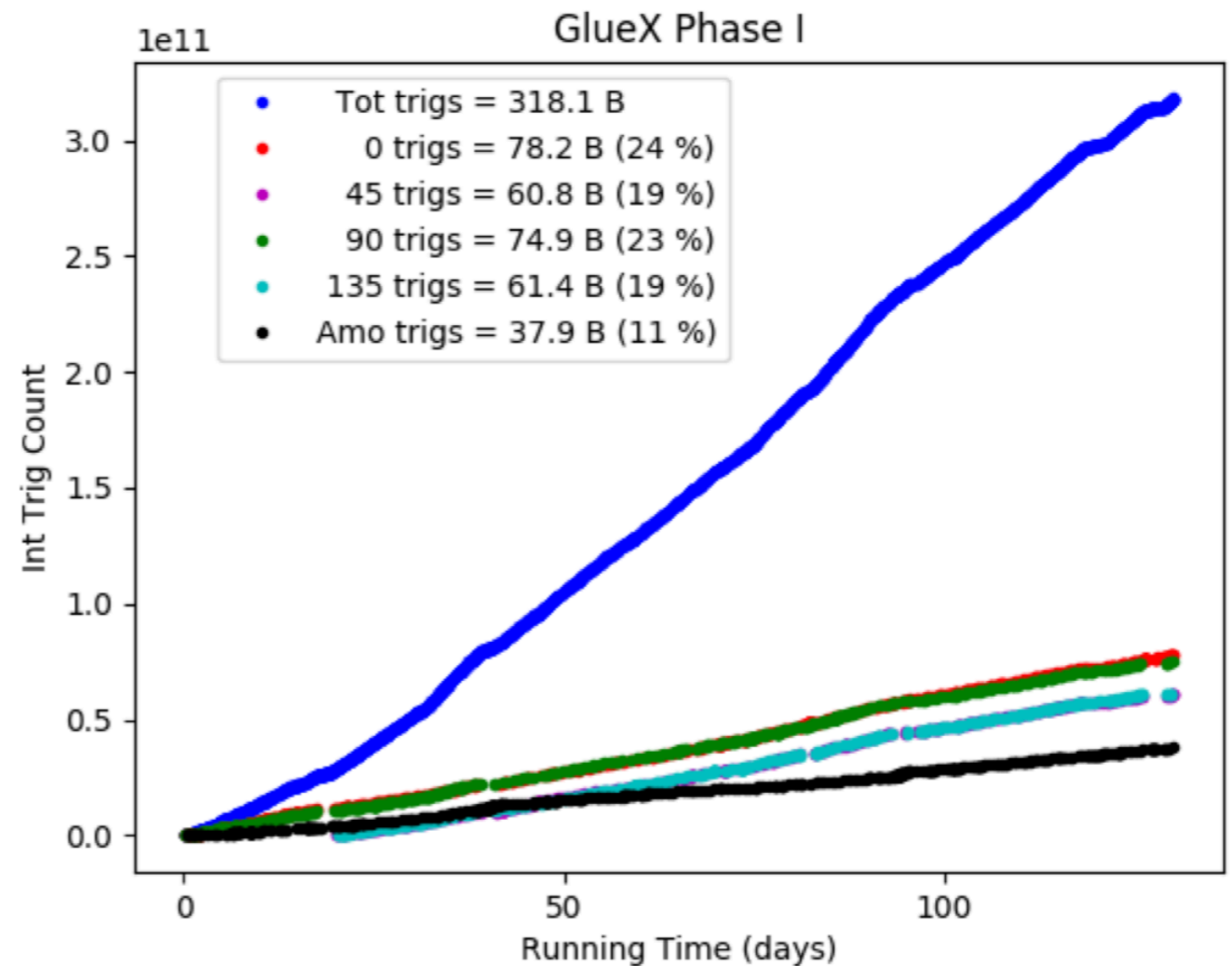
- * **BR**(P_c → J/ ψ p) < 2-4% limit assuming P_c(4450) parameters
- * Forthcoming publication will set **BR**(P_c → J/ ψ p) and cross section upper limit

JPAC model: PRD 94, 034002 (2016)

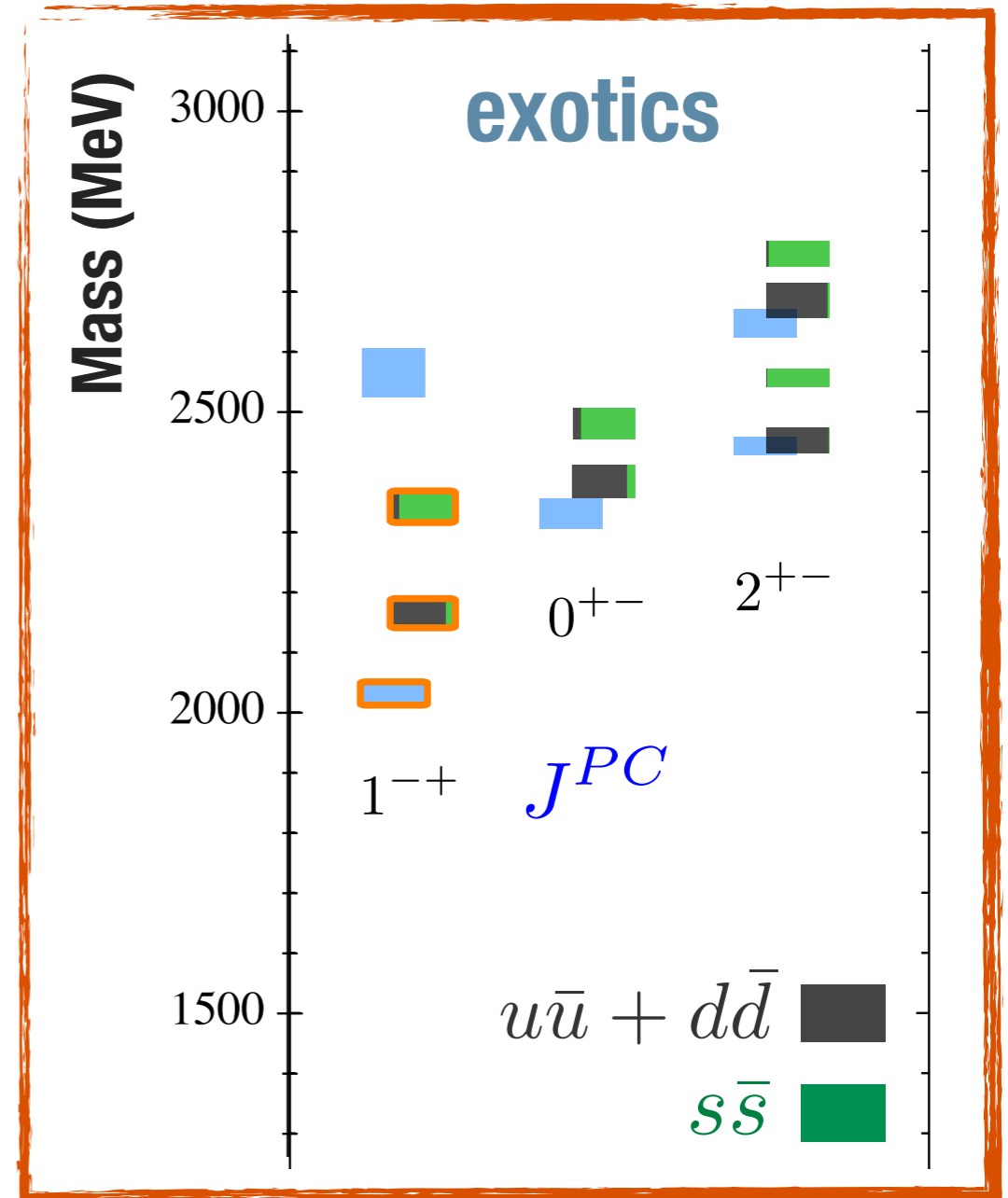
GLUEX Timeline

- * GlueX “Low intensity” Phase-I program completed in 2018
- * ~25% of dataset currently under analysis, full statistics available this year
- * Production mechanisms and identifying known mesons
- * Opportunistic measurements: J/ψ , hyperons, etc.
- * “High intensity” program to begin in Fall 2019

Phase-I dataset: 2016-2018
300 B events and ~5 PB of data



- * 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^{-+}	$KK\pi\pi^\dagger, KK\pi^\dagger, KK\omega^\dagger$

Strangeness program: decay patterns

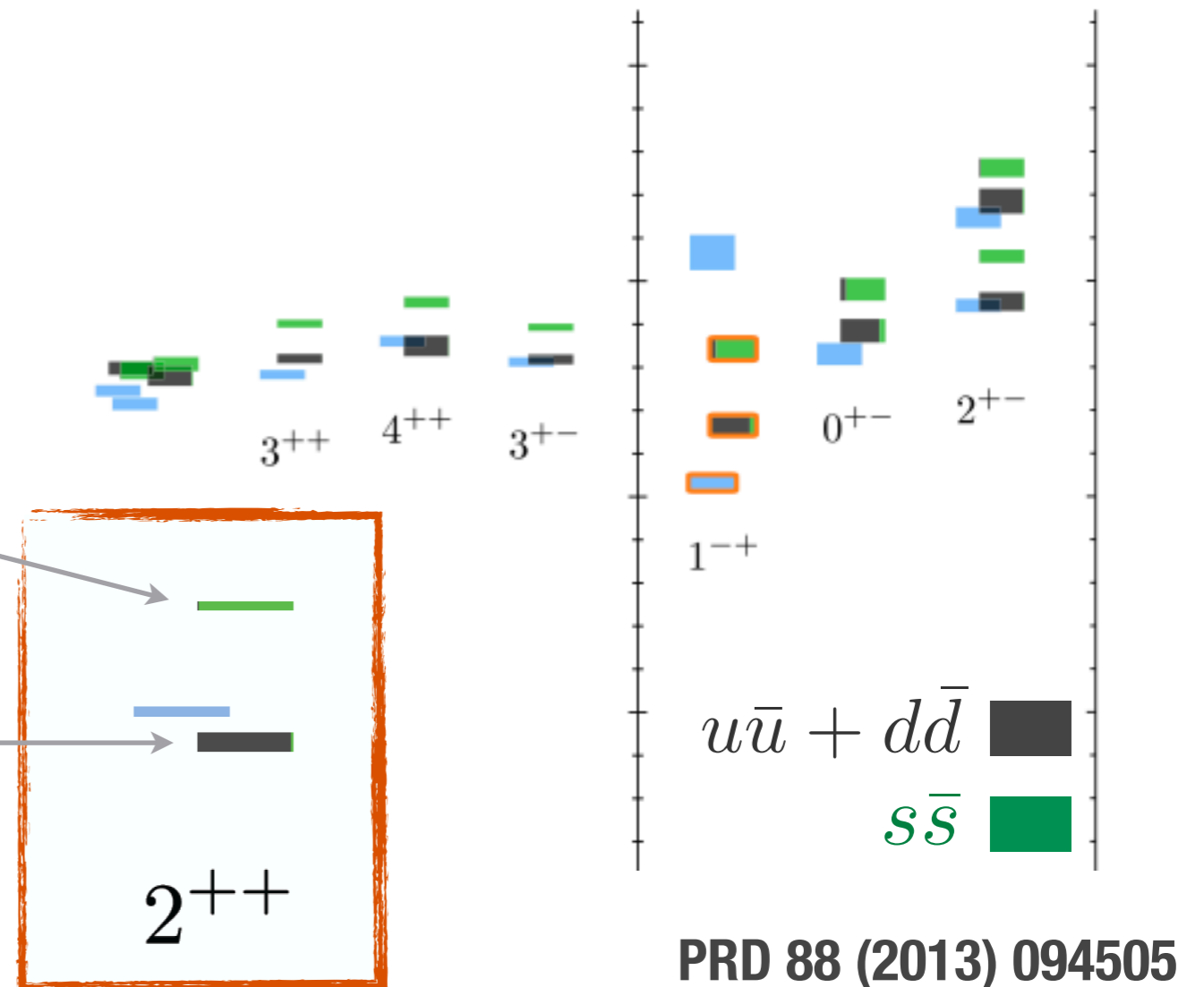
- * Experimentally infer quark flavor composition through branching ratios to strange and non-strange decays

$$\frac{\mathcal{B}(f_2'(1525) \rightarrow \pi\pi)}{\mathcal{B}(f_2'(1525) \rightarrow KK)} \approx 0.009$$

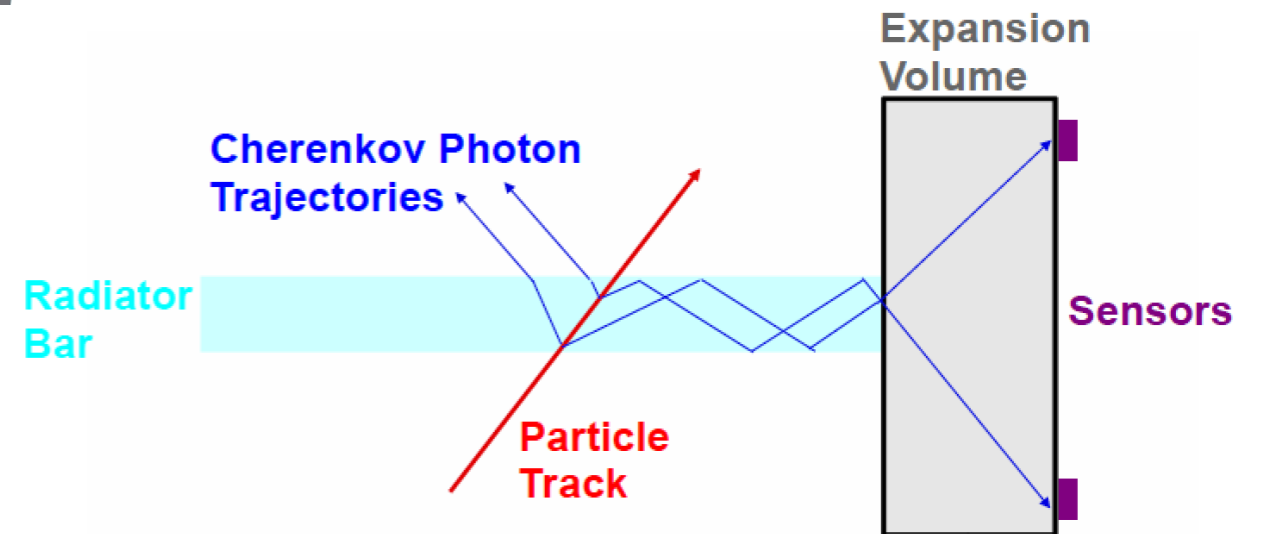
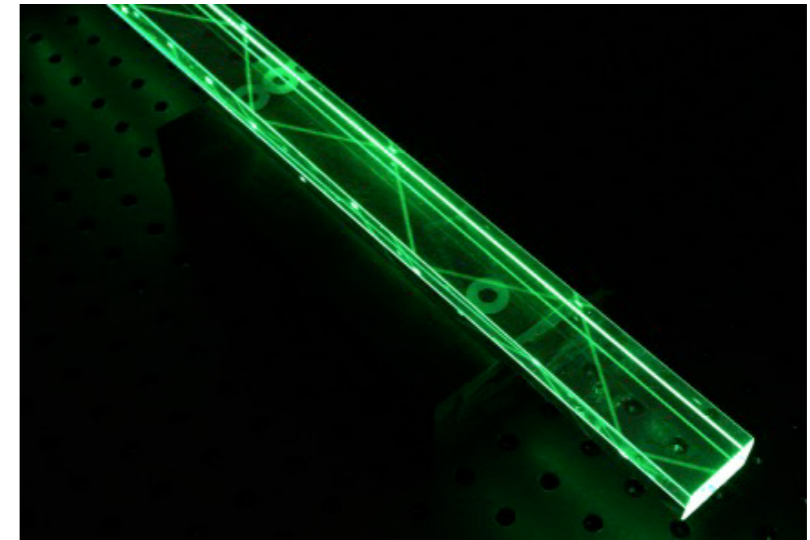
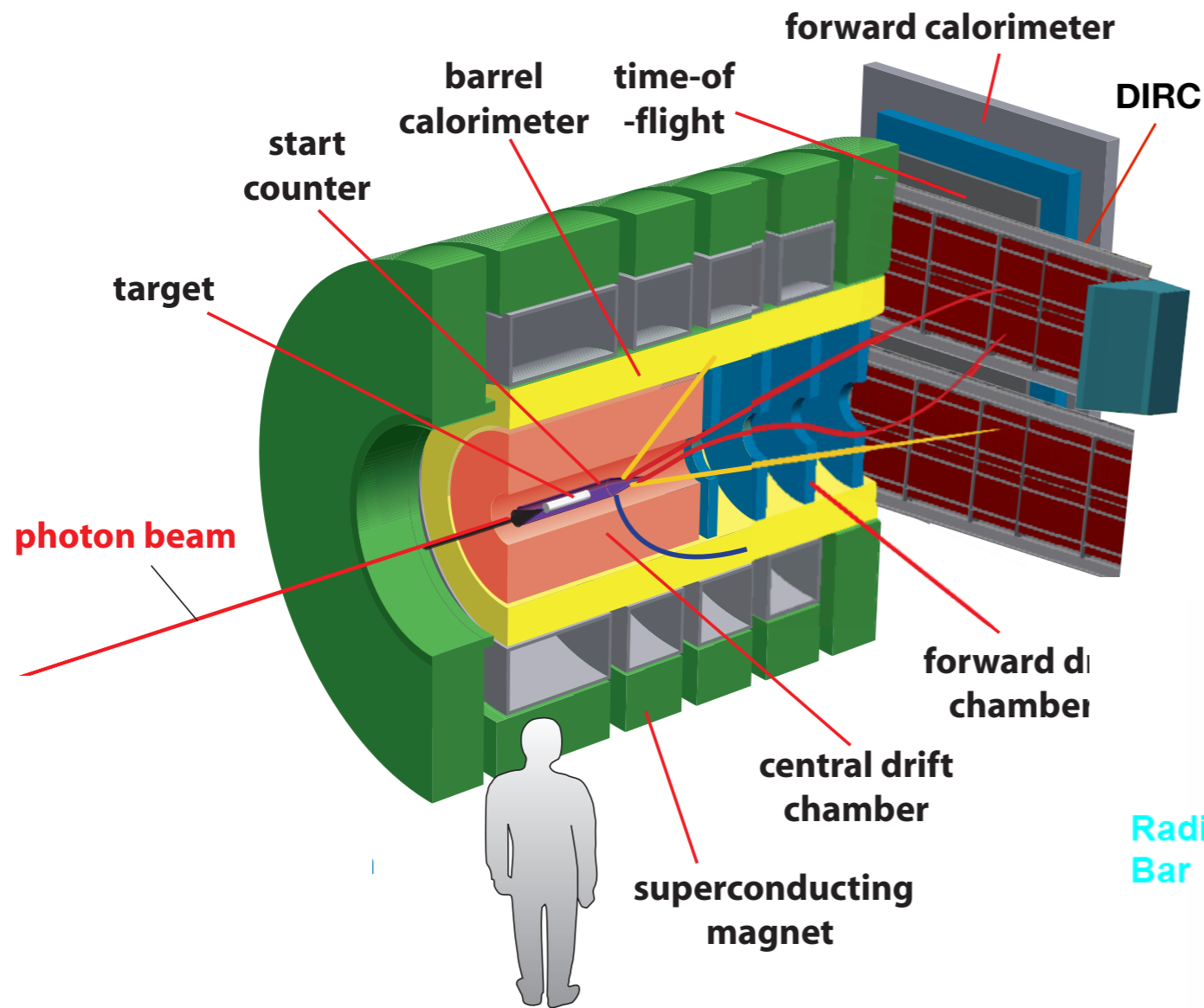
$$\frac{\mathcal{B}(f_2(1270) \rightarrow \pi\pi)}{\mathcal{B}(f_2(1270) \rightarrow KK)} \approx 20$$

- * Consistent with lattice QCD mixing angle for 2^{++} , and predictions for hybrids

- * Need capability to detect strange and non-strange to infer hybrid flavor content

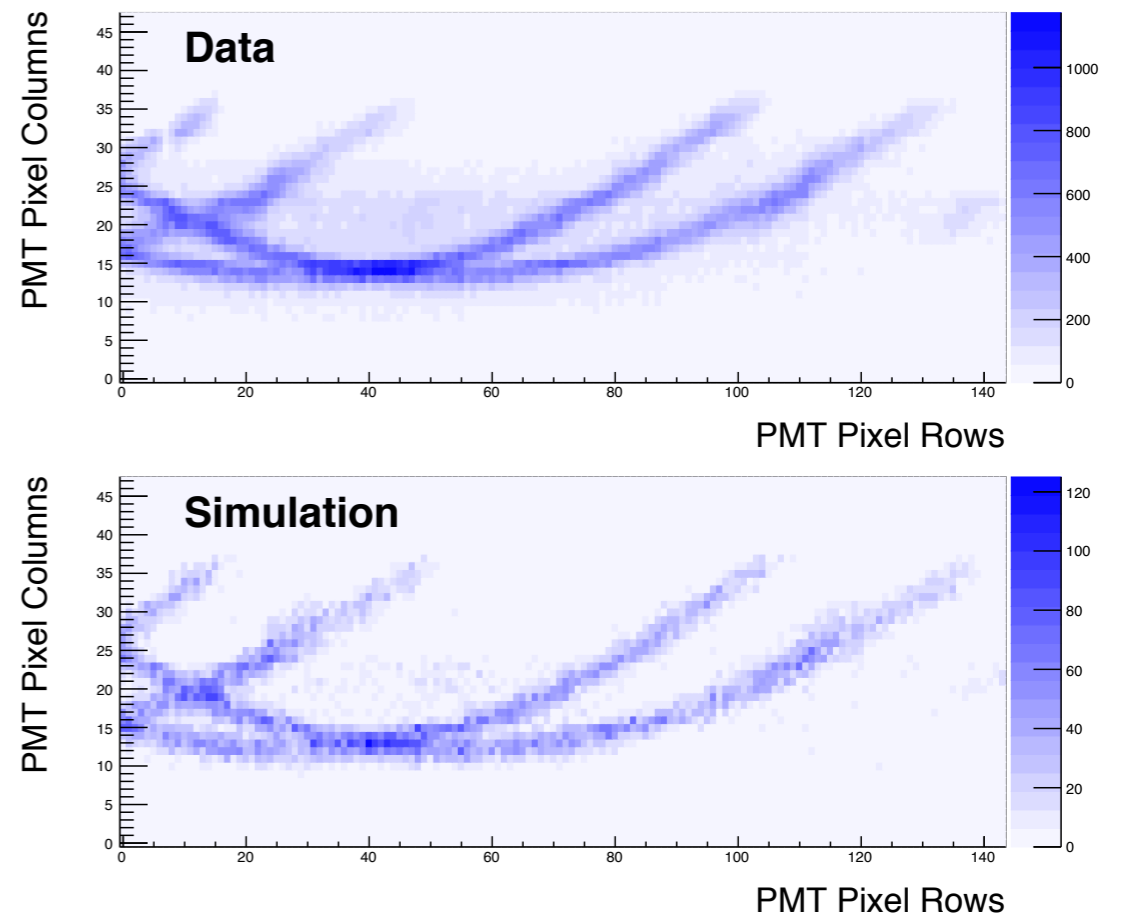
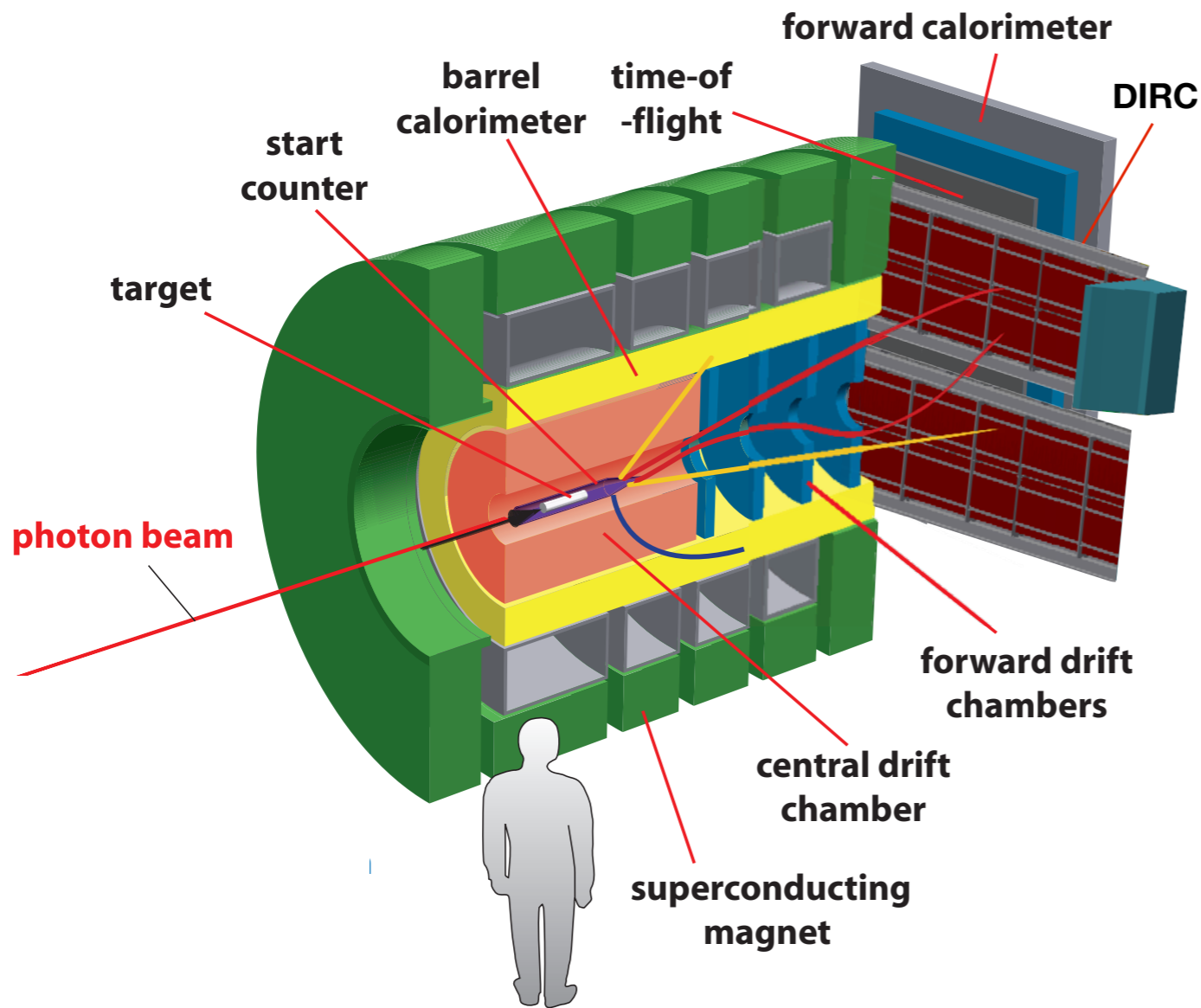


GLUEX DIRC upgrade



- * 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
- * Installation and commissioning this year, physics data in 2019!

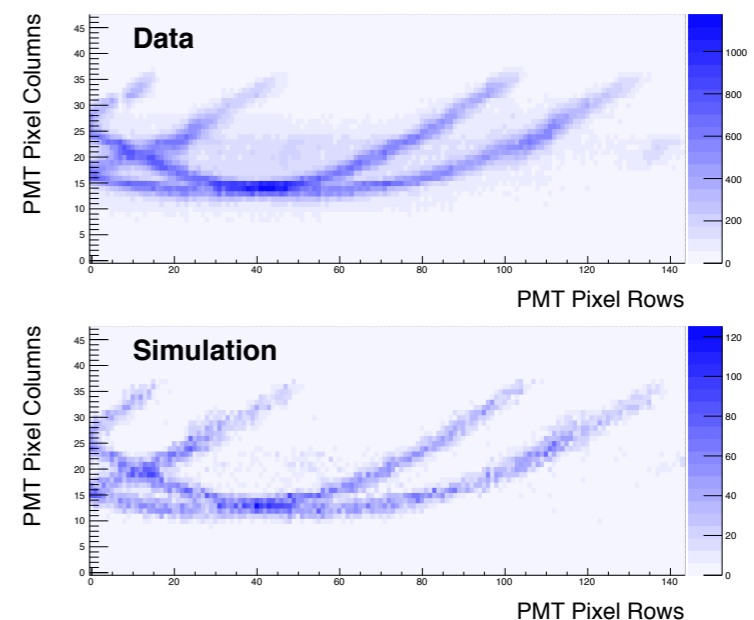
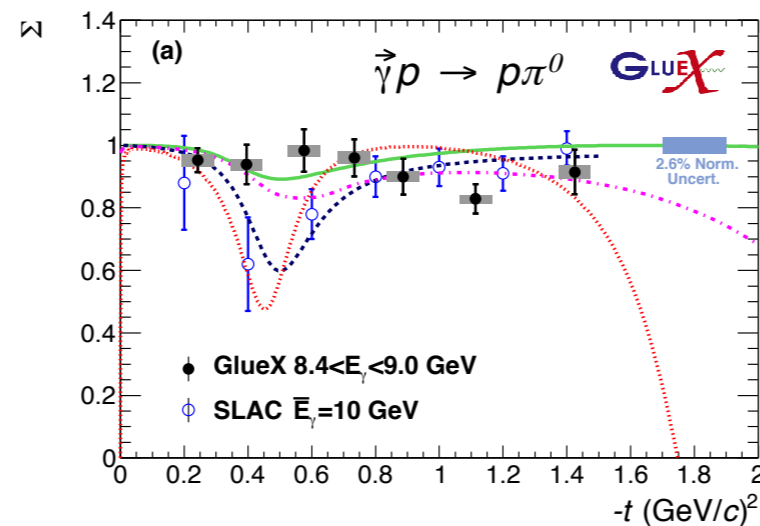
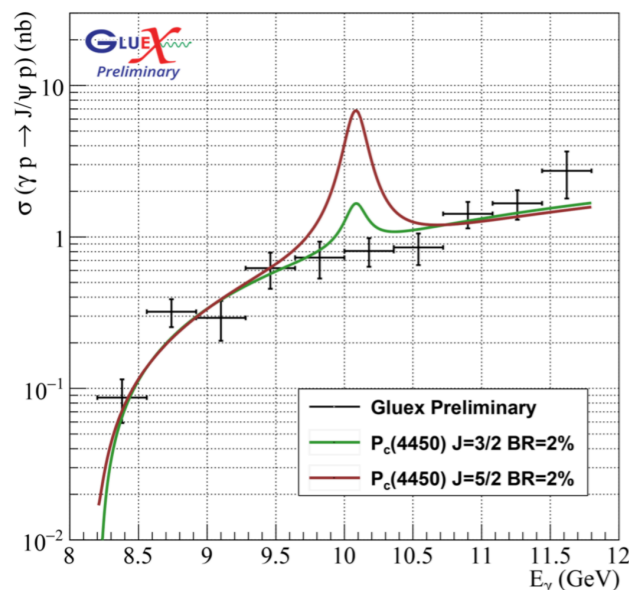
GLUEX DIRC upgrade



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Summary

- ✱ The **GLUEX** experiment is commissioned and the initial meson program is well underway
- ✱ First results aim at understanding the meson photoproduction mechanism through beam asymmetries and other polarization observables
- ✱ An upgrade is in progress to improve the identification of charged kaons to enhance the strange meson spectroscopy program



Supported by DE-SC0018224

