The GlueX Experiment: Status and Prospects

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Bound States in Strongly Coupled Systems
Florence, Italy
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Spectroscopy and "Understanding QCD"

QCD and Spectroscopy

- Features of QCD
  - six flavors of quarks with various masses
  - strongly interacting quarks and gluons
  - asymptotic freedom
  - confinement

Hadron Spectrum (patterns)

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  - spectrum dominated by colorless "quark model" states
  - gluonic degrees of freedom suppressed or difficult to observe
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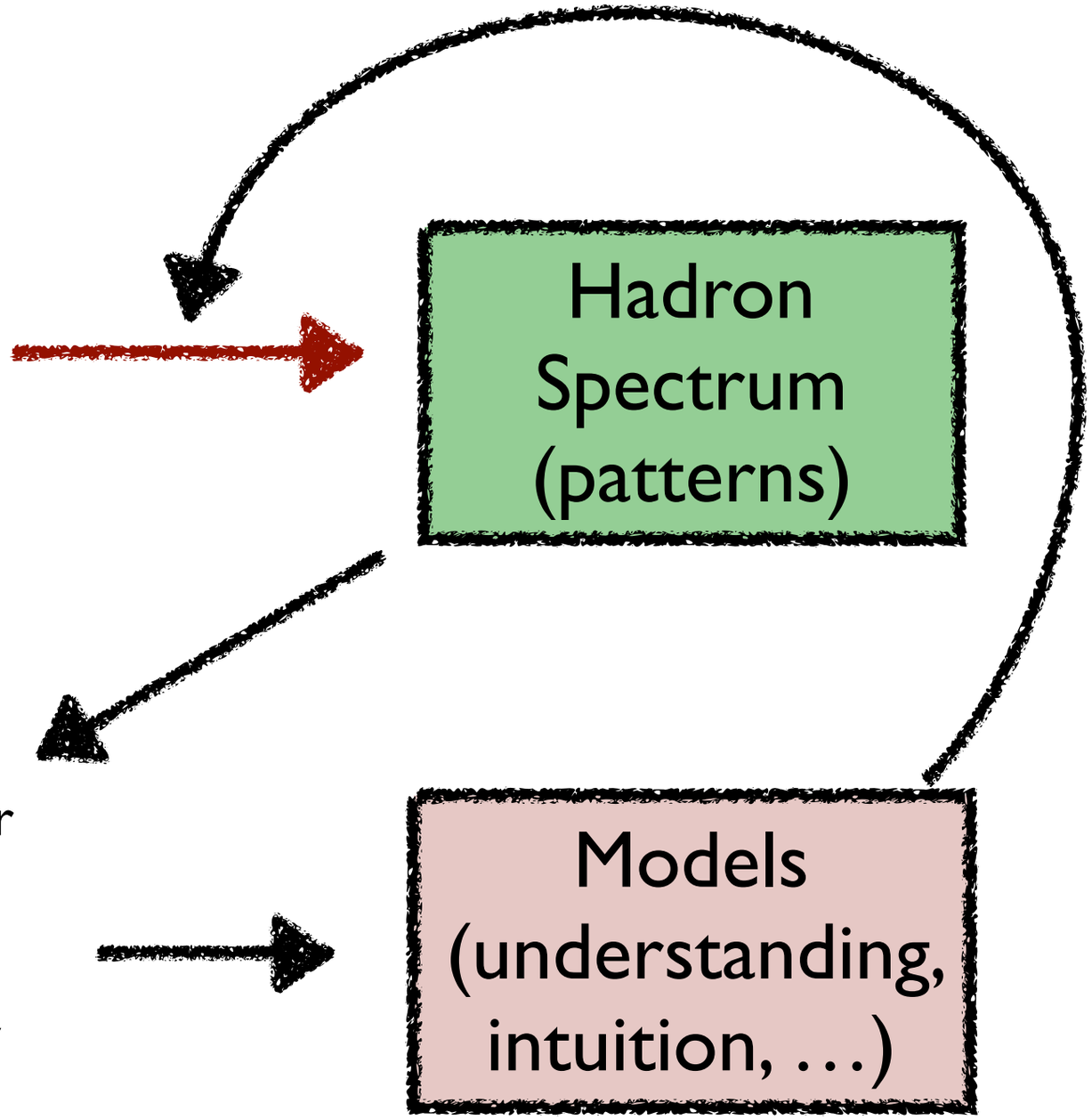
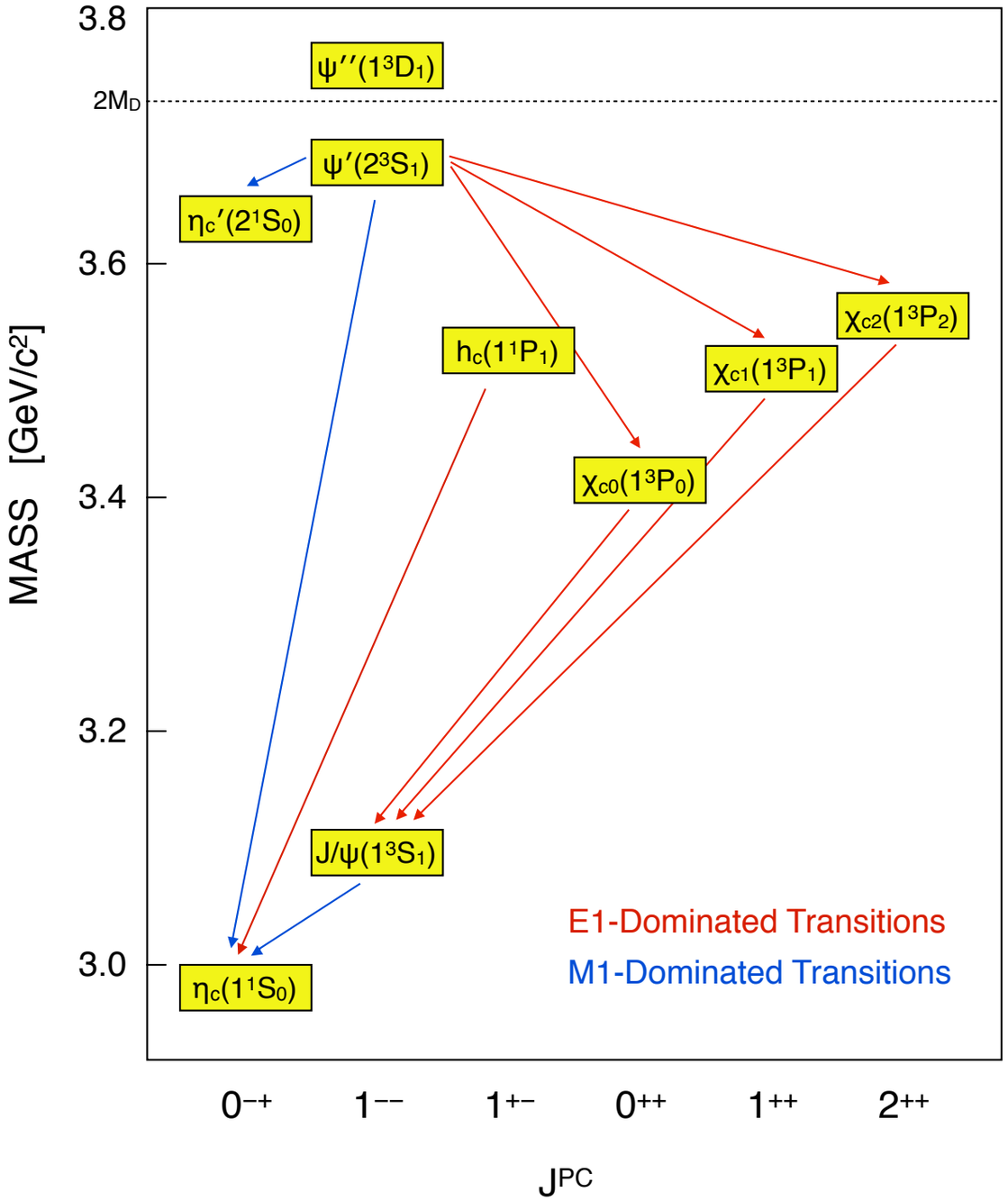
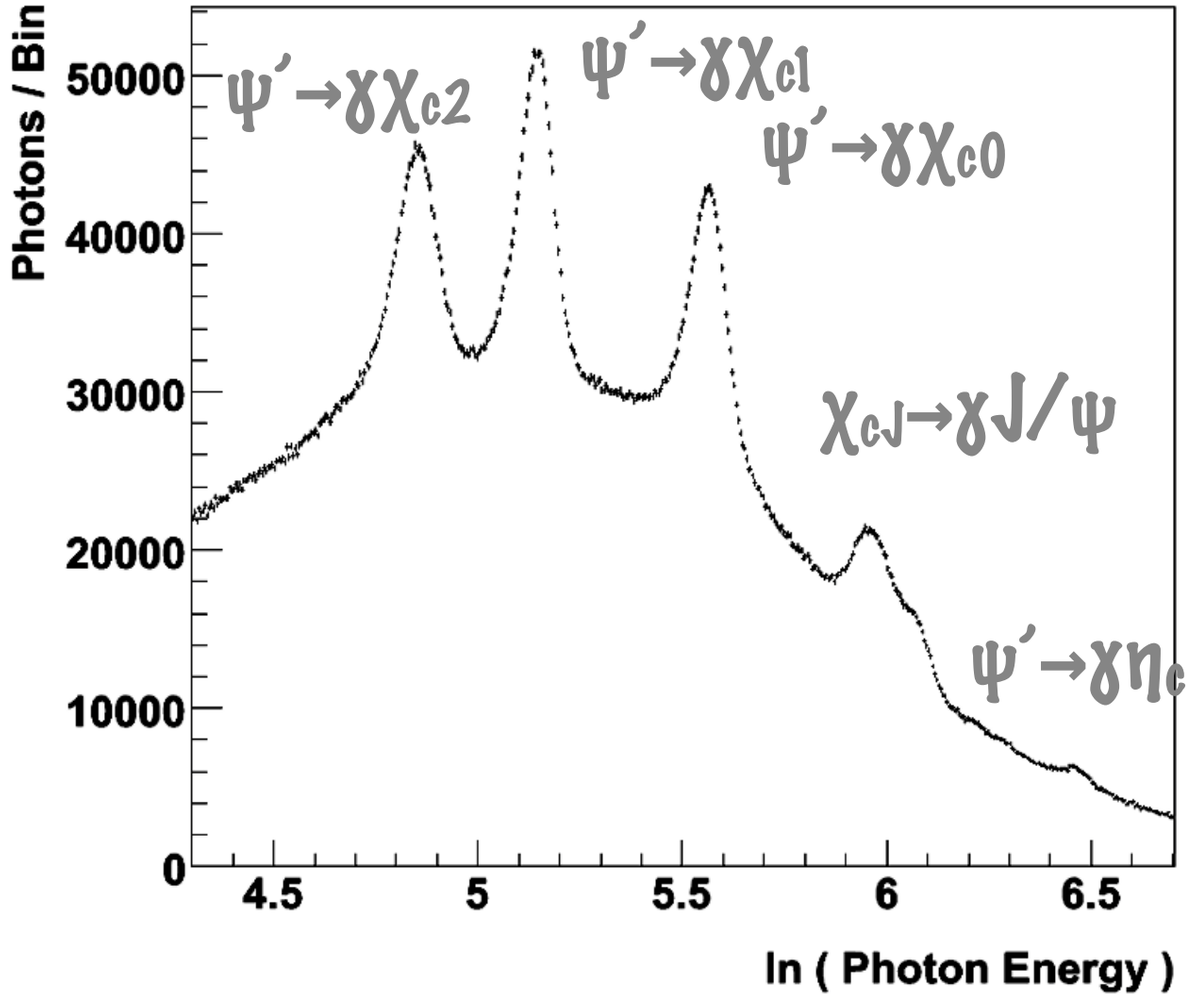


QCD and Spectroscopy

(↑exciting stuff up here↑)





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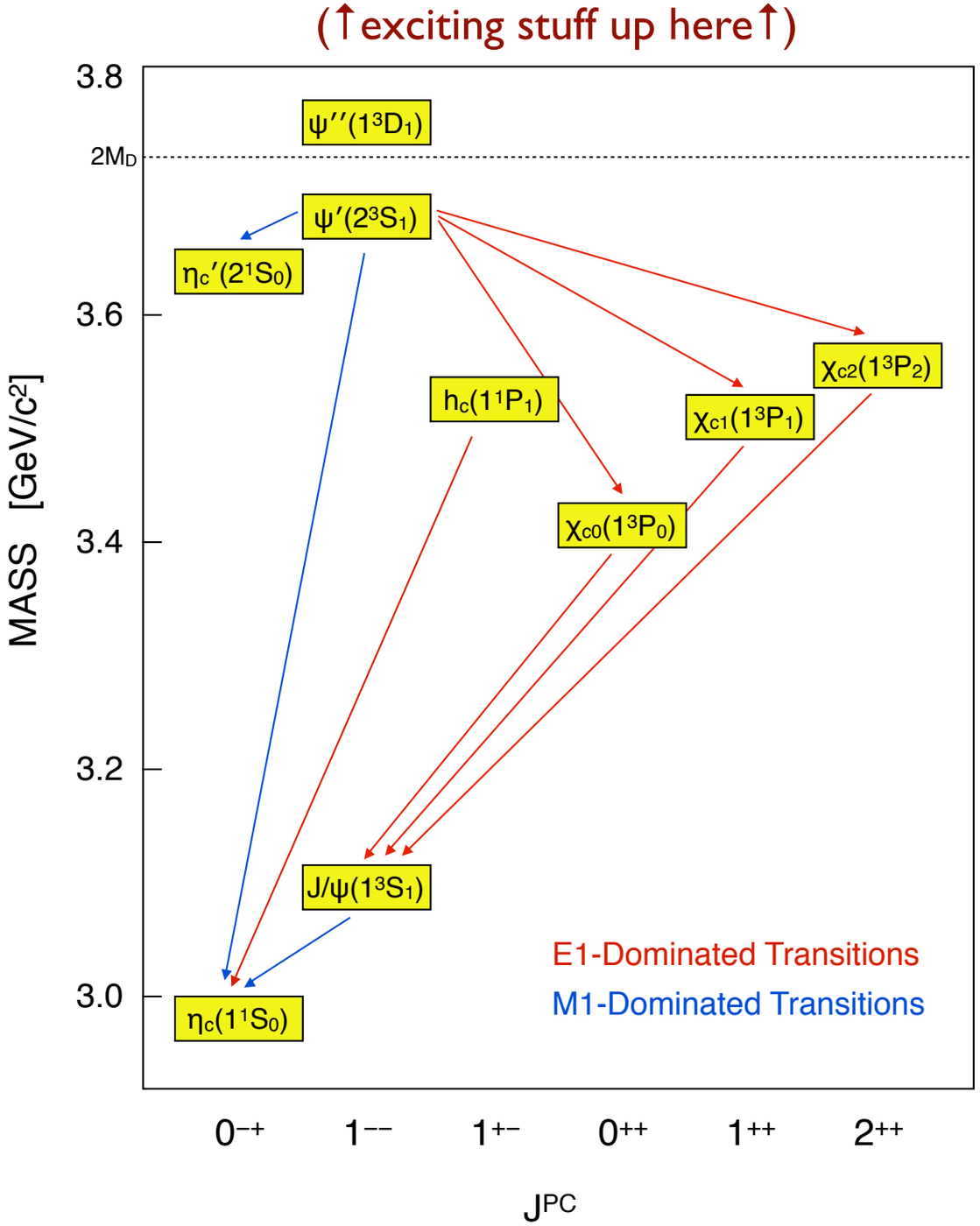
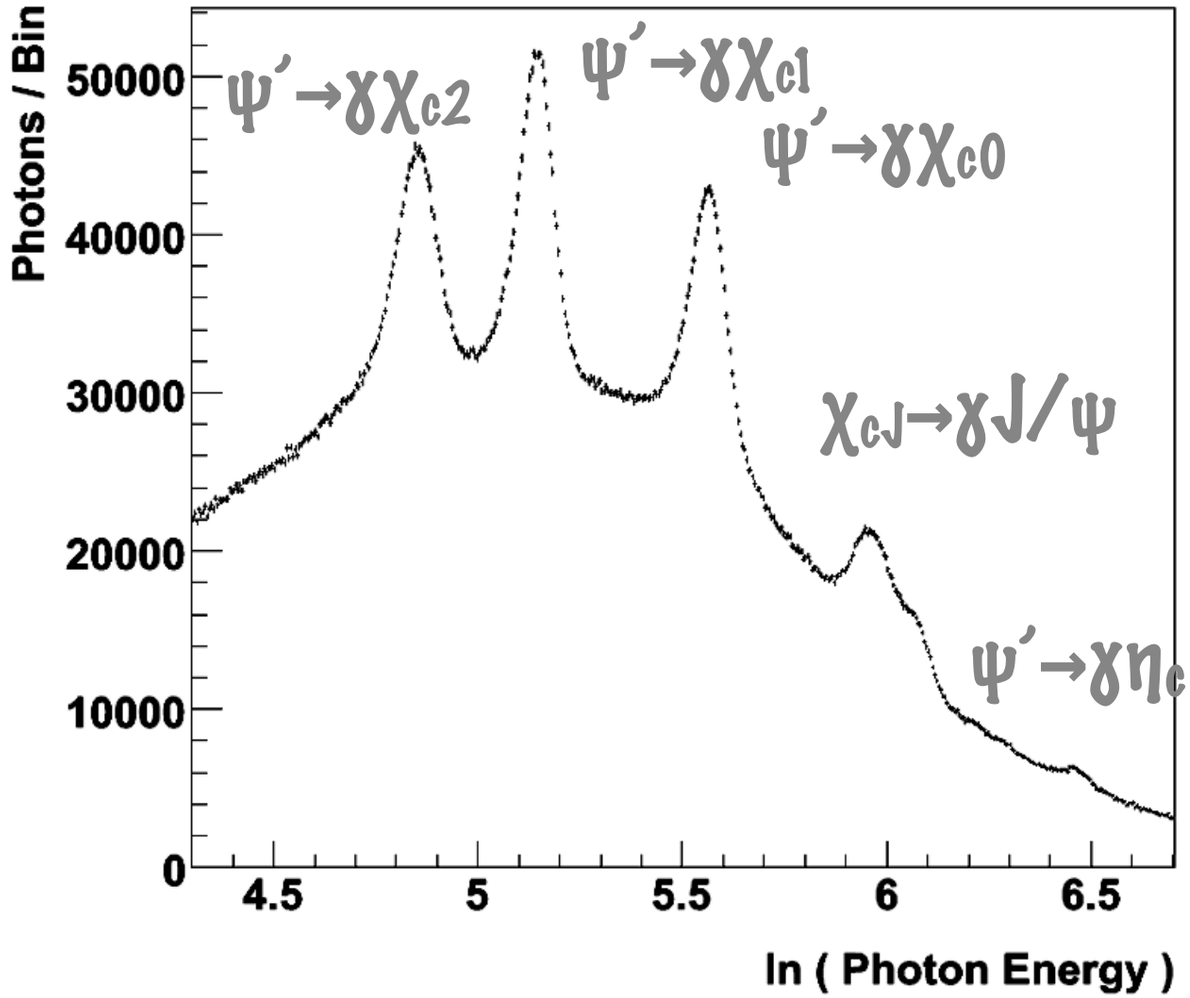
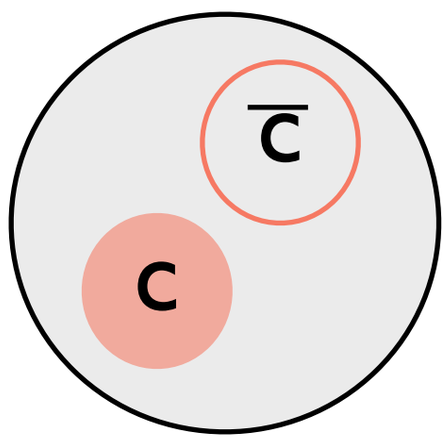


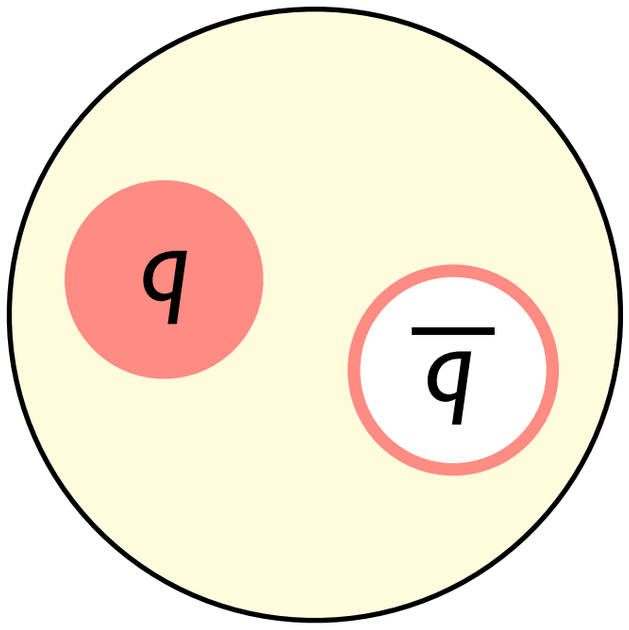




Degrees of Freedom:
a spin-1/2 fermion +
spin-1/2 anti-fermion,
each with mass of 1.5 GeV

Meson Quantum Numbers

color singlet
quark anti-quark

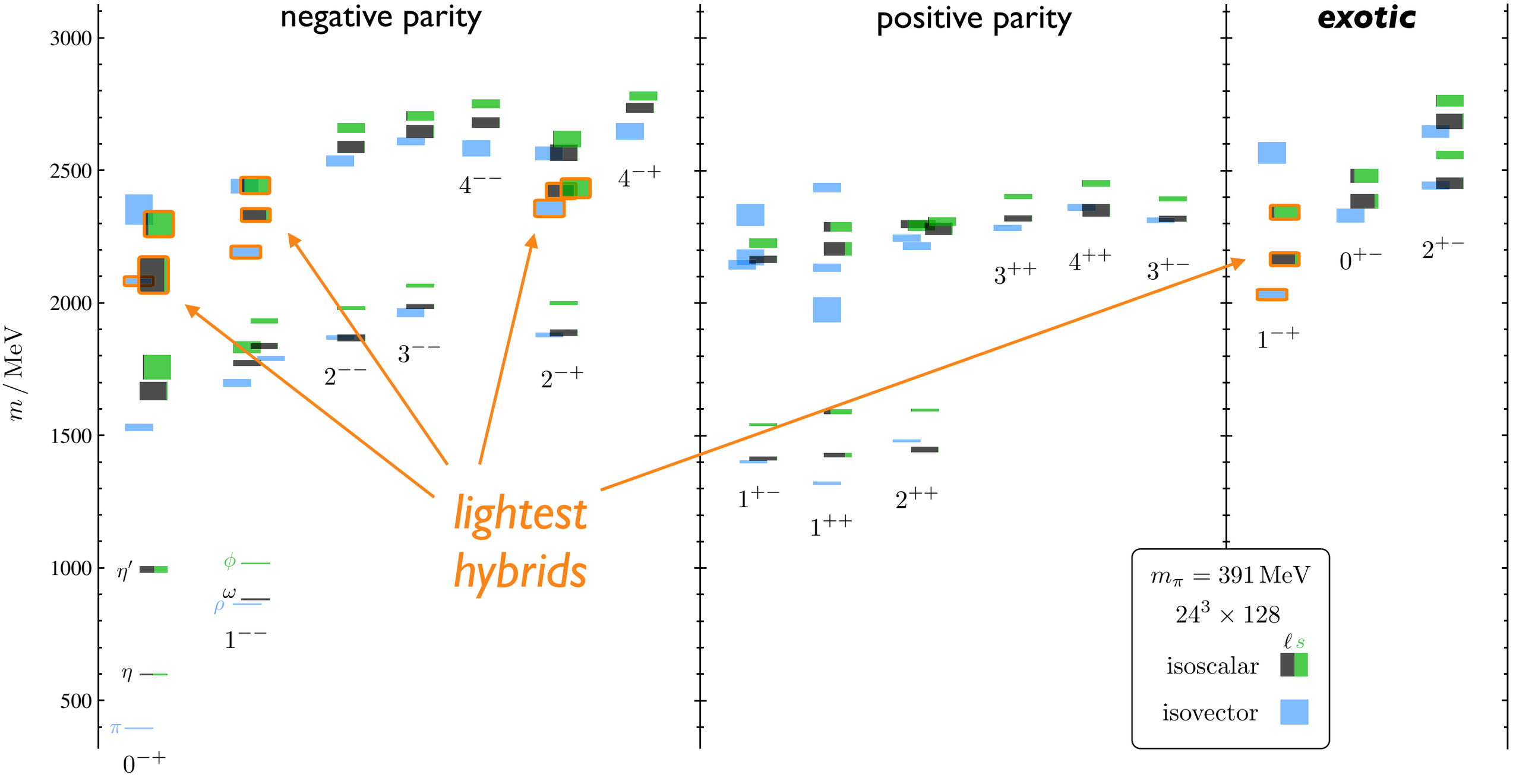


$J = L + S \quad P = (-1)^{L+1} \quad C = (-1)^{L+S}$

Allowed J^{PC}: $0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, \ldots$
Forbidden J^{PC}: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

Light Quark Mesons from Lattice QCD

Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)



A Model for Hybrids

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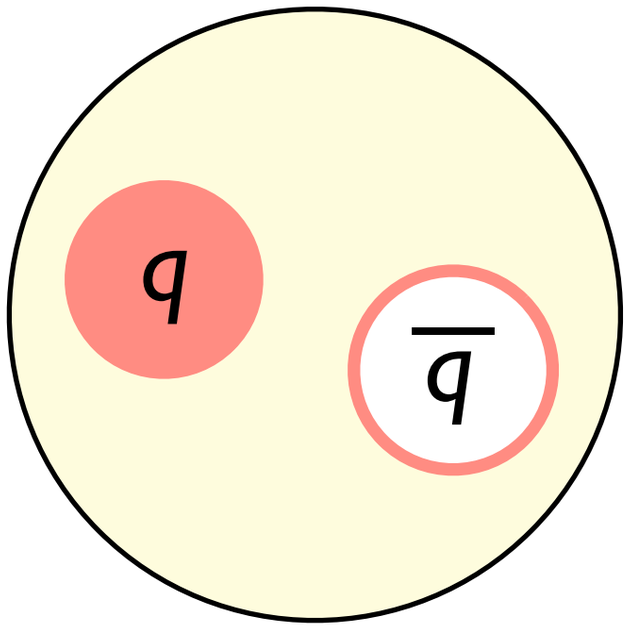

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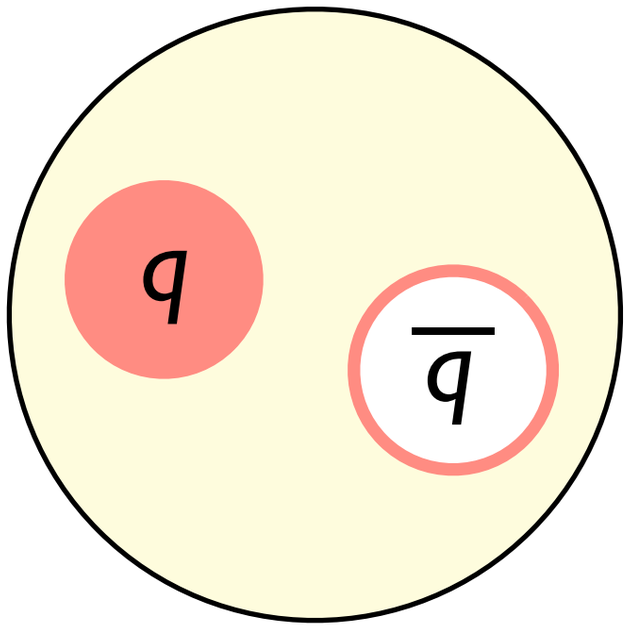

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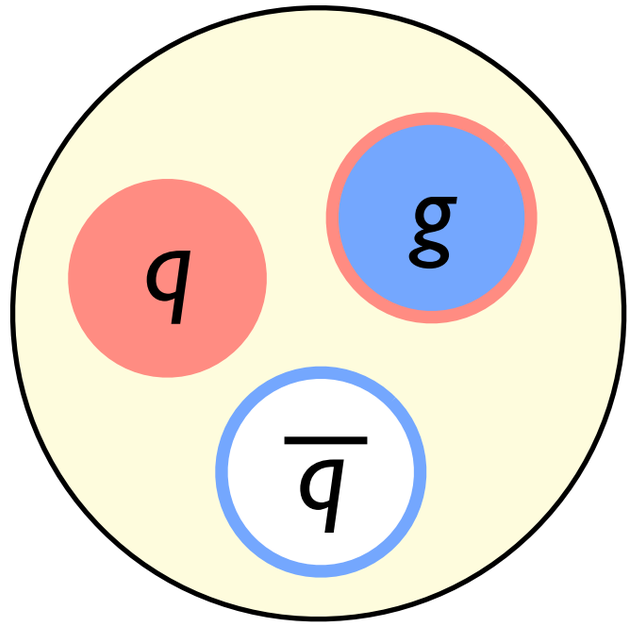
gluonic component:
$(J^{PC})_g = 1^{+-}$
mass ≈ 1.0-1.5 GeV

color-octet
$q\overline{q}$ pair



Lightest Hybrids

	$S_{q\overline{q}} = 1$	$S_{q\overline{q}} = 0$
J^{PC}:	0^{-+}, 1^{-+}, 2^{-+}	1^{--}

"exotic hybrid"

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  - strong evidence for new types of mesons in heavy quark systems
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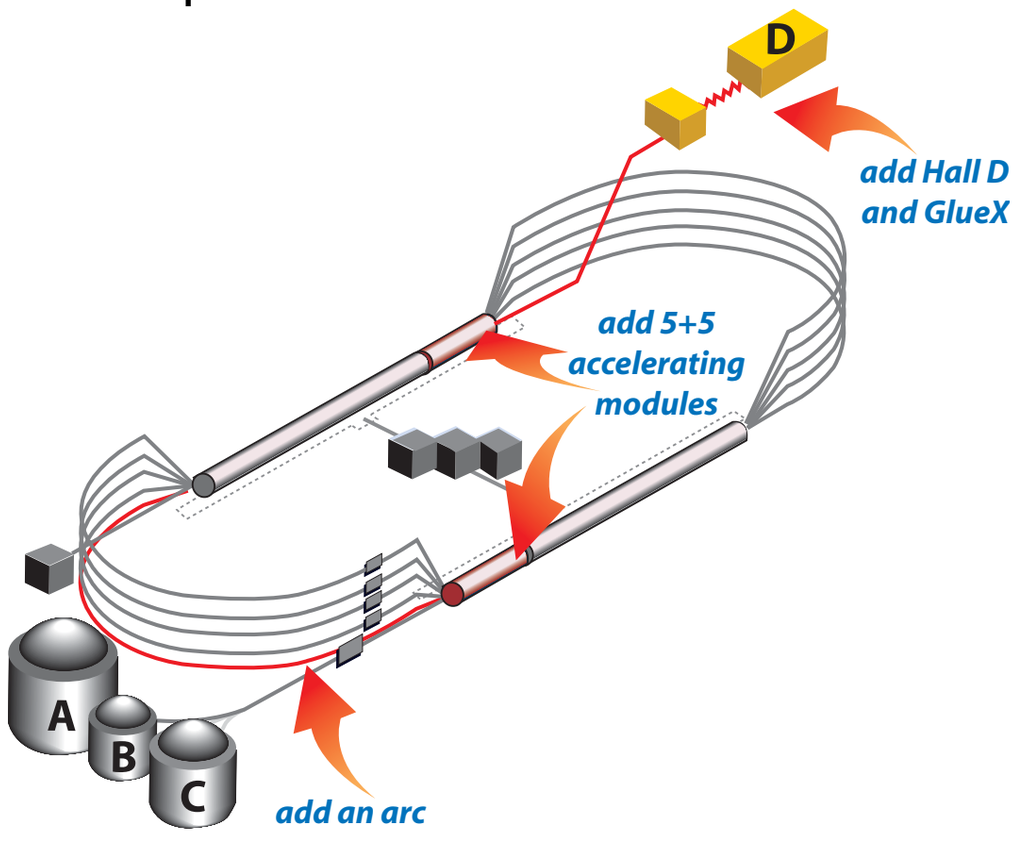
  - *GlueX is complementary: exploration of light quarks*
- *State of the art theory input is essential to constrain models and allow experimental extraction of meaningful observables*

The GlueX Experiment

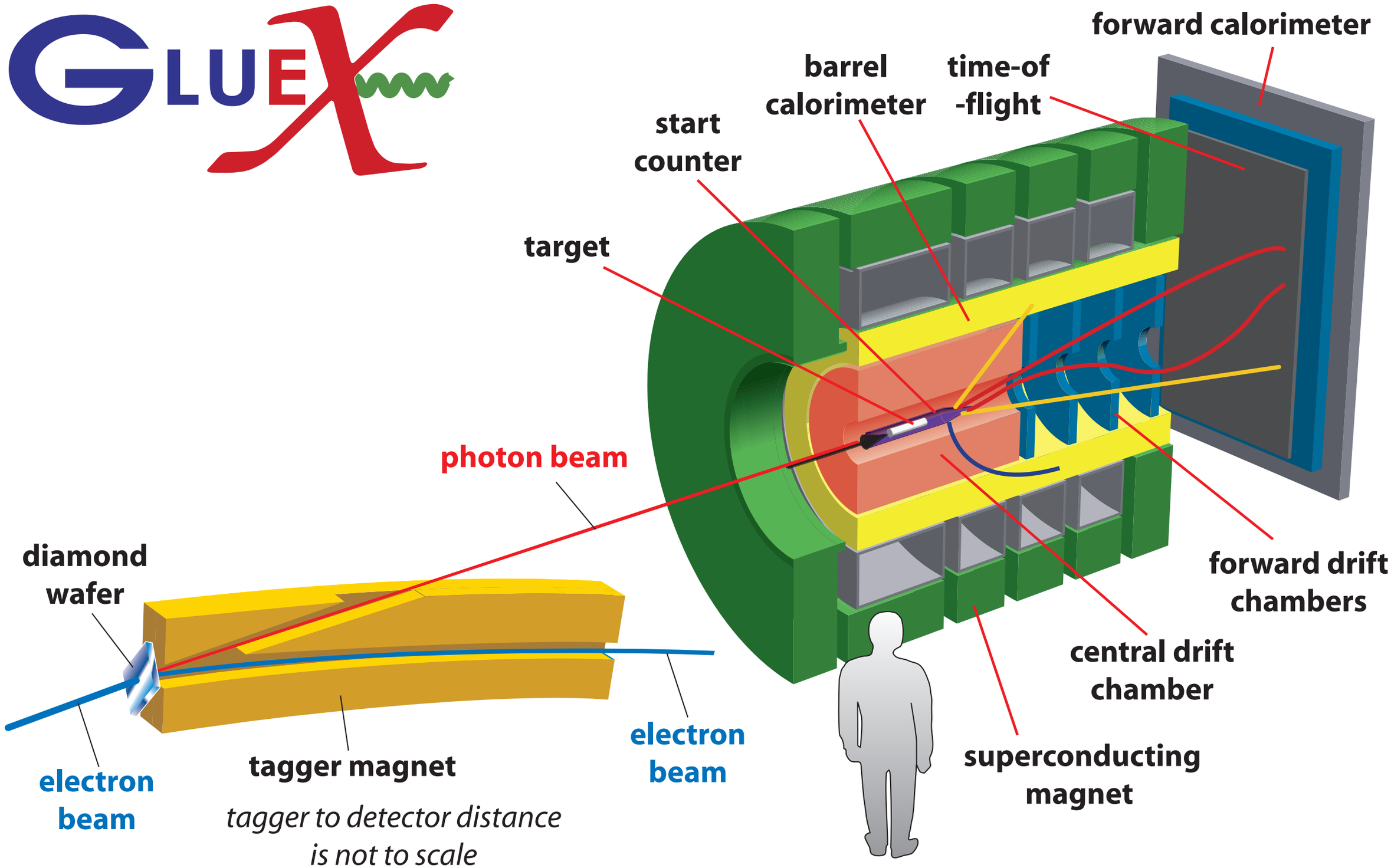
GlueX in Hall D at 12 GeV JLab

- GlueX + Hall D beamline features:
  - beam species: polarized photon; peak polarization at 9 GeV (assuming 12 GeV electron beam)
  - design intensity: 200 kHz hadronic interaction rate around 9 GeV
  - energy optimized for production of mesons with masses up to 3 GeV



GLUEX

120+ members from 26 institutions



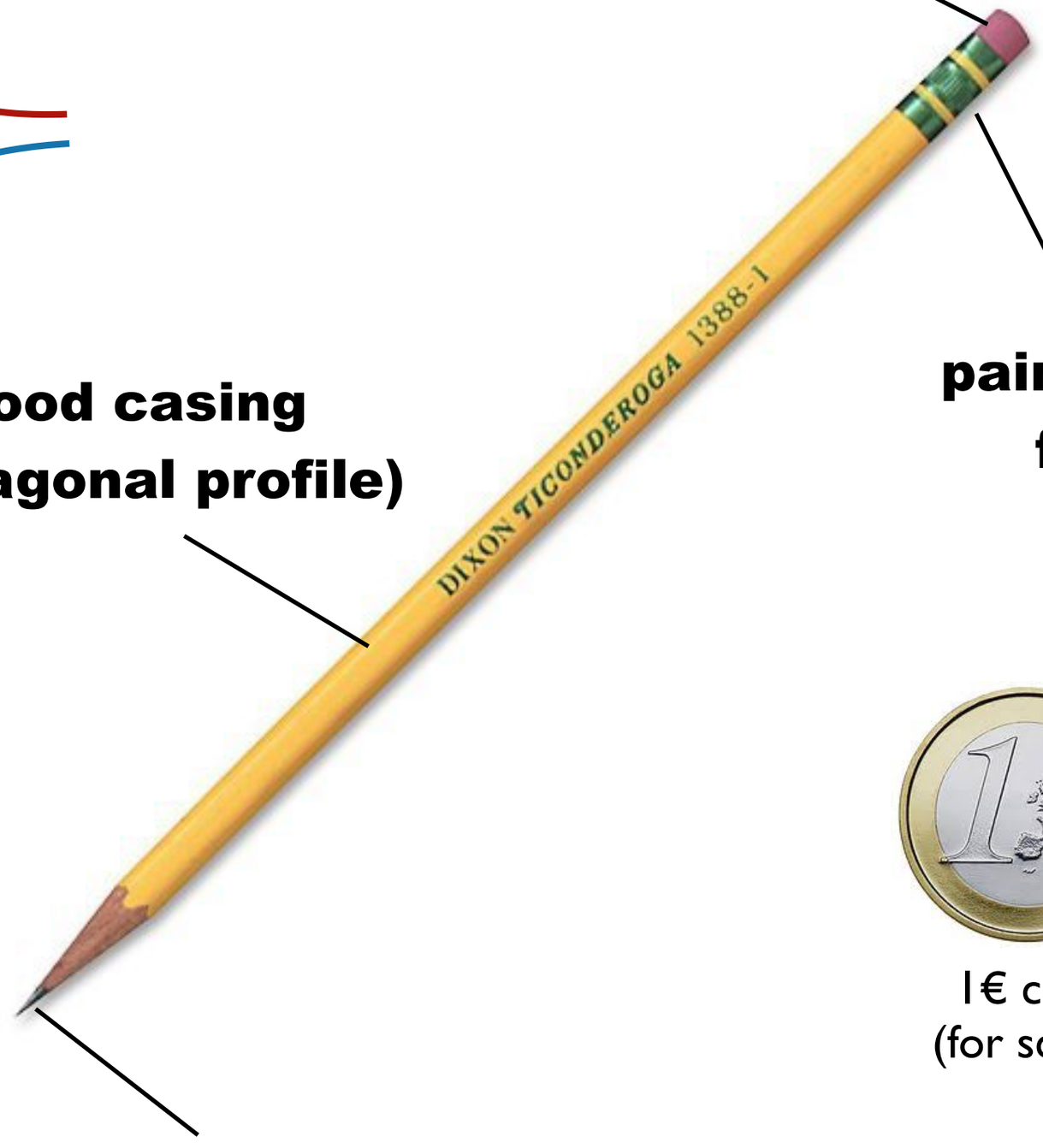
Spring 2018: 40 kHz event rate — about 600 MB/s
(several PB raw data collected to date)

JPAC

rubber
eraser

painted steel
ferrule

hardwood casing
(with hexagonal profile)

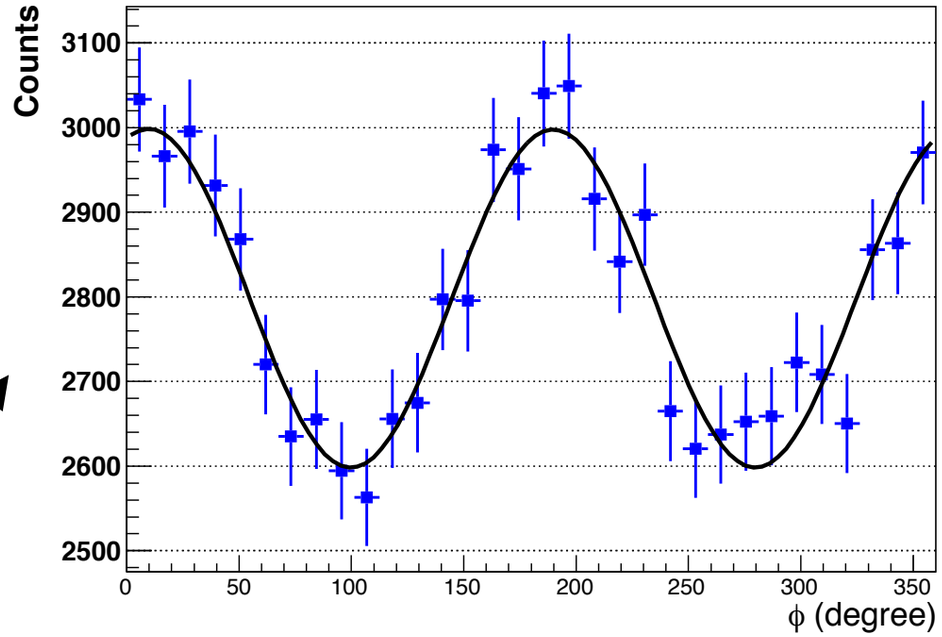


graphite (#2)

Typical data rate:
2-4 lines of equations
per minute

1€ coin
(for scale)

Beam Flux and Polarization



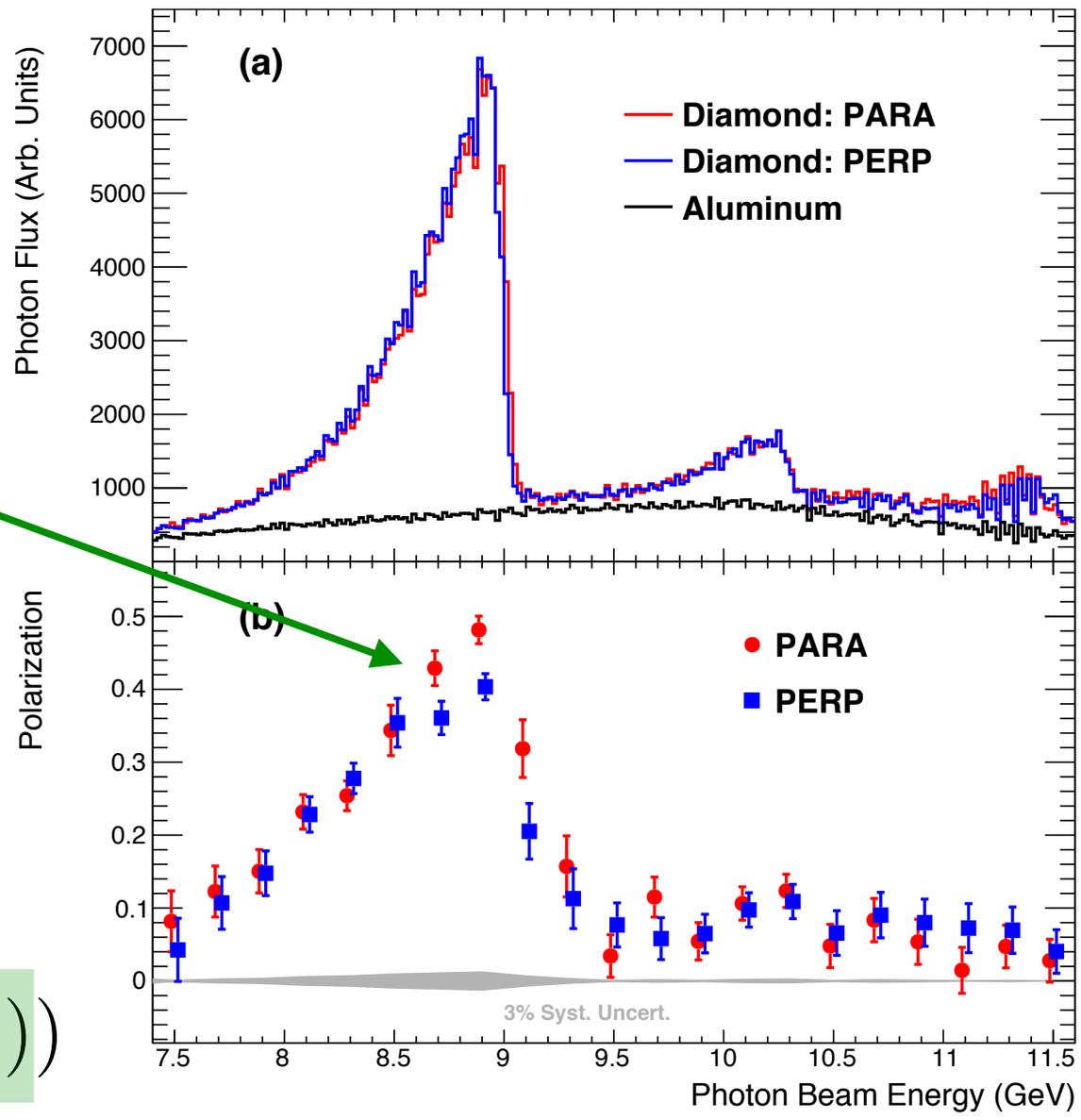
$$\gamma e^- \rightarrow e^+ e^- e^-$$

polarimeter response (simulate)

beam (measure)

QED (calculate)

$$Y_{\parallel}(\phi) \propto A(\phi)(1 - P\Sigma\cos(2(\phi - \phi_{\gamma}^{lin}))$$

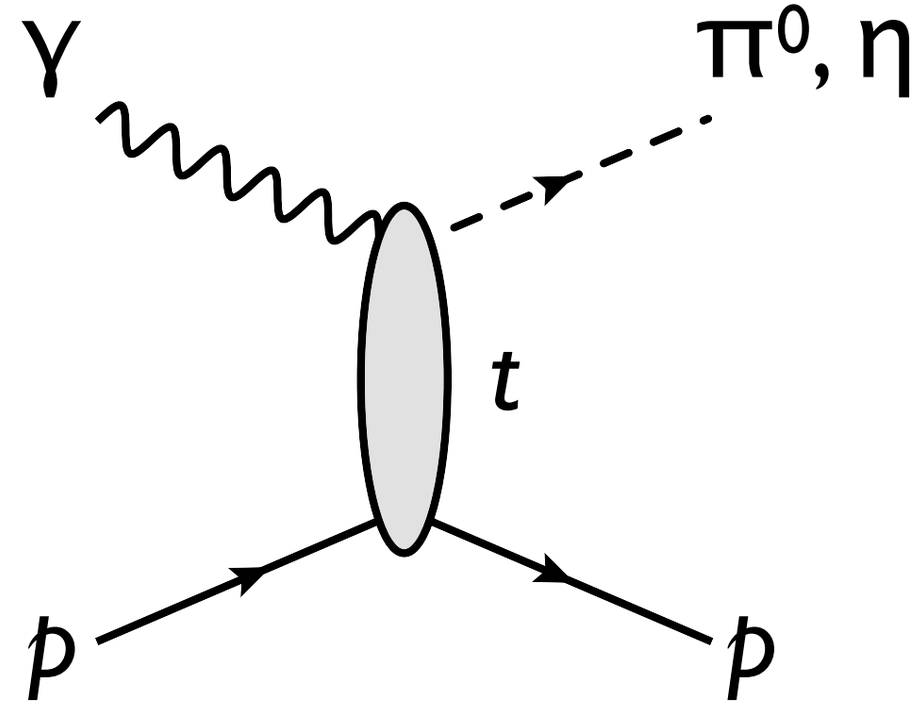


Single Pseudoscalar Production Asymmetry

- Angle between polarization plane and reaction plane is sensitive to parity of exchange

$$\sigma_{pol}(\phi, \phi_\gamma^{lin}) = \sigma_{unpol}\left[1 - P_\gamma \Sigma cos\left(2(\phi - \phi_\gamma^{lin})\right)\right]$$

- Asymmetry Σ can have a *t* dependence
- Constrains *t*-channel backgrounds for *s*-channel baryon resonance production



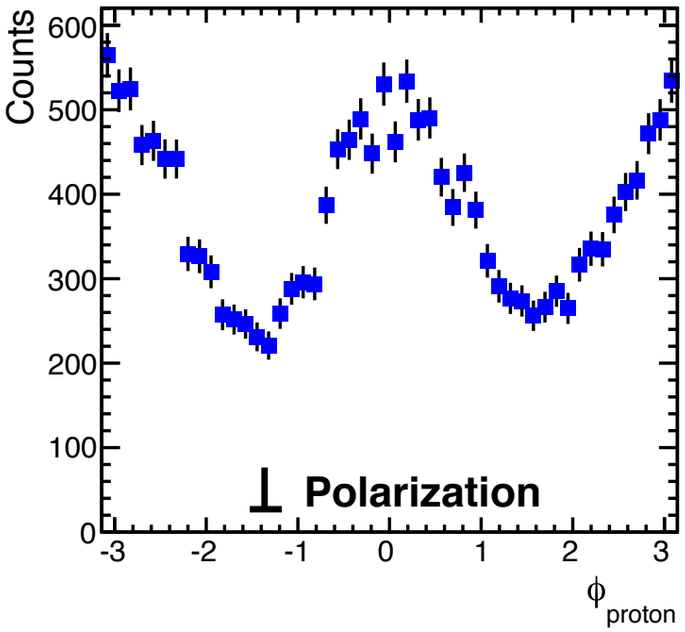
Exchange J^{PC}

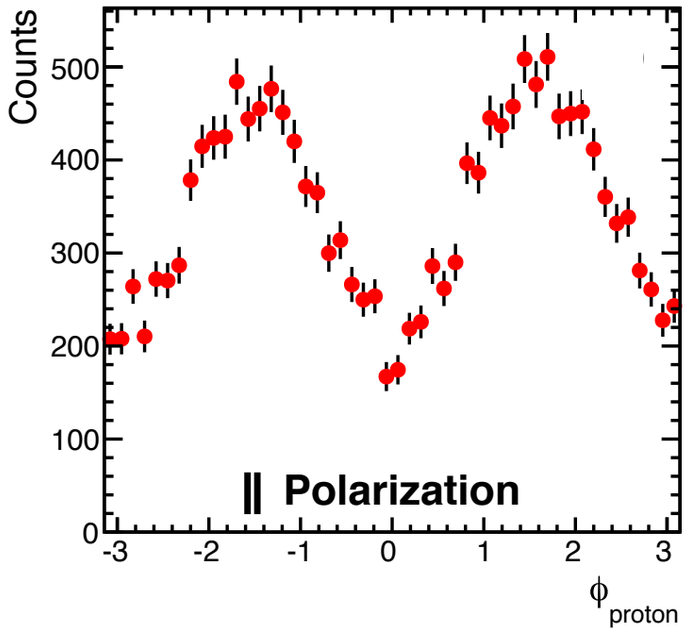
$$1^{--} : \omega, \rho$$

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

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

Asymmetry Measurement





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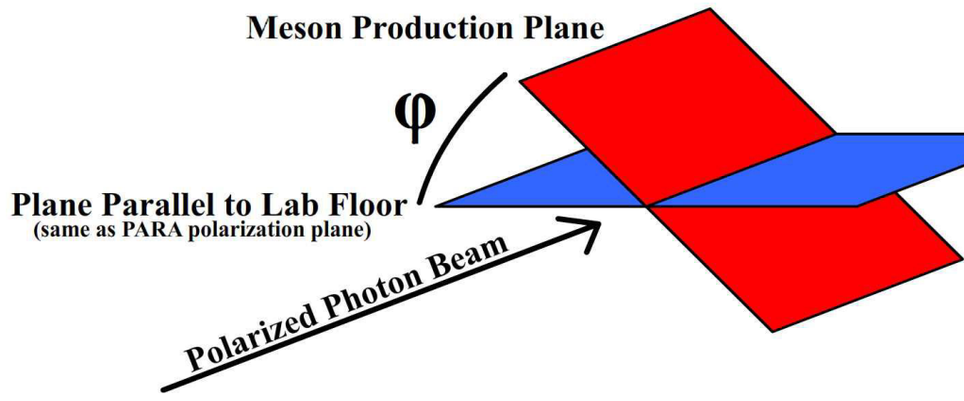
Flux Acceptance

Polarized Yields

$$Y_\parallel(\phi) \sim N_\parallel A(\phi)(1 - P_\parallel \Sigma cos2\phi) \qquad \phi_\gamma^{lin} = 0°$$

$$Y_\perp(\phi) \sim N_\perp A(\phi)(1 + P_\perp \Sigma cos2\phi) \qquad \phi_\gamma^{lin} = 90°$$



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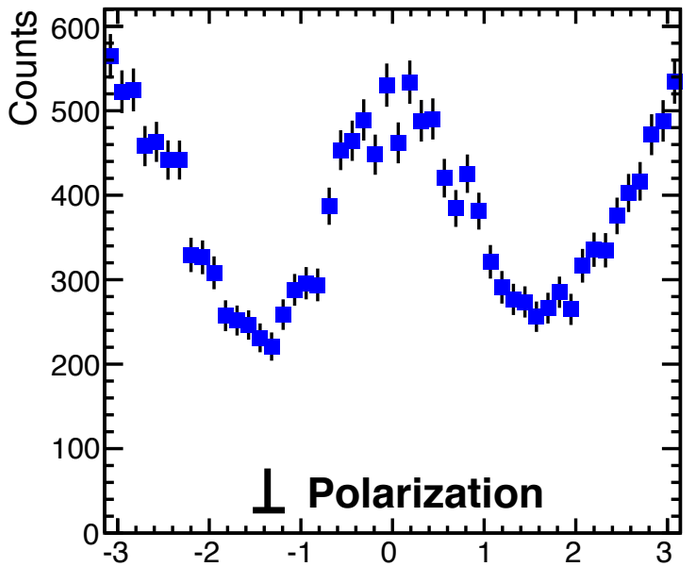

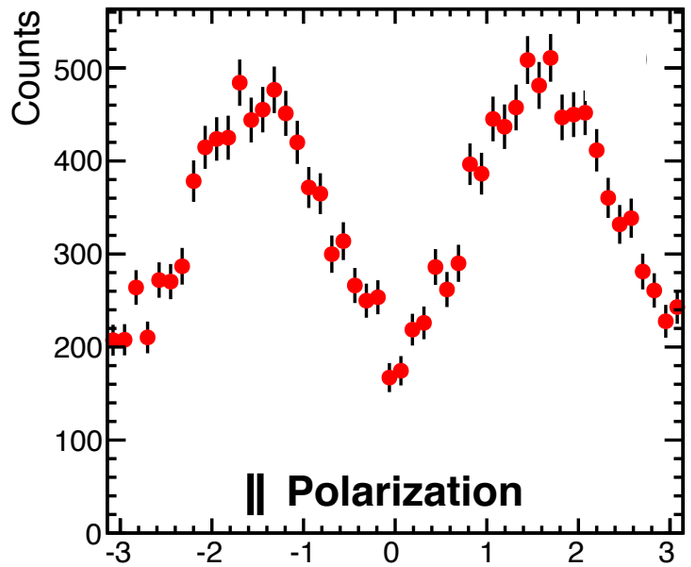

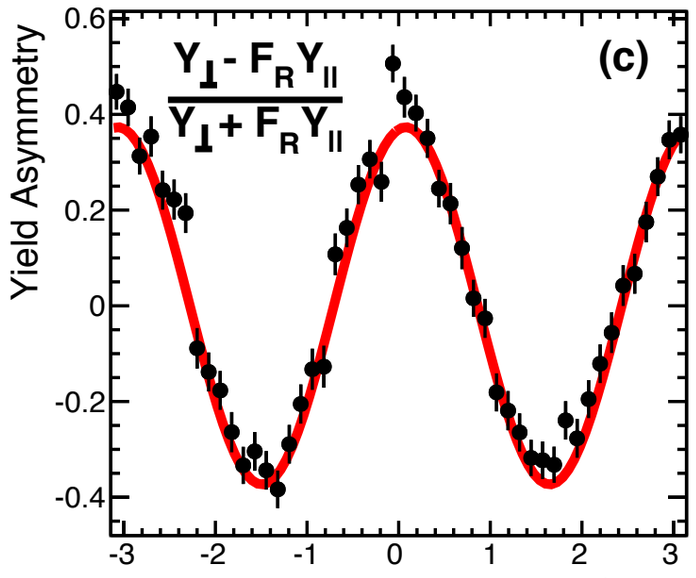

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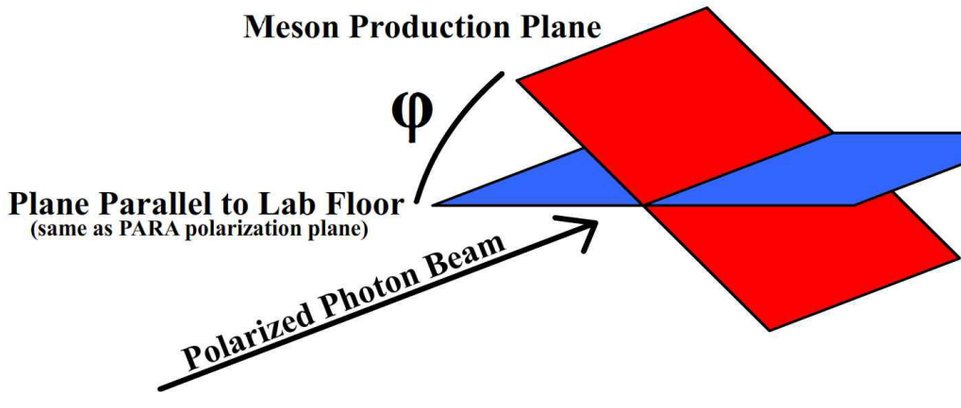
$$F_R = \frac{N_\perp}{N_\parallel}$$



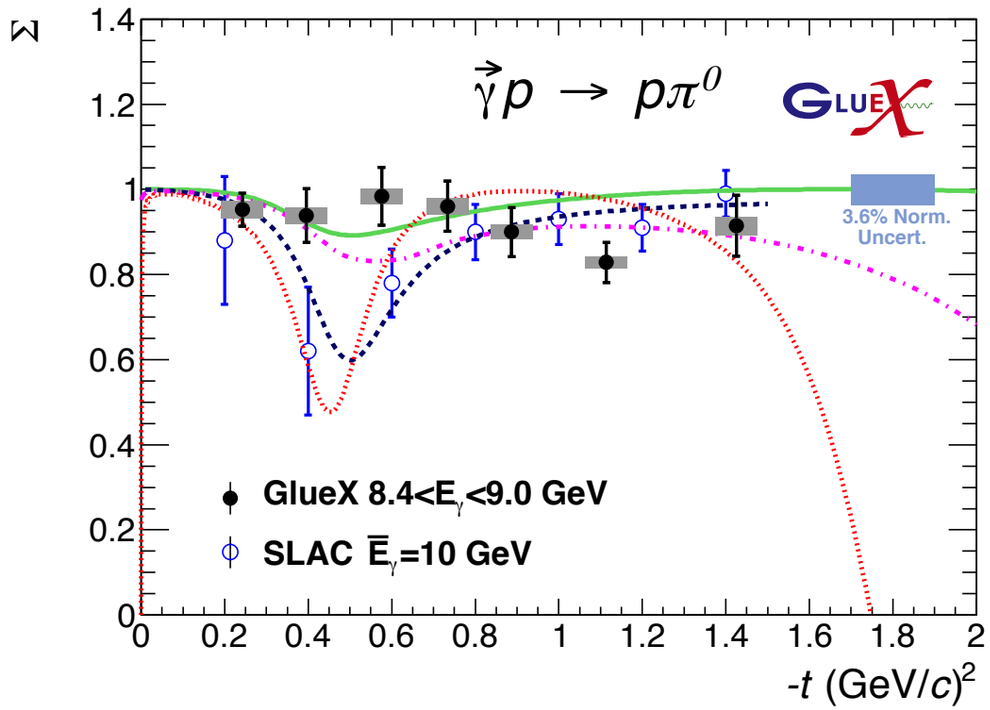
$$\frac{Y_\perp - F_R Y_\parallel}{Y_\perp + F_R Y_\parallel} = \bar{P}\Sigma \cos(2\phi) + \cdots$$

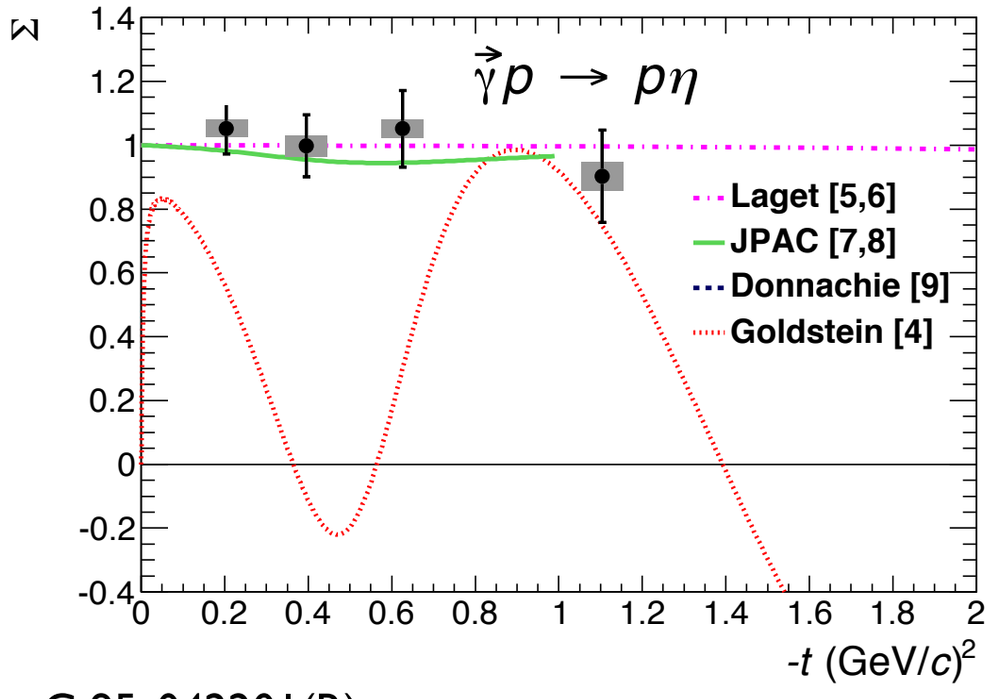
(terms related to differences in beam properties)

physics of production process is encoded here

Single Pseudoscalar Production Asymmetry

- Correlated uncertainty due to polarization: < 5%
- GlueX π^0 production asymmetry
  - more precise than SLAC
  - no dip around t = 0.5 (GeV/c)^2
- First measurements of η production asymmetry
- A test of high energy t-channel production models
- *Similar production mechanism expected for exotics*

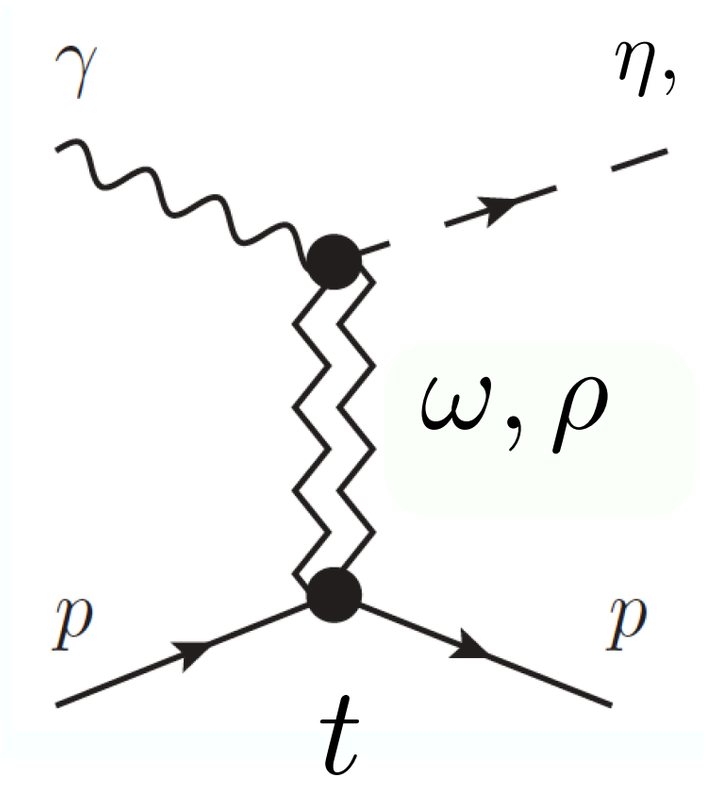




GlueX Collaboration, Phys. Rev. C 95, 042201(R)

Photoproduction of η and η'

- Expect: $\frac{\Sigma_\eta}{\Sigma_{\eta'}} \approx 1$
  - V. Mathieu et al. [*JPAC*], PLB 774, 362 (2017)
- Verifies our understanding of structure of η and η' and production dynamics



contribution from Φ or h?

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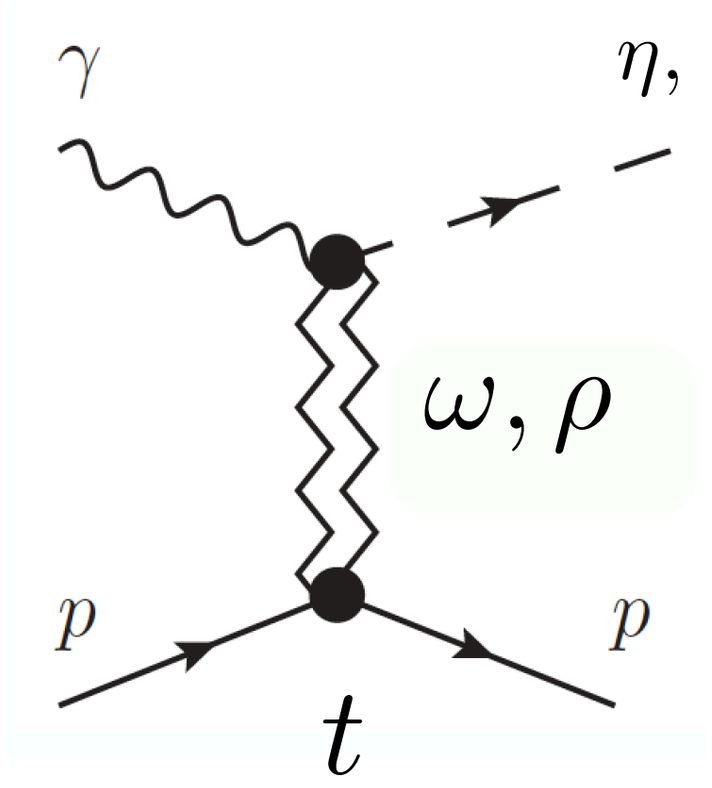

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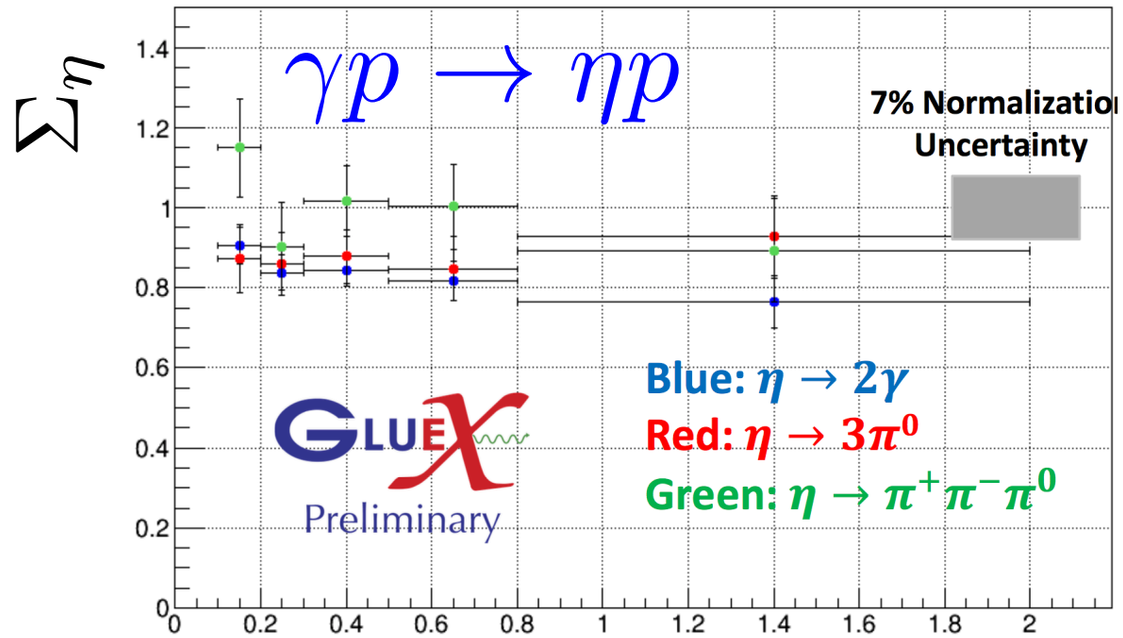
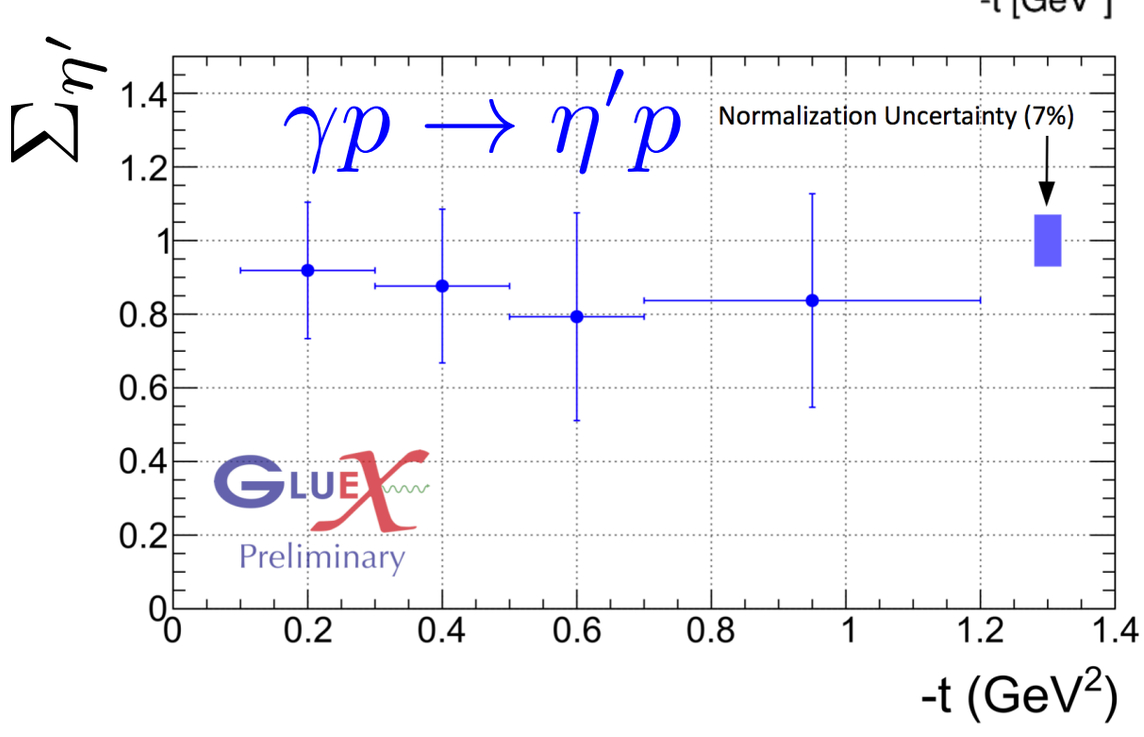
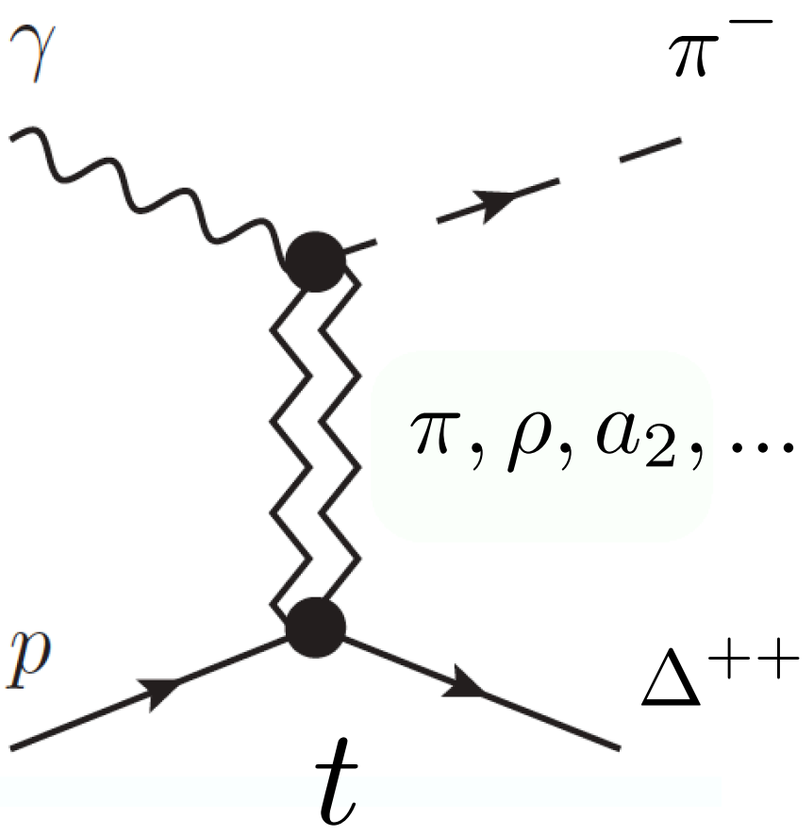
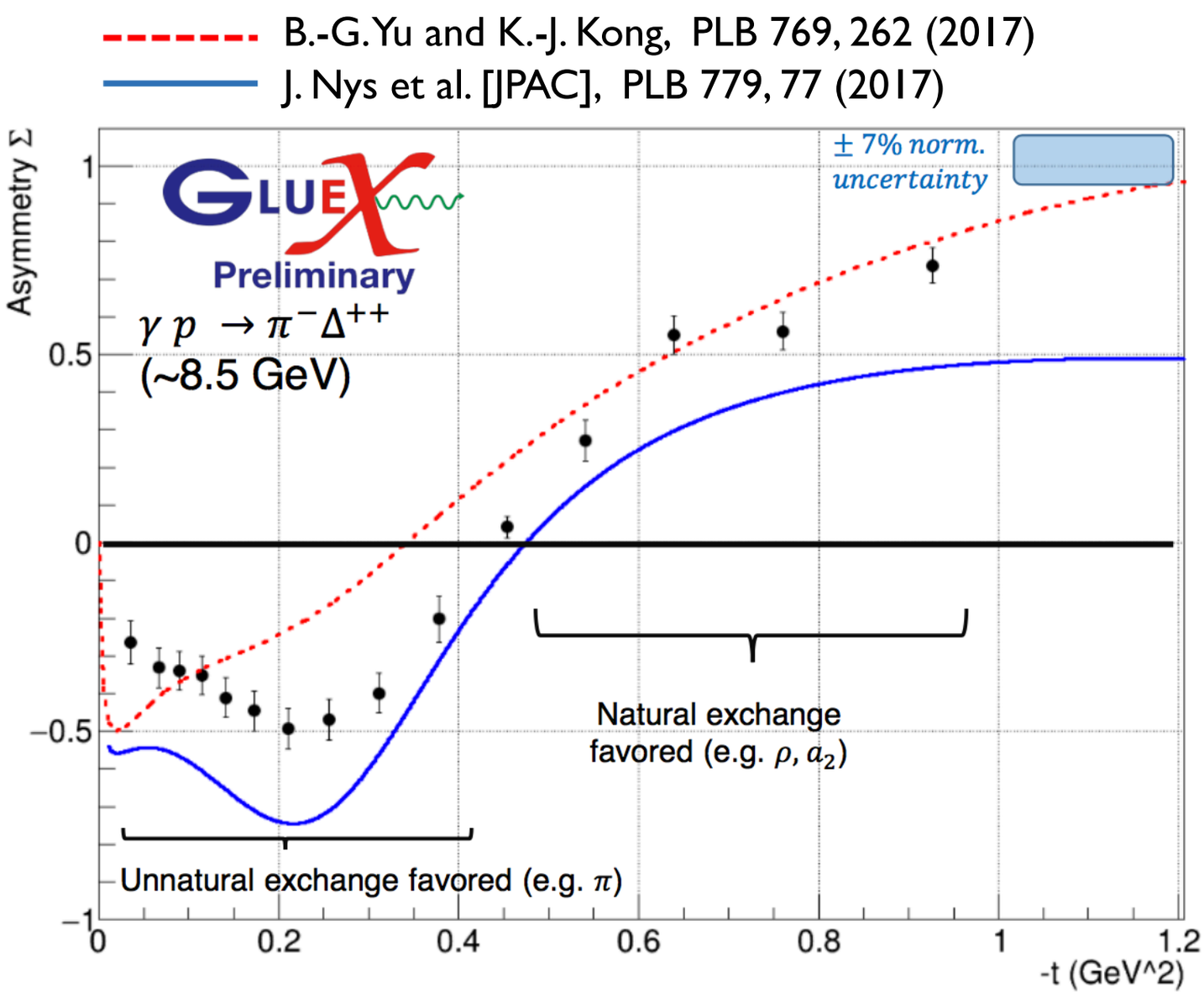




Photoproduction of π^-

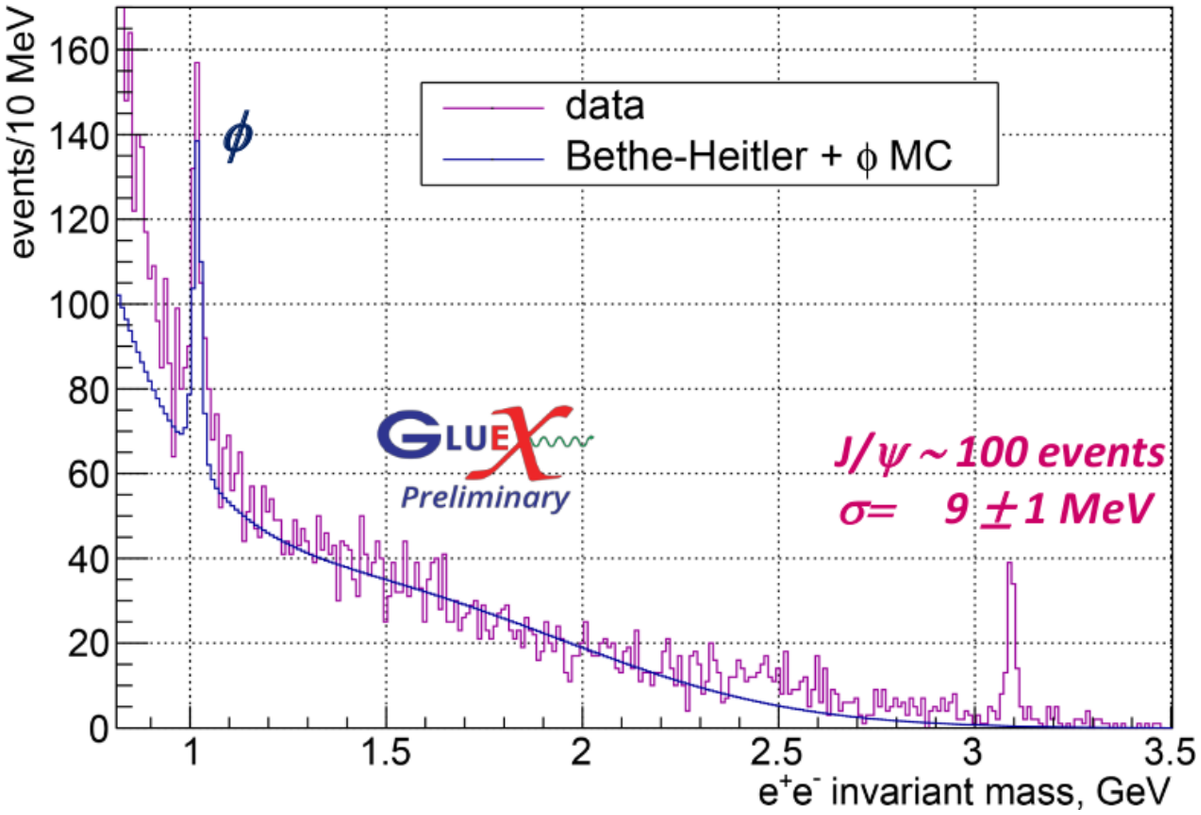
- Charge exchange process
- Dominated by π exchange at low t

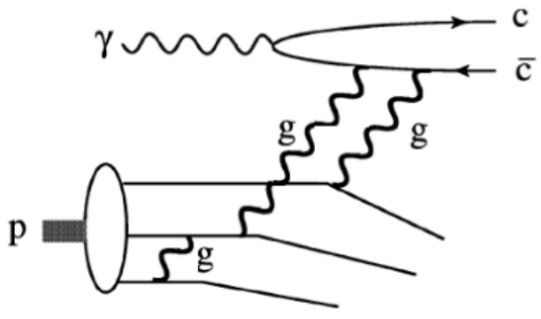


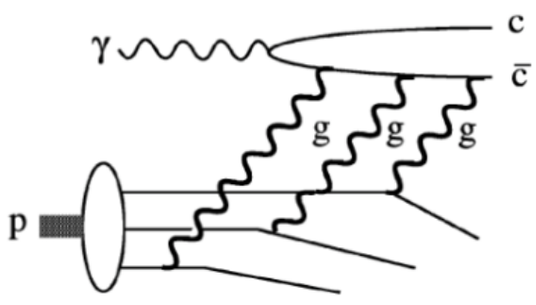


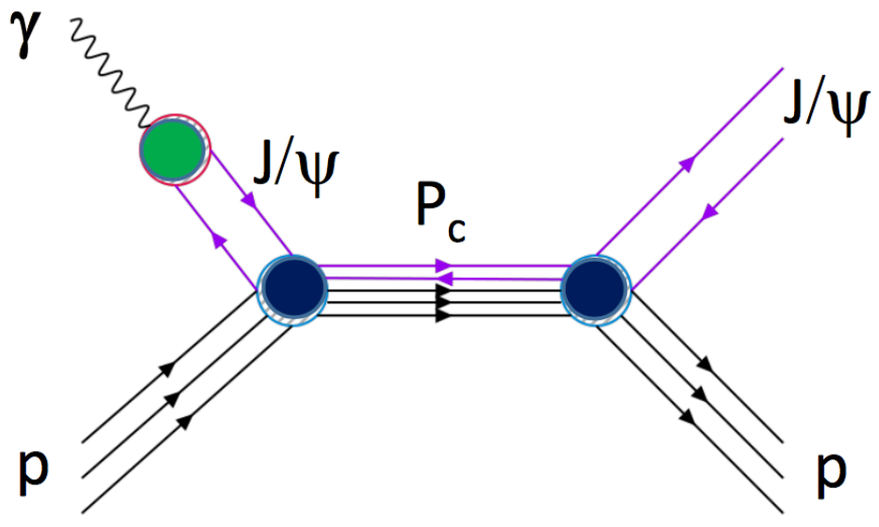
$\gamma p \rightarrow J/\psi p$

- Physics objectives:
  - production dynamics encoded in the shape of cross section at threshold
  - s-channel production of pentaquark candidates observed by LHCb



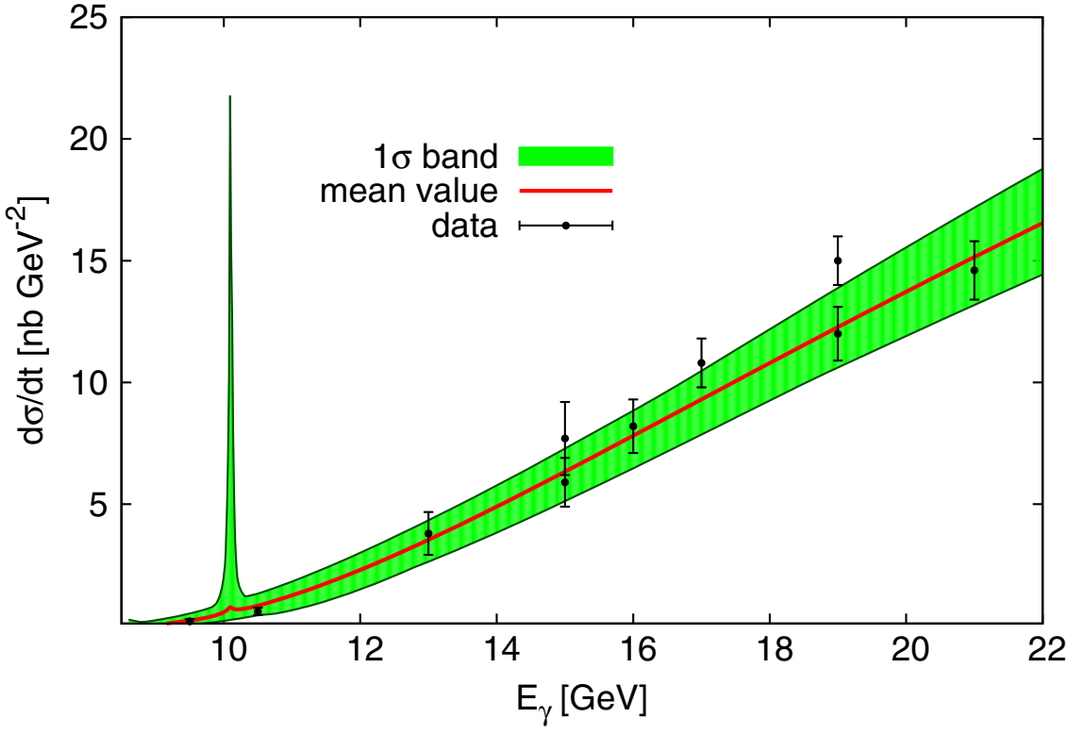






$\gamma p \rightarrow J/\psi p$ Cross Section

- Preliminary results from GlueX:
  - sensitivity to shape at threshold
  - ability to set limits on P_c production
- Compare with P_c production predictions
  - M. Karliner and J.L. Rosner, PLB 752, 329 (2016)
  - A. Blin et al. [JPAC], PRD 94 034002 (2016)



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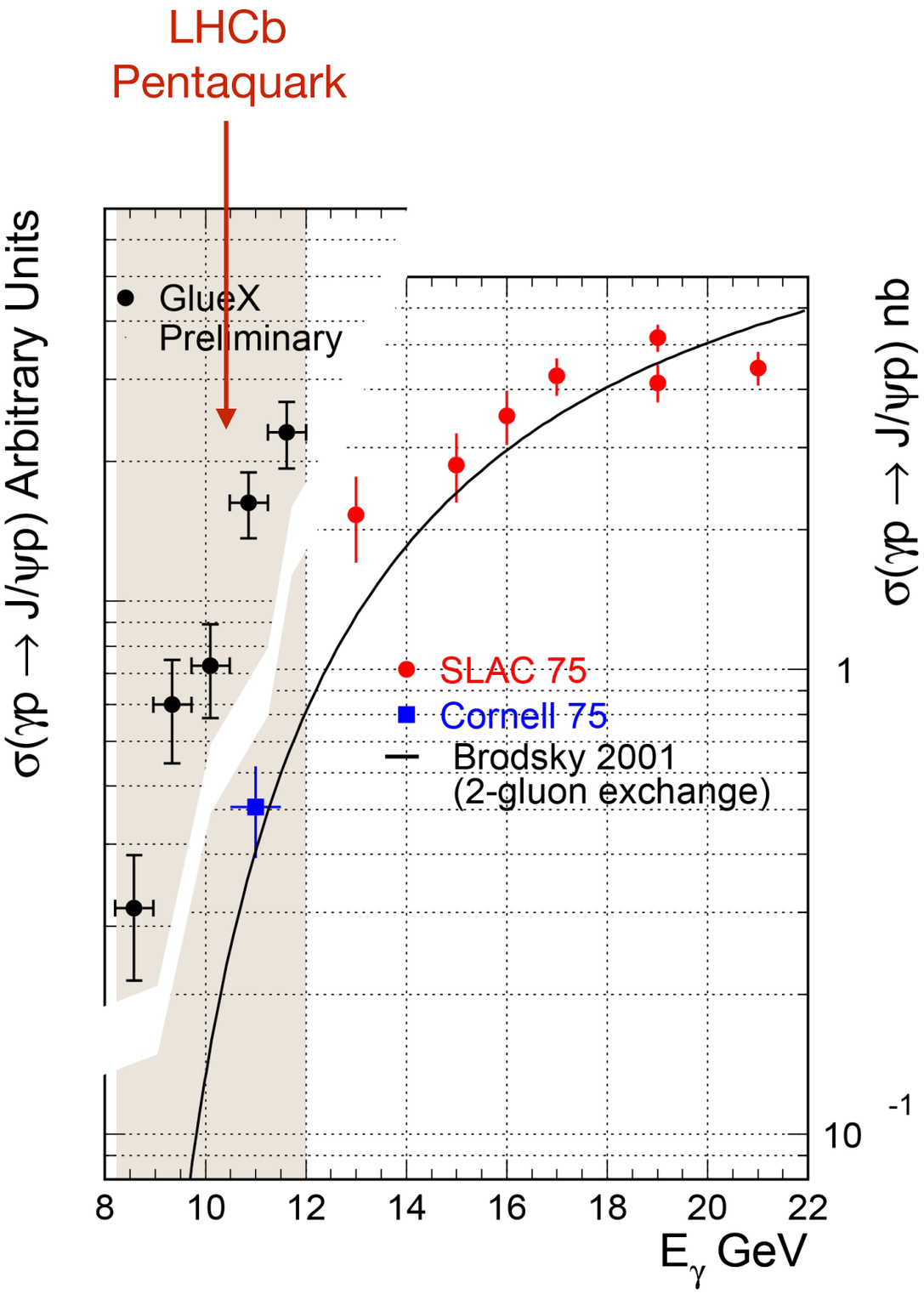
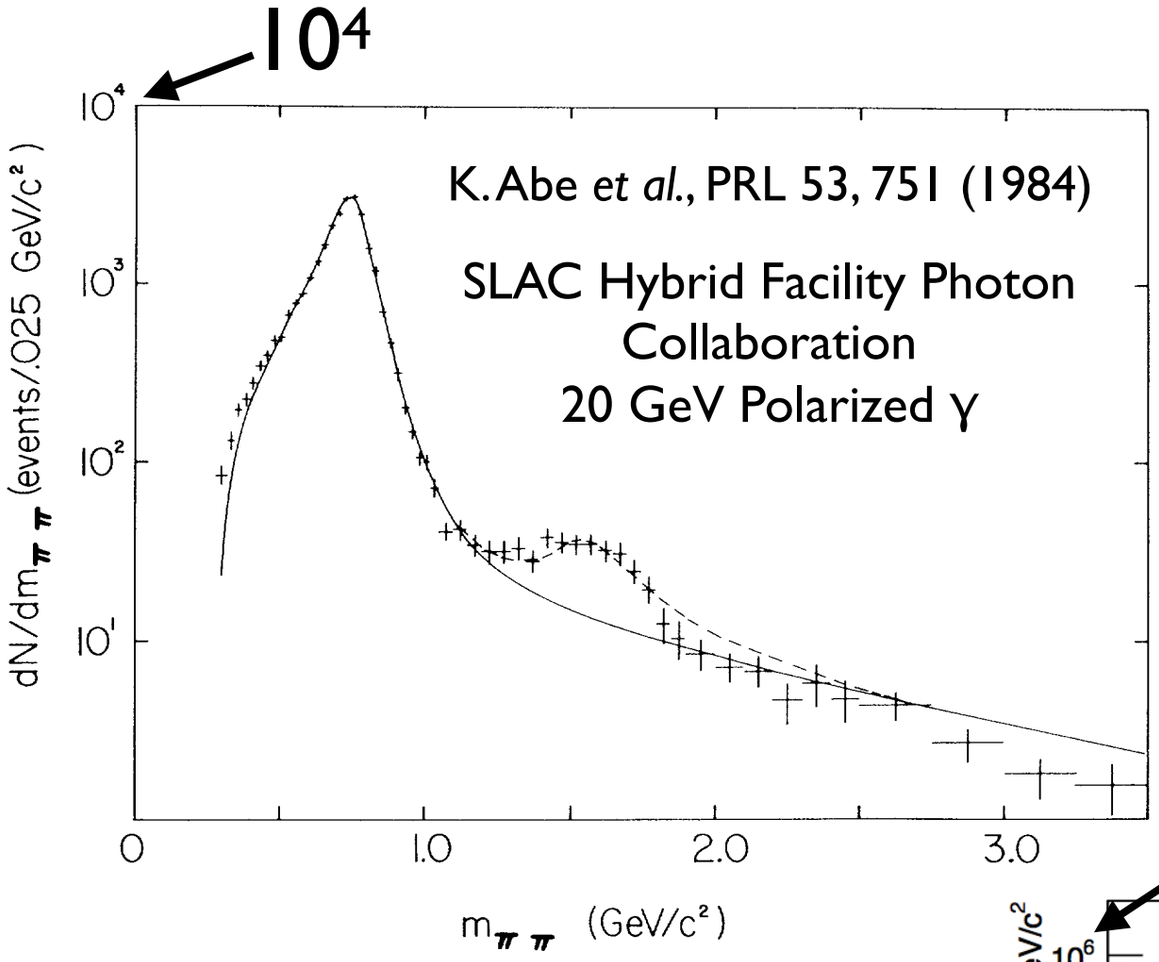
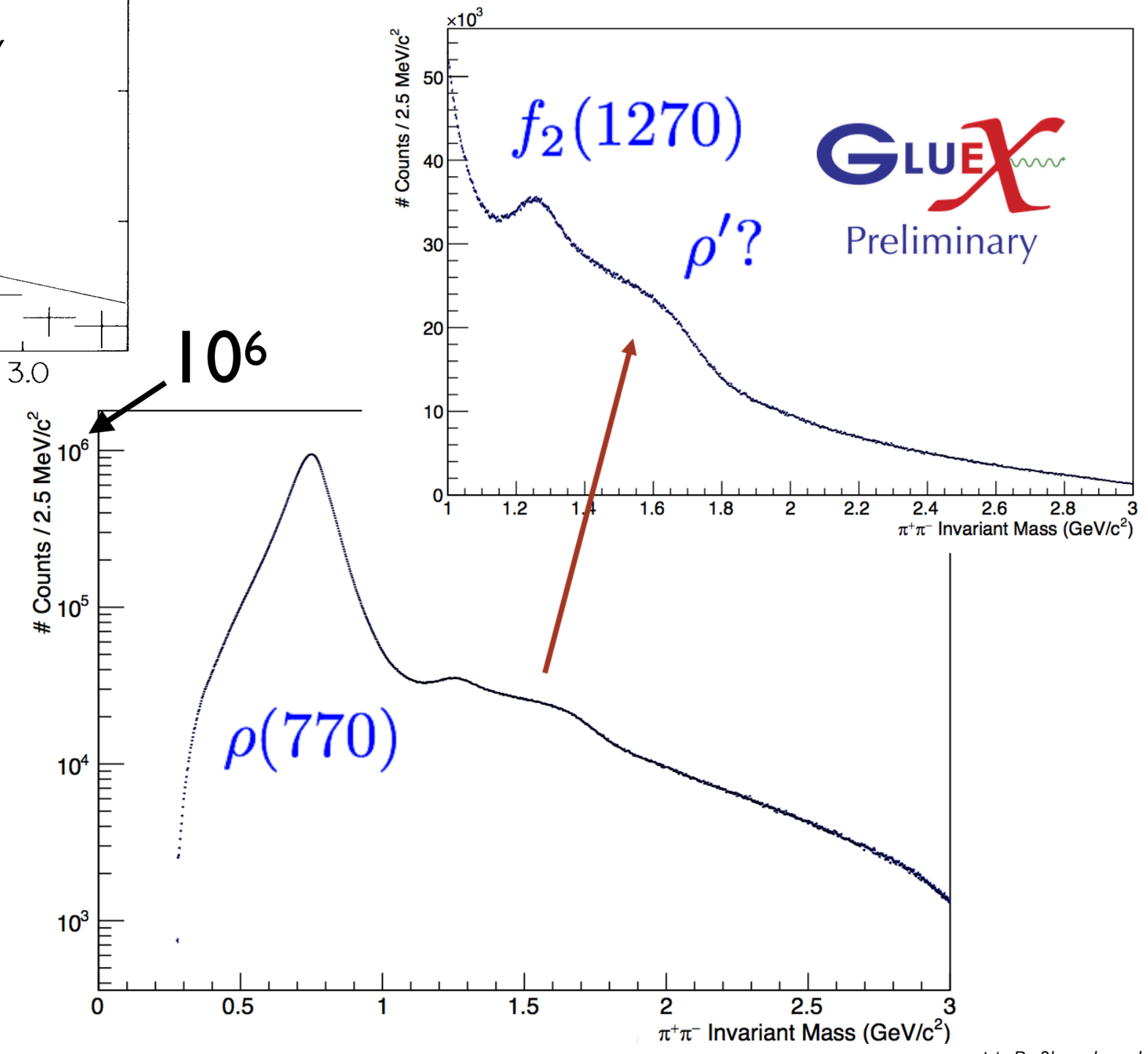


GlueX Intensity





- GlueX is well-positioned to make new discoveries
  - example: 3+ orders of magnitude over previous in πππ channel
- GlueX future: about 10x more data and enhanced sensitivity to final states with strange quarks (mesons and baryons)

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  - bumps in an invariant mass spectrum
  - intensity and phase difference for a various J^{PC} values
  - product of production cross section and branching fraction
  - production features: asymmetry, spin density matrix elements, …

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  - intensity and phase difference for a various J^{PC} values
  - product of production cross section and branching fraction
  - production features: asymmetry, spin density matrix elements, …
- *What input is needed from theory?*
  - how to establish existence of resonances and resonance parameters from bumps, intensities, and phase differences
  - comparative information is perhaps more useful and easier to calculate:
    - hybrid masses relative to known states: number, hierarchy, degeneracies
    - comparative information about total width
    - partial widths of specific decays compared to known states
    - production mechanisms when compared with known states

Summary

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  - most activity in the heavy quark sector
- GlueX is well positioned to carry this momentum into the future
  - unique opportunity to study of the light quark meson spectrum in photoproduction
  - large existing data set: some preliminary results already; well-positioned to launch core spectroscopy program
  - theory input is absolutely essential in order to realize the goals of the experiment