Recent Results from the Gluonic eXcitation Experiment (GlueX) at JLab

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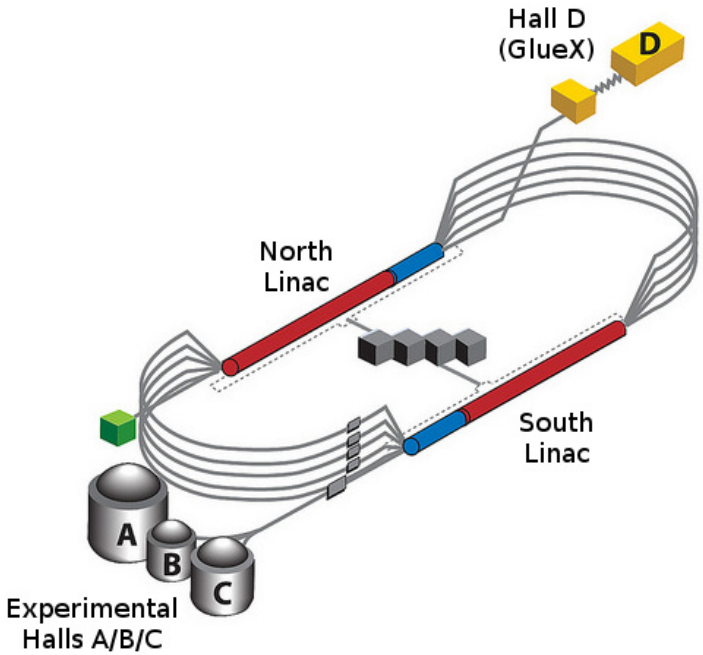
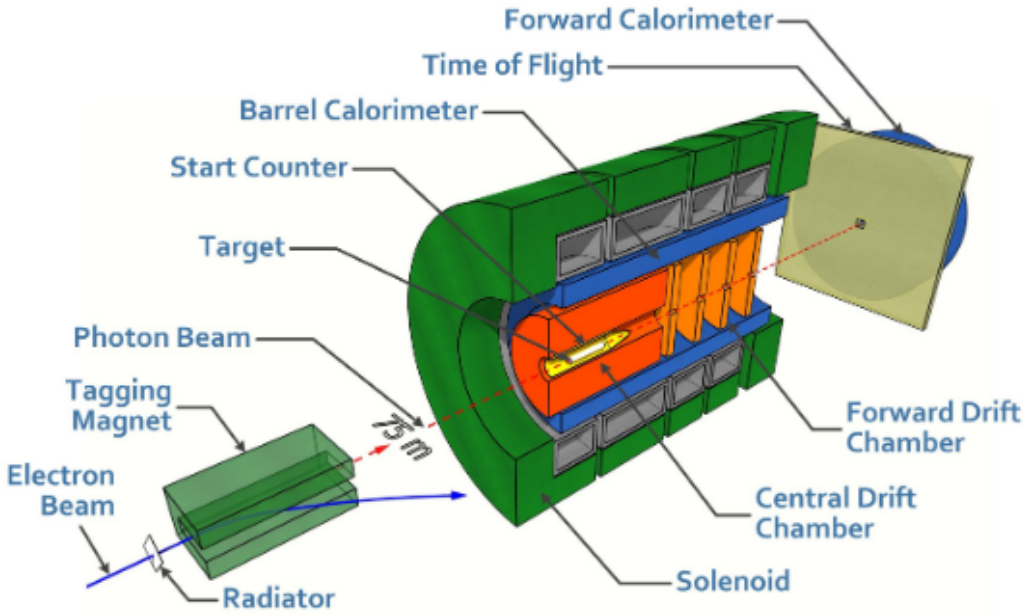
(For the GlueX Collaboration)

Florida State University

05.09.2021

The **Gl**uonic **eX**citations (**GlueX**) Experiment at Jefferson Lab



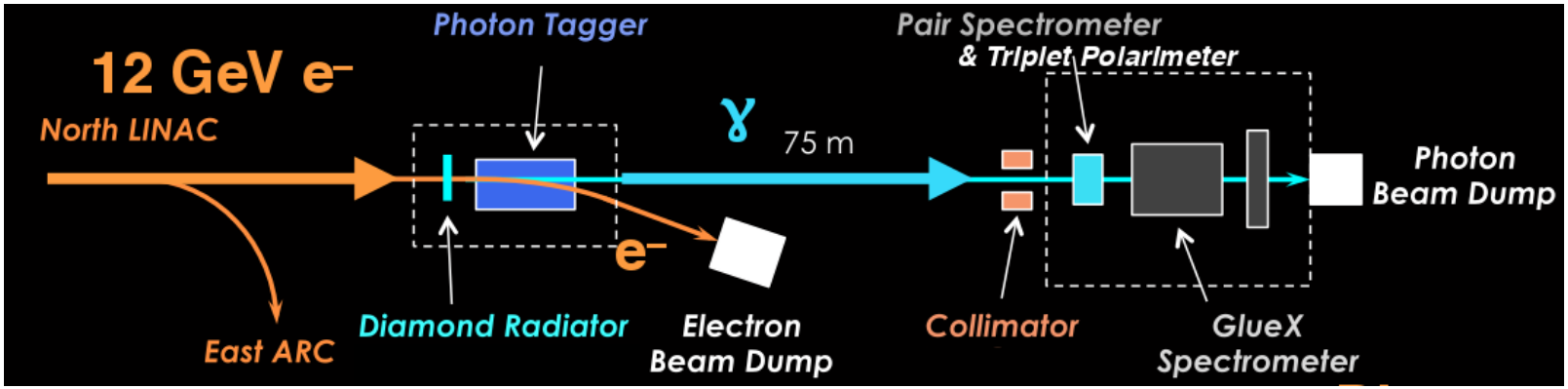


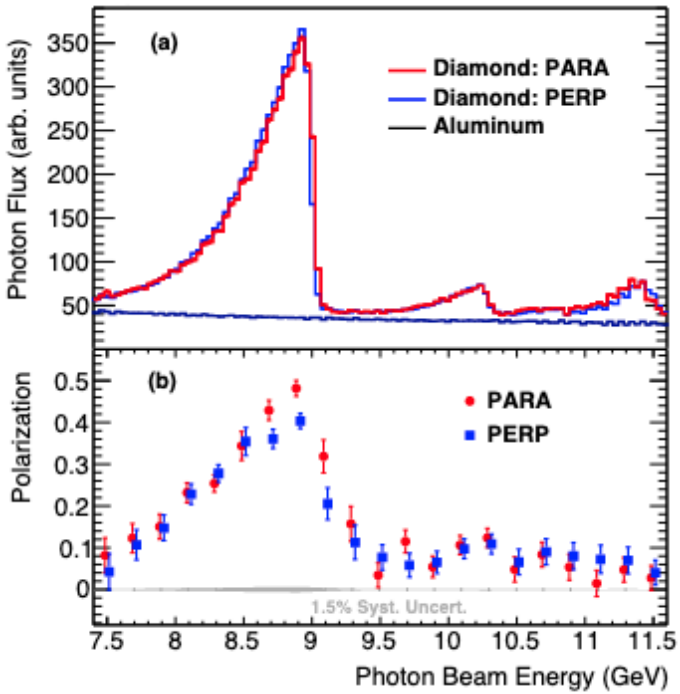
Experimental Hall D:

- Over 130 scientists from:
  - 30 Institutions
  - 10 Countries
- Experiments with polarized photon beam

Phase	GlueX-I	GlueX-II
Run Period	2017-2018	(2020 -)
Raw Data [PB]	4	> 5
Luminosity $[pb^{-1}]$	300	$\sim 3\times$ GlueX-I

Physics with polarized Photon Beams





- 12 GeV electron beam on diamond radiator
- Tagged photon beam with $\sigma(E)/E \sim 1\%$
- Coherent peak*:

E_γ	8.4 GeV - 9.0 GeV
Average polarization	$\sim 35\%$
Trigger rate	~ 40 kHz

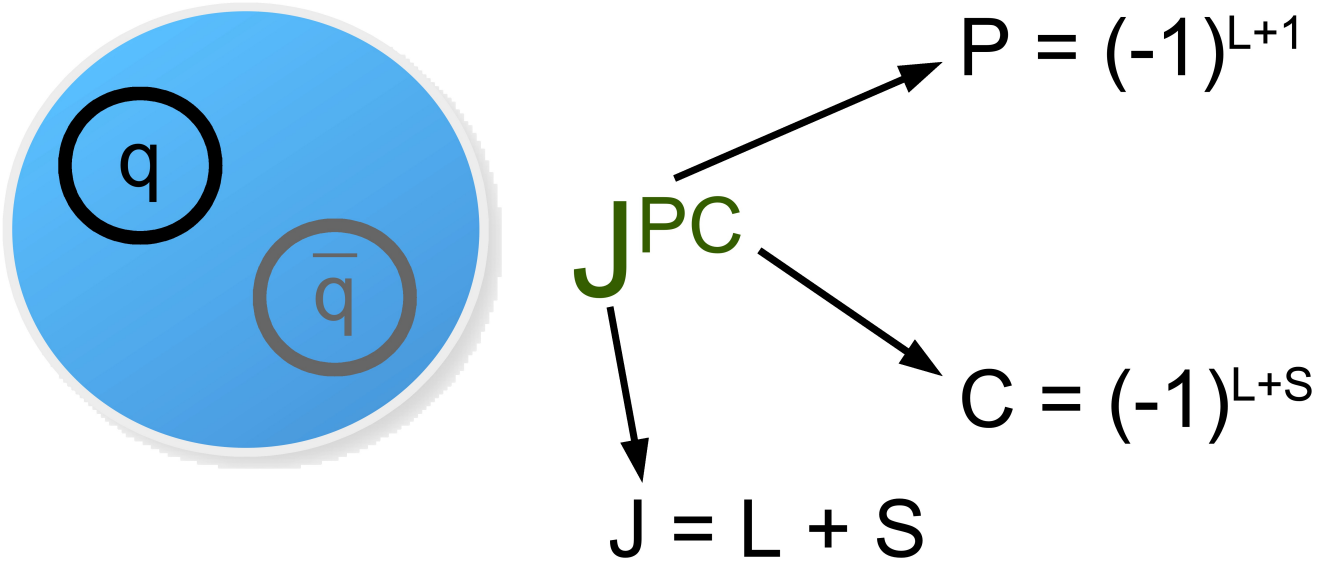
* "The GlueX Beamline Detector"
NIM A987, 164807 (2021)

Two Quark Configurations - Mesons

- Characterize $q\bar{q}$-states:

  Spin: $S = \frac{1}{2} \pm \frac{1}{2} = 0, 1$

  Orbital angular momentum: $L = 0, 1, 2, \cdots$



- Mesons $\Leftrightarrow$ J^{PC} nonets

	$L = 0$	$L = 1$	$L = 2$
$S = 0$	0^{-+}	1^{+-}	2^{-+}
$S = 1$	1^{--}	$0^{++}, 1^{++}, 2^{++}$	$1^{--}, 2^{--}, 3^{--}$

- Forbidden J^{PC}-states $\Rightarrow$ Exotic quantum numbers: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$

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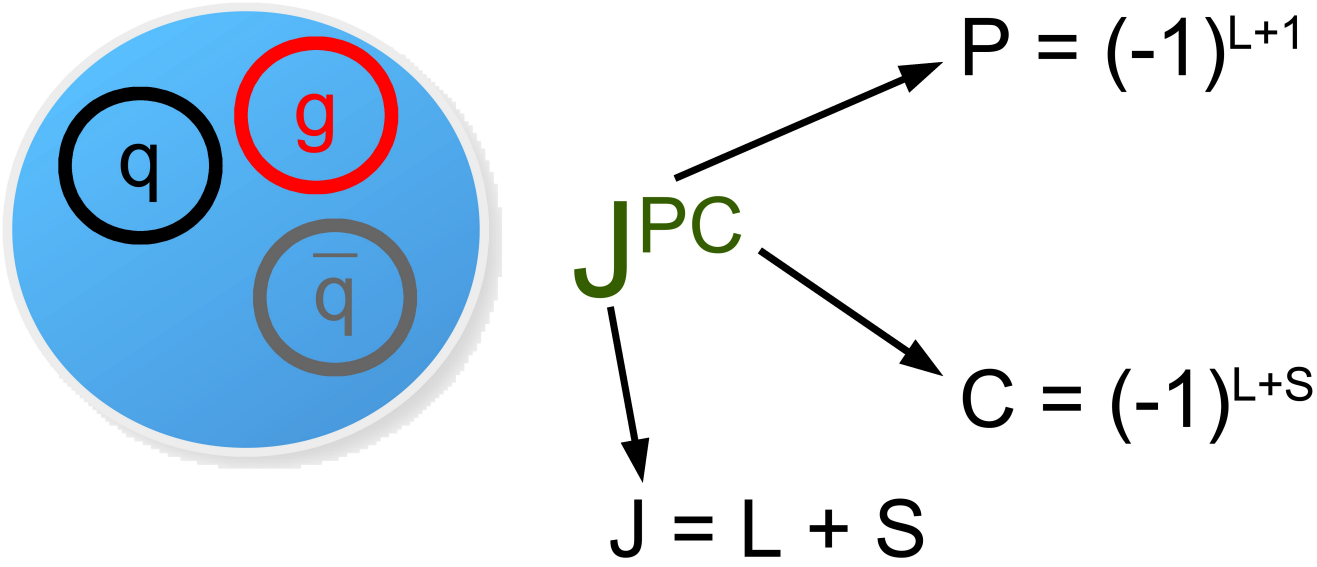

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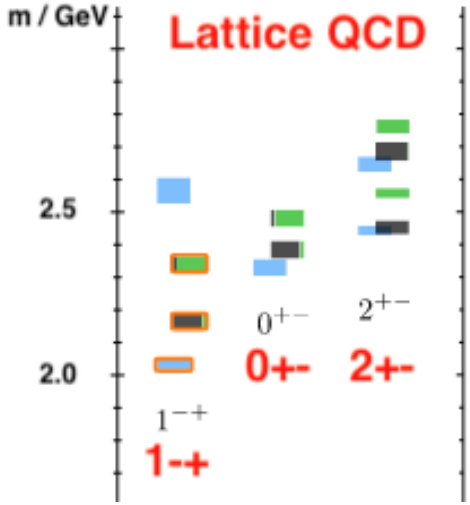
- Forbidden J^{PC}-states $\Rightarrow$ Exotic quantum numbers: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$
  $\Rightarrow$ Hybrid Mesons

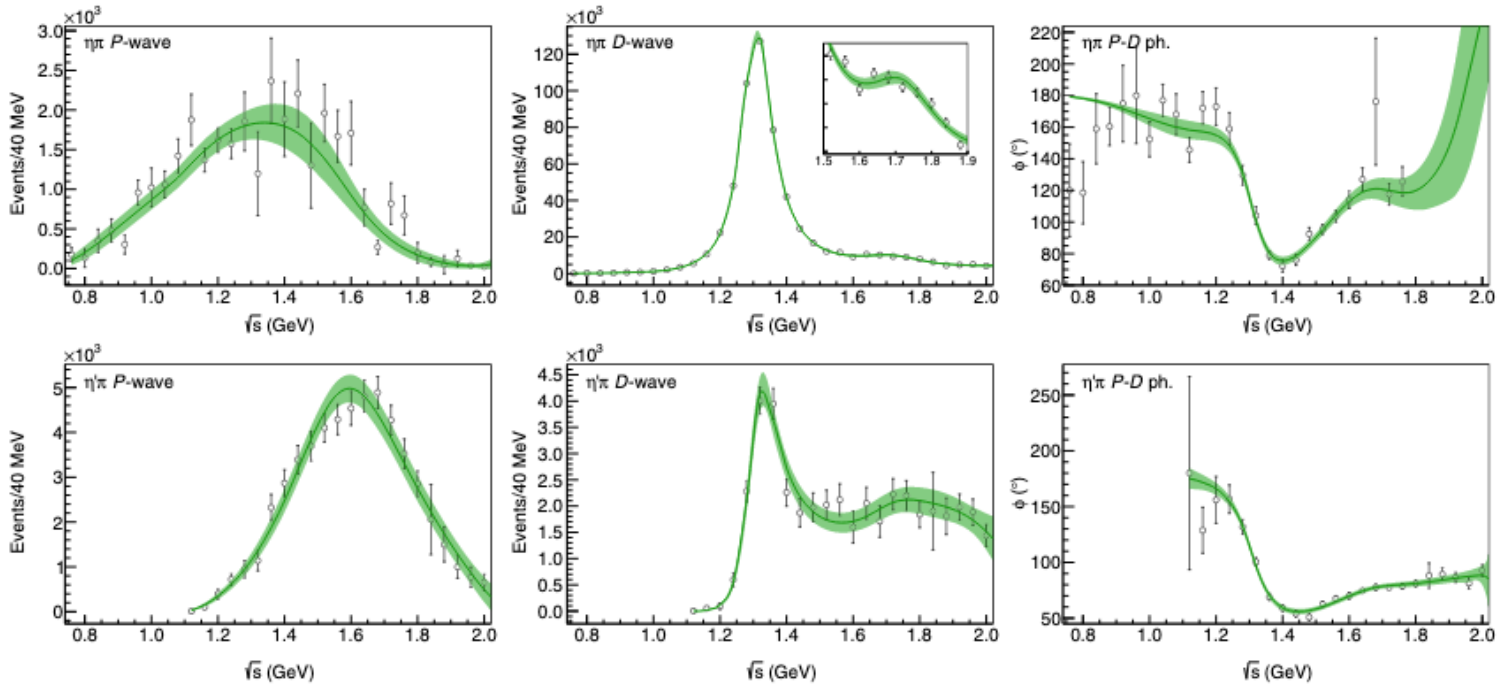
Exotic $J^{PC} = 1^{-+}$ States

- Experimental evidence:

$$\pi_1(1600) \rightarrow \begin{cases} \pi\pi\pi \\ \rho^0\pi^- \\ b_1(1235)\pi \\ \eta'\pi^- \\ f_1(1285)\pi \end{cases}$$



- Input from Lattice QCD
  hadspec coll. Phys. Rev. D 88, 094505 (2013)
- Fit of COMPASS PWA $\eta^{(\prime)}\pi$-data by JPAC **(Phys. Rev. Lett. 122, 042002)**



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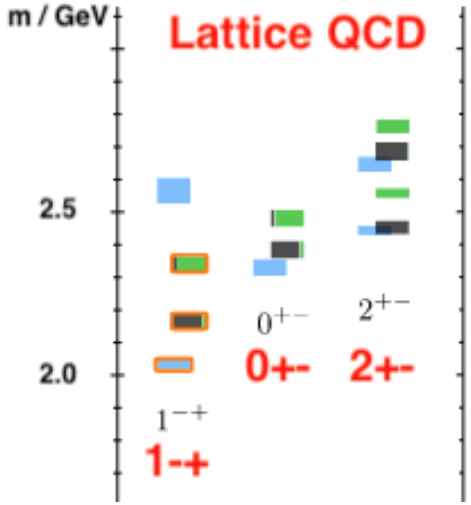

- Input from Lattice QCD
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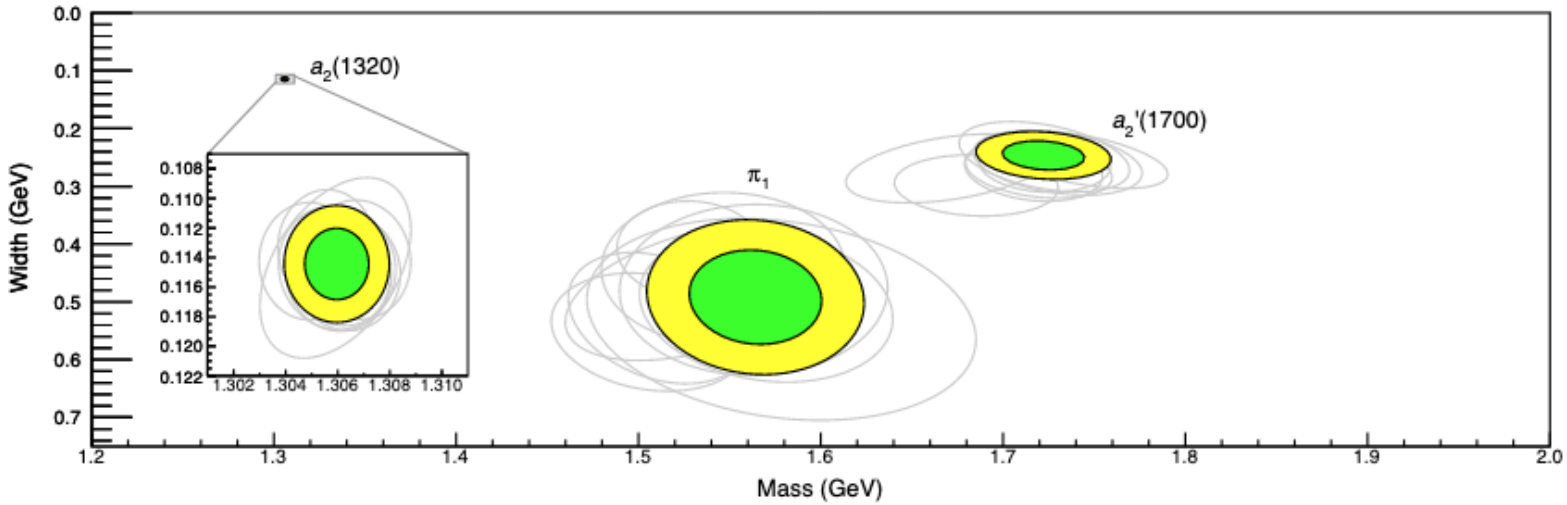
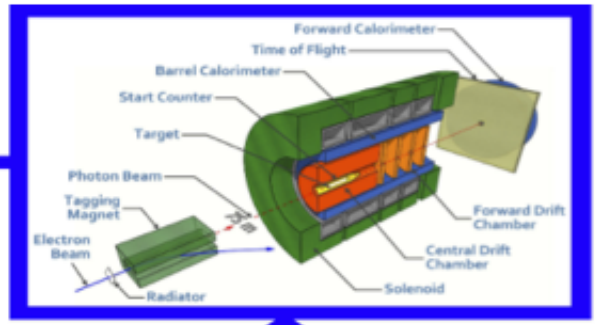
- Fit of COMPASS PWA $\eta^{(\prime)}\pi$-data by JPAC **(Phys. Rev. Lett. 122, 042002)**
  $\Rightarrow$ Exotic π_1 resonant pole: mass $= (1546 \pm 24 \pm 86)\,\mathrm{MeV}$
  and width $= 492 \pm 54 \pm 102$



Exotic Search with GlueX

Opportunistic measurements & new ideas



collect data

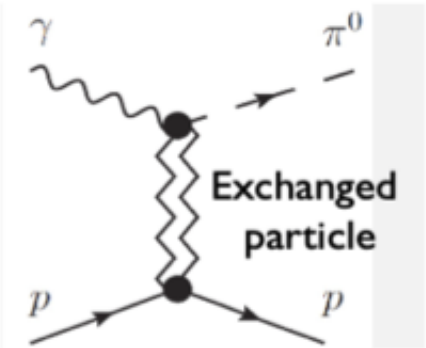
Charmonium production

beam asymmetries,
SDMEs,
Cross sections,...

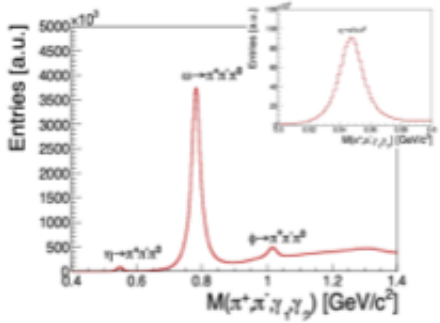
detector acceptance,
event reconstruction,..

Understand production mechanisms

Identify known mesons / meson decays



Amplitude Analysis

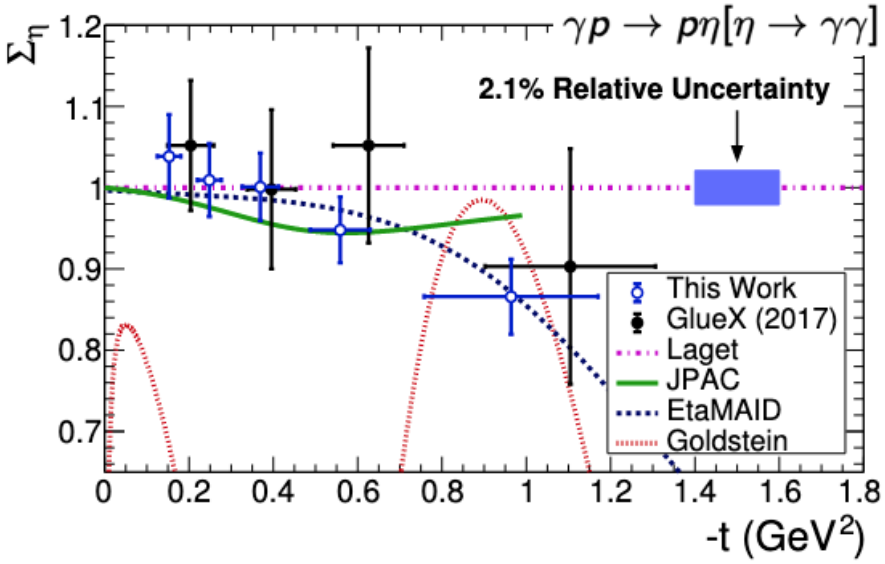


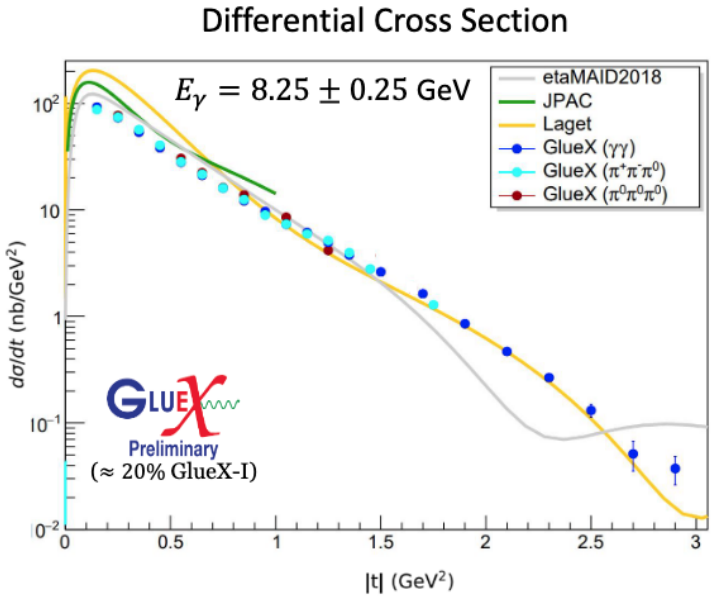
Physics with light meson decays

reproduce existing results,
develop / test software,...

Search for exotics

Photoproduction of η Mesons





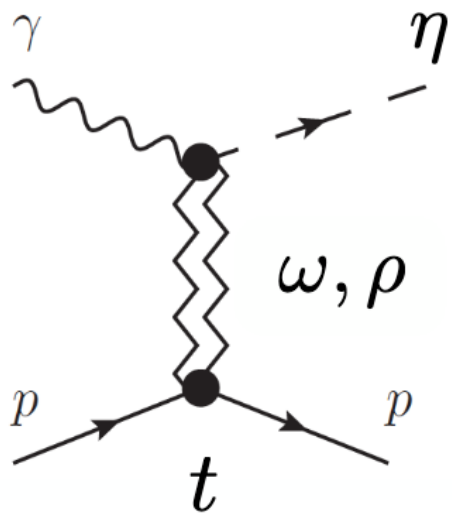
- Determine beam asymmetry* $\Sigma = \frac{\sigma_{\parallel} - \sigma_{\perp}}{\sigma_{\parallel} + \sigma_{\perp}}$

  * **Phys. Rev. C100, 052201(R) (2019)**

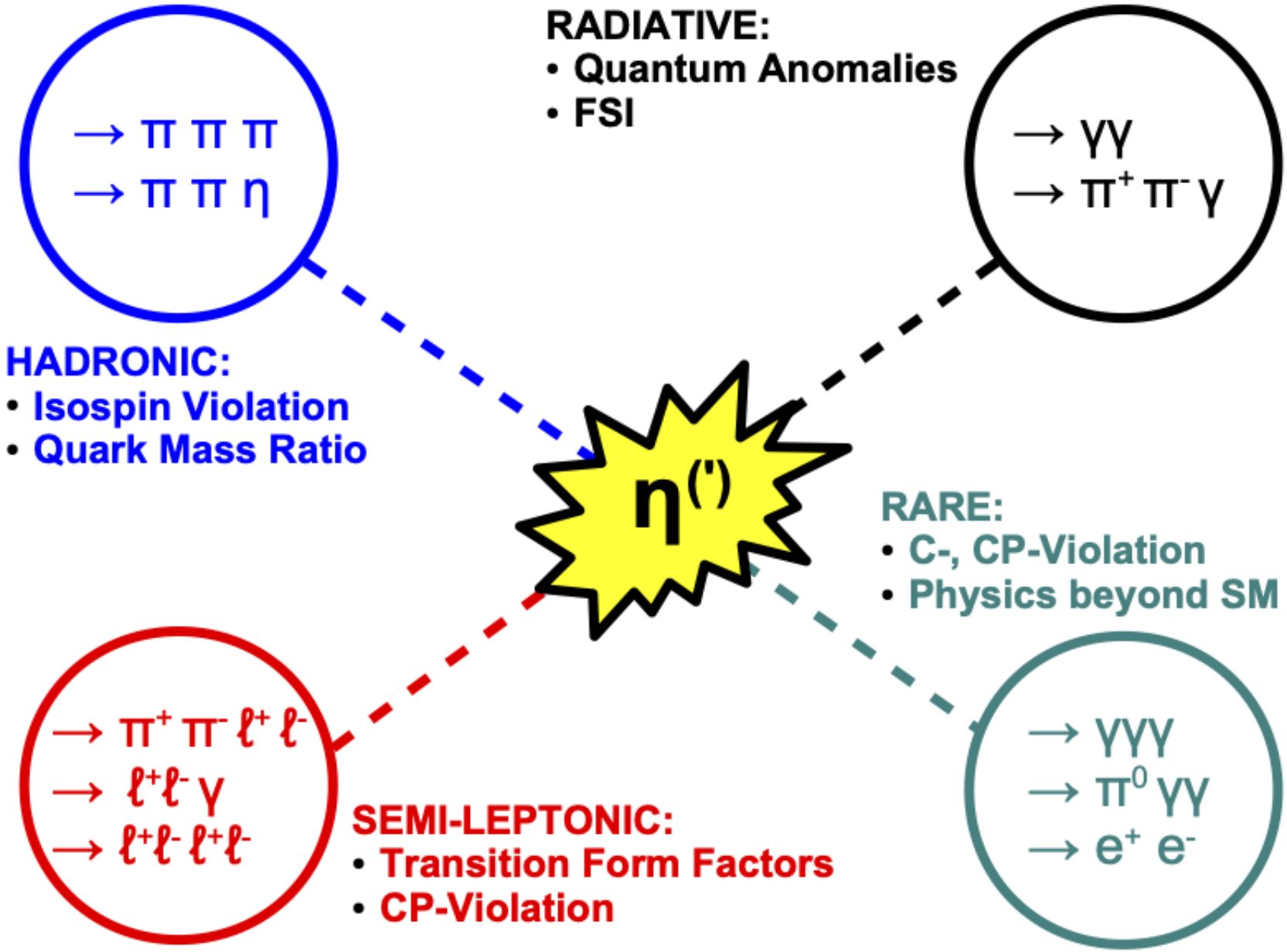
- **η Production mechanism:**
  via ρ and ω exchange

- Consistent observation with cross-section measurement
  - Compare different η-decay modes
  - Understand detector acceptance

- Determined beam asymmetry for η'
  $\rightarrow$ same production mechanism



$\eta/\eta^{(\prime)}$ Decays



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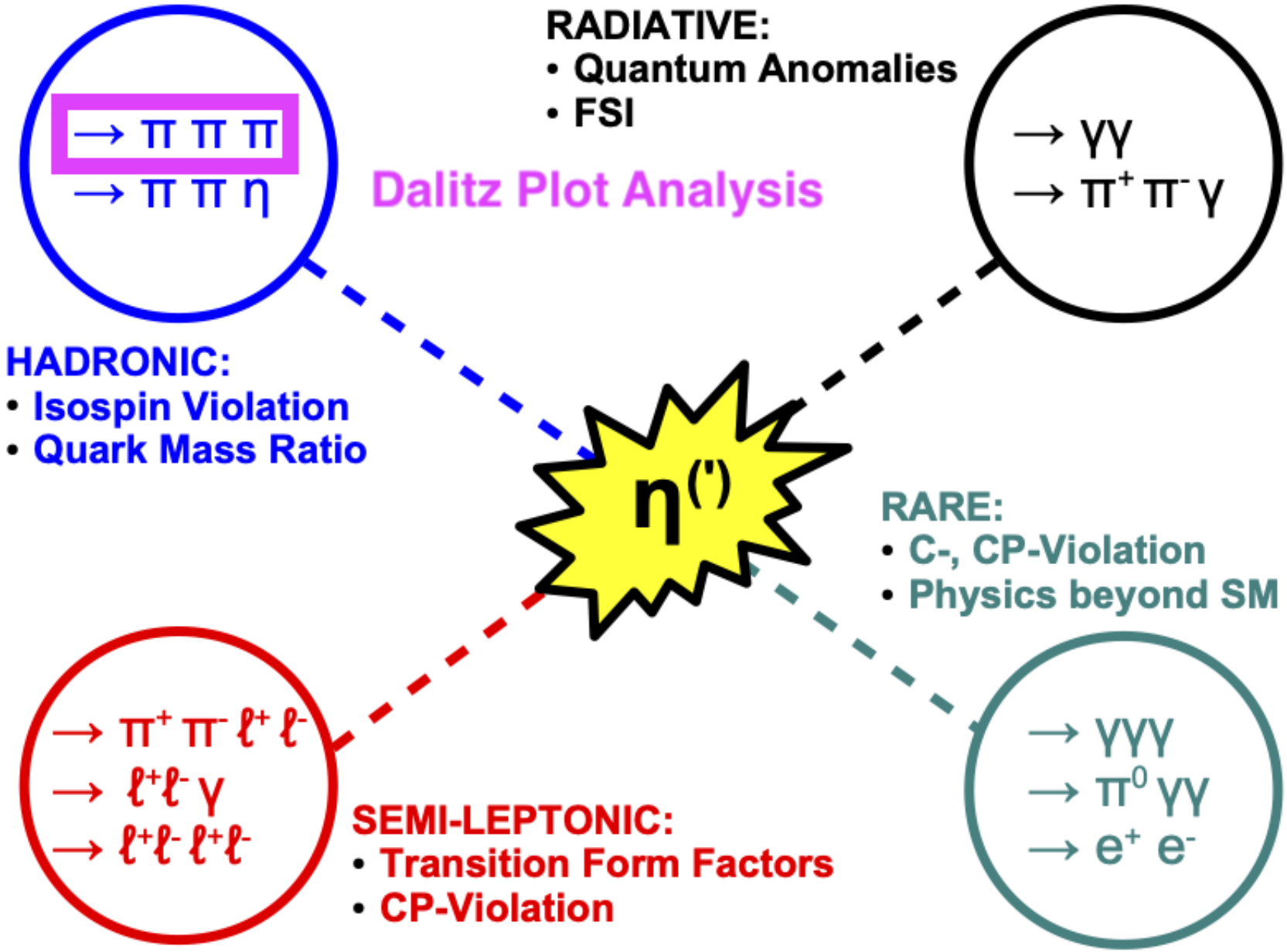

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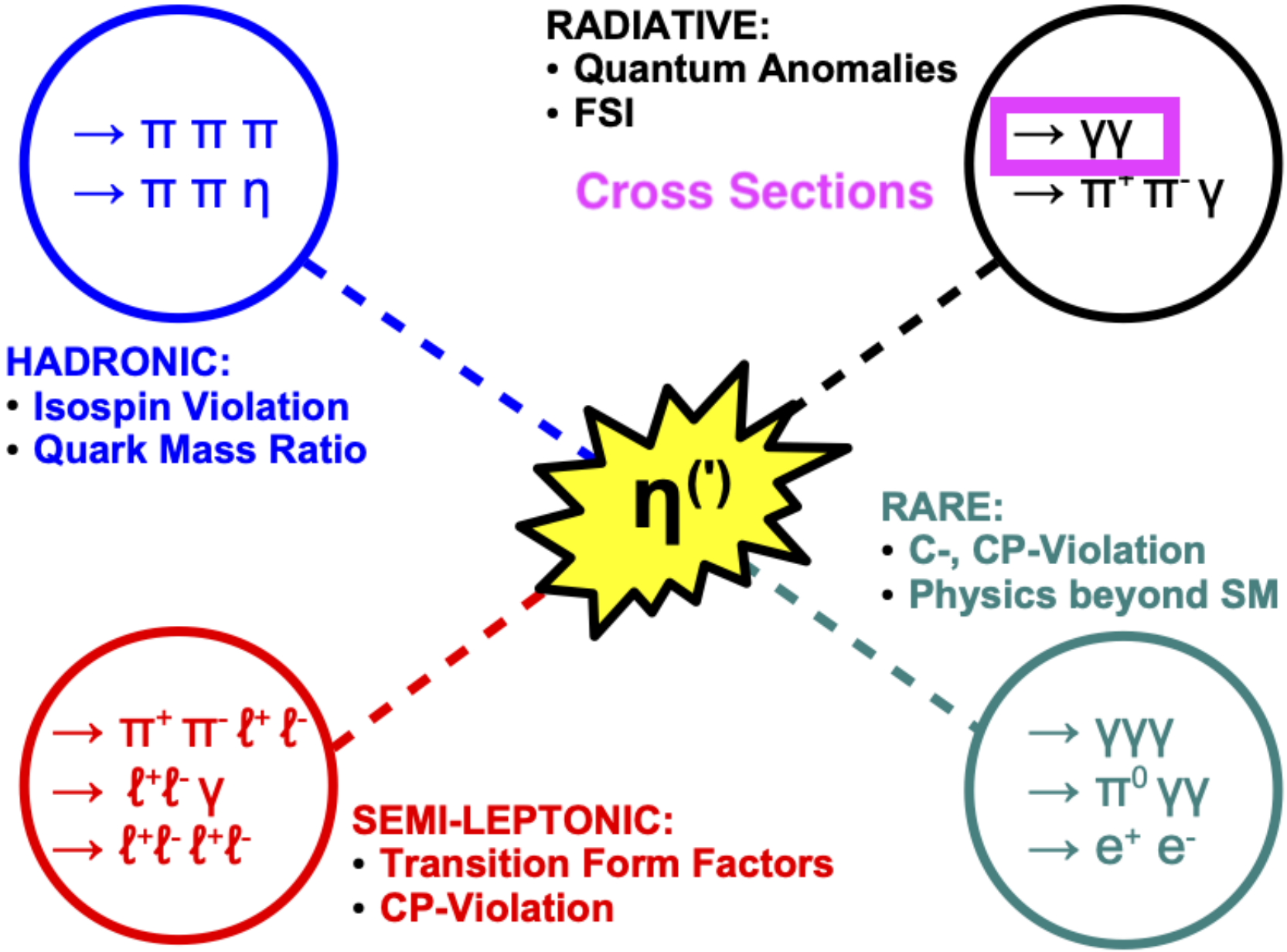

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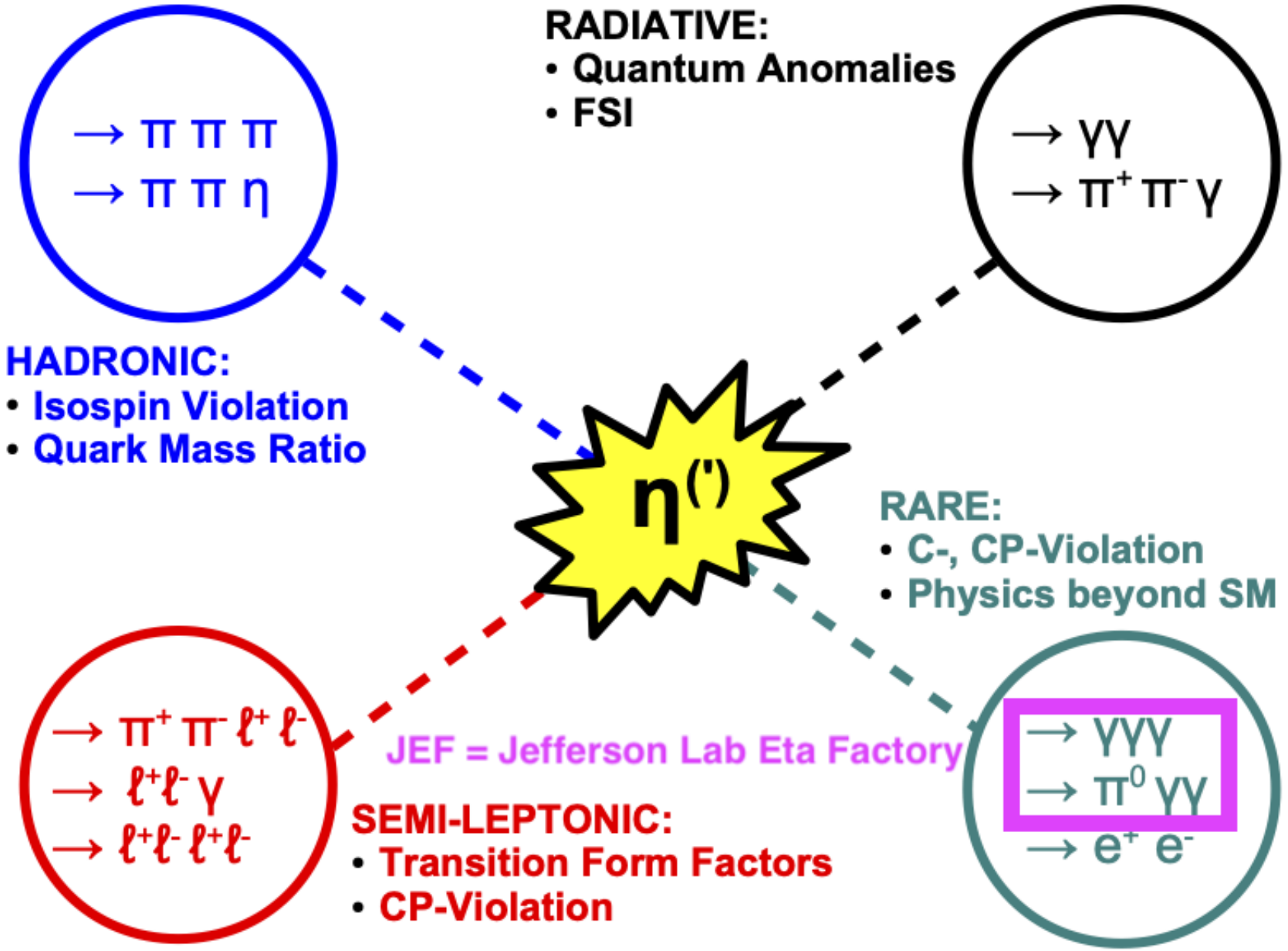


Dalitz Plot Analysis

- Decay width $\Gamma(\eta \to \pi^+\pi^-\pi^0)$:

  $\Gamma \propto Q^{-4}$, $Q^2 = \left(\frac{m_s}{m_d}\right) \times \left[1 - \left(\frac{m_u}{m_d}\right)^2\right]^{-1}$ $\Rightarrow$ Access to quark mass ratio

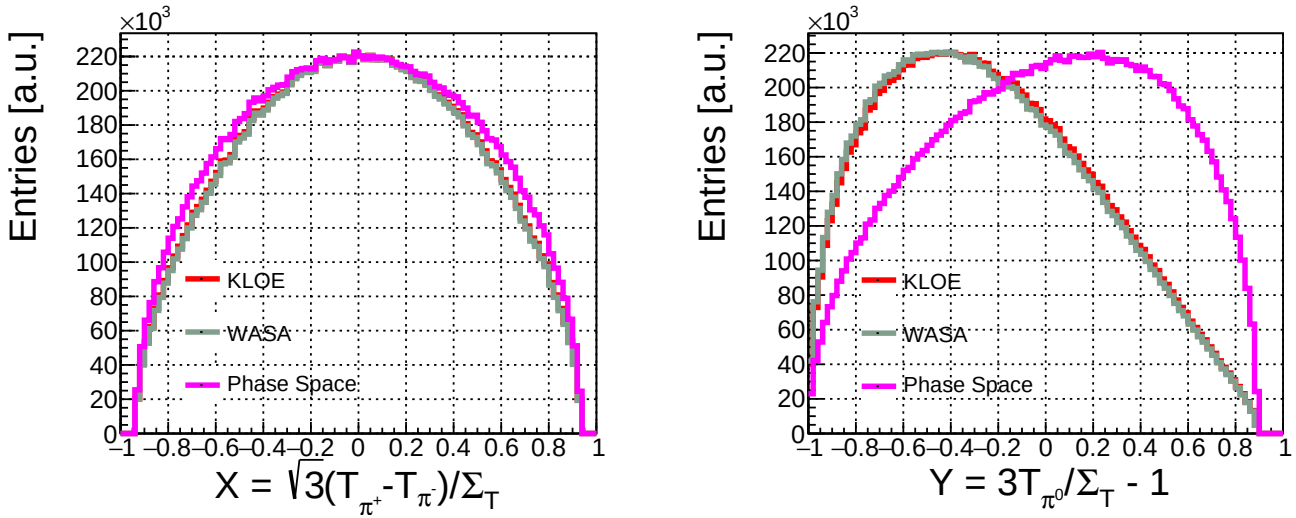
  $\frac{d^2\Gamma}{dXdY} \propto (1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + hXY^2 + lX^3 + \cdots)$

- Dimensionless variables:

  $X = \sqrt{3}(T_{\pi^+} - T_{\pi^-})/\Sigma_T$ $\to$ Sensitive to charge conjugation

  $Y = 3T_{\pi^0}/\Sigma_T - 1$

- **C-conservation:** c = e = h = l =0 $\to$ symmetric X-distribution



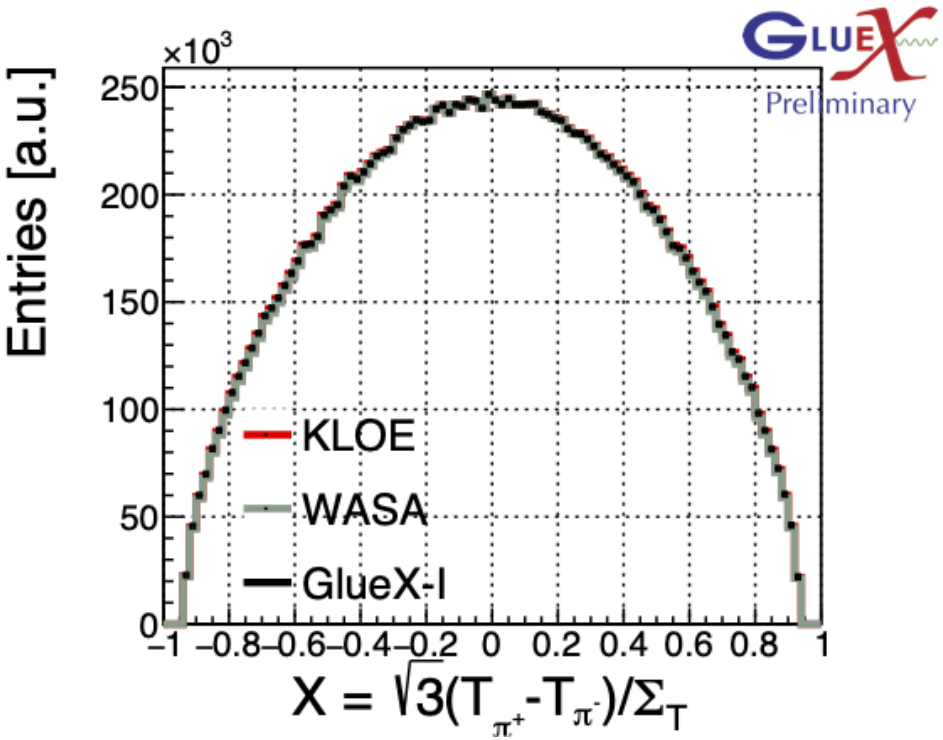
- Tensions between KLOE and WASA results

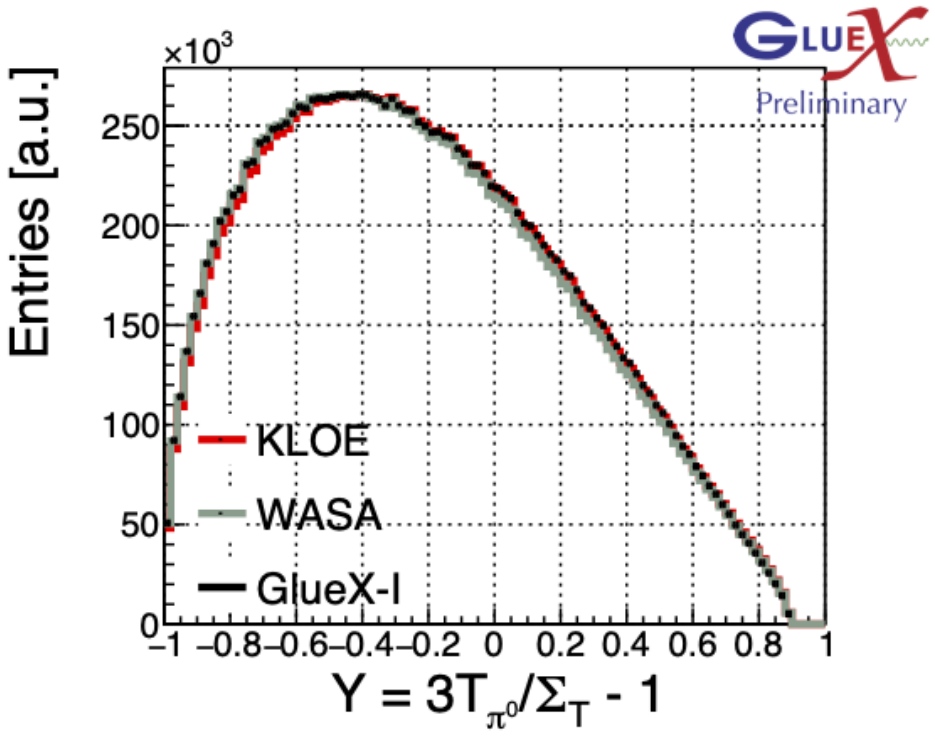
  KLOE coll., *JHEP*, 019, (2016) // WASA-at-COSY coll., *Phys. Rev.*, C90(045207), (2014)

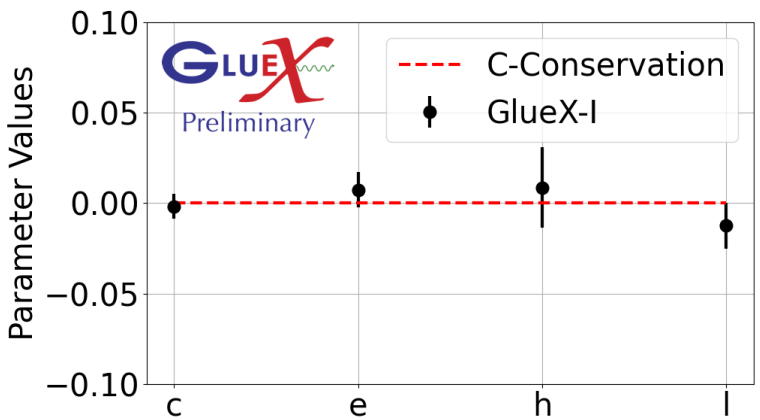
- JPAC used KLOE and WASA results to determine: $Q = 21.6 \pm 1.1$

  Peng Guo et al., Phys. Lett., B771(497-502), (2017)

Results from GlueX







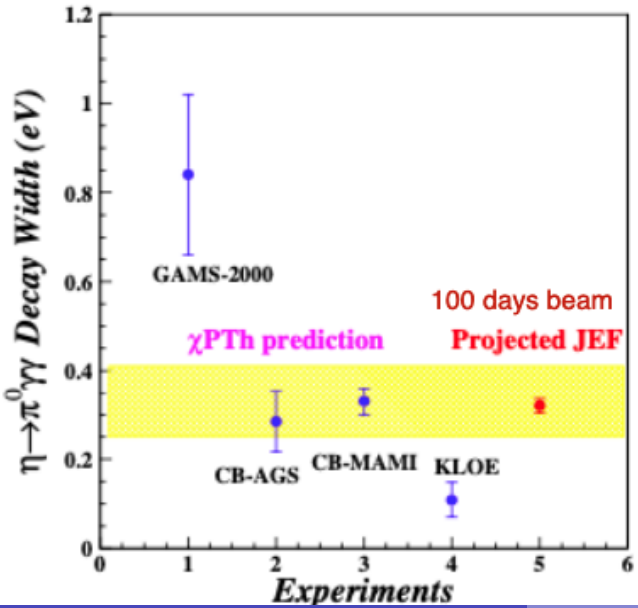
- Analyzed entire phase I data
  $\Rightarrow$ Statistically compatible
- Results consistent with previous experiments
- No C-violation observed
  $\Rightarrow$ X-check detector acceptance
- Analysis under review soon

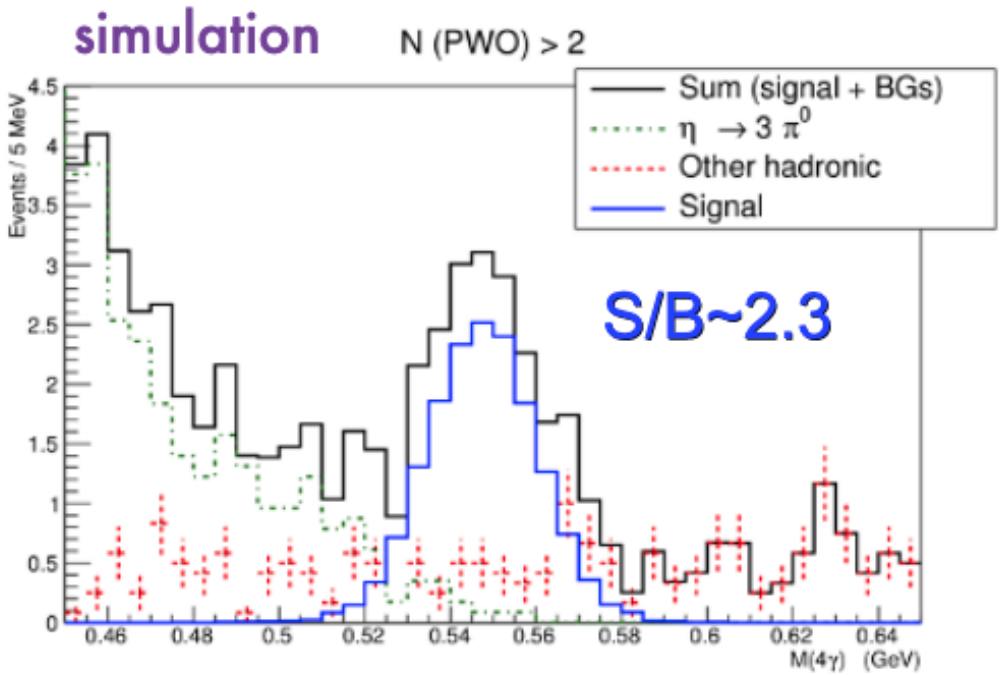
Search for gauge Bosons in $\eta \to \pi^0\gamma\gamma$

- χPTh: Major contributions to decay width $\sim \mathcal{O}(p^6)$
- Possible decays:

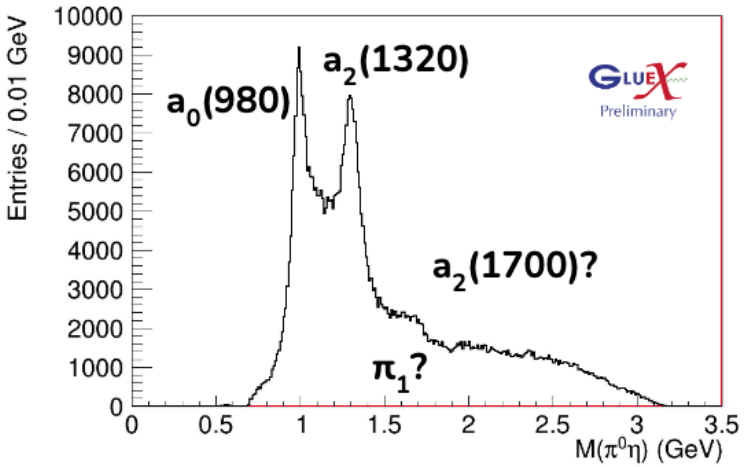
Mode	Gauge Boson
$\eta \to \gamma B'$	Vector $B' \to \pi^0\gamma$
$\eta \to \pi^0 S$	Scalar $S \to \gamma\gamma$

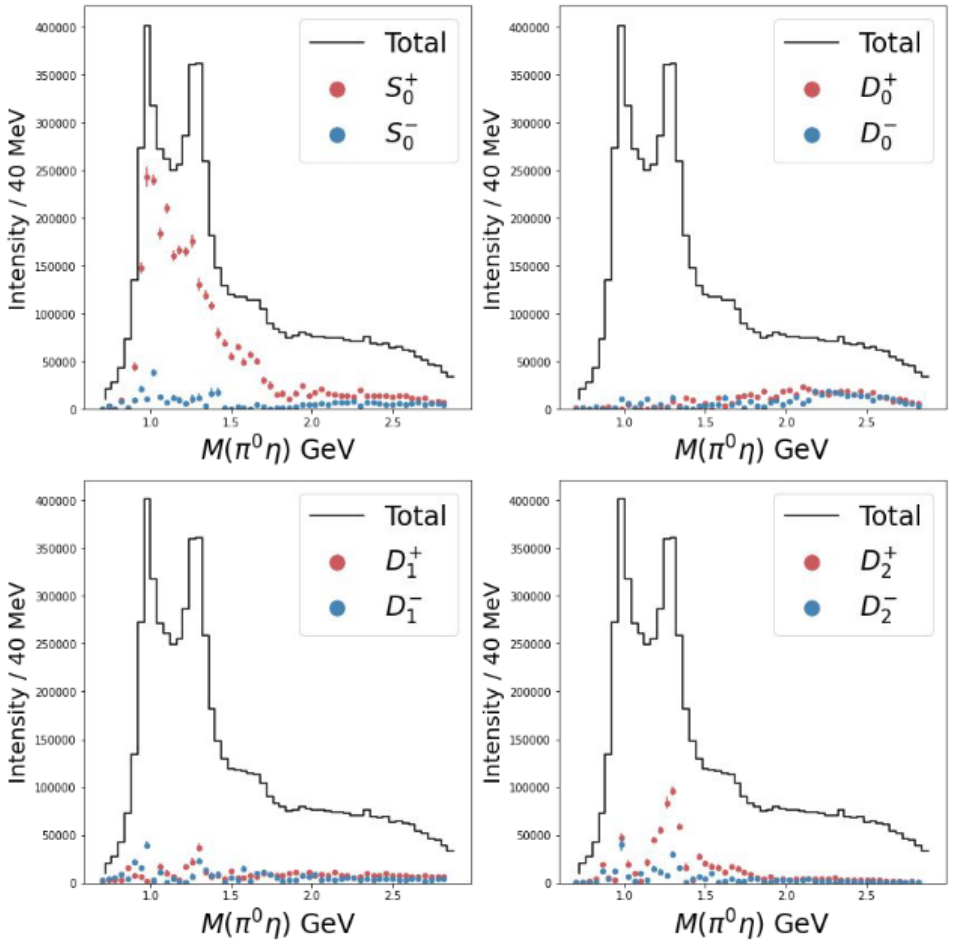
- Challenging background: $\eta \to 3\pi^0$
- Detector upgrade of GlueX forward calorimeter $\Rightarrow$ Improve performance





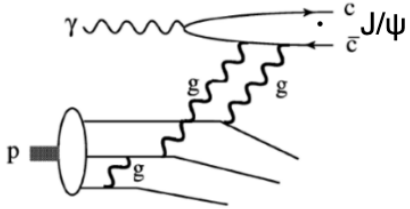
Studying the $\eta\pi^0$ System



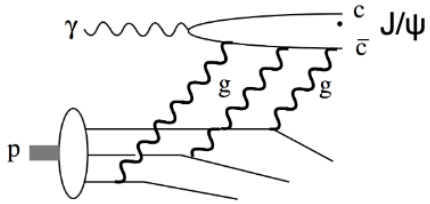


- Analysis of GlueX I data
- **Goal:** Extract π_1-signal
- **Intermediate Goal:** Test / tune and validate amplitude analysis on *a*2(1320)
  - Dominantly produced in D_2^+ wave
  - Significant *S*-wave contributions

Charmonium Production near Threshold

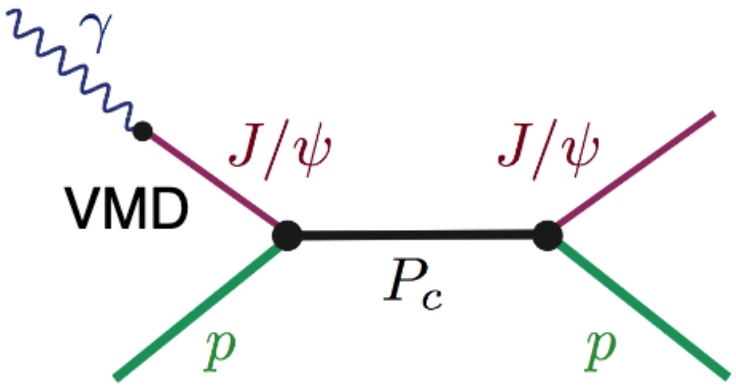


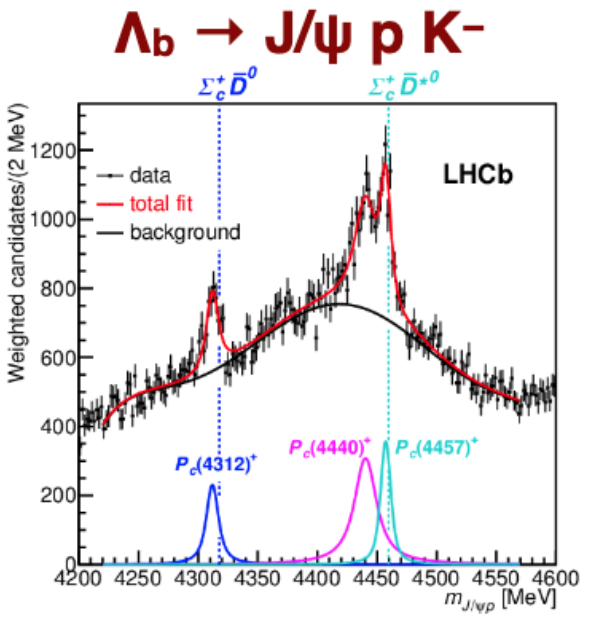
leading-twist



higher-twist

- Study gluonic field in nucleon
- Search for pentaquark candidates P_c
- LHCb reported three candidates



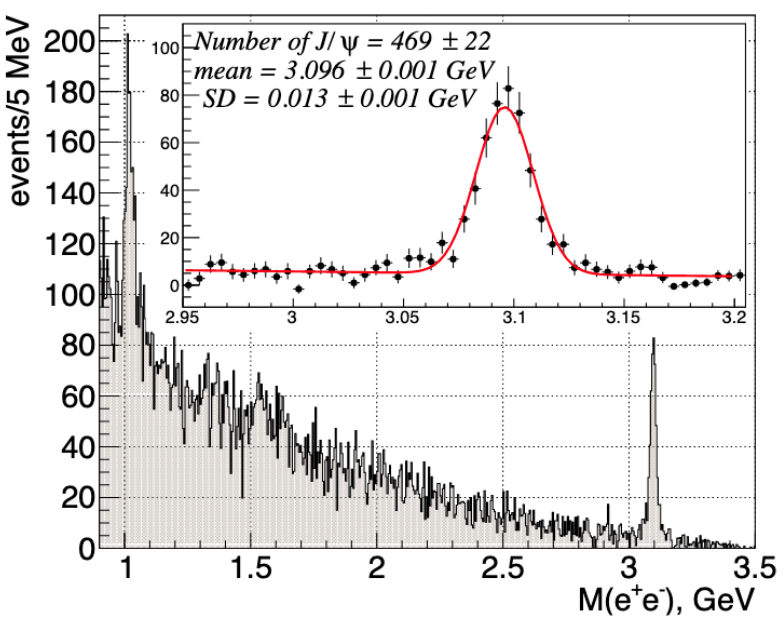


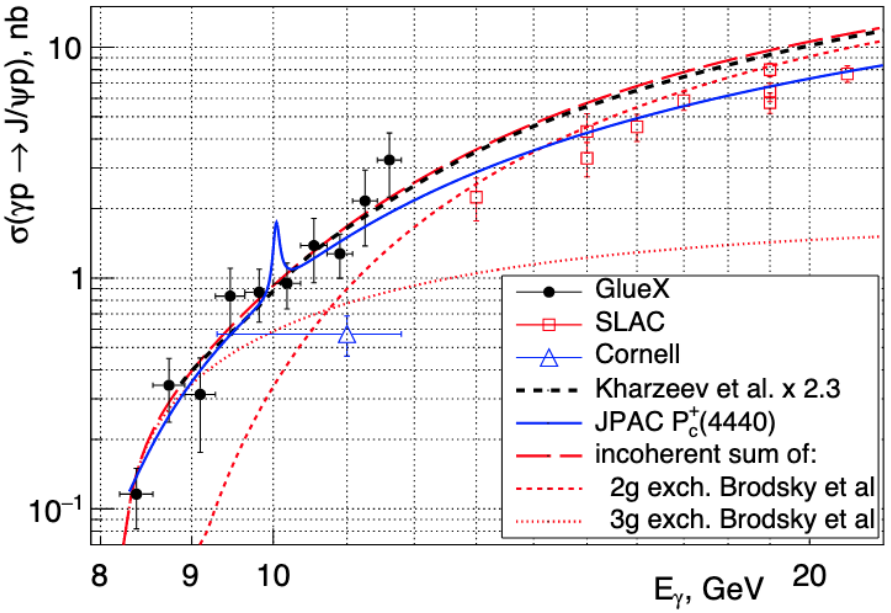
LHCb, PRL 122, 222001 (2019)

$J/\psi \to e^+e^-$ at GlueX

Phys. Rev. Lett. 123, 072001 (2019)

- Reconstructed ≈ 470 $J\psi \to e^+e^-$ events from $\sim 20\%$ of phase I data
- Measured cross section for $E_\gamma \in [8.2\,\mathrm{GeV}, 11.8\,\mathrm{GeV}]$





- Determine model dependent upper limits on LHCb P_c^+ states (at 90% CL)

Branching ratio	Upper limit [%]
$P_c^+(4312) \to J\psi p$	4.6
$P_c^+(4440) \to J\psi p$	2.3
$P_c^+(4457) \to J\psi p$	3.8

- Analysis of full GlueX data is ongoing
- Explore further decay modes (e.g. $J/\psi \to \mu^+\mu^-$, $\chi_{c1} \to \gamma J/\psi$, $\psi(2S) \to \pi^+\pi^- J/\psi$)

Summary and Outlook

- Rich and diverse physics program at GlueX
- Search for exotic mesons
  - Study "known" final states (e.g. $\eta\pi$, $\omega\pi$,..)
  - Develop amplitude analysis tools
  - Extend search to other J^{PC}-states
- Search for pentaquark states with $J/\psi \to e^+e^-$
- Analysis of η meson decays
  - Dalitz plot analysis
  - Physics beyond the Standard Model
  - Understand detector performance and acceptance
- Unfortunately did not show all ongoing efforts
  - Analysis for spin density matrix elements
  - Exotic searches with vector-pseudoscalar final states
  - Dalitz plot analysis for $\eta' \to \eta\pi\pi$, $\eta \to 3\pi^0$
  - ...
- Close collaboration with theory
- Analysis of phase-II data ongoing

GlueX acknowledges the support of several funding agencies and computing facilities (gluex.org/thanks)