

Two-Pseudoscalar Spectroscopy at GlueX

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JLUO Annual Meeting 2023
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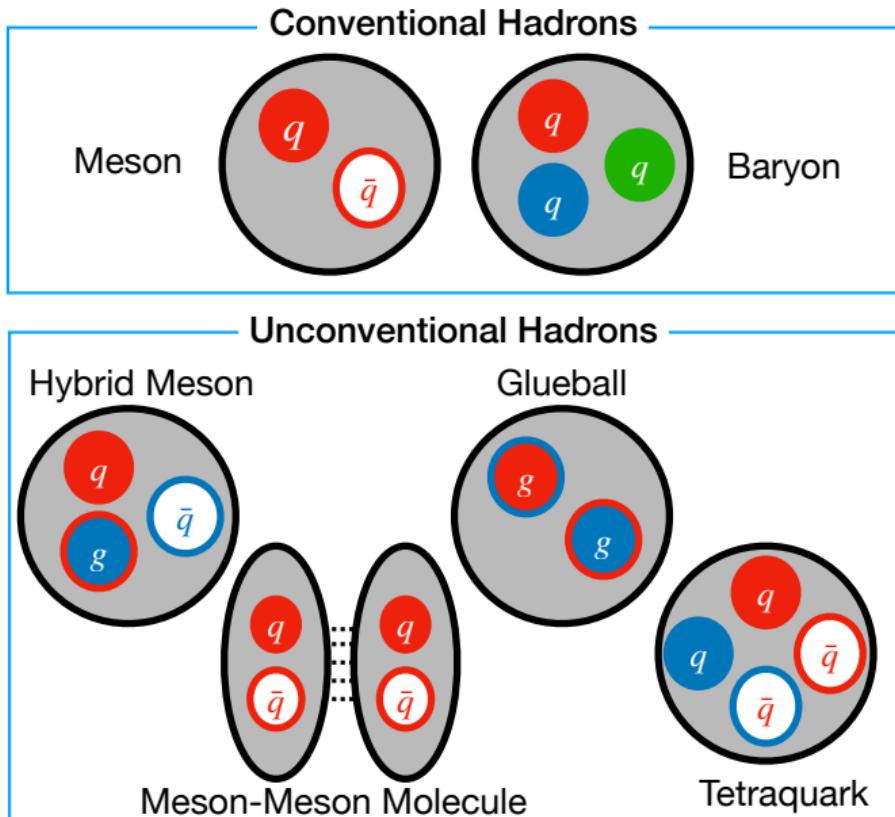


FLORIDA STATE
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QCD and the Hadron Spectrum

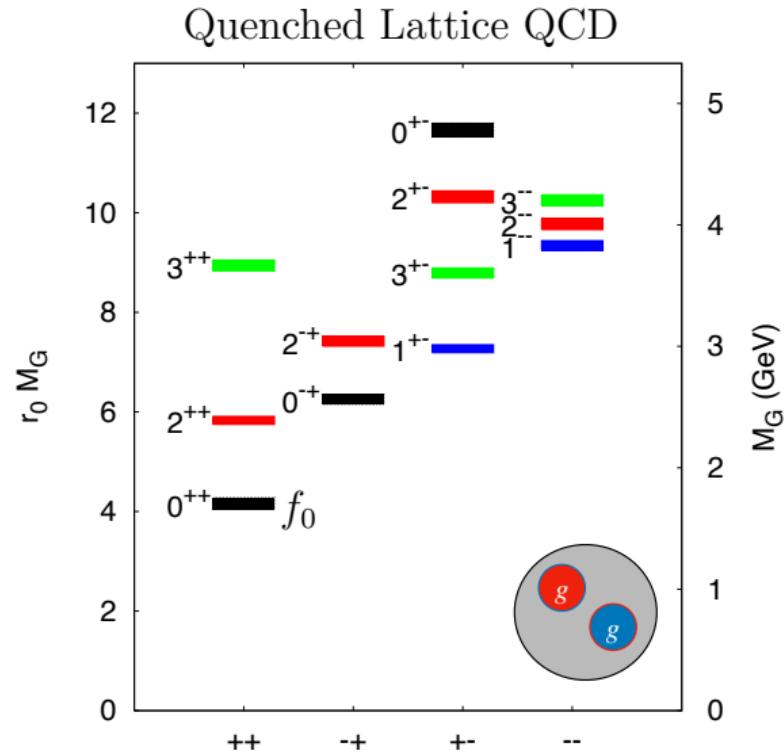
- The hadron spectrum is a consequence of QCD
- Unconventional hadrons are beyond the Quark Model but allowed in QCD
- Can they tell us something new about QCD?
- Experimental challenge: conventional and unconventional hadrons often overlap



Light Scalar Mesons

- Lightest glueball expected to have $J^{PC} = 0^{++}$ and mass 1.3–2 GeV
- Two light scalar mesons are expected between 1 and 2 GeV from the Constituent Quark Model
- Three light scalars have been observed:

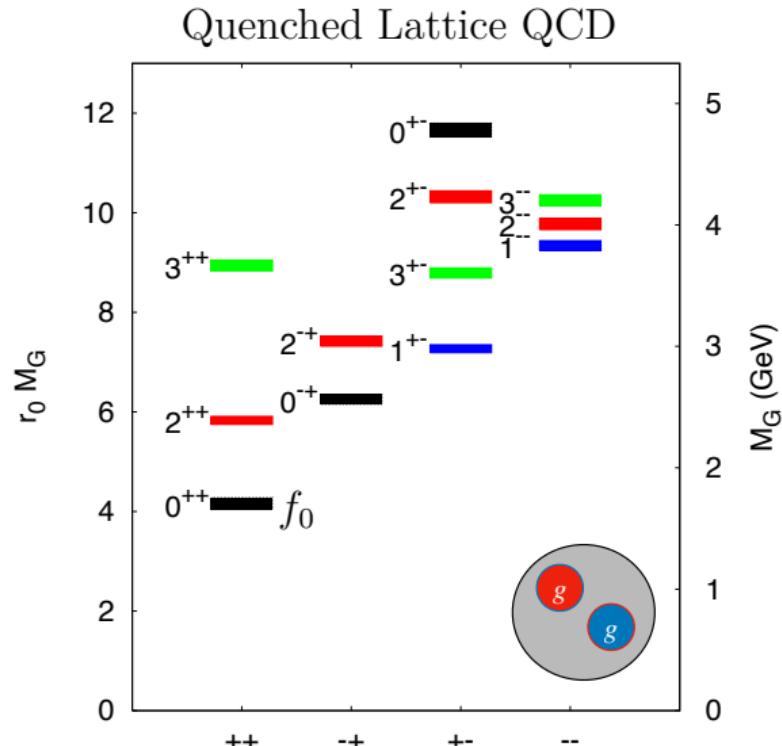
$$f_0(1370) \quad f_0(1500) \quad f_0(1710)$$



[Phys. Rev. D 73, 014516 (2006)]

Light Scalar Mesons

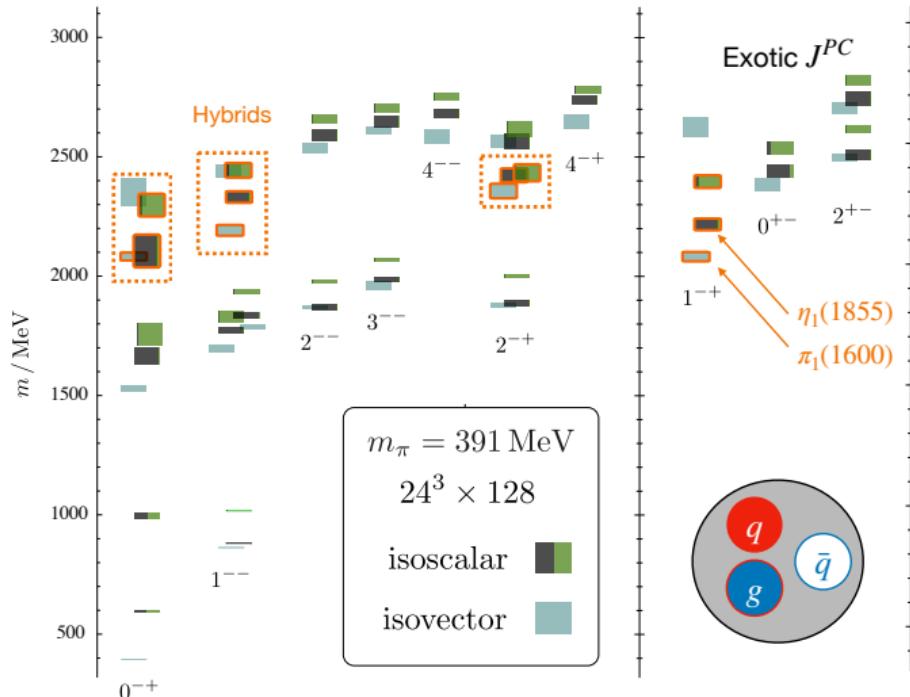
- Lightest glueball expected to have $J^{PC} = 0^{++}$ and mass 1.3–2 GeV
- Two light scalar mesons are expected between 1 and 2 GeV from the Constituent Quark Model
- Three light scalars have been observed:
 $f_0(1370)$ $f_0(1500)$ $f_0(1710)$
- Is one of these states the glueball?
- Is there mixing between two $q\bar{q}$ states and a glueball?
- No consensus on interpretation of the light scalar sector



[Phys. Rev. D 73, 014516 (2006)]

Meson Spectrum on the Lattice

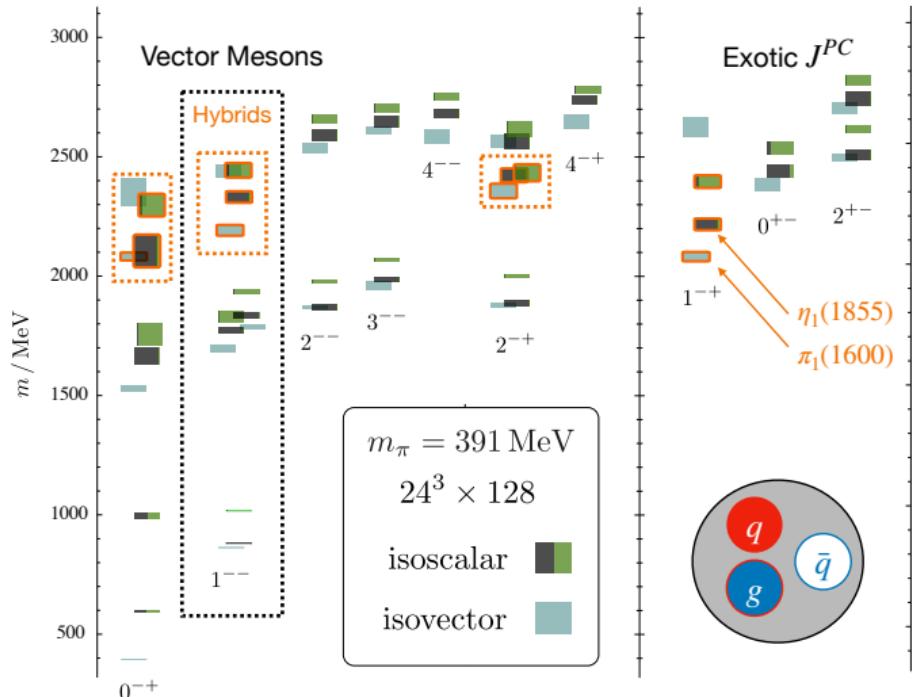
- Several hybrid nonets expected



[Rev. Mod. Phys. 90, 025001 (2018)]

Meson Spectrum on the Lattice

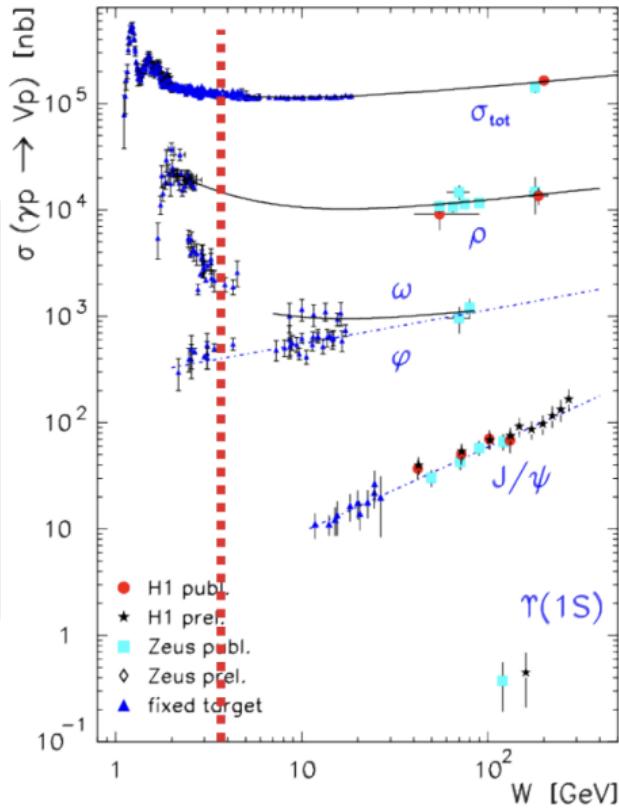
- Several hybrid nonets expected
- Including hybrid vector mesons
- Expected to mix with conventional vector mesons
- Would produce an overpopulation of vector mesons



[Rev. Mod. Phys. 90, 025001 (2018)]

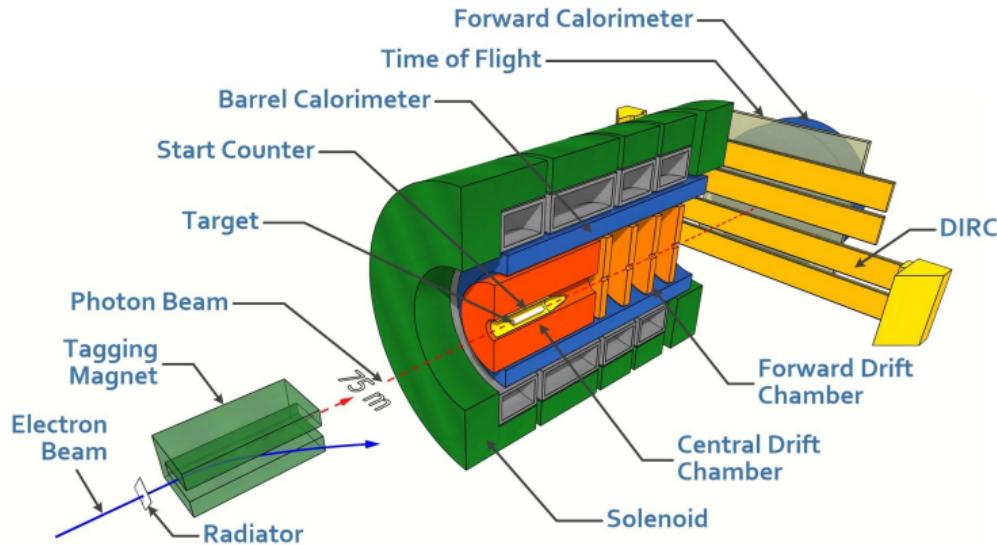
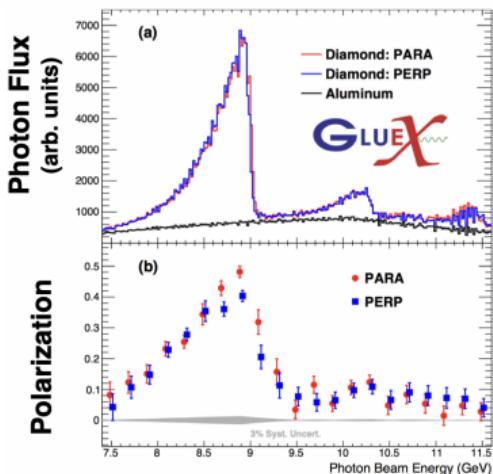
Photoproduction of Vector Mesons

- Lightest vector mesons have large photoproduction cross section
- Limited information about excited states
 - Mostly from e^+e^- annihilation
 - Only produce vector mesons
- Photoproduction is complementary to e^+e^- annihilation
 - Large vector meson cross sections



GlueX Experiment

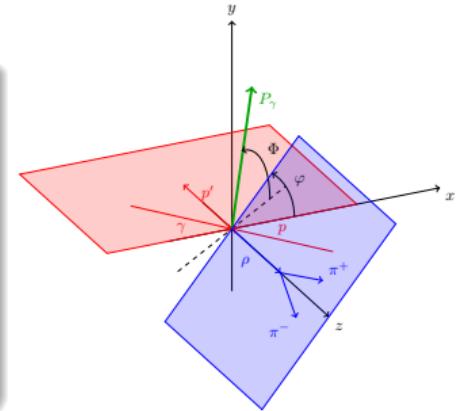
- Nearly hermetic detector
- Charged and neutral particle detection
- Tagged photon beam
- Phase 1 of GlueX now complete



[Nucl. Instrum. Meth. A987, 164807 (2021)]

Spin Density Matrix Elements

- Full angular distribution of vector meson production and decay is described by SDME
 - Detailed theory prediction, but previous measurements limited
 - Sensitive to angular component of detector acceptance
 - Multiple decay modes for some channels
-
- Linear beam polarization provides access to nine linearly independent SDMEs
 - Intensity (W) is a function of $\cos(\theta)$, ϕ , Φ and degree of polarization P_γ



$$W(\cos\theta, \phi, \Phi) = W^0(\cos\theta, \phi) - P_\gamma \cos(2\Phi) W^1(\cos\theta, \phi) - P_\gamma \sin(2\Phi) W^2(\cos\theta, \phi)$$

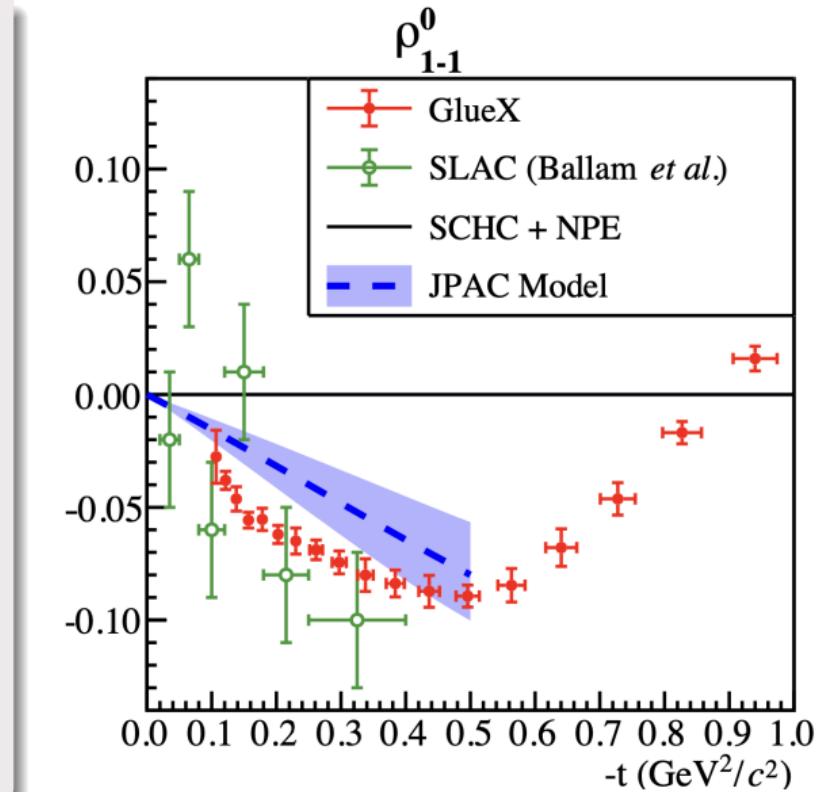
$$W^0(\cos\theta, \phi) = \frac{3}{4\pi} \left(\frac{1}{2}(1 - \rho_{00}^0) + \frac{1}{2}(3\rho_{00}^0 - 1)\cos^2\theta - \sqrt{2}Re\rho_{10}^0 \sin 2\theta \cos \phi - \rho_{1-1}^0 \sin^2\theta \cos 2\phi \right)$$

$$W^1(\cos\theta, \phi) = \frac{3}{4\pi} (\rho_{11}^1 \sin^2\theta + \rho_{00}^1 \cos^2\theta - \sqrt{2}Re\rho_{10}^1 \sin 2\theta \cos \phi - \rho_{1-1}^1 \sin^2\theta \cos 2\phi)$$

$$W^2(\cos\theta, \phi) = \frac{3}{4\pi} (\sqrt{2}Im\rho_{10}^2 \sin 2\theta \sin \phi + Im\rho_{1-1}^2 \sin^2\theta \sin 2\phi)$$

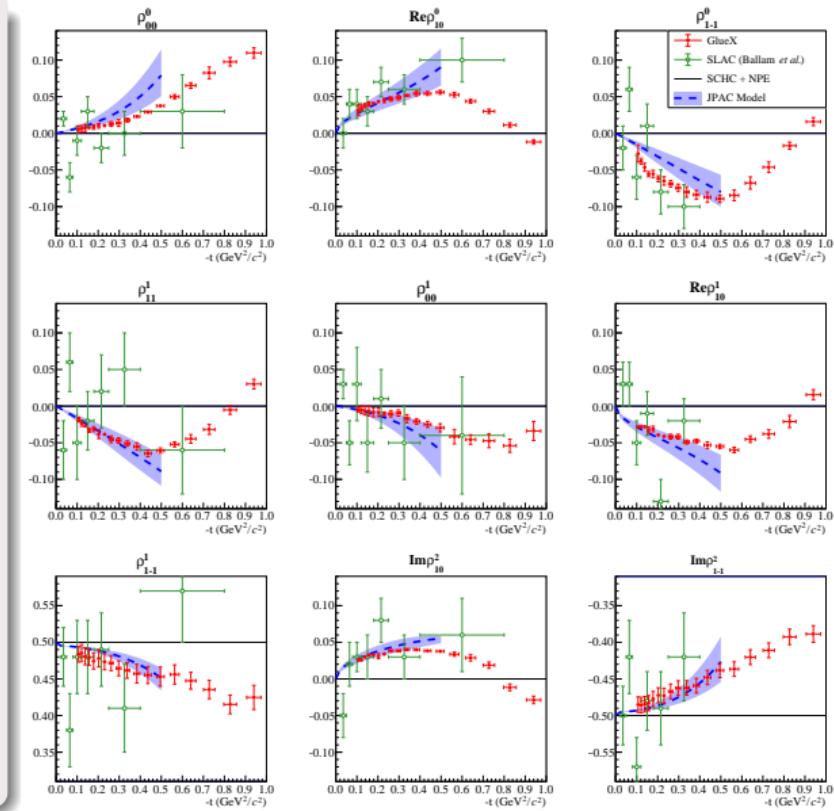
$\rho(770)$ Spin Density Matrix Elements

- High precision with 17% of GlueX-I data
- Detailed investigation of systematic uncertainties
- High precision input for further model development
- Used to develop high-precision multidimensional fit procedure



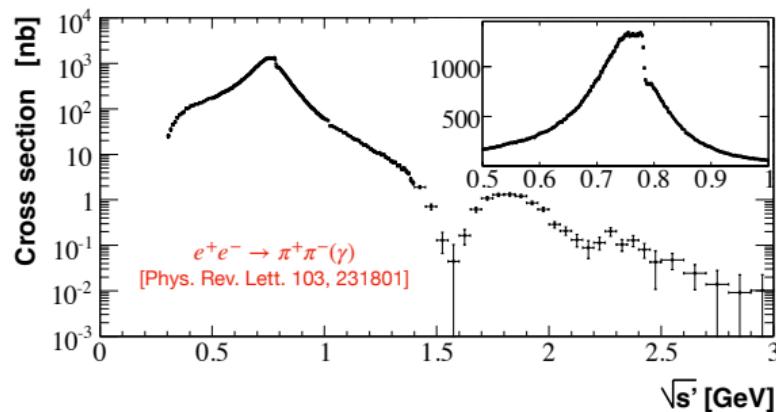
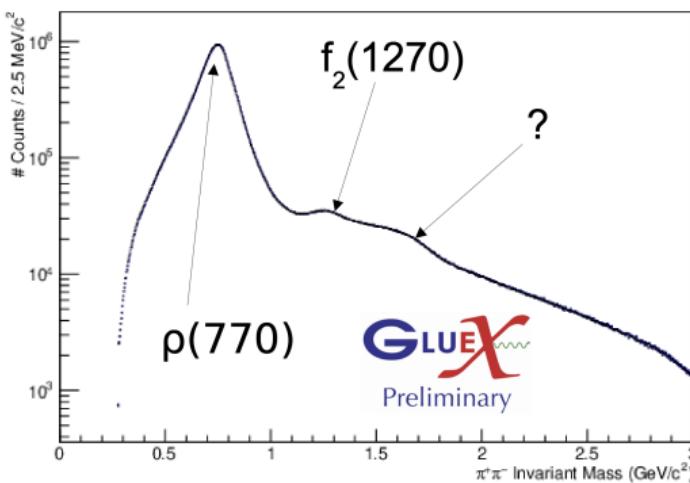
$\rho(770)$ Spin Density Matrix Elements

- High precision with 17% of GlueX-I data
- Detailed investigation of systematic uncertainties
- High precision input for further model development
- Used to develop high-precision multidimensional fit procedure
- Excellent agreement with JPAC model [PRD 97 094003 (2018)]
- Improves and validates our understanding of data and acceptance
- Paper submitted to Phys. Rev. C



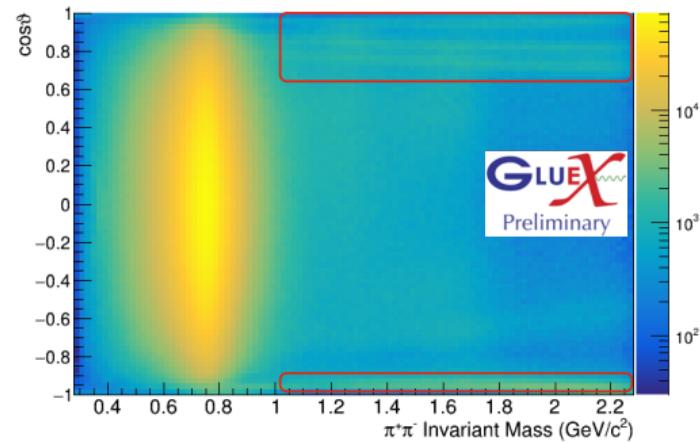
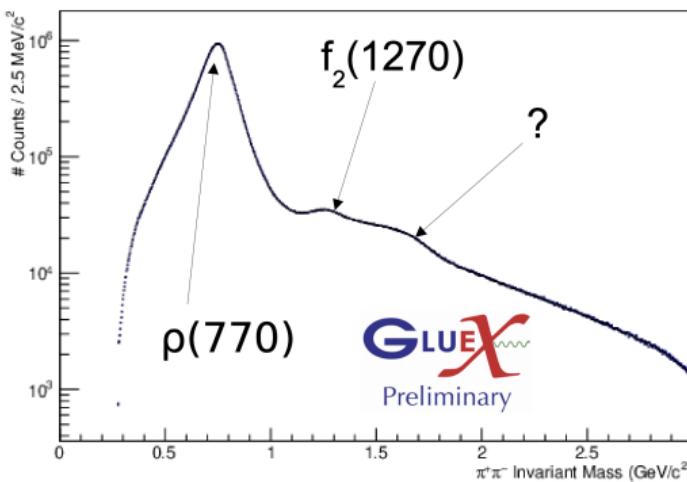
The $\pi^+\pi^-$ Spectrum Beyond the $\rho(770)$

- Abundant $\pi^+\pi^-$ data in GlueX data set
- Relative phase between resonances may differ in e^+e^- and photoproduction
 - Dip in e^+e^- becomes bump in photoproduction?
- Unprecedented detail accessible



The $\pi^+\pi^-$ Spectrum Beyond the $\rho(770)$

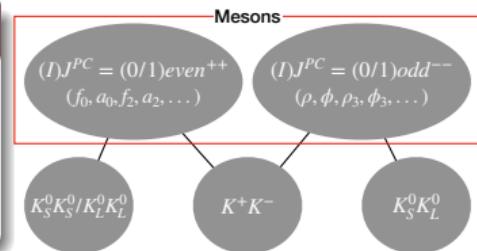
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- Relative phase between resonances may differ in e^+e^- and photoproduction
 - Dip in e^+e^- becomes bump in photoproduction?
- Unprecedented detail accessible
 - Must understand target excitation and double-Regge exchange background



Strangeness Program: 2-Pseudoscalar Final States

Study the $K\bar{K}$ Spectrum

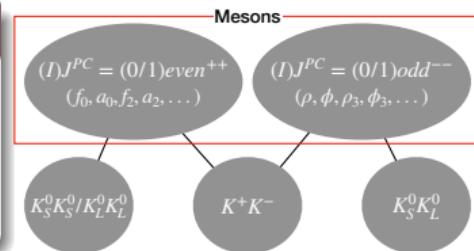
- Multiple final states are experimentally accessible
- Each with different challenges and opportunities
- K_SK_S and K_SK_L select for different physics



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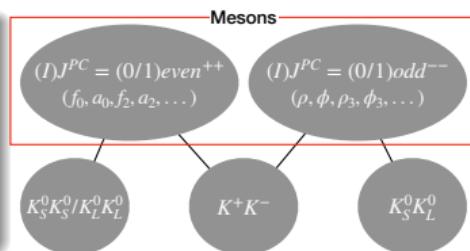
Explore Scalar Sector in K_SK_S

- $f_0(980)$ and $a_0(980)$ couple strongly to $K\bar{K}$
- Little information on photoproduction of:
 $f_0(1370) \quad f_0(1500) \quad f_0(1710)$
- What is their connection to glueballs?

Strangeness Program: 2-Pseudoscalar Final States

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Explore Scalar Sector in K_SK_S

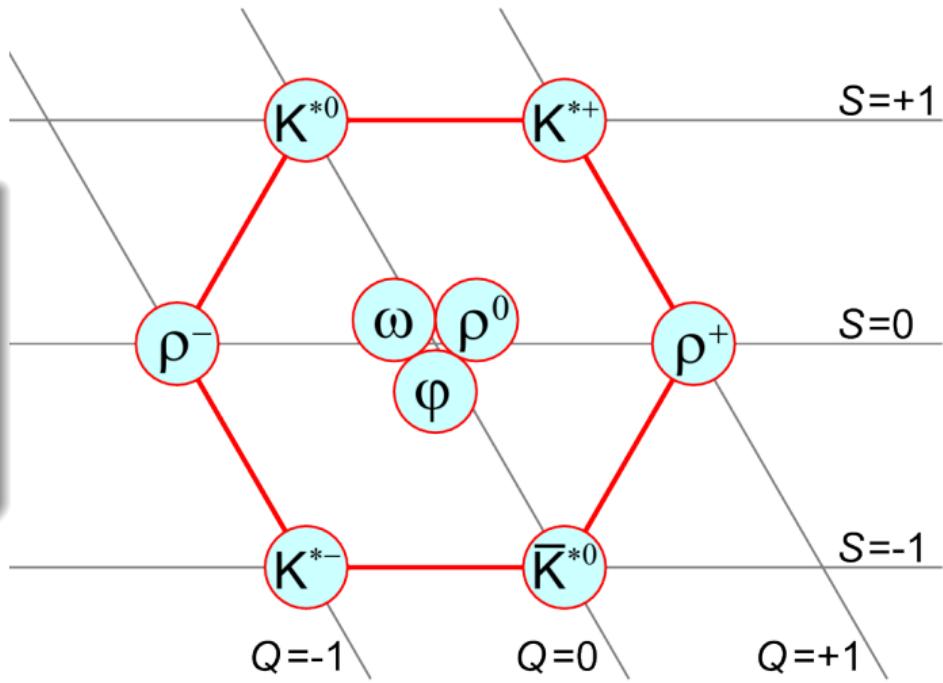
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- Little information on photoproduction of:
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Explore Vector Sector in K_SK_L

- $\phi(1020)$ has large cross section
 - Two decay modes
- Vector mesons considered established by the PDG:
 $\rho(770)$ $\omega(785)$ $\phi(1020)$
 $\rho(1450)$ $\omega(1420)$ $\phi(1680)$
 $\rho(1700)$ $\omega(1650)$
- Understand these states before searching for hybrid vector mesons

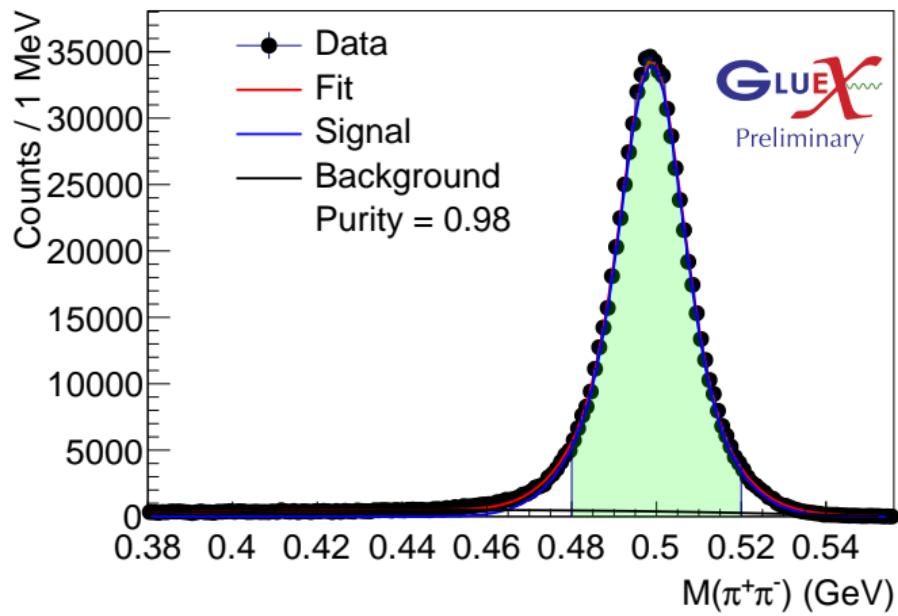
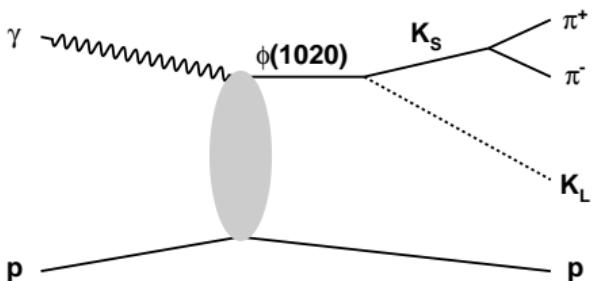
$\phi(1020)$ Spin Density Matrix Elements

- $\phi(1020)$ forms a nonet with $\rho(770)$ and $\omega(782)$
- Described by the same formalism as $\rho(770)$
- Large branching fraction to K_SK_L



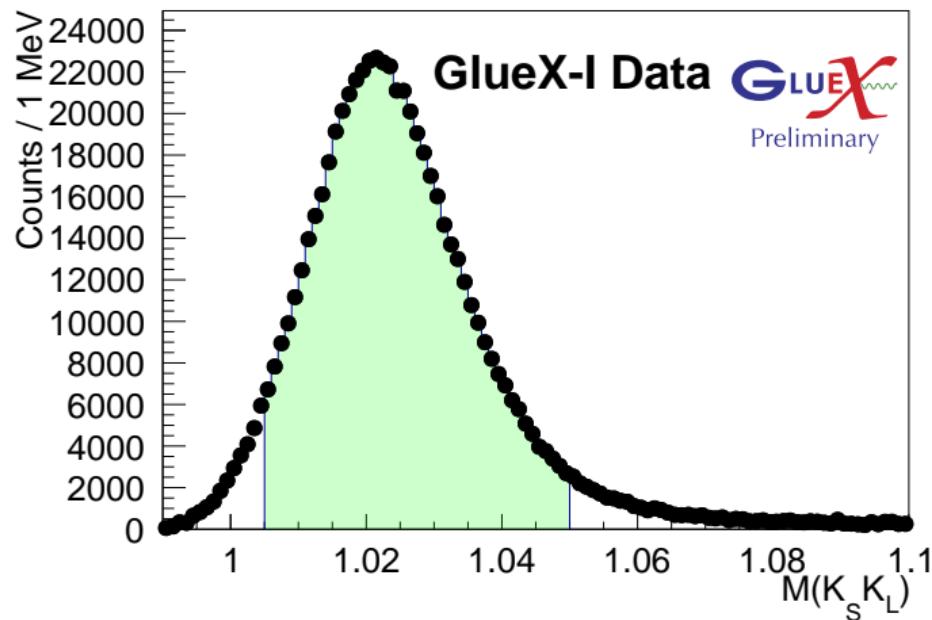
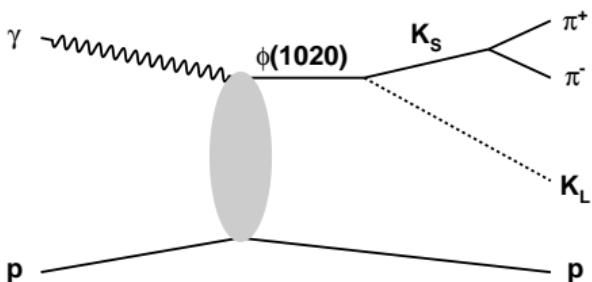
$\phi(1020)$ Spin Density Matrix Elements

- Measure $\phi(1020) \rightarrow K_S K_L$
- Reconstruct $K_S \rightarrow \pi^+ \pi^-$ and recoil proton
- Kinematically fit reaction with missing particle constrained to the K_L mass



$\phi(1020)$ Spin Density Matrix Elements

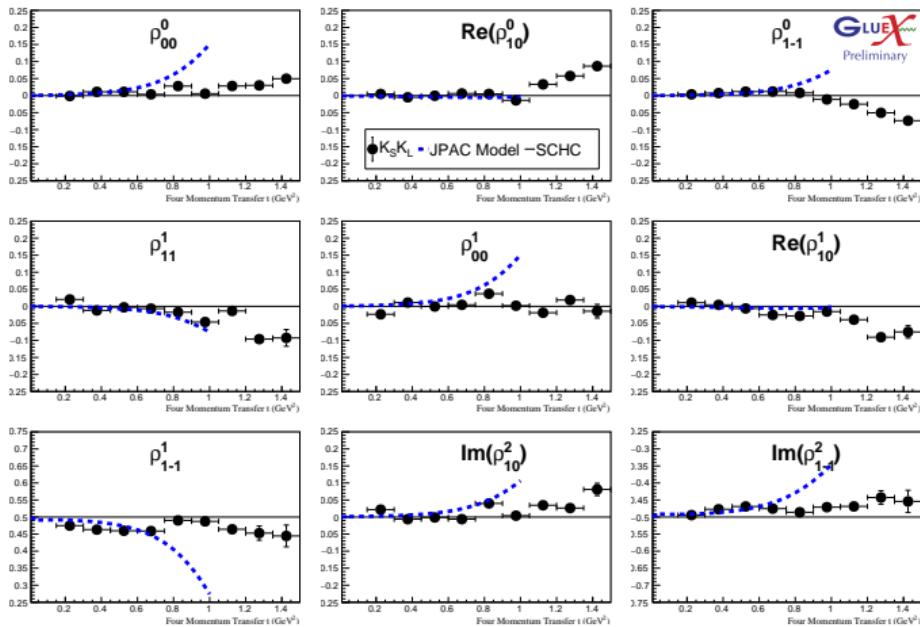
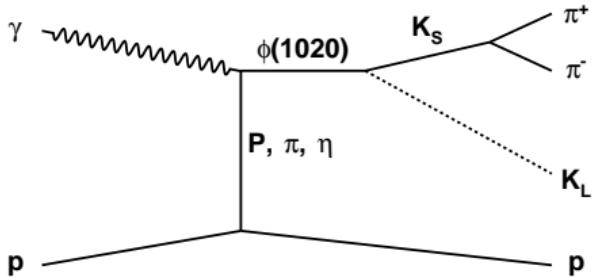
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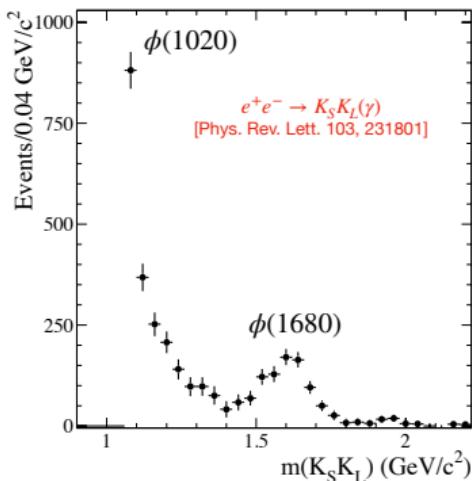
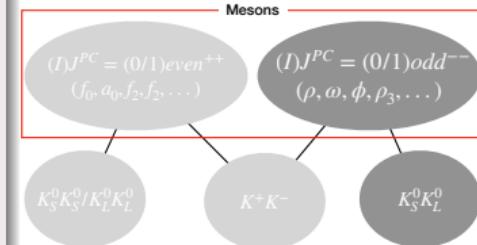
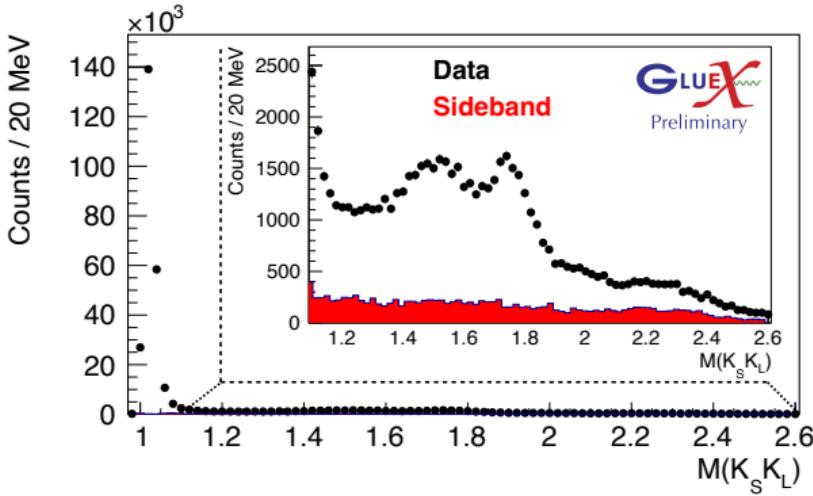
- Complete GlueX-I data
- Only statistical uncertainties shown
- Systematic uncertainties under investigation
- JPAC model deviates from SCHC due to π/η exchange

[PRD 97 094003 (2018)]



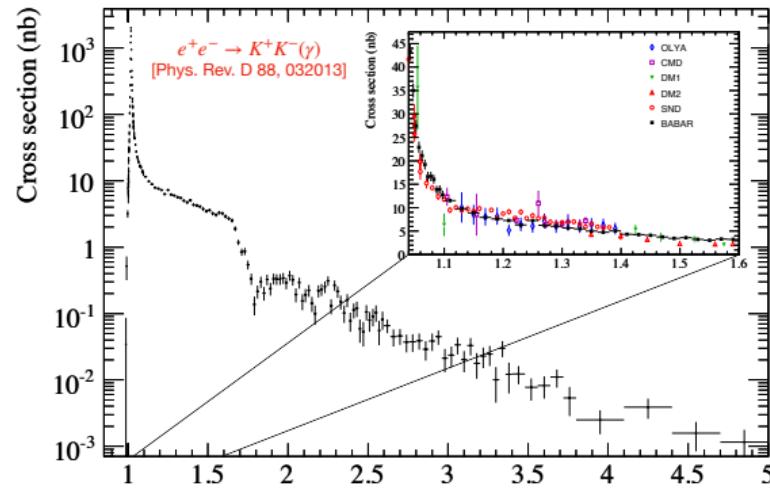
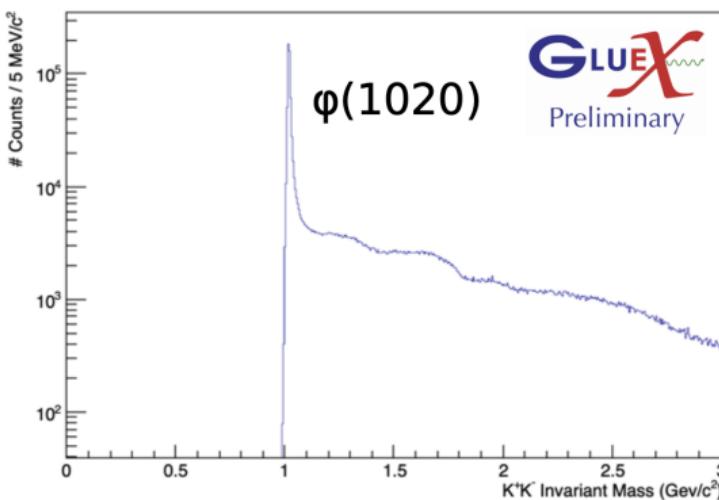
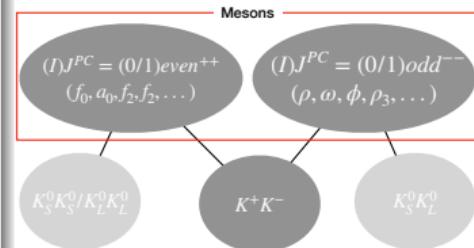
The $K_S K_L$ Spectrum Beyond the $\phi(1020)$

- Partial Wave Analysis underway
 - Same formalism as $\eta\pi$ channel
- Preliminary studies indicate the $K_S K_L$ spectrum is predominantly P-wave
- Two peaks in photoproduction vs. single peak in e^+e^-



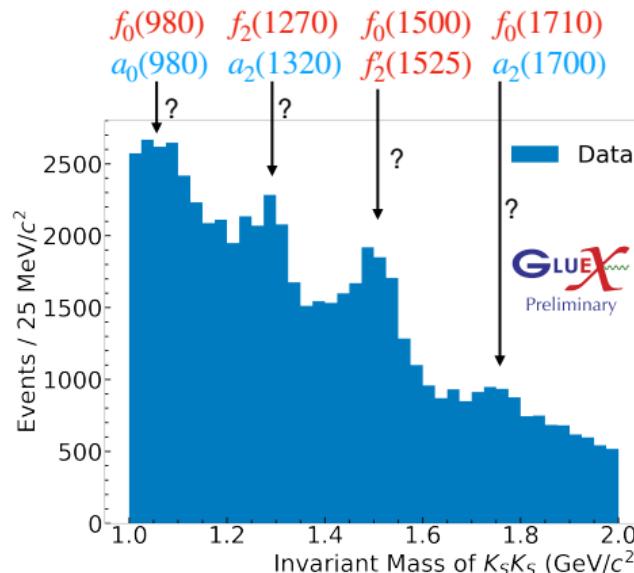
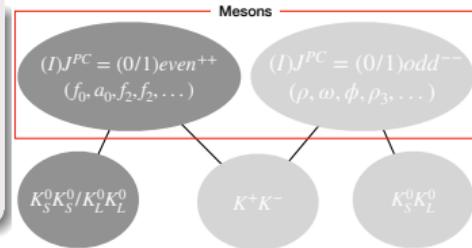
The K^+K^- Spectrum

- $\phi(1020) \rightarrow K^+K^-$ analysis ongoing
- Important step in understanding charged kaon reconstruction
- Charged kaon reconstruction improved with DIRC upgrade



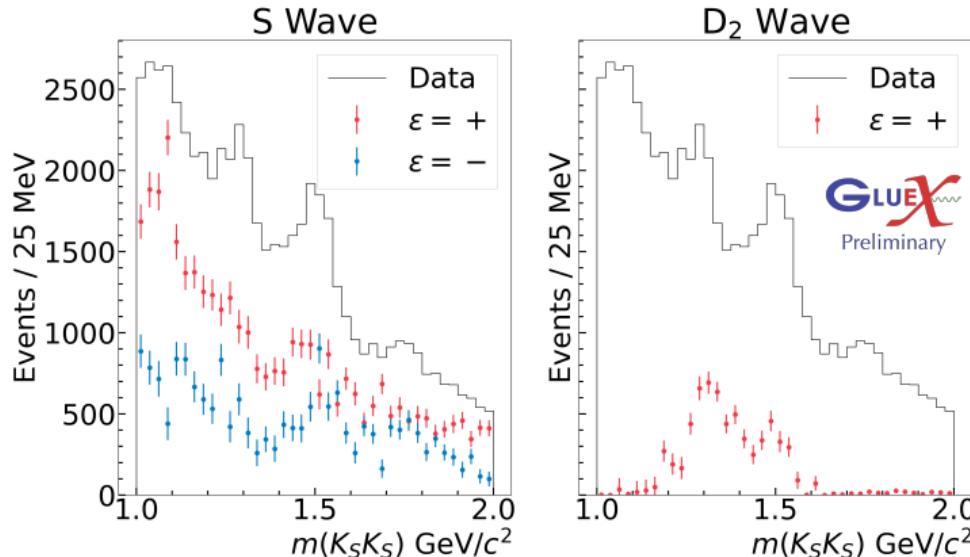
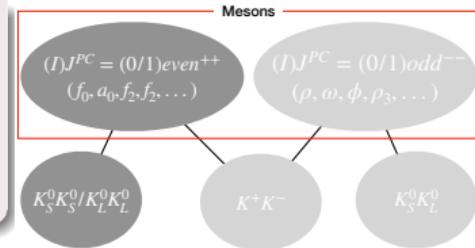
The $K_S K_S$ Spectrum

- Many even-spin light mesons may contribute
 - Partial Wave Analysis may separate spin contributions



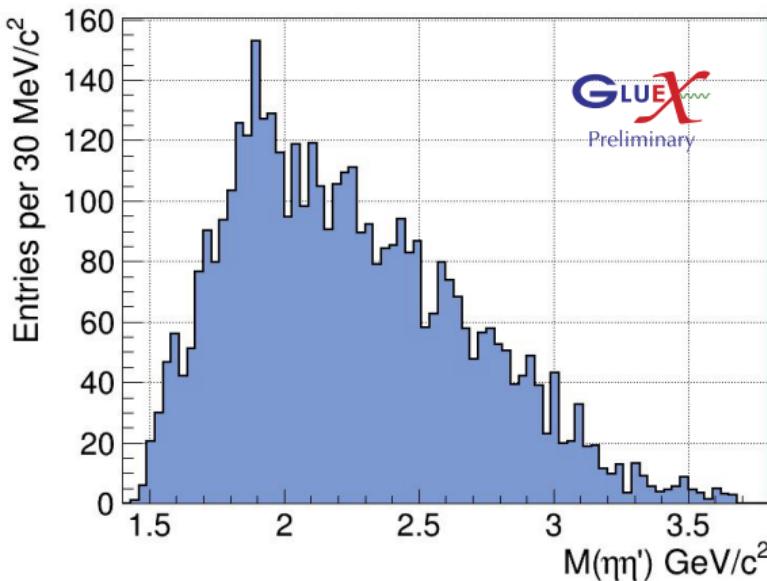
The $K_S K_S$ Spectrum

- Many even-spin light mesons may contribute
- Partial Wave Analysis may separate spin contributions
 - Same formalism as $\eta\pi$ channel
 - Begin with a minimal wave set: S_0^+, S_0^-, D_2^+

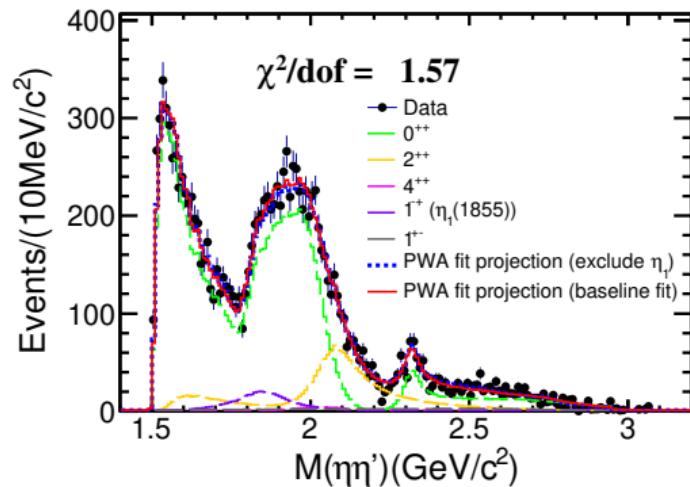


The $\eta\eta'$ Spectrum

- Photoproduction of $\eta\eta'$
 - ~2k total events
 - Single reconstructed topology
 - Expect 3-4x increase with GlueX-II



- BES-III reported evidence for $\eta_1(1855)$ in $J/\psi \rightarrow \eta\eta'\gamma$
 - ~15k total events
 - Two reconstructed topologies



[Phys. Rev. Lett. 129, 192002]

Final Remarks on Two-Pseudoscalar Spectroscopy

- GlueX has collected a large and unique data set on two-pseudoscalar final states

Spin Density Matrix Elements

- $\rho(770)$ analysis paper submitted
- $\phi(1020) \rightarrow K_SK_L/K^+K^-$ analysis ongoing

Photoproduction of Scalar Meson

- Partial Wave Analysis of K_SK_S ongoing

Future Opportunities

- Photoproduction of $\eta_1 \rightarrow \eta\eta'$ with GlueX-II
- Expand strangeonium program with DIRC upgrade
- Search for hybrid vector mesons

Beyond the Lightest Vector Mesons

- High statistics $\pi^+\pi^-$ data set
- Two peak structure observed in K_SK_L

Acknowledgements

