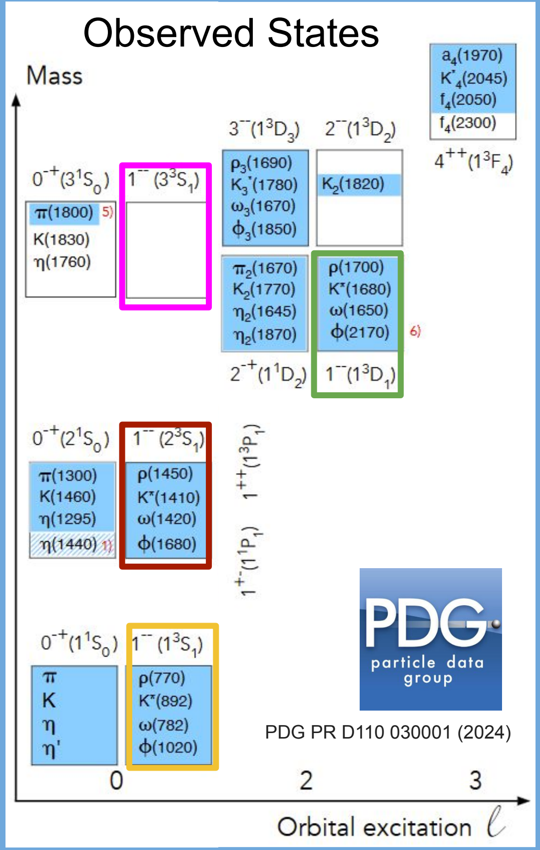
Vector Mesons at GlueX

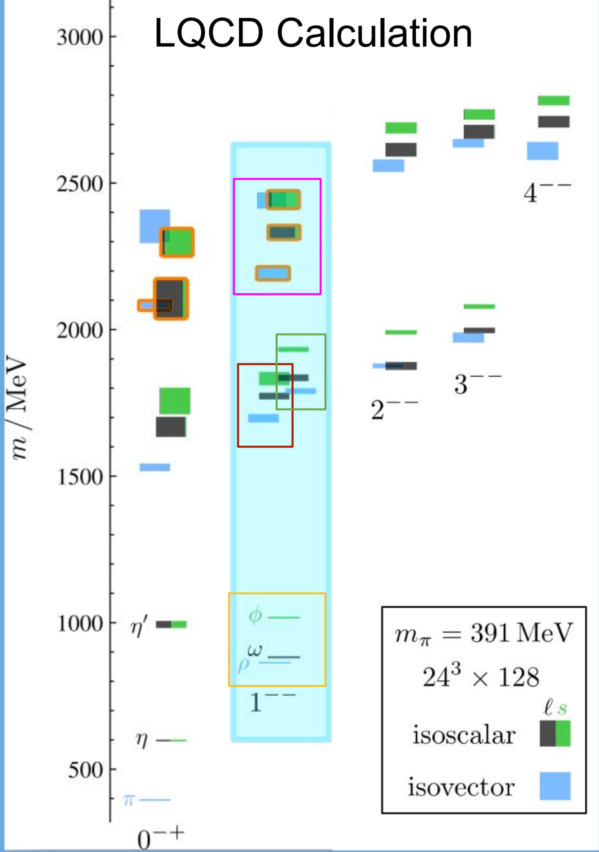
Edmundo S. Barriga
On behalf of the GlueX Collaboration

Vector Meson Spectrum

J. Dudek et al. PR D88 094505 (2013)

- SU(3) flavor multiplets grouped in nonets
- Unrealistic pion masses outputs unreliable masses
- Understanding of QCD dynamics
- Understand the over and under population in groups





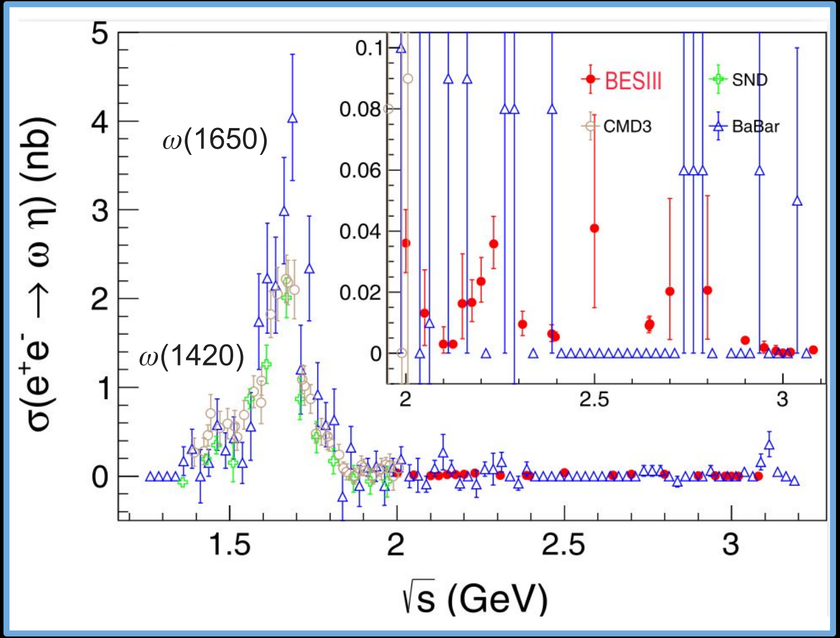
Possible Isoscalar Resonances Decaying to $\omega\eta$

l	J^{PC}		
0		1^{+-}	
1	0^{--}	1^{--}	2^{--}
2	1^{+-}	2^{+-}	3^{+-}
3	2^{--}	3^{--}	4^{--}

- Isoscalar resonances:
  - Need more evidence to properly establish them
  - Expected but never seen
  - Exotic mesons
  - Established but not seen in $\omega\eta$

Observation of Vector States

- Strong interaction conserves J^{PC}
- Enhancements in the cross section can be resonances; observation is not always straightforward
  - High level analysis is able to extract these quantum numbers

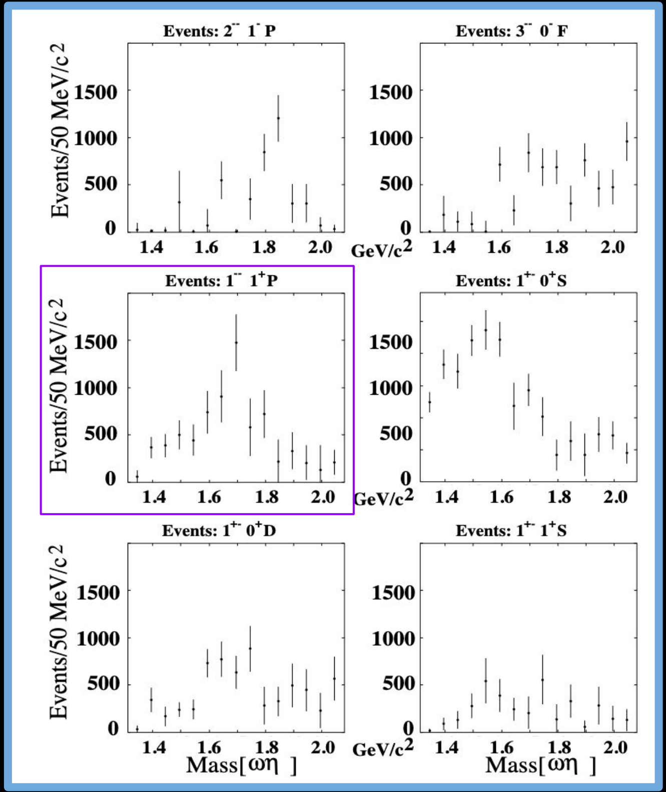


BESIII Collab. PR D99 112004 (2021)

The Power of Partial Wave Analysis (PWA)

- PWA decomposes the intensity into waves corresponding to their angular momentum
- Individual amplitude contributions are extracted
  - Overlapping estates can be separated
  - New enhancements on distributions can be revealed
- Identification of resonances' J^{PC}

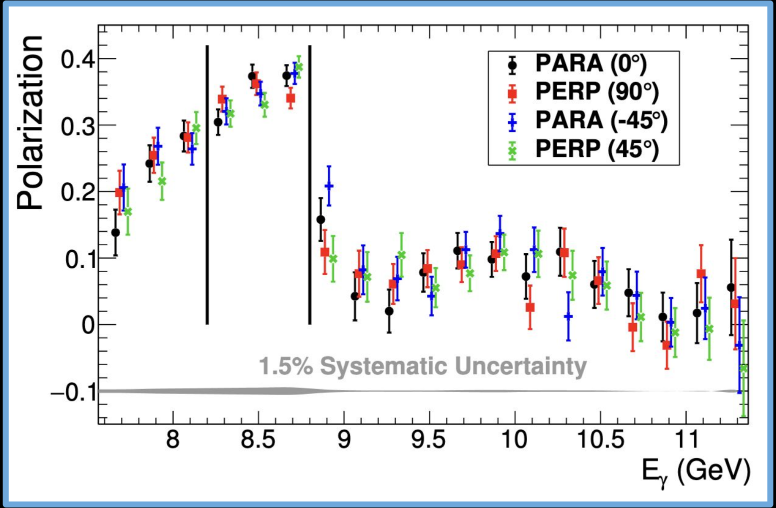
E852 PWA $\pi p \rightarrow \omega \eta$



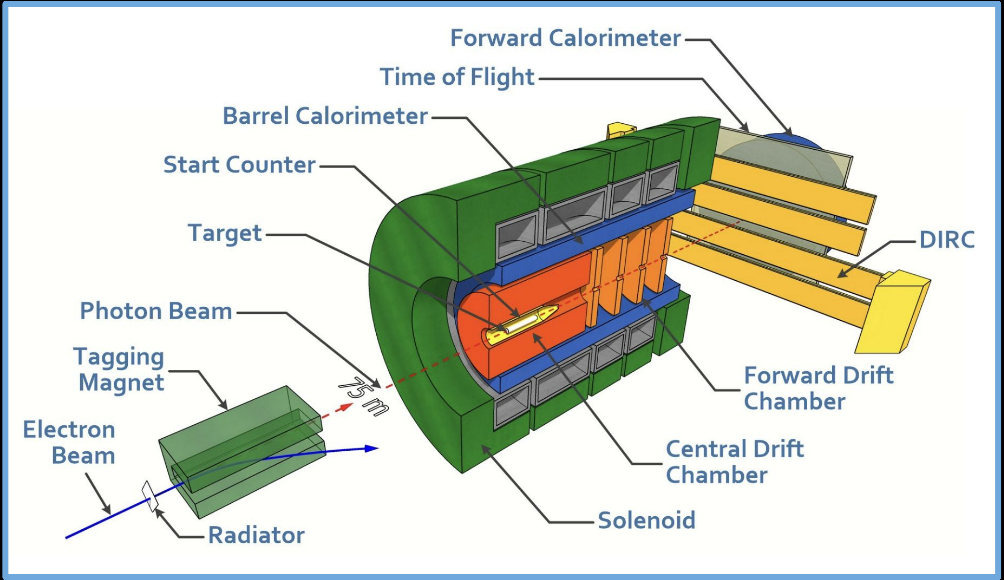
BNL-E852 PL B397 190 (2001)

GlueX Experiment

- Linearly polarized photon beam
- Almost complete angular coverage
- GlueX-I completed
- GlueX-II ~35%

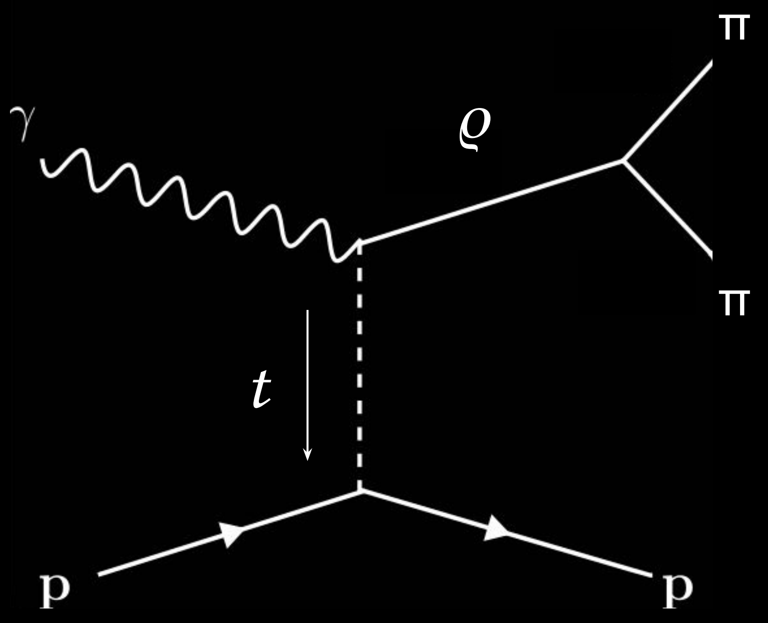


Nucl. Instrum. & Meth. A**987**, 164807 (2021)



SDMEs: a Precursor to PWA

- Spin Density Matrix Elements (SDMEs) analysis extracts the production mechanism of a single resonance
- SDMEs quantify the transfer of the photon spin to the vector meson
- The quantum numbers of the resonance are already known
- The range of the analysis is limited to the resonance



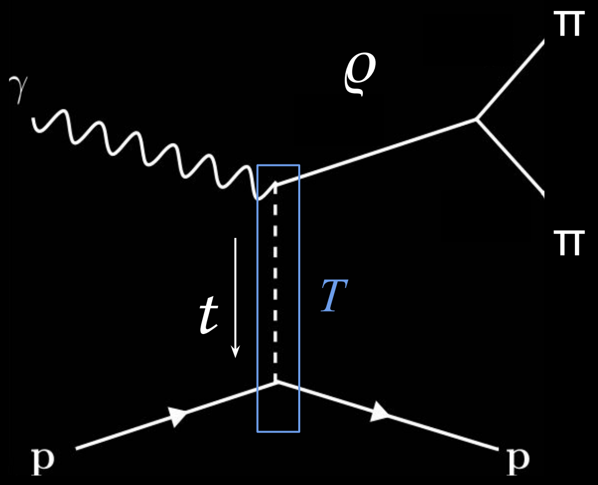
Calculating SDMEs

Photon
spin-density matrix

$$\rho(V) = T\,\rho(\gamma)\,T^*$$

Vector meson
spin-density matrix

Production amplitudes



Calculating SDMEs

Linear polarization

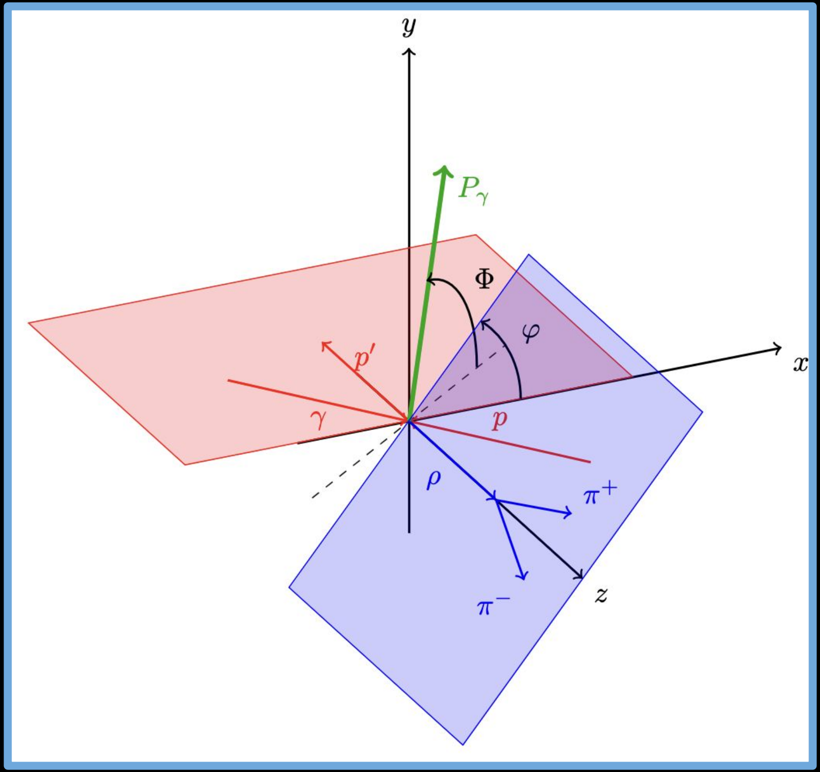
$$\rho(\gamma) = \frac{1}{2} I + \frac{1}{2} \overrightarrow{\mathbf{P}_\gamma} \cdot \vec{\sigma}$$

$$\overrightarrow{\mathbf{P}_\gamma} = P_\gamma(-\cos 2\Phi, -\sin 2\Phi, 0)$$

Polarization Fraction

Angle between polarization vector and production plane

Intensity = $W(\cos\vartheta, \varphi, \Phi)$



Extracting $\rho(770)$ SDMEs

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

Intensity

$$W^0(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^0_{10}\sin 2\vartheta\cos\varphi - \rho^0_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

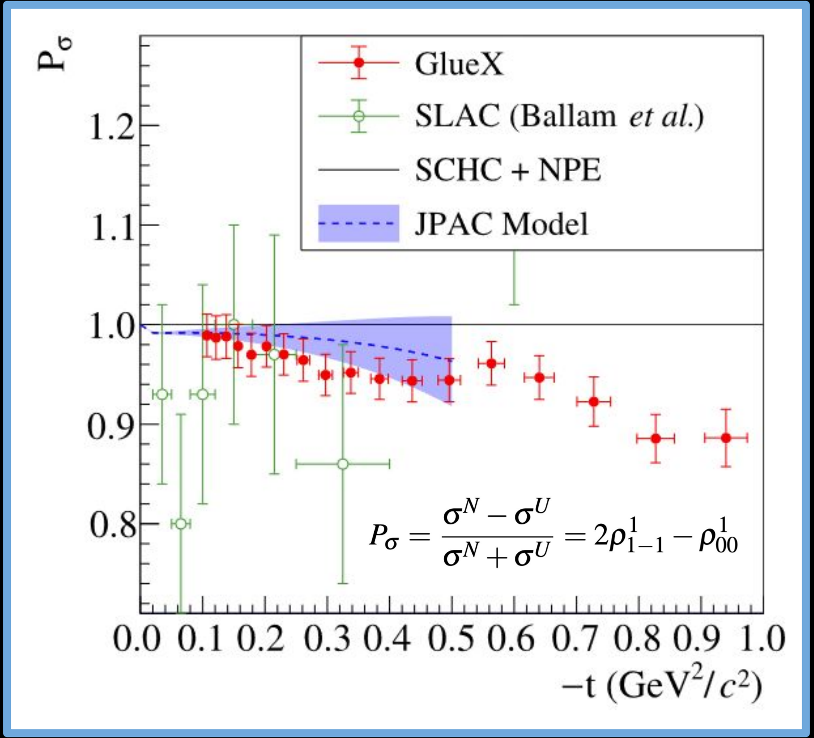
$$W^1(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\rho^1_{11}\sin^2\vartheta + \rho^1_{00}\cos^2\vartheta - \sqrt{2}\mathrm{Re}\rho^1_{10}\sin 2\vartheta\cos\varphi - \rho^1_{1-1}\sin^2\vartheta\cos 2\varphi\right)$$

$$W^2(\cos\vartheta,\varphi) = \frac{3}{4\pi}\left(\sqrt{2}\mathrm{Im}\rho^2_{10}\sin 2\vartheta\sin\varphi + \mathrm{Im}\rho^2_{1-1}\sin^2\vartheta\sin 2\varphi\right)$$

*SDMEs

Recent GlueX Results: ρ (770) SDMEs

- High degree of statistical precision
- Dominance of natural-parity exchange over the full t range
- Reasonable agreement with JPAC model
- Similar machinery as the PWA fits



GlueX Collaboration PhysRevC 108 (2023) 055204

From SDMEs to Moments to PWA

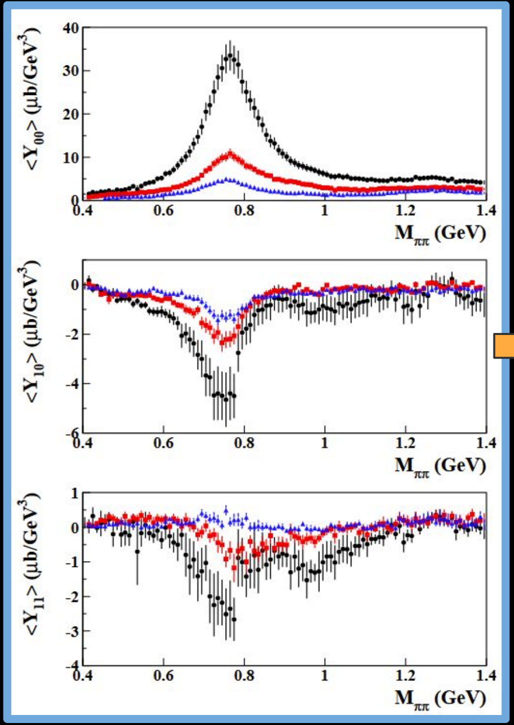
- Moments decompose the intensity in orthogonal functions
- Individual moments have no direct interpretation

$$H(L,M) = \sum \rho^{\ell\ell'}_{mm'} \left[\sqrt{\frac{2L+1}{4\pi}} \sqrt{\frac{2\ell'+1}{2\ell+1}} \langle \ell'0, L0, | \ell 0 \rangle \langle \ell' m', LM | \ell m \rangle \right]$$

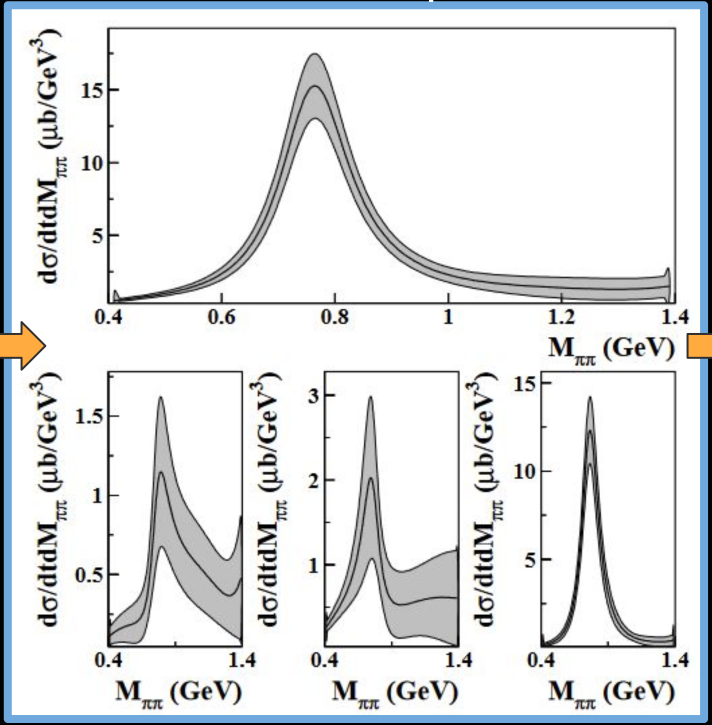
- ρ is the spin density matrix : $\rho(V) = T\rho(\gamma)T^*$ .The amplitudes T are the ones used in the PWA expansion
- Example: “Photoproduction of $\pi^+\pi^-$ meson pairs on the proton” by the CLAS Collaboration

From Moments to PWA to SDMEs

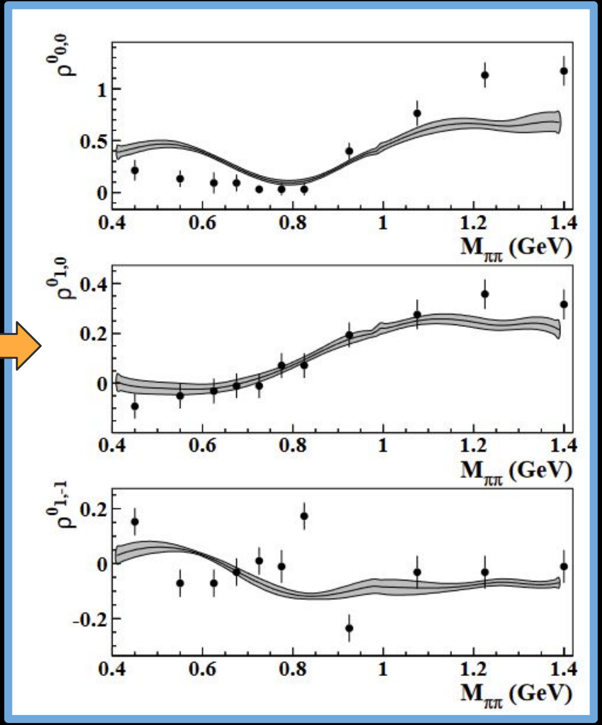
Moments



PWA Decomposition



SDMEs



CLAS Collaboration Phys RevD 80 (2009) 072005

Studying Excited Vectors

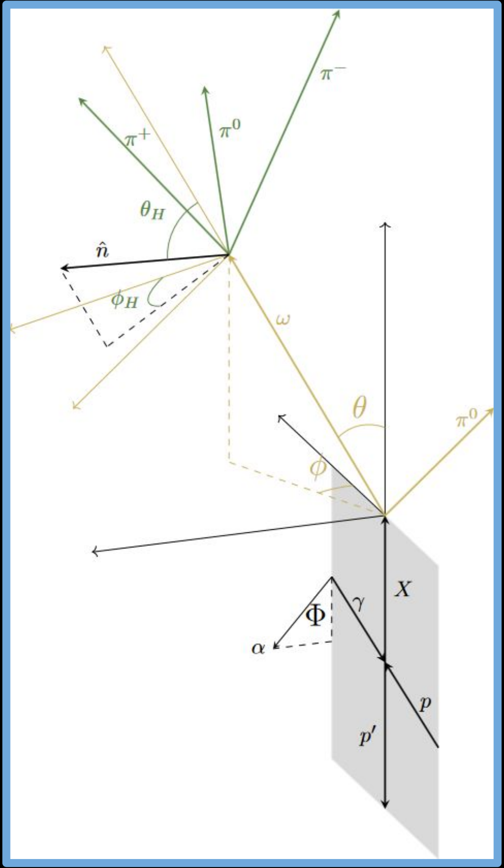
$$I(\Phi,\Omega,\Omega_H) \approx (1-P_\gamma)\left[\left|\sum_{J_\ell,m}[J_\ell]^{(-)}_m \mathrm{Im}(Z^m_{J_\ell})\right|^2 + \left|\sum_{J_\ell,m}[J_\ell]^{(+)}_m \mathrm{Re}(Z^m_{J_\ell})\right|^2\right]$$
$$+(1+P_\gamma)\left[\left|\sum_{J_\ell,m}[J_\ell]^{(+)}_m \mathrm{Im}(Z^m_{J_\ell})\right|^2 + \left|\sum_{J_\ell,m}[J_\ell]^{(-)}_m \mathrm{Re}(Z^m_{J_\ell})\right|^2\right]$$

$$Z^m_\ell(\Phi,\Omega,\Omega_H) = e^{-i\Phi} X^m_\ell(\Omega,\Omega_H)$$

Decay to vector-pseudoscalar

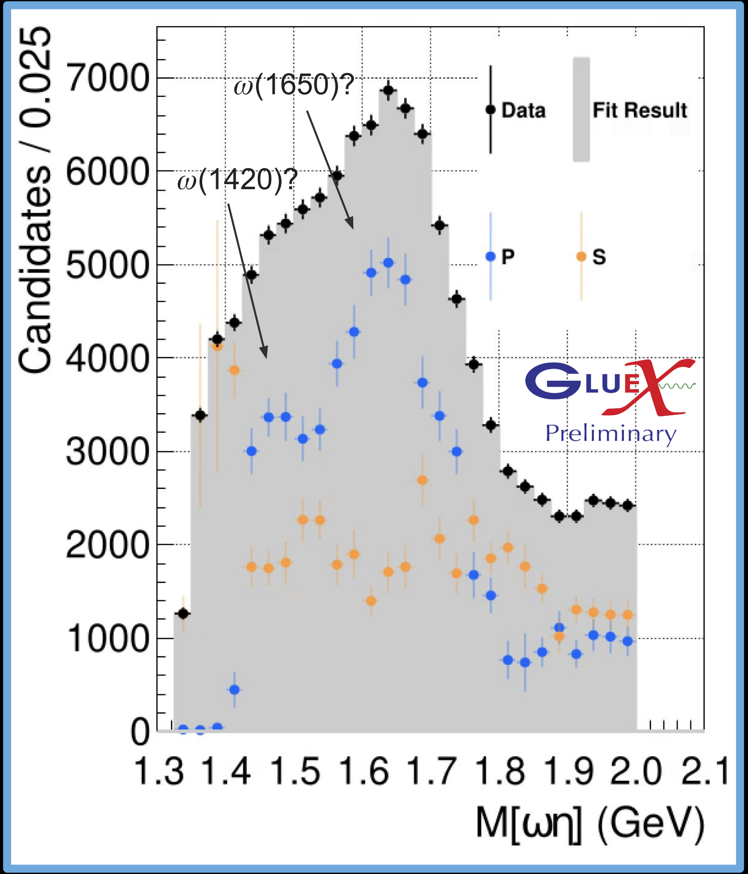
Decay of vector

- natural (unnatural) parity exchange

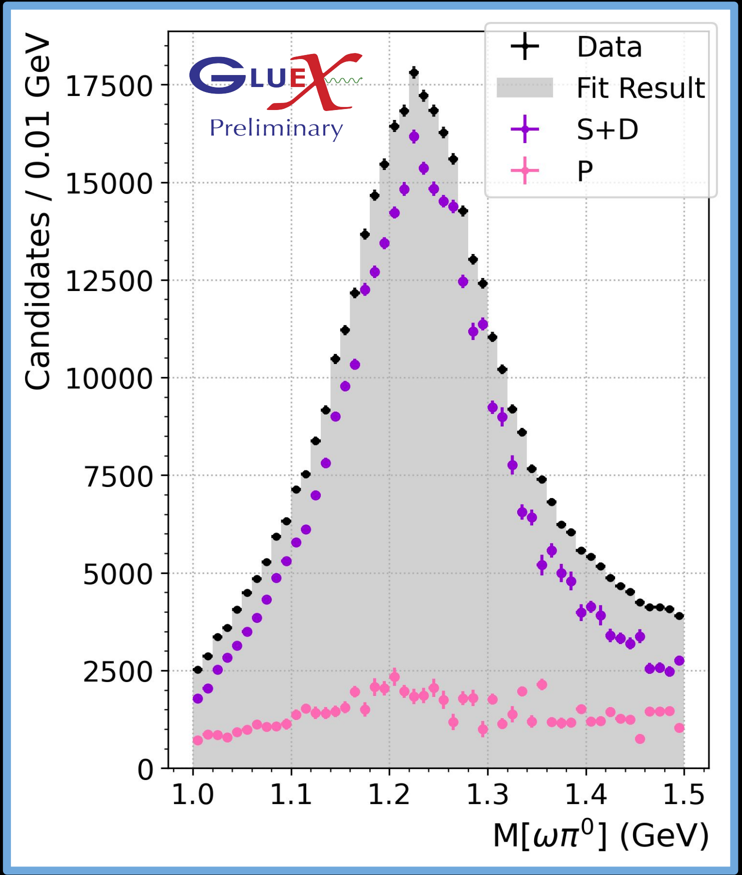


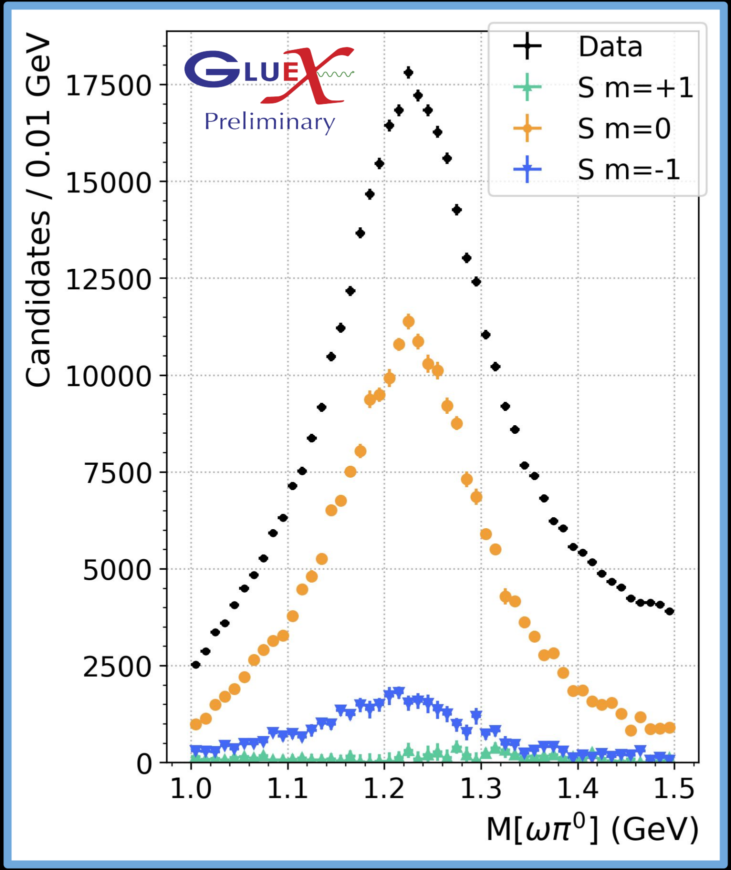
GlueX-I PWA of $\omega\eta$

- Very preliminary results
  - Project in exploratory stage
- Limited wave set with expected dominant waves
- Structure present in the 1^{--} P wave where the ω(1420) & ω(1650) are expected



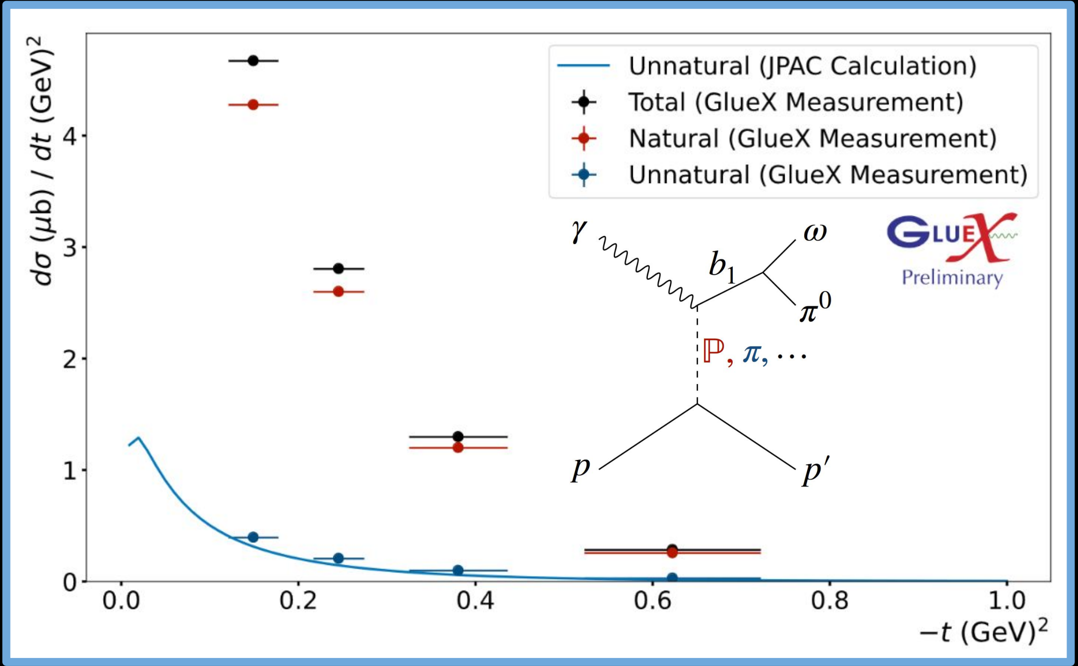
GlueX-I PWA of $b_1 \rightarrow \omega\pi^0$





GlueX-I PWA of $b_1 \rightarrow \omega\pi^0$

- PWA allows the extraction of natural and unnatural cross-sections
- Surprising contribution of natural parity
- Good agreement with JPAC model



Summary and Future Work

- Vector mesons could be key in understanding hybrid mesons
- PWA is challenging but offers a straight interpretation of the results
- SDMEs help build up to PWA and extract the production mechanisms
  - GlueX was able to extract the ρ SDMEs to high statistical precision
- Vector-pseudoscalar analysis add more layers of complexity
  - The $\omega\eta$ channel shows promising structure in the P wave
  - The $\omega\pi^0$ channel allows the extraction of the b_1 cross section; an important resonance in the search of the π_1 exotic state
  - The charged $\omega\pi$ channel is pushing the boundaries of amplitude analysis at GlueX

Backup

A Bigger Challenge: Charged $\omega\pi \rightarrow b_1$

- A charged b_1 recoiling from a Δ requires understanding of upper and lower vertex
- Understanding of the SDMEs of the lower vertex has led to advancements to build the amplitudes