$b_1(1235)$ Photoproduction at GlueX

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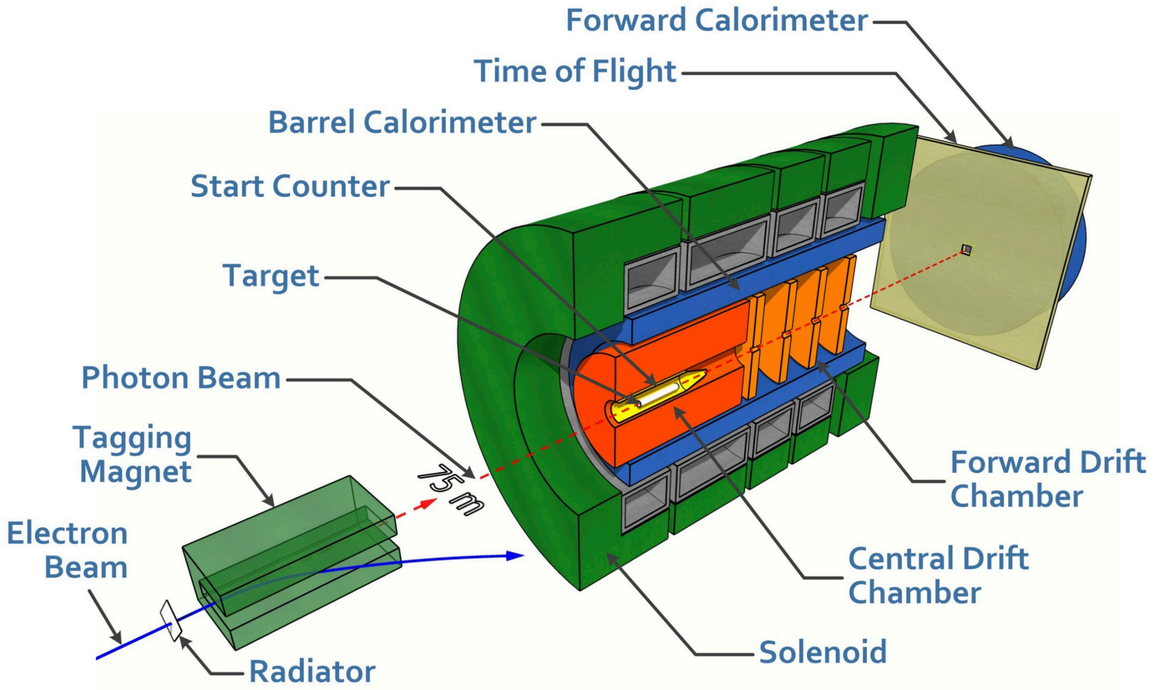
GlueX

Polarized Photoproduction Experiment in Hall D

- Goal: measure and understand the light quark meson spectrum, search for exotic mesons
- Linear polarization (~35%) allows insight into production mechanisms
- Near-hermetic acceptance allows reconstruction and analysis of exclusive final states
- Large dataset collected by three experimental phases allows study of broad range of physics
  - GlueX-I: $\mathscr{L} = 125$ pb^{-1} (these results)
  - GlueX-II (ongoing): $\mathscr{L} \sim$ 3x GlueX-I (so far)
  - GlueX-III (2027+): $\mathscr{L} \sim$ 3x GlueX-I,II (projection)

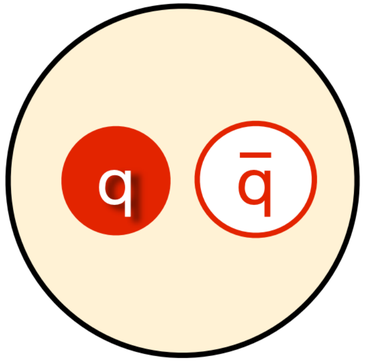


GlueX: NIM A 987, 164807 (2021)

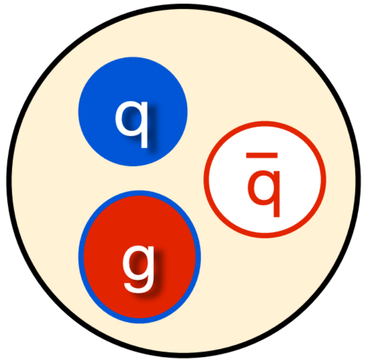
Exotic Mesons

- QCD allows for hybrid mesons, which have gluonic degrees of freedom contributing to the wavefunction
  - Allows for exotic quantum numbers, forbidden to $q\bar{q}$ pair
  - $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$
- Exotic quantum numbers are a “smoking gun” for non-$q\bar{q}$ systems
- NB: Not all hybrid mesons have exotic quantum numbers!

$$J = \left| \vec{L} + \vec{S} \right|$$
$$P = (-1)^{L+1}$$
$$C = (-1)^{L+S}$$



Meson

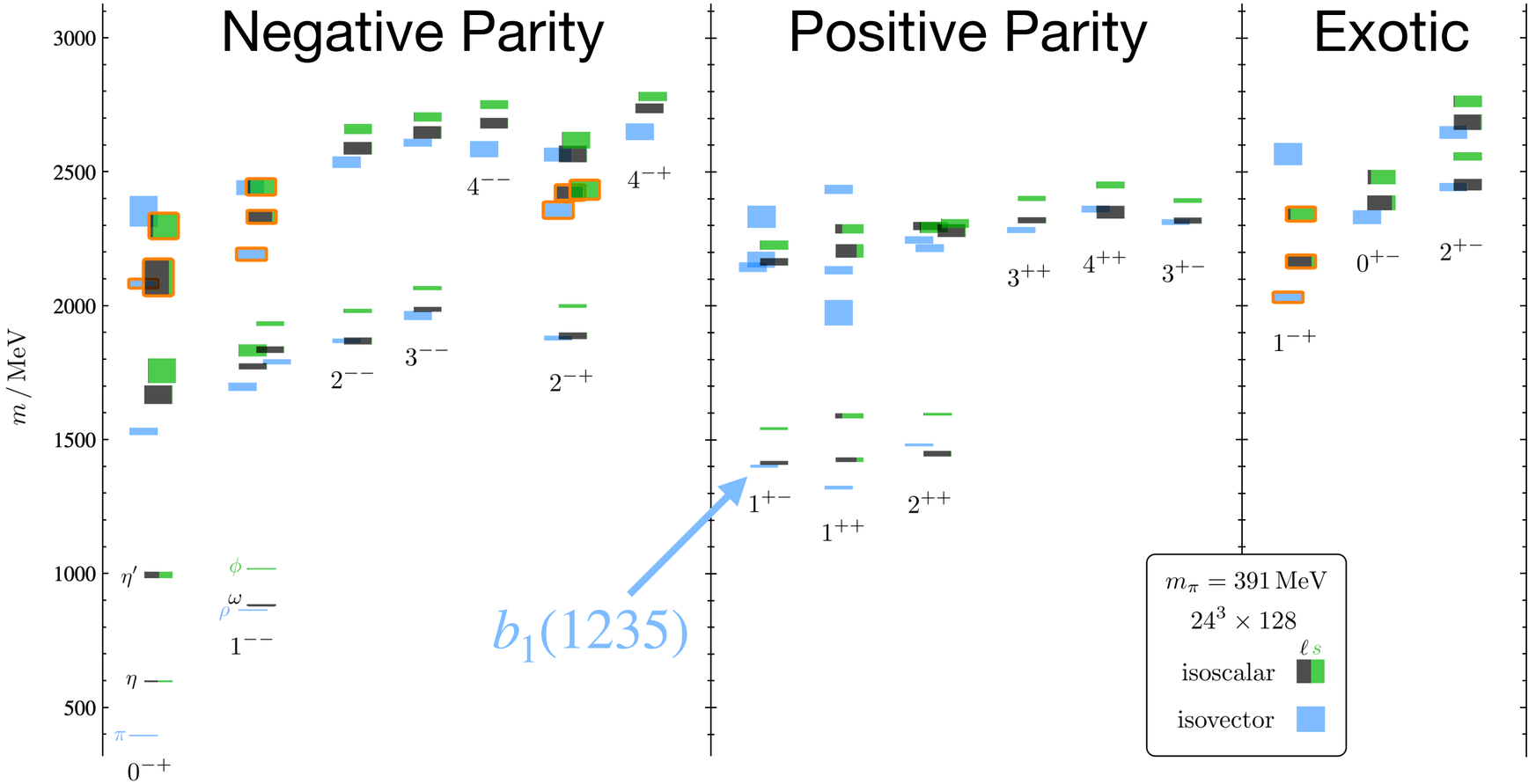


Hybrid Meson

Lattice QCD

Mass Spectrum of Light Quark Mesons

- Lattice calculation from first principles QCD indicates presence of hybrid mesons
- Orange outlines identify supermultiplet of lowest-lying hybrids

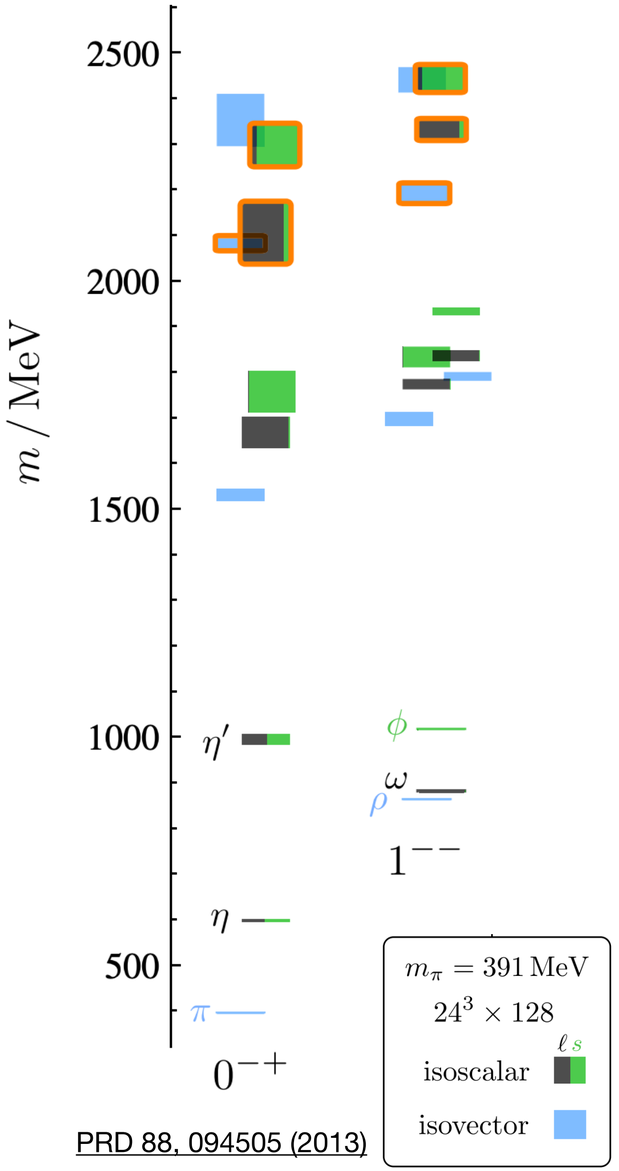


PRD 88, 094505 (2013)

Why Analyze the b_1?

We're interested in hybrids, right?

- Large photoproduction cross section - can act as a reference signal for weaker, potentially hybrid signals in the same decay channel
  - For example, multiple hybrids are predicted to have conventional vector (1^{--}) quantum numbers
  - Measurement of their interference with the b_1 could aid in their identification
- The strong $b_1 \to \omega\pi$ signal also provides a testing ground for this amplitude fit machinery, which can be used for other channels with similar spin structure

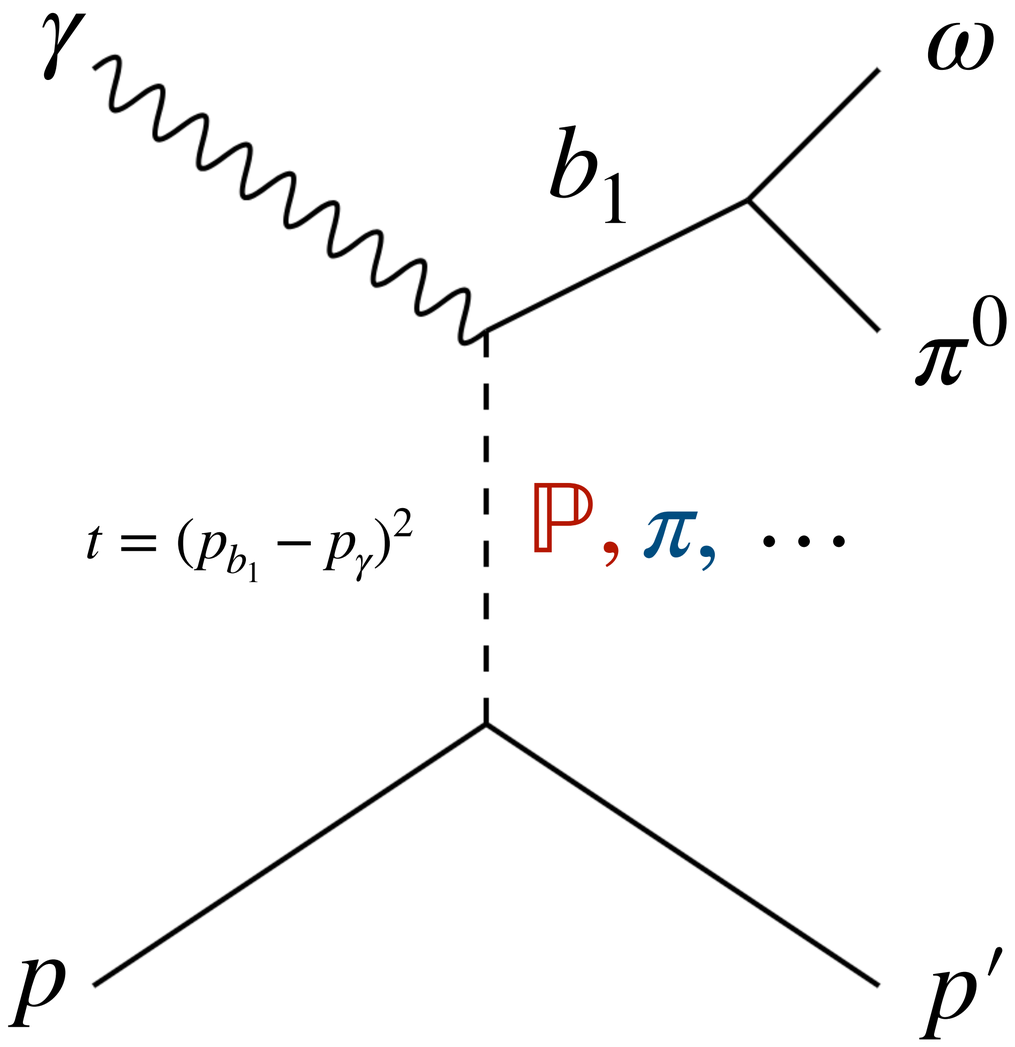


PRD 88, 094505 (2013)

Production Mechanisms

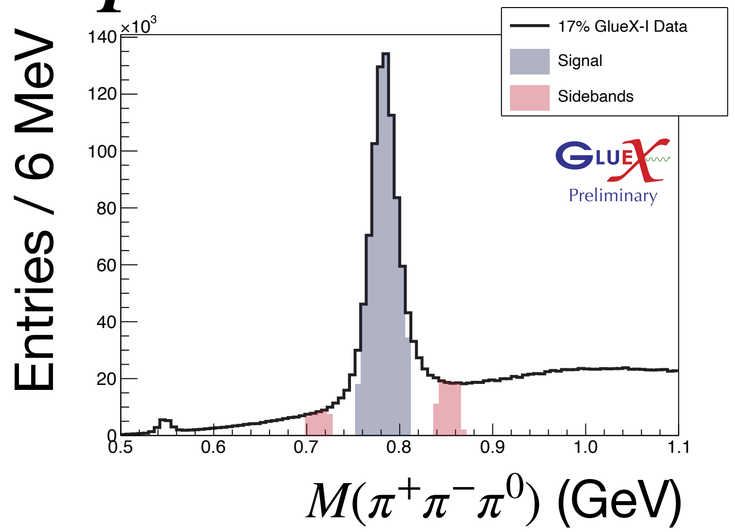
Which ones are preferred in nature?

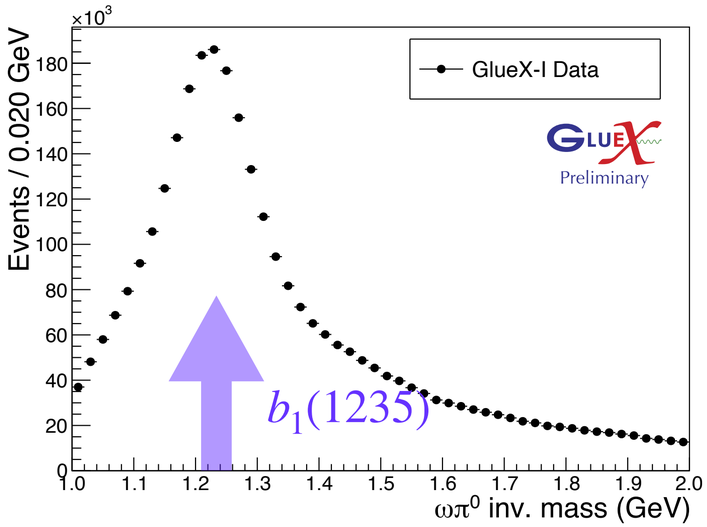
- Photoproduction at GlueX energies proceeds via exchange of a virtual meson in the *t*-channel
- By measuring the angle between the production plane and beam polarization, we can extract the naturality of this virtual exchange particle
- Naturality: $P(-1)^J = \pm 1$
  - Natural mesons: $\mathbb{P}, \rho, \omega, \phi, f_2, a_2 \ldots$
  - Unnatural mesons: $\pi, \eta, b_1, h_1 \ldots$
- By measuring which type of exchange is preferred in nature, we can place constraints on photocouplings



Amplitude Analysis of $\gamma p \rightarrow \omega\pi^0 p$

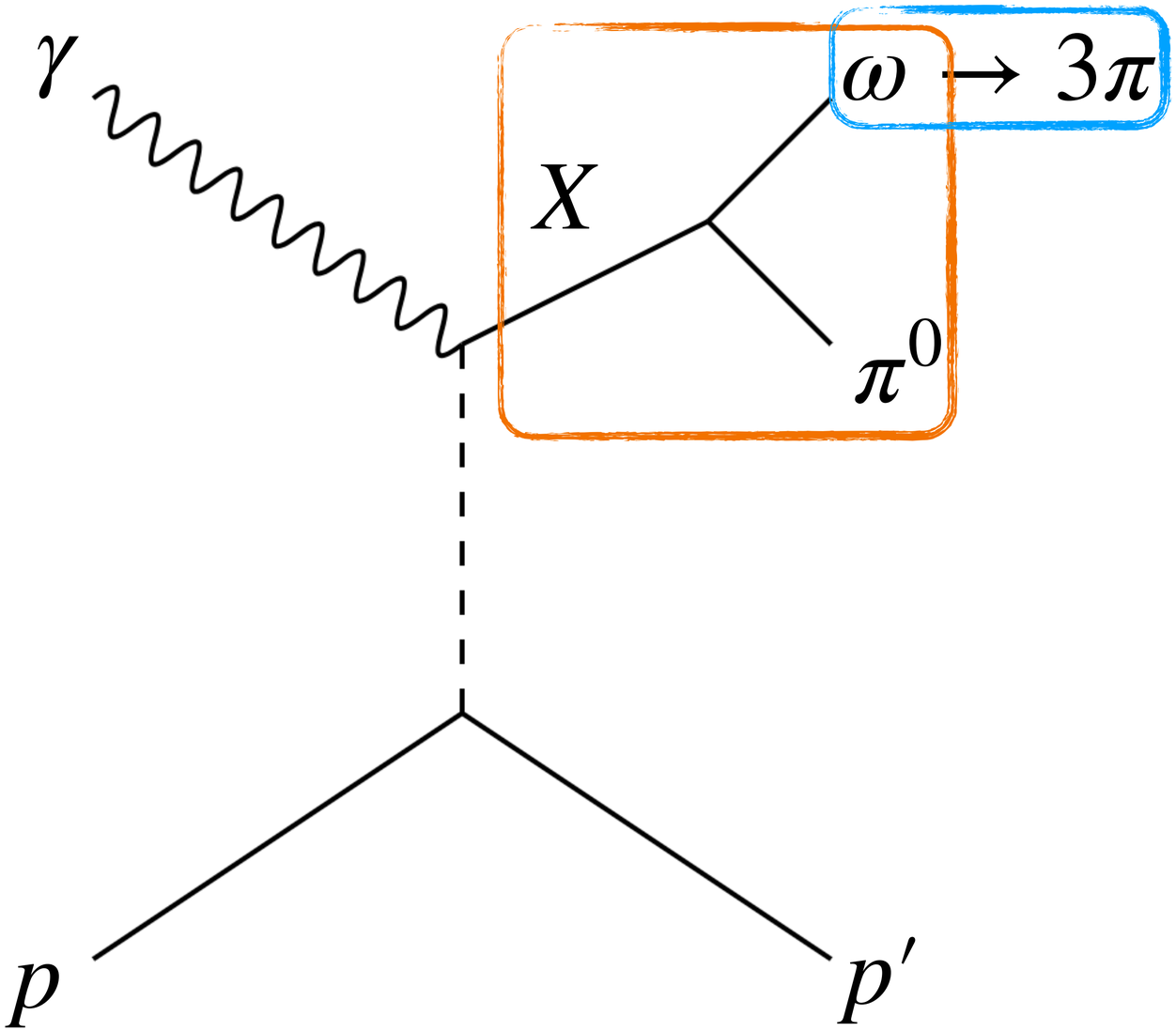
- Reconstruct exclusive $\pi^+\pi^-\pi^0\pi^0 p$ final state
- Sideband subtract the $\pi^+\pi^-\pi^0$ mass around the ω peak - identifies $\omega\pi^0$ events
- Split data into bins of $M(\omega\pi^0)$ and $-t$
- Perform 5-dimensional angular fit to resonance amplitude model





Production & Decay Angles

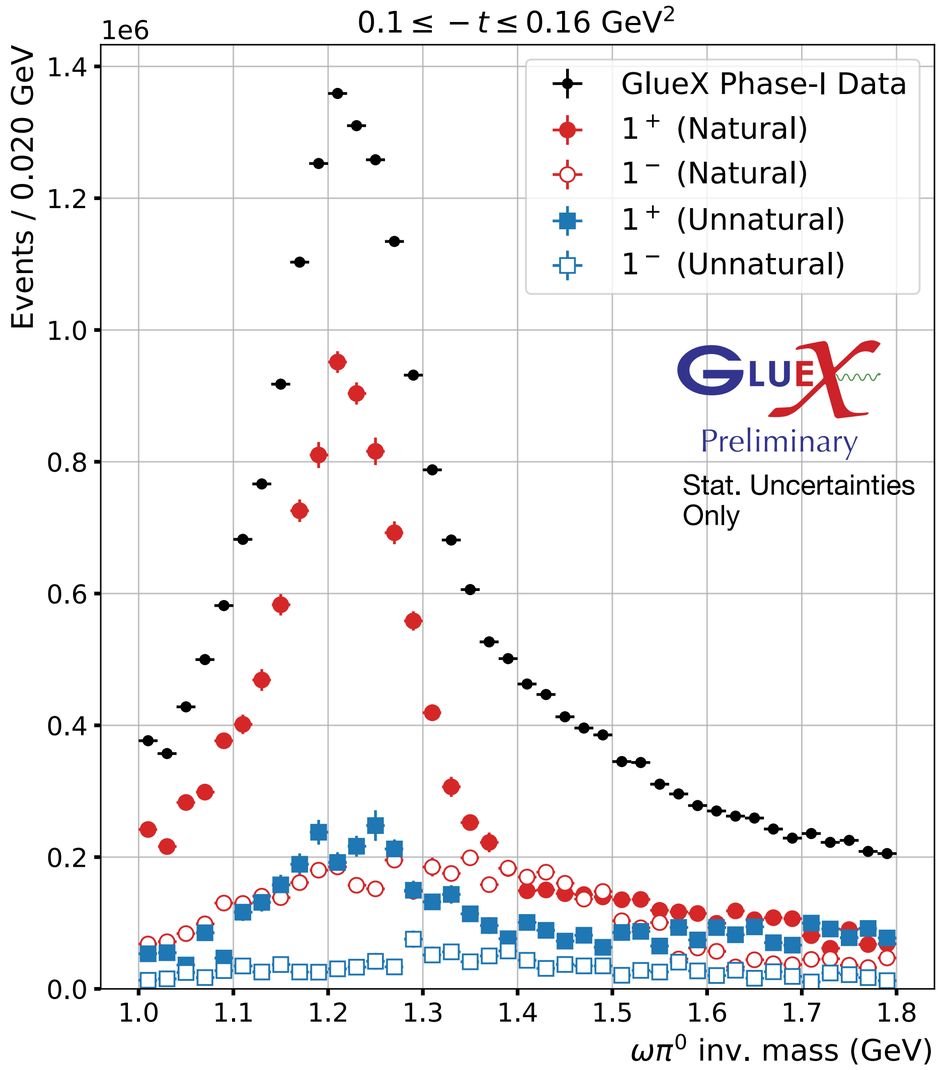
- The production and decay of $\omega\pi^0$ against a proton requires 5 angles to properly describe
- The decay of $X \to \omega\pi^0$ is described by $\Omega = (\theta, \phi)$
- The decay of $\omega \to 3\pi$ is described by $\Omega_H = (\theta_H, \phi_H)$
- And Φ is the angle between the beam polarization and production plane



Mass Independent Fit Results

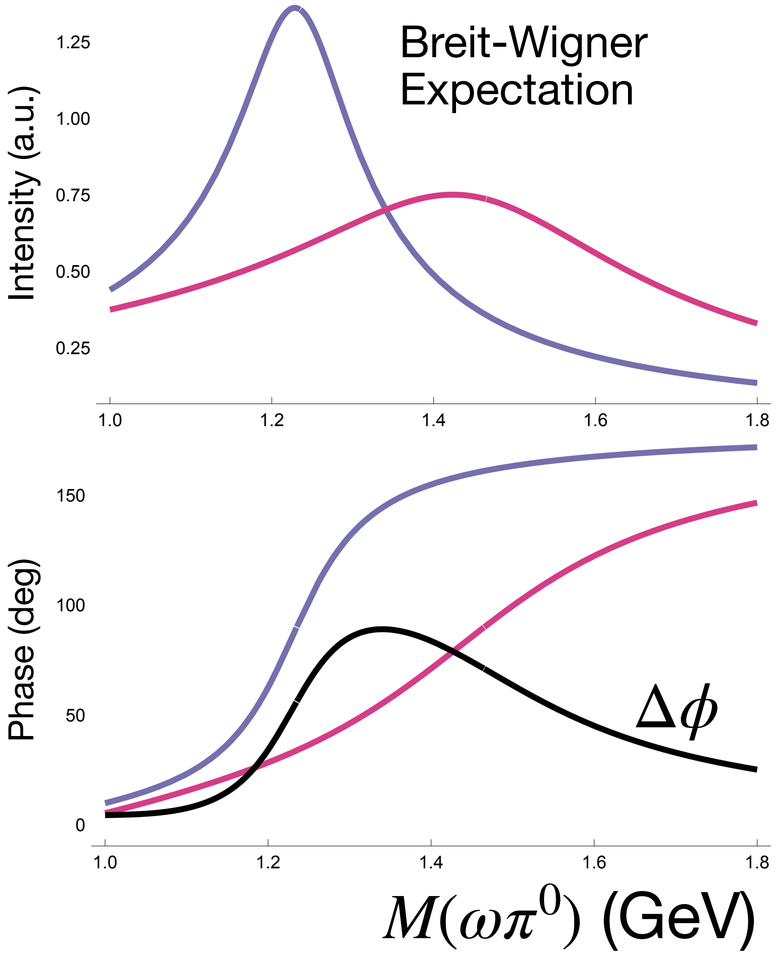
Statistically independent datasets

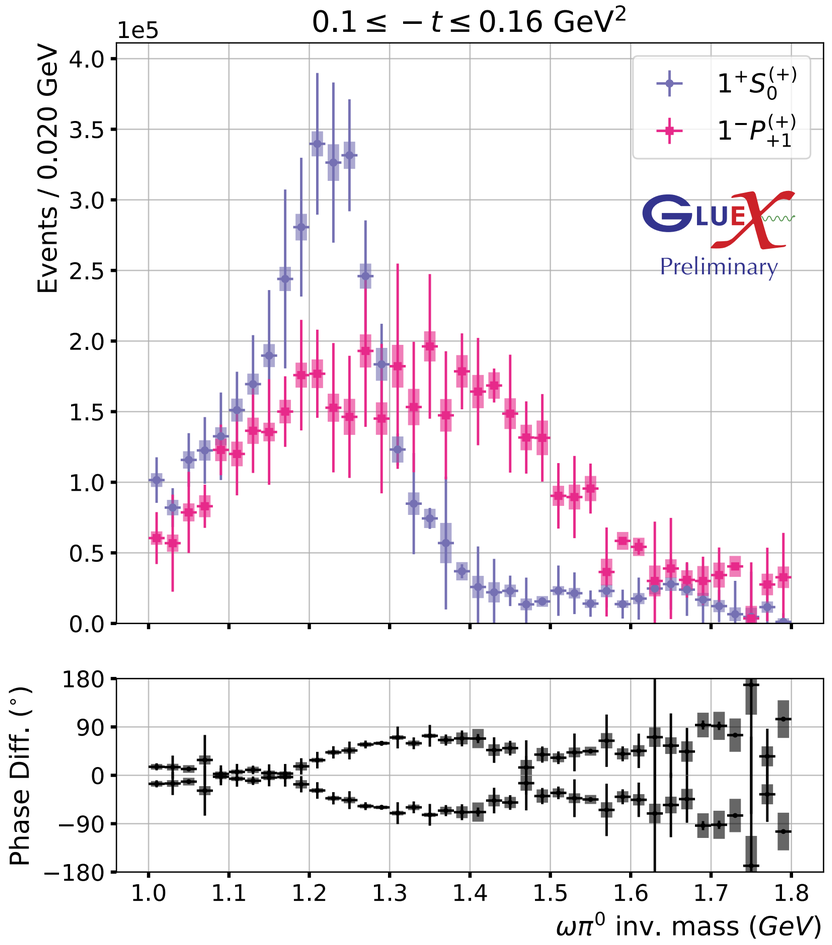
- Break fit results down by naturality of exchange and quantum numbers of produced wave
- Neutral b_1 ($J^{PC} = 1^{+-}$) production is dominated by natural parity exchange
- Vector ($J^{PC} = 1^{--}$) production is also natural exchange dominant
- Can study interference between the dominant partial waves of the b_1 and vector



Studying Resonances Through Interference

- Dominant partial waves from b_1 and vector contributions
- Phase difference displays resonant behavior
- Analysis assumes nothing about resonances in $\omega\pi^0$

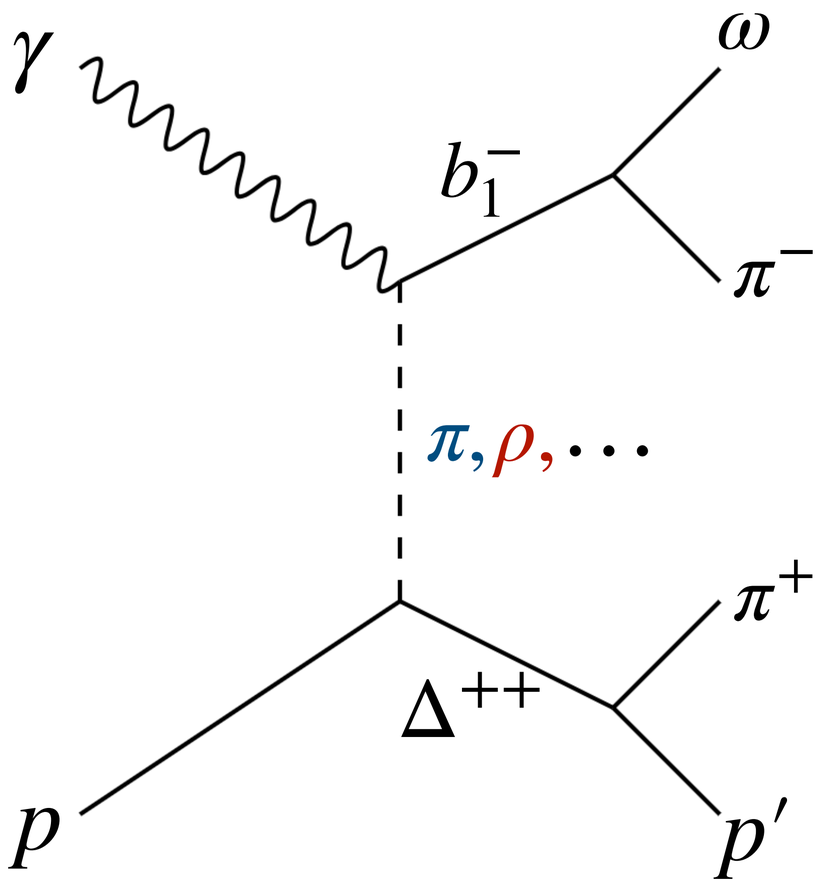




K. Scheuer, Ph.D. Thesis (2026)

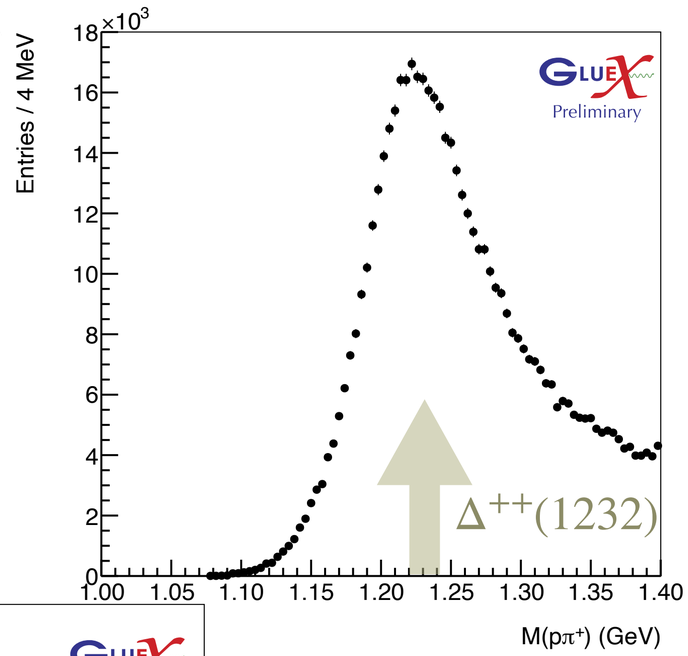
Amplitude Analysis of $\gamma p \to \omega \pi^- \Delta^{++}$

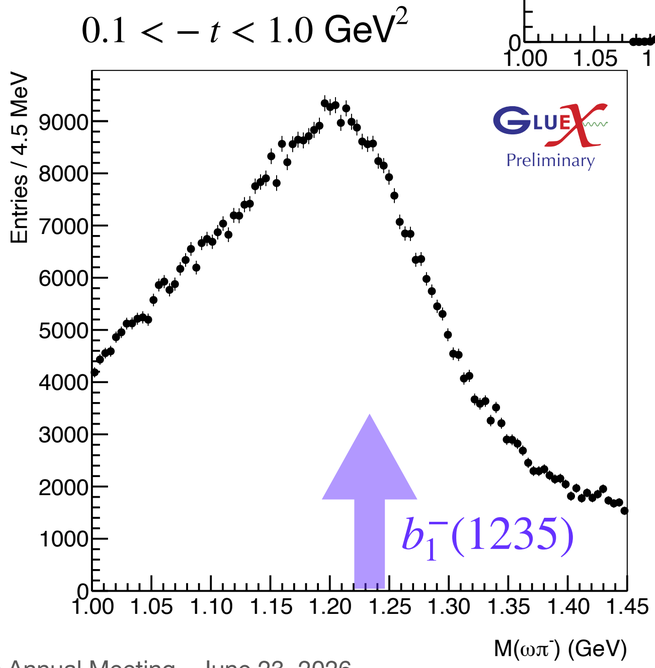
- The b_1 is an isovector - charged versions can also be studied
- Charged exchange mechanism changes requirements on the virtual exchange particle
  - Nothing electrically neutral, $\mathbb{P}$ exchange not possible
  - C-parity doesn't need to be conserved - ρ exchange is now an option
- Consider b_1^- recoiling off a $\Delta^{++}(1232)$
  - Decay of recoil Δ^{++} introduces another pair of angles



Amplitude Analysis of $\gamma p \rightarrow \omega \pi^- \Delta^{++}$

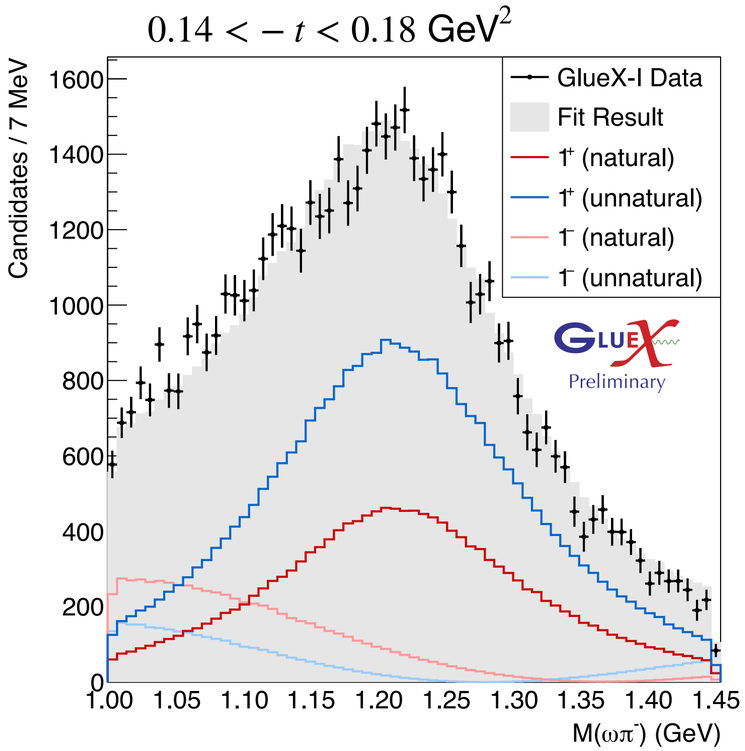
- Reconstruct exclusive $\omega \pi^- \Delta^{++}$ final state
- Similar sideband subtraction as in the neutral case, with additional requirement that $M(p\pi^+)$ is consistent with production of a $\Delta^{++}(1235)$
- Yields 560k $\omega \pi^-$ events - roughly a factor of 10 fewer than the neutral channel

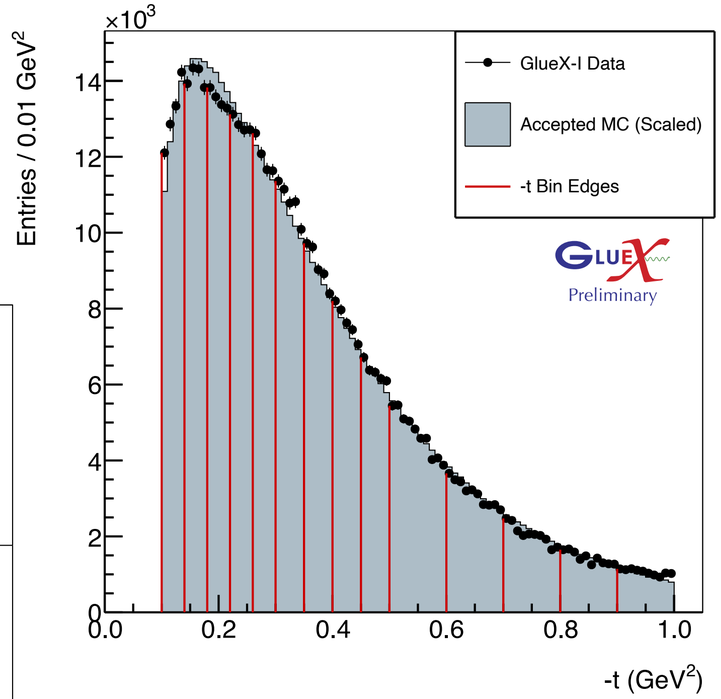




Amplitude Analysis of $\gamma p \rightarrow \omega \pi^- \Delta^{++}$

- Divide data into 14 bins in momentum transfer $-t$
- Fit range around the b_1^- mass peak assuming resonant behavior in $\omega\pi^-$
- b_1^- amplitude is described by a relativistic Breit-Wigner function
- Vector ($J^P = 1^-$) amplitude is described by a complex linear function

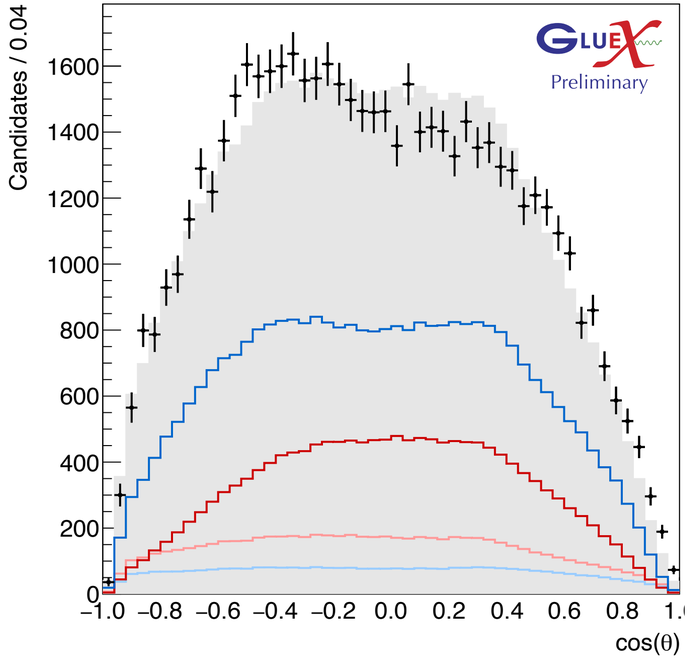


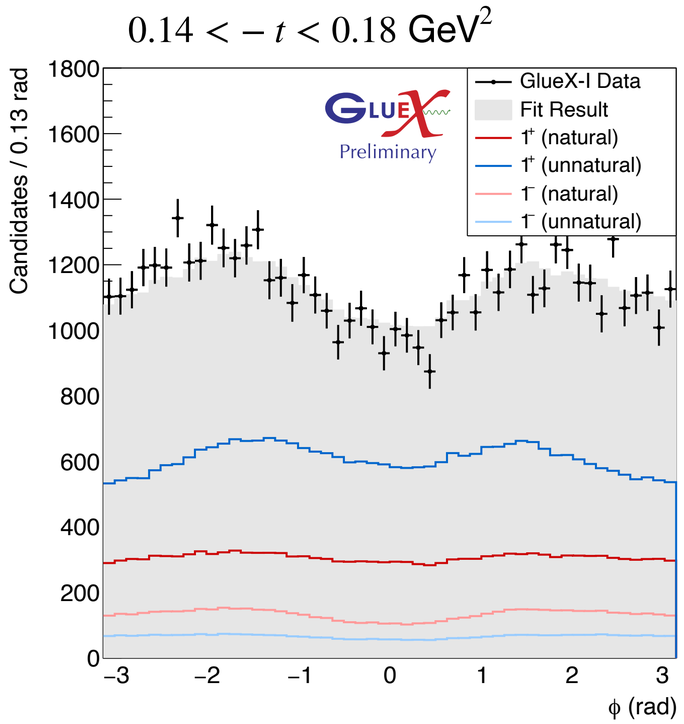


Amplitude Analysis of $\omega\pi^-$

Mass Dependent Fit

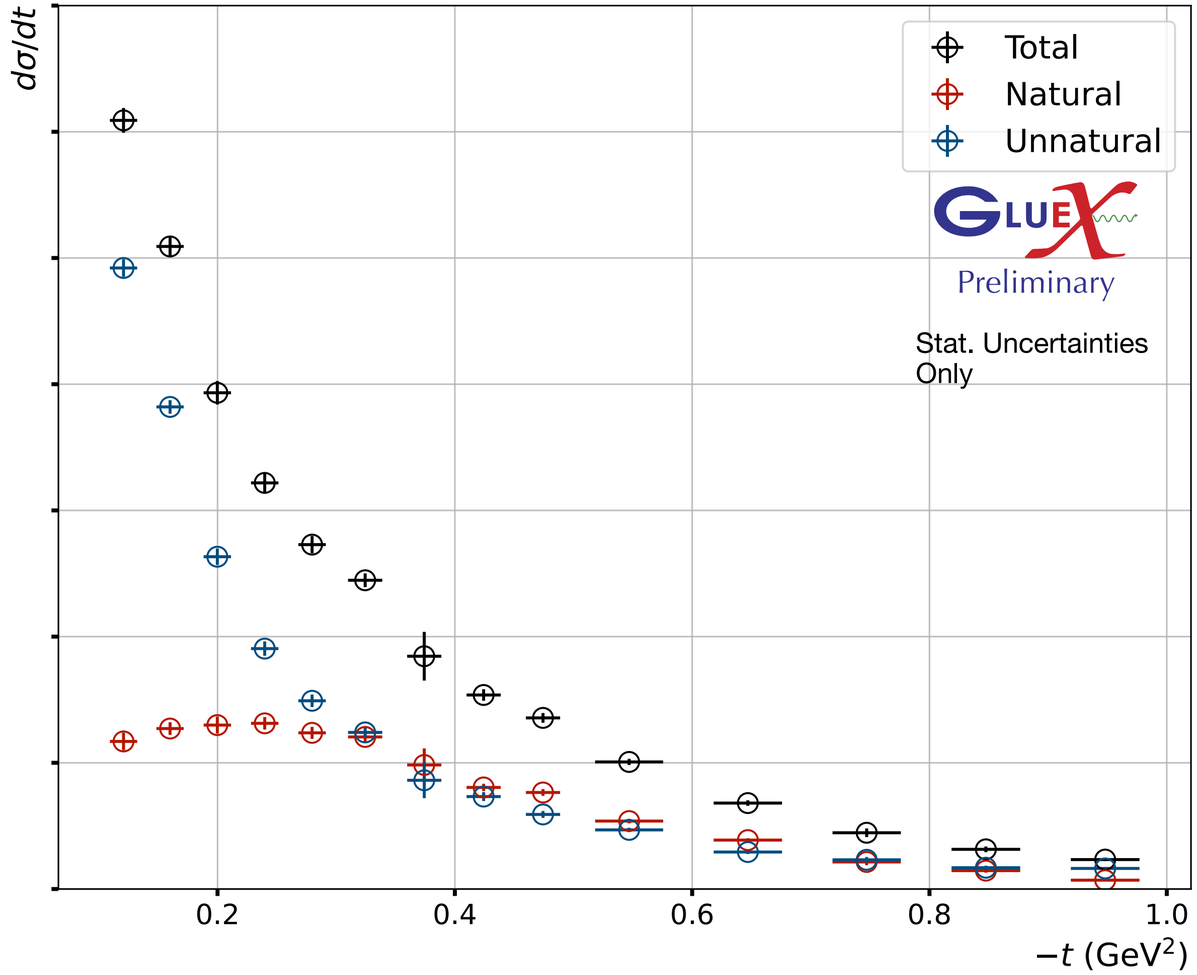
- Meson decay angles are described by a resonance amplitude model, similar to the neutral b_1
- Right: Intensities projected onto angles describing the decay $X^- \to \omega\pi^-$
- $\Delta^{++} \to p\pi^+$ angular distribution is also included in the fit





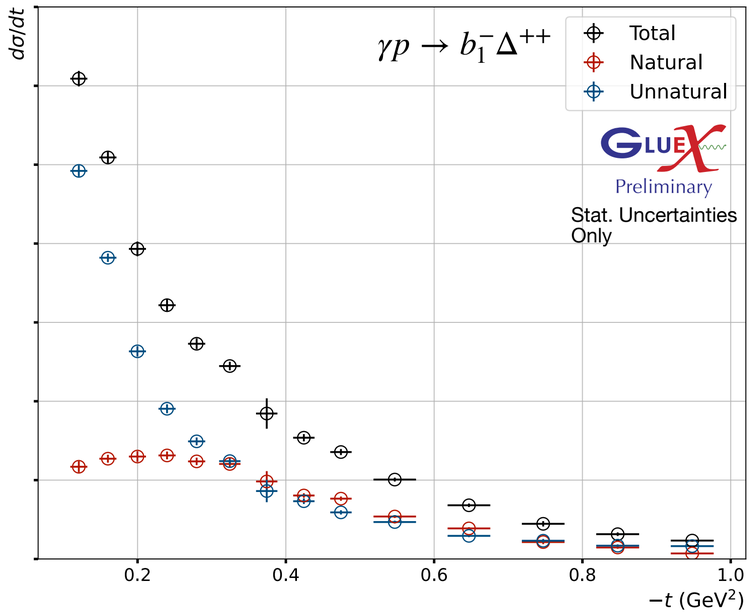
Differential Cross Section of $\gamma p \rightarrow b_1^- \Delta^{++}$

- Unnatural exchange is dominant at very low -*t*
  - The most likely exchange particles are $\pi^{\pm}$ and $\rho^{\pm}$
- Working with JPAC to develop phenomenological models of b_1 production
  - At low -*t*, observe dominance of unnatural exchange in the charged mode, while natural exchange is dominant in the neutral case

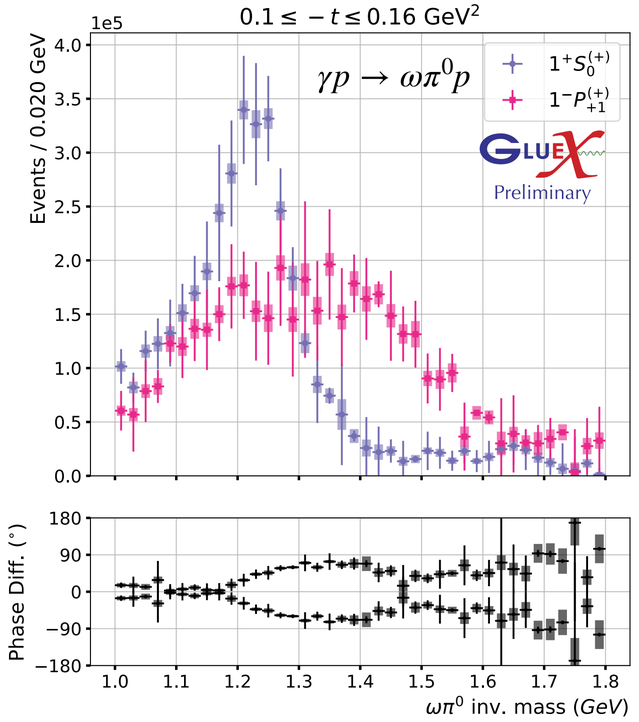


Summary

- Measured the b_1^- cross section, separated by production mechanisms
  - Unnatural exchange is preferred at low -t, unlike in the neutral channel, where natural exchange is dominant
- Measured interference between neutral b_1 and excited vector background

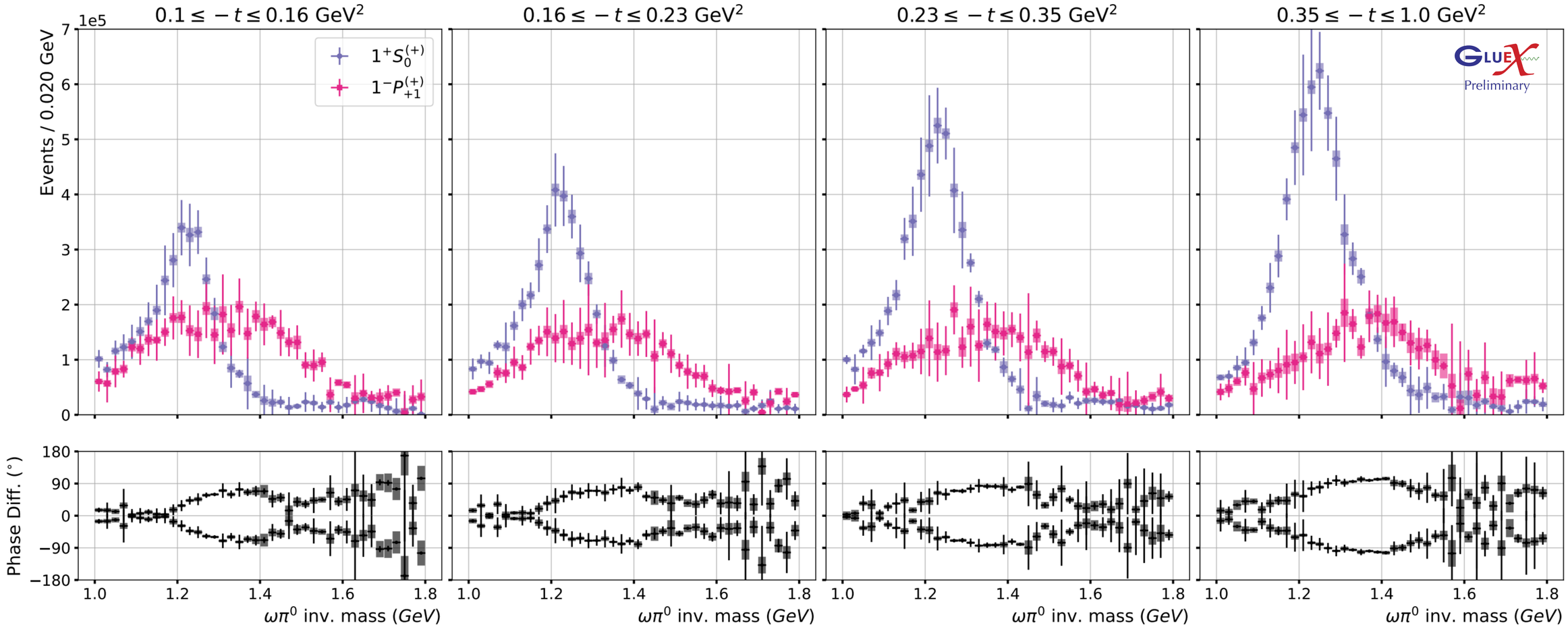


GlueX gratefully acknowledges the support of several funding agencies and computing facilities: gluex.org/thanks



Backup

b_1 Via Analysis of $\omega\pi^0$



K. Scheuer, Ph.D. Thesis (2026)

Cross Section from Amplitude Fits

$$\frac{d\sigma}{dt} = \frac{N_{obs}}{\epsilon} \frac{1}{\mathscr{L}\mathscr{B}(\omega \to 3\pi)\mathscr{B}(\Delta^{++} \to p\pi^{+})f_{b_1}f_{\Delta^{++}}\Delta t}$$

Fit result

Vector-Pseudoscalar Amplitudes

Description of the meson vertex

$$I \propto \left(1 - P_\gamma\right) \left[\left| \sum_{j,m} \left[J^P\right]_m^{(-)} ImZ_m^j\left(\Phi, \Omega, \Omega_H\right) \right|^2 + \left| \sum_{j,m} \left[J^P\right]_m^{(+)} ReZ_m^j\left(\Phi, \Omega, \Omega_H\right) \right|^2 \right]$$

$$+\left(1 + P_\gamma\right) \left[\left| \sum_{j,m} \left[J^P\right]_m^{(+)} ImZ_m^j\left(\Phi, \Omega, \Omega_H\right) \right|^2 + \left| \sum_{j,m} \left[J^P\right]_m^{(-)} ReZ_m^j\left(\Phi, \Omega, \Omega_H\right) \right|^2 \right]$$

$$Z_m^j\left(\Phi, \Omega, \Omega_H\right) = e^{-i\Phi} \sum_\lambda F_\lambda^j D_{m,\lambda}^{J_j^*}(\Omega)\, Y_\lambda^1\left(\Omega_H\right) G$$

SDME Description

Description of Δ^{++} Decay

$$W(\Omega_p, \Phi) \propto \rho^0_{33} \sin^2\theta_p + \rho^0_{11}\left(\frac{1}{3} + \cos^2\theta_p\right) - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^0_{31} \sin 2\theta_p \cos\phi_p - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^0_{3-1} \sin^2\theta_p \cos 2\phi_p$$

$$-P_\gamma \cos 2\Phi \left[\rho^1_{33} \sin^2\theta_p + \rho^1_{11}\left(\frac{1}{3} + \cos^2\theta_p\right) - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^1_{31} \sin 2\theta_p \cos\phi_p - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^1_{3-1} \sin^2\theta_p \cos 2\phi_p\right]$$

$$-P_\gamma \sin 2\Phi \left[\frac{2}{\sqrt{3}}\mathrm{Im}\rho^2_{31} \sin 2\theta_p \sin\phi_p + \frac{2}{\sqrt{3}}\mathrm{Im}\rho^2_{3-1} \sin^2\theta_p \sin 2\phi_p\right]$$

NB: $\rho^0_{11} + \rho^0_{33} = \frac{1}{2}$ and $\Sigma = 2\left(\rho^1_{11} + \rho^1_{33}\right)$