

Search for Hybrid Mesons in Photoproduced $\eta\pi$ Systems at GlueX

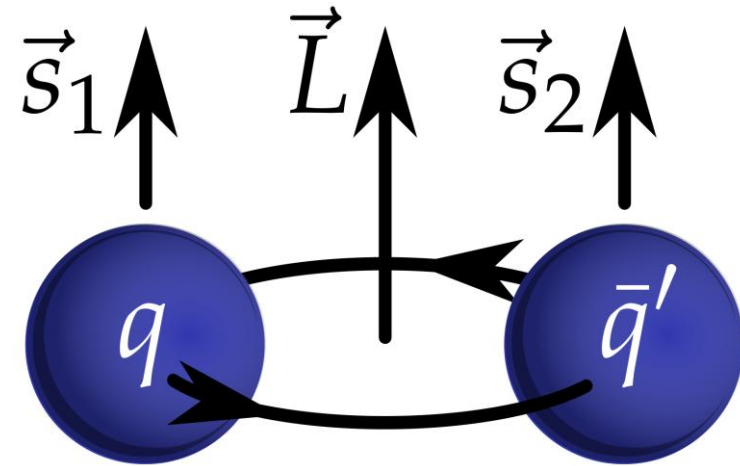
Nizar Septian

On behalf of the GlueX Collaboration

Hybrid Mesons

- **Conventional quark model** J^{PC} quantum number of a meson limited by:

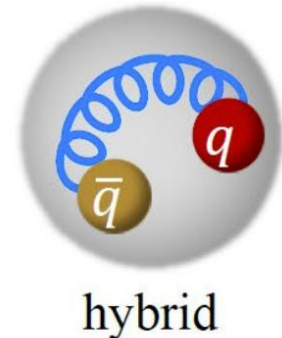
$$J = L + S, P = (-1)^{L+1}, C = (-1)^{L+S}$$
- **Hybrid mesons** contain gluonic excitations that contribute to the quantum numbers.
 - Hybrid mesons may have J^{PC} that are not allowed for conventional $q\bar{q}$ mesons.
- Studying **hybrid mesons** provides access to the role of gluonic excitation in hadrons.
- Observation of forbidden J^{PC} states:
 - Unambiguous evidence for non- $q\bar{q}$ mesons.



Exotic J^{PC} :

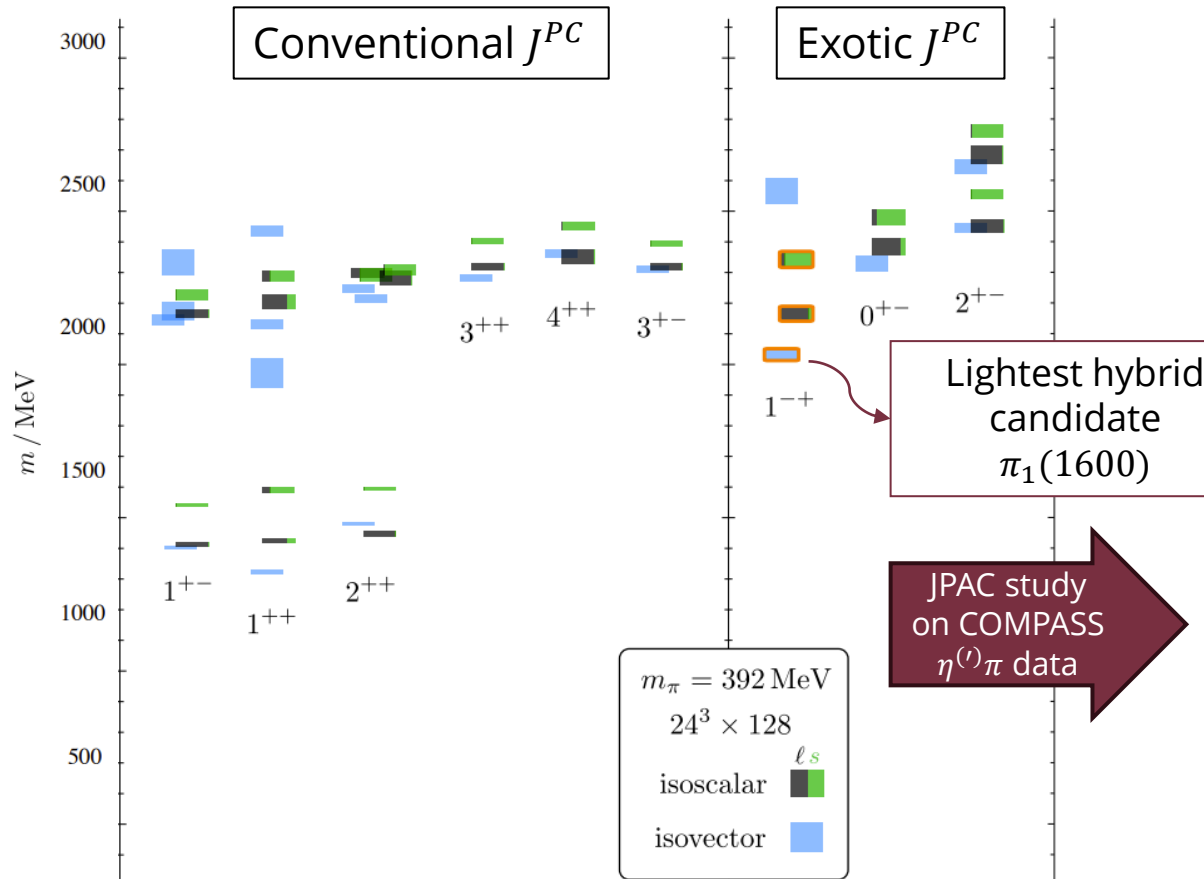
$$\underline{0^{+-}, 1^{-+}, 2^{+-}, \dots}$$

Experimental signature

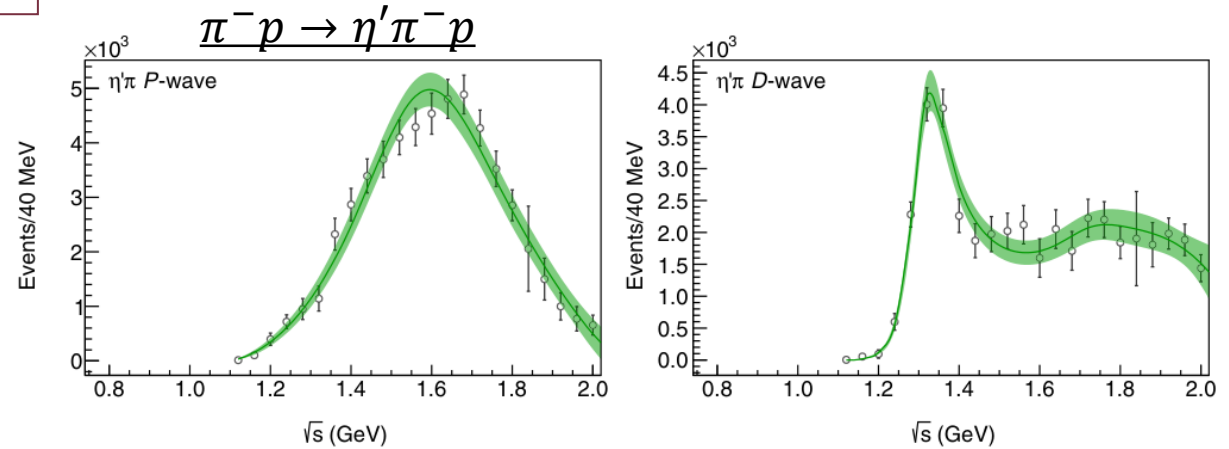
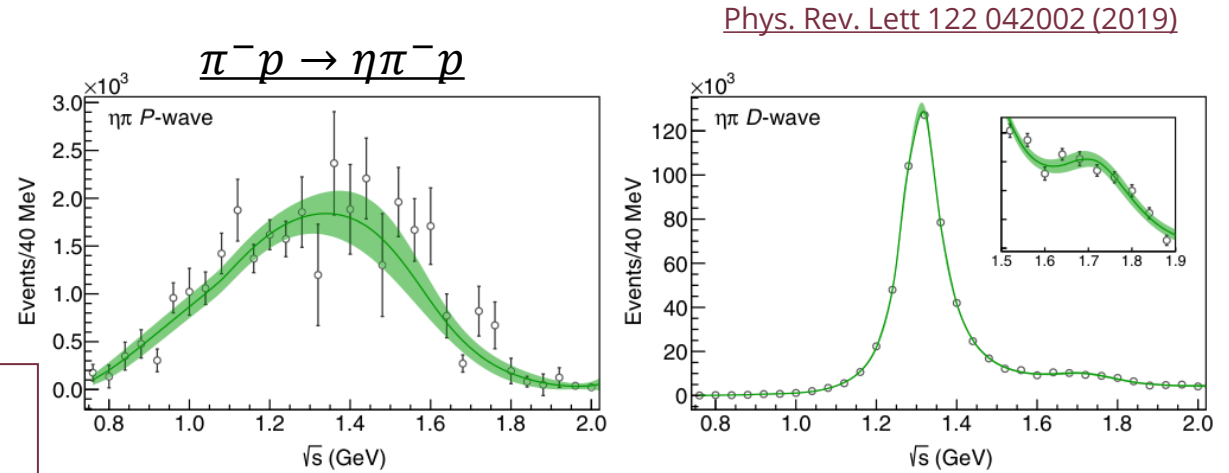


Theoretical Predictions and Observations

Lattice QCD Prediction

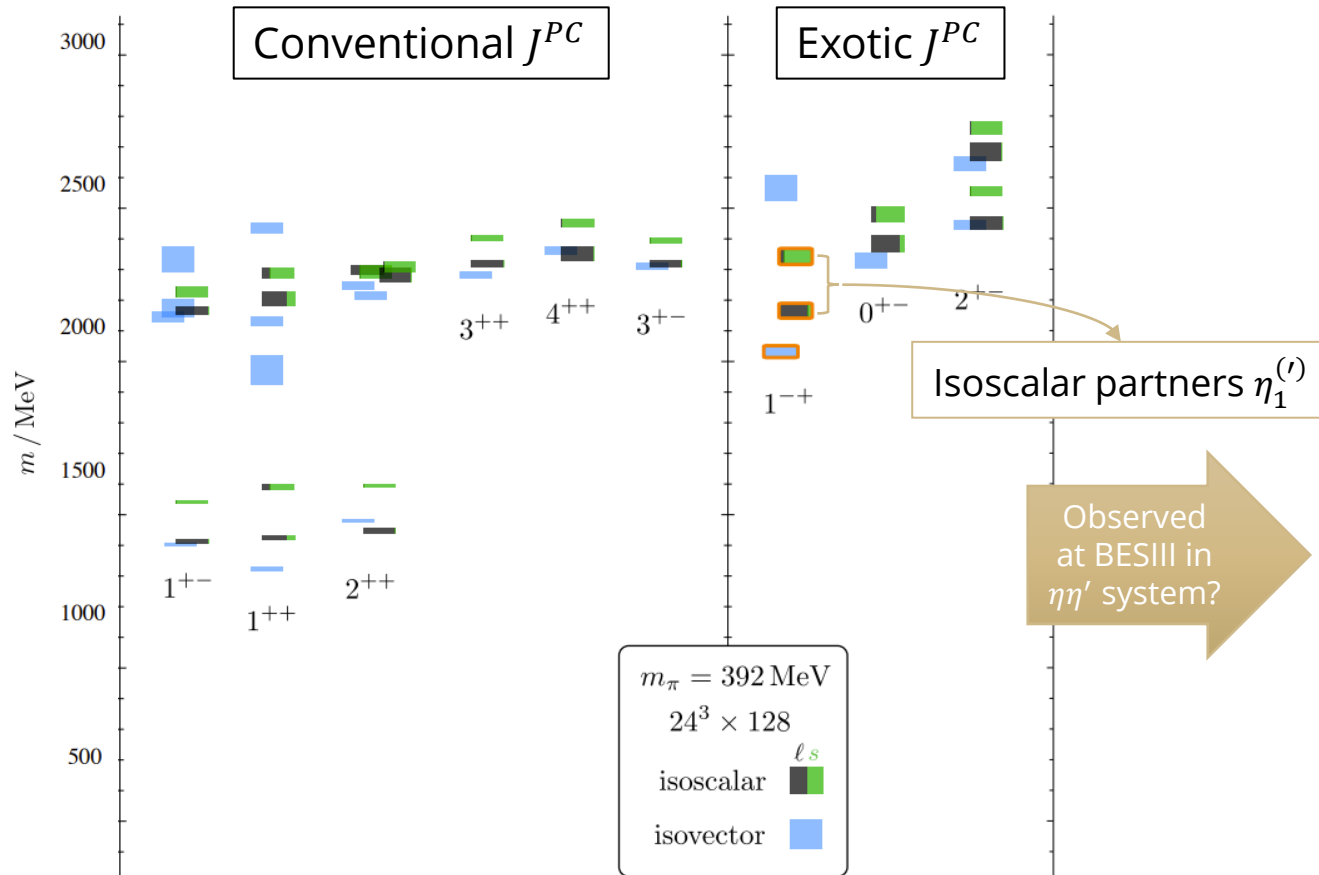


Phys. Rev. D 88 094505 (2013)

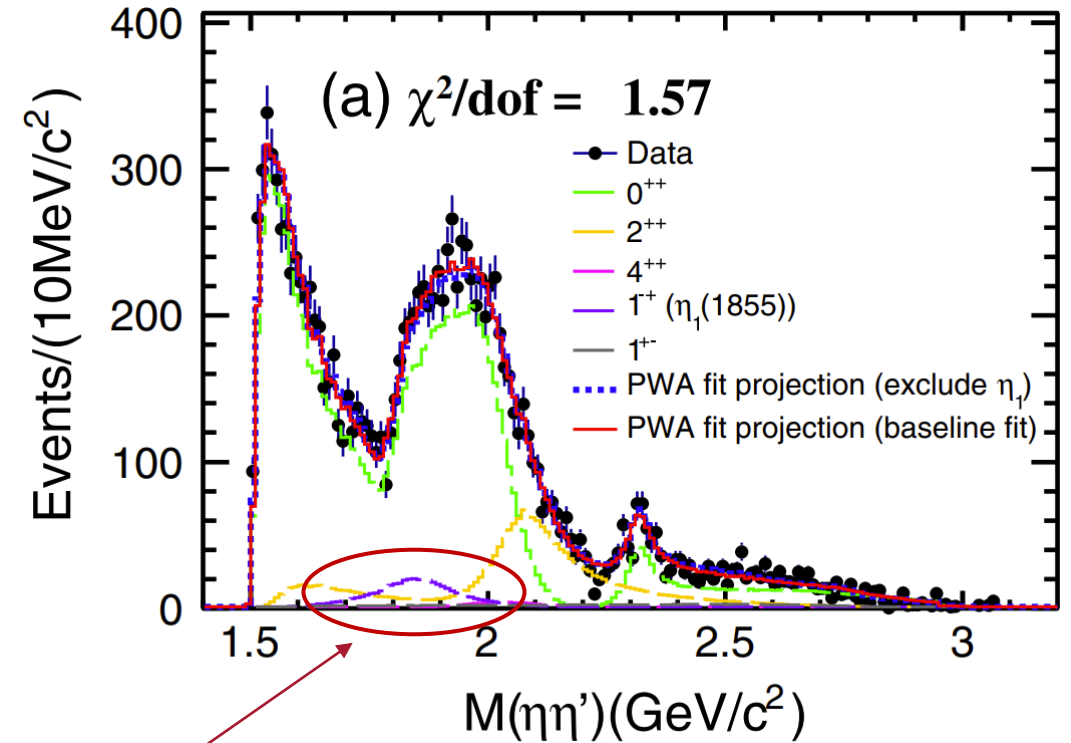


Theoretical Predictions and Observations

Lattice QCD Prediction



Phys. Rev. D 88 094505 (2013)



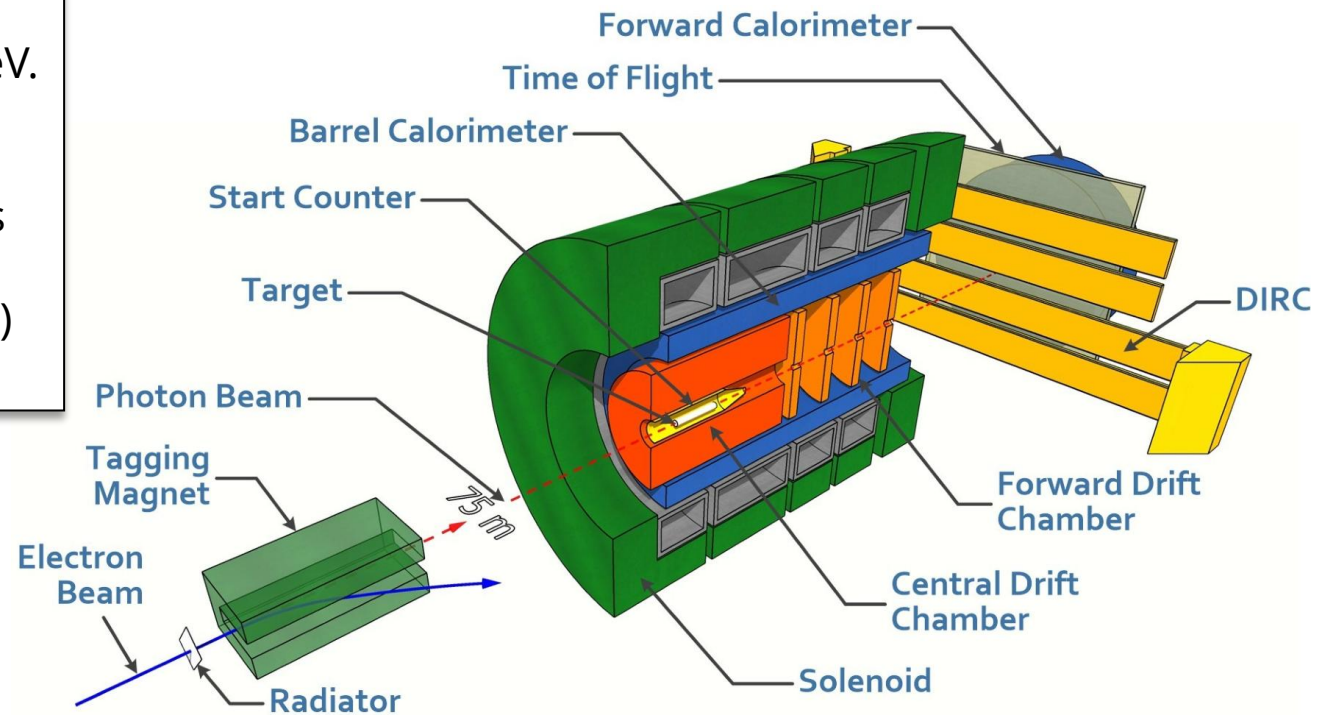
Phys. Rev. Lett 129 192002 (2022)

GlueX detector at Experimental Hall-D:

- ✓ Built to study light meson spectrum.
- ✓ Fixed-target photoproduction experiment with ~35% linearly polarized photon beam at ~8.5 GeV.
- ✓ Polarized photon beam enables Partial-Wave Analysis (PWA).
- ✓ ~4π coverage for photons and charged particles reconstruction.
- ✓ GlueX-I collected $L_{int} = 125 \text{ pb}^{-1}$ (coherent peak)
- ✓ GlueX-II is ongoing.

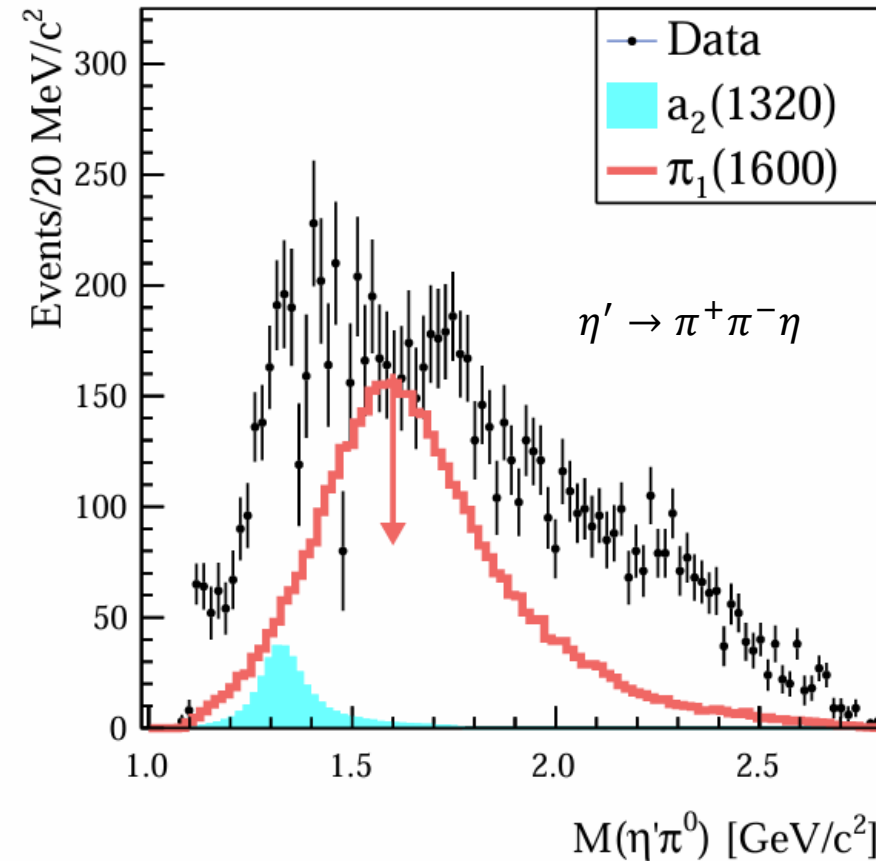
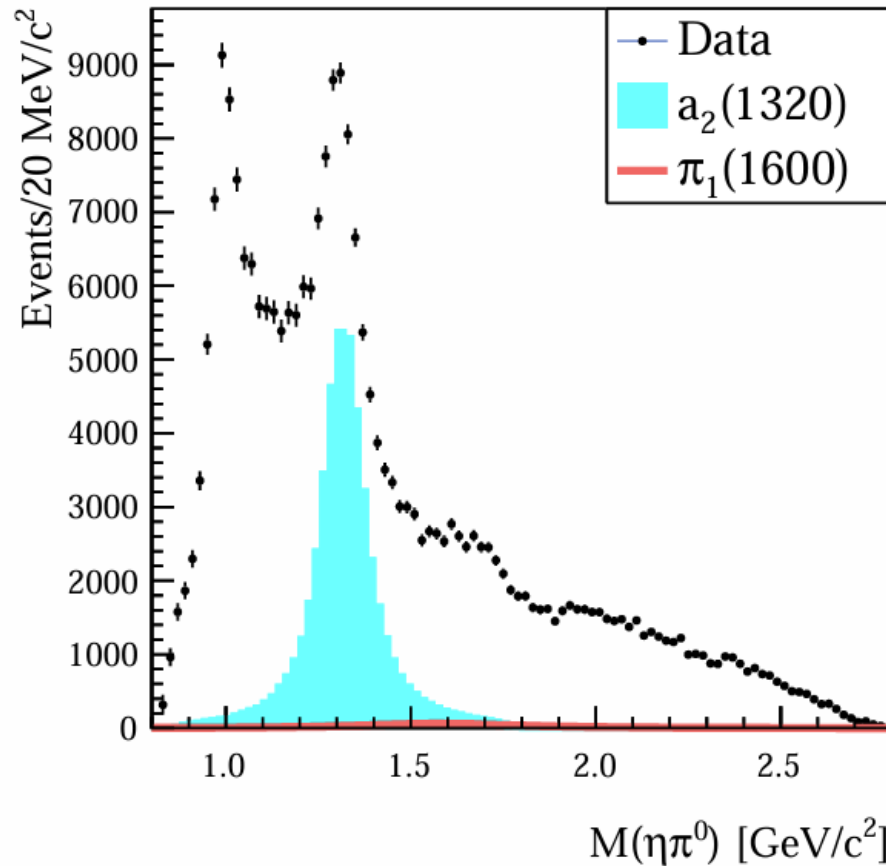
$\eta^{(\prime)}\pi$ systems being analyzed:

- $\gamma p \rightarrow \eta^{(\prime)}\pi^0 p \rightarrow 4\gamma p$
- $\gamma p \rightarrow \eta^{(\prime)}\pi^0 p \rightarrow 4\gamma\pi^-\pi^+ p$
- $\gamma p \rightarrow \eta\pi^-\Delta^{++} \rightarrow 2\gamma\pi^-\pi^+ p$
- $\gamma p \rightarrow \eta'\pi^-\Delta^{++} \rightarrow 2\gamma 2\pi^- 2\pi^+ p$



NIM A 987 164807 (2021)

π_1 Upper Limit in $\eta^{(\prime)}\pi$ from $\omega\pi\pi$ Analysis at GlueX

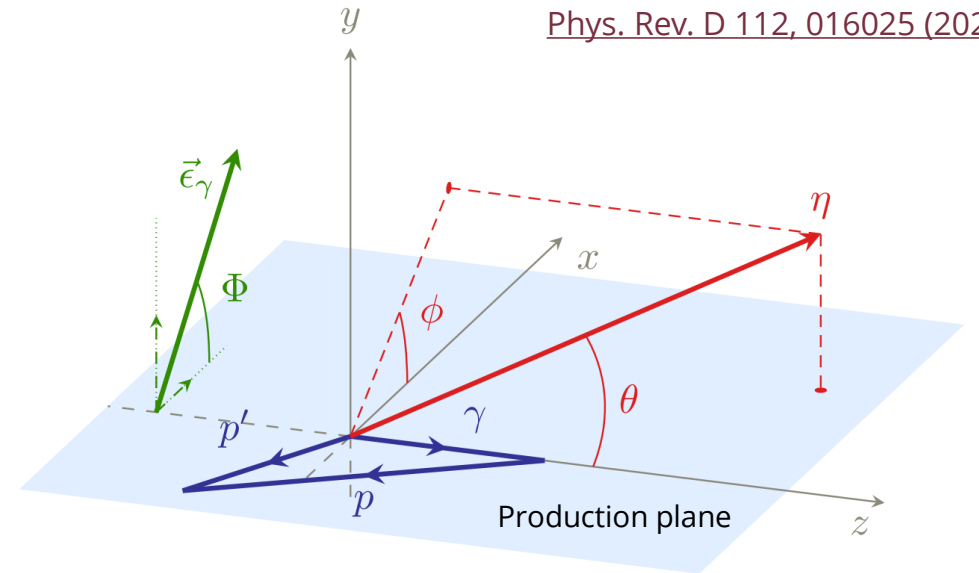
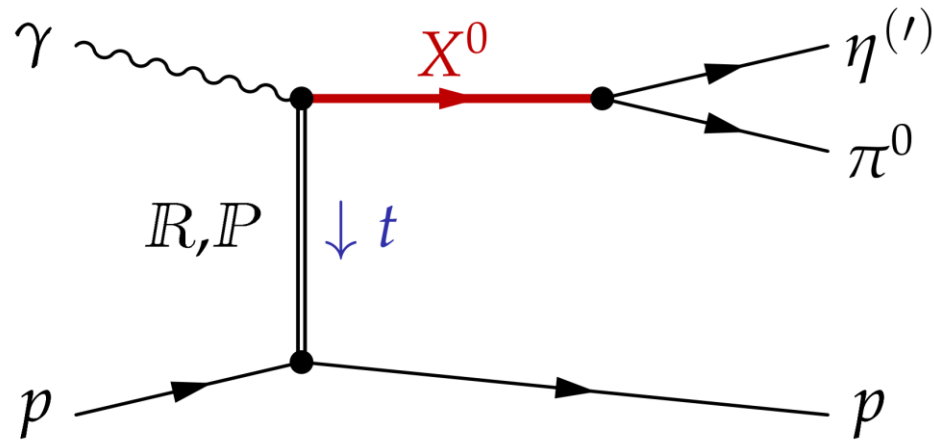


[Phys. Rev. Lett. 133 261903 \(2024\)](#)

- Measure isospin separated $\omega\pi\pi$ cross-sections.
- Fit isospin-1 cross sections with $a_2(1320)$ and $\pi_1(1600)$ shapes.
- Use branching fractions from Lattice QCD to project $\pi_1(1600)$ upper limit to $\eta^{(\prime)}\pi$ final states.

Studying Two-spinless Meson Systems in Photoproduction FSU

Phys. Rev. D 112, 016025 (2025)



Gottfried-Jackson frame of the two-meson systems

The intensity function:

$$I(\Omega, \Phi) \equiv \frac{d\sigma}{dt dm_{h_1 h_2} d\Omega d\Phi} = I_0(\Omega) - I_1(\Omega) P_\gamma \cos(2\Phi) - I_2(\Omega) P_\gamma \sin(2\Phi)$$

$$I_i \propto \sum A(\Omega) A^*(\Omega)$$

$$\overline{A}(\Omega) \propto \sum [l_m^\epsilon] Y_l^m(\Omega)$$

Phys. Rev. D 100, 054017 (2019)

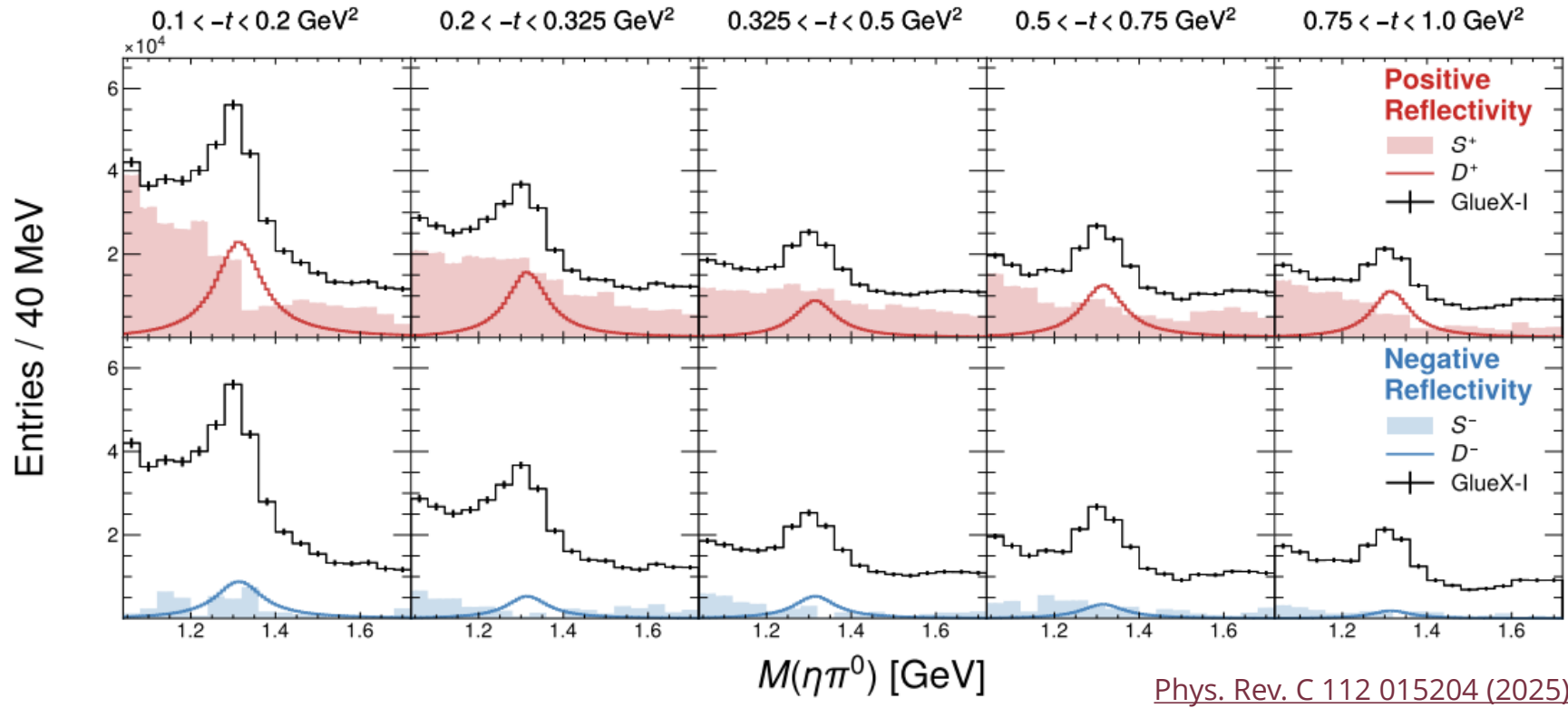
Partial wave amplitudes $[l]$:

- Strengths and phases of produced intermediate states X with spin $J = l$.
- Fit to $\eta\pi^0$ angular distribution (next slide).

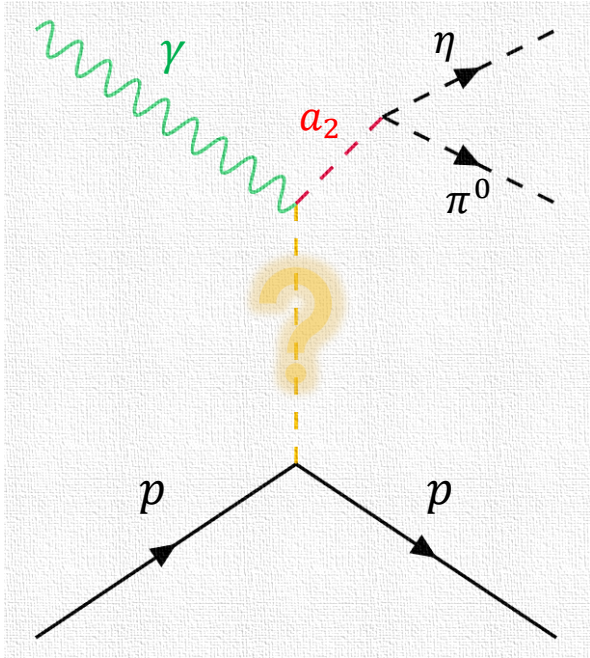
Reflectivity quantum number $\epsilon = \pm$:

- Corresponds to the (exchange) naturality of produced partial waves.
- $\epsilon = +(-)$ refers to the natural (unnatural) parity exchange.

$a_2^0(1320)$ Polarized Photoproduction Cross Section

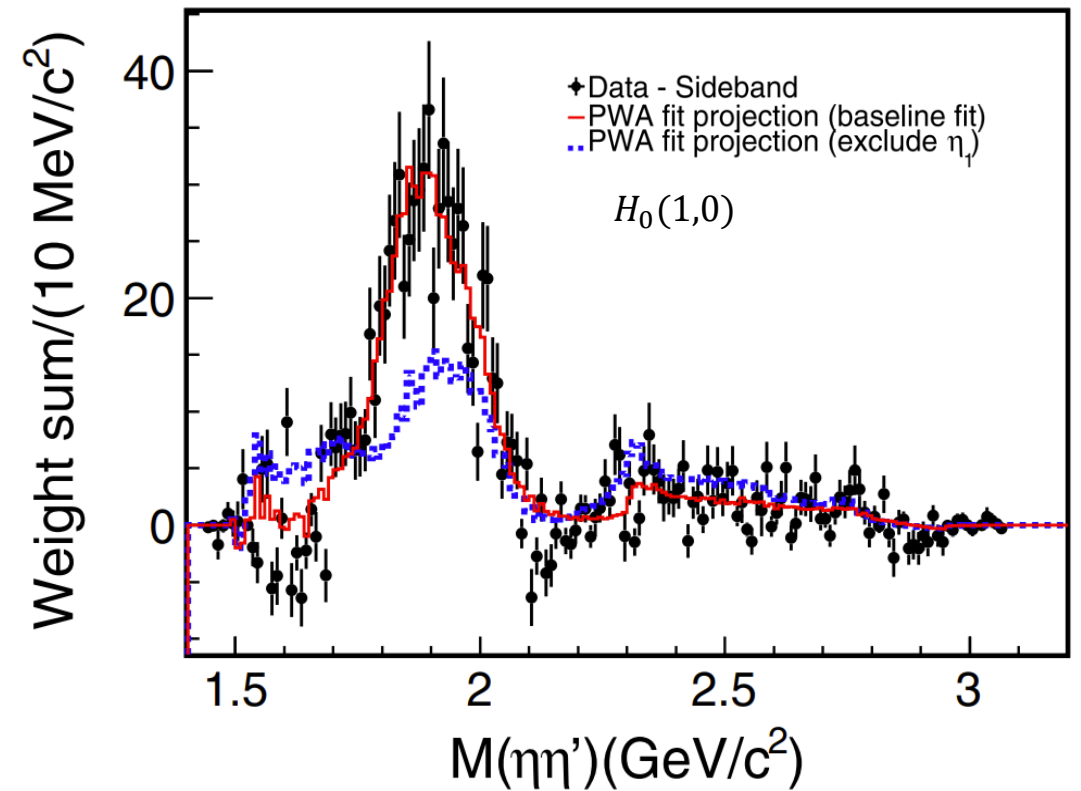
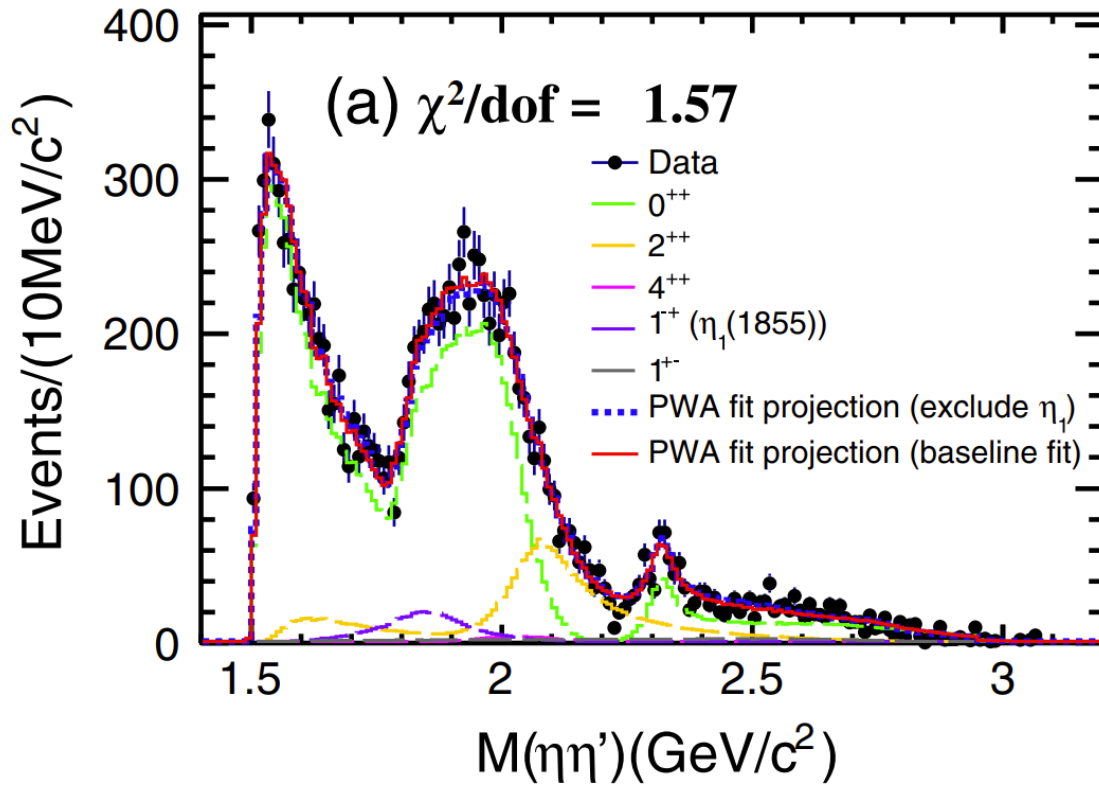


Phys. Rev. C 112 015204 (2025)



- First time measurement of polarized partial-wave amplitudes in $\gamma p \rightarrow \eta\pi^0 p$.
- D - and S -waves sufficiently describe the region of $1.04 < M(\eta\pi^0) < 1.72$ GeV.
- GlueX's polarized photon beam helps to separate natural vs unnatural parity exchange contributions of $a_2(1320)$ photoproduction.

BESIII η_1 Signal



- 1^{+-} ($\eta_1(1855)$) contribution is less obvious visually in PWA fit projections to $M(\eta\eta')$.
- PWA fit including the η_1 contribution describes better $H_0(1,0)$ moment.

[Phys. Rev. Lett 129 192002 \(2022\)](#)

The Moments of Angular Distributions

- Intensity decomposition into a set of orthogonal basis functions, spherical harmonics $Y_L^M(\Omega)$.

$$I(\Omega, \Phi) = I_0(\Omega) - I_1(\Omega)P_\gamma \cos(2\Phi) - I_2(\Omega)P_\gamma \sin(2\Phi)$$

$$I_0(\Omega) = \sum_{L,M} \sqrt{\frac{2L+1}{4\pi}} H_0(L,M) Y_L^M(\Omega)$$

$$I_{1,2}(\Omega) = - \sum_{L,M} \sqrt{\frac{2L+1}{4\pi}} H_{1,2}(L,M) Y_L^M(\Omega)$$

$H_0(L,M)$: unpolarized moments
 $H_{1,2}(L,M)$: polarized moments

- Moments are unique → serve as an intermediate step towards Partial-Wave Analysis.
- Relation between partial-wave amplitudes and moments:

$$H_\alpha(L,M) \propto \sum \sqrt{\frac{2l'+1}{2l+1}} \langle l'0, L0 | l0 \rangle \langle l'm', LM | lm \rangle \times [\text{partial wave amplitude bilinears}]$$

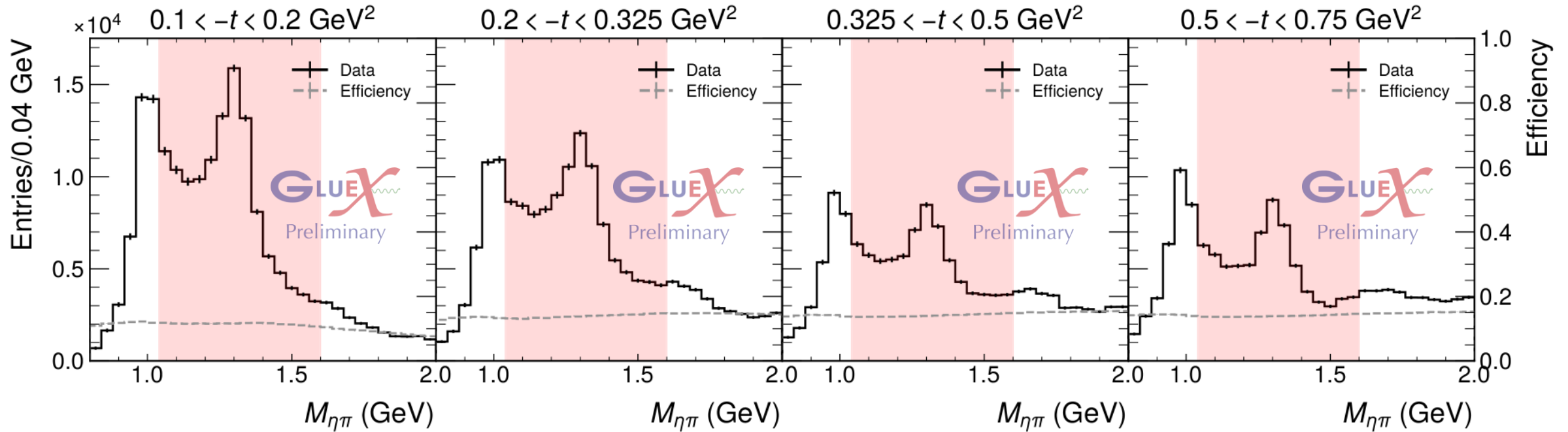
Moments	Amplitude Contributions
$H_0(0,0)$	$\sum S^\pm ^2 + \sum P^\pm ^2 + \sum D^\pm ^2$
$H_\alpha(1,M)$	$(S^\pm P^\pm), (P^\pm D^\pm)$
$H_\alpha(2,M)$	$(S^\pm D^\pm)$
$H_\alpha(3,M)$	$(P^\pm D^\pm)$
$H_\alpha(4,M)$	$(D^\pm D^\pm)$

Assuming no $l > 2$ contributions

}

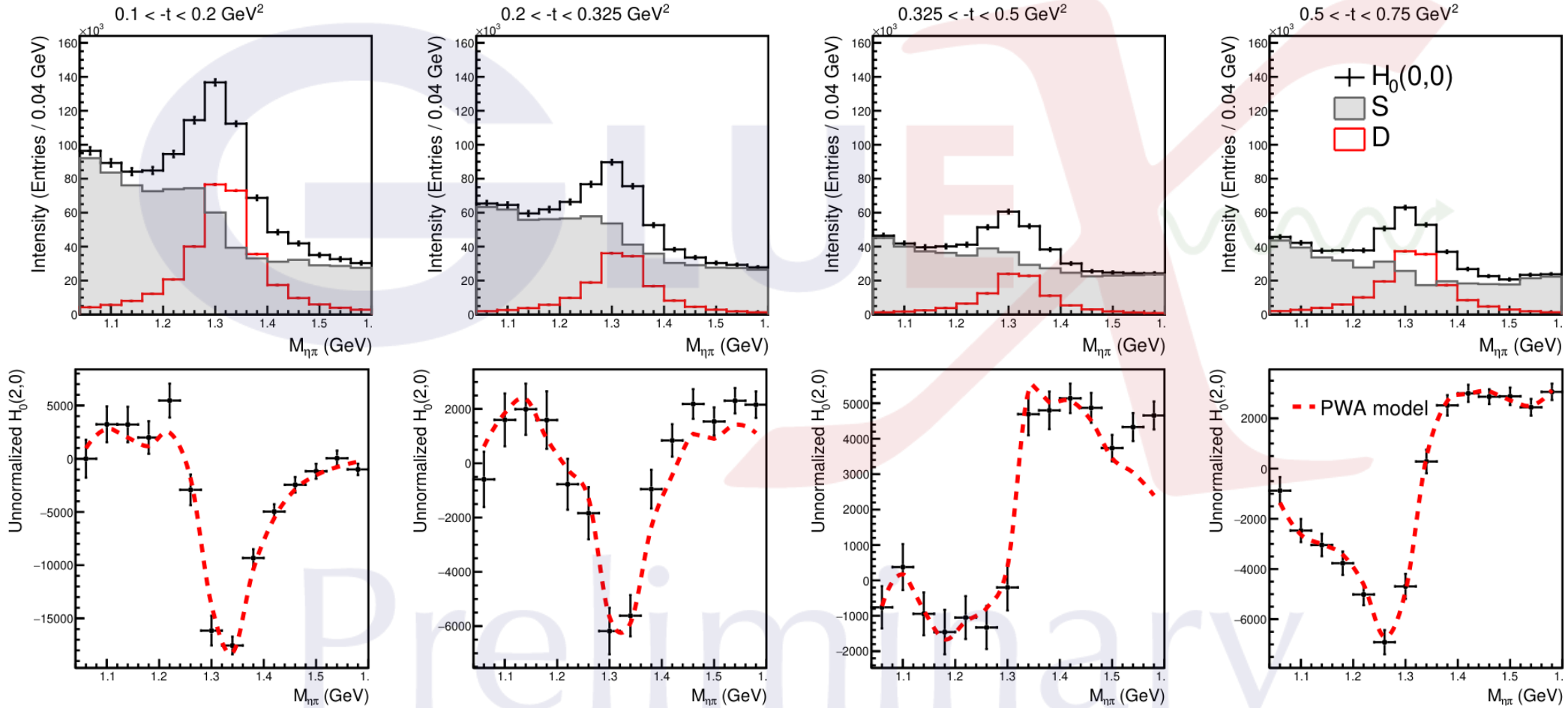
Odd- L moments is sensitive to the exotic P -waves → exotic moments

Moment Analysis in the $a_2(1320)$ Region



- Study how the moments in the $a_2(1320)$ region evolve as a function of t .
- Determine the $a_2(1320)$ cross-section from the measured moments.
 - Consistency check with the published PWA result.

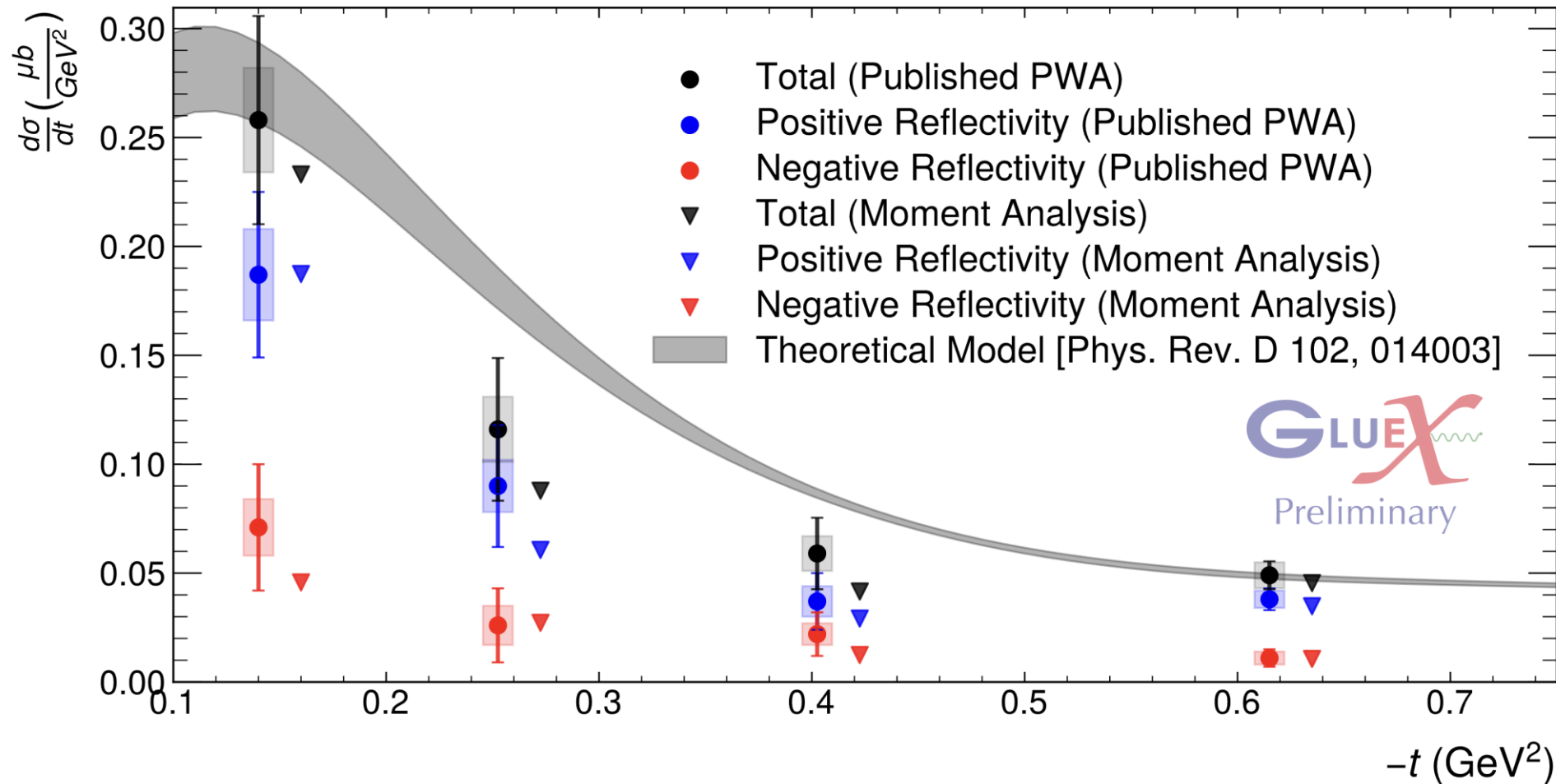
Unpolarized Moments Related to S and D-waves



- ✓ $H_\alpha(L = 0,2,4; M)$ are modelled with $a_2(1320)$ Breit-Wigner in D -waves, piecewise constant S -waves, **zero** P -waves.
- ✓ Observed S, D -waves interfering patterns evolving with t .

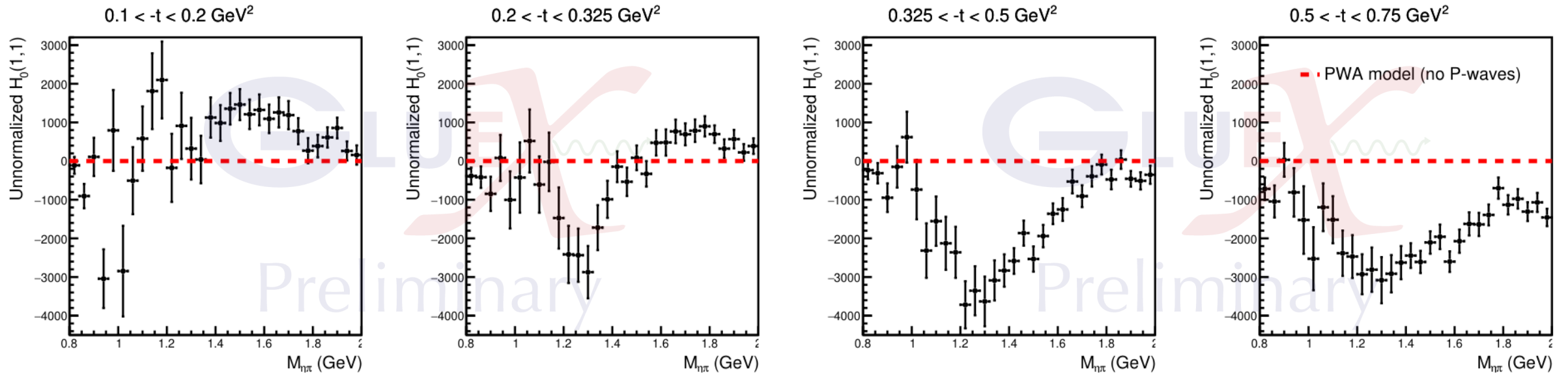
Moments	Amplitude Contributions
$H_0(0,0)$	$\sum S^\pm ^2 + \sum D^\pm ^2$
$H_\alpha(2, M)$	$(S^\pm D^\pm)$

$a_2(1320)$ Differential Cross-Section



- ✓ Measured central values from the extracted moments (GlueX-I+II) are consistent with the published GlueX-I results from [Phys. Rev. C 112 015204 \(2025\)](#).
- ❑ Statistical uncertainties not propagated yet.

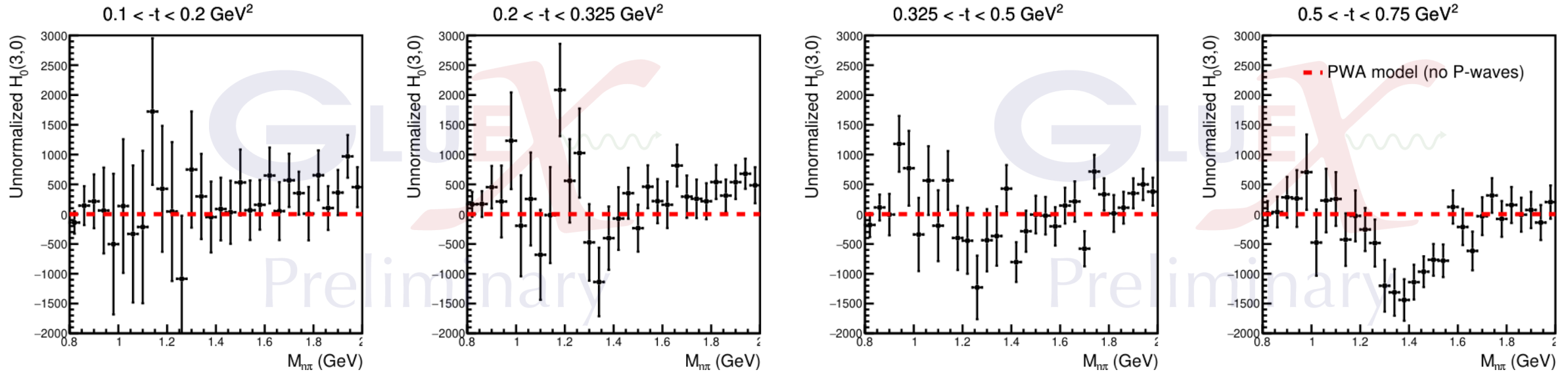
Moments Related to P-waves



- $H_0(1,1)$ suggests non-zero P -waves interfering with S - and D -waves across all t -bins.

Moments	Amplitude Contributions
$H_\alpha(1, M)$	$(S^\pm P^\pm), (P^\pm D^\pm)$

Moments Related to P-waves



- Non-zero $H_0(3,0)$ in the a_2 regions suggests P -waves interfering with a_2 D -waves.

Moments	Amplitude Contributions
$H_\alpha(3, M)$	$(P^\pm D^\pm)$

Summary

- Studying hybrid mesons provides access to the role of gluonic excitation in hadrons.
- $\eta\pi$ channels provide favorable conditions to search for spin-exotic hybrids in photoproduction.
- Angular moments of the $\eta\pi$ systems are sensitive to the possible π_1 contribution.
- PWA model to the $\eta\pi^0$ moments in the $a_2(1320)$ region reproduces the published $a_2(1320)$ polarized photoproduction cross-section.
- First measurement of $\eta\pi^0$ polarized moments in photoproduction shows potential non-zero contributions from exotic P -waves.
 - resonance, non-resonant physics, backgrounds, analysis artifacts.
- Establishing the nature of the non-zero P -waves requires more study and input from theory.



gluex.org/thanks

Backup

Analysis Summary

- Reaction filter:
 - Reaction1 1_14_7_17_14
 - Reaction1:Flags B4_M17_M7
- GlueX-I Datasets
 - Spring 2017, Analysis Launch ver51
 - Spring 2018, Analysis Launch ver02
 - Fall 2018, Analysis Launch ver02
- GlueX-II Datasets
 - Spring 2020, Analysis Launch ver06
- Phase Space Monte Carlo Simulation
 - Generator: gen_amp_V2
 - PhSp with t -slope = 1
 - decay_evtgen: $\eta \rightarrow 2\gamma$
- Analysis frameworks:
 - [nseptian/EtaPi0Analysis](#)
 - [dglazier/brufit](#)
 - [bgrube/Moments](#)
 - [nseptian/Moments2Amplitudes](#)

Quantity	Selections
Beam Energy	GlueX-I: $8.2 < E_\gamma < 8.8$ GeV GlueX-II: $8.0 < E_\gamma < 8.6$ GeV
Beam Bunches Selection	Selected prompt-peak # of out-of-time bunch = 4 Skipped 1 bunch near the prompt peak
Charged Track Selections	$ \vec{P} \geq 0.3$ GeV/c $52 \leq d_z \leq 78$ cm $\frac{dE}{dx_{\text{CDC}}} \geq 10^{-6} \left(0.9 + \frac{e^{3.0-3.5 \vec{P} +0.05}}{0.93827} \right)$
Neutral Shower Selections	$E \geq 0.1$ GeV $2.5^\circ \leq \theta \leq 10.3^\circ$ and $\theta > 11.9^\circ$
Exclusivity Selections	Unused Energy < 0.05 GeV Missing Mass Squared ≤ 0.05 GeV ² $\chi^2 \leq 13.3$ with 4 DOF
Van Hove Angle Cut	$\omega < 29.0 \text{ atan}(-1.05 M(\eta\pi) + 2.78) + 328$
Combinatorial Bkg Cut	! $\left[\begin{array}{l} ((M_{g1g3} < 0.12) * (M_{g2g3} < 0.12)) \parallel \\ ((M_{g1g4} < 0.12) * (M_{g2g4} < 0.12)) \parallel \\ ((M_{g1g3} < 0.15) * (M_{g2g4} < 0.15)) \parallel \\ ((M_{g1g4} < 0.15) * (M_{g2g3} < 0.15)) \parallel \end{array} \right]$