Amplitude Analysis of $\eta\pi$ Final States At GlueX

HADRON 2021

Colin Gleason

Union College
on Behalf of the GlueX Collaboration

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Overview

1. The $\eta\pi$ System
   - What we want to measure
2. The GlueX Experiment
   - Large acceptance detector
   - Polarized γ beam at 8.5 GeV
3. Amplitude Analysis of $\eta\pi$ at GlueX
   - $\gamma p \to \eta\pi^-\Delta^{++}$
   - $\gamma p \to \eta\pi^0 p$
4. Outlook

- The goal of GlueX is to map the spectrum of light hybrid mesons
- The $\eta^{(')}\pi$ system is an ideal place to start
- For orbital angular momentum $L = 0, 1, 2, 3, ..$ of the $\eta(')\pi$ system, we gain access to J^{PC}

L	S	P	D	F	...
J^{PC}	0^{++}	1^{-+}	2^{++}	3^{-+}	...

- $\eta\pi$ in a P–wave results in exotic quantum numbers (non $q\bar{q}$)

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  1. What is the nature and interpretation of the π_1?
     - $-t$ dependence, double Regge exchange
  2. How are hybrid states produced?

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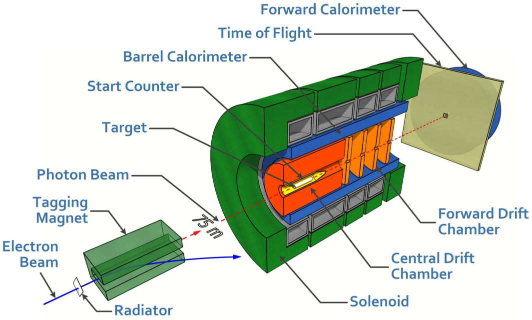
- Build foundation for hybrid searches by studying $\eta\pi$ system
- Focus of this talk is on $a_2(1320) \to \eta\pi$

The GlueX Experiment



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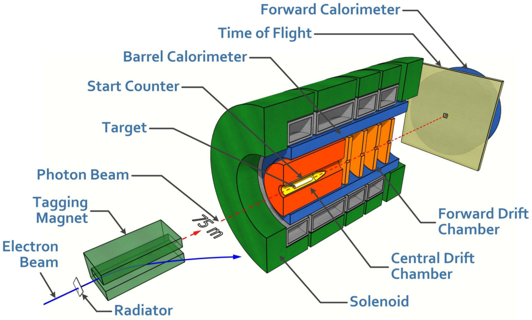

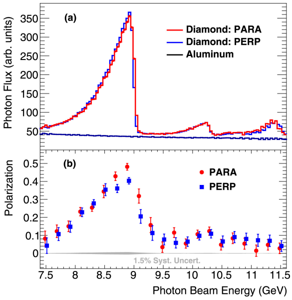

- Linearly polarized photon beam
- Large acceptance for charged and neutral final state particles
- 120 pb^{-1} data collected in GlueX Phase–1

$\eta^{(')}\pi$ Systems With GlueX

First stage: study known resonances (e.g. $a_0(980) \to \eta\pi,\ a_2(1320) \to \eta\pi$) to build the foundation for hybrid meson searches at GlueX.

- Access to multiple channels:

1. $\gamma p \to \eta\pi^0 p$
   - $\eta \to \gamma\gamma$
   - $\eta \to \pi^+\pi^-\pi^0$
2. $\gamma p \to \eta\pi^-\Delta^{++}$
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3. $\gamma p \to \eta'\pi^0 p$,
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4. $\gamma p \to \eta'\pi^-\Delta^{++}$,
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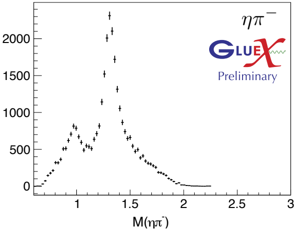
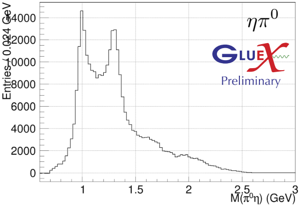
- Different decay modes should contain same physics
  - $\Rightarrow$ Understand Acceptance
  - $\Rightarrow$ Handling of backgrounds
- Charged and neutral decays are complementary
- Incorporation of beam polarization into Amplitude Analysis

$\gamma p \to \eta\pi N$

$0.1 < -t < 0.3$ GeV^2





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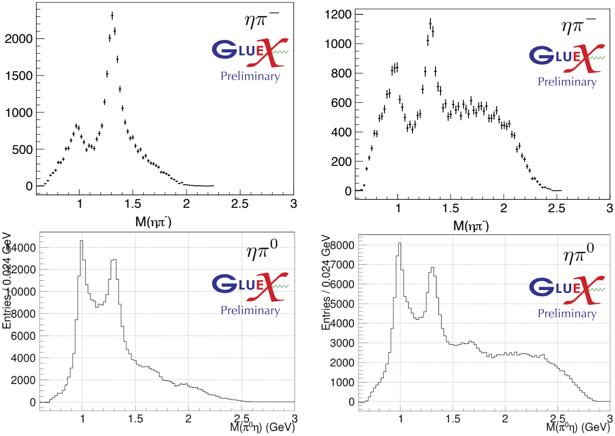
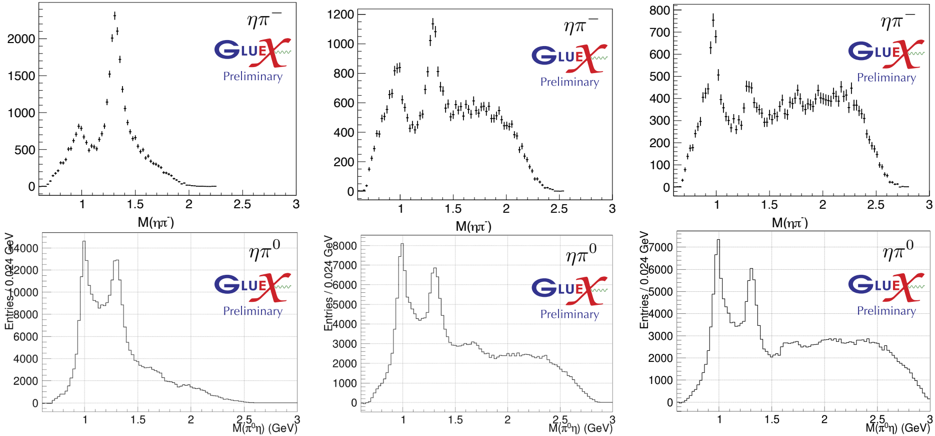


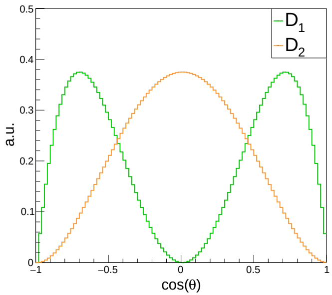
$\gamma p \rightarrow \eta\pi N$

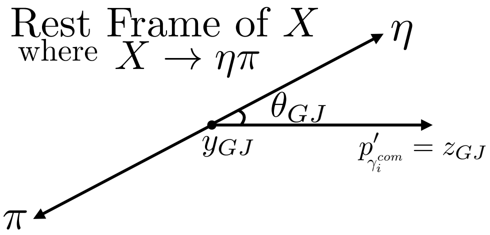
$0.1 < -t < 0.3$ GeV^2 $\quad$ $0.3 < -t < 0.6$ GeV^2 $\quad$ $0.6 < -t < 1.0$ GeV^2



Angular Distributions in $\eta\pi$

Gottfried-Jackson Frame





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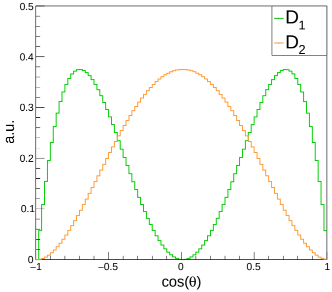

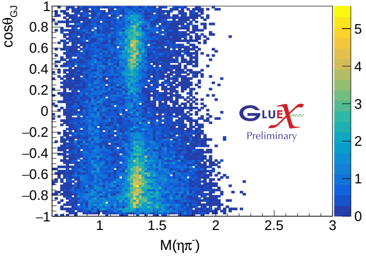

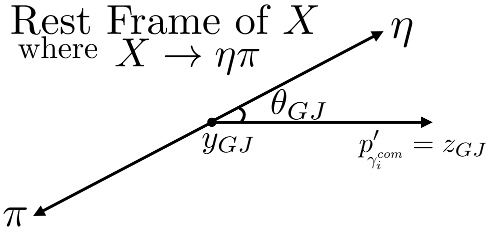

- D_1 ($L = 2,\ m = 1$) structure at ≈ 1300 MeV in $\eta\pi^-$ system ($a_2(1320)$)
- Similar to COMPASS D wave in $\eta\pi^-$

(PLB 740, 303 (2015))

Angular Distributions in $\eta\pi$

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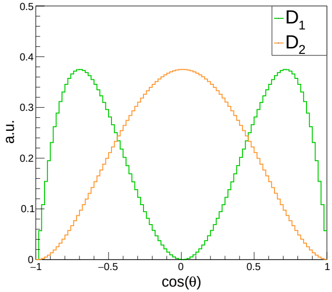

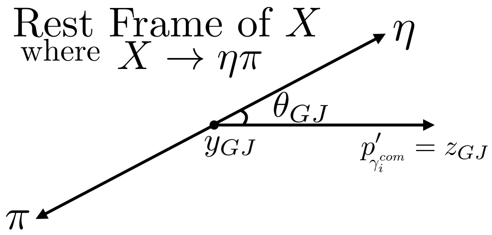

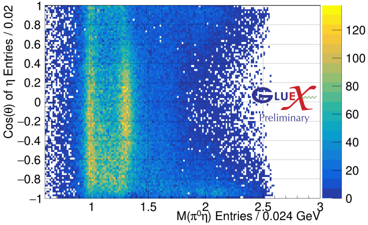

- D_2 ($L = 2$, $m = 2$) structure at ≈ 1300 MeV in $\eta\pi^0$ system ($a_2(1320)$)
- Belle: $\gamma\gamma \to \eta\pi^0$ sees a_2 produced in D_2 state (PRD 80, 032001 (2009))

Amplitude Analysis on $\gamma p \to \eta\pi N$

Polarized Amplitudes (PRD 100 (2019) 5, 054017)

- Introduce polarized photoproduction amplitudes to incorporate beam polarization
- System described by $\Omega = \theta, \phi$ (in GJ or Helicity frame) and Φ, the polarization angle

$$I(\Omega,\Phi) = 2\kappa \sum_k \Bigg\{ (1-P_\gamma)\left|\sum_{\ell,m}[\ell]^{(-)}_{m;k}\mathrm{Re}[Z^m_\ell(\Omega,\Phi)]\right|^2 + (1-P_\gamma)\left|\sum_{\ell,m}[\ell]^{(+)}_{m;k}\mathrm{Im}[Z^m_\ell(\Omega,\Phi)]\right|^2 + (1+P_\gamma)\left|\sum_{\ell,m}[\ell]^{(+)}_{m;k}\mathrm{Re}[Z^m_\ell(\Omega,\Phi)]\right|^2 + (1+P_\gamma)\left|\sum_{\ell,m}[\ell]^{(-)}_{m;k}\mathrm{Im}[Z^m_\ell(\Omega,\Phi)]\right|^2 \Bigg\}$$

- Basis: $Z_l^m(\Omega,\Phi) = Y_l^m(\Omega)e^{-i\Phi}$
- Fit $[\ell]^{\pm}_{m;k}$ coefficients to the data
  - $\pm$ is the reflectivity
  - $m = -\ell, \dots, \ell$

- Reflectivity, $\epsilon = \pm$, corresponds to the naturality, $\eta = P(-1)^J$ of the exchange particle
  - natural parity $J^P = 0^+, 1^-, 2^+, \dots$
  - unnatural parity $J^P = 0^-, 1^+, 2^-$

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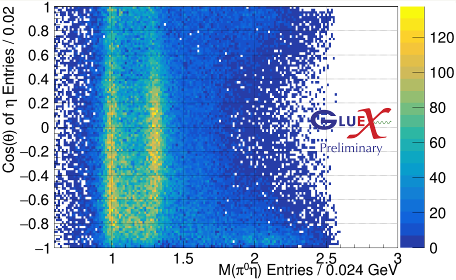
  - unnatural parity $J^P = 0^-, 1^+, 2^-$
- Starting waveset ($S_0^{\pm}$, $D^{\pm}_{-1,0,1}$, D_2^+) set chosen from tensor meson decay model from JPAC (PRD 102 (2020))

$\gamma p \to \eta\pi^0 p$ S wave

$0.1 < -t < 0.3$ GeV^2



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- $+$ reflectivity dominant

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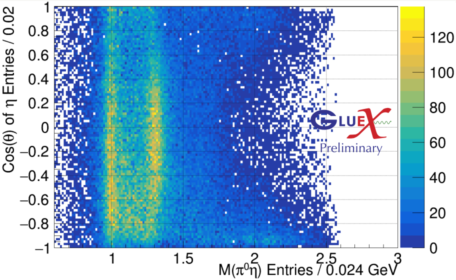

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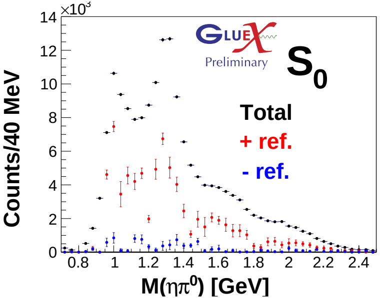

- Dominant structure in $a_0(980)$ is the S_0^+ wave ✓
- Large S_0^+ under $a_2(1320)$
  - Leakage or acceptance effect?
  - Validation with MC

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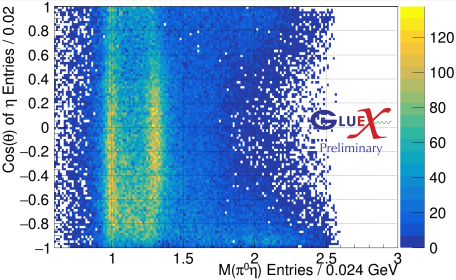

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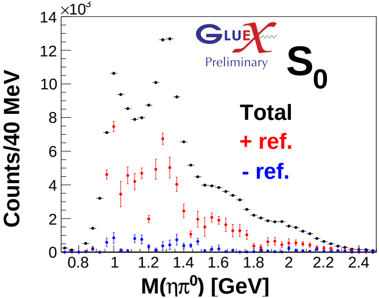

- Dominant structure in $a_0(980)$ is the S_0^+ wave ✓
- Large S_0^+ under $a_2(1320)$
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  - Validation with MC
- D wave should be dominated by D_2^+

$\gamma p \to \eta\pi^0 p$ D waves

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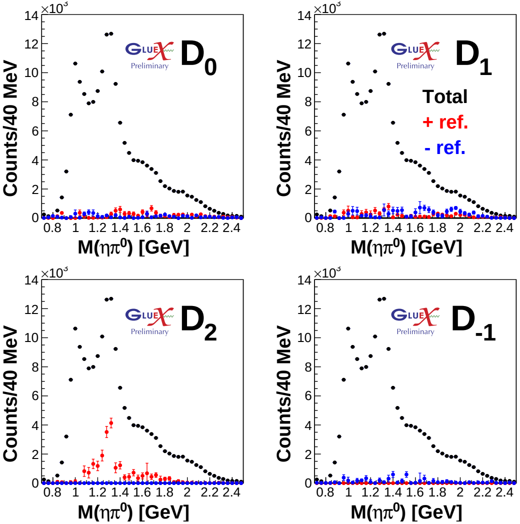

- D_2^+ is the dominant D wave in the $a_2(1320)$ region at low $-t$ ✓

$\gamma p \rightarrow \eta\pi^0 p$ D waves

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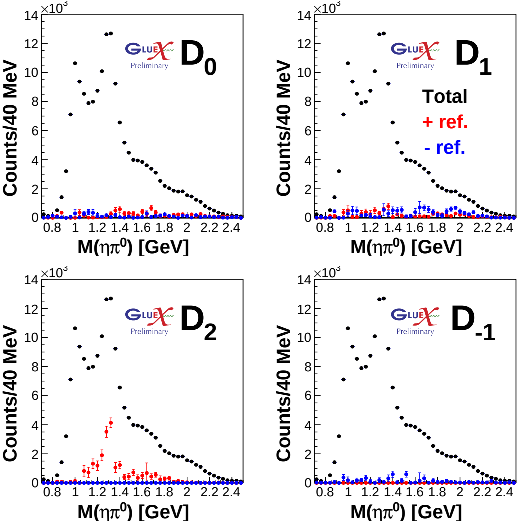

- D_2^+ is the dominant D wave in the $a_2(1320)$ region at low $-t$ ✓
- Structures seen around $a_2(1700)$
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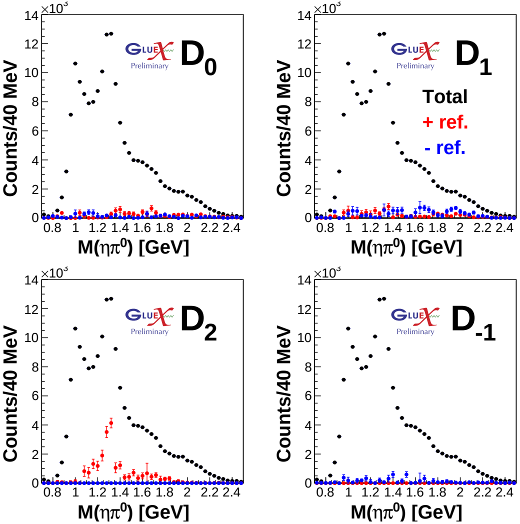
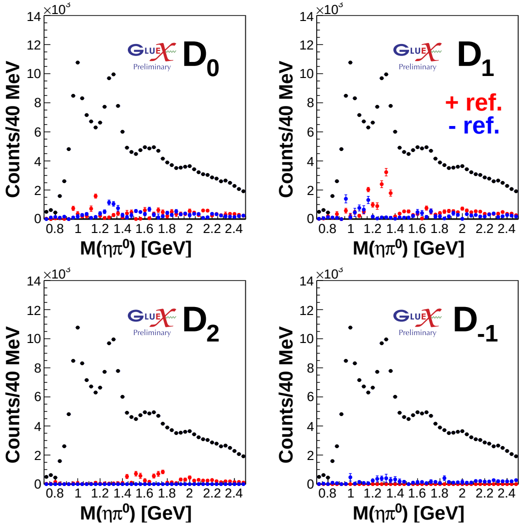


- D_2^+ is the dominant D wave in the $a_2(1320)$ region at low $-t$ ✓
- Structures seen around $a_2(1700)$
  - Will need to identify correct waves and confirm phase motion for hybrid search
- How does D wave evolve as a function of $-t$?

$\gamma p \to \eta\pi^0 p$ D waves

$0.3 < -t < 0.6$ GeV^2



- Shift from dominance of $D_2^+ \to D_1^+$ in $a_2(1320)$
- D_0^- also contributes
  - Unnatural parity exchange (h_1)

$\gamma p \to \eta\pi^- \Delta^{++}$ S wave

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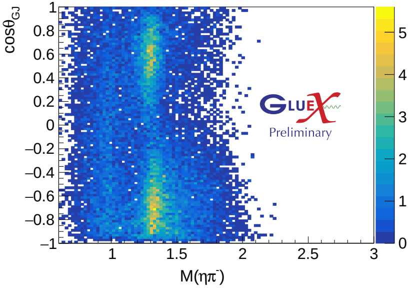

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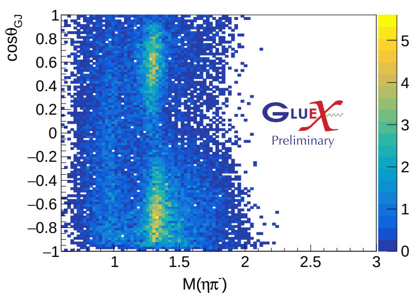

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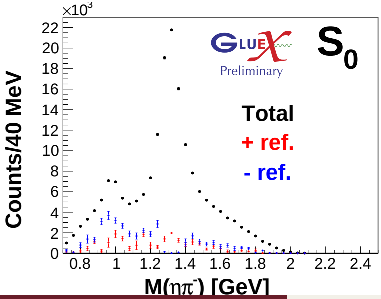

- Dominant structure in $a_0^-(980)$ is the S_0^- wave ✓
- Some S_0^+ under $a_2(1320)$

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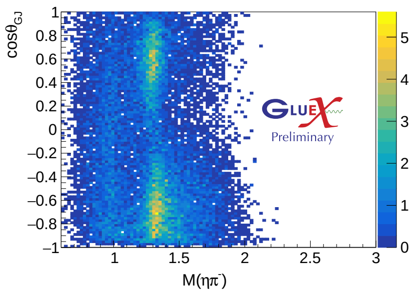

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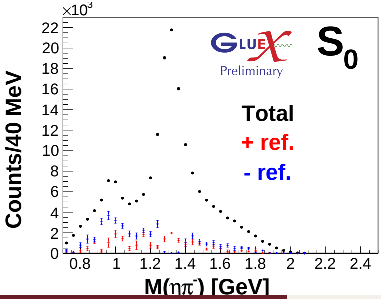

- Dominant structure in $a_0^-(980)$ is the S_0^- wave ✓
- Some S_0^+ under $a_2(1320)$
- $a_2^-(1320)$ should be dominated by D_1^-

$\gamma p \rightarrow \eta\pi^- \Delta^{++}$ D waves

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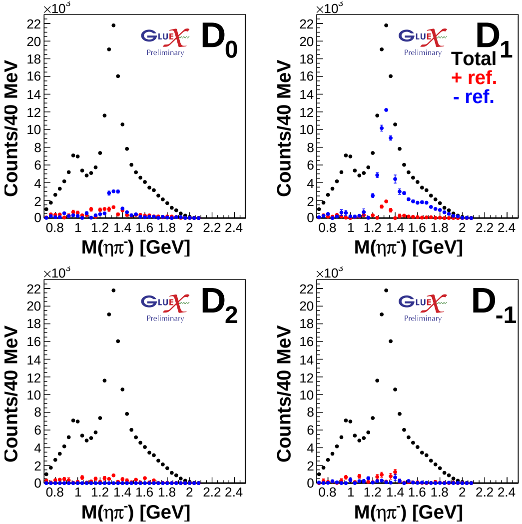

- Dominant structure is D_1^- ✓
  - unnatural (π) parity exchange expected to dominate at low $-t$
- D_0^- also has a large contribution
- Tail in D_1^- wave related to $a_2(1700)$?

$\gamma p \to \eta\pi^- \Delta^{++}$ D waves

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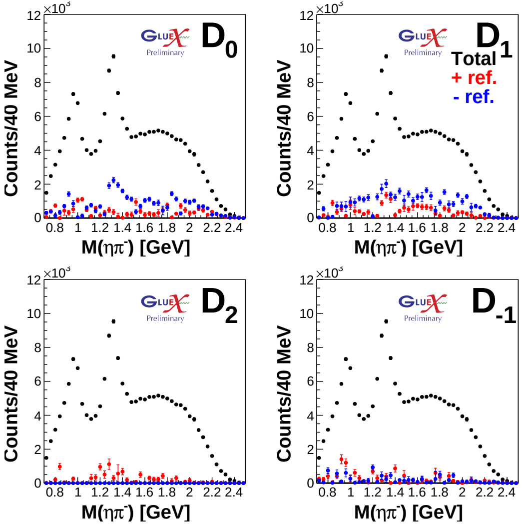
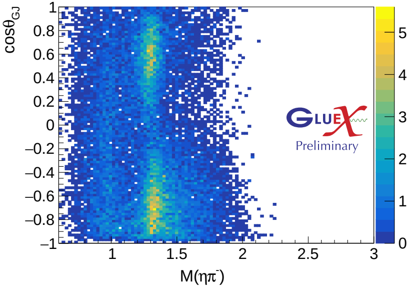
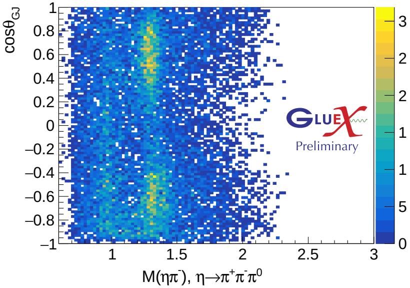


- Shift away from $D_1^- \to D_1^+$ and D_0^-
  - Region in $-t$ where we expect a shift from unnatural (π) to natural (ρ) parity exchange

Complementary Studies

$\eta\pi^-$, $\eta \to \pi^+\pi^-\pi^0$





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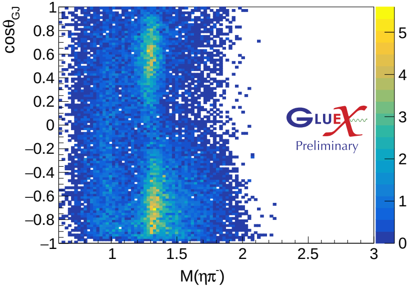

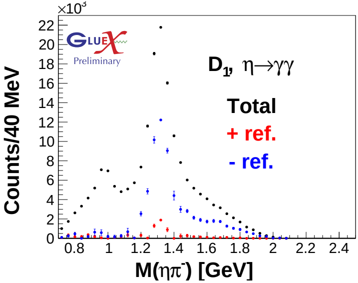

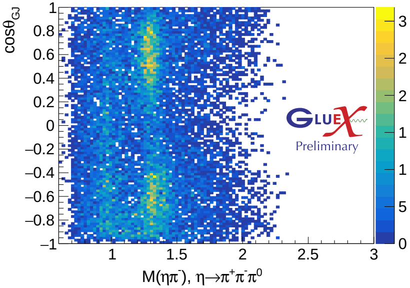

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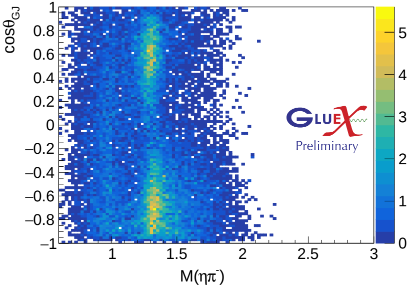

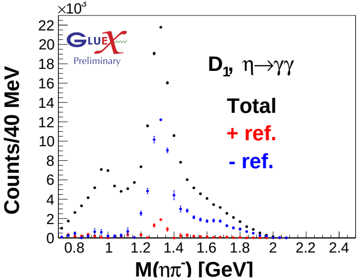

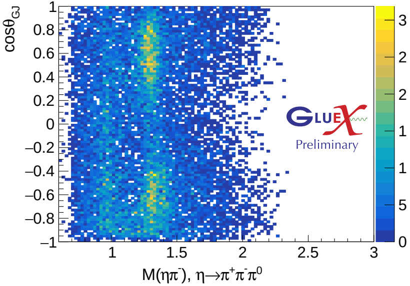

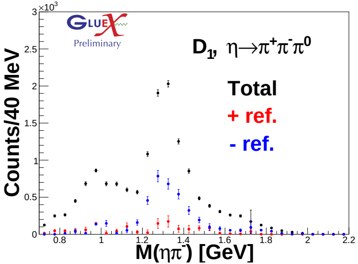

Outlook

- Large data set with access to multiple $\eta\pi$ channels
- Focus on understanding a_2 production before moving onto weaker P wave
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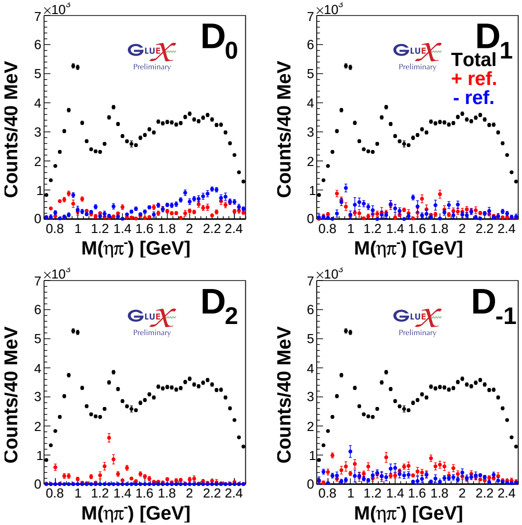
- GlueX Acknowledgments: gluex.org/thanks

Backup

$\gamma p \to \eta\pi^- \Delta^{++}$ D waves

$0.6 < -t < 1.0$ GeV^2



- D_2^+ is the dominant wave at high $-t$
  - Region in $-t$ where we expect natural (ρ) parity exchange to dominate
- D_{-1}^- also contributes