Analysis of $\eta\pi^0$ and $\eta'\pi^0$ Systems at GlueX

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for the GlueX Collaboration

13th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2018)
Palm Springs, CA
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Outline

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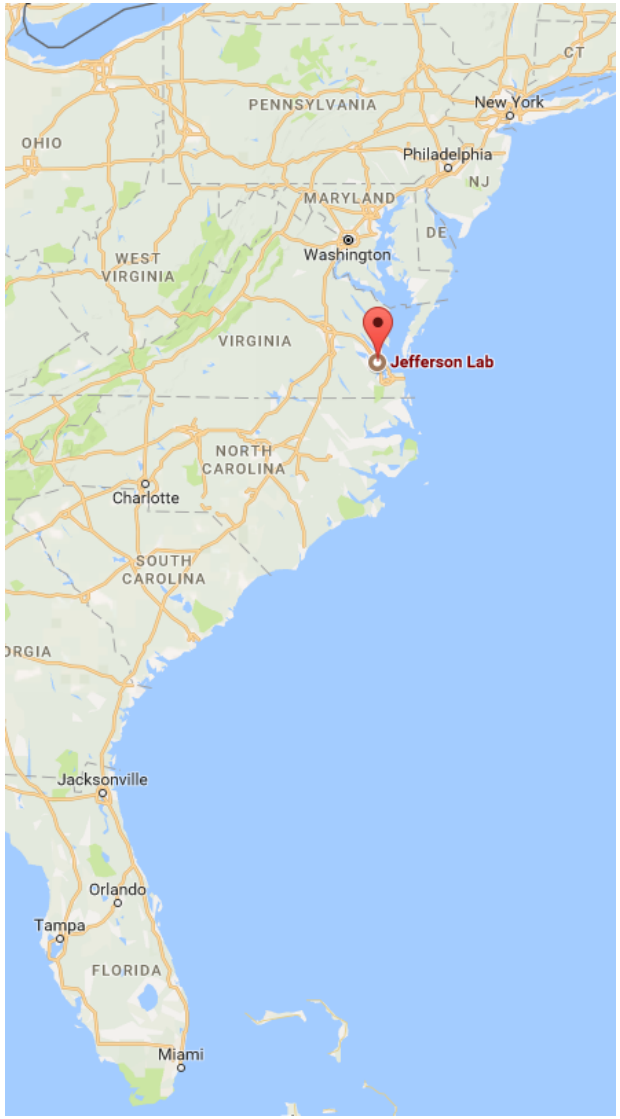
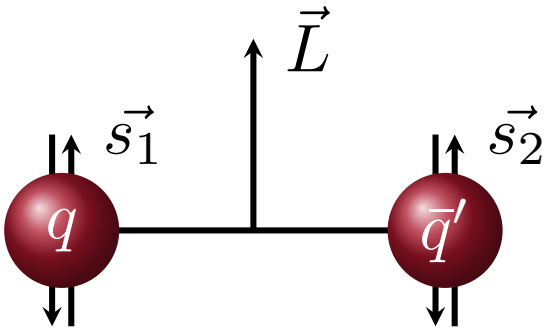
Thomas Jefferson National Accelerator Facility



Meson Spectroscopy



Non-Relativistic Quark Model

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

Meson Spectroscopy

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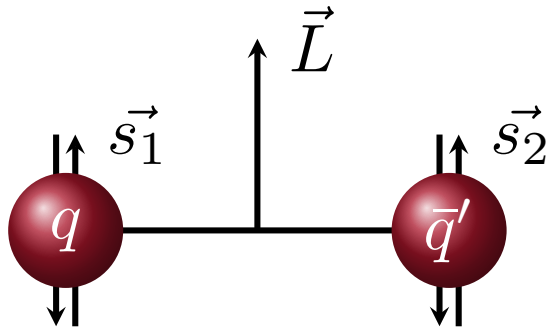

Non-Relativistic Quark Model

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

Not only mesons permitted by QCD

- Exotic quantum numbers $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}, ..$
- Forbidden in constituent quark model
- Observation is direct evidence for exotic states

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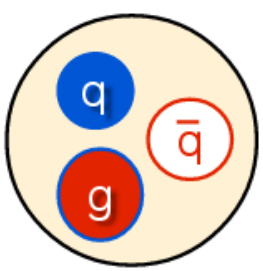
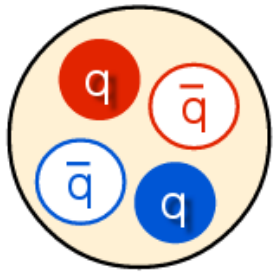
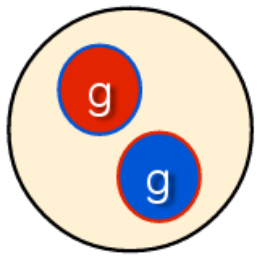


hybrid meson



tetraquark



glueball

Gell-Mann's Totalitarian Principle:
Everything not forbidden is compulsory!

Motivation

- Possible quantum number for the neutral $\pi\eta(')$ system:

L	S	**P**	D	**F**	G	...
J^{PC}	0^{++}	$\mathbf{1^{-+}}$	2^{++}	$\mathbf{3^{-+}}$	4^{++}	...

$$\pi^0 \oplus \eta$$
$$0^{-+} \otimes 0^{-+}$$
$$S = 0\ ,\ J = L$$
$$P = (-1)^L\ ,\ C = +1$$

Motivation

- Possible quantum number for the neutral $\pi\eta(')$ system:

L	S	**P**	D	**F**	G	...
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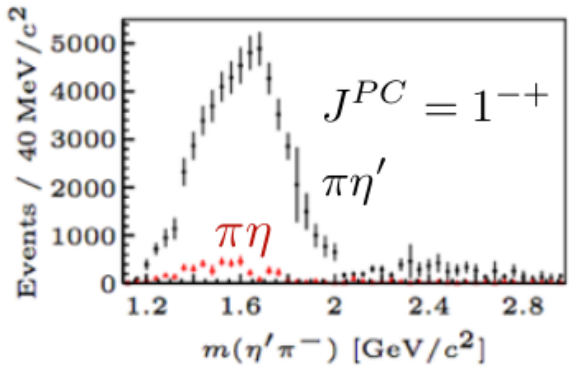
COMPASS [PLB 740 (2015) 303]

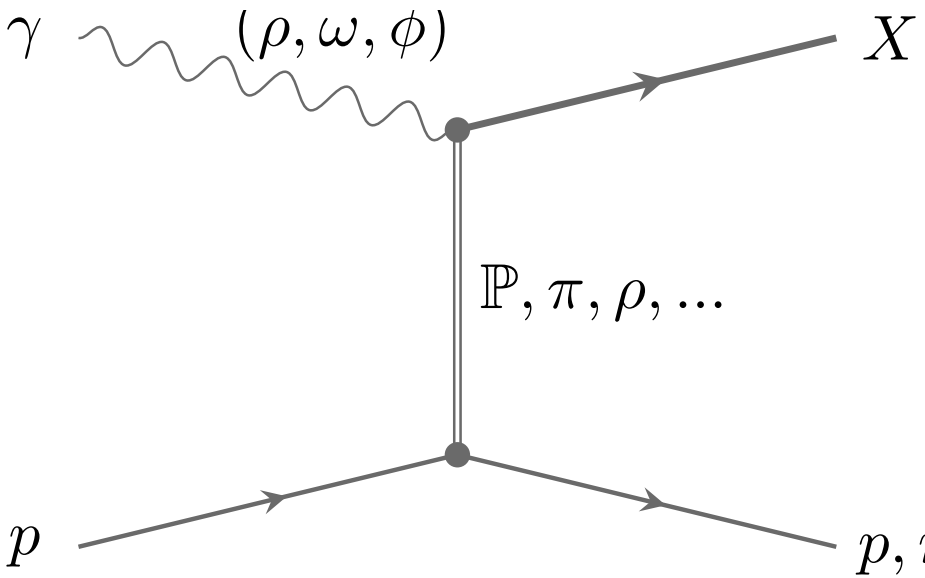


- Many experiments looked for resonances in the *P*-wave:

Experiment	Beam Momentum (GeV/c)	Reaction	Resonance
GAMS	32, 38, 100	$\pi^- p \to \pi^0\eta n$	$\pi_1(1400)$
KEK	6.3	$\pi^- p \to \pi^-\eta p$	?
E852	18	$\pi^- p \to \pi^-\eta(') p$	$\pi_1(1400/1600)$
Crystal Barrel	Annihiation	$\bar{p}n \to \pi^-\pi^0\eta$	$\pi_1(1400)$
VES	37	$\pi^- p \to \pi^-\eta(') p$	$\pi_1(1600)$?
COMPASS	190	$\pi^- p \to \pi^-\eta(') p$	?
CLAS	5.5	$\gamma p \to \pi^-\eta\Delta^{++}$	(not published)

- A strong *P*-wave was found in all $\eta'\pi$ systems, less if any at all in $\eta\pi$
- Interpretation as resonances $\pi_1(1400)/\pi_1(1600)$ is still unclear
- Almost exclusively hadro-production

Photoproduction



Exchange		Exotic Final States	
$\mathbb{P}$	0^{++}	b, h, h'	$2^{+-}, 0^{+-}$
π^0	0^{-+}	b_2, h_2, h_2'	2^{+-}
$\pi^{\pm}$	0^{-+}	$\pi_1^{\pm}$	1^{-+}
ω	1^{--}	π_1, η_1, η_1'	1^{-+}

Complementary Production Mechanism

- Photon coupling via vector meson dominance
- Wide variety of $I^G J^{PC}$ states accessible
- Photon polarization provides additional constraints

Photon Beam Line

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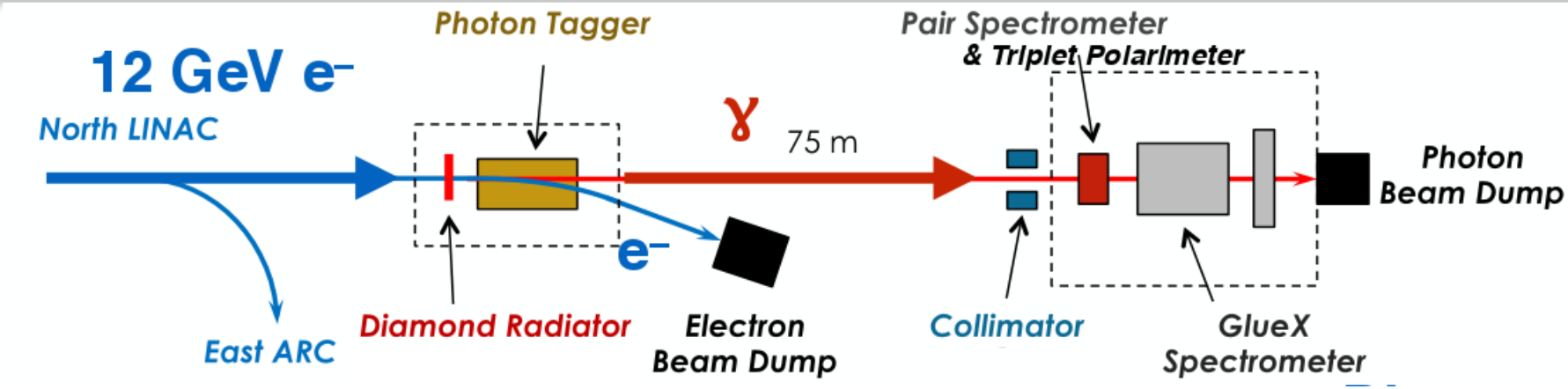

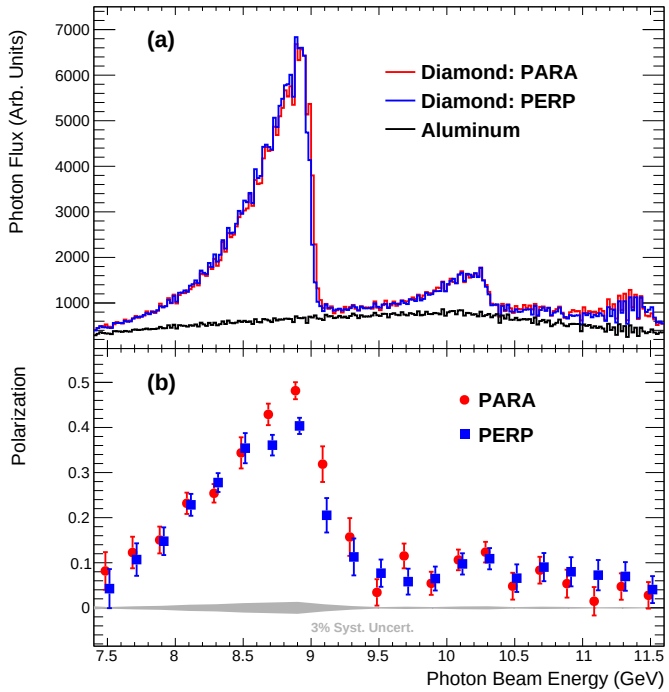

9 GeV Polarized Photon Beam

- Coherent Bremsstrahlung on thin diamond
- Energy tagged by scattered electrons
- Collimator to suppress incoherent part
- Linear polarization in peak $P_\gamma \approx 40\%$
- Beam intensity: $1 - 5 \cdot 10^7\ \gamma/\text{s}$ in peak

GlueX Detector

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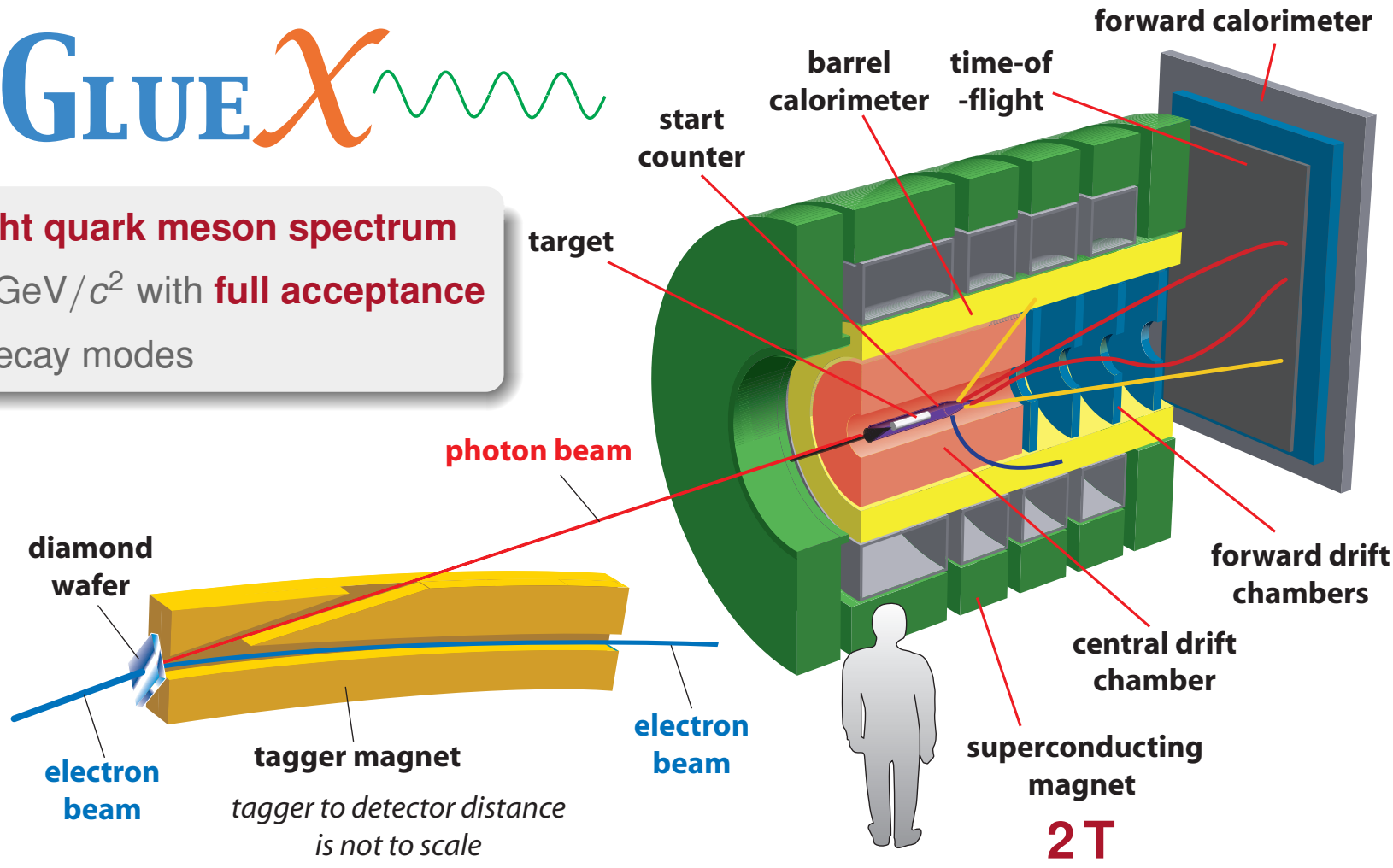
GLUEX

Map **light quark meson spectrum** up to 3 GeV/c^2 with **full acceptance** for all decay modes



→ J.R. Stevens, Recent Results from GlueX [Plenary 2]

$$\gamma + p \to \eta\pi^0 + p$$
$$\hookrightarrow \pi^+\pi^-\pi^0$$

Event Selection

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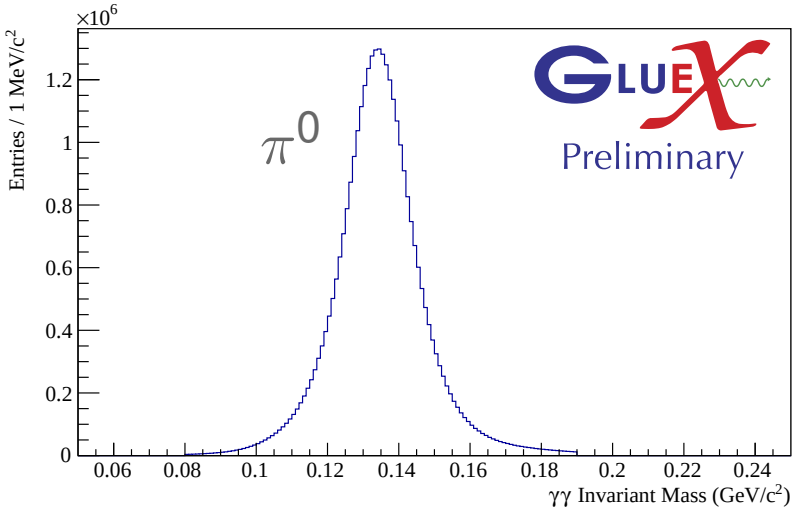

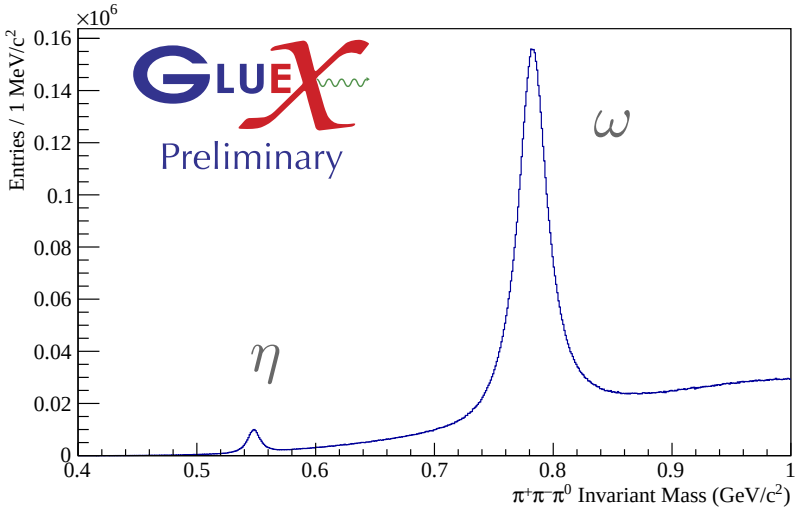

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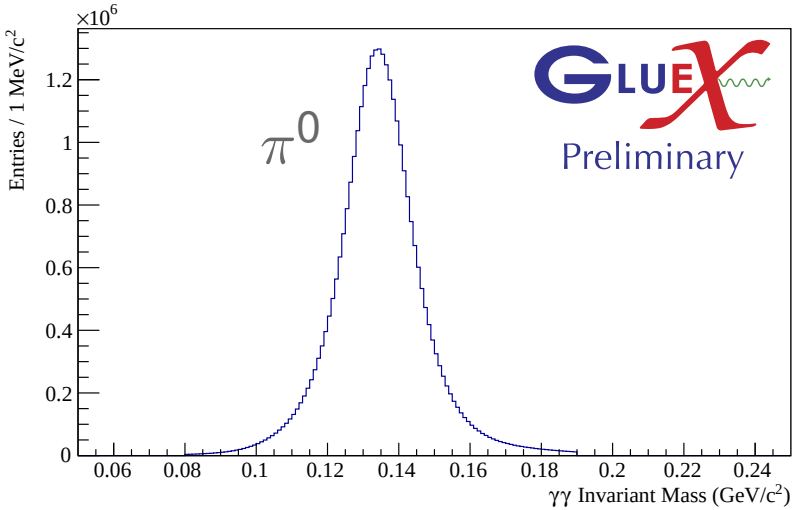

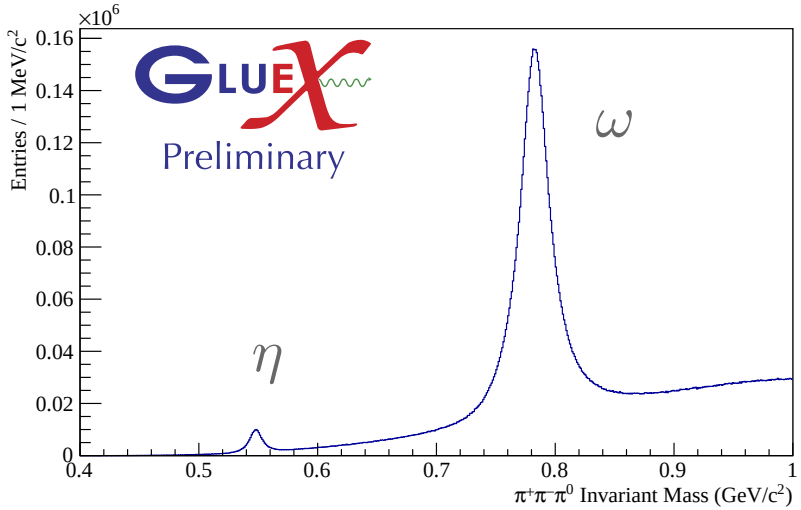

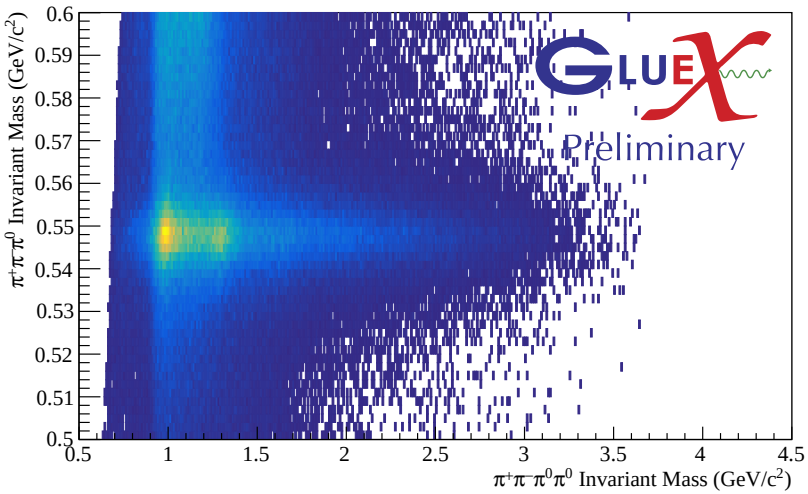

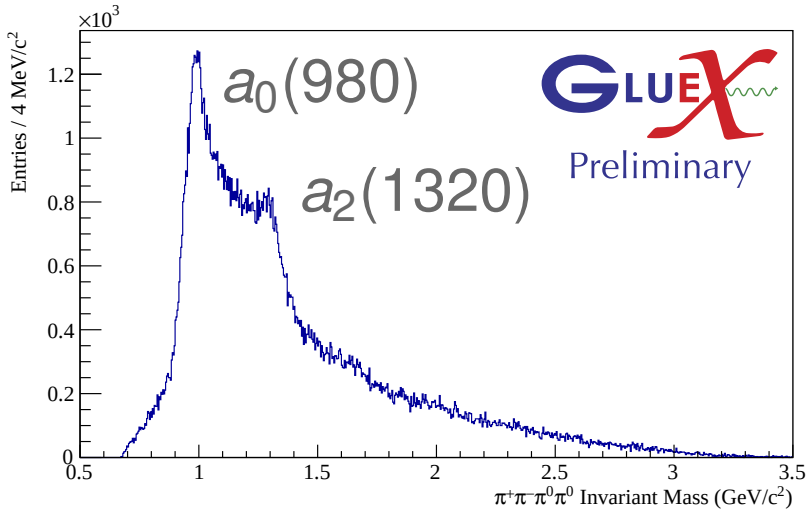

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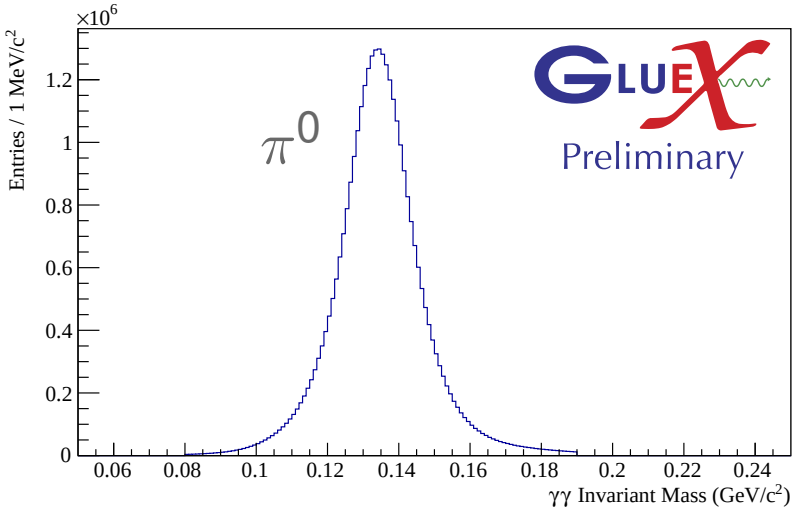
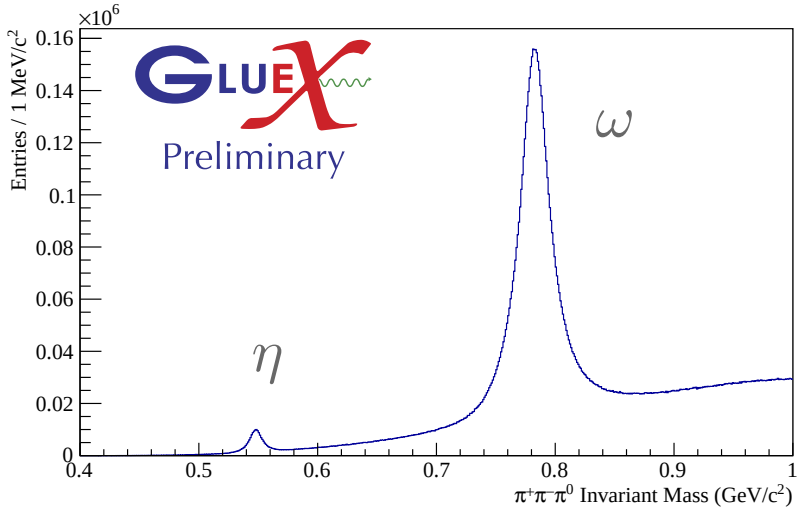
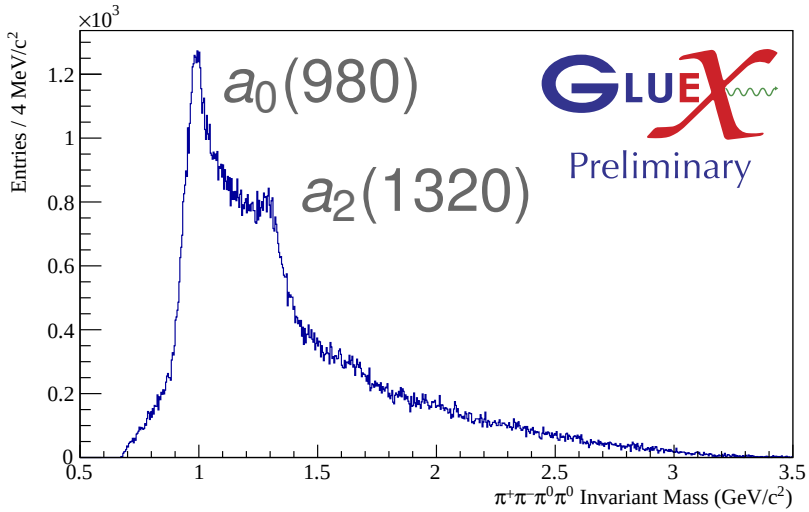


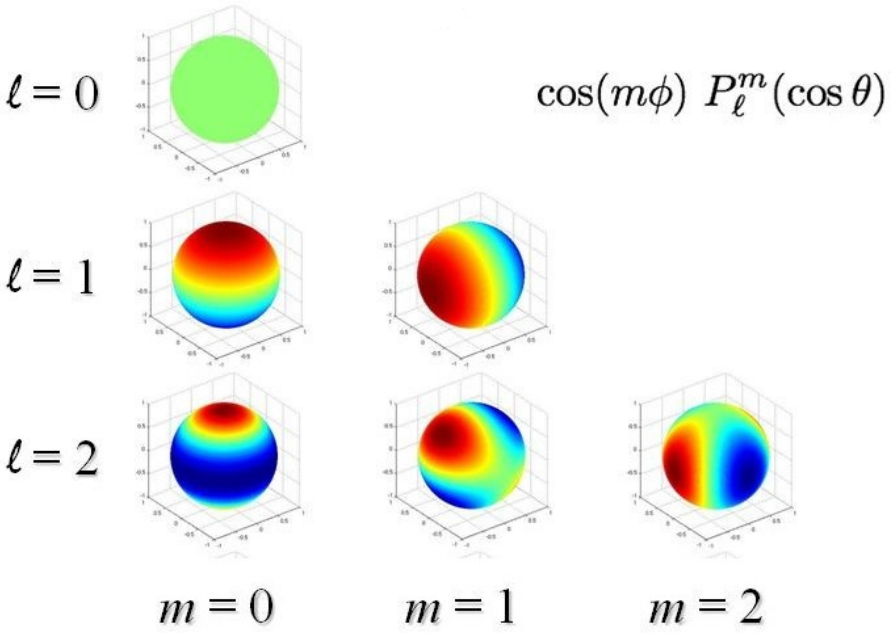


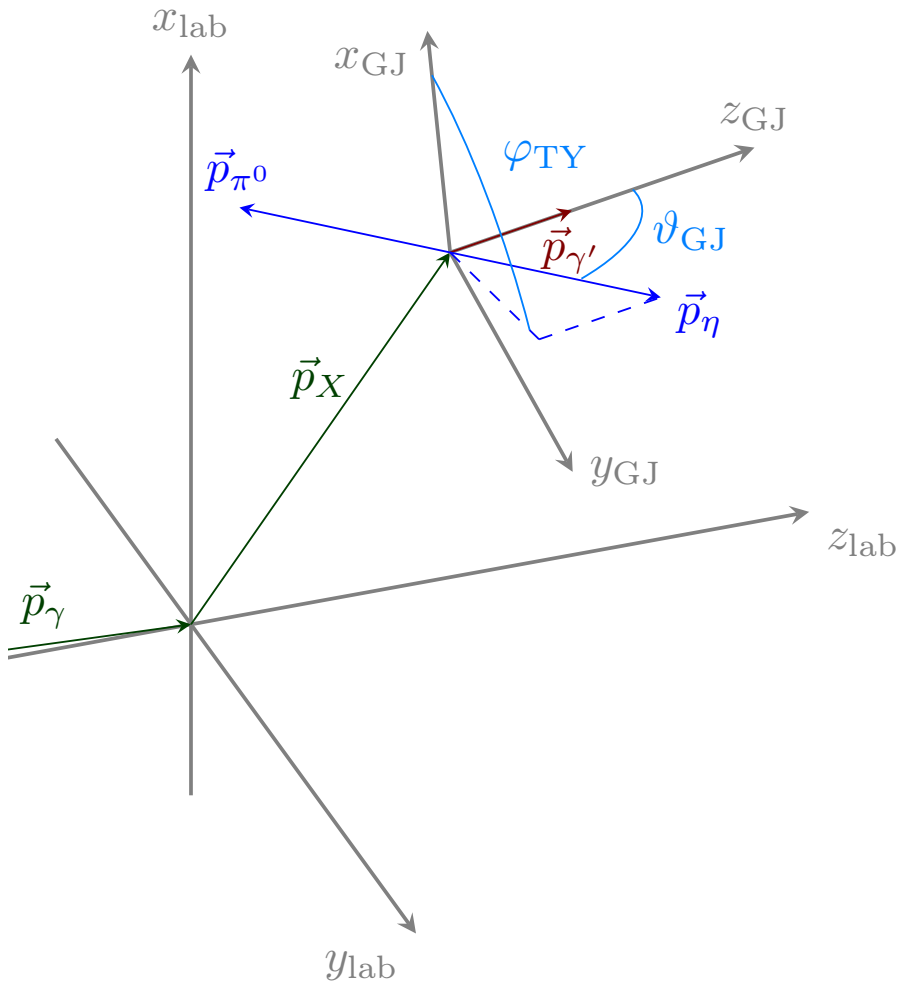
- ≈170k events (preliminary)
- 25% of full GlueX-I data set
- Competitive data sample



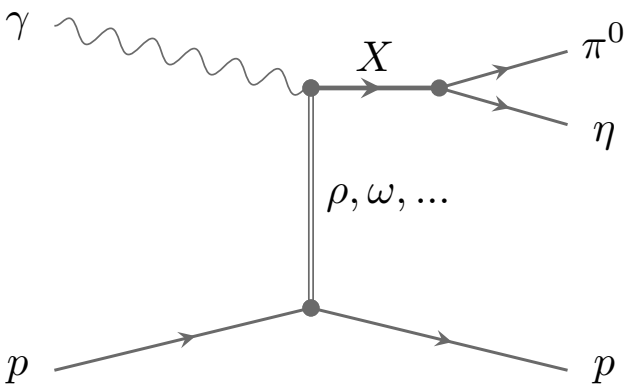
Decay Amplitudes

- Decay described by $m_{\pi\eta}$ and the angles ϑ and φ of the η in the X rest frame (here: GJ frame)
  $\Rightarrow$ spherical harmonics $Y_M^L(\vartheta, \varphi)$



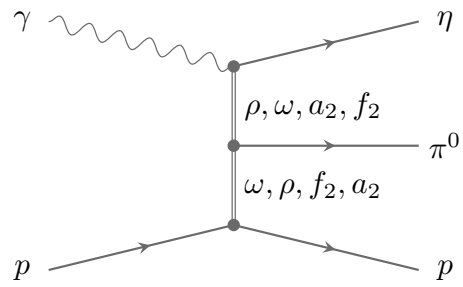


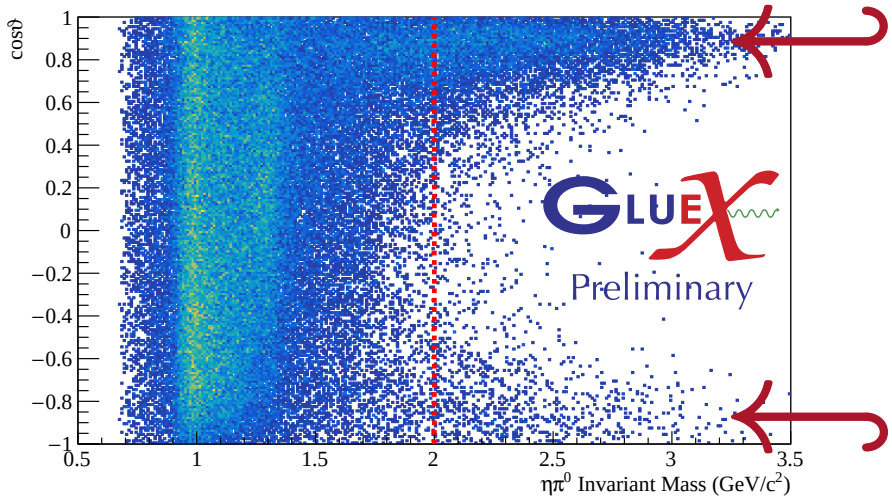
Angular Distribution

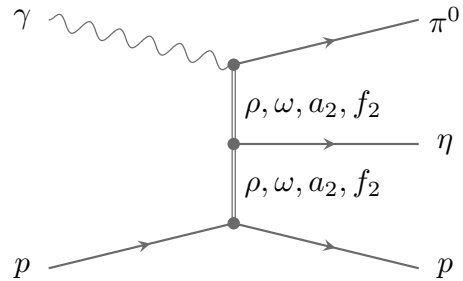


Discussion (not acceptance corrected!)

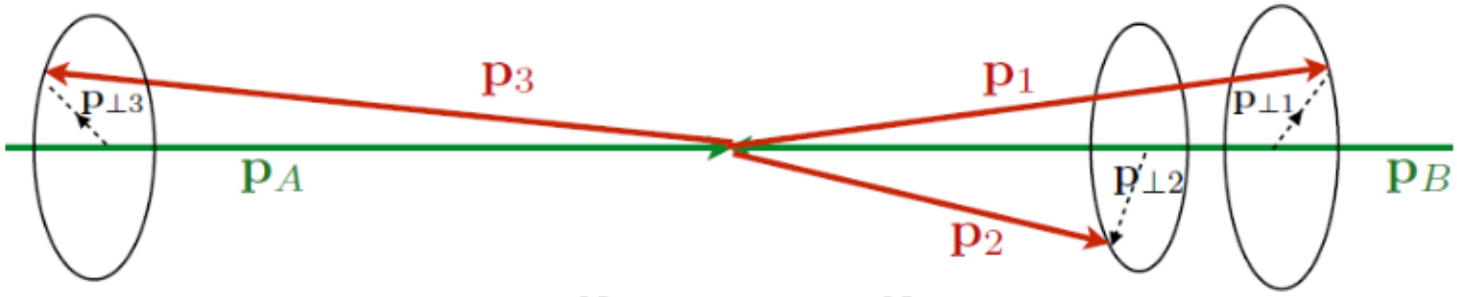
- $a_0(980)$: flat intensity at 1 GeV/c^2
- $a_2(1320)$: interference near 1.3 GeV/c^2
- Contribution from forward η: $cos\vartheta = 1$





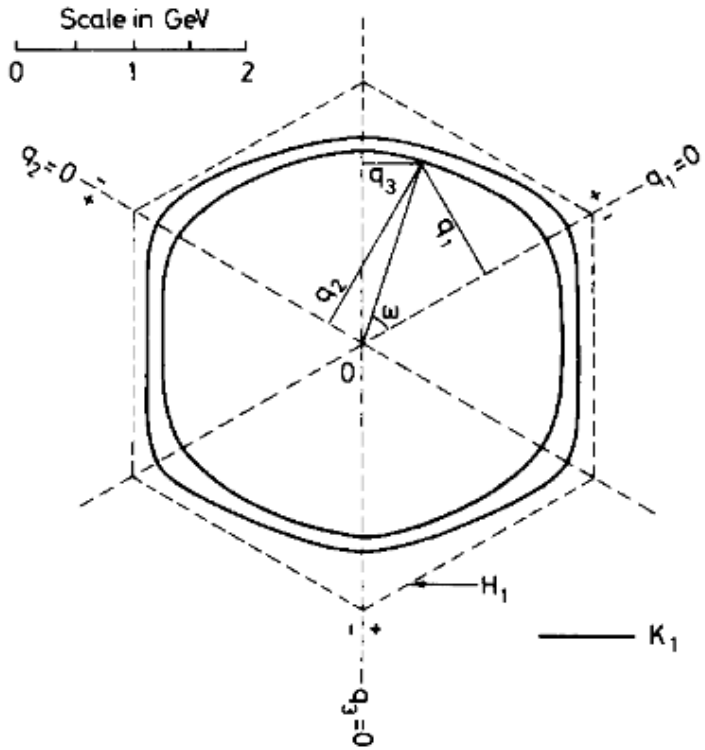


VanHove Distribution



L. VanHove: longitudinal phase-space distribution to qualify multiperipheral reactions

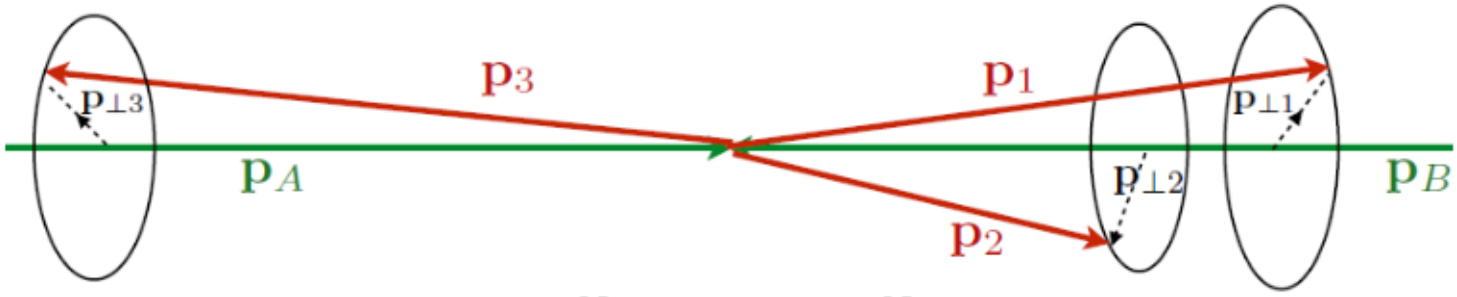
[Nucl. Phys B9 (1969) 331], [Phys. Lett. B28, 6 (1969) 429]



$$p_i = q_i + p_{\perp i} \quad , \quad \sum_{i=1}^{3} q_i = 0$$

$$q_1 = r \sin\omega$$
$$q_2 = r \sin(\omega - \tfrac{2\pi}{3})$$
$$q_3 = r \sin(\omega - \tfrac{4\pi}{3})$$

VanHove Distribution



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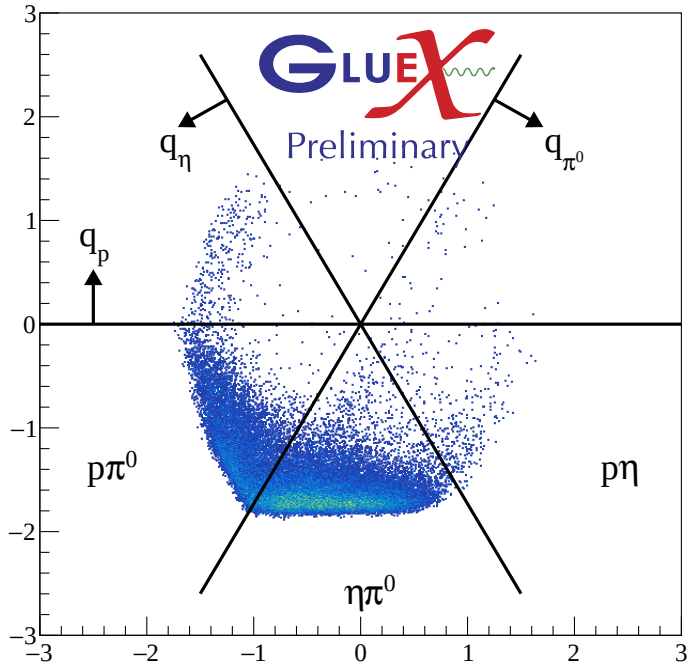
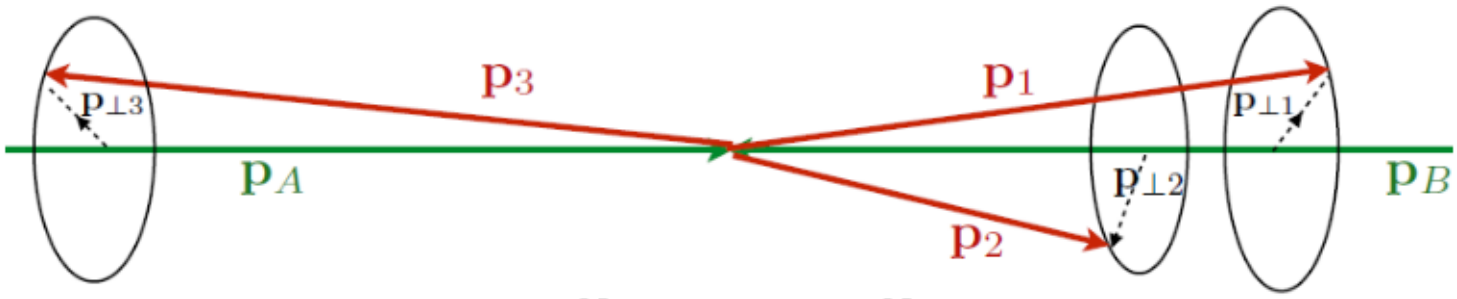


$E_\gamma = 9\,\mathrm{GeV}/c^2$

VanHove Distribution



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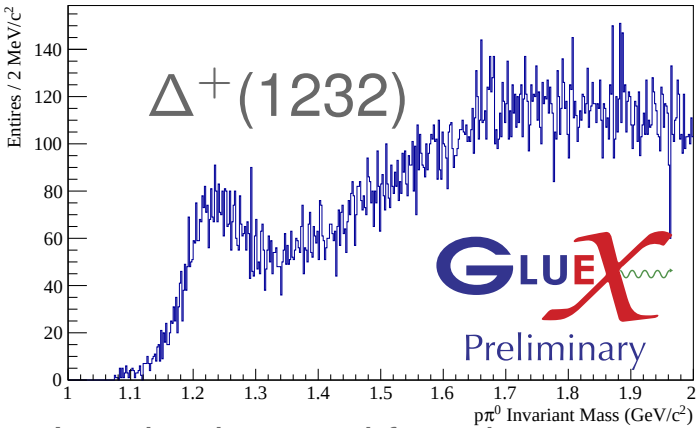
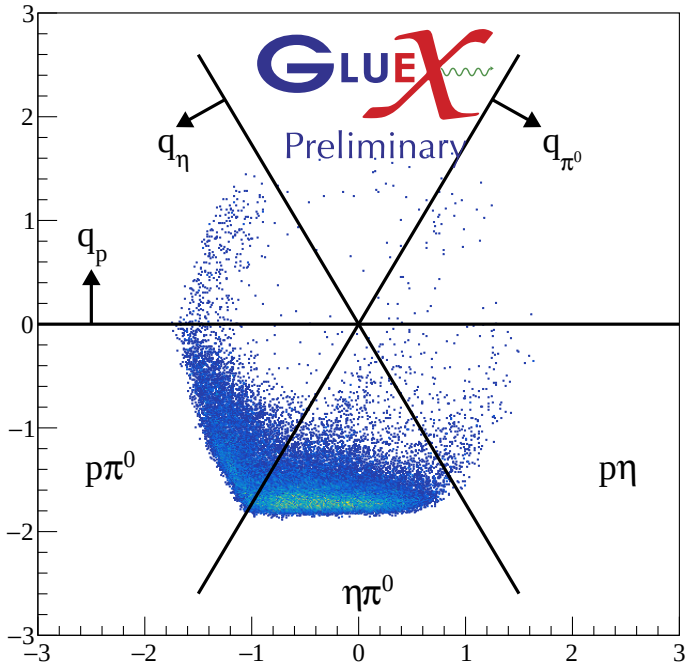


Low background from baryon excitation

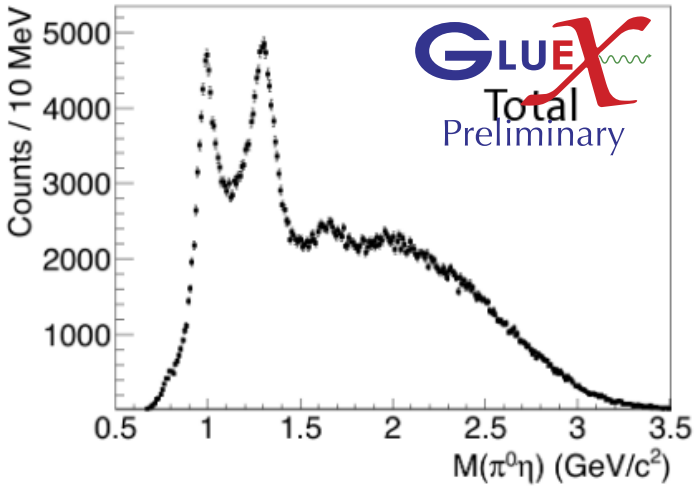


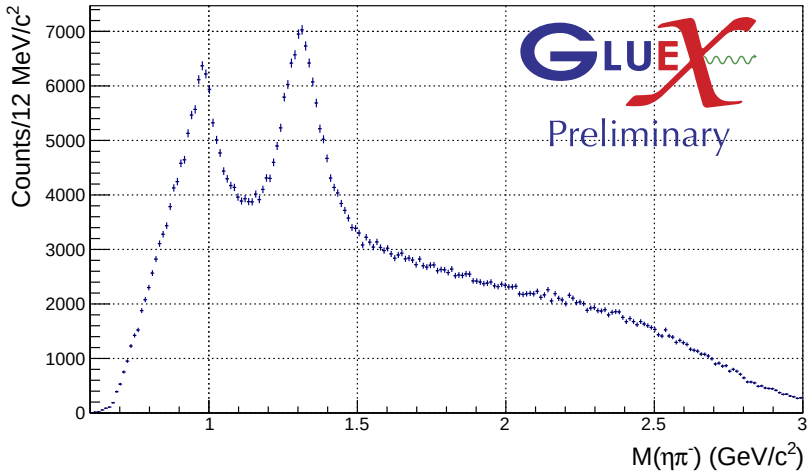
$E_\gamma = 9\,\mathrm{GeV}/c^2$

Alternative Final-States

$$\gamma + p \to \eta\pi^0 + p$$
$$\hookrightarrow \gamma\gamma$$

$$\gamma + p \to \eta\pi^- + \Delta^{++}$$
$$\hookrightarrow \gamma\gamma \quad \hookrightarrow \pi^+ p$$





- Large data set and versatile detector permitts analysis of all modes
- Four-photon final state has better reconstruction efficiency
- Charge exchange reaction limits possible production mechanisms

$$\gamma + p \to \eta'\pi^0 + p$$
$$\hookrightarrow \pi^+\pi^-\eta$$
$$\hookrightarrow \gamma\gamma$$

Event Selection

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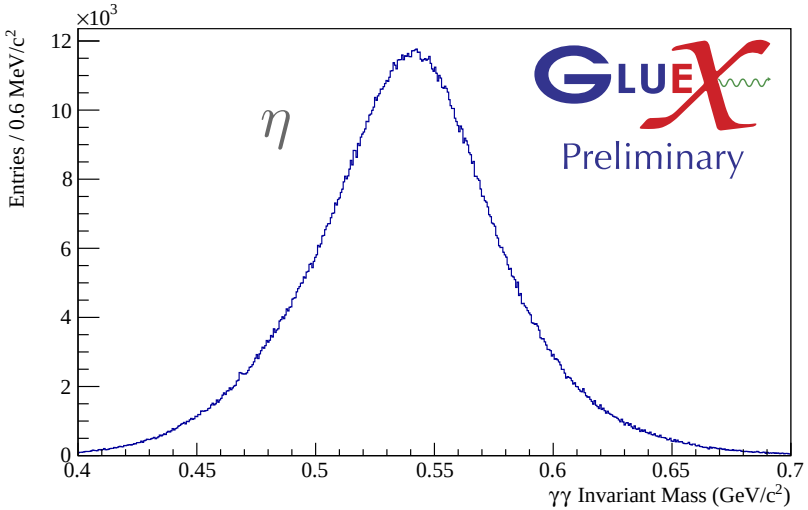

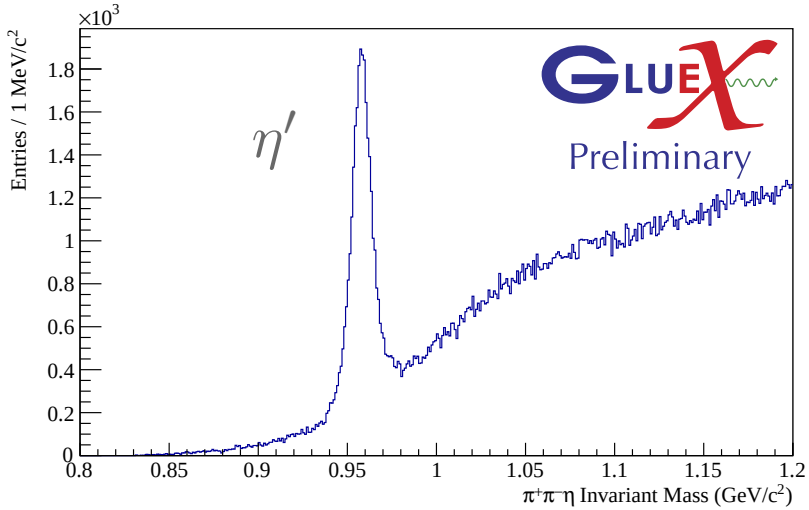

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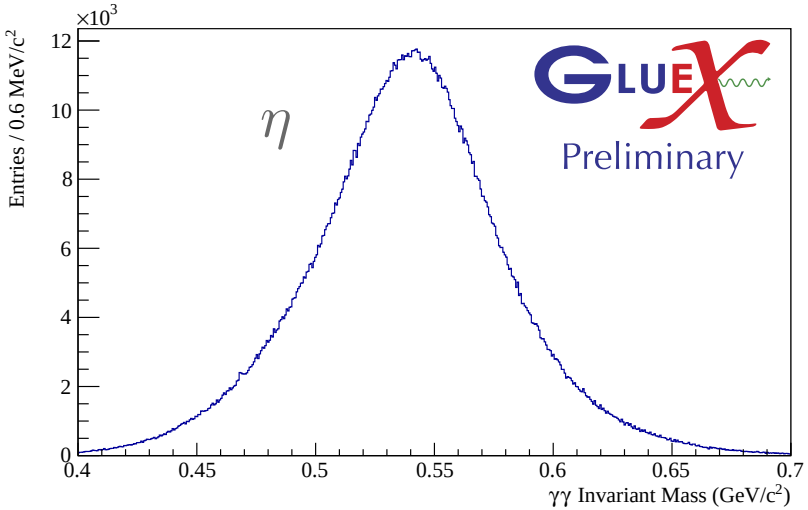

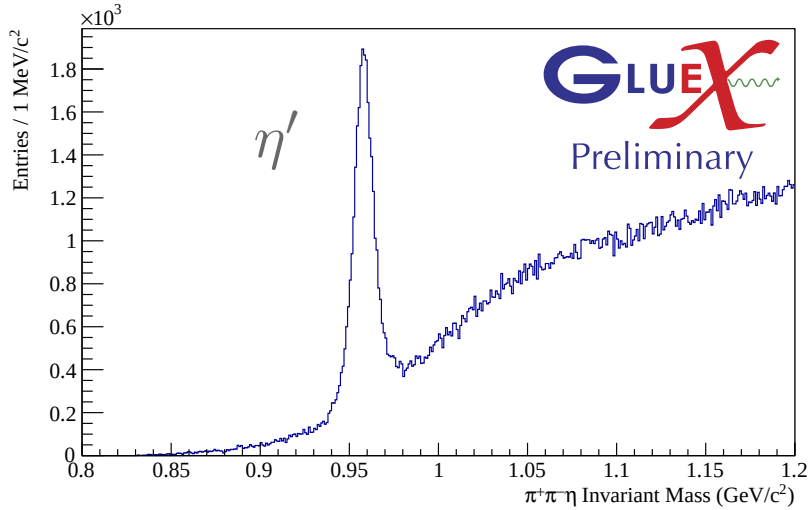

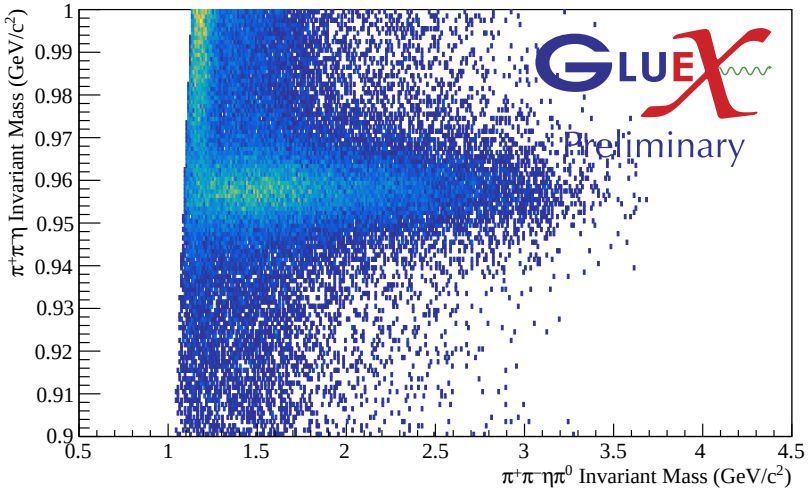

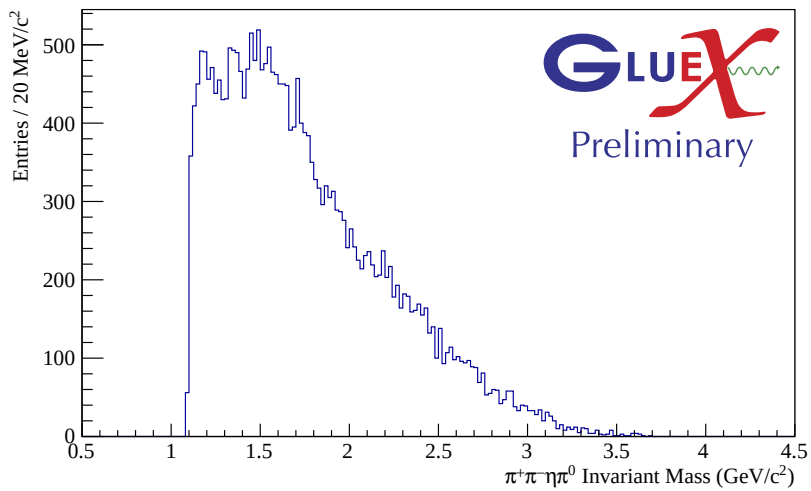

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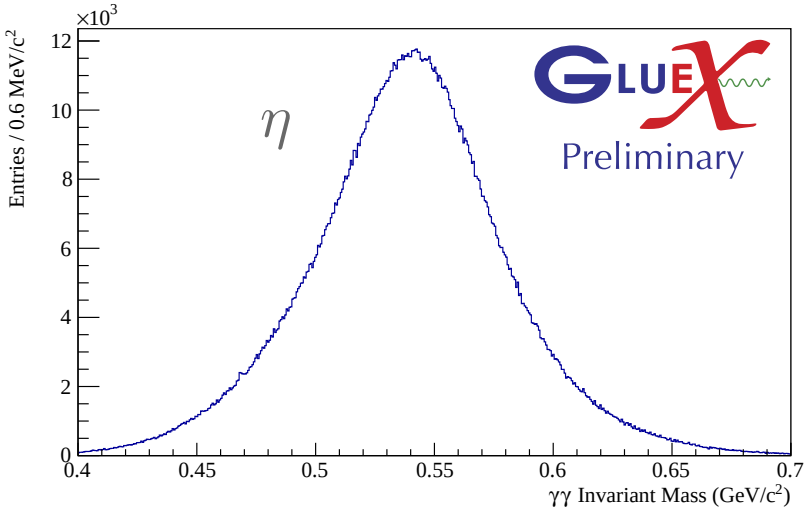

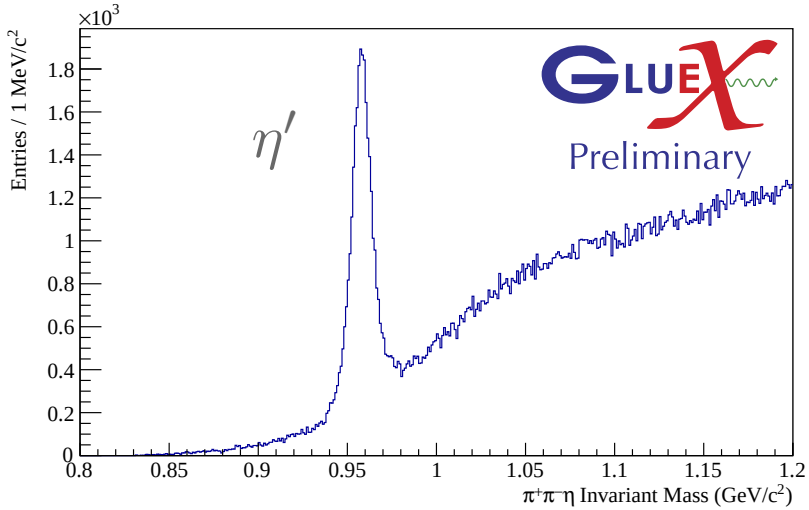

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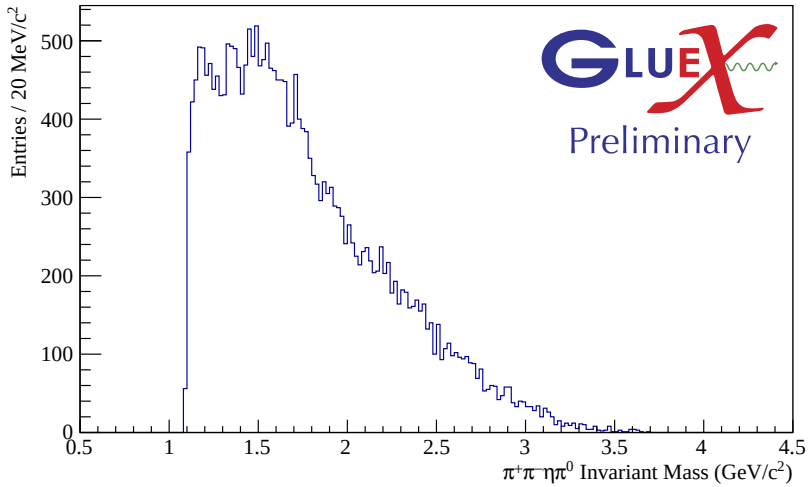

Angular Distribution

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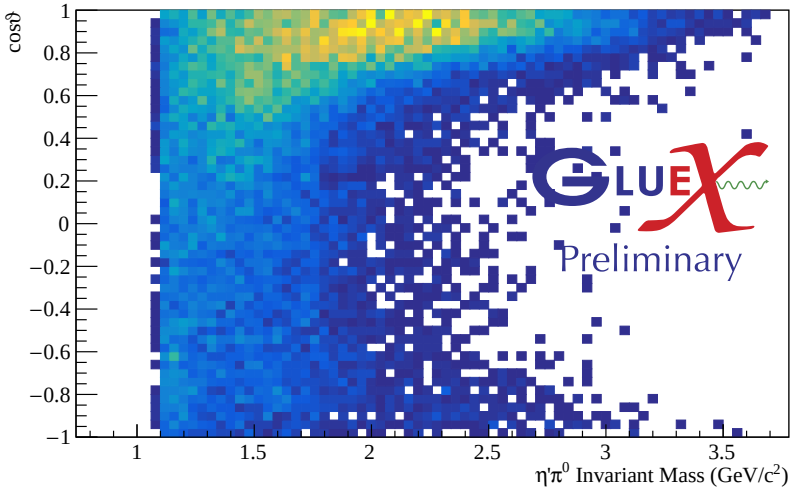
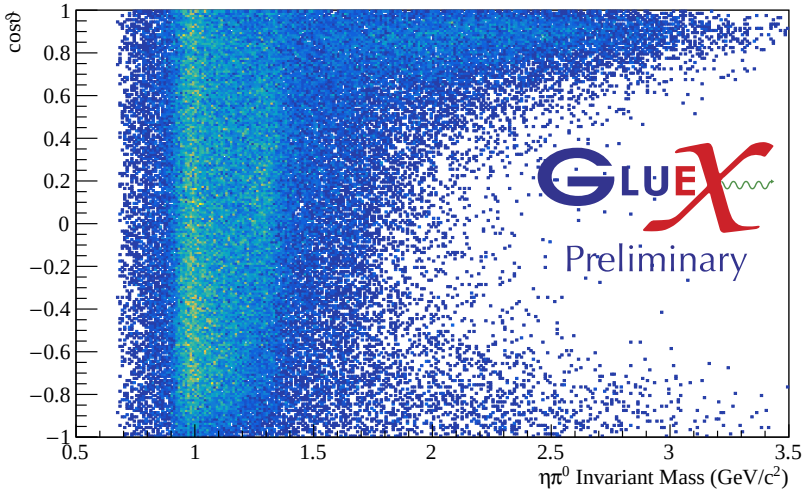
$\eta'\pi^0$

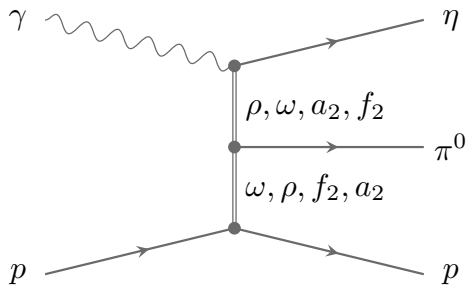


$\eta\pi^0$



Discussion (not acceptance corrected!)

- Contribution from forward-going η': $cos\vartheta = 1$
- Larger asymmetry in resonance region for $\eta'\pi^0$ compared to $\eta\pi^0$



Summary and Outlook

Jefferson Lab
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Summary

- ≈75% of GlueX-I data recorded, ≈25% analyzed
- Competitive statistics in multiple decay modes
- Ongoing studies on production mechanism and systematics

Outlook

- Acceptance-corrected amplitude analysis with polarized beam
- Collaboration with JPAC (Joint Physics Analysis Center) on amplitudes and models
- Reach definitive conclusion on resonance content