

Dalitz Plot Analysis of $\eta \rightarrow \pi^+ \pi^- \pi^0$ with the GlueX Phase I Data Set

Daniel Lersch

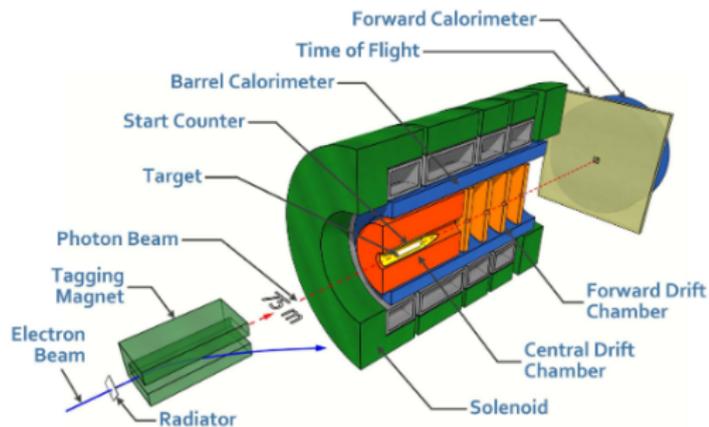
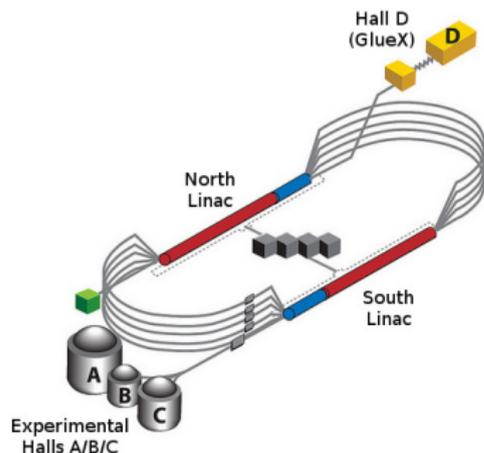
(For the GlueX Collaboration)

Florida State University

04/13/2021



The Gluonic eXcitations (GlueX) Experiment at Jefferson Lab



Experimental Hall D:

- Over 130 scientists from:
 - ▶ 30 Institutions
 - ▶ 10 Countries
- Experiments with polarized photon beam

Phase	Run Period	Raw Data [PB]
GlueX-I	Spring 2017	0.9
	Spring 2018	1.9
	Fall 2018	1.1
GlueX-II	Spring 2020	2.8
	Summer 2020	1.7

Physics Roadmap

Collect Data

Physics Roadmap

Collect Data

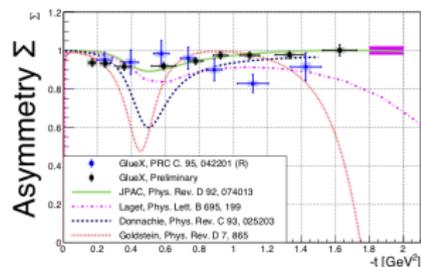
Understand production mechanisms

$$\gamma p \rightarrow (\pi^0, \eta, \eta') p$$

$$\gamma p \rightarrow (\rho, \omega, \phi) p$$

$$\gamma p \rightarrow (\Lambda, \Sigma) K^+$$

$$\gamma p \rightarrow \pi^0 p$$

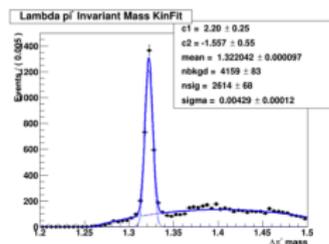


Physics Roadmap

Collect Data

Understand production mechanisms

Measure cross sections



Physics Roadmap

Collect Data

Understand production mechanisms

Measure cross sections

Theoretical Models
(JPAC, ...)

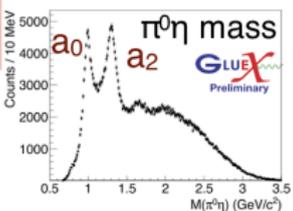
Identify known mesons

$a, f, b, h, \eta, \pi, \dots$

Search for exotics

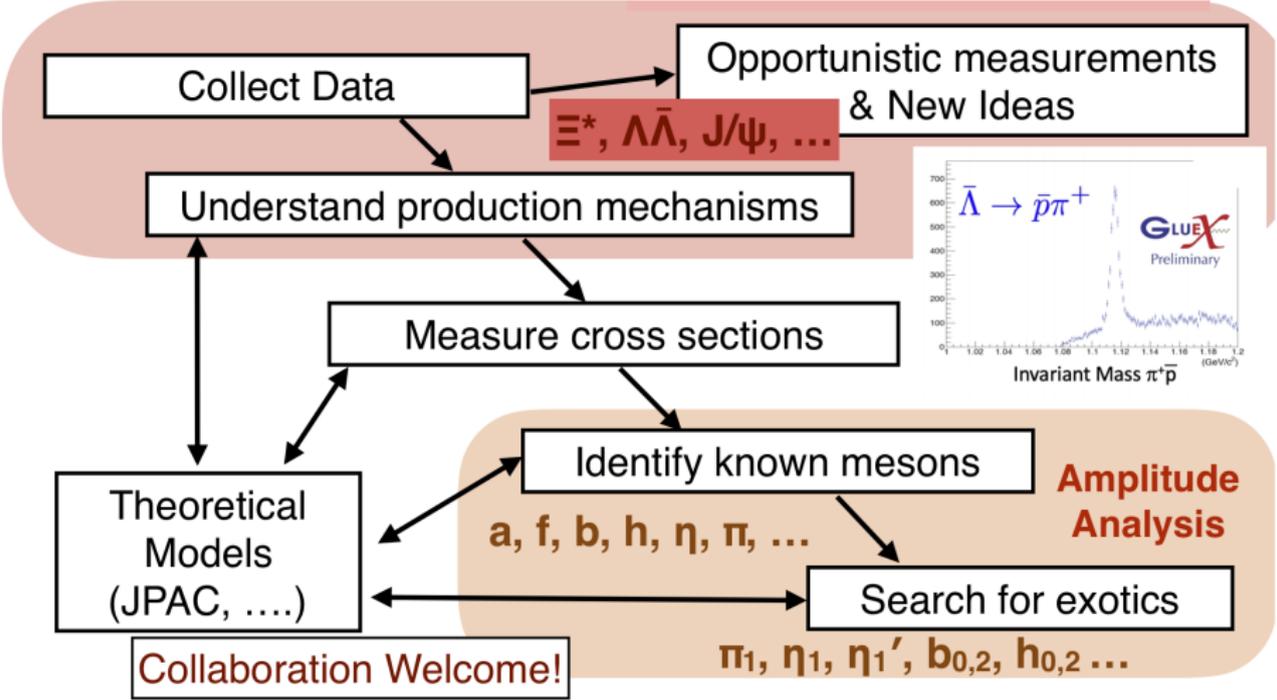
Collaboration Welcome!

$\pi_1, \eta_1, \eta_1', b_{0,2}, h_{0,2} \dots$

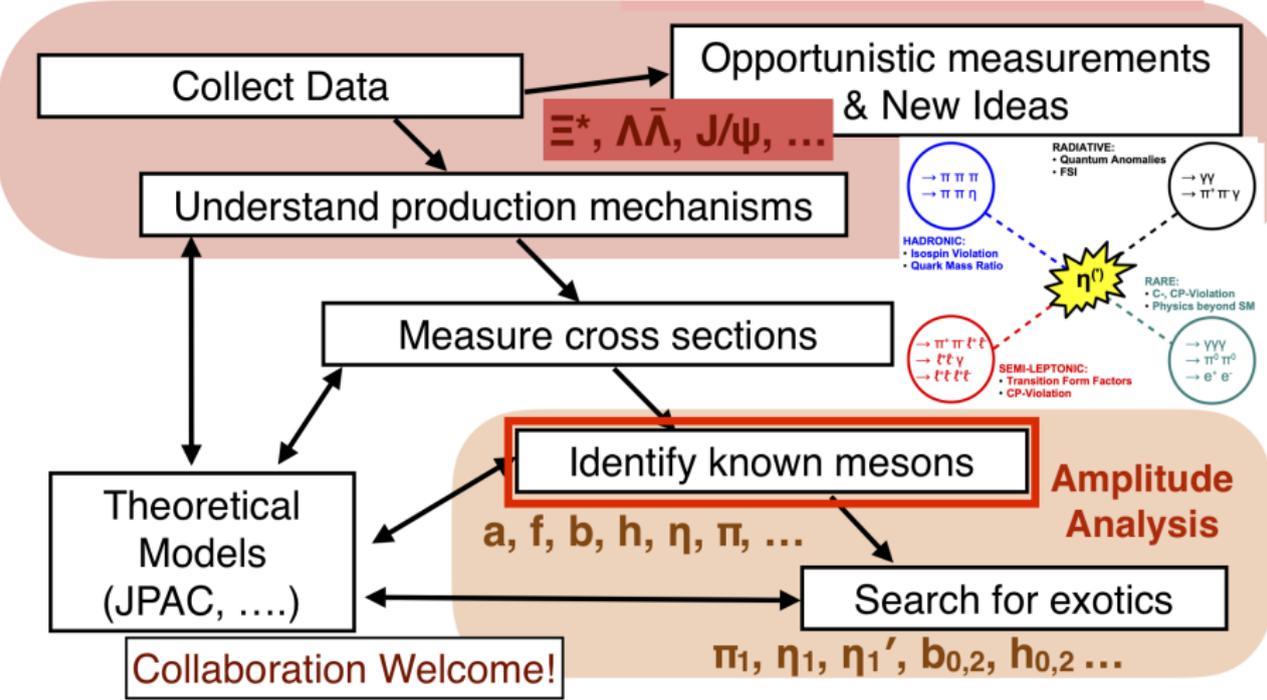


Amplitude Analysis

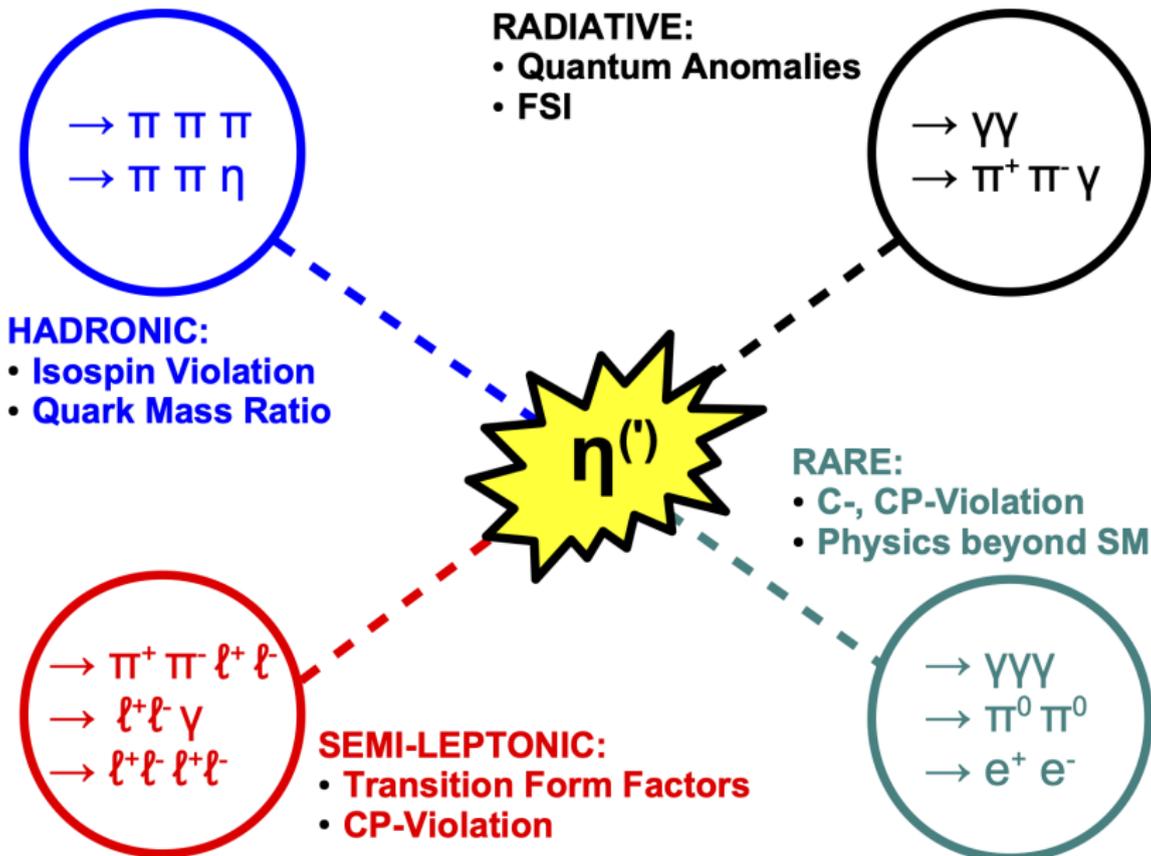
Physics Roadmap



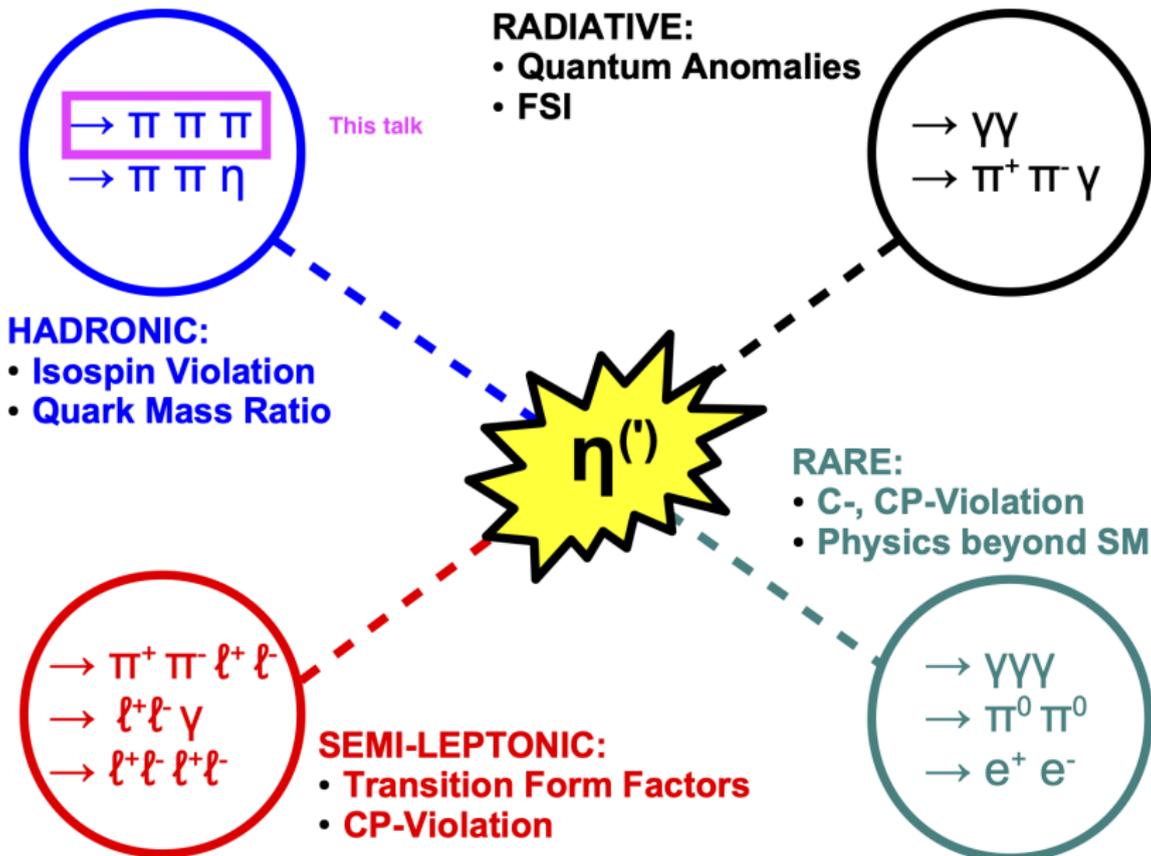
Physics Roadmap



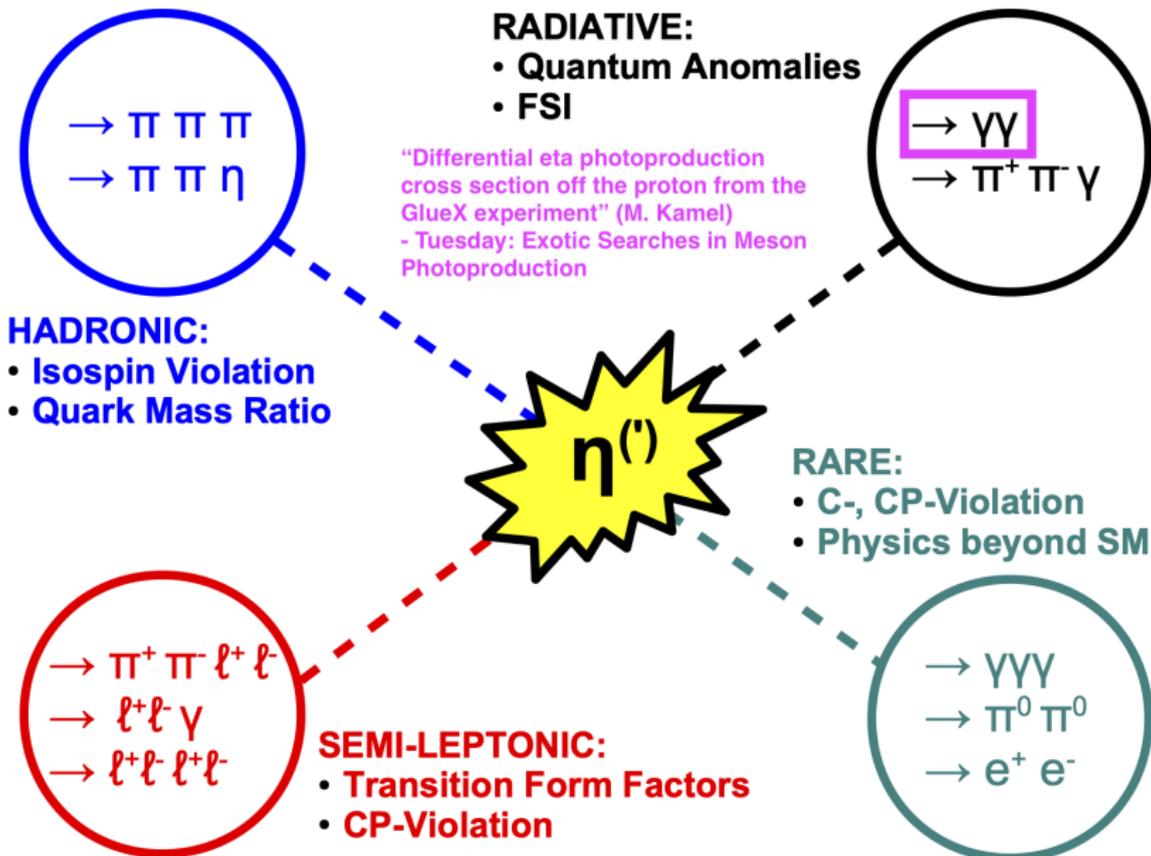
$\eta/\eta^{(\prime)}$ Decays



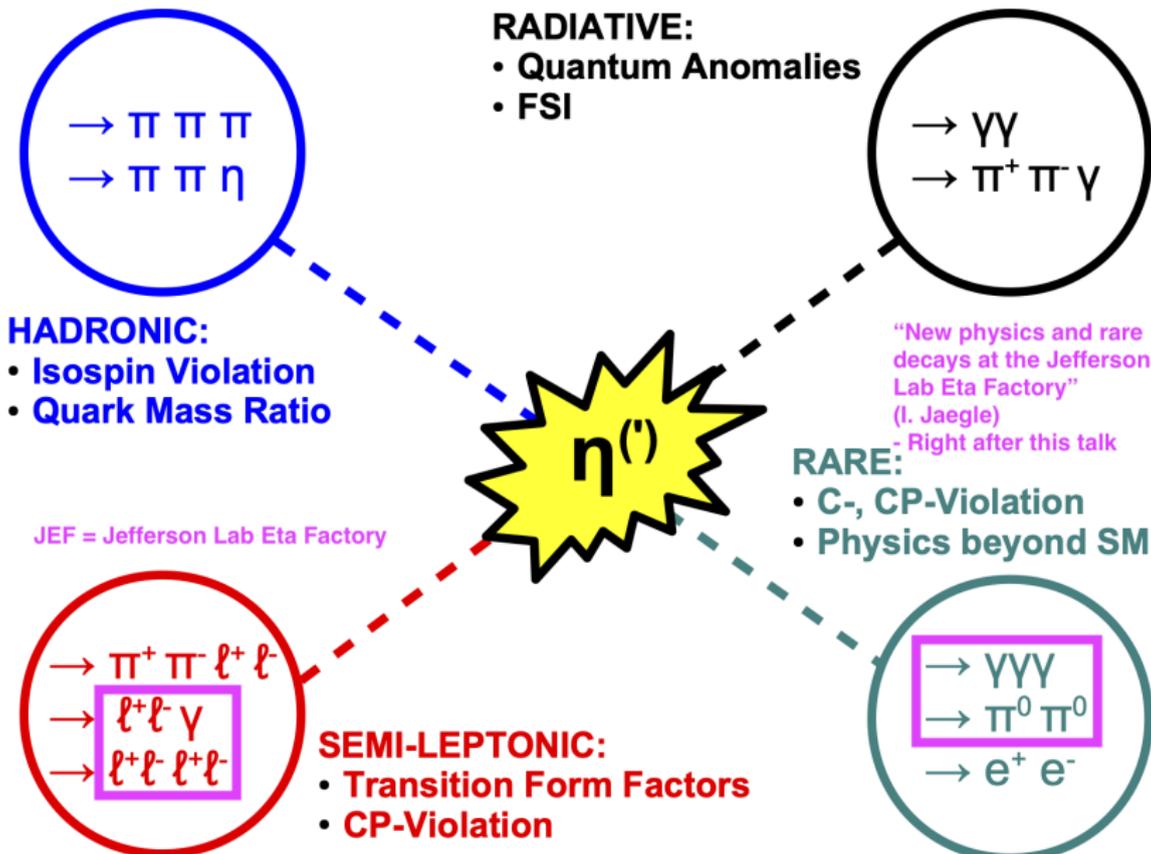
$\eta/\eta^{(\prime)}$ Decays



$\eta/\eta^{(\prime)}$ Decays



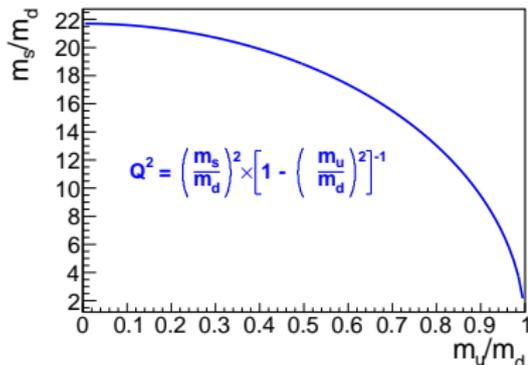
$\eta/\eta^{(\prime)}$ Decays



Decay Properties of $\eta \rightarrow \pi^+\pi^-\pi^0$

System	Isospin $ I, I_z\rangle$	C-Eigenvalue	G-Eigenvalue
η	$ 0, 0\rangle$	+1	+1
$(\pi^+\pi^-\pi^0)$	$ 0, 0\rangle$	-1	-1
$(\pi^+\pi^-\pi^0)$	$ 0, 0\rangle$	+1	-1

- Decay $\eta \rightarrow \pi^+\pi^-\pi^0$ is...
 - ... G-violating
 - ... C-conserving \Leftrightarrow Isospin breaking
- Determine quark mass ratio by measuring decay width: $\Gamma(\eta \rightarrow \pi^+\pi^-\pi^0) \propto Q^{-4}$



\Rightarrow Experimental access to Γ :

- Relative branching fraction: e.g. $\Gamma(\eta \rightarrow \pi^+\pi^-\pi^0)/\Gamma(\eta \rightarrow \gamma\gamma)$
- Dalitz Plot analysis

Dalitz Plot Analysis

- Decay width Γ :

$$\Gamma \propto Q^{-4}, \quad Q^2 = \left(\frac{m_s}{m_d}\right) \times \left[1 - \left(\frac{m_u}{m_d}\right)^2\right]^{-1}$$

Parameterize:

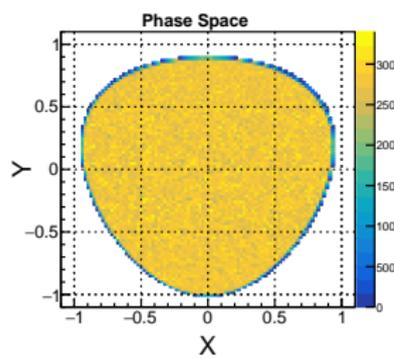
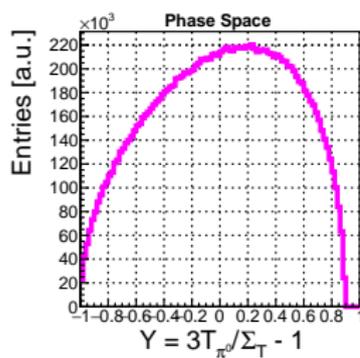
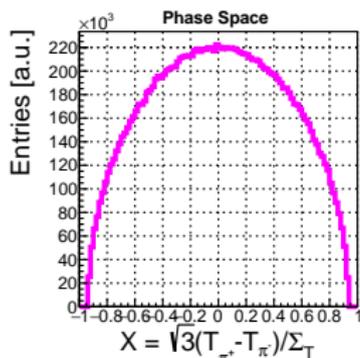
$$\frac{d^2\Gamma}{dXdY} \propto (1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + hXY^2 + lX^3 + \dots)$$

- Dimensionless variables:

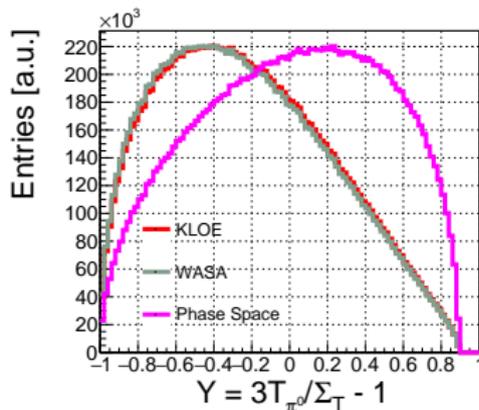
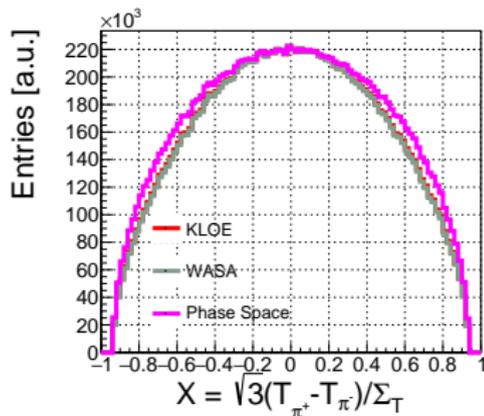
$$X = \sqrt{3}(T_{\pi^+} - T_{\pi^-})/\Sigma_T \rightarrow \text{Sensitive to charge conjugation}$$

$$Y = 3T_{\pi^0}/\Sigma_T - 1$$

- C-conservation: $c = e = h = l = 0 \rightarrow$ symmetric X-distribution



Previous Measurements



Experiment	η -Production	$N(\eta \rightarrow \pi^+ \pi^- \pi^0)$
KLOE*	$e^+ e^- \rightarrow \Phi \rightarrow \eta \gamma$	$\sim 4.7 \text{ M}$
WASA**	$pd \rightarrow {}^3\text{He}$	$\sim 120 \text{ k}$
BESIII***	$e^+ e^- \rightarrow J/\psi \rightarrow \eta \gamma$	$\sim 80 \text{ k}$ (not discussed today)

- Tensions on a and b parameters between WASA and KLOE
- JPAC used KLOE and WASA results to determine: $Q = 21.6 \pm 1.1$
- **Perform Dalitz Analysis on $\gamma p \rightarrow \eta p$ using the GlueX-I data**

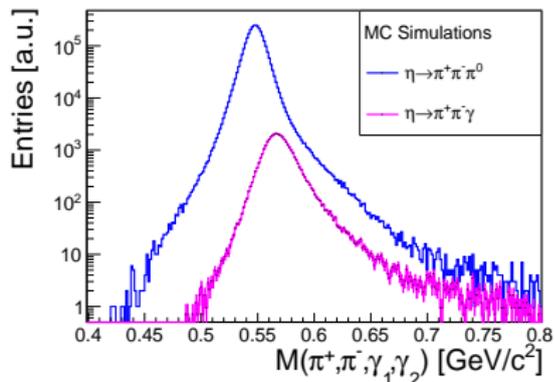
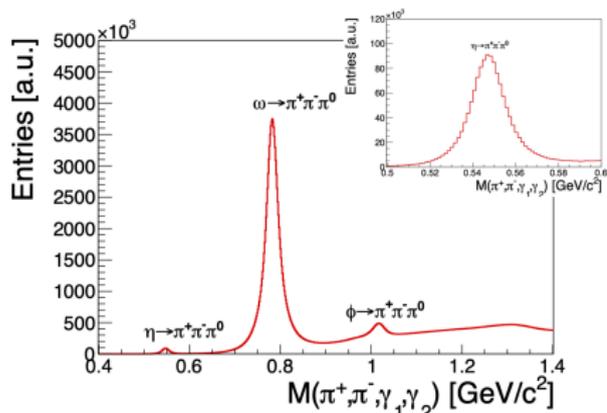
* KLOE coll., *JHEP*, 019, (2016)

** WASA-at-COSY coll., *Phys. Rev.*, C90(045207), (2014)

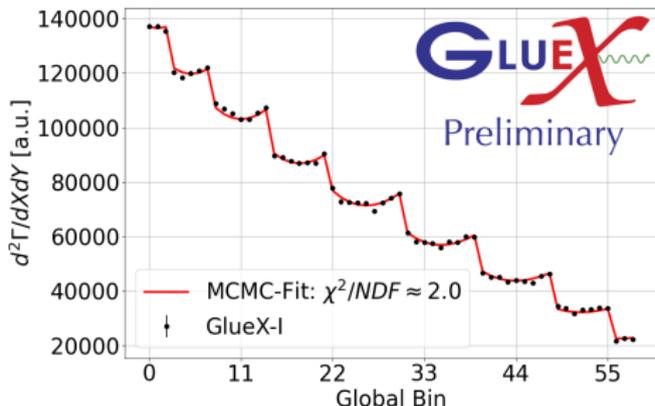
*** BES III coll., *Phys. Rev.*, D92(012014), (2015)

$\pi^+\pi^-\pi^0$ Final States in GlueX-I

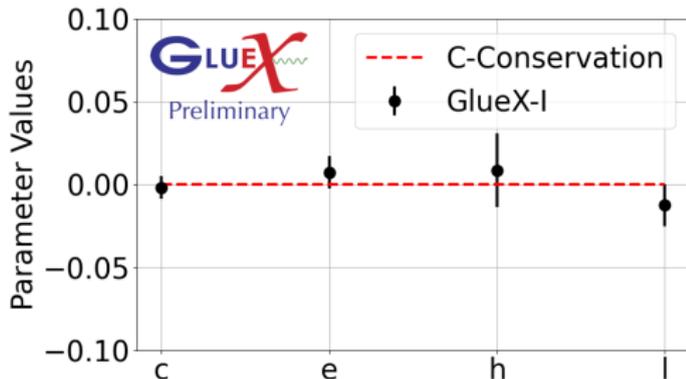
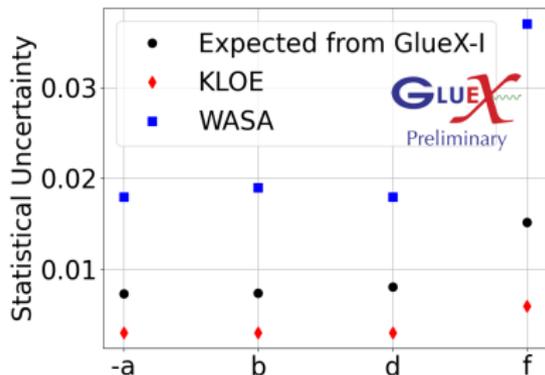
- Selected via kinematic fit
- Reconstructed ~ 1 M $\eta \rightarrow \pi^+\pi^-\pi^0$ with current analysis
- Usage in other analyses:
 - Extraction of spin density matrix elements in $\omega \rightarrow \pi^+\pi^-\pi^0$
 - * "Probing Meson Photoproduction Mechanisms With Observables in Exclusive Vector-Meson Photoproduction" (M. Dalton) - Tuesday: Exotic Searches in Meson Photoproduction
 - Differential η cross section from $\eta \rightarrow \pi^+\pi^-\pi^0$
- MC simulations
 - Based on phase space and GEANT4
 - Contributions from $\eta \rightarrow \pi^+\pi^-\gamma$ negligible



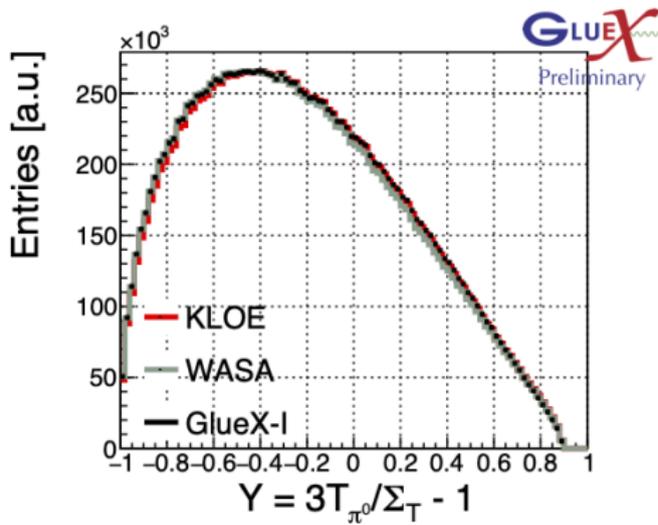
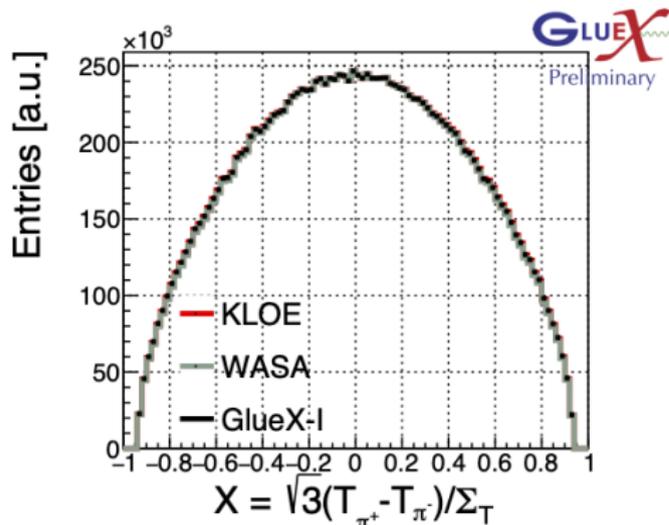
Results from GlueX-I Data



- 1D representation of Dalitz Plot:
Global Bin = $f(X, Y)$
- Fit to GlueX-I data:
 $N \cdot (1.0 + aY^2 + bY + cX + \dots)$
- Use Markov Chain Monte Carlo Ensemble Sampler (**emcee**)



Dalitz Plot Distributions



- Generate X- / Y-distributions from Dalitz plot parameters found in GlueX-I
- Symmetric X-distribution
- Consistent with previous experiments

Summary and Outlook

- Dalitz Plot analysis of $\eta \rightarrow \pi^+ \pi^- \pi^0$ for entire GlueX Phase-I data
 - ▶ Statistics comparable to most recent measurement from KLOE
 - ▶ Contribution to existing Dalitz Plot data
 - ▶ Determination of Q
- Crucial part in evaluating simulations and reconstruction procedures for future analyses
 - ▶ No C-violation observed
 - ▶ Consistency with previous experiments
- Systematic studies currently ongoing
- Dalitz Plot analyses running in parallel:
 - ▶ $\eta \rightarrow 3\pi^0$
 - ▶ $\eta' \rightarrow \pi^+ \pi^- \eta$
- Analysis of GlueX-II data $\sim 3\times$ more $\eta^{(\prime)}$ expected

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

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