FLORIDA STATE UNIVERSITY

Unbinned Maximum Likelihood Fit for $\eta \rightarrow \pi^+\pi^-\pi^0$ Dalitz Plot Analysis at GlueX

Nizar Septian

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$\eta \rightarrow \pi^+\pi^-\pi^0$

	η	$\pi^+\pi^-\pi^0$
I	0	1
G	+1	-1
C	+1	+1

An ideal laboratory for testing Chiral Perturbation Theory.
The decay amplitude[1]:

$$A(s,t,u) = \frac{1}{Q^2}\frac{m_K^2}{m_\pi^2}(m_\pi^2 - m_K^2)\frac{M(s,t,u)}{3\sqrt{3}F_\pi^2},\ Q^2 \equiv \frac{m_s^2}{m_d^2}\left(1 - \frac{m_u^2}{m_d^2}\right)^{-1}$$

- ✓ G violating.
- ✓ Isospin breaking.
- ✓ Induced dominantly by the strong interaction via the u, d mass difference.

$$|A|^2 \propto \Gamma(\eta \rightarrow 3\pi) \propto Q^{-4}$$

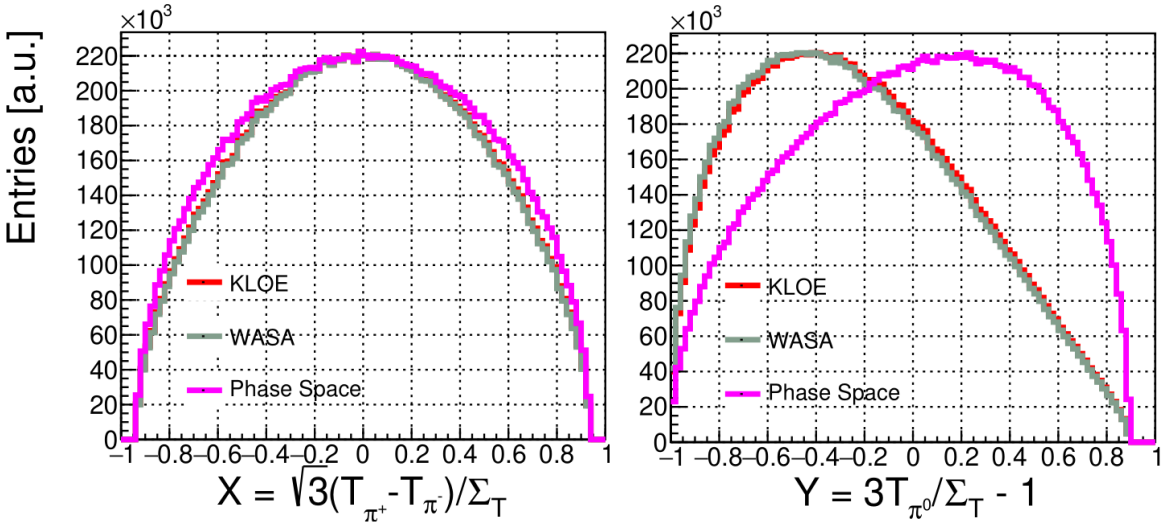
Experimental access to:
- ➢ Decay width, Γ.
- ➢ Quarks mass ratio, Q^2.

Dalitz plot analysis

- A three body decays can be uniquely described by two dimensionless variables, say X and Y.
- Expand $|A(X,Y)|^2$ around $X, Y = 0$:
  $|A(X,Y)|^2 \propto (1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + hXY^2 + lX^3 + \cdots)$
- Dimensionless variables:
  $X \equiv \frac{\sqrt{3}(T_{\pi^+} - T_{\pi^-})}{\sum T}$ and $Y \equiv \frac{3T_{\pi^0}}{\sum T - 1}$, Ts are pion's energies.

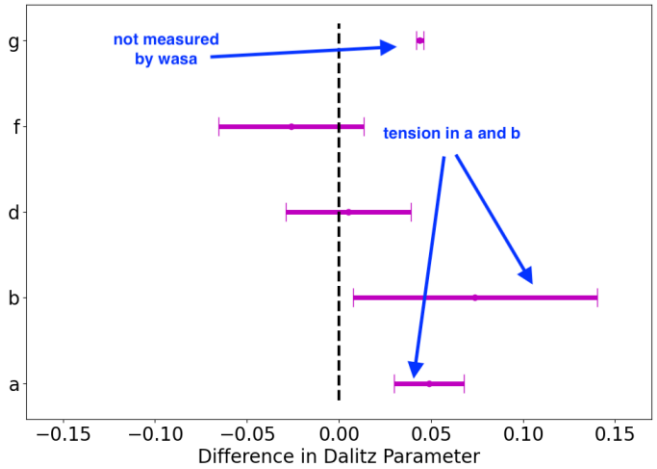
X is sensitive to charge conjugation:
$c = e = h = l = 0$

Previous experiments



Experiment	$N(\eta \to \pi^+\pi^-\pi^0)$
KLOE	~4.7 M
WASA	~120 K

Comparing WASA and KLOE Dalitz Parameters



- Tensions on a and b parameters between WASA[2] and KLOE[3].
- JPAC used KLOE and WASA results to determine: $Q = 21.6 \pm 1.1$. [4]

GlueX@Jefferson Lab

Experimental Hall-D:
- ✓ Fixed-target photoproduction experiment with 40% linearly polarized photon beam at 9-GeV.
- ✓ Relative photon and charged-particles reconstruction efficiency > 90%.
- ✓ ~4π coverage.

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

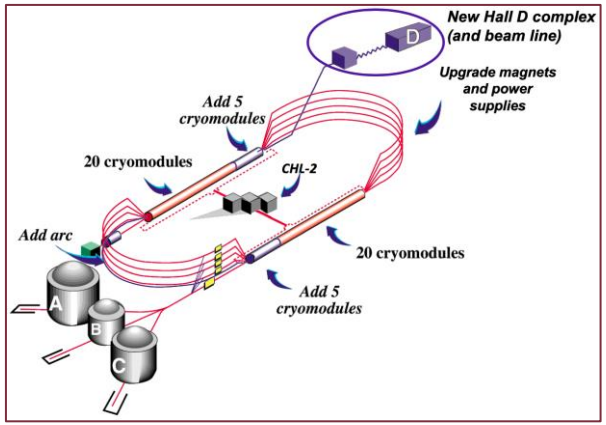
Selected final states:

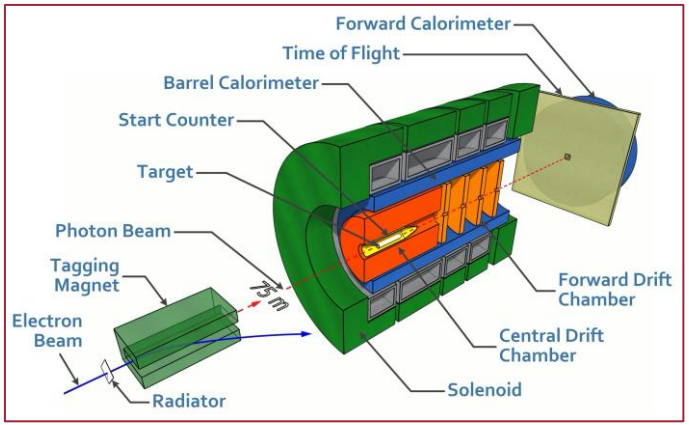
$\gamma p \to \eta p$

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

$\pi^0 \to \gamma\gamma$

Built to search for and map out the spectrum of exotic hybrid mesons using a linearly-polarized photon beam incident on a proton target.

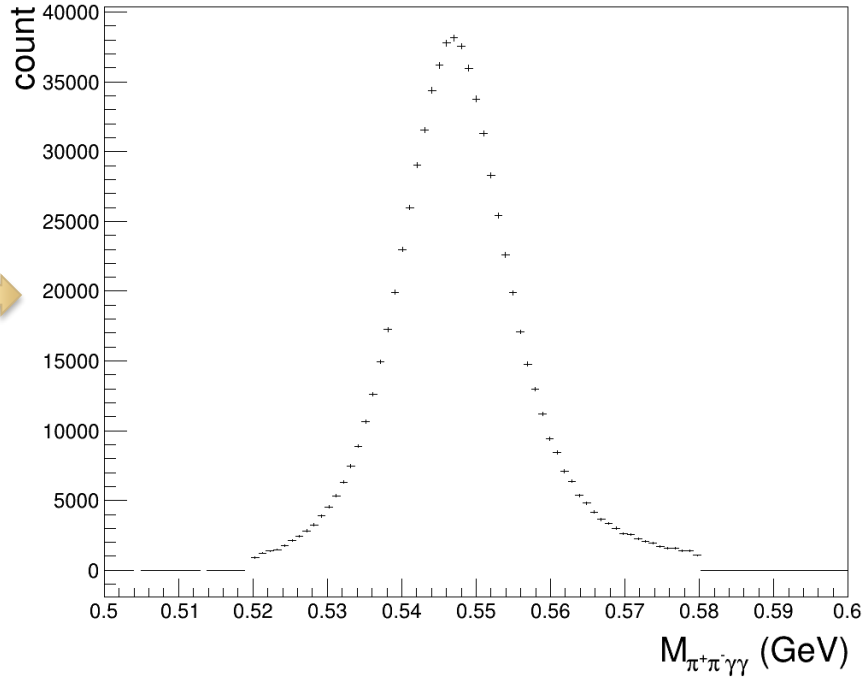




Event selections

We selected $\sim 10^6$ η signal from GlueX-I by utilizing a kinematic fitter to suppress background and improve resolution of X and Y.

Very clean η signal



Unbinned, maximum likelihood fits

- Minimize the following function:

$$-2\ln\mathcal{L} \equiv -2\left(\sum_{i=1}^{N}\ln\mathcal{I}(\mathbf{x}_i;\boldsymbol{\theta}) - \int\mathcal{I}(\mathbf{x}_i\epsilon(x)d\mathbf{x})\right) + c_1$$

  where $\boldsymbol{\theta}$ are fit parameters and c_1 is a constant that does not depend on $\boldsymbol{\theta}$.

- The intensity $\mathcal{I}(\mathbf{x}_i;\boldsymbol{\theta})$ for this analysis is defined as:

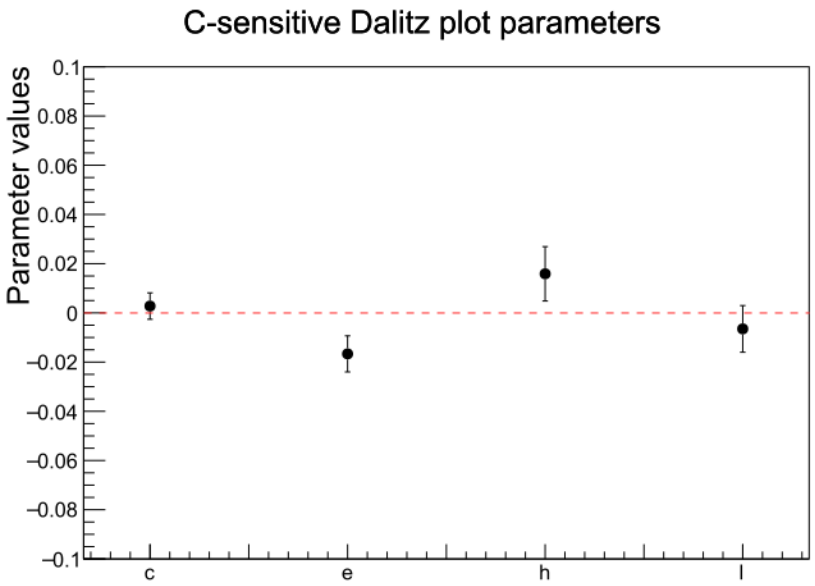
$$\mathcal{I}(X_i, Y_i, a, b, c, d, e, f, g, h, l)$$
$$= \left(1 + aY_i + bY_i^2 + cX_i + dX_i^2 + eX_iY_i + fY_i^3 + gX_i^2Y_i + hX_iY_i^2 + lX_i^3\right)$$

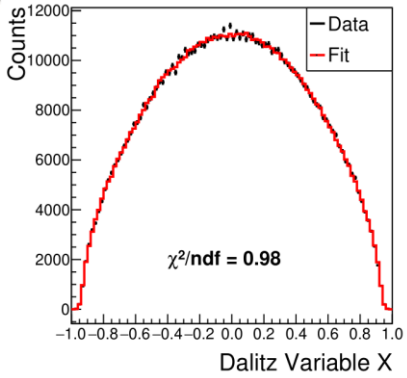
- The efficiency ϵ is calculated from Monte Carlo simulation.
- The $-2\ln\mathcal{L}$ function minimization is handled by **AmpTools** libraries[7].

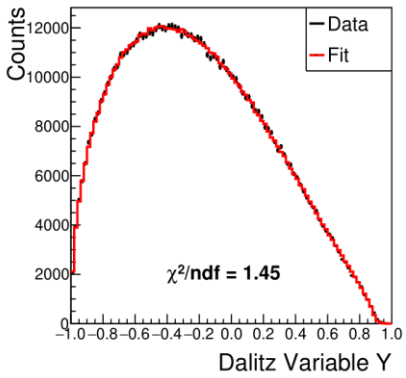
Statistical uncertainty study

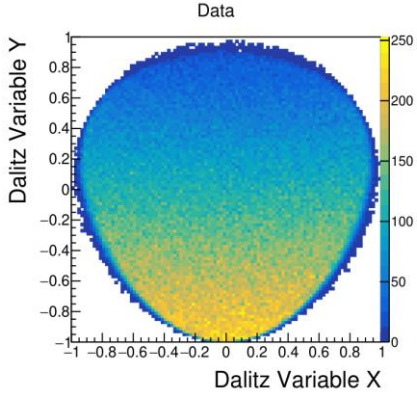
- In order to accurately determine statistical uncertainties of each Dalitz parameter, we complement AmpTools fitter with Bootstrapping technique.
- **Bootstrapping** → resampling the data samples by randomly drawing events from the datasets while keeping the original number of events, some of the events are repeated, some are omitted.
- The work presented here analyzed uniquely randomized 1000 resampled datasets.

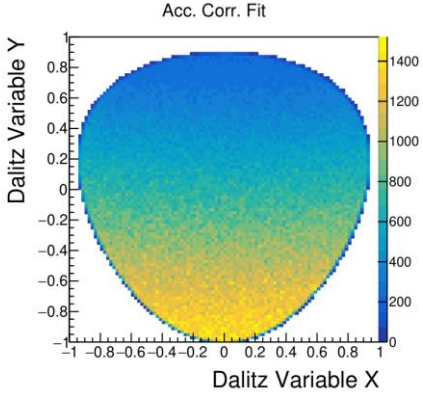
Preliminary Results











C-violating terms, $c = e = h = l \cong 0 \rightarrow$ We do not observe C-violation in the $\eta \rightarrow \pi^+\pi^-\pi^0$ decay on our very first result.

Summary and Outlook

- Reconstructed $\sim 10^6$ η events from GlueX-I.
- Successful implementation of unbinned Likehood fitter for $\eta \to \pi^+\pi^-\pi^0$ Dalitz analysis.
- No *C*-violating contribution observed.
- This results are consistent with binned Dalitz analysis (not shown today).
- Determination of systematic uncertainty.
- Comparison to previous measurement and publication.

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Thank you!