Dalitz Plot Analysis of $\eta' \rightarrow \eta \pi^+ \pi^-$

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Plan of the talk

Motivation

Introduction

Analysis

Result

Summary
Motivation

• Comparative statistics collected in the channel $\eta' \rightarrow \eta \pi^+ \pi^-$ by CLAS in comparison to other experiments reported so far.

• Dalitz plot (DP) provides pure kinematic information of a three body decay.

• DP helps to understand the correct input in theoretical distribution of the effective chiral Lagrangian.

• The decay channel has a low Q-value, thus it will help to study effective chiral perturbation theory at a low Q limit.
### Three body decay of a meson

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 four-vectors</td>
<td>12</td>
</tr>
<tr>
<td>4-momentum conservation</td>
<td>-4</td>
</tr>
<tr>
<td>3 masses</td>
<td>-3</td>
</tr>
<tr>
<td>3 Euler angles</td>
<td>-3</td>
</tr>
<tr>
<td>TOT</td>
<td>2</td>
</tr>
</tbody>
</table>

So, we can describe the 3-body state with two variables.
The two variables are

- The Dalitz variables for $\eta'(P) \rightarrow \eta(p_1) + \pi^+(p_2) + \pi^-(p_3)$ is defined as

$$X = \frac{\sqrt{3} (T_{\pi^+} - T_{\pi^-})}{Q}, \quad Y = \frac{(m_\eta + 2m_\pi)}{m_\pi} \cdot \frac{T_\eta}{Q} - 1, \quad (1)$$

where $T_i \ (i = \pi^+, \pi^-, \eta)$ is kinetic energy of a given particle in the rest frame of $\eta'$ and $Q = T_{\pi^+} + T_{\pi^-} + T_\eta$.

- The boundary of the decay is given by

$$|P_\eta^2 - P_{\pi^+}^2 - P_{\pi^-}^2| \leq 2 \vec{P}_{\pi^+} \cdot \vec{P}_{\pi^-} \quad (2)$$
The Dalitz Plot Geometry

Non-relativistically, circle is boundary of allowed events

dalitz plot

relativistically, boundary is slightly distorted

\[
\frac{T_1 + T_2 + T_3}{Q} = 1
\]

\[
\rho(x, y) = \frac{1}{2J + 1} \sum_{m_j} |A(m_j)|^2
\]
g12 Experiment in Hall B at Jefferson Lab

- g12 Run: $26 \times 10^9$ production triggers recorded
- Beam: Bremsstrahlung process produces a real photon energy from 1.142 to 5.425 GeV
- Target: The target was positioned -90 cm from the CLAS center

Fig: CLAS detector
Event Selection of $\gamma \ p \rightarrow \eta' (\rightarrow \eta \ \pi^+ \ \pi^-) \ p$

- The calibrated and corrected (g12 Corrections) data with one p, one $\pi^+$, one $\pi^-$ and Xn number of neutral particles selected for analysis.
- Beam Energy : 1.4553 to 3.2 GeV
- Kinematic Fitting : 1C fit to the missing mass of p, $\pi^+$ and $\pi^-$ to be an $\eta$ ie. $M_X(p\pi^+\pi^-)=0.547$ GeV is applied. All events with Prob $< 1\%$ are rejected.
- $-0.85 < \cos(\theta)_{cm}$ of $\eta' < 0.85$
Subtraction of Background

- 15 x 15 DP bins in X and Y
- The multi pionic background is subtracted with a polynomial of order 2
- Yield after non-resonant background subtraction is reduced by the “Percentage contribution of $\eta' \rightarrow (\eta)\pi^+\pi^- \rightarrow (\gamma\gamma)\pi^+\pi^-$” DP bin
- So we have the not acceptance corrected DP

The bins with least and most number of events are shown in Fig. (Before reducing percentage contribution of yield)
Channel contribution

- Generated with input Bremsstrahlung beam and DP parameters.
- Normalised with differential cross section and branching ratio.

Efficiency of $\eta' \rightarrow (\eta)\pi^+\pi^- \rightarrow (\gamma\gamma)\pi^+\pi^-$
Simulation

- Using Pluto $2 \times 10^7$ events generated
  - Generated with input Bremsstrahlung beam and Differential Cross section information
  - Decay generated with input $\eta' \rightarrow \eta \pi^+ \pi^-$ DP parameters from BESIII measurement

- Simulation take care of all the cuts and detector response as in data

- $15 \times 15$ DP selected for analysis, the bin-width is 0.2 to both $X$ and $Y$.

- Boundary bins of $\eta' \rightarrow \eta \pi^+ \pi^-$ DP are rejected
Comparison of Momentum, $\theta$ and $\phi$ of Proton
Comparison of Momentum, $\theta$ and $\phi$ of $\pi^+$
Comparison of Momentum, $\theta$ and $\phi$ of $\pi^-$

![Graphs showing comparison of momentum, $\theta$, and $\phi$ for $\pi^-$ particles.](image)
Fit to the Dalitz Plot

\[ \chi^2 = \sum_{n=1}^{N_{bins}} \left( \frac{N_n - \sum_{m=1}^{N_{bins}} \epsilon_{n,m} N_{\text{theory},m}}{\sigma_n} \right)^2 \]

- \(N_n\) is no. of \(\eta' \rightarrow \eta \pi^+ \pi^-\) events in the \(n^{th}\) DP bin.
- \(\epsilon_{n,m}\) is acceptance with smearing matrix, ie. it gives acceptance of \(m^{th}\) bin when events are generated in \(n^{th}\) bin.
- \(N_{\text{theory},m} = \int_{\text{Boundary}} A(1 + aY + bY^2 + cX + dX^2) dX dY\)
- \(\sigma_n\) is the error associated with \(n^{th}\) DP bin.
Cross check to the analysis

Reconstructed events inside the Dalitz plot the boundary.

Comparison of generated and reconstructed DP parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Gen BESIII</th>
<th>CLAS Reco</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>-0.047±0.012</td>
<td>-0.043±0.005</td>
</tr>
<tr>
<td>b</td>
<td>-0.069±0.021</td>
<td>-0.075±0.010</td>
</tr>
<tr>
<td>c</td>
<td>+0.019±0.012</td>
<td>0.019±0.006</td>
</tr>
<tr>
<td>d</td>
<td>-0.073±0.013</td>
<td>-0.079±0.009</td>
</tr>
</tbody>
</table>

Conclusion
We obtain the Generated input parameters from the simulated events, which cross-checks our analysis procedure.
Preliminary Result

\[ \eta' \rightarrow \pi^+ \pi^- \eta \]

![Graph showing Dalitz Plot Fit Parameters](image)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>-0.116 ± 0.011</td>
<td>-0.127 ± 0.018</td>
<td>-0.047 ± 0.012</td>
<td>-0.157 ± 0.010</td>
</tr>
<tr>
<td>b</td>
<td>-0.042 ± 0.034</td>
<td>-0.106 ± 0.032</td>
<td>-0.069 ± 0.021</td>
<td>-0.043 ± 0.019</td>
</tr>
<tr>
<td>c</td>
<td>...</td>
<td>0.015 ± 0.018</td>
<td>0.019 ± 0.012</td>
<td>0.019 ± 0.012</td>
</tr>
<tr>
<td>d</td>
<td>+0.010 ± 0.019</td>
<td>-0.082 ± 0.019</td>
<td>-0.073 ± 0.013</td>
<td>-0.048 ± 0.016</td>
</tr>
<tr>
<td>( \chi^2 )</td>
<td>( \frac{129.3}{114} = 1.13 )</td>
<td>( \frac{504}{476} = 1.05 )</td>
<td>( \frac{291}{97} = 3 )</td>
<td></td>
</tr>
</tbody>
</table>

Summary

Conclusion

- We have reported the Dalitz plot parameters with 87245 events, which is approximately twice than BESIII.
- The parameters are consistent with predictions from theory.
- An overall cross check of the whole analysis is also presented with simulation.

Future Plans

- Improving the $\frac{\chi^2}{NDF}$ for the fits
- Study the systematics

Thank you

Email ID : sghosh@jlab.org
Backup: Comparison of the incident photon beam energy in center-of-mass
Backup: In Peak contribution

- $\eta' \rightarrow \eta \pi^+ \pi^-$ decay generated with DP parameters $a=-0.047$, $b=-0.069$, $c=0.019$, $d=-0.073$ from BESIII[1]

- Signal Channel: $\eta' \rightarrow (\eta)\pi^+ \pi^-$ [42.9] $\rightarrow (\gamma\gamma)\pi^+ \pi^-$ [72.90] $BR_1 = \frac{(42.9 \times 72.90)}{100} = 30.92$

- In Peak background Channel: $\eta' \rightarrow (\eta)\pi^+ \pi^-$ [42.9] $\rightarrow (\pi^+ \pi^- \pi^0)\pi^+ \pi^-$ [27.14] $BR_2 = \frac{(42.9 \times 27.14)}{100} = 11.64$
  - Secondary decay $\eta \rightarrow \pi^+ \pi^- \pi^0$ are produced in phase space.
  - Channel produces combinatorics and has different acceptance to signal

- Background Channel: $\eta' \rightarrow (\eta)\pi^0 \pi^0$ [22.2] $\rightarrow (\pi^+ \pi^- \pi^0)\pi^0 \pi^0$ [27.14] $BR_3 = \frac{(22.2 \times 27.14)}{100} = 6.02$ is generated with DP parameters $a=-0.067$, $b=-0.064$, $c=0.0$, $d=-0.067$ from GAMP[2]
  - Secondary decay $\eta \rightarrow \pi^+ \pi^- \pi^0$ are produced in phase space.
  - Channel produces in peak contribution

[2] A.M.Blik et al., “Measurement of the matrix element for the decay $\eta' \rightarrow \eta \pi^0 \pi^0$ with the GAMS-4\pi spectrometer,” Phys. Atom. Nucl. 72, 231(2009)