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

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Introduction

Abstract

In this talk we present preliminary experimental results of Dalitz plot analysis of the decay $\eta' \rightarrow \eta + \pi^+ + \pi^-$ based on the CLAS data collected during photoproduction experiment γ + p $\rightarrow \eta'$ + p for the center-of-mass energy from 1.96 to 2.72 GeV at Jefferson Lab. The analysis is based on the highest statistics collected in this channel in comparison to the other experiments reported so far. The high statistics will enable us to report precise Dalitz plot parameters with low statistical errors.

- Dalitz plot of $\eta' \to \eta + \pi^+ + \pi^-$ provides kinematic information of the decay, which will enable us to study the low energy dynamics of QCD and heavier mass pseudoscalar meson.
- The $\eta' \to \eta + \pi^+ + \pi^-$ decay has a low Q-value due to relatively heavy decay products, thus help us to test and limit the effective chiral Lagrangian theory.
- Large statistics of CLAS compared to BESIII collaboration will provide lower statistical error.

Parameters	VES	Theory	BESIII	Stat err. in BES	Stat err. in CLAS
a	-0.127±0.018	-0.116±0.011	-0.047±0.012	±0.011	±0.004
b	-0.106±0.032	-0.042±0.034	-0.069±0.021	±0.019	±0.006
c	+0.015	...	+0.019±0.012	±0.011	±0.004
d	-0.082±0.019	+0.010±0.019	-0.073±0.013	±0.012	±0.004

M. Ablikim et al., BESIII Collaboration), Phys.Rev.D 83, 012003 (2011)
V. Dorofeev et al., Phys. Lett. B 651, 22 (2007)

The Dalitz variables for $\eta' \to \eta + \pi^+ + \pi^-$

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

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

Analysis

Event Selection for γ + p$\rightarrow$ (η')$p\rightarrow$ (η+π^++π^-) p from g11

- Ensure track information is available
- Ensure information from different detectors is consistent
- At least one good photon in the tagger
- Difference between start counter and tagger time for the best matching photon is less than 1 ns
- Events selected with atleast a p, π^+ and π^-.
- Events within 0.5<M$_x$($p\pi^+\pi^-$)<0.6 GeV and 0.9<M$_x$(p)<1.0 GeV
- Applied the tagger, momentum and energy loss corrections.

Cuts:

- Beam Energy(E_γ) in the range from 1.6 to 3.502 GeV.
- $\cos(\theta)^{\eta'}_{cm}$ > -0.65 and $\cos(\theta)^{\eta'}_{cm} < 0.85$

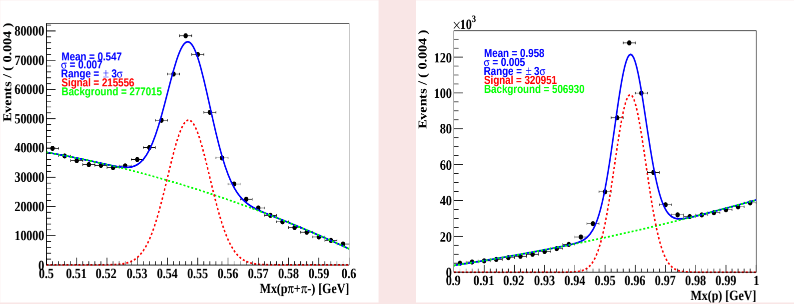


FIGURE: The left plot shows missing mass of $p\pi^+\pi^-$ for events where M_x(p)=0.950 $\pm$ 0.05 GeV and the right plot shows the missing mass of the proton for events where detected particles are in the range of η meson, $M_x(p\pi^+\pi^-)$ = 0.550 $\pm$ 0.05 GeV.

Background Channels

The contribution and kinematics of all the possible background channels with same final state particles are studied. We simulated 2 million events for all channels below in phase space and calculated the percentage of detection as signal.

- $\gamma+\mathrm{p}\rightarrow\eta+\pi^{+}+\pi^{-}+\mathrm{p}$ ($\approx 2.6\,\%$)
- $\gamma+\mathrm{p}\rightarrow\phi+\mathrm{p}\rightarrow K^{+}+K^{-}+\mathrm{p}\rightarrow\pi^{+}+\pi^{0}+\pi^{-}+\pi^{0}+\mathrm{p}$ ($\approx 0.0055\,\%$)
- $\gamma+\mathrm{p}\rightarrow\mathrm{K}^{+}+K^{-}+\mathrm{p}\rightarrow\pi^{+}+\pi^{0}+\pi^{-}+\pi^{0}+\mathrm{p}$ ($\approx 0.0015\,\%$)
- $\gamma+\mathrm{p}\rightarrow\phi+\mathrm{p}\rightarrow K^{S}+K^{L}+\mathrm{p}\rightarrow\pi^{+}+\pi^{-}+K^{L}$ ($\approx 0.0045\,\%$)
- $\gamma+\mathrm{p}\rightarrow\eta'+\mathrm{p}\rightarrow\rho^{0}+\gamma+\mathrm{p}\rightarrow\pi^{+}+\pi^{-}+\gamma+\mathrm{p}$ (No Contribution)
- $\gamma+\mathrm{p}\rightarrow\eta'+\mathrm{p}\rightarrow\omega+\gamma+\mathrm{p}\rightarrow\pi^{+}+\pi^{-}+\pi^{0}+\gamma+\mathrm{p}$ ($\approx 0.39\,\%$)

Q-factor

Similar kinematics for the background and signal allow us to use a more sophisticated event- based procedure(Q-factor method) than the typical sideband subtraction.

Q-factor Procedure:

- We choose the data set with the cuts mentioned, with an additional condition that missing mass of p, π^+ and π^- is an η ($\mathrm{M}_x(p\pi^+\pi^-) = 0.547 \pm 0.014$ GeV within 2σ).
- We choose the non-reference variables, Dalitz X and Y to bin our phase space and we assume the background and signal events to follow different distributions in the reference variable $\mathrm{M}_x(p)$ of the chosen phase cell.
- The event based procedure calculates a distance(d_{seed_eventj}) of all events to a seed event.

$$d_{seed\_eventj} = [\tfrac{1}{3}((\mathrm{X\ of\ }\eta')_{seed\_event} - (\mathrm{X\ of\ }\eta')_j))]^2 + [\tfrac{1}{3}((\mathrm{Y} of \eta')_{seed\_event} - \mathrm{Y\ of\ }\eta')_j))]^2 \quad (2)$$

- Using this distance we find 500 nearest events to fit $M_x(p)$ with appropriate functions for signal(f_s) and background(f_b),

$$f_s(M_x(p)) = A\exp(\frac{-(M_x(p) - 0{,}958212)^2}{2\sigma^2}) \quad (3)$$

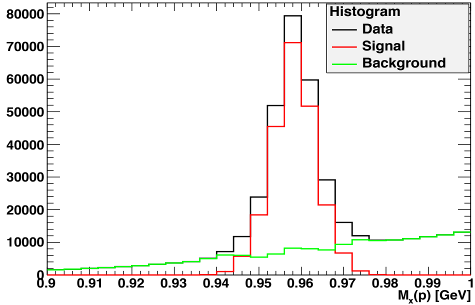
$$f_b(M_x(p)) = \alpha 0 + \mathrm{M}_x(p).\alpha 1 \quad (4)$$

M. Williams, M, Bellis and C. A. Meyer, JINST 4, P10003, (2009).

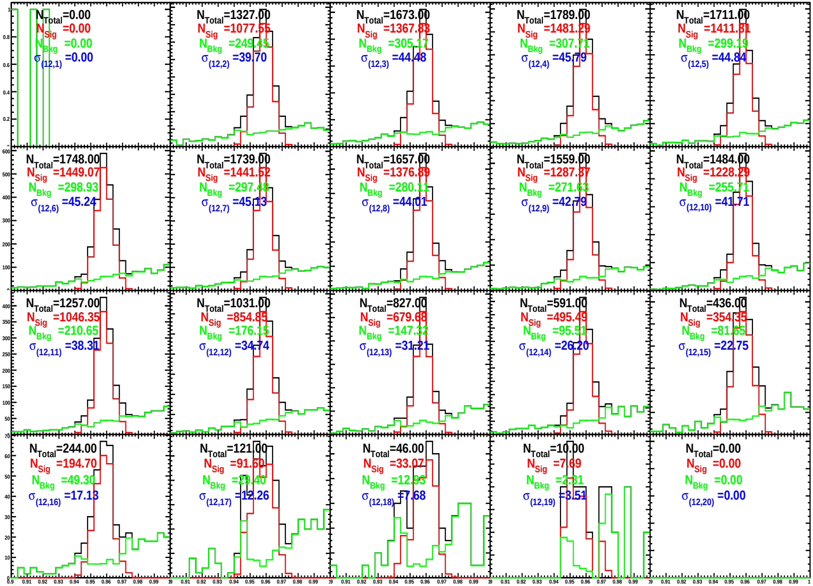
- The fit gives the fraction(f) of signal events in the $M_x(p) distribution, alongwiththevalueof f_s$ and f_b at the seed event Mx(p) bin, we are able to calculate Q-factor(Q) and the error(σ_Q^2) of a single event.

$$Q = \left[\frac{f * f_s}{f * f_s + (1-f) * f_b} \right]_{Mx(p)=seed\_event\_mass} \quad (5)$$

$$\sigma_Q^2 = \sum \frac{\partial Q}{\partial \eta_i} (C_\eta)_{ii} \frac{\partial Q}{\partial \eta_i} \quad (6)$$



Unweighted Q Weighted 1-Q Weighted



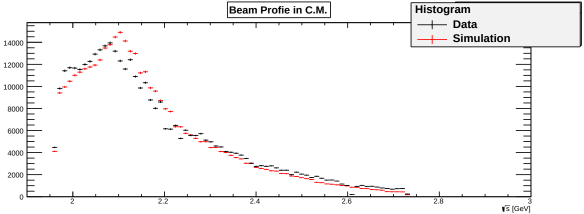
The number of signal and background events from $M_X(p)$ in the 2σ region are calculated using the Q-factor method at X=-1.125, for all the Y bins is shown above.

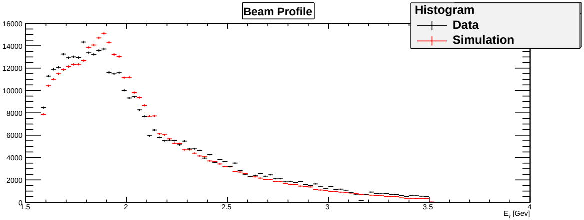
Simulation

- Pluto : A Monte Carlo simulation tool for hadronic physics (https://www-hades.gsi.de/?q=pluto)
- GSIM : Geant based simulation in CLAS
  - Generated events passed though GSIM
  - It simulates decay that may occur along with energy loss and multiple scattering caused by interation with material.
- GPP : (GSIM post processor) It smears detector signal more accurately to reflect the actual resolution.
- RECSIS : Reconstruction program is used to analyze GSIM output in the same manner that the raw experimental data was analyzed.
- Pcor : To remove the discrepancies in the toroidal magnetic field map and/or in the drift chamber survey information
- Eloss : The corrections were made to account for energy lost in the target material (liquid Hydrogen) and walls, the beam pipe, the start counter and the air gap located between the start counter and the Region 1 drift chambers.

Comparison of Simulated events and Q-factor weighted data

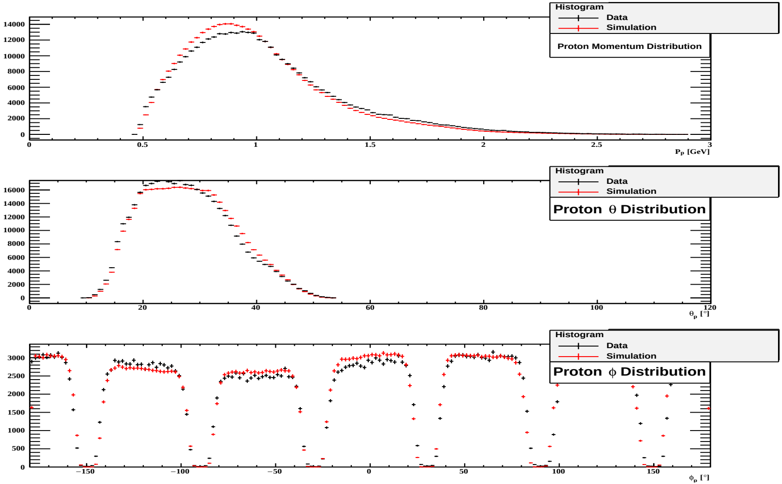
- Comparison in the incident photon beam energy in center-of-mass variable.
- Generated MC via differential cross-sections.





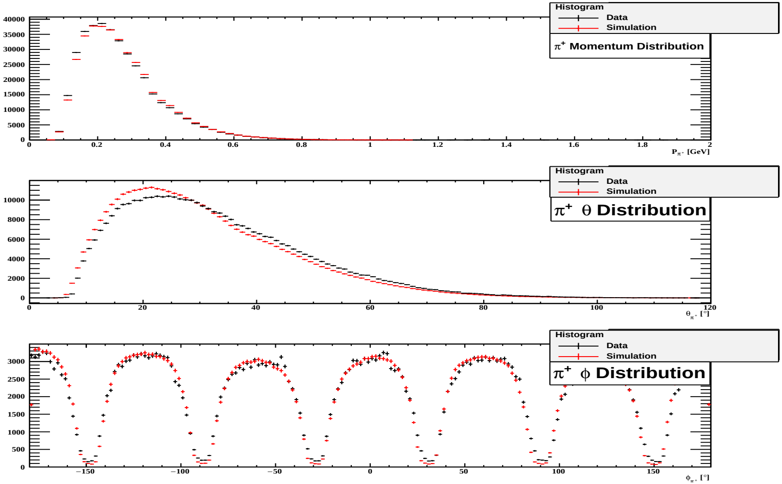
Comparison of Simulated events and Q-factor weighted data

- Comparison of Momentum, θ and ϕ distribution of proton.
- Generated MC via differential cross-sections.



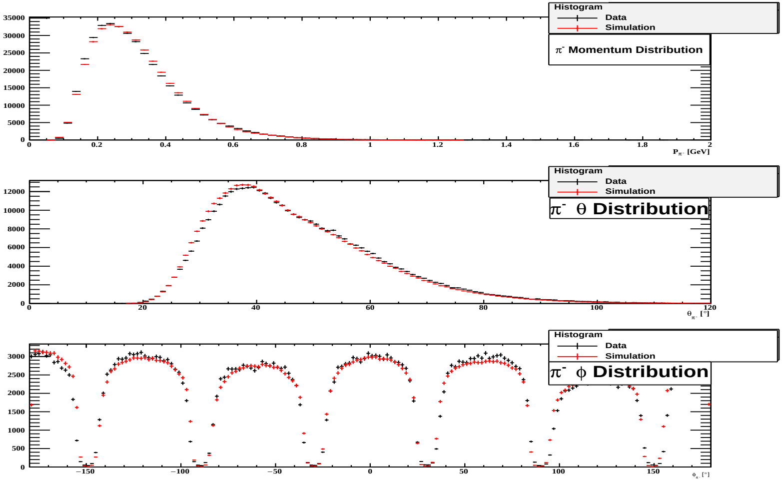
Comparison of Simulated events and Q-factor weighted data

- Comparison of Momentum, θ and ϕ distribution of $\pi+$.
- Generated MC via differential cross-sections.

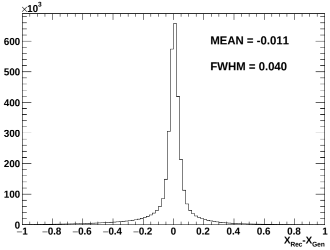


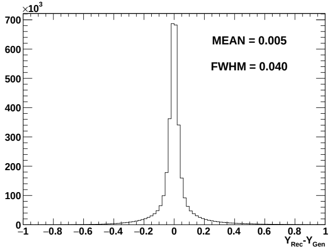
Comparison of Simulated events and Q-factor weighted data

- Comparison of Momentum, θ and ϕ distribution of $\pi-$.
- Generated MC via differential cross-sections.



Resolution of X and Y





The difference of the reconstructed and generated Dalitz variables X(Left) and Y(Right) gives a resolution of 0.04 for each.

Acceptance Correction to the data

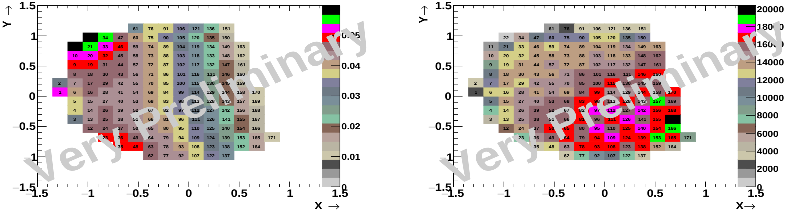
- 60 x 10^6 $\eta' \to \eta + \pi^+ + \pi^-$ events generated.
- All generated and reconstructed $\eta' \to \eta + \pi^+ + \pi^-$ events are fed in two seperate Dalitz plots of 20x20 (X(-1.5,1.5) x Y(-1.5,1.5)) bins.
- Binwise ratio of reconstructed and generated Dalitz plots provides binwise acceptance($\epsilon(X, Y)$).
- We perform the bin wise acceptance correction to the data.

$$\epsilon(X, Y) = \frac{N_{rec}(X, Y)}{N_{gen}(X, Y)} \tag{7}$$

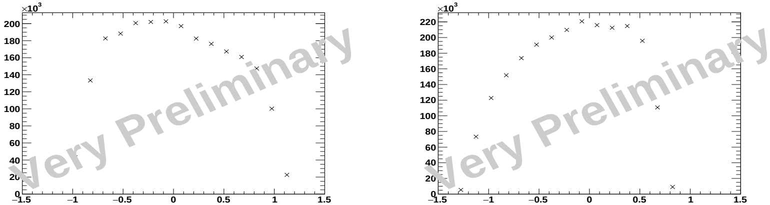
$$N_{acc.corr}(X, Y) = \frac{N_{exp}}{\epsilon(X, Y)} \tag{8}$$

$$\sigma_{acc.corr}(X, Y) = \frac{\sigma_{stat}(X.Y)}{\epsilon(X, Y)} \tag{9}$$

Results



The numbering and position used in the analysis and the colour scale for the left plot shows the acceptance and the right plot shows the acceptance corrected data. Only those bins are included where the no. of η' greater than 10 and acceptance greater than 1 %.



The acceptance corrected X(left) and Y(right) projections of Dalitz variables.

Preliminary Dalitz plot parameter errors with Dalitz bin width=0.15 for $\eta' \to \eta\pi^+\pi^-$ after fitting the total X and Y projections of Dalitz variables with the function,
$f(X_j^c, Y_j^c) = N(1 + a(Y_j^c) + b(Y_j^c)^2 + c(X_j^c) + d(X_j^c)^2)$
for the the center-of-mass energy from 1.96 to 2.1 GeV.

Parameters	VES	Theory	BESIII	CLAS Error
a	-0.127±0.018	-0.116±0.011	-0.047±0.012	±0.002
b	-0.106 ±0.032	-0.042±0.034	-0.069±0.021	±0.004
c	+0.015	...	+0.019±0.012	±0.003
d	-0.082±0.019	+0.010±0.019	-0.073±0.013	±0.004
χ^2/ndf	NR	NR	NR	NA

Summary

Conclusion

To report the Dalitz plot parameters from each bin of Dalitz plot, we need to find the resolution of an (X,Y) bin and we also need to perform Kinematic fitting, which will minimize the migration of events in these (X,Y) bins.

Future Plans

- Apply fudicial cuts to reject the dead detector region.
- Apply the Kinematic Fitting to the analysis.
- Study the systematics.

Thank You

If you have suggestion, comment or query please contact

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