Dalitz plot of $\eta' \to \eta\pi^+\pi^-$

Sudeep Ghosh[1,★] and Ankhi Roy[1]
for the CLAS Collaboration

[1]*Indian Institute of Technology Indore, Khandwa Road, Simrol, M.P - 452020, India*

Abstract. In this talk we present preliminary experimental results of Dalitz plot analysis of the decay $\eta' \to \eta \pi^+ \pi^-$, based on the CLAS data collected during photoproduction experiment γ p $\to \eta'$ p for the center-of-mass energy from 1.90 to 2.62 GeV at Jefferson Lab. This experiment will enable us to report precise Dalitz plot parameters of the $\eta' \to \eta \pi^+ \pi^-$ decay for the first time in a photoproduction experiment.

1 Introduction

The work is on the measurement of Dalitz plot parameters from the $\eta' \to \eta \pi^+ \pi^-$ decay through the "g12" experiment at Thomas Jefferson National Accelerator Facility (JLab), Newport News,VA, USA. A Dalitz plot is used to study the decay dynamics of mesons. Chiral Perturbation Theory is the effective theory to understand mesons in the low energy regime and Dalitz plot helps to understand the correct input to theoretical distribution of the effective chiral Lagrangian. The $\eta' \to \eta \pi^+ \pi^-$ decay has the lowest Q-value compared to the other decay modes of the η' meson, because of its heavier decay products. So a study of this channel attributes to understanding effective chiral perturbation theory at a low Q limit.

Three body decay of the η' meson has two degrees of freedom, and has two independent Dalitz plot variables X and Y below, completely describes the decay.

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

where T_η, T_{π^+} and T_{π^-} are the kinetic energy of a given particles η, π^+ and π^- in the rest frame of η' and $Q = T_{\pi^+} + T_{\pi^-} + T_\eta$, m_η and m_π are the mass of the η and π meson.

2 Experiment

The Continuous Electron Beam Accelerator Facility (CEBAF) at JLab has an ability to accelerate electrons to a maximum energy of 6 GeV. The accelerated electrons are then passed to the experimental hall B, where the electrons find the gold (Au) radiator of 10^{-4} radiation length. The interaction of electrons with the Au foil produces real photons for the "g12" experiment via the bremsstrahlung process. The Dipole Magnet then separates charged electrons from the photons. The recoiled and

---

★e-mail: phd12115113@iiti.ac.in

diverted electrons are then passed to set of E-plane and T-plane scintillators to measure the energy and timing respectively. The whole process indirectly tag the photons and measures the photon energies from 20% to 95% of the incident electron beam energy, in "g12" that makes an available photon energies to range from 1.142 - 5.425 GeV. The extracted photons out of radiator are then collimated before it enters inside the CEBAF Large Acceptance Spectrometer (CLAS) and hits the not polarised liquid hydrogen (lH_2) target placed -90 cm from the CLAS centre. The interaction between the incoming photon beam and proton target produces particles that finds the Start Counter with 6 sectors and 4 scintillator paddles each near to the interaction region. This was used in the event trigger and to measure the start time. Then comes the Superconducting Toroidal Magnet which produces the magnetic field to bend the charge particles and then passed through the three layers of drift chamber with each having six sectors. Finally the particles hit the Time of Flight (TOF) detector where the instant of hit time are recorded. Using all the information recorded starting from the Start Counter to Time of Flight detector the particle identification is done in CLAS. All the sub-detectors together make the CLAS detector well optimised for the detection of charged particles and gives a coverage of 6° to 100° of the polar angle [1].

3 Data Analysis

The complete reaction under this study is $\gamma\, p \rightarrow \eta'(\rightarrow \eta\, \pi^+\, \pi^-)\, p$ and η meson is reconstructed using the missing mass information. The calibrated along with CLAS particle identified "g12" corrected data with one p, one π^+, one π^- and any number of neutral particles is selected for analysis. A total of 661 runs with a photon beam energy range from the η' production threshold of 1.455 to 3.2 GeV is analysed. The selected data is then corrected to set of standard correction procedures in "g12" [2]. The correction includes beam energy, removal of bad TOF paddle and geometric fiducial cut. Events surviving the cuts are corrected and made to pass the tuned "g12 Kinematic Fitter" which improves the signal to background ratio of the selection. The fitter used a 1-C constrained fit requiring the four-momentum of [beam] + [target] - ([π^+] [π^-] [p]) to be an [η] meson. The probability of each event are then calculated and finally a cut is made on 1% Pull probability cut to reject events with very low probability to satisfy the constrained condition. To select the events of interest a cut is placed to $M_x(p\, \pi^+\, \pi^-)$ around the η meson mass window 0.547 ± 0.01 GeV. The η' meson going along the most forward and backward region is eliminated with $|\cos\theta_{center-of-mass}$ of $\eta'|\leq 0.85$ cut to reject the low yield region. The $M_x(p)$ spectrum can then be explained with Voigt signal and the background with a polynomial of order 3 as shown in Fig. 1. The background subtracted events lying within the 3σ region is the total number of signal events.

PLUTO, an event generator is used for this analysis. It uses ROOT based programmes and it is very commonly used in Hadron Physics experiments to generate hadronic production and decay of mesons. The generated events from PLUTO is also modelled with the bremsstrahlung photon, differential cross-setion of the η' meson [3] and Dalitz plot parameters of $\eta' \rightarrow \eta\, \pi^+\, \pi^-$ decay [4]. The modelled Monte Carlo events are then passed through the standard Geant3 - based CLAS simulation software which finally simulates the experimental conditions reflecting proper detector responses. The reconstructed events are then passed through the same conditions in the data before using it for analysis.

3.1 Dalitz plot

The analysis uses a binned Dalitz plot, and the binning in the Dalitz variables X and Y should be greater than the resolution of these variables. Fig. 1 shows the resolution of variables X and Y from
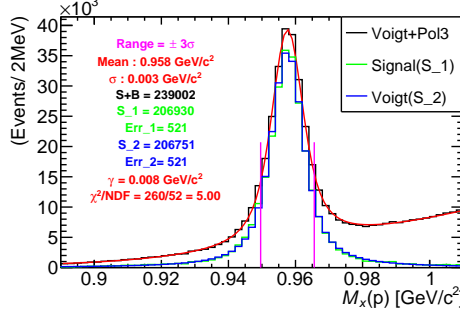
Figure 1: $M_x(p)$ vs the number of events plotted after implementing all correction and conditions. The signal is fitted with the Voigt function and the background fitted with a polynomial of order 3.

the simulation, it is the difference of the true and reconstructed information of the variables. The Dalitz plot analysis is done further with a binning of 15 x 15 bins in X and Y.
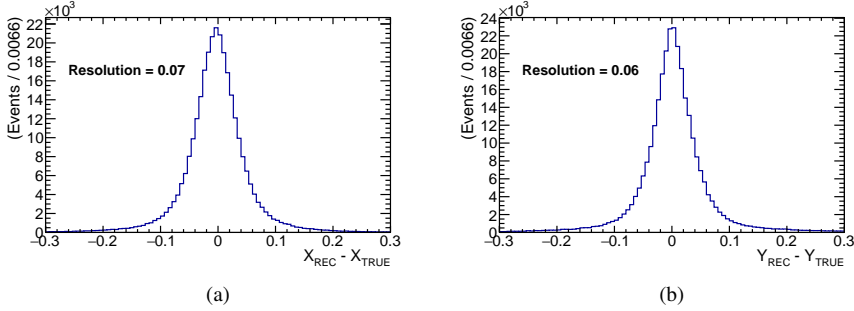

Figure 2: The figure (a) shows the difference of Reconstructed and True value of the events vs the number of events for variable X and the figure (b) shows the difference of Reconstructed and True value of the events vs the number of events for variable Y.

3.2 Background subtracted Dalitz plot

The background subtraction is performed to each bin of the Dalitz plot as explained in Sect. 3 and the number of η' meson events are calculated in each bin of the Dalitz plot. Bins with less than 100 events and low acceptance ($< 1\%$) are rejected from the analysis along with the events lying outside the Dalitz plot boundary.

3.3 Fitting Procedure to the Dalitz Plot

Once the $\eta' \to \eta\,\pi^+\,\pi^-$ events from the data is filled in each bin of Dalitz plot, a Dalitz plot fit with the general parametization function in Eq.(2) is performed. The square of the decay amplitude
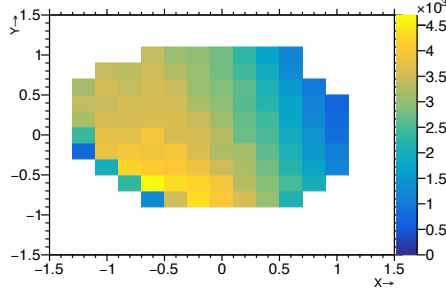
$$M^2 = A(1 + aY + bY^2 + cX + dX^2),\qquad(2)$$

Figure 3: Dalitz variable X vs Y plot for $\eta' \to \eta\,\pi^+\,\pi^-$ events without acceptance correction.

where a, b, c and d are the Dalitz plot parameters of the decay and A is the normalization constant. The fitting is performed with the least square fitting procedure using MINUIT available in ROOT, which minimises the χ^2 using Eq.(3) in each bin of the Dalitz plot [5].

$$\chi^2 = \sum_{i=1}^{Nbins} \left(\frac{N_i - \sum_{j=1}^{Nbins} \epsilon_{i,j} N_{theory,j}}{\sigma_i} \right)^2 \tag{3}$$

Where,

- N_i is the number of $\eta' \to \eta\,\pi^+\,\pi^-$ events in the ith Dalitz plot bin.
- $\epsilon_{i,j}$ is acceptance with smearing matrix, i.e., it gives acceptance of jth bin when events are generated in the ith bin only.
- $N_{theory,j} = \int_{Boundary} A(1 + aY + bY^2 + cX + dX^2)\,dXdY$.
- σ_i is the error associated with the ith Dalitz plot bin.

4 Conclusion

The background subtraction is performed and acceptance with smearing matrix has been calculated for the $\eta' \to \eta\,\pi^+\,\pi^-$ decay. The final Dalitz plot parameters and systematics are under study.

References

[1] B. A. Mecking *et al.* [CLAS Collaboration], Nucl. Instrum. Meth. A **503**, 513 (2003).

[2] Z. Akbar et al. g12 Analysis Procedures, Statistics and Systematics. Technical report, CLAS Technical Note, 2016.

[3] M. Williams *et al.* [CLAS Collaboration], Phys. Rev. C **80**, 045213 (2009)

[4] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D **83**, 012003 (2011)

[5] L. Caldeira Balkestahl [KLOE-2 Collaboration], Acta Phys. Polon. B **46**, no. 1, 31 (2015)