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

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Abstract. In this talk we present preliminary experimental results on the Dalitz plot analysis of the decay $\eta' \rightarrow \eta\, \pi^+\, \pi^-$ based on the CLAS data collected during photo production 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 other experiments reported so far. The high statistics will enable us to report precise statistical error of Dalitz plot parameters.

INTRODUCTION

Quantum Chromodynamics (QCD) is the theory of strong interaction and the Chiral perturbation theory (ChPT) is the effective theory of QCD at low energy. The ChPT is a very successful theory for studying hadronic decay of hadrons, which is the smallest unit of the low energy QCD regime. In this article we study the Datilz plot decay of $\eta' \rightarrow \eta\, \pi^+\, \pi^-$. The decay has two degrees of freedom, and so we are able to make a Dalitz plot with two variables. This study will help us to understand the heavy mass pseudo scalar meson, η'. The decay channel has relatively heavier decay products, and consequently has a smaller Q-value. Hence, it will help us to study the low energy dynamics region of QCD [1]. It will also help us to test the effective chiral Lagrangian theory at low Q-value. The Dalitz variables for the decay are:

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

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

The experimental aim of the present work is to develop the high precision measurement of Dalitz plot parameters of $\eta' \rightarrow \eta\, \pi^+\, \pi^-$ with large statistics, and to obtain the matrix elements of the decay through the general decomposition parameterization. Jefferson Lab (JLab) in Newport News, Virginia, USA, has an accelerator facility, which provides a very suitable range of energies for production and detection of mesons. The "Continuous Electron Beam Accelerator Facility (CEBAF)" produces the accelerated electrons for the experiment. We are using the "CEBAF Large Acceptance Spectrometer (CLAS)" detector data for this study.

Experimental Setup

The CLAS g11 experiment used a 4 GeV electron beam hitting a gold foil of 10^{-4} radiation length. This produces real photons, via the bremsstrahlung process. The recoiling electrons were then analyzed using a Dipole Magnet and Scintillator Hodoscopes to tag the energy of the photons. The Magnetic Spectrometer at Hall B is used to separate electrons from the photon beam. Photons in the energy range from 20% to 95% of the electron beam energy were tagged. So the measured energy had a resolution of 0.1% of the electron beam energy. The physics target, which was filled with liquid hydrogen of density 0.0717 $g.cm^{-3}$, was a 40 cm long cylinder with a radius of 2 cm. A Start Counter of 6 sectors with 4 scintillator paddles each was placed near the interaction region. This was used in the event trigger and to measure the start time. The CLAS detector utilized a non-uniform toroidal magnetic field of peak strength near 1.8 T in conjunction with three regions of Drift Chamber to track charged particles. Each particles track is then used to calculate the momentum [2]. Charged particles with laboratory polar angles in the range 8° to 140° could be tracked

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over approximately 83% of the azimuthal angle. A set of 288 scintillators placed outside the magnetic field region was used in the event trigger and during off-line analysis in order to determine time of flight (TOF) of charged particles. The momentum resolution of the detector was, on average, about 0.5%.

Analysis

The g11 dataset was collected from May 17^{th} to July 29^{th} in 2004 by the CLAS collaboration. Beam current was between 60-65 nA with average unpolarized electron beam of 4.023 GeV. Twenty billion triggers were stored as 21 TB of raw data. The trigger consisted of events that had at least two charged tracks in two different sectors. We begin our analysis with a two positive and one negative skim and we ensured that the track information is available and consistent with signal from different sub-detectors. Every accepted event had at least one good photon in the tagger, and the difference between the start counter and tagger time for a photon was to be less than 1 ns. We used the CLAS particle identification to select events that consisted of at least one proton, one π^+ and one π^-. The analyzed events had a beam energy greater than 1.6 GeV which is higher than the threshold, 1.44 GeV for η', to a maximum of 3.502 GeV. A cut, -0.65 < $\cos(\theta)_{cm}$ < 0.85 was placed on $\cos(\theta)_{cm}$ of η'. This is to ensure that we accept only the region where there has been a good cross-section measurement reported by CLAS. We also applied the tagger, momentum and energy loss corrections to the data. The CLAS is well optimized for the detection of charged particles. The decay of $\eta' \rightarrow \eta\, \pi^+\, \pi^-$ has a branching ratio of 42.9 %. The complete channel for the decay of η' meson under study is: γ p $\rightarrow$ p $\eta'(\eta\, \pi^+\, \pi^-)$. A missing mass technique is used to reconstruction Mx(p) and Mx(p π^+ π^-) from the kinematical information for the two pions and proton as shown in Fig. 1.

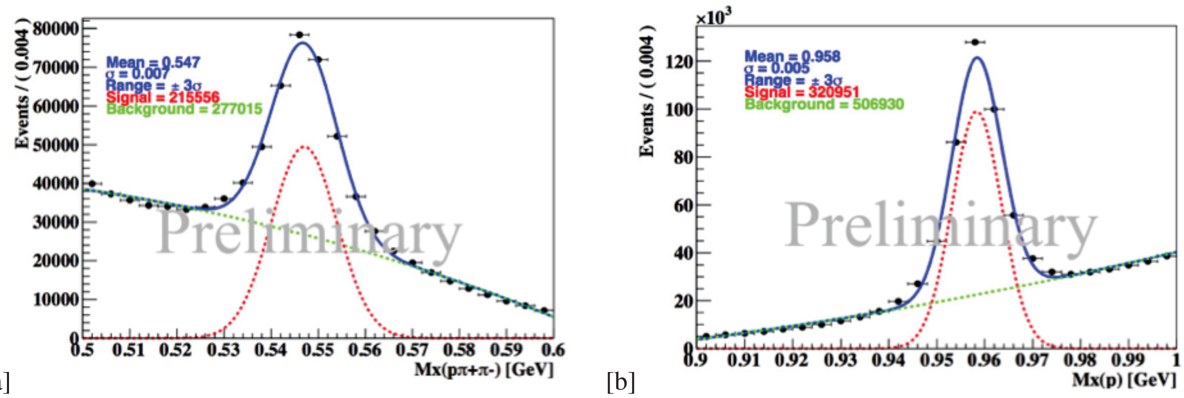

FIGURE 1: The left plot [a] shows missing mass of p π^+ π^- for events where Mx(p)=0.950 ± 0.05 GeV and the right plot [b] shows the missing mass of the proton for events where detected particles are in the range of meson, Mx(η π^+ π^-) = 0.550 ± 0.05 GeV.

Q-factor Background Subtraction Method

We have studied all possible channels, which give a proton, π^+ and $\pi-$ as the final state particles, and we found that the major background comes from the sources listed below:

- γ + p $\rightarrow$ p $\eta\, \pi^+\, \pi^-$
- γ + p $\rightarrow$ η' p $\rightarrow$ $\eta\, \pi^0\, \pi^0$ p $\rightarrow$ 6 $\gamma\, \pi^+\, \pi^-$ p

To take care of the background we used an event-based procedure called the Q-factor method [3]. In this method we first create phase space with the non-reference variables Dalitz X and Y. Then we calculate a distance from a seed event to all the other events as is shown in Eqn. 2

$$distance = \{\frac{1}{3}(X_i - X_j)\}^2 + \{\frac{1}{3}(Y_i - Y_j)\}^2 \qquad (2)$$

where "i" stands for the seed event, and factor 1/3 stands for the normalization. Once we have all the distances, then we select the first "500" nearest neighbor events. We then look at the Mx(p) distribution to fit the signal with a Gaussian and the background with a polynomial of order 1. The fit gives us the number of signal (N_{Sig}) and number of background (N_{Bkg}) from the sample of 500 nearest neighbours, and then we calculate the corresponding Q-factor = $N_{Sig}/(N_{Sig}+N_{Bkg})$ of each event. These Q-factors are later used to weight the events.

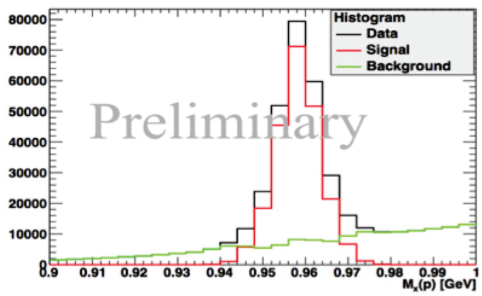

FIGURE 2: The plot shows the Mx(p) distribution, where the black line is the data, the red line is for the Q weighted data (Signal) and the green is the (1 - Q) weighted data (Background).

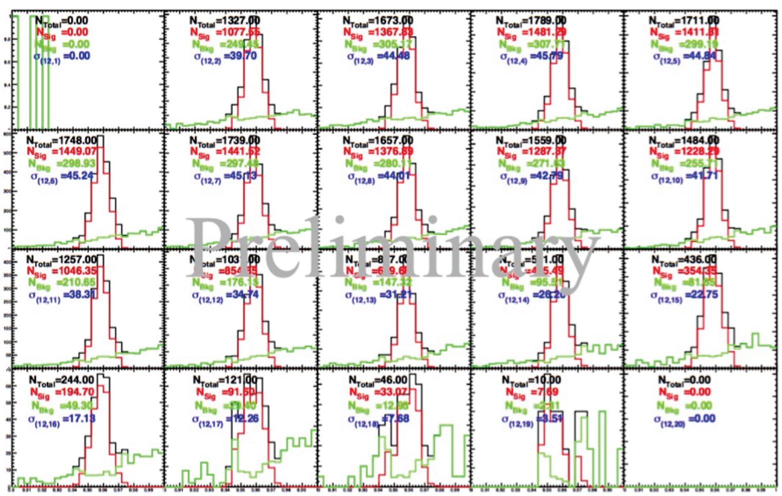

FIGURE 3: The number of signal (N_{Bkg}) and background (N_{Bkg}) events from Mx(p) in the 2σ region at X=-1.125 for all the Y bins.

Simulation

We generate sixty million $\eta' \rightarrow \eta\, \pi^+\, \pi^-$ using the event generator PLUTO, which is a Monte Carlo simulation tool for Hadron Physics. Generated events are produced with the differential cross-section information of the photo production of η'. We then pass these events through GEANT based simulation of CLAS (GSIM). The events are passed through the GSIM post processor (GPP) and are analyzed through the reconstruction program used in the cooking process of the data. These procedures ensure that simulation is processed properly to reflect the actual resolution. A typical energy loss correction is also applied to the data, to account for the energy lost in the detector material, walls, beam pipe and the air gap located between the Start Counter and region 1 of Drift Chamber.

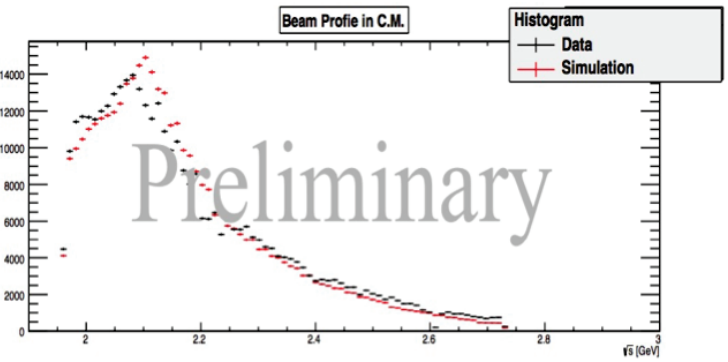

FIGURE 4: Comparison of beam energy in the center of mass variable (W). Black curve represents the Q weighted data and the red curve represents the simulated data.

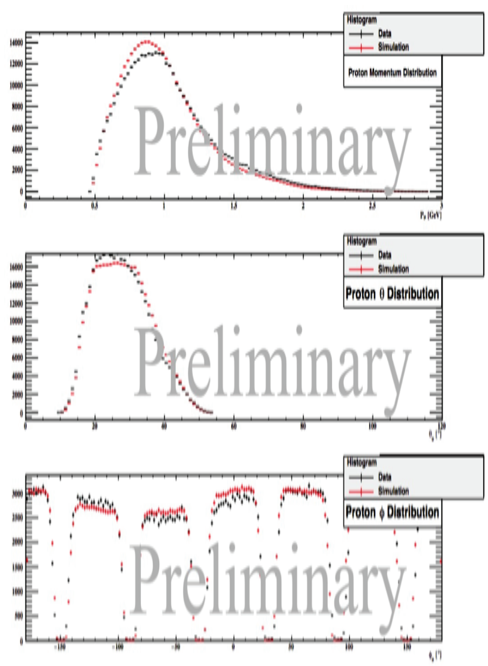

FIGURE 5: The momentum (top), θ (middle) and ϕ (bottom) distribution of proton for simulated data (red) events and Q weighted data (black).

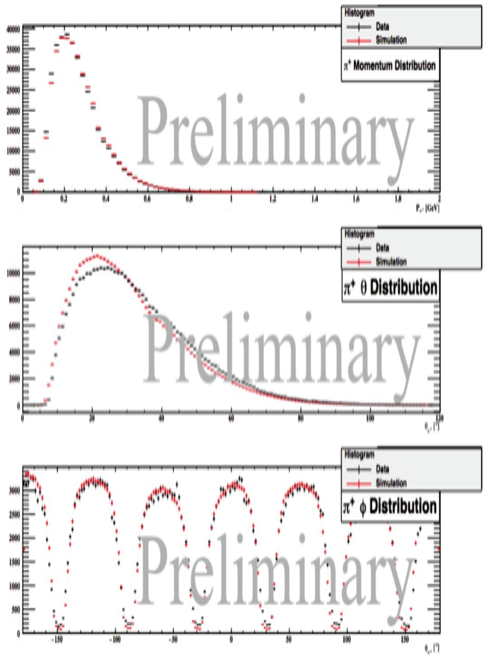

FIGURE 6: The momentum (top), θ (middle) and ϕ (bottom) distribution of π^+ for simulated data (red) events and Q weighted data (black).

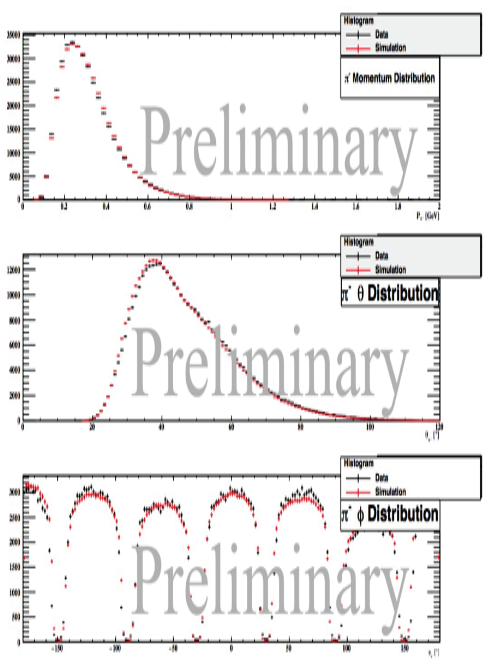

FIGURE 7: The momentum (top), θ (middle) and ϕ (bottom) distribution of π^- for simulated data (red) events and Q weighted data (black).

Result

A 20×20 (X (-1.5, 1.5) × Y (-1.5, 1.5)) binning is used for the Dalitz plot. We get the acceptance from the generated and reconstructed Dalitz plot information in every bin of the Dalitz plot. The Q weighted events in the Dalitz plot is then corrected with the acceptance. A preliminary error calculation for the Dalitz plot parameters for $\eta' \rightarrow \eta\, \pi^+ \pi^-$ is given in Table 1. The Dalitz plot parameters are extracted by fitting the total projections of Dalitz variables (X and Y) with the function below:

$$f(X_j, Y_j) = N(1 + aY_j + bY_j^2 + cX_j + dX_j^2) \tag{3}$$

where X_j and Y_j are the values of Dalitz variables of the j^{th} bin, N is the normalization and a,b,c,d are the Dalitz plot parameters of the parameterization.

TABLE 1: The table shows CLAS g11 errors compared to the theory [4], VES [5] and BESIII [6] errors for the Dalitz plot variables between the W (beam energy in the center of mass) from 1.96 to 2.1 GeV.

	Theory	**VES**	**BESIII**	**CLAS g11**
a	-0.116 ±0.011	-0.127 ±0.018	-0.047 ±0.012	±0.002
b	-0.142 ±0.034	-0.106 ±0.032	-0.069 ±0.021	±0.004
c	...	+0.015	+0.019 ±0.012	±0.003
d	+0.010 ±0.019	-0.082 ±0.019	-0.073 ±0.013	±0.004

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