DALITZ PLOT ANALYSIS OF η INTO 3π FINAL STATE[1]

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Received 3 November 2005, in final form 6 December 2005, accepted 19 December 2005

The KLOE experiment at the Frascati ϕ factory DAϕNE has collected $\simeq$ 450 pb $^{-1}$ in the 2001 - 2002 data taking. The study of the $\eta \to 3\pi$ dynamics, through a fit to the Dalitz plot density distribution, performed with these data is discussed in this paper. A precise measurement of the "slope parameters" can improve the knowledge of the decay amplitude and allows to test theoretical predictions at the level of precision needed to extract the quark mass ratio $(m_s^2 - \hat{m}^2)/(m_d^2 - m_u^2)$ from the decay rate ($\hat{m}$ is the u,d average mass) .

PACS: 12.15.Ff, 14.40.Aq, 13.25.Jx

1 Introduction

The decay of the isoscalar η into three pions occurs primarily due to strong isospin violation and so is in principle a sensitive measure of the up-down quark mass difference. To lowest order in the chiral expansion the decay amplitude is given by [1]:

$$A(s,t,u) = \frac{1}{Q^2}\frac{m_K^2}{m_\pi^2}\left(m_\pi^2 - m_K^2\right)\frac{1}{3\sqrt{3}F_0^2}\frac{3s - 4m_\pi^2}{m_\eta^2 - m_\pi^2} \quad (1)$$

where $Q^2 \equiv (m_s^2 - \hat{m}^2)/(m_d^2 - m_u^2)$ is a combination of quark masses and $F_0 = 92.4$ MeV is the pion decay costant.
Since the decay rate is proportional to Q^{-4}, the transition $\eta \to 3\pi$ represents an extremely sensitive probe allowing a determination of Q. Unfortunately the experimental results and the theoretical predictions for the decay width are in disagreement. The discrepancy can be caused either by an inaccurate value for the $d - u$ quark mass difference or to the importance of higher order final state interaction effects. A precise measurement of the spectral shape with higher statistics, both for the charged and neutral η decays, would allow to clarify the theoretical and experimental scenario.

[1] Presented at the Workshop on Production and Decay of η and η' Mesons (ETA05), Cracow, 15–18 September 2005.
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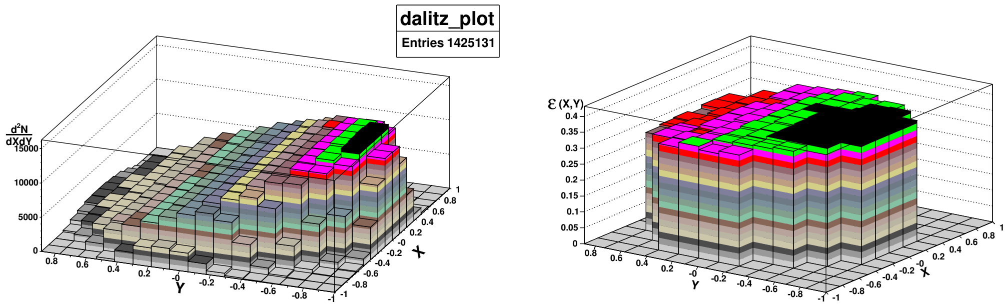

Fig. 1. Left: Dalitz-plot distribution observed on whole data sample. The plot contains 1.43 millions of events in 256 bins. Right: Efficiency as function of Dalitz-plot variables.

2 Dynamics of $\eta \to \pi^+\pi^-\pi^0$

At Kloe η is produced in the process $\phi \to \eta\gamma$ where the radiative photon ($E_\gamma = 363$ MeV) is monochromatic and it is easily selected. To select the final state $\pi^+\pi^-\gamma\gamma\gamma$ we require two tracks from a vertex and three prompt clusters not associated to charged tracks. We perform a kinematic fit imposing energy-momentum conservation to improve the resolution on the photon energy. The Dalitz plot distribution is conventionally described in terms of two variables $X \propto T_+ - T_-$ and $Y \propto T_0$ (where T is the kinetic energy of pions in the η rest frame) and it is parametrized as following:

$$|A(X,Y)|^2 \simeq 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3. \tag{2}$$

In order to obtain a precise measurement of the slope parameters the 2001-2002 statistics, corresponding to about 1.5 millions of events in the Dalitz plot (see Fig. 1), is analyzed.
The efficiency as function of Dalitz plot variables, Fig. 1, is almost flat in the kinematically allowed region and its mean value is about 36%; while the background is at level of few per mill.
The results of the fit are shown in Tab. 1. We clearly observe a quadratic slope in X and a

Tab. 1. Results for the slope parameter of Dalitz-plot. The $\chi^2/ndf. = 142/147$.

a	b	c
$-1.072 \pm 0.006^{+0.005}_{-0.007}$	$0.117 \pm 0.006^{+0.004}_{-0.006}$	$0.0001 \pm 0.0029^{+0.0003}_{-0.0021}$
d	e	f
$0.047 \pm 0.006^{+0.004}_{-0.005}$	$-0.006 \pm 0.008^{+0.013}_{-0.000}$	$0.13 \pm 0.01^{+0.02}_{-0.01}$

cubic slope in Y never measured before; all the other cubic terms different from f are zero. As expected from the C-invariance in the $\eta \to \pi^+\pi^-\pi^0$ decay the parameters c and e are consistent with zero, moreover they can be removed from the fit without affecting the other parameters. The χ^2 probability of fit is 60%. The systematic error is dominated by the choice of the bin width.

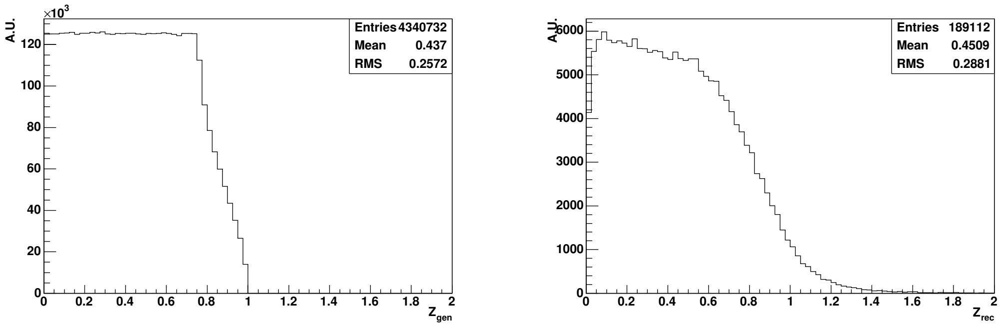

Fig. 2. MC z distribution according to pure phase space. Left: generated. Right: Reconstructed.

Using our fitted results one obtain $Q = 22.8 \pm 0.4$ [2], which differs from the value $Q_{DT} = 24.2$ (Dashen theorem) [3] and agrees with Chiral Perturbation Theory predictions [4], [5].

3 Dynamics of $\eta \to 3\pi^0$

For $\eta \to \pi^0\pi^0\pi^0$ we use a symmetrical Dalitz-plot in which the density is specified by a single parameter: $|A_{\eta\to 3\pi^0}(z)|^2 \sim 1 + 2\alpha z$ where z is the distance from the center of the $\eta \to 3\pi^0$ Dalitz-plot normalized to its maximum allowed value:

$$z = \frac{2}{3}\sum_{i=1}^{3}\left(\frac{3E_i - m_\eta}{m_\eta - 3m_{\pi^0}}\right)^2, \tag{3}$$

the quadratic energy dependence implies that α is a quadratic slope. After a kinematic fit without mass constraint we look for the best pairing of the photons into the pions; then we perform a second kinematic fit constraining the π^0 masses in order to further improve the resolution. The MonteCarlo, MC, z distribution at generation (pure phase space) and after reconstruction shows that resolution effects are not negligible for this analysis, see fig. 2.

The fit procedure is quite complex including a correction for the fraction of wrong pairing of photons and the full convolution with the resolution function. In particular we have tested it generating samples with different values of α and looking at the result of fit for these sample. From MonteCarlo, using a sample with high purity on pairing, we have estimated a correction in the α measurement of 0.002 to be applied on the fitted value.
Much attention has been given to check the MC performance in evaluating the energy resolution for the π^0; fig 3 shows the good agreement Data-MC for the invariant mass of π^0. All the Data-MC comparisons made are satisfactory.

The preliminary result is:

$$\alpha = -0.014 \pm 0.004_{stat} \pm 0.005_{syst}. \tag{4}$$

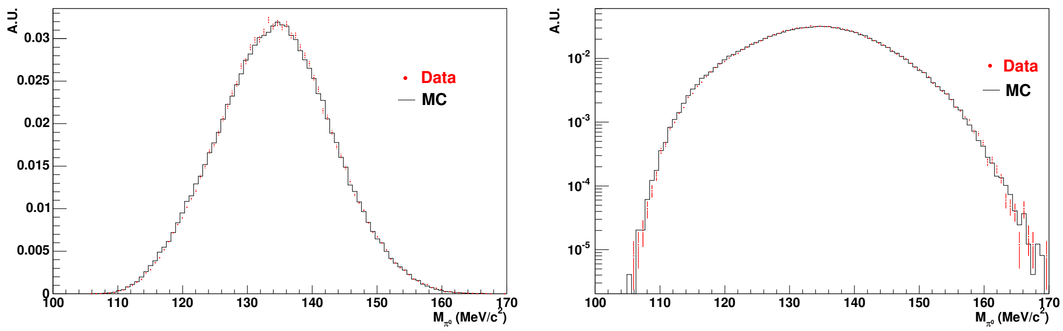

Fig. 3. Comparison of the reconstructed π^0 invariant mass distribution for data and MonteCarlo . Left: linear scale. Right: log scale.

The preliminary evaluation of the systematics has been obtained by changing the range of fit and using the maximum observed variation of α .
We catch up nearly the same accuracy of the Crystall Ball measurement:

$$\alpha = -0.031 \pm 0.004 \tag{5}$$

moreover our result differs in three standard deviations from them.

4 Conclusion

We are analyzing an unprecedented statistics of $\eta \to 3\pi$ decays with negligible background. We have new and accurate values for the Dalitz-plot slopes of both $\pi^+\pi^-\pi^0$ and $3\pi^0$ final state. For $\pi^+\pi^-\pi^0$ channel the analysis finds evidence for an unexpected large cubic slope. The $3\pi^0$ analysis is quite solid in the fitting procedure, the study of systematics has to be completed.

References

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