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

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Abstract

The parameter $\alpha = -0.005 \pm 0.007$ $(stat) \pm 0.002$ $(syst)$ describing the density of events on the $\eta \to 3\pi^0$ Dalitz plot has been measured. The result is compared to previous values and theoretical predictions.

1 Introduction

Chiral perturbation theory offers a consistent description of low energy QCD particularly applicable to meson decays. An outstanding difficulty is the large discrepancy between the predicted and observed rate of the $\eta \to 3\pi$ decay. (1). We report here a measurement of the transition matrix element $|M(\eta \to 3\pi^0)|^2$. The density of events on the Dalitz plot has been calculated theoretically to be uniform by Gasser and Leutwyler (1) and by Di Vecchia (2). More recently a calculation of Kambor, Wiesendanger and Wyler (3) found a density which decreases as the distance from the center of the plot increases.

The Dalitz plot density is specified by a single parameter, conventionally denoted as α. Kambor *et al.* show that both α and the rate $\Gamma(\eta \to 3\pi)$ are sensitive to a parameter of the theory ($\overline{c}$ in their notation). The dependence of α and Γ on $\overline{c}$ is such that a more negative value of α reduces the value of Γ thereby increasing the disagreement with experiment. Two values of α are determined by (3), -0.014 and -0.007, the latter containing higher order corrections and leading to a prediction for $\Gamma(\eta \to 3\pi)$ more consistent with experiment.

To second order in the center of mass pion energy (4) the Dalitz plot density for the decay $\eta \to 3\pi^0$ is parameterized as

$$|M|^2 \propto 1 + 2\alpha z \tag{1}$$

with

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

where E_i is the energy of the i'th pion in the η rest frame and ρ is the distance from the center of the Dalitz plot.

A uniformly populated Dalitz plot (as in (2) and (1)) gives $\alpha = 0$. α has been measured previously by Baglin *et al.* (5) , Alde *et al.* (6) , and Abele *et al.* (7). Recent results are shown in figure 1 along with the result of this work. Reference (7) finds a value significantly different than zero and in probable disagreement (2σ) with theoretical expectations. (5) and (6) are consistent with both zero and the non-zero expectation of (3).

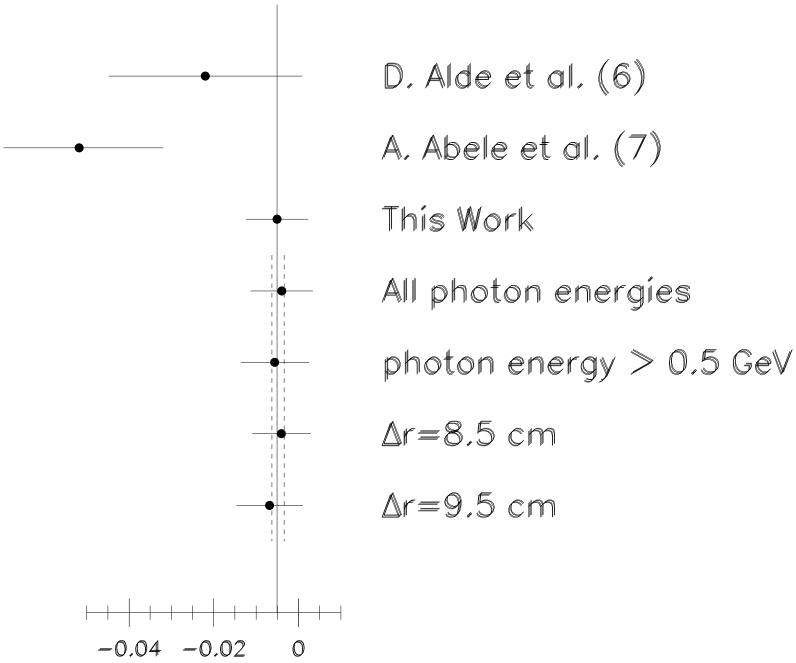

Fig. 1. Previous measurements of α and the result of this work. Also shown are the results obtained by varying the analysis. The dashed lines indicate our estimate of the systematic error in the measurement. See the text for a discussion of systematic errors.

In this work we report on a determination of α from the decay $\eta \to 3\pi^0$ where the η was produced by 18.2 GeV negative pions incident on liquid hydrogen. The data was collected in 1995 by the Brookhaven National Laboratory E852 collaboration. The apparatus has been described previously (8),(9) and consisted of a large, segmented lead glass calorimeter (LGD), a charged particle tracking and veto system and a trigger system capable of determining the charged particle multiplicity and the total energy deposited in the lead glass.

The data used for this analysis was collected with the "all-neutral" trigger which required no charged particles, an energy deposition greater than 12 GeV in the lead glass and no photons in the downstream photon veto.

$\eta \to 3\pi^0$ decays were selected by requiring exactly 6 reconstructed clusters in the LGD and a visible total energy of greater than 16.5 GeV. All combinations of assignments to the hypothesis $3\pi^0$ were tested and if the best χ^2 corresponded to a probability greater than 1% the event was considered a candidate. A preliminary fit using only the π^0 mass constraint was performed to allow evaluation of the $3\pi^0$ effective mass. Figure 2 shows the resulting distribution. Events with a mass less than 0.65 GeV/c^2 (corresponding to 3σ from the η mass) were subjected to a full kinematic fit to the hypothesis $\pi^- p \to \eta n$; $\eta \to 3\pi^0$. A confidence level (CL) cut selected decays for the final analysis.

It also was required that no photon have an energy less than 0.25 GeV and that the minimum separation between photons be larger than 9 centimeters. The effect and purpose of these requirements is discussed below. The final resulting data set contained 87,500 events.

To determine α eqn. 1 is fitted to the observed distribution of z corrected for acceptance and phase space dependence. The acceptance correction was based a monte-carlo taking into account the apertures of the apparatus and a large sample of GEANT generated electromagnetic showers. The requirement on the minimum photon energy and the minimum allowable photon separation mentioned above removed any uncertainties in the monte-carlo associated the transverse development of electromagnetic showers and the behavior of low energy photons. The separation requirement also selected events where the nearest two electromagnetic showers were well resolved. The phase space dependence of z was removed by dividing the observed distribution by the distribution due to a uniformly populated Dalitz plot.

The distribution resulting from removing the phase space dependence and correcting for the acceptance is proportional to M^2 and is shown in figure 3 along with the result of the fit. The distribution has been numerically scaled to give a proportionality constant of one. Our result is $\alpha = -0.0047 \pm 0.0074$ where the error is statistical only.

Systematic effects have been considered and the important contributors are

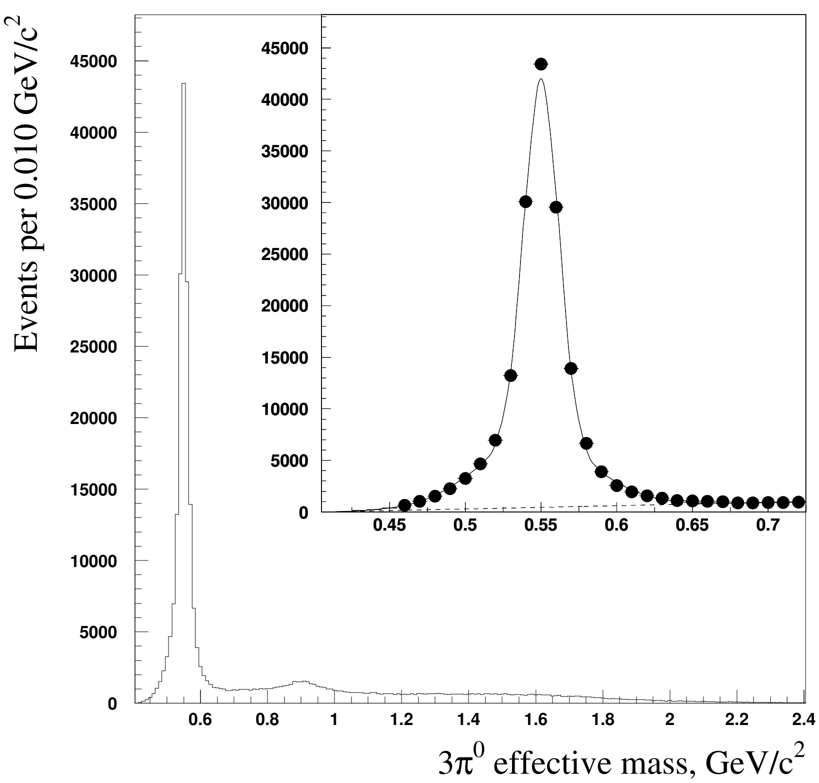

Fig. 2. The observed $3\pi^0$ effective mass distribution. The η signal dominates the data with a secondary peak due to the decay $\mathrm{K}^{*0} \to \mathrm{K}^0_s\pi; \mathrm{K}^0_s \to 2\pi^0$ visible. The inset shows the η region, there are 161,000 events under the peak with an estimated signal to noise ratio of 100 at the mass of the η.

shown in figure 1. The analysis required that no two photons have reconstructed impact positions closer than 9 cm, a distance denoted by Δr. This value was chosen by varying Δr and determining α. It was found that α does not depend on the value of Δr provided $\Delta\mathrm{r} > 9$ cm. The contribution to the systematic error is taken as the difference between our reported value of α and the extrema of values obtained with $8.5 \leq \Delta\mathrm{r} \leq 11$ cm.

A similar analysis was performed to determine the value used for the confidence level cut. It was found that α does not depend on the value used for the confidence level cut provided $\mathrm{CL} \geq 0.3$. A contribution to the systematic error of magnitude similar that of the Δr study was also determined.

The effect of requiring the lowest energy photon to have an energy larger than 0.25 GeV was investigated by removing this requirement and by replacing it with a requirement of 0.5 GeV. A contribution of ± 0.001 to α was found.

Finally, the data set was divided into two statistically independent halves by experimental run number and, separately, by momentum transfer. In both

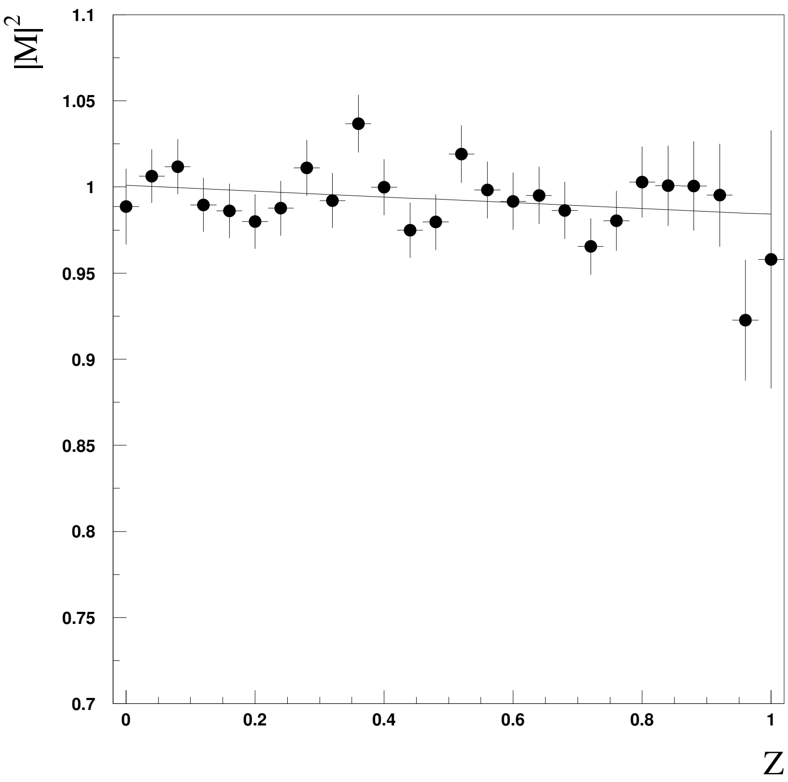

Fig. 3. z-distribution of $\eta \to 3\pi^0$ events on the Dalitz plot. The solid line is the result of a fit corresponding to eqn. 1

cases, the values determined for α were not statistically significantly different leading us to conclude these selections do not contribute to our systematic error. Adding the effects considered in quadrature give our final estimate of the systematic error, ± 0.002

2 Conclusion

We have measured the α parameter of the transition matrix element $M(\eta \to 3\pi^0)$ to be $\alpha = -0.005 \pm 0.007\ (stat) \pm 0.002\ (syst)$. Our result differs from one previous measurement (7) by slightly more than 2σ but is consistent with several other (6), (5) measurements. When compared to theoretical expectations, the value of zero favored by Di Vecchia, Gasser and Leutwyler (2), (1) cannot be ruled out. The result favors the predicted value of -0.007 of Kambor, Wiesendanger and Wyler (3) but their other predicted value, -0.014, is not definitively ruled out.

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