Decay dynamics of the process $\eta \to 3\pi^0$

Crystal Barrel Collaboration

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The parameter $\alpha = -0.052 \pm 0.020$ describing the shape of the $\eta \to 3\pi^0$ Dalitz plot has been determined using the data from the Crystal Barrel detector at LEAR. The value is compared to predictions of chiral perturbation theory.

In this work we report on a measurement of the energy dependence of the transition matrix element $M = A(\eta \to 3\pi^0)$. Up to second order in the pion energy, the amplitude squared can be parameterized as follows:

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

with

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

Here E_i is the energy of the ith pion in the η rest frame and ρ describes the distance to the center of the Dalitz plot. The value ρ_{max} is the maximum value of ρ, reached when one pion is at rest. The parameter α is an important quantity for tests of calculations of chiral perturbation theory. Tab. 1 lists the experimental results obtained to date. Both values are negative but consistent with 0.

Reference	C. Baglin et al. [6]	D. Alde et al. [7]
α	-0.32 ± 0.37	-0.022 ± 0.023
Number of events	192	50k

Table 1
Values for α, as determined in previous measurements.

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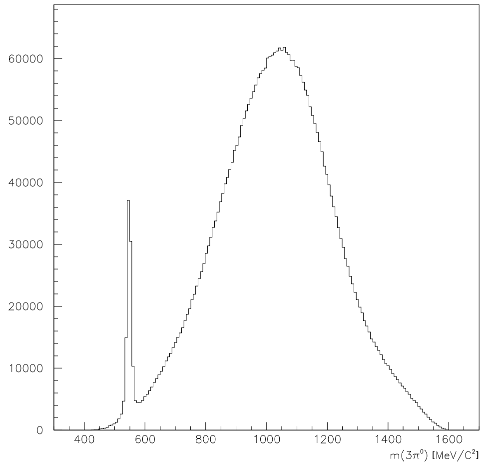

Fig. 1. The invariant $3\pi^0$-mass observed in the process $\bar{p}p \to 5\pi^0$.

Calculations within chiral perturbation theory up to next-to-leading order determine a constant energy-independent matrix element [1, 2]. Such a matrix element would lead to a homogeneously populated Dalitz plot for $\eta \to 3\pi^0$. In the more complete calculation done by J. Kambor, C. Wiesendanger and D. Wyler [3] higher order corrections, so-called unitarity corrections, are taken into account which ensure the unitarity of the decay amplitude. A value for α of either -0.014 or -0.007 results, depending on the model.

We observe the decay $\eta \to 3\pi^0$ in the channel $\bar{p}p \to \eta\pi^0\pi^0 \to 5\pi^0$ in antiproton proton annihilation at rest in liquid hydrogen. The experiment was performed at the low-energy antiproton ring (LEAR) at CERN using the Crystal Barrel detector [4]. The data presented here have been extracted from $16.3 \cdot 10^6$ annihilations at rest with a zero-prong trigger requiring an absence of charged particles in the final state. The reconstruction of the 10γ from raw data determines energies and directions of the photons, as well as their errors. The final state has been identified by kinematic fitting successively to 10γ, $5\pi^0$and $2\pi^0\eta$ with confidence level cuts at 1%, 10% and no cut, respectively. The resulting $3\pi^0$ mass distribution is shown in Fig. 1, with a clear signal of about 98000 $\eta \to 3\pi^0$ events.

The determination of detector acceptance has been estimated with Monte Carlo events based on a full GEANT simulation of the detector. The Monte Carlo data have undergone the same selection criteria as the real data. The errors from photon reconstruction for real and Monte Carlo data provide flat confidence level distributions and Gaussian shaped pulls in the kinematic fits. Uncertainties in the assumed photon-reconstruction errors have very little influence on the value of α. The acceptance Dalitz plot is flat within statistics (173k events). After phase space corrections the fit results in a value

	$\alpha_i \pm \sigma_i$
1	$+0.025 \pm 0.038$
2	-0.038 ± 0.030
3	-0.049 ± 0.026
4	-0.057 ± 0.034
5	-0.039 ± 0.028
6	-0.048 ± 0.030
7	-0.045 ± 0.018
8	-0.037 ± 0.015

Table 2
Values for α for different run periods.

$\alpha = -0.039 \pm 0.017$ where the error is statistical only.

We now turn to a discussion of the systematic errors. This has been done by splitting the data set into eight subsets, one for each run period, before determining a separate value of alpha for each, using the above procedure. The results are given in Tab. 2. The distribution of α results in a χ^2/ndf of 0.49, showing no indications of a systematic error.

We have considered the most likely systematic effects which could affect the value of α, with no significant contributors. The $\pi^0\pi^0\eta$ production dynamics might have some impact on the slope in the $\eta\to 3\pi^0$ Dalitz plot due to incorrect combinatorics or through rescattering of final-state particles; however, this has been discounted by observing that the determination of α, using events from only selected parts of the $\pi^0\pi^0\eta$ Dalitz plot, is unchanged. We have also checked that the error scaling in the kinematic fit does not have any impact on the determination of α. We have altered the minimum photon energy, used in the identification of clusters of crystals with energy deposit in the calorimeter, from 13 MeV to 20 MeV, have included or excluded events with split-off photons in the analysis, all without effect. In particular, masses and momenta of the η in two and six photon decay modes in different final states were checked and no difference was recognized.

Next we discuss the reliability of the reconstruction of the $\pi^0\pi^0\eta$ final state and possible sources of background. We have compared two $\pi^0\pi^0\eta$ Dalitz plots, one from the six-photon final state [5] and one from the present data. The six-photon final state has a background contamination of less than 1%. In the 10γ Dalitz plot there is a combinatorial background. From Monte Carlo data we know that the wrong $\eta\to 3\pi^0$ combinations give an edge enhancement in the $\pi^0\pi^0\eta$ Dalitz plot. From fits to this $\pi^0\pi^0\eta$ data Dalitz plot we estimate the background distribution to 2.6%. In the $3\pi^0$ Dalitz plot the background

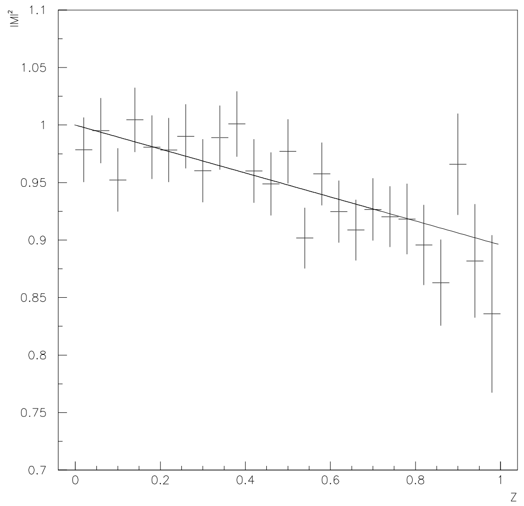

Fig. 2. The final z-distribution from $\eta \rightarrow 3\pi^0$ after subtraction of background and correction of acceptance. The data are fitted to a straight line of the form given in equation 1.

contribution is flat.

The final fit to the z-distribution after background subtraction and phase space corrections is shown in Fig. 2. The fit results in a value $\alpha = -0.052 \pm 0.017$ where the error is statistical only. Adding in quadrature the various systematic errors results in an estimated total systematic error of 0.010.

The final result, taking into account statistical and systematic errors, is therefore

$$\alpha = -0.052 \pm 0.017 \pm 0.010. \tag{3}$$

For the first time we find a value for α which deviates significantly from zero. Nevertheless, this determination is consistent with the results of [6] and [7]. Our result deviates however by 2 standard deviations from the theoretical estimates [3].

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