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Measurement of the $\tau \to \eta\pi\pi^0\nu_\tau$ branching ratio using $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ final states

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Using Aleph data until 1993 (159 thousand tau pairs), the branching ratio of the τ into $\eta\pi\pi^0$ is measured to be: $0.24 \pm 0.04 \pm 0.04\%$. We have evidence for an η signal in both the $\gamma\gamma$ and $\pi^+\pi^-\pi^0$ mass spectra. In the first case, we allow for one missing photon so that the η peak is seen either in one or two dimensions (coupled to a π^0). In the second case, we also allow for only one final state π^0 but fit all events together. This makes for 3 independent measurements which are together consistent (χ^2/d.o.f=.4) and amount to a total statistical significance of about 6 σ.

1 Theoretical and Experimental Overview

1.1 Theoretical interest

The $\eta\pi\pi^0$ final state, having positive G-parity, should be produced from the vector part of the charged hadronic current. It turns out that this vector part, in the chiral limit, couples exclusively to even numbers of pseudo-scalars. The $\eta\pi\pi^0$ decay channel thus provides direct evidence for the chiral anomaly of QCD and can be computed from the "anomalous" Wess-Zumino effective left current [1]: $\mathcal{L}_\mu^{(ano)} = -i\frac{N_c}{24\pi^2 f^6}\epsilon_{\mu\nu\alpha\beta}\mathcal{L}^\nu\mathcal{L}^\alpha\mathcal{L}^\beta$ where $\mathcal{L}_\mu = if^2 U\partial_\mu U^\dagger$ $(U = \exp(i\lambda_a\pi^a/f))$ is the ordinary, chirally symmetric, effective left current. The rate is still difficult to compute because of its sensitivity to various resonance assumptions: [2] gives $Br\ (\tau \rightarrow \eta\pi\pi^0\nu_\tau) \simeq 0.2 \sim 0.3\%$ while [3] is more vague. An alternative way consists in using CVC which relates this decay to the $e^+e^- \rightarrow \eta\pi^+\pi^-$ annihilation. One thus obtains [4]: $Br\ (\tau \rightarrow \eta\pi\pi^0\nu_\tau) = 0.15\%$.

1.2 Experimental status

The decay has only been observed by the CLEO collaboration [5]. Their study was able to make use of all 3 main η decay channels, namely $\eta \rightarrow \gamma\gamma$, $\pi^+\pi^-\pi^0$ or $3\pi^0$, with the result: $Br\ (\tau \rightarrow \eta\pi\pi^0\nu_\tau) = .17 \pm .02_{stat.} \pm .02_{syst.}\%$. In Aleph, only the first 2 final states with 39% and 24% respective branching fractions are of use. We will present measurements in both these cases which correspond to respectively 55 and 23 signal events compared to 77 ± 12 and 29 ± 9 for [5]. The technique will be identical to that of [5] except that, due to higher photon losses, we will allow one missing photon and thus have 2 sub-cases in each final state. Note that the $\eta\pi^\pm\gamma$ states will be deliberately interpreted as $\eta\pi\pi^0$ with one photon lost and not as $\eta\pi^\pm$ (2^{nd}-class current) with one additional photon.

2 Event Selection

2.1 Common methods

Let us briefly describe the part of the selection that is common to both $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$. We start from the Class 24 pre-selection of dileptons and separate all events in 2 opposite hemispheres which are treated separately. We ask for the required number of pions using quality cuts on the track's number of hits and position and a particle identification (any of the available ones would do ...). As for the photons, we first apply basic quality cuts on the shower profile, which are certainly harmless to "true" photons, and ask for a proximity to the charged track's direction. Taking into account the converted photons, in which one track may be lost, we thus get a first count of them. Further cuts will then be applied to sort out the so-called "fake" photons coming either from electro-magnetic shower fluctuations or hadronic interaction residuals.

We use a simple acollinearity cut to dispose of the two photon background and two probability likelihood variables to cut away the Bhabha and hadronic ($Z^0 \rightarrow q\bar{q}$) events. The latter two bear solely on the recoil hemisphere which not only ensures absence of any bias but also allows efficiency checks on the data itself. The Bhabha background is rather small for the $\eta \to \gamma\gamma$ channel (notably because of the required positive pion particle identification) and understandably negligible for the other. As for hadronic events, which are originally at the 30% level in the $\eta \to \pi^+\pi^-\pi^0$ channel, we are able to reduce them to the per mille level, mostly thanks to this variable.

2.2 Selection of the $\pi^\pm$, $4\gamma(3\gamma)$ topology

We rely here on two probability likelihood estimators to distinguish between authentic and "fake" photons. One analyses the shape of two neighbour ECAL clusters to determine whether one is born of the other or really independent. We cut at a value of .5 on the resulting variable which has an efficiency of 95% and a rejection around 98% of the few ($3 \sim 4\%$ of the total) expected electro-magnetic fake photons. The other estimator tackles the more delicate problem of tagging hadronic interaction residuals. The number of these hadronic fake photons, grossly proportional to the number of charged pions, is sizeably larger than that of the electro-magnetic ones. We will use a cut at .5 or .8 probability which has performances harder to ascertain, but we think close to that of the electro-magnetic tag. To minimize the uncertainties relative to this situation, we allow in both 3 or 4 good photon's cases, an additional fake one. The only issue is then how well we separate these two categories.
In the 4 photons topology, we further require a good ECAL energy separation to have a satisfying reconstruction quality. We also reject events with Bulos photons, mainly for purity reasons. By Bulos photon, we mean a calorimetric photon with high mass (from a moment's analysis of the energy deposition) relative to its energy.
We end up with efficiencies of respectively 27% and 17% for 3 and 4 photons. The background, which consists mainly of $\pi 2\pi^0$ and $\pi\pi^0$ τ-decays, is clearly overwhelming (by a factor $\simeq 150$). We will overcome this rate by anti-tagging the additional π^0 of the background events, i.e. ask for no valid π^0 in 3 photons, and for no (π^0, π^0) combination in 4.

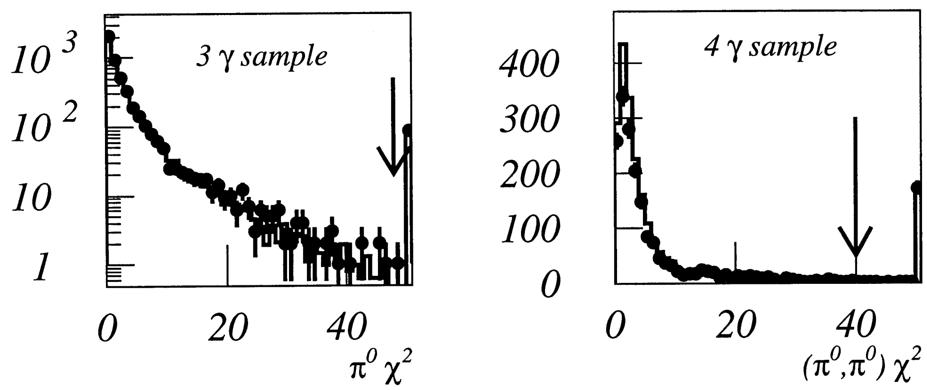

Figure 1: χ^2s to π^0 (left) and (π^0, π^0) (right) hypothesis. The arrow indicates the cut value.

2.3 Selection of the $3\pi^{\pm}$, $2\pi^0(\pi^0\gamma)$ topology

Again we try to disentangle our $3\pi^{\pm}2\pi^0$ signal from a background that differs only in the number of photons. We still rely on the probability for electro-magnetic fake photons but adopt a simpler, more controllable, way for hadronic fakes because of the presence of 3 pions for which the above estimator was not designed. We will now use topology-dependent 2-dimensional cuts in the (distance to charged track - energy) plane of the calorimetric photons. For each original number of photons (3 to 5), we apply slightly different (d,E) cuts and require, depending on the situation, one or two π^0(s). The π^0 quality is estimated from the goodness of a fit of the photon's energies under the constraint of a π^0 invariant mass. It is important for both fit and (d,E) cuts to have an overall calibration and to apply an ad-hoc correction that ensures agreement between data and Monte-Carlo in the invariant mass of photon pairs. The overall efficiencies are respectively 16% and 17% for one and two π^0(s). Again the non-η $3\pi^{\pm}2\pi^0$ decays are dominant but fortunately, the η resonance is narrow and low-lying enough to emerge from them. From a Monte-Carlo of $\tau \to \eta\pi\pi^0$ events, we observe a width of about 10 MeV for the $\eta \to \pi^+\pi^-\pi^0$ peak (after refitting the π^0).

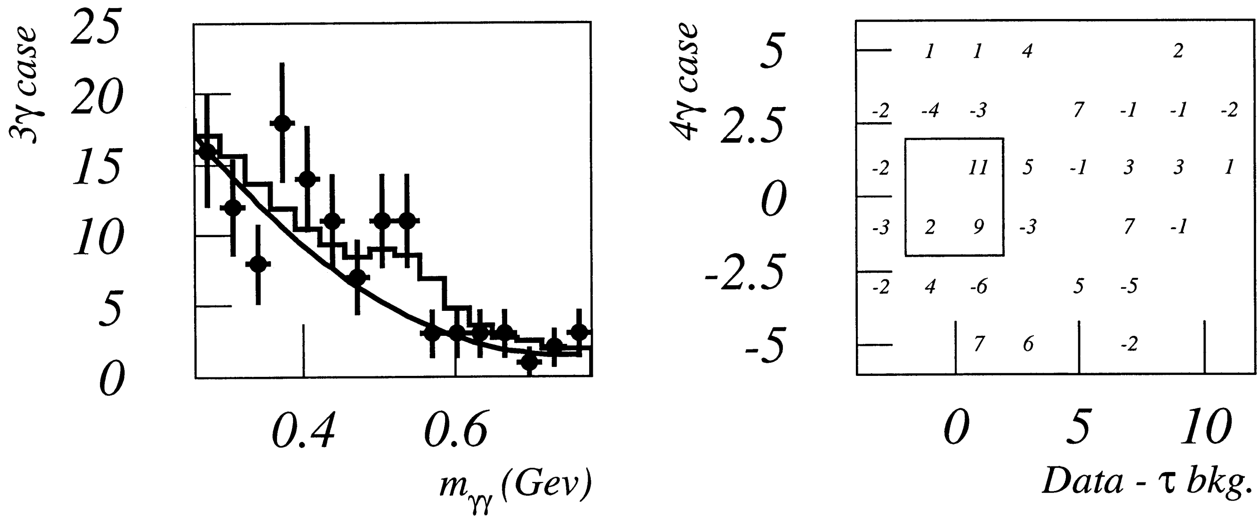

Figure 2: 1 and 2 dimensional plots showing the $\eta \to \gamma\gamma$ resonance. Left: Parabola + signal fit. Right: Data - Monte-Carlo with 2 σ box around (m_η, m_{π^0}).

3 Branching ratio by $\eta \to \gamma\gamma$

3.1 Case of 3 photons

Rejecting all events with a good π^0 (figure 1), we gain a factor $\simeq 25$ in the signal to noise ratio. The price is a 57% loss of the signal, mainly through wrong combinations within $\eta\gamma$. We observe a good agreement between data and Monte-Carlo both in normalisation and shape (π^0 mass at 138 MeV and 18 MeV's width) in the π^0 peak of the rejected events. In the remaining events, we plot all 3 pair masses and fit the relative contributions of background (flattish) and signal (η peak of $\simeq 55$ MeV's width). We perform a binned maximum likelihood fit between 260 and 780 MeV , region unaffected by the preceding anti-π^0 cut. We find that the background is $20 \pm 20\%$ larger than expected and that the signal has $\alpha_3 = 24 \pm 13$ entries (figure 2). Using the Monte-Carlo to relate this last figure to the number of signal events, we obtain a branching ratio of:

$$Br\ (\tau \to \eta\pi\pi^0)_3 = 1.7 \pm .6_{stat}\ 10^{-3}$$

The statistical error is smaller than that of the fit because part of the latter is really background and not data statistics related.

3.2 Case of 4 photons

Similarly, we require that there be no good π^0 pair among the 4 photons (figure 1). The signal to noise factor is improved by a factor 12 only because of the $\pi^\pm 3\pi^0$ background which, due to combinatorics, is less efficiently tagged than $\pi^\pm 2\pi^0$. We then apply a 2-dimensional binned maximum likelihood fit to the data which again estimates the relative proportions of a flattish background versus a (η, π^0) peaked signal. The background is found $6\pm8\%$ lower than predicted by the simulation and the signal represents $\alpha_4 = 64\pm27$ entries (figure 2). Using the same procedure as for 3 photons yields:

$$Br\ (\tau \to \eta\pi\pi^0)_4 = 2.5 \pm .7_{stat}\ 10^{-3}$$

3.3 Systematic errors

The common systematic errors due to the luminosity, $\eta \to \gamma\gamma$ branching fraction or selection procedure (outside of the photon's issues) are negligible in the face of $30-40\%$ statistical errors. We need only consider the decisive anti-π^0(s) cut and background shape and overall level uncertainties. Both fits turn out to be quite insensitive to the background shape (and thus composition) and robust towards variations in the value of the anti-π^0 χ^2 cut. The main uncertainty is by far our ignorance of the background quantity. Using the above mentioned background uncertainties, we find variations as large as $\delta\alpha_3 = 10$ and $\delta\alpha_4 = 20$. Finally, we check the stability against variations in the binning or range. The results are summarized in the table below:

	$bkg.shape$	$bkg.level$	χ^2	$range$	$binning$	$TOTAL$
$\delta\alpha_3$	3	10	$\simeq 3$	≤ 1	2	11
$\delta\alpha_4$	2	20	$\simeq 8$	4	6	23

We thus obtain:

$$\begin{cases} Br\ (\tau \to \eta\pi\pi^0)_3 = 1.7 \pm .6_{stat} \pm .8_{syst}\ 10^{-3} \\ Br\ (\tau \to \eta\pi\pi^0)_4 = 2.5 \pm .7_{stat} \pm .9_{syst}\ 10^{-3} \end{cases}$$

4 Branching ratio by $\eta \to \pi^+\pi^-\pi^0$

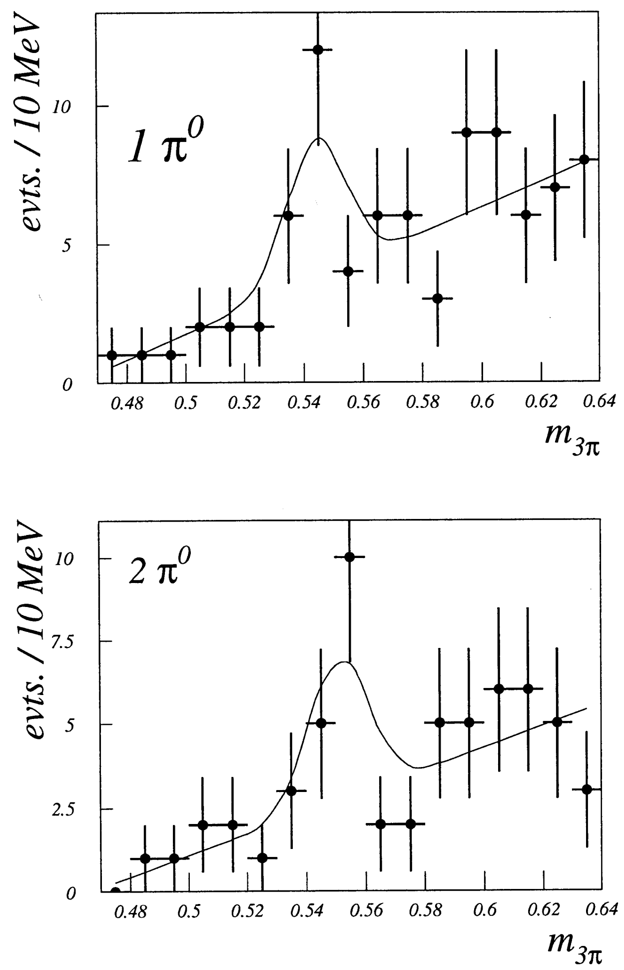

Figure 3: Data $(\pi^+\pi^-\pi^0)$ mass spectra for 1 and 2 π^0 cases with fit result superimposed. Close-up view around m_η

4.1 Fit of the η resonance

We have again a possible lost photon i.e. $3\pi^\pm\pi^0\gamma$ or $3\pi^\pm 2\pi^0$. In the first case, there are only two combinations per event but the η meson has been lost about half of the time. In the second case, there are four combinations but one should always correspond to the η decay products. This causes the two situations to have similar $(\pi^+\pi^-\pi^0)$ invariant mass spectra. Figure 3 indeed shows their similarity and the presence of an η signal in both. We will for simplicity fit the sum of the two spectra. We use a binned maximum likelihood fit to estimate the relative proportions of entries coming from a flat distribution and a gaussian one. The fit is performed on the largest possible range of flatness of the background which is up to the beginning of the ω resonance (745 MeV). The width of 10 MeV is taken from a $\tau \rightarrow \eta\pi\pi^0$ Monte-Carlo since data statistics are not sufficient to fit it. We then simultaneously fit background slope, relative proportion and gaussian center. The fitted resonance mass is $m = 543 \pm 4\ MeV$, the slope $p = 2.18 \pm 0.05$ and proportion of signal: $f = 5.6 \pm 1.9\%$. From that fraction and the $\tau \rightarrow \eta\pi\pi^0$ Monte-Carlo, we deduce the total number of signal events and, via the efficiency, the number of $\tau \rightarrow \eta\pi\pi^0$ decays analysed. Figure 4 shows the fit result, the flatness of the background and the peak from which we have extracted the η width; it yields:

$$Br\ (\tau \rightarrow \eta\pi\pi^0) = 3.0 \pm 1.0_{stat}\ 10^{-3}$$

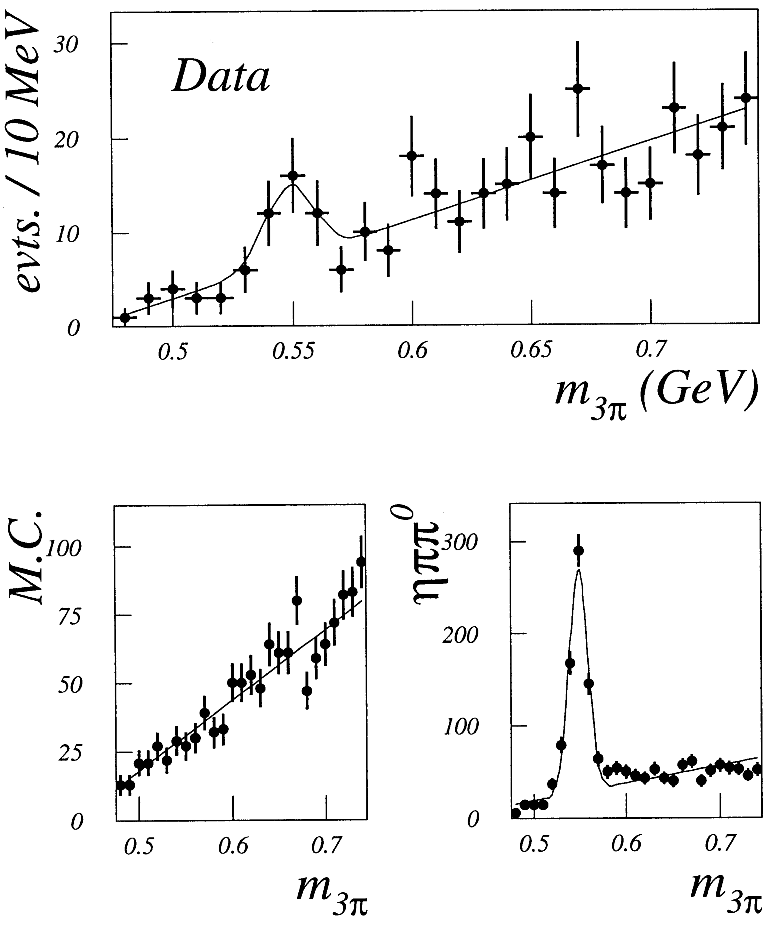

Figure 4: Top: Data $(\pi^+\pi^-\pi^0)$ invariant mass spectrum with straight line + gaussian fit superimposed. Bottom: Expected mass spectra for non-η τ events and η signal.

4.2 Systematic errors

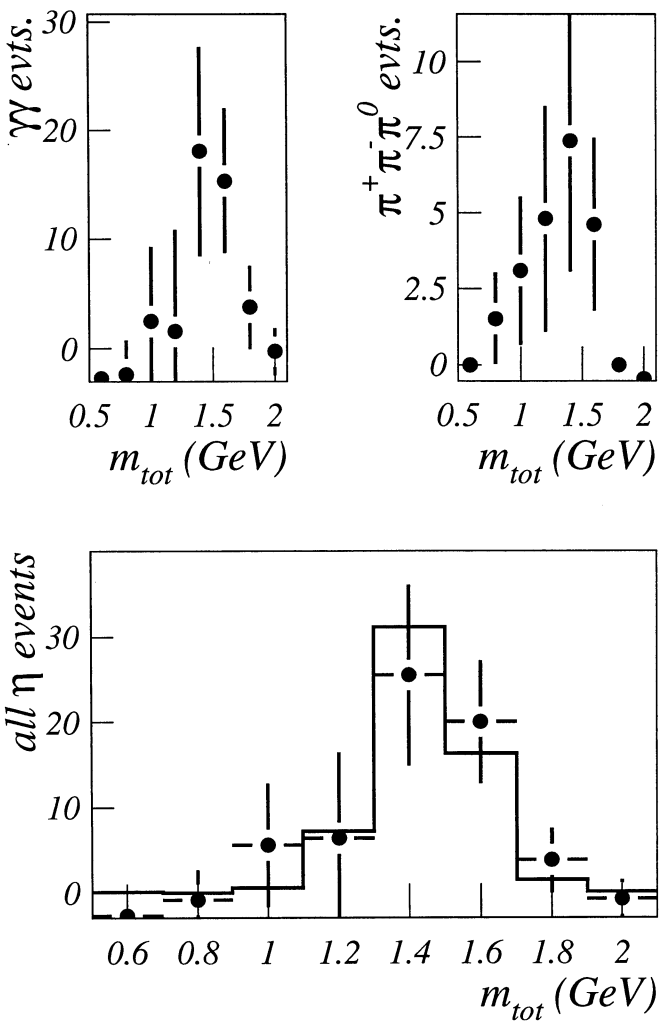

Figure 5: Top: Total mass for $\eta \to \gamma\gamma$ (left) and $\eta \to \pi^+\pi^-\pi^0$ (right) candidates. Bottom: Sum of the 2 channels compared to the Monte-Carlo expectation for a $\tau \to \eta\pi\pi^0$ decay.

As in the $\eta \to \gamma\gamma$ case, the relative statistical error is quite large (34%) which renders the common systematic errors like non-τ background contributions or luminosity normalisation rather negligible. There is a small relative uncertainty on Br ($\eta \to \pi^+\pi^-\pi^0$) of 2.5%. We find a 5% error from investigating the effect of restraining the fit range to lower masses. We observe also that the slope knowledge allows for another 8% uncertainty on our result. There is also our extrapolating from the gaussian content to the number of signal events which suffers mainly from the limited $\eta\pi\pi^0$ Monte-Carlo statistics. Finally, we recompute the branching ratio for different sets of good photon selection cuts to check our sensitivity. All these errors are summarized in the table below.

	Br ($\eta \to \pi^+\pi^-\pi^0$)	*range*	*slope*	*extrapolation*	(d, E)*cuts*	*TOTAL*
$\frac{\Delta B}{B}$ (%)	2.5	5	8	5	$\simeq 9$	14

We thus obtain:

$$Br\ (\tau \rightarrow \eta\pi\pi^0) = 3.0 \pm 1.0_{stat} \pm 0.4_{syst}\ 10^{-3}$$

5 Conclusion

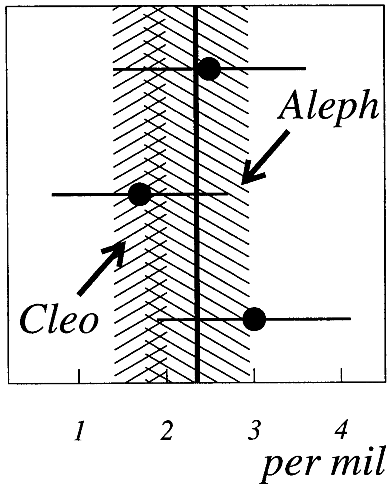

Figure 6: The three results of this paper with full error bars. The wide band shows their combination while the narrower one represents the CLEO value

We have observed an $\eta\pi\pi^0$ signal in τ decays in both $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ final states. We have fitted its value on resonance peaks in $(\gamma\gamma)$ and $(\pi^+\pi^-\pi^0)$ invariant mass spectra. We have thus obtained 3 independent measurements. The global χ^2 per d.o.f., with systematic error included, is .4 . We can thus combine these figures to obtain:

$$\boxed{\mathbf{Br\ (\tau \rightarrow \eta\pi\pi^0) = 0.24 \pm 0.04_{stat} \pm 0.04_{syst}\%}}$$

This result is consistent with the only available measurement [5] (figure 6) and so is the total mass of the candidate events, shown on figure 5.

References

[1] G Kramer and W. F. Palmer, Z Phys C25 (1984)

[2] A. Pich, PL B196 4 (1987)

[3] G Kramer and W. F. Palmer, Z Phys C39 (1988)

[4] F. J. Gilman, PR D35 11 (1987)

[5] CLEO Collaboration, PRL 69 (1992)