NEW TESTS OF CHIRAL PERTURBATION THEORY IN η DECAYS USING THE CRYSTAL BALL

B.M.K. NEFKENS AND S. PRAKHOV
for the Crystal Ball Collaboration [*†]

UCLA, Los Angeles, CA 90095, USA

The G-parity violating $\eta \to 3\pi^0$ decay occurs primarily as a consequence of the up-down quark mass difference, $m_u - m_d$. In the standard notation [1] $A(\eta \to 3\pi^0) \sim (m_u - m_d)(1 + \alpha z)$ and $\Gamma(\eta \to 3\pi^0) \sim (m_u - m_d)^2(1 + 2\alpha z)$, where α is the quadratic slope parameter, $z = (\rho/\rho_{\max})^2 \sim \sum(E_i^{\pi^o} - m_\eta/3)^2$, ρ is the distance from the center of the Dalitz plot. Thus far χPTh has not succeeded in accounting fully for the experimental $\eta \to 3\pi$ decay rate. The expanded $\mathcal{O}(p^4)$ calculation which includes pion-pion rescattering to all orders [2] is still too low by $(34 \pm 10)\%$. It has been suggested [3] that this might be due to dynamical effects with terms $\mathcal{O}(p^6)$ such as $\mathcal{L}^6 \sim F_\pi^2 trmD^\mu UD_\mu U^\dagger trD^\nu UD_\nu U^\dagger$. This possibility may be explored by a precise measurement of the quadratic slope parameter α in $\eta \to 3\pi^0$ decay. The existing data are inconclusive. GAMS-2000 [4] obtained $\alpha = -(22 \pm 23) \times 10^{-3}$. The Crystal Barrel [5] has reported $\alpha = -(52 \pm 15 \pm 10) \times 10^{-3}$. The theoretical prediction [2] is $\alpha = -(14 \text{ to } 7) \times 10^{-3}$.

In our recent experiment at the AGS we have produced a sample of 6×10^6 $\eta \to 3\pi^0$ in $\pi^- p \to \eta n$ near threshold using the Crystal Ball, CB [6]. We have selected a very pure subsample of 1×10^6 $\eta \to 3\pi^0$ decays with a background $< 1\%$ using a kinematic fit to the process $\pi^- p \to \eta n \to 3\pi^0 n \to 6\gamma n$. Our data are compared in great detail to a full scale Monte Carlo simulation. A straight line fit of the ratio of the z-distributions of our data and the MC gives the slope parameter, see Fig.1a : $\alpha = -(33 \pm 3_{\rm stat} \pm 6_{\rm syst}) \times 10^{-3}$. We agree with theory [2] in the sign but not in the value of α.

From $\alpha_{\rm dyn} = \alpha_{\rm exp} - \alpha_{\rm th}$, see Ref [3], we obtain $\alpha_{\rm dyn}^{000} = -(26 \pm 2 \pm 6) \times 10^{-3}$,

*The Crystal Ball Collaboration: E. Berger, M. Clajus, A. Marušić, S. McDonald, B.M.K. Nefkens, N. Phaisangittisakul, S. Prakhov, M. Pulver, A. Starostin and W.B. Tippens, *UCLA*, D. Isenhower and M. Sadler, *ACU*, C. Allgower and H. Spinka, *ANL*, J. Comfort, K. Craig and T. Ramirez, *ASU*, T. Kycia, *BNL*, J. Peterson, *UCo*, W. Briscoe and A. Shafi, *GWU*, H.M. Staudenmaier, *UKa*, D.M. Manley and J. Olmsted, *KSU*, D. Peaslee, *UMd*, V. Bekrenev, A. Koulbardis, N. Kozlenko, S. Kruglov and I. Lopatin, *PNPI*, G.M. Huber, N. Knecht, G.J. Lolos and Z. Papandreou, *UReg*, I. Slaus and I. Supek, *RBI*, D.Grosnick, D. Koetke, R. Manweiler and S. Stanislaus, *ValU*.

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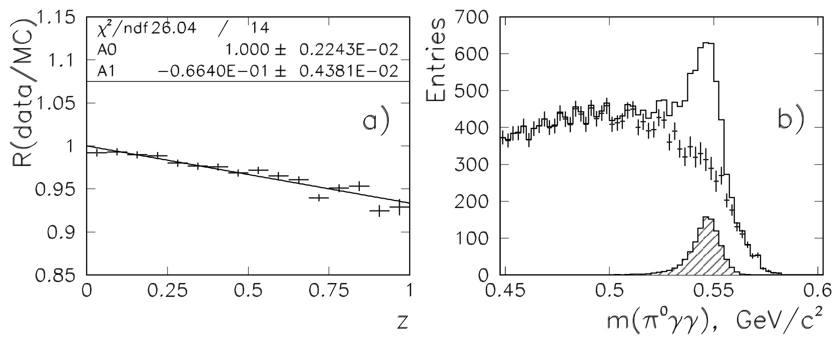

Figure 1. a) - Ratio of the z-distributions of our data and MC; normalizing $A_0 \to 1.0$ we have $\alpha = \frac{1}{2}A_1$. b) - The invariant mass distribution of a subsample of $\pi^0\gamma\gamma$ candidates before (solid line) and after subtraction of the background from $\eta \to 3\pi^0$ (shown by crosses). The expected contribution from $\eta \to \pi^0\gamma\gamma$ events occuring at the decay rate of GAMS-2000 is shown by the hatched histogram.

using the value $\alpha^{000}_{\rm th} = -7 \times 10^{-3}$ from Ref [2]. Isospin invariance implies that $\alpha^{000}_{\rm dyn} = \alpha^{+-0}_{\rm dyn}$. The meager experimental data [7] supports this within errors, $\alpha^{+-0}_{\rm dyn} = -(23 \pm 15) \times 10^{-3}$. The WASA collaboration is planning a precise measurement of α^{+-0}. It is interesting to compare our $\eta \to 3\pi^0$ slope with the one for $K^0_L \to 3\pi^0$ reported in Ref. [8]. The kaon data has the same sign as the η but the value is much smaller: $\alpha^{000}_K = -(1.6 \pm 0.6 \pm 0.4) \times 10^{-3}$.

The rare decay $\eta \to \pi^0\gamma\gamma$ has drawn much attention over the years, especially in connection with testing χPTh as summarized in Table 1 . The only known measurement [4] yielded $\Gamma(\eta \to \pi^0\gamma\gamma) = 0.84 \pm 0.19$ eV. This value is greater than every prediction based on χPTh. Table 1 shows that the decay $\eta \to \pi^0\gamma\gamma$ is a unique test of the $\mathcal{O}(p^6)$ of χPTh. We have used the CB η run which yielded 18.9×10^6 η's to search for $\eta \to \pi^0\gamma\gamma$ decays. After applying a series of carefully crafted cuts to the initial sample of 7×10^6 four cluster events and making a kinematic fit to the $\pi^-p \to \pi^0\gamma\gamma n \to 4\gamma n$ hypothesis we are left with a set of events, their invariant mass distribution shows a peak at the η mass atop a background remaining from reaction $\pi^-p \to \pi^0\pi^0 n$. This peak is mostly produced by $\eta \to 3\pi^0$ decays with 2×2 overlapping clusters. We have made detailed investigations of this decay with the CB. So we feel confident of subtracting it from the data, the result is shown in Fig.1b. Thus

Table 1. Theoretical prediction for the $\eta \to \pi^0\gamma\gamma$ decay rate.

Theory	$\Gamma(\eta \to \pi^0\gamma\gamma)[eV]$	Reference
χPTh, $\mathcal{O}(p^2)$	0	Y. Nemoto, *PR* **D54** (1996) 6777
χPTh, $\mathcal{O}(p^4)$	0.004	Ll. Amettler.., *PL* **B276** (1992) 185
χPTh, $\mathcal{O}(p^6)+..$	0.42 ± 0.20	Ll. Amettler.., *PL* **B276** (1992) 185
χPTh, $\mathcal{O}(p^6)+..$	0.47	P.Ko, *PL* **B349** (1995) 555
χPTh, ENJL	0.58 ± 0.03	S. Belluci.., *NP* **B452** (1995) 626
χPTh, ENJL	0.27 ± 0.18	J. Bijnens.., *PL* **B379** (1996) 209
VMD	0.30 ± 0.15	J. Ng .., *PR* **D46** (1992) 5034
Q box	0.70	J. Ng.., *PR* **D47** (1993) 4937
VMD	0.4	W. Allen.., *NC* **A45** (1966) 272

far we have not identified a clear signal. At present we prefer to state only the upper limit $\Gamma(\eta \to \pi^0\gamma\gamma)\ < 0.3$ eV which is consistent with χPTh, $\mathcal{O}(p^6)$.

An independent demonstration that the GAMS result on $\Gamma(\eta \to \pi^0\gamma\gamma)$ is too large comes from the CB experiment on $\eta \to 3\gamma$ which is a test of C-invariance. We have achieved $BR(\eta \to 3\gamma) < 5 \times 10^{-5}$ which is a factor 10 better than the published limit. We have found (16 ± 33) $\eta \to 3\gamma$ events. The largest background in this search is from $\eta \to \pi^0\gamma\gamma$. If the GAMS result were correct we expect to have 78 events in our $\eta \to 3\gamma$ sample due to $\eta \to \pi^0\gamma\gamma$.

For an interesting excercise in analysis we are looking for the rare decay $\eta \to \pi^0\pi^0\gamma\gamma$. This is particularly challenging in view of the monumental background from $\eta \to 3\pi^0$. Our preliminary result is $BR(\eta \to \pi^0\pi^0\gamma\gamma) < 3.1 \times 10^{-3}$. A theoretical prediction [9] based on χPTh $\mathcal{O}(p^4)$ is about 10^{-6}.

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