Measurement of the branching ratio of the rare decay $\eta \rightarrow \pi^0\gamma\gamma$ with WASA-at-COSY

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Introduction

The doubly radiative decay $\eta \rightarrow \pi^0\gamma\gamma$, a rare decay of the η meson has attracted the attention of both the experimentalists as well as theoreticians. This is primarily, because there are large discrepancies between theoretical calculations and widely different experimental results. The interest in this decay channel stems from the fact that it tests Chiral Perturbation Theory to order O(p^6). The uncertainties in the Chiral Perturbation Theory calculations of the amplitude for the $\eta \rightarrow \pi^0\gamma\gamma$ transition are due to the fact that the lowest order term of the Lagrangian (O(p^2)) of the Chiral Perturbation Theory is zero as neither π^0 nor η can emit a photon. The order O(p^4) terms are suppressed due to large mass of the kaons and G parity invariance of the terms involving pions. The situation is therefore uncertain on the theoretical front as shown in (TABLE I).

TABLE I: Theoretical calculations for the decay width of $\eta \rightarrow \pi^0\gamma\gamma$ [1].

Theory	$\Gamma(\eta \rightarrow \pi^0\gamma\gamma)$ eV
$\chi PTh, O(p^2)$	0
$\chi PTh, ... + O(p^4)$	0.004
$\chi PTh, ... + O(p^6)$	0.42 ± 0.20
$\chi PTh, ... + O(p^6)$	0.47
$\chi PTh, ENJL..... + O(p^6)$	0.58 ± 0.30
$\chi PTh, ENJL..... + O(p^6)$	$0.27^{0.18}_{0.07}$
VMD	0.30 ± 0.15
Q box	0.70
$\chi PTh, ... + O(p^6)$	0.44 ± 0.09
unitarized χPTh	0.47 ± 0.10

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The first sizable contribution to the $\eta \rightarrow \pi^0\gamma\gamma$ decay amplitudes comes from the O(p^6) counter terms that are needed in Chiral Perturbation Theory to cancel various divergences. The coefficients of these counter terms are not determined by Chiral Perturbation Theory itself, they depend on the model used for the calculation. The discrepancy between the previous experimental results (TABLE II) of the branching ratio of $\eta \rightarrow \pi^0\gamma\gamma$ is because of the orders of magnitude larger backgrounds coming from other decay channels.

TABLE II: Experimental Measurements

Experiments	BR ($\eta \rightarrow \pi^0\gamma\gamma$)
GAMS-2000	$(7.1 \pm1.4) \times 10^{-4}$ [2]
Crystal Ball	$(3.5\pm0.7_{stat} \pm 0.6_{sys}) \times 10^{-4}$ [1]
KLOE	$(8.4 \pm2.7_{stat} + 1.4_{sys}) \times 10^{-5}$[3]

Experimental Setup

The Wide Angle Shower Apparatus (WASA) is a 4π multi detector system with the capability of detecting both neutral as well as charged particles. This is essential for kinematically complete multi particle final states. This offers a unique opportunity to measure the branching ratio of this rare decay mode of η meson. COSY delivers phase space cooled protons and deuterons in the momentum range between 0.3 GeV/c to 3.7 GeV/c. WASA is an internal experiment operating with a pellet target. It consists of a forward part for the measurement of scattered particles and a central part to measure the decay products of the mesons.

Analysis

Here we present the preliminary results of the analysis of the decay $\eta \rightarrow \pi^0\gamma\gamma$ with WASA. The data presented here are obtained during the production run where a proton beam with kinetic energy T_{beam} =1.0GeV interacted with deuteron (pellet target), resulting in approximately 10^7 η mesons. The extraction of the branching ratio of $\eta \rightarrow \pi^0\gamma\gamma$, relies heavily on thorough understanding of the background channels (BR($\eta \rightarrow 3\pi^0$)=32%, $\sigma(2\pi^0$=1.5μb)), since their contributions to the data sample exceeds that of the signal(BR($\eta \rightarrow \pi^0\gamma\gamma$)=4.4×$10^{-4}$ (PDG value).

To select the $\eta \rightarrow \pi^0\gamma\gamma$ events, we use the following selection criteria arrived at by extensive simulations:

- One charged particle in the Forward Detector.
- Four neutral cluster in the Central Detector with energy deposited greater than 20 MeV.
- One and only one π^0 – The $m_{\gamma\gamma}$ spectrum of the invariant mass of the two photons not originating from the π^0 extends through the mass of the π^0. However, these events are overwhelmed by the pd→^{3}He $\pi^0\pi^0$ background where the two photons always arise from the presence of a second π^0. It is necessary to exclude this mass region to reduce the pd→^{3}He $\pi^0\pi^0$ background. This is done by asserting that no more than one pair of photons reconstructs the π^0 mass within 3σ of the mean reconstrcted π^0 mass, here $\sigma = 16MeV$.
- $m_{\gamma\gamma} > 0.200$ GeV/c^2 – In events where a single π^0 is identified by using above condition 3, an additional condition on the invariant mass of the remaining pair of photons requires that they have to be 4σ above m_{π^0}. This further reduces the pd→^{3}He $\pi^0\pi^0$ background.
- Condition on invariant mass of η – This condition restricts the search to the invariant mass region populated by the η (0.529 - 0.565 GeV/c^2).
- Missing energy of the system has to be in the range of -0.08 GeV to 0.08 GeV to reduce $\eta \rightarrow 3\pi^0$ background.

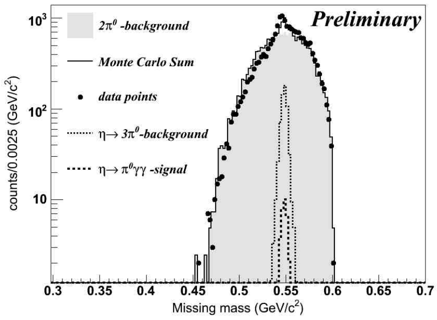

FIG. 1: Best fit of the Monte Carlo missing mass of ^{3}He for background from $\eta \rightarrow 3\pi^0$ and pd→^{3}He $\pi^0\pi^0$ with the signal $\eta \rightarrow \pi^0\gamma\gamma$ to the measured data on a logarithmic scale.

- Scattering angle (θ_η) has to be less than 55^0
- Confidence level has to be greater than 0.1 in kinematic fitting.

The Sum of Monte Carlo for the signal $\eta \rightarrow \pi^0\gamma\gamma$ and background from $\eta \rightarrow 3\pi^0$ and pd→^{3}He $\pi^0\pi^0$ describes the experimental data (FIG.1) therefore contribution from the $\pi^0\pi^0$ background can be subtracted directly from the data. Our next task is to exclude the remaining $\eta \rightarrow 3\pi^0$ events. We would then be in a position to count the number of $\eta \rightarrow \pi^0\gamma\gamma$ from the plot of missing mass of the outgoing ^{3}He. This is the preferred method as the resolution in the Forward Detector is $\sim$ 5MeV. We would then calculate the branching ratio of this decay channel.

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