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Study of the $a_0(980)$ meson via the radiative decay $\phi \to \eta\pi^0\gamma$ with the KLOE detector

KLOE Collaboration

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ABSTRACT

We have studied the $\phi \to a_0(980)\gamma$ process with the KLOE detector at the Frascati ϕ-factory DAΦNE by detecting the $\phi \to \eta\pi^0\gamma$ decays in the final states with $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$. We have measured the branching ratios for both final states: $Br(\phi \to \eta\pi^0\gamma) = (7.01 \pm 0.10 \pm 0.20) \times 10^{-5}$ and $(7.12 \pm 0.13 \pm 0.22) \times 10^{-5}$, respectively. We have also extracted the $a_0(980)$ mass and its couplings to $\eta\pi^0$, K^+K^-, and to the ϕ meson from the fit of the $\eta\pi^0$ invariant mass distributions using different phenomenological models.

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1. Introduction

The problem of the internal structure of the scalar mesons with mass below 1 GeV is still open [1]. It is controversial whether they are $q\bar{q}$ mesons [2], $qq\bar{q}\bar{q}$ states [3], bound states of a $K\bar{K}$ pair [4] or a mixing of these configurations.

An important part of the program of the KLOE experiment, carried out at the Frascati ϕ-factory DAΦNE, has been dedicated to the study of the radiative decays $\phi(1020) \to P_1P_2\gamma$ ($P_{1,2} =$ pseudoscalar mesons). These decays are dominated by the exchange of a scalar meson S in the intermediate state ($\phi \to S\gamma$, and $S \to P_1P_2$), and both their branching ratios and the P_1P_2 invariant mass shapes depend on the scalar structure.

The $\phi \to \eta\pi^0\gamma$ decay has been already used by KLOE and by other experiments to study the neutral component of the isotriplet $a_0(980)$ [5,6]. This process is well suited to study the $\phi \to a_0(980)\gamma$ dynamics, since it is dominated by the scalar production, with small vector background, contrary to $\pi^0\pi^0\gamma$ and $\pi^+\pi^-\gamma$ cases, where a large irreducible background interferes with the $f_0(980)$ signal [7].

In this Letter the result of the analysis of the $\phi \to \eta\pi^0\gamma$ decay, performed on a sample with 20 times larger statistics than the previously published Letter [5], is presented. The final states corresponding to $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ have been selected. The $\eta\pi^0$ invariant mass distributions have been fit to two models of parametrization of the $\phi \to a_0(980)\gamma$ decay, to extract the relevant $a_0(980)$ parameters (mass and couplings).

2. DAΦNE and KLOE

The Frascati ϕ-factory DAΦNE is an e^+e^- collider operating at a center of mass energy $\sqrt{s} = M_\phi \simeq 1020$ MeV. The beams collide at an angle of $(\pi - 0.025)$ rad, thus producing ϕ mesons with small momentum ($p_\phi \simeq 13$ MeV) in the horizontal plane. The KLOE detector [8] consists of two main subdetectors: a large volume drift chamber (DC) and a fine sampling lead-scintillating fibers electromagnetic calorimeter (EMC). The whole apparatus is inserted in a 0.52 T axial magnetic field, produced by a superconducting coil. The DC is 3.3 m long, with inner and outer radii of 25 and 200 cm respectively. It contains 12 582 drift cells arranged in 58 stereo layers uniformly distributed in the sensitive volume and it is filled with a gas mixture of 90% helium and 10% isobutane. Its spatial resolution is 200 μm and the tracks coming from the beam interaction point (IP) are reconstructed with $\sigma(p_\perp)/p_\perp \leqslant 0.4\%$. The position resolution for two track vertices is about 3 mm.

The DC is surrounded by the EMC, that covers 98% of the solid angle, and is divided into a barrel, made of 24 trapezoidal modules about 4 m long, with the fibres running parallel to the barrel axis, and two endcaps of 32 module each, with fibers aligned vertically. The read-out granularity is $\sim 4.4 \times 4.4$ cm^2, for a total of 2440 cells, read at both ends by photomultipliers. The coordinate of a particle along the fiber direction is reconstructed from the difference of the arrival time of the signals at the two ends of the cell. Cells close in time and space are grouped together into clusters. The cluster energy is the sum of the cell energies, while the cluster time and position are energy weighed averages. The energy and time resolutions for photons are $\sigma_E/E = 5.7\%/\sqrt{E(\text{GeV})}$ and $\sigma_t = 57$ ps$/\sqrt{E(\text{GeV})} \oplus 100$ ps, respectively. Cluster positions are measured with resolutions of 1.3 cm in the coordinates transverse to the fibers, and 1.2 cm$/\sqrt{E(\text{GeV})}$ in the longitudinal coordinate. The detection efficiency for photons of $E \simeq 20$ MeV is greater than 80% and reaches almost 100% at $E > 80$ MeV.

The KLOE trigger is based on the detection of two energy deposits in the EMC, with $E > 50$ MeV in the barrel and $E > 150$ MeV in the endcaps.

3. Event selection

The results are based on the data collected during the 2001–2002 run, at $\sqrt{s} \simeq M_\phi$. Of the two selected decay chains, the fully neutral one is characterized by high statistics and large background, while the charged one has small background but lower statistics. These two decay chains have been selected with different criteria and slightly different data samples have been used: 414 pb^{-1} for the fully neutral and 383 pb^{-1} for the charged decay. Monte Carlo (MC) samples of signal and of background processes have been produced with the simulation program of the experiment [9]. They have been generated on a run-by-run basis, simulating the machine operating conditions and background levels as measured in the data. Three MC samples, generated with different luminosity scale factors ($\text{LSF} = L_{\text{MC}}/L_{\text{data}}$), have been used:

1. The *rad* sample contains all the radiative ϕ-decays plus the non-resonant process $e^+e^- \to \omega\pi^0$, with LSF = 5;
2. The *kk* sample contains $\phi \to K^0\overline{K^0}$ with all subsequent kaon decays generated with LSF = 1;
3. The *all* sample contains all the ϕ decays with LSF = 1/5; it is used to find possible backgrounds not included in the two main samples.

The shape of the $\eta\pi^0$ invariant mass distribution has been simulated according to the spectrum obtained from the previously published analysis [5].

3.1. $\phi \to \eta\pi^0\gamma$ with $\eta \to \gamma\gamma$

This final state is characterized by five prompt photons originating from the IP. A prompt photon is defined as an EMC cluster not associated to any charged track in the DC and satisfying the condition $|t - r/c| < \min[5\sigma_t(E), 2\text{ ns}]$, where t is the photon flight time, r is the corresponding path length, and c is the speed of light. Events with exactly five prompt clusters, with $E > 3$ MeV and polar angle $\vartheta > 21°$ with respect to the beam line, are selected.

The main background originates from the other five photon final states, $\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$ and $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$, and from the seven photon process, $\phi \to \eta\gamma$ with $\eta \to 3\pi^0$, which can mimic five photon events due to either photon loss or cluster merging. Also the three photon final states, $\phi \to \eta(\pi^0)\gamma$ with $\eta(\pi^0) \to \gamma\gamma$, give a small contribution to the selected sample, when fake clusters are produced either by accidental coincidence with machine background or by cluster splittings. Other background processes are negligible.

The following analysis steps are then applied to the selected events.

1. First kinematic fit which imposes the total 4-momentum conservation and the speed of light for each photon, with 9 degrees of freedom. Events with $\chi^2_{\text{fit1}} > 27$ are rejected. A cut