

Search for $\phi \rightarrow K^0 \overline{K}^0 \gamma$ decay with KLOE

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The KLOE collaboration has searched for the $\phi \rightarrow K^0 \overline{K}^0 \gamma$ decay using a sample of 1.4 fb^{-1} of $e^+ e^-$ collisions at $\sqrt{s} \sim M(\phi)$ collected with the KLOE experiment at the Frascati $e^+ e^-$ collider DAΦNE. No previous search exists for this decay, while many theory models predict a BR of $\approx 10^{-8}$ for this channel. We set a preliminary value of the U.L. on this BR to $1.8 \cdot 10^{-8}$ at 90% C.L.. This limit rules out most of the existing theory predictions.

1. Introduction

We present the results of a search for the decay $\phi \rightarrow K^0 \overline{K}^0 \gamma$ using 1.4 fb^{-1} of the KLOE data

sample. This decay has never been searched before. The ϕ resonance is produced through $e^+ e^-$ collisions at center of mass energy $\sqrt{s} \sim 1020$

MeV. In this decay the $K^0\bar{K}^0$ pair is produced with positive charge conjugation, so that the state of the two kaons can be described as

$$|K^0\bar{K}^0\rangle = \frac{|K_S K_S\rangle + |K_L K_L\rangle}{\sqrt{2}}. \quad (1)$$

The signature of this decay is provided by the presence of either 2 K_S or 2 K_L and a low energy photon. This process has a limited phase space due to the small difference between the ϕ mass (1019.5 MeV) and the production threshold of two neutral kaons (995 MeV). This results in a very narrow photon energy spectrum, ranging from 0 up to a maximum energy obtained when the two kaons are collinear and the KK invariant mass is equal to twice the kaon mass, that is (neglecting the small ϕ momentum due to the e^+e^- crossing angle):

$$E_{\gamma,max} = \frac{M_\phi^2 - (2M_K)^2}{2M_\phi} = 23.8 \text{ MeV} \quad (2)$$

Among the possible final states, we searched for that one where a $K_S K_S$ pair has both K_S decaying to $\pi^+\pi^-$. This corresponds to reduce the rate of the searched events of a fraction

$$\frac{1}{2} \times B.R.(K_S \rightarrow \pi^+\pi^-)^2 = 23.9\% \quad (3)$$

This decay chain is characterized by a clean signature: 2 vertices close to the interaction region, with both vertices having two tracks with opposite sign, an invariant mass equal to the kaon mass, and an invariant mass of the 2 kaons significantly lower than the ϕ mass. Moreover, a low energy photon should be present in the event.

In the paper, we first discuss the motivations of this search, we then describe the analysis method including the Montecarlo study, and we conclude by extracting the upper limit on the branching ratio and compare it with the theory expectations.

2. Motivations

The $\phi \rightarrow K^0\bar{K}^0\gamma$ process was considered in the KLOE proposal as a possible background source for the CP violation measurement. The conclusion was that only for branching ratios in excess of $\sim 10^{-6}$ such a background could be critical for

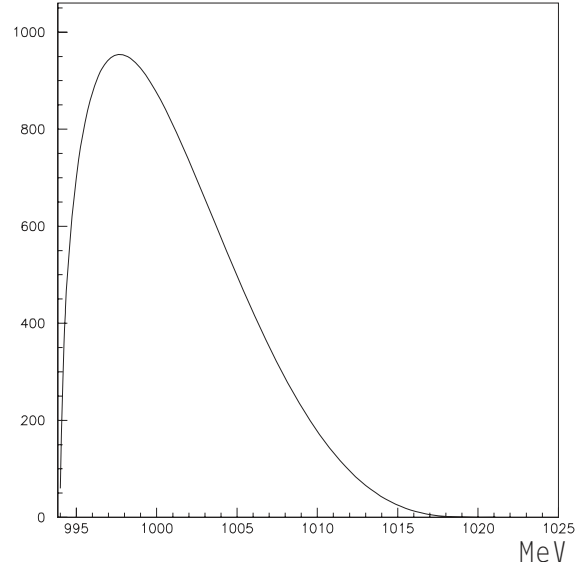


Figure 1. Expected scalar meson's invariant mass spectrum according to phase-space and radiative decay dynamics.

the measurement if no selection on the photon and on the kinematics was applied.

On the other hand the value of the branching ratio gives relevant information on the scalar mesons structure. The $K^0\bar{K}^0$ state can have scalar quantum numbers in both triplet and singlet isospin state, so that the reaction is expected to proceed mainly through the chain $\phi \rightarrow (f_0(980) + a_0(980))\gamma \rightarrow K^0\bar{K}^0\gamma$. The prediction on the branching ratio depends on the way the scalar dynamics is introduced and on the size of the couplings of the scalars to the kaons. Interference effects between f_0 and a_0 amplitudes can also be present.

Theory predictions on the $BR(\phi \rightarrow K^0\bar{K}^0\gamma)$ found in literature spread over several orders of magnitude. The latest evaluations essentially concentrate in the region of 10^{-8} . All of them are well below the critical limit of 10^{-6} so that no significant effect is expected for the CP violation studies at a ϕ -factory.

Some of the reported predictions do not include

explicitly the scalar mesons, but consider them as dynamically generated in the theory [1,2,3]; most of the theory instead includes explicitly the scalars mesons[4,5,6,7,8,9,10] in the calculation of the BR, in such a way that the predicted value depends on this modeling. For instance, the two predictions of ref.6 are evaluated assuming a 2-quark or a 4-quark structure for the scalar mesons. in such a way that the predicted value depends on the way they are treated. The two predictions differ by one order of magnitude.

In the other cases the width of the allowed band is due to the uncertainty on the coupling constants used in the parametrization of the amplitude which is extracted by experimental analysis of $\phi \rightarrow \pi\pi\gamma$ and $\phi \rightarrow \eta\pi\gamma$. The latter approach is particularly interesting, since it allows to make a global analysis of KLOE data including $\pi\pi\gamma$ and $\eta\pi\gamma$ [11,12,13,14] to test consistency of the overall picture.

Other predictions[15,16] do not include the scalars so that have to be considered as “backgrounds” in the search for effects due to scalars;

3. Experimental setup

The KLOE experiment is performed at the Frascati ϕ factory DAΦNE, an $e^+ e^-$ collider running at $\sqrt{s} \sim 1020$ MeV (ϕ mass). Beams collide with a crossing angle of $(\pi - 0.025)$ rad. From 2001 to 2005, the KLOE experiment has collected an integrated luminosity of 2.5 fb^{-1}

The KLOE detector consists of a large-volume cylindrical drift chamber [17] (3.3 m length and 4m diameter), surrounded by a sampling calorimeter [18] made of lead and scintillating fibres. The detector is inserted in a superconducting coil producing a solenoidal field $B=0.52$ T. Large-angle tracks from the origin ($\theta > 45^\circ$) are reconstructed with momentum resolution $\sigma_p/p = 0.4\%$. Photon energies and times are measured by the calorimeter with resolutions $\frac{\sigma_E}{E} = 5.7\%/\sqrt{E(\text{GeV})}$ and $\sigma_t = 54 \text{ ps}/\sqrt{E(\text{GeV})} \oplus 50 \text{ ps}$.

4. Analysis strategy

The event selection performed by this analysis is based on kinematic cuts on the charged pion tracks detected by the drift chamber, and on the photon cluster identification in the calorimeter.

We analysed 1.4 fb^{-1} of data collected at the ϕ peak; we also used our Monte Carlo (MC) to generate an equivalent statistics of background, which is mainly due to $\phi \rightarrow K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^-$ with the K_L decaying close to the IP and an additional ISR, FSR photon. Our simulation is generated on a run-by-run basis, using as input the real data taking conditions for both detector and collider.

We have also generated a MC signal sample of 10k events, to study the analysis selection efficiency. The main ingredient of this simulation is the scalar meson’s invariant mass shape, which slightly depends on the scalar meson structure. We did not use any of the models quoted above, but instead relied on general assumptions of BR dependence on the radiated photon’s energy and on phase space. In Fig.1 the generated invariant mass spectrum is shown.

We look for two K_S decaying into charged pions, by requiring the presence of two vertices close to the interaction point, inside a fiducial volume defined as a cylinder of 3 cm radius in the transverse plane, and ± 8 cm along the beam line. Each vertex should have two charged tracks attached to.

For each vertex, the two track reconstructed mass, $M_{2\pi}$, is built in the pion hypothesis. For the signal, the event density in the $M_{2\pi}(1)$, $M_{2\pi}(2)$ plane is well contained inside a circle of few MeV radius around the K_S mass. We require the events to satisfy a 4 MeV cut on this radius. With the reconstructed masses and momenta of the two K_S candidates we calculate the invariant mass of the kaon pair. As expected by the signal simulated mass spectra shown in Fig.1, the M_{KK} distribution peaks at 1000 MeV, while the background is peaked at M_ϕ as shown in Fig.2. A large background reduction is obtained by rejecting events with $M_{KK} > 1010$ MeV. Moreover, the 4-momentum conservation in the $\phi \rightarrow K_s K_s \gamma$ decay allows to build a missing

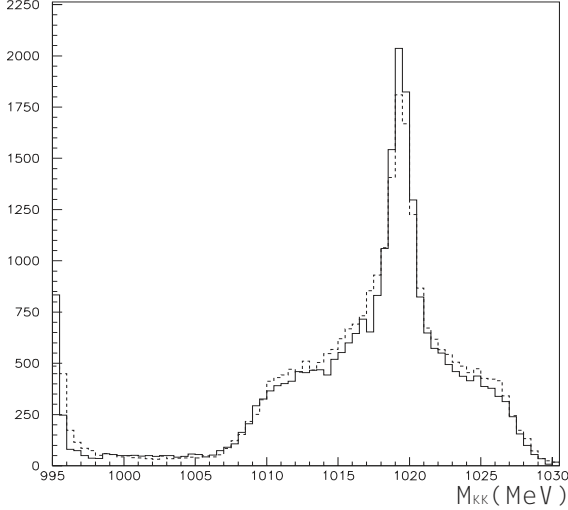


Figure 2. Invariant mass of the kaon pair M_{KK} for Monte Carlo (solid) and Data (dashed).

4-momentum $\widetilde{P}_\gamma = \widetilde{P}_\phi - \widetilde{P}_{K1} - \widetilde{P}_{K2}$ based only on track reconstructed variables. A selection variable $M_\gamma^2 = E_{miss}^2 - P_{miss}^2$ is built, which is expected to be ≈ 0 for the signal. We retain events with $|M_\gamma^2| \leq 300 \text{ MeV}^2$.

Events that survive all these cuts are searched for the presence of one photon matching missing momentum. We require the presence of one cluster in the calorimeter not associated with any charged track. Cluster's timing must be compatible with a photon coming from the interaction point, and cluster's position and energy must agree within resolution with the missing momentum.

5. Results

All the above mentioned cuts have been decided upon an U.L. maximization based on MC samples. We estimate an efficiency of 20.6% for the signal, while we find no event surviving in the background MC. When looking at DATA we observe one event. DATA-MC comparison is still under way, so we do not use background evaluation for this preliminary result. However we

can set an upper limit based on Poisson statistics without background subtraction at 90% C.L. to 3.9 events.

We evaluate our B.R. upper limit in the following way: $BR(\phi \rightarrow K_0 \overline{K}_0 \gamma) =$

$$\frac{U.L.(\mu_{sig})}{\int \mathcal{L} dt \cdot \sigma(e^+e^- \rightarrow \phi) \cdot \frac{1}{2} \cdot (BR(K_S \rightarrow \pi^+\pi^-))^2 \cdot \epsilon} \quad (4)$$

in which $\mathcal{L} dt$ is 1.4 fb^{-1} , the factor 1/2 accounts for the fact that we are selecting only the $K_S K_S$ combination for $K_0 \overline{K}_0$, ϵ is our signal efficiency. The following limit on the branching ratio is obtained:

$$BR(\phi \rightarrow K_0 \overline{K}_0 \gamma) < 1.8 \cdot 10^{-8} \quad (5)$$

at 90% C.L. In Fig.3 our limit is compared to theoretical predictions. Most of them are excluded by our result.

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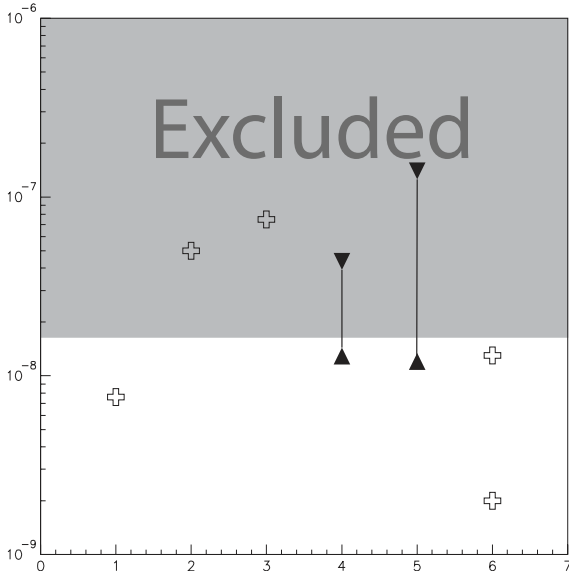


Figure 3. Comparison between theoretical predictions and our measurement. In abscissa is directly reported the reference number (according to the reference list). For ref.6 two predictions are reported: the upper one is for 4-quark hypothesis, the lower one for 2-quark hypothesis. For refs.4,5 the prediction is represented as a band .