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KLOE measurement of BR($K_S \rightarrow \gamma\gamma$) and direct search for the decay $K_S \rightarrow e^+e^-$

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We present a measurement of the branching ratio for the decay $K_S \rightarrow \gamma\gamma$ and a direct search for the decay $K_S \rightarrow e^+e^-$ made with the KLOE detector. The analyses use a sample of $e^+e^- \rightarrow \phi \rightarrow K_S K_L$ events produced at DAΦNE, the Frascati ϕ-factory. Using an integrated luminosity of 1.6 fb^{-1} we measure BR($K_S \rightarrow \gamma\gamma$) = $(2.27 \pm 0.13^{+0.03}_{-0.04}) \times 10^{-6}$ in agreement with $O(p^4)$ prediction of χPT. No $K_S \rightarrow e^+e^-$ events were found exceeding the expected background in a sample of 1.3 fb^{-1} and we derive the upper limit BR$(K_S \rightarrow e^+e^-) < 2.1 \times 10^{-8}$ at 90% CL.

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1. Measurements of BR($K_S \to \gamma\gamma$)

1.1 Introduction

A precise measurement of the $K_S \to \gamma\gamma$ decay rate is an important test of the predictions of Chiral Perturbation Theory (χPT). The decay amplitude of $K_S \to \gamma\gamma$ has been evaluated at the leading $O(p^4)$ order of χPT with a few percent precision [1] giving $BR(K_S \to \gamma\gamma) = 2.1\times10^{-6}$. This result was in agreement with the measurement of NA31, $BR(K_S \to \gamma\gamma) = (2.4 \pm 0.9) \times 10^{-6}$ [2]. The more recent measurement of this decay, published from NA48 [3], indicates a branching ratio of 2.78×10^{-6} with a total uncertainty below 3%. This result differs from $\chi PT\ O(p^4)$ prediction of about 30% suggesting the presence of important contributions from higher order corrections.

We present our search based on a luminosity of 1.6 fb^{-1} of e^+e^- collisions collected with the KLOE detector [4, 5, 6] at DAΦNE [7], the Frascati ϕ-factory. The data sample analyzed corresponds to the production of $\sim$1.7 billions of K_SK_L pairs. An equivalent statistics of simulated events for the background is used while the simulation of the signal is amplified by a factor $\sim$10. These samples allow us to reach a statistical error of 5.6% on the signal, worse than the NA48 results, but with the novelty of having a completely different background composition and origin of systematics.

1.2 K_S Tagging

At the center of mass energy of M_ϕ, the mean decay lengths of the K_S and K_L mesons are $\lambda_S \sim 0.6$ cm and $\lambda_L \sim 340$ cm. About 50% of K_L mesons reach the calorimeter before decaying. K_S mesons are tagged with an efficiency of $\sim$30% by identifying a K_L interaction in the calorimeter (K_L-crash in the following) which has a very distinctive signature given by a delayed ($\beta_K = 0.2$) energy cluster not associated to any track. Thus the K_L-crash provides a very clean K_S tagging. Both analyses presented here use a K_S tagged with the K_L-crash algorithm.

1.3 Analysis

The main source of background is due to $K_S \to 2\pi^0$ events when two photons are not detected, either because they are not in the acceptance, or they are not reconstructed in the calorimeter, or the clusters are merged. For the Monte Carlo simulation, MC, of the background, we use a production of $\phi \to K_SK_L$ decays corresponding to an equivalent luminosity of $\sim$ 1.1 fb^{-1}. For the signal MC we use a production equivalent to $\sim$18 fb^{-1}.

After tagging, we select events by counting the number of prompt ($\beta = 1$) neutral clusters, N_γ. For signal counting, we require $N_\gamma = 2$, while for normalization purposes we require $N_\gamma = 4$. A tight constraint on β is applied to reduce the effect of event losses due to accidental clusters from machine background. To reject the main background from $K_S \to 2\pi^0$ decays, we count photons with energy above 7 MeV and produced in a large angular acceptance, $|cos(\theta)| < 0.93$. To improve the background rejection we also require a veto from the small angle calorimeter, QCAL [8]. Events with at least one hit in QCAL in time with the collision and with energy above the pedestal are rejected.

The first step to improve the signal over background ratio requires the application of a kinematic fit which imposes 4-momentum conservation on $\phi \to K_SK_L$ and $K_S \to \gamma\gamma$ decays, and $\beta = 1$

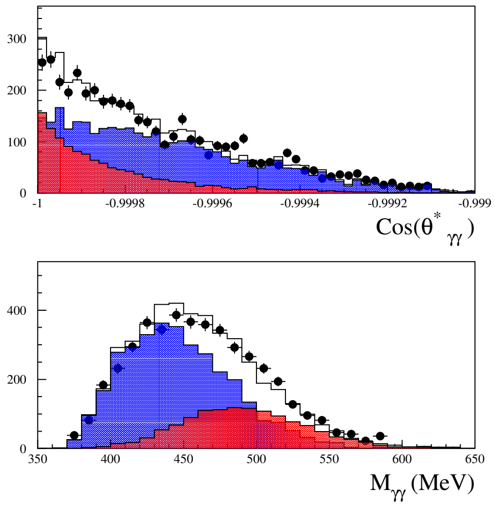

Figure 1: Distributions of $\cos\theta^*_{\gamma\gamma}$ and $M_{\gamma\gamma}$ as weighted by the fit. Solid line: data, red area: MC signal, blu area: MC background, dashed line: MC signal+background.

for each energy cluster. To improve the energy resolution of photons, the fit uses the precise measurement of the K_S direction provided by the K_L-crash position.

Two other variables with a powerful discrimination against background are the two-photon invariant mass, $M_{\gamma\gamma}$, and the opening angle between the two photons in the K_S center of mass system, $\theta^*_{\gamma\gamma}$. For the K_S-tagged events, a binned max-likelihood fit to the $M_{\gamma\gamma} - \theta^*_{\gamma\gamma}$ 2D distribution is done using the MC shapes. The likelihood function properly takes into account the statistics of data and MC distributions. The χ^2 of the fit is 50 for 41 d.o.f. Fig. 1 shows the result of the fit for the two-photon invariant mass and the angle distributions. The angle distribution for the signal has a shape more peaked around $\cos\theta^*_{\gamma\gamma}$ = -1 than for the background. The $M_{\gamma\gamma}$ distribution shows a gaussian shape around the K_S mass for the signal, while the background populates the lower mass values. We count $N(2\gamma|tag) = 600 \pm 35$ signal events in a total of 2280 events.

The branching ratio is normalized to the number of $K_S \to 2\pi^0$ events recorded in the same data sample by counting the K_S tagged events with $N_\gamma = 4$:

$$BR(K_S \to 2\gamma) = \frac{N(2\gamma)}{N(2\pi^0)} \times \frac{\varepsilon(2\gamma|tag)}{\varepsilon(2\pi^0|tag)} \times BR(K_S \to 2\pi^0)$$

The signal efficiency is the product of the efficiencies for the acceptance selection, the QCAL veto and the χ^2-cut: $\varepsilon(2\gamma|tag) = (50.8 \pm 0.6^{+0.5}_{-0.4})\%$. The number of $K_S \to 2\pi^0$ events after correcting for the selection efficiency is $(159.8 \pm 0.5) \times 10^6$. Using BR($K_S \to 2\pi^0$) = $(30.69 \pm 0.05)\%$ [10], we obtain:

$$BR(K_S \to \gamma\gamma) = (2.27 \pm 0.13(stat.)^{+0.03}_{-0.04}(syst.)) \times 10^{-6}$$

where the second error includes the systematics due to fit procedure and to a small difference in photon energy scale between data and MC.

2. Direct search for $K_S \to e^+e^-$

The decay $K_S \to e^+e^-$, like $K_L \to e^+e^-$ or $K_L \to \mu^+\mu^-$, is a flavour-changing neutral-current process, suppressed in the Standard Model and dominated by the two-photon intermediate state [9]. For both K_S and K_L, the e^+e^- decay is suppressed with respect to the $\mu^+\mu^-$ decay by a factor of ~ 250. Using χPT to order $O(p^4)$, Ecker and Pich evaluated the ratio $\Gamma(K_S \to e^+e^-)/\Gamma(K_S \to \gamma\gamma) = 8 \times 10^{-9}$ with 10% uncertainty [9]. Using the present average, BR($K_S \to \gamma\gamma$) = $(2.71 \pm 0.06) \times 10^{-6}$ [10], the Standard Model prediction is $\mathrm{BR}(K_S \to e^+e^-) \simeq 10^{-15}$. A value significantly higher than expected would point to new physics. The best experimental limit has been obtained by CPLEAR [11]: $BR(K_S \to e^+e^-) < 1.4 \times 10^{-7}$ at 90% CL.

2.1 Analysis

K_S decays are tagged using the K_L-crash algorithm. $K_S \to e^+e^-$ events are selected requiring the presence of two tracks of opposite charge that form a vertex inside a cylinder centered on the origin of radius ρ = 4 cm and length 10 cm along the beam line. The track momenta and polar angles must satisfy the cuts $120 < p < 350$ MeV/c and $30^\circ < \theta < 150^\circ$. The tracks must also reach the calorimeter without spiralling, and have an associated cluster with $E > 50$ MeV.

The main backgrounds are $K_S \to \pi^+\pi^-$ decays where two pions are misidentified, and $\phi \to \pi^+\pi^-\pi^0$ decays where one prompt photon simulates K_L-crash and the other is not detected. For the first, the M_{ee} invariant mass is peaked at low values: a cut $M_{ee} > 420\ MeV/c^2$ rejects most of the background. After preselection we are left with $\sim 10^6$ events.

To improve the separation between signal and background, a χ^2-like variable is defined, using information from the clusters associated to the two tracks. Using the MC signal events we built likelihood functions based on the following variables:

- the sum and the difference of δt for the two tracks; $\delta t = t_{cluster} - L/\beta c$ where L is the length of the trajectory and β is evaluated in the electron hypothesis;
- the ratio E/p between the cluster energy and the track momentum, for both charges;
- the cluster position relative to the extrapolation of the track, for both charges.

Fig. 2 shows the correlation between the χ^2 and M_{ee} for MC signal and background. Two sidebands are defined to check the consistency of MC with data and the normalization: region 1 ($M_{ee} < 460\ MeV/c^2$), dominated by $K_S \to \pi^+\pi^-$ events, and region 3 ($M_{ee} > 530\ MeV/c^2$) mostly populated by $\phi \to \pi^+\pi^-\pi^0$ events.

A signal box to select $K_S \to e^+e^-$ events can be conveniently defined in the χ^2-M_{ee} plane; nevertheless other independent requirements have been used to reduce the background contamination before applying the χ^2-M_{ee} selection. These requirements have been studied by MC and tuned on the sidebands. Pions from $K_S \to \pi^+\pi^-$ decay have mometum in the K_S frame p^*_π = 206 MeV/c: the cut $min(p^*_{\pi 1}, p^*_{\pi 2}) > 220\ MeV/c$ rejects $\sim$98% of this background. $\phi \to \pi^+\pi^-\pi^0$ events with one undetected photon are characterized by small values of the missing mass, $M^2_{miss} = (P_\phi - P^+_\pi - P^-_\pi)^2$, while M_{miss} is peaked around 430 MeV/c^2 for the signal: the cut $M_{miss} > 380\ MeV/c^2$ rejects almost completely this background.

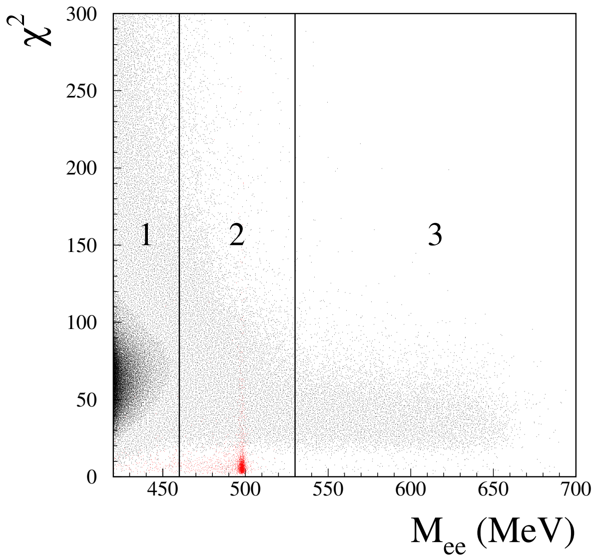

Figure 2: Distribution of χ^2 as a function of the two-track invariant mass, M_{ee}, for MC signal (red) and background events (black)

The signal box is chosen with an optimization procedure based only on MC. The boundaries are $492 < M_{ee} < 504\ MeV/c^2$ and $\chi^2 < 20$, corresponding to a total signal efficiency of 55.8%. Applying this selection to the data sample we obtain $N_{obs} = 3$. The background estimated from MC is $\mu_B = 7.1 \pm 3.6$, the value takes into account events fluctuations and normalization factors. Using a bayesian approach [12], we evaluate the upper limit on the expected number of signal events $\mu_S <$ 4.3 at 90% CL. The chosen interval for M_{ee} selects $K_S \to e^+e^-(\gamma)$ events with $E_\gamma < 6\ MeV$. Then we derive an upper limit for the branching ratio $BR(K_S \to e^+e^-(\gamma)\ ; E_\gamma < 6\ MeV) < 2.1 \times 10^{-8}$ at 90% CL.

References

[1] G. D'Ambrosio, D. Espriu, Phys. Lett. B175 (1986), 237.

[2] G. D. Barr, *at al.*, Phys. Lett. B493 (1995), 29.

[3] J. R. Batley, *at al.*, Phys. Lett. B551 (2003), 7.

[4] KLOE collaboration, M. Adinolfi *et al.*, Nucl. Instr. Meth. A488 (2002), 51.

[5] KLOE collaboration, M. Adinolfi *et al.*, Nucl. Instr. Meth. A482 (2002), 364.

[6] KLOE collaboration, M. Adinolfi *et al.*, Nucl. Instr. Meth. A492 (2002), 134.

[7] S. Guiducci, in: P. Lucas, S. Weber (Eds.), Proceedings of the 2001 Particle Accelerator Conference, Chicago, Il., USA, 2001.

[8] KLOE collaboration, M. Adinolfi *et al.*, Nucl. Instr. Meth. A483 (2002), 649.

[9] G. Ecker and A. Pich, Nucl. Phys. B366 (1991) 189.

[10] W.-M. Yao et al., J. Phys. J. G 33 (2006) 1.

[11] A. Angelopoulos et al., Phys. Lett. B413 (1997) 232.

[12] O. Helene, Nucl. Instr. Meth. 212 (1983) 319.