$K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ search at a ϕ-factory

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Abstract

The possibility of measuring $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ transitions at a very high luminosity ϕ-factory is discussed. Two different machine designs are taken into consideration. In both options, this requires exceptionally high luminosities, and an extremely hermetic photon detector.

INTRODUCTION

The observation of $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decays and the measurement of the relative branching ratio is the most relevant goal for kaon physics in this decade. Actually, the rate of these transitions is extremely well calculable in the framework of the Standard Model; therefore its measurement would be a stringent test of the latter and a possible signal of the presence of new physics[1]. Unfortunately, the experimental challange is tremendous, because of the smallness of the expected branching ratio, *O*(10^{-11}), and the faintness of the signal, which consists of two photons and nothing else. For the above reasons, since several years already, many groups all over the world have started a relevant experimental effort to address the problem, as reported in this Workshop by several authors[2][3].

In the present paper I will discuss the possibility to observe the $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay at a high luminosity ϕ-factory.

$K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ AT A ϕ-FACTORY: WHY?

There are several good reasons for which a ϕ-factory can be considered as the best tool to perform such an experiment[4]. First, K^0 mesons are *tagged* since they are produced in correlated K_L^0-K_S^0 pairs. Second, by reconstructing the K_S^0 decay kinematics, one can determine momentum and direction of the K_L^0, that is a powerful instrument for background rejection. Third, a ϕ-factory is naturally free of the contamination of neutral hadrons background.

On the other hand, the performance of the accelerator in terms of delivered luminosity need to be exceptional: at the ϕ resonance, $\sim 10^6$ K_L^0-K_S^0 pairs are produced every delivered pb^{-1}. Thus, under the assumption that the branching ratio of our transition is in the ballpark of 3 10^{-11}, one could hope to produce a few dozens events per year, only if the luminosity reaches the record value of 10^{35} cm^{-2}s^{-1}.

Even in this case, however, the *total detection efficiency* cannot be much lower than $\sim 10\%$, which, as we'll see in the following, is also a very difficult task for the experimentalist.

In the following, I will take into consideration two extremely different machine designs. The first one, the *"conventional"* option, is similar to DAΦNE [5], with beams colliding at a small angle at (or very close to) the ϕ resonance peak. The second, the *"forward"* option, consists of two higher energy beams, say 1-1.5 GeV each, colliding at an angle properly tuned to obtain a center of mass energy equal to the ϕ mass. For instance, the crossing angle α, as defined in figure1, is equal to $\sim$60(40) degrees for 1. (1.5) GeV beams.

Due to the smallness of the branching ratio of the decay of interest, it is understood that the main requirement for the detector is to maximise background rejection, while keeping the efficiency for the signal at a reasonable level. Of the many possible background sources the most dangerous one is due to $K_L^0 \rightarrow \pi^0\pi^0$ decays with two photons lost. In the following I will concentrate on this issue only.

THE DETECTOR

Given the above considerations, the key requirement for the detector is to be as much efficient and hermetic as possible, for photons over a wide range of energies.

Detector Dimensions

The dimensions of the detector are determined by the request of maximising geometric acceptance while keeping complexity and costs to a reasonable level. This translates however into two completely different detector designs, depending on the kind of solution, either conventional or forward, chosen for the machine.

In the forward option, due to momentum conservation, and after convolution with the $sin^2(\theta)$ angular distribution in the ϕ rest frame, one sees that kaons are emitted within a narrow cone along the forward direction. For instance, the beam profile at 1 m distance from the i.p. for a 1 GeV/beam machine has a radius of $\sim$12 cm; particles populate mostly the sides of this cone, a consequence of the $sin^2(\theta)$ distribution in the ϕ reference frame. K_S^0 mesons decay within the first $\sim$ 20 cm, and can be used to tag the event by the insertion of a properly designed detector. After the first meter or so, a large and hermetic detector for K_L^0 decays can thus be inserted.

The previous idea, is schematically explained by figure 1. The dimensions shown in the figure correspond to a calorimetric surface (which determines the cost of the detector, to first approximation) of $\sim$ 80 m^2, and to a geometrical acceptance for K_L^0 decays of $\sim$23%. A simple Monte Carlo simulations shows that, under the assumption that there are no dead zones for photons produced inside the

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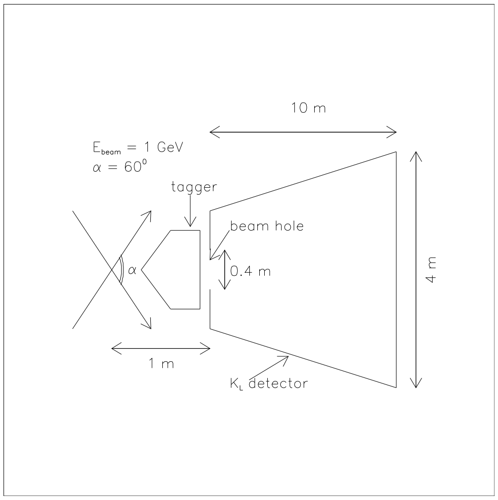

Figure 1: A scheme for the "forward' detector.

decay region other than the beam hole, the probability for loosing two photons from $K^0_L \to \pi^0\pi^0$ decays is $\sim 10^{-7}$.

In the conventional option one has to build a standard 4π detector around the interaction point, closely following the design of KLOE [6]. One can also assume a detector with similar shape and dimensions (i.e. a cylinder of $\sim$ 2 m radius, $\sim$ 4 m length, to first approximation), a choice which has been already proven to be both efficient and cost effective.

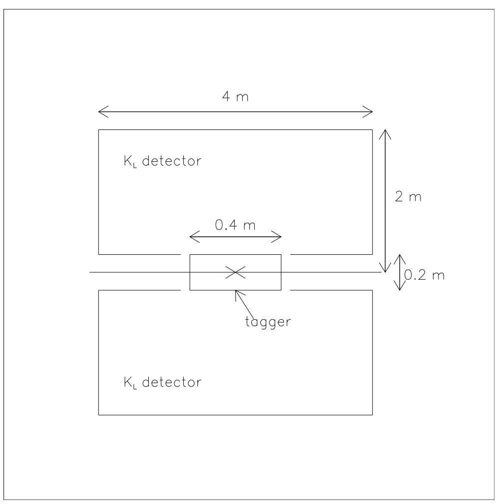

Figure 2: A scheme for the "conventional" detector.

It has to be underlined here the relevance of having an effective design of the interaction region. In order to achieve very high luminosities, the low-β quadrupoles have to be placed very close to the interaction point, $\sim$20 cm on each side. Since the K^0_L decay products are emitted almost in all directions, some active coverage of the quadrupoles has to be conceived, as for the KLOE *QCAL*s. There remains however a small region unistrumented for photon detection, due to the need of inserting a tracking device around the i.p. to tag the event through $K^0_S \to \pi^+\pi^-$ decays. The actual size of this region is determined by the balance between the need of maximising photon detection efficiency and that of maximising the event tagging efficiency.

A sketchy drawing of the detector, is shown in figure 2, corresponding to a total calorimeteric surface of $\sim$ 80 m^2, and a geometrical acceptance of $\sim$30%.

Unfortunately, in this case, backward emitted photons can be lost due to interactions on the beam pipe or on the tagging detector material. In the above scheme, the amount of events with two photons lost can be kept at the same level of the one seen for the forward option, only at the price of considerably reducing the geometrical acceptance (to about $\sim$15%) for the decays. This because the farther to the i.p. the decay occurs, the smaller is the angle through which the dead zone is seen by the emitted photons.

It has to be underlined the fact that while in the forward detector the amount of lost photons depends *only* on geometry, in the other case it is very much dependent on the choice of the techinque and consequently of the materials used for the tagging detector.

Photon Detection

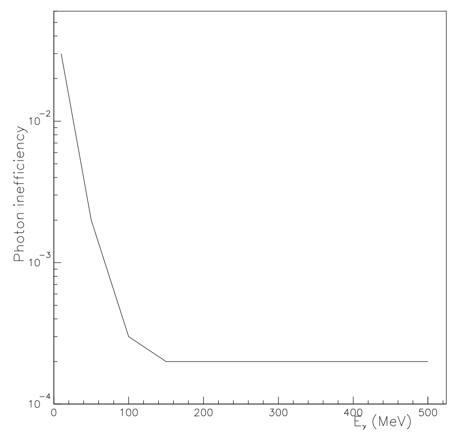

Figure 3: Parameterization of the photon detection inefficiency as a function of energy used in the present work.

The above considerations are valid only in the limit of infinite photon detection efficieny. This is never the case, however. An obvious advantage of the high energy option is that photon detection inefficiency is highest for lower energy photons. Since photon detection is a key issue for this search, detailed studies on several techinques and on the related efficiencies can be found in the literature. In the present paper i will not make any assumption about the technique to be used for neither of the two detectors, but rather assume for both a response to photons as shown in figure 3, which is similar to the one assumed for the KOPIO detector [7].

By convolving this distribution with the spectrum of the photons from $2\pi^0$ decays, one obtaines the probability for loosing two photons to be $\sim 10^{-5}$ in both detector options! This is about 2 order of magnitude too low to obtain a S/B ratio of ~ 1, that is what KOPIO claims to be able to obtain at this level of event selection.

However, since most of the lost photons are by construction low energy ones, some cut on the total energy of the event can help in discriminating background from signal, at the price of loosing some of the latter. Obviously, here energy resolution comes into play. However, even assuming infinite energy resolution, in the case of the conventional detector, one can reject all background events only by reducing the total efficiency for the signal down to $\sim 6\%$, a simple consequence of the decay kinematics. A similar conclusion can be drawn for the forward detector. Therefore it is *photon detection efficiency* (more than energy resolution) that remains the key issue for such an experiment to be successful, whichever option is chosen.

Tagging Device

As mentioned before, one key advantage of a ϕ-factory comes from the fact that one can determine *a priori* the presence of a K_L^0 by the observation of the decay of the accompanying K_S^0 into two pions. The KLOE experience confirms the naive expectation that a good tagging can be provided *only* by the decay into two charged pions, with a reasonable reconstruction of the decay kinematics. In the conventional option, this can be provided by a good tracking system around the IP, and a solenoidal field of moderate intensity. This is essentially the KLOE choice, which has been proven to be effective and robust. The drawback of this option, as seen before, is that the tagging device cannot be kept completely separate from the K_L^0 decay products.

In the forward option, an even more refined solution has to be envisaged. Here the problem comes from the fact that the pions from K_S^0 decays, are emitted in a relatively narrow region almost parallel to the direction of the beams. As a consequence of this, one cannot think to measure easily the momentum of the pions by a magnetic spectrometer without also interfering with the beams. Clearly, one could think to model the shape and intensity of the magnetic field in the region of interest. However, at present i cannot see any easy solution to this problem.

DAQ, Trigger and related

Whichever would be the detector design, it is clear that triggering and DAQ issues will be a challange. At a luminosity of 10^{35} cm^{-2}s^{-1} the ϕ production rate is 300 kHz. Bhabha diffusion would contribute an additional burden which strongly depends on the event acceptance, but very unlikely can be below 1 MHz.

One has also to take care of machine background. High luminosity would imply high currents and most likely very short lifetimes (i.e. very high fluxes of particles lost by the beams). This can easily kill the measurement unless a wise scheme of shieldings is foreseen. The forward design is probably favoured under this respect, since the K_L^0 decay region is relatively far from the interaction region.

However, there is no *a priori* solution to the two above mentioned problems in neither of the options. Thus, the detector has to be designed *also* to cope with them.

CONCLUSIONS

The hunt for $\mathrm{K}_L^0 \to \pi^0 \nu\overline{\nu}$ is opened all over the world. This is a very difficult measurement *whichever tecnique one thinks to use*. We have seen that the use of kaons produced in ϕ decays has many natural advantages in terms of background suppression. We have also seen, however, that given the present know-how about accelerators and detectors it is most likely a dream that cannot become reality in a short time range. But...?

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