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Recent results from NA48 experiment

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A measurement of the branching ratio of the $K_S \to \gamma\gamma$ performed by the NA48 experiment is presented. It shows that ChPT contributions of $O(p^6)$ are relevant for this decay mode. A preliminary result of the branching ratio of the $K_S \to \pi^0\gamma\gamma$ is also shown.

1 Introduction

Chiral Perturbation Theory (ChPT) is used to describe low energy processes where the QCD is non perturbative. It is based on perturbative expansion of momenta and masses which appear in the theory with terms of the form $\frac{p^2}{4\pi F_\pi}$ and $\frac{m^2}{4\pi F_\pi}$ where $4\pi F_\pi \simeq 1.2$ GeV. This makes the theory very suitable for the description of Kaon decays. In particular for the two decays $K_S \to \gamma\gamma$ and $K_S \to \pi^0\gamma\gamma$ it is $O(p^2) = 0$ and the term $O(p^4)$ can be precisely predicted [1] since no counter-terms exist [2–4]. A measurement of the branching ratio can easily test the contribution of the higher order terms of the theory. The existing calculation, extended up to $O(p^4)$, predict for the $BR(K_S \to \gamma\gamma) = 2.1 \times 10^{-6}$ to an accuracy of about 5% [1]. The measured value [5] of $BR(K_S \to \gamma\gamma) = (2.6 \pm 0.5) \times 10^{-6}$ is in agreement with this prediction but the experimental error were still too large to allow an accurate comparison.

2 The NA48 Experiment

The NA48 Experiment is located at the SPS accelerator at CERN. The fig. 1 shows schematically the structure if the detector. Charged particles are measured by a magnetic spectrometer consisting of a dipole magnet giving a momentum kick of 265 MeV/c and four drift chambers with a momentum resolution of

$$\sigma_p/p = 0.48\% \oplus 0.009\% \times p/(1\text{GeV/c})$$

A set of seven iron/scintillator anticounters are located along the beam line and act as a veto for neutral decays with gamma's running out of the detector acceptance.

A scintillator hodoscope composed of two planes orthogonal strips is located after the spectrometer to provide a precise time measurement for charged particles.

The energy, impact point and arrival time of photons are measured by a quasi-homogeneous liquid krypton (LKr) electromagnetic calorimeter with a projective tower readout. The energy resolution is

$$\sigma_E/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\% \qquad \text{(E in GeV)}$$

while the spatial resolution better that 1 mm above 25 GeV.

An iron-scintillator hadron calorimeter is located downstream of the electromagnetic calorimeter, followed by a muon counter made of three plane of scintillator separated by 80 cm think iron walls.

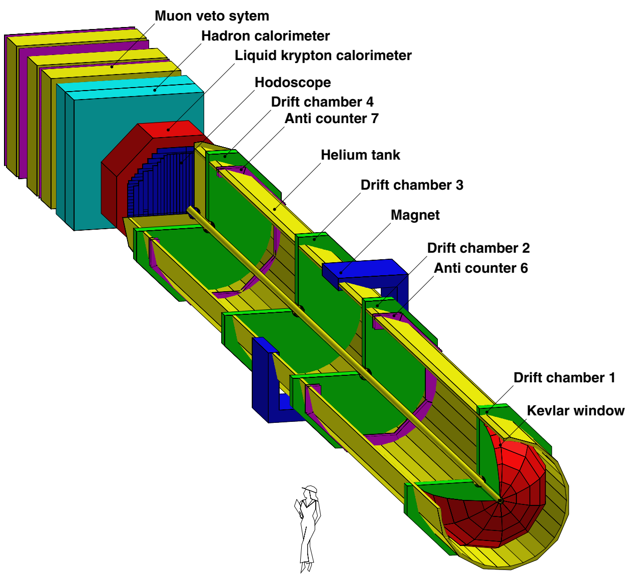

Figure 1. The NA48 detector

The years 1997-1999 and 2001 have been dedicated to the direct CP violation mesurement [$\Re(\varepsilon'/\varepsilon)$]. During the 2000 year run the spectrometer was not available so that half of the data taking took place under ε'/ε conditions while the second half of the run period was performed with a high intensity (200 times larger with respect to the ε'/ε runs) K_S beam. The results on the $K_S \to \gamma\gamma$ and $K_S \to \pi^0\gamma\gamma$ presented here derive from the analysis of the data collected during this "special" year.

The detection of the photons by the LKr allows the determination of the z position (along the beam pipe) of the decay vertex by assuming a kaon decay using the shower energies $E_{i,j}$, distances $d_{i,j}$, and the nominal kaon mass m_K (fig. 2)

$$z_{vertex} = z_{calorimeter} - \frac{1}{m_K}\sqrt{\sum_{i>j} E_i E_j d_{ij}^2} \qquad (1)$$

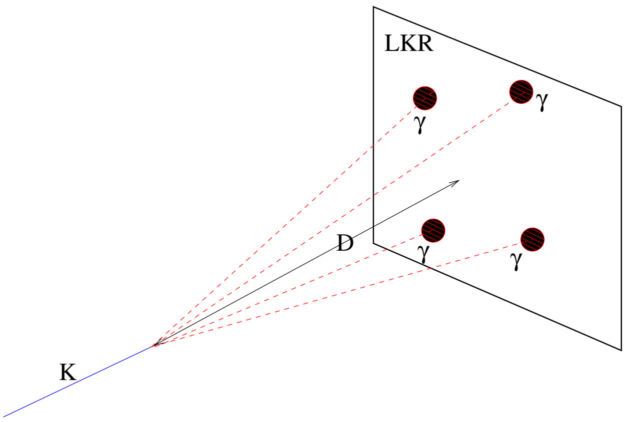

Figure 2. z vertex reconstruction from cluster energy and position measurement for a $K_S \to \pi^0\pi^0$ decay.

For this reason it is very important to have a good resolution in the measurement of the cluster energy and impact point.

If photons are lost, the missing energy shifts the vertex position down-stream toward the calorimeter. If the decay contains one or more intermediate π^0, background can be suppressed by requiring the π^0 decay vertex to be consistent with the kaon decay vertex.

3 $K_{S,L} \to \gamma\gamma$

For a decay rate measurement of $K_S \to \gamma\gamma$ in a fixed-target experiment an irreducible background of $K_L \to \gamma\gamma$ events has to be subtracted. Therefore, a precise determination of $K_L \to \gamma\gamma$ is necessary while the current world average on $BR(K_L \to \gamma\gamma)$ has a relative error of about 3% [6].

For this reason the ratio $\Gamma(K_L \to \gamma\gamma)/\Gamma(K_L \to 3\pi^0)$ has been measured very accurately using the data collected with the K_L target run in 2000. The $K_L \to \gamma\gamma$ background has been subtracted, by measuring the $K_L \to 3\pi^0$ rate in the high intensity K_S run 2000.

3.1 The measurement of $\Gamma(K_L \to \gamma\gamma)/\Gamma(K_L \to 3\pi^0)$

In the K_L target run, the backgrounds from $K_L \to \pi^0\pi^0$ or other K_L decays are completely negligible, in particular $K_L \to e^+e^-\gamma$ Dalitz decays are swept out by the spectrometer magnet. The only remaining background source is hadronic activity, e.g. from Λ decay products, which in rare cases might enter the decay volume vie the K_L beam line. The estimation of this background gives a contribution of $(0.6 \pm 0.3)\%$ to the signal.

The normalization channel $K_L \to 3\pi^0$, which needs three good $\pi^0 \to \gamma\gamma$ combinations to be selected, is virtually background-free. Both, signal and normalization channel have trigger efficiencies larger than 99 %. For the analysis only 25 % of the K_L target run data were used which already provides sufficient statistics. Evaluating the event numbers in the vertex region $-1\text{m} < Z < 5\text{m}$ (measured from the K_S collimator) and taking the acceptance ratio from Monte Carlo simulation, NA48 finds

$$\frac{\Gamma(K_L \to \gamma\gamma)}{\Gamma(K_L \to 3\pi^0)} = (2.81 \pm 0.01_{stat} \pm 0.02_{sys}) \times 10^{-3}$$

The systematic error is dominated by uncertainties in the $\gamma\gamma/3\pi^0$ acceptance ratio. This result improves the current world average by about a factor of four.

3.2 $K_S \to \gamma\gamma$ branching ratio

In addition to the irreducible $K_L \to \gamma\gamma$ decays more background sources have to be taken into account when selecting $K_S \to \gamma\gamma$ candidates:

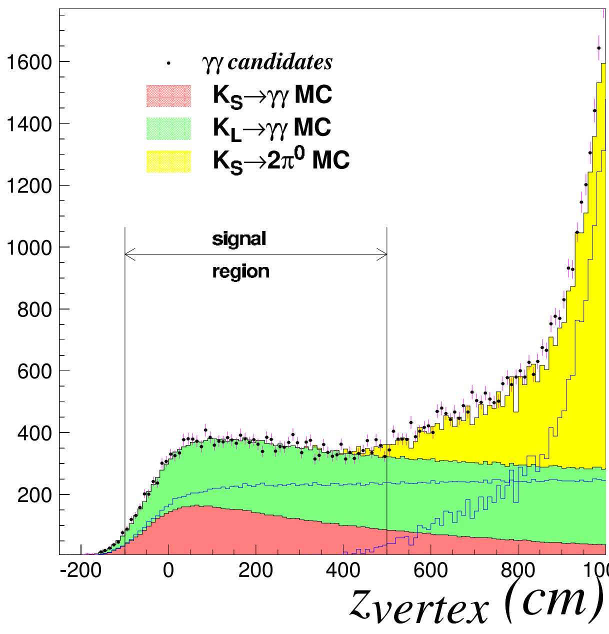

Figure 3. z vertex distribution of $\gamma\gamma$ candidates. The shift of the vertex for $K_S \to \pi^0\pi^0$ decay is clearly visible in the right part of the plot. A cut at $Z < 500$ cm reduces strongly this background.

$K_S \to 2\pi^0$ with lost and/or overlapping photons may fake a good $\gamma\gamma$ event. Since in these cases energy is lost, the neutral vertex is shifted downstream. Background from $K_S \to 2\pi^0$ can therefore be efficiently rejected by restricting the allowed vertex range to be within -1 and 5 m behind the final collimator. Doing so, the remaining background from $K_S \to 2\pi^0$ is estimated to $(0.8 \pm 0.2)\%$, where the uncertainty is arising from the shower overlap probabilities being different in the simulation as in the data.

Further background sources are hadronic events (originating e.g. from scattering at the collimator) or from accidentally overlapping events. This background has been estimated to $(0.8 \pm 0.3)\%$.

Finally, Dalitz decays $\pi^0 \to e^+e^-\gamma$ and $K^0 \to e^+e^-\gamma$ have to be taken into account. As in the high intensity K_S running in 2000, the NA48 experiment had no magnetic field in the detector, many Dalitz e^+e^- pairs did not separate and were overlapping in the calorimeter. From Monte Carlo simulation, the probability of the Dalitz decay misidentified as $\gamma\gamma$ pair was estimated to about 30%. With Dalitz decay probabilities assumed to be equal for $K^0 \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$, the effect is twice as big for the $K_S \to 2\pi^0$ normalization than in the $K^0 \to \gamma\gamma$ events and results in a relative correction to the $K_S \to \gamma\gamma$ branching ration of $(+1.5 \pm 0.3)\%$.

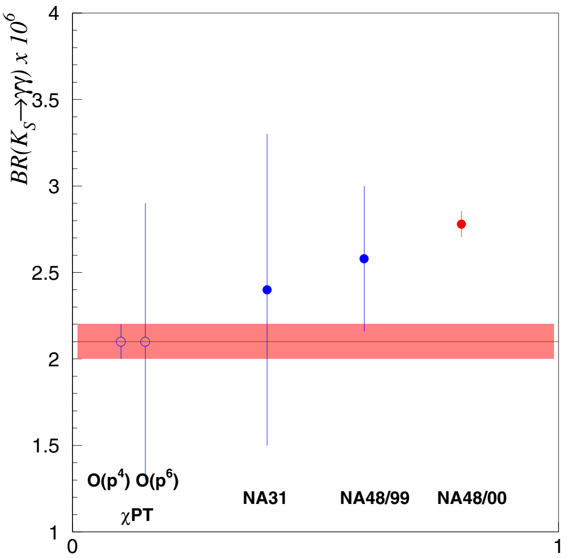

Figure 4. Comparison between experimental results and theoretical prediction of the BR($K_S \to \gamma\gamma$). The pink area represent the theoretical calculation at $O(p^4)$ and its uncertainty.

The decay vertex distribution of the NA48 $\gamma\gamma$ candidates is shown in fig. 3 together with the estimated contributions of $K_S \to \gamma\gamma$,$K_L \to \gamma\gamma$ and $K_S \to 2\pi^0$ background which has been normalized to the absolute K_S flux. In the fiducial region between -1 and 5 m about 20000 $\gamma\gamma$ candidates were found. Subtracting all background contributions and normalizing to fully reconstructed $K_S \to 2\pi^0$ events, the branching fraction was determined to

$$BR(K_S \to \gamma\gamma) = (2.78 \pm 0.06_{stat} \pm 0.04_{syst}) \times 10^{-6}$$

The systematic uncertainty is dominated by the branching fraction of the $K_S \to 2\pi^0$ normalization ($\pm 0.9\%$), the estimation of the hadronic and accidental background ($\pm 0.7\%$) and the Monte Carlo statistics ($\pm 0.6\%$). This new result significantly improves the provious measurements and it is in clear discrepancy with the $O(p^4)$ prediction as shown in fig. 4. demonstrating that the contribution of the higher order term of the theory is not negligible.

4 The $K_S \to \pi^0\gamma\gamma$ decay

For this decay one theoretical investigation based on ChPT exists [4] which predicts the shape of the $m(\gamma_3\gamma_4)$ distribution (fig. 5) and the branching fraction $BR(K_S \to \pi^0\gamma\gamma)|_{z>0.2} = 3.8 \times 10^{-8}$ where $z = m(\gamma_3\gamma_4)^2/m_K^2$.

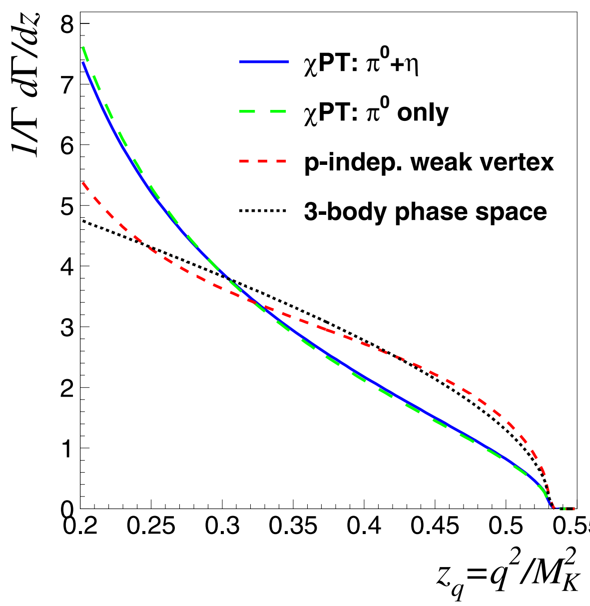

Figure 5. Theoretical prediction for $z = q^2/m_K^2$ in $K_S \to \pi^0\gamma\gamma$ from three-body phase space and ChPT.

No experimental observation or limit has been published so far.

Because of the smallness of the expected branching fraction, the main experimental problem is represented by the background suppression. For this reason any non-γ activity in the photon-anticounters, drift chambers, and hadron calorimeter is vetoed. To suppress the $K_S \to \pi^0\pi^0$ events, the $\chi^2_{2\pi^0}$ of the event for being a $K_S \to 2\pi^0$ decay is required to e very large so that the mis-measured $K_S \to 2\pi^0$ becomes a negligible fraction. This decay, however gives a contribution to the background due to the events in which one photon is lost but is replaced by another one which is accidentally in-time.

Other source of backgrounds is coming from $K_S \to \pi^0\pi^0_D$ rejected by kinematic cuts and the decay chain $\Xi^0 \to \Lambda\pi^0 \to n\pi^0\pi^0$ which can be identified by the neutron shower distribution and the asymmetry in the γ's energy distribution. Of course the irreducible background from $K_L \to \pi^0\gamma\gamma$ has to be taken into account. However due to the longer K_L lifetime it represents a small fraction of the signal.

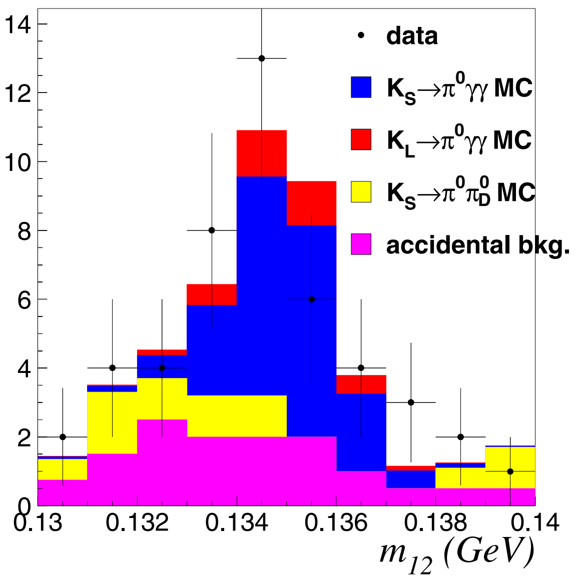

Figure 6. Invariant $m_{\gamma_1\gamma_2}$ mass for the selected $K_S \to \pi^0\gamma\gamma$ candidates with estimated background.

The plot in fig. 6 shows the superimposition of the different background contributions. The value of the branching ratio, obtained using the $K_S \to \pi^0\pi^0$ as the normalization channel, is:

$$BR(K_S \to \pi^0\gamma\gamma)_{z>0.2} = (4.9 \pm 1.6_{stat} \pm 0.8_{syst}) \times 10^{-8}$$

This is in agreement with the theoretical prediction within the statistical error. However the collected statistics is not enough to distinguish between a pure phase space and the ChPT approach as the fig. 7 shows.

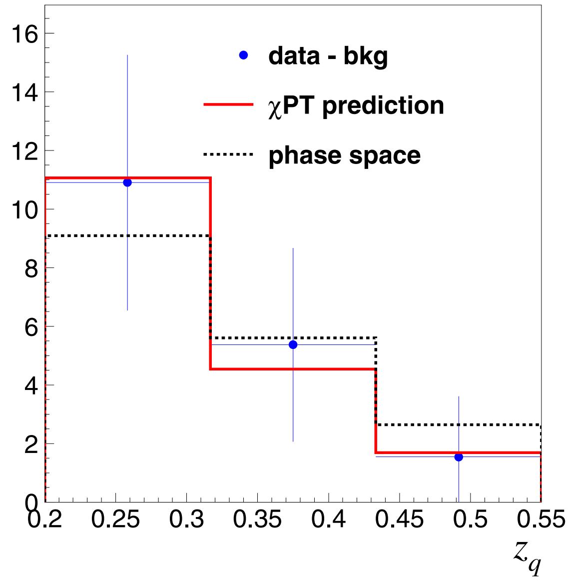

Figure 7. Measured $z_q = q^2/m_K^2$ for the fitted $K_S \to \pi^0\gamma\gamma$ signal and predictions.

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