RESULTS FROM K_S AND NEUTRAL HYPERONS DECAYS FROM THE NA48/1 EXPERIMENT AT CERN

M. MARTINI

FERRARA University and INFN

(1211 Geneva 23, Switzerland; e-mail: mara.martini@cern.ch)

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The NA48/1 experiment employed an intense neutral beam to collect K_S and neutral hyperon decays. The experiment run in 2000 (accessing only fully neutral final states) and in 2002 (with final states with also charged particles). Overall the experiment has improved the K_S world statistics by a factor of ≈ 50. In this talk, a precise measurement of the $K_S \to \gamma\gamma$ decay rate and the first observation of the decay $K_S \to \pi^0\gamma\gamma$ are reported. These decays are interesting in the framework of the chiral perturbation theory, the theory of the strong interaction at low energy.

The decays $K_{S,L} \to \gamma\gamma$ and $K_{S,L} \to \pi^0\gamma\gamma$ are important probes of Chiral Perturbation Theory (ChPT), an effective field theory of the Standard Model at low energies.

The NA48 experiment has been designed to measure direct CP violation in neutral kaon decays and comprises K_S and K_L beams created at two targets, near and far from the decay region, which can be run together or separately[1, 7].

The NA48/1 experiment [8] uses the near target beam which contains K^0 mesons and hyperons. The beam was produced on a beryllium target by 10^{10} 400 GeV protons at a production angle of 3.0 mrad in the vertical plane. The target is followed by a sweeping magnet and by a 0.36 cm diameter and 1.5 m long collimator.

During the year 2000 data taking, the 90 m long evacuated tube which followed the collimator system was connected with the tank which contained the drift chambers which were removed because damaged by the implosion of the beam pipe. The detector elements used in the analysis are the following:

- a liquid krypton calorimeter (LKr) [3] to measure the energy, position, and time of the electromagnetic shower initiated by photons.
- a sampling hadron calorimeter composed of steel-plates interleaved with scintillator planes with a readout in horizontal and vertical projections.
- a scintillator hodoscope upstream of the calorimeters to detect charged particles.
- photons escaping the outside limits of the calorimeter acceptance are detected by seven ring-shaped scintillator counters with iron converters.

The trigger decision is based on quantities which are derived from the projections of the energy deposited in the electromagnetic liquid krypton calorimeter[4]. The trigger required that the total deposited energy E_{tot} be larger than 50 GeV, the radius of the center of energy be smaller than 15 cm, and the proper life time of the kaon be less than 9 K_S lifetimes downstream of the collimator. The inefficiency of the trigger was measured to be at the level of 0.1%.

In the reconstruction of neutral decays, it is assumed the kaon mass and the z position of the decay vertex can be calculated from the shower energies and the distances $d_{i,j}$ between the clusters. Therefore if photons are lost, the missing energy shifts the vertex position down-stream towards the calorimeter.

1. $K_S \to \gamma\gamma$ Decay

This decay amplitude can be calculated unambiguously at the leading order $O(p^4)$ of the perturbative expansion giving a branching ratio of (2.1×10^{-6}) with an uncertainty of only few per cent [2]. The theoretical prediction for $K_L \to \gamma\gamma$ is much less accurate. The $K_S \to \gamma\gamma$ decay rate was measured by NA48 to be $(2.58 \pm 0.42) \times 10^{-6}$ in good agreement with ChPT using data from the two-day test run with a high-intensity short neutral beam, collected in September 1999. However, this result is not precise enough to resolve the higher order effects which are predicted to be of the order of 20% of the $O(p^4)$ decay amplitude.

Using data taken during the 40-day run with a high-intensity short beam in 2000, an accuracy of a few % has been achieved.

The measurement is based on the principle to keep small the systematic error derived from the subtraction of the irreducible $K_L \to \gamma\gamma$ component. While the current world average on BR($K_L \to \gamma\gamma$) has a relative error of about 3% [6], we have measured the relative rate $\Gamma(K_L \to \gamma\gamma)/\Gamma(K_L \to 3\pi^0)$ using a very similar setup and the far target beam and obtaining $(2.81 \pm 0.01_{\rm stat} \pm 0.02_{\rm syst}) \times 10^{-2}$. This result improves the current world average by about a factor of four. Also the K_L flux has been derived using $K_L \to 3\pi^0$ decays.

In order to remove events with hadronic or overlapping showers from the $\gamma\gamma$ sample, a cut on the shower width is required to be less than 3σ above the average value for photon showers of a given energy. The background from $K_S \to \pi^0\pi^0$ decays has been strongly reduced by choosing a very short decay region only few meters down-stream of the collimator exit.

In the near target data, almost 20000 events passed the $\gamma\gamma$ selection cuts of which 7461 ± 172 have been estimated as $K_S \to \gamma\gamma$. The z distribution of candidates and background sources is shown in Fig. 1 Acceptances were calculated using Monte Carlo with full detector simulation.

Using the BR$(K_S \to \pi^0\pi^0)$ given in [6], we obtain:

$$\begin{aligned}&\mathrm{BR}(K_S \to \gamma\gamma) = \\ &= (2.78 \pm 0.06_{\rm stat} \pm 0.03_{\rm syst} \pm 0.02_{\rm ext}) \times 10^{-6} = \\ &= (2.78 \pm 0.07) \times 10^{-6}, \qquad (1)\end{aligned}$$

where the external uncertainty is the one for BR$(K_S \to \pi^0\pi^0)$.

The result is in agreement with previous measurements, but has much better precision. It shows the significant difference with respect to the $O(p^4)$ calculations of ChPT and indicates that higher order corrections increase the decay rate by about 30%.

2. $K_L \to \pi^0\gamma\gamma$ Decay

With four photons in the final state the decay $K_L \to \pi^0\gamma\gamma$ has almost the same signature as the CP violating decay $K_L \to \pi^0\pi^0$, therefore the same data as for the ε'/ε have been used. This decay is finite at one loop in χPT [10], but only 1/3 of the measured rate is predicted at $O(p^4)$. At $O(p^6)$, the rate can be reproduced including vector mesons exchange (VMD) and a tail at low $m_{\gamma\gamma}$ is predicted. The VMD contribution is parametrized by the coupling constant a_V, which has to be experimentally determined. The a_V magnitude is linked to the CP conserving component of the $K_L \to \pi^0 e^+e^-$ decay as could enhance the state $J = 2$ for the two photons, otherwise in the $J = 0$ state which is helicity-suppressed.

This rare decay is experimentally difficult to measure because it has not a clear signature and in addition is

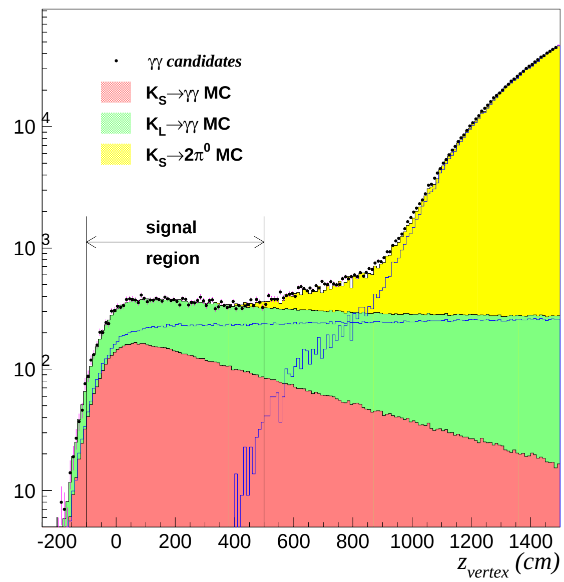

Fig. 1. z vertex distribution of $\gamma\gamma$ candidates

affected by a very high background. In particular in order to reject the $2\pi^0$ background, a cut on the χ^2 of the best $2\pi^0$ combination distinguishes between $\pi^0\pi^0$ and $\pi^0\gamma\gamma$ events. A cut on the transverse momentum of the lowest energy gamma of the unpaired photons and the spectrometer used to veto conversions and Dalitz decays reduce the residual background to a negligible level. The $2\pi^0$ background has been measured from the same analysis performed on a sample of tagged $K_S \to \pi^0\pi^0$ events. However, the highest source of background comes from $K_L \to 3\pi^0$ decays where several topologies as missing photons, missing and overlapping, and completely overlapping photons mimic the signal channel. We cut on the $z_{\rm vertex} < 3000$ cm and on the center of gravity of the energy at the calorimeter front-face which are overestimate in case of an event not complete. We also reject events if 2 (or 3) clusters reconstruct 1 (or 2) π^0 more than 6 m upstream of the K decay vertex which is obviously wrong in case of $3\pi^0$ event. This cut strongly reduces the background but also the 49% of the signal. We are finally left in the signal region, defined as $132 < m_{1,2} < 138$ MeV$/c^2$, with 2558 candidates affected by the 3.2% of background. The unpaired photons invariant mass distribution is shown in Fig. 2 together with the MC expectation and the residual background. The result is[9]:

BR$(K_L \to \pi^0\gamma\gamma) =$

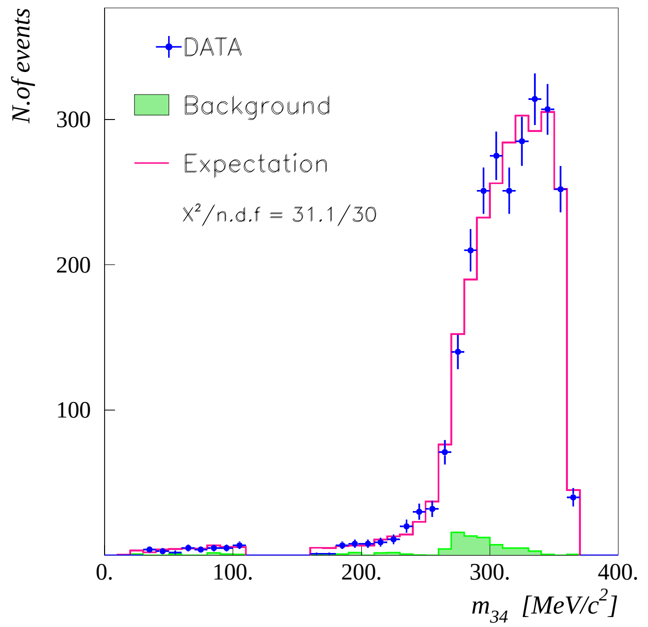

Fig. 2. $m(\gamma_3, \gamma_4)$ invariant mass distribution for the selected $K_L \to \pi^0\gamma\gamma$ candidates

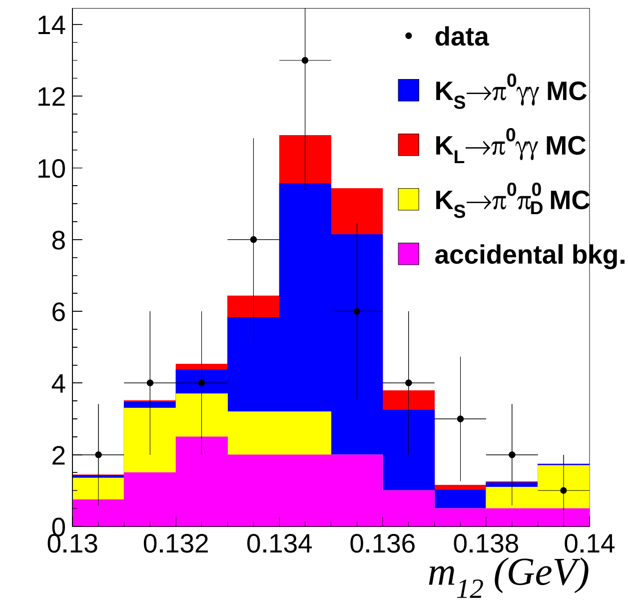

Fig. 3. $m(\gamma_1, \gamma_2)$ invariant mass distribution for the selected $K_S \to \pi^0\gamma\gamma$ candidates. The data in the control region are compatible with background while the signal region contains an excess of events

$$= (1.36 \pm 0.03_{\rm stat} \pm 0.04_{\rm syst}) \times 10^{-6}$$
$$\text{and } a_V = -0.46 \pm 0.03_{\rm stat} \pm 0.04_{\rm syst}, \quad (2)$$

where the systematic error comes mainly from the acceptance evaluation. For the low-$m_{\gamma\gamma}$ invariant mass region, we quote a model-independent upper limit:

$$\mathrm{BR}(K_L \to \pi^0\gamma\gamma,$$
$$30 < m_{\gamma\gamma} < 110 \text{ MeV}/c^2, 0 < y < 0.2) < 6 \times 10^{-9} \quad (3)$$

3. $K_S \to \pi^0\gamma\gamma$ Decay

In the $K_S \to \pi^0\gamma\gamma$, the photon pair is produced by a pseudo-scalar meson pole. In the ChPT this pole is dominated by the π^0 contribution and the lowest order is non-vanishing. Due to the presence of the dominating $K_S \to \pi^0\pi^0$ background, a cut on the two-photon invariant mass is required: $z = m_{\gamma\gamma}{}^2/m_K{}^2 > 0.2$. The predicted branching fraction for this kinematic region is (3.8×10^{-8}) with higher order corrections expected to be small [11]. In addition, the ChPT predicts the momentum dependence of the weak vertex which can be tested provided sufficient statistics is available from the z spectrum distribution. No experimental observation has been published so far.

From the high-intensity near-target data taken in year 2000, 31 $K_S \to \pi^0\gamma\gamma$ candidate events have been extracted. The irreducible $K_L \to \pi^0\gamma\gamma$ background was estimated using Monte Carlo and assuming equal K_L and K_S production at the target. The backgrounds from $K_S \to \pi^0\pi^0$ and $K_S \to \pi^0\pi^0_{\rm Dalitz}$have been suppressed using kinematic cuts. Background from the beam pile-up has been reduced using veto counters and imposing tight time constraints on the showers detected in the LKr.

Fig. 3 shows the distribution of the invariant mass $m_{1,2}$ reconstructed from the $\gamma\gamma$ pair associated with the π^0 compared to the expected background contributions.

After background subtraction, (17.4 ± 6.2) events remain in the sample. Using the BR($K_S \to \pi^0\pi^0$) from [6], one obtains

$$\mathrm{BR}(K_S \to \pi^0\gamma\gamma)_{z>0.2} = (5.1 \pm 1.6_{\rm stat} \pm 0.9_{\rm syst})^{-8}, \quad (4)$$

which agrees with the predictions. Unfortunately, the statistical and background subtraction uncertainties do not allow us to conclude on the momentum dependence of the weak vertex.

Conclusions

The precise measurement of $K_S \to \gamma\gamma$ decay indicates a significant $O(p^6)$ contribution and provides an input for higher loop calculations in ChPT.

The precise measurement of $K_L \to \pi^0\gamma\gamma$ suggests a small vector meson contribution and a small CP conserving component in the $K_L \to \pi^0 e^+ e^-$ process.

The decay $K_S \to \pi^0\gamma\gamma$ has been observed for the first time with a branching ratio in agreement with ChPT.

Interesting results on hyperon semileptonic and radiative decays are coming soon.

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РЕЗУЛЬТАТИ NA48/1-ЕКСПЕРИМЕНТУ В ЦЕРНІ З РОЗПАДІВ K_S ТА НЕЙТРАЛЬНИХ ГІПЕРОНІВ

М.Мартіні

Р е з ю м е

Експеримент NA48/1 використовує інтенсивний нейтральний пучок для того, щоб відібрати розпади K_S та нейтральні гіперони. Експеримент проходив у 2002 р. (з доступом до тільки повністю нейтральних кінцевих станів) і в 2002 р. (з кінцевими станами, що мають також і заряджені частинки). В цілому, експеримент покращив світову статистику для K_S на фактор близько 50. У цій роботі описано точне вимірювання швидкості розпаду для $K_S \to \gamma\gamma$ і перше спостереження розпаду $K_S \to \pi^0\gamma\gamma$. Ці розпади становлять інтерес в рамках кіральної теорії збуджень, теорії сильної взаємодії при низьких енергіях.

РЕЗУЛЬТАТЫ NA48/1-ЭКСПЕРИМЕНТА В ЦЕРНЕ ПО РАСПАДАМ K_S И НЕЙТРАЛЬНЫХ ГИПЕРОНОВ

М.Мартини

Р е з ю м е

Эксперимент NA48/1 использует интенсивный нейтральный пучок для того, чтобы отобрать распады K_S и нейтральные гипероны. Эксперимент проходил в 2002 г. (с доступом к только полностью нейтральным конечным состояниям) и в 2002 г. (с конечными состояниями, содержащими также и заряженные частицы). В целом, эксперимент улучшил мировую статистику для K_S на фактор около 50. В этом докладе представлены точное измерение скорости распада для $K_S \to \gamma\gamma$ и первое наблюдение распада $K_S \to \pi^0\gamma\gamma$. Эти распады представляют интерес в рамках киральной теории возмущения, теории сильных взаимодействий при низких энергиях.