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NA48 RESULTS ON KAON RARE DECAYS

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ABSTRACT

The latest results of the NA48 experiment at CERN about rare K_L and K_S decays are reviewed. In particular the first observation of the decays $K_S \to \pi^0 e^+ e^-$ and $K_S \to \pi^0 \mu^+ \mu^-$ made by NA48 using the data collected during the 2002 K_S high intensity run are discussed. The measurement of the branching ratio of the $K_L \to e^+ e^- e^+ e^-$ decay using the 1998 and 1999 data is also presented.

1 Introduction

The NA48 experiment at CERN was designed to measure the direct CP violating parameter $Re(\epsilon'/\epsilon)$ using two simultaneous K_S and K_L beams. The

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final result, based on the analysis of the data collected from 1998 to 2001, has been published [1]. Together with its main program, NA48 has also developed a research program on K_L and K_S rare decays. In 2002 the K_L beam was removed and decays from the K_S target only were collected with a proton intensity increased by about a factor 1000.

The NA48 detector revealed the products of the particles decaying in a 100 m long evacuated tube downstream to the K_S target. The detector, placed at the end of the decay tube, was composed by: a magnetic spectrometer consisting of 4 drift chambers separated by a dipole magnet, a quasi-homogeneous liquid krypton electromagnetic calorimeter, an iron scintillator hadronic calorimeter and a muon detector made by 3 scintillators planes separated by iron walls 80 cm thick [2].

2 The $K_S \to \pi^0 l^+ l^-$ decays

The parameter η of the Wolfenstein parametrization of the CKM matrix can be experimentally extracted from the measurement of the direct CP-violating component of the branching ratio of the $K_L \to \pi^0 l^+ l^-$ decay. However, also a CP conserving component and an indirect CP violating component contribute to the total branching ratio of this channel. The first component can be derived from the $K_L \to \pi^0 \gamma\gamma$ decay [3], while the second component from the $K_S \to \pi^0 l^+ l^-$ decays. Consequently the measurement of the branching ratio of the $K_S \to \pi^0 l^+ l^-$ decays allows η to be extracted from the $K_L \to \pi^0 l^+ l^-$ decay.

Because the predicted branching ratio for the $K_S \to \pi^0 l^+ l^-$ decay was about 10^{-9}, only few events were expected in the 2002 data taking period. We performed a blind analysis: a $2.5\sigma_{m_K} \times 2.5\sigma_{m_{\pi^0}}$ signal region and a $6.0\sigma_{m_K} \times 6.0\sigma_{m_{\pi^0}}$ control region were defined and kept masked until the selection cuts were fixed by using both data control samples and Monte Carlo simulations of signal and background.

2.1 The $K_S \to \pi^0 e^+ e^-$ decay

The $K_S \to \pi^0 e^+ e^-$ events were defined by two opposite charged tracks with momentum less than 40 GeV/c and at least 95% of their energy released in the electromagnetc calorimeter.

The backgrounds from final states with π^0 decaying in Dalitz mode ($\pi^0 \to \gamma e^+ e^-$) or with γ conversions in the detector were studied using Monte Carlo

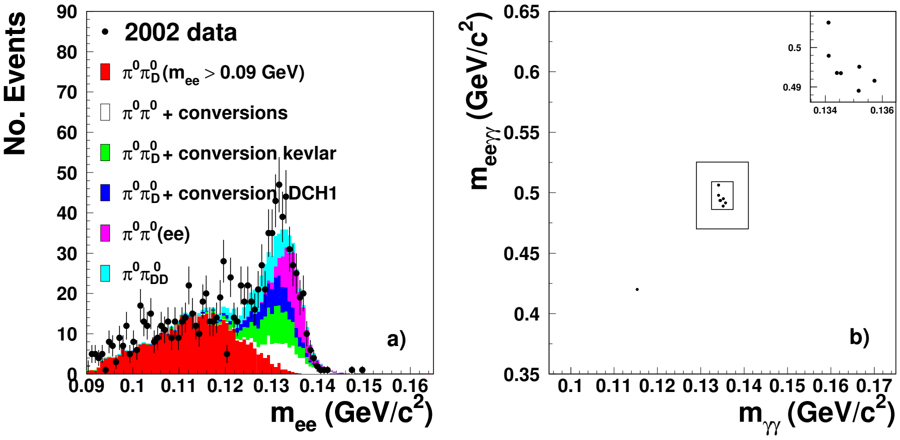

Figure 1: *(a) m_{ee} distribution of the Dalitz decays and γ conversions for data (dots) and Monte Carlo (curves). (b) Candidate events in m_K vs $m_{\gamma\gamma}$ mass plane. The boxes correspond to the control and signal region.*

simulations. An upper cut at 0.165 GeV/c^2 on m_{ee} was applied to reduce the expected contamination in signal region at a level of 0.01 event (see fig.1 (a)). The $K_L \to e^+e^-\gamma\gamma$ background was studied using 2001 K_L data and $0.08^{+0.03}_{-0.02}$ events were expected in signal region. The expected background from possible decays of the Ξ^0 in the beam was reduced at a negligible level by applying a cut on track momentum asymmetry. An accidental background due to the overlapping of different kaon decays was also taken into account by studying the data in extended time windows. About 0.07 events from accidental background were expected in signal region.

Seven events were found in signal region with an overall expected background of $0.15^{+0.10}_{-0.04}$. No events were found in control region, in agreement with the expectation (see fig.1 (b)). The signal acceptance was computed assuming an unit form factor in the $K_S \to \pi^0 e^+e^-$ simulation. The final result is [4]:

$$BR(K_S \to \pi^0 e^+e^-) = (5.8^{+2.8}_{-2.3}(stat) \pm 0.8(syst)) \times 10^{-9}. \qquad (1)$$

The main part of the systematic error comes from the extrapolation from the $m_{ee} > 0.165$ GeV/c^2 to the full m_{ee} region.

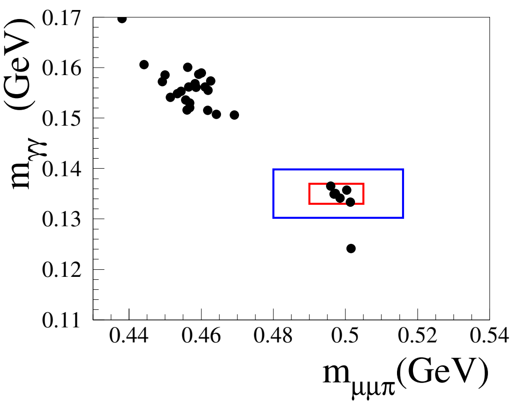

Figure 2: *The $K_S \to \pi^0\mu^+\mu^-$ candidates in the $m_{\gamma\gamma}$ vs m_K plane. The events at large $m_{\gamma\gamma}$ are consistent with $K_L \to \pi^+\pi^-\pi^0$ background, the event at low $m_{\gamma\gamma}$ with accidental background.*

2.2 The $K_S \to \pi^0\mu^+\mu^-$ decay

The $K_S \to \pi^0\mu^+\mu^-$ events were selected similarly to the $K_S \to \pi^0 e^+e^-$, but requiring the tracks to be associated to hits in the Muon Counters.

Suitable kinematical cuts allowed the expected background in the signal region from $K_L \to \pi^+\pi^-\pi^0$ events with two pions decaying in flight to be less than 0.02 events, as derived from Monte Carlo simulations. The background from Ξ^0 decays were rejected using a cut on track momentum asymmetry. Monte Carlo studies have shown an expected residual background in signal region from $K_L \to e^+e^-\mu^+\mu^-$ of 0.04 ± 0.04 events. The accidental background was taken into account as in the $K_S \to \pi^0 e^+e^-$ analysis. The accidental events expected in signal region were $0.18^{+0.18}_{-0.11}$.

Six events were found in signal region with an expected background of $0.22^{+0.19}_{-0.12}$. No events were found in control region in agreement with the expectation (see fig.2). As in the $K_S \to \pi^0 e^+e^-$ analysis, the signal acceptance was computed assuming an unit form factor in the $K_S \to \pi^0\mu^+\mu^-$ simulation. The final result is:

$$BR(K_S \to \pi^0\mu^+\mu^-) = (2.9^{+1.5}_{-1.2}(stat) \pm 0.2(syst)) \times 10^{-9}. \qquad (2)$$

2.3 Interpretation of the results

In the Chiral Perturbation Theory the branching ratio of the $K_S \to \pi^0 l^+ l^-$ depends on two parameters, a_S and b_S, that describe the $K_S \to \pi^0 l^+ l^-$ form factors [5]. The Vector Meson Dominance (VMD) model predicts $b_S/a_S = 0.4$. In this framework the parameter a_S, extracted independently from both the $K_S \to \pi^0 l^+ l^-$ branching ratio measurements, is:

$$|a_S|_{\pi^0 ee} = 1.06^{+0.26}_{-0.21} \pm 0.07 \tag{3}$$

$$|a_S|_{\pi^0 \mu\mu} = 1.55^{+0.38}_{-0.32} \pm 0.05 \tag{4}$$

These results agree each other within the errors. Moreover, the a_S and b_S extracted independently by a log-likelihood fit result compatible with the VMD.

2.4 Implications for $K_L \to \pi^0 l^+ l^-$

The CP violating component of the BR($K_L \to \pi^0 l^+ l^-$) can be written as:

$$BR(K_L \to \pi^0 l^+ l^-)_{CPV} \times 10^{12} = C_{MIX} \pm C_{INT} \left(\frac{\Im(\lambda_t)}{10^{-4}} \right) + C_{DIR} \left(\frac{\Im(\lambda_t)}{10^{-4}} \right)^2 . \tag{5}$$

C_{DIR} describes the direct CPV component, C_{MIX} and C_{INT} the indirect and interference CP violation part and depend on $|a_S|$. From the previous measurements of $|a_S|$, we can extract the overall dependence of $BR(K_L \to \pi^0 l^+ l^-)_{CPV}$ on $\Im(\lambda_t)$ within a sign ambiguity. Finally, taking $\Im(\lambda_t) = (1.36 \pm 0.12) \times 10^{-4}$ [6], we obtain:

$$BR(K_L \to \pi^0 e^+ e^-)_{CPV} \times 10^{12} = 17_{indirect} \pm 9_{interference} + 5_{direct} \tag{6}$$

$$BR(K_L \to \pi^0 \mu^+ \mu^-)_{CPV} \times 10^{12} = 9_{indirect} \pm 3_{interference} + 1_{direct} \tag{7}$$

3 The $K_L \to e^+e^-e^+e^-$ decay

The $K_L \to e^+e^-e^+e^-$ decay is expected to proceed mainly via the intermediate state $K_L \to \gamma^*\gamma^*$ [7, 8]. Therefore it depends on the structure of the $K_L \to \gamma^*\gamma^*$ vertex whose knowledge allows the CKM parameter ρ to be extracted from the $K_L \to \mu^+\mu^-$ decay.

NA48 has measured the branching ratio of the $K_L \to e^+e^-e^+e^-$ decay using the data collected in 1998 and 1999. 4-Tracks events were identified as candidate signal events if the tracks released in the electromagnetic calorimeter at least 93% of their energy. In the plane defined by the 4-tracks invariant mass, m_{eeee}, and the squared transverse momentum, p_t^2, the signal region was identified by the cuts 475 MeV/c^2 $< m_{eeee} <$515 MeV/c^2 and $p_t^2 < 0.0005$(GeV/c)^2.

200 Events were found in signal region with a background less than 1.0%. The background came from $K_L \to \pi^0\pi^0$ and $K_L \to \pi^0\pi^0\pi^0$ decays where at least two π^0 decayed in Dalitz mode or two γ's made conversion. The $K_L \to \pi^+\pi^-\pi^0$ decay was used as normalization channel and its acceptance, together with the signal acceptance, was computed using Monte Carlo simulations. The branching ratio was corrected for the electron identification efficiency measured both from data and Monte Carlo samples. The result is:

$$BR(K_L \to e^+e^-e^+e^-) = (3.30 \pm 0.24_{stat} \pm 0.14_{syst} \pm 0.10_{norm}) \times 10^{-8}. \quad (8)$$

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