NA48/1 K_S RARE DECAYS AND HYPERONS

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A first measurements of the BR($K_S \to \pi^0 e^+ e^-$) and BR($K_S \to \pi^0 \mu^+ \mu^-$) has been performed in NA48/1. During 89 days of the 2002 run with high intensity K_S beam 7 events of $K_S \to \pi^0 e^+ e^-$ and 6 of $K_S \to \pi^0 \mu^+ \mu^-$ have been collected leading to the following branching fraction results:
BR($K_S \to \pi^0 e^+ e^-$) $= [3.0^{+1.5}_{-1.2}(stat) \pm 0.2(syst)] \cdot 10^{-9}$ for $m_{ee} > 165 MeV$
BR($K_S \to \pi^0 \mu^+ \mu^-$) $= [2.8^{+1.5}_{-1.2}(stat) \pm 0.2(syst)] \cdot 10^{-9}$
New measurements of $\Xi^0 \to \Lambda\gamma$ decay asymmetry and BR were also performed using 1999 data. The branching fraction of the decay has been measured to be Br($\Xi^0 \to \Lambda\gamma$) $= (1.16 \pm 0.05(stat) \pm 0.06(syst)) \cdot 10^{-3}$, and the first evidence of a negative decay asymmetry $\alpha(\Xi^0 \to \Lambda\gamma) = -0.78 \pm 0.18(stat) \pm 0.06(syst)$ has been shown.

1 Introduction

After the successful study of direct CP violation in K^0 decays the NA48 collaboration has started a new research program on K^0_S rare decays and neutral hyperons physics called NA48/I. The main goal of this new fase of data taking was to measure the BR of K_S into $\pi^0 l^+ l^-$ decays. This new investigation has begun with a 2 days test run during 1999 in witch trigger and beam for 2002 were set-up. Using this data we have also measured the BR and the decay asymmetry of the radiative decay $\Xi^0 \to \Lambda\gamma$

The experimental setup used is the same of that for ϵ'/ϵ [1] except for the fact that NA48/1 has no K_L beam and higher K_S intensity. In this paper were shortly describe some of the major results obtained by the experiment, up to now, in this new configuration during 1999 and 2002 runs.

1.1 *Interest of* $K_S \to \pi^0 l^+ l^-$

The importance of the BR $K_S \to \pi^0 l^+ l^-$ is due to his relation with the indirect CP violating component of $K_L \to \pi^0 l^+ l^-$. The branching ratio of that decay contains three contributions: a CP conserving part that can be constrained by $K_L \to \pi^0 \gamma\gamma$, an indirect CP violating part that can be evaluated from BR($K_S \to \pi^0 l^+ l^-$), and a direct CP violating part. The last one gives the possibility to measure directly the CMK matrix element η if the corresponding K_S decay BR is known. The following formulas show that the two decay are linked by the parameter a_S [2].

$$BR(K_S \to \pi^0 e^+ e^-) = 5.2 \cdot 10^{-9} \cdot a_S^2 \tag{1}$$

$$BR(K_L \to \pi^0 e^+ e^-) = \left[15.3 a_S^2 \pm 6.8 a_S \frac{Im(\lambda_t)}{10^{-4}} + 2.8 \left(\frac{Im(\lambda_t)}{10^{-4}}\right)^2\right] \cdot 10^{-9} \tag{2}$$

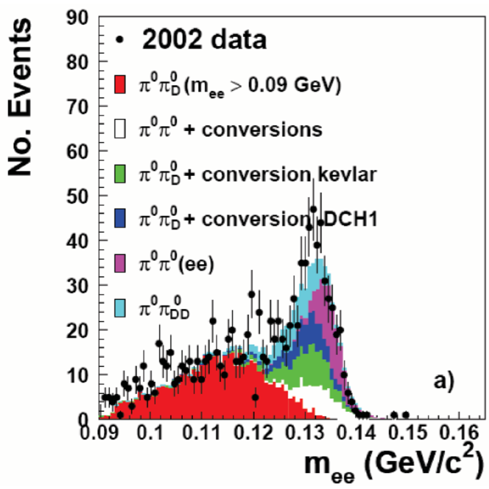

Figure 1: Distribution of m_{ee} after all cuts. Superimposed we show the Monte Carlo predictions from all important sources.

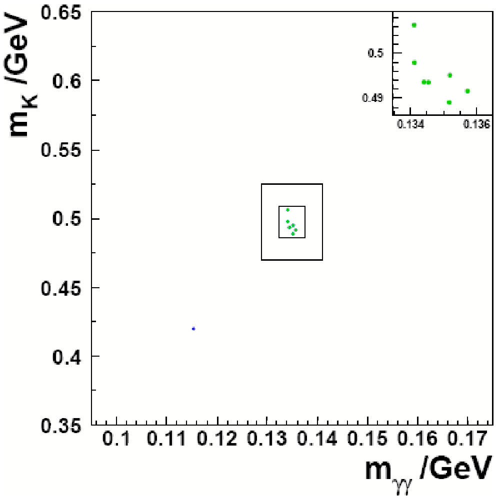

Figure 2: Scatter plot of $m_{ee\gamma\gamma}$ versus m_{ee} for events passing all the cuts. The region 3σ and 6σ are shown.

As you can see in Eq. 2 the BR depends only on two parameters: a_S and $Im(\lambda_t)$. According to Eq. 1 a_S can be evaluated from the K_S decay and once this is known a measurement of the K_L BR would give a direct information on $Im(\lambda_t)$. Before NA48/1 none of the BR of $K_S \to \pi^0 l^+ l^-$ has never been measured.

2 K_S to $\pi^0 e^+ e^-$ $\pi^0 \mu^+ \mu^-$ rare decays

Due to the very small value of the branching fraction of both decays (order of 10^{-9})[2] a blind analysis strategy has been chosen. A signal region and a control region were defined and kept masked until the final set of cuts was chosen. The cuts were tuned, using Monte Carlo simulation, in order to maximize the ratio signal/background.

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

The signal reconstruction for this decay is based on the identification of 4 clusters in the calorimeter two of which associated to a track in the spectrometer. To identify the spectrometer's track as electron or positron an E/p between 0.95 and 1.05 is required. The signal and control region are defined as follow:

- Signal region: $|m_{\gamma\gamma} - M_{\pi^0}| < 2.5 \cdot \sigma_{m_{\gamma\gamma}}$ & $|m_{ee\gamma\gamma} - M_K| < 2.5 \cdot \sigma_{m_{ee\gamma\gamma}}$
- Control region: $3 \cdot \sigma_{m_{\gamma\gamma}} < |m_{\gamma\gamma} - M_{\pi^0}| < 6 \cdot \sigma_{m_{\gamma\gamma}}$ & $3 \cdot \sigma_{m_{ee\gamma\gamma}} < |m_{ee\gamma\gamma} - M_K| < 6 \cdot \sigma_{m_{ee\gamma\gamma}}$

There are many sources of background that may affect this measurements. They can derive from K decays, hyperon decays, or from overlapping fragment of two different decays. Montecarlo simulation indicate that the main contribution is given by $K_S \to \pi^0\pi^0$ when one or more photons from the π^0 decay convert (either internally or externally). To reject this type of background a severe cut on m_{ee} has been applied m_{ee} >165 MeV/c^2. As shown in Fig.1 this cut is very effective against this type of background source. At the end of the Montecarlo analysis only three contribution to the background were found to be not negligible:

- $K_{L,S} \to e^+e^-\gamma\gamma$: $0.08^{+0.03}_{-0.02}$ events
- $K_S \to \pi^0_D\pi^0_D$: < 0.01 events

- Accidental backgrounds: $0.07^{+0.07}_{-0.03}$ events

At the end of this procedure the signal region was disclosed and 7 events were found as shown in Fig.2. To obtain the acceptance for m_{ee} >165 MeV/c^2 a theoretical prediction for the decay amplitude was taken from Chiral Perturbation Theory [2]. The branching ratio for m_{ee} >165 MeV/c^2 was computed to be:

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-, m_{ee} > 165\ MeV/c^2) = [3.0^{+1.5}_{-1.2}(stat) \pm 0.2(syst)] \cdot 10^{-9}$$

To extract the branching ratio in the whole m_{ee} region the previous result was extrapolated using a vector matrix element with no form factor dependence.

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) = [5.8^{+2.8}_{-2.3}(stat) \pm 0.8(syst)] \cdot 10^{-9}$$

The result is in good agreement with theoretical prediction[2].

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

The event selection for this decay is very similar to the previous one. In this case the muon is identified matching the spectrometer tracks with muon veto hits. The control and signal region were defined as before only replacing electrons with muon in the invariant mass reconstruction. Many background sources were studied and the following contributions were estimated to be non negligible:

- $K_{L,S} \to \mu^+ \mu^- \gamma\gamma$: $0.04^{+0.04}_{-0.03}$ events
- $K_S \to \pi^+ \pi^- \pi^0$ with both $\pi^\pm$ decaying in flight: < 0.018 events
- Accidental backgrounds: $0.18^{+0.18}_{-0.11}$ events

After the signal region was disclosed 6 signal events were found and the branching ratio was calculated to be:

$$BR(K_S \to \pi^0 \mu^+ \mu^-) = [2.9^{+1.5}_{-1.2} \pm 0.2(syst)] \cdot 10^{-9} \tag{3}$$

2.3 a_S value comparison

According to Eq. 4 and 5 a value of a_S can be extracted from both decays and the results compared. Using χPT prediction for the branching ratios of $K_S \to \pi^0 l^+ l^-$:

$$BR(K_S \to \pi^0 e^+ e^-) = 5.2 \cdot 10^{-9} a_S^2 \tag{4}$$

$$BR(K_S \to \pi^0 \mu^+ \mu^-) = 1.2 \cdot 10^{-9} a_S^2 \tag{5}$$

Using the measured BR and the relation below we can extract the following a_S value:

$$|a_S|_{(\pi^0 e^+ e^-)} = 1.06^{+0.26}_{-0.21}(stat) \pm 0.07(syst) \tag{6}$$

$$|a_S|_{(\pi^0 \mu^+ \mu^-)} = 1.54^{+0.40}_{-0.32}(stat) \pm 0.06(syst) \tag{7}$$

The two value are in reasonable agreement within experimental errors.

3 Hyperon physics NA48/1

The study of radiative hyperon decay, in particular $\Xi^0 \to \Lambda\gamma$ and $\Xi^0 \to \Sigma\gamma$, gives important information about the SU(3) symmetry breaking. After the unexpected discovery of a large decay asymmetry in the decay $\Sigma^+ \to p\gamma$ models were developed which tried to obtain large decay asymmetries in spite of weak SU(3) breaking. One category, pole models, satisfy the Hara[4] theorem, and use an approach based on chiral perturbation theory (χPT). They predict negative decay asymmetries for all weak radiative hyperon decays. Vector meson dominance models and calculations based on the quark model on the other hand violate the Hara theorem. This second group of models favours a positive decay asymmetry only for the channel $\Xi^0 \to \Lambda\gamma$. Before NA48/1 the value of $\alpha(\Xi^0 \to \Lambda\gamma)$ had never been measured.

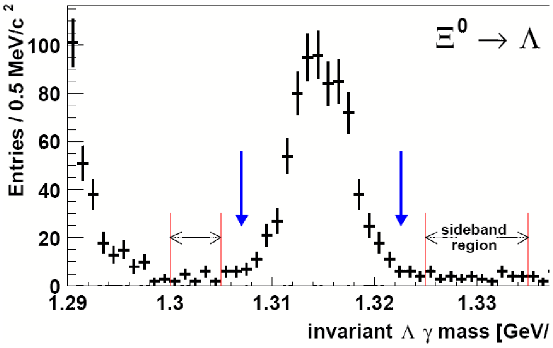

Figure 3: Distribution of the invariant Ξ^0 mass for $\Xi^0 \to \Lambda\gamma$ decays. The signal region is indicated by the vertical arrows.

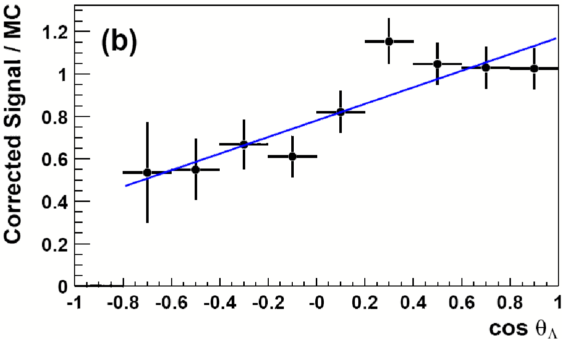

Figure 4: Ratio of background-corrected signal candidates over isotropic Monte Carlo simulation. The line shows the result of the fit.

3.1 The $\Xi^0 \to \Lambda\gamma$ decay asymmetry and BR

During the two days of 1999 test run for K_S beam and trigger setup a considerable number of hyperons decay were collected. At the end of the selection cuts in the signal region, defined by a mass cut on the nominal Ξ^0 mass ±7.8 MeV, 730 $\Xi^0 \to \Lambda\gamma$ candidate were found with an estimated background of ∼58 events. The invariant mass distribution is shown in Fig.3. To extract the decay asymmetry $\alpha(\Lambda\gamma)$, one measures the distribution, in the Ξ^0 rest frame, of the angle Θ_Λ between the incoming Ξ^0 and the outgoing proton deriving from Λ decay.

$$\frac{dN}{dcos\Theta_\Lambda} = N_0(1 - \alpha(\Lambda \to p\pi^-) \cdot \alpha(\Xi^0 \to \Lambda\gamma) \cdot cos\Theta_\Lambda) \qquad (8)$$

To extract the asymmetry we consider the ratio between data and Monte Carlo generated with no asymmetry at all. This ratio would be flat in $\cos\Theta_\Lambda$ in absence of asymmetry. The ratio of background-corrected signal over Monte Carlo is shown in Fig.4. A fit with $\alpha(\Lambda \to p\pi^-)\cdot\alpha(\Xi^0 \to \Lambda\gamma)$ and the normalization as free parameter leads, after dividing for the well known value of $\alpha(\Lambda \to p\pi^-)$, to the result: $\alpha(\Xi^0 \to \Lambda\gamma) = -0.78 \pm 0.18(stat) \pm 0.06(syst)$. The systematic error is dominated by the error on background asymmetry estimate. Using the central value of our new result on the decay asymmetry, the overall acceptance for $\Xi^0 \to \Lambda\gamma$ can be evaluated. The main background for the BR measurements come from $\Xi^0 \to \Lambda\pi^0$ with a lost gamma, visible in the left-side in Fig.3. The background contribution in signal region has been evaluated using the sidebands between red lines. Subtracting the background and using BR($\Xi^0 \to \Lambda\pi^0$) as a normalization channel we found: $Br(\Xi^0 \to \Lambda\gamma) = 1.16 \pm 0.05(stat) \pm 0.06(syst)$. The systematic error is dominated by the uncertainty on the decay asymmetry (∼ 5%).

References

1. A. Lai *et al.* [NA48 Collaboration], Eur. Phys. J. C **22**, 231 (2001)
2. G. D'Ambrosio, G. Ecker, G. Isidori and J. Portoles, JHEP **9808**, 004 (1998)
3. J. R. Batley *et al.* [NA48/1 Collaboration], Phys. Lett. B **576**, 43 (2003)
4. Y. Hara, Phys. Rev. Lett. **12**, 378 (1964)
5. A. Lai *et al.* [NA48 Collaboration], Phys. Lett. B **584**, 251 (2004)