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Rare Hyperon Decays in the CERN NA48 Experiment

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The NA48 Collaboration has already investigated rare hyperon decays in special high intensity runs during 1999 and 2001. For 2002, the changes to the NA48 beam line will allow systematic studies on neutral hyperon decays at sensitivities greatly in excess of current values. The programme of data-taking and the range of analyses are discussed.

1. Introduction

NA48 has searched for rare K_L, K_S and neutral hyperon decays in data collected from 1998 to 2001. These searches were performed with the simultaneous K_L and K_S beams during the ϵ'/ϵ programme, and, in 1999 and 2001, using a dedicated higher intensity K_S and hyperon beam for short runs, but without major beam line modifications.

With the completion of the ϵ'/ϵ programme it became possible to upgrade the K_S beam, in the absence of the K_L beam, by a factor of several hundred in intensity. Thus the run, with data-taking beginning in June 2002, will allow us to make very significant improvements in the measurement of many rare K_S decay channels. We will also be able to perform systematic studies on neutral hyperon decays at sensitivities greatly in excess of current values.

Some channels accessible to the experiment are discussed below.

2. The detector and beam in 2002

The experimental layout, described in detail elsewhere [1], includes a spectrometer (drift chambers and dipole magnet), an electromagnetic calorimeter, and arrangements of scintillators for vetoing photons outside the calorimeter acceptance. Further downstream are a hadronic calorimeter and muon counters.

We have made a number of improvements to the new, dedicated, intense K_S beam. The main changes were the exploitation of a longer SPS duty cycle, the insertion of an absorber and a sweeping magnet at the K_S collimator in order to reject photon conversions, and an upgraded readout for the drift chambers and the electromagnetic calorimeter. This should allow the primary proton flux to be increased to 1×10^{10} per pulse, corresponding to about 3×10^{10} K_S decays per year in the fiducial volume of the experiment.

With these conditions the instantaneous rate in the principal detectors will remain tolerable, limited to $\sim$1.5 times those previously observed.

3. $K_S \to \pi^0 e^+ e^-$

The interest in this decay mode is that it provides a bound on the indirect CP violating term in the decay $K_L \to \pi^0 e^+ e^-$. The decay $K_L \to \pi^0 e^+ e^-$ will provide clean evidence for direct CP violation and will test whether it arises from within or beyond the standard model.

There are three contributions to the $K_L \to \pi^0 e^+ e^-$ decay: direct CP violating, indirect CP violating, and CP conserving. The CP conserving contribution can be obtained by measuring the low $m_{\gamma\gamma}$ component for the $K_L \to \pi^0 \gamma\gamma$ decay. The direct and the indirect contributions interfere, and their relative contribution to the branching ratio ($BR \times 10^{12}$) can be written [2] as:

$$15.3 a_s^2 - 6.8 a_s \frac{Im(\lambda_t)}{10^{-4}} + 2.8 \left(\frac{Im(\lambda_t)}{10^{-4}}\right)^2 ,$$

where $Im(\lambda_t) = V_{ts}^* V_{td}$ is the relevant combination of CKM matrix elements which describe the short distance CP violation.

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Table 1
Some rare hyperon decays accessible to this experiment.

Decay mode	Comment	Branching ratio ($\times 10^{-3}$)
$\Xi^0 \to \Sigma^+ e^- \bar{\nu_e}$		$0.254 \pm 0.011 \pm 0.016$
$\Xi^0 \to \Sigma^+ \mu^- \bar{\nu_\mu}$		$(2.6^{+2.7}_{-1.7} \pm 0.6) 10^{-3}$
$\Lambda \to p e^- \bar{\nu_e}$		0.832 ± 0.014
$\Lambda \to p \mu^- \bar{\nu_\mu}$		0.157 ± 0.035
$\Xi^0 \to \Lambda\gamma$	BR and asymmetry	1.06 ± 0.16
$\Xi^0 \to \Sigma^0\gamma$	BR and asymmetry	3.5 ± 0.4
$\Sigma^0 \to \Lambda\gamma\gamma$	not seen yet, search	
$\Xi^0 \to p\pi^-$	$\Delta S = 2$ transition, improve best limit	$< 4 \times 10^{-5}$
	M_{Ξ^0} improve mass measurement	
	$M_{\bar{\Xi}^0}$ not measured yet	
	Ξ^0-Lifetime worst known for all hyperons	Error: 3%
	Polarisation of Ξ^0 and Λ and anti particles	
	CPT tests on masses and lifetimes	

The a_s parameter describes the strength of the indirect CP violating component in the $K_L \to \pi^0 e^+ e^-$decay. It is related to $BR(K_S \to \pi^0 e^+ e^-)$ via the relation:

$$BR(K_S \to \pi^0 e^+ e^-) = 5.2 \times 10^{-9} |a_s|^2.$$

According to naive dimensional analysis in chiral perturbation theory, $a_s \sim O(1)$. However, the prediction does not have any degree of confidence, so it is clearly important to measure $BR(K_S \to \pi^0 e^+ e^-)$ experimentally.

Our analysis of the data from the high intensity K_S run in 1999, when we find no event after applying all selection criteria, gives an upper limit of:

$$BR(K_S \to \pi^0 e^+ e^-) < 1.4 \times 10^{-7}$$

at 90% confidence level [3].

The high intensity run in 2002 should yield about 8 events at a branching ratio of 5×10^{-9}, assuming an estimated total acceptance after cuts of 5%. The main background is due to $K_S \to \pi^0\pi^0$ decays with the subsequent Dalitz decay of either π^0. The most effective rejection can be done requiring the invariant mass of the electron pair to be above the m_{π^0} kinematic limit, in order to take into account possible resolution effects or interactions in the detector material. The background is estimated to be < 0.15 events. Other backgrounds like $K_S \to \pi^0_D \pi^0_D$ or $K_{L,S} \to e^+ e^- \gamma\gamma$ are under investigation but should be very small.

3.1. $K_S \to \pi^0 \mu^+ \mu^-$

The $K_S \to \pi^0 \mu^+ \mu^-$ decay will also be investigated but the backgrounds are quite different (e.g. $K_L \to \pi^+ \pi^- \pi^0$ with two pion decays), and the branching ratio is expected to be suppressed by a factor of five due to phase space.

4. Hyperon Physics

A detailed list of some hyperon decays which are accessible is shown in Table 1, and the most significant measurements are briefly described below.

4.1. *Hyperon electromagnetic mass splitting*

The hyperon electro-magnetic mass splittings amongst the SU(3) octet members can now be predicted by lattice calculations [4]. NA48 with its high-resolution photon detector will enable a very precise measurement of the mass of the Ξ^0 to be made. From a first analysis of the 1997 data and using the mean value for the mass of the Ξ^- [5], we obtain:

$$M(n) - M(p) + M(\Xi^-) - M(\Xi^0) + M(\Sigma^+) - M(\Sigma^-) = (-0.30 \pm 0.25) \text{ MeV},$$

consistent with zero as predicted [6]. With a high intensity run in the K_S neutral beam and additional systematic studies on the energy calibration, we will be able to reduce the experimental uncertainty to 0.1 MeV, which is the current error on $M(\Xi^-)$.

4.2. *Hyperon radiative decays*

Radiative hyperon decays between flavour octet states are allowed by isospin conservation in SU(3)-symmetric models. The Σ^0 and Λ are orthogonal three quark states with different isospin. In this way, the study of the radiative decays $\Xi^0 \to \Lambda\gamma$ and $\Xi^0 \to \Sigma\gamma$ gives information about SU(3)-breaking effects. Since non-leptonic weak interactions are complicated by hadronic effects, different model calculations result in branching ratios ranging over an order of magnitude. In the 2002 high intensity run, the event sample size will increase by a factor of 100. By reducing the systematic error by a factor of 2 we will obtain a result for the branching ratios with 5% uncertainty.

4.3. *Hyperon β decays*

The β decay of the Ξ^0 hyperon ($\Xi^0 \to \Sigma^+ e^- \bar{\nu}$), with a branching ratio of 2.5×10^{-4}, can be detected in NA48 by identifying the electron in the LKr calorimeter and the Σ^+ by its decay to $p\pi^0$ (51%). We expect to collect $\sim$ 10,000 events in the run. These events will be used for a new consistency check of SU(3) symmetry and the Cabibbo model in hyperon decays.

4.4. $\Xi^0 \to p\pi^-$

This decay with a double strangeness change ($\Delta S = 2$) should exist in the second order weak interactions. The present experimental limit is a branching ratio $\leq 4\times10^{-4}$ at 90% CL [7], and we should be able to improve this by a factor of 100. The theoretical prediction [8] is of order 10^{-17}, so that an observation would certainly be a sign of new physics.

REFERENCES

1. V. Fanti *et al.*, Phys. Lett. B **465**, 335 (1999).
2. G. D'Ambrosio, G. Ecker, G. Isidori, and J. Portoles, JHEP 9808:004,1998.
3. A. Lai *et al.*, Phys. Lett. B **514**, 253 (2001).
4. A. Duncan *et al.*, Nucl. Phys. Proc. Suppl. **53**, 299 (1997).
5. Review of particle physics, Eur. Phys. J. C **15**, 1 (2000).
6. S.L. Glashow, Phys. Rev. Lett. **6**, 423 (1961).
7. C. Geweniger *et al.*, Phys. Lett. B **57** 193 (1975).
8. X.-G. He and G. Valencia, Phys. Lett. B **409**, 469 (1997), Erratum ibid. B **418** 443, (1998).