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Hyperon physics in NA48

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Abstract. During 89 days of data taking in 2002, NA48/I collected a large sample of hyperon beta decays. The status and the perspectives for the study of Ξ^0 beta decay will be shown. Na48 is studying hyperon radiative decays as well.

1 Introduction

After the successful study of direct CP violation [1] in $K^0 \to \pi\pi$ (1997-1999 and 2001 runs) the NA48 collaboration has started a new research program on K_S^0 rare decays and neutral hyperons physics (NA48/I) with two periods of data taking in 2000 and 2002. In fact the "so called" K_S^0 target, is also a good source of hyperon particles, with fluxes sufficient to study rare decays. I will focus on 2002. In that year, after 89 days of data taking, NA48 was able to collect the largest world sample of Ξ^0 beta decay.

2 Experimental set-up

2.1 The beam

NA48/I was performed at the CERN SPS accelerator and it used a 400 GeV/c proton beam impinging on a Beryllium target to produce beam of neutral long-lived particles (K^0, Λ^0, Ξ^0, n and γ). The charged particles were deflected with a sweeping magnet positioned immediately after the target.

The beam is similar to the one used for the ϵ'/ϵ data, but the K_L beam was stopped and magnetic bending, rather than crystal channeling, was used to maximize the intensity.

The duty cycle was 4.8 s out of 16.2 s cycle time. The proton intensity was fairly constant during the spill with a mean of 5×10^{10} particles per pulse.

To reduce the number of photons in the neutral beam, primarily from π^0 decays, a platinum absorber 24 mm thick was placed in the beam between the target and the sweeping magnet.

In order to minimize the interactions of the neutral beam with air the beam collimator was immediately followed by a ~90 m long evacuated tank containing the fiducial decay region. The detector was located downstream of this tank.

2.2 The detector

The experimental layout is described in detail elsewhere [2]. To detect charged particles the detector included a spectrometer (4 drift chambers and a dipole magnet) with a momentum resolution that can be parameterized as $\sigma_p/p = 0.48\% \oplus 0.015\% \times p$ where p is in GeV/c. The time for charged decays was measured by a hodoscope of fast scintillators with a time resolution on the single track of ~250 ps.

The neutral particles were detected by a liquid krypton electromagnetic calorimeter (LKr) having an energy resolution $\Delta E/E = 3.2\%\sqrt{E(\mathrm{GeV})} \oplus 90MeV/E \oplus 0.42\%$.

Further downstream were an iron-scintillator sandwich hadron calorimeter and muon counters.

Seven rings of scintillation counters were used to veto photons and other particles outside the acceptance region of the experiment defined by the LKr calorimeter and the spectrometer.

3 The hyperon trigger

Special triggers have been dedicated to hyperon decays.

At trigger level the main difficulty comes from neutral kaon decays. In particular the decay $K_S \to \pi^+\pi^-$ was a huge background to be rejected. In 2002 the charged $\pi^+\pi^-$ trigger (used in the ϵ'/ϵ measurement) was instead used in veto. The effect of such a trigger are shown in Fig. 1.

For decays with a secondary Λ a further request was to have a two tracks vertex with an invariant mass compatible with the Λ^0 mass (Λ trigger). The reconstructed Λ^0 must have a large transverse momentum with respect to the beam axis in order to veto Λ^0's coming directly from the target.

For all other hyperon decays the request was to have the same Λ trigger in veto.

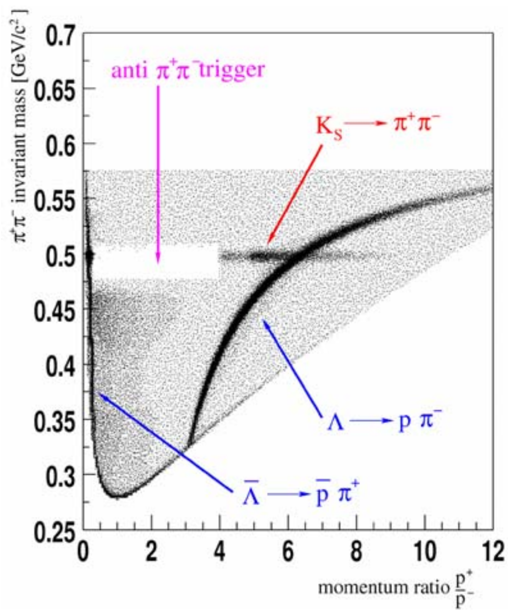

Fig. 1. Effect of the charged $\pi^+\pi^-$ trigger used in veto on events with two tracks. The *scatter plot* shows the momentum ratio of the two track versus their invariant mass computed assuming the pion mass for the two tracks

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Table 1 shows the rare hyperon decays that were accessible in the 2002 run and the present measurements of their branching ratios.

$\sim$5 milions events of the main decay mode $\Xi^0 \to \Lambda\pi^0$ have also been collected, with a trigger which was downscaled by a factor 4 during most of the run. Besides being useful for normalization they will allow measurements of mass, lifetime and of the production polarization.

Useful measurements can be also performed on $\bar{\Xi}^0$ and $\bar{\Lambda}^0$ in order to test CPT and to extract more informations on the polarization mechanism.

The measurements concerning Ξ^0 beta decay are described in more details below.

5 The Ξ^0 beta decay

From the experimental side, the Ξ^0 beta decay is interesting from many points of view. As other semileptonic hyperon decays it can provide information on the V_{us} element of the CKM matrix. With the avaiable measurements [3], this is still limited by statistics, but the channel offers some experimental advantages. In fact the possibility to reconstruct the mass of the emitted hyperon Σ^+ from the decay $\Sigma^+ \to p\pi^0$, is enough to reduce the background substantially, since the 2 body decay with the same outgoing hyperon produced ($\Xi^0 \to \Sigma^+ \pi^-$) is kinetically forbidden.

From the theoretical point of view the Ξ^0 beta decay is important essentially for two reasons:

The first aspect is the fact that a more precise determination of the sine of the Cabibbo angle, the V_{us} element of CKM matrix, allows tighter constraints on the CKM unitarity.

Table 1. Rare hyperon decays accessible to NA48/I

decay	measurements	BR ($\times 10^{-3}$)
$\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$	BR and form factors	0.254±0.011±0.016
$\Xi^0 \to \Sigma^+ \mu^- \bar{\nu}_\mu$	BR	$(2.6^{+2.7}_{-1.7} \pm 0.6)10^{-3}$
$\Lambda^0 \to p e^- \bar{\nu}_e$	BR and form factors	0.832 ± 0.014
$\Lambda^0 \to p \mu^- \bar{\nu}_\mu$	BR and form factors	0.157 ± 0.035
$\Xi^0 \to \Lambda^0 e^+ e^-$	BR	
$\Xi^0 \to \Lambda^0 \gamma$	BR and asymmetry	1.06 ± 0.16
$\Xi^0 \to \Sigma^0 \gamma$	BR and asymmetry	3.5 ± 0.4
$\Xi^0 \to p\pi^-$	($\Delta S = 2$) BR	$< 4 \times 10^{-5}$

One of the unitarity relations to be satisfied is the following:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \simeq |V_{ud}|^2 + |V_{us}|^2 = 1 \quad (1)$$

where the last approximation is explained by the current value measured for V_{ub} [4] [5]: $|V_{ub}|^2 \sim 10^{-5}$

Up to now V_{us} is measured from charged and neutral kaon beta decays, giving the following value [6]:

$$(V_{us})_{ke3} = 0.2196 \pm 0.0026$$

Asking for CKM unitarity we extract the following expected value for V_{ud}:

$$V^U_{ud} = 0.9756 \pm 0.0005$$

where the U indicates the unitarity hypothesis.

This is in disagreement, at the level of 2.7 standard deviation, with the value precisely measured from free neutron decay and nuclear decays [4] [7]:

$$V_{ud} = 0.9734 \pm 0.0008$$

A more recent result [8] on the semileptonic branching ratio of the kaon improves this agreement, but the picture requires some clarification both from the theoretical and experimental point of view.

The agreement is slightly better if V_{us} is determined only from hyperon beta decays. Here averaging the main experimental results the result is [9]:

$$(V_{us})_{Hyp} = 0.2250 \pm 0.0027$$

This value is substantially in agreement with both the set of measurements on kaon beta decays and on neutron beta decay, but the experimental and theoretical uncertainties are larger. In this context new data would be desirable.

The second aspect is the study of the form factors appearing in the decay amplitudes of the decay. Here we can search for SU(3) breaking effects and extract useful information on the mechanism of the possible breaking.

Up to now there is only one work extracting form factors for the Ξ^0 beta decay [10]. That measurement gives

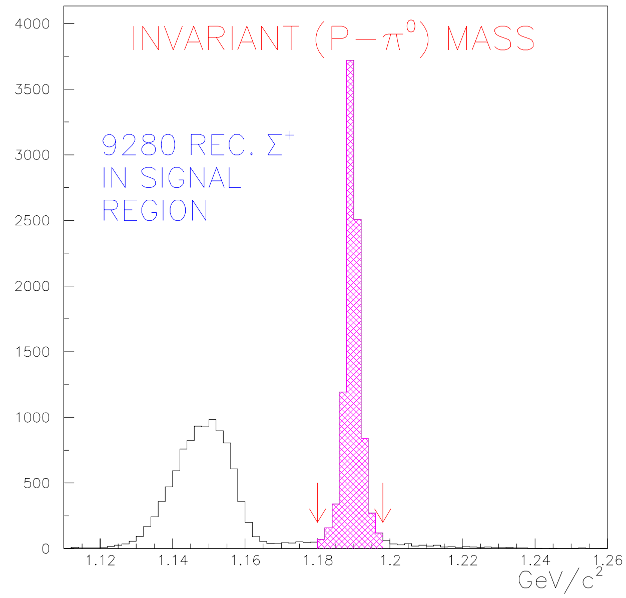

Fig. 2. After a preliminary analysis this is the spectrum we obtain for the p π^0 invariant mass. The peak in the region of Σ^+ mass (1.189 GeV/c^2) is the clear signature of Ξ^0 beta decay. The background on the *left* of the signal region is mainly due to the decay $\Xi^0 \to \Lambda^0\pi^0$ with a subsequent beta decay for the Λ^0

the value of the ratio between g_1, the axial-vector form factor and f_1, the vector form factor. The result doesn't show SU(3) breaking effects, since the ratio is compatible with the one measured in neutron beta decay. Indeed here more precise results are also useful.

In the 2002 run NA48 has collected the largest world sample of Ξ^0 beta decay events.

The γs coming from the π^0 decay are detected with the LKr calorimeter; combining this information with the tracks detected in the spectrometer we can first fully reconstruct the Σ^+ decay vertex (position and 4-momentum) and then we can also find the position of the primary vertex corresponding to the Ξ^0 beta decay.

After a preliminary analysis, considering all the data collected in 2002 run, we find ∼9000 events. At this level the background estimation is around 3%. The statistics is more than a factor 10 larger with respect to the other existing samples for the same decay. The results are shown in Fig. 2.

The statistics power of the 2002 run is emphasized in Fig. 3 which shows the data collected for the Ξ^0 semileptonic decay with an outgoing muon. After the background subtraction we remain with ∼100 events. This sample shows a remarkably clear evidence for the decay $\Xi^0 \to \Sigma^+\mu^-\bar{\nu}_\mu$.

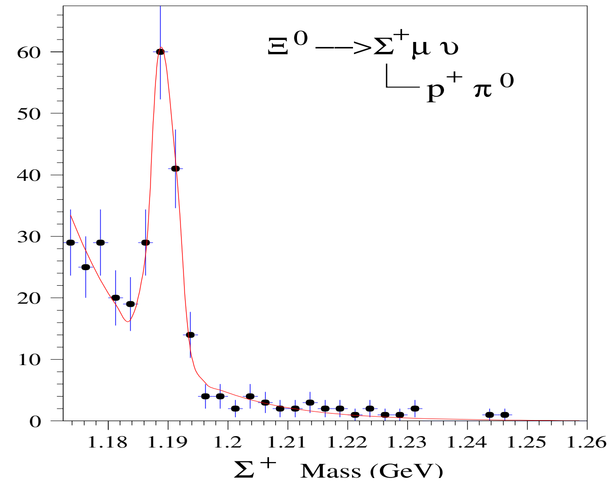

Fig. 3. invariant p-π^0 mass for the decay $\Xi^0 \to \Sigma^+\mu^-\bar{\nu}_\mu$

6 Ξ^0 radiative decays

Radiative hyperon decays between flavour octet states are allowed by isospin conservation in the SU(3) symmetry framework. The Σ^0 and Λ^0 are orthogonal three quark states with different isospin. Then the study of the radiative decays $\Xi^0 \to \Lambda^0\gamma$ and $\Xi^0 \to \Sigma^0\gamma$ gives information about SU(3)-breaking effects. Since non-leptonic weak interaction are complicated by hadronic effects, different model calculations result in branching ratios ranging over an order of magnitude. To understand the same hadronic effects is also useful to measure the decay asymmetry on the distribution of emitted particles.

In the 2002 run we were able to increase the event sample size at least by a factor of 100 with respect to the previous measurements.

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