RARE Ξ^0 DECAYS: NEW RESULTS FROM NA48

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The NA48 Collaboration has investigated rare decays of the Ξ^0 hyperon. Using data collected during a special high intensity run at the end of 1999, we determined the following preliminary branching fractions of the weak radiative decays to $\Lambda\gamma$ and $\Sigma^0\gamma$: $\mathrm{Br}(\Xi^0 \to \Lambda\gamma) = (1.9 \pm 0.1 \pm 0.2) \times 10^{-3}$ and $\mathrm{Br}(\Xi^0 \to \Sigma^0\gamma) = (3.7 \pm 0.5) \times 10^{-3}$. In addition, we report on the observation of the Ξ^0 beta decay and a search for the $\Delta S = 2$ transition $\Xi^0 \to p\pi^-$.

1 Introduction

Weak radiative Ξ^0 decays can be used to study the mechanisms of SU(3) symmetry breaking. However, past investigations have not led to a conclusive picture. On the theoretical side, a variety of models exist with predictions varying by an order of magnitude.[1,2,3,4,5] Experimentally, the situation is unclear, too: Branching ratio measurements agree for $\Xi^0 \to \Sigma^0\gamma$,[6,7] but do not for $\Xi^0 \to \Lambda\gamma$.[6,8]

The interest in $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$, the analogue to neutron beta decay, stems from its potential to study flavor symmetry violation.

Last but not least, the theoretical prediction for the $\Delta S = 2$ transition $\Xi^0 \to p\pi^-$ is of order 10^{-17}.[9] An observation would therefore be an unambiguous sign for new physics.

2 Experimental Set-Up

2.1 Beam-Line Set-Up

The data used for the analyses described here were taken with the NA48 detector at CERN during a two-day special data taking period in September 1999. The NA48 experiment has been designed to measure the parameter $\mathcal{R}(\epsilon'/\epsilon)$ of direct CP violation in the decay of neutral kaons to two pions. In the usual data taking mode, a 450 GeV/c proton beam from the CERN-SPS is directed to two different targets. The first ("K_L") target, around 120 m upstream of the decay volume, is exposed to the full proton beam intensity and produces a pure K_L beam. A small fraction of the protons which pass the K_L target is redirected to a second ("K_S") target — about 6 m upstream of the fiducial volume — to generate a neutral beam consisting mainly of K_S mesons and neutral hyperons. However, during the special period used for the investigations decribed here, this beamline was altered: The K_L target was removed and a proton beam with about 200 times the usual intensity was directed to the K_S target.

2.2 The NA48 Detector

The detector components most relevant to measure Ξ^0 decays are the magnetic spectrometer and the liquid krypton calorimeter.

The spectrometer consists of four drift chambers, each comprised of eight planes of sense wires in 4 different views. Between the second and the third drift chamber a dipole magnet applies a kick of 265 MeV/c to the horizontal transverse momenta of charged particles. The momentum resolution is $\Delta p/p = 0.5\% \oplus 0.009\% \times p[\mathrm{GeV/c}]$.

The quasi-homogeneous liquid krypton electromagnetic calorimeter consists of an electrode structure of copper/beryllium ribbons in longitudinal direction, forming 13212 read-out cells with 2×2 cm^2 cross section each. The energy resolution is $\Delta E/E = 3.2\%/\sqrt{E[\mathrm{GeV}]} \oplus 0.5\% \oplus 100\ \mathrm{MeV}/E$.

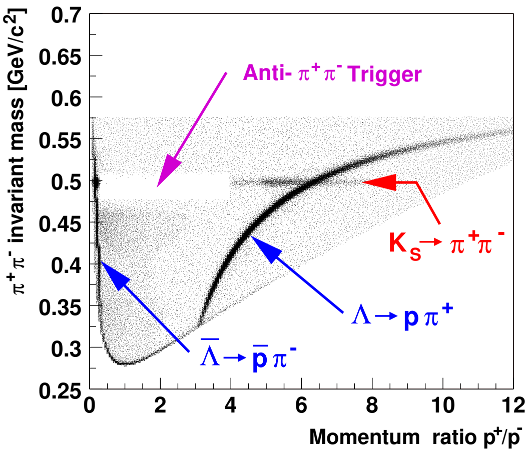

Figure 1. Invariant 2-track mass under the assumption of two pions versus the momentum ratio between the positive and the negative track. The $K_S \rightarrow \pi^+\pi^-$ anti-trigger is clearly visible as well as the 'banana-shape' $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ candidates. The flatly distributed background is mostly due to $K_L \rightarrow \pi^+\pi^-\pi^0$ decays.

2.3 Trigger Conditions

For the K_S and hyperon data taking, the trigger conditions were changed with respect to normal ϵ'/ϵ running. To suppress $K_S \rightarrow \pi^+\pi^-$, a special two-track trigger was applied, requiring the invariant mass of the two charged tracks (under $\pi^\pm$ assumption) to be inconsistent with the nominal K^0 mass *and* the ratio p^+/p^- between the momenta of the positive and the negative track to be greater than 4 or smaller than 0.25. The effect of these trigger conditions is shown in Fig. 1.

In total, 41 million 2-track events were collected, including 17 million $\Lambda \rightarrow p\pi^-$ and about 2 million $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ decays.

3 Event Selection and Normalization

The following essential selection criteria were applied: The charged tracks have to be less than 4.5 ns apart in time and are required to form a vertex within 40 m of the target. Under a $p\pi^-$ assumption, the invariant mass of the track pair has to be within 2.5 MeV/c^2 of the nominal Λ or Ξ^0 mass, respectively.

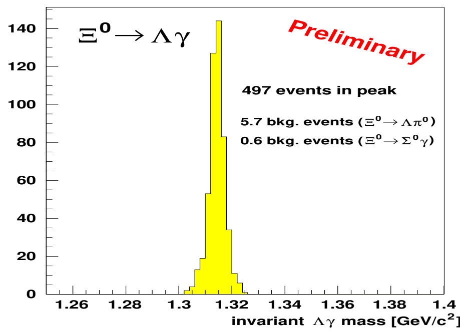

Figure 2. Invariant $\Lambda\gamma$ mass for $\Xi^0 \rightarrow \Lambda\gamma$ candidates.

Photon candidates in the calorimeter are required to be within 3 ns in-time with the tracks, to have an energy greater than 3 GeV (15 GeV for $\Xi^0 \rightarrow \Lambda\gamma$), and to be well separated from the track extrapolations and from the calorimeter edges. Candidate π^0's have to have an invariant $\gamma\gamma$ mass within 10 MeV/c^2 of the nominal π^0 mass. In addition, all $K_L \rightarrow \pi^+\pi^-\pi^0$ candidates are rejected.

The abundant decay $\Xi^0 \rightarrow \Lambda\pi^0$ is used for normalization. With two charged tracks plus calorimeter activity it has a topology similar to those of the investigated decays. As the dominant Ξ^0 decay, it is virtually free of any backgrounds. Applying the selection criteria described above, we find about 115,000 accepted candidates. With an acceptance of 4.7%, derived from Monte Carlo simulation, this number corresponds to a total of about 2.45 million Ξ^0 decays in the fiducial volume.

4 Results

4.1 $\Xi^0 \rightarrow \Lambda\gamma$

We observe 497 candidates for the decay $\Xi^0 \rightarrow \Lambda\gamma$ (Fig. 2). The background estimate is 5.7 events from $\Xi^0 \rightarrow \Lambda\pi^0$ and 0.6 events from $\Xi^0 \rightarrow \Sigma^0\gamma$ decays with missing photons in the signal region. The detection efficiency is 10.5%. From this, we obtain a preliminary branching ratio of

$$\mathrm{Br}(\Xi^0 \rightarrow \Lambda\gamma) = (1.9 \pm 0.1 \pm 0.2) \times 10^{-3}.$$

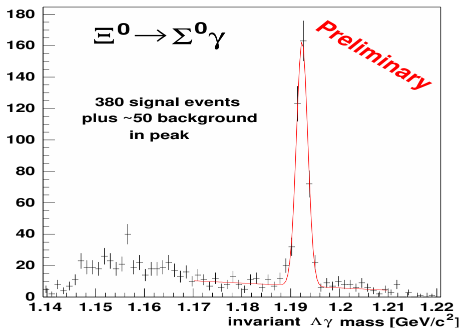

Figure 3. Invariant $\Lambda\gamma$ mass for $\Xi^0 \to \Sigma^0\gamma$ candidates. The Ξ^0 mass was used as constraint. The line is the fit to signal and background.

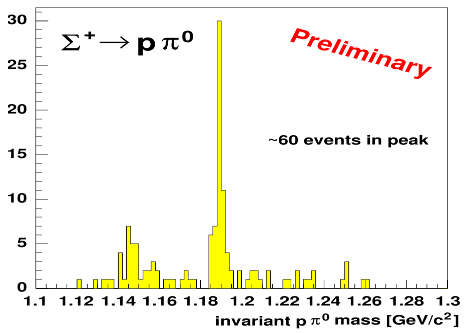

Figure 4. Invariant $p\pi^0$ mass for $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$ candidates.

The systematic error is dominated by uncertainties in the Ξ^0 polarization and the $\Xi^0 \to \Lambda\gamma$ decay asymmetry. The result is in agreement with a previous NA48 measurement on a different data set.[6] However, it is inconsistent with the Fermilab measurement.[8]

4.2 $\Xi^0 \to \Sigma^0\gamma$

The Σ^0 directly decays to $\Lambda\gamma$. The $\Xi^0 \to \Sigma^0\gamma$ decay therefore has a signature similar to $\Xi^0 \to \Lambda\pi^0$. Our Σ^0 signal, shown in Fig. 3, contains roughly 380 events on top of a background of about 50 events. The background is consistent with arising exclusively from $\Xi^0 \to \Lambda\pi^0$ decays. The detection efficiency has been determined to be 4.1%. We obtain

$$\mathrm{Br}(\Xi^0 \to \Sigma^0\gamma) = (3.7 \pm 0.5) \times 10^{-3}$$

(with statistical and systematic error combined), in agreement with a previous Fermilab measurement.[7]

4.3 $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$

The Σ^+ candidates are selected via their decay to $p\pi^0$. The background stems from $\Xi^0 \to \Lambda\pi^0$ with subsequent $\Lambda \to p\pi^-$ or $\Lambda \to pe^-\bar{\nu}_e$ decays. Fig. 4 shows the Σ^+ signal for events with an additional e^-. We find roughly 60 signal candidates and expect to have a future measurement of the branching fraction with an accuracy of $\sim 15\%$.

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

For $\Xi^0 \to p\pi^-$ we expect backgrounds only at small decay lengths and therefore require the two-track vertex to have a distance greater than 10 m from the target. We find no event in the signal mass region and expect to obtain an upper limit of $\mathcal{O}(10^{-6})$, which is about an order of magnitude below the existing limit.[10]

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