

Recent results in hyperon physics from the NA48 and KTeV experiments

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Recent results from the NA48 and KTeV experiments on neutral hyperon decays are presented.

1. INTRODUCTION

The NA48 experiment was performed at the CERN SPS accelerator and used a 400 GeV/c proton beam impinging on a Be target to produce a neutral beam [1]. In 2002, the beam line was modified to increase the K_S and neutral hyperon intensity while the K_L line was blocked. The target position and the production angle (-4.2 mrad) were chosen in such a way that the beam axis passed through the center of the electromagnetic calorimeter [2]. In order to minimize the interaction of the neutral beam with air, the final collimator was followed by a 90 m long evacuated tank terminated by a 0.3% X_0 thick kevlar window. The NA48 detector [1] was located downstream of this region in order to collect the products of the particles decaying in the volume contained by the tank. For a detailed description of the detector and the trigger, see [2]. On average, about 1.4×10^4 Ξ^0 per spill, with energy between 70 and 220 GeV, decayed in the fiducial volume (vertex position between 5 m and 50 m from the target). In this fiducial volume large numbers of $\Xi^0 \rightarrow \Lambda\pi^0$ and $\bar{\Xi}^0 \rightarrow \bar{\Lambda}\pi^0$ were recorded: $N(\Xi^0) = (2.422 \pm 0.003_{stat} \pm 0.018_{syst}) \cdot 10^9$, $N(\bar{\Xi}^0) = (2.254 \pm 0.012_{stat} \pm 0.017_{syst}) \cdot 10^8$ and mainly used for normalizing the various branching ratio measurements. The accumulated statistics allow high precision studies of K_S and hyperons.

The KTeV experiment took place at the Tevatron accelerator. The data analysed here were taken in 1999 during the E799-II configuration of KTeV [3]. An intense 800 GeV/c proton

beam was directed onto a BeO target. After a system of collimators, converters and dipoles, the surviving neutral beams entered a 65 m long vacuum tank, that defined the decay region, which began 94 m from the target. The KTeV detector was located downstream of this region; for a detailed description of the detector and the trigger, see [3]. About 3×10^8 Ξ^0 decayed in the decay region, with momentum peaked at 290 GeV/c. The sweeping magnets in the beamline were designed and operated so that the integrated magnetic field delivered Ξ^0 hyperons polarised (with about 10% polarization) in the positive or negative vertical direction. The magnetic field was reversed regularly so that the net polarization was zero for the data discussed here.

2. Ξ^0 BETA DECAYS

The study of hadron beta decays gives important information on the interplay between the weak interaction and hadron structure, determined by the strong interaction. In this context the Ξ^0 beta decay allows testing both of SU(3) symmetry, via its strong analogy with the well-known neutron beta decay, and of the quark mixing model, via extraction of V_{us} (the sine of the Cabibbo angle).

NA48 collected a sample of 6316 $\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e$ events (with the Σ^+ decaying into $p\pi^0$) with energy between 70 and 220 GeV and decay vertex between 5 m and 50 m from the final collimator. With a background of about 2%, a value for the branching ratio has been extracted: $BR(\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e) = (2.51 \pm 0.03_{stat} \pm 0.09_{syst}) 10^{-4}$, where the systematic error is dominated by the trigger efficiency determination, the geometrical ac-

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ceptance and the form factors. This value is in agreement with the KTeV measurement, based on 625 events: $BR_{KTeV}(\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e) = (2.54 \pm 0.11_{stat} \pm 0.16_{syst})10^{-4}$ [4]. Including the dependence of the form factors on the momentum transfer and the radiative corrections, the value for V_{us} extracted from the branching ratio measurement is: $V_{us} = 0.208 \pm 0.006^{+0.030}_{-0.025} g_1/f_1$, in agreement with the Standard Model expectation of 0.2274 ± 0.0021 [5]. The systematic error is largely dominated by the error on the ratio of the form factors $g_1/f_1 = 1.267 \pm 0.035$ taken from PDG. Alternatively, a value for g_1/f_1 can be extracted from the measured branching ratio, using $V_{us} = 0.2257$ [5], giving: $g_1/f_1 = 1.20 \pm 0.04_{br} \pm 0.03_{ext}$, where the last uncertainty includes contributions from V_{us} , Ξ^0 lifetime and form factor f_2/f_1 . The agreement with the prediction for exact SU(3) symmetry favours SU(3) breaking models that leave g_1/f_1 unchanged.

A sample of 102 $\Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}_\mu$ events was selected, with a background of 32 ± 3.0 (see Fig. 1). Using the electron decay as normalization channel, the measurement of the muon branching ratio was extracted: $BR(\Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}_\mu) = (2.2 \pm 0.3_{stat} \pm 0.2_{syst})10^{-6}$. This is the largest sample of semi-muonic decays so far collected.

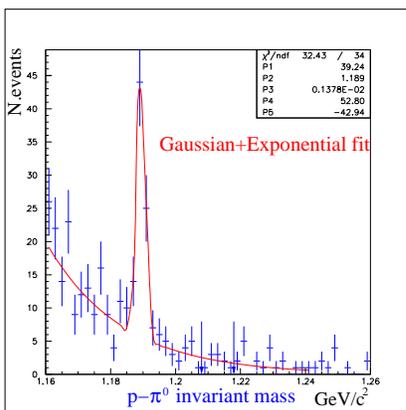


Figure 1. Distribution of $p\pi^0$ invariant mass for selected events with negative muon in NA48. A clear signal for Σ^+ is visible.

KTeV collected a sample of 9 $\Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}_\mu$ events (with the Σ^+ decaying into $p\pi^0$), and a sample of 1139 $\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e$ for normalization purpose, requiring 2 charged particles (one being an electron or a muon) and 2 neutral clusters. The distribution of events that survived the selection is shown in a plot of p_t^2 (the square of the transverse momentum relative to the beam) of the $\Sigma^+ \mu^-$ versus the invariant mass of the $p\pi^0$ system (see Fig. 2). For details on the selection, see [3]. The box is defined by the Monte Carlo simulation to accept 90% of the signal events. There are 9 signal events inside the box, clustered around $1.189 \text{ GeV}/c^2$, and 1 event outside. The background, evaluated using Monte Carlo simulation and data with wrong sign assignments for tracks, was found to be negligible inside the signal box; 54 background events were subtracted from the normalization channel. Using these samples, the ratio of the decay rates is measured to be $\Gamma(\Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}_\mu)/\Gamma(\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e) = (1.8^{+0.7}_{-0.5}(stat) \pm 0.2(syst)) \times 10^{-2}$. The systematic uncertainties receive contributions from the statistics in the normalization mode, the ratio of acceptances, and the muon identification efficiency. Using the value $Br(\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e) = (2.7 \pm 0.4) \times 10^{-4}$ [6], the branching ratio for the muon semileptonic decay is found to be: $Br(\Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}_\mu) = (4.7^{+2.0}_{-1.4}(stat) \pm 0.8(syst)) \times 10^{-6}$, where the systematic error also includes the contribution from the uncertainty of the electron beta decay.

3. ASYMMETRY IN RADIATIVE DECAYS

The weak radiative hyperon decays are quite accessible experimentally, in terms of the branching ratio and the asymmetry of the baryon emission with respect to the initial spin. However, despite their simplicity, there are theoretical difficulties in explaining these decays, mainly because predictions using the quark model do not match predictions from an analysis at the hadron level[7]. Hara theorem proved that the asymmetry is zero in the SU(3) limit for Ξ^- and Σ^+ decays, assuming CP invariance and U-spin symmetry[10]. An estimate, based on single quark $s \rightarrow d$ transitions and that takes into account

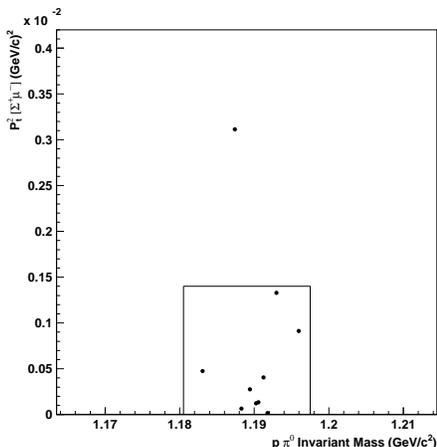


Figure 2. Distribution of $p\pi^0$ invariant mass for selected events with negative muon in KTeV.

SU(3) breaking, predicts a modest positive asymmetry[11]. However, the only asymmetry been accurately measured so far is -0.76 ± 0.08 for $\Sigma^+ \rightarrow p\gamma$ [12]. To constrain the theoretical models, it is important to measure accurately the parameters of weak radiative decays for all hyperons.

In the decay $\Xi^0 \rightarrow \Lambda\pi^0$, the proton angular distribution with respect to the Ξ^0 direction in the Λ rest frame can be written as $dN/d\cos\Theta_\Lambda = N_0(1 + \alpha_\Xi\alpha_\Lambda\cos\Theta_\Lambda)$, where α_Ξ is the weak decay asymmetry and $\alpha_\Lambda = 0.642$ is the Λ weak decay asymmetry. A similar formula is valid for $\Xi^0 \rightarrow \Lambda\gamma$, where the sign minus can be understood in terms of fundamental angular momentum considerations[5]: $dN/d\cos\Theta_\Lambda = N_0(1 - \alpha_\Xi\alpha_\Lambda\cos\Theta_\Lambda)$. This can be extended to the $\Xi^0 \rightarrow \Sigma^0\gamma$ decay, considering the angles $\Theta_{\Xi\Lambda}$ of the Λ direction with respect to the Ξ direction in the Σ rest frame, and $\Theta_{\Sigma p}$ of the proton direction with respect to the Σ direction in the Λ rest frame: $d^2N/d\cos\Theta_{\Xi\Lambda}d\cos\Theta_{\Sigma p} = N_0(1 + \alpha_\Xi\alpha_\Lambda\cos\Theta_{\Xi\Lambda}\cos\Theta_{\Sigma p}) = N_0(1 + \alpha_\Xi\alpha_\Lambda x)$.

From the 2002 data, NA48 selected $\sim 4 \times 10^6$ $\Xi^0 \rightarrow \Lambda\pi^0$, ~ 52600 $\Xi^0 \rightarrow \Lambda\gamma$ and ~ 15600 $\Xi^0 \rightarrow \Sigma^0\gamma$ events. The background is respectively 0.1% (mainly from $\Xi^0 \rightarrow \Sigma^0\gamma$), 0.7% (mainly from $\Xi^0 \rightarrow \Lambda\pi^0$, fake Λ s and fragments of 2 events

overlapping in time), and 3% (mainly from $\Xi^0 \rightarrow \Lambda\pi^0$). From these samples, measurements of the decay asymmetries were obtained from the respective distributions of $\cos\Theta$ (or x); the obtained values are shown in Table1, together with the previous measurements to which they all agree. In all cases, the NA48 measurements represent a significant improvement in precision. The major sources of systematic uncertainties come from the acceptance correction and the trigger efficiency.

Table 1

Preliminary NA48 measurements of asymmetries for weak Ξ^0 decays, compared to the previous ones from literature.

$\alpha_\Xi\alpha_\Lambda(\Lambda\pi^0)$	$-0.282 \pm 0.003_{stat} \pm 0.028_{syst}$
PDG	-0.264 ± 0.013
$\alpha_\Xi\alpha_\Lambda(\Lambda\gamma)$	$-0.439 \pm 0.013_{stat} \pm 0.038_{syst}$
NA48(1999)[8]	-0.50 ± 0.13
$\alpha_\Xi\alpha_\Lambda(\Sigma\gamma)$	$-0.438 \pm 0.020_{stat} \pm 0.041_{syst}$
KTeV[9]	-0.40 ± 0.06

4. Ξ^0 LIFETIME

Several experiments in the 1960s and 1970s performed measurements of the Ξ^0 lifetime, yielding a world average, based on an integrated data sample of less than 8000 events, of $\Gamma(\Xi^0) = (2.90 \pm 0.09) \times 10^{-10} s$ [5]. In the last 30 years or so, no new measurements have been published. The Ξ^0 lifetime is an important input to other Ξ^0 -related parameters, like V_{us} from hyperon beta decays, and is also theoretically interesting. When assuming the full validity of the $\Delta I = 1/2$ rule in hadronic weak decays, the decay matrix elements of the neutral and charged $\Xi \rightarrow \Lambda\pi$ should simply be connected by $M(\Xi^0 \rightarrow \Lambda\pi^0) = M(\Xi^- \rightarrow \Lambda\pi^-)/\sqrt{2}$ because of isospin arguments. Taking into account the slightly different masses of the particles involved, as well as the rare decays to other final states[5], the lifetimes should follow the relation $\Gamma(\Xi^0)/\Gamma(\Xi^-) \approx 2.031$. The comparison of measured lifetimes is a good test for $\Delta I = 1/2$ violating effects. Using the previous

measured lifetimes [5], the experimental value of the ratio is 1.77 ± 0.06 .

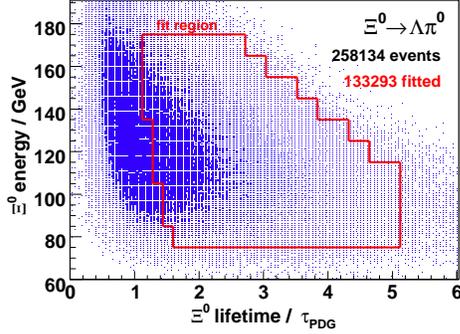


Figure 3. Distribution of Ξ^0 energy versus Ξ^0 lifetime in units of PDG lifetime.

From a sample of ~ 258000 $\Xi^0 \rightarrow \Lambda\pi^0$ events collected in NA48 with a minimum bias trigger, the Ξ^0 lifetime has been measured for decays that occur outside the final collimator. The distribution of Ξ^0 energy versus Ξ^0 lifetime in units of PDG lifetime is shown in Fig. 3 for collected events; the contour indicates the events used for the lifetime measurements. Distributions of lifetime for data and Monte Carlo events (simulated with the PDG lifetime) were produced and their ratio was fitted in 10 energy bins of 10 GeV each, from 75 GeV to 175 GeV. The distribution of the ratio, summed over all energy bins, is shown in Fig. 4. The distribution of the fit results, expressed as relative deviations from the PDG measurement, is flat in bins of Ξ^0 energy. The preliminary value obtained is $\tau(\Xi^0)/\tau_{PDG} = 1.0626 \pm 0.0044_{stat} \pm 0.0043_{syst}$ which corresponds to a lifetime of $\tau(\Xi^0) = (3.082 \pm 0.013_{stat} \pm 0.012_{syst}) \times 10^{-10}$ s. Using the measured value for $\Gamma(\Xi^-) = (1.639 \pm 0.015) \times 10^{-10}$ s[5], the ratio of the neutral over charged lifetime is found to be 1.880 ± 0.020 .

5. CONCLUSIONS

Recent results from the NA48 and KTeV experiments on neutral hyperon decays have been

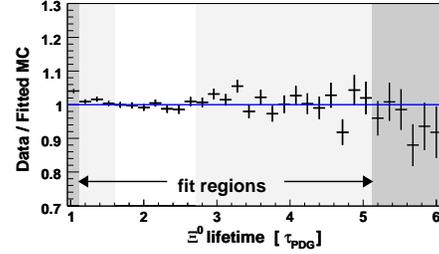


Figure 4. Ratio of lifetimes for data and Monte Carlo events (simulated with the PDG lifetime) as a function of Ξ^0 lifetime.

presented. Preliminary measurements have been summarised for the Ξ^0 muon-beta decay for both experiments; preliminary values from NA48 for the Ξ^0 lifetime and for weak decay asymmetries in various decay channels have been shown.

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