Hyperon physics in NA48

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The NA48 experiment at CERN has a program to study rare hyperon decays both as a byproduct of its ε'/ε running and as a separate experiment.

1. Introduction

The NA48 experiment at CERN was designed to measure direct CP violation in the neutral kaon system. Besides its main goal, the availability of an intense neutral beam and a high-performance detector allow other physics studies to be carried out, mainly concerning rare K^0 and hyperon decays.

Several interesting measurements of neutral hyperon properties are accessible to NA48:

- The measurement accuracy of the electromagnetic mass splitting $M(\Xi^-) - M(\Xi^0)$ is dominated by the error on the Ξ^0 mass (0.6 MeV/c^2), and is now accessible to lattice calculations. The high energy resolution of the NA48 calorimeter allows a precise measurement of the Ξ^0 mass, reaching the level of uncertainty of the Ξ^- mass.
- The measurement of hyperon radiative decays between flavour octet states gives information on SU(3)-breaking effects. The theoretical framework is unclear, with model-dependent predictions for the branching ratios spanning an order of magnitude.
- The beta decay of the Ξ^0 hyperon ($\Xi^0 \to \Sigma^+ e^- \nu$) was detected by the KTeV experiment Affolder et al. [1999], and it can be measured with great accuracy in NA48, allowing for new consistency checks of SU(3) flavour symmetry and the Cabibbo model (F/D couplings).
- The double strangeness-changing decay $\Xi^0 \to p\pi^-$ should be driven by second-order weak interactions, and the current experimental limit on this branching ratio is $\leq 4 \cdot 10^{-5}$ at 90% confidence level, which could be improved by a large amount.
- Measurement of the $\overline{\Xi}^0$ mass and improvements on the knowledge of Ξ^0 lifetime, neutral hyperon polarizations and form factors should be possible, as well as Σ^0 physics from $\Xi^0 \to \Sigma^0\gamma$ decays. Other possibilities include the improvement of the measurement of the Λ semi-leptonic decay ($\Lambda \to p\mu^-\overline{\nu}$ is measured with ~ 10 events), and the search for $\Sigma^0 \to \Lambda\gamma\gamma$ decays.

2. The experiment and the detector

In NA48, during ε'/ε running, the K_S beam is derived from a small fraction ($\sim 3.7 \cdot 10^7$ out of $1.5 \cdot 10^{12}$ per 2.4 s SPS pulse) of the primary 450 GeV/c protons used to produce a K_L beam. The proton beam can be directed without loss directly on the K_S production target, located 6 m before the beginning of the 40 m long fiducial region for decays. This allows an increase of the K_S beam intensity by a large factor ~ 500 with respect to the two-beam configuration. The average Ξ^0/Λ decay length is about 10 m.

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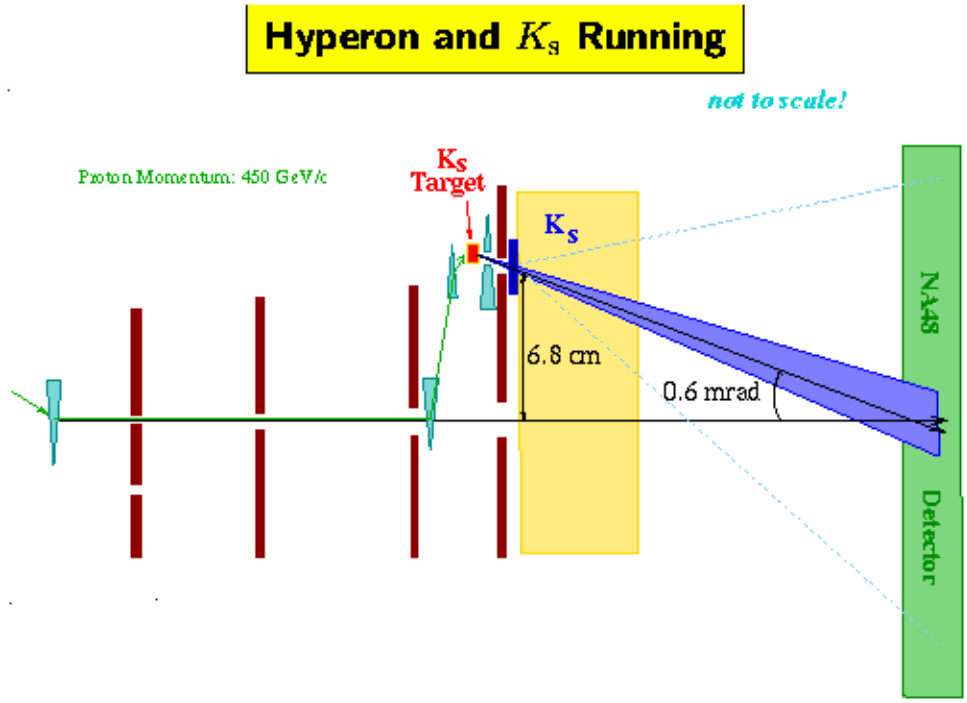

Figure 1: Schematic drawing of the single-beam NA48 beam setup.

Neutral particles are detected in NA48 by a fine-grained quasi-homogeneous liquid krypton calorimeter, working as an ionization chamber with no gain and longitudinal tower structure Barr et al. [1996]. The initial current induced by the ionization drift on copper ribbon electrodes in the ≈ 13000 2×2 cm^2 cells is read and continuously flash-digitized at 40 MHz, allowing for a fast response and high-rate capability. The energy resolution is measured to be $\sigma(E)/E = 3.2\%/\sqrt{E(\mathrm{GeV})} \oplus 90\,\mathrm{MeV}/E \oplus 0.42\%$ and the spatial resolution better than 1.3 mm above 20 GeV.

Charged particles are detected by a magnetic spectrometer, consisting of four large drift chambers and a dipole magnet providing a 265 MeV/c transverse momentum kick. Each chamber Anvar et al. [1999] has four double planes of staggered wires with $\simeq 99.5\%$ efficiency. The momentum resolution is measured to be $\sigma(p)/p = 0.5\% \oplus 0.009\% \cdot p$ (GeV/c), resulting in a Λ mass resolution below 1 MeV/c^2. Other detectors are used for triggering and background suppression, such as a plastic scintillator hodoscope, a hadron calorimeter, a set of muon counters and annular veto counters.

Up to ~ 400 times the standard ε'/ε proton flux (i.e. $1.2 \cdot 10^{10}$ ppp) can be achieved with the present detector, and more with modest upgrades, and a proposal for a studying rare K_S and hyperon decays has been approved by CERN to run in 2002 Batley et al. [2000]. The SPS will run with improved duty cycle (5.2 s over 14.4 s), and the rates on detectors will be within a factor 1.5 with respect to the standard running conditions.

3. Test run results and perspectives

A two-day special run with $7 \cdot 10^9$ protons per spill on the K_S target (200 times the ε'/ε intensity) was performed in 1999, corresponding to ≈ 17 million $\Lambda \to p\pi^-$ decays and ≈ 2 million $\overline{\Lambda} \to \overline{p}\pi^+$ decays in the detector. The trigger was based on two-track events, with an invariant-mass cut to reject $K_S \to \pi^+\pi^-$ decays.

Using $\Xi^0 \to \Lambda\pi^0 \to p\pi^-\gamma\gamma$ as normalization channel, roughly 115000 background-free $\Lambda\pi^0$ decays were collected, together with ~ 500 $\Xi^0 \to \Lambda\gamma$ (with $\sim 1\%$ background) and ~ 400 $\Sigma^0\gamma$ (with $\sim 10\%$ background).

A preliminary measurement from this data is $\mathrm{BR}(\Xi^0 \to \Lambda\gamma) = (1.9 \pm 0.1 \pm 0.2) \cdot 10^{-3}$, whose main systematics error is due to the Ξ^0 polarization and asymmetry.

The $\Xi^0 \to p\pi^0$ decay suffers from severe background due to $\Xi^0 \to \Lambda\pi^0$ with non-leptonic or semi-leptonic decay of the Λ. Roughly 60 events were found in the 1999 sample, allowing for a $\sim$ 15% measurement. The same data could allow improvement of the $\Xi^0 \to p\pi^-$ branching ratio limit by a factor of 10.

A 40-day high-intensity single-beam run was performed in year 2000, with no magnetic spectrometer available. A continuous vacuum was established up to the scintillator hodoscope, and 400 GeV/c protons were used, with 3.2/14.4 SPS duty cycle. $\sim 9 \cdot 10^9$ protons per pulse were delivered on target, resulting in $\approx$ 40 million $\Lambda \to p\pi^-$ decays in the detector. The data collected during this run is being analyzed.

4. Conclusions

The best measurements of branching ratios for neutral hyperon radiative decays are from the KTeV experiment, which measured a few thousands of each; in 2002 the NA48 sample of radiative hyperon decays should reach several thousands for both $\Xi^0 \to \Lambda\gamma$ and $\Xi^0 \to \Sigma^0\gamma$, thus allowing - together with a reduction of the current systematics by a factor 2 - to obtain a measurement with 5% accuracy.

Preliminary results on beta decays of the Ξ^0 have been also shown by KTeV Affolder et al. [1999], with $\sim$ 600 $\Xi^0 \to \Sigma^+ e^- \overline{\nu}$ and 5 $\Xi^0 \to \Sigma^+ \mu^- \overline{\nu}$ decays. Around 25000 Ξ^0 beta decay events should be collected in 2002, and the current limit on the Ξ^0 $\Delta S = 2$ decay should be improved by a factor 100.

Moreover, during the 2002 run it should be possible to reach an accuracy of 0.1 MeV/c^2 on the Ξ^0 mass measurement.

The experimental program of the NA48/2 experiment is well defined and the analysis of test runs' data is in progress. The technical preparation for the 2002 high-intensity run is well under way.

References

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