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Results and prospects on kaon physics with the NA62 experiment at CERN

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Summary. — The measurement of the ratio of the rates of leptonic kaon decays performed by NA48/2 and NA62 (R_K phase) experiments is presented, together with the description of the NA62 experiment that will start collecting data in 2015 at the CERN SPS with the main goal of measuring the branching ratio(BR) of the rare decay $K^+ \to \pi^+ \nu\bar{\nu}$ with a precision of 10%.

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PACS 12.15.Hh – Determination of CKM matrix elements.

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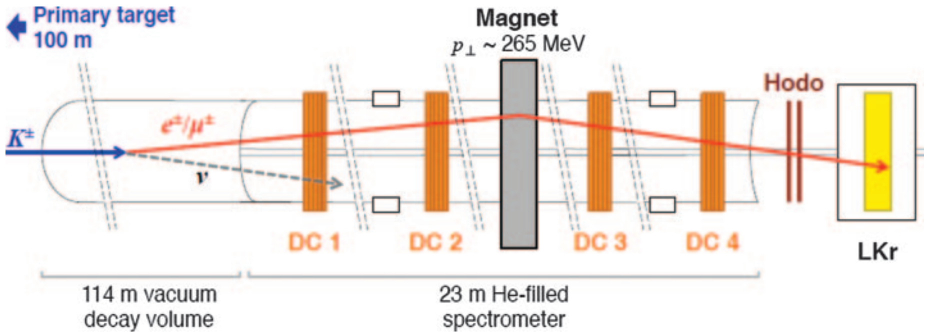

Fig. 1. – NA48 and NA62 (R_K phase) experimental layout.

1. – NA48/2 and NA62 (R_K phase) beams and detector

In 2003-04 the NA48/2 experiment at the CERN SPS collected the world largest sample of charged kaon decays, with the main goal of studying direct CP violation [1]. In 2007-08 the NA62 experiment (R_K phase) collected data with the same beam line and experimental setup but different data taking conditions, with the main goal of measuring the ratio of the rates of leptonic kaon decays [2]. An unseparated charged kaon beam was used, produced by the 400 GeV/c primary proton beam from SPS hitting a beryllium target. A 100 m long beam line selected the momentum of the secondary beam to (75 ± 3) GeV/c and the beam entered a decay volume, housed in a 100 m long vacuum tank. The detector (see fig. 1) was designed to detect particles from the kaon decays in the vacuum region. In order to track the charged particle from the K^+ decays, a magnetic spectrometer, consisting of 4 drift chambers separated by a dipole magnet, was used. It provided a transverse momentum kick of 265 MeV/c, corresponding to a momentum resolution of $\sigma_p/p = (0.48 \oplus 0.009 \times p)\%(p \text{ in GeV}/c)$. A scintillator hodoscope gave the main trigger for the event topologies including charged particles and set the time reference for the other detectors. A quasi-homogeneous electromagnetic calorimeter with liquid kripton as active material (LKr) was used mainly for particle identification. The measured energy resolution was $\sigma(E)/E = 0.032/\sqrt{E} \oplus 0.09/E \oplus 0.0042(E \text{ in GeV})$.

2. – NA62 results on R_K

The decays of pseudoscalar mesons to light leptons are helicity suppressed in the Standard Model (SM) due to the $V - A$ structure of the electroweak charged current coupling. Because of the decay constant f_P, the SM predictions for leptonic decay rates are affected by hadronic uncertainties; however ratios of decay rates of the same parent meson do not depend on f_P and can be computed very precisely. In particular, the SM prediction for $R_K = \Gamma(K^\pm \to e^\pm \nu_e)/\Gamma(K^\pm \to \mu^\pm \nu_\mu)$, inclusive of internal bremsstrahlung (IB) radiation, is [3]

$$(1) \qquad R_K^{SM} = \left(\frac{M_e}{M_\mu}\right)^2 \left(\frac{M_K^2 - M_e^2}{M_K^2 - M_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \times 10^{-5},$$

where $\delta R_{QED} = (-3.79 \pm 0.04)\%$ is the electromagnetic correction. Within extensions of the SM involving two Higgs doublets, R_K is sensitive to lepton flavour violating effects induced by loop processes with the charged Higgs boson exchange [4].

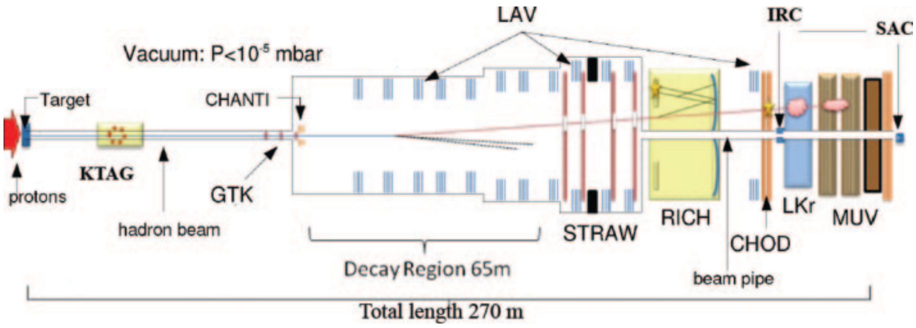

Fig. 2. – NA62 experimental layout.

About 65% of data were taken with the K^+ beam only, 8% with the K^- only and the rest with simultaneous $K^\pm$. Dedicated data taking were performed in order to validate with data the background estimation. In particular 55% of data were collected with a lead bar in front of the LKr) to measure directly on data the μ-electron misidentification probability. The selection criteria and the analysis strategy including the treatment of all systematic effects are described in [2]. A sample of 145958 $K \to e\nu$ candidates, with an estimated background of $(10.95 \pm 0.27)\%$, was collected providing a final result with an overall uncertainty of 0.4%:

$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}. \tag{2}$$

3. – NA62 for $K^+ \to \pi^+\nu\bar{\nu}$ and other rare decays: strategy and prospects

The NA62 experiment will start its data taking in 2015 with a new generation detector [5], optimized for the experiment goal: the measurement of the BR of the ultra-rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$ with uncertainty less than 10%, collecting ~ 100 events in 3 years of data taking according to the SM branching fraction. This is a flavor changing neutral current (FCNC) process strongly suppressed in the SM, that predicts a BR of $(7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$ [6], and is dominated by top-quark loop contributions. Because of the excellent precision in the theoretical prediction even relatively small difference with respect to the SM could be a clear signal of new physics. In addition the precise measurement of $K^+ \to \pi^+\nu\bar{\nu}$ will be an alternative measurement of V_{td} with respect to the B decays. Experimentally 7 candidates of the $K^+ \to \pi^+\nu\bar{\nu}$ decay have been observed by the BNL E787/E949 experiments with a BR of $1.73^{+1.15}_{-1.05} \times 10^{-10}$ [7].

The layout of the NA62 experiment is shown in fig. 2. A high intensity and high energy kaon beam is exploited to provide kaon decays in flight over a long decay region. It is part of an unseparated hadron beam obtained, like for NA62 R_K phase, by the primary 400 GeV/c proton beam from the SPS accelerator impinging on a beryllium target. About 6% of the total amount of particles in the secondary 75 GeV/c beam are kaons; the rest are mainly pions ($\sim 70\%$) and protons ($\sim 23\%$). The identification of the kaons in the beam is done by a differential hydrogen Čerenkov counter (KTAG). A silicon pixel beam spectrometer (Gigatracker) placed on the hadron beam, measures the momentum and the direction of the particles working at a rate of 750 MHz. A CHarged ANTI-counter (CHANTI) follows, which is required in order to reduce the critical background induced by inelastic interaction of the beam with the collimator and the Gigatracker stations. The decay region is housed in a ~ 80 m long ~ 2.5 m diameter evacuated tube

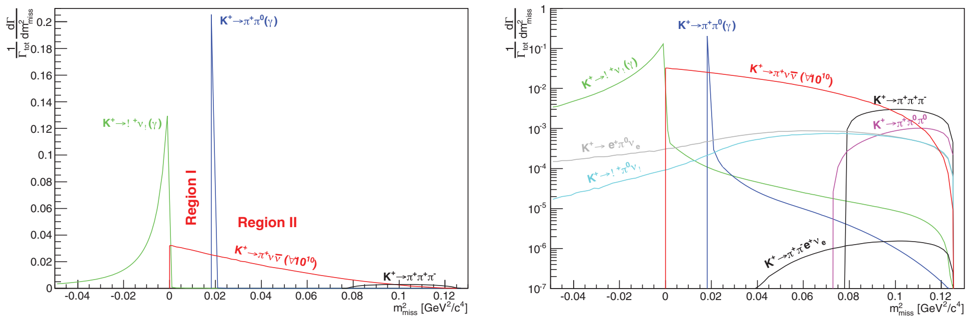

Fig. 3. – Shape of the squared missing mass for signal and background events under the hypothesis that the charged track is a pion.

(10^{-6} mbar). The charged particles produced in kaon decays (pions, muons and electrons) are measured by a straw tubes spectrometer (STRAW), composed by four stations and an analyzing magnet integrated directly inside the evacuated decay region. The Straw spectrometer is very thin ($< 0.5X_0$ per chamber) to minimize the interactions of photons coming from the kaon decays. The LKr (the same used for the NA48/2 and NA62 R_K phase) is devoted to measure photons and electrons in the forward direction. A group of 12 rings of lead glass blocks (LAVs) are placed along the decay region to identify the large angle photons. A 1 atm Neon RICH is used to distinguish among muons and pions in the 15–35 GeV/c range, increasing the particle identification power of the muon identification system (MUVs) placed just beyond the LKr.

The signature of the signal is one track in the final state matched to one K^+ track in the beam. Backgrounds come from all the kaon decays with one track left in the final state and from accidental tracks reconstructed downstream matched by chance to a track upstream. The variable m^2_{miss} is used for the kinematic rejection and it defined as

$$m^2_{miss} = (P_K - P_\pi)^2 \tag{3}$$

where P_K and P_π are the measured four-momenta of the K^+ and π^+. It defines two regions (region I and region II) almost free of the backgrounds coming from the main K^+ decays (see fig. 3). The residual sources of background are tails of the m^2_{miss} of the main K^+ decay channels due to the detector resolution and to the corresponding radiative processes, semileptonic K^+ decays like $K^+ \to e^+\pi^0\nu_e$ and rare decays like $K^+ \to \pi^+\pi^-e^+\nu_e$.

Different techniques have to be employed in combination to reach the required level of background rejection: kinematic rejection, precise timing, high efficient photon vetoes, precise particle identification systems to distinguish π^+, μ^+ and e^+. The kinematic rejection requires a minimal material budget for the kaon and pion tracking systems. A precise timing is required for a proper kaon-pion matching, given the different rate environments upstream and downstream. The detector is almost hermetic for photons originating from π^0 in the decay region and the overall photon veto system composed of LAV, LKR, SAC, IRC provides an inefficiency less than 10^{-8} for a π^0 coming from $K^+ \to \pi^+\pi^0$ decay. The conversions of low energy photons in the upstream material (RICH, beam tube) will be detected by the CHOD. Decays with muons in the final state will be suppressed using the muon-pion identification based on RICH and MUV for which the total inefficiency should be less than 5×10^{-6}.

Apart from the $K^+ \to \pi^+\nu\bar{\nu}$ process, the high kaon fluxes (accompanied by $2\times10^{12}\pi^0$ decays from $K \to \pi\pi^0$), the excellent particle identification capabilities and the precise kinematical reconstruction of the events will open several possibilities to improve the experimental knowledge on many rare or forbidden kaon decays. The measurement of R_K will be improved, pushing the experimental accuracy to a level closer to the theoretical one. Studies of the prospects for searches for lepton-flavor (LF) or lepton-number (LN) violating and other forbidden decays with NA62 are underway. Preliminary estimates of the single-event sensitivities (defined as the reciprocal of the product of the number of accepted decays) give results at the level of 10^{12} for K^+ decays to states such as $\pi^+\mu^\pm e^\mp$ (LFV), $\pi^-\mu^+e^+$ (LFNV), and $\pi^-e^+e^+$ or $\pi^-\mu^+\mu^+$ (LNV), and at the level of 10^{11} for π^0 decays to $\mu^\pm e^\mp$ [8].

4. – Conclusion

The most precise measurement of R_K has been performed from a sample of about 150×10^3 $K \to e\nu$ candidates collected by the NA48/2 and NA62 (R_K phase) experiments. The result is $R_K = (2.488 \pm 0.010) \times 10^{-5}$, consistent with the earlier measurements and with the SM prediction. The experimental uncertainty on R_K is still an order of magnitude larger than the one on the SM expectation. The NA62 experiment at the CERN SPS will start collecting data in 2015. The main goal of the experiment will be the measurement of BR of $K^+ \to \pi^+\nu\bar{\nu}$ decay, predicted by the SM with high precision. A discrepancy at level of $\sim 20\%$ with respect to the predicted value will be a clear signal of physics beyond the SM. With $10^{13}K^+$ in its fiducial volume in three years of data taking, the NA62 experiment will have a single event sensitivity of $10^{12}(10^{11})$ for a number of $K^+(\pi^0)$ LFV decays, as well as the potential to improve the upper limits for several searches for effects and particles not foreseen in the SM.

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