Standard Model Tests at the NA62 CERN Experiment

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Abstract.
The physics program of the NA62 experiment aims to search for phenomena beyond the Standard Model by measuring the ratio $R_K = \frac{\Gamma(K\to e\nu_e(\gamma))}{\Gamma(K\to\mu\nu_\mu(\gamma))}$ and studying the ultra rare decay $K^+ \to \pi^+\nu\overline{\nu}$. The status of the R_K analysis based on $\sim 40\%$ of the data collected during 2007 and 2008 is summarized and the proposed detector layout to measure the branching ratio of the $K^+ \to \pi^+\nu\overline{\nu}$ decay is described.

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THE NA62 EXPERIMENT

The NA62 experiment is a fixed target experiment located at the CERN SPS north area which inherits the experience, the infrastructure and some of the detectors from the NA48 apparatus. Two phases can be distinguished: the goal of the first one is the measurement of the ratio of leptonic kaon decay rates (R_K) with an precision better than 0.4%, the aim of the second is the measurement of $BR(K^+ \to \pi^+\nu\overline{\nu})$ with a $\sim 10\%$ accuracy.

PHASE I - $K_{e2}/K_{\mu 2}$

In the Standard Model of Particle Physics (SM) sub-permille accuracy can be reached in the prediction of ratios of purely leptonic decay rates of light pseudoscalar mesons ($R_p = \Gamma(p^\pm \to e^\pm\nu)/\Gamma(p^\pm \to \mu^\pm\nu), p = K,\pi$) due to the cancellation of hadronic uncertainties [1]. The R_K ratio can be written as:

$$R_K = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_{QED}) = (2.477 \pm 0.001) \times 10^{-5}$$

where $\delta R_{QED} = (-3.78 \pm 0.04)\%$ is a correction due to the *IB* part of the $K_{e2\gamma}$ radiative decay. By definition the *IB* part is included in R_K, while the *DE* structure dependent

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(SD^+) is not. The m_e^2/m_μ^2 factor accounts for the strong helicity suppression of the K_{e2} mode, which makes the amplitude sensitive to contributions from physics beyond the SM. Recently, it has been pointed out [2] that Lepton Flavour Violating effects arising in super-symmetric extensions of the SM can induce sizable violations of the $\mu - e$ universality, shifting R_K from the SM value by a relative amount that can be in the percent range.

The current world average $R_K = (2.45 \pm 0.11) \times 10^{-5}$ [3] dates back to three experiments performed in the 1970s and has insufficient precision ($\sim 4.5\%$) for stringent tests of the SM. A series of recent preliminary (NA48/2 [4]) and final (KLOE [5]) results represents a significant improvement that combined with the PDG value yields a precision of $\sim 1.3\%$. To further reduce this uncertainty, NA62 collected $\sim 160\,k$ K_{e2} decays during a dedicated run in 2007 and 2008, aiming to reach a precision on the R_K measurement of $\sim 0.4\%$ [6]. The presented results are based on a partial K^+ beam only data sample (40%).

Experimental setup

For its first phase, the NA62 apparatus was largely based on the existing NA48 detector; based on the experience of previous studies, the running conditions were optimized for the K_{e2} measurement. The K12 beam line is capable of delivering simultaneous $K^\pm$ beam with a narrow momentum band: a central value of $75\,GeV/c$ was chosen. Most of the data were recorded with the K^+ beam only because the muon sweeping system was more effective in rejecting μ^+; conversely, about 10% of the data were recorded with K^- beam only in order to measure the background induced by the beam halo via $\mu \to e$ decays. After passing a set of collimators, the kaon beam enters a fiducial decay volume in a $114\,m$ long cylindrical vacuum tank, which is followed by the main detector. The sub-detectors relevant for the measurement are:

- a magnetic spectrometer composed by four drift chambers (DCHs) and a magnet that provides the track reconstruction;
- a liquid krypton electromagnetic calorimeter (LKr) used for photon detection and particle identification;
- a plastic scintillator hodoscope (HOD) used for timing measurement and to produce fast trigger signals.

A detailed description of the apparatus can be found elsewhere [7].

A minimum bias trigger configuration was employed, resulting in relatively low purity, but high efficiency for leptons with momentum $p > 10\,GeV/c$.

The main data sample was taken during a four months long run in 2007: $\sim 4 \times 10^6$ SPS spills were recorded, corresponding to $300\,TB$ of raw data. Additional data were collected in 2008 to address in detail some systematic uncertainties.

Analysis technique

K_{e2} and $K_{\mu 2}$ decays were collected simultaneously, consequently the result does not rely on the kaon flux measurement and several systematic effects, such as parts of the trigger and detection efficiencies, cancel in the ratio. Monte-Carlo simulation is only used to evaluate geometric acceptance corrections and background contribution from energetic bremsstrahlung muons.

The measurement is performed by counting the reconstructed candidate events in track momentum bins (10 bins in the range $15 \div 65\, GeV/c$) due to a strong dependence of acceptances and backgrounds on this quantity:

$$R_K = \frac{N(K_{e2}) - N_{BG}(K_{e2})}{N(K_{\mu 2}) - N_{BG}(K_{\mu 2})} \cdot \frac{A(K_{\mu 2})}{A(K_{e2})} \cdot \frac{f_\mu}{f_e} \cdot \frac{\varepsilon(K_{\mu 2})}{\varepsilon(K_{e2})} \cdot \frac{1}{D} \cdot \frac{1}{f_{LKr}}$$

where $N(K_{l2})$ are the numbers of selected K_{l2} candidates ($l = e, \mu$), $N_{BG}(K_{l2})$ the numbers of background events, $A(K_{l2})$ the geometrical acceptances, f_l the particle ID efficiencies, $\varepsilon(K_{l2})$ the trigger efficiencies, D is the downscaling factor of the $K_{\mu 2}$ trigger and f_{LKr} the global read out efficiency of the electromagnetic calorimeter.

As the K_{e2} and $K_{\mu 2}$ decay modes are topologically equal, a large part of selection criteria are common for both channels leading to cancellations of the related systematic uncertainties. The two class of events are then separated using kinematical identification by reconstructing the squared missing mass (i.e. the neutrino mass) in the electron or muon track assumption according to $M^2_{miss}(l) = (P_K - P_l)^2$, where P_K and P_l ($l = e, \mu$) are the kaon and lepton four-momenta (the average momentum of the incoming kaons is measured with $K \to 3\pi$ decays). For track momenta higher than $25\, GeV/c$, where the kinematical separation is not possible, the ratio between the energy deposition in the calorimeter (E) and the momentum measured by the spectrometer (p) is used by requiring $0.95 < E/p < 1.10$ for electrons and $E/p < 0.85$ for muons.

Detailed studies based on data and Monte-Carlo events were performed in order to identify and measure the main background sources. The $K_{\mu 2}$ sample is almost background free ($B/S \sim 0.2\%$), while the following contributions to K_{e2} were identified (Fig. 1):

- $K_{\mu 2}$ **decay**: the probability for a muon to be mis-identified as an electron due to a high ("catastrophic") energetic bremsstrahlung in the LKr ($P(\mu \to e)$) is only few 10^{-6}; however, due to the helicity suppression of the K_{e2} mode, the background originating from $K_{\mu 2}$ decays turns out to be the major contribution; a direct measurement of $P(\mu \to e)$ with a few percent accuracy was performed on data by installing a $\sim 9\, X_0$ thick lead wall in front of the calorimeter; tracks traversing the wall and depositing $> 95\%$ of their energy in the LKr represent a sufficiently pure sample of catastrophic bremsstrahlung muons (electron contamination $< 10^{-7}$); the background contribution is $B/S = (7.4 \pm 0.2)\%$, where the accuracy can be improved by using the whole available data sample;
- $K_{e2\gamma}$ **decay**: the structure dependent (SD^+) radiative decay is considered a background by definition of R_K and its rate is similar to that of K_{e2}; the background contamination is estimated by a Monte-Carlo simulation to be $B/S = (1.6 \pm 0.3)\%$, where the large uncertainty is due to the poor knowledge of the process;

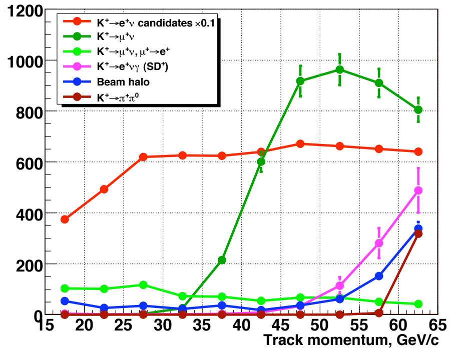

FIGURE 1. Numbers of K_{e2} candidates and background events in track momentum bin.

- **Beam halo**: the background induced by beam halo tracks via $\mu \to e$ decays is studied by looking at reconstructed K_{e2} candidates of the charge not present in the beam on separate K^+ and K^- beam only samples; the amount of induced background is $B/S = (1.23 \pm 0.07\%)$;
- **Other decay modes**: minor sources of background are electrons from $K_{2\pi}$ and K_{e3} decays (contributions at the level of 0.1%).

Analysis status and prospects

After applying all selection criteria, about $60\,k$ K_{e2} and $17.2\,M$ $K_{\mu 2}$ candidate events remain from a partial sample of 40% of the total accumulated statistics (Fig. 2). The total background to signal ratio in the K_{e2} sample is estimated to be $B/S = 12.3\%$; improvements for each background source are forseen.

The 10 measurements of R_K in bins of the track momentum are found to be compatible and independent of p (Fig. 3), indicating good control over the main systematic effects. The estimated total uncertainty for the reduced data sample is $0.6 \div 0.7\%$, improving

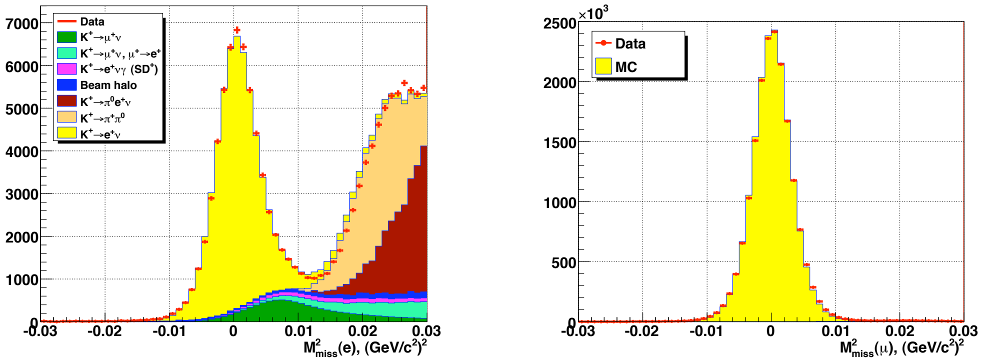

FIGURE 2. Reconstructed squared missing mass distributions for K_{e2} (left) and $K_{\mu 2}$ (right) candidates: data (crosses) and expectations for backgrounds and signal (filled areas).

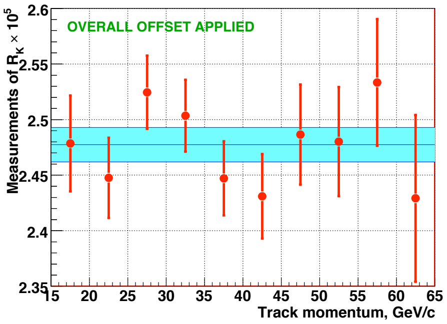

FIGURE 3. R_K measurements in track momentum bins for the 40% data sample (an overall off set to the SM expectation is applied to hide the result). The error band represents the total error, including the correlated uncertainties.

by a factor of 2 the present world average precision. Further studies of second order effects and minor background sources are currently underway in order to finalize the measurement with the considered statistics. By using the full data set ($\sim 160\,k$ K_{e2} decays) the statistical error can be pushed below 0.3% and an overall uncertainty of 0.4%, as stated in the proposal [6], is within reach.

PHASE II - $K^+ \rightarrow \pi^+\nu\overline{\nu}$

The unique feature of the $K^+ \rightarrow \pi^+\nu\overline{\nu}$ ultra rare decay is that its branching ratio ($\sim 8 \times 10^{-11}$) can be computed to an exceptionally high degree of precision ($\sim 5\%$) within the SM [8] as hadronic matrix elements can be extracted from the well-measured $K^+ \rightarrow \pi^0 e^+ \nu$ decay rate. The clean theoretical character of this Flavor Changing Neutral Current channel remains valid in all realistic extensions of the SM: as a result, the precise measurement of its BR provides a unique information about the flavor structure of any extension of the SM. The precision of the theoretical predictions is however in contrast with the large uncertainty affecting the current experimental measurement [9].

To provide a decisive test of new physics scenarios, the NA62 programme foresees a measurement of $BR(K^+ \rightarrow \pi^+\nu\overline{\nu})$ [10] with a $\sim$ 10% accuracy by collecting $\mathscr{O}(100)$ events in two years of data taking and keeping the background contamination at the level of 10%. The overall experimental design requires sophisticated technology for which an intense R&D program has started in 2006.

Decay in flight technique is chosen: the beam line is required to provide 10^{13} kaon decays from an highly intense ($800\,MHz$ rate) $75\,GeV/c$ positively charged unseparated beam (kaon fraction $\sim 6\%$). The experimental signature of the $K^+ \rightarrow \pi^+\nu\overline{\nu}$ channel is a single reconstructed charged track in the detector downstream the decay volume in time coincidence with a kaon measured by the upstream beam tracker. Kinematic selection is performed using kaon momentum reconstructed by three stations of hybrid Si pixels (a time resolution of at least $200\,ps$ per station is required to provide a suitable tagging) and pion momentum measured by a magnetic spectrometer consisting of low mass straw chambers that operates in vacuum to reduce multiple scattering. In addition to kinematic rejection (which provides large reduction of $K_{\mu 2}$, $K_{2\pi}$ and $K_{3\pi}$ decays, but is not sufficient for background suppression), the following techniques are used to provide redundancy. Particle identification is based on an existing differential Cerenkov counter (*CEDAR* [11]) for kaons, and a RICH [12] detector filled with Ne at atmospheric pressure for pions. A series of photon detectors are used to provide a hermetic photon veto with an inefficiency of $\sim 10^{-5}$: ring shaped stations made of lead glass blocks [13] recovered from the OPAL electromagnetic calorimeter at large angles of $10 \div 50\,mrad$, the existing NA48 LKr calorimeter at $1 \div 10\,mrad$ and a set of small angle vetoes based on shashlyk technology at low angles. In addition, a specific detector to veto muons will be used downstream.

The R&D program is close to the end and the construction has already started. The first physics run is expected to take place in 2012.

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