Searches for Lepton Number Violation and resonances in the $K^\pm \rightarrow \pi\mu\mu$ decays at the NA48/2 experiment

Karim Massri
University of Liverpool
E-mail: karim.massri@cern.ch

The NA48/2 experiment at CERN collected a large sample of charged kaon decays into final states with multiple charged particles in 2003–2004. A new upper limit on the rate of the lepton number violating decay $K^\pm \rightarrow \pi^\pm \mu^\pm \mu^\pm$ obtained from this sample is reported: $\mathcal{B}(K^\pm \rightarrow \pi^\pm \mu^\pm \mu^\pm) < 8.6 \times 10^{-11}$ at 90% CL. Searches for two-body resonances in the $K^\pm \rightarrow \pi\mu\mu$ decays (including heavy neutral leptons $N_4$ and inflatons $\chi$) in the accessible range of masses and lifetimes are also presented. In the absence of a signal, upper limits are set on the products of branching ratios $\mathcal{B}(K^\pm \rightarrow \mu^\pm N_4) \mathcal{B}(N_4 \rightarrow \pi\mu)$ and $\mathcal{B}(K^\pm \rightarrow \pi^\pm \chi) \mathcal{B}(\chi \rightarrow \mu^+\mu^-)$ as functions of the resonance mass and lifetime. These limits are in the $10^{-10} - 10^{-9}$ range for resonance lifetimes below 100 ps.

38th International Conference on High Energy Physics
3-10 August 2016
Chicago, USA
Lepton Number Violation and resonances in the $K^\pm \rightarrow \pi \mu \mu$ decays

Karim Massri

1. Introduction

The NA48/2 experiment at CERN SPS was a multi-purpose $K^\pm$ experiment which collected data in 2003–2004, whose main goal was to search for direct CP violation in the $K^\pm \rightarrow \pi^\pm \pi^\mp \pi^\mp$ and $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ decays [1]. The large statistics of the samples of charged kaon decays into final states with multiple charged particles collected allows to search for the forbidden LNV $K^\pm \rightarrow \pi^\pm \mu^\mp \mu^\mp$ decay, as well as for two-body resonances in $K^\pm \rightarrow \pi \mu \mu$ decays. Since a particle $X$ produced in a $K^\pm \rightarrow \mu^\pm X (K^\pm \rightarrow \pi^\pm X)$ decay and decaying promptly to $\pi^\pm \mu^\mp (\mu^\mp \mu^\mp)$ would produce a narrow spike in the invariant mass $M_{\pi \mu}$ ($M_{\mu \mu}$) spectrum, the invariant mass distributions of the collected $K^\pm \rightarrow \pi \mu \mu$ samples have been scanned looking for such a signature.

2. Selected data samples

The event selection is based on the reconstruction of a three-track vertex: given the resolution of the vertex longitudinal position ($\sigma_{vtx} = 50$ cm), $K^\pm \rightarrow \pi^\pm \mu^\mp \mu^\mp$ and $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$ decays (denoted $K^\text{LNV}_{\pi \mu \mu}$ and $K^\text{LNC}_{\pi \mu \mu}$ below) mediated by a short-lived ($\tau \lesssim 10$ ps) resonant particle are indistinguishable from a genuine three-track decay. The size of the selected $K_{\pi \mu \mu}$ samples is normalised relative to the abundant $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ channel (denoted $K^{3\pi}_{\pi \mu \mu}$ below), from which the number of $K^\pm$ decays in the 98 m long fiducial decay region is obtained: $N_F = (1.64 \pm 0.01) \times 10^{11}$. The $K_{\pi \mu \mu}$ and $K^{3\pi}$ samples are collected concurrently using the same trigger logic.

The invariant mass distributions of data and MC events passing the $K^\text{LNV}_{\pi \mu \mu}$ and $K^\text{LNC}_{\pi \mu \mu}$ selections are shown in Fig. 1. One event is observed in the signal region after applying the $K^\text{LNV}_{\pi \mu \mu}$ selection, while 3489 $K^\text{LNC}_{\pi \mu \mu}$ candidates are selected with the $K^\text{LNC}_{\pi \mu \mu}$ selection. A peak search assuming different mass hypotheses is performed over the distributions of the invariant masses $M_{ij}$ ($ij = \pi^\pm \mu^\mp, \mu^+ \mu^-$) of the selected $K_{\pi \mu \mu}$ samples. In total, 284 (267) and 280 mass hypotheses

![Figure 1: Invariant mass distributions of data and MC events passing the $K^\text{LNV}_{\pi \mu \mu}$ (left) and $K^\text{LNC}_{\pi \mu \mu}$ (right) selections. The signal mass regions are indicated with vertical arrows.](image-url)
are tested respectively for the search of resonances in the \( M_{\pi\mu} \) distribution of the \( K_{\pi\mu}^{L\text{N}V} \) (\( K_{\pi\mu}^{L\text{NC}} \)) candidates and in the \( M_{\mu\mu} \) distribution of the \( K_{\pi\mu}^{L\text{NC}} \) candidates, covering the full kinematic ranges.

3. Results

3.1 Upper Limit on \( \mathcal{B}(K^\pm \to \pi^\pm \mu^\pm \mu^\pm) \)

The upper limit (UL) at 90% confidence level (CL) on the number of \( K^\pm \to \pi^\pm \mu^\pm \mu^\pm \) signal events in the \( K_{\pi\mu}^{L\text{N}V} \) sample corresponding to the observation of one data event and a total number of expected background events \( N_{bkg} = 1.163 \pm 0.867_{\text{stat}} \pm 0.021_{\text{sys}} \pm 0.116_{\text{sys}} \) is obtained applying an extension of the Rolke-Lopez method [2]: \( N_{\pi\mu\mu}^{L\text{N}V} < 2.92 \) at 90% CL. Using the values of the signal acceptance \( A(K_{\pi\mu}^{L\text{N}V}) = 20.62\% \) estimated with MC simulations and the number \( N_K \) of kaon decays in the fiducial volume (Sec. 2), the UL on the number of \( K^\pm \to \pi^\pm \mu^\pm \mu^\pm \) signal events in the \( K_{\pi\mu}^{L\text{N}V} \) sample leads to a constraint on the signal branching ratio \( \mathcal{B}(K^\pm \to \pi^\pm \mu^\pm \mu^\pm) \):

\[
\mathcal{B}(K^\pm \to \pi^\pm \mu^\pm \mu^\pm) = \frac{N_{\pi\mu\mu}^{L\text{N}V}}{N_K \cdot A(K_{\pi\mu}^{L\text{N}V})} < 8.6 \times 10^{-11} \quad \text{at 90\% CL.} \tag{3.1}
\]

3.2 Results of the search for two-body resonances

No signal is observed, as the local significances of the signals in each mass hypothesis never exceed 3 standard deviations. In absence of a signal, ULs on the product \( \mathcal{B}(K^\pm \to p_1 X) \mathcal{B}(X \to p_2 p_3) \) \( (p_1 p_2 p_3 = \mu^\pm \pi^\pm \mu^\pm, \mu^\pm \pi^\pm \mu^\pm, \pi^\pm \mu^\pm \mu^-) \) as a function of the resonance lifetime \( \tau \) are obtained for each mass hypothesis \( m_i \), by using the values of the acceptances \( A_{\pi\mu\mu}(m_i, \tau) \) and the ULs on the number \( N_{\text{sig}}^{i} \) of signal events for such a mass hypothesis:

\[
\mathcal{B}(K^\pm \to p_1 X) \mathcal{B}(X \to p_2 p_3) \bigg|_{m_i, \tau} = \frac{N_{\text{sig}}^{i}}{N_K \cdot A_{\pi\mu\mu}(m_i, \tau)} \tag{3.2}
\]

The obtained ULs on \( \mathcal{B}(K^\pm \to p_1 X) \mathcal{B}(X \to p_2 p_3) \) \( (p_1 p_2 p_3 = \mu^\pm \pi^\pm \mu^\pm, \mu^\pm \pi^\pm \mu^\pm, \pi^\pm \mu^\pm \mu^-) \) as a function of the resonance mass, for several values of the resonance lifetime, are shown in Fig. 2.

4. Conclusions

The searches for the LNV \( K^\pm \to \pi^\pm \mu^\pm \mu^\pm \) decay and resonances in \( K^\pm \to \pi\mu\mu \) decays at the NA48/2 experiment, using the 2003–2004 data, are presented. No signals are observed. An UL of \( 8.6 \times 10^{-11} \) for \( \mathcal{B}(K^\pm \to \pi^\pm \mu^\pm \mu^\pm) \) has been established, which improves the best previous limit [3] by more than one order of magnitude. ULs are set on the products \( \mathcal{B}(K^\pm \to \mu^\pm N_4) \mathcal{B}(N_4 \to \pi\mu) \) and \( \mathcal{B}(K^\pm \to \pi^\pm \chi) \mathcal{B}(\chi \to \mu^\pm \mu^-) \) as functions of the resonance mass and lifetime. These limits are in the \( 10^{-10} - 10^{-9} \) range for resonance lifetimes below 100 ps.

References

**Figure 2:** Obtained ULs at 90% CL on the products of branching ratios as functions of the resonance mass and lifetime: a) $\mathcal{B}(K^\pm \to \mu^{\pm} N_4)\mathcal{B}(N_4 \to \pi^{\pm} \mu^{\pm})$; b) $\mathcal{B}(K^\pm \to \mu^{\pm} N_4)\mathcal{B}(N_4 \to \pi^{\mp} \mu^{\mp})$; c) $\mathcal{B}(K^\pm \to \pi^{\pm} \chi)\mathcal{B}(\chi \to \mu^{+} \mu^{-})$. All presented quantities are strongly correlated for neighbouring resonance masses as the mass step of the scan is about 8 times smaller than the signal window width.