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

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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 $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ obtained from this sample is reported: $\mathscr{B}(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}) < 8.6 \times 10^{-11}$ at 90% CL. Searches for two-body resonances in the $K^{\pm} \to \pi\mu\mu$ decays (including heavy neutral leptons N_4 and inflatons χ) 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 $\mathscr{B}(K^{\pm} \to \mu^{\pm}N_4)\mathscr{B}(N_4 \to \pi\mu)$ and $\mathscr{B}(K^{\pm} \to \pi^{\pm}\chi)\mathscr{B}(\chi \to \mu^{+}\mu^{-})$ as functions of the resonance mass and lifetime. These limits are in the $10^{-10} - 10^{-9}$ range for resonance lifetimes below 100 ps.

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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 $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ 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 $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ decay, as well as for two-body resonances in $K^{\pm} \to \pi\mu\mu$ decays. Since a particle X produced in a $K^{\pm} \to \mu^{\pm}X$ ($K^{\pm} \to \pi^{\pm}X$) decay and decaying promptly to $\pi^{\pm}\mu^{\mp}$ ($\mu^{+}\mu^{-}$) would produce a narrow spike in the invariant mass $M_{\pi\mu}$ ($M_{\mu\mu}$) spectrum, the invariant mass distributions of the collected $K^{\pm} \to \pi\mu\mu$ 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), $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ and $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ decays (denoted $K^{\rm LNV}_{\pi\mu\mu}$ and $K^{\rm LNC}_{\pi\mu\mu}$ 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 $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ channel (denoted $K_{3\pi}$ below), from which the number of $K^{\pm}$ decays in the 98 m long fiducial decay region is obtained: $N_K = (1.64 \pm 0.01) \times 10^{11}$. 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 $K^{\rm LNV}_{\pi\mu\mu}$ and $K^{\rm LNC}_{\pi\mu\mu}$ selections are shown in Fig. 1. One event is observed in the signal region after applying the $K^{\rm LNV}_{\pi\mu\mu}$

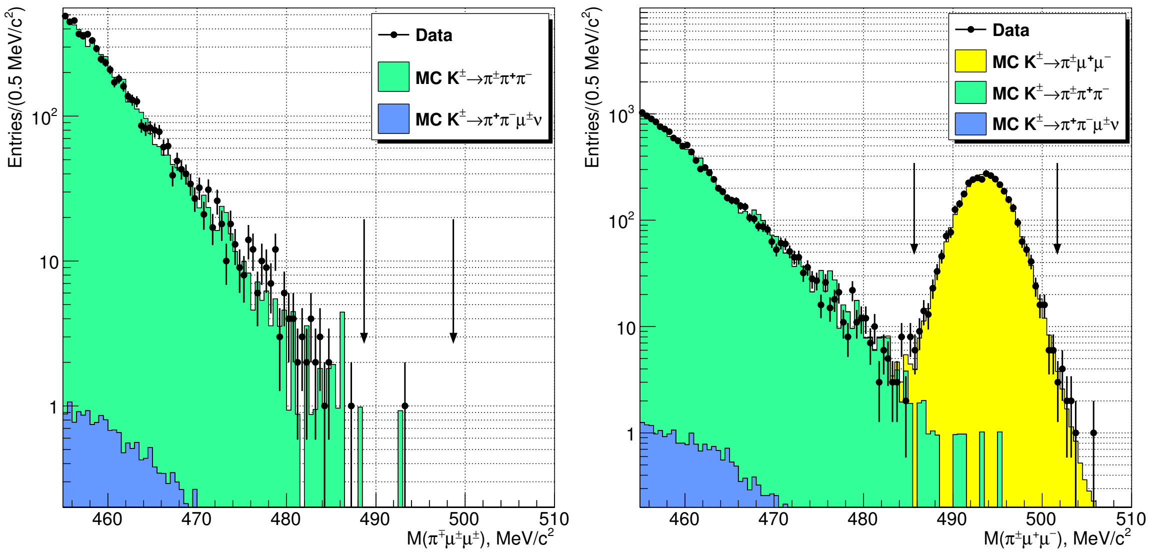

Figure 1: Invariant mass distributions of data and MC events passing the $K^{\rm LNV}_{\pi\mu\mu}$ (left) and $K^{\rm LNC}_{\pi\mu\mu}$ (right) selections. The signal mass regions are indicated with vertical arrows.

selection, while 3489 $K^{\rm LNC}_{\pi\mu\mu}$ candidates are selected with the $K^{\rm LNC}_{\pi\mu\mu}$ 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 are tested respectively for the search of resonances in the $M_{\pi\mu}$ distribution of the $K^{\rm LNV}_{\pi\mu\mu}$ ($K^{\rm LNC}_{\pi\mu\mu}$) candidates and in the $M_{\mu\mu}$ distribution of the $K^{\rm LNC}_{\pi\mu\mu}$ candidates, covering the full kinematic ranges.

3. Results

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

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

$$\mathscr{B}(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}) = \frac{N^{\rm LNV}_{\pi\mu\mu}}{N_K \cdot A(K^{\rm LNV}_{\pi\mu\mu})} < 8.6 \times 10^{-11} \quad @\ 90\%\ \text{CL}. \tag{3.1}$$

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 $\mathscr{B}(K^{\pm} \to p_1 X)\mathscr{B}(X \to p_2 p_3)$ ($p_1 p_2 p_3 = \mu^{\pm}\pi^{\mp}\mu^{\pm}, \mu^{\pm}\pi^{\pm}\mu^{\mp}, \pi^{\pm}\mu^{+}\mu^{-}$) as a function of the resonance lifetime τ 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^i_{sig} of signal events for such a mass hypothesis:

$$\mathscr{B}(K^{\pm} \to p_1 X)\mathscr{B}(X \to p_2 p_3)\big|_{m_i,\tau} = \frac{N^i_{sig}}{N_K \cdot A_{\pi\mu\mu}(m_i, \tau)}. \tag{3.2}$$

The obtained ULs on $\mathscr{B}(K^{\pm} \to p_1 X)\mathscr{B}(X \to p_2 p_3)$ ($p_1 p_2 p_3 = \mu^{\pm}\pi^{\mp}\mu^{\pm}, \mu^{\pm}\pi^{\pm}\mu^{\mp}, \pi^{\pm}\mu^{+}\mu^{-}$) 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 $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ 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 8.6×10^{-11} for $\mathscr{B}(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm})$ has been established, which improves the best previous limit [3] by more than one order of magnitude. ULs are set on the products $\mathscr{B}(K^{\pm} \to \mu^{\pm}N_4)\mathscr{B}(N_4 \to \pi\mu)$ and $\mathscr{B}(K^{\pm} \to \pi^{\pm}\chi)\mathscr{B}(\chi \to \mu^{+}\mu^{-})$ as functions of the resonance mass and lifetime. These limits are in the $10^{-10} - 10^{-9}$ range for resonance lifetimes below 100 ps.

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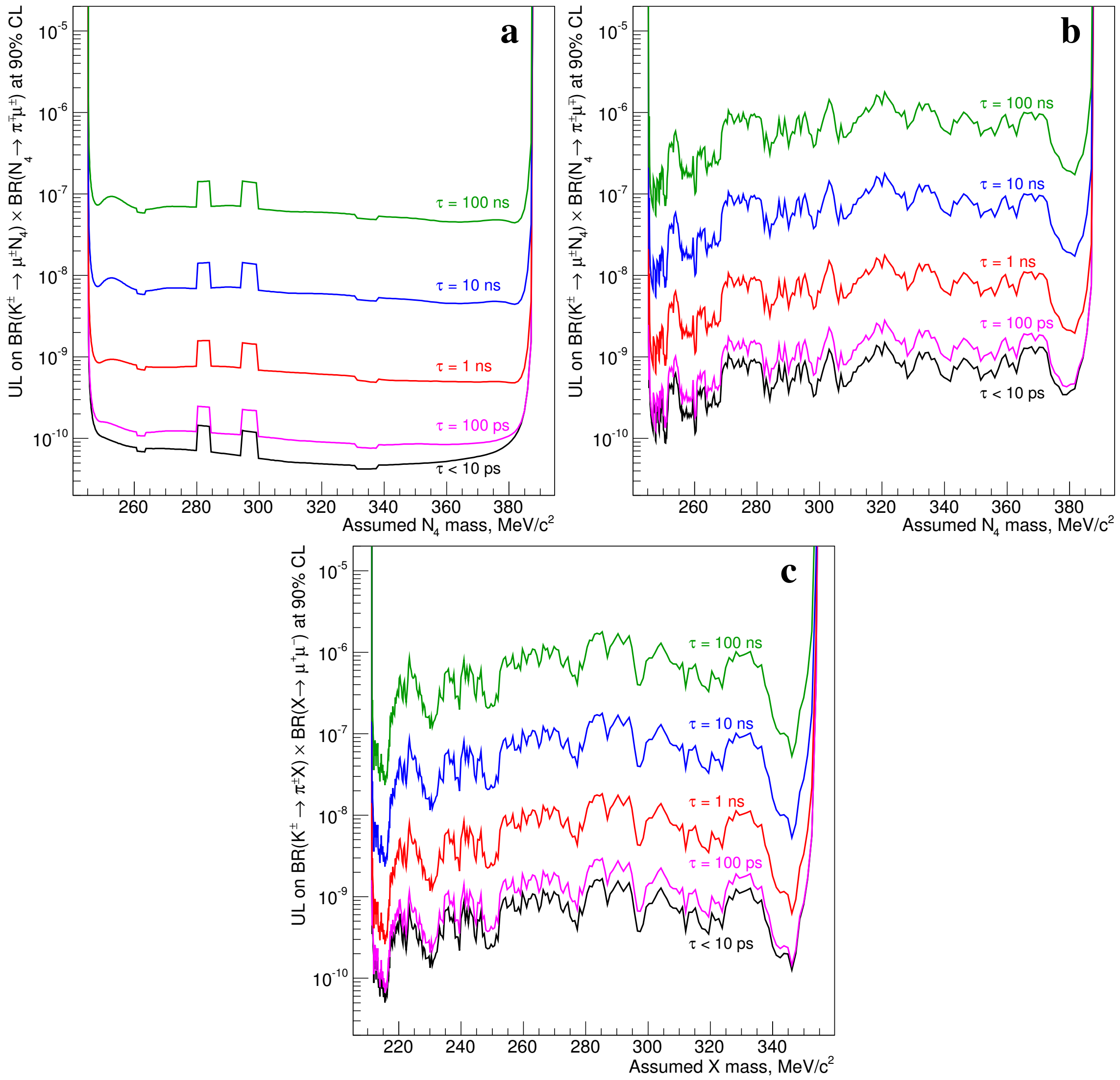

Figure 2: Obtained ULs at 90% CL on the products of branching ratios as functions of the resonance mass and lifetime: a) $\mathscr{B}(K^{\pm} \to \mu^{\pm}N_4)\mathscr{B}(N_4 \to \pi^{\mp}\mu^{\pm})$; b) $\mathscr{B}(K^{\pm} \to \mu^{\pm}N_4)\mathscr{B}(N_4 \to \pi^{\pm}\mu^{\mp})$; c) $\mathscr{B}(K^{\pm} \to \pi^{\pm}\chi)\mathscr{B}(\chi \to \mu^{+}\mu^{-})$. 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.