Study of Radiative Decay $K^- \to \mu^-\nu\gamma$ at ISTRA+ Setup

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Abstract

The radiative decay $K^- \to \mu^-\nu_\mu\gamma$ has been studied at ISTRA+ setup in a new kinematical region: $30 < E < 130 MeV, 150 < E < 230$ MeV. About 22500 events of $K^- \to \mu^-\nu_\mu\gamma$ have been observed . Branching fraction has been found to be $BR(K^- \to \mu^-\nu_\mu\gamma)=[1.25\pm0.04(stat)\pm 0.02(norm)] \times 10^{-3}$ which is in good agreement with theoretical prediction $BR_{th} = 1.28 \times 10^{-3}$ for this kinematical region.

1 Introduction

Radiative kaon decays are dominated by long distance (low energy) physics. For low energy processes there are no predictions from SM and effective theories such as Chiral perturbation theory (ChPT) are used. ChPT gives decay rates for most kaon decay modes. That's why radiative kaon decays provide a testing ground for ChPT. Moreover, these decays are sensitive to New Physics.

The decay $K^- \to \mu^-\nu_\mu\gamma$ is sensitive to hadronic weak currents in low-energy region. The decay amplitude includes two terms: internal bremsstrahlung (IB) and structure dependent term (SD). IB contains radiative corrections from $K^- \to \mu^-\nu_\mu$. SD allows to probe electroweak structure of kaon.

The differential decay rate is calculated within ChPT and can be written in terms of standard kinematical variables $x=2E^\star_\gamma/M_k$ and $y = 2E^\star_\mu/M_k$ (see [1] for details).

2 Experimental setup

The experiment has been performed at the IHEP 70 GeV proton synchrotron U-70. The experimental setup "ISTRA+" (Fig.1)has been described in some details elsewhere[2].

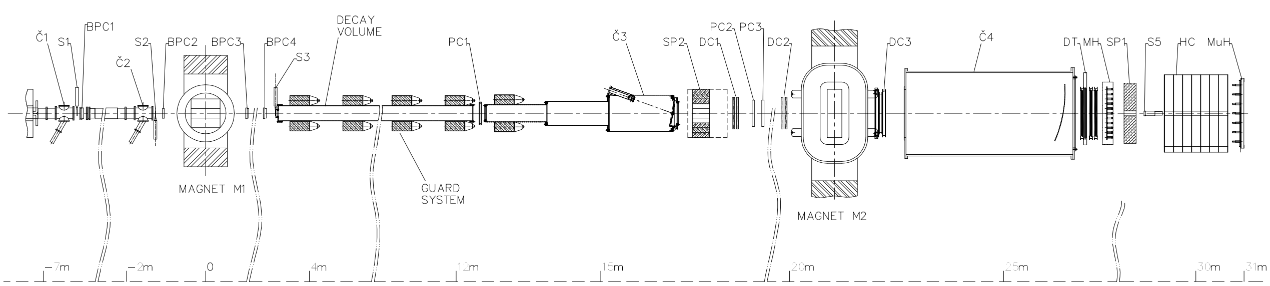

Figure 1: Elevation view of the "ISTRA+" detector.

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The setup is located in the negative unseparated secondary beam. The beam momentum in the measurements is $\sim$ 25 GeV with $\Delta p/p \sim 1.5\%$. The admixture of K^- in the beam is $\sim 3\%$. The beam intensity is $\sim 3{\cdot}10^6$ per 1.9 sec. U-70 spill. The beam particle deflected by M_1 is measured by $BPC_1 \div BPC_4$ (PC's with 1mm wire step), the kaon identification is done by $\check{C}_0 \div \check{C}_2$ threshold $\check{C}$-counters. The 9 meter long vacuumed decay volume is surrounded by 8 lead glass rings $LG_1 \div LG_8$ used to veto low energy photons. SP_2 is a lead glass calorimeter to detect/veto large angle photons. The decay products deflected in M2 with 1Tm field integral are measured by $PC_1 \div PC_3$ (2mm step proportional chambers); $DC_1 \div DC_3$ (1cm cell drift chambers) and finally by 2cm diameter drift tubes $DT_1 \div DT_4$. Wide aperture threshold Cerenkov counters $\check{C}_3$, $\check{C}_4$ are filled with He and are not used in the present measurements. SP_1 (ECAL) is a 576-cell lead glass calorimeter, followed by HC- a scintillator-iron sampling hadron calorimeter. HC is subdivided into 7 longitudinal sections 7×7 cells each. MH is a 11×11 cell scintillating hodoscope, used to improve the time resolution of the tracking system, MuH is a 7×7 cell muon hodoscope.
The trigger is provided by $S_1 \div S_5$ scintillation counters, $\check{C}_0 \div \check{C}_2$ Cerenkov counters, analog sum of amplitudes from the last dinodes of the SP_1 : $T = S_1 \cdot S_2 \cdot S_3 \cdot \bar{S}_4 \cdot \check{C}_0 \cdot \bar{\check{C}}_1 \cdot \bar{\check{C}}_2 \cdot \bar{S}_5 \cdot \Sigma(SP_1)$, here S_4 is a scintillator counter with a hole to suppress beam halo ; S_5 is a counter downstream the setup at the beam focus; $\Sigma(SP_1)$- a requirement for the analog sum of ECAL amplitudes to be above ~700 MeV - a MIP signal. The last requirement serves to suppress the $K \to \mu\nu$ decay.

3 Event selection

The event selection criteria for K$\to \mu\nu\gamma$ are: one charged track, μ flag in HCAL; one shower in ECAL not associated with a charged track; z-coordinate of the decay vertex within interval $300 < z_{vertex} < 1650$ cm. Additional cuts are applied to suppress backgrounds:

- missing energy > 1GeV;
- no photons in SP2 calorimeter;
- missing momentum points to ECAL aperture.

Main background comes from 2 decay modes: K$^- \to \mu^-\nu\pi^0 (K\mu3)$ and K$^- \to \pi^-\pi^0 (K\pi2)$ with one gamma lost from $\pi^0 \to \gamma\gamma$ and π misidentified as μ. Distribution over M($\mu\nu\gamma$) is used for signal observation. $M^2(\mu\nu\gamma) = (P_\mu + P_\nu + P_\gamma)^2$ where P_μ, P_ν, P_γ are 4-momenta of corresponding particles; missing mass is supposed to be equal to 0 so that $\overrightarrow{p}_\nu = \overrightarrow{p}_K - \overrightarrow{p}_\mu - \overrightarrow{p}_\gamma; E_\nu = |\overrightarrow{p}_\nu|$. M($\mu\nu\gamma$) peaks at K$^-$ mass for signal.

4 Signal extraction

To extract signal, the following procedure is applied:

- all kinematical (x,y) region is divided into little bins;
- we look at M($\mu\nu\gamma$) in each bin;
- bins with signal peak are selected(see fig. 2). The selected kinematical region is $30 < E^\star_\gamma < 120 MeV; 150 < E^\star_\mu < 230 MeV$ (fig.3, red);
- Fitting M($\mu\nu\gamma$) gives the number of K$^- \to \mu^-\nu\gamma$ events (the shape of background distribution is taken from MC).

Total number of K$^- \to \mu^-\nu\gamma$ events is 22472±465. To measure BR(K$^- \to \mu^-\nu\gamma$), we normalize on BR(K$^- \to \mu^-\nu\pi^0$). $K\mu3$ events are selected with similar criteria. Supposing PDG04 value for BR($K\mu3$) we obtain BR(K$^- \to \mu^-\nu\gamma$) = $[1.25 \pm 0.04(stat) \pm 0.02(norm)] \times 10^{-3}$ which is in good agreement with theory: BR$_{th}$ $\sim 1.28 * 10^{-3}$. Our kinematical region is complementary to that of previous experiments[3],[4] (see fig. 3).

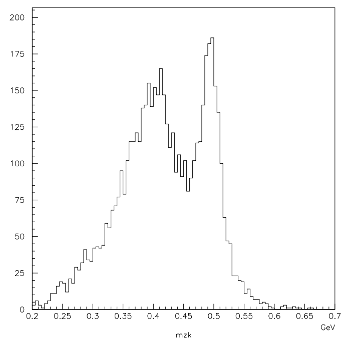

Figure 2: *M(μνγ) for (x,y) bin, real data*

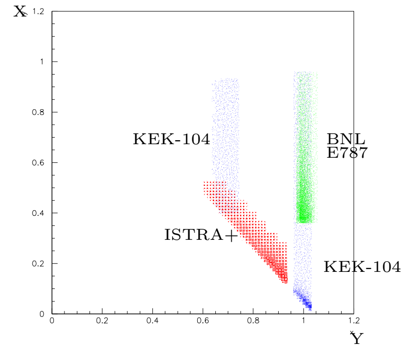

Figure 3: x=$2E^{\star}_{\gamma}/M_k$, $y = 2E^{\star}_{\mu}/M_k$ *ISTRA+(red); BNL E787(green);KEK-104(blue)*

5 Conclusion

The radiative decay $K^- \to \mu^- \nu_\mu \gamma$ has been studied using in-flight decays at ISTRA+ setup. About 22500 events of $K^- \to \mu^- \nu_\mu \gamma$ (it is the largest statistics for this decay) have been observed in a new kinematical region. The measured branching fraction BR($K^- \to \mu^- \nu_\mu \gamma$)=$[1.25\pm0.04(stat)\pm 0.02(norm)] \times 10^{-3}$ is in good agreement with theoretical prediction 1.28×10^{-3} .

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