Snowmass2021 - Letter of Interest

US Participation in Current & Future Rare Kaon Decay Experiments

Submitted to Rare Processes and Precision Measurements:
Weak decays of strange and light quarks (RF02)

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Abstract: Precise measurements of rare kaon decay branching ratios provide a window into potential new physics that is complementary to that of direct searches at the energy frontier. US involvement in rare kaon decay experiments in Europe and Japan continues at a low level. Plans for future upgrades and/or next-generation rare kaon decay experiments are beginning. The US particle physics community should consider ways to contribute to these important probes of possible new physics and be prepared to launch a larger effort in the case that the current generation of experiments yields results inconsistent with the Standard Model. We should also consider the possibility of medium-scale US-based experiments that could be enabled by future upgrades to the Fermilab accelerator complex.

Precise measurements of rare kaon decay branching ratios provide a window into potential new physics that is complementary to that of direct searches at the energy frontier. Because their branching ratios are highly suppressed but precisely calculated within the Standard Model, $K \to \pi\nu\bar{\nu}$ decays are particularly sensitive to BSM effects. Virtual processes in $K \to \pi\nu\bar{\nu}$ loop diagrams allow us to learn about the flavor- and CP-violating couplings of any new particles that may be discovered at the LHC and to potentially observe the effects of new particles with masses higher than those accessible by the LHC.

The NA62[1] and KOTO[2] experiments are currently searching for $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L \to \pi^0\nu\bar{\nu}$ decays, respectively. NA62 has been collecting data since 2015 and recently reported observation of $K^+ \to \pi^+\nu\bar{\nu}$ decay with 3.5σ significance using data collected in 2016-2018[3]. NA62 plans to continue running when CERN's SPS resumes operation in 2021 and expects to reach 5σ sensitivity on the observation of $K^+ \to \pi^+\nu\bar{\nu}$ decay. The currently measured branching ratio is consistent with the previous measurement from E787/949[4] and with the Standard Model within theory and measurement uncertainties. A few US physicists have contributed to NA62. KOTO at J-PARC began taking data in 2013 and have reduced the limit on the $K_L \to \pi^0\nu\bar{\nu}$ branching ratio to within an order of magnitude of the Standard Model prediction. The most recently reported unblinded analysis contains data taken through 2018, which revealed an unexpected source of background. Since this analysis was reported, a campaign of analysis and special runs has been undertaken to investigate this background[5]. KOTO plans to continue taking data and expects to reach single-event sensitivity of approximately 2-3 times the Standard Model prediction by 2024. Several US groups have played significant roles in KOTO. BNL physicists have recently been collaborating with KOTO at a low level to investigate potential contributions to KOTO computing, simulation, and analysis efforts, funded by the US-Japan Cooperation program.

There are several plans for future kaon experiments under discussion within the community. KLEVER[6] is a proposed experiment to study $K_L \to \pi^0\nu\bar{\nu}$ decay at the CERN SPS with a goal of observing 60 events at the SM branching ratio with a signal-to-background ratio of about one. KLEVER is envisioned to be the next in the series of experiments occupying the current NA62 site, but would require a new detector to meet the stringent experimental requirements. KLEVER and NA62 collaborators are working together to plan a multi-stage program at the SPS to study charged and neutral kaon decays[7, 8]. A next-generation $K_L \to \pi^0\nu\bar{\nu}$ experiment at J-PARC is also being discussed. This experiment, called KOTO Step-2, would aim to detect order 100 events at the SM level. This would require significant upgrades both to the facility (extension to target hall and new beamline) and to the KOTO detector. KLEVER, NA62, and KOTO are exploring possibilities for collaboration on future experiments. Finally, there are well-developed plans for a US-based $K_L \to \pi^0\nu\bar{\nu}$ experiment[9, 10] that have not been pursued to date, but could potentially be accommodated by planned upgrades to the Fermilab accelerator complex.

While rare kaon decay experiments have not been a major focus of US particle physics in recent years, there remains significant expertise and interest in this physics within the US community. As we enter this Snowmass, where one of the biggest questions facing our community is how to plan for the future in the absence of major discoveries of new physics to guide our direction, the potential for rare kaon decays to provide access to new physics at very high mass scales is an important consideration. In particular, if hints of new physics were to emerge from NA62 and/or KOTO data, the US particle physics community would want to be in a position to make major contributions to the next-generation experiments that would surely follow. To be in this position, and to continue our rich history of contributions and discoveries across all of particle physics, requires some continued US engagement with kaon physics and with the current generation of flavor-physics experiments. We express our interest in exploring how this may be achieved.

References

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