Precision measurements of rare pion and muon decays

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In the past five years the PIBETA experiment at PSI has conducted a comprehensive precision study of rare pion and muon decays. This project has achieved significant improvements in precision of the measured branching ratios of these rare processes: (a) pion beta (π_β) decay, $\pi^+ \to \pi^0 e^+ \nu$, (sevenfold) (b) radiative pion decay ($\pi^+ \to e^+ \nu \gamma$), (ninefold) and (c) radiative muon decay ($\mu^+ \to e^+ \nu \bar{\nu} \gamma$), (fourteenfold). In doing so, the experiment has provided the most sensitive test to date of the CVC hypothesis in a meson, and moved the pion beta decay significantly closer to competitively constraining the CKM matrix element V_{ud}. PIBETA improved the experimental precision of the pion form factors F_A and F_V eightfold, thus providing critical input to chiral perturbation theory. Our radiative pion decay measurement has also resulted in a new stringent limit on the SM-excluded pion tensor form factor, $F_T < 2 \times 10^{-4}$ at 68 % C.L. Likewise, our muon radiative decay measurement has produced a new limit on the Michel parameter $\bar{\eta} < 0.33$ at 68 % C.L., improving the world average by a factor of ~ 2.5.

This detailed new understanding of rare π and μ decays, as well as of the PIBETA apparatus, has opened the way for PEN, a new measurement of the decay $\pi^+ \to e^+ \nu$, which was used as the normalizing process in the PIBETA experiment. PEN aims to measure the π_{e2} decay branching ratio with an uncertainty of $\Delta B/B \leq 5 \times 10^{-4}$, using the PIBETA detector system at PSI. Exceptionally well controlled theoretical uncertainties for the π_{e2} decay render this process the most accurate experimental test of lepton universality available. At present, accuracy of the π_{e2} decay measurements lags behind the theoretical precision by an order of magnitude. A number of exotic physics scenarios outside the Standard Model would lead to a violation of lepton universality. Lepton universality, and lepton properties in general, have acquired added significance in the light of developments in the neutrino sector, and will remain centrally relevant in the future.

This series of precision measurements is in its highly productive phase, and will continue to producing significant new results with modest investments of resources in the next five to ten years. The program should be continued to its ultimate precision limit in a timely manner, while beam time at pion factories remains available.