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PIONEER: Precision measurements of rare pion decays

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In the past several years, there have been a number of experimental signals pointing to potential violation of lepton flavor universality. The PIONEER experiment, utilizing the Paul Scherrer Institutes' (PSI) infrastructure for particle physics (CHRISP), seeks to probe such Beyond the Standard Model (BSM) universality violating effects through the measurement of the branching ratio of the charged pion. These branching ratios are extremely sensitive to quantum effects of new particles at very high mass scales, and so can provide a window into physics beyond that which is directly accessible at colliders.

The Standard Model (SM) prediction for the charged pion branching ratio $R_{e/\mu} \equiv \Gamma(\pi^+ \to e^+\nu(\gamma))/\Gamma(\pi^+ \to \mu^+\nu(\gamma))$ is known to the order of 10^{-4}. This makes it one of the most precisely calculated hadronic quantities in the SM and is 15 times more precise than the current experimental average. Even with these large uncertainties, the experimental result exhibits a 1σ tension with universality. In the first phase of the experiment, we intend to match the theoretical uncertainty by measuring $R_{e/\mu}$ to 0.01%. This will allow us to test lepton flavor universality at an unprecedented level and probe mass scales up to the PeV range. In the second phase of the experiment, a 0.06% measurement of the branching ratio of pion beta decay, $R_{\pi\beta} \equiv \Gamma(\pi^+ \to \pi^0 e^+\nu(\gamma))/\Gamma(\text{all})$, will provide another window into potential physics beyond the SM by providing a theoretically pristine measurement of $|V_{ud}|$.

The experimental design incorporates lessons learned from the previous generation PIENU and PEN/PIBETA experiments at TRIUMF and PSI. In the PIONEER experiment design, an intense pion beam is brought to rest in a segmented, instrumented (active) target (ATAR). The proposed technology for the ATAR is based on low-gain avalanche detectors (LGADs), which can provide precise spatial and temporal resolution for particle tracks and thus separate even very closely spaced decays and decay products. The proposed detector will also include a 3π sr, 25 radiation length (X_0) electromagnetic calorimeter, which measures the energy of the final state products from π^+ decay. A cylindrical tracker surrounding the ATAR is used to link the locations of pions stopping in the target to showers in the calorimeter. Our design boasts excellent energy and timing resolutions, a greatly enhanced calorimeter depth to reduce leakage, large solid angle coverage, and many more improvements. Each of these aspects is being actively modeled in simulation to ensure we will be able to meet our experimental goals.

Here, we present some theoretical motivations for PIONEER, discuss the experiment design, and show recent results from simulations and a first testing campaign at the PSI PiE5 charged pion beamline.

In-person or Virtual?

In-person

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