Precision Measurement of the $\pi^+ \to e^+ \nu_e$ Branching Ratio in the PIENU Experiment

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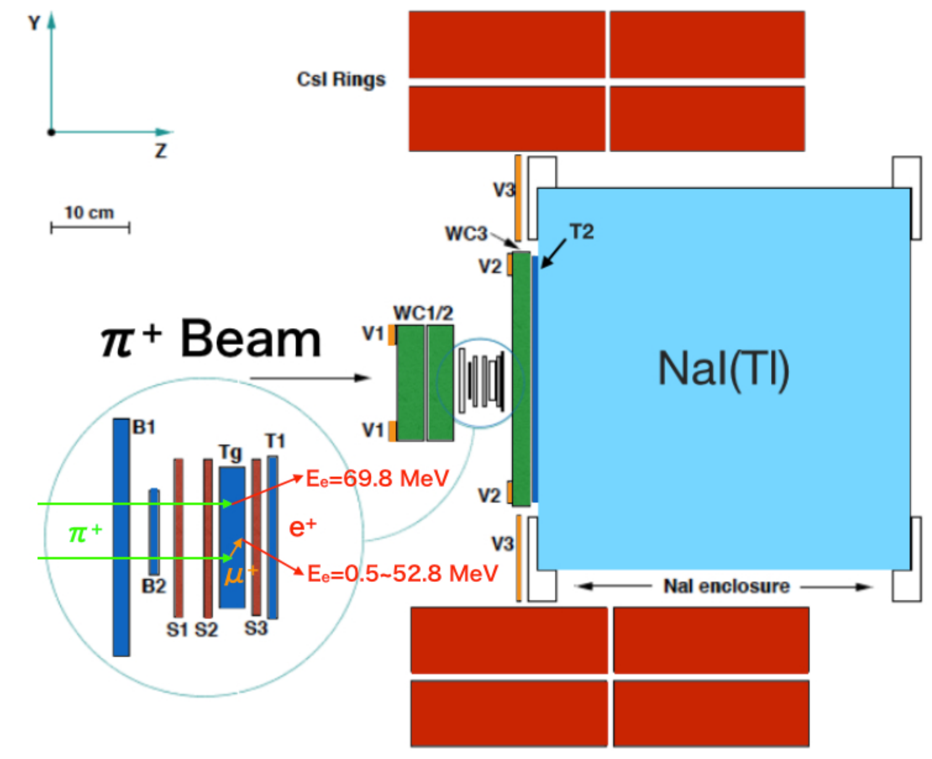
The Pion Branching Ratio Measurement and the PIENU Experiment

Study of rare decays is an important approach to search for new physics beyond the Standard Model. In the SM, the ratio of the charged pion decay branching ratios, $\mathrm{R}^\pi = \Gamma[\pi^+ \to e^+ \nu_e(\gamma)]/\Gamma[\pi^+ \to \mu^+ \nu_\mu(\gamma)]$ is precisely calculated with $\mathrm{R}^\pi_{\mathrm{SM}} = (1.2352 \pm 0.0002) \times 10^{-4}$. While the previous experimental values are $\mathrm{R}^\pi_{\mathrm{exp}} = [1.2265 \pm 0.0034(\mathrm{stat}) \pm 0.0044(\mathrm{syst})] \times 10^{-4}$ (1992, TRIUMF) and $\mathrm{R}^\pi_{\mathrm{exp}} = [1.2346 \pm 0.0035(\mathrm{stat}) \pm 0.0036(\mathrm{syst})] \times 10^{-4}$ (1993, PSI), which indicate that there is a room for improvement by two orders of magnitude in precision. The PIENU experiment at TRIUMF was designed to measure R^π_{exp} more presicely than 0.1%.

Precise measurement of R^π provides one of the most stringent tests of the hypothesis of electron-muon universality in weak interactions. Examples of the new physics inducing universality violation are R-parity violating SUSY, heavy neutrino mixing, leptoquarks, and the effects of charged Higgs bosons. By measuring R^π with precision of $< 0.1\%$, it allows potential accsess up to the pseudoscalar mass scale of 1000 TeV.

The PIENU Detector



WC1–3:Wire Chamber S1 – 3:Silicon strip

B1, B2, B3, T1, T2, V1, V2, and V3: Plastic scintillator

A.A.Aguilar-Arevalo *et al.*,Nucl.Instrum.Meth.A791.38-46(2015)

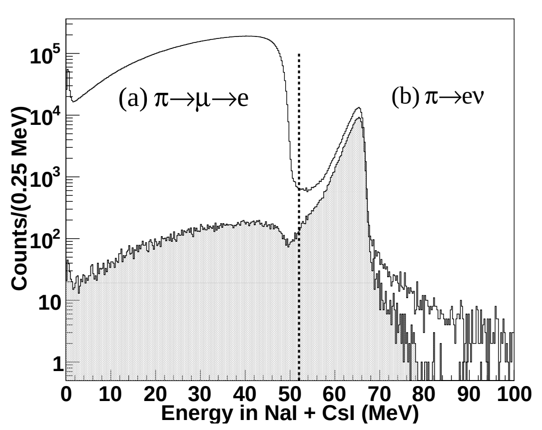
The R^π Measurement

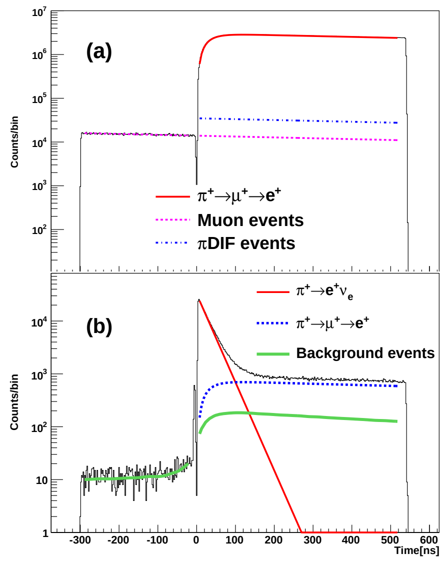
Decay positrons from $\pi^+ \to e^+ \nu_e$ decays ($E_e = 69.8$ MeV) and $\pi^+ \to \mu^+ \nu_\mu$ decays followed by $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ decays ($\pi^+ \to \mu^+ \to e^+$, $E_e = 0.5 \sim 52.8$ MeV) were detected by NaI(Tl). In order to detect shower leakage, pure CsI crystals surrounded the NaI.

The R^π was extracted by time spectra fitting with some corrections (e.g. $\pi^+ \to e^+ \nu_e$ low energy tail). The amount of low energy tail was estimated by suppressing dominant $\pi^+ \to \mu^+ \to e^+$ decays (filled energy spectrum), and using mono-energetic 70 MeV positron beam. The amount of the low energy $\pi^+ \to e^+ \nu_e$ tail was estimated to be $(3.07 \pm 0.12)\%$.

Another systematic correction came from the different relative acceptance of $\pi^+ \to e^+ \nu_e$ and $\pi^+ \to \mu^+ \to e^+$ events. The uncertainty of acceptance correction was estimated within 0.03%.

Energy and Time Spectra





Results and Current Status

Data taking of the PIENU experiment was completed in 2012, and the analysis of a partial data set taken in 2010 has been completed. The partial data set corresponds to about 4×10^5 $\pi^+ \to e^+ \nu_e$ decay events. For this data set with all corrections including low energy tail is

$$\mathrm{R}^\pi_{\mathrm{exp}} = [1.2344 \pm 0.0023(\mathrm{stat}) \pm 0.0019(\mathrm{syst})] \times 10^{-4} (0.24\%)$$

which is consistent with previous work and the SM prediction. The present result improves the test of electron-muon universality compared to previous experiments by a factor of two: $g_\mu/g_e = 1.0004 \pm 0.0012$ for charged current. This result was already published in

A. Aguilar-Arevalo *et al.*, Phys. Rev. Lett. 115, 071801 (2015).

The analysis of the remaining data is in progress and another data set taken in 2011 was also completed. The combined result of 2010 and 2011 data sets is

$$\Delta \mathrm{R}^\pi_{\mathrm{exp}} = [0.0014(\mathrm{stat}) \pm 0.0013(\mathrm{syst})] \times 10^{-4} (0.15\%).$$

The statistical uncertainty by full data set analysis is expected to be improved to 0.0007. It is anticipated that the systematic uncertainty will also be substantially improved.

Discussion & Conclusion

- Precision of 0.24% allowed potential access to new physics up to 500 TeV/c^2, and 820 TeV/c^2 by current result.
- Some theories beyond the SM were constrained (e.g. Massive neutrino search in $\pi^+ \to e^+ \nu_e$ decay.)

  S. Ito *et al.*, Hyperfine Interact (2017) 238: 1.
- Full data set analysis and massive neutrino search are in progress.
- It is anticipated that analysis of full statistics will be finished in 2017, and precision of R^π will be improved to $< 0.1\%$.