Search for Heavy Neutrinos in $\pi^+ \to \mu^+ \nu_\mu$ Decay

S.Ito[0,1], A.Aguilar-Arevalo[2], M.Aoki[1], M.Blecher[3], D.I.Britton[4], D.A.Bryman[5], D.vom Bruch[5], S.Chen[6], J.Comfort[7], S.Cuen-Rochin[5], L.Doria[8], P.Gumplinger[8], A.Hussein[9], Y.Igarashi[a], S.Kettell[b], L.Kurchaninov[8], L.Littenberg[b], C.Malbrunot[5], R.E.Mischke[8], T.Numao[8], D.Protopopescu[4], A.Sher[8], T.Sullivan[5], and D.Vavilov[8]
[0]Okayama University, Japan, [1]Osaka University, Japan, [2]Institudo de Ciencias Nuclears, Mexico, [3]Virginia Tech, USA, [4]University of Glasgow, UK, [5]University of British Columbia, Canada, [6]Tsinghua University, China, [7]Arizona State University, USA, [8]TRIUMF, Canada, [9]University of North British Columbia, Canada, [a]KEK, Japan, [b]Brookhaven National Laboratory, USA

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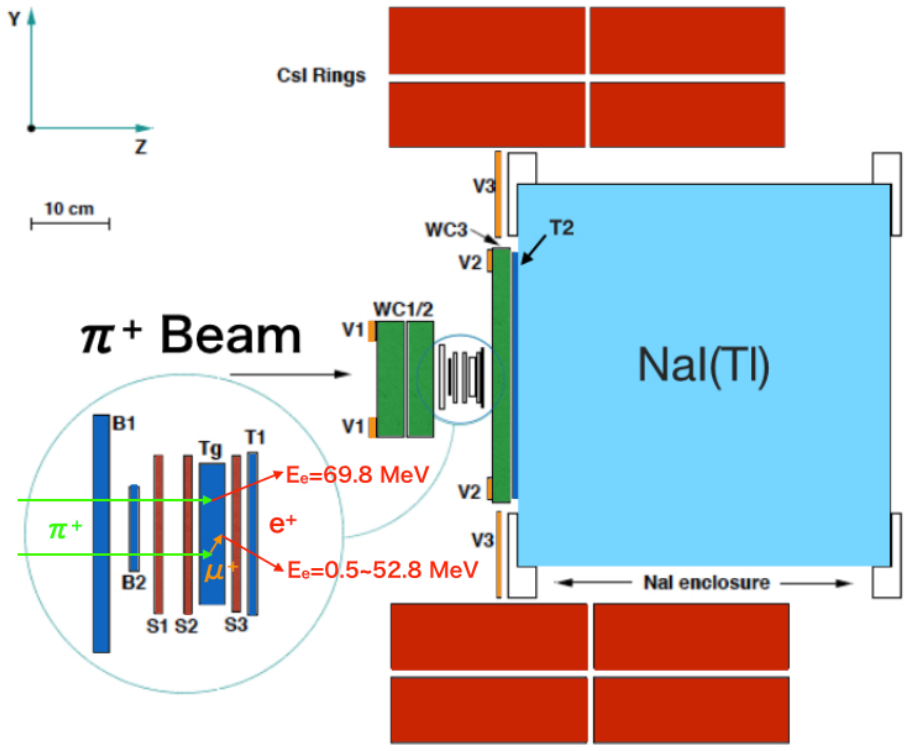
The PIENU Experiment and Search for Heavy Neutrinos

Neutrino oscillations indicate that at least two of the known neutrinos are massive. A natural extension of the Standard Model (SM) incorporating neutrino mass and possibly explaining the origin of dark matter involves the inclusion of heavy (e.g. sterile) neutrinos mixing with the ordinary neutrinos. An example of a sterile neutrino model is the Neutrino Minimal Standard Model that adds to the SM three massive gauge-singlet fermions. A search for extra peaks in $\pi^+ \to \mu^+ \nu_\mu$ decay is much sensitive to heavy neutrinos.

The PIENU experiment was carried out to measure the pion branching ration $\Gamma[\pi^+ \to e^+ \nu_e(\gamma)]/\Gamma[\pi^+ \to \mu^+ \nu_\mu(\gamma)]$ more precisely than 0.1%. First result of the pion branching ratio analysis using partial data set was published in Phys. Rev. Lett. 115, 071801 (2015), improving by a factor of two compared to the previous experiments. The analysis to search for heavy neutrinos in $\pi^+ \to \mu^+ \nu_\mu$ was performed using the PIENU data set.

The PIENU Detector



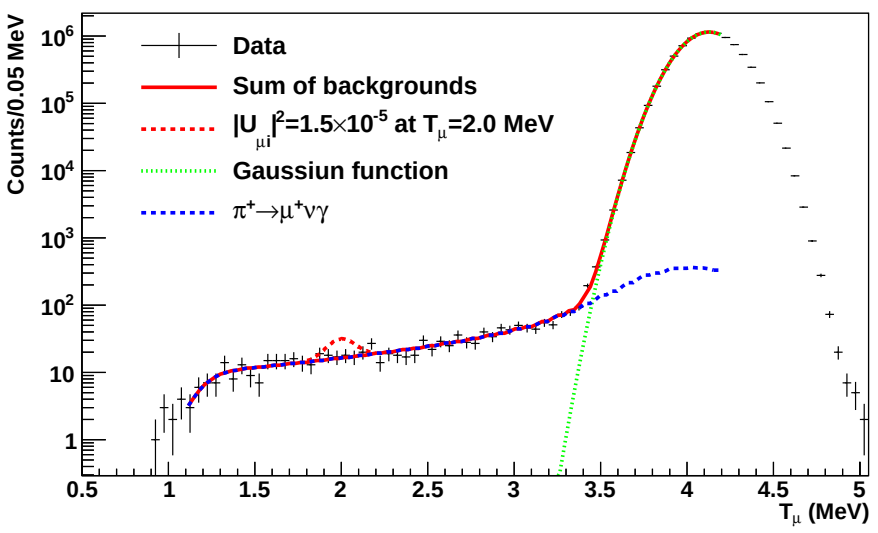
WC1−3 are wire chambers, S1 − 3 are silicon strips, and B1, B2, B3, T1, T2, V1, V2, and V3 are plastic scintillators (Nucl. Instrum. Meth. A791. 38-46(2015)).

Additional muon kinetic energy in $\pi^+ \to \mu^+ \nu_\mu$ decay is $T_\mu = 4.1$ MeV in B3 counter. All the plastic scintillators were recored using 500 MHz Flash ADC waveform digitizers. By precise waveform analysis in the target (B3), the muon energy spectrum could be obtained.

Analysis of The Region $T_\mu > 1.2$ MeV

A second pulse in B3 is due to muon kinetic energy. By requiring the muon pulse time window $80 - 150$ ns with respect to the first pulse (pion stop), the muon pulse could be identified. In the previous experiment performed by R. Abela et al. (Phys. Lett. 105B, 263 (1981)), accidental background (mainly decay positron from muon background) was dominant.

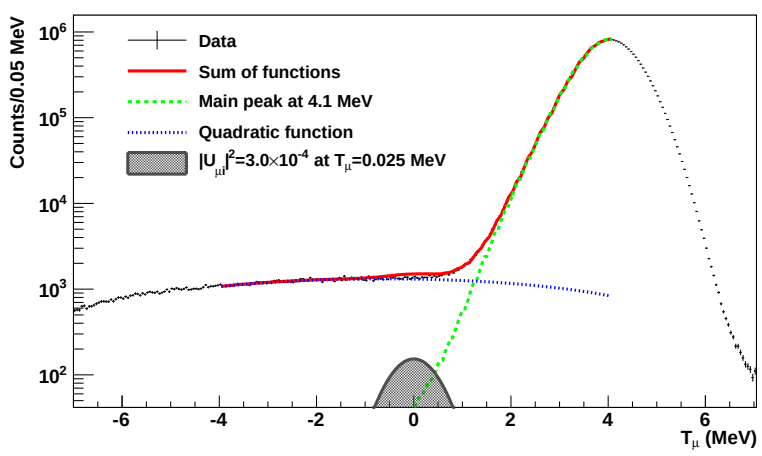
By employing fast waveform digitizers, precise tracking devices, and the calorimeters with higher energy resolution, accidental background could be minimized to be negligible. In this analysis, the main background was due to pion radiative decay $\pi^+ \to \mu^+ \nu_\mu \gamma$. The muon kinetic energy spectrum was fitted to Gaussian for 4.1 MeV peak, $\pi^+ \to \mu^+ \nu_\mu \gamma$ decay generated by MC, and signal function. Figure shows the muon kinetic energy spectrum with fitting function. The peak at 2.0 MeV indicates a hypothetical signal for $|U_{\mu i}|^2 = 1.5 \times 10^{-5}$.



Analysis of The Region $T_\mu < 1.2$ MeV

When the muon energy involving ν_H was < 1.2 MeV, the pulse detection logic could not efficiently identify the pulse. Thus, in the region $T_\mu < 1.2$ MeV, all the pulse in B3 containing pion and decay positron were integrated. The energy spectrum was shifted by aligning the peak at 4.1 MeV, and fitted for extra peak search.

Previous experiment done by D.A. Bryman and T. Numao (Phys. Rev. D53, 558 (1996)) was limited by πDIF background (the events below the main peak). For the PIENU experiment, πDIF could be suppressed using the tracking information of WC1,2 and S1,2.



Results & Conclusion

No evidence for massive neutrinos in $\pi^+ \to \mu^+ \nu_\mu$ decay was observed. Upper limits on the neutrino mixing parameter $|U_{\mu i}|^2$ were obtained for the region 15.7< m_H <33.8 MeV/c^2. The improvement factors were approximately an order of magnitude compared to the previous experiments. This result was already submitted to Phys. Lett. B and arXiv is available on arXiv:1904.03269.