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# Measurement of $\pi \rightarrow e\nu$ / $\pi \rightarrow \mu\nu$ branching ratio

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Study of rare decays is an important approach for exploring physics beyond the Standard Model (SM). New physics could be seen if deviations from well-calculated SM predictions occur. In particular, the branching ratio of pion decays, $\frac{\Gamma(\pi^+ \to e^+\nu_e + \pi^+ \to e^+\nu_e\gamma)}{\Gamma(\pi^+ \to \mu^+\nu_\mu + \pi^+ \to \mu^+\nu_\mu\gamma)}$ is one of the most accurately calculated decay process involving hadrons and has so far provided the most stringent test of the hypothesis of electron-muon universality in weak interactions. It has been calculated in the SM to better than 0.01% to be $R_{SM} = 1.2353(1) \times 10^{-4}$. The PIENU experiment at TRIUMF aims to reach an accuracy five times better than the current world average value, so as to confront the theoretical calculation at the level of $\pm 0.1\%$. At this level,"new physics" at potentially very high mass scales could be revealed, or sensitive constraints on hypotheses can be obtained for new pseudoscalar, axial vector, or scalar interactions.

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## 1. Introduction

The branching ratio of pion decays, R=$\Gamma(\pi \to e\nu + e\nu\gamma)/\Gamma(\pi \to \mu\nu + \mu\nu\gamma)$, has provided the best test of the hypothesis of electron-muon universality in weak interactions. The most recent experimental results of the branching ratio are: R=$(1.2265 \pm 0.0034(stat) \pm 0.0044(syst)) \times 10^{-4}$ (TRIUMF) [1], and R=$(1.2346 \pm 0.0035(stat) \pm 0.0036(syst)) \times 10^{-4}$ (PSI) [2]. The new TRIUMF PIENU experiment aims to improve the precision of the branching ratio measurement by a factor of $> 5$, confronting the Standard Model (SM) prediction of R(SM)=$1.2352(1) \times 10^{-4}$ [3, 4] to better than 0.1 %. At that level, new physics may be heralded by a deviation from the precise SM expectation. In particular, it is very sensitive to helicity unsuppressed decays involving pseudo-scalar interaction. Because any pseudo-scalar contribution comes as an interference with the dominant axial-vector interaction, the contribution is proportional to $1/m_\Lambda^2$, where $m_\Lambda$ is the mass of a hypothetical particle. This feature is in contrast to a $1/m_\Lambda^4$ dependence in lepton flavor-violating decays. Ignoring small contributions from $\pi \to \mu\nu$ decay in the presence of pseudoscalar interactions and assuming a coupling similar to the weak coupling, the deviation of the new branching ratio from the SM prediction can be parameterized as

$$1 - \frac{R_{e/\nu}^{Exp}}{R_{e/\nu}^{SM}} \sim \pm \frac{\sqrt{2}\pi}{G_\mu} \frac{1}{\Lambda_{eP}^2} \frac{m_\pi^2}{m_e(m_d + m_u)} \sim (\frac{1TeV}{\Lambda_{eP}})^2 \times 10^3 \tag{1.1}$$

[5] where $\Lambda_{eP}$ is a mass scale of new pseudoscalar interaction in $\pi \to e\nu$ decay. This property makes the measurement of the branching ratio at a 0.1% level sensitive to the mass scales of $O$(1000 TeV) for pseudoscalar interactions.

Scalar couplings arising from physics beyond the SM (i.e. scalar couplings which don't follow the SM Higgs mass dependence) will also induce pseudo-scalar interactions through loop corrections and, in many cases, the $\pi \to e\nu$ branching ratio measurement provides substantially stronger limits than ones from $\beta$-decay measurements [6].

Stronger limits on the existence of massive neutrinos in the mass region 50 to 130 MeV/c$^2$ with mixing angle of 0.0005 can also be set with improved statistics on the $\pi \to e\nu$ decay. Candidate examples of the new physics probed include the R-parity violating SUSY [7], effects of high scale four-fermion operators due to excited gauge bosons (*e.g.* from extra dimensions) [8], leptoquarks [9], compositeness [10] or charged Higgs bosons [7].

## 2. The PIENU Experiment

Figure 1 shows the detector arrangement. A 75-MeV/c $\pi^+$ beam from the TRIUMF M13 channel with an intensity of 50–100 kHz is identified by two beam counters and stopped in an active scintillator target. Beam tracking is provided by two wire chambers, and two silicon-strip counters located immediately upstream of the target.

Positrons from decay $\pi^+ \to e^+\nu$ and $\pi^+ \to \mu^+\nu$ followed by $\mu^+ \to e^+\nu\bar{\nu}$ decay ($\pi^+ \to \mu^+ \to e^+$ decay) are measured in the positron telescope. It consists of a silicon-strip counter, two thin plastic counters, a third acceptance-defining wire chamber covering the front of a 48-cm-diameter, 48-cm-long single NaI(Tl) crystal (BINA), which provides the primary energy measurement. The solid angle of the telescope counters is 20%. Two layers of 8.5-cm-thick, 2×25-cm-long pure CsI

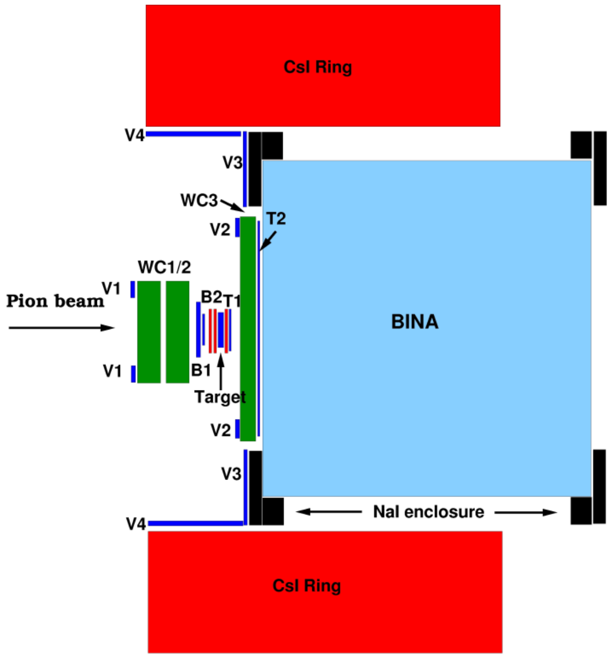


**Figure 1:** Experimental setup.

counters surround the NaI to capture shower leakage. Analog signals from plastic scintillators (Si-strip, NaI and CsI detectors) are recorded by 500 MHz Copper ADCs [11] (60 MHz VF48 ADCs [12]).

## 3. The Measurement technique

Simultaneous fitting of the time distributions (see Fig.2) of low-energy (E$<$ 55 MeV) and high-energy (E$>$ 55 MeV) regions provides the yields of $\pi \to \mu \to e$ and $\pi \to e\nu$ decays, respectively.

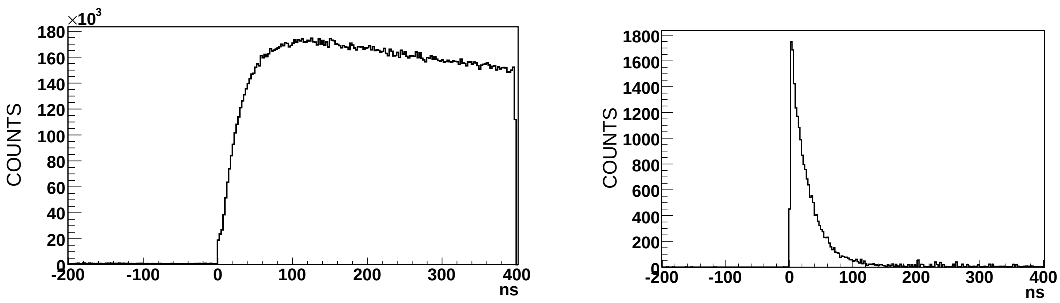


**Figure 2:** Beamtest data. **Right**: $\pi \to \mu \to e$ time spectrum (E<55 MeV); **Left**: $\pi \to e \to \nu$ time spectrum (E >55 MeV).

The dominant uncertainty in the previous TRIUMF experiment [1] was in the knowledge of the low-energy tail of $\pi \to e\nu$ events in the energy region of the $\pi \to \mu \to$ e population. The same technique employed in [1] will be used to deduce the low-energy tail correction based on the positron energy spectrum in which the $\pi \to \mu \to$ e background is suppressed by selecting a small time window after the pion stop and using pulse shape and energy information in the target. The majority of remaining low-energy events in the background-suppressed spectrum came from in-flight decays of pions around the target. Pion tracking near the target is expected to provide an additional background suppression factor of two. An overall improvement factor of $> 5$ including improved statistics is expected for this correction.

| Sources | Ref.[1] | Present |
|---|---|---|
| Statistical | 0.0028 | 0.0005 |
| Low energy $\pi \to e\nu$ | 0.0025 | 0.0003 |
| Acceptance difference | 0.0011 | 0.0003 |
| Pion lifetime | 0.0009 | 0.0002 |
| Others | 0.0011 | 0.0003 |
| Total | 0.0047 | 0.0006 |

Table I: Summary of uncertainties normalized to the branching ratio.

Table I summarizes the expected uncertainties of the present experiment, together with those in Ref.[1]. With statistics of $>$ 30 times those of the previous experiments and substantially reduced systematic uncertainties, the expected precision of the PIENU experiment for the branching ratio of the pion decays will be $< 0.1$ %, which corresponds to $< 0.05$ % uncertainty in the ratio of the coupling constants $g_e/g_\mu$.

## 4. Beam and detectors performances

Since the detector system is located on the beam axis, positrons in the beam ($\sim 1/4$ of pions) cause serious impact on the trigger rates and background in the $\pi \to e\nu$ ($E > 55$ MeV) time spectrum. The TRIUMF M13 channel has been modified to have three bending magnets for reduction of the positron contamination in the beam. A momentum selected beam by the first bending magnet passes through a 1.5 mm thick Lucite absorber that causes a momentum difference between positron and pion beams, resulting in a 5 cm separation after the second bending magnet as shown in Fig.3. A collimator is placed before the third bending magnet to select pions.

The beam commissioning tests confirmed that the $e^+$ contamination with respect to the pion rate after the collimator was $< 2$ %, while maintaining a high enough pion rate.

The response function of the NaI/CsI system was measured using 50–85 MeV/c positron beams. The energy resolution was 2 % (FWHM) including the beam contribution, and the low energy tail for the beam entrance angles of 0–50$^o$, due mostly to shower leakage escaping the CsI crystals, was 0.1–0.4 %, consistent with Monte Carlo simulations as illustrated in Fig.4.

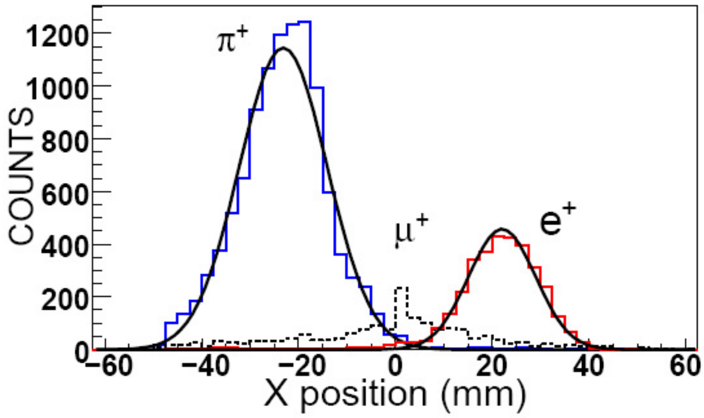


**Figure 3:** Pion, muon and positron position distributions at the location of the collimator. The heavy lines are fitted Gaussian curves for positrons and pions.

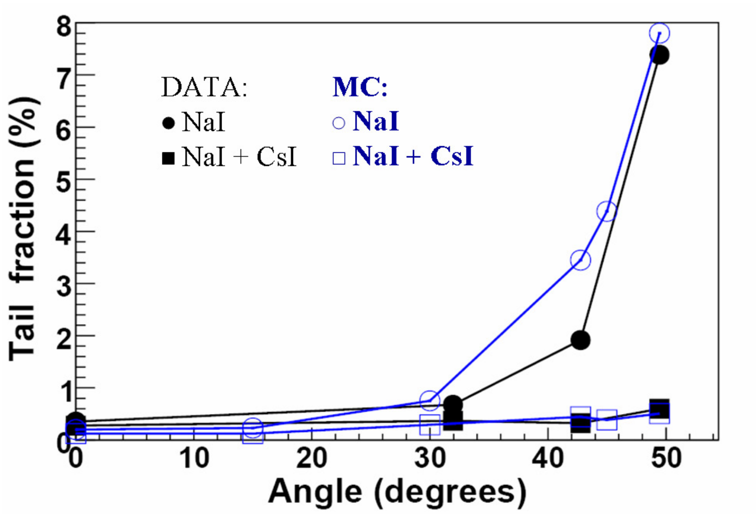


**Figure 4:** Fraction of events below 50 MeV/c vs. the angle of incidence on the face of the NaI crystal. Using energy measured in the CsI ring surrounding the NaI crystal brings the low energy tail below 1% for all measured $e^+$ entrance angles.

The experiment is currently in the engineering phase. Beamline and major detectors have been tested and satisfy the requirements to achieve the goal of measuring the pion decay's branching ratio : $\frac{\Gamma(\pi^+ \to e^+ \nu_e + \pi^+ \to e^+ \nu_e \gamma)}{\Gamma(\pi^+ \to \mu^+ \nu_\mu + \pi^+ \to \mu^+ \nu_\mu \gamma)}$, to an accuracy five times better than the current world average value. Physics data taking is expected to begin in mid-2009.

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