Study of rare decays is an important approach for exploring physics beyond the Standard Model (SM). The branching ratio of the helicity suppressed $\pi^+ \rightarrow e^+\nu$ decay, 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. The branching ratio has been calculated in the SM to better than 0.01% accuracy to be $R = 1.2353(1) \times 10^4$. The PIENU experiment at TRIUMF, which started taking physics data in September 2009, aims to reach an accuracy five times better than the previous PSI and TRIUMF experiments so as to confront the theoretical calculation at the level of 0.1%. If a deviation from the SM branching ratio is found, “new physics” beyond the SM, at potentially very high mass scales (up to 1000 TeV), could be revealed. Alternatively, sensitive constraints on hypotheses can be obtained for pseudoscalar or scalar interactions, or on the mass and couplings of heavy neutrinos. So far, around five millions pion to electron decay events have been accumulated by the PIENU experiment. Data taking will continue in 2011 to increase the statistics to the $10^7$ level. The presentation will outline the physics motivations, describe the apparatus and techniques designed to achieve high precision and present the status of the analysis.
The PIENU Experiment

a sensitive probe in the search for new physics

Chloé Malbrunot

For the PIENU Collaboration

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2. Brookhaven National Laboratory
3. KEK
4. Osaka University
5. TRIUMF
6. University of British Columbia
7. University of Northern British Columbia
8. University of Glasgow
9. Virginia Polytechnic Institute & State University
10. Tsinghua University
11. Instituto de Ciencias Nucleares

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Introduction to pion decay

Pion is the lightest meson (~140 MeV): can only decay to lighter leptons (e or μ) + associated

From phase-space, decay to positron is favoured over decay to muon (but no detection before 19
Introduction to pion decay

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V-A theory of weak interaction
Introduction to pion decay

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From phase-space, decay to positron is favoured over decay to muon (but no detection before 19

V-A theory of weak interaction

Because of helicity the $\pi^+ \rightarrow e^+\nu$ decay is suppressed over the $\pi^+ \rightarrow \mu^+\nu$ decay by a factor $(m_e/m_\mu)^2$

$$R_{e/\mu}^{SM} = \frac{\Gamma(\pi \rightarrow e\nu + \pi \rightarrow e\nu\gamma)}{\Gamma(\pi \rightarrow \mu\nu + \pi \rightarrow \mu\nu\gamma)} = 1.2352(1) \times 10^{-4}$$

A Precision Experiment

Current world average: TRUMF, PSI:

\[ R_{e/\mu}^{\text{exp}} = 1.231 \pm 0.004 \times 10^{-4} \]


SM value:

\[ R_{e/\mu}^{\text{SM}} = \frac{\Gamma(\pi \rightarrow e\nu + \pi \rightarrow e\nu\gamma)}{\Gamma(\pi \rightarrow \mu\nu + \pi \rightarrow \mu\nu\gamma)} = 1.2352(1) \times 10^{-4} \]


2 orders of magnitude difference in precision → window for BSM physics

PIENU goal: improvement x5 → precision < 0.1% on the BR

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Universality test

\[ \Gamma_{\pi \rightarrow l + \nu_l} = G^2 \frac{m_\pi + f_\pi + m_l^2}{8\pi} \left(1 - \frac{m_l^2}{m_{\pi}^2}\right)^2 \left[1 + RC\right], \quad \frac{G}{\sqrt{2}} = \frac{g_l^2}{8M_W} \]

\[ R_{e/\mu} = \frac{\Gamma_{\pi \rightarrow e\nu_e}}{\Gamma_{\pi \rightarrow \mu\nu_\mu}} \]
Universality test

\[ \Gamma_{\pi \rightarrow l + \nu_l} = G^2 \frac{m_\pi + m_\mu^2}{8\pi} \left( 1 - \frac{m_\mu^2}{m_\pi^2} \right)^2 \left[ 1 + RC \right] \]

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\[ R_e/\mu = \frac{\Gamma_{\pi \rightarrow e\nu_e}}{\Gamma_{\pi \rightarrow \mu\nu_\mu}} \]

\[ g_e = g_\mu = g_\tau \]

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>((g_\mu/g_e)^2)</th>
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<tbody>
<tr>
<td>(\tau \rightarrow \mu/\tau \rightarrow e) *</td>
<td>1.0018 ± 0.0014</td>
</tr>
<tr>
<td>(\pi \rightarrow \mu/\pi \rightarrow e) *</td>
<td>1.0021 ± 0.0016</td>
</tr>
<tr>
<td>(K \rightarrow \mu/K \rightarrow e)</td>
<td>0.9960 ± 0.005</td>
</tr>
<tr>
<td>(K \rightarrow \pi\mu/K \rightarrow \pi e)</td>
<td>1.002 ± 0.002</td>
</tr>
<tr>
<td>(W \rightarrow \mu/W \rightarrow e)</td>
<td>0.997 ± 0.010</td>
</tr>
</tbody>
</table>

* \(\tau\) and \(\pi\) are complementary

Pion branching ratio is **one of the most precise** test of CC lepton universality

0.1% measurement in the BR → 0.05% in \(g_e/g_\mu\)
Beyond SM search

\[ 1 - \frac{R^{Exp}}{R^{SM}} \sim \pm \frac{\sqrt{2\pi}}{G} \frac{1}{\Lambda^2} \frac{m^2_\pi}{m_e(m_d + m_u)} \sim \left( \frac{1\,\text{TeV}}{\Lambda_{eP}} \right)^2 \times 10^3 \]

0.1\% measurement \rightarrow \Lambda_{eP} \sim 1000 \, \text{TeV}

Massive \nu's

Scalar coupling

R-Parity violation SUSY

... 

Real deviation from the SM \rightarrow new physics observation
Agreement with SM \rightarrow constraints
Massive neutrino

\[
\begin{bmatrix}
e

\end{bmatrix}
\begin{bmatrix}
\mu

\end{bmatrix}
\begin{bmatrix}
\tau

\end{bmatrix} + \nu_{\chi_1} \ldots \nu_{\chi_K}
\]

e.g. Neutrino Minimal Standard Model
T. Asaka et al., JHEP 1104, 11 (2011)

The presence of an heavy neutrino changes the helicity relation and alter the value of the branching ratio

If the heavy neutrino mass is \( M_\nu = 60-130 \text{ MeV/c}^2 \) additional low energy positron peak can detected in the \( \pi^+ \rightarrow e^+ \nu_\chi \) spectrum.
Experimental Method

- Stop pions in an active target Scintillator
- Yield measurement

Target

$\pi^+$

$\mu^+$

$4 \text{ MeV}$

$e^+$

$e^+$

Time spectrum

Counts

Energy spectrum

Counts

Time relative to prompt [ns]

Nal energy [MeV]
The PIENU detector (cont'd)

Monolithic NaI(Tl) crystal surrounded by 97 pure CsI crystals

1 CsI crystal

Acceptance Wire Chamber

PIENU II is movable and detachable from PIENU I for line shape measurement at various e+ entrance angles

07/28/2011

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Branching Ratio

Simultaneous Fit of both time spectra: Raw Branching ratio

Many corrections have to be applied

<table>
<thead>
<tr>
<th>Source</th>
<th>Error</th>
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<tbody>
<tr>
<td>Statistical</td>
<td>0.05%</td>
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<tr>
<td>Low energy tail</td>
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<td>Monte Carlo</td>
<td>0.03%</td>
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<tr>
<td>Pion lifetime</td>
<td>0.03%</td>
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<tr>
<td>Others</td>
<td>0.03%</td>
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<tr>
<td>Total systematic uncertainties</td>
<td>0.06%</td>
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</table>
Massive neutrinos

Search for extra peak in the $\pi^+ \rightarrow e^+ \nu_e$ spectrum

M. Aoki et al. Submitted to PRD
## Conclusions

<table>
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<tr>
<th>Year</th>
<th>Month</th>
<th>Description</th>
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<td>10-12</td>
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Data used for massive neutrino analysis

$1/2$ million $\pi^+ \rightarrow e^+\nu$ events after selection cuts
## Conclusions

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Data used for massive neutrino analysis
1/2 million $\pi^+ \rightarrow e^+\nu$ events after selection cuts

6 million $\pi^+ \rightarrow e^+\nu$ events accumulated so far

BRANCHING RATIO ANALYSIS UNDERWAY!