Initial Results From the TRIUMF PIENU Experiment

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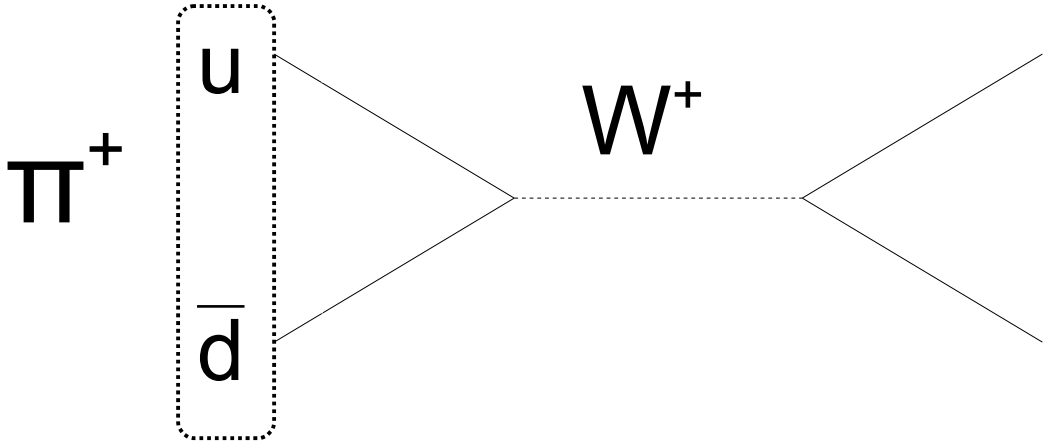
For the PIENU Collaboration

Pion Decay



$M_\pi = 139.6$ MeV

$E_e = 69.3$ MeV

$E_\mu = 4.1$ MeV

Standard Model prediction:

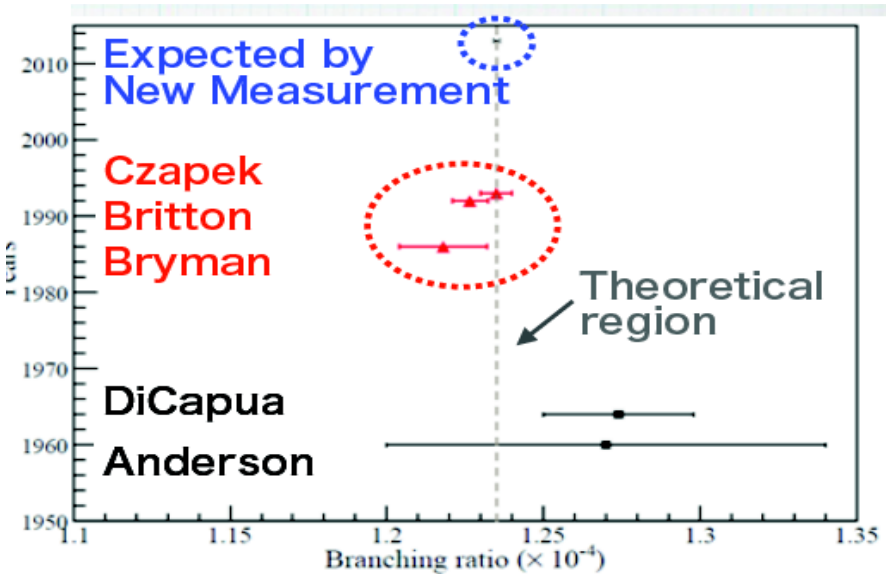
$$R_\pi = \frac{\Gamma((\pi \to e\,\nu) + (\pi \to e\,\nu\,\gamma))}{\Gamma((\pi \to \mu\,\nu) + (\pi \to \mu\,\nu\,\gamma))} = (1.2352 \pm 0.0002) \cdot 10^{-4}$$

One of the most accurately predicted SM observables involving quarks

Experimental Status

$R_{exp} = (1.230 \pm 0.004) \cdot 10^{-4}$
Good agreement but ~20 times less precise

Still one of the best tests of lepton universality



$$\frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} = \frac{g_e^2}{g_\mu^2} R_{e/\mu}^{th}$$

Decay Mode	g_μ / g_e	Year
τ —> μ / τ —> e	1.0018 ± 0.0014	2010
π —> μ / π —> e	1.0021 ± 0.0016	1994
K —> μ / K —> e	0.996 ± 0.005	2011
K —> πμ / K —>π e	1.002 ± 0.002	2007
W —> μ / W —> e	0.997 ± 0.010	2008

BSM Physics

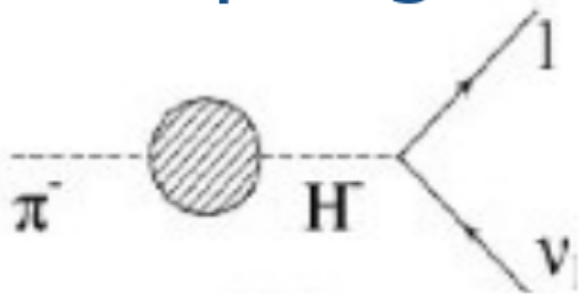
New pseudo-scalar interactions (no helicity suppression)

(0.1% precision)

$$1-\frac{R^{exp}}{R^{SM}} \sim \mp \frac{\sqrt{2}\pi}{G_\mu}\frac{1}{\Lambda^2}\frac{m_\pi^2}{m_e(m_d+m_u)} \sim (\frac{1\mathrm{TeV}}{\Lambda})^2 \times 10^3 \Rightarrow 1000\mathrm{TeV}$$

Charged Higgs (non-SM couplings)

Relevant for SUSY models



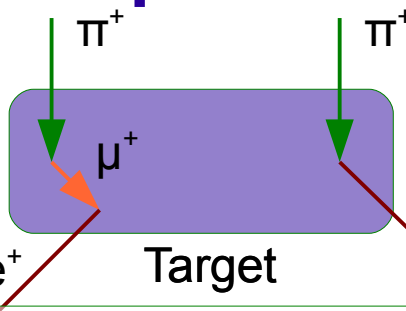
$$1-\frac{R^{exp.}}{R^{SM}} \sim \mp \frac{2m_\pi^2}{m_e(m_d+m_u)}\frac{m_W^2}{m_{H^\pm}}\lambda_{ud}(\lambda_{e\nu}-\frac{m_e}{m_\mu}\lambda_{\mu\nu})$$

For current precision $M_{H^\pm} > 400$ GeV

W. Marciano et al, Annual Reviews of Nuclear and Particle Science, 2011

Experimental Method

τ_μ = 2197 ns



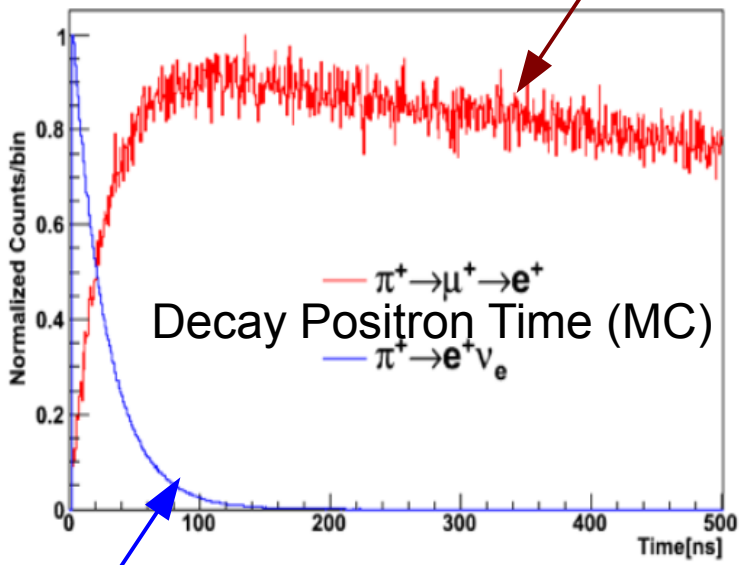
τ_π = 26 ns

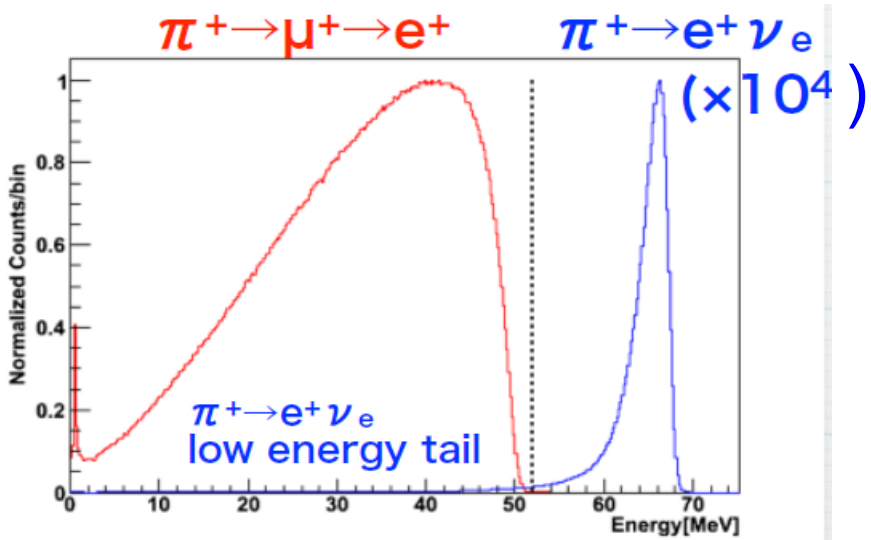
E_e = 0.5-52.8 MeV

E_e = 69.8 MeV

Calorimeter

$\pi^+ \rightarrow \mu^+ \rightarrow e^+$: $N_{PIMU} / (\tau_\mu - \tau_\pi) \times (e^{-t/\tau_\mu} - e^{-t/\tau_\pi})$





Decay Positron Energy (MC)

$\pi^+ \rightarrow e^+$: $(N_{PIE} / \tau_\pi)\, e^{-t/\tau_\pi}$

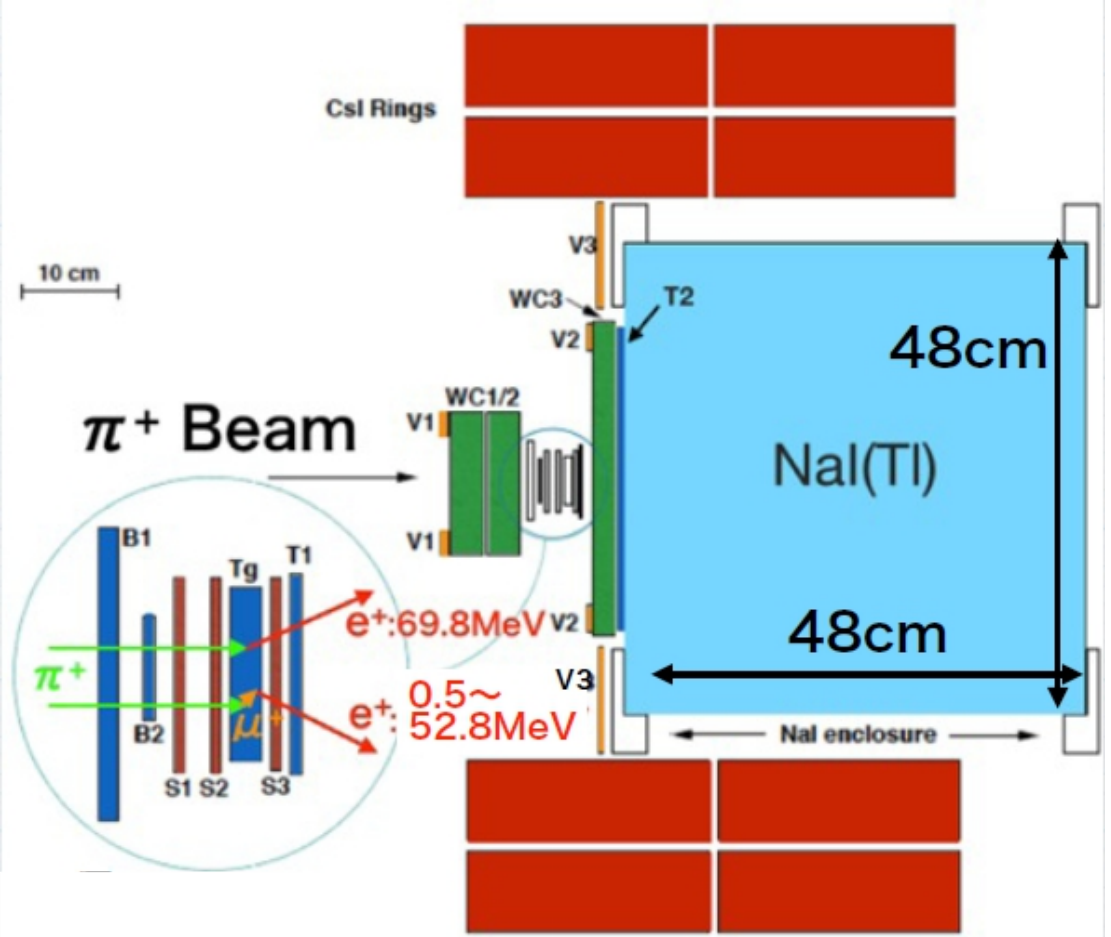
PIENU Detector

π^+ beam:

- ~ 60 KHz on B1
- 75 ± 1 MeV / c
- $\pi^+ : \mu^+ : e^+ = 85 : 14 : 1$

Detector:

- Acceptance ~ 20%
- Energy Resolution 2.2% (FWHM) at 70 MeV
- 19 radiation lengths of NaI, 9 of CsI
- Pion and positron times obtained from fitting B1 and T1 waveforms, respectively
- Wire chambers & silicon strips for π^+ beam and decay e^+ tracking

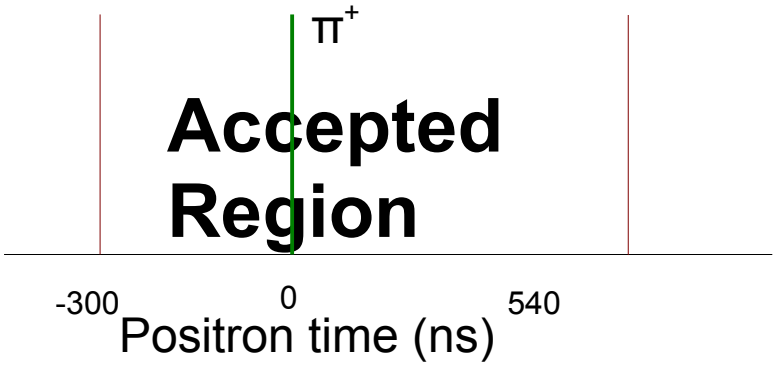


WC: Wire Chamber

SS: Silicon Strip

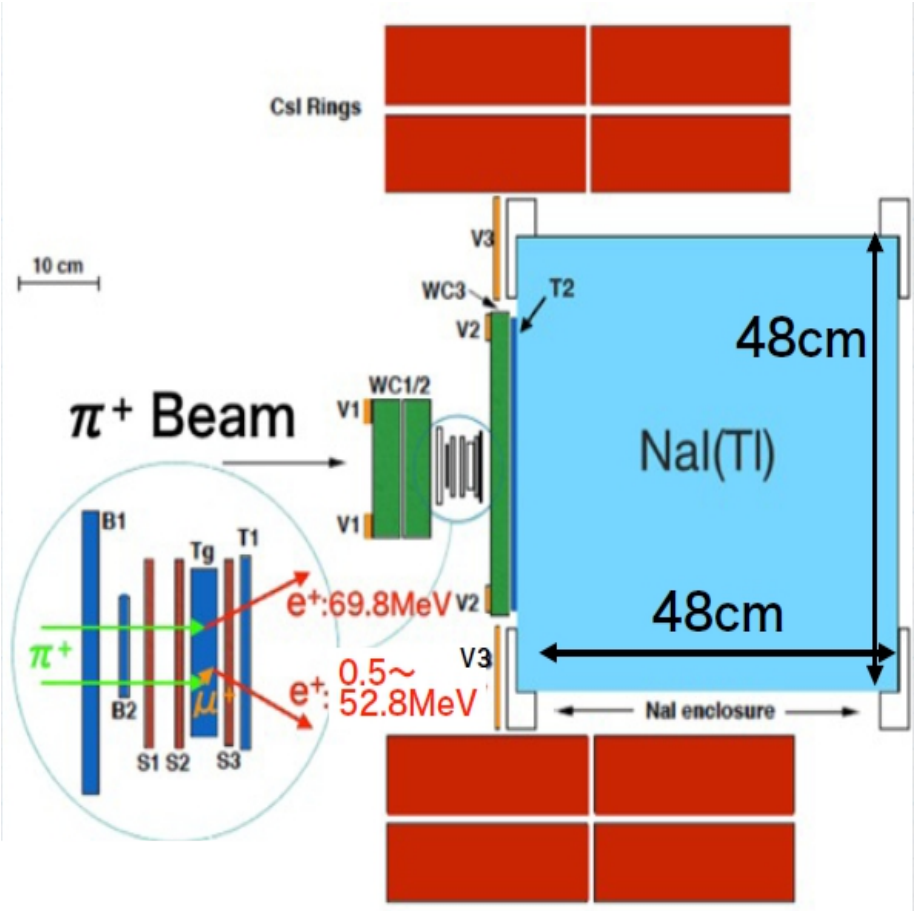
B1, B2, Tg, T1, T2: Plastic Scintillator

Trigger and Event Selection



Event Selection Cuts:

- PID: pion energy deposit in B1 and B2
- Pileup: no extra hits in B1, B2, T1, or T2 in a window from -7 μs to 1.4 μs with respect to the pion stop
- Acceptance: reconstructed positron track within 60 mm of the centre of wire chamber 3



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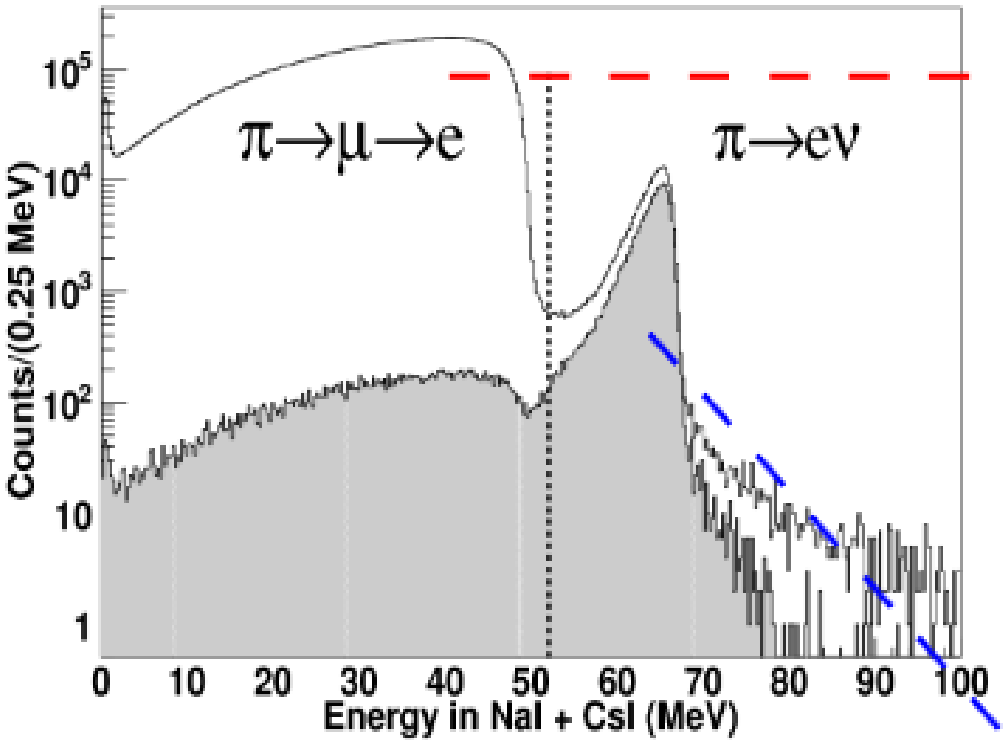
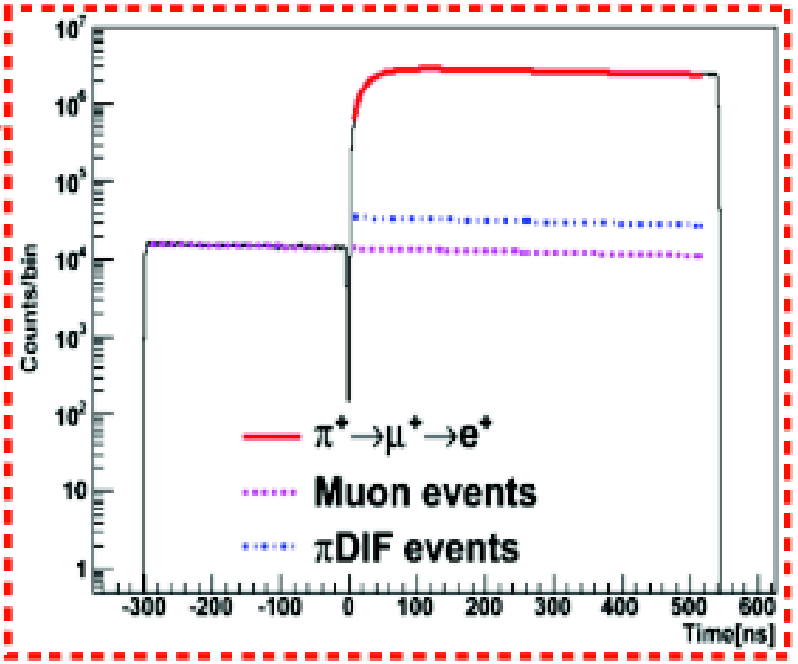
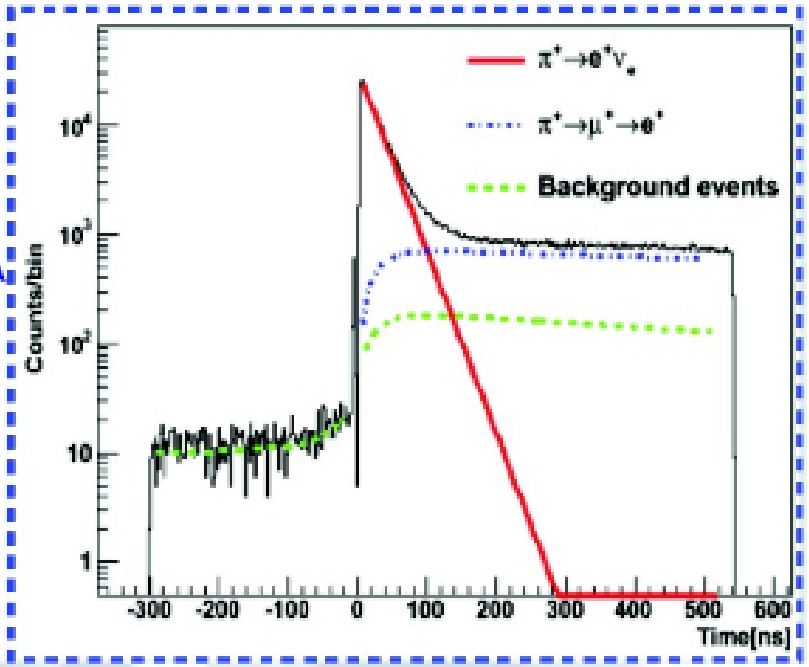
Raw Branching Ratio Extraction



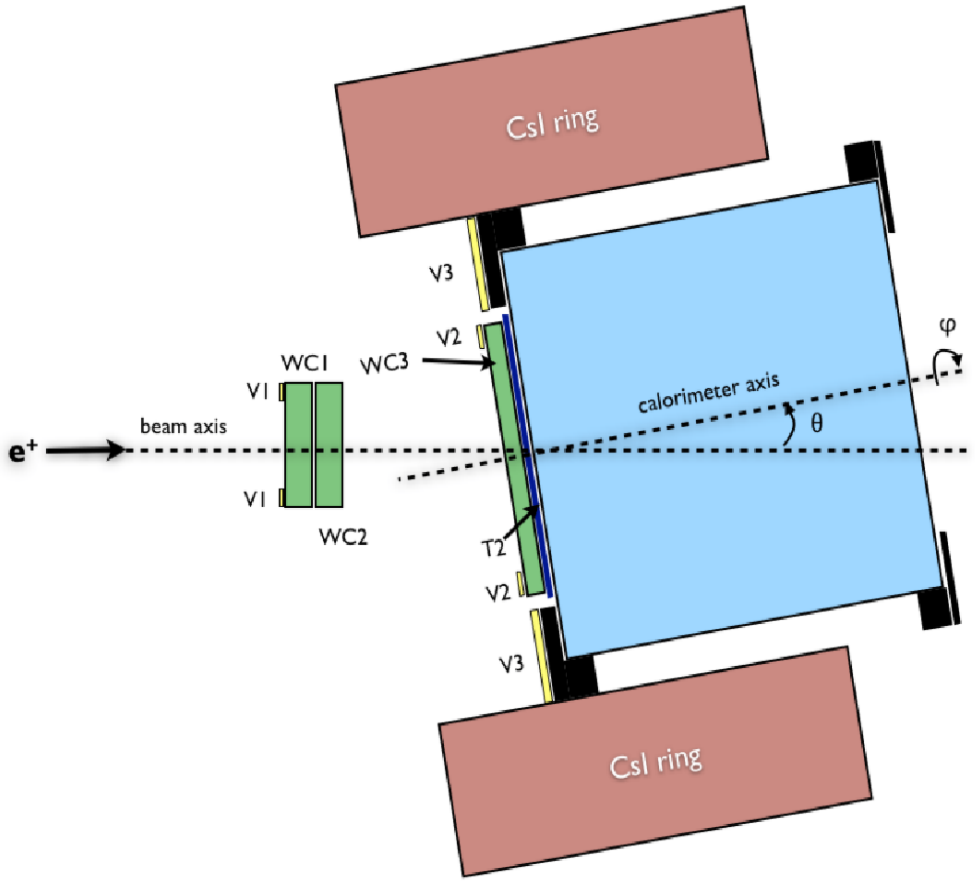


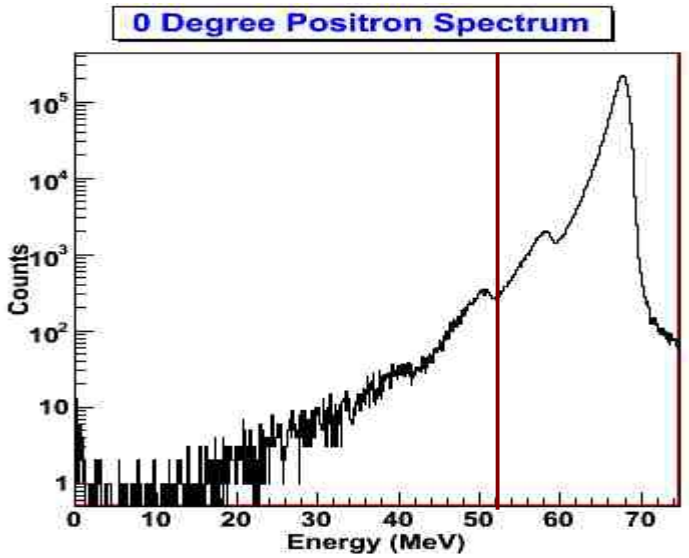


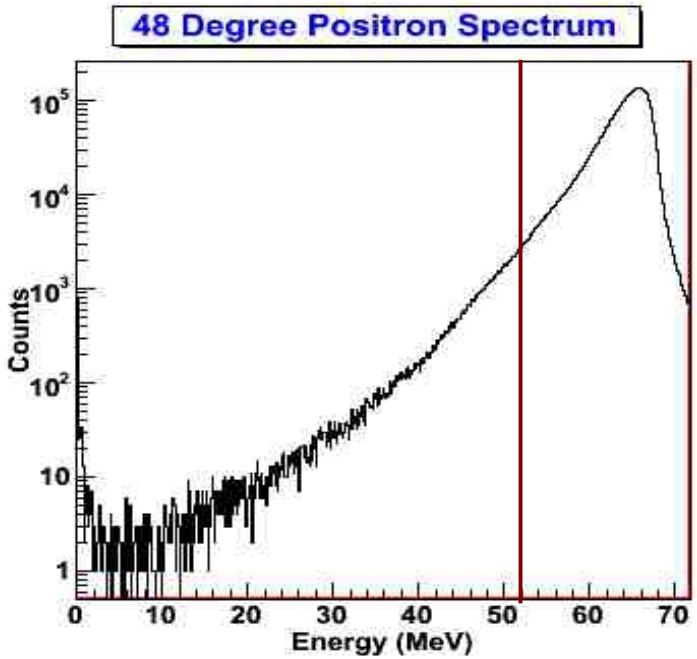
- Data from November 2010
- 4.0 x 10^5 clean π —> e ν events
- Fitting time spectra simultaneously gives raw branching ratio:

$$R_{raw} = [1.1972 \pm 0.0022\ (stat) \pm 0.0005\ (syst)] \cdot 10^{-4}$$

NaI Response Function



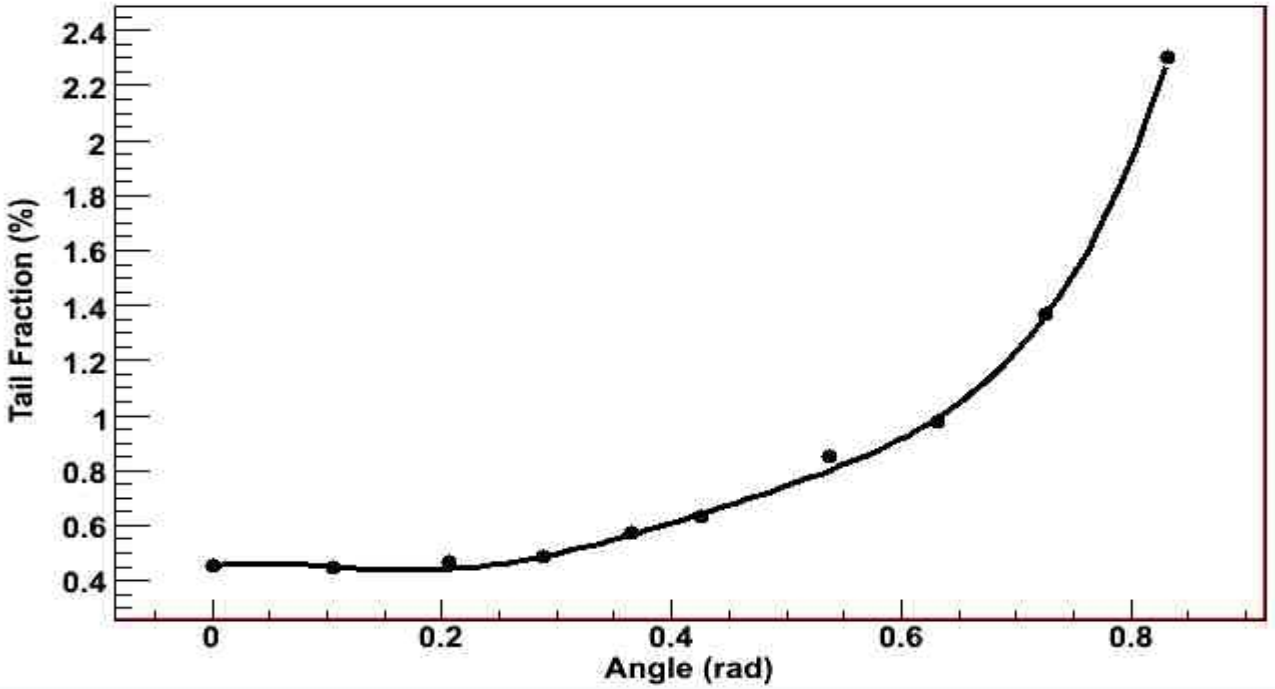




0 degree tail fraction: 0.45%
48 degree tail fraction: 2.3%

Tail Correction I

Tail Vs. Angle, Positron Beam Data



To equate to pion decay case, fit with polynomial and take angular average with isotropic weights. Result is

Tail Fraction = 0.98%

Tail Correction II

Tail Fraction for simulated π —> e ν = 2.98%

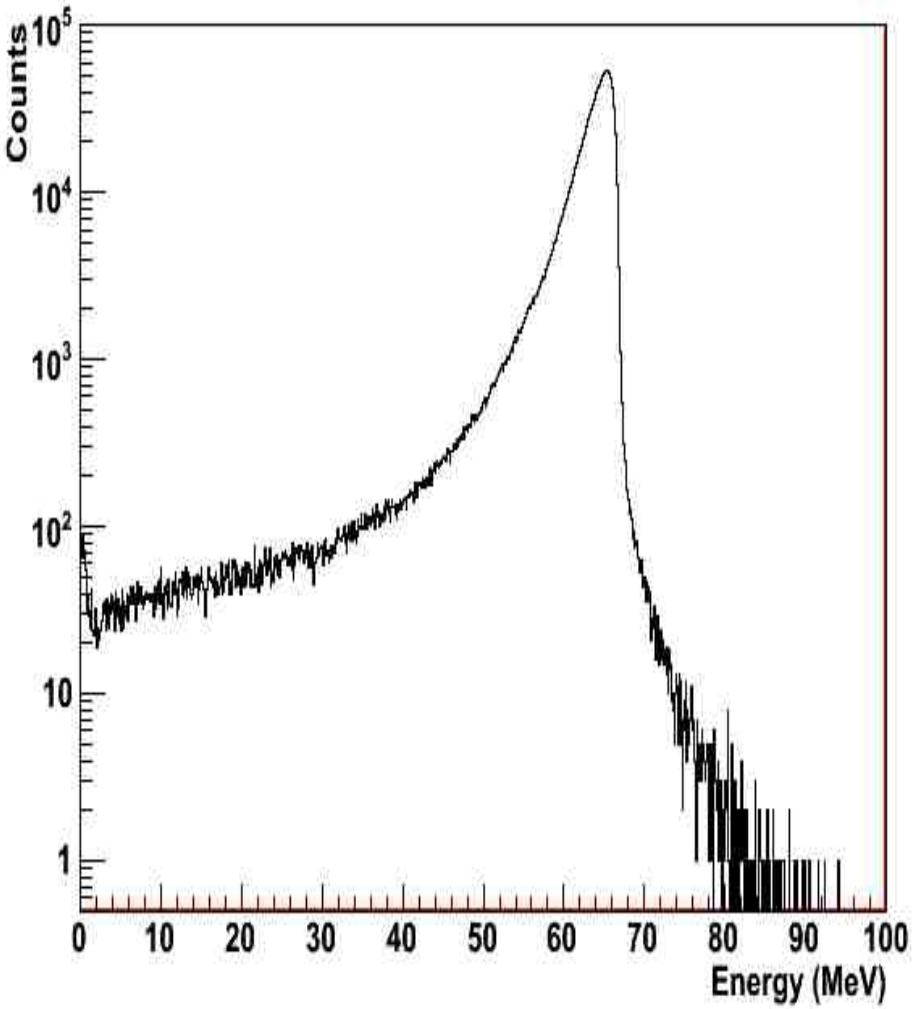
Small difference due to radiative decay; main difference due to extra material

Bhabha scattering can cause low-energy electrons to trigger

Combine this with positron data to get final tail

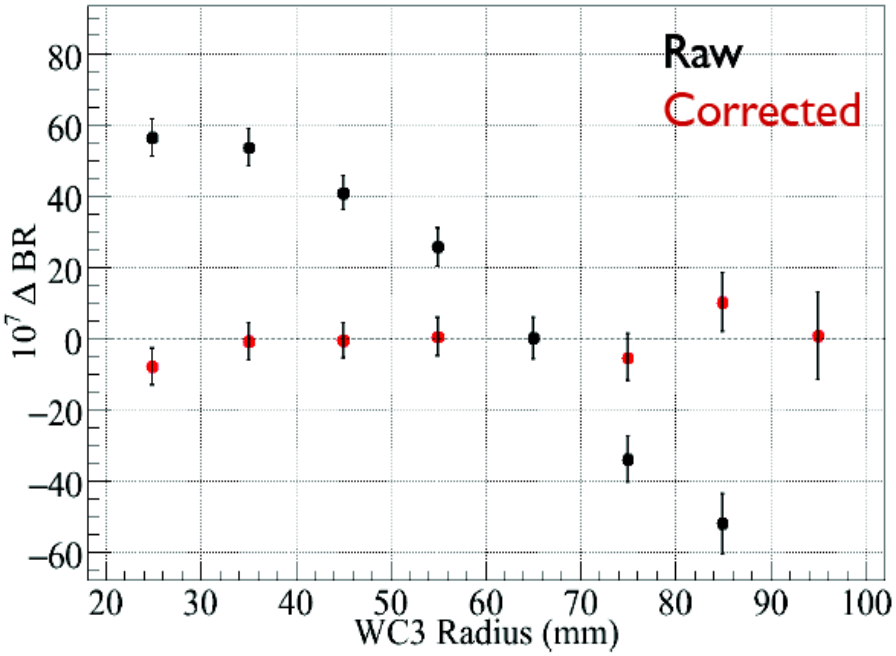
Final Tail Fraction = 3.19% ± 0.03% (stat) ± 0.08% (syst)

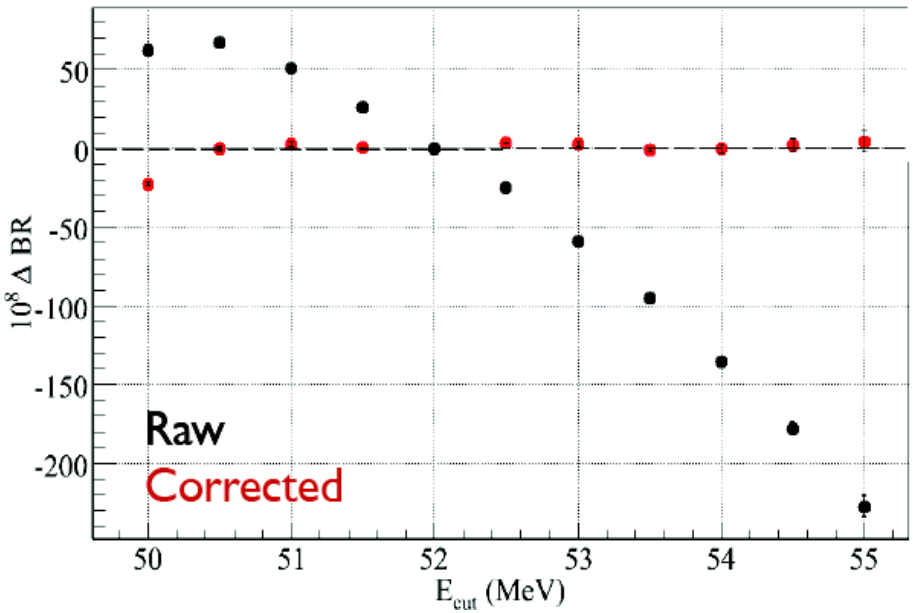
Simulated π —> e ν Energy



Branching Ratio Stability Checks

- Acceptance Radius Dependence
- R= 60 mm





- Energy cut dependence
- Tail/muDIF corrections applied

Result I (2010 data)

$$R_{corr} = [1.2344 \pm 0.0023\ (stat) \pm 0.0019\ (syst)] \cdot 10^{-4}$$

Factor of two improvement over previous generation of experiments

New Universality result: $g_\mu / g_e = 1.0004 \pm 0.0012$

Pion decay once again provides the most sensitive test

A. Aguilar-Arevalo et al, Physical Review Letters, 2015

Future Prospects

$$R_{2011} = [1.2xxx \pm 0.0018\ (stat) \pm 0.0013\ (syst)] \cdot 10^{-4}$$

2012 data set ~5 times bigger than 2010; cuts and fitting functions must be improved due to higher statistics. Analysis is ongoing

Error	PIENU 2010	PIENU goal
Statistical	0.19%	0.07%
Time Spectrum	0.04%	0.04%
Tail Correction	0.12%	0.06%
Others	0.07%	0.04%
Total	0.24%	< 0.1%