

Status of PIENU Experiment

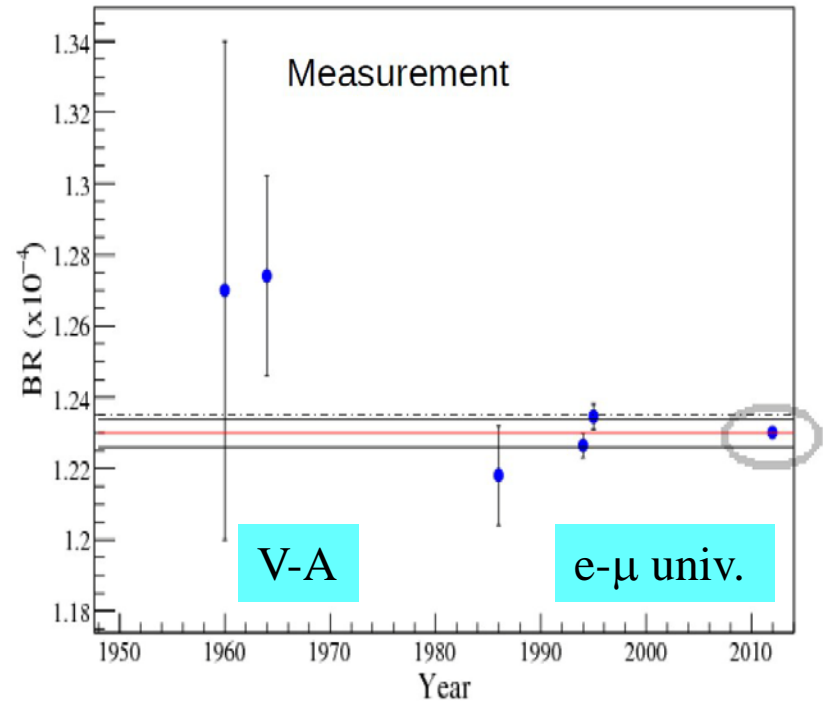
---Precision measurement of $\text{BR}(\pi \rightarrow e\nu/\pi \rightarrow \mu\nu)$ ---

Toshio Numao
TRIUMF

SM branching ratio calculations

$$\begin{aligned}
 R_{e/\mu}^0 &= \frac{\Gamma(\pi \rightarrow e\nu)}{\Gamma(\pi \rightarrow \mu\nu)} \\
 &= \frac{g_e^2 m_e^2 (m_\pi^2 - m_e^2)^2}{g_\mu^2 m_\mu^2 (m_\pi^2 - m_\mu^2)^2} \\
 &= 1.284 \times 10^{-4}
 \end{aligned}$$

$$\begin{aligned}
 R_{e/\mu}^{\text{th}} &= \frac{\Gamma(\pi \rightarrow e\nu + \pi \rightarrow e\nu\gamma)}{\Gamma(\pi \rightarrow \mu\nu + \pi \rightarrow \mu\nu\gamma)} \\
 &= 1.2352(1) \times 10^{-4} \quad \text{Cirigliano, Rosell 2007}
 \end{aligned}$$



Experimental status:

$$\begin{aligned}
 R_{\text{exp}} &= 1.2265 (34) (44) \times 10^{-4} \quad (\text{TRIUMF, 1992}) \\
 &= 1.2346 (35) (36) \times 10^{-4} \quad (\text{PSI, 1993})
 \end{aligned}$$

Test of e- μ universality

$$R_{e/\mu}^{th} = \frac{\Gamma(\pi \rightarrow e\nu + \pi \rightarrow e\nu\gamma)}{\Gamma(\pi \rightarrow \mu\nu + \pi \rightarrow \mu\nu\gamma)} = (1 - 2\delta g^{W_{e\nu}} + 2\delta g^{W_{\mu\nu}}) R_{e/\mu}^{SM}$$

Endo and Yoshinaga arXiv:1404.4498

Electro-Weak Precision Observables

- G_μ , M_Z , α

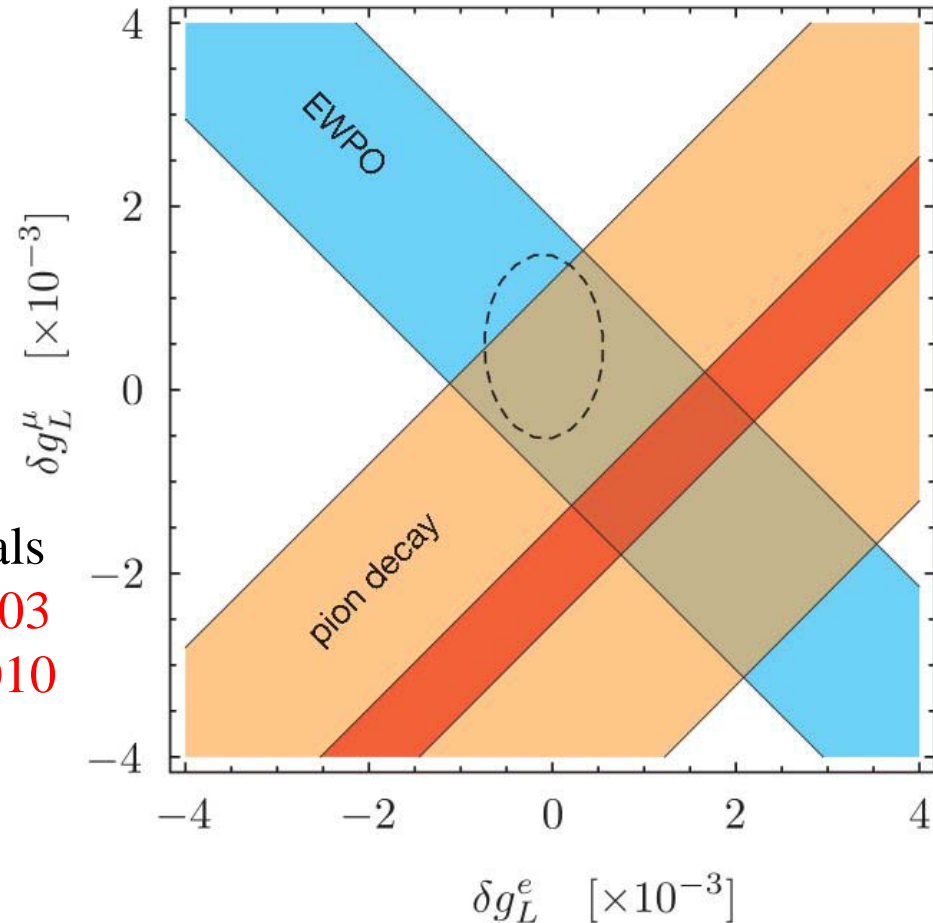
-W mass and width

-Z coupling with leptons

Γ_Z , σ_{hadron} , R_f , A_f (f=e, μ , τ)

$$\delta g^{W_{e\nu_e}} + \delta g^{W_{\mu\nu_\mu}}$$

Modes	g_e/g_μ	Goals
π -e ν / π - μ ν	0.9979 ± 0.0016	$\rightarrow 0.0003$
K-e ν / K- μ ν	1.0022 ± 0.0018	$\rightarrow 0.0010$
τ -e $\nu\nu$ / τ - μ $\nu\nu$	0.9980 ± 0.0015	
W-e ν /W- μ ν	0.999 ± 0.011	



Suppressed decays

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{NewPhysics}}$$

↑ Highly suppressed
Well calculated

Helicity suppression for V-A \rightarrow Pseudoscalar interactions
Branching ratio: $\Gamma(M \rightarrow e\nu)/\Gamma(M \rightarrow \mu\nu)$, $M = \pi$ or K
Clean: Hadronic contributions cancel in the ratio

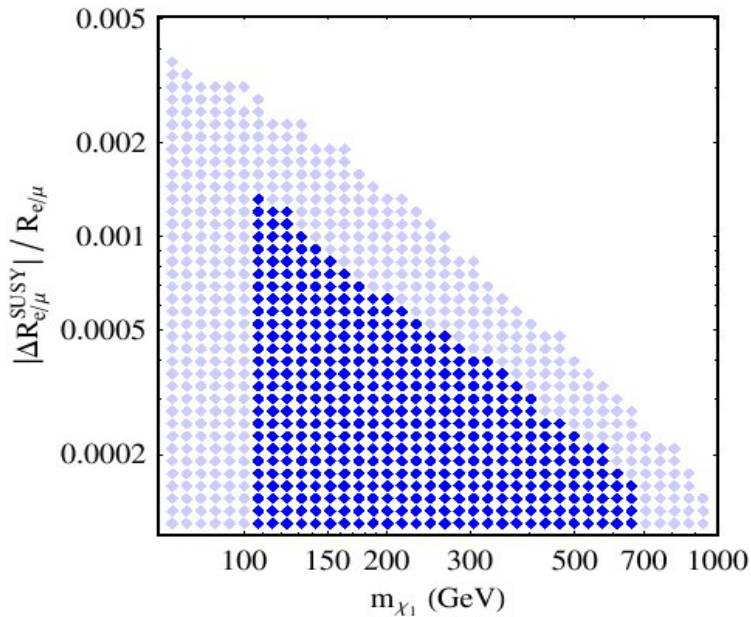
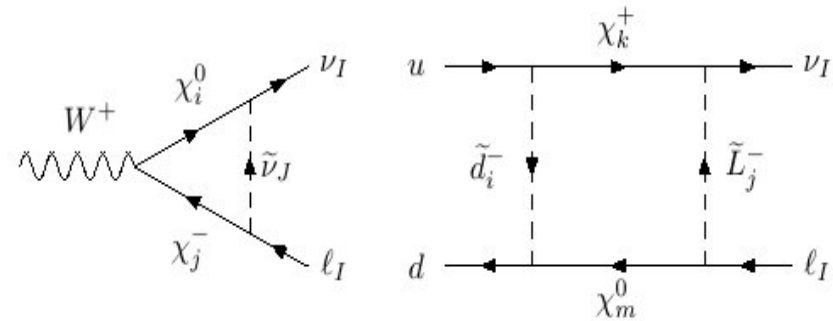
PIENU and PEN for pion and NA62 and TREK for K

Beyond the Standard Model

- Mass scale up to 1000 TeV for 0.1 % measurement.
- Sterile neutrinos, extra leptons
- Leptoquarks, charged Higgs
- SUSY...

Beyond the Standard Model

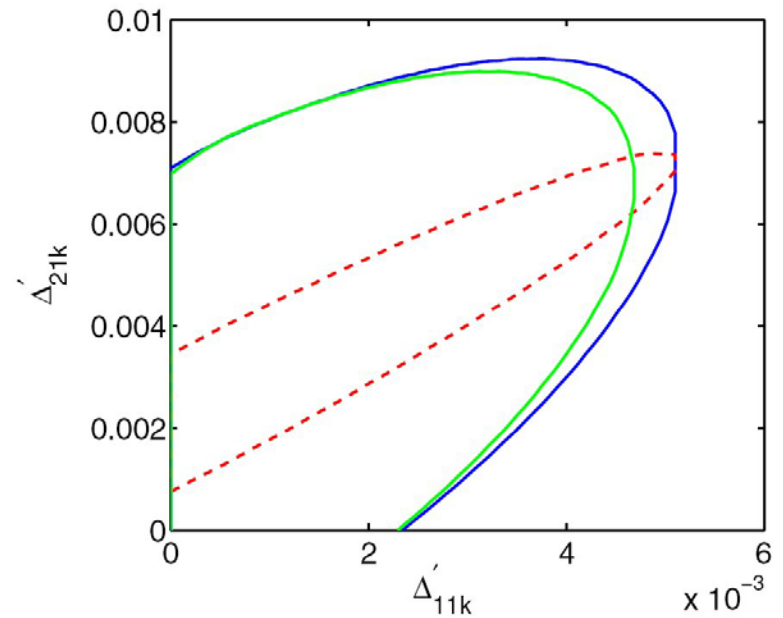
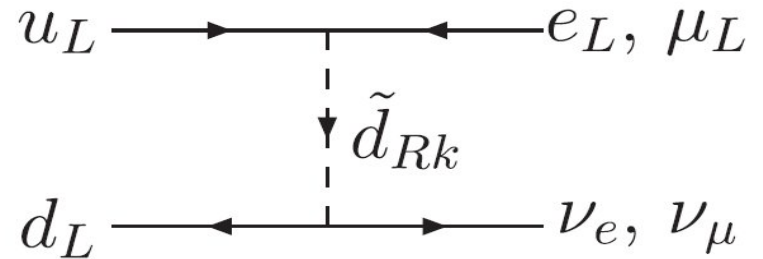
Minimal SUSY SM



Lowest chargino mass

Ramsey-Musolf... PRD76 095017 (2007)

R-Parity Violating SUSY



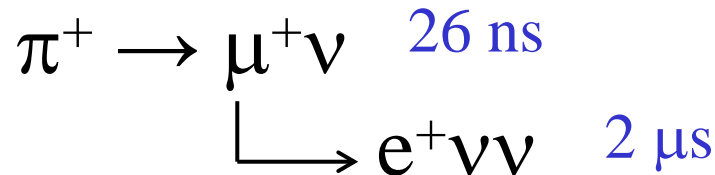
Method

$$\Lambda(\pi \rightarrow e\nu) / \Lambda(\pi \rightarrow \mu \rightarrow e)$$

TRIUMF 1992

Use stopped π^+

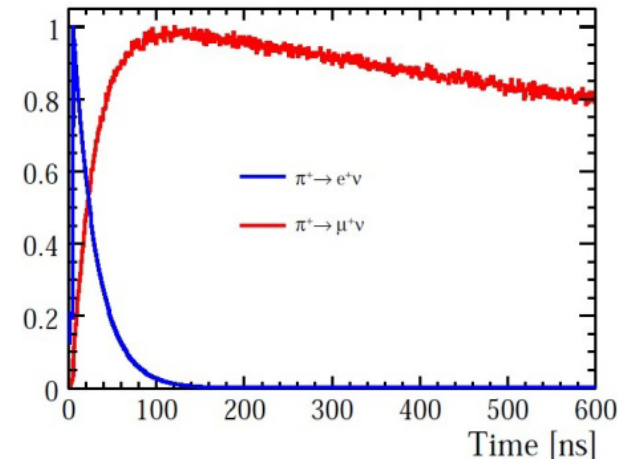
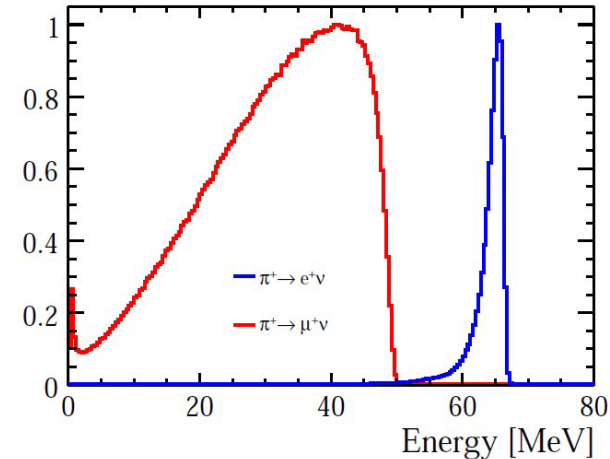
Measure positrons



Obtain the amplitude ratio

Apply corrections

- Low energy tail of the $\pi \rightarrow e\nu$ peak.
- Small energy-dependent effects.



PIENU Experiment

NaI+CsI: 2 % (FWHM) @70MeV

Radiation length: 20

Solid angle: 25 % ; Detector in the beam

Pion stop: 50-70 kHz

Time window -300 to 500ns

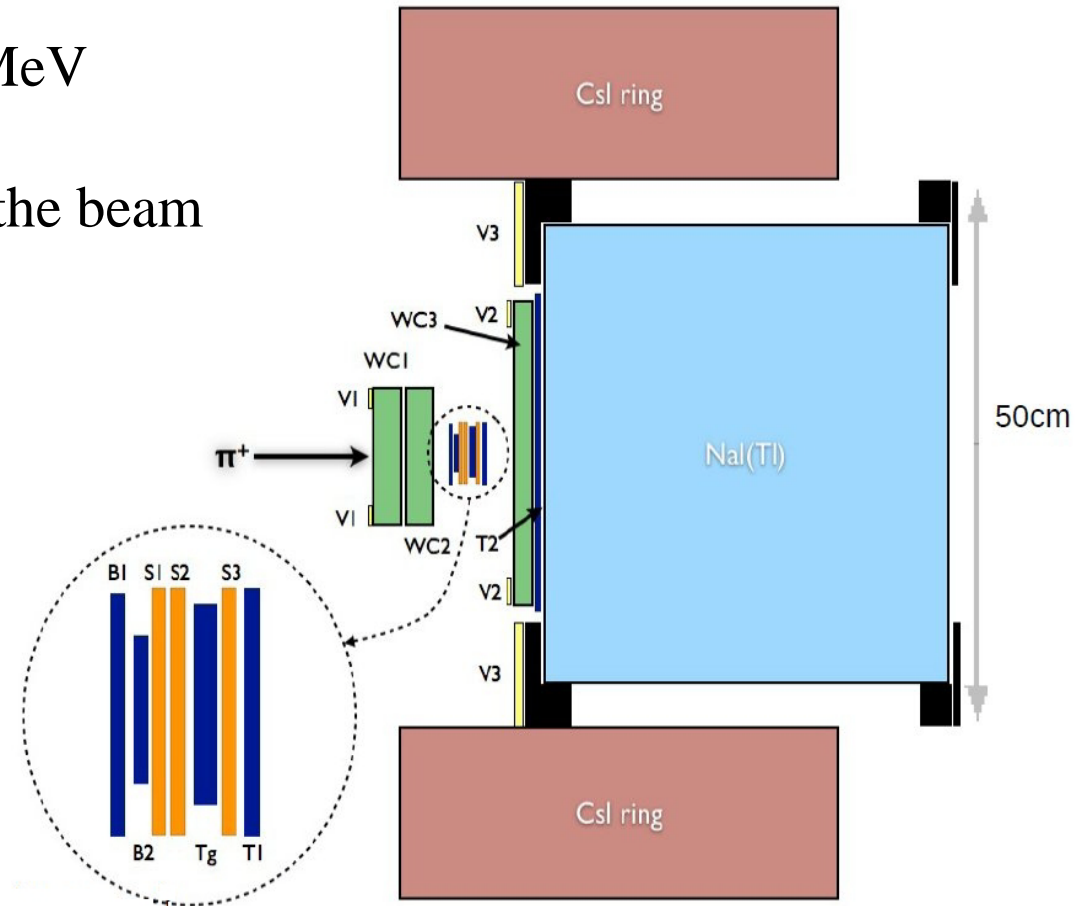
Enhance π -ev decay @ trigger

- Early decays (5-40ns), or
- High energy (>45MeV)

Goal: <0.1 %

Data taking: -2012

No. of pienu: 5 M (clean)



Data Analysis

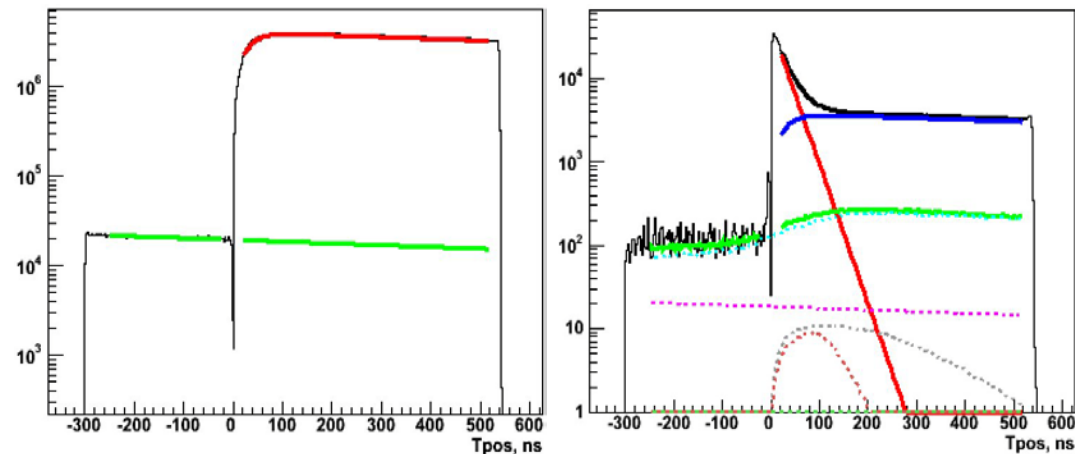
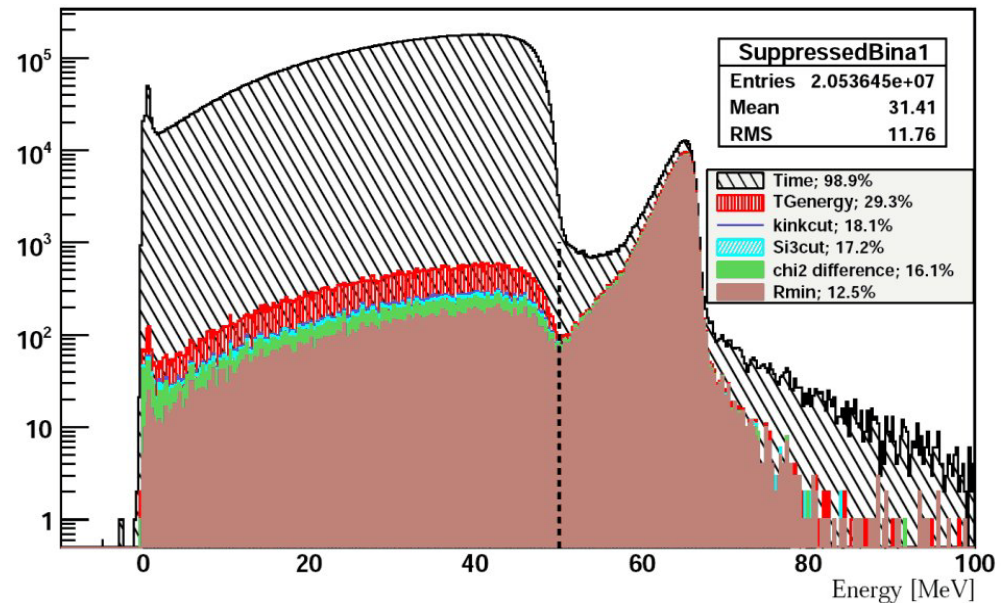
- Select single π stops.
- Select single positron events.
- Separate time spectra (50 MeV)
- Fit simultaneously

LE:

- $\pi-\mu-e$
- π DIF, μ beam
- old μ

HE:

- $\pi-e\nu$, (μ DIF)
- LE $\times r$ (Res., Rad. μ , nPU)
- Other backgrounds



Other Backgrounds in HE spectrum

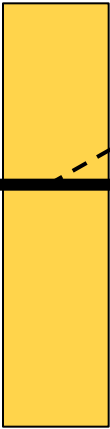
NaI

Two basic processes.

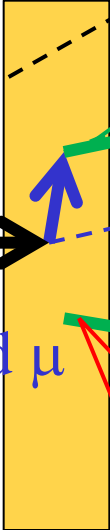
But many BG types with different shapes.
 Knowledge of the amplitudes and shapes.

Good π

- π Time
- μ Time
- e time
- random



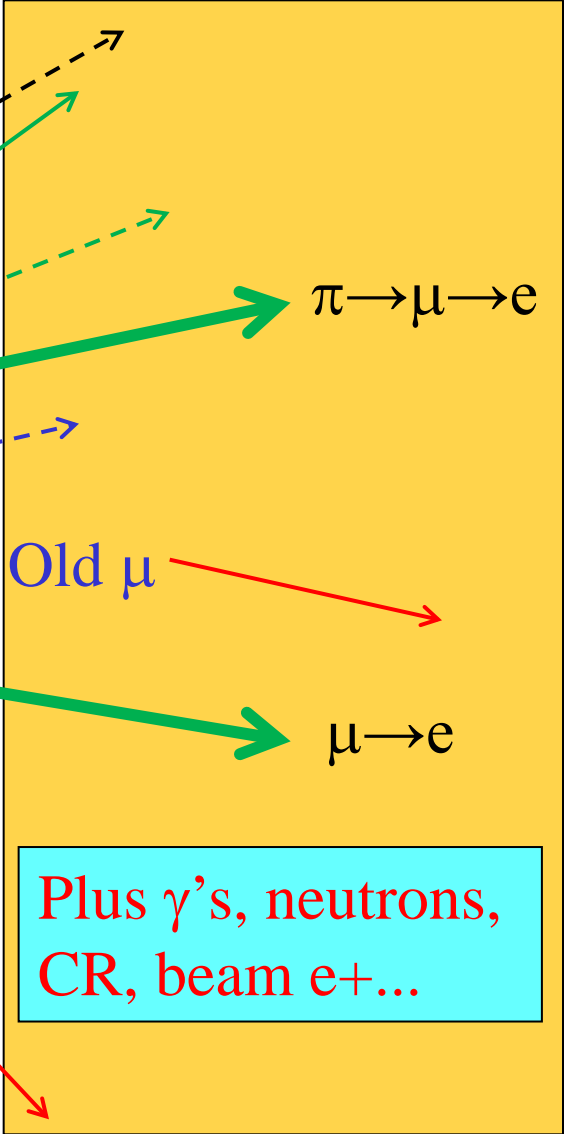
Bm



Tg



Tel



Plus γ 's, neutrons,
 CR, beam e+...



CsI

-2nd order effects: $\pm 0.05 > \%$.

Full analysis in future:

-3rd order effects (full analysis).

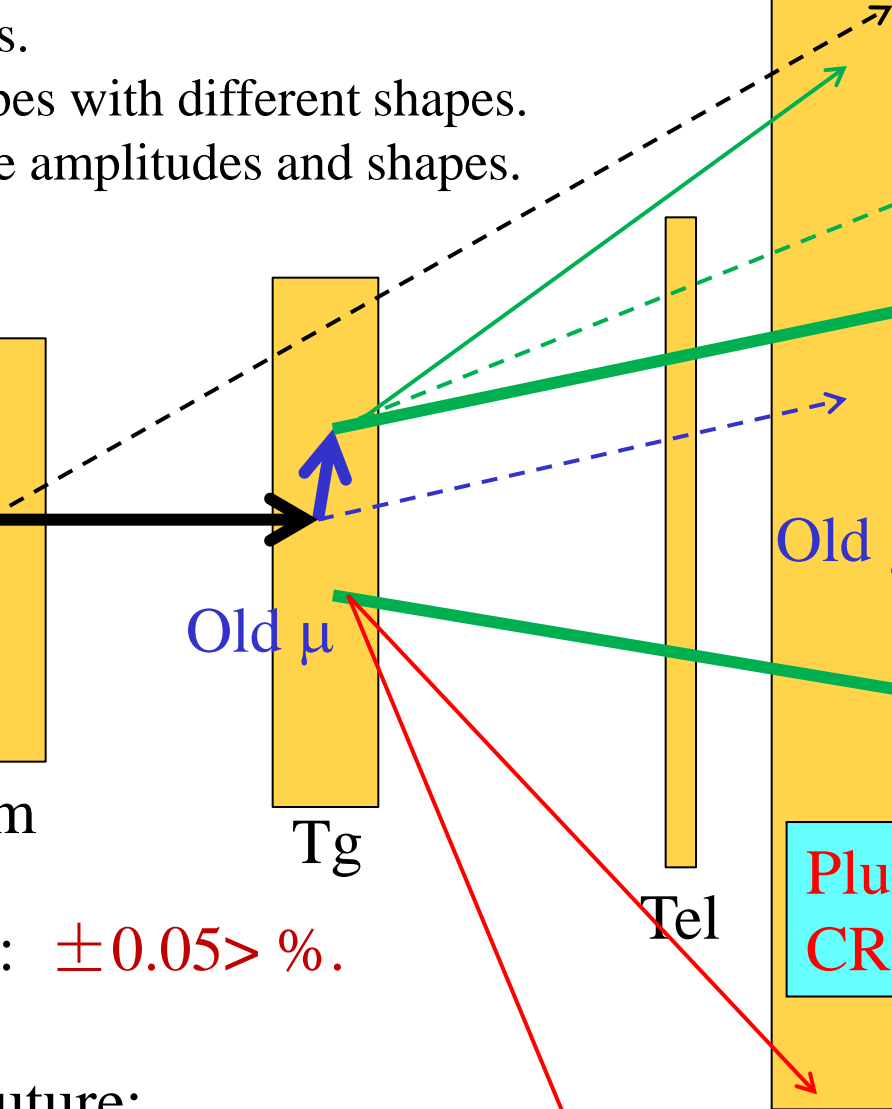
$\pi \rightarrow \mu \rightarrow e$

$\mu \rightarrow e$

Old μ

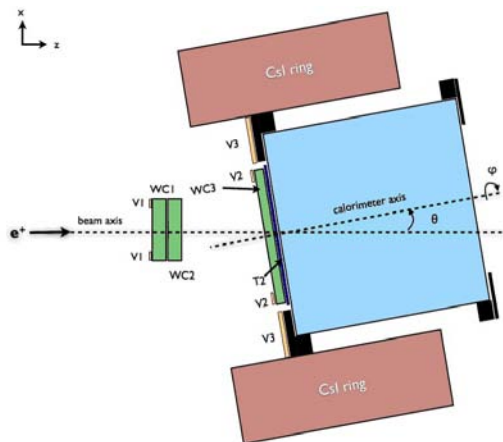
Old μ

↑



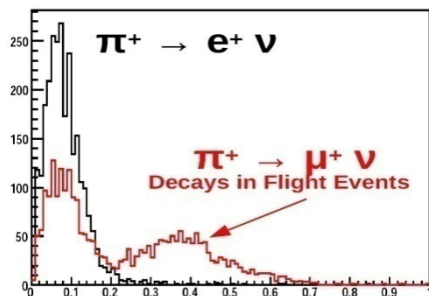
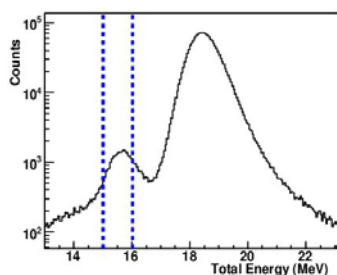
Correction for low energy π - ν (tail)

Response function measurement



Upper bound = $2.2 \pm 0.06 \%$

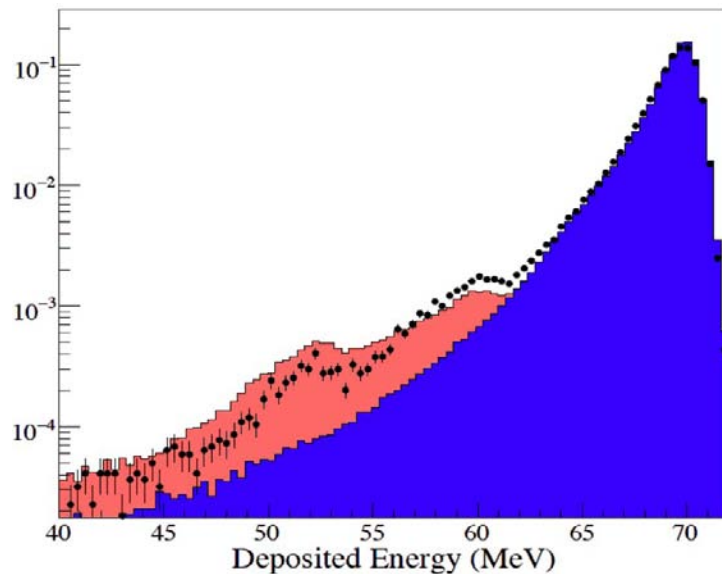
Lower bound



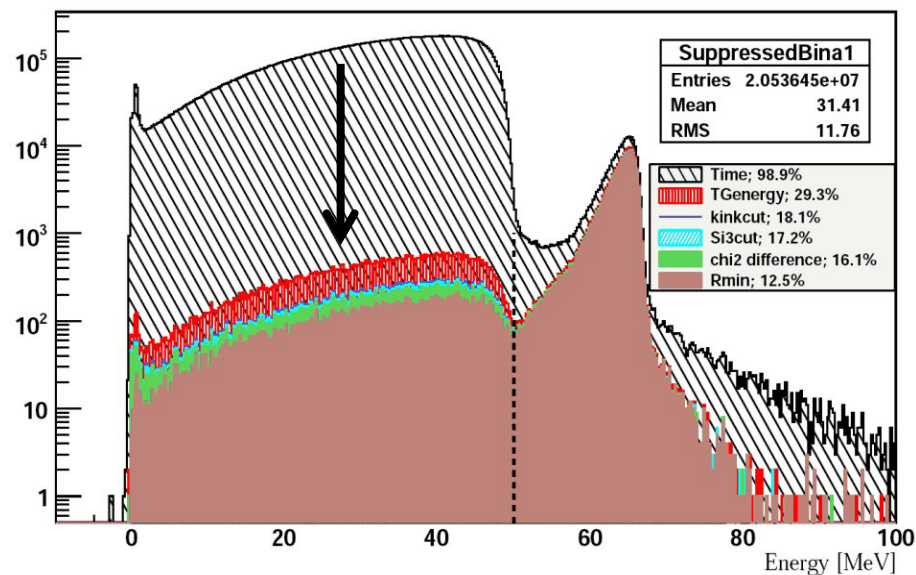
- Suppress π - μ - e background.
- Subtract π, μ DIF background.
- Correct for selection bias.

Lower bound = $2.2 \pm 0.2 \%$

Fraction = $2.2 \pm 0.1 \%$



70 MeV e^+ at 0° .



BG suppressed spectra

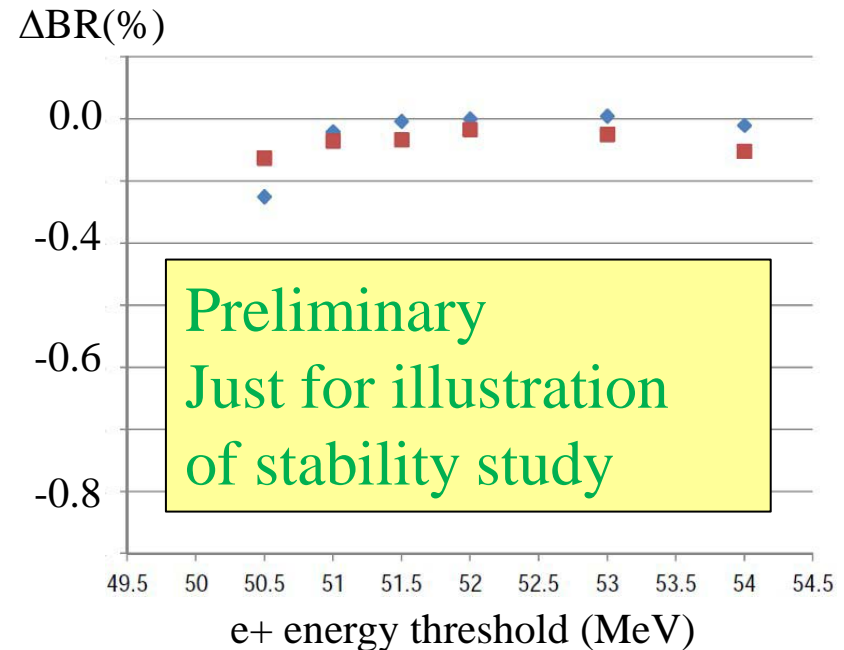
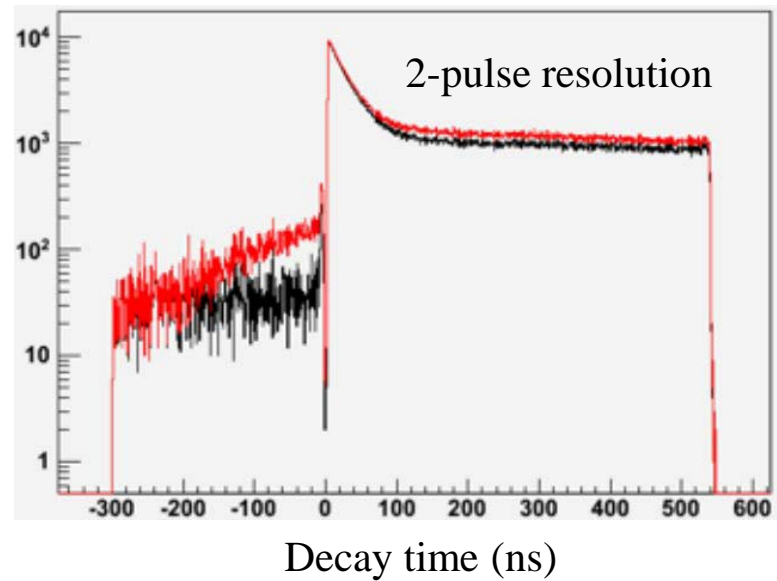
Analysis status

Use a part of 2010 data to establish the analysis procedures.

- Find cuts without bias or understand structure.
- Identify background components.
- Estimate the amplitude by enhancing it.
- Estimate corrections(*e.g.* low energy tail...).

- Stability against all possible parameters;
Rates, cuts,...
(understand everything)
- Fix the analysis, obtain all corrections.
- Unblind.

Repeat the above (Full analysis).



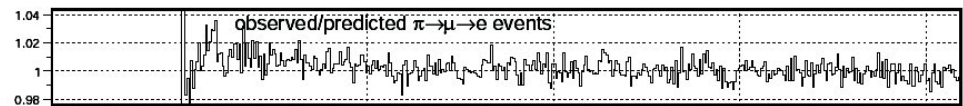
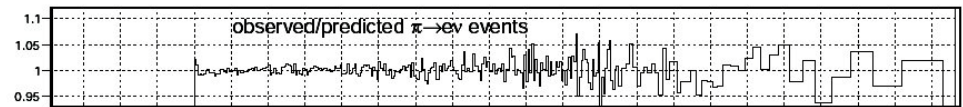
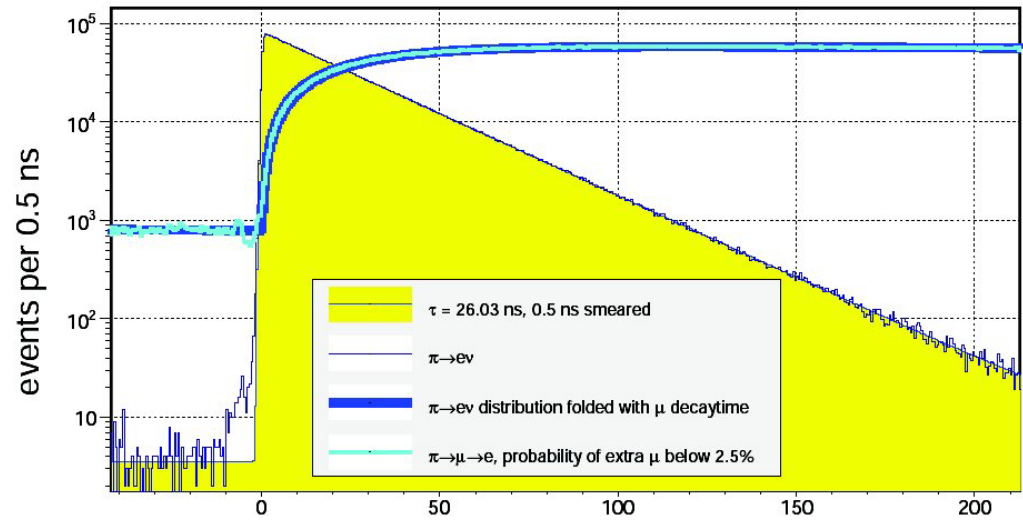
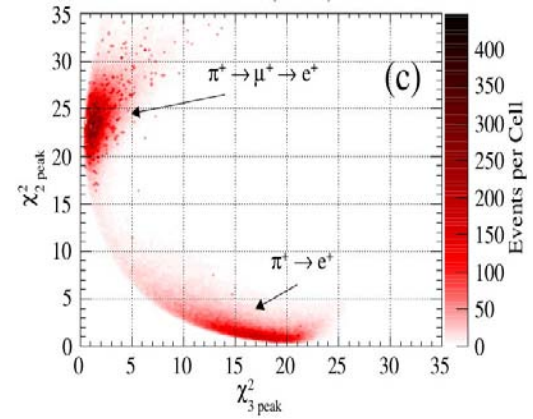
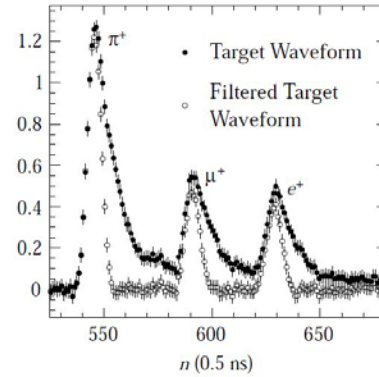
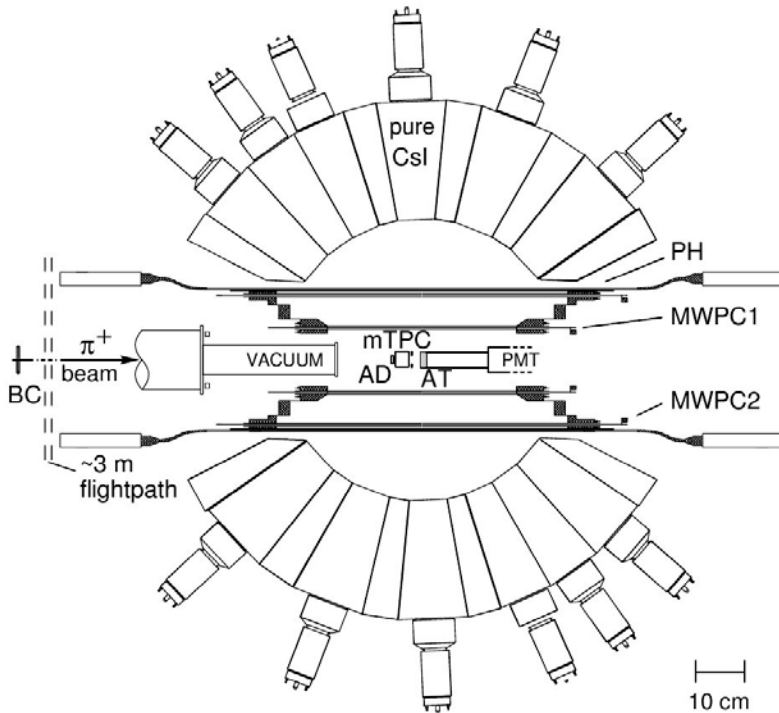
Test tail and μDIF corrections.

Summary of uncertainties (%)

	Old Triumf	2010 Prelim.	PIENU Goals
Statistical	0.28	0.2	0.05
Low-energy tail	0.25	0.1>	0.03
Accept diff.	0.11	0.1>	0.03
Pion life	0.09	0.02	0.02
Other	0.11	0.05>	0.03
Total	0.47	0.3	0.06

PEN at PSI

Data taking: -2010
 CsI: 6 % (FWHM) @70 MeV
 Radiation length: 12
 Solid angle: 70 %
 Pion Stop: 10-50 kHz
 Goal: <0.1 %
 No. of pienu: 22 M



decay time [ns]

Summary of uncertainties

From original proposals

Source	Old Triumf	PIENU	PEN
Statistical	0.28	0.05	0.02
Low-energy tail	0.25	0.03	
Accept diff.	0.11	0.03	0.02
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Other	0.11	0.03	0.02
Total	0.47	0.06	0.05

Conclusion

$\pi\text{-e}\nu/\pi\text{-}\mu\nu$ branching ratio measurements are extremely sensitive to a presence of PS interactions. The ratio also provides the best test of e- μ universality. Nearly a factor of two improvement is expected soon and a factor of 3-5 improvement in a few years.