TRIUMF

PI E NU

Canada's national laboratory for particle and nuclear physics /Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

The PIENU Experiment

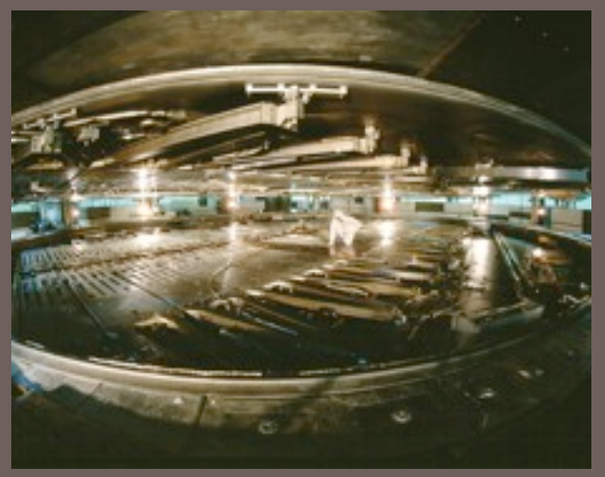
a sensitive probe in the search for new physics

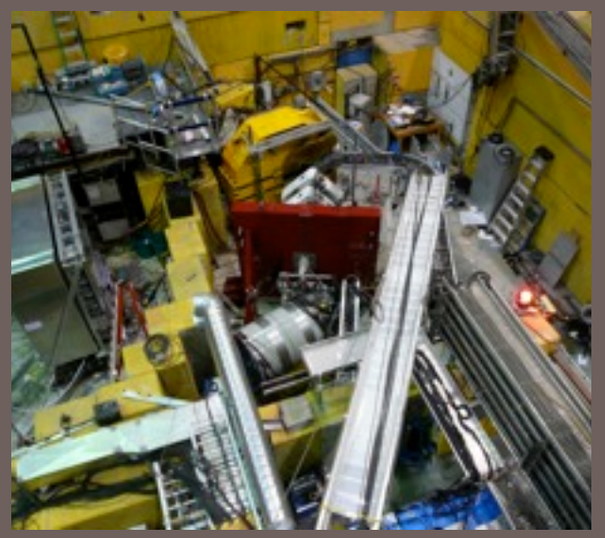
Chloé Malbrunot

For the PIENU Collaboration

A. Aguilar-Arevalo[11], M. Aoki[4], M. Blecher[9], D.I. Britton[8], D. Bryman[6], S. Chen[10], J. Comfort[1], M.Ding[10], L. Doria[5], P. Gumplinger[5], A. Hussein[7], Y. Igarashi[3], N. Ito[4], S. Kettell[2], Y. Kuno[4], L. Kurchaninov[5], L. Littenberg[2], C. Malbrunot[6], T. Numao[5], R. Poutissou[5], A. Sher[5], T. Sullivan[6], D. Vavilov[5], K. Yamada[4], Y. Yoshida[3]

1. Arizona State University
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



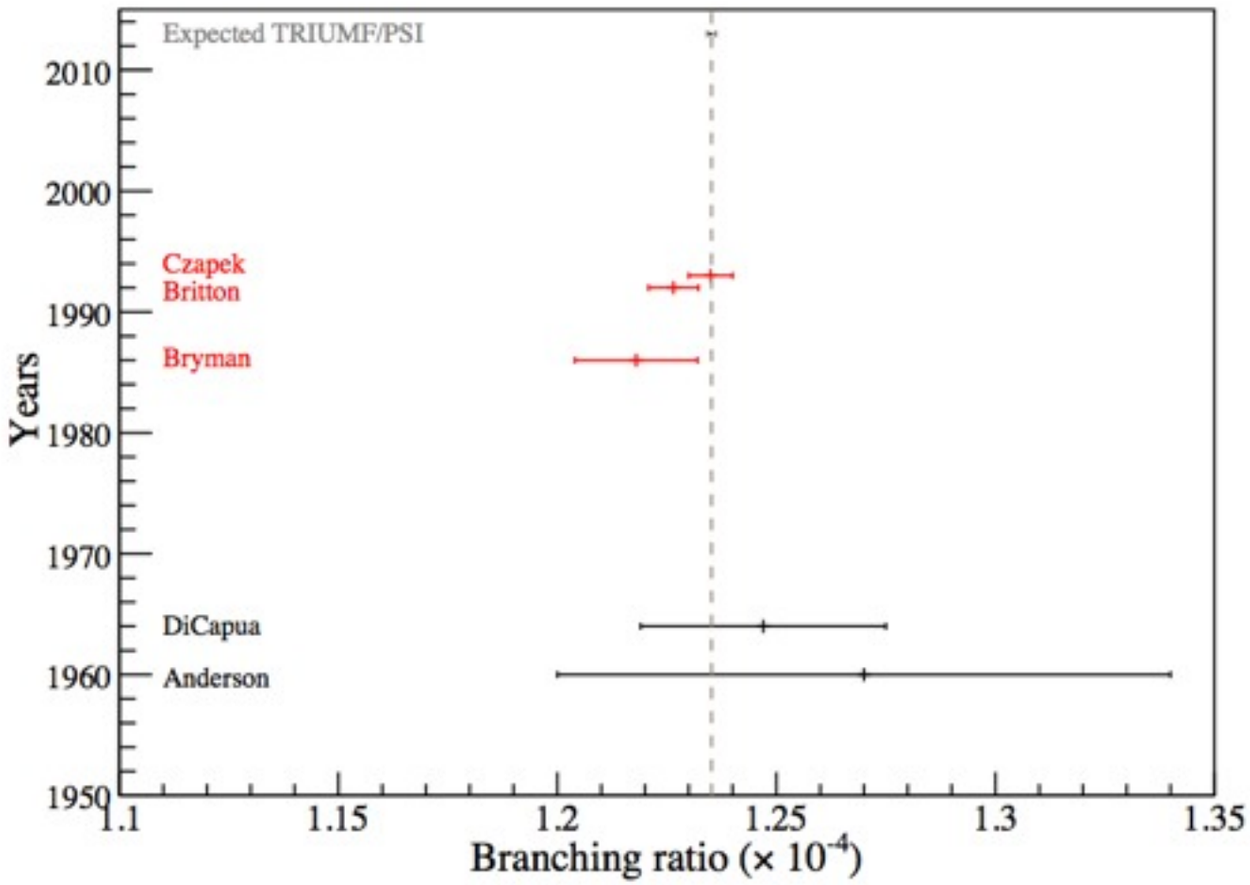


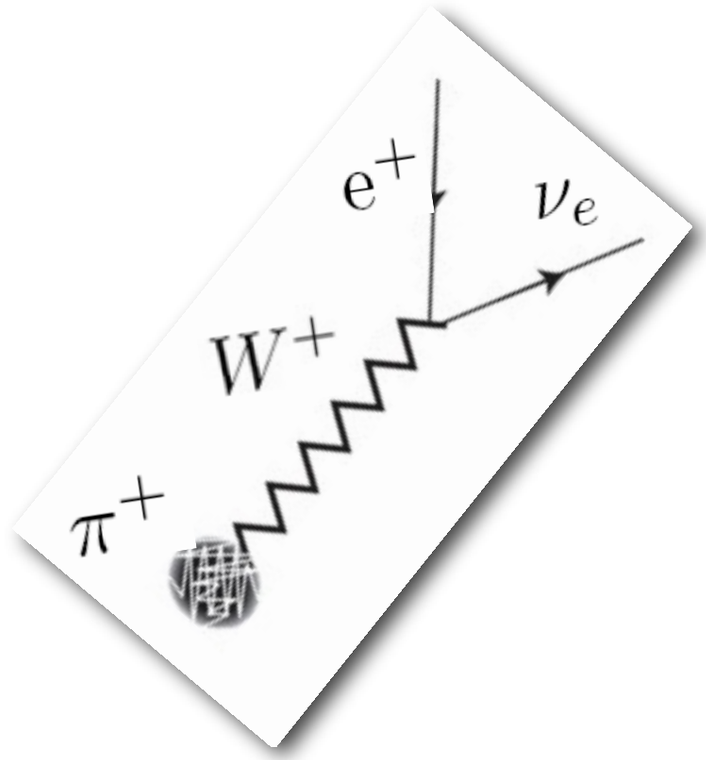
PANIC 2011

A Precision Experiment

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

V.Cirigliano, I.Rosell, Phys. Rev. Lett. 99, 231801 (2007)
W.J. Marciano, A. Sirlin, Phys. Rev. Lett. 71, 3629-3632 (1993)





Current world average : TRIUMF, PSI :

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

TRIUMF : D.A.Bryman, T.Numao, et al. Phys.Rev.D53:558-559,1996
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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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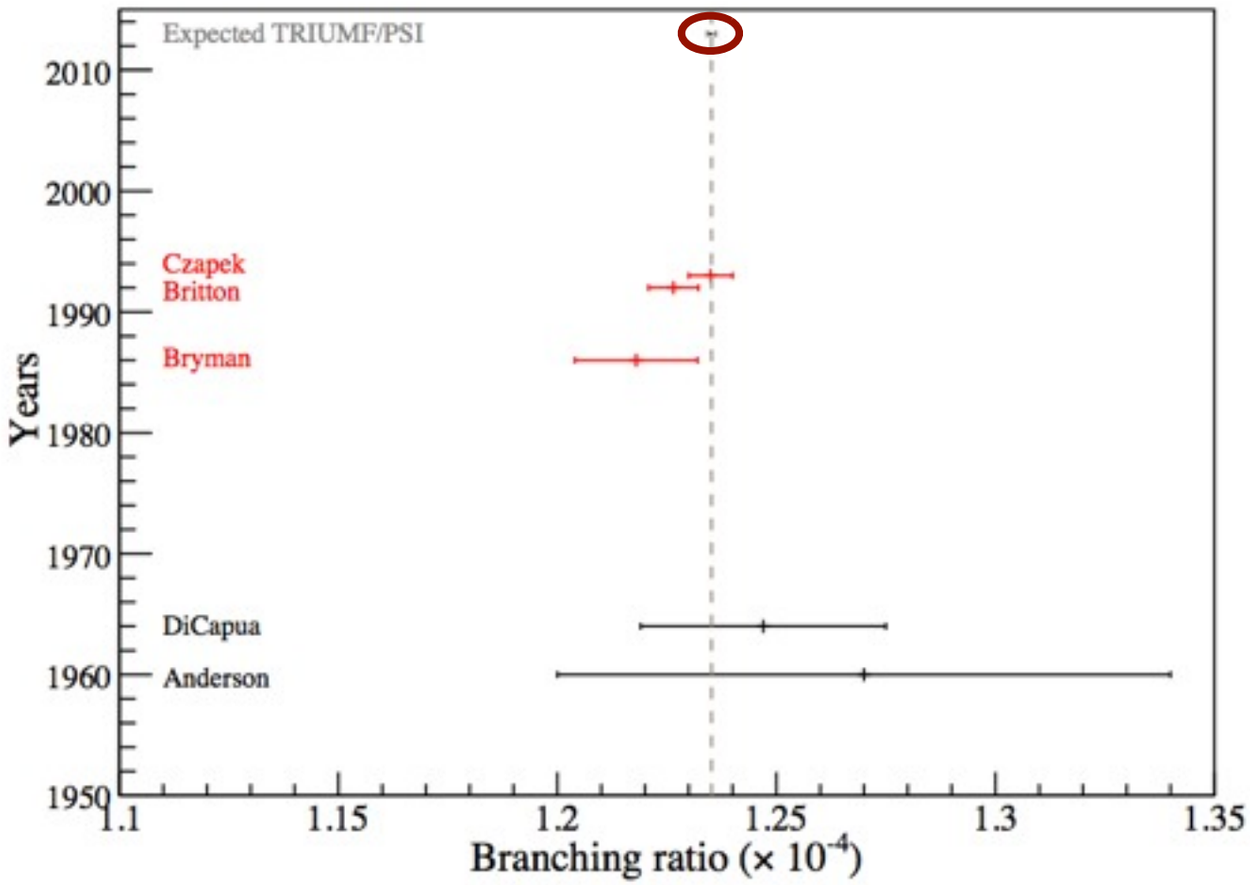

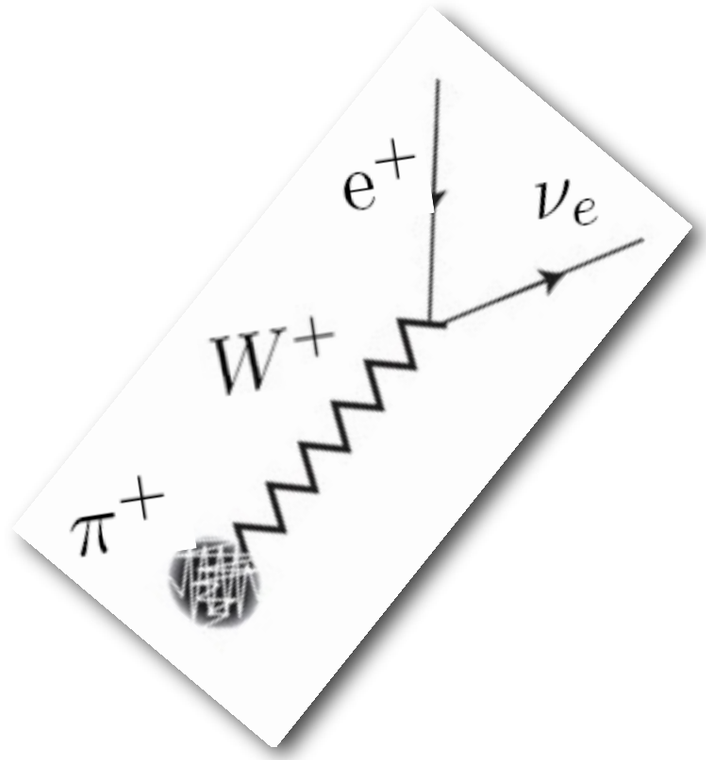

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BSM search / Universality test

$$\Gamma_{\pi\to l+\nu_l} = G^2 \frac{m_{\pi+} f_{\pi+}^2 m_l^2}{8\pi}(1-\frac{m_l^2}{m_{\pi+}^2})^2[1+RC] \quad ; \quad \frac{G}{\sqrt{2}} = \frac{g_l^2}{8M_{W+}}$$

$$1-\frac{R_{e/\mu}^{New}}{R_{e/\mu}^{SM}} \sim \mp\frac{\sqrt{2}\pi}{G_\mu}\frac{1}{\Lambda_{eP}^2}\frac{m_\pi^2}{m_e(m_d+m_u)}$$

$$\sim (\frac{1TeV}{\Lambda_{eP}})^2 \times 10^3$$

0.1% measurement → Λ_{eP}~ 1000 TeV

Massive ν's
R.E Schrock Phys.Rev.D 24, 5 (1981)

Scalar coupling
B.A. Campbell & David W. Maybury Nucl. Phys. B, 709 419-439 (2005)

R-Parity violation SUSY
M. J. Ramsey-Musolf, S. Su & S.Tulin, Phys. Rev. D 76, 095017 (2007)

...

Decay mode	$(g_\mu/g_e)^2$
$\tau \to \mu/\tau \to e$ *	1.0018 ± 0.0014
$\pi \to \mu/\pi \to e$ *	1.0021 ± 0.0016
$K \to \mu/K \to e$	0.9960 ± 0.005
$K \to \pi\mu/K \to \pi e$	1.002 ± 0.002
$W \to \mu/W \to e$	0.997 ± 0.010

* τ and π 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_μ

- Real deviation from the SM → new physics observation
- Agreement with SM → constraints

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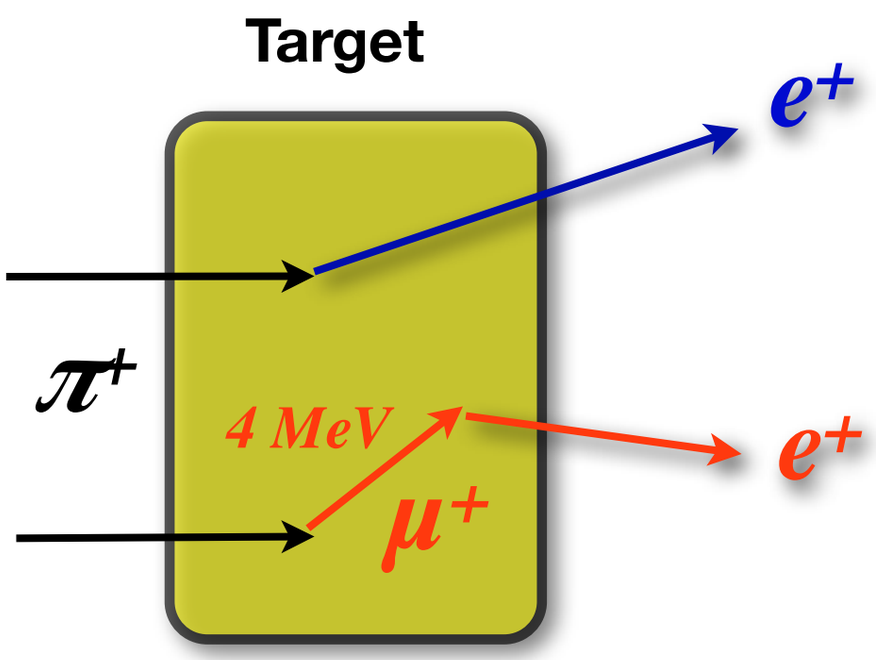
Experimental Technique

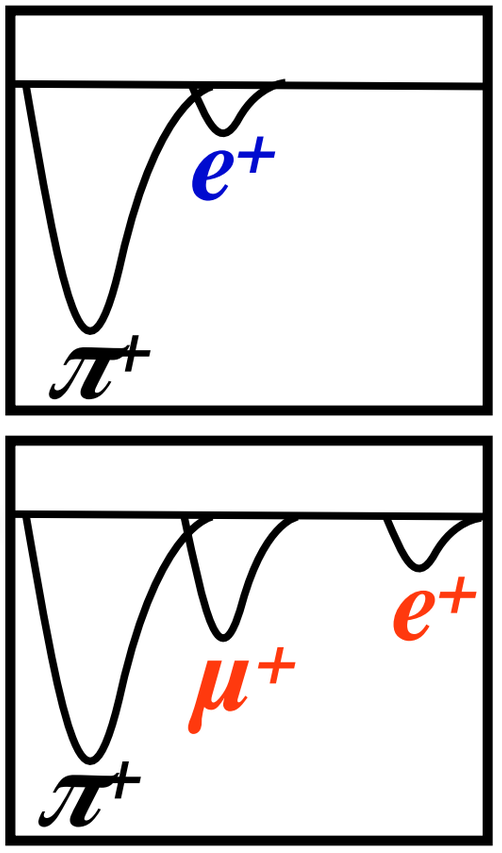
Experimental Method

- Stop pions in an active target Scintillator
- Yield measurement

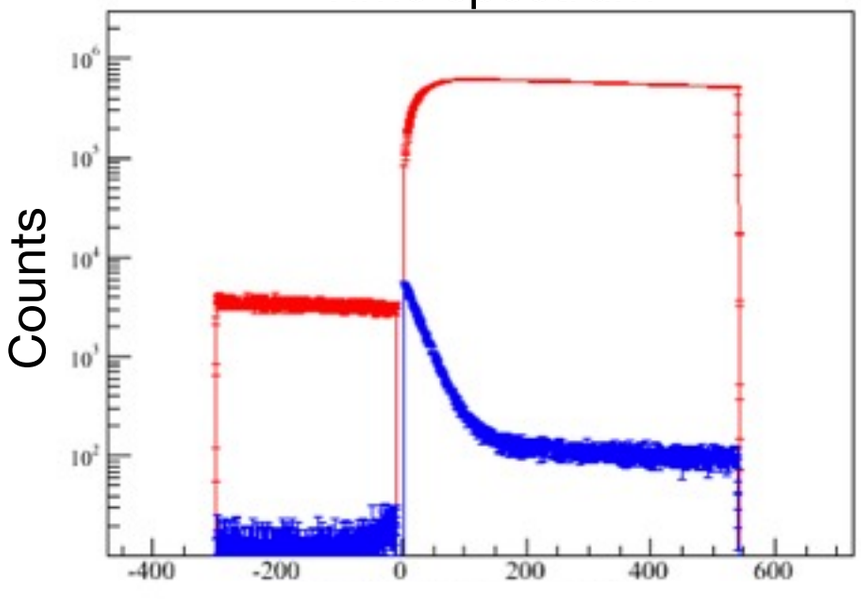
Required

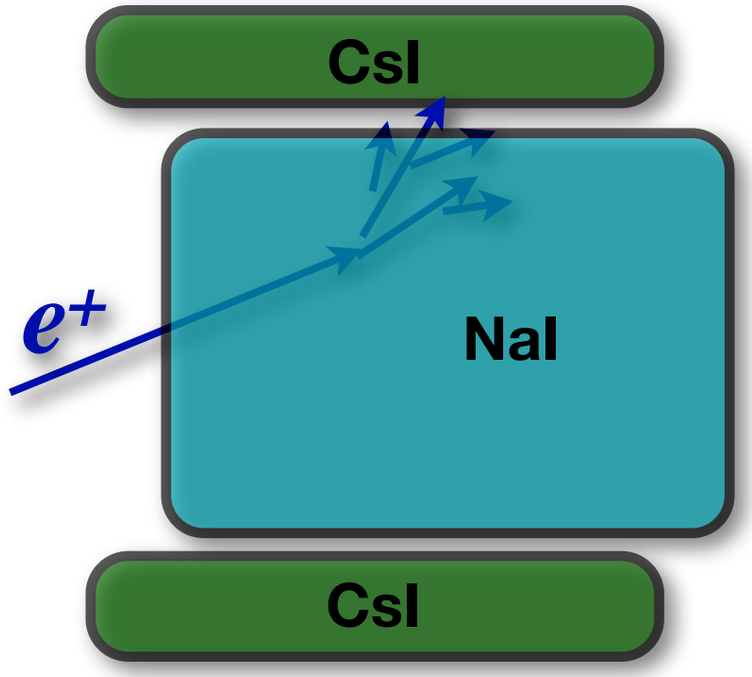
- High purity pion beam
- High speed pulse digitization
- Suppress decays in flight (DIF)
- Knowledge of response function of calorimeter



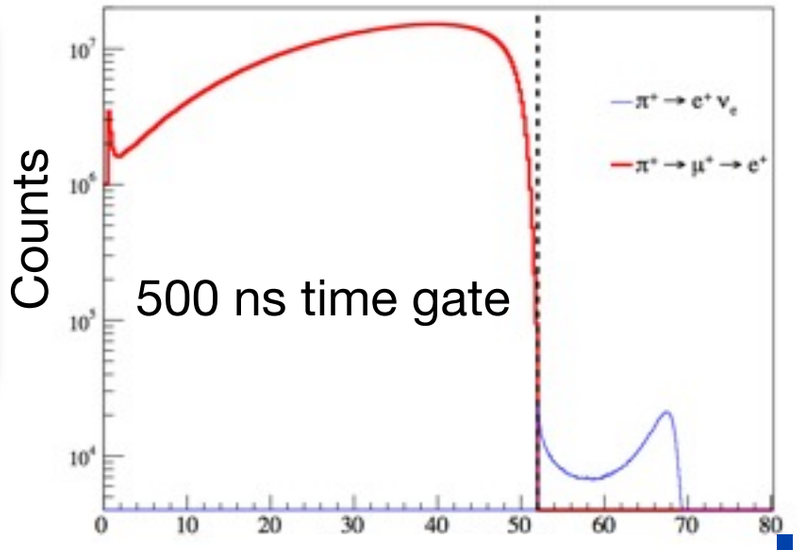


Time spectrum





Energy spectrum



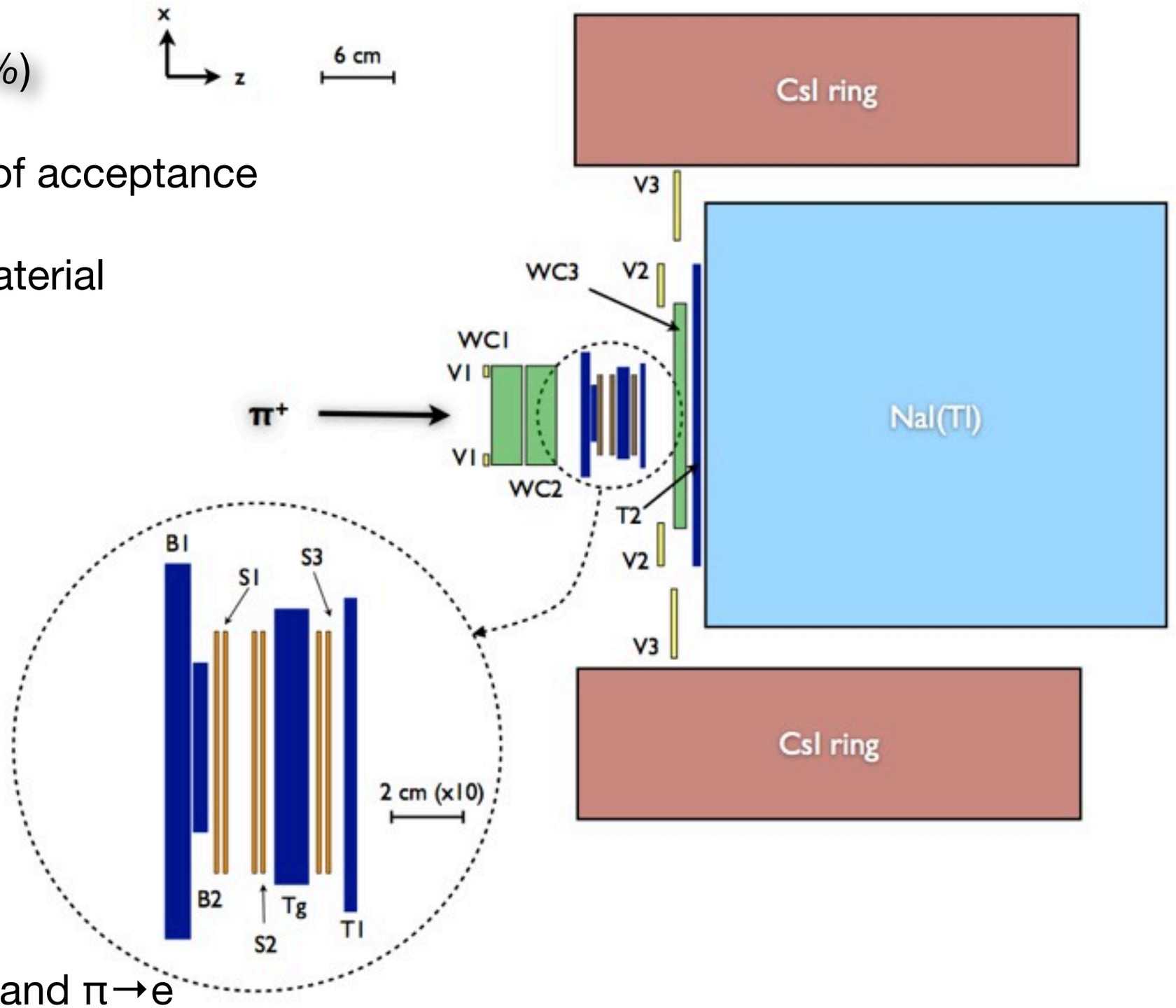
The PIENU detector

- Large solid angle ($\Omega/4\pi$ = 20%)
  Good statistics
  Minimal energy dependence of acceptance
  Contain shower leakage (CsI)
  Decay positron travels few material

- Silicon near target & WC
  Good tracking
  Detection of Decay In Flight

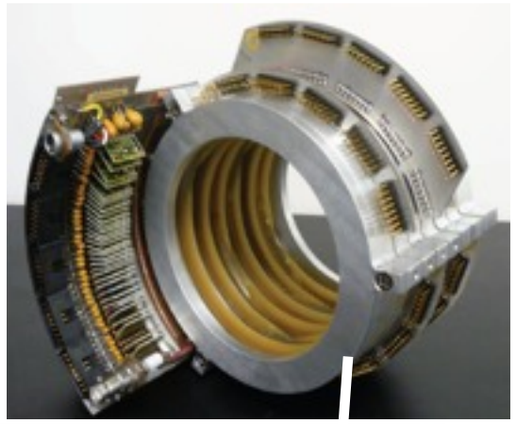
- High resolution calorimeter
  NaI :1% σ at 70 MeV

- Use of fast digitizers
  500 MHz
  separation between π→μ→e and π→e

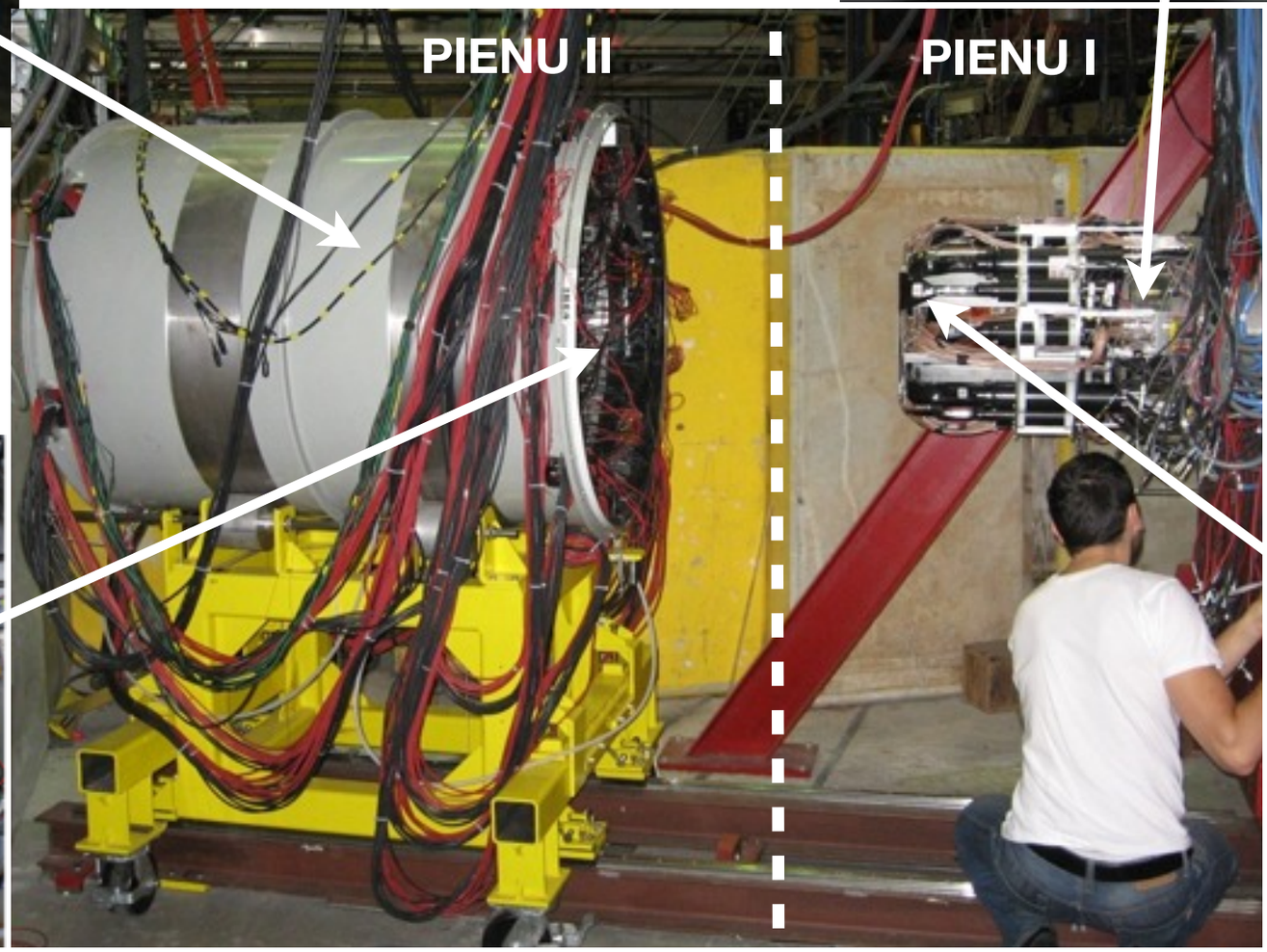


The PIENU detector (cont'd)

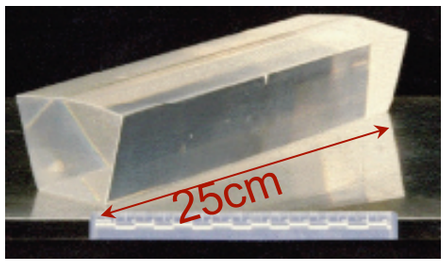
Monolithic NaI(Tl) crystal surrounded by 97 pure CsI crystals



Beam Wire Chamber

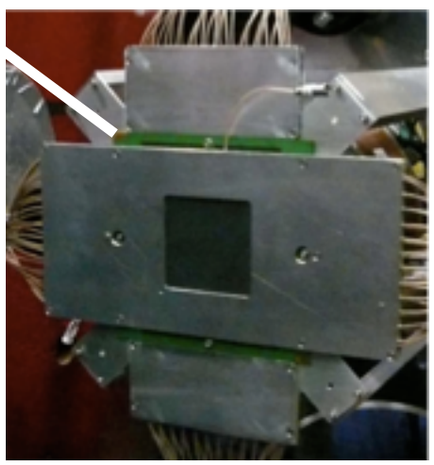


1 CsI crystal

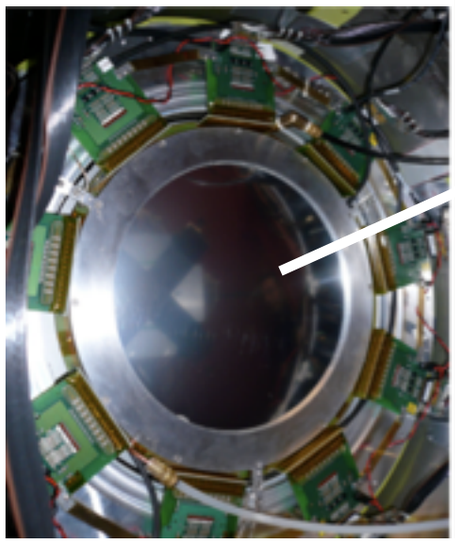


$\leftarrow \pi^+$

Silicon Trackers



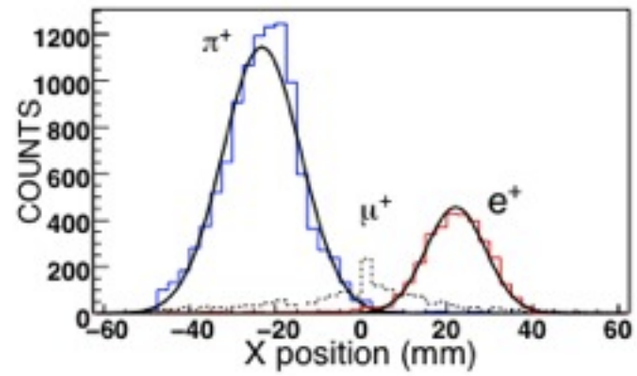
Acceptance Wire Chamber



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

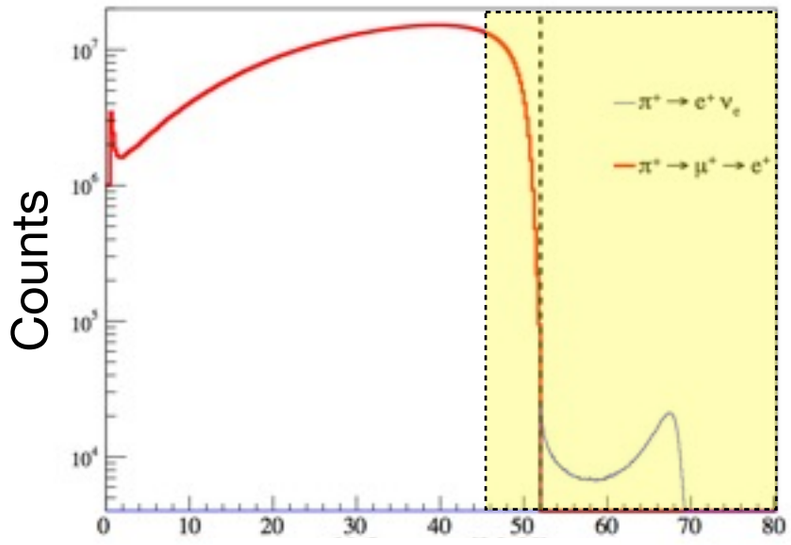
Data taking conditions

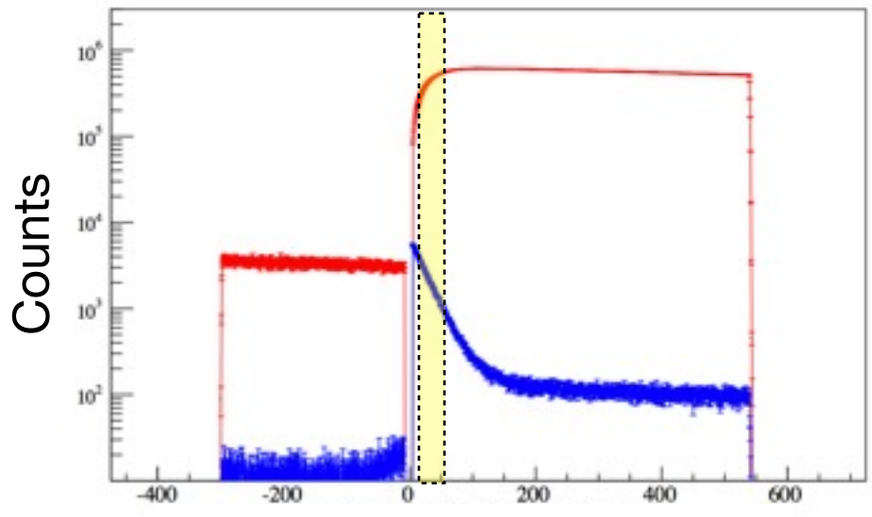
- 50 kHz pion stop in Target with 2% positrons and 10% muons



A. Aguilar-Arevalo et al., Nucl. Instr. and Meth. A 609 (2009)

- Triggers : 600Hz
  - $\pi \rightarrow e\,\nu$: $E_{NaI+CsI} > 45$ MeV
    Early (2-50 ns)





Inspection period -300ns to 500ns

  - $\pi \rightarrow \mu \rightarrow e$: prescaled (1/16)
  - monitor and calibration triggers: e^+ beam, Xe, cosmic-ray

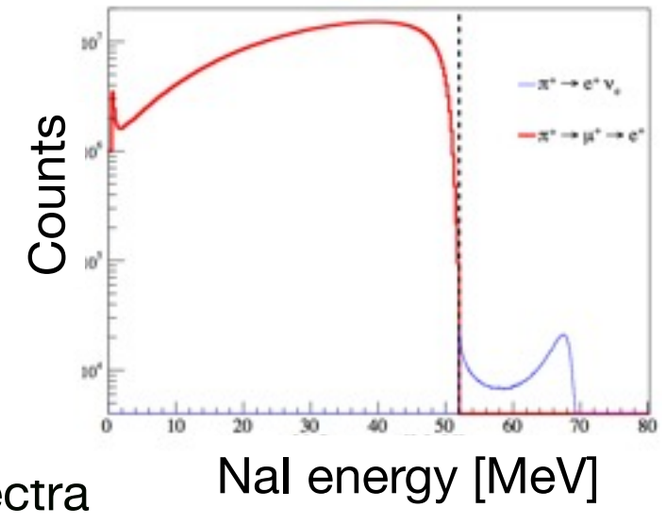
- Waveforms are recorded

Time Spectrum

Raw Branching ratio

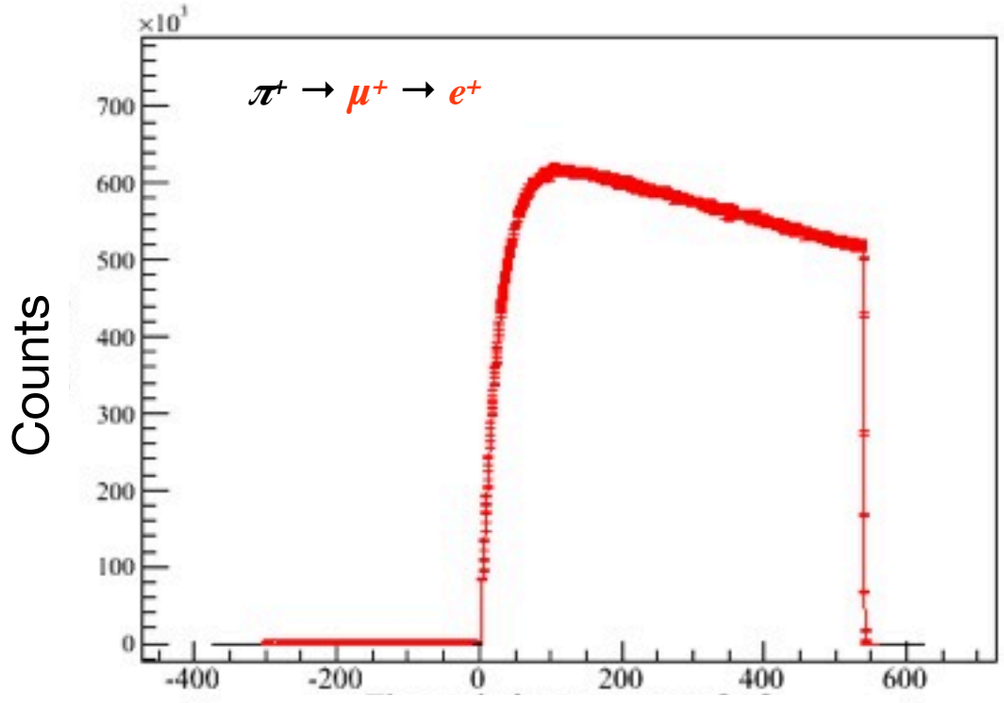
30 x more statistics than last experiment

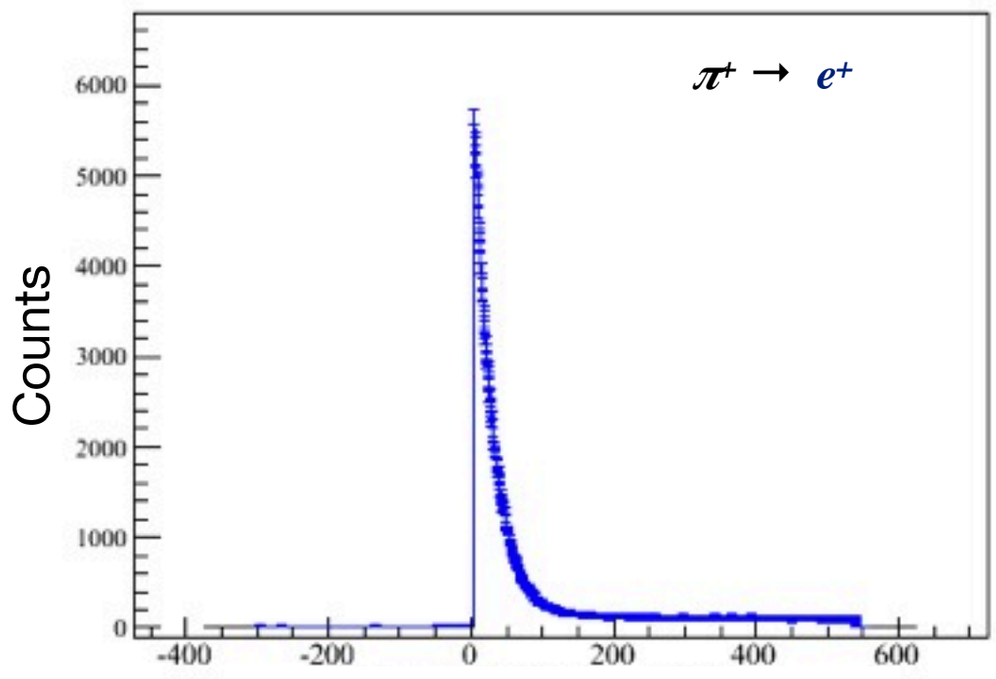
Rejection of Background with appropriate cuts (decrease statistic error)



Good fit (decrease systematic error) -> **Simultaneous fit** of both decay time spectra
(Minimization of common χ^2)

Understand BG shape -> Addition of all known background in the fit
Understand Non-linearity effect of electronics -> **dedicated linearity runs** with beam taken every weeks





Corrections & Systematics

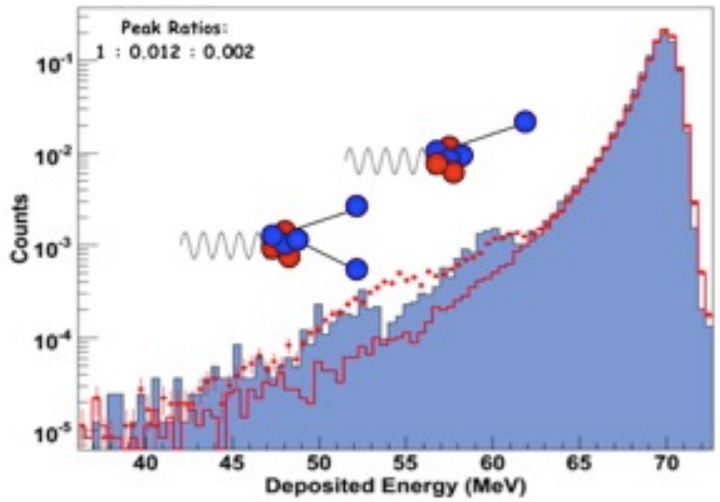
Source	E248 TRIUMF	PIENU
Statistical	0.28%	0.05%
Low energy tail	0.25%	0.03%
Monte Carlo	0.11%	0.03%
Pion lifetime	0.09%	0.03%
Others	0.11%	0.03%
Total systematic uncertainties	0.5%	0.06%

3 major sources of errors :

- Statistical
- Tail correction
- Monte Carlo

Low energy tail estimation

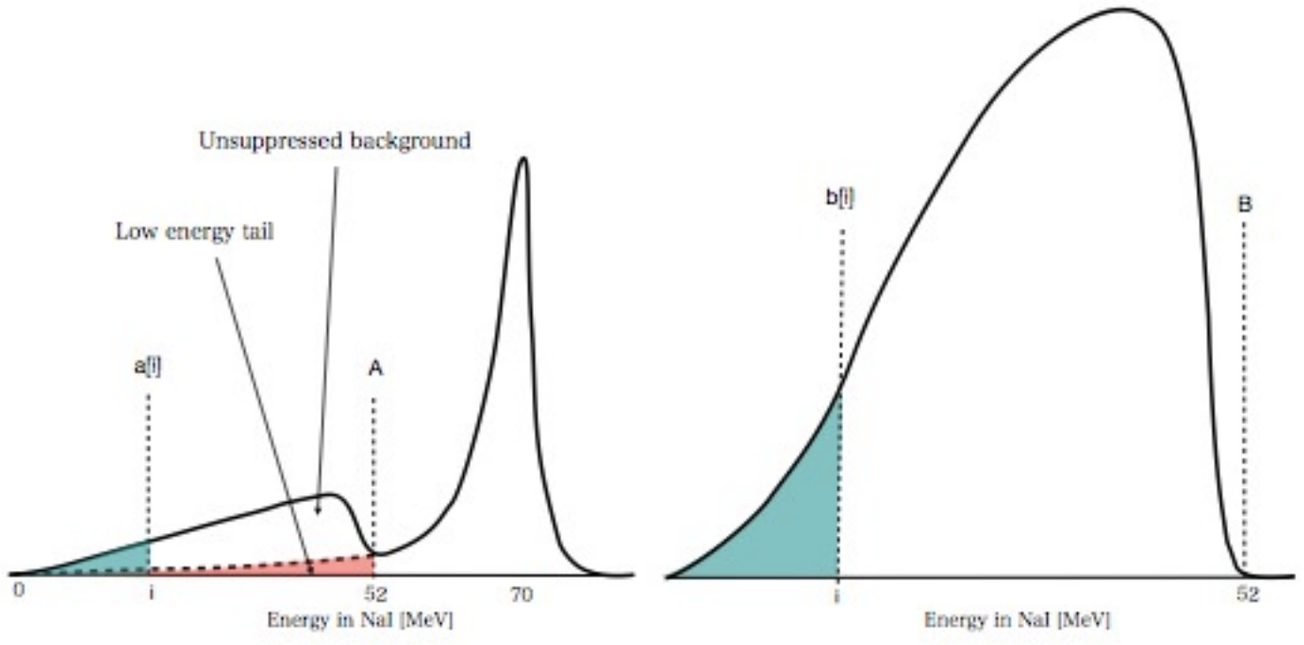
The presence of photo-nuclear reactions in the NaI affects slightly the tail



A. Aguilar-Arevalo et al., Nucl. Instr. and Meth. A (2010)

3 methods to estimate the low energy tail :

- **Upper and Lower limit** from Suppressed spectrum and Lineshape data



- Estimation from **Monte-Carlo** calculations

Simulation of photonuclear effects
Check agreement MC and data for lineshape & suppressed spectrum

- **Likelihood analysis** : Make PDFs for all known backgrounds in the suppressed spectrum

Massive neutrino search

heavy υ

Kinematic factor

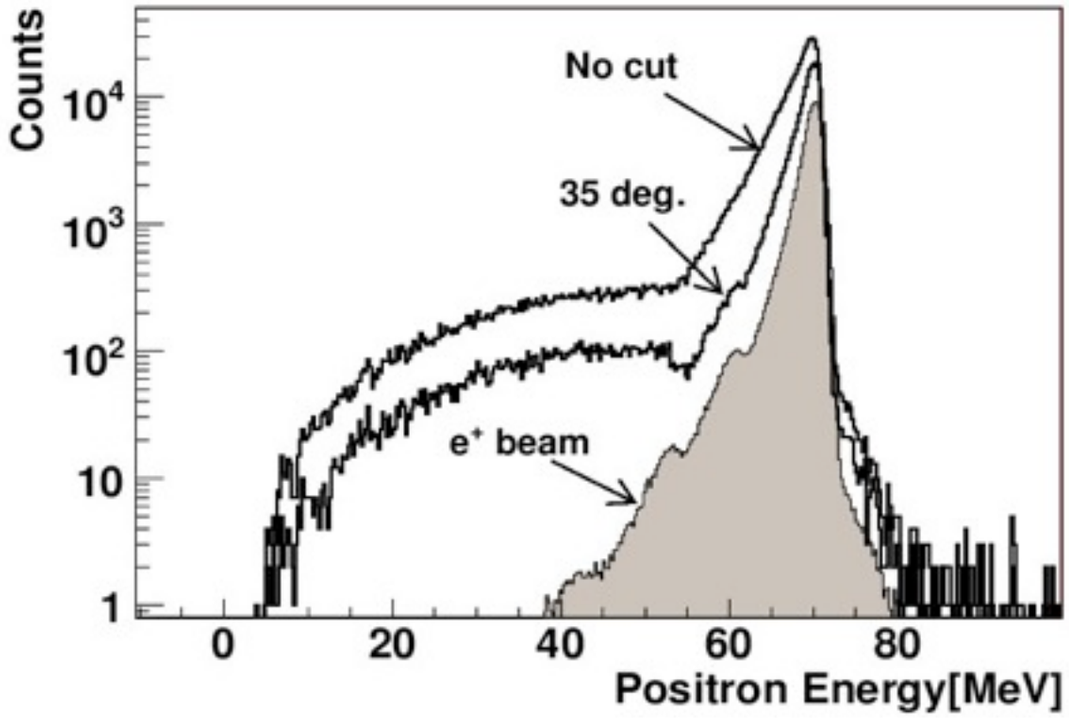
$$R_{ei} = \frac{\Gamma(\pi \to e\nu_i)}{\Gamma(\pi \to e\nu_l)} = |U_{ei}|^2 \rho_{ei}$$

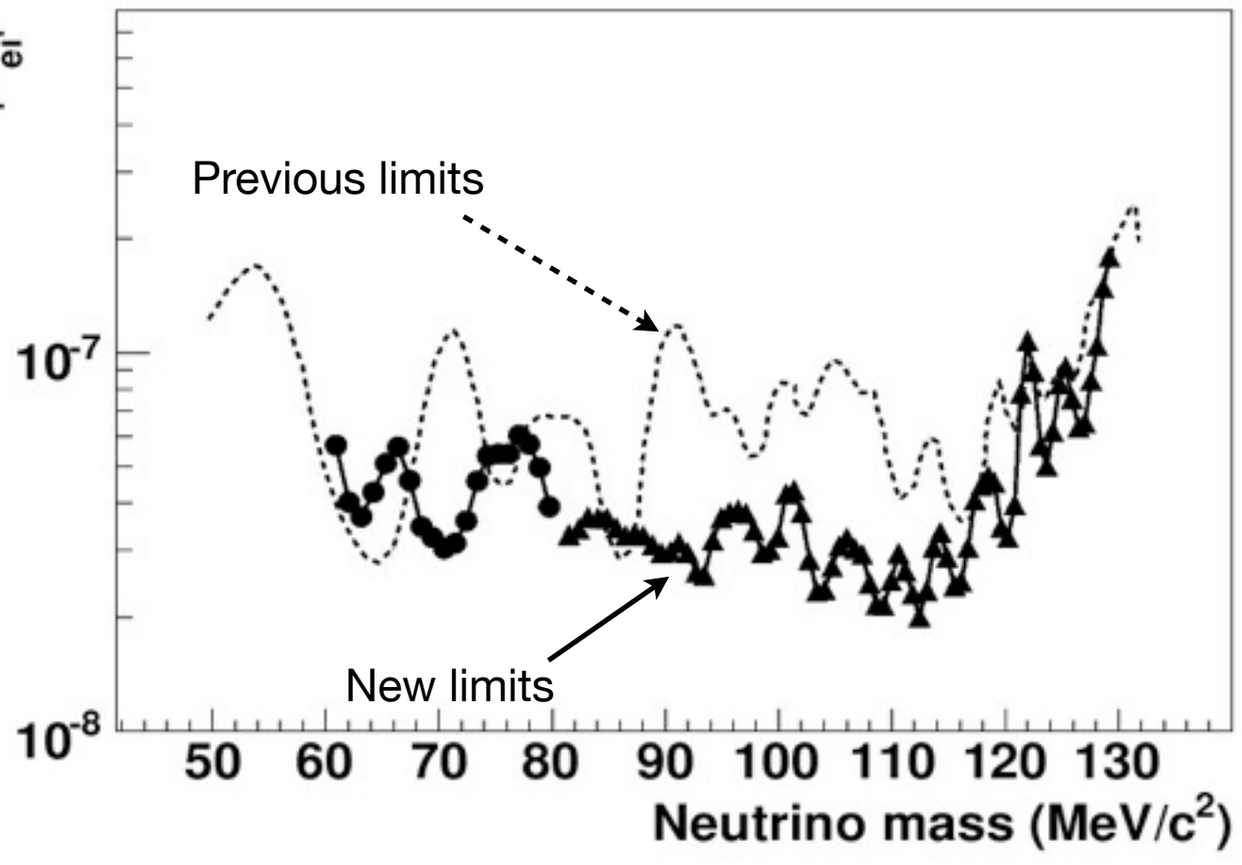
conventional υ

$$\nu_\ell = \Sigma_{i=1}^{3+k} U_{\ell i} \nu_i$$

$$\ell = e, \mu, \tau, \chi_1, \chi_2 \cdots \chi_k$$

Search for extra peak in the suppressed spectrum





M.Aoki et al. Submitted to PRD

See Talk : C.Malbrunot -Parallel 5F - Neutrino Oscillations II

Conclusions

2008	09	End of beamline extension work
	10-12	Test run
2009	05	PIENU detector completed
	05-09	Run I
	09-12	Run II
2010	03	Temperature enclosure completed
	04-09	Run III
	10-12	Run IV
2011	08-12	Run V
2012		Run VI

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

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BRANCHING RATIO ANALYSIS UNDERWAY !