Title: Measurement of the Pion Branching Ratio at TRIUMF : A Sensitive Probe in the Search for New Physics

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Abstract: Study of rare decays is an important approach for exploring physics beyond the Standard Model (SM). The branching ratio of the helicity suppressed p ? e? 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).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, â€œnew physicsâ€• 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.

TRIUMF

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

PIENU

The PIENU Experiment

a sensitive probe in the search for new physics

Chloé Malbrunot

For the PIENU Collaboration

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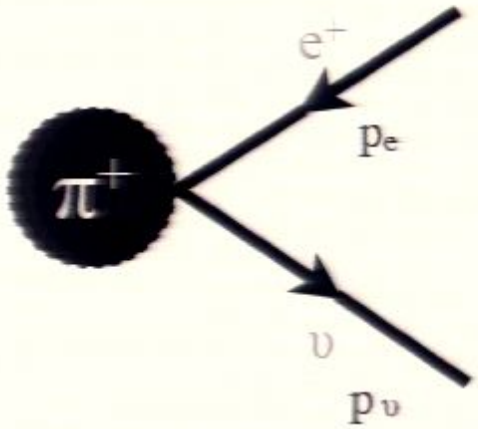
Women in Physics Canada

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



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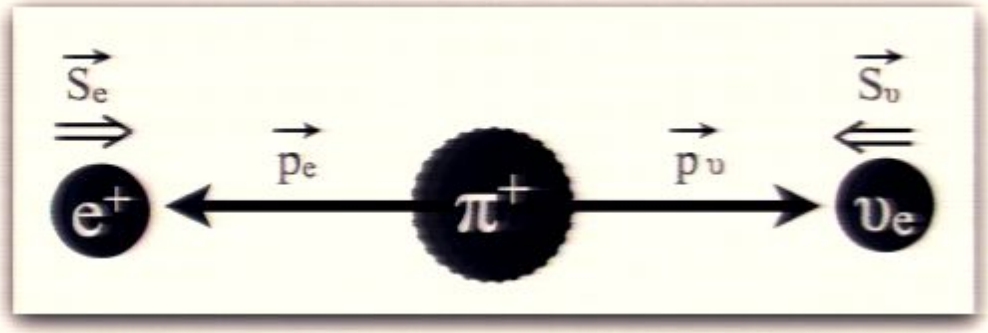
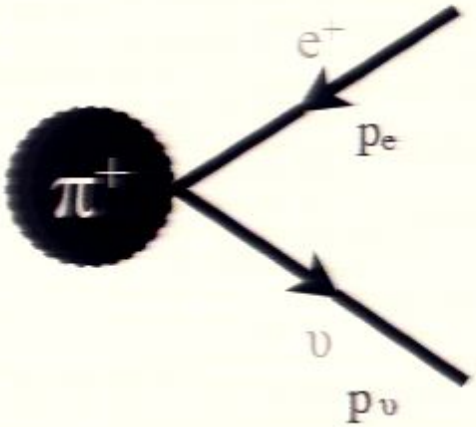
V-A theory of weak interaction





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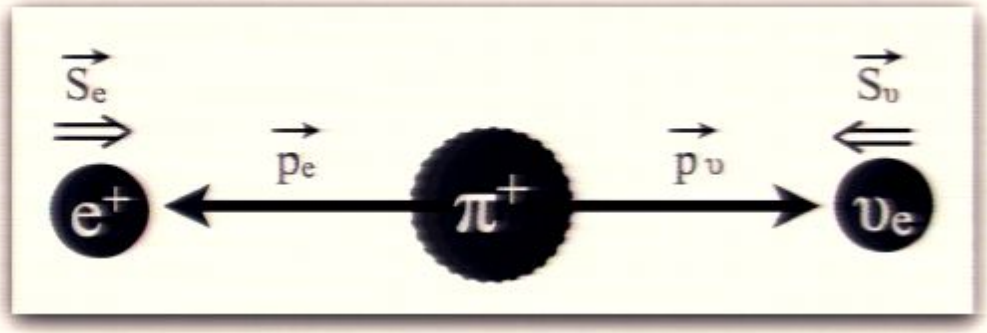

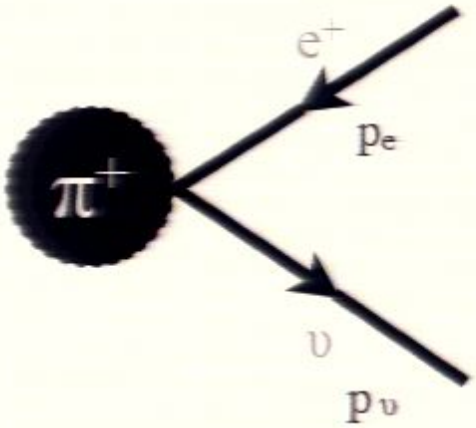

Because of helicity the $\pi^+ \rightarrow e^+\nu$ decay is **suppressed** over the $\pi^+ \rightarrow \mu^+\nu$ decay by a factor $(m_e/m_\mu)^2$

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

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

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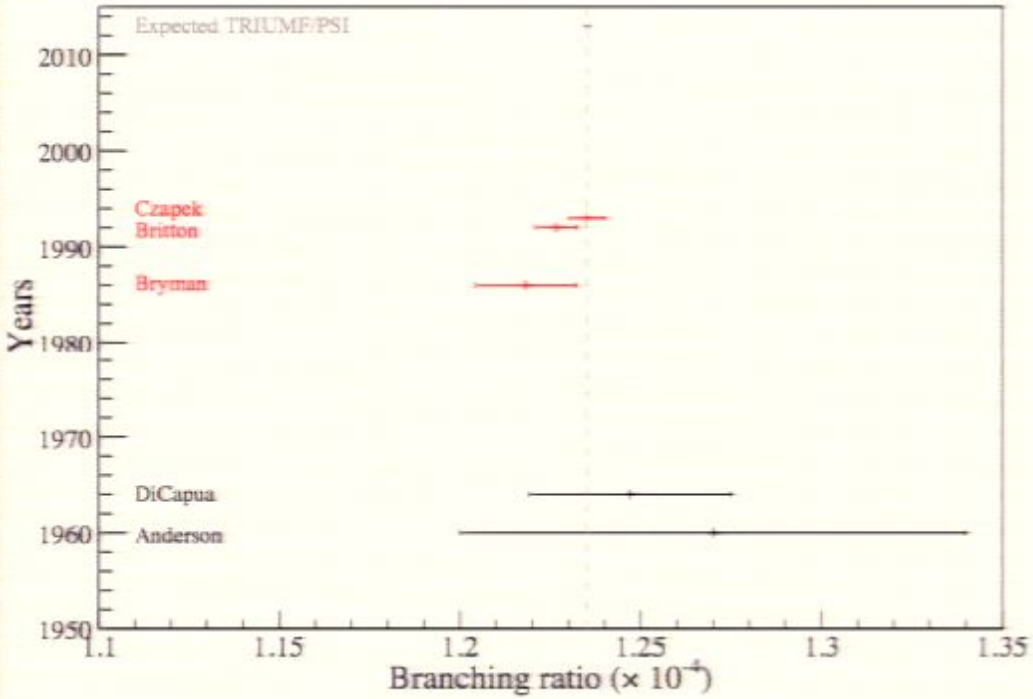
Theory ★★★★★ Experiment ★★ Analysis ★★ Conclusion ★

A Precision Experiment



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.D63:558-559,19
PSI : G. Czapek et al. Phys.Rev.Lett.70:17-20,1993

SM value :

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

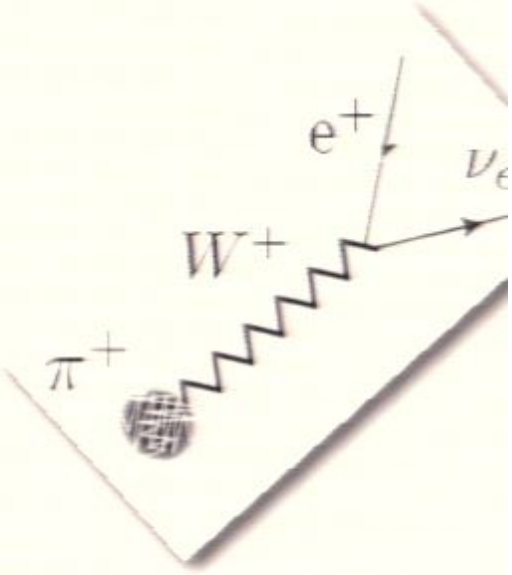
V.Cirigliano, I.Rosell, Phys. Rev. Lett. 99, 231801 (2007)
W.J. Marciano, A. Sirlin, Phys. Rev. Lett. 71, 3629-3632 (1993)

2 orders of magnitude difference in precision → window for BSM physics
PIENU goal : improvement x5 → precision < 0.1% on the BR

Universality test

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

$$R_{e/\mu} = \frac{\Gamma_{\pi\to e\nu_e}}{\Gamma_{\pi\to\mu\nu_\mu}}$$



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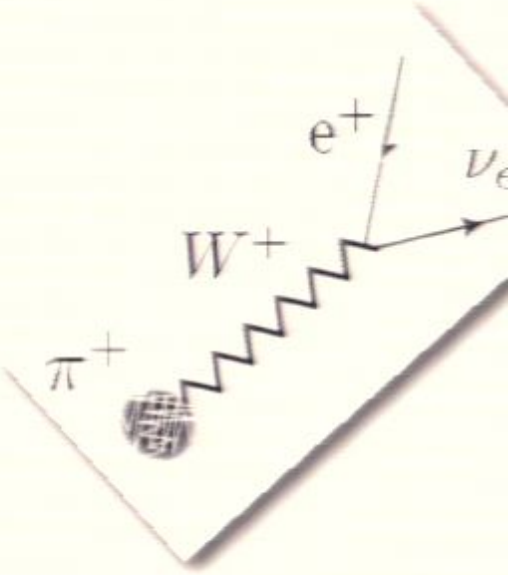
$$R_{e/\mu} = \frac{\Gamma_{\pi\to e\nu_e}}{\Gamma_{\pi\to\mu\nu_\mu}}$$

$$g_e \stackrel{?}{=} g_\mu \stackrel{?}{=} g_\tau$$

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

Beyond SM search

$$1 - \frac{R^{Exp}}{R^{SM}} \sim \pm \frac{\sqrt{2\pi}}{G} \frac{1}{\Lambda^2} \frac{m_\pi^2}{m_e(m_d + m_u)} \sim (\frac{1TeV}{\Lambda_{eP}})^2 \times 10^3$$

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)

...

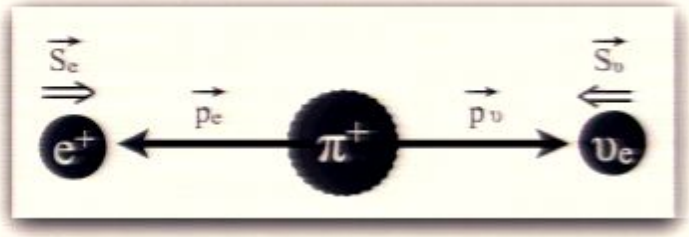
- Real deviation from the SM → new physics observation
- Agreement with SM → constraints

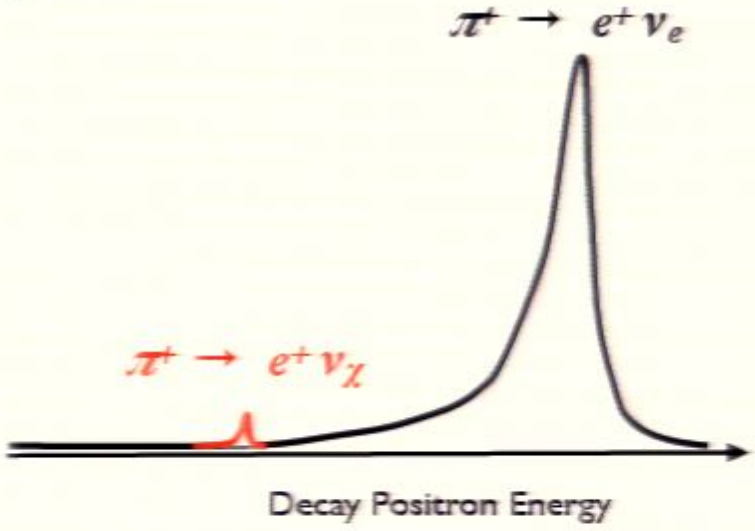
Massive neutrino

$$\begin{bmatrix} e \\ \nu_e \end{bmatrix}\begin{bmatrix} \mu \\ \nu_\mu \end{bmatrix}\begin{bmatrix} \tau \\ \nu_\tau \end{bmatrix} + \nu_{\chi 1} \cdots \nu_{\chi \kappa}$$

e.g. Neutrino Minimal Standard Model

A. Boyarsky et al., Ann. Rev. Nucl. Sci., 59 191 (2009)
T. Asaka et al., JHEP 1104, 11 (2011)





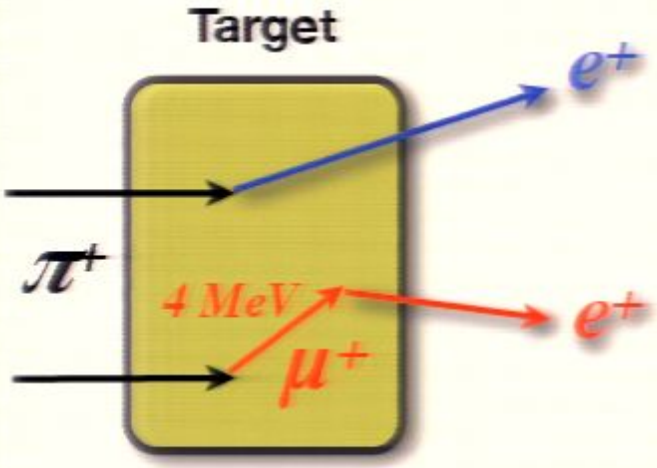
The presence of an heavy neutrino **changes the helicity relation** and alter the value of the branching ratio

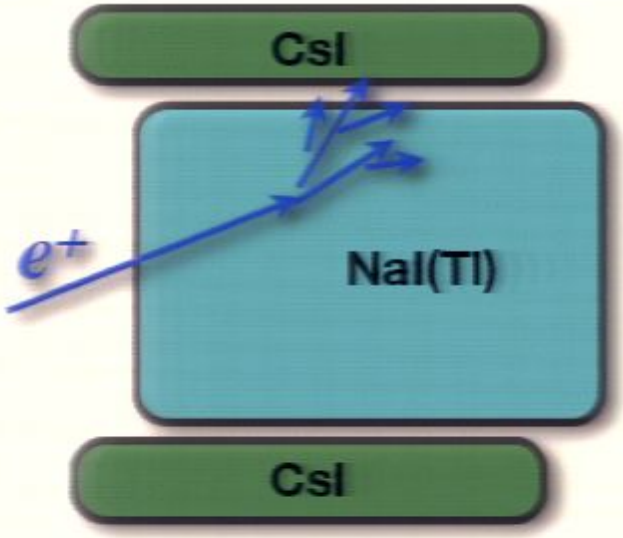
If the heavy neutrino mass is M_ν= 60~130 MeV/c^2 **additional low energy positron peak** can detected in the $\pi^+ \rightarrow e^+$ spectrum

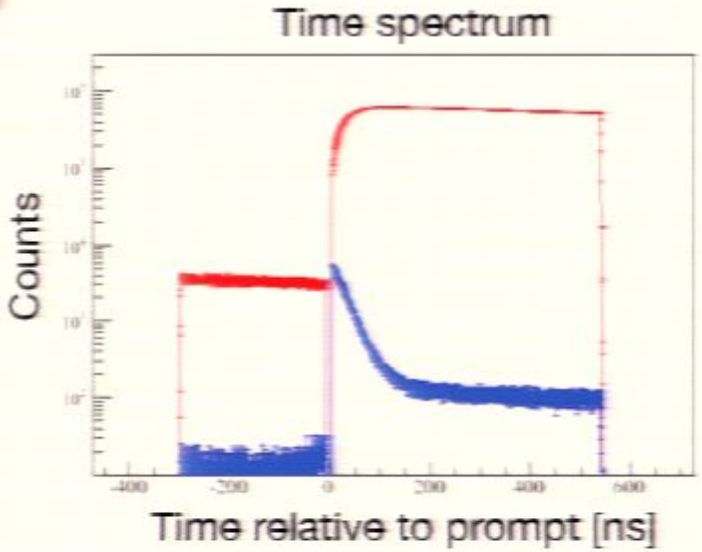
Experimental Technique

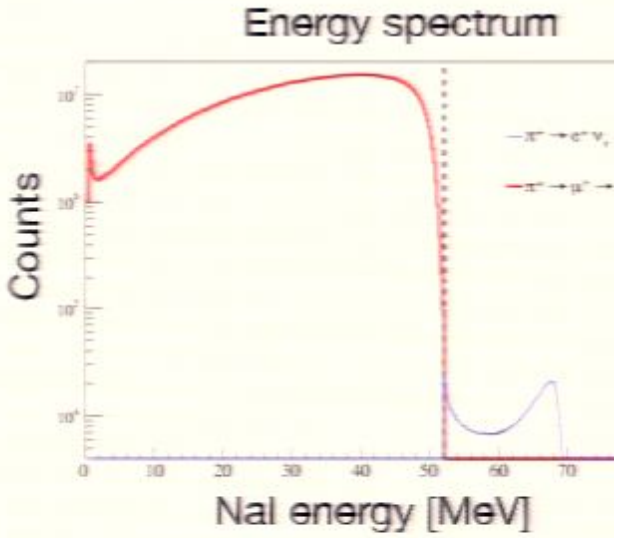
Experimental Method

- Stop pions in an active target Scintillator
- Yield measurement









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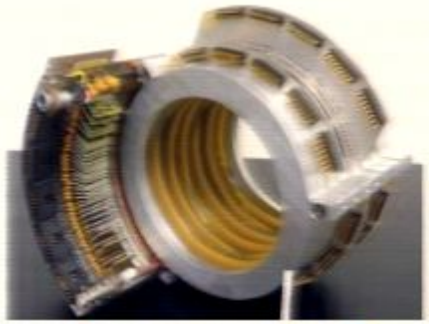
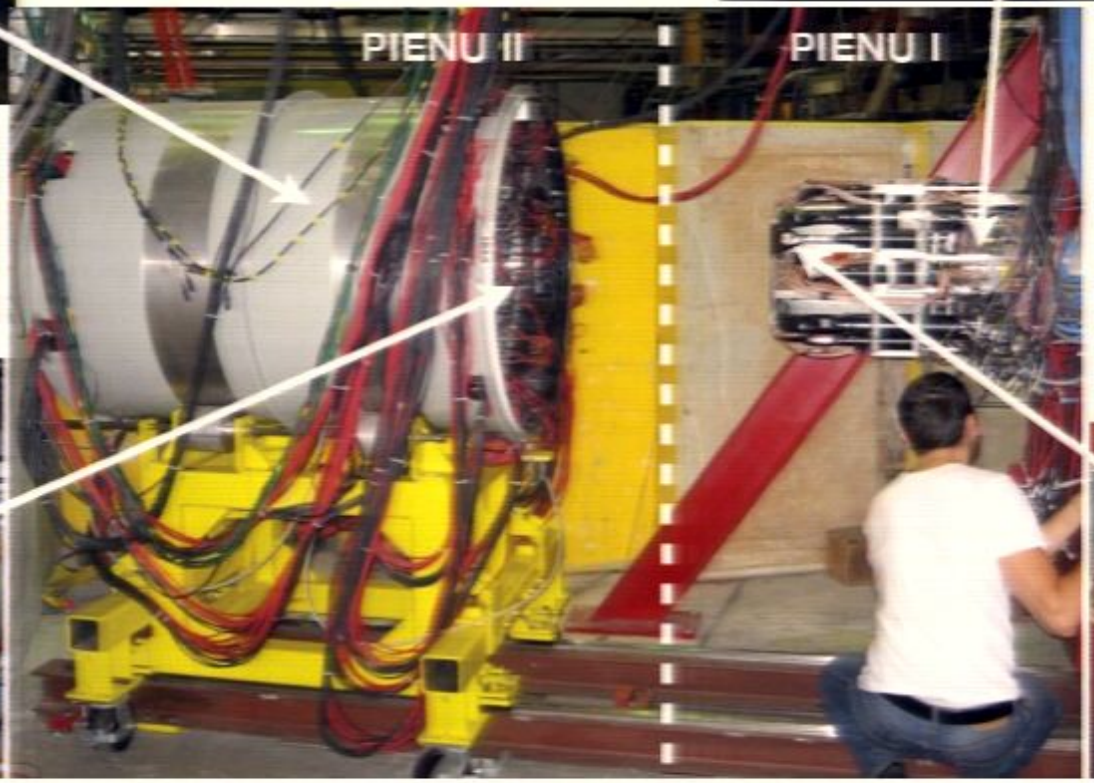
The PIENU detector (cont'd)

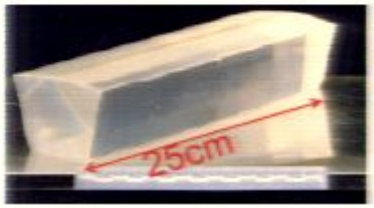
Monolithic NaI(Tl) crystal surrounded by 97 pure CsI crystals



Beam Wire Chamber

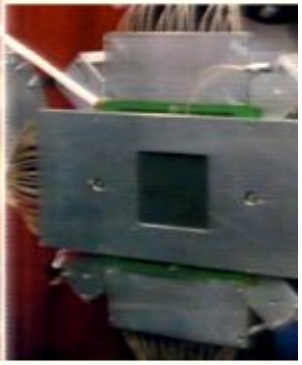


1 CsI crystal

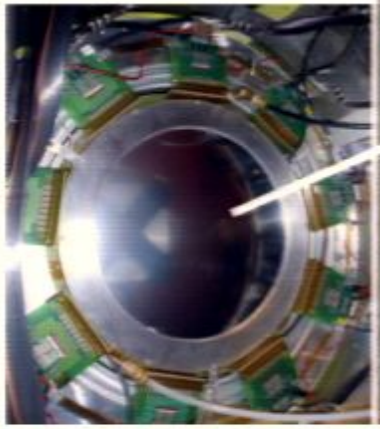


π^+

Silicon Trackers



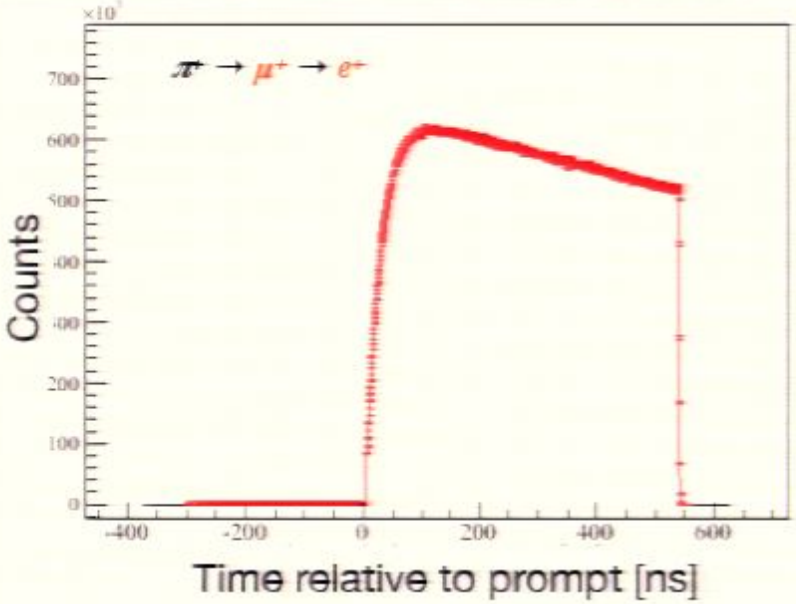
Acceptance Wire Chamber

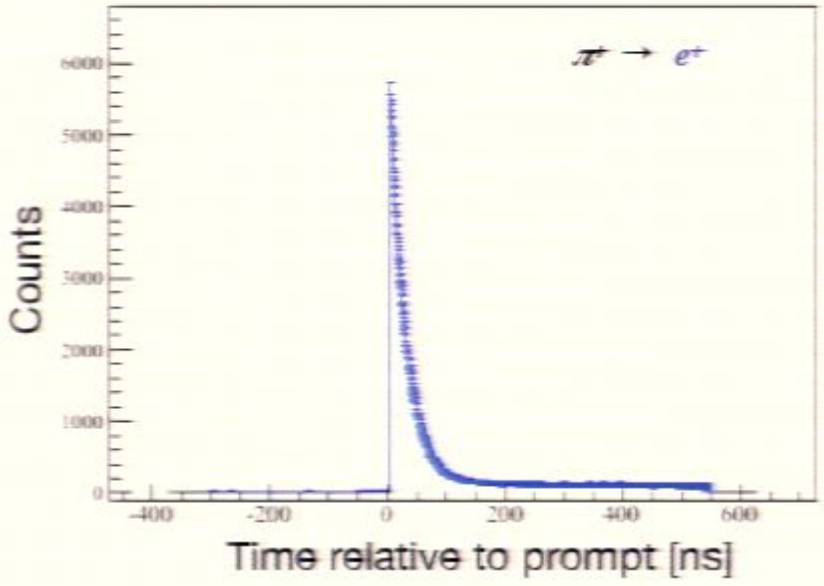


PIENU II is movable and detachable from PIENU I for line shape measurement at various e+ entrance angl

Branching Ratio

Simultaneous Fit of both time spectra : Raw Branching ratio



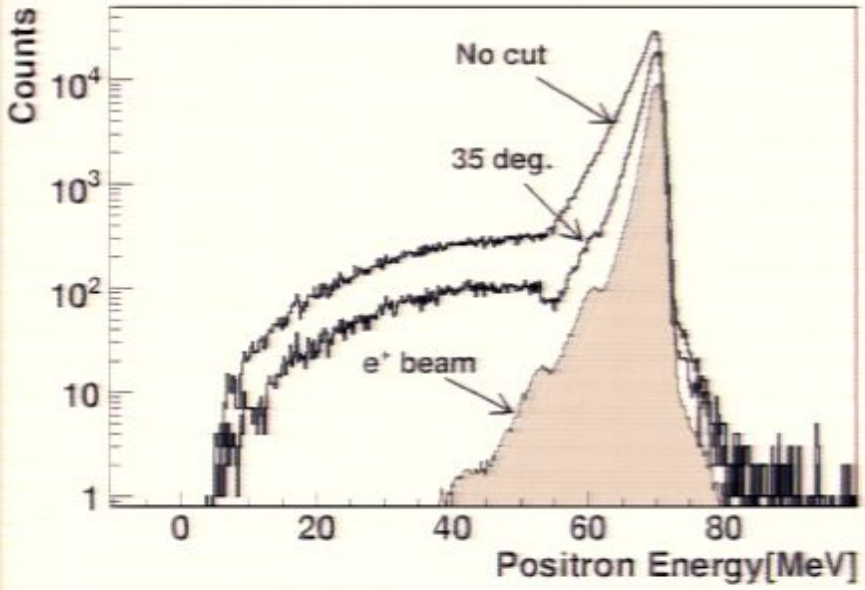


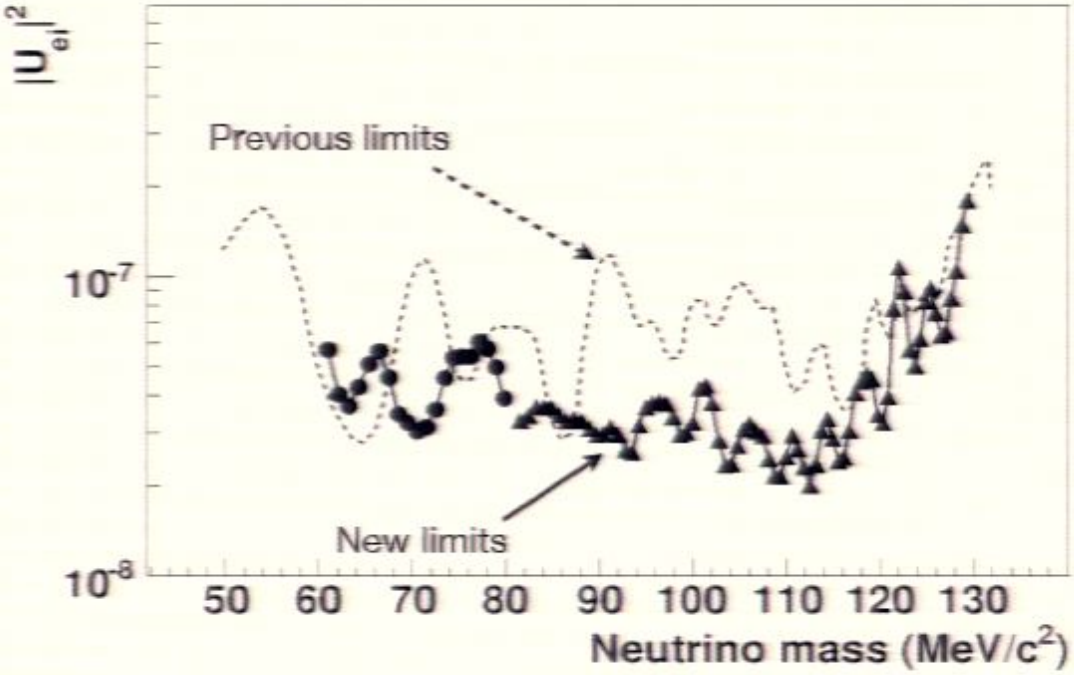
Many corrections have to be applied

Source	Error
Statistical	0.05%
Low energy tail	0.03%
Monte Carlo	0.03%
Pion lifetime	0.03%
Others	0.03%
Total systematic uncertainties	0.06%

Massive neutrinos

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





M.Aoki et al. Submitted to PRD

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Theory ★★★★★ Experiment ★★ Analysis ★★ Conclusion ★

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

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

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

BRANCHING RATIO ANALYSIS UNDERWAY !