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

Search for Massive Neutrinos

in the decay $\pi^+ \rightarrow e^+ \nu$

Chloé Malbrunot

For the PIENU Collaboration

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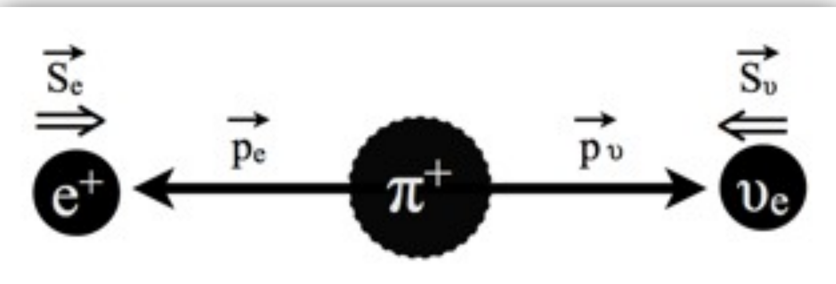
PANIC 2011

π→eν decay and massive ν



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

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

(For measurement of the pion branching ratio at TRIUMF, see Talk : C.Malbrunot -Parallel 5G - Lepton Universality and Forward Jets)

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

$$\begin{bmatrix} e \\ \nu_e \end{bmatrix} \begin{bmatrix} \mu \\ \nu_\mu \end{bmatrix} \begin{bmatrix} \tau \\ \nu_\tau \end{bmatrix} + \nu_{\chi 1} \ldots \nu_{\chi K}$$

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

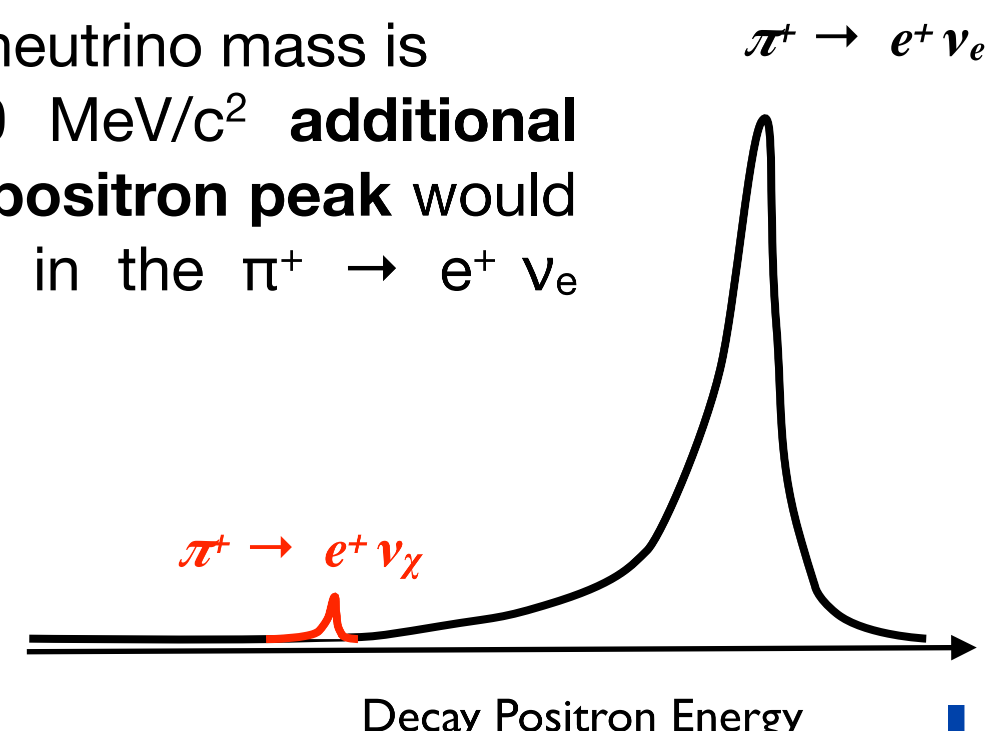
$$\ell = e, \mu, \tau, \chi_1, \chi_2 \cdots \chi_k$$

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)

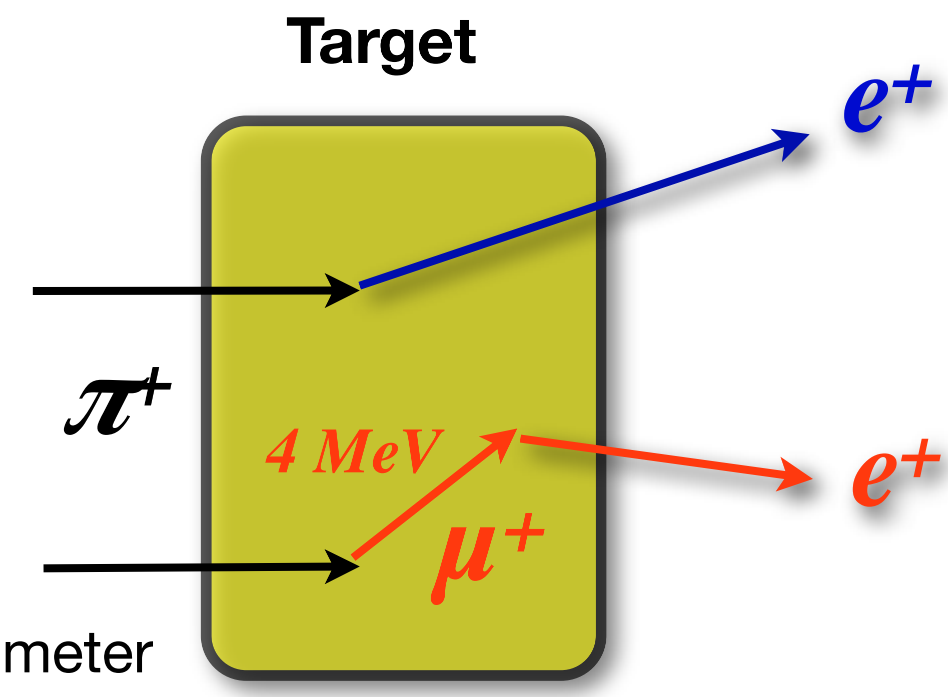
If the heavy neutrino mass is M_ν= 60~130 MeV/c^2 **additional low energy positron peak** would be detected in the $\pi^+ \to e^+ \nu_e$ spectrum

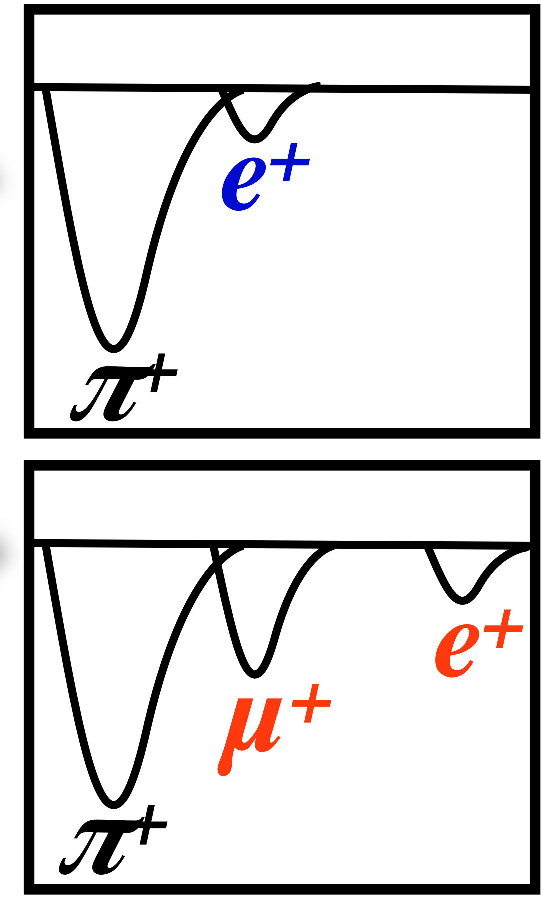


Experimental Technique

Experimental Method

- Stop pions in an active target Scintillator
- Select $\pi^+ \rightarrow e^+$ events

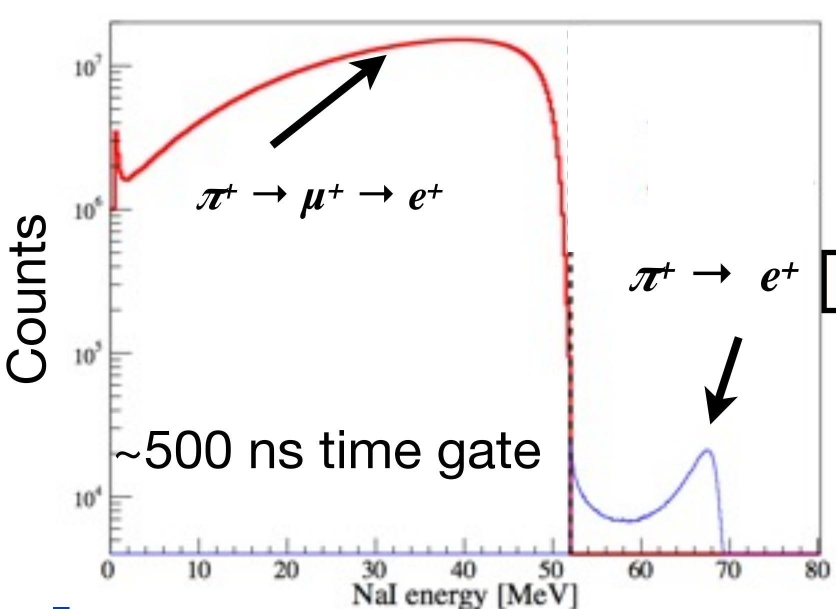




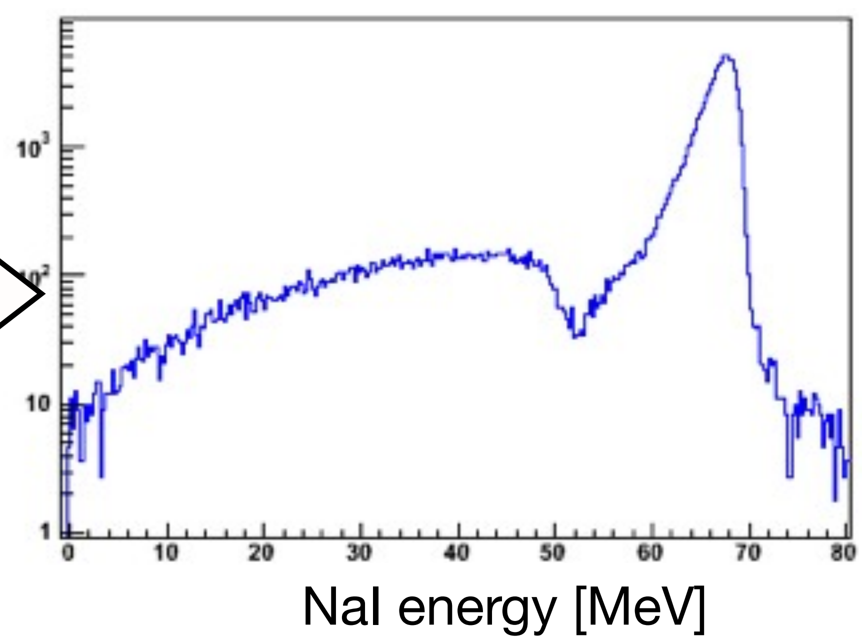
Required

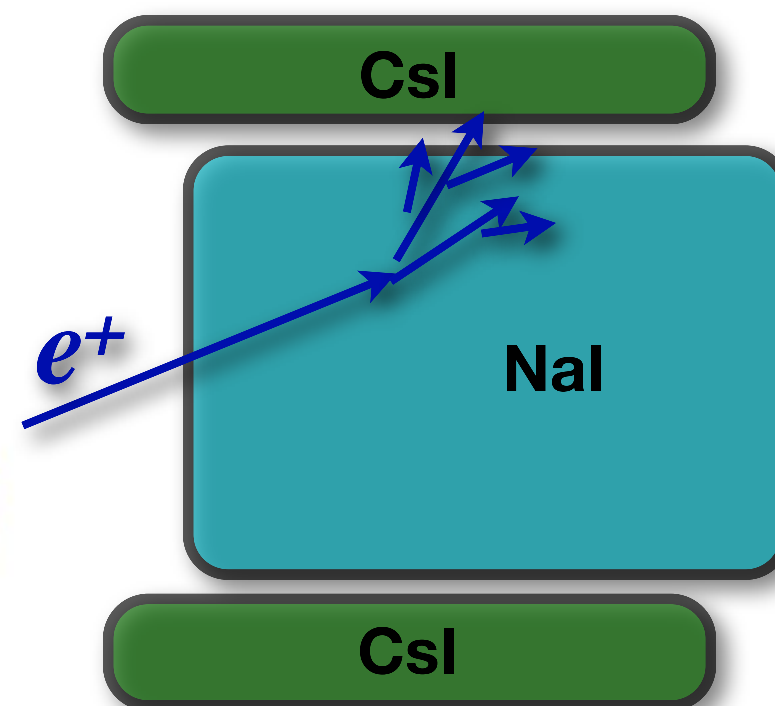
- High purity pion beam
- Knowledge of response function of calorimeter
- Good $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ background suppression

Full Energy spectrum



Suppressed Energy spectrum





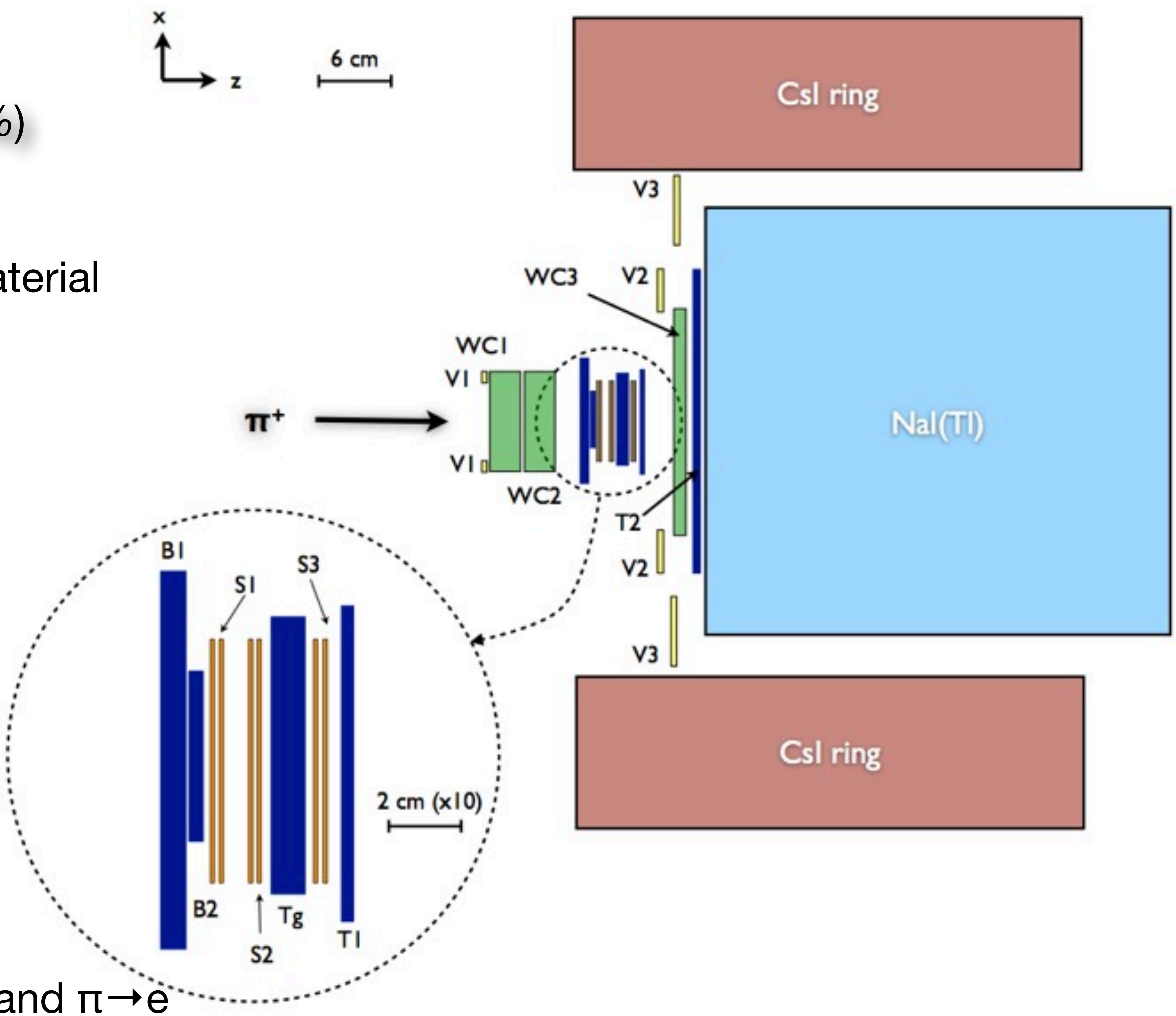
The PIENU detector

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

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

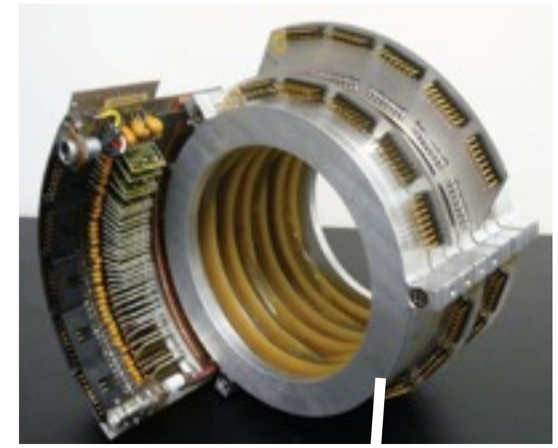
- High resolution calorimeter
  NaI :1% σ at 70 MeV

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



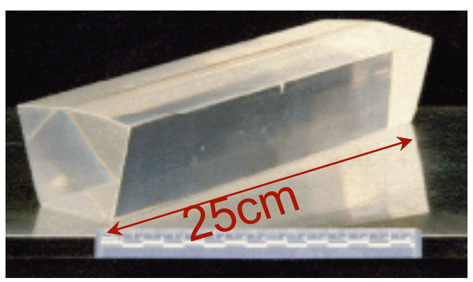
The PIENU detector (cont'd)

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

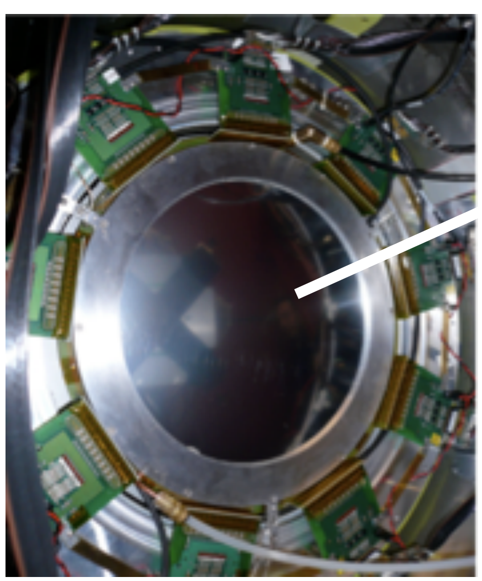


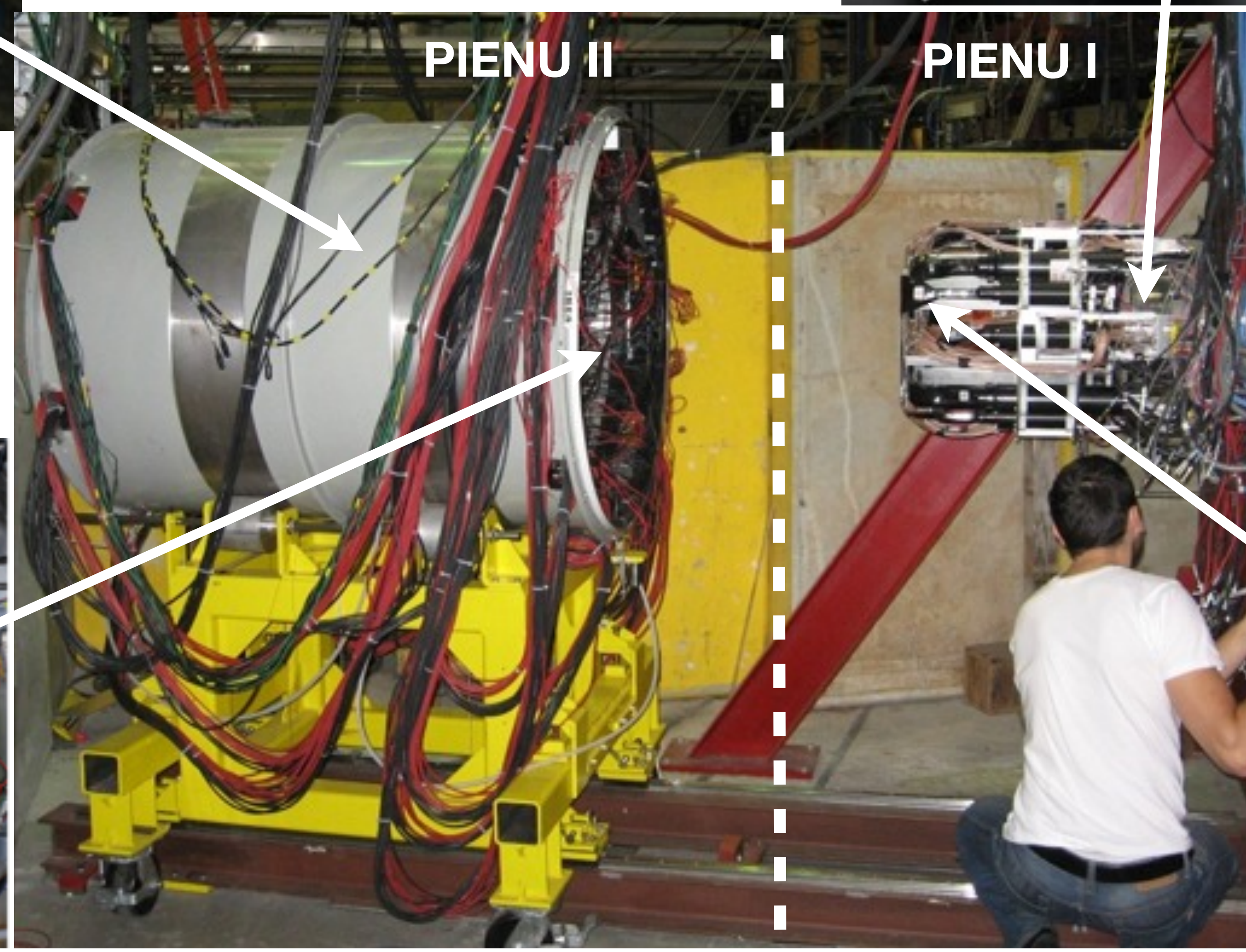
Beam Wire Chamber

1 CsI crystal



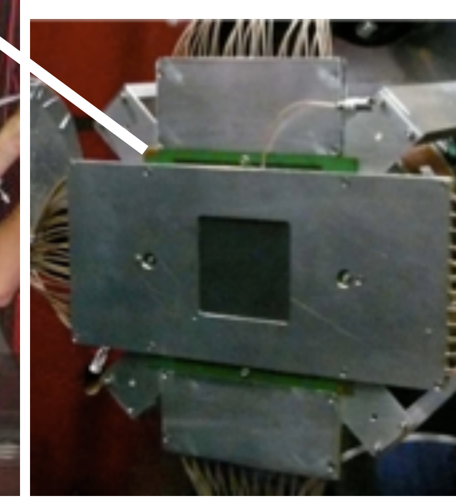
Acceptance Wire Chamber





π^+

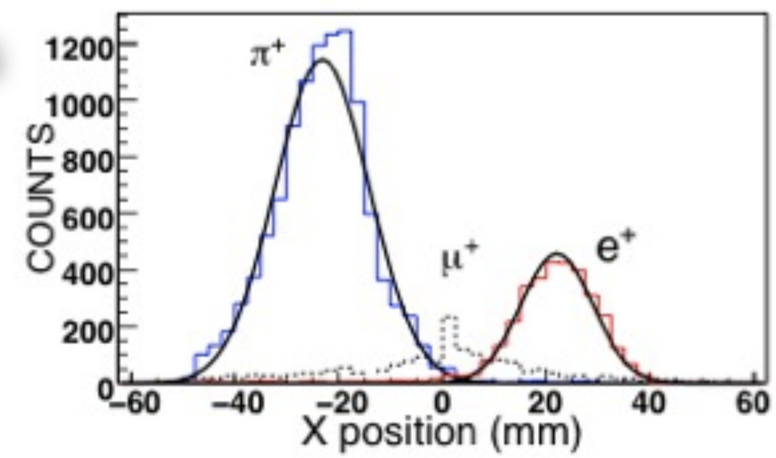
Silicon Trackers



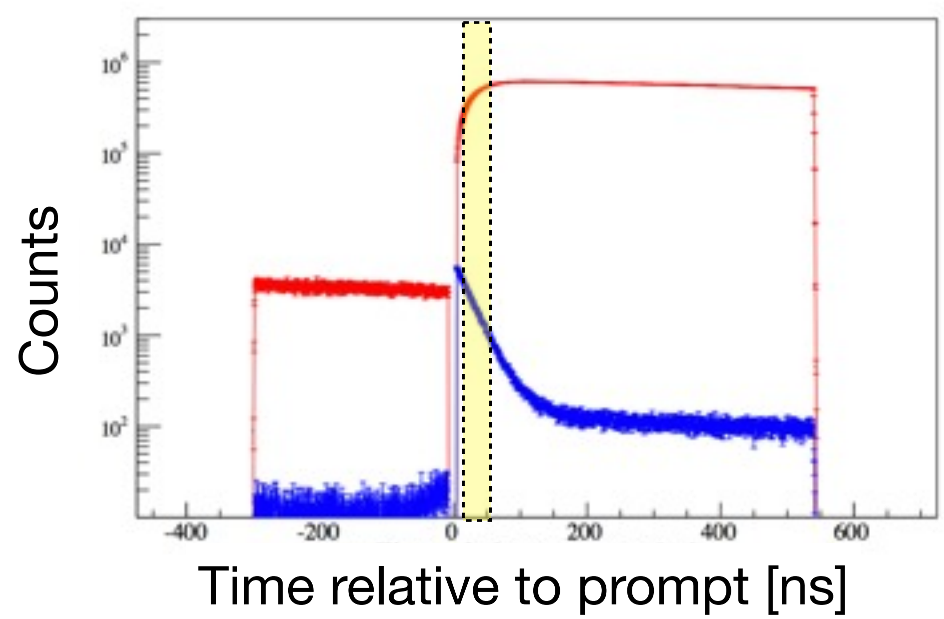
PIENU II is movable and detachable from PIENU I for line shape measurement at various e+ entrance angles

Data taking conditions

- 50 kHz pion stop in Target with 2% positrons and 10% muons
- Triggers : 600Hz
  - $\pi \to e\,\nu$: Early (2-50 ns)



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

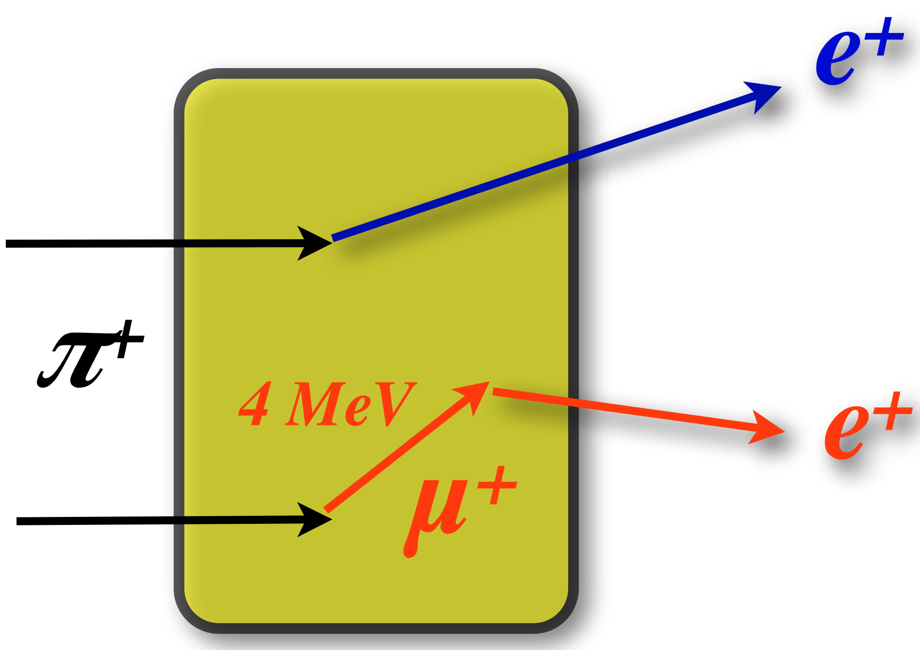


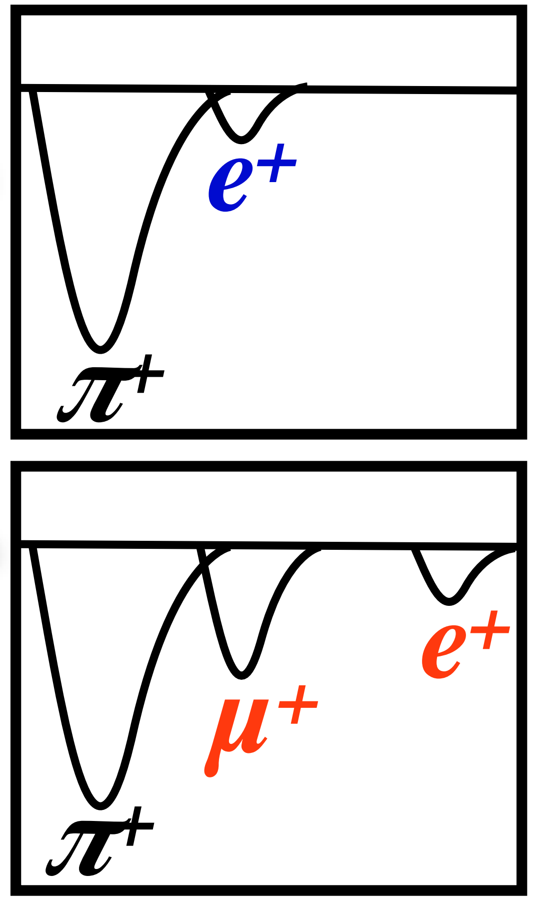
Inspection period -300ns to 500ns

  - $\pi \to \mu \to e$: Prescaled (1/16)
  - monitor and calibration triggers: e^+ beam, Xe, cosmic-ray
- Waveforms are recorded

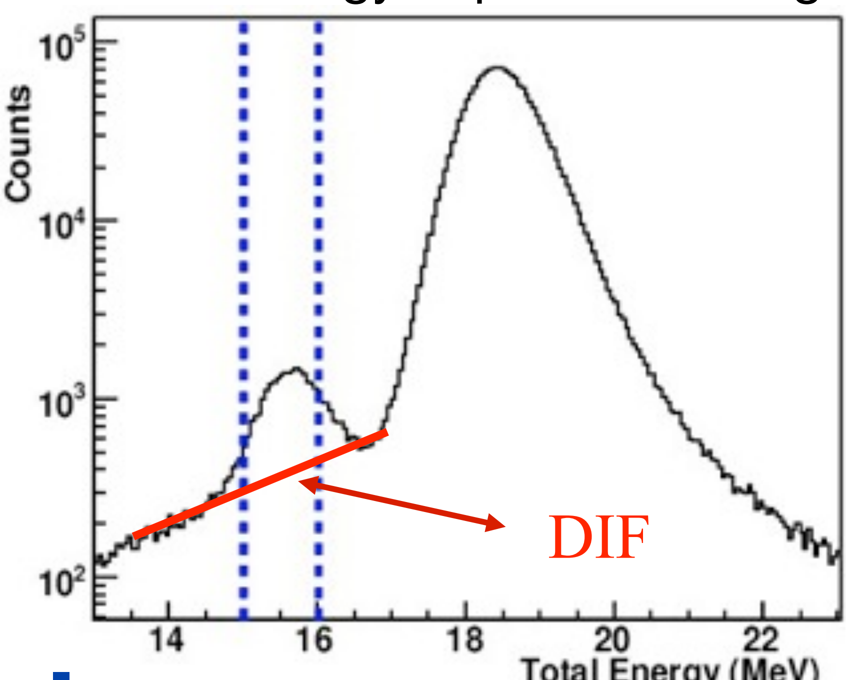
Suppression of background

- Target energy

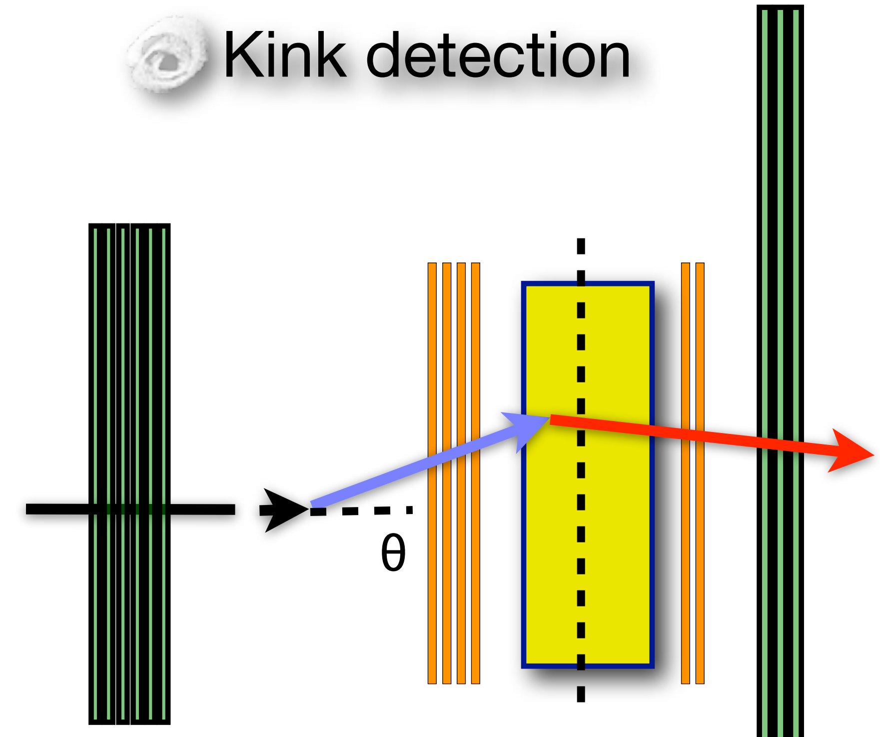


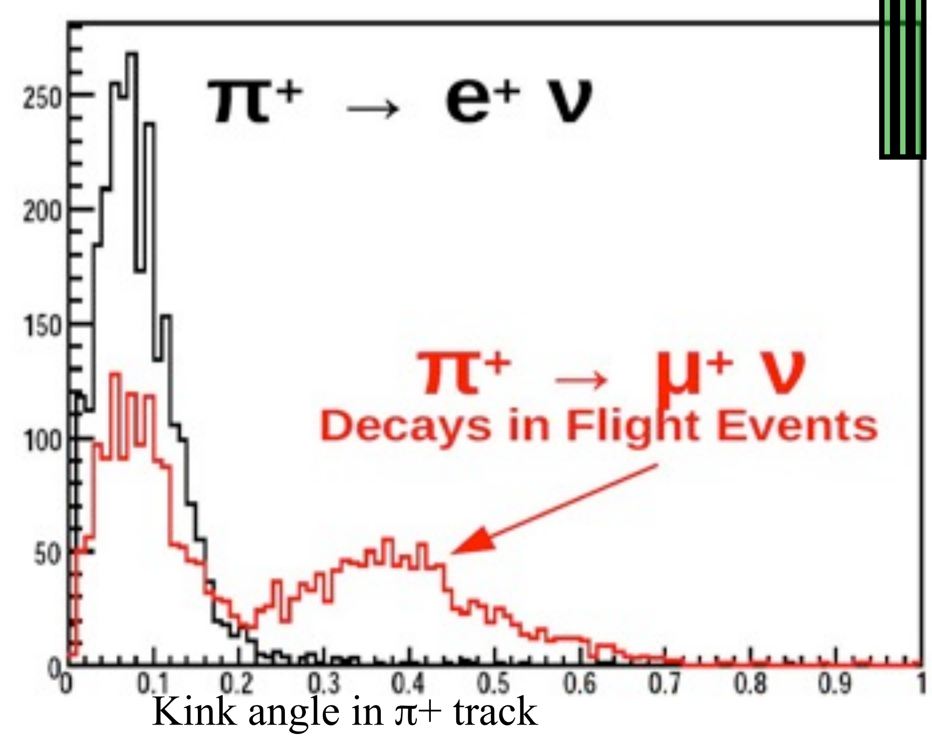


Total Energy deposited in Target



- Kink detection





Downstream & Upstream tracking enables background suppression based on **vertex position**

Suppression of background (cont'd)

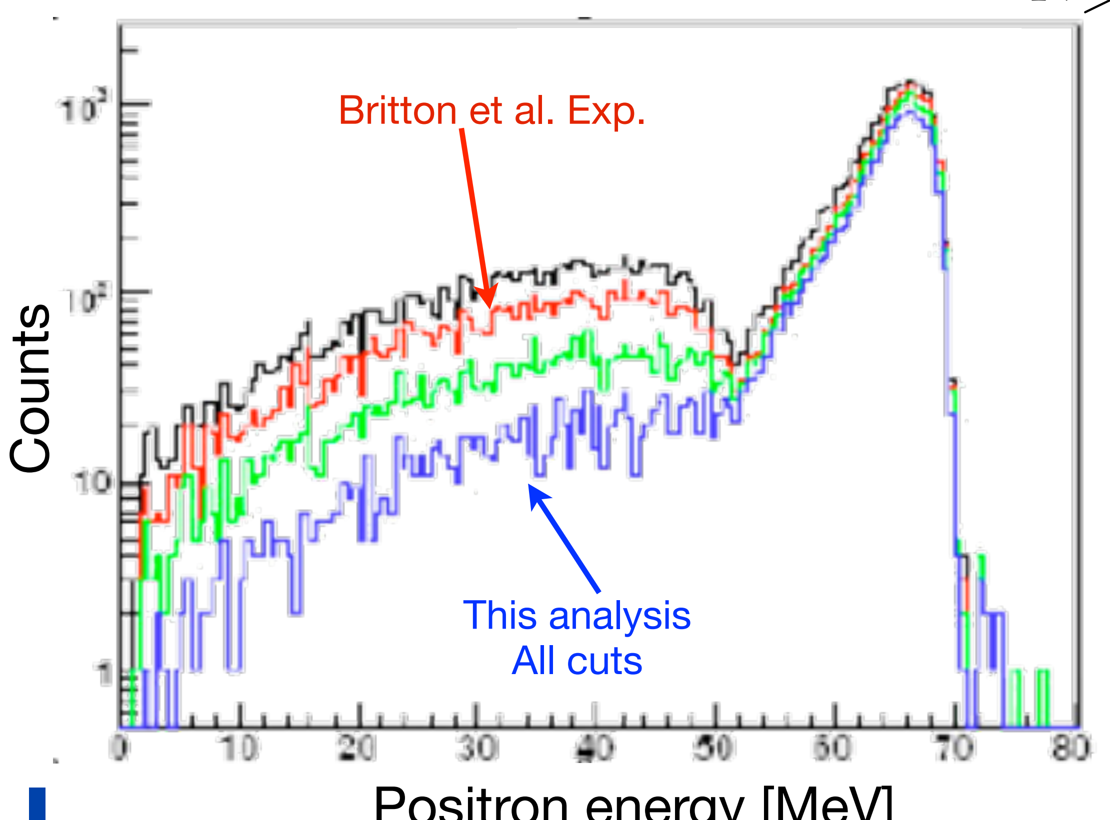
Summary of cuts :

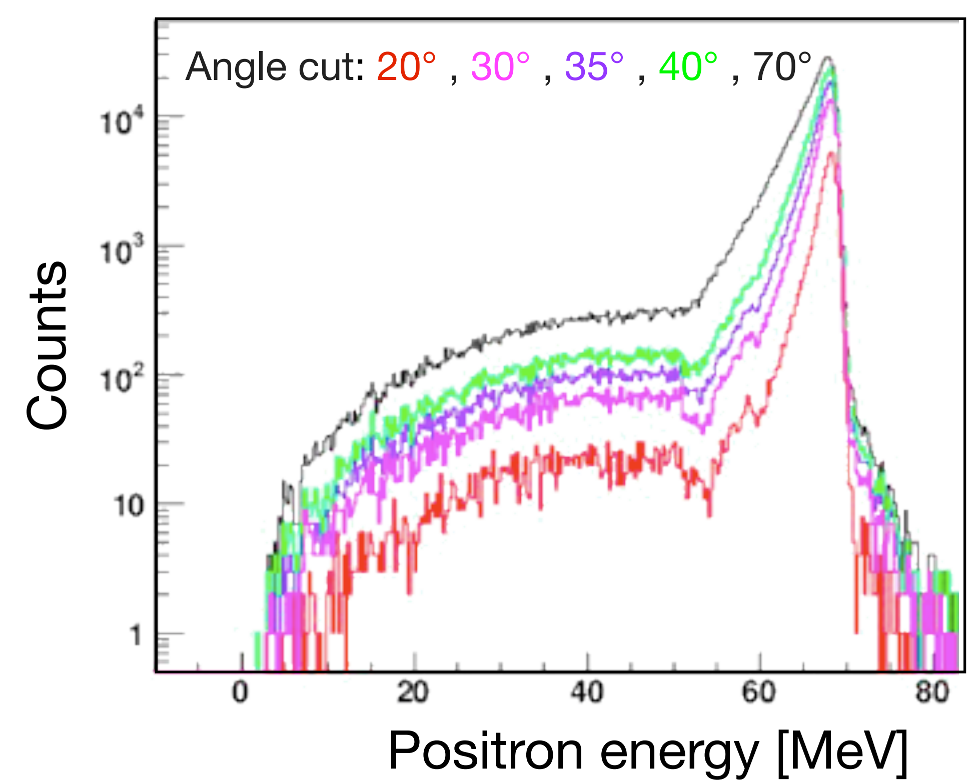
* Cuts with energy dependence

- Time cut (takes advantage of the difference in lifetimes)
- Target energy cut *
- kink cut
- Pulse Shape cut
- Z vertex *
- CsI veto *
- Radial cut in WC3 *

Tighter angular cuts = better peak resolution
Only effective above 47 MeV
Analysis region divided :
1) 0-47 MeV : no angular cut
2) 47-60 MeV : 35 deg cut

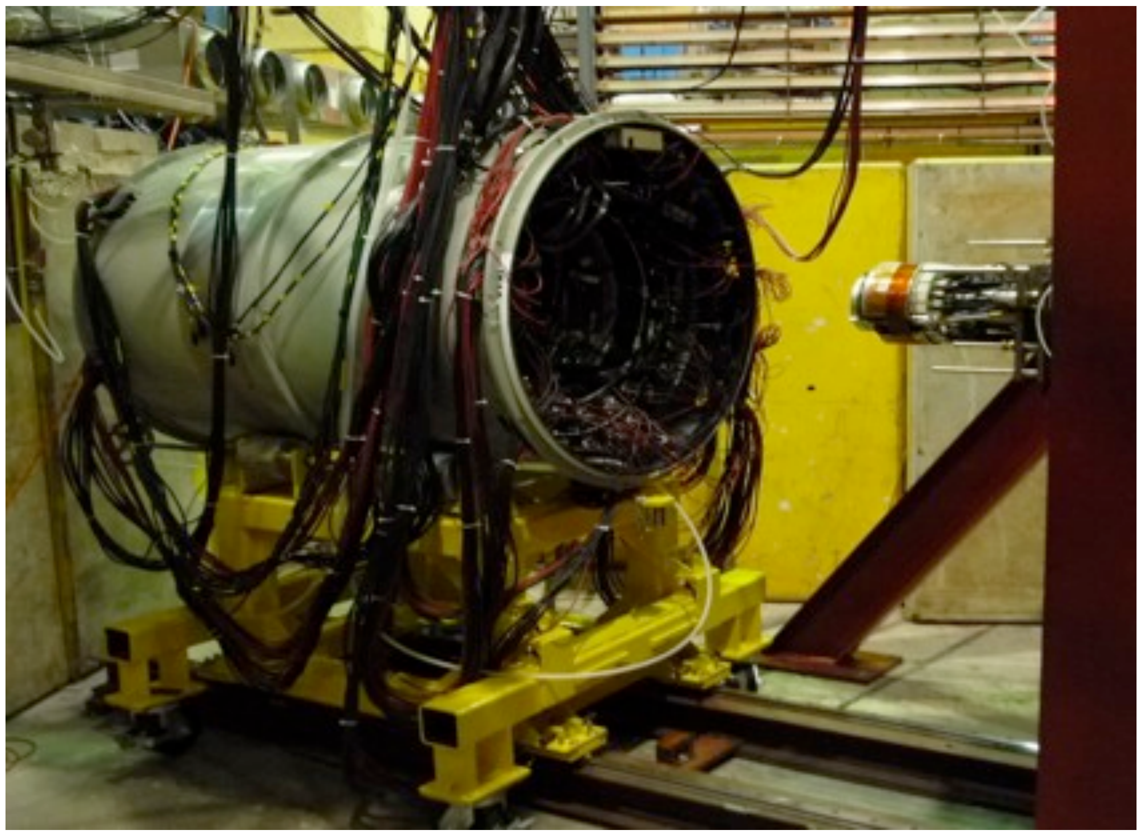
Optimization of cuts by minimizing $S = \frac{\sqrt{N_{<54MeV}}}{N_{>54MeV}}$

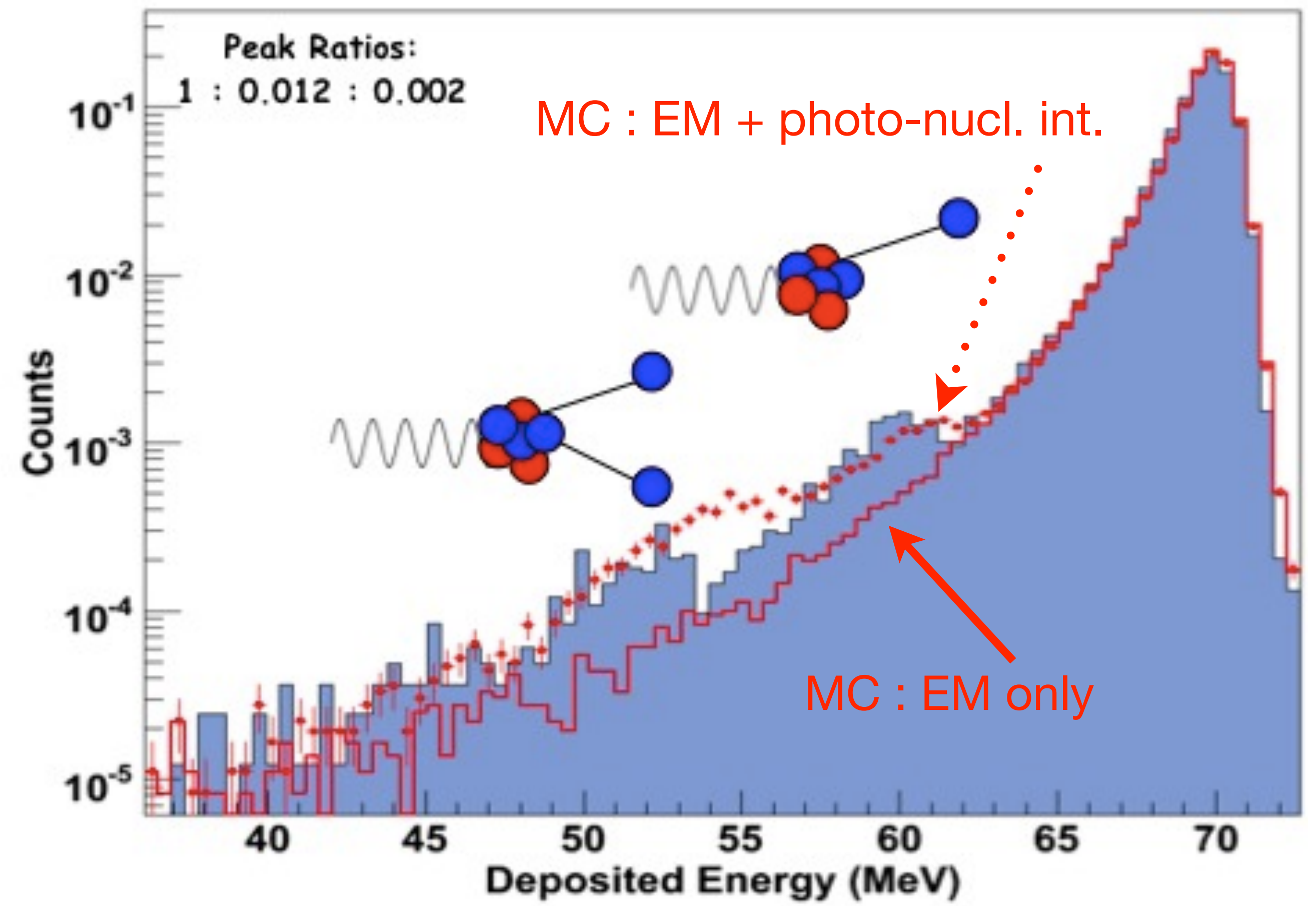




Low energy tail

Response function of the calorimeter was measured with a positron beam at various angles. **Photo-nuclear reactions** in the NaI crystal were discovered





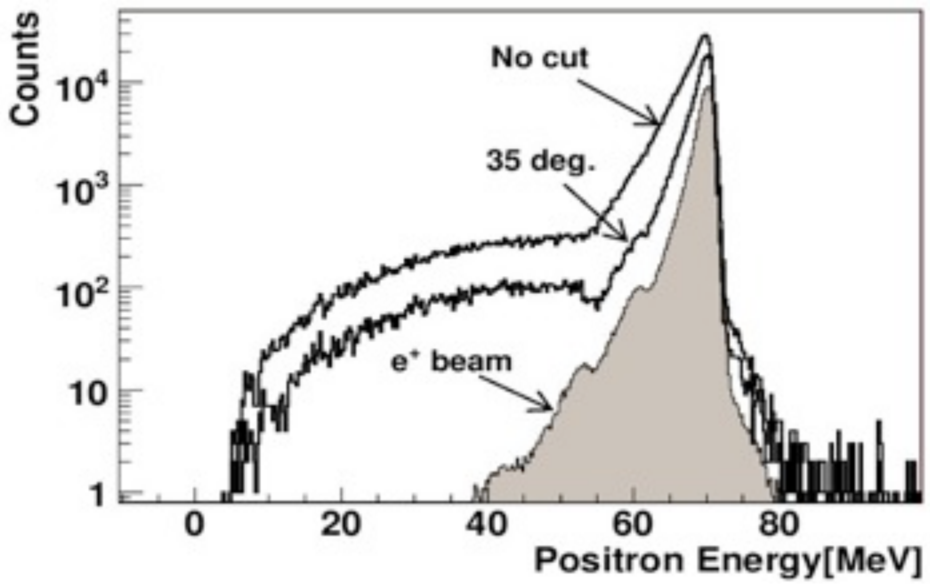
A. Aguilar-Arevalo et al., Nucl. Instr. and Meth. A (2010)

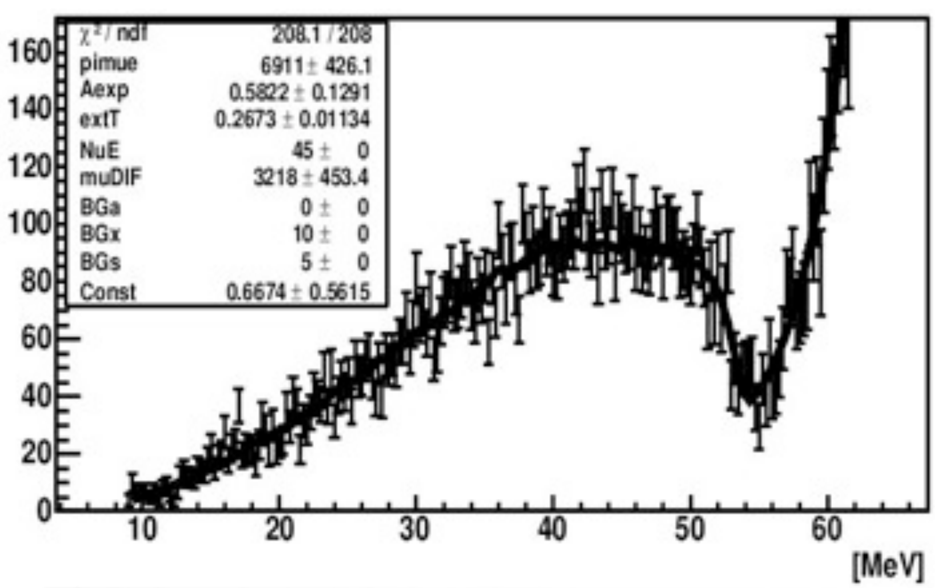
Neutrons are generated by photo-nuclear reactions I(γ,n) in NaI. If the **neutron escapes** from the crystal, the separation energy of the neutron is lost.

The lineshape spectrum is **subtracted** from the pienu data before performing the massive neutrino search

Massive neutrino search

Search for extra peak in the suppressed spectrum





Fit of 35 deg. spectrum without peak.
X^2/DOF = 1.00
πDIF=2% of pienu
μDIF=3 % of pienu

Components of the fit:

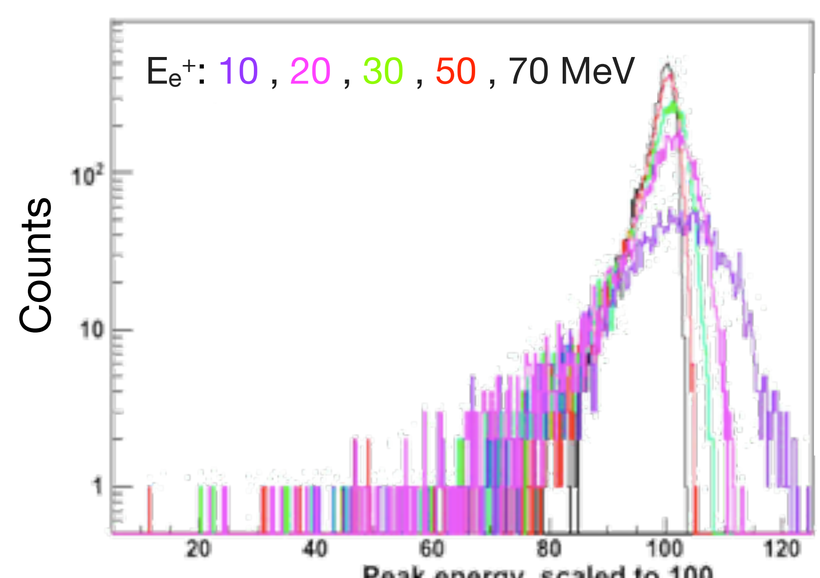
- π–μ–e (Michel spectrum for t = 150-500 ns)
- μDIF (distorted Michel spectrum)
- A*exp(B*t) + C (to simulate background and tail)
- Extra peak (MC generated)

Fitting regions :

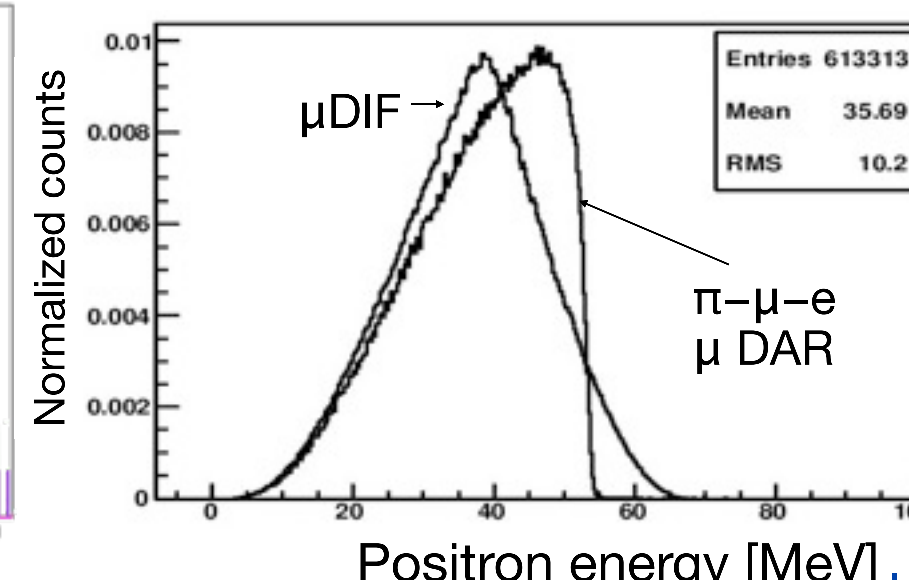
9-62 MeV (35 degree cut)
9-50 MeV (No angle cut)

0.5 MeV steps. Peak position fixed. Fit over entire energy region.

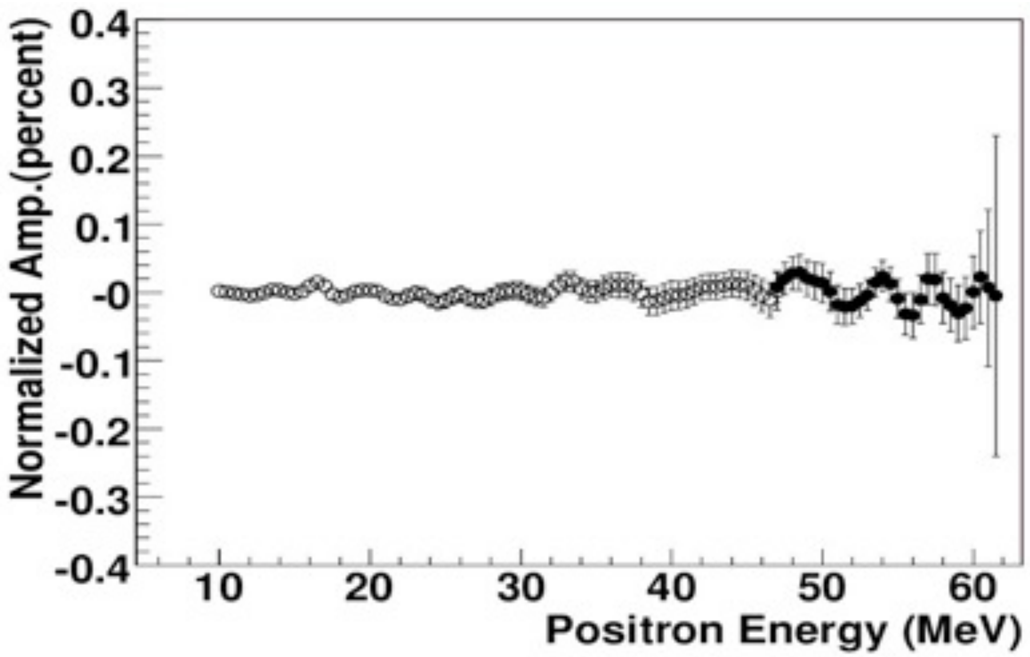
Peak shapes for 35 deg. data



Energy spectrum for μDAR and μDIF



Results



Normalized amplitudes to the 70 MeV peak for 35 deg. data (closed circles) and no cut data (open circles).

Amplitude of the potential peaks and the associated errors **converted to upper limit** on the ratio Γ(π+ → e+νi)/Γ(π+ → e+νe) as a function of positron energies (or massive ν mass).

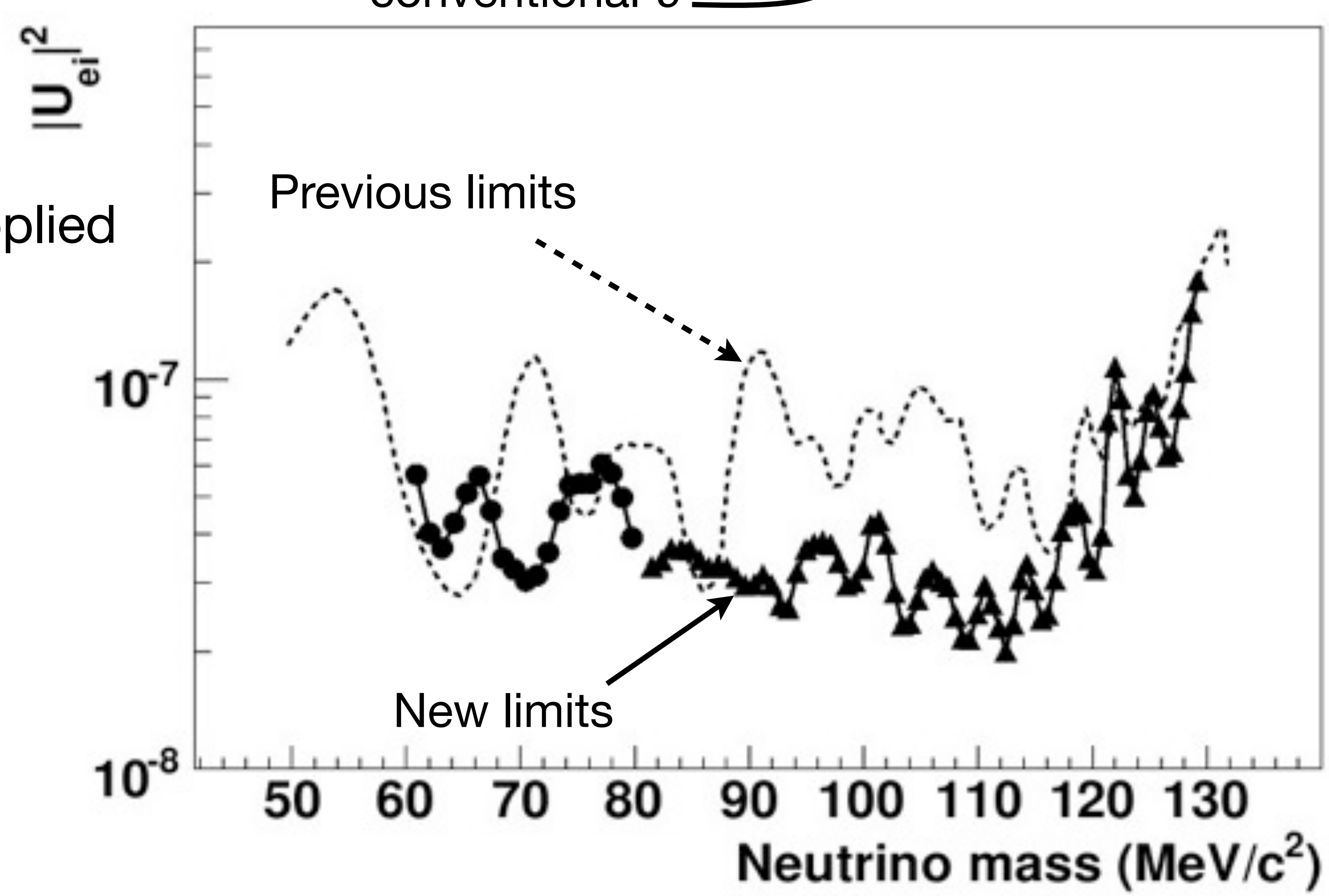
heavy υ

Kinematic factor

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

conventional υ

Acceptance correction for energy dependent cuts applied



> Factor of 5 improvement over prior limits on the mass range M_ν= 90~115 MeV/c^2

M.Aoki et al. Submitted to PRD

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 this analysis
1/2 million $\pi^+ \rightarrow e^+$ events after selection cuts

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