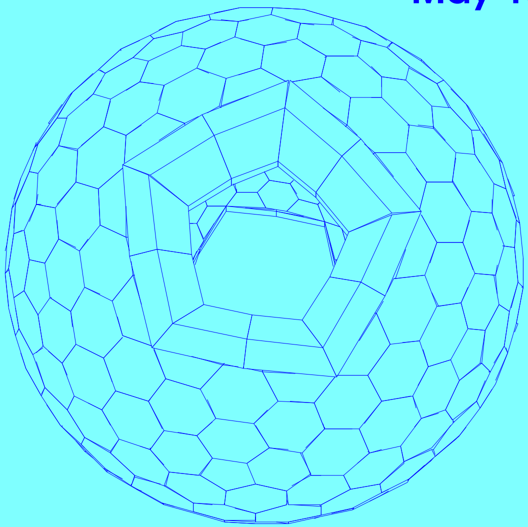
Two new $\pi \to e\nu$ experiments



Contents

1 Testing lepton universality

Allowing for violations of universality of the couplings g_l between W and a $l_i\overline{\nu_i}$ pair:

$$\Gamma^{\rm tree}_{\pi\to e\overline{\nu}} = \frac{g_e^2 g_{ud}^2 V_{ud}^2}{256\pi}\frac{f_\pi^2}{M_W^4} m_e^2 m_\pi (1-\frac{m_e^2}{m_\pi^2})^2$$

$$\Gamma^{\rm tree}_{\pi\to \mu\overline{\nu}} = \frac{g_\mu^2 g_{ud}^2 V_{ud}^2}{256\pi}\times\frac{f_\pi^2}{M_W^4} m_\mu^2 m_\pi (1-\frac{m_\mu^2}{m_\pi^2})^2$$

leading to a branching ratio:

$$R^{\rm tree}_{e/\mu} \equiv \frac{\Gamma^{\rm tree}_{\pi\to e\overline{\nu}}}{\Gamma^{\rm tree}_{\pi\to \mu\overline{\nu}}} = (\frac{g_e}{g_\mu}\times\frac{m_e}{m_\mu}\times\frac{1-m_e^2/m_\pi^2}{1-m_\mu^2/m_\pi^2})^2$$

Radiative corrections lower this value by 3.74(1)% [1]. Within the SM $g_e = g_\mu = 1$ which leads to:

$$R^{\rm SM}_{e/\mu} = 1.2350(5)\times 10^{-4}$$

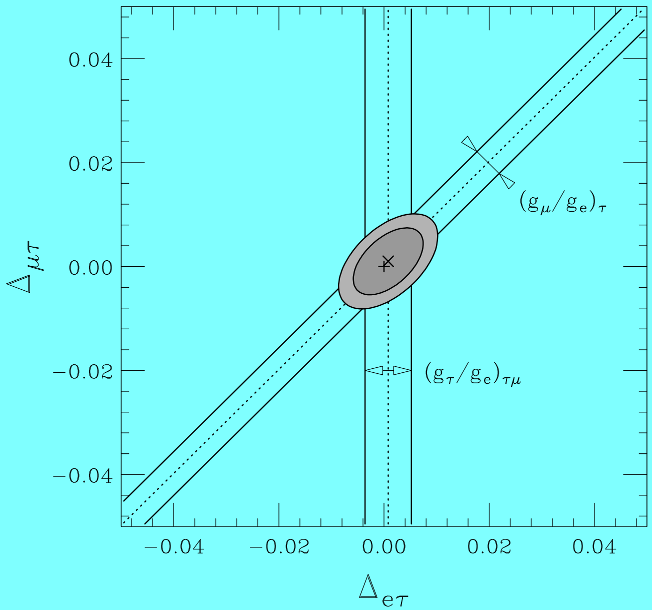
Two experiments [2] contribute to the present world average for the measured value:

$$R^{\rm exp}_{e/\mu} = 1.230(4)\times 10^{-4}$$

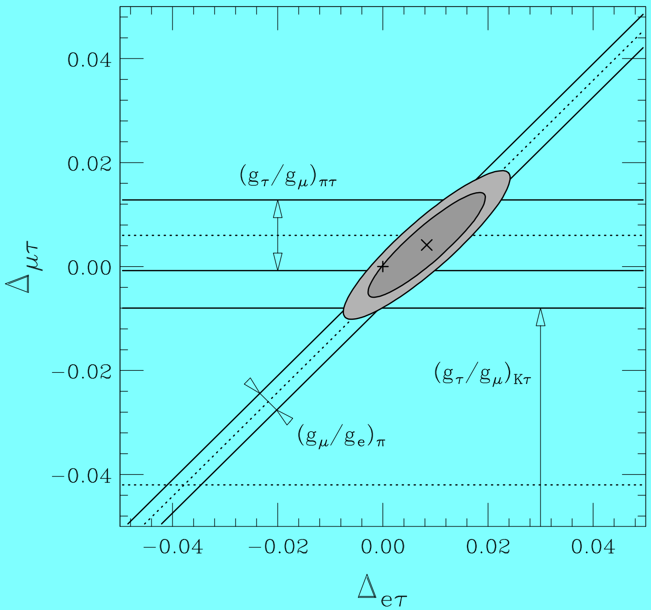
As a result μe universality has been tested at the level: g_μ/g_e=1.0021(16)

[1] R. Decker and M. Finkemeier, Nucl. Phys. B 438, 17 (1995).
[2] G. Czapek *et al.*, Phys. Rev. Lett. 70, 17 (1993).
D.I. Britton *et al.*, Phys. Rev. Lett. 68 (1992) 3000.

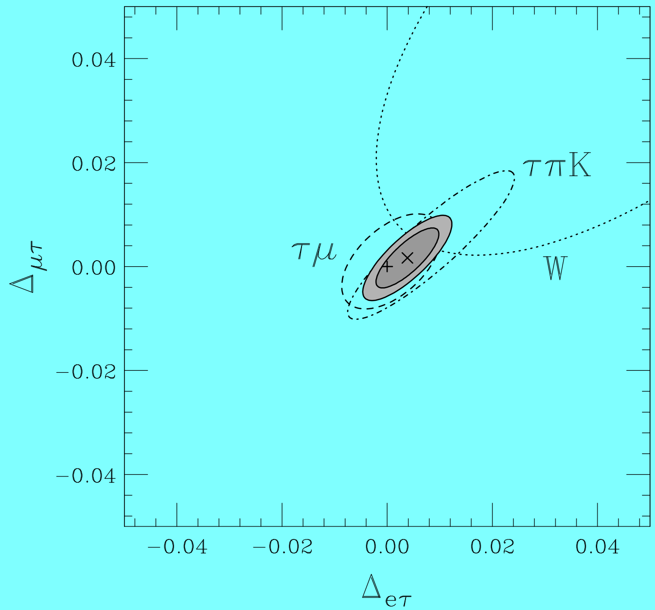
Defining $\boldsymbol{\Delta_{ij} = 2(\frac{g_i}{g_j} - 1)}$:



from $\boldsymbol{\tau}$ decay



from $\boldsymbol{\pi}$ and $\boldsymbol{K}$ decay



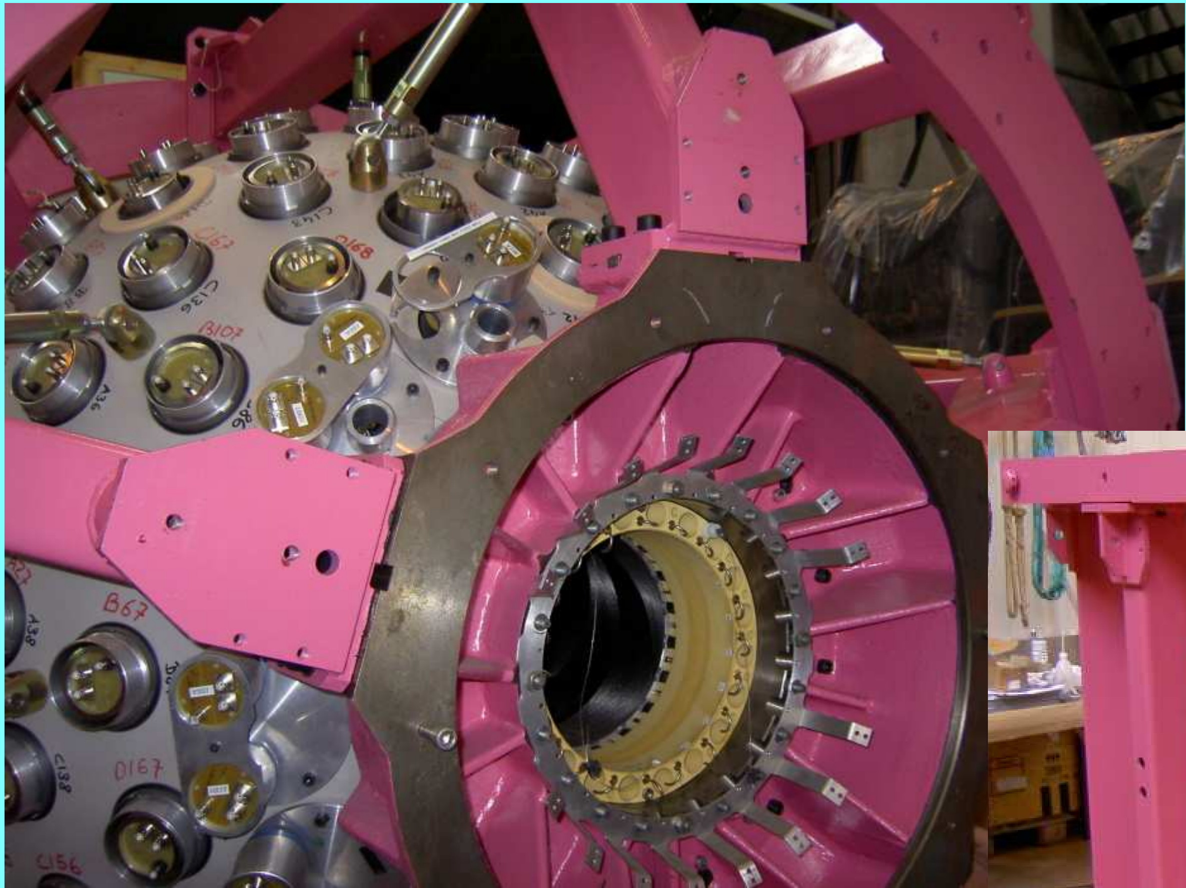
combined result

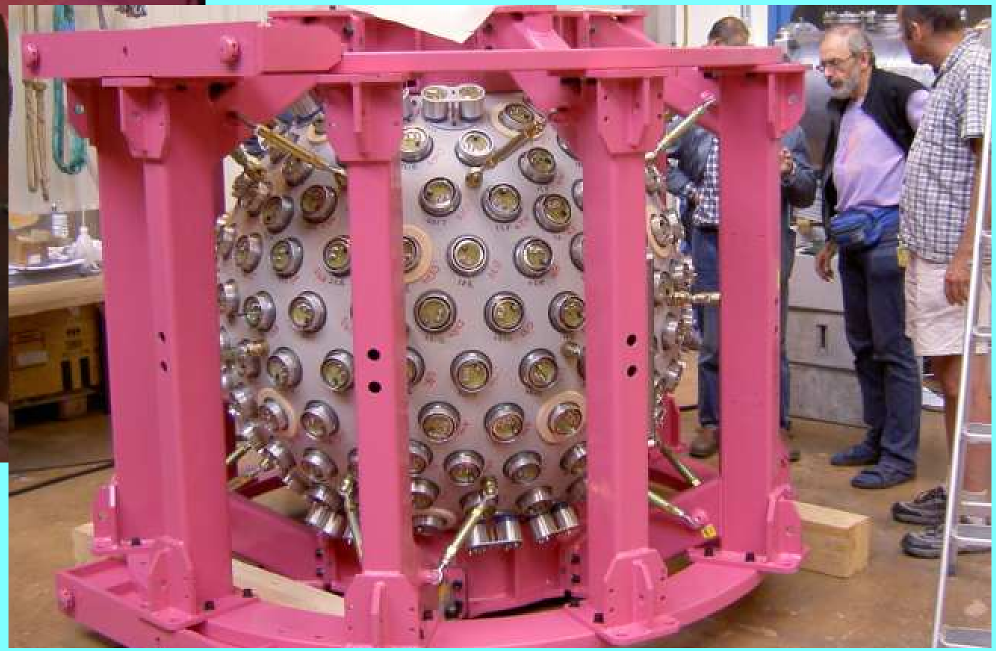
Experimental constraints on violations of lepton universality.

W. Loinaz *et al.*, Phys. Rev. D 70 (2004) 113004.

2 The PSI experiment

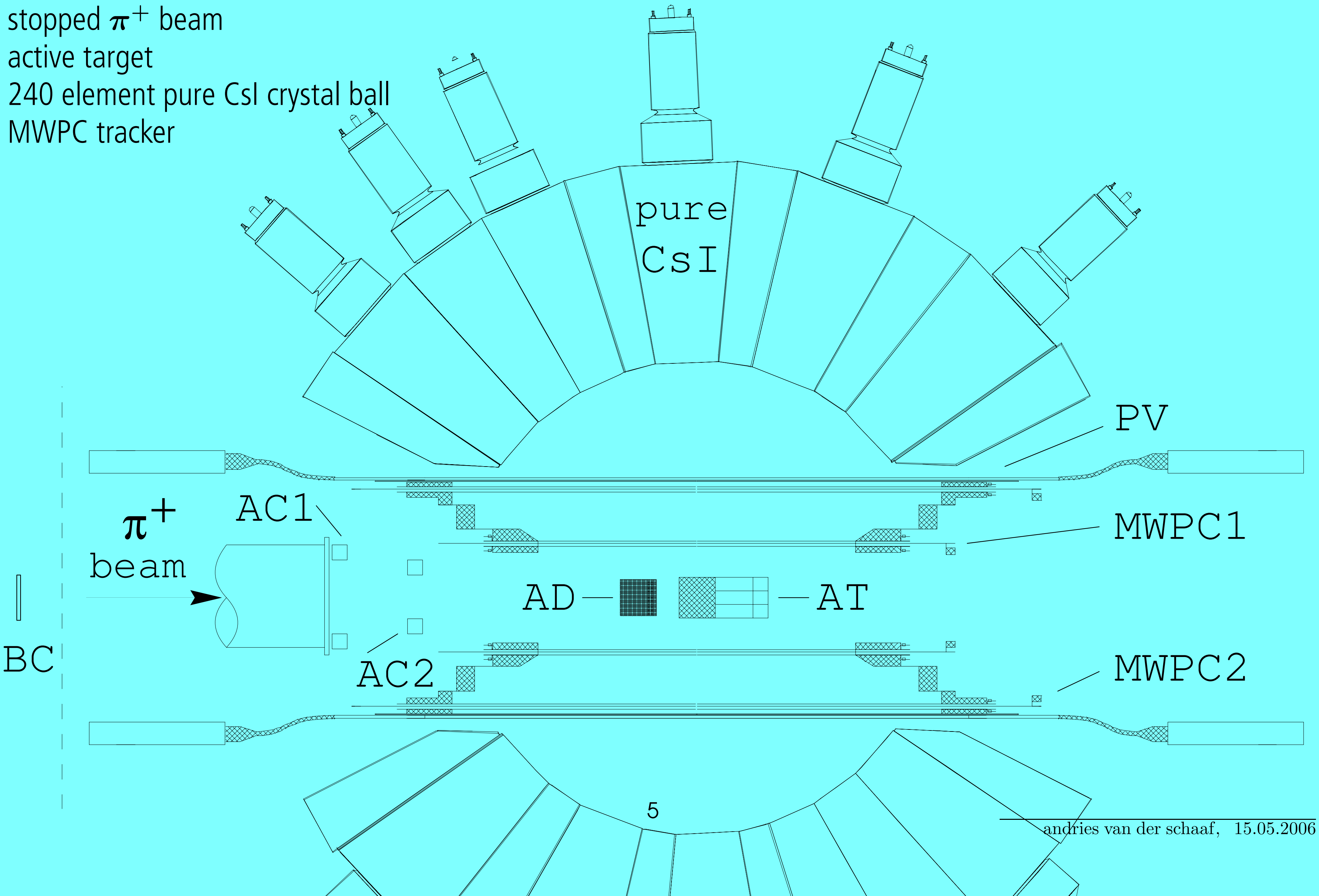
- Virginia
- PSI
- Dubna
- Swierk
- Tbilisi
- Zagreb
- Zurich

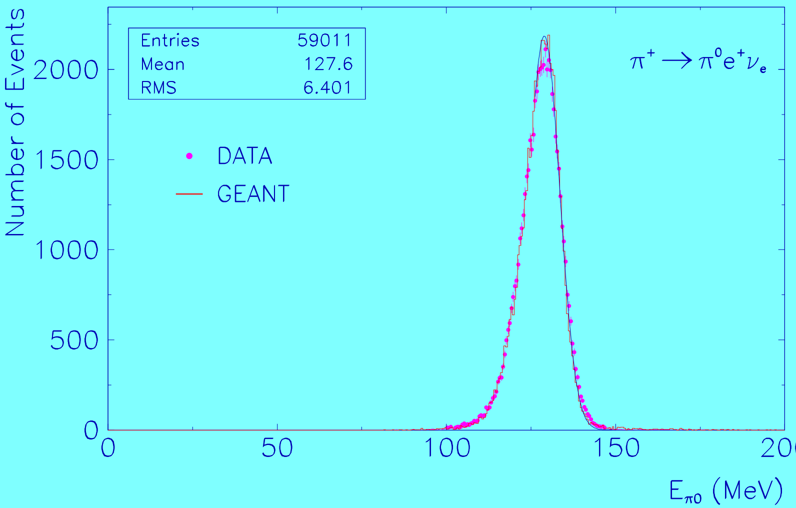




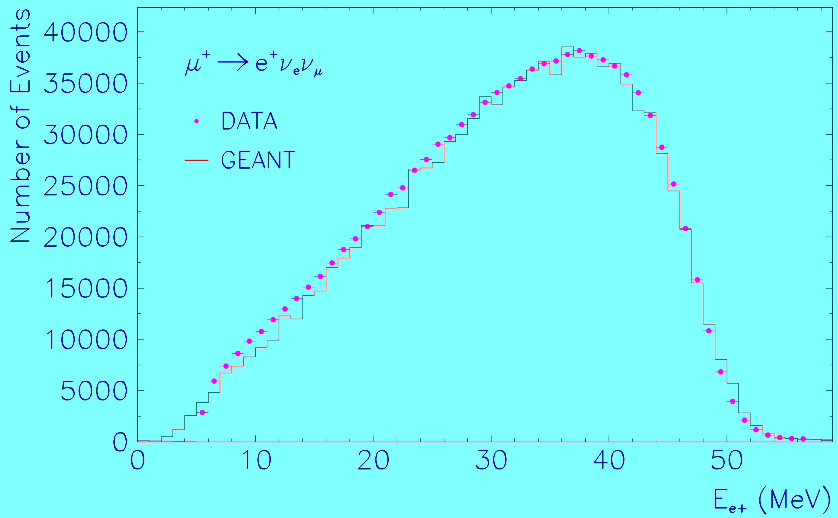
2.1 Setup

- stopped π^+ beam
- active target
- 240 element pure CsI crystal ball
- MWPC tracker

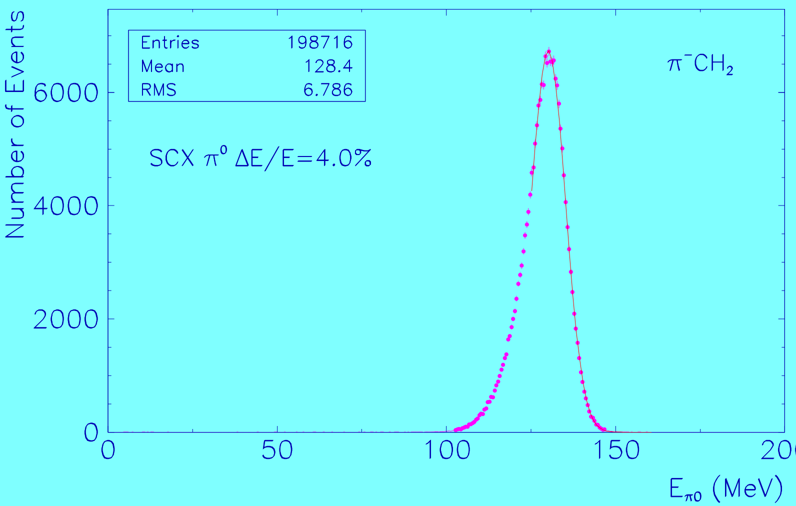




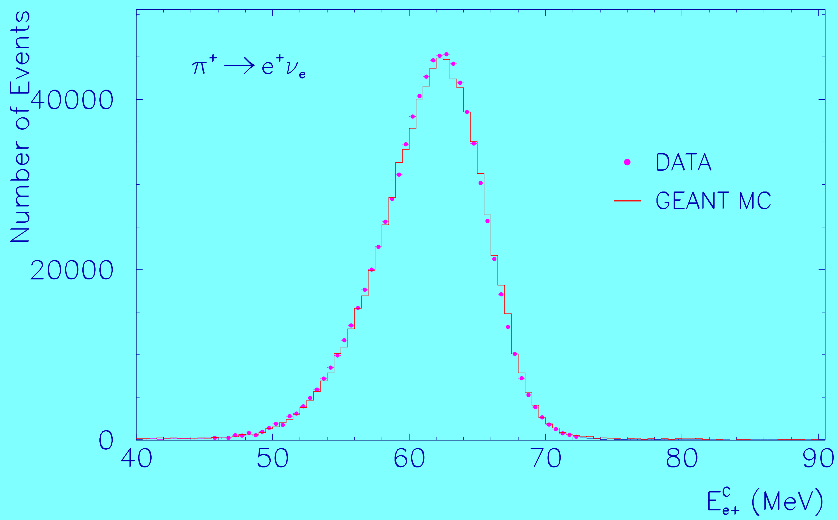
$\pi^+ \to \pi^0 e^+ \nu_e, \pi^0 \to 2\gamma$



$\mu^+ \to e^+ \nu_e \overline{\nu_\mu}$

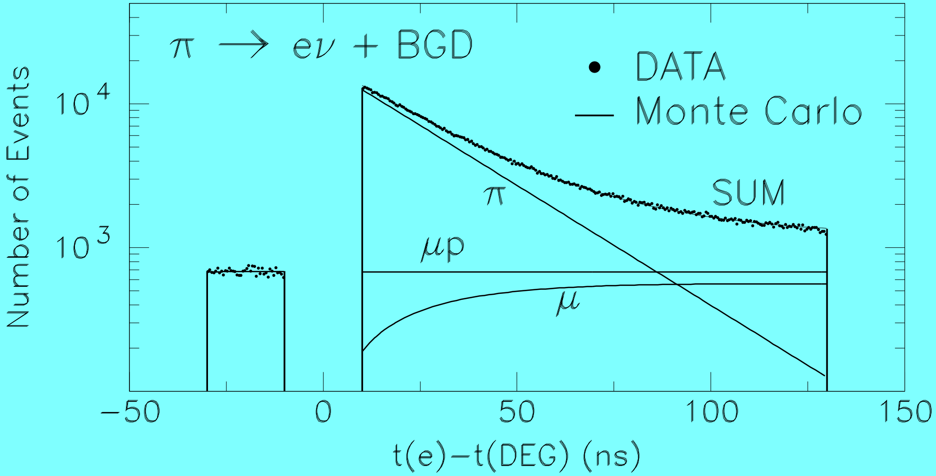


$\pi^- p \to \gamma n$

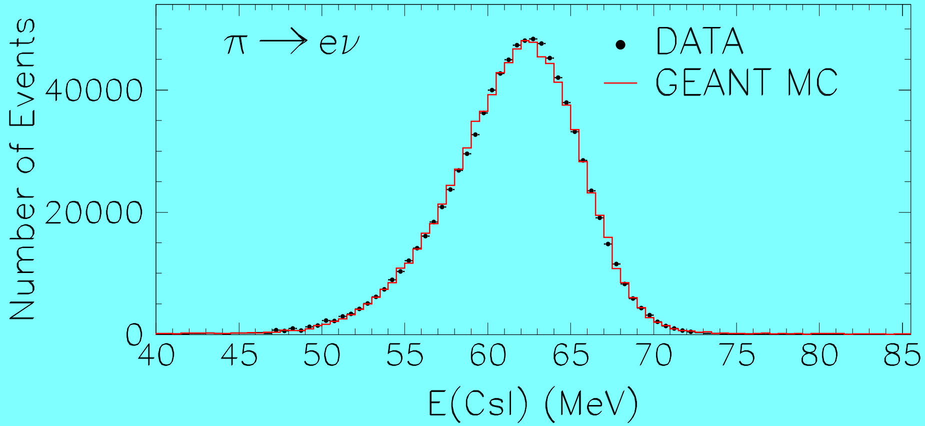


$\pi^+ \to e^+ \nu_e$

2.2 $\pi \to e\nu$ data taken during $\pi\beta$ decay running

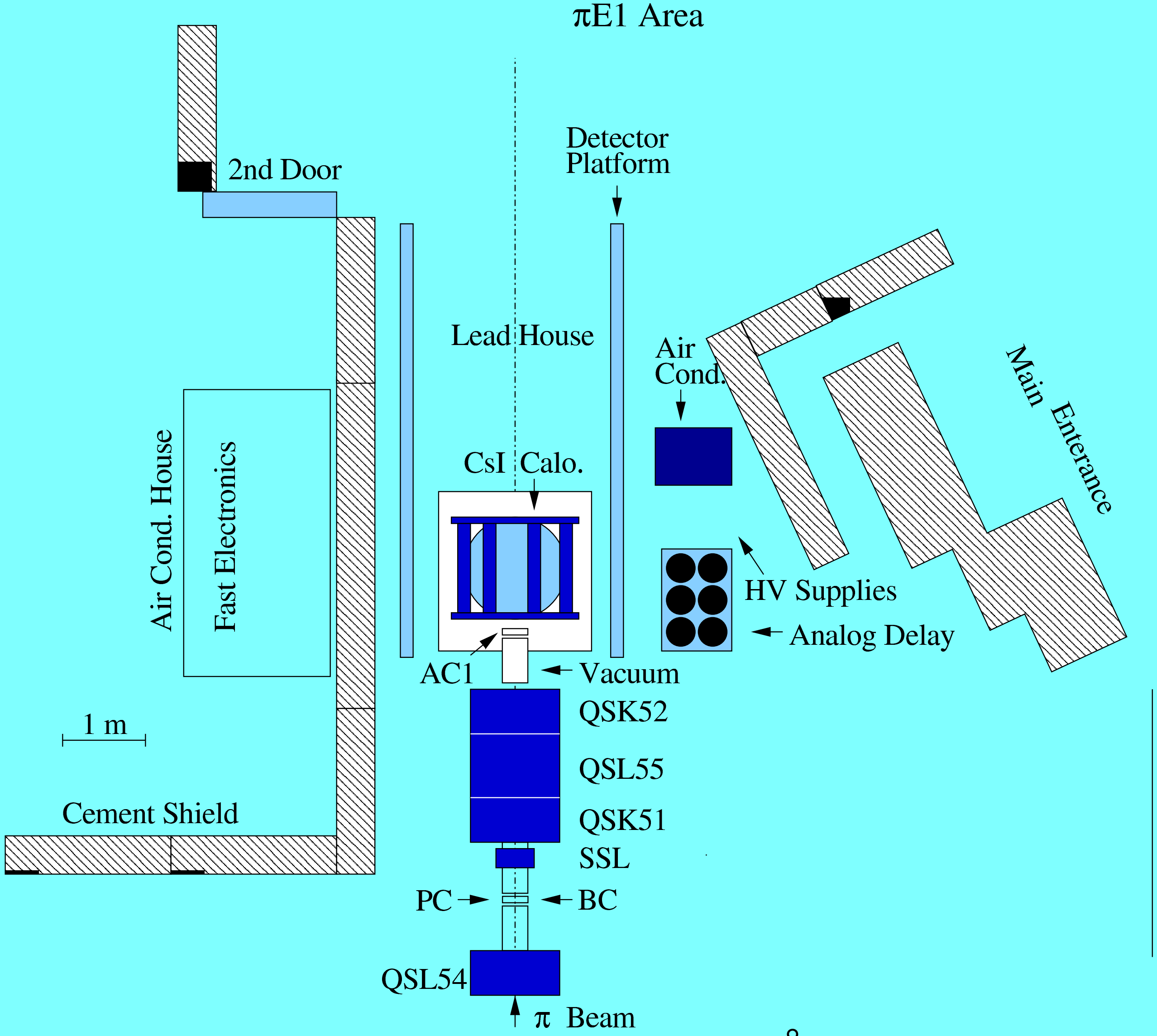


- Delay between pion stop and positron detection.
- The measured data are nicely described by $\pi^+ \to e^+$ decay, $\pi^+ \to \mu^+ \to e^+$ decay chain and pile-up (accidental coincidences).
- The prompt region has been removed at trigger level.

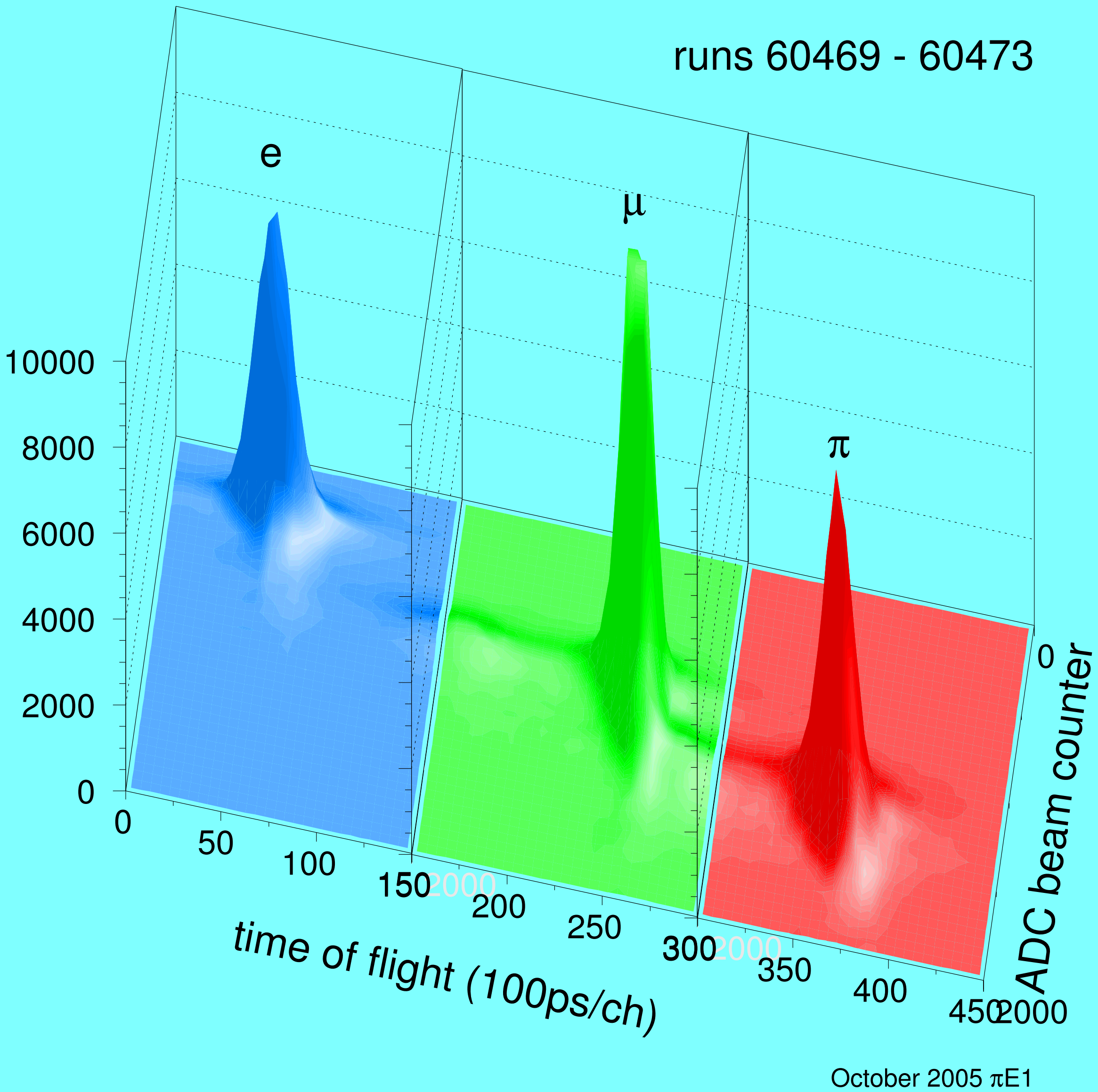


Distribution of CsI total energy for $\pi^+ \to e^+\nu$ decays after background subtraction.

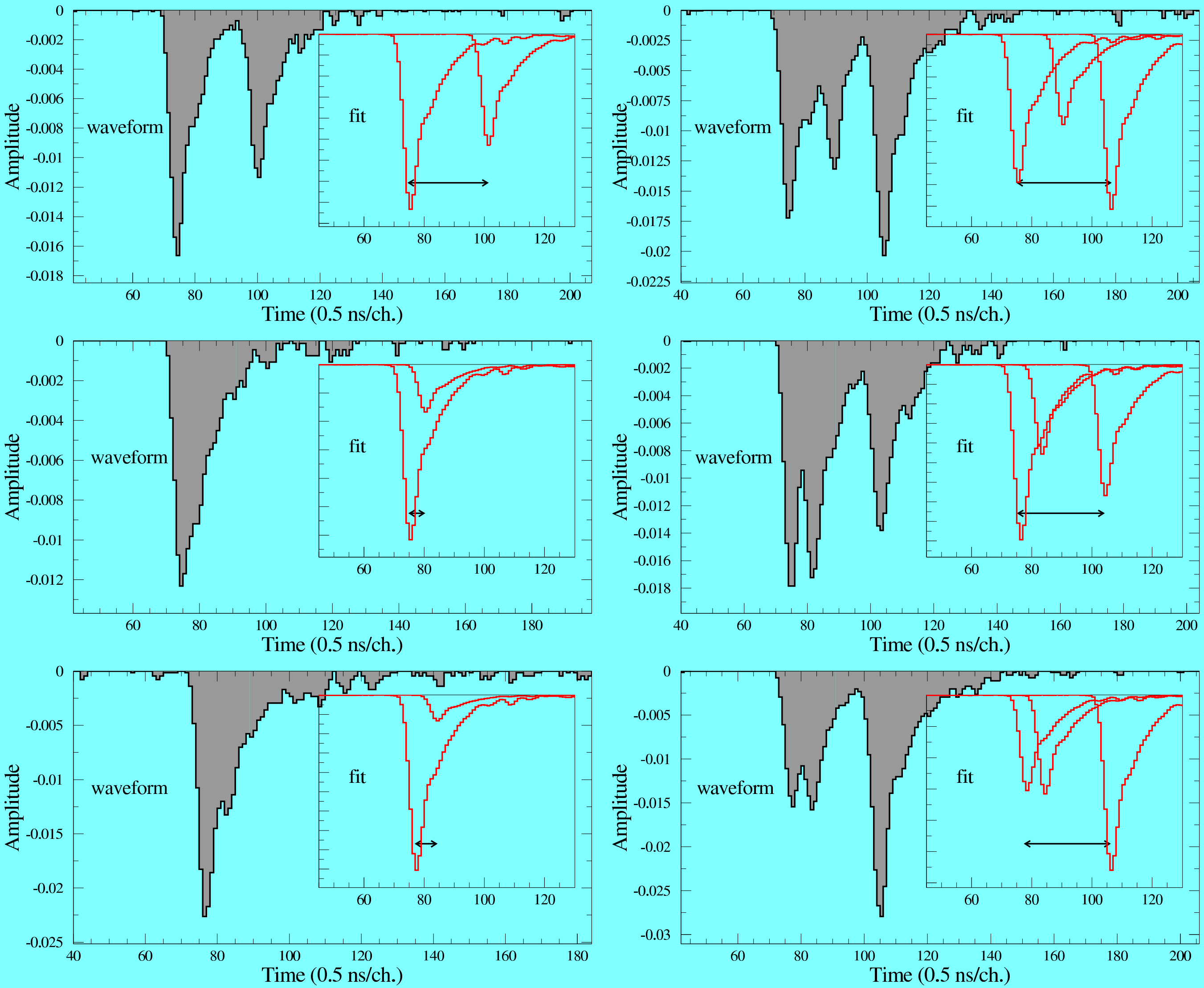
2.3 Experimental area



2.4 Test results

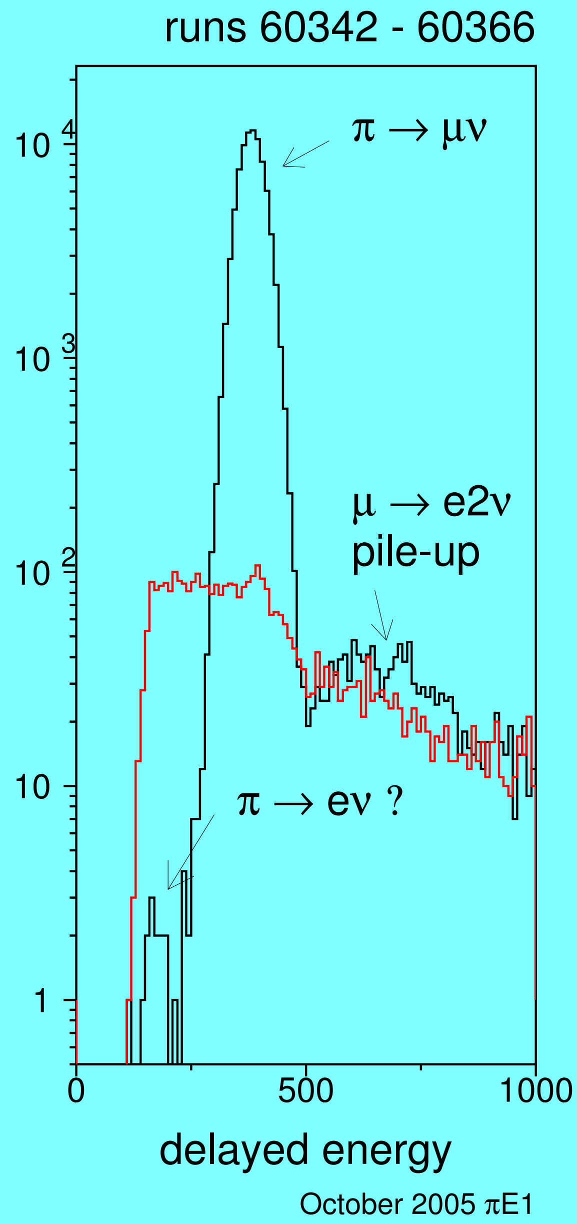


- Distribution of flight time along the last ≈4 m of the πE1 beam-line and energy loss in a moderator counter.
- Pions, muons and electrons are clearly separated.
- This information will be crucial in estimating the contribution from pion decay in flight in the final data.
- The time of flight will also allow a precise determination of the pion momentum.

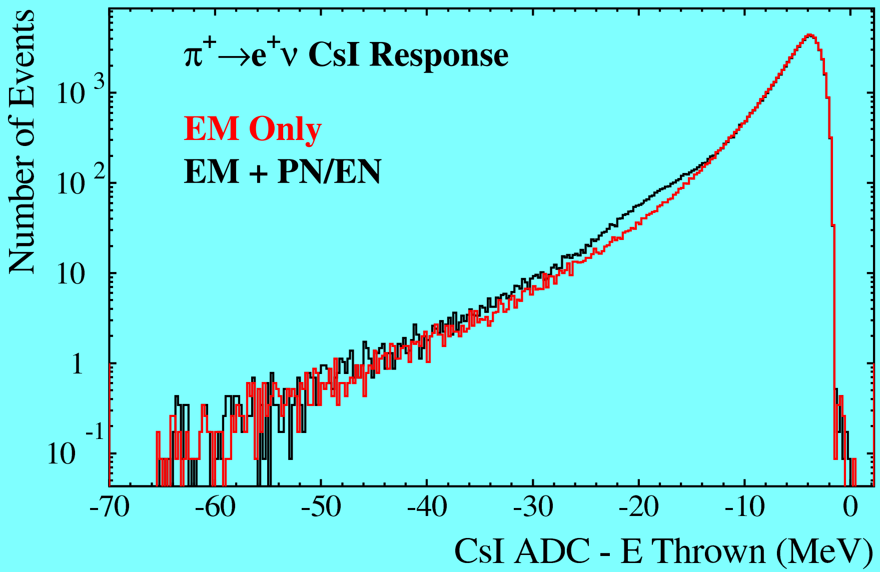


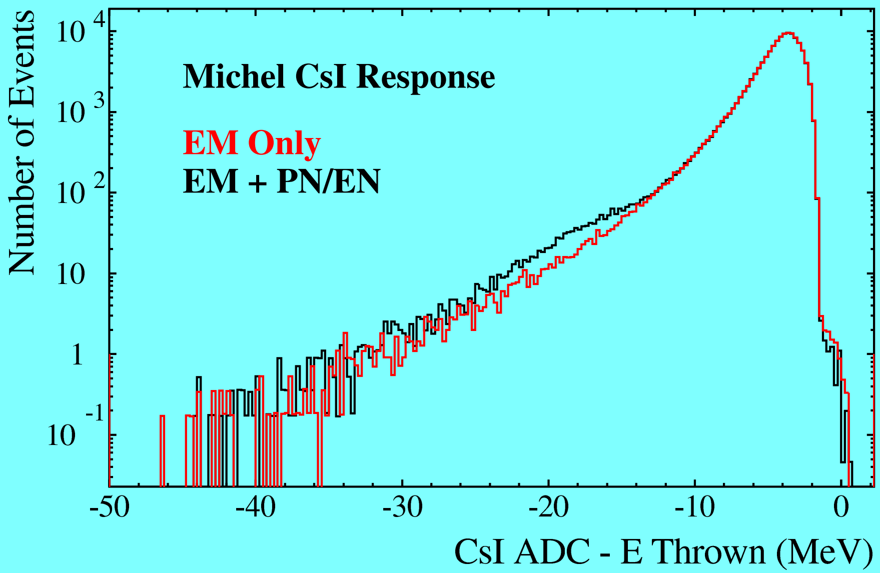
Target waveforms for

- (left) $\pi \to e\nu$ events
- (right) $\pi \to \mu\nu$ followed by $\mu \to e\nu\overline{\nu}$



- Secondary (black) and tertiary (red) target signals.
- The secondary signals are totally dominated by muons from pion decay at rest.
- The very low background left of the peak is close to the level expected from $\pi \to e\nu$.





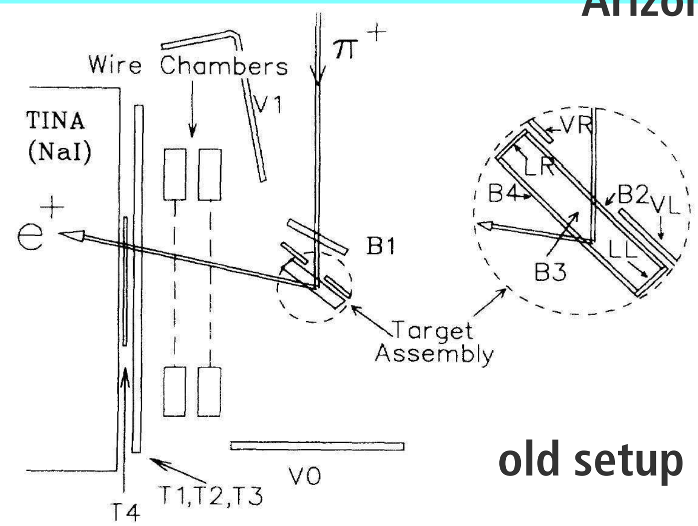
GEANT4 simulation of the response to

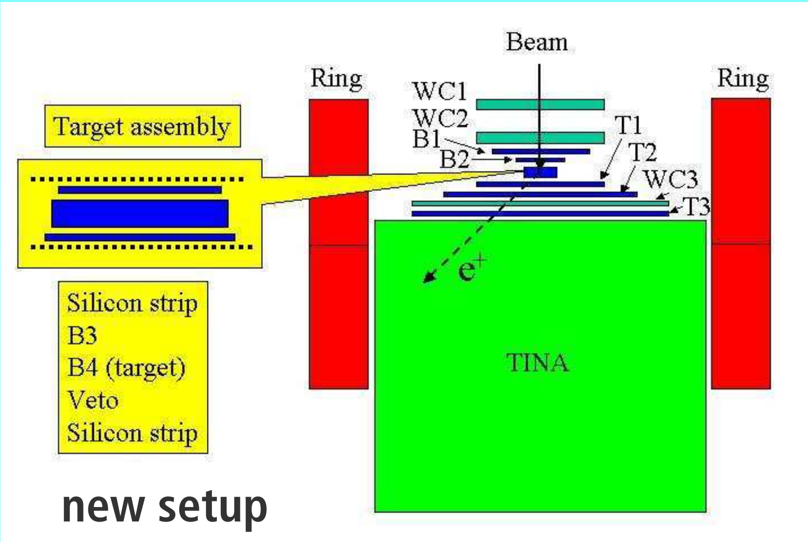
- (top) $\pi \to e\nu$
- (bottom) $\mu \to e\nu\overline{\nu}$.
- (red) without nuclear interactions
- (black) including nuclear interactions

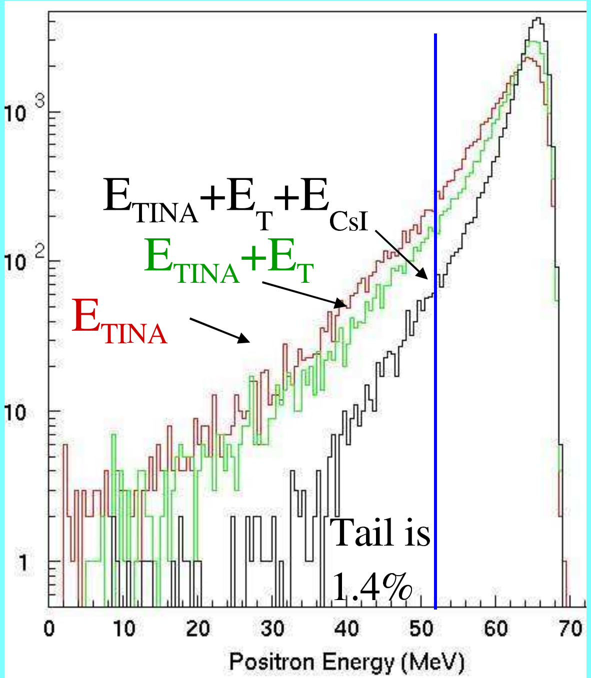
- 0.84(3)% of the $\pi \to e\nu$ events result in an energy in the $\mu \to e\nu\overline{\nu}$ region.
- Uncertainties in the low-energy tail of the response function are the main source of systematic error. For this reason it is crucial to check the simulation with measured data.

3 The TRIUMF experiments

Arizona - BNL - Caltech - Carleton - Kurchatov - Osaka - TRIUMF - UBC





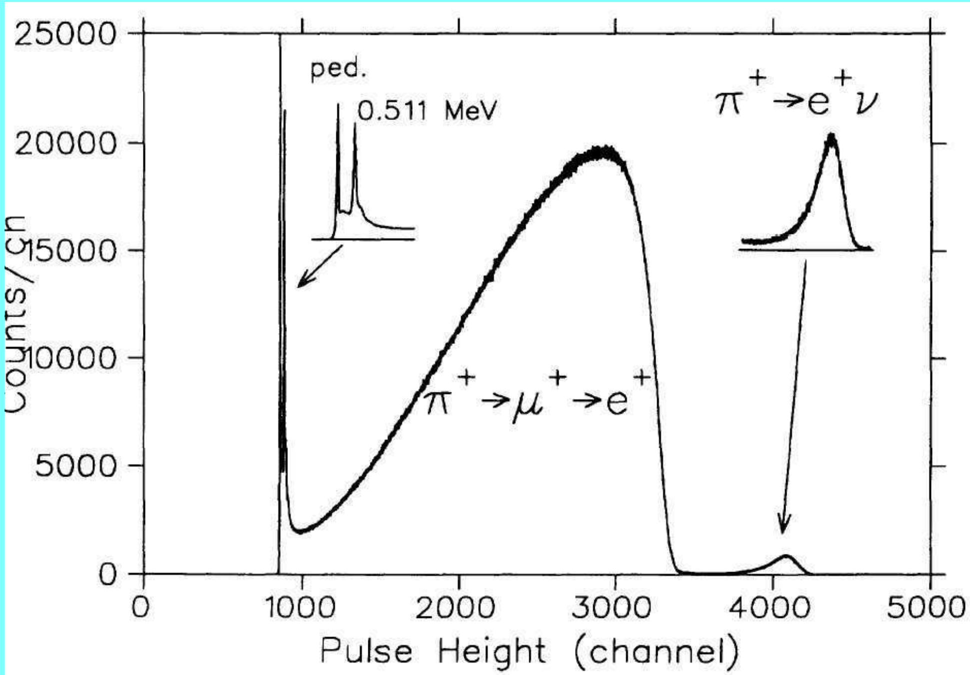


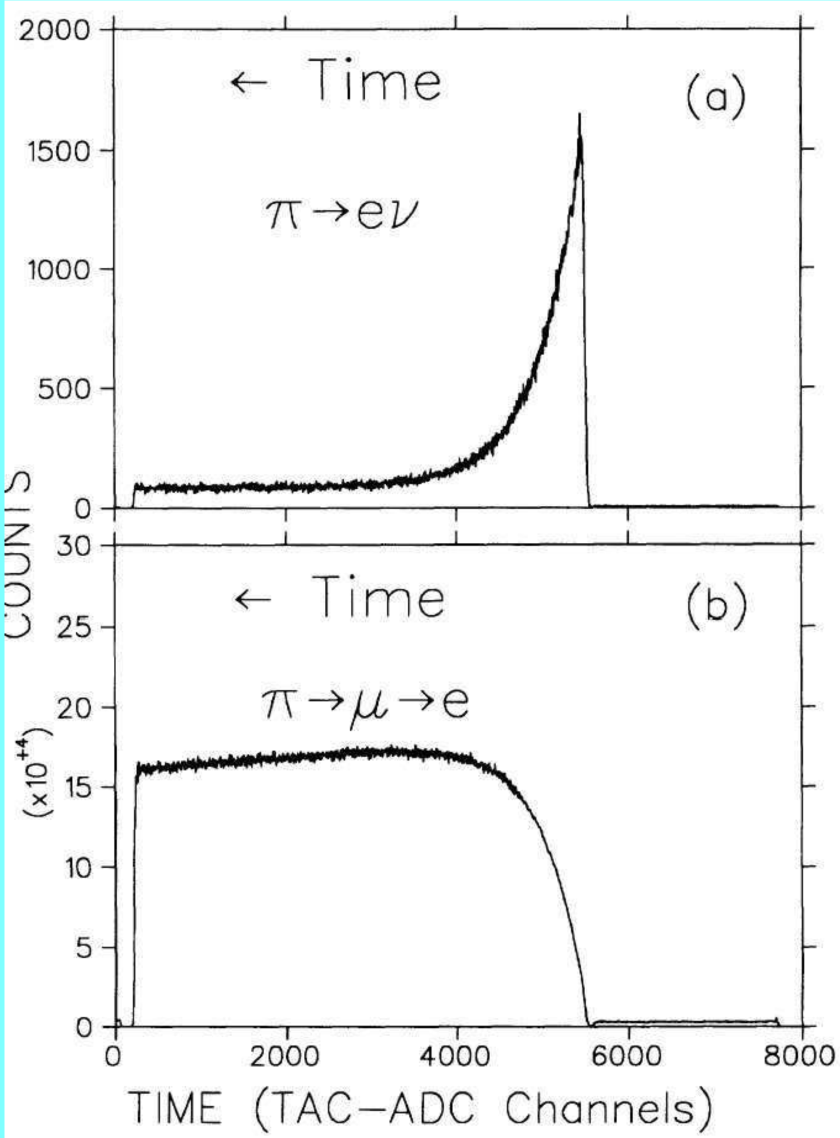
- The new setup will have additional CsI crystals which will reduce the low-energy tail of the positron response function.
- Statistics will be improved by a factor 30.
- Goal is a precision for the branching ratio $<0.1\%$.

3.1 E_{e^+} v.s. $\Delta t_{\pi e}$

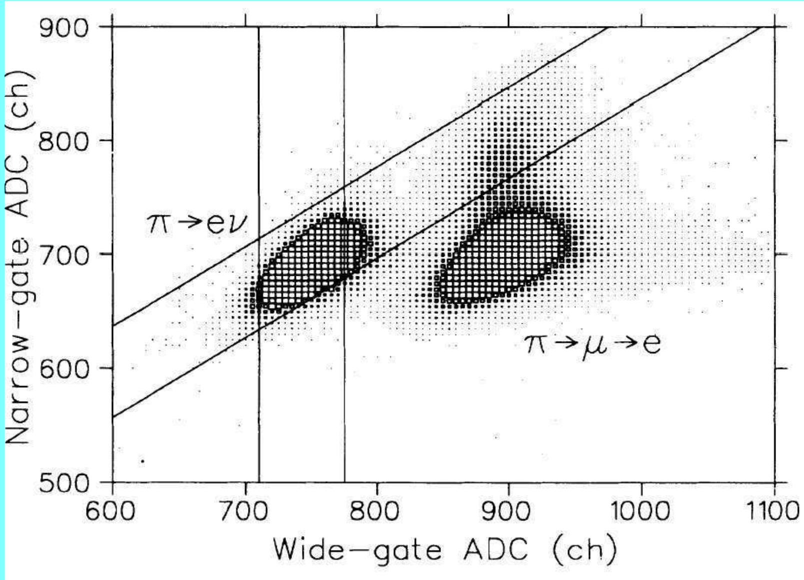
The electron and muon final states are separated on the basis of their different distributions of

- positron energy
- positron time delay w.r.t. the pion stop

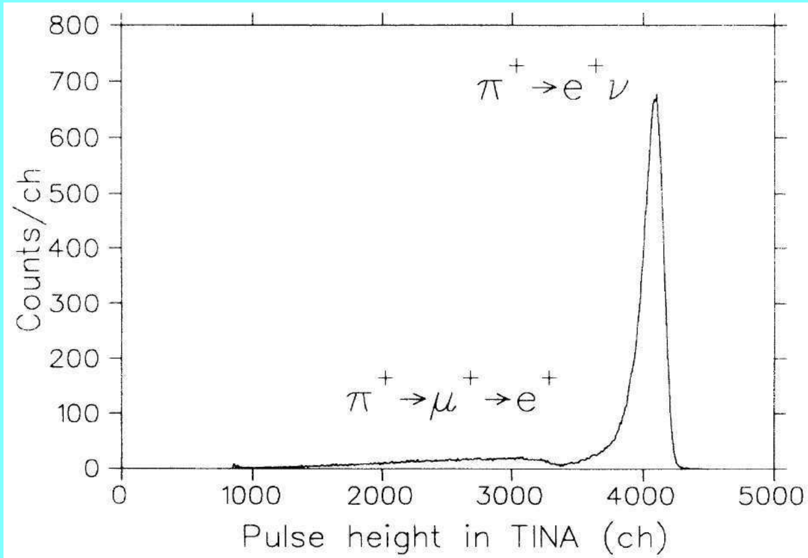




3.2 Enhancing $\pi \to e\nu$



- The $\pi \to e\nu$ decay can be $10^5\times$ enhanced relative to $\pi \to \mu \to e$ with the help of timing cuts and target analysis.
- The resulting spectrum can be used to study the $\pi \to e\nu$ response function which is the main source of systematic error.



4 Comparing the two experiments

Main parameters

	PSI	TRIUMF
beam momentum (MeV/c)	70 - 75	70 - 75
resolution	0.5%	1%
π rate	≈3000	$5 - 10 \times 10^4$
$\pi/\mu/e$	1:1:1	100:10:1
Ω	3π	π
$\Delta E_e/E_e$	13%	5%
tail fraction	0.8%	1.4%
final error	<0.05%	0.1%

Time table

preliminary data	2006	2006
engineering run	2006	2007
production run	2007/8	2008