Precision Measurements with Pions

Measurements of $(\pi \to e\nu)/(\pi \to \mu\nu)$ Branching Ratio

Toshio Numao

TRIUMF

$\pi \to e\nu$ decay

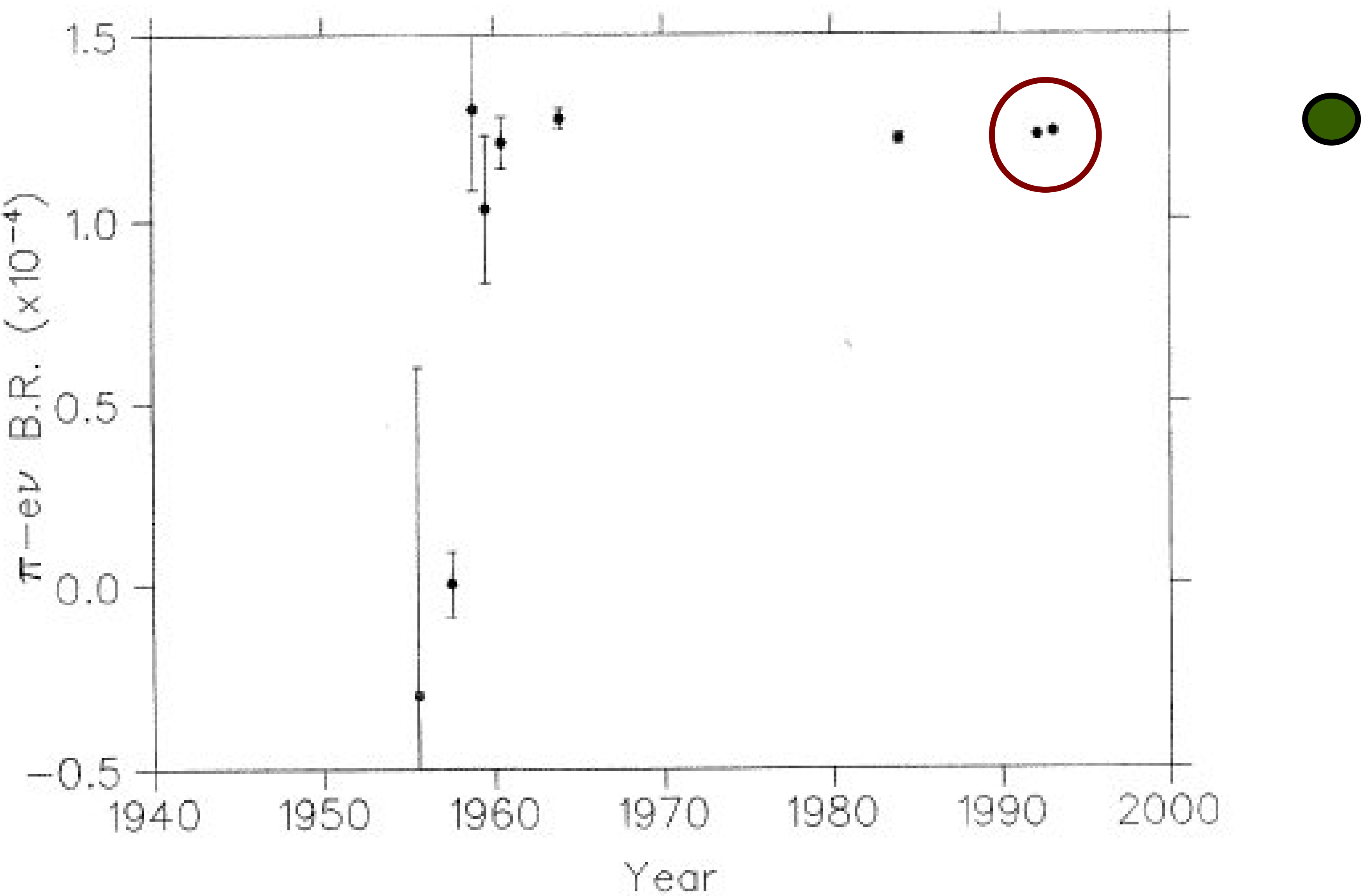
première réussite expérimentale est l'observation, attendue depuis si longtemps, de la désintégration d'un pion en un électron et un neutrino, août 1958.

Commissioning of CERN's first accelerator, a 600 MeV Proton Synchrocyclotron. The first experimental success is the long-awaited observation of a pion decaying into an electron and a neutrino, August 1958.

Il primo acceleratore del CERN, un Sincrociclotrone a protoni da 600 MeV, viene messo in funzione. Il primo

CERN PS's first successful exp.

History of $\pi \rightarrow e\nu$ decay



SM branching ratio calculations

$$R^0_{e/\mu} = \frac{\Gamma(\pi\to e\nu)}{\Gamma(\pi\to\mu\nu)} = \frac{g_e^2}{g_\mu^2}\frac{m_e^2}{m_\mu^2}\frac{(m_\pi^2 - m_e^2)^2}{(m_\pi^2 - m_\mu^2)^2}$$

$$= 1.284\times10^{-4}$$

$$R^{th}_{e/\mu} = \frac{\Gamma(\pi\to e\nu + \pi\to e\nu\gamma)}{\Gamma(\pi\to\mu\nu + \pi\to\mu\nu\gamma)} = R^0_{e/\mu}(1+3\alpha/\pi\ \ln(m_e/m_\mu))$$

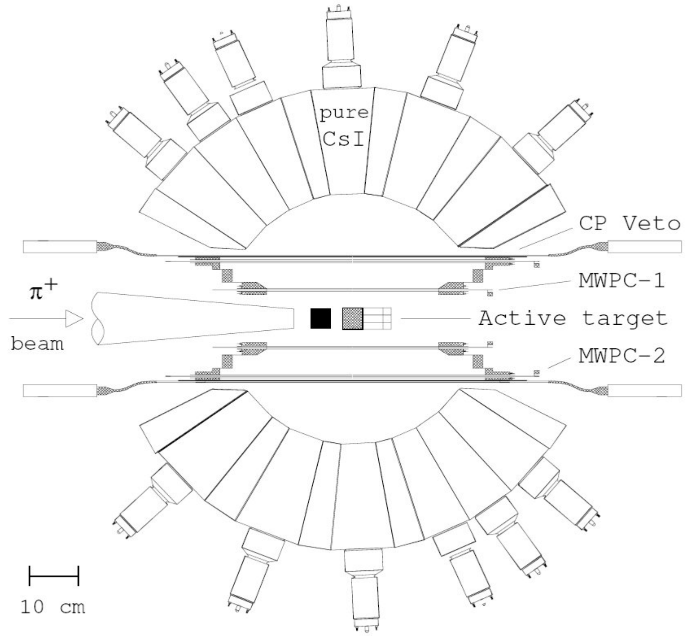
$= 1.233\times10^{-4}$ Kinoshita 1959

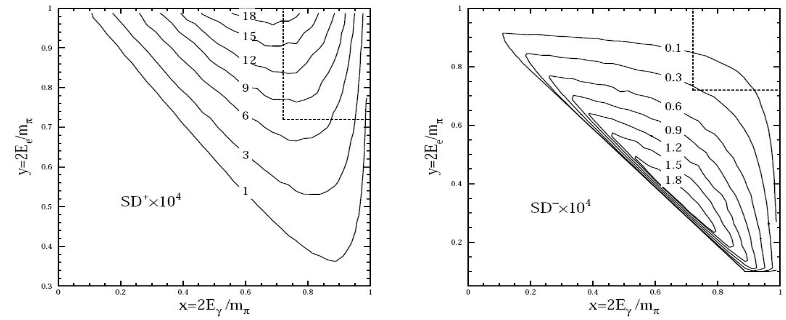
$1.2352(5)\times10^{-4}$ Marciano,Sirlin 1993

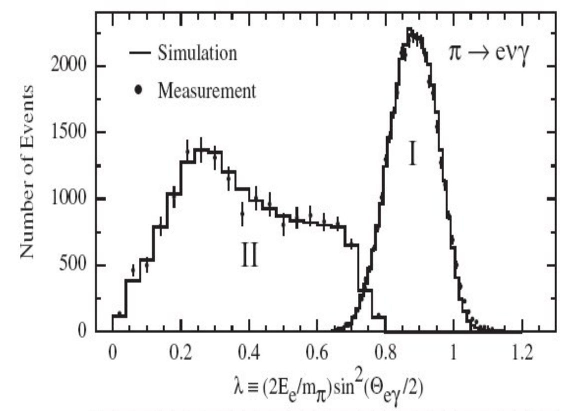
$1.2352(1)\times10^{-4}$ Cirigliano,Rosell 2007

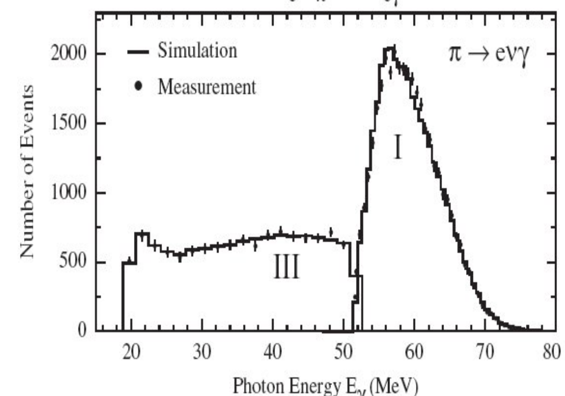
Inputs: F_A/F_V, F_π... : $\pi\to e\nu\gamma$, pion life

$\pi \rightarrow e\nu\gamma$









$F_V=0.0258(17)$

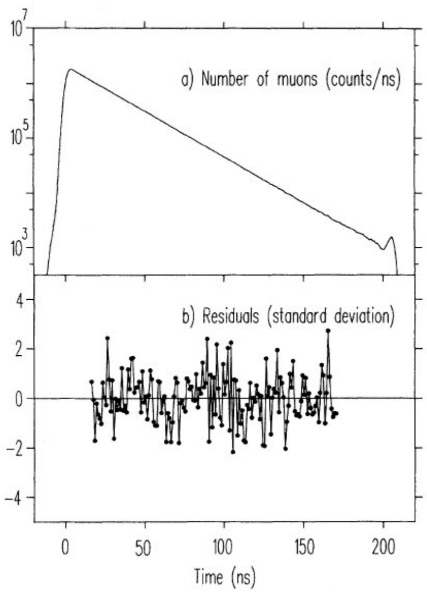
$F_A=0.0117(17)$

$F_T=(-0.6\pm2.8)\times10^{-4}$

PRL 103 051802 (2009)

π^+ life

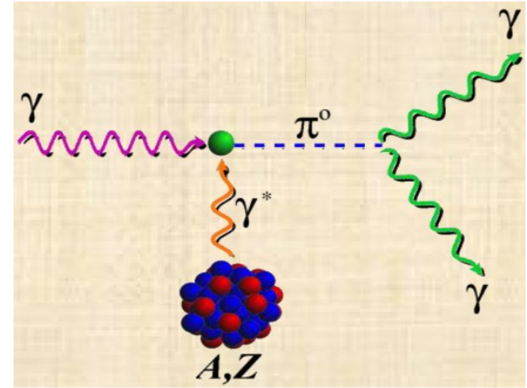
$$\Gamma_\pi = \frac{G_F^2 f_\pi^2}{4\pi m_\pi^3} \mid V_{ud} \mid^2 \sum_{l=e,\mu} m_l^2 (m_\pi^2 - m_l^2)^2$$

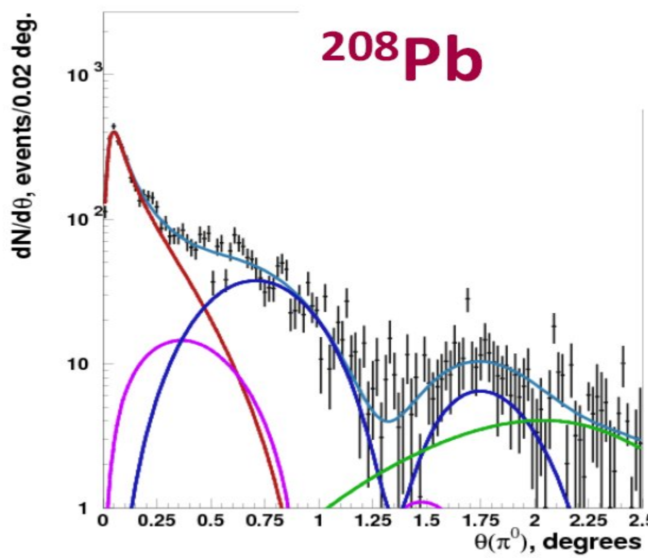


Beamline experiment

26.0231((50)(84) ns '95 TRIUMF
26.0361(52) ns '95 Koptev...

π^0 life





"New" result by Primex group will be published soon.

Present Status of $\pi \rightarrow e\nu$ Measurements

$$R_{e/\mu}^{SM} = 1.2352 \pm 0.0001 \times 10^{-4}$$

$$R_{e/\mu}^{exp} = 1.2265 \pm 0.0034 \pm 0.0044 \times 10^{-4} \text{ (TRIUMF, '92)}$$

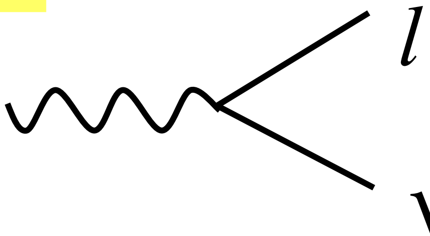
$$R_{e/\mu}^{exp} = 1.2346 \pm 0.0035 \pm 0.0036 \times 10^{-4} \text{ (PSI, '93)}$$

Two new initiatives for 0.1> % measurements

- PIENU at TRIUMF
- PEN at PSI

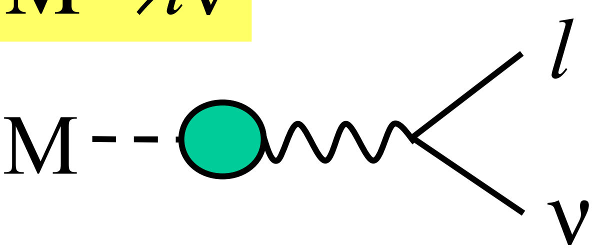
μ-e Lepton Universality

W



$$R^{W}_{e/\mu} = \frac{\Gamma(W \to e\nu)}{\Gamma(W \to \mu\nu)} \propto \frac{g_e^2}{g_\mu^2}$$

$M \to l\nu$



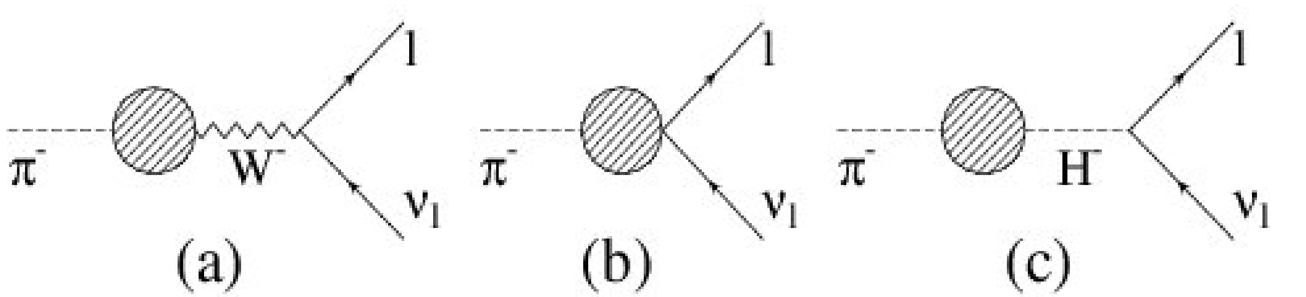
$$R^{\pi}_{e/\mu} = \frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} \propto \frac{g_e^2}{g_\mu^2} \frac{m_e^2}{m_\mu^2}$$

Mode	g_e/g_μ
$\pi\text{–}e\nu/\pi\text{–}\mu\nu$	0.9985 ± 0.0016
$K\text{–} e\nu/K\text{–}\mu\nu$	1.0018 ± 0.0026
$\tau\text{–}e\nu\nu/\tau\text{–}\mu\nu\nu$	1.0001 ± 0.0020*
$\nu e/\nu\mu$ scatt.	1.10 ± 0.05
W decays	0.999 ± 0.011
$K\text{–} \pi e\nu/K\text{–} \pi\mu\nu$	0.9979 ± 0.0025

*to be updated.

Beyond the Standard Model

New PS interaction



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

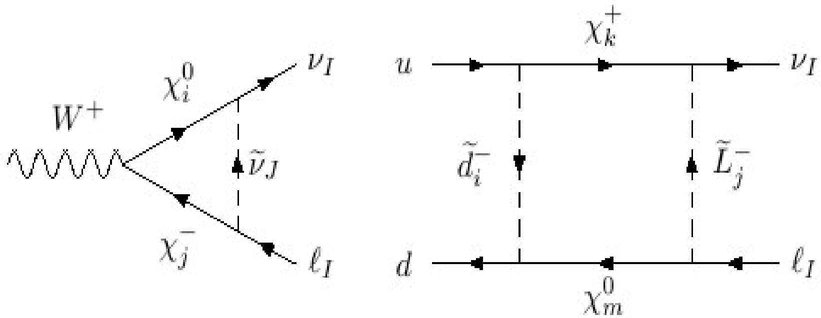
$$\sim \left(\frac{1TeV}{\Lambda_{eP}}\right)^2 \times 10^3$$

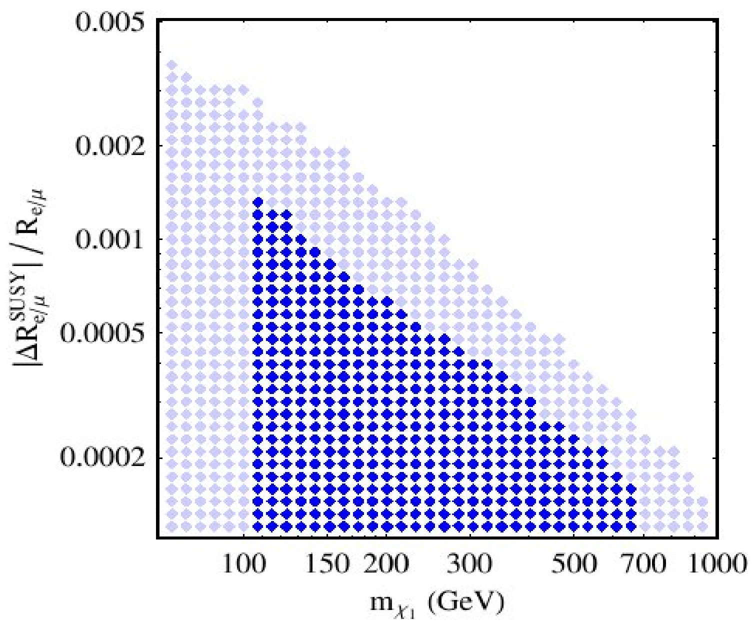
0.1 % measurement → Λ~1000TeV

Marciano…

Beyond the Standard Model

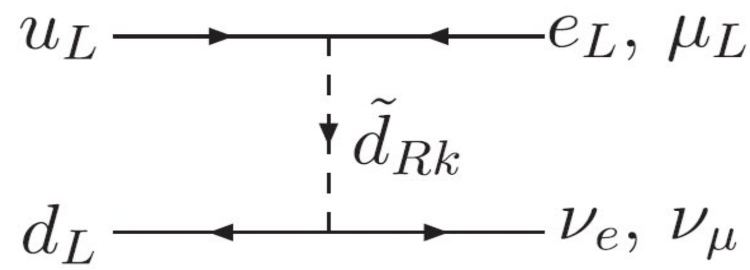
Minimal SUSY SM

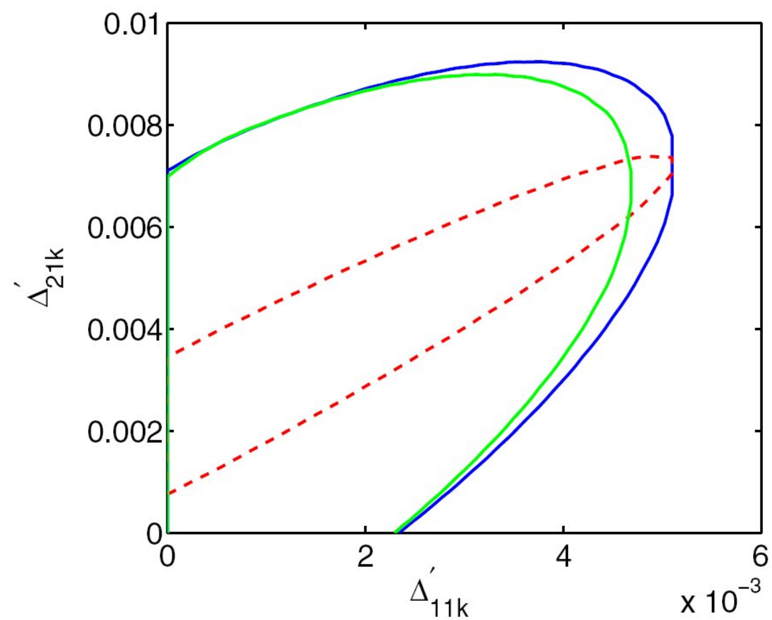




Lowest chargino mass

R-Parity Violating SUSY





Ramsey-Musolf… PRD76 095017 (2007)

Beyond the Standard Model

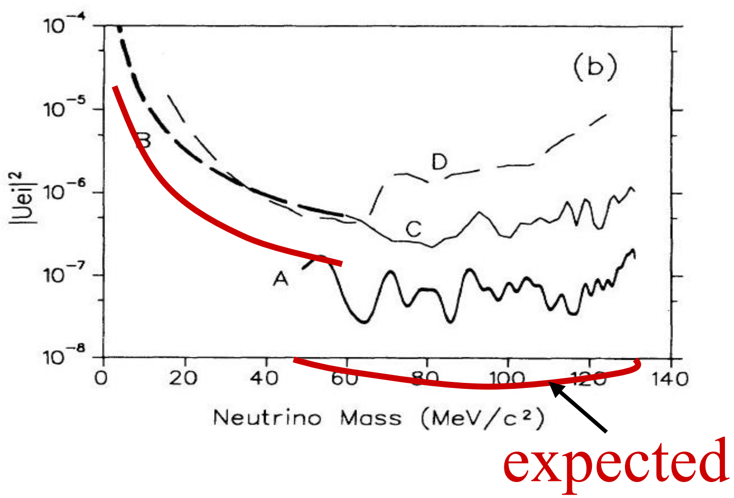
MSSM LFV

$$lH^{\pm}\nu_{\tau} \rightarrow \frac{g_2}{\sqrt{2}}\frac{m_{\tau}}{M_W}\Delta_R^{3l}\tan^2\beta \qquad l = e, \mu$$

A few x 10^{-4} deviation is expected.

Masiero,Paradisi,,,

Massive neutrino



Others

- Leptoquarks
- Extra Higgs
- Excited gauge bosons
- Compositeness
- SU(2)xSU(2)xSU(2)xU(1)
-...

Method

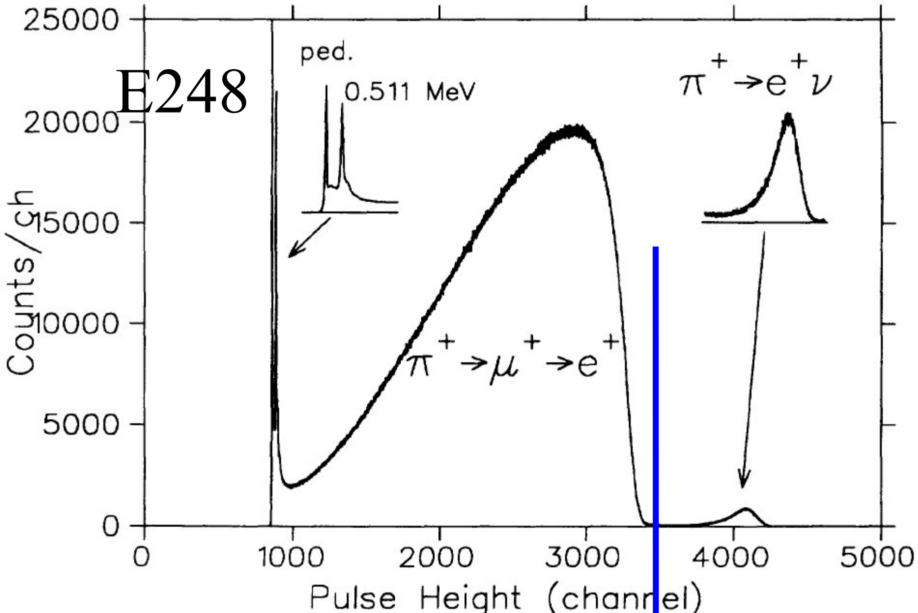
$A(\pi \to e\nu)$ normalized by the number of stopped pions.
- T0, decay in flight, acceptance...

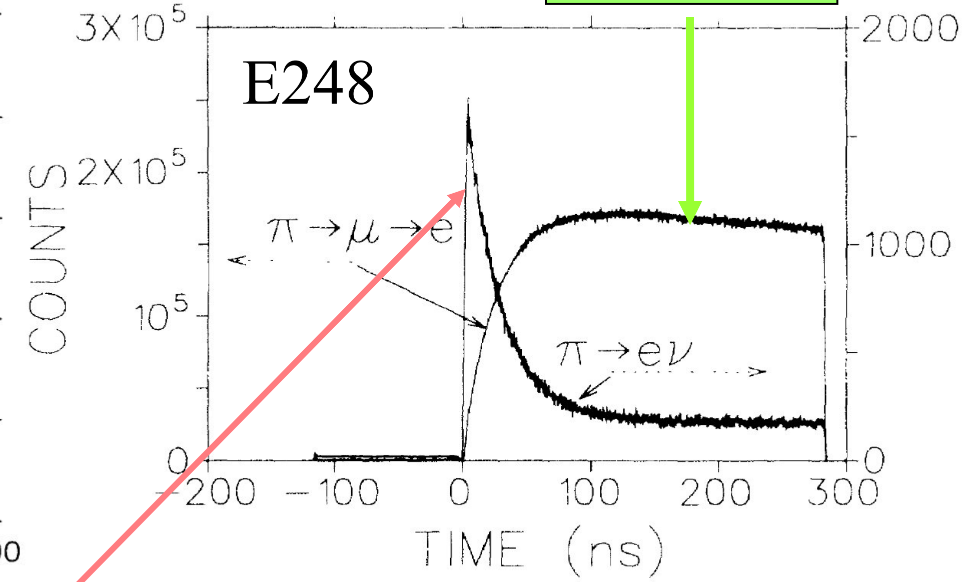
$A(\pi \to e\nu)/A(\pi \to \mu\nu)$ Czapek et al.
- Acceptance difference,...

$A(\pi \to e\nu)/A(\pi \to \mu \to e)$ Britton et al.
- Pion life, Energy dependent cross section...

Common uncertainty
- Low energy tail of the $\pi \to e\nu$ peak.

Method





π–μ–e

π–μ–e

π–eν

Fit both time spectra Simultaneously and obtain the ratio.

Correct for low-energy tail (~2%) and energy dependent acceptance (~0.3%).

Old (TRIUMF E248) experiment

$$R=(1.2265 \pm 0.0034 \pm 0.0044) \times 10^{-4}$$

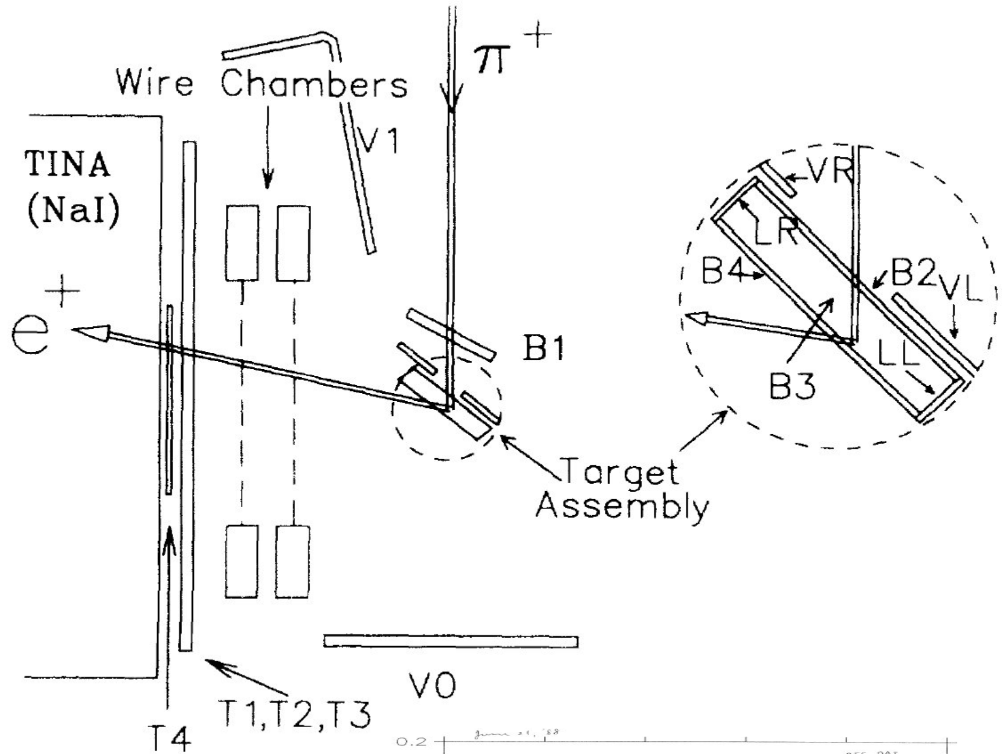
Measured positrons from

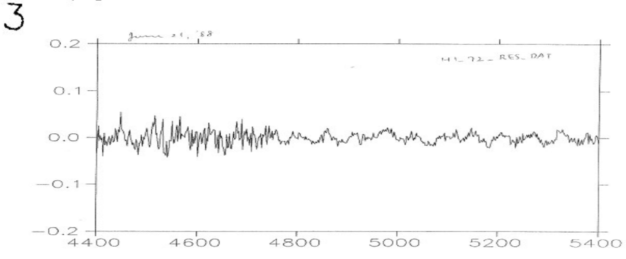
$\pi \rightarrow e\nu$ $(\tau = 26\text{ns})$

$\pi \rightarrow \mu\nu$

$\mu \rightarrow e\nu\nu$ $(\tau = 2\mu\text{s})$

- small solid angle
- pile-up (neutron)
- material along e+/s pass
- distortion in time spectra





Setup of the TRIUMF experiment E1072

NaI in beam

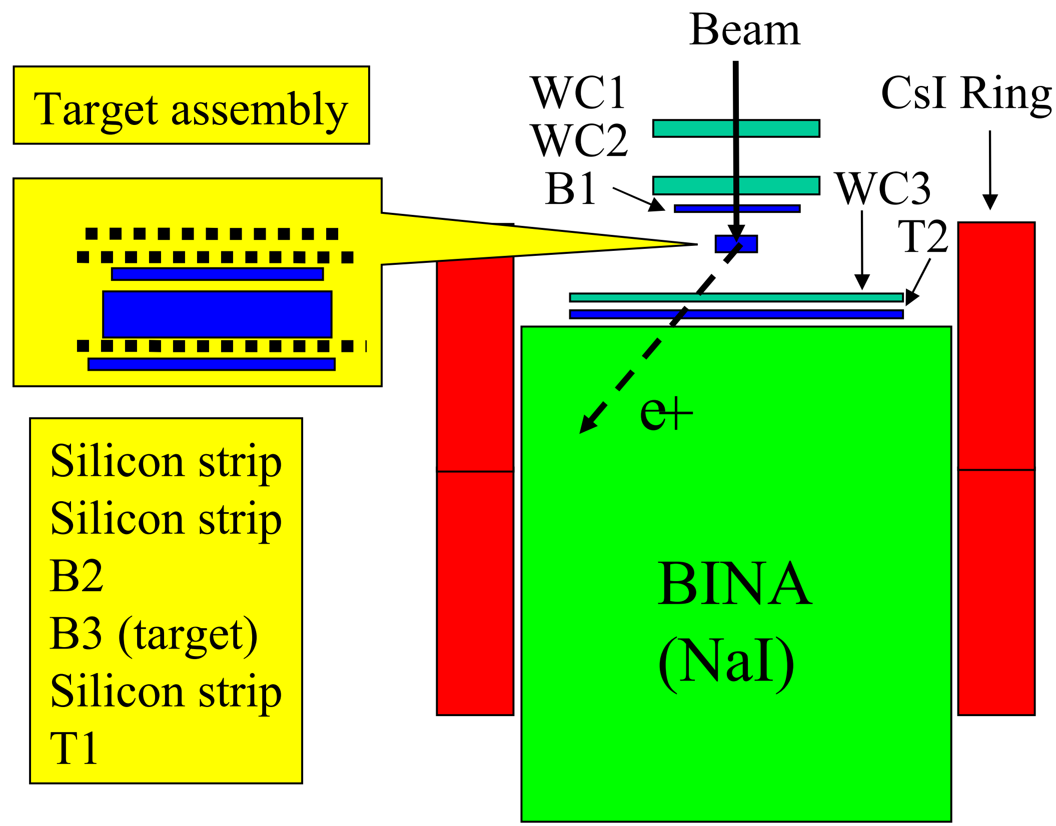
Solid angle = 20 %

Separated beam

Ring counter (CsI)

π,e tracking

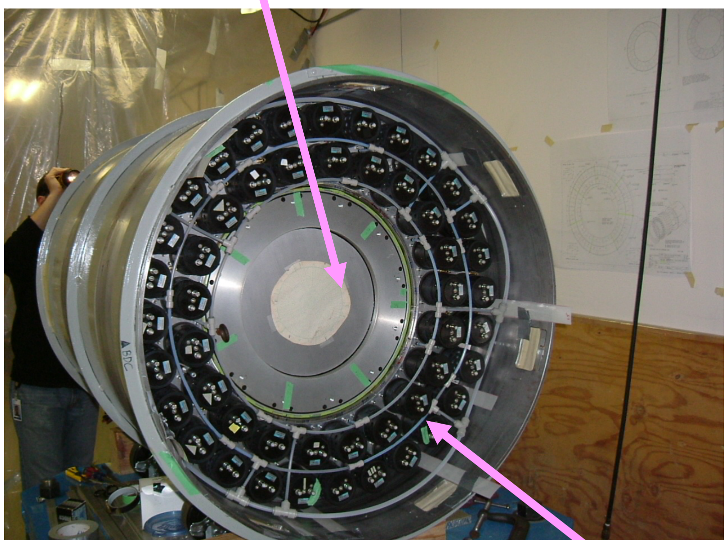
Close T1 to targ.

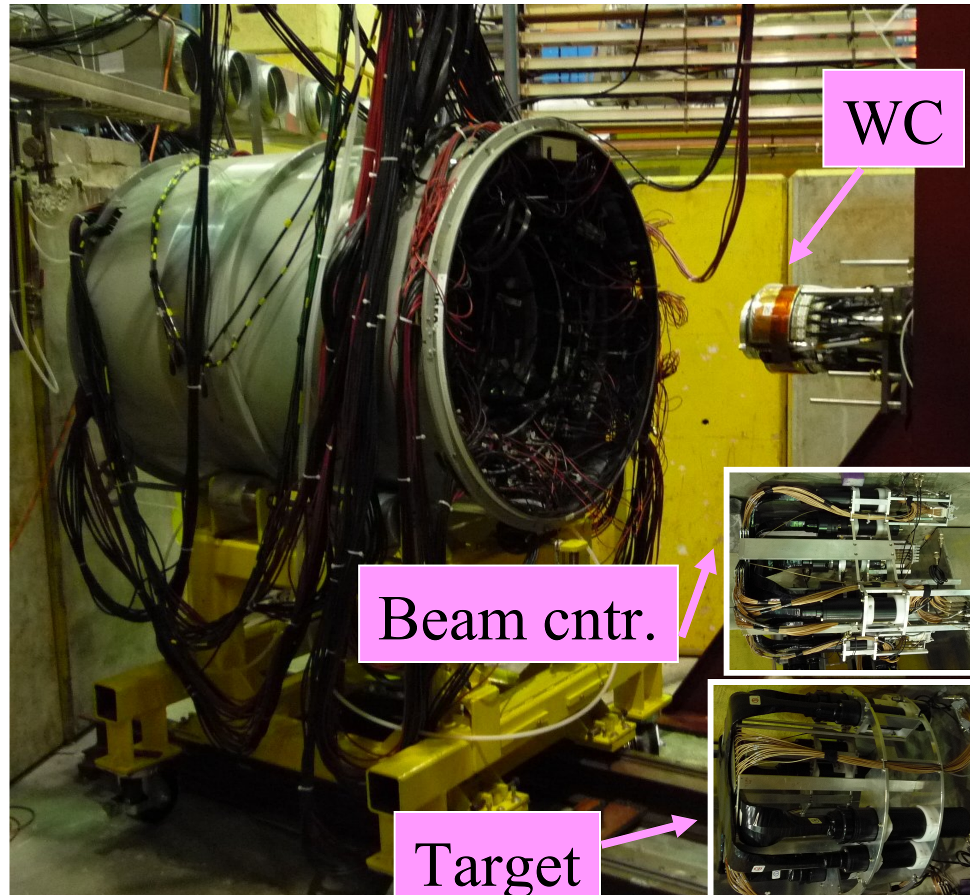


Lower beam rate (70 kHz)

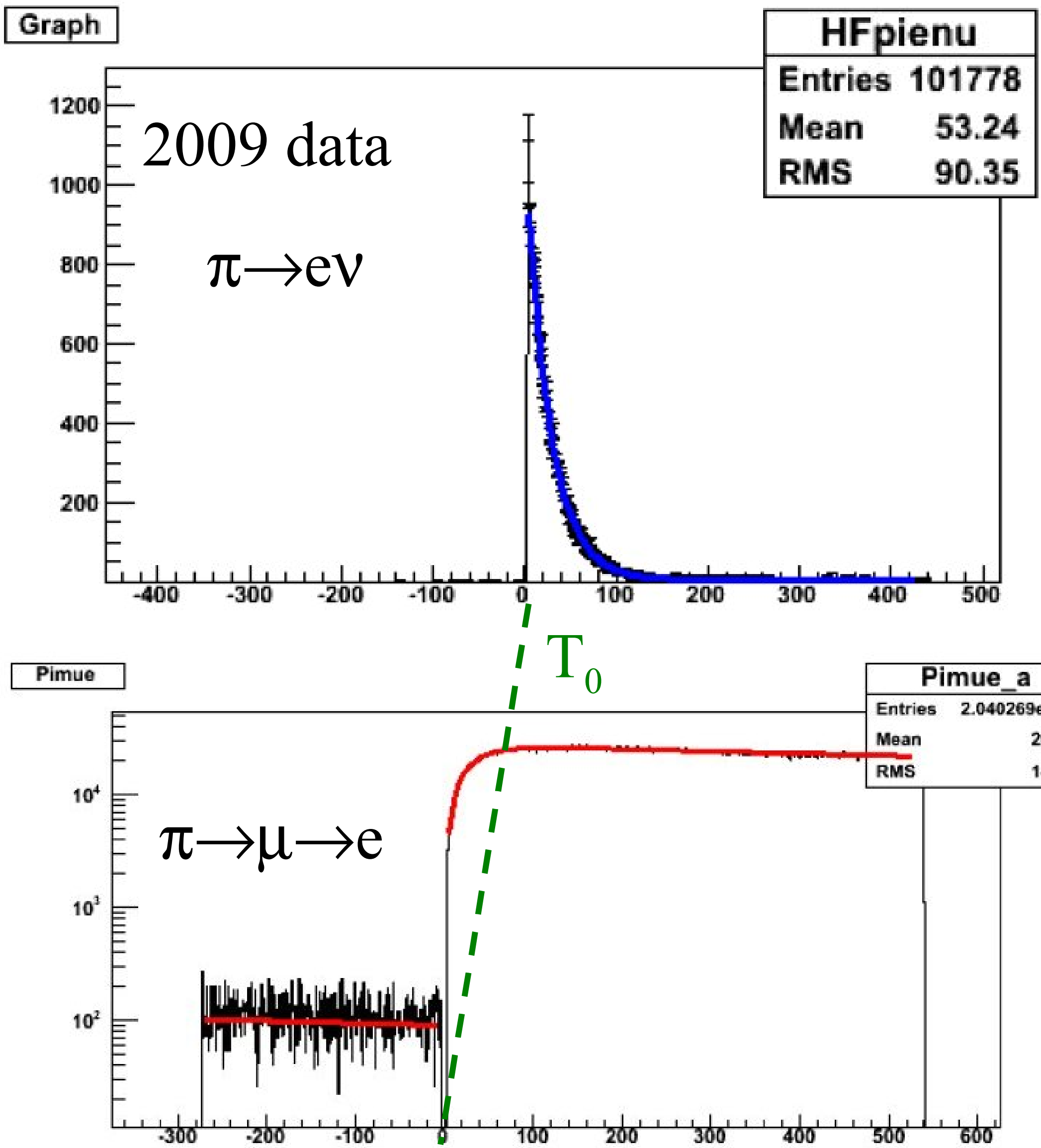
pion/positron>50

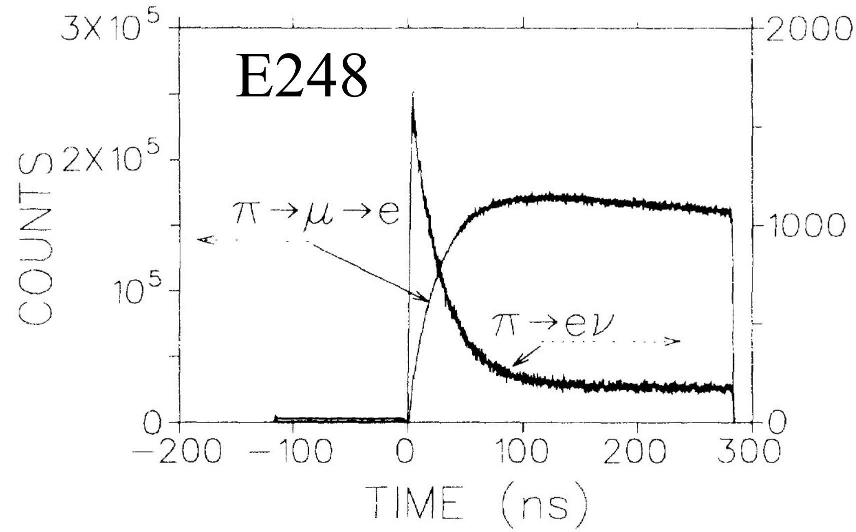
PIENU Detector





Time spectra (PIENU)





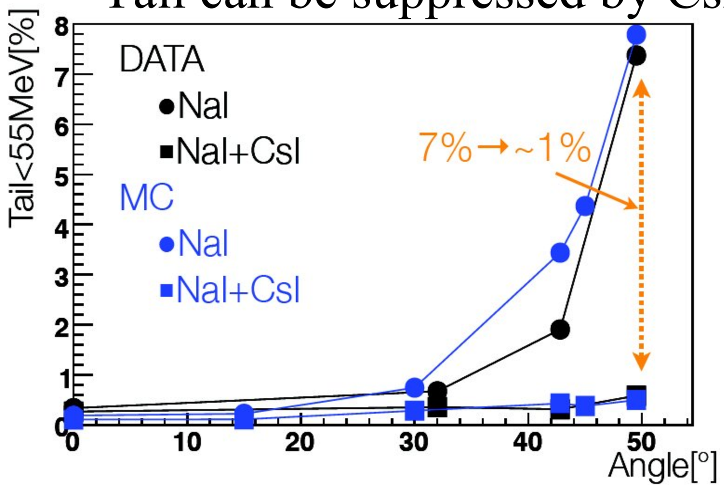
-10x less BG in π→eν region.
BG is from neutral PU.
More *n* shield, more distance.

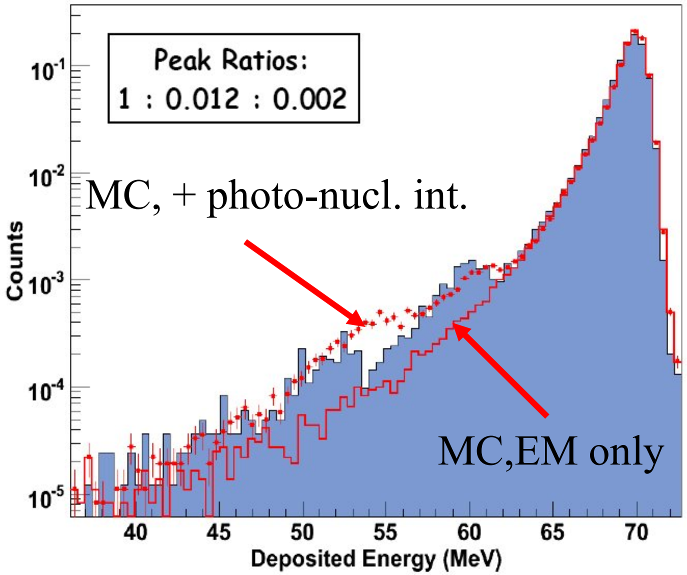
-Twice wider time range.
To fit exp(-λt),exp(-2λt),const.

-Lower-rate/cleaner beam.

Low energy tail

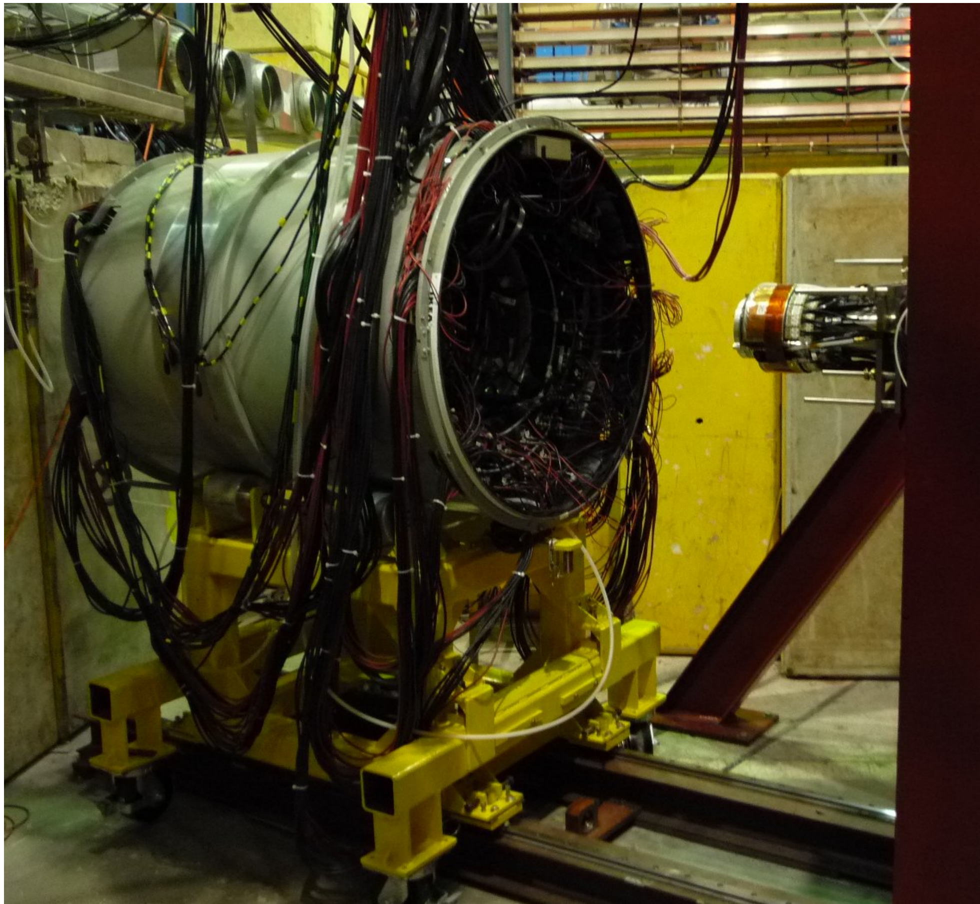
Tail can be suppressed by CsI.





NaI doesn't see *n* separation energy if *n* escapes (published in NIM).

Response function of the calorimeter was measured with a positron beam at variour angles.



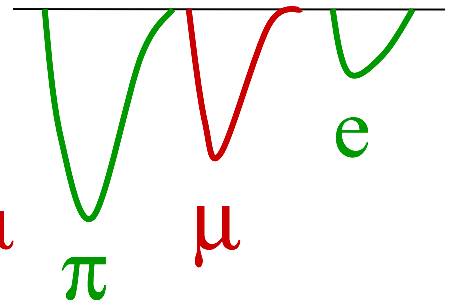
Tail correction

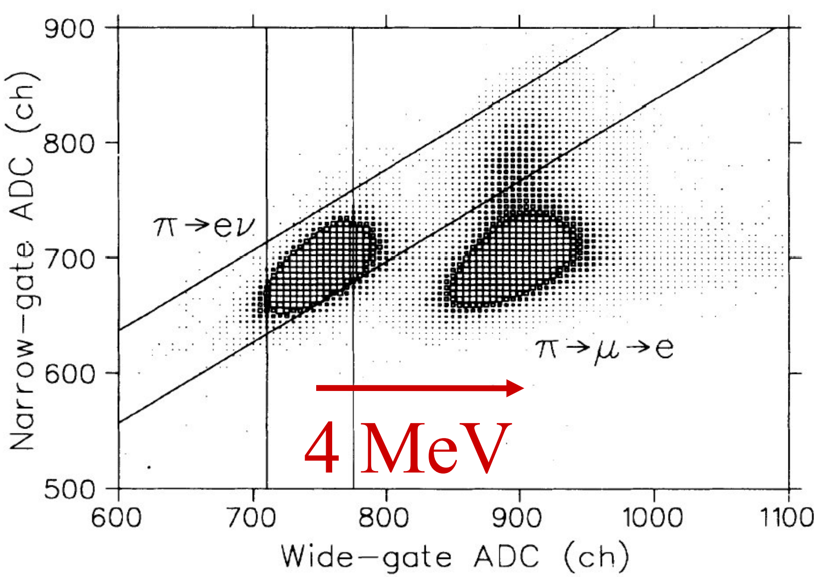
$\pi - e\nu$

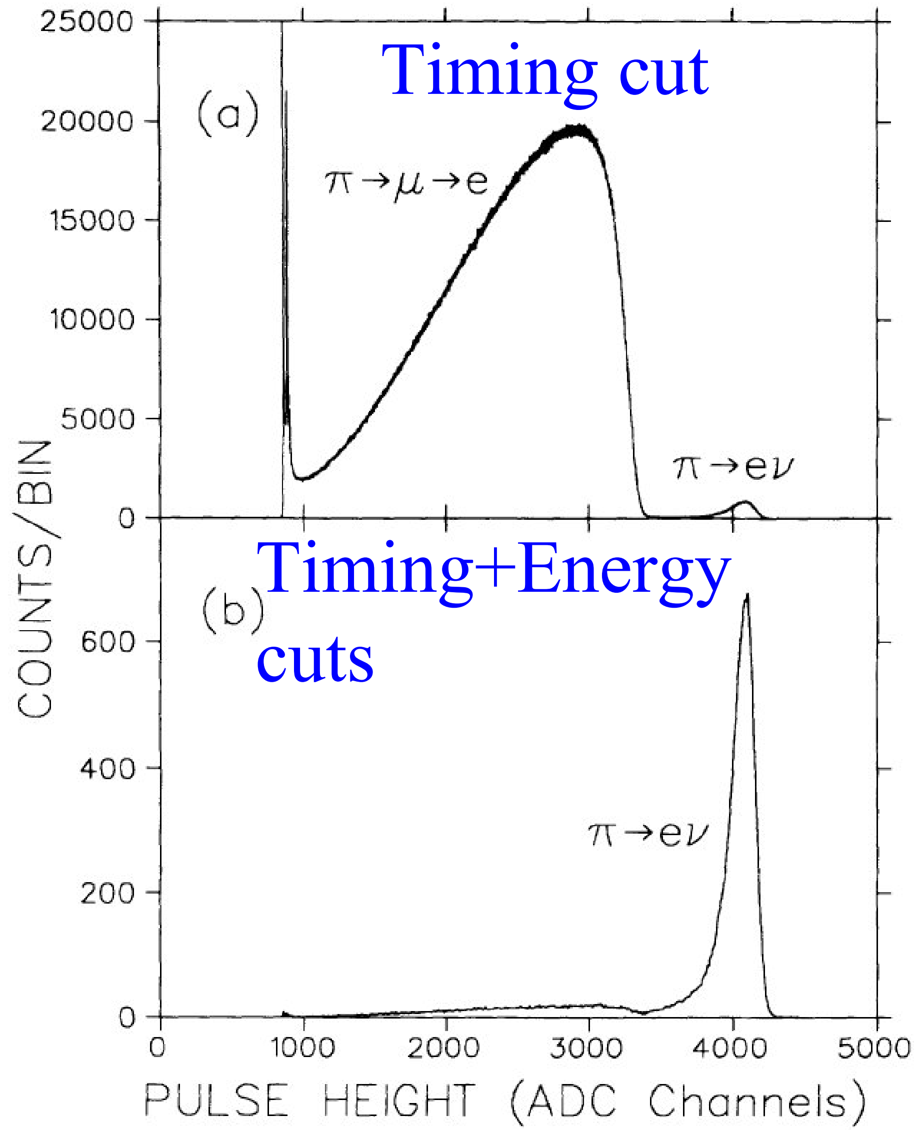
$T_\pi + \Delta E_e$

$\pi - \mu - e$

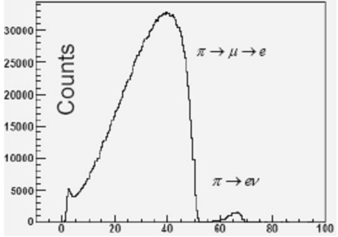
$T_\pi + \Delta E_e + E_\mu$



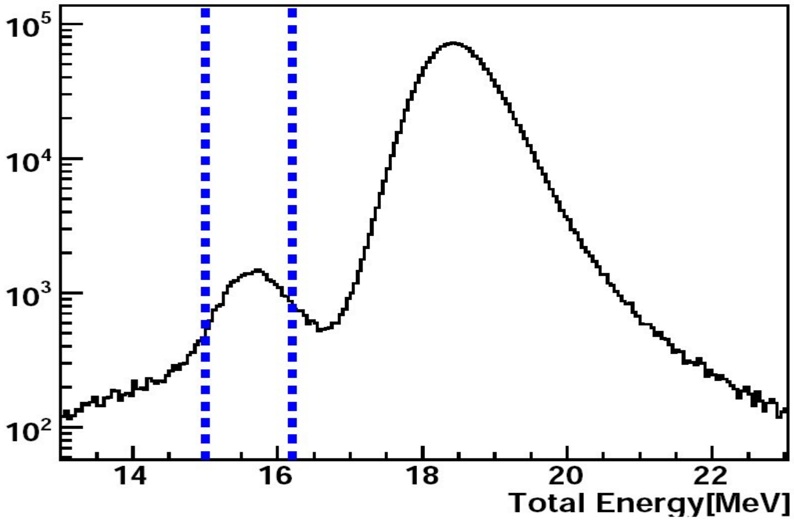




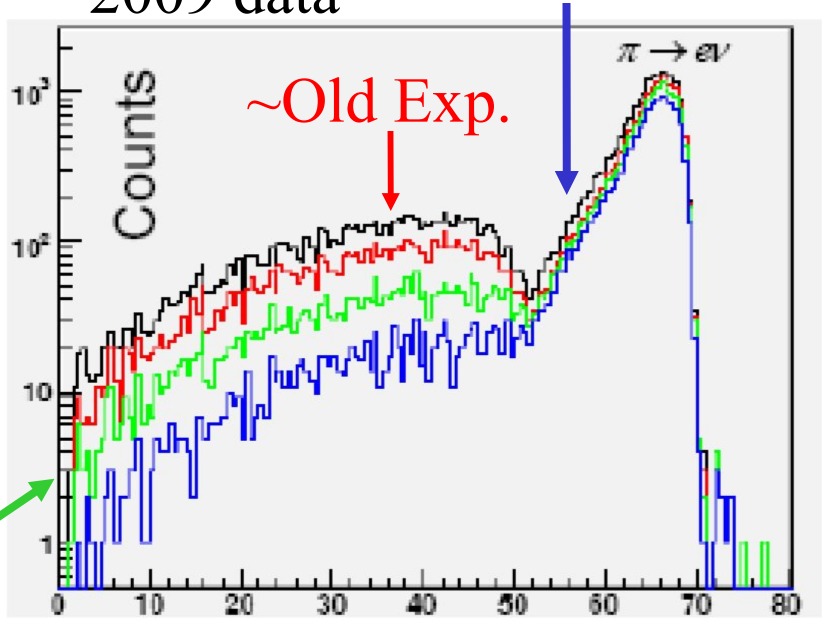
Empirical Tail correction



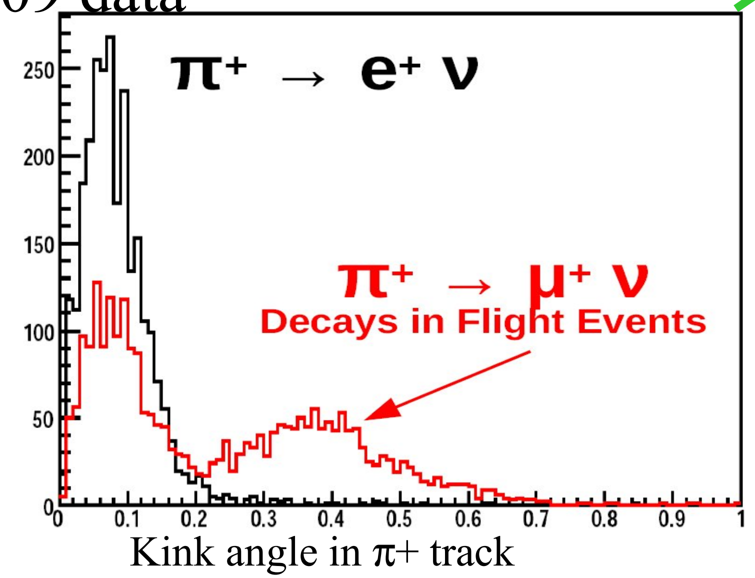
2009 data



2009 data



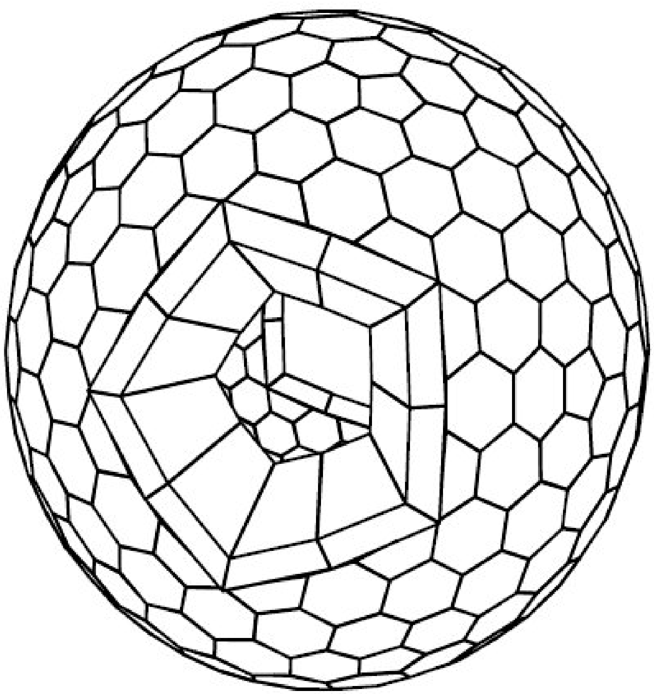
2009 data



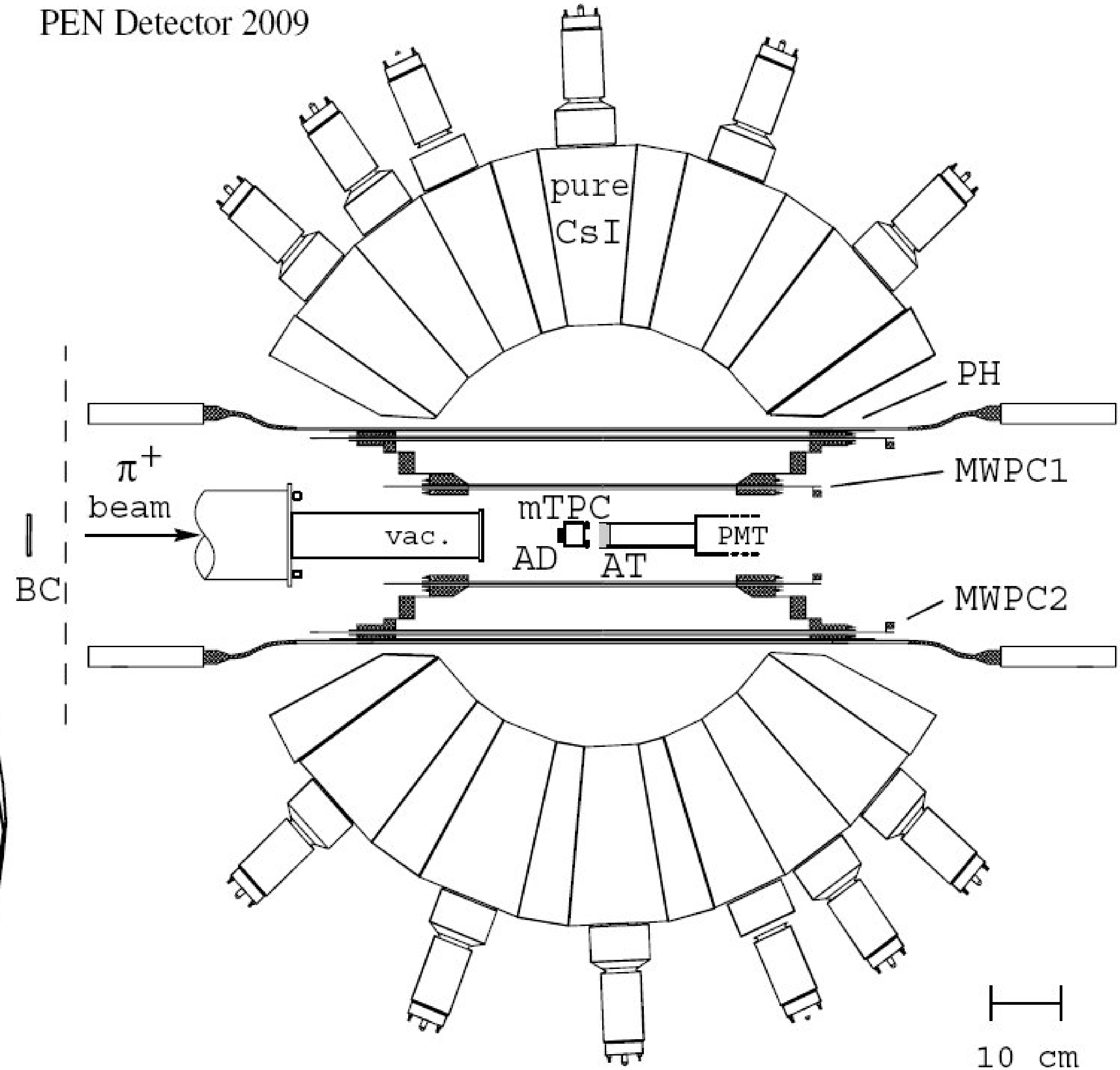
- Time and target-pulse infomation suppresses π→μ→e decays.
- Upstream tracking suppress Decay In Flight events.
- Combined tracking further suppresses DIF events.
- Expected improvement 0.25%→0.03% (combined with 30x statistical improvement)

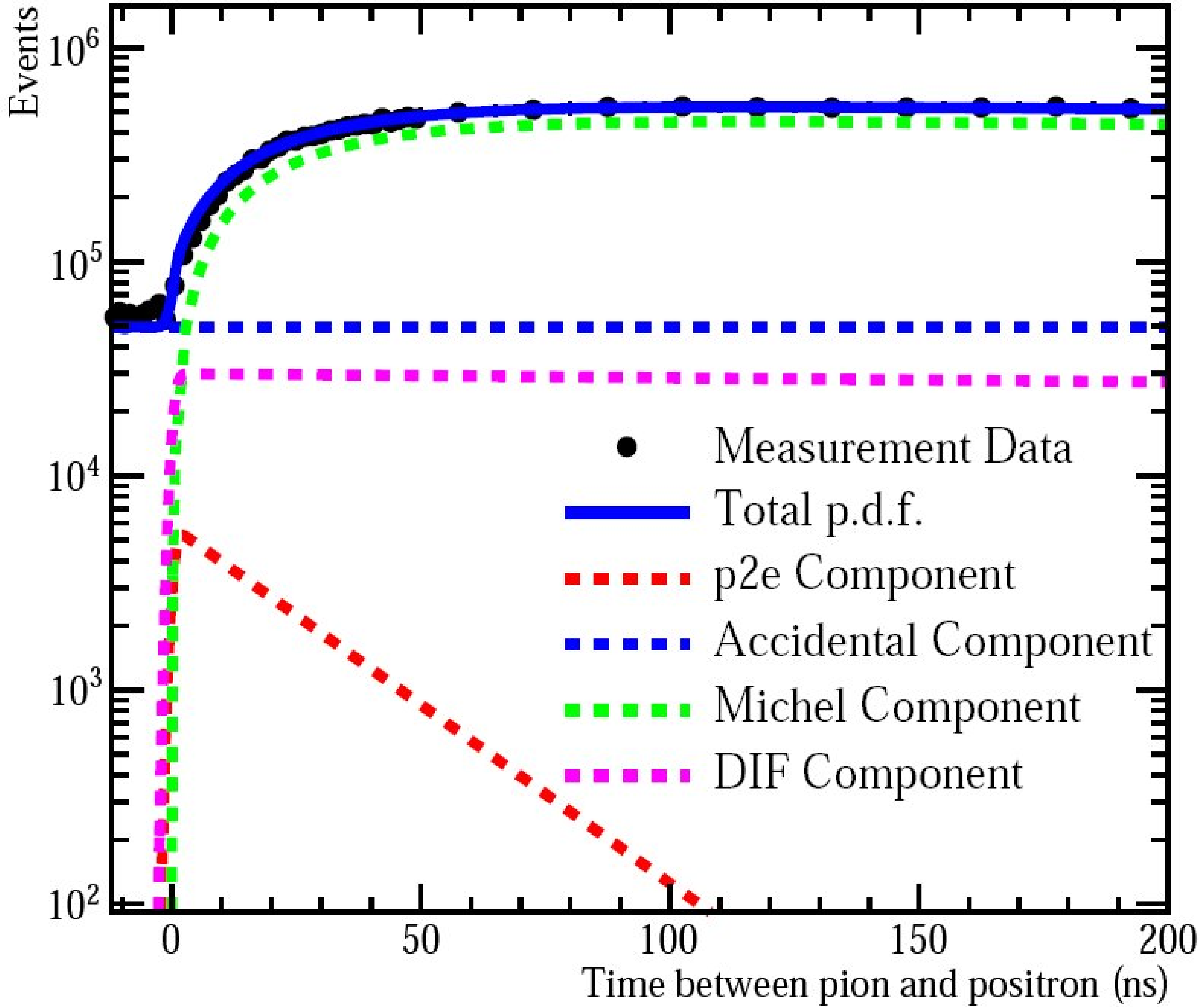
The PEN apparatus

- stopped π^+ beam
- active target counter
- 240-det. CsI(p) calo.
- central tracking
- digitized PMT signals
- stable temp./humidity

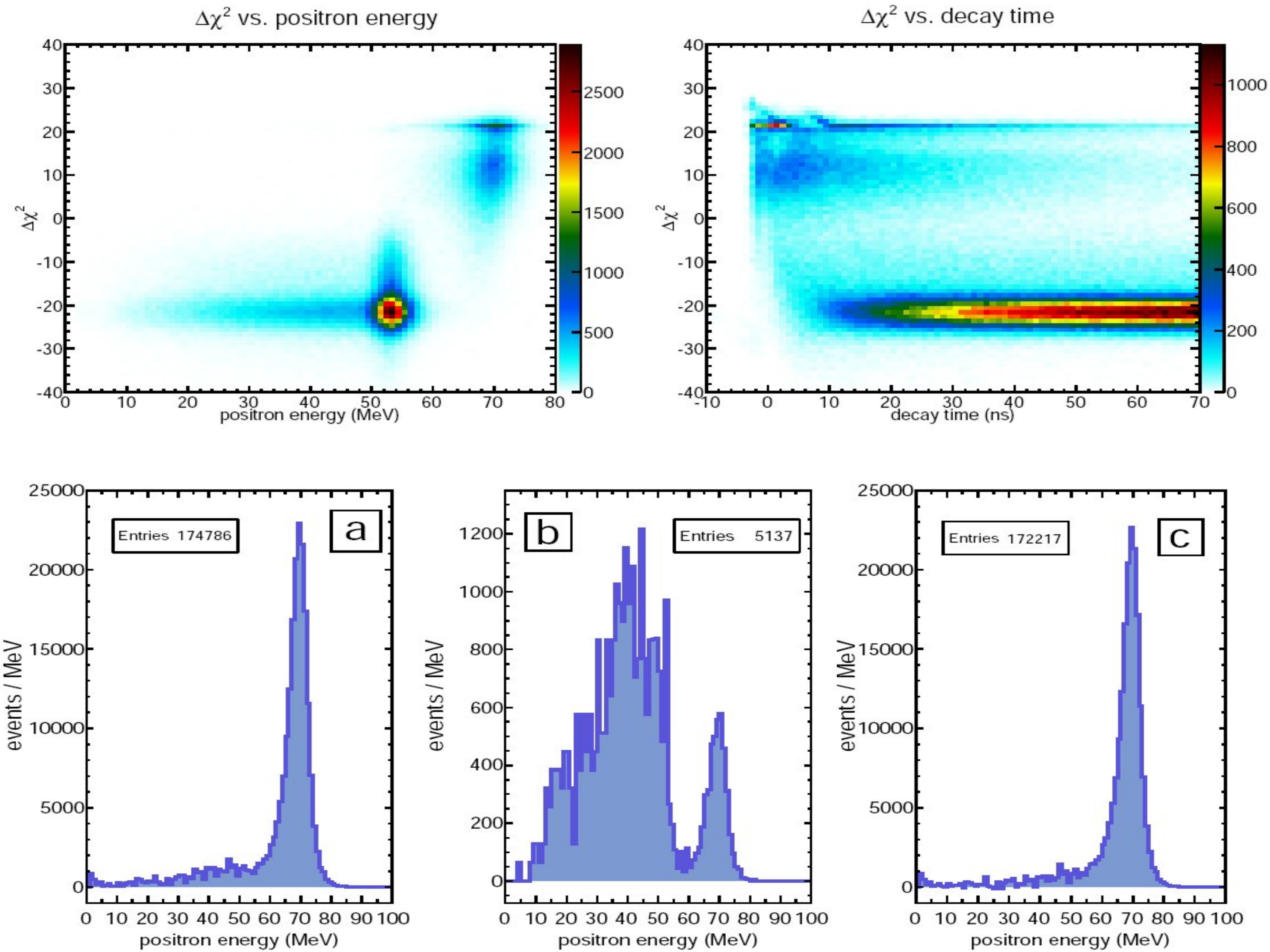


PEN Detector 2009





Events
10^6
10^5
10^4
10^3
10^2
0
50
100
150
200
Time between pion and positron (ns)
Measurement Data
Total p.d.f.
p2e Component
Accidental Component
Michel Component
DIF Component



$\Delta\chi^2$ vs. positron energy
$\Delta\chi^2$
positron energy (MeV)
$\Delta\chi^2$ vs. decay time
$\Delta\chi^2$
decay time (ns)
a
Entries 174786
b
Entries 5137
c
Entries 172217
events / MeV
positron energy (MeV)

Status

PIENU
Accumulate 3 M clean events by the end of 2010
Another 3 M events in 2011

PEN
Accumulated 5 M clean events.
Running for another 5 M events in 2010.

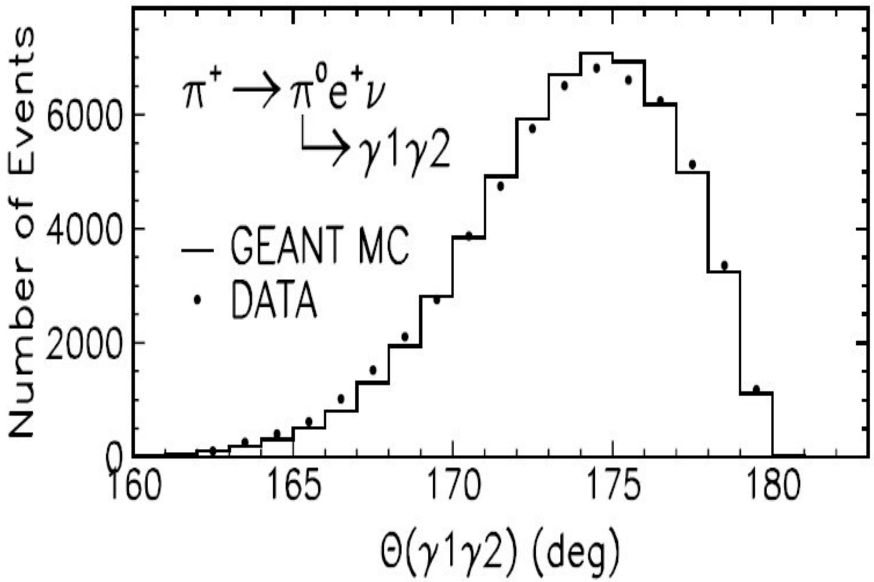
Summary of uncertainties

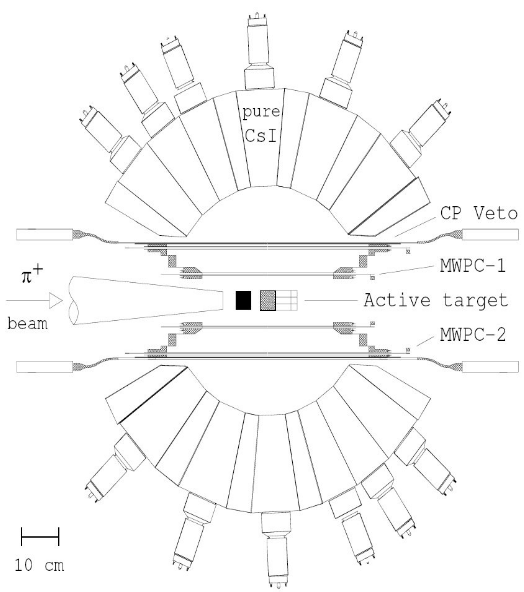
Source	Old Triumf	PIENU	PEN
Statictical	0.0028	0.0005	0.0002
Low-energy tail	0.0025	0.0003	
Accept diff.	0.0011	0.0003	0.0002
Pion life	0.0009	0.0002	
Other	0.0011	0.0003	0.0002
Total	0.0047	0.0006	0.0005

For normalization

Pion Beta Decays

- Vud measurement.





$R=[1.036\pm0.004\pm0.005]\times10^{-8}$

$V_{ud}=0.9728(30)$

0.9738(5) Nucl. β decay

PRL 93 181803-1 (2004)

Conclusion

-π-eν is not rare decay---it is used even for normalization.

-Precision measurement of π-eν provides the best test of μ-e universality.

- π-eν is sensitive to the presence of PS interactions---physics beyond the SM..

-Two experimental results at <0.1 % precision are expected to come out in a few years.