Precision Test of electron-muon Universality with Pions

---*TRIUMF PIENU Experiment*---

Toshio Numao

TRIUMF

PIENU Collaboration

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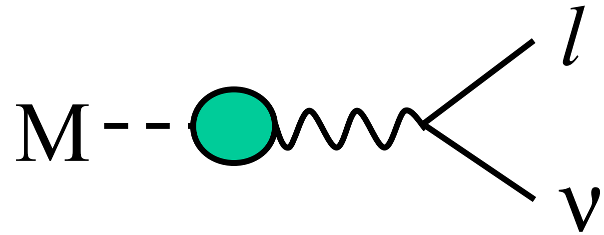
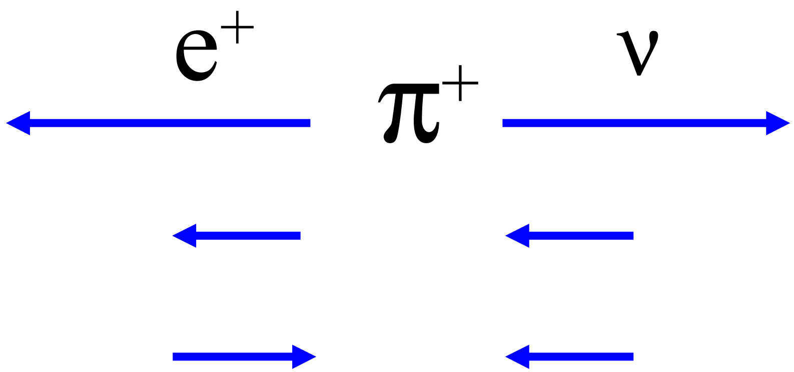
UNAM, Osaka University, VPI, University of Glasgow, UBC, Tsinghua University, Arizona State University, TRIUMF, UNBC, BNL, KEK, Los Alamos

$\pi \rightarrow e\nu$ decay

Parity violation
Small correction for Strong int.





Momentum

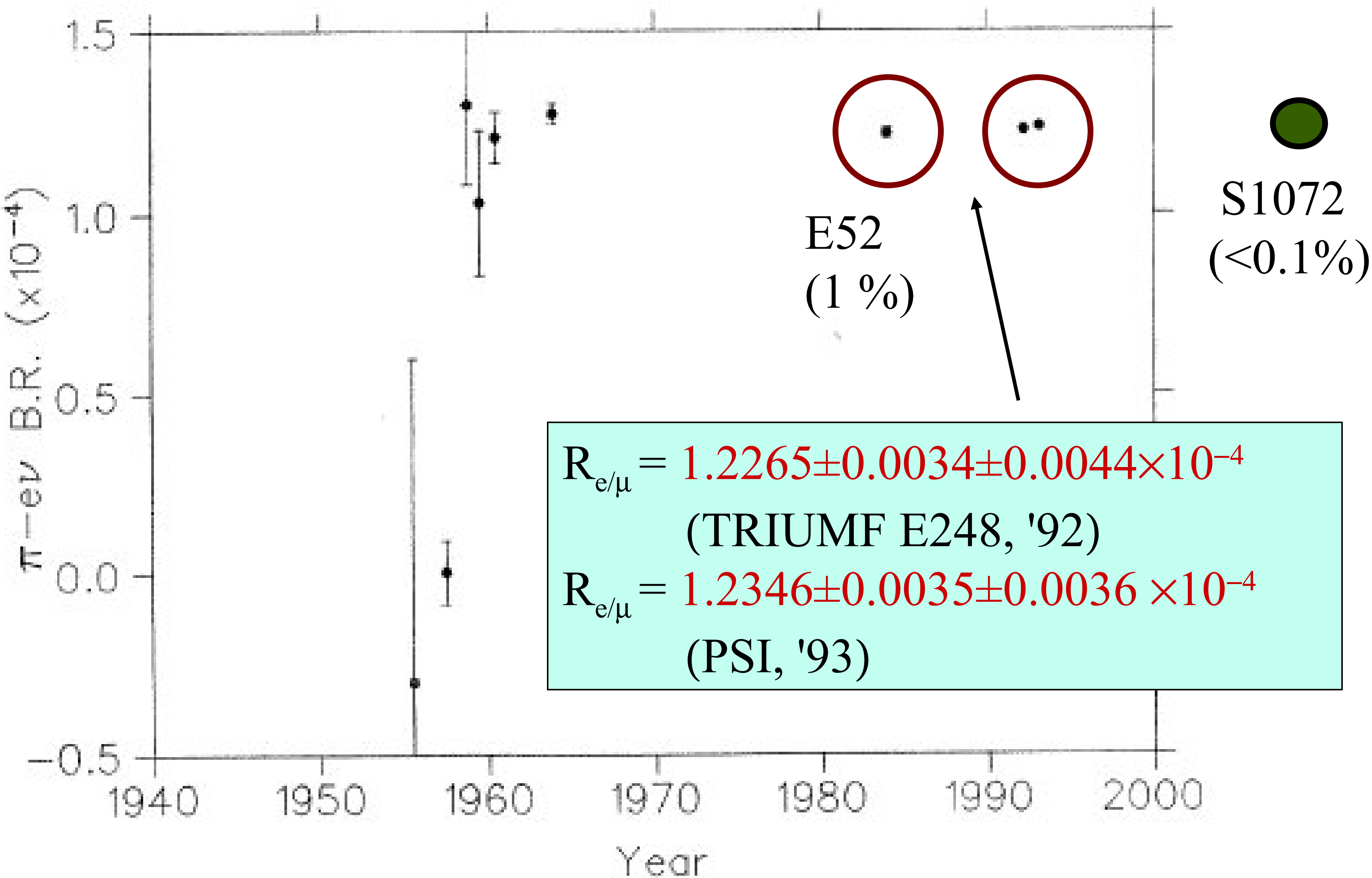
V–A

Angular M.

Helicity mismatch suppresses $\pi \rightarrow e\nu$ decay by $(m_e/m_\mu)^2 \sim 10^{-5}$.

The major decay mode of the pion is $\pi \rightarrow \mu\nu$: 99.99%.

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



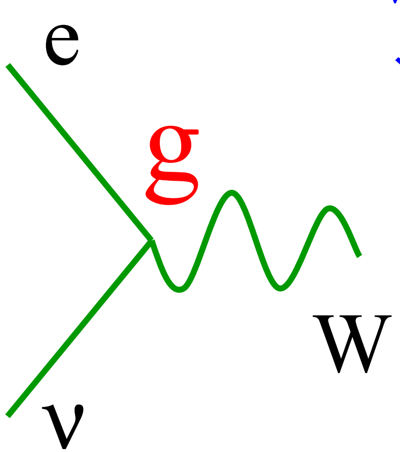
$R_{e/\mu} = 1.2265 \pm 0.0034 \pm 0.0044 \times 10^{-4}$
(TRIUMF E248, '92)

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

Charged current in the Standard Model

$$\begin{bmatrix} u \\ d \end{bmatrix}_L \quad \begin{bmatrix} c \\ s \end{bmatrix}_L \quad \begin{bmatrix} t \\ b \end{bmatrix}_L$$

$$\updownarrow W \quad \begin{bmatrix} e \\ \nu_e \end{bmatrix}_L \quad \begin{bmatrix} \mu \\ \nu_\mu \end{bmatrix}_L \quad \begin{bmatrix} \tau \\ \nu_\tau \end{bmatrix}_L$$

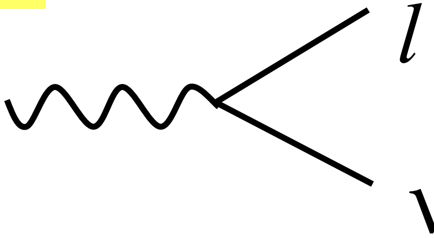


$$g_e \qquad g_\mu \qquad g_\tau$$

$g_e = g_\mu$? Lepton Universality

μ-e Universality

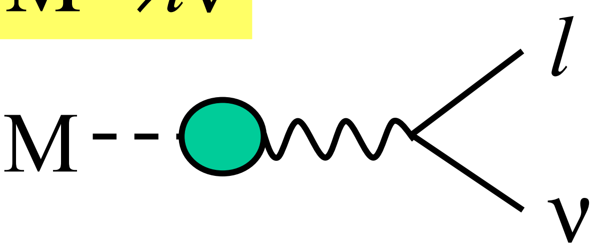
W



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

Mode	g_e/g_μ
$\pi\!-\!e\nu/\pi\!-\!\mu\nu$	0.9985 ± 0.0016
$K\!-\!e\nu/K\!-\!\mu\nu$	1.0018 ± 0.0026
$\tau\!-\!e\nu\nu/\tau\!-\!\mu\nu\nu$	0.9981 ± 0.0014
ν_e/ν_μ scatt.	1.10 ± 0.05
W decays	0.999 ± 0.011
$K\!-\!\pi e\nu/K\!-\!\pi\mu\nu$	0.9979 ± 0.0025

$M \to l\nu$



$$R^{\pi}_{e/\mu} = \frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} = \frac{g_e^{\,2}}{g_\mu^{\,2}} \quad R^{theory}_{e/\mu}$$

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	point-like π
$1.2352(5)\times10^{-4}$	Marciano,Sirlin 1993	loop
$1.2352(1)\times10^{-4}$	Cirigliano,Rosell 2007	ChPT

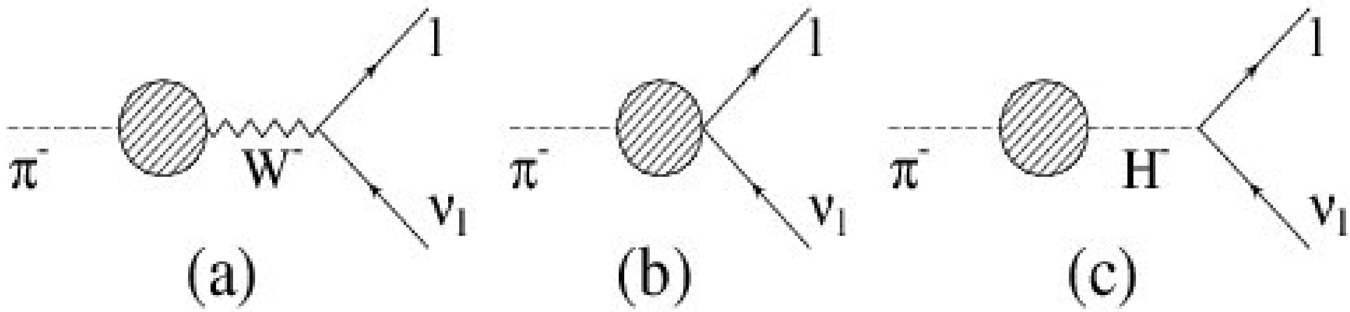
Inputs: F_A/F_V, F_π... : $\pi\to e\nu\gamma$, pion life

$R^{exp}=1.230(4)\times10^{-4}$ (TRIUMF+PSI)

Beyond the Standard Model

New PS interaction

Marciano *et al.*



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

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

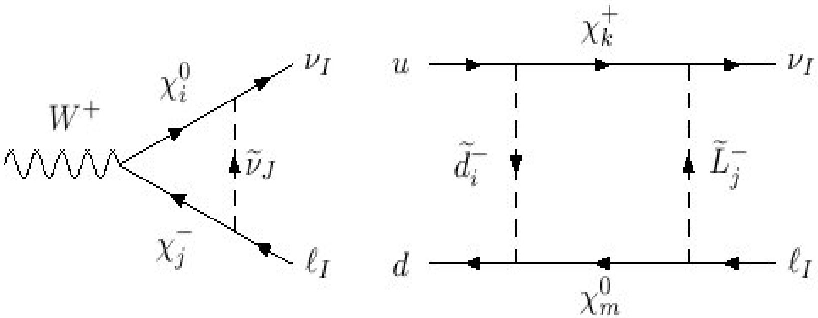
$\Lambda_{eP} \sim$ 1000 TeV

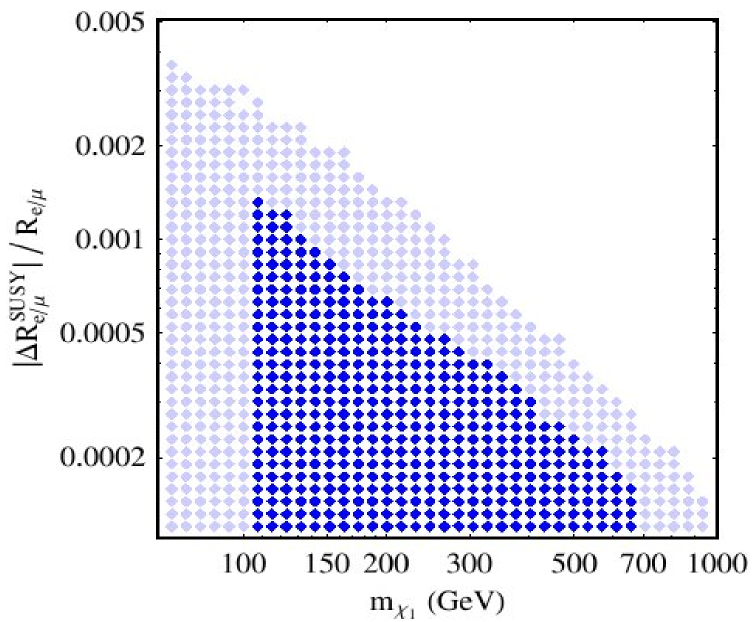
$\Lambda_A \sim$20TeV

$\Lambda_S \sim$60TeV via induced scalar coupling

Beyond the Standard Model

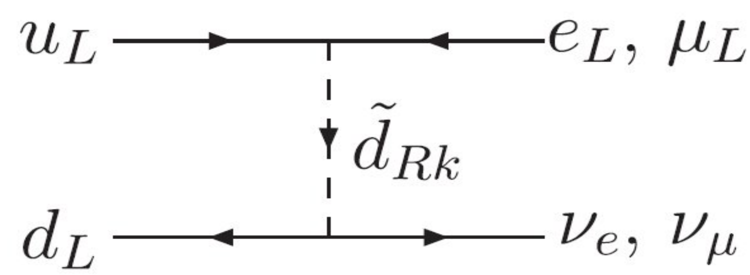
Minimal SUSY SM

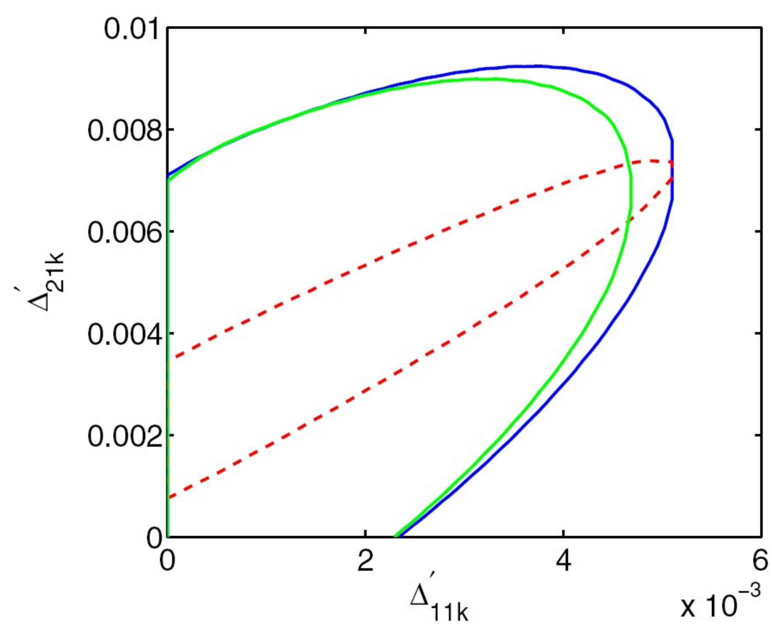




Lowest chargino mass

R-Parity Violating SUSY





Ramsey-Musolf… PRD76 095017 (2007)

Beyond the Standard Model

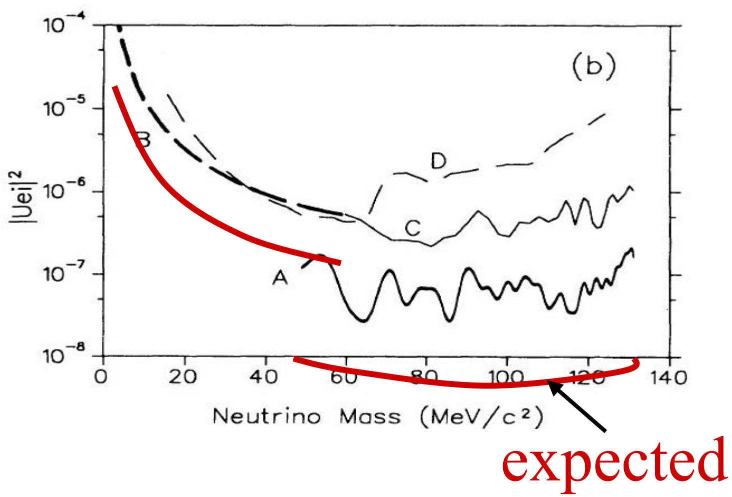
MSSM LFV

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

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)
-...

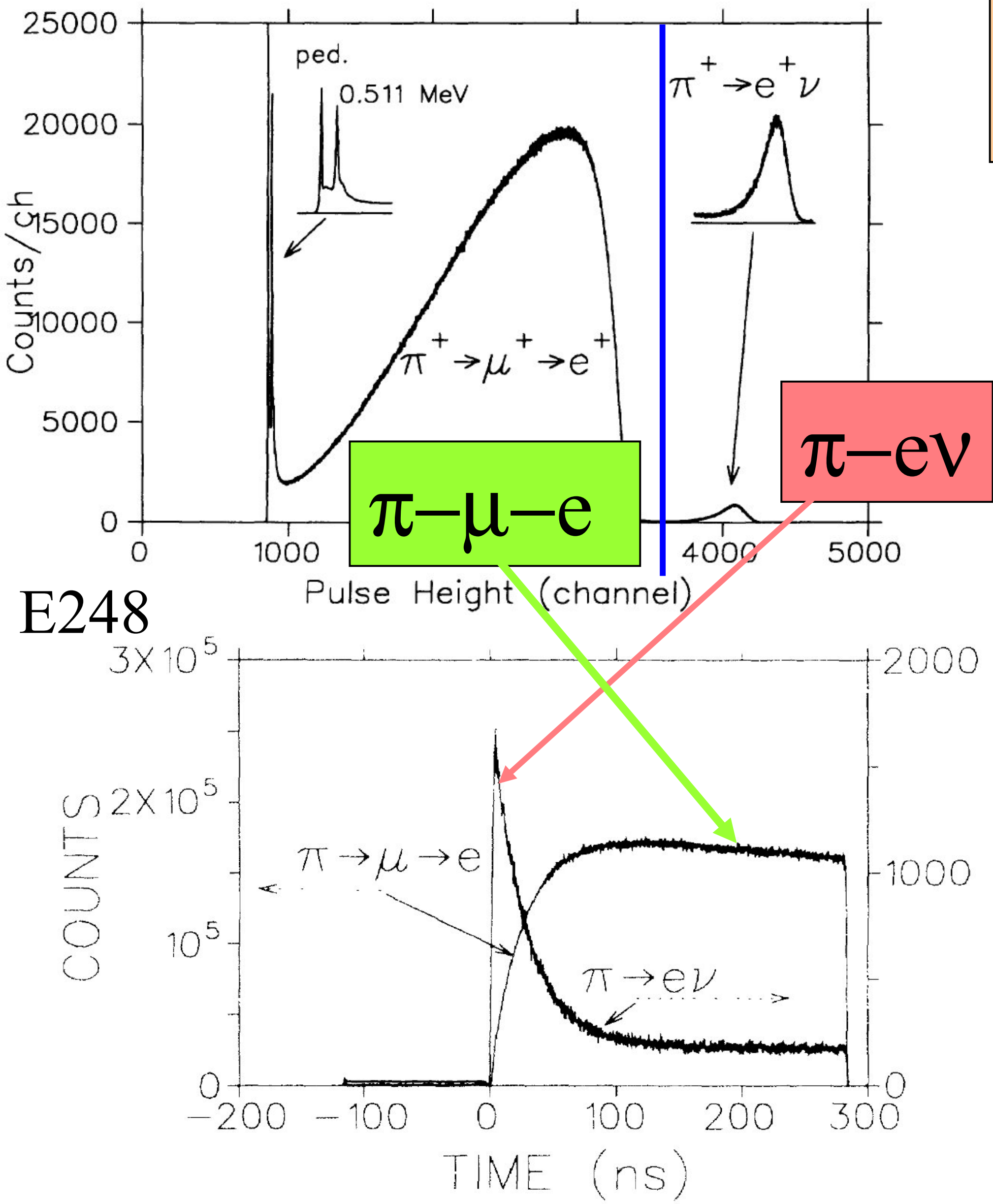
Experimental method

Use stopped pions.

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

$\pi \rightarrow \mu\nu$

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



Fit both time spectra simultaneously and obtain the ratio.

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

The same method with refinements will be used.

Corrections (E248)

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

Items	Corrections (%)	Limited
Low energy tail	0.0193 ± 0.0025	Stat.
Energy dep. (MC)	0.0027 ± 0.0011	Geom.
π lifetime	0.0000 ± 0.0009	→ new
T0 difference	-0.0002 ± 0.0008	Stat.
Others	0.0005 ± 0.0007	BG,

Previous (TRIUMF E248) experiment

$R=(1.2265\pm0.0034\pm0.0044)\times10^{-4}$

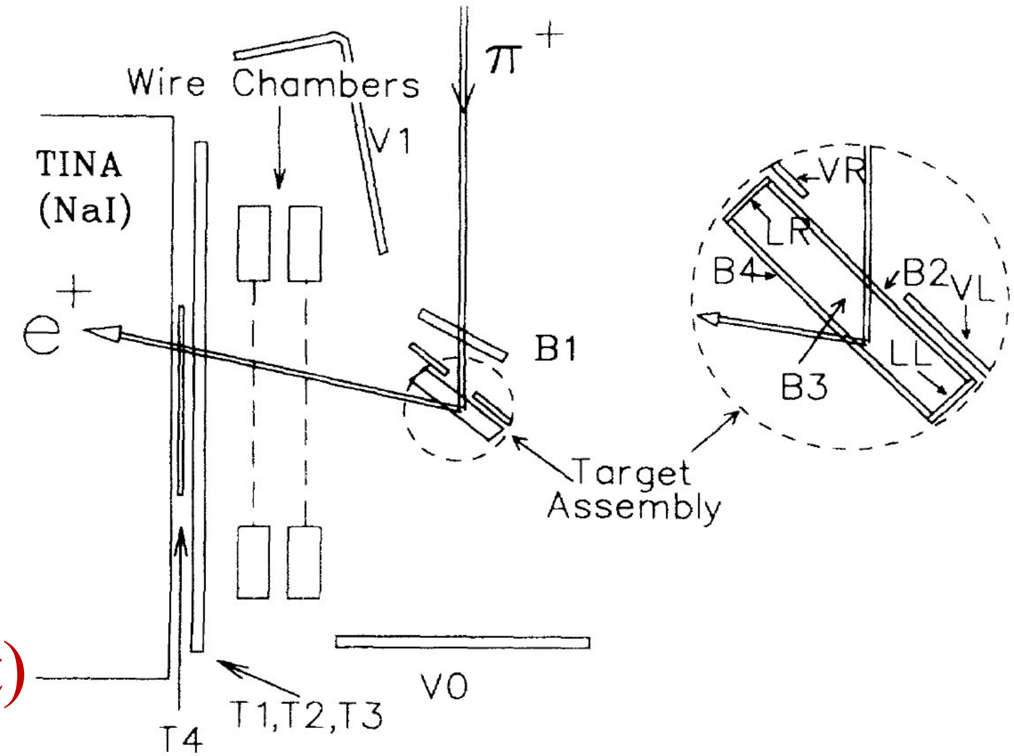
Measured positrons from

$\pi\rightarrow e\nu$ (τ=26ns)

$\pi\rightarrow\mu\nu$

$\mu\rightarrow e\nu\nu$ (τ=2μs)

- small solid angle
- pile-up (due to neutrons from the production target)
- material along e+ path and locations of counters.



Setup of the TRIUMF experiment E1072

NaI in beam

- Solid angle = 20 %
- Less material for e+

Ring counter (CsI)

- Less shower leakage.

Better NaI resolution

π,e tracking

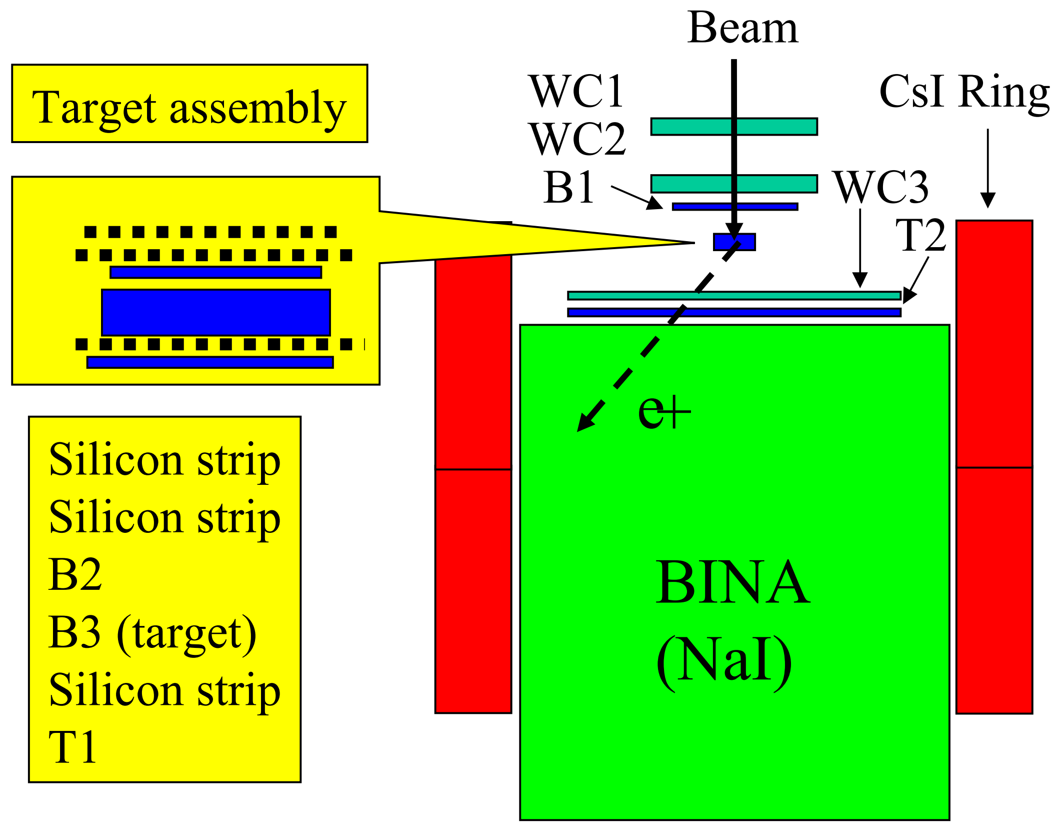
- Less BG, syst. study

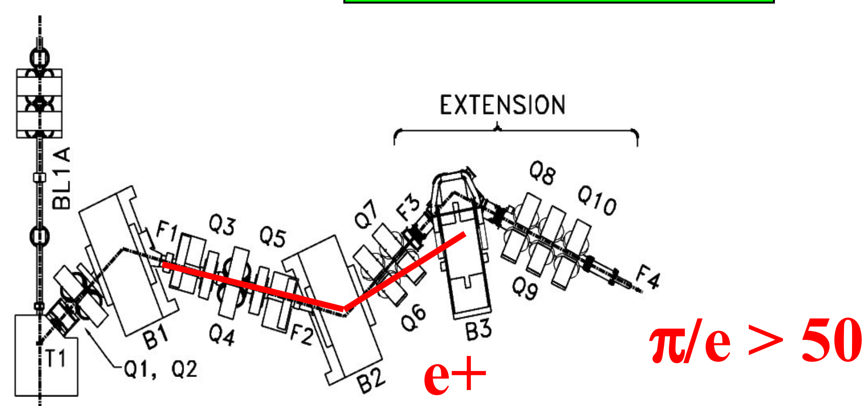
Far from the prod. Targ.

- Less neutrons → Less BG

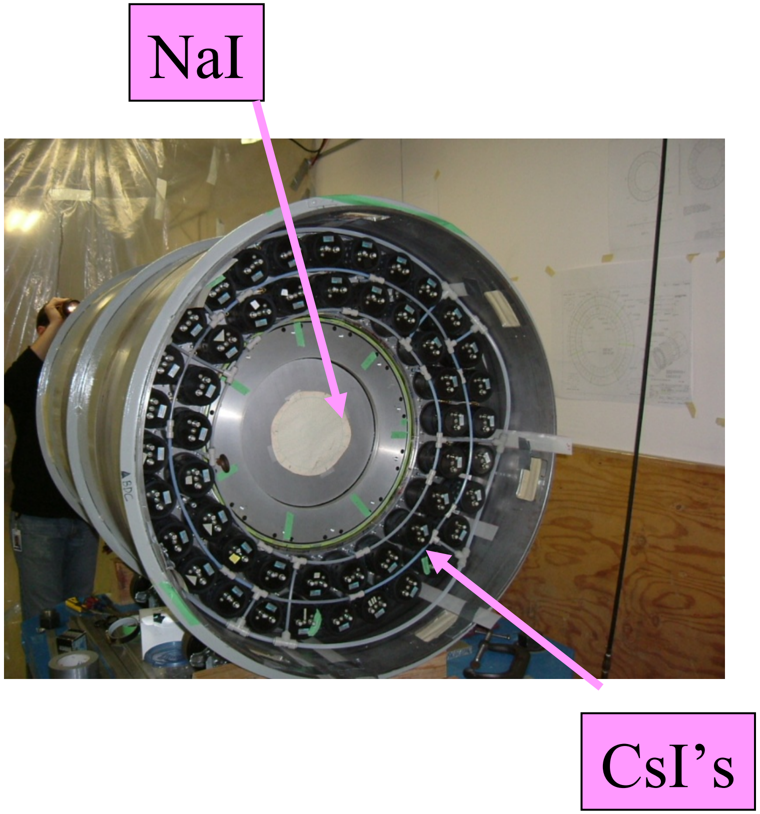
Lower beam rate (70 kHz)

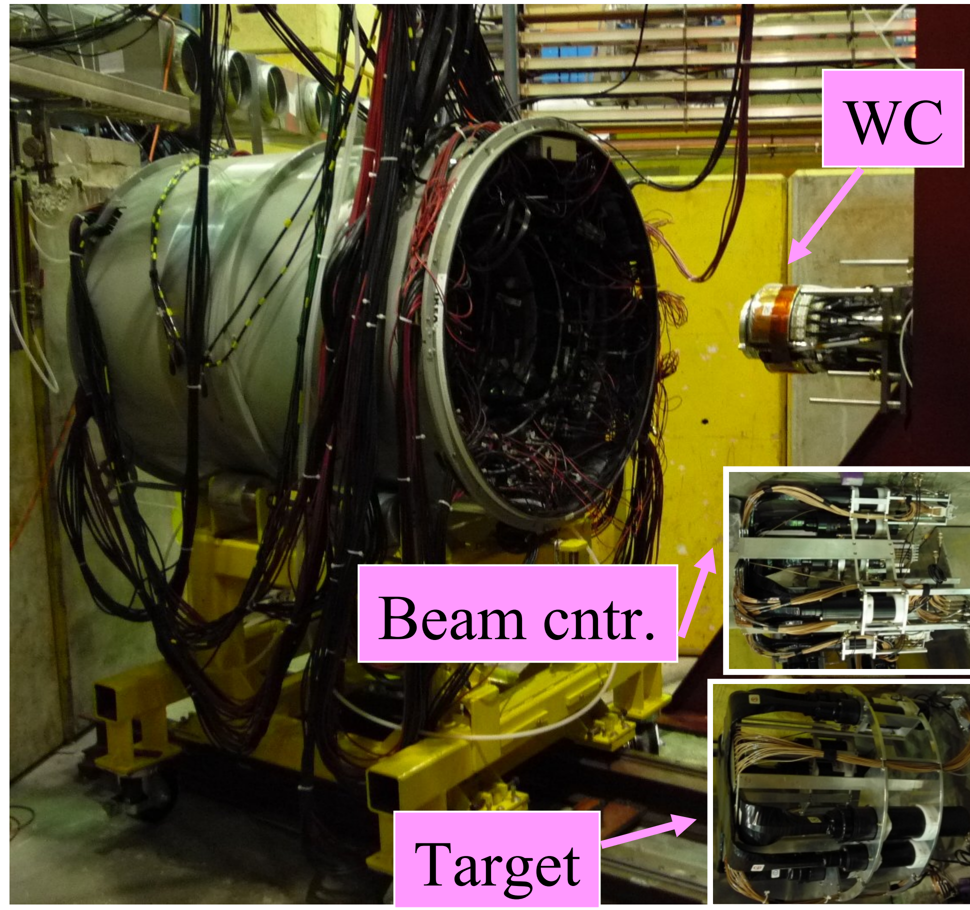
- Less BG





PIENU Detector





Data Taking

-50k/s pions with 2% positrons and 10% muons

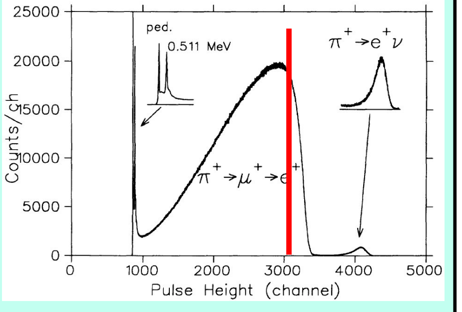
-Triggers (600 /s)

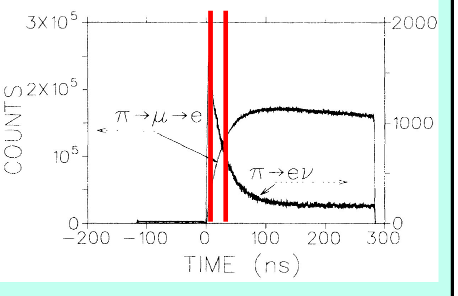
π–eν; $E_e > 45$MeV

early (2-50ns)

π–μ–e ; prescaled (1/16)

monitor; e^+beam, Xe, cosmic-ray

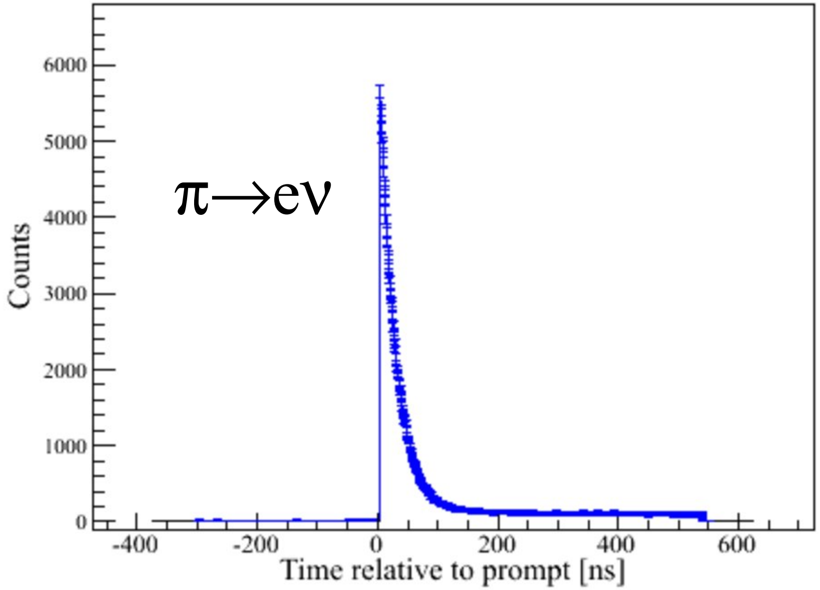


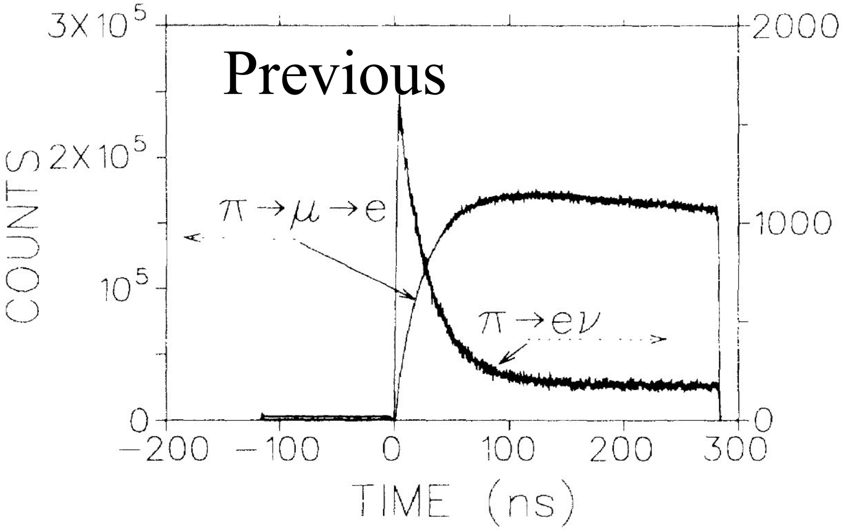


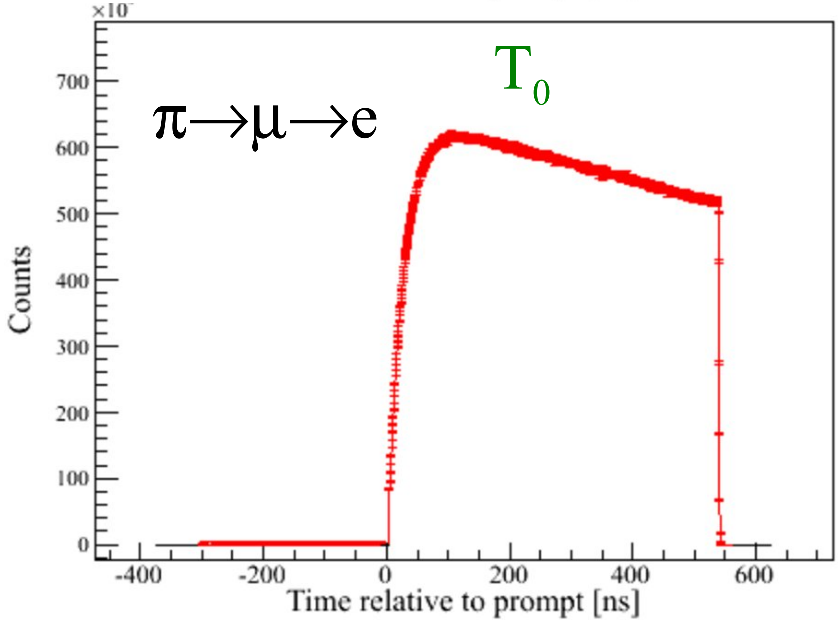
-Inspection period -300ns to 500ns

-Record waveforms

Time spectra (PIENU)



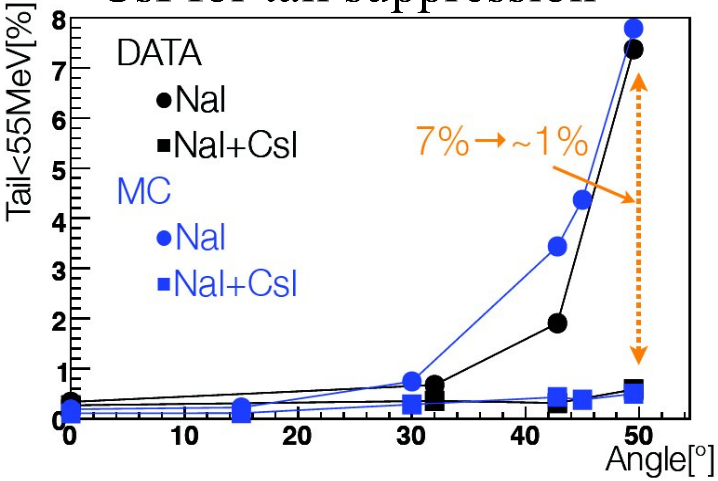


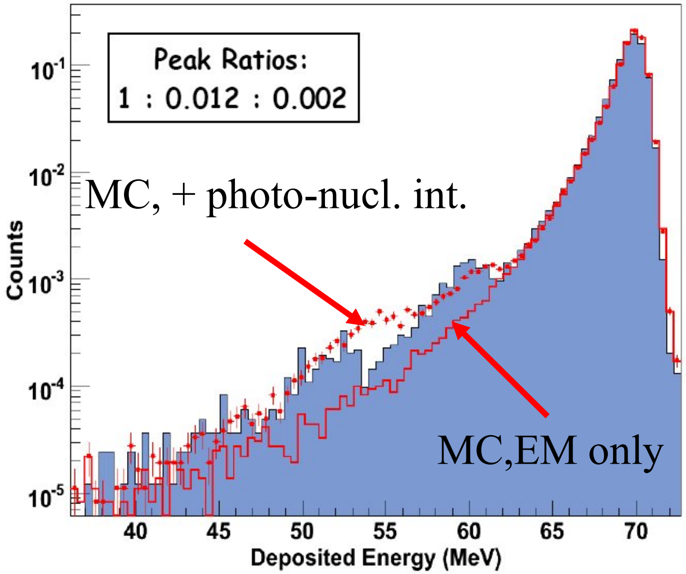


Comparing to previous exp.
- -10x less BG in π→eν region.
  (BG is from neutral PU.)
  Less BG uncertainty.
- -Twice wider time range.
  To fit exp(-λt),exp(-2λt),const.
- -So far, 3 M clean π→eν events.

Low energy tail-I

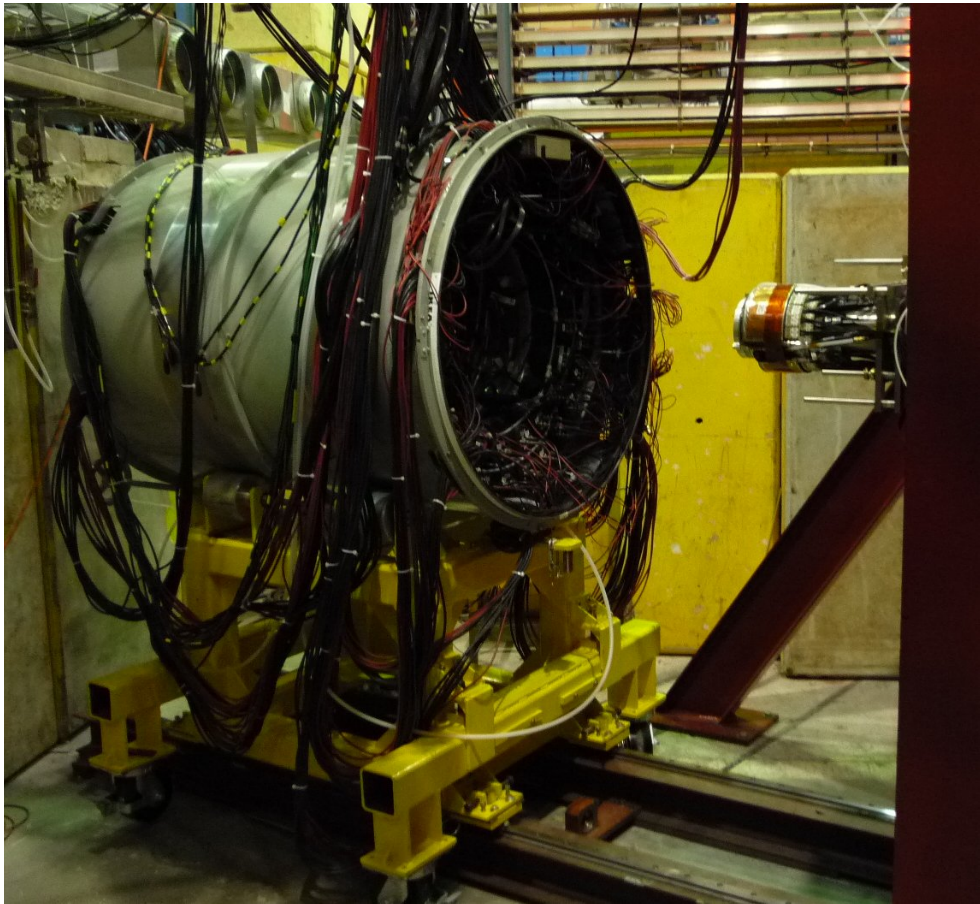
CsI for tail suppression



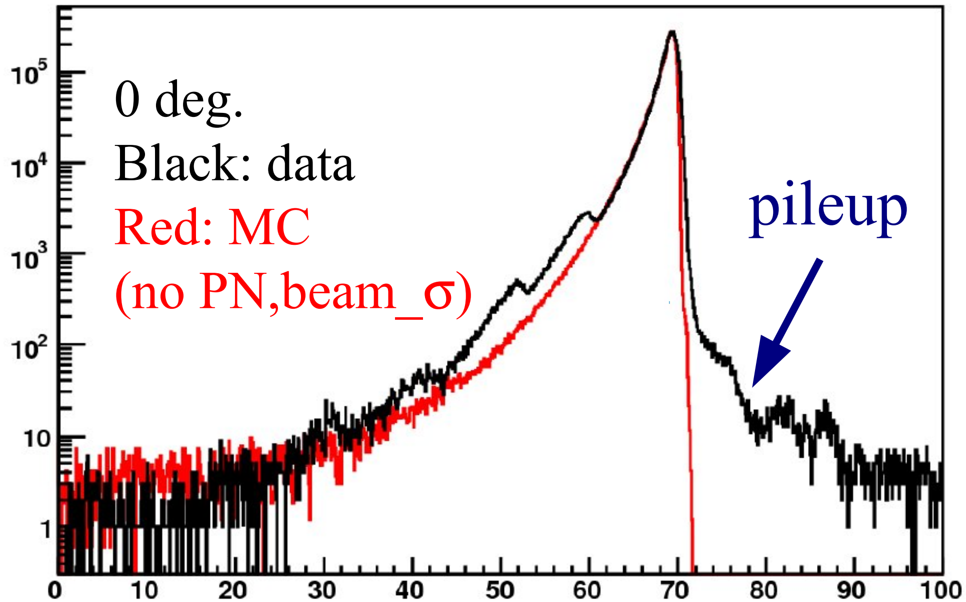


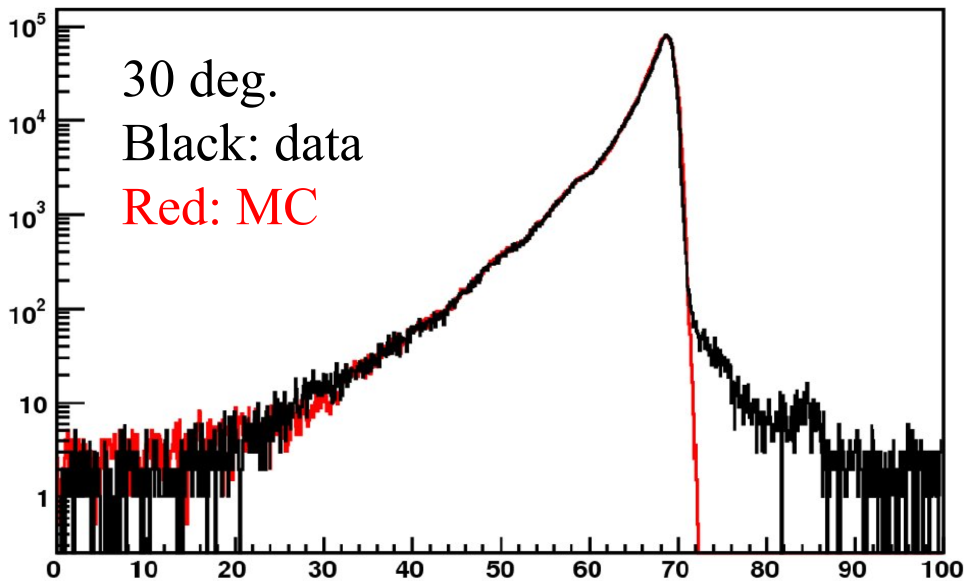
NaI doesn't see *n* separation energy if *n* escapes (NIM A621 188(2010)).

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



Evaluation of Low energy tail





- -70 MeV positrons.
- -Use 0 deg. Data.
- -Tune the parameters in MC calculations.
- -Confirm MC lineshapes at larger angles.

- -Estimate the fraction below 55MeV for $\pi \to e\nu$ decays.

Low energy tail-II

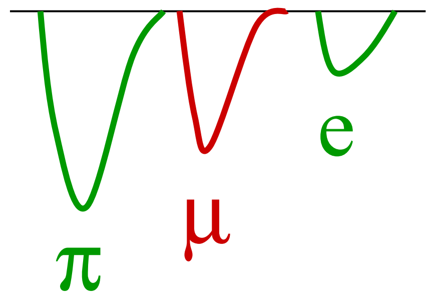
Empirical tail evaluation

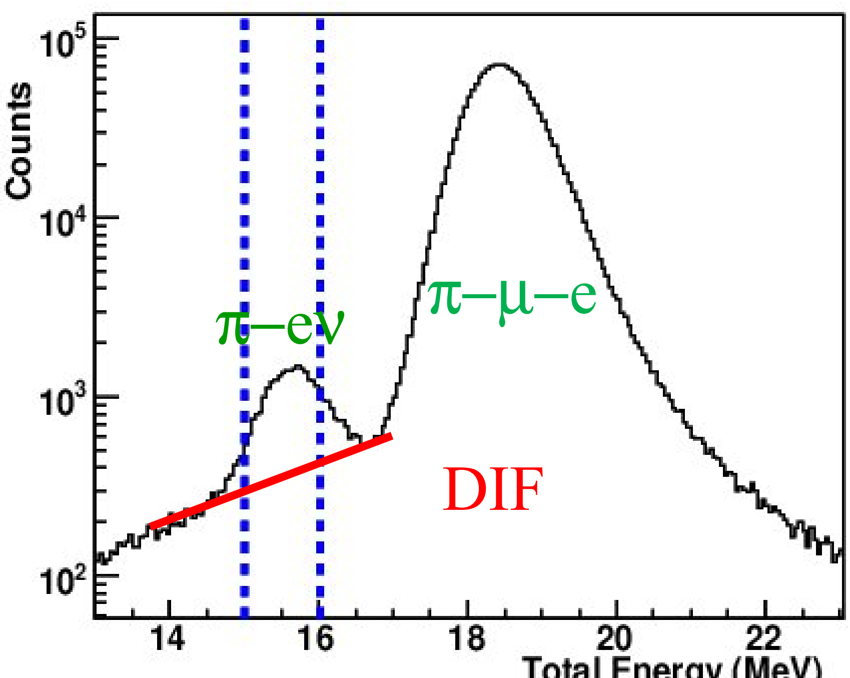
$\pi - e\nu$

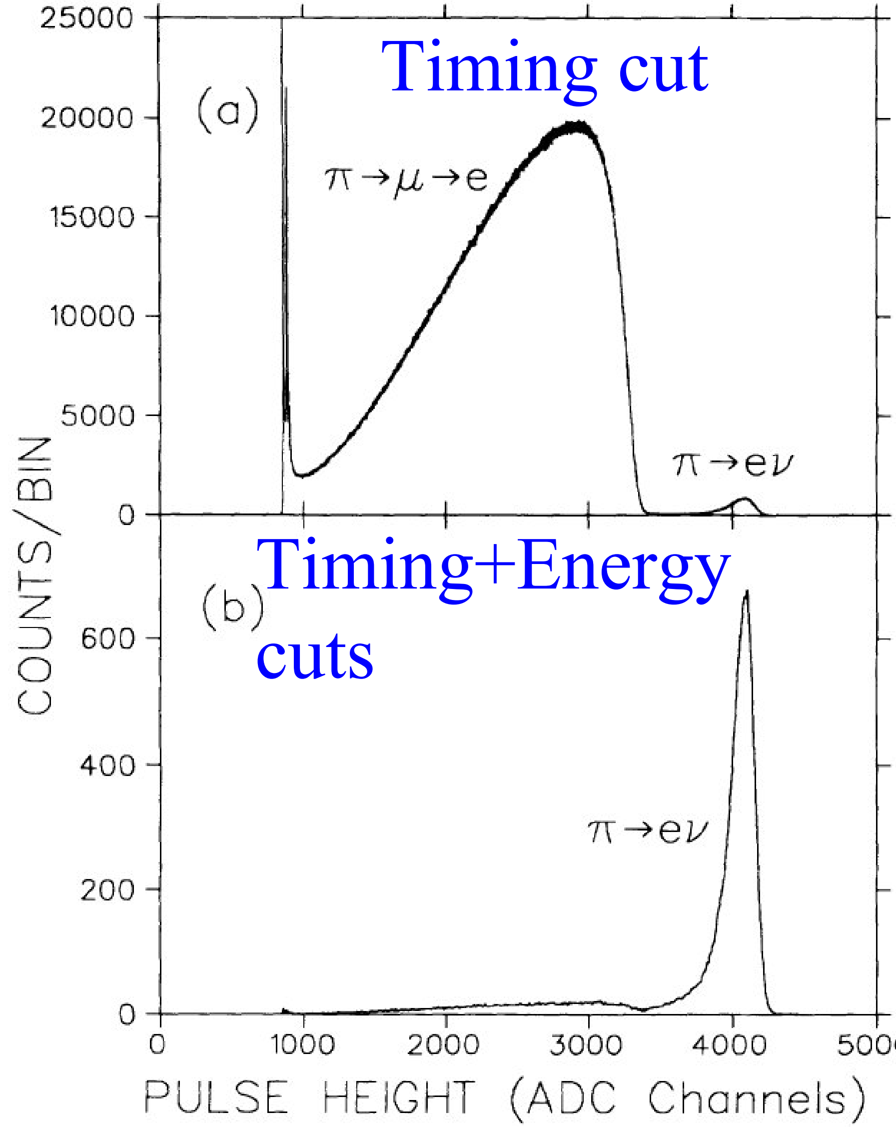
$T_\pi + \Delta E_e$

$\pi - \mu - e$

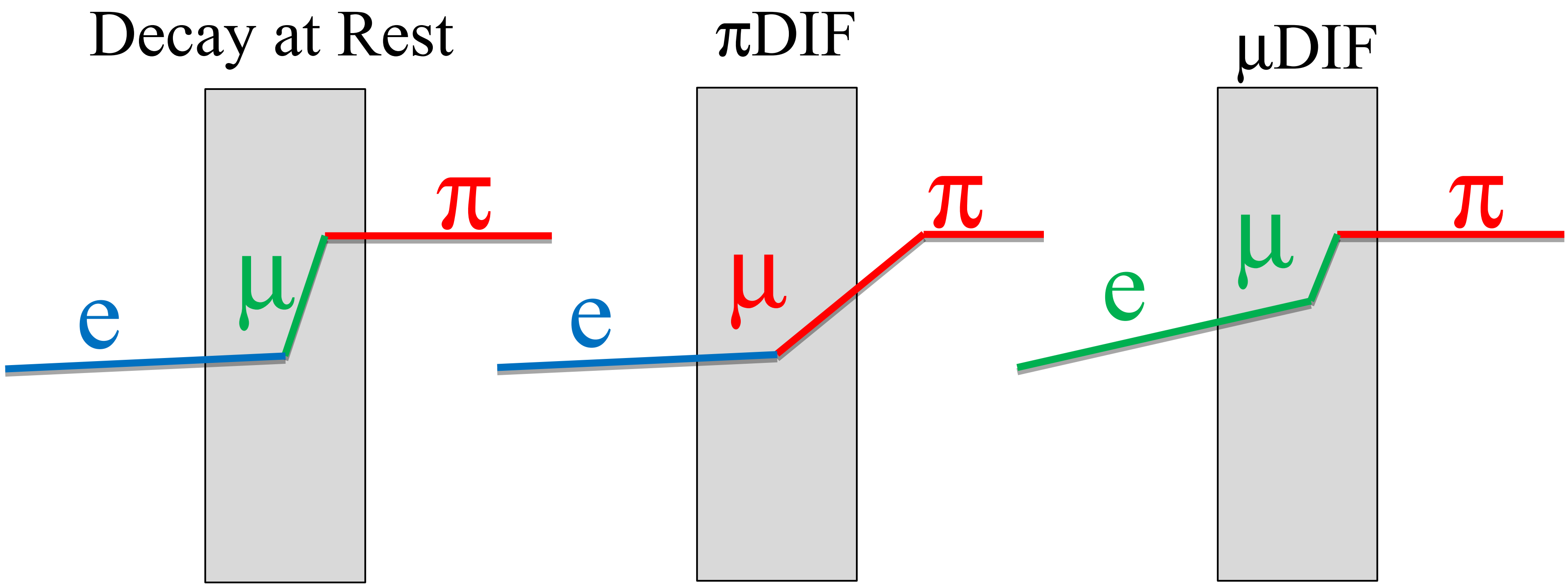
$T_\pi + E_\mu + \Delta E_e$

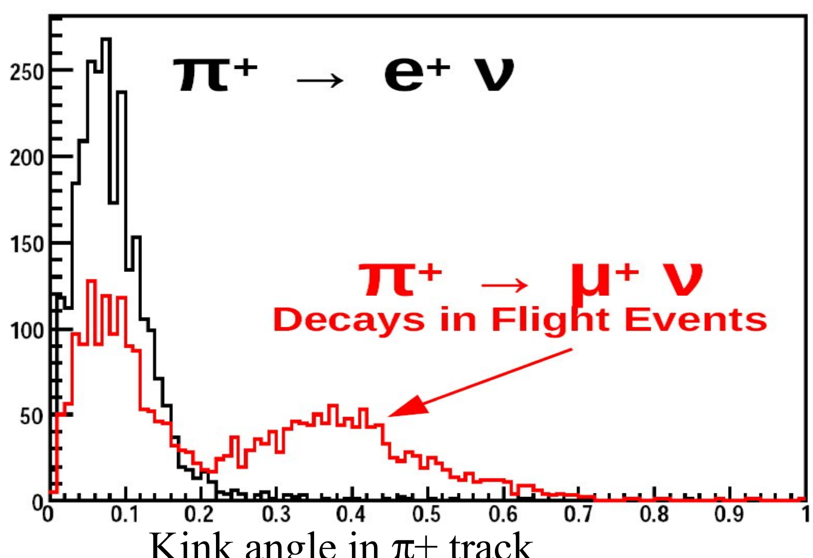


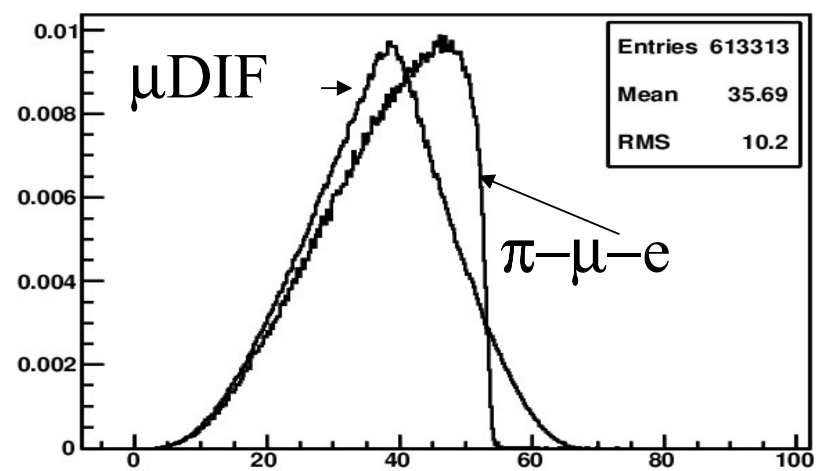




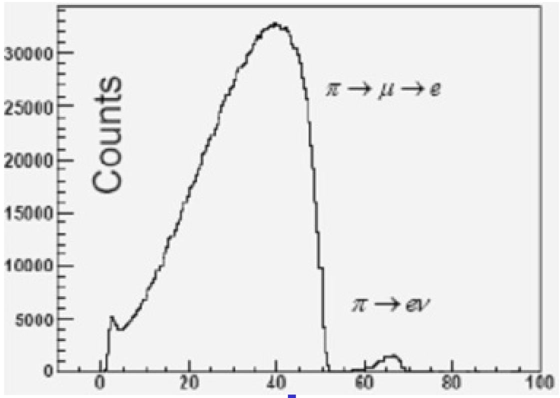
Remaining Background

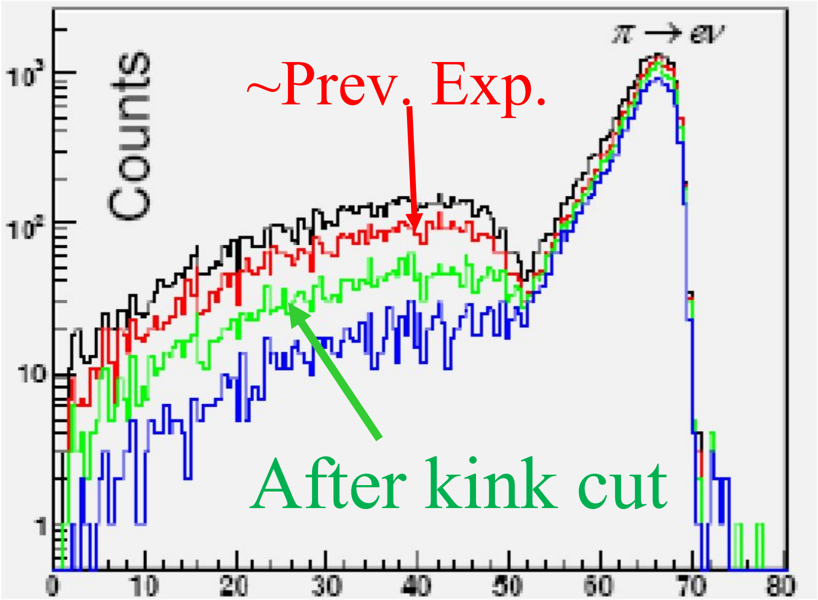


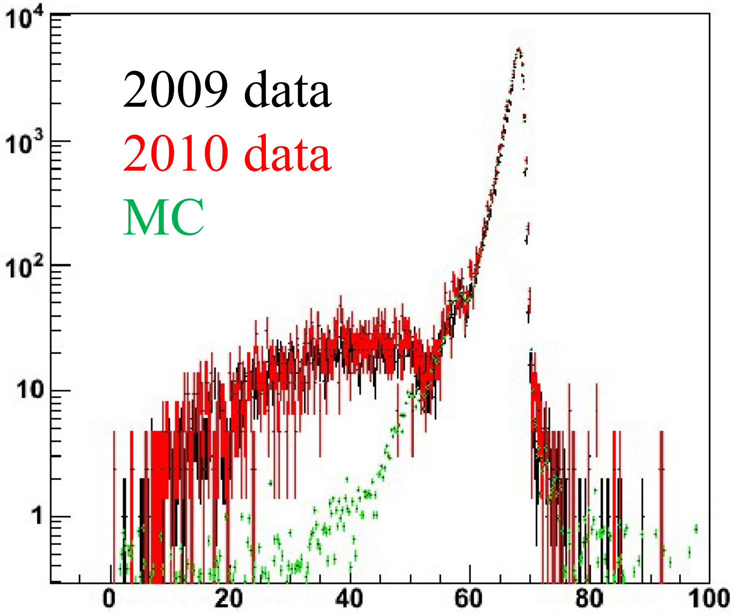




Empirical tail evaluation







- -Time and target-pulse infomation suppresses π→μ→e decays.
- -Upstream tracking suppresses Decay In Flight events.
- -Expected improvement 0.25%→0.02% (combined with 30x statistical improvement)

Summary of uncertainties

Source	E248	S1072
Statistical	0.0028	0.0005 → 0.0003
Low-energy tail	0.0025	0.0003 → 0.0002
Accept diff.	0.0011	0.0003 → 0.0002
Pion life	0.0009	0.0002
Other	0.0011	0.0003 → 0.0002
Total Systematic	0.0044	0.0006 → 0.0004

Massive Neutrino Search

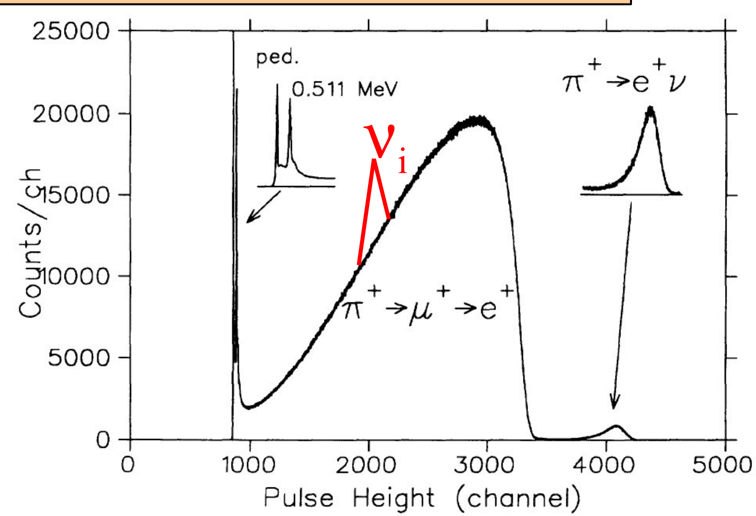
$$\begin{bmatrix} e \\ \nu_e \end{bmatrix}\begin{bmatrix} \mu \\ \nu_\mu \end{bmatrix}\begin{bmatrix} \tau \\ \nu_\tau \end{bmatrix} + \nu_{\chi_1} \ldots \nu_{\chi_\kappa}$$

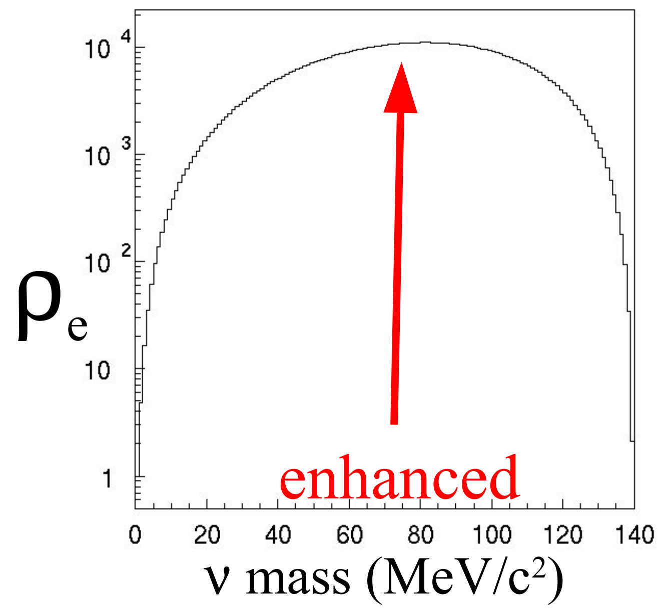
$$\nu_\ell = \Sigma_{i=1}^{3+k} U_{\ell i} \nu_i$$

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

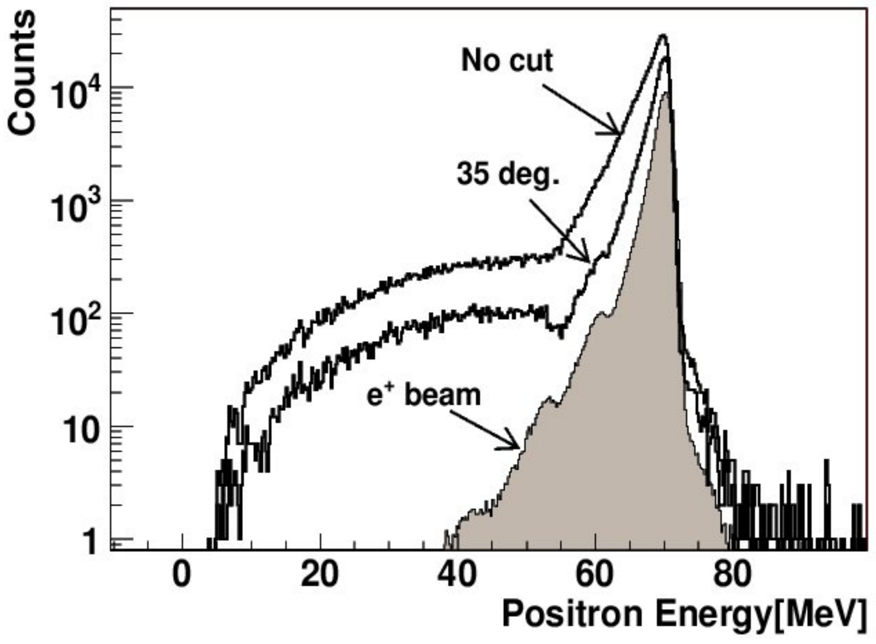
$$\frac{\Gamma(\pi\text{–}e\nu_i)}{\Gamma(\pi\text{–}e\nu_1)} = \rho_e \, |Uei|^2$$

Extra peak at low energy





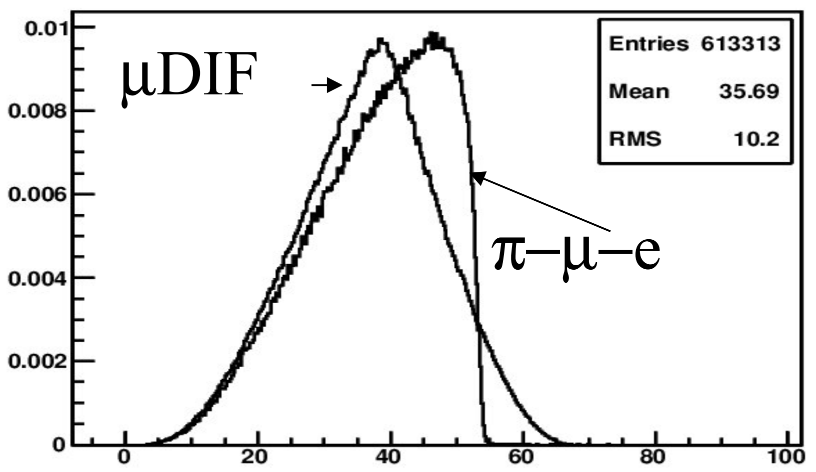
Positron spectra and BGs

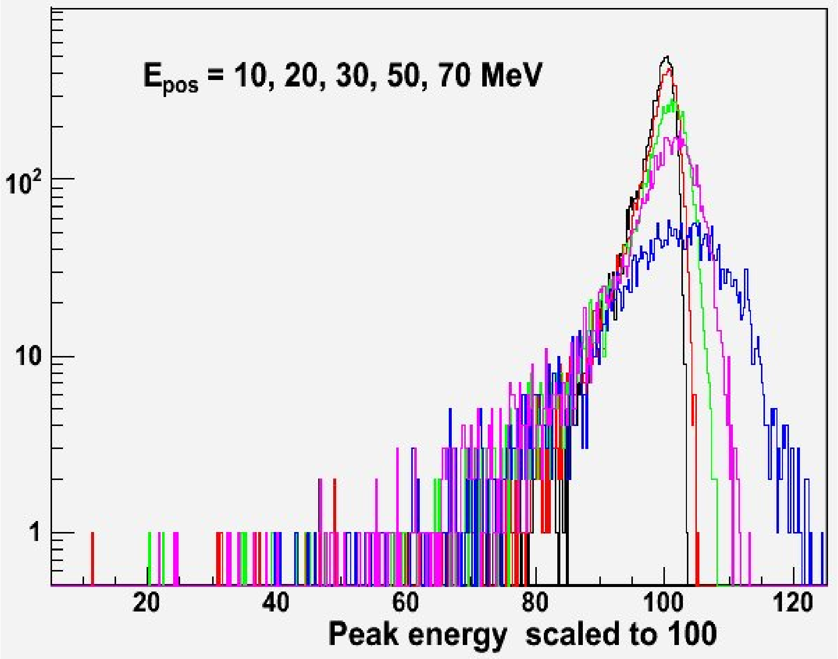


The beam positron spectrum was subtracted before fitting.

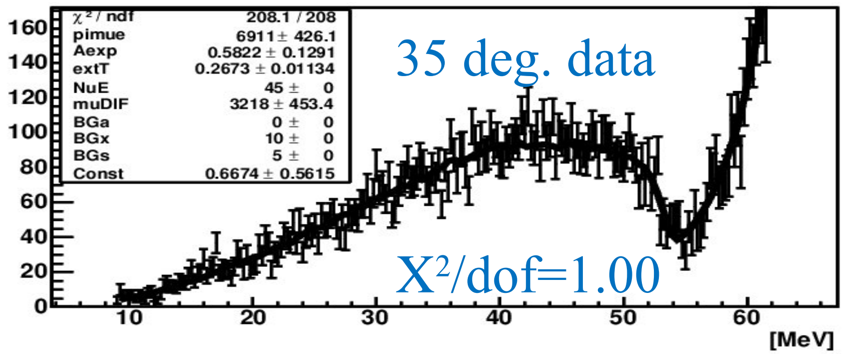
Components:

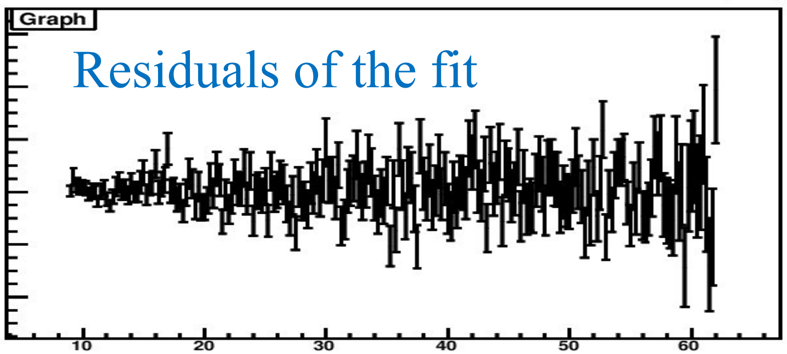
- π–μ–e (t = 150-500 ns)
- μDIF (π–μ–e → in flight)
- a*exp(b*E) + c
- Extra peak (MC generated)

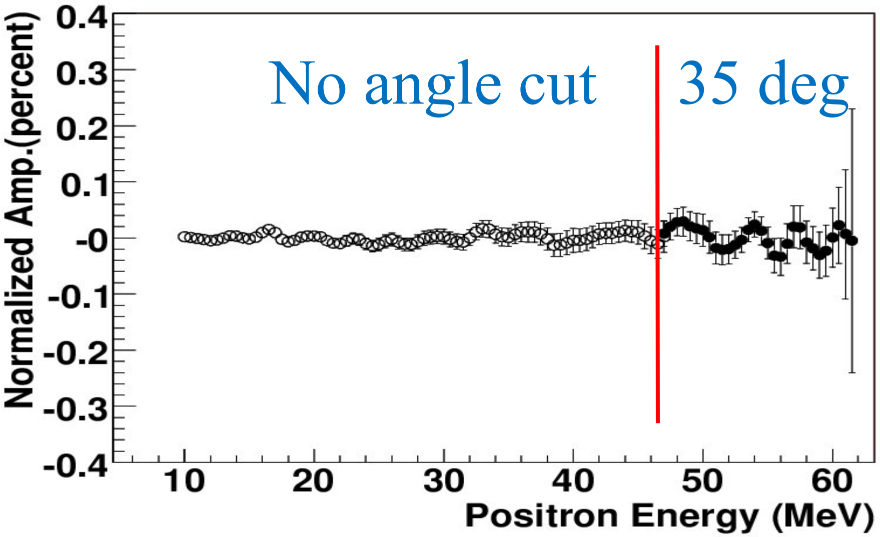


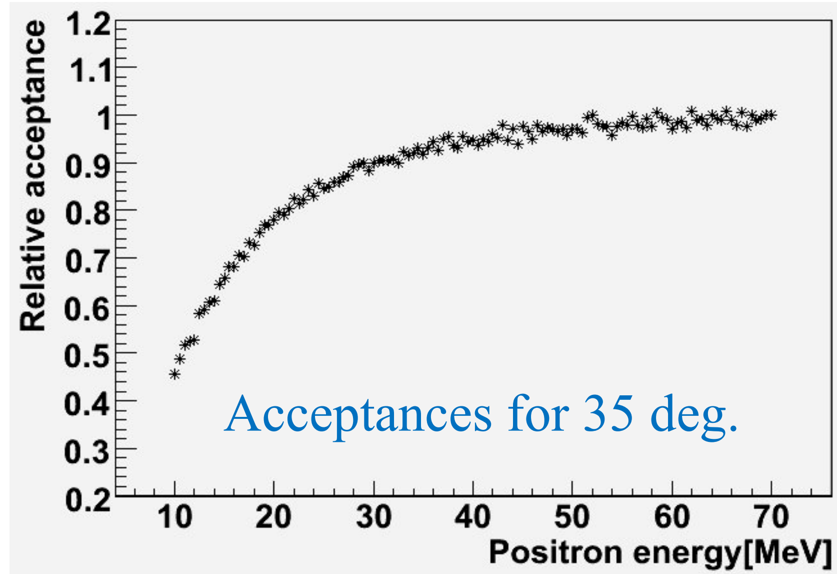


Fit results







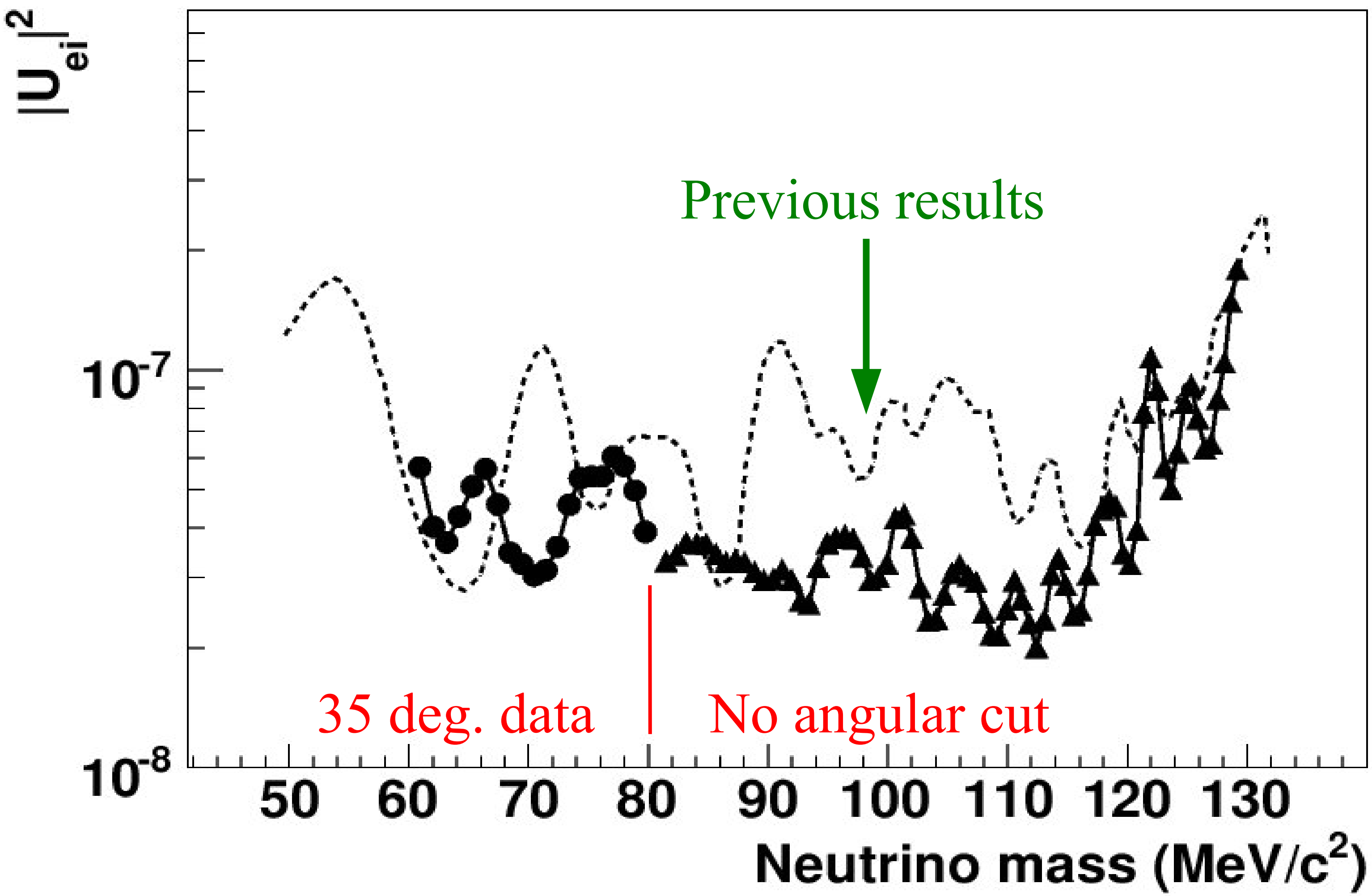


Assume Gaussian probability distribution and physical region to be positive.

→ 90% c.l. upper limit.

$$\frac{\Gamma(\pi - e\nu_i)}{\Gamma(\pi - e\nu_1)} = \rho_e \, |U_{ei}|^2$$

90 % C.L. Upper limits

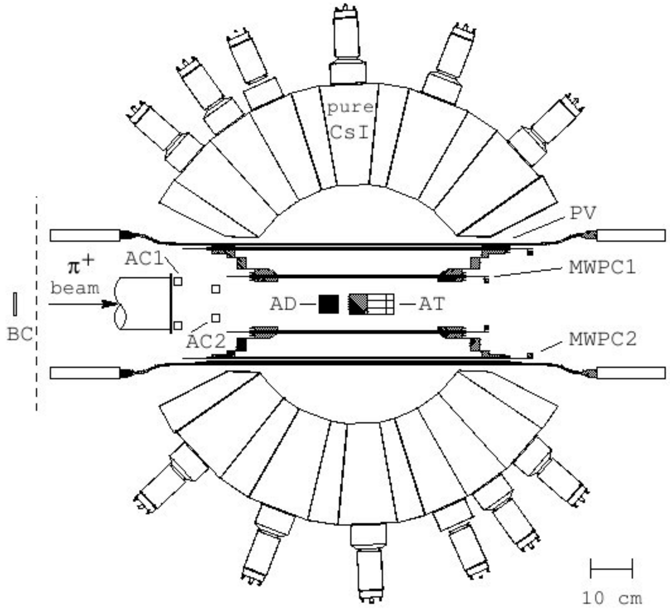


To be published in Phys. Rev. D.

Progress/plan

2005.12 Experiment was approved.
2009. 4 Engineering run (detector,trigger,tests…)
9 Production run (100 days); 1M clean π–eν events.
2010 Production run (200 days); 3M π–eν events in total.
2011 Production run (100 days);
2012+ More production run. 10 M clean π–eν events.

PEN group at PSI
- -12 r.l. Pure CsI crystals covering 3π.
- -Completed data taking in 2010.
- -Accumulated 10 M π–eν events.
- -Analysis in progress



Conclusion

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

- $\pi \rightarrow e\nu$ is sensitive to the presence of PS interactions--- searches physics beyond the SM up to 1000TeV.

-Precision of <0.1 % in the branching ratio is expected from the data in 2010-2012+.

-Further improvement in the massive neutrino search.