High Precision Measurement of the $\pi^+ \rightarrow e^+\nu$ branching ratio

~A sensitive probe in the search for new Physics~

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UBC/Osaka University

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3. KEK, 4. Osaka University,
5. TRIUMF, 6. Tsinghua University 7. University of British Columbia,
8. University of Northern British Columbia, 9. Virginia Tech

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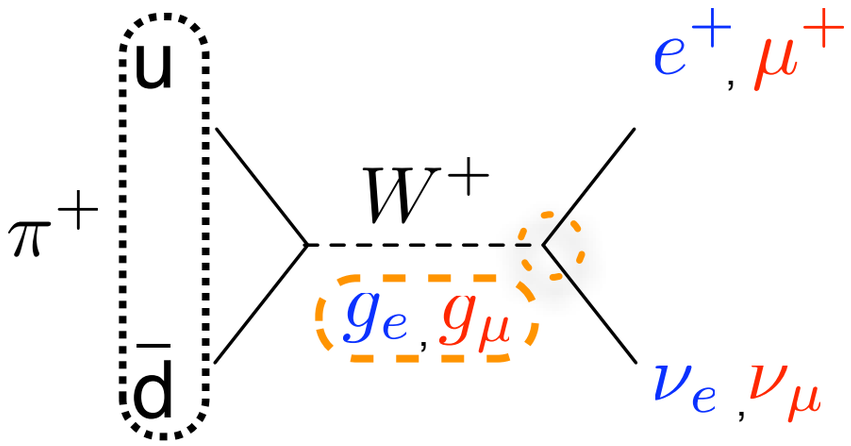
$\pi^+ \rightarrow e^+\nu$ branching ratio

Standard Model Prediction



- Lepton universality
  $g_e = g_\mu$
- Helicity suppression

$$R^{SM} = \frac{\Gamma(\pi^+ \rightarrow e^+\nu_e + \pi^+ \rightarrow e^+\nu_e\gamma)}{\Gamma(\pi^+ \rightarrow \mu^+\nu_\mu + \pi^+ \rightarrow \mu^+\nu_\mu\gamma)} = 1.2353(1) \times 10^{-4}$$

(0.01%)

Experimental Result

- TRIUMF (E248) : R^{exp}=1.2265±0.0034(stat)±0.0044(sys) x 10^{-4} (1992) 0.5%
- PSI : R^{exp}=1.2346±0.0035(stat)±0.0036(sys) x 10^{-4} (1993) 0.4%

Physics beyond the SM

- Non universality
- **Pseudo-scalar interaction** : charged Higgs, etc
- Others : R-parity violating SUSY, Massive neutrino etc

Process	g_e/g_μ
$\pi \rightarrow e\bar{\nu}/\pi \rightarrow \mu\bar{\nu}$	0.9985±0.0016
$K \rightarrow e\bar{\nu}/K \rightarrow \mu\bar{\nu}$	1.012±0.01
$\tau \rightarrow e\bar{\nu}\nu/\tau \rightarrow \mu\bar{\nu}\nu$	0.9999±0.0021
$\nu_e\nu_\mu$ scattering	1.10±0.005
W decays	0.999±0.011

Goal of our experiment

- Measurement within 0.1% accuracy

------> **sensitive to ~1000 TeV pseudo-scalar particle!!**

The PIENU experiment

- Aims to measure R=Γ($\pi^+ \rightarrow e^+\nu_e + e^+\nu_e\gamma$)/Γ($\pi^+ \rightarrow \mu^+\nu_\mu + \mu^+\nu_\mu\gamma$) within 0.1% accuracy
- TRIUMF M13 beam area, 75MeV ~60kHz π^+ beam ----> Next speaker
- Collaboration
  - ~25 people from Canada, USA, Japan and China
- Schedule
  - 2005.12 Experiment was approved
  - 2008.10 M13 beam line extension was completed
  - 2008.11 Test in M13 with all detector's components

  - 2009.4 Engineering run
  - 2009.9 Production run
  - 2010.4 Production run

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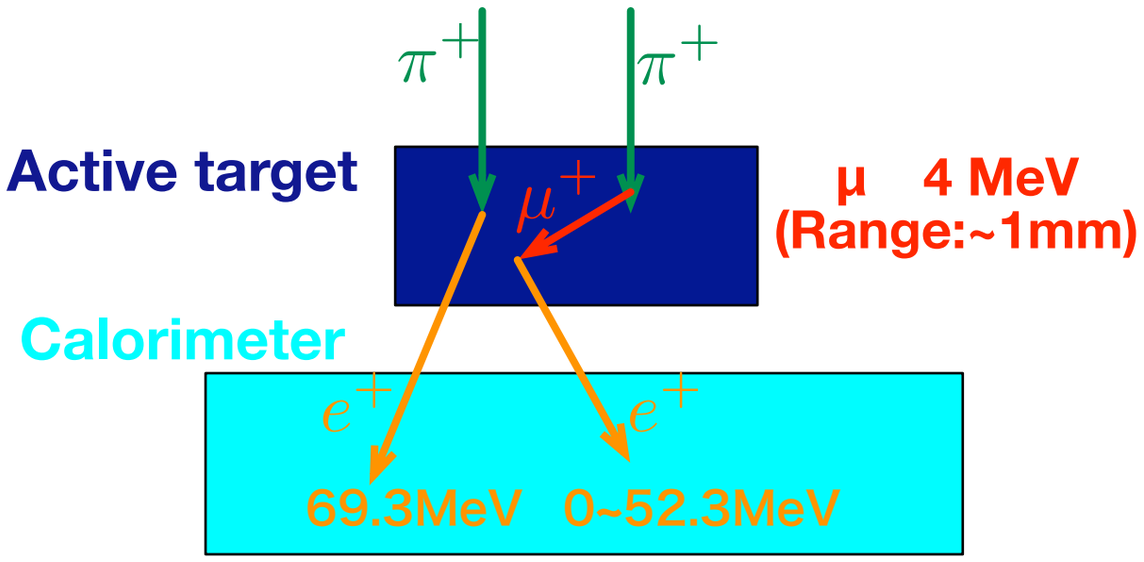
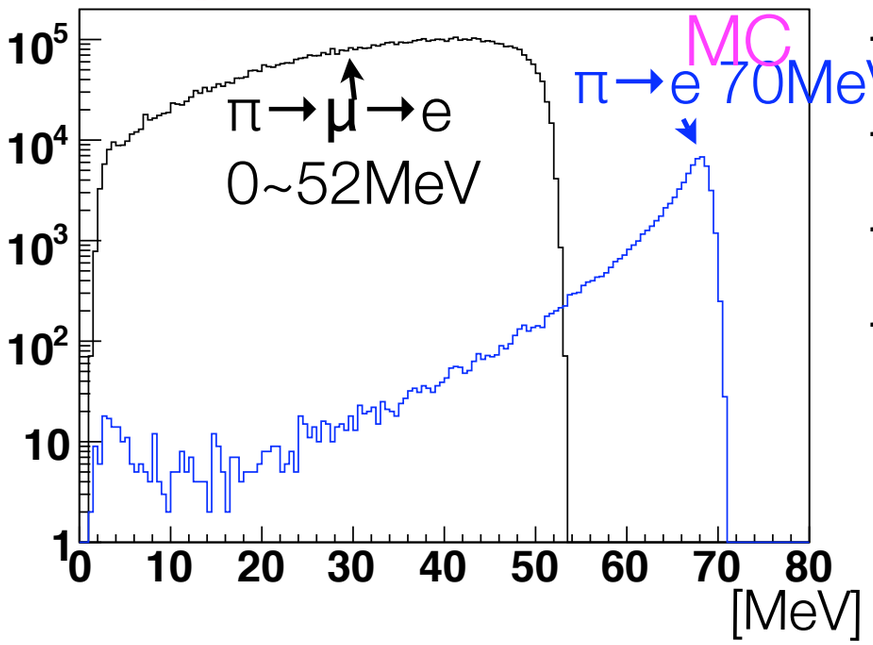
PIENU has just started!!

Experimental Method

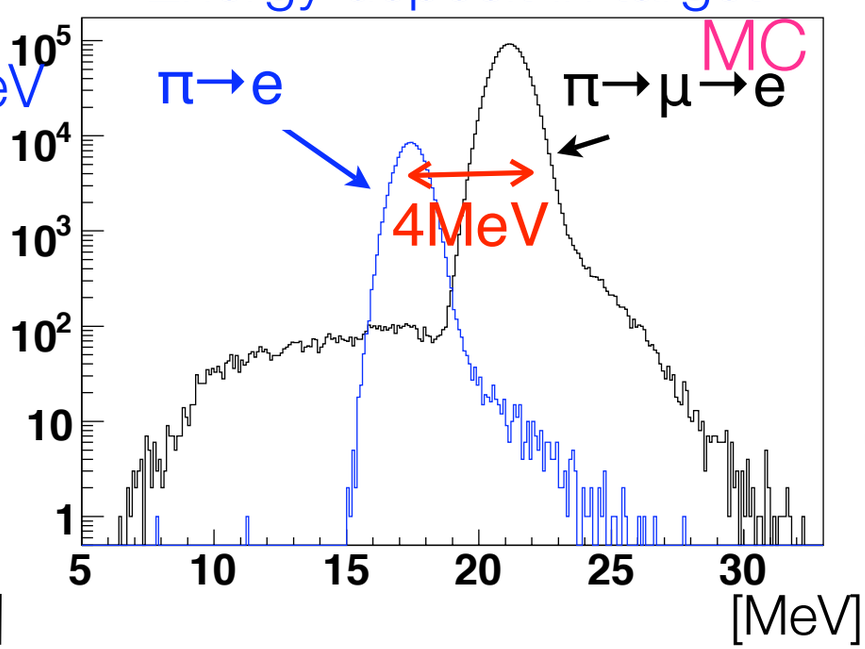


1. Discrimination of the decay mode
   - Energy deposit in calorimeter
   - Energy deposit in target
2. Estimation of raw branching ratio
   - Simultaneous fitting of time spectra
3. Some corrections
   - Tail correction and etc
     - Shower leak
     - Pion decay in flight event

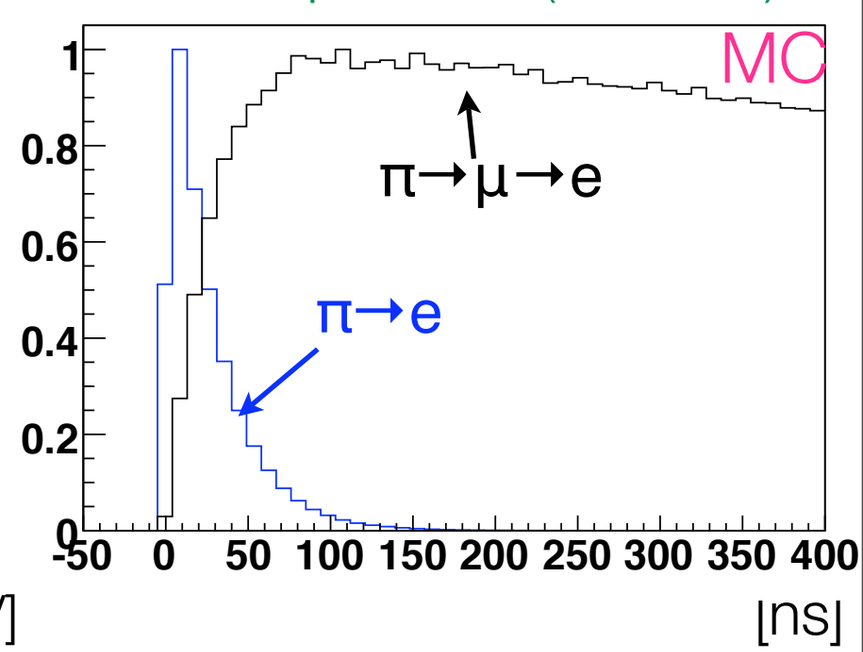
Energy deposit in calorimeter



Energy deposit in target



Time spectrum (Tπ⁺- Te⁺)



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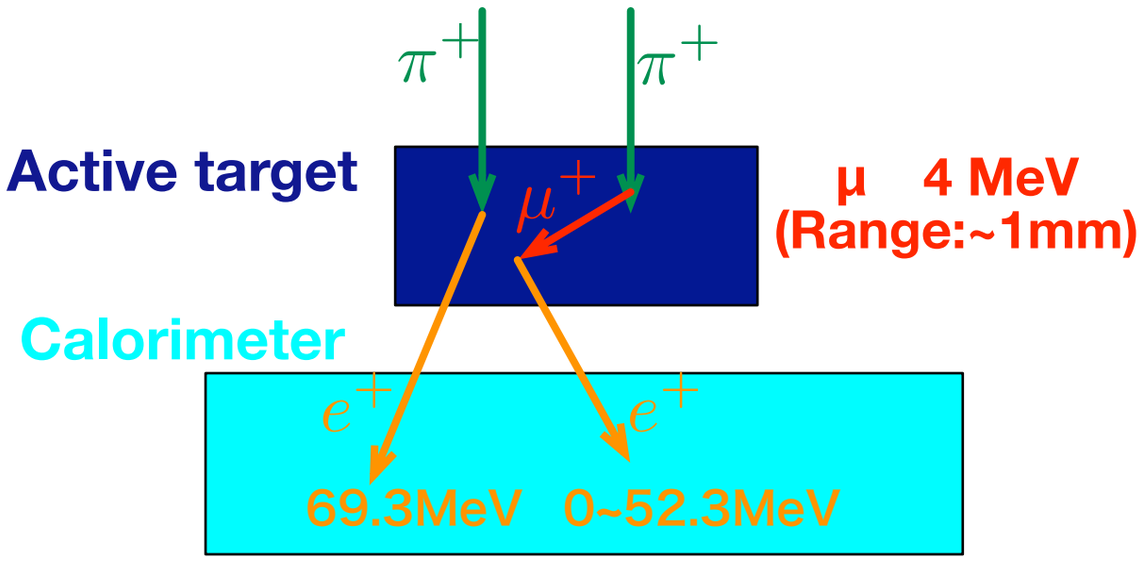

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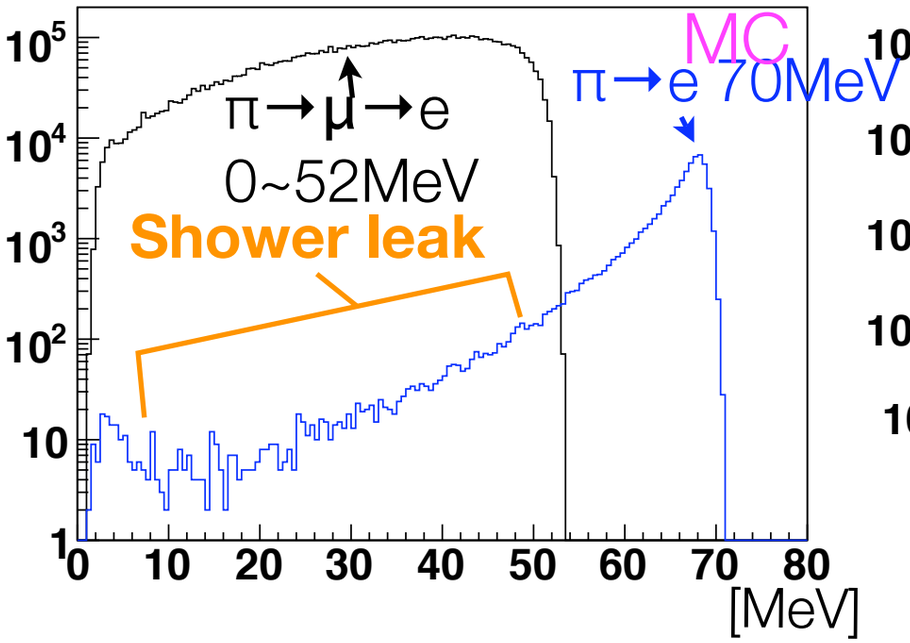
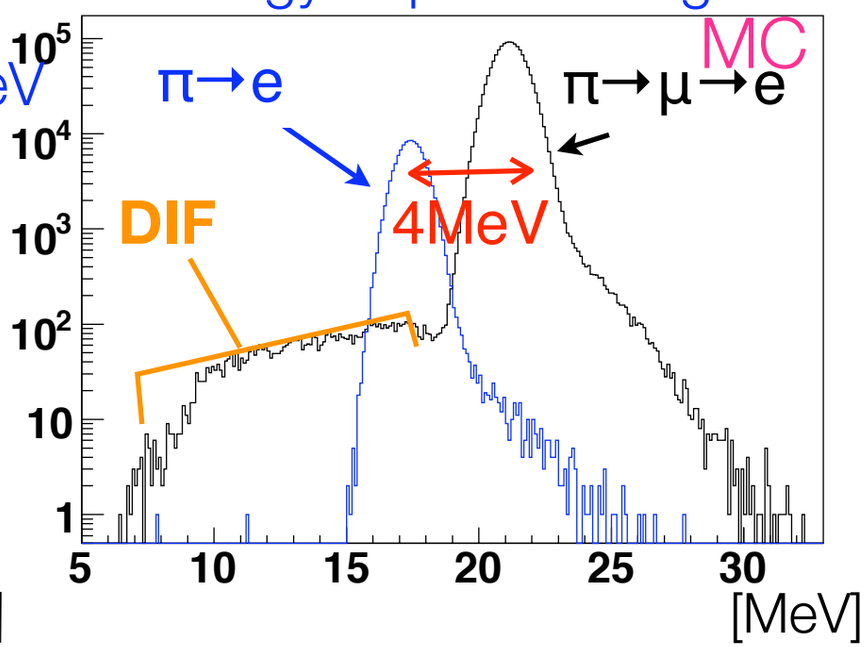
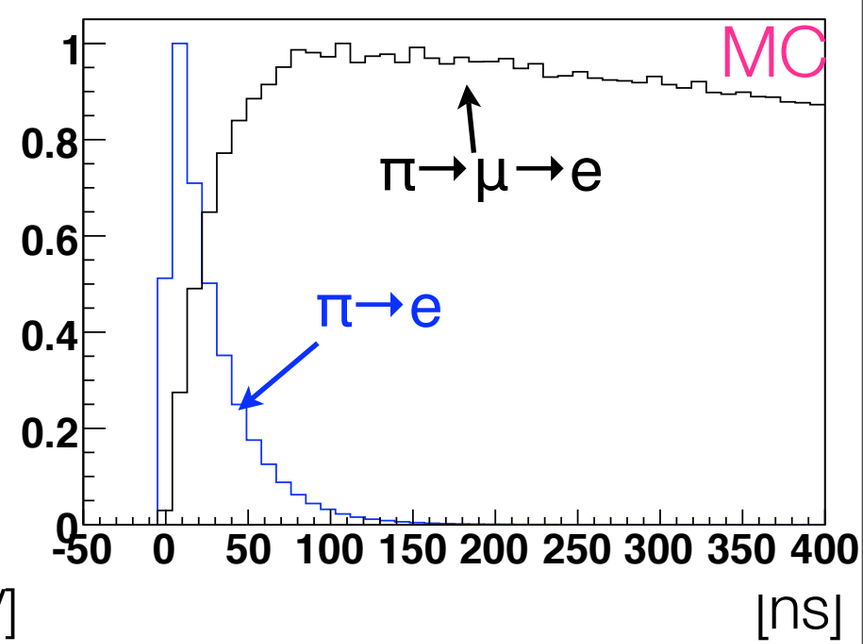


Energy deposit in target



Time spectrum ($T\pi^+$- Te^+)



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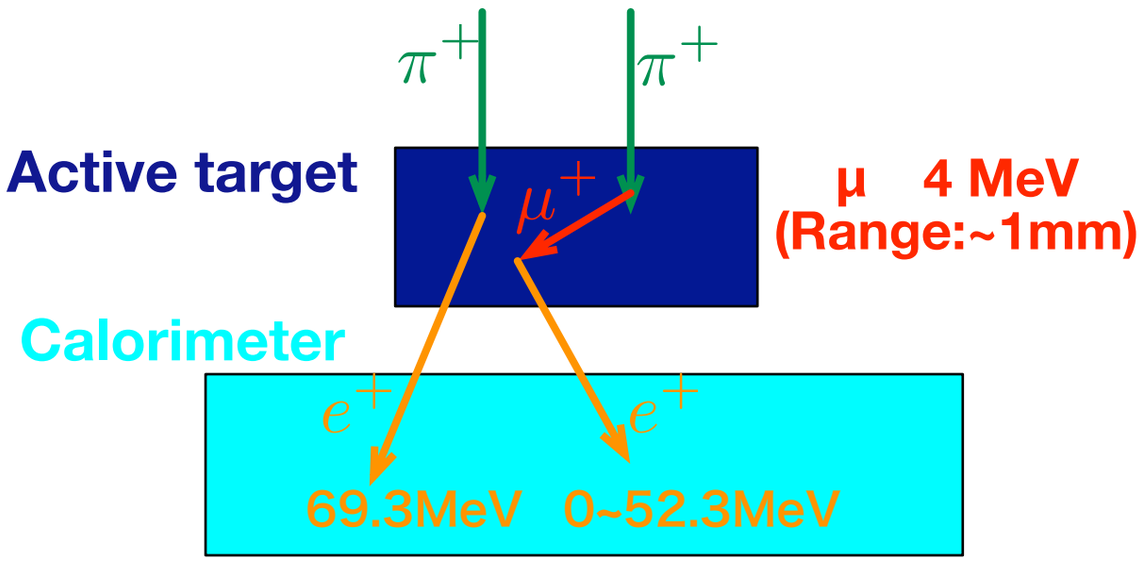

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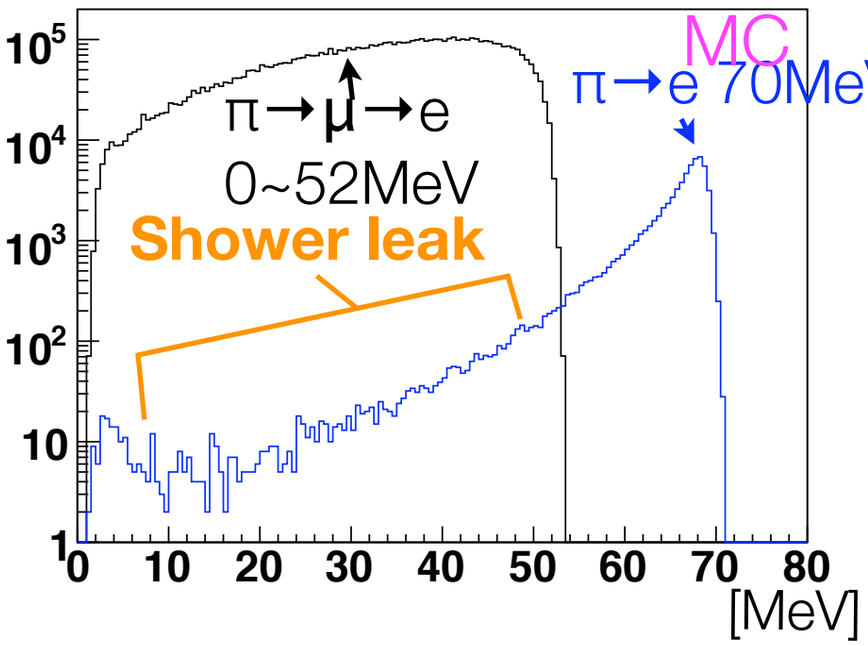
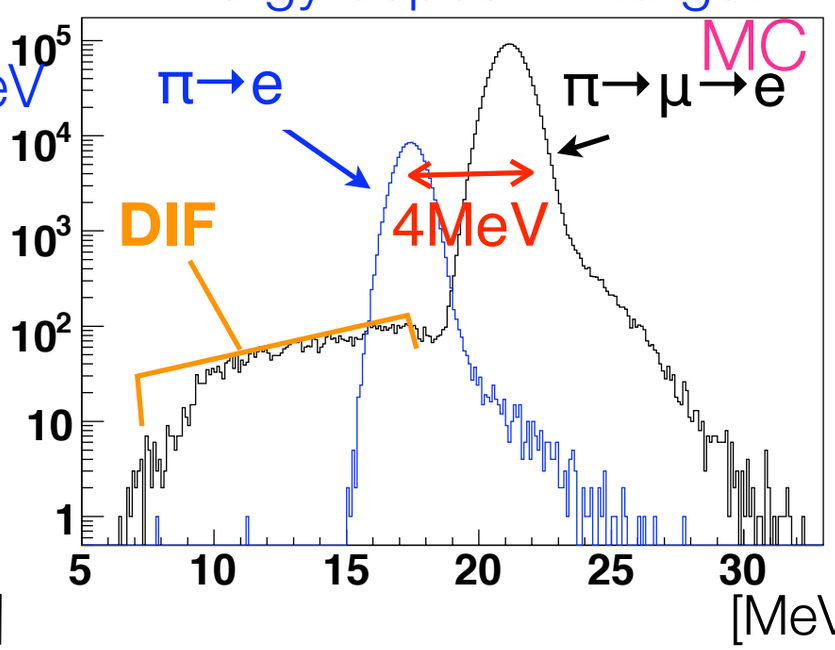
     Biggest source of error

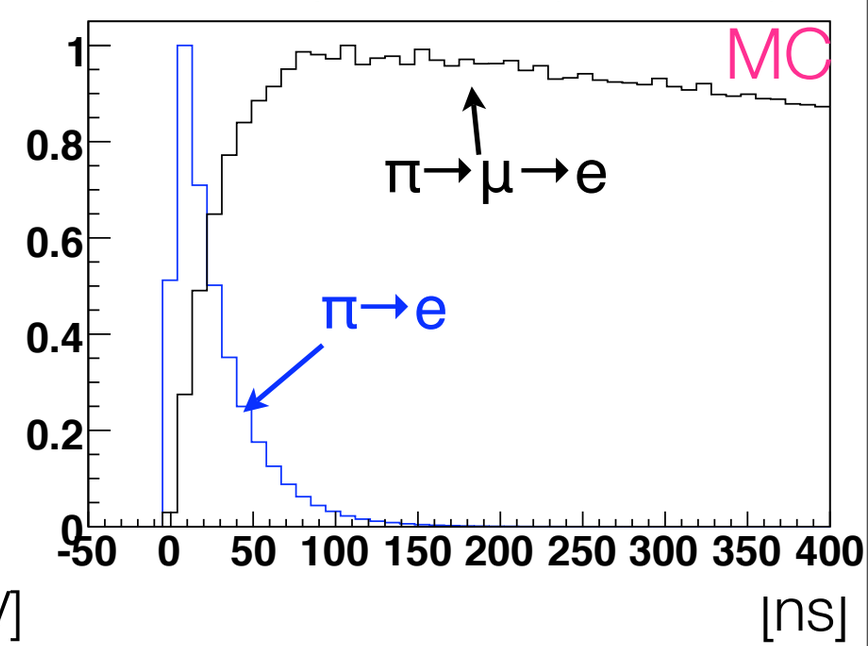
Energy deposit in calorimeter



Energy deposit in target



Time spectrum ($T\pi^+ - Te^+$)



PIENU Detector

- NaI crystal near target
  - Large solid angle(25%)
- CsI crystal
  - Detect shower leak from NaI
  - Reduce e+ low energy tail (8%->2%)
- Si-strips
  - Tracking of particle upstream and downstream of the target
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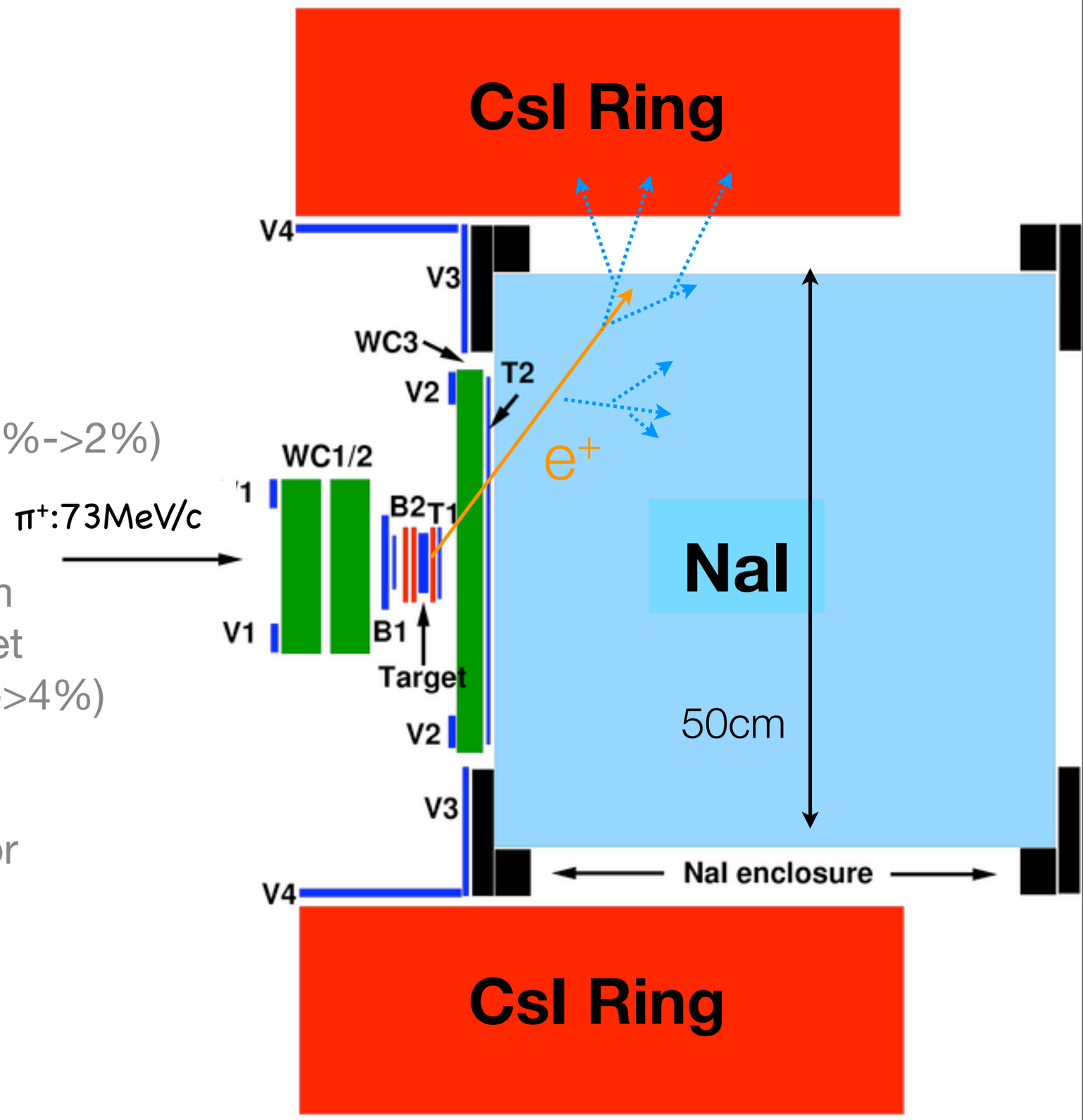
- Fast readout module
  - 500MHz FADC for Scintillator
  - 60MHz FADC for Crystals
  - Pileup rejection



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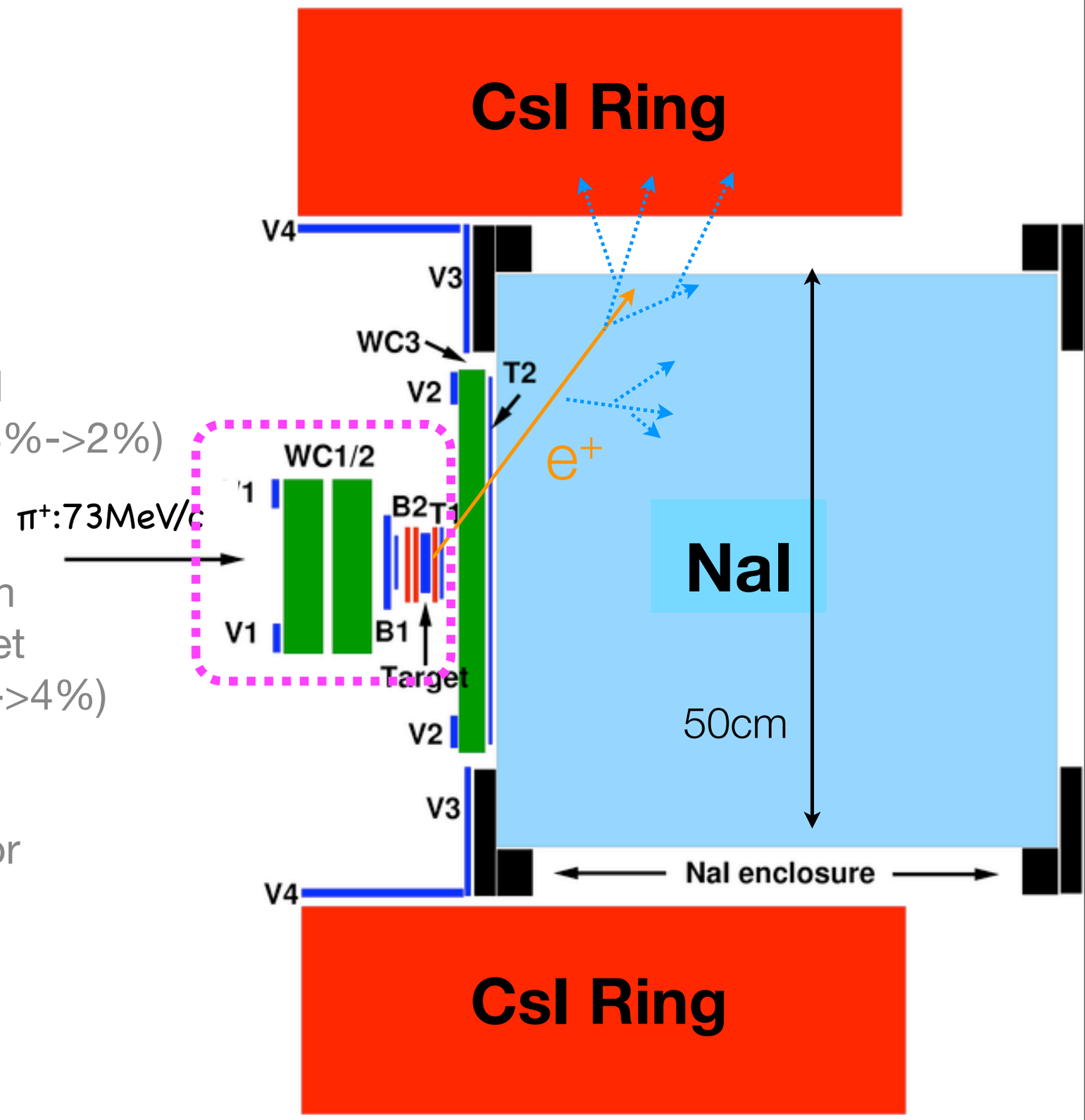

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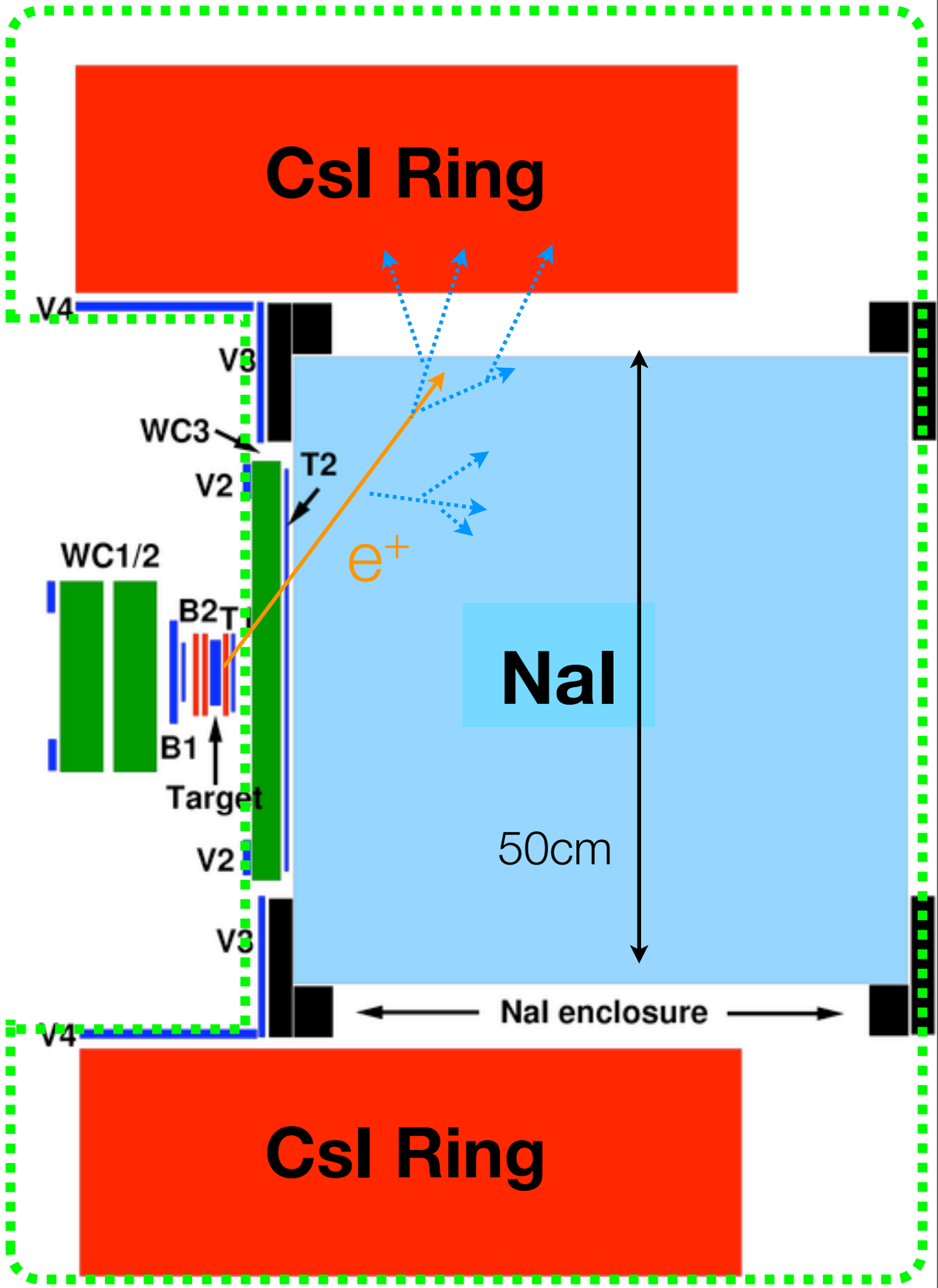
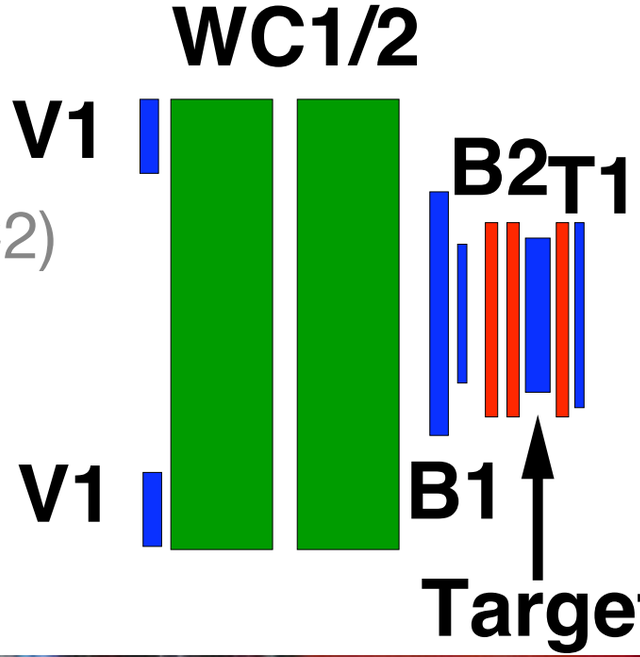
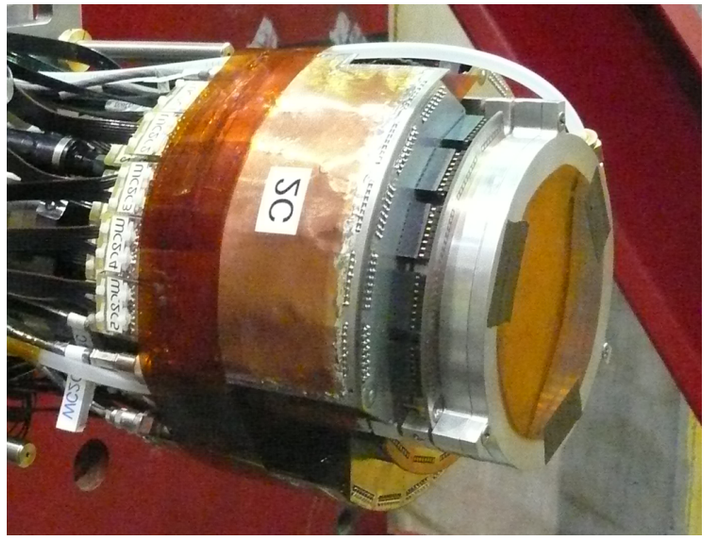
π^+:73MeV/c

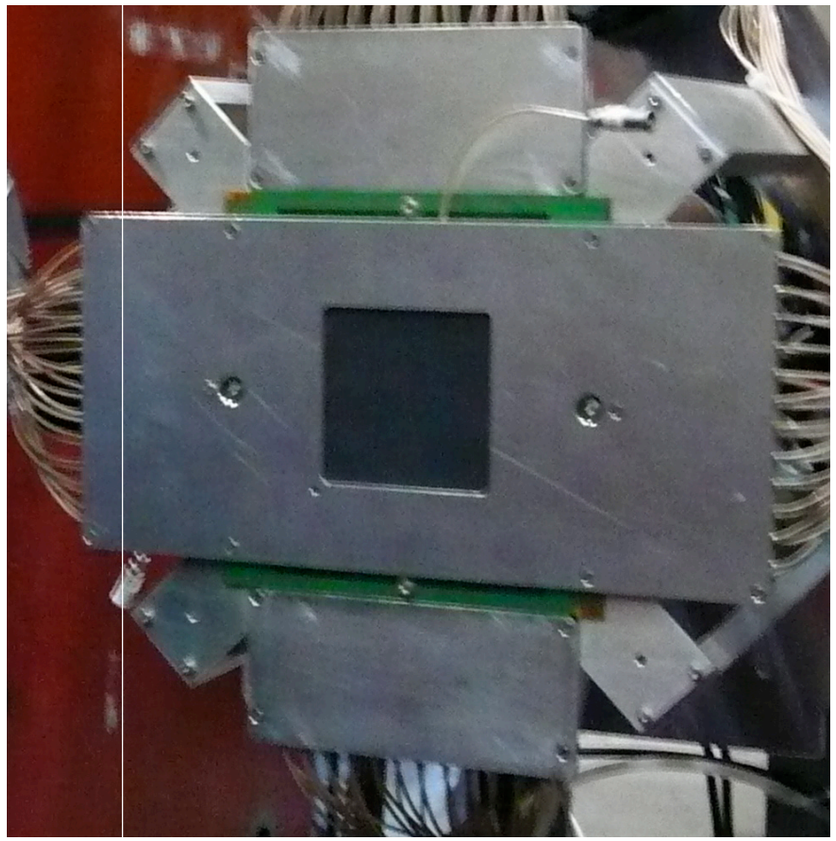


Actual Detector Setup 1

- Annular veto counter(V1)
- Beam wire chambers(WC1,WC2)
- Beam counters(B1,B2)
- Si-strip detectors(Ss1,Ss2)
- Target counter
- Si-strip detector(Ss3)
- Telescope counter(T1)

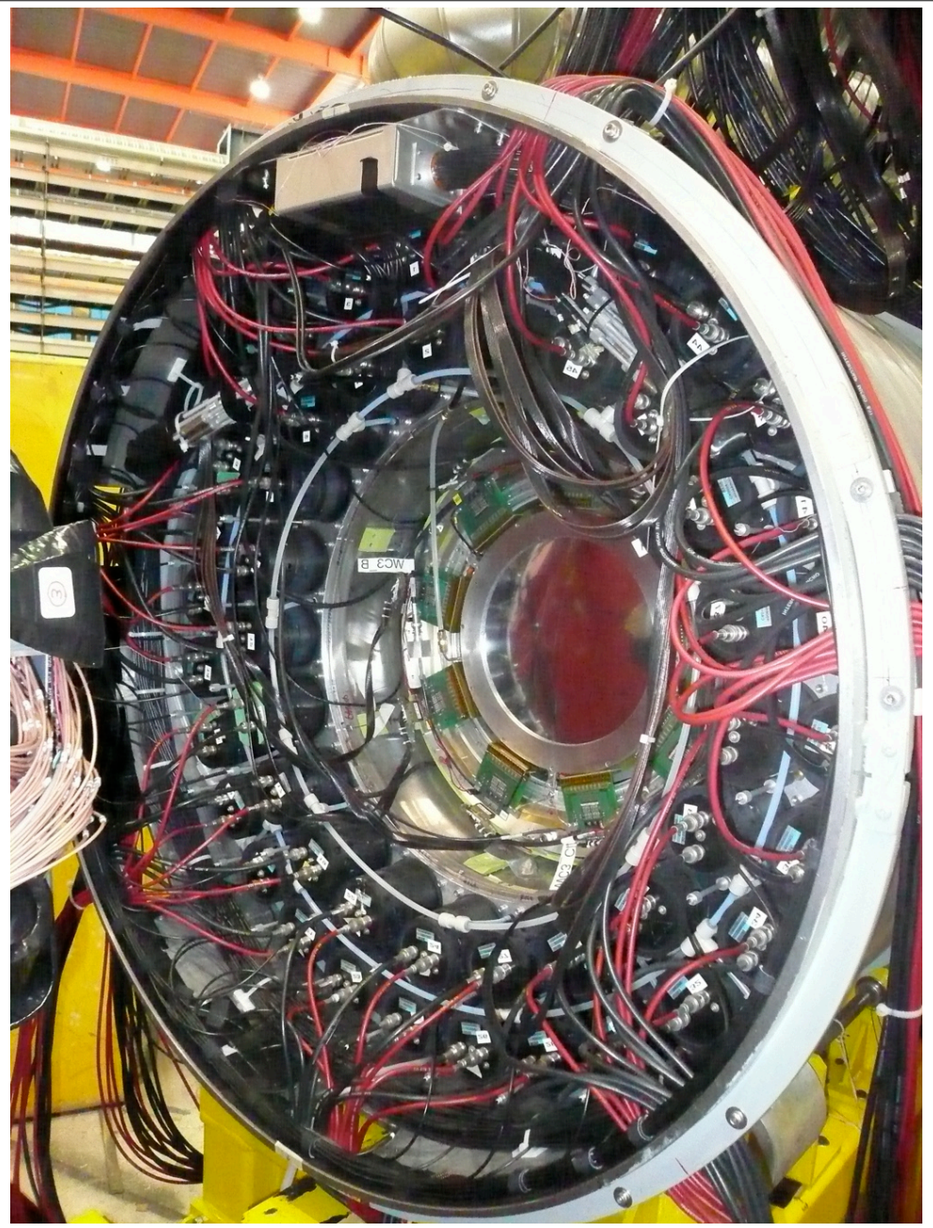


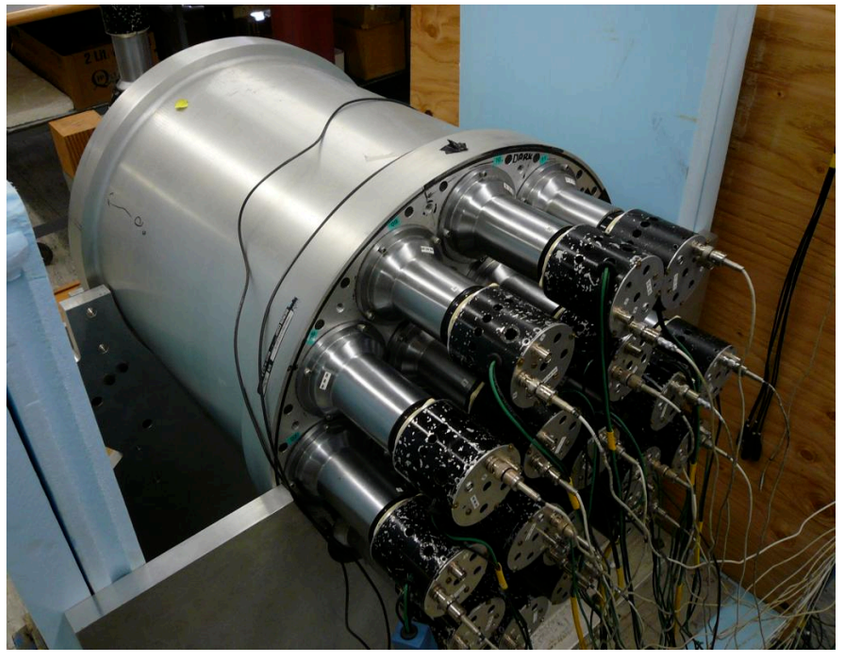




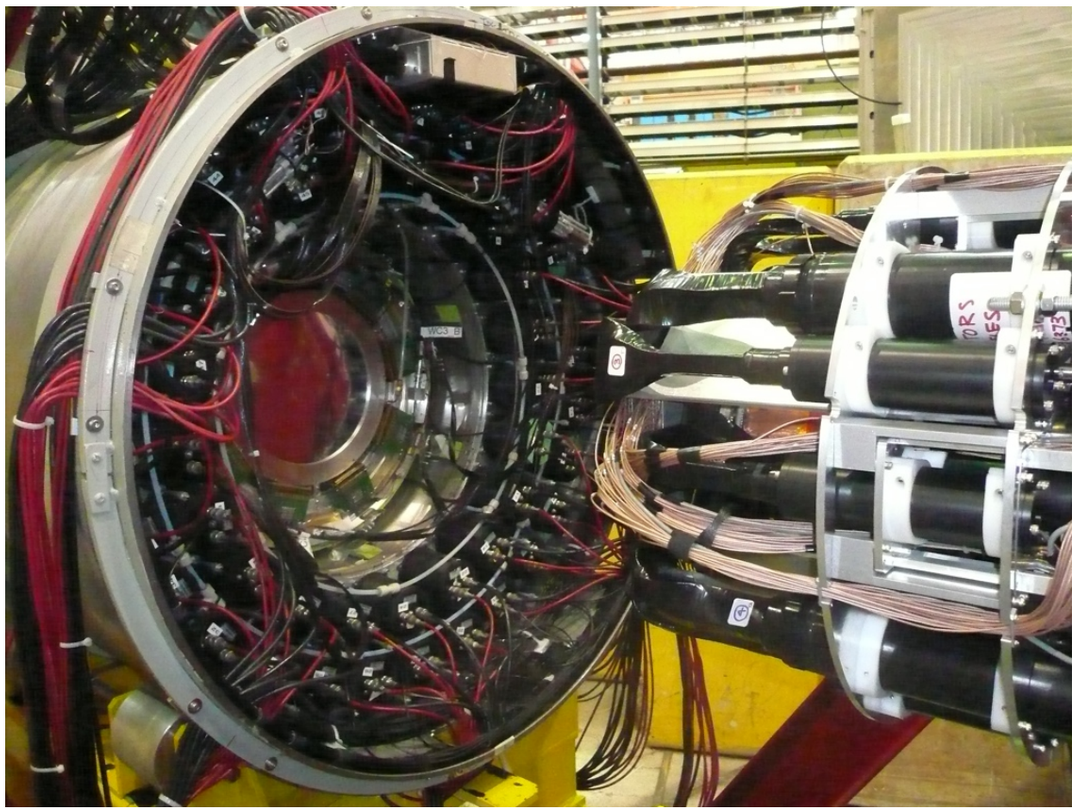
Actual Detector Setup 2

- Wire chambers(WC3)
- Telescope counter(T2)
- NaI calorimeter
- CsI ring calorimeter



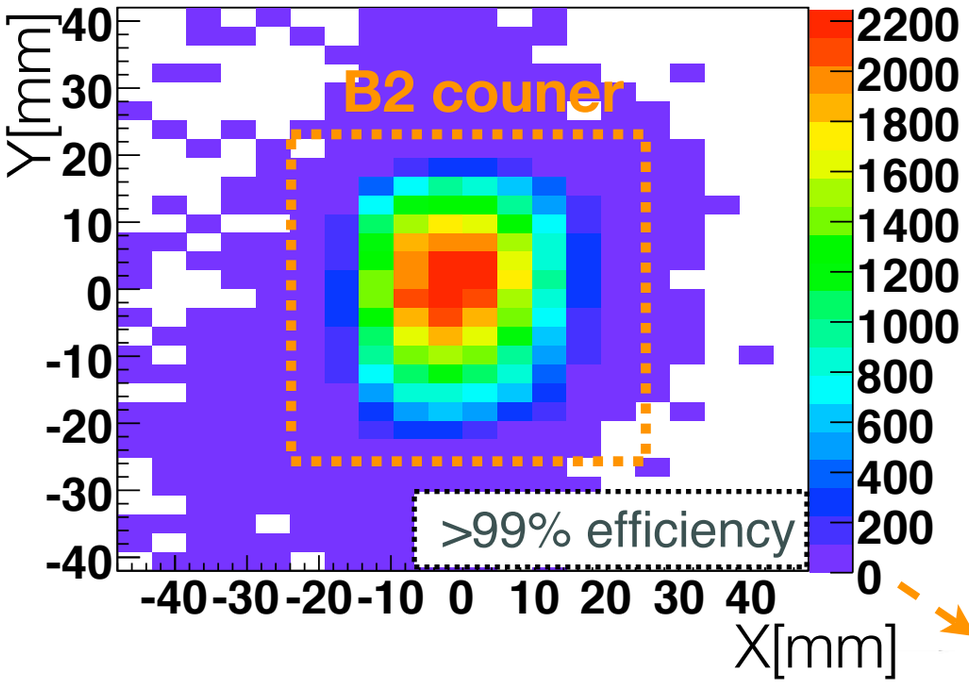


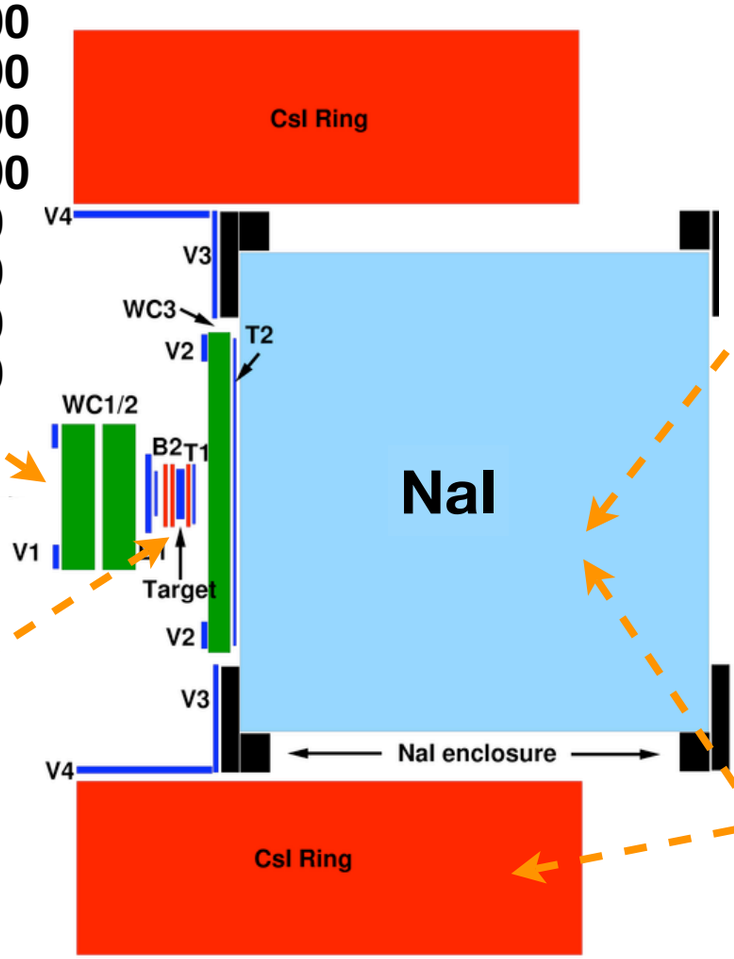
Overall view of PIENU setup



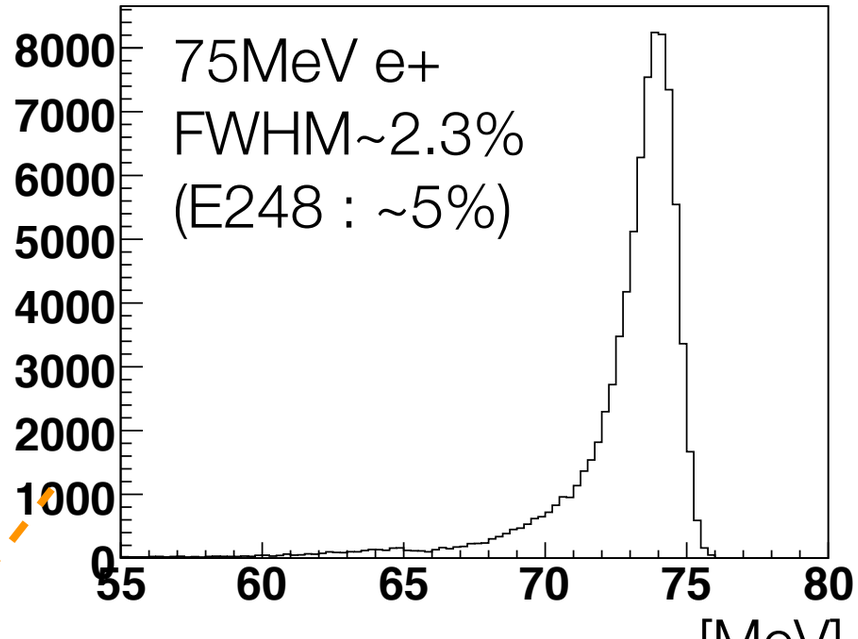
Detectors performances

Beam profile with WC1

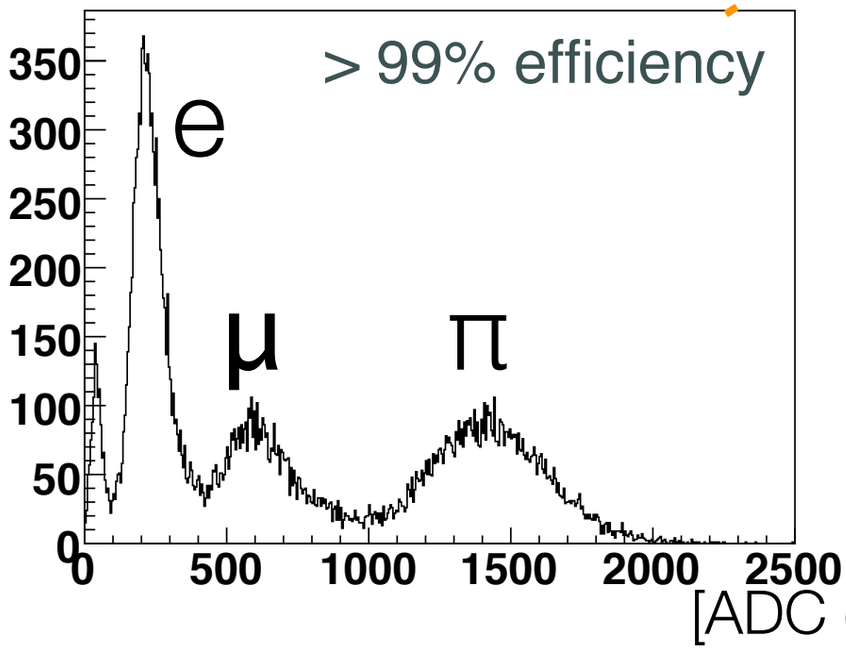




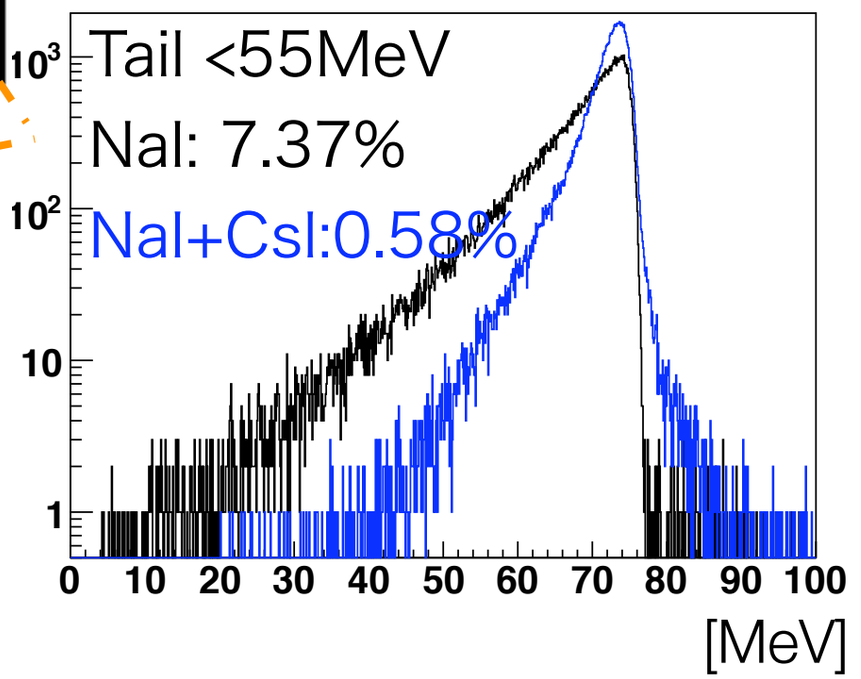
NaI energy spectrum



Si-strip energy deposit



e+ energy spectrum (75MeV e+ beam, Detector 50°)



Expected precision

Source	E248 TRIUMF 1992	PIENU	
Statistical	0.28%	0.05%	x10 acceptance & x3 run time
Low energy Tail	0.25%	0.03%	Reduction of shower leak and DIF event Crystal response study with e+ beam
Acceptance difference	0.11%	0.03%	Larger solid angle & better MC
Pion lifetime	0.09%	0.03%	Latest experimental result
Others	0.11%	0.03%	better calibration etc....
Total	0.5%	0.06%	

Summary

- PIENU aims to measure the branching ratio
  $R=\Gamma(\pi^+\to e^+\nu_e+e^+\nu_e\gamma)/\Gamma(\pi^+\to\mu^+\nu_\mu+\mu^+\nu_\mu\gamma)$ within **0.1%** accuracy

- **CsI ring** reduces shower leak in e+ energy measurement

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PIENU has just started
and may indicate new physics!!

Backup

Lepton Universality and New Physics

$$\frac{g_e}{g_\mu} = 1?$$

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$\pi \to e\bar{\nu}/\pi \to \mu\bar{\nu}$	0.9985 ± 0.0016
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W decays	0.999 ± 0.011

PiENu : $g_e/g_\mu < 0.05\%$

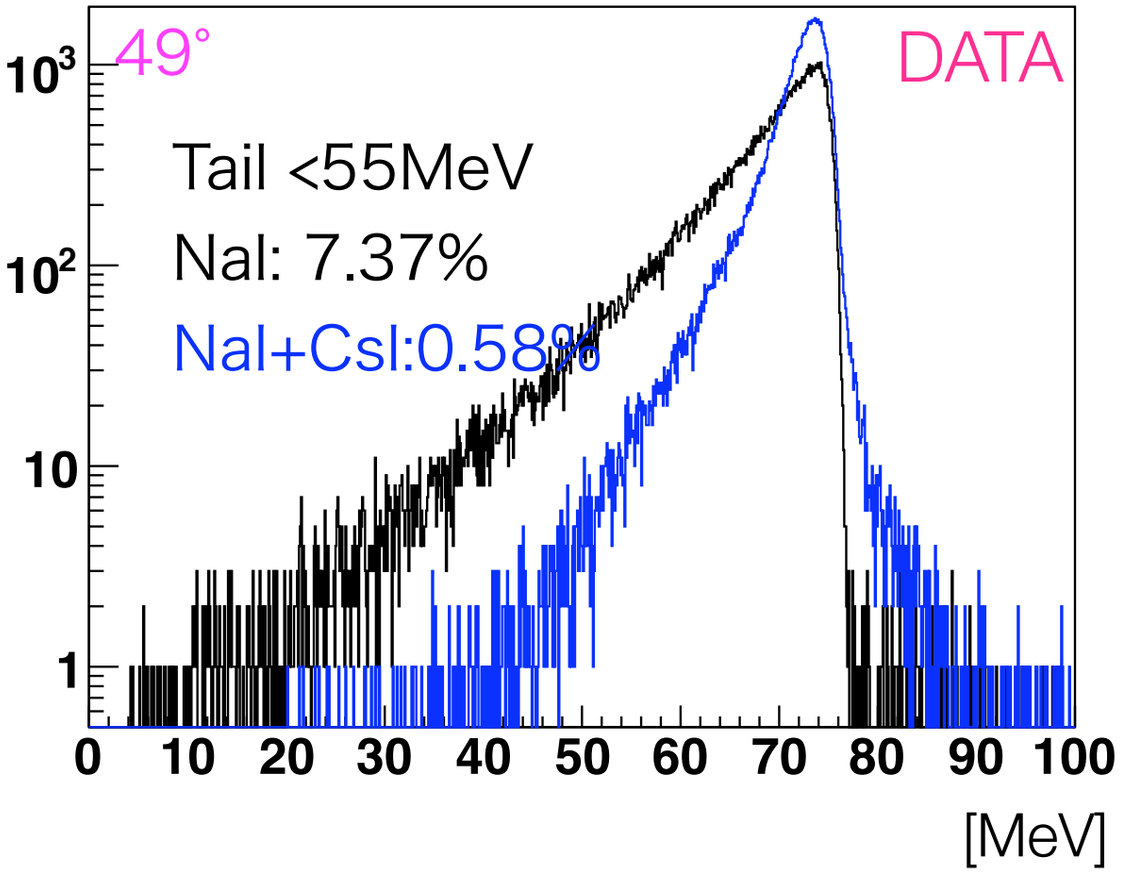
New pseudoscalar interaction:

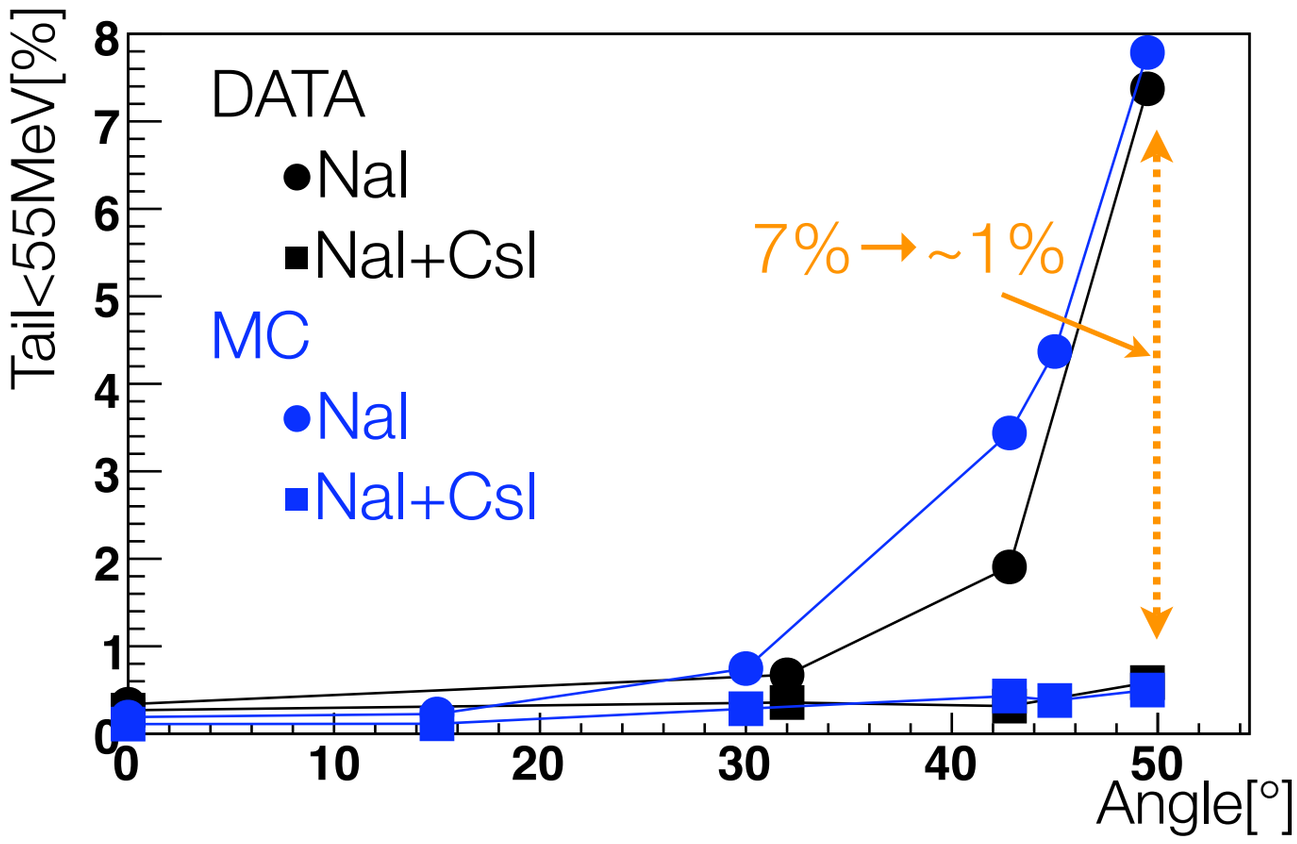
$$1 - \frac{R^{New}_{e/\mu}}{R^{SM}_{e/\mu}} \sim \mp \frac{\sqrt{2}\pi}{G_\mu} \frac{1}{\Lambda^2_{eP}} \frac{m_\pi^2}{m_e(m_d + m_u)}$$
$$\sim (\frac{1TeV}{\Lambda_{eP}})^2 \times 10^3$$

0.1% measurement $\Longrightarrow$ $\Lambda_{eP} \sim$ *1000 TeV*

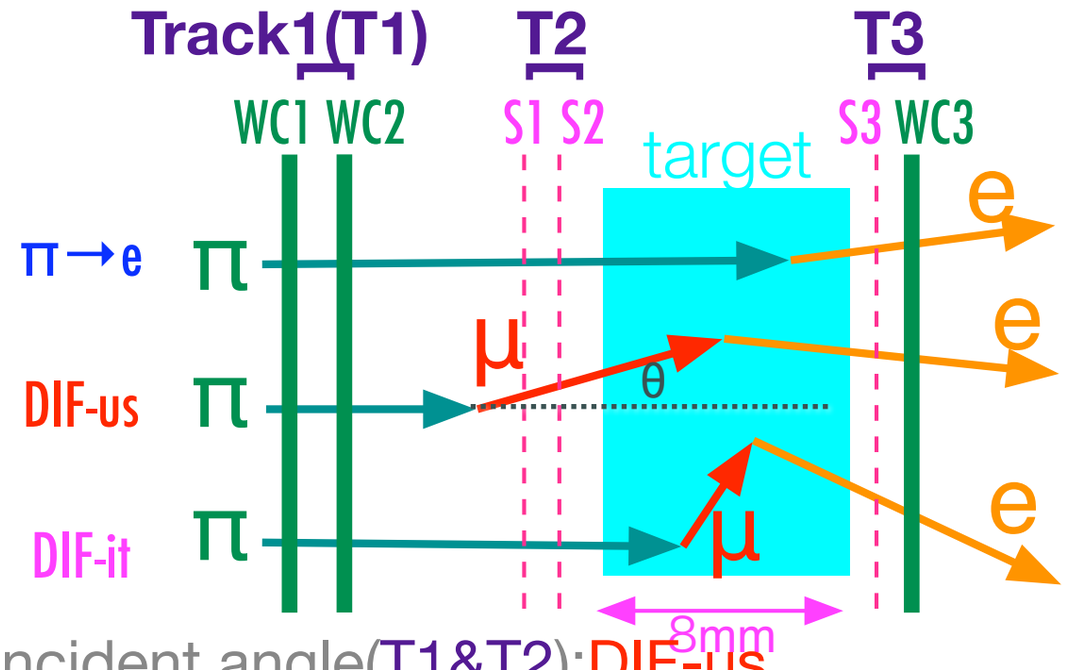
- *Massive ν's*
- *Scalar coupling*
- *Leptoquarks*
- *Compositeness*
- *R-Parity violation SUSY*
- . . .

Shower leak detection

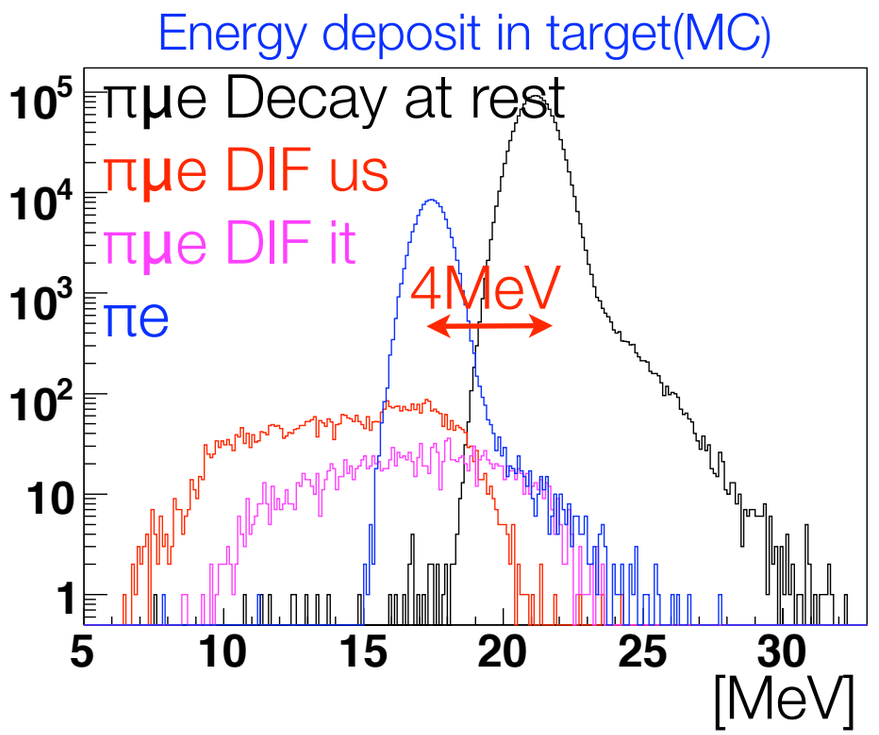




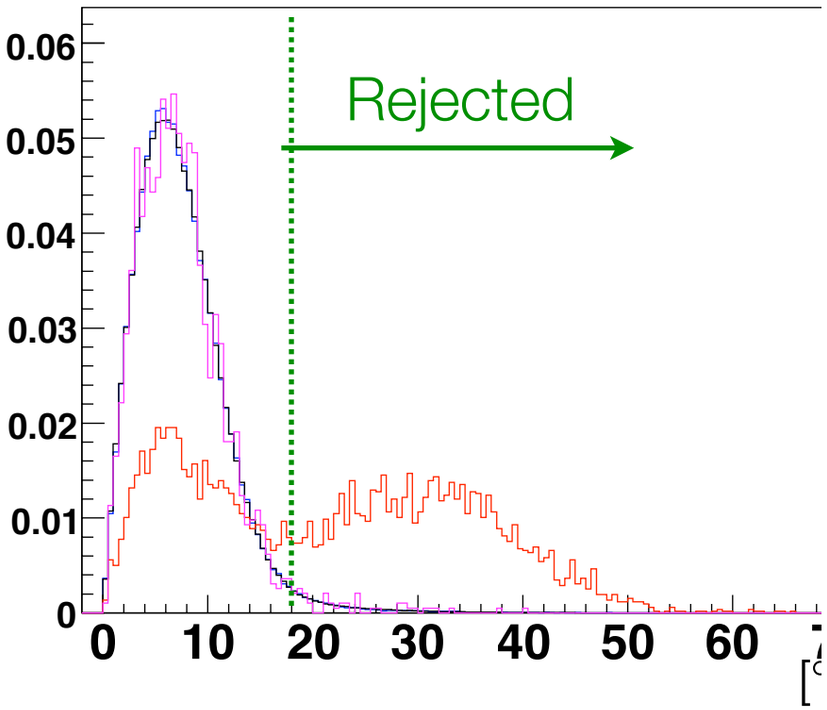
Decay In Flight

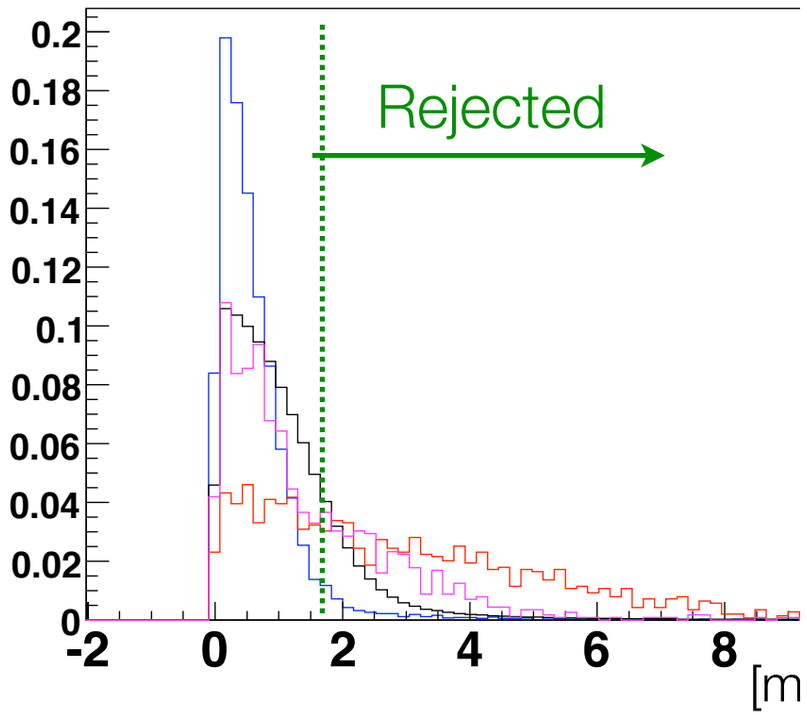


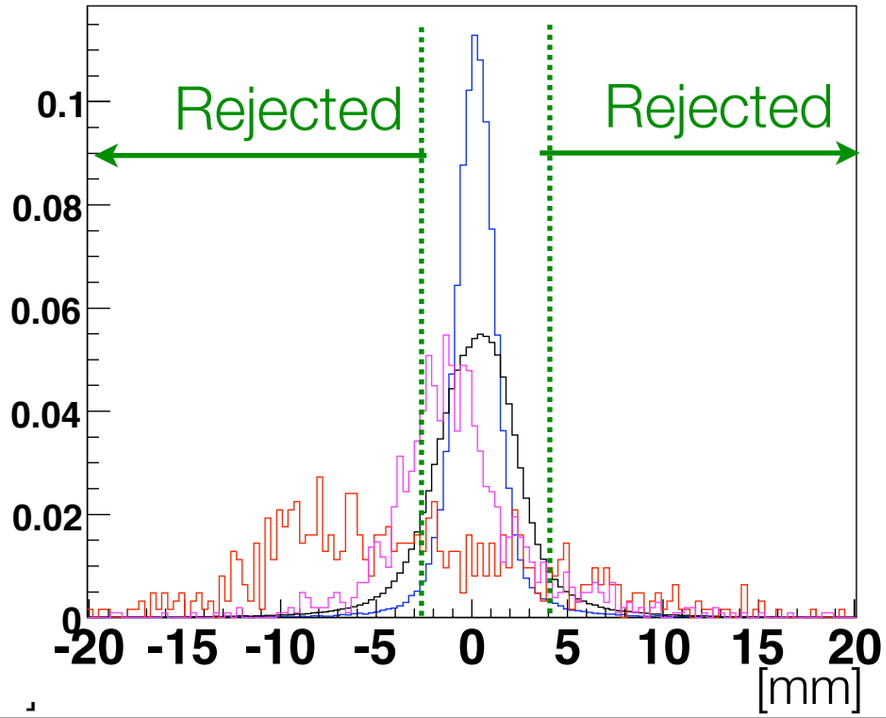
- incident angle(T1&T2):DIF-us
- vertex reconstruction (T2&T3):DIF-us DIF-it



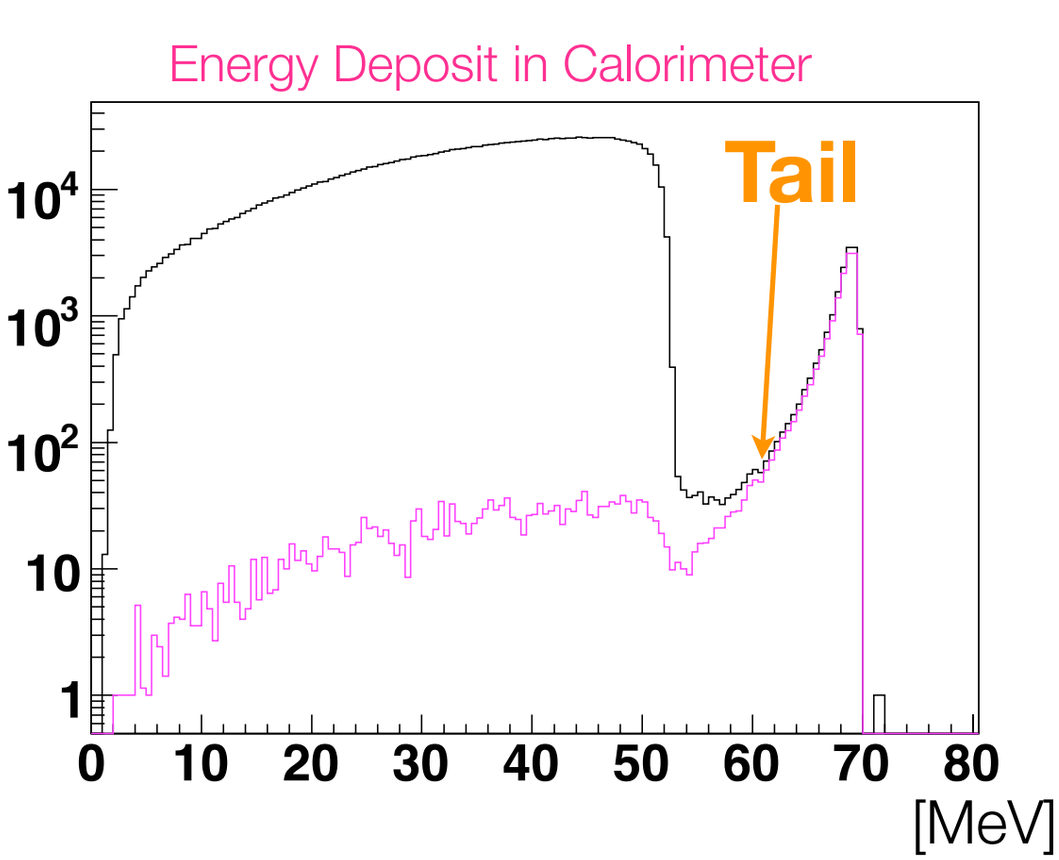
DIFevent 18%−>2%

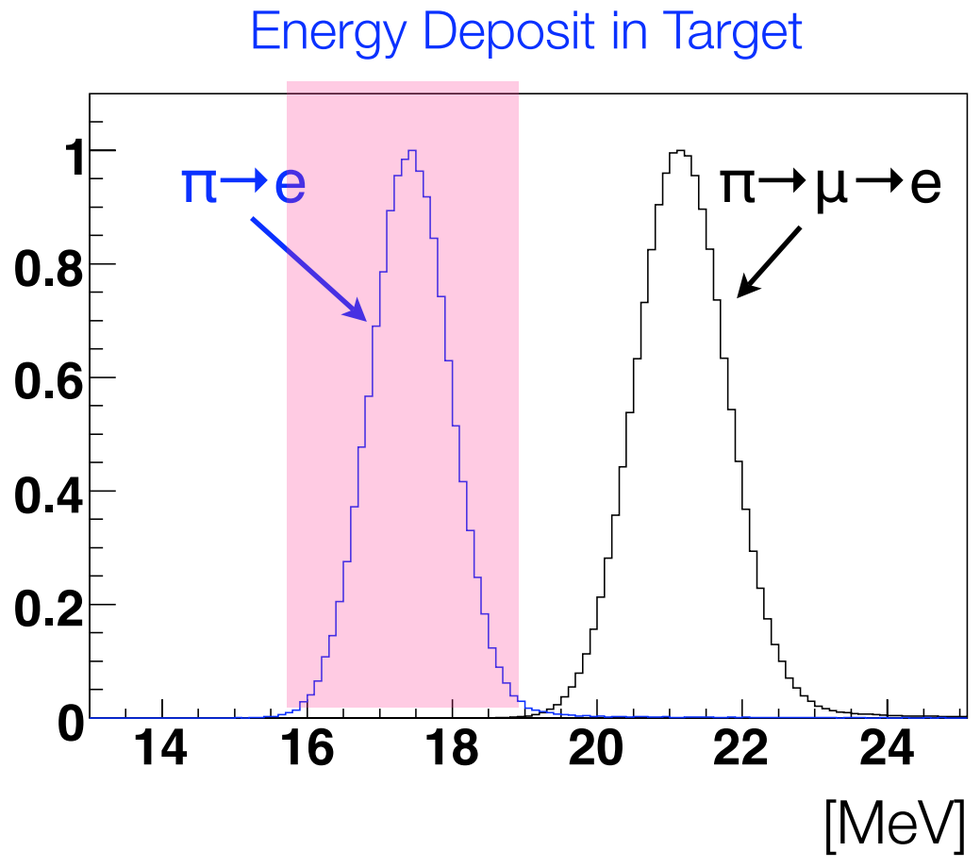




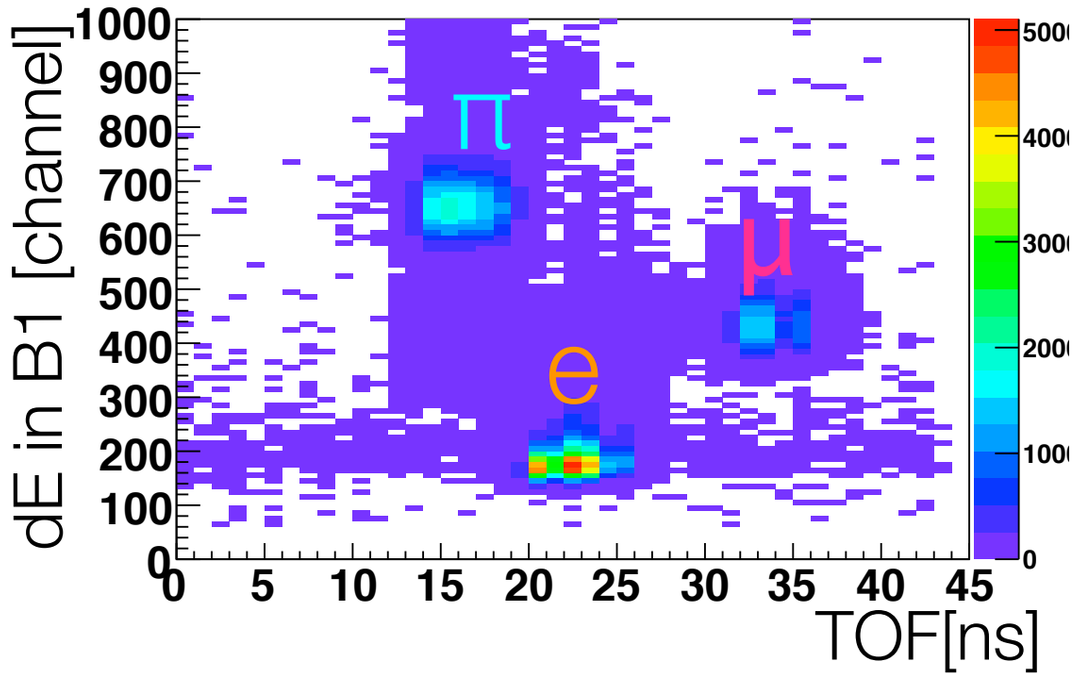


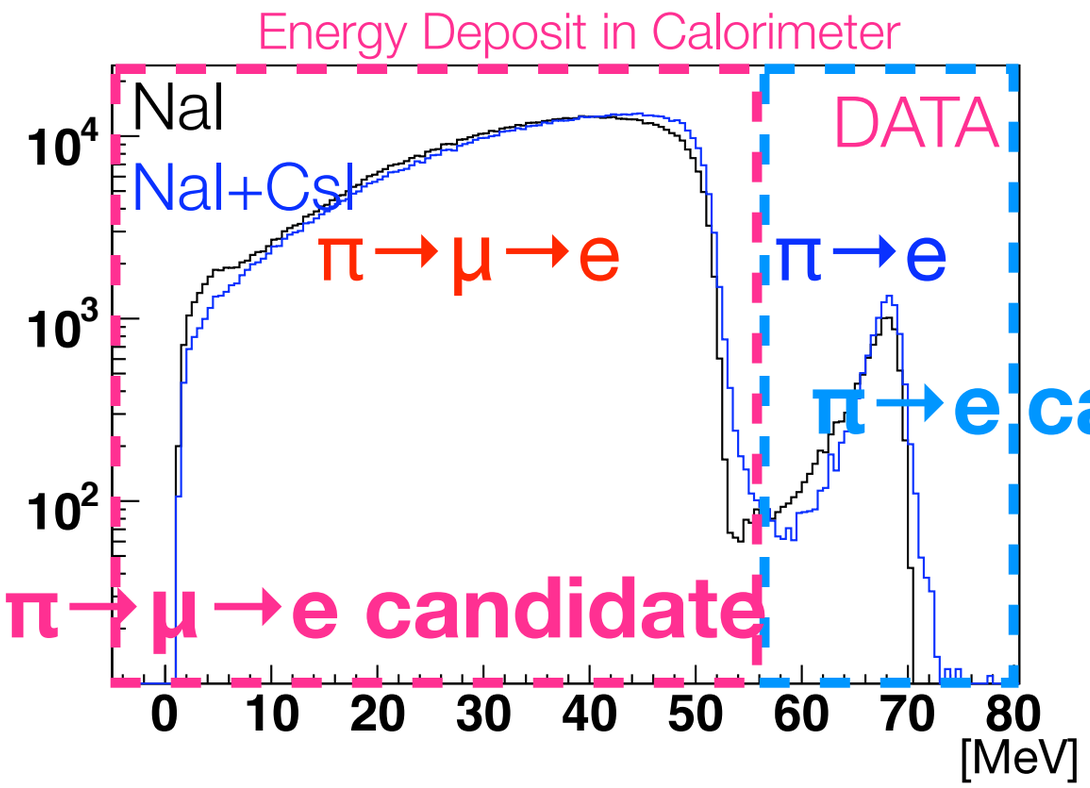
Tail correction

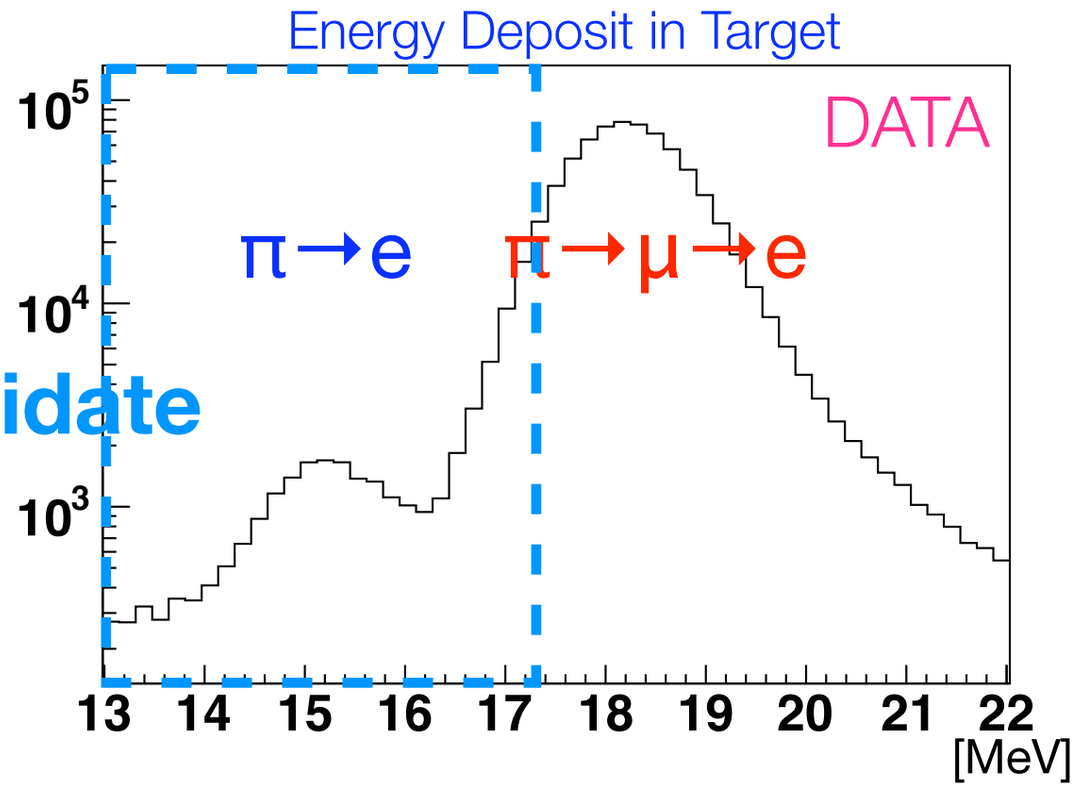




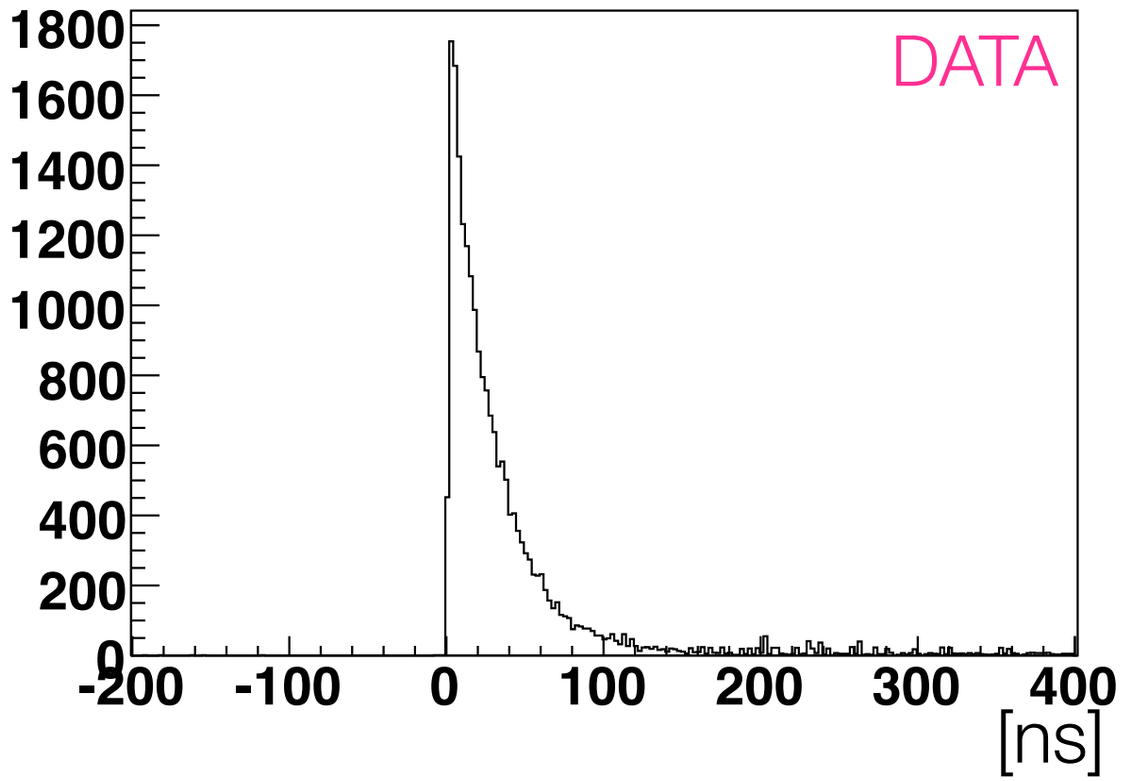
Data

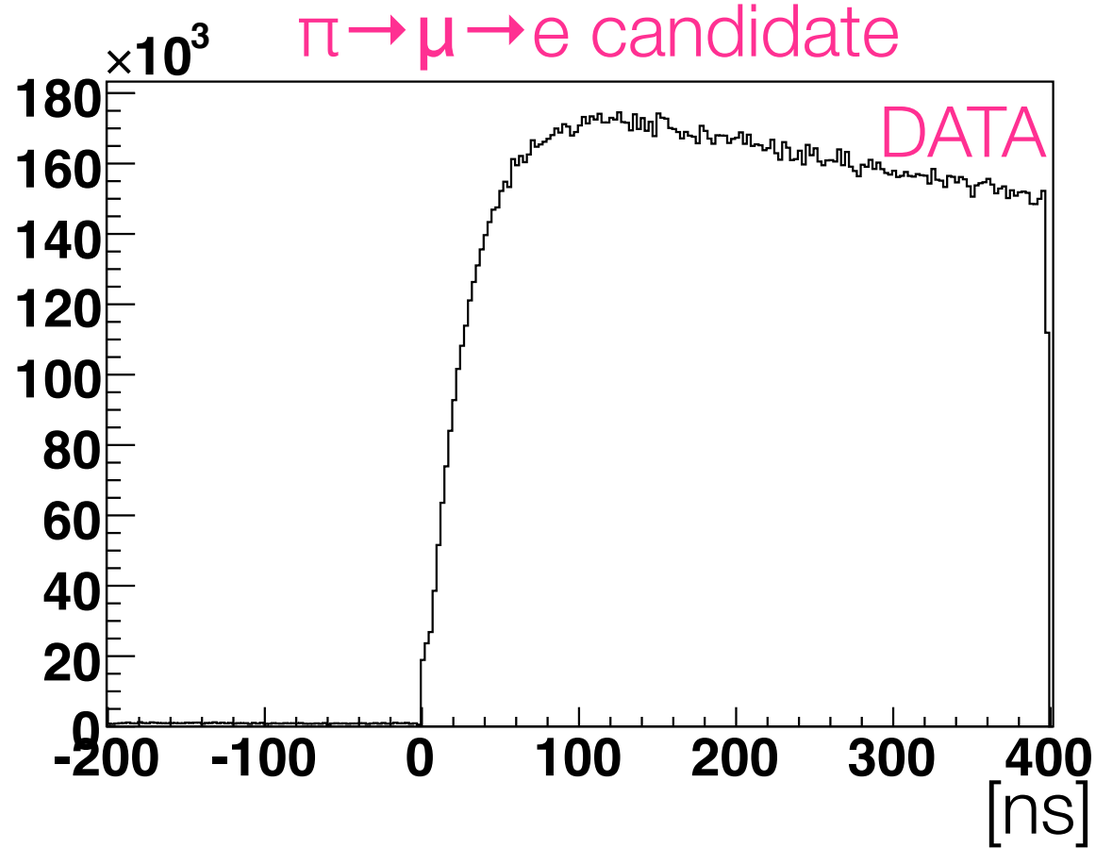

dE in B1 [channel]
1000
900
800
700
600
500
400
300
200
100
0
π
μ
e
0
5
10
15
20
25
30
35
40
45
TOF[ns]


Energy Deposit in Calorimeter
NaI
NaI+CsI
DATA
π→μ→e
π→e
π→μ→e candidate
10^4
10^3
10^2
0
10
20
30
40
50
60
70
80
[MeV]


Energy Deposit in Target
DATA
π→e
π→μ→e
π→e candidate
10^5
10^4
10^3
13
14
15
16
17
18
19
20
21
22
[MeV]

Time Spectrum (Te - Tπ)

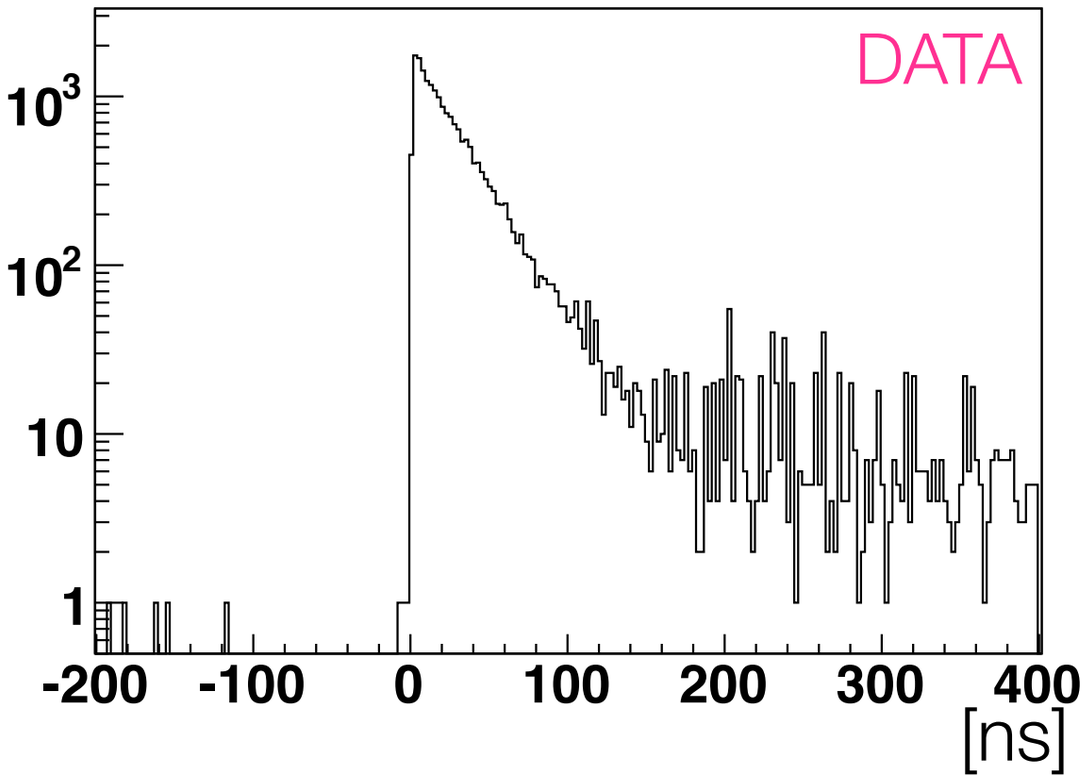




Time Spectrum (Te - Tπ)

PIENU

π→e candidate



π→μ→e candidate