Tail Correction and Decay-In-Flight

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Rare Pion Decay Workshop
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Tail Correction Significance

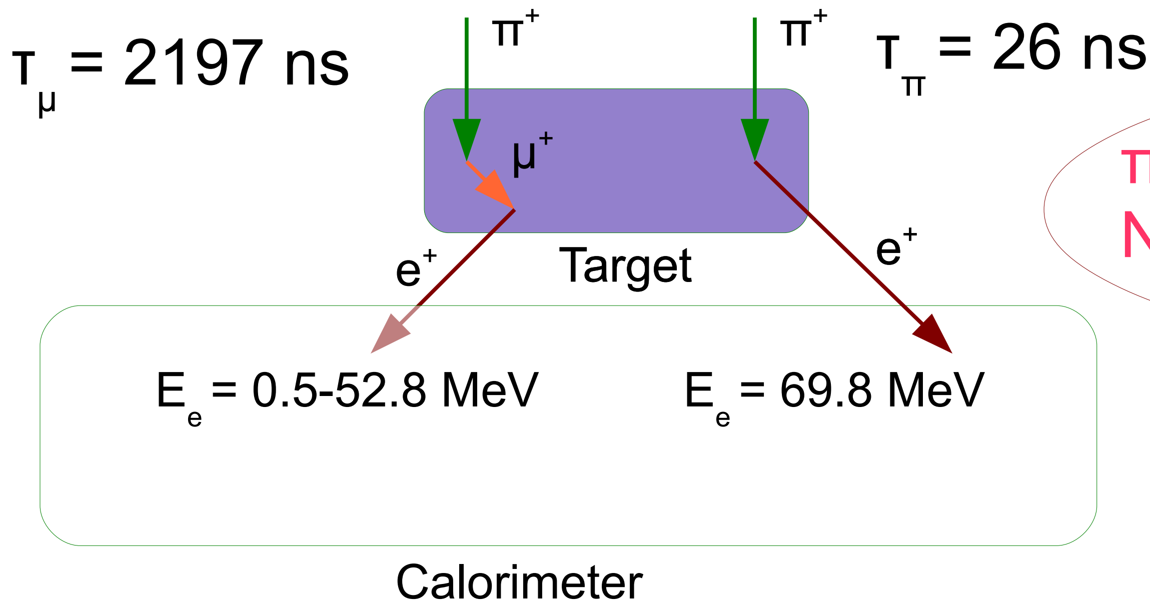
TRIUMF PIENU experiment, from 1994

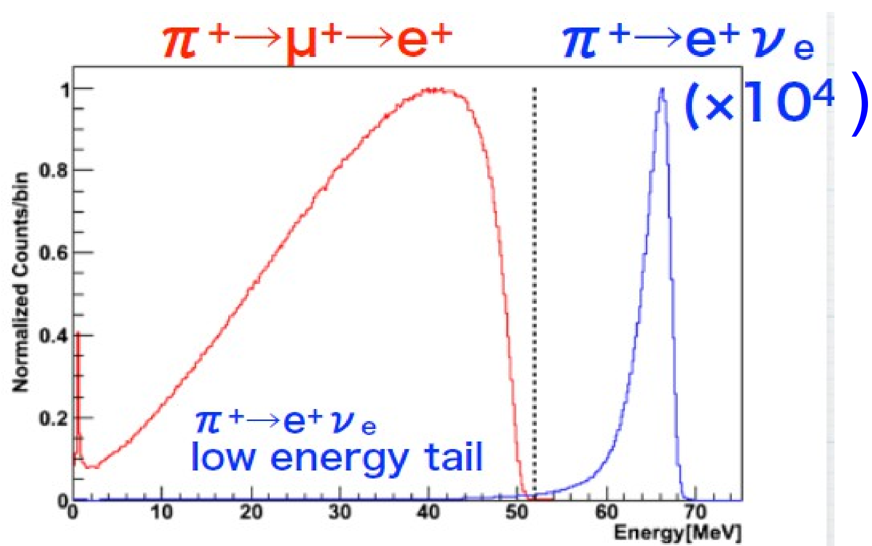
Raw branching ratio R' ($\times 10^{-4}$)	1.1994 ± 0.0034(stat) ± 0.0023(sys)
Multiplicative corrections	
Tail correction	1.0193 ± 0.0025
Pion stop time t_0	0.9998 ± 0.0008
Time calibration	1.0000 ± 0.0003
Monte Carlo	1.0027 ± 0.0011
$V1$ veto	1.0009 ± 0.0005
Wire-chamber inefficiency	0.9998 ± 0.0004
π lifetime	1.0000 ± 0.0009
Branching ratio R_{expt} ($\times 10^{-4}$)	1.2265 ± 0.0034(stat) ± 0.0044(sys)

TRIUMF PIENU experiment, from 2015

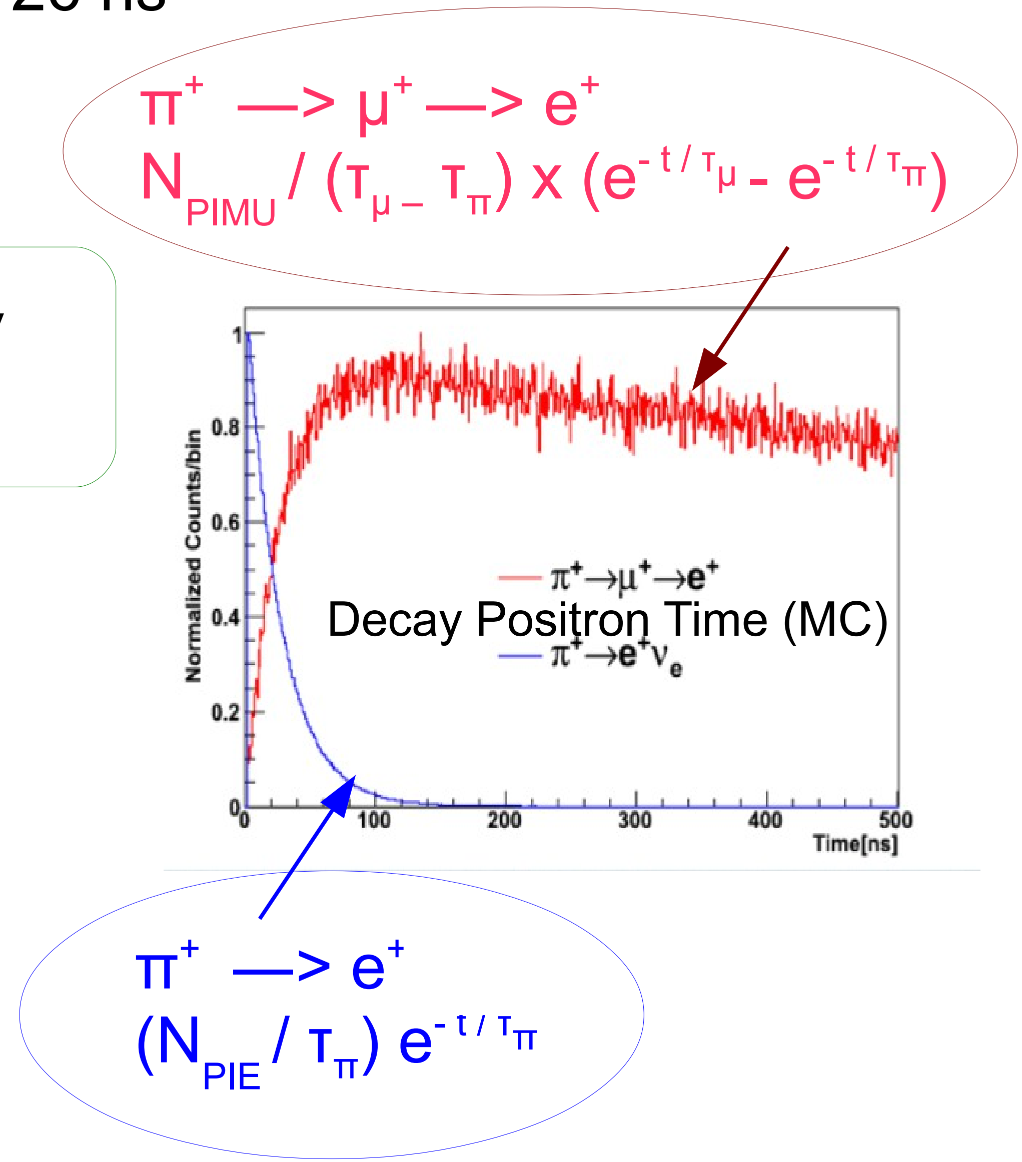
	Values	Uncertainties	
		Stat	*Syst*
$R_{e/\mu}^{Raw}$ (10^{-4})	1.1972	0.0022	0.0005
π,μ lifetimes			0.0001
Other parameters			0.0003
Excluded components			0.0005
Corrections			
Acceptance	0.9991		0.0003
Low-energy tail	1.0316		0.0012
Other	1.0004		0.0008
$R_{e/\mu}^{Exp}$ (10^{-4})	1.2344	0.0023	0.0019

Experimental Method





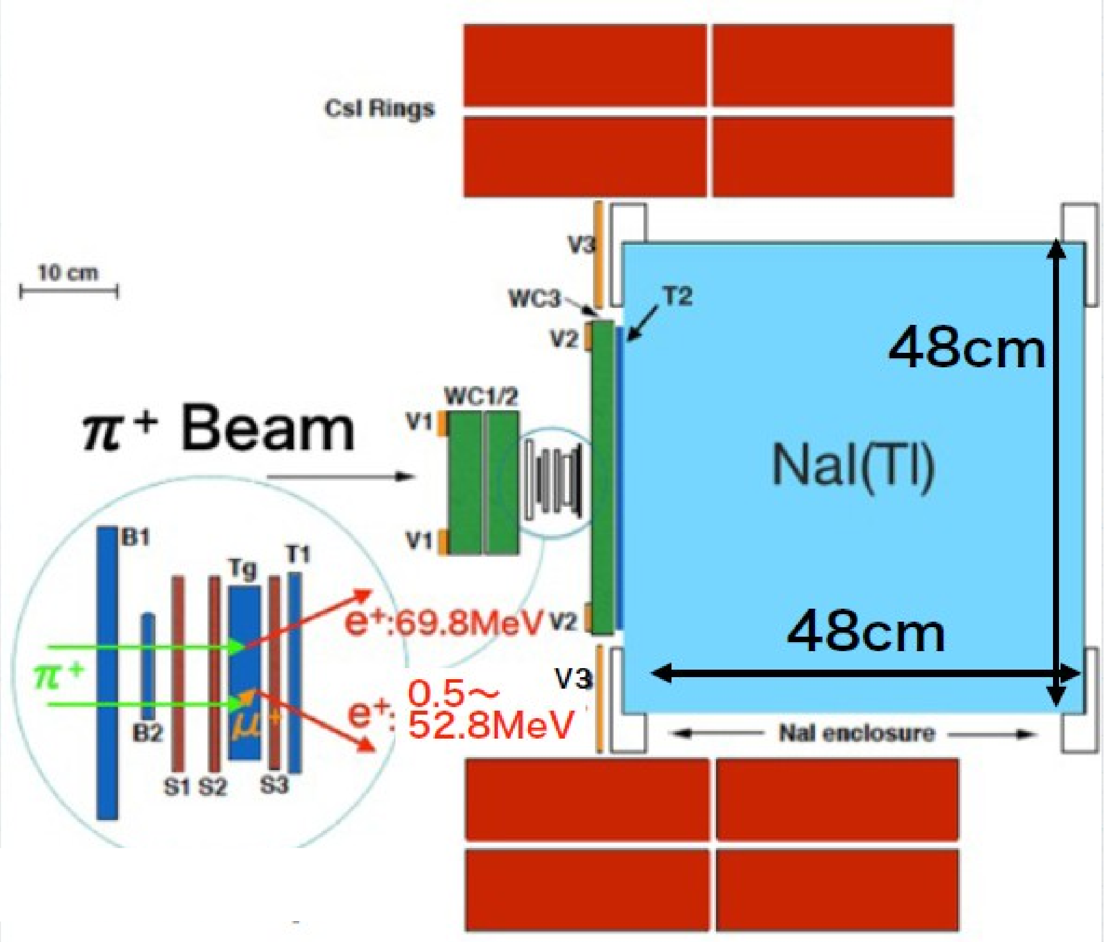
Decay Positron Energy (MC)



Detector

Detector:

- Acceptance ~ 20%
- Energy Resolution 2.2% (FWHM) at 70 MeV
- 19 radiation lengths of NaI, 9 of CsI
- Pion and positron times obtained from fitting B1 and T1 waveforms, respectively
- Wire chambers & silicon strips for π^+ beam and decay e^+ tracking

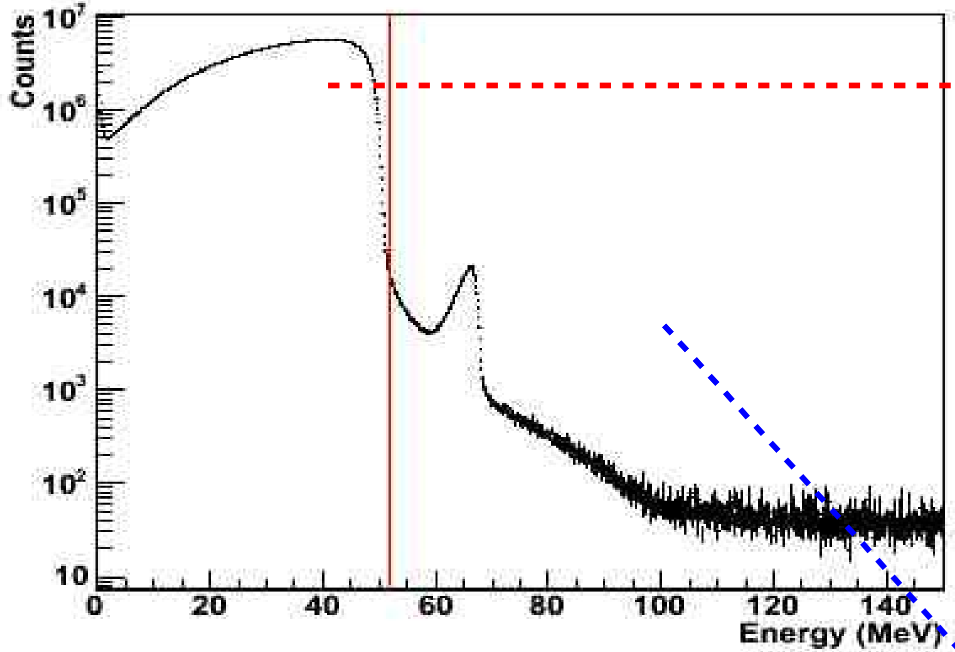


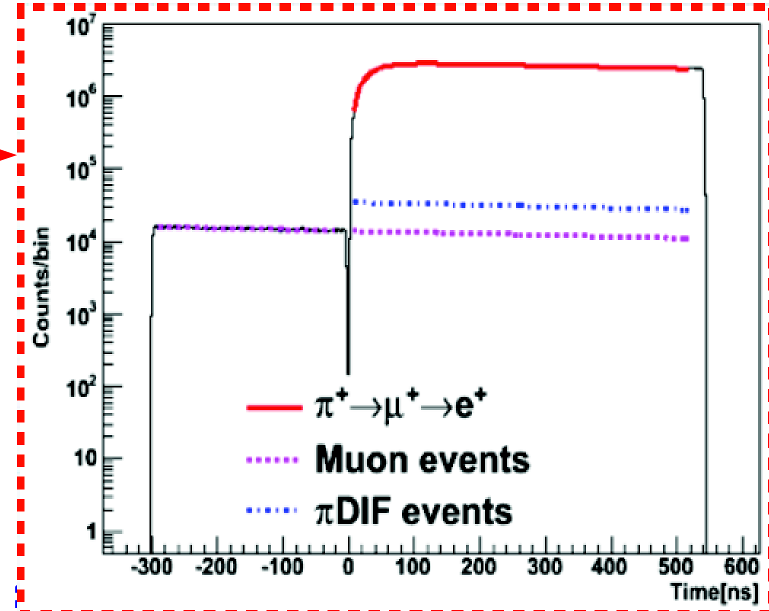
WC: Wire Chamber

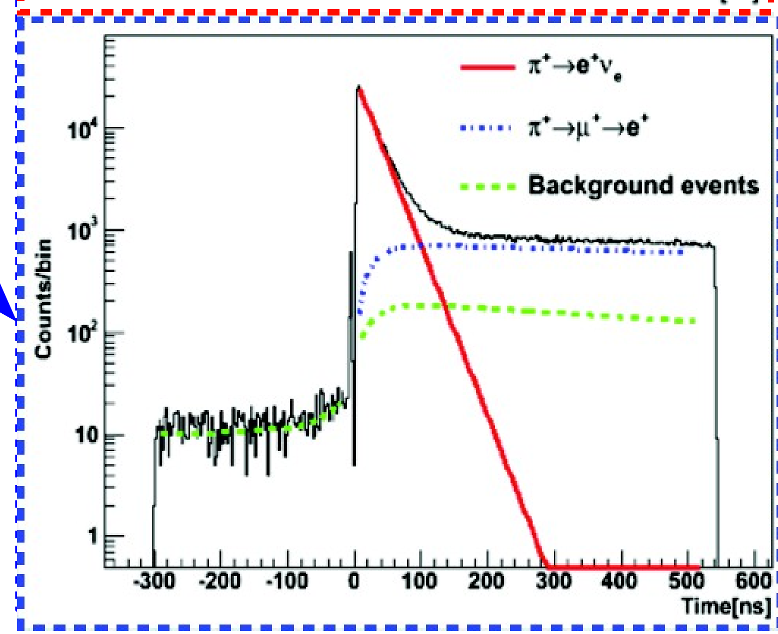
SS: Silicon Strip

B1, B2, Tg, T1, T2: Plastic Scintillator

Raw Branching Ratio Extraction







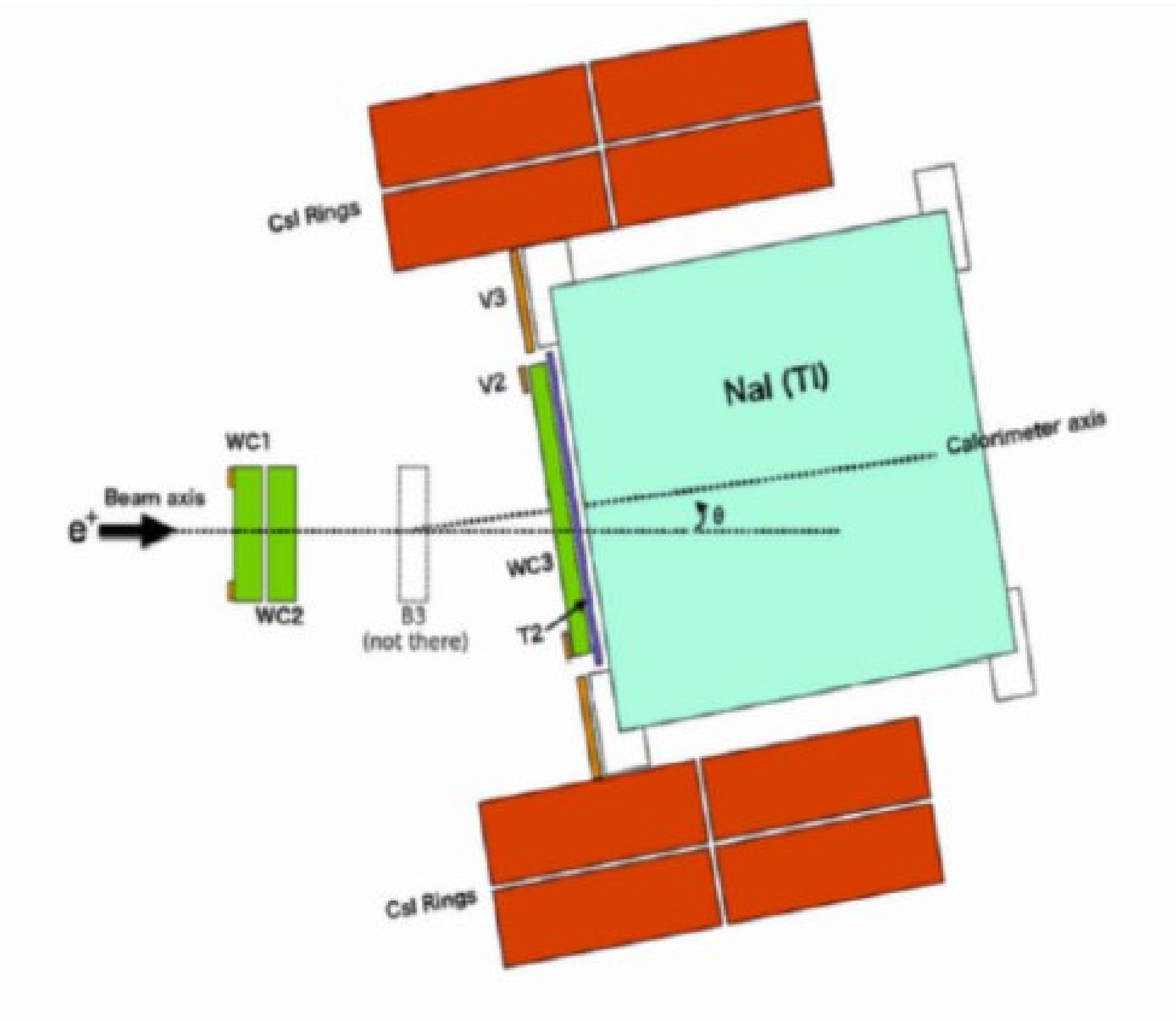
Red line indicates cutoff between high-energy and low-energy spectra (52 MeV)

π → e events with energy below cutoff end up in low-energy time spectrum

Too small to fit; must be corrected for

This is the so-called tail correction

Positron Beam Data



70 MeV/c positron beam

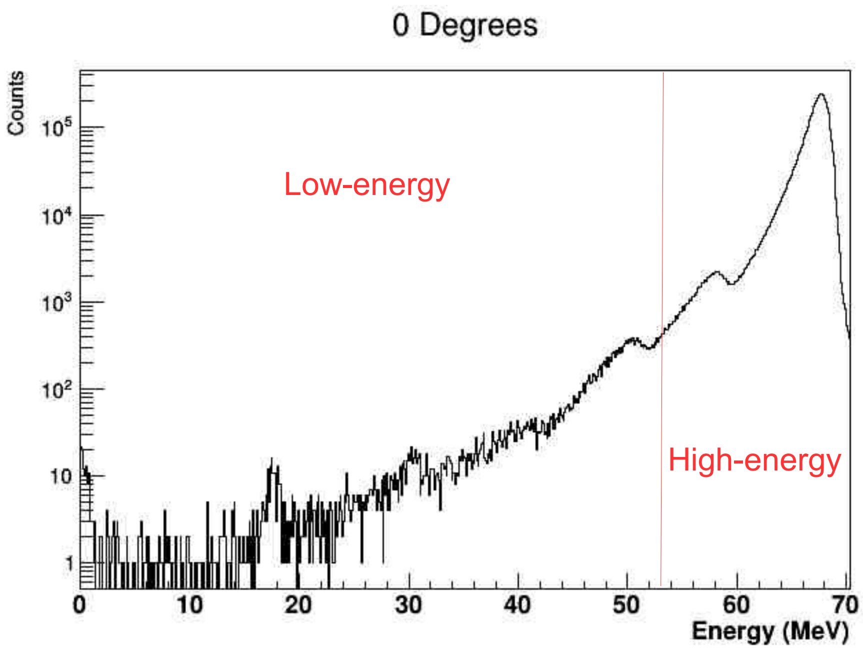
Many detector elements removed: B1, B2, Tg, T1, S1, S2, S3

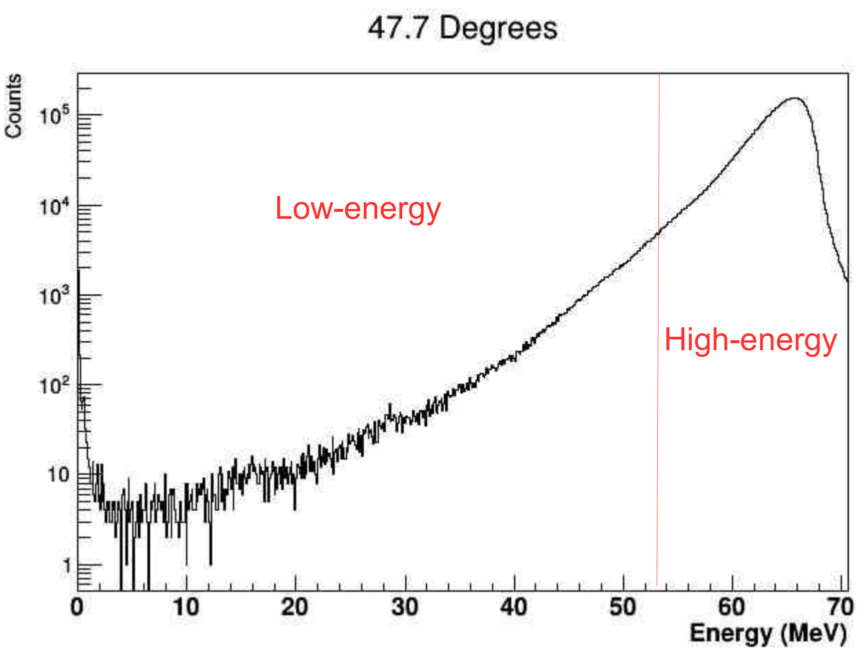
Data taken at ten angles

Tail fraction increases significantly as a function of angle

Requires clean positron beam: PIENU beam had ~1% momentum spread, low-energy tail intrinsic to beam <= 0.01%

Positron Beam Energy Spectra





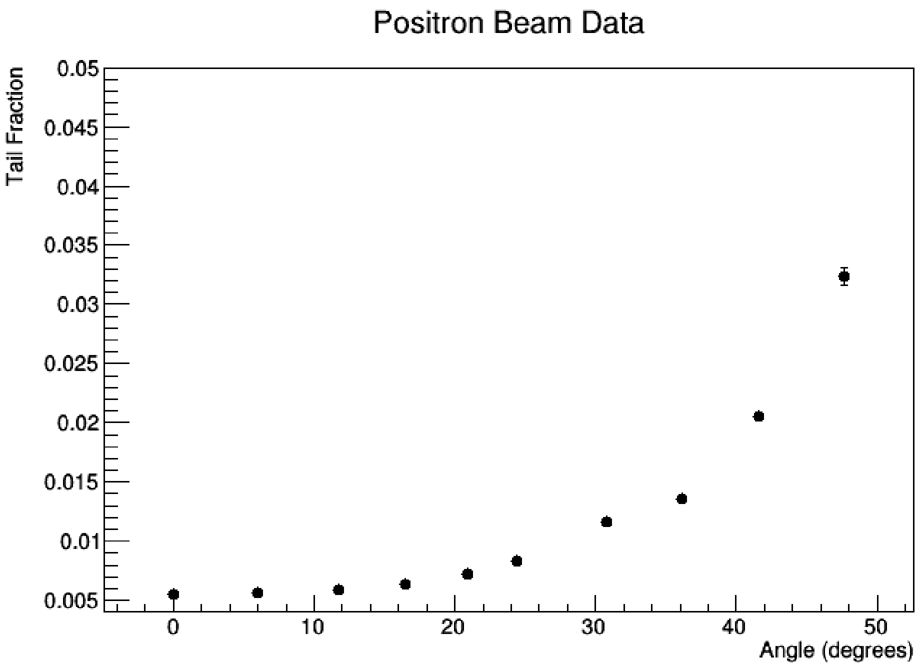
0.55% ± 0.01% of the spectrum below cutoff

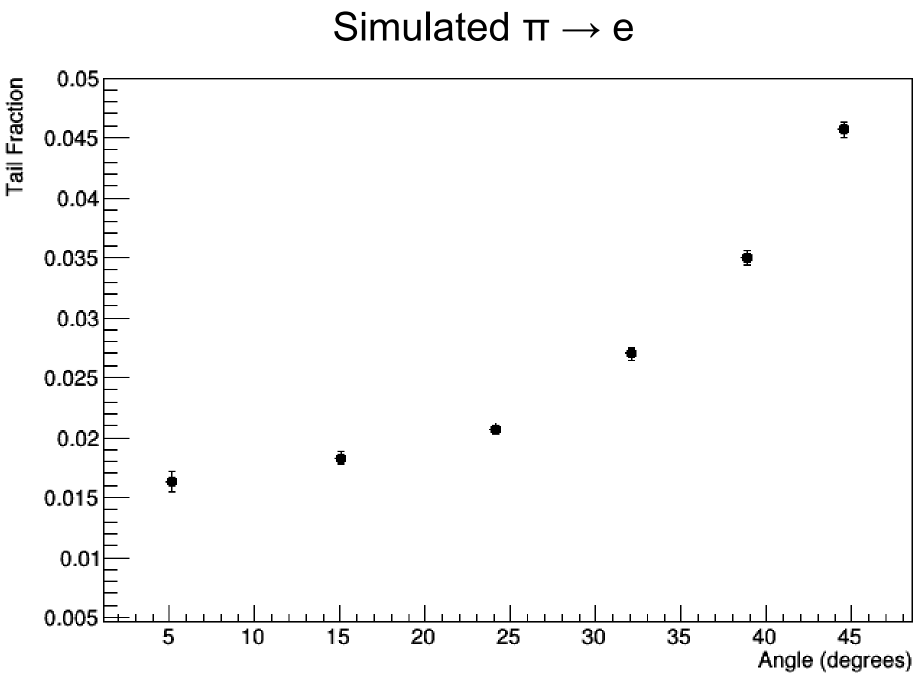
3.23% ± 0.07% of the spectrum below cutoff

Extra peaks at 50 MeV and 58 MeV due to photonuclear reactions in ^{127}I

Extra peaks still present, but invisible underneath tail due to shower leakage

Tail fraction as a function of angle

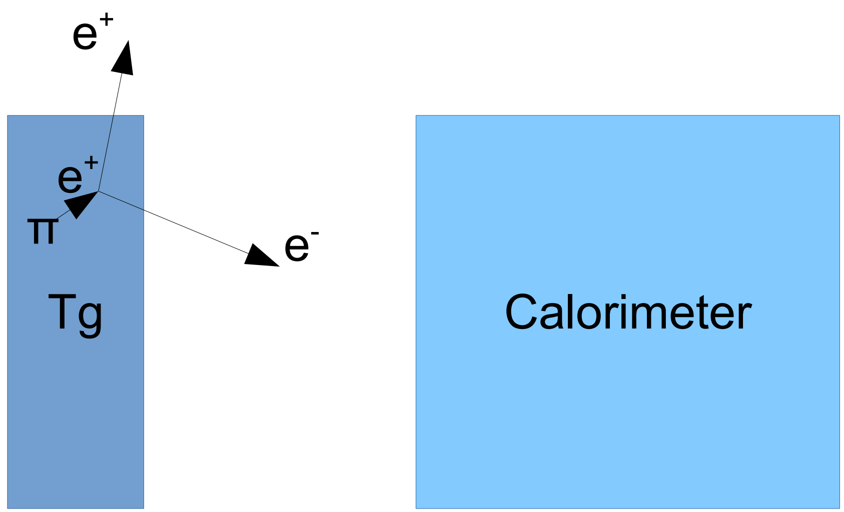




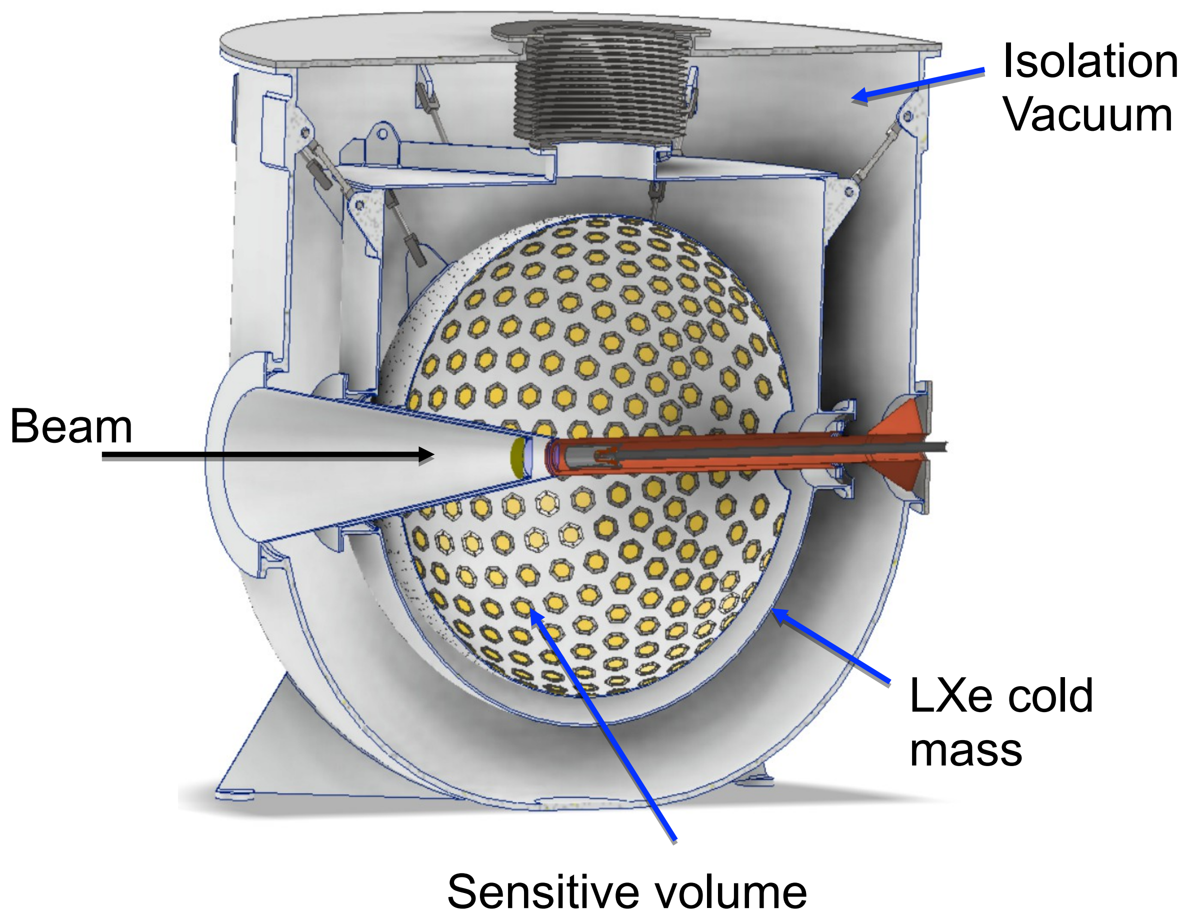
Errors on the right are MC statistics, errors on the left are stat + syst (mostly syst)

Plateau at small angles for π → e events is due to Bhabha scattering upstream of calorimeter: positron scatters out of acceptance and low-energy electron triggers

Leading systematic errors on π → e tail are energy calibration, geometry, photonuclear cross-section



Considerations for PIONEER



Positron beam measurement impossible for nominal geometry

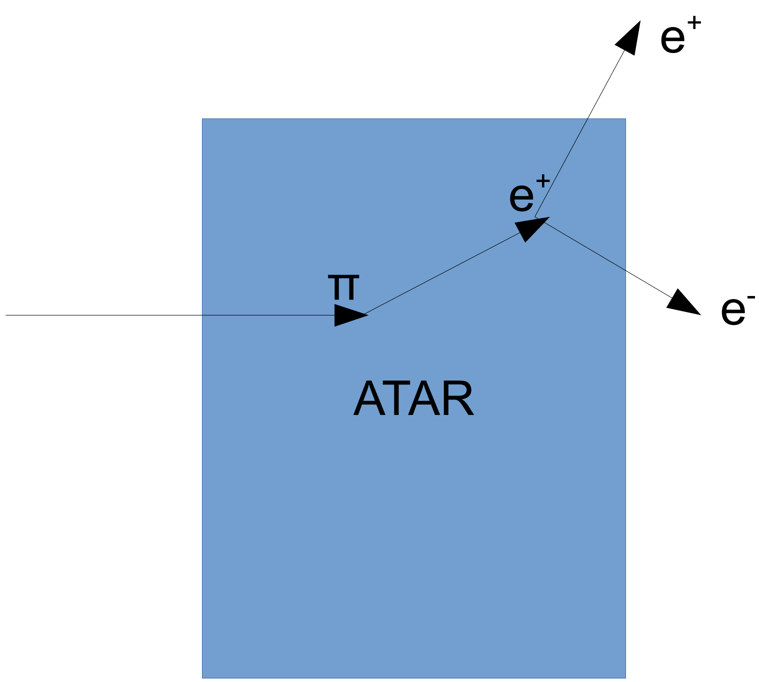
For Pacman geometry, can inject beam into the forward part of the detector

Design will be as spherically symmetric as possible, so will provide decent information on calorimeter response

Will not be perfectly symmetrical in reality, so will need to supplement with other measurements, e.g. Michel decays

Would need to know beam properties and photonuclear cross-section very well

Bhabha Scattering in PIONEER



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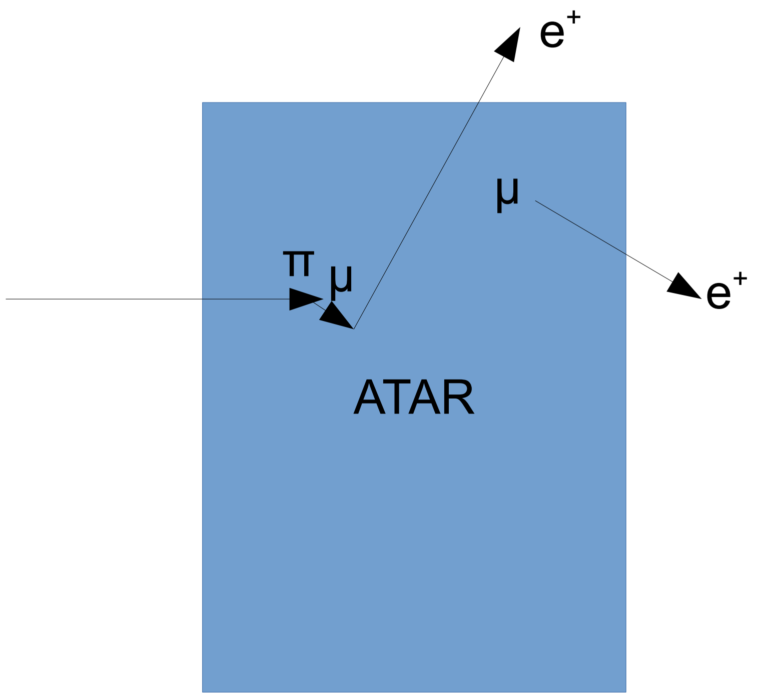


Impact of Bhabha scattering on the tail correction will be reduced in PIONEER due to higher acceptance; still not zero

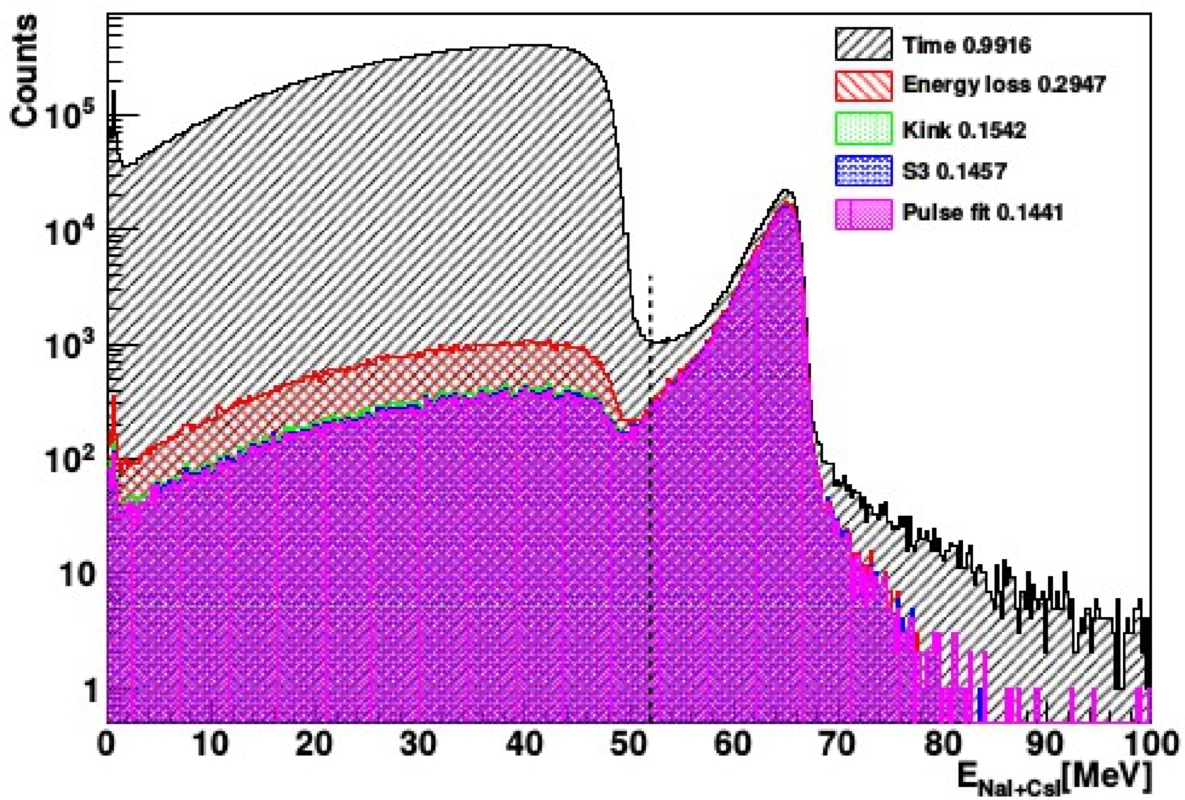
Potential to confuse Bhabha events with π →μ → e plus old muon decay events needs to be carefully studied

In principle, the ATAR gives us many handles on distinguishing these topologies. Crucially dependent on performance of real sensor.

In Situ Tail Measurement

- Timing cut: keep only early events
- Total energy cut: keep only events with $\pi \rightarrow e$ like energy deposit in the target and upstream counters
- Kink cut: remove events with angle between S12 track and WC12 track, for removing pion decay-in-flight events
- A couple of others that helped slightly

In Situ Tail Measurement

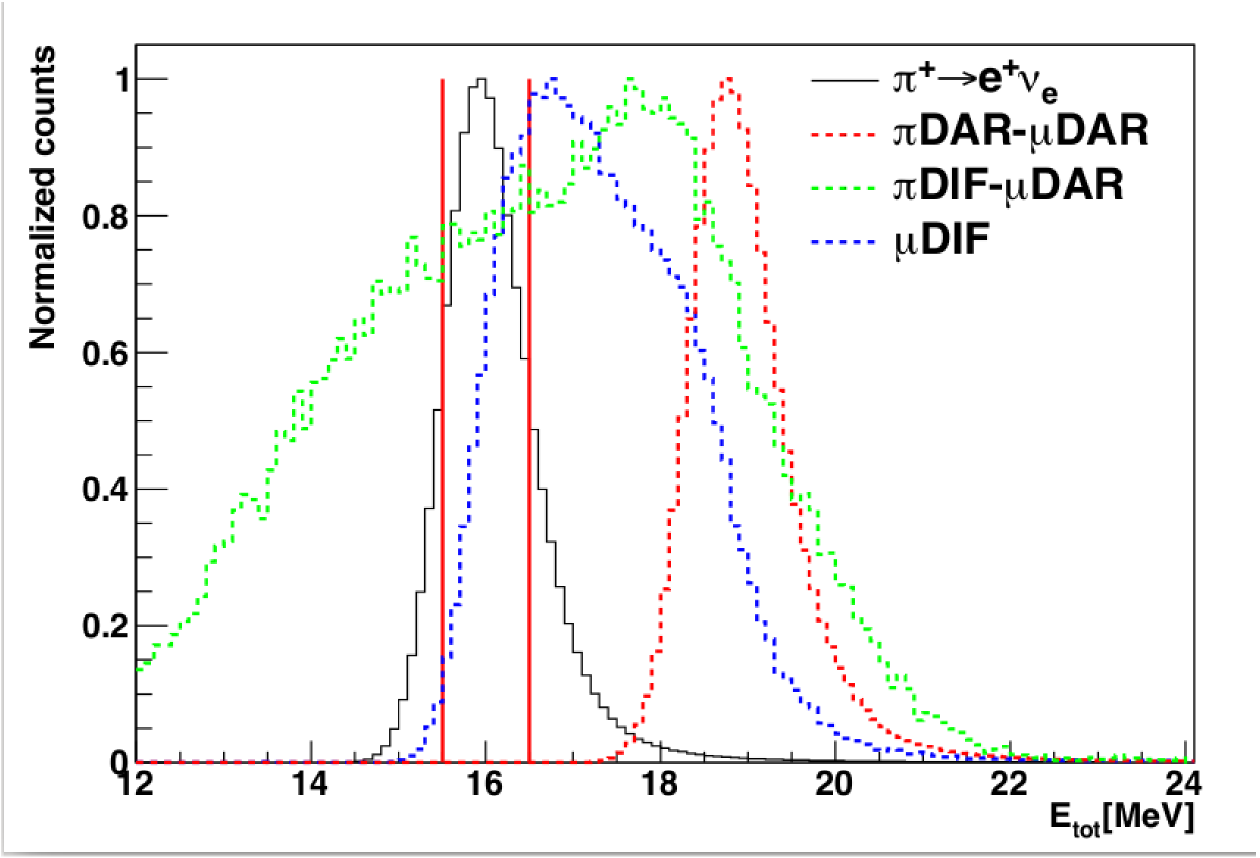


In tail region, still many more π →μ → e events than π →e events

This limited the accuracy of the technique

Main problem was decay-in-flight (DIF)

Decay in Flight



Simulated distributions, normalized to same height

Red lines show selected region

Largest background contribution is πDIF-μDAR

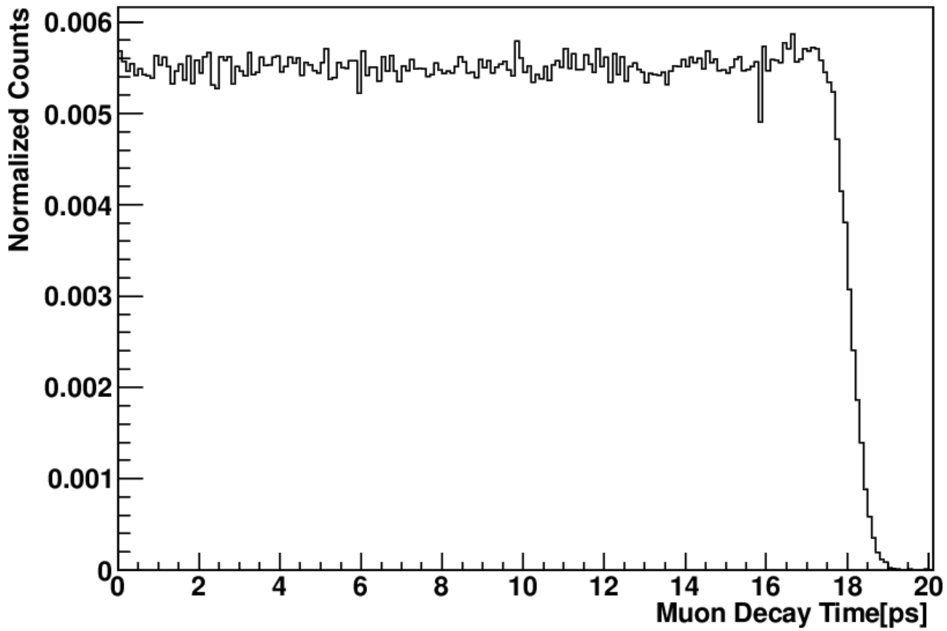
Tail of π →e distribution contains Bhabha scattering events; these must be corrected for

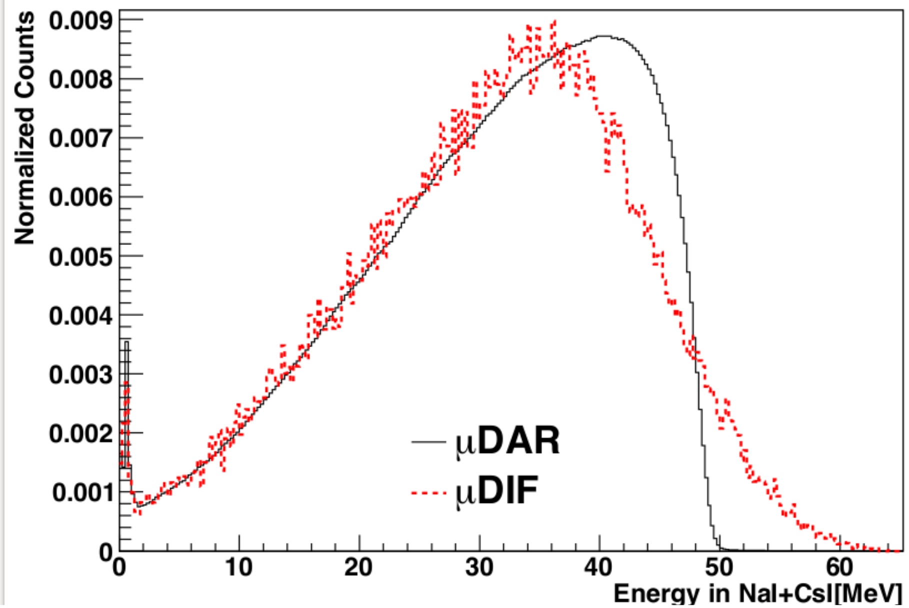
Considerations for PIONEER

- Again, ATAR should give extra handles for

  $\pi \rightarrow \mu \rightarrow e$ suppression
- πDIF events can potentially be identified based on angle, layer-by-layer energy deposit
- But again, need to know real ATAR performance in order to do good simulations
- All in all, a more promising technique for PIONEER than the positron beam measurement: see Vincent's talk tomorrow

Muon DIF





Muons from πDAR have about 4 MeV of kinetic energy, and stop in < 20 ps in plastic scintillator

Nevertheless, a correction must be made for μDIF: these events have π →e timing, and some have energy above the cutoff

For PIENU, the size of the correction was about 0.25%