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Development of a Versatile Calibration Method for Electro-Magnetic Calorimeters Using a Stopped Cosmic-ray Beam

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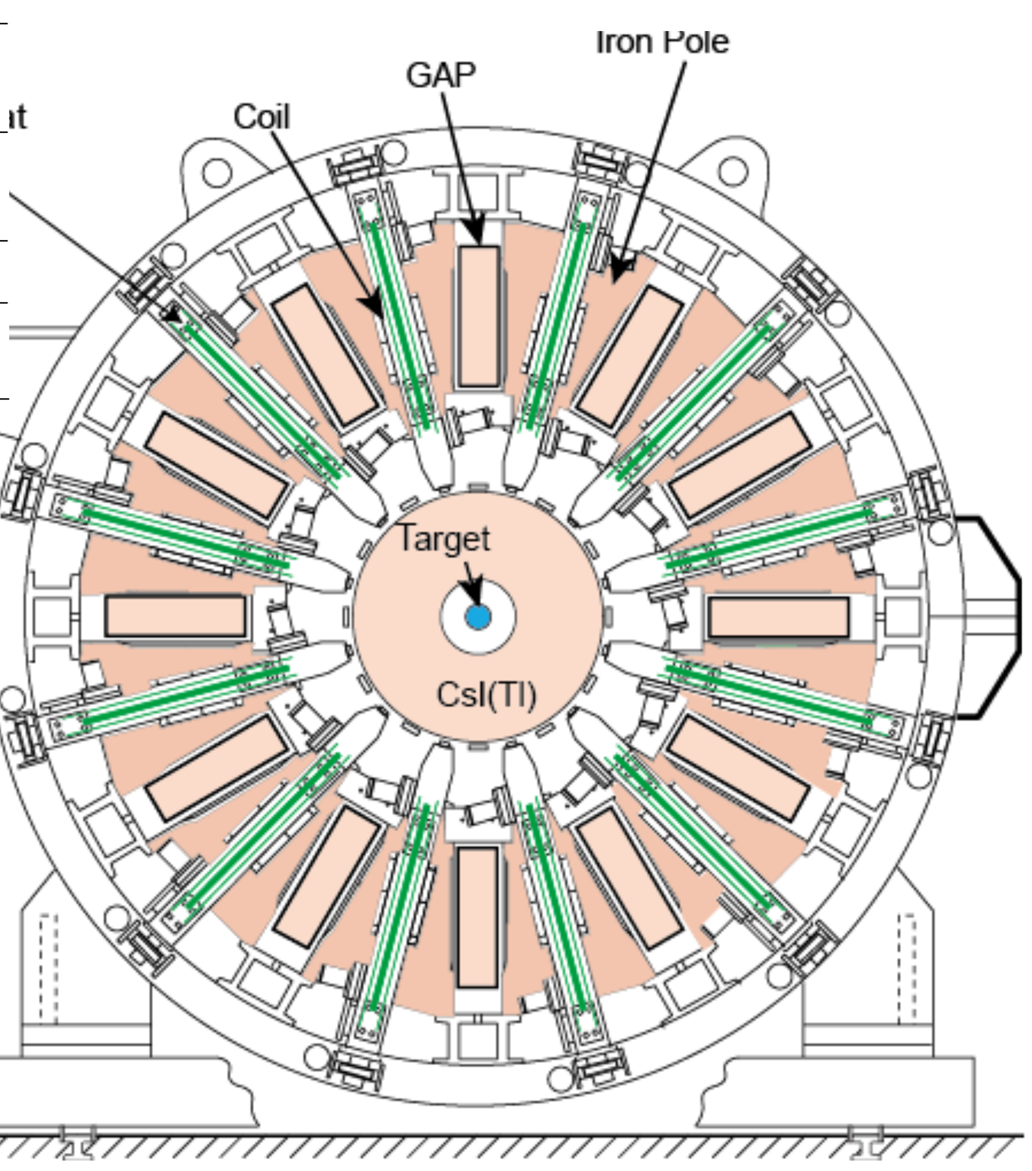
J-PARC E36 Experiment

Precise Measurement of $R_K = \Gamma(K^+ \to e^+\nu_e)/\Gamma(K^+ \to \mu^+\nu_\mu)$ using stopped positive kaons @ J-PARC K1.1BR

$$R_K{}^{SM} = \frac{m_e{}^2}{m_\mu{}^2}\left(\frac{m_K{}^2 - m_e{}^2}{m_K{}^2 - m_\mu{}^2}\right)^2 (1+\delta_\gamma)$$

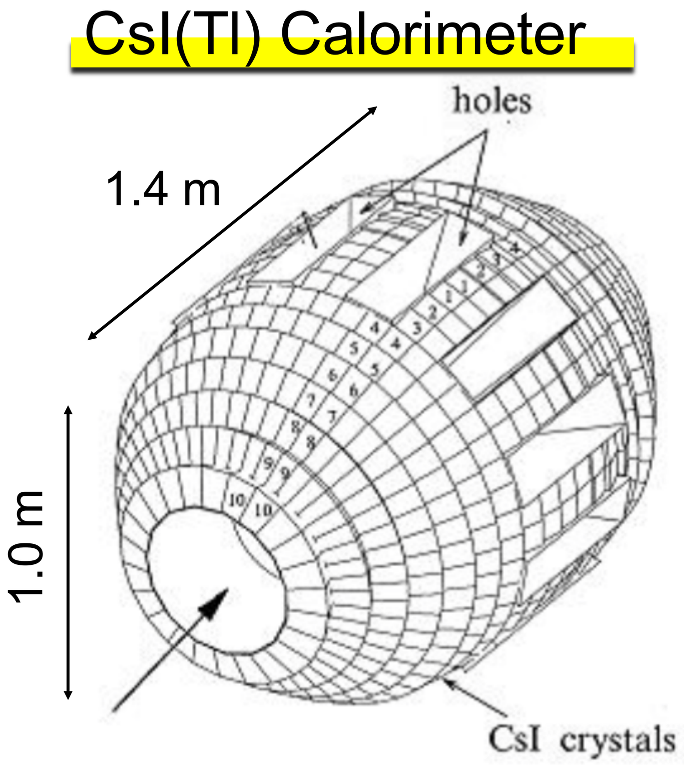
	$R_K \times 10^5$	$\Delta R_K/R_K$
KLOE (2009)	$2.493 \pm 0.025 \pm 0.019$ (stat) (sys)	1.26%
NA62 (2013)	$2.488 \pm 0.007 \pm 0.007$ (stat) (sys)	0.40%
SM	2.472 ± 0.001	0.04%
Goal of E36		0.25%



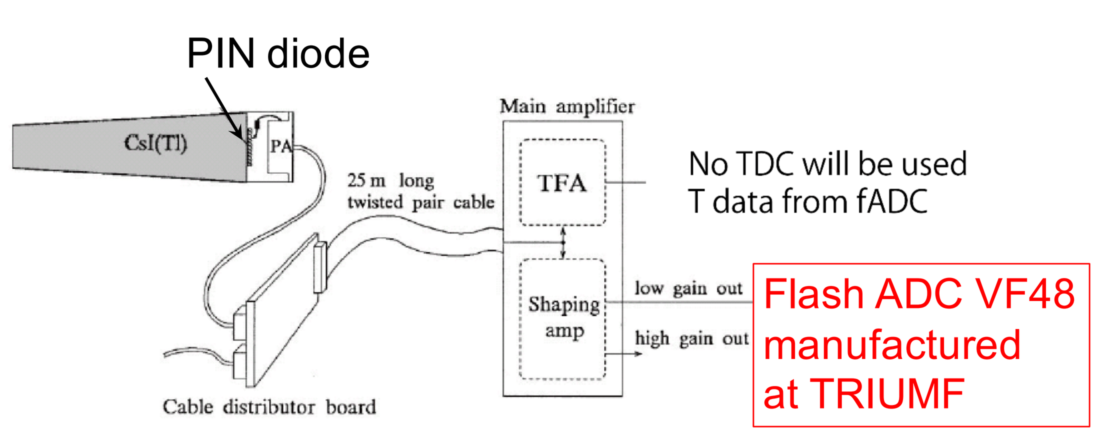
Detector

- Beam Cherenkov for K^+/π^+
- Active Target
- Spiral Fiber Tracker (SFT)
- MWPC (C2, C3, C4)
- TOF1, TOF2
- Aerogel Cherenkov (AC)
- Pb Glass Counter (PGC)
- CsI(Tl) Calorimeter
- Gap Veto

CsI(Tl) Calorimeter



Background: $K^+ \to e^+\nu_e\gamma$ (SD)

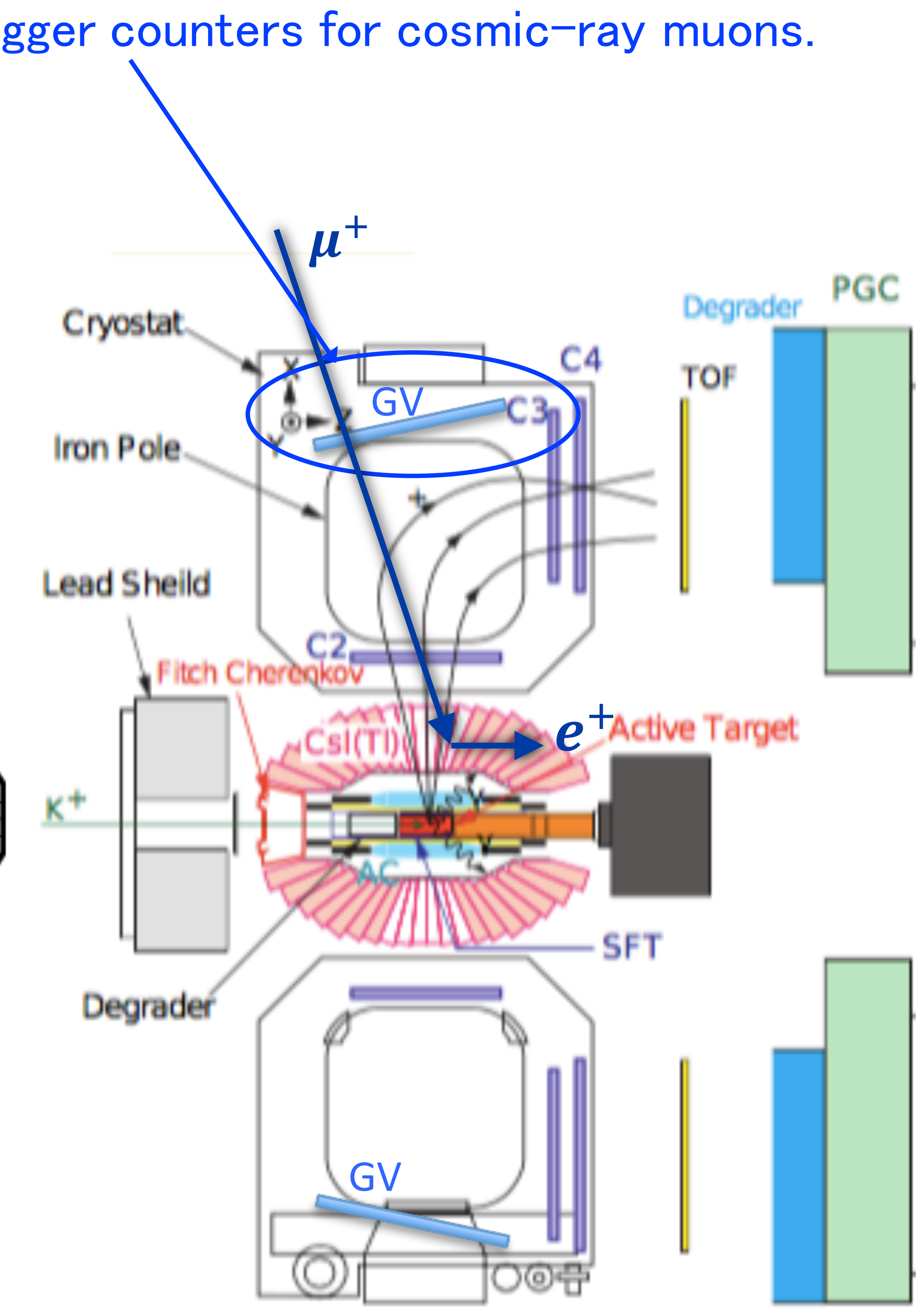


- 768 CsI(Tl) crystal modules
- 18 x 18 (28 x 28) mm² PIN diode
- Pre-amplifier + Shaping amplifier
- Flash ADC VF48 (25 MHz)

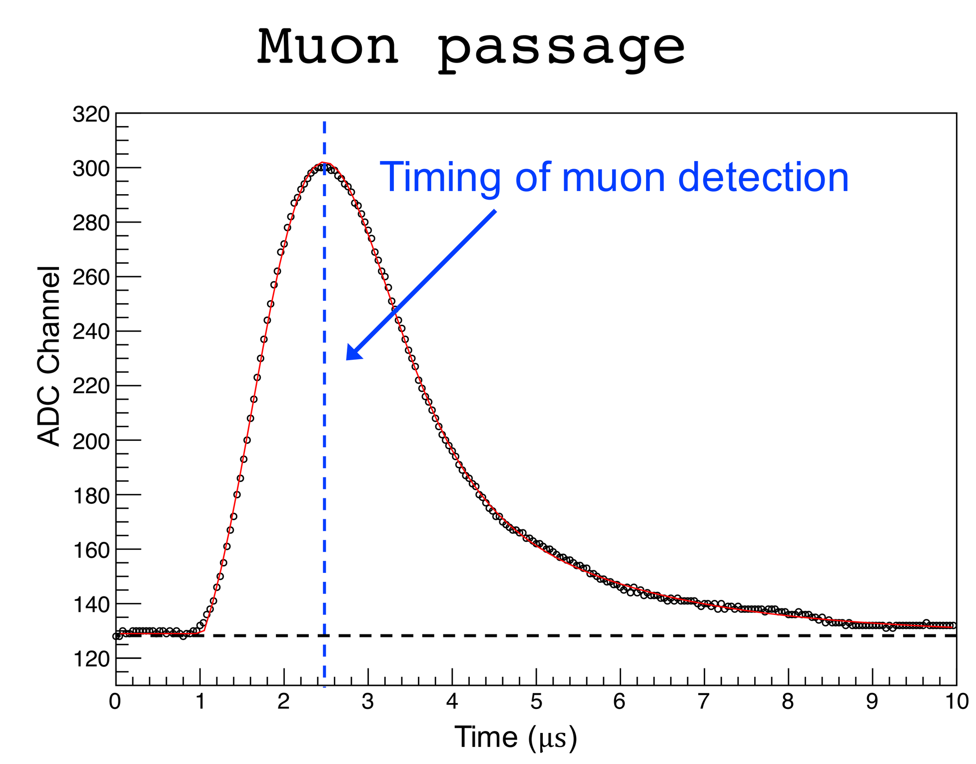
Experimental setup

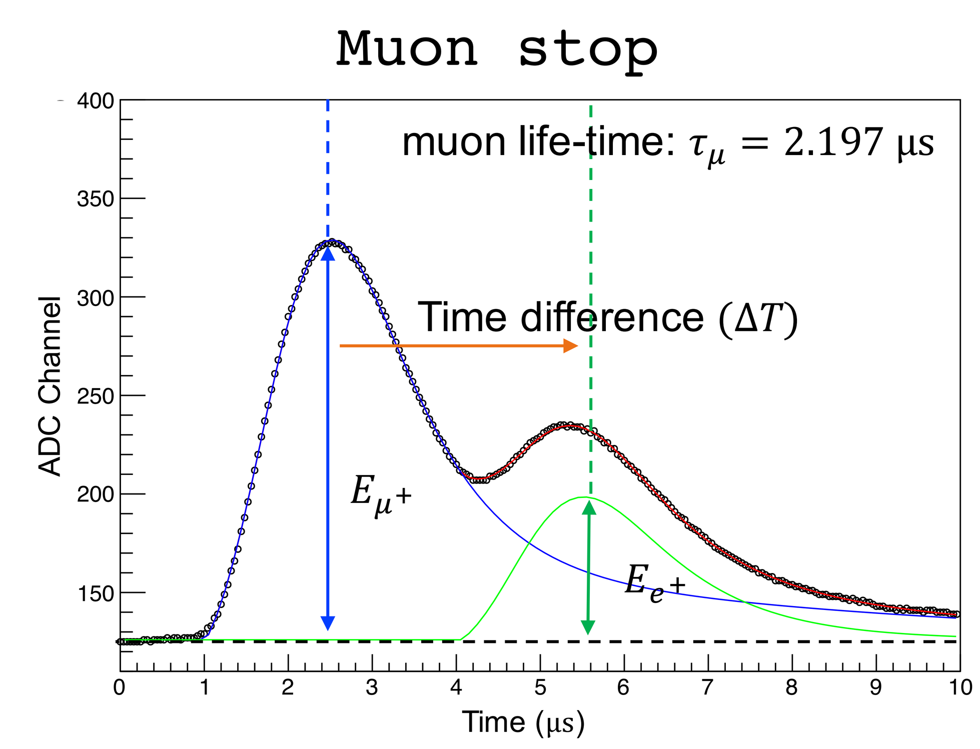
Setup

The Gap veto counter was used as the trigger counters for cosmic-ray muons.



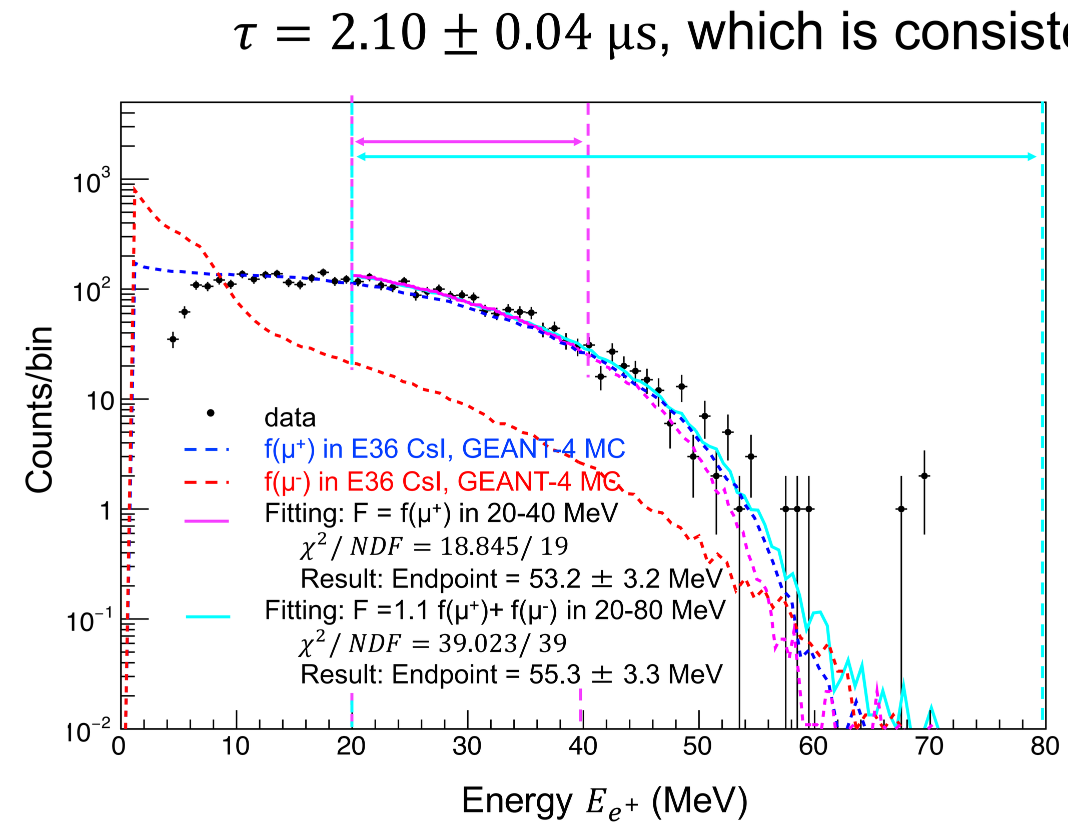
Flash ADC Typical Waveform

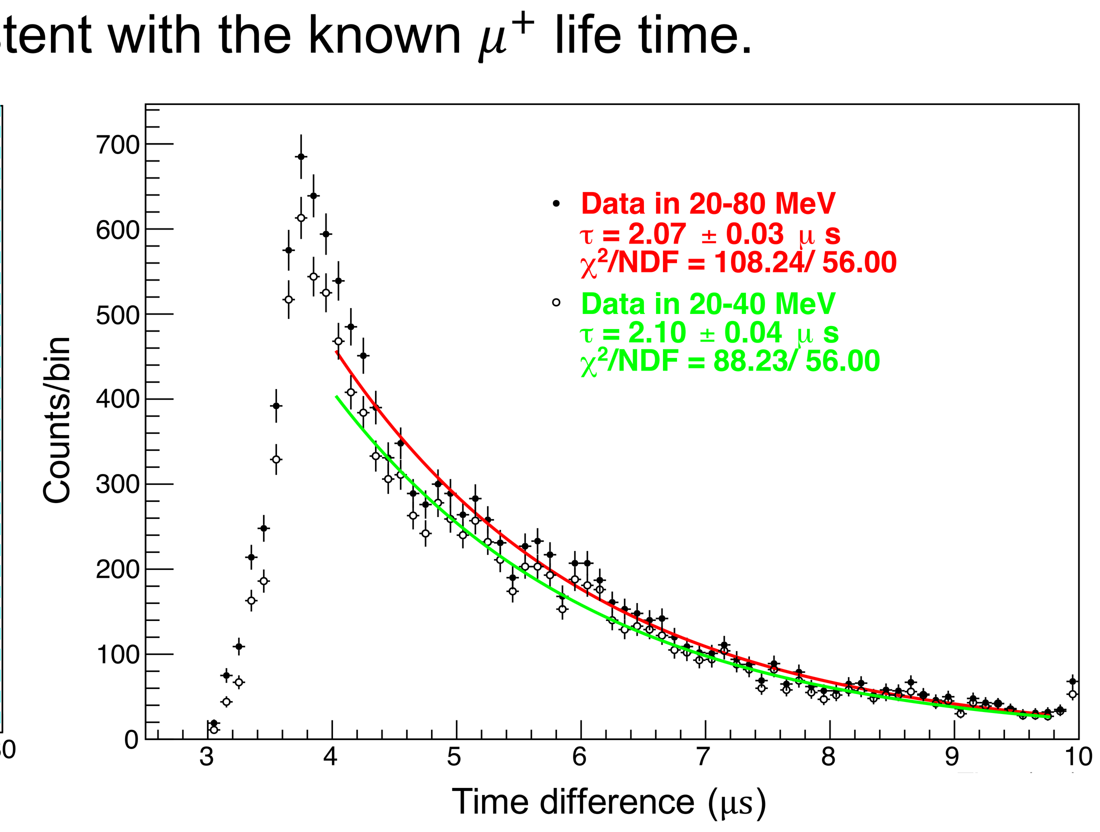




Analysis

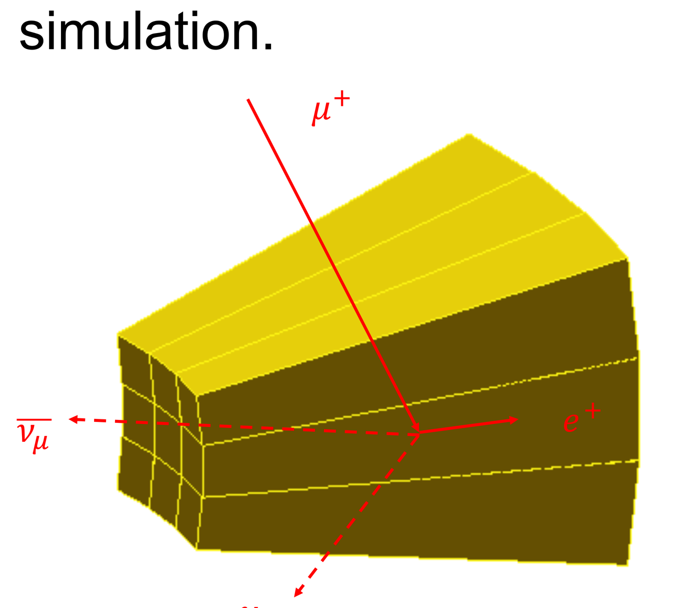
- The expected spectra of absolute energy, E_{e^+} and E_{e^-}, were calculated with a MC simulation assuming uniform muon stopping in a crystal (blue and red lines, respectively).
- The experimental data (black dots) were fitted to these simulated spectra by adjusting the energy gain factor (horizontal scale), mainly using the e⁺ region between $20 - 40$ MeV. The magenta dotted line is the fitted line.
- A good fit was obtained with $\chi^2/NDF = 18.85/19$. The end-point energy of 53.2 ± 3.2 MeV was determined.
- Right figure shows the time difference distribution between the first and second pulses under the conditions of $20 < E_{e^+} < 80$ MeV (closed circles) and $20 < E_{e^+} < 40$ MeV (open circles). Using μ^+ dominant events selected by $20 < E_{e^+} < 40$ MeV, the exponential decay constant was determined as $\tau = 2.10 \pm 0.04$ μs, which is consistent with the known μ^+ life time.

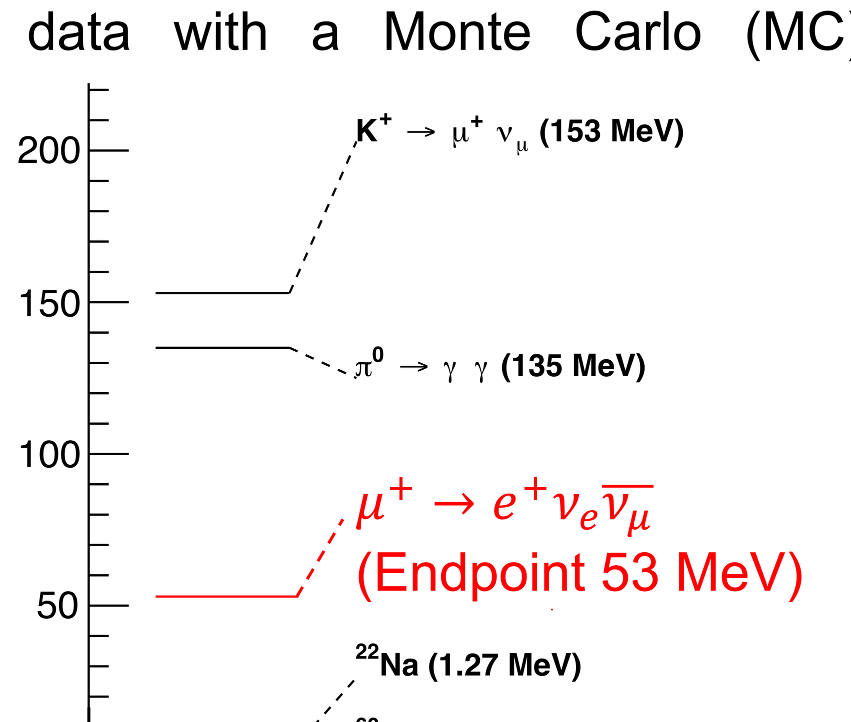




Calibration using Cosmic Rays

In this study, a new calibration method for EM-calorimeters was developed using the Michel spectrum end point of muon decays ($\mu^+ \to e^+\nu_e\overline{\nu_\mu}$) in the crystal. This method was established by comparing the experimental data with a Monte Carlo (MC) simulation.





Advantages

- Non accelerator method
- Enable for versatile EM-calorimeter
- 53 MeV interpolating gap of 1-100 MeV

Condition

- Stopped cosmic-ray muons
- Use of Flash ADC
- Waveform analysis

Results and conclusion

A new energy calibration method of EM-calorimeters using stopped cosmic-ray muons was established. The end point of the energy spectrum of the FADC second signal can be used as the calibration point of 53.2 ± 3.2 MeV. This method is applicable to various calorimeters, and it has been adopted by the J-PARC E36 experiment.