Calibration of the Mu2e Electromagnetic Calorimeter

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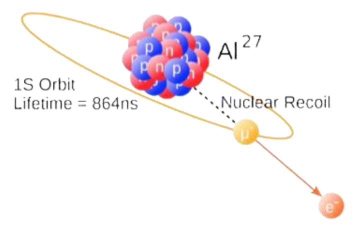
The Mu2e experiment at Fermilab

Mu2e will search for CLFV conversion of a negative muon into an electron:

$$\mu^- + Al \rightarrow e^- + Al$$

Goal is to reach sensitivity of $R_{\mu e} \sim 8 \cdot 10^{-17}$, an improvement of 10^4 over current sensitivity

- High statistics: most intense muon beam in the world
- High background rejection



Experimental signature:
Single monoenergetic electron
$E_e = 104.69$ MeV

Electrons are detected by a high precision tracker and a crystal calorimeter

- The calorimeter provides particle identification to enhance background suppression:

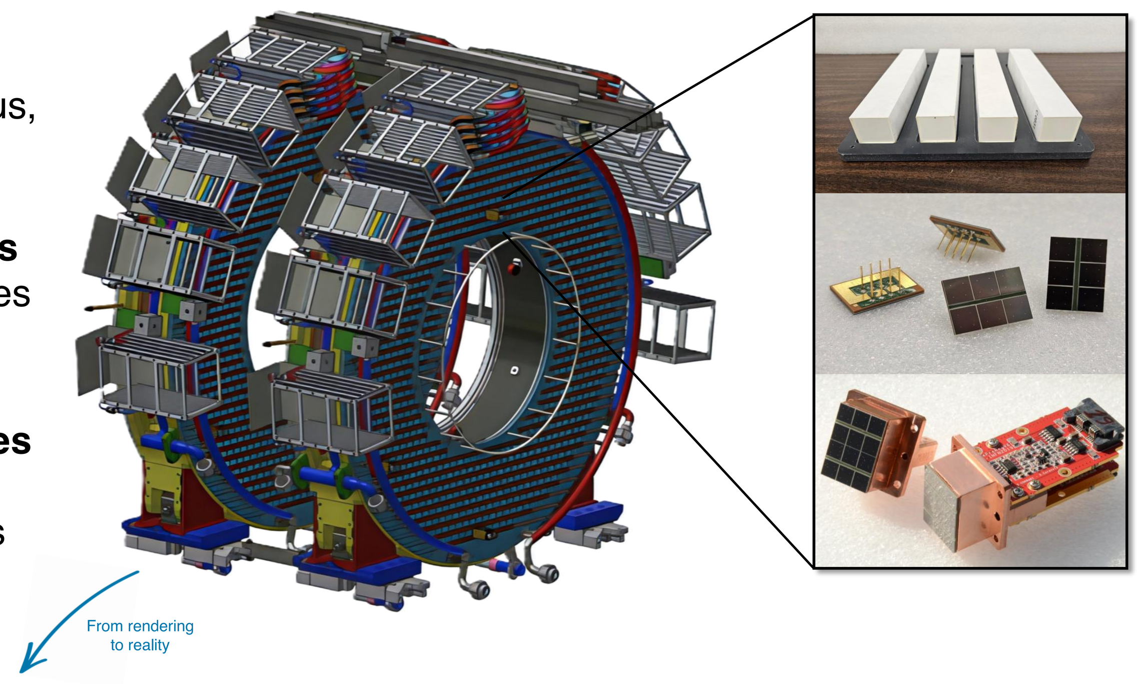
Calorimeter requirements @ 100 MeV		
	Energy resolution	$\sigma(E)/E < 10\%$
	Time resolution	$\sigma(T) < 500$ ps

The Mu2e Electromagnetic Calorimeter

Two annular disks
37/66 cm inner/outer radius, 70 cm disk spacing

140 DIRAC+MZB boards
Housed in aluminum crates mounted on each disks

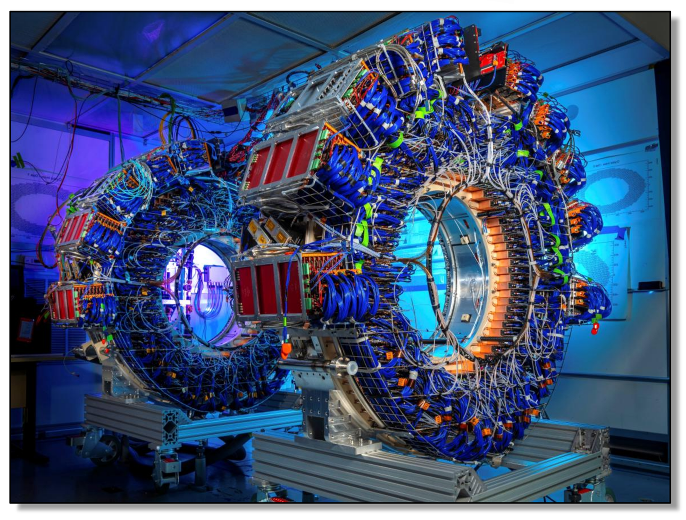
Three calibration sources
Activated liquid source, green laser, cosmic rays



674 CsI crystals per disk
$3.4 \times 3.4 \times 20$ cm^3, emission peak ~ 310 nm

2696 readout channels
Two independent UV-extended SiPMs per crystal

FEE mounted on SiPM pins
For signal amplification and shaping

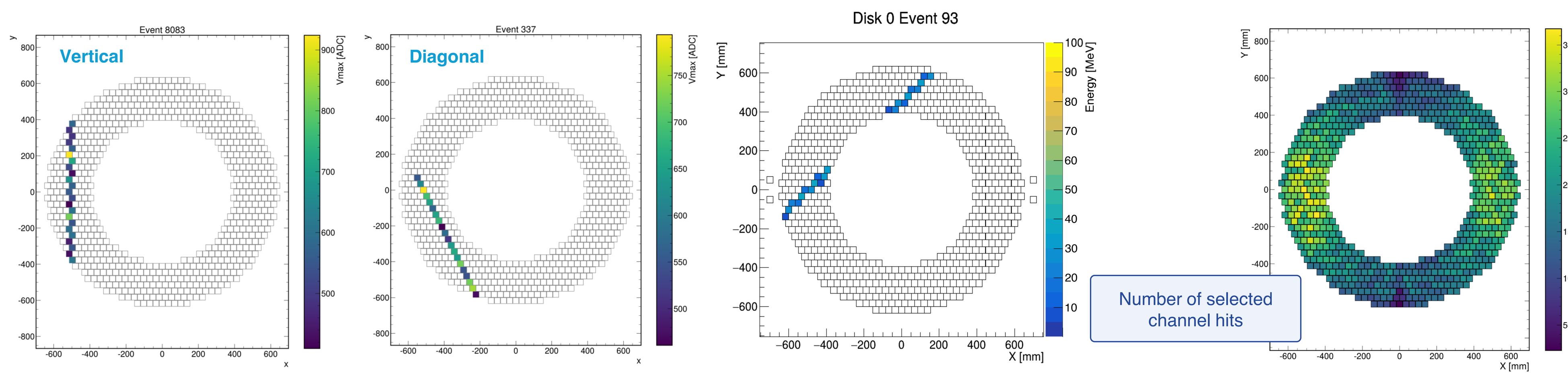


- Fully assembled at Fermilab's Silicon Detector (SiDet) facility
- Commissioning of the disks at SiDet completed in June 2025
- Transport and integration of detector services in the Mu2e experimental hall completed in April 2026
- Commissioning in the hall with the calorimeter fully operational using cosmic rays and laser events ongoing

Commissioning with cosmic ray events

Calibration procedure validated with cosmic ray runs of few hours:

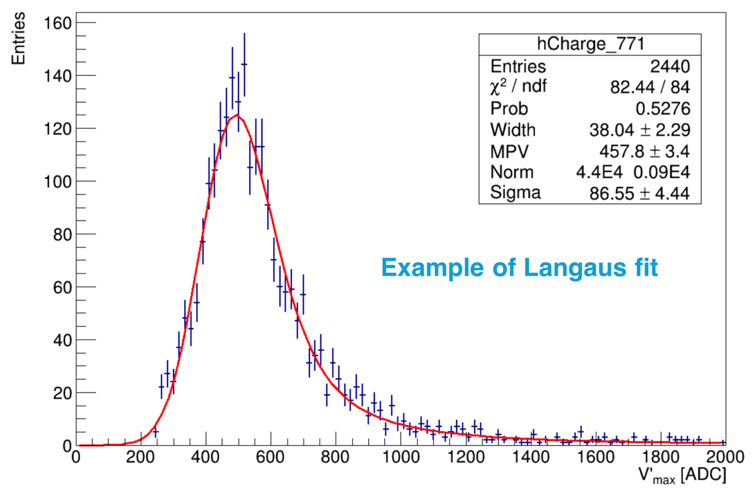
- MIP events selected applying 2D linear fit to calo-hits and classified based on the track topology
- Path length correction to account for tracks with different inclinations



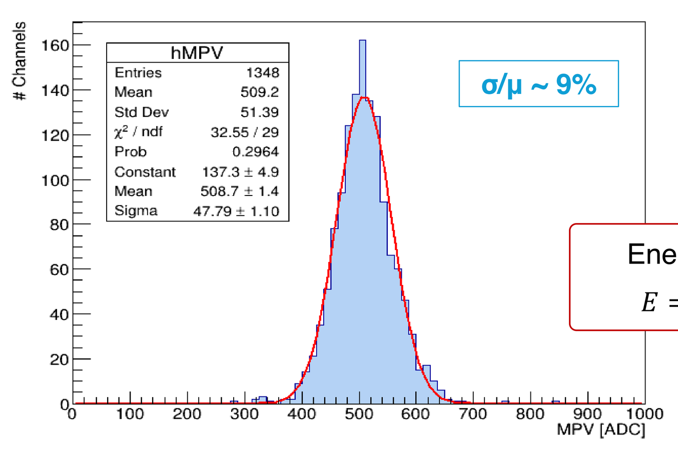
Energy calibration

Average MIP energy deposition inside a crystal is 20 MeV: used for the ADC-to-energy conversion

- MIP charge distribution fitted to a convolution of Landau and Gaussian to extract the MPV

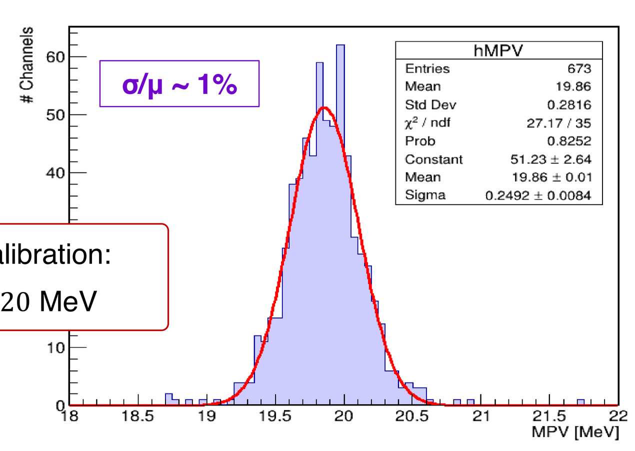


Pre-calibration channel MPV distribution



Energy scale calibration:
$E = Q/MPV \times 20$ MeV

MPV spread after calibration reduced to ~1%



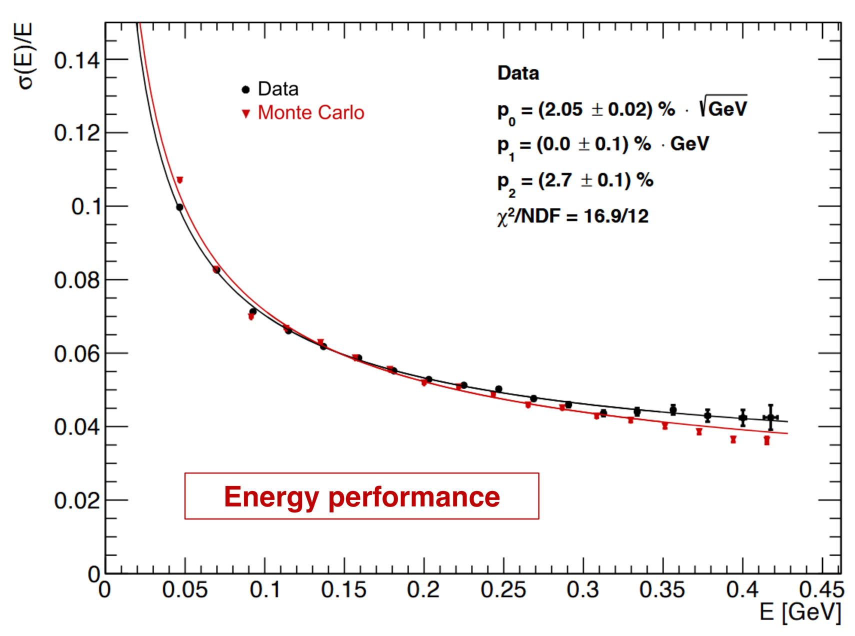
Performance evaluation

MIP calibration applied to cosmic ray events to characterize the energy resolution of the calorimeter

Truncated-mean method used to suppress Landau fluctuations and recover a Gaussian response

Fitted to standard energy resolution parametrization

$$\frac{\sigma(E)}{E} = \sqrt{\frac{p_0^2}{E} + \frac{p_1^2}{E^2} + p_2^2}$$



$\sigma(E)/E \sim 6\%$ @ 100 MeV
Good data-MC agreement

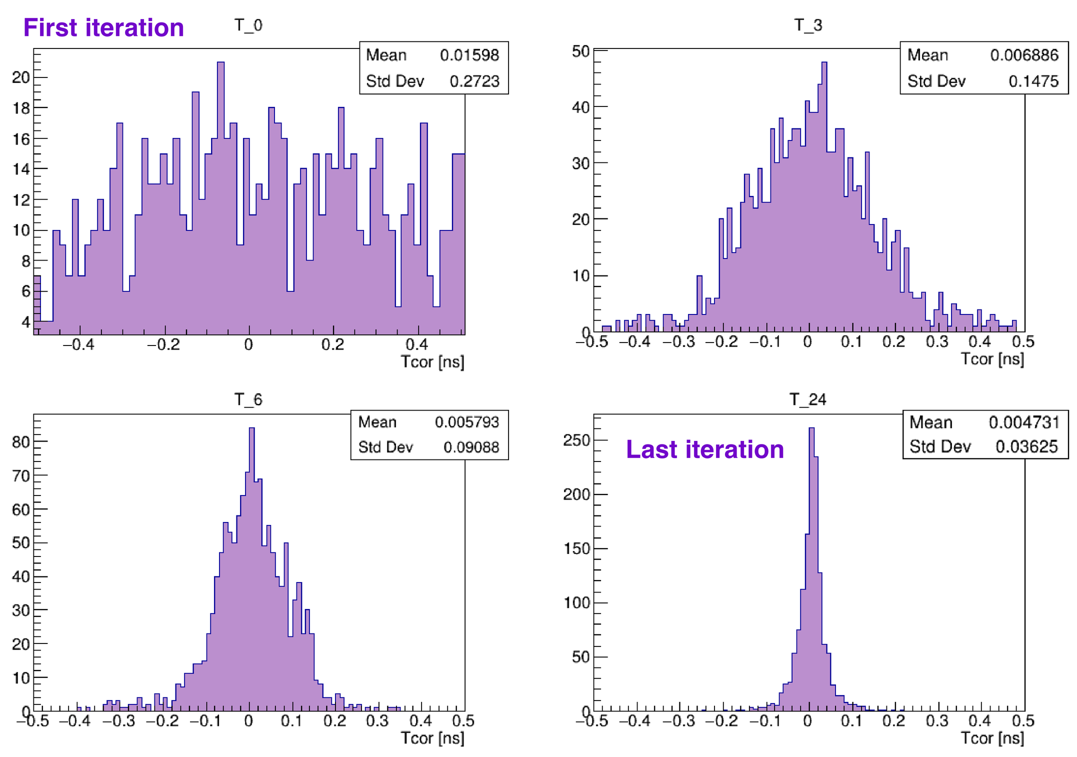
Time calibration

Relativistic nature of MIPs allows time response alignment without the need for any external time reference

- Channel-by-channel time offsets evaluated with an iterative algorithm exploiting time residuals

$$T_{res} = T + \frac{Y_{cel}}{c \cdot cos(\theta)} - T_0^{evt}$$

Mean residual from each iteration step applied as correction in the next iteration



Time residuals well centered near zero with RMS ~ 36 ps after 25 iterations

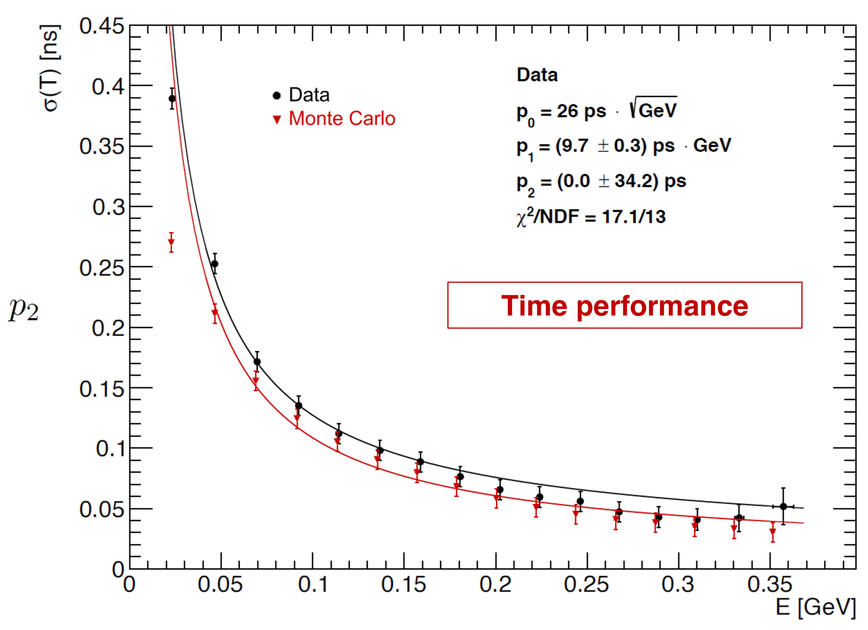
Performance evaluation

Calibrated T_0 offsets applied to cosmic ray events to characterize the time resolution of the calorimeter

Energy-weighted average of the crystal times computed after subtracting the time of flight

Fitted to standard time resolution parametrization

$$\sigma(T) = \frac{p_0}{\sqrt{E[GeV]}} \oplus \frac{p_1}{E[GeV]} \oplus p_2$$



130 ps resolution @ 100 MeV
Data consistent with MC simulation

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