MIP Energy and Time Calibration

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Mu2e CM - Calorimeter Workshop

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Fermilab

INFN Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

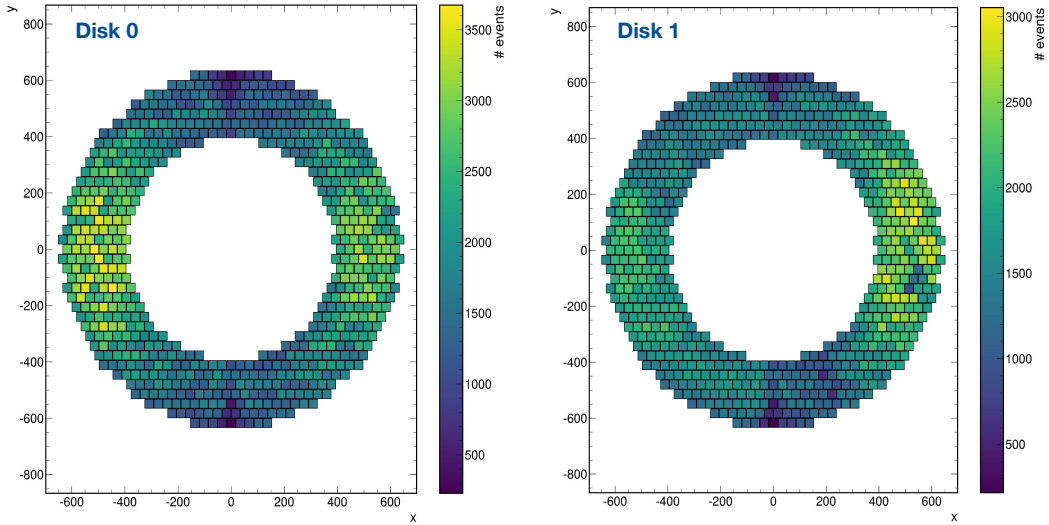
Overview

- ➔ Energy and time calibration studies with cosmic rays data taken in May 2025:
  - ➔ Procedure to extract the MPV of the energy deposition distribution for every crystal of the calorimeter
  - ➔ T0-alignment procedure test

May 2025 cosmics runs

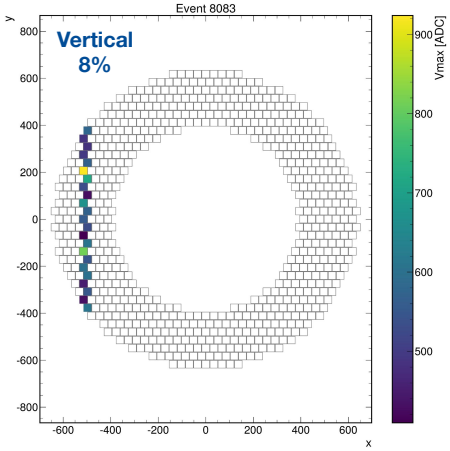
- ➔ Data on both disks, acquired half disk at a time
- ➔ ~15 hours of data taking
- ➔ ~400k events for each half, enough to have more than 500 selected events for each channel
- ➔ Two HV configurations:
  1. Vop
  2. Vrescaled

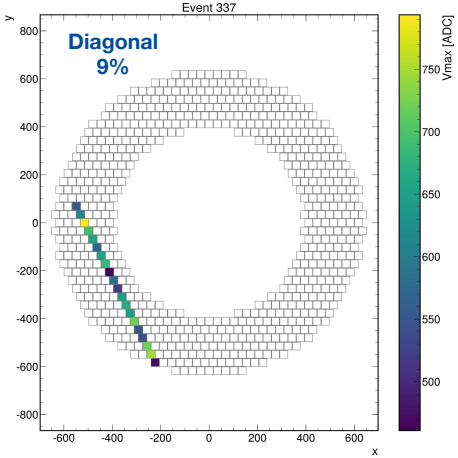
Visualization of number of selected events for each disk

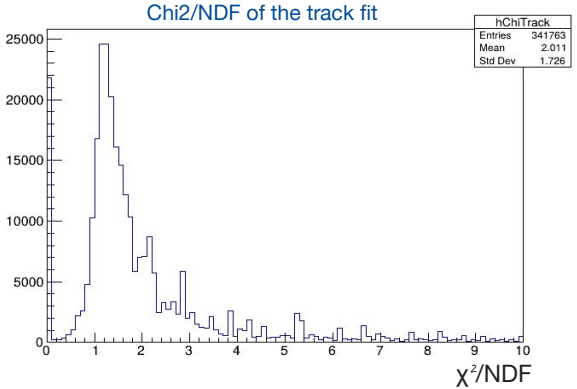


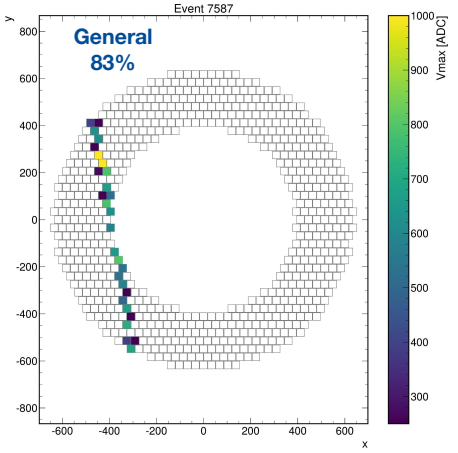
Event selection

- ➔ Nhits > 4
- ➔ Vmax > 250 ADC counts
- ➔ Straight tracks (3 types):
  1. Vertical: $\Delta X < 34$ mm
  2. Diagonal: CRs hitting 1 crystal per layer
  3. General: $\chi^2/NDF < 2.5$
- ➔ Path length correction for diagonal and general tracks





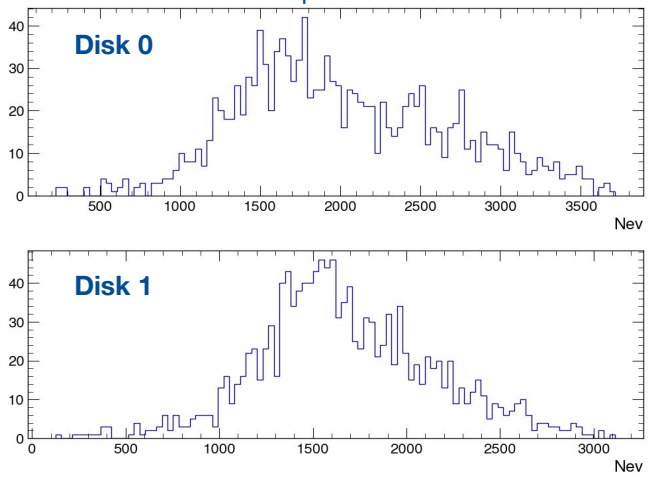


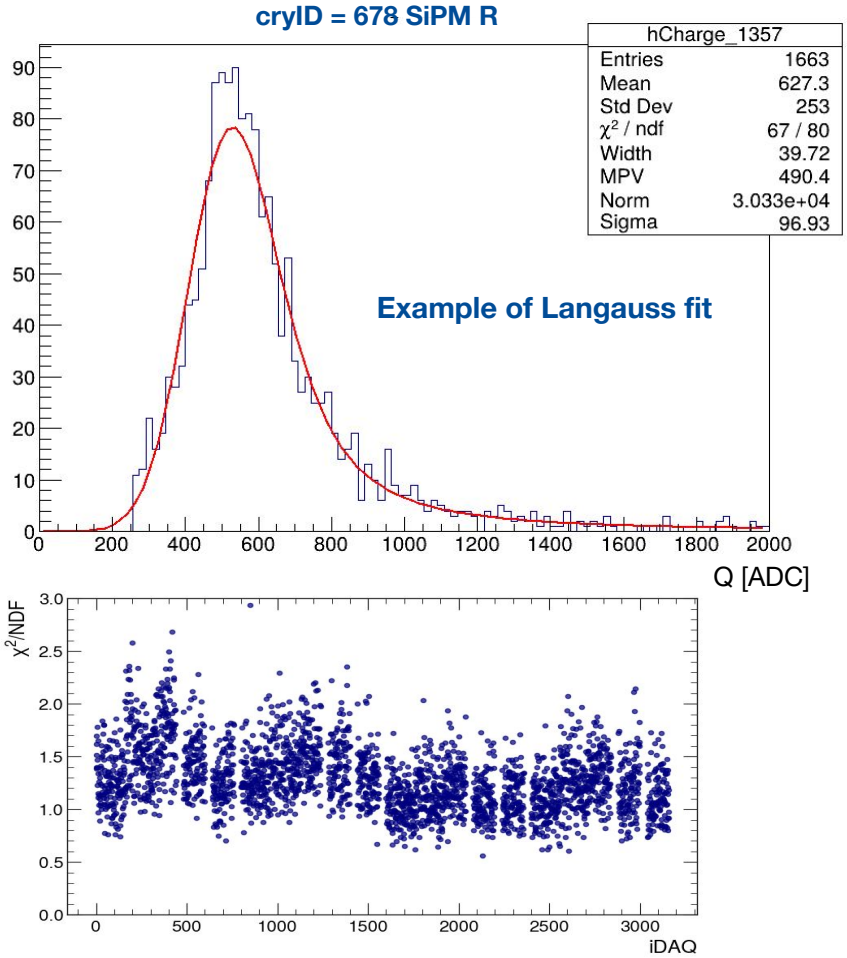


Langauss fits

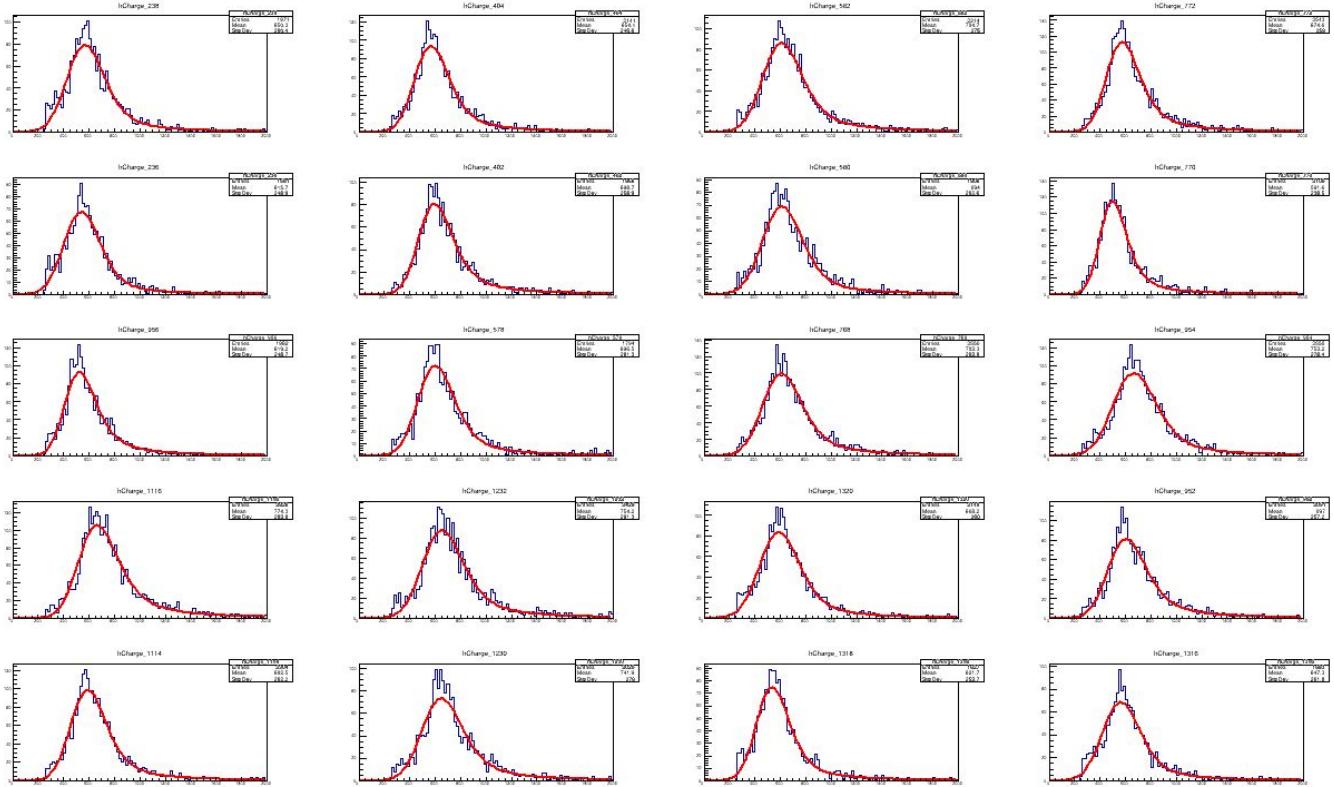
➔ For each channel, the charge distribution is fitted to a Langauss in order to extract the MPV

Distribution of events per channel after selection





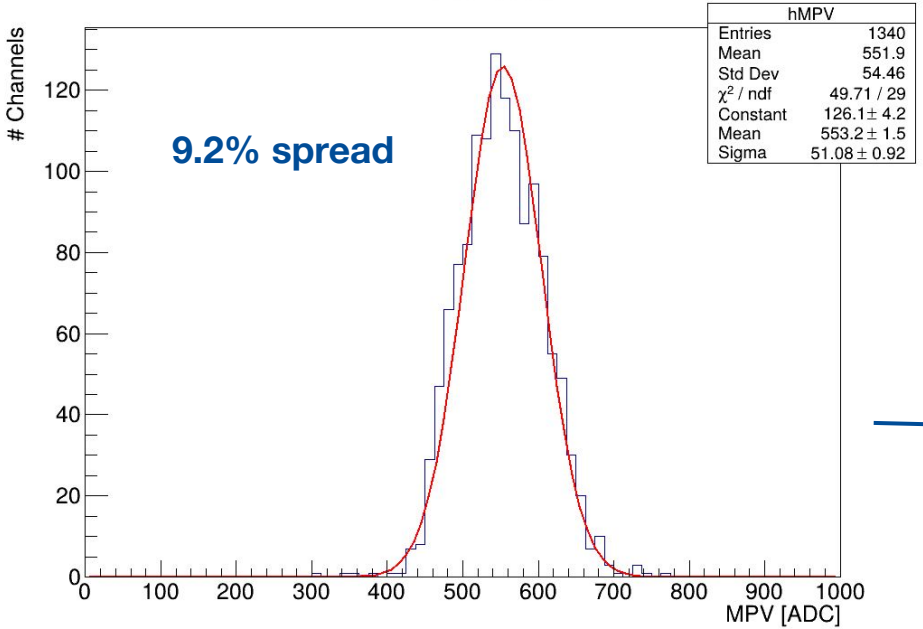
Langauss fits

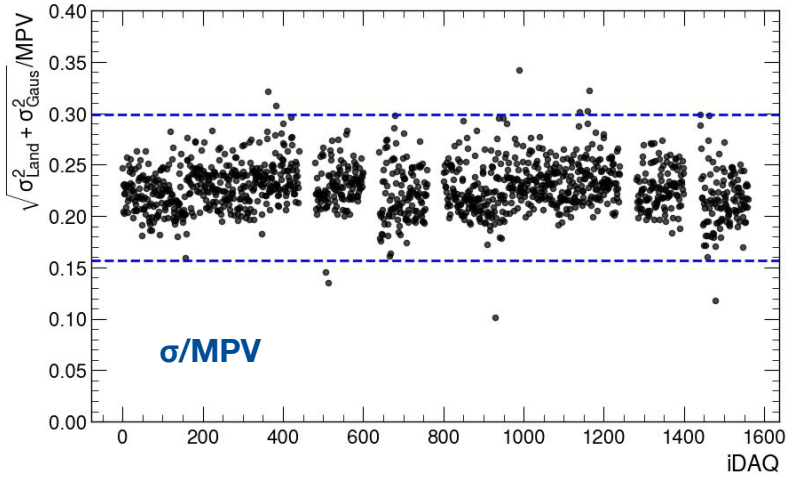


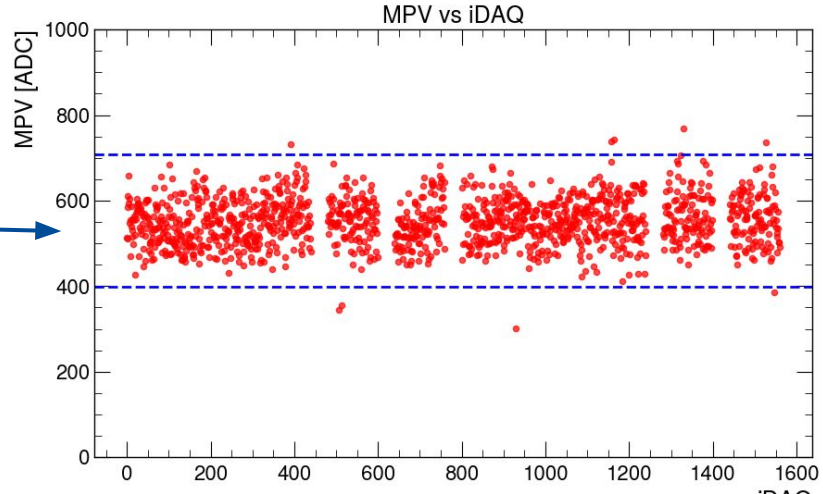
Example of Langauss fits for an entire board (Board 12)

MPV distribution @ Vop

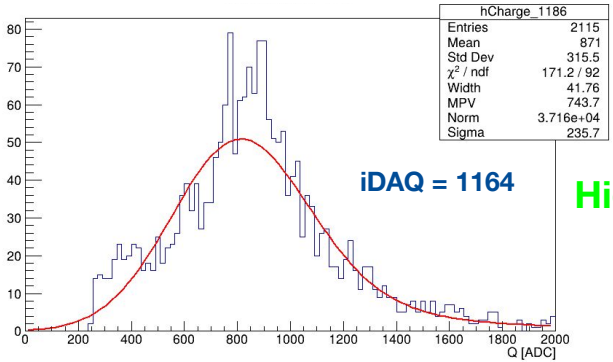
Disk 0





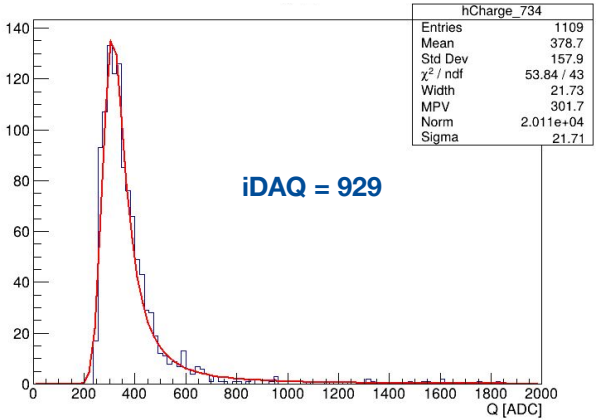


MPV distribution @ Vop



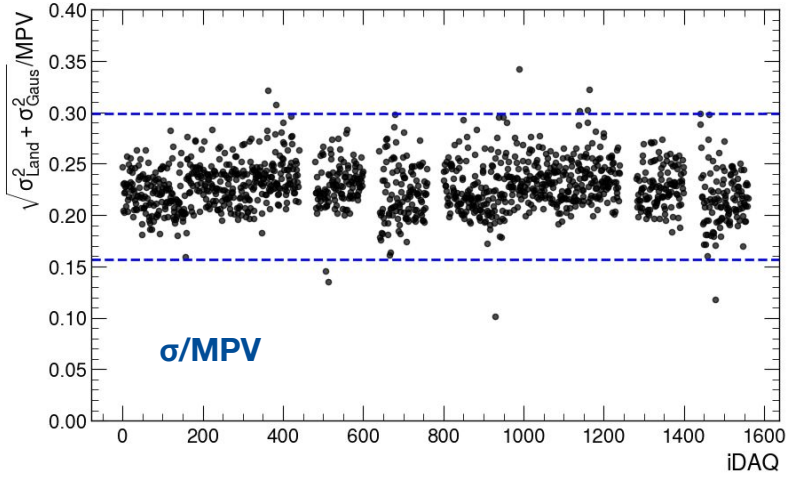
iDAQ = 1164

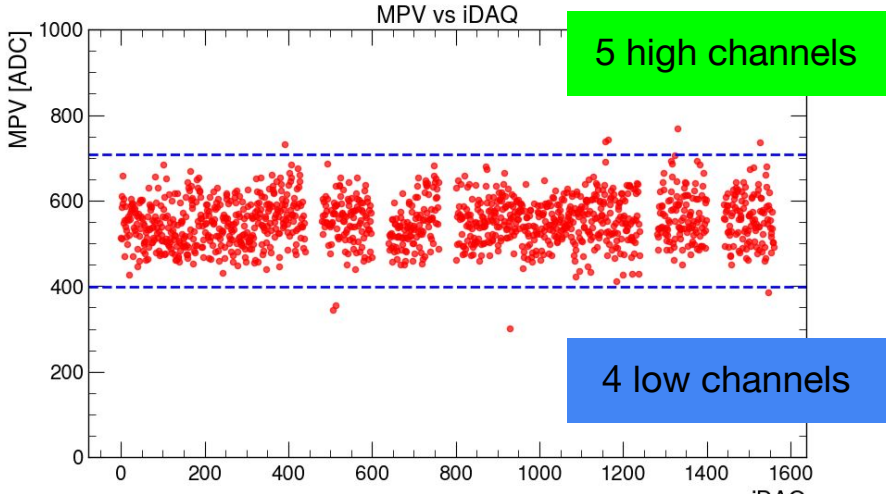
High channel



Low channel

iDAQ = 929



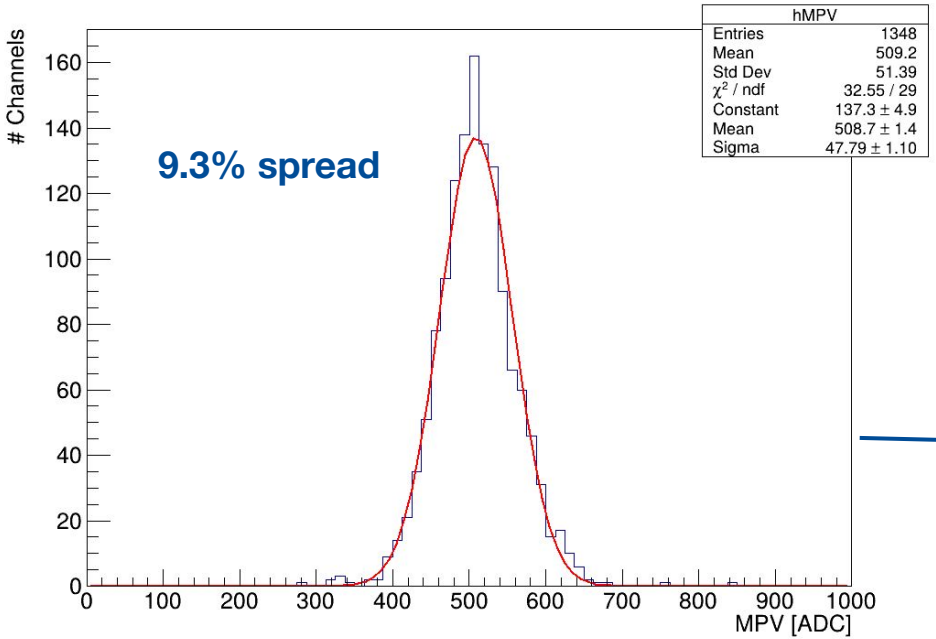


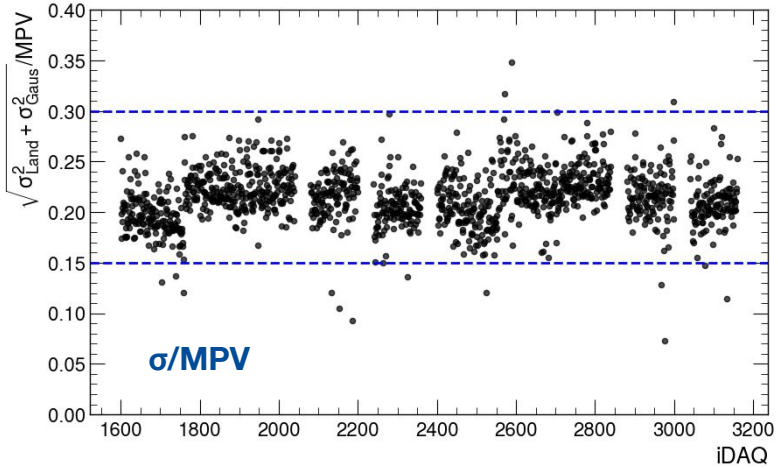
5 high channels

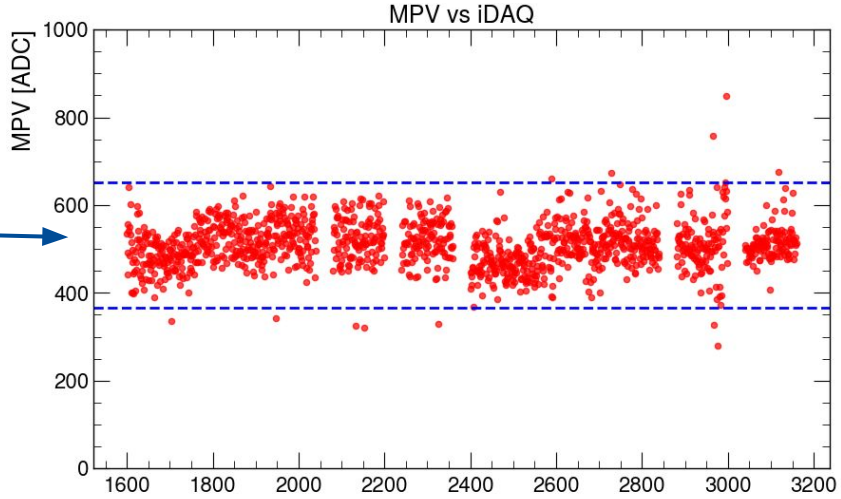
4 low channels

MPV distribution @ Vop

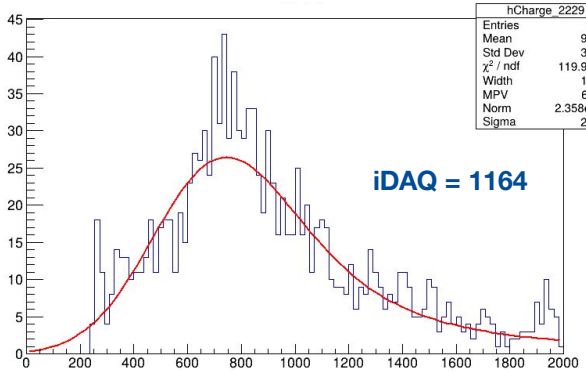
Disk 1



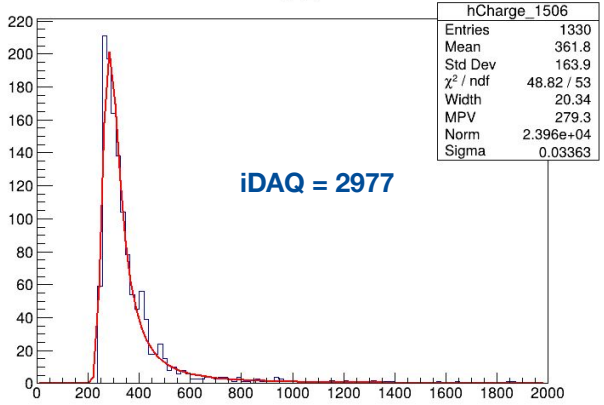




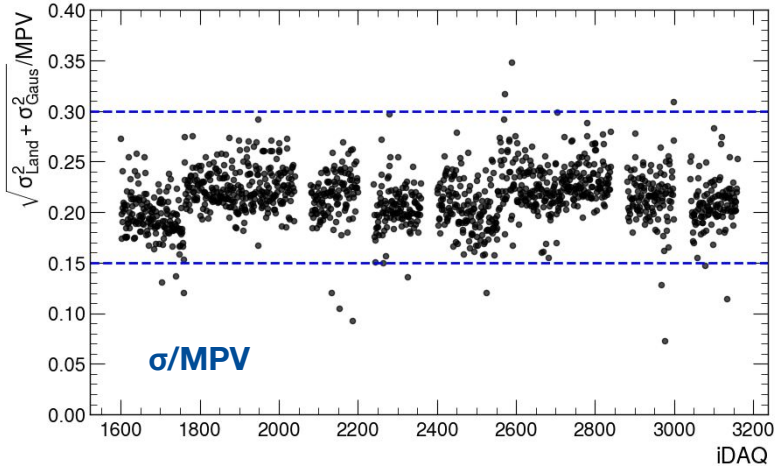
MPV distribution @ Vop

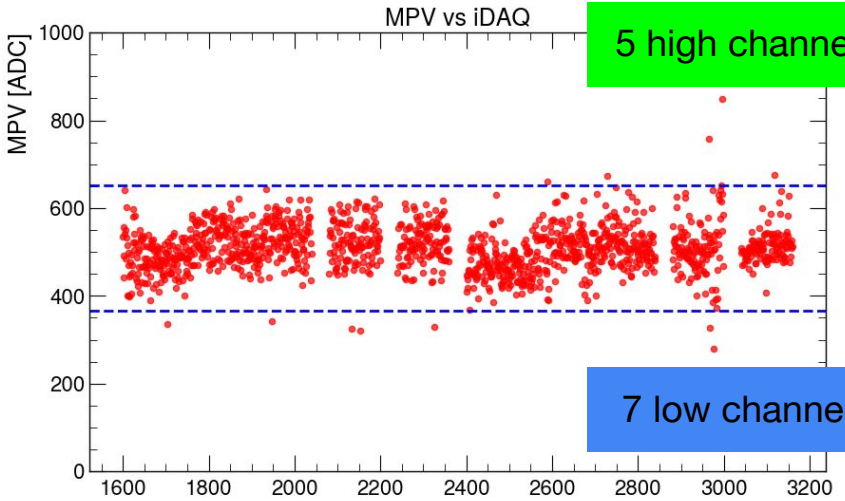


High channel



Low channel



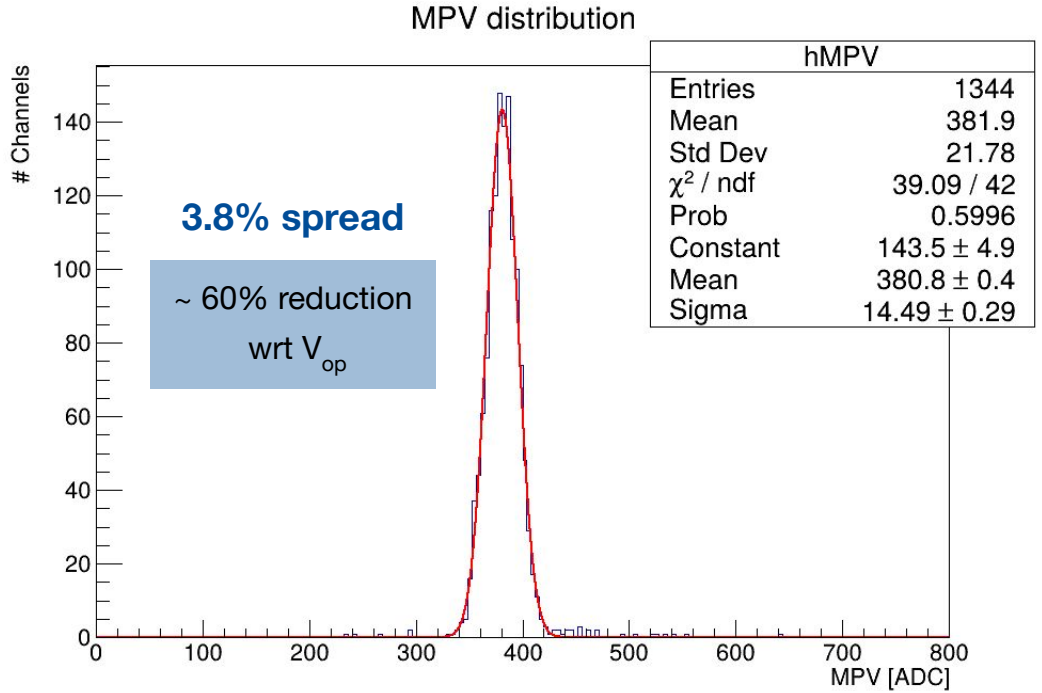


5 high channels

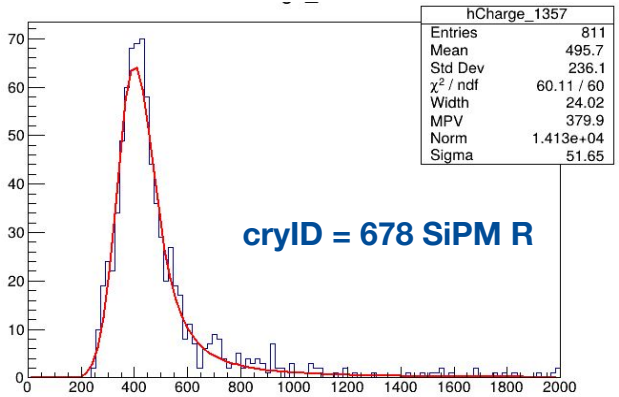
7 low channels

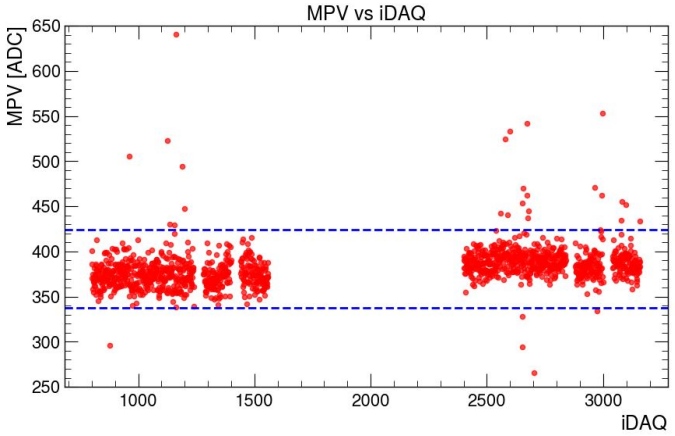
Rescaled HV

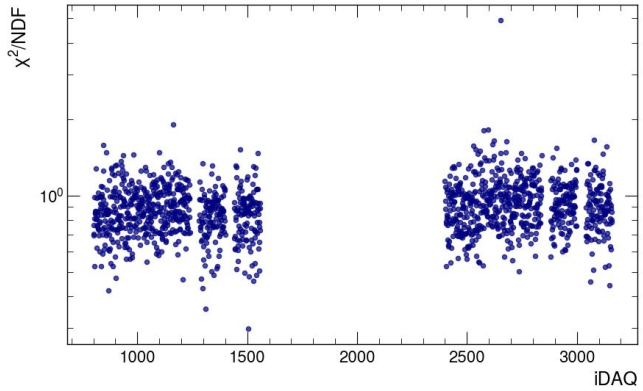
- ➔ In order to be able to match the 6MIP dynamic range, data with rescaled HV were acquired
- ➔ The HV were rescaled using the MPV values extracted with Langauss fits from March 2025 data at Vop
- ➔ Data for half of each disk (Phi = 1)
- ➔ The same energy calibration procedure was applied

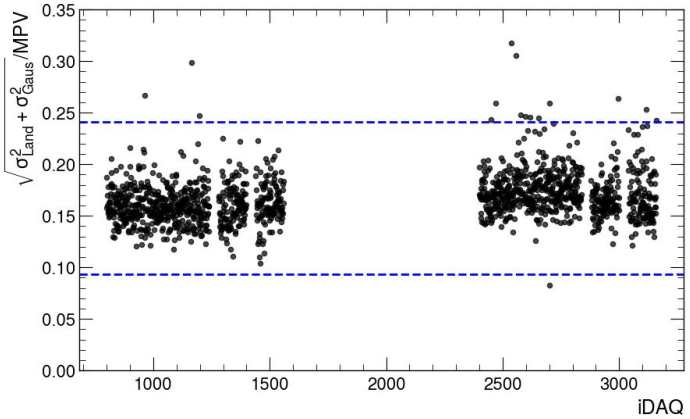


Rescaled HV


hCharge_1357
Entries 811
Mean 495.7
Std Dev 236.1
χ² / ndf 60.11 / 60
Width 24.02
MPV 379.9
Norm 1.413e+04
Sigma 51.65
cryID = 678 SiPM R

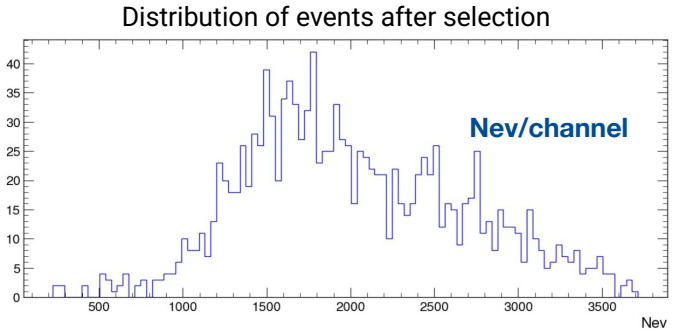

MPV vs iDAQ
MPV [ADC]
iDAQ

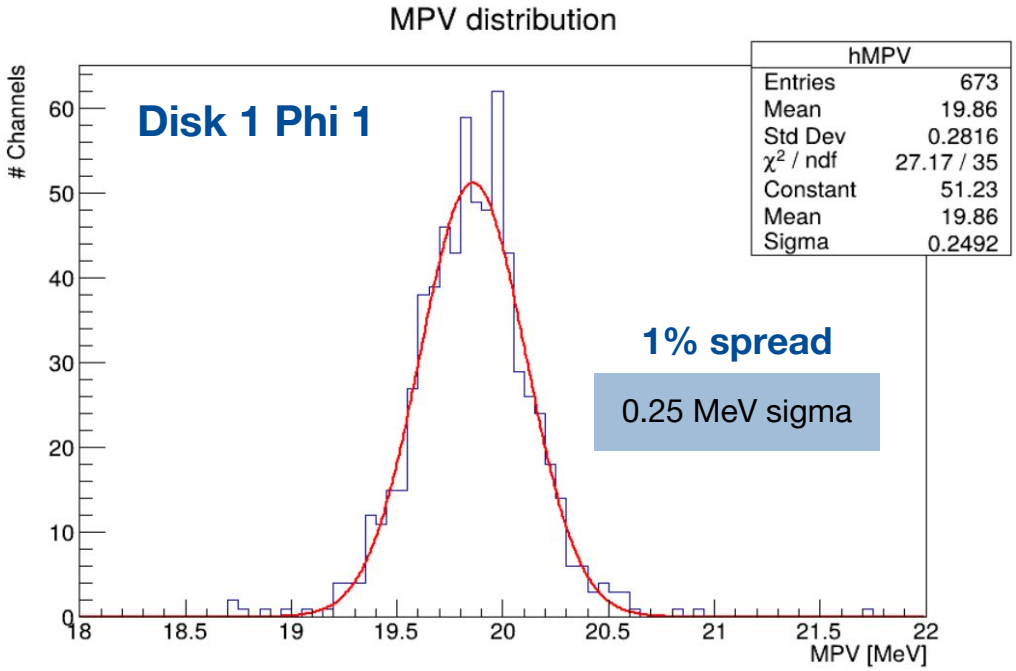

χ²/NDF
iDAQ


iDAQ

Energy calibration results

- ➔ To test the energy calibration procedure, the data sample for Disk 1 Phi 1 at Vop was split in half
- ➔ One half used to extract the MPV for each channel
- ➔ The other half was rescaled in MeV using the extracted MPVs

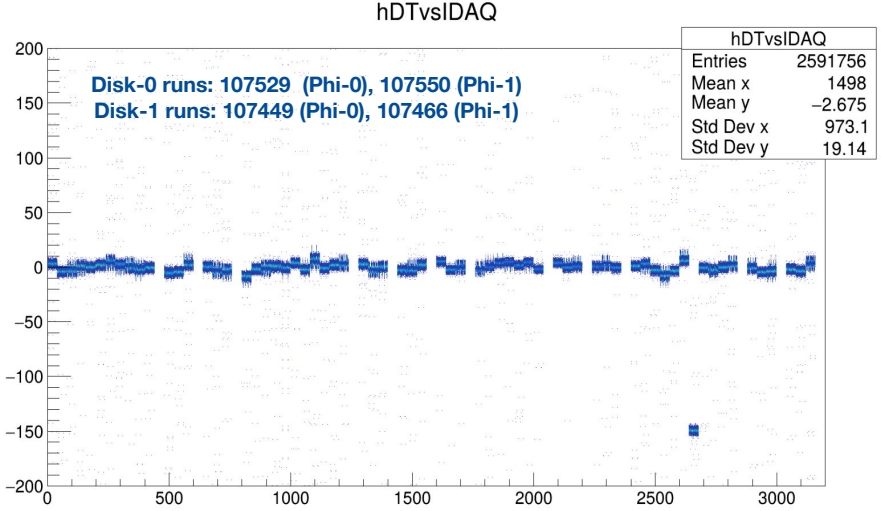


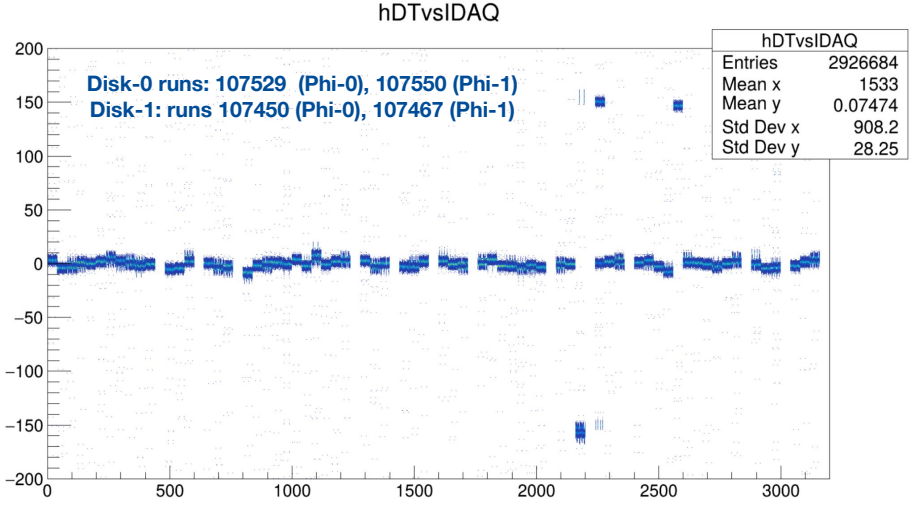


➔ E [MeV] = Q / MPV * 20 MeV

Time calibration

- ➔ Test of the T0-alignment procedure for both disks using May data
- ➔ Fit Template is the old one used for Module-0
- ➔ Procedure organized in two steps. First step with laser not performed:
  - ➔ Starting time offsets up to 12 ns for Disk-0 and up to 150 ns for Disk-1
  - ➔ DT jumps from board to board vary for different runs



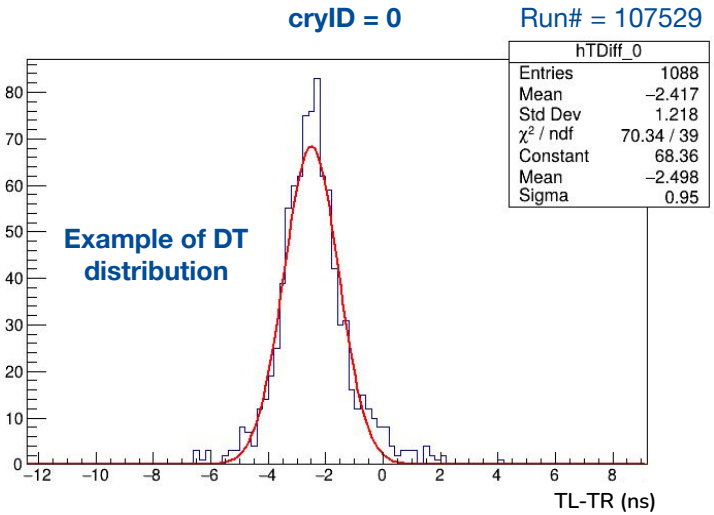


Time calibration

- ➔ For each event and for each crystal, the time difference between SiPM left and right is evaluated
- ➔ The distribution of DT for each channel is then fitted to a Gaussian distribution
- ➔ The same is done for the mean time, evaluated as:

$$T_{mea} = \frac{T_L + T_R}{2} - \Delta T - T^0_{mean}$$

- ➔ T^0_{mean} is the average time for each event in order that all channels are corrected from the Tmarker.
- ➔ T_{mea} are used as T0 correction in the second step of the time calibration procedure, and times are corrected for the DT



Time calibration

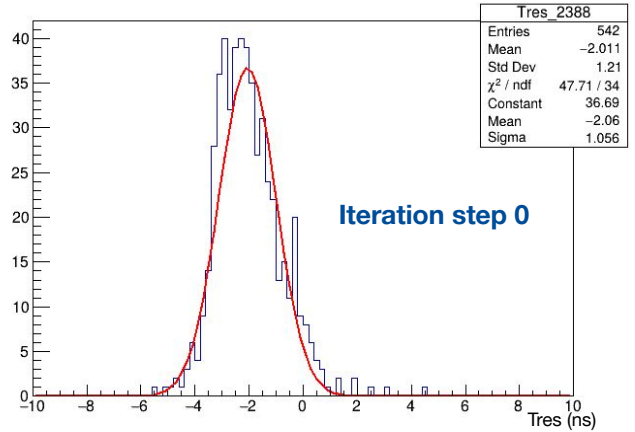
➔ The second step is an iterative procedure consisting of the following sequence:

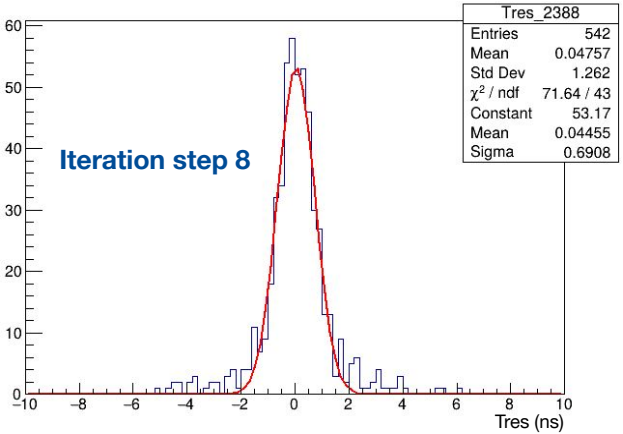
1. The angle between the CR track and the X coordinate is evaluated with a 2D linear fit;
2. For each event, a common energy-weighted of the event is determined;
3. For each event and each hit, the time residuals are evaluated as:

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

4. For each channel, the distribution of residuals is fitted to a Gaussian distribution to extract T_{cor}
5. The obtained T_{cor} is subtracted from the measured time in the following iteration.

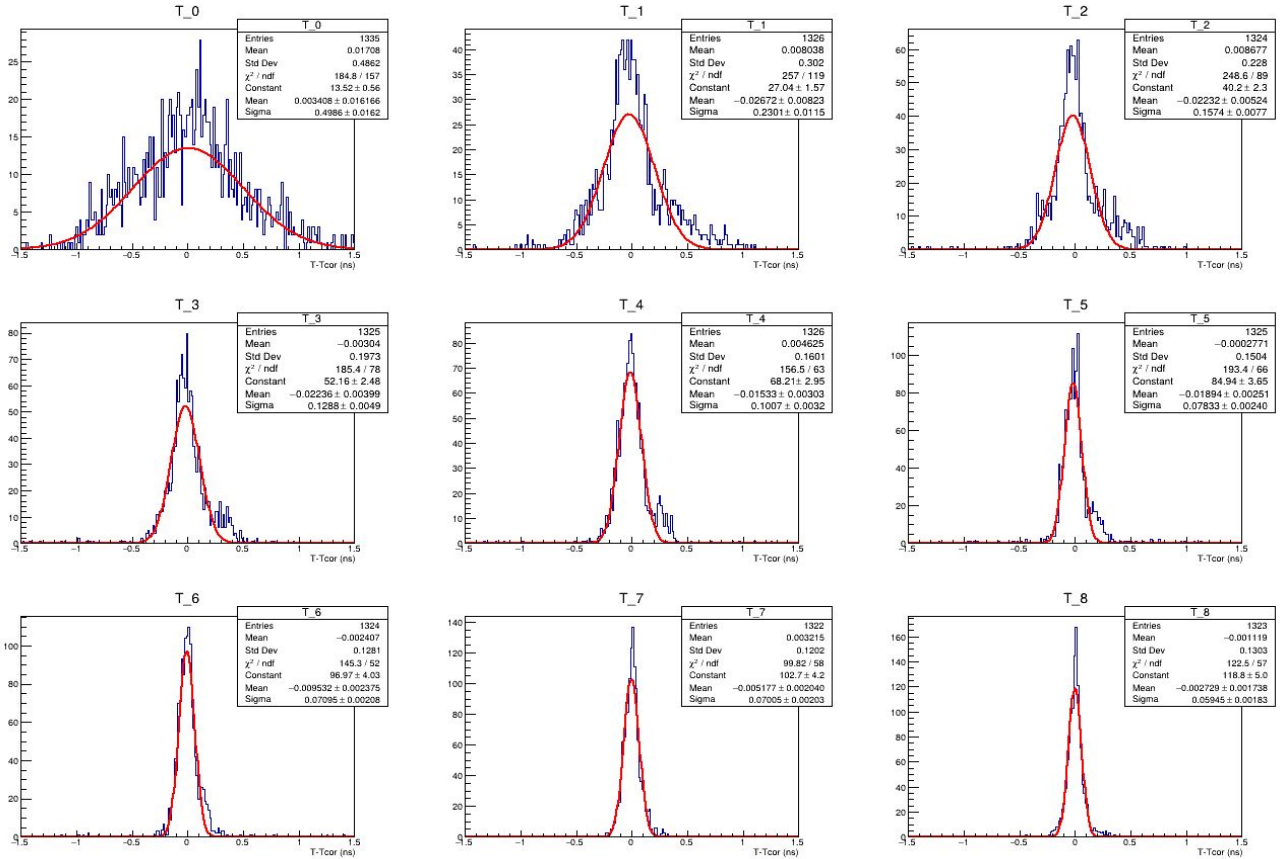
iDAQ = 2726 - Tres distribution





Time calibration

Run# = 107529, 107550

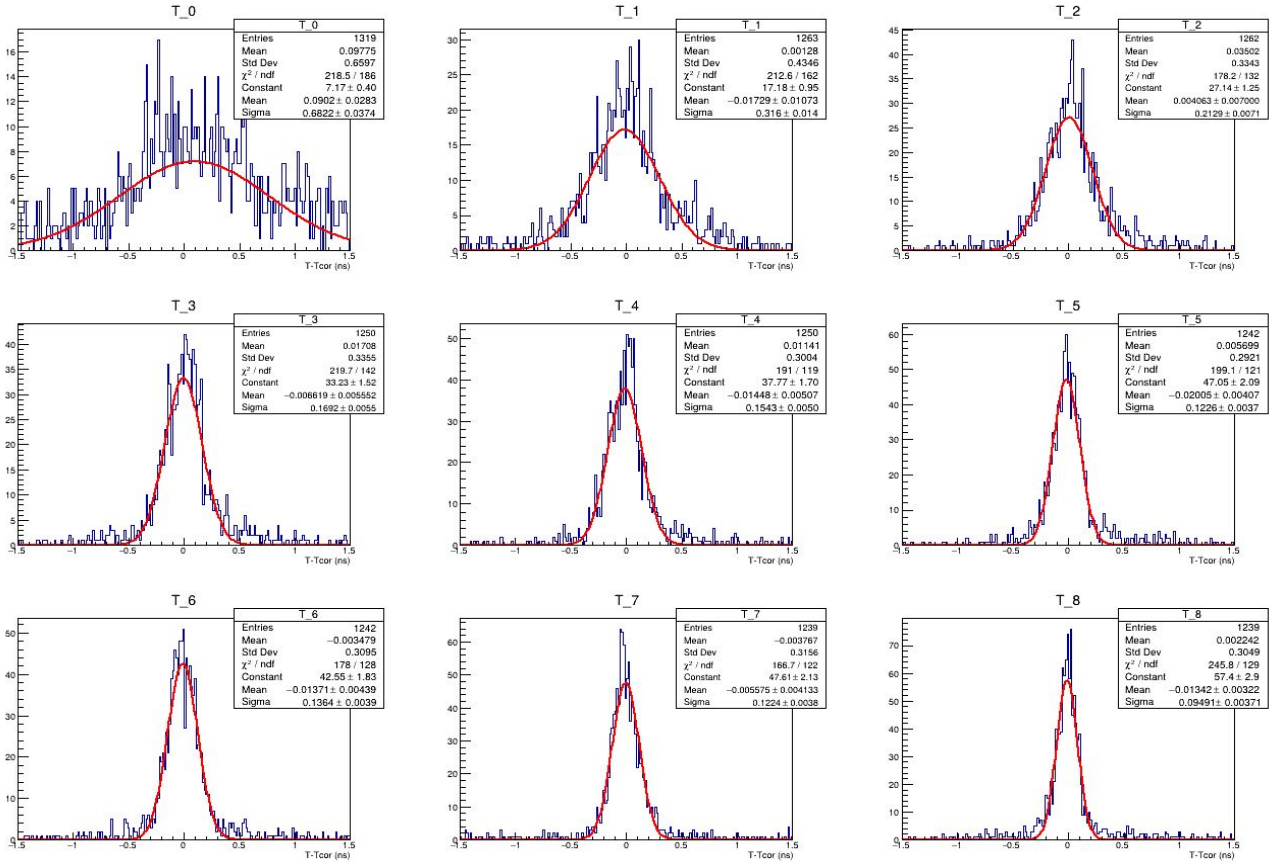


Disk 0

The T0-alignment procedure is finally converging. The spread of the T0s improves from a starting 500 ps to around 60 ps after 9 iterations.

Time calibration

Run# = 107449, 107466



Disk 1

The final spread obtained with the T0 alignment procedure on Disk-1 is worse than on Disk-0 due to the much larger initial spread on the boards. It improves from 682 ps to 95 ps.

Conclusions

- ➔ MIP energy calibration successfully tested on both disk-0 and disk-1.
- ➔ The channel-by-channel spread is better than 10% in the Vop configuration and gets reduced to a 3.8% spread setting a better working point a 380 ADC counts.
- ➔ The average response of Disk-0 is 10% larger than Disk-1 as expected.
- ➔ Reproducibility between calibration in different runs is better than 0.25 sigma.
- ➔ A first successful test of the T0 alignment procedure done for Disk-0 and Disk-1.
- ➔ Disk-0 calibration provided a final spread for the residuals below 60 ps.
- ➔ Disk1 calibration provided a large spread (98 ps) due to the worst starting conditions.
- ➔ Improvement expected looking at the data with the new Firmware releases.

Backup slides

Path length correction

- ➔ The track is defined by: $y = m \cdot x + q$
- ➔ The intersection with the edges of the crystal in the X-Y plane are evaluated:

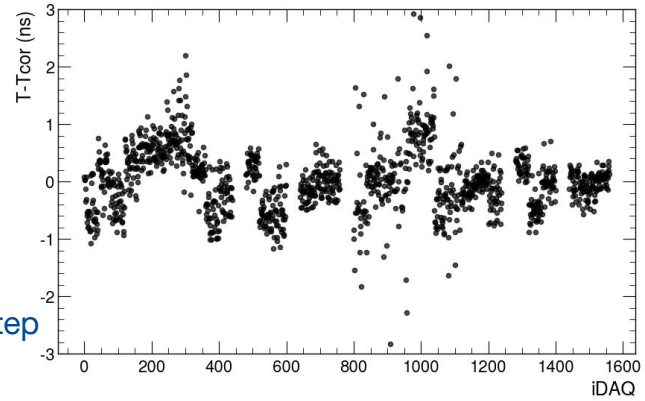
$$x_{\text{up}} = \frac{(y+17)-q}{m}, \quad x_{\text{low}} = \frac{(y-17)-q}{m} \qquad y_{\text{left}} = m \cdot (x-17) + q, \quad y_{\text{right}} = m \cdot (x+17) + q$$

- ➔ Tracks crossing top-bottom: $\text{path} = 34 \cdot \sqrt{1 + \frac{1}{m^2}}$
- ➔ Tracks crossing left-right: $\text{path} = 34 \cdot \sqrt{1 + m^2}$
- ➔ In general: $\text{path} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$

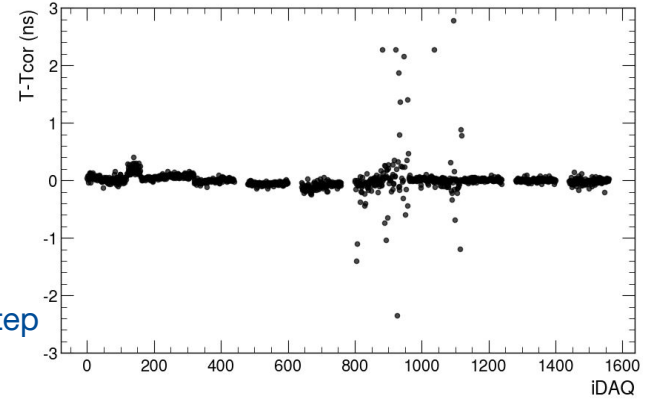
Tres vs iDAQ

Disk 0:

First step

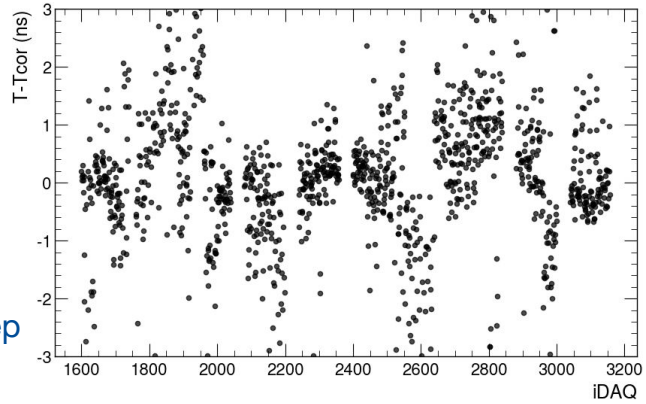


Last step



Disk 1:

First step



Last step