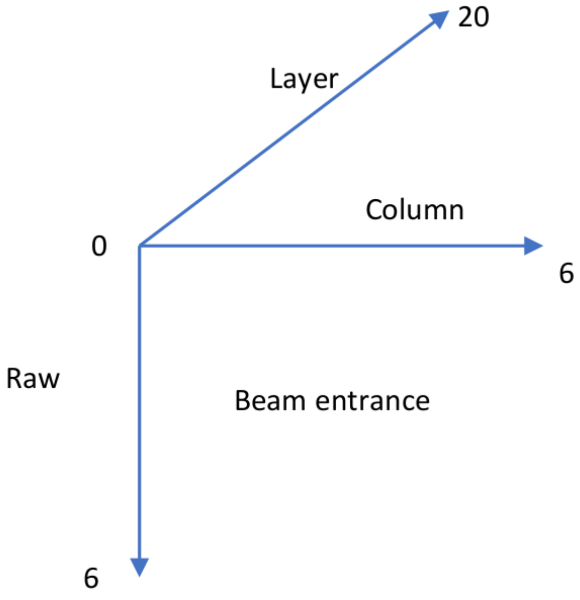
Electron analysis – HERD beam test SPS2023

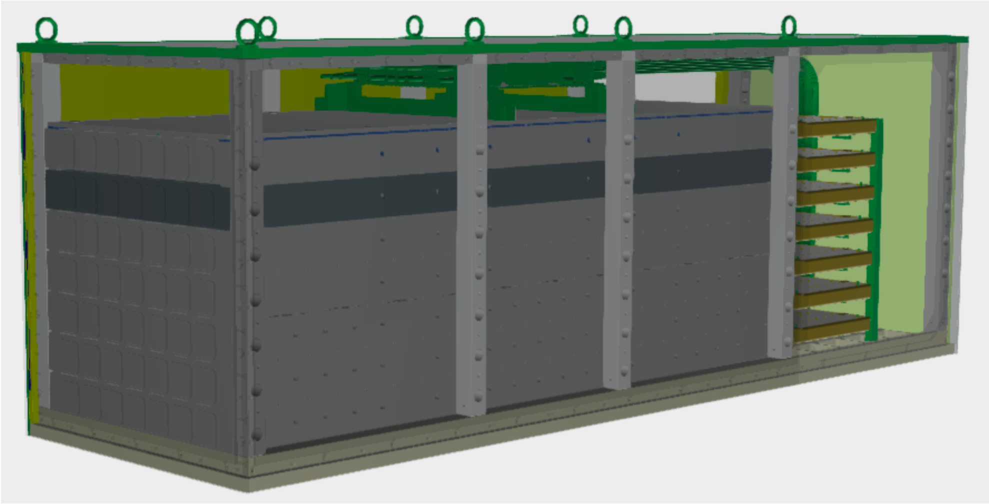
Pietro Betti
“We should discuss later”
“We should publish soon”

Analyzed files

- 250 GeV: run 302
- 200 GeV: run 305, 310, 311 (noise run 311)
- 150 GeV: run 303
- 100 GeV: run 312
- 50 GeV: run 304
- 20 GeV: run 313

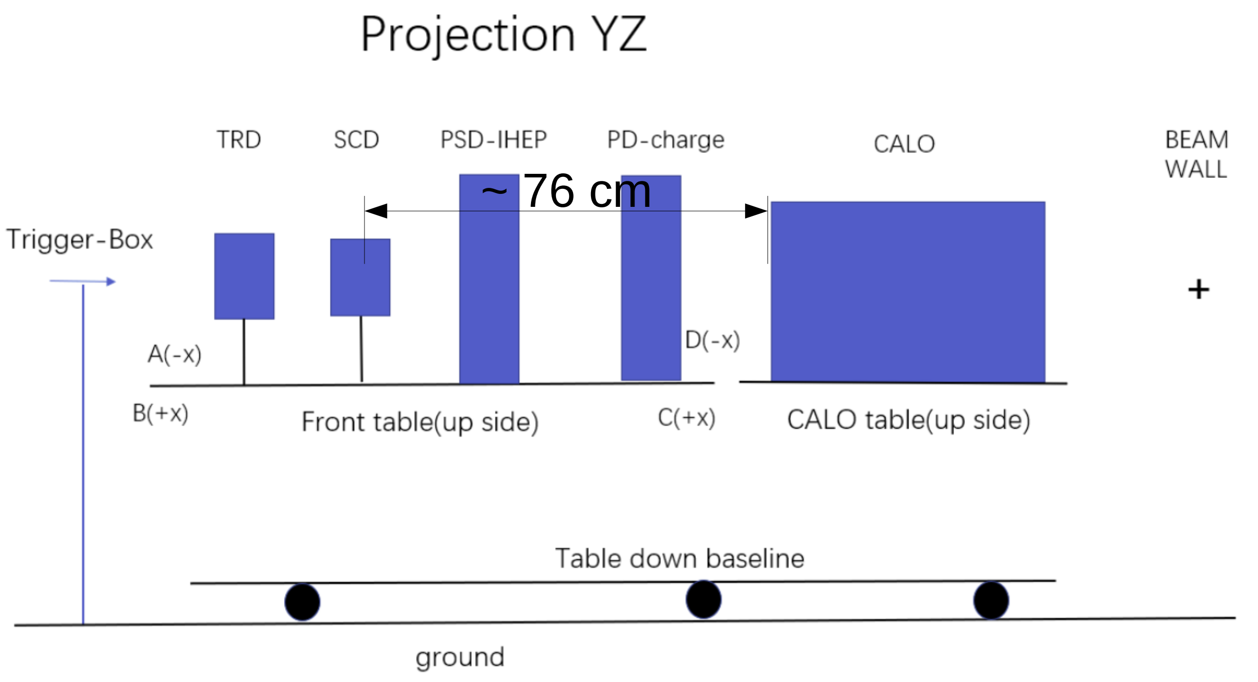
Beam Test Geometry - Calorimeter





- LYSO density ~ 7,1 g/cm^3
- Carbon fiber density~ 1.65 g/cm^3

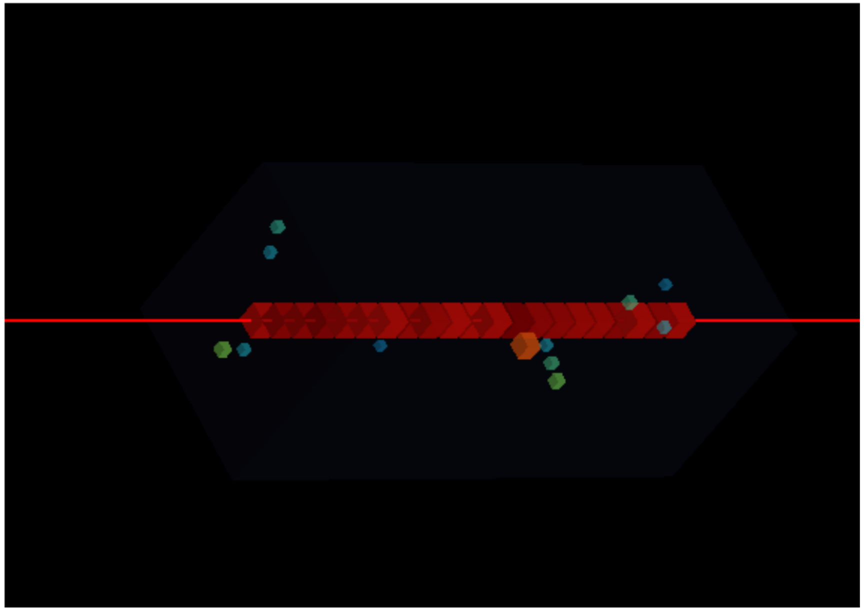
Beam Test Geometry – all detectors



Calorimeter Calibration with muons

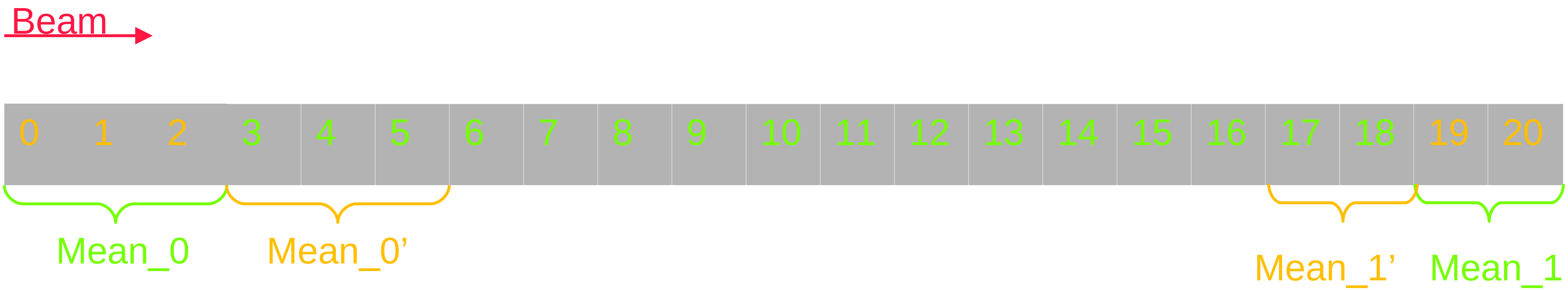
Calorimeter Calibration

- 5 GeV muons scan at PS
- Only 3x3 CALO core is considered



Event selection

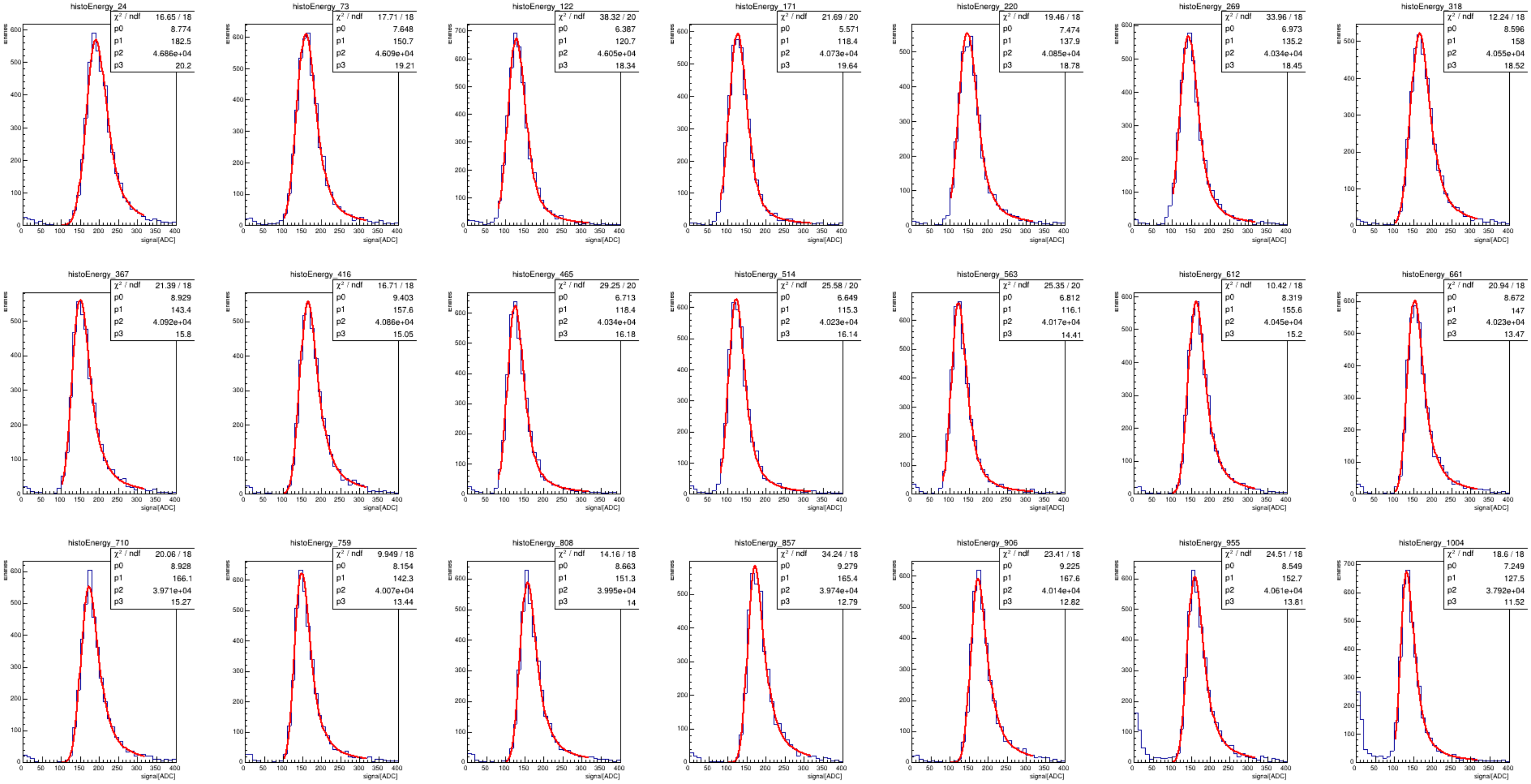
- Select events with threshold on total energy release
  - Event in Cube 3-18 if Mean_0 and Mean_1 above thresholds
  - Event in Cube 0-2 and 19-20 if Mean_0' and Mean_1' above thresholds



- Fit of Landau convolute with Gaussian on muons MIP histograms

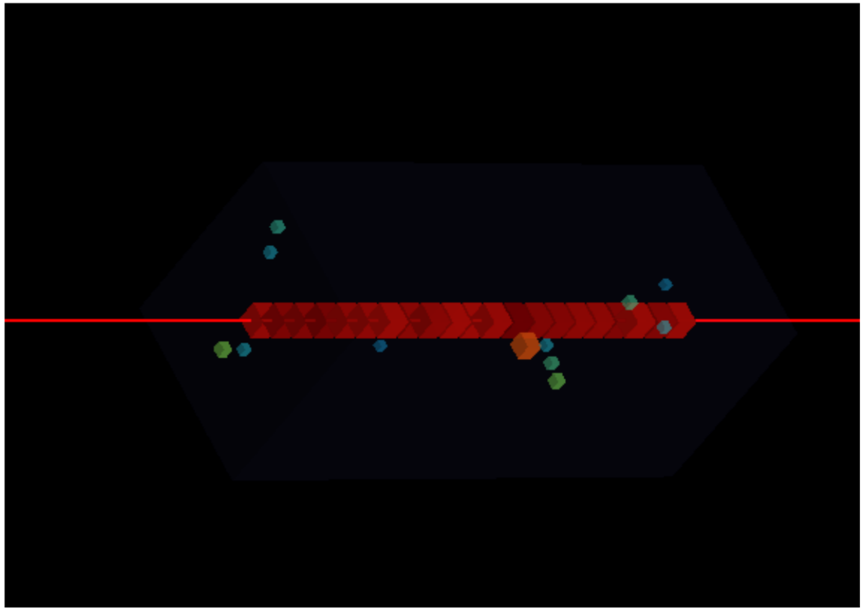
LanGau Fit on MIP real data

- Fit of Landau convolute with Gaussian on muons MIP histograms



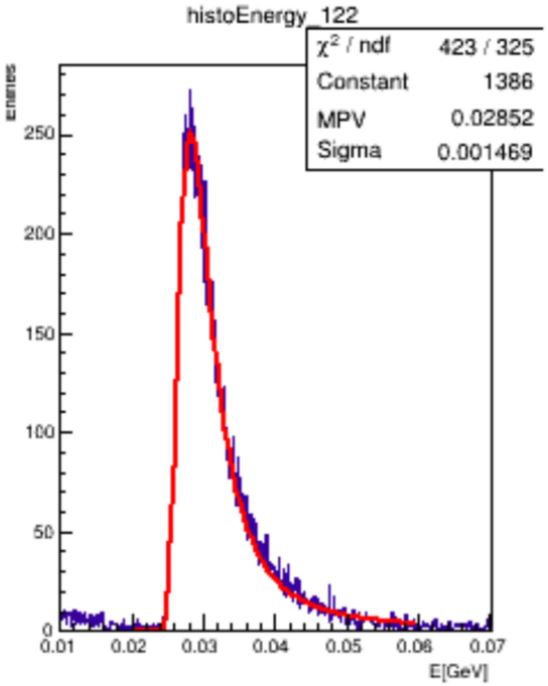
Muons simulations

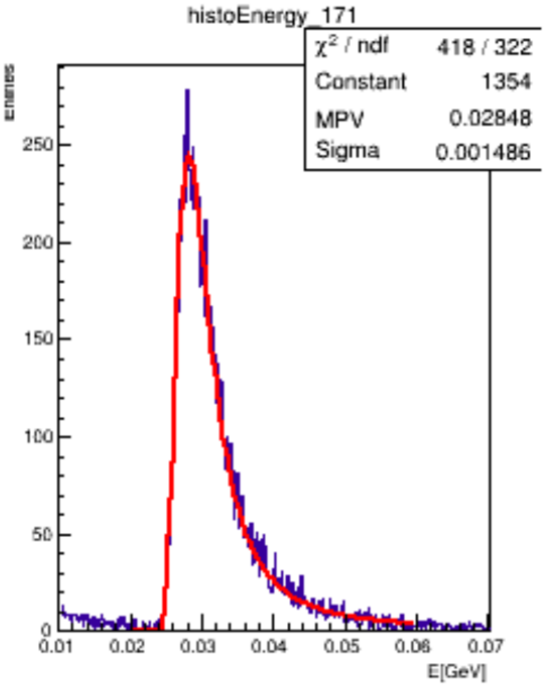
- Uniform beam of muons that cover the 3x3 CALO core
  - No tracker information (beam distribution information) at PS
  - Muons beam was wide and covered multiple crystals

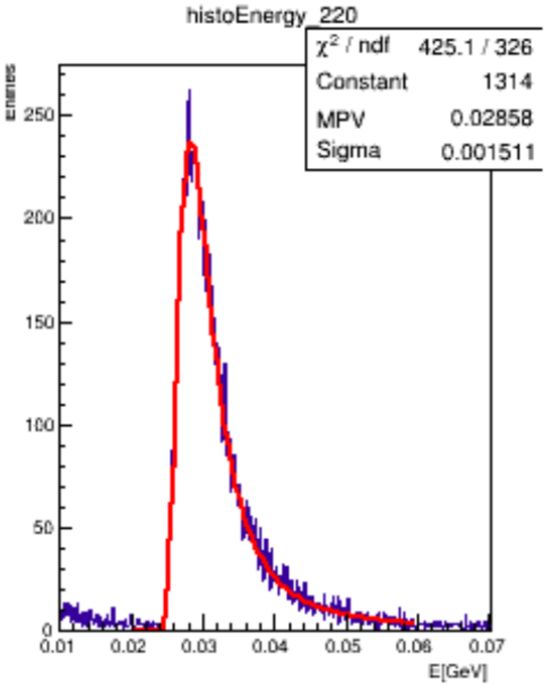


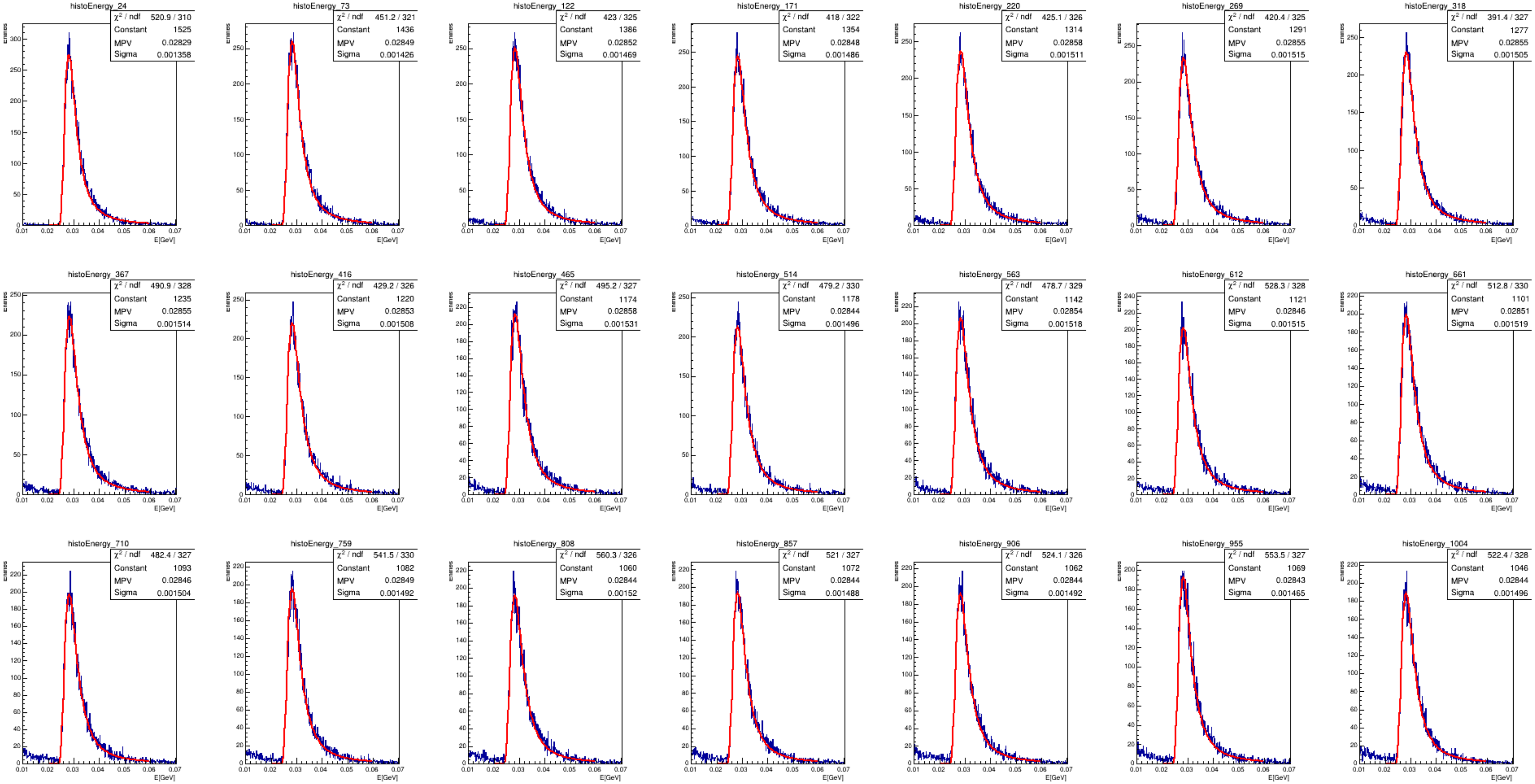
ADC→GEV - iteration 0

- Landau fit on MC muons histograms without digitization
- First estimation of MIP→GeV



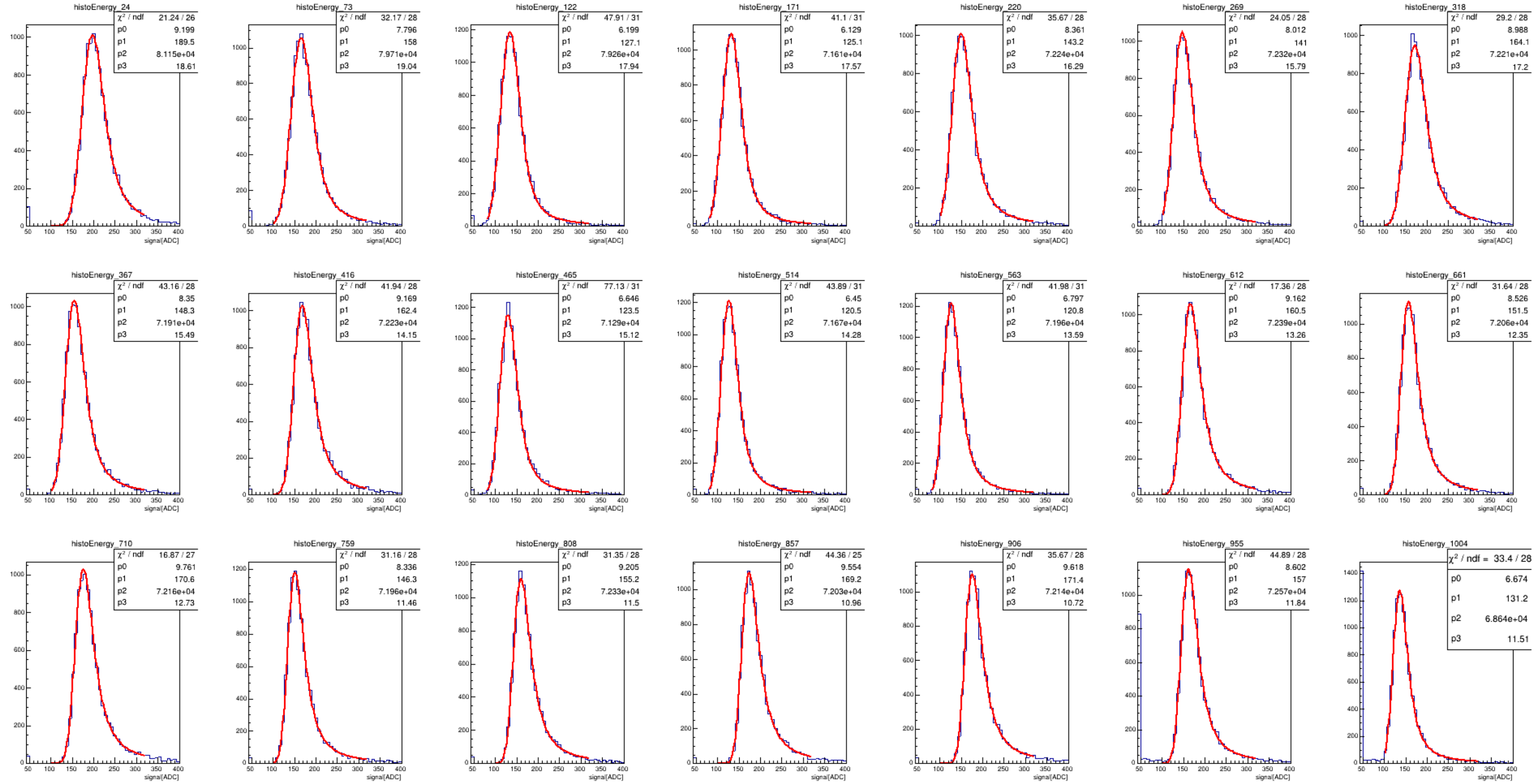




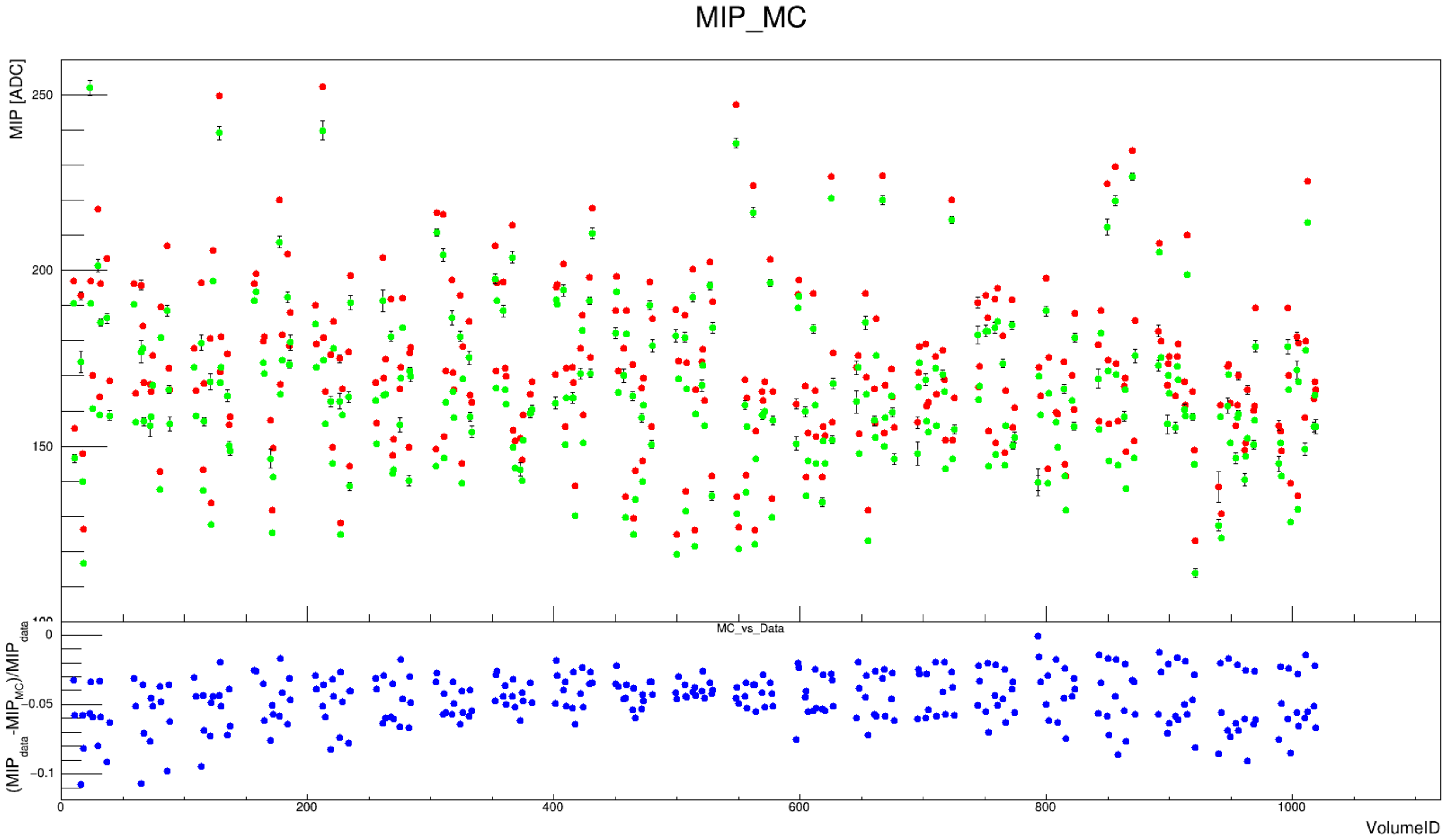


histoEnergy_24
χ2 / ndf 520.9 / 310
Constant 1525
MPV 0.02829
Sigma 0.001358
histoEnergy_73
χ2 / ndf 451.2 / 321
Constant 1436
MPV 0.02849
Sigma 0.001426
histoEnergy_122
χ2 / ndf 423 / 325
Constant 1386
MPV 0.02852
Sigma 0.001469
histoEnergy_171
χ2 / ndf 418 / 322
Constant 1354
MPV 0.02848
Sigma 0.001486
histoEnergy_220
χ2 / ndf 425.1 / 326
Constant 1314
MPV 0.02858
Sigma 0.001511
histoEnergy_269
χ2 / ndf 420.4 / 325
Constant 1291
MPV 0.02855
Sigma 0.001515
histoEnergy_318
χ2 / ndf 391.4 / 327
Constant 1277
MPV 0.02855
Sigma 0.001505
histoEnergy_367
χ2 / ndf 490.9 / 328
Constant 1235
MPV 0.02855
Sigma 0.001514
histoEnergy_416
χ2 / ndf 429.2 / 326
Constant 1220
MPV 0.02853
Sigma 0.001508
histoEnergy_465
χ2 / ndf 495.2 / 327
Constant 1174
MPV 0.02858
Sigma 0.001531
histoEnergy_514
χ2 / ndf 479.2 / 330
Constant 1178
MPV 0.02844
Sigma 0.001496
histoEnergy_563
χ2 / ndf 478.7 / 329
Constant 1142
MPV 0.02854
Sigma 0.001518
histoEnergy_612
χ2 / ndf 528.3 / 328
Constant 1121
MPV 0.02846
Sigma 0.001515
histoEnergy_661
χ2 / ndf 512.8 / 330
Constant 1101
MPV 0.02851
Sigma 0.001519
histoEnergy_710
χ2 / ndf 482.4 / 327
Constant 1093
MPV 0.02846
Sigma 0.001504
histoEnergy_759
χ2 / ndf 541.5 / 330
Constant 1082
MPV 0.02849
Sigma 0.001492
histoEnergy_808
χ2 / ndf 560.3 / 326
Constant 1060
MPV 0.02844
Sigma 0.00152
histoEnergy_857
χ2 / ndf 521 / 327
Constant 1072
MPV 0.02844
Sigma 0.001488
histoEnergy_906
χ2 / ndf 524.1 / 326
Constant 1062
MPV 0.02844
Sigma 0.001492
histoEnergy_955
χ2 / ndf 553.5 / 327
Constant 1069
MPV 0.02843
Sigma 0.001465
histoEnergy_1004
χ2 / ndf 522.4 / 328
Constant 1046
MPV 0.02844
Sigma 0.001496
E[GeV]
entries

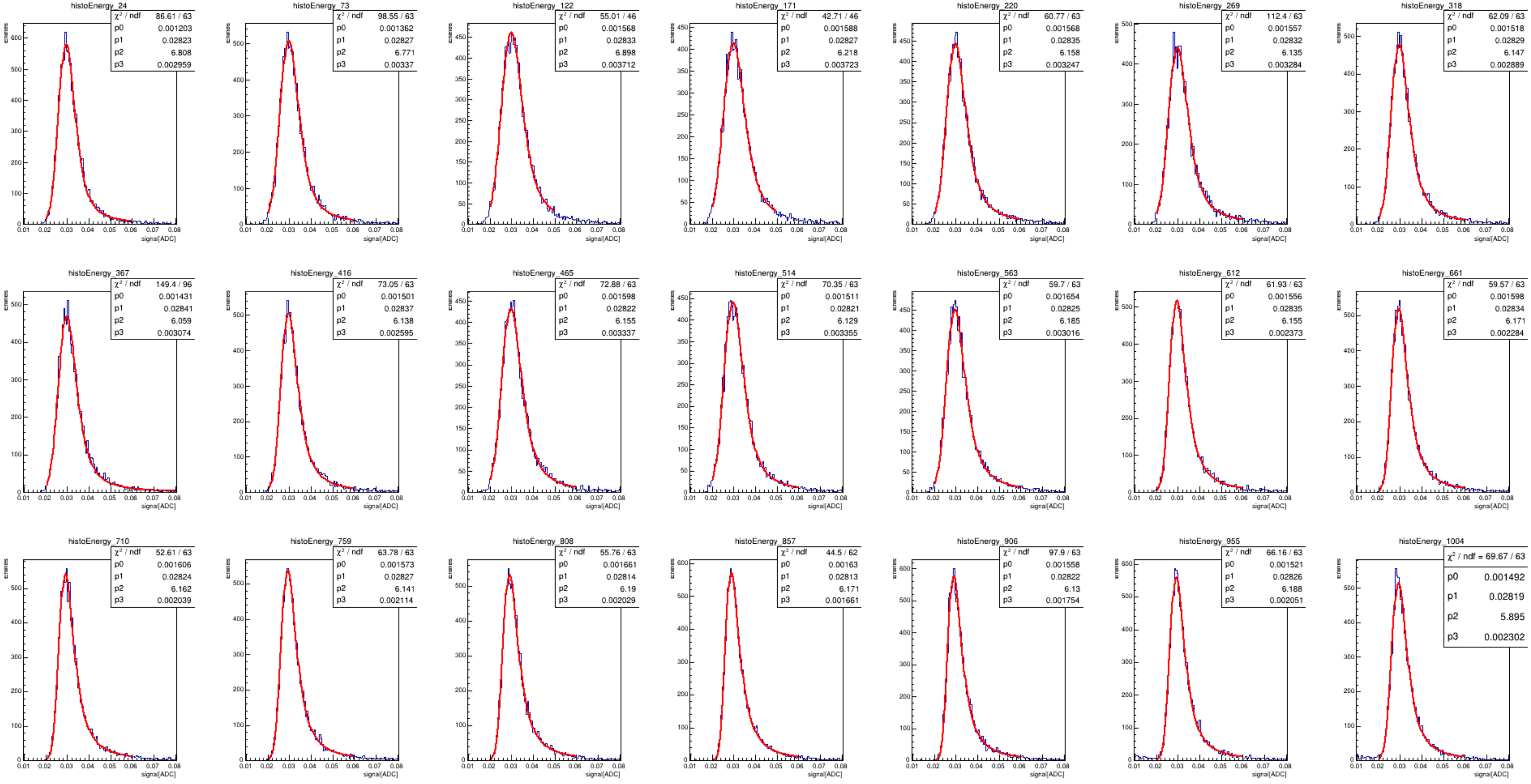
- Digititice MC muons using MIP → ADC from real data and MIP → GeV from Landau
- LanGau fit on MC digitized muons



- Compared new MIP ADC peaks with the tue ones from real data
- There big differences → a new iteration is needed

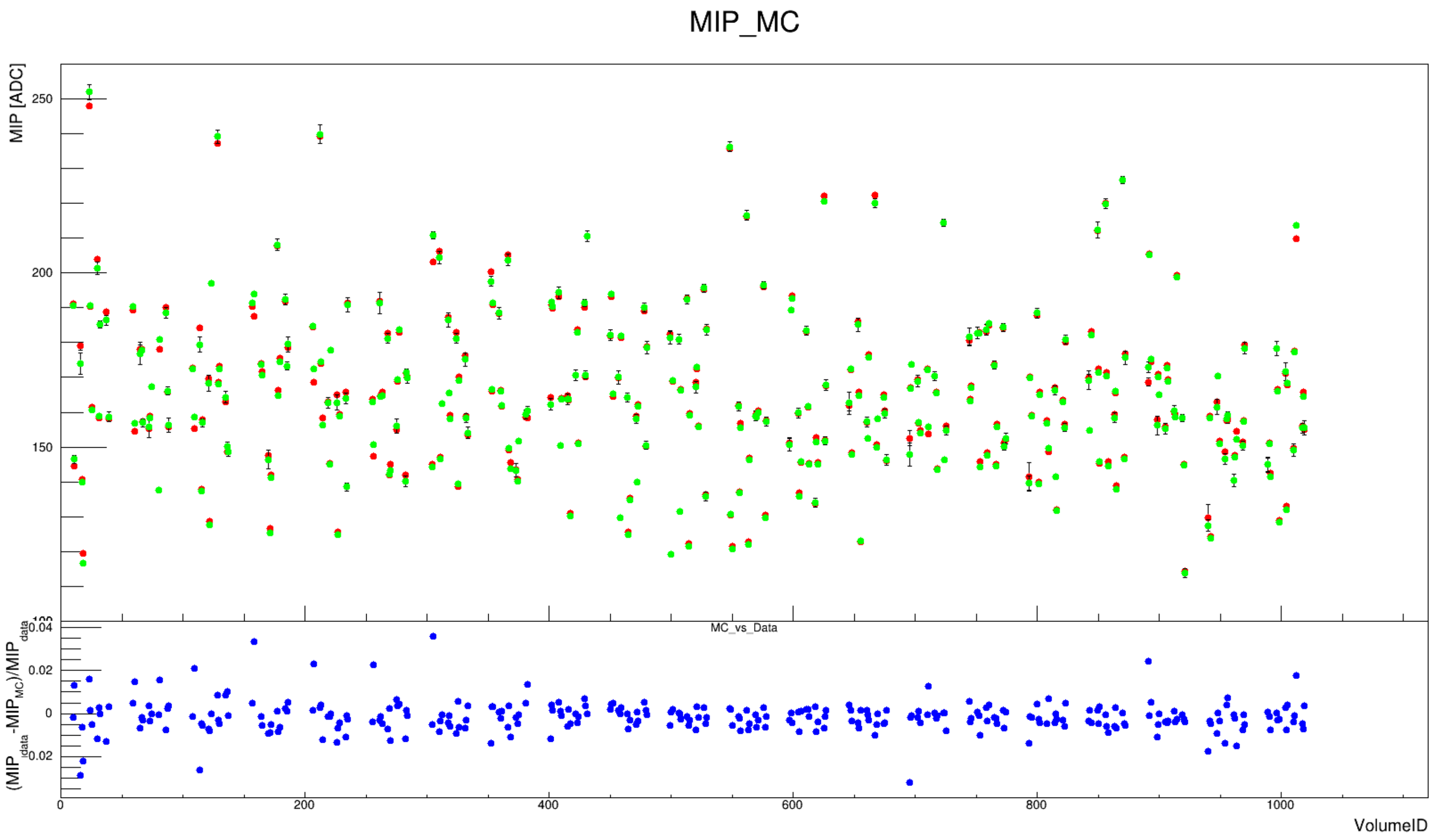


- Calibrated MC digitized MIP in GeV
- Fit LanGau to estimate new MIP → GeV conversion factor



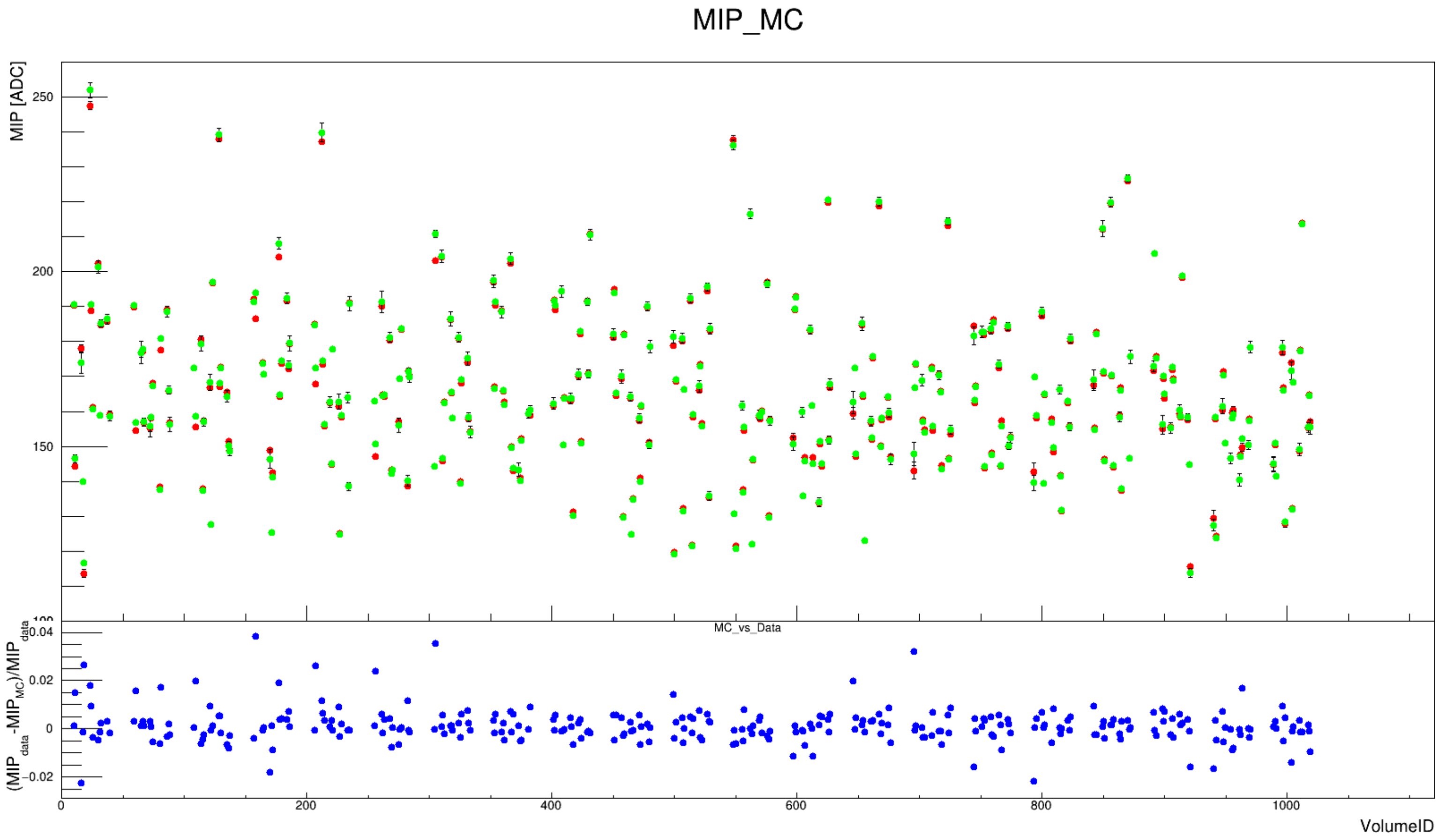
ADC→GEV - iteration 1

- Much better!

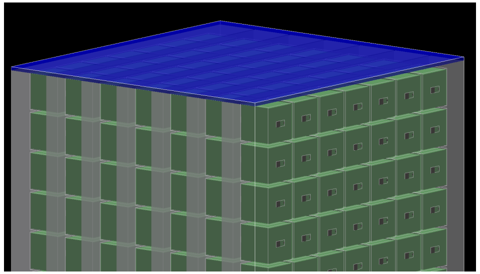


ADC→GEV - iteration 2

- Not significative improvement respect to prior iteration
- We can stop here our calibration procedure



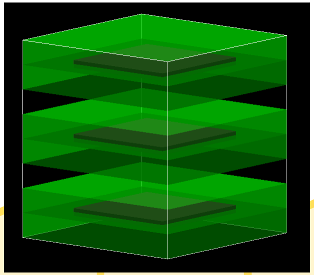
Simulation configuration



CALO
(detailed simulation)

PSD (what we can get from the cad)

TRD (only aluminum of the box)



Charge Tagger (detailed simulation)

SCD (one silicon with total thickness)

Trigger (detailed simulation)

Simulation configuration

- Beam divergence only along y axis
- Beam uniform distribution
- Single energy beam
- Pure electron beam

Digitization

Digitization

- Conversion parameters used to digitize and calibrate
- Noise form pedestal events
- Low-gain noise = high-gain noise since no low-gain pedestal events acquired

Digitization – Gain change jump

- “hole” between high-gain end and low-gain start
- Due to problem in HiDRA-2 chip (“the HOLD who was not a HOLD”)
- Problem that can not be easily corrected in the analysis
- Depends on:
  - Particle rate
  - Energy deposit in the crystal

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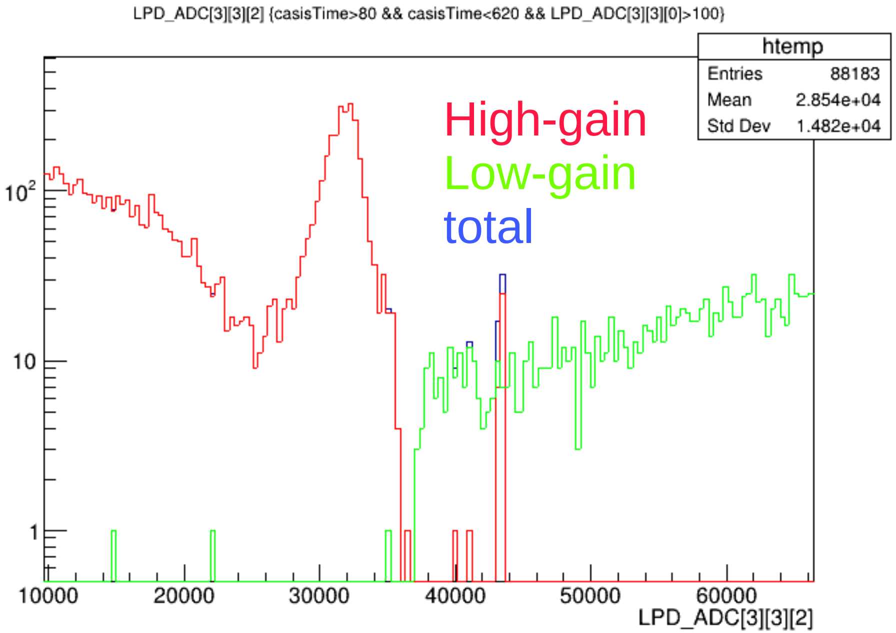

Digitization – Gain change jump

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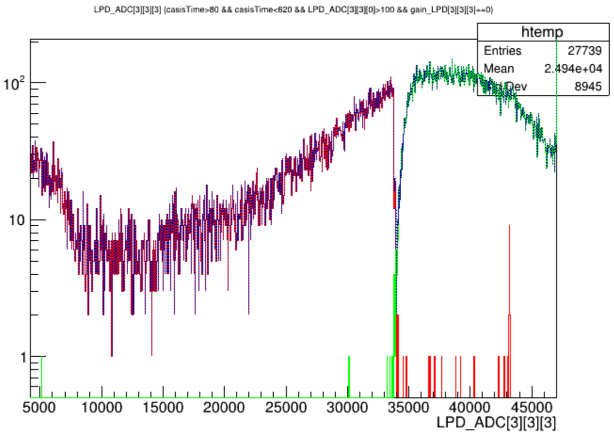

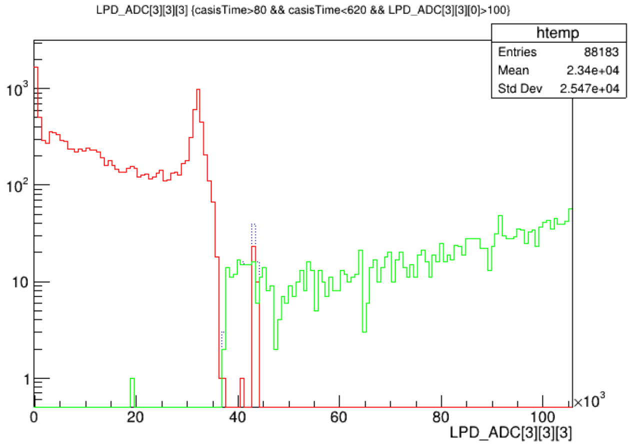

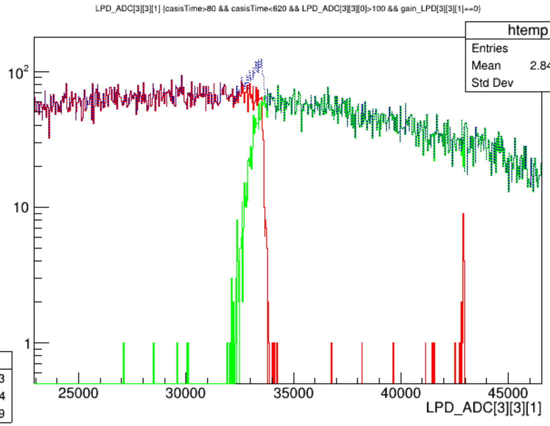

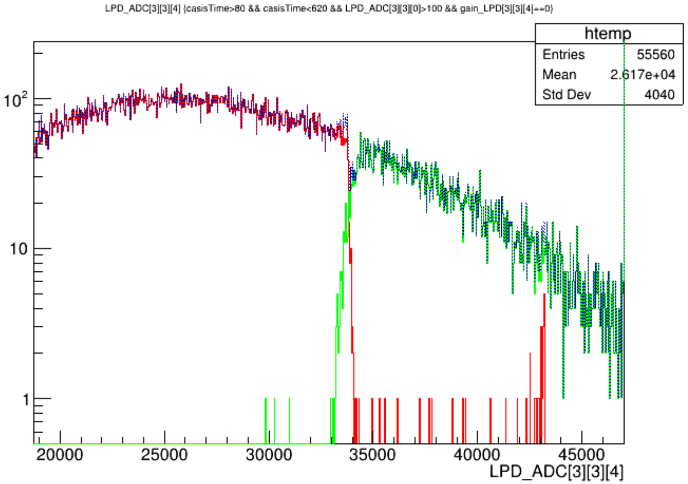

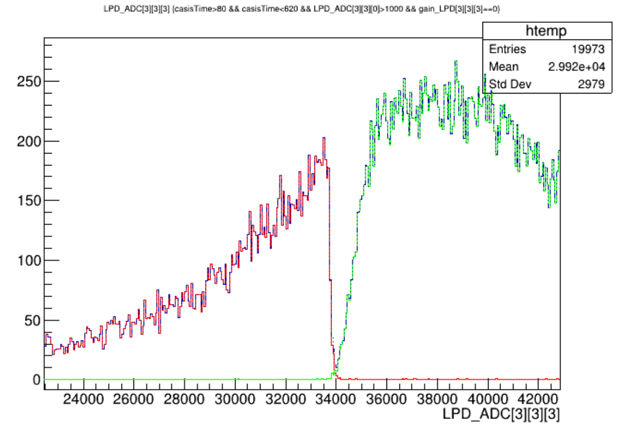

Digitization – Gain change jump

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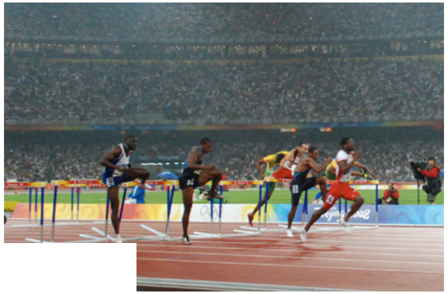
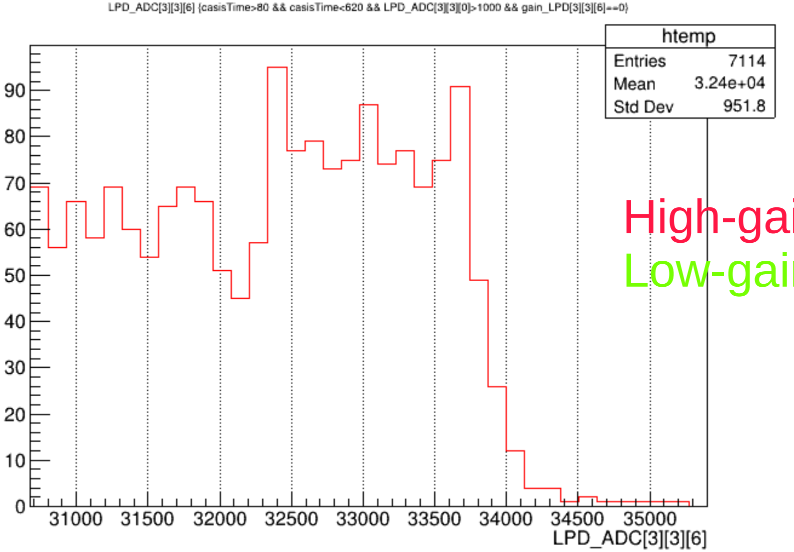
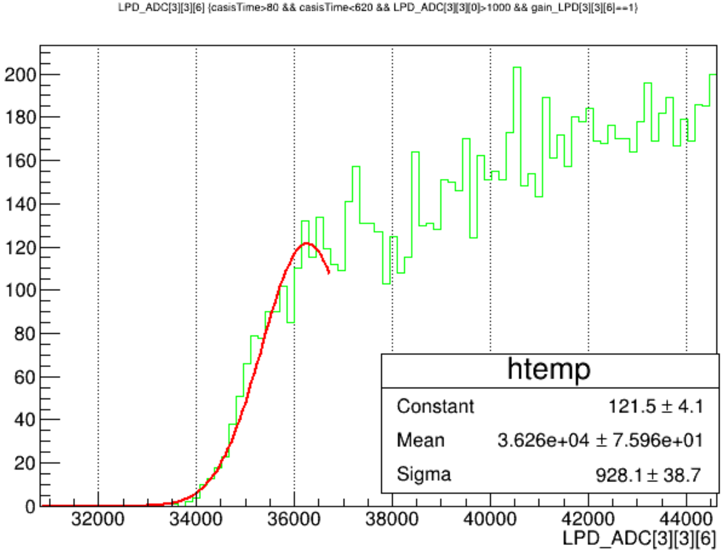


- Try to “model” the effect and add it in simulation



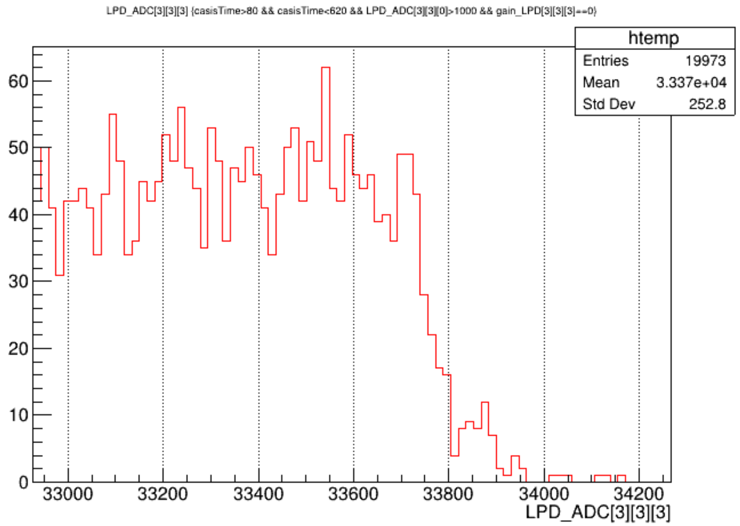
High-gain
Low-gain



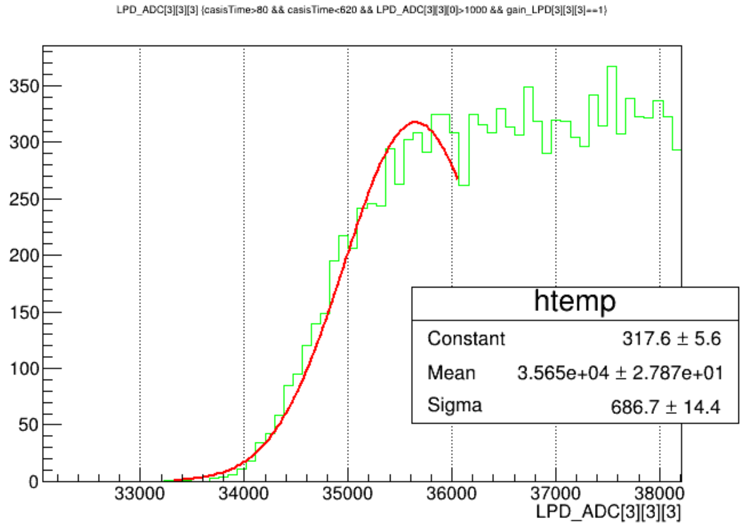
Gaussian fit to estimate the fluctuations of the gap

250 GeV beam

Gain jump gap ~ 36260 - 34000 ~ 2260 ADC
Sigma 928 ADC

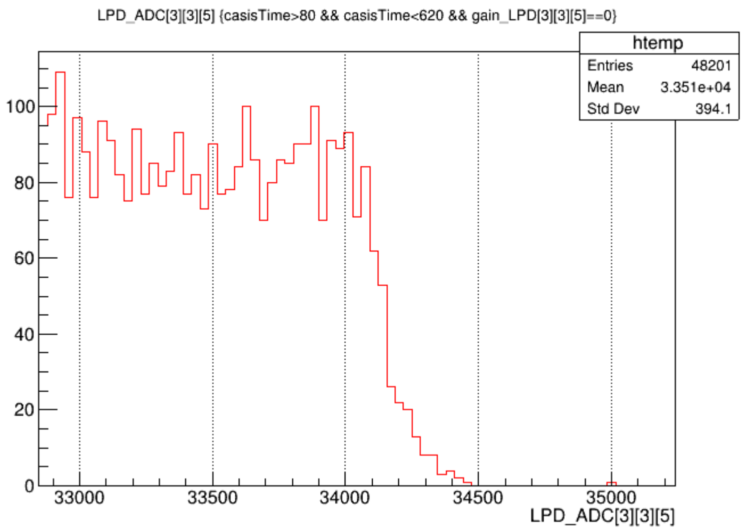


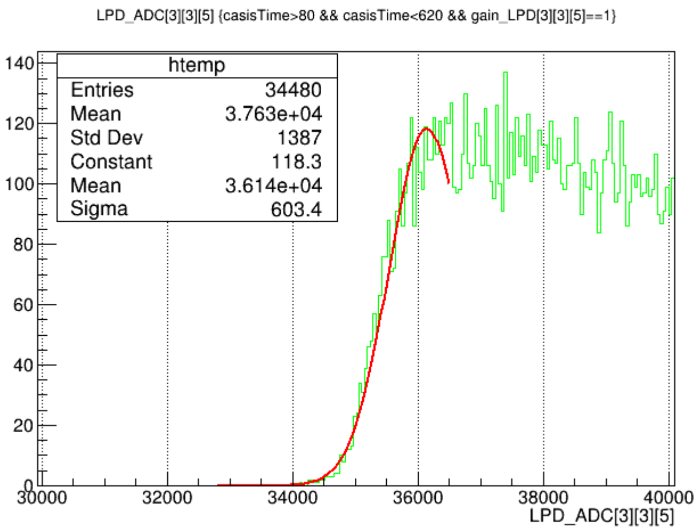
High-gain
Low-gain



DeltaX ~ 35650 - 33800 ~ 1850 ADC
Sigma 687 ADC

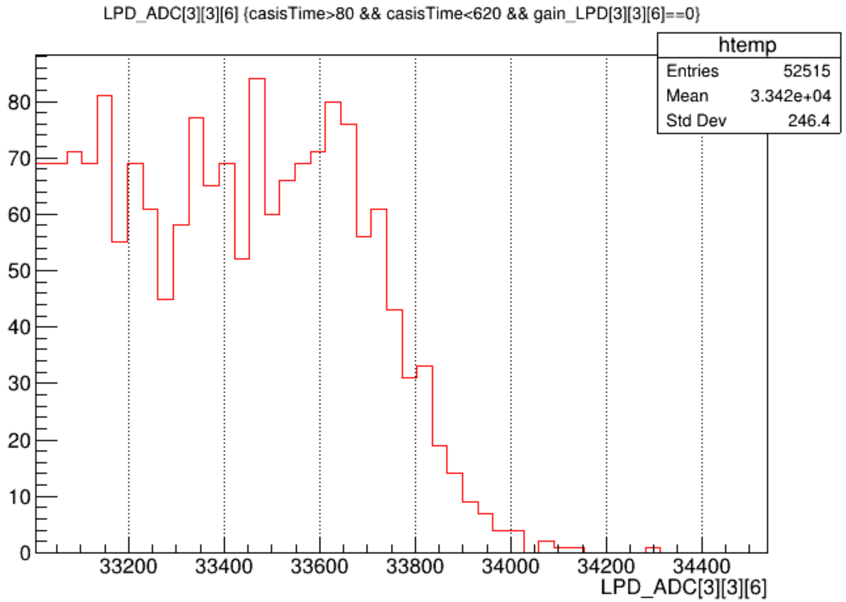
50 GeV
beam

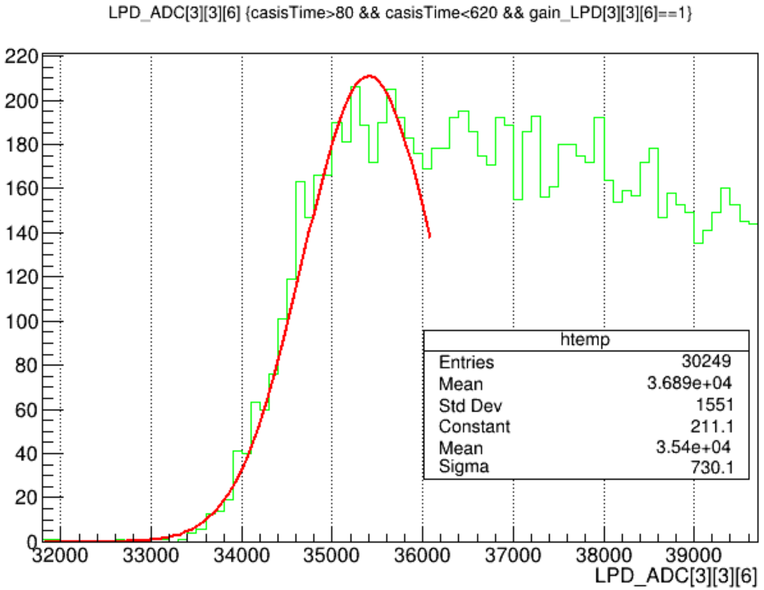




DeltaX ~ 36140 - 34200 ~ 1940 ADC
Sigma 603 ADC

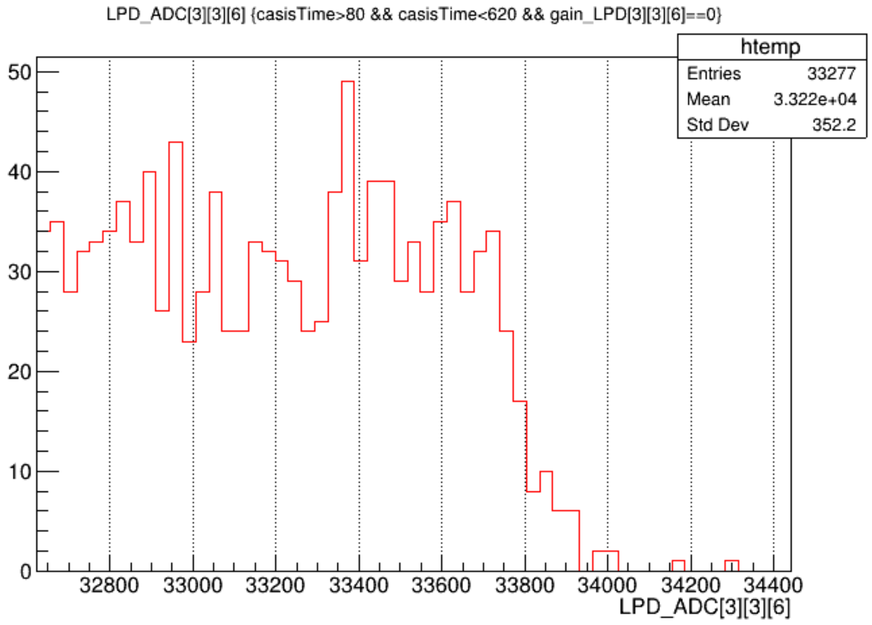
100 GeV
beam

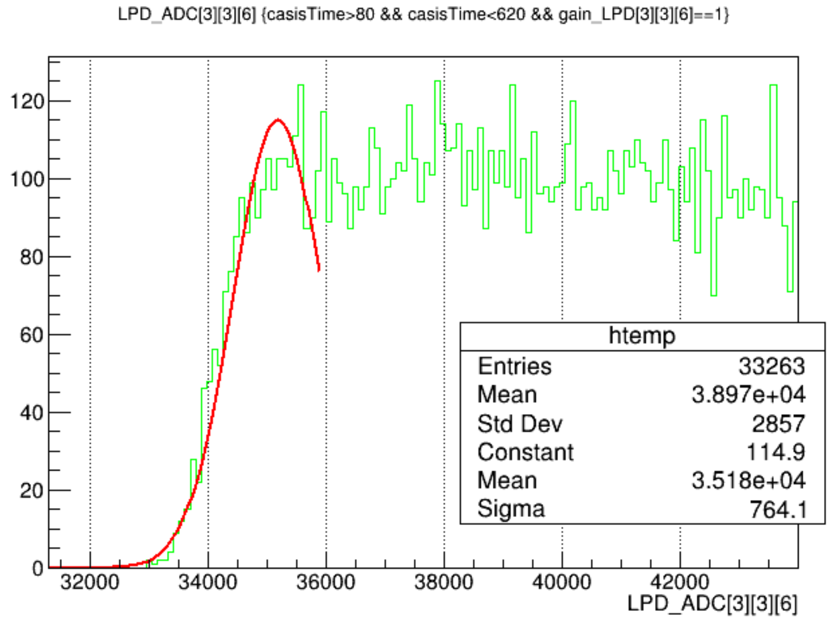




150 GeV
beam

DeltaX ~ 35400 - 33800 ~ 1600 ADC
Sigma 730 ADC





200 GeV
beam

DeltaX ~ 35180 - 33700 ~ 1480 ADC
Sigma 764 ADC

Digitization – Gain change jump

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- Assume that the effect is equal for all the channels (wrong)
- If the signal is in low gain
  - Add to the ADC signal a contribution: gain jump gap, smeared as a Gaussian with the sigma of the Gaussian fit

Digitization – Gain change jump Solution

- Jump the hurdle
  - Discard all the events in which at least one cube has a signal inside the gain change gap

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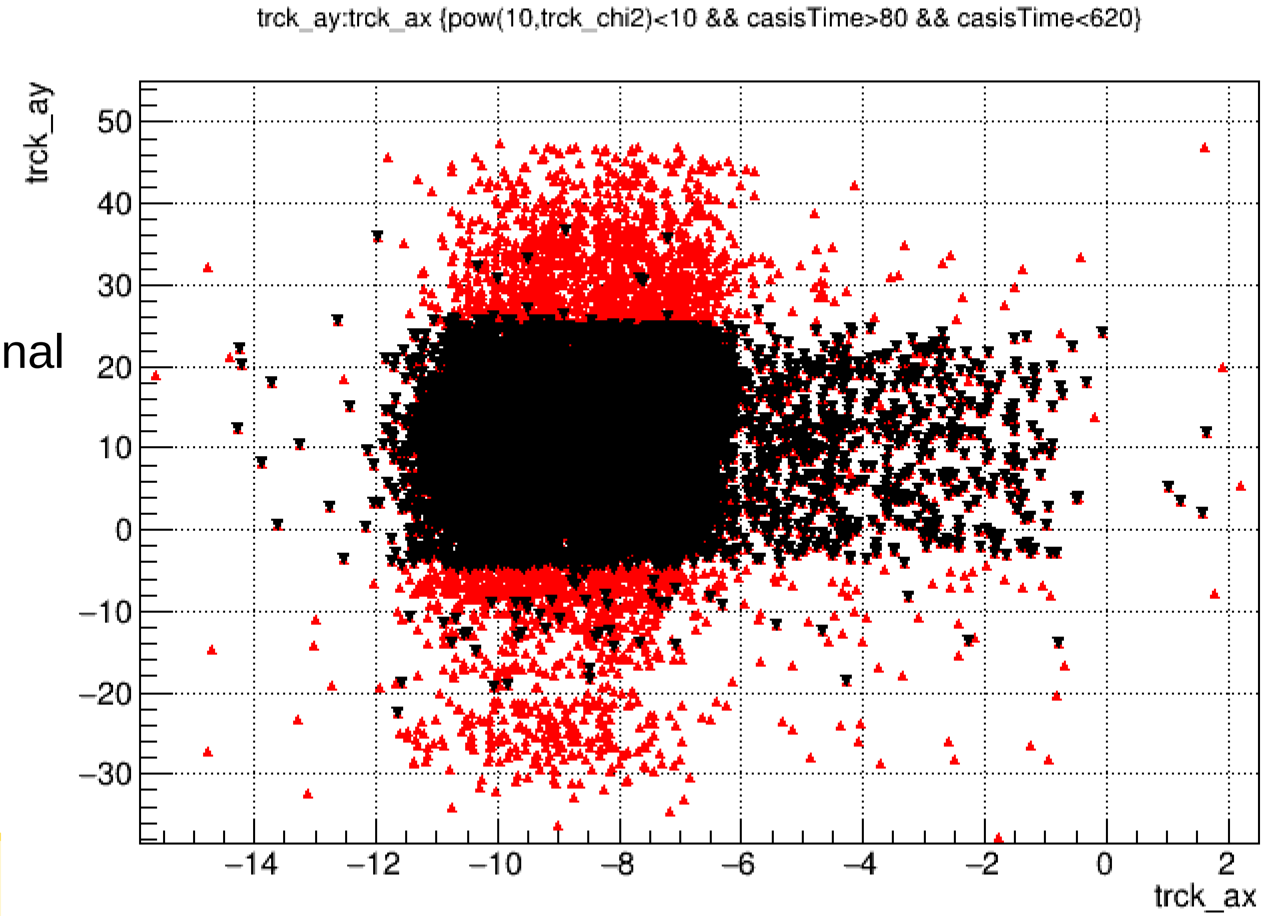
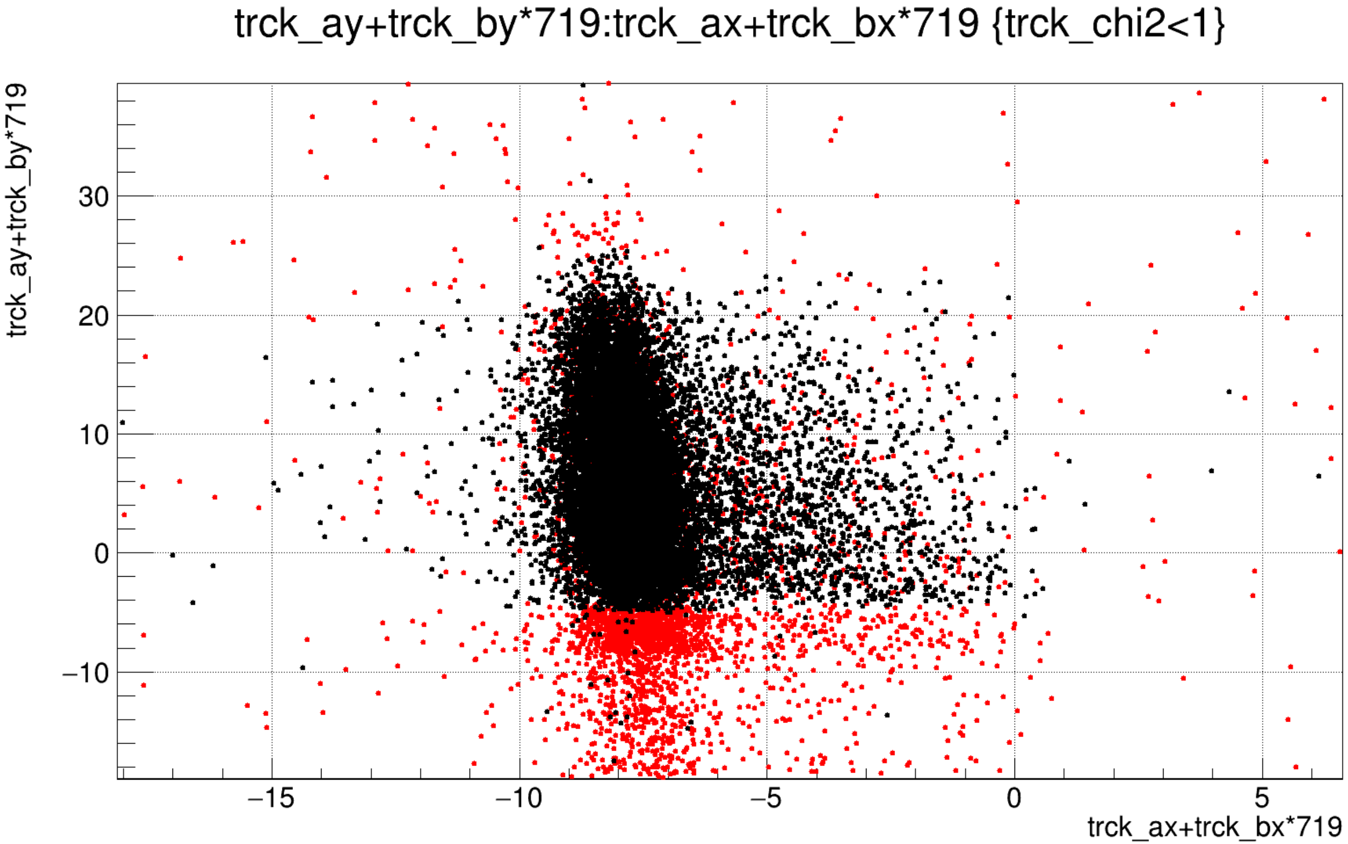
Calo-SCD-Beam alignment

Run 302 – 250 GeV

All events
Selection on first cube signal

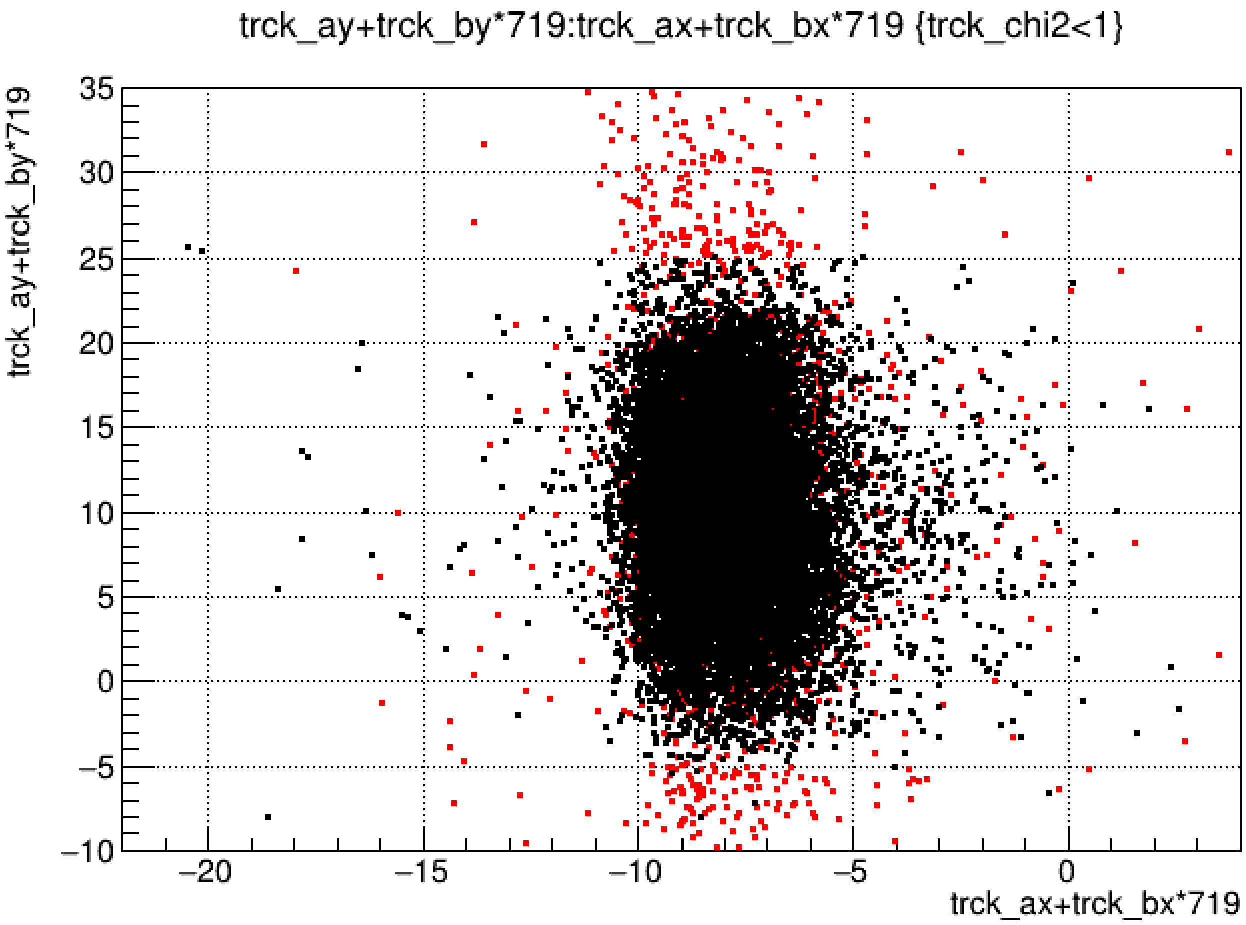


Run 305+310+311 – 200 GeV



All events
Selection on first cube signal

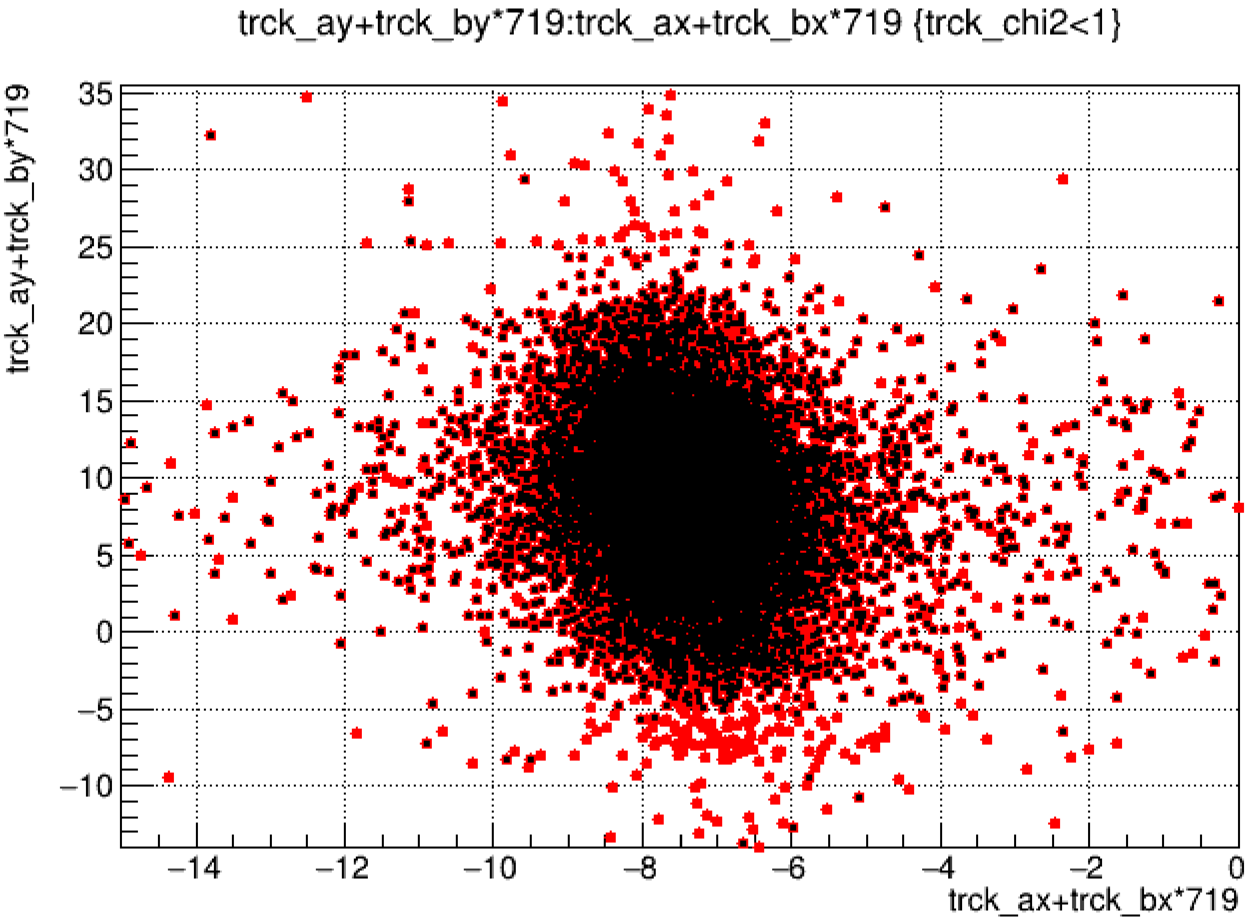
Run 303 -150 GeV



All events

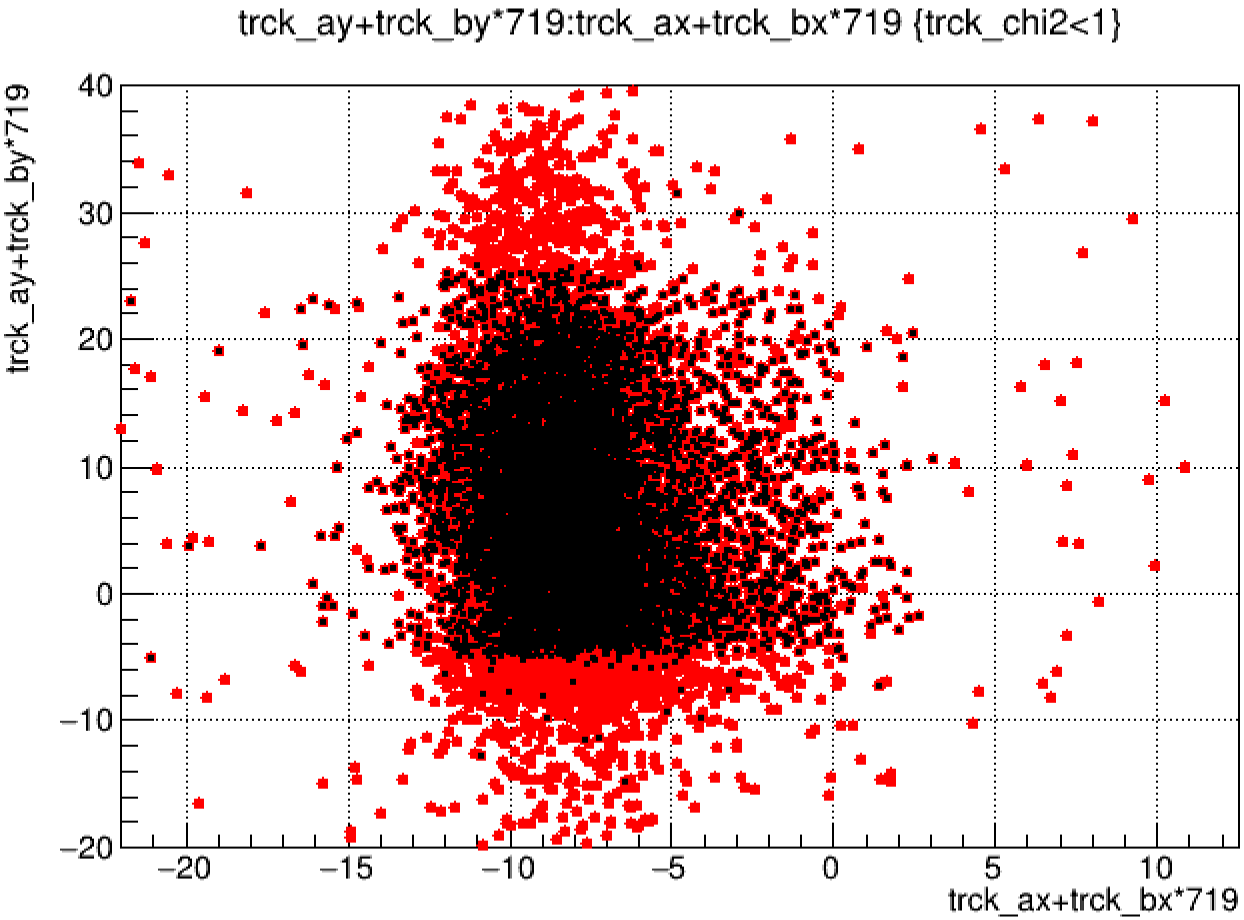
Selection on first cube signal

Run 312 – 100 GeV



All events
Selection on first cube signal

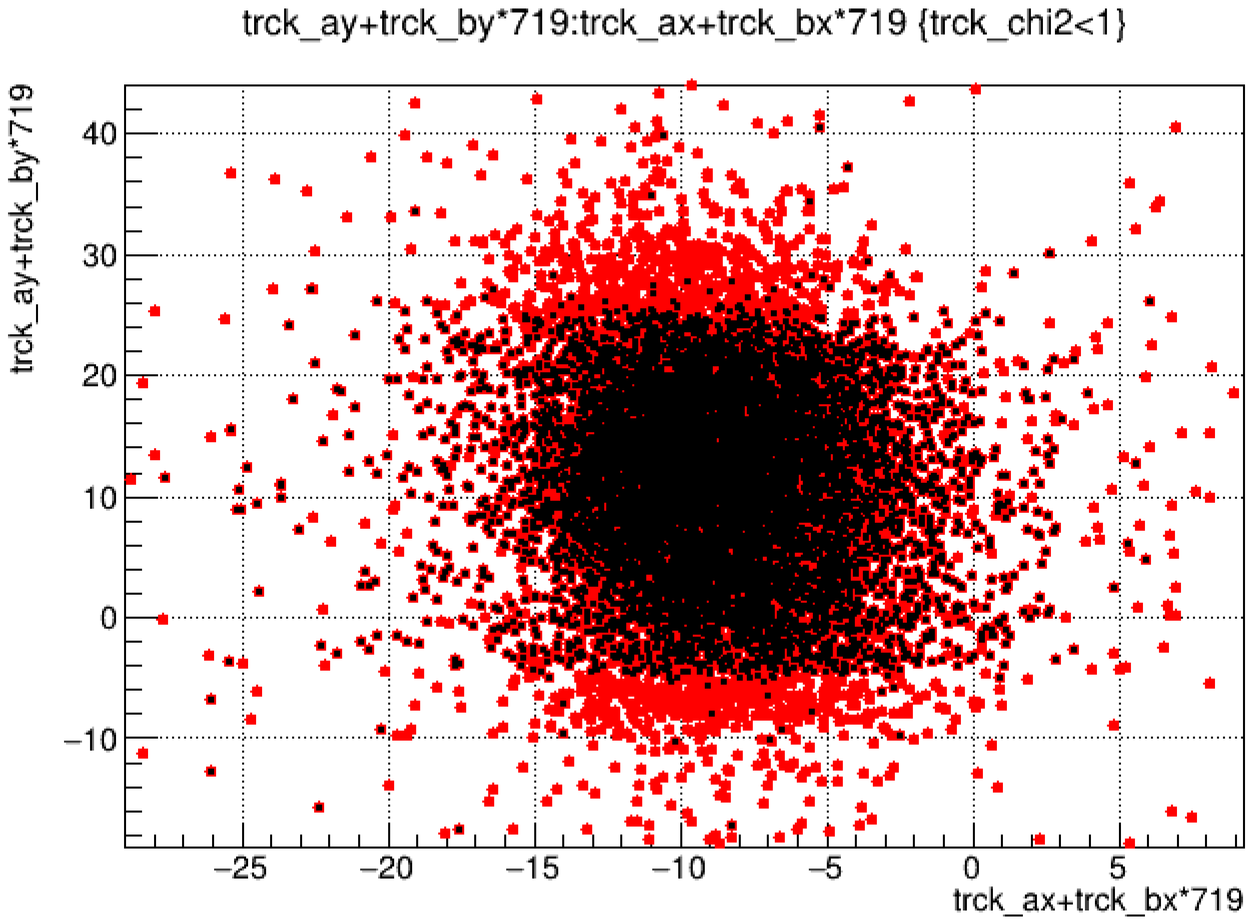
Run 304 – 50 GeV



All events

Selection on first cube signal

Run 313 – 20 GeV



All events

Selection on first cube signal

Alignment

- Along Y for all data acquired the first cube is in the same Y position (-5 mm; +25 mm) in the SCD coordinate system
- Sistematic shift along Y to align Calo and SCD
- Along X the beam does not cover all the crystal and does not it any border of the crystal → no simple alignment procedure
- In addition we need to check for possible inclination of the calorimeter respect to beam and SCD

Centers Of Gravity (COG) method

- For every layer of the calorimeter computation of (X;Y) coordinate of the center of gravity

$$x_{reference}^{new} = \frac{1}{E_{tot}} \cdot \sum_{i=layer\ crystals} E_i \cdot \left(x_i - x_{reference}^{old} \right)$$

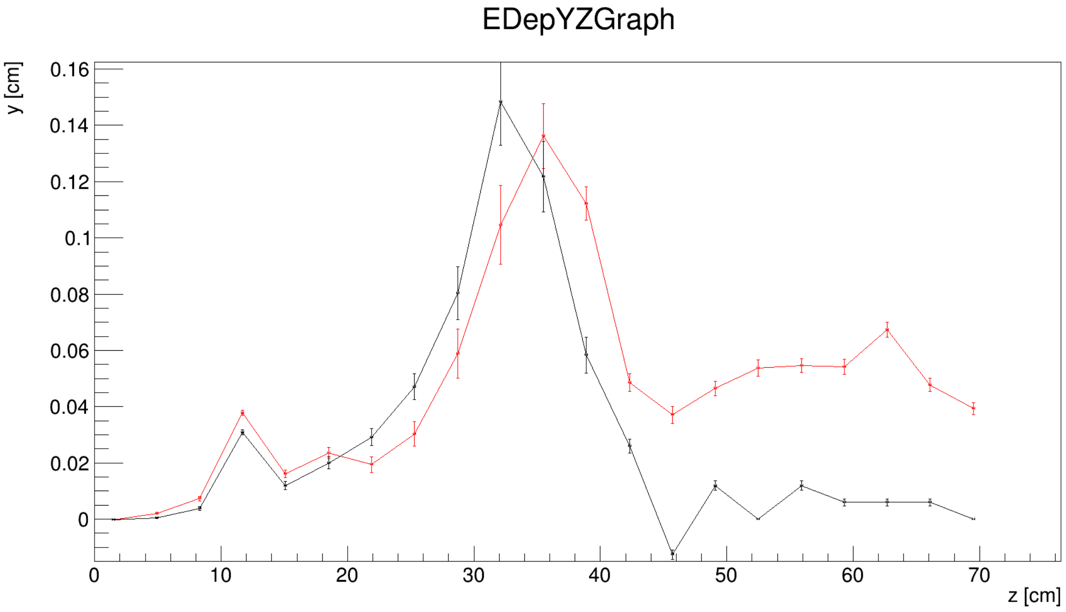
- Iterative method until

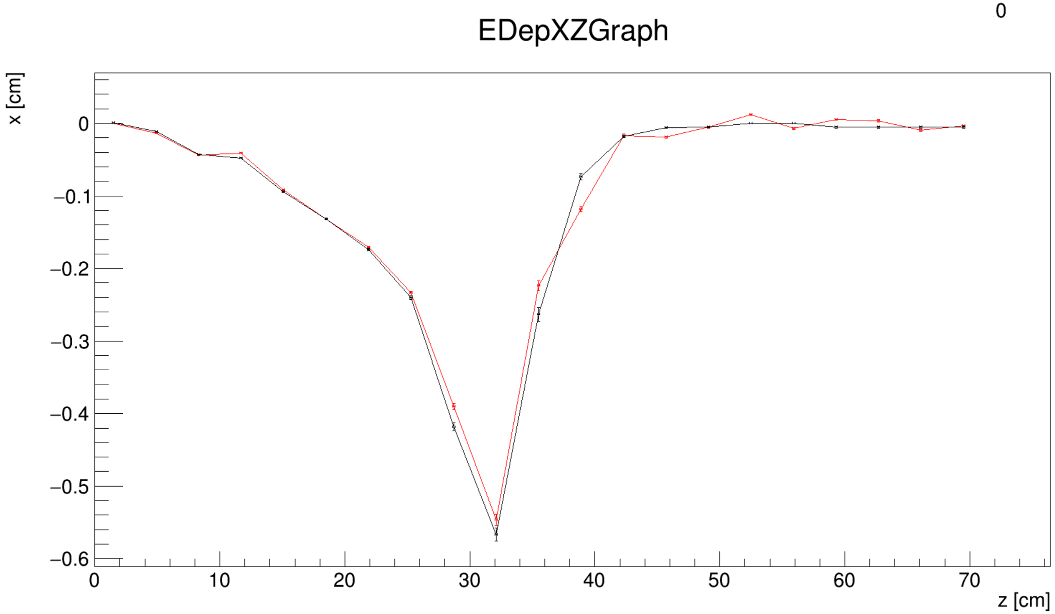
$$\begin{cases} x_{reference}^{new} - x_{reference}^{old} < 100\,um \\ y_{reference}^{new} - y_{reference}^{old} < 100\,um \end{cases}$$

COG method result for every energy

- Using the COG method for every beam energy and after osme long tuning for the inclination of the Calo repsect to the beam along the Y axis
- Beam is centered along the X axis at about -0.35 cm respect to the calo center
- Along X selected a region of 5 mm for the beam acceptance (beam is narrow along X)
- Along Y selected a region of 1 cm centered on the calo center

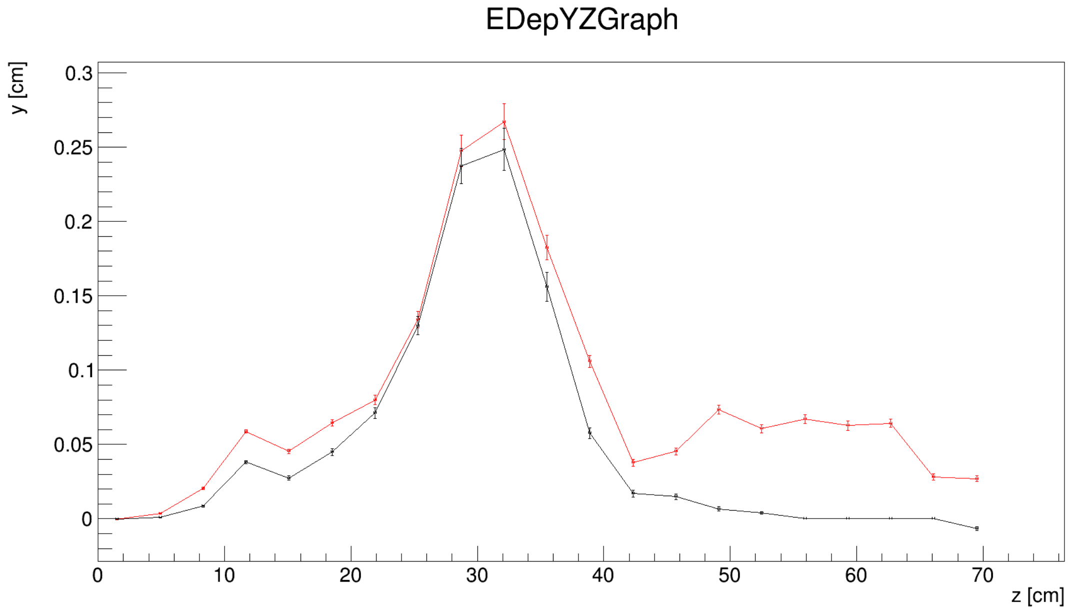
250 GeV

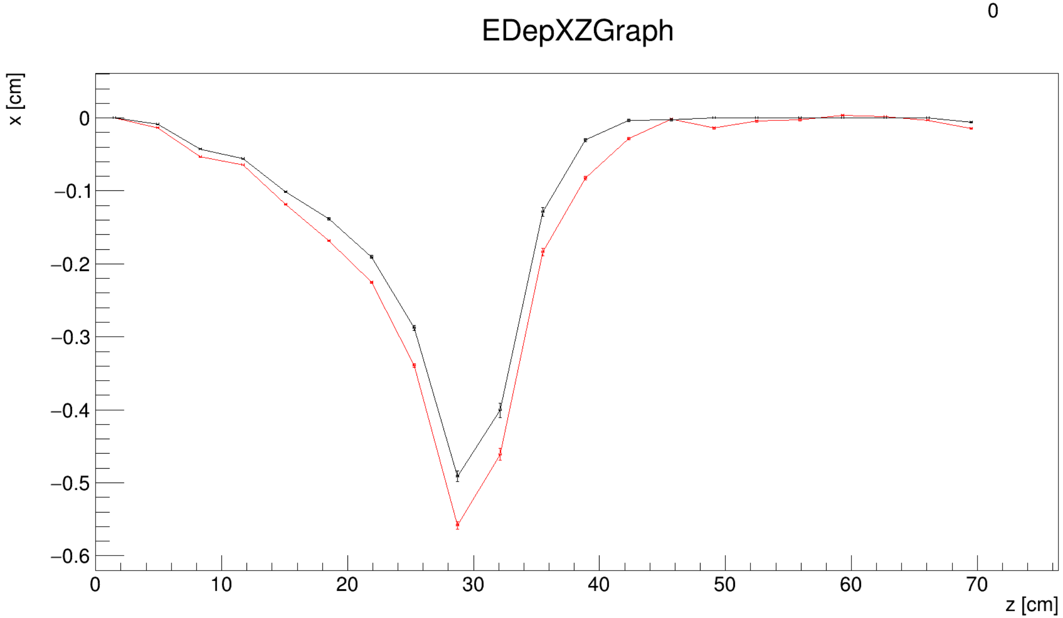




Data
MC

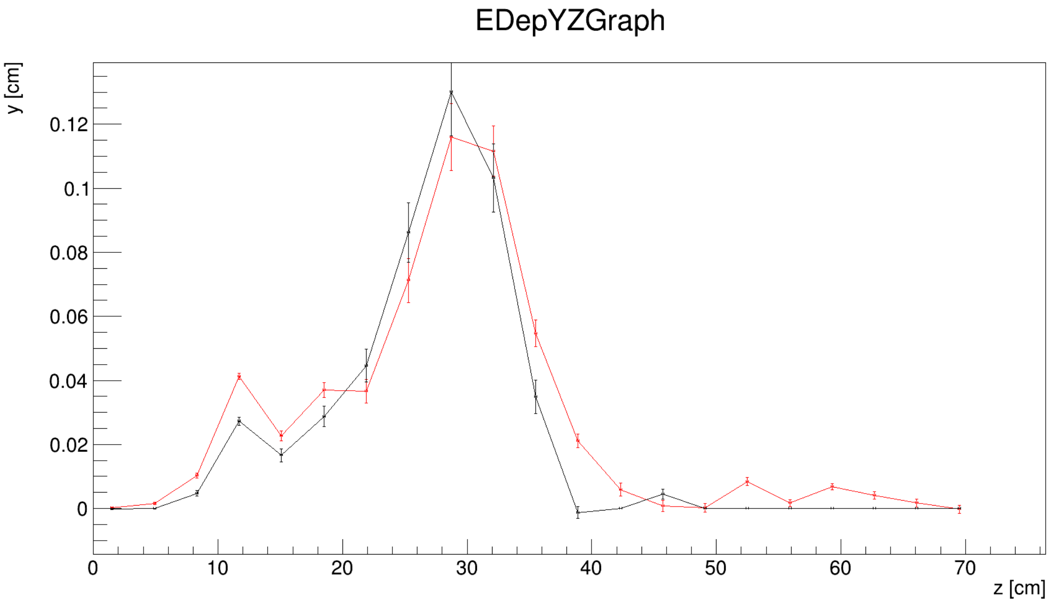
200 GeV

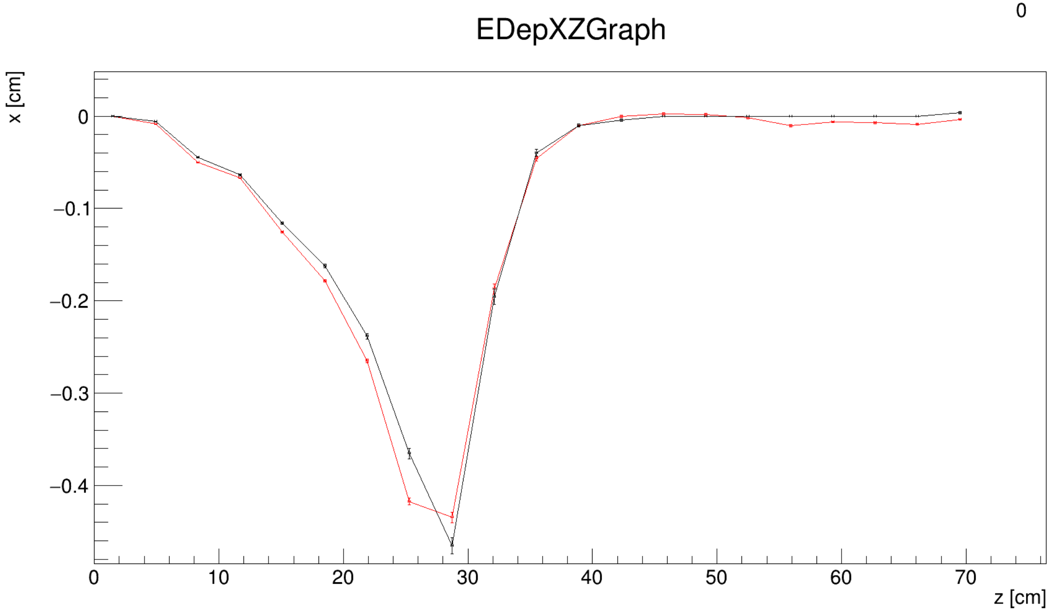




Data
MC

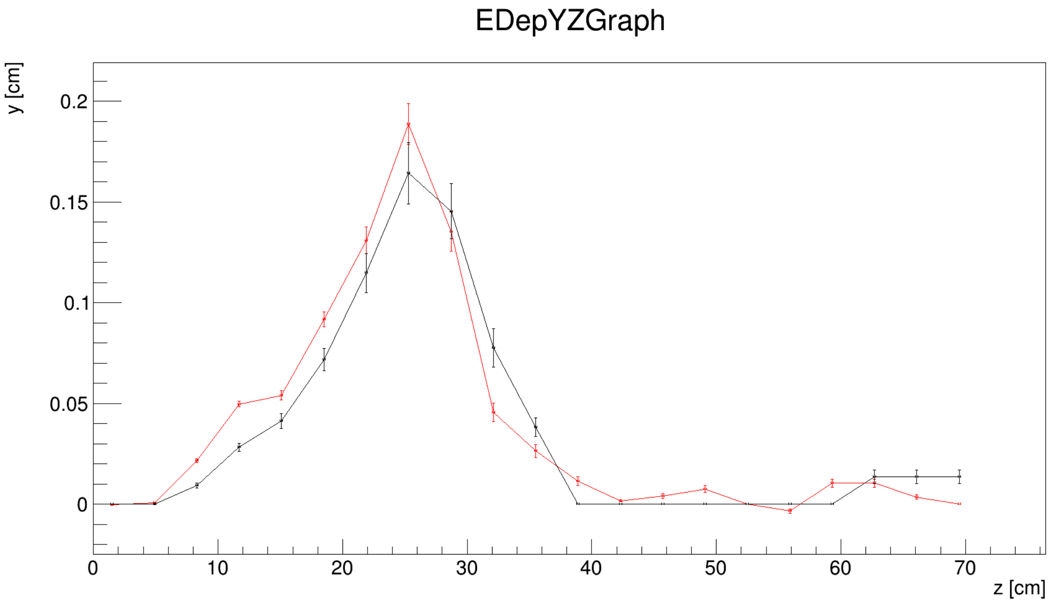
150 GeV

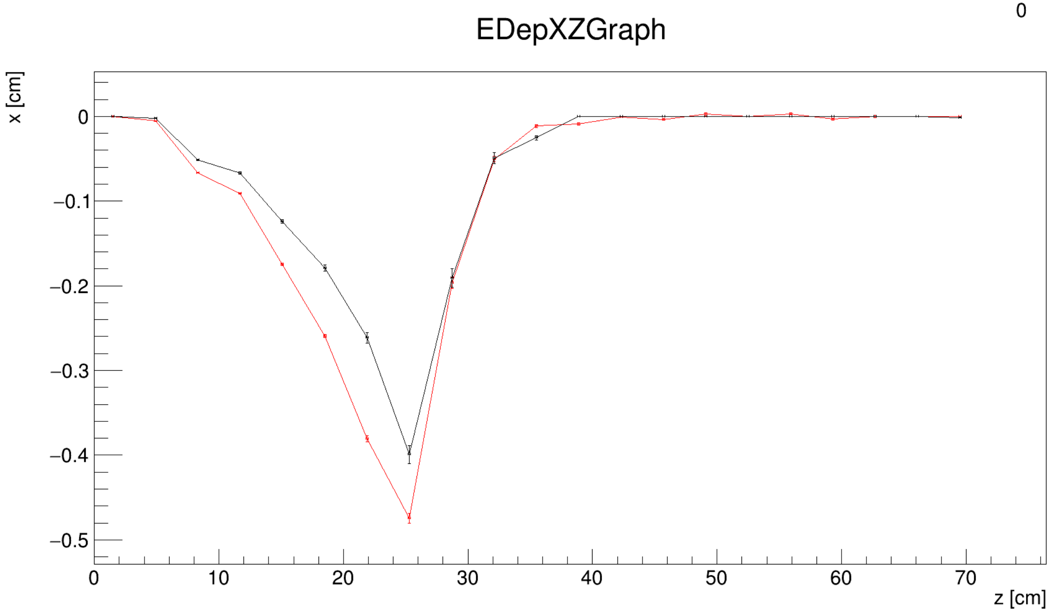




Data
MC

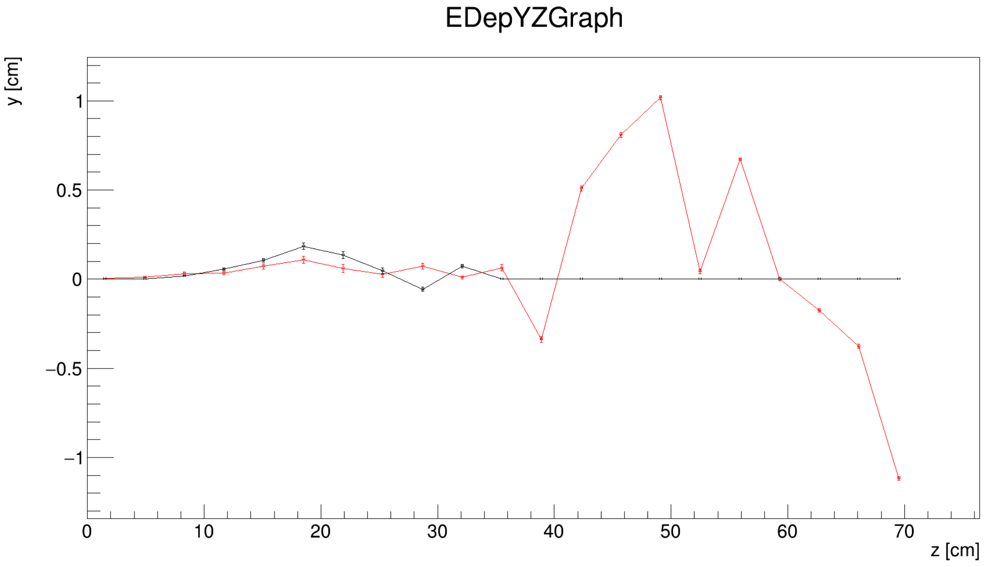
100 GeV

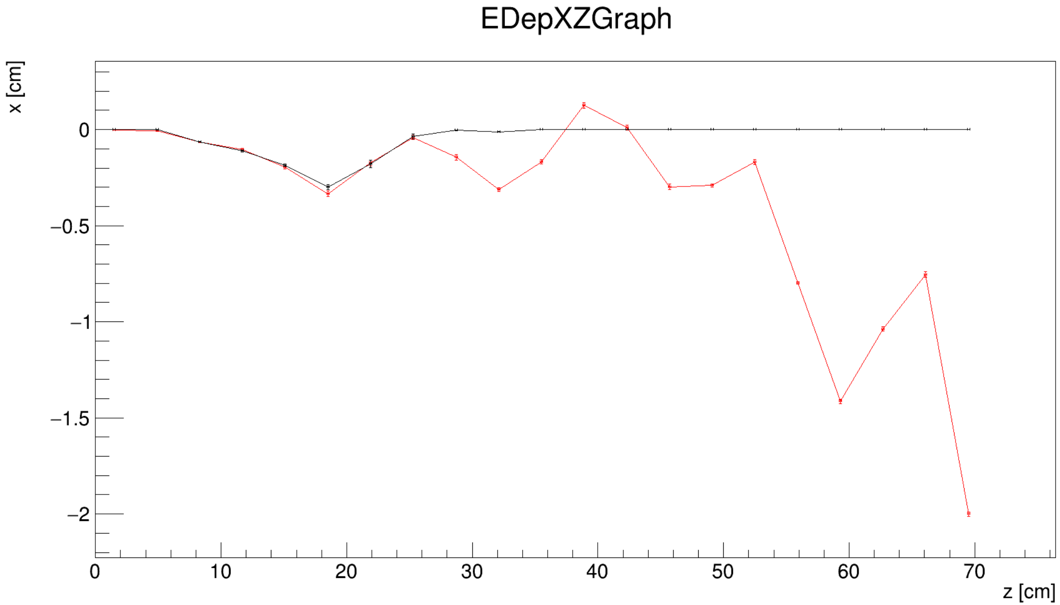




Data
MC

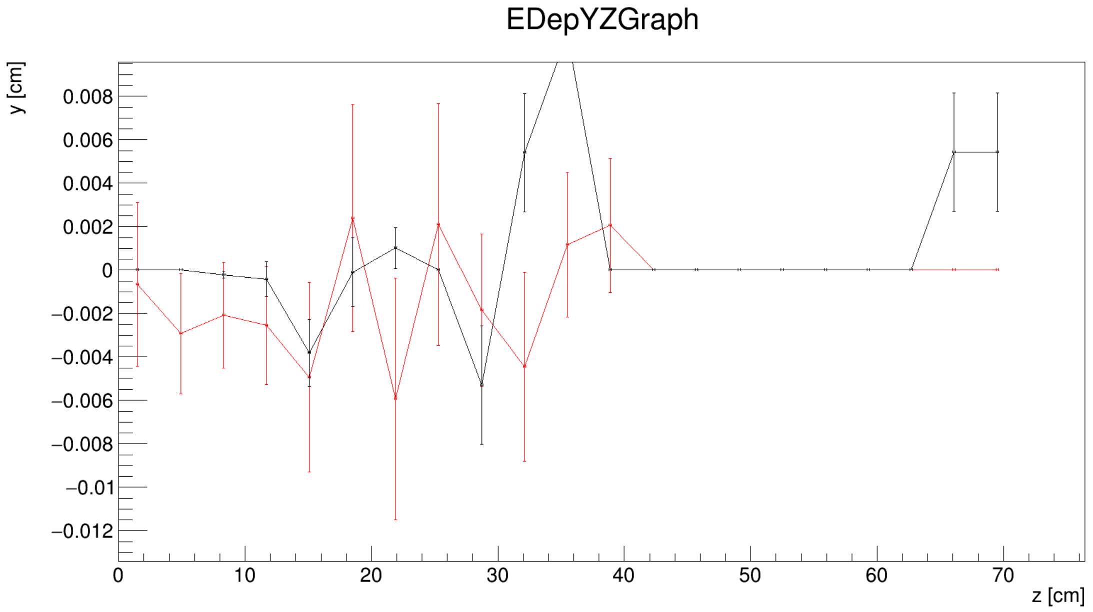
50 GeV

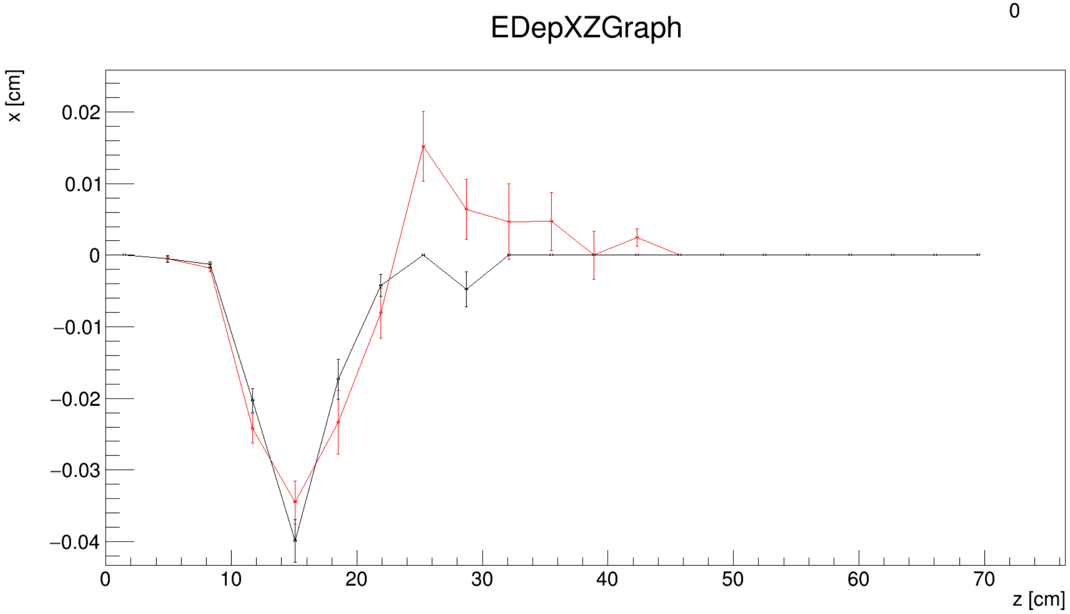




Data
MC

20 GeV





Data
MC

Energy resolution

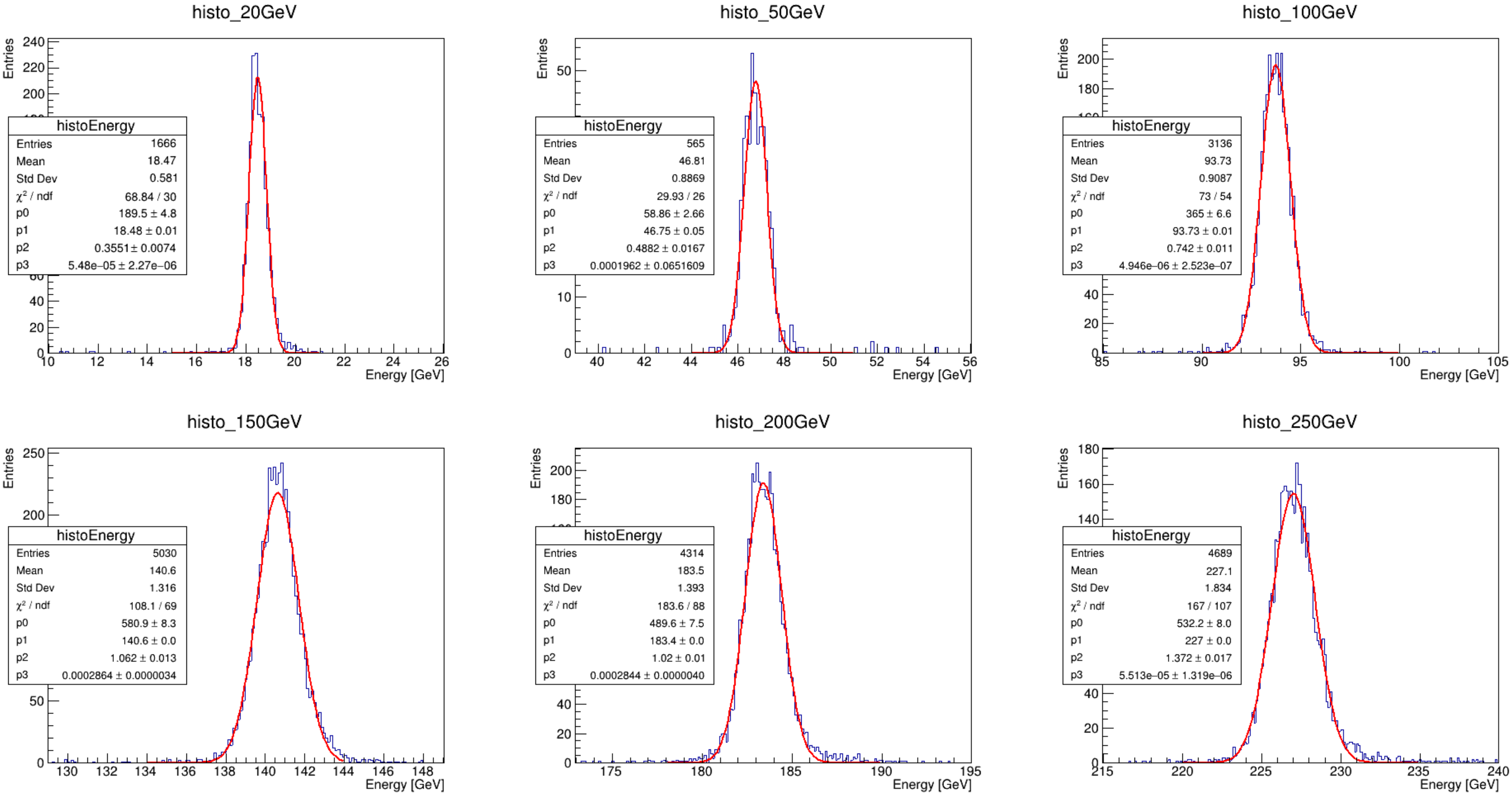
Energy resolution

- Build histogram of total energy deposit (use layers 0-14 ~36.4 X_0)
- Fit with Logarithmic Gaussian (Grupen)

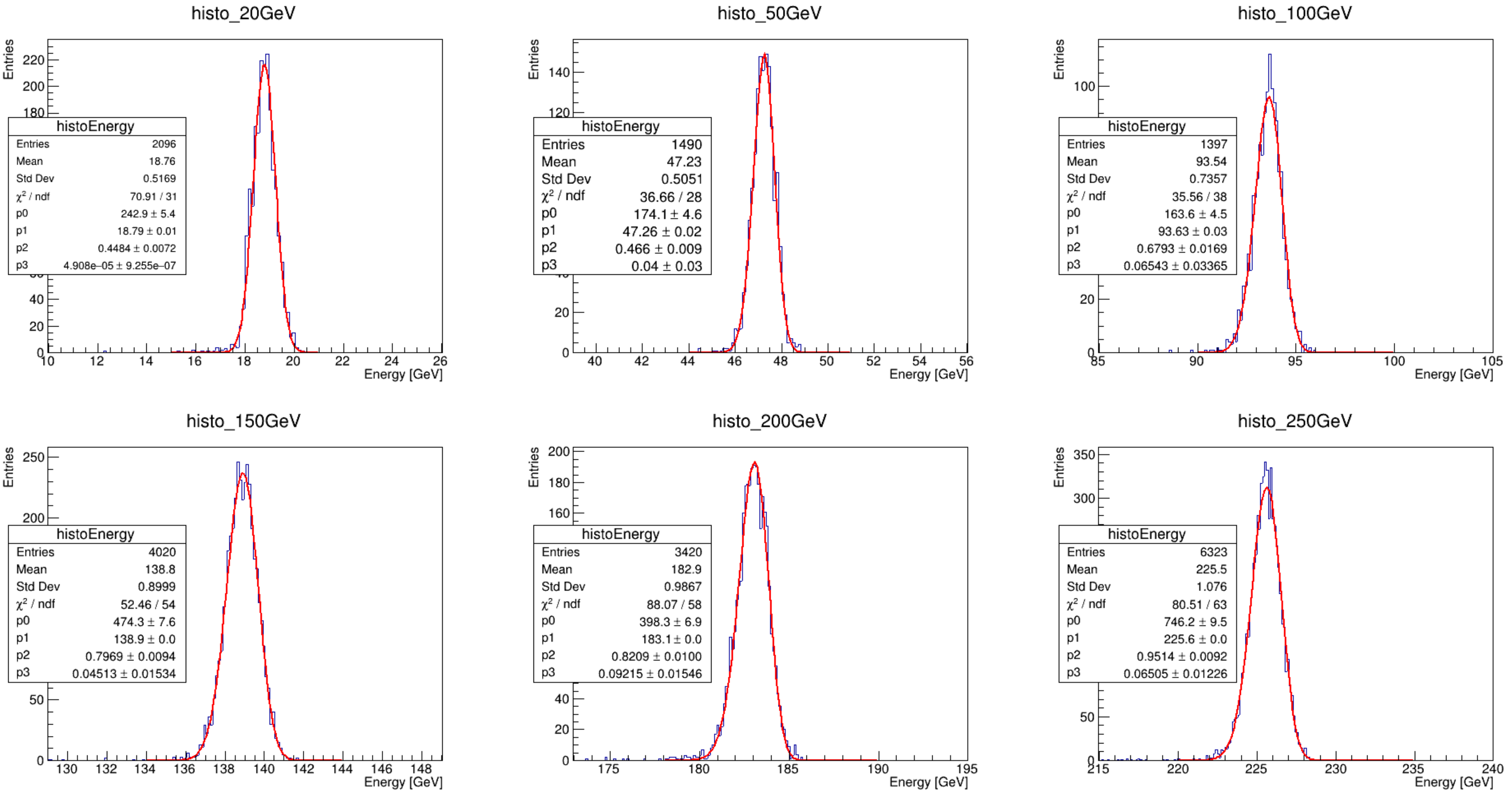
$$\mathrm{d}W = \exp\left\{-\frac{\ln^2[1-\eta(E-E_\mathrm{p})/\sigma]}{2s_0^2} - \frac{s_0^2}{2}\right\} \frac{\eta\,\mathrm{d}E}{\sqrt{2\pi}\sigma s_0}$$

- Estimate distribution width using confidence level at 68%

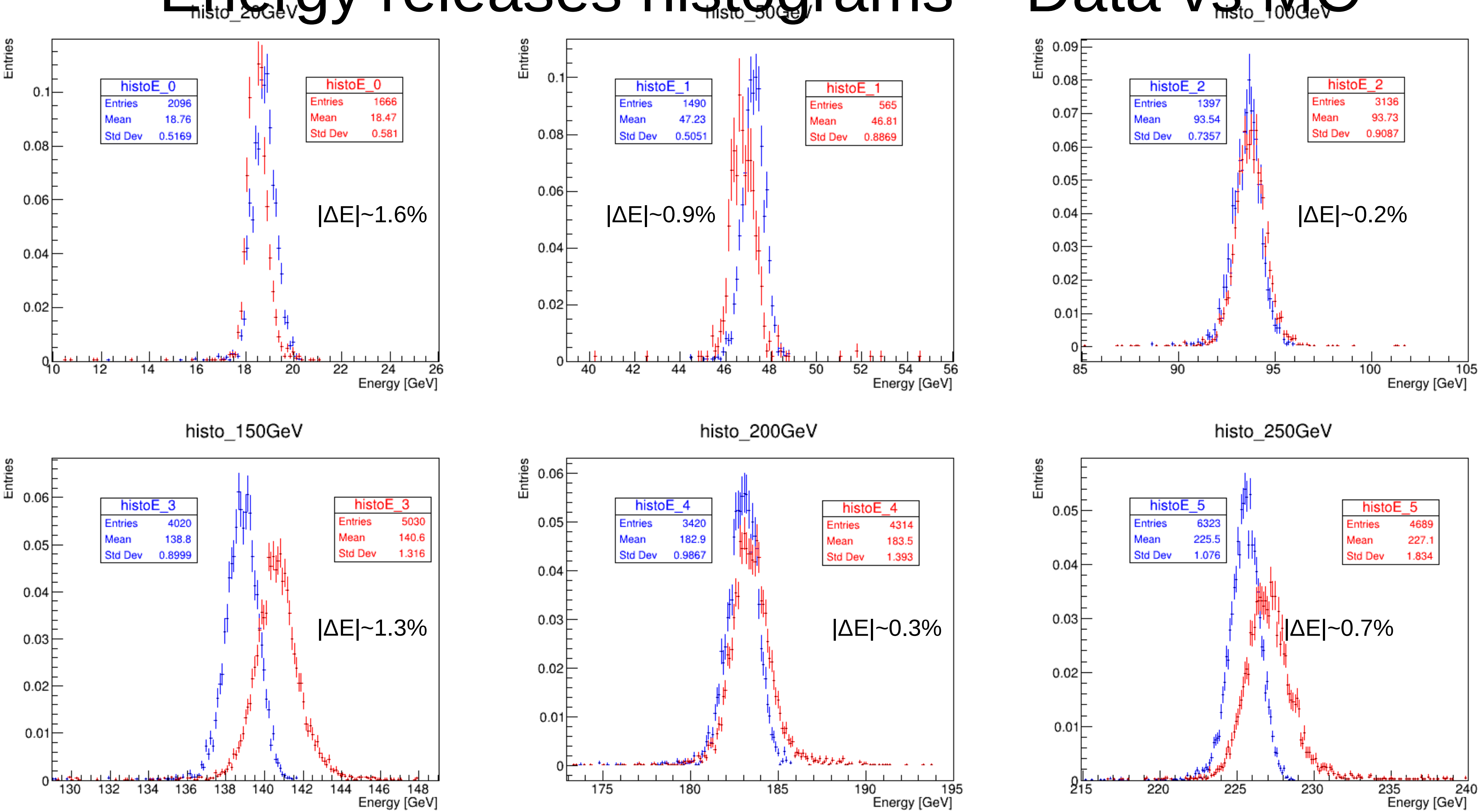
LogGuas fit on real data



LogGuas fit on MC data



Energy releases histograms – Data vs MC



Energy resolution estimation

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c \left[\oplus \frac{d}{\sqrt[4]{E}} \oplus e \ln(E) \right]$$

$\oplus$ indicates the quadrature sum

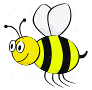
a
- Fluctuations in the development of the em or hadronic shower
- **Sampling-related effects**
- Fluctuations in photoelectron statistics in the light sensor

c
- Calibration uncertainty
- Non-uniformity and damage
- Absence of compensation (electromagnetic fraction in hadronic showers)

b
- Electronic noise

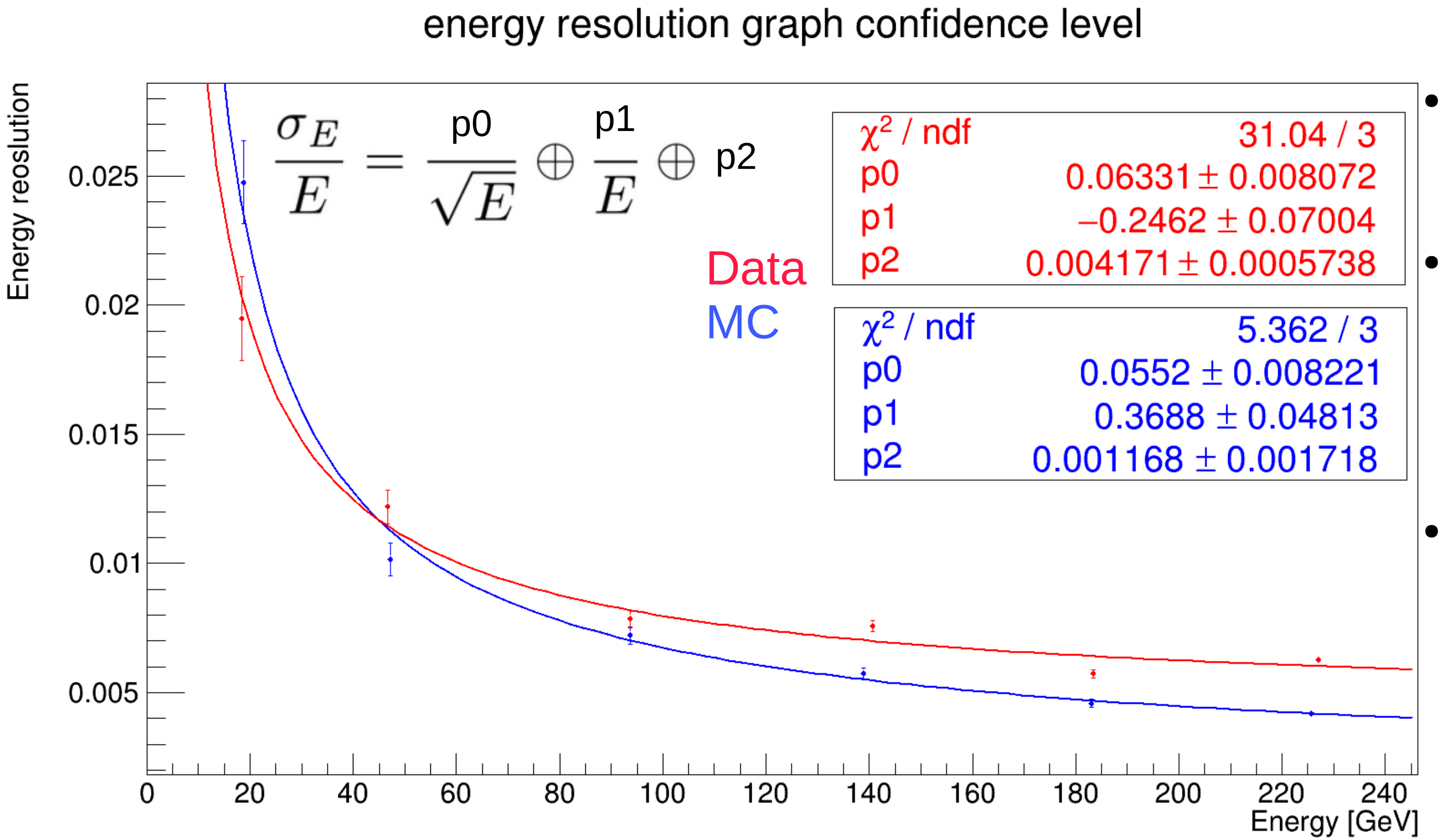
~~**d**~~
- ~~Lateral leakage~~

~~**e**~~
- ~~Longitudinal leakage~~



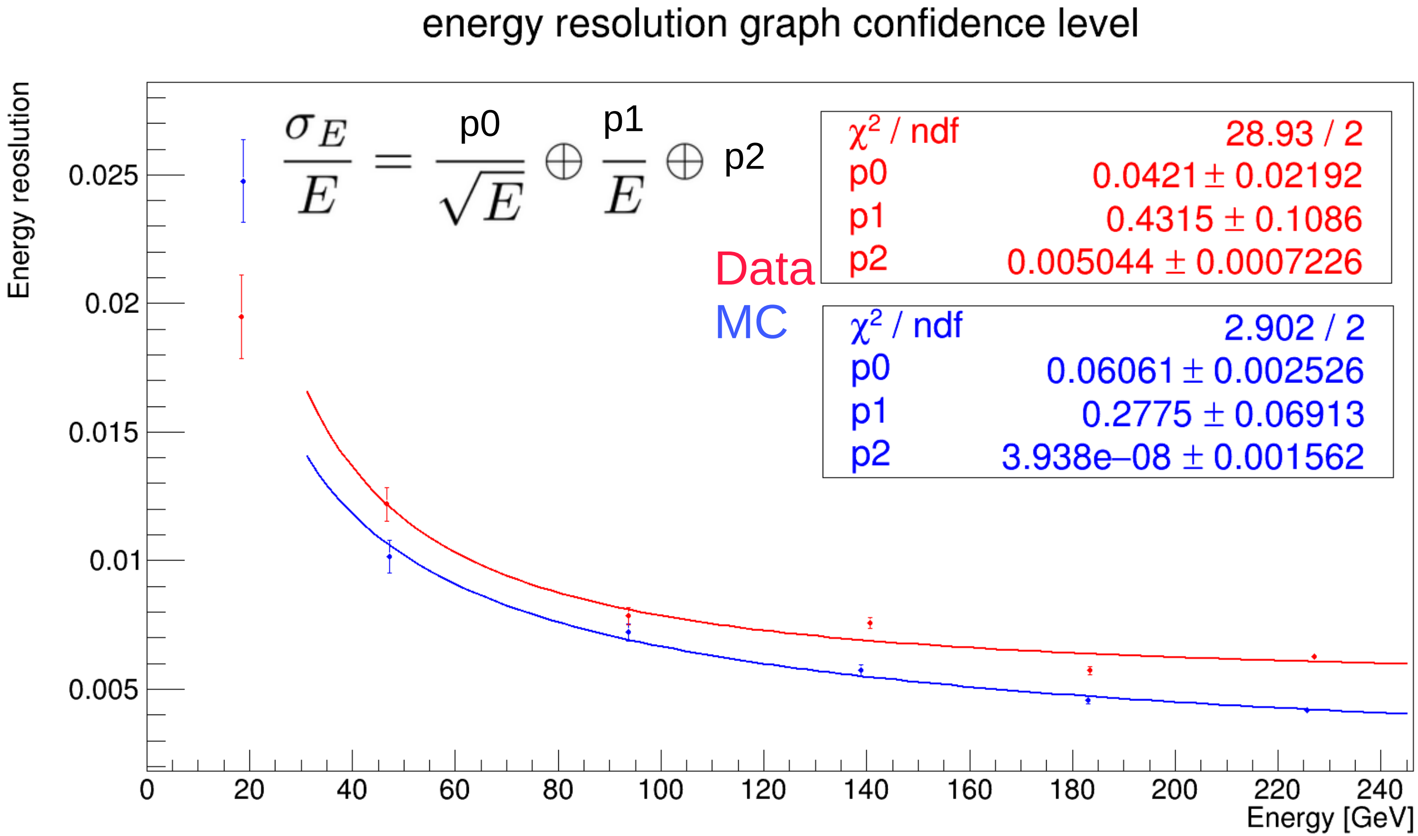
Thank you Eugenio!

Energy resolution – Data vs MC



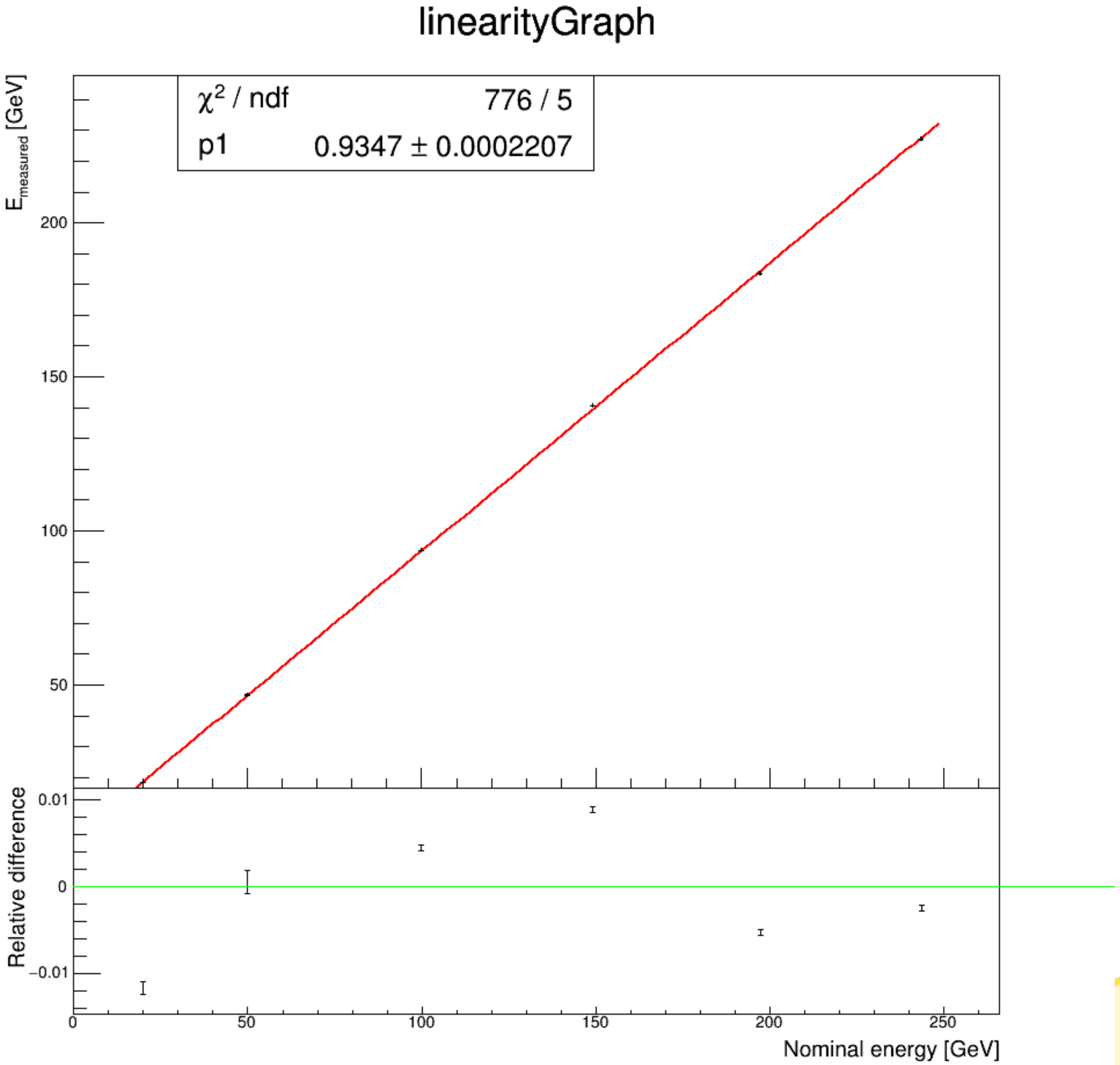
- (p2) Calibration uncertainty term bigger in real data (as expected)
- (p0) similar stochastic term: shower fluctuations and sampling effects (simulations seems quite good!)
- (p1) Electronic noise effect bigger in simulations than in data (over estimated in digitization or other effects?)

Energy resolution – Data vs MC excluding 20 GeV point



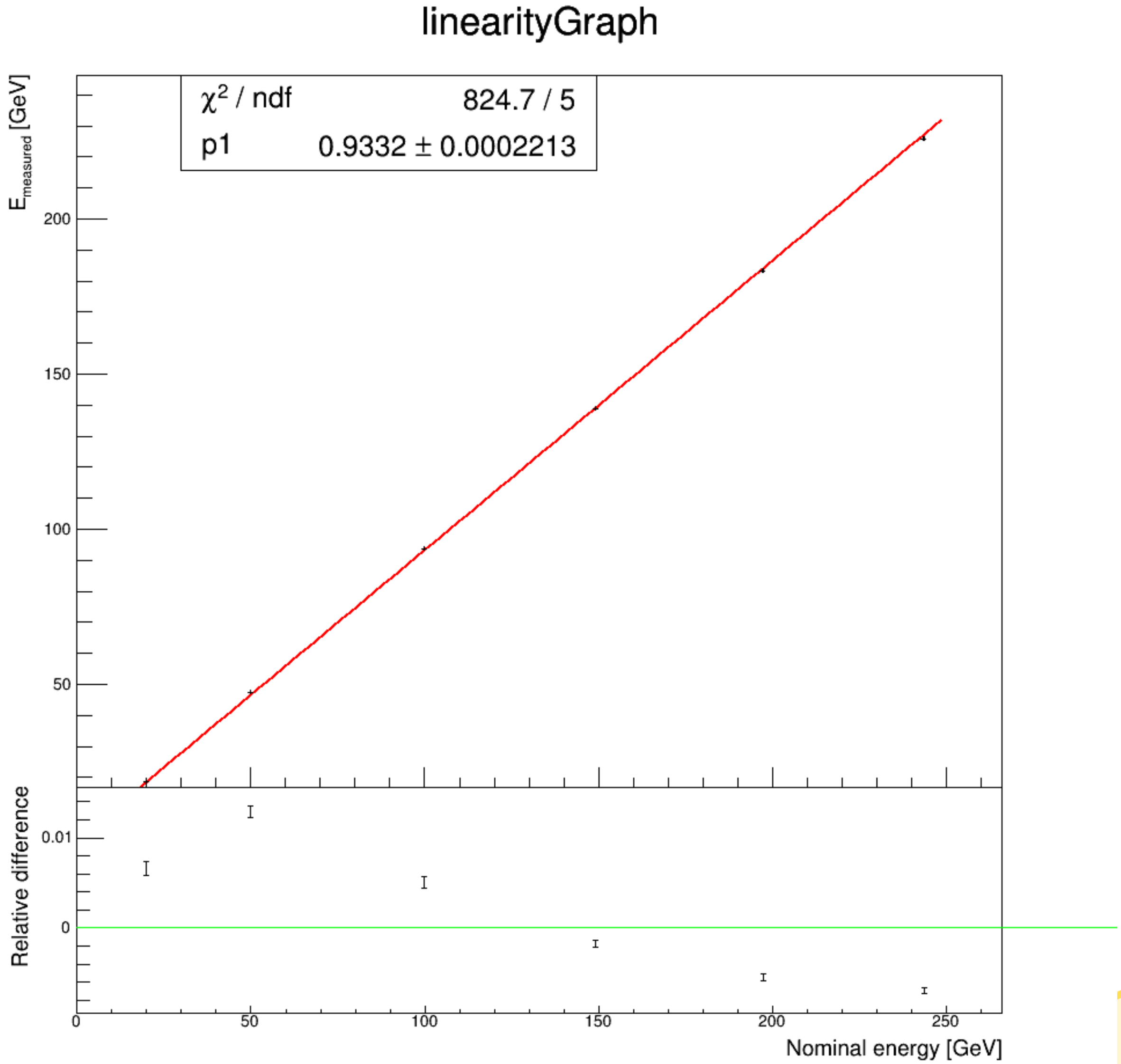
- (p2) Calibration uncertainty term present in real data and not in simulation (as expected)
- (p1) Electronic noise effect bigger in real data (under estimated in simulations?)
- (p0) stochastic term: shower fluctuations and sampling effects bigger in simulations (since electronics noise term is smaller?)

Energy linearity - Data



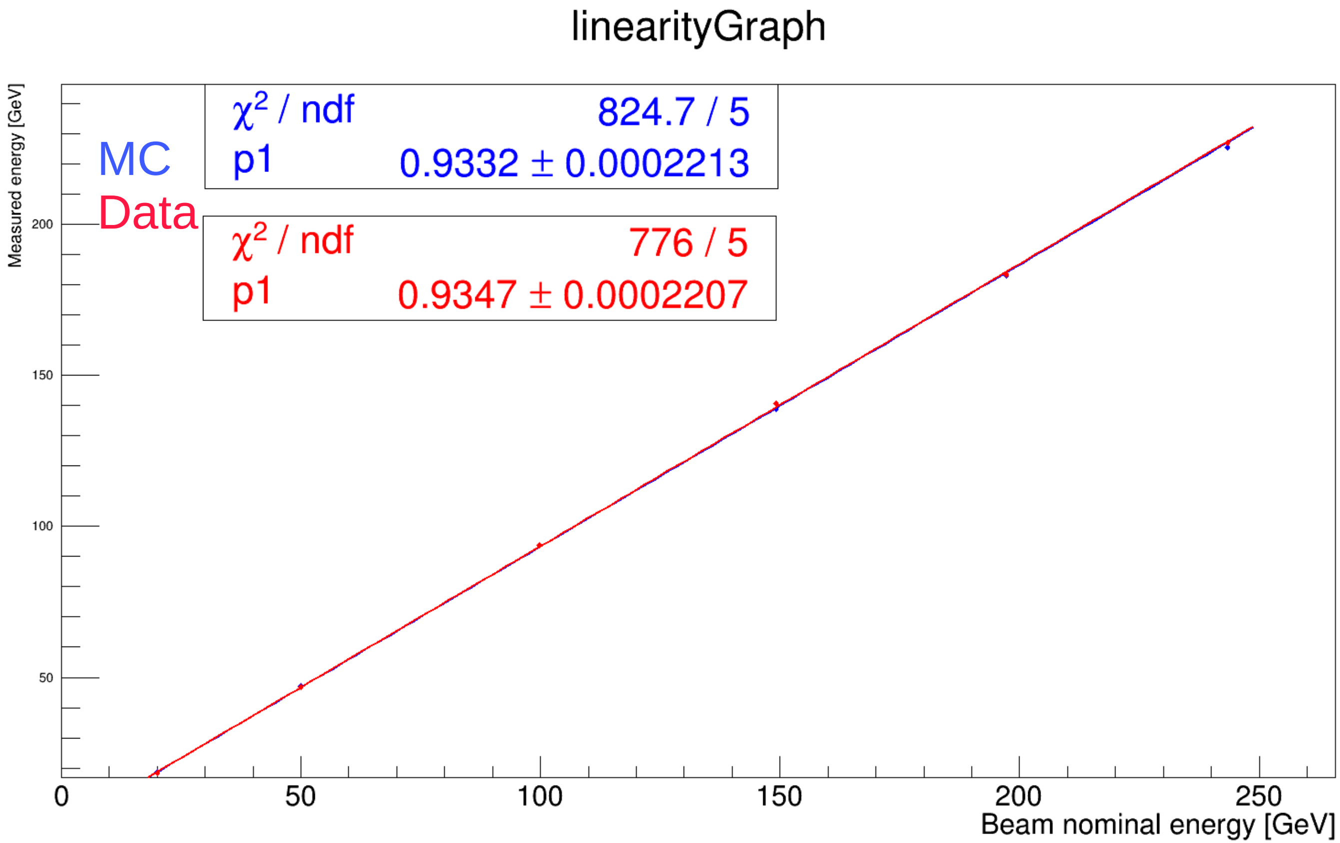
Non linearity less than ~1%

Energy linearity - MC



Non linearity less than ~1%

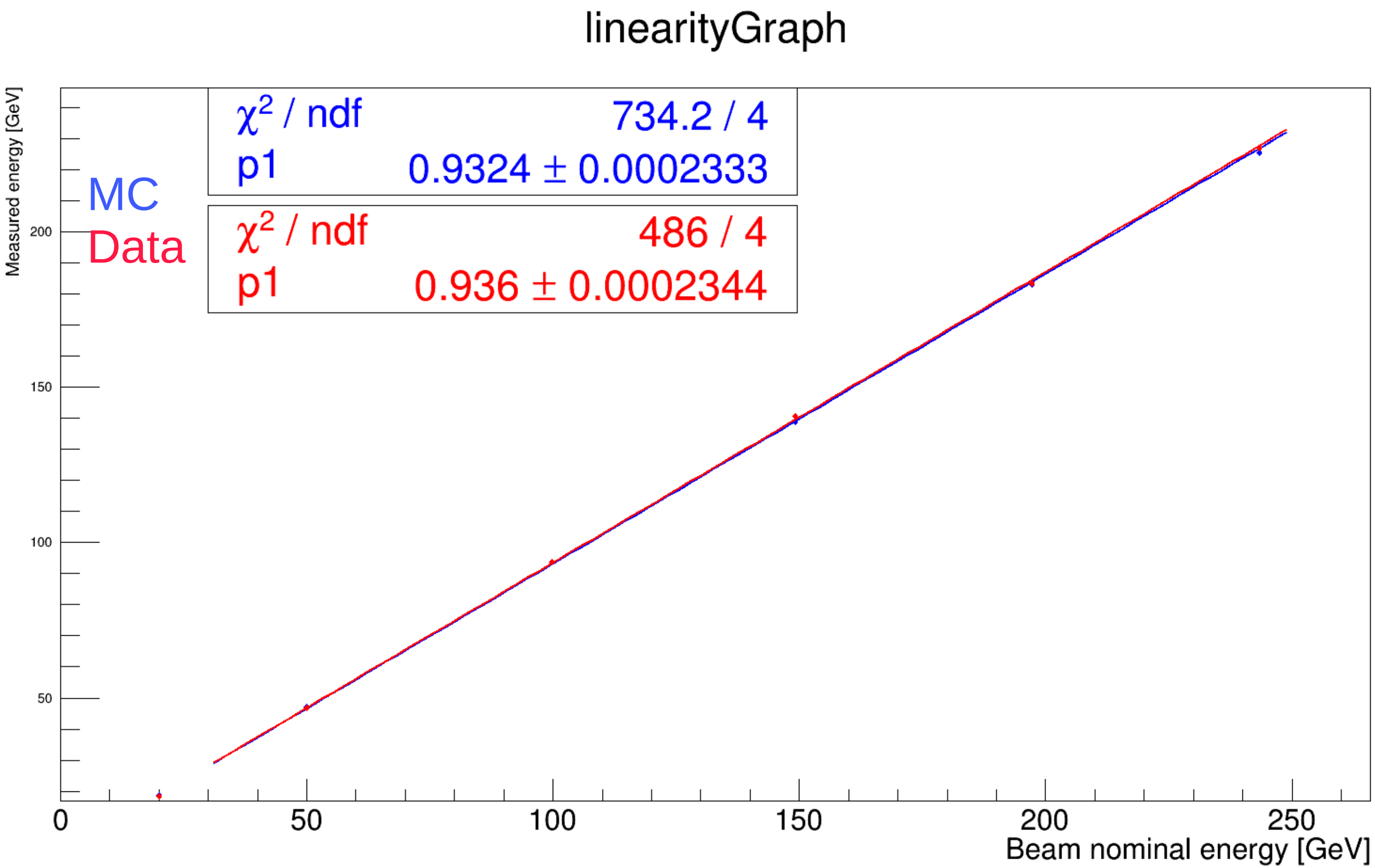
Energy linearity – Data vs MC



p0 = 0 forced

Relative difference of p1 ~0.16%

Energy linearity – Data vs MC excluding 20 GeV point

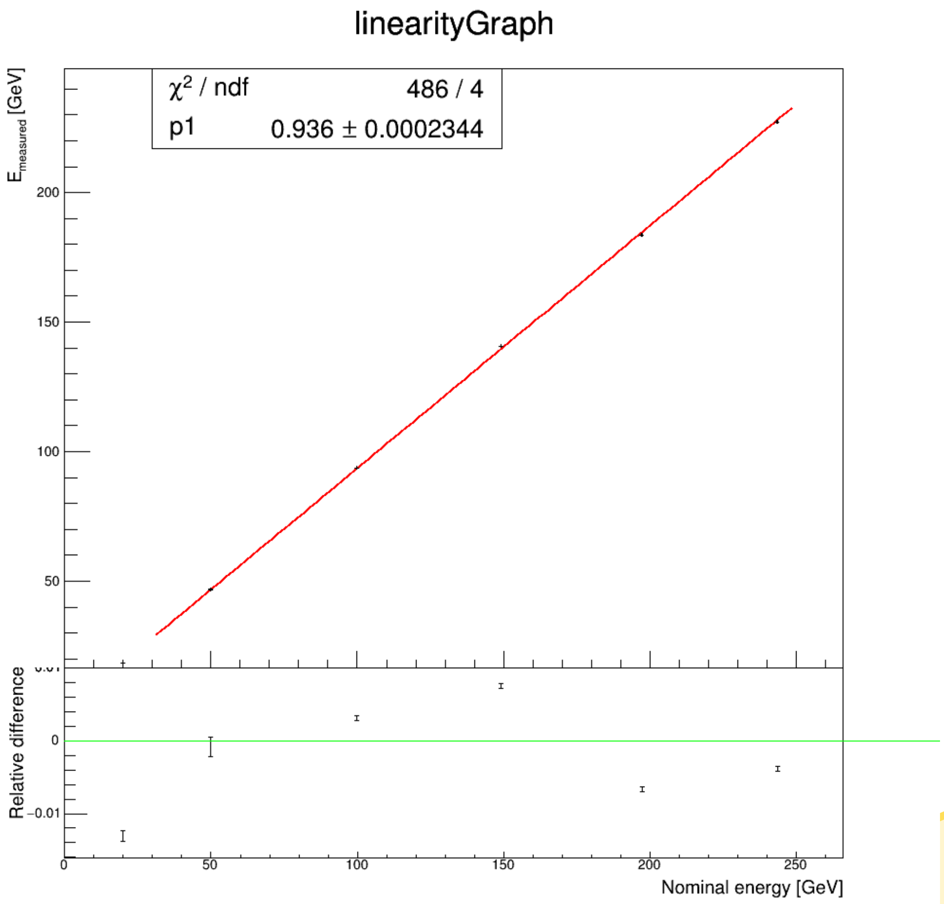


p0 = 0 forced

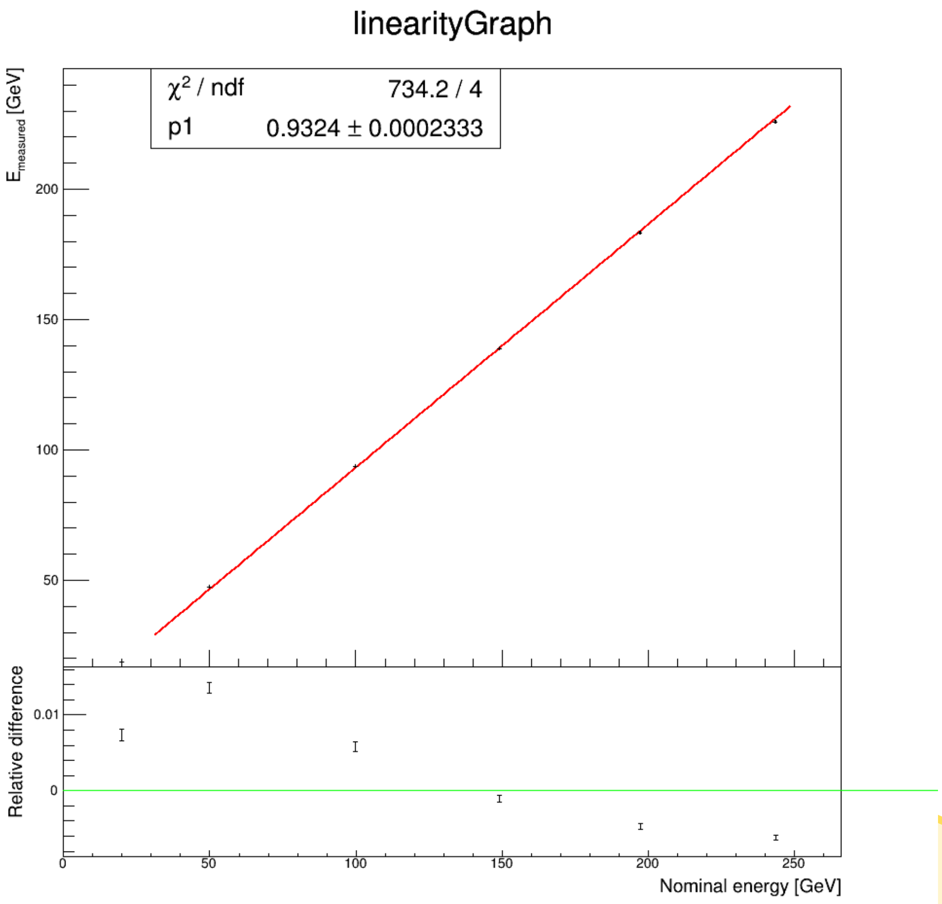
Relative difference of p1 ~0.4%

Energy linearity – excluding 20 GeV point

Real data



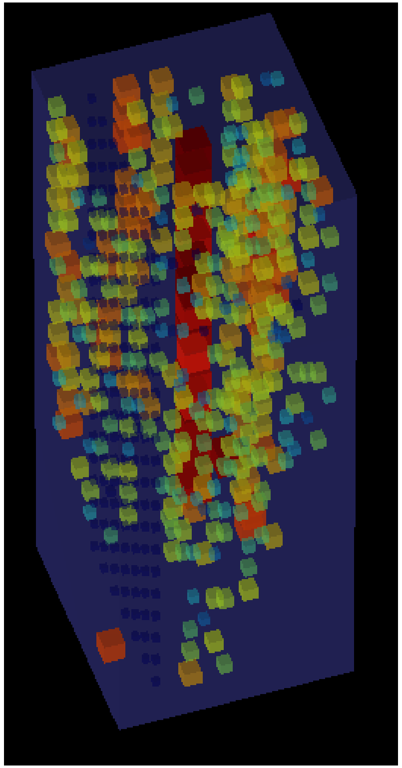
Simulations



Not considered effects

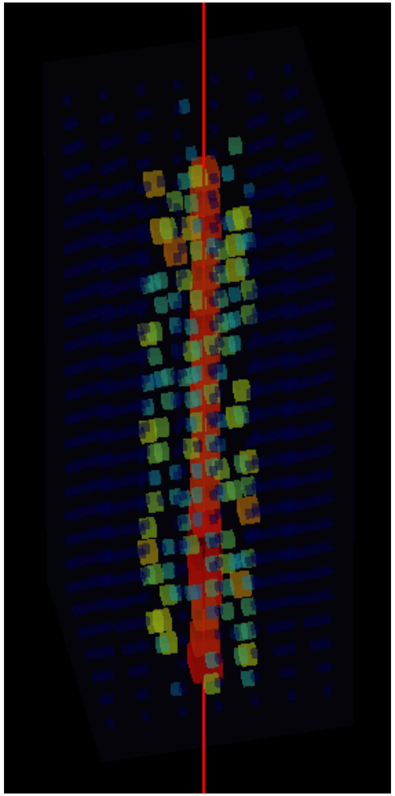
- Geometry
  - Slightly different density of the crystals
  - Uncertainty on material budget between Calo and beam pipe
  - Uncertainty on Calo inclination respect to beam
- Beam
  - Simulated uniform profile of beam
  - Beam divergence only along y axis
  - Uncertainty on beam energy?
  - Hadron contamination
- Other effects
  - Gain jump effect assumed equal for all the channels for all the energies
  - Calibration uncertainty
  - Effect of different signal due to “generation point” of scintillation photons in the crystal (Chinese article)
  - Physics list used in simulation
  - Quenching effect (seems to have no impact on energy resolution from Paolo’s preliminary studies)
  - Noise from pedestal events
  - Pedestal shift correction effect on energy resolution neglected
  - Reliability of SCD tracks
-

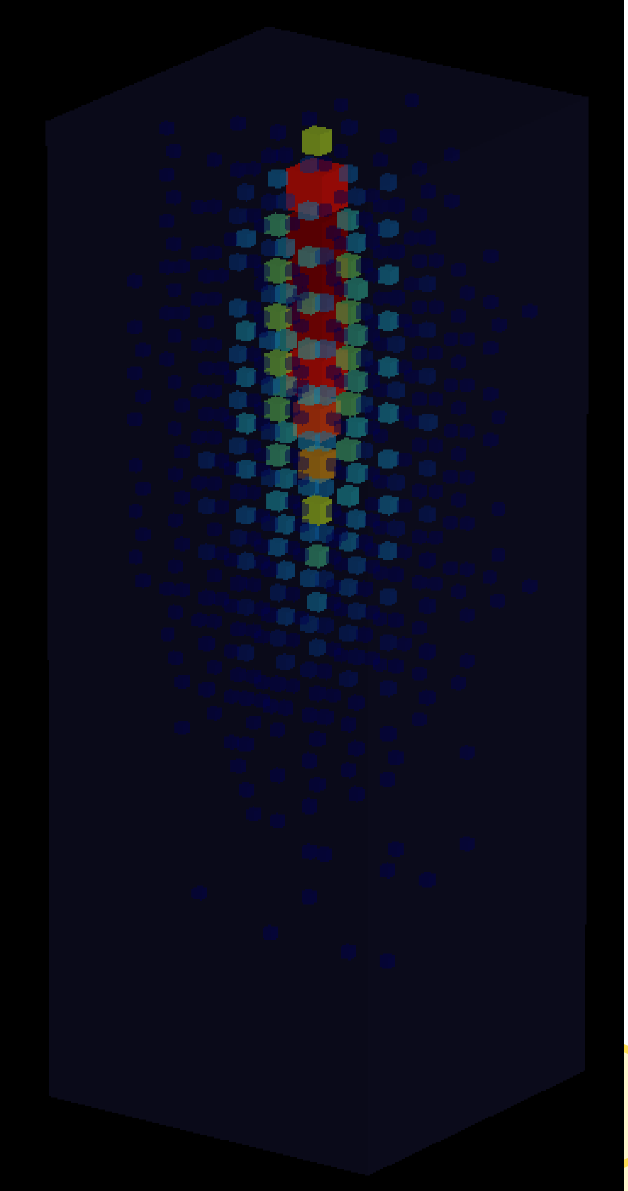
Noise from pedestal events….



Real
Muon

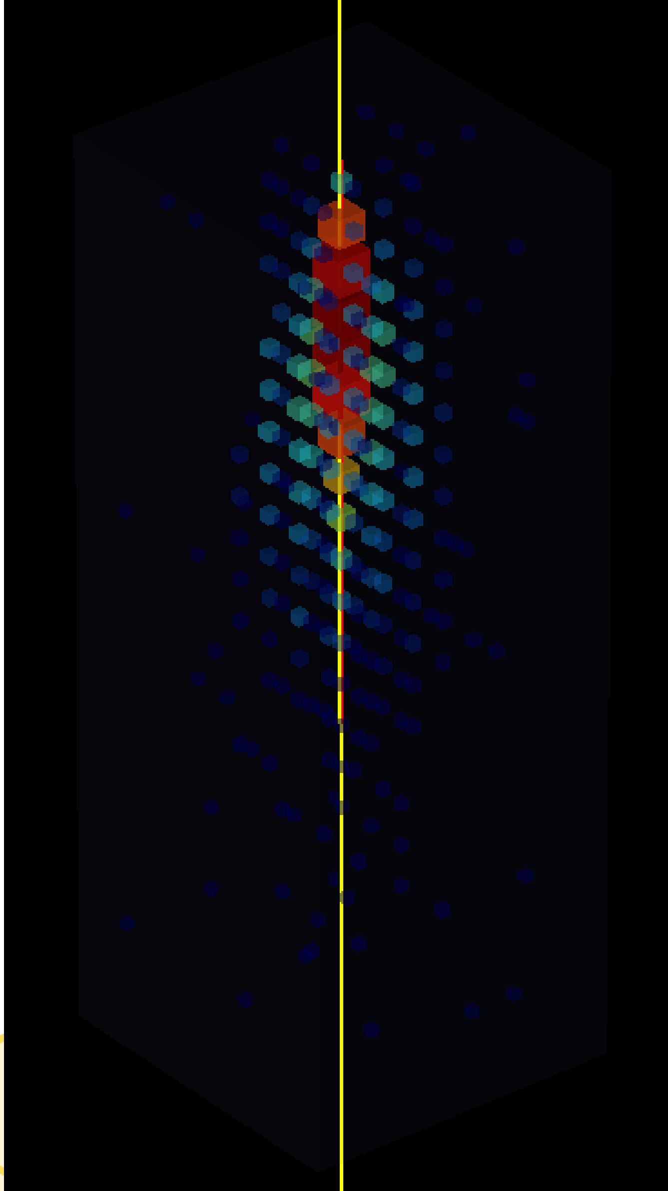
Simulated and
digitized

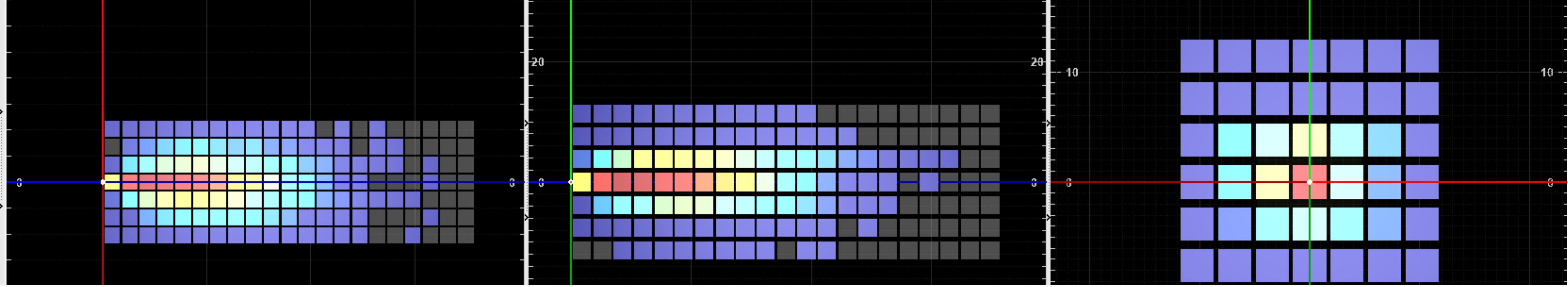




Real 250 GeV electron

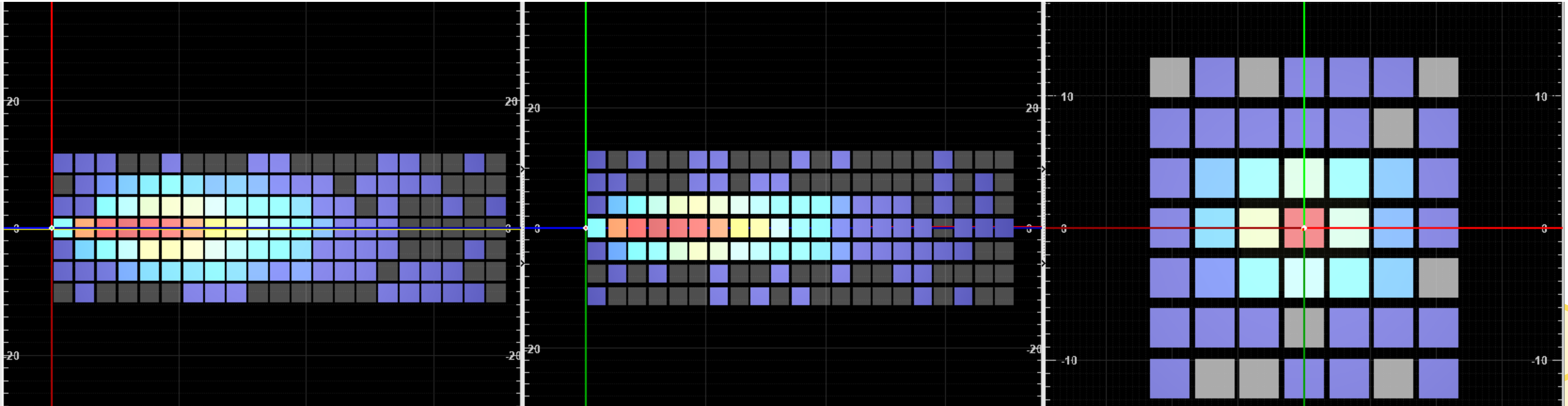
Simulated 250 GeV electron





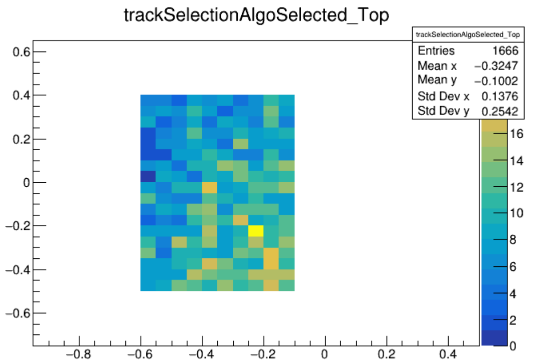
Real 250 GeV electron

Simulated 250 GeV electron

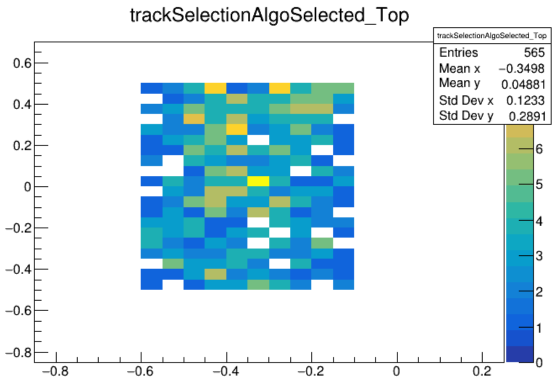


Beam profile

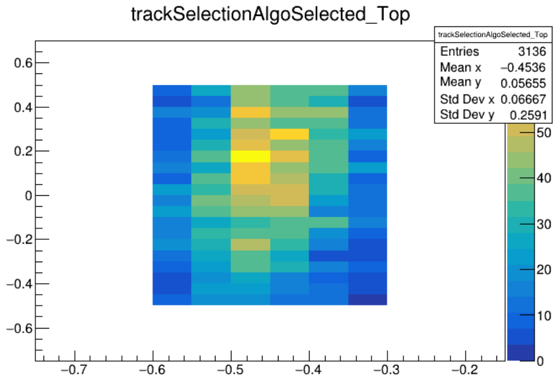
20 GeV



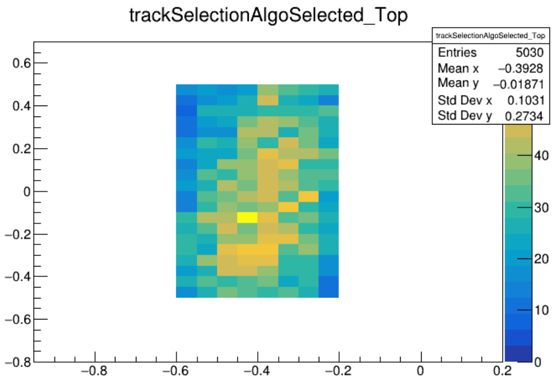
50 GeV



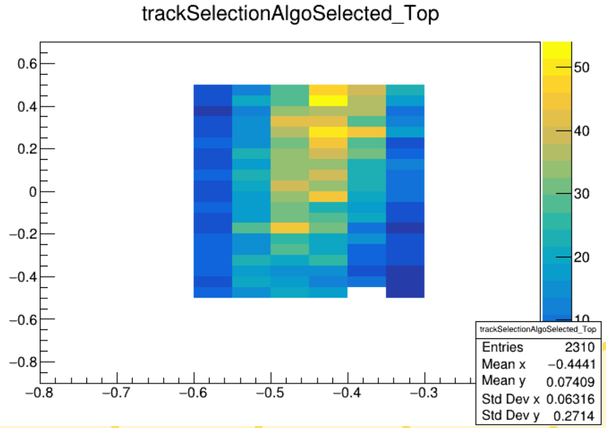
100 GeV



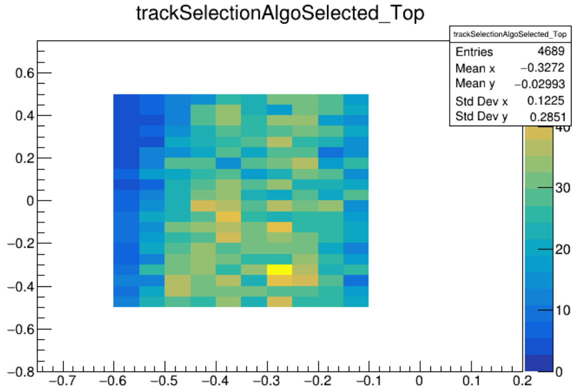
150 GeV



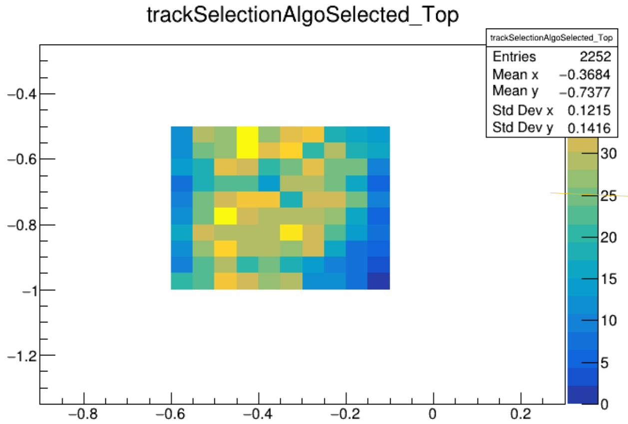
200 GeV

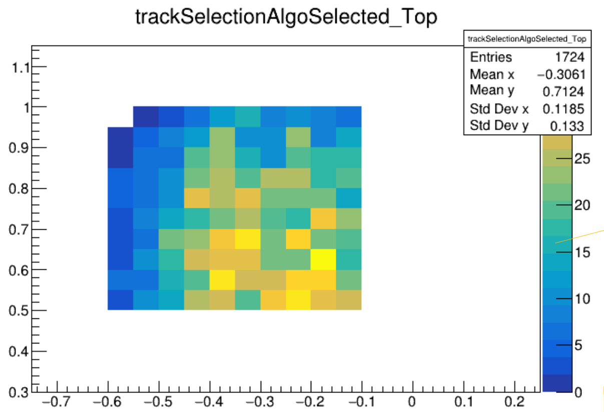


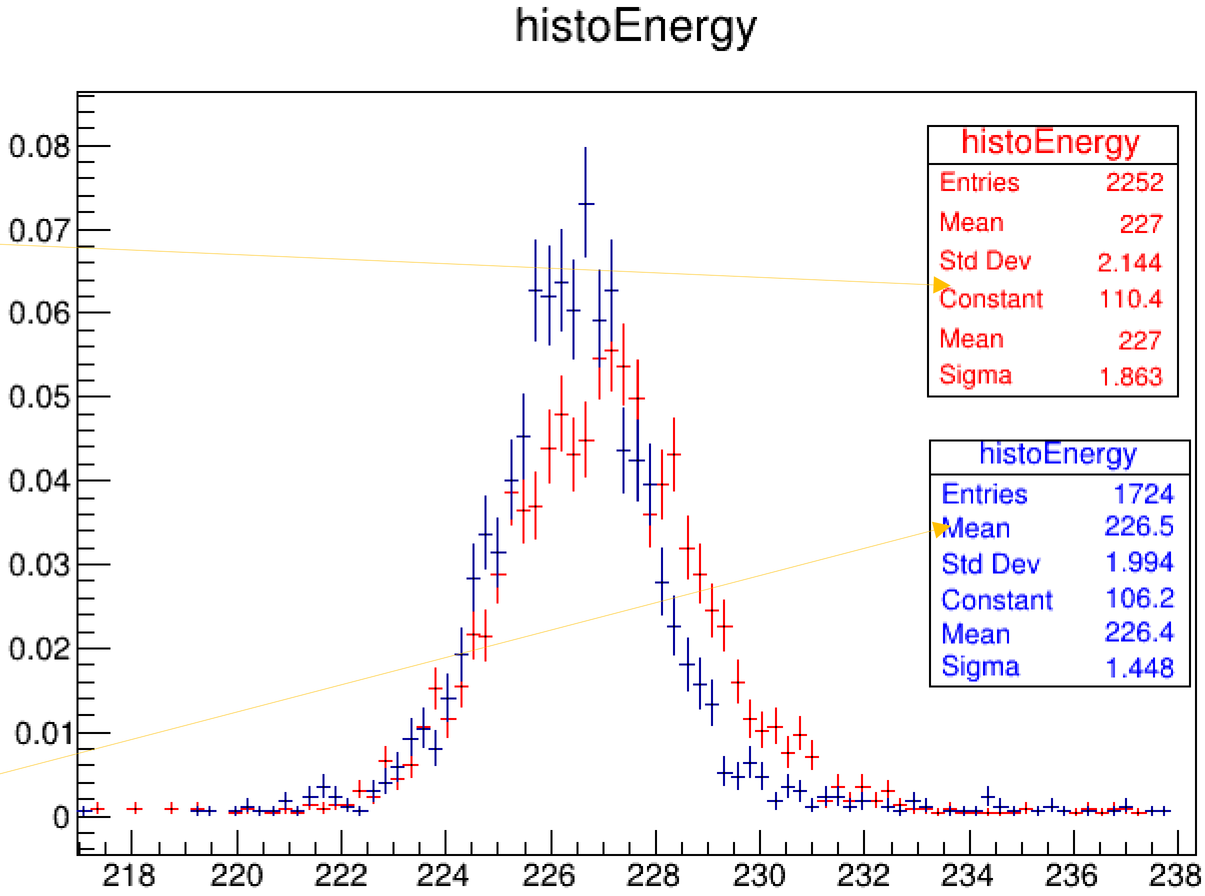
250 GeV



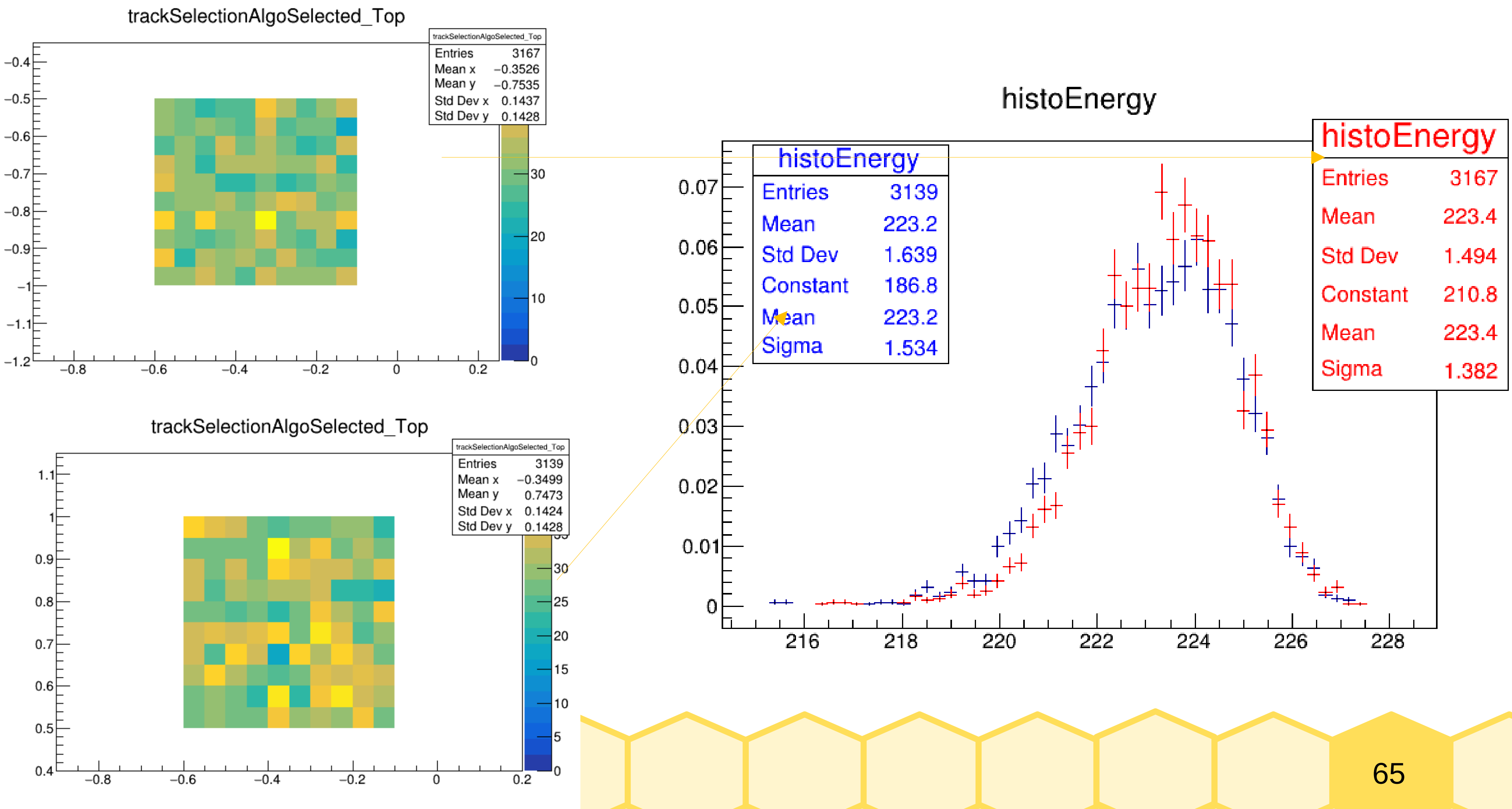
Signal in function of particle incidence on the crystal - Data







Signal in function of particle incidence on the crystal - MC



Beam energy

- Energy loss due to synchroton emission (Grupen):

The energy loss per turn in a circular accelerator is

$$\Delta E = P \cdot \frac{2\pi r}{c} = \frac{e^2}{3\varepsilon_0} \frac{\gamma^4}{r} = 8.85 \cdot 10^{-5} \frac{E^4\ [\mathrm{GeV}^4]}{r\ [\mathrm{m}]}\ \mathrm{GeV}\ . \qquad (1.88)$$

$$\frac{DE}{E^4} = k$$

Orginal E	E after beam line	K
20	20	<10-8
50	49.99	1.60*10^-9
100	99.83	1.70*10^-9
150	149.12	1.74*10^-9
200	197.27	1.71*10^-9
250	243.48	1.67*10^-9

Effect of “generation point” of photons in the crystal

Energy resolution for a 21x21x21 HERD calorimeter with isotropic particle electron gun
CALO read-out by WLSFs