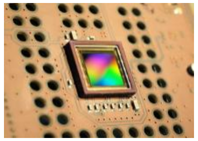
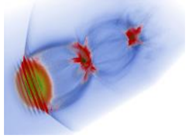
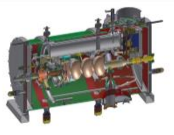
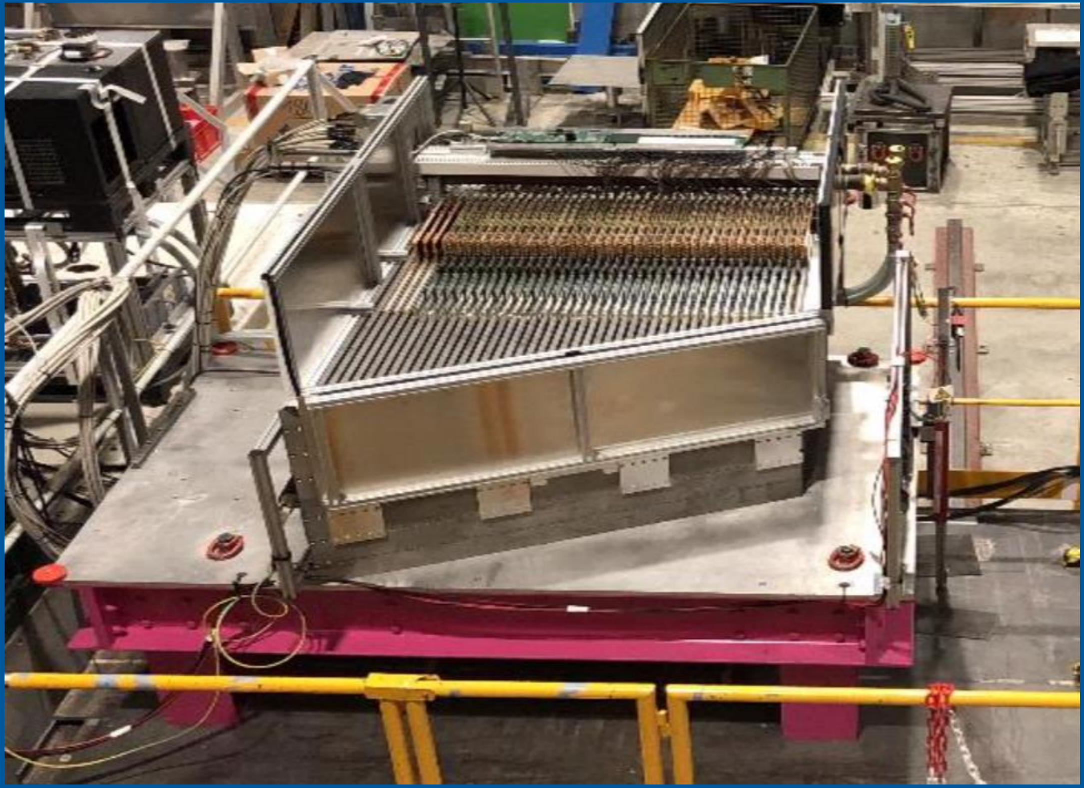
Matter and Technologies







Calibration and SIPM saturation of the CALICE 2018 Analogue Hadron Calorimeter Prototype



O.Pinto, D. Heuchel, Y. Sudo
DESY, Hamburg

4th March 2018

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

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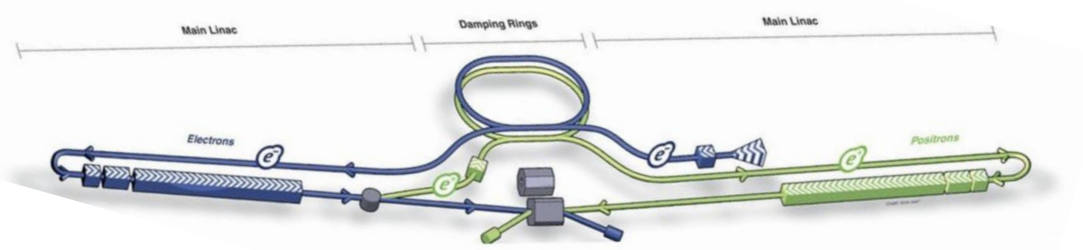
Overview

- ✓ Introduction
  - ✓ International Linear Collider (ILC)
  - ✓ CALICE - AHCAL 2018 technological prototype
- ✓ Overview of calibration
- ✓ Saturation correction
- ✓ Conclusion

The International Linear Collider

World's next major particle collider

- ✓ e^+e^- linear collider
- ✓ $\sqrt{s}$ = 250 GeV (to 1 TeV)
- ✓ Polarised beams
- ✓ Low background and radiation
- ✓ Detectors: **International Large Detector (ILD)** and Silicon Detector (SiD) optimized for particle flow



Goals:

- ✓ Higgs precision/top mass measurement
- ✓ Higgs self coupling
- ✓ Searching new particles beyond standard model …

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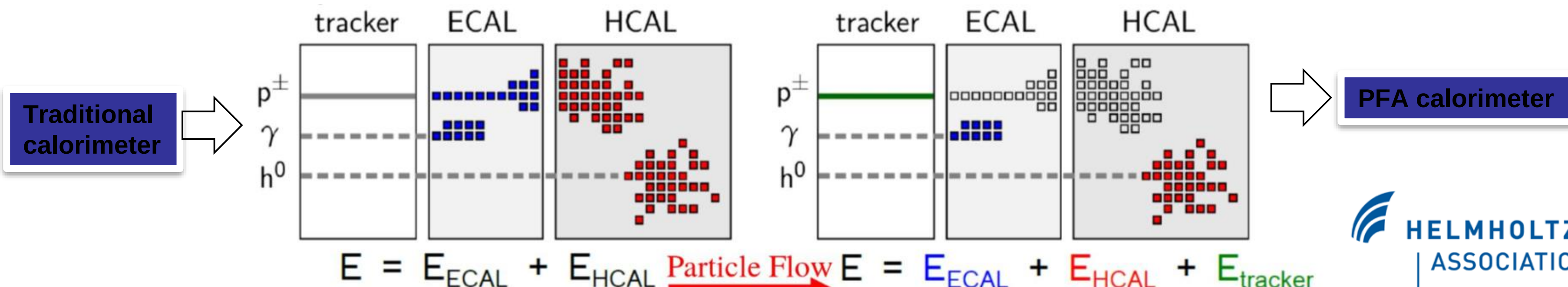
Particle Flow Approach (PFA)

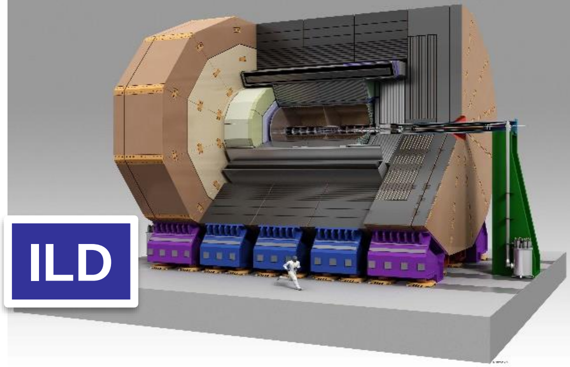
Optimization with High Granularity

- ✓ Requirement at the ILC: Jet energy resolution of 3-4 % for jet energies between 40-500 GeV
- ✓ Typical jet composition - 70 % hadrons measured with limited hadronic energy resolution
- ✓ **PFA: Measure energy/momentum of each particle with detector providing best resolution**
  - ✓ 62% charged particles → tracker, 27% photons → ECAL, 10% neutral hadrons → ECAL + HCAL
    - ✓ Highly granular calorimeters required: Energy deposition to track assignment, identifying neutral hadrons to avoid confusion

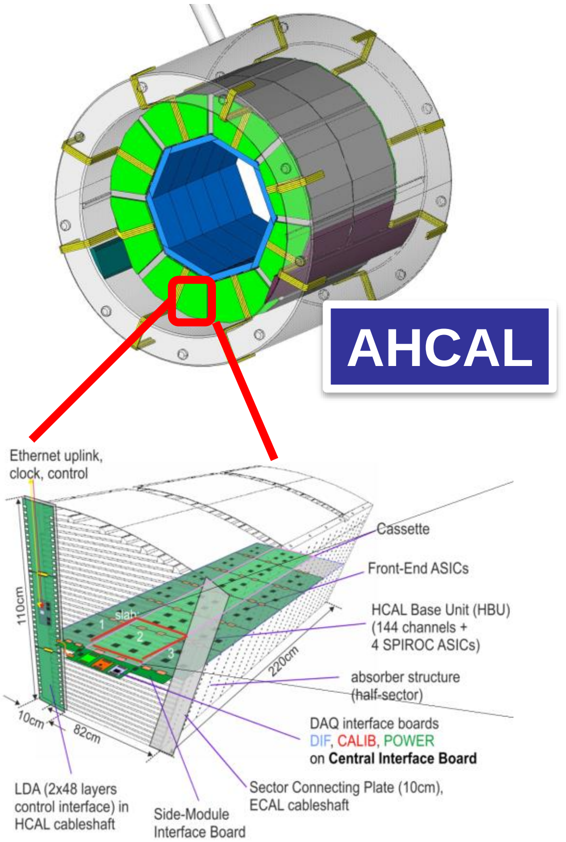


AHCAL for ILD

Detector Concept



- ✓ Highly granular sampling calorimeter (~8 million channels)
- ✓ Wrapped scintillator tile of 3 x 3 cm^2 coupled to SiPM readout
- ✓ Integrated electronics and LED calibration system, no cooling within active layers
- ✓ HCAL Base Unit: 36 x 36 cm^2 featuring 4 ASIC's reading out 144 channels
  - ✓ 1 Layer – 3 slabs of 6 HBU's (18 HBUs),
  - ✓ Full ILD ~55000 HBU's



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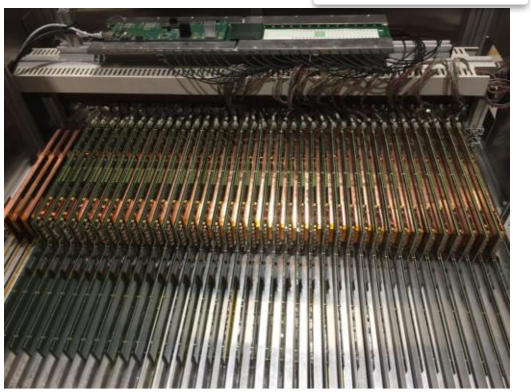
AHCAL Technological Prototype - 2018

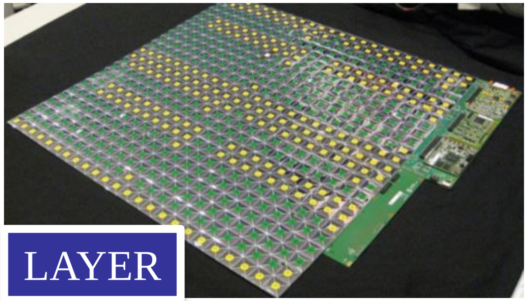
Detector Concept

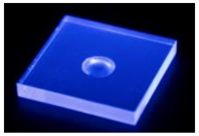
- ✓ 38 active layers of 72 x 72 cm^2 alternating with ~1.72 cm thick passive steel absorbers (~4 λ_n)
- ✓ 1 layer = 16 ASICS (SPIROC2E) = 576 SiPM-on-tile channels
  - ✓ Total of 608 ASICS, 21888 channels

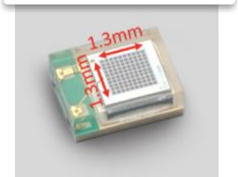
Goals:

- ✓ Scalability of calorimetry and reliable detector operation
- ✓ Study on energy linearity, resolution and particle identification









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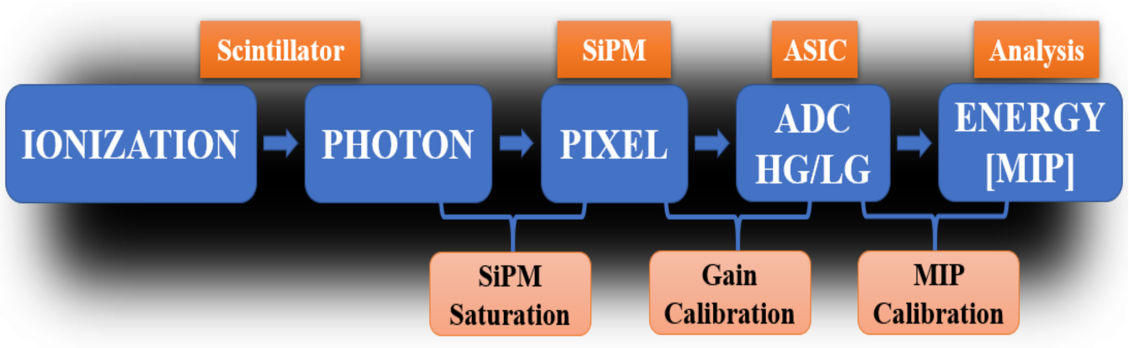
AHCAL Calibration

From ADC to MIP

- ✓ From electronic scale in ADC to Physics scale in MIPs



$$\boxed{E_{calibrated}[MIP] = f_{desat}(pixel) \cdot \frac{(ADC - Pedestal)/IC}{MIP}}$$

$$pixel = \frac{(ADC - Pedestal)/IC}{Gain}$$

$$f_{desat}(pixel) = 1 \quad for\; pixel \ll N_{max,pixel}$$

Pedestals: Electronic noise level in ADC units

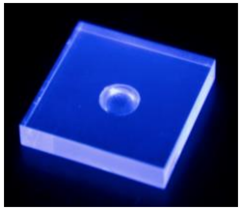
MIP: Most probable energy deposition of a MIP in ADC units

Gain: Distance between two photo electron peaks in ADC units

Inter calibration (IC): HG/LG ratio

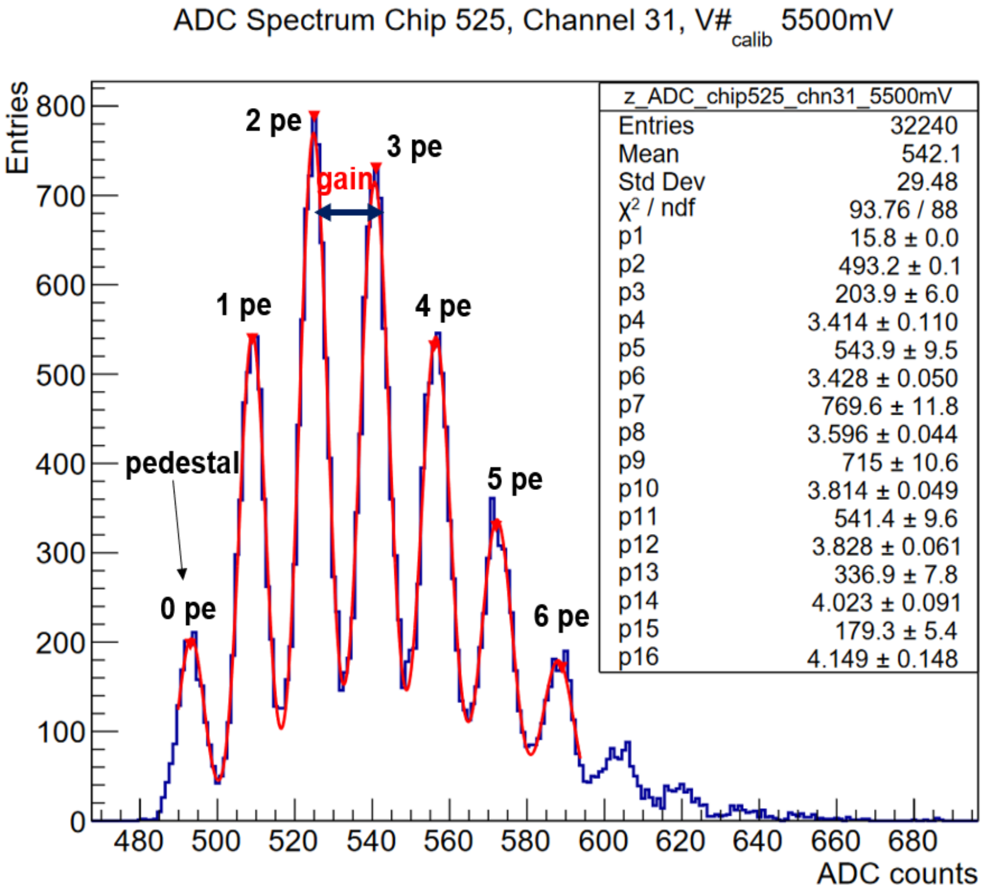
Pedestal and Gain Calibration

Calibration procedure



- ✓ Short LED pulse: 2 to 10ns (~450nm)
- ✓ A peak corresponds to a certain number of photoelectrons (0 pe, 1 pe)
- ✓ n=0 (no photon detected) pedestal
- ✓ Peaks n =1,2,3… corresponds to simultaneously firing pixels

- ✓ Spectrum is fitted - multigaussian function to measure the exact peak distance and distance is forced to be the same



Requirement for good fit/spectrum:

- ✓ Chi2/NDF < 2

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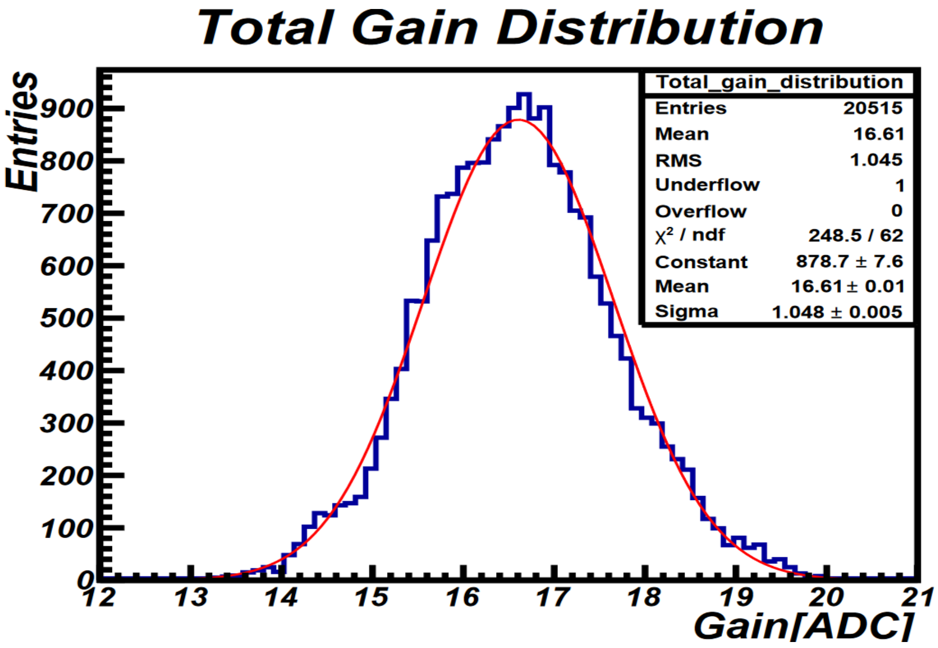
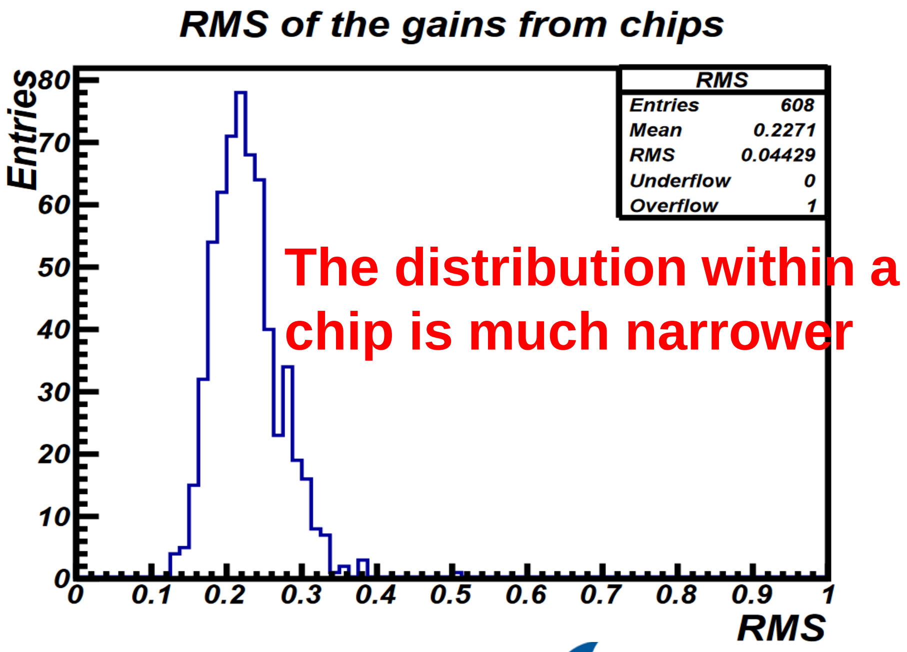
Calibration

Gain for 2018 AHCAL prototype

- ✓ Gain value is extracted for individual channels (21,888)
- ✓ Gain value acquired for 2018 prototype ~16ADC with a RMS of 1.05 ADC





MIP calibration

Calibration procedure

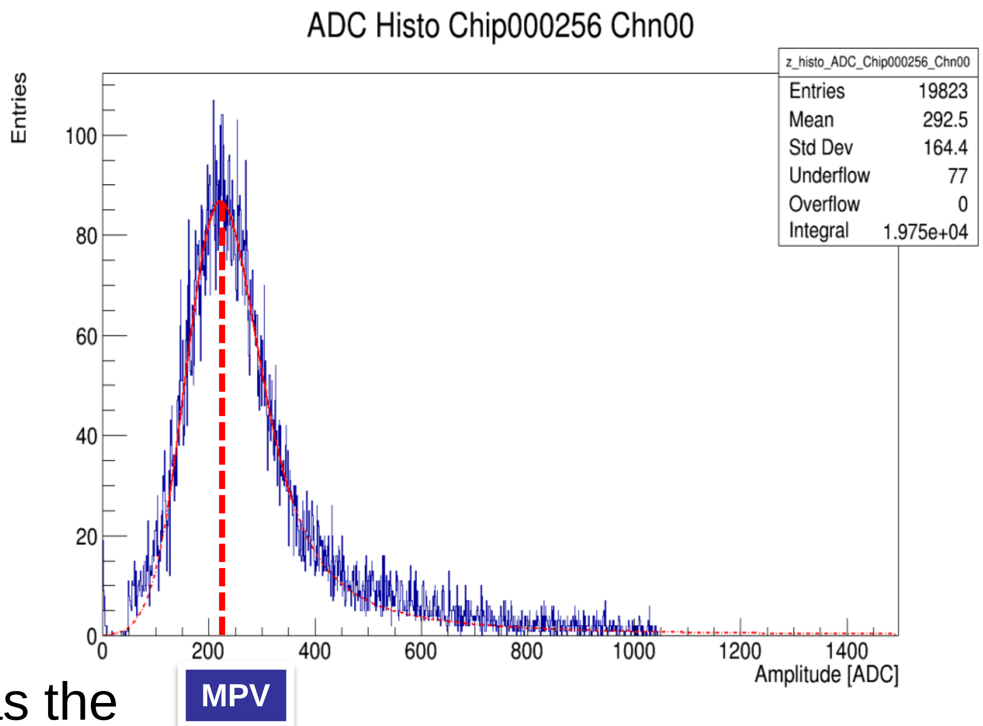
Incident particles are muons [MIP]

Energy deposited follows a Landau distribution

- ✓ Fill histogram for each channel
- ✓ Apply 3-step Landau convoluted Gaussian fit
- ✓ Extract maximum of fit function as the MIP constant for each channel

Requirements for good spectrum/fit:

- ✓ Minimum number of hits: 1000
- ✓ $Chi^2/Ndf < 5$



MIP Constant : Most Probable Value (Maximum) of Landau convoluted Gaussian fit

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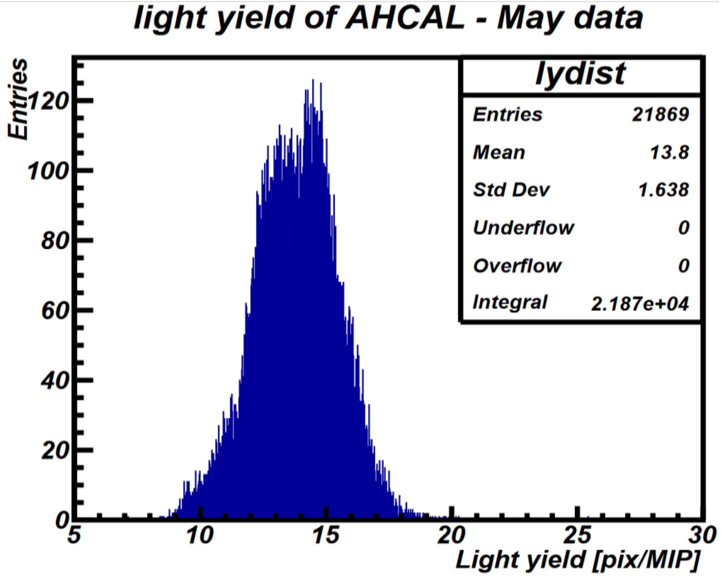
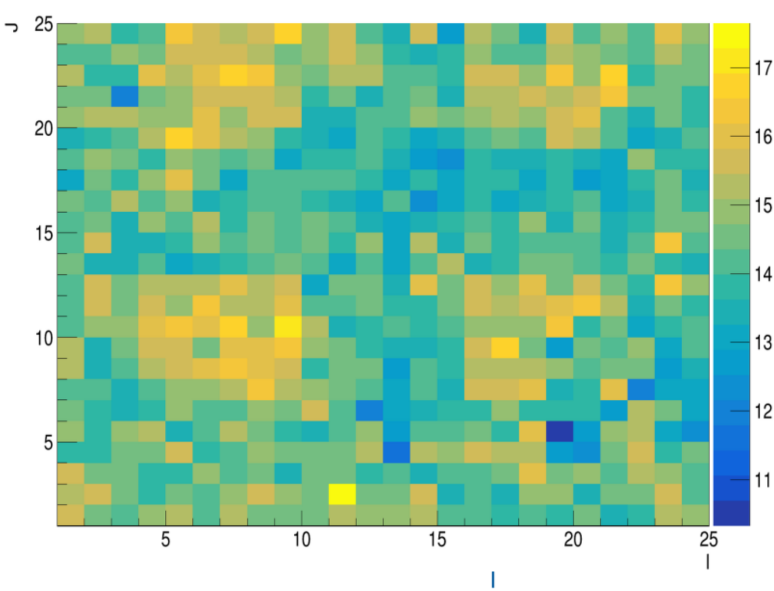
Light Yield

Results

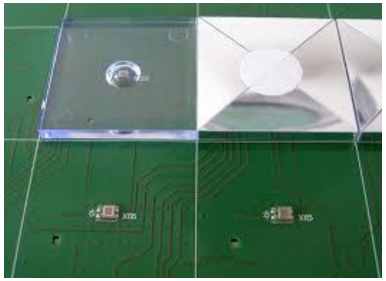
$$LY_i = MIP_i / Gain_i$$

- ✓ Definition: Most probable amount of SiPM pixels fired per incident MIP
- ✓ Mean light yield of main AHCAL channels: ~13.8 pix/MIP, RMS: ~ 1.6 pix/MIP
  - ✓ RMS LY/Mean LY = 11.6%
- ✓ Light yield map of the detector channels shows slight inhomogeneities (different types of tile wrapping)





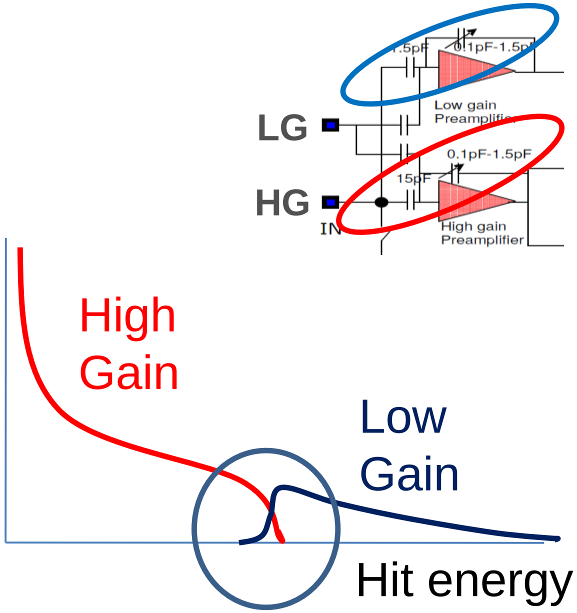
Wrapped tile

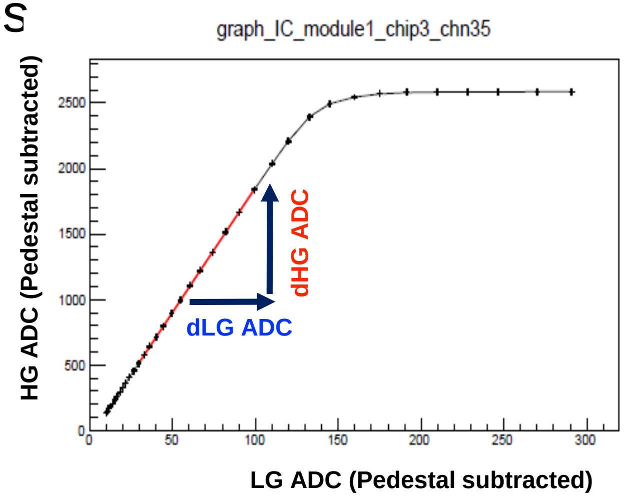


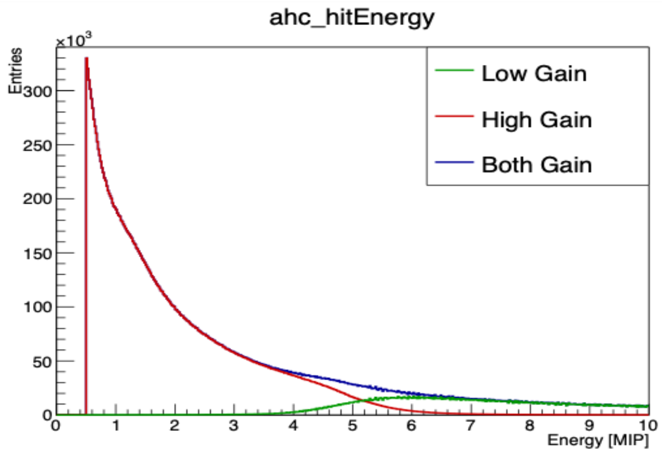
Inter calibration

Calibration technique

- ✓ SPIROC2E: High Gain (HG) and Low gain (LG) signal output
  - ✓ HG : small deposited energy hits
  - ✓ LG : large deposited energy hits
- ✓ Inter-calibration (IC) factors required for smooth transition between HG and LG hit energies
- ✓ Consecutive LED runs with different LED voltages for HG or LG mode for individual channels
  - ✓ Measure resulting slope: IC = dHG (ADC) / dLG (ADC)

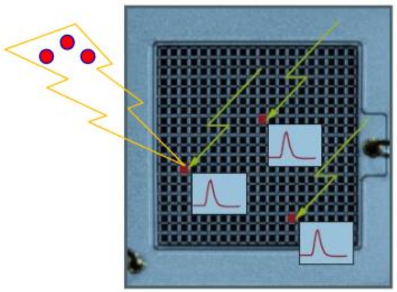


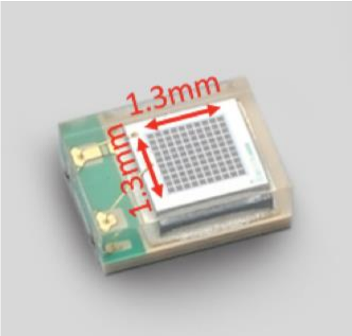




SIPM Saturation

Why saturation



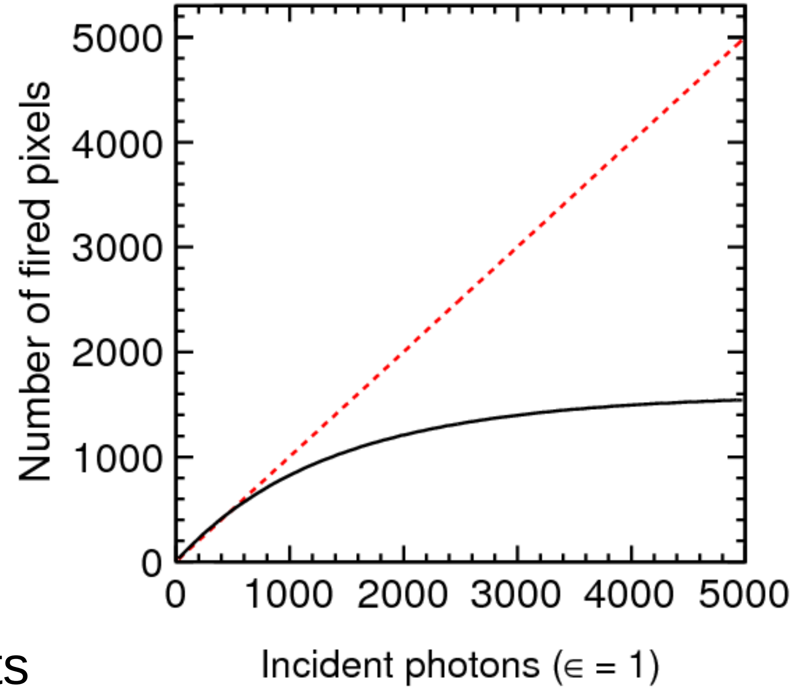


SIPM S13360-1325PE

- ✓ Due to limited number of pixels in SiPM (2668 pixels, 1.3 x 1.3 mm^2)
- ✓ Need to correct the non-linear response of SiPM at high energy deposition – impact of pixel recovery
- ✓ Apply a de-saturation function to enable linear SiPM response:

$$pixel_{desat} = f_{desat}(pixel_{sat})$$

$$N_{\mathrm{fire}}^{\mathrm{LO}'} = N_{\mathrm{pix}}^{\mathrm{eff}}\left(1 - \mathrm{e}^{-\epsilon N_{\mathrm{in}}/N_{\mathrm{pix}}^{\mathrm{eff}}}\right)$$



arXiv:1510.01102

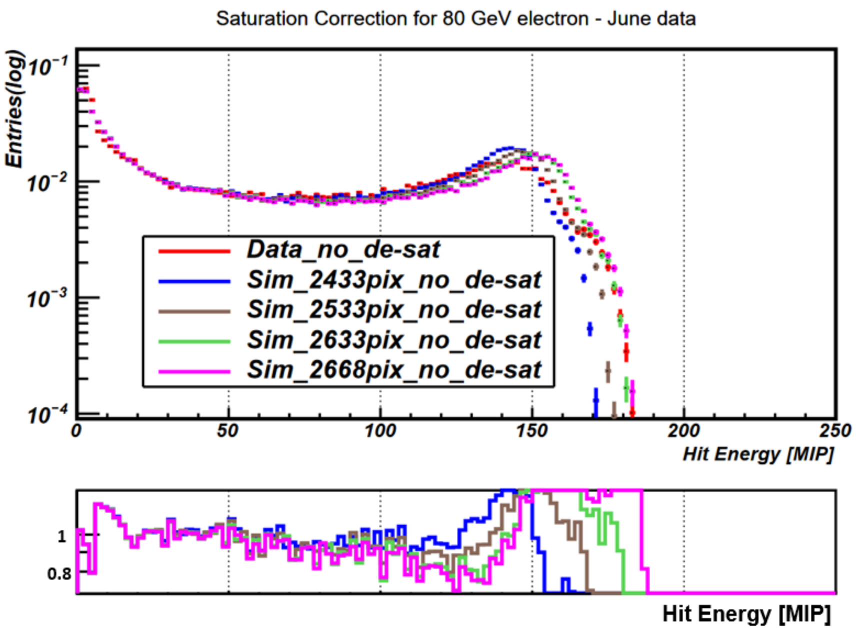
- ✓ Apply linear continuation function for hits above certain threshold (> 0.95 * Neff pixels).

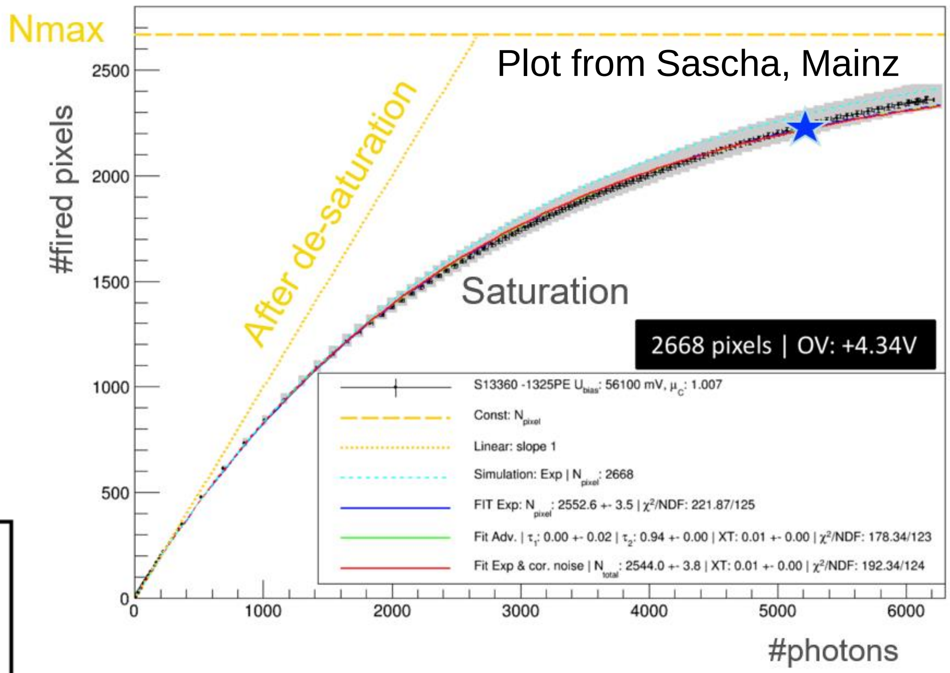
Saturation

Saturation correction

- ✓ Saturation studies on bare SIPM have shown best agreement on data/simulation for:

$$N_{effpix} = 2533pixel$$





- ✓ Electron energy of 80 GeV selected
- ✓ # effective pixel is tuned in simulation and corrected for high hit amplitudes

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Summary & Conclusion

- ✓ The ILD-AHCAL is a highly granular SiPM-on-tile calorimeter for the ILC

ILD AHCAL - 2018 Prototype

- ✓ All calibration constants (pedestal, gain, MIP and inter-calibration) required for the energy reconstruction from ADC to MIP are extracted
- ✓ Calibrations are performed:
  - ✓ Check for Stability in time, uniformity and to understand any variations
- ✓ Dedicated calibration allows to start “reliable” analysis
  - ✓ Energy linearity/resolution, shower shapes, shower separation etc…
- ✓ Saturation effects understood and tuned for best agreement between data and simulation

THANK YOU

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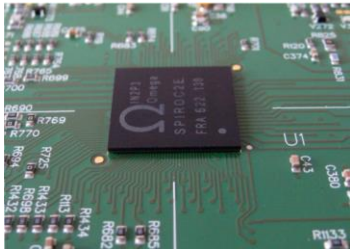
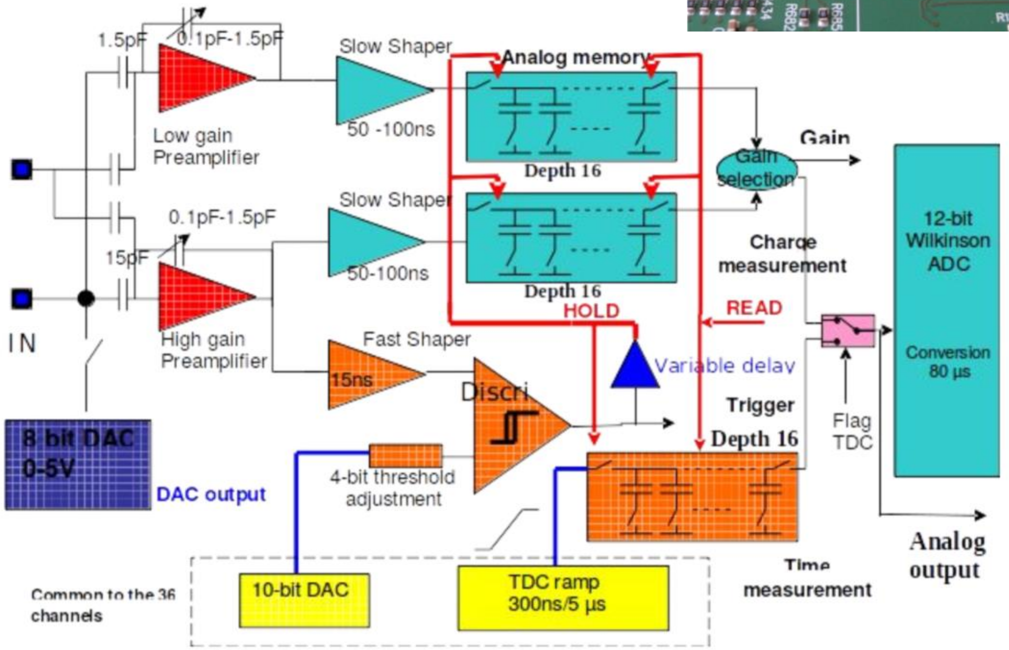
SPARES

The AHCAL Readout Chip SPIROC2E

- ✓ One chip reads out 36 channels
- ✓ If signal amplitude of one channel exceeds threshold, amplitude of all 36 channels is stored (auto-trigger)
- ✓ External trigger operation possible to trigger all chips and channels
- ✓ Each channel features 16 analog buffers (memory cells)
- ✓ TDC ramp to store timing information of each hit



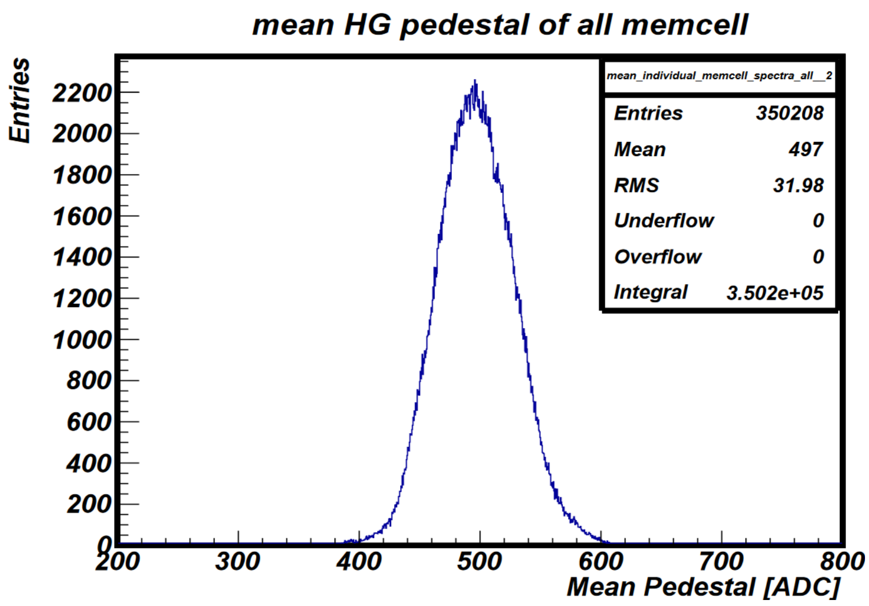


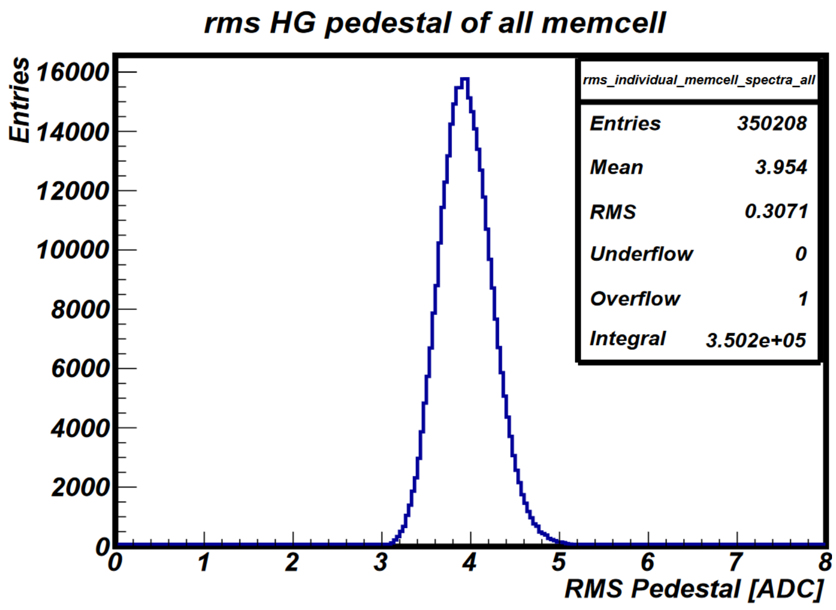
Readout schematic for one channel

Pedestal

From external trigger

memory cells = 21,888 channels x 16 memory cells each = 350208





- ✓ Mean pedestal: 497 ADC
- ✓ Spread: 31.98 ADC

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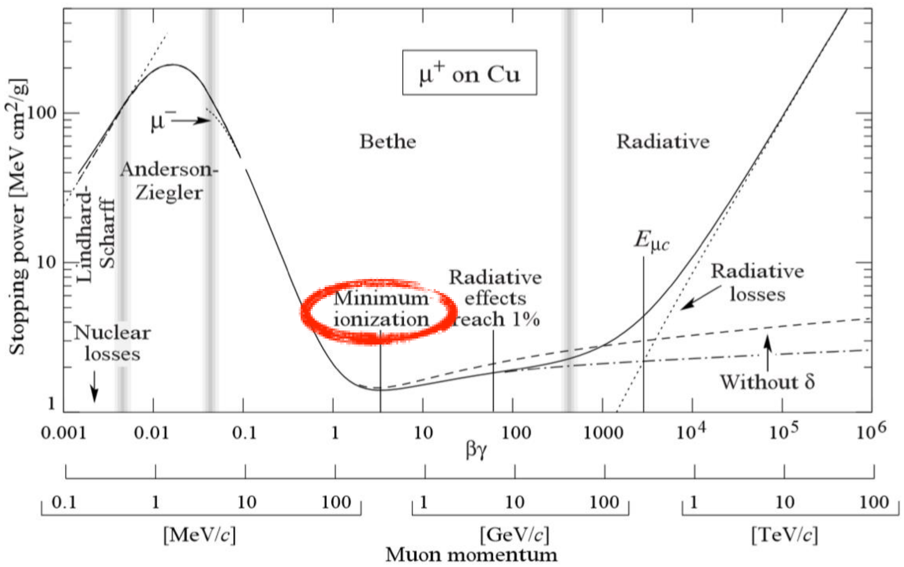
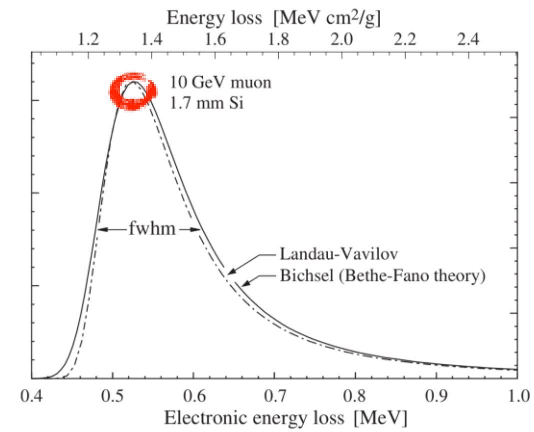
MIP

- ✓ The raw hit amplitudes of the AHCAL channels are measured in ADC units
- ✓ Need of physical energy scale: Energy deposition in Minimum Ionizing Particle (MIP) equivalents
  - ✓ Well defined energy deposition spectrum of MIP's (muons) in matter by ionization processes
  - ✓ Spectrum follows Landau-convoluted-Gaussian function with maximum as **Most Probable Value (MPV)** defining the deposition scale for each channel





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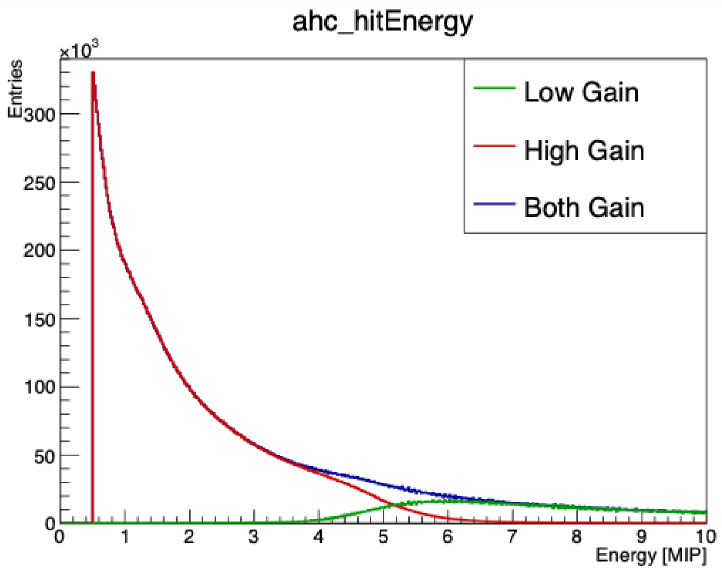
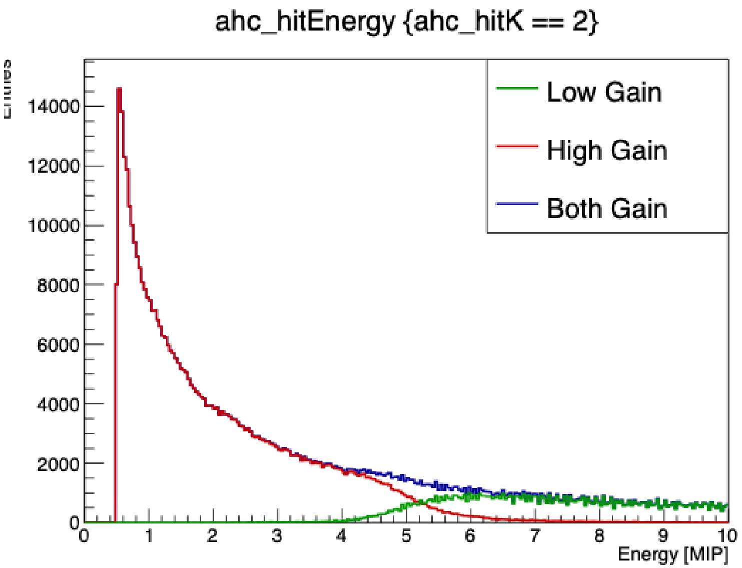
High Gain/Low Gain Transition Check

Global Level



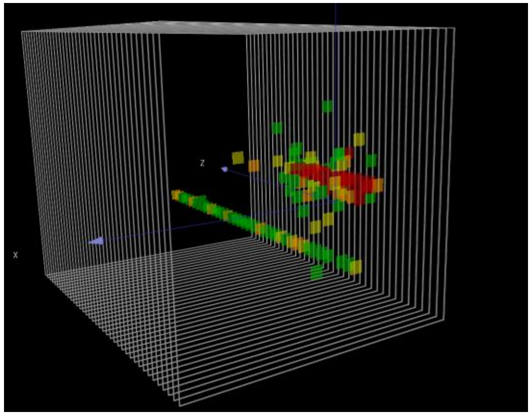
Layer Level



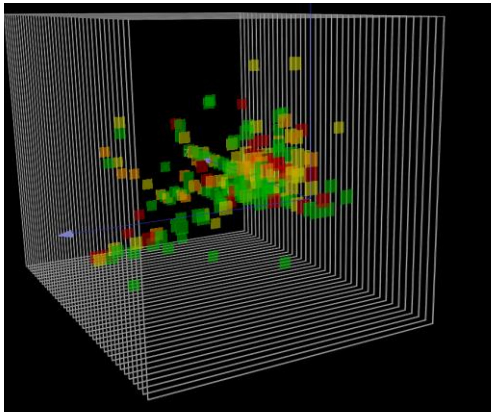
✓ **HG/LG transition smooth**

Event displays

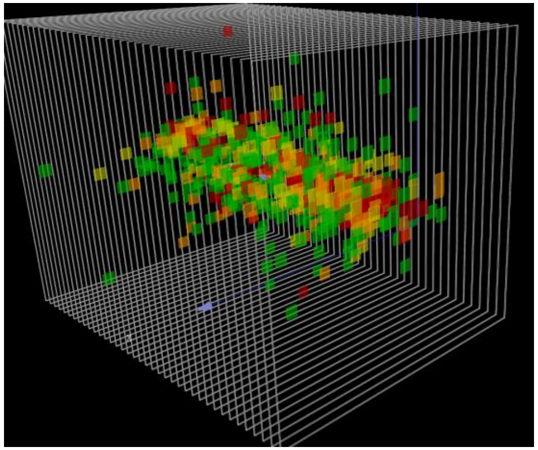
Muon



Electron



Pion



Pion