

Calibration issues for the CALICE 1m3 AHCAL

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- Equalization of the cell response in AHCAL
- MIP & Gain & Saturation of SiPMs
- Validation of the AHCAL calibration



Calibration chain: ADC to MIP

AHCAL signal chain:

Particle shower $\rightarrow$ MIPs $\rightarrow$ scintillator $\rightarrow$ photons (UV)
 $\rightarrow$ SiPM (non-linear) $\rightarrow$ photo-electrons $\rightarrow$
amplification $\rightarrow$ electronics

Calibration:

convert detector signal into number of MIPs deposited by particle traversing the tile
& correct for non linear response of SiPM & scale vis. MIP to tot. dep. energy in GeV

$$E_i[MIP] = \frac{A_i[ADC]}{C_i^{MIP}} \times f_{sat}(A_i[pix])$$

$$f_{sat}(A_i[pix]) = f_{sat}\left(\frac{A_i[ADC]}{I_C} \times G_{pix}\right)$$

What do we need:

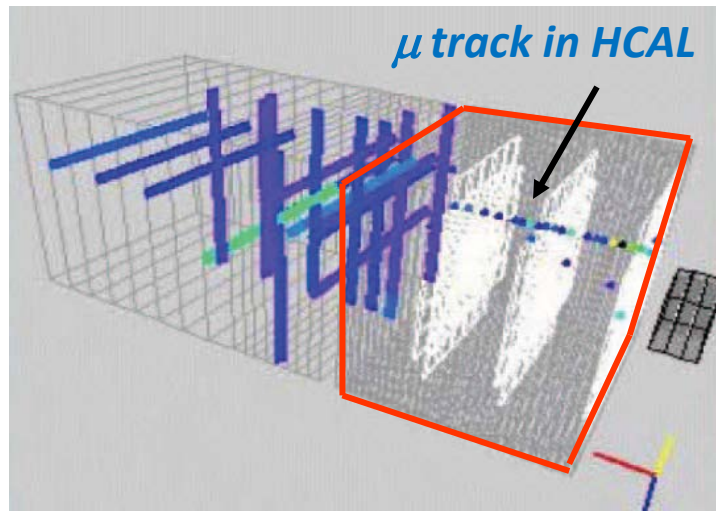
Lightyield in [pix/MIP]:

- **MIP amplitude** in ADC bins ... C_i^{MIP}
- **SiPM gain:** (CalibMode) ADC bins converts to pixel ... G_{pix}
- **Electronics Intercalibration:** between PM/CM mode ... I_C
- **SiPM response function:** corrects the non-linear response of the SiPM ... $f_{sat}(A_i[pix])$

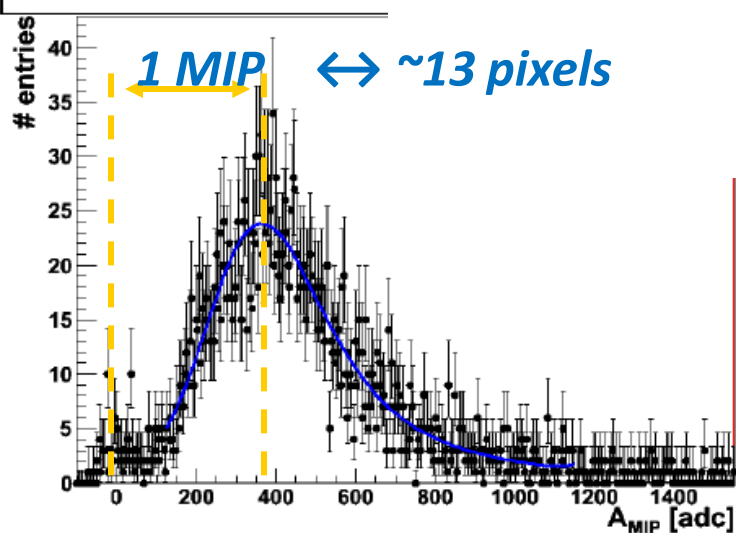


Cell response equalization with MIP

Using muon signal

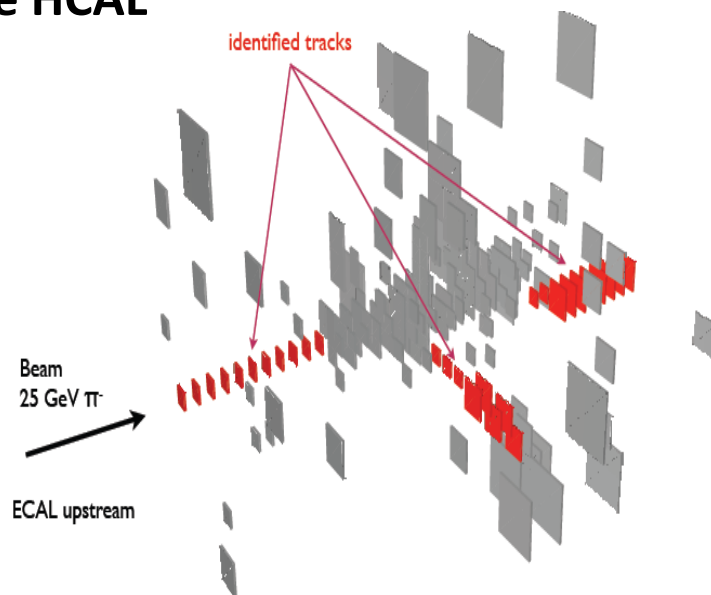


Module:29_chip:0_channel:1



Using pion shower

select MIP stubs using the high granularity of the HCAL



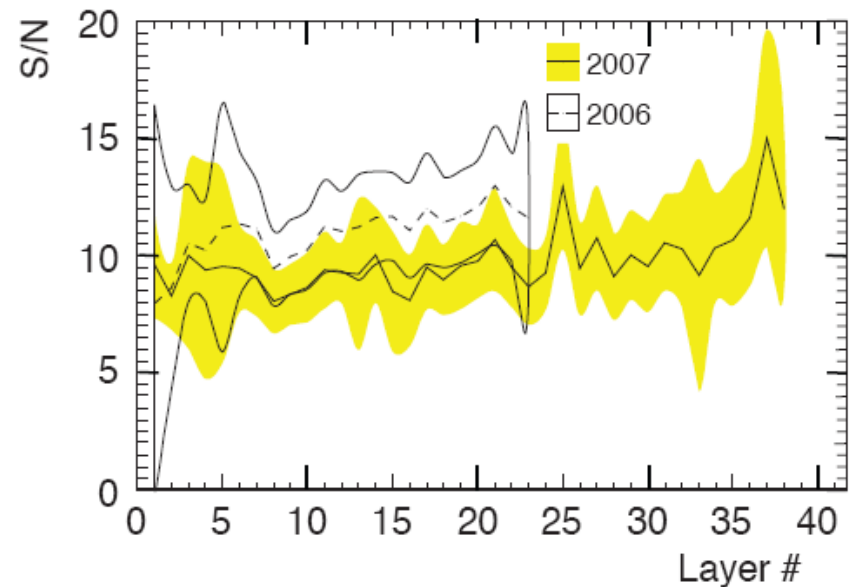
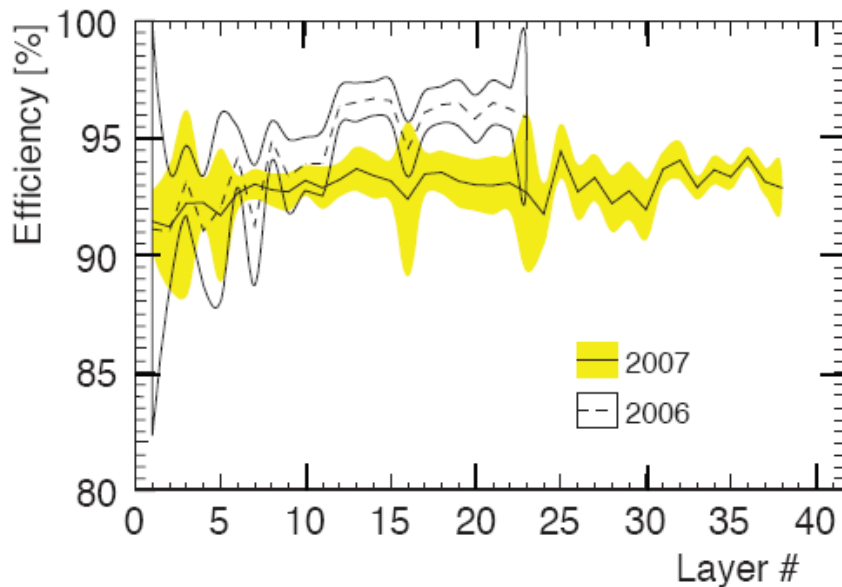
Luminosity requirement for in-situ calibration with MIP stubs from jets (ILC detector)

	Luminosity at 91 GeV	Luminosity at 500 GeV
layer-module to 3% to layer 20	1 pb ⁻¹	1.8 fb ⁻¹
layer-module to 3% to layer 48	10 pb ⁻¹	20 fb ⁻¹
HBU to 3% to layer 20	20 pb ⁻¹	36 fb ⁻¹

more statistics obtained from $Z_0 \rightarrow \mu\mu$ events

MIP calibration

- Calibration obtained at CERN with ~ 2 M muon events (80 GeV)
- broad muon beam covering the whole 1×1 m² calorimeter face
 - minimum 500 events required for a good fit ($G \otimes L$) in one cell



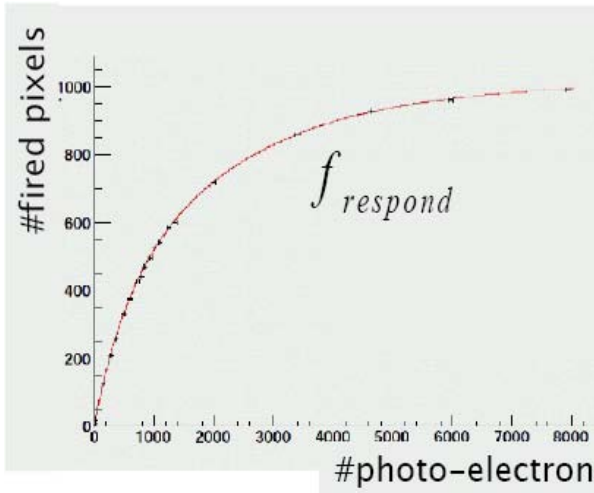
➤ MIP detection efficiency above
0.5*MIP threshold $\sim 93\%$

➤ Signal to noise ratio ~ 10

➤ MIP error uncertainty (coming mainly from fits) is 2% of energy scale

Importance of monitoring/calibration

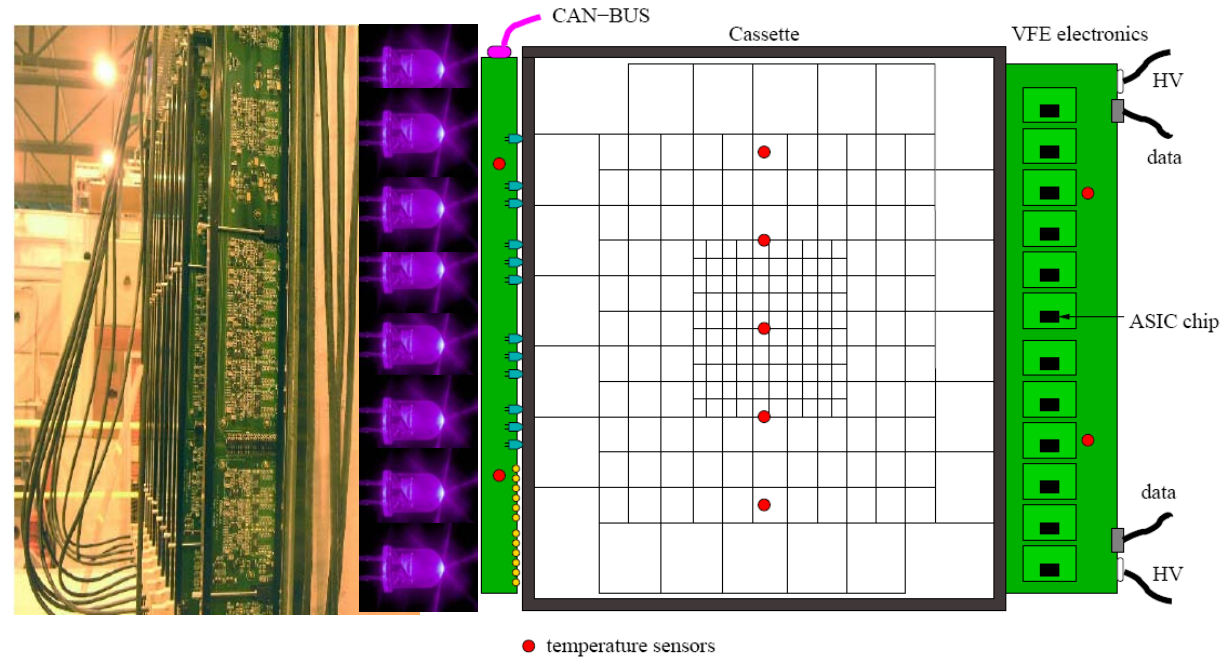
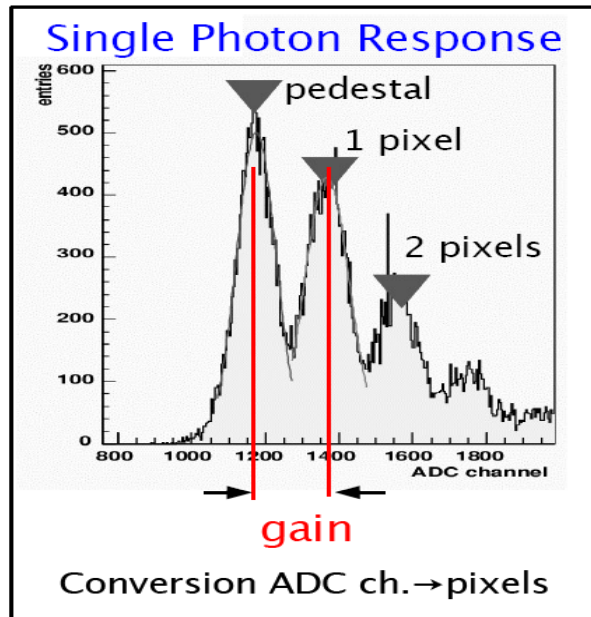
SiPM response is non-linear



Redundant calibration system delivers:

- Low intensity light for SiPM Gain calibration
- High intensity of light for saturation monitoring
- Medium intensity light for electronics intercalibration

AHCAL layer (1CMB=12LEDs) = 216 tiles



- *Light intensity for 7608 channels within factor 2*
- *> 94% calibration efficiency on full calorimeter*

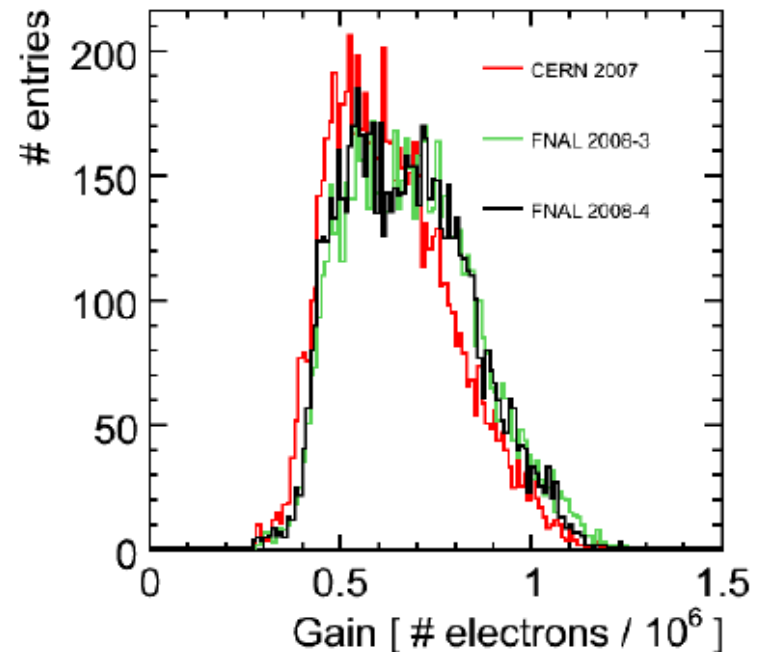
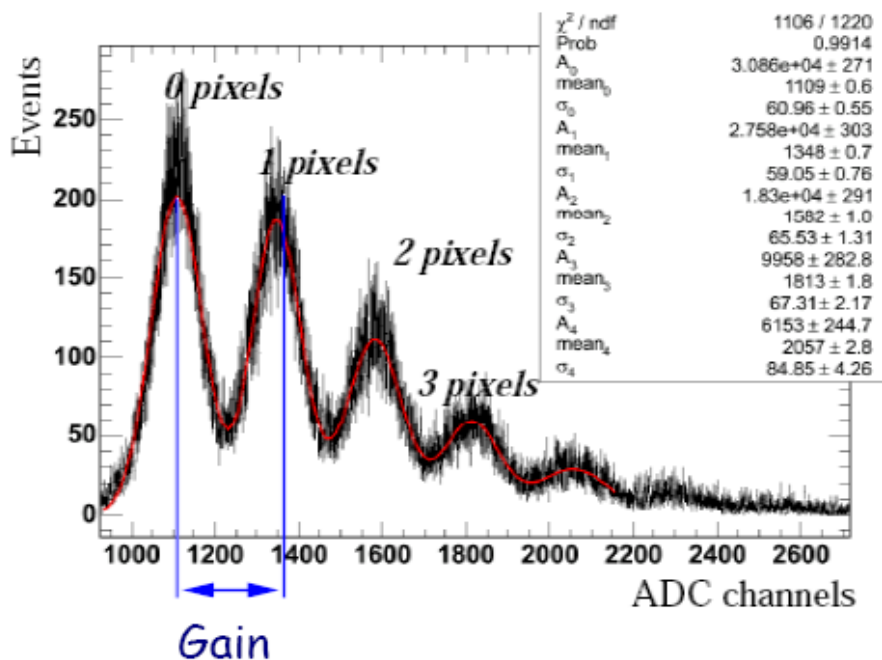
SiPM gain calibration

- Gain extracted from a multi-Gaussian fit to LED calibration data
- ~15 min data taking necessary for one gain scan
- Repeated ~every 6-8h during data taking

Efficiency (#ch. calibrated):

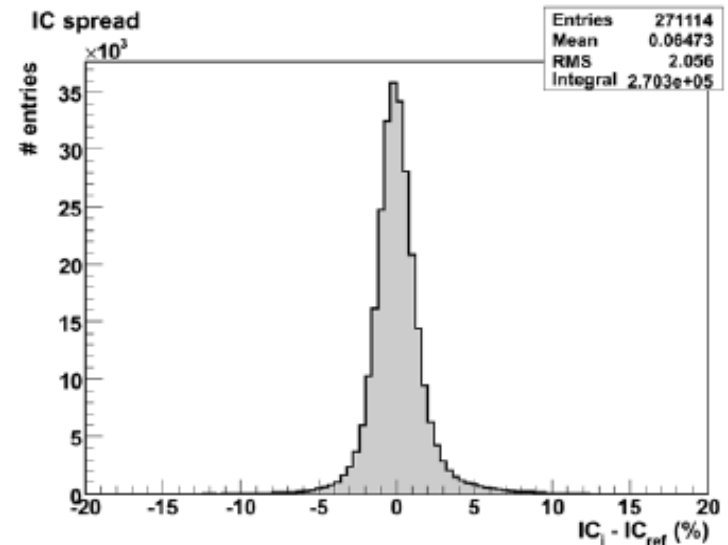
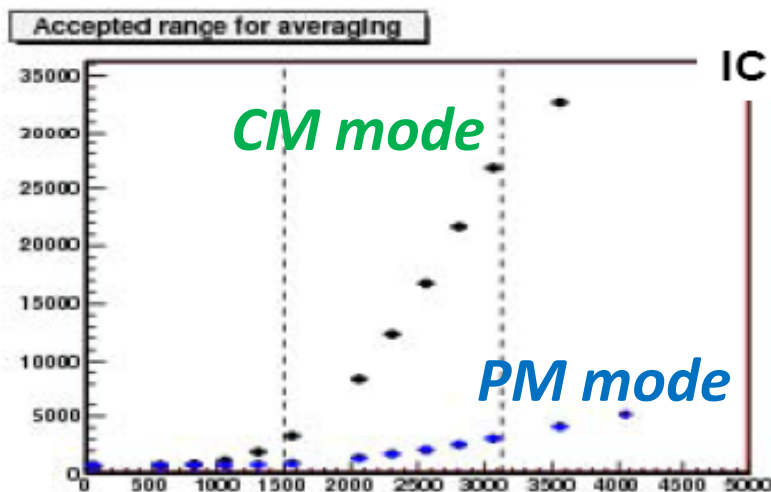
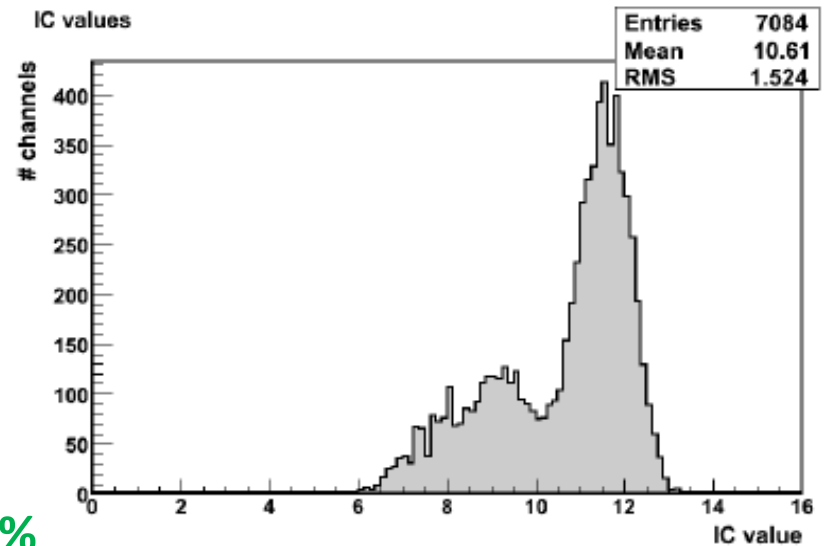
CERN 96%, FNAL 97% → Mainly quality of LED system

➤ Uncertainty on Gain determination (mainly due to fit) is ~2% for good cells

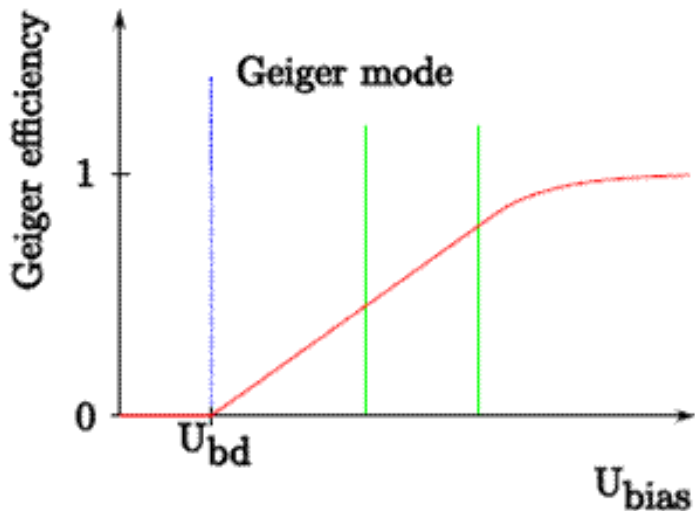
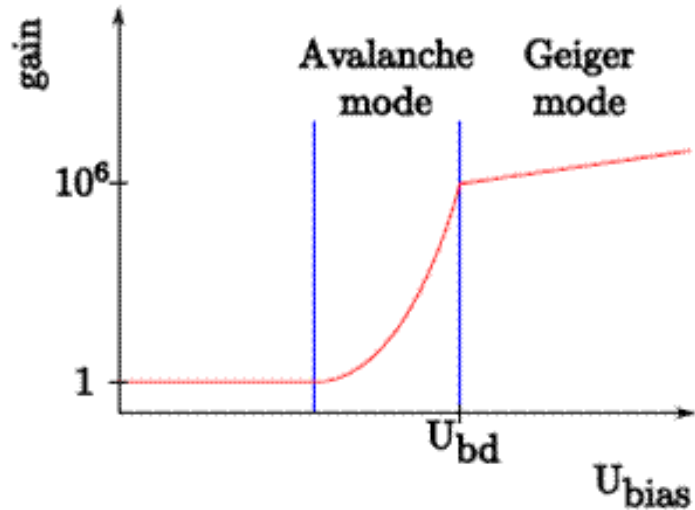


ASIC mode inter-calibration

- values for 94% of all channels
- $\approx 4\%$ of channels failed due to problems with the CMB hardware
- $\approx 2\%$ dead channels
- method efficiency near 100%
- stability: 2% RMS over data taking period
➔ reduced to $<0.5\%$ in later analysis
- IC coefficient uncertainty is better than 1 %



Temperature and voltage dependence



- SiPMs (operated in Geiger mode):

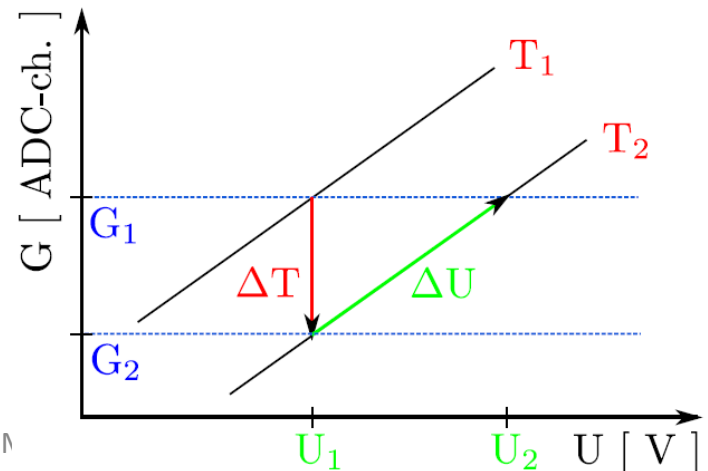
Gain G , Geiger efficiency ε

- $G, \varepsilon \propto (U_{bias} - U_{bd})$ $O(2\%/100\text{mV})$
- $U_{bd} \rightarrow T \propto G, \varepsilon \propto (-T)$ $-1.7\%/K$
- **Muons response $A_{MIP} \propto \varepsilon \times G$** $-3.7\%/K$

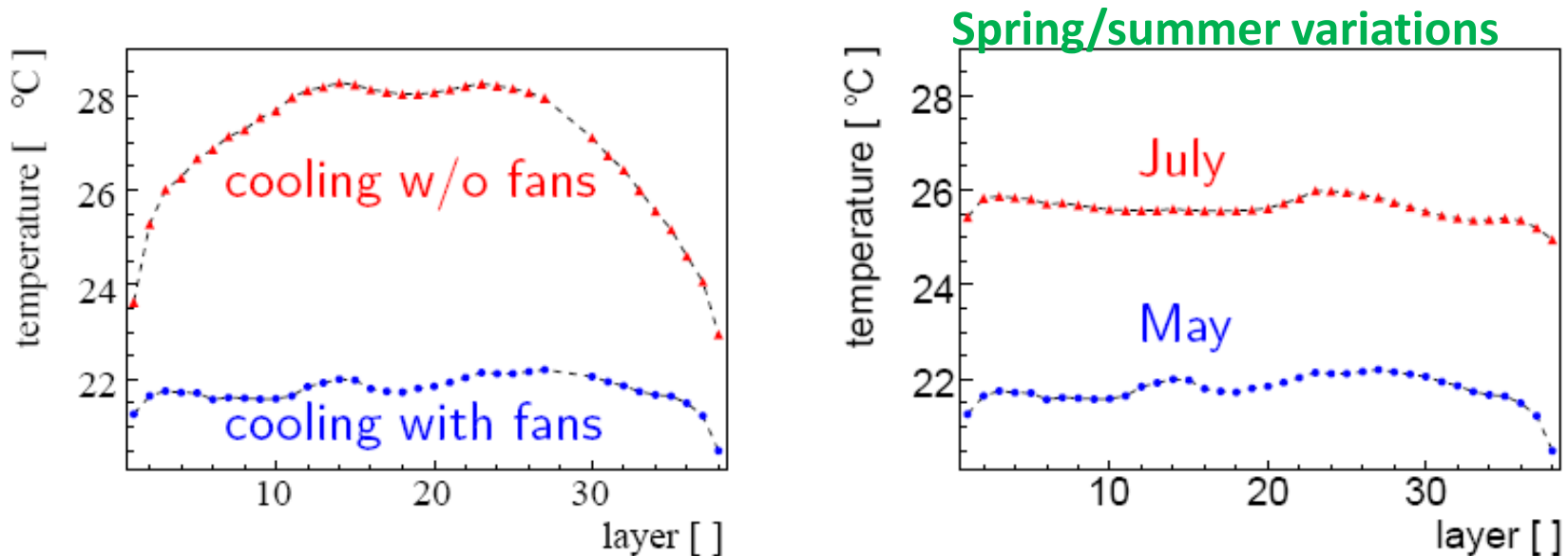
➤ Compensation of Temperature Changes (HV Adjustment)

compensate the effect of T increase (increase of U_{bd}) by increasing the bias voltage (increase of ΔU)

➔ Price to pay: increase of noise above threshold (for fix threshold)



Temperature variations at TB



- gradient along the calorimeter length
- gradient across a module (<0.5 deg)

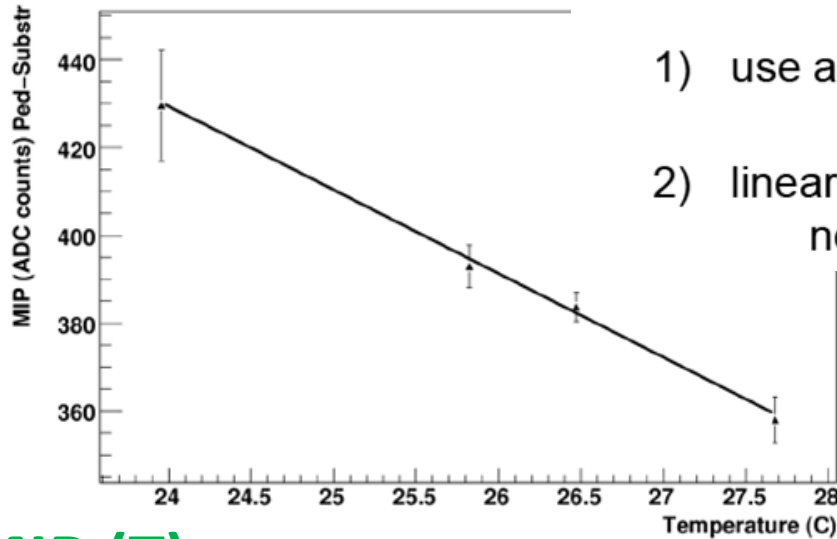
Important point for a ILC detector:

- cell equalization (with muon) **cannot be** repeated in situ
- test beam calibration **can be** ported to the ILC detector
- what about correction of long term T fluctuation (if any)?

MIP & Gain T&V dependence

Different methods to determine dA^{MIP} / dT :

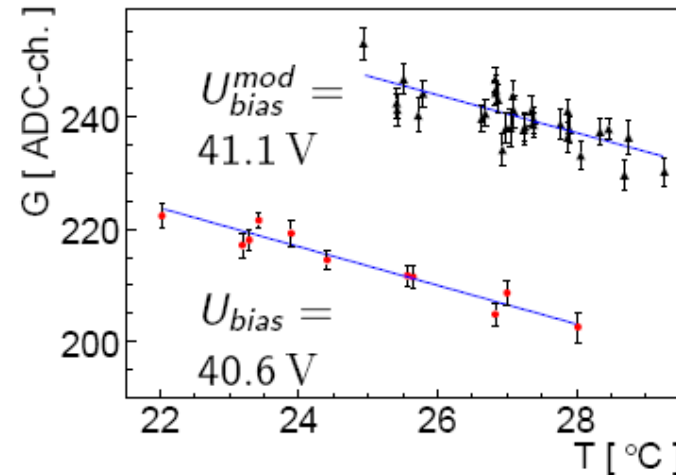
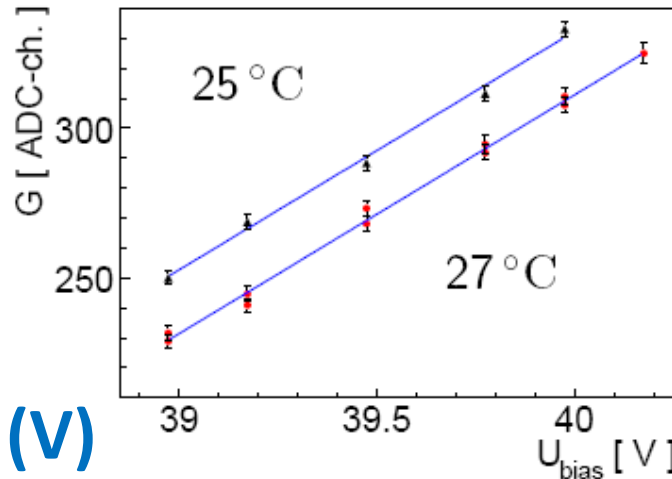
- 1) use average $1 / A^{MIP} dA^{MIP} / dT = -3.8 \text{ \%}/K$ (at $27 \text{ }^{\circ}C$)
- 2) linear fit for each channel (χ^2 approach):
need set of mip runs for each point, only few points



➤ $1/G dG/U = 2\%/100mV$

➤ $1/G dG/dT = -1.7\%/K$

MIP (T)



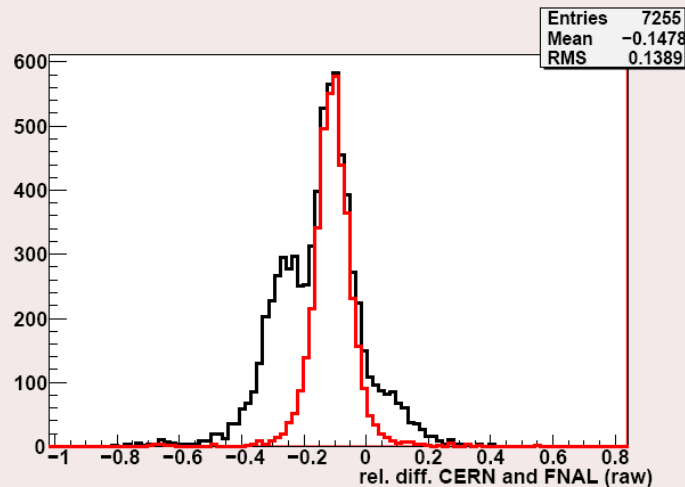
Gain (T)

Correction to MLP calibration set

- Comparison between **T/U calibrated** FNAL and reference CERN sample

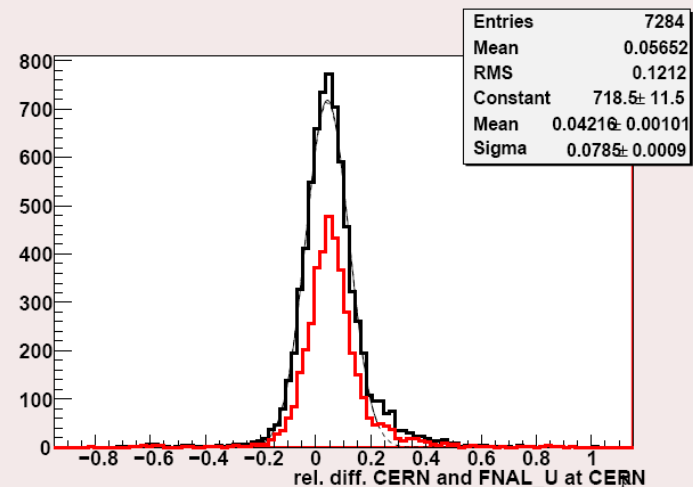
Before T/U correction:

- Black: before transport
- Red: $U_{\text{CERN}} = U_{\text{FNAL}}$



After T/U correction:

- Black: after transport
- Red: $U_{\text{CERN}} = U_{\text{FNAL}}$



- Remaining 4% **offset** consistent with different muon beam energies (32 GeV at FNAL, 80 GeV at CERN)
- Results: shift = 4.2% , spread = 7.8%

Saturation curves

❑ Saturation curves for single SiPM should be universal...

BUT:

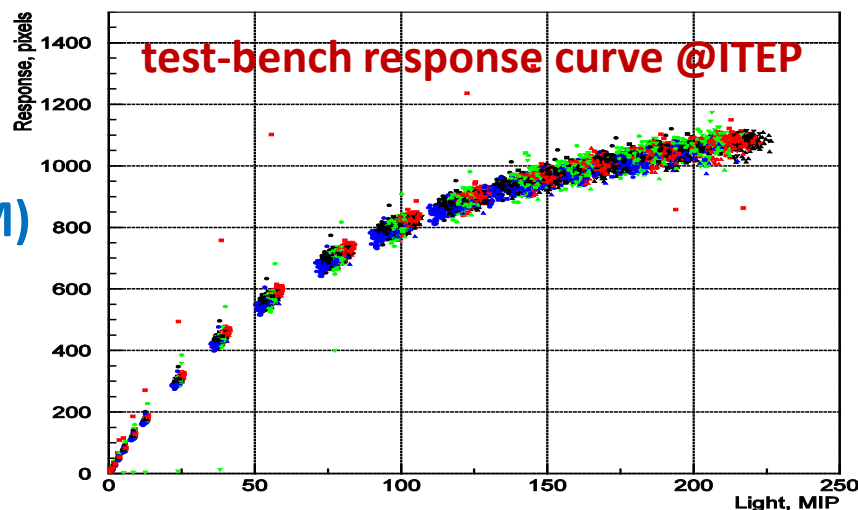
❑ Disagreement between ITEP (bare SiPM) and in-situ (on-tile) measurement

- Not all pixels illuminated by WLS light!
- Ratio of geometrical area it is expected that only 78.5 % of the SiPM area (square) is illuminated by the WLF fiber
- different number of dead pixels in each SiPM could change this number

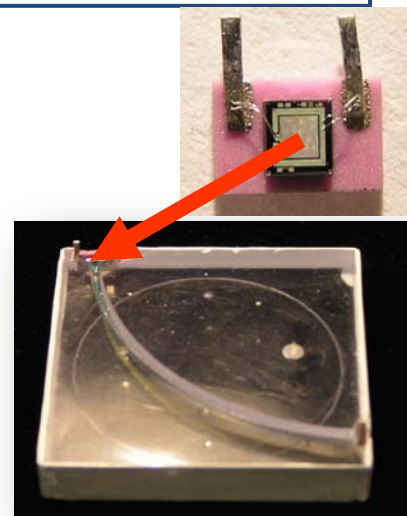
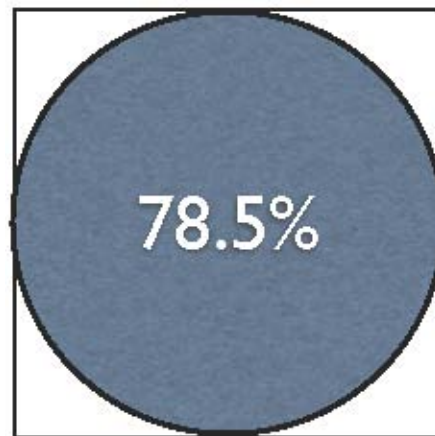
→ **determination saturation factor for each channel separately**

- *extract saturation factor for all channels*
- *apply calibration to pixels & temp corrections*
- *averaged over all runs → consistent results?*

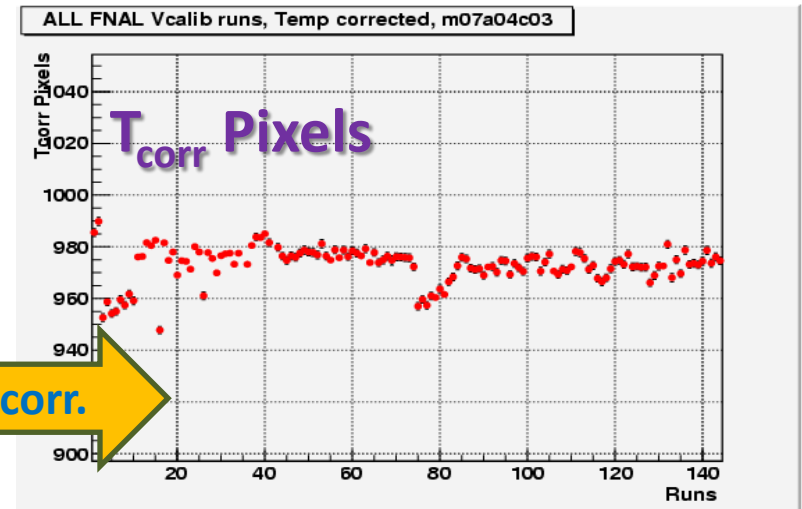
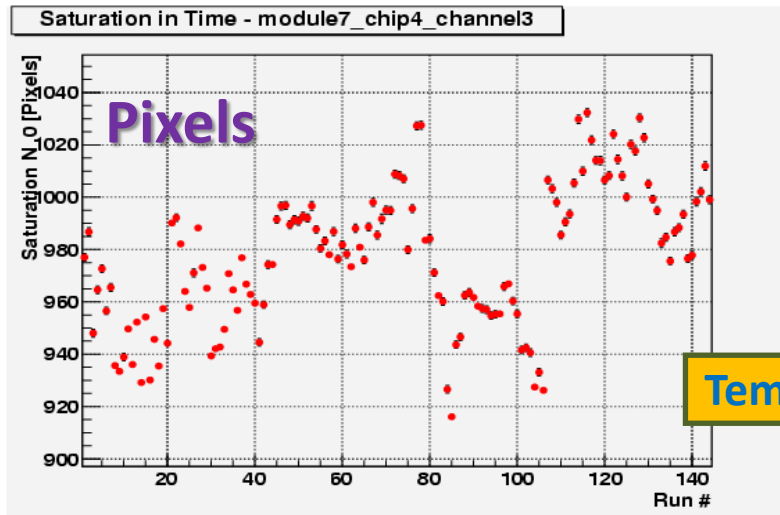
Total number of pixels in a SiPM = 1156



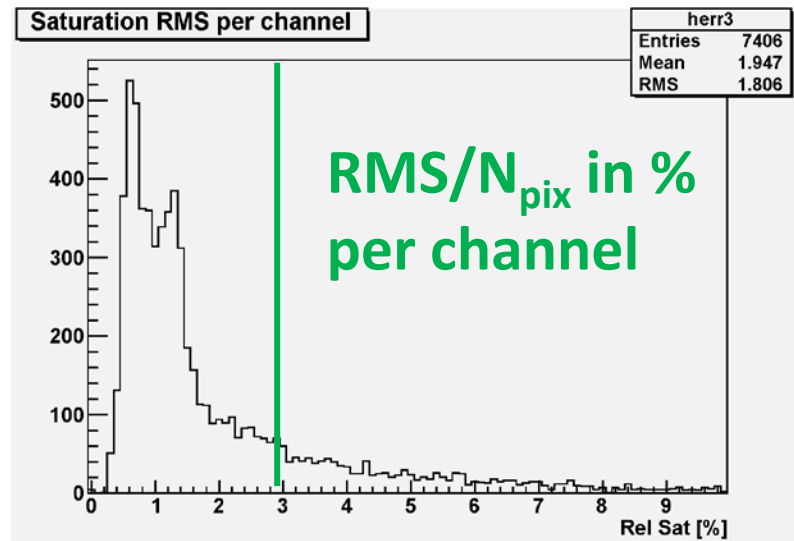
$$A_{pix} = N_{tot} \left[1 - \exp(-A_{ph.e.} / N_{tot}) \right]$$



Saturation: temperature correction

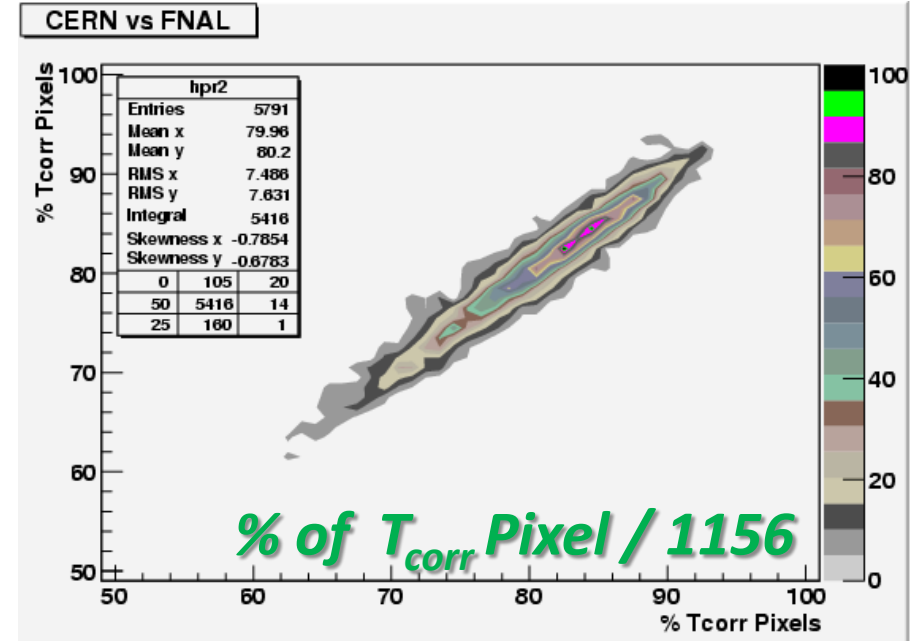
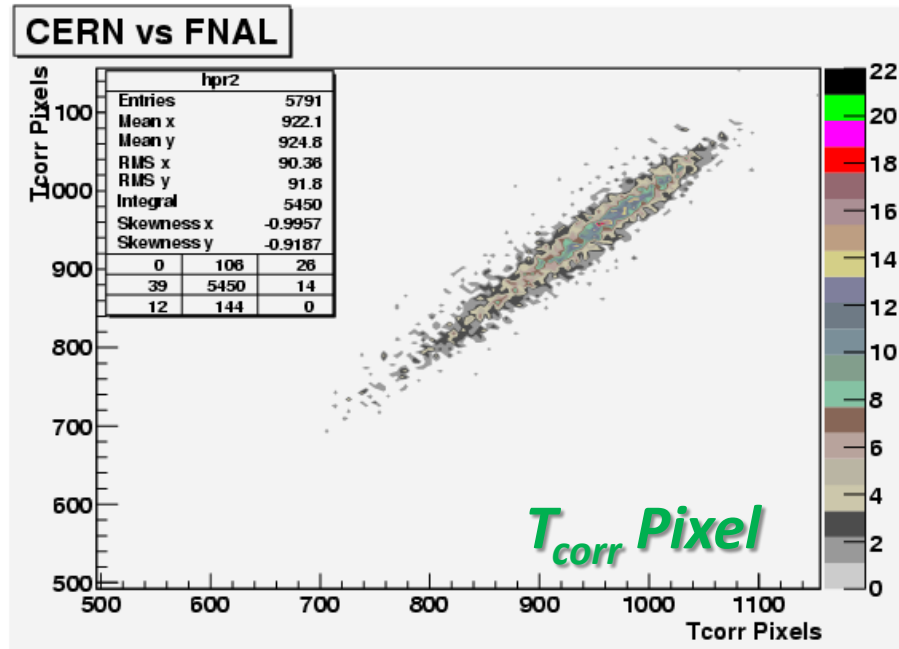


Temperature corr.



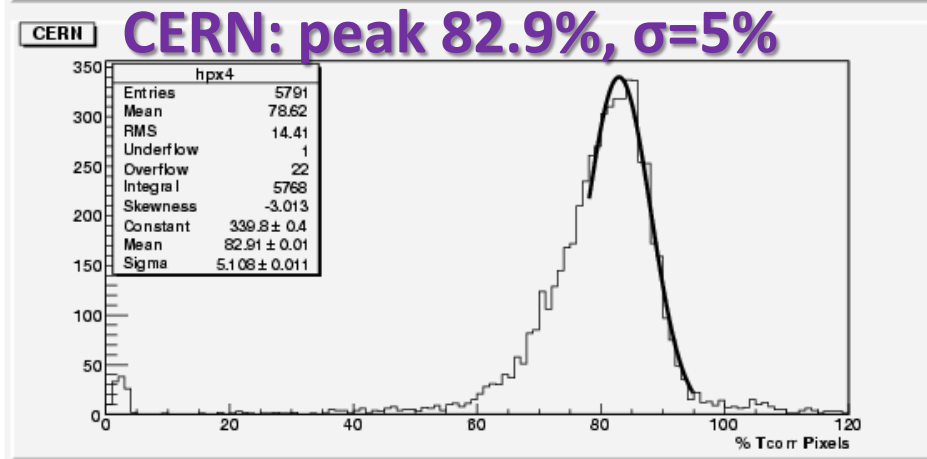
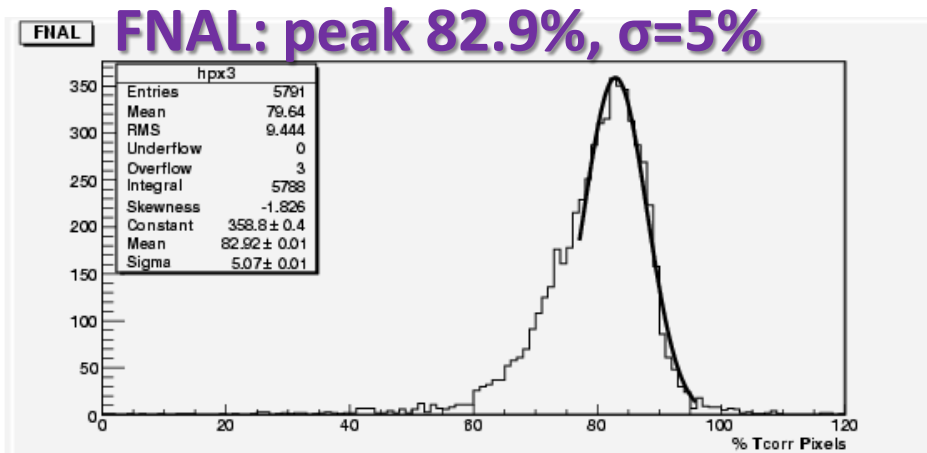
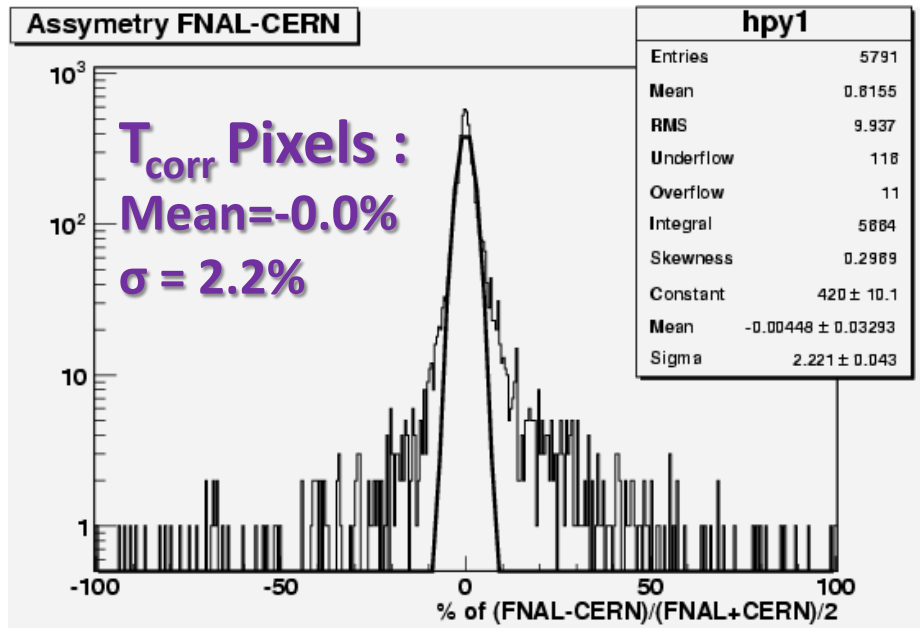
- Temperature correction works well
- Efficiency 97% in TB data period
- 75% (5524 of 7406) channels vary by less 3% of RMS over all data taking time

Saturation: FNAL versus CERN



- Good correlation between saturation point extracted from CERN and FNAL data
- Both data sets shows average effective number of pixels at a level of 80% of phys. number (w/ RMS ~ 7%)
- Distribution (lab vs in-situ) N_{mount}/N_{bare} gives 80.5%, with RMS 9%

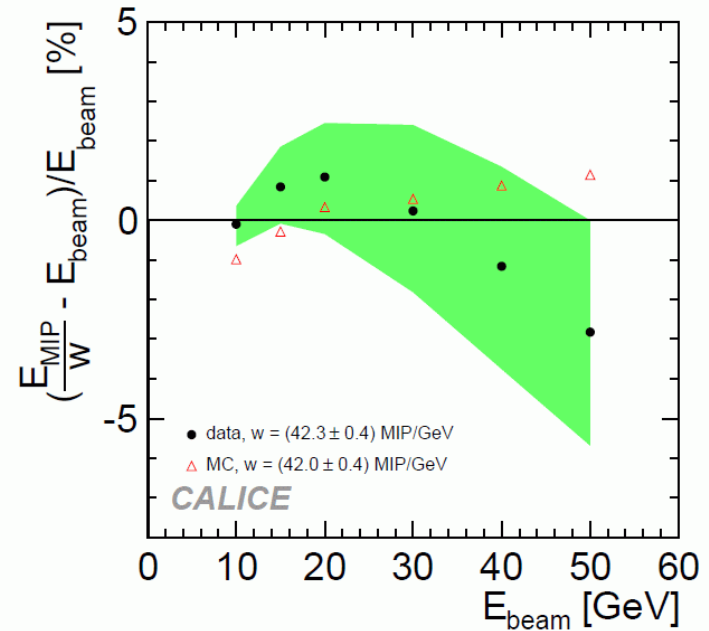
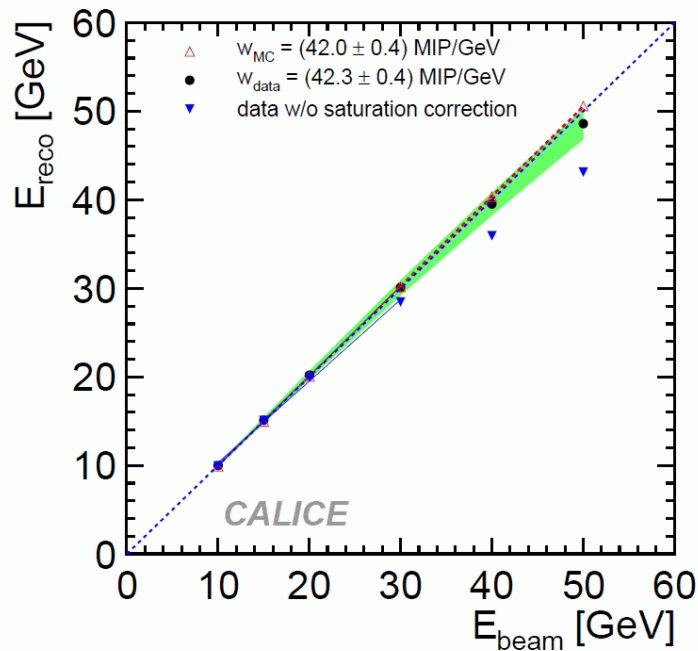
FNAL-CERN Asymmetry



~10% outside 3σ -range

- Temperature correction cancels the difference in mean.
- The signal does not degrade (small error of T correction factor)
- But still long tails with wrong fit either at CERN or FNAL or both.

Current status of calibration



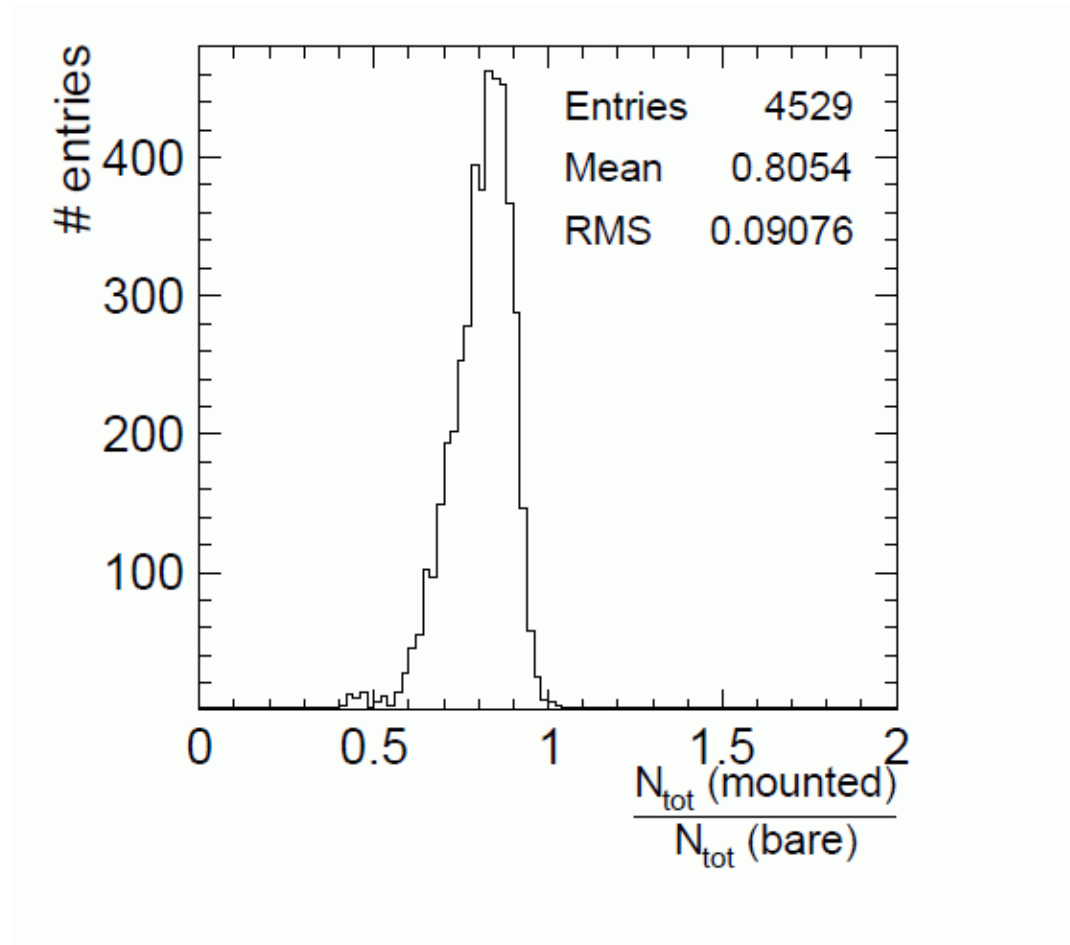
- Green band indicates variations of the fit result due to calibration uncertainties on both the Gain and saturation scales.
- Non-linearity $\sim 3\%$ @ 50 GeV
- Remaining non-linearity for $> 40\text{GeV}$ electron shower *still under investigation*
- In hadronic showers smaller energy density (at the same particle E)
→ *non-linearity effects are less relevant for hadrons*

Conclusion

- We have operated a calorimeter with ~ 7600 cells read out by SiPM during 4 years test beam campaigns (next one 'W' in progress)
- The equalization of the cell response is done at the MIP scale
 - light yield ~ 13 pixels / mip, $S/N \sim 10$
- SiPM response measured for each device:
 - Lower saturation point measured after mounting SiPM on tile
 - Both data sets FNAL & CERN give consistent results:
 $\sim 83\%$ of pixels illuminated by WLS fiber light
- Transportation of the calibration due to changing temperature and voltage works well and can be used for whole detector
- Calibration procedure validated with EM data

Backup

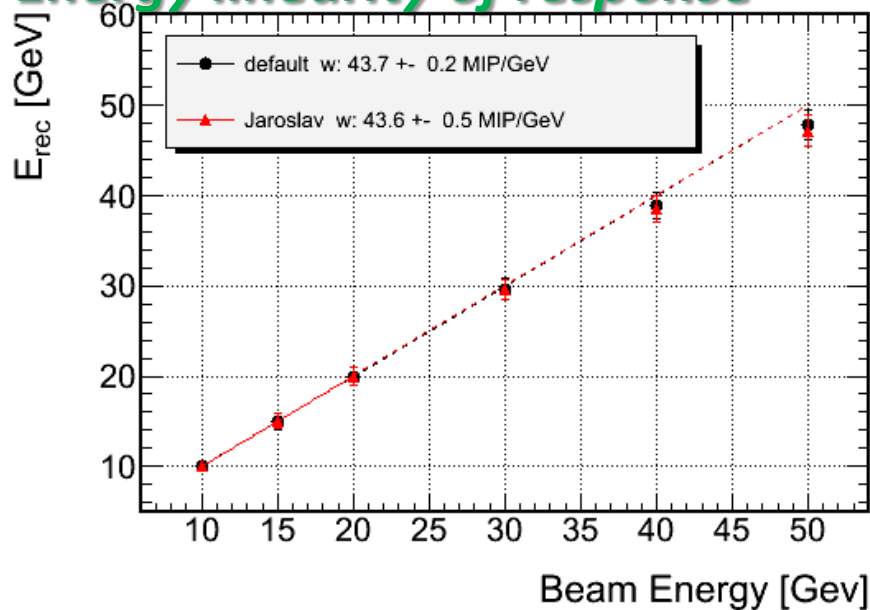
Saturation: mounted/bare



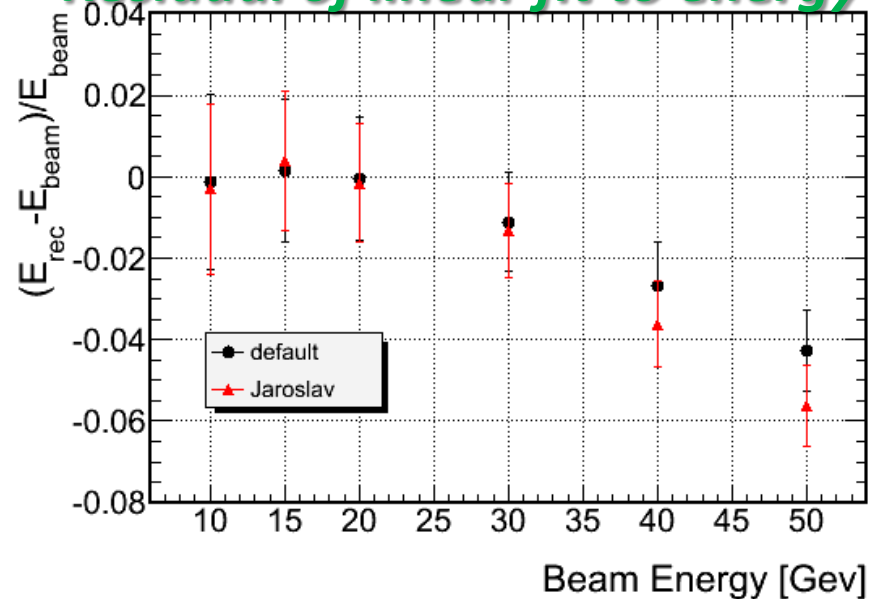
Effect of channel-by-channel corrections on EM analysis

global rescaling factor **X** single cell saturation

Energy linearity of response

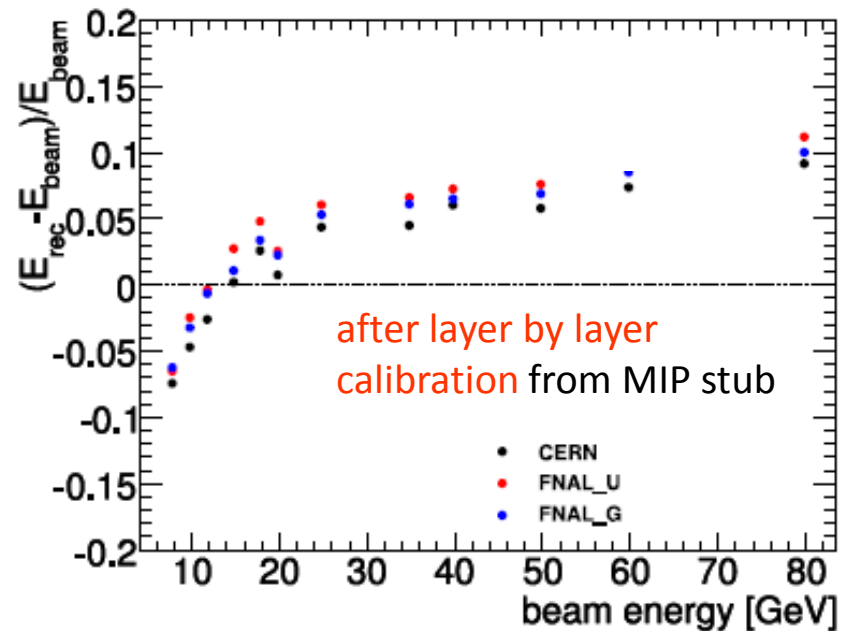
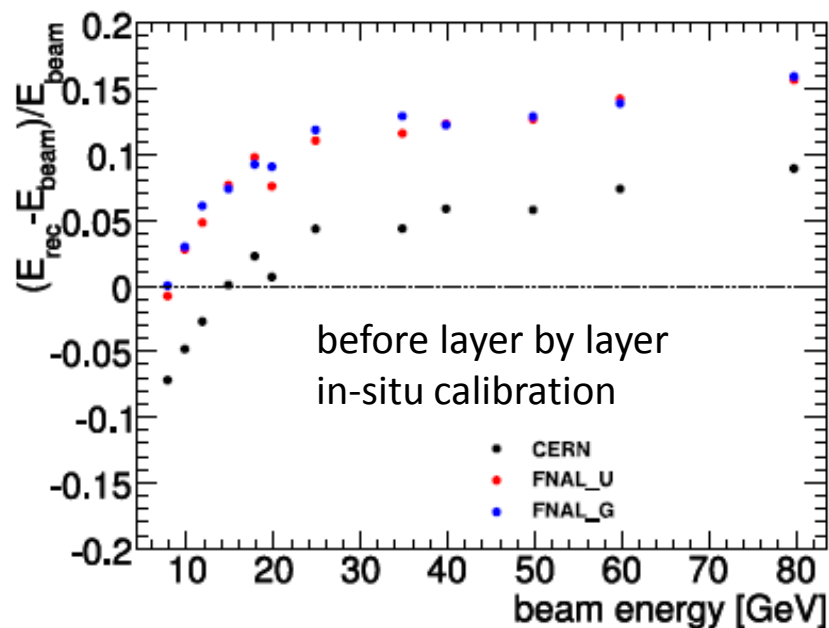


Residual of linear fit to energy



- single-cell calibration does not improve the linearity w.r.t. a common rescaling factor
- ➔ simplifies calibration chain of high-multi channel calor.

Impact on hadron analysis



~5% shift between CERN reference and transported samples

➔ Corrected by the in-situ layer-by-layer calibration using MIP stubs from pion showers

➔ After transport of calibration consistent results within analysis uncertainties