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 → MIPs → scintillator → photons (UV) → SiPM (non-linear) → photo-electrons → amplification → electronics

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

Calibration:

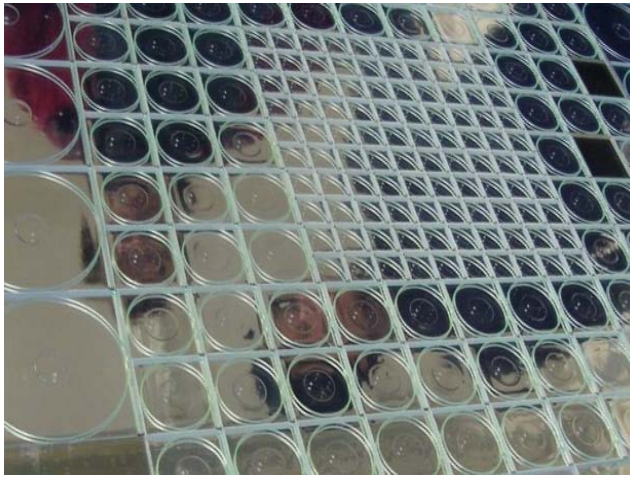
convert detector signal into number of MIPs deposited by particle traversing the tile & correct for non linear response of SiPM & scale vis. MIP to tot. dep. energy in GeV

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

What do we need:

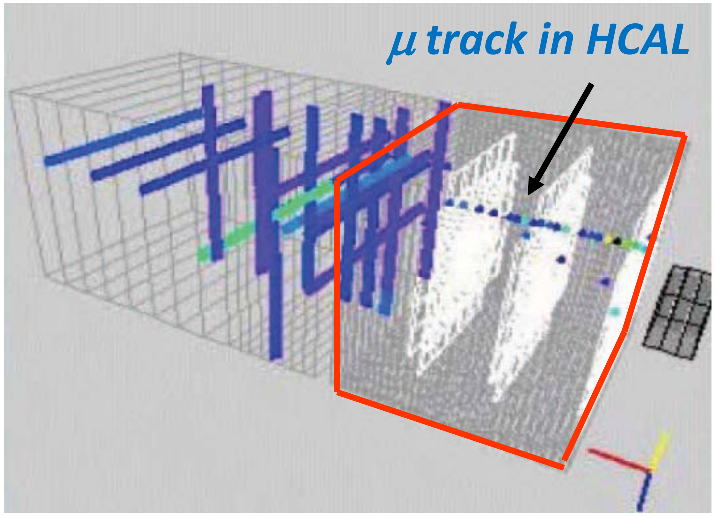
Lightyield in [pix/MIP]:

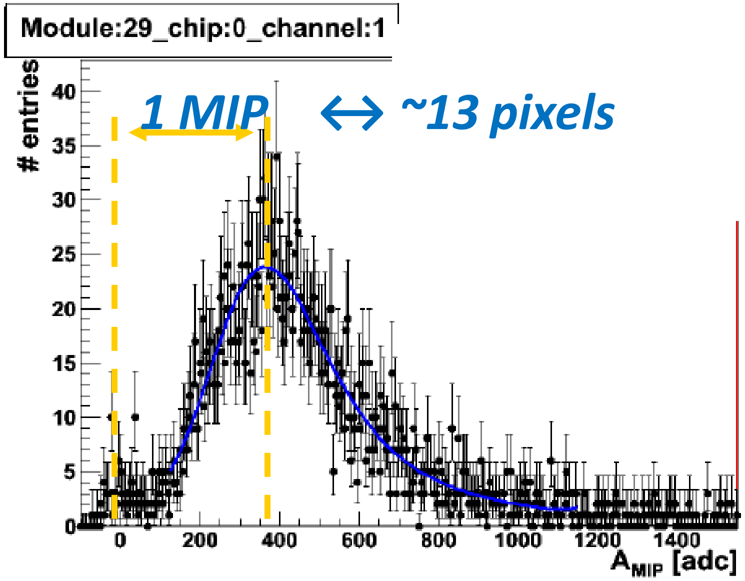
- **MIP amplitude** in ADC bins ... C_i^{MIP}
- **SiPM gain**: (CalibMode) ADC bins converts to pixel ... G_{pix}
- **Electronics Intercalibration**: between PM/CM mode ... I_C
- **SiPM response function:** corrects the non-linear response of the SiPM ... $f_{sat}(A_i[pix])$



Cell response equalization with MIP

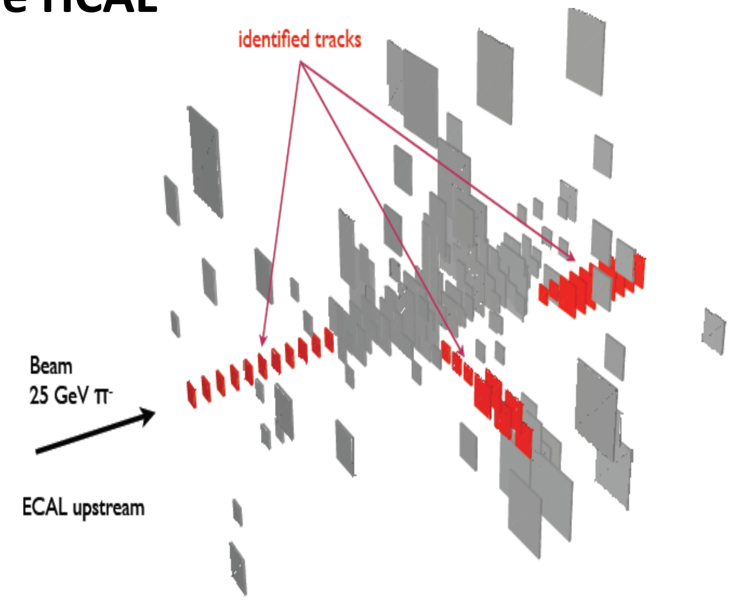
Using muon signal





Using pion shower

select MIP stubs using the high granularity of the HCAL



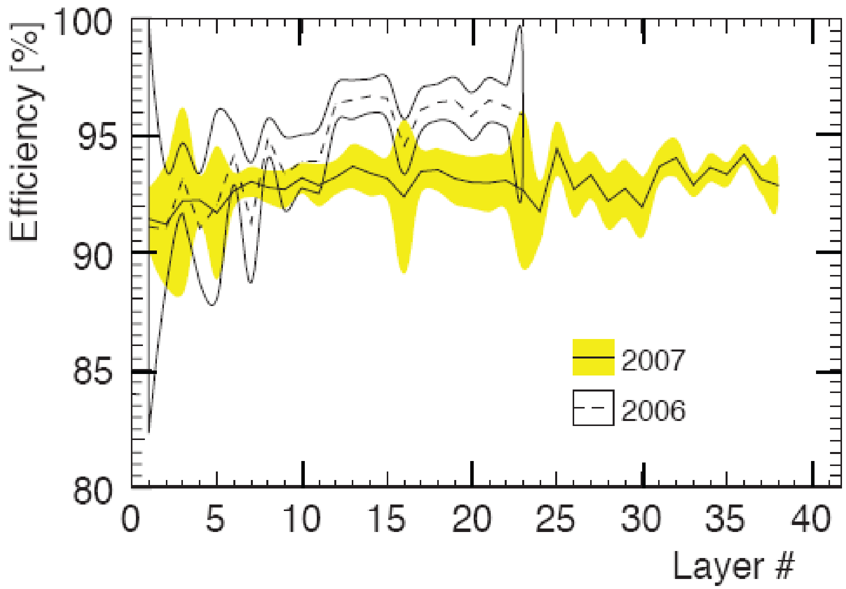
Luminosity requirement for in-situ calibration with MIP stabs from jets (ILC detector)

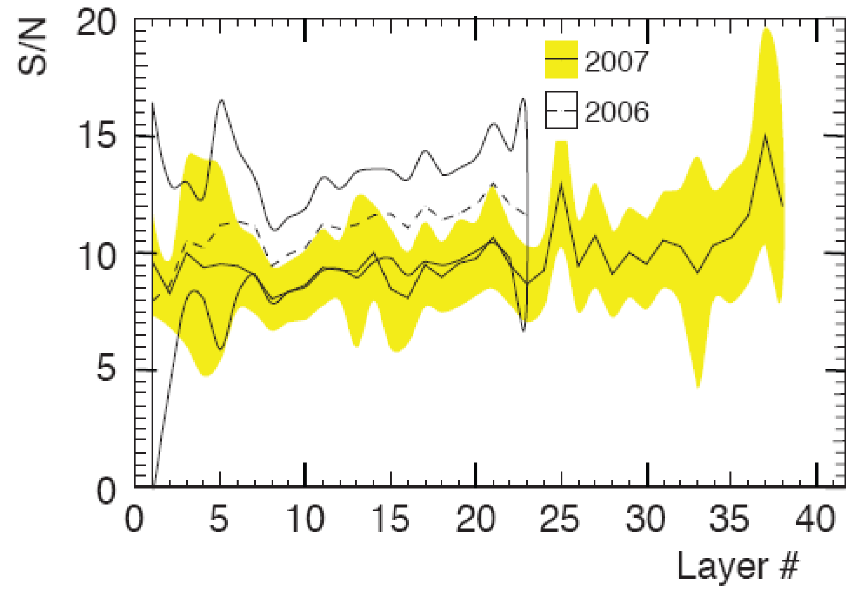
	Luminosity at 91 GeV	Luminosity at 500 GeV
layer-module to 3% to layer 20	1 pb^{-1}	1.8 fb^{-1}
layer-module to 3% to layer 48	10 pb^{-1}	20 fb^{-1}
HBU to 3% to layer 20	20 pb^{-1}	36 fb^{-1}

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 1x1 m^2 calorimeter face
- minimum 500 events required for a good fit (G ⊗ L) in one cell

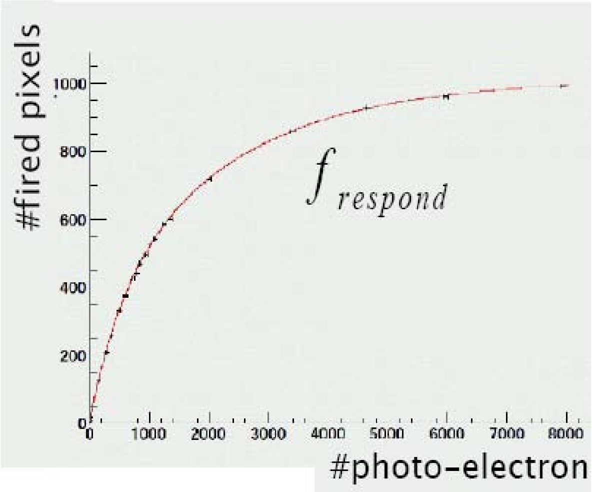


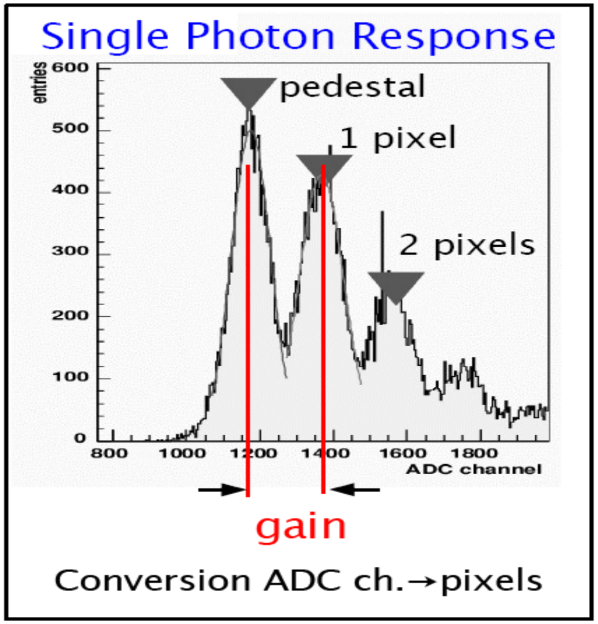


- **MIP detection efficiency above 0.5*MIP threshold ~ 93%**
- **Signal to noise ratio ~ 10**
- **MIP error uncertainty (coming mainly from fits) is 2% of energy scale**

Importance of monitoring/calibration

SiPM response is non-linear

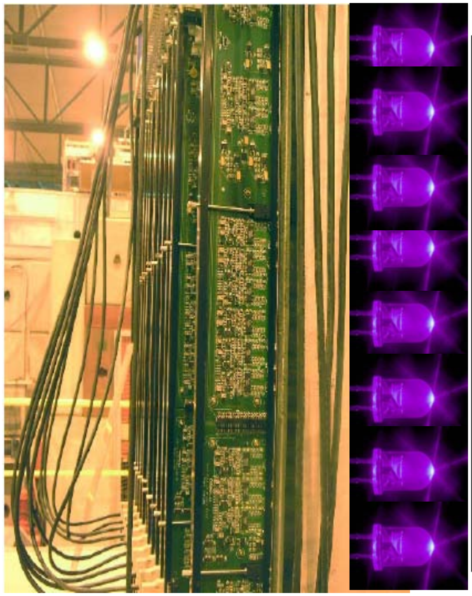


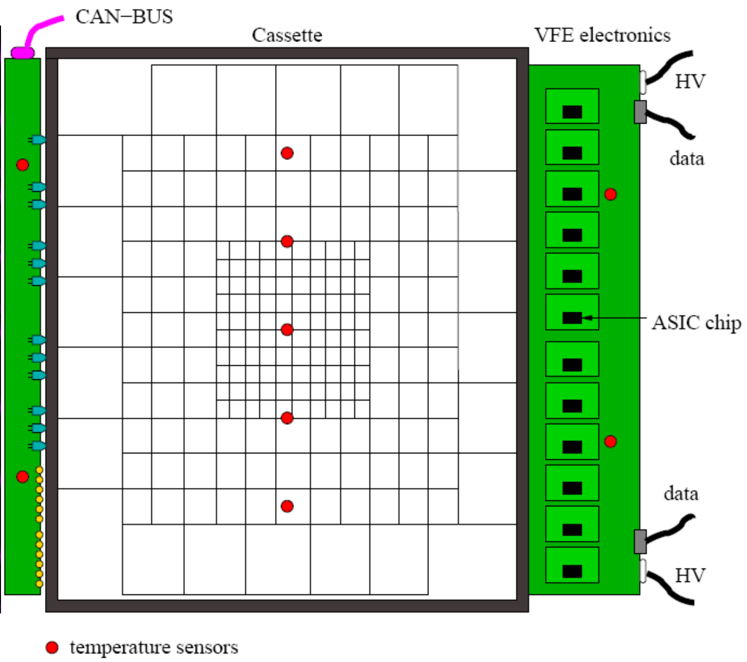


Redundant calibration system delivers:

- **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

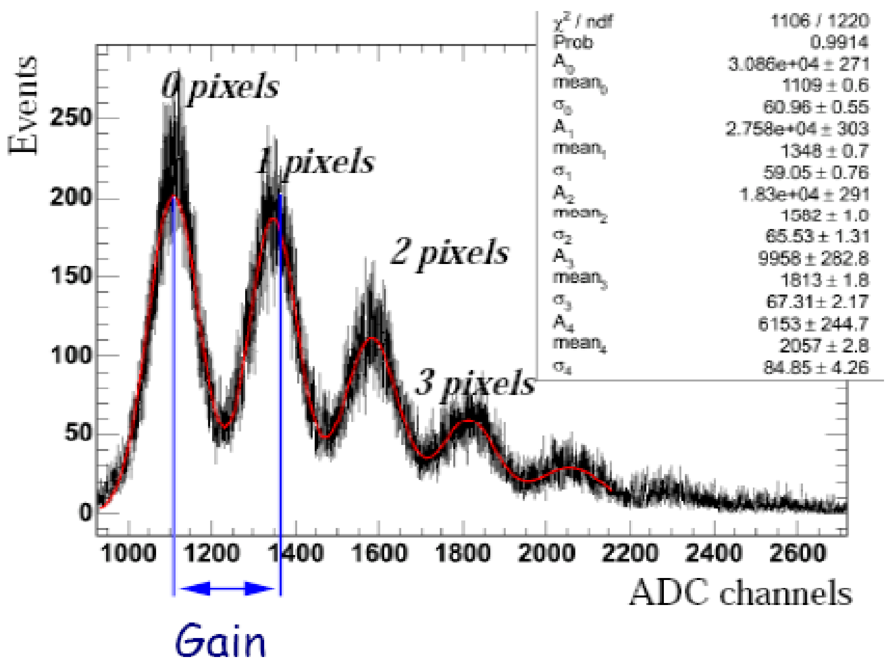
~15 min data taking necessary for one gain scan

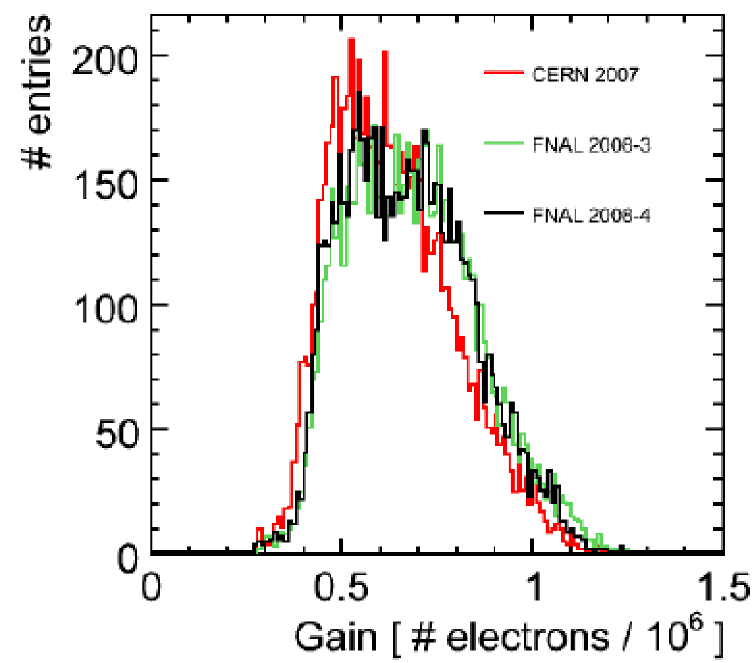
- Repeated ~every 6-8h during data taking

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**





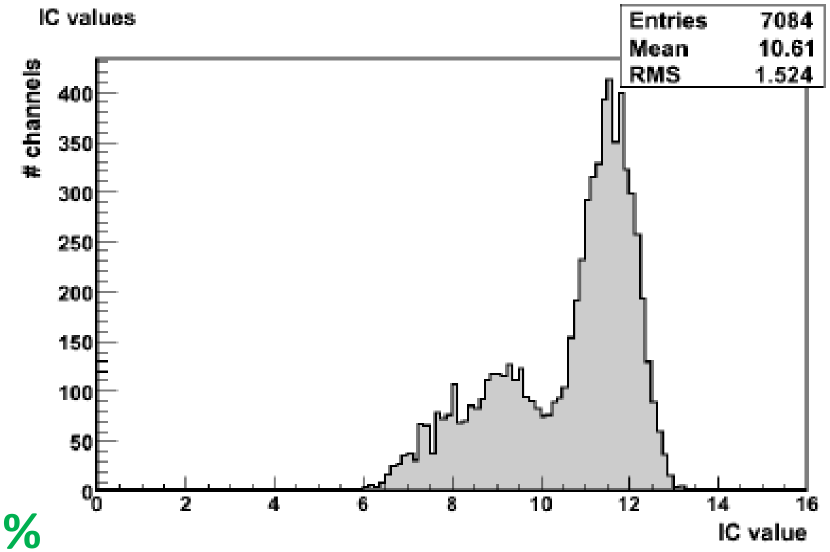
ASIC mode inter-calibration

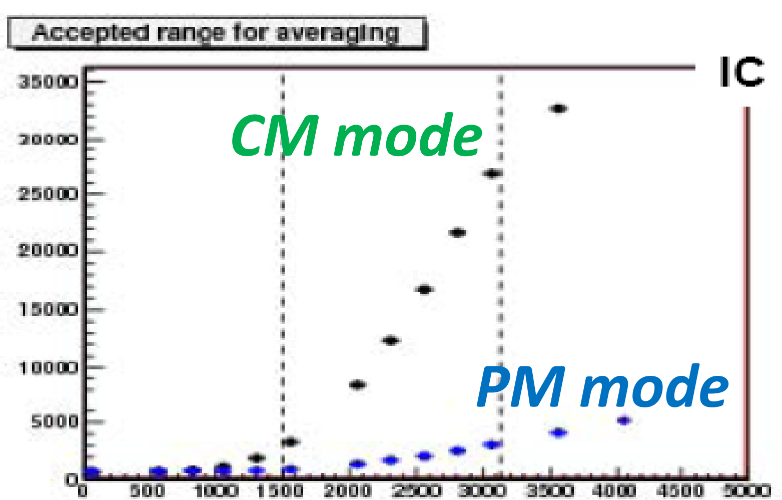
- values for 94% of all channels
- ≈ 4% of channels failed due to problems with the CMB hardware
- ≈ 2% dead channels
- method efficiency near 100%

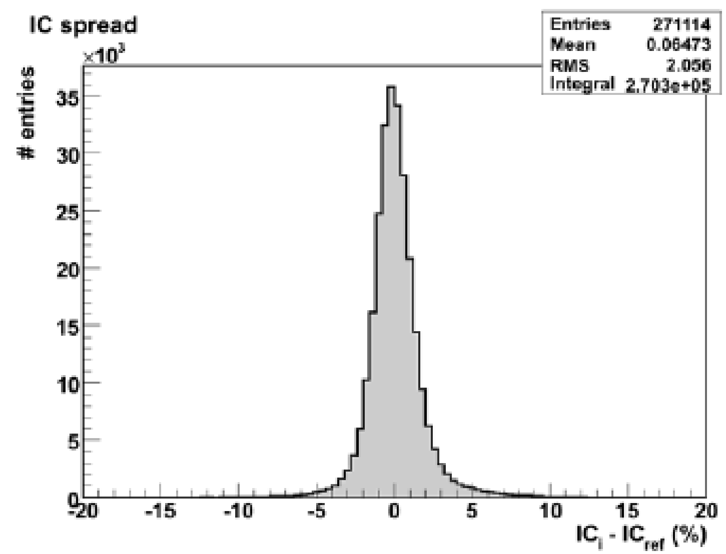
- stability: 2% RMS over data taking period

➔ reduced to <0.5 % in later analysis

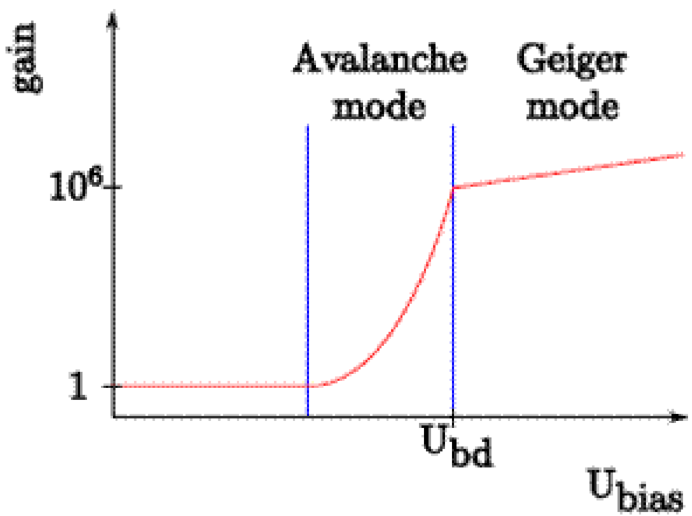
➢ IC coefficient uncertainty is better than 1 %

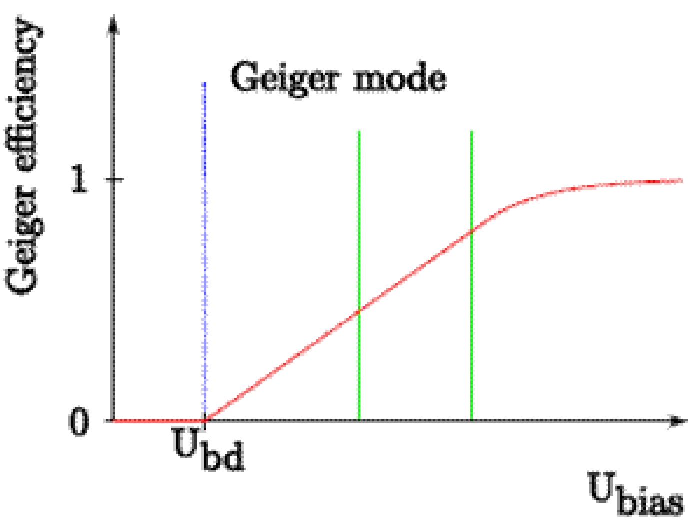






Temperature and voltage dependence

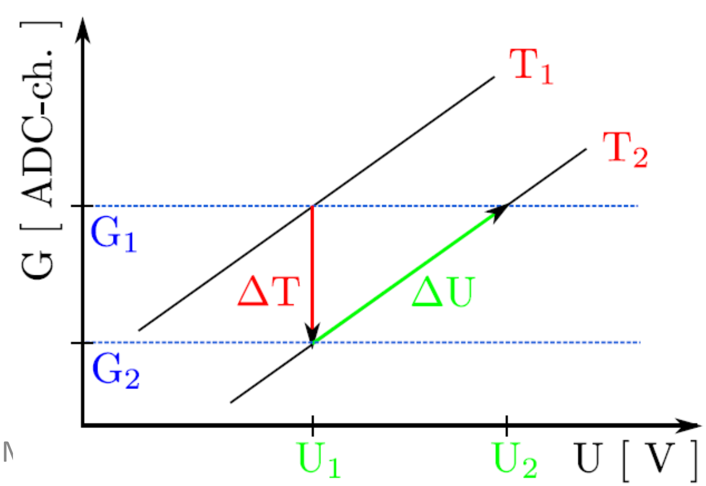




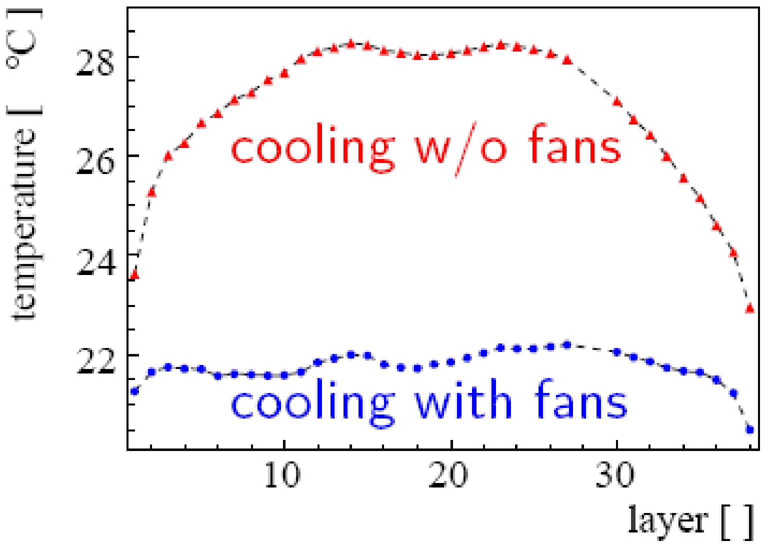
- **SiPMs (operated in Geiger mode):** **Gain *G*, Geiger efficiency *ε***
- ***G, ε ∝ (U*** $_{bias}$ ***– U*** $_{bd}$ ***)*** O(2%/100mV)
- ***U*** $_{bd}$ ***→ T ∝ G, ε ∝ (-T)*** -1.7%/K
- ***Muons response A*** $_{MIP}$ ***∝ ε × G)*** -3.7%/K

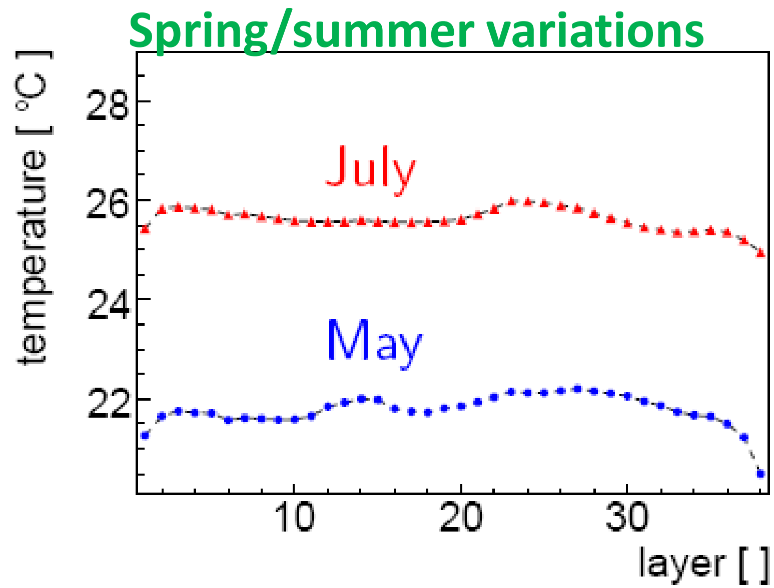
➢ **Compensation of Temperature Changes (HV Adjustment)**

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:

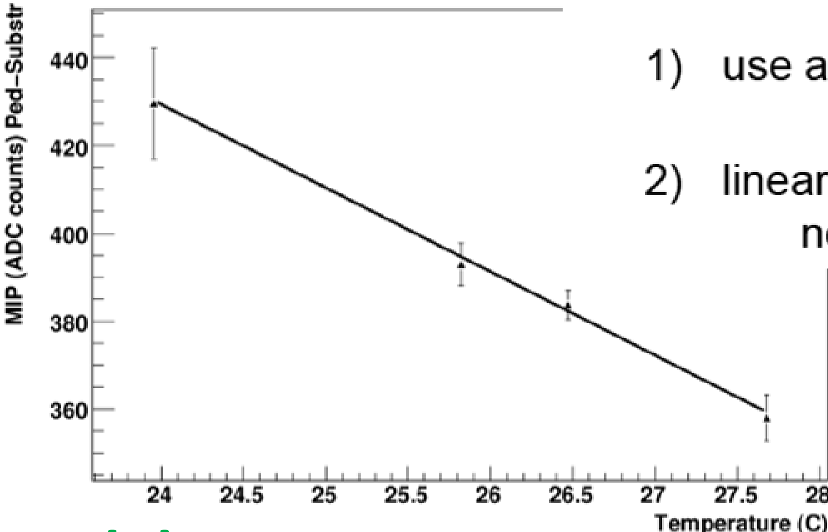
- **cell equalization (with muon) cannot be repeated in situ**
- **test beam calibration can be ported to the ILC detector**
- **what about correction of long term T fluctuation (if any)?**

MIP &Gain T&V dependence

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

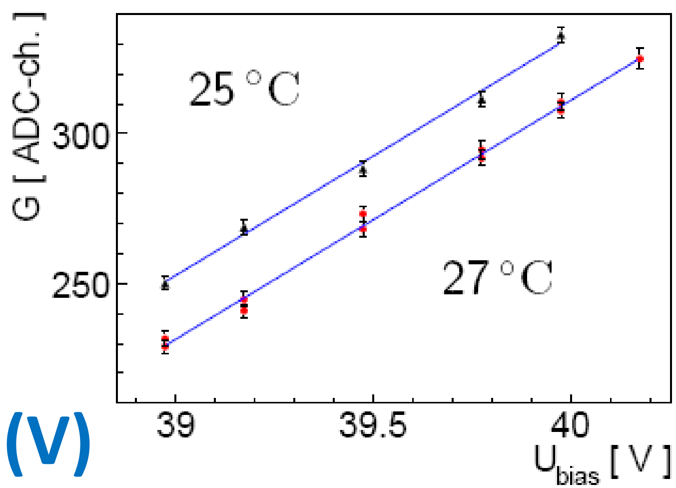
1) use average $1 / A^{MIP} \; dA^{MIP} / dT$ = -3.8 %/K (at 27 °C)

2) linear fit for each channel (χ^2 approach):
   need set of mip runs for each point, only few points

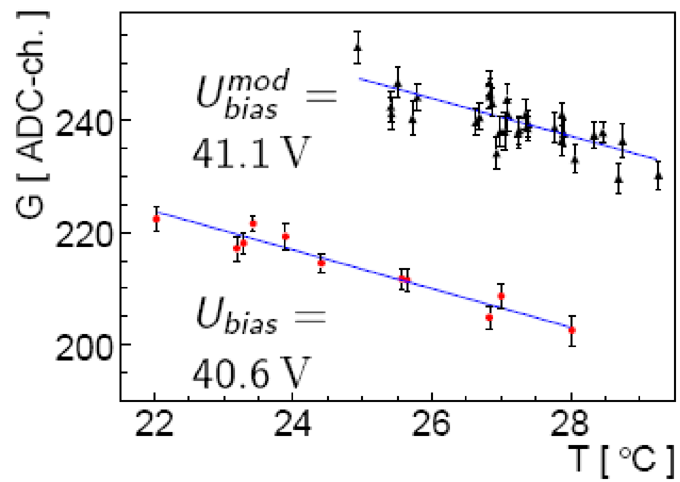


MIP (T)

- **1/G dG/U = 2%/100mV**
- **1/G dG/dT = -1.7%/K**



Gain (V)



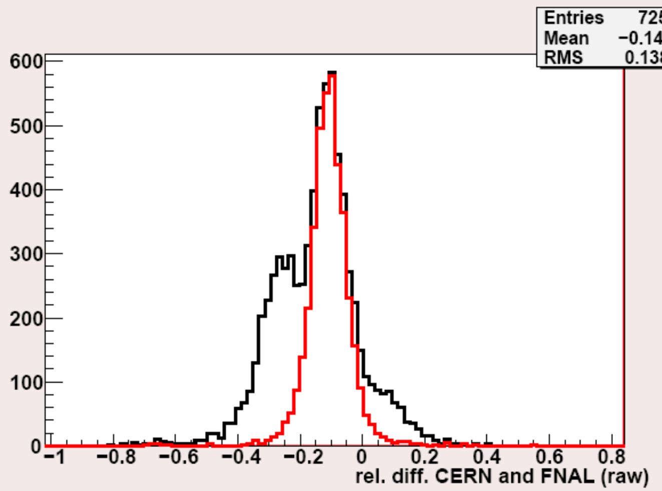
Gain (T)

Correction to MIP calibration set

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

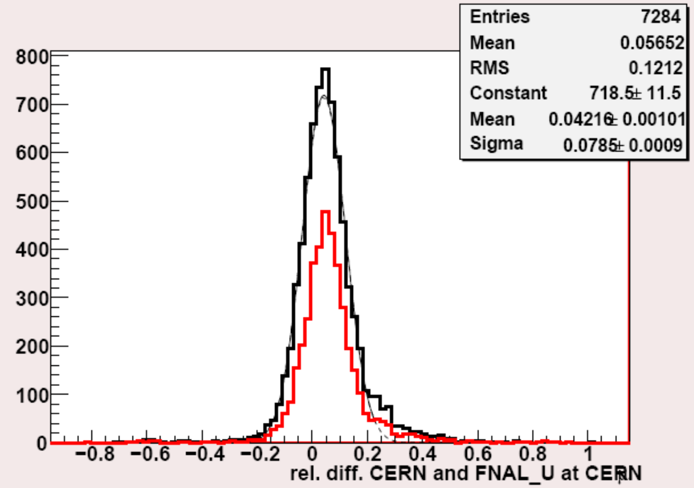
Before T/U correction:

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



After T/U correction:

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



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

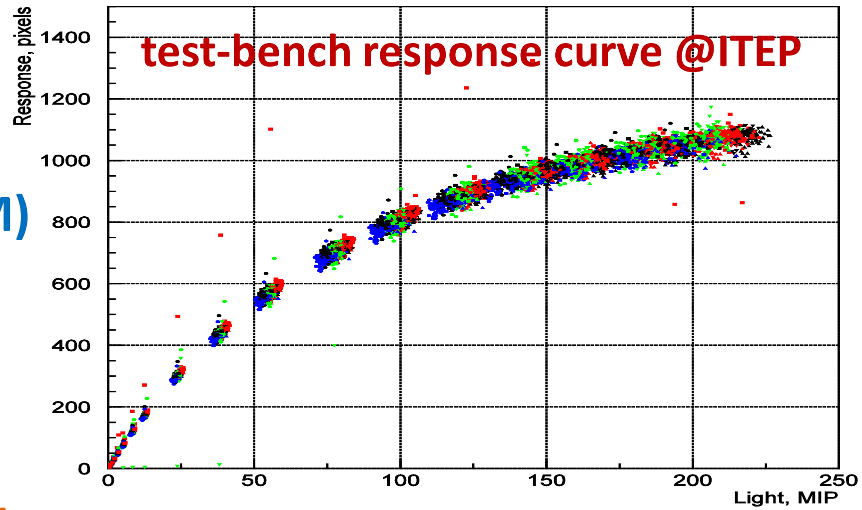
Saturation curves

Total number of pixels in a SiPM = 1156

- ❑ Saturation curves for single SiPM should be universal…

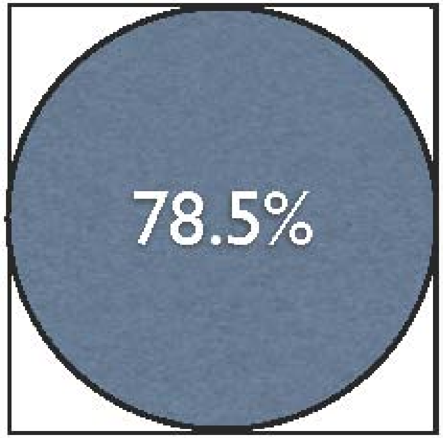
BUT:

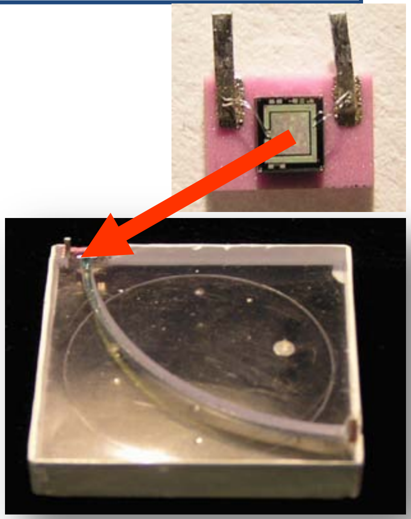
- ❑ Disagreement between ITEP (bare SiPM) and in-situ (on-tile) measurement



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

- ➢ 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

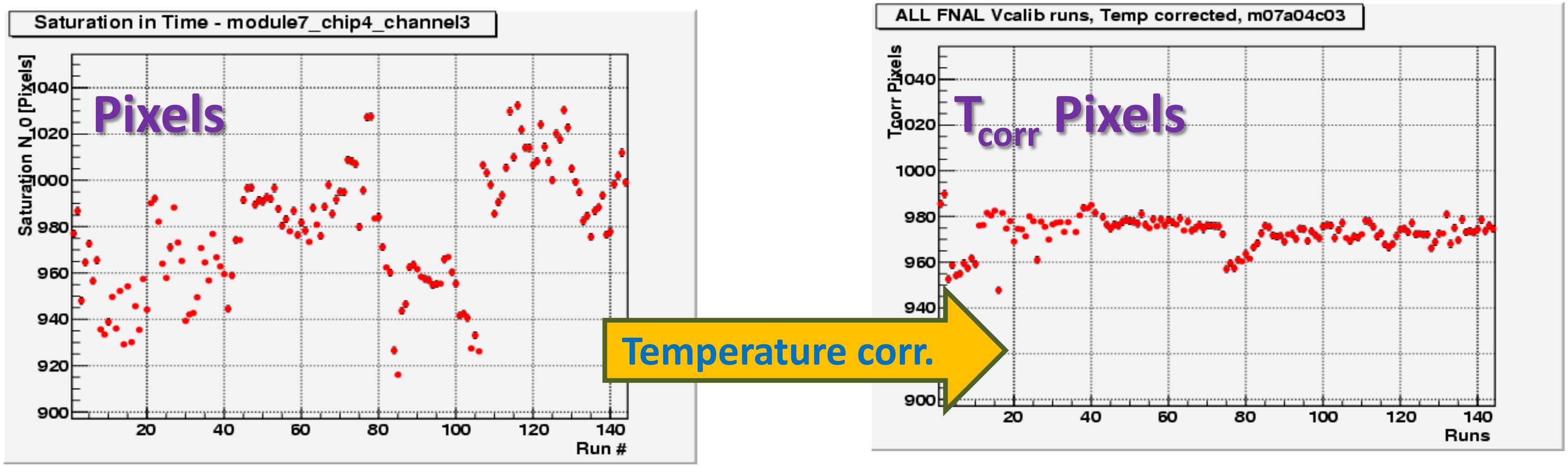


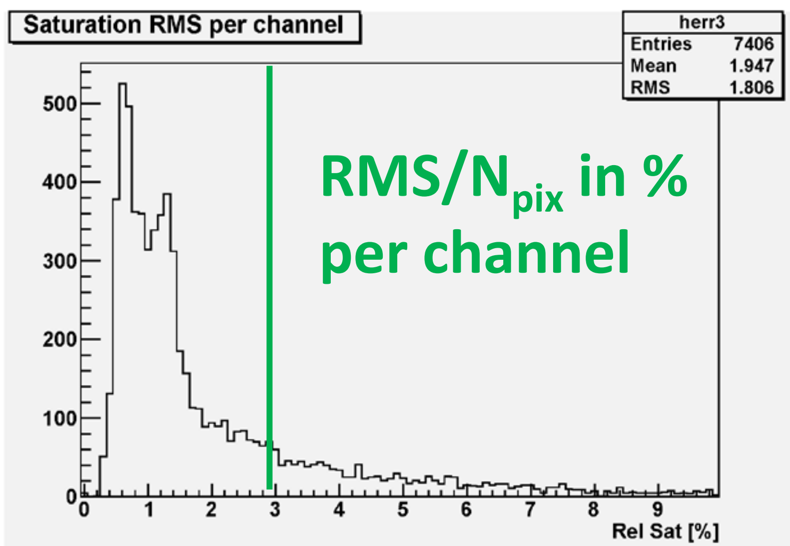


→ determination saturation factor for each channel separately

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

Saturation: temperature correction

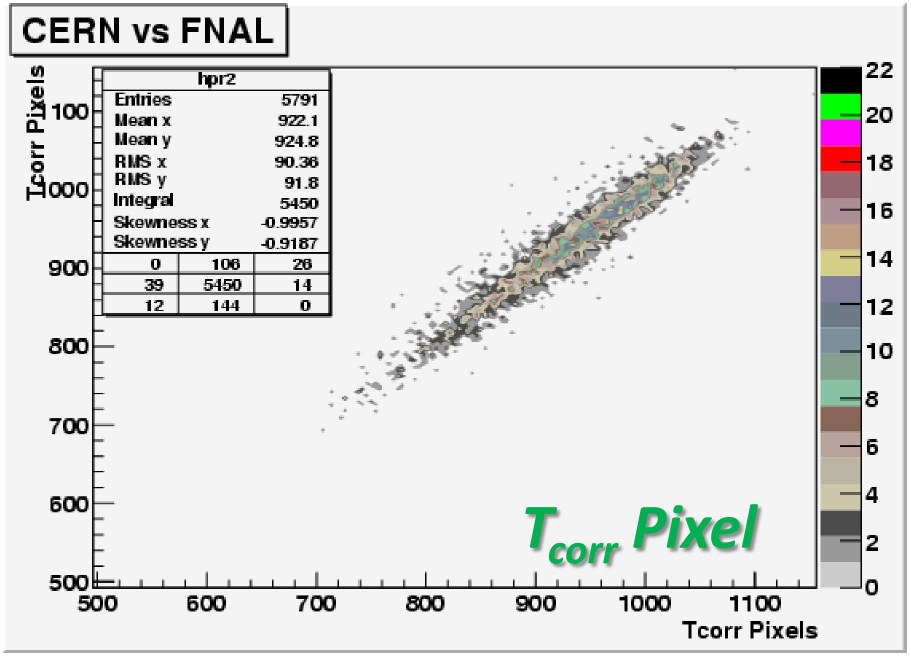


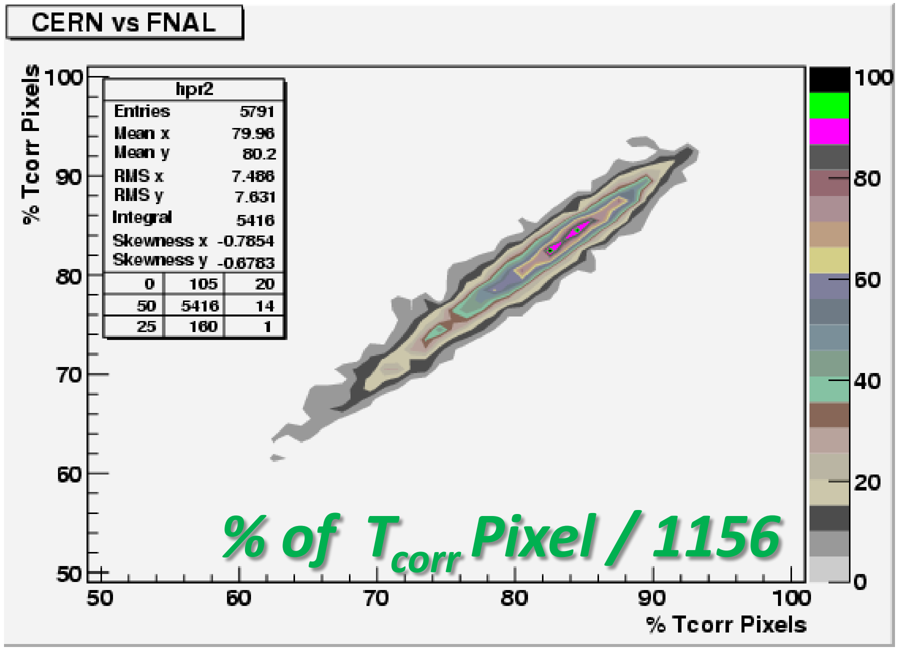


- Temperature correction works well

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

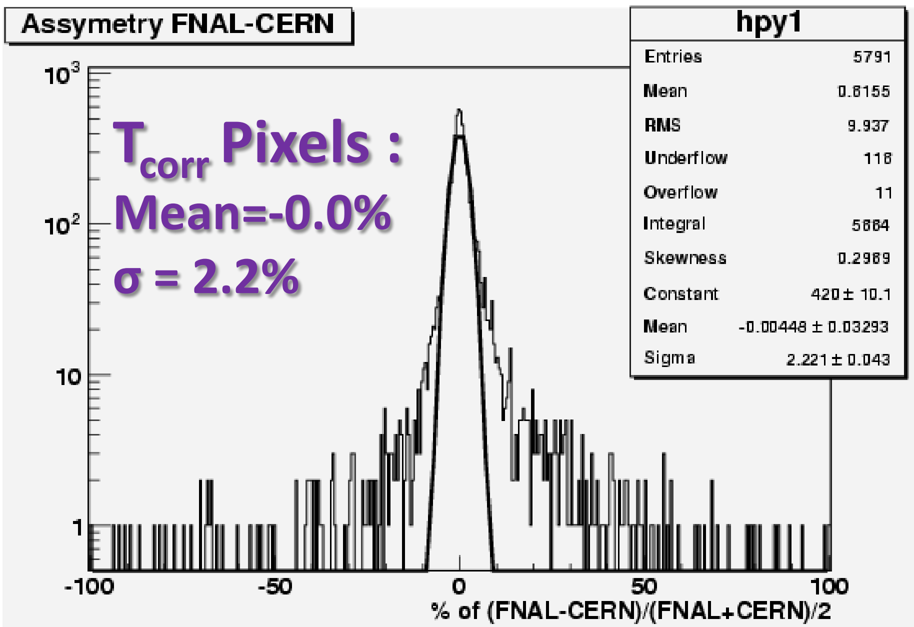
Saturation: FNAL versus CERN

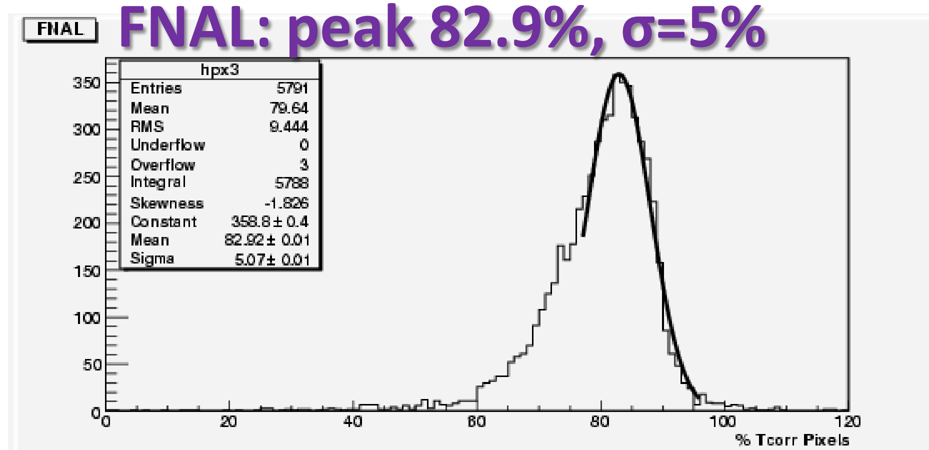


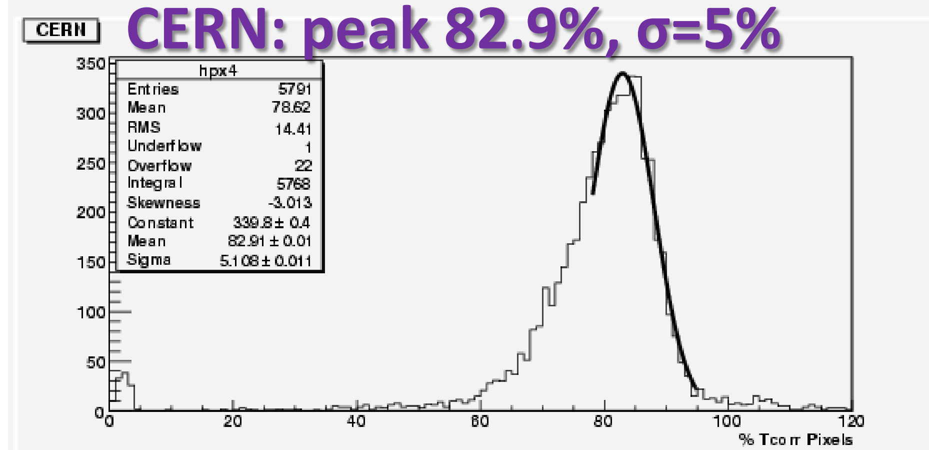


- Good correlation between saturation point extracted from CERN and FNAL data
- Both data sets shows average effective number of pixels at a level of 80% of phys. number (w/ RMS ~ 7%)
- Distribution (lab vs in-situ) N_{mount}/N_{bare} gives 80.5%, with RMS 9%

FNAL-CERN Asymmetry



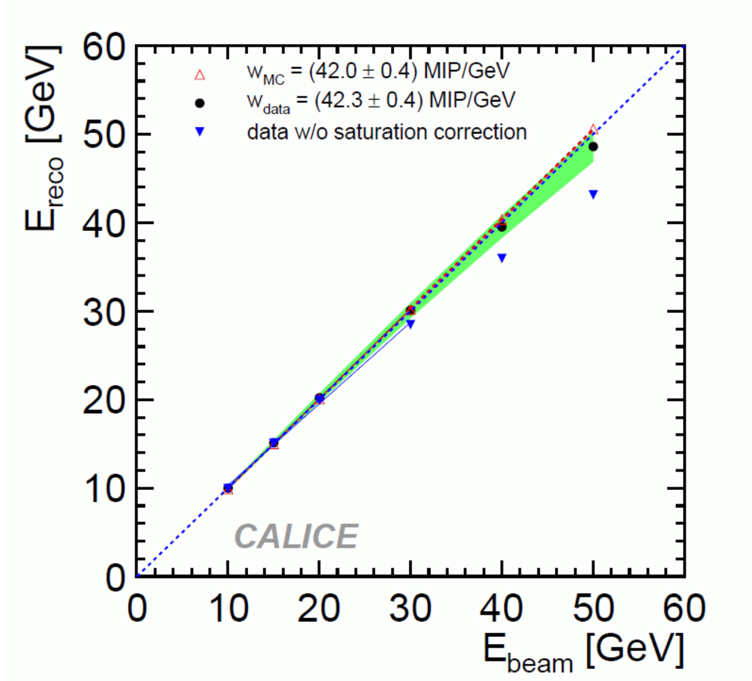


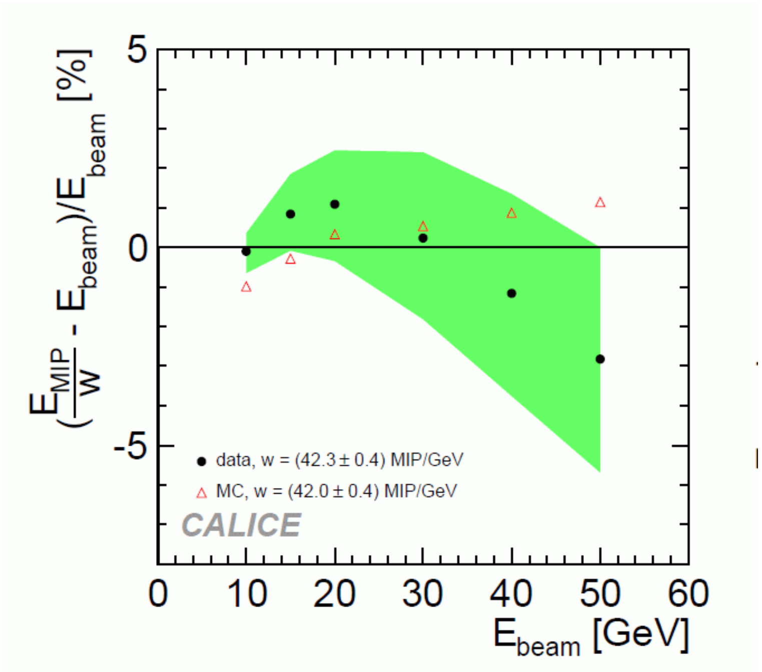


~10% outside 3σ-range

- **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 ~3% @ 50 GeV
- Remaining non-linearity for > 40GeV electron shower *still under investigation*
- In hadronic showers smaller energy density (at the same particle E)
  → *non-linearity effects are less relevant for hadrons*

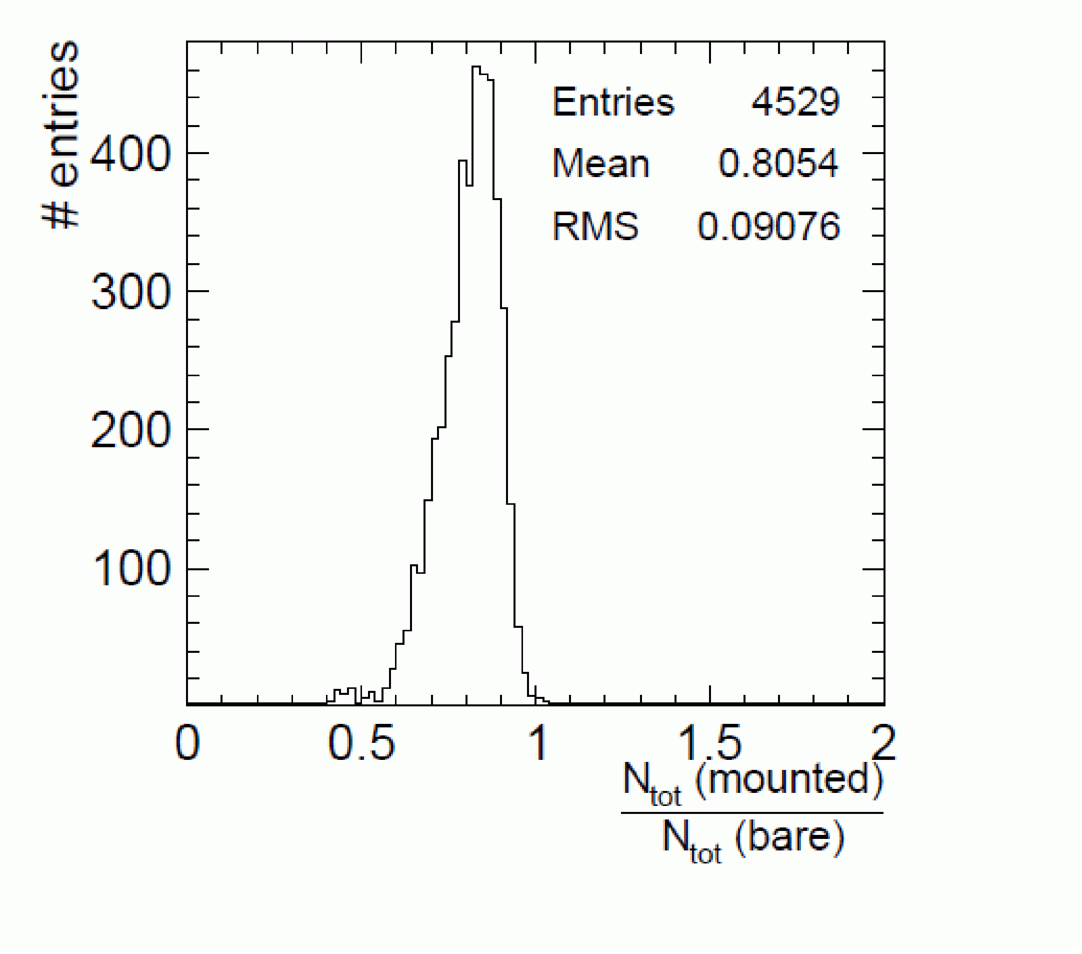
Conclusion

- 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 ~ 10
- SiPM response measured for each device:
  - Lower saturation point measured after mounting SiPM on tile
  - Both data sets FNAL & CERN give consistent results:

    ~83% of pixels illuminated by WLS fiber light
- Transportation of the calibration due to changing temperature and voltage works well a can be used for whole detector
- Calibration procedure validated with EM data

Backup

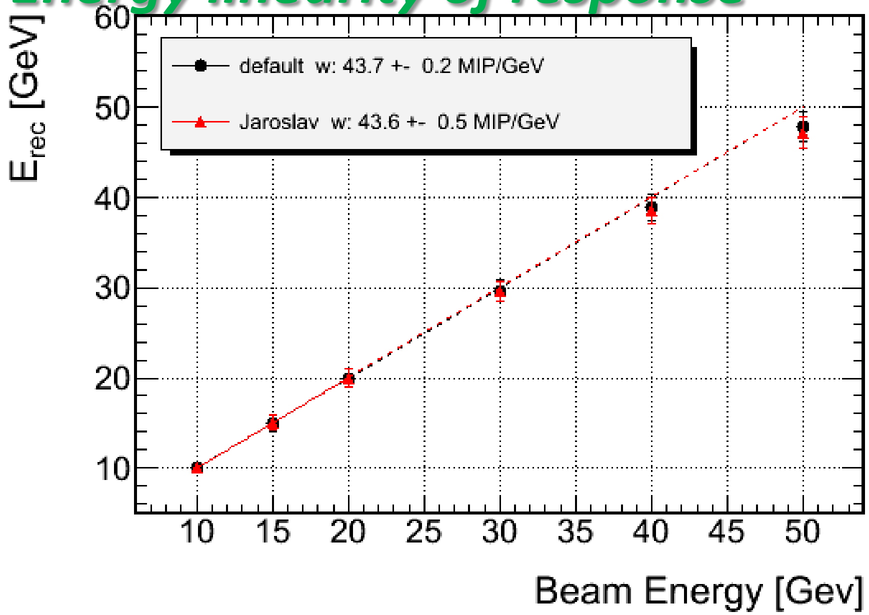
Saturation: mounted/bare



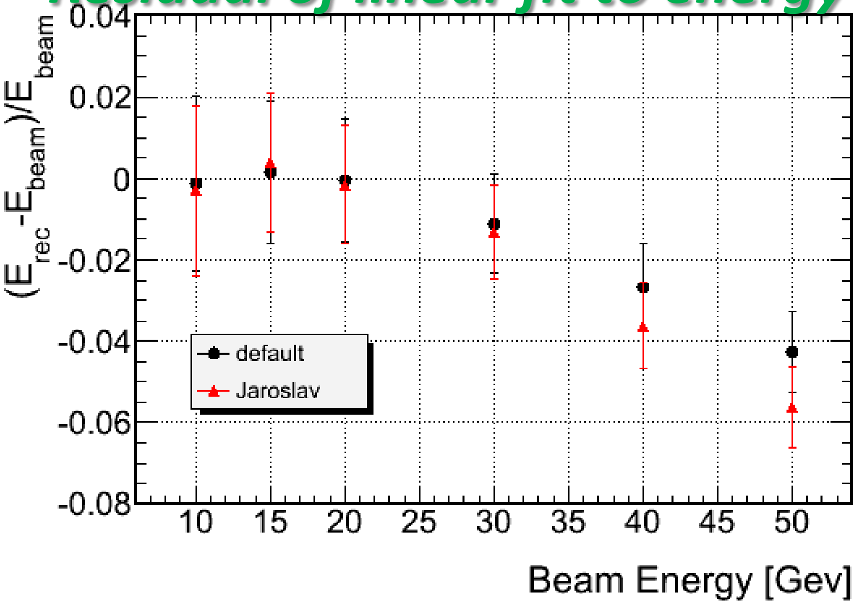
Effect of channel-by-channel corrections on EM analysis

global rescaling factor X single cell saturation

Energy linearity of response



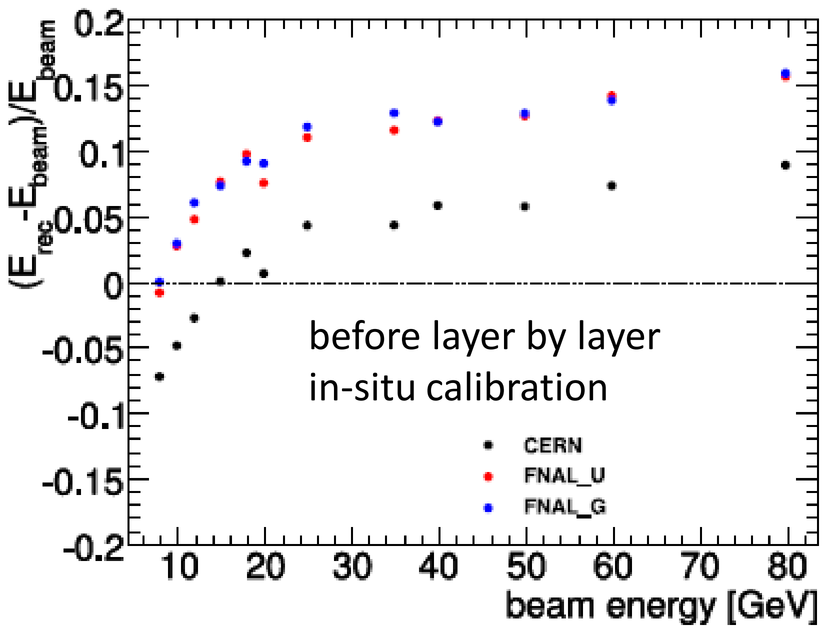
Residual of linear fit to energy

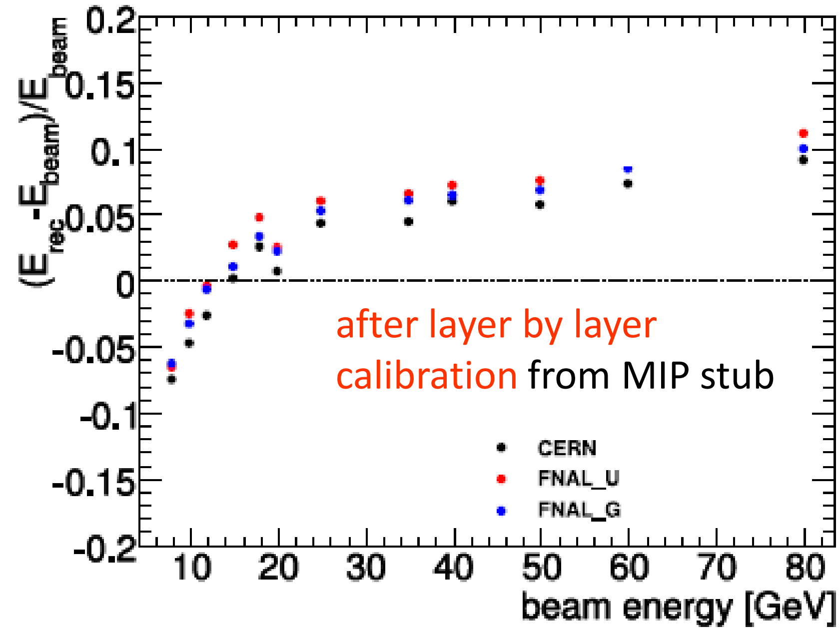


- ➢ **single-cell calibration does not improve the linearity w.r.t. a common rescaling factor**

→ 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