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**

ECFA Study
Physics and Detectors for a Linear Collider

Institute of Physics AS CR

CALICE
Calorimeter for ILC

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:

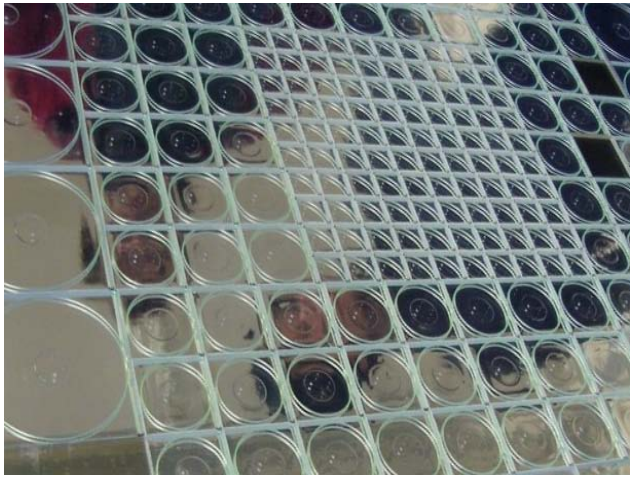
convert detector signal into number of MIPs deposited by particle traversing the tile & correct for non linear response of SiPM

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

What do we need:

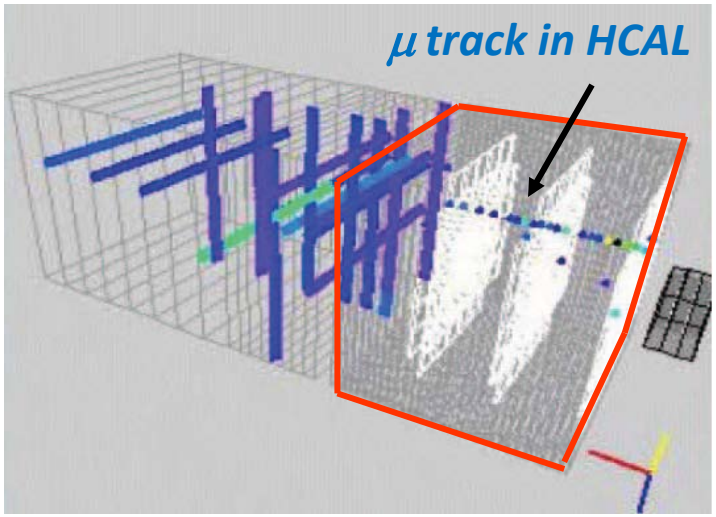
Lightyield in [pix/MIP]:

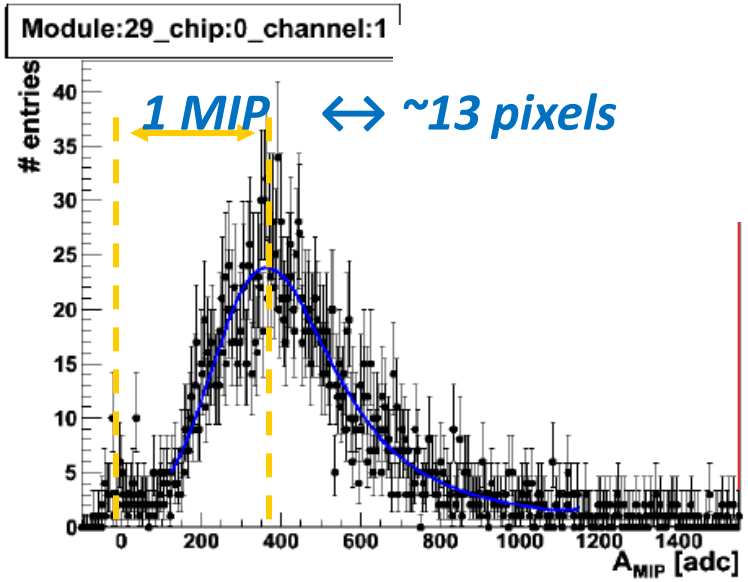
- **MIP amplitude** in ADC bins ... C_i^{MIP}
- **SiPM gain**: (CalibMode) ADC bins converts to pixel ... G_{pix}
- **Electronics Intercalibration**: between PM/CM mode ... I_C
- **SiPM response function:** corrects the non-linear response of the SiPM ... $f_{sat}(A_i[pix])$



Cell response equalization with MIP

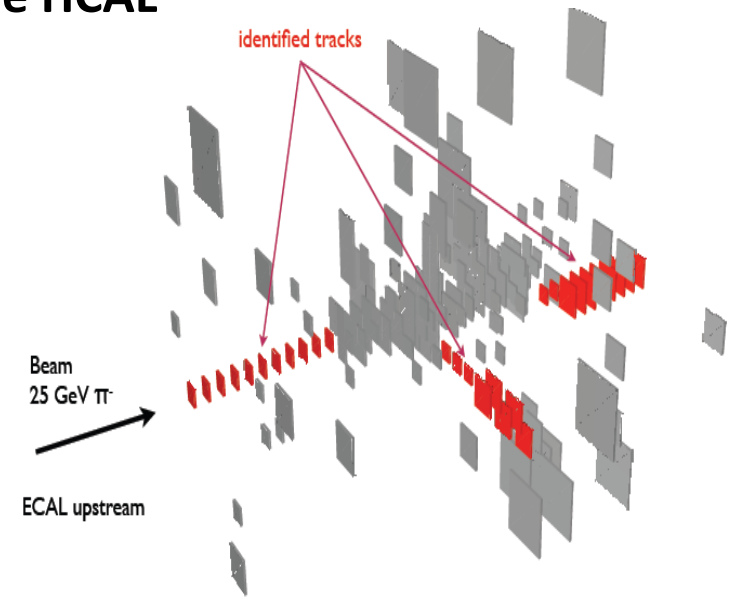
Using muon signal





Using pion shower

select MIP stubs using the high granularity of the HCAL



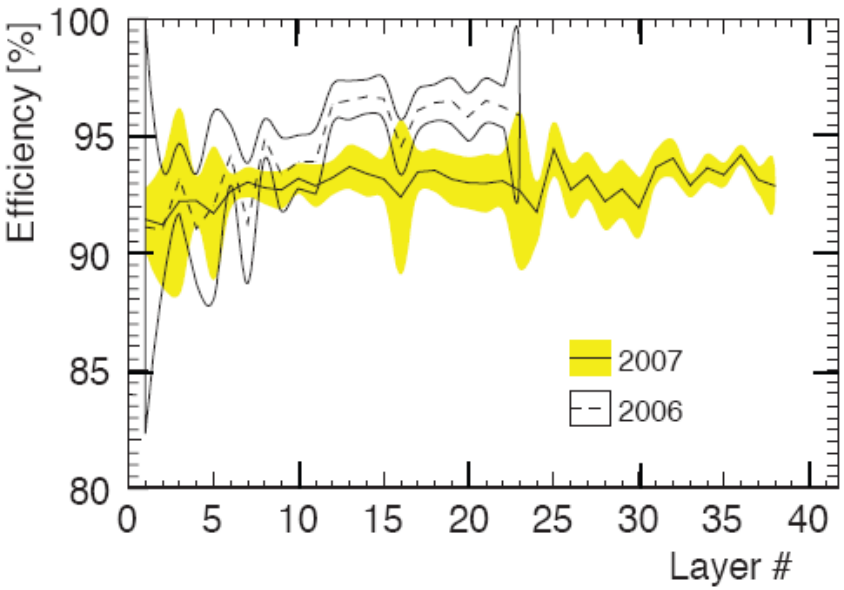
Luminosity requirement for in-situ calibration with MIP stabs from jets (ILC detector)

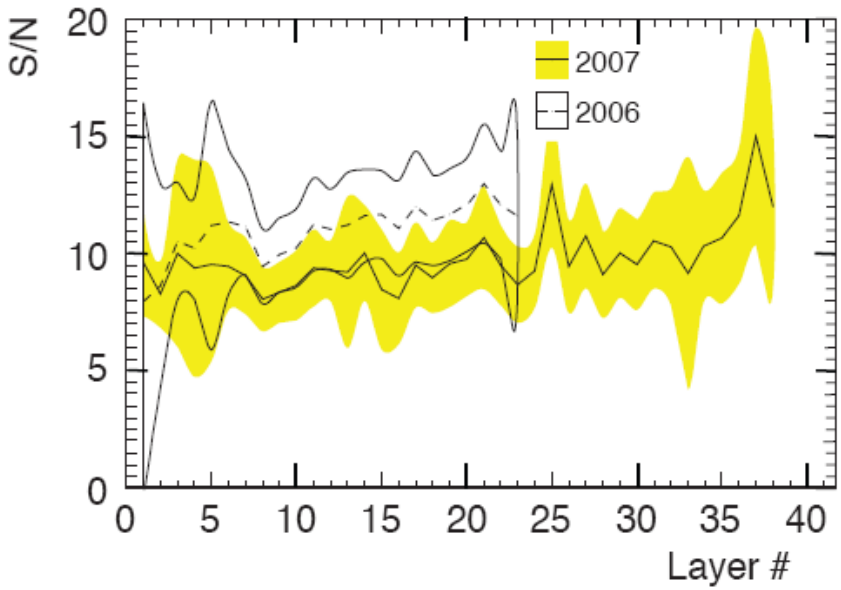
	Luminosity at 91 GeV	Luminosity at 500 GeV
layer-module to 3% to layer 20	1 pb^{-1}	1.8 fb^{-1}
layer-module to 3% to layer 48	10 pb^{-1}	20 fb^{-1}
HBU to 3% to layer 20	20 pb^{-1}	36 fb^{-1}

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

MIP calibration

Calibration obtained at CERN with ~2 M muon events (80 GeV)
- broad beam covering the whole 1x1 m^2 calorimeter face
- minimum 500 events required for a good fit in one cell

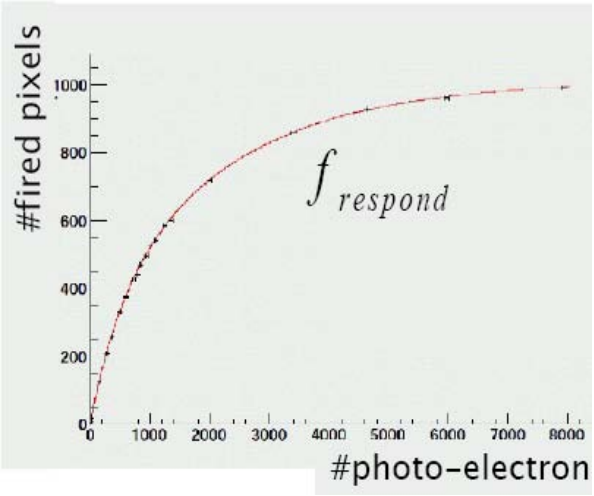


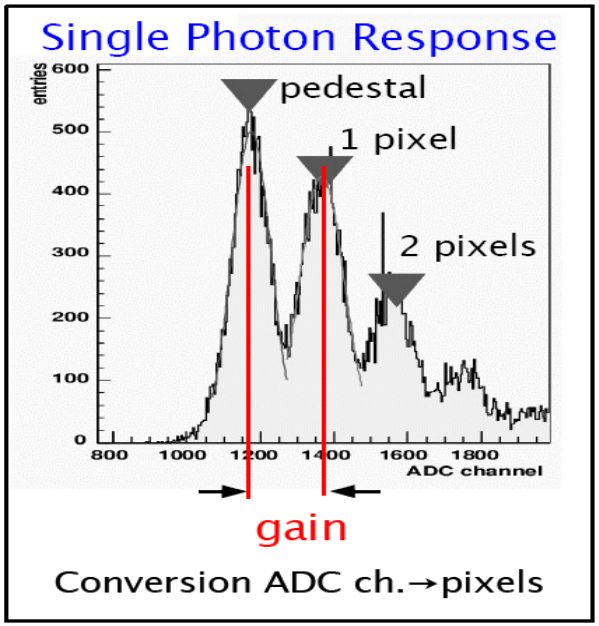


- **MIP detection efficiency above 0.5*MIP threshold ~ 93%**
- **Signal to noise ratio ~ 10**

Importance of monitoring/calibration

SiPM response is non-linear

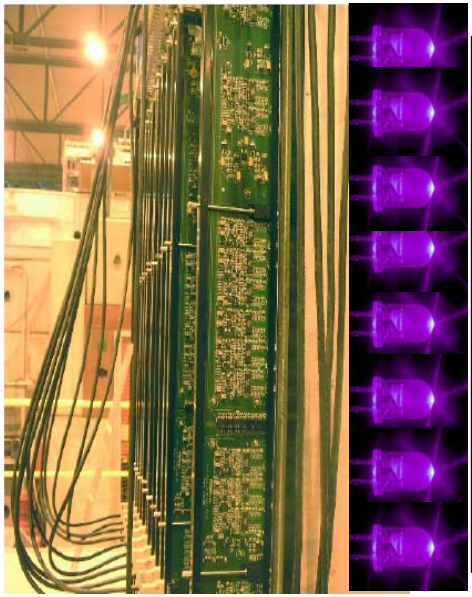


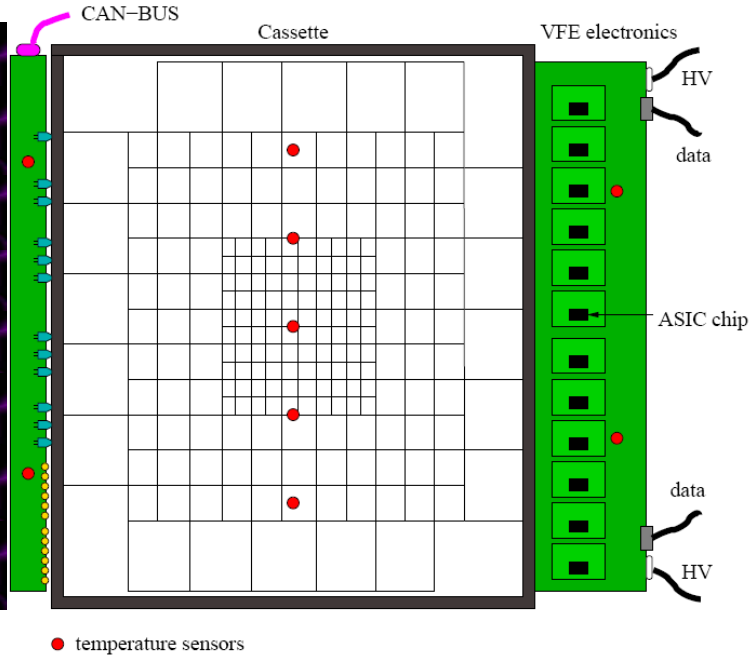


Redundant calibration system delivers:

- **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



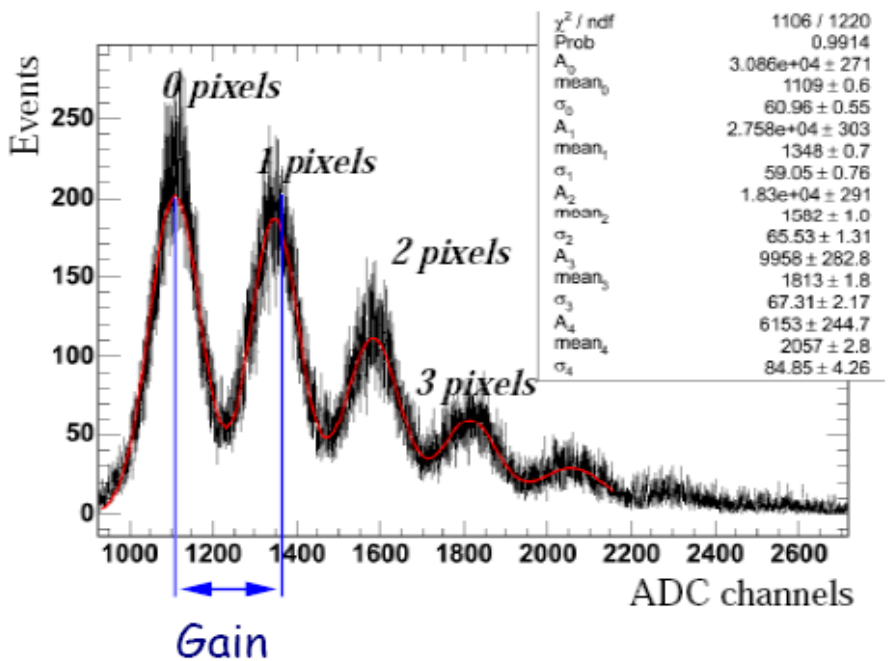


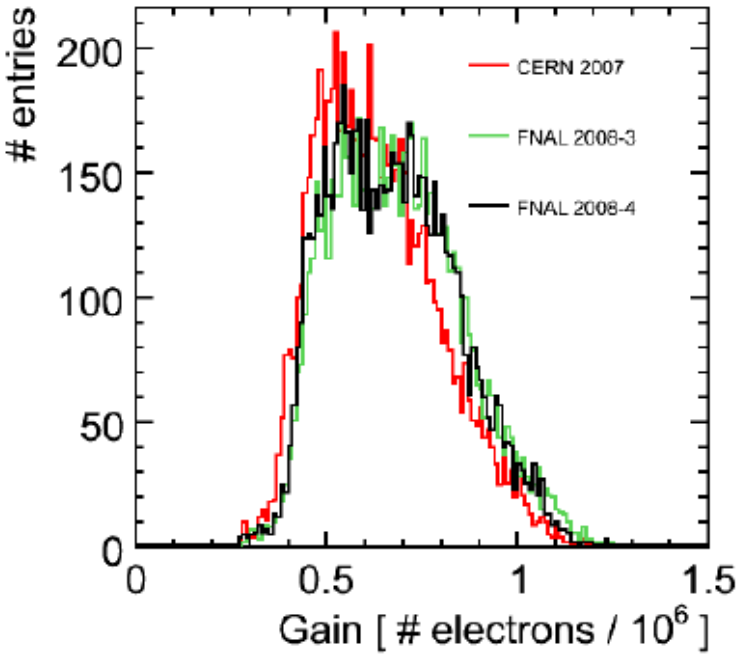
- ***Light intensity for 7600 channels within factor 2***
- ***> 94% calibration efficiency on full calorimeter***

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 96.4%, FNAL 97% ➔ Mainly quality of LED system



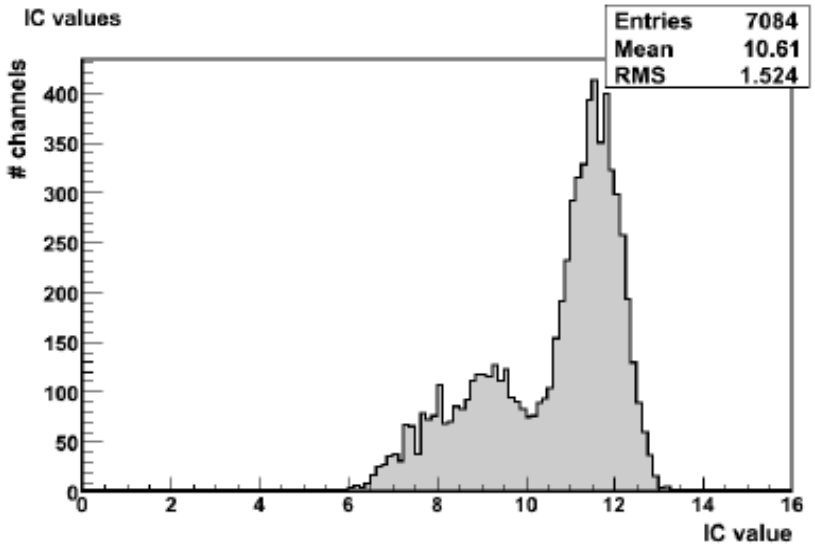


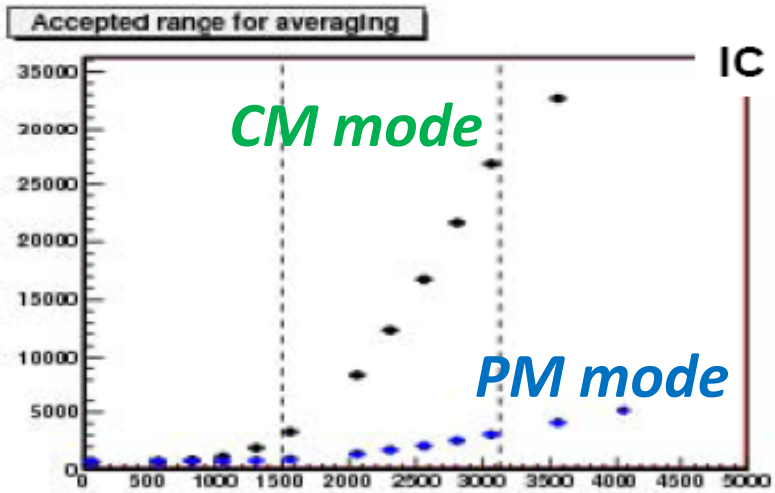
ASIC mode inter-calibration

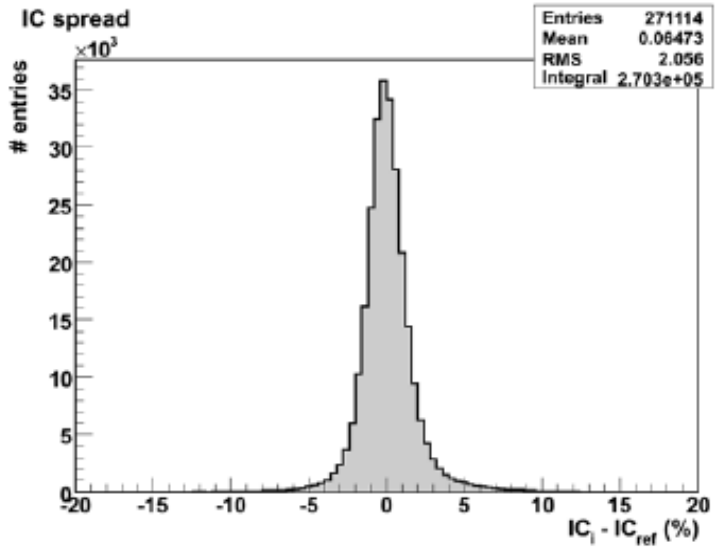
- values for 93% of all channels
- ≈ 4% of channels failed due to problems with the CMB hardware
- ≈ 2% dead channels
- method efficiency near 100%

- stability: 2% RMS over data taking period
- tails are under investigation

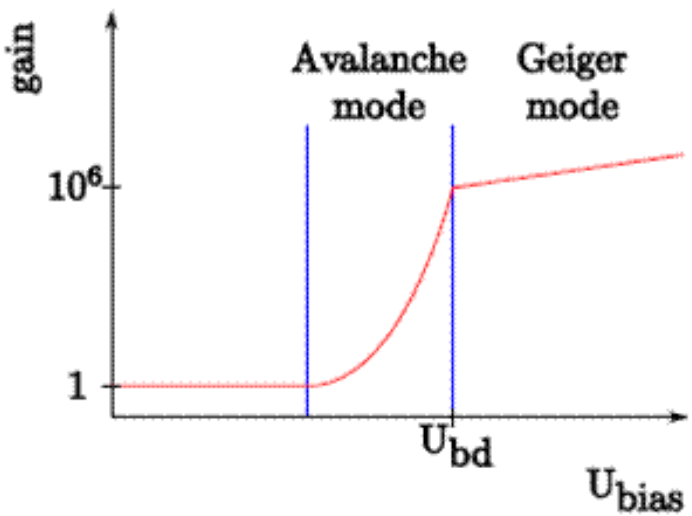
➔ reduced to <0.5 % in later analysis

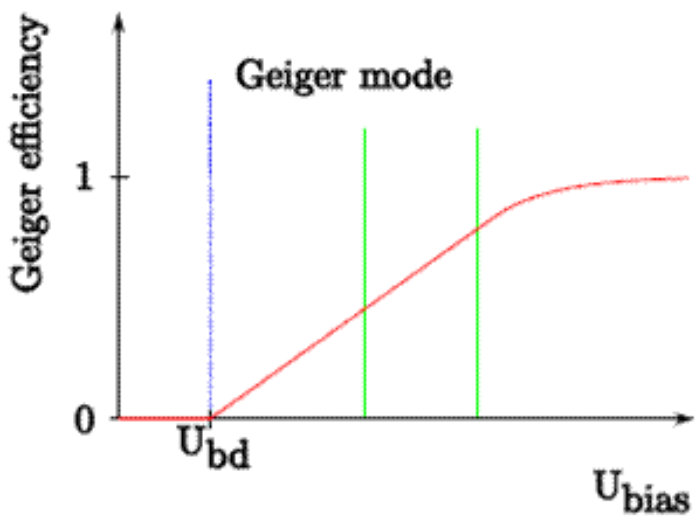






Temperature and voltage dependence



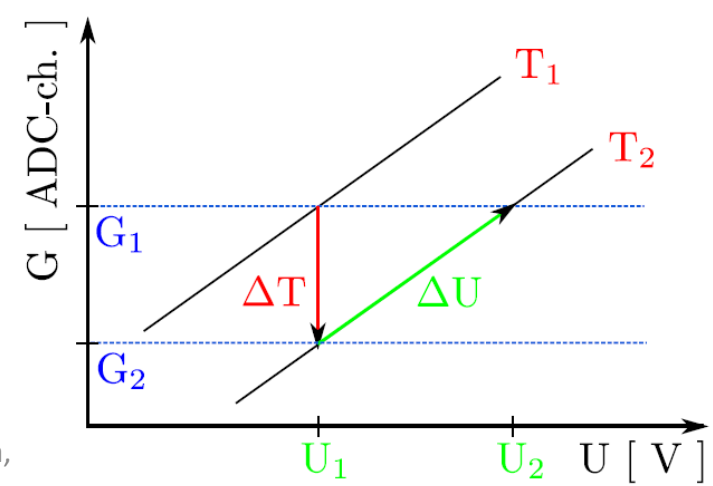


- **SiPMs (operated in Geiger mode): Gain *G*, Geiger efficiency *ε***
- ***G, ε* ∝ *($U_{bias} - U_{bd}$)*** **O(2%/100mV)**
- ***U_{bd}* → *T* ∝ *G, ε* ∝ *(-T)*** **-1.7%/K**
- ***Muons response A_{MIP} ∝ ε × G)*** **-3.7%/K**

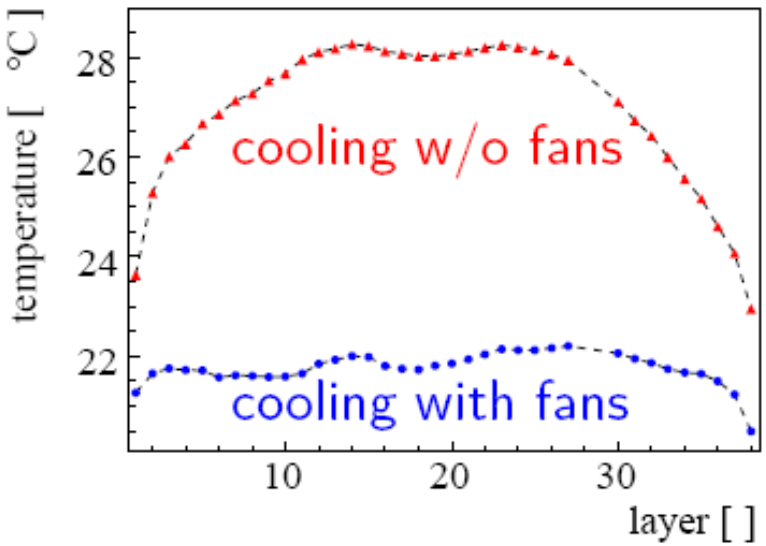
➢ Compensation of Temperature Changes (HV Adjustment)

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

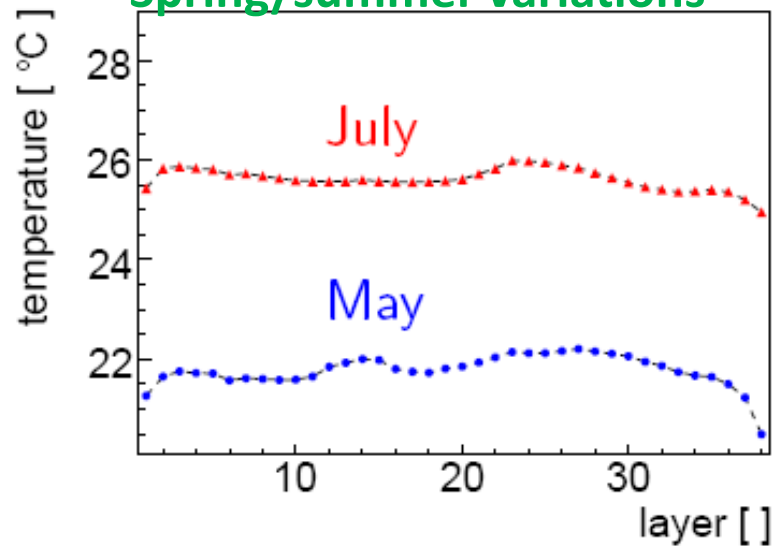
➔*Price to pay: increase of noise above threshold (for fix threshold)*



Temperature variations at TB



Spring/summer variations



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

Important point for a ILC detector:

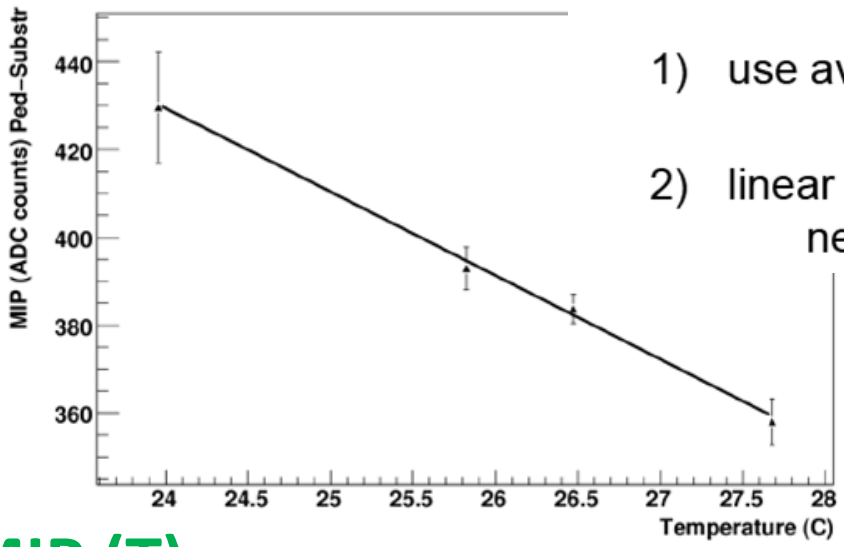
- cell equalization (with muon) cannot be repeated in situ
- test beam calibration can be ported to the ILC detector
- what about correction of long term T fluctuation (if any)?

MIP &Gain T&V dependence

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

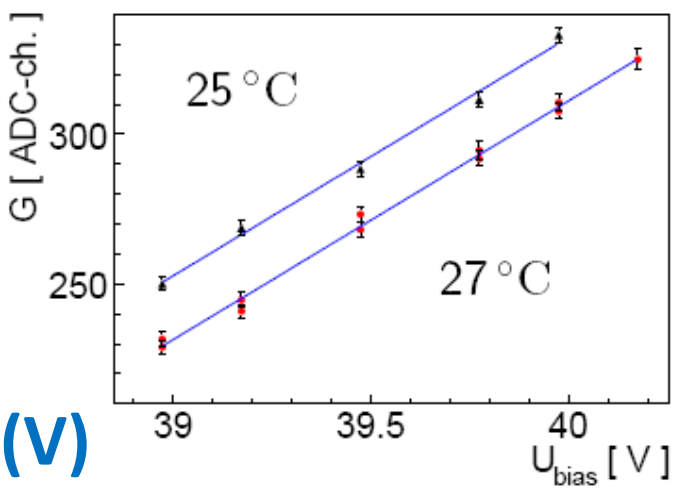
1) use average $1 / A^{MIP} \; dA^{MIP} / dT = -3.8$ %/K (at 27 °C)

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

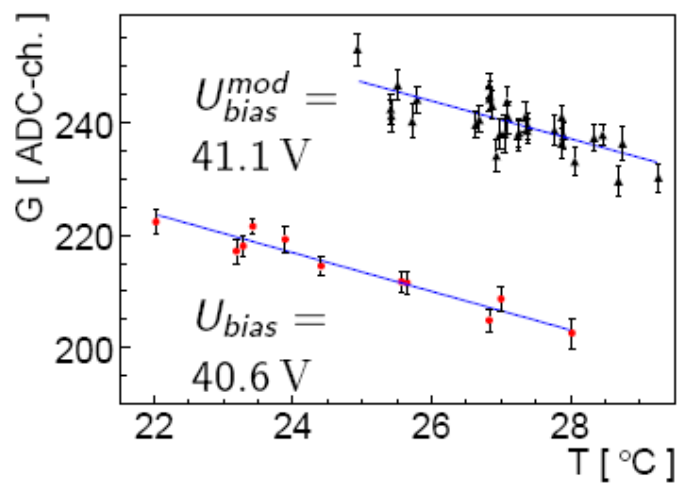


MIP (T)

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



Gain (V)



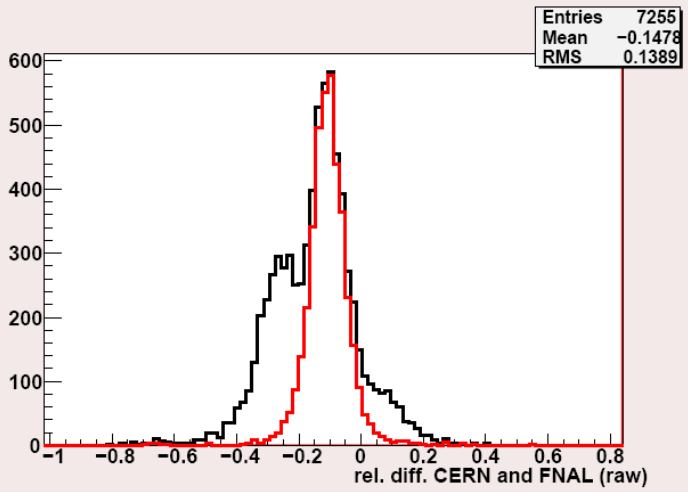
Gain (T)

Correction to MIP calibration set

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

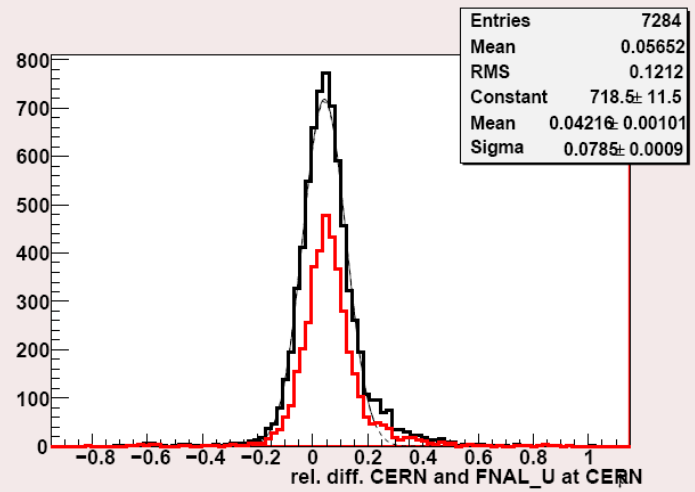
Before T/U correction:

- 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%

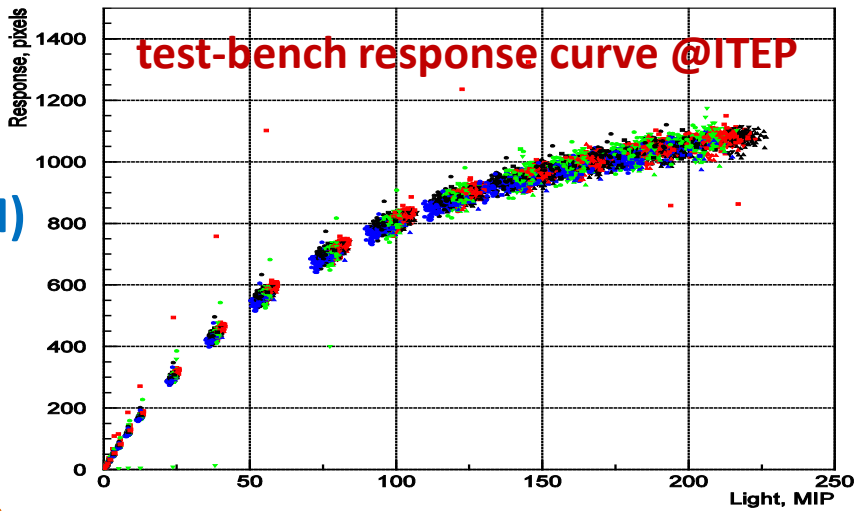
Saturation curves

Total number of pixels in a SiPM = 1156

- ❑ Saturation curves for single SiPM should be universal…

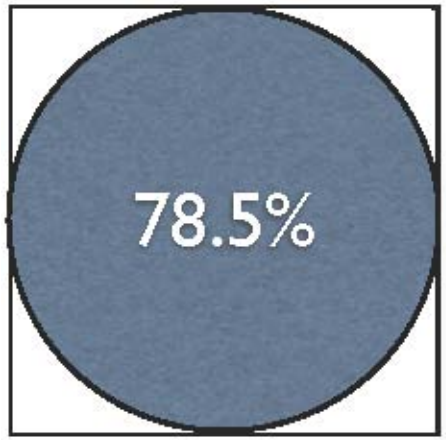
BUT:

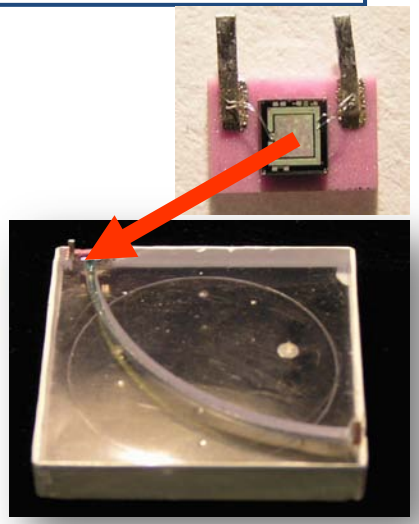
- ❑ Disagreement between ITEP (bare SiPM) and in-situ (on-tile) measurement



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

- ➢ 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

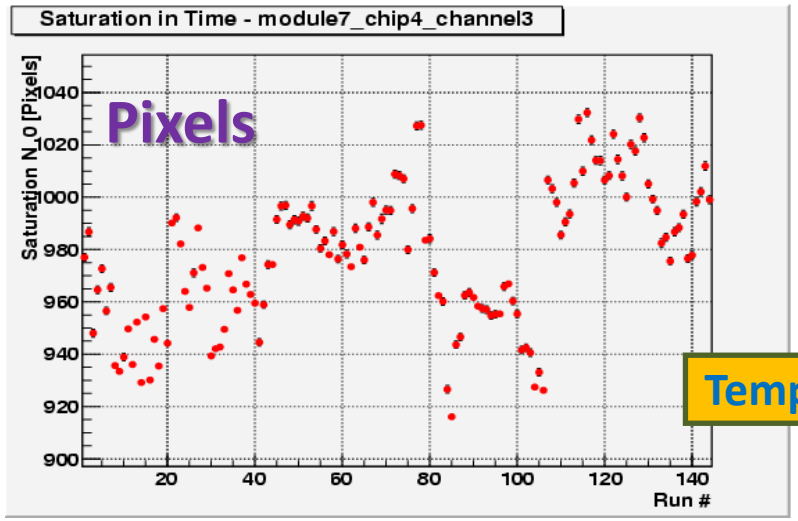




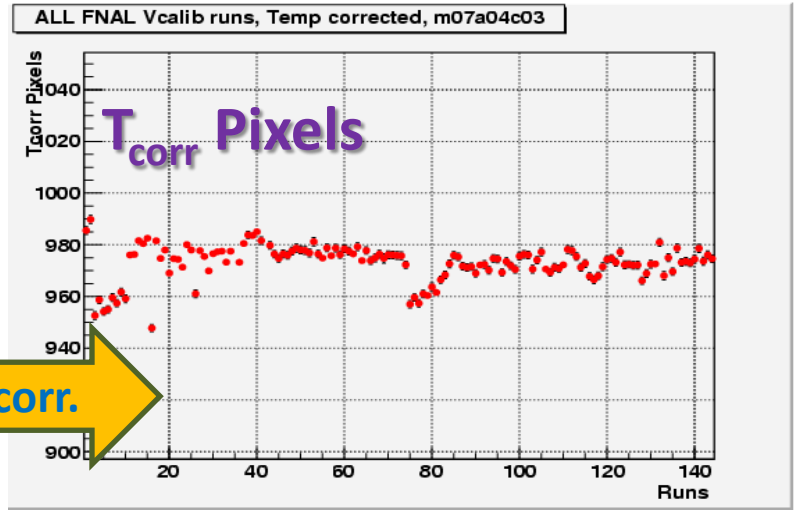
→ determination saturation factor for each channel separately

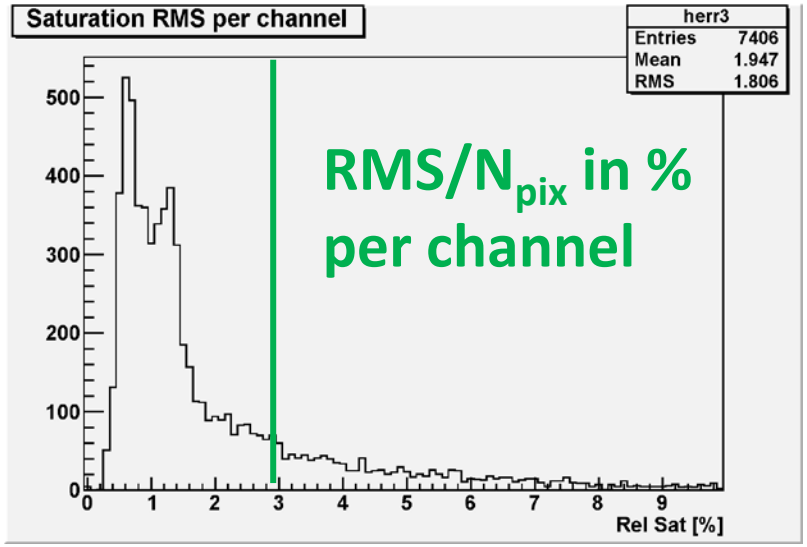
- *extract saturation factor for all channels*
- *apply calibration to pixels & temp corrections*
- *averaged over all runs → consistent results?*

Saturation: temperature correction



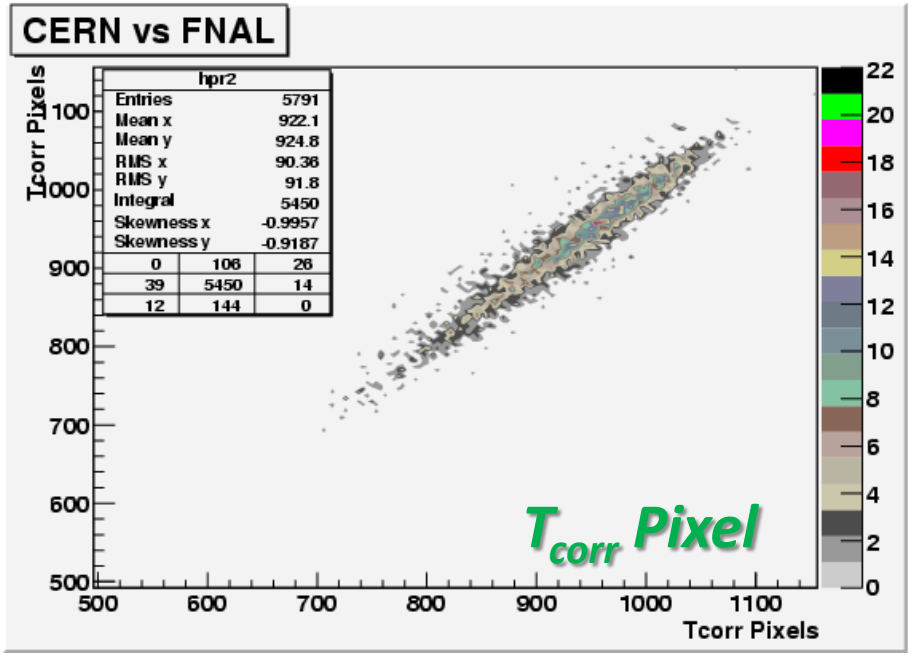
Temperature corr.

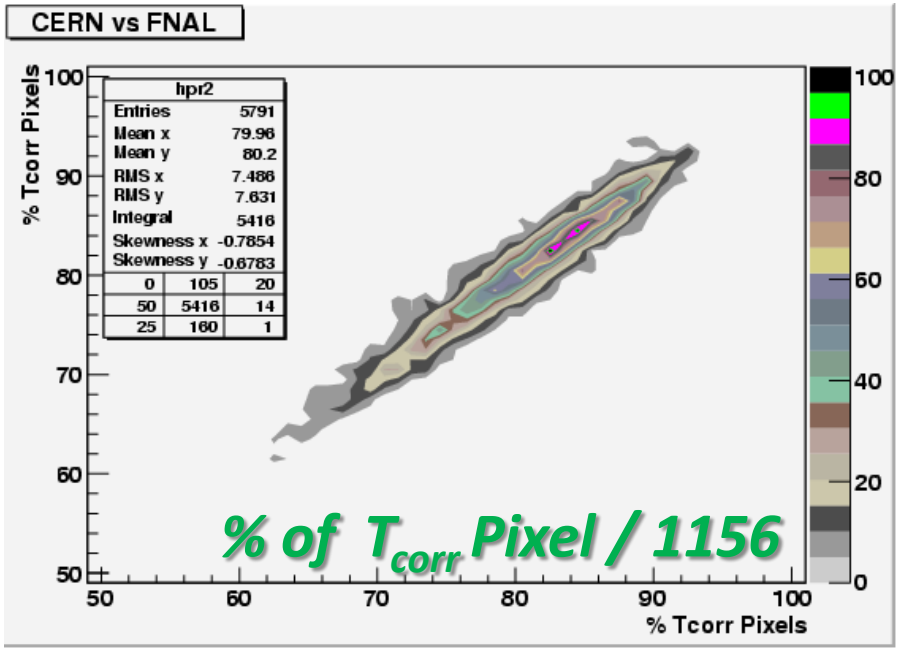




- **Temperature correction works well**
- **73% (5524 of 7608) channels vary by less 3% of RMS over all data taking time**

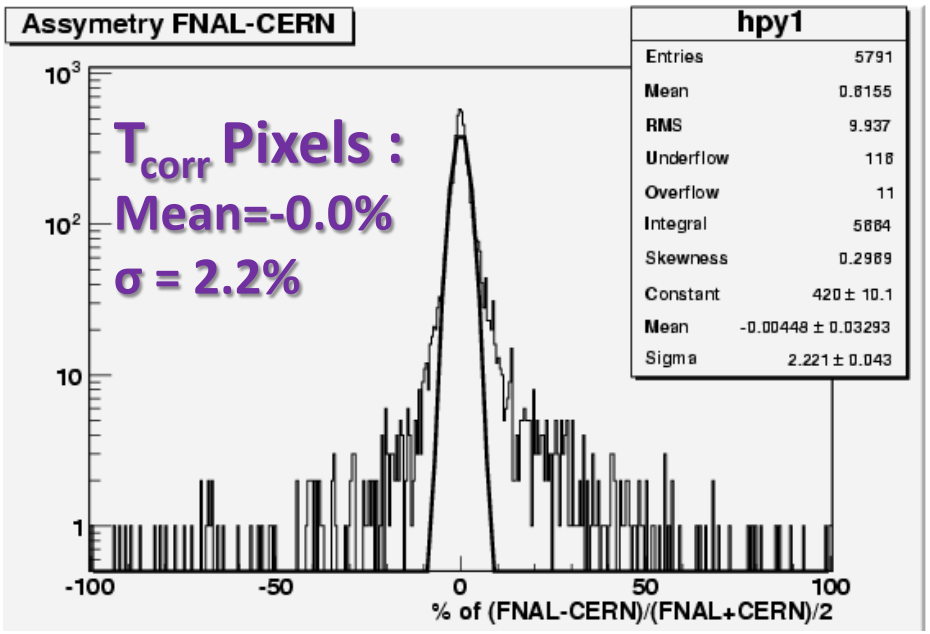
Saturation: FNAL versus CERN

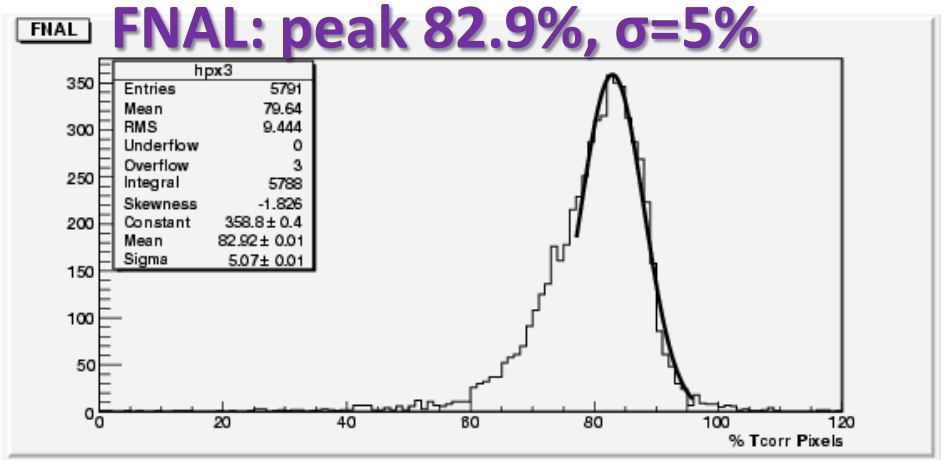


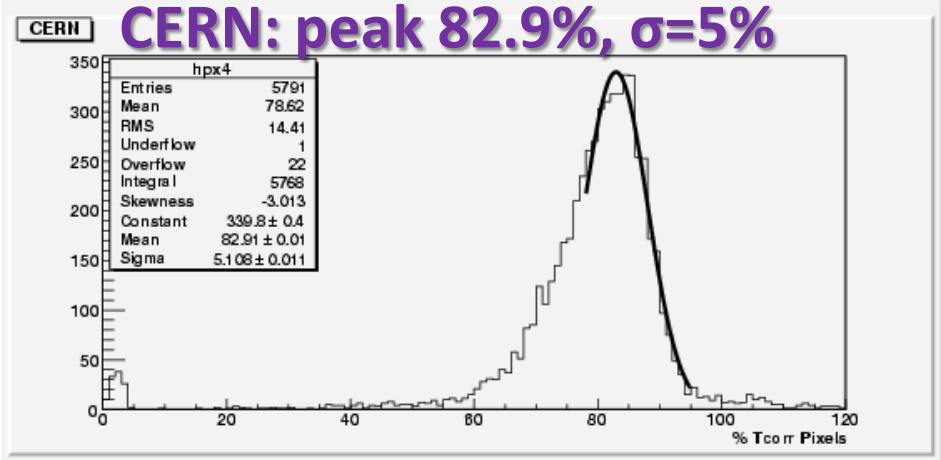


- Good correlation between saturation point extracted from CERN and FNAL data
- Both data sets shows average effective number of pixels at a level of 80% of phys. number (w/ RMS ~ 7%)

FNAL-CERN Asymmetry



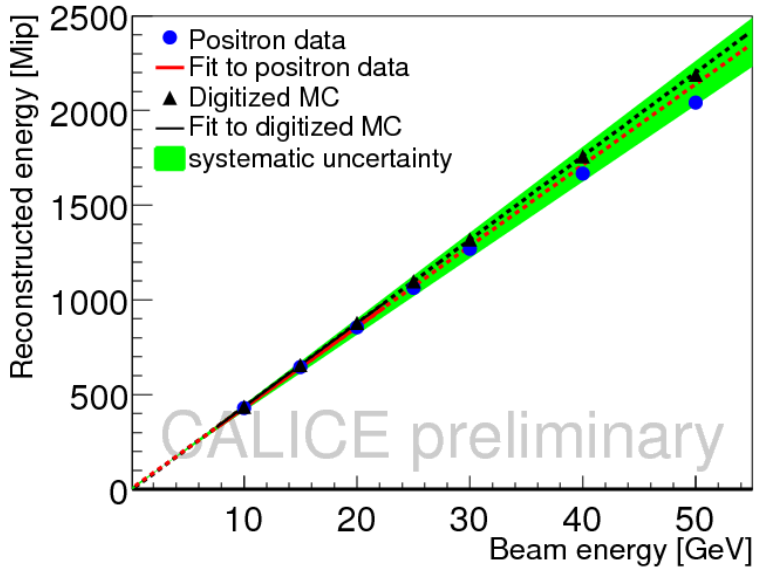


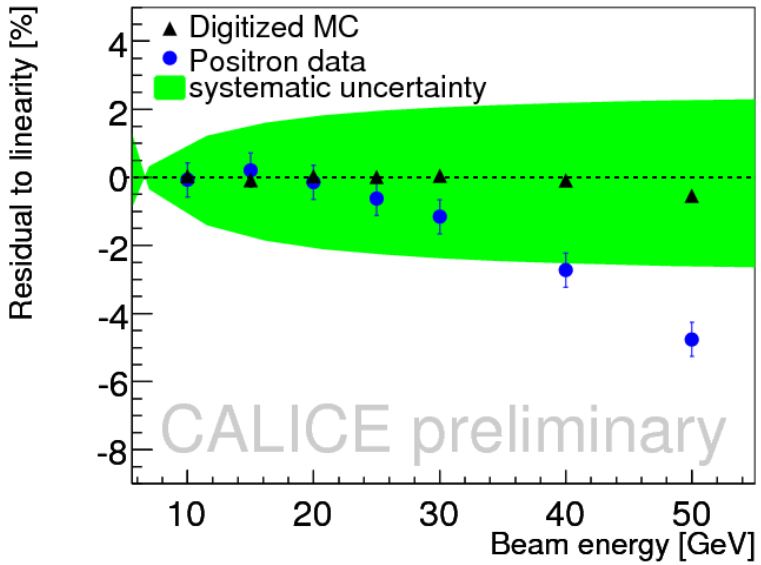


~10% outside 3σ-range

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

Current status of calibration





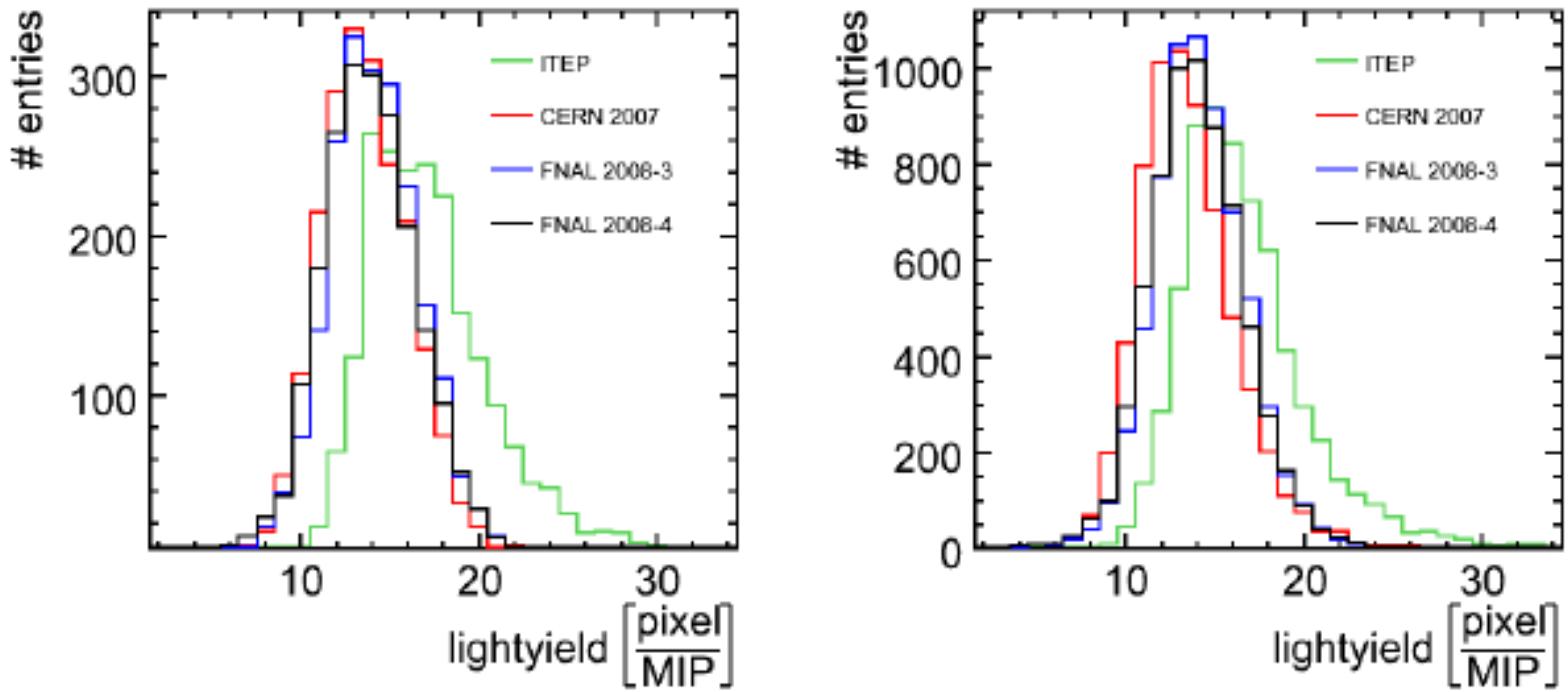
- **green band indicates variations of the fit result due to calibration uncertainties on both the MIP and saturation scales.**
- **Non-linearity ~4% @ 50 GeV**
- **Remaining non-linearity for > 40GeV electron shower *still under investigation***
- **In hadronic showers smaller energy density (at the 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 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 (84% ch.) 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
- Possible additional per layer energy scale correction (in-situ)
- Calibration procedure validated with EM data

Backup

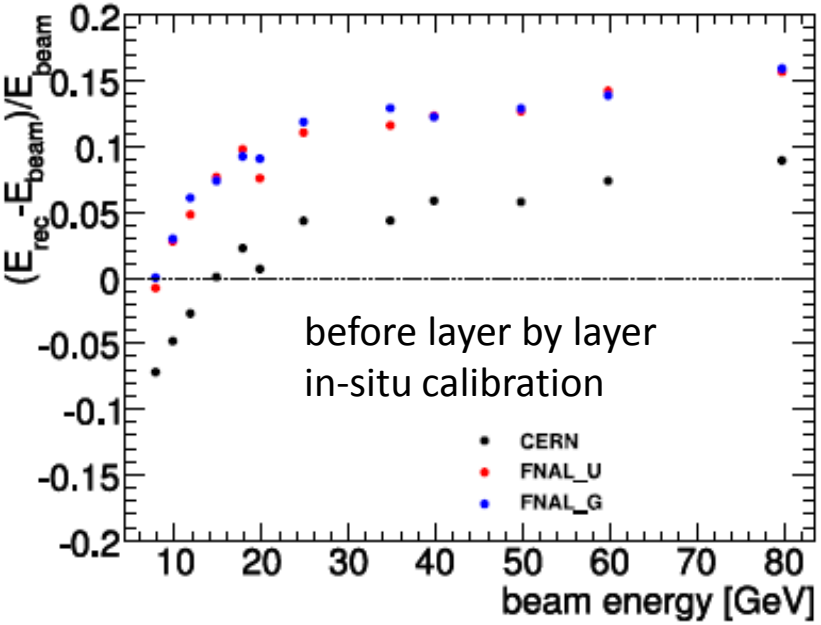
Figure of merit: light yield

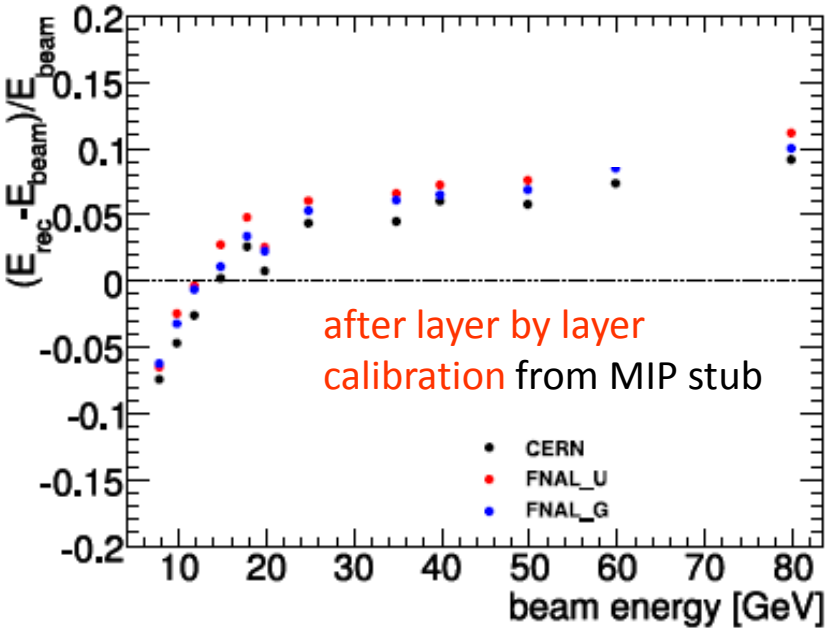


- Adjustment requires the knowledge of SiPM response - T & V -
- Remaining discrepancy due to different MIP sources
  ---> to be validated with MC

➢ **MIP: muon 80 GeV (CERN), muon 32 GeV (FNAL), Sr-source (ITEP)**

Impact on hadron analysis





~5% shift between CERN reference and transported samples

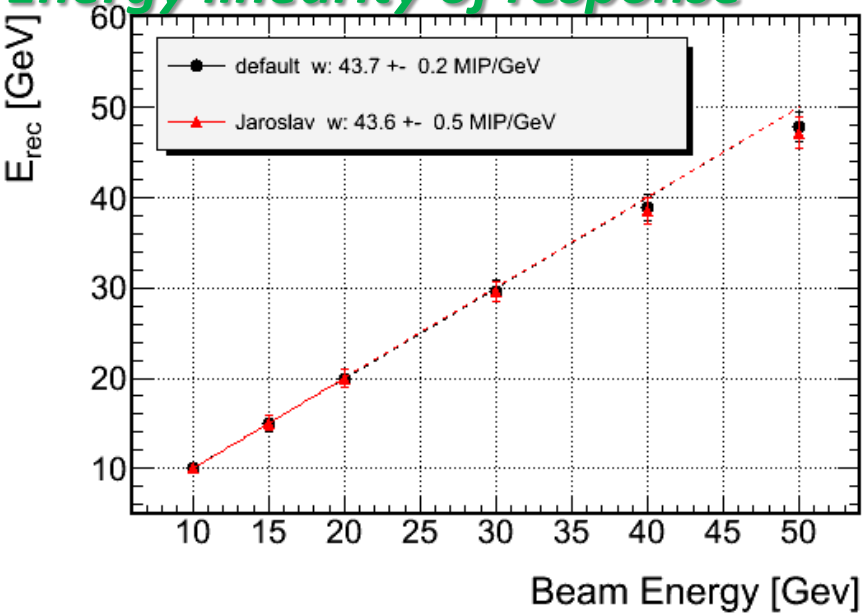
➔ Corrected by the in-situ layer-by-layer calibration using MIP stubs from pion showers

➔ After transport of calibration consistent results within analysis uncertainties

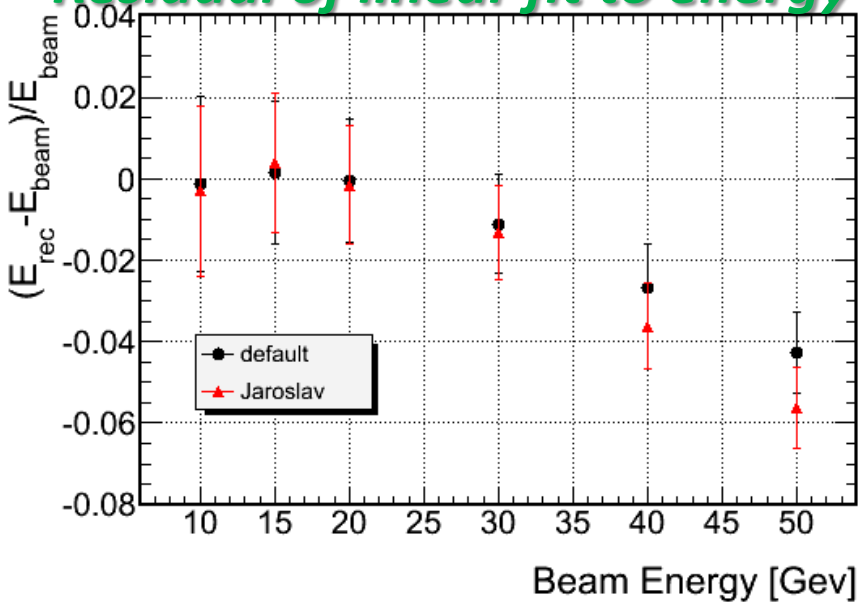
Effect of channel-by-channel corrections on EM analysis

global rescaling factor X single cell saturation

Energy linearity of response



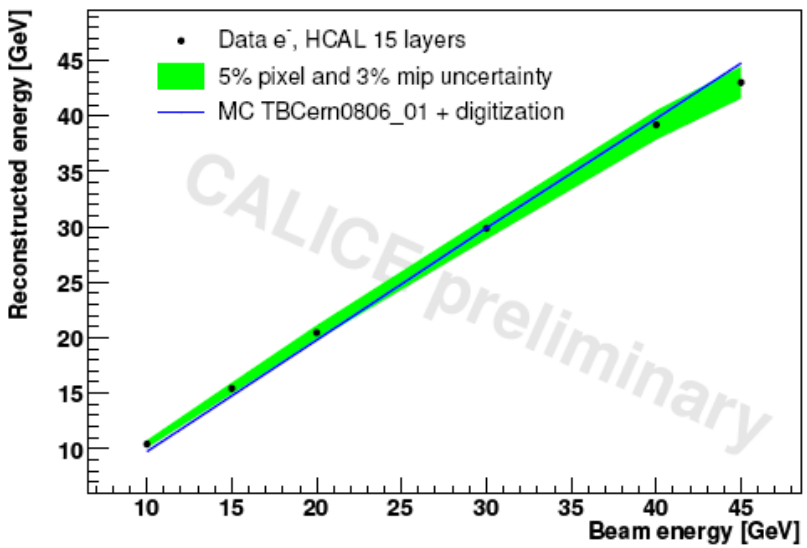
Residual of linear fit to energy

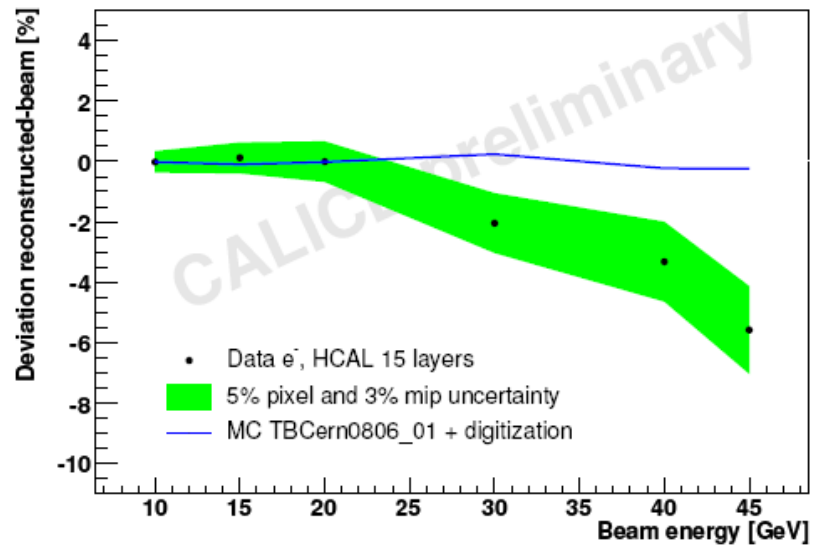


- **single-cell calibration does not improve the linearity w.r.t. a common rescaling factor**

→ simplifies calibration chain of high-multi channel calor.

Current status of calibration





- **Remaining ~5% non-linearity for >40GeV electron shower**
- **In hadronic showers smaller energy density (at the same particle E)**
- **non-linearity effects are less relevant for hadrons**

Non-linearity does not effect shower separation (PFlow)
But single particle (not jet) energy resolution sets the scale