Calibration and Monitoring of a Scintillator HCAL with SiPMs

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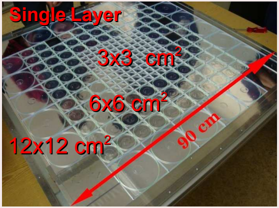
On behalf of the CALICE analog HCAL group

Overview

The Scintillator HCAL Prototype

1 m^3 calorimeter:

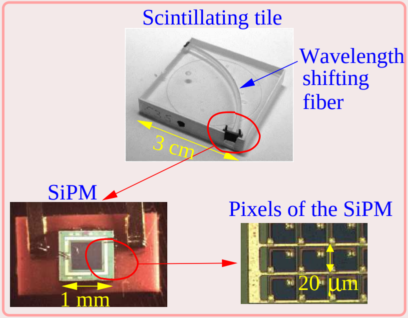
- Purpose:
  - test shower simulation and validate particle flow algorithm (talk by **E. Garutti** on Thursday)
  - establish the SiPM technology on large scale
- 7608 channels, each read out by a SiPM
- 38 layers in sandwich structure: scintillator tiles + 2 cm steel as absorber



- Test beams: 2006/2007 CERN, 2008 FNAL

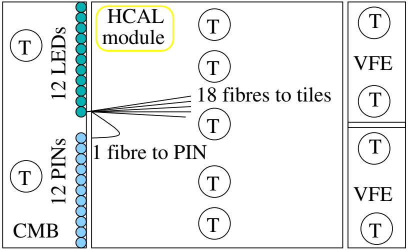
Silicon Photomultiplier (SiPM)

- developed by MEPhi/Pulsar
- matrix of independent pixels, each similar to an avalanche photodetector in Geiger mode
- Bias voltage $\sim$ 50 V
- Gain $\sim 10^6$



Calibration and Monitoring System

- SiPM response depends on temperature and voltage
  $\Rightarrow$ **LED monitoring system**
- One LED illuminates 18 SiPMs and one PIN photodiode to monitor the LED signal



CMB = calibration and monitoring board
T = temperature sensor

- Functionalities of the LED system:
  1) **gain calibration** at low intensity light
  2) provide reference pulses monitored by PIN diodes (not used)
  3) provide **full dynamic range** for checking the SiPM response function

- Temperature monitored by **temperature sensors**

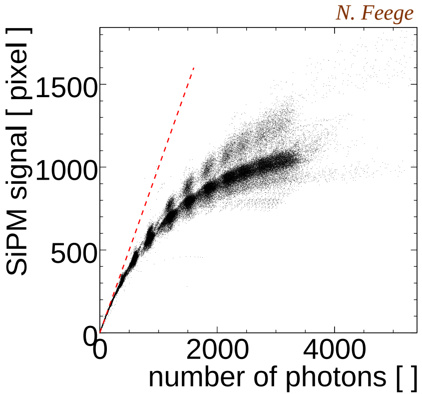
HCAL Calibration Chain

- $\text{SiPM signal} = \sum N_{fired\ pixels}$
- But: limited number of pixels (1156) and finite pixel recovery time (20-500 ns) $\Rightarrow$ **non-linear** response curve
- **From measured amplitude to MIPs**:

$$E[MIP] = \frac{A}{A_{MIP}} \cdot f_{resp}\left(\frac{A}{A_{pixels}}\right)$$

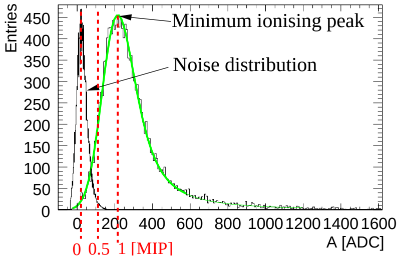
f_{resp} - SiPM response function
$A_{MIP} \leftarrow$ MIP calibration
$A_{pixel} \leftarrow$ gain calibration

- Saturation curves provided by ITEP (Russia) for each SiPM, measured with 'bare' SiPM on the test bench



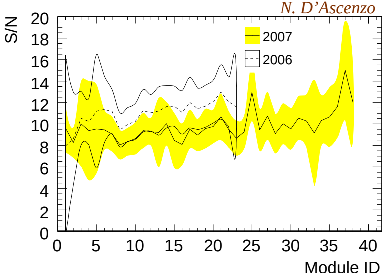
HCAL MIP Calibration with Muons

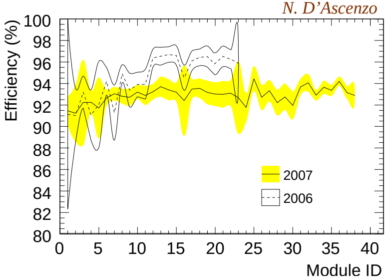
- use **muon** particles as MIPs
- Gaussian + Landau fit of the amplitude for the 216 tiles of every HCAL module
- Zero-suppression: reject hits below **0.5 MIP** $\Rightarrow$ MIP uncertainties affect reconstructed energy and noise level



$$\frac{signal}{noise} = \frac{MIP}{\sigma_{noise}} \sim 9$$

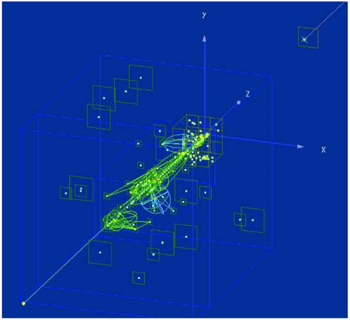
$$\text{MIP Efficiency} = \frac{MIP}{\sigma_{MIP}} \sim 93\%$$





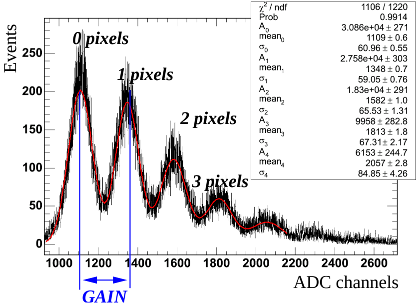
MIP Calibration with Hadrons

1. For a deep-site detector, (cosmic) muons may not be so many
2. Idea (proposed by Alexei Raspereza, 2004): use hadrons as additional MIPs, since $\lambda_i \sim 17$ cm (~ 8 layers) $\Rightarrow$ long tracks within hadron showers are abundant
3. Recent studies done in the Munich group (**Frank Simon**), see later



Gain Calibration

- Purposes:
  - obtain the pixel scale for applying saturation correction
  - monitoring (direct look at the SiPMs)
- Procedure:
  - use the LED system and take spectra at low intensity light for all channels
  - fit single photon spectra
  - **Gain** $\sim$ difference between 2 single photon peak



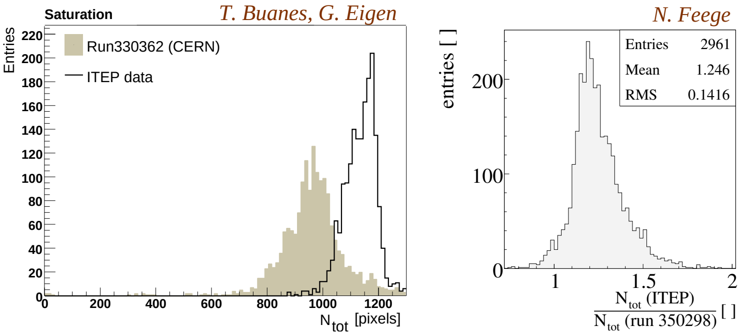
- Efficiency for the CERN test-beam:
  - 96.9% calibrated (1.7% LEDs off, 1.4% missing calibration)
  - modules with missing calibrations calibrated at DESY

Saturation Correction

- Use simple model to describe SiPM response function, e.g.:

$$N_{pixel} = N_{total} \cdot [1 - \exp(-N_{p.e}/N_{total})])$$

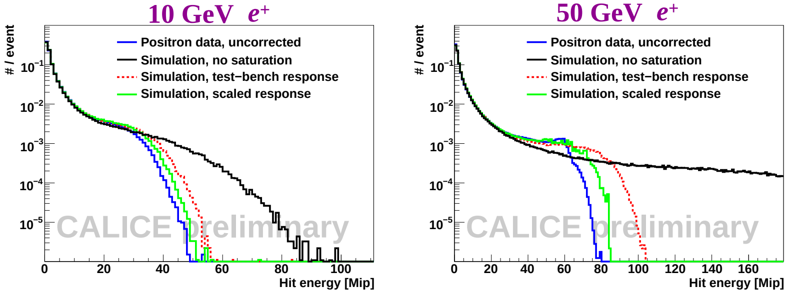
- Compare ITEP and CERN measurements



- Clear shift between N_{tot} from ITEP and CERN measurements (about 20% higher at ITEP)
- Reason: $\Rightarrow$ fiber does not illuminate whole SiPM
  $\Rightarrow$ less effective pixels contributing to light detection

Saturation Rescaling in Electron Data

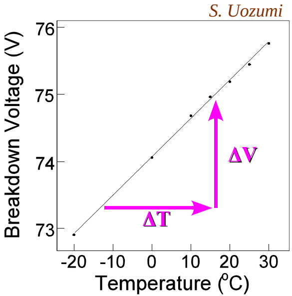
- In-situ saturation curves differ from ITEP measurements
  $\Rightarrow$ Rescale the saturation curves with a factor $N_{tot}(\mathrm{CERN})/N_{tot}(\mathrm{ITEP})$
- Example: e^+ data at CERN 2007

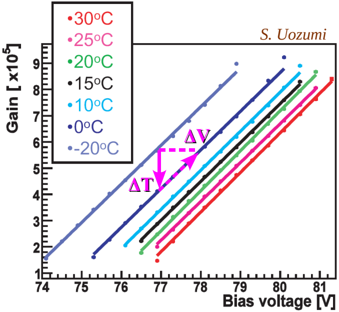


- Energy spectrum with scaled response closer to data
- Still deviations $\Rightarrow$ need exact beam profile to judge how well the saturation is simulated

Time Dependence: Voltage and Temperature Variations

- SiPMs are operated in Geiger mode: $V_{bias} = V_{breakdown} + \Delta V$ ($\sim 50 - 60$ V)
- SiPM signal (charge) depends on gain and Geiger efficiency: $A \propto G \cdot \epsilon$
- Both depend on overvoltage: $\Delta V = V_{bias} - V_{breakdown}$

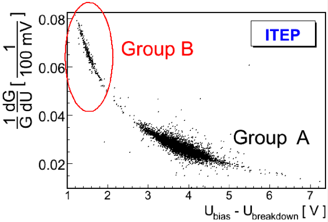




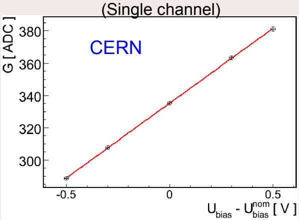
- For $x = A,\ G:\ dx/dT = -dx/dU \cdot dU_{breakdown}/dT$
- Ratio of amplitude and gain coefficient is the same for V and T dependence

G and A dependencies

- Measured at ITEP $\Rightarrow$ 2 groups of SiPMs observed, depending on the applied voltage

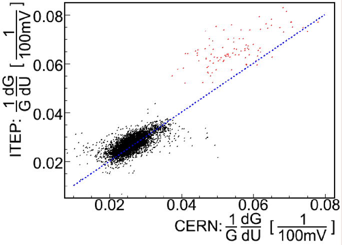


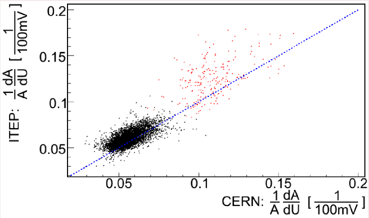
- CERN: different test set-up (different DAQ, etc) $\Rightarrow$ dependencies are reproduced



Relative dependencies: ITEP vs. CERN

A. Kaplan, N. Feege



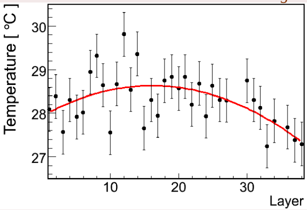


Temperature Dependence

CERN measurements

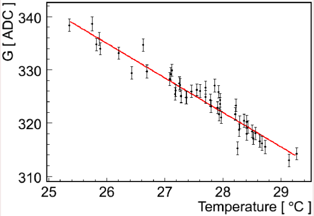
- Measured in test-beam only (i.e. CERN)
- Temperature profile for one T sensor

N. Feege



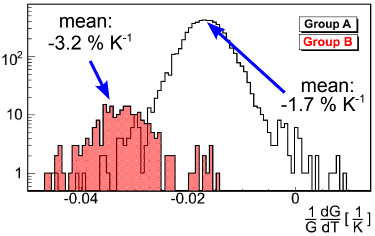
- Gain dependence on T for one SiPM:

N. Feege



Relative dependencies

N. Feege



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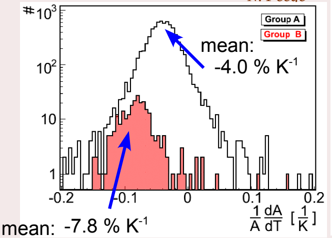
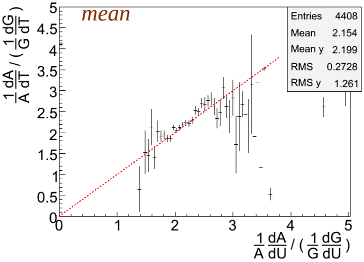
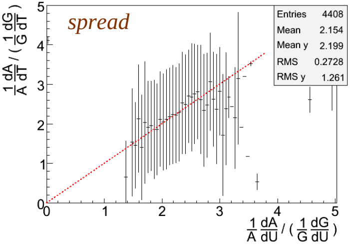


Relation of the Dependencies

- From $\frac{dG}{dT} = \frac{dG}{dV} \cdot \frac{dV}{dT}$ and $\frac{dA}{dT} = \frac{dA}{dV} \cdot \frac{dV}{dT}$ follows $\boxed{\frac{dA/dT}{dG/dT} = \frac{dA/dV}{dG/dV}}$
- Testing this hyphothesis:

A. Kaplan, N. Feege





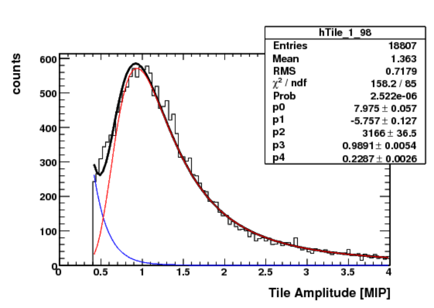
- T and V dependencies are correlated $\Rightarrow$ correcting for one variable accounts for the other

Temperature Correction in Hadron Data

- Hadron data analysed by the Munich group (Frank Simon)
- 'Deep analysis' algorithm of Vassily Morgunov used to select track-like clusters in HCAL
- Amplitude spectra of single tiles fitted with exponential + Landau fit

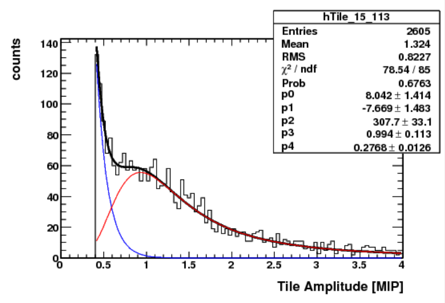
Tile very close to beam axis

- clear MIP peak



Tile outside beam axis

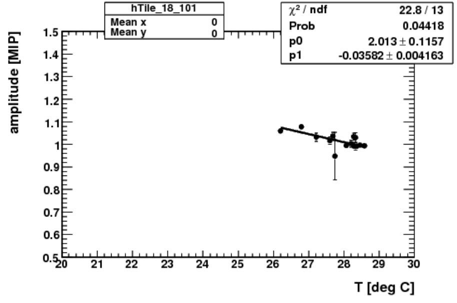
- large background contribution



Temperature Correction in Hadron Data - continued

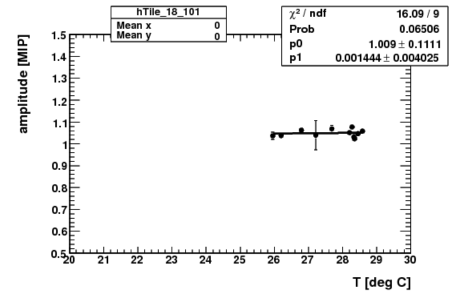
No temperature correction

- Temperature effect from slope of amplitude vs temperature



With temperature correction

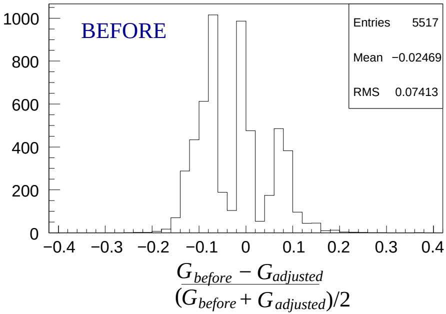
- slope consistent with zero

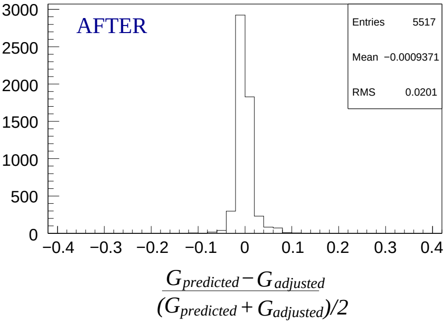


Gain Adjustements

- Aim: correct the effects of temperature changes on the SiPM gain
- Method: determine dG/dV dependency and adjust bias voltage to correct gain deviations: $\Delta U = \dfrac{G - G_0}{dG/dV}$
- Check (FNAL data): $\boxed{G_{predicted} = G_{before} + \Delta U \cdot \dfrac{dG}{dV} \Longleftrightarrow G_{adjusted}}$???

  $\Rightarrow$ corrected gain has the expected behaviour





Conclusions

1. Scintillator HCAL:
   first experiment to handle large sample of SiPMs ($\sim 10^4$)
2. Temperature dependence can be corrected for;
   benefit to be demonstrated
3. Gain monitoring:
   way to look at each SiPM directly
4. Voltage adjustement:
   interesting possibility to correct for gain dependence on temperature