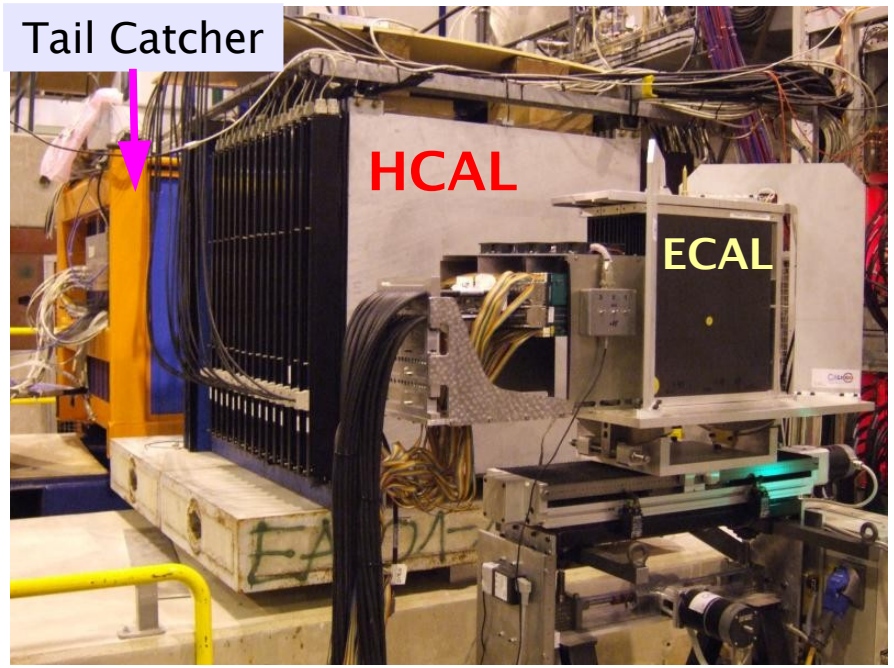
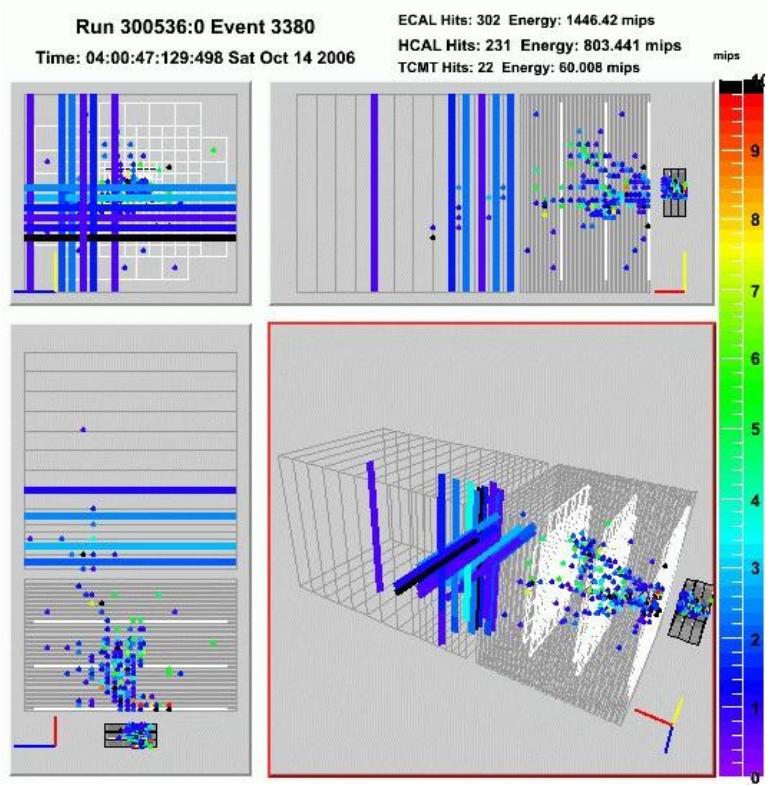
First CALICE Results from CERN Testbeam Data

Sebastian Schätzel, DESY
for the CALICE Collaboration

19 July 2007
EPS Conference Manchester





Calorimeter goals at the ILC

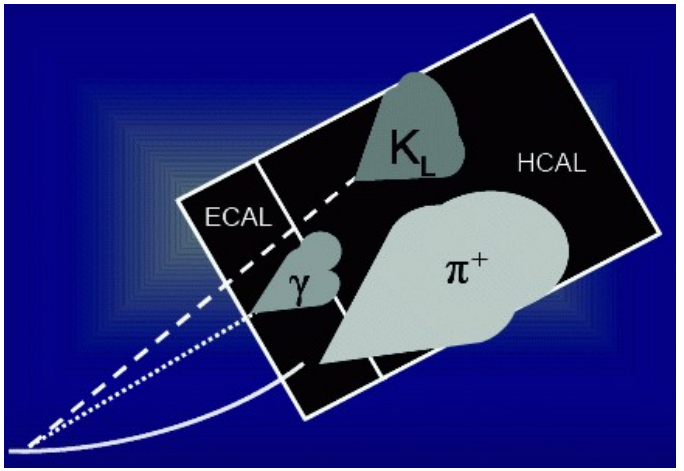
an ILC detector concept: Particle Flow

tracker energy resolution for charged particles better than calorimeter

→ tracker: all charged particles
calorimeter: neutrals

isolate the neutral particle clusters

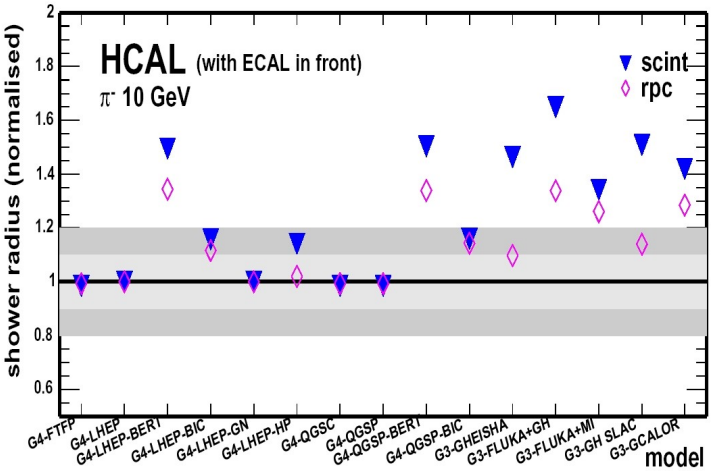
→ unprecedented granularity
1x1cm^2 ECAL, 3x3cm^2 HCAL



CALICE Prototype goals:

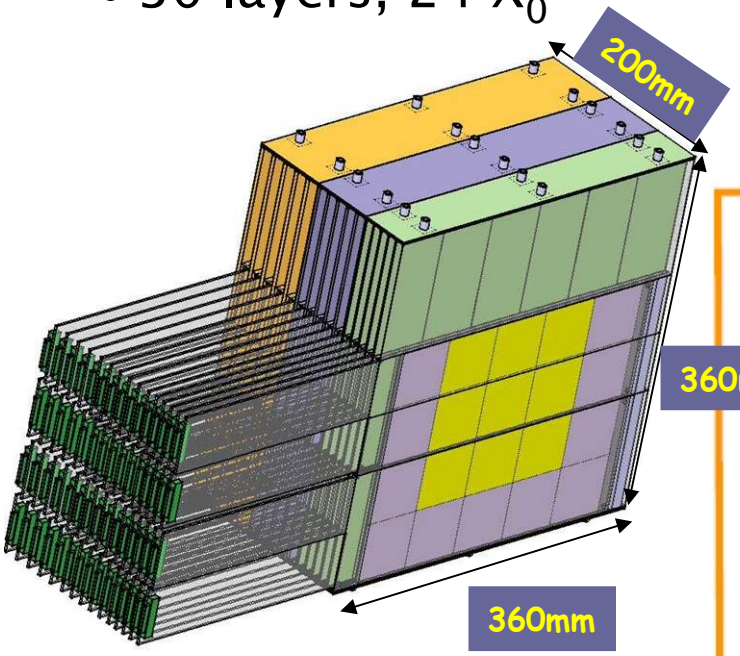
- establish technology that allows high granularity
- resolve fine structures of showers and test models and reconstruction algorithms

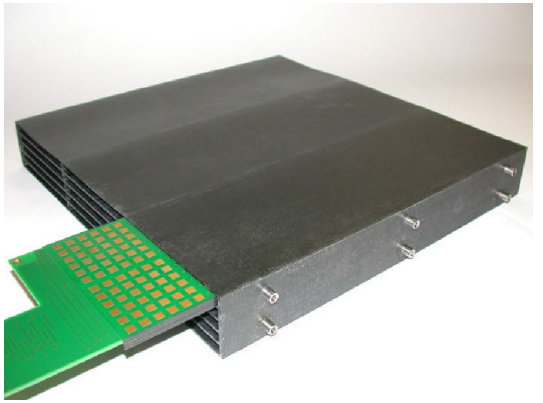
hadronic shower models:



EM calorimeter

- silicon tungsten sandwich
- analogue read-out with silicon pads
- cell size: 1x1cm^2 (~$R_{Moliere}$(W))
- 30 layers, 24 X_0





6 active wafers

- 36 silicon PIN diodes each → 216 channels per board.
- Diode size: $1 \times 1\,\mathrm{cm}^2$.

Calibration chips

- 2 calibration switches chips.
- 6 calibration channels per chip.
- 18 diodes per calibration channel.

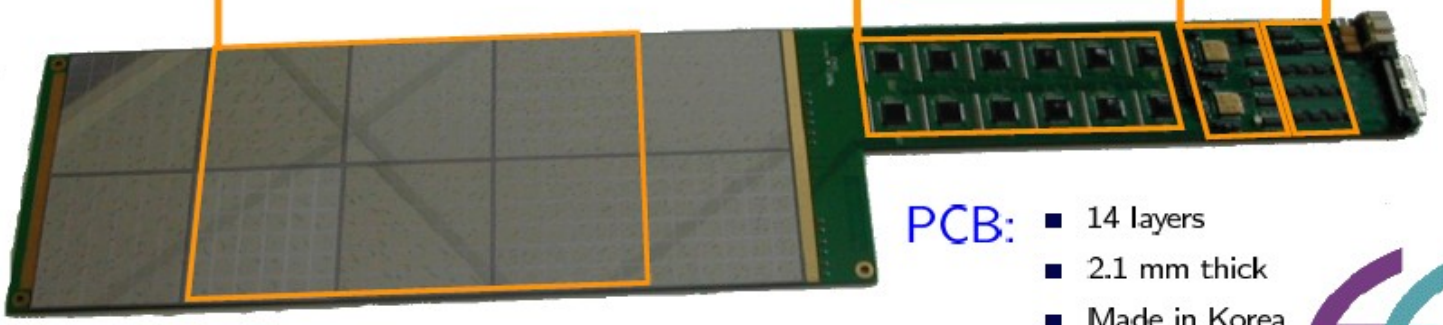
Front-End chip

12 FLC_PHY3 front-end chip

- 18 channels / chip
- 13 bit dynamic range

Line buffers

- To DAQ part
- Differential.

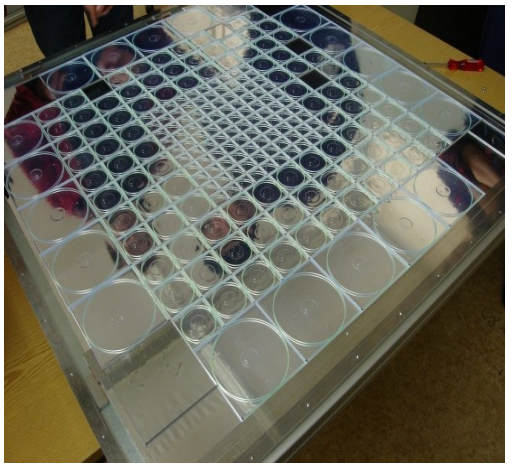


PCB:

- 14 layers
- 2.1 mm thick
- Made in Korea

HCAL structure

- scintillator steel sandwich
- tiles: polystyrene, 0.5 cm thick
- 3x3cm^2 granularity in inner core (6x6 and 12x12 around)
- 216 tiles per layer (1x1m^2), 38 layers
- 8000 read-out channels
- 2cm steel plates



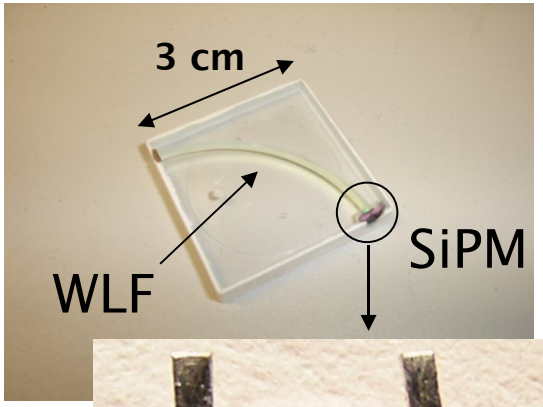
Photosensor mounted on tile:

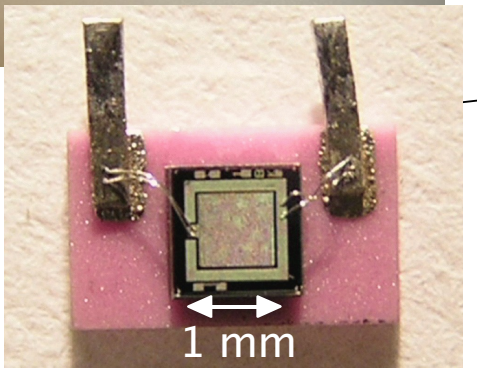
Silicon Photomultiplier (SiPM)

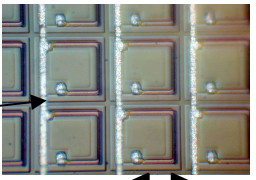
- 1mm^2 active area, 1156 pixels
- matrix of Geiger mode photo diodes
- signal is charge sum of all fired pixels
- signal and gain depends on temperature

$$\frac{1}{Q}\frac{dQ}{dT} = -(3..4)\%/\mathrm{K} \qquad \frac{1}{G}\frac{dG}{dT} \approx -2\%/K$$

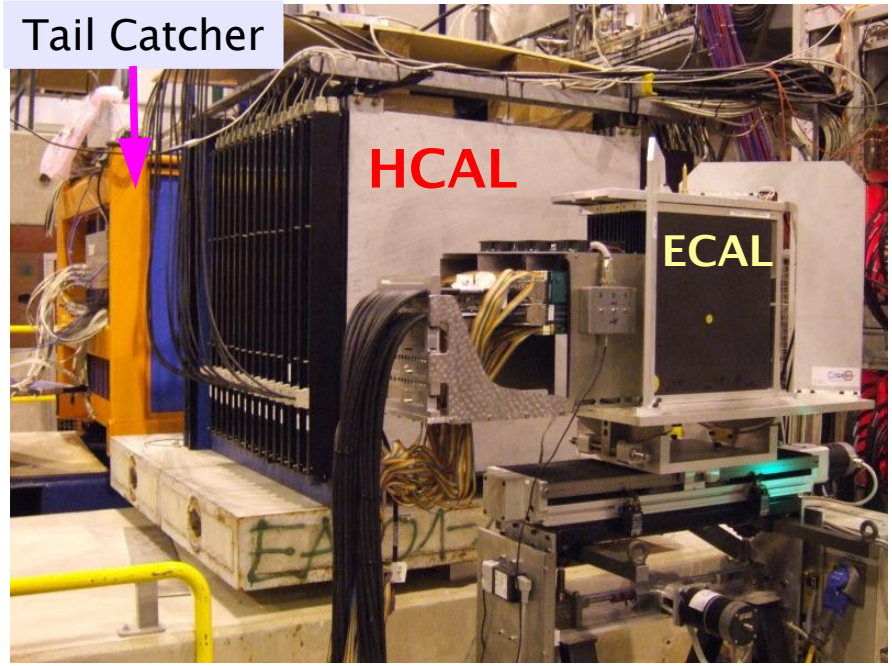
- non-linear response due to pixel dead-time (corrected off-line)







Combined CALICE beam test at CERN SPS



August/October 2006

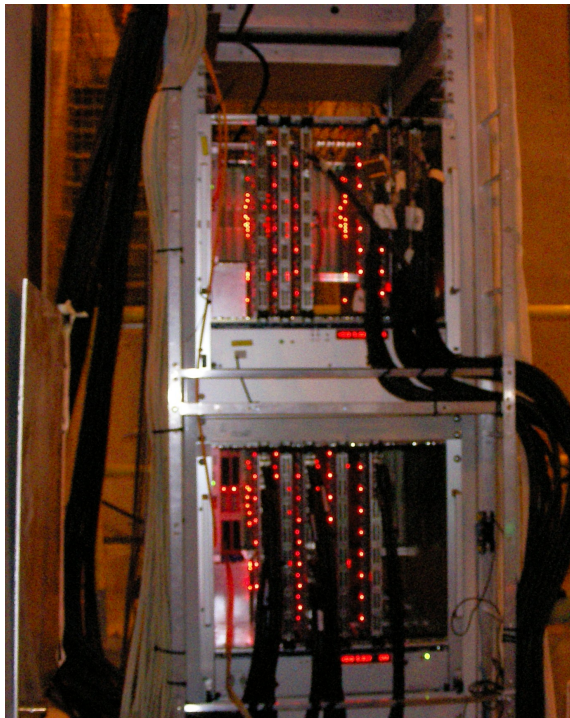
21 days of data taking+12d parasitic μ

combined effort:
tungsten ECAL+ scintillator HCAL+ Tail Catcher
readout through one DAQ system

- 70 Million events recorded
- very stable detector:
  availability>90% (all components!)

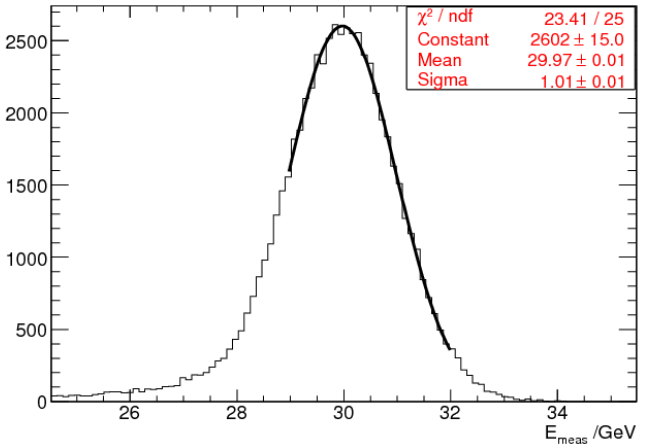
beam	events (10^6)
$e^{+/-}$ 6–50 GeV :	3.5
$\pi^{+/-}$ 6–80 GeV:	22
$e^{+/-}$ without ECAL:	3
Muon calibration:	42

DAQ:
- 500Hz peak rate
- 100Hz typical (limited by particle rate in beam)

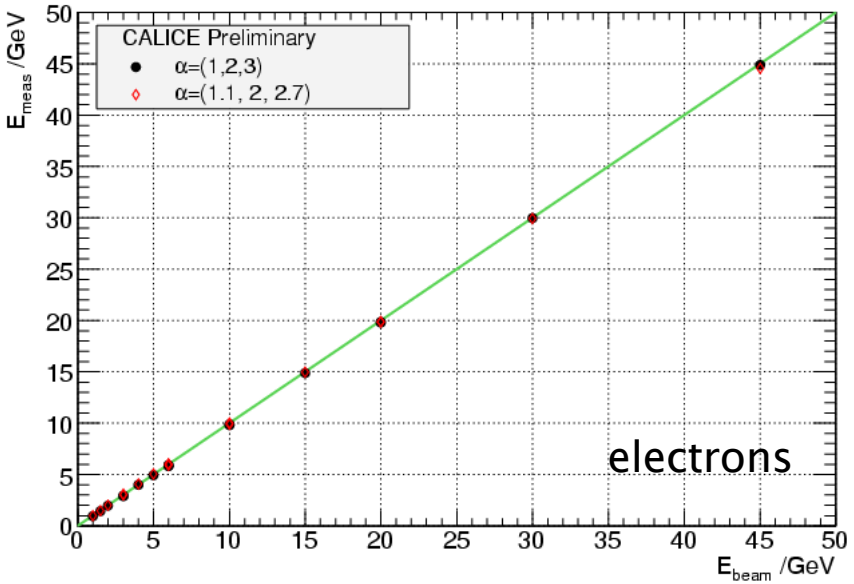


ECAL linearity and energy resolution

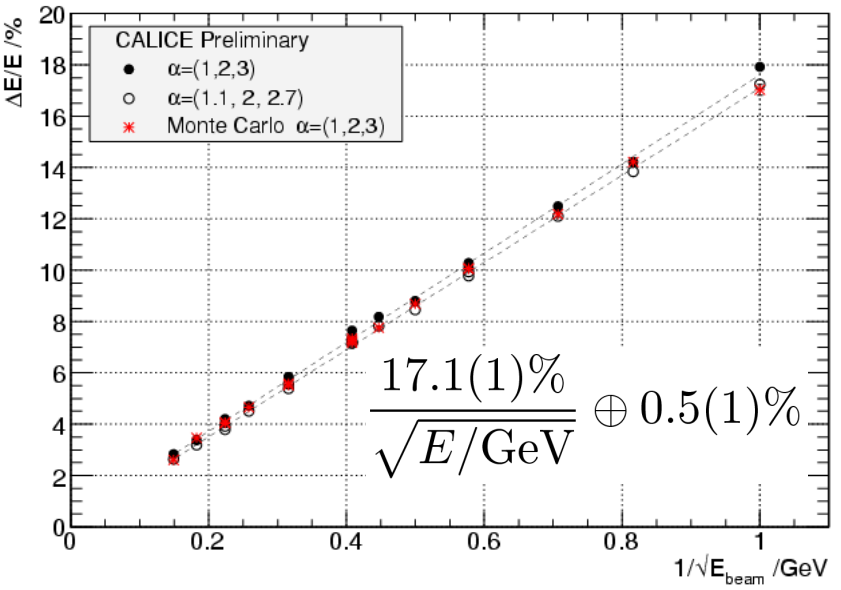
energy sum



linear within 1% from 1–45 GeV

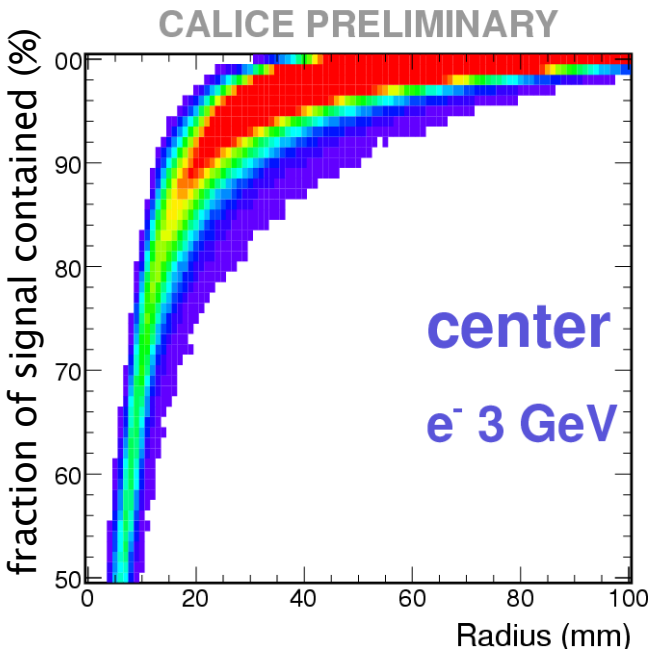


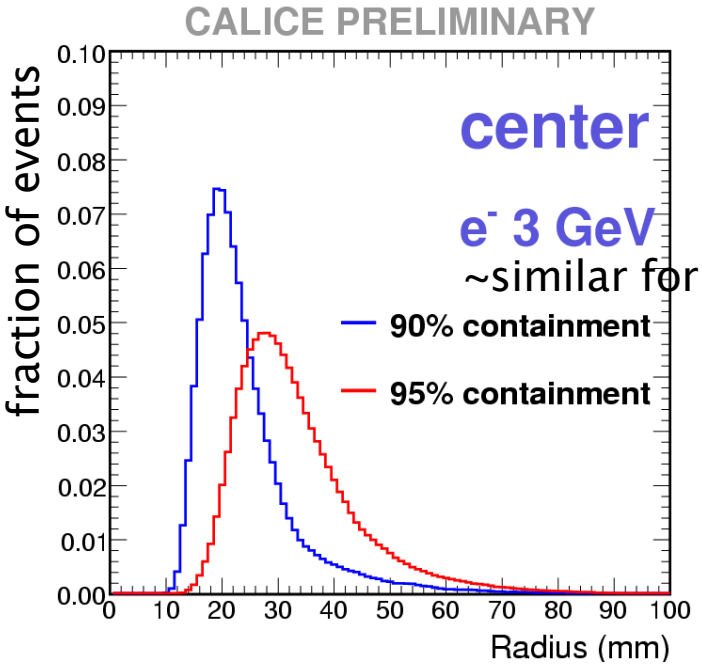
relative energy resolution (electrons)



close to MC expectations

ECAL transverse shower profile





~similar for 1-6 GeV

tungsten: $R_{Moliere} \approx 9$ mm
but ECAL layer structure: $R_{effective} \approx 20$ mm

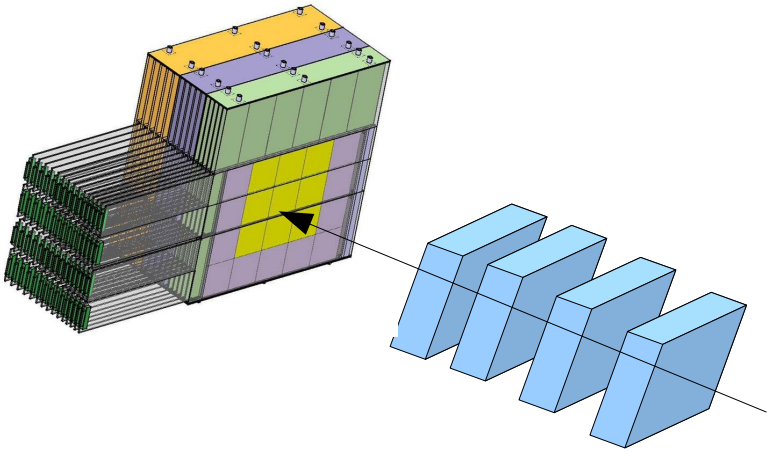
R&D ongoing to reduce the thickness
of Silicon pads+PCB structure (currently 2.1mm)

Tracking with ECAL

reconstruct position $(\bar{x}, \bar{y})$
of shower in each layer

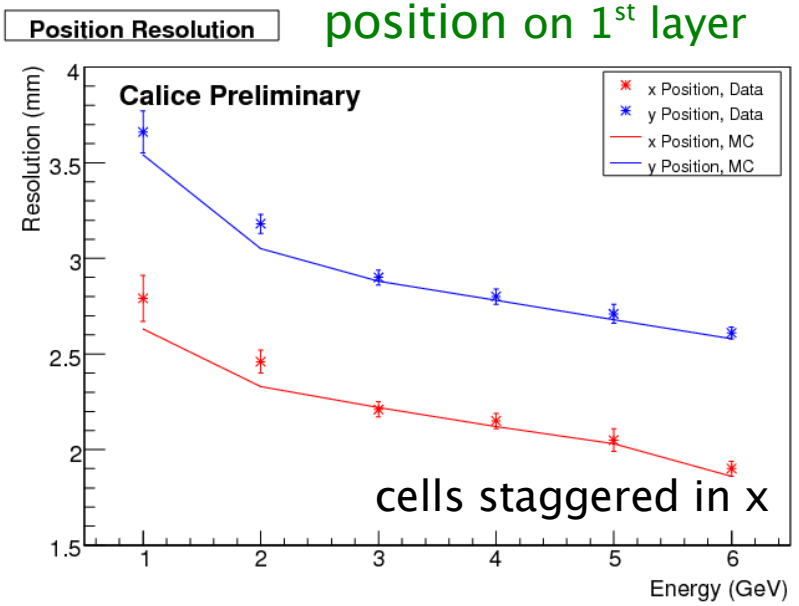
$$\bar{x} = \frac{\sum_i E_i x_i}{\sum_i E_i}$$

➡ track in ECAL

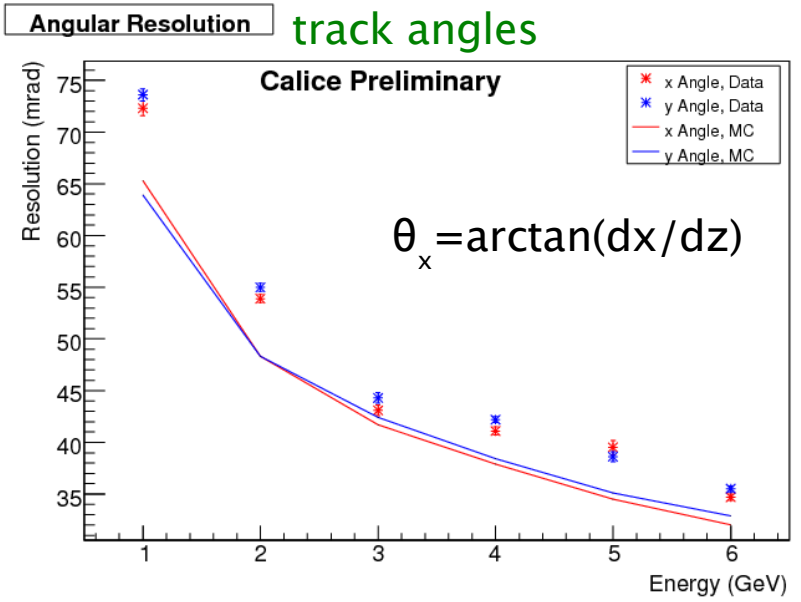


4 drift chambers

determine resolution from difference to drift chamber track

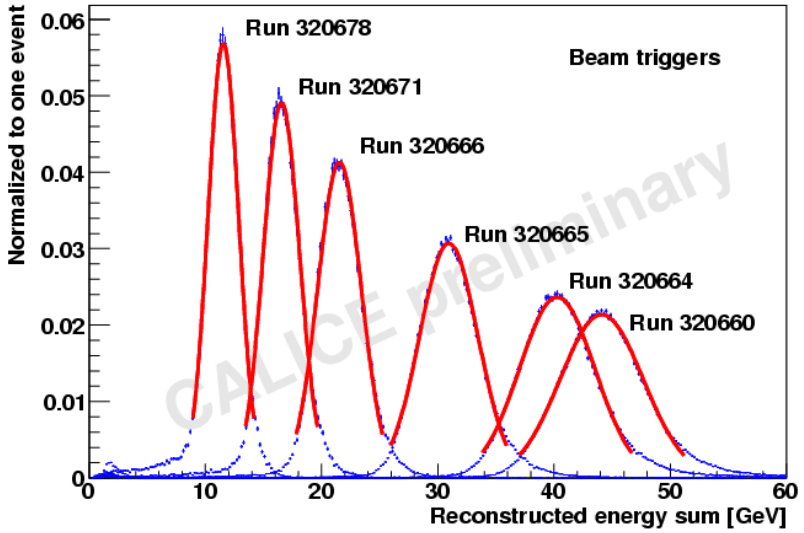


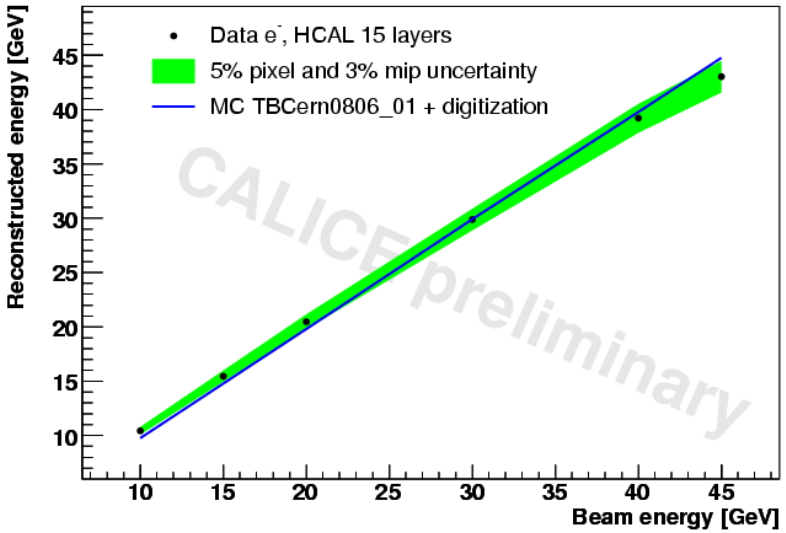
3–4x σ(drift chamber)



10x σ(drift chamber)

HCAL: Electron data





establish calibration procedure for use in hadron analysis

energy scale:

defined by

$E_{rec}(20\ GeV) - E_{rec}(10\ GeV) \equiv 10\ GeV$

linearity after correcting SiPM non-linearity:

within 3% below 30 GeV

6% below 45 GeV

additional noise in data under investigation

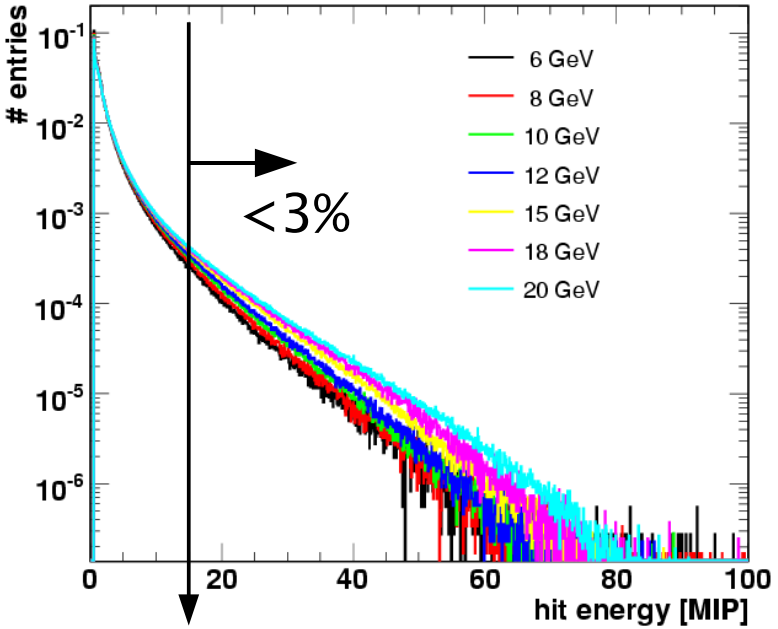
HCAL: Hadron data

6–20 GeV π^-

contained showers selected by veto on tail catcher detector

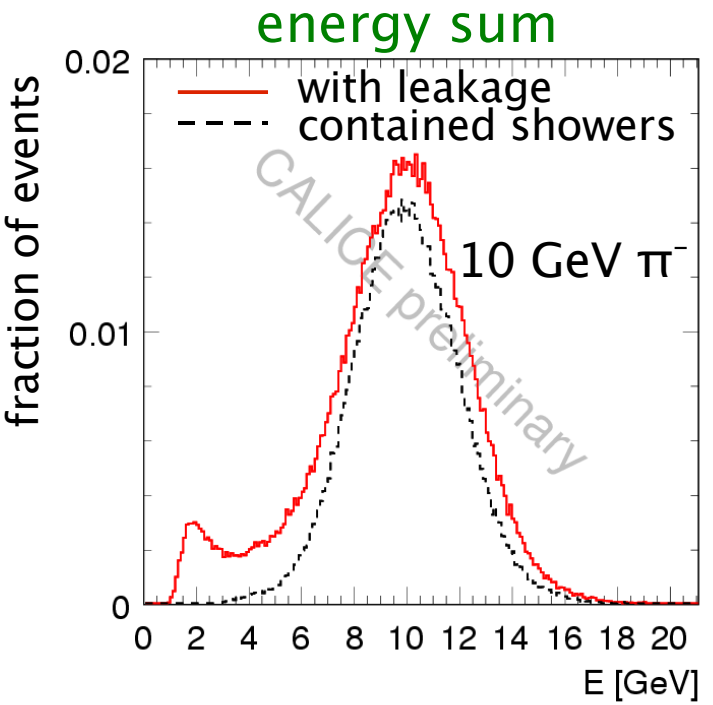
lower hit energy than EM showers

hit energy spectrum



only 10% SiPM non-linearity

energy sum



Systematic errors:

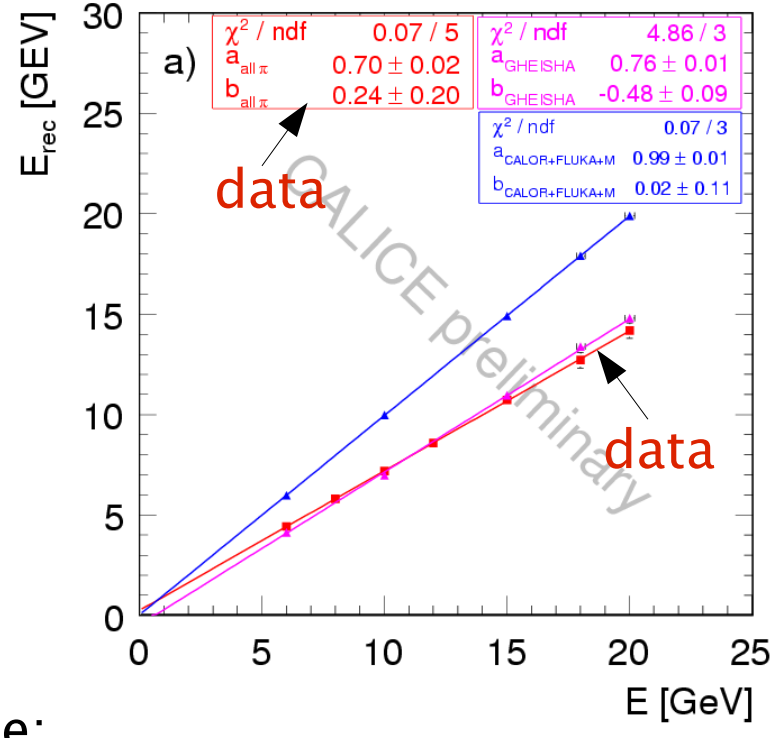
- SiPM non-linearity correction known within 2% (from EM data)
- temperature varied by 1K (day/night)
  ⇨ SiPM signal change by 3..4%

HCAL: energy linearity and resolution

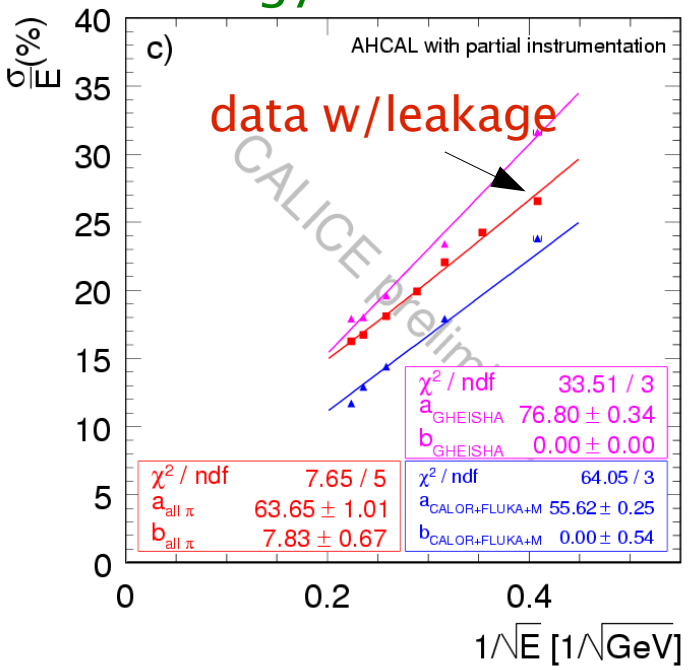
linear response from 6-20 GeV
no offset

energy scale:
defined by scaling E_{rec} by
$E_{rec}(10\ \mathrm{GeV})/10\ \mathrm{GeV}=1.4$

Fits: $aE+b$



energy resolution



with leakage:

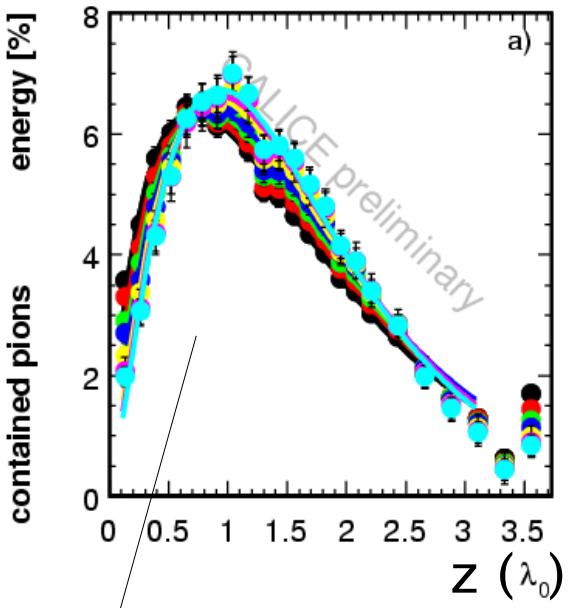
$$\frac{64(1)\%}{\sqrt{E/\mathrm{GeV}}} \oplus 8(1)\%$$

contained showers:

≈60% with vanishing constant term

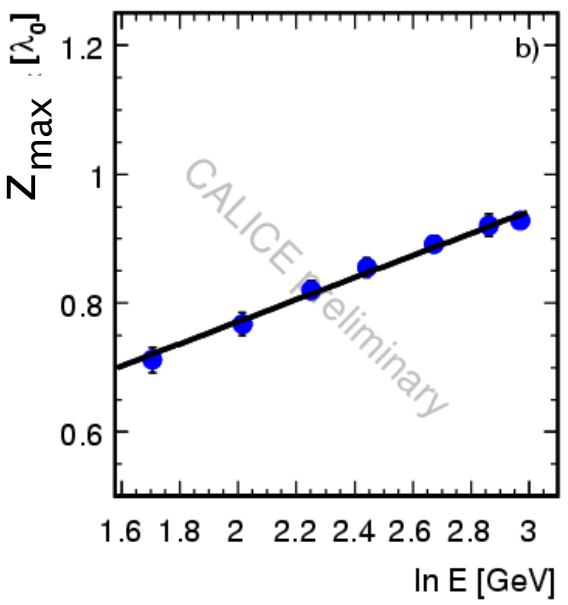
HCAL: longitudinal hadron shower profile

shower profile
for different energies

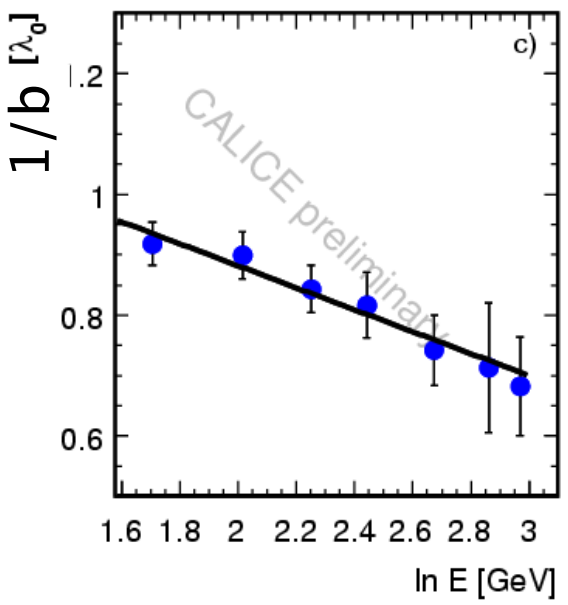


Fits: $Nz^a e^{-bz}$

position of maximum
energy deposition



attenuation



depth of “shower maximum” and “attenuation” of shower depend linearly on log(E/GeV)

Conclusions & Outlook

- prototypes for ILC calorimeters built and operated in test beam
- unprecedented granularity

- First preliminary measurements have been shown
- The detectors are understood in terms of MC simulation
- energy resolution as expected from MC
- shower profiles show expected behaviour
- HCAL calibration established: SiPM saturation correction understood within 3% below 30 GeV

Outlook:

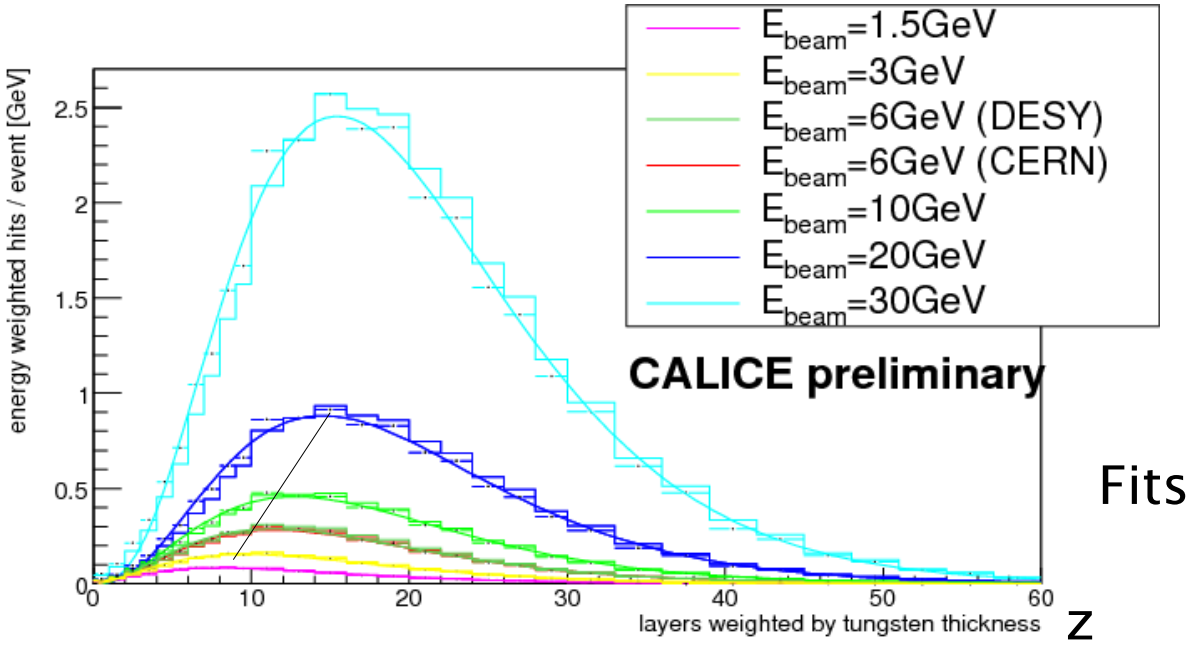
- R&D is ongoing to improve for large-scale prototype (EUDET)
- HCAL: further SiPM stabilisation (temperature) using LED calibration system

- detailed comparisons with shower models
- shower decomposition based on energy density and “tracks”

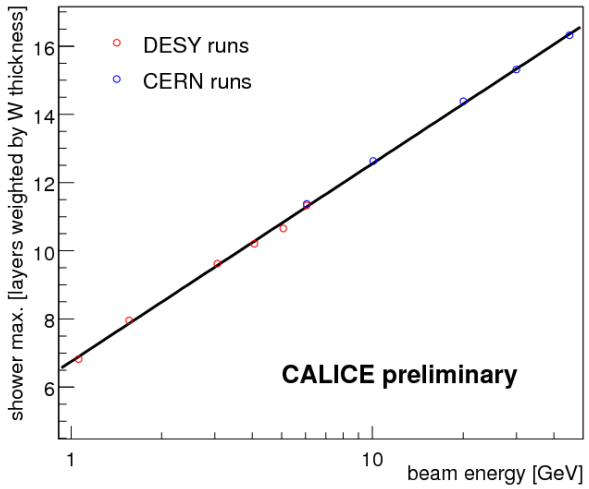
- new data is being taken at the moment at CERN (full instrumentation)

Backup Slides

ECAL: longitudinal shower profile



Fits: $N z^a e^{-bz}$



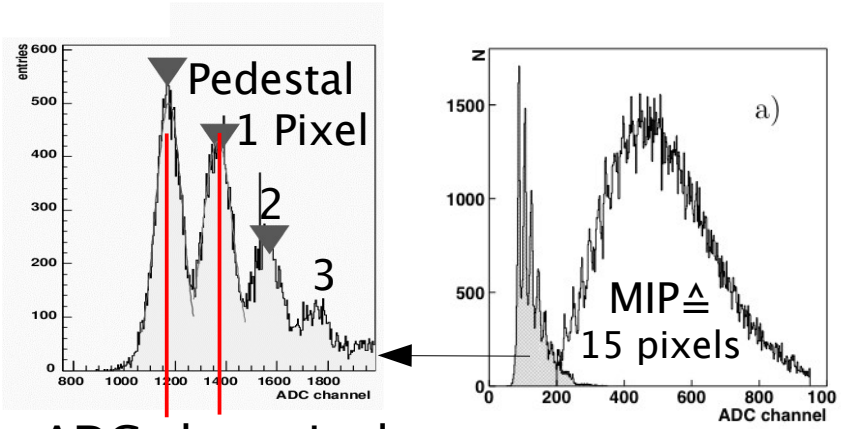
depth of "shower maximum" depends linearly on log(E/GeV)

Scintillator HCAL Calibration

SiPM non-linear response

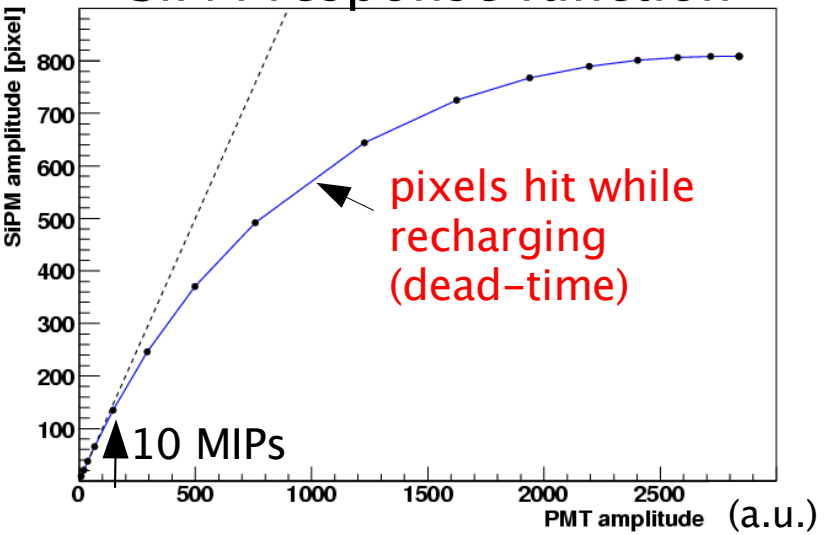
using laboratory-measured curve of every SiPM to translate signal to a linear scale

Low intensity LED light

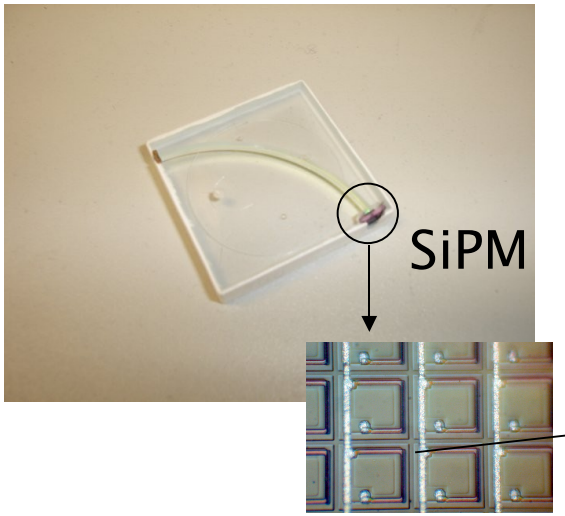


ADC ch.↔pixels conversion factor (2% precision)

SiPM response function



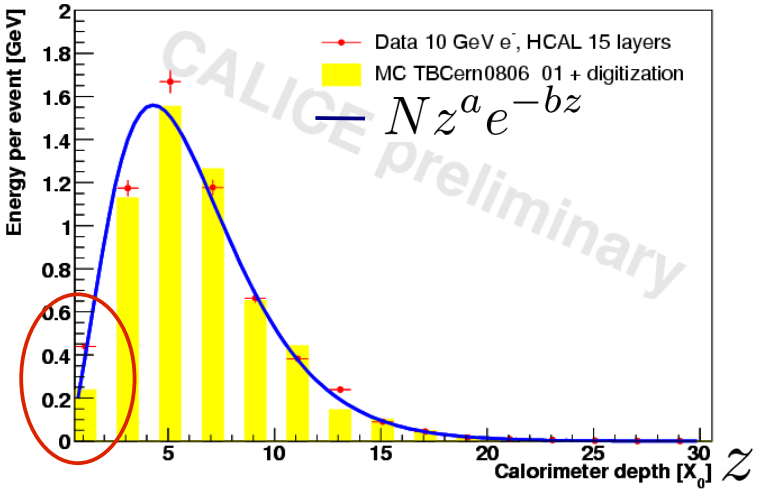
intensity (linear scale) known to 5% (dominated by uncertainty of curve)



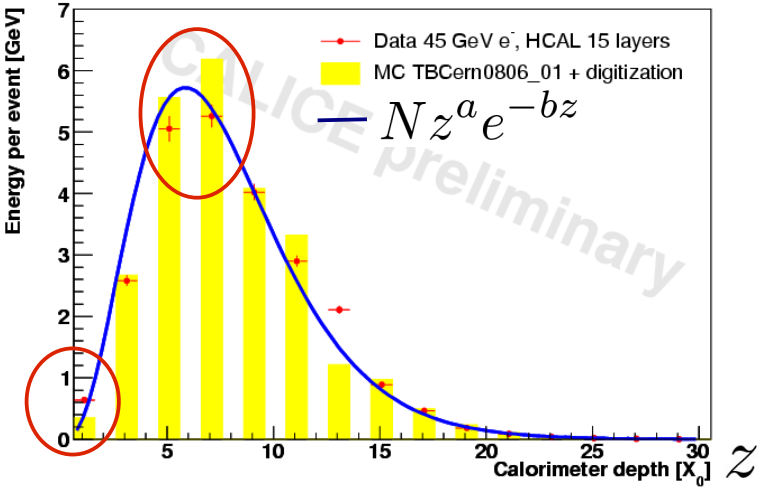
pixel recharge time $\tau = RC = 20\text{-}30\text{ns}$

HCAL: electron longitudinal shower profile

10 GeV e⁻



45 GeV e⁻



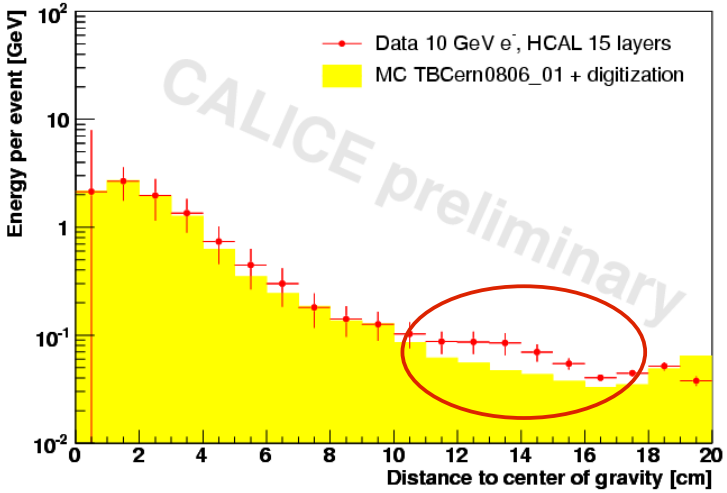
more energy in first layer than predicted

energy in core not well described

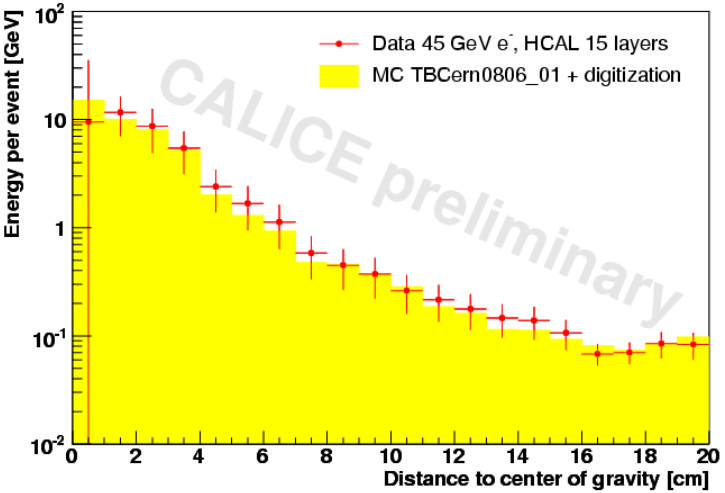
⇨ needs investigation

HCAL: electron transverse shower profile

10 GeV e^-



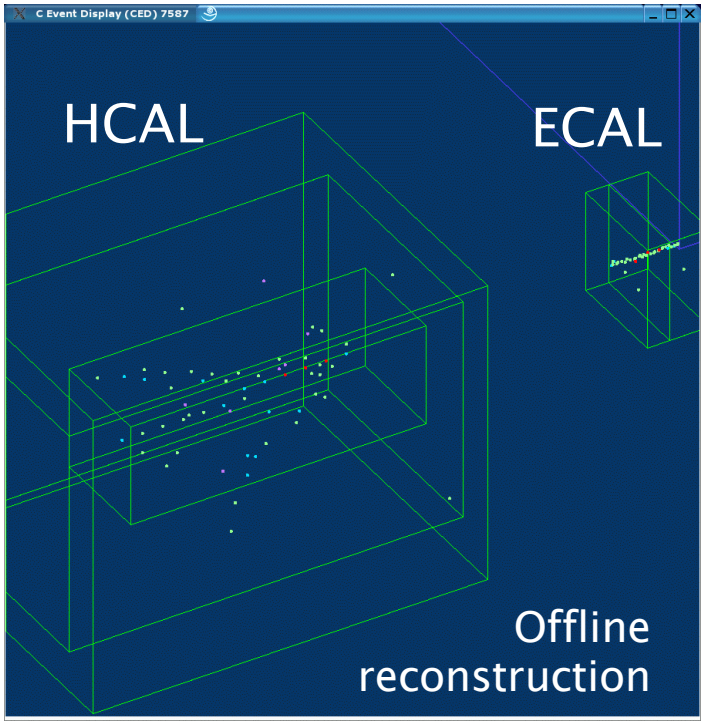
45 GeV e^-



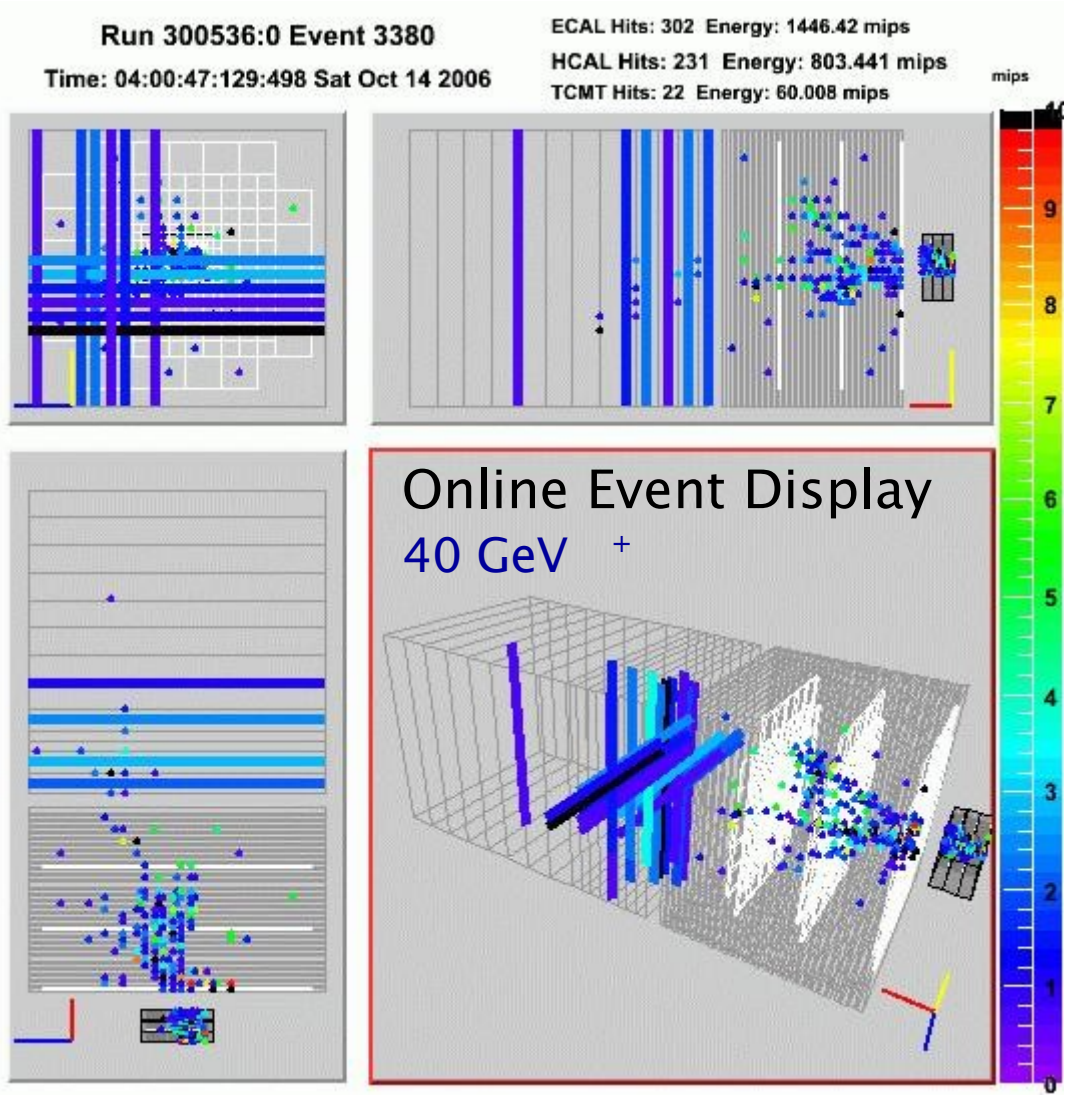
good overall agreement

more energy away from centre than predicted
⇨ needs investigation

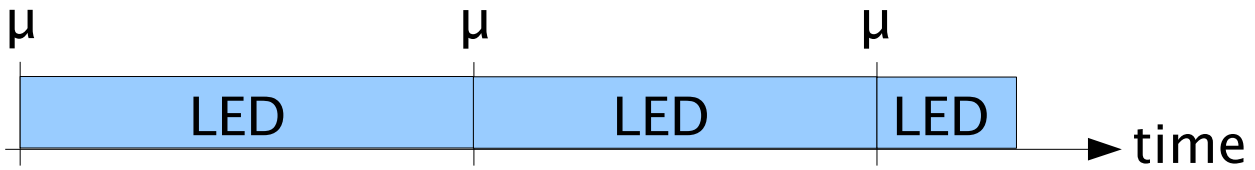
Event Displays



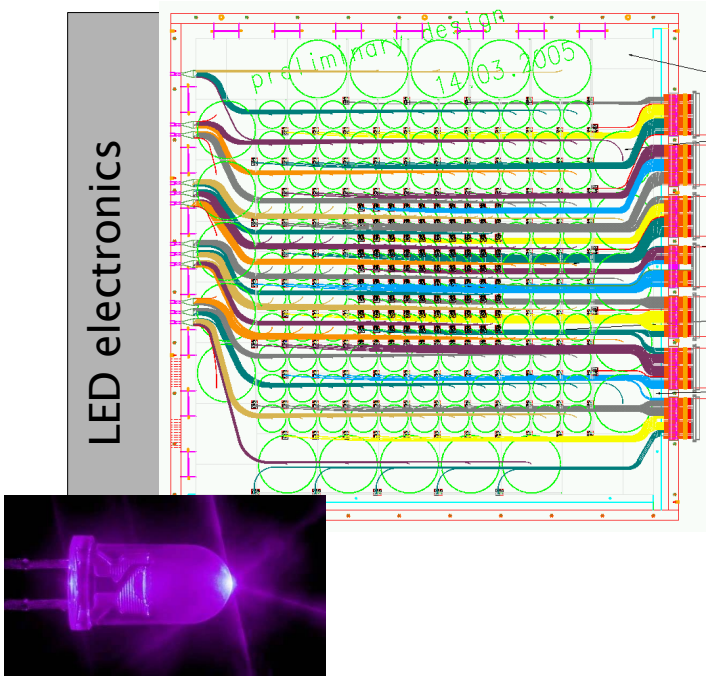
beam



HCAL LED System



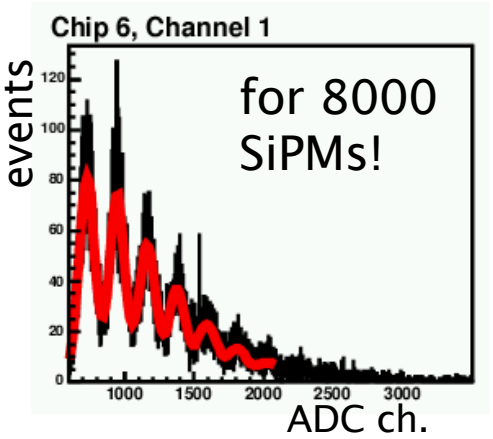
Muon calibration runs and LED monitoring



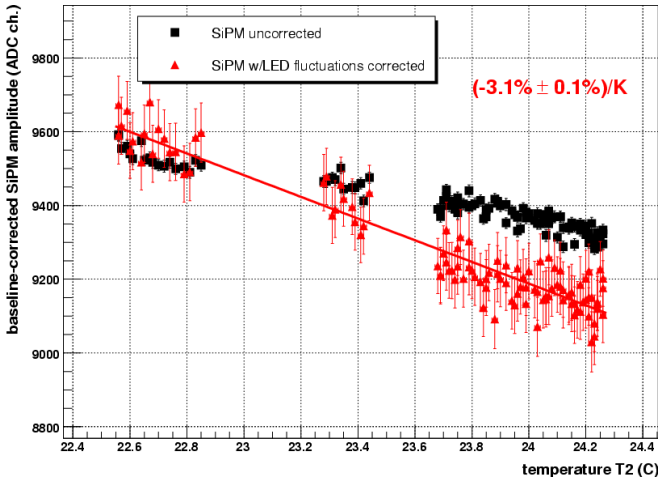
LED system:

- 10ns pulses
- Intensity: 0–100 MIPs (steered from DAQ)
- 424 UV-LEDs (18 SiPMs pro LED)
- Light distribution via optical fibres
- 424 PIN photodiodes to measure LED intensity

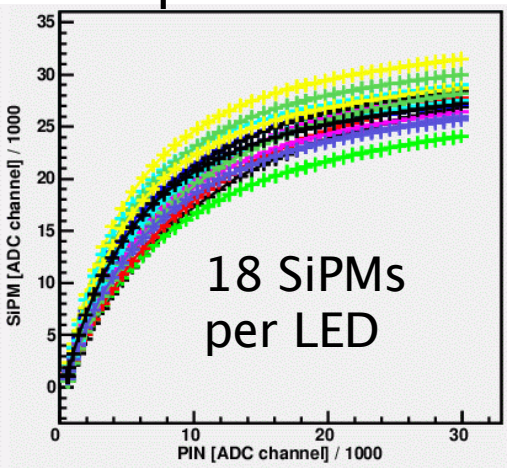
ADC ch.↔#Pixel



Temperature:



Monitoring of response curve



Tail Catcher

- extruded silicon strips (5cm x 1m), thickness 0.5cm
- alternating horizontal and vertical orientation
- SiPM readout (via WLF)
- uses AHCAL readout electronics
- LED system

- 20 strips per layer
- 320 readout channels
- Sandwich:
  - 8 layers with 2cm steel
  - 8 layers with 10cm steel
  - total: 5.7λ
- weight: 10t