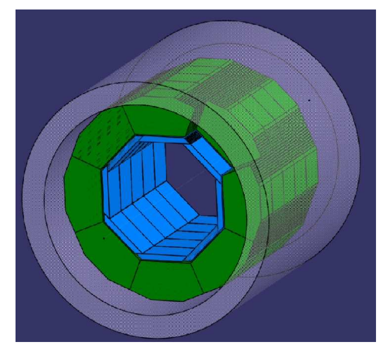
Tile AHCAL Test-Beam Data Analysis

Riccardo Fabbri

on behalf of the *CALICE* Collaboration

LCWS-ILC 2008 **Chicago, 18 November 2008**

- **The Scintillator HCAL Prototype**
- **Calibrations**
- **Positron Data**
- **Pion Data**
- **Shower Separation**
- **Conclusions and Outlook**



The Scintillator HCAL Prototype

- **Prototype of Analogue Scintillator Hadronic Calorimeter (AHCAL) for ILC detector**

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  combine Calo+Tracking+Software info to achieve jet energy resolution of $\approx 30\%$

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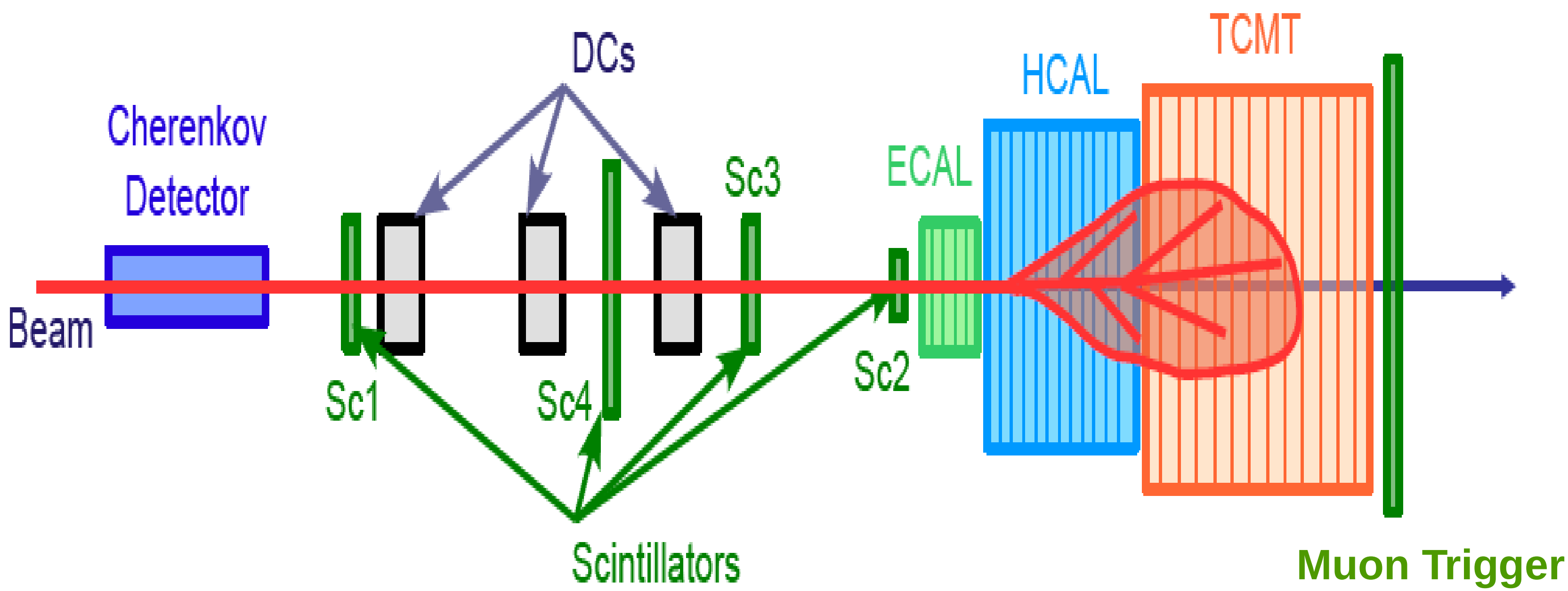

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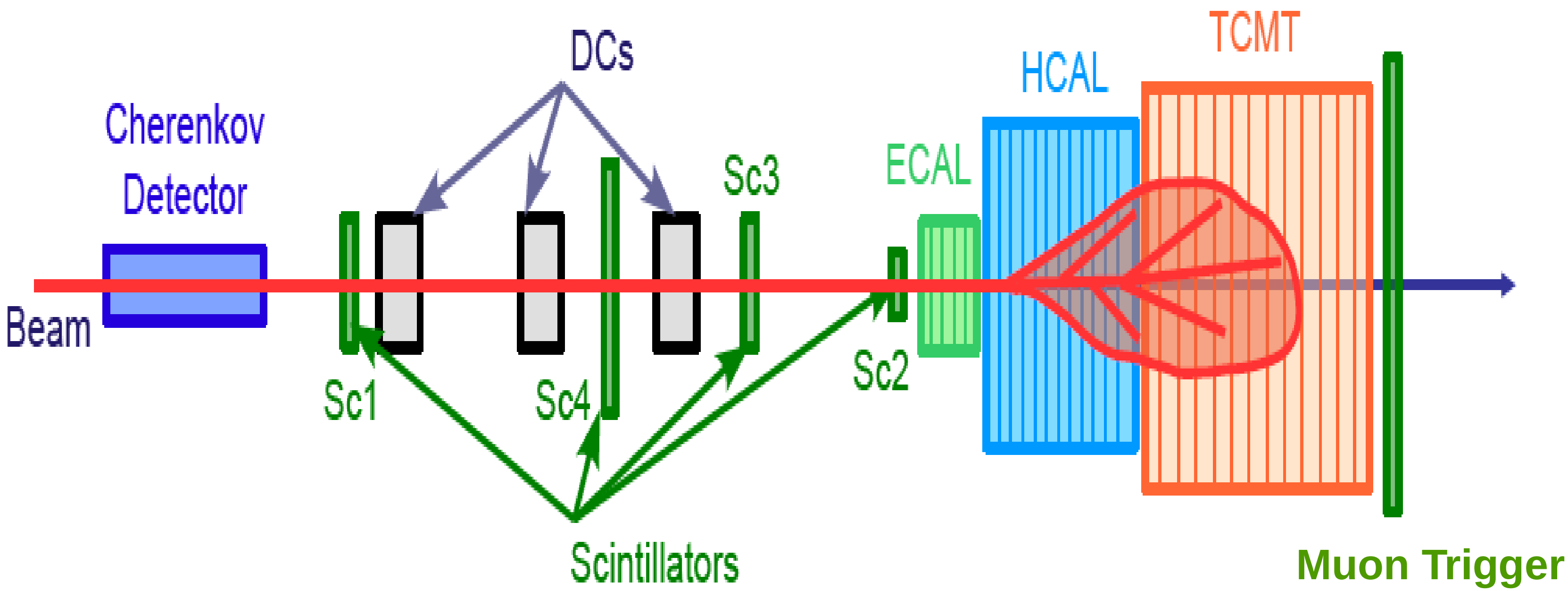


- **Test beam goal:**

  — establish technology to use

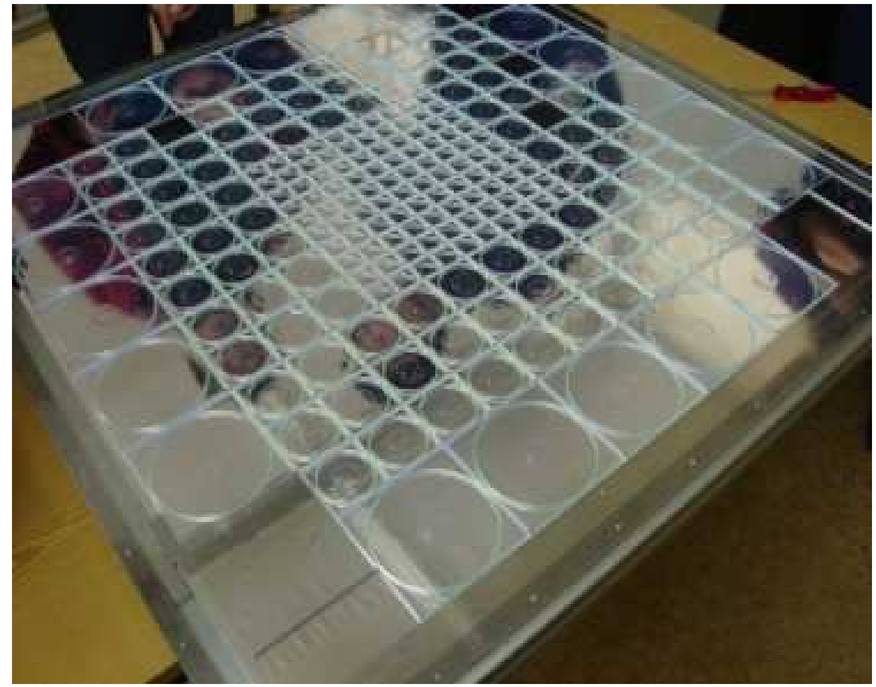
  — tune the reconstruction algorithms

  — validate/tune Monte Carlo models

The Scintillator HCAL Prototype

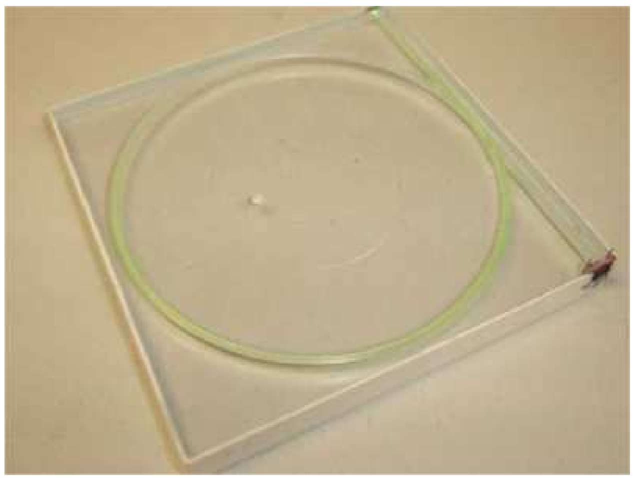
Prototype setup [1 m^3]:

- **38 layers in sandwich structure:**
  — scintillator tiles + 2 cm absorber (steel)
  — total interaction length 4.5 λ
- **Tile size: 3x3 cm^2, 6x6 cm^2, 12x12 cm^2**

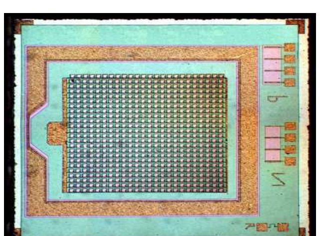


Tot nr. of tiles:

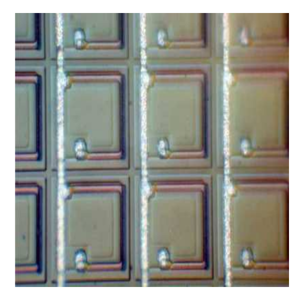
7608



- **One SiPM (1x1 mm^2) per tile:**
  — wavelength-shifter coupled
  — developed by MEPhi/Pulsar



- **1156 pixels (30x30 μm^2) per SiPM:**
  — Geiger mode



Calibrations

Gain Calibration

- Gain defined as $G = \frac{Q_{pixel}}{e}$: $\Longrightarrow$ typically $Q_{pixel} \approx$ a few 100 fC $\approx 10^6$ e
- Each SiPM has its own gain
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  - **— illuminate SiPMs with low intensity LED light**
  - **— fit single-pixel spectra for each SiPM**
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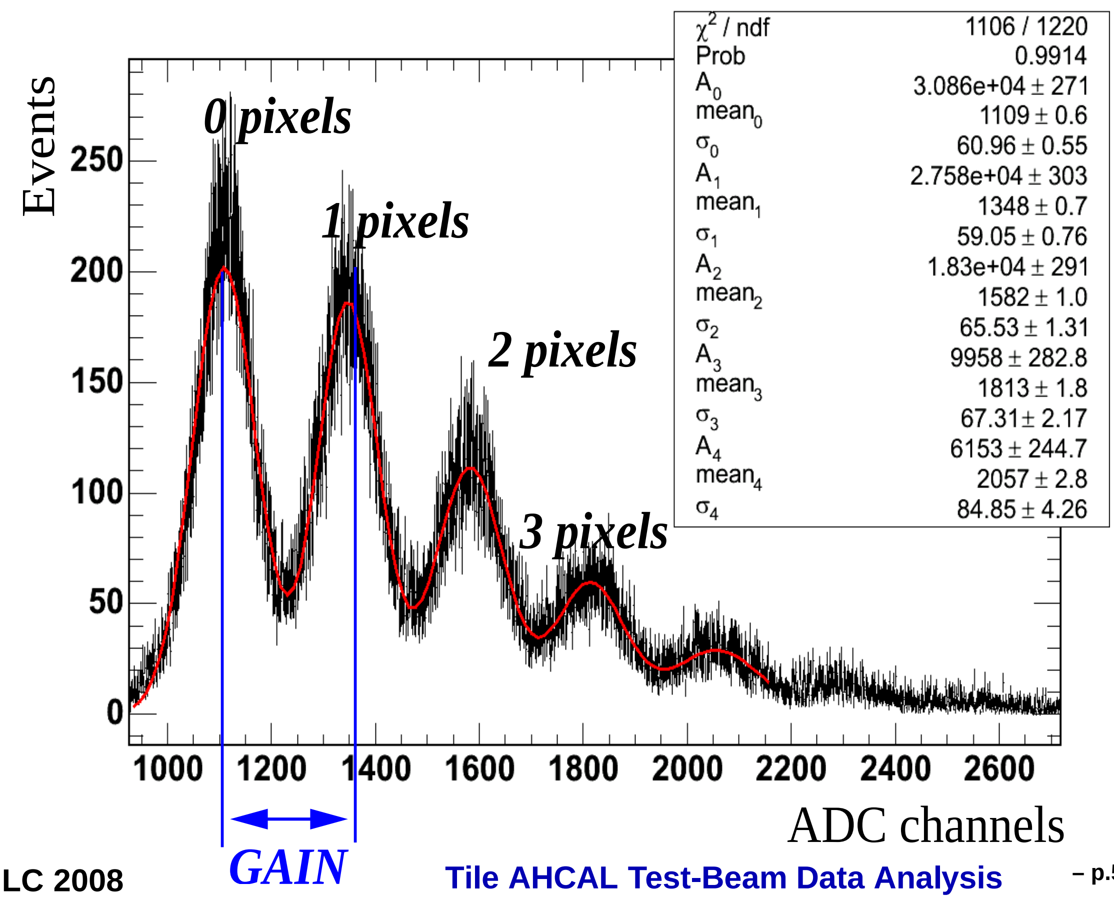

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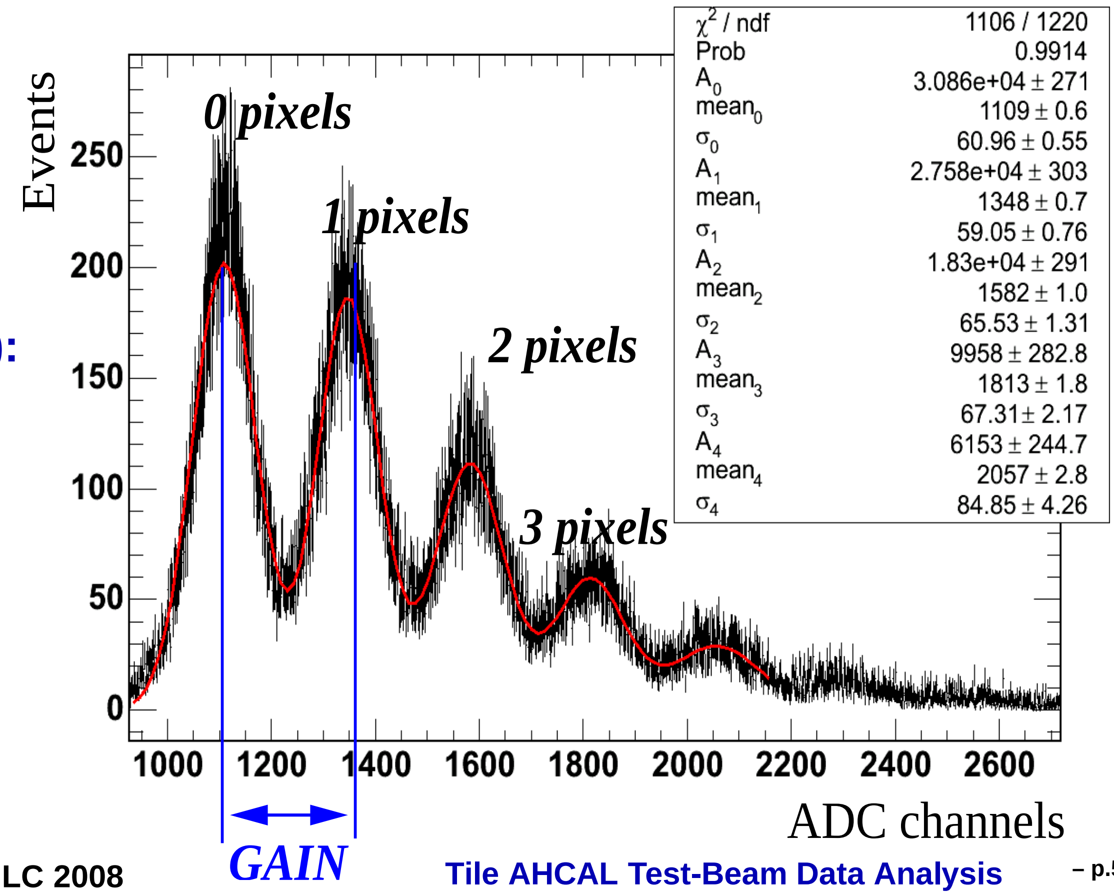

- **Calibration efficiency (CERN data):**
  - — 96.9% SiPMs calibrated
  - — 1.7% LEDs off
  - — 1.4% missing calibration

MIP Calibration

- **MIP calibration: conversion from Hw ADC values (variable from channel to channel) to a physical quantity**

  $\Rightarrow$ **SiPM response to passage of minimum ionizing particles**

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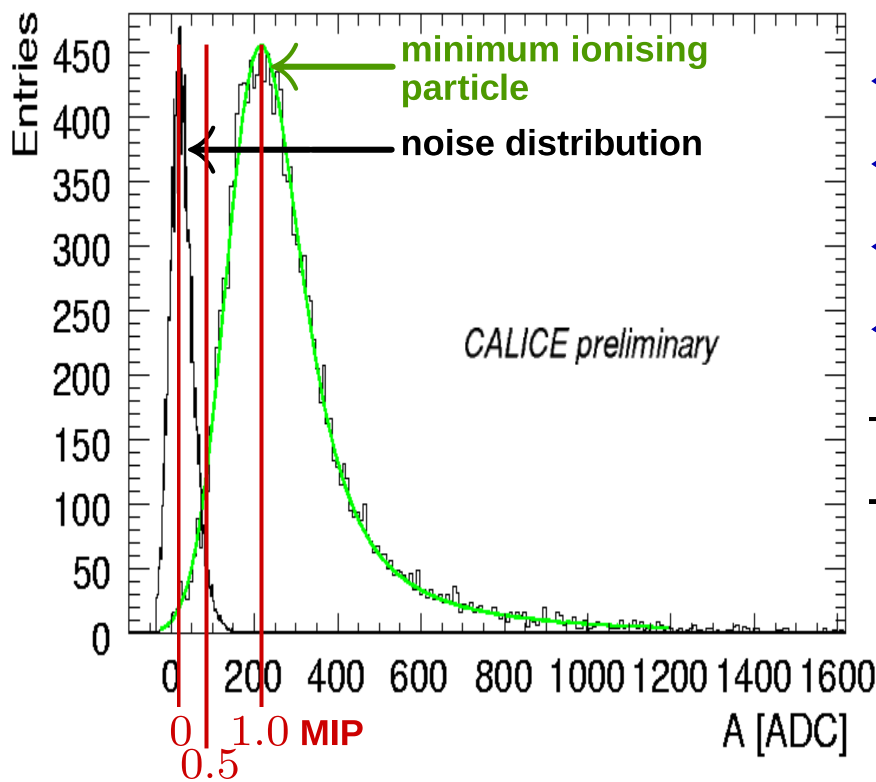

For every tile:

- **fit muon signal with Gauss+Landau**
- **set MIP to MPV from fit**
- **from Monte Carlo: 1 MIP = 0.861 MeV**
- **in analysis reject hits below 0.5 MIP**

— **mip detection efficiency** (A_{mip}/σ_{mip}) $\approx 93\%$

— **MIP scale total uncertainty:** $\approx 2\%$

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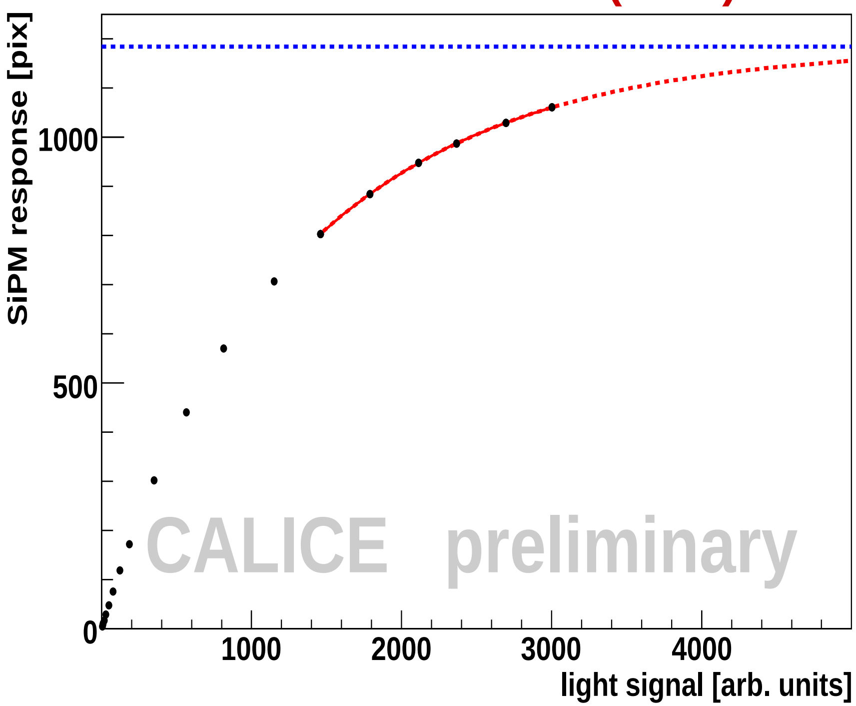
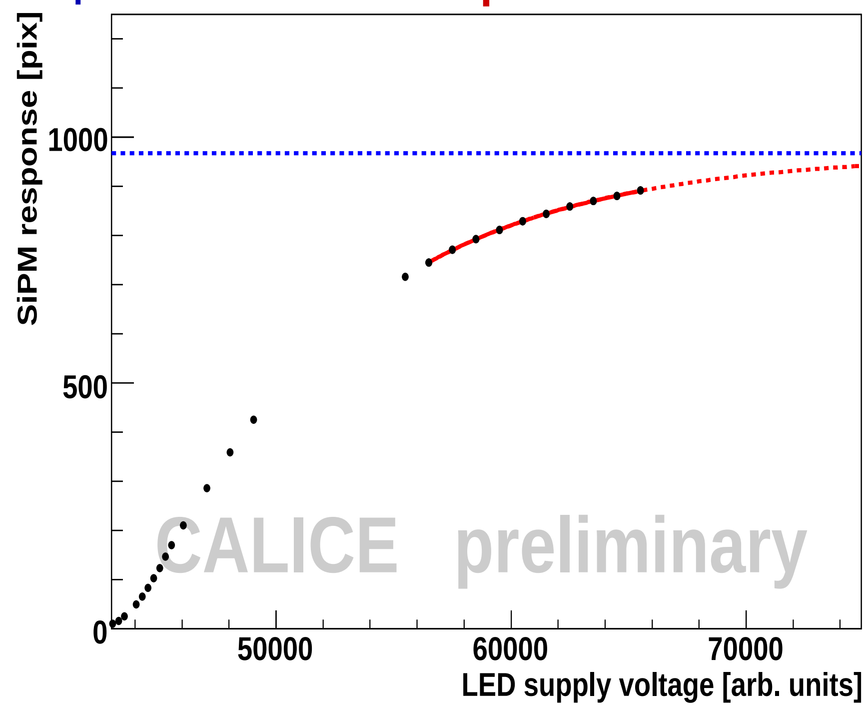
- Non-linearity corrected with saturation curves [response vs input signal]
  - — two sets of curves available: ITEP and LED monitoring system
  - — differences between them originated by fiber-SiPM mis-alignement

test-bench curve (ITEP) One SiPM example: in-situ response curve





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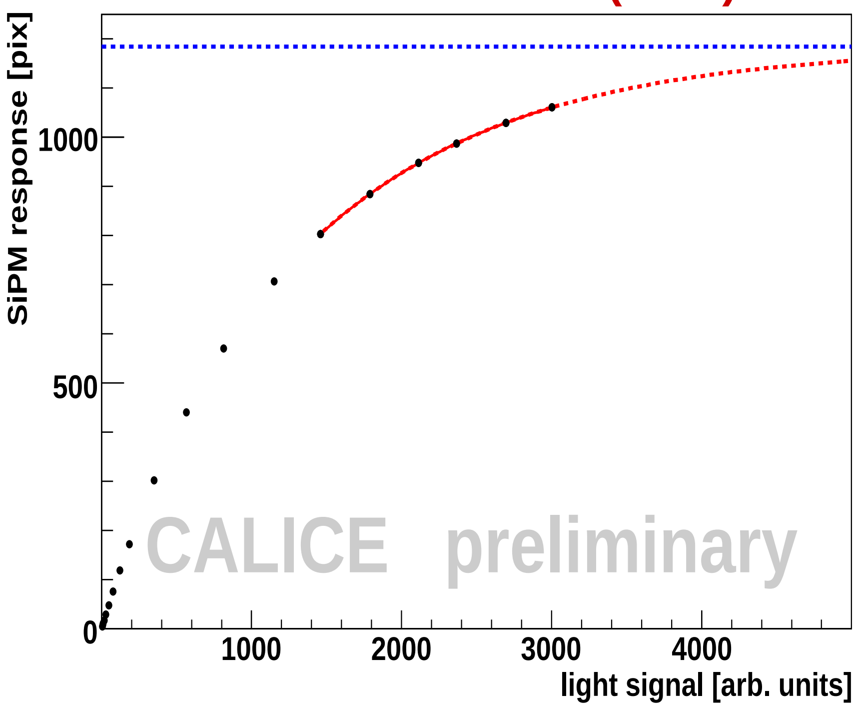

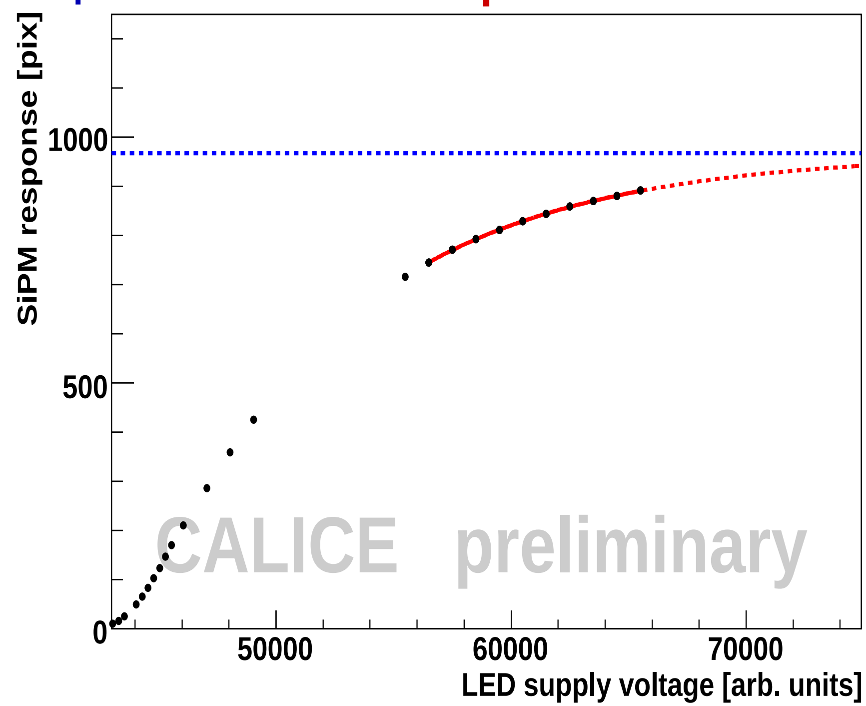

- **UP to 2007: curves from ITEP**
- **NOW: extract asymptotic level from in-situ curves and rescale ITEP curves**

$\Rightarrow$ **improvement in calorimeter response**

Temperature Correction of SiPM Gain

- **SiPMs operated in Geiger mode:** $V_{bias} = V_{breakdown} + \Delta V$ **($\approx 50 - 60V$)**

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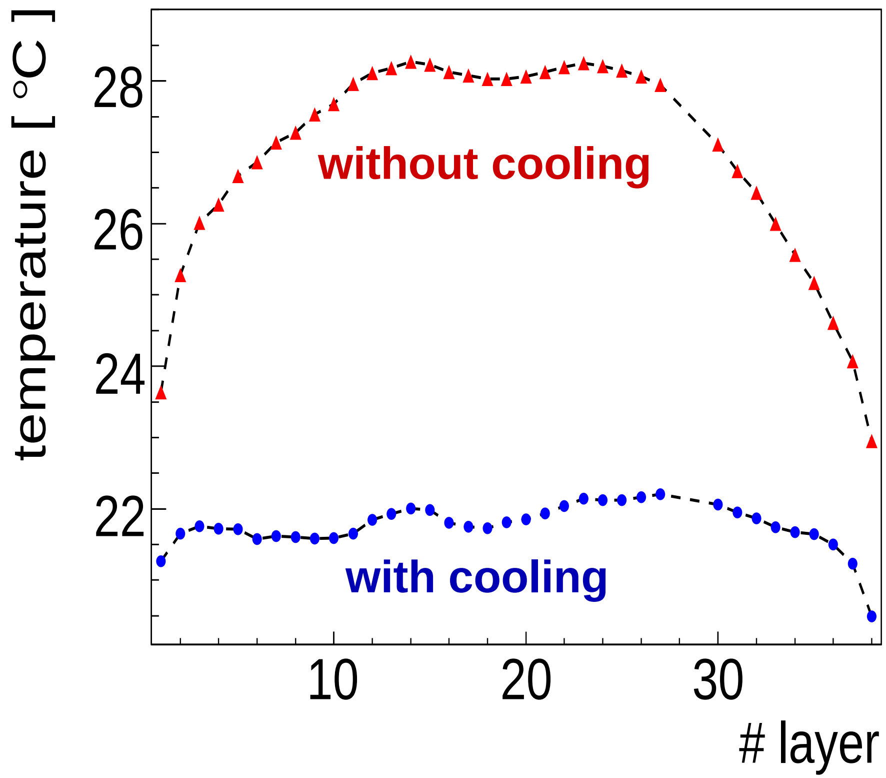

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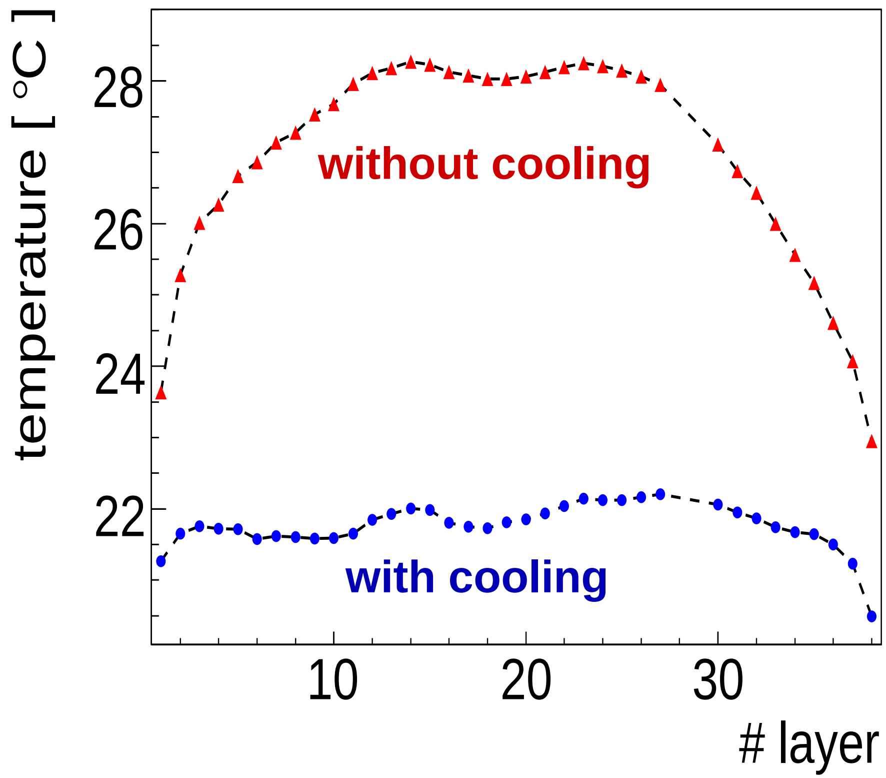

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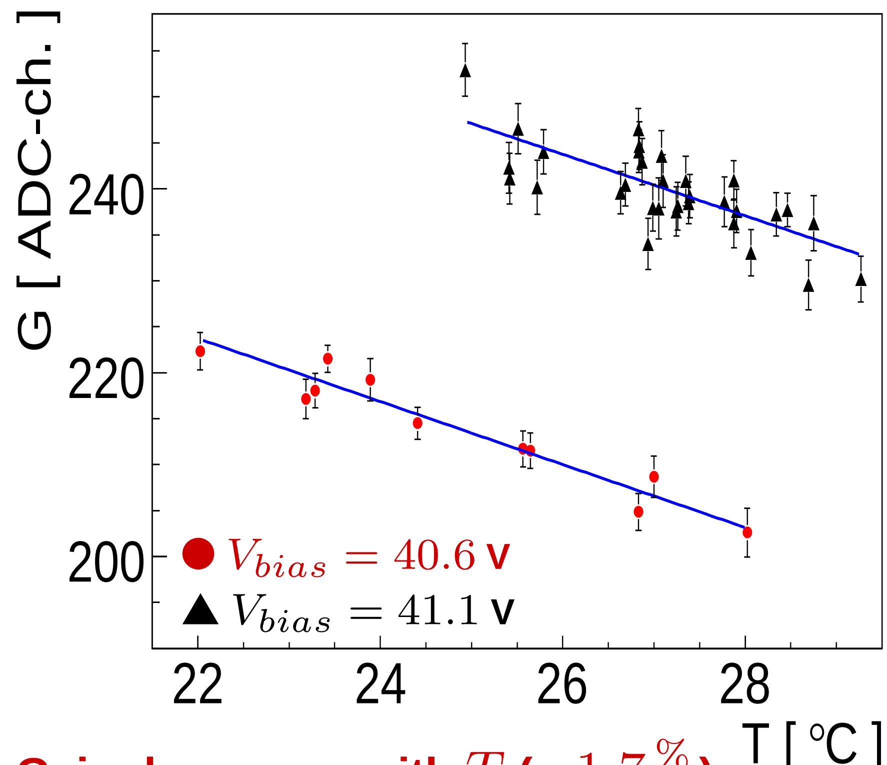

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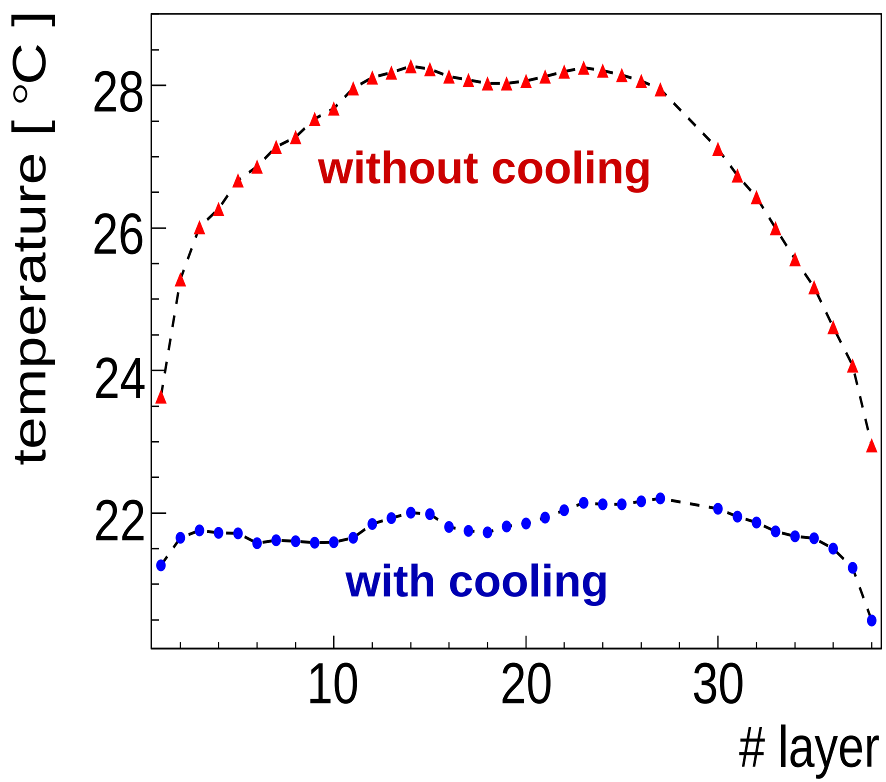

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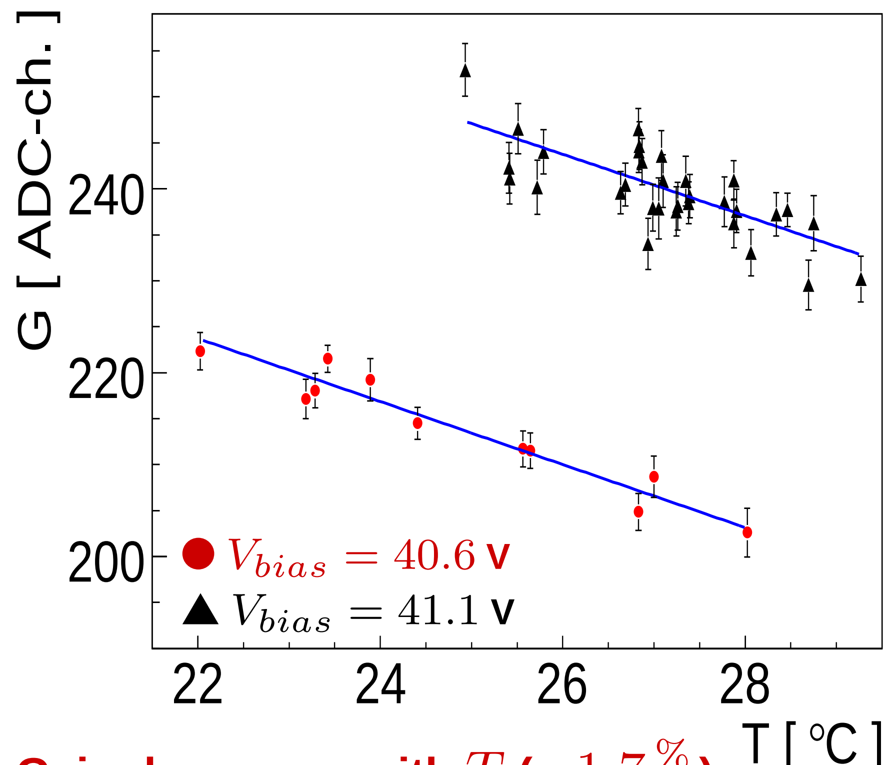

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- **Temperature correction (also for A_{MIP}) implemented in the analyses presented here**

Positron Data Analysis

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- **Electromagnetic analysis needed to validate calibration procedure & MC digitization**
  - **— up-to-date corrections to data**
  - **— up-to-date MC digitization**
  - **— using CERN 2007 data (38 layers)**

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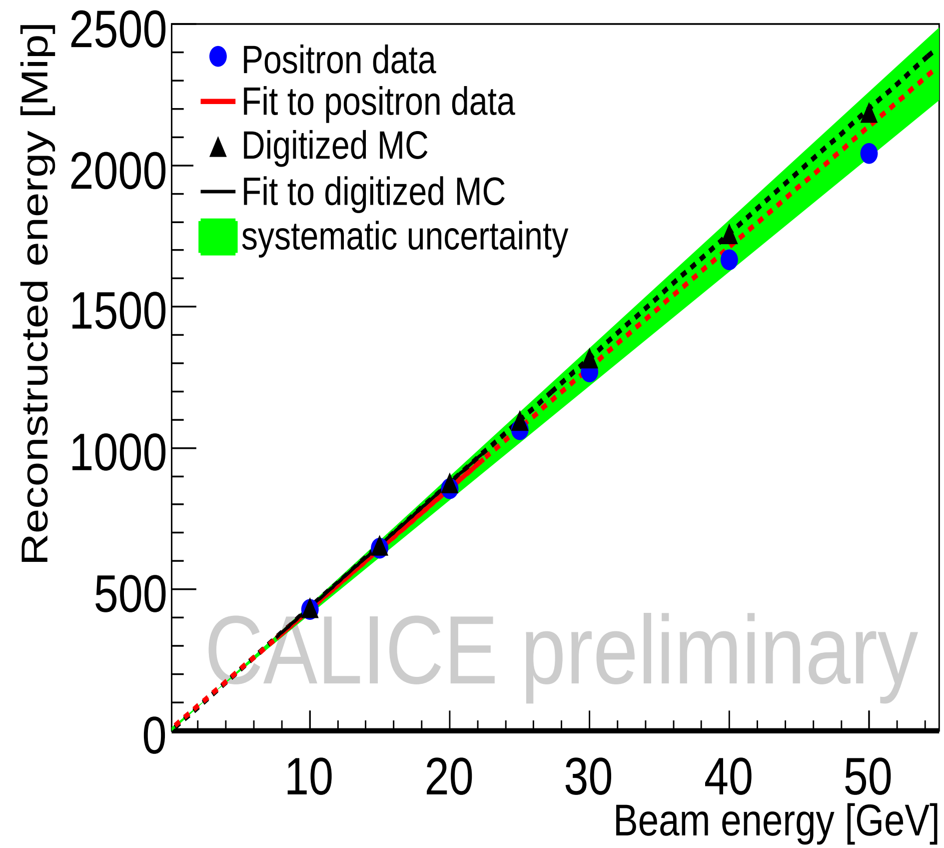

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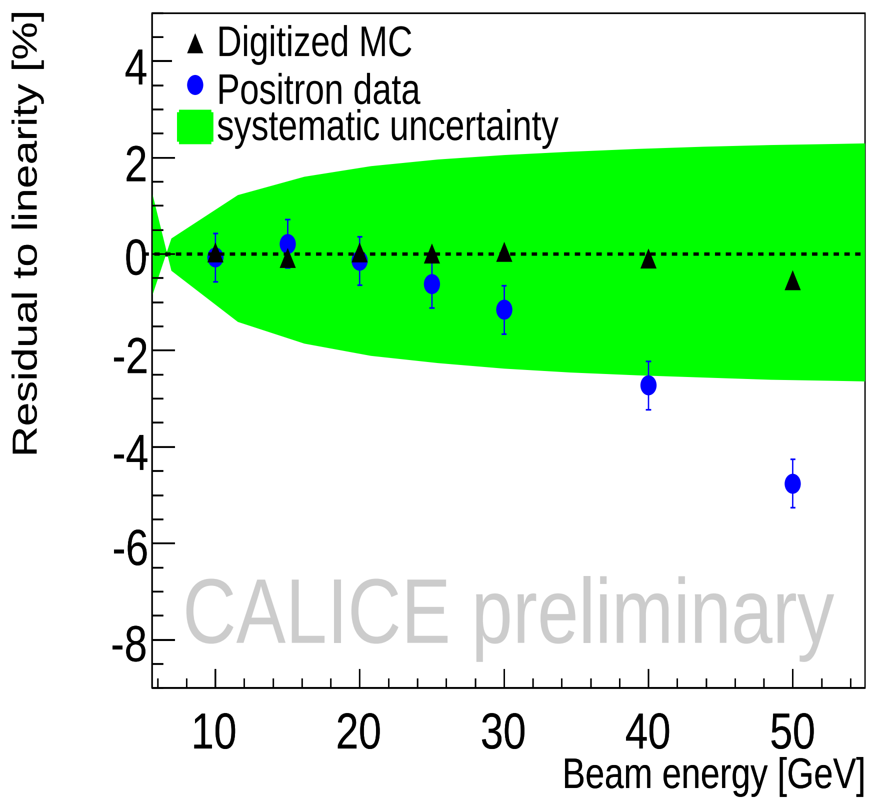

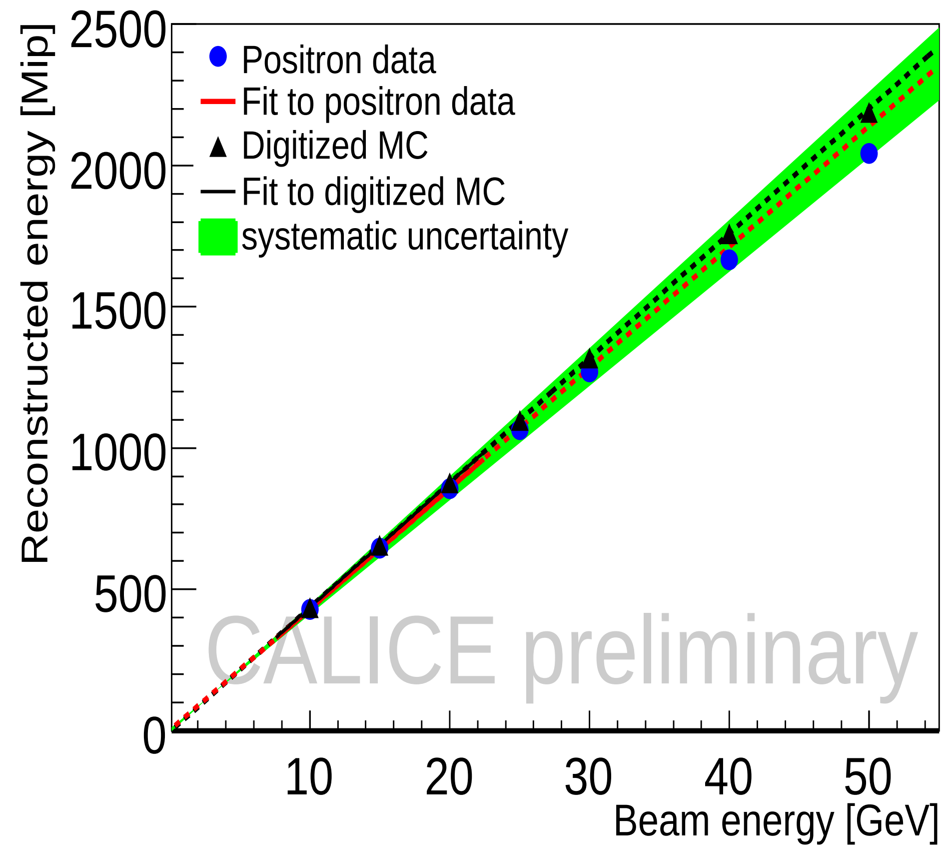

✔ **Linearity up to 30 GeV**

✔ **At 50 GeV: $\approx 4\%$ non-linearity**

$\Rightarrow$ **it was $\approx 8\%$ in 2007 analysis**

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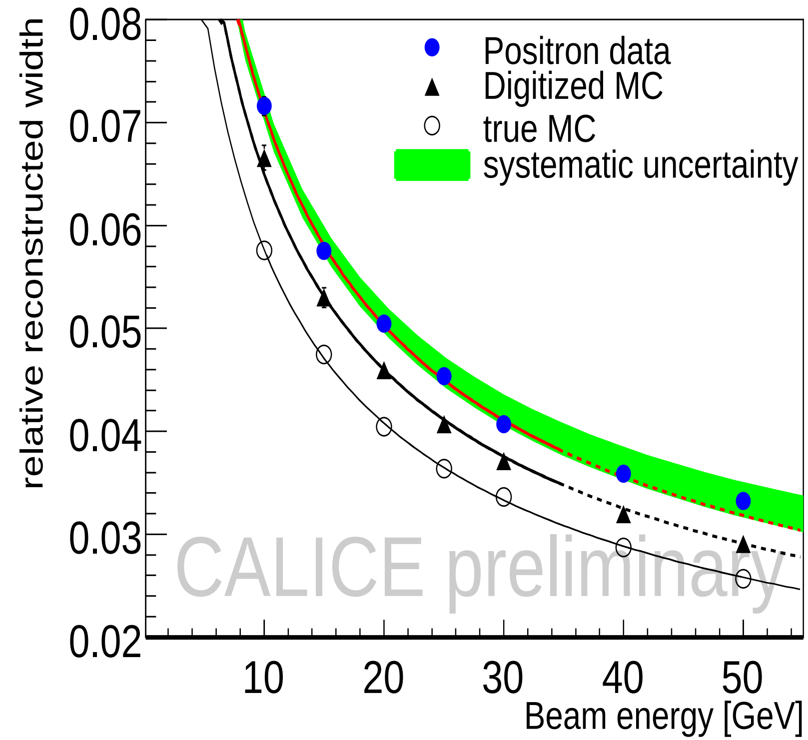

Data stochastic term:

$$a = 22.5 \pm 0.1_{stat.} \pm 0.4_{syst}\%$$

Data constant term:

$$b = 0 \pm 0.1_{stat} \pm 0.1_{syst}\%$$

Noise term fixed to 2 MIP

$\Rightarrow$ **RMS of pedestal events**

NOTE: not all uncertainties of calibrations are in MC digitization yet

Response to EM showers linear up to tens of GeV; enough for hadron analysis

Pion Data Analysis

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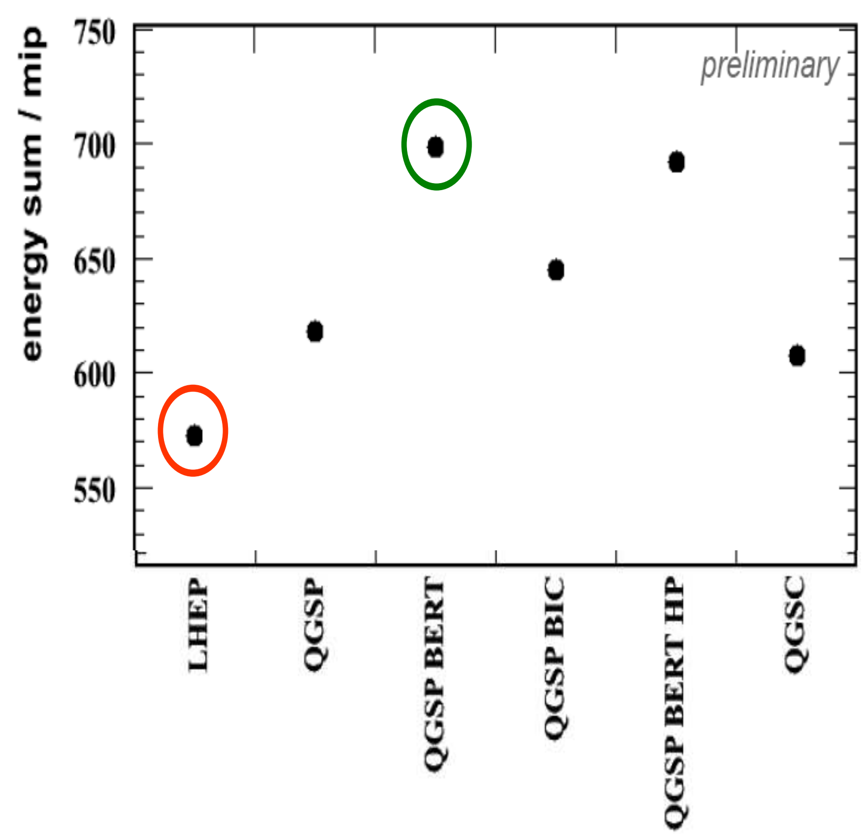
- **Different Monte Carlo physics model lists available**
  - **— large variation among predictions**
  - **— as a starting point, use model lists LHEP and QGSP BERT for comparison**
    - **$\Rightarrow$ largest discrepancy among investigated models**



Pion Data Analysis

- **Linear response to pions**

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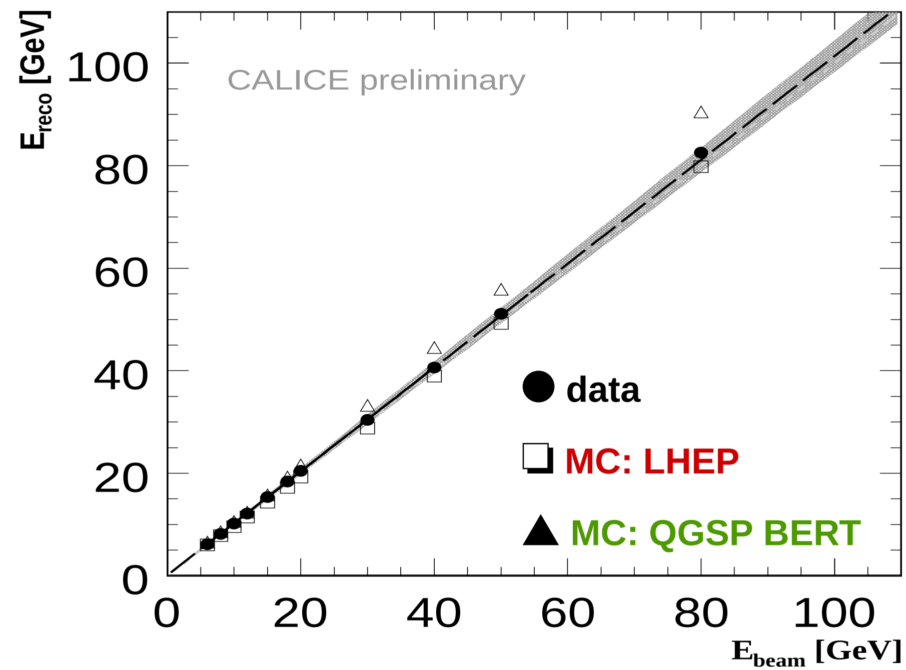
  — combined AHCAL+TCMT data

  — latest state-of-art corrections to data

  — latest Monte Carlo digitization

  ⇒ Birks' law included



larger discrepancy for QGSP_BERT

vs data at high energy

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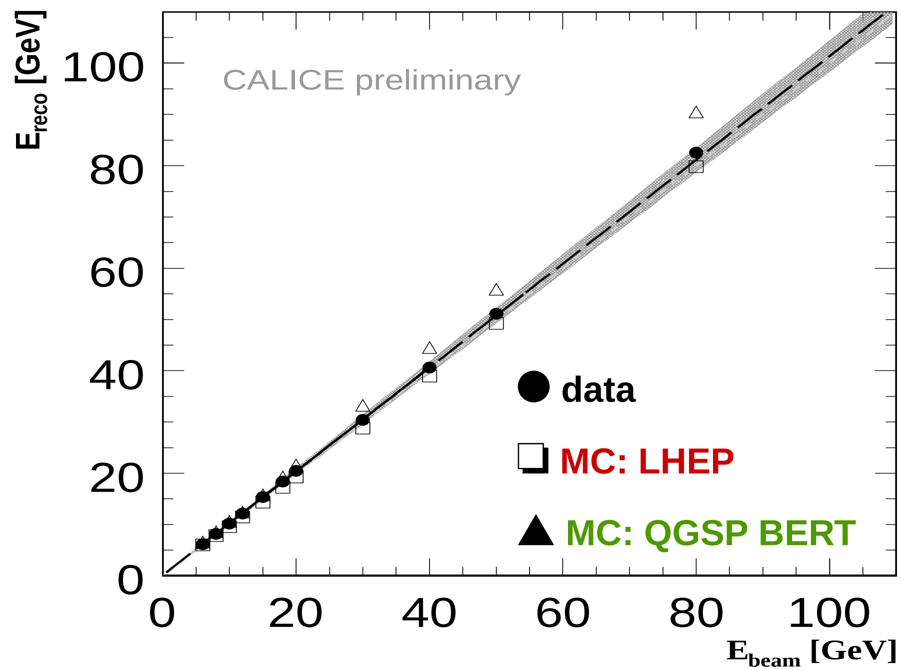
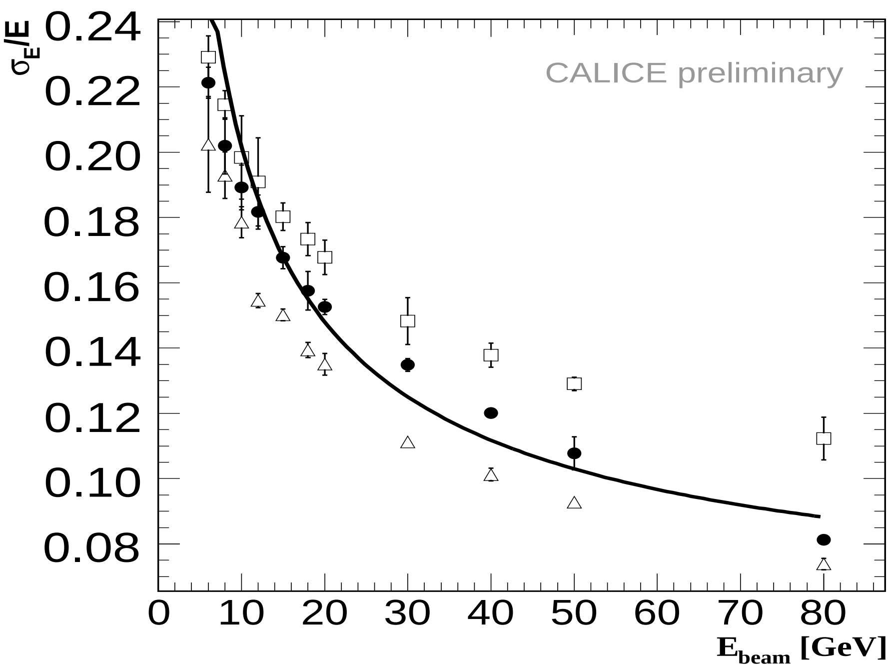


Energy resolution



larger discrepancy for QGSP_BERT vs data at high energy

Pion Data Analysis

- **Longitudinal shower profile**

Online Display

FRONT

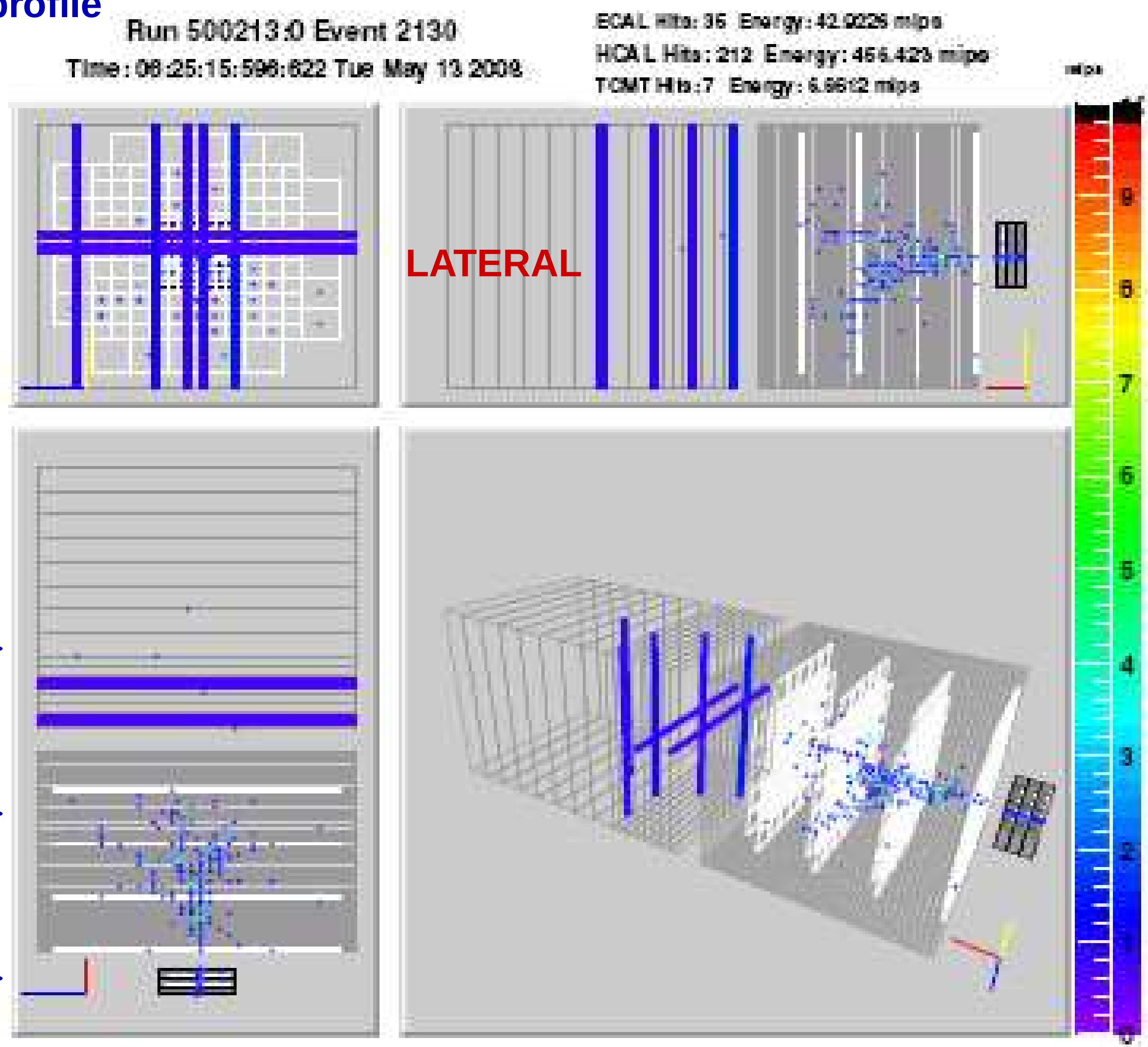
LATERAL

TOP

TCMT →

HCAL →

ECAL →



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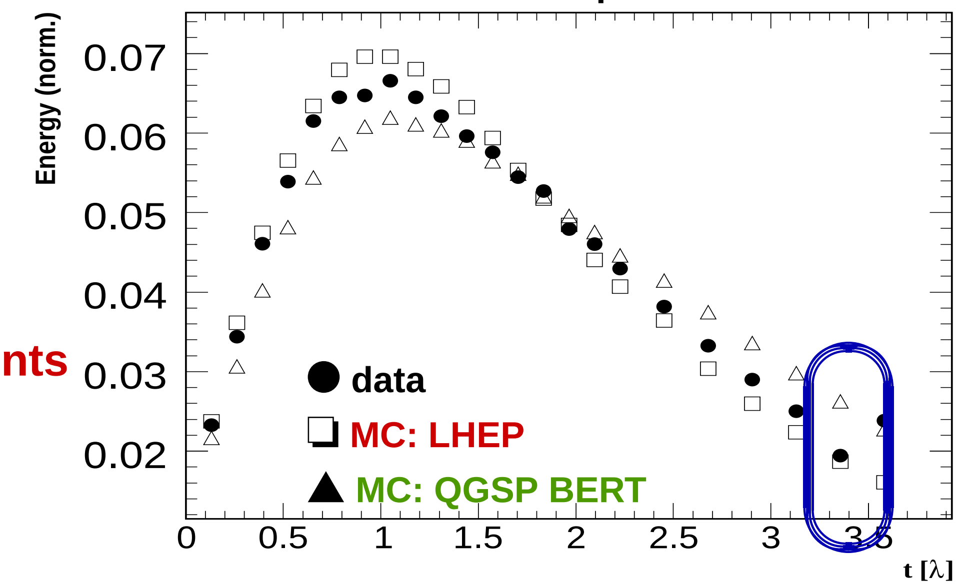
  $\Rightarrow$ **longit. granularity can provide contraints to hadronic shower models!**

t **:= calorimeter depth**



known layers with low efficiency excluded from normalization

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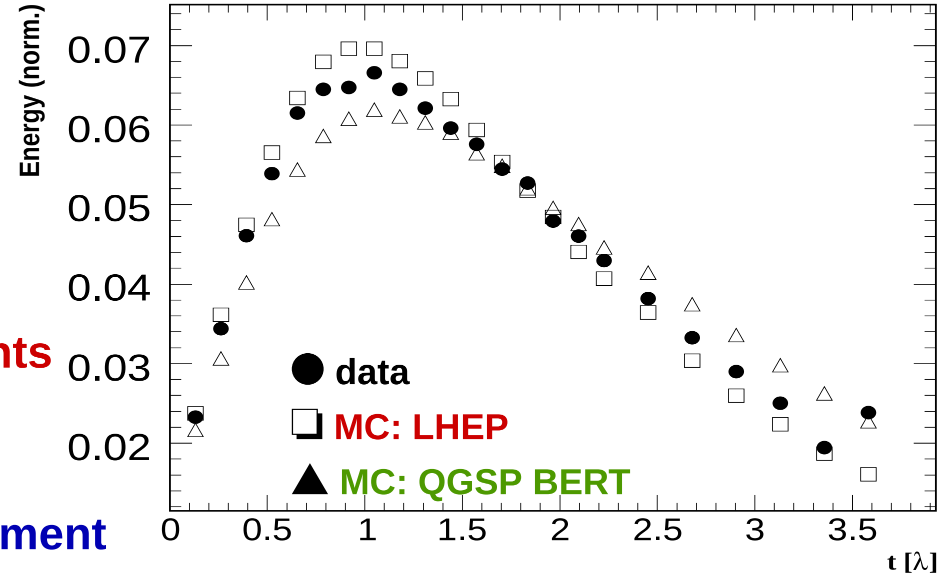

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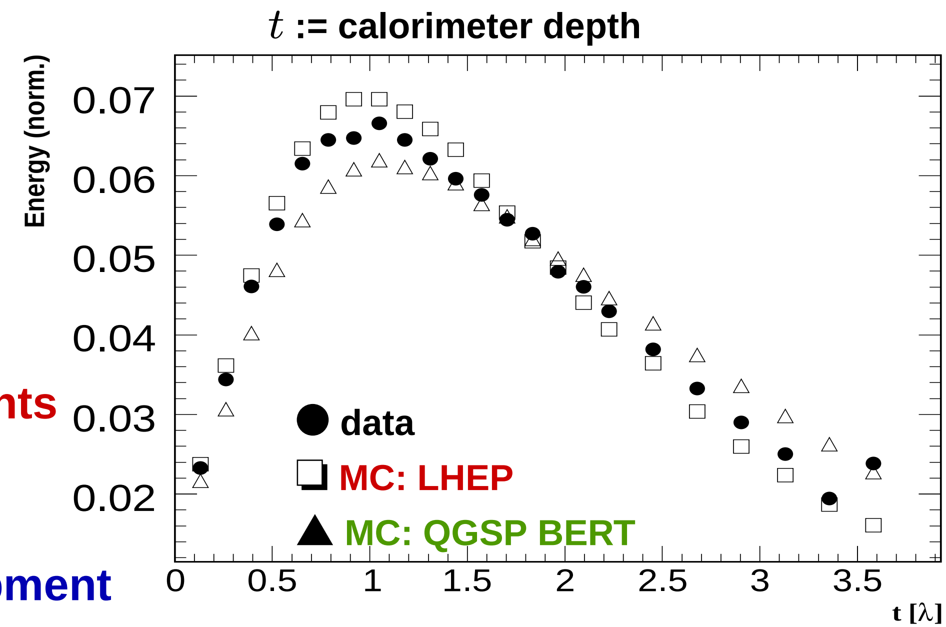

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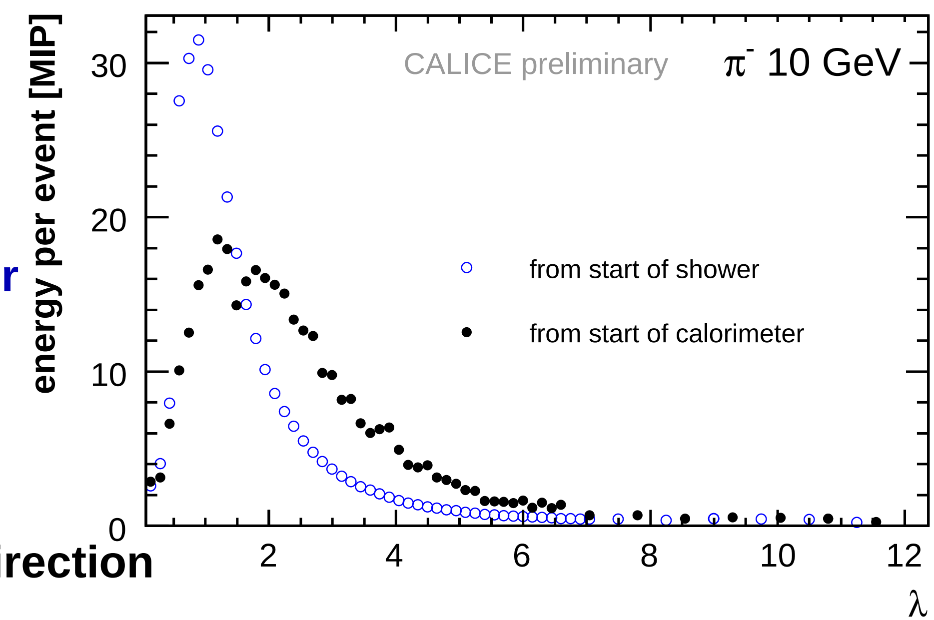
- **Calo longitudinal granularity allows shower profile investigation w.r.t. shower start**

  — using CERN 2007 data (38 layers)

  — no ECAL before HCAL

  — detector at 30^o w.r.t. impinging beam direction



Pion Data Analysis

- π^- **interaction length**

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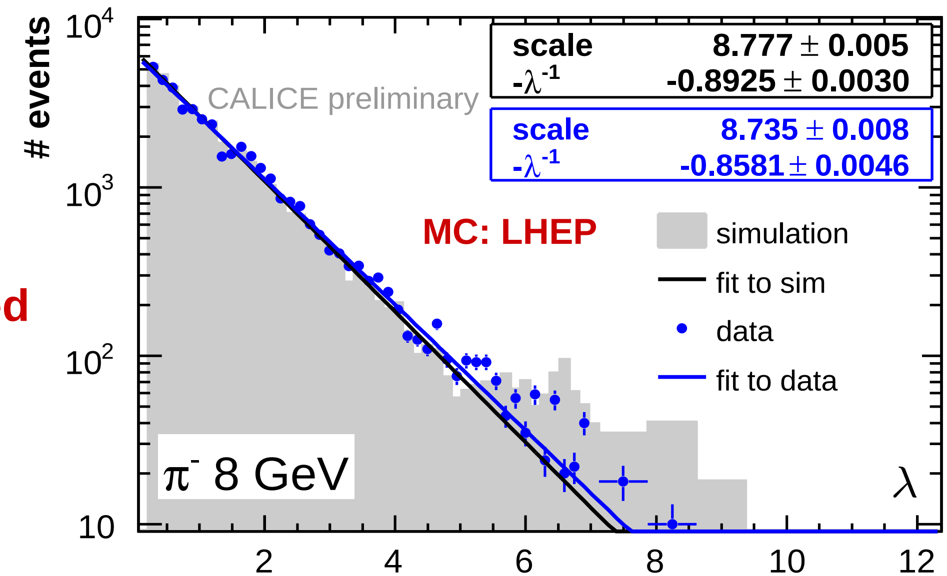

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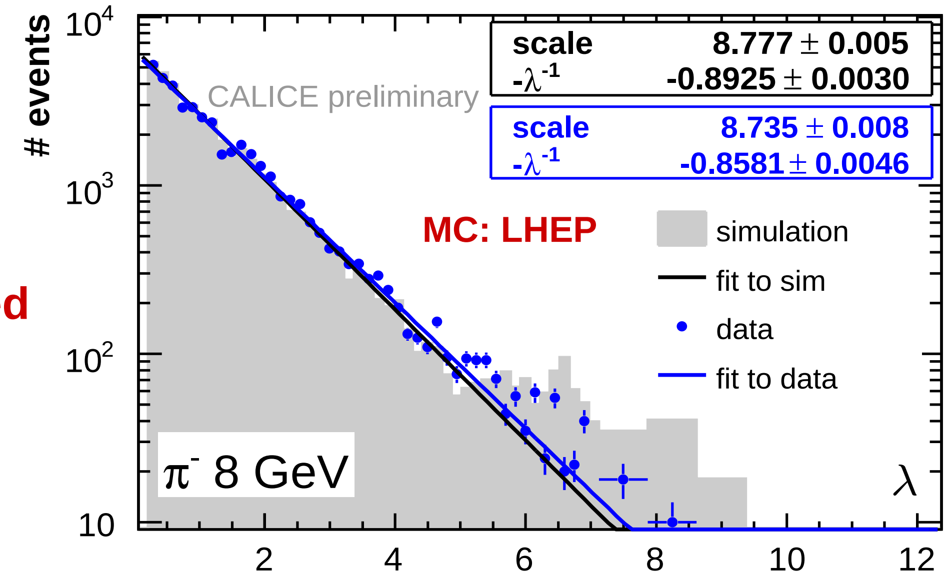

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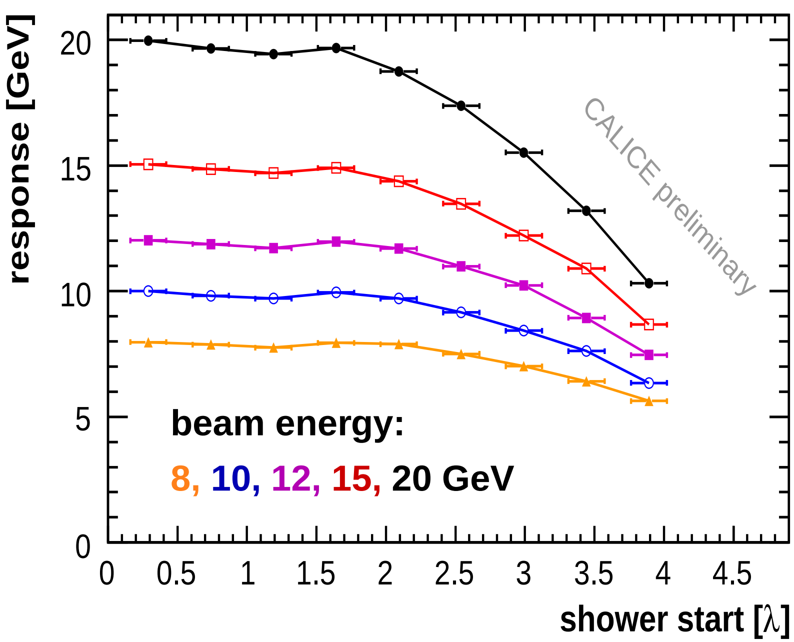

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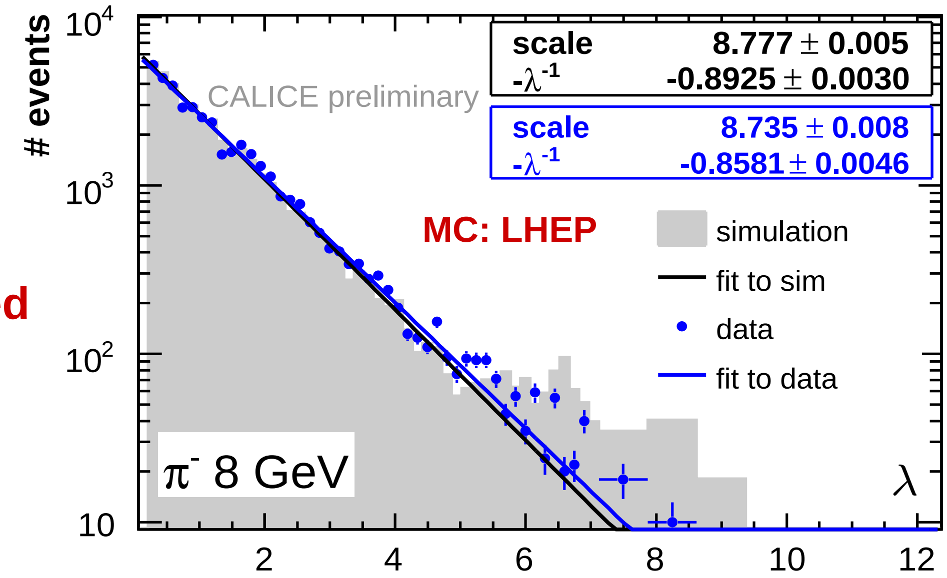

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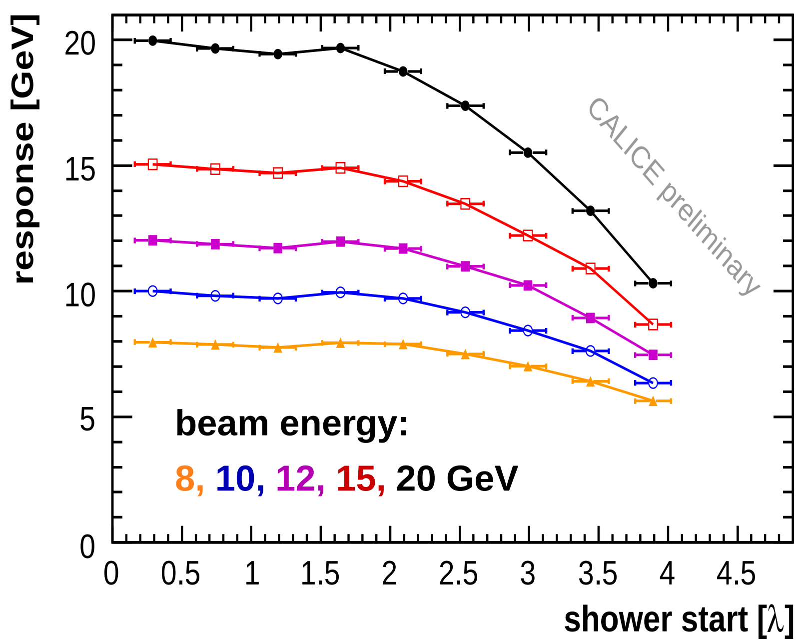
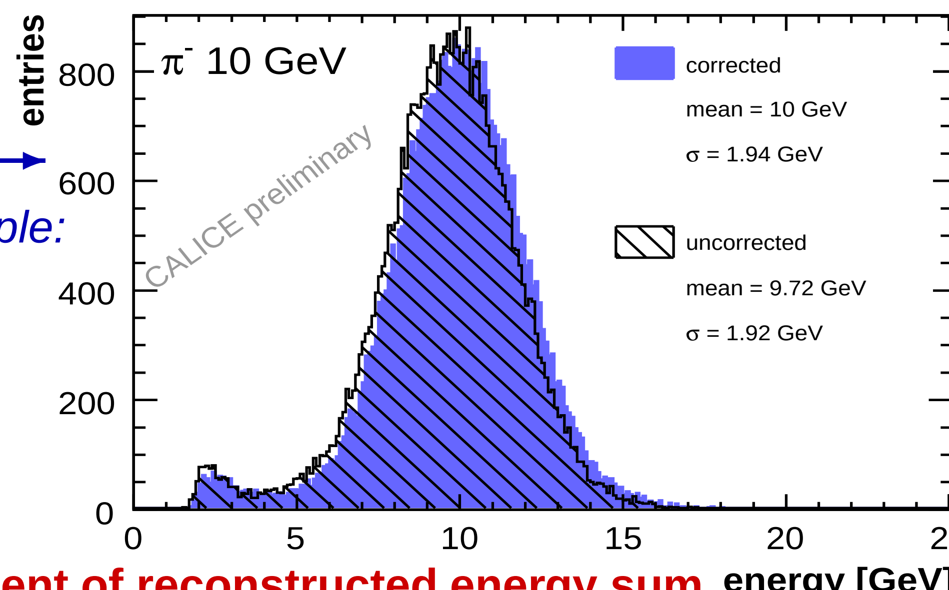


Example:



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Shower Separation

- **Key feature for particle flow approach (PFA):**

  combined Tracking+ECAL+HCAL+Software info for jet energy resolution

cluster reconstruction

charged tracks	γ_s	**neutral hadrons**	
60%	**30%**	**10%**	$\Leftarrow$ **relative contributions to jet structure**

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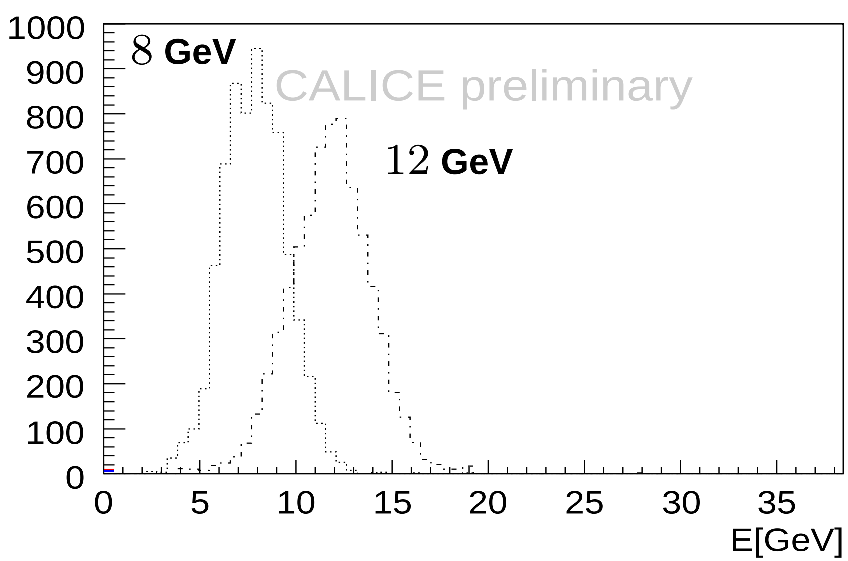

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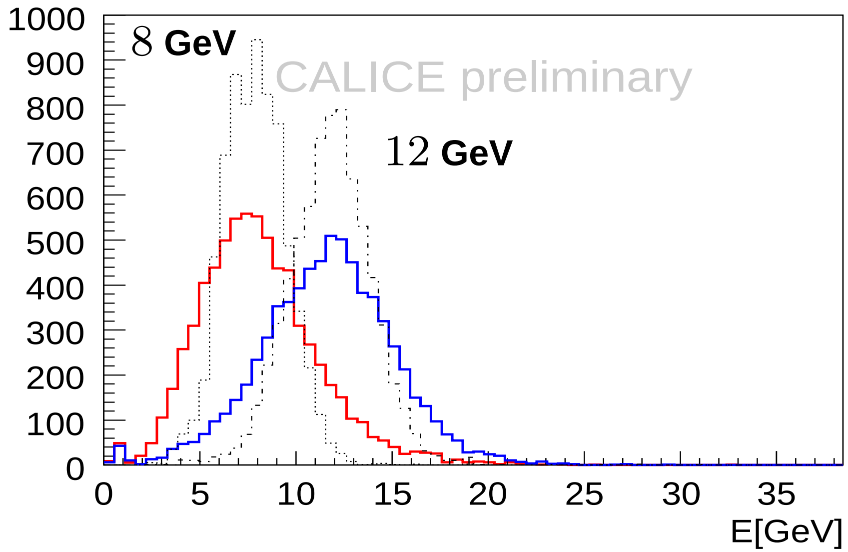

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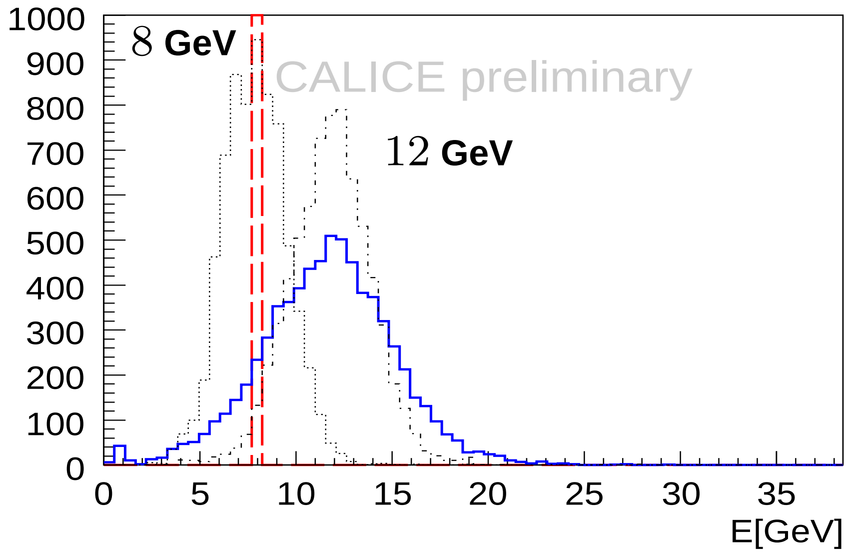
  charged track + neutral $\hookrightarrow$ fix charged track energy from test-beam energy



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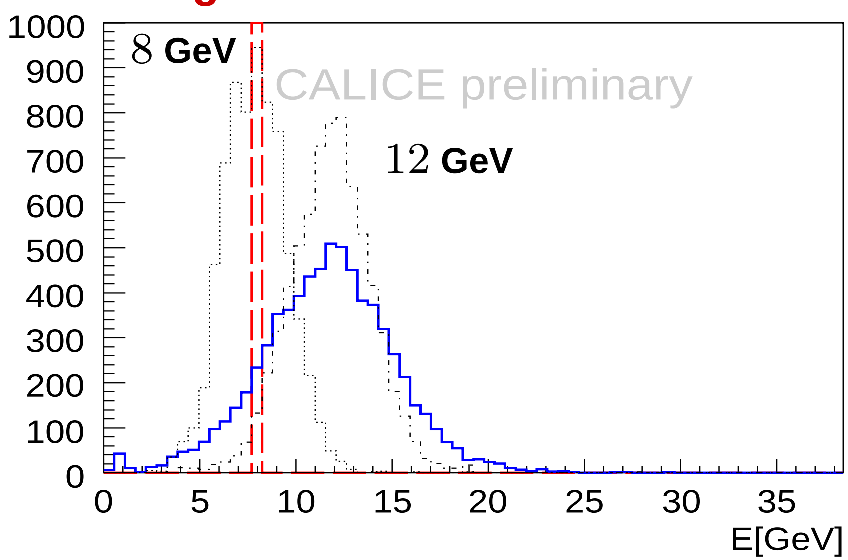
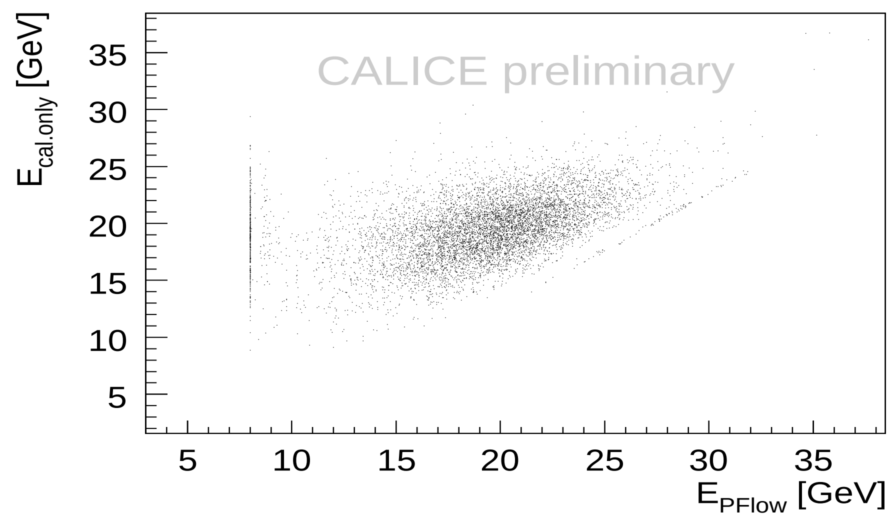




- **Effects of PF approach on $\sum E_{cluster}$ still limited:**

  — too short track impact point distances available so far (only up to $\approx$ 10cm)

Shower Separation

- **Key feature for particle flow approach (PFA):**

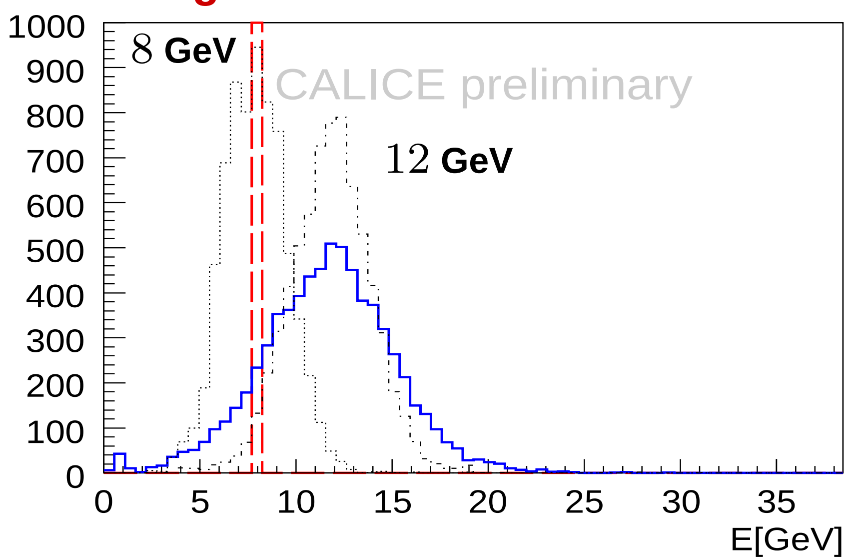
  combined Tracking+ECAL+HCAL+Software info for jet energy resolution

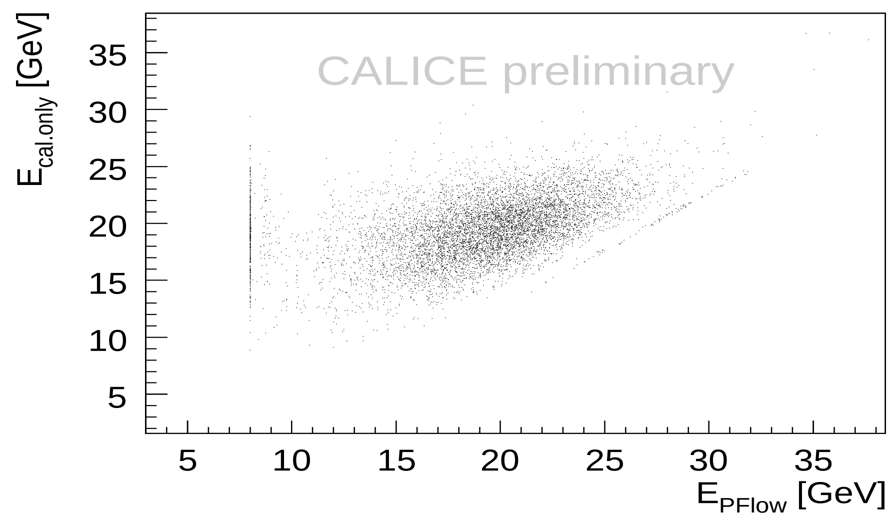
- **Consider HCAL reconstructed E from distinct events (charged tracks initiated)**

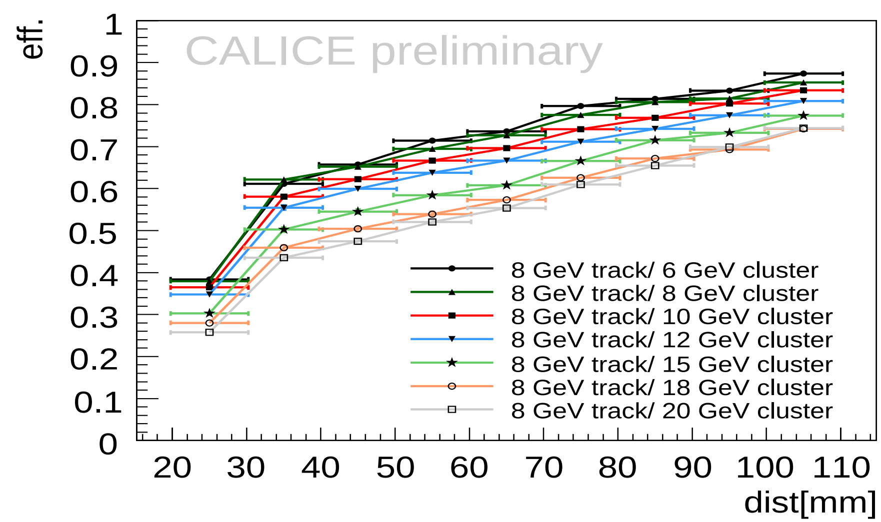
  — merge events and reconstruct showers

  — assume a PFA scenario:

  charged track + neutral







- **Effects of PF approach on $\sum E_{cluster}$ still limited:**

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- **Reconstruction algorithm efficiency**

Summary and Outlook

- State-of-art of AHCAL test beam data analysis shown
- Improved calibrations implemented

  $\Longrightarrow$ energy scale established (MIP)

  $\Longrightarrow$ new SiPM saturation correction applied

  $\Longrightarrow$ temperature correction to SiPMs signal applied
- Detector response to electromagnetic showers understood
- Analysis on hadronic showers ongoing

  $\Longrightarrow$ different physics model lists under investigation

  — possibly providing constraints on Monte Carlo models

  $\Longrightarrow$ determination of shower starting point

  $\Longrightarrow$ π^- interaction length measured
- Particle flow approach investigation started

Summary and Outlook

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- Lateral profile analysis / Shower decomposition
- Effects from tile granularity on energy reconstruction
- Low energy data / inclined beam incidence data / π^+-π^- shower difference ...

Back Slides

Status at LCWS-ILC 2007

- **At last conference preliminary results were shown, using data taken with partially instrumented HCAL [CERN 2006: 15/23 layers $\longrightarrow$ 3240/4968 readout chans]**

  — SiPM non-linearity: response-curves measured at ITEP

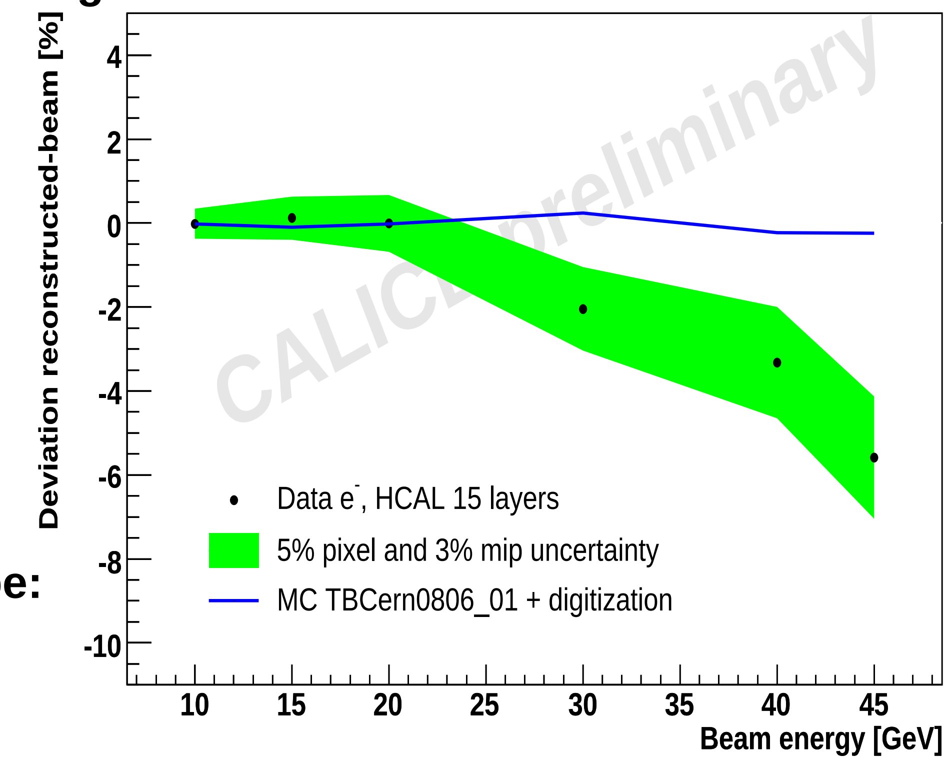
  — Gain $G = \frac{Q_{pixel}}{e}$: temperature correction not applied

  — MIP calibration: conversion from Hdw ADC values to physical quantity
  $\Rightarrow$ response to passage of minimum ionizing particles
  $\Rightarrow$ calibration done using muon beam at CERN

- **Example:**

  Previous result on linearity

  $\Rightarrow$ deviation from linearity up to $\approx 8\%$ at 50 GeV



- **Since then [$\Longrightarrow$ subject of this talk]:**

  — data from fully instrumented prototype: 38 layers

  — improved treatment of the data

Particle Flow Approach

CALICE Test-Beam Program

- **2006**

— **DESY: W/Si ECAL commissioning**

— **CERN: W/Si ECAL, AHCAL, TCMT commissioning**

— **CERN: W/Si ECAL, AHCAL(23 layers), TCMT combined physics runs**

- **2007**

— **DESY: W/ScintStrip ECAL commissioning**

— **CERN: W/Si ECAL, AHCAL(28 layers), TCMT combined physics runs**

$\Rightarrow$ **inclined beam incident / calo scan**

— **FNAL: DHCAL test**

- **2008**

— **FNAL: W/Si ECAL, AHCAL, TCMT combined physics runs**

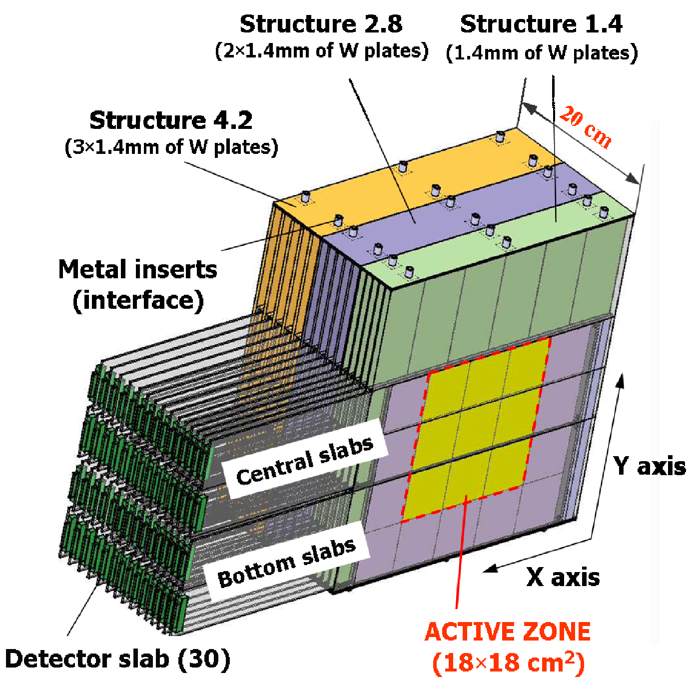
$\Rightarrow$ **inclined beam incident / calo scan**

$\Rightarrow$ **energy range extended down to ≈ 2 GeV**

— **FNAL: W/ScintStrip ECAL, AHCAL, TCMT combined physics runs**

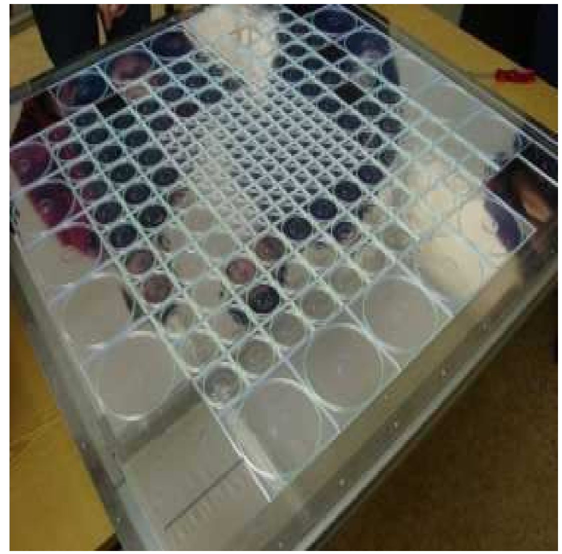
Detector Setup

ECAL



- W/Si sandwich structure
- 30 layers of 3x3 modules
- 1 module: 6x6 1cm^2 pads
- Si PIN diode readout
- total rad. length: 24X_0
- $\lambda/X_0 = 27.4$

HCAL



- Tile/steel sandwich struct.
- 38 layers
- 7608 tiles
  size: 3x3/6x6/12x12 cm^2
- SiPM readout
- 4.5λ interaction length

TCMT

- size: 109x109x142 cm^3
- 16 layers
- 1 layer: 8 scintill.strips
- 1 strip: 100x5x0.5 cm^3
- 1 SiPM readout per strip
- 2/10 cm steel absorber
- 5.5λ interaction length

Monte Carlo Physics Model Lists

- **LHEP (Low/High Energy Parameterization)**

  — two sets of parameterization of existing data from GHEISHA for E$<$55 GeV and E$>$25 GeV. Randomly pick up one of the two lists in common energy region
- **QGSP (Quark-Gluon String)**

  — model for the primary projectile-nucleon collision plus the precompound model for de-excitation of the nucleus. Used for E$>$12 (E$>$20) GeV for protons, neutrons, pions, kaons (other particles). Outside this energy range LHEP is used
- **QGSP_BERT (QGSP + Bertini cascade model)**

  — used for E$<$10 GeV for nucleons, pions, kaons and hyperons

  — includes remnant nucleus de-excitation, Fermi breakup and fission
- **QGSP_BERT_HP**

  — High Precision package for neutron transport used in QGSP_BERT for E$<$100 MeV.
- **QGSP_BIC (QGSP + Binary cascade model)**

  — model valid for E$<$3 GeV protons and neutrons, E$<$1.5 GeV pions, and E$<$3 GeV/A light ions. Remnant nucleus de-excitatiion handled by precompound model
- **QGSC**

  — QGS for the primary projectile-nucleon collision

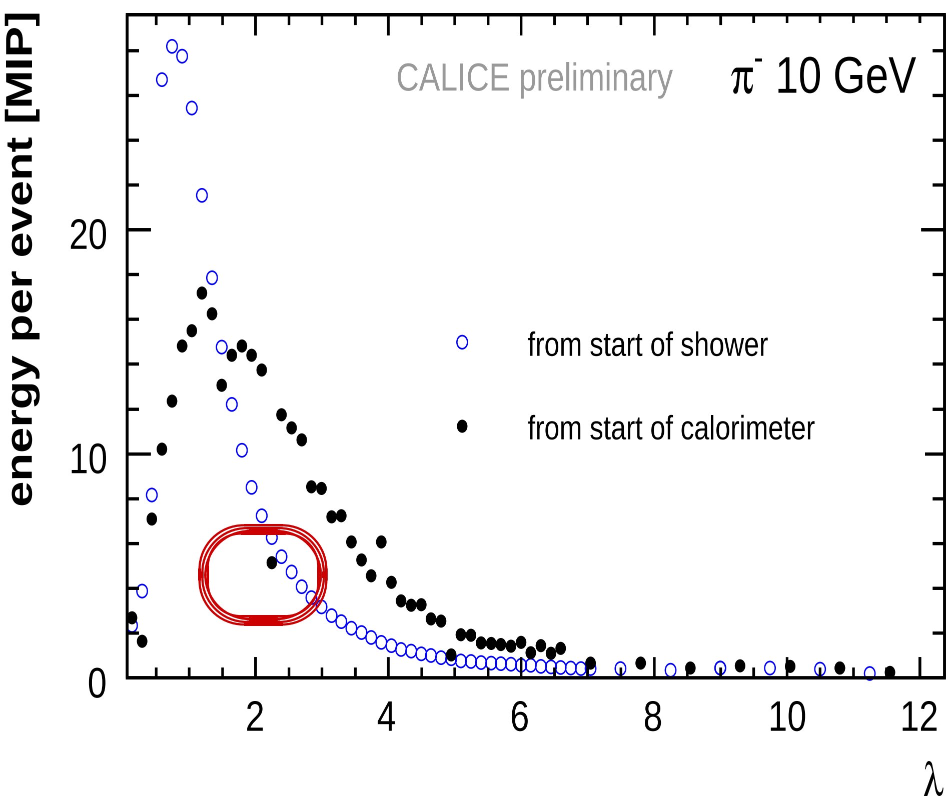
  — Chiral Invariant Phase Space model for nucleus de-excitation

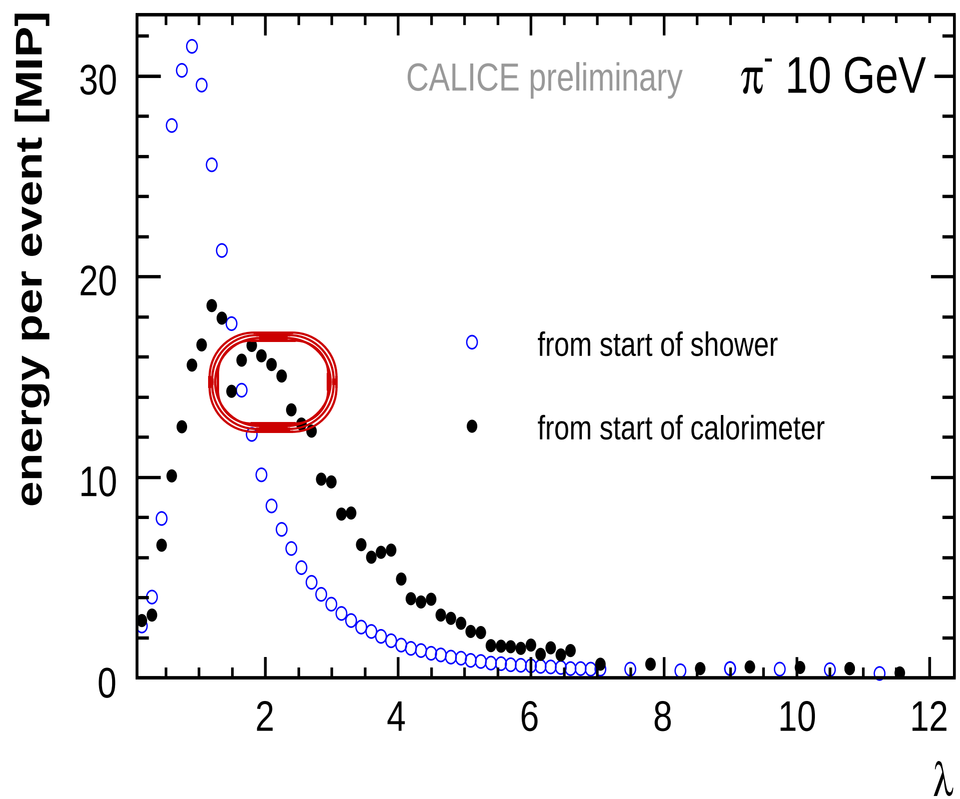
Recover of Some Missing SiPM MIP Calibration

- **Apply latest calibrations of detector**

EXAMPLE: longitudinal shower profile using AHCAL+TCMT (no ECAL before AHCAL)

Before: **Now:**





⇒ Improvement due to recovering of previously not-calibrated SiPMs

Birks' Law

- **Describes the light output of organic scintillators**
- **Fluorescence S in general not proportional to energy loss**

  $\Rightarrow$ **quenching effects between excited molecules**

  — **with low energy electrons (< 125 KeV)**

  — **scintillation by heavy ions $<$ than by electrons**

- $\Delta S \propto \frac{\Delta E}{1+k_B(\Delta E/\Delta x)}$

  — k_B **is the Birks' constant**

  $\Rightarrow$ **must be determined for each scintillator**