CALICE - Calorimeters for the ILC

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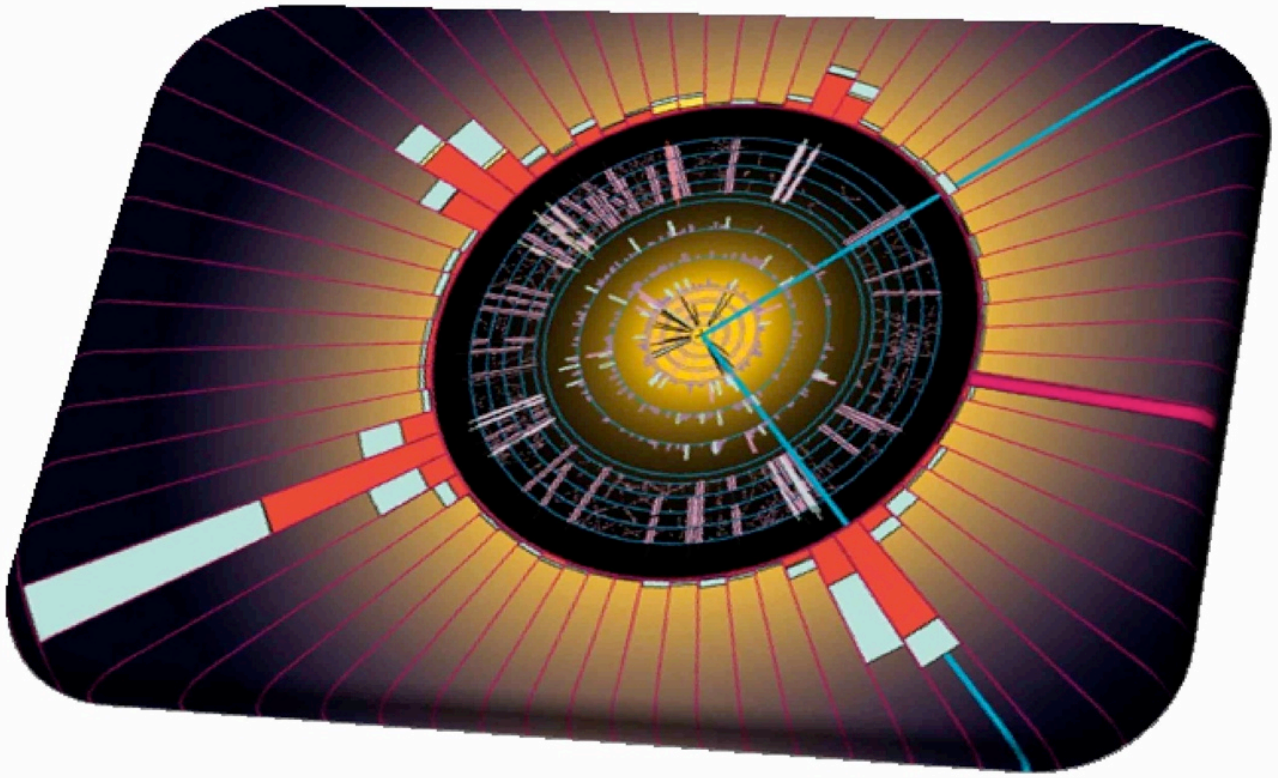
Calorimeter for ILC

Excellence Cluster
Universe

CALICE: A new Type of Calorimetry



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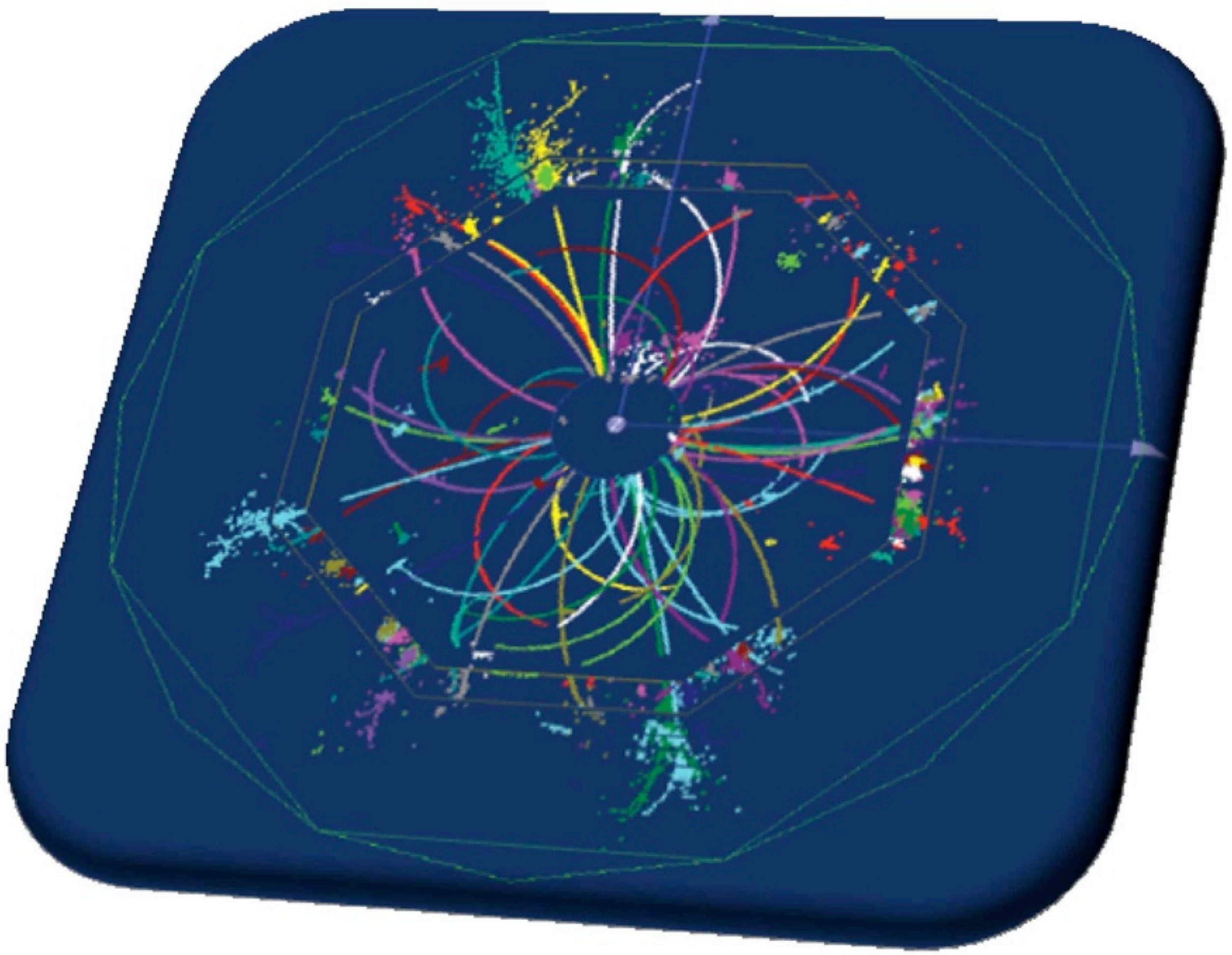


with unprecedented granularity in the calorimeters

Outline

- Motivation: unprecedented jet energy resolution for precision physics
- The CALICE Detectors: Highly granular electromagnetic and hadronic calorimeters
- First results from the test beam program
- Investigation of different detector technologies
- Summary & Outlook

Motivation: Precision Physics

- Many final states require tagging of heavy bosons:

Multi bosons	**Multifermions + Boson(s)**
ZH	e^+e^- **H** , **e+e− Z**
WW	νν **H** , νν **Z**
ZZ	**ttH**
ZHH	**e** ν **W**
ZZZ	νν **WW**, νν **ZZ**
ZWW	**ttbar in bbar WW**

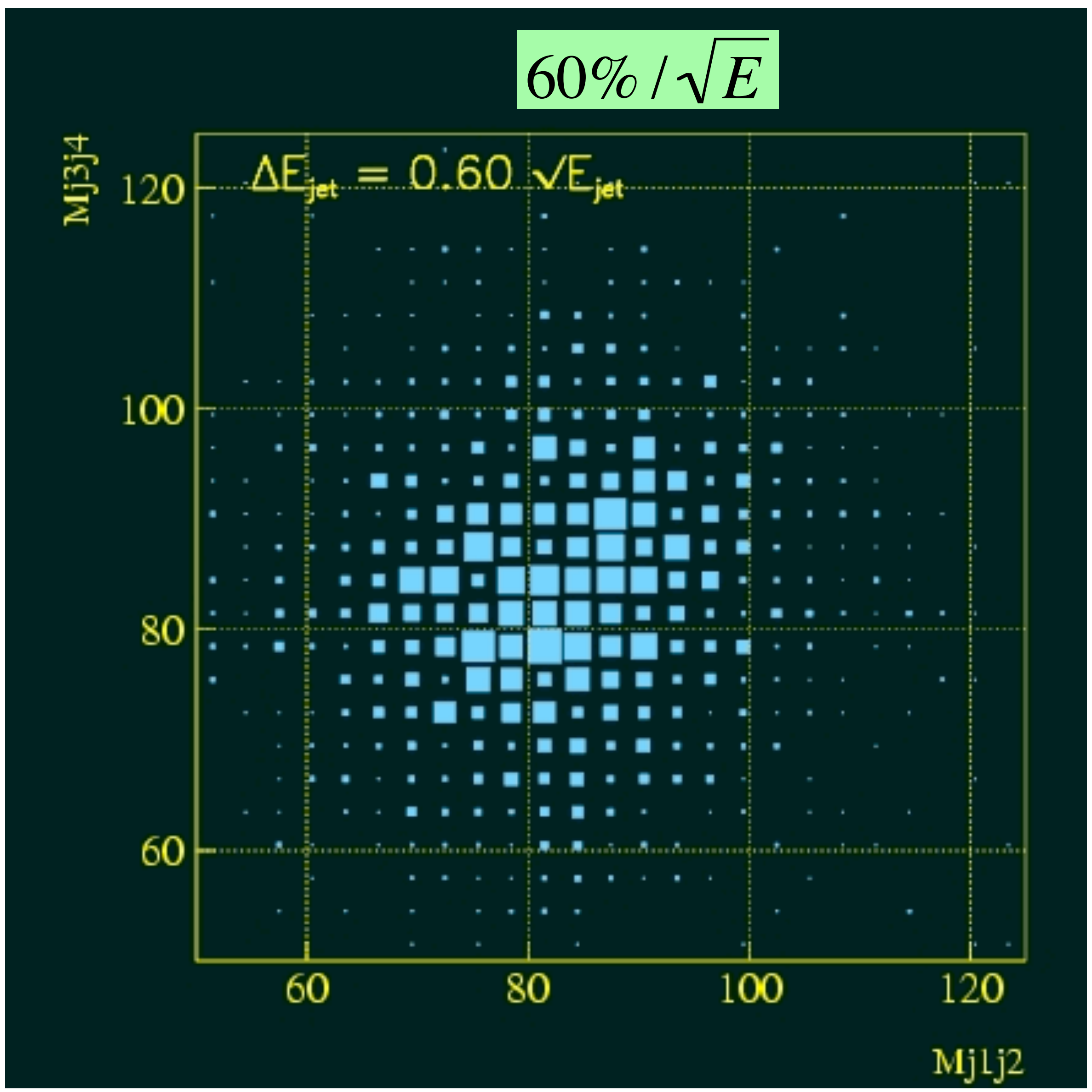
etc... but also tau decay reconstruction for SUSY, CP...

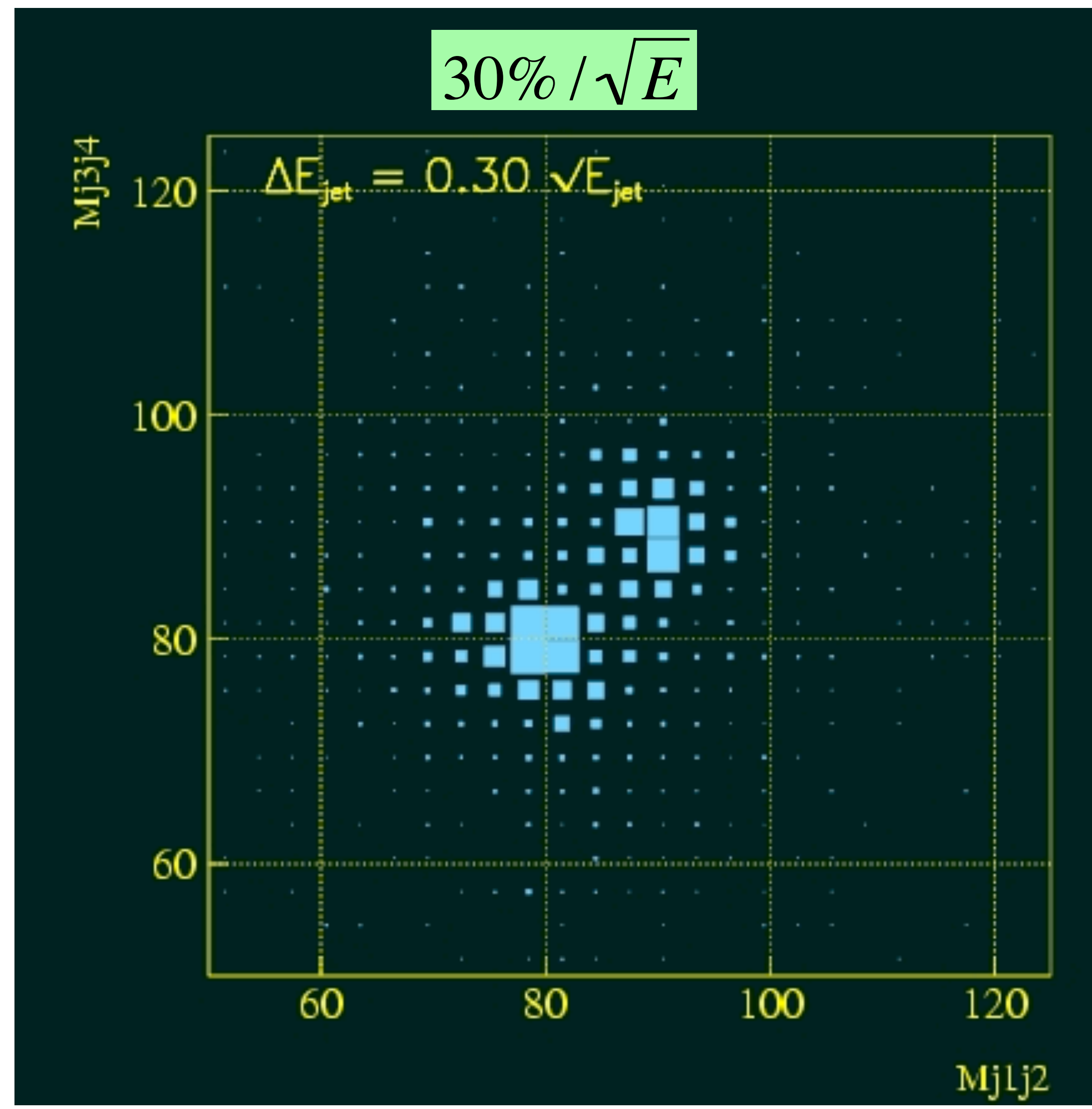
- most efficient use of luminosity by including large branching fraction into jets:
  - Z^0, $W^\pm$: ~ 70%, SM Higgs (120 GeV) > ~ 85%

▸ Detectors optimized for jet energy resolution crucial for the ILC

Jet Energy Resolution: Goal

- Boson ID improves significantly when $\sigma_{DiJet} < 0.5\ (M_Z - M_W)$
  - translates into 30%/$\sqrt{E}$ at the Z mass

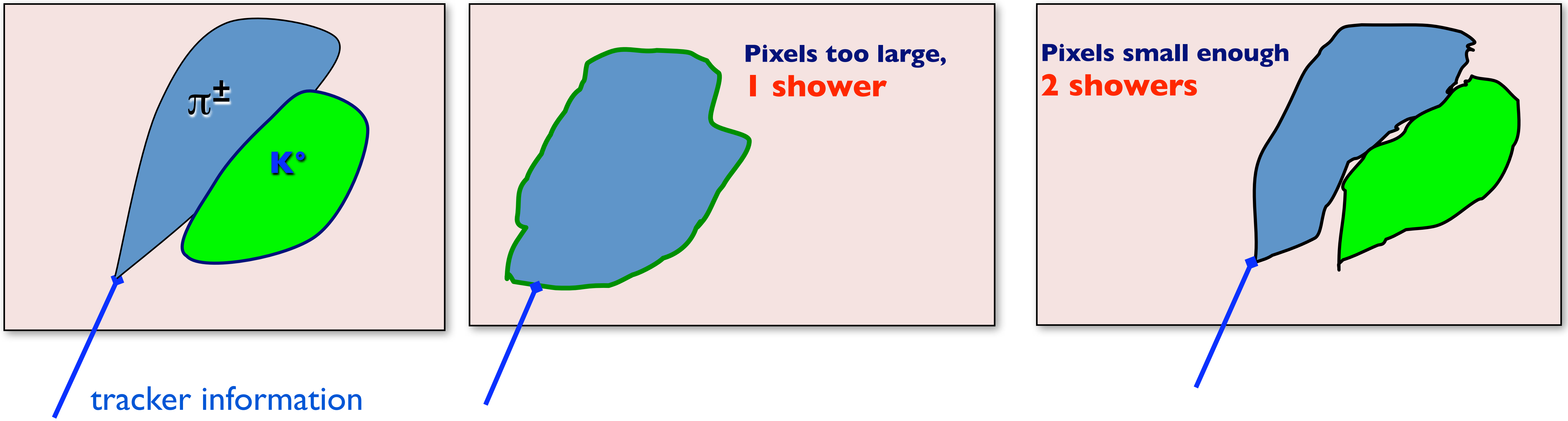




Particle Flow

- Use the best energy information available for each particle in a jet
  - Tracker information for charged hadrons and low to mid-energy electrons
  - ECAL information for photons and high-energy electrons
  - HCAL information for long-lived neutral hadrons

‣ Requires highly granular calorimeters to allow geometrical separation of particles



CALICE: Technology

- All calorimeters designed for Particle Flow
  - high granularity: unprecedented longitudinal and transverse segmentation
- Compact devices to accommodate large channel count
  - integrated electronics on detector where possible:
    - ASICs mounted on active material
    - photon sensors directly on scintillator tiles
- Investigation of different technologies:
  - silicon vs scintillators
  - scintillators vs gaseous detectors
  - analog vs digital

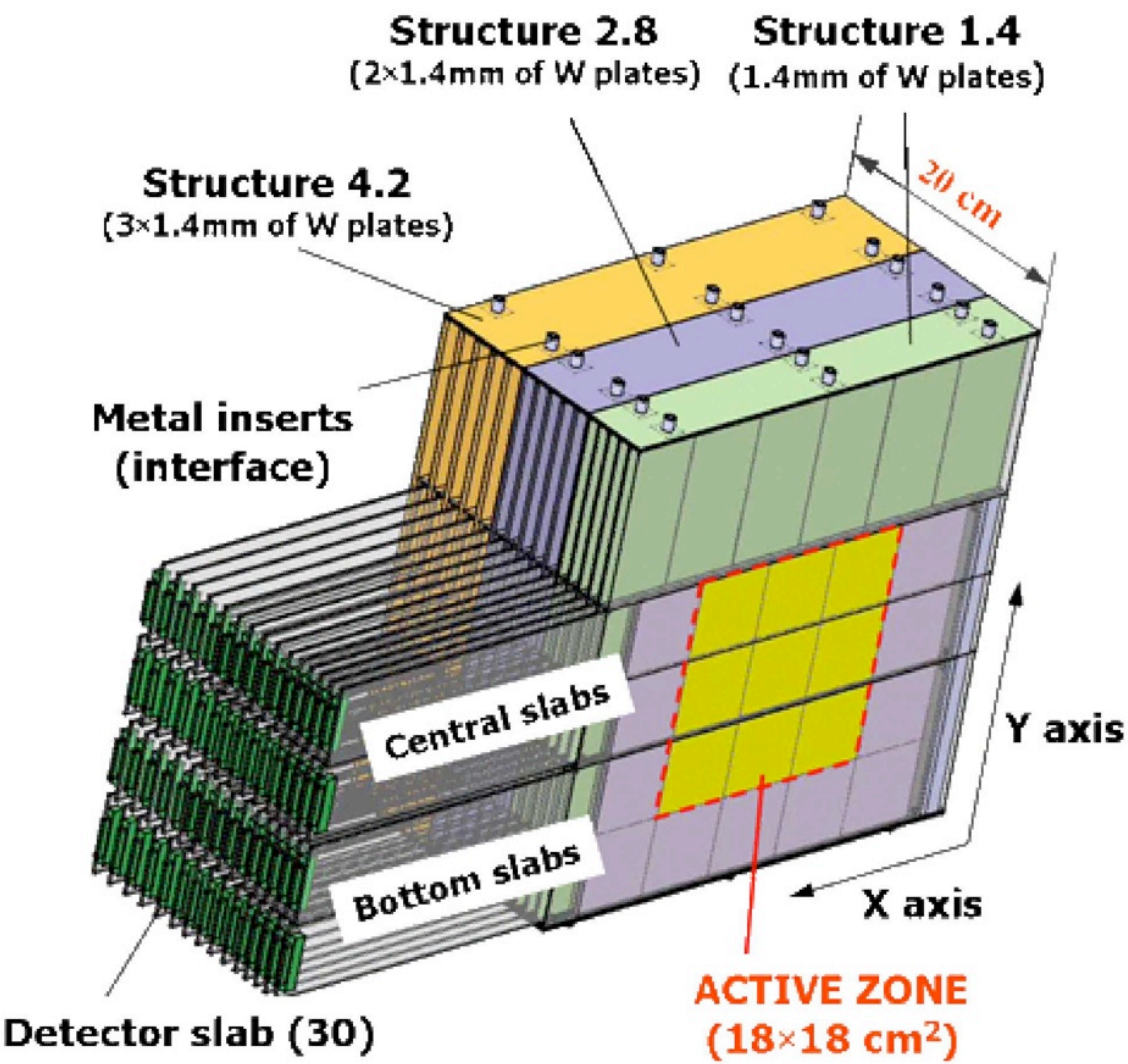
The CALICE Subsystems

- Electromagnetic Calorimeter
  - **Silicon - Tungsten: Si-Pad detectors**
    - MAPS - Option
  - Scintillator-Tungsten

- Hadronic Calorimeter
  - **Analog: Steel - Scintillator tiles with SiPM readout**
  - Digital: Steel - RPC / MicroMegas / GEM

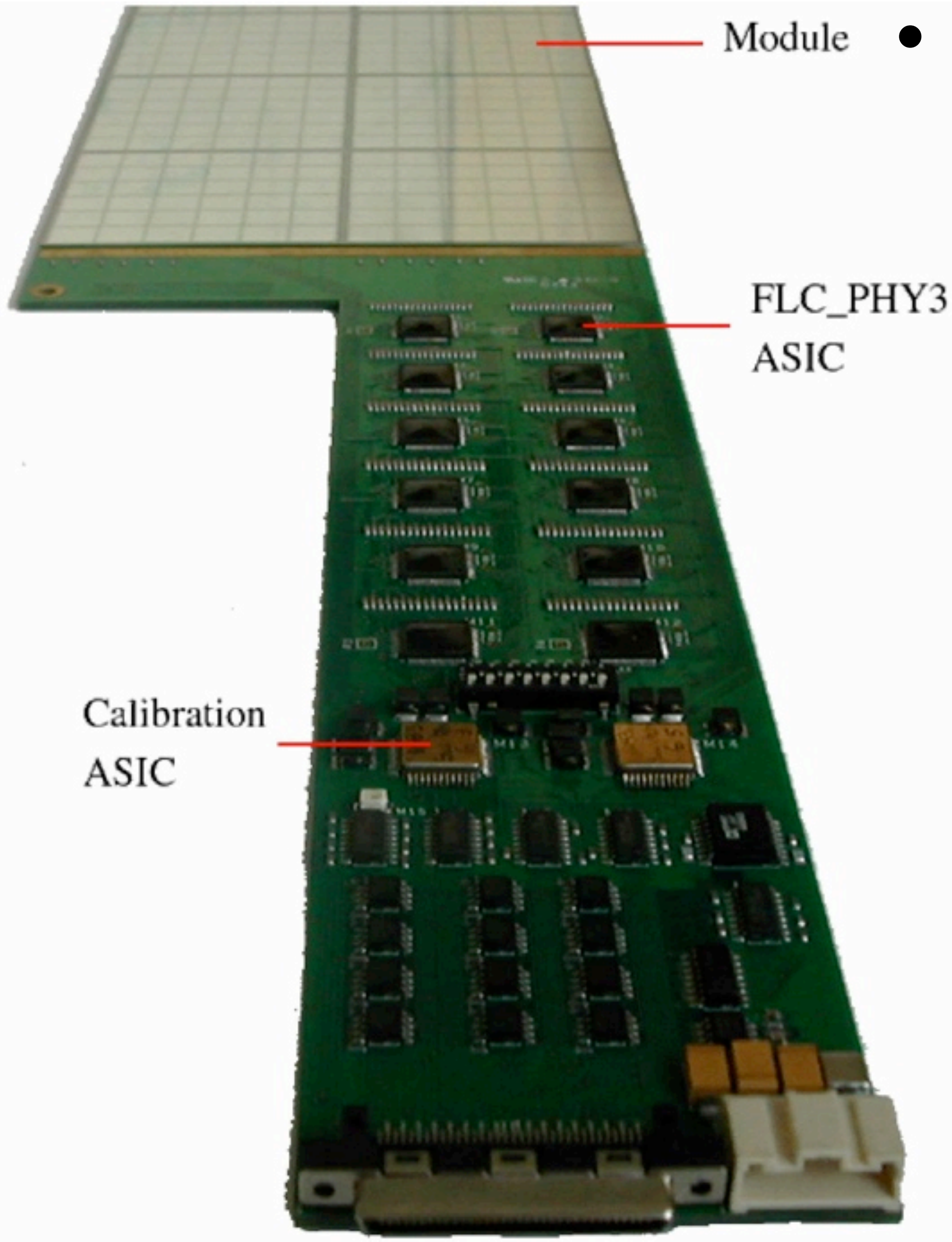
- Tailcatcher:
  - **Analog: Steel - Scintillator strips with SiPM readout**

Si-W ECAL



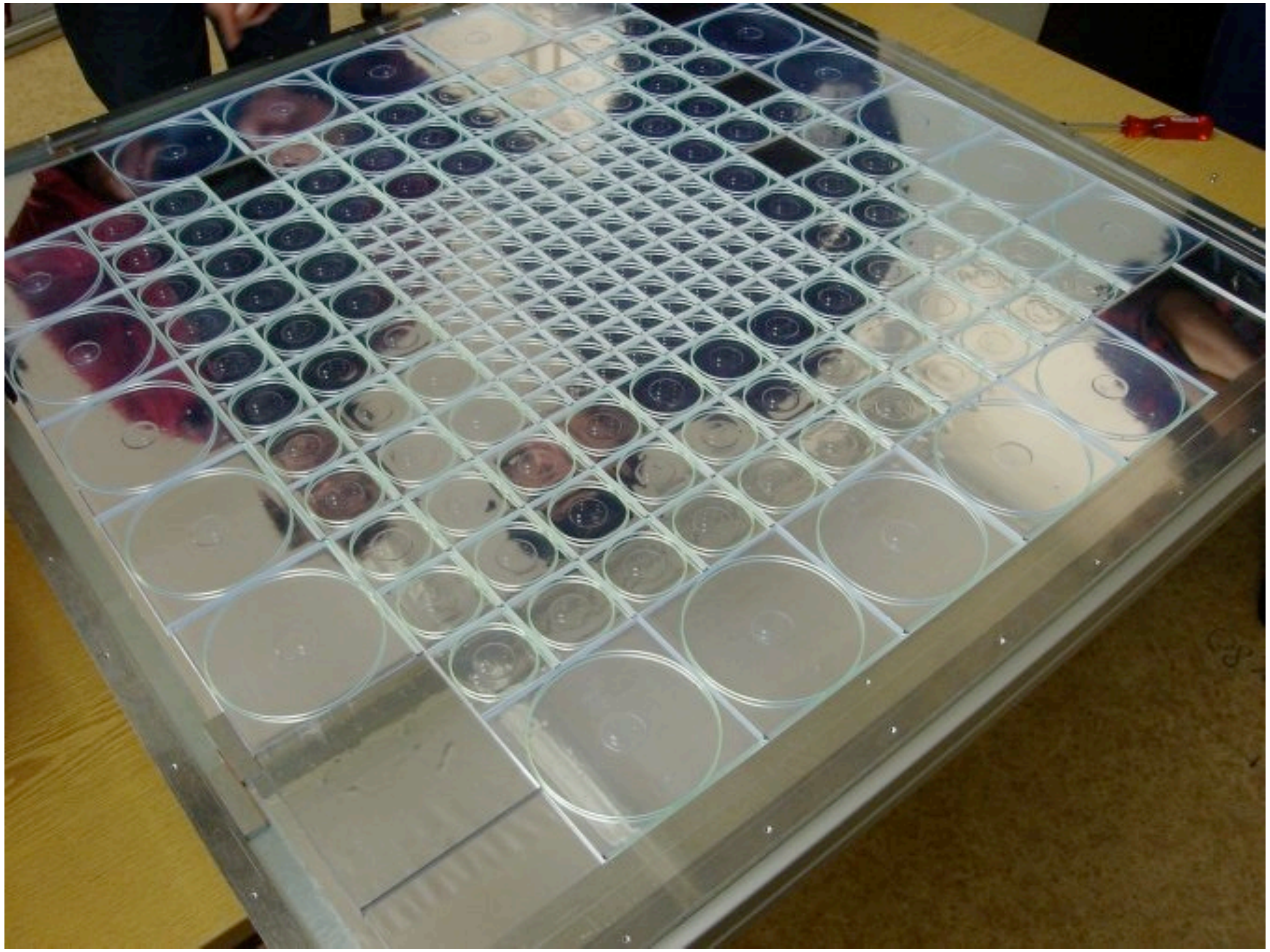
- 18 x 18 cm^2 active area
- 30 layers of Tungsten:
  - 10 x 1.4 mm (0.4 X_0)
  - 10 x 2.8 mm (0.8 X_0)
  - 10 x 4.2 mm (1.2 X_0)
  - 24 X_0 total

Si-W ECAL: Detectors

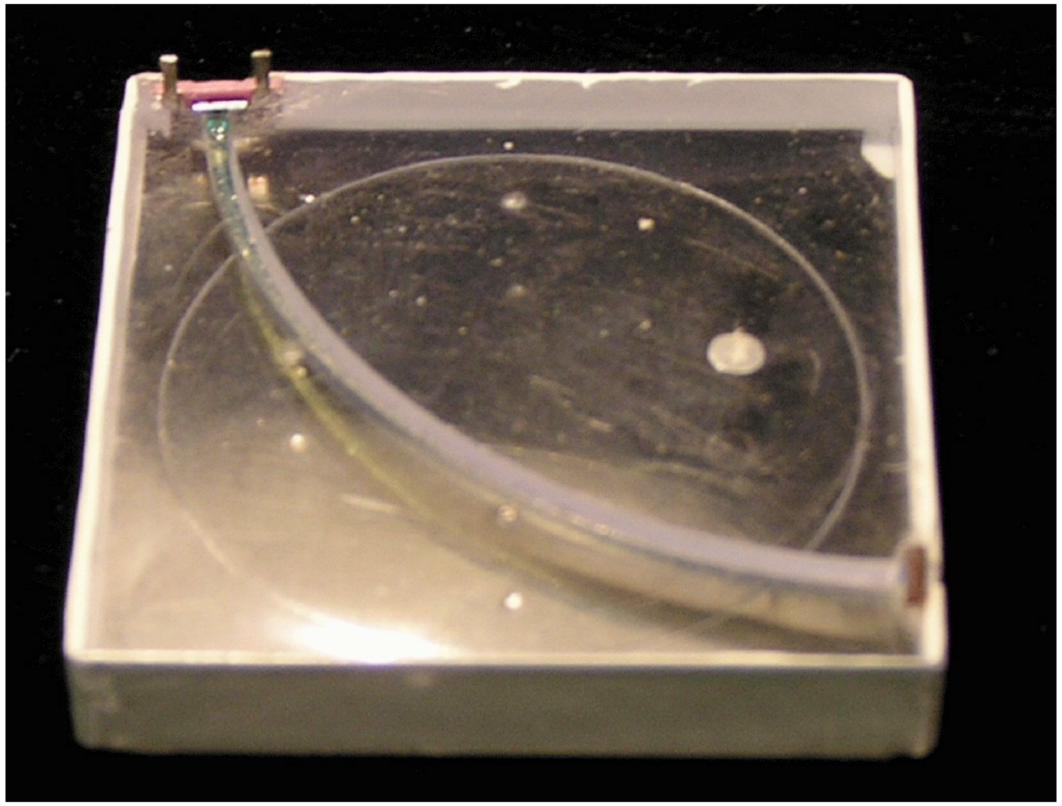


- Active Elements: Si-Pad Detectors (PIN diodes)
  - 1 x 1 cm^2 pads adapted to Moliere radius of W (9 mm)
  - modules with 6 x 6 pads
  - 525 μm wafer thickness

Analog HCAL



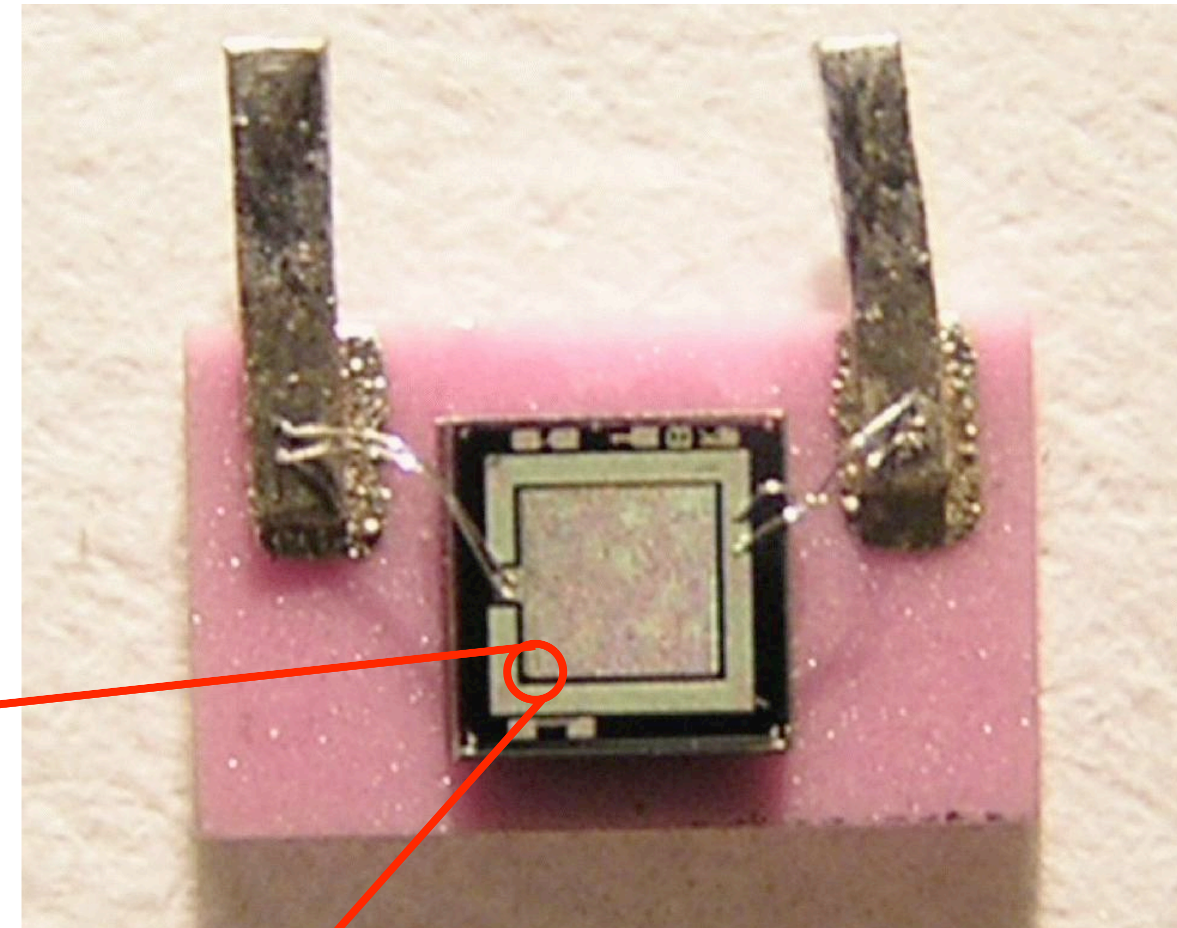
- Steel absorber structure
  - 38 layers
  - 2 cm layer thickness
    (1.1 X_0, 0.12 λ)
  - total ~ 4.5 λ

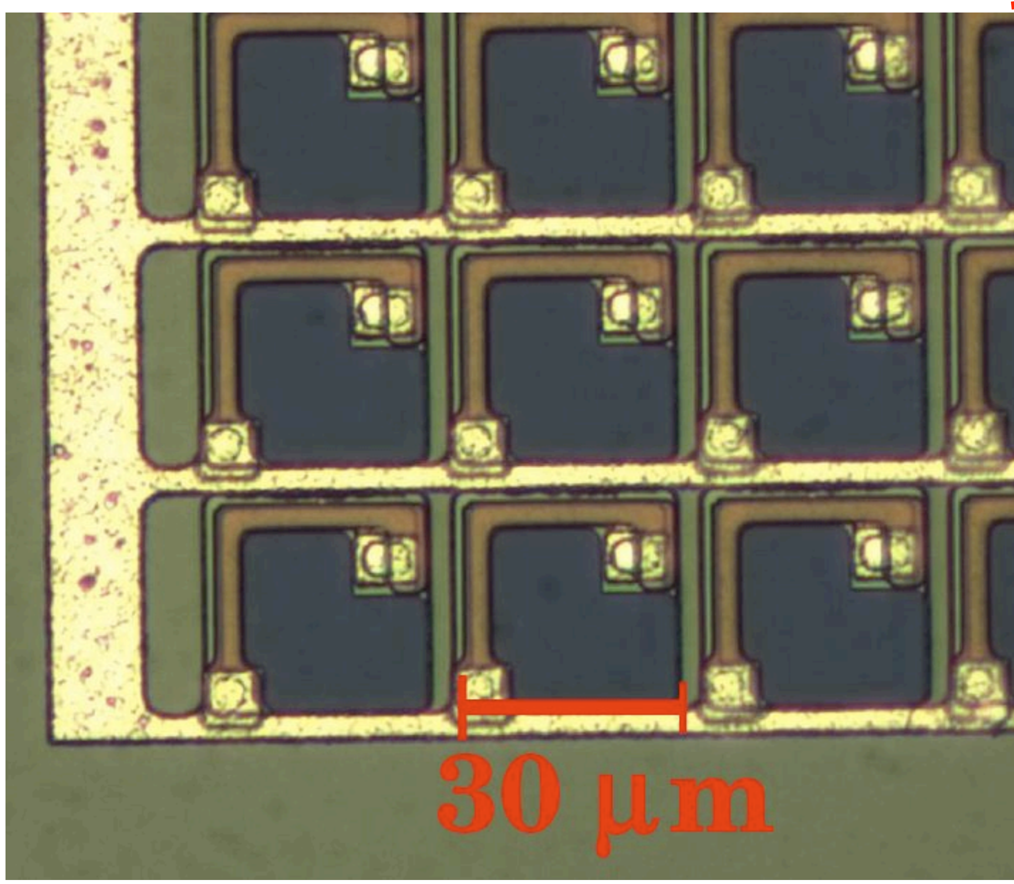


- Active layers: Scintillator tiles
  - high granularity in the layer center
    100 3x3 cm^2 tiles, then 6x6 cm^2 and 12 x12 cm^2
  - light collection via wls fiber

Analog HCAL: SiPM Readout

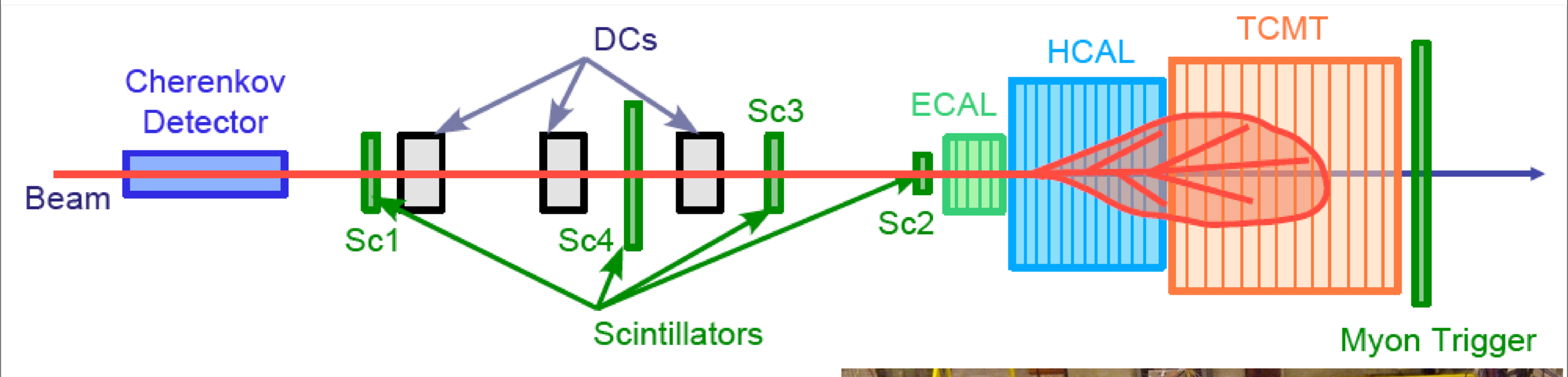
- Silicon Photomultipliers as photon detectors to read out each scintillator tile separately
  - array of small APDs operated in limited Geiger mode, read out through one common line



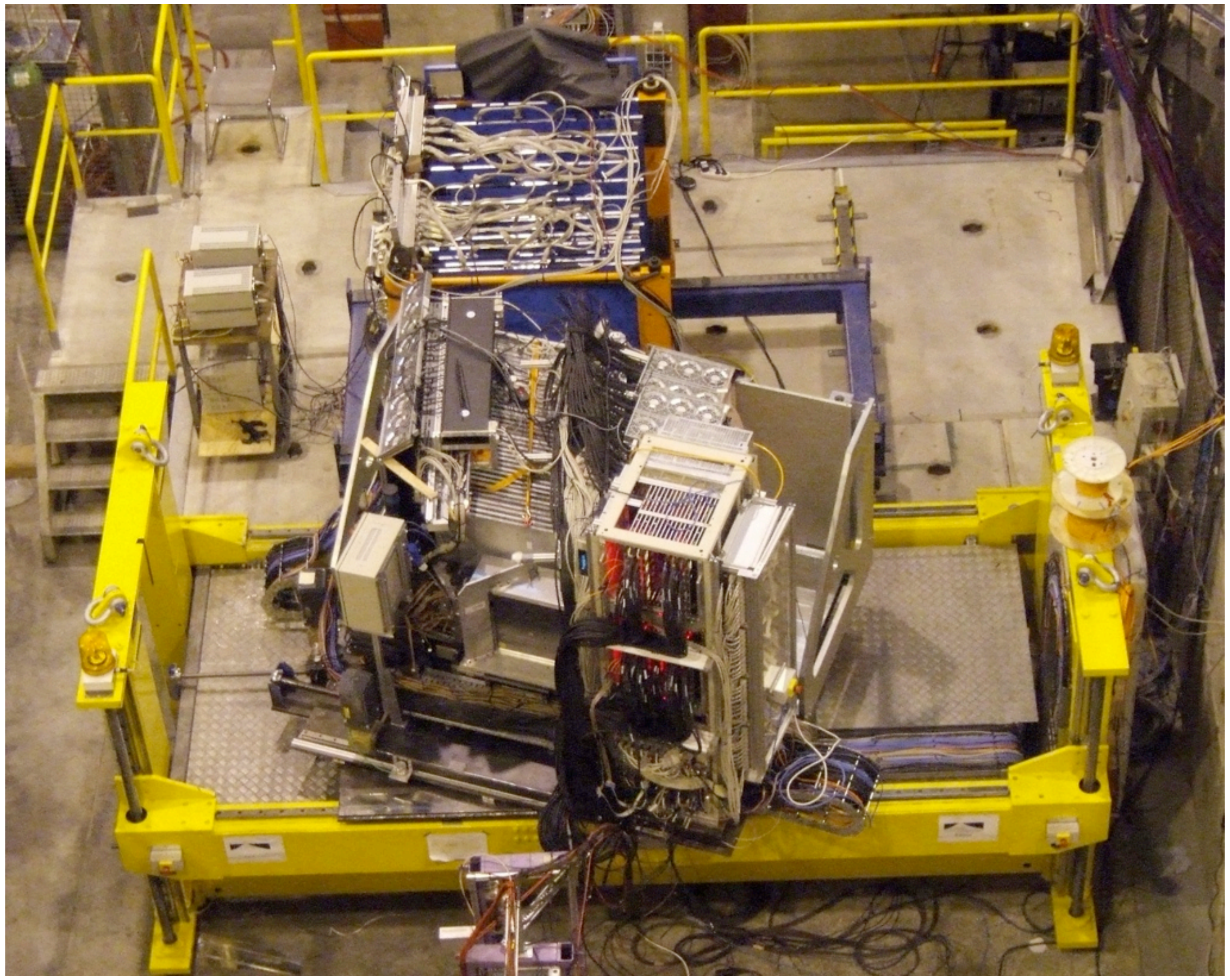


- sensitive area 1.1 x 1.1 mm^2
- 1156 pixels, 32 x 32 μm^2

CALICE Test Beam Program

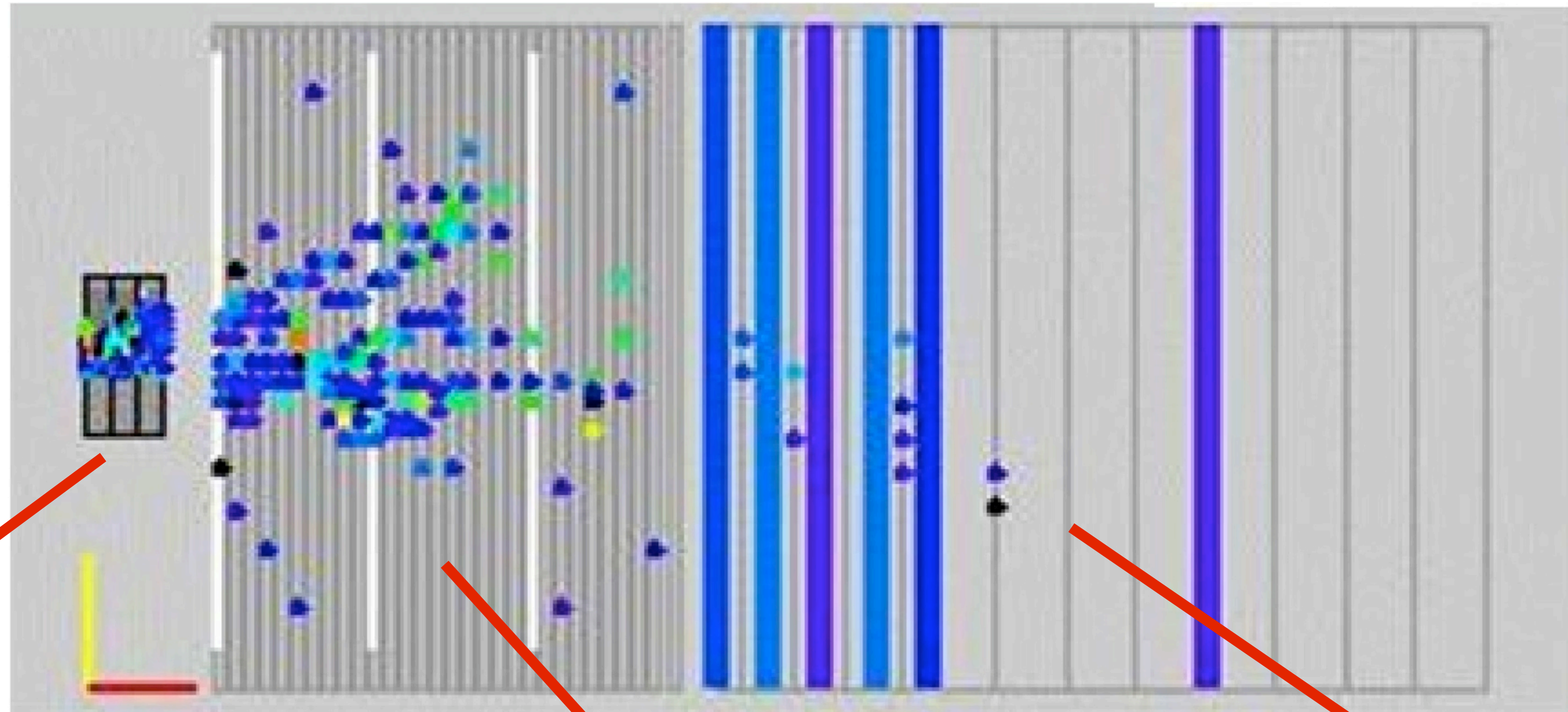


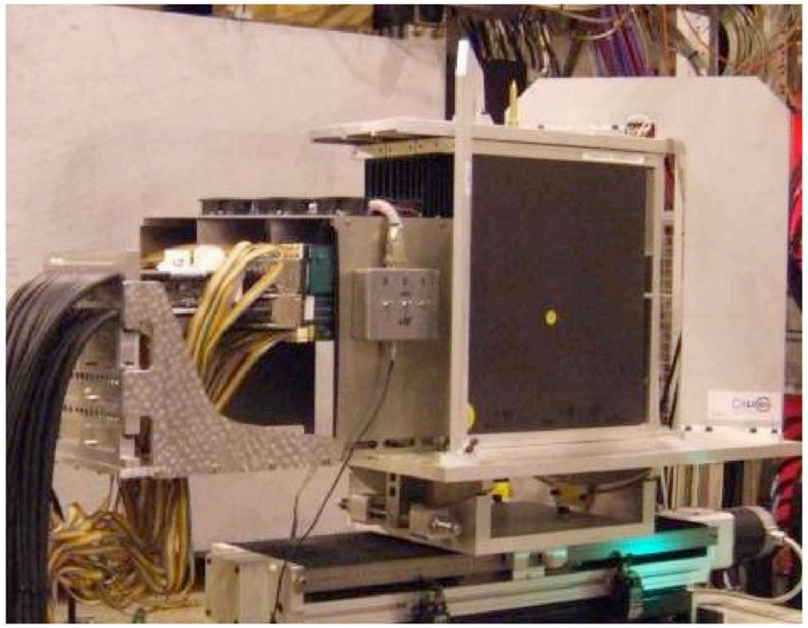
- Extensive test beam campaign
  - CERN: 2006, 2007
  - FNAL: 2008, ...
- Wide variety of beam energies and particle species
  - 2 GeV to 80 GeV
  - muons, $e^{\pm}$, $\pi^{\pm}$, unseparated hadrons



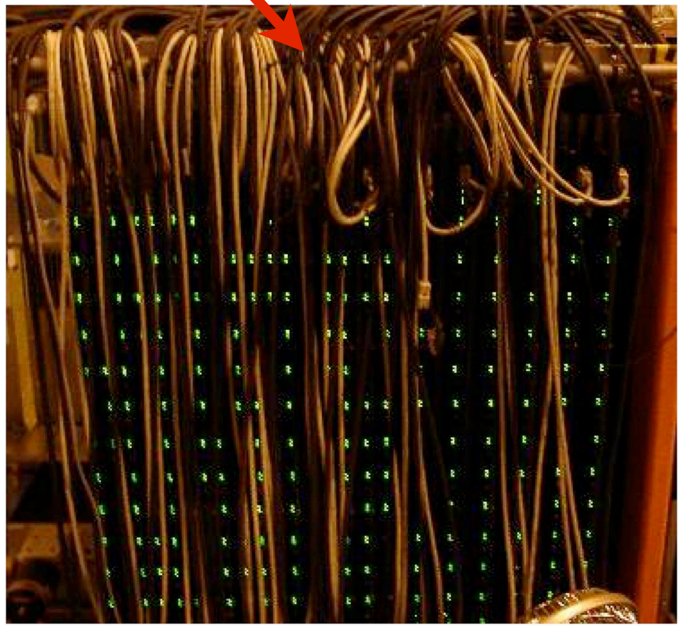
CALICE Calorimeter Setup

- 40 GeV negative pions

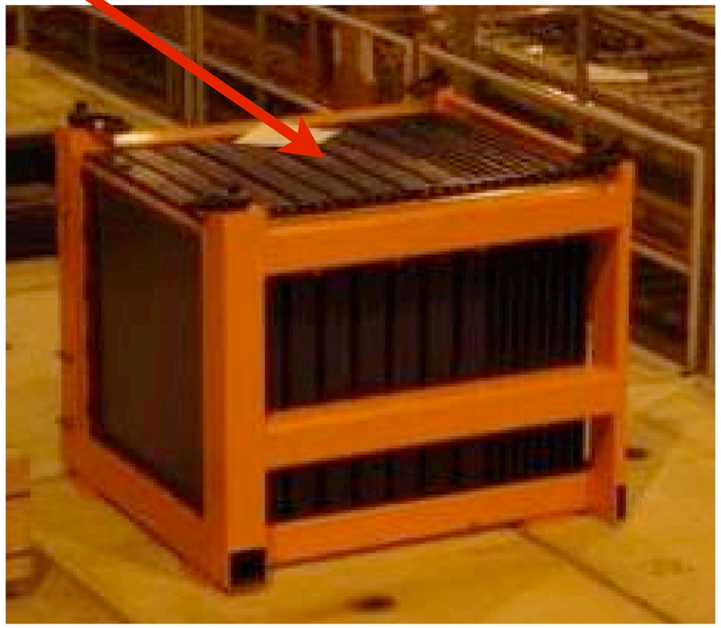




Si-W ECAL
1x1 cm^2 lateral segmentation
30 layers, ~ 0.9 λ, 30 X_0
~ 10 k channels

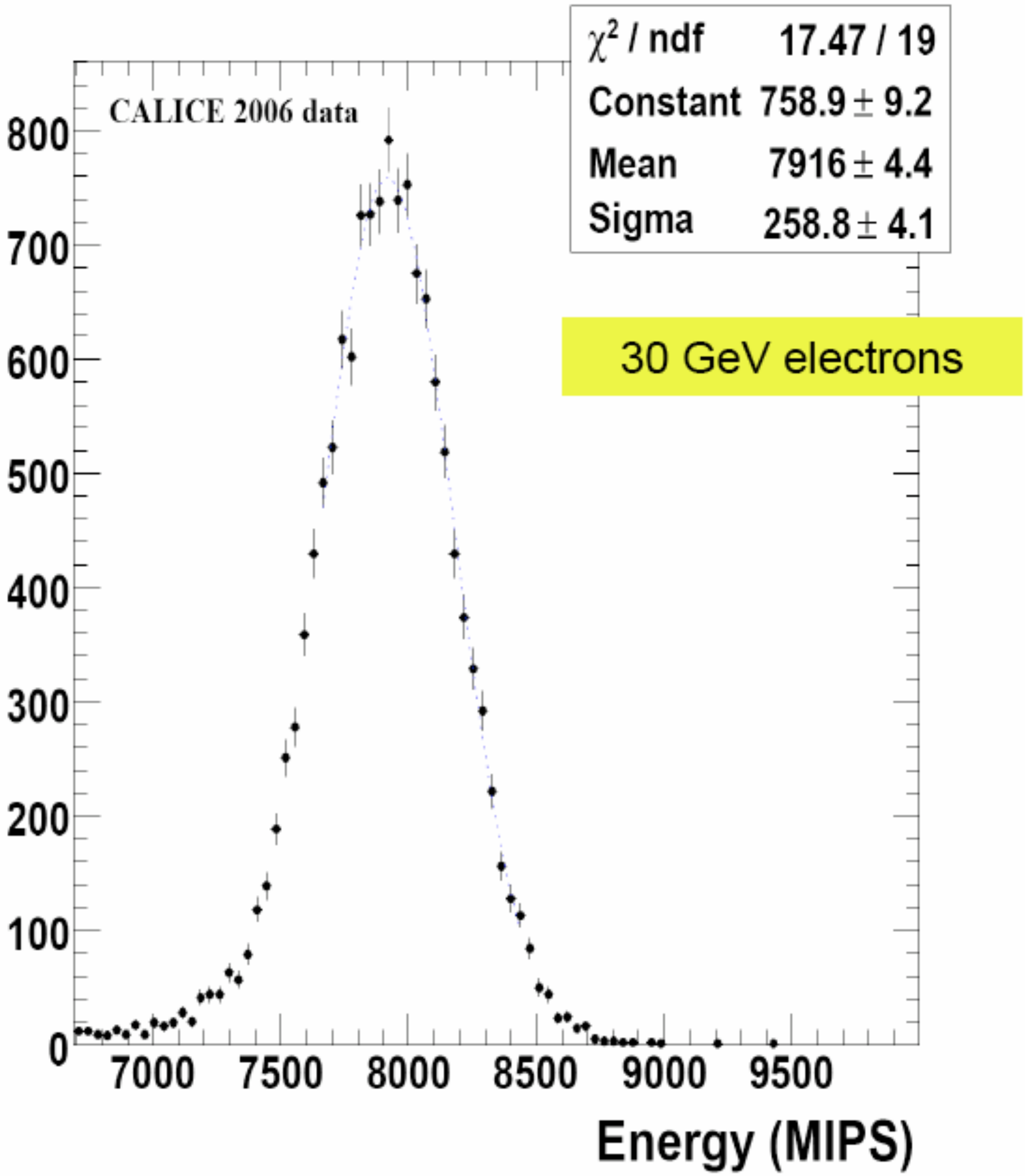


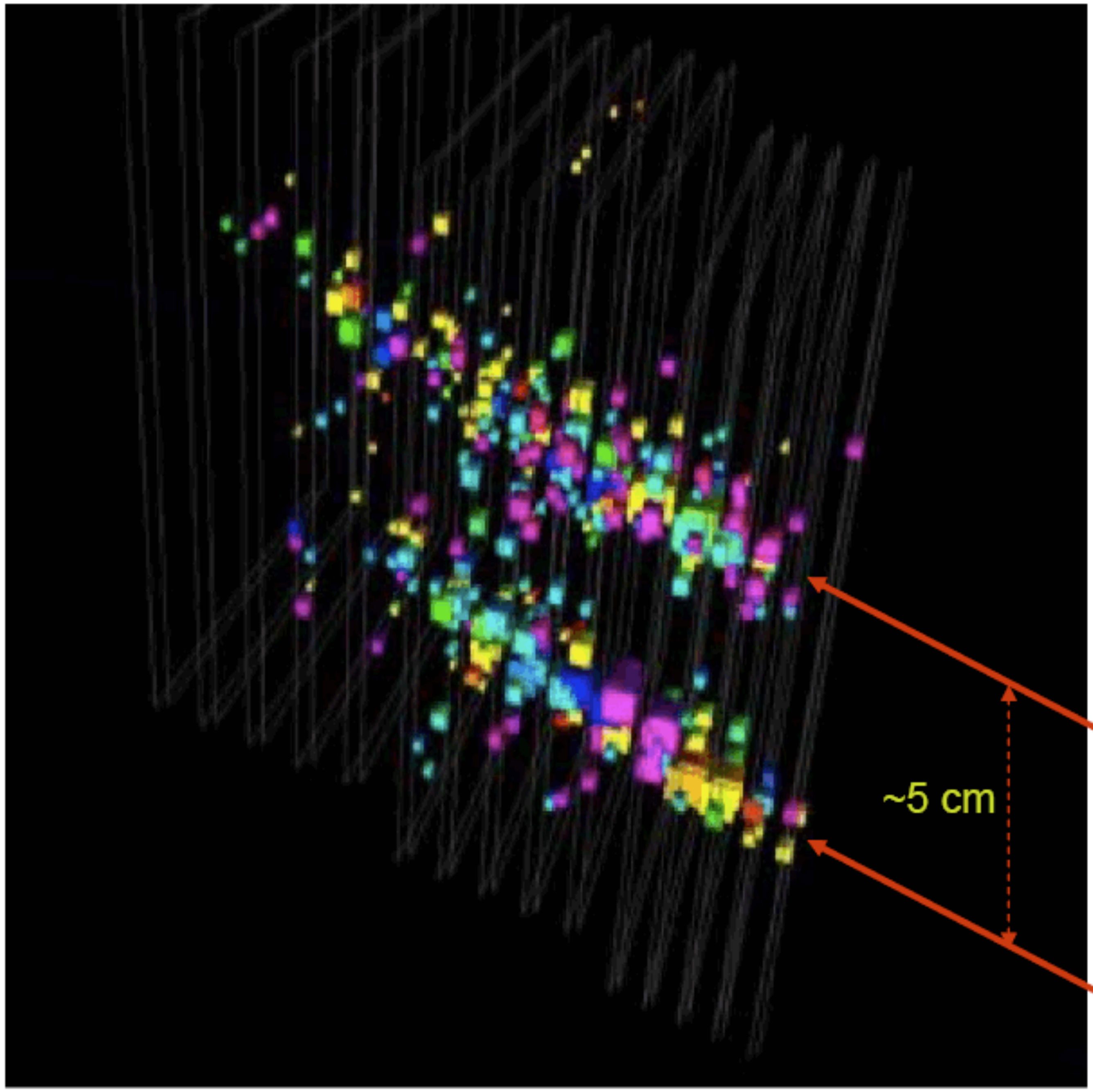
Analog HCAL
3x3 - 12x12 cm^2 lateral segmentation
38 layers, ~ 4.5 λ
~ 8 k channels



Tail Catcher / Muon Tracker
5 x 100 cm^2 Scintillator Strips
16 layers
~ 300 channels

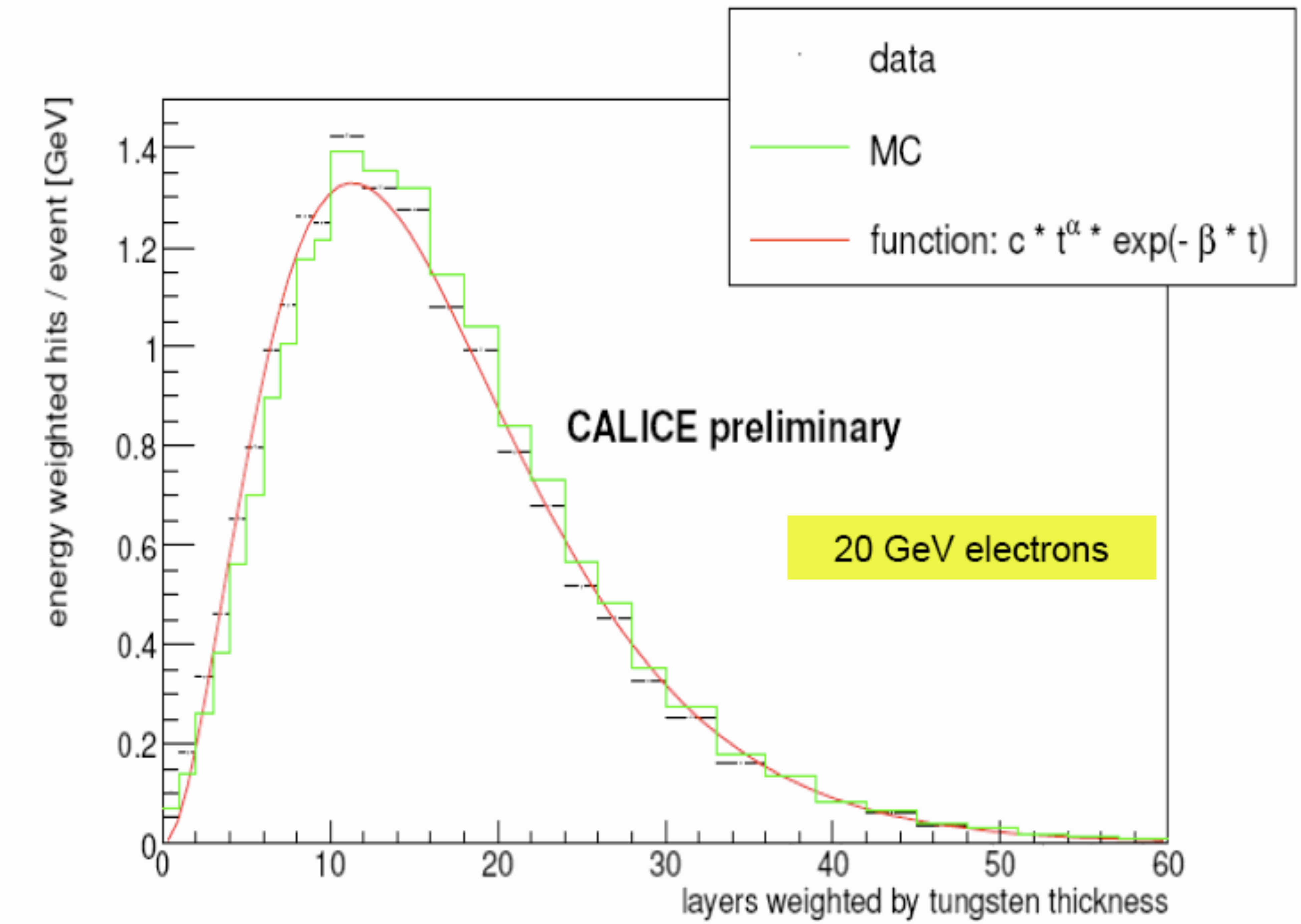
Si-W ECAL Performance





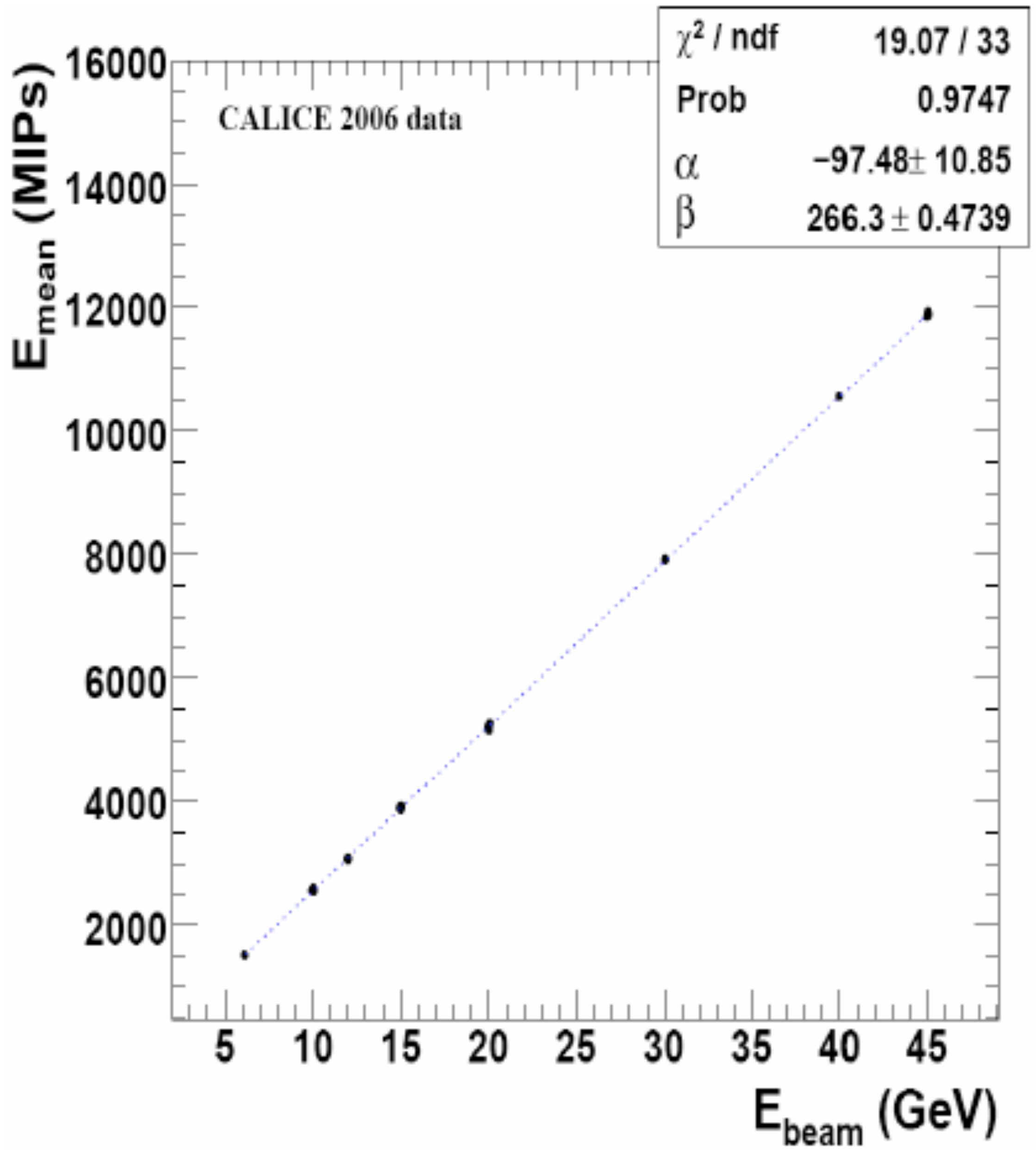
- Gaussian energy distribution, good spatial separation of nearby showers

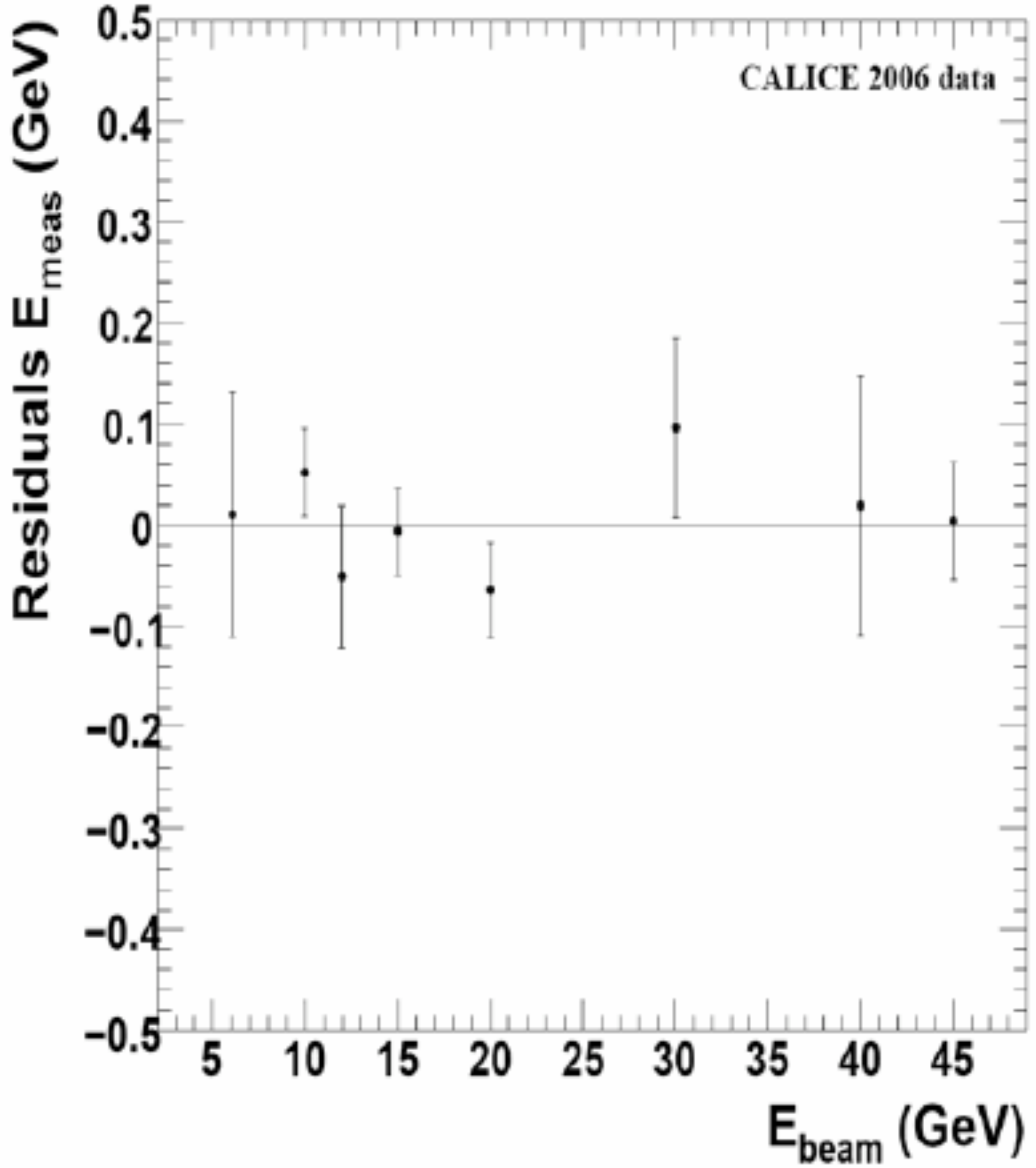
Si-W ECAL Performance: Longitudinal Profile



- longitudinal shower profile well described by simulations
  - discrepancies attributed to uncertainty in material upstream of the calorimeter

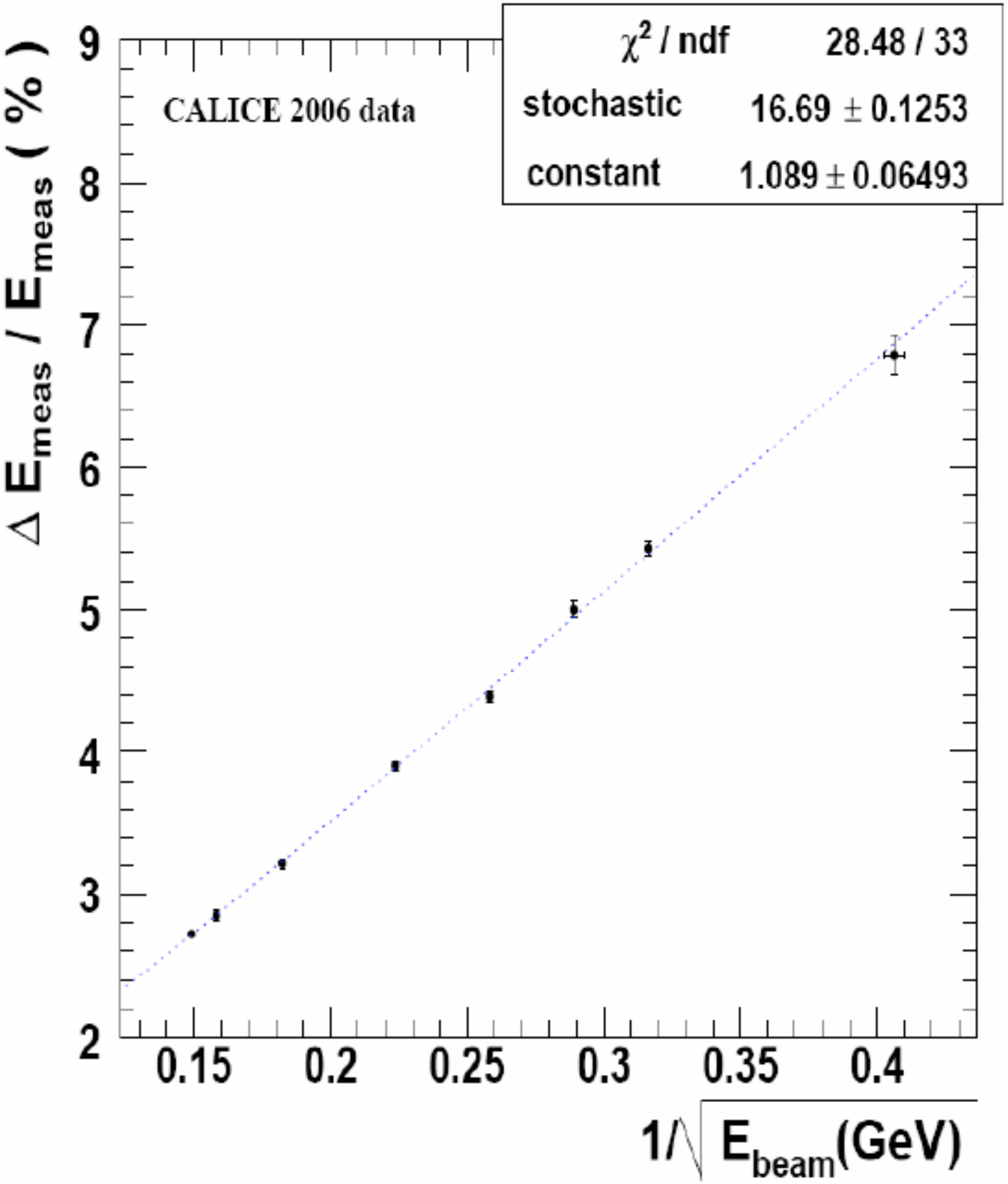
Si-W ECAL Performance: Linearity





- linearity better than 1% out to 45 GeV

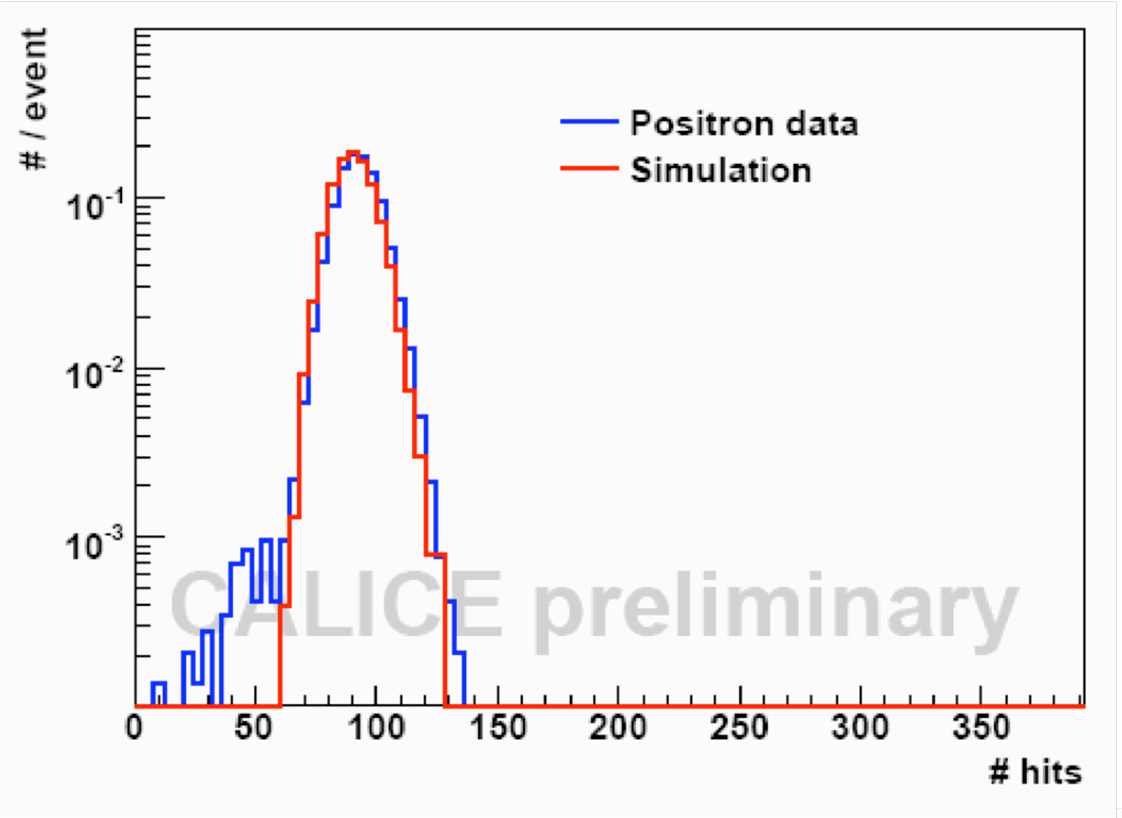
Si-W ECAL Performance: Resolution



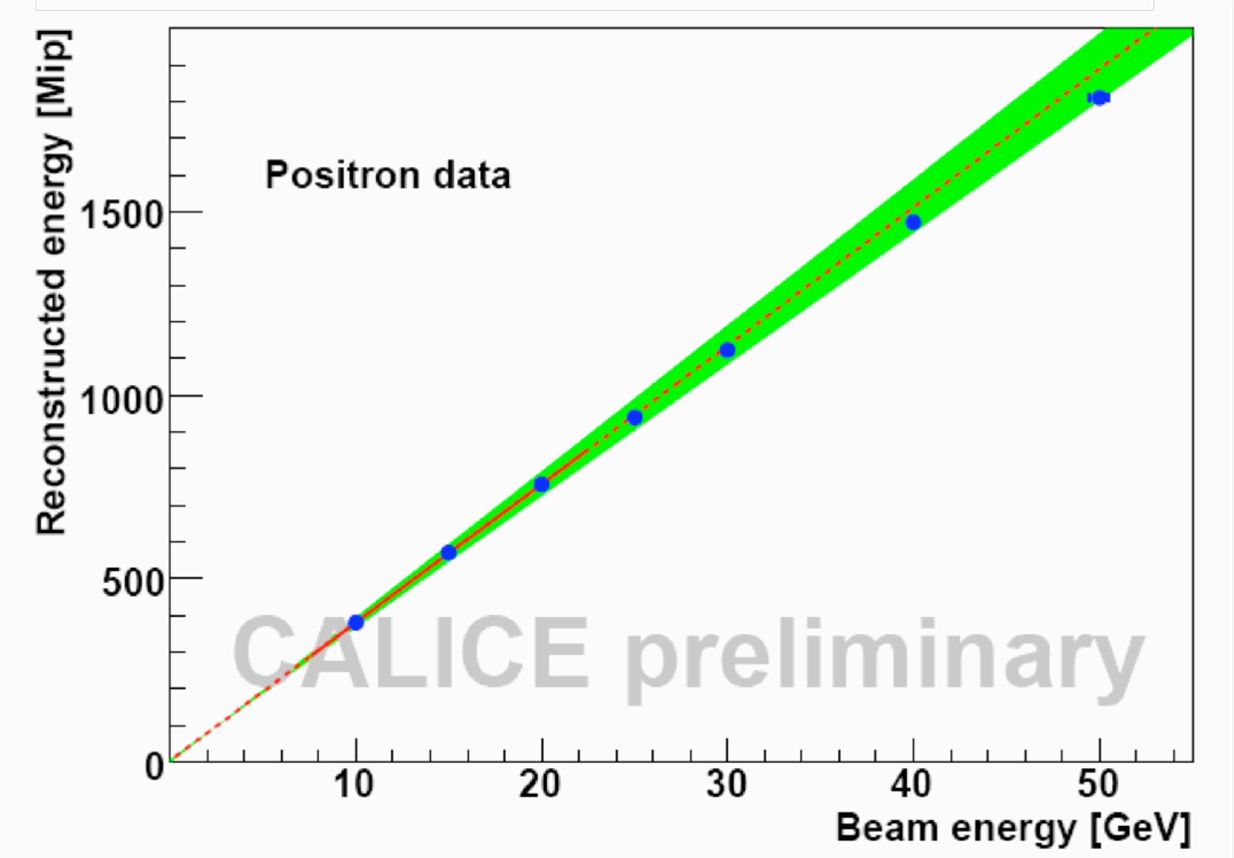
- Energy resolution
  - stochastic term
    16.7 %
  - constant term
    1.1 %

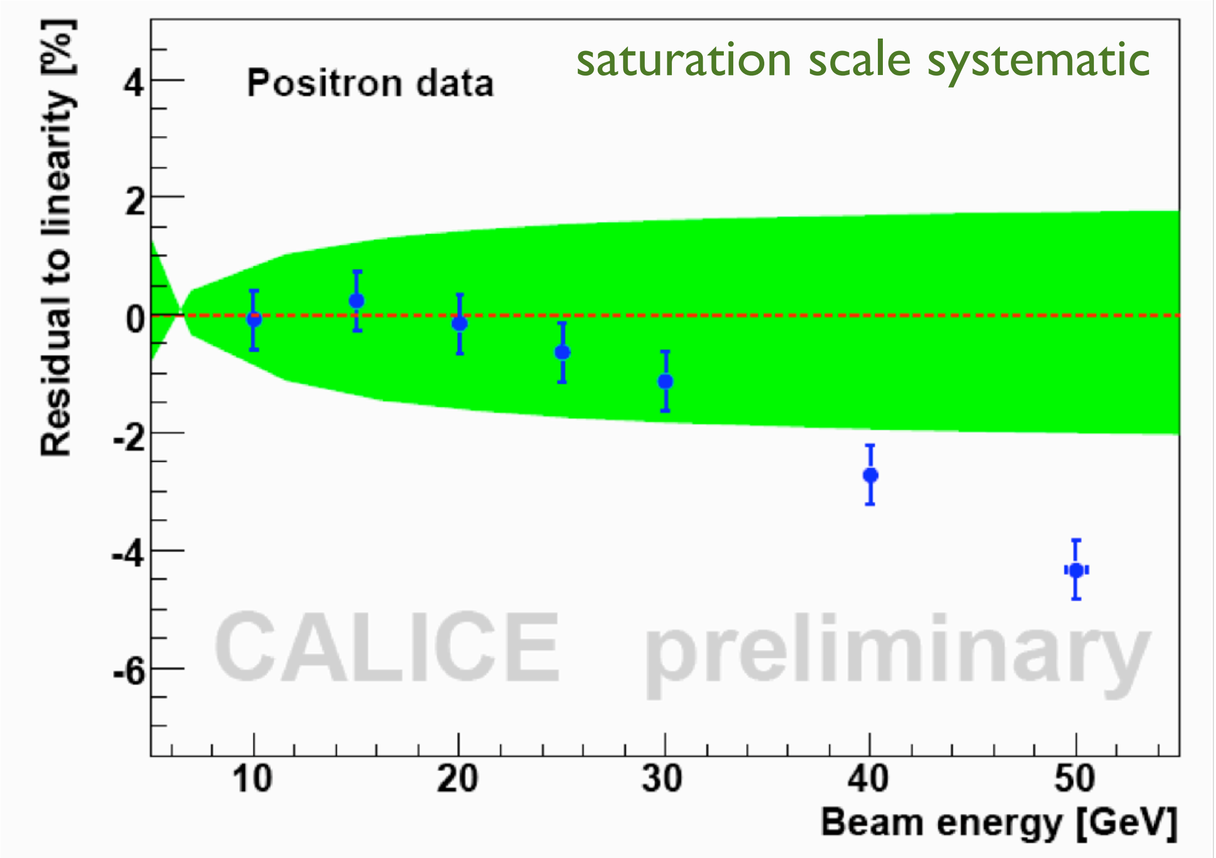
  - corrected for energy spread in the beam

AHCAL Performance: Positrons

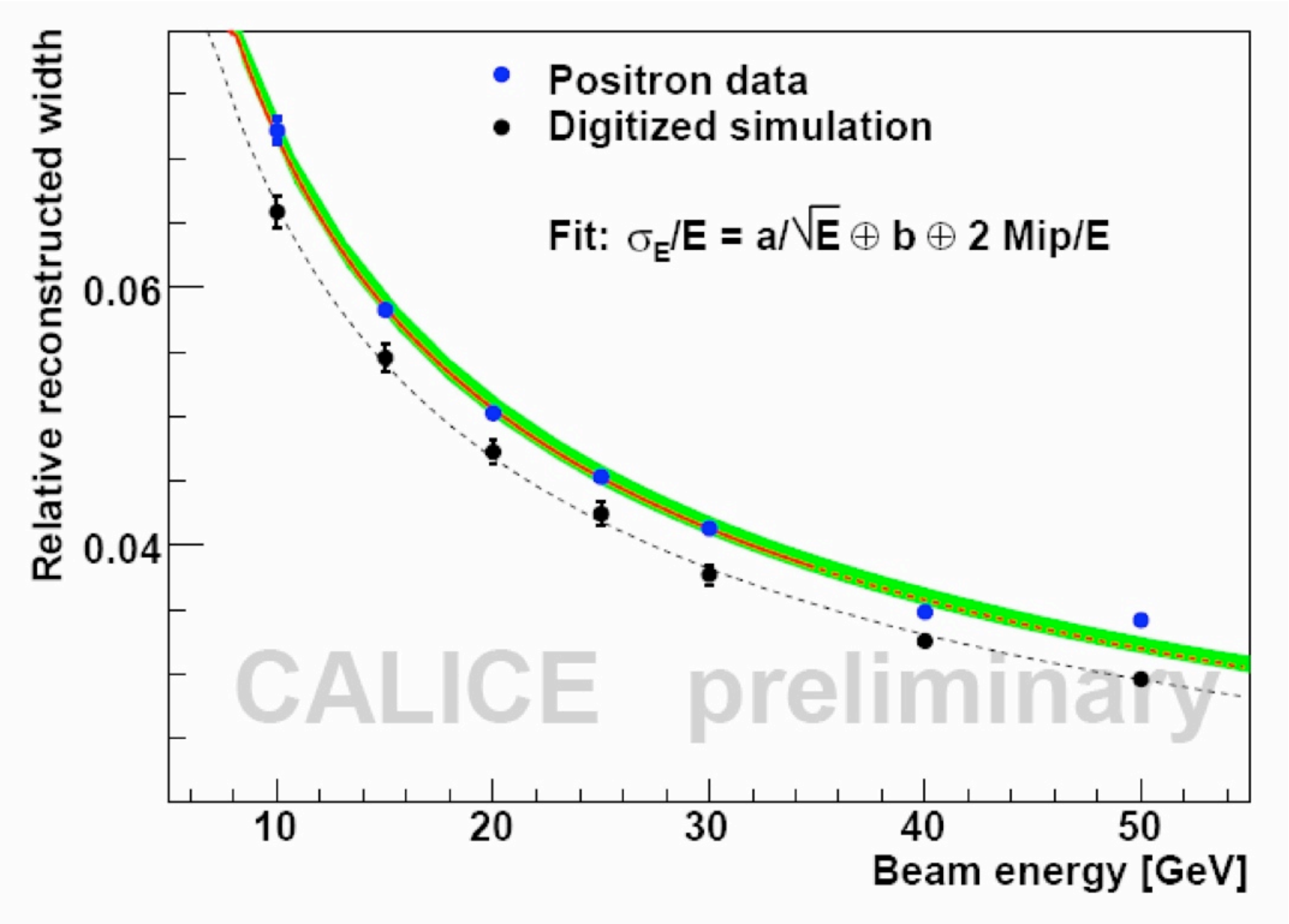


- Electromagnetic probes to validate detector calibration and MC understanding
- good agreement for cells above threshold
- linearity of calibrated calorimeter response better than 4% out to 50 GeV





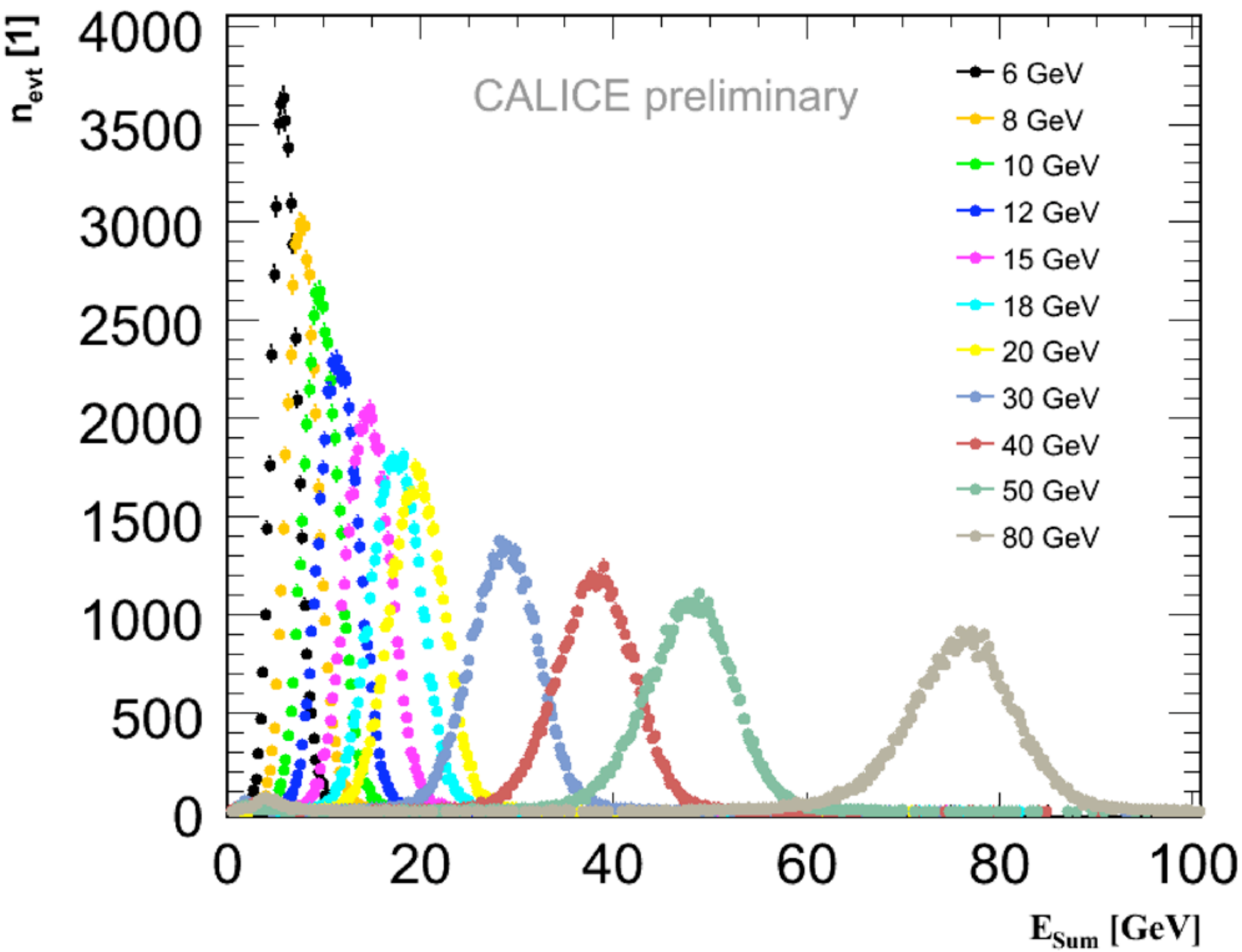
AHCAL Performance: EM Energy Resolution



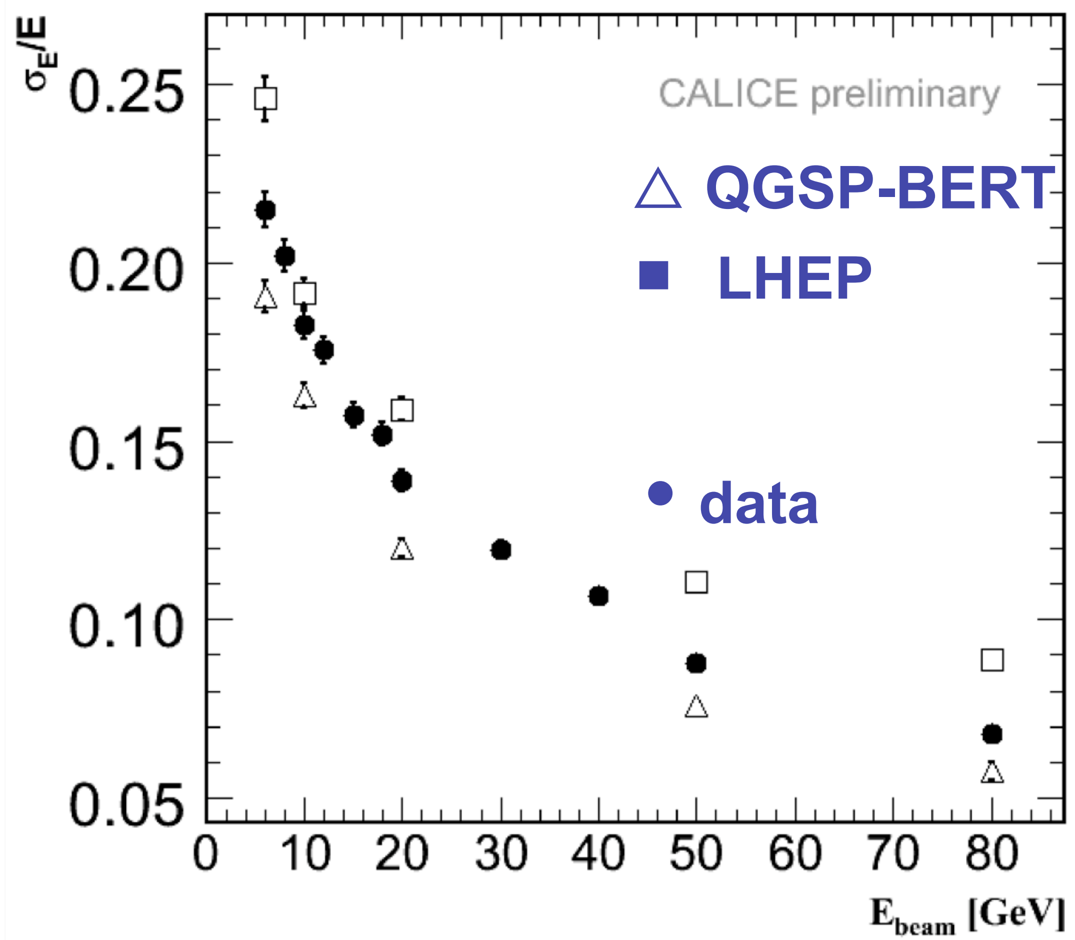
- Fit results:
  - stochastic term
    $22.6 \pm 0.1_{fit} \pm 0.4_{calib}$ %
    (MC: $20.9 \pm 0.3_{fit}$ %)
  - constant term
    $0 \pm 1.4_{fit} \pm 0.3_{calib}$ %
    (MC $0 \pm 2.2_{fit}$ %)
  - noise term
    fixed from random trigger events
    2 MIP ~ 50 MeV

- Satisfactory understanding of detector resolution on the electromagnetic scale, remaining deviations of MC and data < 10%

AHCAL Performance: Pions

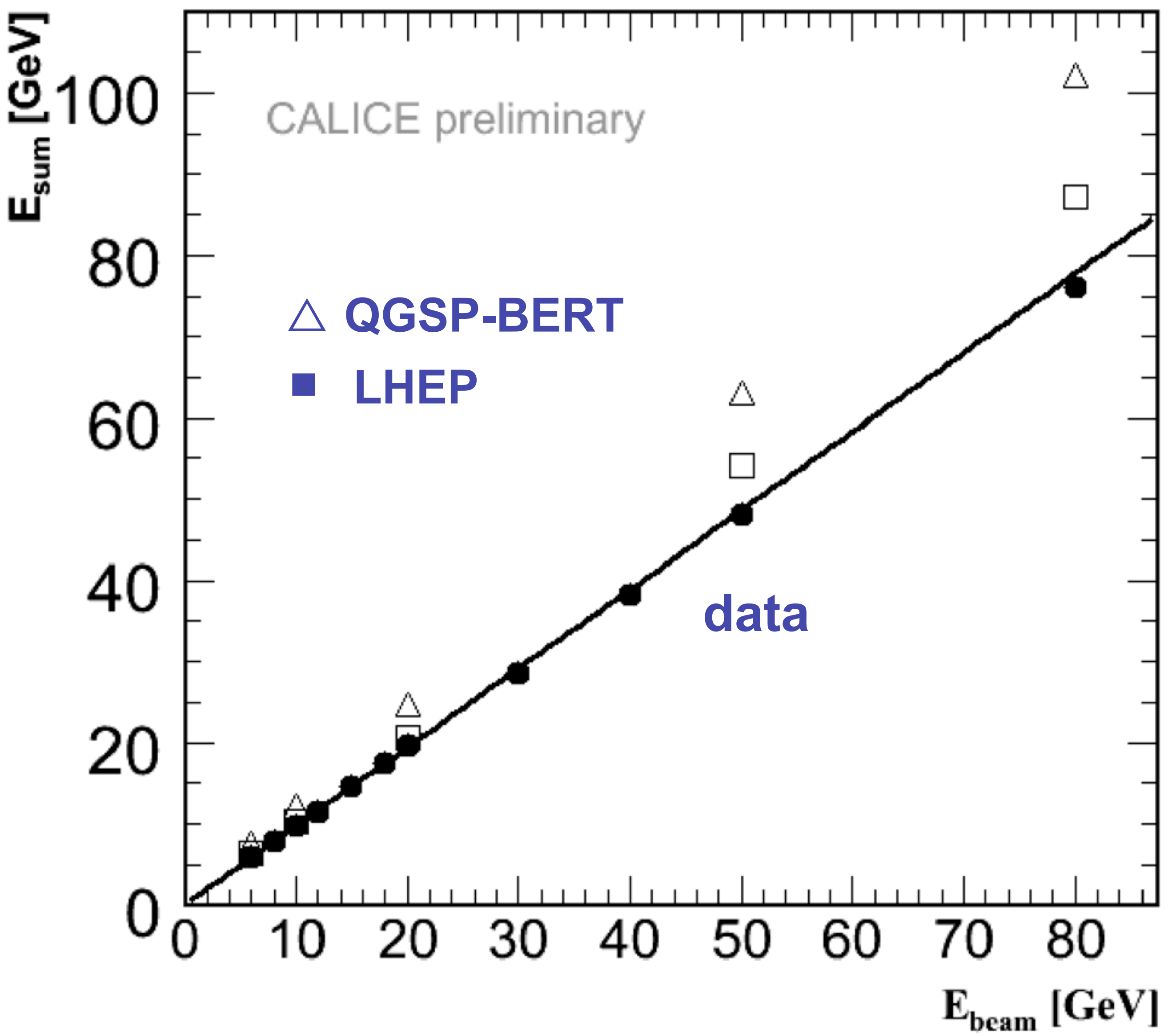


- contained pion showers in AHCAL and TCMT
- comparison to MC calculations based on two different physics lists



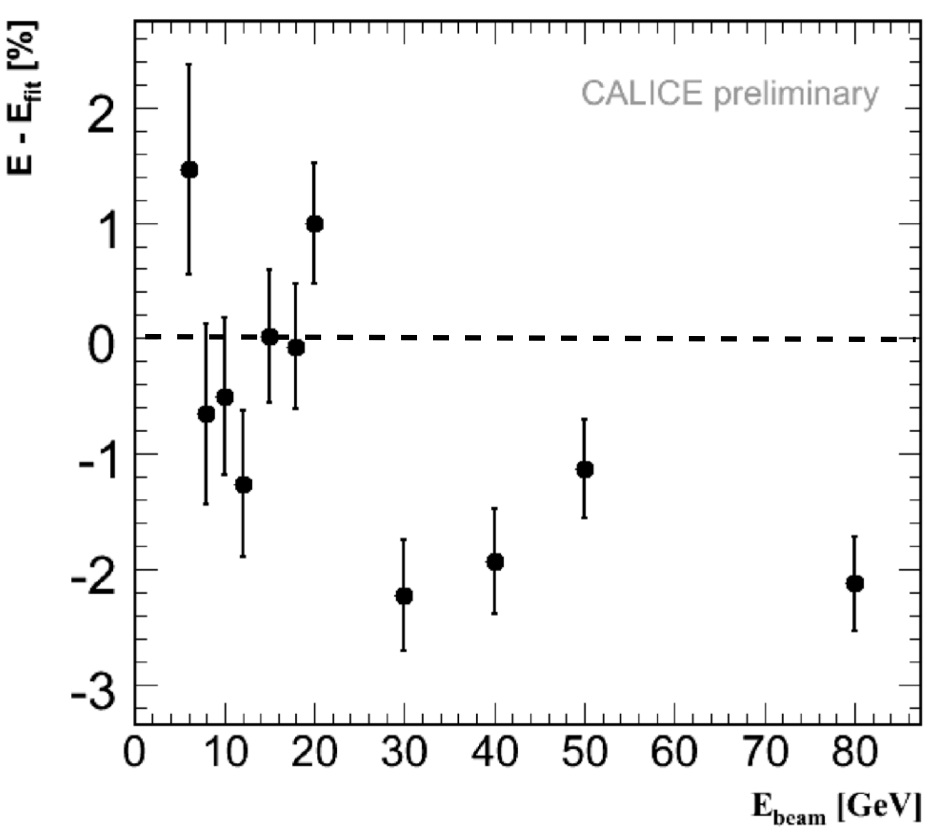
- Gaussian shape of energy distributions
  - Energy determined by fit: $\Delta E = \sigma$

AHCAL Performance: Linearity

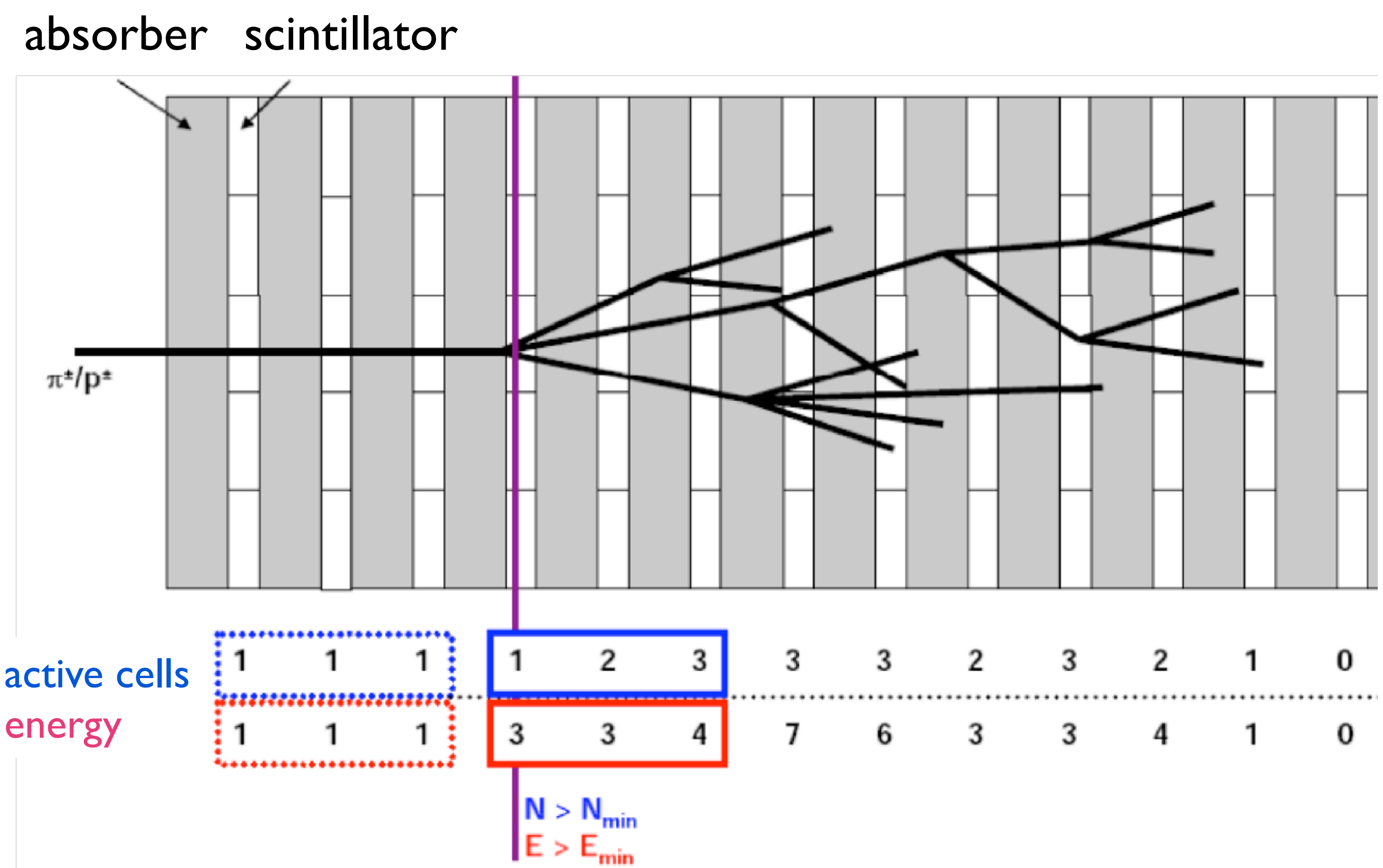


- Surprisingly linear response to hadrons
- detector systematics to be quantified

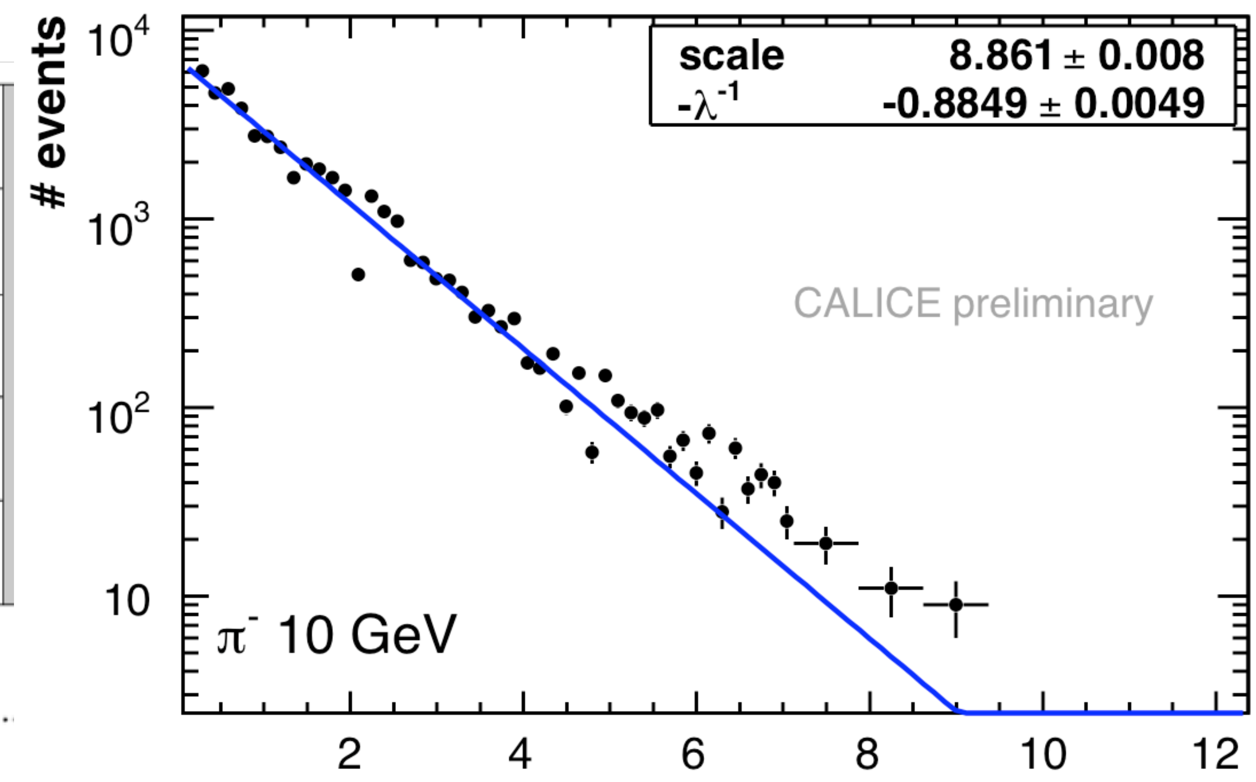
residuals to linear fit from 6 - 20 GeV

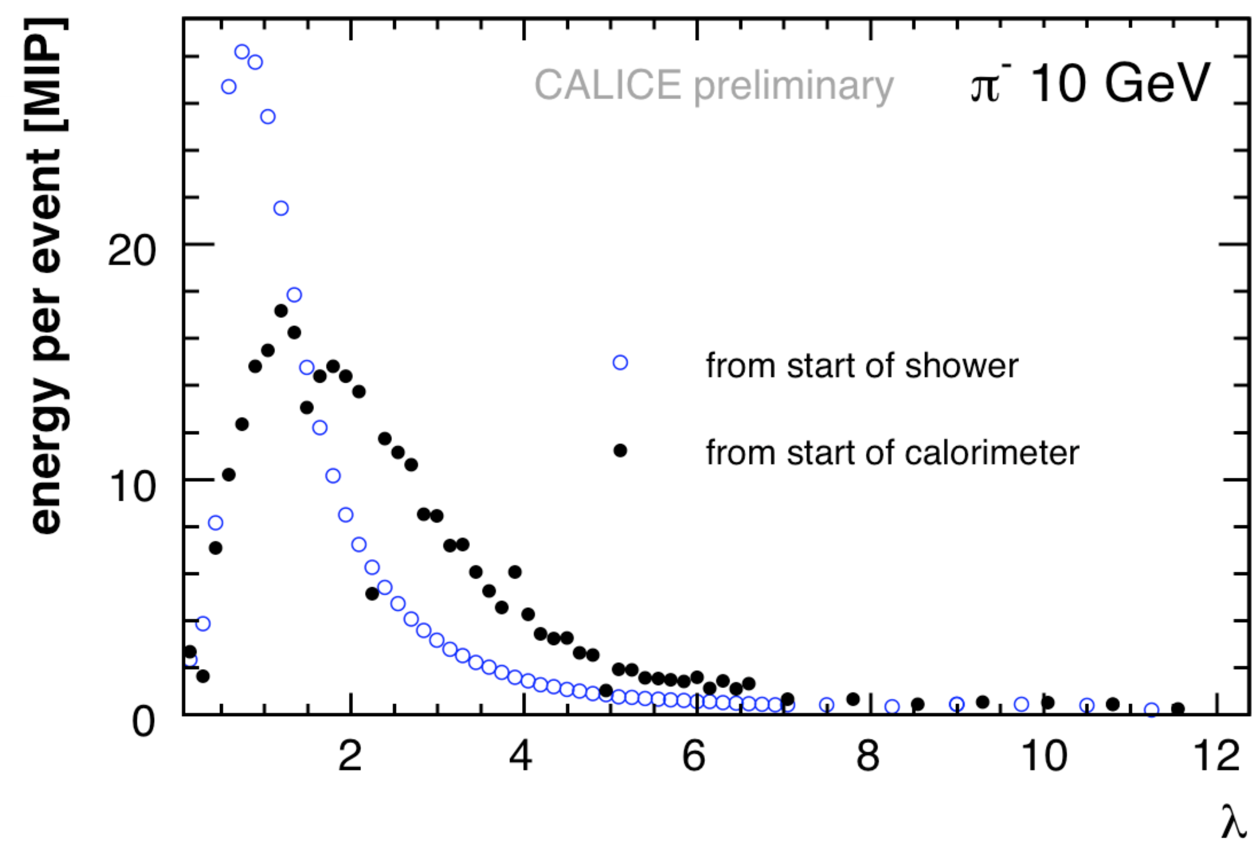


AHCAL: Shower Starting Point

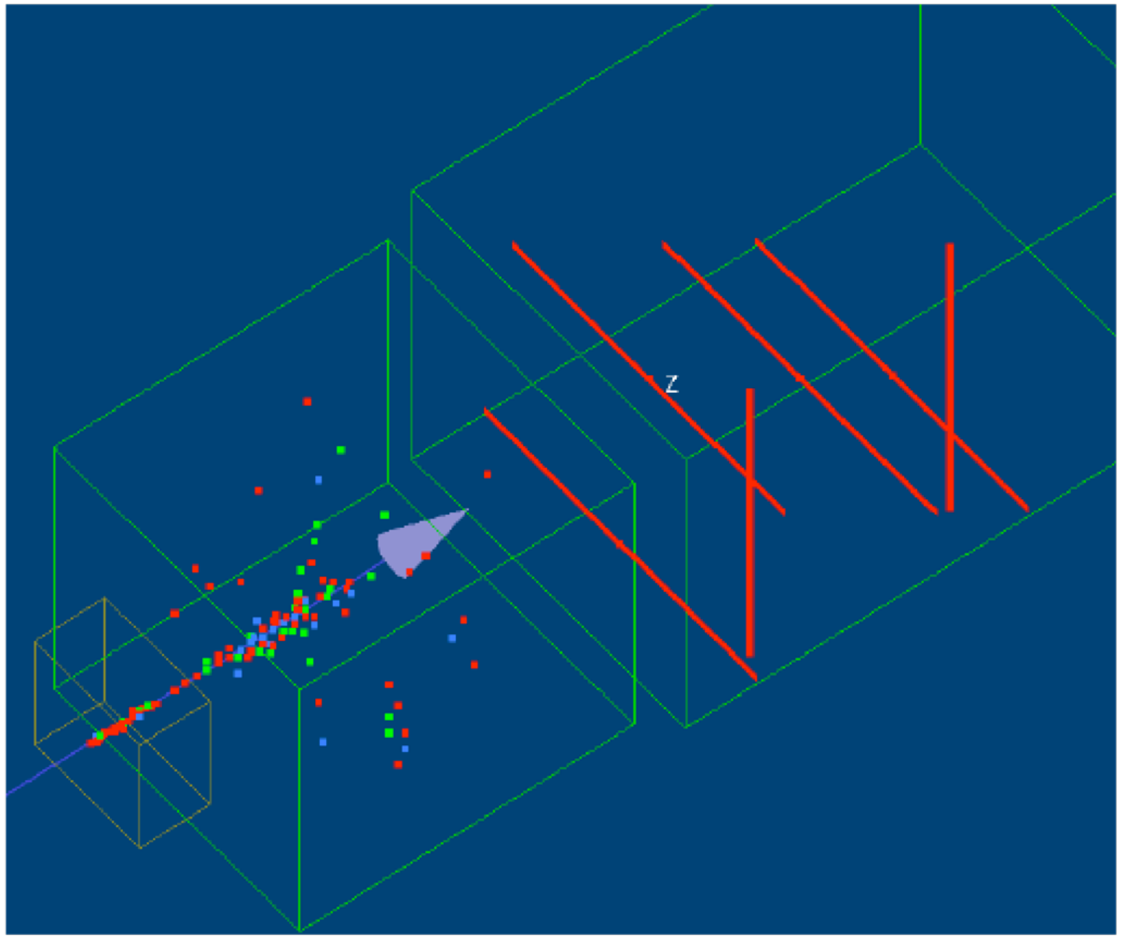


- High granularity allows identification of the shower start: Increased activity, track turns into shower
- starting point shows expected exponential fall-off
- longitudinal profile corrected for starting point optimal for MC comparison

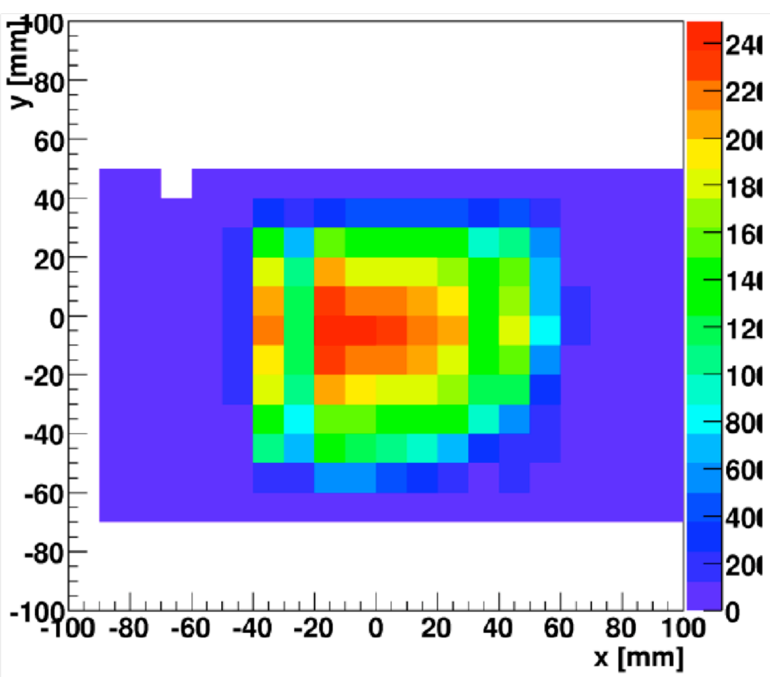




AHCAL: Test of Particle Flow

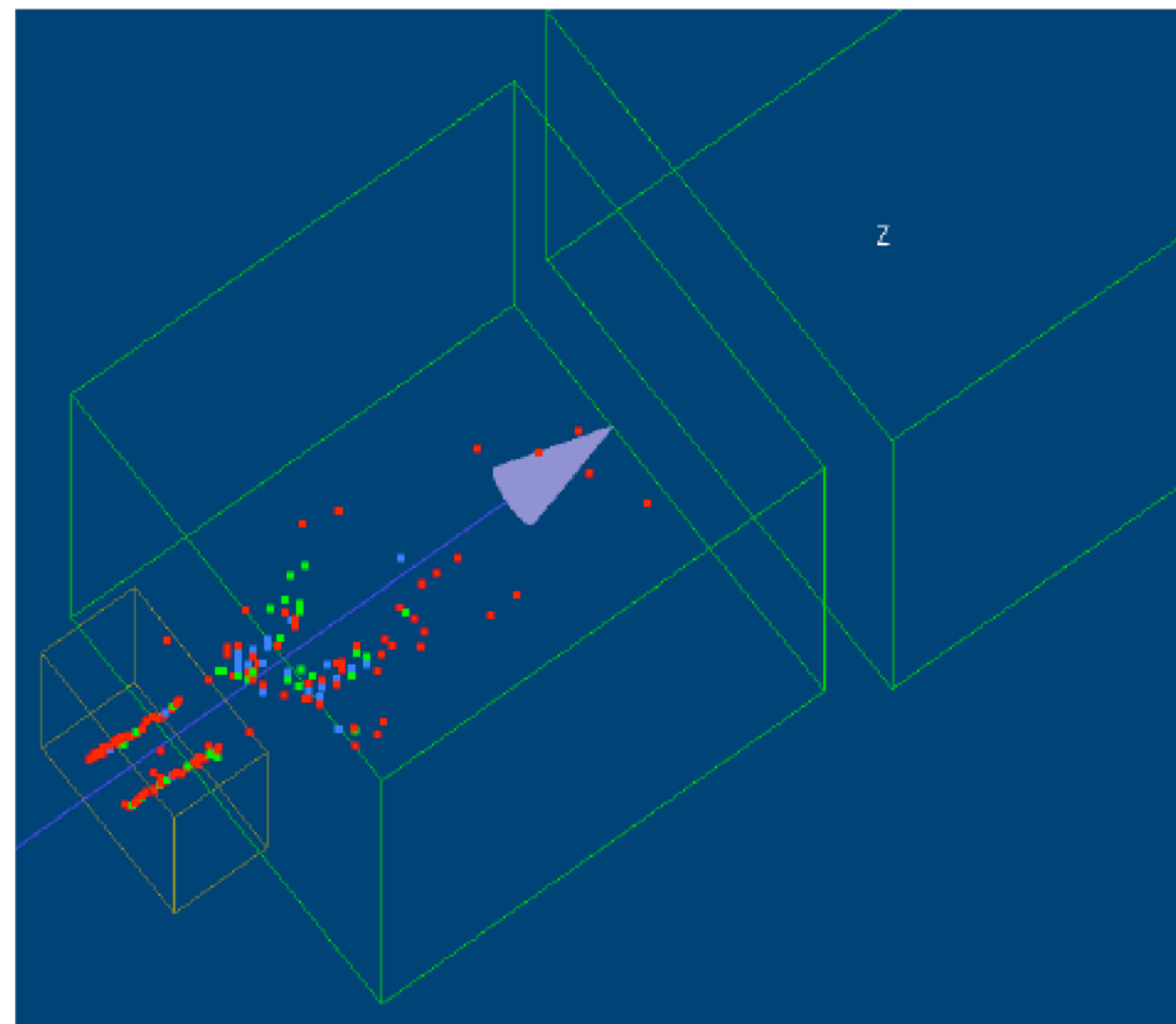


- Mostly single particle events in the beam test
- Build two-particle events from two events by adding cell content
- Advantages: Well defined particle separation, flexibility in energy, energy known



select two event according to desired energy and distance

overlay in software



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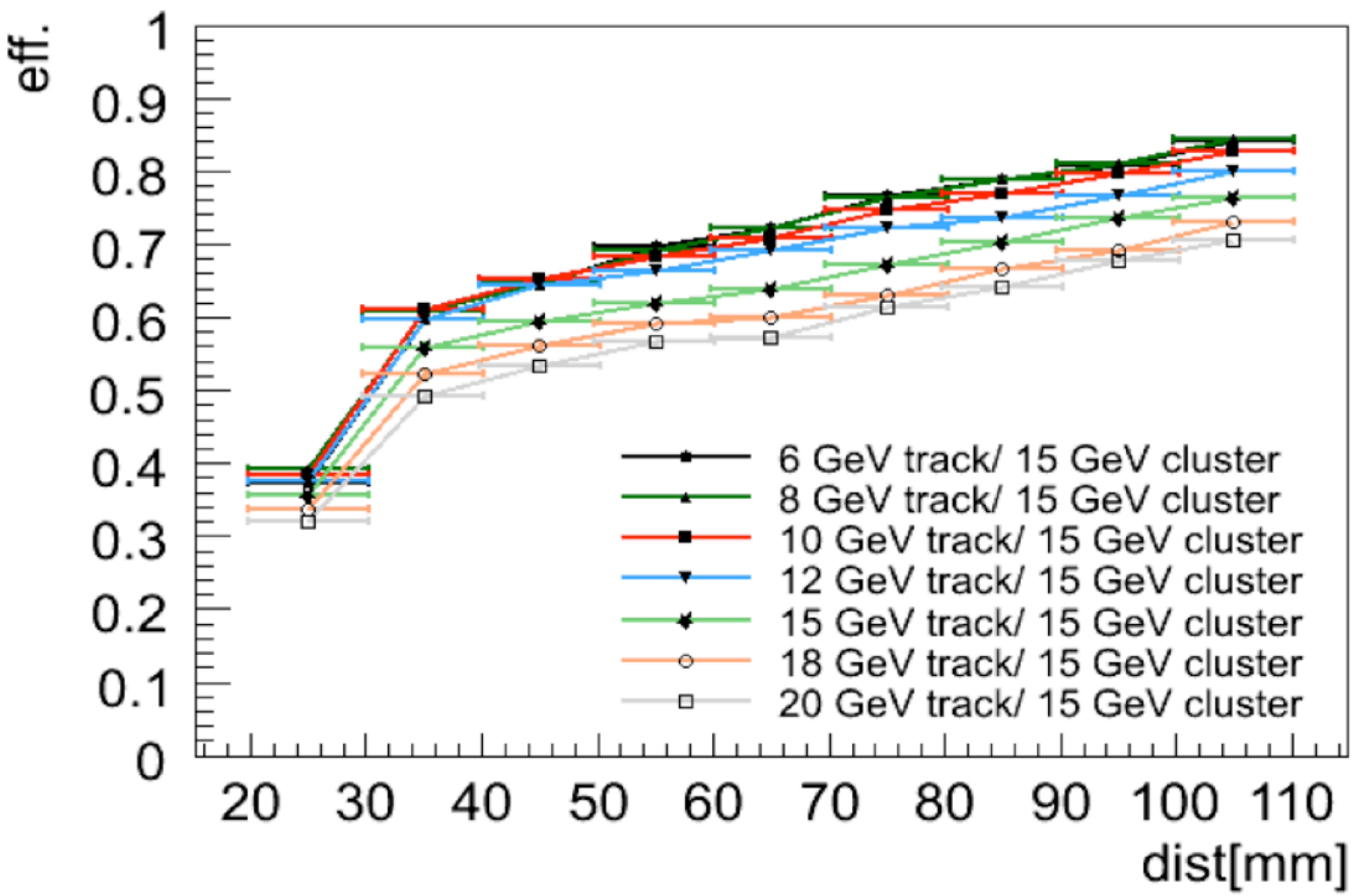
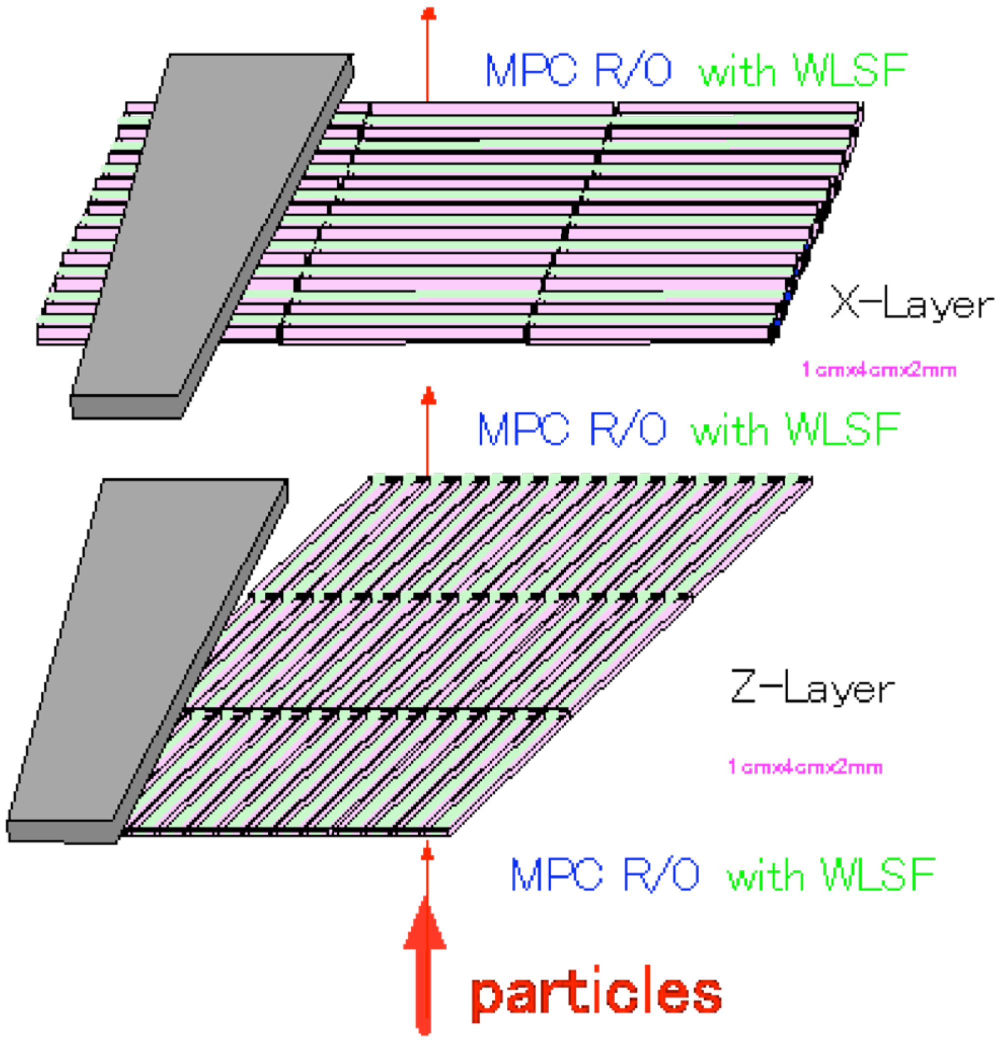


- Naive Particle Flow:
  - "Track-wise" clustering in HCAL
  - assume one cluster belongs to a charged hadron with known energy, substitute cluster energy with track energy

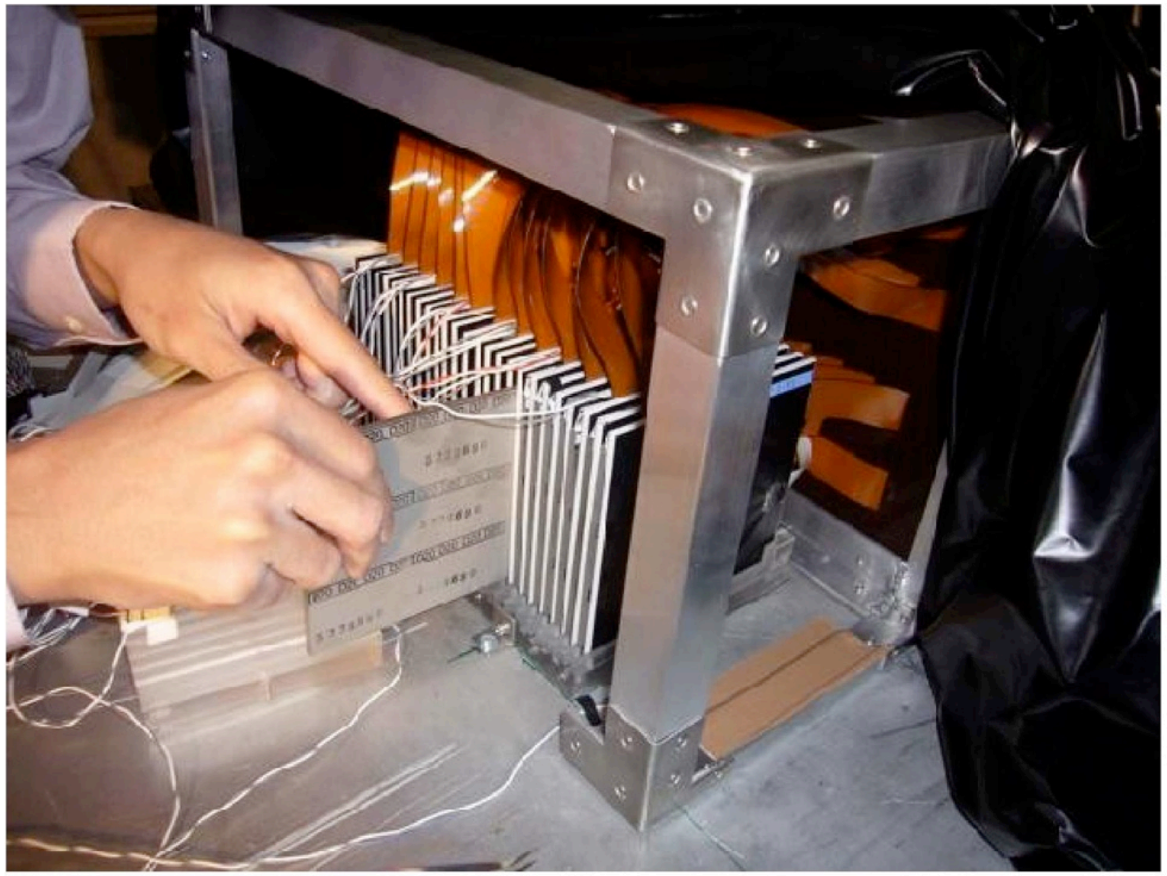
- Separation efficiency as a function of particle distance
  - second particle counted as identified if two clusters are found and the second energy is correctly reconstructed within 3 σ

Changing Setup: Scintillator ECAL



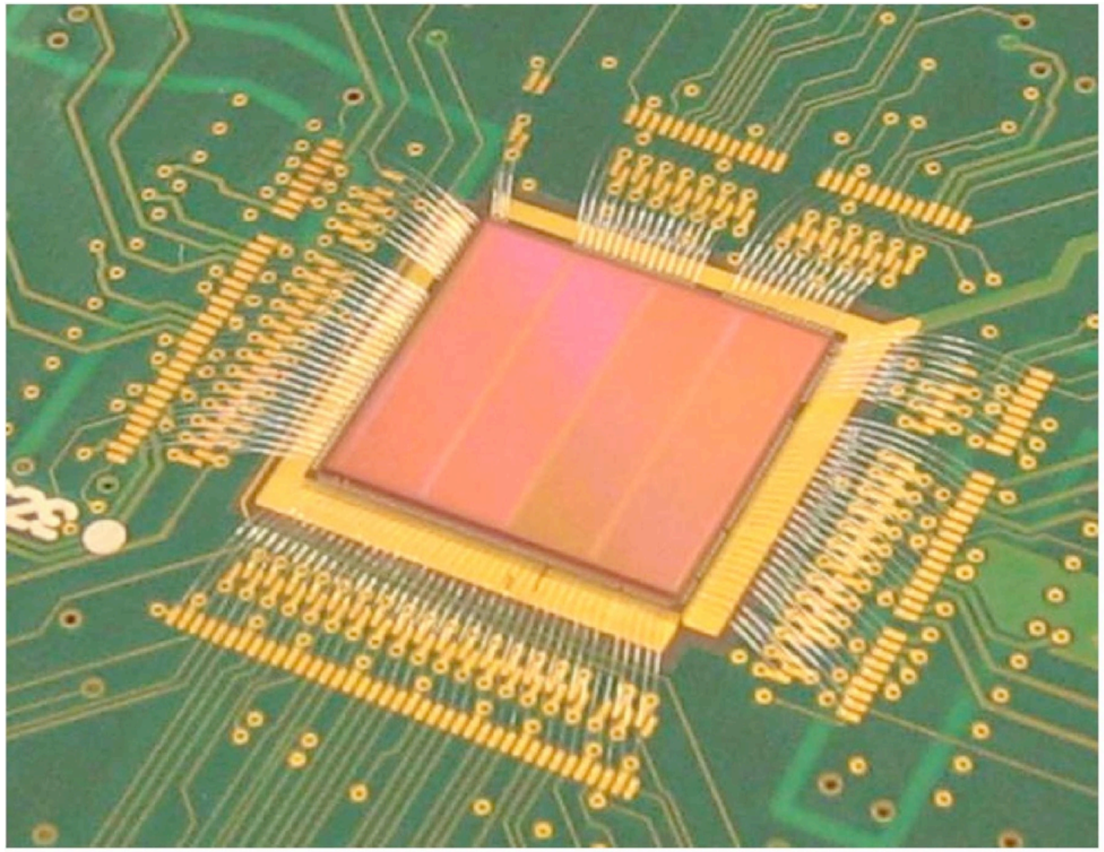
- Tungsten absorber
- Scintillator with MPPC readout
  - 1 x 5 cm^2 , 3.5 mm thick scintillator strips
  - embedded wavelength shifting fiber
  - three different scintillator types tested

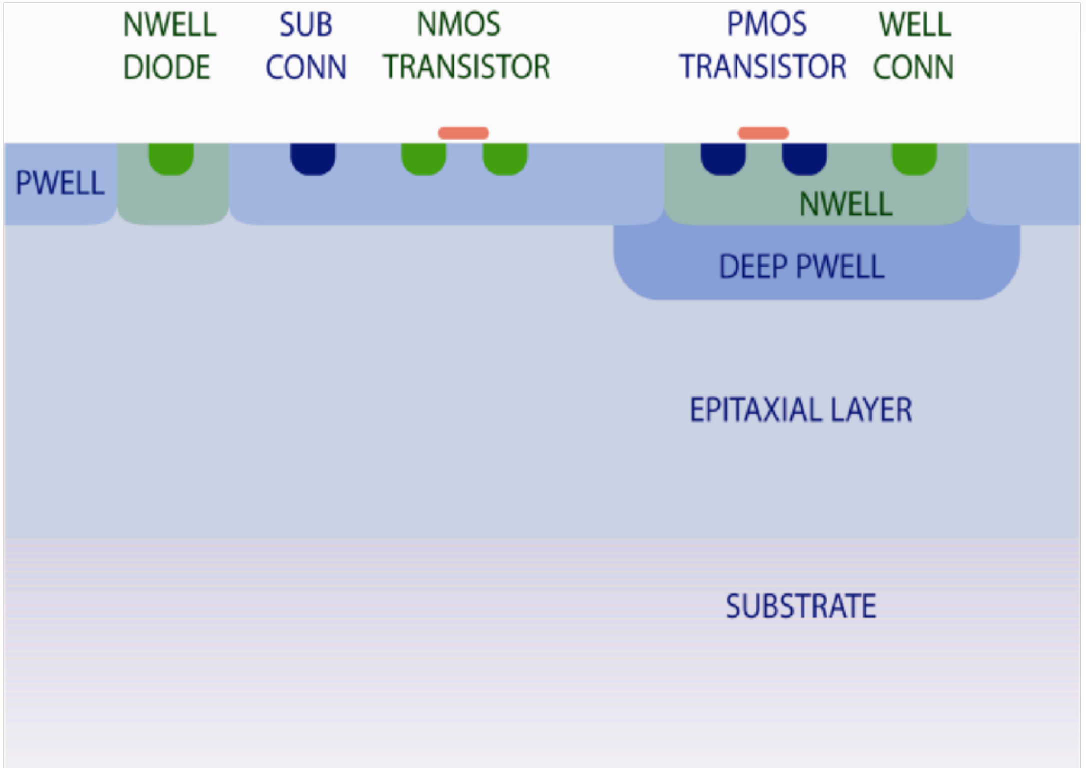
- First tests in DESY test beam in 2007
- Now installed in CALICE setup at FNAL, replacement for Si-W ECAL, beam time starting tomorrow



New Si-W Concepts: MAPS

- MAPS instead of Si Pads:
  - Determine Energy by counting particles, not by measuring energy deposit
  - Extreme granularity needed to preserve linearity
    - 50 x 50 μm^2 pixels
    - binary readout
    - electronics integrated into pixel

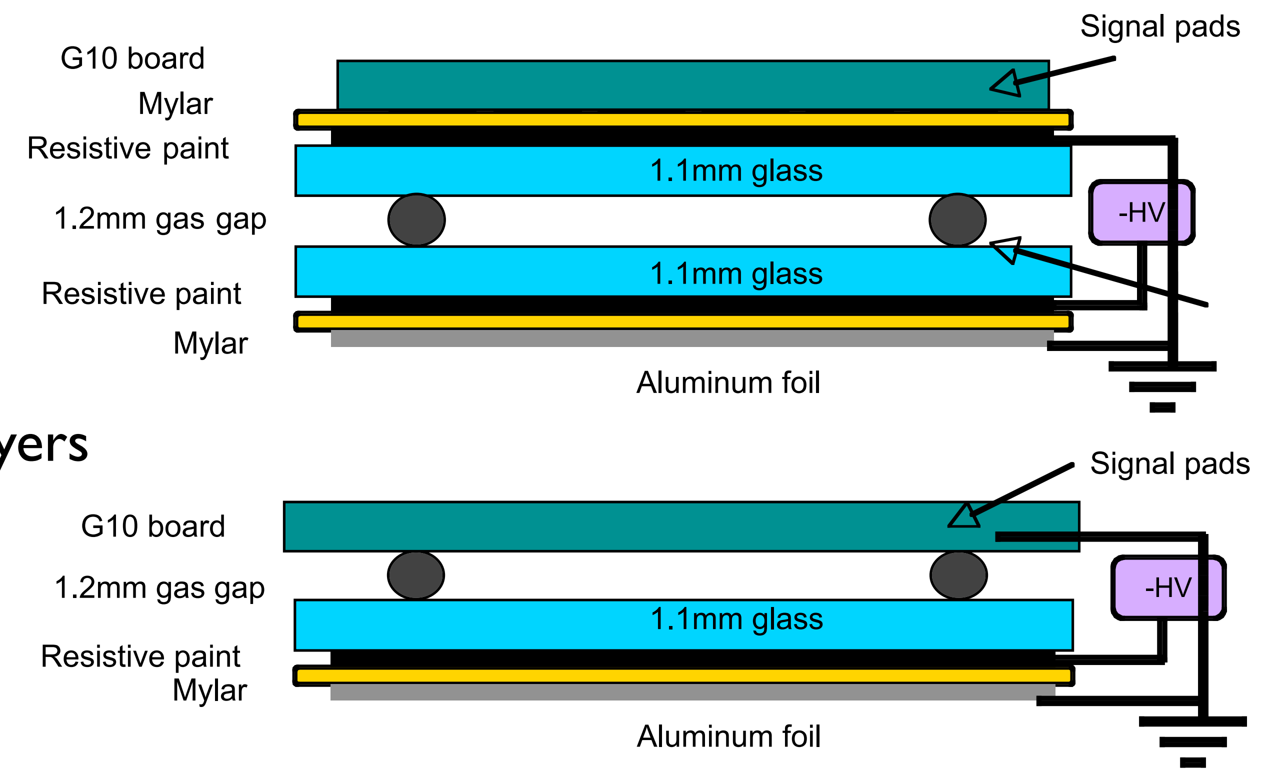




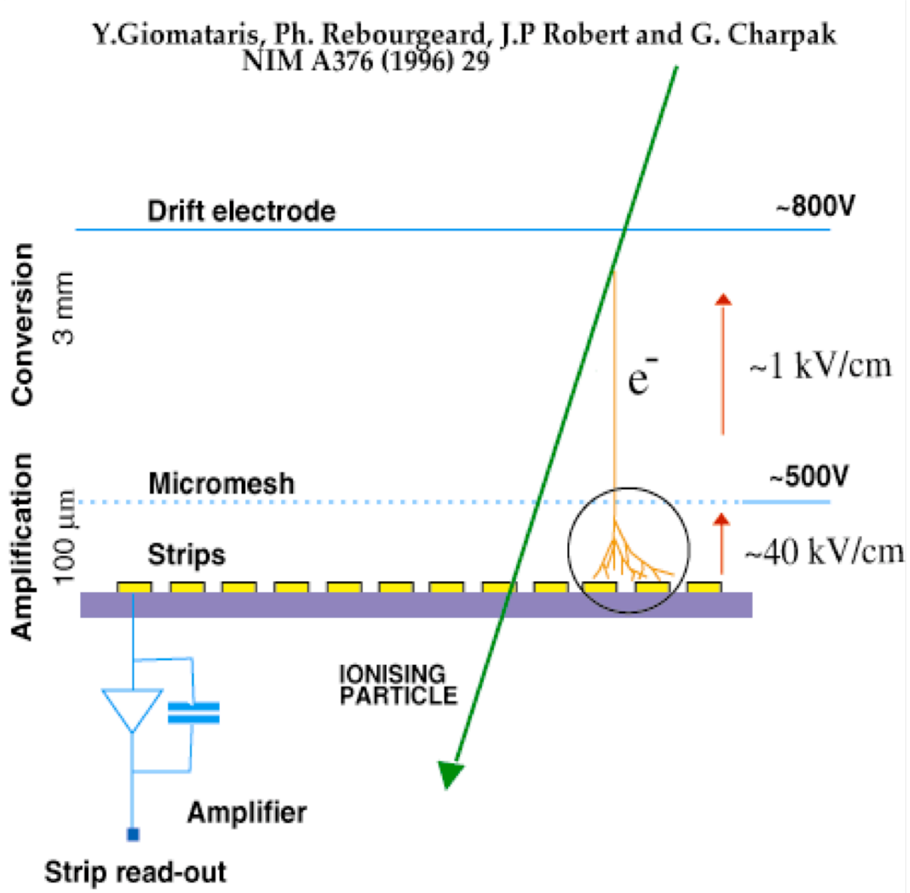
Changing Setup: Digital HCAL

- Digital (or semi-digital) HCAL
  - ~ 1 x 1 cm^2 pads
  - gas detector readout, different technologies being explored

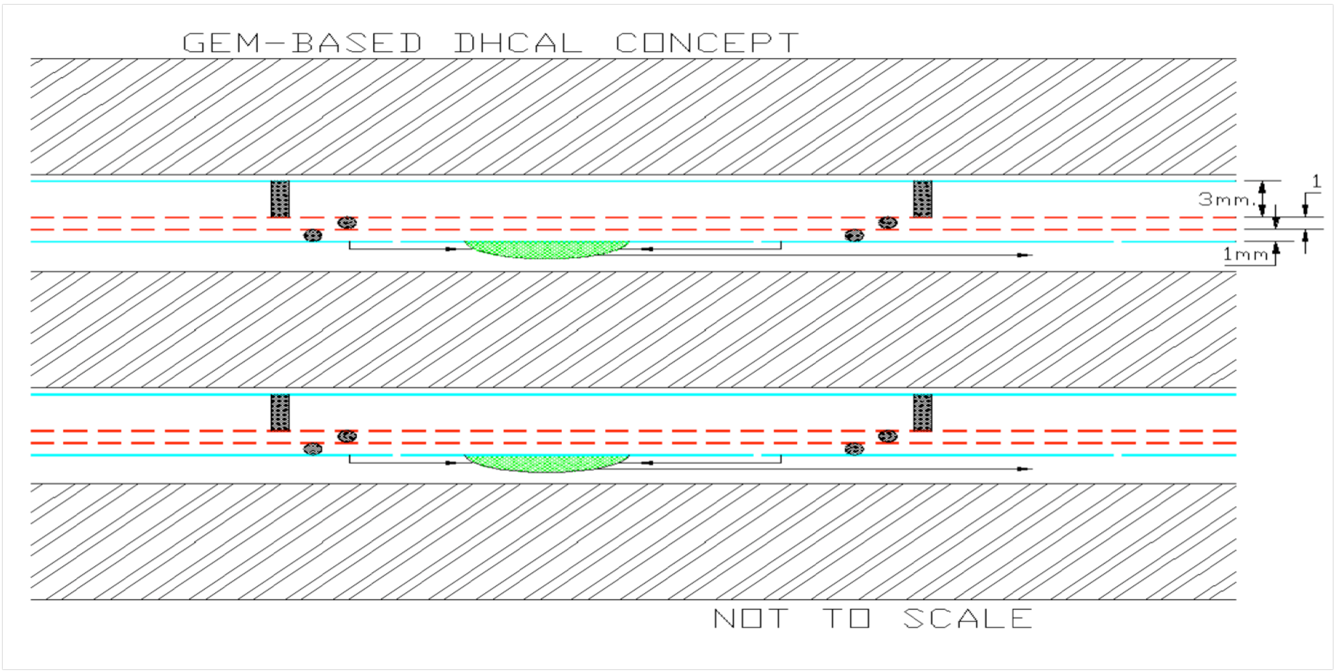
RPCs:
1 or 2 glass layers



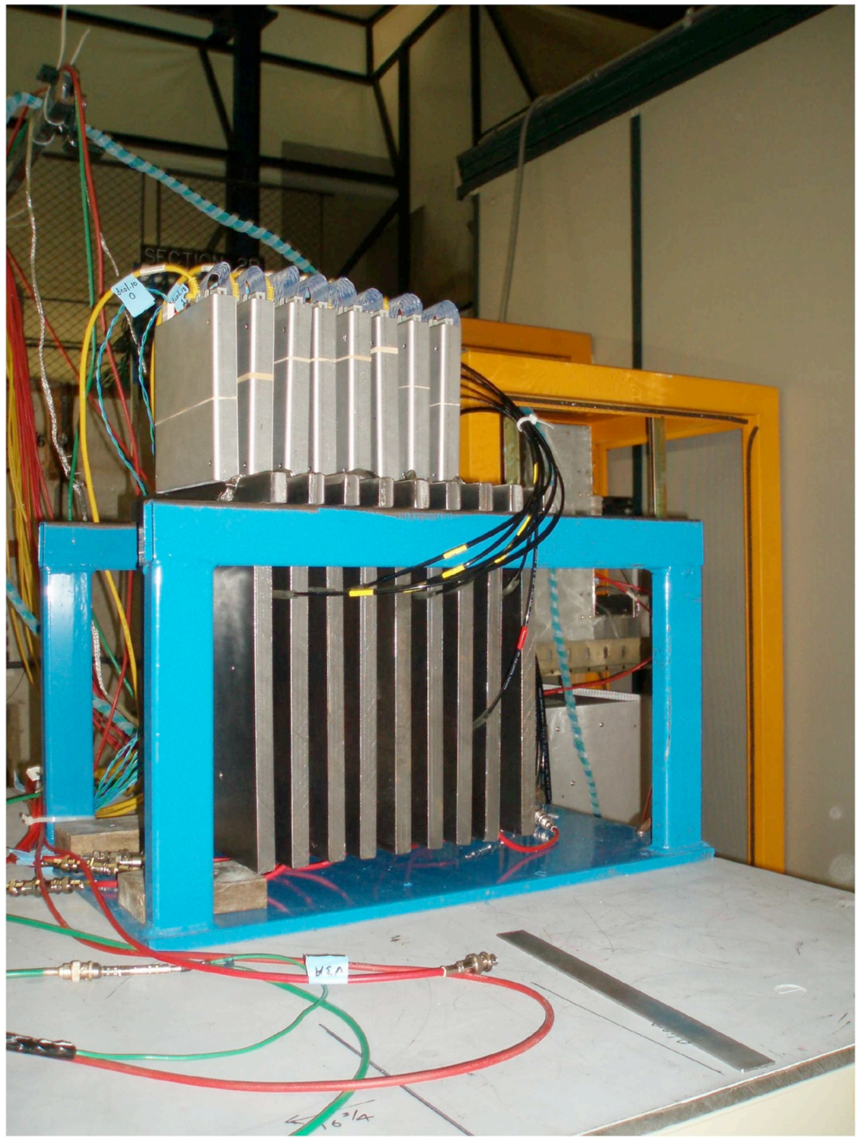
MicroMegas

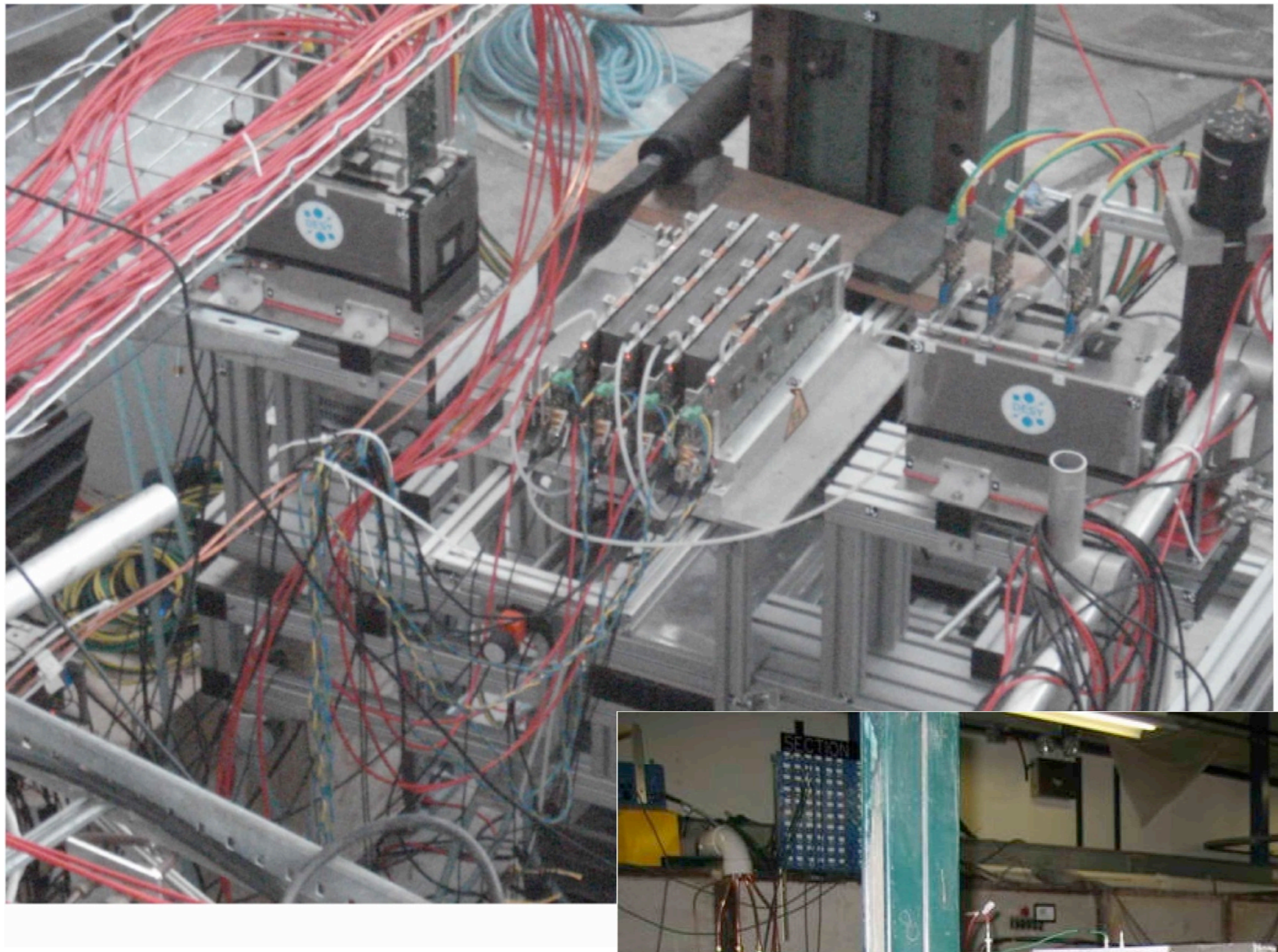


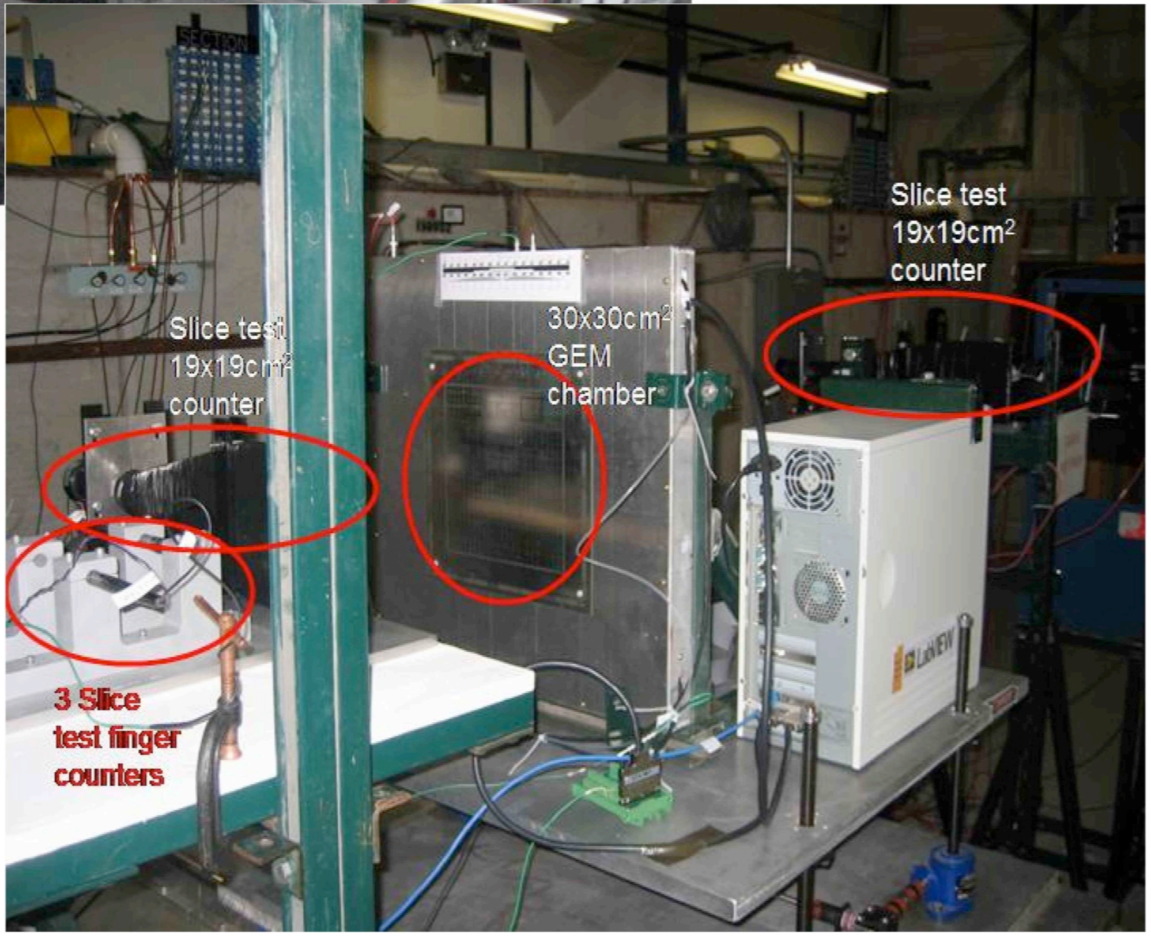
GEM (Double GEM, ThickGEM, ...)



Changing Setup: Digital HCAL







- Technologies tested in Beams
- Installation of 10 1 m^2 RPC layers in CALICE @ FNAL early 2009, completion of 1 m^3 prototype in 2009

CALICE Hardware: Outlook

- Proof of Concept of highly granular calorimeters with present setup
  - Comparison of technologies:
    - Si-W vs Scint-W ECAL
    - Analog vs Digital HCAL
- Next steps:
  - Development of next-generation prototypes within the EUDET framework:
    - realistic ECAL and HCAL modules

Summary & Outlook

- The CALICE Collaboration has established an extensive program to test highly granular calorimeters for the International Linear Collider
  - Test beams at CERN SPS and Fermilab
  - Comparison of different technologies

- Extensive analysis program, first results shown here are just the beginning...
  - Investigation of detector performance
  - Proof of the particle flow concept
  - Validation of hadronic shower models

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... and much more to come!