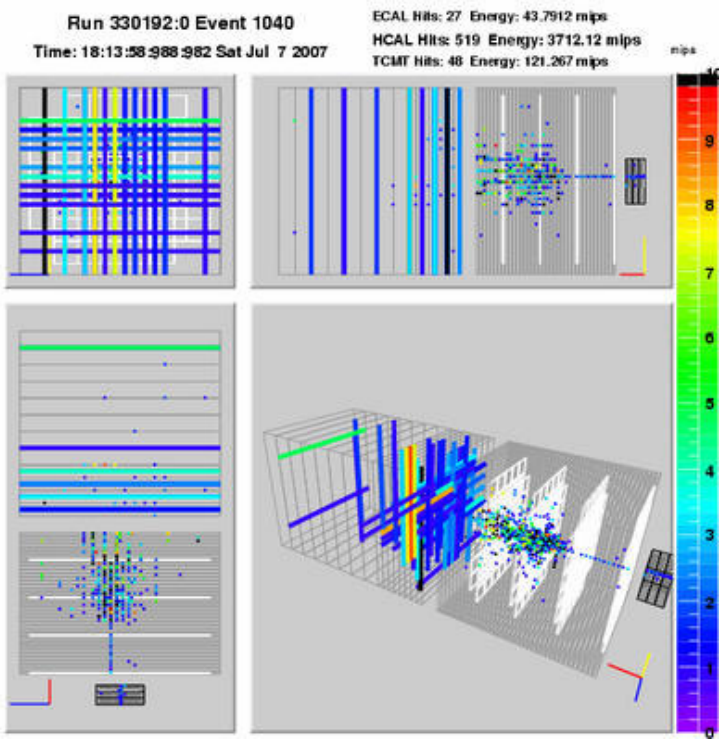
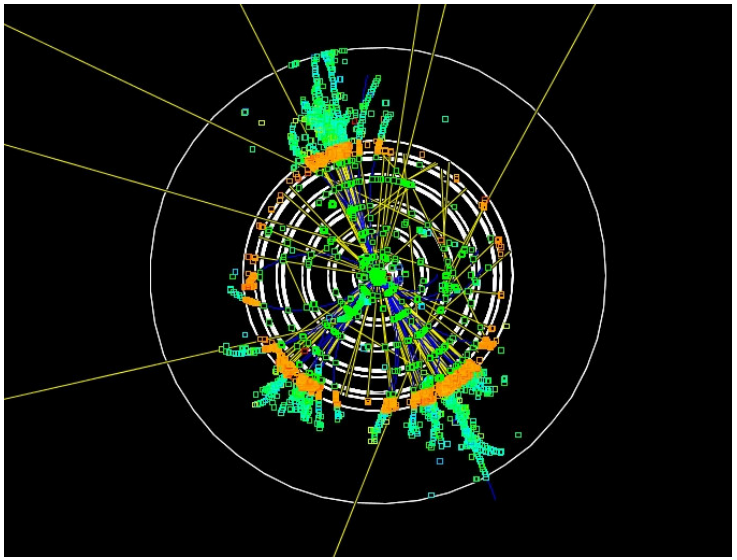
CALICE Report





Nigel Watson

(Birmingham Univ.)

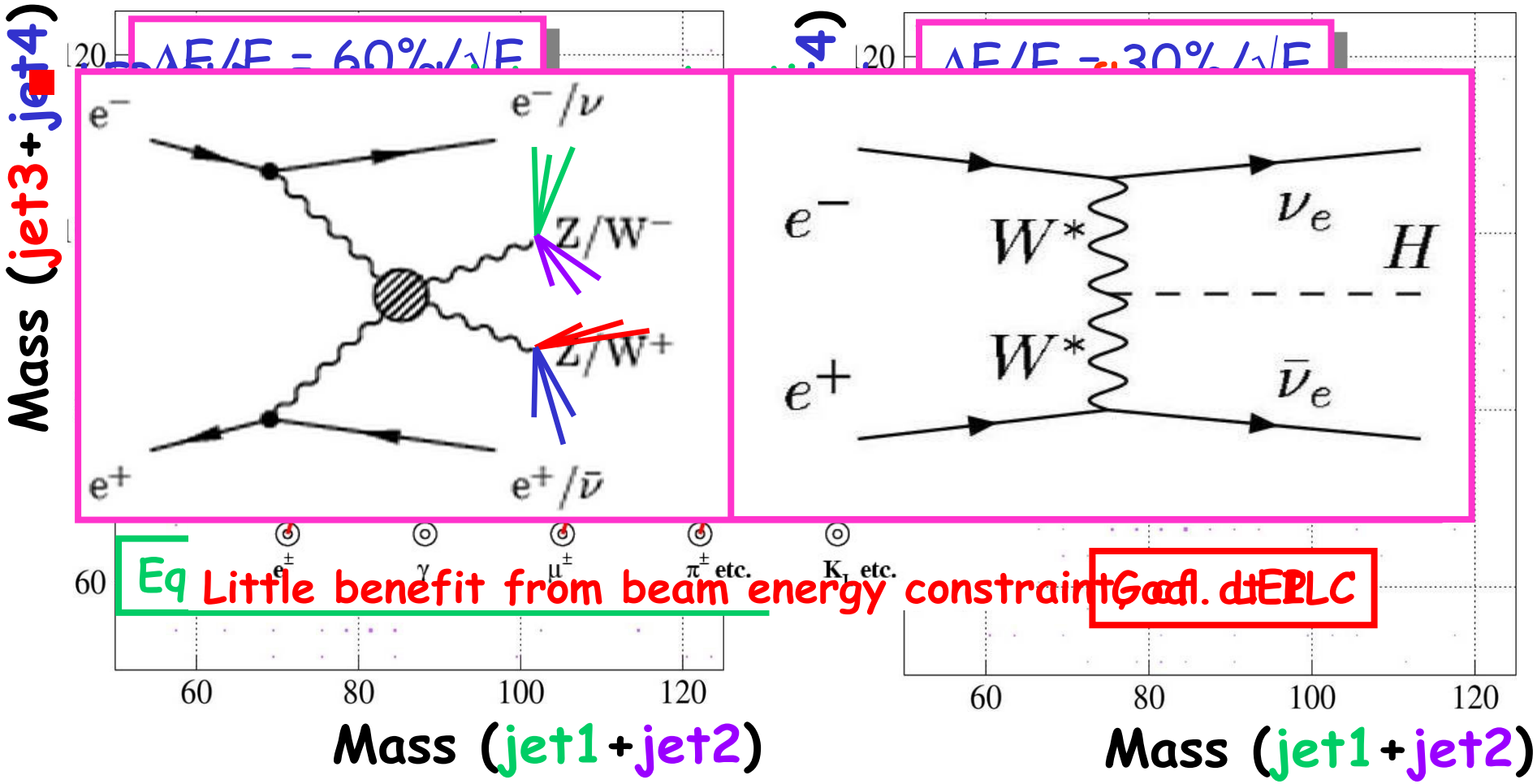
- Motivation
- Test beam programme
- Current results
- Summary

For the CALICE Collaboration

[Particular thanks to Erika Garutti, Fabrizio Salvatore, David Ward]

ILC: high performance calorimetry

- Essential to reconstruct jet-jet invariant masses in hadronic final states, e.g. separation of $\nu\nu W^+W^-$, $\nu\nu Z^0Z^0$, tth, Zhh, $\nu\nu H$

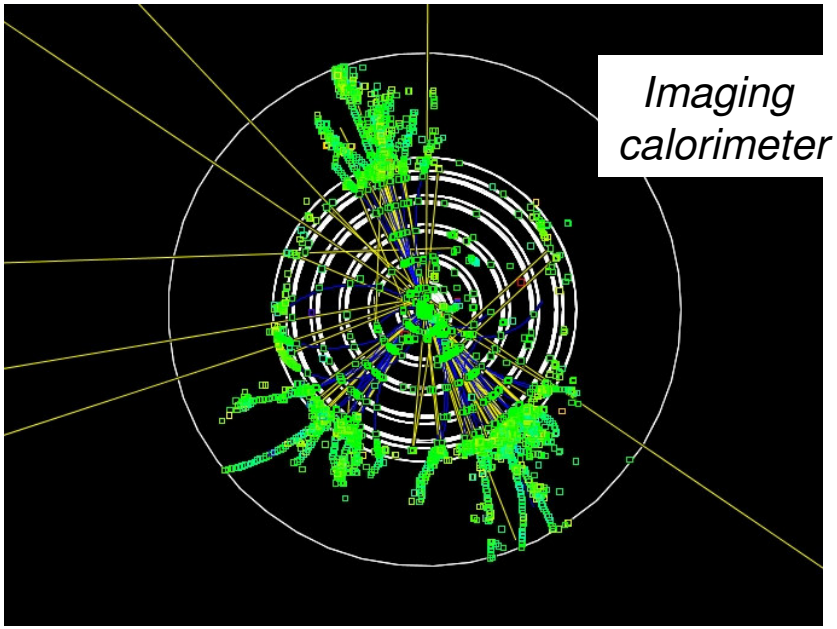


Implications, e.g. for ECAL design

- Shower containment in ECAL, ΣX_0 large
- Small $R_{moliere}$ and X_0 – compact and narrow showers
- λ_{int}/X_0 large, ∴ EM showers early, hadronic showers late
- ECAL, HCAL inside coil
  - Lateral separation of neutral/charged particles/'particle flow'
- Strong B field to suppresses large beam-related background in detector
  - Compact ECAL (cost of coil)
- Tungsten passive absorber
- Silicon pixel readout, minimal interlayer gaps, stability
- …but expensive…
- Also considering "Swap-in" alternatives to Si diode detector designs, e.g. in LDC, SiD
- CMOS MAPS process? Scintillators?

CALICE: from MC to reality

CAlorimeter for the LInear Collider Experiment



Final goal:

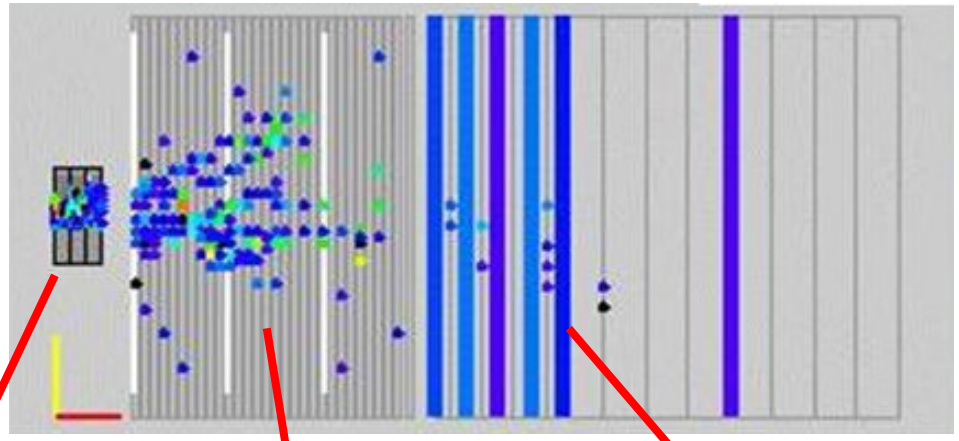
A high granularity calorimeter optimised for the Particle Flow measurement of multi-jets final state at the International Linear Collider

Intermediate task:

Build prototype calorimeters to
- Establish the technology
- Collect hadronic showers data with unprecedented granularity to
  - tune reconstruction algorithms
  - validate existing MC models

Test beam prototypes

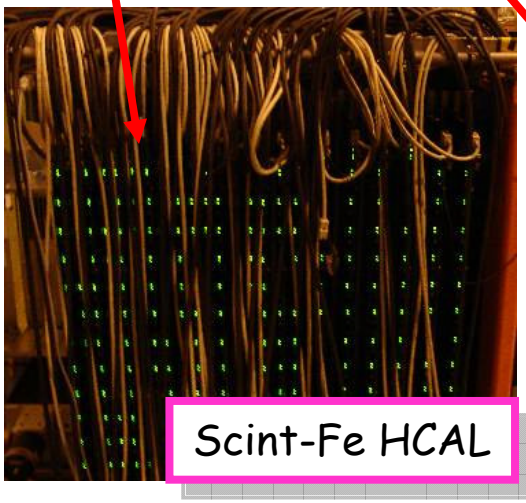
10 GeV pion shower
@ CERN test beam



beam

SiW ECAL

1x1cm^2 lateral segmentation
1 X_0 longitudinal segment.
~1λ total material, ~24 X_0



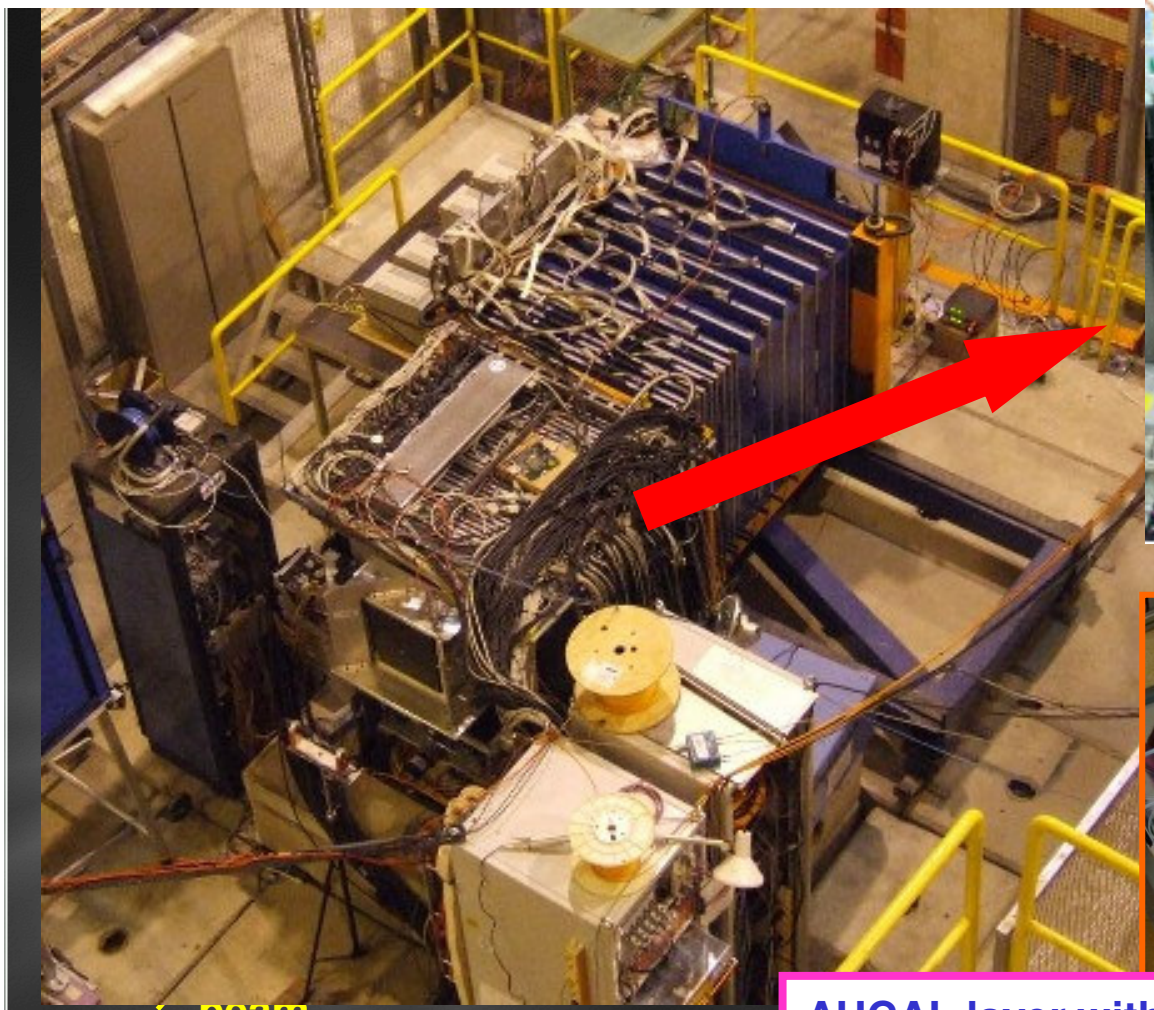
Scint-Fe HCAL

3x3cm^2 tiles lateral segmentation
~4.5 λ in 38 layers

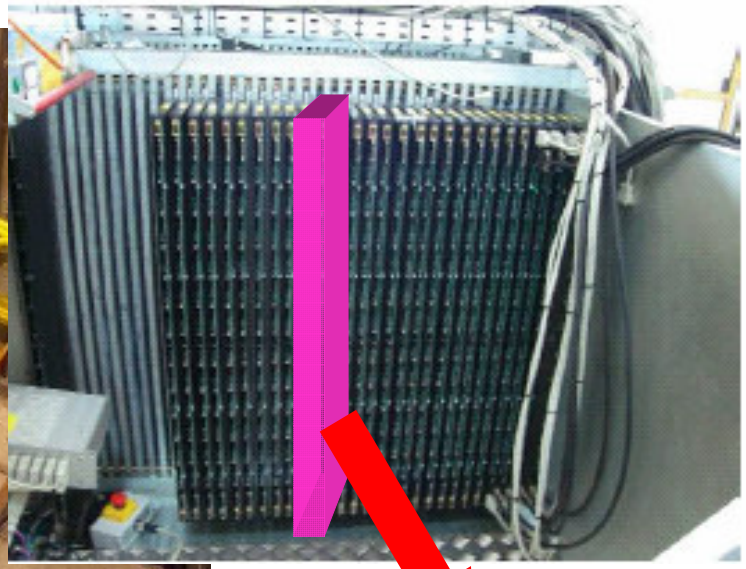
Scint-Fe tail catcher/
muon tracker

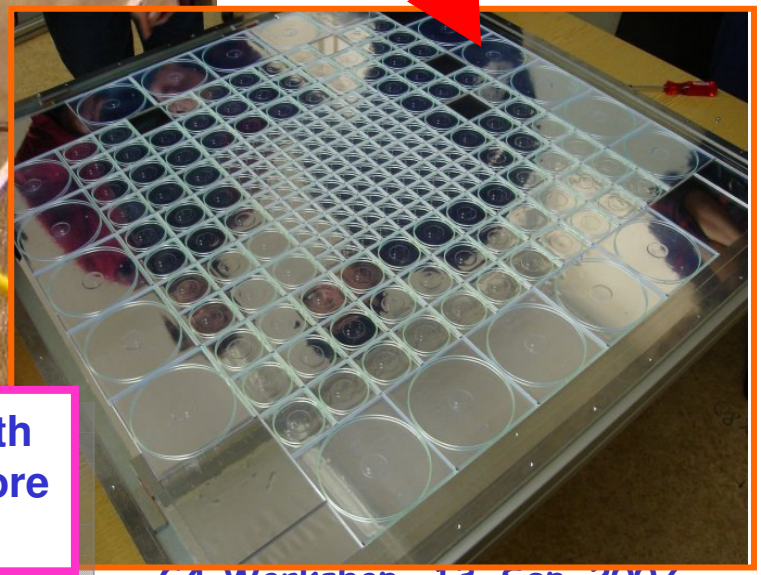
5x100cm^2 strips
~5 λ in 16 layer

The 2006 CERN installation



beam

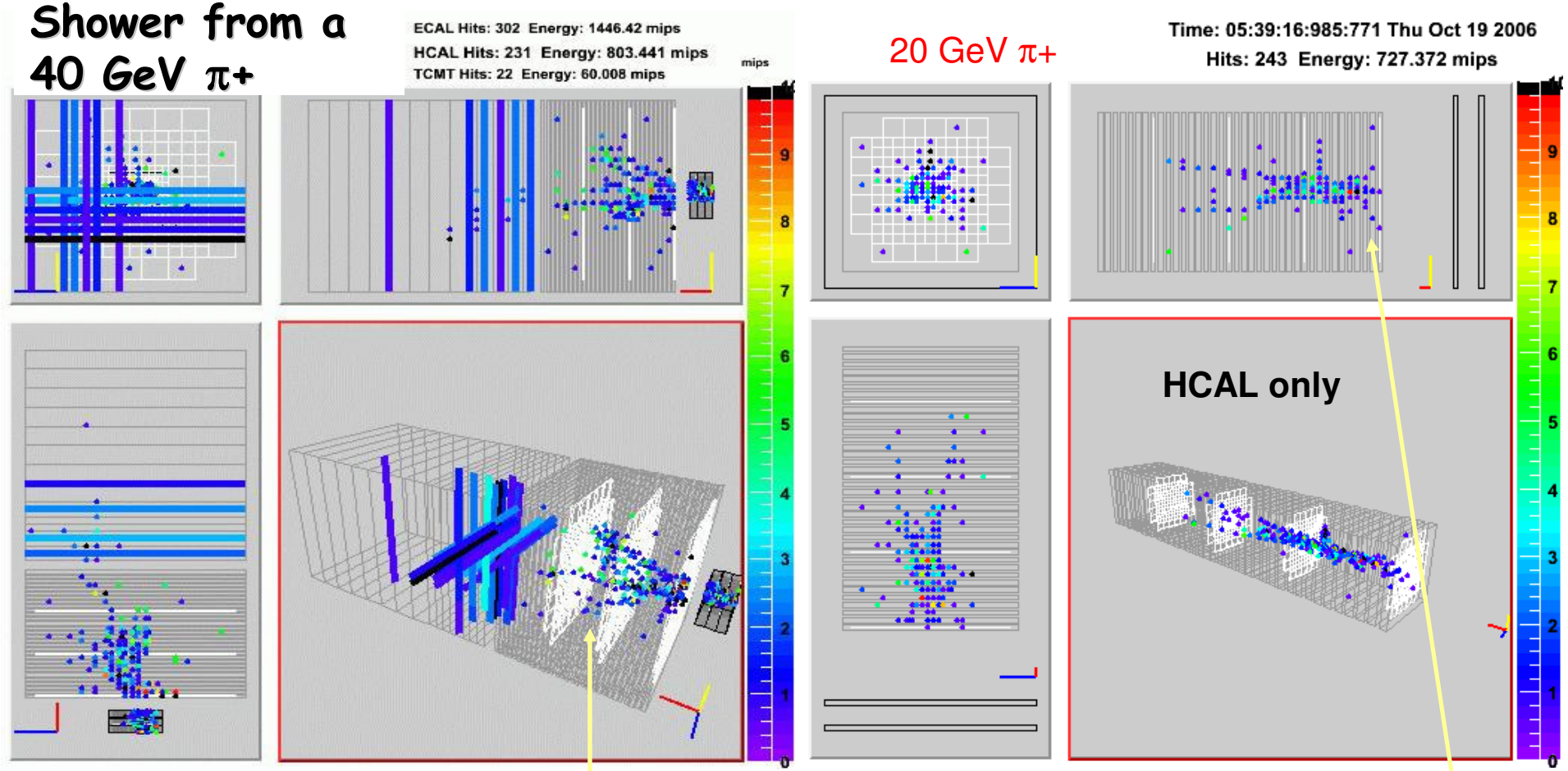




AHCAL layer with high granular core readout

Event display

REAL DATA!

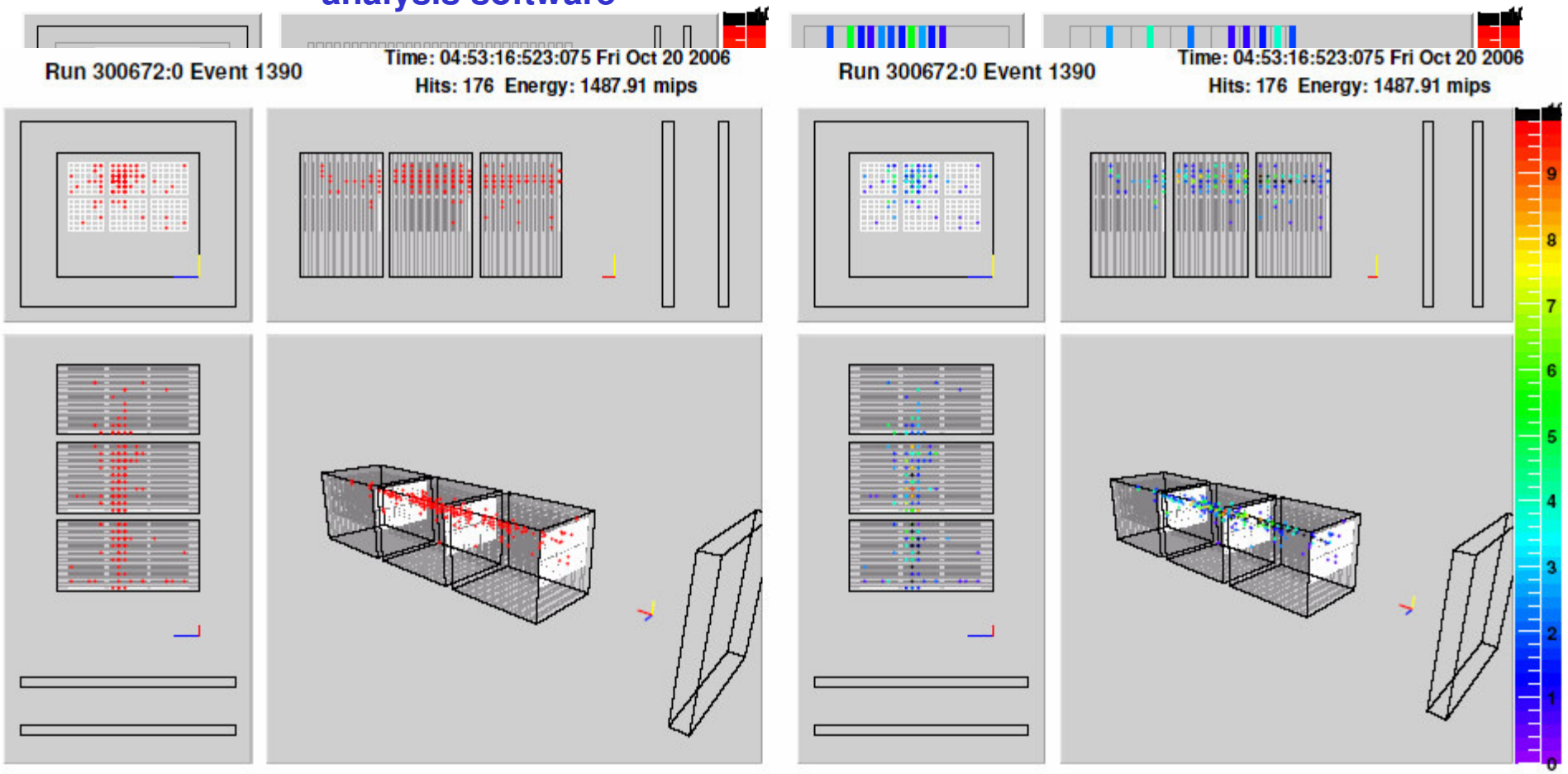


Event display

REAL DATA!

40GeV/c pion with CALICE online analysis software

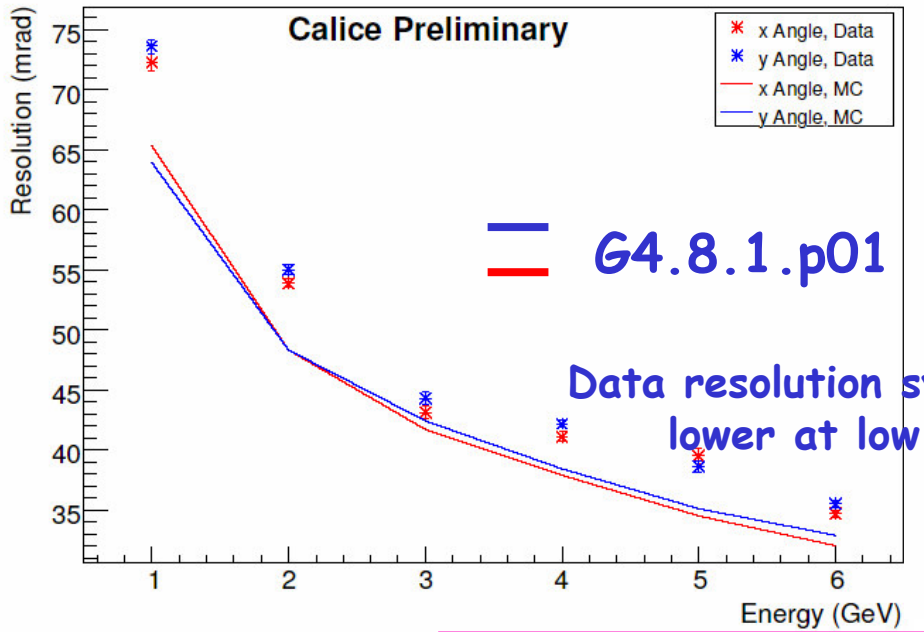
HCAL **TCMT**



(digital display) (analogue display)

Beamline instrumentation modelling

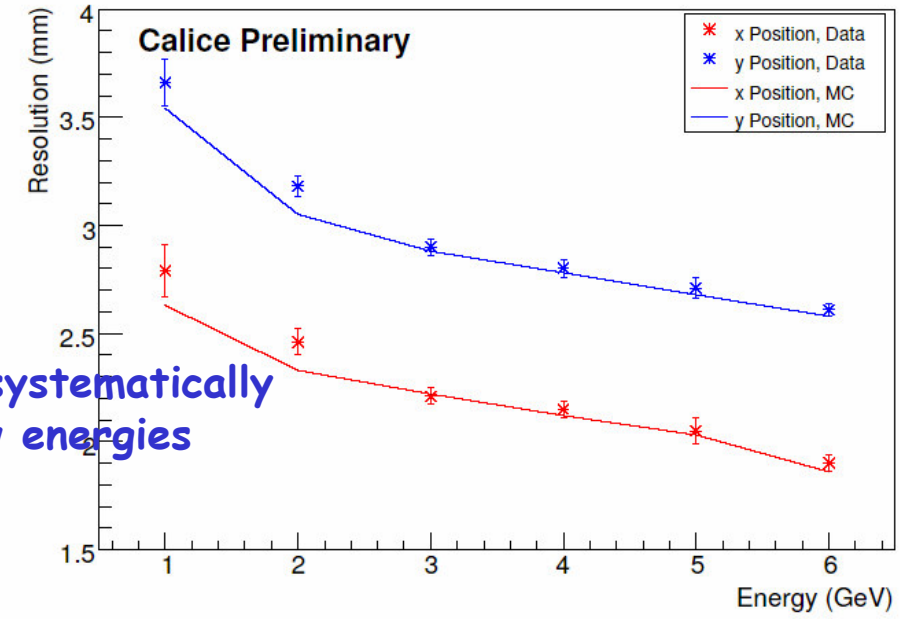
Angular Resolution



= G4.8.1.p01

Data resolution systematically lower at low energies

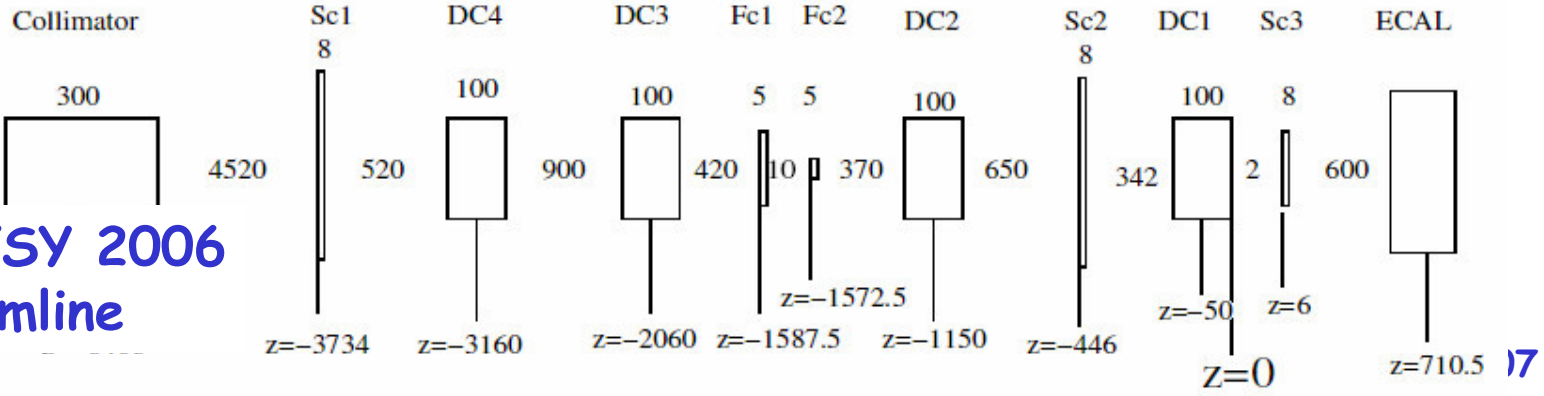
Position Resolution



Essential to model upstream material accurately to understand tracking system – effect ~0.03X_0

beam

e.g. DESY 2006 beamline



Nigel W

2006 Data

	e^+ (kEvt)	e^- (kEvt)		π^+ (kEvt)	π^- (kEvt)
6 GeV	208	128		480	1800
8 GeV		218			1800
10 GeV	152	172		960	1800
12 GeV		211			1600
15 GeV	476	124		720	1600
16 GeV	310				1700
18 GeV	303	231		770	1600
20 GeV	390	210		3300	
30 GeV	409			1400	
50 GeV	305			1500	
80 GeV				1800	

Combined ECAL+HCAL+TCMT data samples from CERN

Samples for less than whole system also analysed

Preliminary results for ECAL and AHCAL

Concentrate on electromagnetic response

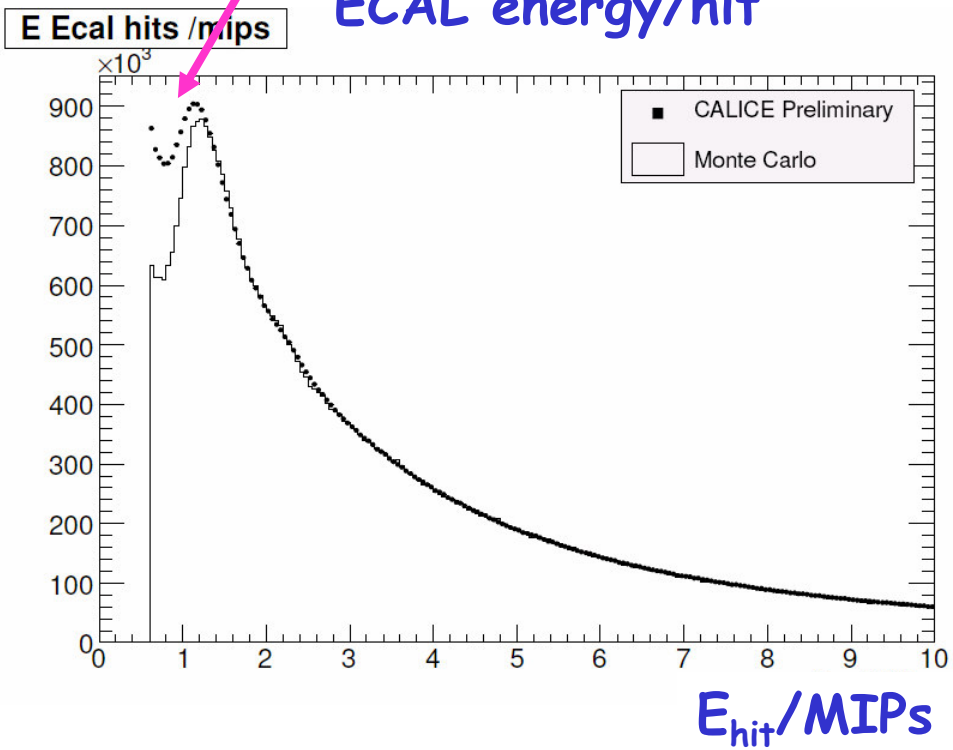
- ECAL, AHCAL for electrons
- AHCAL for charged pions

ECAL hit energy, 30 GeV e^-

Low energy excess (below MIP peak)
not 100% understood
Minor effect on total energy

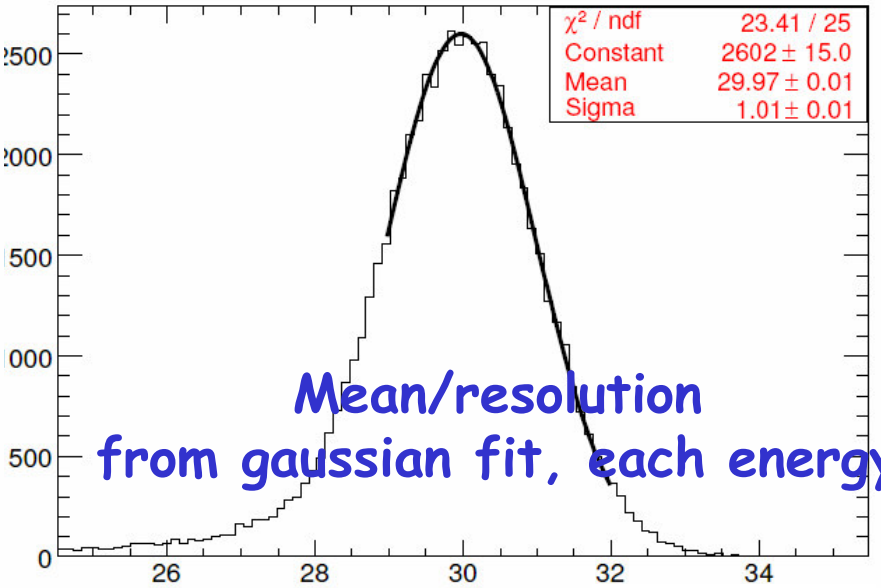
Geant 4.8.1.p01

ECAL energy/hit



E_{hit}/MIPs

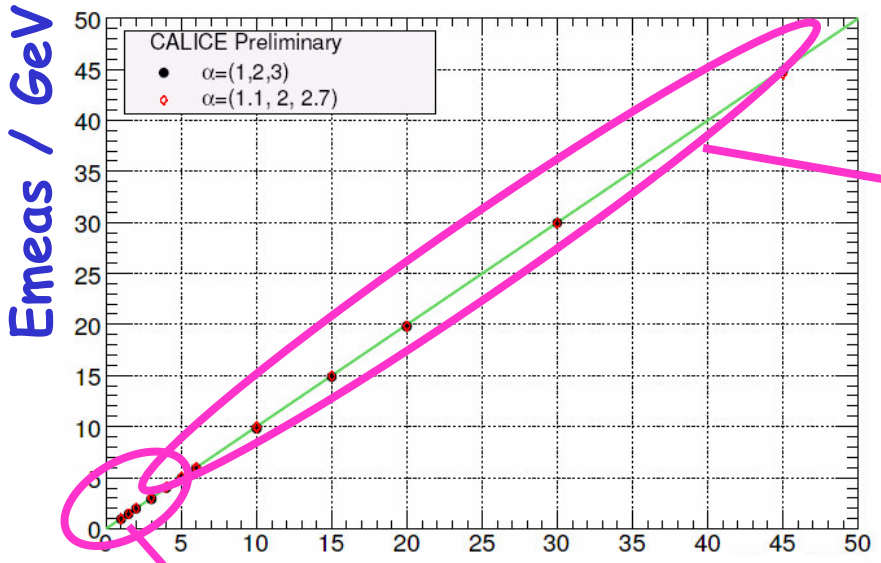
Total ECAL Energy/event

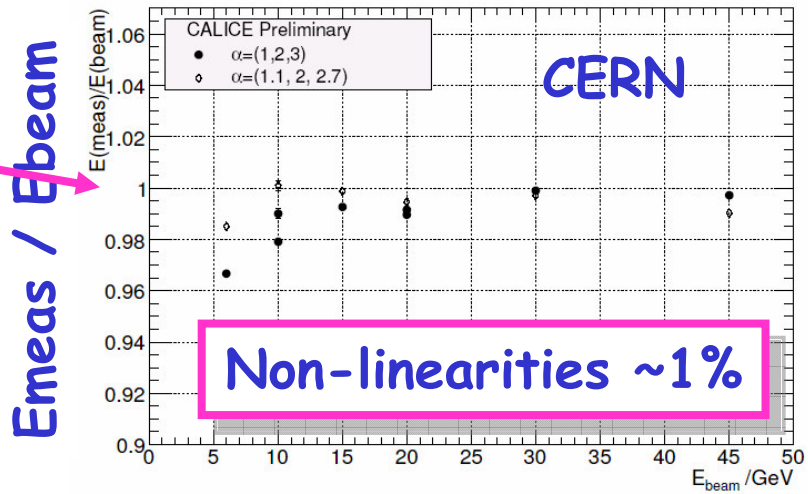


Mean/resolution
from gaussian fit, each energy

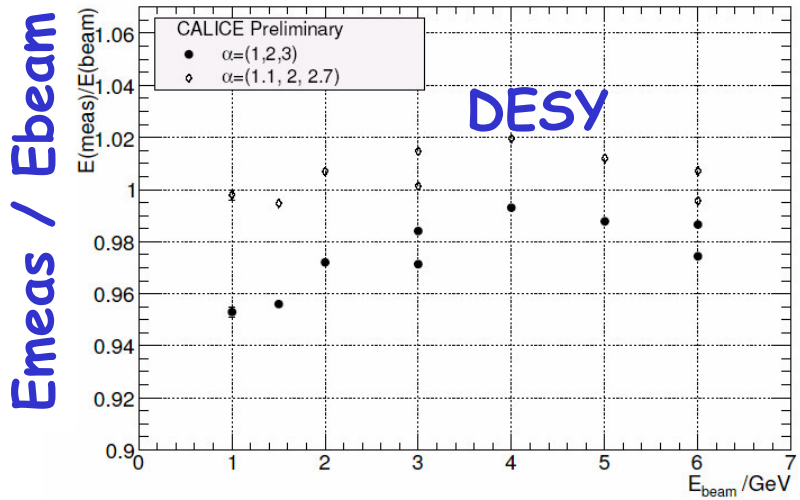
E_{meas}/GeV

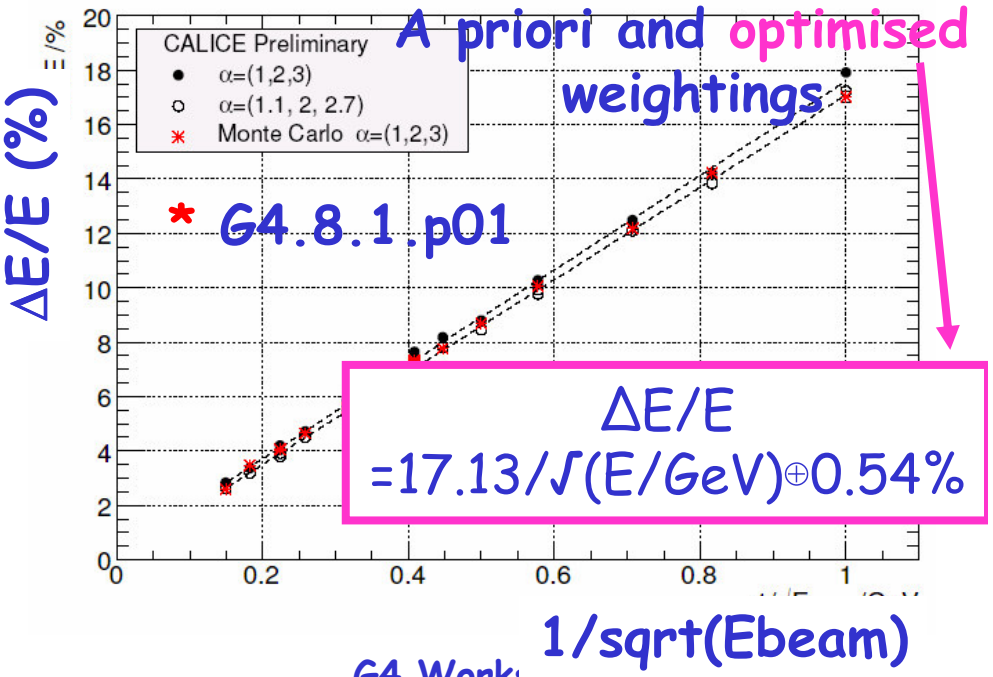
ECAL linearity/resolution



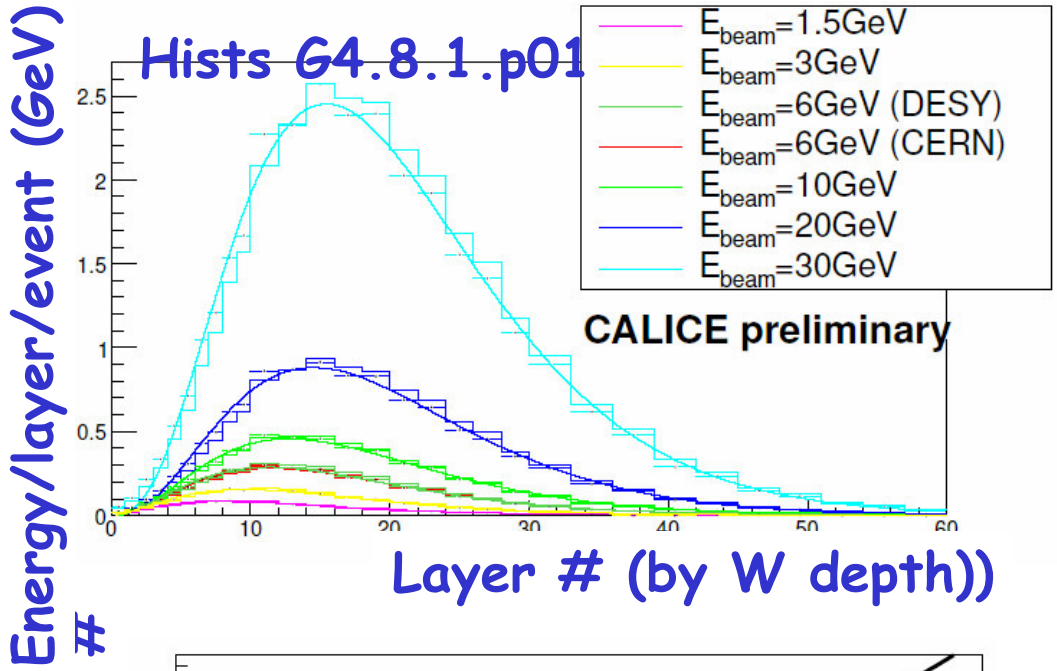


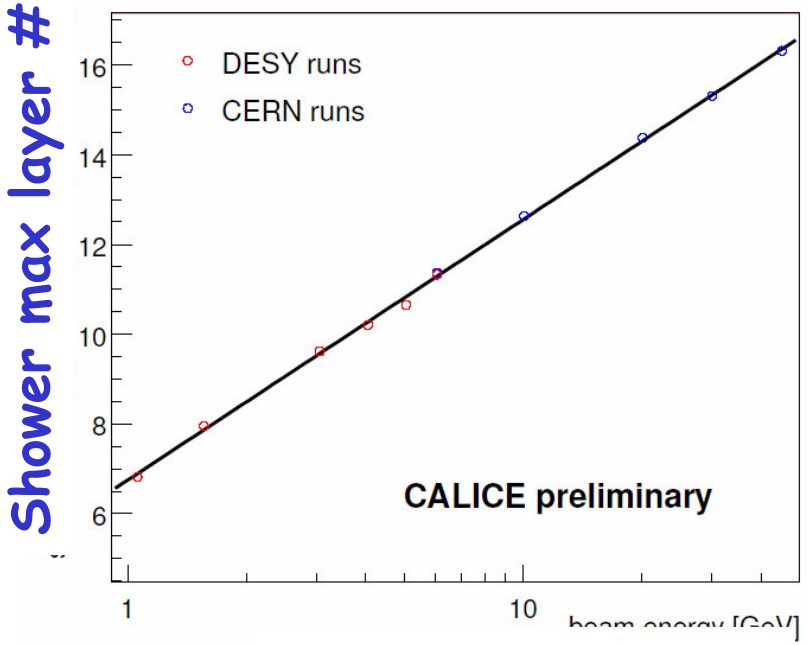
Linearity

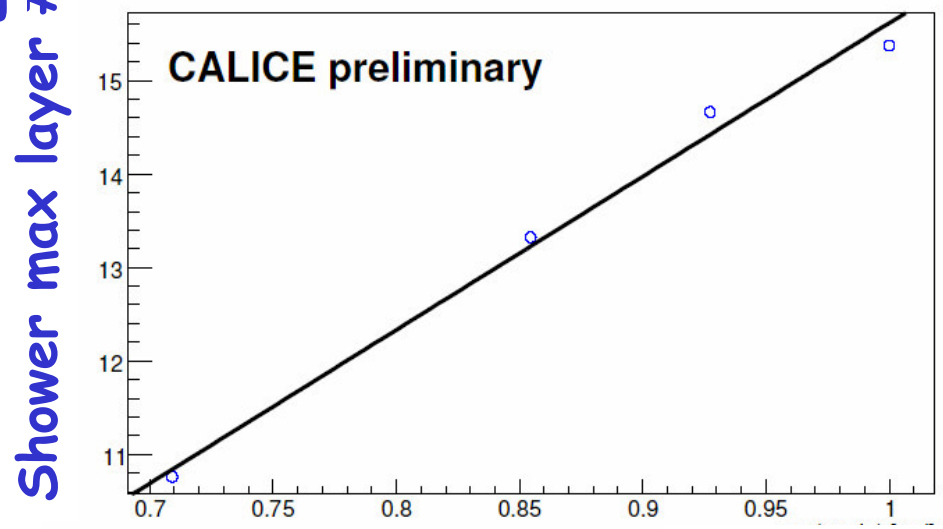




ECAL longitudinal profile





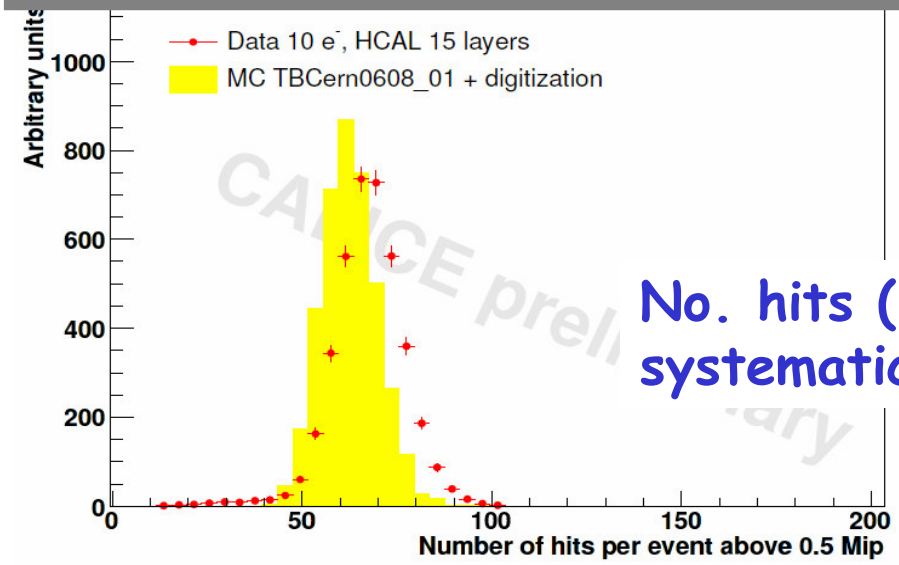


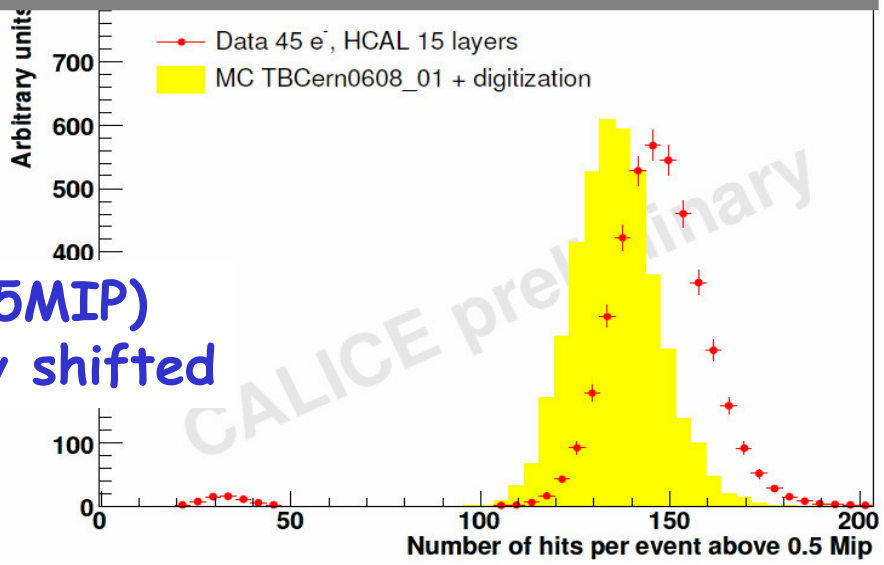
Expected logarithmic behaviour of shower max., and angular dependence

AHCAL

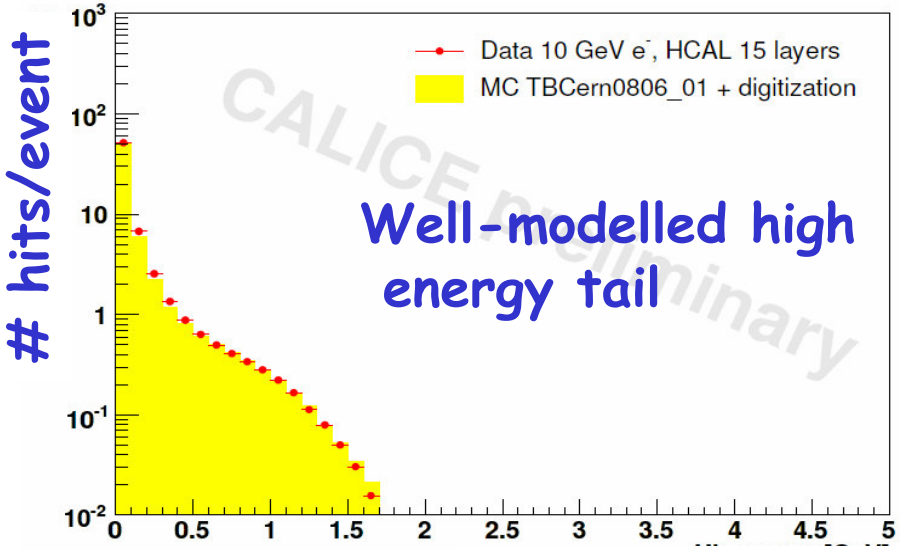
- Hadronic showers intrinsically more interesting than electromagnetic
  - More challenge to model and build detector
- Proper understanding of electromagnetic showers (e^-, μ^-) mandatory first step, prior to hadronic studies
  - Performance monitoring, multi-stage calibration,
  - Unlike ECAL, do need digitisation simulation for meaningful comparison of data/MC
- Calibration is much more complicated than Si-W ECAL.
  - Muons for MIP calibration; equalise response, zero suppression
  - SiPM non-linearity corrections. Lab calibration and LED light injection
  - Temperature sensitivity: 1C → 3% systematic uncertainty
- 96.3% of channels calibrated, ~50% of remaining few % are dead
- Show August 2006 data - 15 planes (=29 X_0) contains e.m. shower
- Complications: MC digitisation scheme required to compare MC with data
  - Cross talk; non-linearity + Poisson statistics at pixel level; noise; dead channel removal
- Selection of results to follow

AHCAL response to e⁻

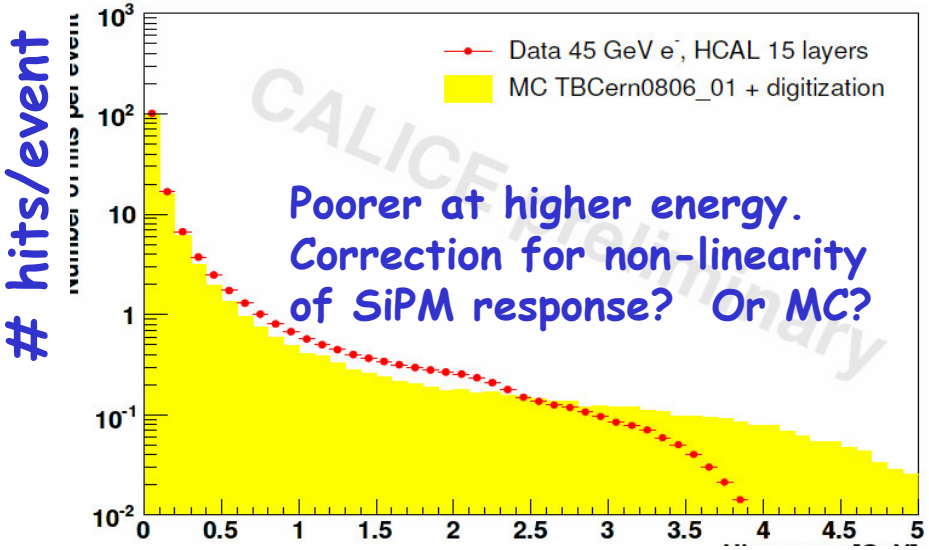




No. hits (>0.5MIP) systematically shifted



Well-modelled high energy tail

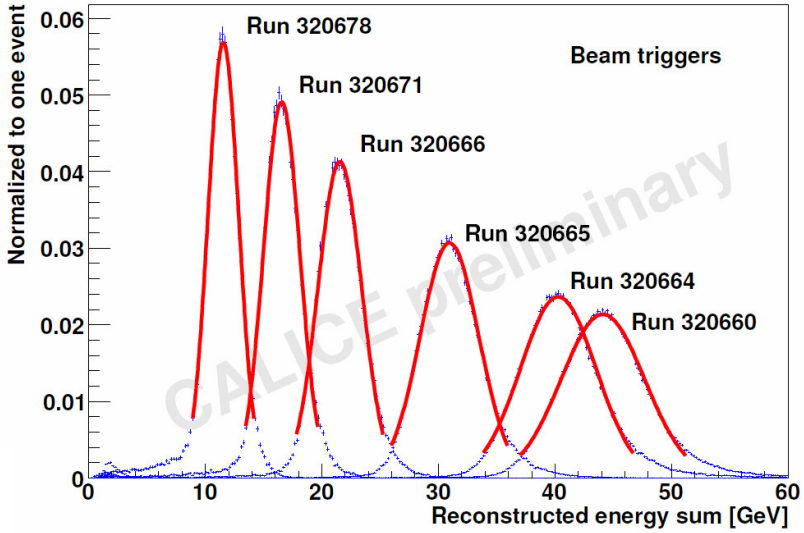


Poorer at higher energy. Correction for non-linearity of SiPM response? Or MC?

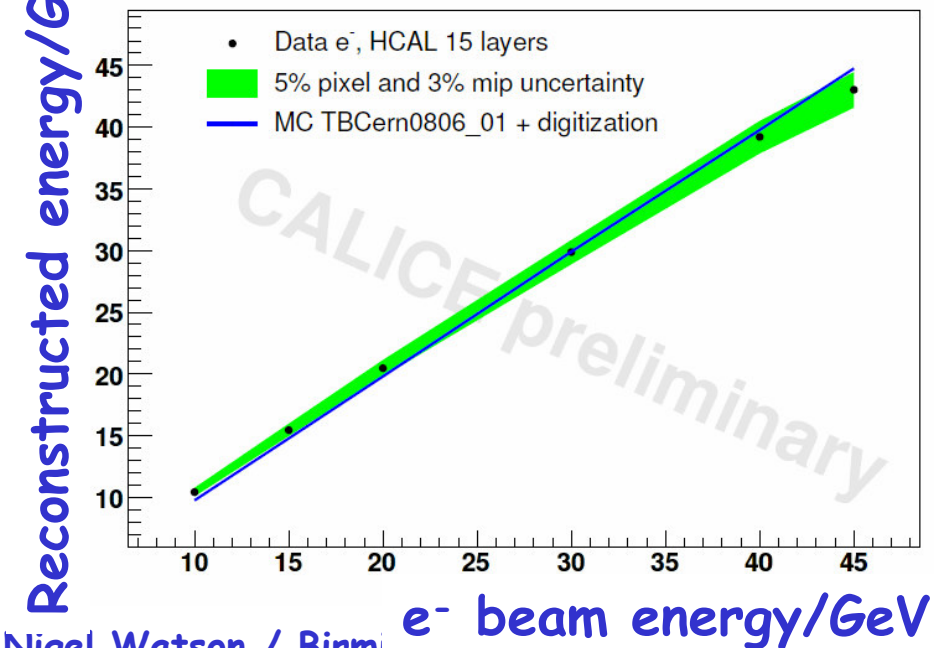
Nigel Watson / Birmingha

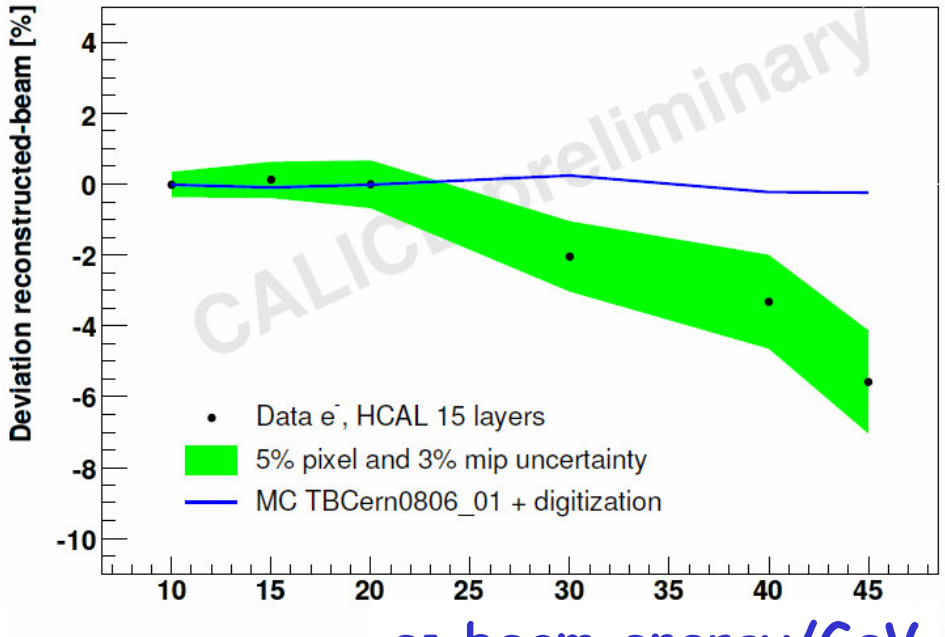
G4 Wor

AHCAL linearity for e⁻



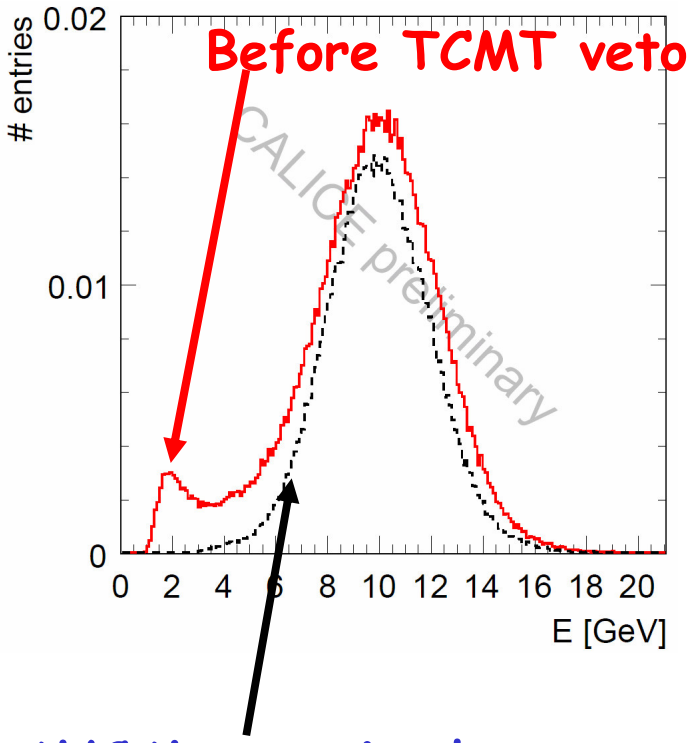
- Extract response+resolution from fits at each energy
- Linearity OK
- Residuals ~5% at 45 GeV





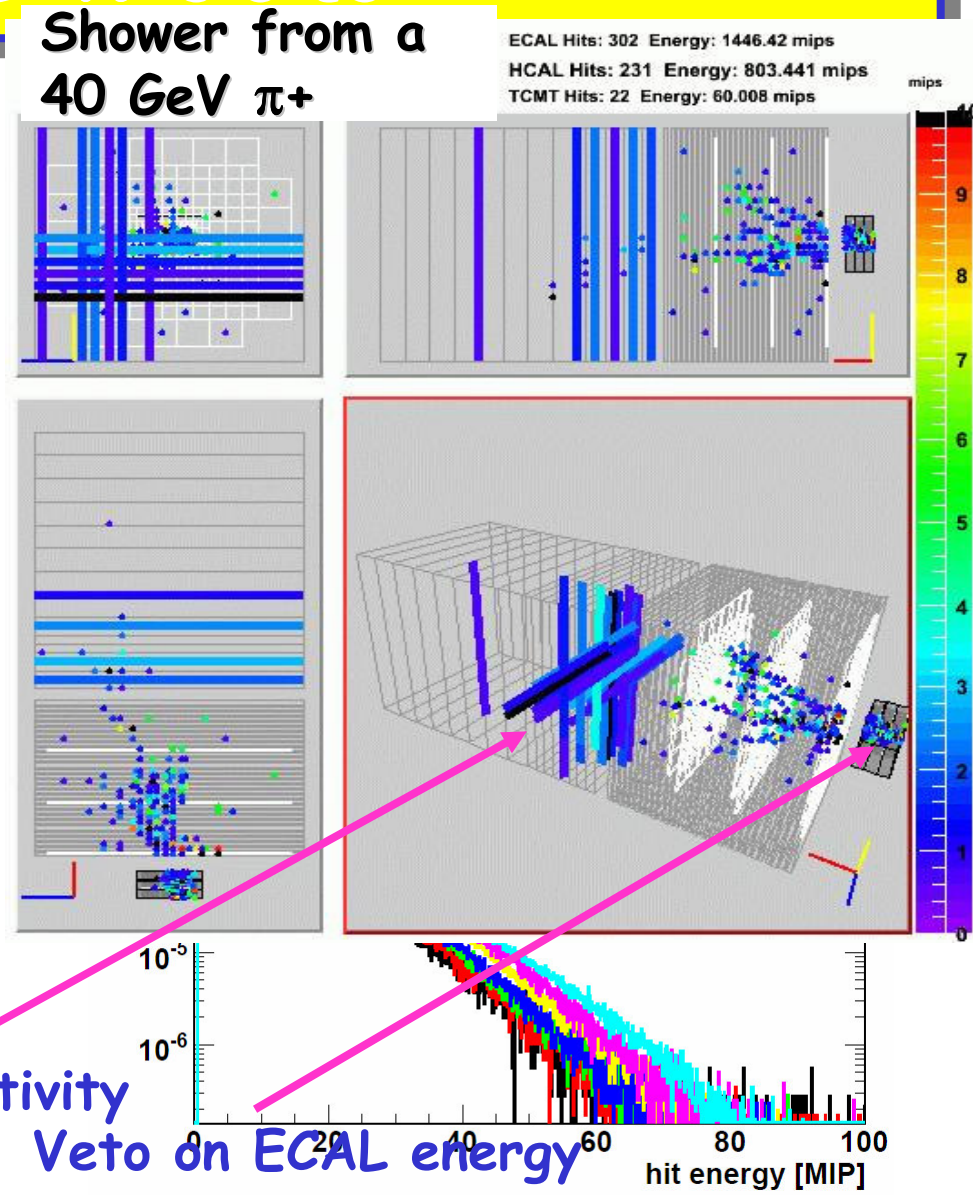
AHCAL π data

AHCAL hit energies for pion data



AHCAL contained events

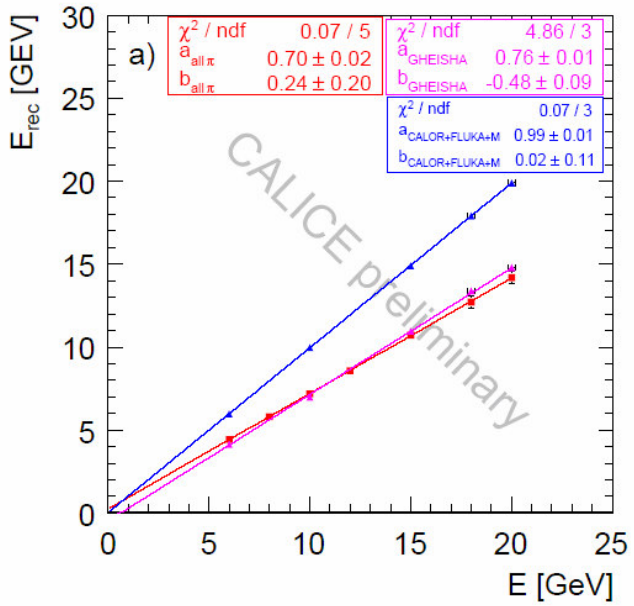
Shower from a 40 GeV π+

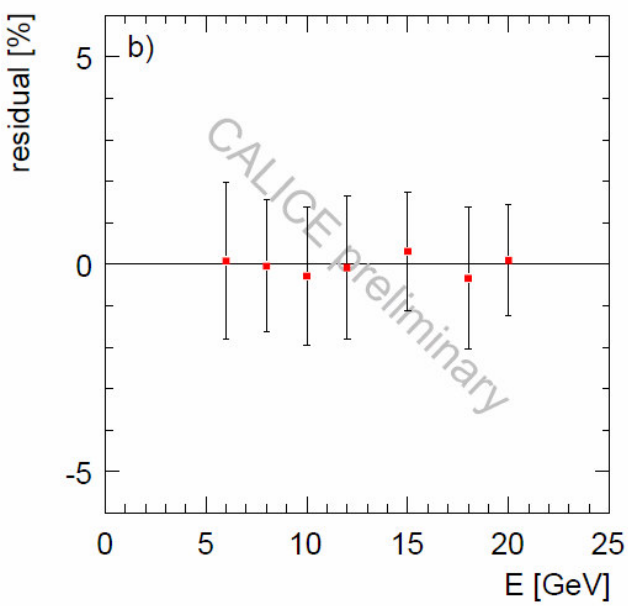


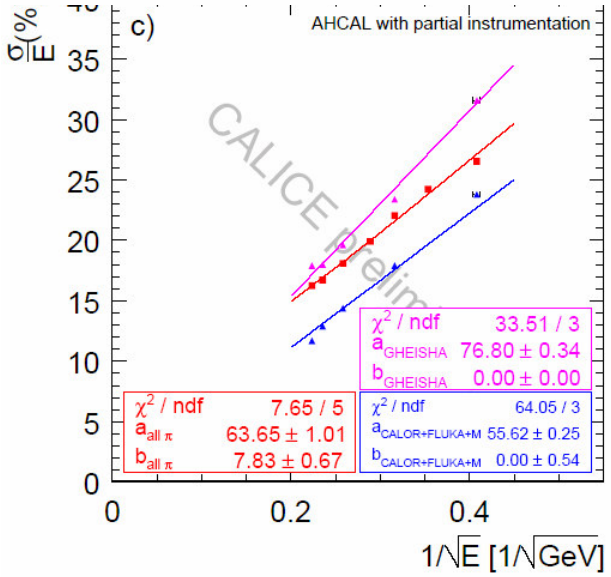
Veto on TCMT activity

Veto on ECAL energy

π linearity and resolution

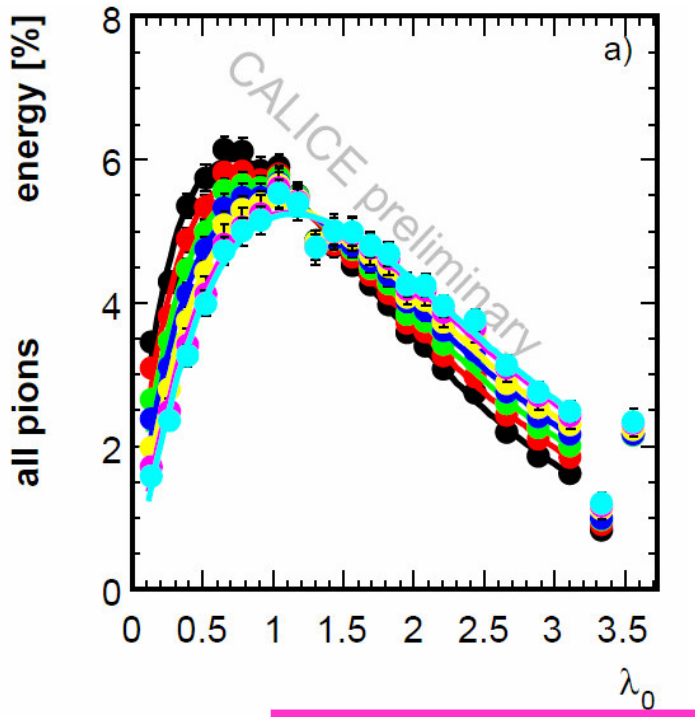


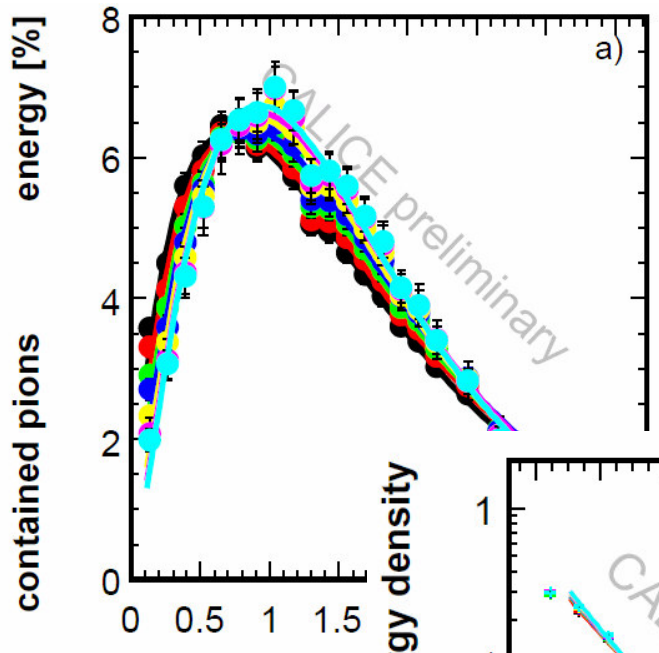


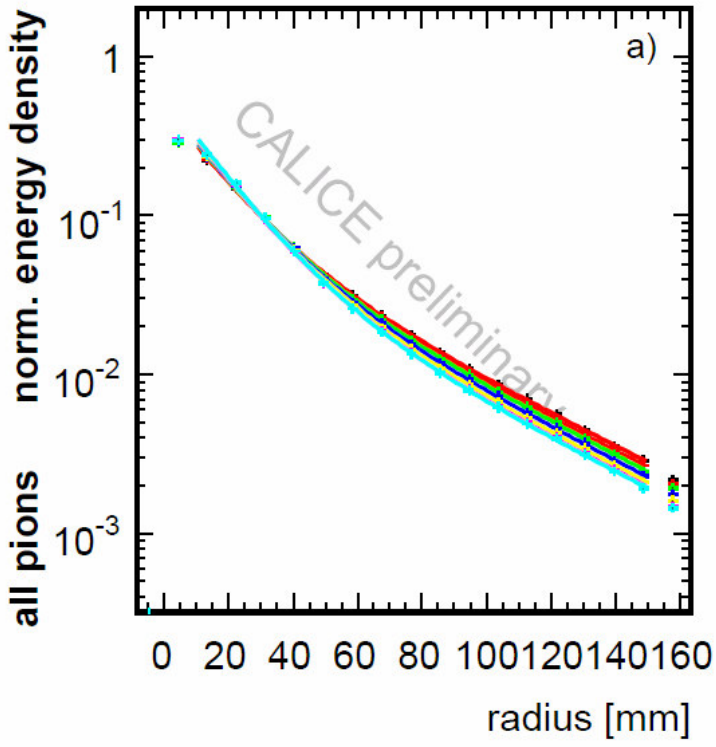


- Resolution ~ compatible with (Geant3) MC models
- Not yet comparison with G4 v8/9…
- Coming soon…

AHCAL energy profiles







Longitudinal – contained in AHCAL

Outlook

- Complete understanding of 2007 data
  - In process of adding yet more realism to testbeam model (material, instrumented regions, etc.)
  - Understanding beamline – characterisation of beam itself empirically, or by modelling ~accelerator-style the transport line (BDSIM et al?)
- Longer term plans include
- Detailed study of hadronic shower substructure
  - separation of neutrons, e.m., hadronic components, mip-like, …. – "deep analysis"
- Clearly sensitive to details of models and CALICE actively pursuing this
- Significant impact on particle flow algorithms, in development for detector optimisation
  - e.g. PandoraPFA, which uses such assignments to improve event reconstruction
- Essential to compare data from high granular detectors with simulations
- Integrated approach to develop optimal calorimety, not just HCAL
- Work on "deep analysis" ongoing, but not ready for public consumption yet!

2007 CERN Testbeam

- ECAL: 54 PCBs (30 layers)
  - 216 channels/PCB in central part and 108/PCB in bottom part
  - Total channels: 9072
  - Total radiation length: 24 X_0
- AHCAL: 38 fully commissioned modules
  - 30 modules with fine granularity = 216 tiles
    8 modules with coarse granularity = 141 tiles
  - Total channels: 7608
  - Total interaction length: 4.5 λ
- TCMT: 16 layers – fully instrumented
  - Alternated cassettes (from layer 2 to 16) have been staggered in X and Y

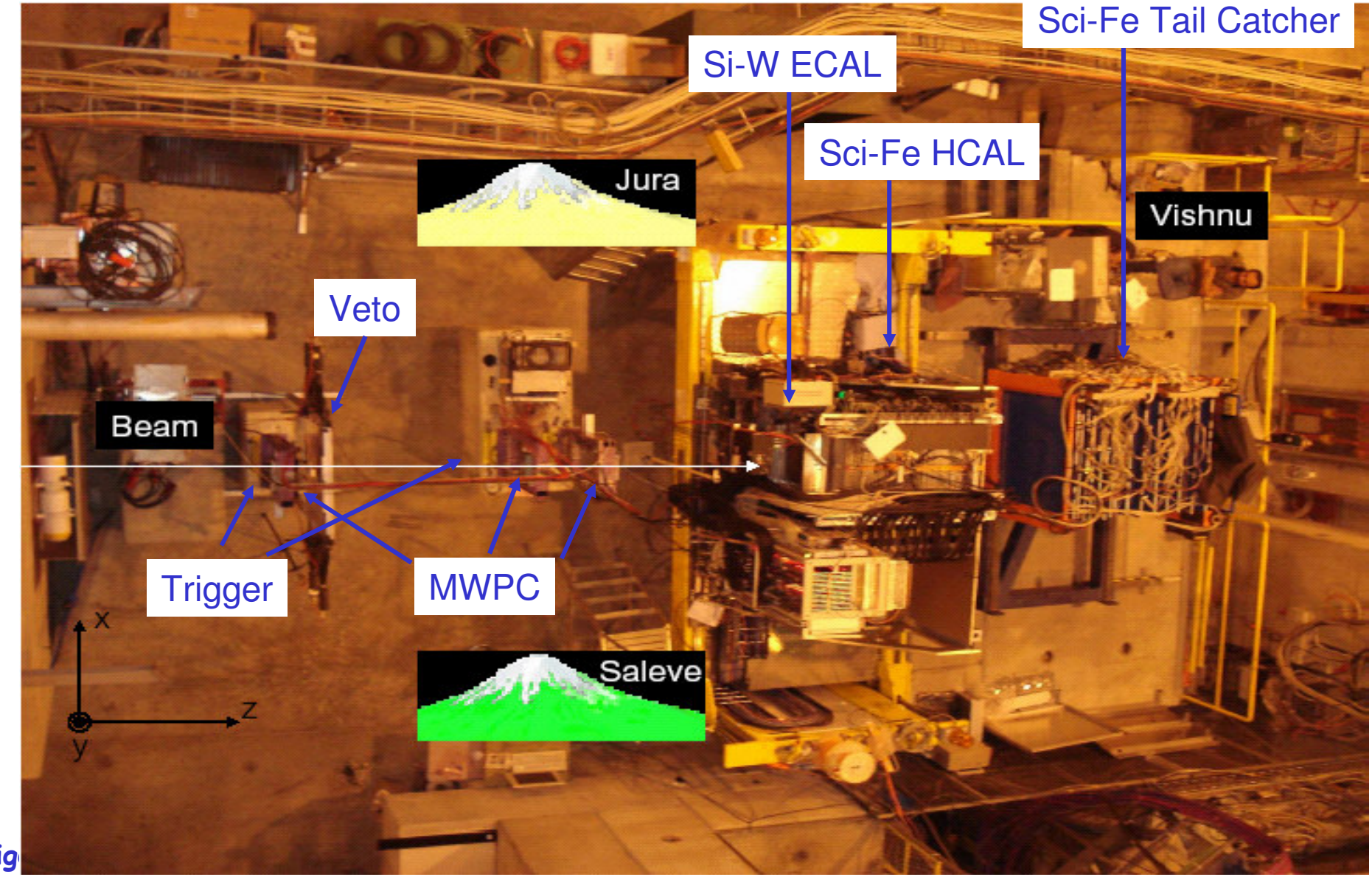
    $\Rightarrow$layer 2 = nominal; layer 3 (vert) = -1 inch in X;
    layer 4 (hor) = +1 inch in Y;

    repeated up to layer 16

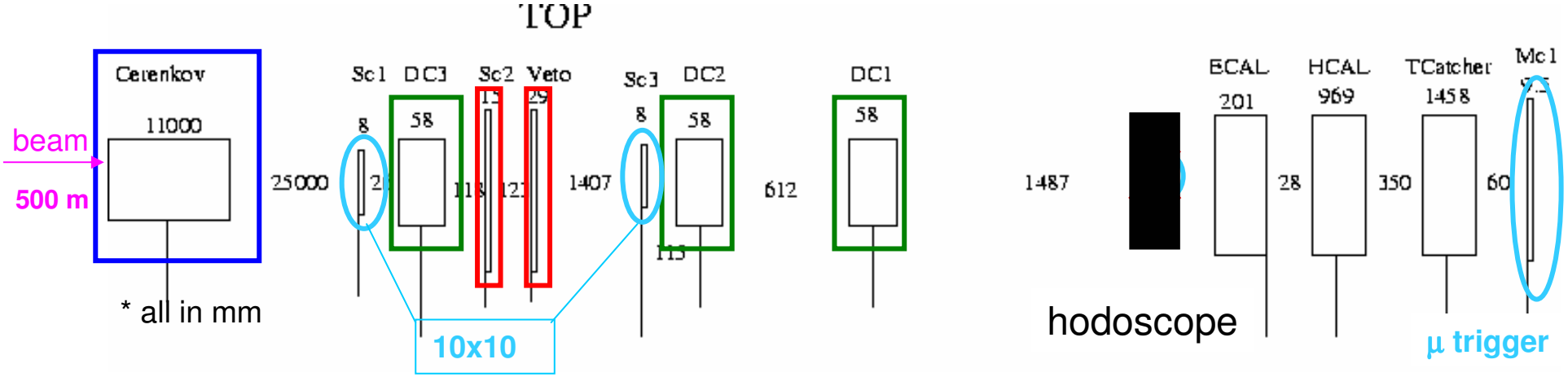
A difficult start…..

http://www.pp.rhul.ac.uk/~calice/fab/WWW/Pictures.htm

The setup two weeks later….

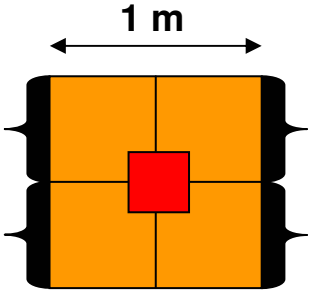


2007 Beam instrumentation description



News on the beamline

1) Cherenkov operated for e/π and π/p separation
2) 3 x/y pairs of MWPC with double readout
3) 10x10 cm trigger only (no 3x3)
4) amplitude r/o of 1cm thick scint. counter (20x20 inner veto)
   + outer veto with 20x20 cm hole to tag double particle



5) hodoscope installed for initial muon runs and from ECAL chip irradiation to end

MWPCs and Veto

- Three MWPC (from CERN)
  - 50/50 Ar/CO_2 gas mixture
  - X, Y readout
    - $\Rightarrow$200 mV threshold (100 mV after August 8th)
  - Aligned wrt beam-line with 0.2 mm precision
- Veto counters
  - 4 scintillator counters
  - Total dimension: 100X100cm, with 20x20cm hole corresponding to the 20x20cm trigger scintillator

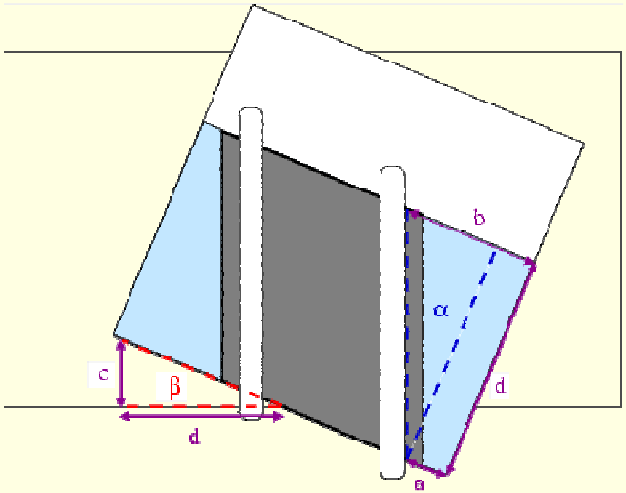
Energy points and particle types

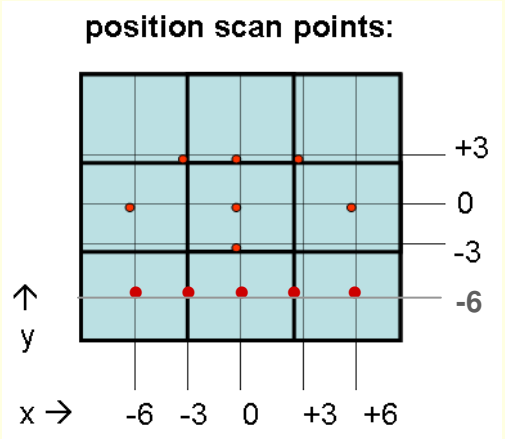
	Proposed in TB plan	Collected during TB
Energy (GeV)	6,8,10,12,15,18,20,25,30,40,50,60,80	6,8,10,12,15,18,20,25,30,40,50, 60,80,100,120,130,150,180
Particles	$\pi^{\pm}/e^{\pm}$	$\pi^{\pm}/e^{\pm}$/protons

- Beam energies extrapolated from secondary beam
  - Electron beam obtained sending secondary beam on Pb target
- π/e separation achieved using Cherenkov threshold detector filled with He gas
  - Possible to distinguish π from e for energies from 25 to 6 GeV
- π/proton separation achieved using Cherenkov threshold detector with N_2 gas
  - Possible to distinguish π from protons for energies from 80 to 30 GeV

http://www.pp.rhul.ac.uk/~calice/fab/WWW/runSummary.htm

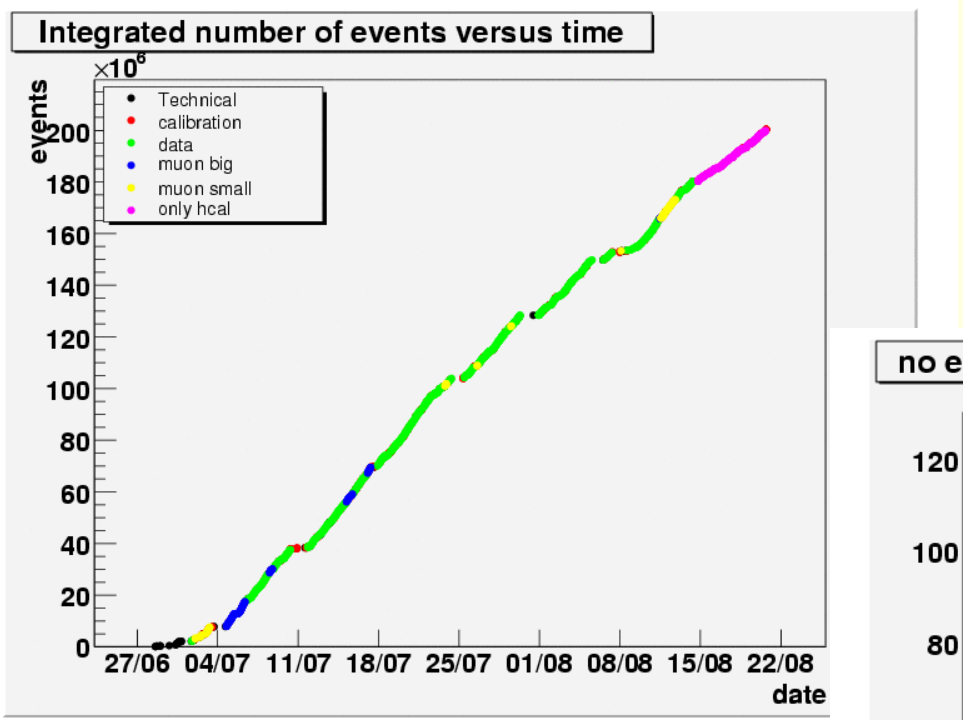
Angle and position scans





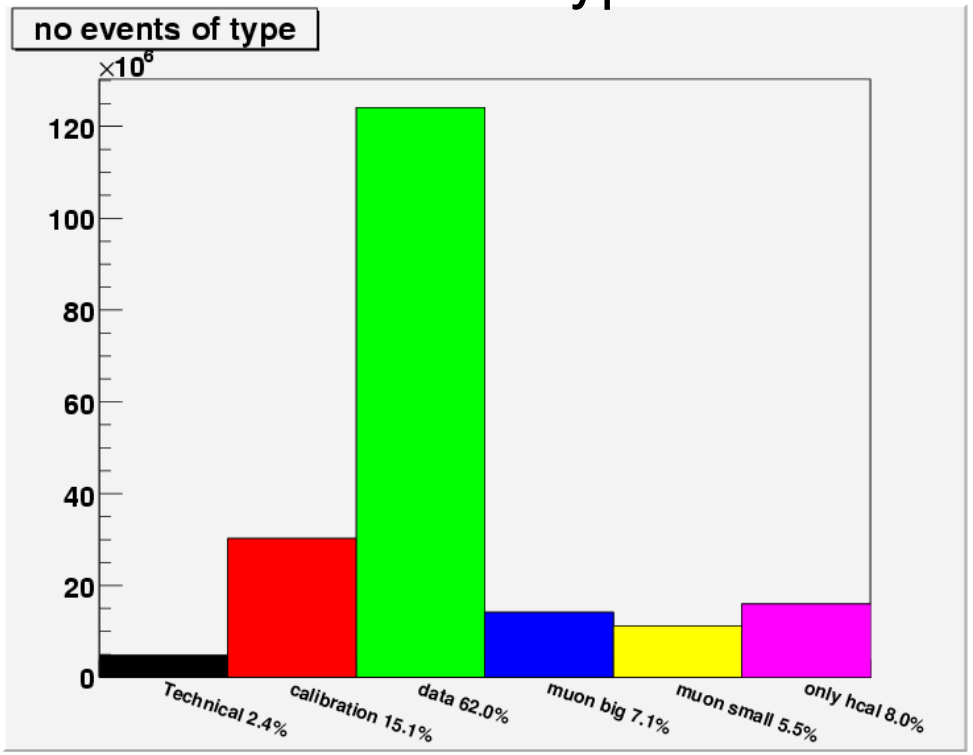
	Proposed in TB plan	Collected during TB
Angles	0, 10, 15, 20, 30	0, 10, 20, 30
Position scans	Centre of ECAL	Centre of ECAL ±6cm from ECAL centre wafer Bottom slab of ECAL (±6,0,±3cm, -3cm)
	Centre of AHCAL	Centre of AHCAL Centre of ECAL; AHCAL ±6cm off beam-line
	Inter-alveolae	Inter-alveolae (±3cm, ±3cm)

Total events collected



Integrated Luminosity

Event Types



http://www.pp.rhul.ac.uk/~calice/fab/WWW/dataSummary.htm

Total events on disk

Combined ECAL+AHCAL

Last run	33 1693
Number of runs	1 693
Combined runs to grid	1 693 (100%)
Converted runs to grid	1 693 (100%)
Disk space	8 274 GB
Disk space for converted runs	5 965 GB
Total disk space used	13 TB, 927 GB

AHCAL only

Last run	35 0395
Number of runs	395
AHCAL runs to grid	395 (100%)
Converted runs to grid	395 (100%)
Disk space	598 GB
Disk space for converted runs	369 GB
Total disk space used	0 TB, 967 GB

http://www.pp.rhul.ac.uk/~calice/fab/WWW/dataSummary.htm

Summary

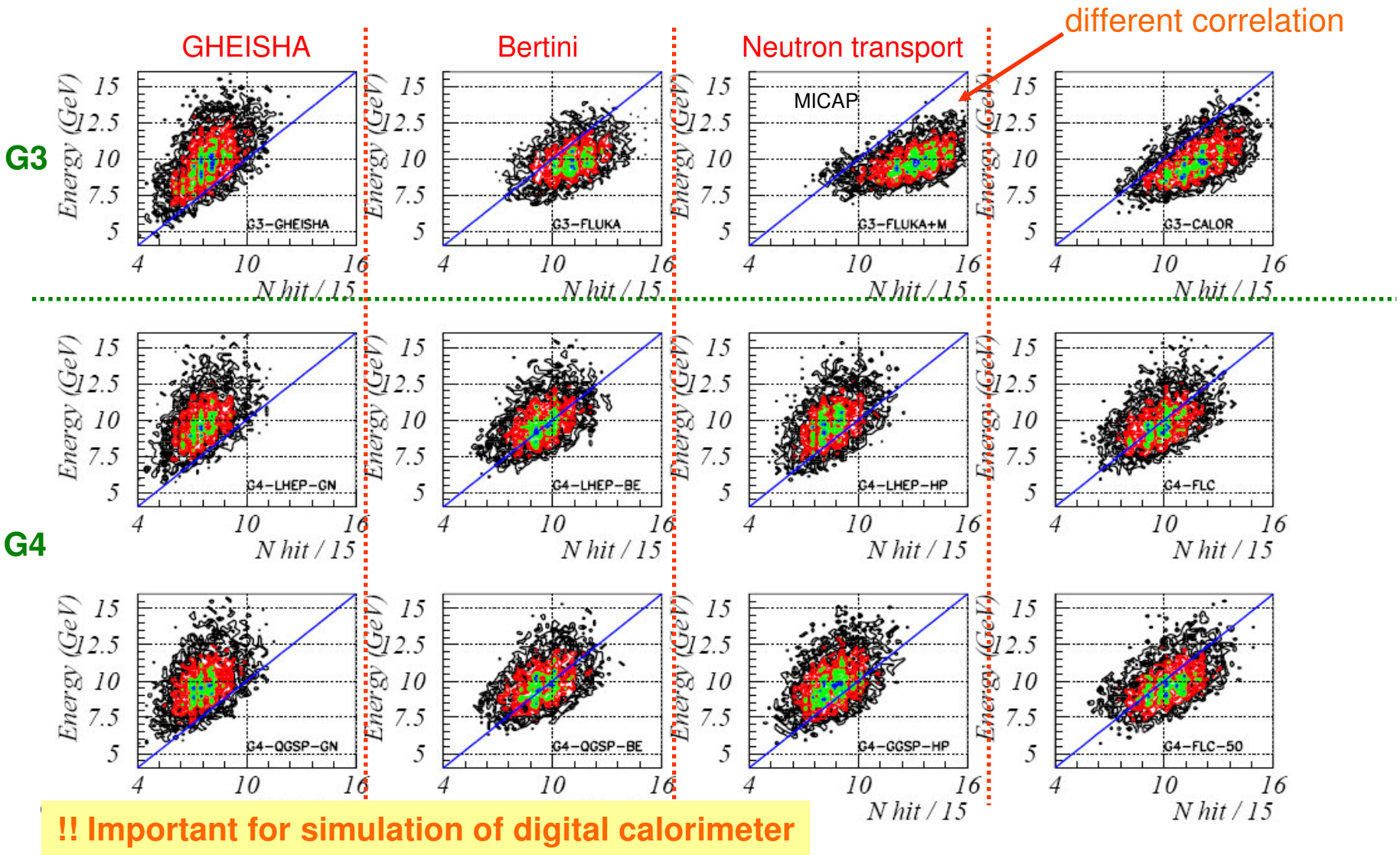
- CALICE is developing exceptionally performant calorimetry for ILC
- Excellent opportunity to further "stress test" hadronic models
- First significant results from 2006 test beam runs at CERN/DESY Summer 2007
- Very large data sets from CERN in 2007, substantially more than planned for
  - Analysis in progress
- Careful, realistic simulation of beamline and detectors essential before most useful comparisons with hadronic models
  - Enhancements to modelling being made, ~month
- Plans for detailed comparisons, results to come soon
- Welcome suggestions for additional model tests from the respective authors

Backup slides…

- Selection of slides shown at G4 Review, 15-20/4/2007 by Erika Garutti (+Vasily Morgunov)

Models comparison

Integrated quantities

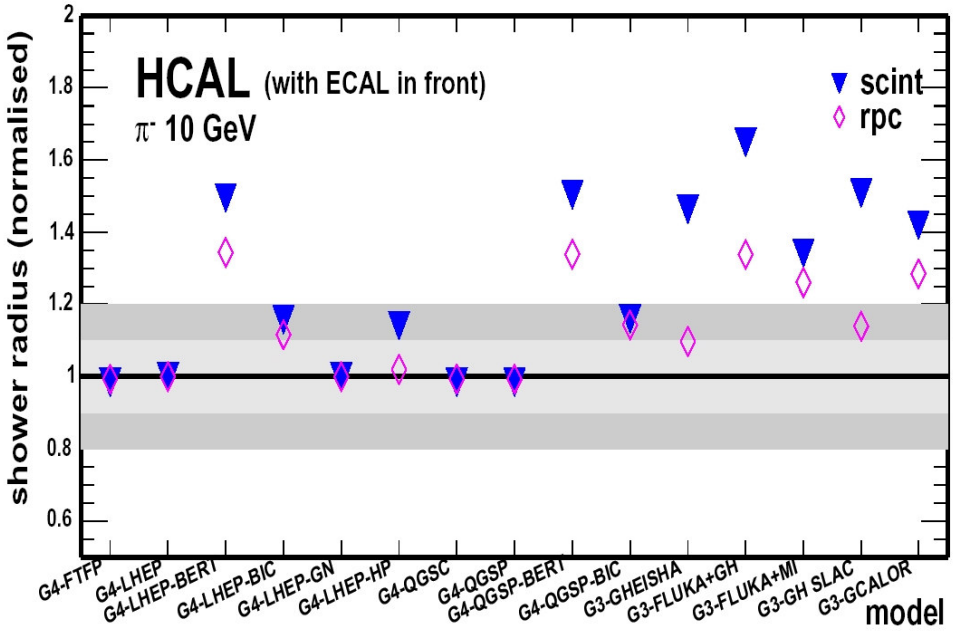


!! Important for simulation of digital calorimeter

Models comparison

Differential quantities

Study on hadronic shower profiles, G. Mavromanolakis (2004)



The HCAL high granularity offers the possibility to investigate longitudinal and lateral shower shapes with unprecedented precision:

- 38 points for longitudinal profile (if ECAL and TCMT included up to 84)
- 9 points for lateral profile