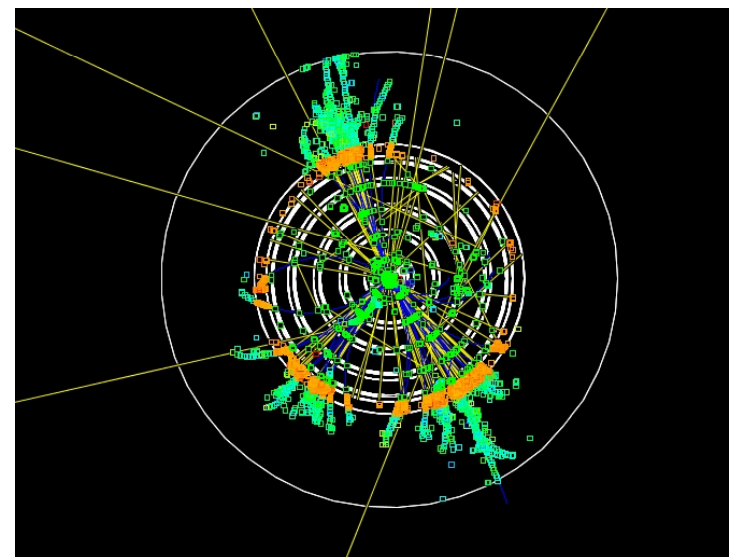
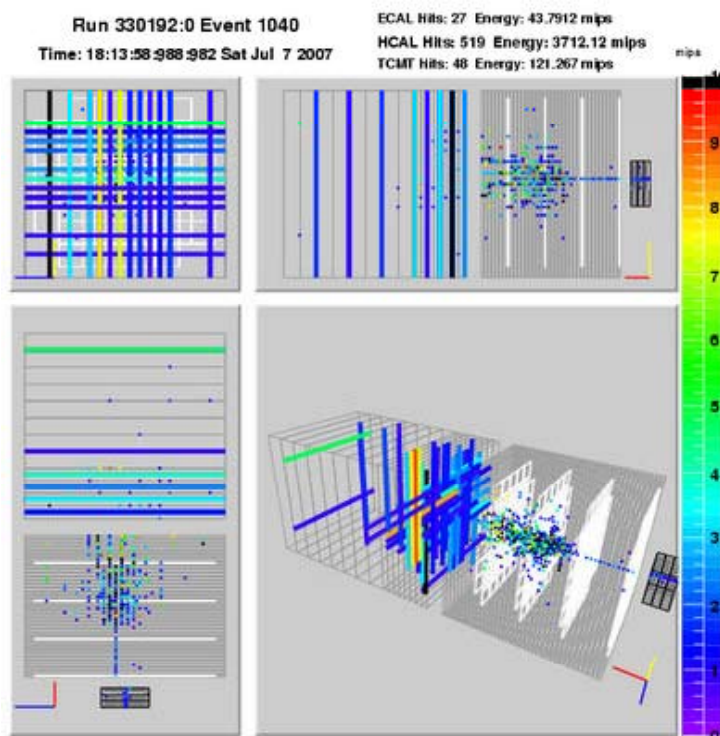


CALICE Report



Nigel Watson
(Birmingham Univ.)

- Motivation
- Test beam programme
- Current results
- Summary

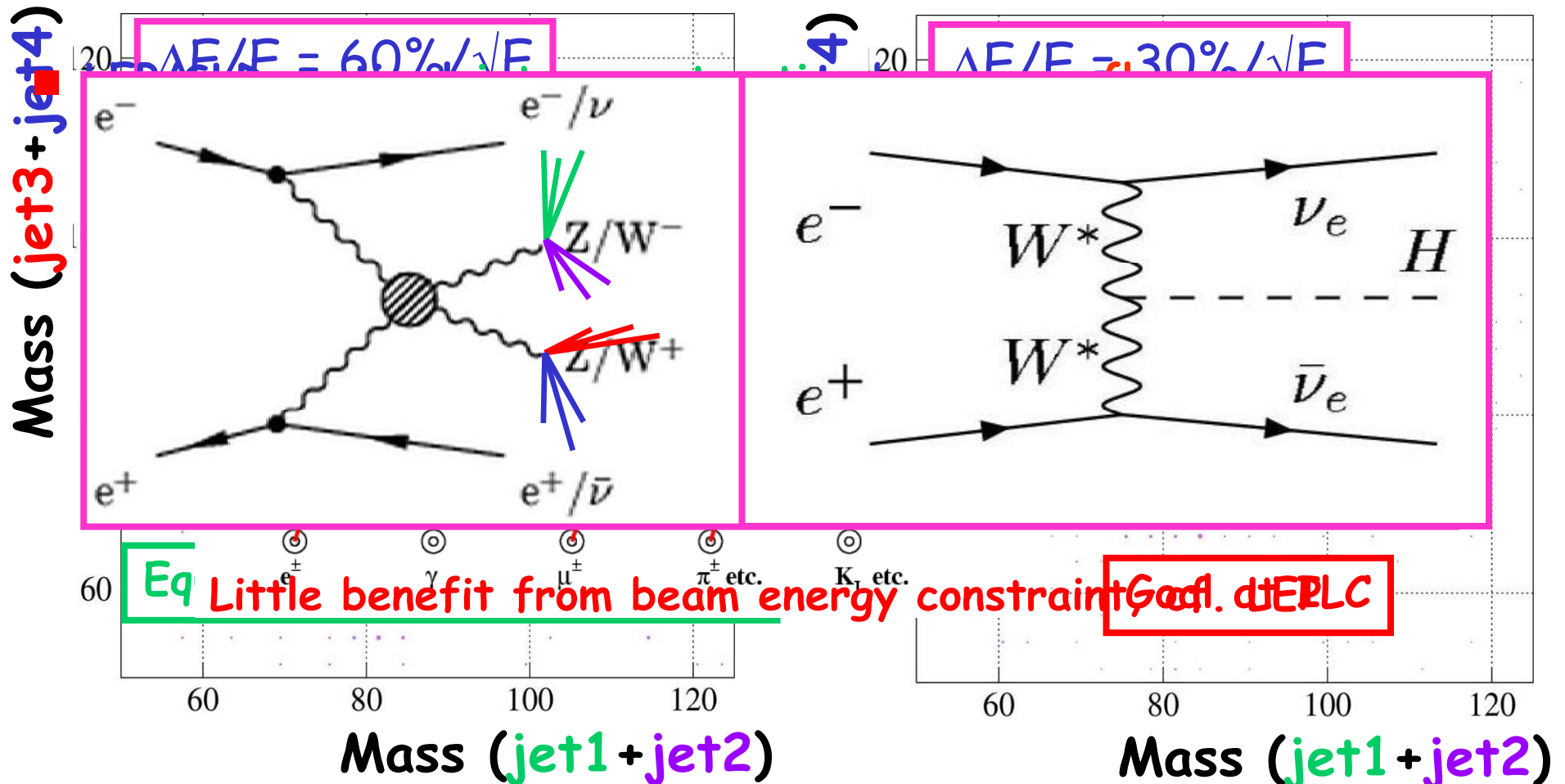


For the CALICE Collaboration

[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 $\nu\nu W^+W^-$, $\nu\nu Z^0Z^0$, $t\bar{t}h$, 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, \therefore 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

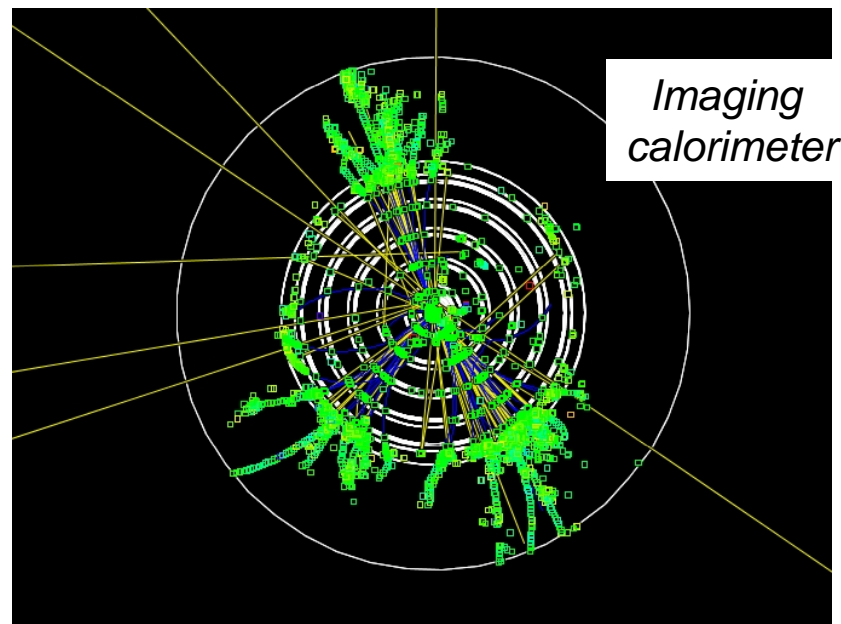
Final goal:

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

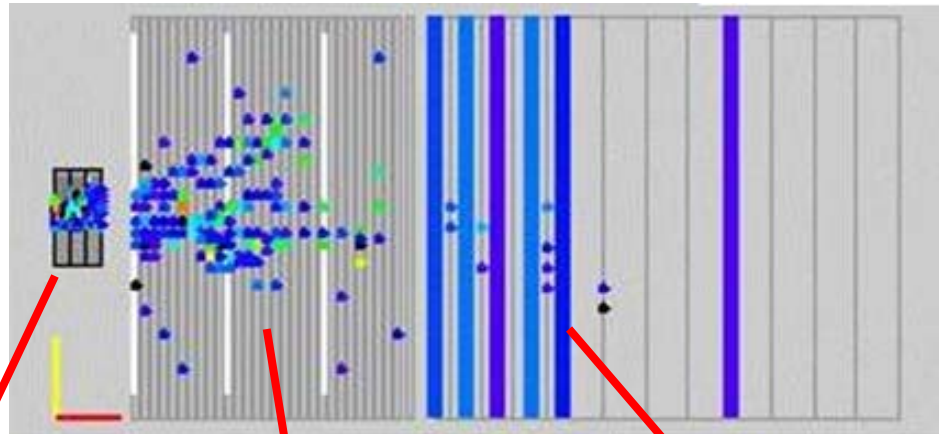
- Establish the technology
- Collect hadronic showers data with **unprecedented granularity** to
 - tune reconstruction algorithms
 - validate existing MC models



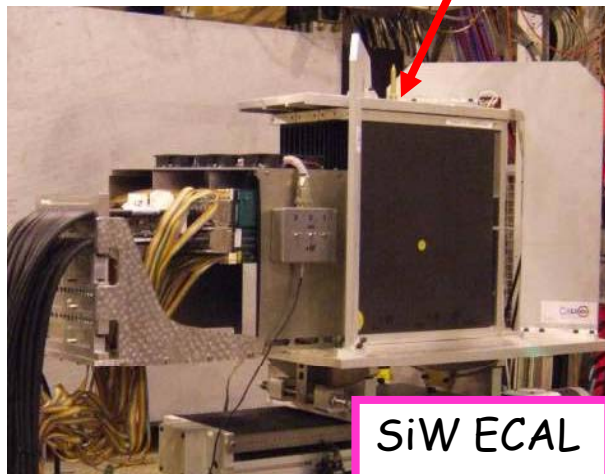
Test beam prototypes

10 GeV pion shower
@ CERN test beam

→
beam

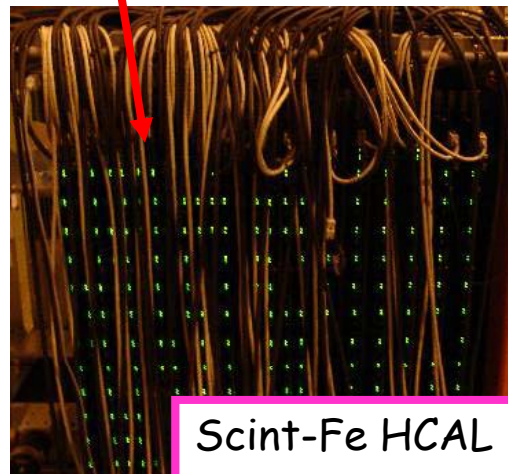


CALICE
Calorimeter for ILC



SiW ECAL

1x1cm² lateral segmentation
1 X₀ longitudinal segment.
~1λ total material, ~24 X₀



Scint-Fe HCAL

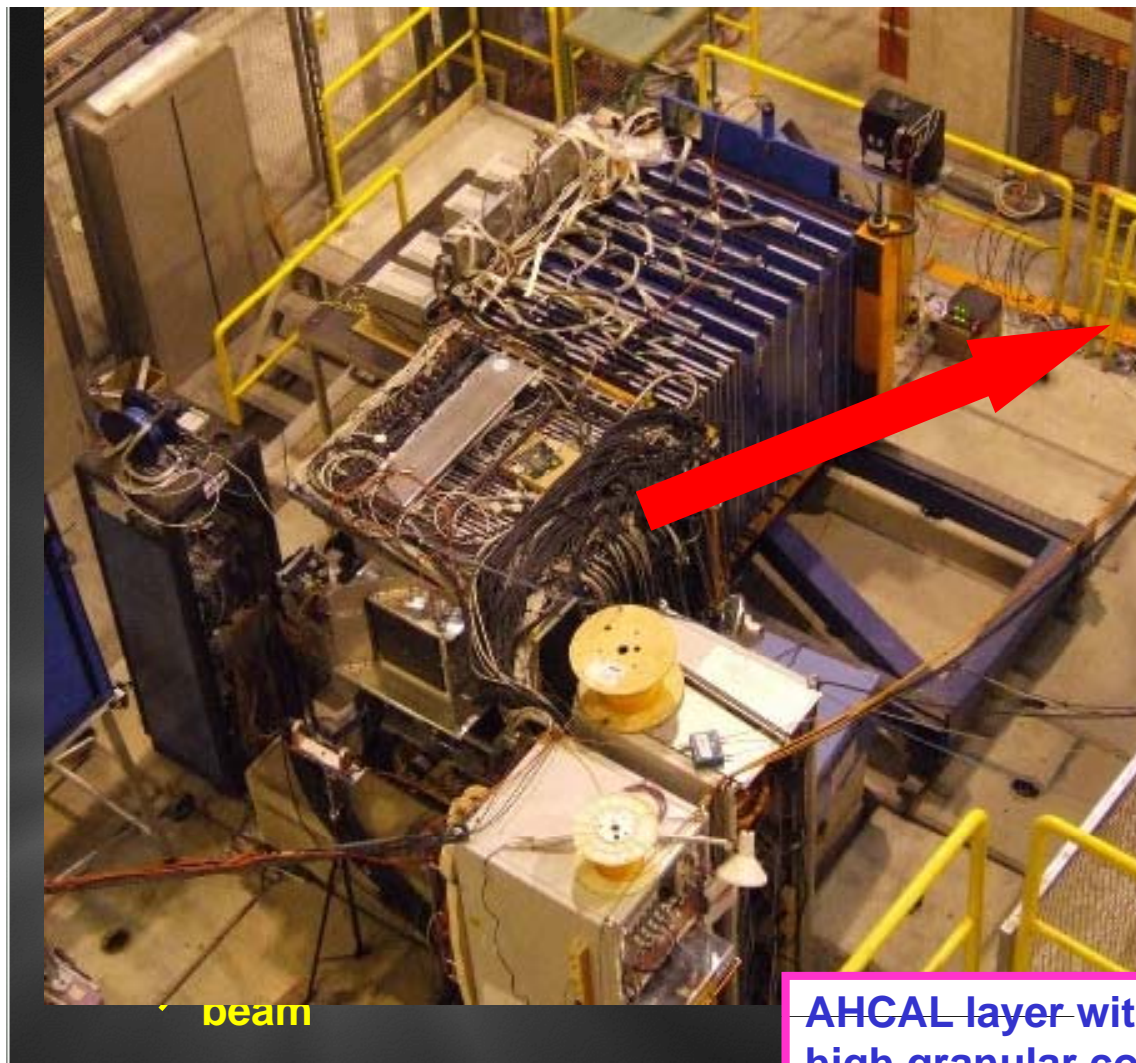
3x3cm² tiles lateral
segmentation
~4.5 λ in 38 layers



Scint-Fe tail catcher/
muon tracker

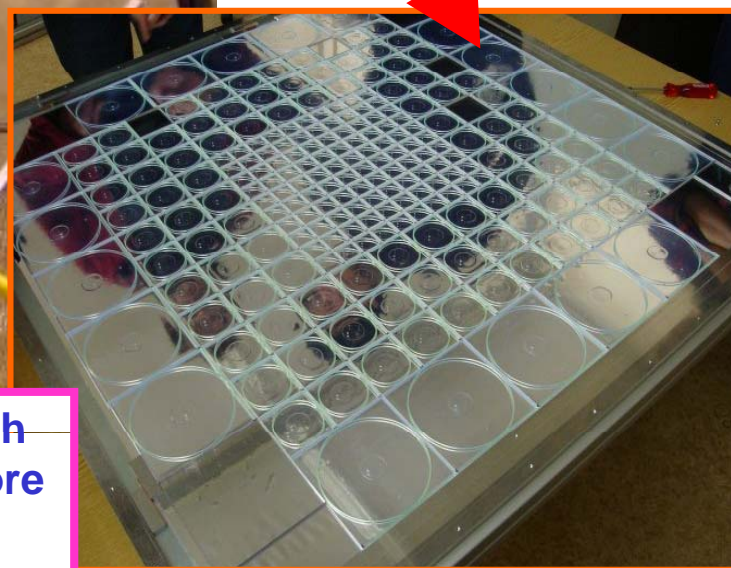
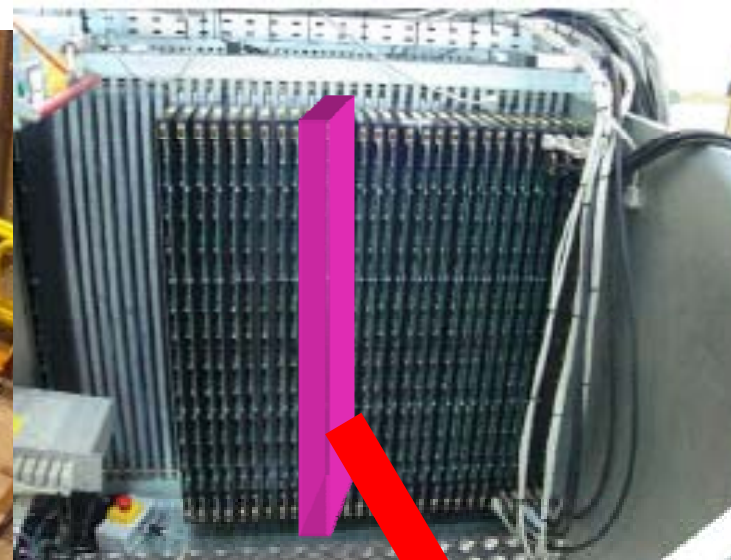
5x100cm² strips
~5 λ in 16 layer

The 2006 CERN installation



beam

AHCAL layer with
high granular core
readout



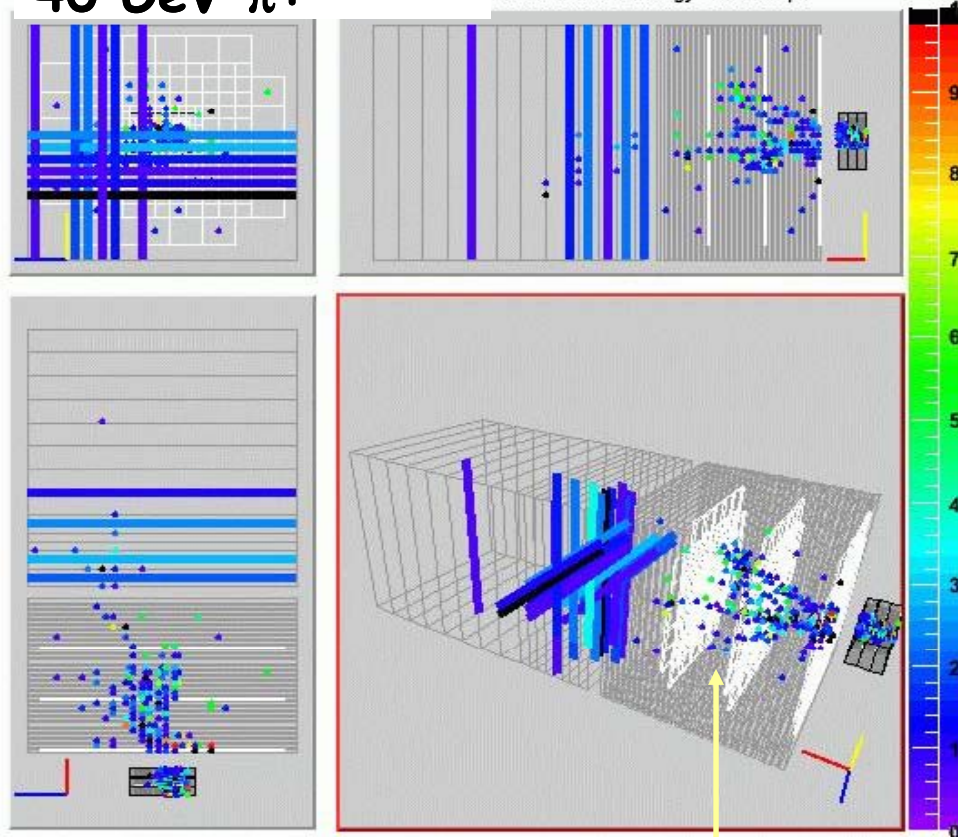


Event display

REAL DATA!

Shower from a
40 GeV π^+

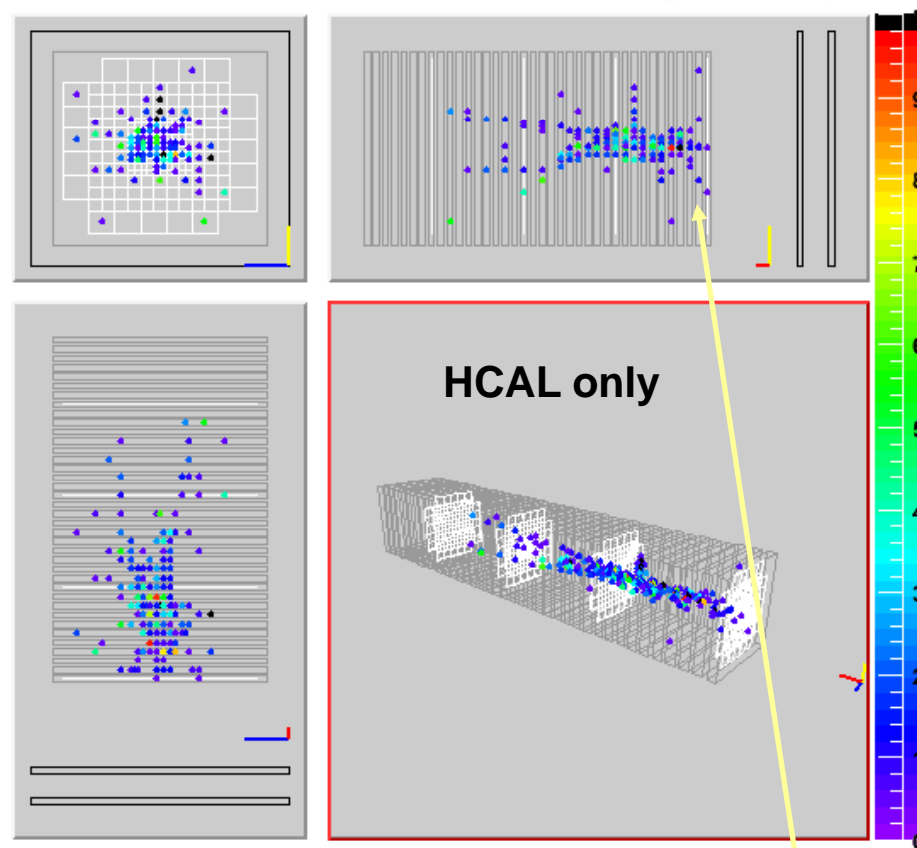
ECAL Hits: 302 Energy: 1446.42 mips
HCAL Hits: 231 Energy: 803.441 mips
TCMT Hits: 22 Energy: 60.008 mips



Clear structure visible in hadronic shower
Nigel Watson / Birmingham

20 GeV π^+

Time: 05:39:16:985:771 Thu Oct 19 2006
Hits: 243 Energy: 727.372 mips



Back-scattered particle
G4 Workshop, 13-Sep-2007



Event display

REAL DATA!

40GeV/c pion
with CALICE online
analysis software

HCAL

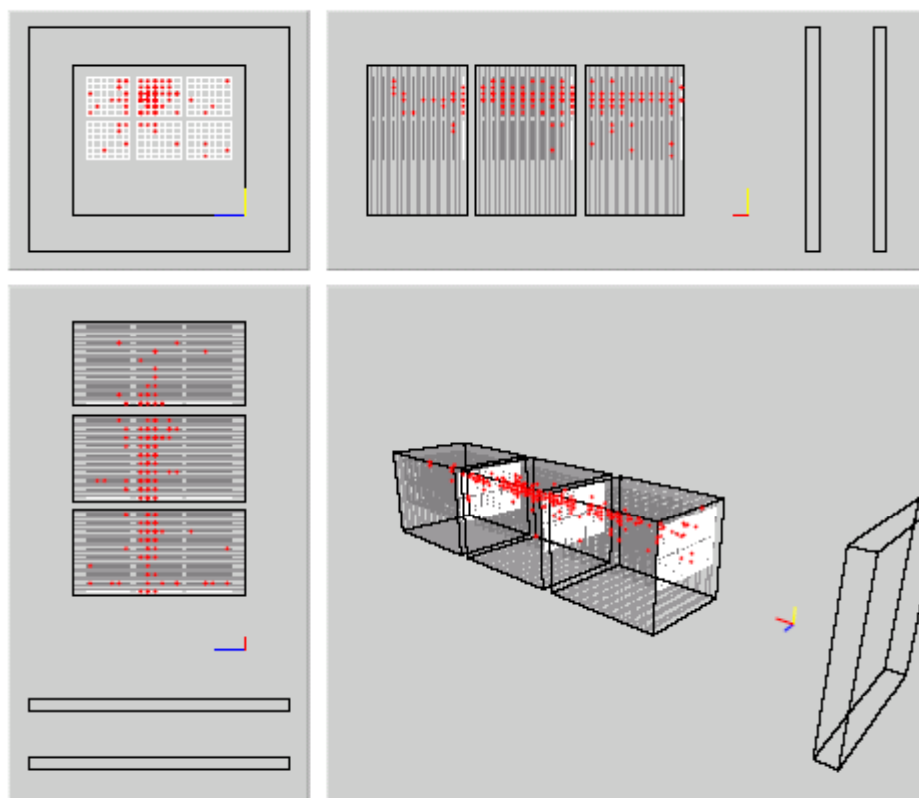
TCMT

Run 300672:0 Event 1390

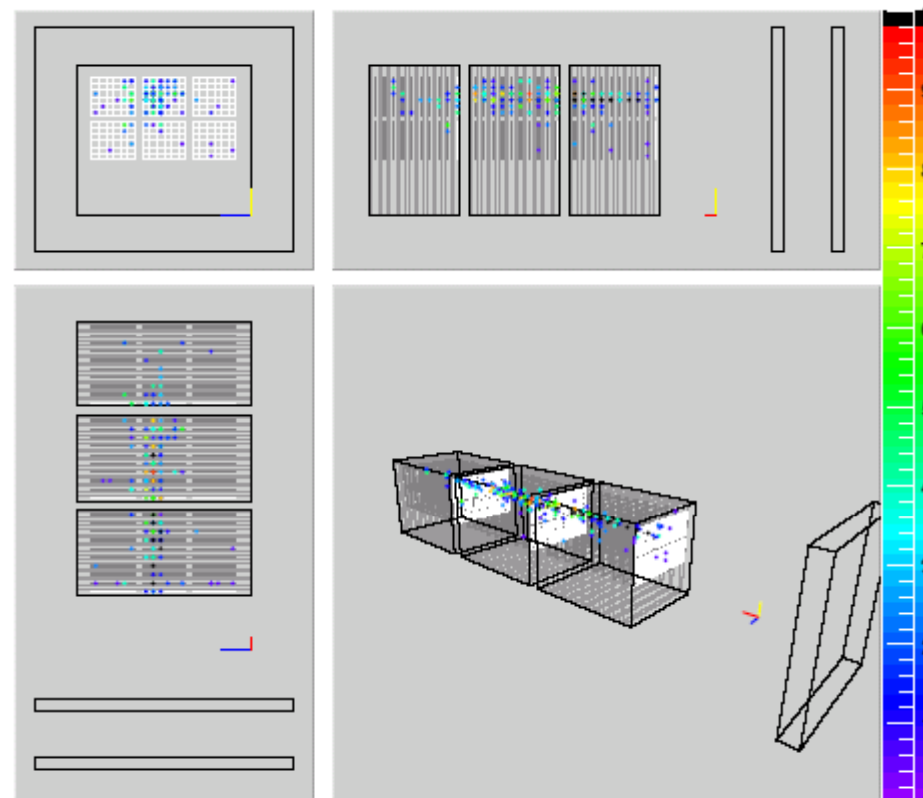
Time: 04:53:16:523:075 Fri Oct 20 2006
Hits: 176 Energy: 1487.91 mips

Run 300672:0 Event 1390

Time: 04:53:16:523:075 Fri Oct 20 2006
Hits: 176 Energy: 1487.91 mips



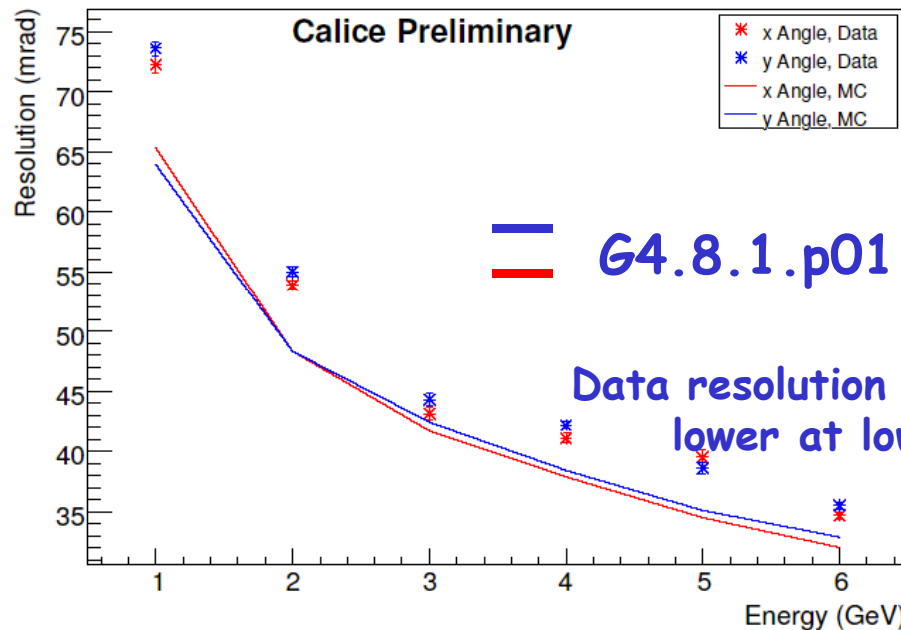
(digital display)



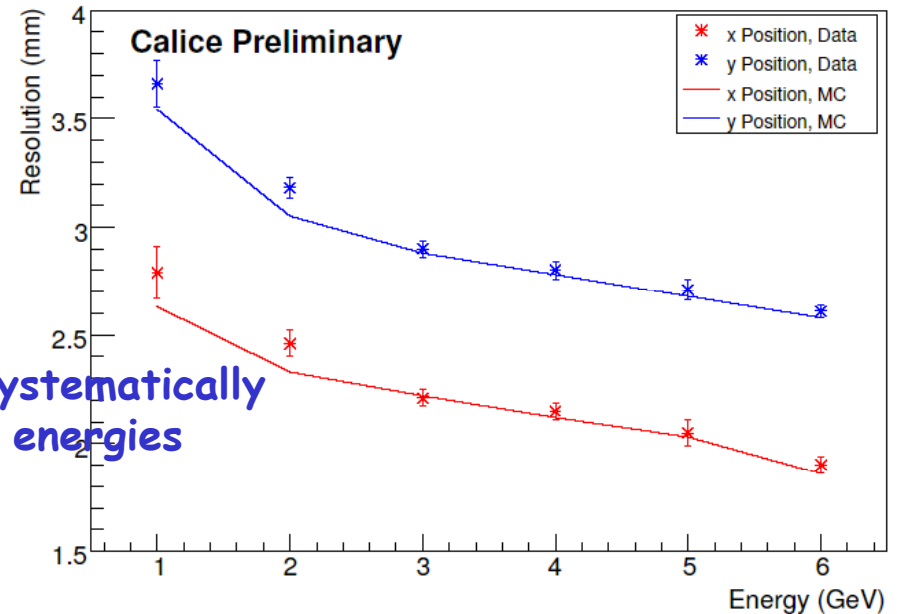
(analogue display)

Beamline instrumentation modelling

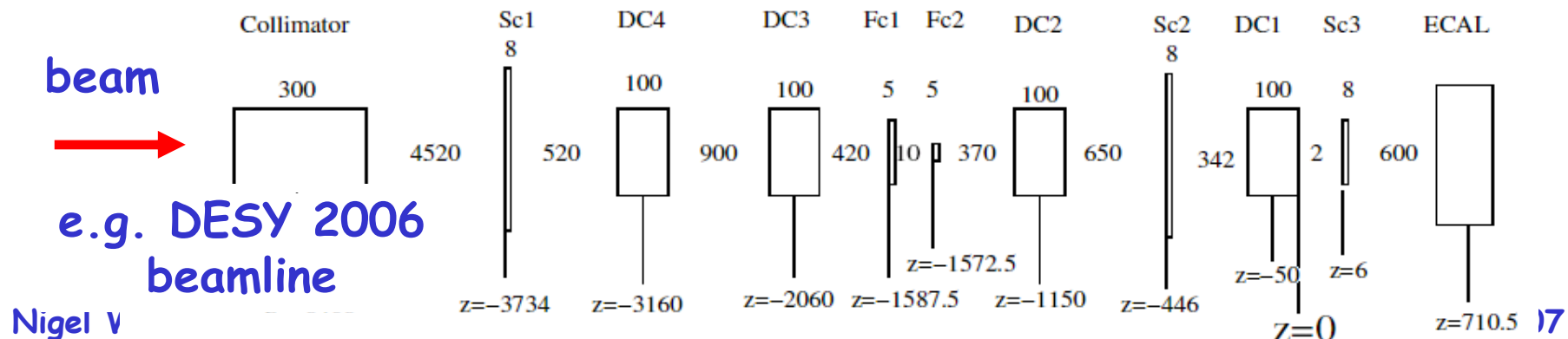
Angular Resolution



Position Resolution



Essential to model upstream material accurately to understand tracking system - effect $\sim 0.03X_0$



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

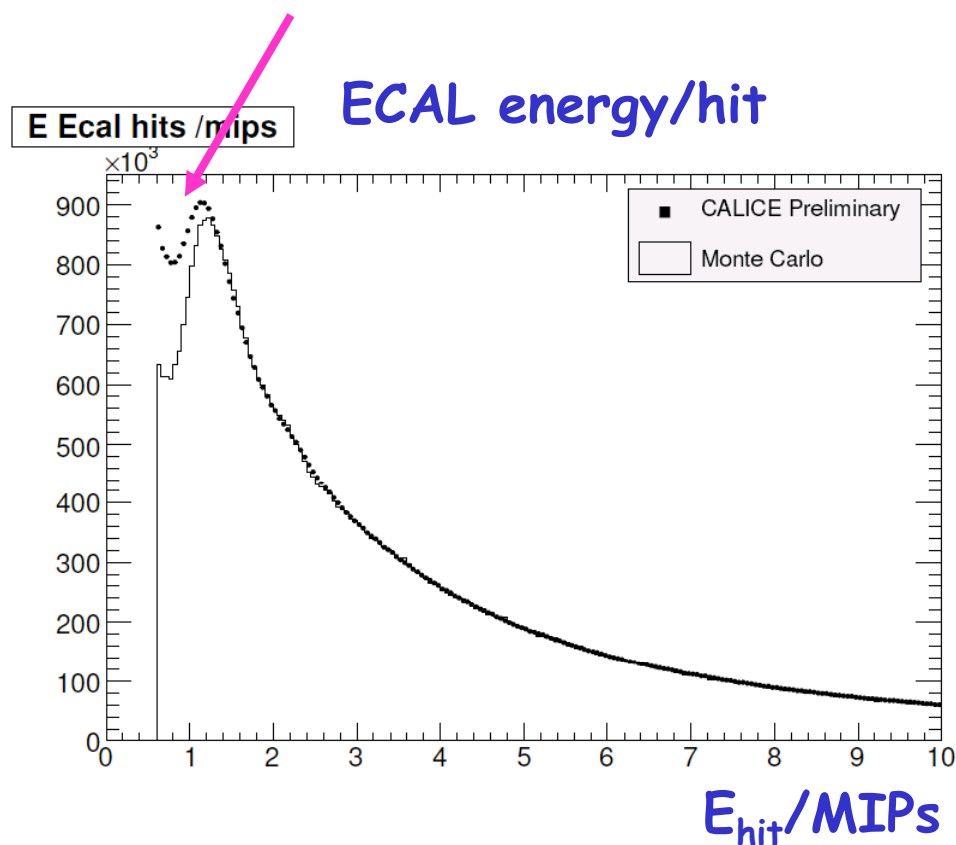
- ECAL, AHCAL for electrons
- AHCAL for charged pions

ECAL hit energy, 30 GeV e^-

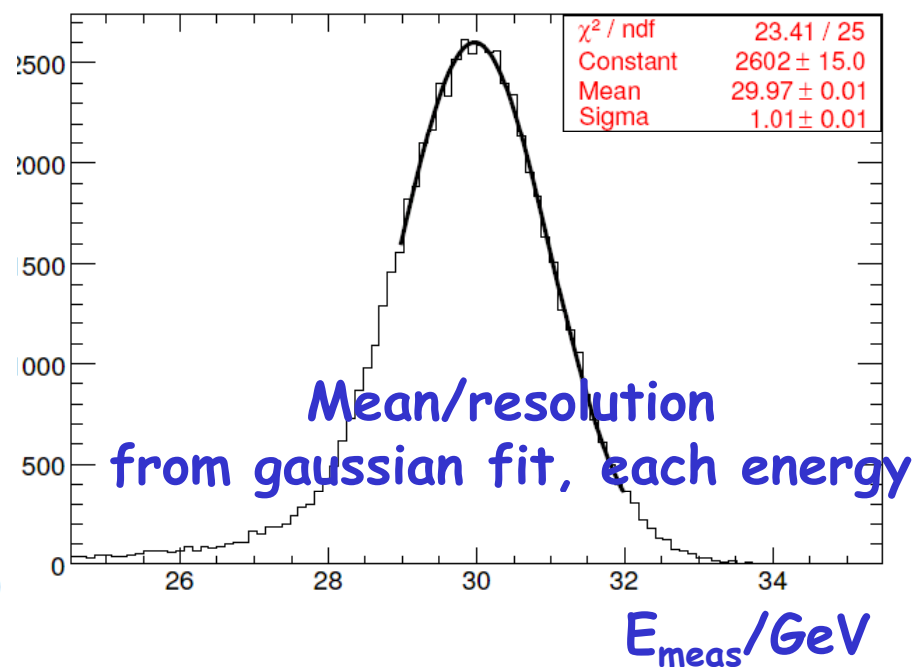
Low energy excess (below MIP peak)
not 100% understood

Minor effect on total energy

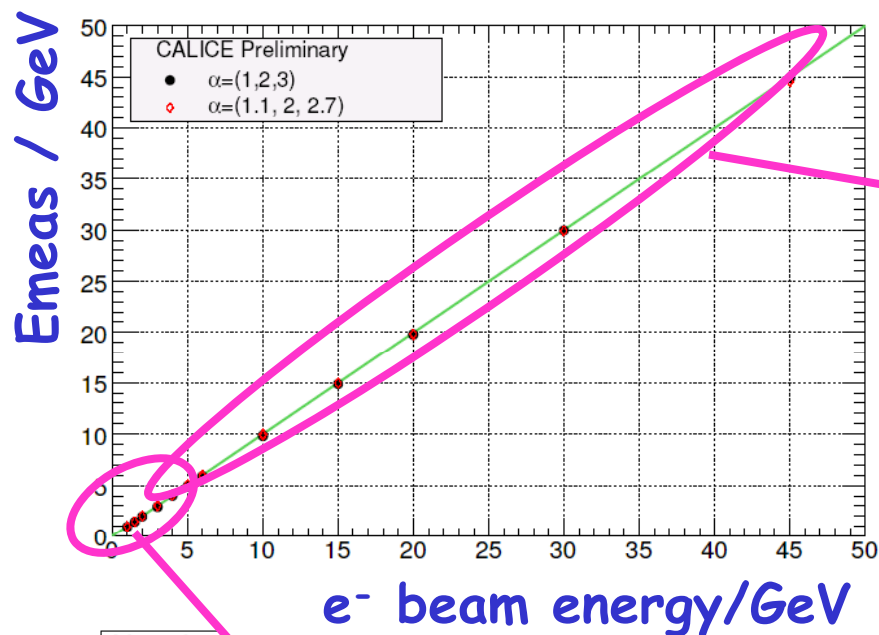
Geant 4.8.1.p01



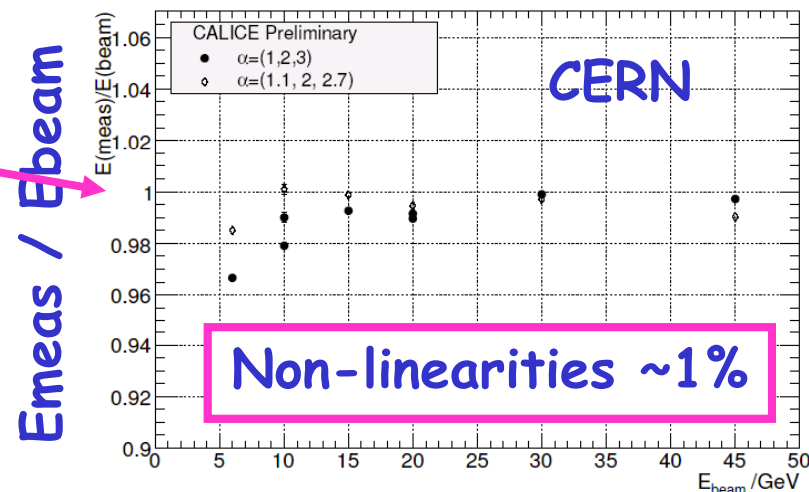
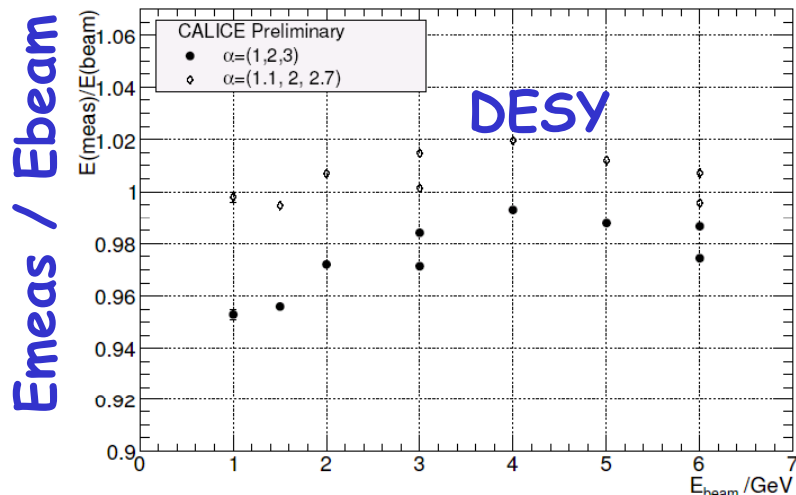
Total ECAL Energy/event



ECAL linearity/resolution

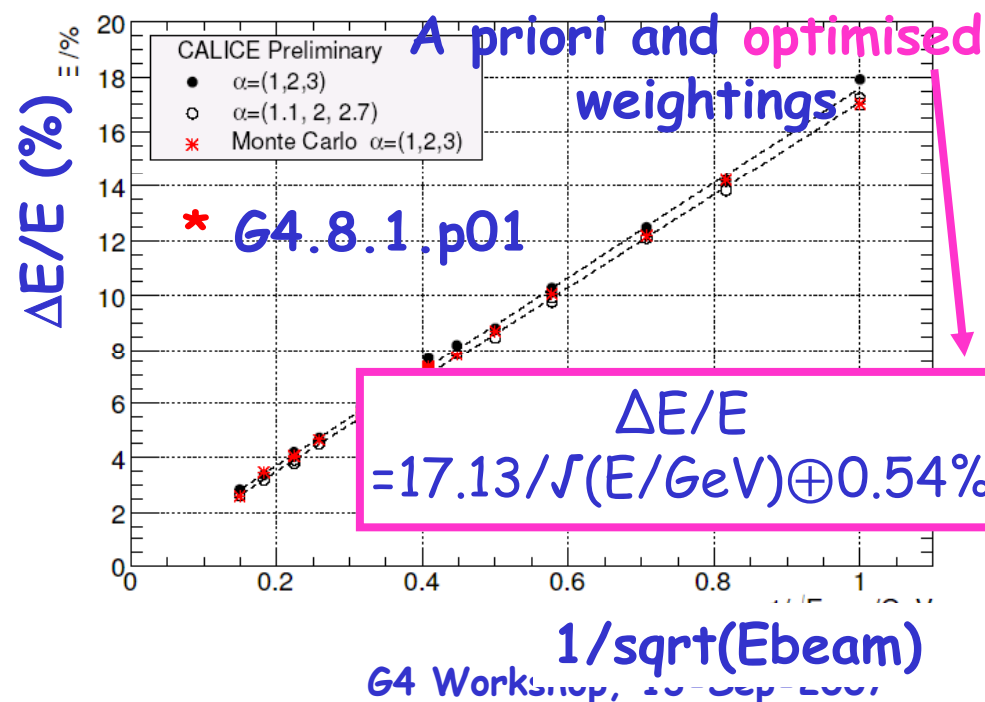


Linearity



CERN

Non-linearities $\sim 1\%$

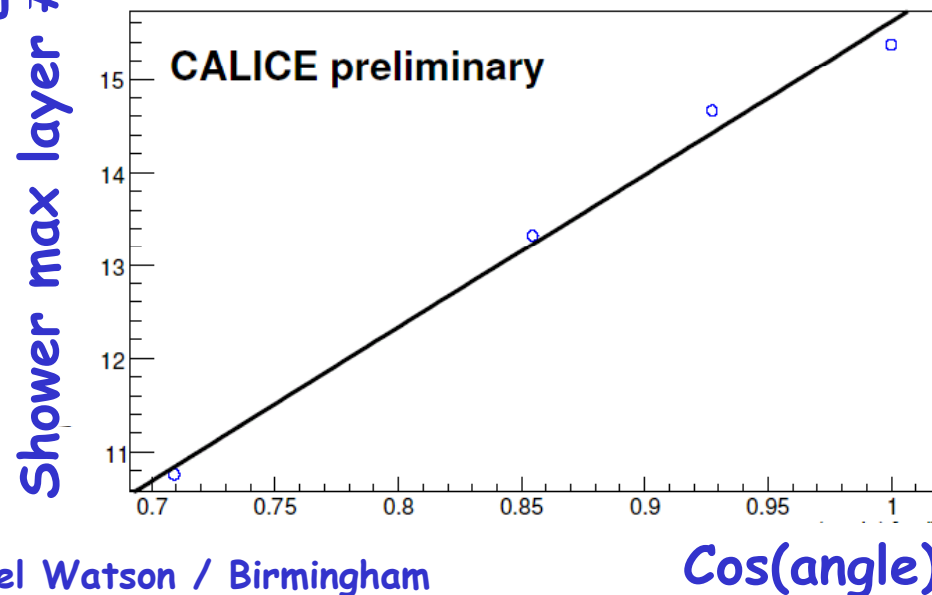
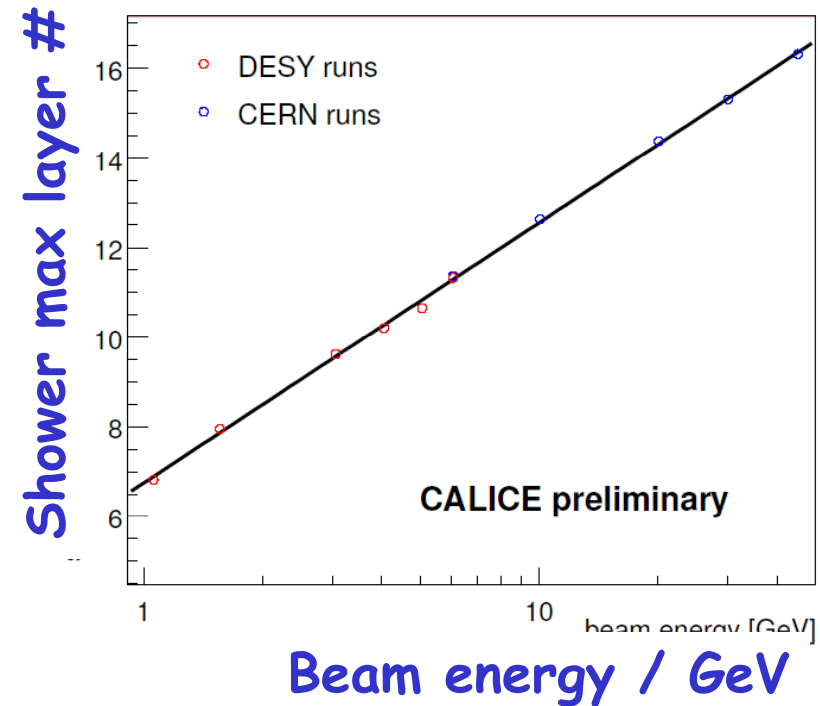
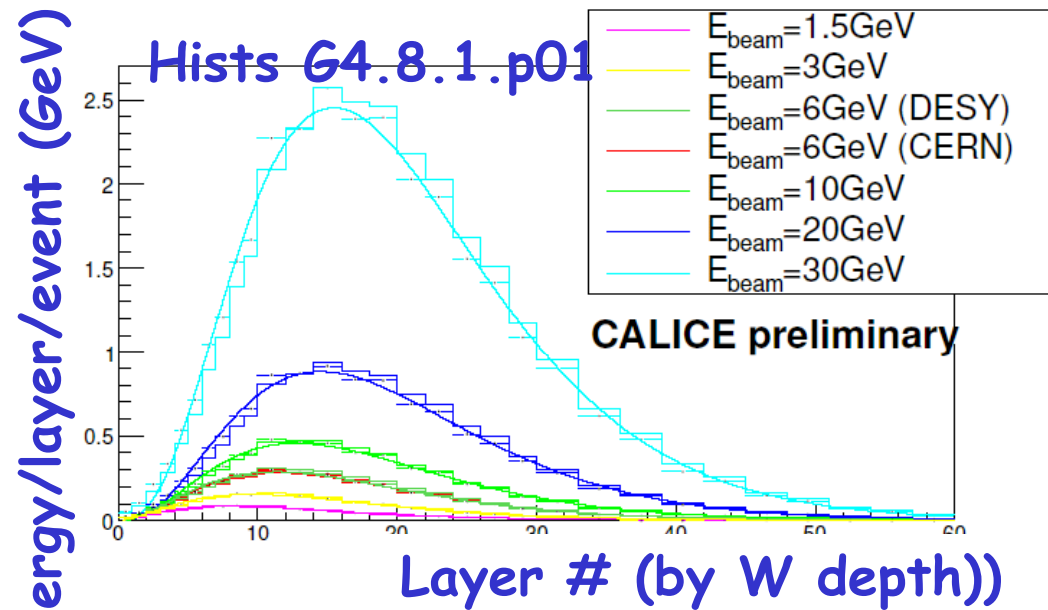


A priori and optimised weightings

G4.8.1.p01

$$\Delta E / E = 17.13 / \sqrt{E / \text{GeV}} \oplus 0.54\%$$

ECAL longitudinal profile

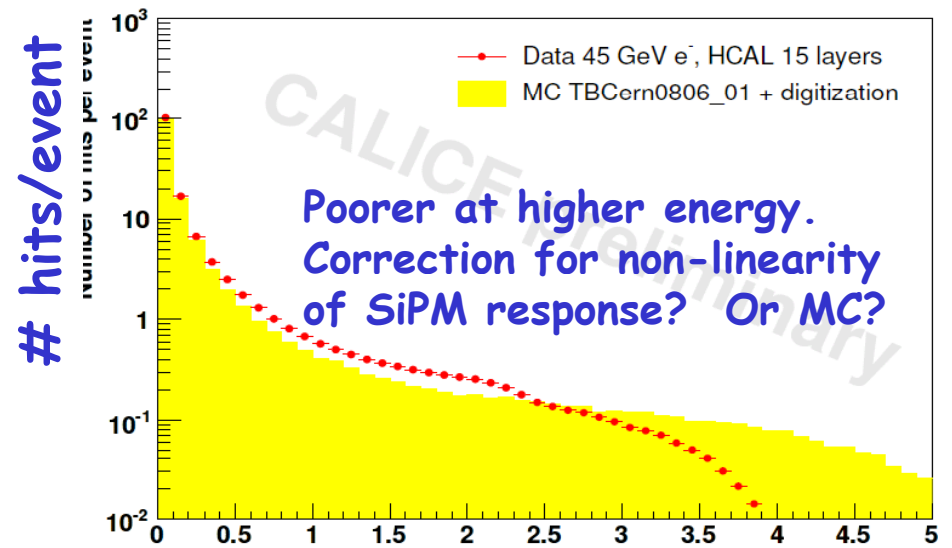
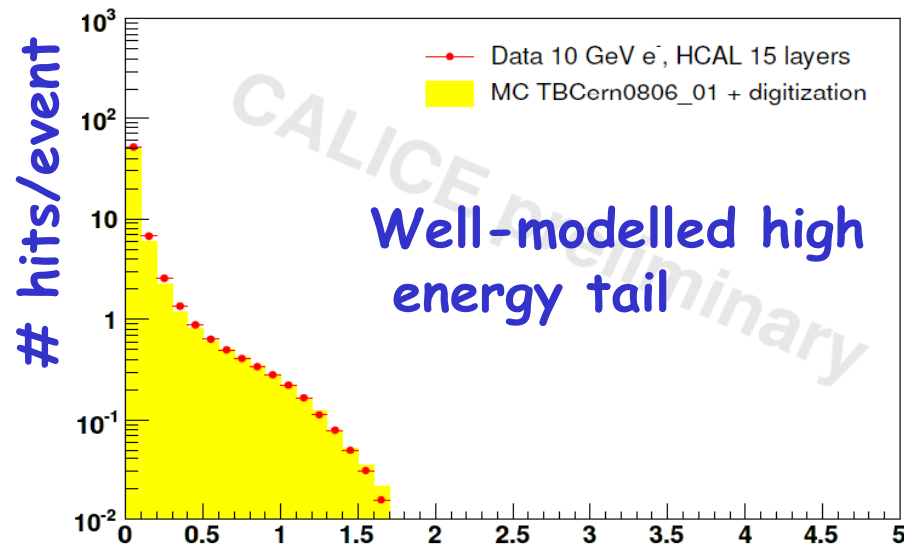
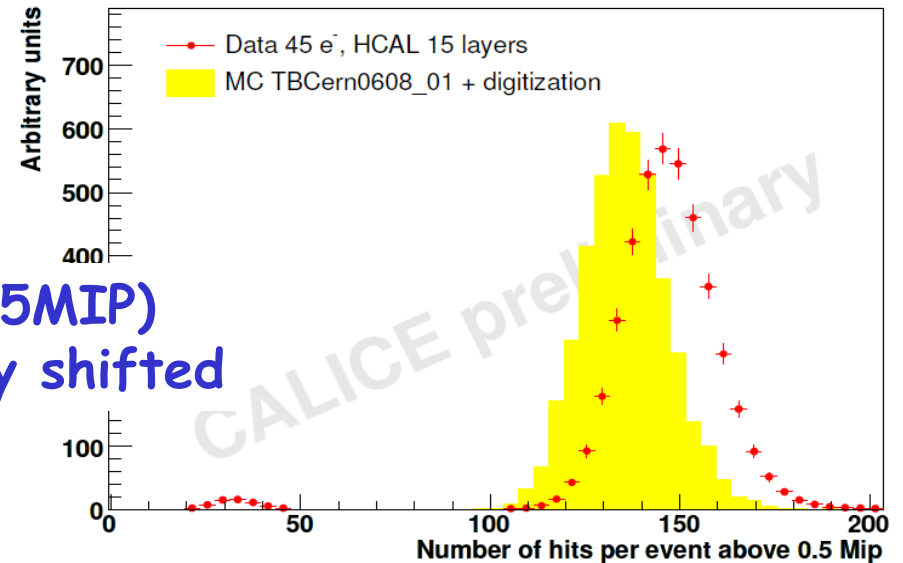
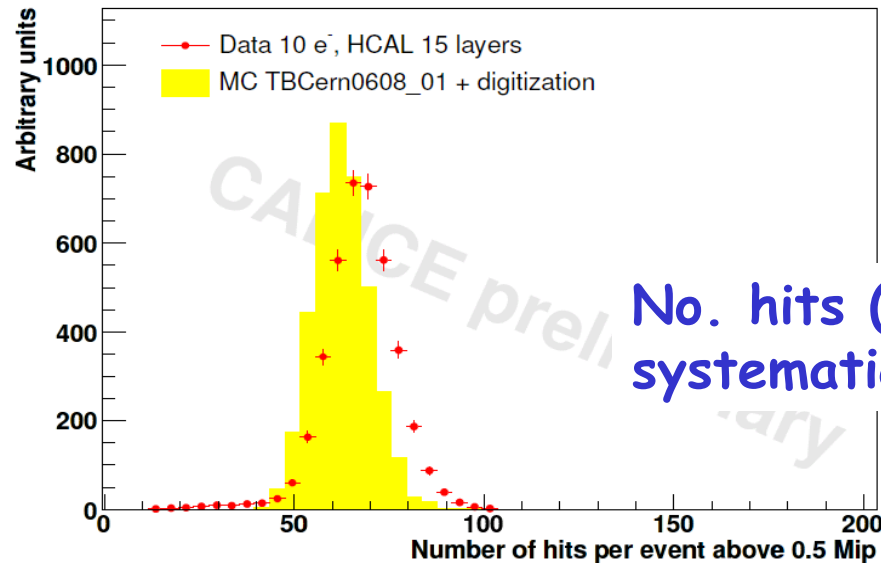


Expected logarithmic
behaviour of shower max.,
and angular dependence

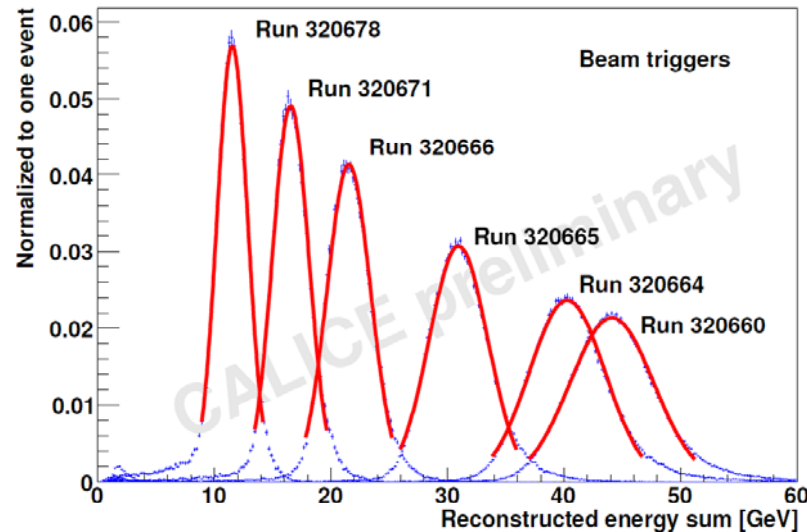
AHCAL

- 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: $1^\circ\text{C} \rightarrow 3\%$ 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^-



AHCAL linearity for e^-

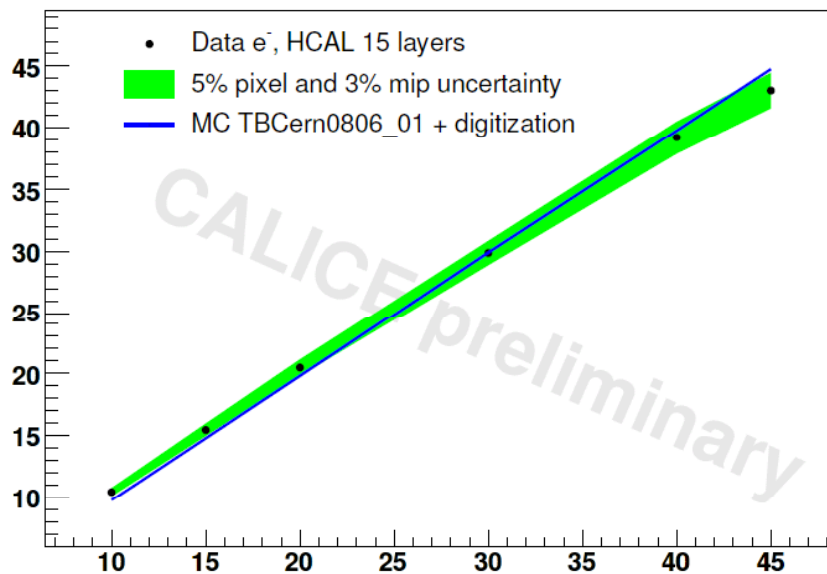


■ Extract response+resolution from fits at each energy

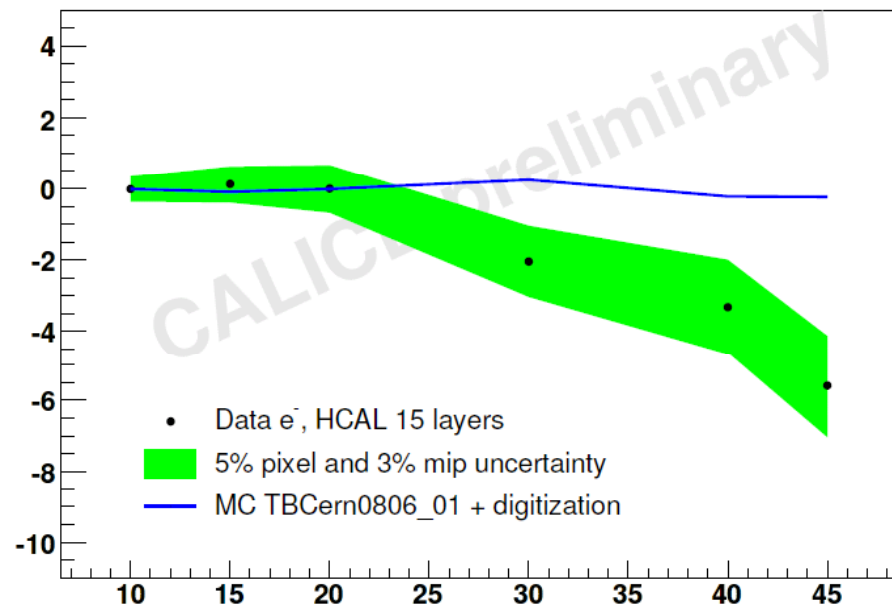
■ Linearity OK

■ Residuals ~5% at 45 GeV

Reconstructed energy/GeV



Deviation reconstructed-beam [%]

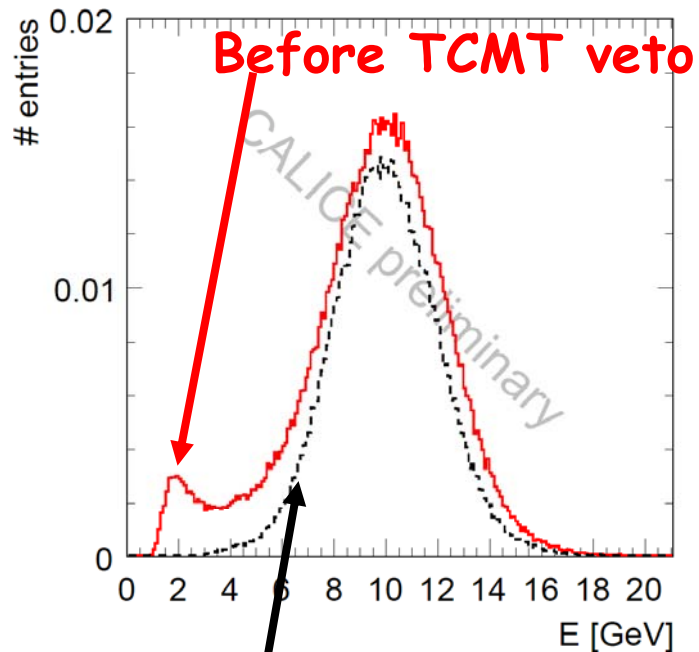


AHCAL π data

Shower from a 40 GeV π^+

ECAL Hits: 302 Energy: 1446.42 mips
HCAL Hits: 231 Energy: 803.441 mips
TCMT Hits: 22 Energy: 60.008 mips

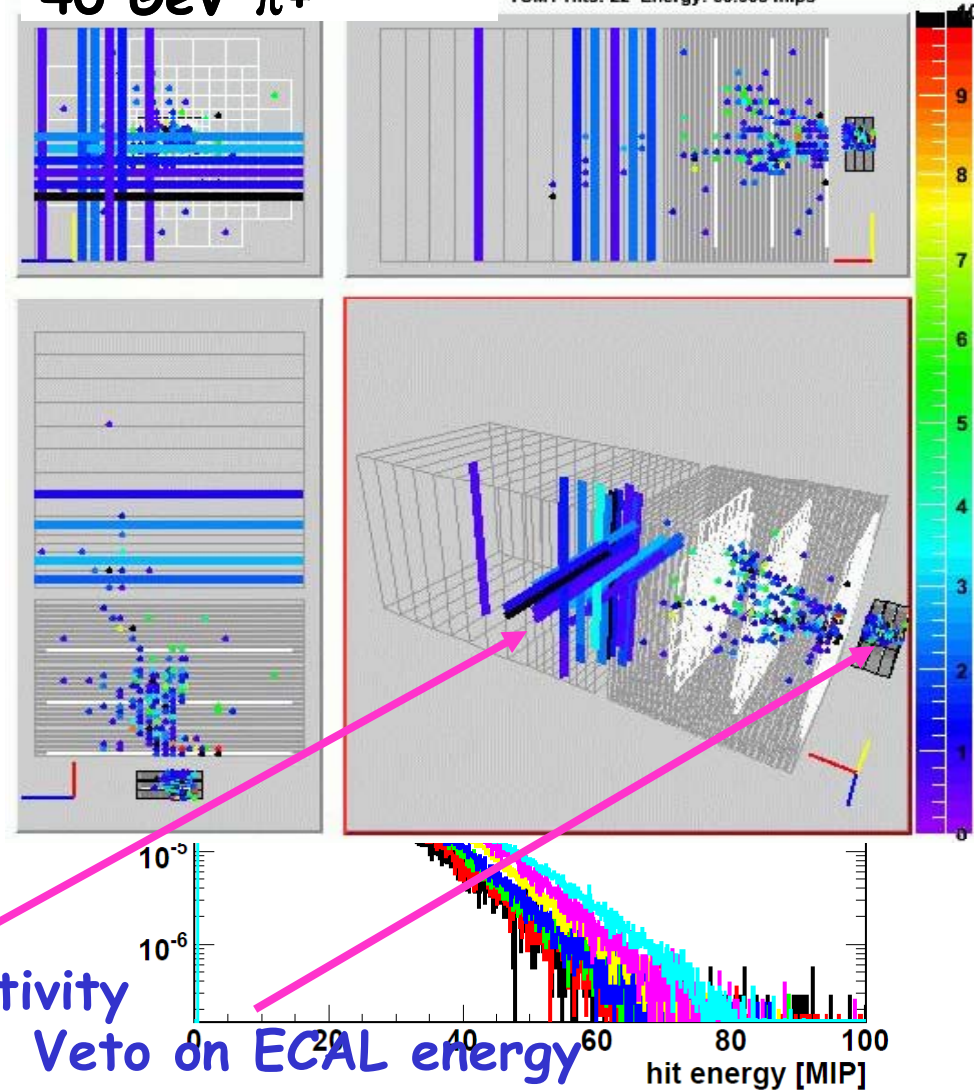
AHCAL hit energies for pion data



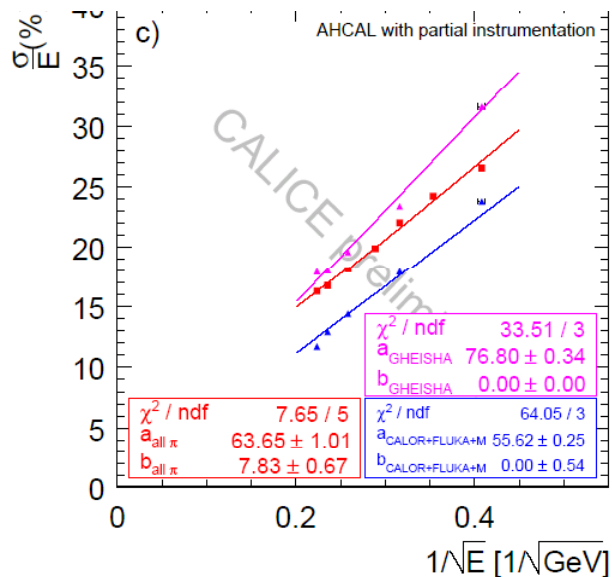
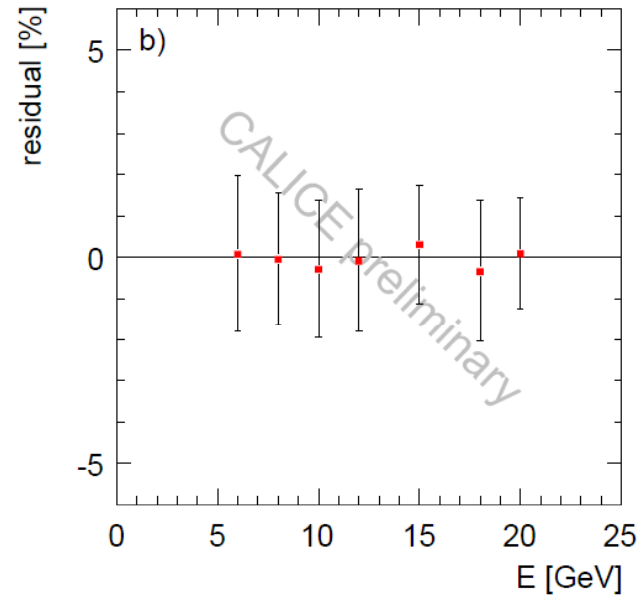
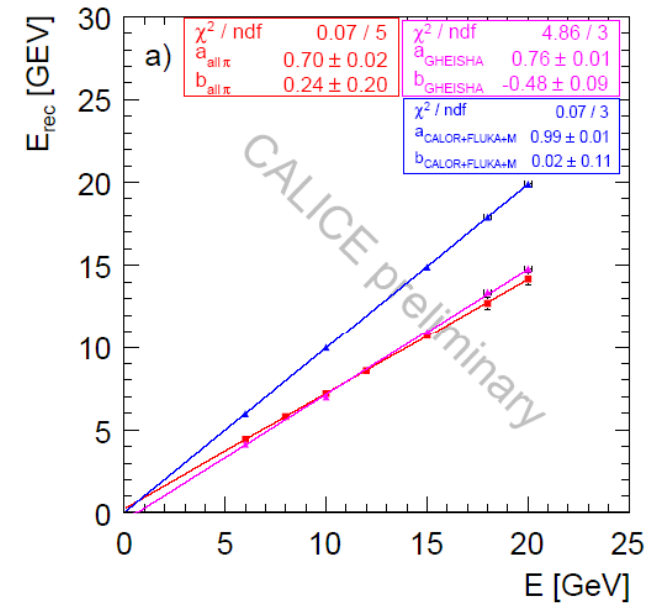
AHCAL contained events

Veto on TCMT activity

Veto on ECAL energy

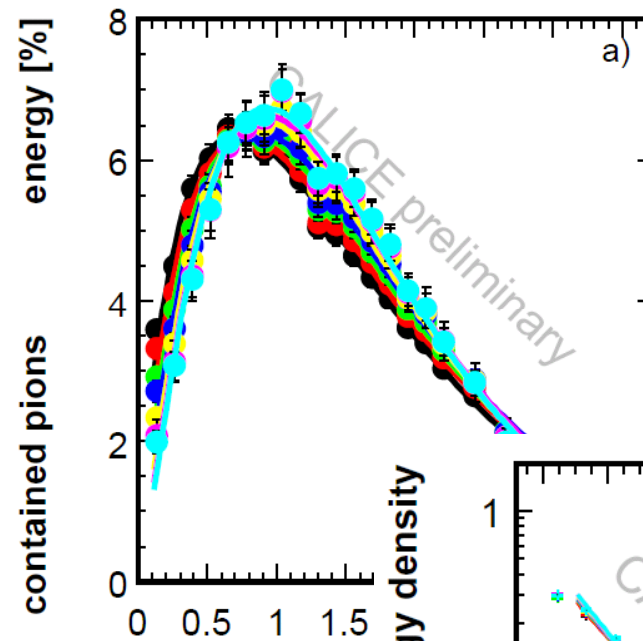
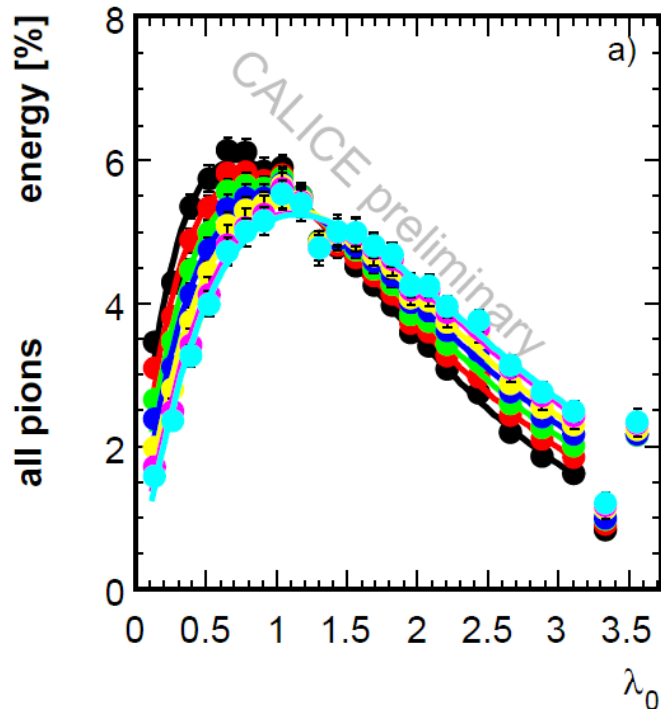


π linearity and resolution

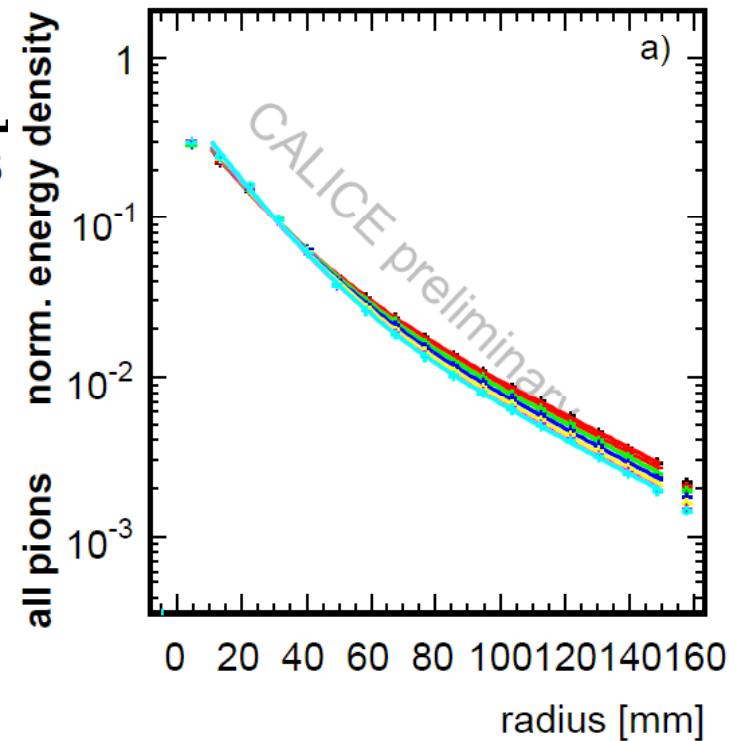


- Resolution ~ compatible with (Geant3) MC models
- Not yet comparison with G4 v8/9...
- Coming soon...

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 calorimetry, not just HCAL
- Work on “deep analysis” ongoing, but not ready for public consumption yet!

2007 CERN Testbeam

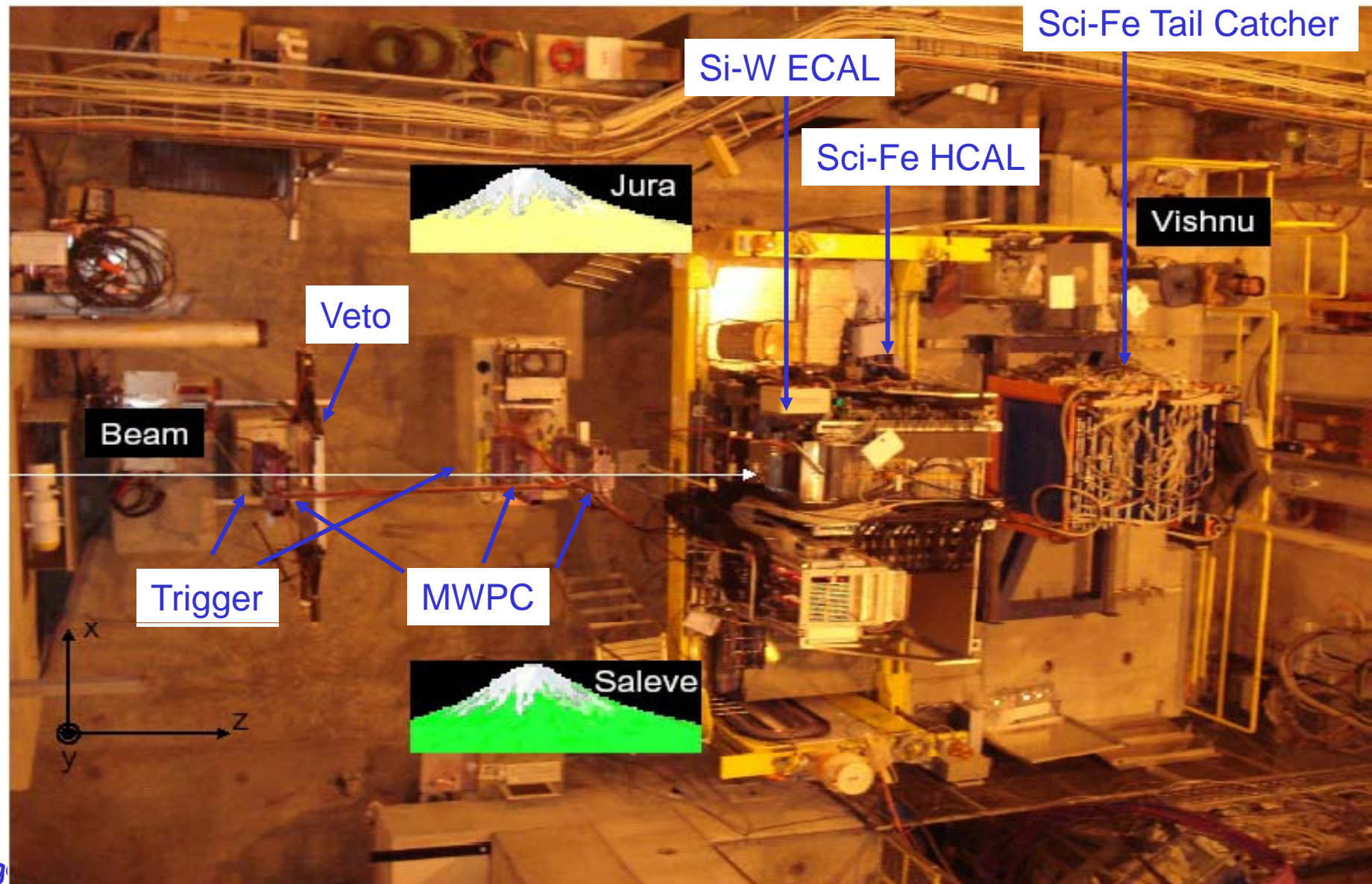
- **ECAL: 54 PCBs (30 layers)**
 - ▶ 216 channels/PCB in central part and 108/PCB in bottom part
 - ▶ Total channels: 9072
 - ▶ Total radiation length: $24 X_0$
- **AHCAL: 38 fully commissioned modules**
 - ▶ 30 modules with fine granularity = 216 tiles
8 modules with coarse granularity = 141 tiles
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

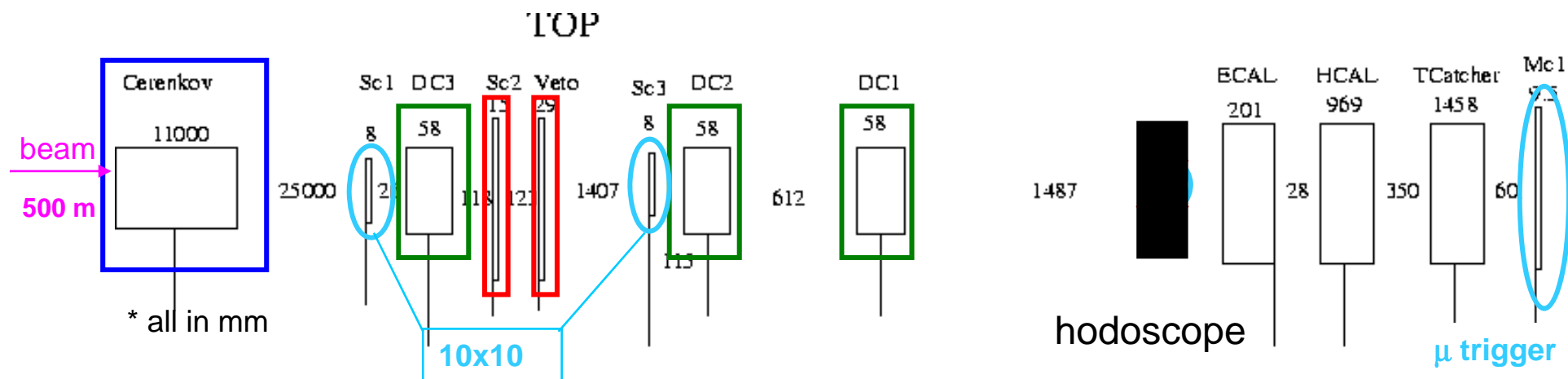


<http://www.pp.rhul.ac.uk/~calice/fab/WWW/Pictures.htm>

The setup two weeks later....

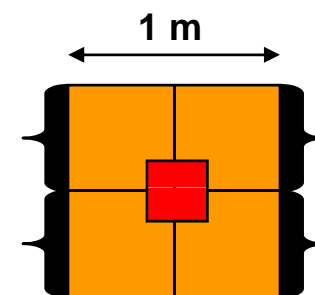


2007 Beam instrumentation description



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

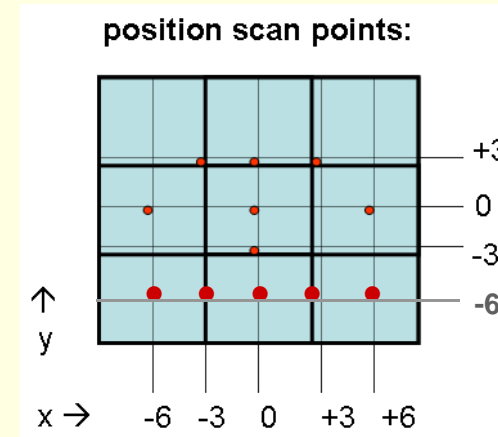
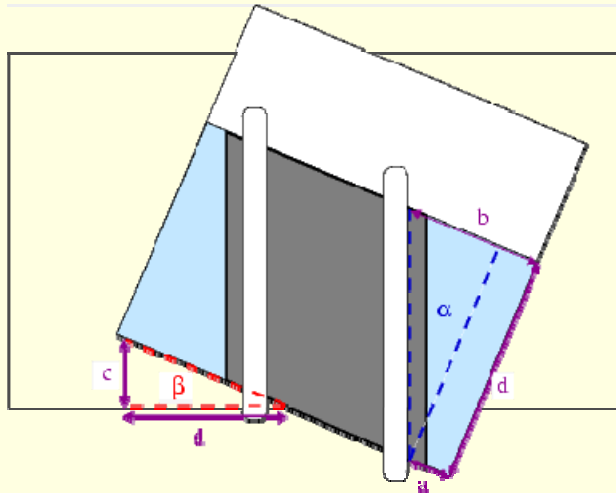
- Three MWPC (from CERN)
 - ▶ 50/50 Ar/CO₂ gas mixture
 - ▶ X, Y readout
 - ⇒ 200 mV threshold (100 mV after August 8th)
 - ▶ Aligned wrt beam-line with 0.2 mm precision
- Veto counters
 - ▶ 4 scintillator counters
 - ▶ Total dimension: 100X100cm, with 20x20cm hole corresponding to the 20x20cm trigger 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	π^\pm/e^\pm	π^\pm/e^\pm /protons

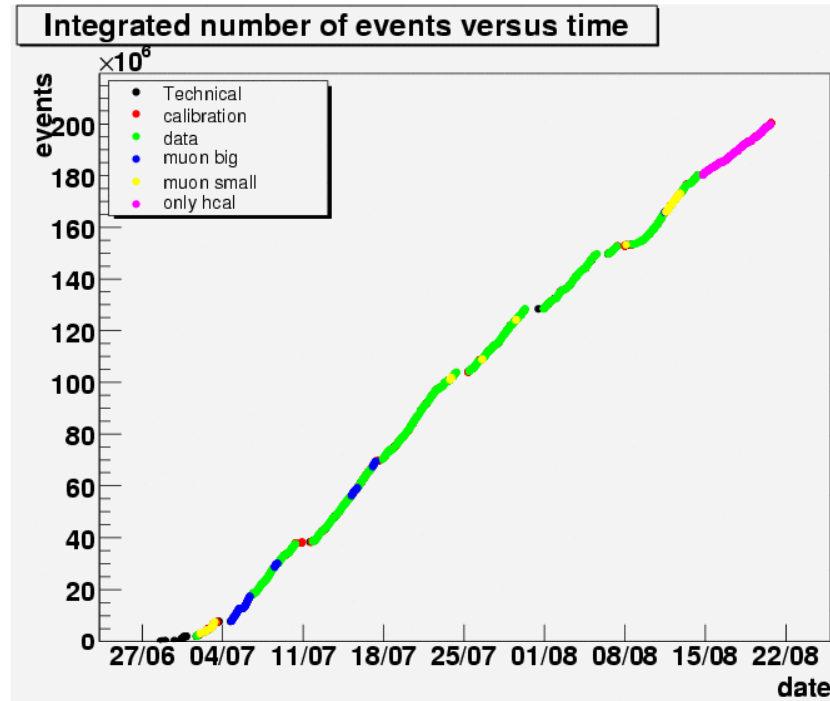
- **Beam energies extrapolated from secondary beam**
 - Electron beam obtained sending secondary beam on Pb target
- **π/e separation** achieved using **Cherenkov threshold** detector filled with **He gas**
 - Possible to distinguish π from e for energies from 25 to 6 GeV
- **π /proton separation** achieved using **Cherenkov** threshold detector with **N₂ gas**
 - Possible to distinguish π from protons for energies from 80 to 30 GeV

Angle and position scans

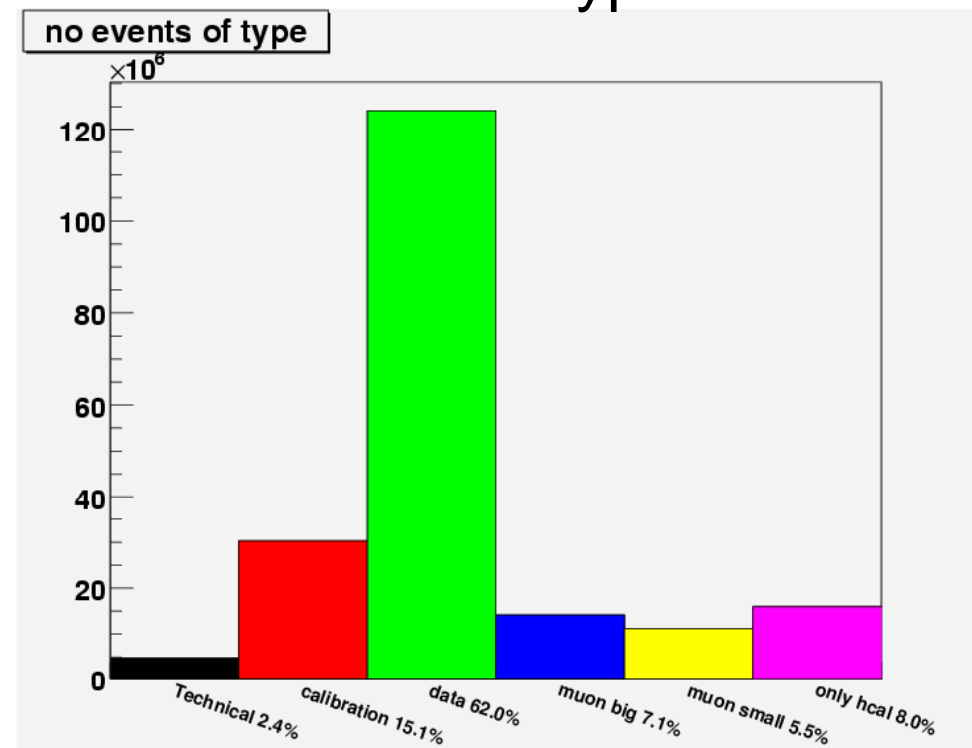


	Proposed in TB plan	Collected during TB
Angles	0, 10, 15, 20, 30	0, 10, 20, 30
Position scans	Centre of ECAL	Centre of ECAL $\pm 6\text{cm}$ from ECAL centre wafer Bottom slab of ECAL ($\pm 6, 0, \pm 3\text{cm}, -3\text{cm}$)
	Centre of AHCAL	Centre of AHCAL Centre of ECAL; AHCAL $\pm 6\text{cm}$ off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

Total events collected



Event Types



Integrated Luminosity

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

Summary

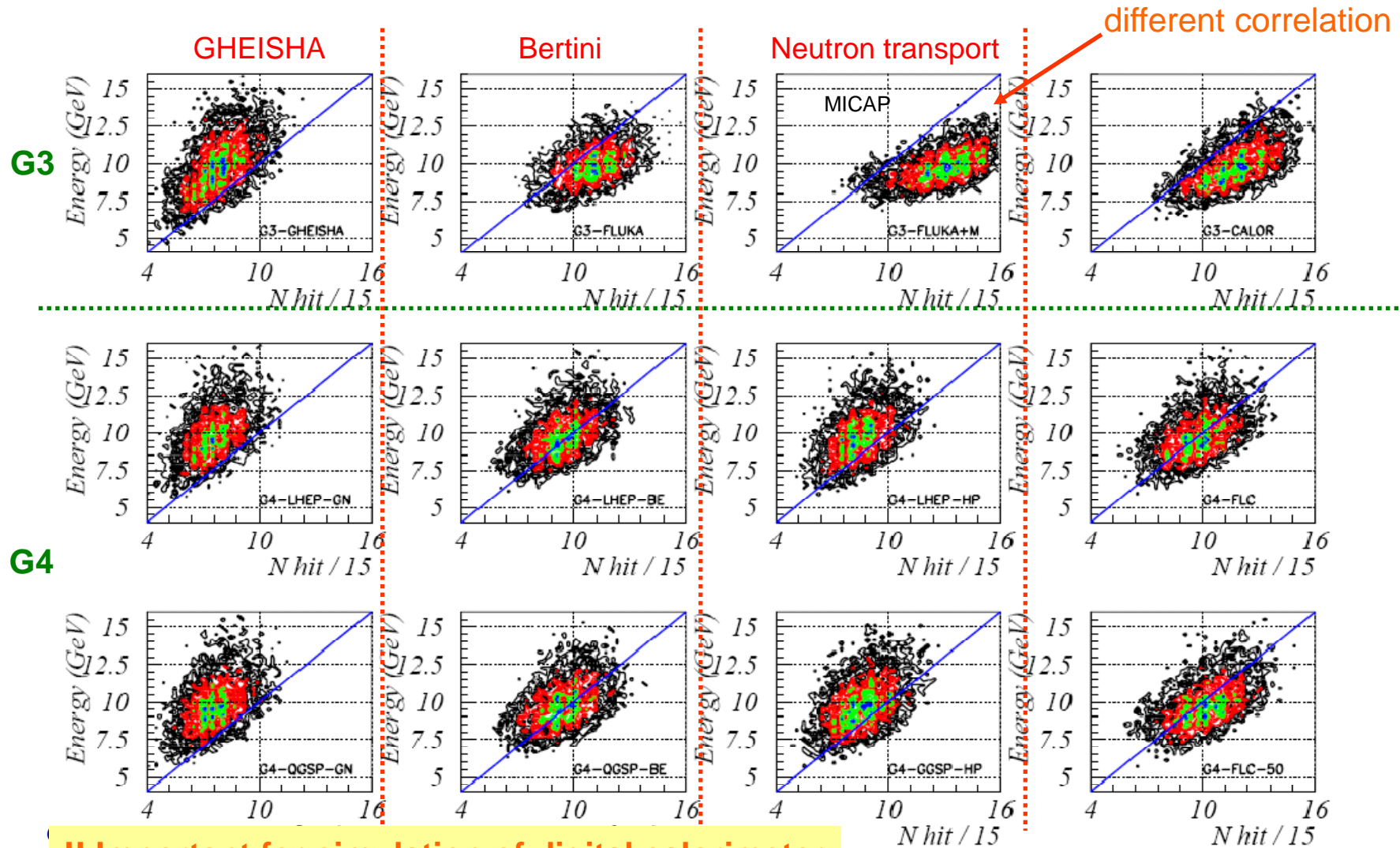
- CALICE is developing exceptionally performant calorimetry for ILC
- Excellent opportunity to further “stress test” hadronic models
- First significant results from 2006 test beam runs at CERN/DESY Summer 2007
- **Very large data sets** from CERN in 2007, substantially more than planned for
 - ▶ **Analysis 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

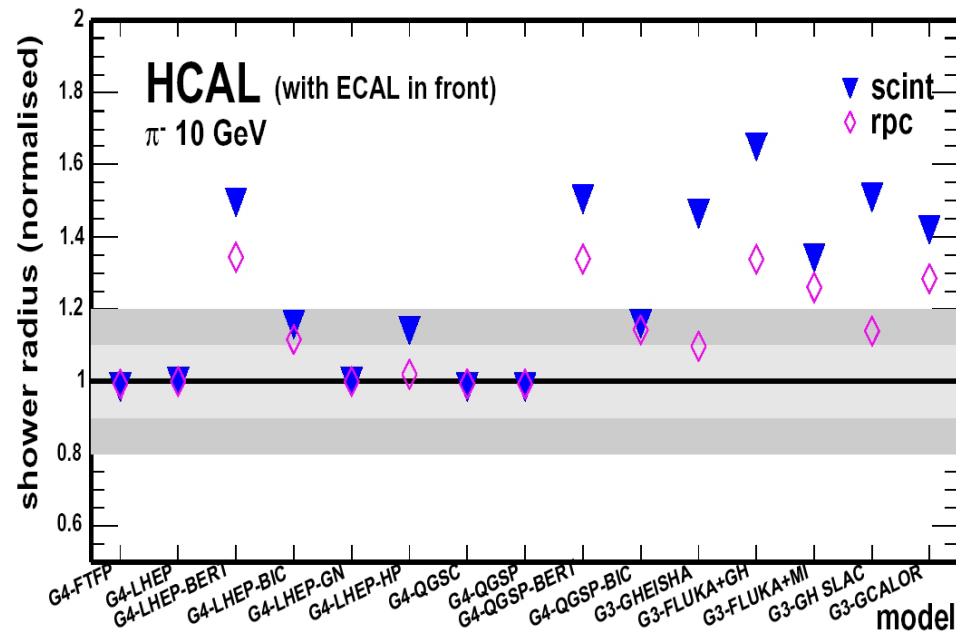


!! Important for simulation of digital calorimeter

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