CALICE – Calorimetry for the International Linear Collider

Birmingham, Cambridge, Imperial, Manchester, RHUL, RAL, UCL

- Introduction to ILC/CALICE
- Status of Calice-UK; report on progress
- Today's proposal – contains five work packages; discuss WP1/WP5 here →
- P.Dauncey – presents other three work packages + summary.

International Linear Collider

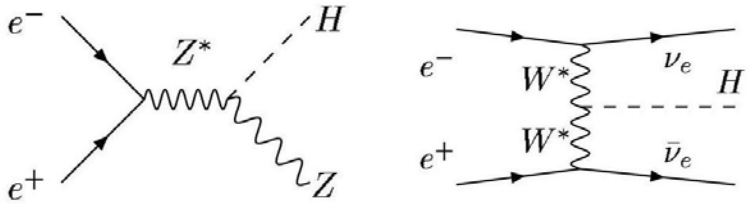
- e^+e^- linear collider operating at 0.5-1 TeV.
- Widespread support worldwide for the project.
- August 2004 International Technology Review Panel recommended adoption of superconducting (TESLA-like) technology. Europe, N America and Asia all lined up behind this, collaborating on technical design.
- Timeline defined by International Linear Collider Steering Group envisages formation of experimental collaborations in 2008 and TDRs in 2009.
- This proposal aims to conform to this schedule and ensure that the UK is well prepared to make a leading contribution to calorimetry.

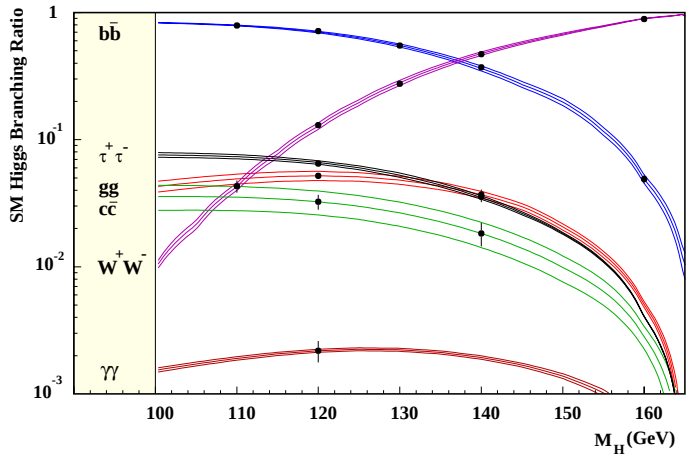
ILC Physics Objectives

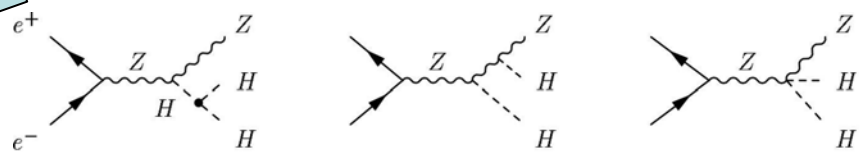
- Complementary to LHC. **(LHC-LC Study Group, hep-ph/0410364)**
- ILC will provide precision measurements (masses, branching fractions etc.) of physics revealed by the LHC.
- For example, Higgs boson(s); characterisation of the SUSY spectrum; precise measurements of top quark; strong electroweak symmetry breaking and much more.
- Many of the interesting processes are characterised by multi-jet final states, as well as leptons and missing energy.
- Precise measurements of jets will be vital in disentangling these final states. Calorimetry has a vital rôle to play here.

e.g. Higgs Physics at ILC

- Precise characterisation of nature of Higgs
- Model-independent Higgs mass (<1‰) and width (O(5%))
- Couplings to fermions, gauge bosons.
- Spin and parity
- Determine Higgs self-coupling using ZHH
- Higgs Yukawa coupling in ttH.

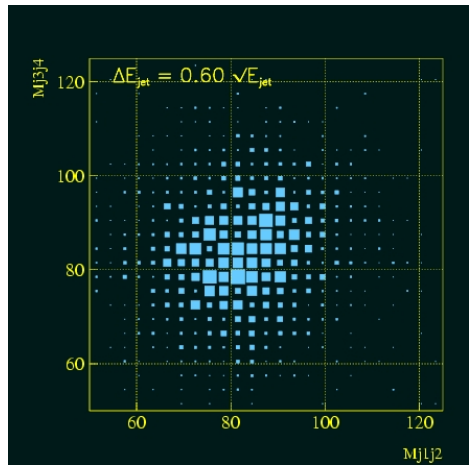


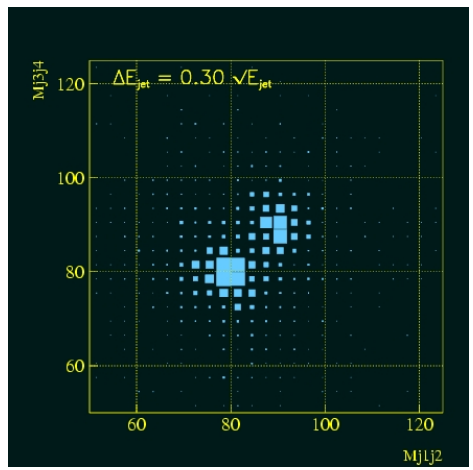




Calorimetry at the ILC

- Aim – distinguish W→qq from Z→qq Requires σ(E)/E~30%√E (c.f. best achieved at LEP ~60%√E)
- Particle flow (or Energy flow) approach promises to be able to achieve this.
- On average, 65% of a jet's energy in charged particles – measure using tracking. Measure photons and neutral hadrons in calorimetry (ECAL and ECAL+HCAL respectively).
- Need to disentangle different energy deposits in calorimeters. → Good spatial resolution more important than ultimate energy resolution.
- Leads one to adopt a highly granular calorimeter system (both longitudinal and transverse); located inside magnet coil to minimise confusion caused by preshowering.



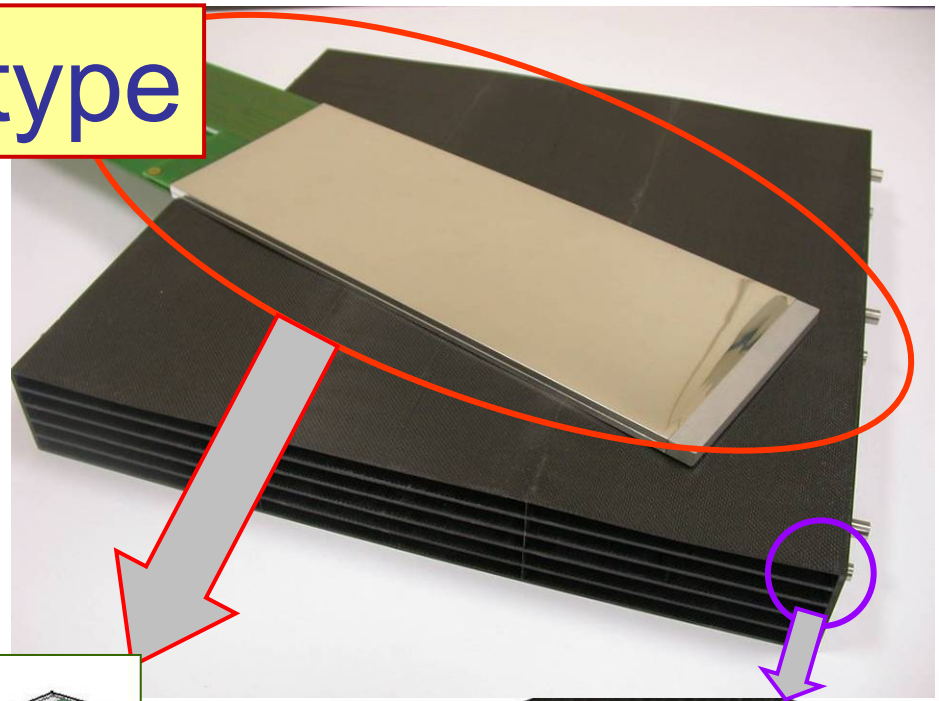


CALICE

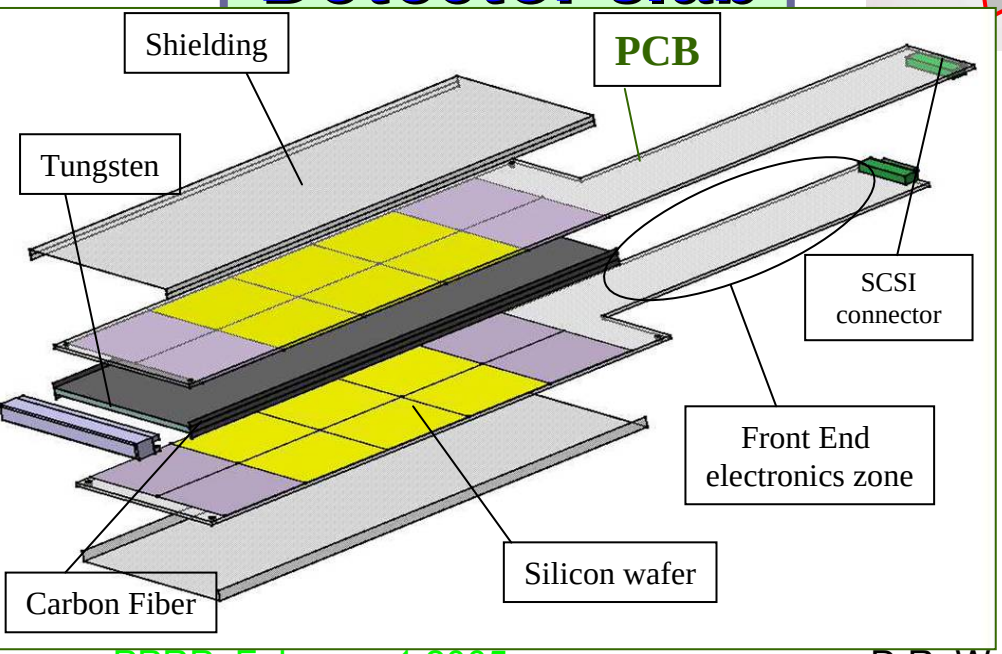
- Collaboration of 167 physicists (26 institutes; Europe, US, Asia). Include Birmingham, Cambridge, Imperial, Manchester, UCL. And now RHUL and RAL.
- R&D on calorimetry; working towards beam tests of pre-prototypes in a common framework (hardware+software) to evaluate and compare hardware concepts and validate simulation tools.
- Focus on highly granular calorimetry, optimised for energy flow.
- ECAL – Si-W with ~ 1x1cm^2 pads and up to 40 layers.
- Analogue HCAL – Scintillating tiles (≥ 3x3cm^2) + Fe.
- "Semi-digital" HCAL – small tiles with dual thresholds for readout.
- Digital HCAL – ~1x1cm^2 cells - RPCs or GEMs.

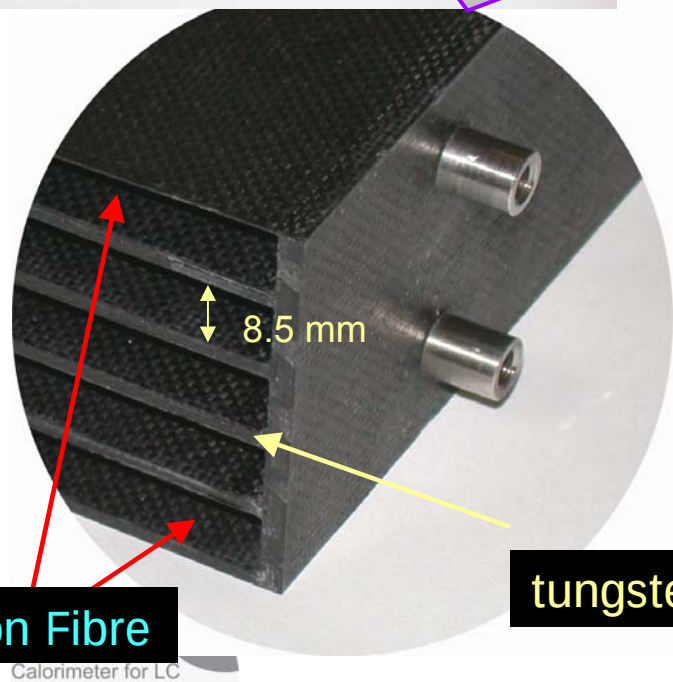
The ECAL prototype

Si-W 30 Layers
W thickness 1.4, 2.8, 4.2 mm
Instrumented volume
= 18x18x18 cm^3

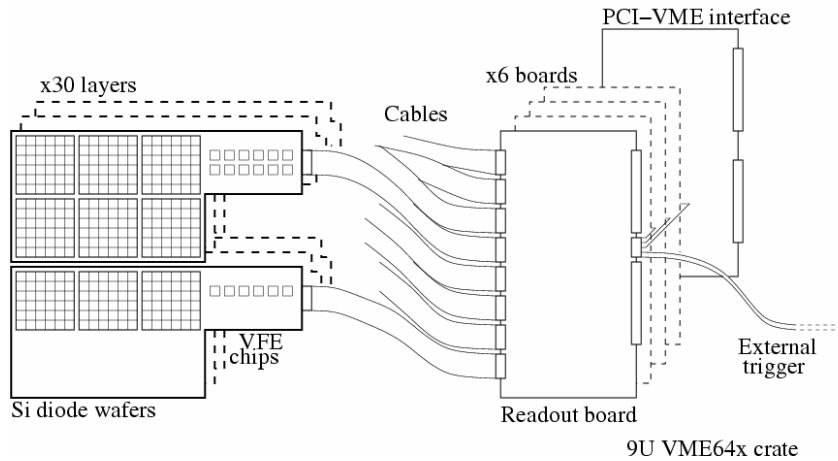


Detector slab

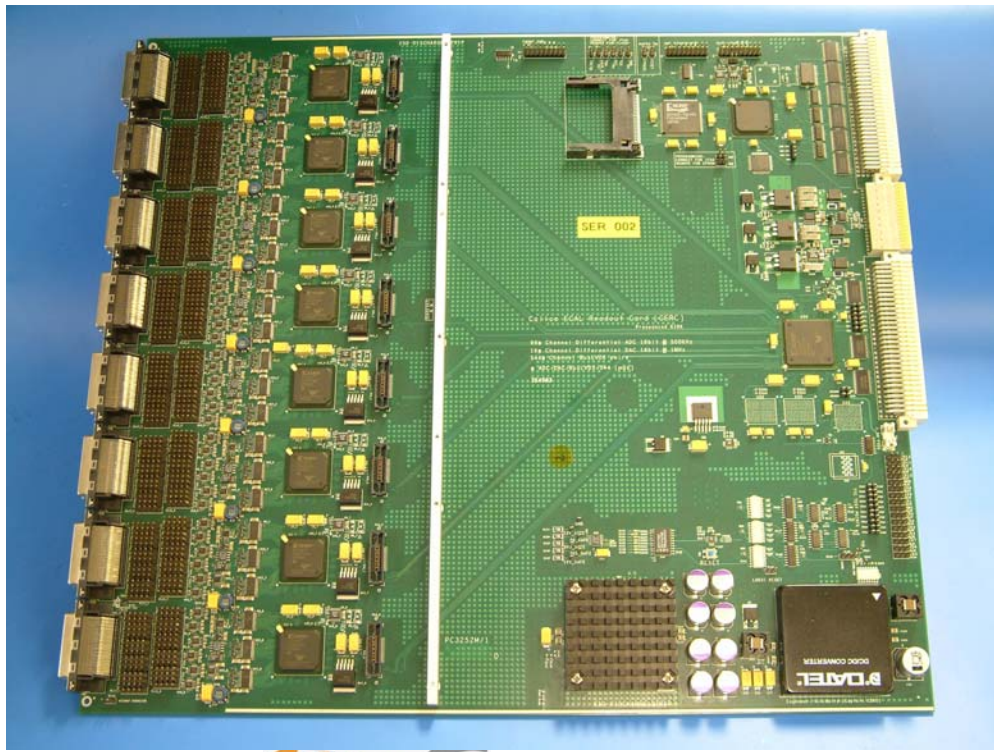




ECAL Electronics

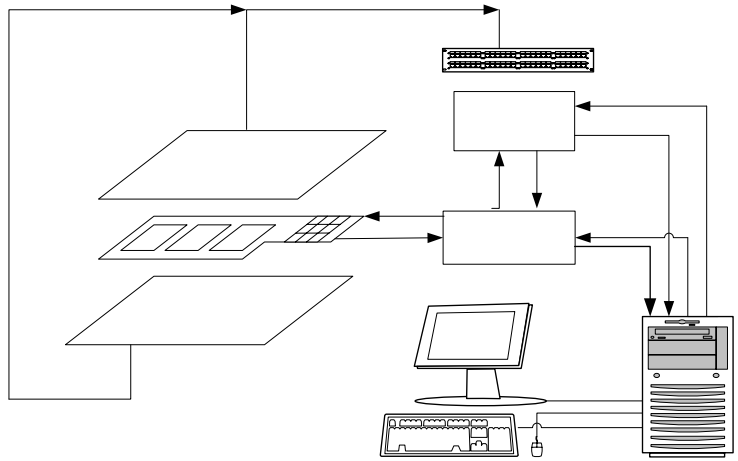


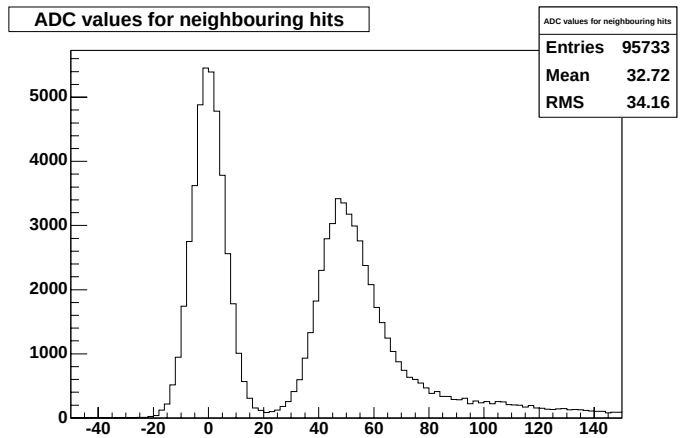
- Calice Readout Card (CRC)
- Development based on CMS tracker front-end driver board.
- Receives 18-fold multiplexed analogue data from up to 96 VFE chips.
- Digitises; on-board memory to buffer ~2000 events during spill.
- Also trigger logic and control provided by one board.
- Prototypes tested summer 2004. First two production boards received November. Remaining 7 boards by February.
- AHCAL now plan to use CRCs as well.



Cosmic tests

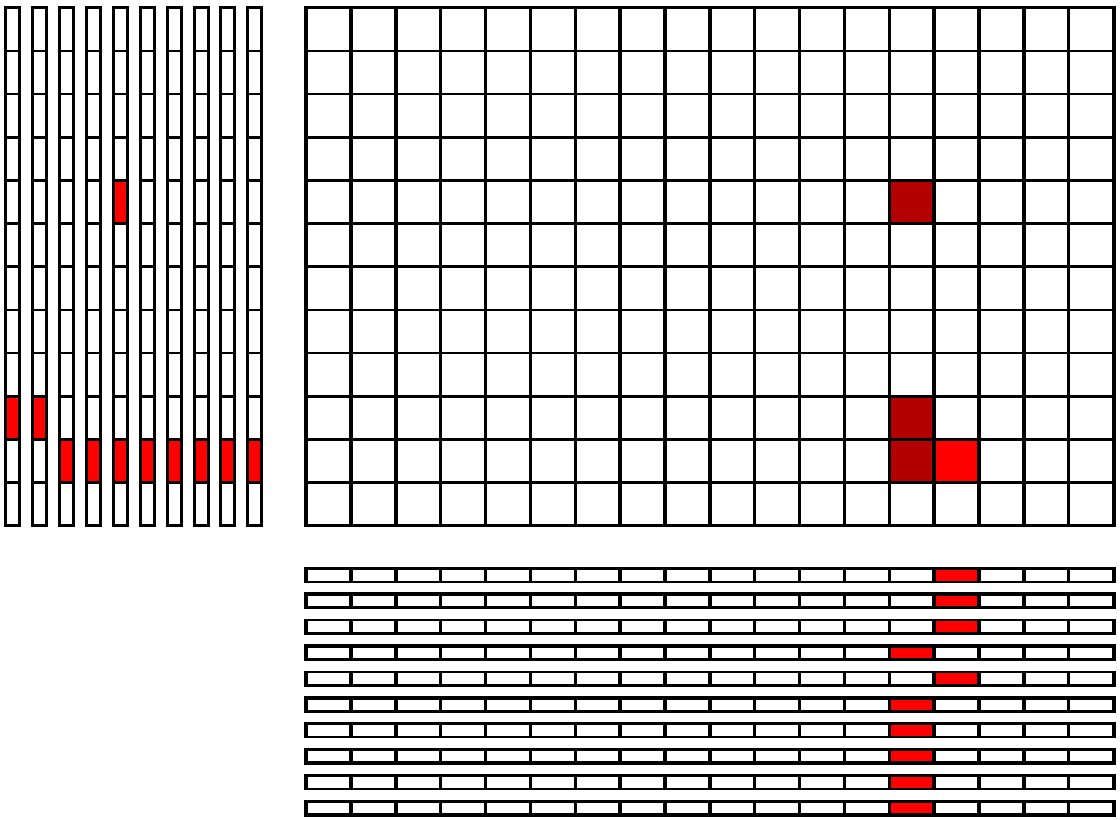
- First production modules (Tungsten + Si Pads + PCB + VFE ASIC) equipped with UK electronics and UK DAQ system – underwent cosmics tests in Paris December 2004.
- MIP peak seen above pedestal;
- noise ~6.5 ADC counts;
- S/N ~ 9:1 (better than required)



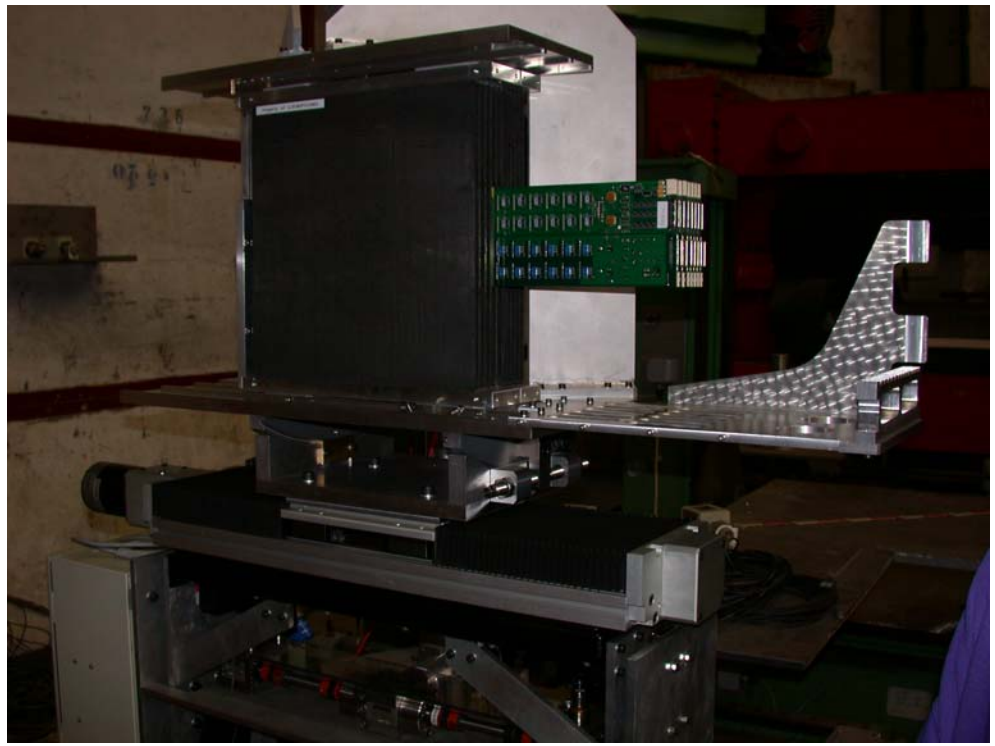


Cosmic Muon

Ten layers instrumented at this stage.

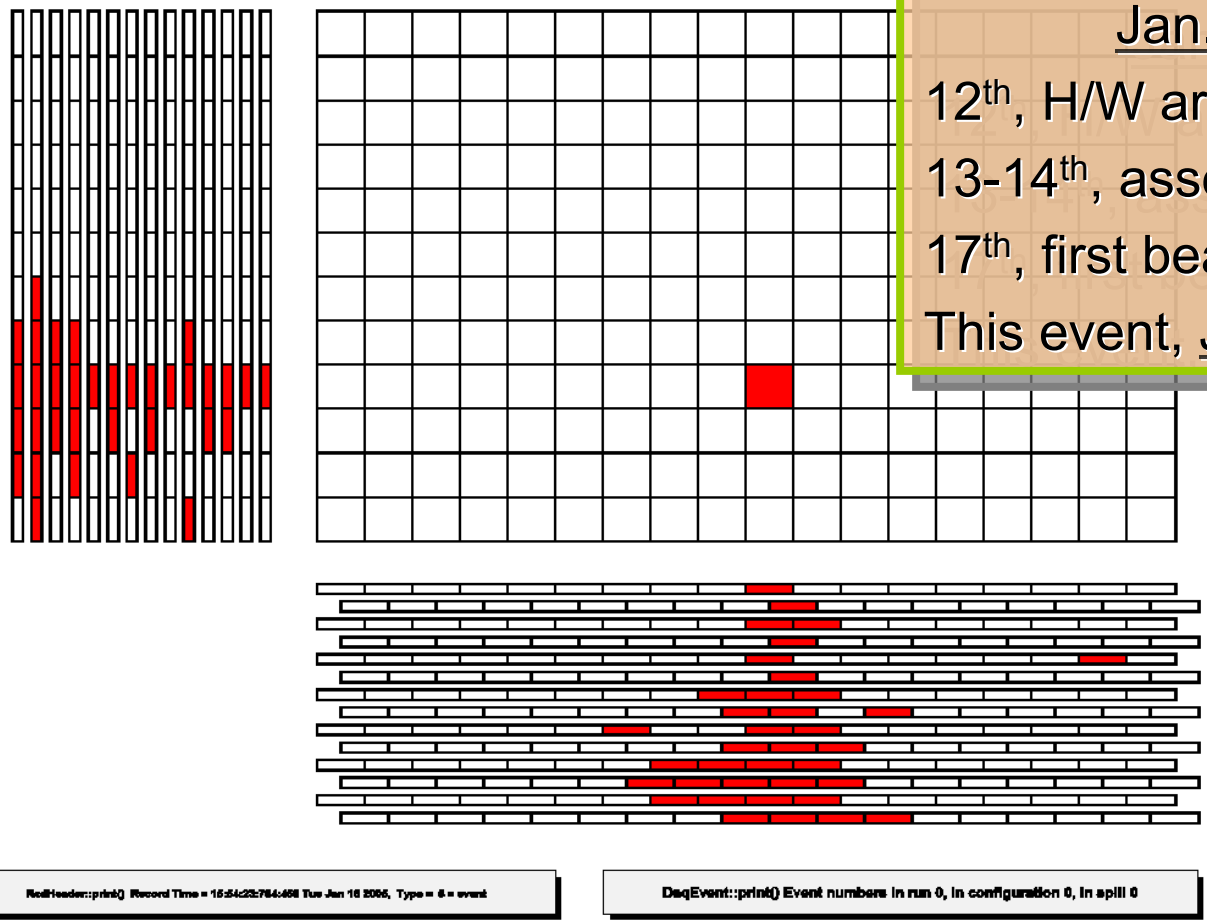


Test beam setup at DESY



Electron beam event

14 layers instrumented at this stage.



Jan. 2005

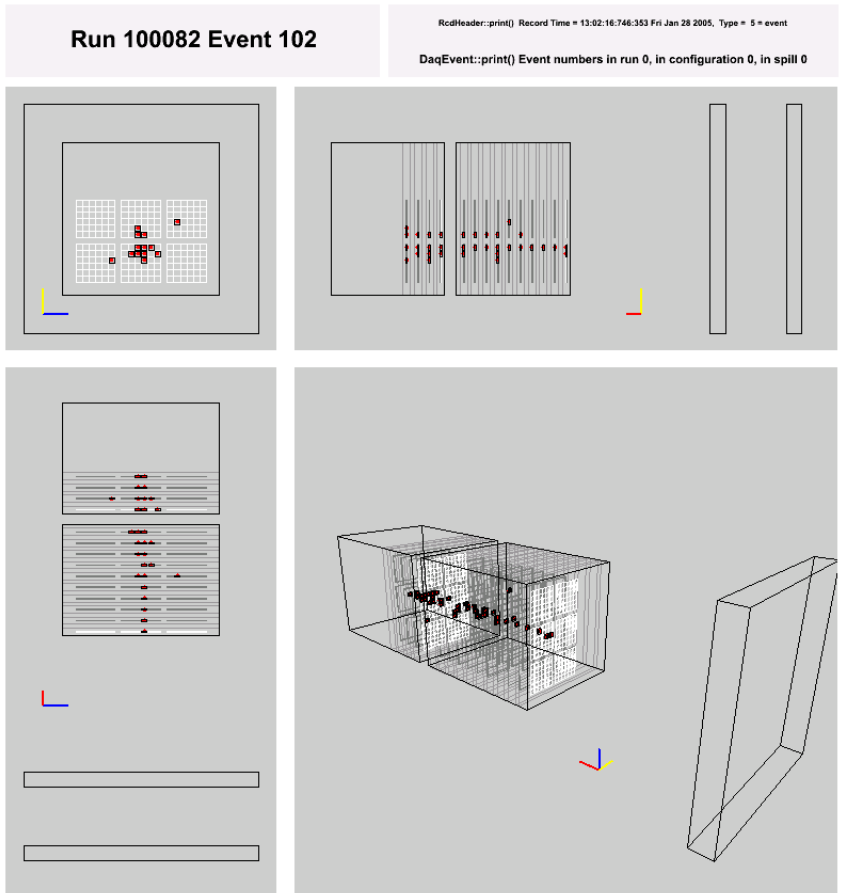
12th, H/W arrived DESY

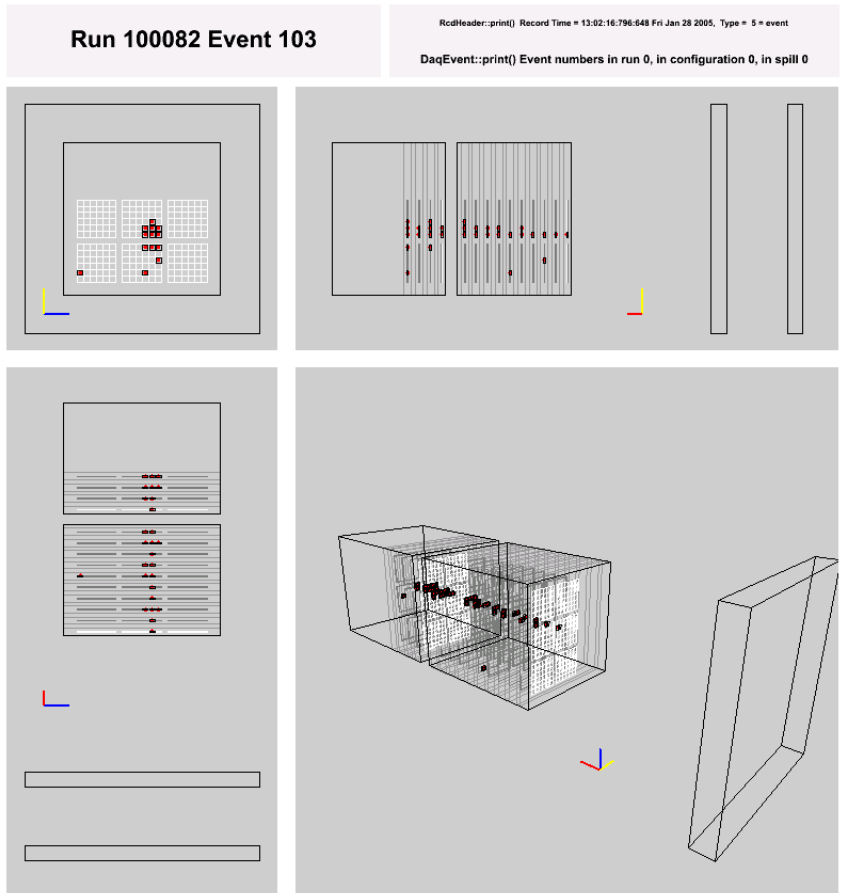
13-14th, assembled

17th, first beam recorded

This event, Jan. 18

A couple more 3 GeV electron events





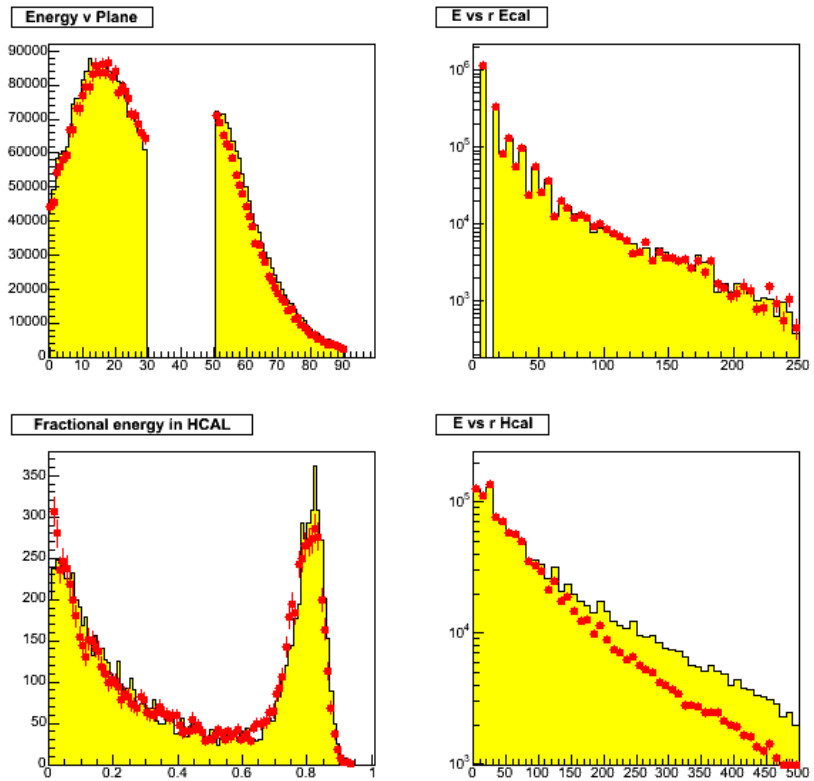
CALICE ECAL status

- All items required for first full prototype are in hand or in production.
- First 14 layers of full prototype moved to low energy electron test beam at DESY in January 2005; building up to full detector by Easter 2005. Then extended electron tests.
- Autumn 2005 onwards: expose prototype to higher energy electron beam, and hadron beam at FNAL in combination with HCal prototypes (various options) through 2006-7.
- UK electronics and DAQ has been successful (equipment on budget); now being adopted by AHCAL.

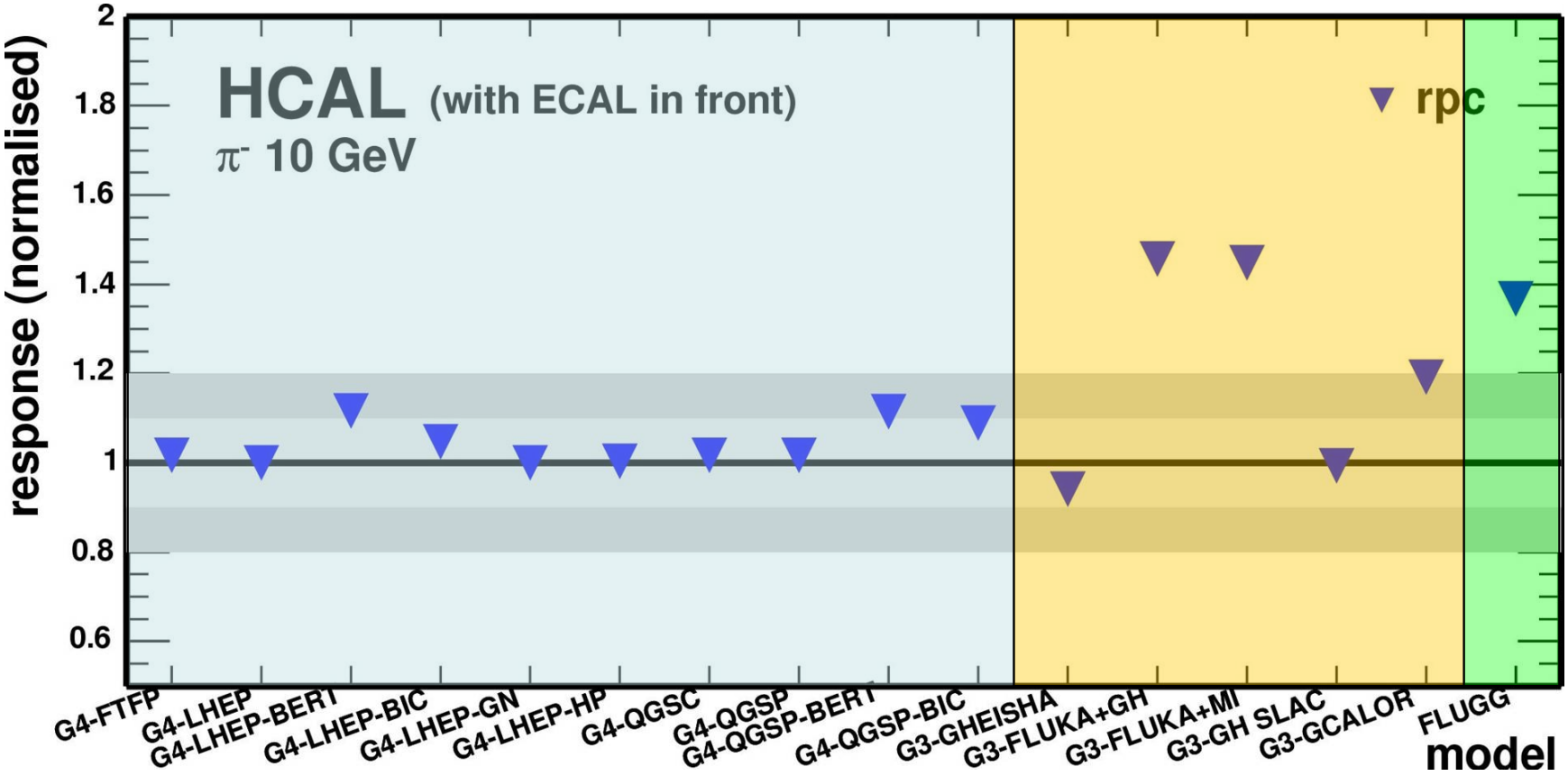
UK simulation studies

- Systematic comparisons between hadronic models in GEANT3/GEANT4/FLUKA.
- Sizeable differences seen. Vary with energy and from particle to particle. Emphasises need for data.
- Important input in defining test beam strategy (energy, statistics etc.)

5 GeV π^+

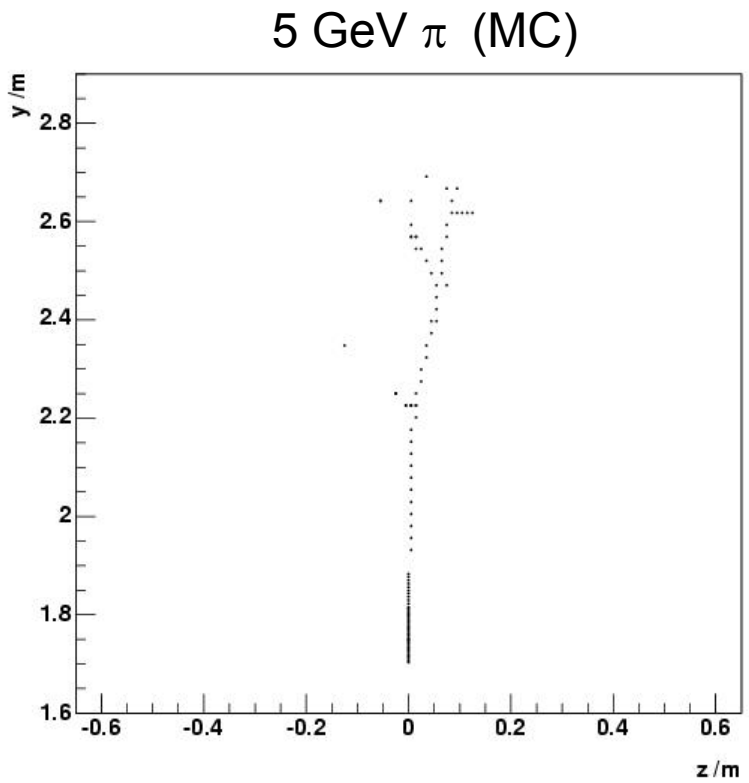


Studies of hadronic models



Energy flow work in UK

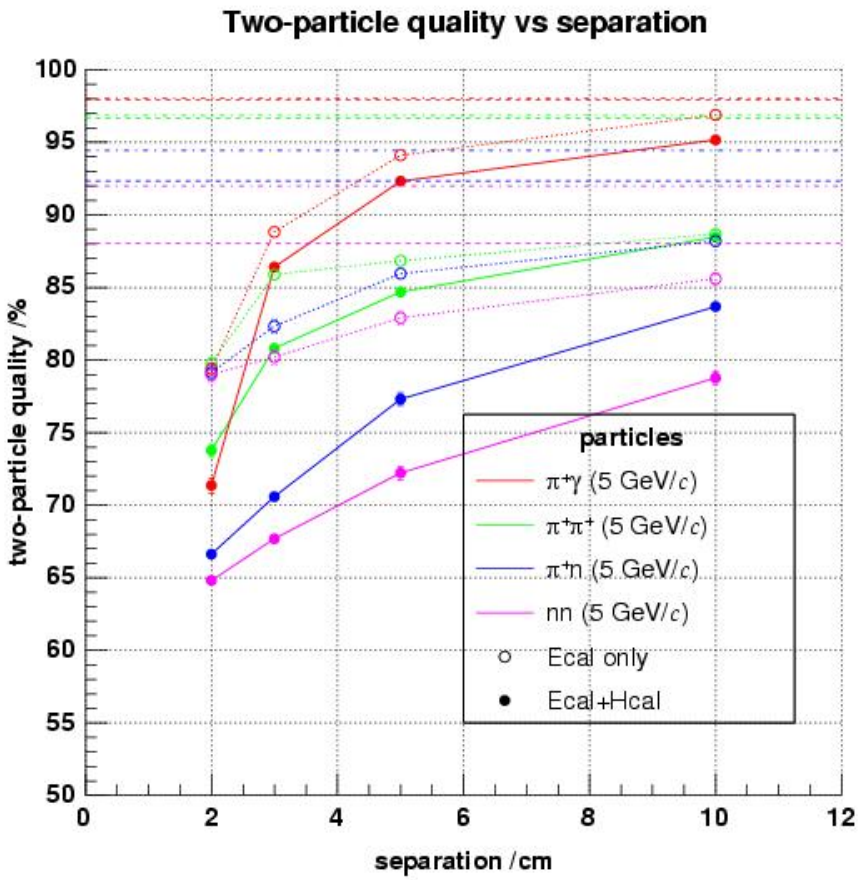
- Typical jet – energy divided ~65:25:10 between charged, photons, neutral hadrons.
- With expected resolutions for tracks, ECAL (~10%/√E) and HCAL (~40-50%/√E), ideally could achieve ~15%/√E for jets. In practice the jet energy resolution is determined by confusion, not intrinsic calorimeter energy resolution.
- Hence, pattern recognition in calorimeters is crucial. Need cunning algorithms to exploit potential of high granularity.



Note track-like quality of many showers in the calorimeter

Clustering / Energy flow

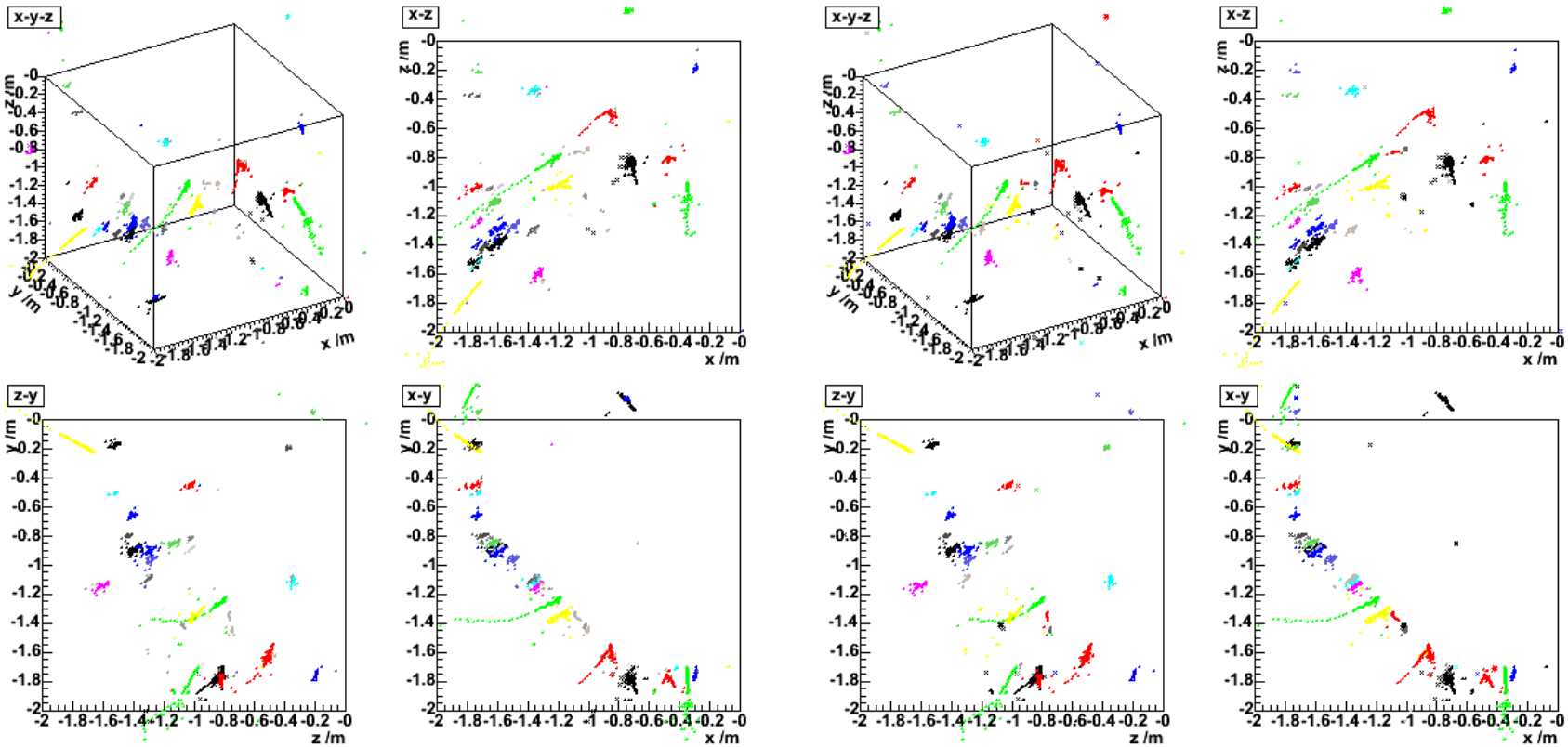
- Two complementary algorithms under development in UK:
- Bottom-up "tracking-like" algorithm. Track outwards through layers matching hits to existing clusters (using directional info) or seeding new clusters. Example of performance:
- Top-down Minimal Spanning Tree algorithm. Cluster all cells into MST, then cluster by cutting longest branches.



Zoom of a jet (Z^0) event

Reconstructed clusters

True particle clusters



CALICE-UK Proposal

- In 2002 we requested a 3-year program.
- PPRP approved 2 years, inviting us to return to seek funding for completion of the test beam program, and to propose a program of future work.
- Electronics + DAQ constructed and working. Beam tests just started - will continue 2005-6.
- Good progress on software side – simulation and reconstruction.
- Now requesting funding for a 3-year program (2005-2008) from the PPRP for completion of the test beam data and further generic calorimetry R&D.

Work Packages

Propose 5 work packages:

WP1. Completion of test beam program
(leader D.R.Ward / Cambridge)

WP2. Data Acquisition
(leader M.Wing/UCL)

WP3. Monolithic Active Pixel Sensors
(leader P.Dauncey/Imperial)

WP4. Mechanical and thermal studies
(leader R.J.Barlow/Manchester)

WP5. Simulation and Physics
(leader N.K.Watson/Birmingham)

WP1 – Test Beam

- ECAL beam tests at DESY just started.
- Expect all planes installed by Easter, then 1-6 GeV electron beam data till June/July.
- Move ECAL to Fermilab MTBF around September 2005 for high energy electron beam.
- Also exposure of ECAL to hadron beam has been shown to have worthwhile sensitivity to hadron models; placing tungsten absorbers in front of calorimeter.
- AHCAL plans to move to Fermilab for combined tests around November 2005. Run till mid-2006.
- Aim for samples of ~10^6 events at various energies, angles.
- DHCAL plans depend on US funding. Anticipate beam tests in 2006-7.

WP1 Tasks

- 1.1 Support for beam tests. Maintenance of firmware and DAQ as HCAL joins in. Running shifts.
- 1.2 Analysis of DESY test beam data. Understanding of e/μ response is a vital prerequisite to interpreting hadron beam data. UK in prime position to make a big contribution, because of our DAQ and simulation work.
- 1.3 Analysis of Hadron test beam data. Vital input for development of particle flow algorithms; global detector optimisation.
- n.b. urgency of continued WP1 funding

WP5 Simulation and Physics

- Build on expertise established over past two years, and the results obtained from test beam. Develop tools so we can make an impact on global design studies.
- Task 5.1 Energy Flow algorithms. Build on the UK's calorimeter pattern recognition work to develop full particle flow code. Aims: flexibility, adaptable to different geometries and simulation packages, so that meaningful comparisons between detector designs can be drawn. Exploit Calice data on hadronic showering.

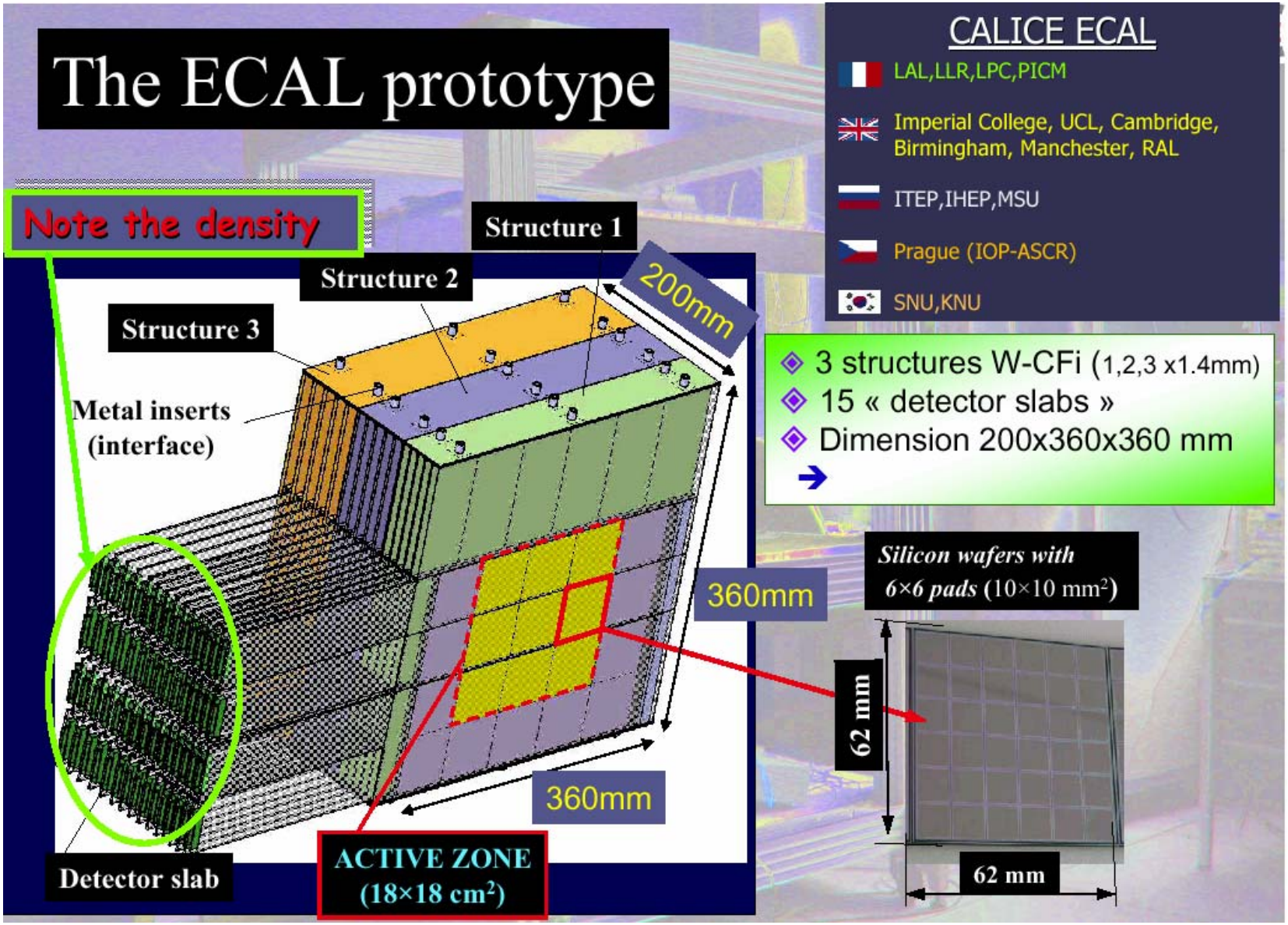
WP5 tasks (contd.)

- Task 5.2 Global Detector Design. This is where our work can impact decisions on key detector parameters (technology; dimensions etc.). Use benchmark physics processes + generic tools.
- Task 5.3 Support of other WPs. All other WPs will need simulation work, and a strong simulation group will enable this to be done effectively.
- Task 5.4 Physics Studies. Mainly devoted to establishing benchmark analyses for use in energy flow and design studies.

Over to Paul Dauncey

Backup slides …

The ECAL prototype

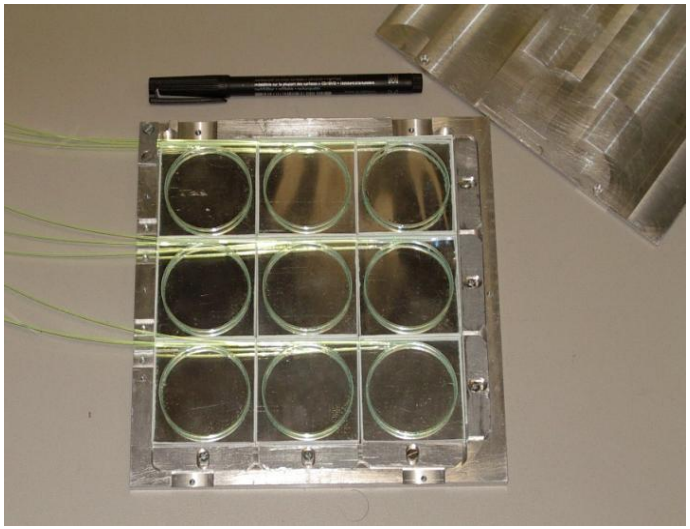


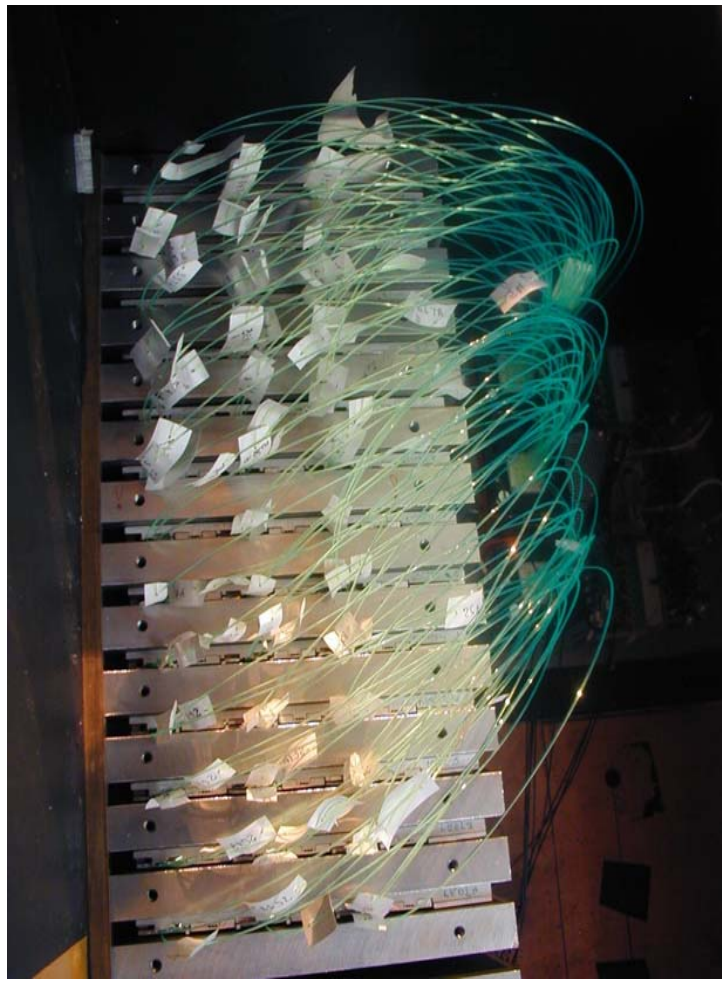
CALICE ECAL

- LAL,LLR,LPC,PICM
- Imperial College, UCL, Cambridge, Birmingham, Manchester, RAL
- ITEP,IHEP,MSU
- Prague (IOP-ASCR)
- SNU,KNU

- 3 structures W-CFi (1,2,3 x1.4mm)
- 15 « detector slabs »
- Dimension 200x360x360 mm

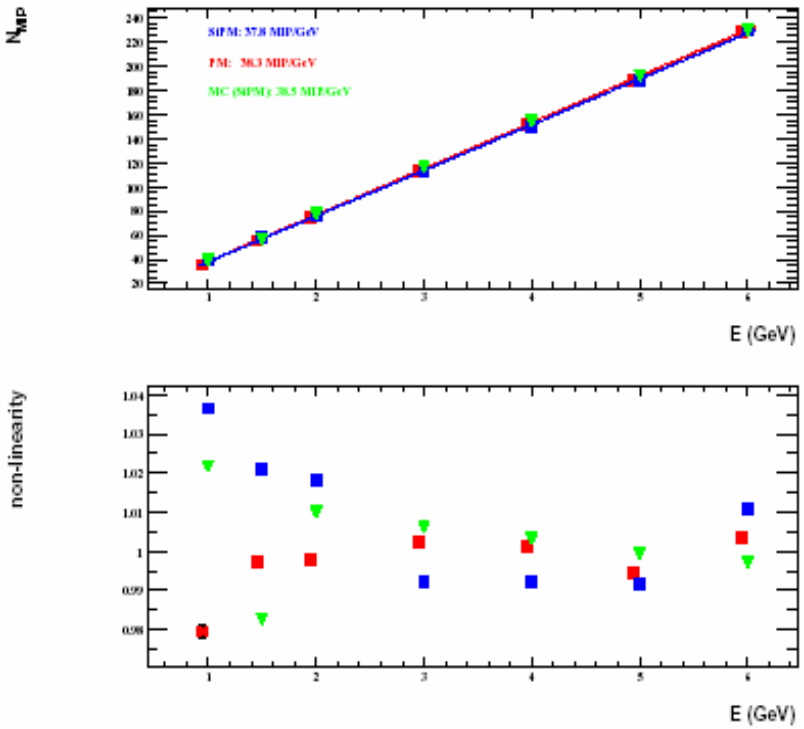
MiniCAL – preparation for HCAL prototype

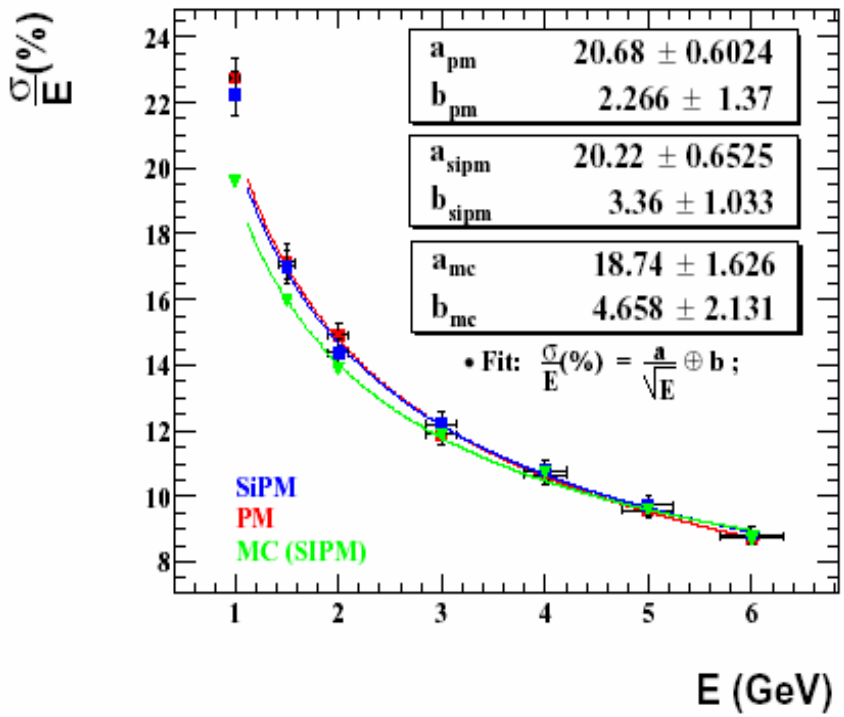




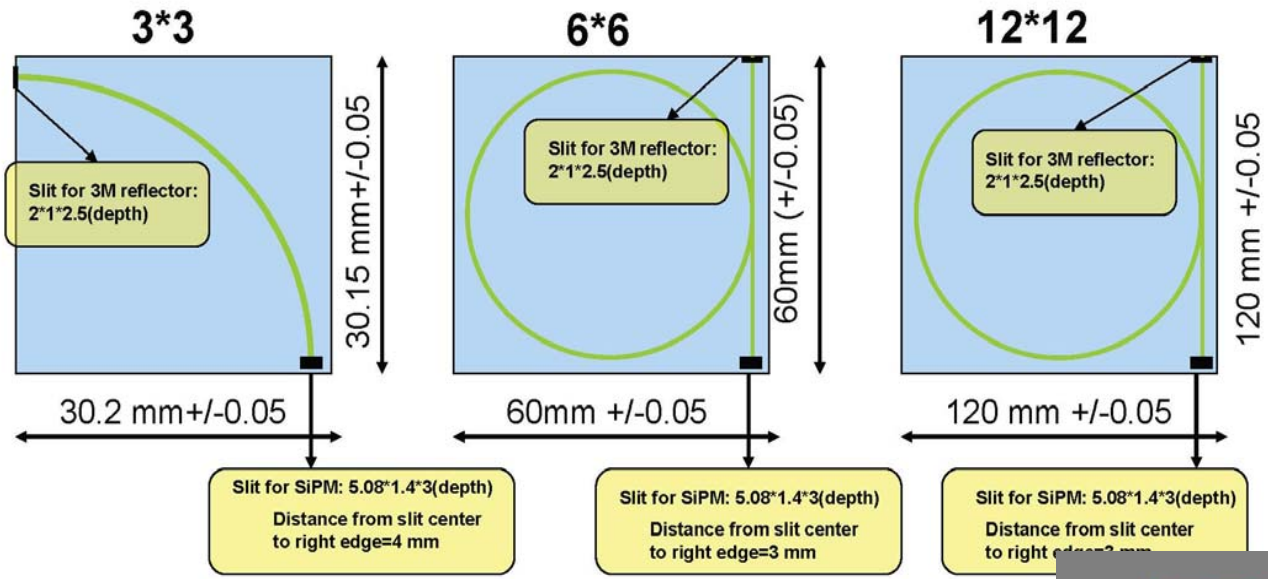
- Small test module for 5x5cm^2 tile AHCAL already tested in electron beam at DESY, with various photodetectors.
- Plan to include RPC modules soon.

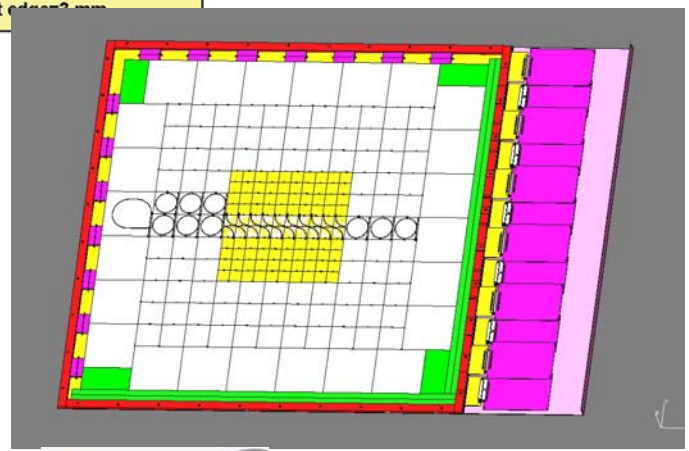
Minical results





AHCAL Scintillating Tile prototype



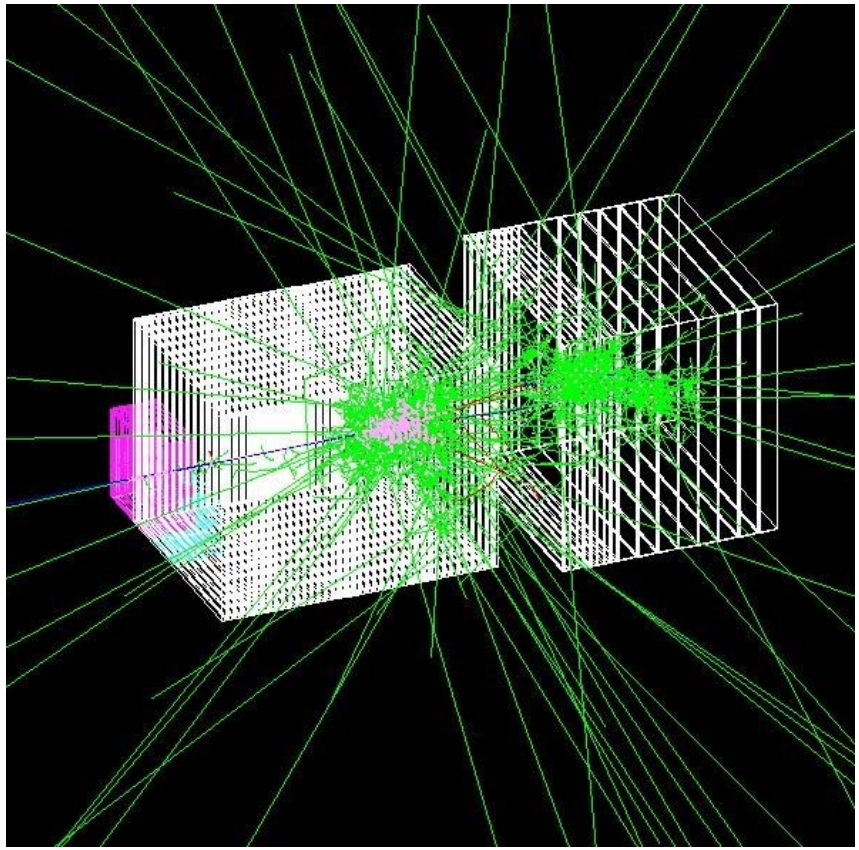


Constructing 1m^3 prototype; 40 layers of Fe; to be integrated with ECAL and tested with hadron beam.

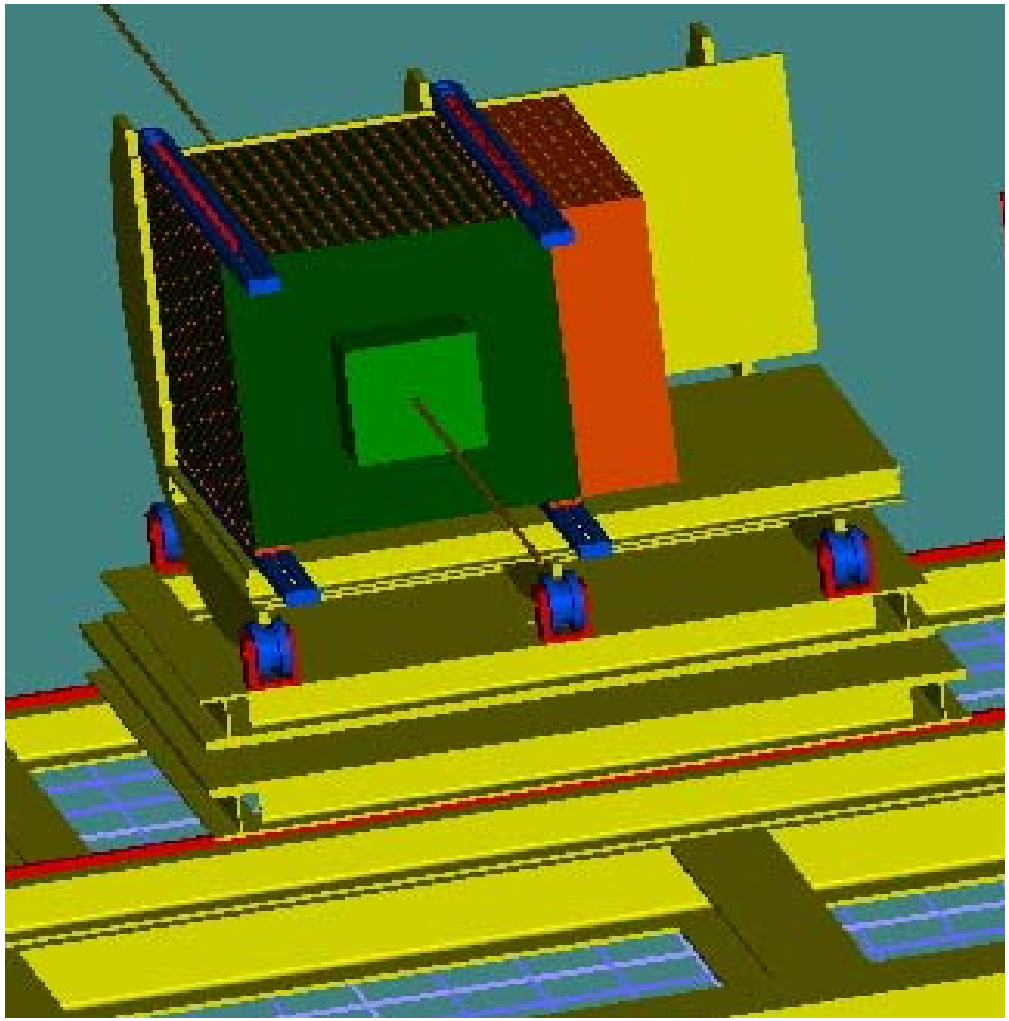
Will use UK off-detector electronics

Tail Catcher/Muon Tracker (TCMT)

- Detect leakage from HCAL
- Fine" section (8 layers)
  2 cm thick steel
- "Coarse" section (8 layers)
  10 cm thick steel
- 5mm thick, 5cm wide strips
- Tyvek/VM2000 wrapping
- Alternating x-y orientation
- Si-PM photo detection
- Common readout with AHcal
- Weight ~10 tons



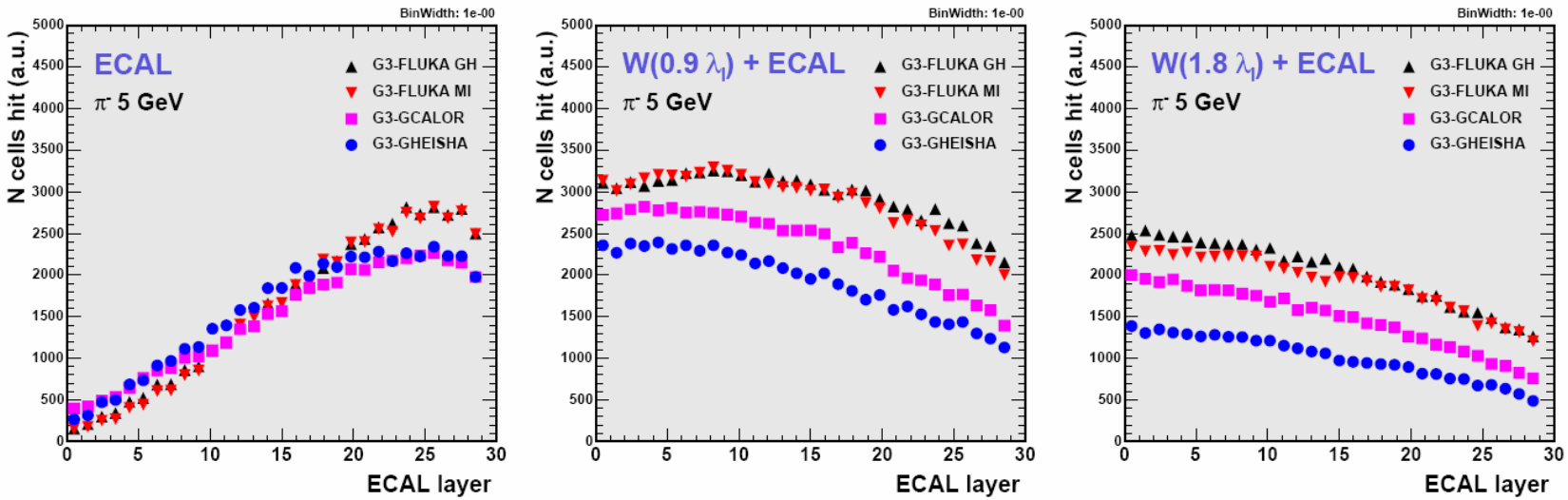
Prototype setup



- Iron plate structure (1 m^3 40 layers), in which various detectors will be placed (tiles, RPC, GEM).
- ECAL prototype in front.
- Rotatable table.
- Also tail catcher (scintillator strips) to be installed behind

shower longitudinal profile by W block + ECAL

W block $18 \times 18 \times 8.4\ cm^3$ **W block** $18 \times 18 \times 16.8\ cm^3$



- differences among models start to show up at the end of ECAL
- use W block to have similar shower development as in ECAL
- models clearly distinguishable with block of W in front of ECAL
- combine "photos" to reveal inclusive longitudinal profile

WP1 Request

- Travel funds. Mainly for test beam running, but also to attend collaboration meetings and workshops. Needed from April 05.
- Continuation of Cambridge RA post. Vital to keep this expertise at this juncture.
- Small M&O request for test beam work.
- New RA posts. Original bid requested 1 year RA at UCL in FY05-6 for exploitation of data. Now seeking RAs at UCL/Imperial/Birmingham, mainly for other WPs, who would contribute to WP1 running and data analysis.

WP5 - Request

- Largely manpower – continuation of Cambridge RA post and new RAs in Birmingham, Imperial, RHUL and UCL (shared with other work packages to ensure cross-fertilisation).
- Travel – collaboration within Calice and in the context of worldwide activities is vital – attending workshops and specialised meetings to give exposure to our work and to ensure our contribution is relevant.