CALICE
Calorimetry for LC

- Motivation
- Calice and data
- UK programme
- Summary

Recent additions

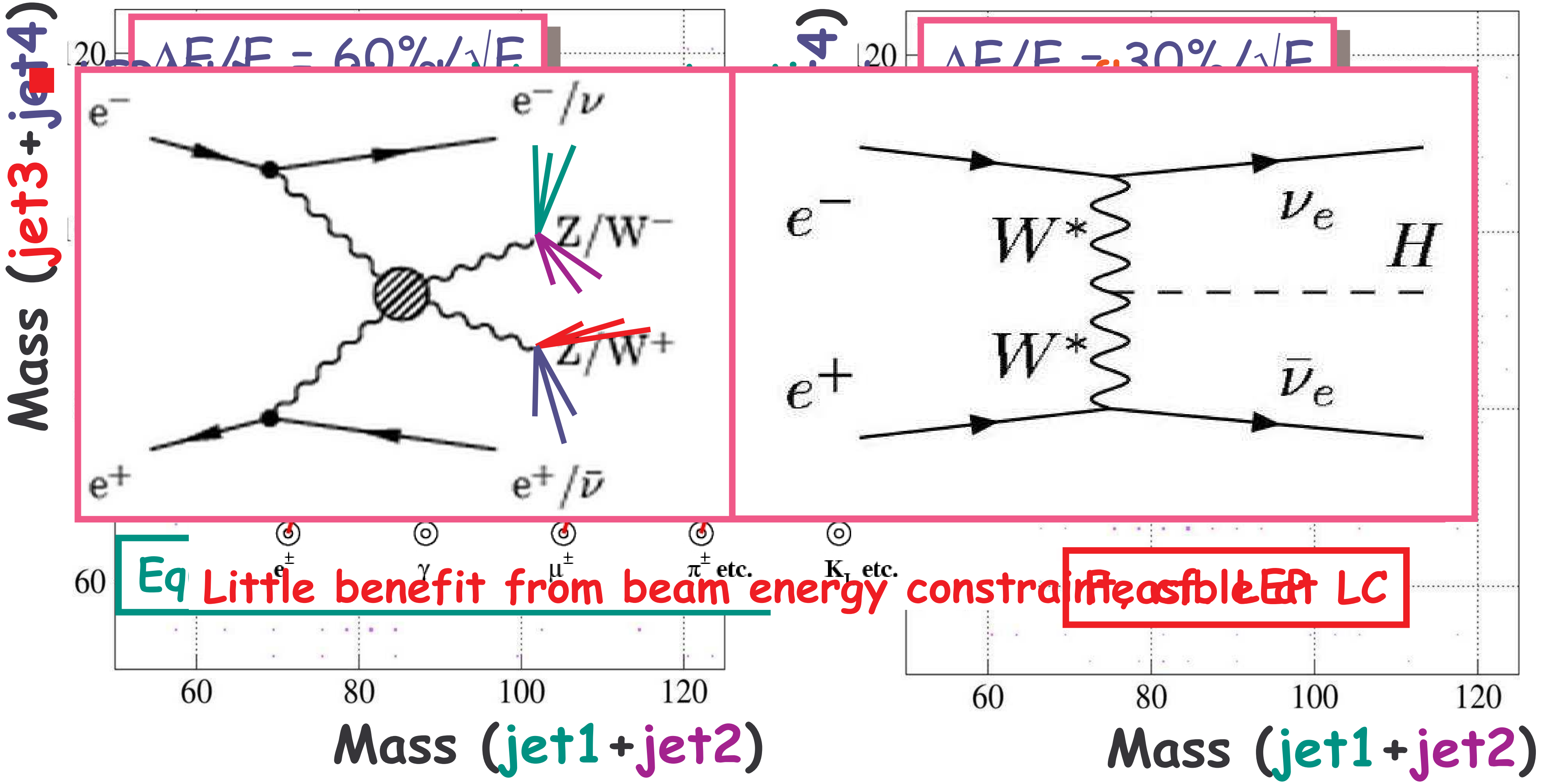
Canada (McGill, Regina)
France (Annecy, Grenoble, Lyon)
Korea (Ewha)
USA (Boston)

~180 physicists
28 institutes
8 countries

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

High Performance Calorimetry

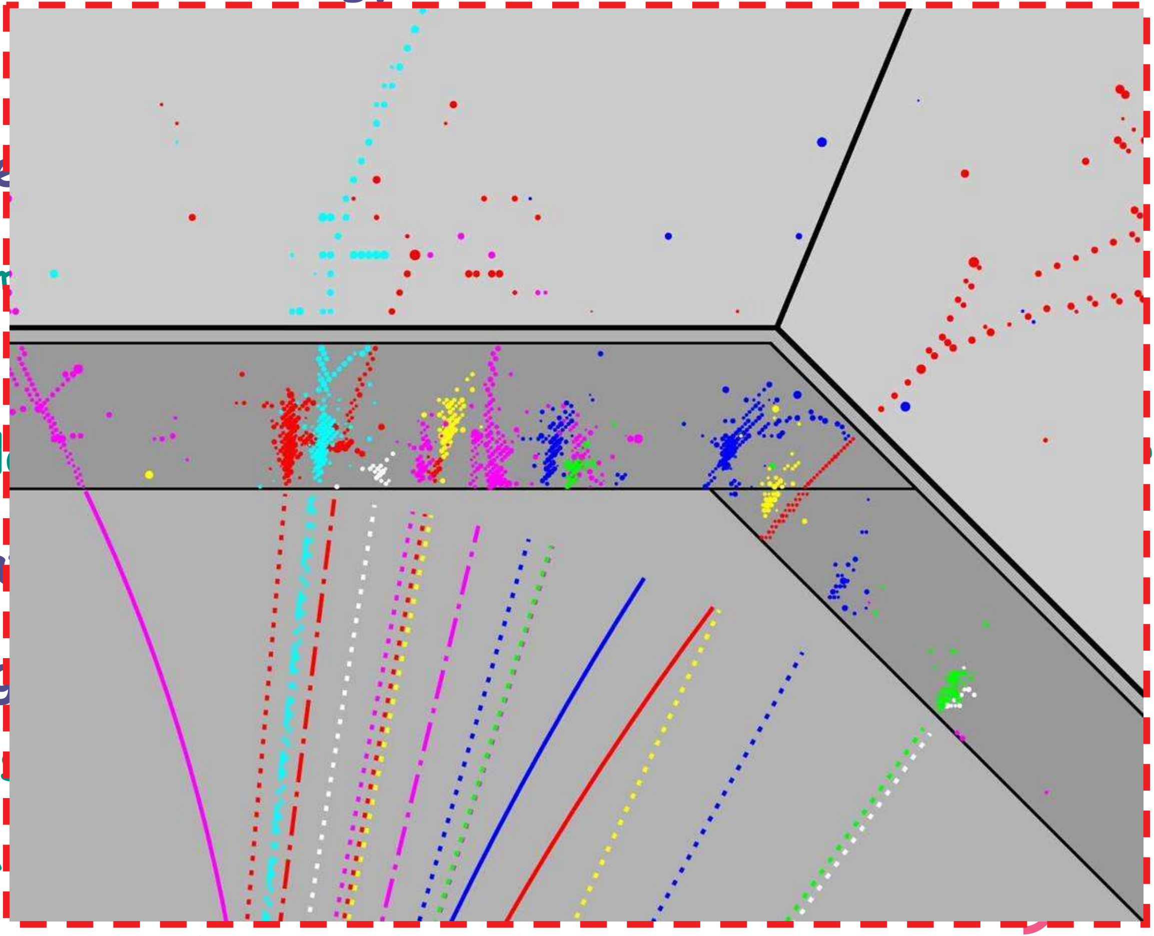
- Essential to reconstruct jet-jet invariant masses in hadronic final states, e.g. separation of $\nu\nu W^+W^-$, $\nu\nu Z^0Z^0$, tth, Zhh



Little benefit from beam energy constraint, cf. LEP

Feasible at LC

ECAL Design Principles



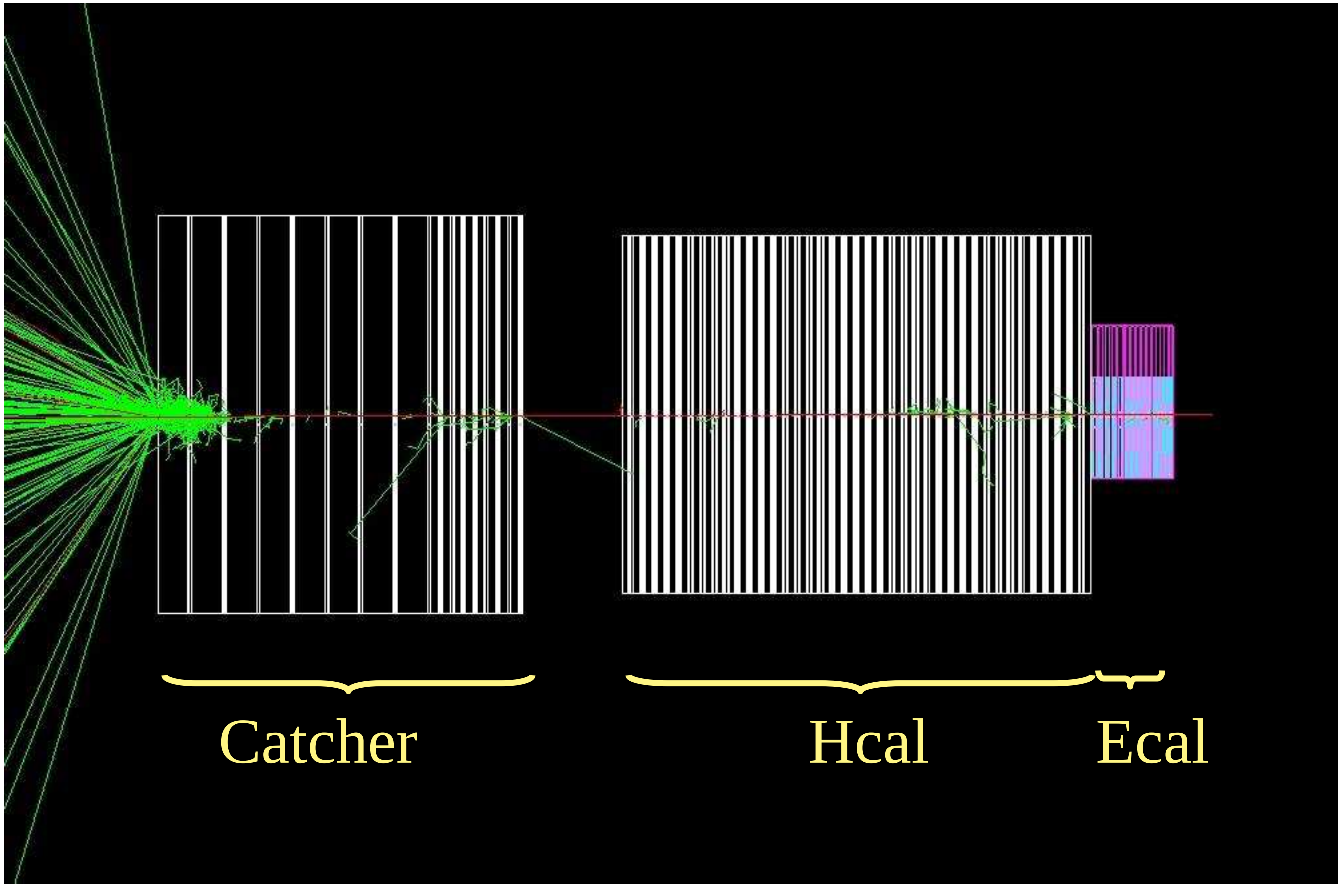
- Measure 100% EM energy
  - shower
- Resolve ene
  - small R_m
- Separation
  - λ_{int}/X_0 l
  - s late
- Minimal ma
- Strong mag
  - lateral
  - keeps a

ECAL, HCAL
inside coil
(cost!)

- Active medium: Silicon

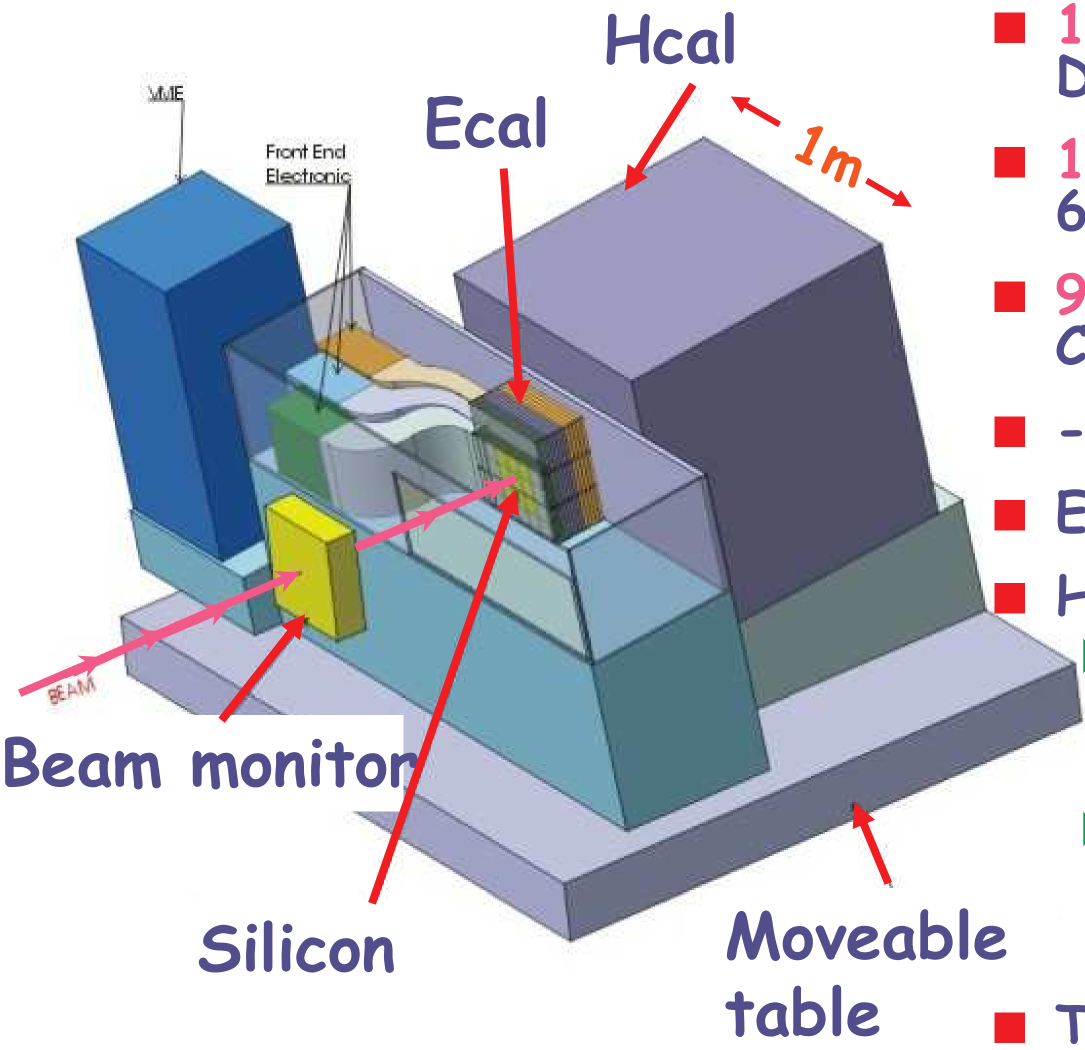
⇒ Pixel readout, minimal interlayer gaps, stability

CALICE Programme



- Fine granularity calorimetry for energy/particle flow
- Integrated ECAL/HCAL R&D, both h/w and s/w
- Technology demonstration
- Validate simulation, allow design optimisation à test beams

Test Beam Schedule

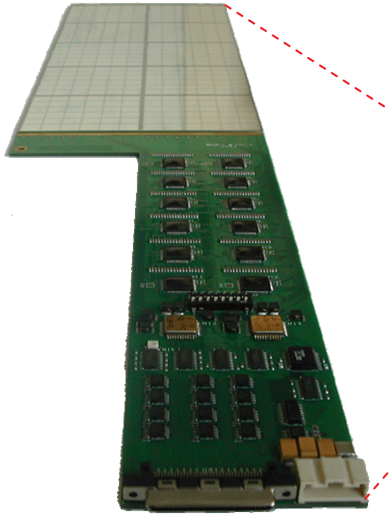


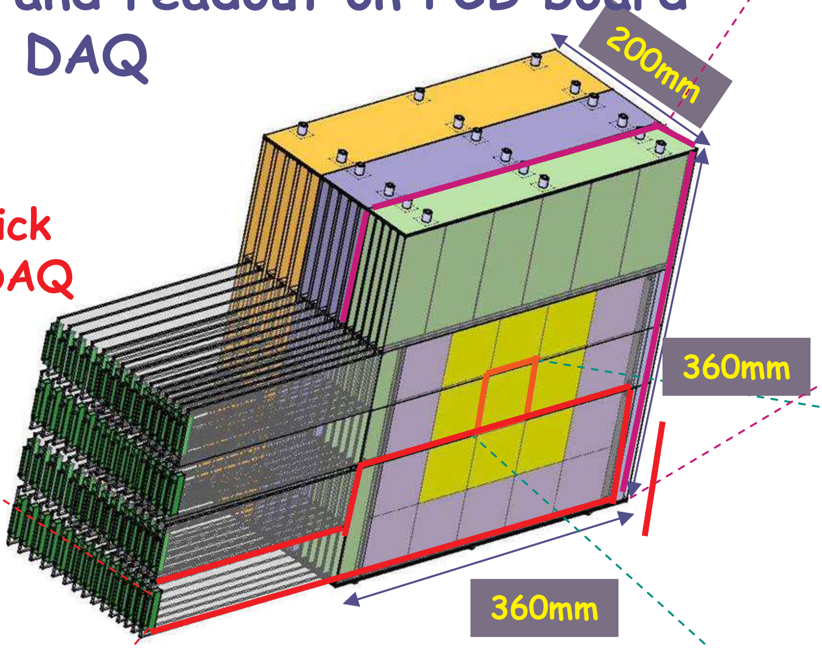
- 10-12/2005: ECAL cosmics@ DESY
- 1-3/2006: run 2 @ DESY, 6 GeV e^-, (complete ECAL)
- 9-11/2006: physics run at CERN incl. AHCAL
- -"-, ~mid-2007, FNAL MTBF
- ECAL: 30 layers
- HCAL: 40 layers Fe +
  - "analogue" tiles
    - ⇒ scintillator tiles
    - ⇒ (8k, 5x5cm^2)
  - "digital" pads
    - ⇒ GEM, RPC
    - ⇒ 350k, 1x1cm^2
- Tail catcher/muon tracker steel
  - 8 x 2cm layers, 8 x 10cm
  - 5cm scintillator strips

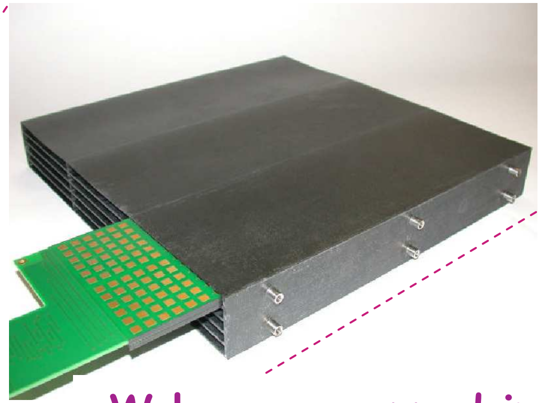
ECAL Prototype Overview

- 30 layers of variable thickness Tungsten
- Active silicon layers interleved
- Front end chip and readout on PCB board
- Signals sent to DAQ

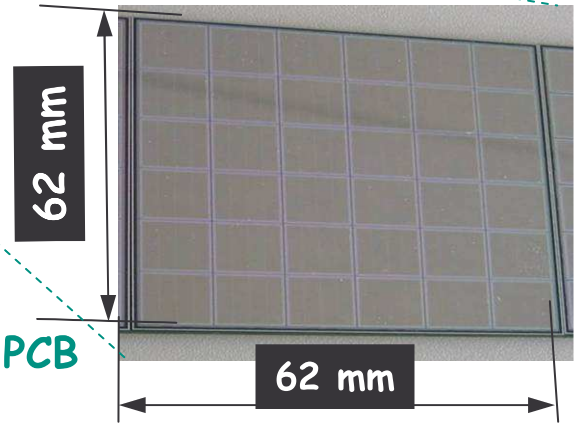
- PCB, with VFE
- 14 layers, 2.1mm thick
- Analogue signals → DAQ







- W layers wrapped in carbon fibre
- PCB+Si layers:8.5 mm



- 6x6 1x1cm^2 Si pads
- Conductively glued to PCB

Production & Testing

- •PCB designed in LAL-
  (KNU)
- •60 Required for Prot
- •Automation, glue : E
- •Glue/place (± 0.1 mm
  pads
- •~ 10k points of glue.
- •Production line set u

luing

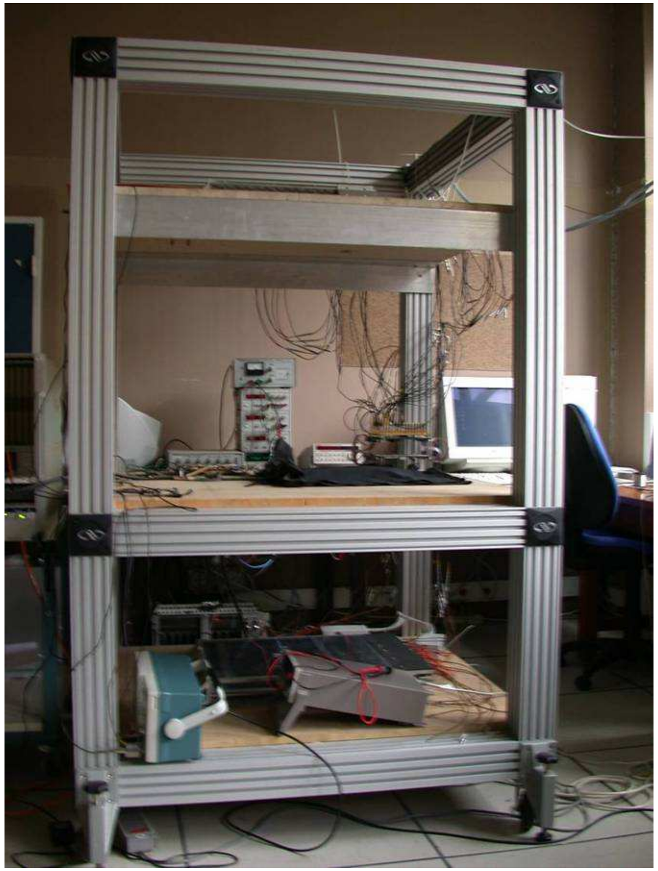
12 VFE chips

2 calibration switch chips

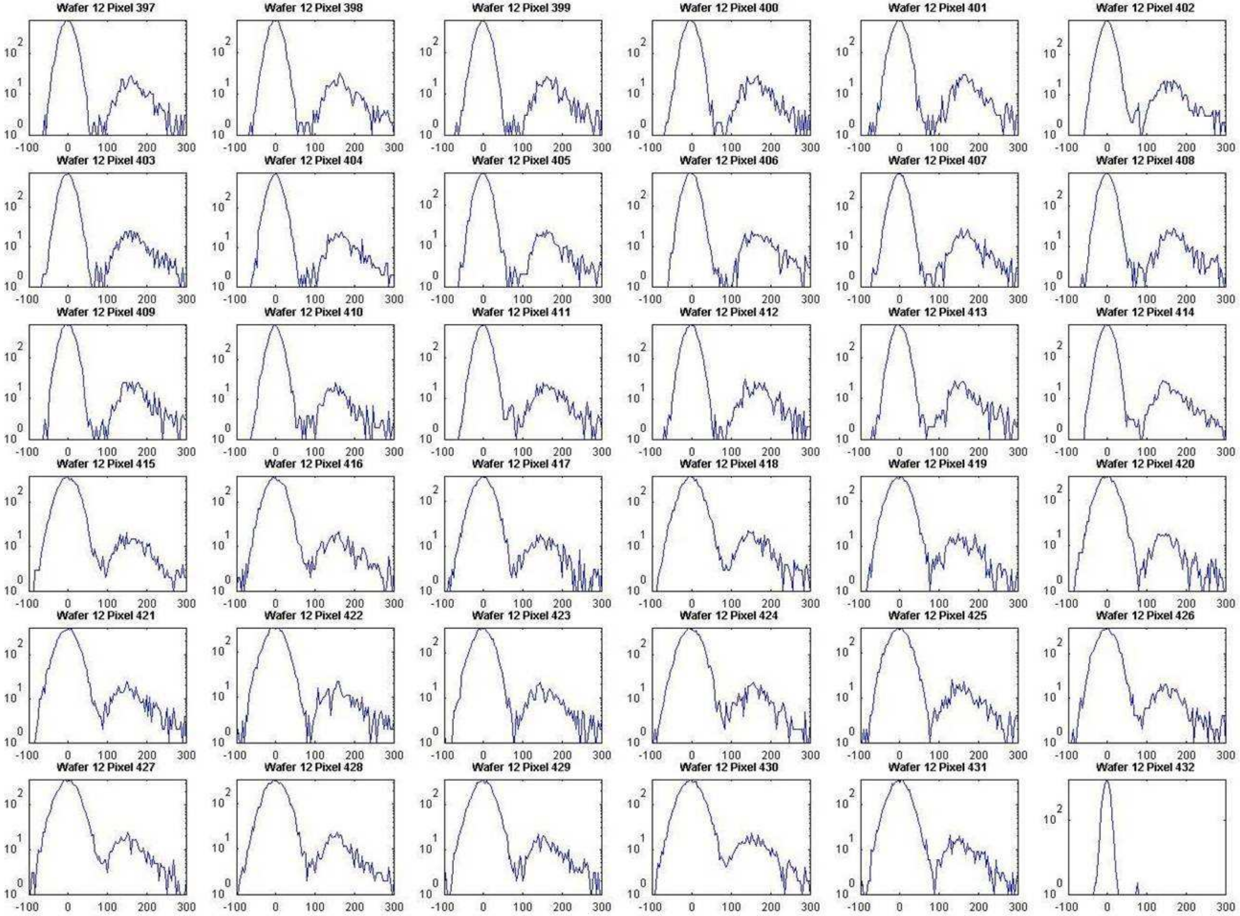
Line Buffers To DAQ

6 active silicon wafers

Cosmics Tests

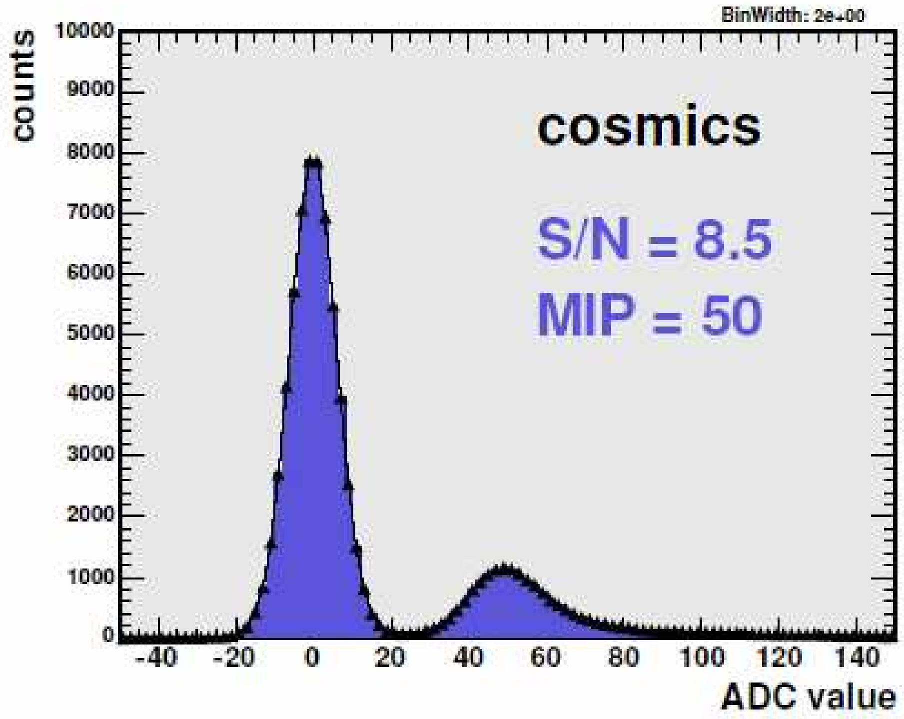


- Dec. 2004



Cosmic calibration, example from 6x6 cm wafer

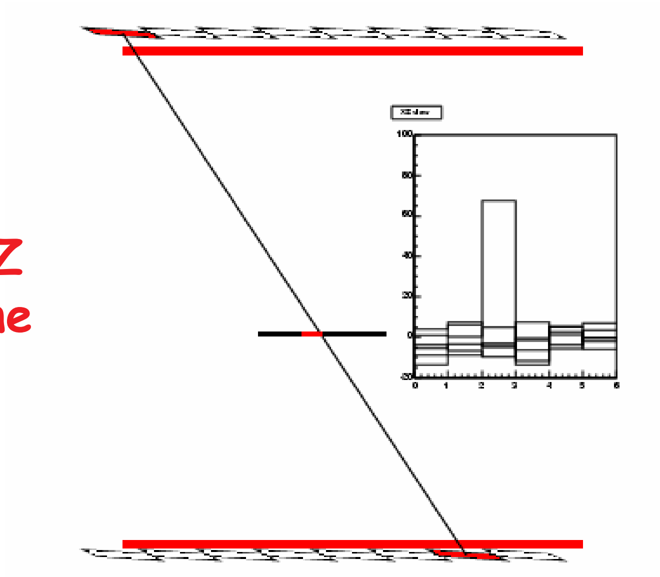
Calibration with cosmics



▷ a typical channel: gaussian noise, landau signal

[G.Mavromanolakis]

Cosmics Tests: Single Layer

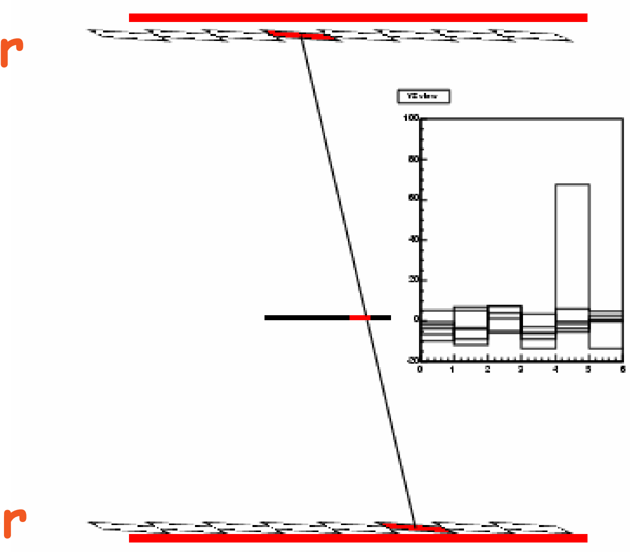


X-Z plane

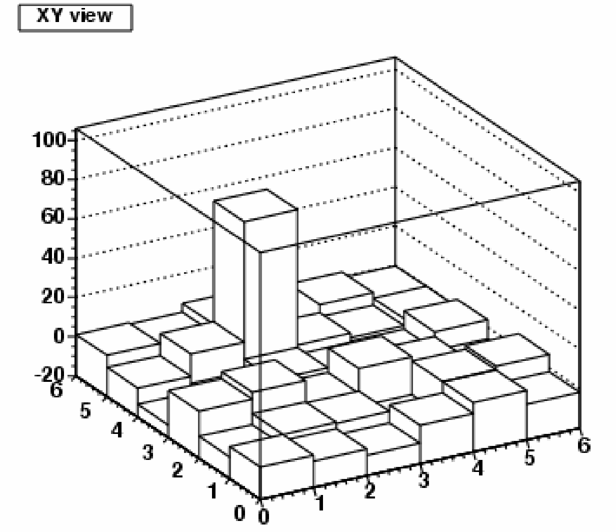
Scintillator

Wafer

Scintillator

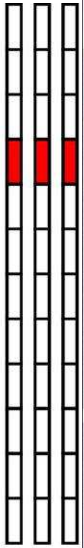


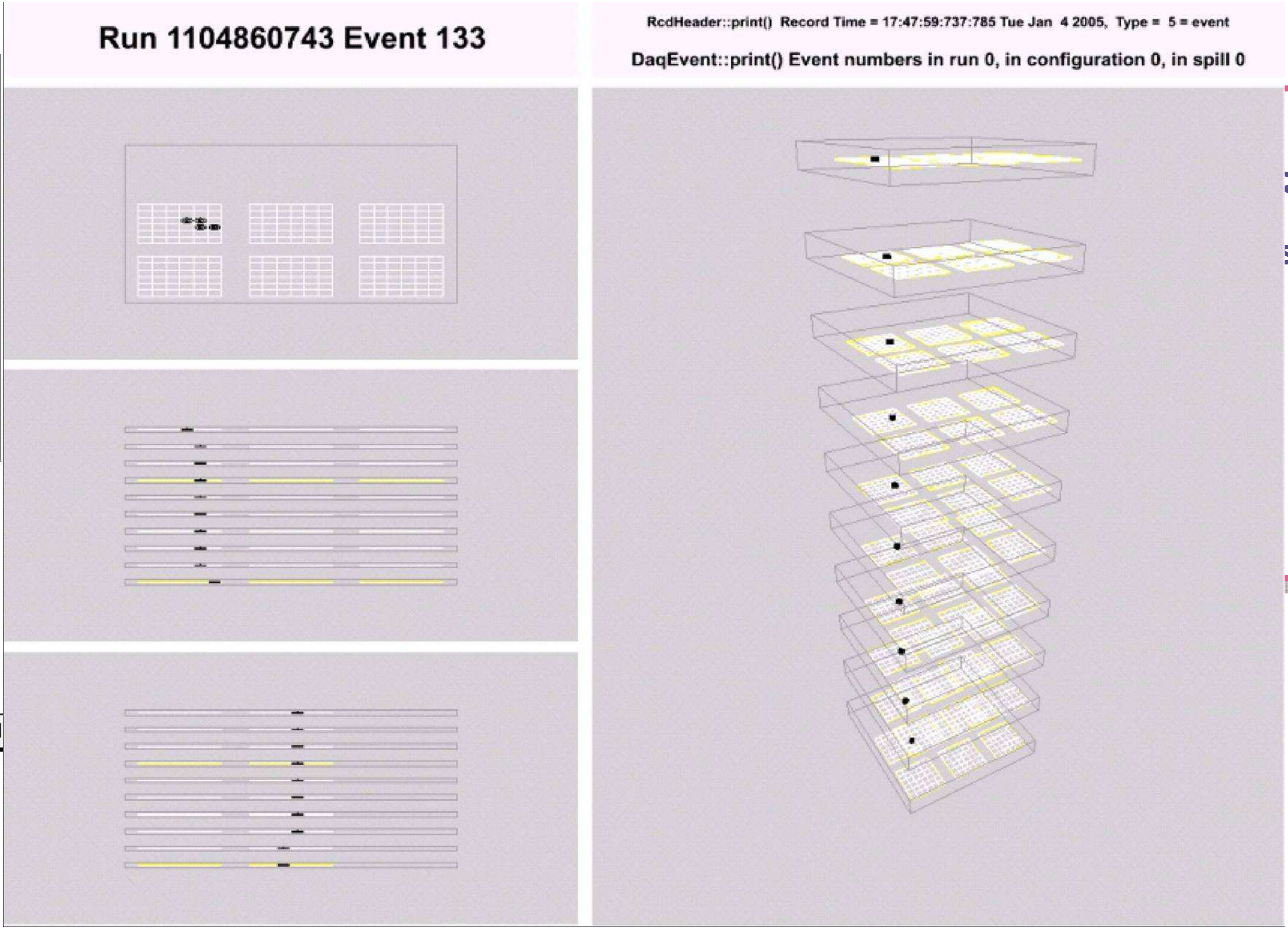
Y-Z plane



- Example of Cosmic Event
- Passes through scintillators
- Extrapolated through silicon
- Clear signal above background
- Full readout chain used

Cosmics Tests, 10 layers





Run 1104860743 Event 133

RcdHeader::print() Record Time = 17:47:59:737:785 Tue Jan 4 2005, Type = 5 = event

DaqEvent::print() Event numbers in run 0, in configuration 0, in spill 0

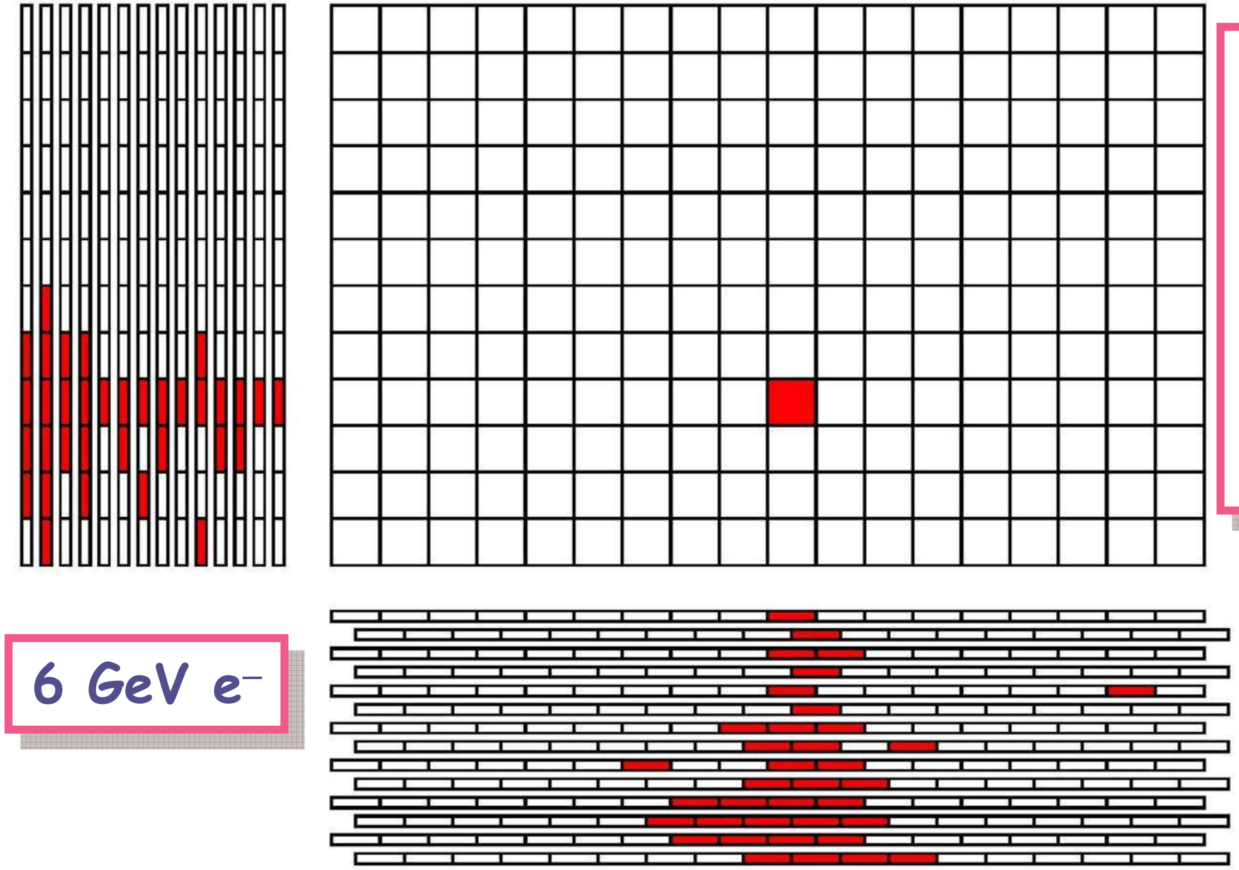
R

s

Rcd

Nigel

1st Beam Data From DESY



6 GeV e⁻

Jan. 2005

12th, H/W arrived DESY

13-4th, assembled

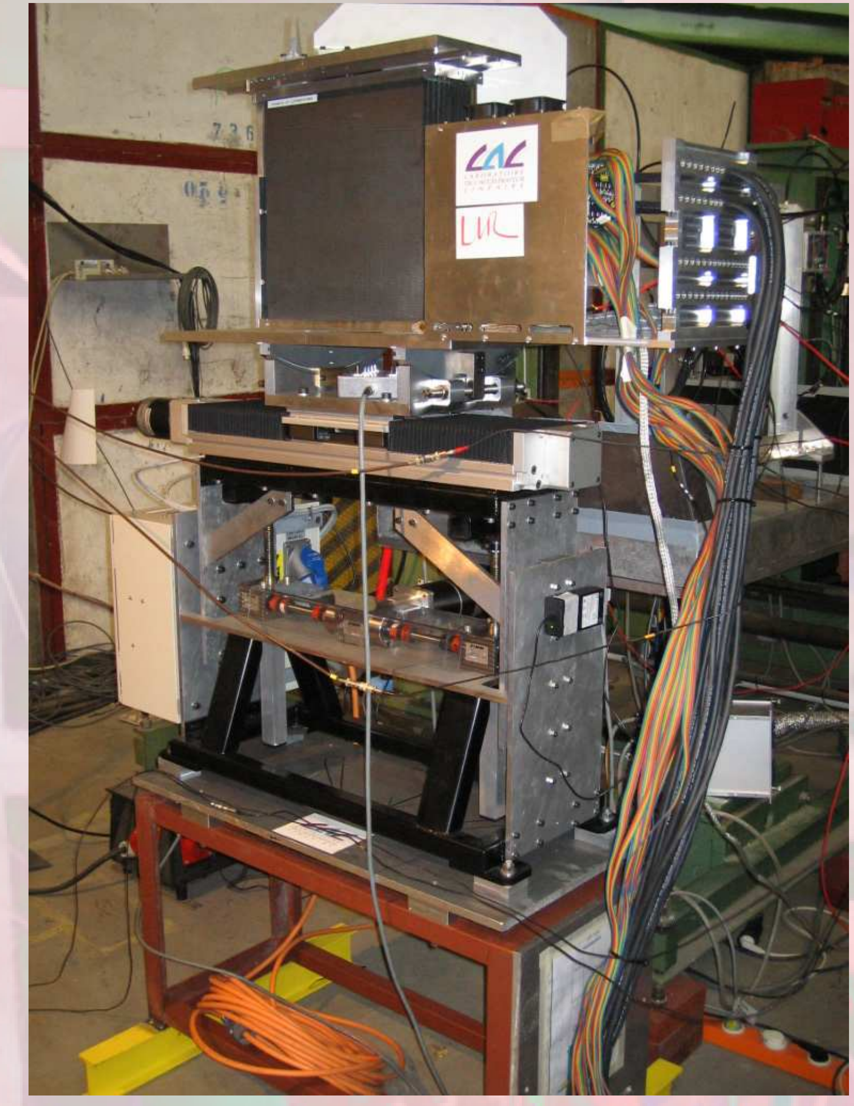
17th, 1st beam recorded

This event, Jan. 18

```
RcdHeader::print()  Record Time = 15:54:23:784:456 Tue Jan 18 2005,  Type =  5 = event
```

```
DaqEvent::print() Event numbers in run 0, in configuration 0, in spill 0
```

Test beam DESY



February 2005 Test :

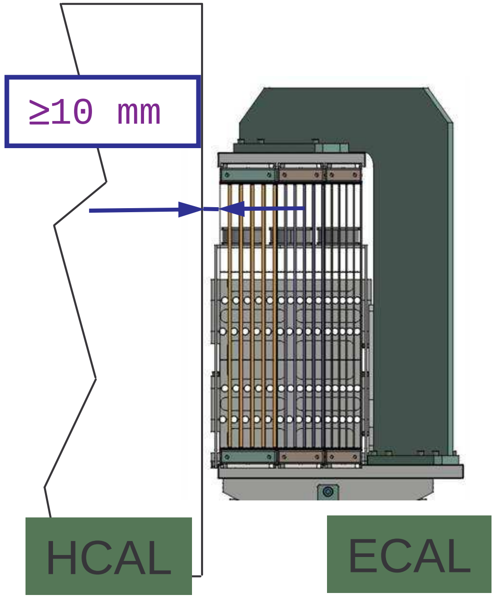
- Ecal
  - Structure 1 and 2
  - 7 Slab, 14 layer
  - 84 matrices à 3024 pixels
- Motorized XY support
- Drift chamber (200 μm resolution)
- VME DAQ

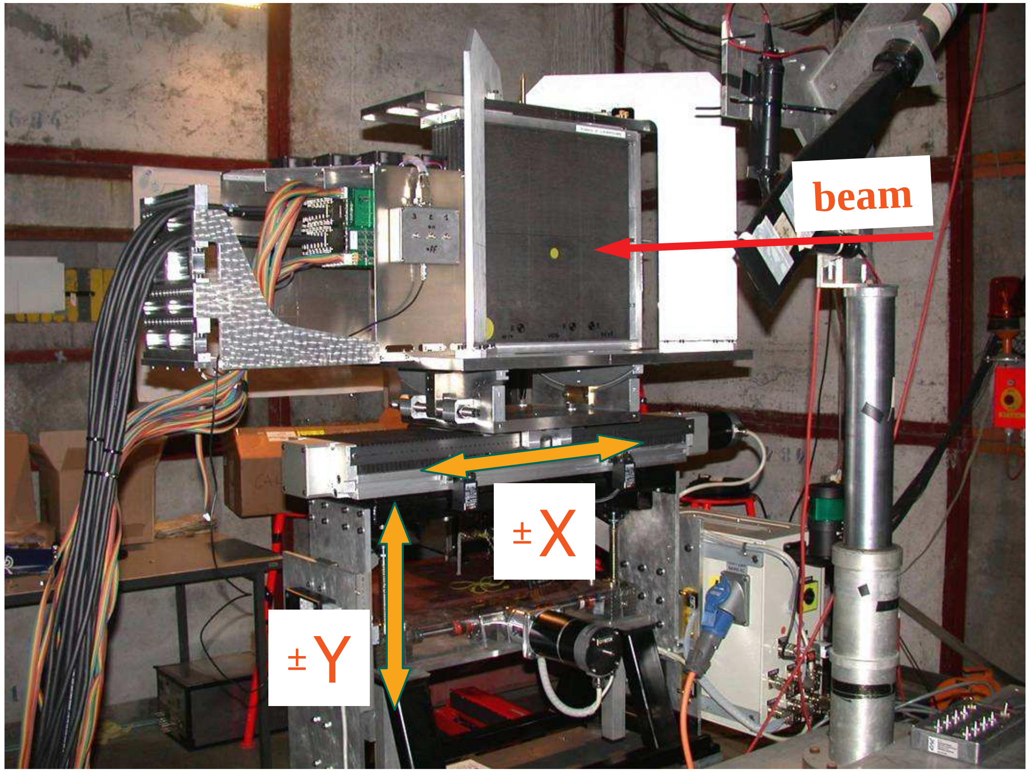
~ 13 full days of run

Great thanks you to Norbert Meyners and all Calice AHCAL people for their help.

Mechanical support

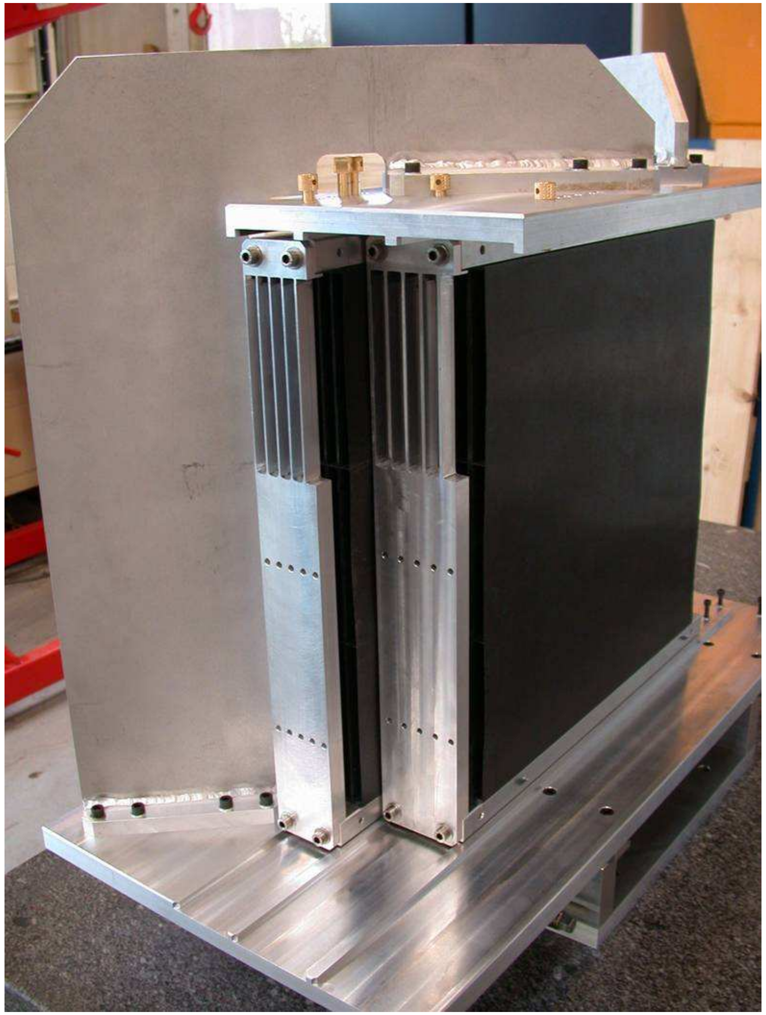
- X and Y motions to move the point of impact of the beam or ECAL in front of HCAL
  - Tilt : 5°
  - Axe X : 150 mm (motorised)
  - Axe Y : 100 mm (motorised)
- 6 indexed angular configurations (0°, 10°, 20°, 30° , 40° and 45°)
- Gap mini with HCAL : 13 mm



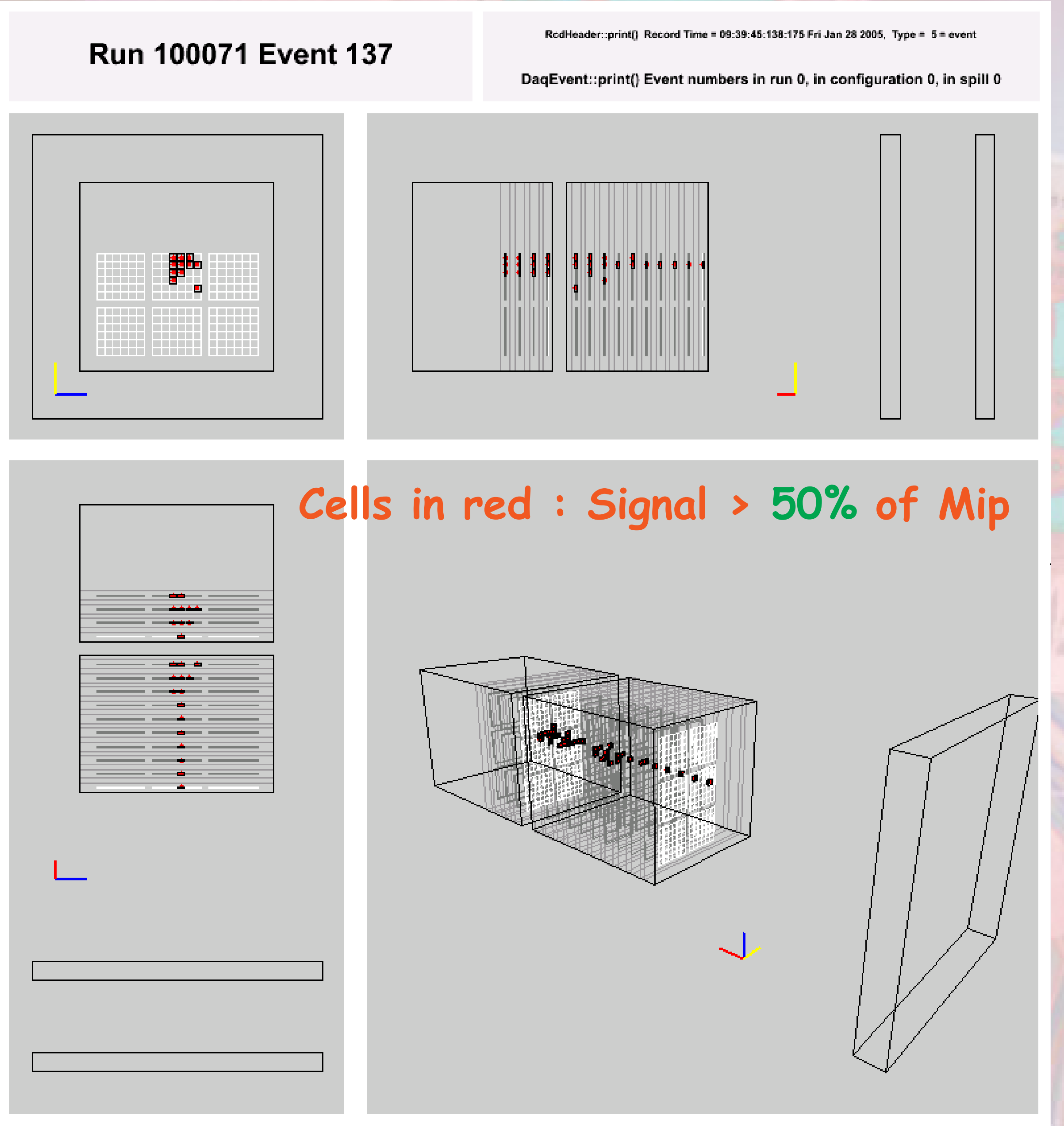


Programme
Position scans within/across wafers
Energy scans 1—3 GeV (some data 4—6 GeV)
Normal incidence and 10^0, 20^0, 30^0

Mechanical structure for TestBeam



Test beam DESY : nice event…



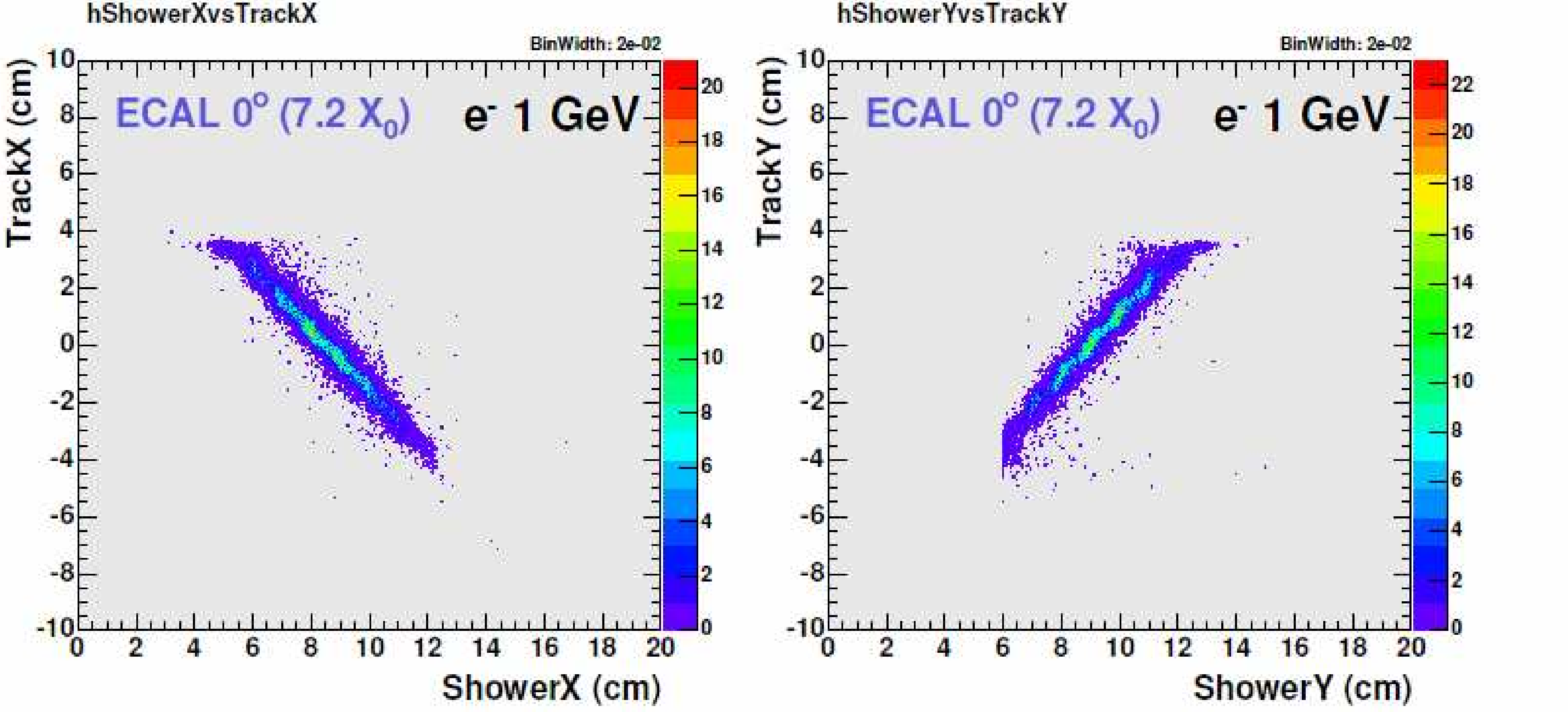
Run 100071 Event 137

RcdHeader::print() Record Time = 09:39:45:138:175 Fri Jan 28 2005, Type = 5 = event

DaqEvent::print() Event numbers in run 0, in configuration 0, in spill 0

Cells in red : Signal > 50% of Mip

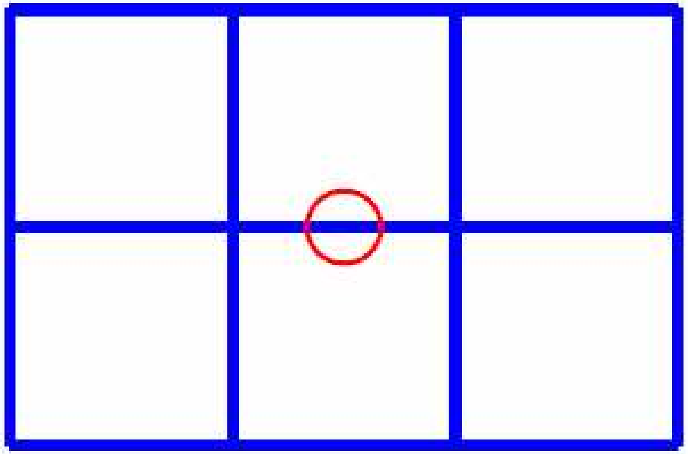
Position scan

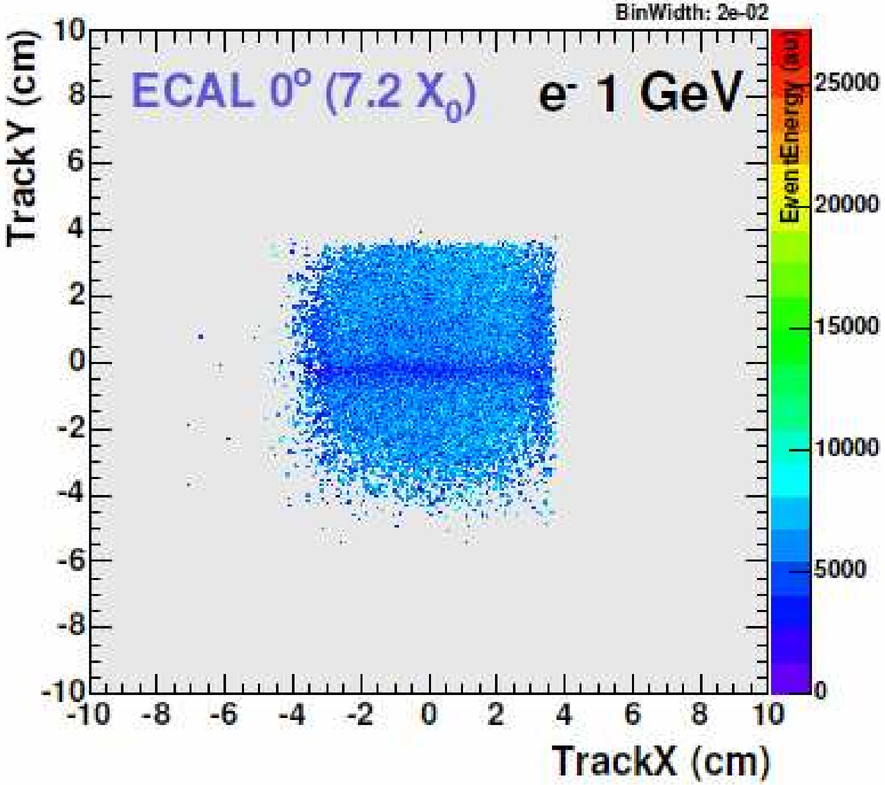


- ShowerX,Y from barycenter in ecal
- TrackX,Y from 4 drift chambers

[G.Mavromanolakis]

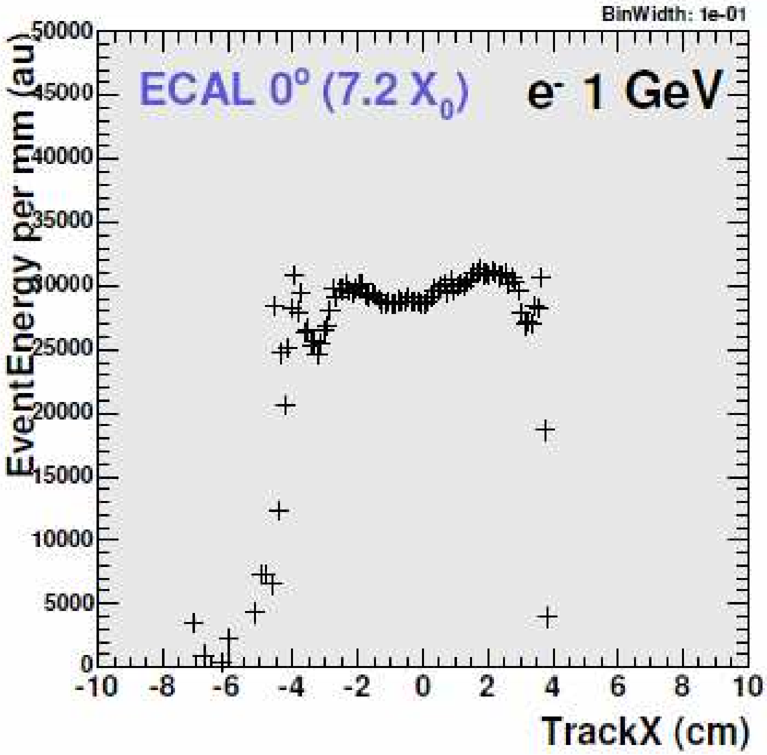
Position scan - edge of wafer

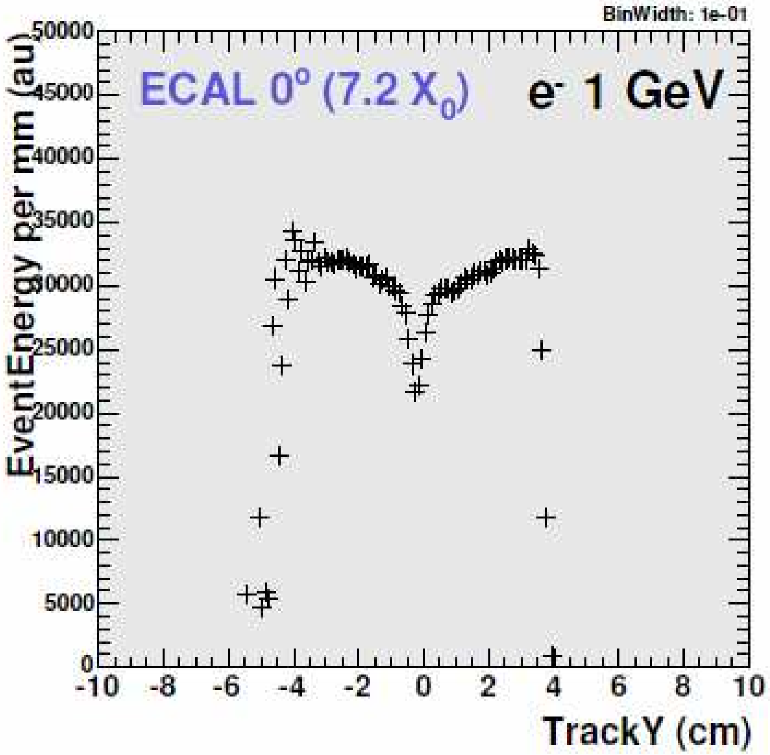




[G.Mavromanolakis]

Position scan - edge of wafer

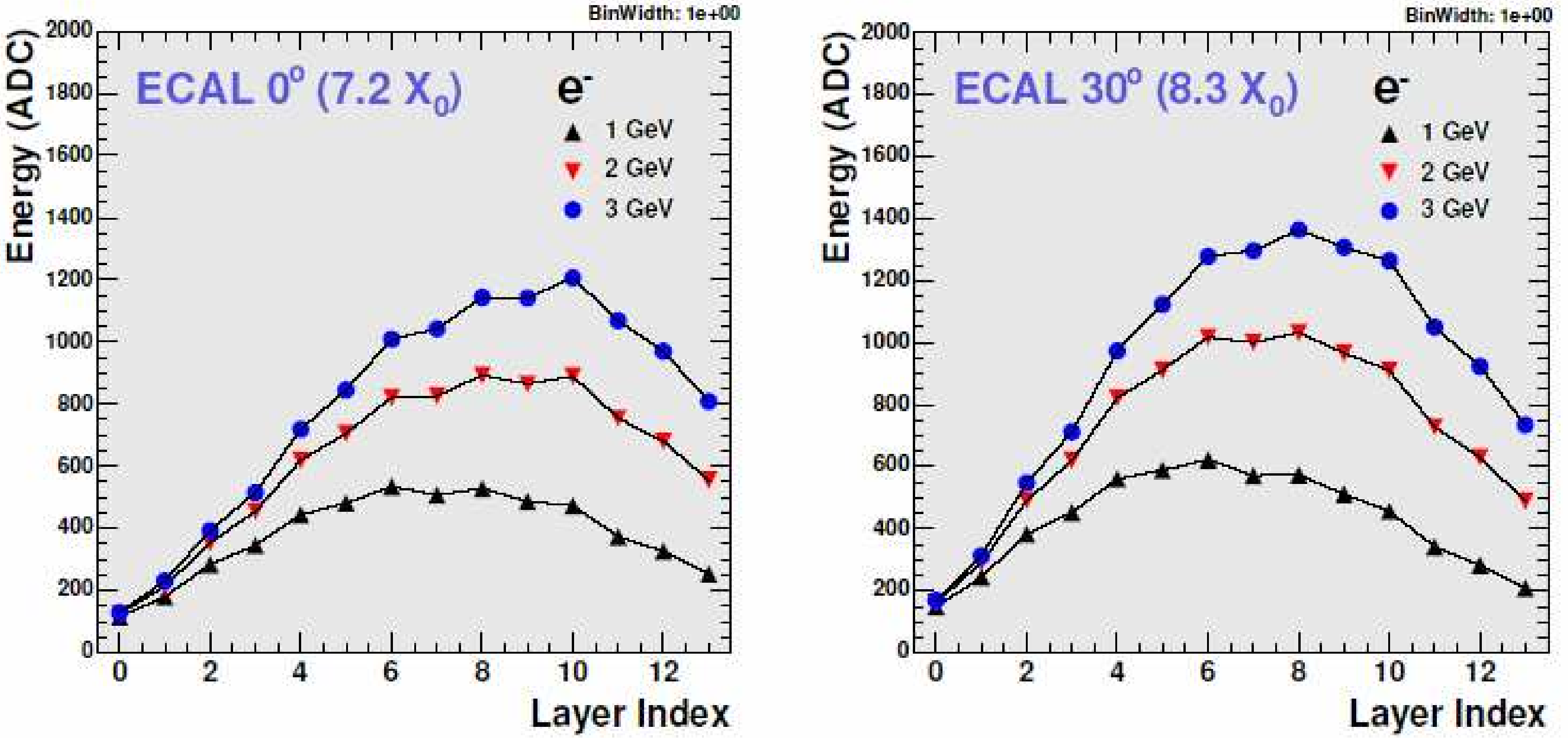




▷ PRELIMINARY

[G.Mavromanolakis]

Shower longitudinal profile



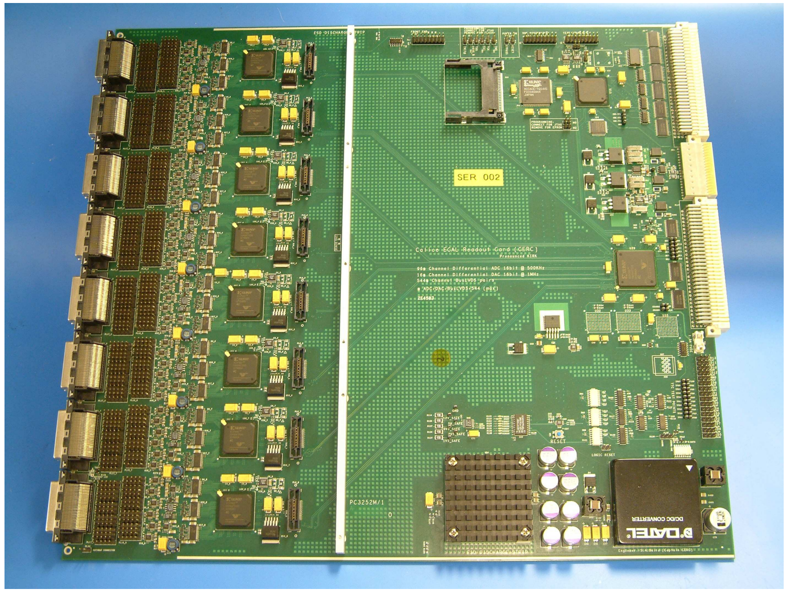
- ▷ no weighting, no event selection, no tracking
- ▷ showers better contained at 30°

[G.Mavromanolakis]

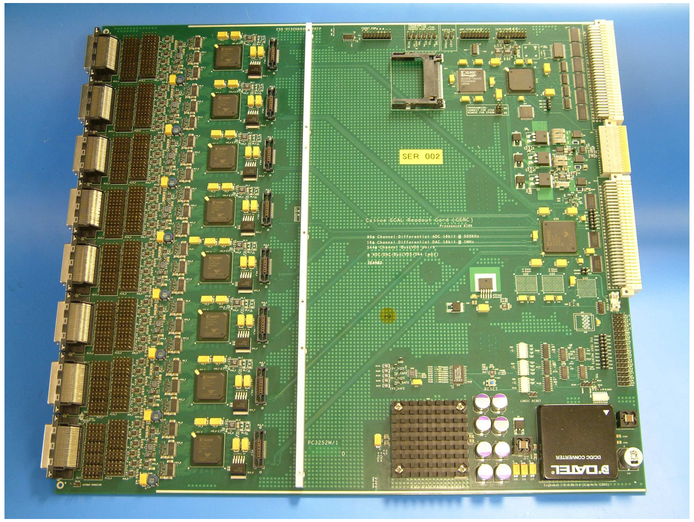
Electronics and DAQ

ECAL

- 30 layer prototype = 9720 channels
- 6 x 9U VME boards ("Calice Readout Card" – CRC)
  - 18 fold multiplexed analogue from 96 VFE chips
  - On board buffering for 2k events
- Based on CMS FED
  - Saved time
- Designed/built Imperial, RAL ID, UCL
- Prototypes 11/2003, pre-prod$^{n.}$ 5/2004
- Board fab. 10/2004



CRC hardware status



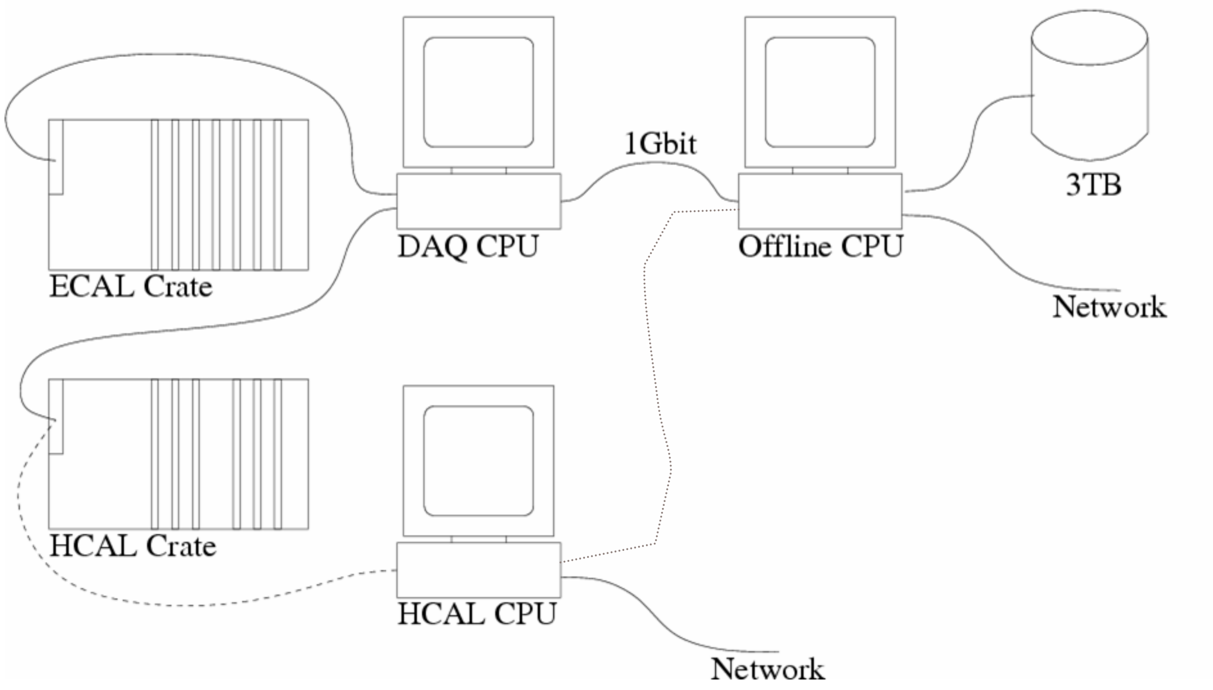
- Need 13 CRCs total
  - ECAL à 6 CRCs
  - AHCAL à 5 CRCs
  - Trigger (probably) à 1 CRC
  - Tail catcher à 1 CRC
- Status
  - 9 exist (2 preproduction, 7 production), testing
  - 7 being manufactured via RAL, delivery in Nov ‘05
  - Ł 13 plus 3 spares by end of year
- DHCAL readout still very uncertain
  - Funding limited; cannot afford system already designed
  - May use CRCs to save money; à 5 CRCs (like AHCAL - ∴ use theirs!)
  - No running with DHCAL planned before 2007; ignore for now

DAQ hardware layout

- DAQ CPU
  - Trigger/spill handling
  - VME and slow access
  - Data formatting
  - Send data via dedicated link to offline CPU
  - Redundant copy to local disk?

- Offline CPU
  - Write to disk array
  - Send to permanent storage
  - Online monitoring
  - Book-keeping

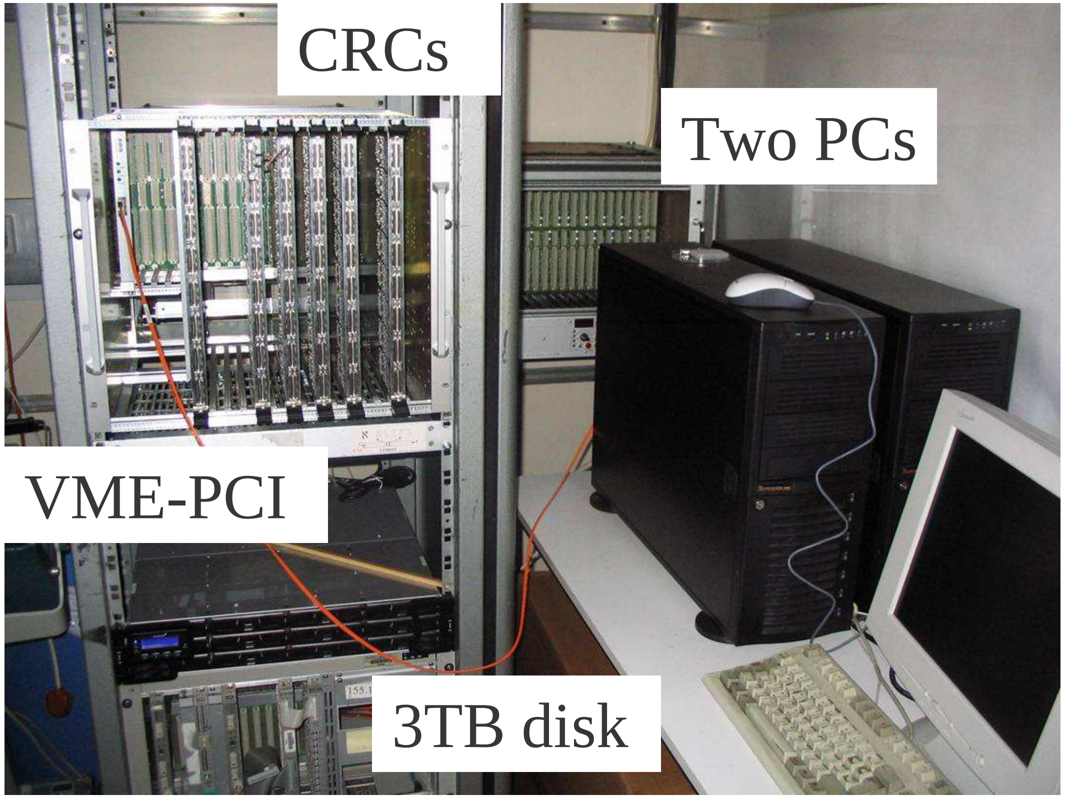
- HCAL PC
  - Partitioning
  - Alternative route to offline PC



Status of non-CRC hardware

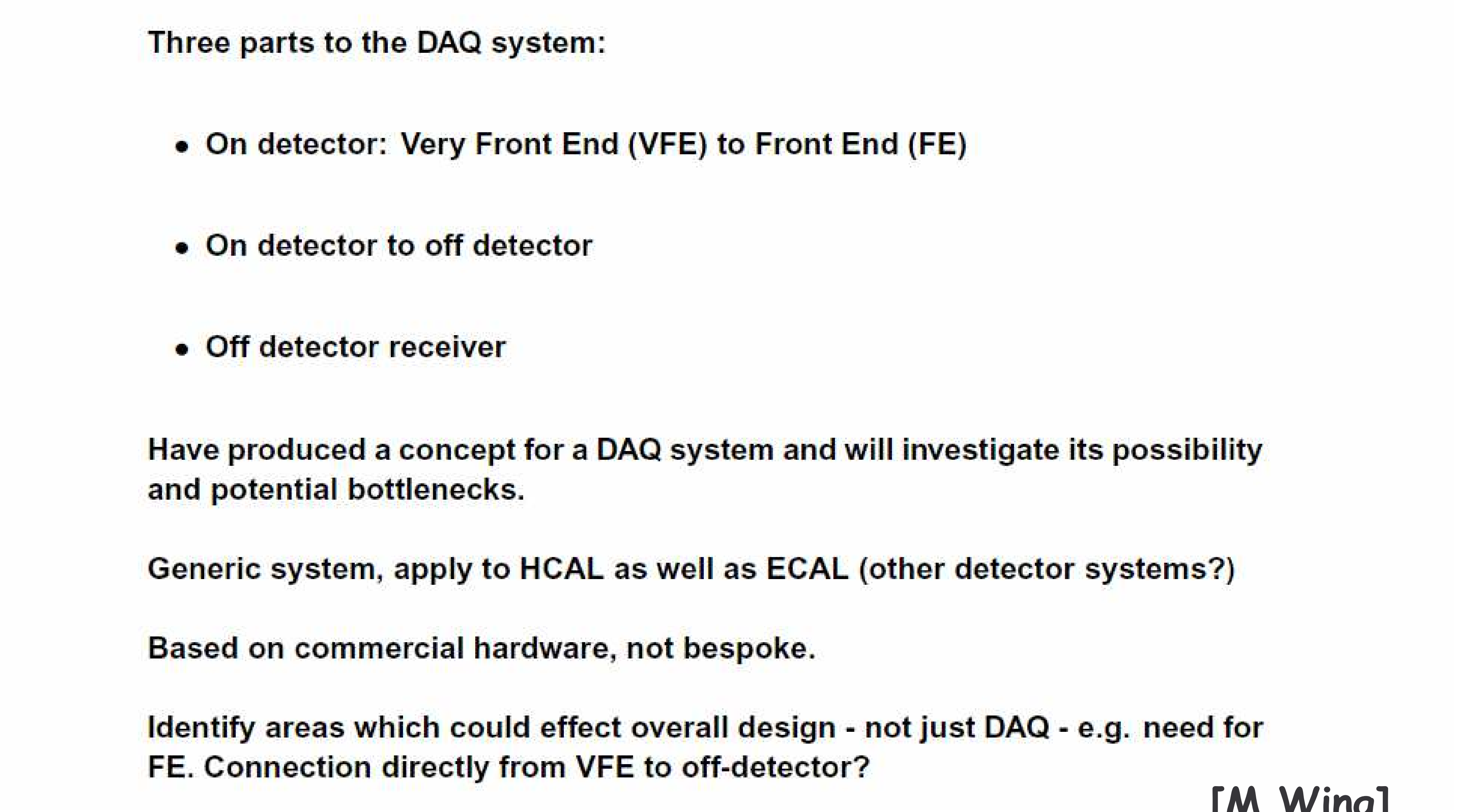
- Two 9U VME crates with custom backplanes needed
  - One for ECAL and trigger
  - One for AHCAL and tail catcher
  - Exist at DESY but no spares (for parallel testing, etc)

Test station at Imperial



- Three VME-PCI bridges needed
  - All purchased and tested
- 100 mini-SCSI cables needed
  - Purchased 70 but not halogen free (needed at CERN)
  - May need to buy more
- Three PCs and disk
  - All purchased and tested

DAQ R&D



Three parts to the DAQ system:

- On detector: Very Front End (VFE) to Front End (FE)
- On detector to off detector
- Off detector receiver

Have produced a concept for a DAQ system and will investigate its possibility and potential bottlenecks.

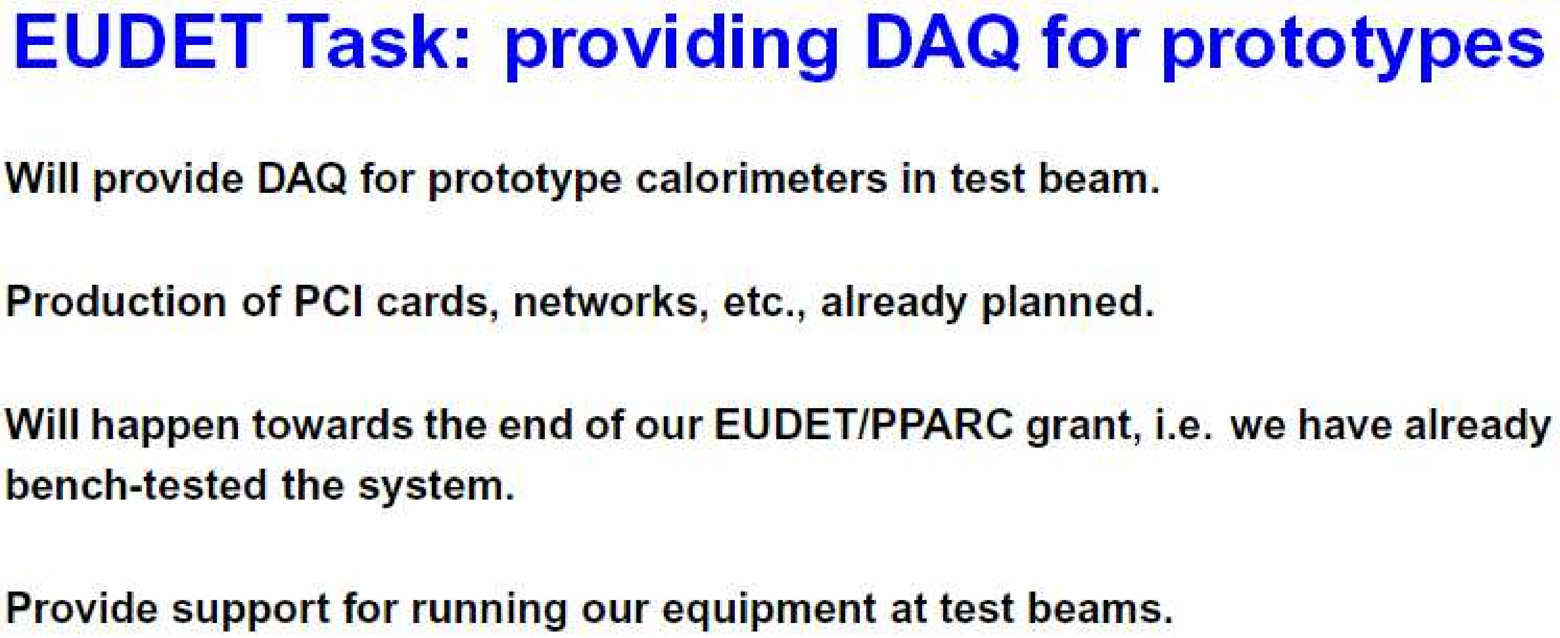
Generic system, apply to HCAL as well as ECAL (other detector systems?)

Based on commercial hardware, not bespoke.

Identify areas which could effect overall design - not just DAQ - e.g. need for FE. Connection directly from VFE to off-detector?

[M.Wing]

IA as I3



EUDET Task: providing DAQ for prototypes

Will provide DAQ for prototype calorimeters in test beam.

Production of PCI cards, networks, etc., already planned.

Will happen towards the end of our EUDET/PPARC grant, i.e. we have already bench-tested the system.

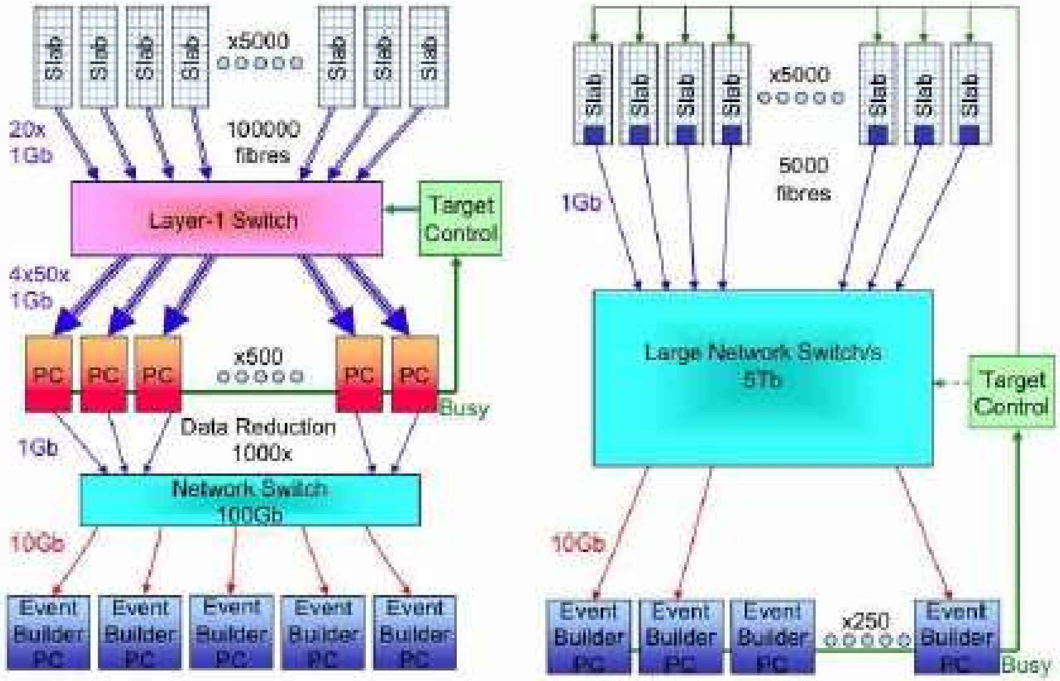
Provide support for running our equipment at test beams.

Allowed ~original programme to be retained
A record for rapid (&successful) submission?

[M.Wing]

Specific R&D topics

- e.g. C
  - Mi
  - Mo
  - St
- Reado
- Under
- Trans
- Protot

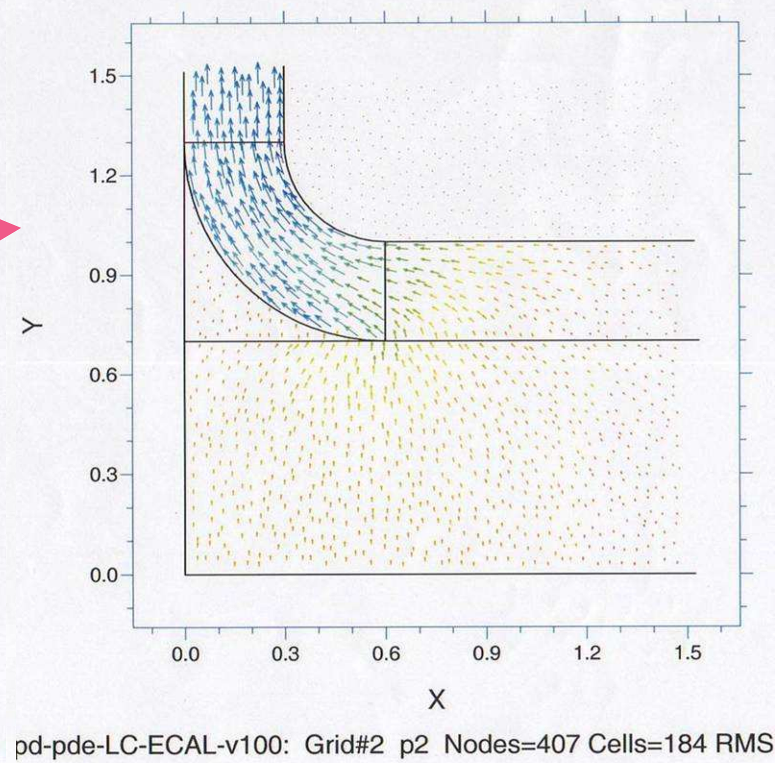


Thermal/Mechanical Studies

MANCHESTER
1824

The University of Manchester

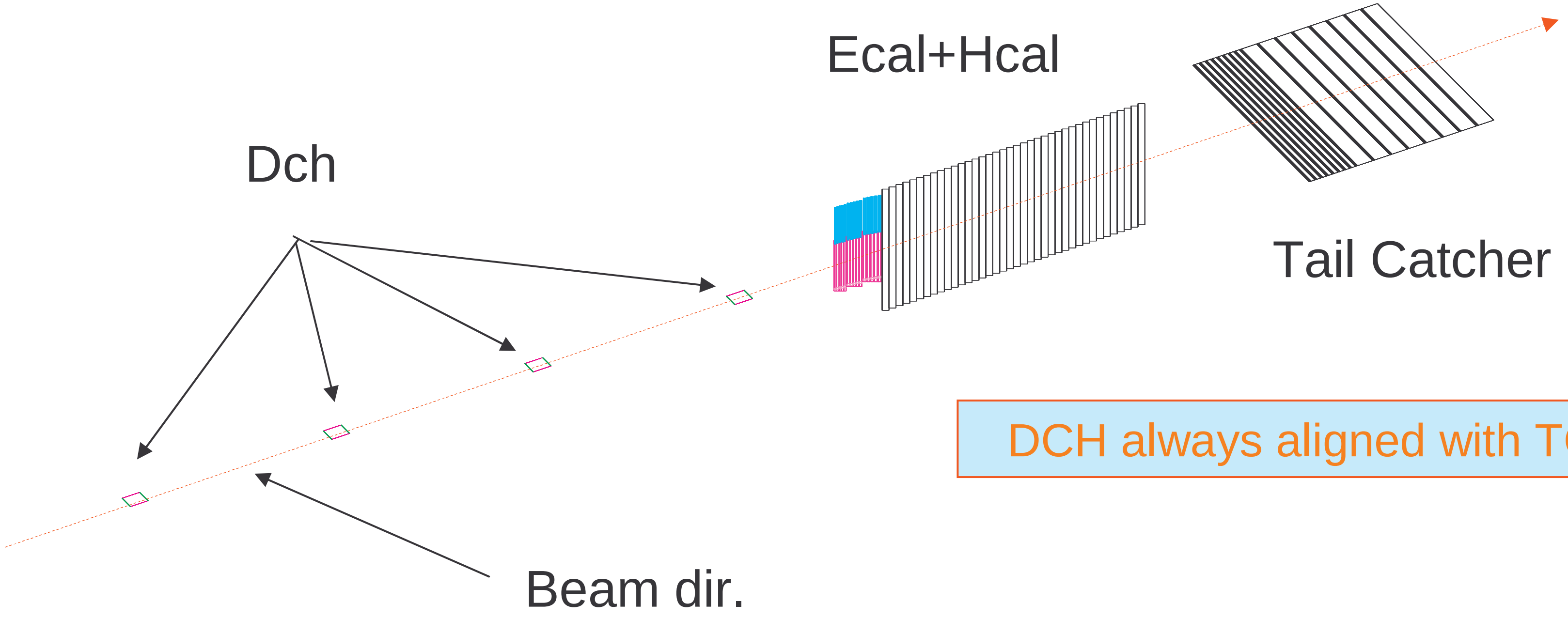
- **Thermal**
  - Simulations of heat flow in detector
  - Measurements to complement simulations



- **Mechanical**
  - Learn about glue types and properties
  - Simulate aging by thermal cycling

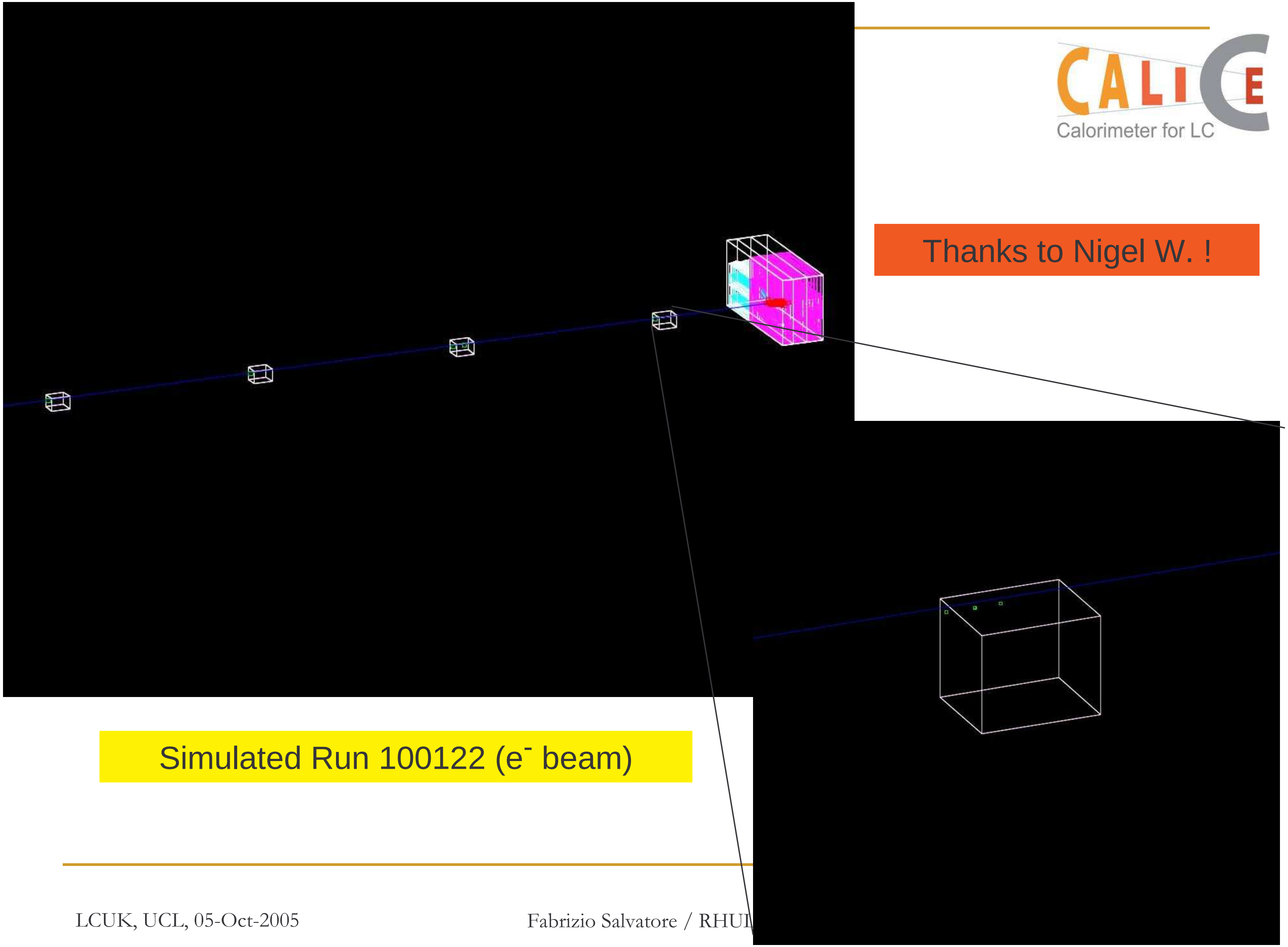
Simulation and Reconstruction

Test beam drift chamber now modelled in Mokka



DCH always aligned with TC

[F.Salvatore]



Thanks to Nigel W. !

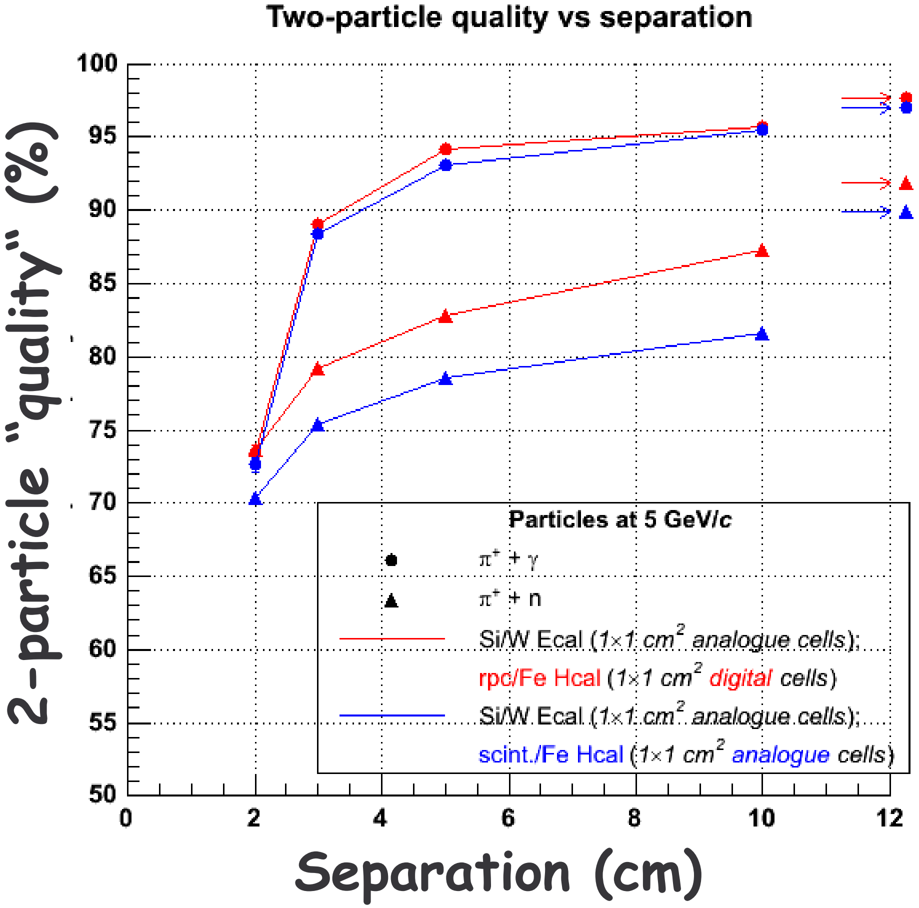
Simulated Run 100122 (e$^-$ beam)

Calorimeter Clustering in UK

- Minimal Spanning Trees ("gNIKI"), G.Mavromanolakis
- Tracking like algorithm ("MAGIC"), C.Ainsley, included in evolving MarlinReco package

- Goal: to distinguish charged clusters from neutral clusters in calorimeters.
- Propose a figure of merit to gauge performance of algorithm:

  Quality = fraction of event energy that maps in a 1:1 ratio between reconstructed and true clusters.
- Higher quality ⇔ less "confusion".
- Measured quality with **Si/W Ecal** and, alternately, **rpc/Fe Hcal** (Mokka "**D09**" model) and **scint./Fe Hcal** (Mokka "**D09Scint**" model) for $\pi^+\gamma$ and π^+**n** separation (all 5 GeV particles).
- Quality improves with separation for both (naturally).
- Apparently, significantly better cluster separation achieved with **rpc/Fe Hcal** than with **scint./Fe Hcal** (stat. error bars ~ marker size).
- Advantage particularly pronounced for π^+**n** separation.
- Appears to be due to more isolated, disconnected hits in **n** showers in the scint./Fe Hcal…

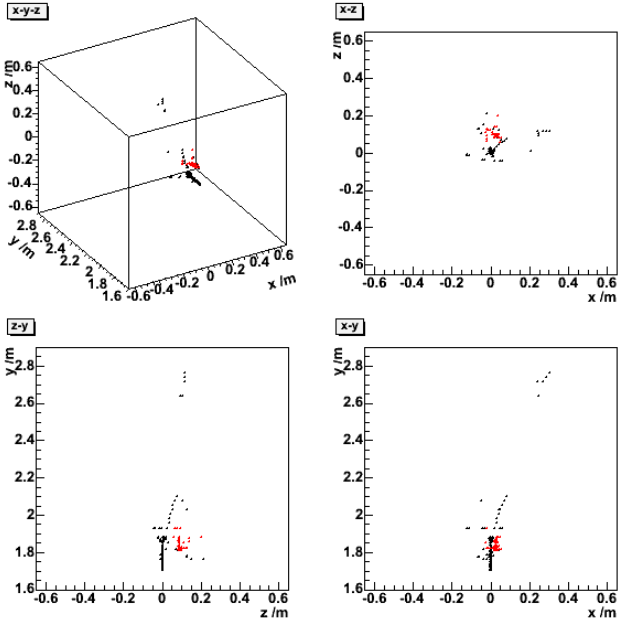


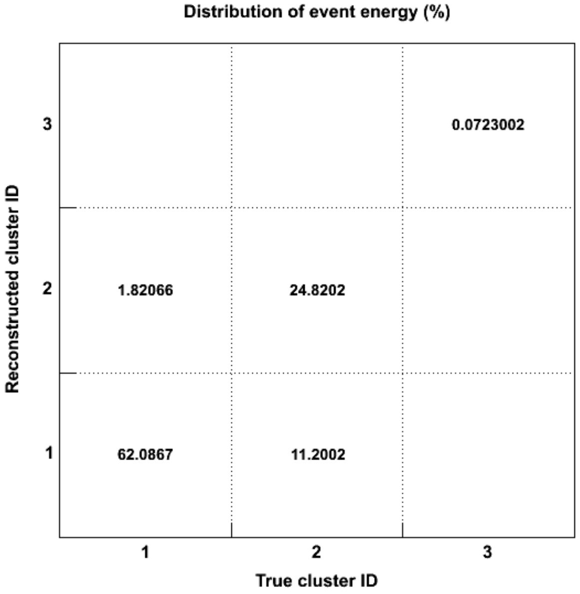
[C.Ainsley]

Testing the performance of the algorithm (3)

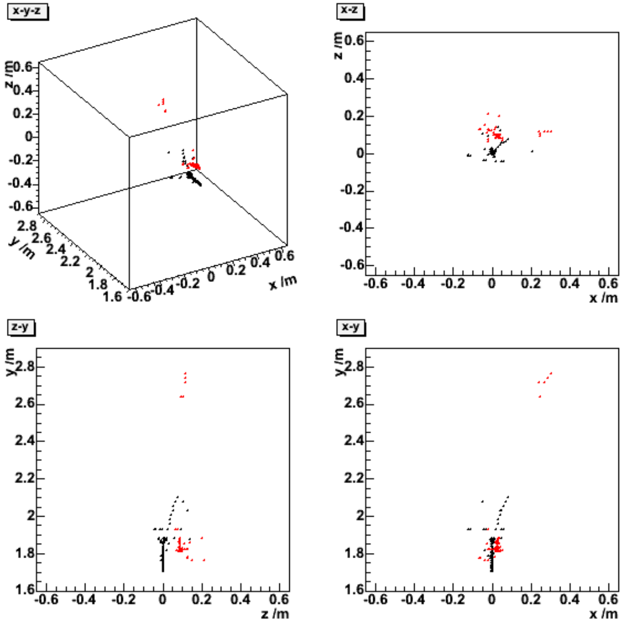
π^+ vs. n for RPC Hcal

Reconstructed clusters





True clusters



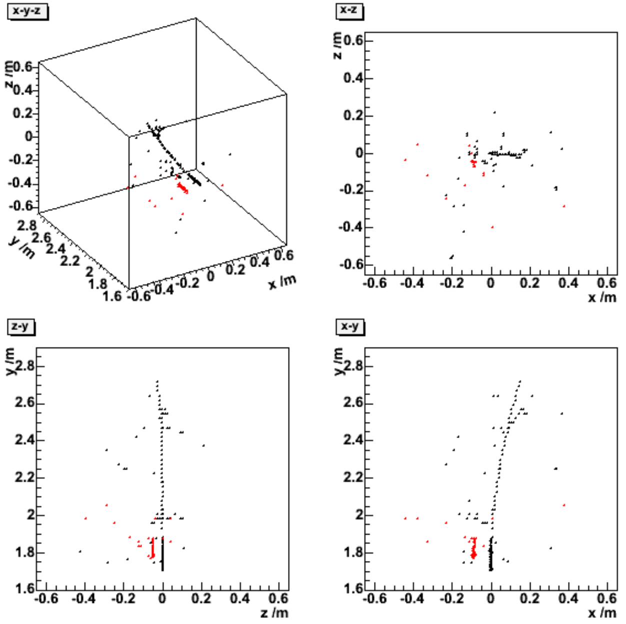
- π^+ / n at 10 cm separation: (analogue) **Si/W Ecal**, (digital) **rpc/Fe Hcal** (Mokka "**D09**" model).
- Cluster energies calibrated according to:

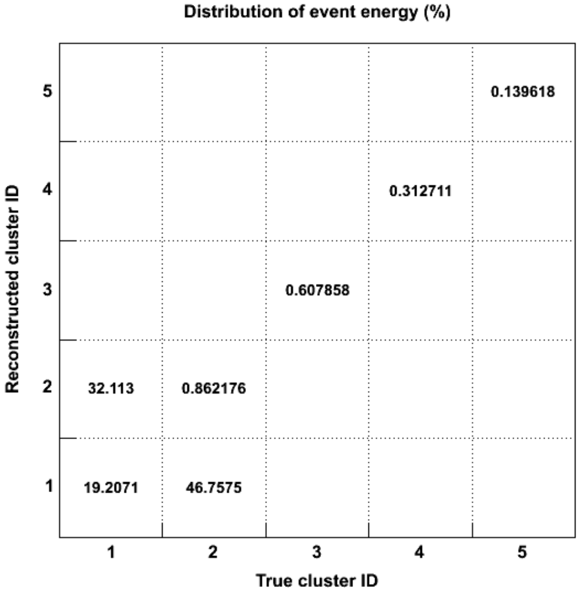
  $$E = \alpha[(E_{\text{Ecal; 1-30}} + 3E_{\text{Ecal; 31-40}})/E_{\text{Ecal mip}} + 20N_{\text{Hcal}}]\ \text{GeV}.$$
- Hits map mostly ***black*** ↔ ***black*** **(π^+)** and ***red*** ↔ ***red*** **(n)** between reconstructed and true clusters.
- Fraction of event energy in 1:1 correspondence = **62.1 + 24.8 + 0.1 = 87%**.

Testing the performance of the algorithm (4)

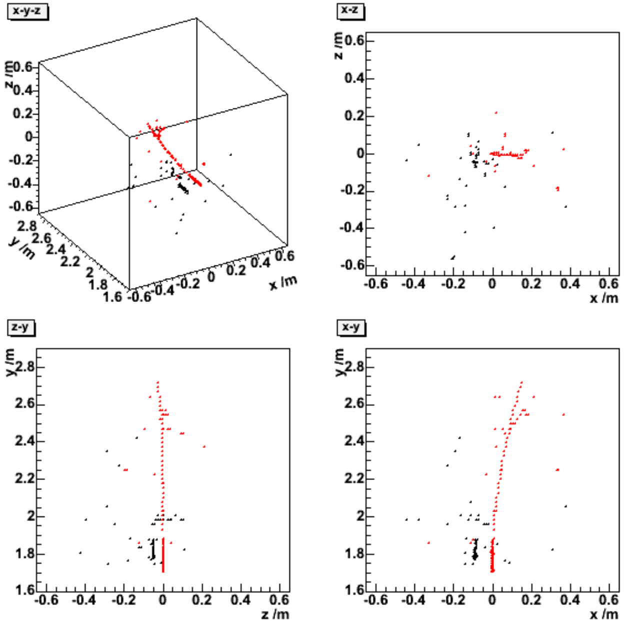
π^+ vs. n for Scint.Hcal

Reconstructed clusters





True clusters



- π^+ / **n** at 10 cm separation: (analogue) **Si/W Ecal**, (analogue) **scint./Fe Hcal** (Mokka "**D09Scint**" model).
- Cluster energies calibrated according to:

$$E = \alpha[(E_{\text{Ecal; 1-30}} + 3E_{\text{Ecal; 31-40}})/E_{\text{Ecal mip}} + 5E_{\text{Hcal}}/E_{\text{Hcal mip}}] \text{ GeV.}$$

- Hits map mostly ***black*** ↔ ***red*** **(π^+)** and ***red*** ↔ ***black*** **(n)** between reconstructed and true clusters.
- Fraction of event energy in 1:1 correspondence = **46.8 + 32.1 + 0.6 + 0.3 + 0.1 = 80%**.

Monolithic Active Pixel Sensors

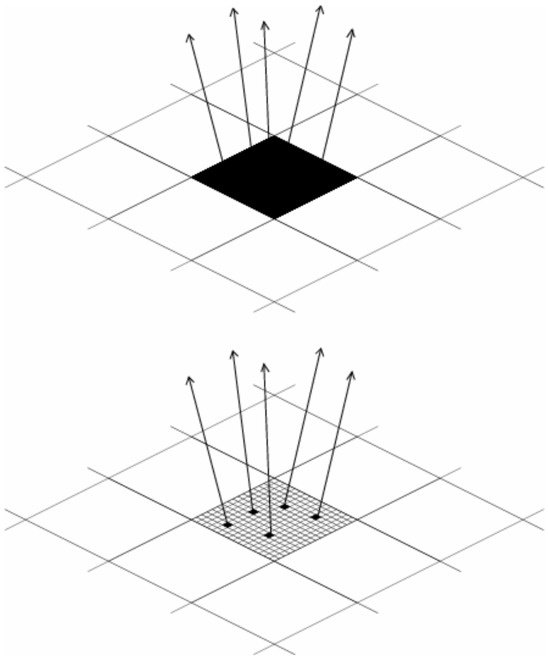
- Who?
  - Birmingham, Imperial, RAL ID, RAL PPD
- Why?
  - Alternative to standard silicon diode pad detectors in ECAL
  - Potential to be cheaper and/or better

Digital ECAL

- What?
  - Attempt to prove or disprove “MAPS-for-ECAL” concept over next 3 years

- Two-pronged approach: hardware…
  - Two rounds of sensor fabrication and testing, including cosmics and sources
  - Electron beam test, to check response in showers and single event upsets
- …and simulation
  - Model detailed sensor response to EM showers and validate against hardware
  - Simulate effect on full detector performance in terms of PFLOW

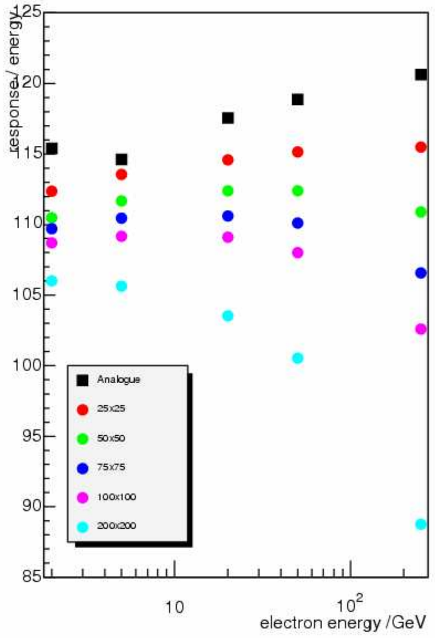
Basic concept for ECAL



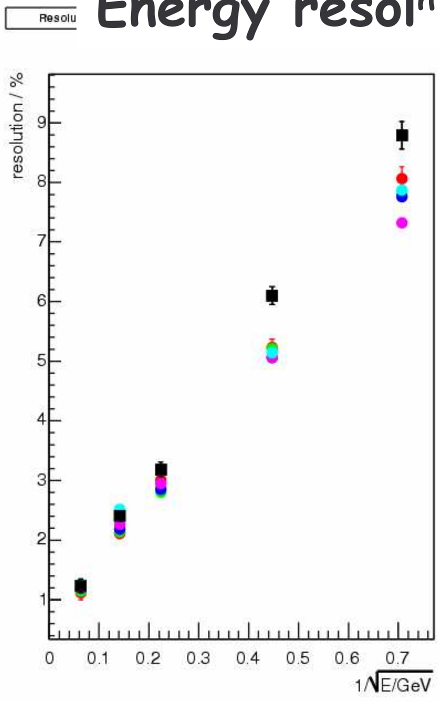
- Replace 1×1 cm^2 diode pads with much smaller pixels
  - Make pixels small enough that at most one particle goes through each
  - Then only need threshold to say if pixel hit or not; “binary” readout, i.e. DECAL

- How small is small?
  - EM shower core density at 500GeV is ~100/mm^2
  - Pixels must be < 100×100μm^2; working number is 50×50μm^2
  - Gives ~10^{12} pixels for ECAL!

Energy linearity



Energy resol^n



MAPS 50 x 50
micron pixels

ZOOM

SiD 16mm area
cells

Occupancy in SiD

- Implemented 3 MAPS variants (within sidaug05_np)
- Pixel sizes: 25x25, 50x50 and 100x100 microns

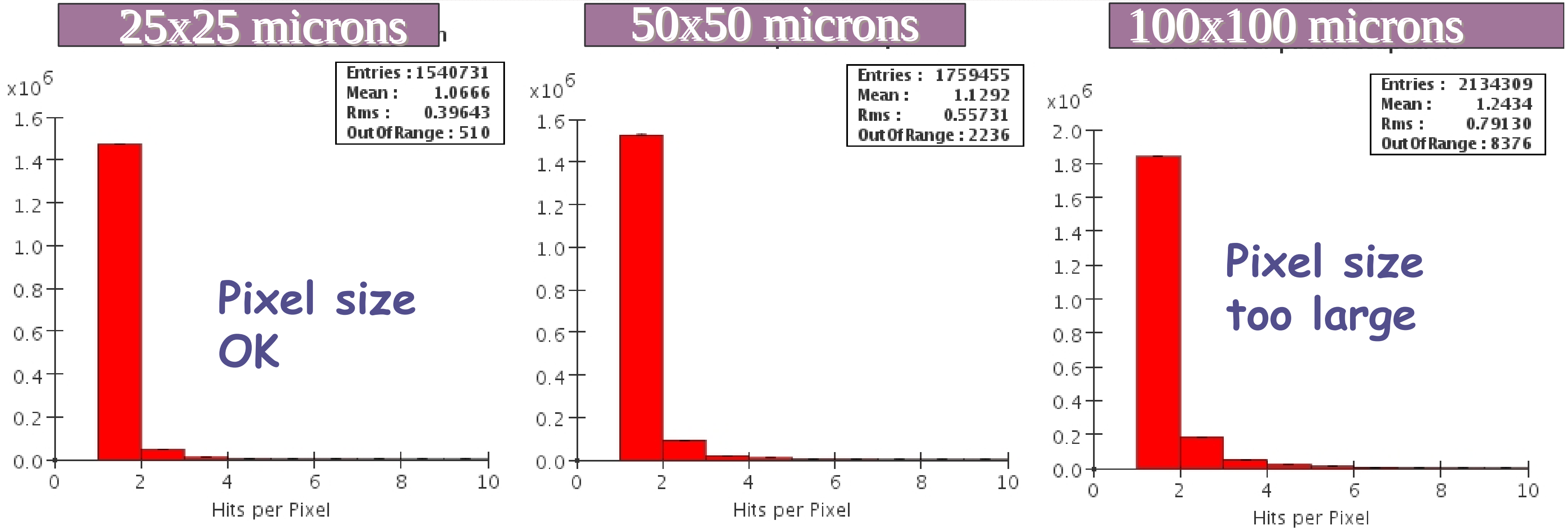
```
<readout name="EcalBarrHits">
        <segmentation type="NonprojectiveCylinder" gridSizePhi="0.05" gridSizeZ="0.05" />
        <id>layer:6,system:6,phi:20,barrel:32:3,z:-20</id>
    </readout>
```

Change order of bit assignation

Set pixel size (mm)

- Find new MIP threshold, since new epitaxial thickness.... = 1.6 KeV

Example pixel occupation study, 250GeV electrons



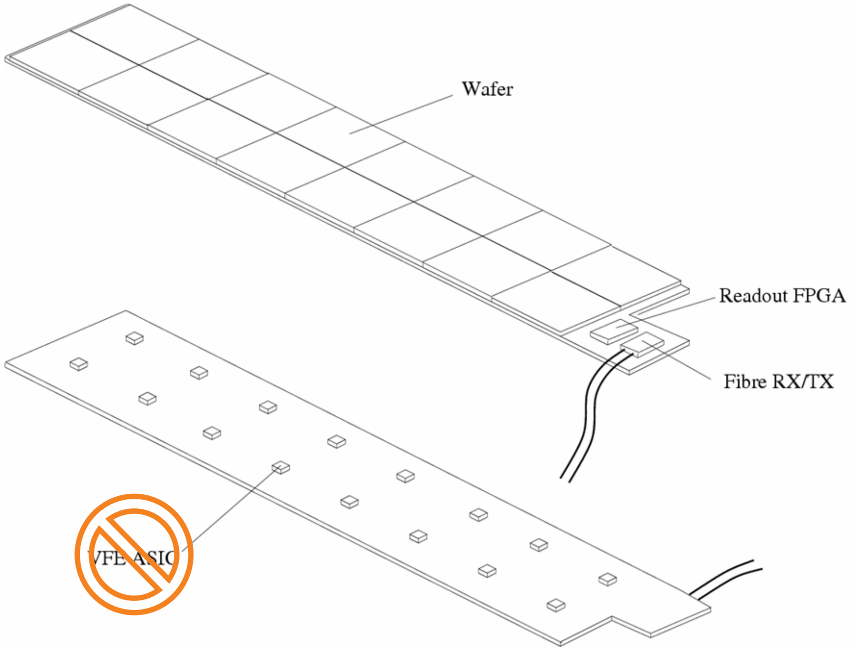
25x25 microns

50x50 microns

100x100 microns

ECAL as a system

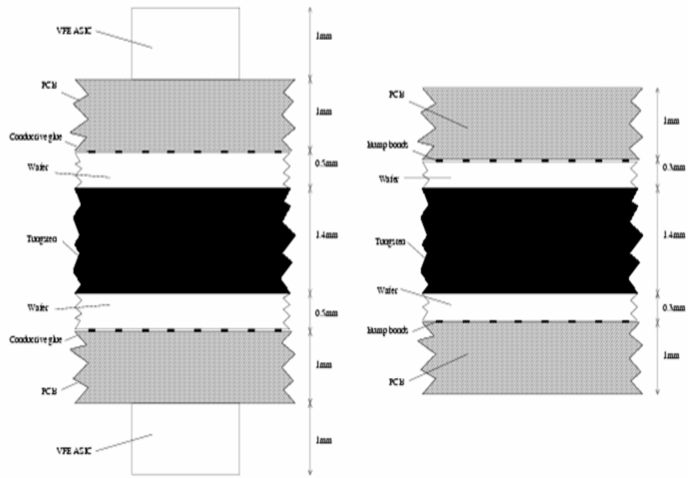
- Replace diode pad wafers and VFE ASICs with MAPS wafers
  - Mechanically very similar; overall design of structure identical
  - DAQ very similar; FE talks to MAPS not VFE ASICs
    - Both purely digital I/O, data rates within order of magnitude



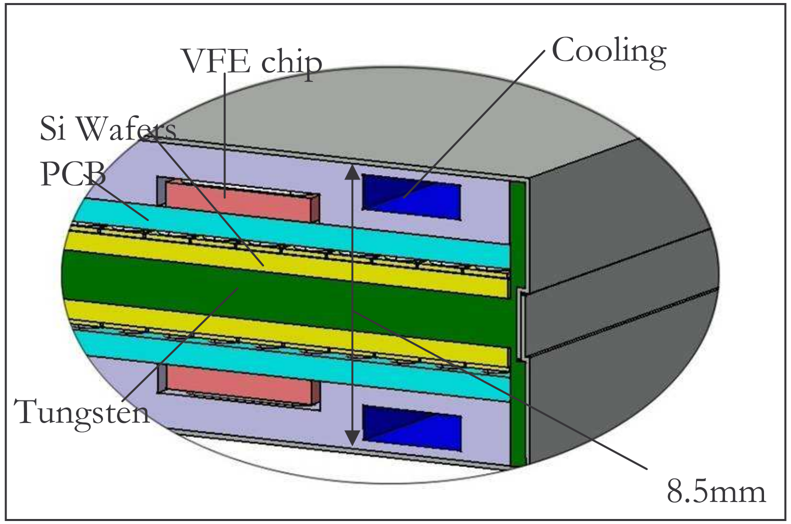
- Aim for MAPS to be a “swap-in” option without impacting too much on most other ECAL design work
- Requires sensors to be glued/solder-pasted to PCB directly
  - No wirebonds; connections must be routed on sensor to pads above pixels
  - New technique needed which is part of our study

Potential advantages

- Slab thinner due to missing VFE ASICs
  - Improved effective Moliere radius (shower spread)
  - Reduced size (=cost) of detector magnet and outer subdetectors



6.4mm thick 4.0mm thick



- Thermal coupling to tungsten easier
  - Most heat generated in VFE ASIC or MAPS comparators
  - Surface area to slab tungsten sheet ~1cm^2 for VFE ASIC, ~100cm^2 for final MAPS

- **COST!** Standard CMOS should be cheaper than high resistivity silicon
  - No crystal ball for 2012 but roughly a factor of two different now
  - TESLA ECAL wafer cost was 90M euros; 70% of ECAL total of 133M euros
  - That assumed 3euros/cm^2 for 3000m^2 of processed silicon wafers

Other requirements

- Also need to consider power, uniformity and stability
  - Power must be similar (or better) that VFE ASICs to be considered
    - Main load from comparator; ~2.5µW/pixel when powered on
    - Investigate switching comparator; may only be needed for ~10ns
    - Would give averaged power of ~1nW/pixel, or 0.2W/slab
    - There will be other components in addition
    - VFE ASIC aiming for 100µW/channel, or 0.4W/slab
  - Unfeasible for threshold to be set per pixel
    - Prefer single DAC to set a comparator level for whole sensor
    - Requires sensor to be uniform enough in response of each pixel
    - Possible fallback; divide sensor into e.g. four regions
  - Sensor will also be temperature cycled, like VFE ASICs
    - Efficiency and noise rate must be reasonably insensitive to temperature fluctuations
    - More difficult to correct binary readout downstream

Planned programme

- Two rounds of sensor fabrication
  - First with several pixel designs, try out various ideas
  - Second with uniform pixels, iterating on best design from first round
- Testing needs to be thorough
  - Device-level simulation to guide the design and understand the results
  - “Sensor” bench tests to study electrical aspects of design
  - Sensor-level simulation to check understanding of performance
  - “System” bench tests to study noise vs. threshold, response to sources and cosmics, temperature stability, uniformity, magnetic field effects, etc.
  - Physics-level simulation to determine effects on ECAL performance
- Verification in a beam test
  - Build at least one PCB of MAPS to be inserted into pre-prototype ECAL
  - Replace existing diode pad layer with MAPS layer
  - Direct comparison of performance of diode pads and MAPS

Summary

- 1st test beam run very smooth, 14/30 ECAL
- 2nd run, 30 layers, Jan. 2006@DESY
- Spring/summer 2006, incl HCAL, @ CERN or FNAL
- PPARC funding for next 3.5 years, from 10/2005
  - ~6 month delay, 5 iterations,2 committees… total ~£2.5M
  - Success in EU FP6 funding (EUDET), thanks to UCL, ~€0.32M
- Strong and increasing effort in all of
  - Existing beam tests
  - DAQ
  - MAPS (digital Ecal)
  - Thermal/Mechanical
  - Simulation/algorithms/global design
- Back to work!