CALICE: A calorimeter for the ILC

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- **Introduction and physics motivation for the calorimeter**
- **General design of the calorimeter**
- **Physics prototypes**
- **Data from physics prototypes**
- **R&D in CALICE-UK**

Introduction

Introduction

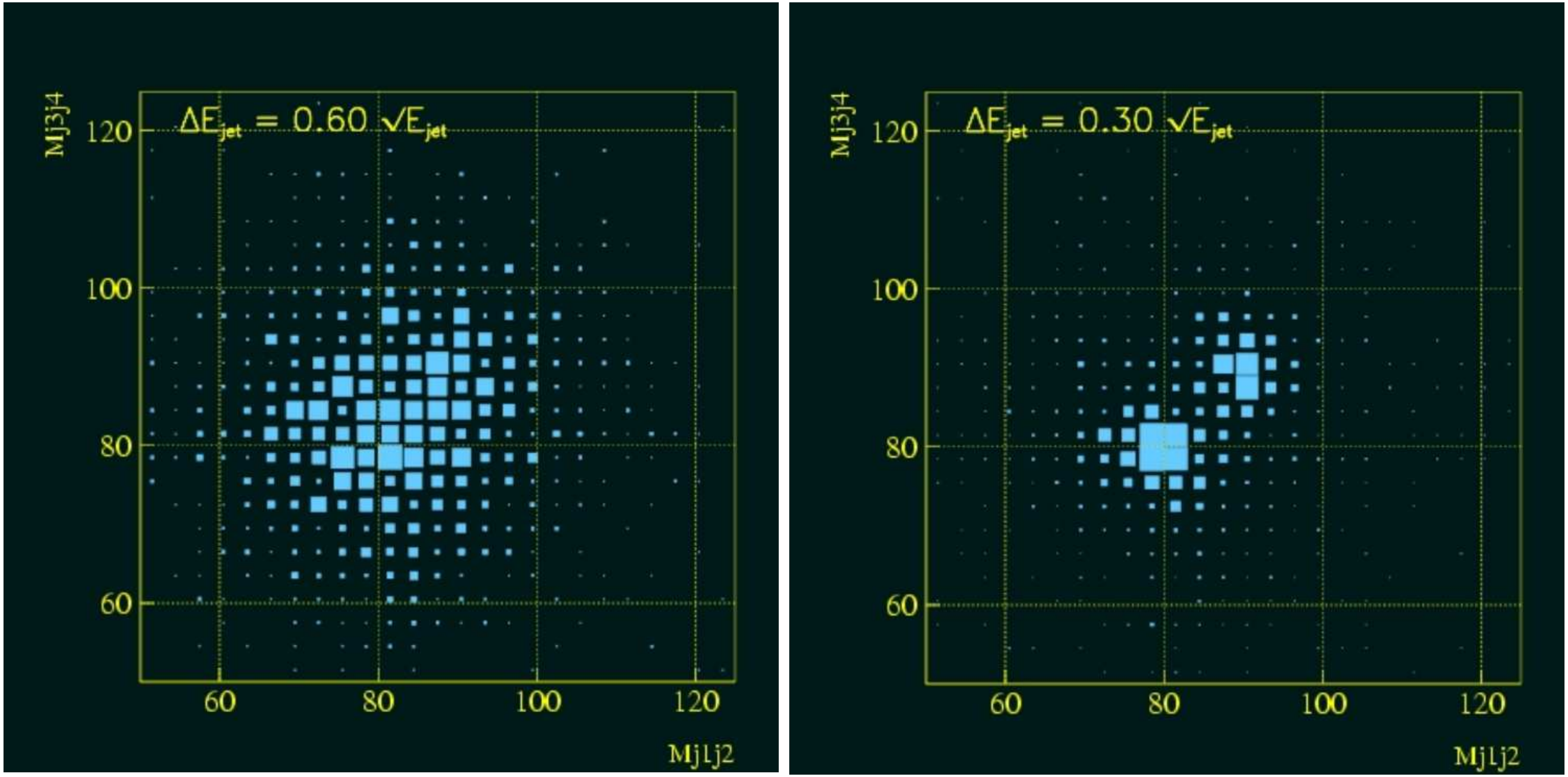
Many interesting physics results need an excellent calorimeter: 6-jet events, SUSY scans, WW/ZZ separation, etc..

Need to be able to reconstruct the final state, particularly jets, accurately

Want a calorimeter with excellent jet energy resolution:

- **good intrinsic energy resolution**
- **excellent spatial resolution**

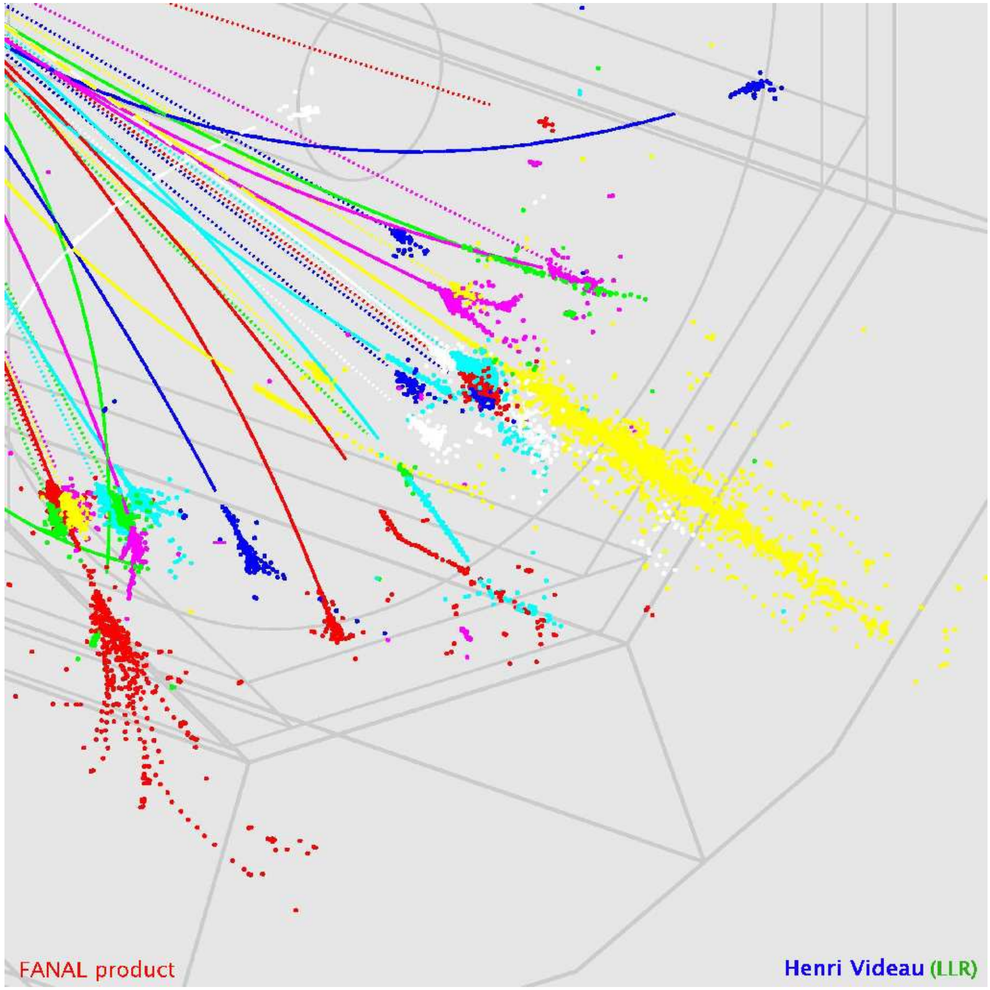
A high-resolution calorimeter

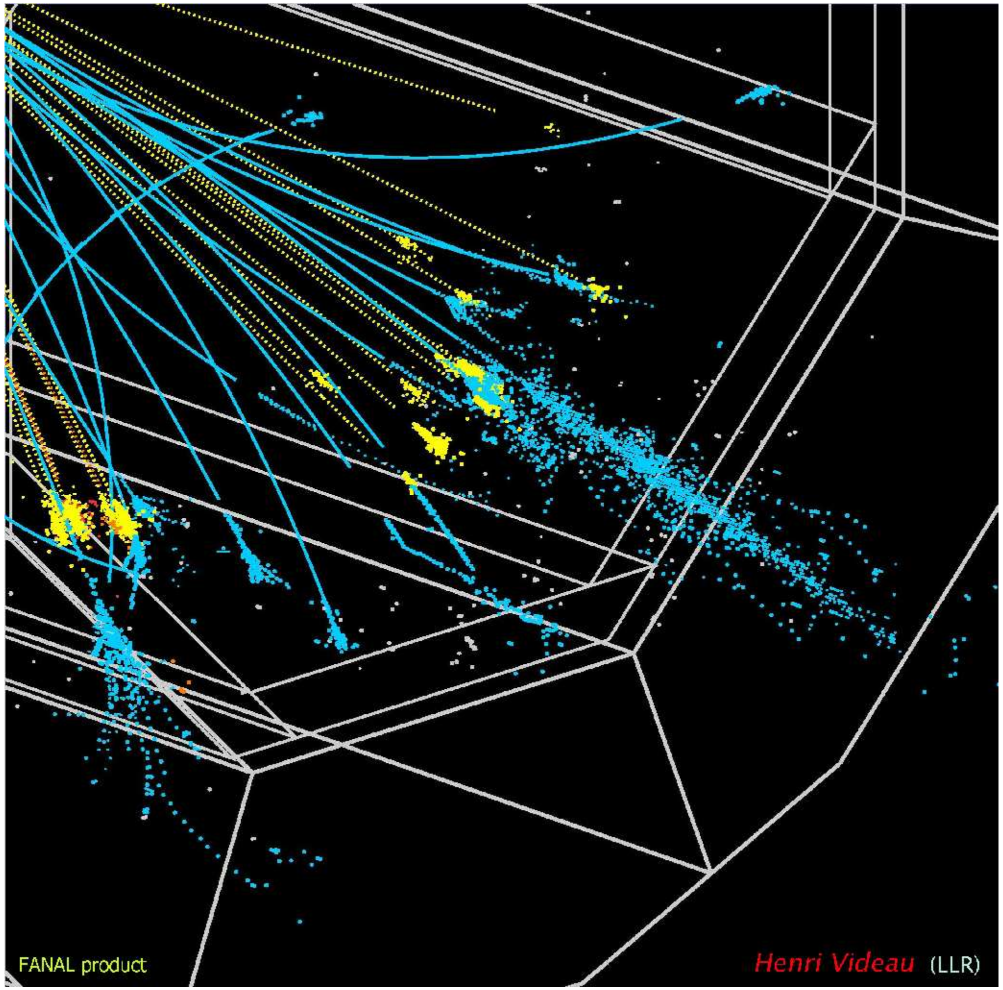


ZZ/WW **discrimination in calorimeter**

A tracking calorimeter

Truth $\longrightarrow$ **Reconstructed**





CALICE calorimeters

CALICE and its calorimeters

CALICE is a collaboration of 200 physicists/engineers from 35 institutes, from Europe, US and Asia.

Focus on high granularity, optimised for energy flow (65% charged particles, 25% photons, 10% neutral hadrons).

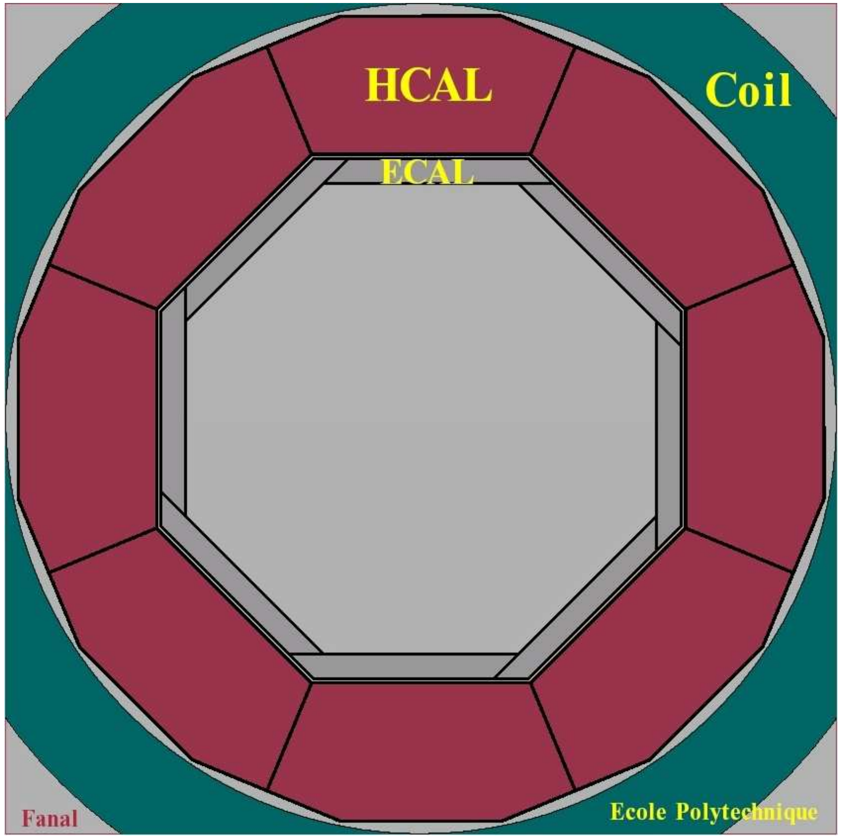
ECAL: Si-W with ($<$) 1 $\times$ 1 cm^2 pads and up to 40 layers

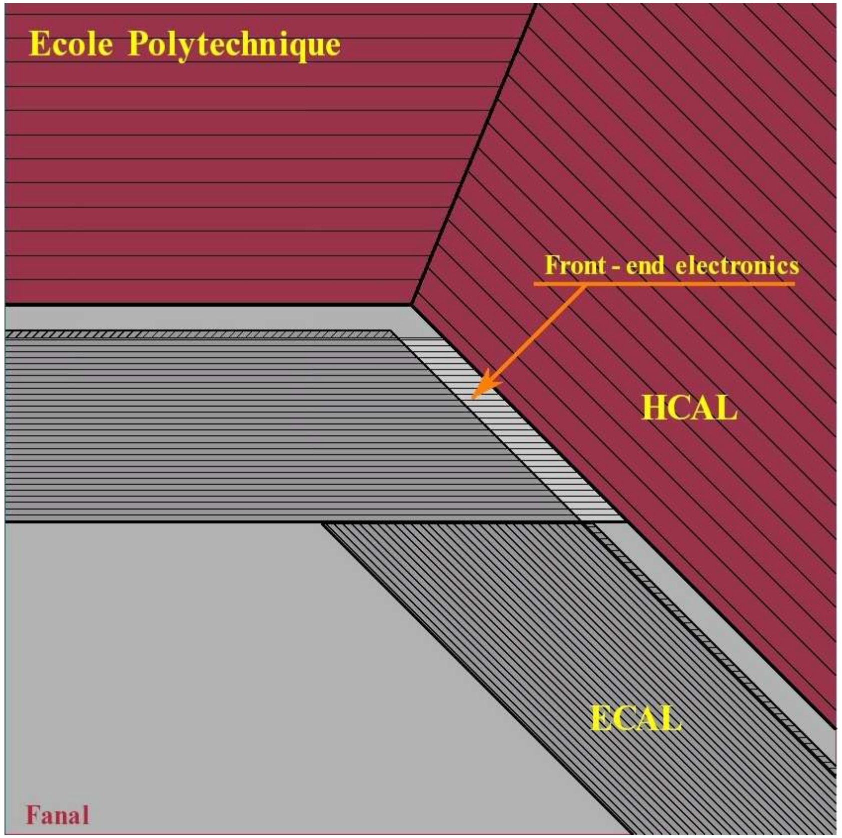
Analogue HCAL: Scintillating tiles ($\geq$ 3 $\times$ 3 cm^2) and Fe

Digital HCAL: 1 $\times$ 1 cm^2 cells - RPCs or GEMs

“Semi-digital” HCAL

Layout of calorimeters

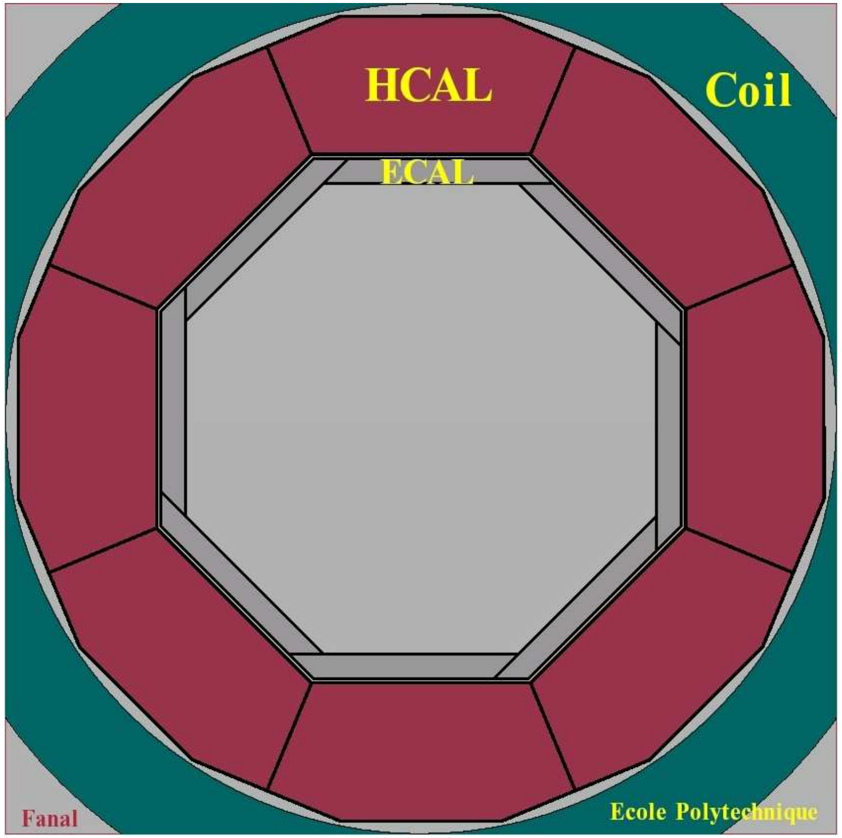


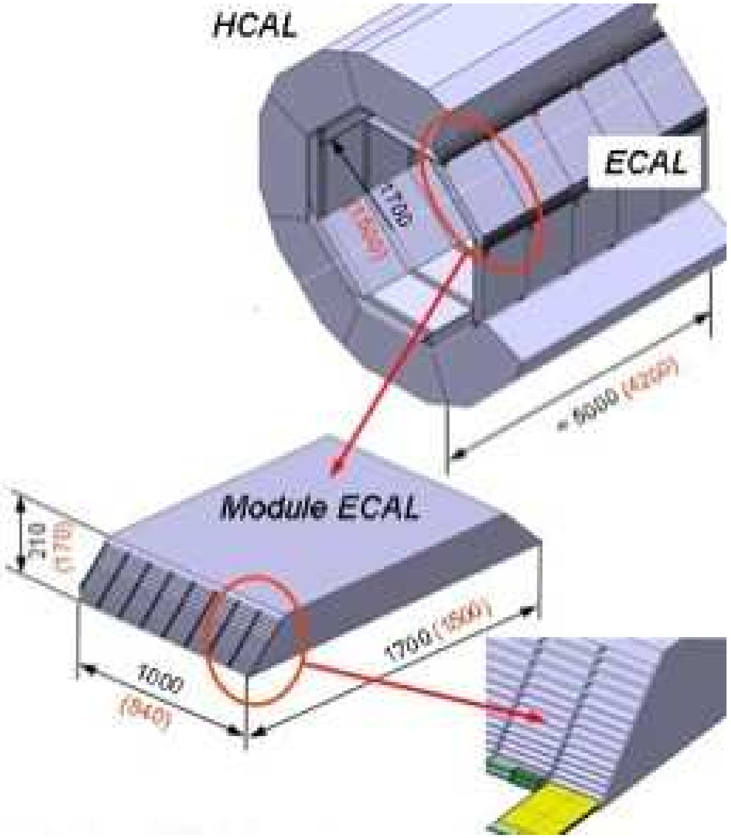


Calorimeters within magnetic coil

Compact: very small space for electronics and cooling

Layout of ECAL





6000 slabs, length $\sim$ 1.5 m, each containing 4000 silicon pads.

Small $X_0 \sim$ 3.5 mm

Small Molière radius $\sim$ 9 mm.

Calorimeter modelling

Principles well-motivated, but will they work?

Large variations in shower models (even for ECAL)

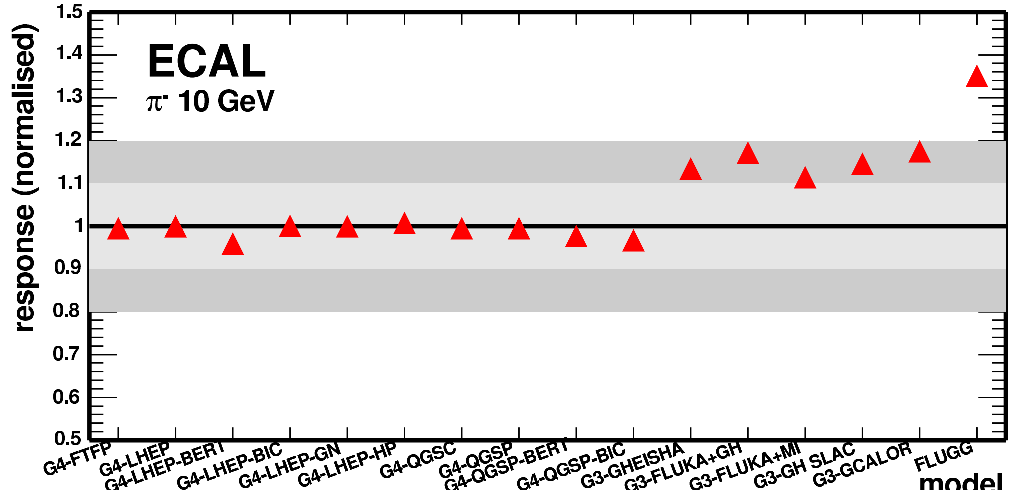
Need for test-beam data

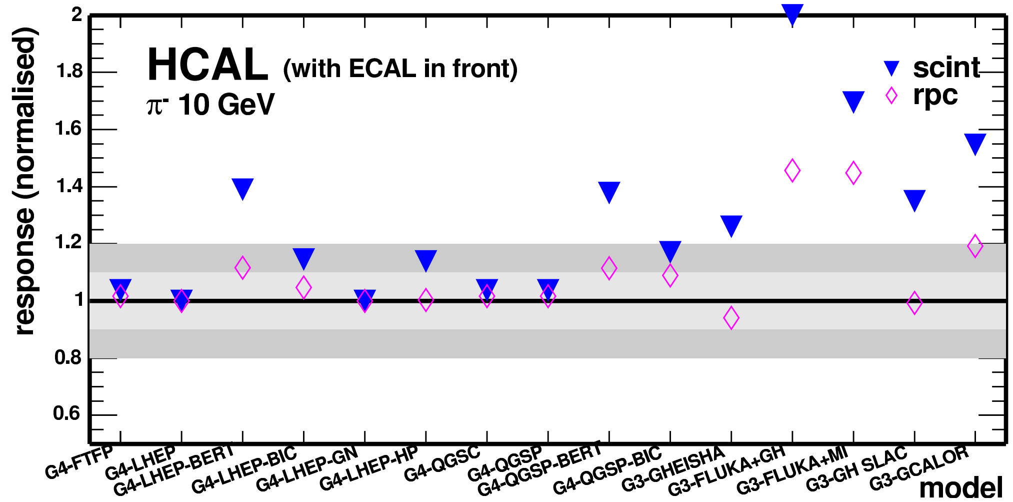
Si-W ECAL $\sim$ 10k channels

Tile-Fe AHCAL $\sim$ 8k channels

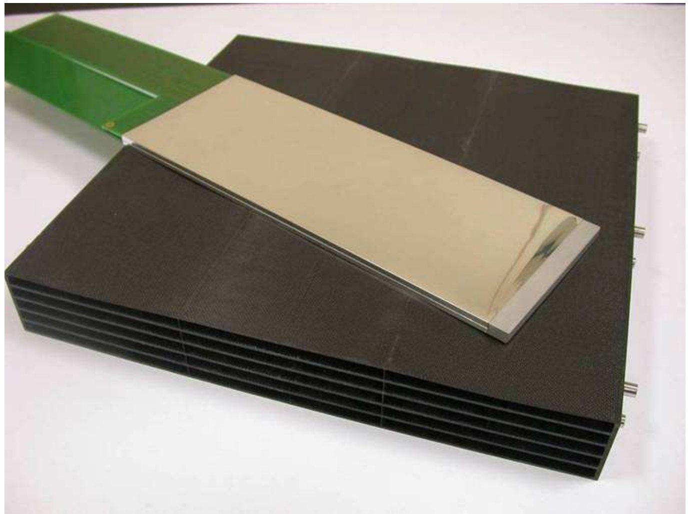
RPC/GEM-iron DHCAL $\sim$ 380k channels

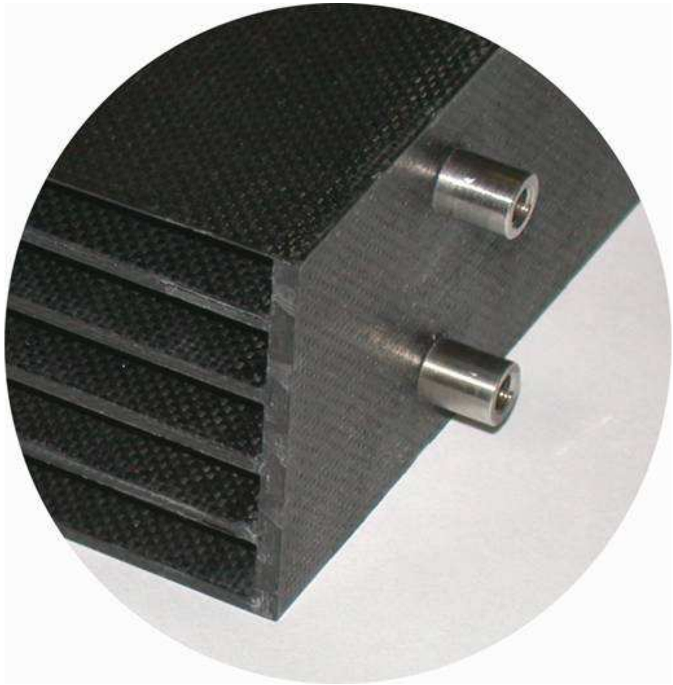
Beam tests 2005-7

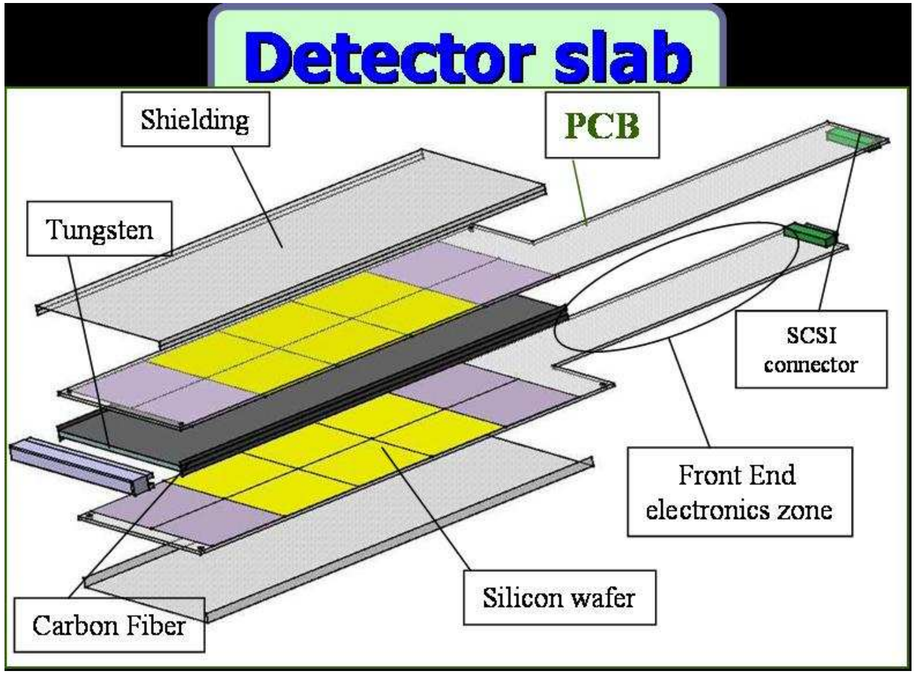




Structure of ECAL pre-prototype

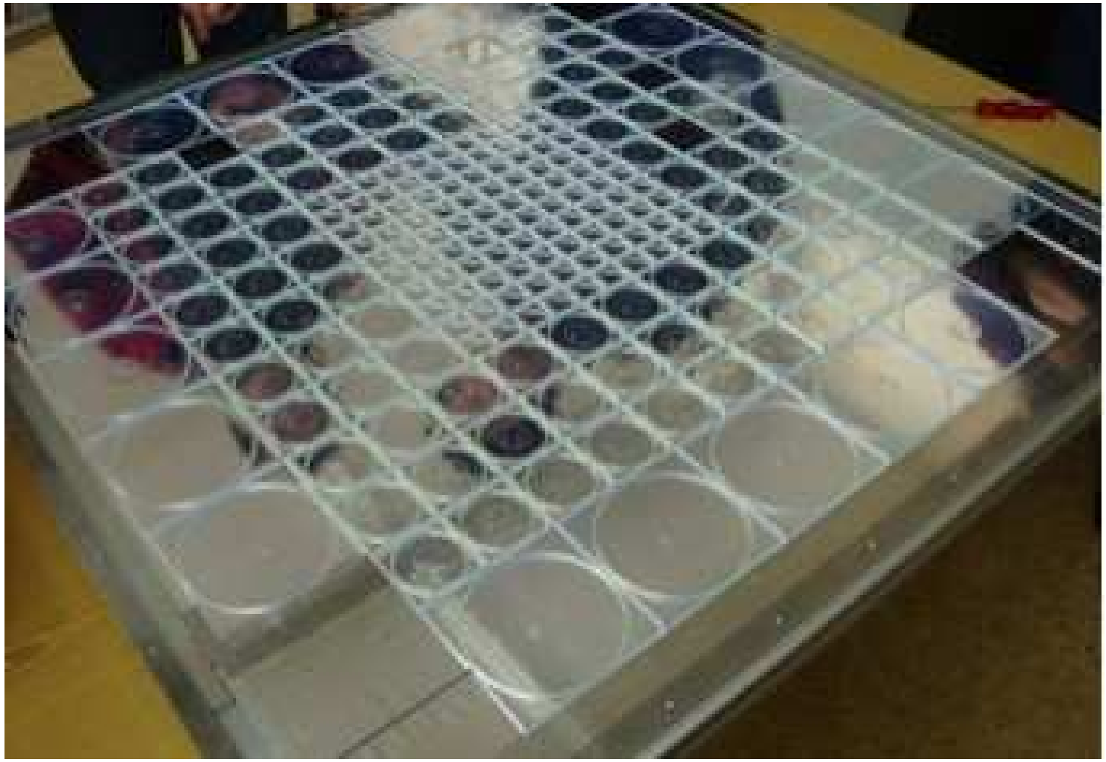


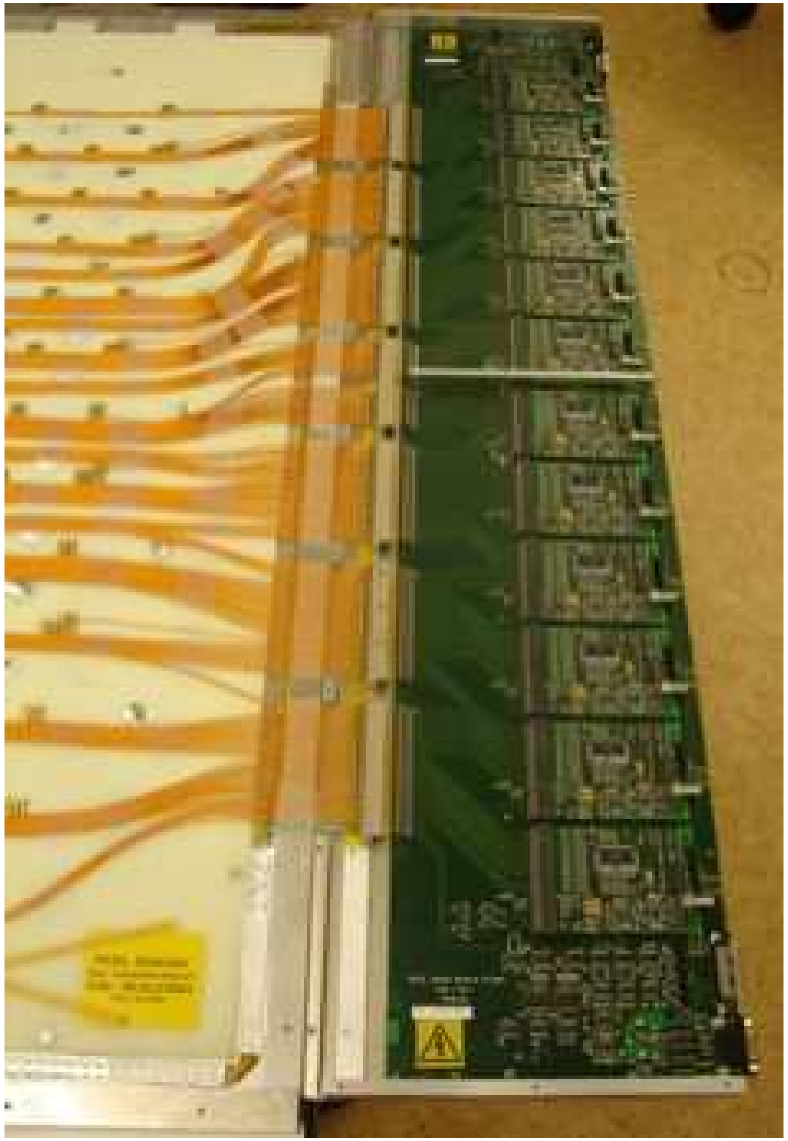




ECAL in test beam area at DESY

AHCAL structure





1 m^3, 38 layers, Tiles 3 $\times$ 3 cm^2 to 12 $\times$ 12 cm^2

Modified ECAL ASIC, same connector as ECAL

DHCAL technologies

Binary readout of 1 $\times$ 1 cm^2 cells

- **GEMs: lower operation voltage, flexible technology**
- **RPCs: robustness and larger signals**

Same electronics to be used for both options (gain switch on pre-amp. to handle smaller GEM signals)

May use AHCAL readout - US funding dictating production

Same mechanical support for AHCAL and DHCAL. Movable table compatible with CERN and FNAL.

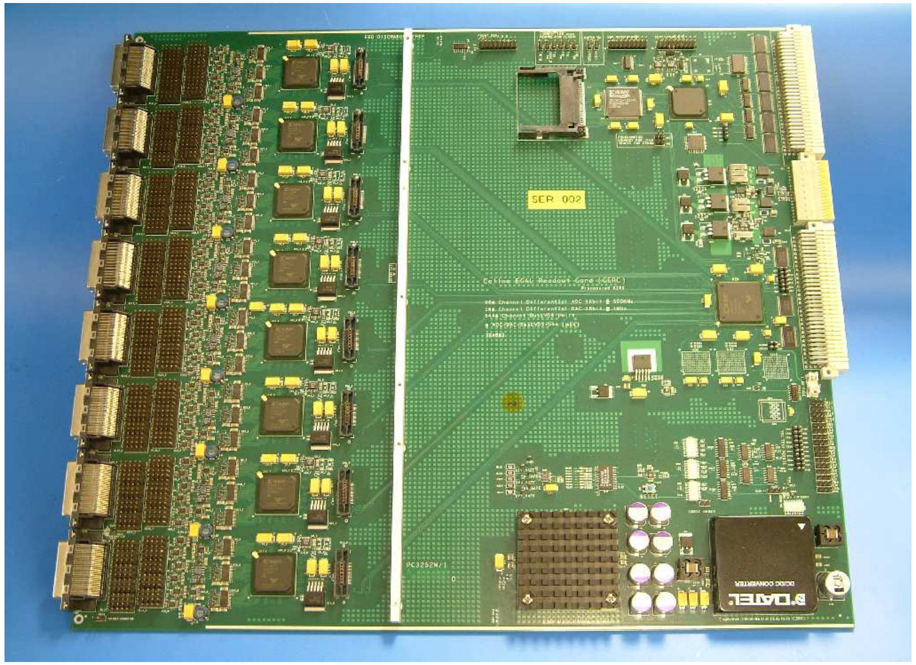
CALICE-UK contribution

Calice Readout Card (based on CMS tracker front-end driver board).

Receives analogue data from up to 96 ASICs, digitises and buffers up to $\sim$ 2000 events. Controls trigger.

AHCAL and Tail-catcher use CRCs as well.

UK responsible for all VME readout.



DAQ online system: Crate $\rightarrow$ DAQ CPU $\rightarrow$ Offline CPU

Simulation and software development (see earlier and later)

Test beam plan

Ran ECAL with 14 layers Jan-Mar 2005 at DESY (1–6 GeV electrons) $\longrightarrow$ first data

Next stage to start in May for 3 weeks: more layers, with HCAL

Move to CERN for three stages:

- **ECAL only with high-energy electron beam in July (2 weeks)**
- **AHCAL only in August (2 weeks)**
- **Combined tests in October (2 weeks)**

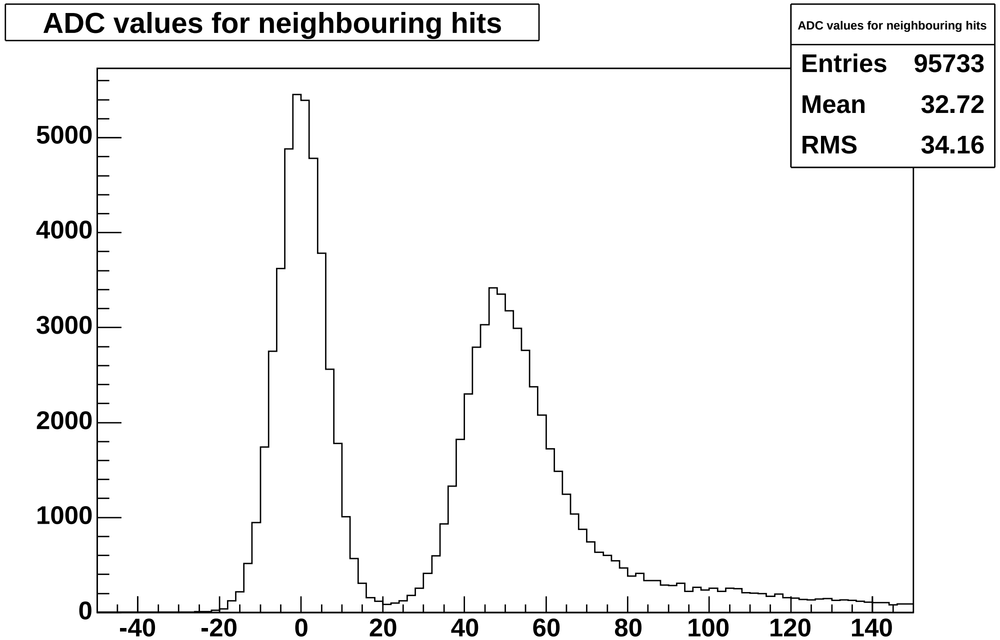
ECAL/AHCAL/DHCALs/Tail catcher at Fermilab during 2007

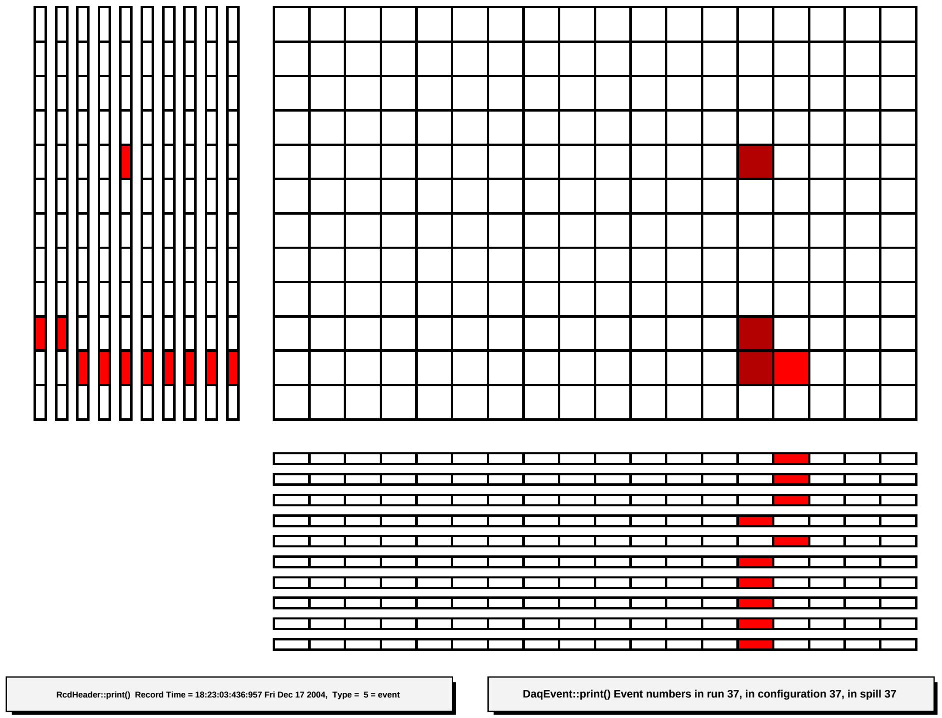
First data

Cosmic muon

First cosmic tests in December 2004.

MIP peak seen above pedestal, S/N $\sim$ 9:1.



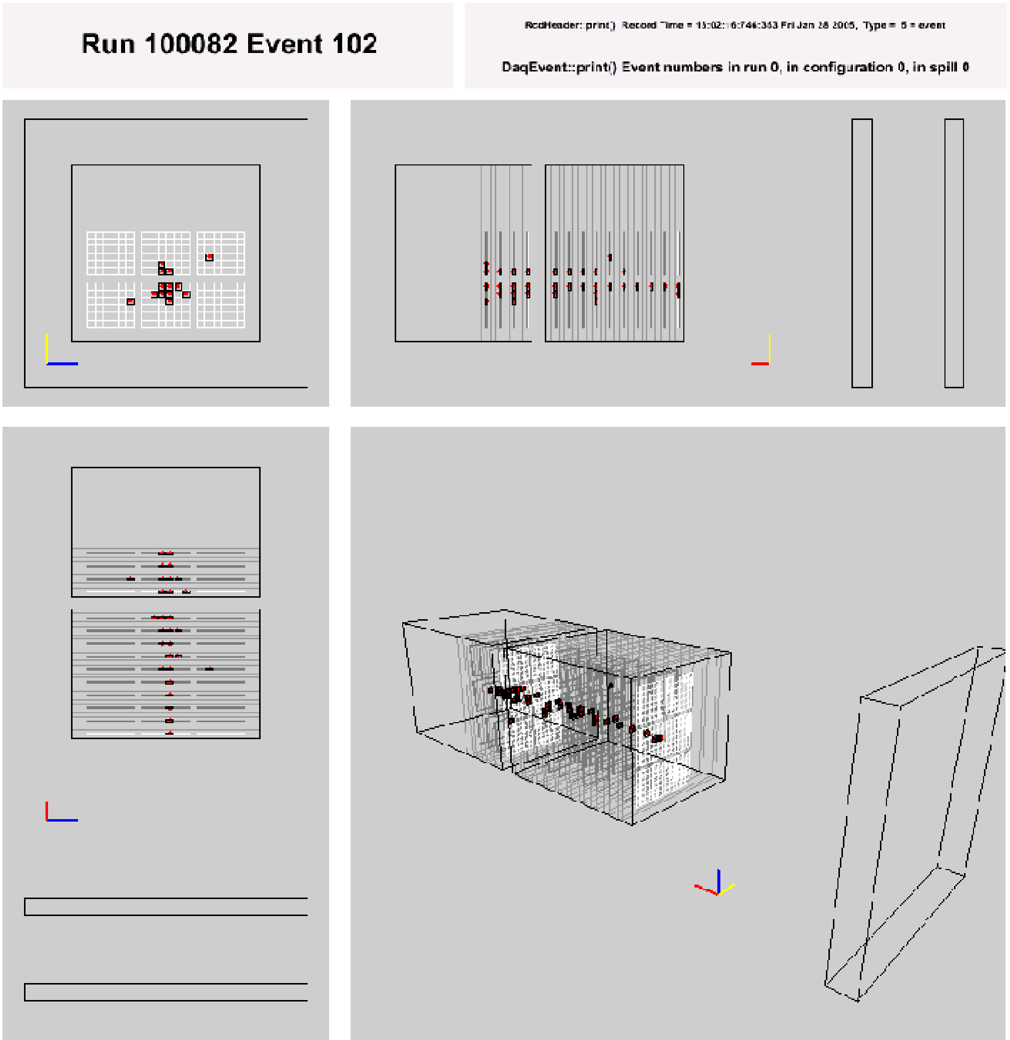


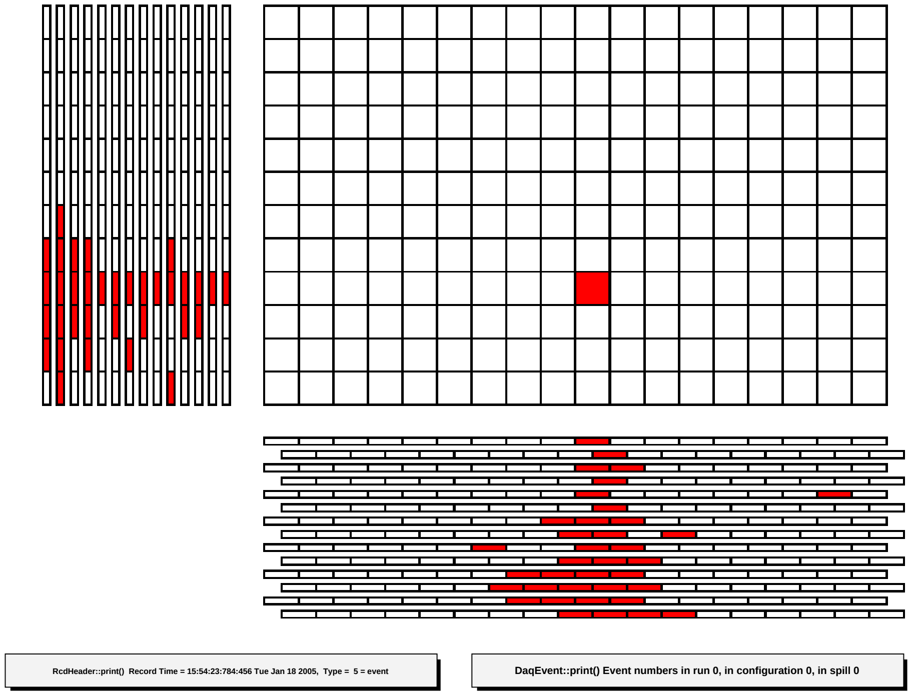
Electron beam event

1-6 GeV electron beam

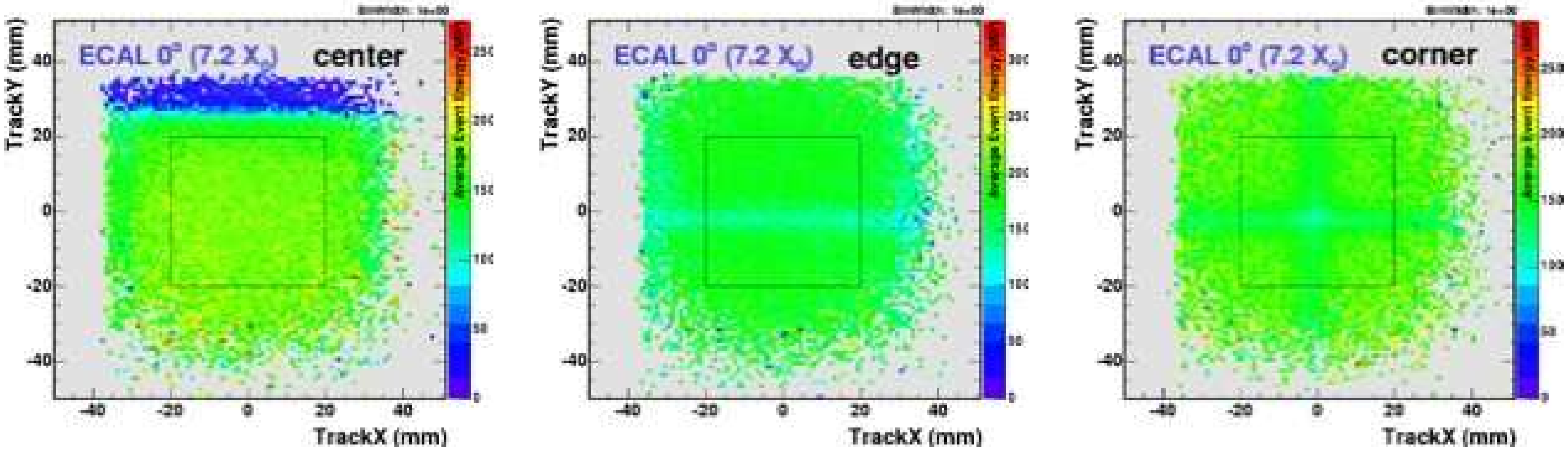
14 layers, 3024 channels

Different energies, angles of incidence, centred on pads, on edges





Position and its resolution

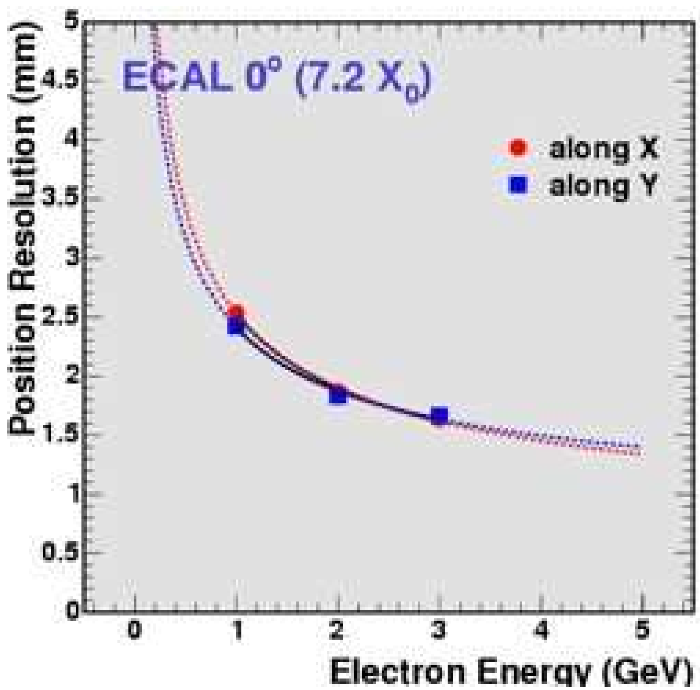


Response across the inter-wafer gap

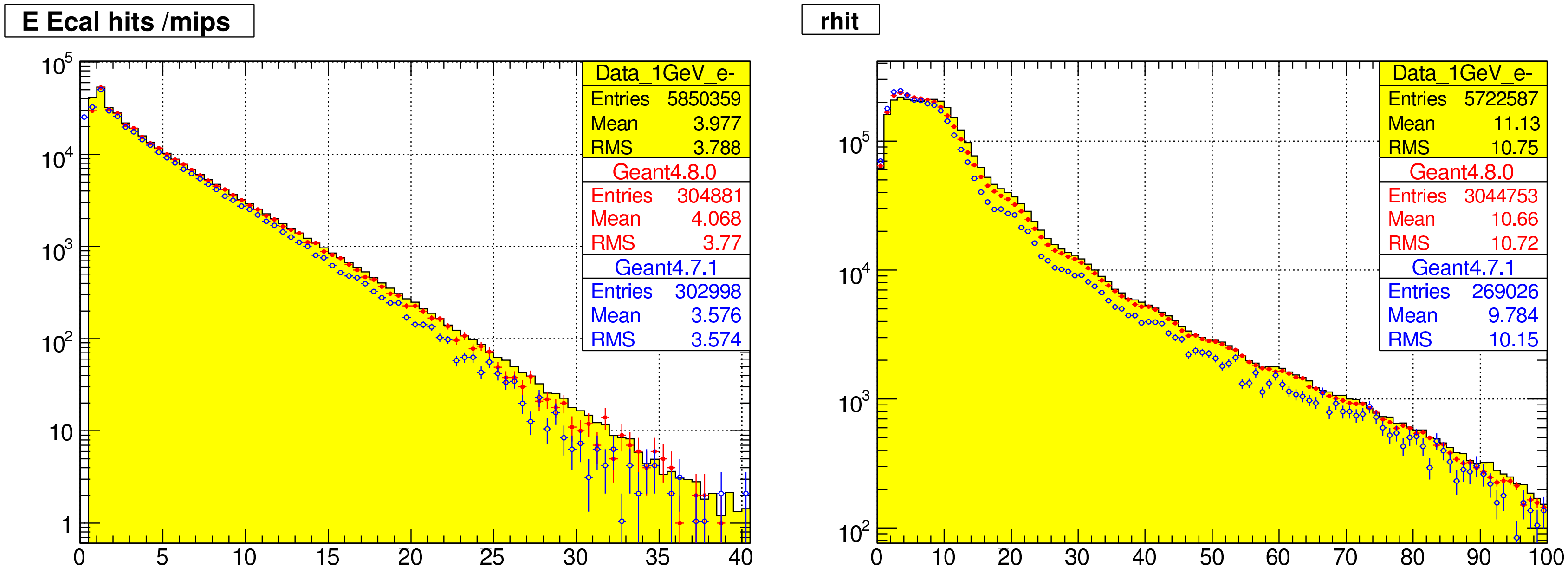
Energy weighted position per layer

Use whole shower to give electron entry position and compare with tracker

Resolution a few mm



Comparison with GEANT models



Poor description by GEANT 4.7.1. Improved by changing tracking cut-off to 200 nm (20 times slower).

Fixed in GEANT 4.8.0 which gives a much better description of the data.

Data impacting already on constraining models.

Future and current (UK) R&D

Next steps for CALICE

First priority is to have successful beam-tests with all calorimeters and understanding of detectors and simulations

Award of EU money for project EUDET will allow us to build technical (real) prototypes, i.e. scalable parts of the detector

Current ideas:

- build module structure (can be used by other designs)
- instrumented ECAL 1.5 m slab and 30 layer tower (30×12 cm).
- instrumented HCAL 2 m slab and 38 layer tower
- common electronics and DAQ architectures

Future R&D

Award of funding from PPARC for October 2005 - March 2009: Birmingham, Cambridge, Imperial, Manchester, RAL EID/PPD, RHUL, UCL

- **Completion of test-beam programme**
- **Data acquisition**
- **Monolithic active pixel sensors (MAPS)**
- **Mechanical and thermal studies**
- **Simulation and physics.**

Also members of EUDET to provide DAQ for upcoming prototypes, January 2006 - December 2009

Test-beam and simulation

- **Complete test-beam programme; maintenance of DAQ electronics, taking and analysing data.**

Use test-beam data and previous simulation work to have an impact on global design studies:

- **Energy-flow algorithms - flexible, generic for comparison between detector designs.**

- **Global detector design - impact decisions on key detector issues (technology, dimensions, etc.).**

- **Support for other workpackages.**

- **Physics studies - establishing benchmark analyses for design issues.**

Data acquisition - general concept

Will be able to build an ECAL DAQ system, but challenging issues exist:

Plan is NOT to build DAQ system now.

Build DAQ for full prototypes and position to build for final system.

Designed DAQ concept (“backplaneless”) and identified bottlenecks in system.

Some of the R&D could lead to changes in the calorimeter design.

Try and do R&D generic enough for, e.g. MAPS, different number of channels.

Use commercially available products instead of traditional bespoke apparatus.

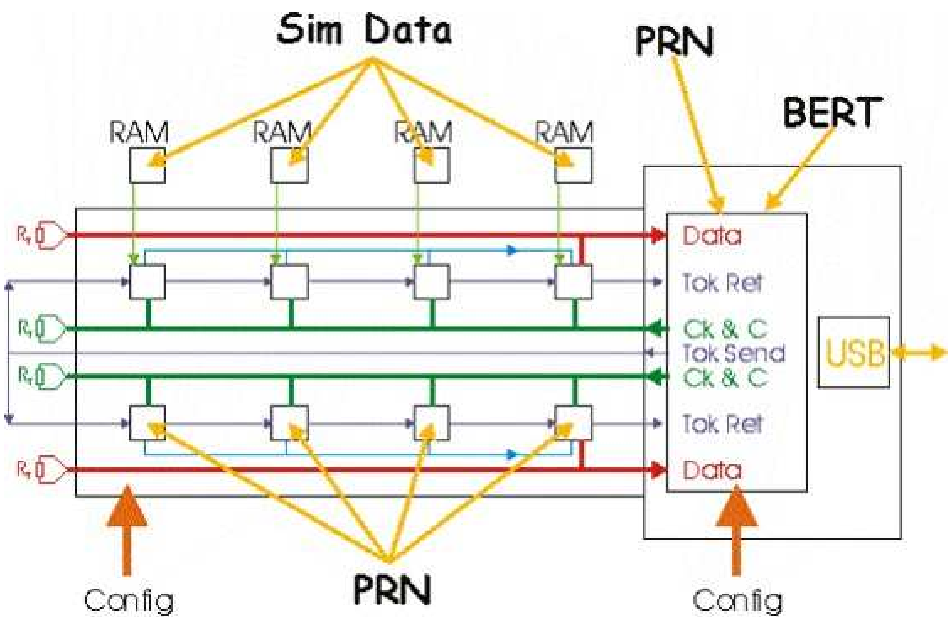
- **Data transportation from ASICs to front-end electronics.**
- **Shipping data off detector to receiver.**
- **Structure of off-detector receiver.**

Data transfer on 1.5 m PCB

Build 1.5 m slab with connected FPGAs to test data transfer.

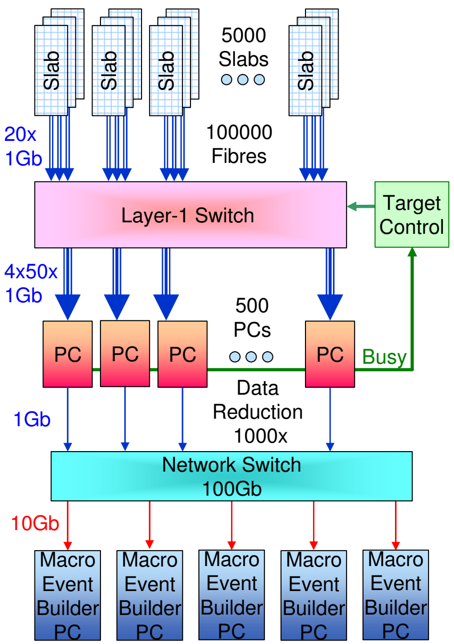
CAD modelling and bench testing

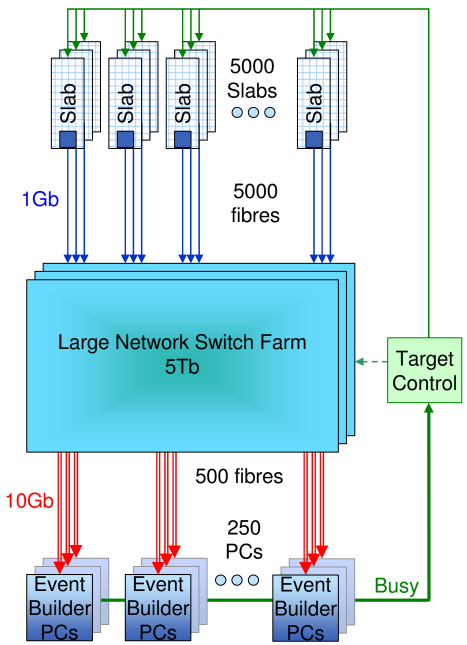
Multiple/single lines, noise, interference, power issues, space between layers, lines for clock and control.

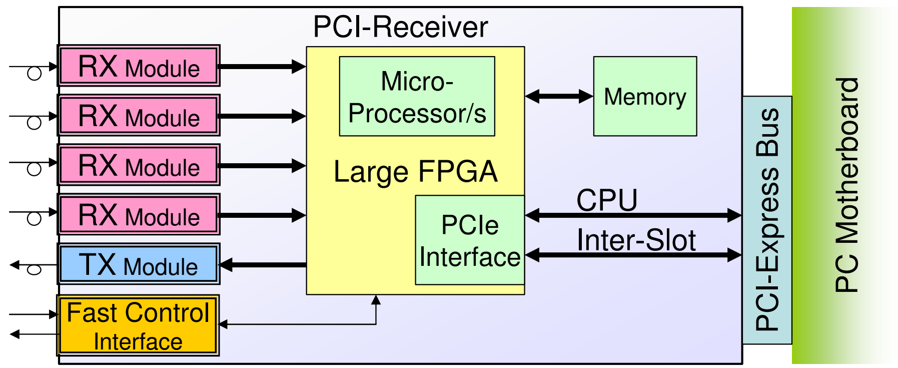


Information to feed into build of technical prototype.

Data off-detector







PCI card is data collector and processor

Optimise different network scenarios

Combination of bench-testing and use practically in technical prototype.

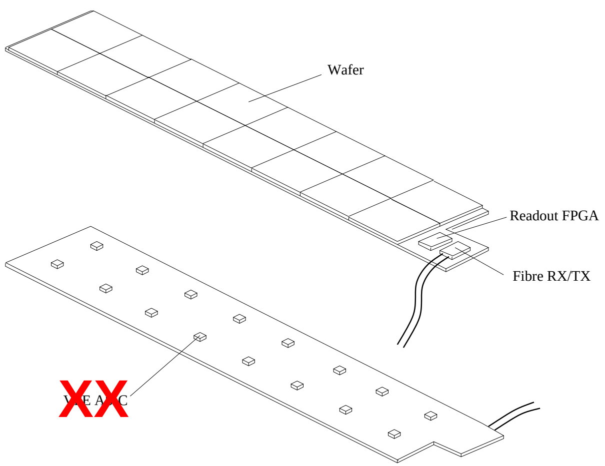
MAPS - a new design

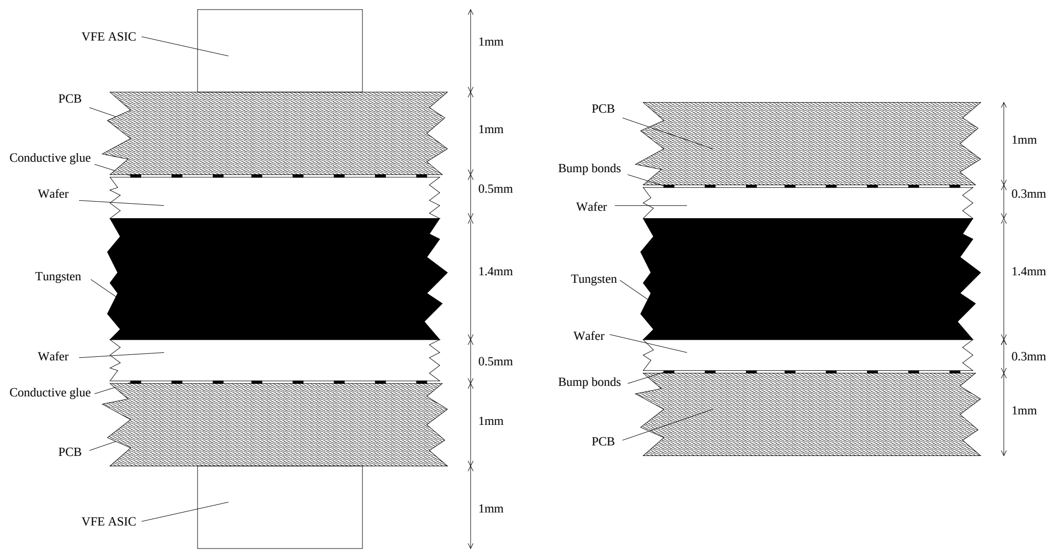
Considering alternative technology which may be cheaper.

Instead of silicon diodes, use Monolithic Active Pixel Sensors (MAPS).

Readout integrated into the MAPS - no need for separate chip.

- **Reduced Molière radius, i.e. better shower containment.**
- **Smaller (radius) ECAL, i.e. smaller solenoid, which leads to a big saving.**



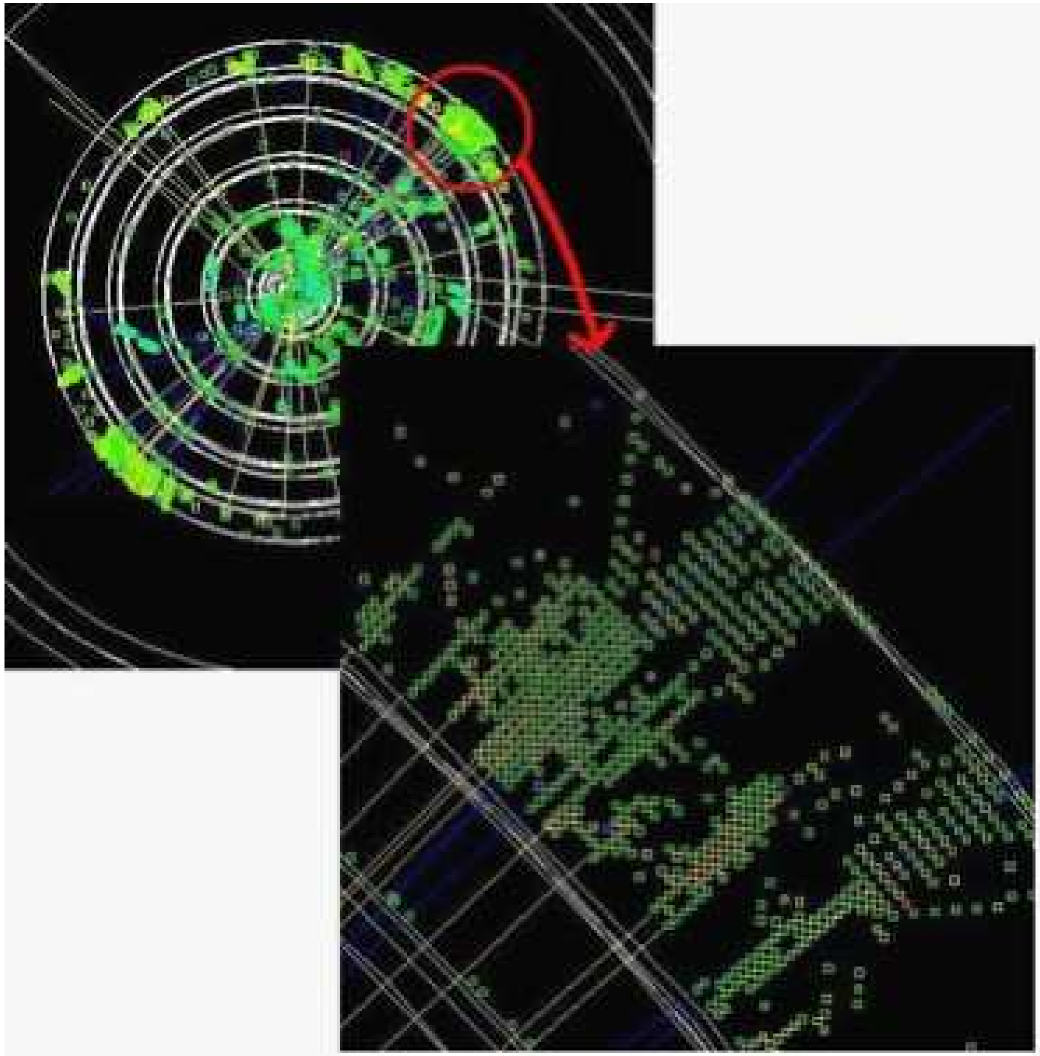


Pixel size e.g. 50 $\times$ 50 μm^2. Binary decision - effective digital ECAL.

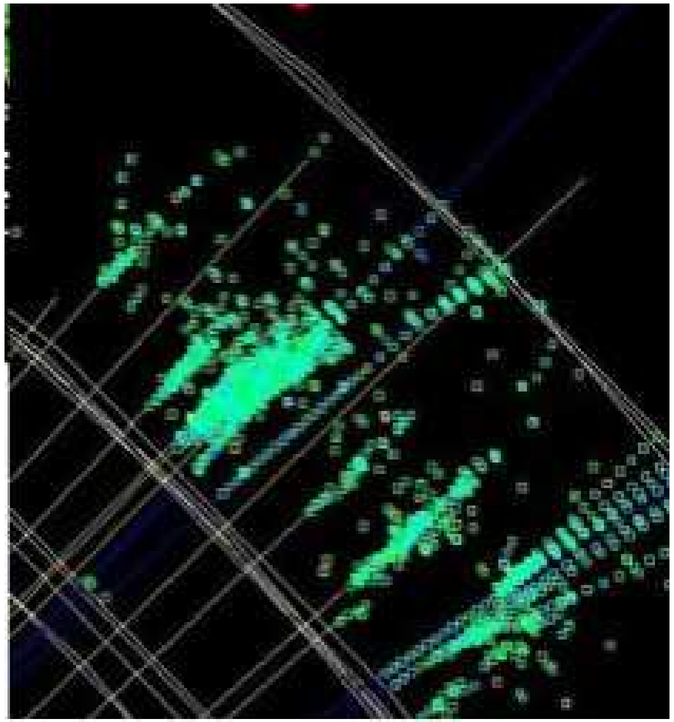
Due to finer granularity, improved two cluster separation - endcaps?

Heat production more evenly spread over surface of sensor.

MAPS physics simulation



Looks good by eye, detailed simulation needed.



Diodes

MAPS

MAPS - Sensors

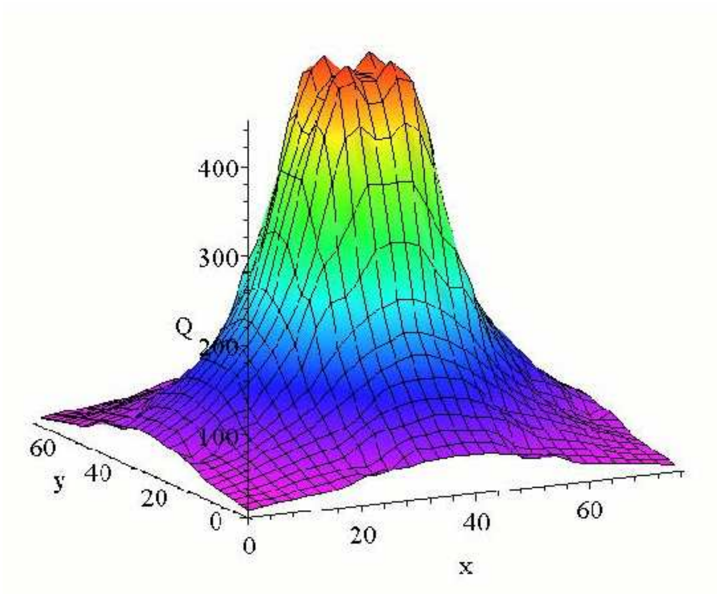
Two rounds of sensor production:

- **To start actual design for first round - had independent reviewers**
- **To have four variants of pixel design on sensor**
  - **number of charge collection diodes per pixel?**
  - **pixel memory storage local or clustered?**
  - **comparator fixed or tracking?**
  - **pixel reset: explicit of charge leakage?**

Sensor simulation started:

- **guide and interpolation for sensor design**
- **efficiency and cross-talk response for physics simulation**

Charge diffusion within epitaxial layer →



To be tested against real sensors

Mechanical/Thermal issues

Getting cooling into compact area - main heat source VFE chip.

Thermal modelling and comparison with measurements on slab mock-ups; feed-back to VFE and mechanical design team. 14 °C temperature change across PCB

Long term effects of conductive glue attaching diode pads to PCB?

Current glue resistance increases with temperature but does not return to its previous value when cooled.

Tests to be performed on production wafers.

Alternatives to glue?

Work starting on structure of end-caps.

Summary

This year will be a very important year for the concept of such a highly granular "tracking" calorimeter.

R&D has started towards building a real prototype by 2009.

UK groups making leading contributions and following new ideas.