CAlorimeter for the LInear Collider Experiments

Overview and Prospects

Anne-Marie Magnan

Imperial College London

On behalf of the Calice-UK collaboration

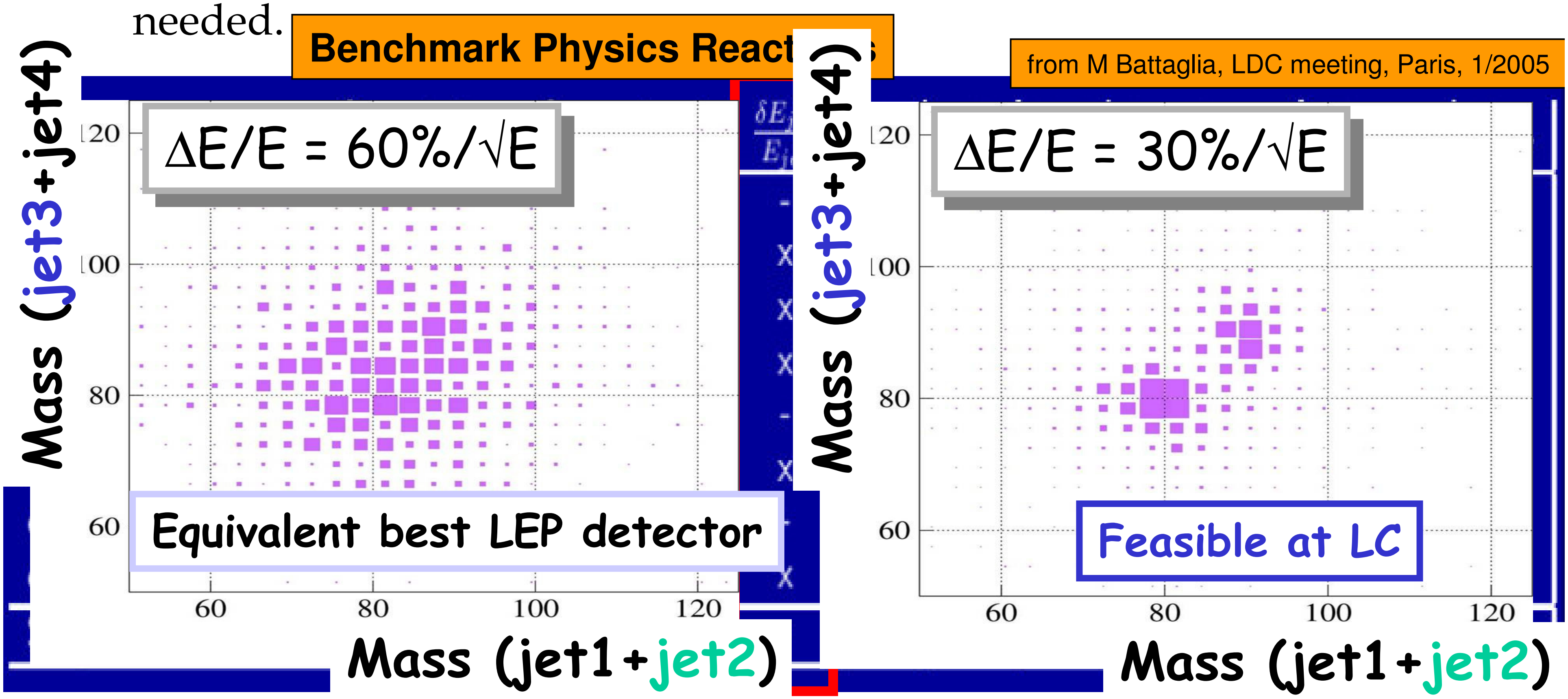
People and Institutions

- ~ 200 Physicists and Engineers
- From 36 institutes...
- ... 10 countries...
- ... all around the world : Europe, Asia, America.
- UK counts for ~35 physicists and engineers in
  Birmingham, Cambridge, Imperial College, Manchester, RAL, RHUL, and UCL.

- With a common DAQ and software : effective comparison of several designs to find the best one for the future International Linear Collider Physics Program.
- Timescale for TDR : less than 4 years now !

Physics Requirements as the milestone

- In order to be able to achieve the LC physics program, we need a really good reconstruction of jets ➔ Performant particle flow algorithm (PFA) together with a high granularity calorimeter are needed.

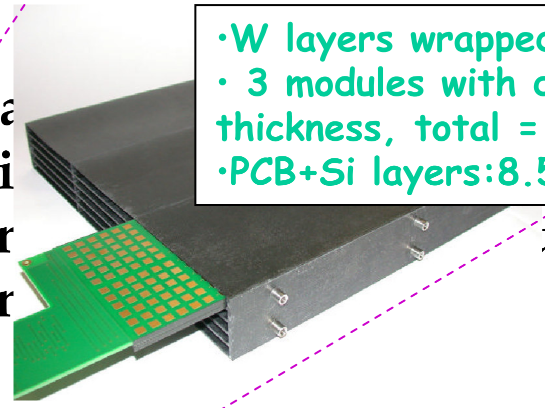


CALICE concretely - Electromagnetic part

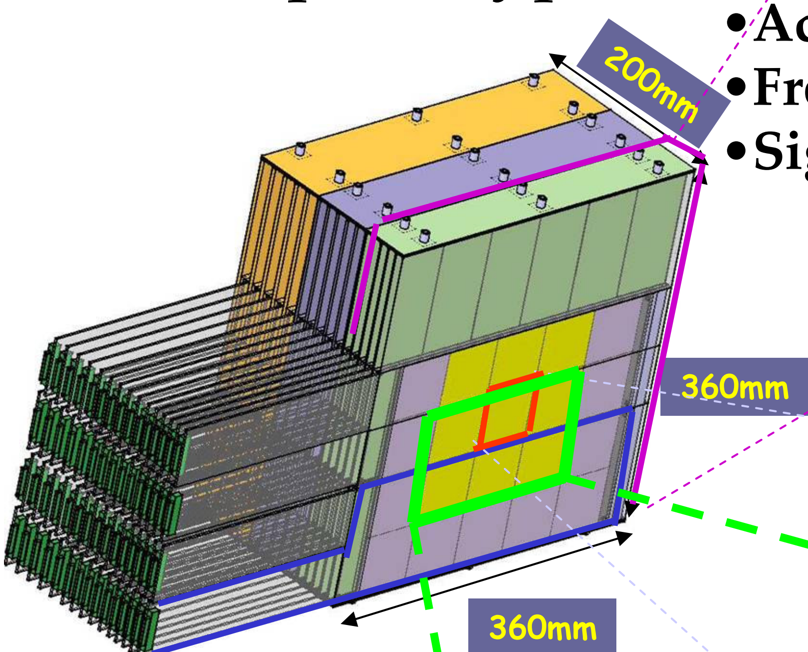
- <u>ECAL prototype:</u>

•30 la
•Acti
•Fror
•Sigr

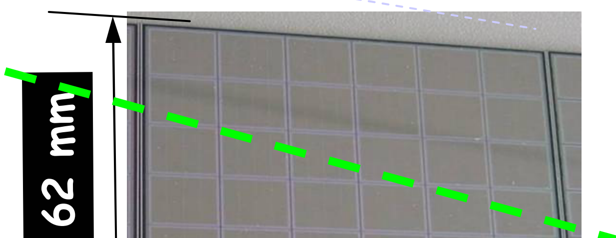
ıt on PCB board

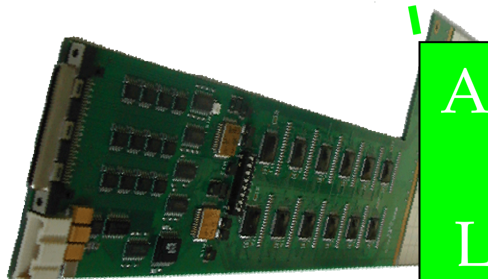


•W layers wrapped in carbon fibre
• 3 modules with different tungstene thickness, total = 24 X_0.
•PCB+Si layers:8.5 mm



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

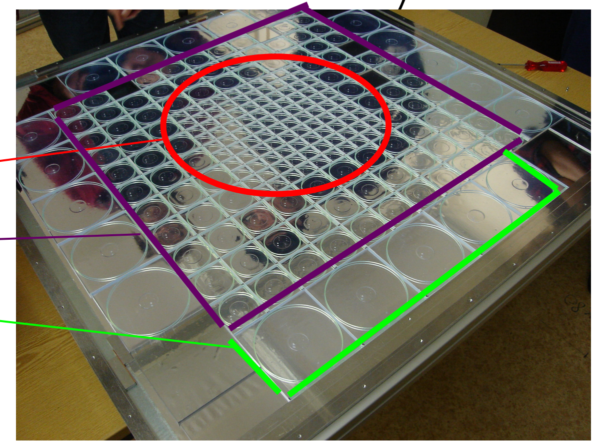




Area now completed for 30 layers
Last year : only 14 layers
Last 1/3rd expected in May 2007.

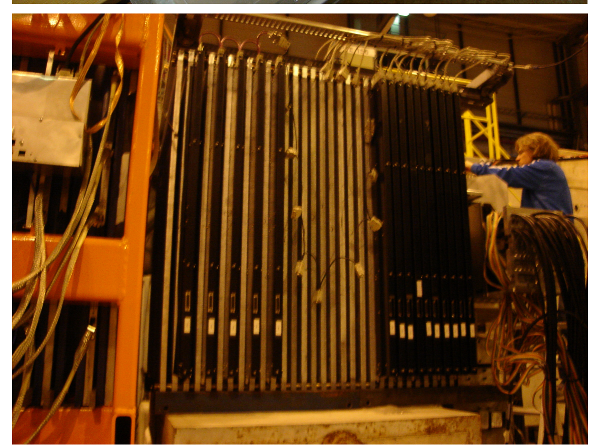
CALICE concretely - hadronic part with analog readout

- Analog HCAL prototype : scintillator tiles
- Recently completed by tail catcher and 2 layers of muons scintillators



➔38 scintillator tile layers (90 x 90 cm2) = 4.5 λ
➔ Absorber : steel
➔ High granularity : 100 tiles with 3*3 cm² surface, surrounded by 6*6 cm ² and 12*12 cm² tiles
➔ 8000 channels, read out by SiPM in 16-bits ADCs.
➔ followed by a tail catcher + muon tracker (TCMT) (~10 λ) to measure the shower leakage and tag muons : 96 cm of iron absorber instrumented with 16 layers of 5mm*5cm scintillator strips.
➔ Common ECAL-AHCAL-TCMT DAQ

Currently 24 sensitive layers completed for AHCAL, Expect completion by March 2007.



CALICE concretely – hadronic part with digital readout

- Digitial HCAL :

Assumption Confusion term is the dominant contribution to jet energy resolution

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$
Confusion		Required for 30%/√E	**$\leq 0.24^2\ E_{jet}$**

(Charged, Photons, Neutral Hadrons: 18%/√E)

Minimize confusion term Maximize segmentation of calorimeter = digital readout

➔ Two main technical concepts :

Gas-ResistivePlateChambers and GasElectronMultipliers

1*1 cm^2 pad size, ~380,000 channels

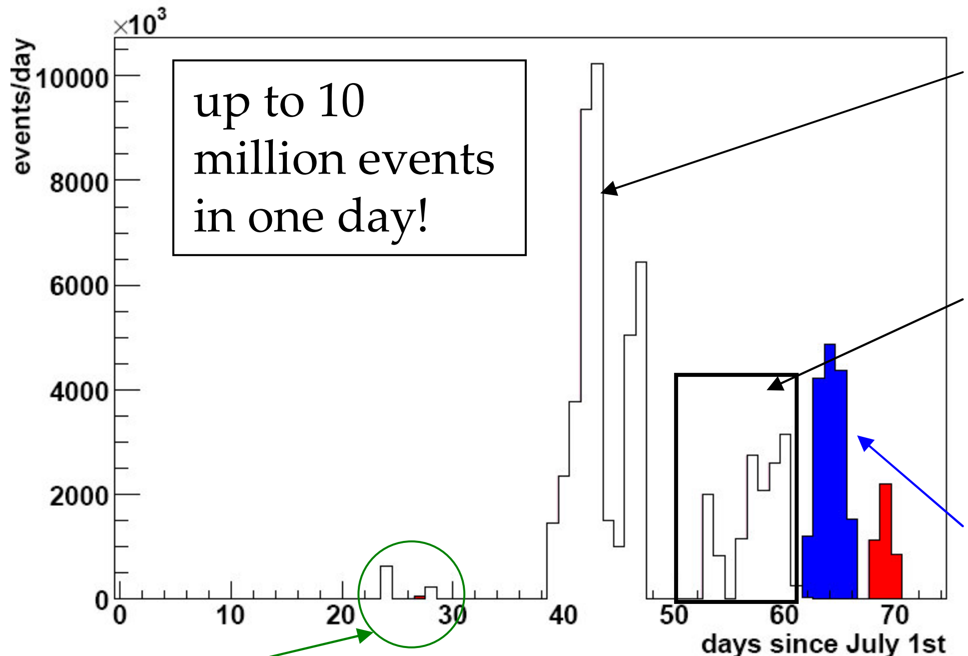
Adaptable in AHCAL steel structure for comparison.

➔ First prototype with RPC planned for November 2007.

Real content of this talk

I. Summary of DESY and CERN testbeam 2006 (still on-going at CERN) and plans for next year
II. Overview and last year progress and plans for both ECAL concepts
   1. Data acquisition board : design, building and tests in the UK
   2. Thermal and Mechanical studies
   3. MAPS design
III. UK-specifc Algorithm development
   1. Pandora PFA
   2. Mokka/Geant4
   3. ZHH analysis to characterize/compare detector performances
IV. Conclusion

The data taken



CERF period: parasitic muon
high intensity, wide distribution
➔ Very important for calibration !!!

Combined run, goal: ECAL EM program
- e 10-45 GeV, from 50 GeV beam, with 0,10,20,30 deg
- small samples of π 30-80 GeV
  too large distance ECAL-AHCAL

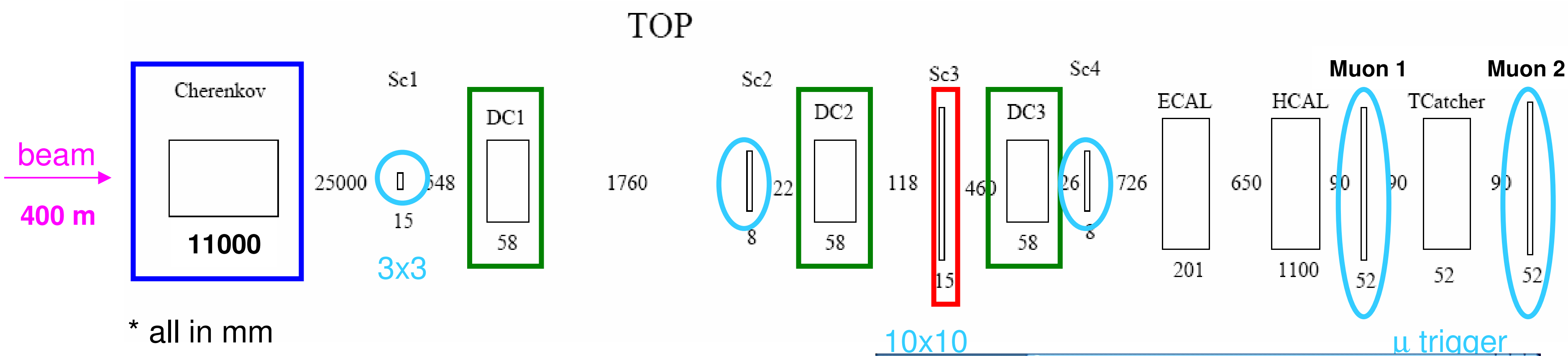
AHCAL stand alone, ECAL removed
- 1 day @ 10 GeV secondary beam
  tested π / e 6,10,15,20 GeV
- 3 days @ 50 GeV secondary beam
  e 10-45 GeV and p 30-80 GeV

All what was collected in the ECAL run:
60 GeV secondary beam, tested e 10-45 GeV and π 30-80 GeV.

!!! large fraction of time invested in beam tuning !!!

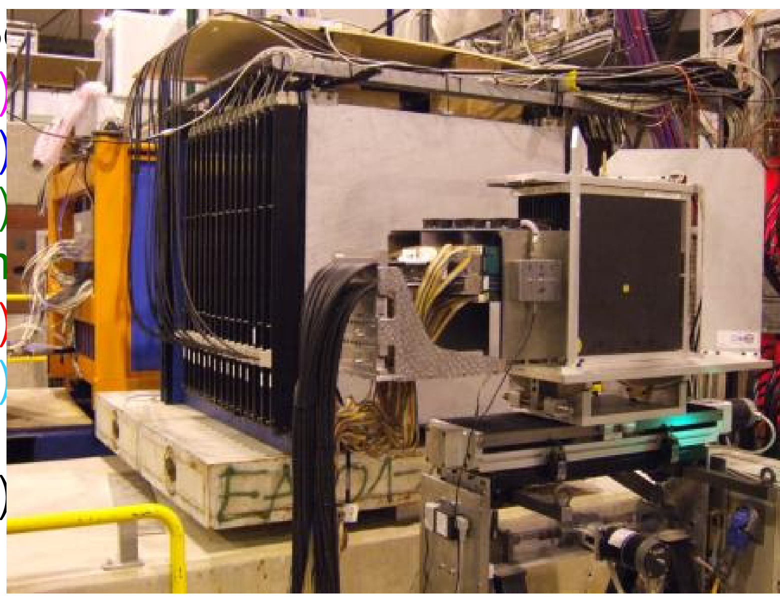
➔ 3 additional days “courtesy” of ATLAS: AHCAL and TCMT out of beam line, ECAL re-installed for high statistics low energy runs (thanks to all voluntary shifters)

A *technical* installation

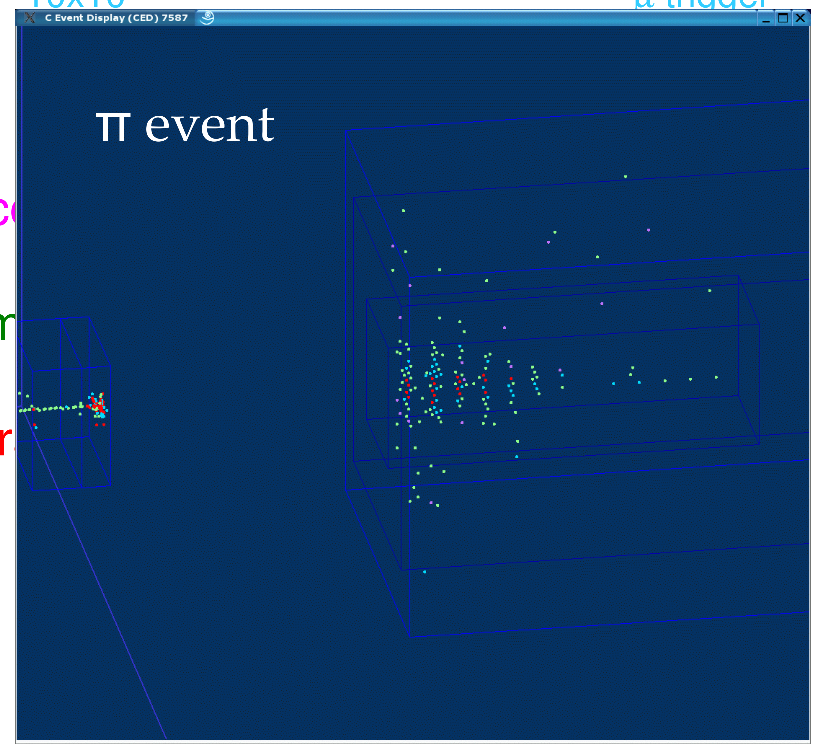


B
1)
2)
3)
m
4)
5)

2)



gnets, c
on < 40
al Cham
to separ
nd read



DAQ

Paul Dauncey, IC London

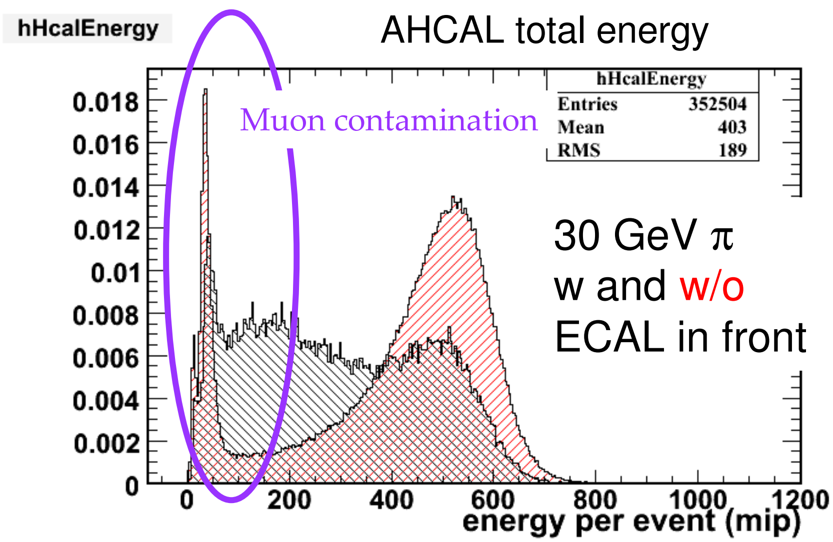
- SCSI cables for all detectors delivered in time, working fine
- 5 (ECAL) + 4 (AHCAL+TCMT+veto+trigger) CRC boards used
- Tuning finished before data taking started
- All beam component successfully integrated (Cherenkov, MWPC, veto, triggers)
- Excellent performance thereafter: - 120 Hz max average rate, ~500 Hz peak rate in spill
- Stable operation, continuous running w/o failures
- Data taking inefficiency related to:
  - human mistakes in DAQ handling (selection of triggers, start up procedure)
  - missing communication to beam database
- Special development for TCMT achieved in time before operation, required very complex firmware update (one CRC only)

➔ In general: DAQ has fulfilled all expectations!!!

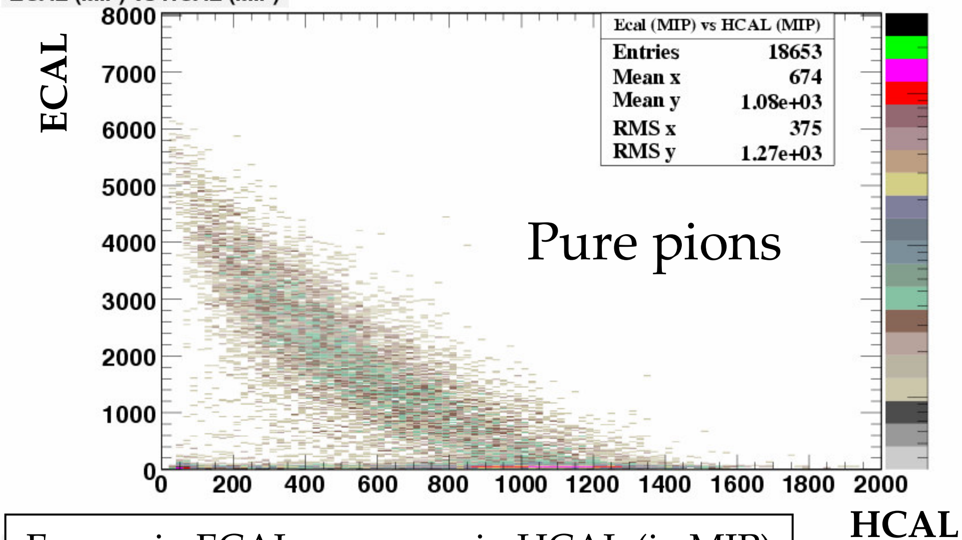
Data transfer and conversion

- High speed data transfer possible (1 Gbit switch to CERN, 20Mbyte/s to DESY)
- Data stored to DESY dCache (extra disk space available for CALICE)
- Conversion to LCIO smooth, data available for analysis few hours after data taking

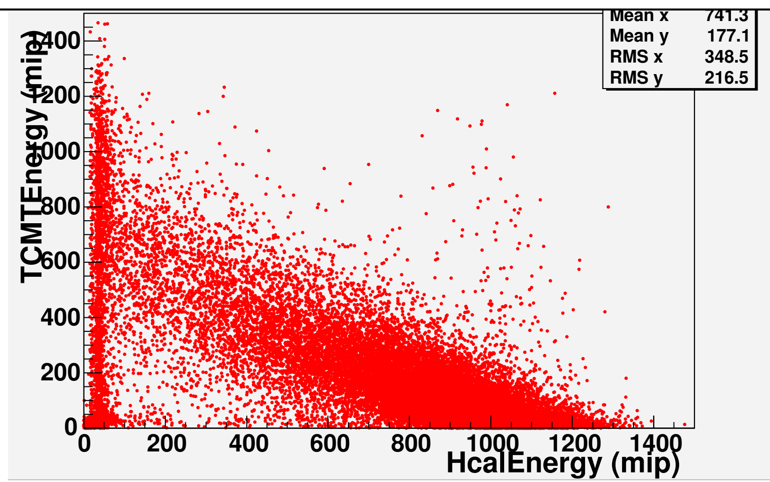
A few plots of real data taken at CERN



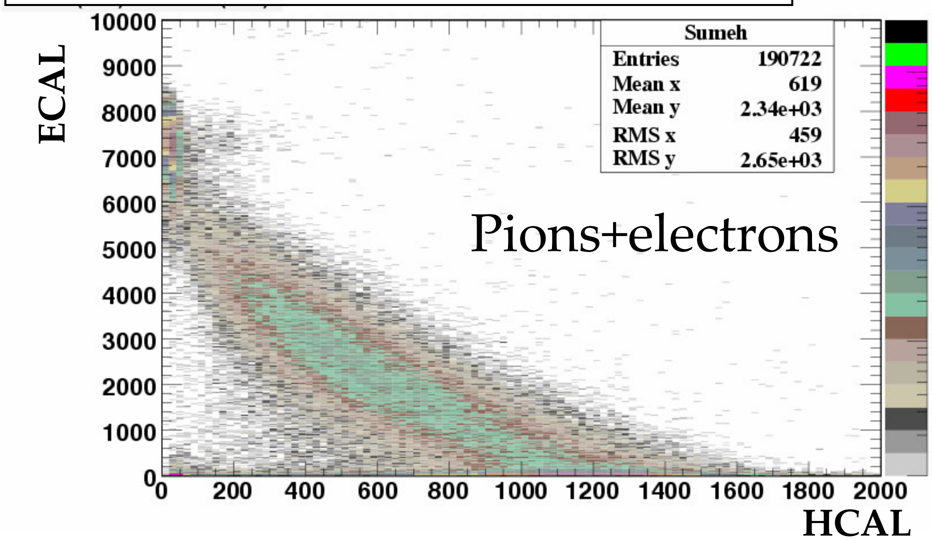
Energy in ECAL vs energy in HCAL (in MIP)



Energy in TCMT vs Energy in HCAL (in MIP)



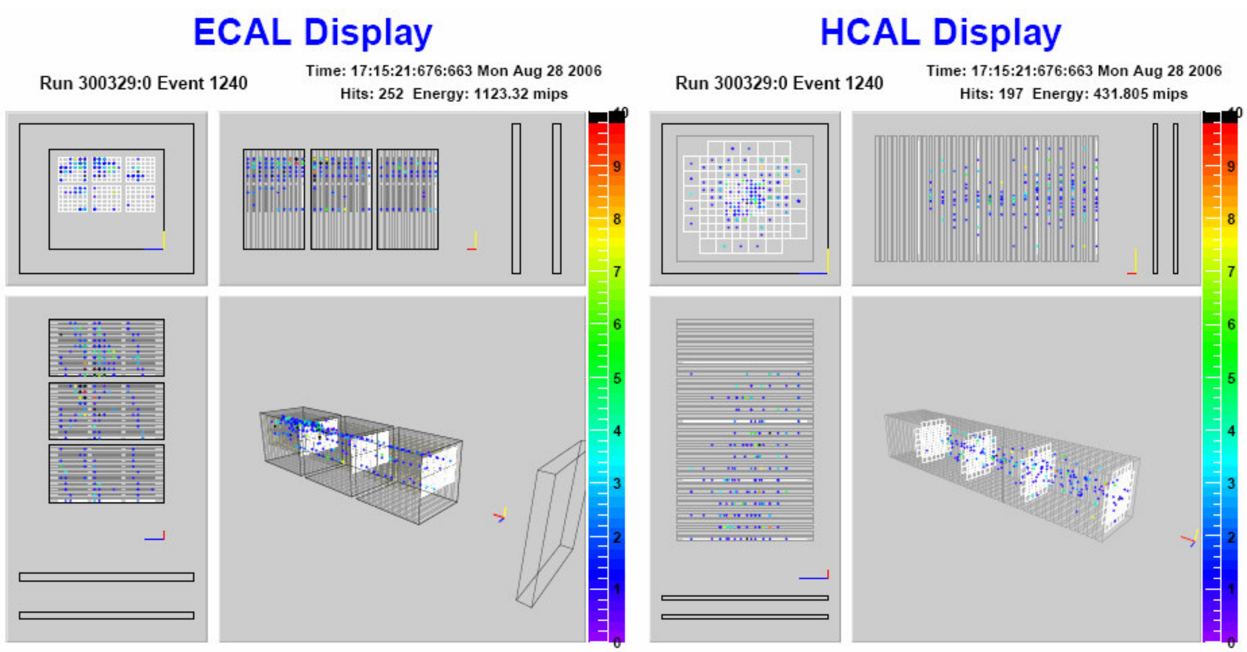
Energy in ECAL vs energy in HCAL (in MIP)



Testbeam monitoring

George Mavromanolakis, Cambridge

a self-contained, light and robust application to do reconstruction and first level analysis for comprehensive detector and data quality monitoring during or after data taking

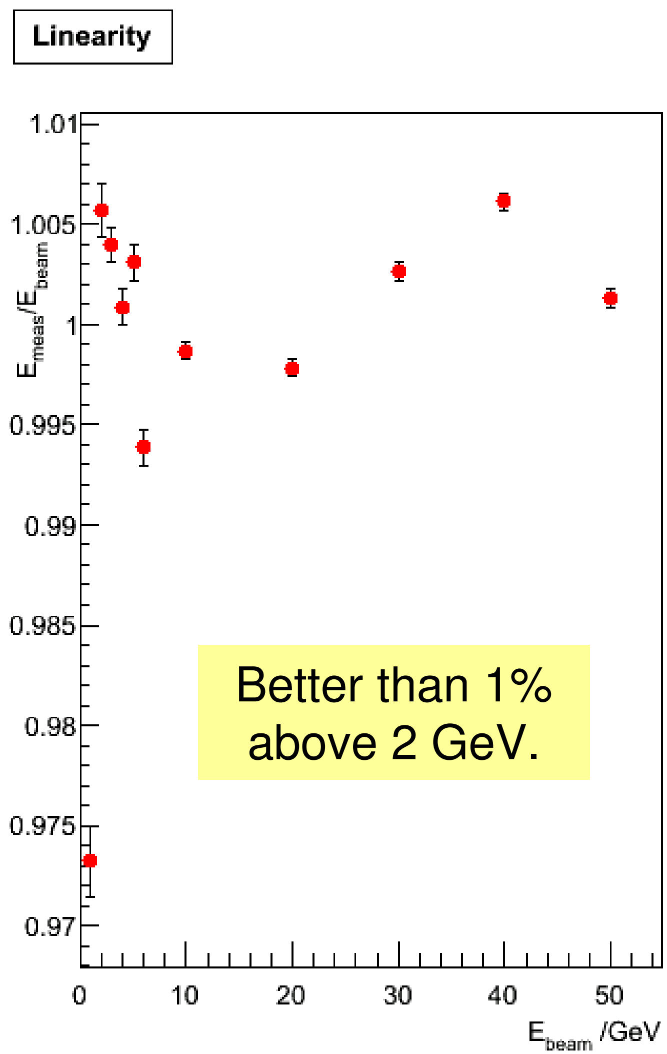


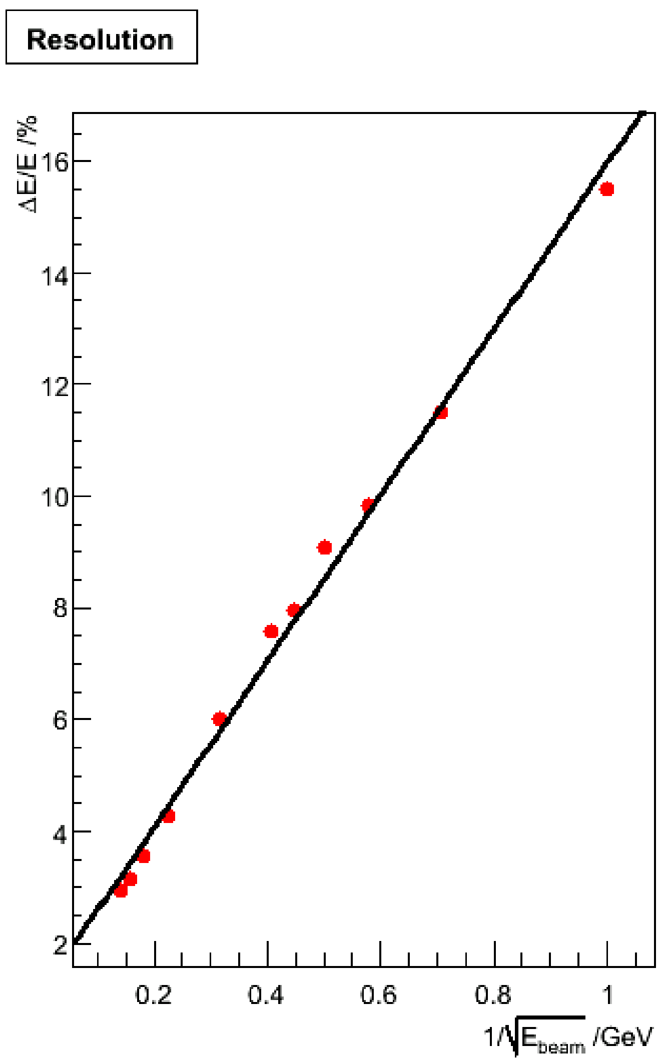
➔ Really useful to have immediate feedback of data quality.

Linearity + resolution in DESY/CERN data

VERY PRELIMINARY

David Ward, Cambridge





Testbeam plans

<u>Next run planned for October 11th – 24th :</u>

- Expect to have another 30 M events.

- ECAL and AHCAL will be complete by May ➔ tests at CERN in May-Jul next year.

Key dates for beam-tests CERN 2007:
Start East Hall: May 2nd 2007
Start North Area (physics): May 25th 2007
End of PS/SPS physics: Nov 12th 2007

- When DHCAL prototype is ready ➔ tests at FNAL.

FERMILAB planned for end 2007-early 2008. No more details for now on.
Plans : Lower energy hadrons + DHCAL running.

I. Summary of DESY and CERN testbeam 2006 (still on-going at CERN) and plans for next year

II. Overview and last year progress and plans for both ECAL concepts

1. Data acquisition board : design, building and tests in the UK
2. Thermal and Mechanical studies
3. MAPS design

III. UK-specifc Algorithm development

1. Pandora PFA
2. Mokka/Geant4
3. ZHH analysis to characterize/compare detector performances

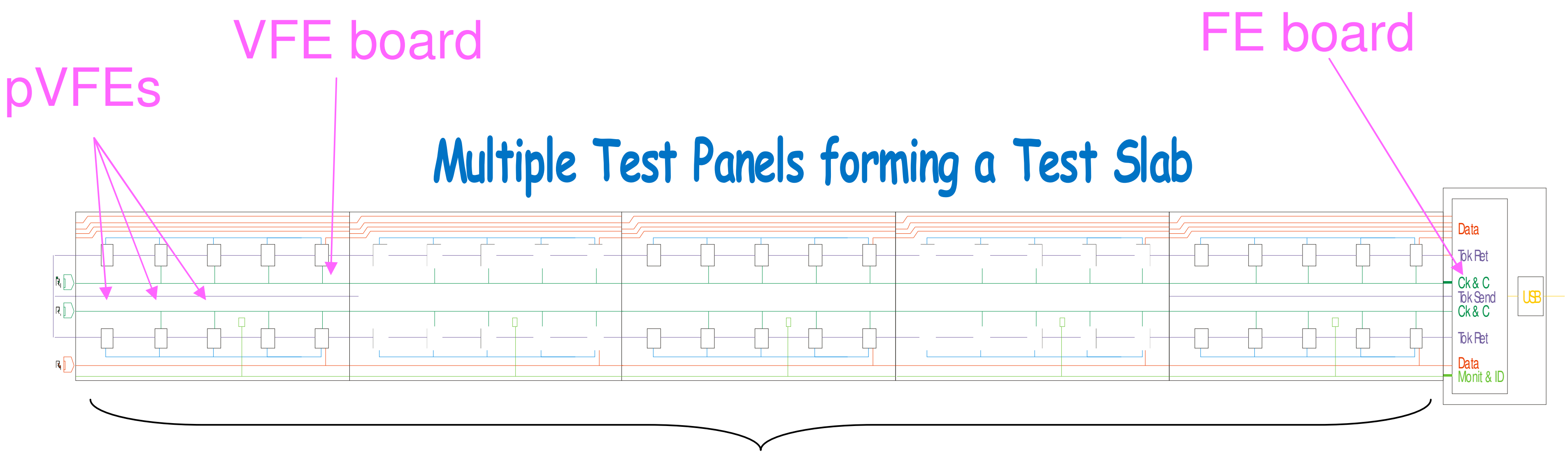
IV. Conclusion

DAQ for the “EUDET” ECAL module

Matthew Wing, UCL

- Using next generation ASIC : collaboration with french labs.
- Whole module : one 1.5m long PCB to test the transmission of signal and the mechanical requirements.

  + 29 other layers smaller to have full depth to contain the showers.
- Concept for the new slab :



5 PCBs stitched together

ASIC testing and model slab

Maurice Goodrick & Bart Hommels, Cambridge

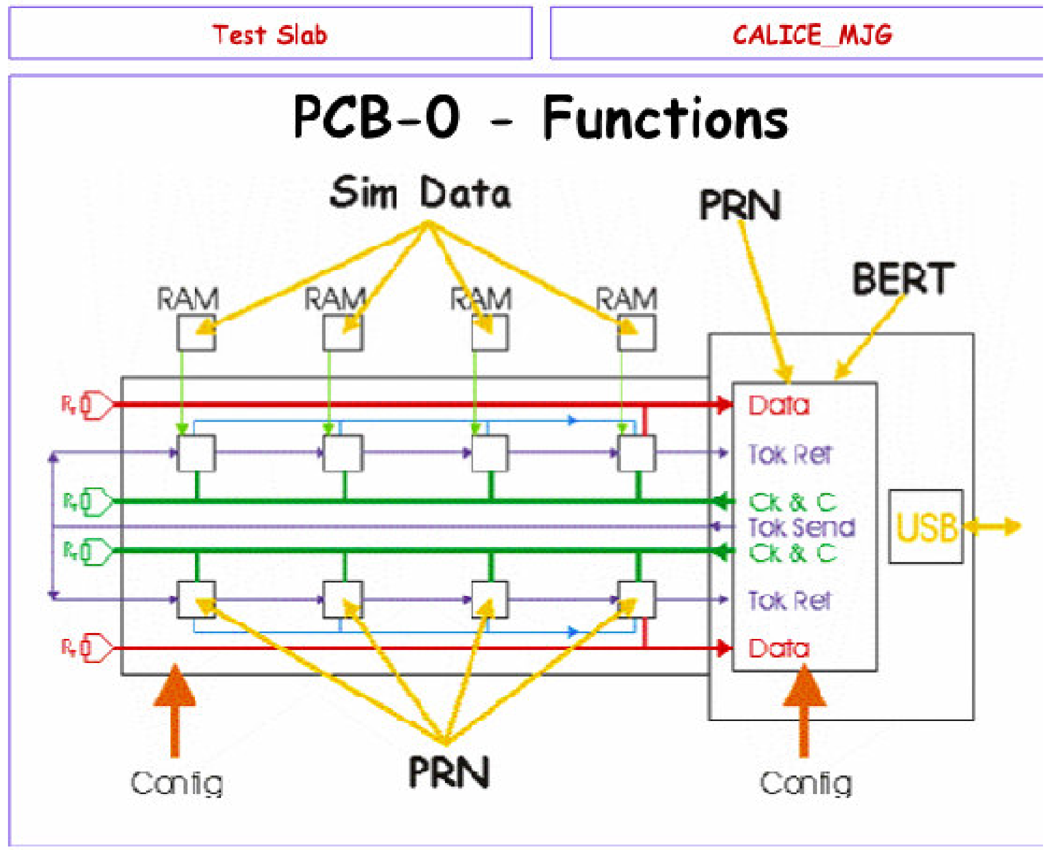
Plan

• emulate multiple VFE chips on long PCBs
• study transmission behaviour: noise, crosstalk, etc.
• optimise VFE PCB with respect to data rate requirements

Needs

• segmented test slab PCBs
• FPGAs emulating VFE chips, “pVFEs”
• FE boards for distribution and reception of clock, controls, data, etc.

➔ these studies will contribute to ASIC and PCB design for EUDET (and final) modules.

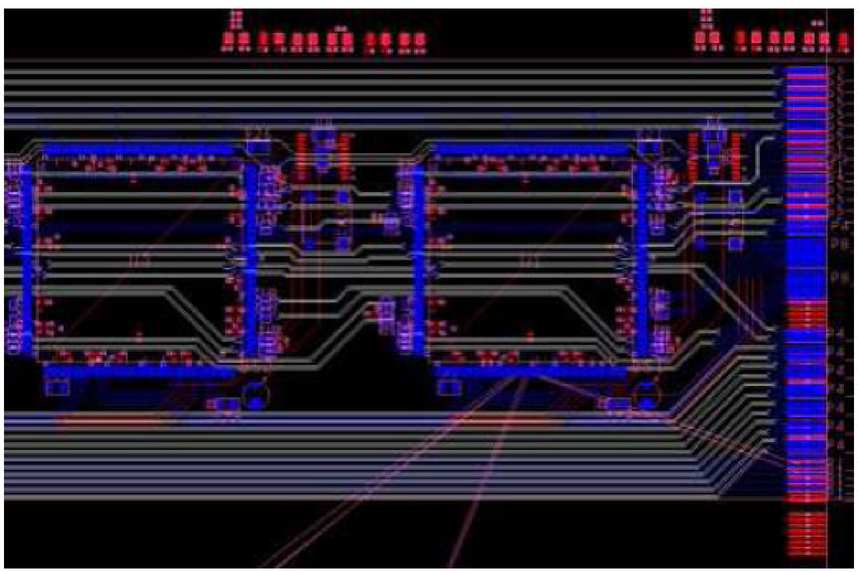


Board development

Maurice Goodrick & Bart Hommels, Cambridge

Board design and layout

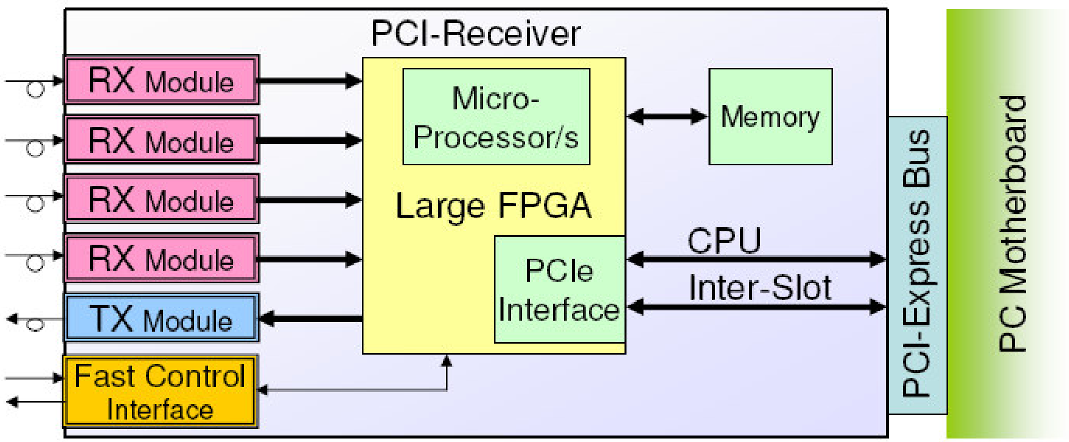
- Assumed: 5 × 5mm^2 pads, 72 channels/ASIC !
- 1 ASIC covers 6 × 12 pads, or 3 × 6 cm^2
- Traces for various clock distribution and/or readout architectures incorporated
- Row of 4 FPGAs per board, every FPGA mimics 2 VFE chips
- Schematics finished, layout almost finished.



Model slab to be finished soon and ready for tests

Connection and off-detector receiver

Matthew Warren, UCL
Marc Kelly, Manchester



<u>PCI cards specifications :</u> Simpler to just buy the cards !!

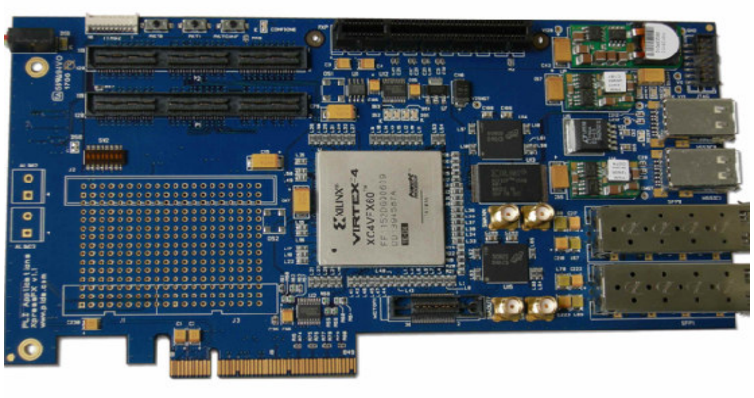
Bought PCIe cards from PLD applications (http://www.plda.com/):

- model: XpressFX100
- FPGA: Xilinx Virtex4 FX100
- bus: PCIexpress x8 lane.
- Gbit optical and copper transceivers

➔ Hosted in computers in labs.

➔ Currently working on firmware and test software

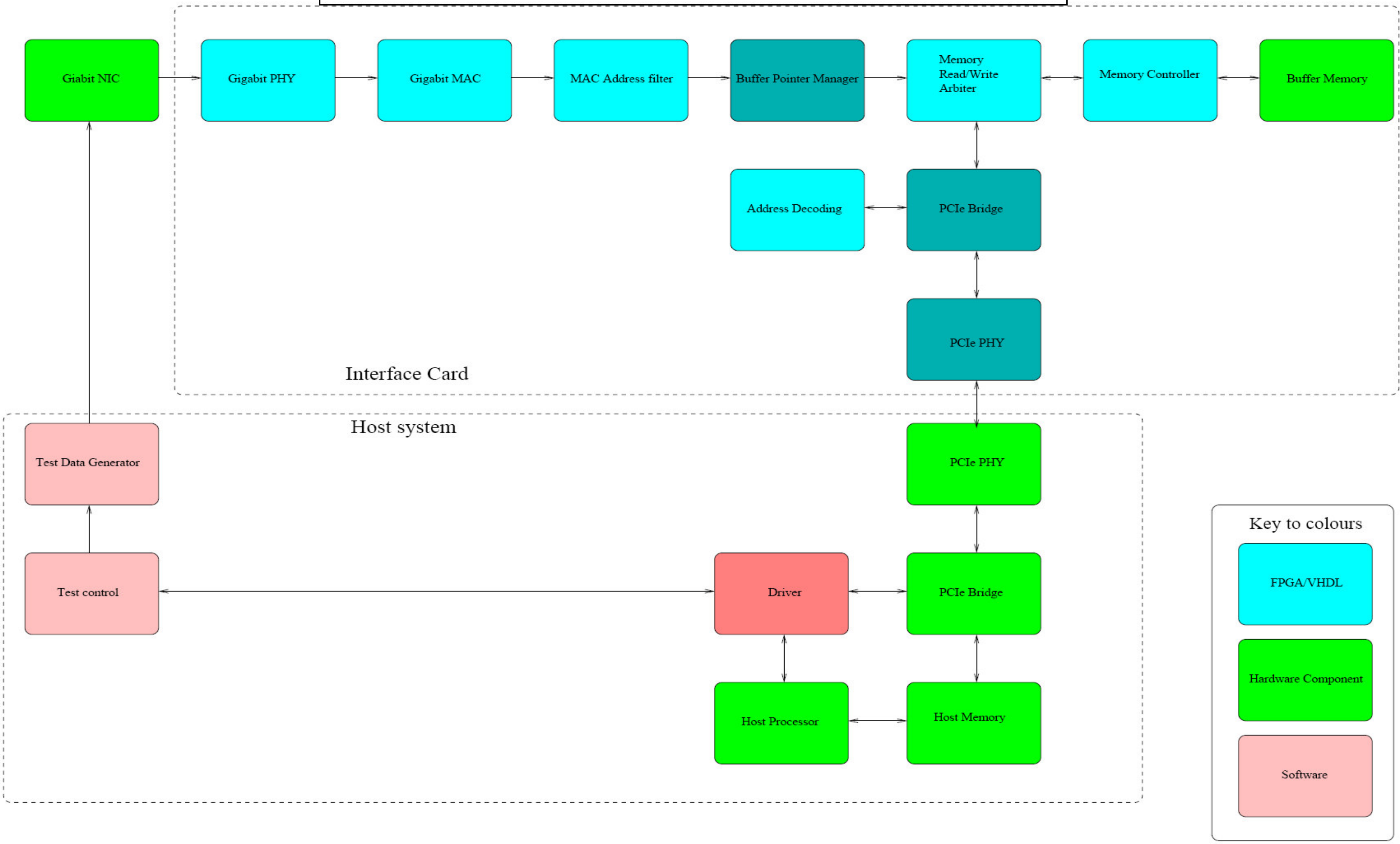
Off-detector receiver PCI card



Off-detector electronics

Barry Green, RHUL

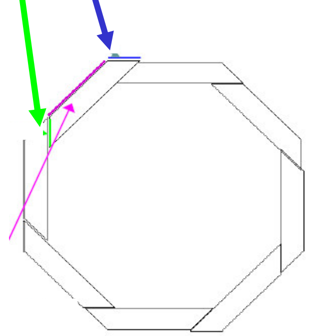
PCI cards box diagram of Stage 1



Thermal studies in ECAL Barrel

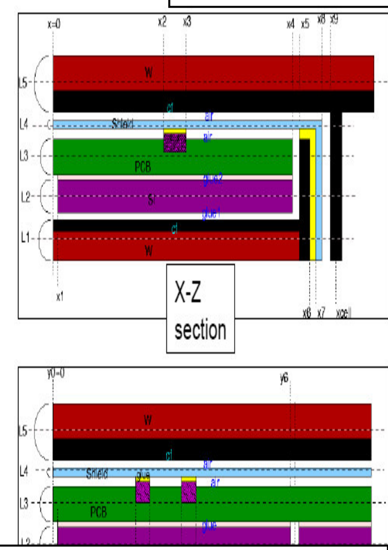
David Bailey, Manchester

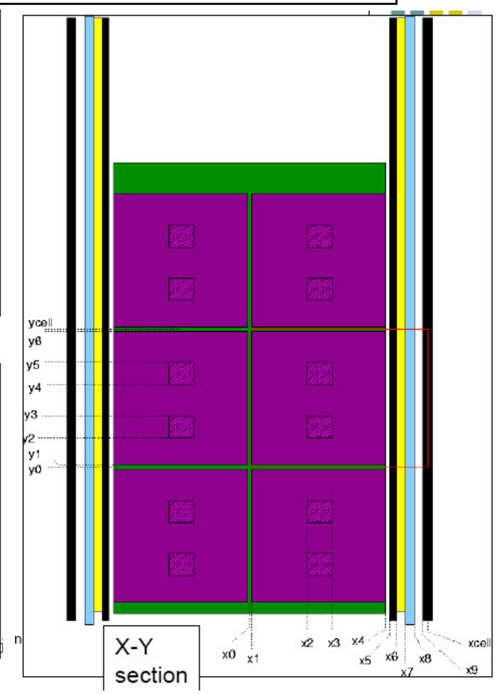
- A CALICE module will dissipate at least 300 W ➔ active cooling required
- Obvious places : this end. Problem : already busy with slab readout.
- Alternatively : this end. Disadvantage : dead area.



- Or this face.
  Disadvantage :
  poor conductivity in the perpendicular direction.

Implementation in the simulation





RESULTS :

➔Assuming a module is 26 cells long :

$\Delta T_{bothEnds}$ = 10.3 °C   only one end cooled

$\Delta T_{middleEnds}$ = 2.6 °C   both ends cooled

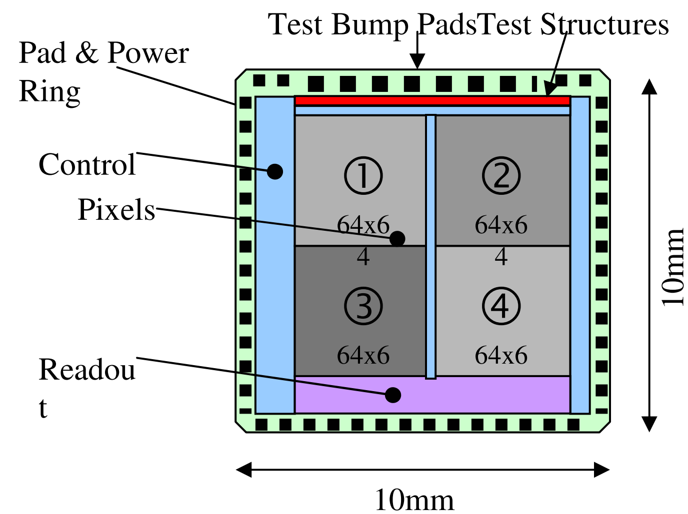
➔ Manchester will build a cooling test setup to verify simulation

➔ environment for active cooling tests

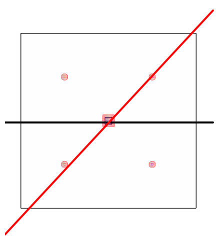
MAPS Sensor developments and 3D simulation

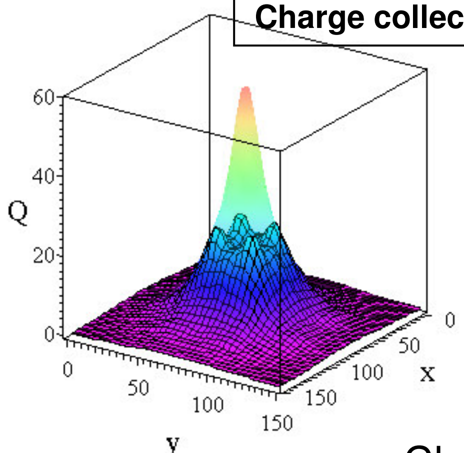
Renato Turchetta & Jamie Crooks, RAL
M.Tyndel & E.G.Villani, RAL

- Sensor studies : expect to have a test structure by March 2007, with several designs for comparison of performances.
Ex: read out several pixels at the same time
➔ minimisation of dead area.
- Simulation studies: developed in parallel to check the actual charges collected by the diodes in function of the diodes size, distance between them, position of the central NWELL.

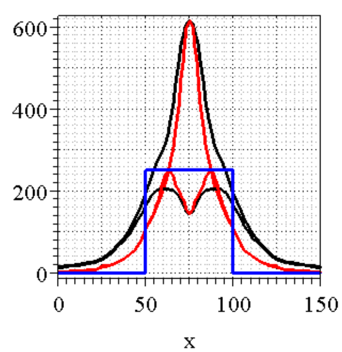


Exemple of a MIP crossing the central NWELL :

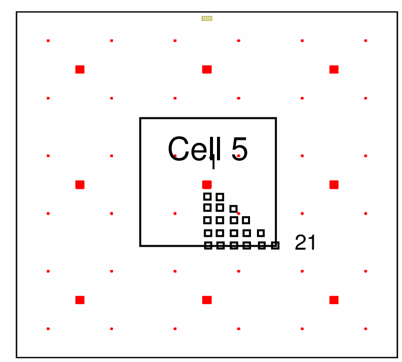




Charge collected by central Nwell



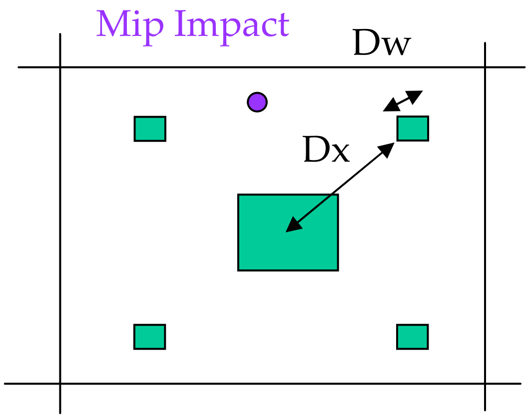
Output ➔



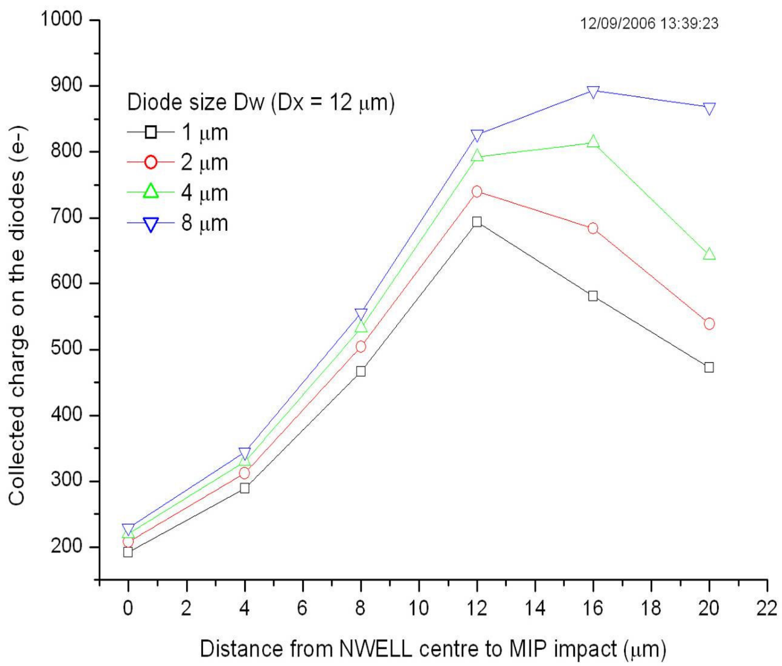
Charge lost by central N Well around 620 e^-

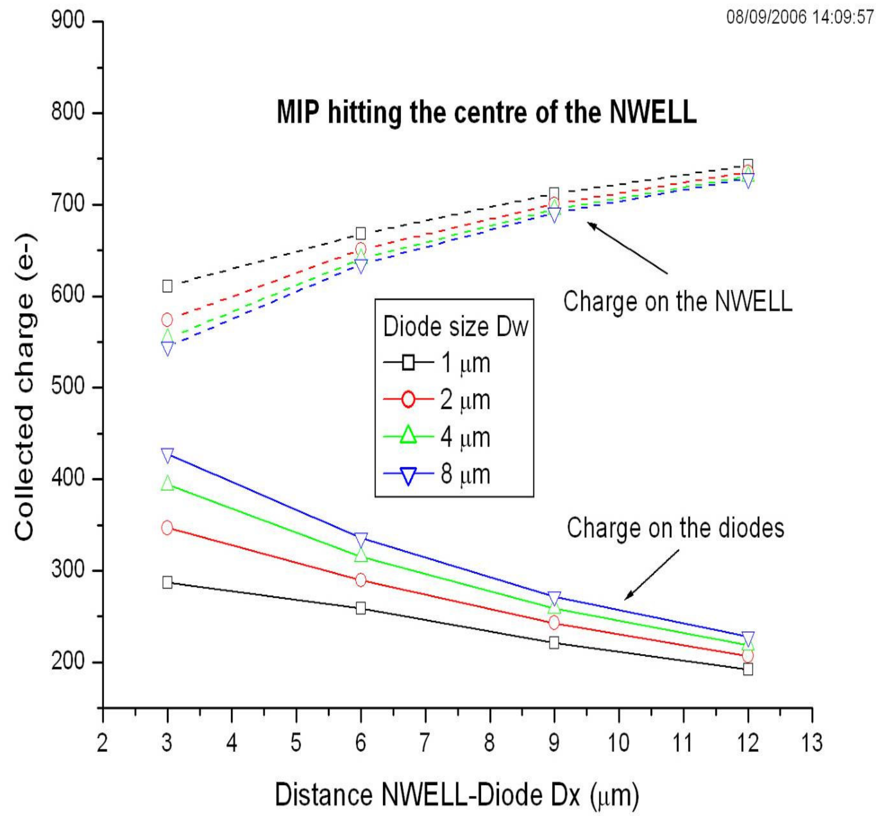
Sensor simulation : 2D

Konstantin Stefanov, RAL



Results obtained in 2D simulation, varying the diodes size and the distance between them for example.

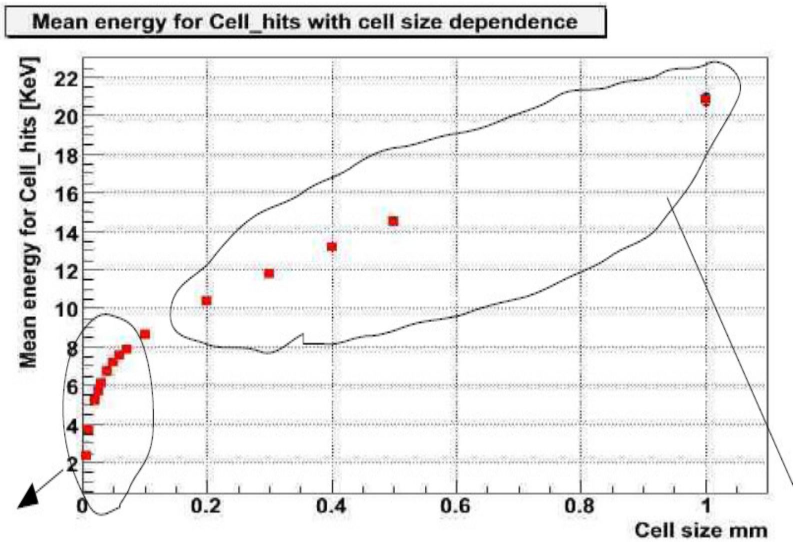


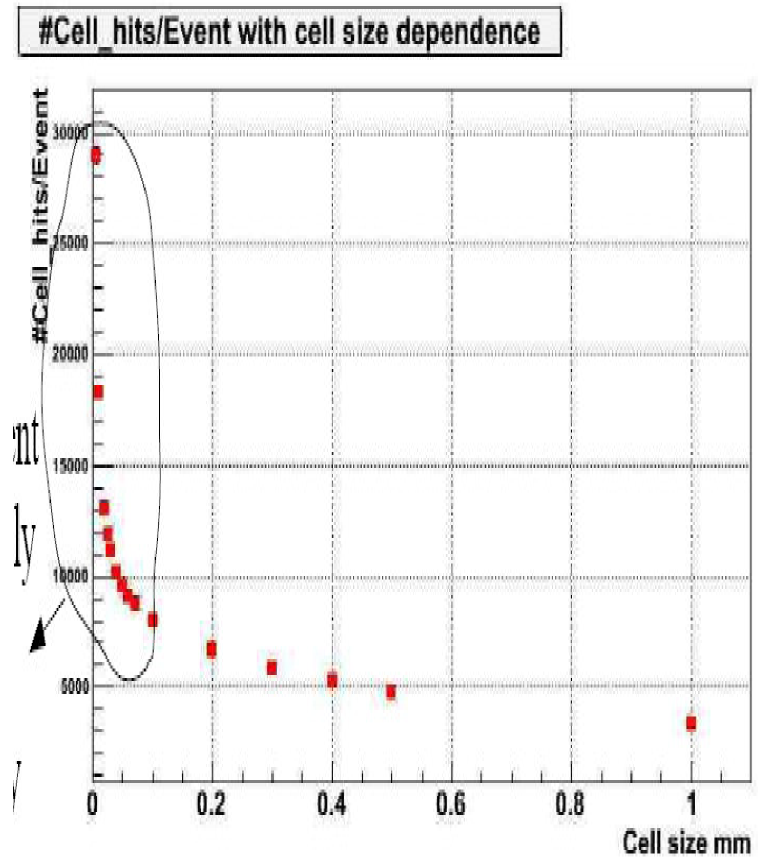


MC studies

MAPS implemented in Mokka

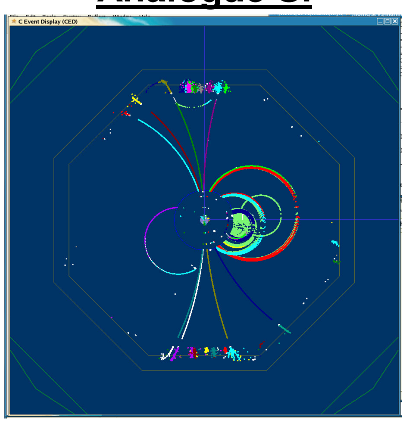
Yoshi Mikami & Bradley Hopkinson, Birmingham
AMM, ICL



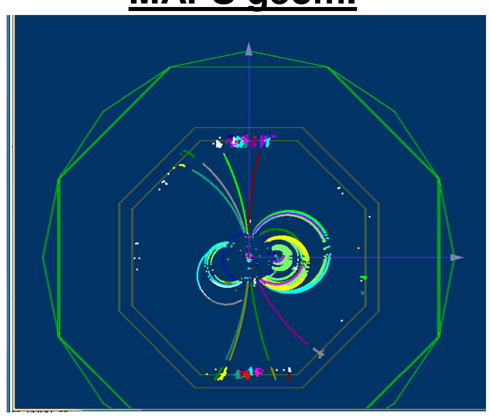


Work on clustering started @ Birmingham:

Analogue Si



MAPS geom.



➔ Still a lot to understand ! But still on time.

I. Summary of DESY and CERN testbeam 2006 (still on-going at CERN) and plans for next year

II. Overview and last year progress and plans for both ECAL concepts

   1. Data acquisition board : design, building and tests in the UK
   2. Thermal and Mechanical studies
   3. MAPS design

III. UK-specifc Algorithm development and physics analysis

   1. Pandora PFA
   2. Mokka/Geant4
   3. ZHH analysis to characterize/compare detector performances

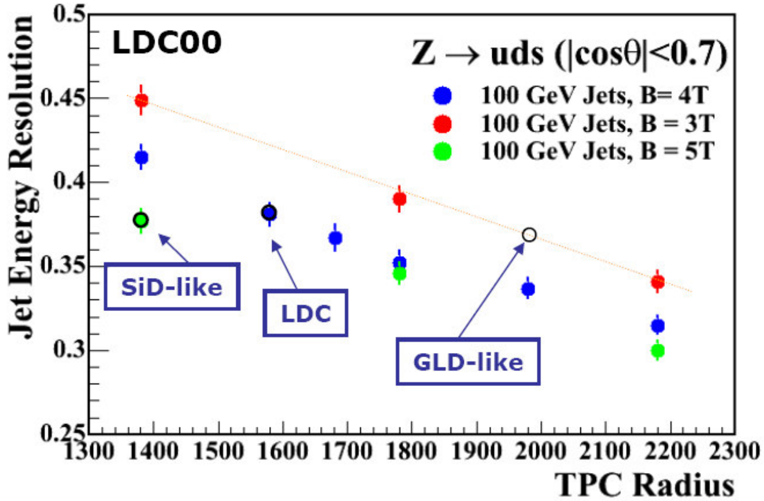
IV. Conclusion

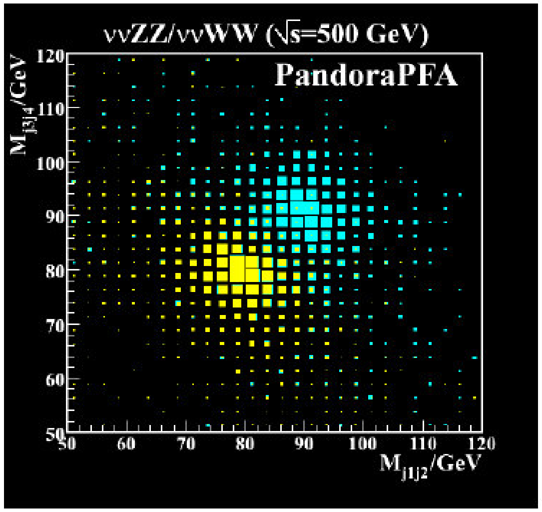
Pandora PFA

Mark Thomson, Cambridge

Overview:

- ★ **Preparation**
  - ★ Isolation cuts, hit ordering, track quality
- ★ **Initial clustering to form ProtoClusters**
  - ★ ProtoClusters are heavyweight objects:
    - ★ much more than a collection of hits
    - ★ know how to grow (configured when created)
    - ★ information about shape, direction, isPhoton,...
    - ★ can be configured to fragment tracks...
    - ★ +much more (not all used)...
- ★ **Cluster association/merging**
  - ★ Tight Topological linking of clusters
  - ★ Looser merging of clusters
  - ★ Track-driven merging
- ★ **PFA**
  - ★ Final track-cluster matching





Mokka/geant4 developments

Fabrizio Salvatore, RHUL

Summary

- New version of Mokka (06-02) will be available soon, with several important improvements and new detectors for the simulation of Desy and CERN test beam data
  - Ready to start producing MC events to compare with data taken this summer
- New Mokka WEB page, will provide up-to-date information on all detector models, software, database, etc…
  - Join in to help us improving it !

ZHH Analysis as benchmark

Michele Faucci-Gianelli, Fabrizio Salvatore
& Mike Green, RHUL

- Pandora Pythia:
  - M(Higgs) = 120 GeV
  - Electron polarization 80%
  - Positron polarization 0%
  - E_{CM} = 500 GeV
- LDC00:
  - RPC Hcal
  - TPC has 200 layers
  - ECal is 30+10 layers
- LDC01: smaller radius than LDC00
  - RPC Hcal
  - TPC has 185 layers
  - ECal is 20+10 layers

- Marlin 0.9.4 with MarlinReco 0.2
  - Processors used:
    - VTXDigi
    - FTDDigi
    - SimpleCaloDigi
    - TPCDigi
    - CurlKiller
    - LEPTracking
    - TrackwiseClustering } Pandora PFA
    - Wolf } Pandora PFA
    - PairSelector
    - SatoruJetFinder
    - BosonSelector
    - MyROOTProcessor & analysis

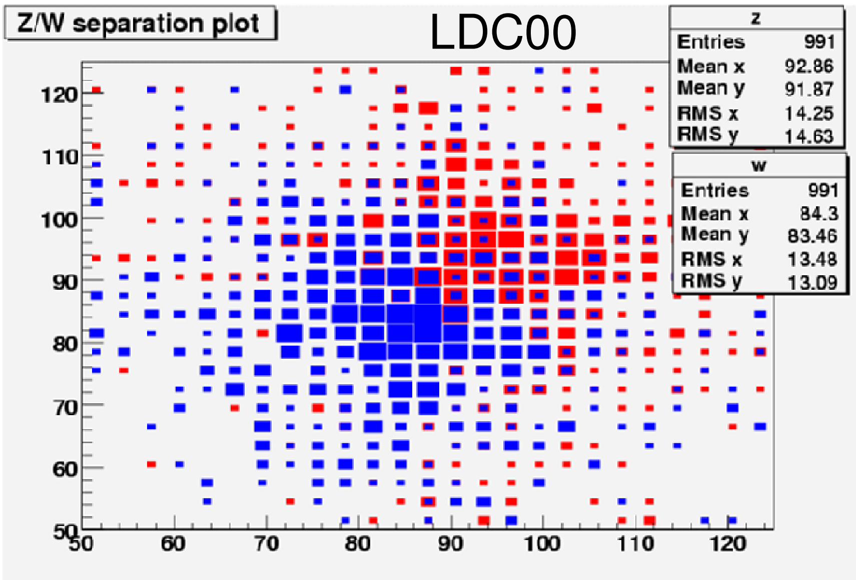
Z/W separation

Michele Faucci-Gianelli, Fabrizio Salvatore
& Mike Green, RHUL

WOLF

+

TrackWise Clustering

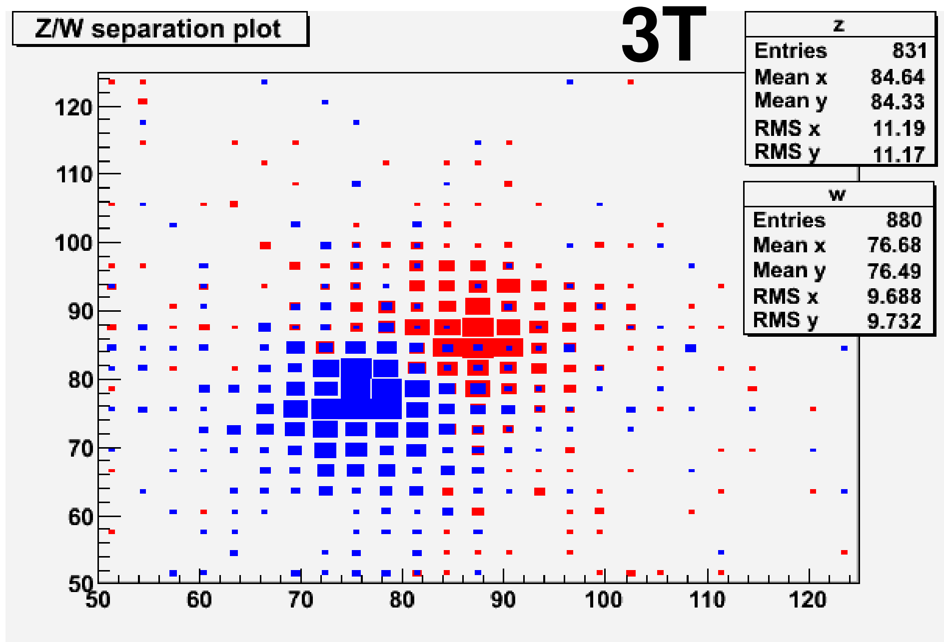


Blue is WW

Red is ZZ

PandoraPFA

Very Preliminary

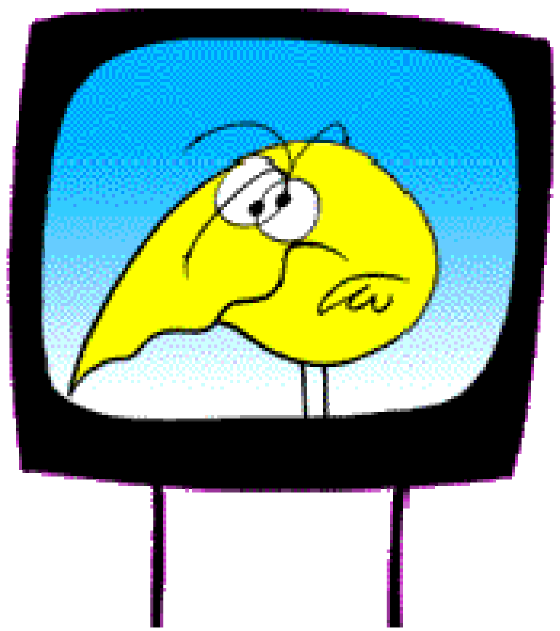


Conclusion

- CERN testbeam successfull until now ! Real conclusion after October period. But lots of data already available for calibration and preliminary studies.
- Getting prepared for the whole "EUDET" module : lots of progress from UK groups on the DAQ.
- MAPS design : UK-exclusive for now on !! Sensor will be ready for testing in march 2007. Simulation still needs to include realistic digitisation with input from sensor simulation @RAL.
- 2 analyses as detector Benchmark are making good progress : ZHH (RHUL) and WWυυ/ZZυυ (Cambridge)

➔ Stay tuned, a lot more progress are expected in the coming year !!

Thank you for your attention !



backup

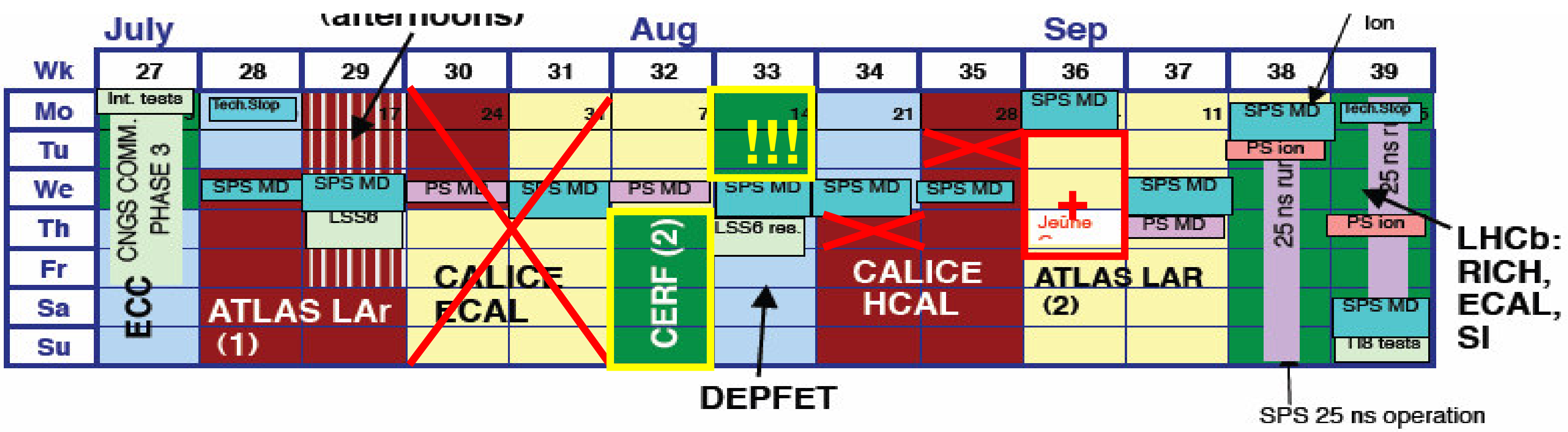
Summary of data taking
CERN first and second period (july/August 2006)

Some numbers:

Total data taking time (including first “ECAL period”) = 11 days
people on shift ~20 (~30 including ECAL period)
beam duty cycle (during running time) ~ 60%
detector up time > 90% (including ECAL + AHCAL + TCMC + DAQ)

Some comments:

+ very nice experience of cooperation within the collaboration
+ the detector is robust and reliable
- Beam tuning and beam quality understanding



The Beam Line

- 7 main dipoles + quadrupoles + trimmers + collimators to focus the beam on our detector ➔ our responsibility to do it right !!!

- Two main modes of operation:

pion: no secondary target, Pb absorber (365 m)* to filter electrons
possible energies ~ $E_{\text{secondary beam}}$ +/- E_{sb} /2
rates 80-120 Hz

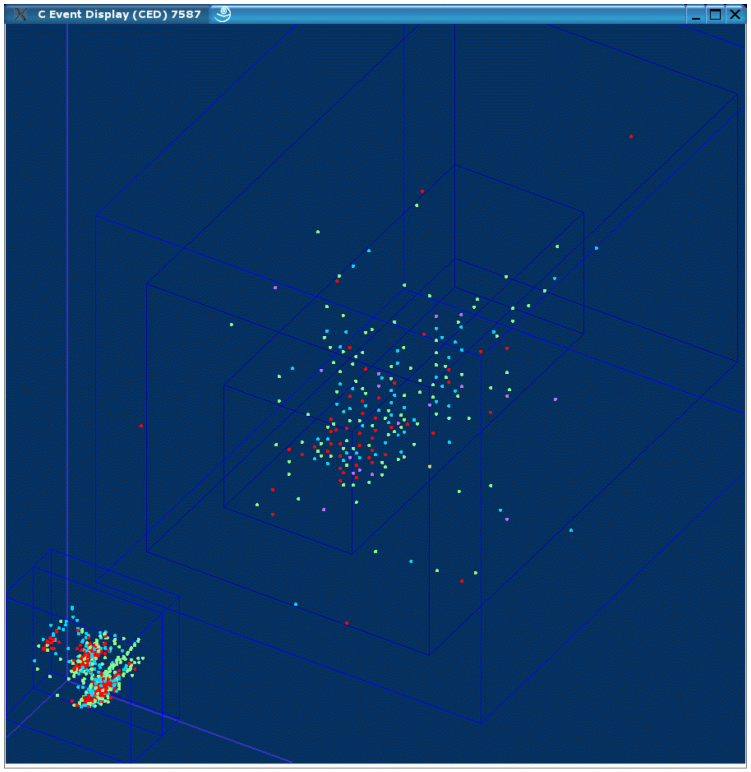
electron: 3 mm Pb target (126 m)*, no absorber
possible energies ~ $E_{\text{secondary beam}}$ – N GeV
rates 10-100 Hz

In both cases: relatively pure beam

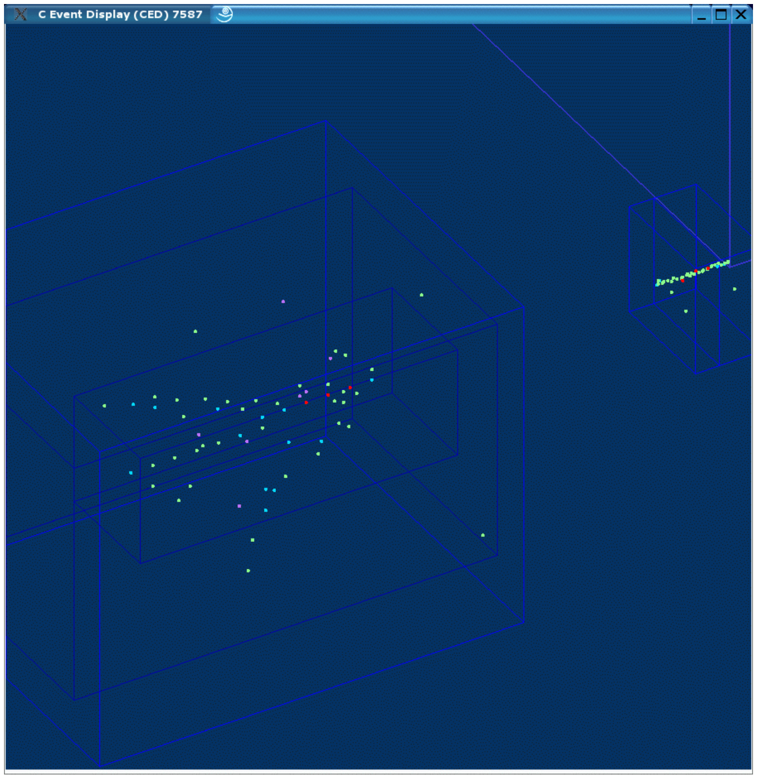
*H6B experiment at ~ 540 m

Some event displays

Multiparticle event :
2 electrons + 1 pion ??



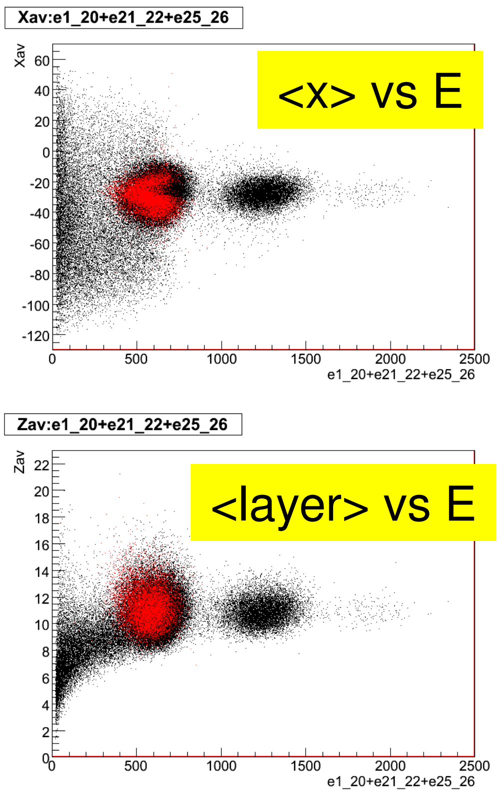
One pion event

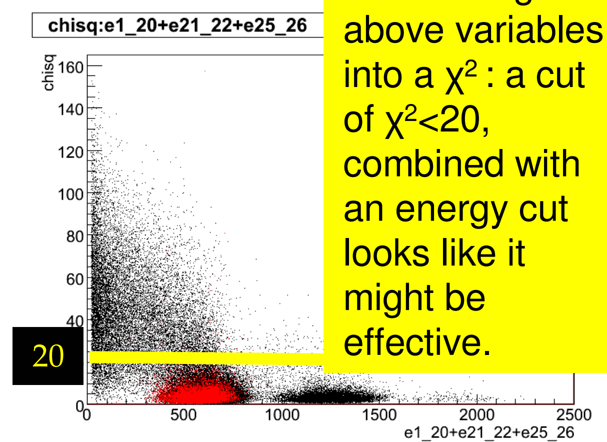


First look at DATA/MC comparison : Separation of junk from signal?

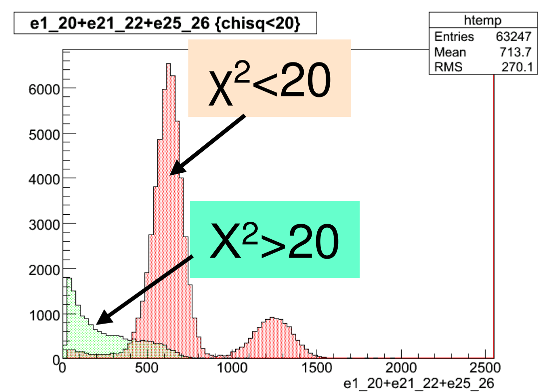
David Ward, Cambridge

3 GeV e-





- Combining the above variables into a χ^2 : a cut of χ^2<20, combined with an energy cut looks like it might be effective.



Data – black
MC - red

Next generation of Si-W prototype

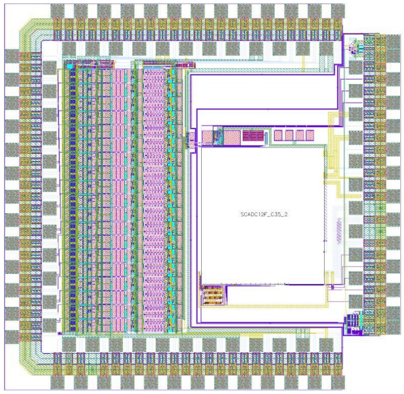
Next generation ASIC :
ILC_PHY5
LPC/LAL/LLR/UCL/ICL

Paul Dauncey, IC London
LAL & LLR, Paris

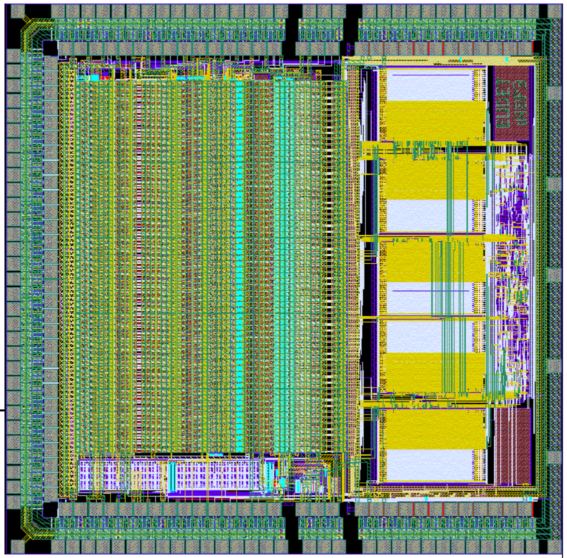
Requirements for ILC_PHY5

- Designed for 5*5 mm^2 pads
- 72 channels
- Detector AC/DC coupled
- Auto-trigger
- 2 gains / 12 bit ADC → 2000 MIP
  Energy resolution :4.89 GeV (cf JCB)
- 24 bits Bunch Crossing ID
- Internal SRAM with data formatting
- Output & control with daisy-chain
- Power pulsing, programmable stage by stage
- Calibration injection capacitance
- Embedded bandgap for references
- Embedded DAC for trig threshold
- Compatible with physics proto DAQ
  - Serial analogue output
  - External "force trigger"
- Probe bus for debug

ILC_PHY4 (2005)



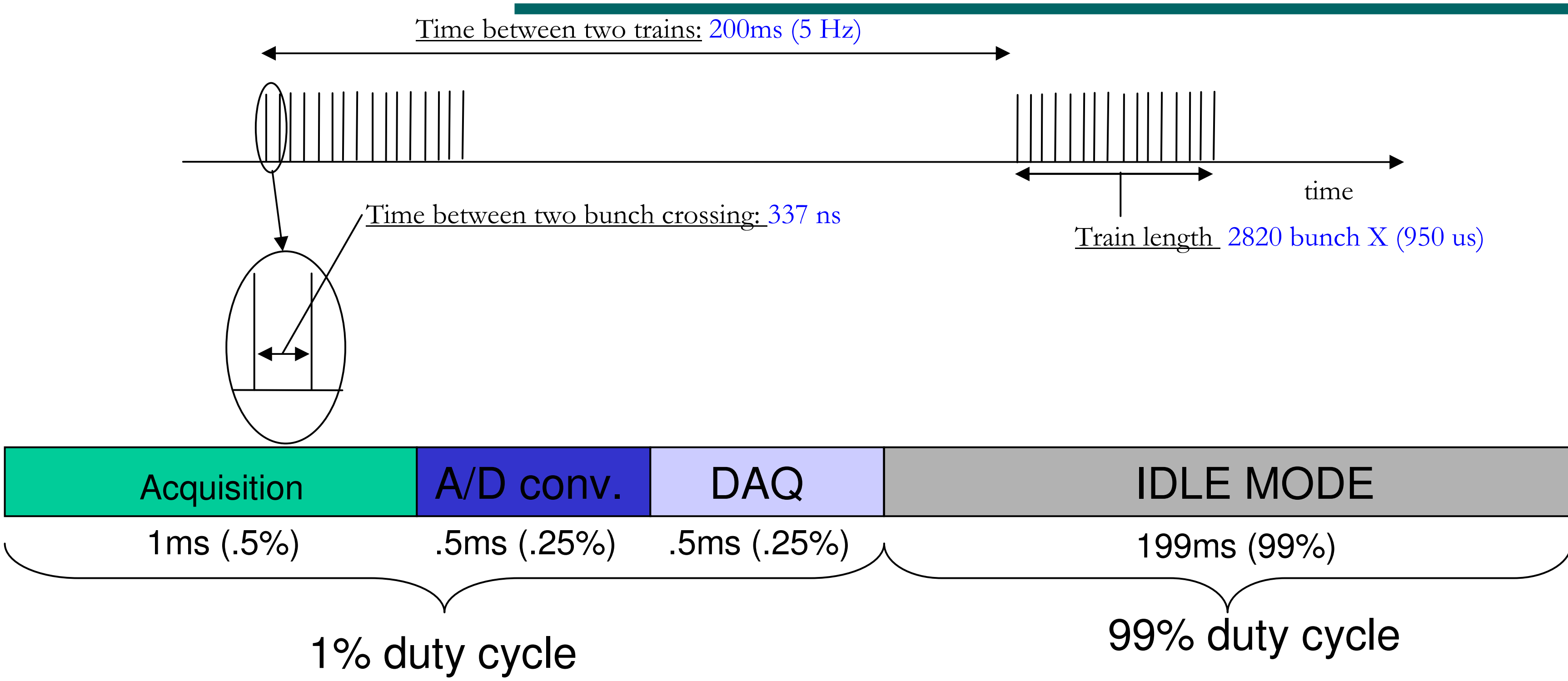
HaRD_ROC (2006)



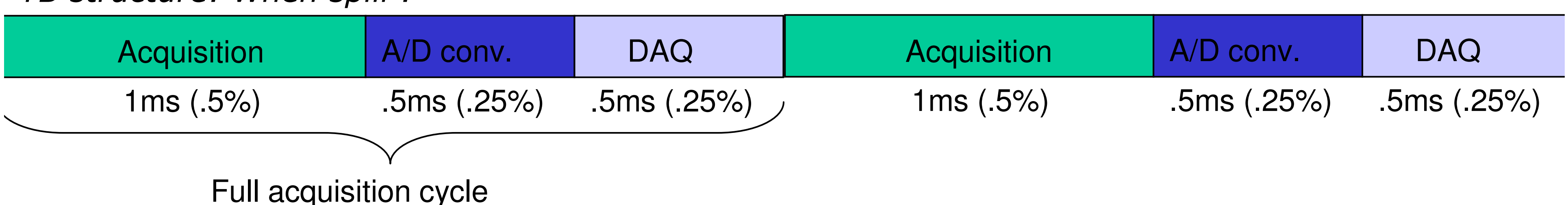
Conclusion:

- Work is going on
- Complexity increases quickly
- Collaboration has to organize its effort on electronic/microelectronic to achieve the outstanding expectations within the very tight schedule

Time considerations



TB structure: When spill :



When no spill :

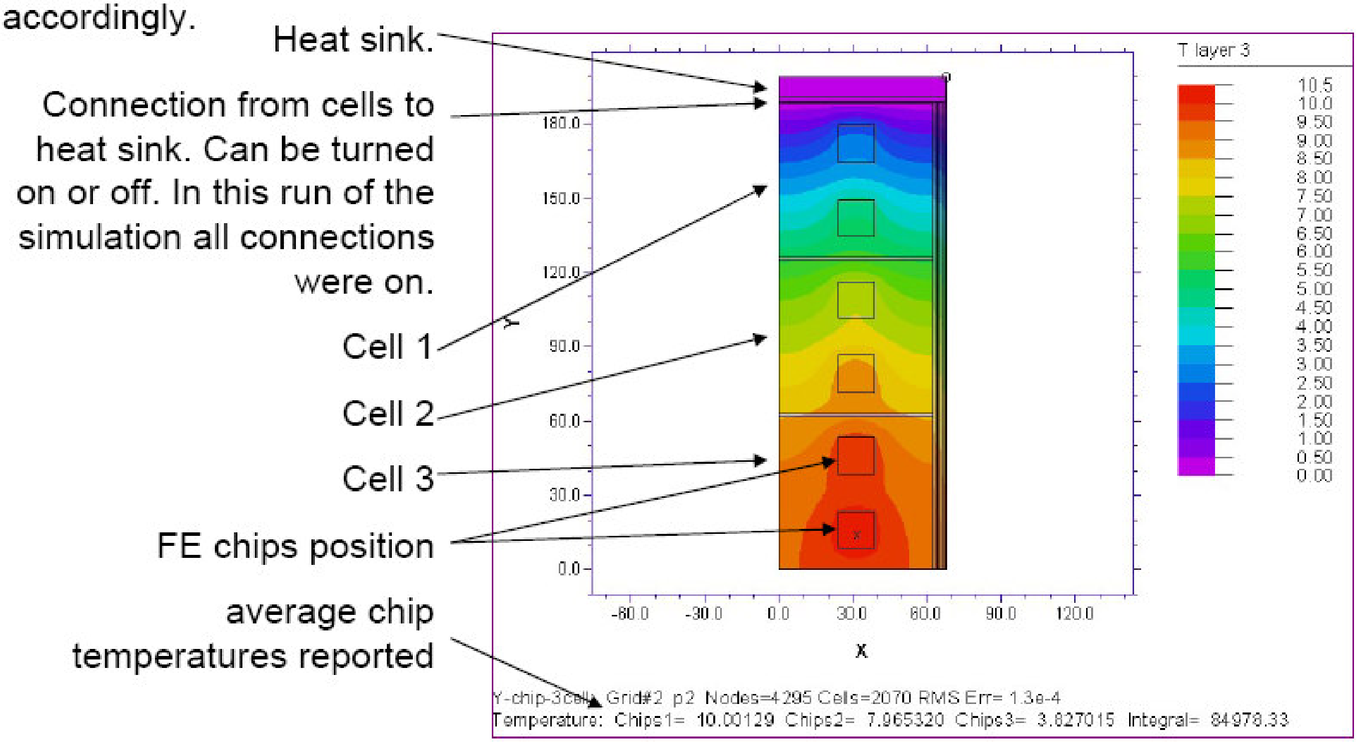
IDLE MODE

Thermal studies of ECAL

Temperature map

Here is a typical temperature map from a simulation of three adjacent cells, cooled at the top end.

In this simulation heat is input to the cells at the rate of 1 W per cell, whereas the power expected in CALICE is 0.015 W/cell, so temperatures should be scaled accordingly.



David Bailey, CALICE Meeting, Montreal, May 2006