Status and Prospects of the CALICE Project

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On behalf of the Calice-UK collaboration

Outline

- Calorimetry at the ILC
- Detector concepts
  - SiW ECAL, Scintillator strips ECAL
  - Analog HCAL and Digital HCAL
- Summary of 2006 test beams and preparation for 2007 test beam programme
- Progress in UK work on ECAL design
  - Data acquisition for final ILC detector
  - Mechanical studies: glue studies
  - MAPS design
- UK work on PFAs and physics studies
- Conclusion and Outlook

Calorimetry at the ILC

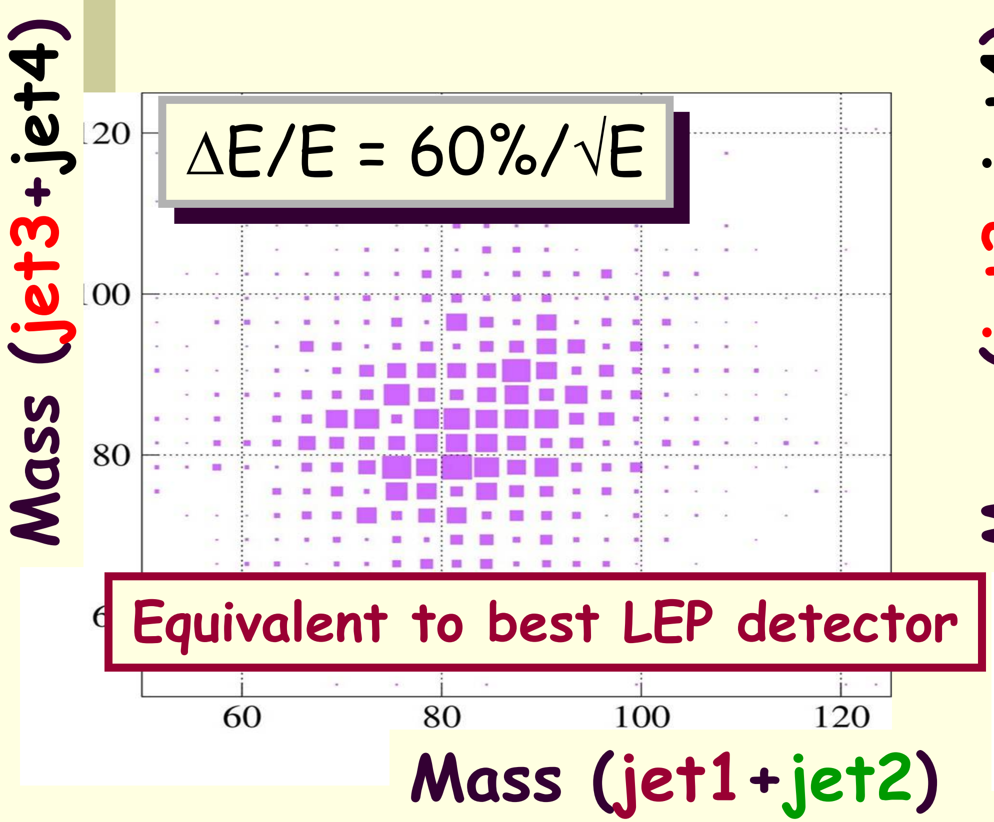
- Calorimetry is one of key ingredients for a high-specs detector at the ILC
  - Need high granularity for precise jet energy resolution
  - $$\sigma_{jet} = \sigma_{charg} \oplus \sigma_{phot} \oplus \sigma_{neut} \oplus \sigma_{confusion}$$
- Design, build and operate a novel detector which fulfils stringent requirements: $\sigma_{jet} = 30\% / \sqrt{E}$

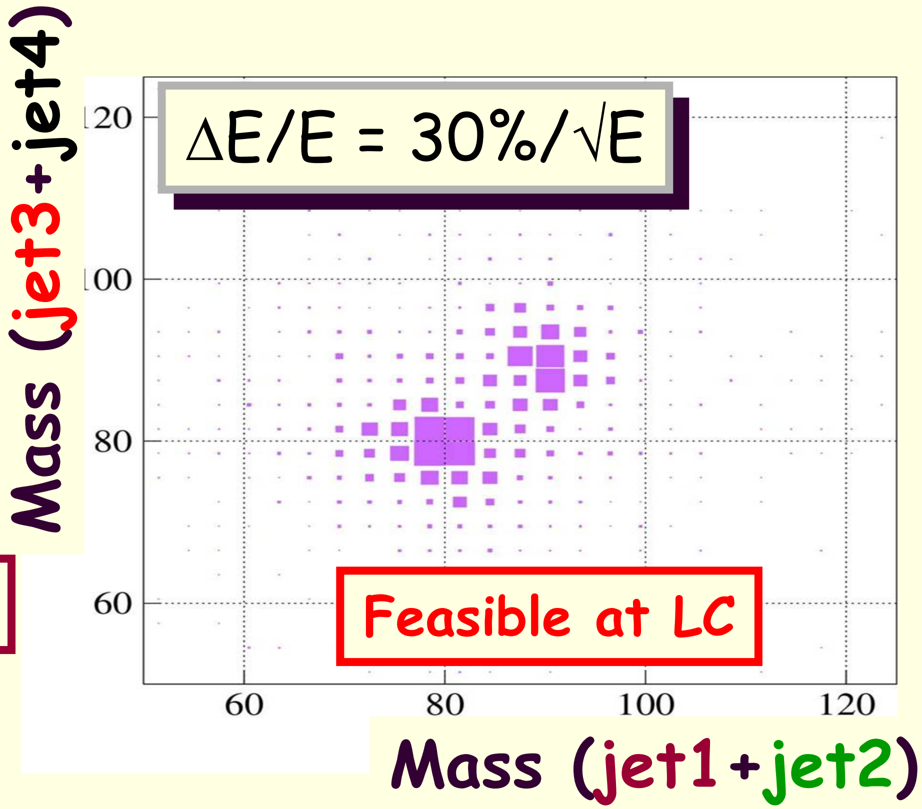
particles in jet	fraction of energy in jet	detector	single particle resolution	jet energy resolution
charged particles	60 %	tracker	$\frac{\sigma_{p_t}}{p_t} \sim 0.01\% \cdot p_t$	negligible
photons	30 %	ECAL	$\frac{\sigma_E}{E} \sim 15\%/\sqrt{E}$	$\sim 5\%/\sqrt{E_{jet}}$
neutral hadrons	10 %	HCAL+ECAL	$\frac{\sigma_E}{E} \sim 45\%/\sqrt{E}$	$\sim 15\%/\sqrt{E_{jet}}$

- Extensive test-beam programme of detector prototypes

The Particle Flow Paradigm

- Highly performing Particle Flow Algorithms (PFA) combined with high granularity calorimeters are a must to fulfil the LC physics programme





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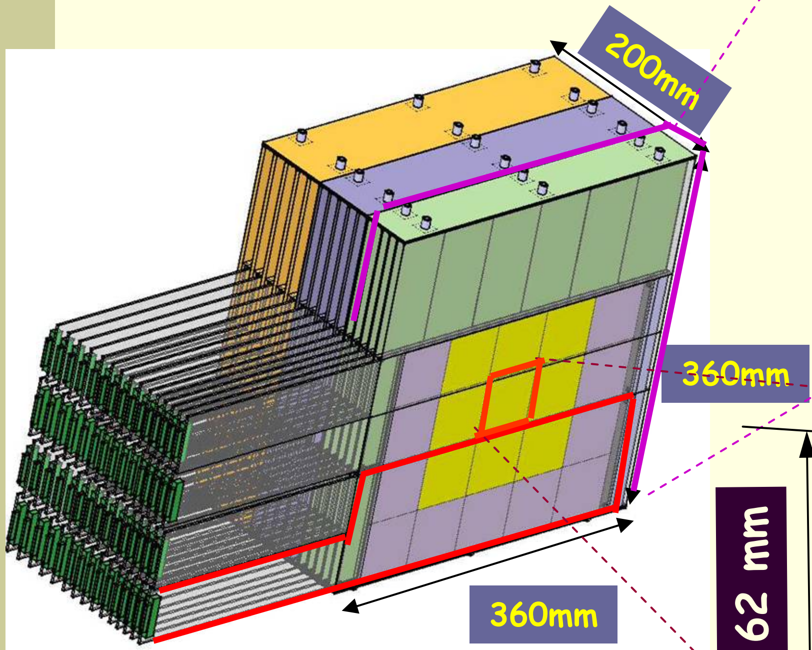
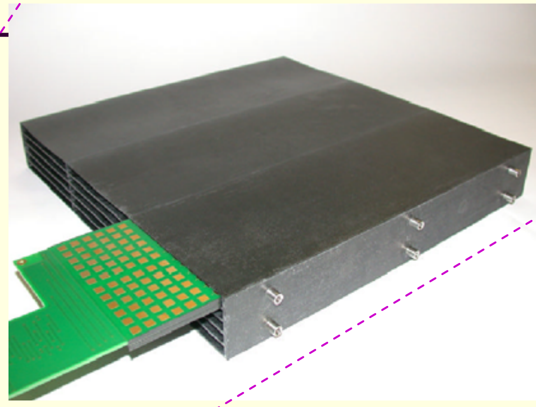
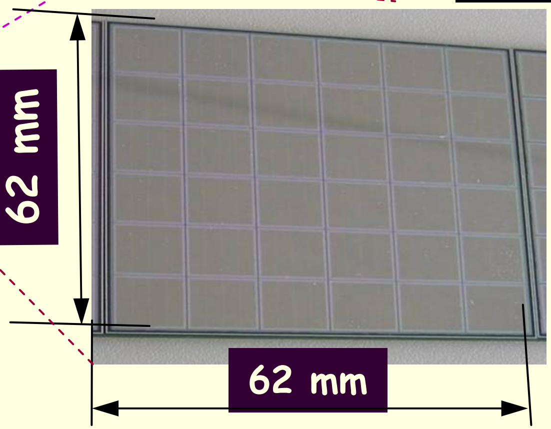
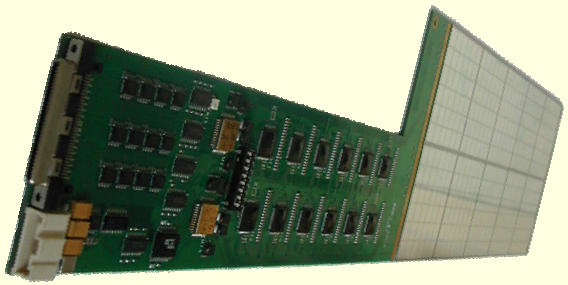
SiW ECAL prototype





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





- W layers wrapped in carbon fibre
- 3 modules with different tungstene thickness, total = 24 X_0
- Active silicon layers interleaved: PCB+Si layers = 8.5 mm
- FE chip and readout on PCB board

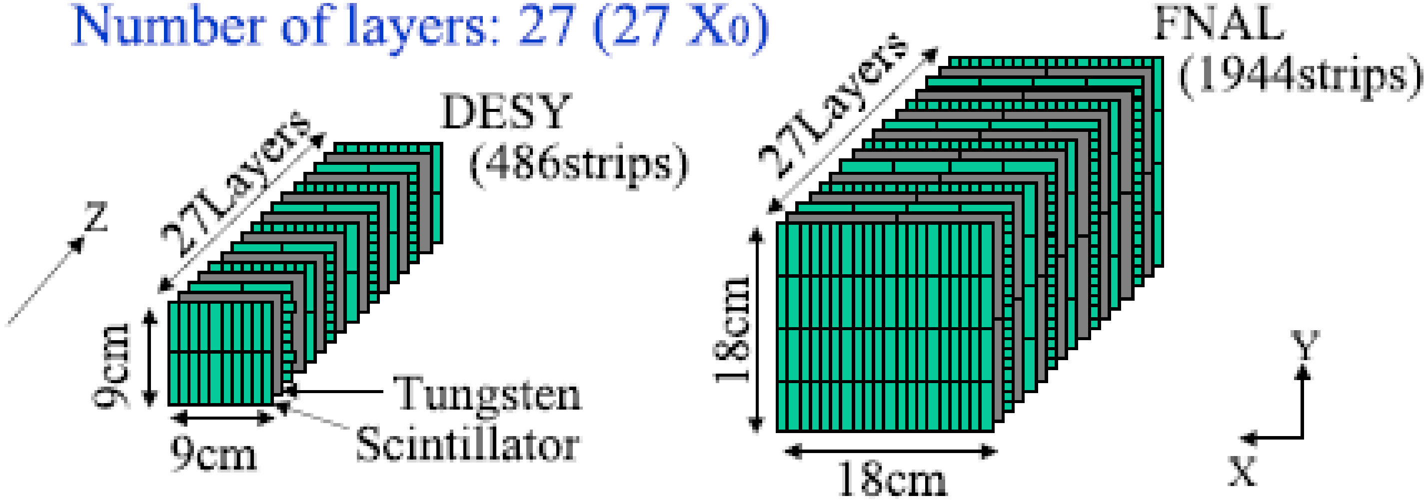
Scintillator strips ECAL

Prototype ECAL - MPPC readout

Tungsten:3.5mm Sci. strip:3mm

Strip size: 1cm (width) x 4.5cm (length)

Number of layers: 27 (27 X_0)



Cross section 9cmx9cm Test@DESY(This winter)

-> In EM shower (Non linearity of MPPC)

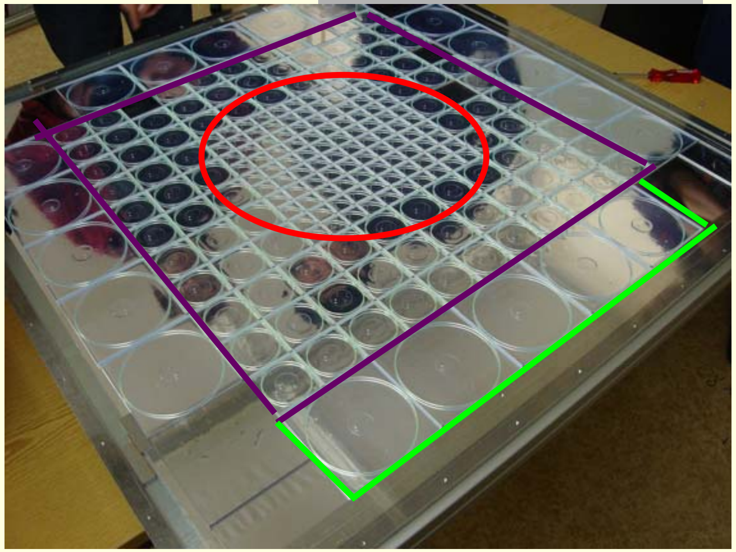
Cross section 18cmx18cm Test@Fermilab(2007)

-> In multi particle injection / Pi0 reconstruction

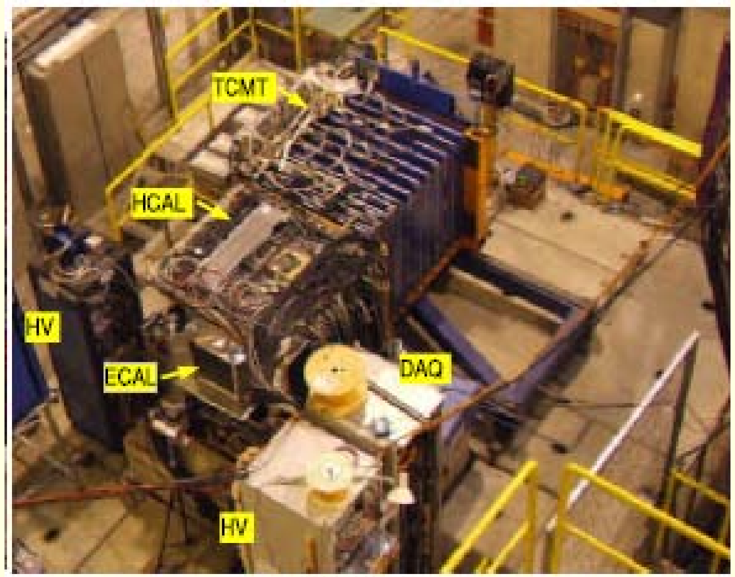
(slide by T.Takeshita)

Analog HCAL prototype

- 38 layers of scintillator tiles (90x90 cm^2) with steel absorber
- High granularity
  - 3x3 + 6x6 + 12x12 cm^2 tiles
  - 8000 readout channels (SiPM)



- Measurements of shower leakage and muon identification provided by Tail Catcher + Muon Tracker (TCMT)
  - 96 cm of iron absorber with 16 layers of 5*50mm^2 scintillator strips (~10 λ)

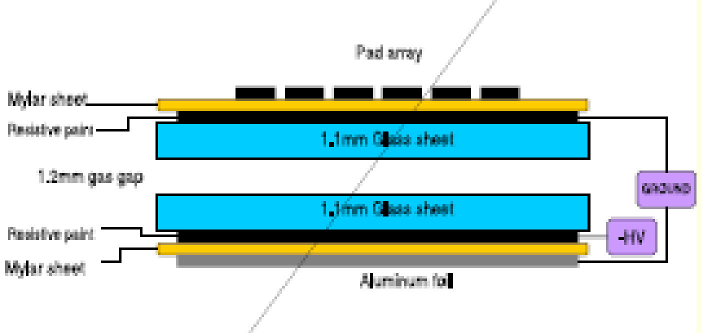


(top view)

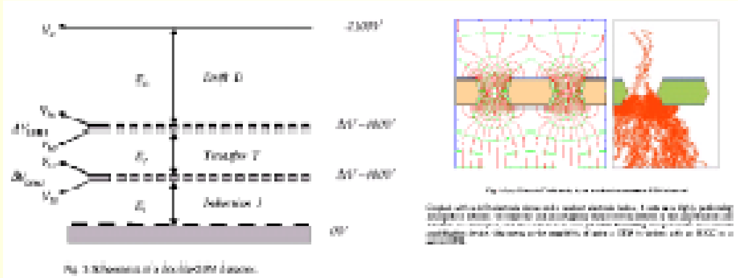
- Common ECAL+HCAL+TCMT DAQ

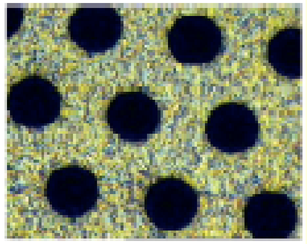
Digital HCAL prototype

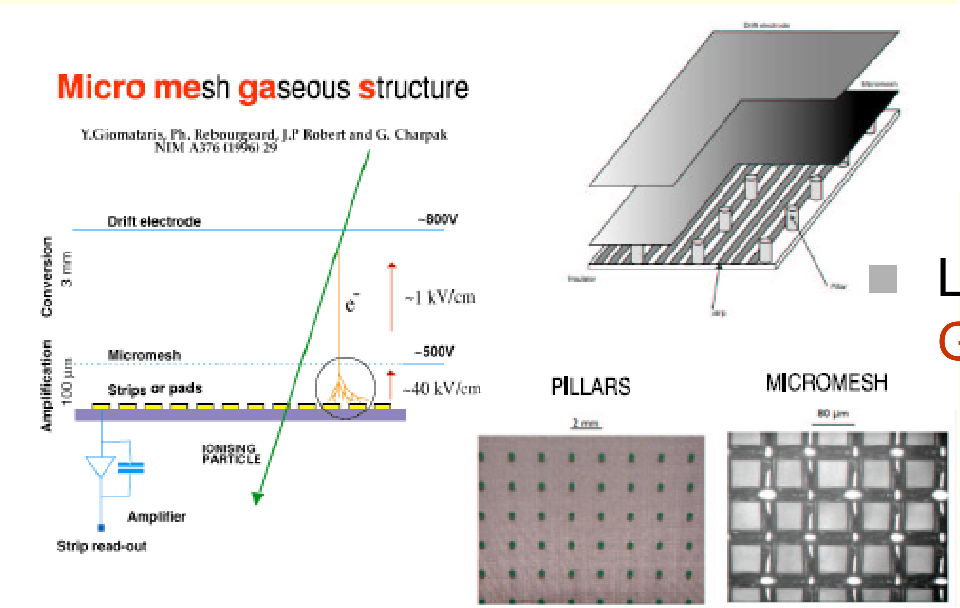
- RPC + steel absorber (1x1 cm^2)
  - $1m^3$ prototype, 4.5 λ_I
  - 40K channels



- GEMs + steel absorber (1x1 cm^2)
  - $1m^3$ prototype, 4.5 λ_I
  - 40K channels







- Layers equipped with Micro MEsh GAseous Structure chambers
  - Readout by pads or strips

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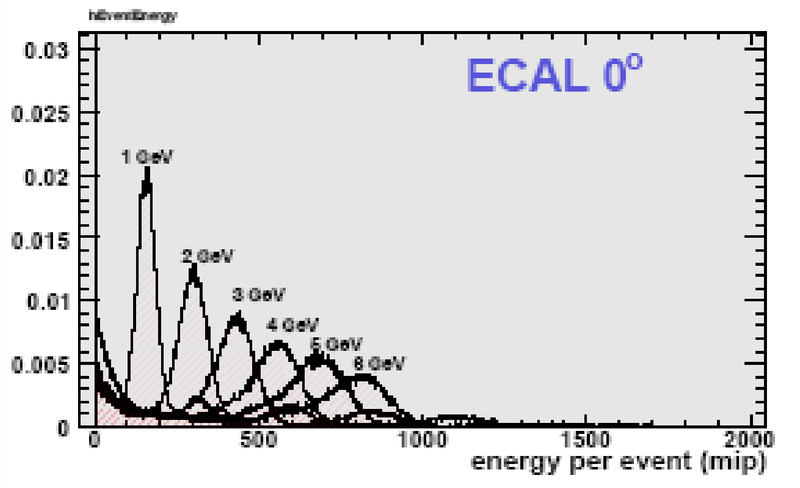
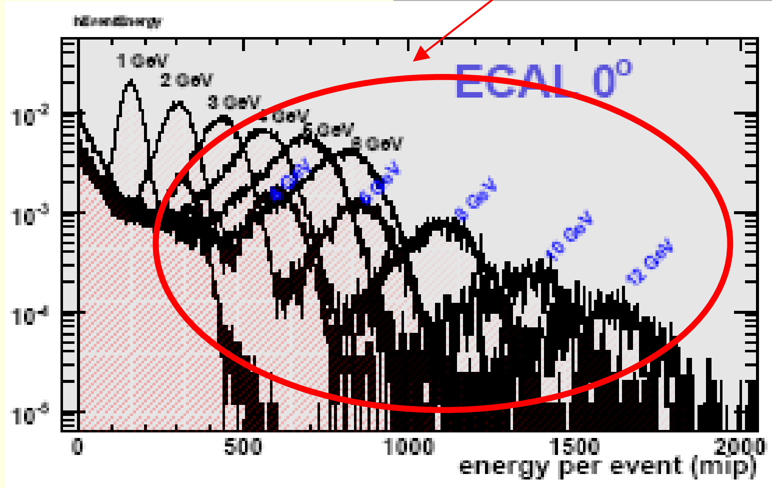
Desy run – May 2006

- SiW prototype tested on electron beam at energies from 1 to 6 Gev
  - 24 layers equipped with 18x12 matrix of Si cells
    - 3 W thicknesses (1.4, 2.8, 4.2 mm)
    - Cell size 1x1 cm^2
    - ~5200 channels
- > 8M events collected
  - Position scans: centre, edge, corner of wafers
  - Energy scans: 1, 1,5, 2, 3, 4, 5, 6 GeV runs
  - Angle scans: 0, 10, 20, 30, 45 degrees

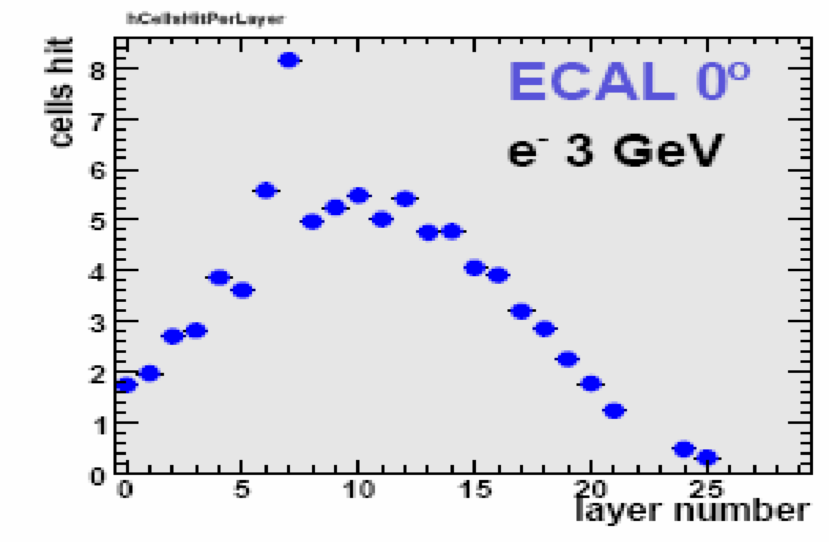
ECAL response

Double particle events

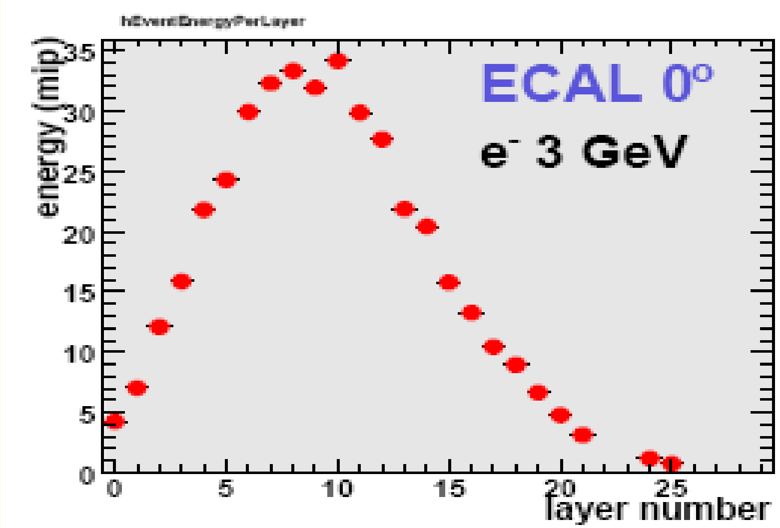




Hits per layer



E per layer

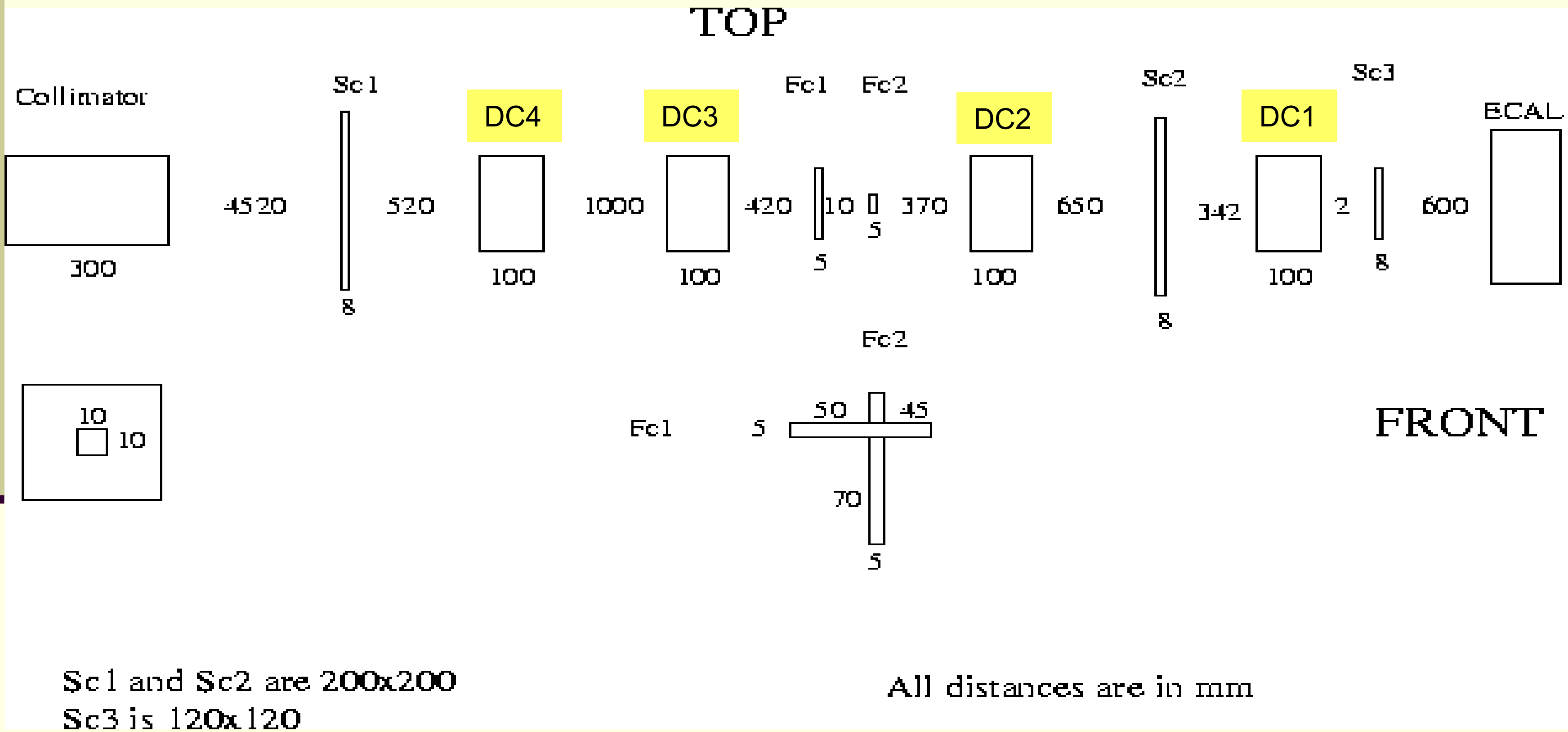


G. Mavromanolakis

Showers well contained

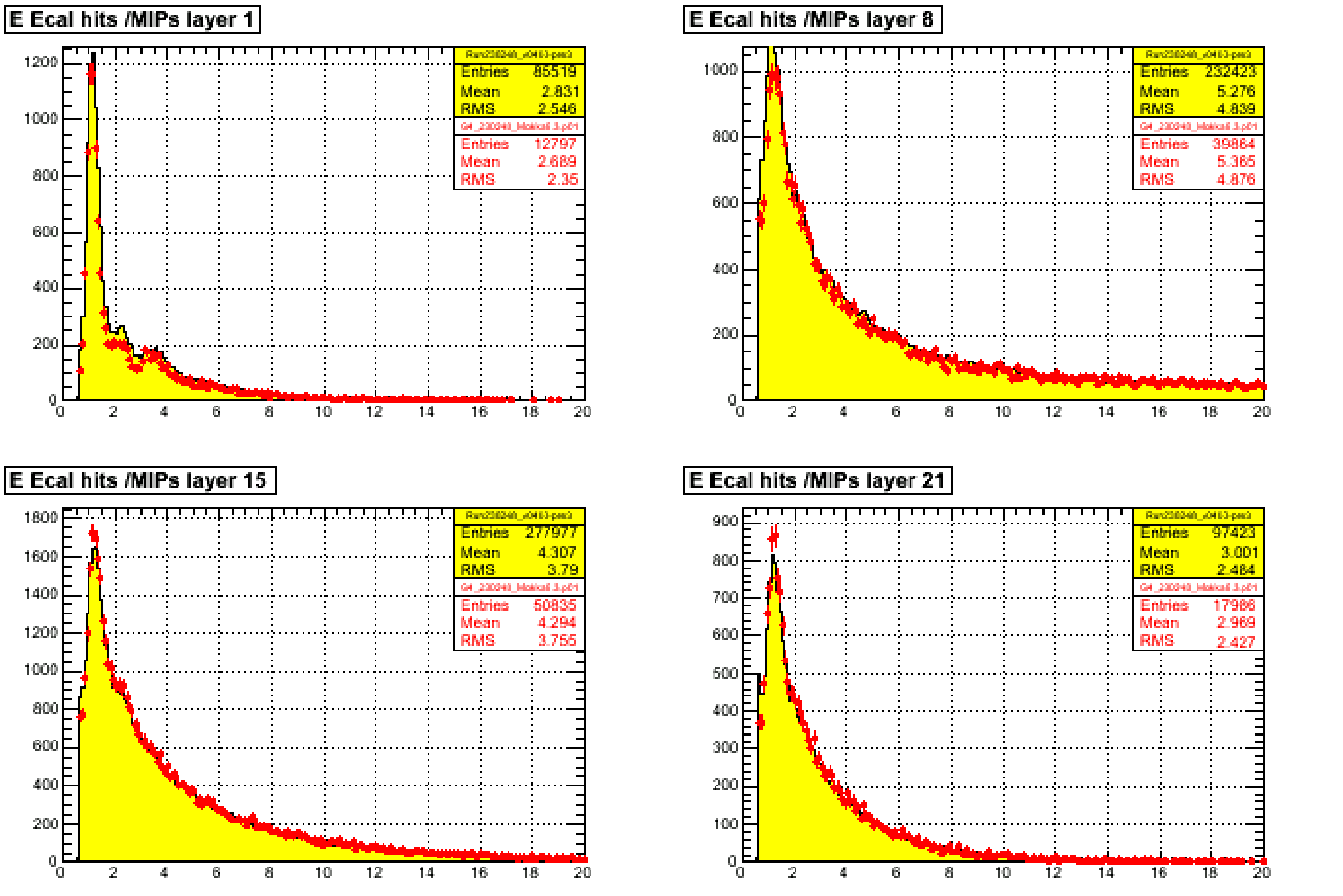
Test beam Monte Carlo

- Full G4 simulation of Desy test beam setup available in Mokka (v06-03p01)



F. Salvatore

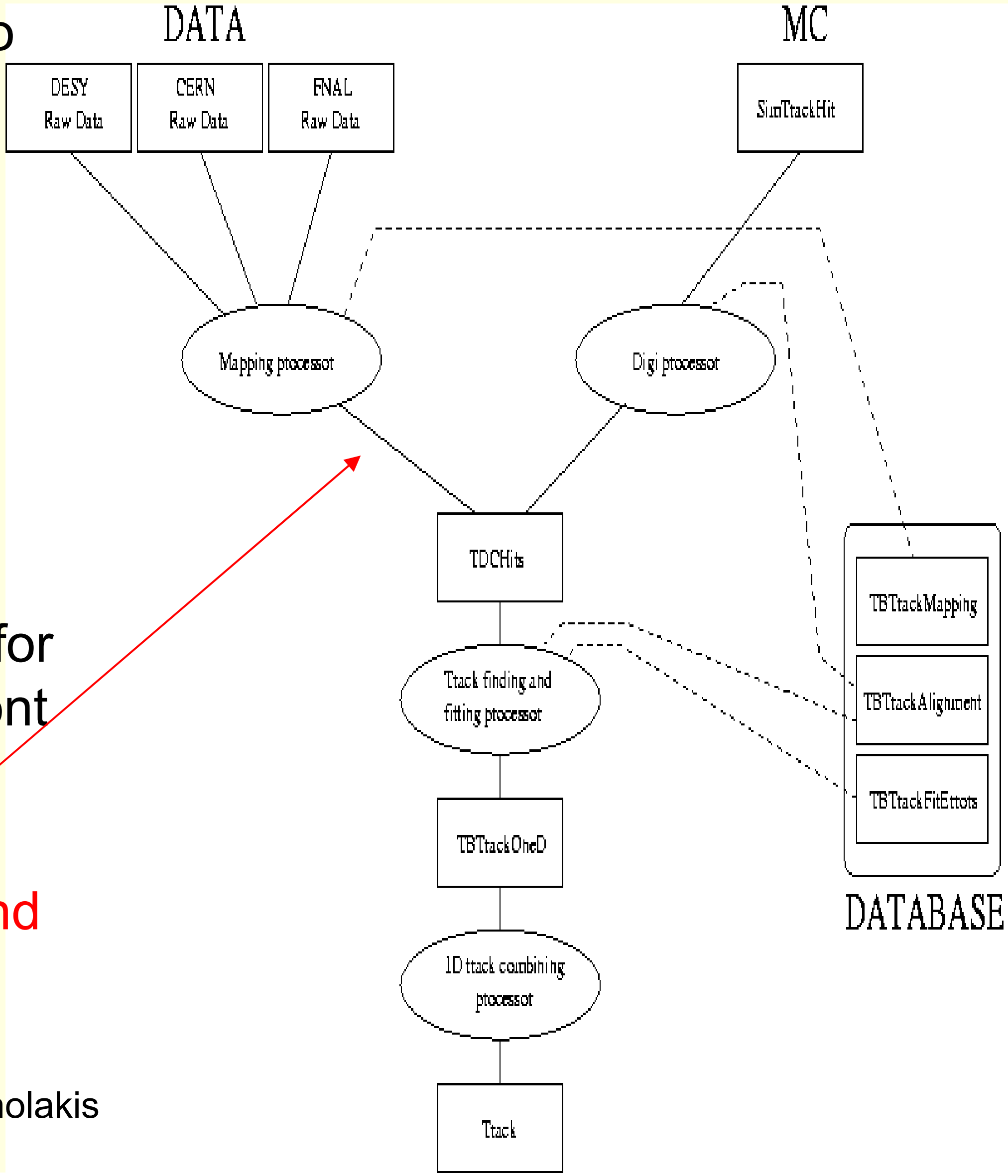
Data/MC comparison – e$^-$ 3 GeV



D. Ward

Track reconstruction

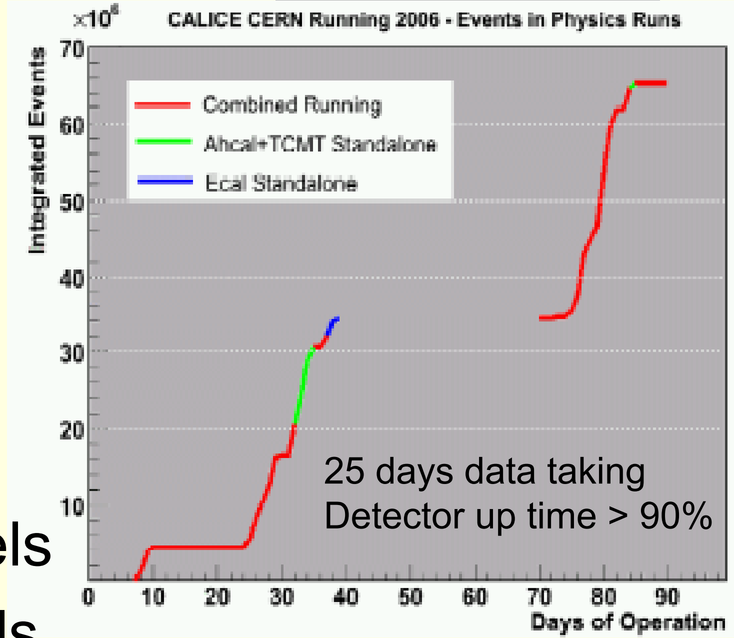
- Use info from data and MC to reconstruct drift chamber's tracks
- Evaluate drift velocity of chambers from data
- Use MC to evaluate error matrix of track fit, including multiple scattering effects
- Reconstruct 1D tracks and extrapolate at any point in Z for resolution studies on Ecal front face
- Working towards a common software structure for data and MC for tracking

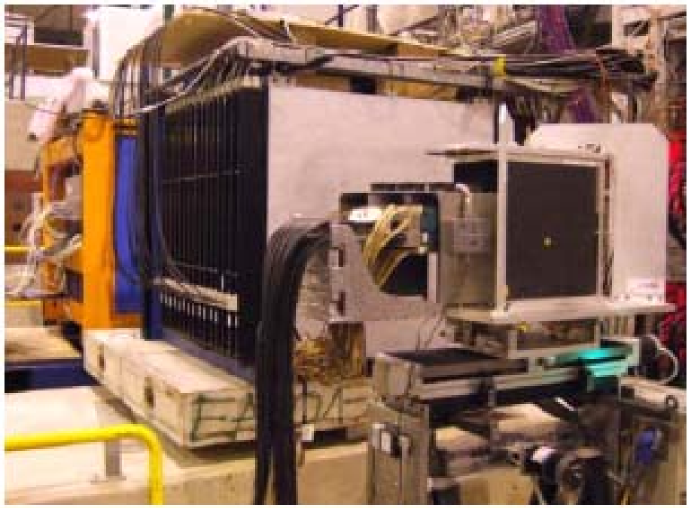


M. Faucci Giannelli, F. Salvatore, M. Green
P. Dauncey, H. Yilmaz, A-M. Magnan, G. Mavromanolakis

CERN run – Aug & Oct 2006

- SiW ECAL prototype:
  - 30 layers, 18x12 matrix of Si cells
    - 3 W thicknesses
    - Cell size 1x1 cm^2
    - ~6500 channels
- HCAL:
  - Aug: 15 modules, ~3200 channels
  - Oct: 23 modules, ~5000 channels
- TCMT:
  - Aug: 8 modules, 160 channels
  - Oct: 16 modues, 320 channels
- Common DAQ: 120 Hz max average rate, ~500 Hz peak rate in spill





Summary of run conditions

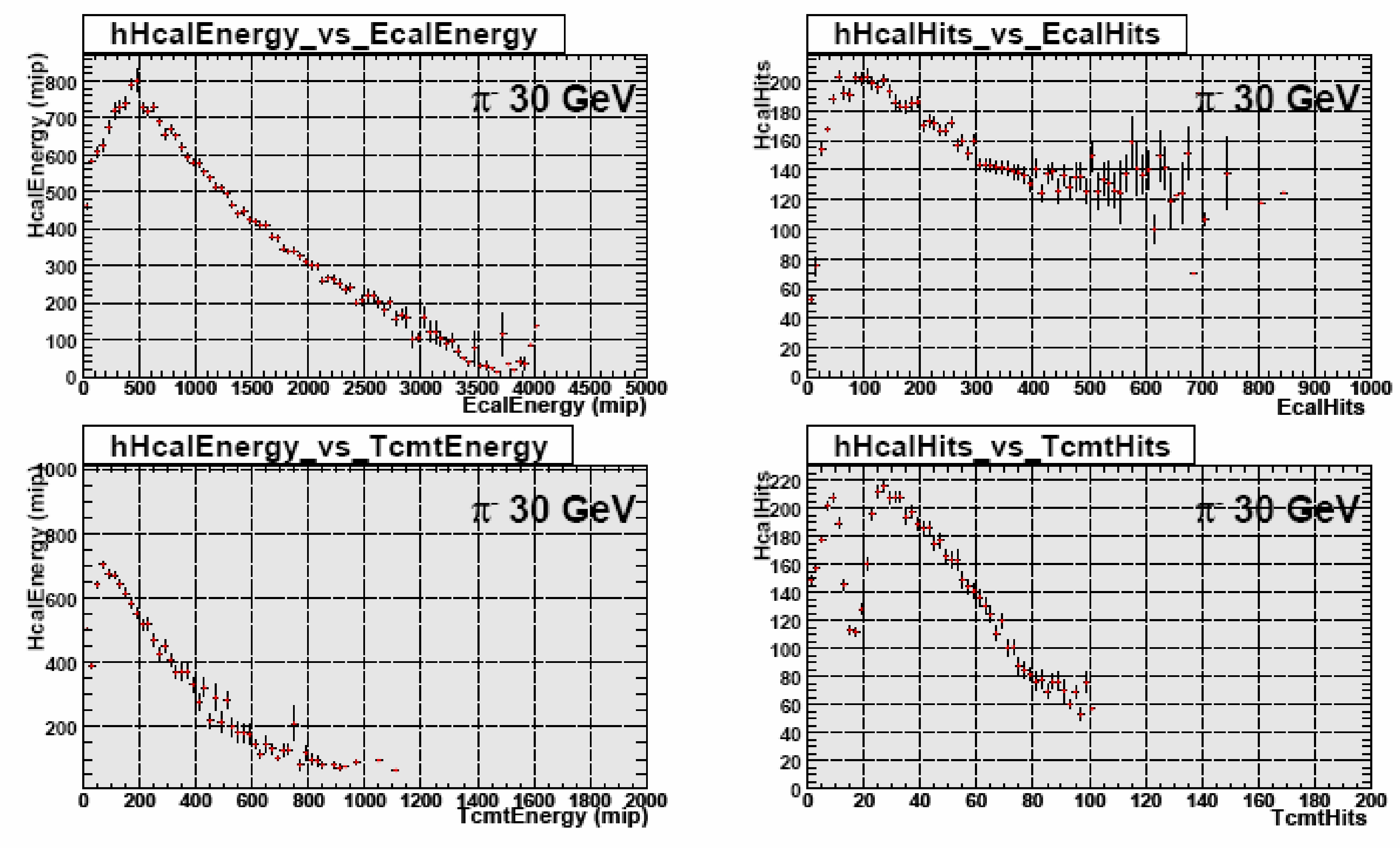
Aug 2006

- HCAL alone, no ECAL
  - e^- beam: 6 to 45 GeV
  - π^- beam: 6 to 80 GeV
- ECAL+HCAL
  - π^- beam: 30 to 80 GeV
- ECAL alone
  - e^- beam: 6 to 45 GeV
  - Angle scan: 0, 30, 45 deg
- 600K events per sample

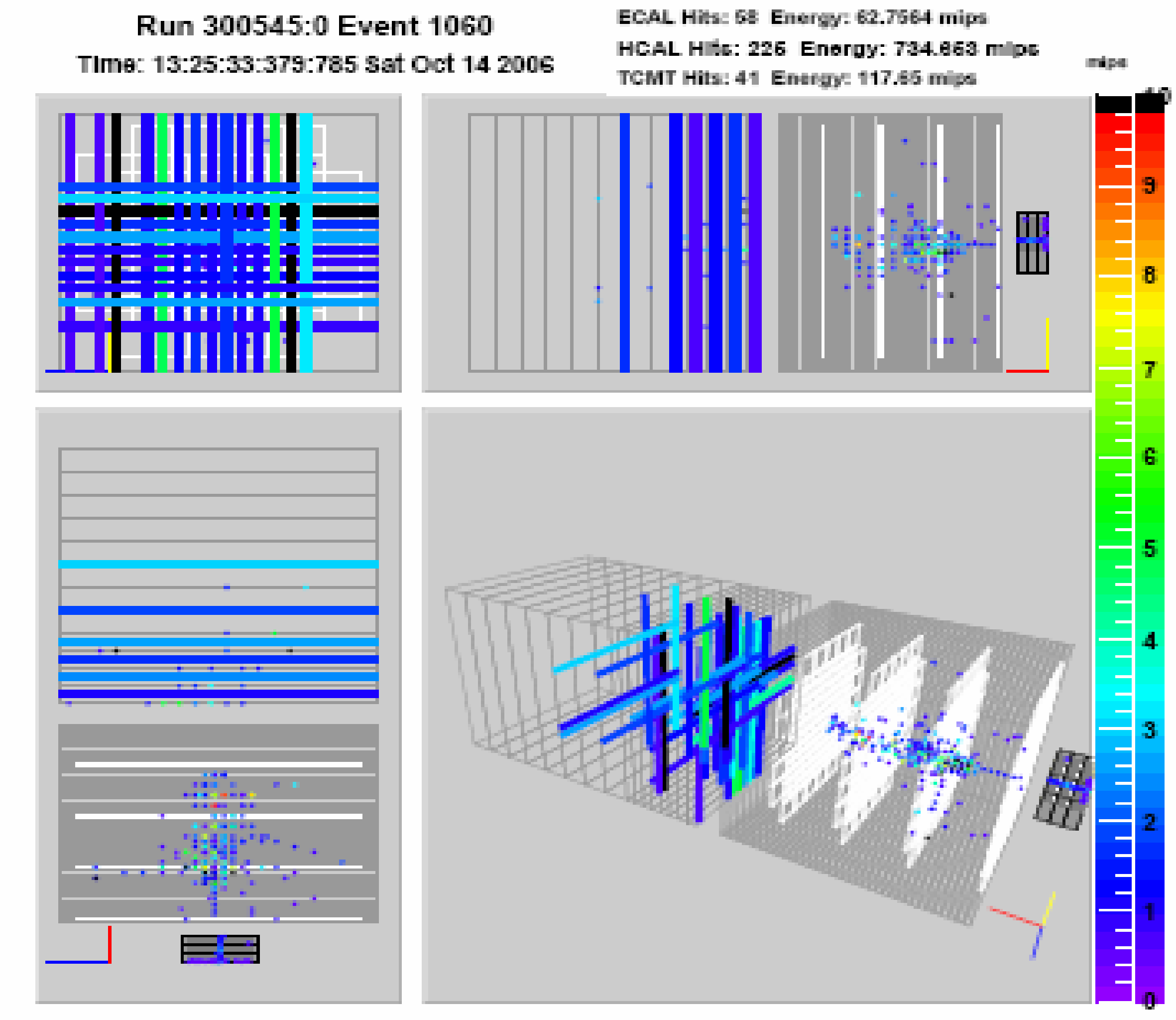
Oct 2006

- ECAL+HCAL+TCMT
  - π^- beam: 6 to 80 GeV
  - 500K events per sample
- HCAL alone, no ECAL
  - e^+ beam: 10 to 50 GeV
  - 600K events per sample
- ECAL alone
  - e^+ beam: 10 to 50 GeV
  - 300K events per sample
- Parasitic run: 25M μ events collected

ECAL vs HCAL vs TCMT response



Beam monitoring



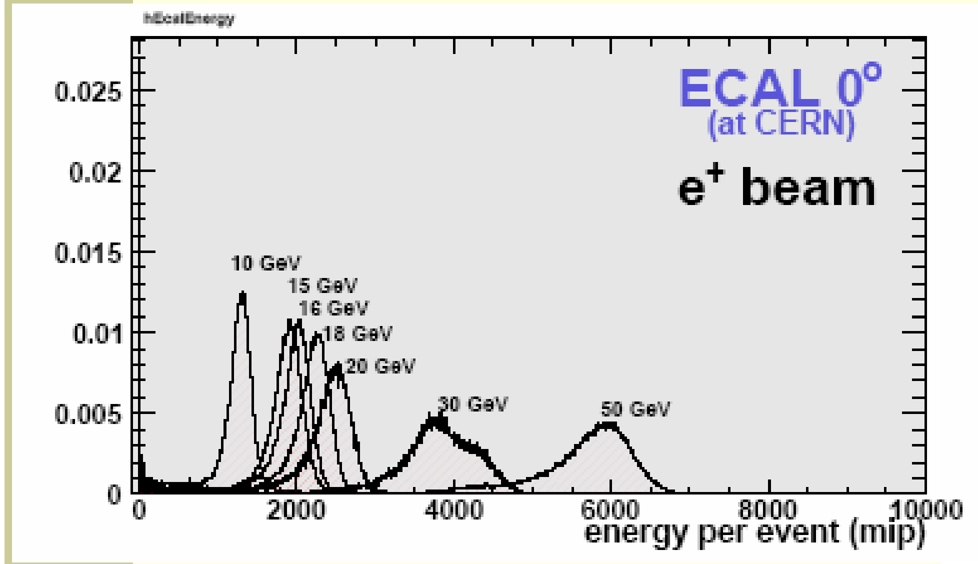
π^- 30 GeV

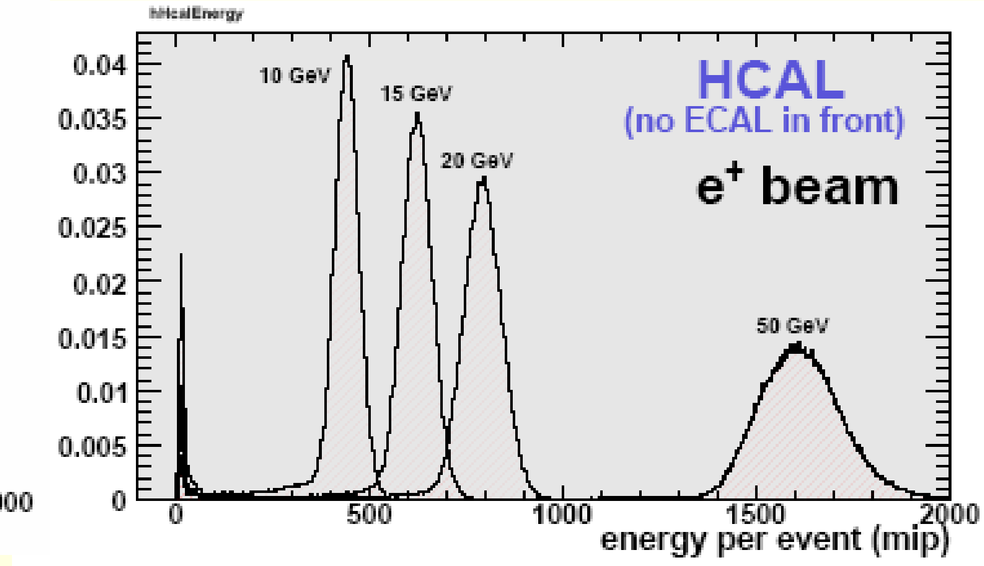
ECAL threshold = 0.5 mip
HCAL threshold = 0.5 mip
TCMT threshold = 0.7 mip

Tracking calorimeters

G. Mavromanolakis

ECAL and HCAL response to positrons

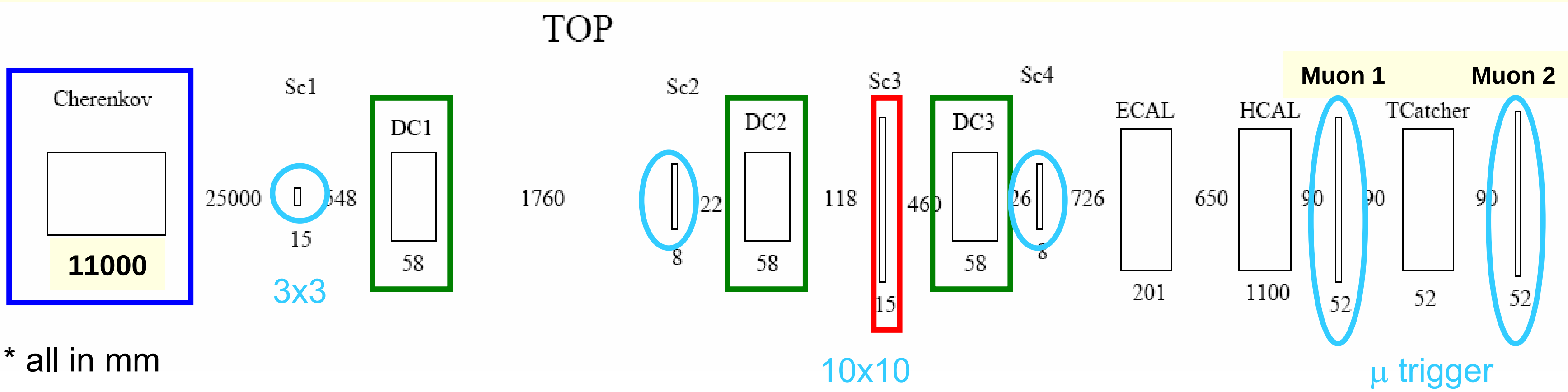




- Most runs with typical behaviour
- At 30 GeV response affected by noise/unstable layers

- Runs used for e/π studies
- Useful for SiPM saturation studies

Full G4 MC simulation



Beam instrumentation:

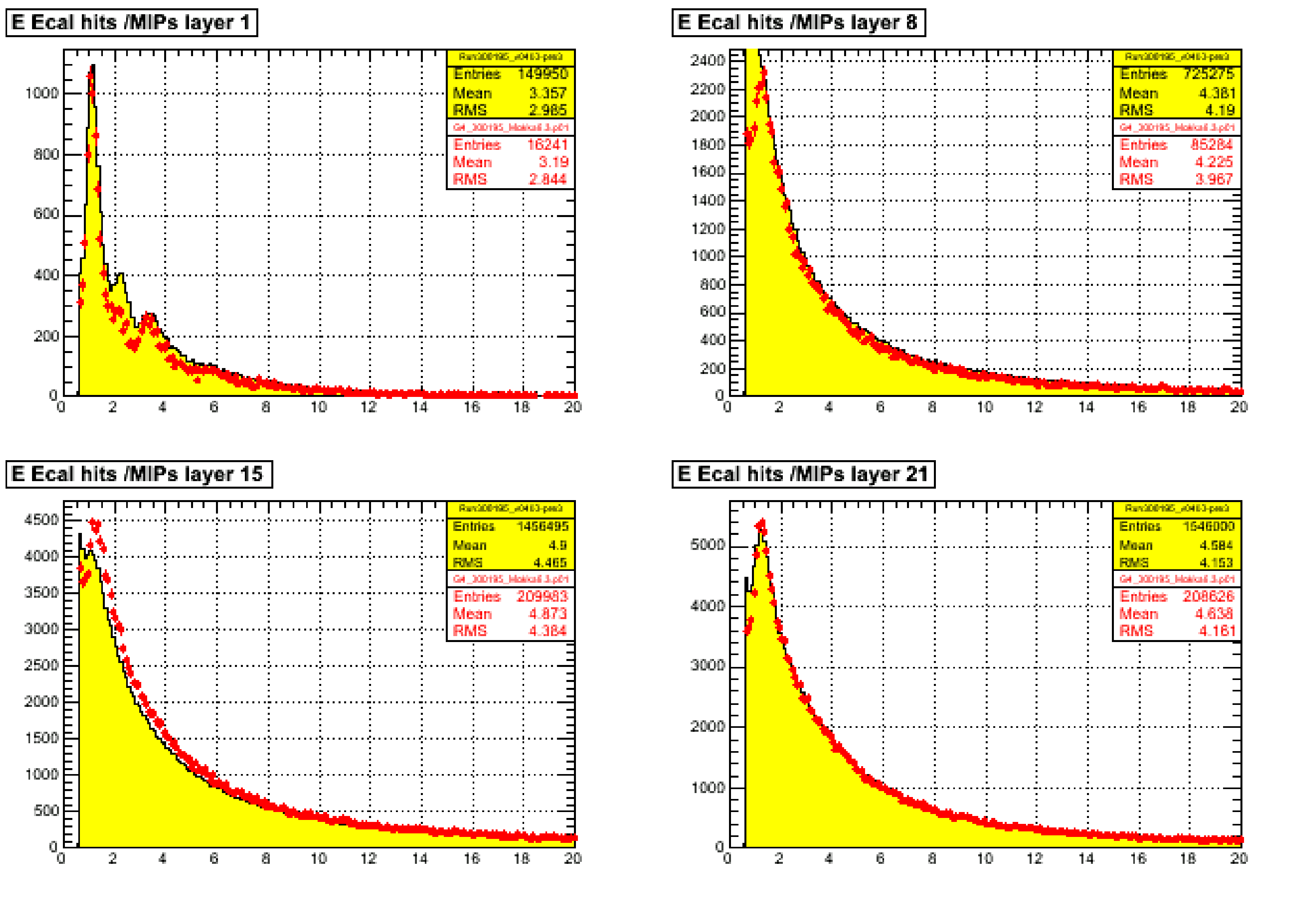
1) Cherenkov detector for e/π separation < 40 GeV

2) 3 x/y pairs of Multi Wires Proportional Chambers (MWPC) with double readout, multi-hit capability

3) veto counter, r/o analog amplitude, to separate multi-particle events

4) trigger system

Data/MC hits by layer @ 45 GeV



D. Ward

Data processing status

- All tb data from CERN and Desy converted to LCIO using v04_02 of the reconstruction package
  - Using ILC Software for data processing
- Preparing next version of reconstruction
  - Includes tracking, a full HCAL reconstruction and an improved calibration
    - Still in the testing phase
- All Calice data available on the grid
  - VO Calice has ~40 members as of today
  - Whole data processing and simulation work will use grid facilities
- Calice is the first ILC project using systematically the grid
  - Will deliver valuable input for the whole ILC community

Test beam summary

- Extremely successful test beam programme in 2006
  - Huge amount of data collected
  - Leading UK role throughout
- First results of tb analysis will be presented at LCWS07 conference at Desy (30th May – 3rd June)
  - UK groups leading the analysis effort
- This year's test beam programme already started
  - Two weeks test of ECAL-scint at Desy in March
    - Significant UK contribution in DAQ and monitoring
  - Two 2-weeks periods in July and August at CERN
    - Installation starting June 10th
  - Moving all detectors to FNAL in October
    - ECAL-AHCAL-TCMT test with low energy hadrons
    - Combined ECAL-DHCAL test beam

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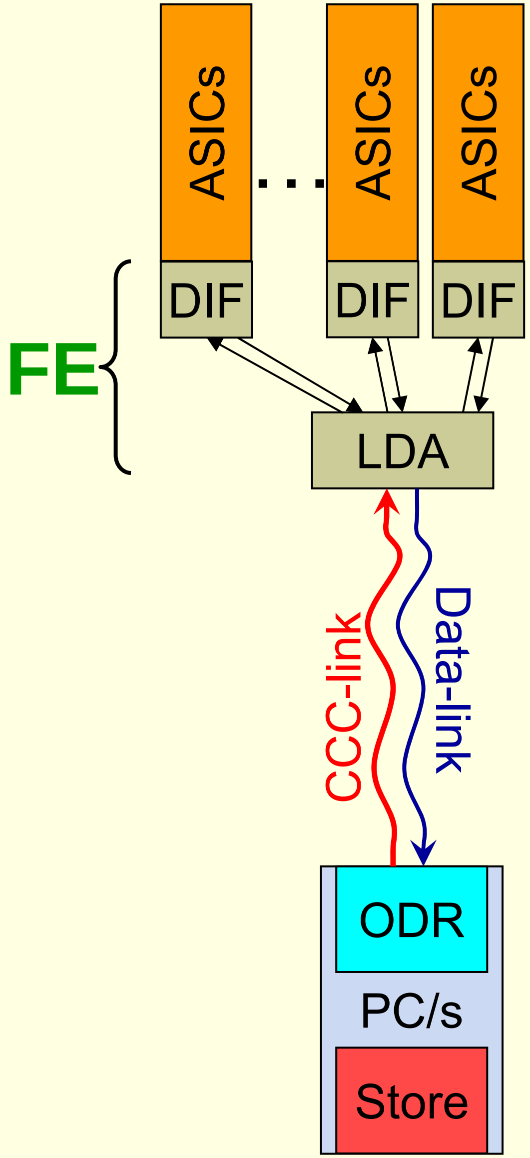
DAQ structure

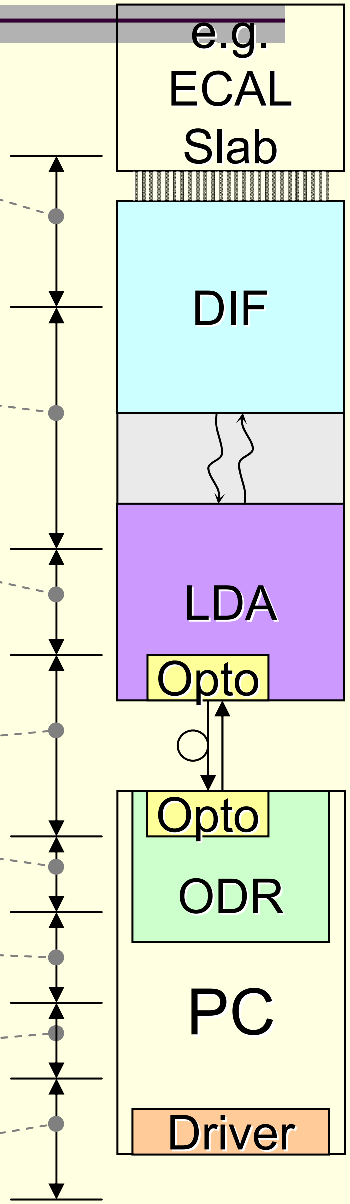
V. Bartsch, C. Targett-Adams, M. Postranecky, M. Warren, M. Wing,
B. Green, M. Green, A. Misiejuk, T. Wu, P. Dauncey, M. Noy,
M. Kelly, R. Hughes-Jones, R. Barlow, D. Bailey
M, Goodrick, B. Hommels

- Detector ASICs on e.g. ECAL slab
- Front-End (FE)
  - FE Detector Interface (DIF): Detector specific
  - FE Link/Data Aggregator (LDA): Generic
- Data-link (FE to Off-Detector Receiver)
- CCC-link (Clock+Control+Config to FE)
- DAQ PC
  - Off-Detector Receiver/s (ODR)
    - Drives CCC-link
  - Data Store
- DAQ Software



DAQ overview

- **Detector Interface (DIF)** (Cam, IC)
  - Sub-detector specific, in conjunction with detector groups
- **DIF to LDA** (Man/RHUL/UCL)
  - Generic, Copper links (100Mbit)
- **Link/Data Aggregator (LDA)** (Man)
  - Data format
  - Clock/Commands fan-out
- **LDA to ODR opto-links** (Man, RHUL, UCL)
- **Off-Detector Receiver** (Cam, RHUL, UCL)
- **ODR to disk** (RHUL)
  - PCI-Express driver software
- **Local Software DAQ** (RHUL)
- **Full blown Software DAQ** (IC, RHUL, UCL)



Data link and Off-Detector receiver

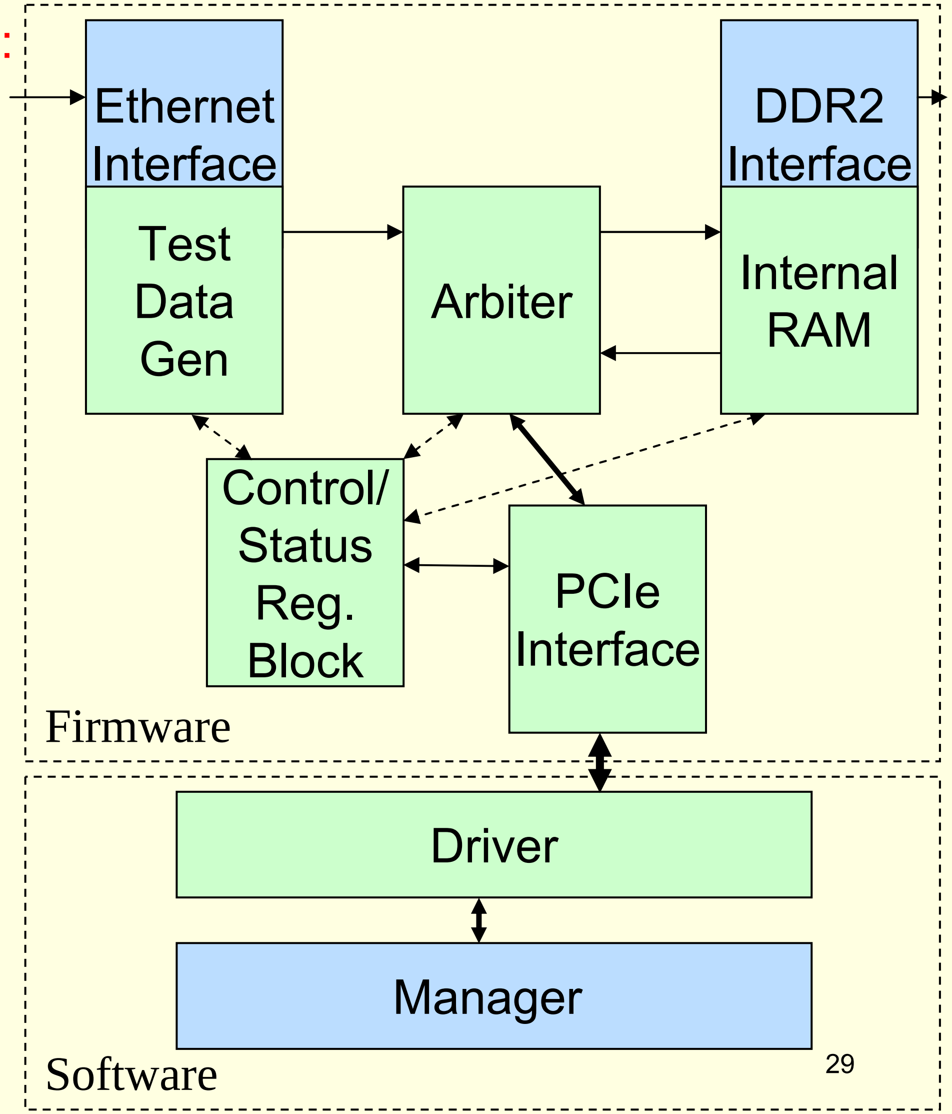
- Data link: use most common networking fibre-optics
  - Multimode with LC connectors
  - SFP (mini-GBIC) interfaces
  - 1Gbit rate
  - Ethernet

- ODR:
  - PCI Express Card
  - Virtex 4, FX100 FPGA (big!)
  - Hosts opto-links
    - 2xSFP, 2xHSSDC2 on board
  - Source of C+C (Control link)
    - Initially copper (SMA connectors?)
    - Later fibre
  - Will use external clock and sync signals for multi-PC operation

Commercial components

ODR status

- Firmware AND software underway:
  - PCIe interface **DONE**
  - Register read/write **DONE**
  - DMA access **DONE**
  - Linux driver **DONE**
  - Ethernet Interface **IN-PROGRESS**
  - DDR2 Interface **IN-PROGRESS**
  - Optimised Disk Store **IN-PROGRESS**
  - Manager Software **IN-PROGRESS**
  - Performance profiling **IN-PROGRESS**
  - Clock and Control Uplink **PLANNING PHASE**
  - DAQ software **PLANNING PHASE**

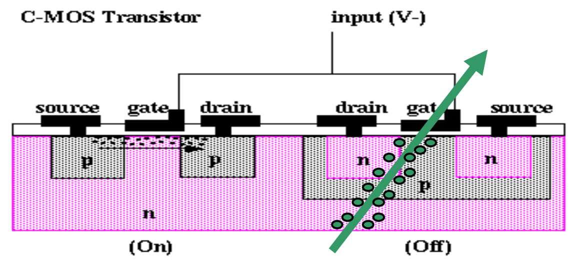


Optical ("layer 1") switching

- Part of CALICE-UK is to evaluate the use of a "layer-1" switch
  - DAQ PC failover - Redirect data to spare unused DAQ PC on the fly
  - "Router" - Can change data destination per bunch-train
    - Regulate load by sending data directly to free resources
- Programmable optical patch panel (large installation)

- Several manufacturers offering similar products, in same price range e.g. Glimmerglass, Polatis - difficult to differentiate between them
- Decided on Polatis
  - can switch dark fibre (i.e. not MEMS based)
  - Multimode fibre capable
  - Fastest switching time (20ms)
- 16x16 array with 50µm multimode LC connectors

Single Event Upsets



- Attempting to find out expected SEU rates in FE
  - Influences choice of technology for final FE
  - Influences re-configure/reset rate of FE
- Provide framework and data for use when making hardware decisions later
- Simulated expected environment at end of ECAL slabs
  - Results are compared with existing FPGA measurements

Virtex II X-2V100 Virtex II X-2V6000	0.005 SEUs/h
Altera Stratix	0.062 SEUs/h
Xilinx XC4036XLA	**0.001 SEUs/h**
Virtex XQVR300	0.012 SEUs/h
9804RP	0.005 SEUs/h

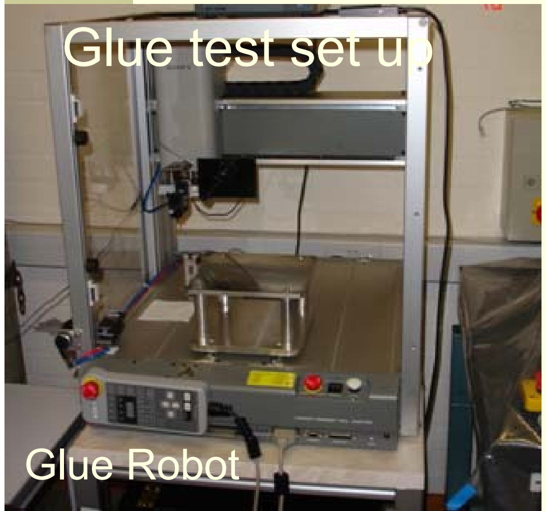
⇒one SEU/device every 40 days

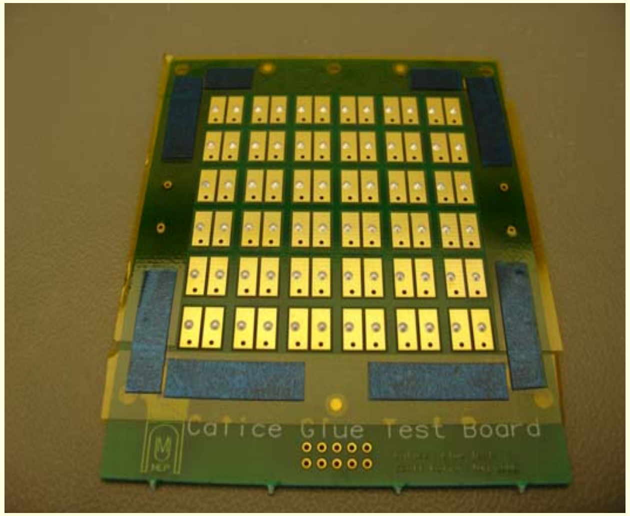
DAQ summary

- UK proposes to take responsibility for a large part of the readout chain
  - Design based on commercial components
- Key areas for development identified:
  - Baseline structure
  - Individual group responsibilities identified
- DAQ design applicable to both ECAL and HCAL
  - ECAL is entirely a UK responsibility
  - HCAL may need to manufacture own FE PCB
- Design applicable to upcoming prototypes being built within the EUDET project
  - We will provide the DAQ for these systems

Mechanical studies

- Studies on conducting glue
  - Silver filled 2 part epoxy

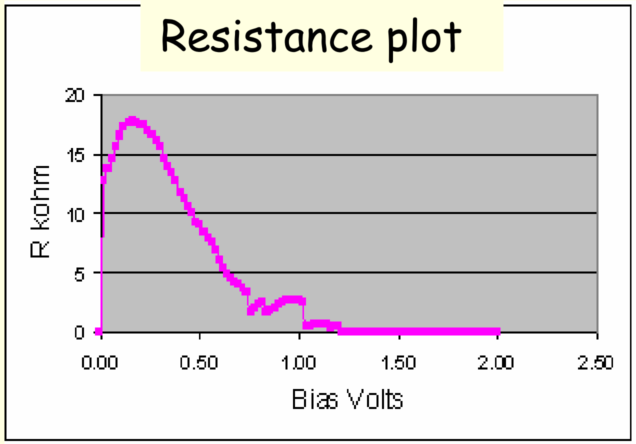




• On first application of voltage IV curve can show high resistance at low voltage (<500 mv) then chaotic transitions to lower resistance states as the is voltage increased

• Finally a step transition to " normal " state ~1 ohm typically at a few volts. Once this state has been established it seems permanent.

• Consistent with Atlas experience

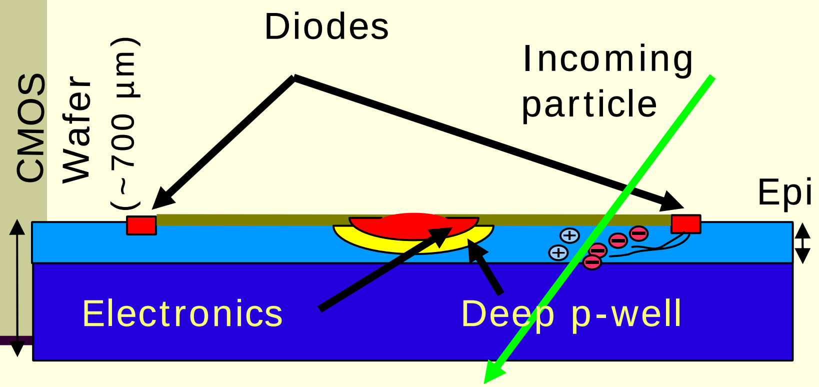


R. Thompson

MAPS Design

Y. Mikami, O. Miller, V. Rajovic, N.K. Watson, J.A. Wilson,
M. Thomson, J.A. Ballin, P.D. Dauncey, A.-M. Magnan,
M. Noy, J.P. Crooks, M. Stanitzki, K.D. Stefanov,
R. Turchetta, M. Tyndel, E.G. Villani

- Monolithic Active Pixel Sensors
  - Alternative readout sensor for the Calice ECAL
  - High granularity and digital readout
  - CMOS manufacturing: now a mature technology
- "Swap-In": leaving mechanical structure untouched

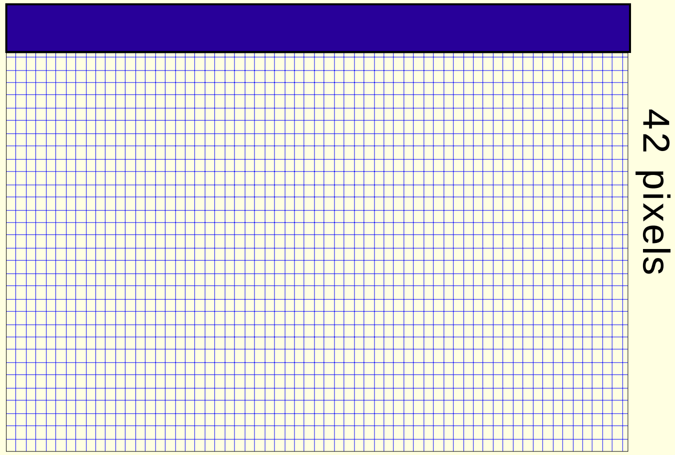


- Specific Design for Calice
  - Pixel Size 50 x 50 µ
  - Binary readout: 1 bit ADC realized as comparator
  - 4 diodes for charge collection
  - 13 bit time stamping
  - Hit buffering for entire bunch train
  - Capability to mask individual pixels
  - Threshold adjustment for each pixel

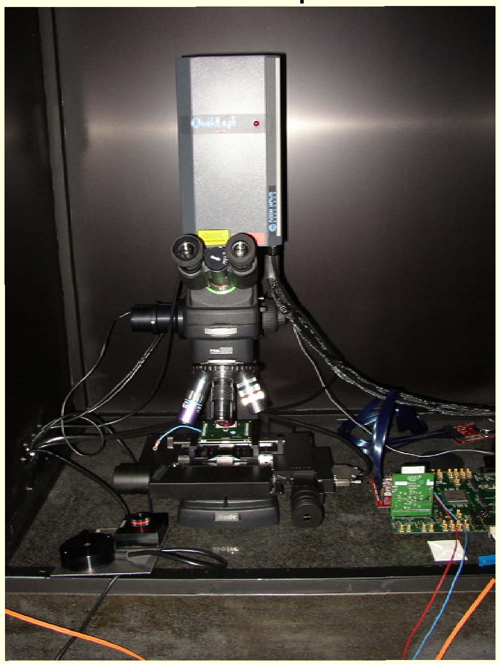
- Sensor and electronics in one wafer
- Charge collection in epi-layer
  - Charge collected by diffusion
- n-well isolated with 3 µm thick "deep p-well"
- Novel *INMAPS* process for the CALICE MAPS

Test sensor (V1.0) and test setup

- Development of DAQ board and firmware has started
- Complete test setup
  - Cosmics
  - Sources
  - Laser
  - Test beam



- RAL Laser setup
  - 1064, 532 and 355 nm Wavelength
  - Accurate focusing (<2 μm)
  - 50 Hz repetition rate
  - Fully automatized



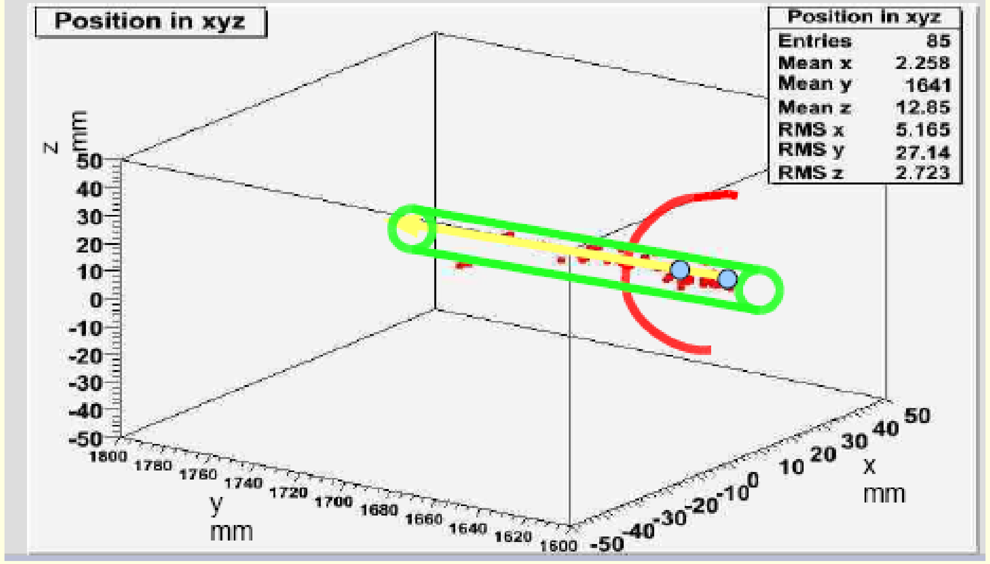
Detector simulation using MAPS

- MAPS ECAL implemented in simulation as a patch to Mokka v06-02
  - Detector model used LDC01(Sc)
  - 50x50 μm pixel size
  - 15 μm "Active Area" (Epi-layer)
  - ECAL with 30 layers
    - 20 layers 2.1 mm Tungsten
    - 10 layers 4.2 mm Tungsten
  - Charge diffusion and thresholds are implemented in a separate "digitization" step

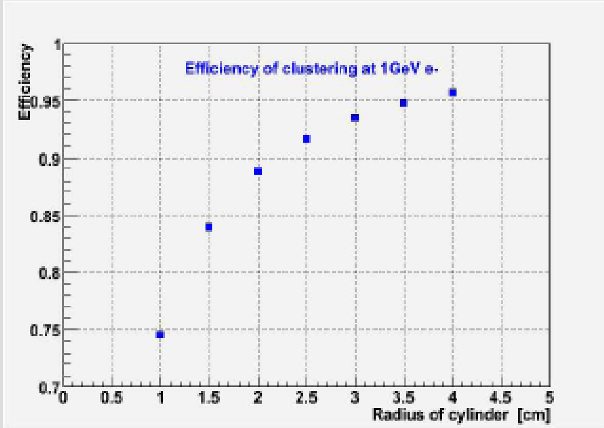
MAPS clustering algorithm

Y. Mikami

1. **Finding initial group of hits within one of inner layers.**
   - Requiring several hits are within circle of mm order radius.
2. **Deciding direction of cluster :** Searching hits in outer layers which has located within hemisphere from initial hit. -> From the centre of gravity in the initial grouping within inner layer to the centre of gravity in the hemisphere.
3. **Adding all hits in 30 layers within cylinder of Moliere radius order.**



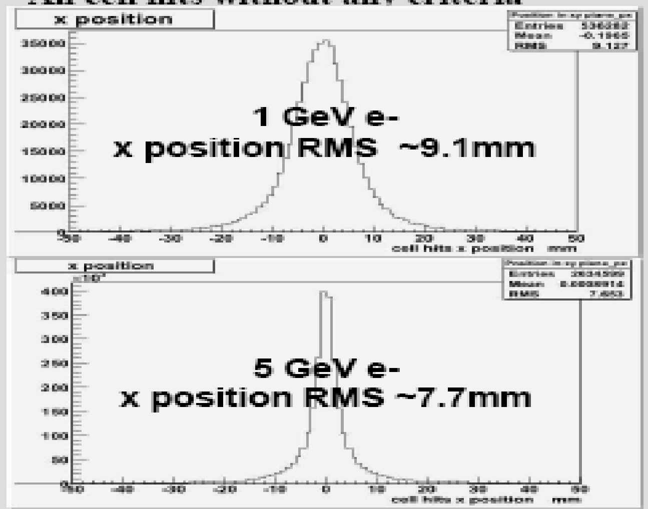
Efficiency = #Cell hits inside cylinder / All #cell hits in event
(With 1800eV energy threshold for both case.)



Cylinder radius have to be optimized with physics events.
(In order to avoid merging two neighbour clusters)
-> Temporarily clustering cylinder radius is 2.0 cm.

Sower spread distributions:

- B fields is off
- Electron is injected from IP to zenith
- All cell hits without any criteria



Next steps

- Submit Sensor V1.0 Mid April
- Sensor V1.0 due back Mid July
- Improve/enhance GEANT simulation
- Testing Sensor V1.0
- Do physics analyses with a MAPS based ECAL
- Improve sensor simulation with data from V1.0
- Design Sensor V2.0 using all the experience made with V1.0
- Submit Sensor V2.0

Outline

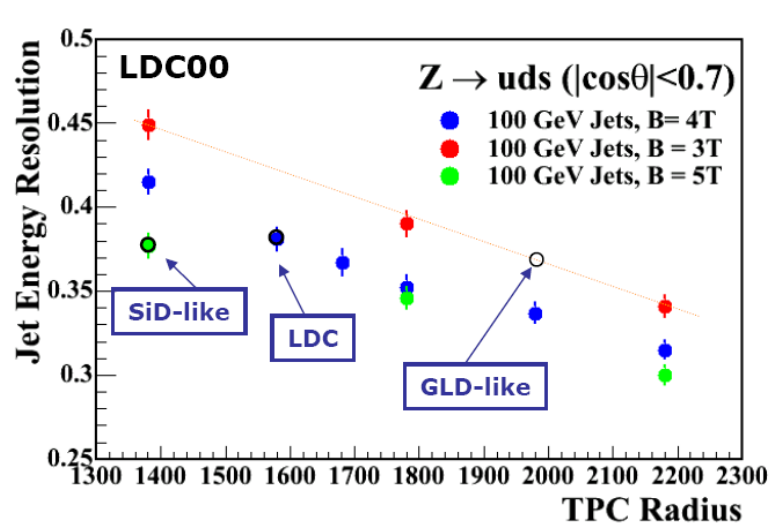
- Calorimetry at the ILC
- Detector concepts
  - SiW ECAL, Scintillator strips ECAL
  - Analog HCAL and Digital HCAL
- Summary of 2006 test beams and preparation for 2007 test beam programme
- Progress in UK work on ECAL design
  - Data acquisition for final ILC detector
  - Mechanical studies: glue studies
  - MAPS design
- UK work on PFAs and physics studies
- Conclusion and Outlook

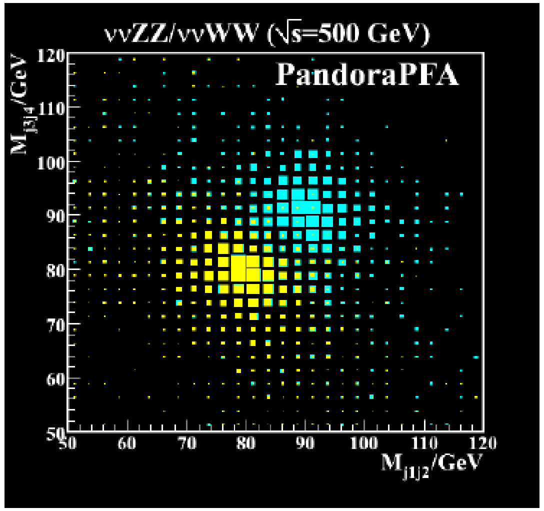
Particle Flow Algorithms

Overview: Pandora PFA

M. Thomson

- 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





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ZHH benchmark channel

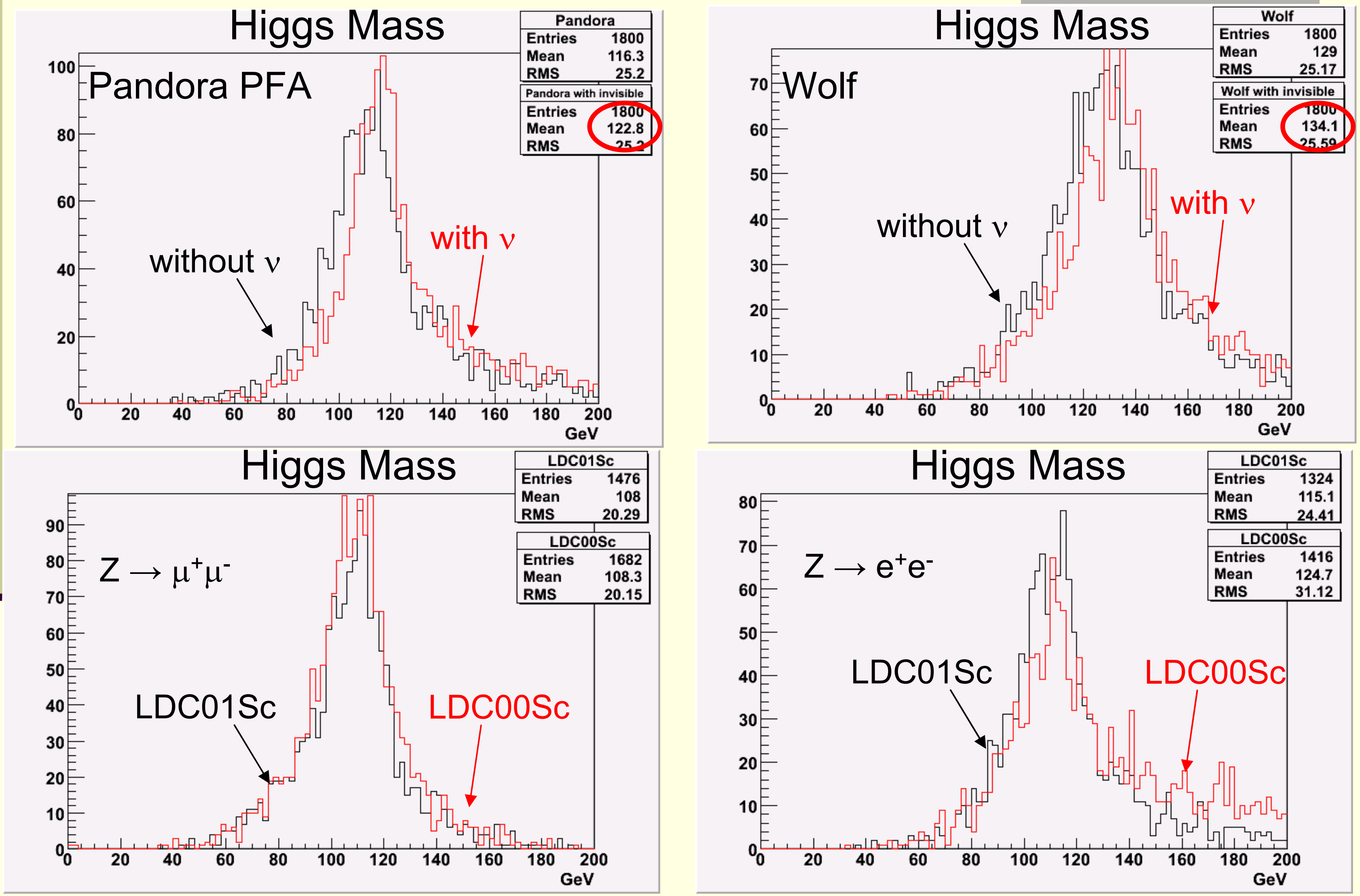
- Pandora Pythia:
  - M(Higgs) = 120 GeV
  - Electron polarization 80%
  - Positron polarization 0%
  - ECM = 500 GeV
- LDC00:
  - RPC Hcal
  - TPC has 200 layers
  - ECal is 30+10 layers
- LDC01: smaller radius than LDC00
  - RPC Hcal
  - TPC has 185 layers
  - ECal is 20+10 layers

- 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

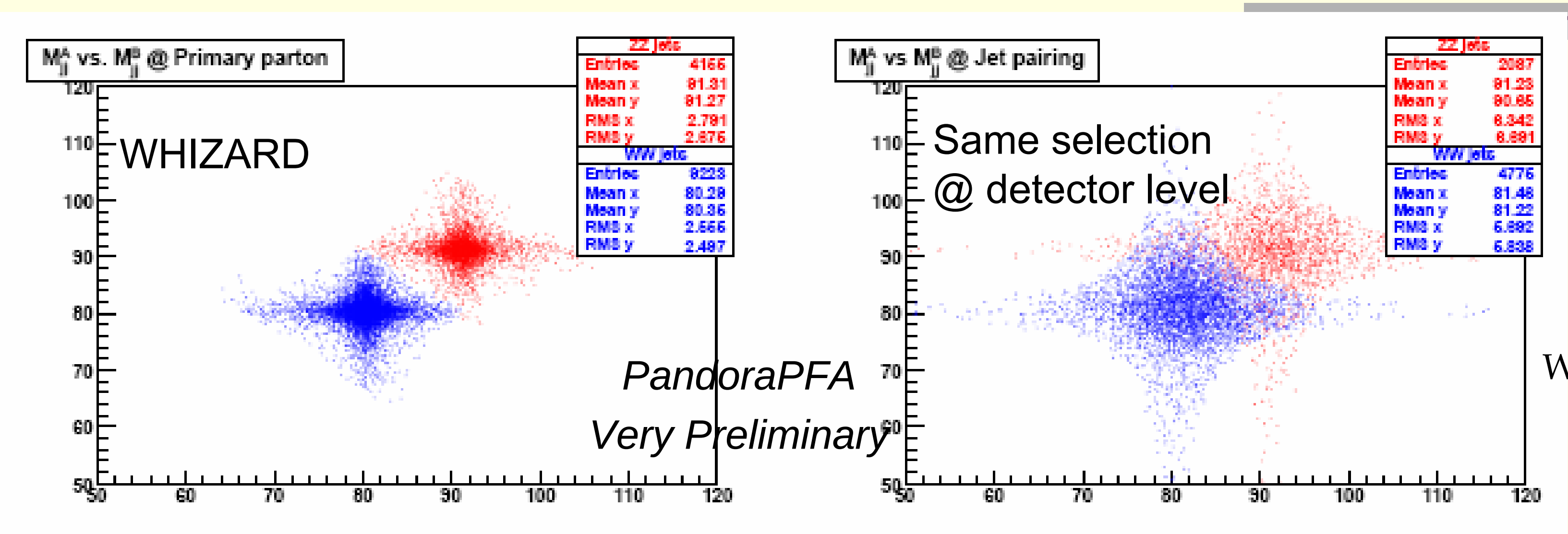
Use this channel to compare different detector models and PFAs

M. Faucci Giannelli, F. Salvatore, M.Green

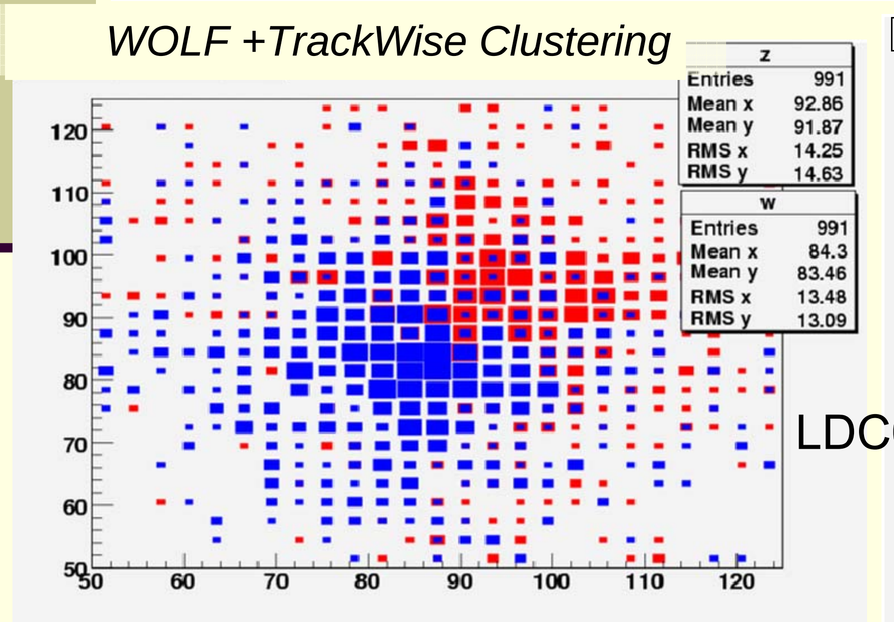
Comparing detector models and PFAs

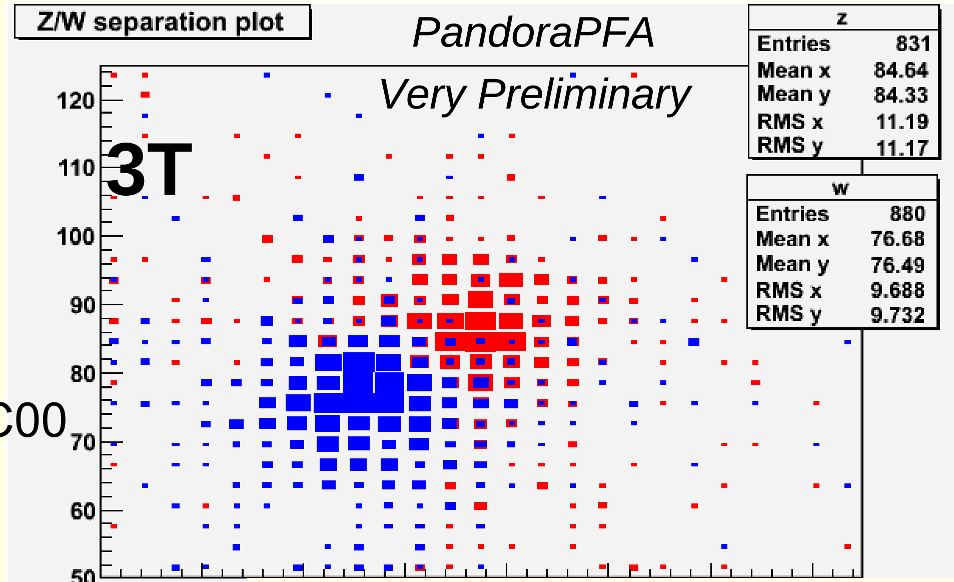


Z/W separation



W. Yan





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Conclusion and Outlook

- Test beam programme a real success
  - UK groups leading the DAQ, on-line monitoring and data analysis efforts
  - Getting ready for this year's test beam programme
- Significant progress in the design of the final DAQ for ILC
- MAPS design:
  - Ready to start tests on first prototype
  - Much improved simulation
  - 100% UK project
- Physics analysis:
  - UK leading efforts to benchmark different detector models using well understood physics channels
  - Also testing available particle flow algorithms

Backup slides