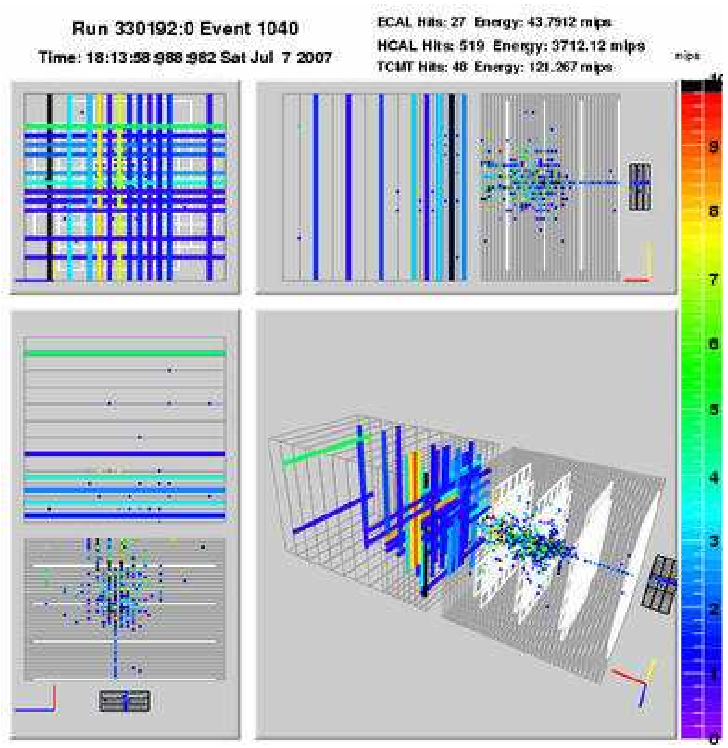
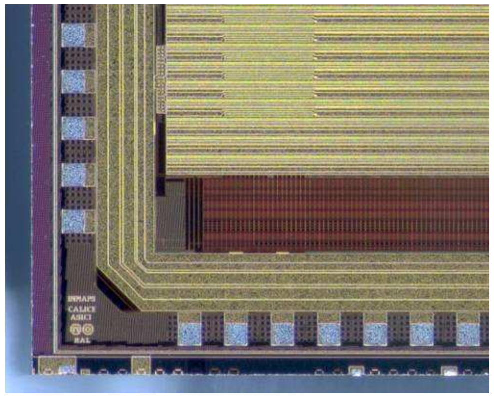
CALICE-UK and the ILD detector



Nigel Watson
(Birmingham Univ.)

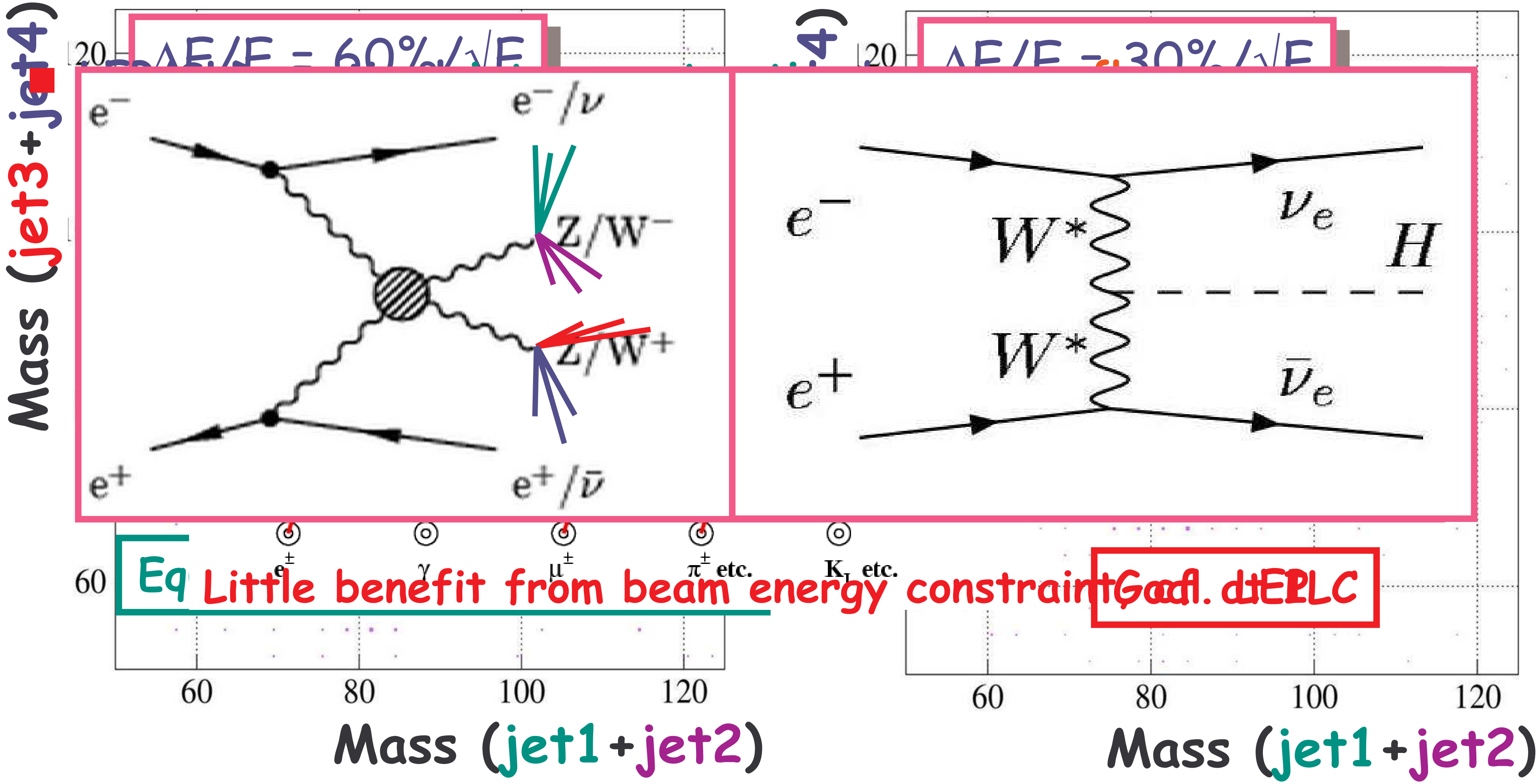
- Motivation
- Testbeam
- Particle Flow
- Physics Studies
- MAPS ECAL
- Summary



For the CALICE UK group

ILC: 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, $\nu\nu H$



ECAL design principles

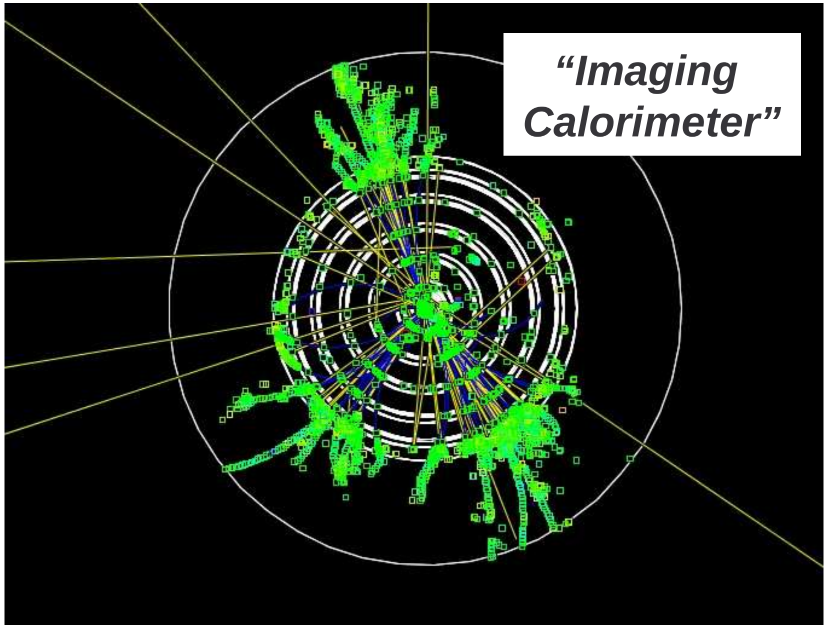
- Shower containment in ECAL, ΣX_0 large
- Small $R_{moliere}$ and X_0 – compact and narrow showers
- λ_{int}/X_0 large, ∴ EM showers early, hadronic showers late
- ECAL, HCAL inside coil
  - Lateral separation of neutral/charged particles/'particle flow'
- Strong B field to suppresses large beam-related background in detector
  - Compact ECAL (cost of coil)
- Tungsten passive absorber
- Silicon pixel readout, minimal interlayer gaps, stability – but expensive…
- Develop "swap-in" alternatives to baseline Si diode designs in ILD (+SiD)
  - e.g. MAPS

CALICE: from MC to reality to MC

CAlorimeter for the LInear Collider Experiment

Ultimate goal

High granularity calorimeter optimised for the Particle Flow measurement of multi-jet final state at the International Linear Collider



Initial task

Build prototype calorimeters to
- Establish viable technologies
- Collect hadronic shower data with unprecedented granularity
  - tune reconstruction algorithms
  - validate existing MC models

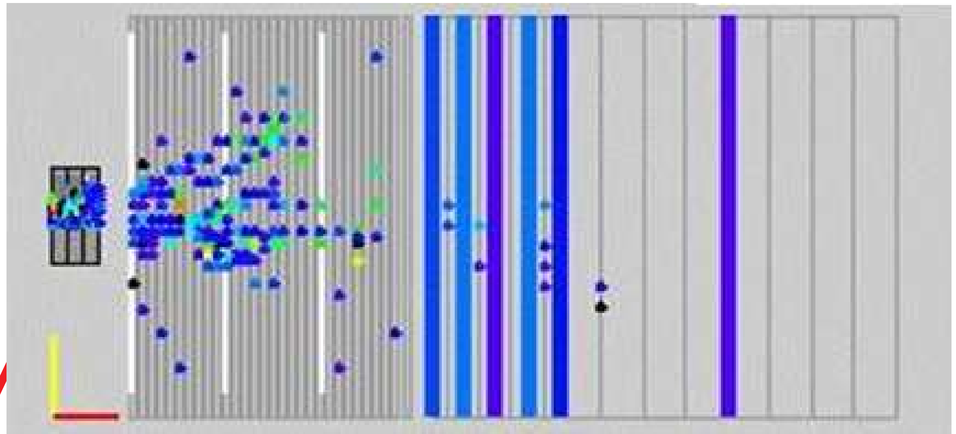
Next task

Exploit validated models for whole detector optimisation

Test beam prototypes

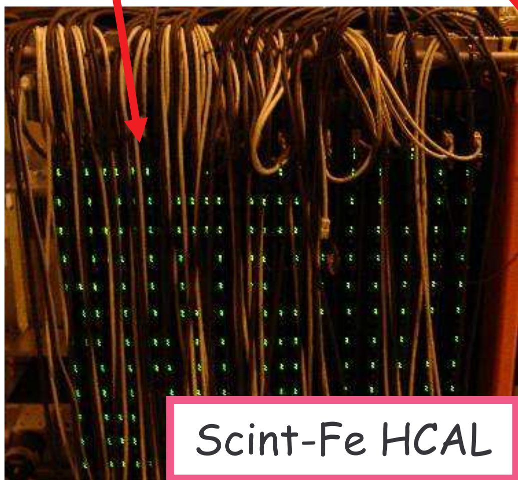
10 GeV pion shower
@ CERN test beam

beam



SiW ECAL

1x1cm^2 lateral segmentation
~1 X_0 longitudinal segment.
~1λ total material, ~24 X_0



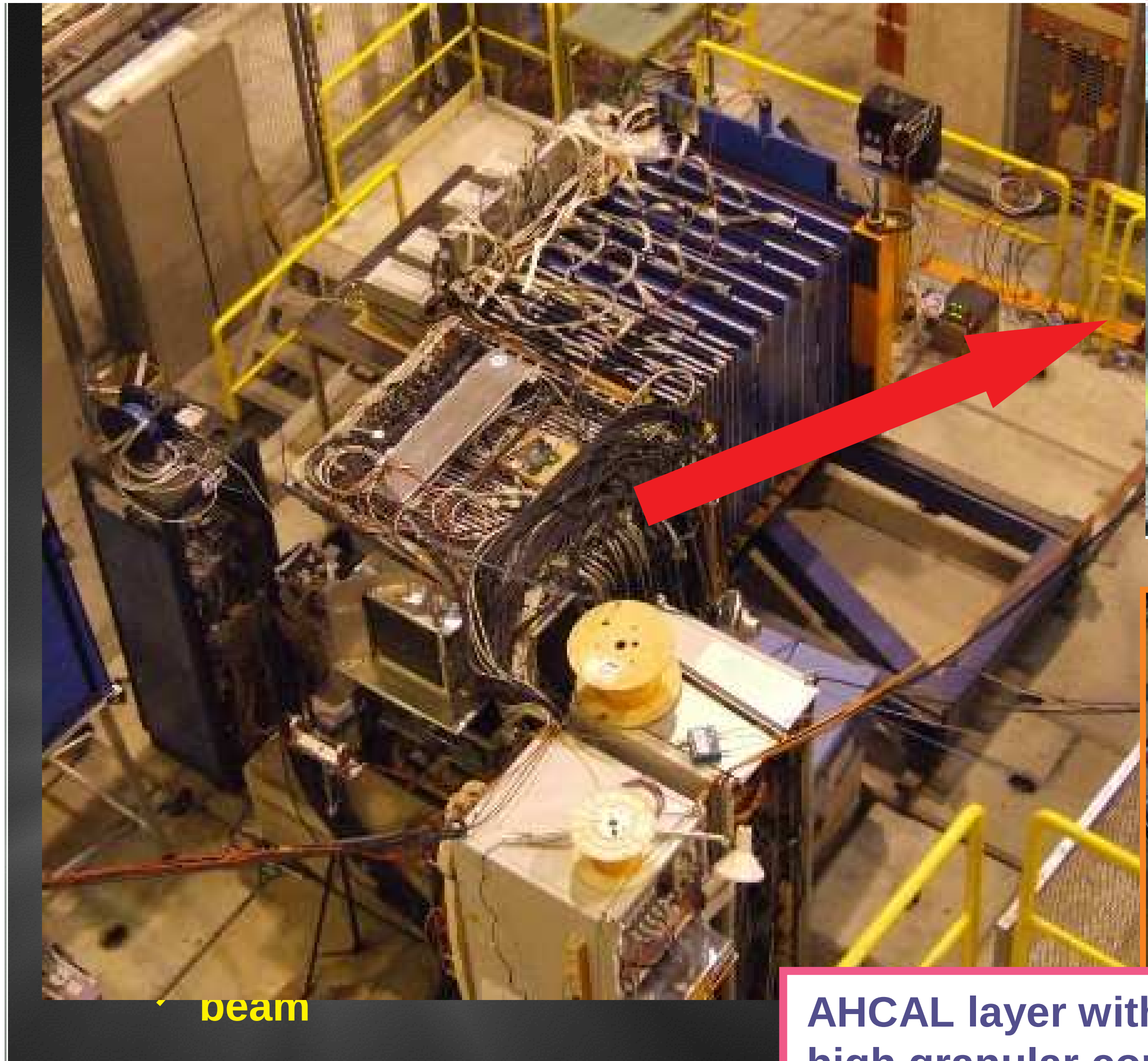
Scint-Fe HCAL

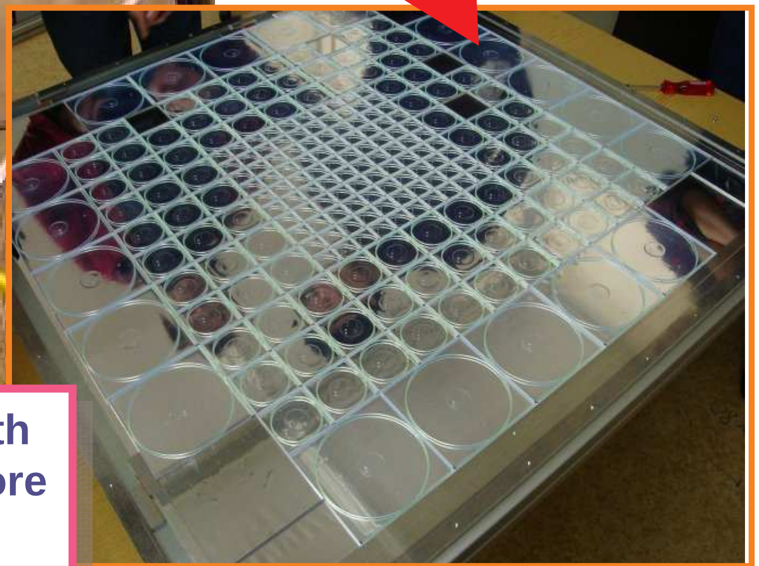
3x3cm^2 tiles lateral segmentation
~4.5 λ in 38 layers

Scint-Fe tail catcher/ muon tracker

5x100cm^2 strips
~5 λ in 16 layer

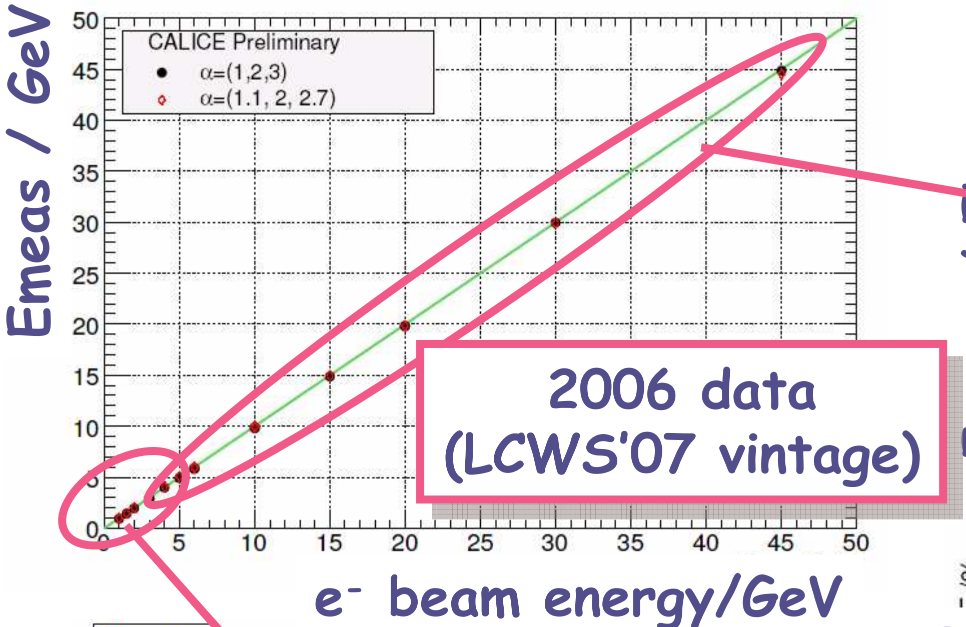
The 2006 CERN installation

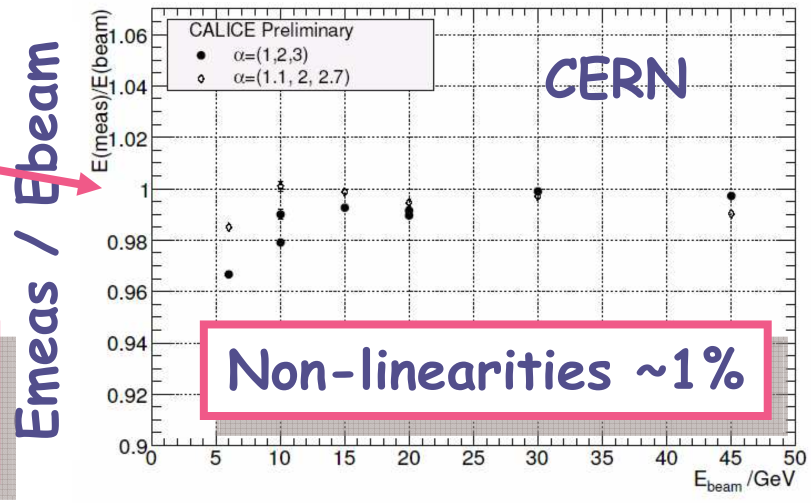


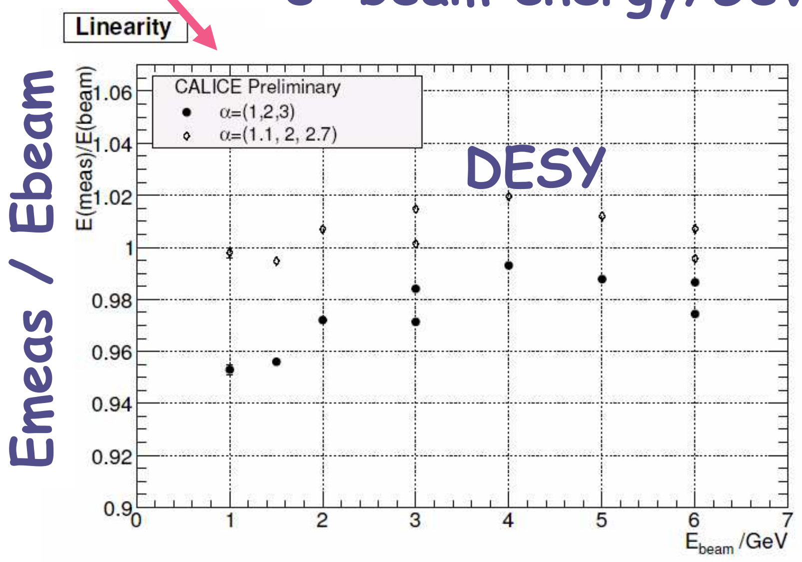


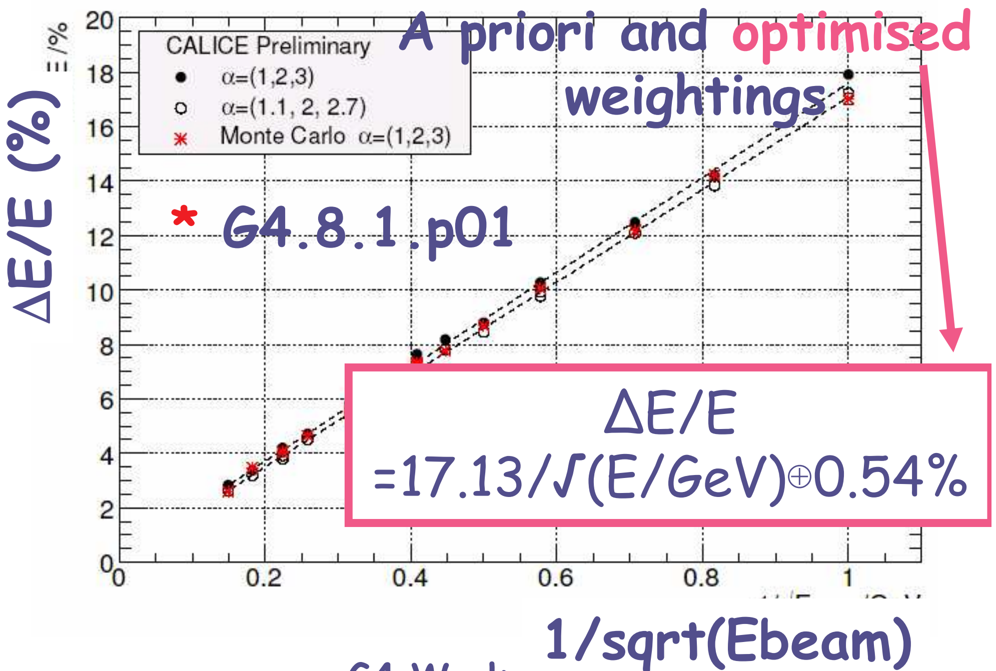
AHCAL layer with high granular core readout

Reality: ECAL linearity/resolution









CALICE testbeam outlook to date

- Integrated approach to develop optimal calorimety, not just HCAL
- Complete understanding of 2006-7 data
  - Adding yet more realism to testbeam model (material, instrumented regions, etc.)
  - Understanding beamline – characterisation of beam itself empirically, or by modelling ~accelerator-style the transport line (BDSIM et al?)
- Include experience with modelling test beam prototypes into uncertainties in "whole detector" concept models
- Detailed study of hadronic shower substructure
  - Separation of neutrons, e.m., hadronic components, mip-like, …. – "deep analysis"
- Data will reduce interaction modelling uncertainties
  - Useful for particle flow algorithms, in development for detector optimisation, e.g. PandoraPFA

Recent developments with PandoraPFA…

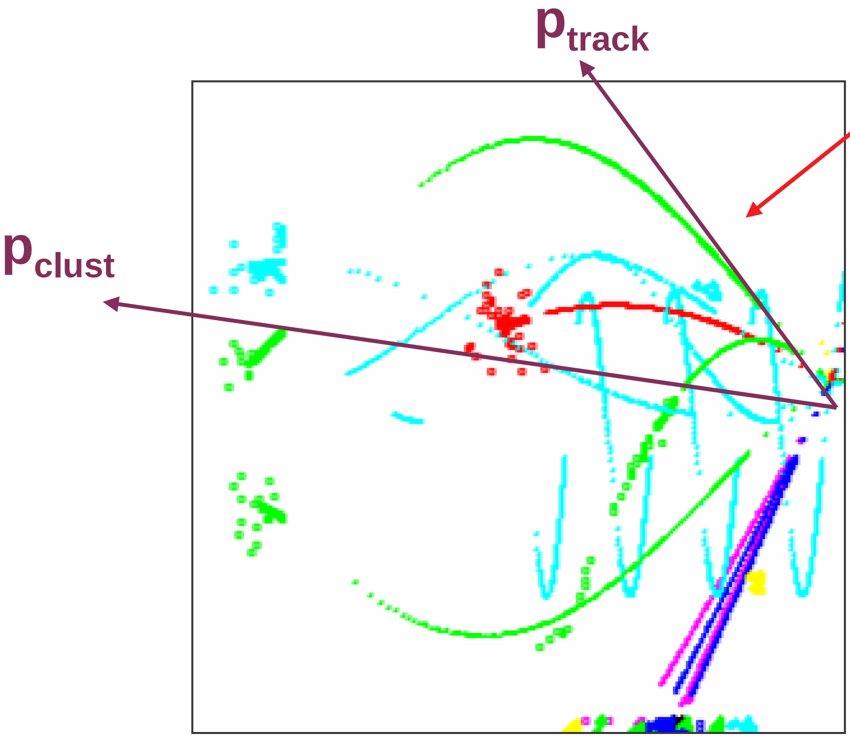
Recent Improvements

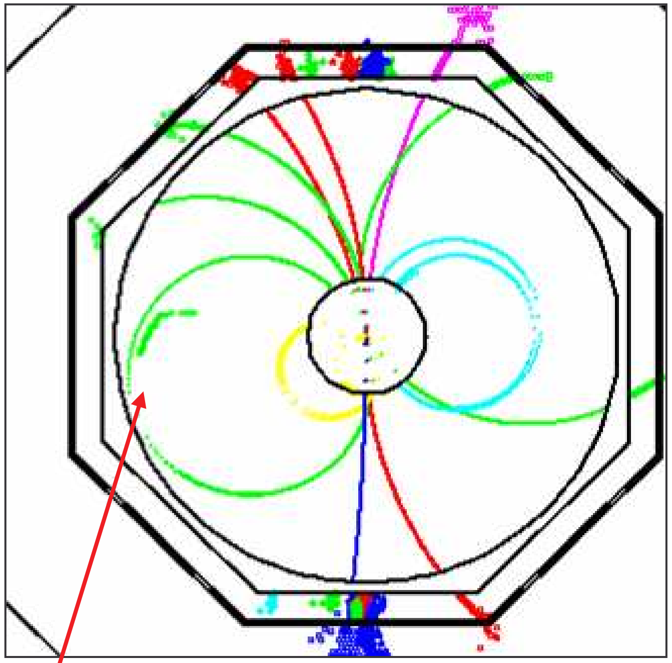
Overview:

- Technical Improvements
  - minor bug fixes
  - reduced memory footprint (~ factor 2) by on-the-fly deleting of temporary clusters, rather than waiting to event end
- Use of tracks (still TrackCheater)
- Photon Identification
  - EM cluster profile identification
- Particle ID
  - Much improved particle ID : electrons, conversions, $K_S \to \pi^+\pi^-$, $\Lambda \to \pi^- p$ (no impact on PFA)
  - Some tagging of $K^\pm \to \mu^\pm \nu$ and $\pi^\pm \to \mu^\pm \nu$ kinks
  - No explicit muon ID yet
- Fragment Removal
- "Calibration" – some interesting issues…

e.g. Tracking I : extrapolation

- If a track isn't matched to a cluster – previously track was dropped (otherwise double count particle energy)
- Not ideal – track better measured + <u>direction</u>

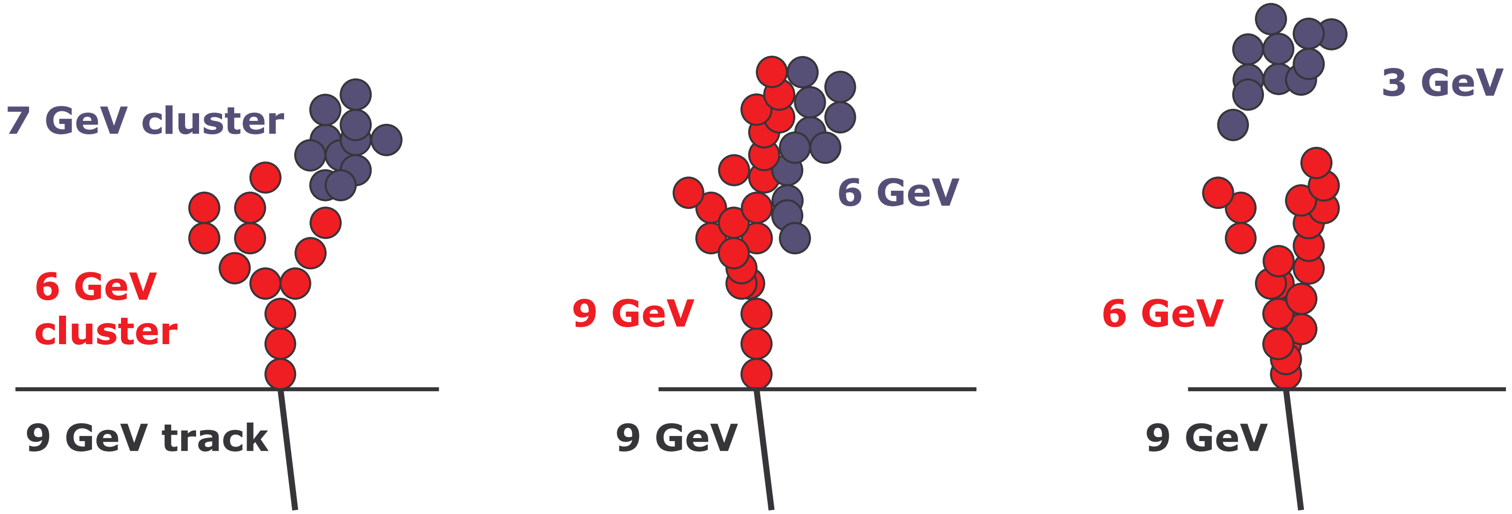




- Now try multiple (successively looser) track-cluster matching requirements e.g. "circle matching"
- As a result, fewer unmatched looping endcap tracks

Fragment Removal

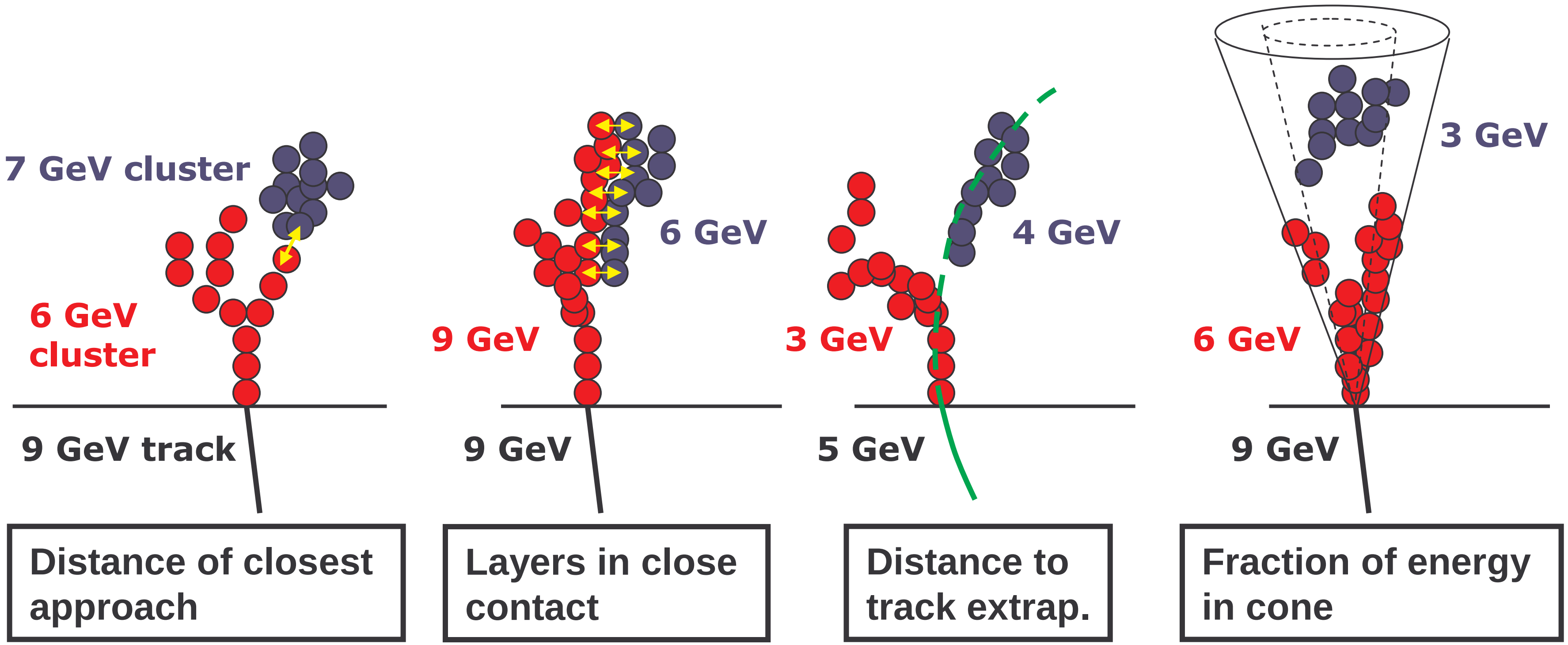
- One of the final stages of PandoraPFA is to identify "neutral fragments" from charged particle clusters



- Previously the code to do this was "a bit of a mess"
- This has been significantly improved – but not yet optimised

Fragment removal : basic idea

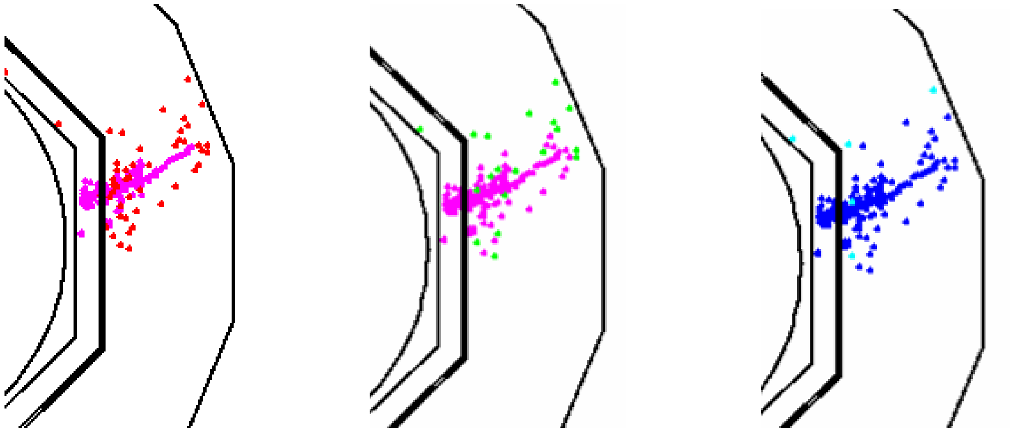
- Look for "evidence" that a cluster is associated with another



- Convert to a numerical evidence score **E**
- Compare to another score "required evidence" for matching, **R**, based on change in E/p chi-squared, location in ECAL/HCAL etc.
- If **E > R** then clusters are merged
- Rather *ad hoc* but works well (slight improvement wrt. previous)

“Calibration” cont.

- Effect depends on cluster energy and isolation cut



Isolation cut: 10cm 25cm 50cm

Fraction of energy rejected as isolated

	5 GeV K_L	10 GeV K_L	20 GeV K_L
10 cm	16.1 %	12.7 %	6.7 %
25 cm	8.1 %	6.1 %	2.8 %
50 cm	3.6 %	2.7 %	1.1 %

Δ = 10 %

Δ = 5 %

Δ = 2.5 %

- Non linearity degrades PFA performance
- For now increase isolation cut to 25 cm (small improvement for PFA)
- Best approach ?

Current Performance cont.

Caveat : work in progress, things will change

PandoraPFA v01-01

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.295	4.4 %
100 GeV	0.305	3.0 %
180 GeV	0.418	3.1 %
250 GeV	0.534	3.4 %

PandoraPFA v02-α

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.227	3.4 %
100 GeV	0.287	2.9 %
180 GeV	0.395	2.9 %
250 GeV	0.532	3.4 %

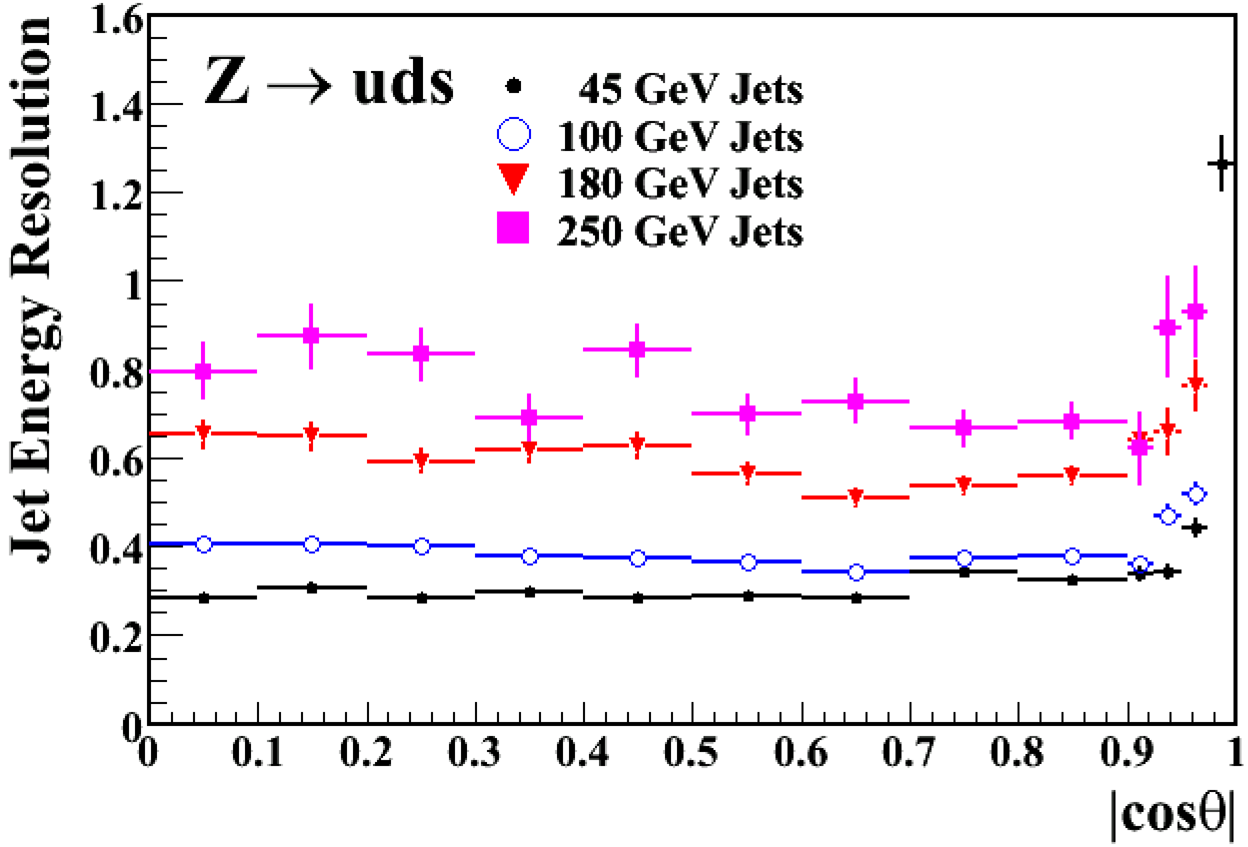
- For 45 GeV jets, performance now equivalent to

23 % / $\sqrt{E}$

- For TESLA TDR detector "sweet spot" at just the right place 100-200 GeV jets !
- However, only modest improvements at higher energy…

Evolution

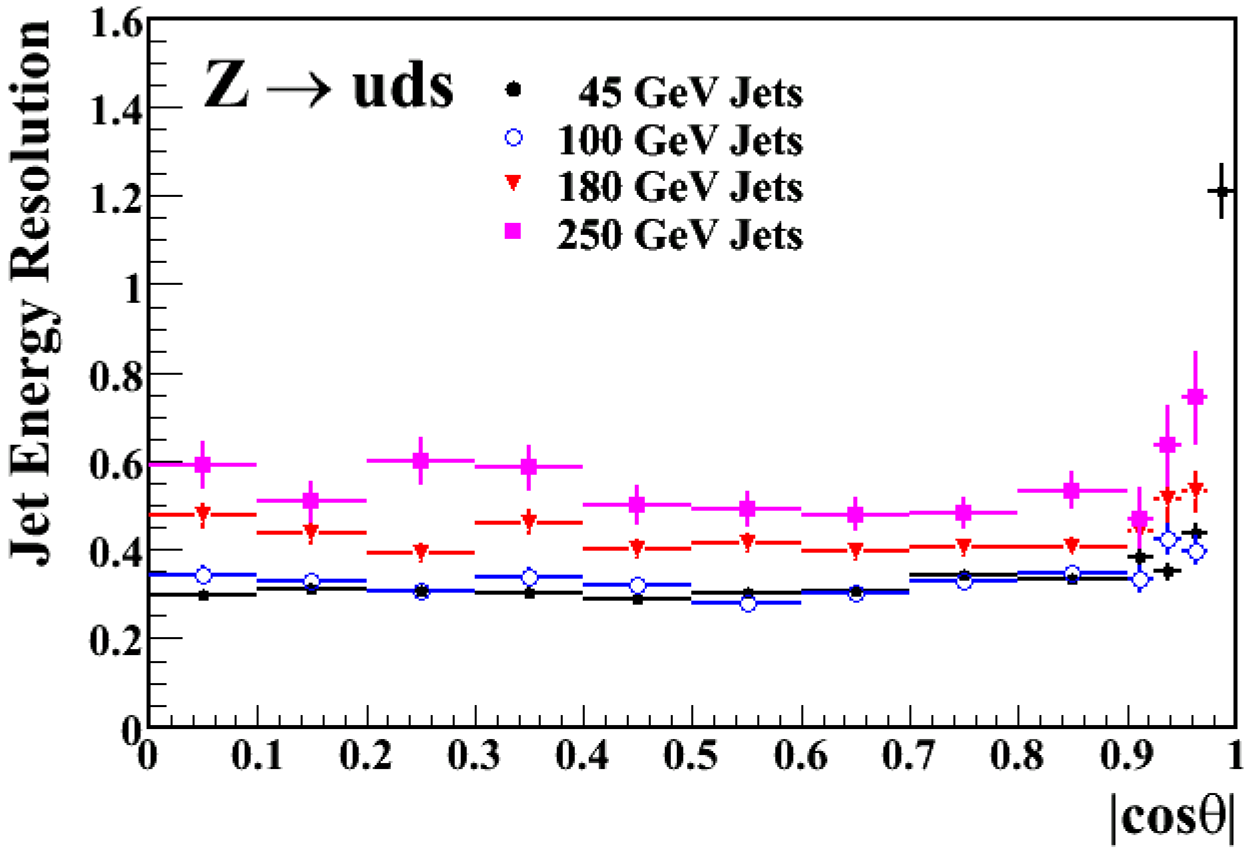
PandoraPFA v00-α



09/2006

Evolution

PandoraPFA v01-01



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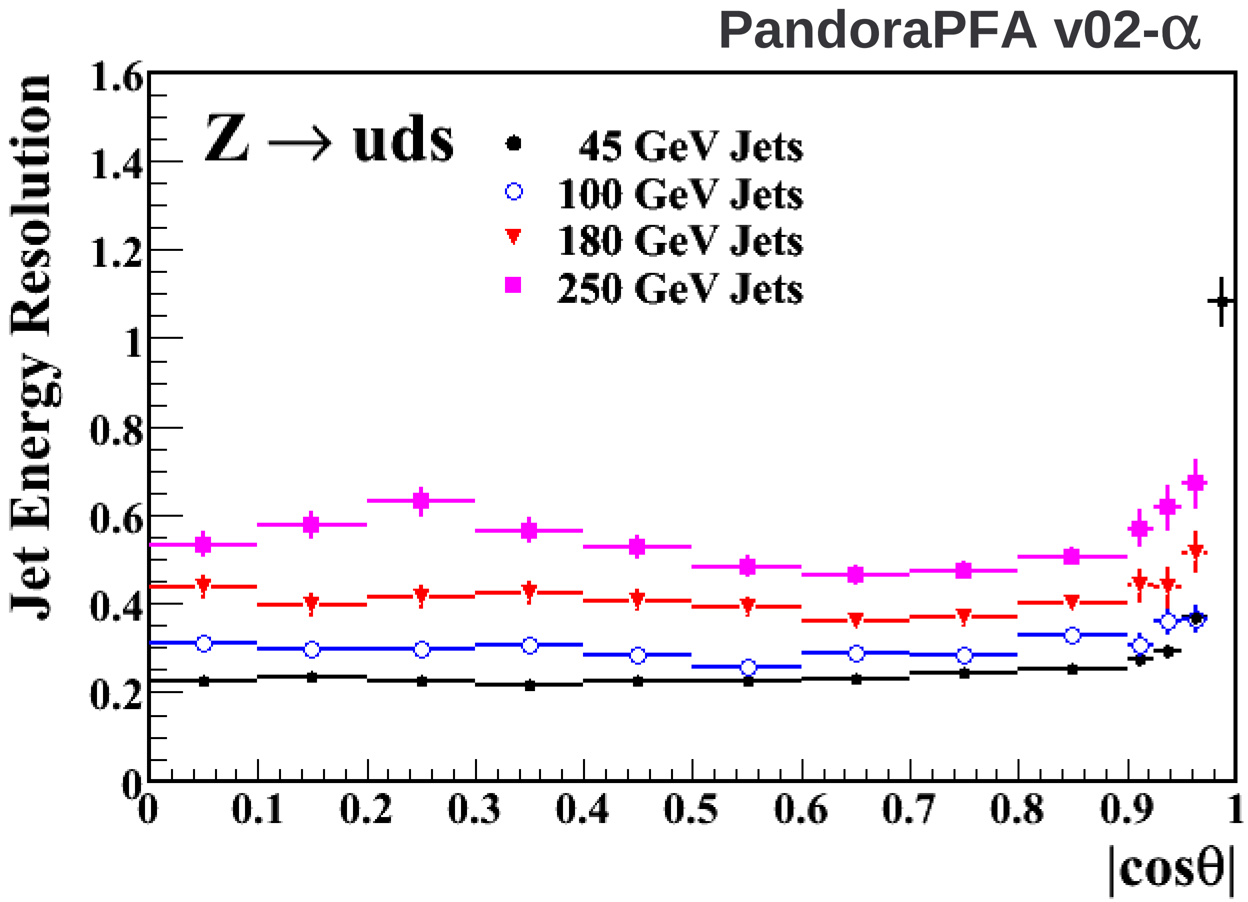
Evolution



09/2007

Summary

Summary:

- « Concentrated on lower energy performance – major improvements !
- « Also improvements in structure of code
  + almost certainly some new

- « Some small improvements for higher energy jets

Perspective:

- « Development of high performance PFA is **highly** non-trivial
- « User feedback **very** helpful (thanks Wenbiao)
- « Major improvements on current performance possible
  - "just" needs effort + fresh ideas
- « PandoraPFA needs a spring-clean (a lot of now redundant code)
  + plenty of scope for speed improvements
  - again needs new effort (I just don't have time)

What Next

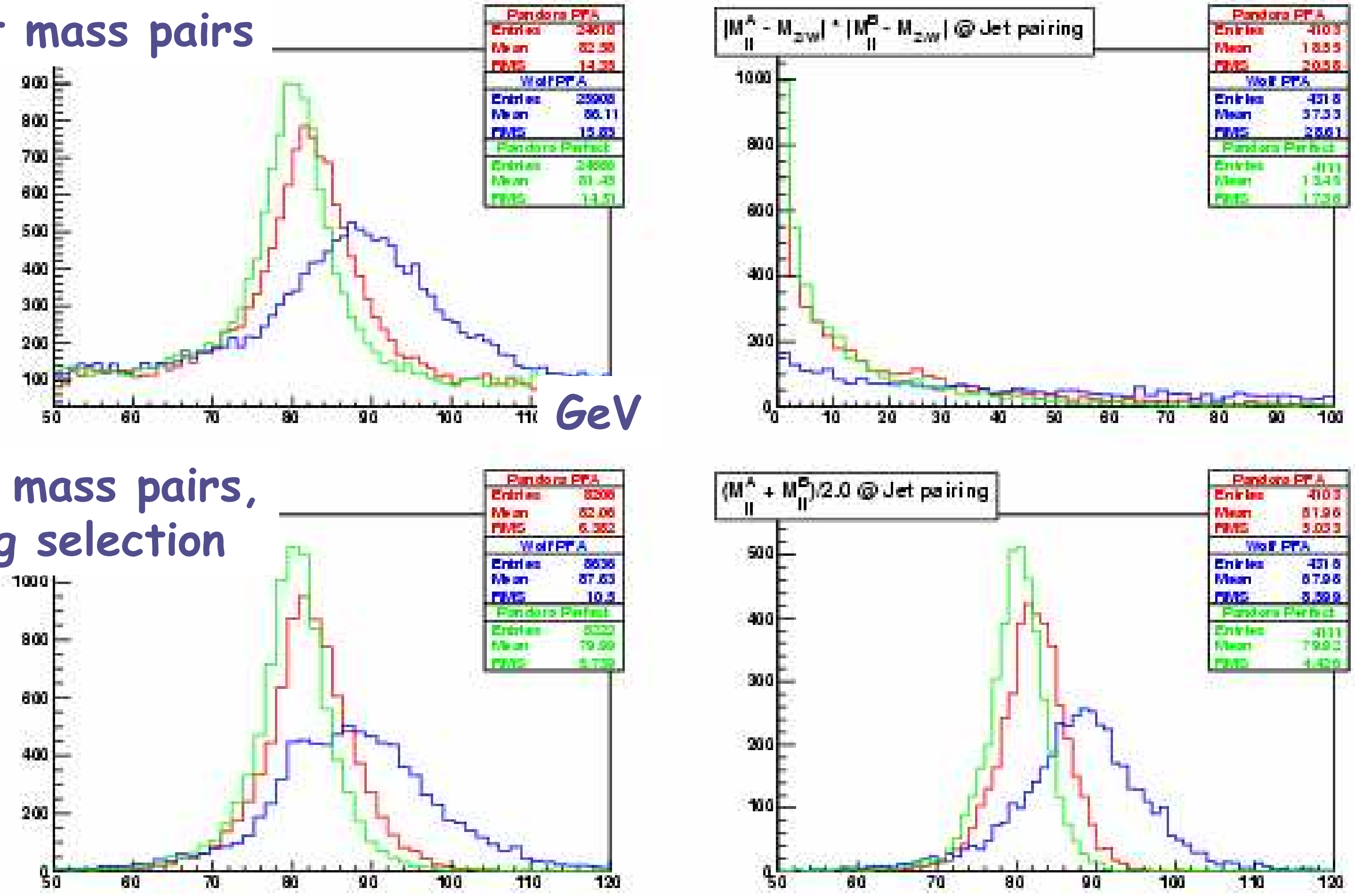
Plans:

- « Optimisation of new code
  - Slow procedure… takes about 6 CPU-days per variation
  - Only small improvements expected – have found that the performance is relatively insensitive to fine details of alg.
- « More study of non-linear response due to isolation
  - Will look at RPC HCAL
- « Detailed study of importance of different aspects of PFA, e.g. what happens if kink finding is switched off…
- « Revisit high energy performance
- « Update code to use LDCTracking
- « Release version 02-00 on timescale of 1-2 months.

Compare PFAs using W^+W^- scattering

All 2-jet mass pairs

2-jet mass pairs, pairing selection

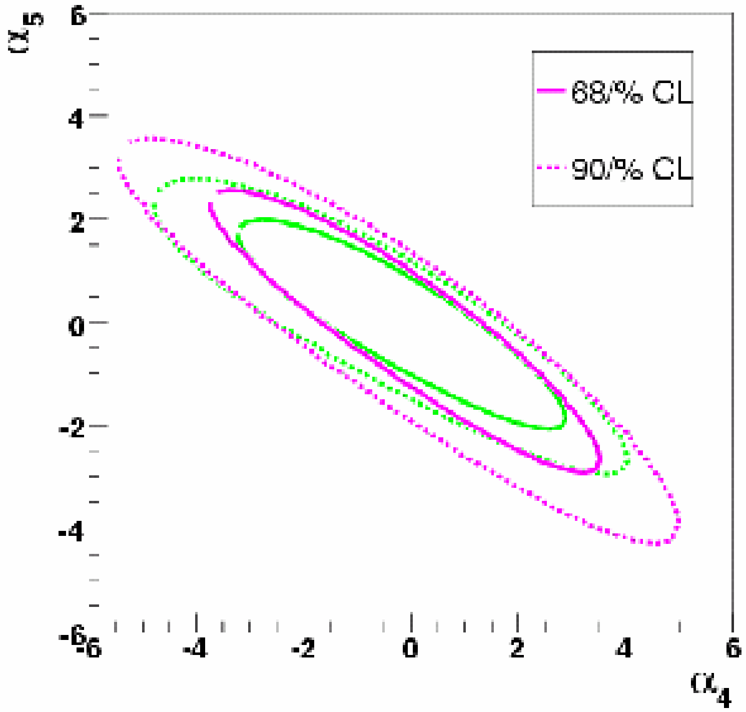


GeV

[W.Yan, DR Ward]

- Without W mass cut @ LDC00Sc: W peak @ Wolf PFA ???

LDC01Sc: Pandora PFA vs. Perfect case



- likelihood from combined WW/ZZ fitting
- Pink: Pandora PFA
- Green: Perfect Pandora PFA

Summary and outlook

- We study WW scattering with LDC00Sc & LDC01Sc detector model, and extract α_4 & α_5, which are comparable with that of TESLA fast simulation.

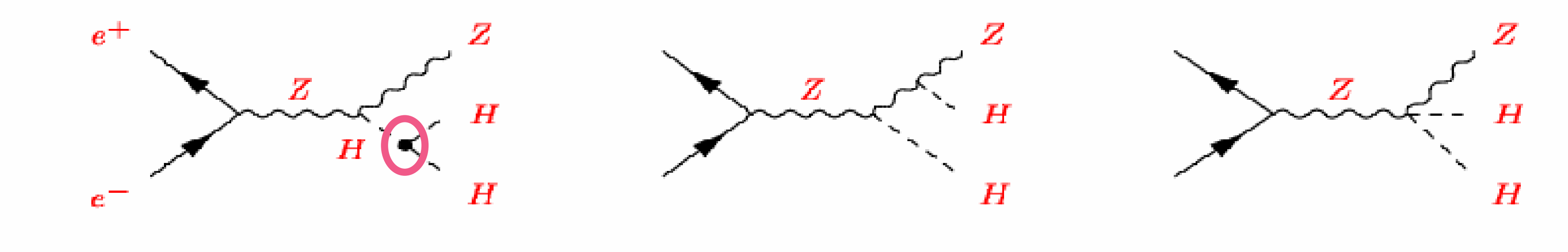
- Calibration constants @ PFAs for LDC00Sc and LDC01Sc
  - wrong calibration constants $\Longrightarrow$ unreliable conclusion ???

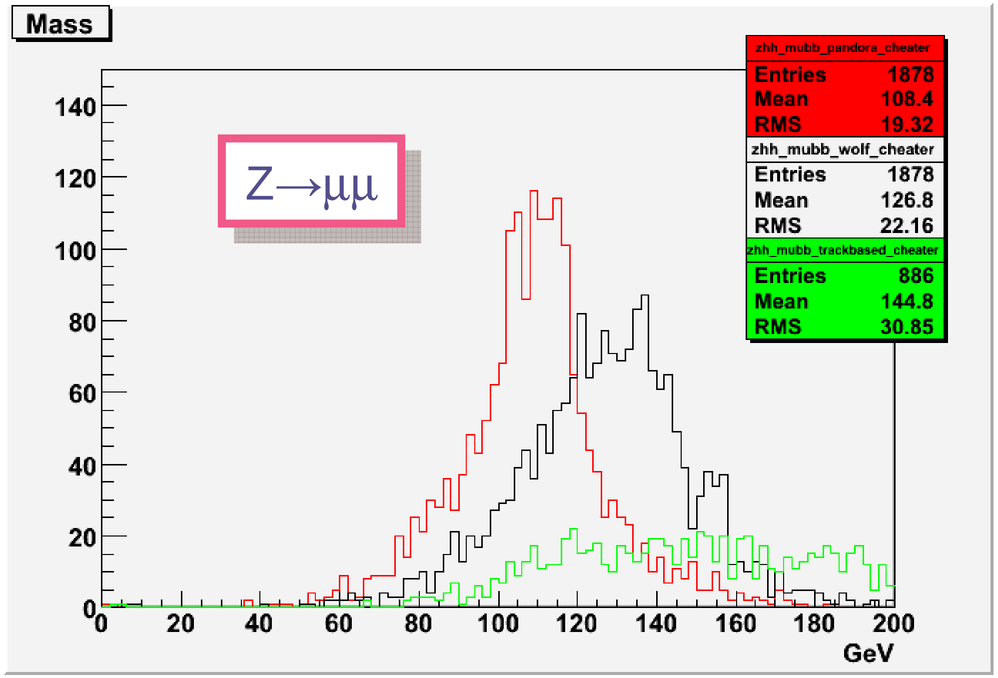
- Pandora PFA vs. Wolf PFA
  - W/Z peak @ Wolf PFA ???
    - $*$ not used for α_4 & α_5 fitting due to W/Z mass cut in the analysis
  - Pandora PFA $\sim$ Perfect Pandora PFA

- LDC00Sc vs. LDC01Sc
  - fitted α_4 & α_5 are comparable.
  - for selected events number, LDC00Sc : LDC01Sc = 1: 0.96
  - distributions of LDC00Sc are comparable with that of LDC01Sc

Calibration of PFAs is essential to understand ultimate detector capabilities.
Mandatory to have "fair", objective comparisons!

Higgs self coupling study





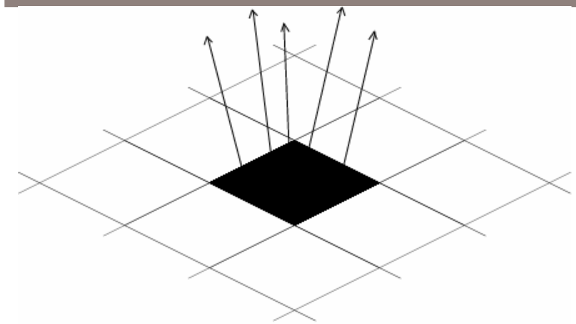
- Exploits PandoraPFA, compares with other public algorithms (Wolf, newer trackbased PFA)
- Significantly better performance in Pandora PFA in mean and resolution

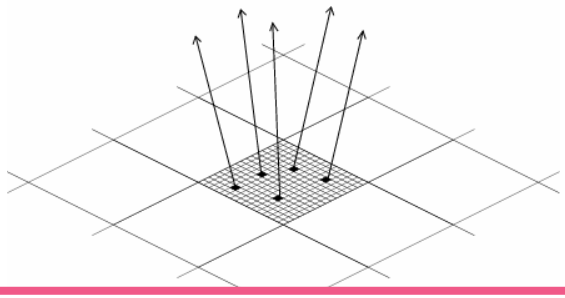
[M.Faucci Giannelli]

MAPS

- Silicon pixel readout, minimal interlayer gaps, stability – prohibitive cost?
- UK developing "swap-in" alternative to baseline Si diode designs in ILD (+SiD)
- CMOS process, more mainstream:
  - Industry standard, multiple vendors (schedule, cost)
  - (At least) as performant – ongoing studies
  - Simpler assembly
  - Power consumption larger than analogue Si, ~x40 with 1st sensors, BUT
    - ⇒ ~Zero effort on reducing this so far
    - ⇒ Better thermal properties (uniform heat load), perhaps passive cooling
    - ⇒ Factor ~10 straightforward to gain (diode size, reset time, voltage)

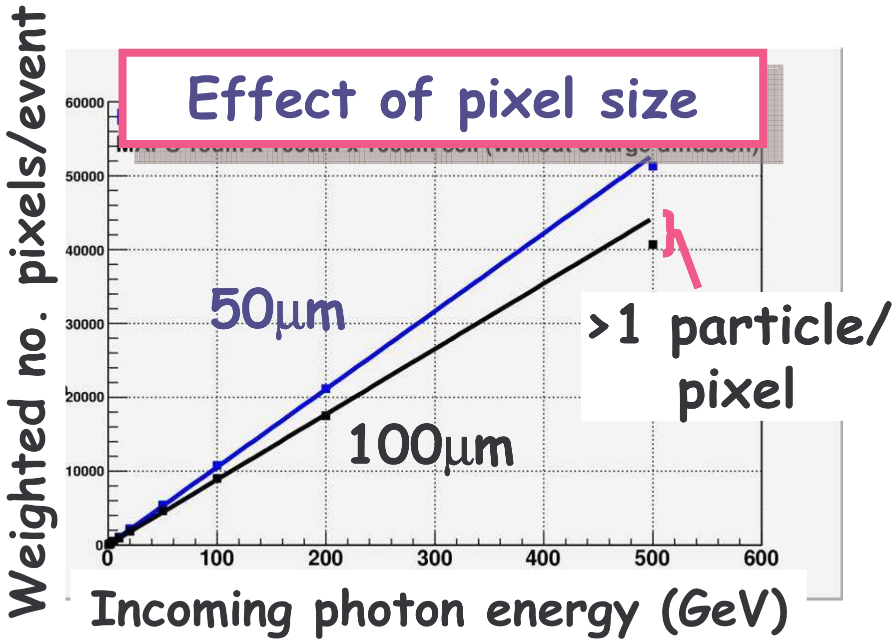
Basic concept for MAPS



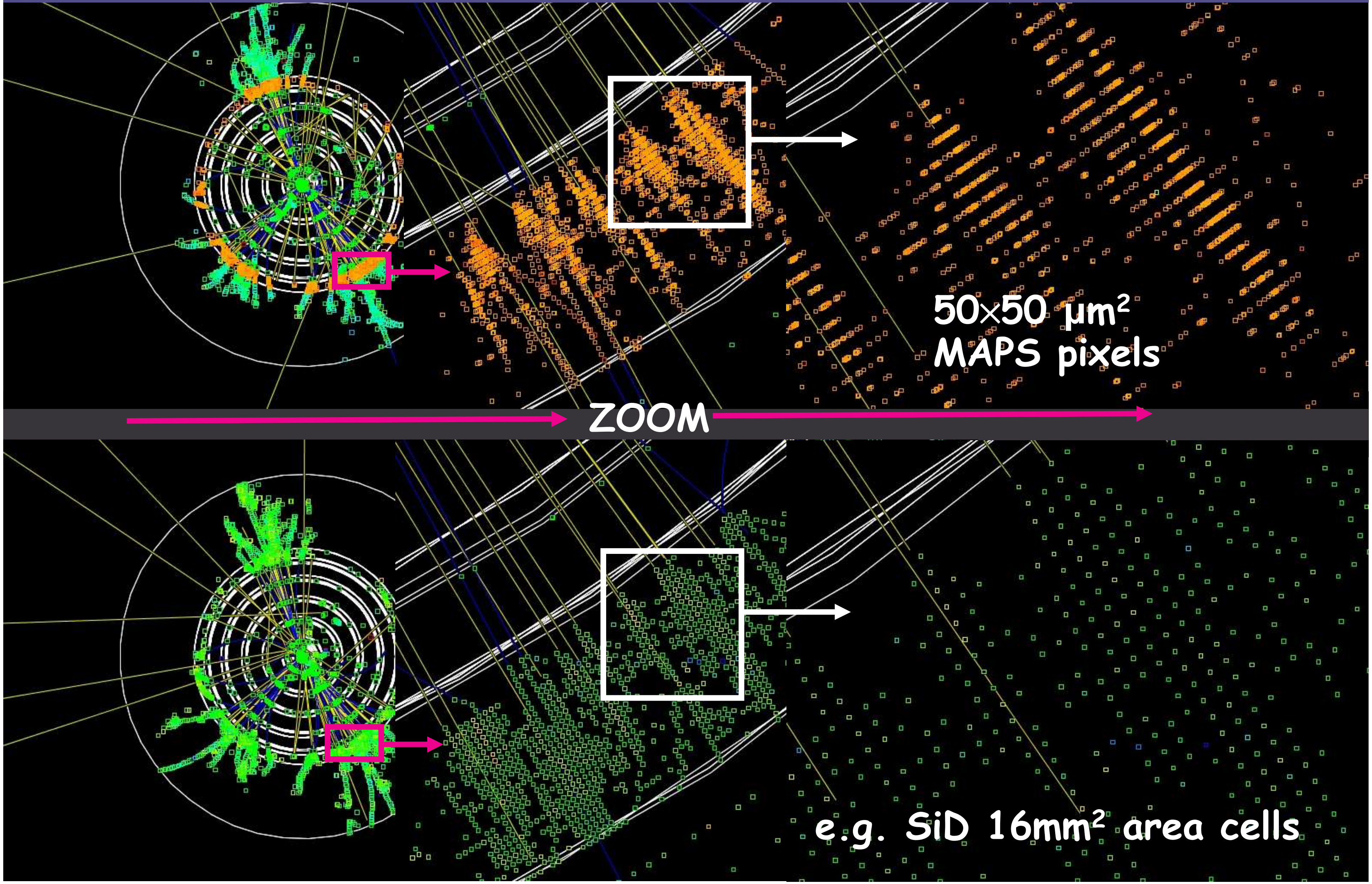


- Swap ~0.5x0.5 cm^2 Si pads with small pixels
  - "Small" := at most one particle/pixel
  - 1-bit ADC/pixel, i.e. **Digital ECAL**

- How small?
  - EM shower core density at 500GeV is ~100/mm^2
  - Pixels must be <$100\times100\mu m^2$
  - Our baseline is $50\times50\mu m^2$
  - Gives ~10^{12} pixels for ECAL – "Tera-pixel APS"

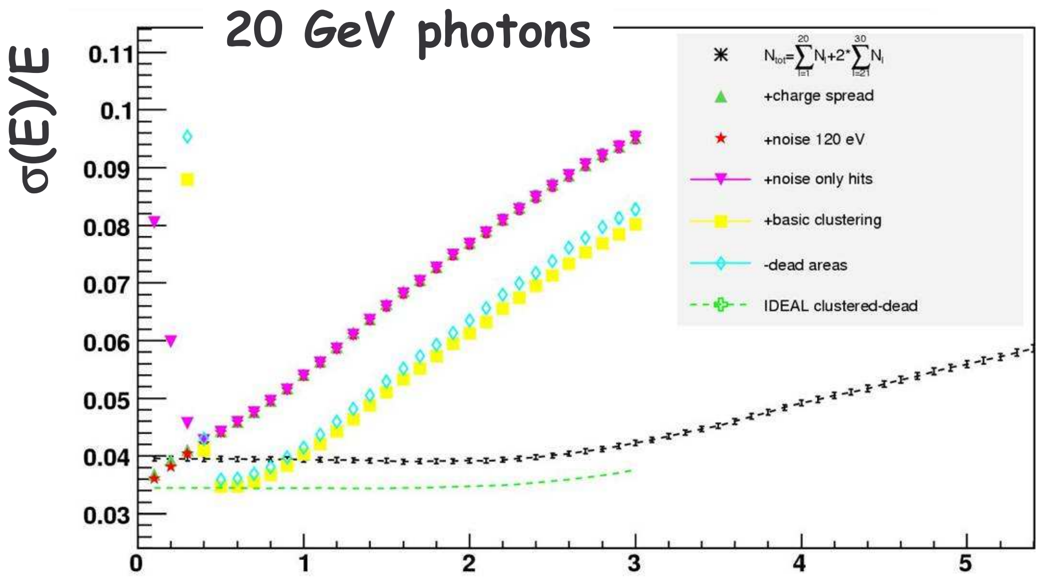


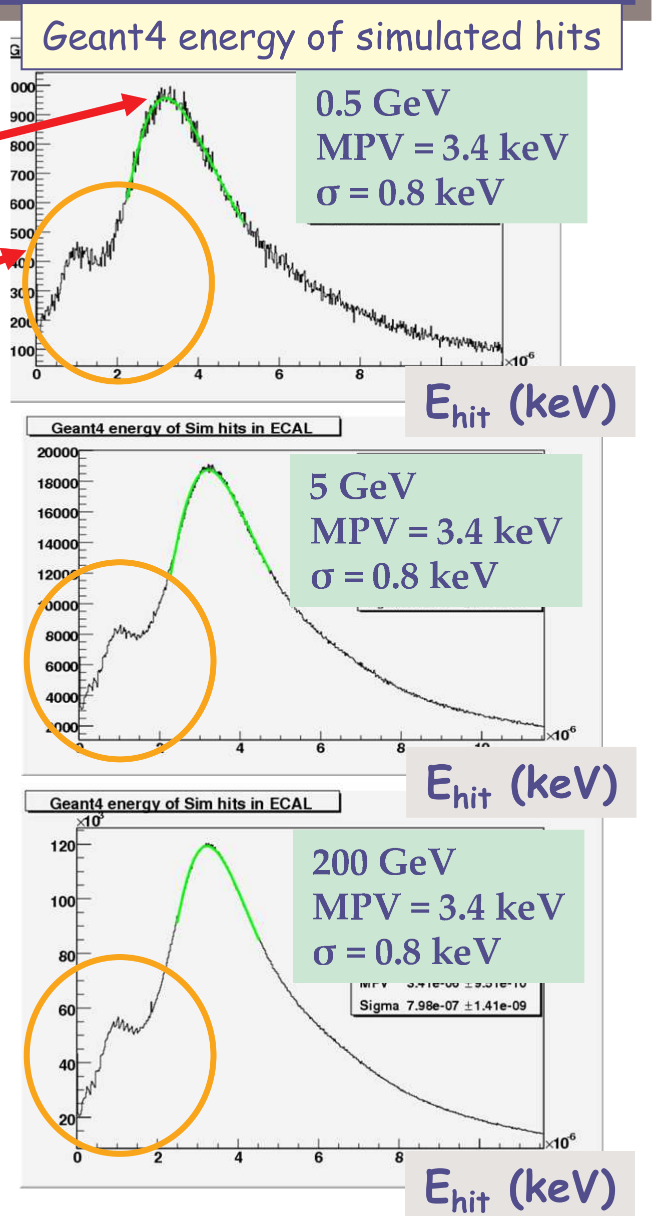
Tracking calorimeter



Physics simulation

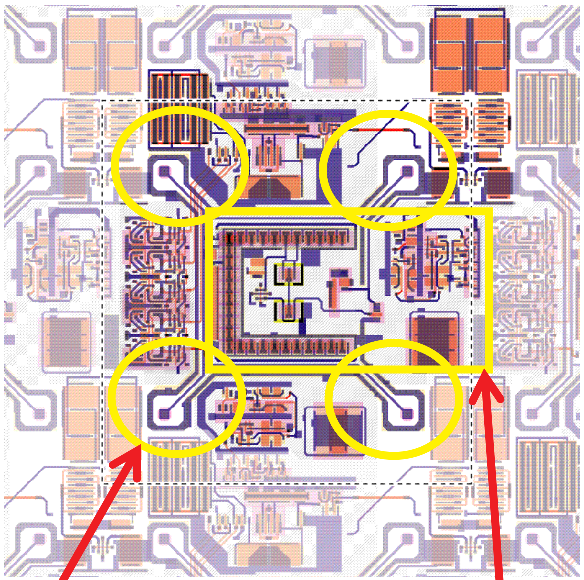
- MAPS geometry implemented in Geant4 detector model (Mokka) for LDC detector concept
- Peak of MIP Landau stable with energy
- Definition of energy: $E \propto N_{pixels}$
- Artefact of MIPS crossing boundaries
  - Correct by clustering algorithm
- Optimal threshold (and uniformity/stability) important for binary readout





CALICE INMAPS ASIC1

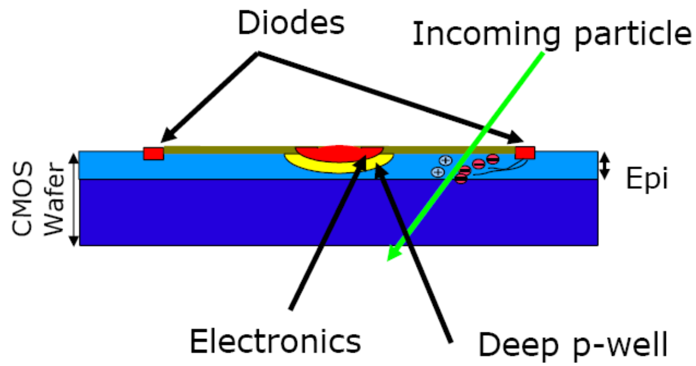
First round, four architectures/chip
(common comparator+readout logic)



4 diodes
Ø 1.8 μm

Architecture-specific
analogue circuitry

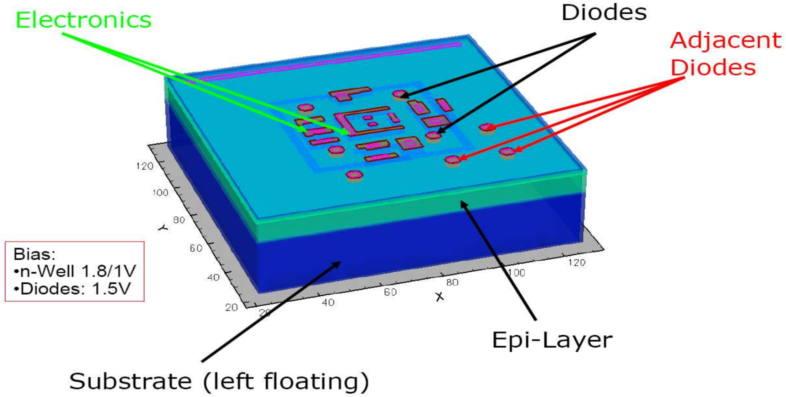
0.18μm feature size



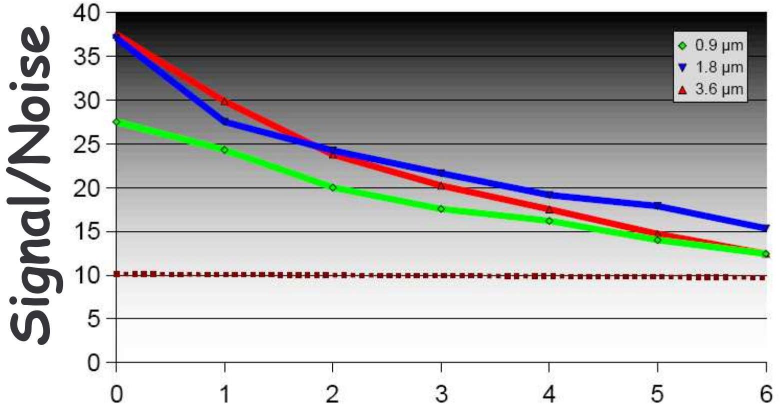
INMAPS process: deep p-well implant 1 μm thick under electronics n-well, improves charge collection

Device level simulation

- Physics data rate low – noise dominates
- Optimised diode for
  - Signal over noise ratio
  - Worst case scenario charge collection
  - Collection time



Signal/noise

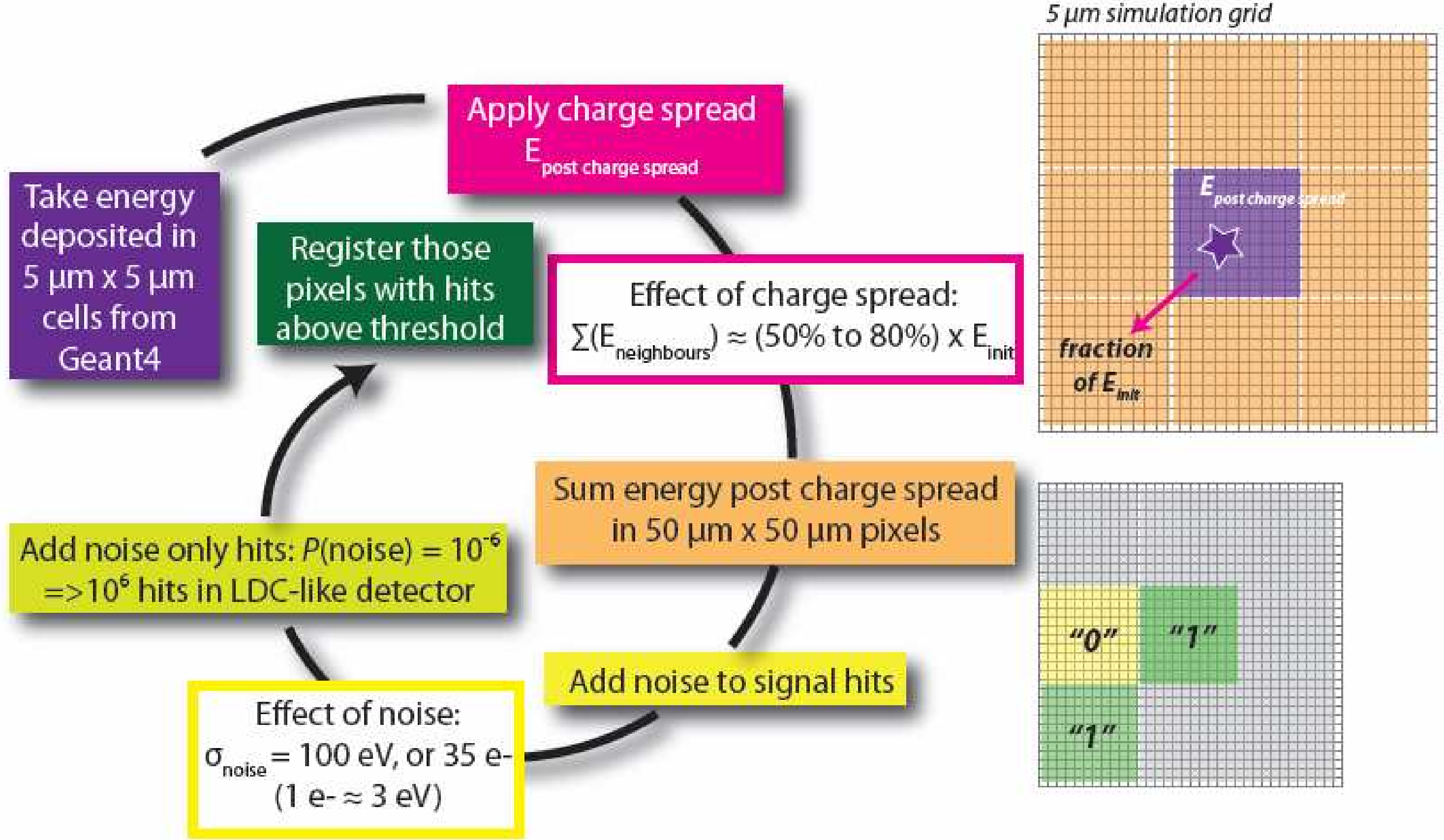


Distance to diode (charge injection point)

— 0.9 µm
— 1.8 µm
— 3.6 µm

Attention to detail 1: digitisation

Digital ECAL, essential to simulate
charge diffusion, noise, in G4 simulations

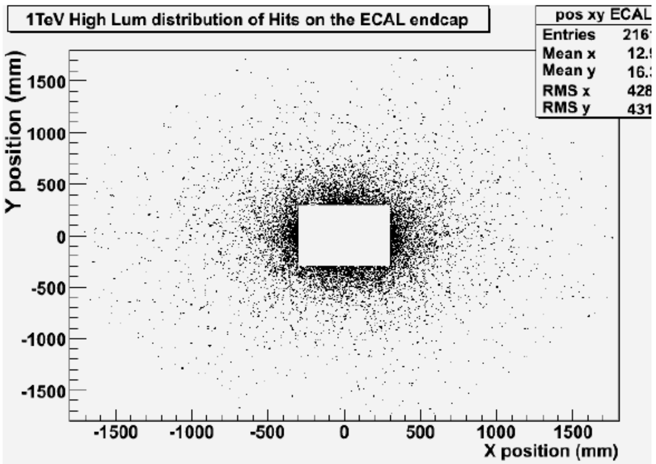


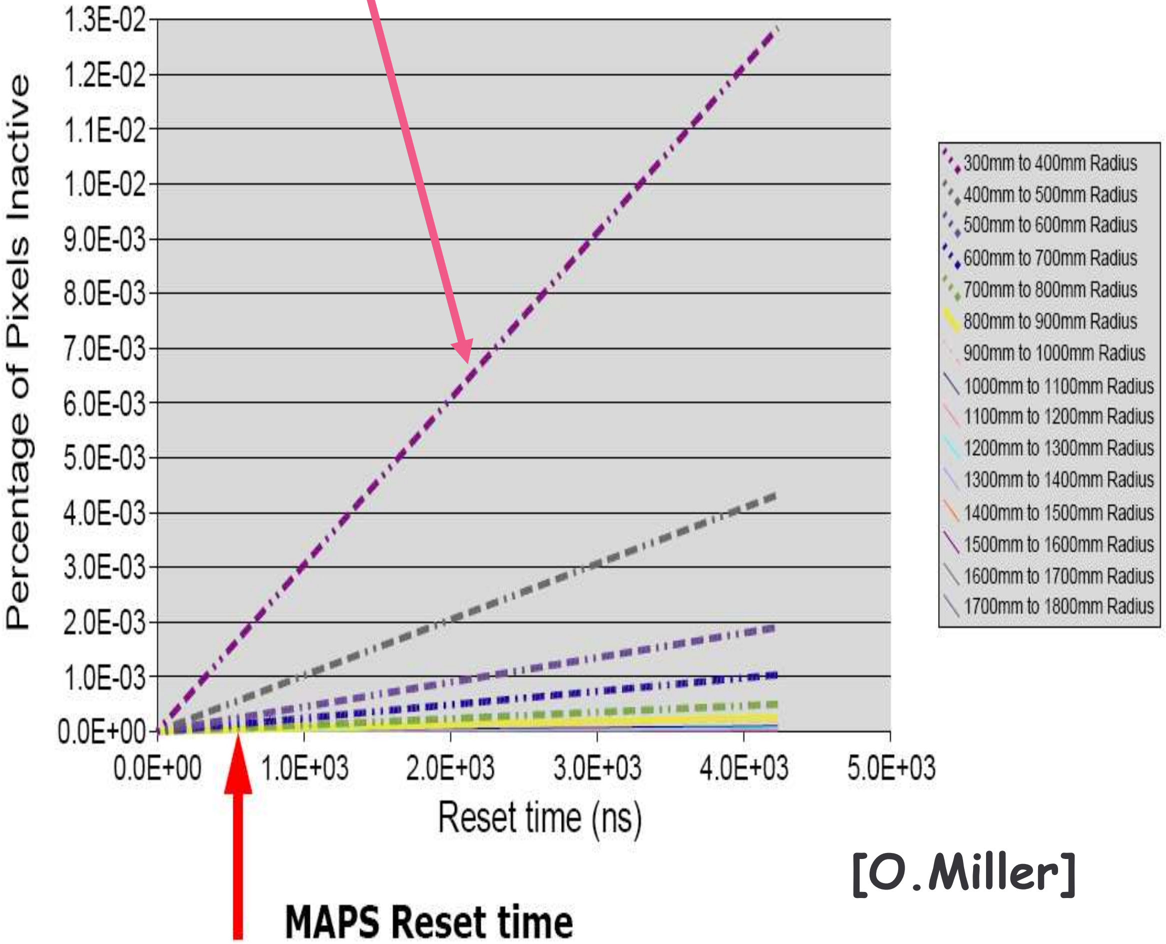
[J.Ballin/A-M.Magnan]

Attention to detail 2: beam background

- Beam-Beam interaction by GuineaPig
- Detector: LDC01sc
- 2 scenarios studied :
  - 500 GeV baseline,
  - 1 TeV high luminosity

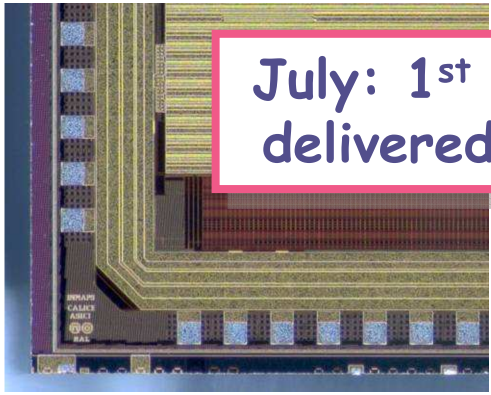
purple = innermost endcap radius
500 ns reset time Ł ~ 2‰ inactive pixels

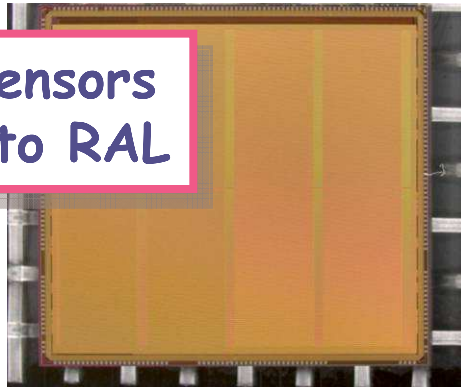




[O.Miller]

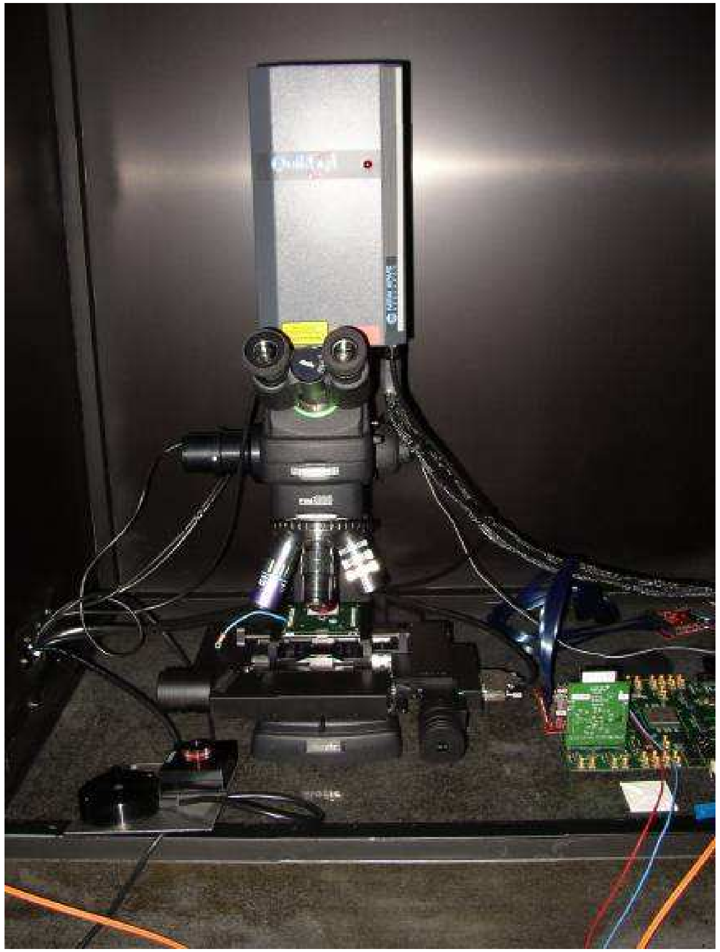
Near future plans





July: 1st sensors delivered to RAL

- Sensors mounted, testing has started
  - No show stoppers so far
- Test device-level simulations using laser-based charge diffusion measurements at RAL
  - λ=1064, 532,355 nm,focusing < 2 μm, pulse 4ns, 50 Hz repetition, fully automated
- Cosmics and source setup, Birmingham and Imperial, respectively.
- Potential for beam test at DESY end of 2007
- Expand work on physics simulations
  - Early studies show comparable peformance to LDC baseline (analogue Si)
  - Test performance of MAPS ECAL in ILD and SiD detector concepts
  - Emphasis on re-optimisation of particle flow algorithms



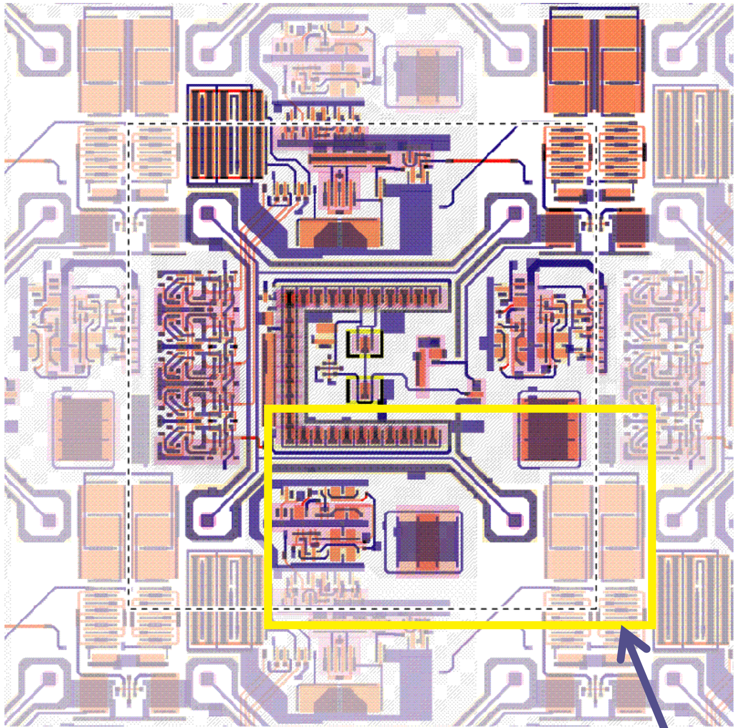
Summary

- UK well placed to play big part in ILD
  - Make use of large CALICE datasets to optimise detector design
    - ⇒ Test hadronic models / reduce dependence on MC model unknowns
    - ⇒ Design detectors that we have proven we can build
    - ⇒ Cannot test complete PFA algorithms directly with testbeam data – but can examine some key areas, e.g. fragment removal, etc.
- Physics studies for LoI
  - Two mature examples already, others in preparation, more essential!
  - Easy to get involved, quick start up with ILC s/w framework, PFA
    - ⇒ "local" expertise/assistance available
- PandoraPFA
  - The most performant PFA so far
  - Essential tool for ILD (+other) concepts – but needs further development and optimisation
  - …and people – from where?
- ECAL senstive detector: alternative to (LDC) baseline SiW
  - CMOS MAPS digital ECAL for ILC
    - ⇒ Multi-vendors, cost/performance gains
  - New INMAPS deep p-well process (optimise charge collection)
  - Four architectures for sensor on first chips, delivered to RAL Jul 2007
  - Tests of sensor performance, charge diffusion to start in August
  - Physics benchmark studies with MAPS ECAL to evaluate performance relative to standard analogue Si-W designs, for both SiD and LDC detector concepts
- Now is a good time to join ILC detector concept study

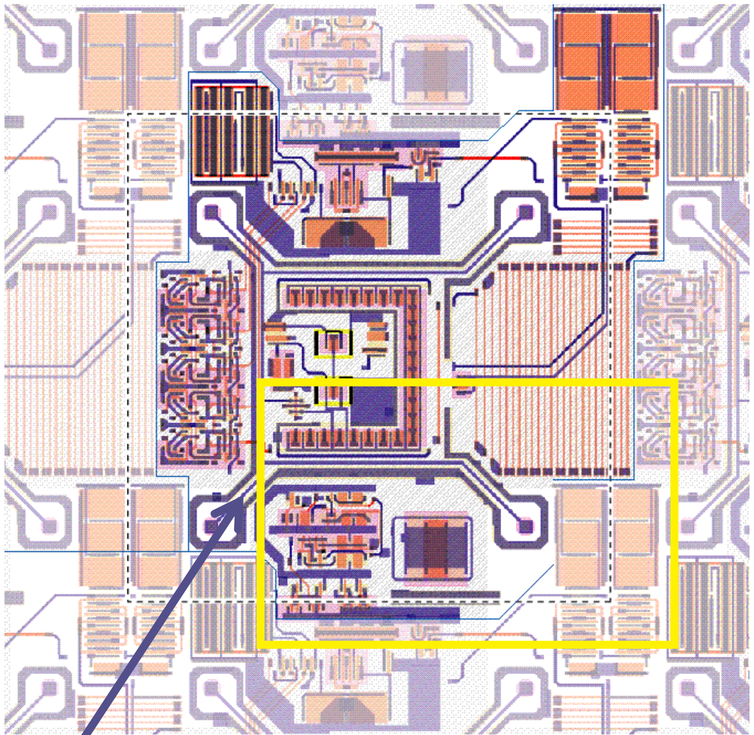
Backup slides…

Architectures on ASIC1

Presampler



Preshaper



Type dependant area: capacitors, and big resistor or monostable

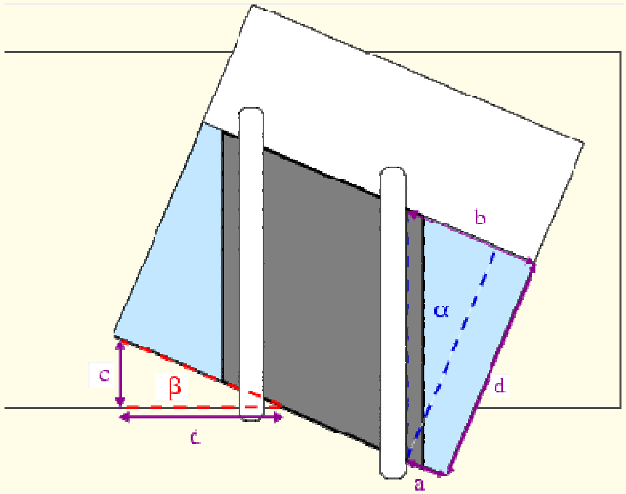
Energy points and particle types

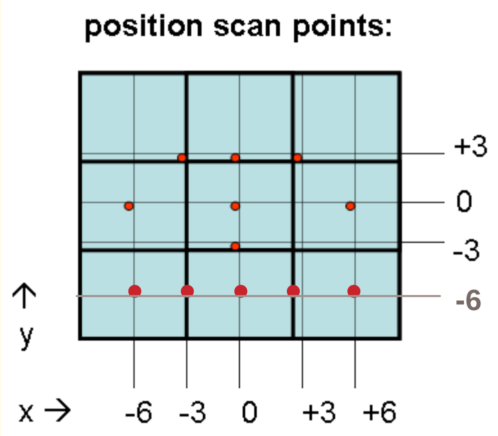
	Proposed in TB plan	Collected during TB
Energy (GeV)	6,8,10,12,15,18,20,25,30,40,50,60,80	6,8,10,12,15,18,20,25,30,40,50, 60,80,100,120,130,150,180
Particles	$\pi^{\pm}/e^{\pm}$	$\pi^{\pm}/e^{\pm}$/protons

- Beam energies extrapolated from secondary beam
  - Electron beam obtained sending secondary beam on Pb target
- π/e separation achieved using Cherenkov threshold detector filled with He gas
  - Possible to distinguish π from e for energies from 25 to 6 GeV
- π/proton separation achieved using Cherenkov threshold detector with N_2 gas
  - Possible to distinguish π from protons for energies from 80 to 30 GeV

http://www.pp.rhul.ac.uk/~calice/fab/WWW/runSummary.htm

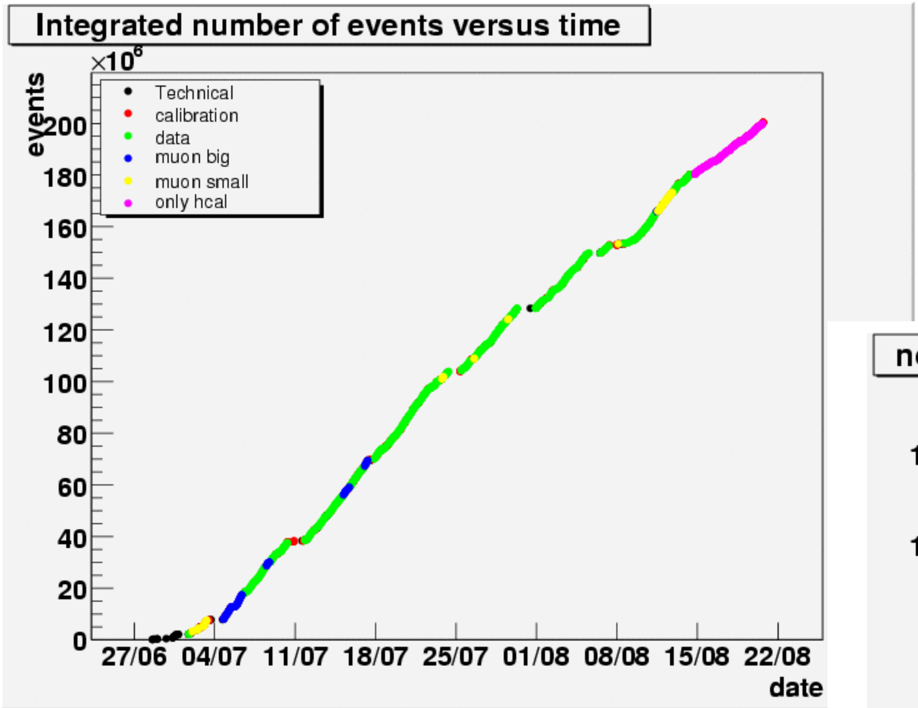
Angle and position scans





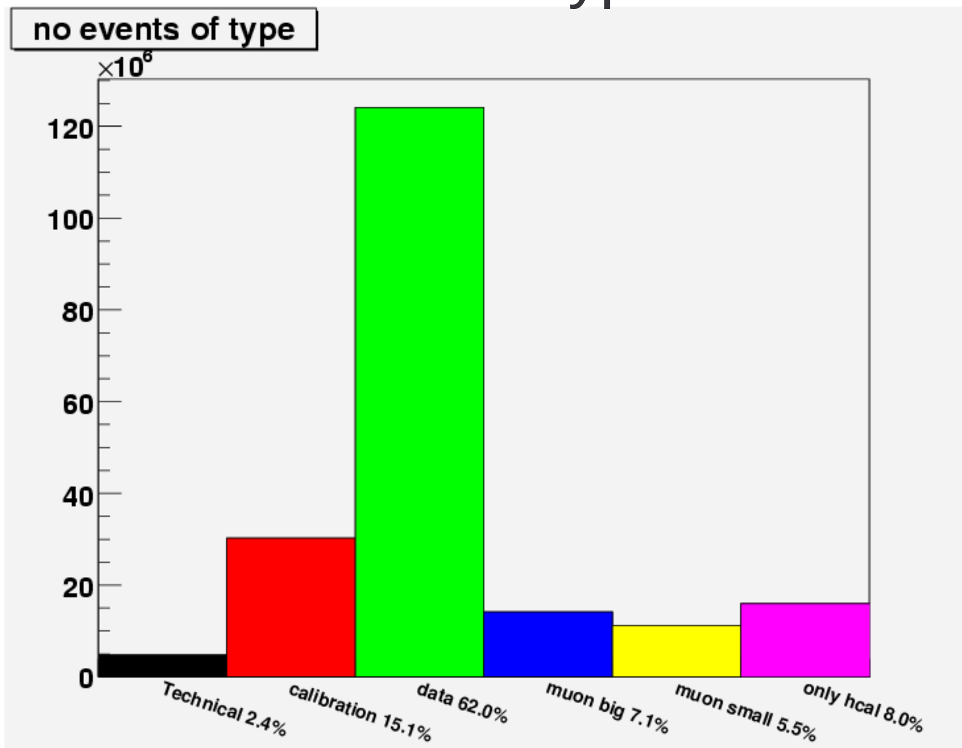
	Proposed in TB plan	Collected during TB
Angles	0, 10, 15, 20, 30	0, 10, 20, 30
Position scans	Centre of ECAL	Centre of ECAL ±6cm from ECAL centre wafer Bottom slab of ECAL (±6,0,±3cm, -3cm)
	Centre of AHCAL	Centre of AHCAL Centre of ECAL; AHCAL ±6cm off beam-line
	Inter-alveolae	Inter-alveolae (±3cm, ±3cm)

Total events collected



Integrated Luminosity

Event Types

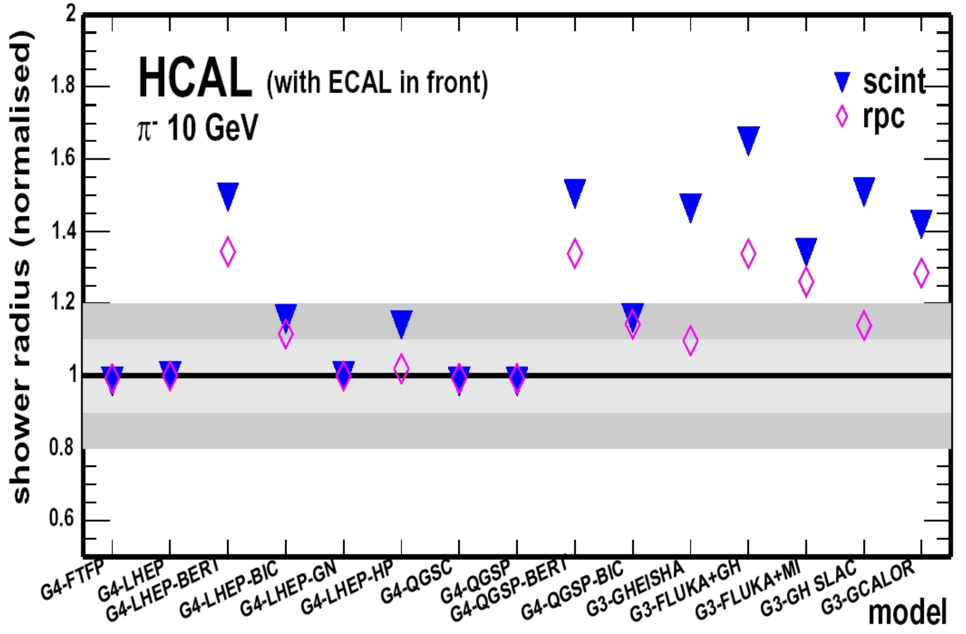


http://www.pp.rhul.ac.uk/~calice/fab/WWW/dataSummary.htm

Models comparison

Differential quantities

Study on hadronic shower profiles, G. Mavromanolakis (2004)

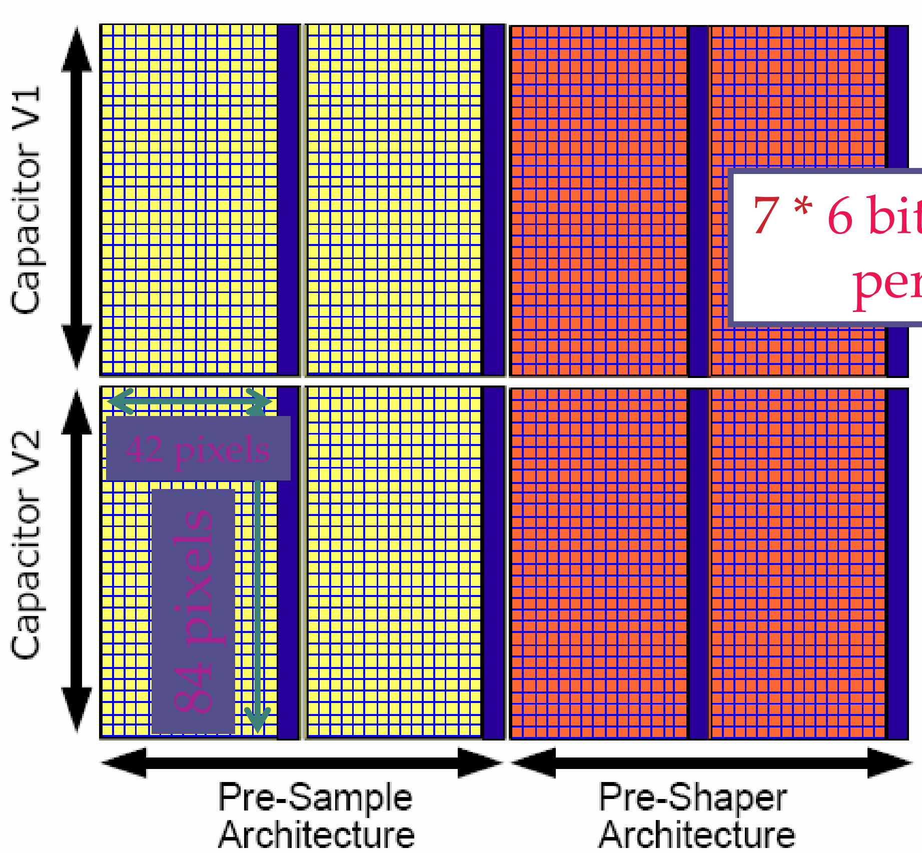


The HCAL high granularity offers the possibility to investigate longitudinal and lateral shower shapes with unprecedented precision:

- 38 points for longitudinal profile (if ECAL and TCMT included up to 84)
- 9 points for lateral profile

The sensor test setup

1*1 cm^2 in total
2 capacitor arrangements
2 architectures
6 million transistors, 28224 pixels



7 * 6 bits pattern per row

5 dead pixels for logic :
-hits buffering (SRAM)
- time stamp = BX (13 bits)
- only part with clock lines.

Row index

Data format

3 + 6 + 13 + 9 = 31 bits per hit

Impact of digitisation

- **E initial : *geant4 deposit***

•What remains in the cell after charge spread assuming perfect P-well

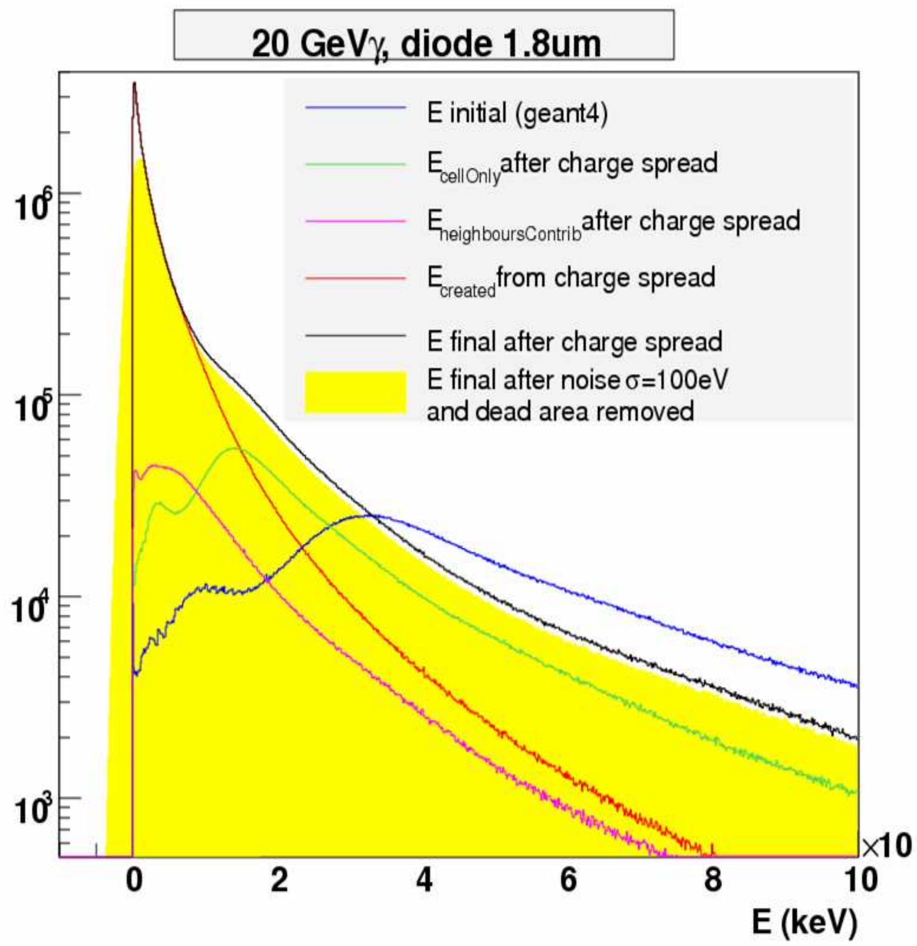
•Neighbouring hit:

- •hit ? Neighbour's contribution
- •no hit ? Creation of hit from charge spread only

•All contributions added per pixel

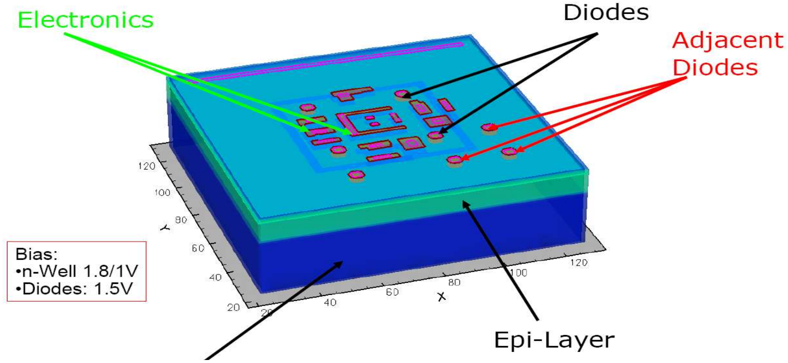
•+ noise σ = 100 eV

•+ noise σ = 100 eV, minus dead areas : 5 pixels every 42 pixels in one direction



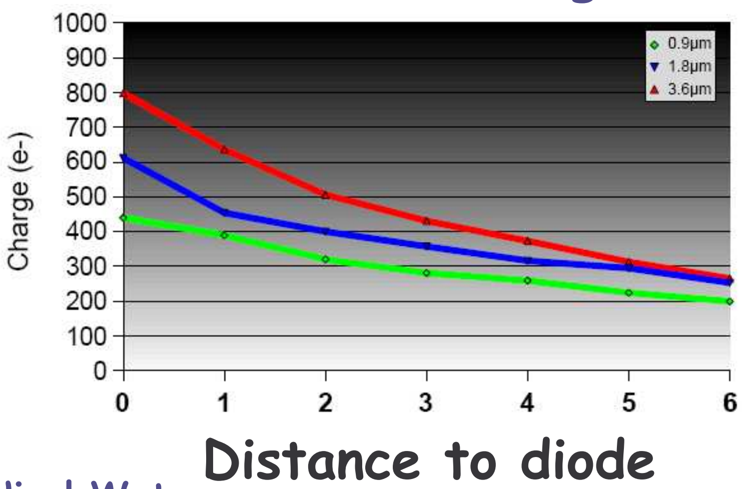
Device level simulation

- Physics data rate low – noise dominates
- Optimised diode for
  - Signal over noise ratio
  - Worst case scenario charge collection
  - Collection time.

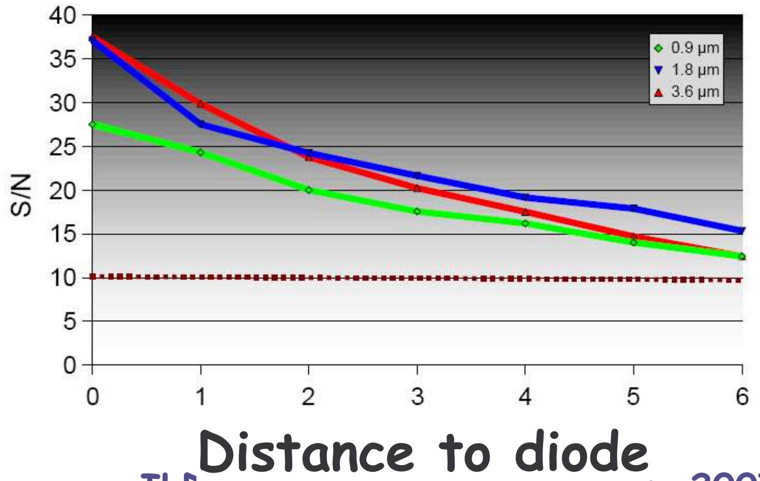


Using **Centaurus TCAD** for sensor simulation + CADENCE GDS file for pixel description

Collected charge



Signal/noise



0.9 µm
1.8 µm
3.6 µm