Concepts, Calorimetry and PFA

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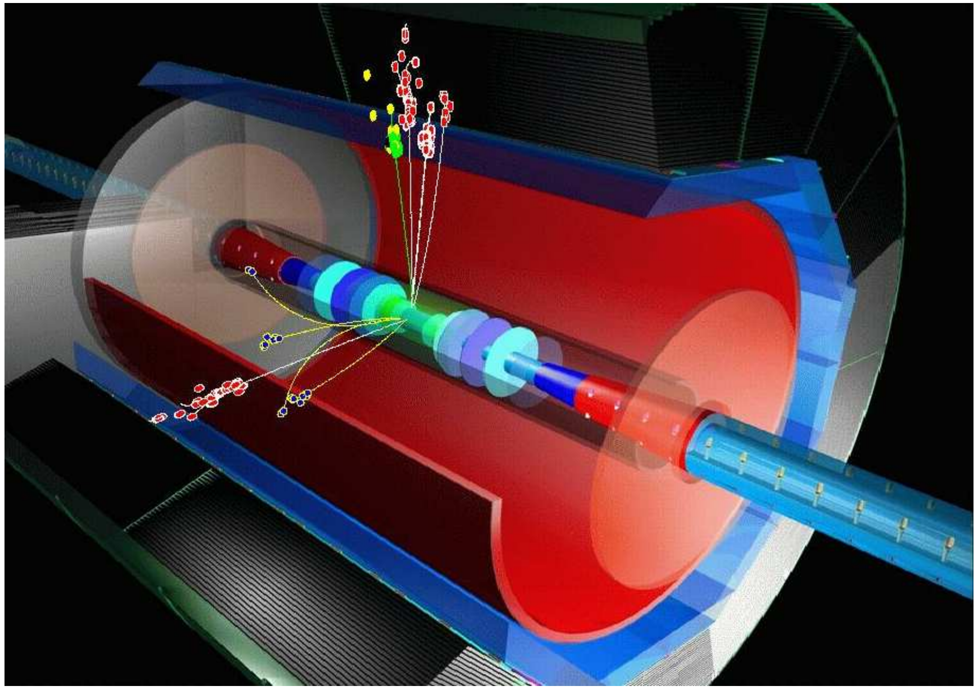
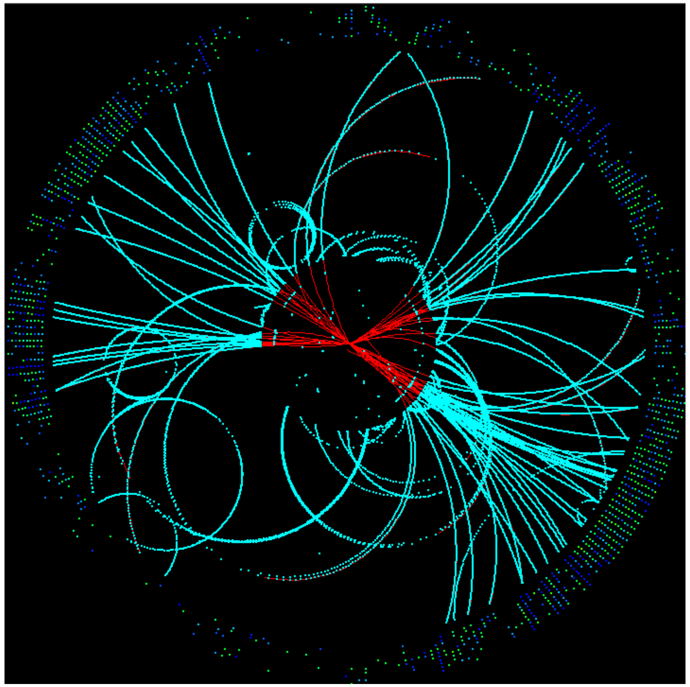




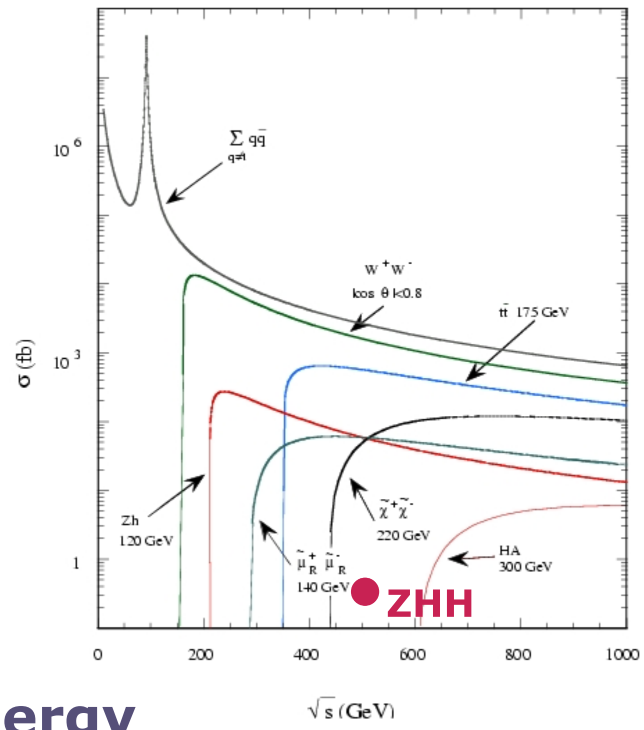
<u>This Talk:</u>

- ILC Physics/Detector Requirements
- Detector Concepts and optimisation
- Calorimetry at the ILC
- Particle Flow Status
- PFA in near future
- Conclusions

ILC Physics / Detector Requirements

Precision Studies/Measurements

« **Higgs** sector
« **SUSY** particle spectrum
« **SM particles** (e.g. W-boson, top)
« and much more...



Difficult Environment:

« **High Multiplicity final states**
often **6/8 jets**

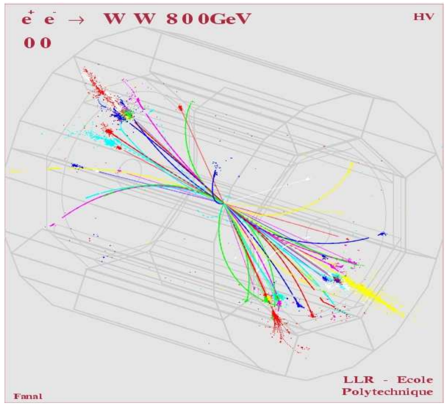
« **Small cross-sections**
e.g. $\sigma(e^+e^- \rightarrow ZHH) = 0.3$ fb

« **Many final states have "missing" energy**
neutrinos + neutrilinos(?)/gravitinos(?) + ????

› **Detector optimized for precision measurements in difficult environment**
› **Only 2 detectors (1?) – make sure we choose the right options**

ILC Detector Requirements

- **Momentum:** $\sigma_{1/p} < 7\times10^{-5}$/GeV **(1/10 x LEP)**
  - **(e.g. Z mass reconstruction from charged leptons)**
- **Impact parameter:** $\sigma_{d0} < 5\mu m \oplus 5\mu m/p(GeV)$ **(1/3 x SLD)**
  - **(c/b-tagging in background rejection/signal selection)**
- **Jet energy :** $\delta E/E = 0.3/E(GeV)$ **(1/2 x LEP)**
  - **(W/Z invariant mass reconstruction from jets)**
- **Hermetic down to :** $\theta = 5$ mrad
  - **(for missing energy signatures e.g. SUSY)**
- **Sufficient timing resolution to separating events from different bunch-crossings**

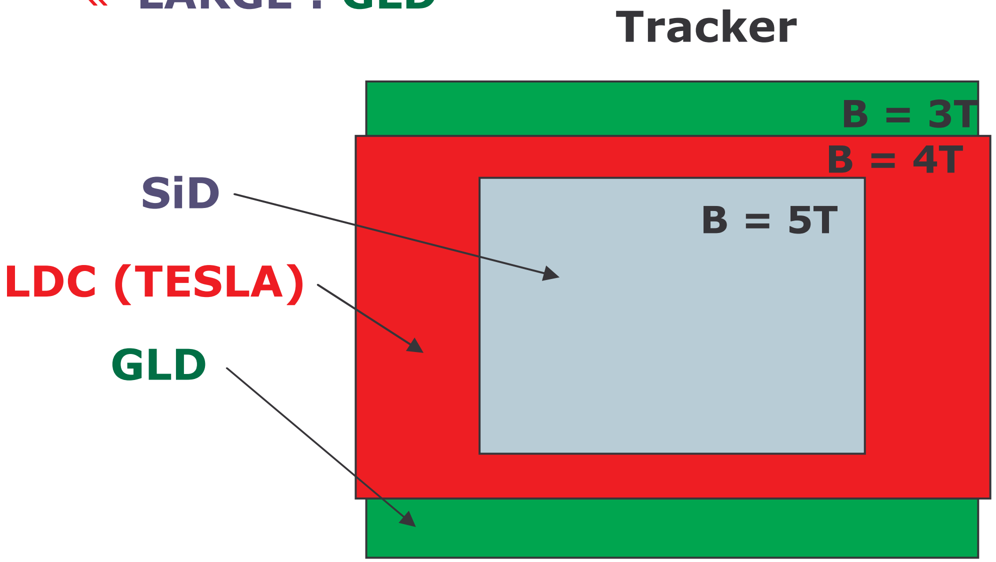


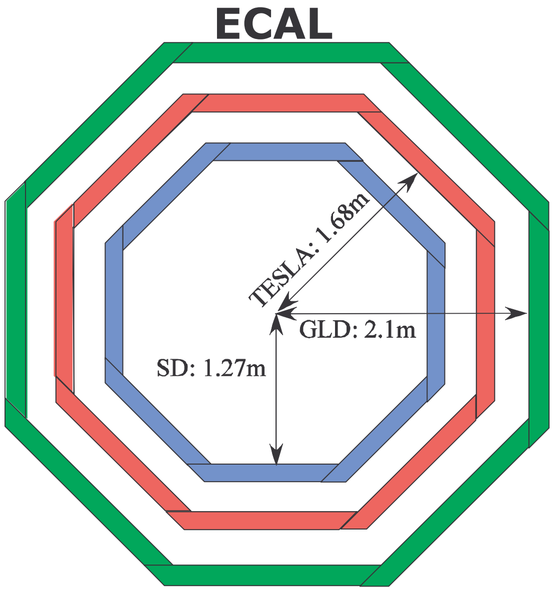
Must also be able to cope with high track densities due to high boost and/or final states with 6+ jets, therefore require:

- **High granularity**
- **Good pattern recognition**
- **Good two track resolution**

Detector Concepts

- Currently 3 detector concepts
  - « COMPACT: Silicon Detector (SiD)
  - « TESLA-like: Large Detector Concept : (LDC)
  - « LARGE : GLD



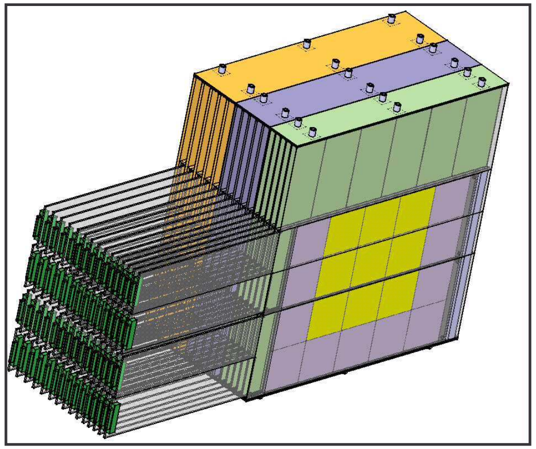


	VTX	Tracker	ECAL	HCAL
SiD	yes	Si	SiW	?
LDC	yes	TPC	SiW	?
GLD	yes	TPC	Scint-W	Scint-Pb

What is the purpose of the Concepts ?

- Explore phase space for ILC detector design
- Produce costed "conceptual design reports" by end of **2006**
- Place detector R&D (e.g. CALICE) in context of a real detector
- Perform some level of cost-performance optimisation
- Possible/likely to be nucleus around which real collaborations form

Relevance to CALICE ?



- SiW ECAL is not cheap !
  - big cost driver for overall detector
- Can it be justified ?
  - are the physics benefits worth the cost
  - do we need such high granularity
- would very high granularity help ?
  - MAPS

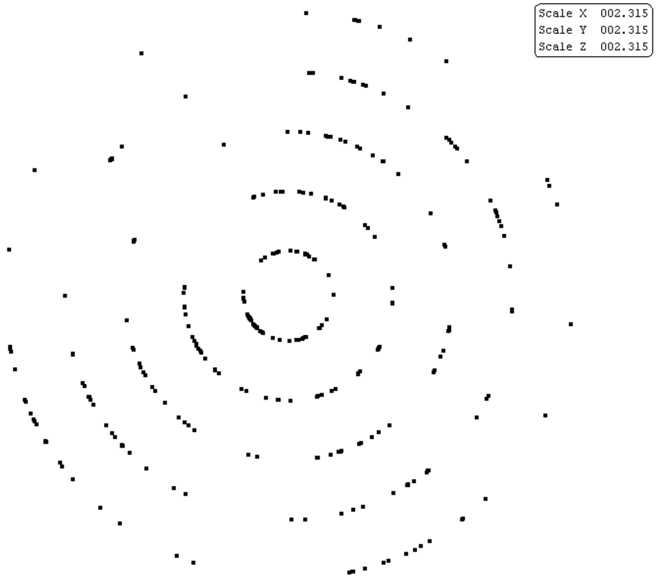
★ **These are important questions.**
The concept studies will hopefully provide the answers

What to Optimize ?

The Big Questions (to first order):

CENTRAL TRACKER

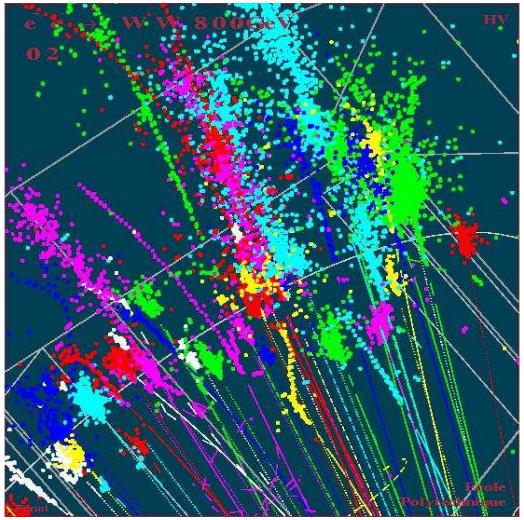
« **TPC vs Si Detector**



« **Samples vs. granularity – pattern recognition in a dense track environment with a Si tracker ?**

ECAL

- Widely (but not unanimously) held view that a high granularity SiW ECAL is the right option
- BUT it is expensive
- Need to demonstrate that physics gains outweigh cost
- + optimize pad size/layers



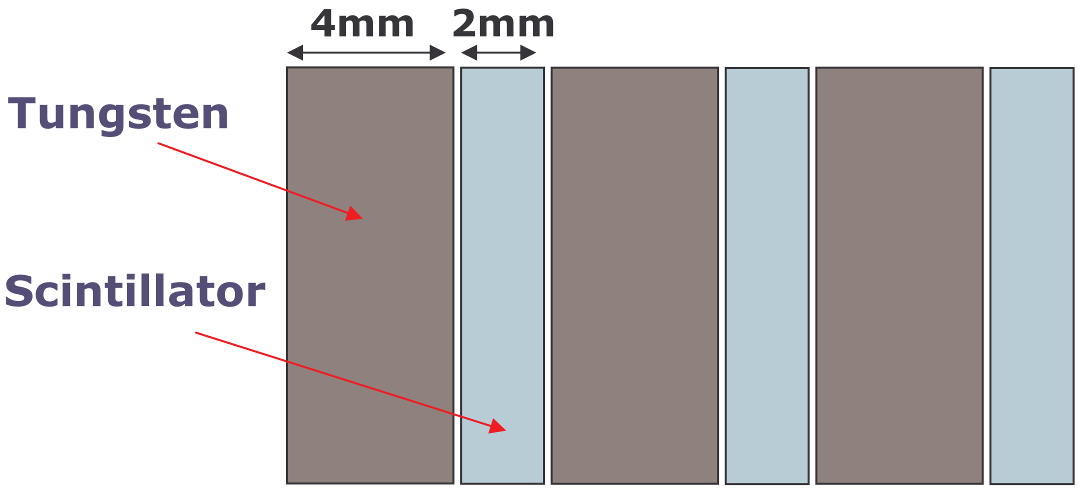
HCAL

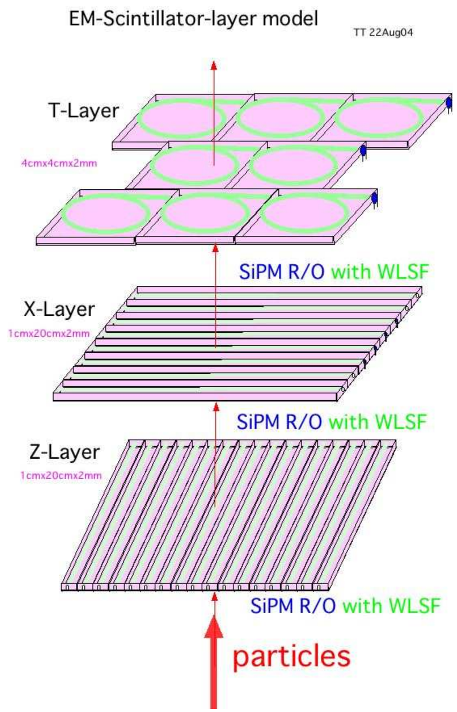
- Higher granularity digital (e.g. RPC) vs lower granularity analog option (e.g. scint-steel)

SIZE

- Physics argues for:
  large + high granularity
- Cost considerations:
  small + lower granularity
- What is the optimal choice ?

Aside: the GLD ECAL





Initial GLD ECAL concept:

- Achieve effective ~1 cm x 1cm segmentation using strip/tile arrangement
- Strips : 1cm x 20cm x 2mm
- Tiles : 4cm x 4cm x 2mm

- **Ultimate design needs to be optimised for particle flow performance**

+ question of pattern recognition in dense environment

Calorimetry at the ILC

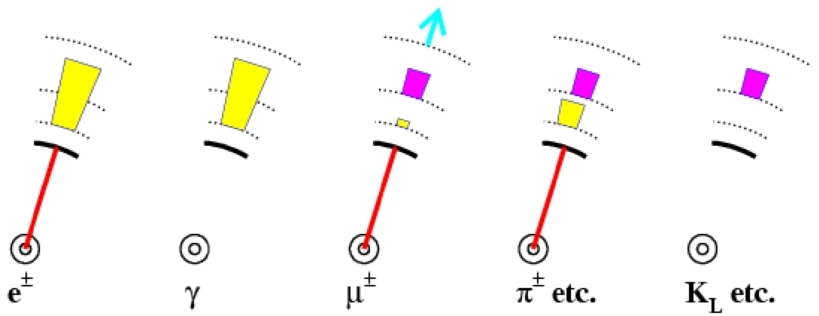
- « Much **ILC** physics depends on reconstructing invariant masses from jets in hadronic final states
- « Kinematic fits won't necessarily help – **Unobserved particles (e.g. ν),** + (less important ?) Beamstrahlung, ISR
- « Aim for jet energy resolution ~ Γ_Z for "typical" jets - the point of diminishing return
- « Jet energy resolution is the key to calorimetry

The visible energy in a jet (excluding ν) is:

60 % charged particles : 30 % γ : 10 % K_L,n

The Energy Flow/Particle Flow Method

- Reconstruct momenta of individual particles avoiding double counting



Charged particles in **tracking chambers**
Photons in the **ECAL**
Neutral hadrons in the **HCAL** (and possibly **ECAL**)

« Need to separate energy deposits from different particles

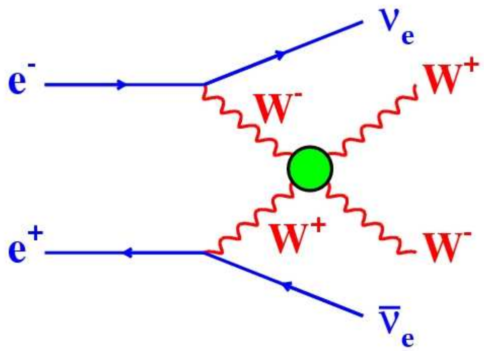
THIS ISN'T EASY !

Jet energy resolution:

Best at LEP (ALEPH):
$\sigma_E/E = 0.6(1+|\cos\theta_{Jet}|)/\sqrt{E(\text{GeV})}$

ILC GOAL:
$\sigma_E/E = 0.3/\sqrt{E(\text{GeV})}$

« **Jet energy resolution directly impacts physics sensitivity**

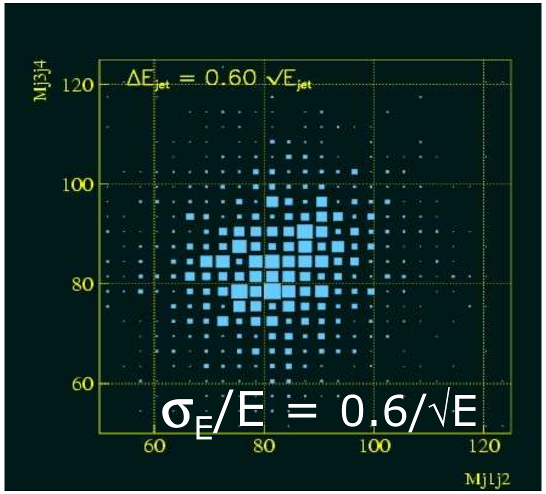


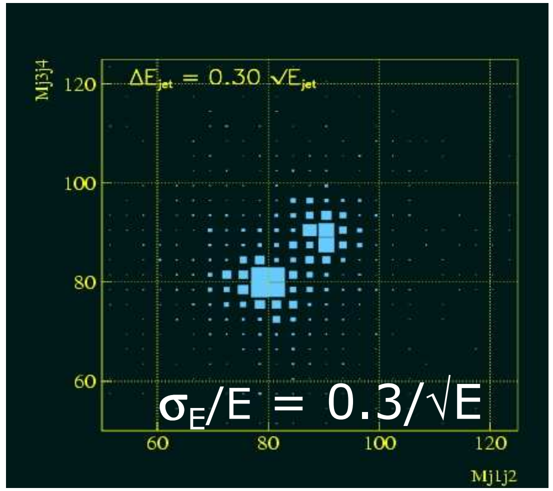
Reconstruction of two di-jet masses allows discrimination of WW and ZZ final states

Often-quoted Example:

If the Higgs mechanism is not responsible for EWSB then QGC processes important

$e^+e^-\rightarrow\nu\nu WW\rightarrow\nu\nu qqqq$, $e^+e^-\rightarrow\nu\nu ZZ\rightarrow\nu\nu qqqq$





« **EQUALLY applicable to any final states where want to separate $W\rightarrow qq$ and $Z\rightarrow qq$!**

« Best resolution achieved for TESLA TDR : $0.30\sqrt{E_{jet}}$

Component	Detector	Frac. of jet energy	Particle Resolution	Jet Energy Resolution
Charged Particles($X^{\pm}$)	Tracker	0.6	$10^{-4}\,E_X$	neg.
Photons(γ)	ECAL	0.3	$0.11\sqrt{E_\gamma}$	$0.06\sqrt{E_{jet}}$
Neutral Hadrons(h^0)	HCAL	0.1	$0.4\sqrt{E_h}$	$0.13\sqrt{E_{jet}}$

morgunov

« In addition, have contributions to jet energy resolution due to "confusion" = assigning energy deposits to wrong reconstructed particles (double-counting etc.)

$$\sigma_{jet}^2 = \sigma_{x\pm}^2 + \sigma_\gamma^2 + \sigma_{h^0}^2 + \sigma_{confusion}^2 + \sigma_{threshold}^2$$

Will come back to this later

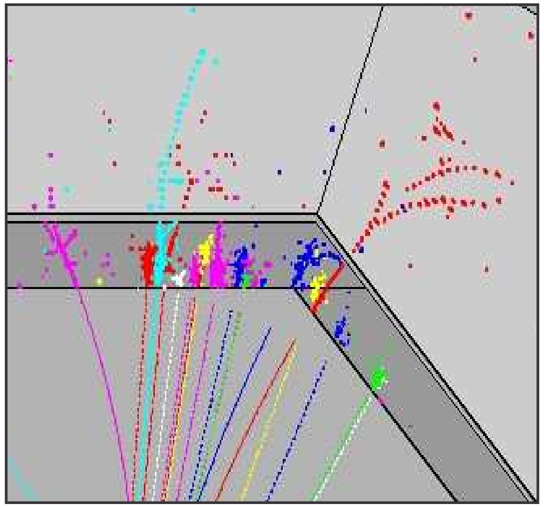
« Single particle resolutions not the dominant contribution to jet energy resolution !

granularity more important than energy resolution

Calorimeter Requirements

Particle flow drives calorimeter design:

- Separation of energy deposits from individual particles
  - small X_0 and $R_{Moliere}$: compact showers
  - high lateral granularity : $O(R_{Moliere})$
- Discrimination between EM and hadronic showers
  - small X_0/λ_{had}
  - longitudanal segmentation
- Containment of EM showers in ECAL



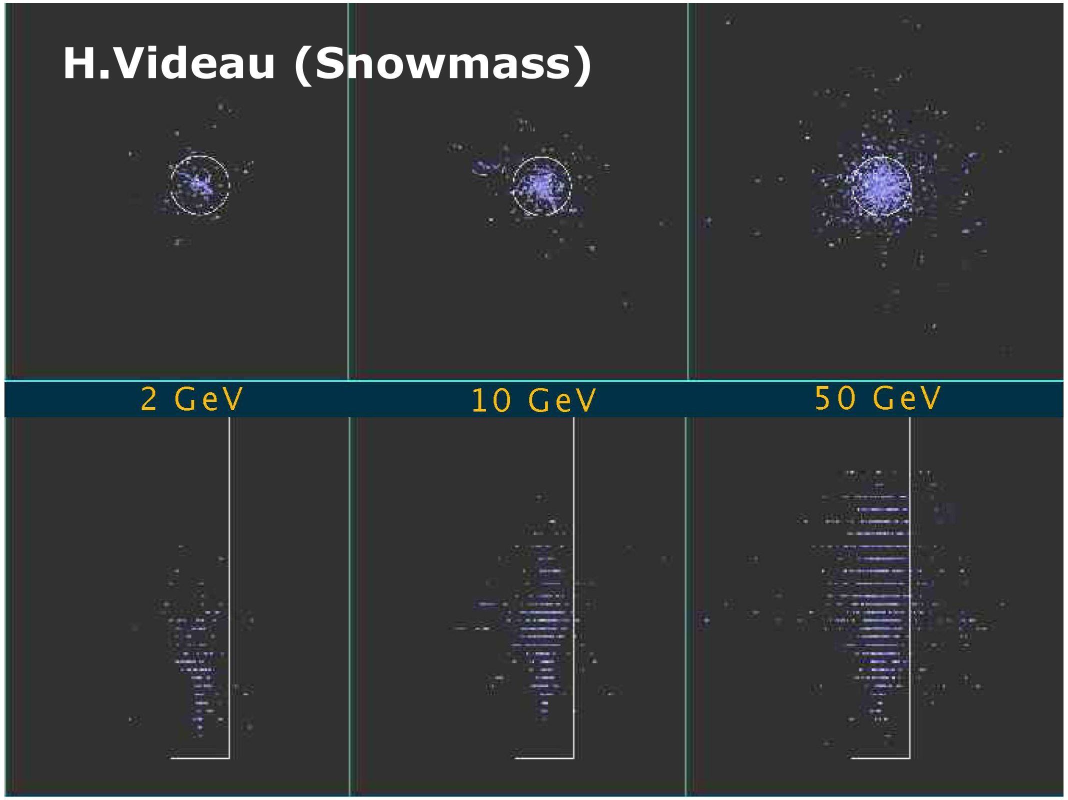
Some COMMENTS/QUESTIONS:

- $R_{Moliere}$ ~ 9mm for solid tungsten
  - gaps between layers increase effective $R_{Moliere}$
  - an engineering/electronics issue
- $R_{Moliere}$ is only relevant scale once shower has developed
  - in first few radiation lengths higher/much higher lateral segmentation should help
- + Many optimisation issues !

ECAL Granularity : is the R_{Mol} the correct scale ?

Personal View:

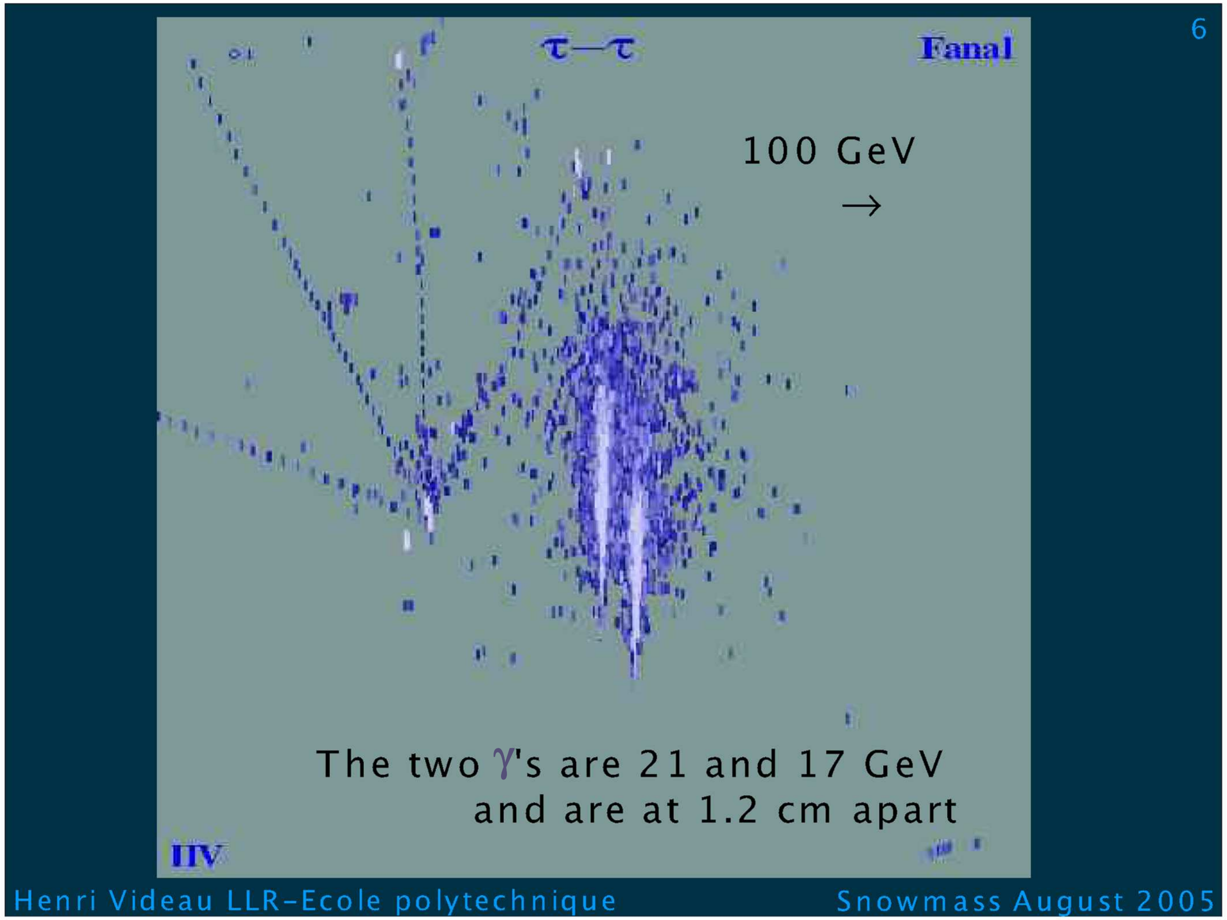
- Moliere radius is only relevant towards shower max
- At start of shower (ECAL front) much higher granularity may help
  - MAPS ....?
- At end of shower can probably reduce granularity



e.g. electrons in SiW with 1 mm x 1 mm segmentation

- Higher granularity clearly helps
- particularly at shower start

Another example: $\tau^+ \rightarrow \rho^+ \nu \rightarrow \pi^+ \pi^0$



- **General view now leaning towards higher granularity**
- **IF SiW ECAL cost driven mainly by Si cost – no problem**

Hadron Calorimeter

Highly Segmented – for Energy Flow

- Longitudinal: ~10 samples
- ~5 λ_{had} (limited by cost - coil radius)
- Would like fine (1 cm² ?) lateral segmentation (how fine ?)
- For 5000 m² of 1 cm² HCAL = 5×10^{7} channels – cost !

Two(+) Options:

« Tile HCAL (Analogue readout)

Steel/Scintillator sandwich

Lower lateral segmentation

5x5 cm² (motivated by cost)

« Digital HCAL

High lateral segmentation

1x1 cm²

digital readout (granularity)

RPCs, wire chambers, GEMS…

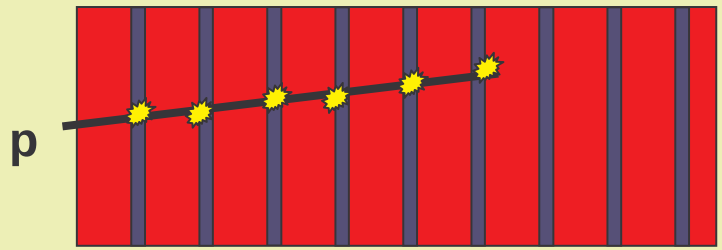
« Semi-Digital option ?

★ OPEN QUESTION

The Digital HCAL Paradigm

- Sampling Calorimeter:

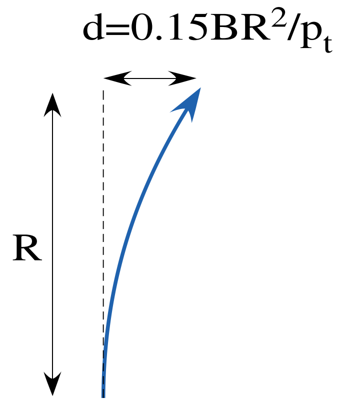
  Only sample small fraction of the total energy deposition



- Energy depositions in active region follow highly asymmetric Landau distribution

Particle Flow Status

- Particle flow in an ILC highly granular ECAL/HCAL is very new
  - No real experience from previous experiments
- We all have our personal biases/beliefs about what is important
  - BUT at this stage, should assume we know very little
- Real PFA algorithms vital to start learning how to do this type of "calorimetry"



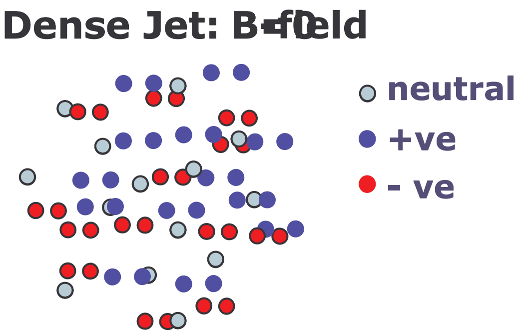
Example:

- Often quoted F.O.M. for jet energy resolution:
  BR^2/σ ($R=R_{ECAL}$; σ = 1D resolution)
  i.e. transverse displacement of tracks/"granularity"
- Used to justify (and optimise) SiD parameters
- BUT it is almost certainly wrong !

★ B-field just spreads out energy deposits from charged particles in jet
– not separating collinear particles

★ Size more important - spreads out energy deposits from all particles

★ R more important than B



So where are we ?

- Until recently we did not have the software tools to optimise the detector from the point of view of **Particle Flow**
- **This has changed !**
- <u>The basic tools are mostly there:</u>
  - **Mokka :** now has scalable geometry for the LDC detector
  - **MARLIN:** provides a nice (and simple) reconstruction framework
  - **LCIO:** provides a common format for worldwide PFA studies
  - **SLIC:** provides a G4 simulation framework to investigate other detector concepts (not just GLD, LDC and SiD)
  - **Algorithms:** in MARLIN framework already have ALGORITHMS for TPC tracking, clustering + PFA

We are now in the position to start to learn how to optimise the detector for PFA

<u>Some Caution:</u>

- This optimisation needs care: can't reach strong conclusions on the basis of a single algorithm
- A lot of work to be done on algorithms + PFA studies
- Not much time : aim to provide input to the detector outline

<u>**BUT :**</u> **real progress for Snowmass (mainly from DESY group)**

Perfect Particle Flow

What contributes to jet energy resolution in ideal "no confusion" case (i.e. use MC to assign hits to correct PFOs) ?

$e^+ e^- \rightarrow Z^0 \rightarrow q\bar{q}$ at 91.2GeV

Studies by P.Krstonosic

Effect	σ [GeV] separate	σ [GeV] not joined	σ [GeV] total ($\%/\sqrt{E}$)	σ to total
$E_\nu > 0$	0.84	0.84	0.84 (8.80%)	12.28
$Cone < 5^o$	0.73	1.11	1.11(11.65%)	9.28
$P_t < 0.36$	1.36	1.76	1.76(18.40%)	32.20
σ_{HCAL}	1.40	1.40	2.25(23.53%)	34.12
σ_{ECAL}	0.57	1.51	2.32(24.27%)	5.66
M_{neutral}	0.53	1.60	2.38(24.90%)	4.89
M_{charged}	0.30	1.63	2.40(25.10%)	1.57

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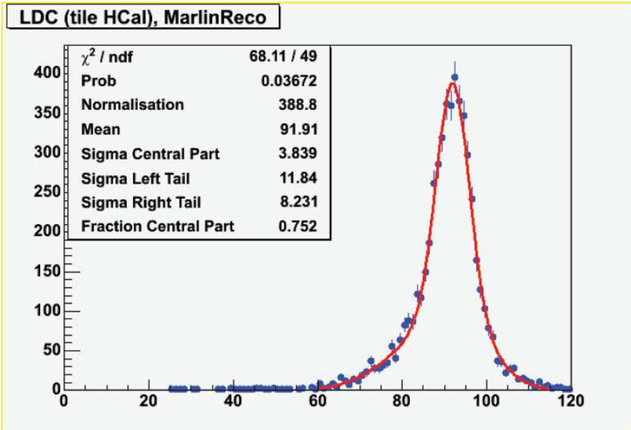
Missed tracks not a negligible contribution !

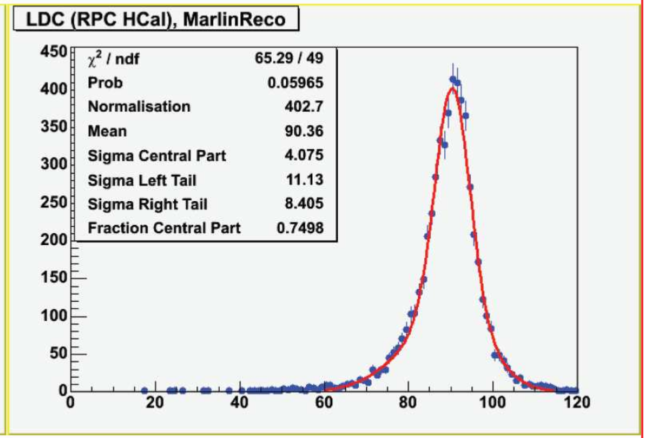
Example : full PFA results in MARLIN (Alexei Raspereza)

Z^0 => u,d,s jets at 91.2 GeV, no ISR, no beamstrahlung

Analogue Tile HCal (3x3 cm^2 tile size)



Digital RPC HCal (1x1 cm^2 pad size)



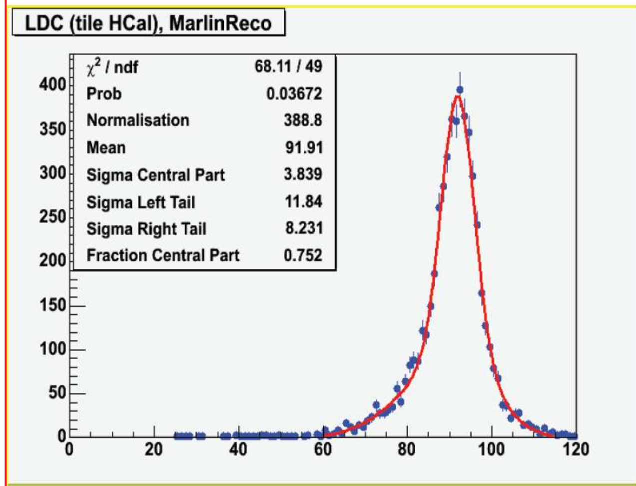
Simple gaussian fit gives 4.6(4.7) GeV resolution for tile(RPC) HCal, but fit has very poor χ^2

Alexei Raspereza, DESY, ILC Workshop, Snowmass, August 22, 2005 15

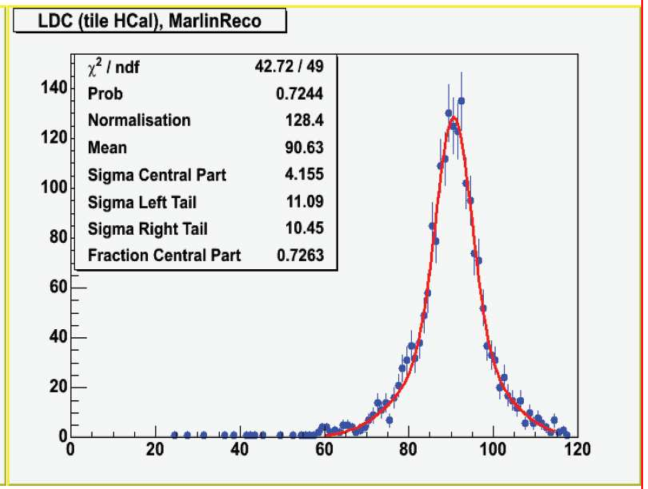
NOTE: currently achieving 0.40/√E

PFA Performance vs. HCAL Granularity

tile Hcal (3x3 cm^2 tile size)



tile Hcal (6x6 cm^2 tile size)



Alexei Raspereza, DESY, ILC Workshop, Snowmass, August 22, 2005

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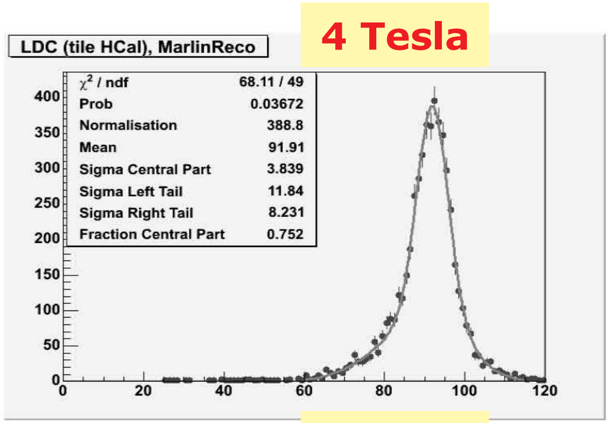
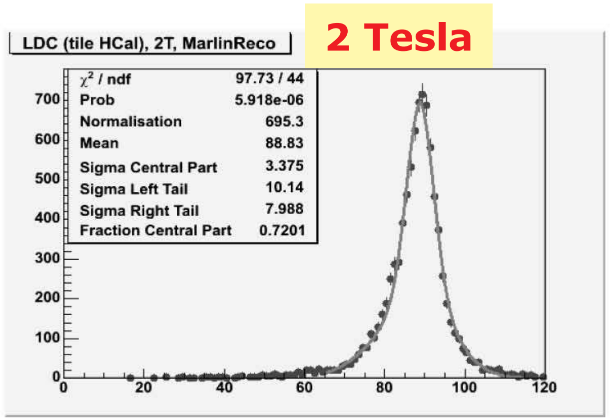
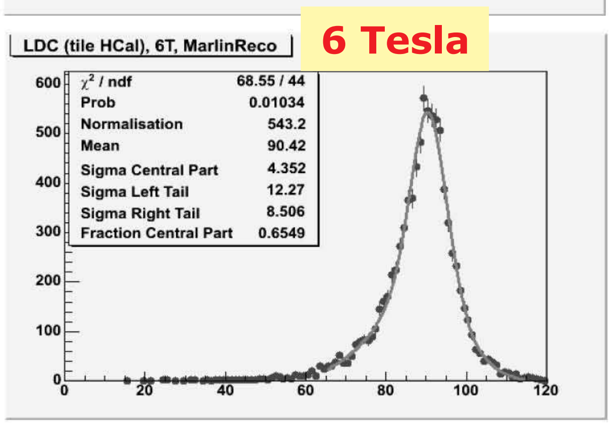
« During Snowmass attempted to investigate PFA performance vs B-field for LDC

Preliminary Studies







	$\sigma_E/\sqrt{E}$
2 T	0.35
4 T	0.40
6 T	0.46

- Not yet understood – more confusion in ECAL with higher field ?
- But could just be a flaw in algorithm….

PFA Studies in Near Future

(Steve Magill, Felix Sefkow, Mark Thomson and Graham Wilson)

Proposal:

- Arrange monthly PFA phone conferences
- Forum for people form to present/discuss recent progress
- Goal : realistic PFA optimisation studies for Bangalore (and beyond)
- Try and involve all regions : need to study EACH detector performance with multiple algorithms
- First xday of each month 1600-1800 (CET)
  - not ideal for all regions but probably the best compromise
- I will start to set up an email list next week…

- We can make **real** and **rapid** progress on understanding what really drives PFA
- Provide significant input into the overall optimisation of the ILC detector concepts

- **UK perspective:** we could make a big impact here
- BUT need to start soon…
- To date, UK input to detector concepts very limited !

At Snowmass, identified the main PFA questions…

Prioritised PFA list

(from discussions + LDC, GLD, SiD joint meeting)

The A-List (in some order of priority)

1) B-field : is BR^2 the correct performance measure (probably not)
2) ECAL radius
3) TPC length
4) Tracking efficiency
5) How much HCAL – how many interactions lengths 4, 5, 6…
6) Longitudinal segmentation – pattern recognition vs sampling frequency for calorimetric performance
7) Transverse segmentation
8) Compactness/gap size
9) HCAL absorber : Steel vs. W, Pb, U…
10) Circular vs. Octagonal TPC (are the gaps important)
11) HCAL outside coil – probably makes no sense but worth demonstrating this (or otherwise)
12) TPC endplate thickness and distance to ECAL
13) Material in VTX – how does this impact PFA

The B-List

1) Impact of dead material
2) Impact (positive and negative) of particle ID - (e.g. DIRC)
3) How important are conversions, V^0s and kinks
4) Ability to reconstruct primary vertex in z

Goals for Vienna:

- **B-field dependence:**
  - **Requires realistic forward tracking (HIGH PRIORITY)**

- **Radial and length dependence:**
  - **Ideally with > 1 algorithm**

- **Complete study of "perfect particle flow"**

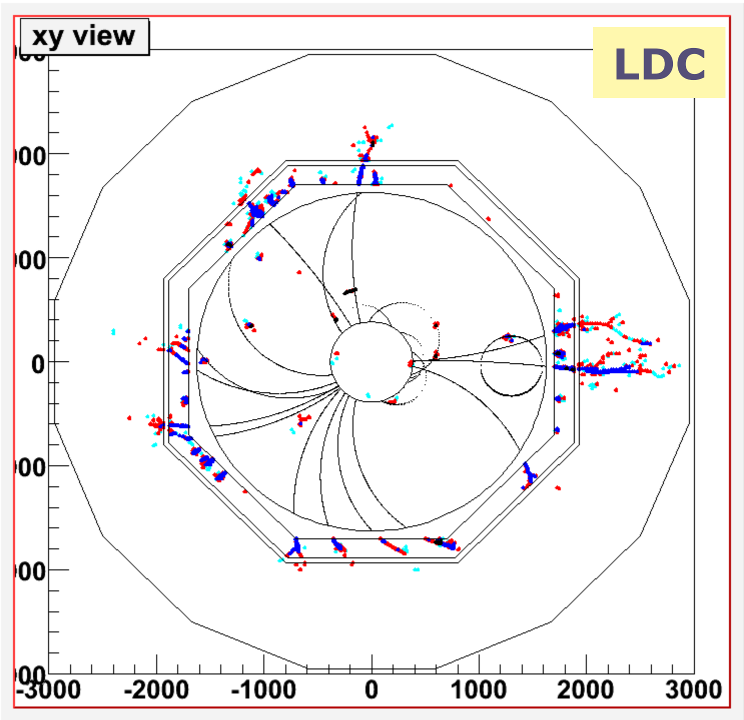
- **Try to better understand confusion term**
  - **Breakdown into matrix of charged-photon-neutral hadron**

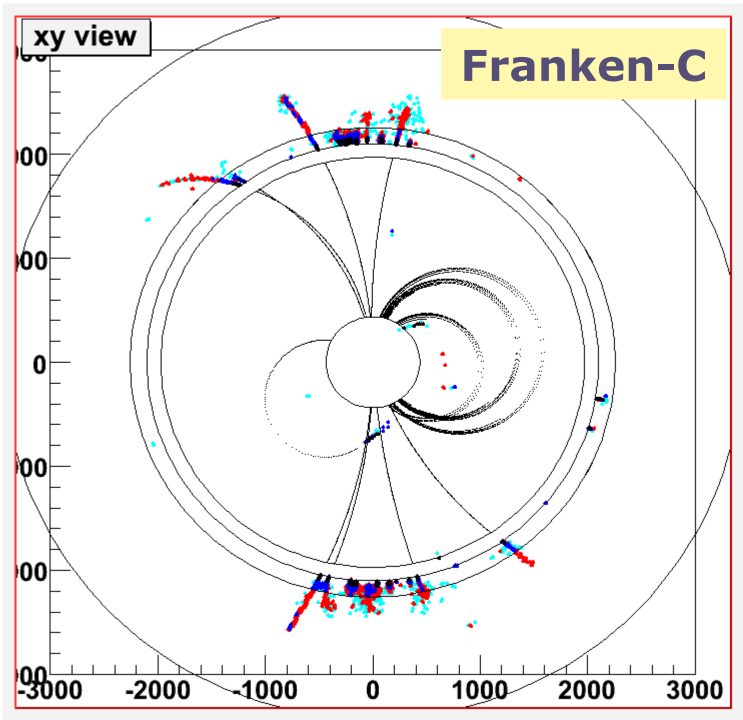
- **Study HCAL granularity vs depth**
  - **already started (AR)**
  - **how many interaction lengths really needed ?**

- **ECAL granularity**
  - **how much ultra-high granularity really helps ?**
  - **granularity vs depth**

What can we do….

- Developing PFA algorithms isn't trivial !
- BUT to approach the current level…..
- Started writing generic PFA "framework" in MARLIN
- Designed to work on any detector concept





Possible to make rapid progress !

Conclusions

- **Calorimetry at ILC is an interesting problem**
- **Design driven by Particle Flow**
- **Only just beginning to learn what matters for PFA**
- **Significant opportunity for UK to make a big impact**
- **BUT need to start very soon**