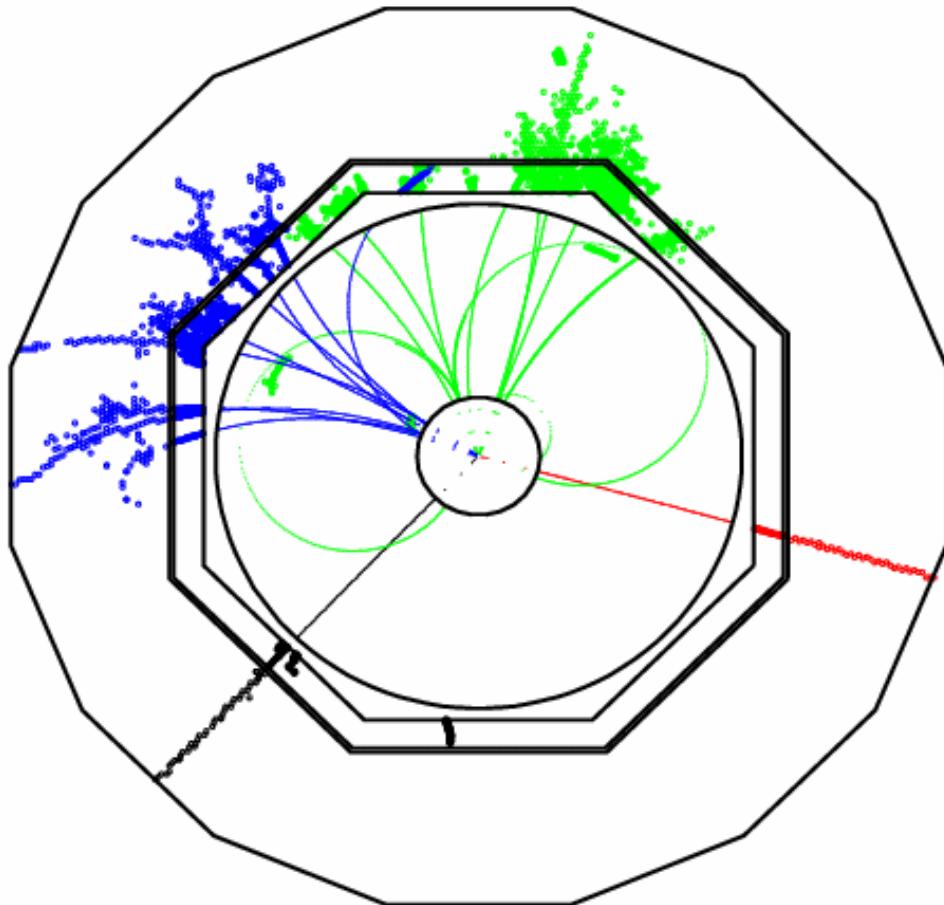


ILD Detector Optimisation

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This Talk:

- ① LDC/GLD and ILD
- ② ILD Detector Optimisation
- ③ LDC Optimisation studies
- ④ Physics Benchmarking
- ⑤ UK ILD physics strategy
- ⑥ Summary

① LDC → ILD ← GLD

★ How will GLD/LDC evolve into ILD ?

GLD/LDC have common features:

- ★ Both are Large Detector concepts, “Large” tracking volume
 - For particle separation
- ★ Both have TPC
 - For pattern recognition in dense track environment
- ★ Both have high granularity ECAL/HCAL
 - for Particle Flow

| | LDC | GLD | ILD ? |
|---------|-------|--------------|-----------------|
| Tracker | TPC | TPC | TPC |
| R = | 1.6 m | 2.1 m | 1.5–2.0 m ? |
| B = | 4 T | 3 T | 3–4 T |
| ECAL | SiW | Pb/Scint | SiW or Pb/Scint |
| HCAL | Steel | RPC Scint | Pb/Scint |
| | | | yes |

Goal of
ILD Optimisation
Study

② ILD Detector Optimisation

- ★ Aim to arrive at optimised “baseline” ILD parameters on timescale of 6 months
- ★ Challenging but:
 - Good starting point: well advanced GLD/LDC studies
 - Have the “realistic” software tools needed
- ★ LDC/GLD (and SiD) designed for **particle flow calorimetry**
 - motivation for very high granularity (and cost) ECAL/HCAL



PFA plays a special role in design of an ILC Detector

- ★ VTX : design driven by heavy flavour tagging, machine backgrounds, technology
- ★ Tracker : design driven by σ_p , track separation, pattern recognition
- ★ ECAL/HCAL : single particle σ_E not the main factor
 - ➡ jet energy resolution ! Impact on particle flow drives calorimeter design + detector size, B field, ...



PFA is a (the?) major £££ driver for the ILC Detectors

ILC PFA Goal ?

★ What drives the ILC jet energy resolution goal ?

★ Aim for jet energy resolution giving di-jet mass resolution similar to Gauge boson widths

★ For a pair of jets have:

$$m^2 = m_1^2 + m_2^2 + 2E_1 E_2 (1 - \beta_1 \beta_2 \cos \theta_{12})$$

★ Aim for invariant mass resolution comparable to Gauge boson width (i.e. once width dominates have reached the point of diminishing return)

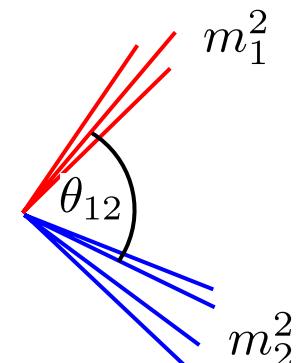
★ For di-jet mass resolution of order

$$\frac{\sigma_m}{m} \approx \frac{2.5}{91.2} \approx \frac{2.1}{80.3} \approx 0.027$$



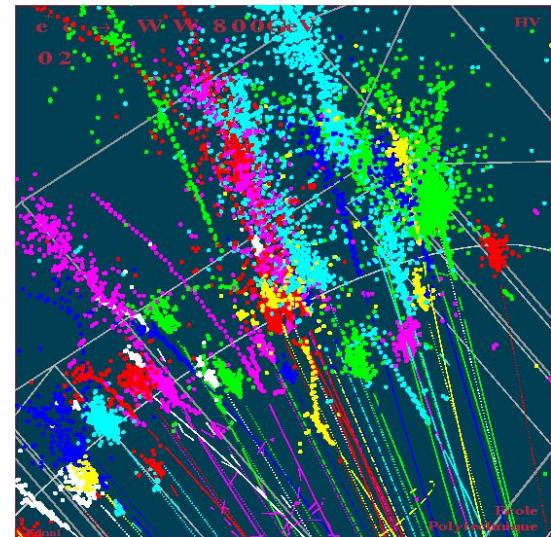
$$\sigma_{E_j}/E_j < 3.8\%$$

+ term due to θ_{12} uncertainty



PFA and ILC detector design ?

- ★ Need to understand what makes a good detector for PFA
(within constraint of finite £££)
- ★ Want to optimise detector performance on basis of certain criteria:
 - jet energy resolution
 - heavy flavour tagging efficiency
- ★ BUT ultimately it is “physics performance” that matters
- ★ Particle flow calorimetry very different from “standard calorimetry”
 - complex reconstruction
 - still in infancy..
- ★ As a result detector performance = **DETECTOR + SOFTWARE**
- ★ Non-trivial to separate the two effects
- ★ **NEED REALISTIC SIMULATION + REALISTIC RECONSTRUCTION !**
 - at this stage **fast simulation** is of little (no?) use.



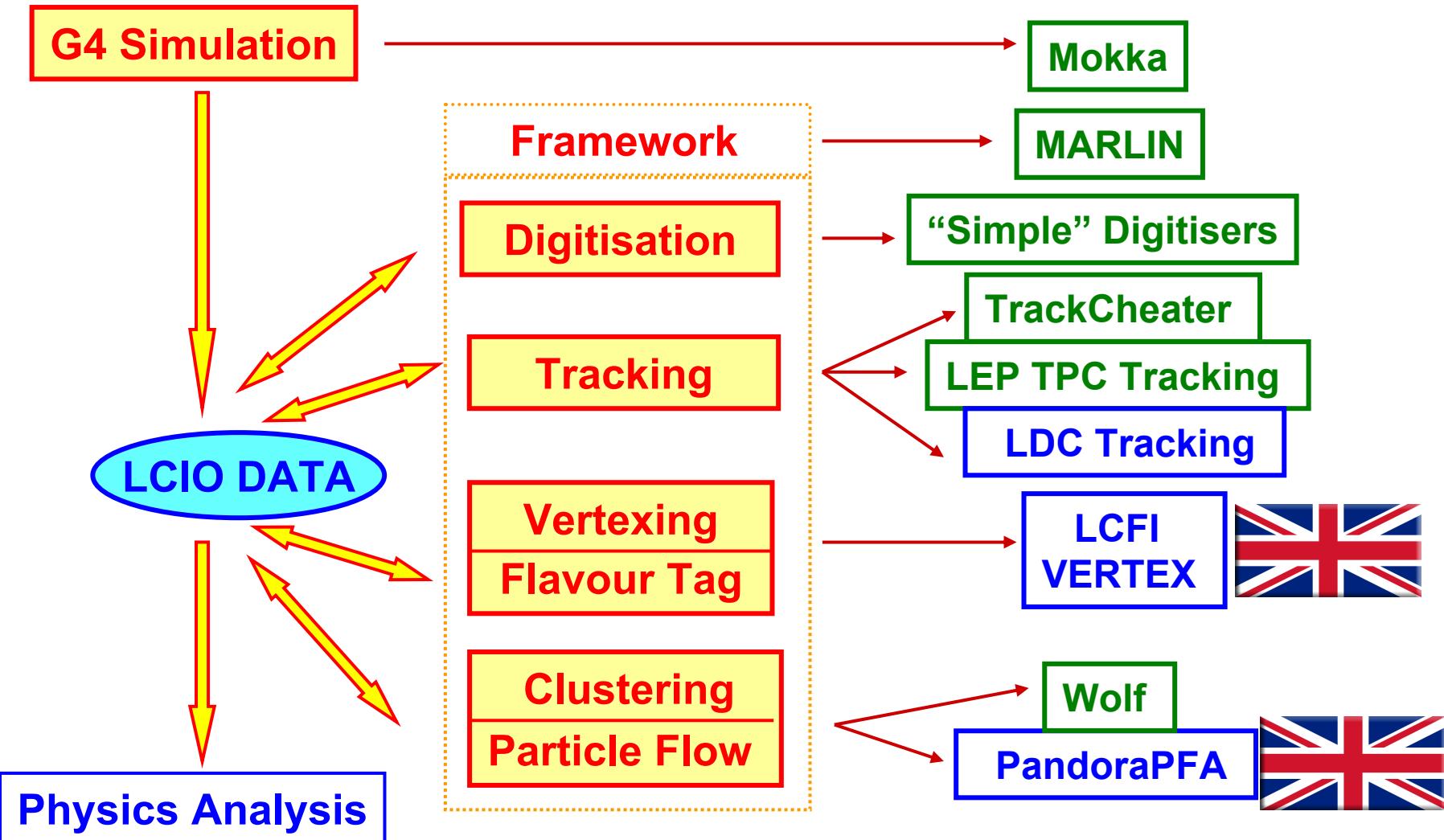
**For design of ILC Particle Flow Detectors:
need realistic reconstruction chain
~10 years before start of ILC !!!
(x years before start of LHC)**

**(even more challenging: the software has to work
for multiple detector design parameters)**

For LDC (ILD) have a first version (Frank's talk)....

European ILC Software Framework

What software is needed?

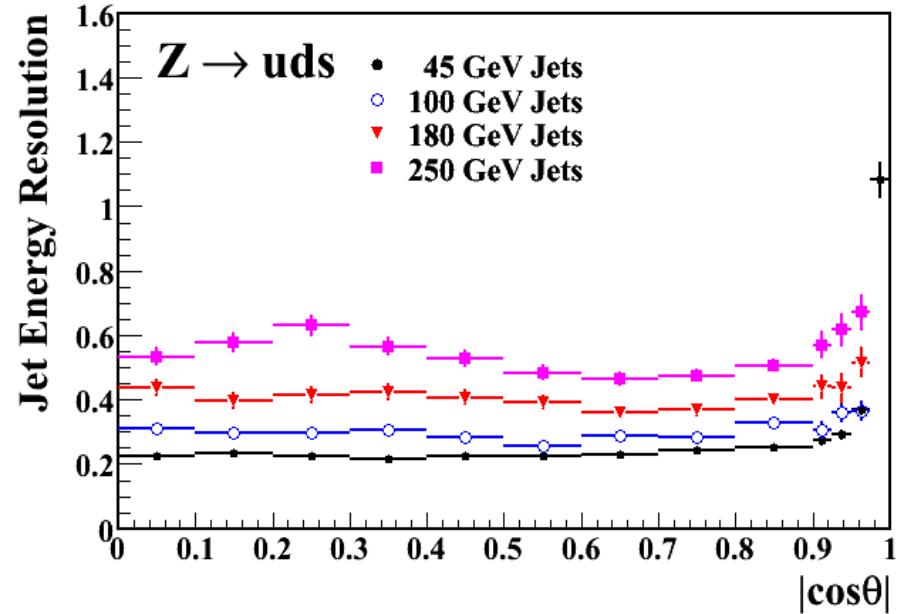


Current LDC PFA Performance

Caveat : work in progress, things will change

PandoraPFA v02- α

| E_{JET} | $\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $ \cos\theta < 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

$$23 \% / \sqrt{E}$$

★ Comfortably meet ILC performance goals

★ All very well but....

Not The End

- ★ What jet energy resolution is really needed at the ILC ?

★ NOT $30\%/\sqrt{E}$

★ Ideally reach point where dominated by Z/W width

★ NOT the same as

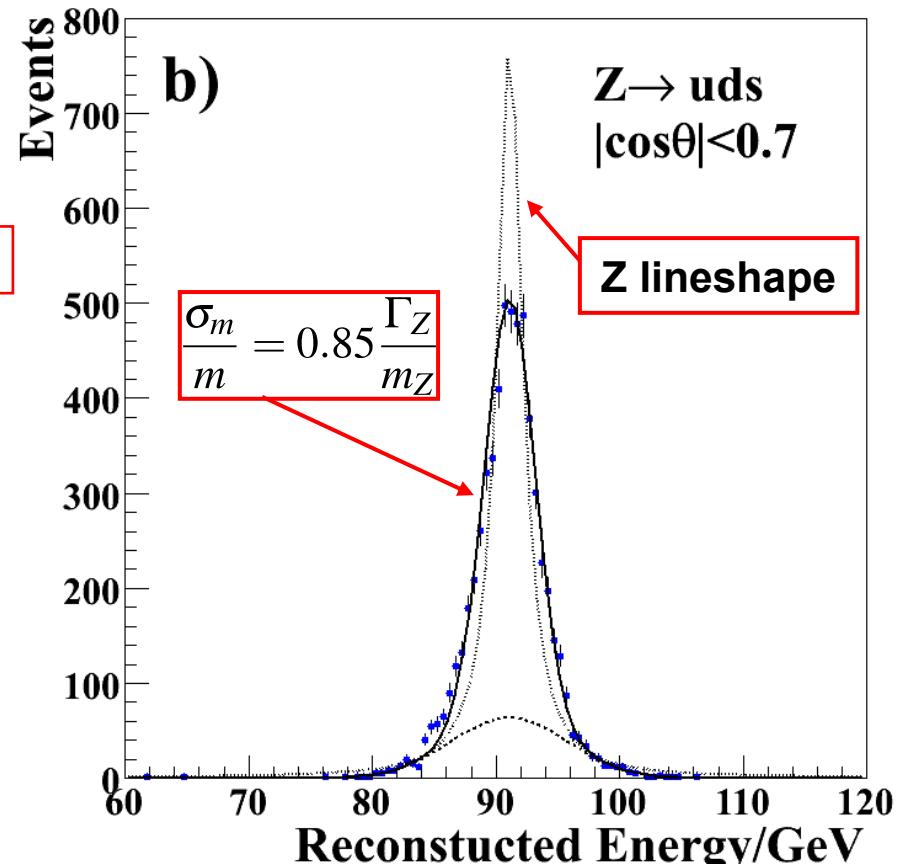
$$\frac{\sigma_m}{m} \sim \frac{\Gamma_Z}{m_Z}$$

★ Suggests

$$\frac{\sigma_m}{m} < \frac{\Gamma_Z}{m_Z}$$

★ Significant advantages in further improvements ?

★ Ultimate criterion – “physics performance”



③ LDC Optimisation Studies

- ★ First PFA detector optimisation studies performed with LDC
- ★ Main questions (the major cost drivers):

- Size : performance vs. radius
- Granularity (longitudinal/transverse): ECAL and HCAL
- B-field : performance vs. B

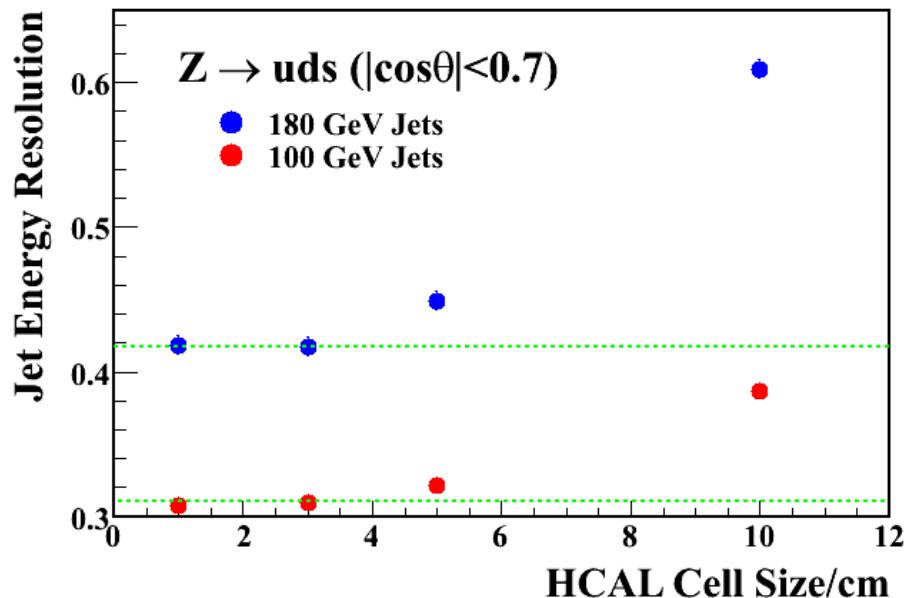
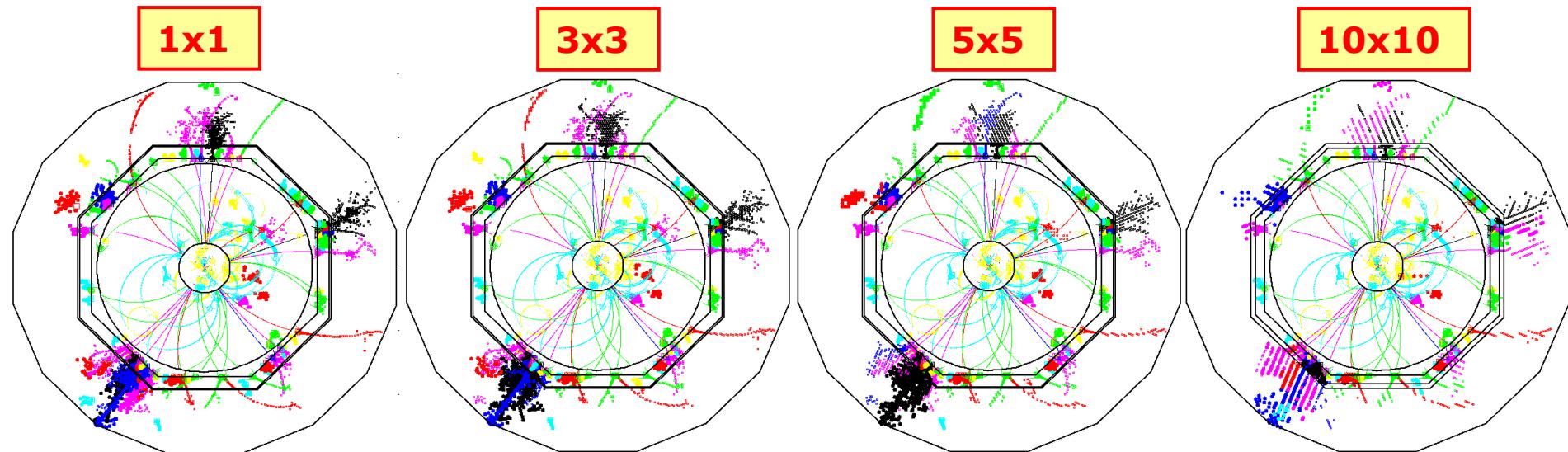
- ★ Again the caveat : simulation + PFA algorithm



- Need a good simulation (including hadronic showers)
- Need realistic PFA algorithms
(ideally want/need results from multiple algorithms)

- ★ ...and the caveat: interpretation of results needs care
 - observe effects of detector + software
- ★ Optimisation studies for LDC presented at LCWS07
(not yet updated for with latest PFA)

★ Analogue scintillator tile HCAL : change tile size $1\times 1 \rightarrow 10\times 10 \text{ mm}^2$



"Preliminary Conclusions"

♦ 3x3 cm² cell size

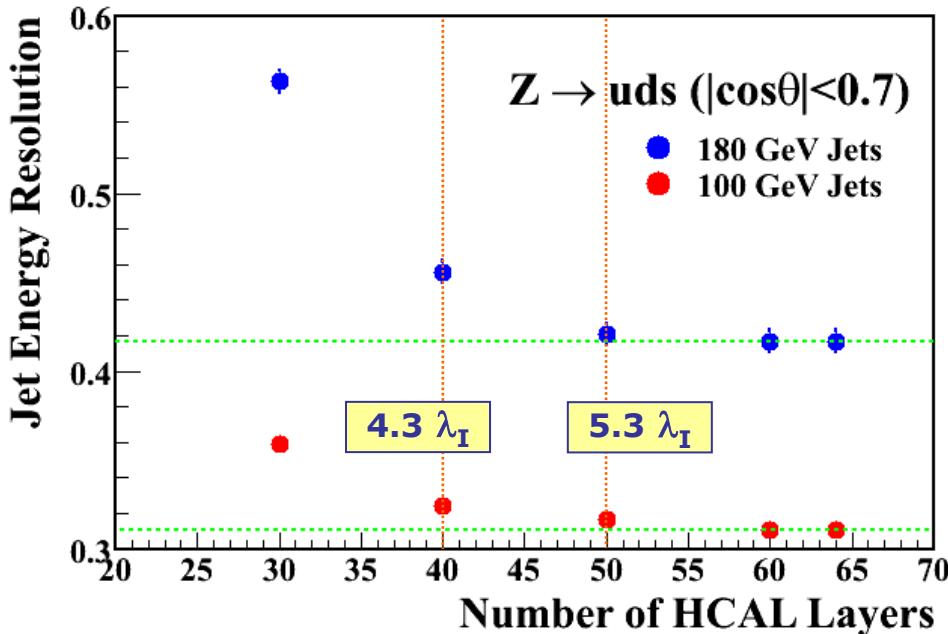
LDC "default"

Could probably decrease segmentation deeper in HCAL
(any significant cost benefit?)

HCAL Depth : shower containment

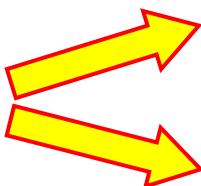
★ Investigated HCAL Depth (interaction lengths)

- Generated $Z \rightarrow uds$ events with a large HCAL (63 layers)



- HCAL leakage is significant for high energy jets
- Large effect !
- Argues for $\sim 5 \lambda_I$ HCAL
- Thicker than default LDC

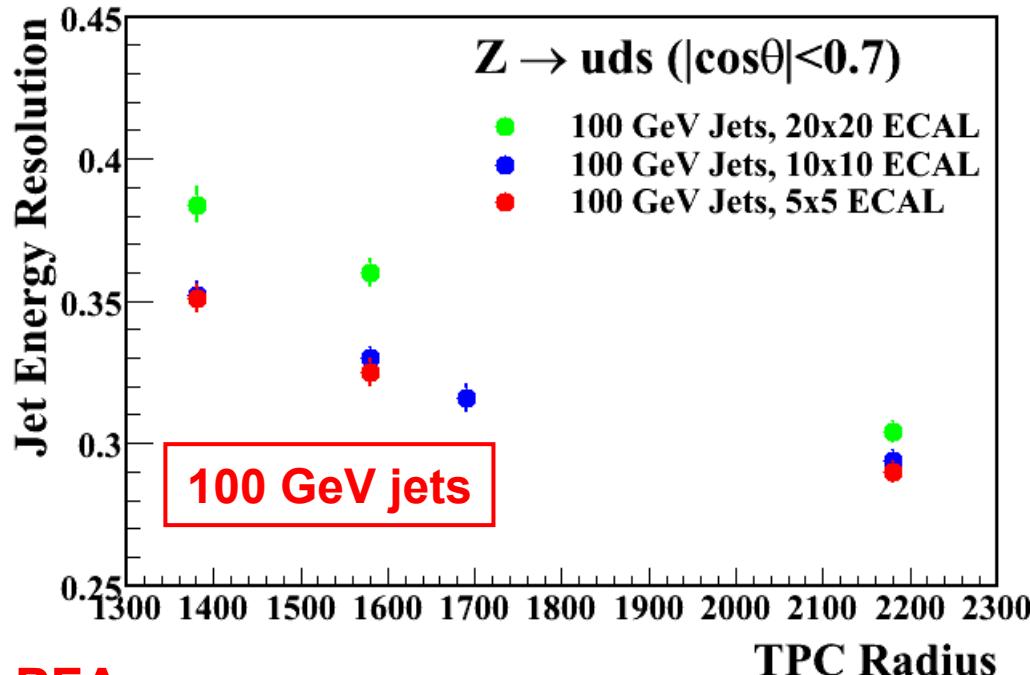
Increased number of HCAL layers in “default” ILD



Should study: use of muon chambers as tail-catcher
: or some HCAL outside coil

ECAL Transverse Granularity

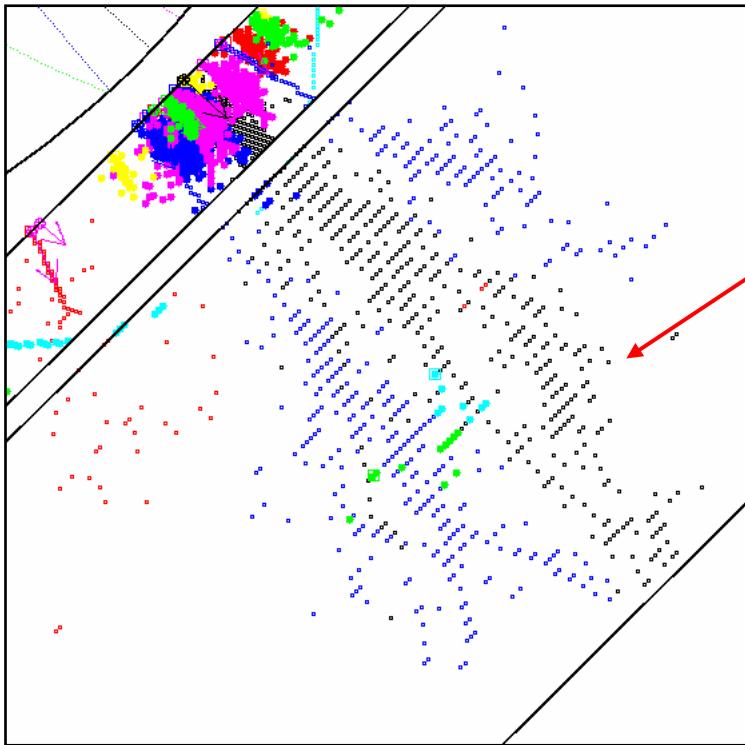
- e.g. $Z \rightarrow uds$ events @ 200 GeV with different ECAL segmentation: **5x5, 10x10, 20x20 [mm²]**



With PandoraPFA

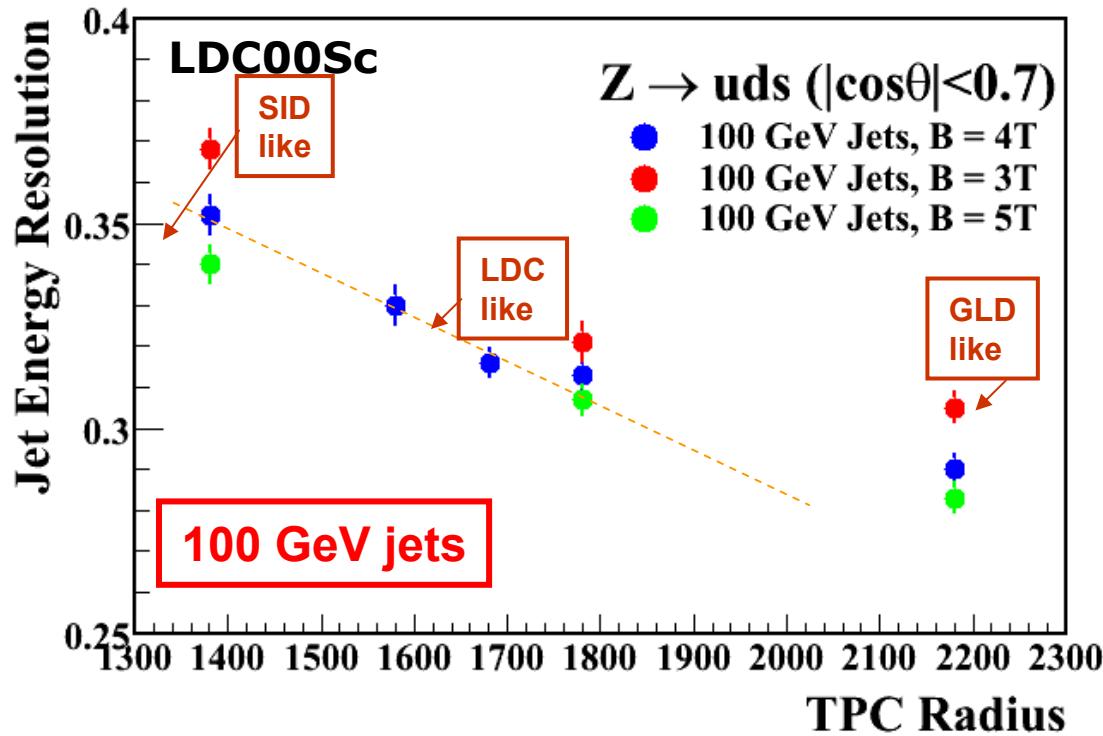
- 20x20 mm² segmentation looks too coarse
- For 100 GeV jets, not a big gain going from 10x10 → 5x5mm²
[confusion inside the ECAL is not the main issue for PFA]

- ★ confusion inside the ECAL is probably not the main issue for PFA
- ★ confusion in “broad” hadronic showers in HCAL probably dominates



- Need to separate in space
- Large radius

Radius vs Field



Radius more
important
than B-field

ILD
?

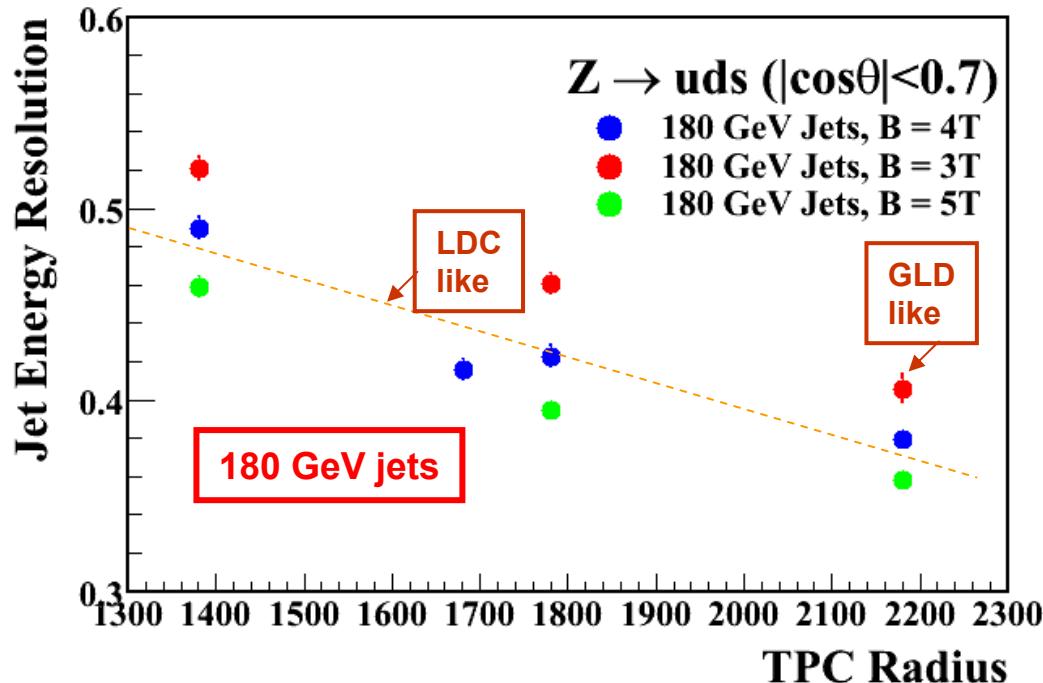
For PFA suggests : size ↑

B ↓

ILD cost benefit of going to 3.0 T
or 3.5 T rather than LDC 4.0 T?

- Cost related to stored energy: $\text{Stored energy} \sim LB^2R^2$

Radius vs Field: 180 GeV Jets



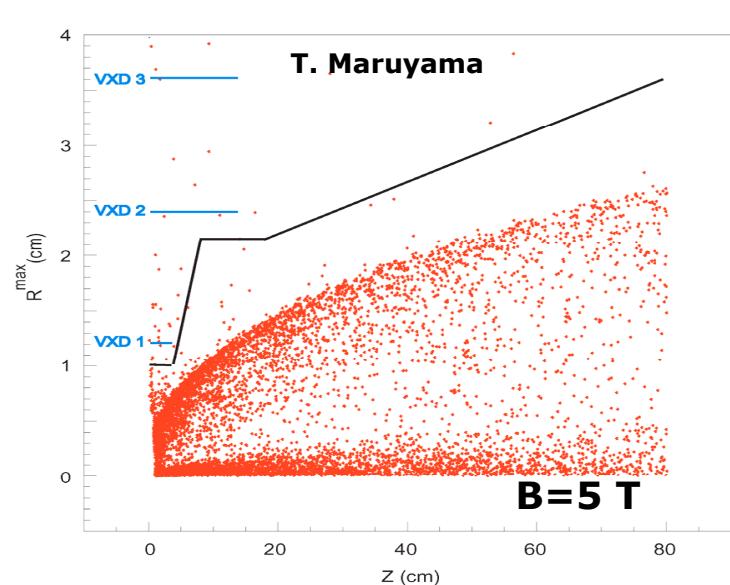
Radius is even
more important
for higher energy
jets



ILD larger than LDC ?

Other considerations

- ★ For PFA want : Large field + large radius
- ★ BUT MANY OTHER CONSIDERATIONS...
 - Tracking:
 - momentum measurement argues for large detector
 - Flavour tagging:
 - want inner layer of Vertex detector as close to IP as possible
 - limited by beam background
 - argues for large B



Cost Optimisation

- ★ Ideally ILC detector is large with high B field...
- ★ But cost...

LDC

| System | Fractional Cost | Proportional to |
|---------------|-----------------|-------------------------------|
| ECAL | 0.29 | Active area |
| Solenoid+Yoke | 0.21 | $U^{0.66} = (LR^2B^2)^{0.66}$ |
| HCAL | 0.16 | Volume |
| TPC | 0.08 | Fixed |
| SiT/FTD | 0.06 | Fixed |
| Vertex | 0.025 | Fixed |
| Muon | 0.025 | Fixed |
| FCAL | 0.02 | Fixed |
| Other | 0.12 | Fixed |

- ★ Cost-performance optimisations is highly non-trivial, need:
 - realistic cost estimate
 - realistic PFA
 - realistic Vertexing/Flavour tag

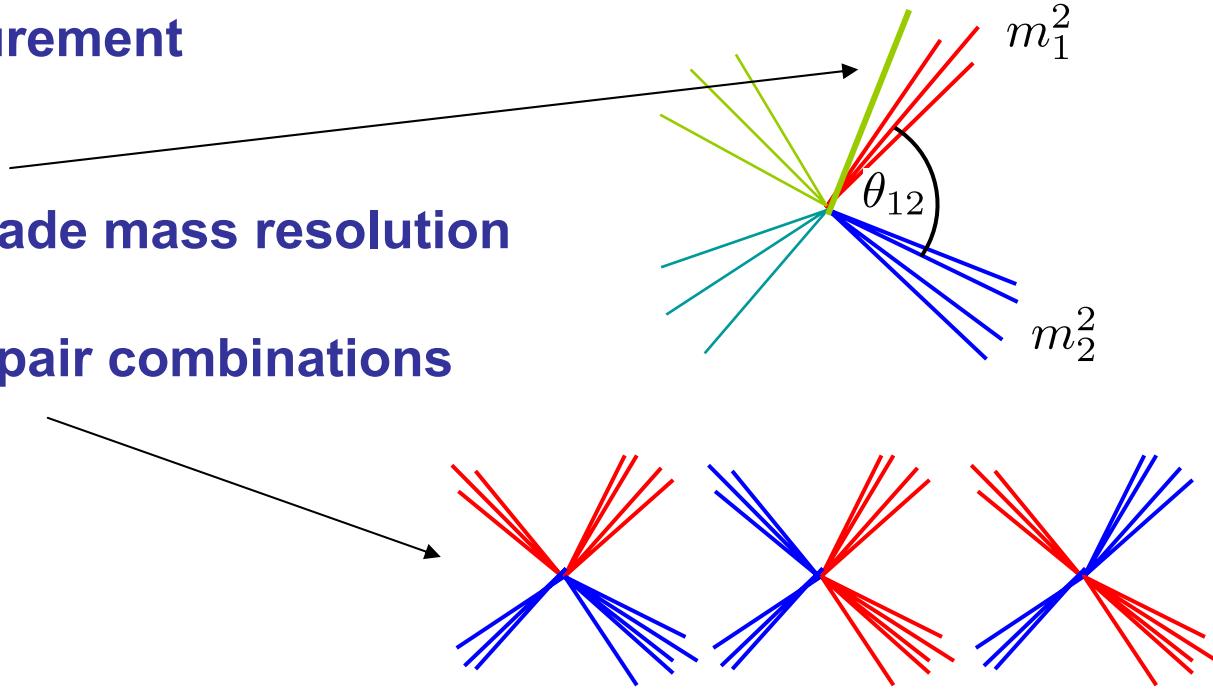
UK well placed to lead
these studies for ILD

4

Physics Benchmarking

- ★ So far used “jet energy resolution” as PFA figure of merit
- ★ But in a physics analysis, there are other effects:

- jet angle measurement
- jet finding
 - not perfect
 - will degrade mass resolution
- jet pairing
 - multiple jet-pair combinations



Relative importance of these effects ?

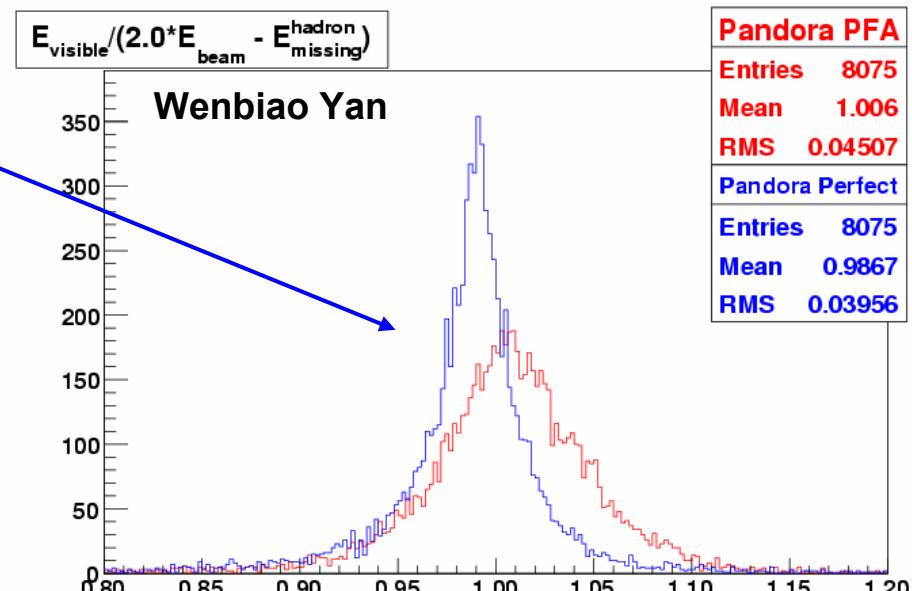
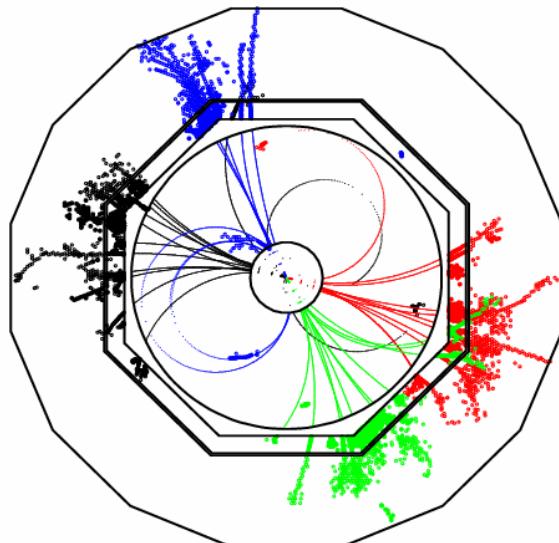
e.g. WW scattering

e.g. $e^+e^- \rightarrow \nu\bar{\nu}W^+W^- \rightarrow \nu\bar{\nu}qqqq$

$\sqrt{s} = 800 \text{ GeV}$

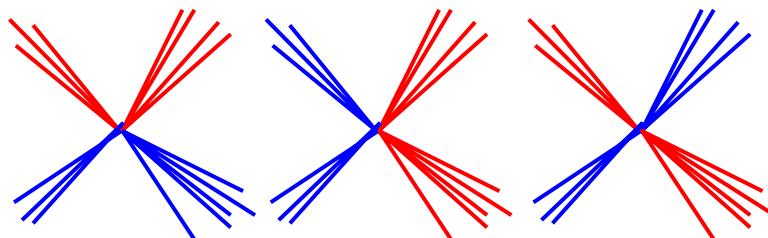
★ First compare visible energy from PFA with expected
(i.e. after removing neutrinos/forward tracks+clusters)

- ◆ PerfectPFA gives better energy resolution than PandoraPFA (as expected)

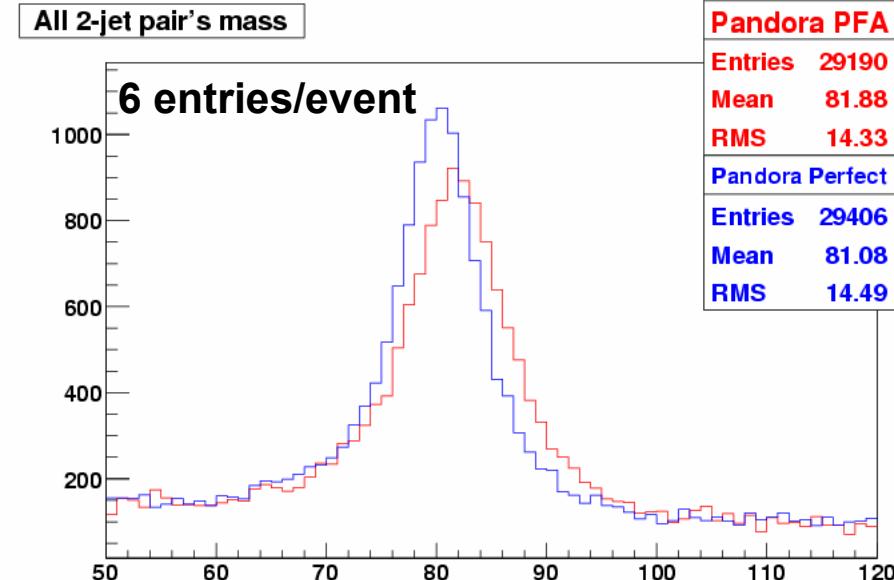
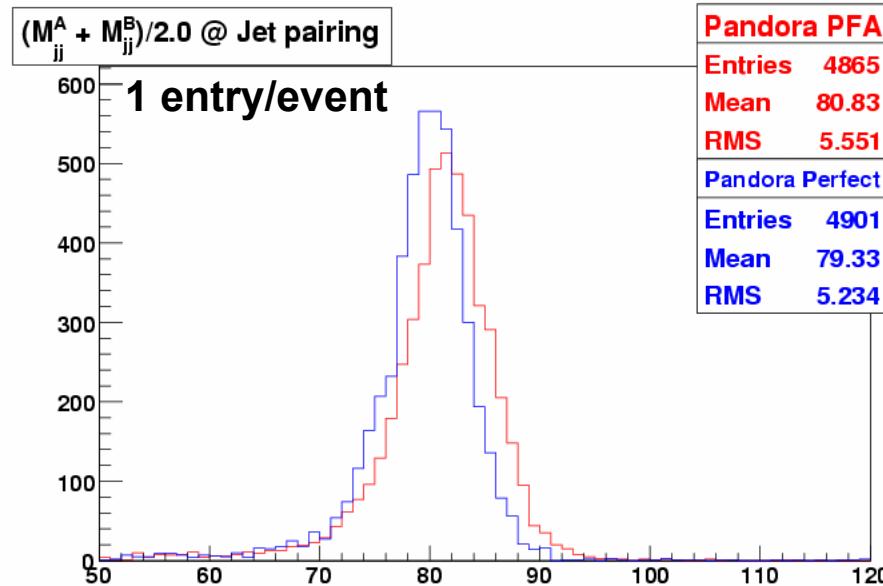


★ Does this difference make it through to a physics analysis (i.e. after jet finding/jet pairing) ?

- ★ Force event into 4 jets (Durham)
- ★ Plot masses of the 2 Ws formed from the 3 possible jet-pairings



HERE: PandoraPFA ~ PerfectPFA



- ★ Choose pairing with smallest mass difference
- ★ Plot average mass of the 2 Ws

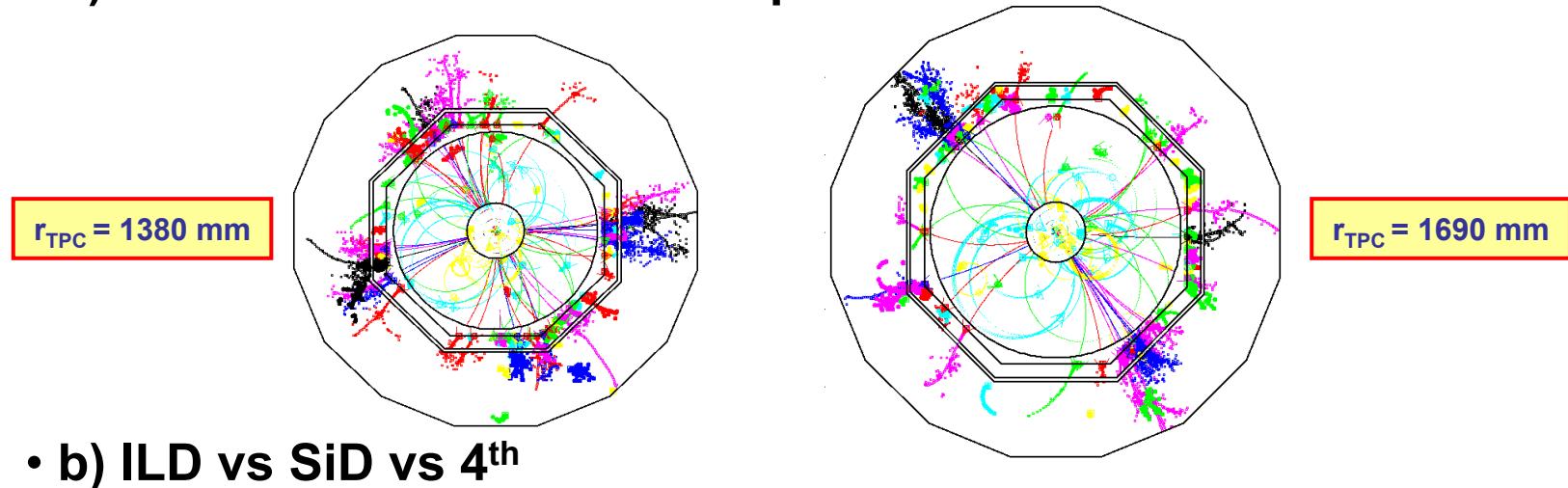
HERE: PandoraPFA ~ PerfectPFA

→ Jet-finding “dilutes PFA performance”

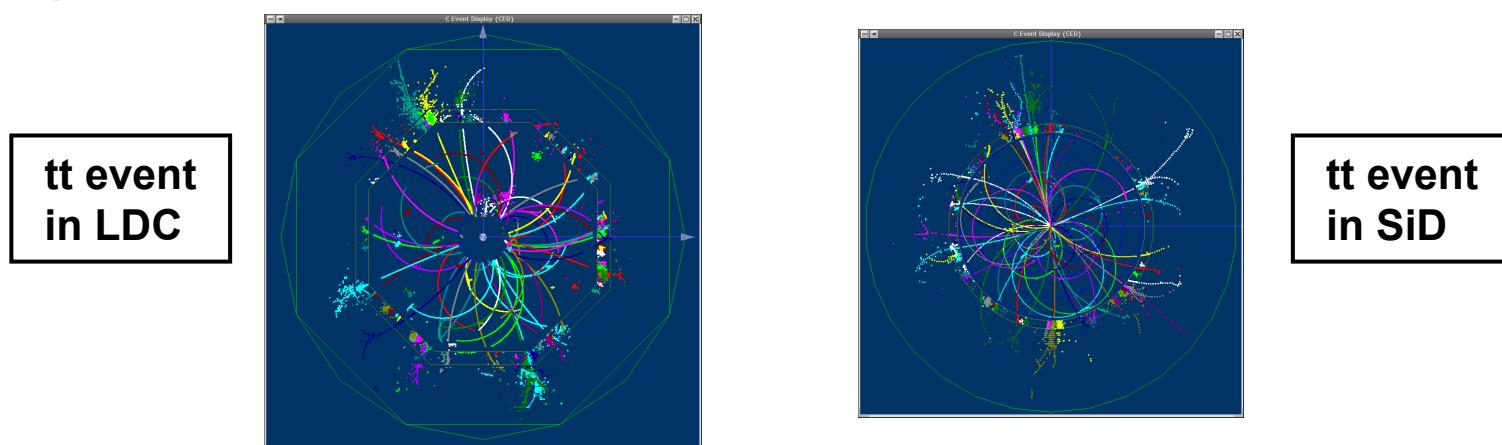
OPTIMISATION NEEDS CARE

ILC Detector Benchmarking

- ★ Simple measures of performance (e.g. jet energy resolution) useful
- ★ BUT, really need to compare physics performance of:
 - a) ILD with different detector parameters:

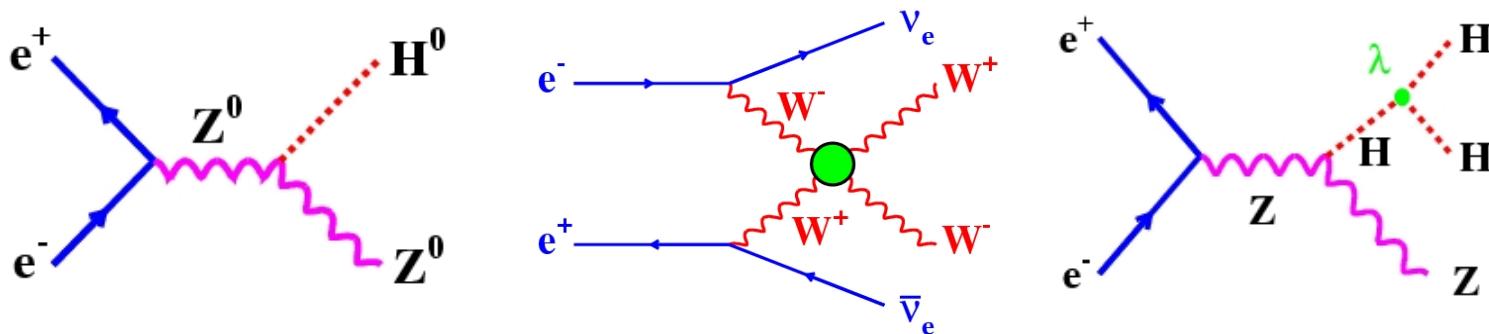


- b) ILD vs SiD vs 4th



Ideal approach:

- ★ choose the key “benchmark” processes which challenge detector



This is the EASY PART !

- ★ perform realistic physics analysis with

- full GEANT4 simulation }
- realistic reconstruction }

This is somewhat harder...

- ★ This has been talked about for a number of years...

- ★ For ILD now have the tools...

- ★ MAJOR FOCUS OF ILD WORK OVER THE NEXT YEAR



★ ILD physics studies very high priority

- Needed to optimise the detector for the L₀L
- Needed to demonstrate that ILD can deliver...

★ UK Perspective:

- In a strong position to undertake these studies
 - PFA from CALICE-UK
 - Flavour tagging from LCFI
- Significant interest in working on this area for ILD
- UK can potentially make a (the) leading contribution in this area

★ TWO main aspects:

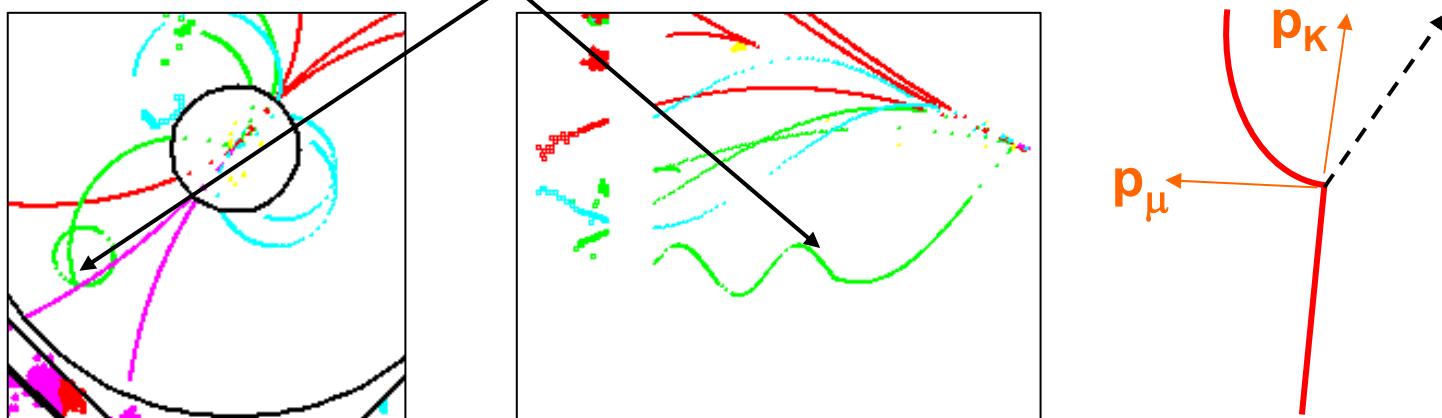
- Developing the physics analysis
- Understanding how to use an ILC detector...

★ ILC detectors are very different from previous detectors

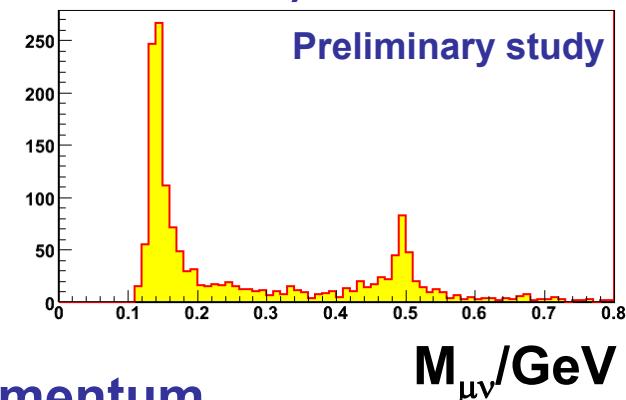
- Large improvements in performance c.f. other detectors
(jet energy, impact parameter, momentum)
- Need to learn how to take advantage of this....

e.g. Kink reconstruction

- ★ Recent improved PFA performance for low energy jets
 $29\%/\sqrt{E} \rightarrow 23\%/\sqrt{E}$ partly due to improved use of TPC tracking
- ★ e.g. kink reconstruction



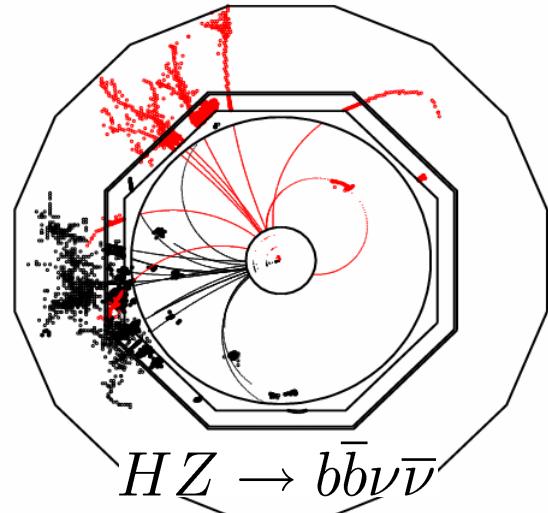
- ★ Identify kink in TPC (currently use MC cheated PatRec)
 - ♦ Consider hypothesis, e.g. $K^\pm \rightarrow \mu^\pm \nu$
 - ♦ Use Helix fits to start and end of tracks
 - ♦ Can then reconstruct primary mass
 - ♦ If consistent with $K^\pm \rightarrow \mu^\pm \nu$ or $\pi^\pm \rightarrow \mu^\pm \nu$ tag decay and have effectively ν energy
- ★ By taking advantages of TPC/excellent momentum resolution significant gains...



Other Ideas...

Two important areas where the UK can have major impact:

★ b-jet energy reconstruction



- ◆ If there is a light Higgs
- ◆ Reconstruct mass from $H \rightarrow b\bar{b}$
- ◆ PFA jet energy resolution is important
- ◆ BUT mass resolution limited by neutrinos from semi-leptonic b decays
- ◆ Given excellent vertex detector, excellent momentum resolution + PFA particle reco.
- ◆ **reconstruct neutrino momentum**

Could have very large impact on ILC physics performance



PFA + Vertexing : UK very well placed to study this

★ τ identification/decay reconstruction

- ◆ Identifying τ decay mode, e.g

vs.

$$\begin{aligned} \tau^- &\rightarrow \pi^- \nu_\tau \\ \tau^- &\rightarrow \rho^- \nu_\tau \rightarrow \pi^- \pi^0 \nu_\tau \rightarrow \pi^- \gamma \gamma \nu_\tau \end{aligned}$$

handle on tau polarization

**PFA +
Impact
parameter**



ILD Physics Studies

- ★ Need to recognise that developing a realistic (i.e. useful) ILC physics analysis is not at all trivial
- ★ Try to do a few studies very well rather than many less well

For UK ILD studies propose (open to discussion):

- ★ concentrate on a few (two/three) important channels, e.g.

$$e^+e^- \rightarrow ZH \quad e^+e^- \rightarrow ZHH \quad e^+e^- \rightarrow t\bar{t}$$

PFA

Flavour tagging

- + Rich in terms physics measurements
- + potentially important in early stages of ILC

- ★ Need to think how to make best uses of resources
 - centralized generation of Monte Carlo Samples ?
 - centralized reconstruction of samples ?
(experts ensure correct use of PFA/Flavour tagging)
 - UK ILD physics analyses could then start from common files of reconstructed particles (good starting point)
 - Share ideas/analysis techniques

⑥ Summary

- ★ Particle Flow drives global detector design at ILC
- ★ Need realistic (i.e. sophisticated) reconstruction in order to perform meaningful detector optimisation studies
- ★ Many physics analyses will need both realistic PFA and Vertex reco.
 - UK leading both – implemented in LDC software framework !
- ★ Building on this expertise
 - UK can take a leading role in defining/optimising ILD

Current Status

- ★ Full ILD simulation/reconstruction chain is
 - “ready for real physics studies”
- ★ Already demonstrated LDC can meet ILC “detector goals”
 - presumably ILD will be even better...
- ★ Ideal time to start physics-based ILD optimisation
- ★ Already looks like we will have significant number of UK groups working in this area
- ★ Potential to build a very strong ILC physics group
 - a great time to get involved in ILD...