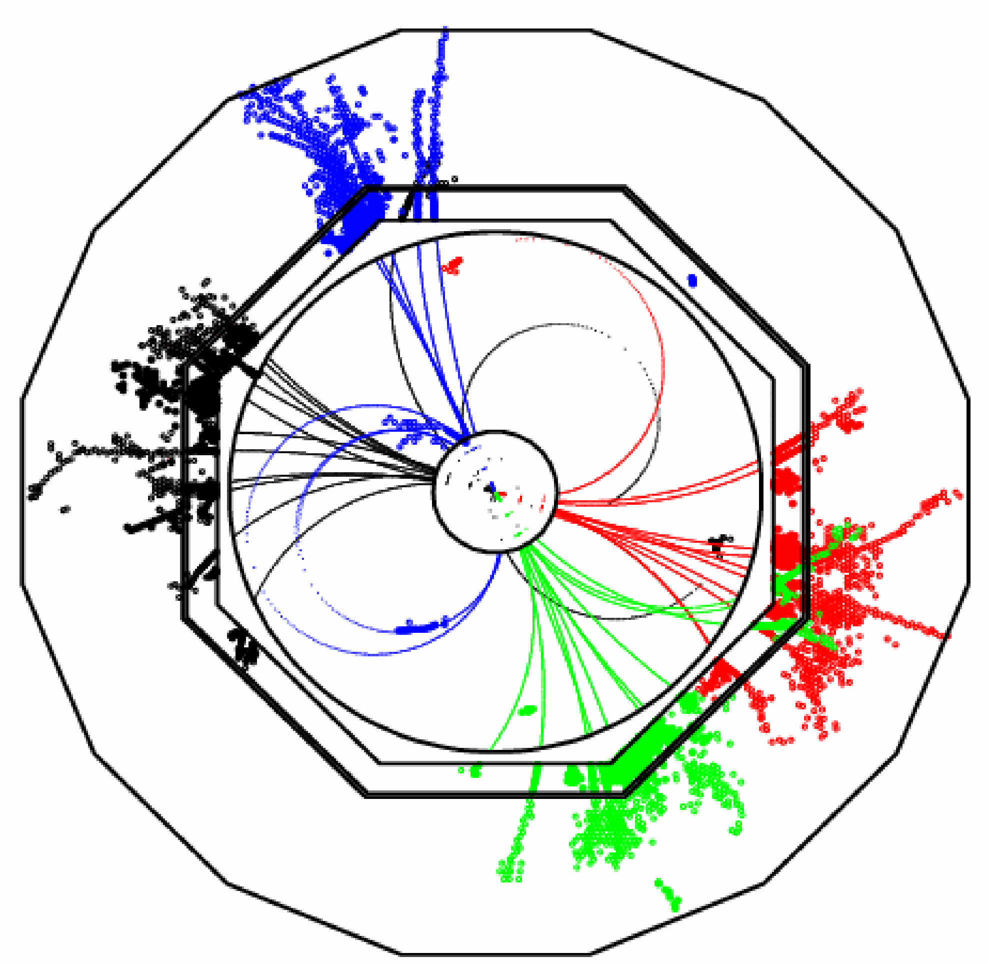
Optimising ILD

Mark Thomson
University of Cambridge



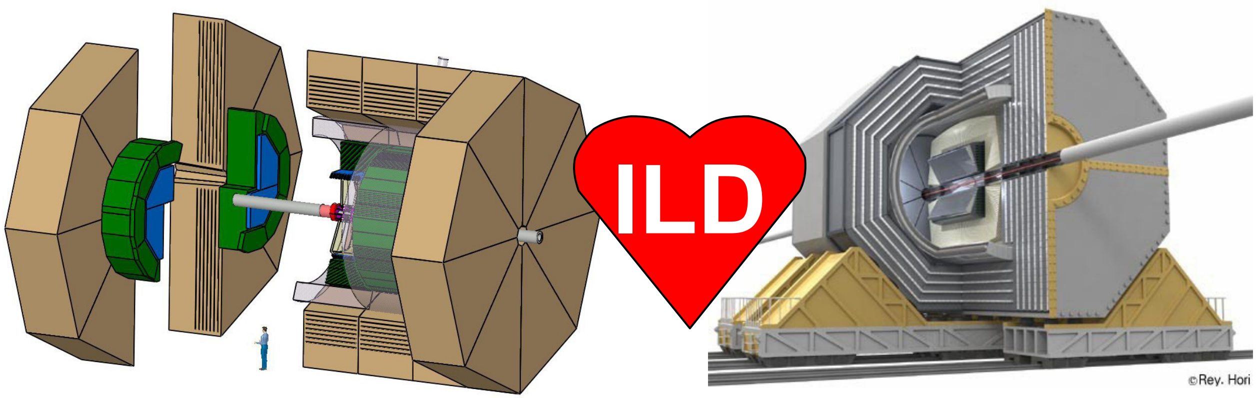
This talk:

❶ LDC → ILD ← GLD
❷ PFA and Optimisation
❸ Optimisation Strategy I
❹ Simulating ILD
❺ Reconstruction
❻ PFA Status
❼ Towards Virtual Physics
❽ Optimisation Strategy II
❾ Conclusions

❶ LDC → ILD ← GLD

The first challenge

- ★ At the moment there is no baseline ILD model
- ★ Starting from LDC and GLD

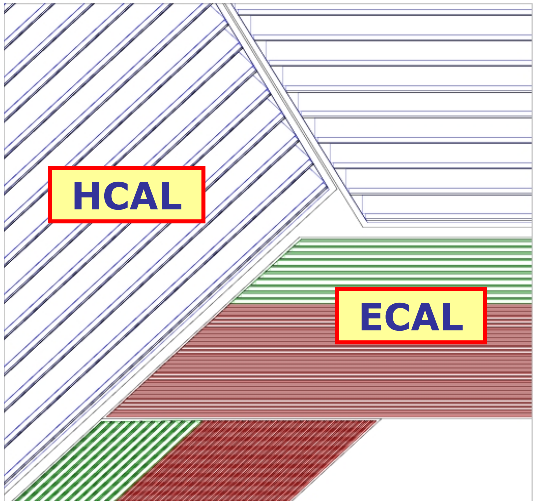


GLD/LDC have common features:

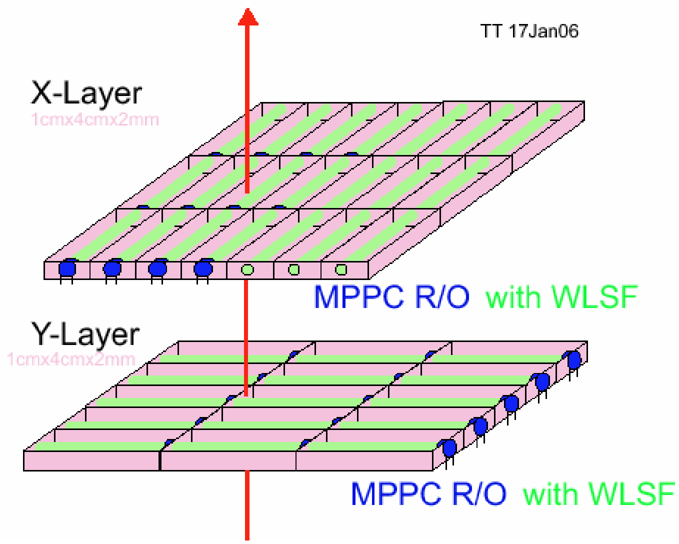
- ★ Both are Large Detector concepts, "Large" tracking volume
  - for particle separation
- ★ Both have TPC
  - for pattern recognition in dense track environment
- ★ Both have high granularity ECAL/HCAL
  - for Particle Flow Calorimetry

★ **But also significant differences, e.g.**
- size
- B-field
- ECAL

★ **CALICE-style SiW calorimeter:**
- Lateral segmentation: ~1cm^2 ~ $R_{Moliere}$
- Longitudinal segmentation: 30 layers
- Typical resolution: $\sigma_E/E = 0.15/\sqrt{E(GeV)}$



★ **GLD-style Scint-W calorimeter:**
- Achieve effective ~1cm^2 segmentation using strips
- Strips : 1cm x 4cm



LDC → ILD ← GLD

★ So how will GLD/LDC evolve into ILD ?

	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

First Goal of ILD Optimisation Study

⇩

Fix main detector parameters

Other Optimisation Goals:

★ Establish ILC physics reach with realistic simulation/reconstruction, e.g. what is the real sensitivity to Higgs trilinear coupling

★ Provide input to R&D collaborations, e.g. what parameters of HCAL design impact Physics

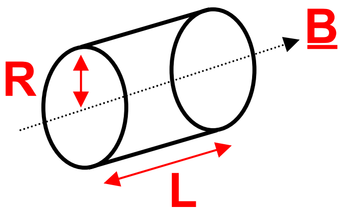
Role of Particle Flow:

Particle flow motivates ILD design – central to optimisation

❷ PF and ILD Optimisation

Particle Flow Calorimetry

- ★ ILD designed for Particle Flow (PF) Calorimetry
- ★ Optimisation of the detector driven by optimisation of PF
- ★ In particular, "global parameters" of the detector, **B**, **R** and **L** driven by PF performance



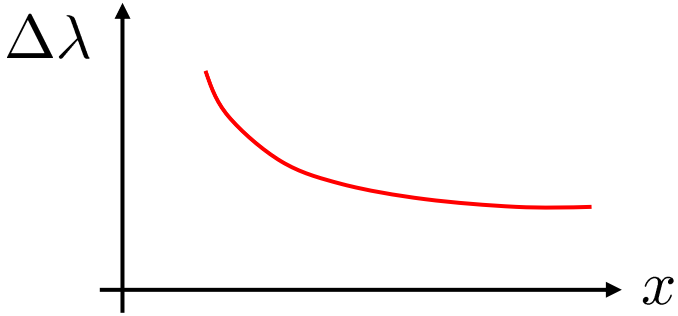
- ★ PF Calorimetry relatively new, don't yet have a detailed understanding of what really matters, e.g. $B^{\alpha}R^{\beta}$ dependence, impact of material, …

Tracking/Vertex Reconstruction

- ★ Important in own right !
- ★ Less impact on "global parameters" of the detector
  - design driven by **technology/detector R&D**
- ★ BUT both vital to any PF driven detector optimisation studies:
  - **Tracking** is a major component of any PFA
  - Many physics studies rely on **flavour tagging**

Optimisation : How ?

- ★ Optimise detector based on physics performance vs cost
- ★ First step is to parameterise physics performance vs **R**, **B**, **L**, …



Probably won't see many minima !

- ★ Then fold in cost to motivate baseline ILD design

BUT: non-trivial:

- ★ PFA reconstruction is complex
- ★ Tracking plays a major role in own right and in PFA reconstruction
- ★ Flavour tagging essential to many physics studies

Beware short-cuts…

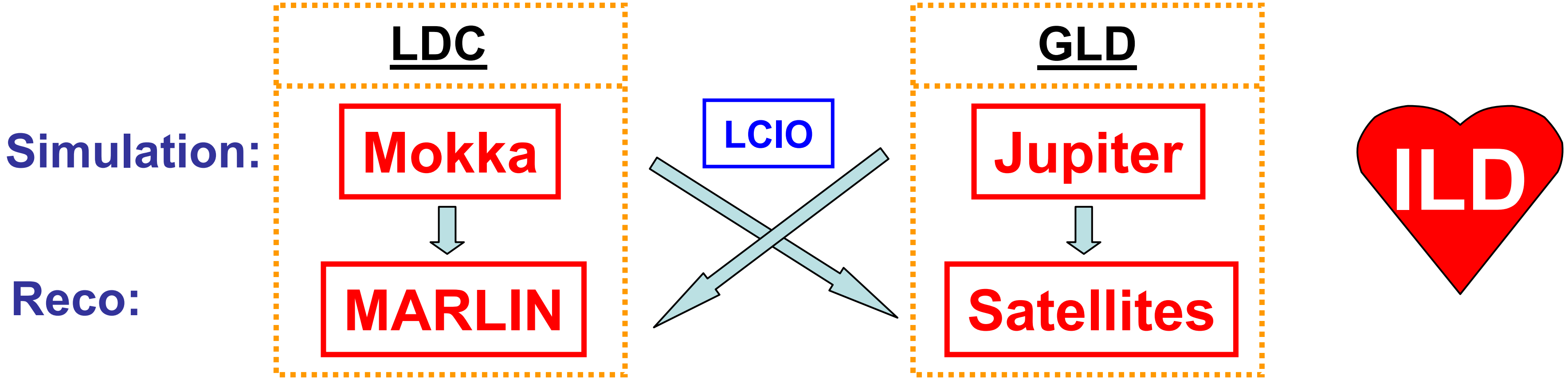
Solid study of ILC detector performance/optimisation **requires** a full detector simulation and REALISTIC reconstruction

- ★ Also requires detailed physics studies – want to make this as easy as possible for analysers

❸ ILD Optimisation Studies

★ Currently GLD and LDC use different G4 simulations/ reconstruction frameworks (this is not ideal but it is what we have got)

★ Connected by common data format



★ Given the timescale, perform ILD detector studies in context of both GLD and LDC software frameworks

★ Study physics performance dependence by changing global parameters e.g. Radius, field

★ Compare GLD and LDC results – provide some cross check of conclusions

LDC'/GLD' Common Parameters

★ **Have defined** a common point: LDC' and GLD' : a larger version of LDC and a smaller version of GLD ⟹ direct point of comparison

Sub-Detector	Parameter	GLD	LDC	GLD'	LDC'
TPC	R_{inner} (m)	0.45	0.30	0.45	0.30
	R_{outer} (m)	2.00	1.58	1.80	1.80
	Z_{max} (m)*	2.50	2.16	2.35	2.35
Barrel ECAL	R_{inner} (m)**	2.10	1.60	1.82	1.82
	Material	Sci/W	Si/W	Sci/W	Si/W
Barrel HCAL	Material	Sci/W	Sci/Fe	Sci/Fe	Sci/Fe
Endcap ECAL	Z_{min} (m)***	2.80	2.30	2.55	2.55
Solenoid	B-field	3.0	4.0	3.50	3.50
VTX	Inner Layer (mm)	20	16	16	15

START GENERATION WITH LDC'/GLD'

THEN WITH LDC/GLD

THEN MAXI-LDC/J4LDCGLD

First 3 Points in detector space to guide ILD design

What can we achieve on LoI Timescale ?

- ★ At this stage, no definitive answer to this question…
- ★ Believe we can fix main detector parameters
  - + address some more sub-detector specific questions
- ★ Also want to build strong connection with R&D collaborations

BUT

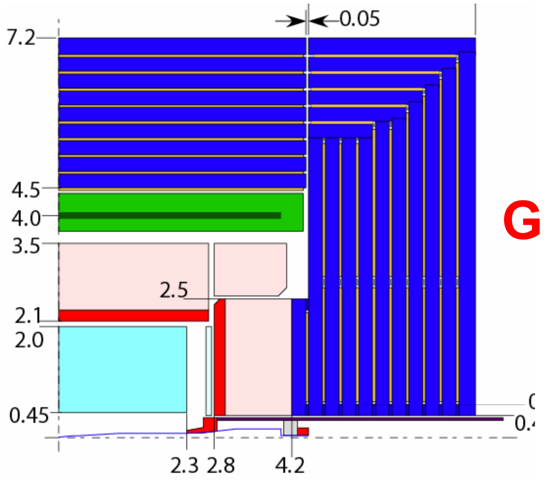
- ★ The LoI is not the end of this effort
- ★ Want to put in place solid framework for studies beyond the LoI

DETECTOR SIMULATION

FULL RECONSTRUCTION

ANALYSIS FRAMEWORK

❹ Simulating ILD

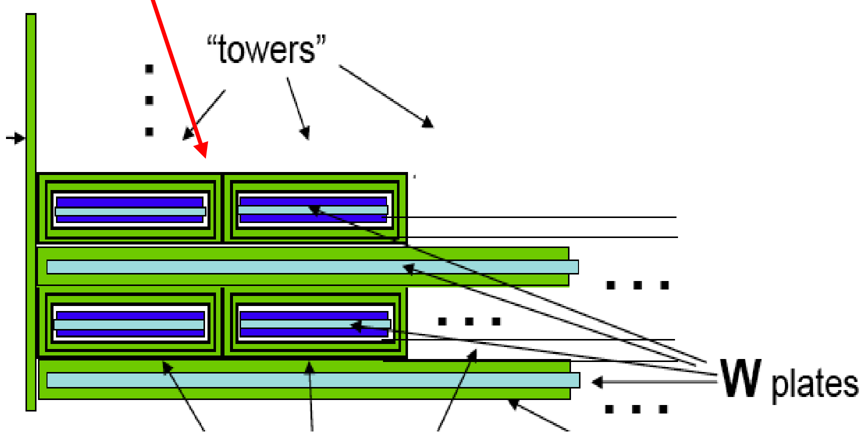


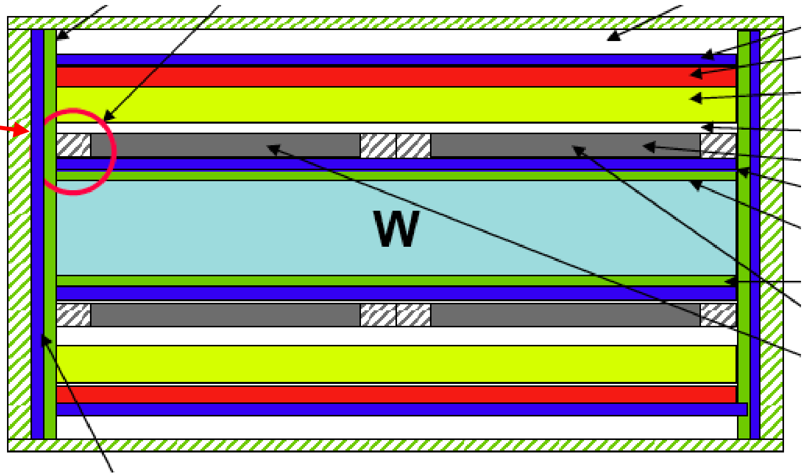
★ Start from existing GLD and LDC **GEANT 4** detector simulations

- During the last few months – a lot of progress in defining new LDC detector models (LDC and LDCprime) and GLD models
- For LDC changes to G4 models for **most** sub-detector drivers !
  - More realism (good/bad)
  - A lot more flexibility
- Philosophy:
  - driven by needs of global detector optimisation
  - but also want to make as useful as possible for sub-detector groups (VTX, HCAL, Si-tracking) provided does not impact the main aim

e.g Improved Ecal Model (LDC)

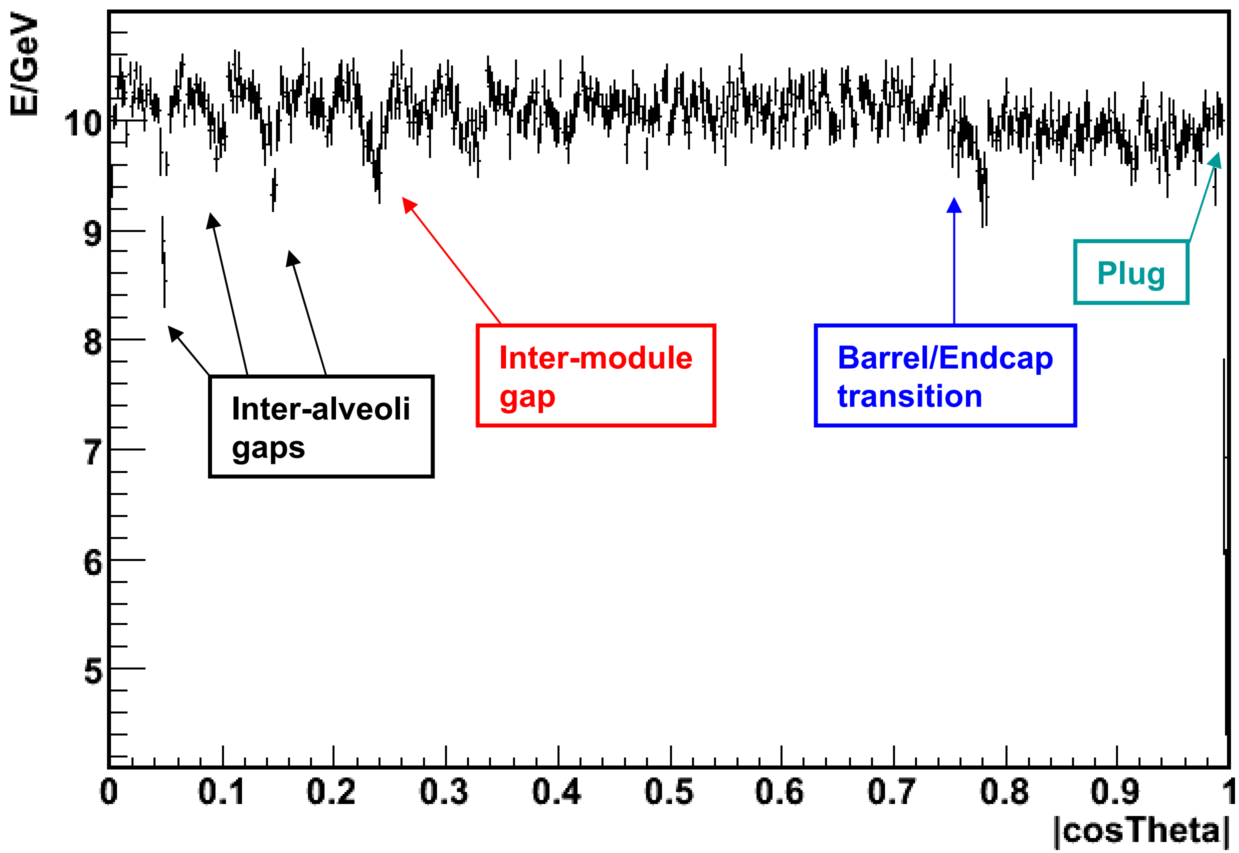
- Detailed, "first order engineering level" description
- Larger dead areas
  - edge of wafers
  - inter-alveolar gaps



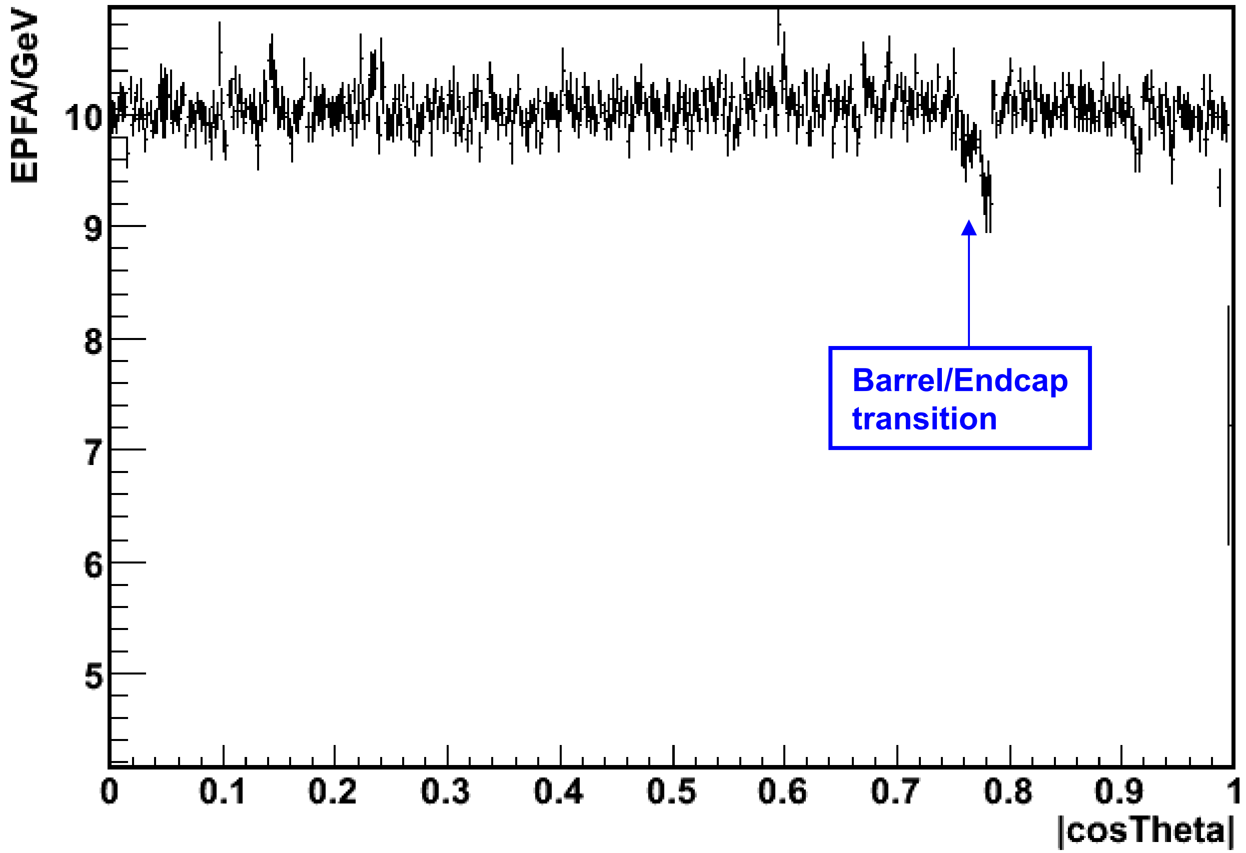


- Gaps will degrade detector performance !
- But, if want a reasonable estimate of real detector performance can't be ignored
- By including them, can determine impact
- Also means need to include first software corrections

★ e.g. 10 GeV photons at random angles
★ Look at RAW response
★ As expected effect of gaps observed

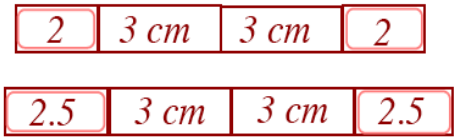


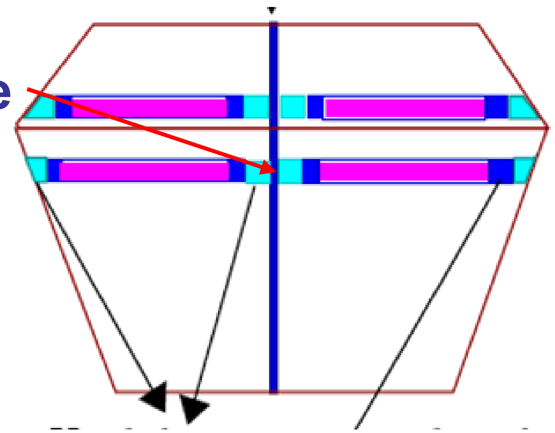
★ **First order software corrections now included in reconstruction**



e.g. Improved HCAL

- ★ Increased realism/more flexibility
- ★ Introduced additional caps in middle of module
    - ♦ may not be small
    - ♦ “gaps” line up and point to IP
- ★ Also introduced realistic scintillator tiling

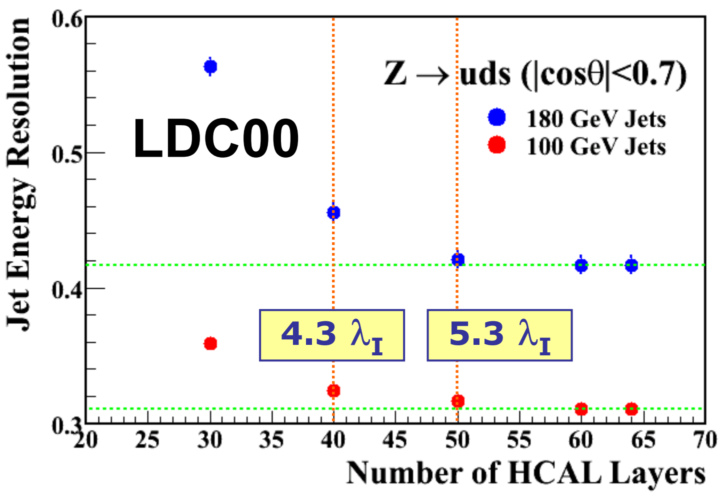




Comments:

- ★ Impact of large gaps on PFA is not known – needs study
- ★ Increased flexibility: study of impact of HCAL design on PFA !

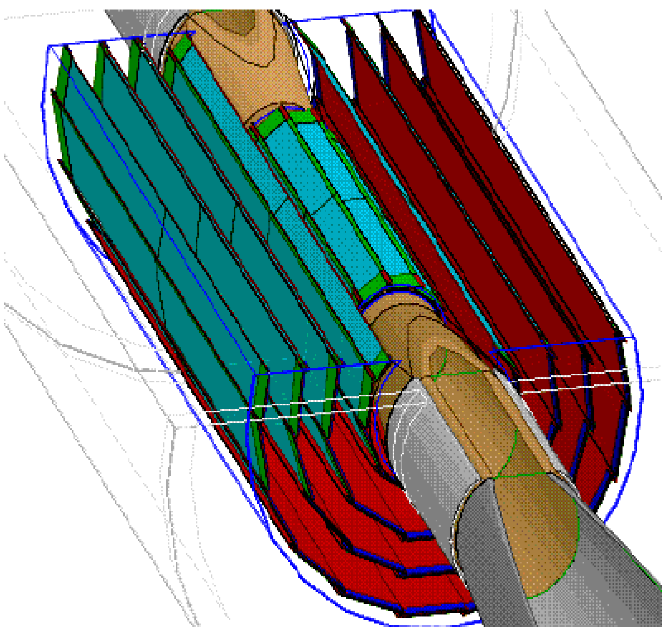
e.g.

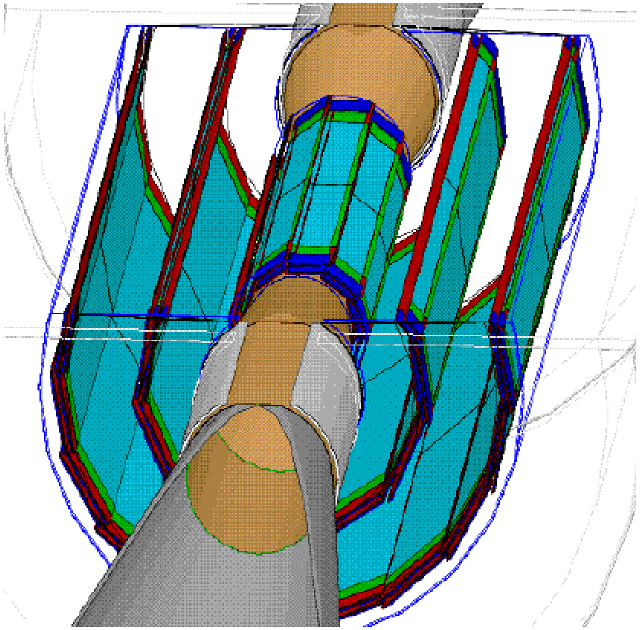


- Over next few months many studies planned
- Watch this space…

e.g. Improved Vertex Models

- ★ Two new drivers
- ★ LDC-like geometry and GLD-like geometry
- ★ Flexible for VTX optimisation studies
- ★ Models driven by VTX community (a very positive move)





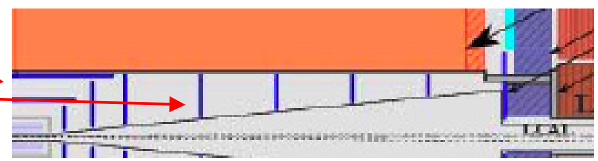
- ★ Sensor active area and response for different technologies can be implemented at digitiser stage
- ★ Powerful tool for optimisation of both global detector and sub-detector

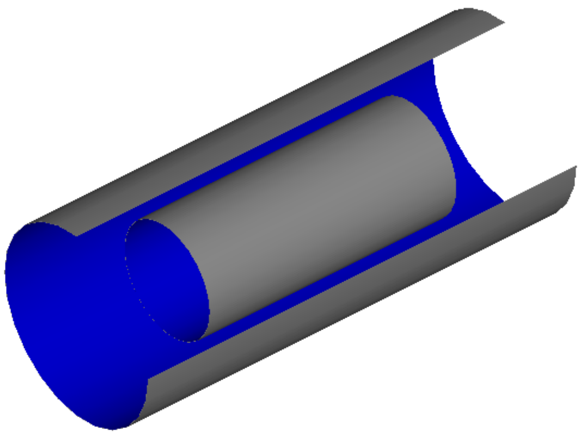
Silicon Tracking

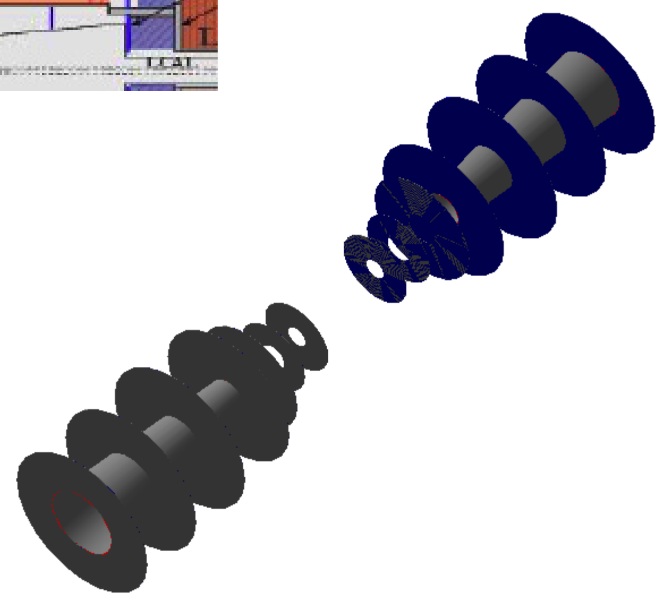
- ★ New drivers from SiLC
  - more realism
  - closer ties with detector R&D

e.g. Inner Tracking

- ★ SIT
- ★ FTD

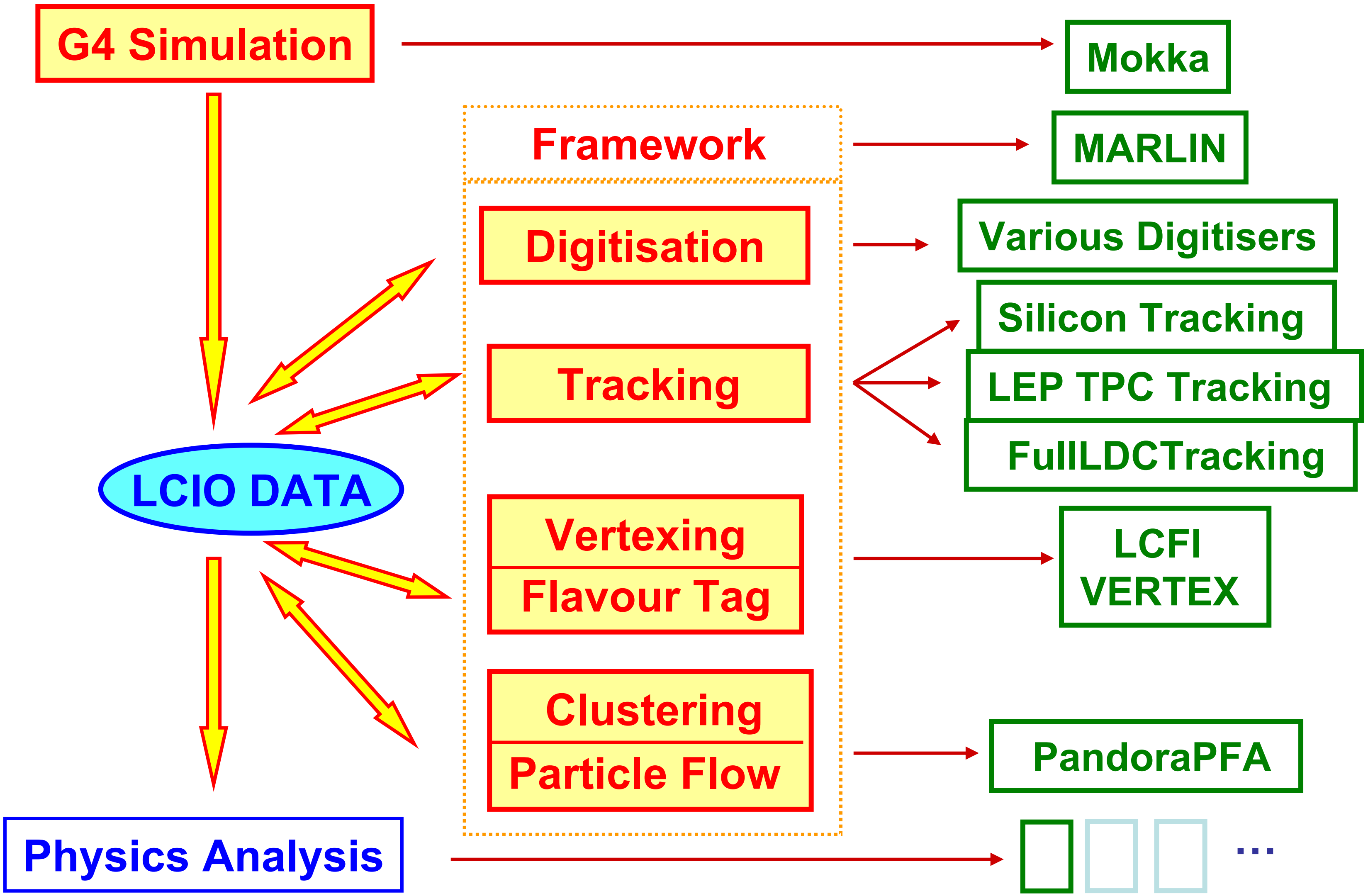






❺ Reconstruction (LDC)

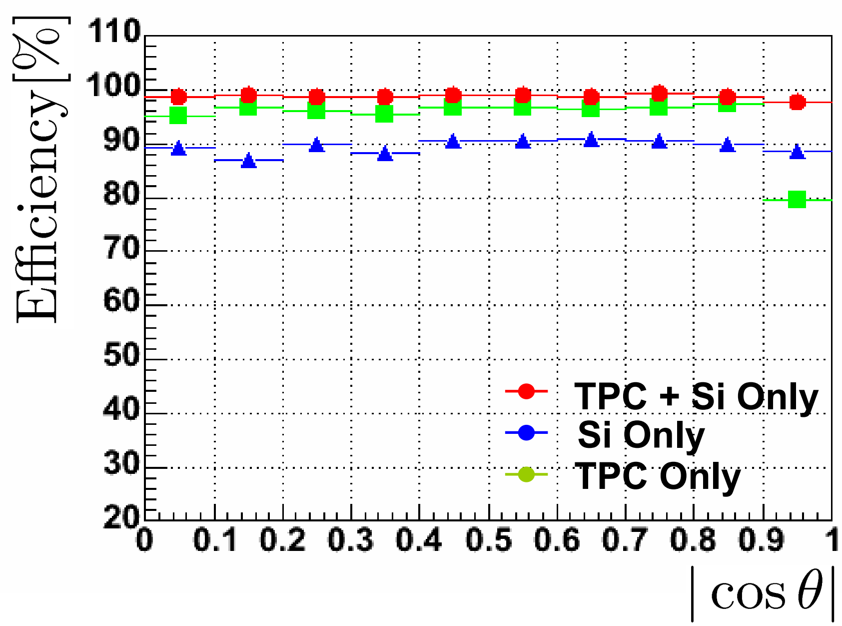
★ Everything exists - to get to this point has been non-trivial !!!



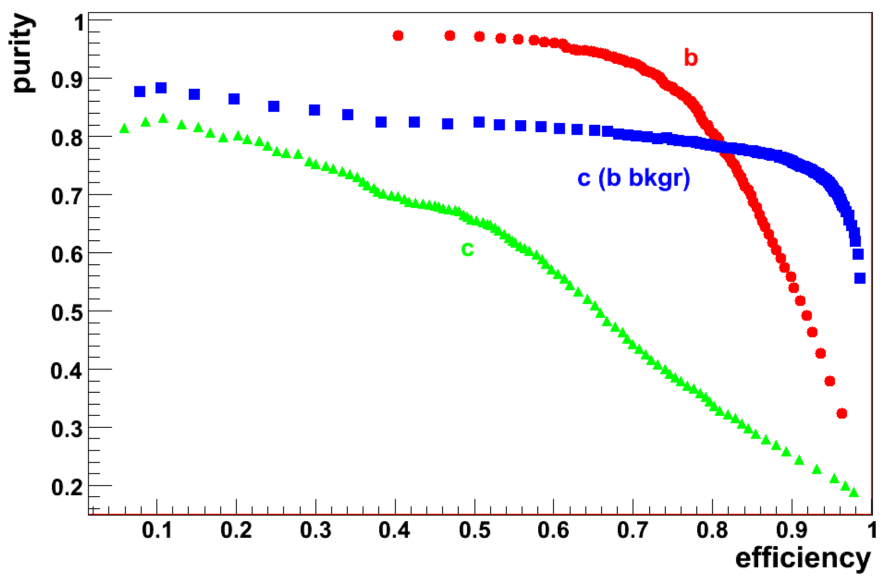
Reconstruction cont.

★ Level of sophistication of tracking/flavour tagging software not too different from what existed at LEP !!!!

Tracking efficiency



Flavour tagging



★ Represents a great deal of high quality work !

★ Vital in order to obtain solid measures of detector and ILC physics performance

❻ PFA

- ★ ILD designed for Particle Flow Calorimetry
- ★ Optimisation studies require "realistic PFA reconstruction"
  - don't want to tune detector design to flaws in algorithm
- ★ Essential to establish what such a detector can achieve

⇨ **PandoraPFA**

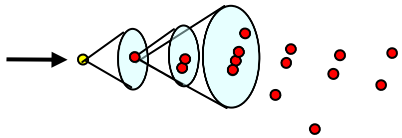
- ★ Currently the best available
- ★ Sophisticated algorithm…
- ★ Full reconstruction – no MC information used
- ★ Much more than clustering
- ★ Tracking information essential to PFA reconstruction

PandoraPFA Algorithm Overview

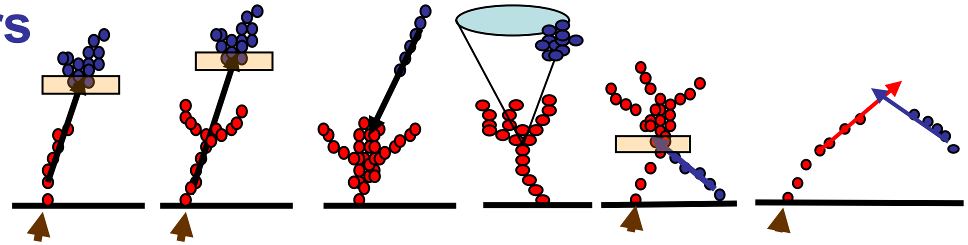
<u>The Eight Main Stages:</u>

i. Preparation/Tracking

ii. Loose clustering in ECAL and HCAL

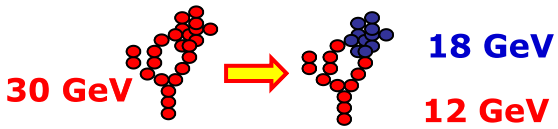


iii. Topological linking of clearly associated clusters

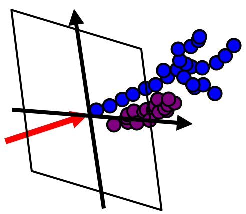


iv. Courser grouping of clusters

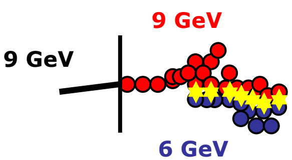
v. Iterative reclustering (using tracks)



vi. Photon Recovery



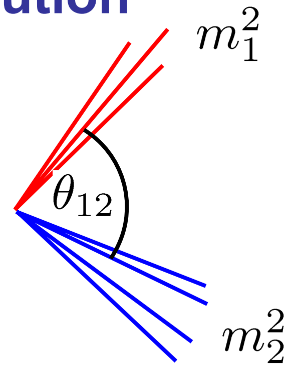
vii. Fragment Removal



viii. Formation of final Particle Flow Objects

PFA "Goals" (revision)

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



★ For a pair of jets have:

$$m^2 = m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2\cos\theta_{12})$$

★ For di-jet mass resolution of order $\Gamma_{W/Z}$

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

⇒ $\sigma_{E_j}/E_j < 3.8\%$

+ term due to θ_{12} uncertainty

or (perhaps misleadingly) expressed as

$$\alpha(E_j) < 0.027\sqrt{E_{jj}(\mathrm{GeV})}$$

⇒

E_{jj}/GeV	$\alpha(E_{jj})$
100	< 27 %
200	< 38 %

COMMENTS

★ $\Gamma_{W/Z}$ is FWHM, gain further by improving on the numbers

★ In multi-jet environment won't achieve this mass resolution; **jet-finding** and **jet-pairing** ambiguities

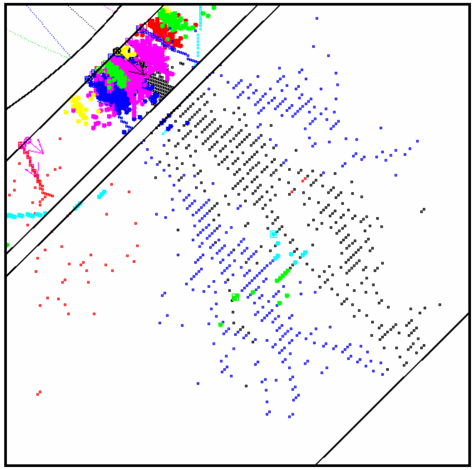
Performance ("old version")

★ Validated using full reconstruction chain, e.g.

PandoraPFA v02-01 + FullLDCTracking

rms90

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.24	3.5 %
100 GeV	0.31	3.1 %
180 GeV	0.43	3.2 %
250 GeV	0.56	3.6 %



★ For 45 GeV jets, performance equivalent to **24 % / √E**

★ Performance degrades at higher energies
- particles in jets become less well spatially separated

★ But $\sigma_E/E < 3.8\ \%$ for jet energies less than 250 GeV

★ Will improve, but probably already "good enough" for ILC @ 1 TeV
- mostly dealing with 4+ fermion final states

PARTICLE FLOW CALORIMETRY WORKS !

... at least in simulation

Hadron Shower Models

- ★ People have rightly expressed concerns about sensitivity to hadron shower models…
- ★ First look: compare **LHEP** & **QGSP_BERT** models.
- ★ Large model differences
  - 30 % in raw energy deposition
  - longitudinal/transverse development

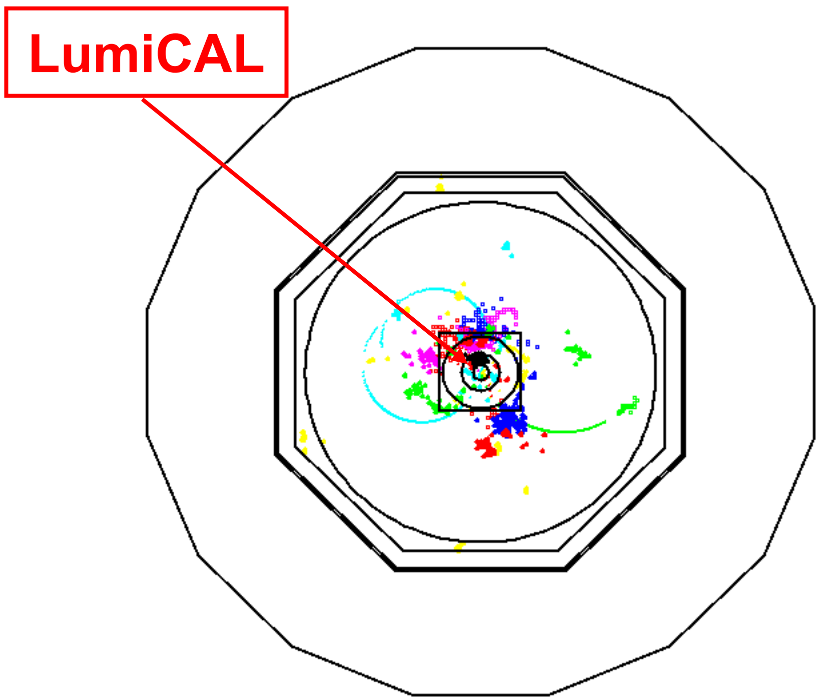
(PandoraPFAv02 +trackCheater)		E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$
LDC00Sc	**QGSP_BERT**	**45 GeV**	**22.6 %**
LDC00Sc	**LHEP**	**45 GeV**	**23.2 %**
LDC00Sc	**QGSP_BERT**	**100 GeV**	**29.3 %**
LDC00Sc	**LHEP**	**100 GeV**	**30.2 %**

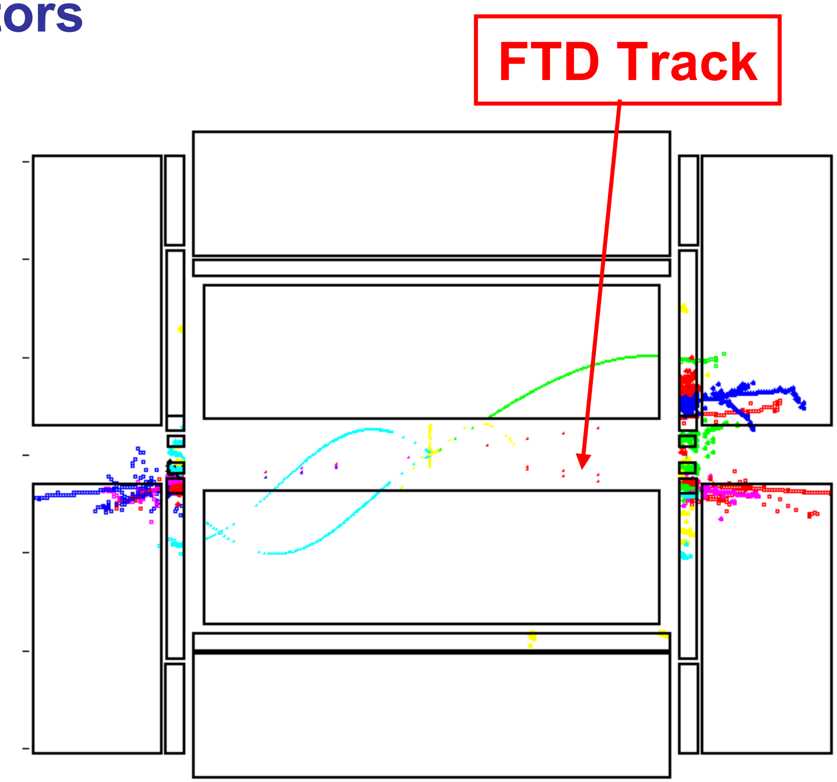
- ★ Differences rather small (+code not re-optimised for LHEP)

- ★ Sensitivity to Hadronic shower development may not be so large
  - needs more study
  - ultimately CALICE data will show the way

Recent developments

- ★ **Many small improvements**
- ★ **Improvements for new LDC detector models**
  - **e.g. muon chamber hits now incorporated in reconstruction (only to tag particles leaving detector)**
  - **e.g. Full use of forward detectors**





- ★ **Fairly new, so only limited performance studies**

LDC00 (Tesla)

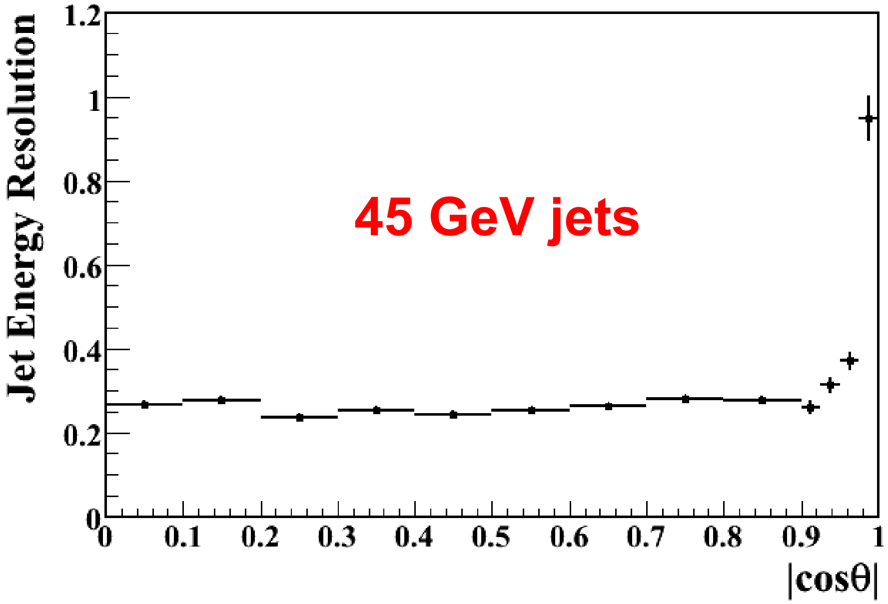
E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.24	3.5 %
100 GeV	0.31	3.1 %
180 GeV	0.43	3.2 %
250 GeV	0.56	3.6 %

LDCprime_02Sc (ILD)

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.25	3.6 %
100 GeV	0.31	3.1 %
180 GeV	?	?
250 GeV	?	?

★ Slight degradation in performance - more realism in detector ?

★ good performance for all but very forward jets



Ready for ILD physics studies…

❼ Towards Virtual Physics

Practicalities of Detector Optimisation

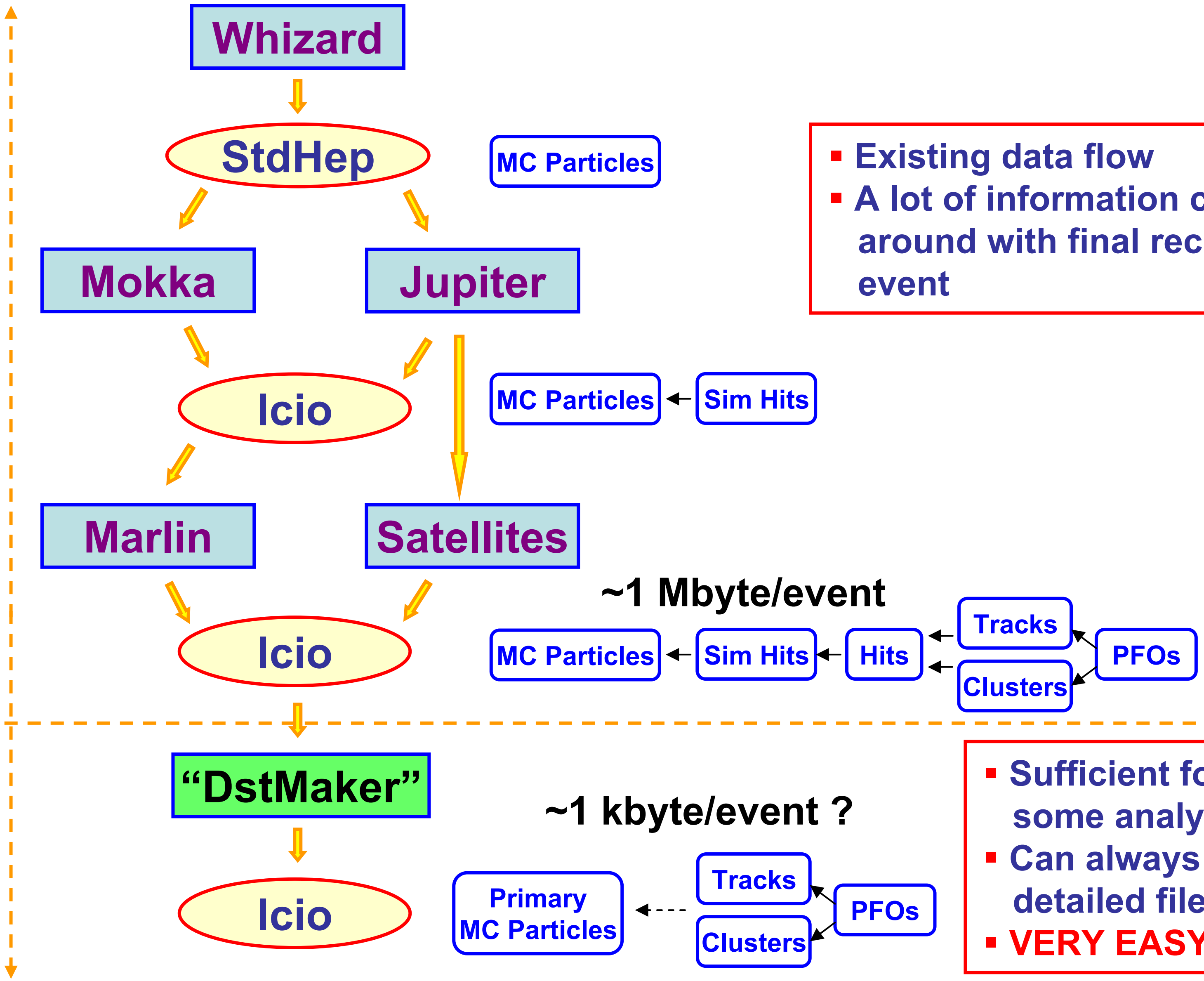
- Simulation/Reconstruction is very time-consuming
- Centralise as much as possible (consistent simulation/reconstruction)
- Need significant computing resources – i.e. the GRID
- Intend (LDC) to start by generating full Standard Model Sample for 500 GeV

Proposed (preliminary)		
Process	**fb^{-1}**	**#events**
ee->6f	500	1197236
ee->4f	50	3358252
ee->2f	20	1192784
ee->hX	500	299278
nn(n*g)	20	841726
ee->ee	0.1	6953510
eg->eg	0.1	344270
gg->X	0.1	554782
ee->gg(n*g)	10	306954
rest	1	517376
Total		**15566168**

Comparable to a LEP experiment MC data set !

- GRID production has already started…
- In ~4 days have about 10 % of the above !!! (thanks to Ivan Marchesini)
- Next step, start generating signal samples (to be discussed)
- Exact strategy developing with experience

Making Physics "Easy"…



- Existing data flow
- A lot of information carried around with final reconstructed event

- Sufficient for some analyses
- Can always use detailed files
- VERY EASY TO USE

★DST Also includes jet based flavour tagging !

```
////////////////////////////////////
EVENT: 0
RUN: 2011907
DETECTOR: LDCPrime_02Sc
COLLECTIONS: (see below)
////////////////////////////////////

---------------------------------------------------------------------------
COLLECTION NAME               COLLECTION TYPE          NUMBER OF ELEMENTS
===========================================================================
FTFinal_2Jets                 ReconstructedParticle             2
FTFinal_3Jets                 ReconstructedParticle             3
FTFinal_4Jets                 ReconstructedParticle             4
FTFinal_5Jets                 ReconstructedParticle             5
FTFinal_6Jets                 ReconstructedParticle             6
FTFinal_7Jets                 ReconstructedParticle             7
FTFinal_8Jets                 ReconstructedParticle             8
IPVertex                      Vertex                            1
LDCTracks                     Track                            70
MCParticlesSkimmed            MCParticle                      202
PandoraClusters               Cluster                          64
PandoraPFOs                   ReconstructedParticle            65
RecoMCTruthLink               LCRelation                       65
ZVRESVertices_2Jets           Vertex                            1
ZVRESVertices_3Jets           Vertex                            1
ZVRESVertices_4Jets           Vertex                            1
ZVRESVertices_5Jets           Vertex                            1
ZVRESVertices_6Jets           Vertex                            1
ZVRESVertices_7Jets           Vertex                            1
ZVRESVertices_8Jets           Vertex                            1
---------------------------------------------------------------------------
```

★Should make getting started with ILC physics rather easy…

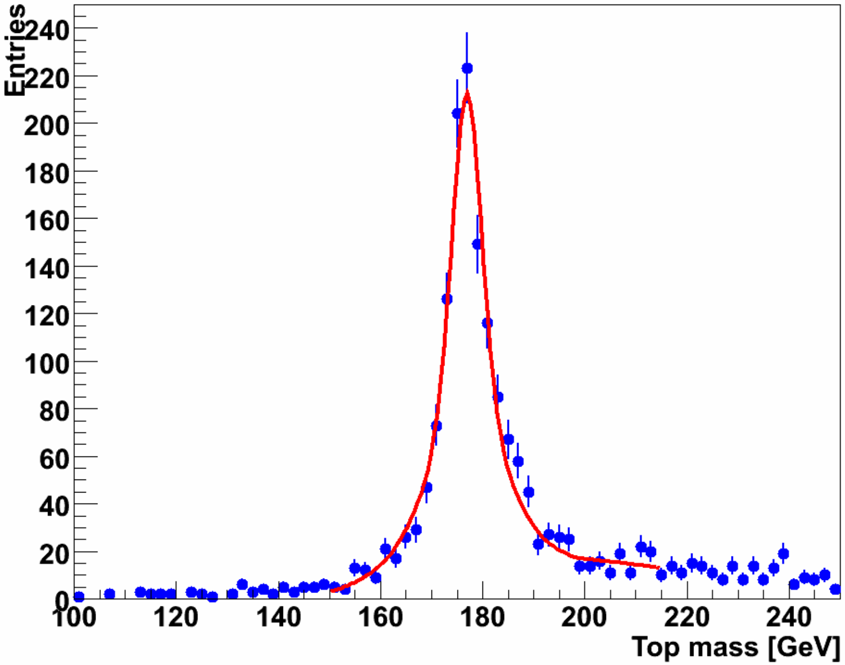
❽ Optimising ILD part II

- ★ The software tools are in place (tagged last Friday)
  - Huge effort – important contributions from many !
- ★ The GRID is working for ILD
- ★ Can now perform physics analyses
  - This work has started…

e.g. top mass reconstruction in 6 jet events…

(see Andreas Moll's Talk)

FullLDCTracking
PandoraPFA
LCFI Flavour Tags
Kinematic Fitting



and now over to GLD

- ★ Have spoken mostly about LDC effort
  - this concentrated on development of sophisticated tools
- ★ This work is going on in parallel with that on the GLD side

GLD Optimisation Effort:

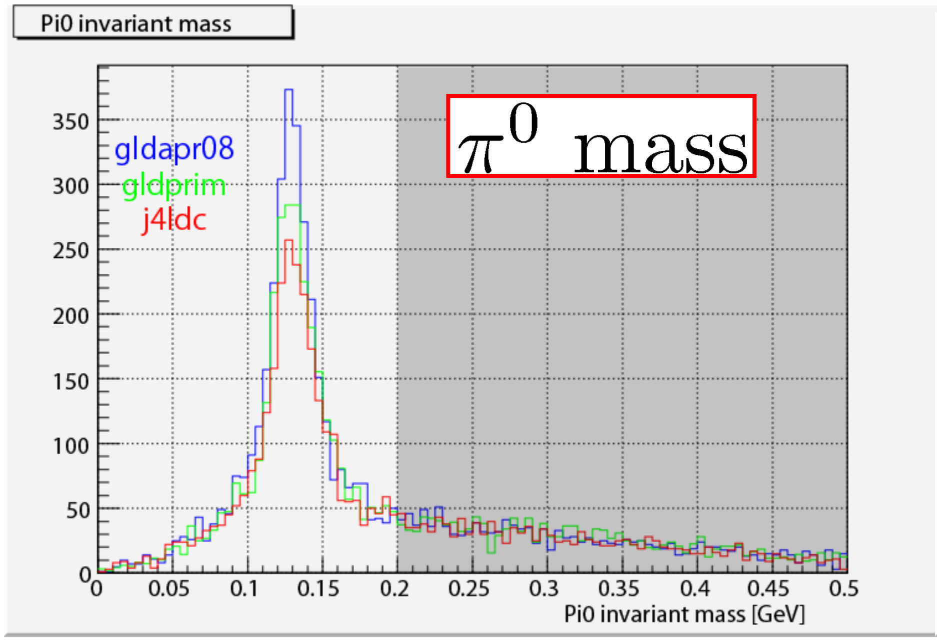
- ★ Use Jupiter simulation of GLD
- ★ Events reconstructed with FullLDCTracking and PandoraPFA,
  (soon to include LCFIVertexing)
- ★ Analysis in GLD root-based framework
- ★ Made possible by common (LCIO) data format

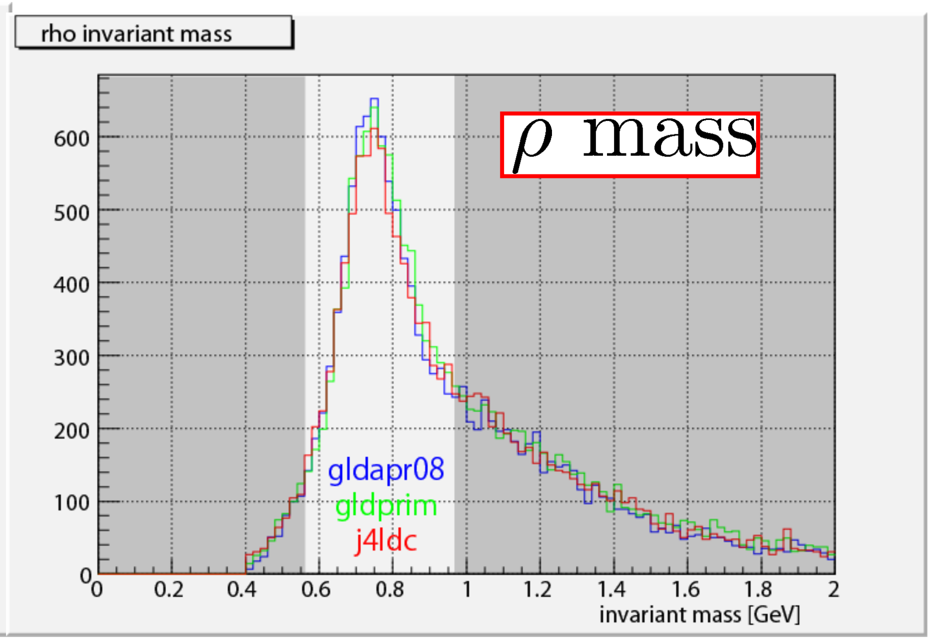
GLD Physics Studies

★ Many detailed physics studies being developed (talks at this meeting)
- no time to go into details (see Yoshioko-san's talk this p.m.)

Example 1:

★ Tau reconstruction at √s = 500 GeV $\tau^- \rightarrow \rho^- \nu_\tau \rightarrow \pi^- \pi^0 \nu_\tau$



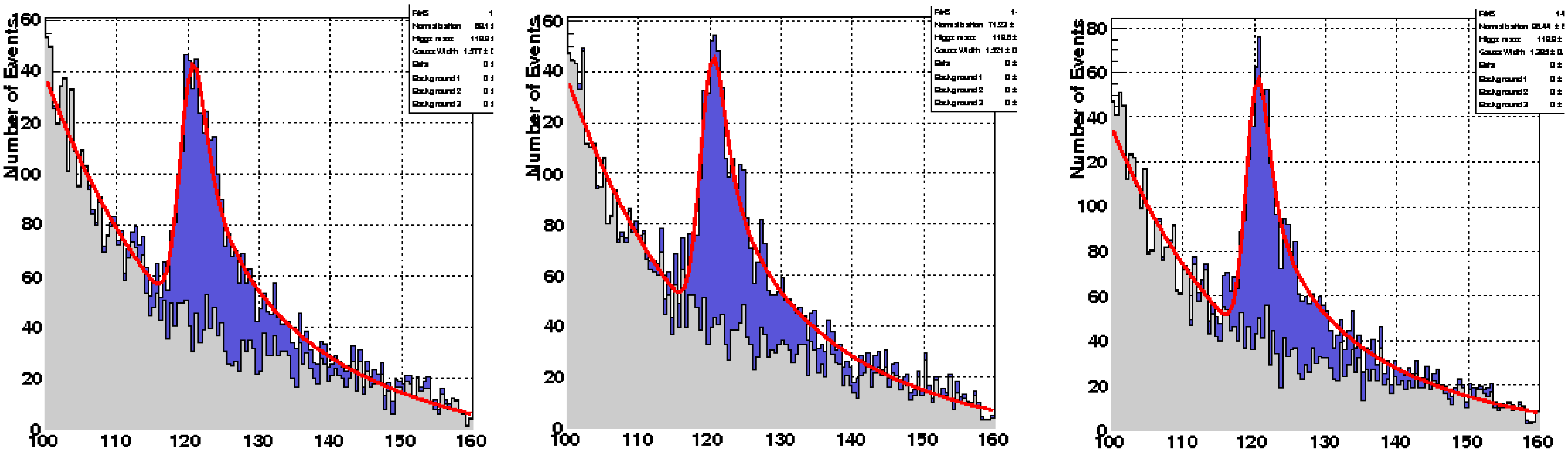


★ Compare 3 different sized detectors

Example 2: Higgs recoil mass vs detector size

$\mathrm{HZ} \rightarrow \mathrm{He^+e^-} \,/\, \mathrm{H}\mu^+\mu^-$

GLD → GLDPrime → J4LDC



★ Many studies, geared towards filling performance/detector matrix…

GLD Optimization Matrix (As of May 30th)

Process	Observable	Target	GLD	GLD’	J4LDC	Comments
Δpt/pt@500GeV		< 5e-5	3.9e-5	4.1e-5	4.5e-5	
σ(IP)@500GeV			4.0um	3.7um	3.6um	
σ(rms90)@zpole		< 30%?	30.3±0.7	28.7±0.6	30.8±0.7	
ZH → $\mu\mu$H	$\Delta\sigma$		2.10%	2.20%	2.07%	
	ΔMh		86.5	81.9	79.8	No b-tag
ZH → eeH	$\Delta\sigma$		2.65%	1.80%	1.67%	
	ΔMh		130	139	100	No b-tag
ZH → llH	$\Delta\sigma$		1.64%	1.45%	1.40%	
ZH → llH	ΔMh		75.0	70.9	63.4	No b-tag
τ pair	AFB		49.76	49.73	49.44	
	Pi0 width		14.7	15.0	16.5	
Smuon	$\Delta M(\mu^{\pm})$		0.36%	0.31%	0.36%	
	$\Delta M(\chi_1^0)$		0.38%	0.34%	0.38%	

Very Preliminary

★ **Don’t take results seriously at this stage – need careful consideration**

★ **Indicative of what is to come in the run up to the LoI**

FULL SIM./RECO. PHYSICS BASED OPTIMISATION STARTED

❾ Conclusions

Progress to date:

- ★ Developed powerful simulation/reconstruction tools
  - ~ at level of a LEP experiment !
- ★ Believe this level of detail is essential for solid performance studies
  - PFA is new : parametric studies may not be appropriate
- ★ Large MC samples are being generated as we speak
  - ~ MC sample size of a LEP experiment !
- ★ Effort will now concentrate of physics studies
- ★ Precise optimisation strategy will develop with experience

Huge effort from many talented and dedicated people !

Personal comments:

- ★ Believe we have made real progress over last six months
- ★ On simulation side, increased connection to R&D is a big plus
- ★ Collaboration with Asian colleagues has been extremely positive (and enjoyable)
  - Believe we have all benefited from this
- ★ The next few months are going to be very interesting…

Watch this space !