LDC01Sc and PandoraPFA

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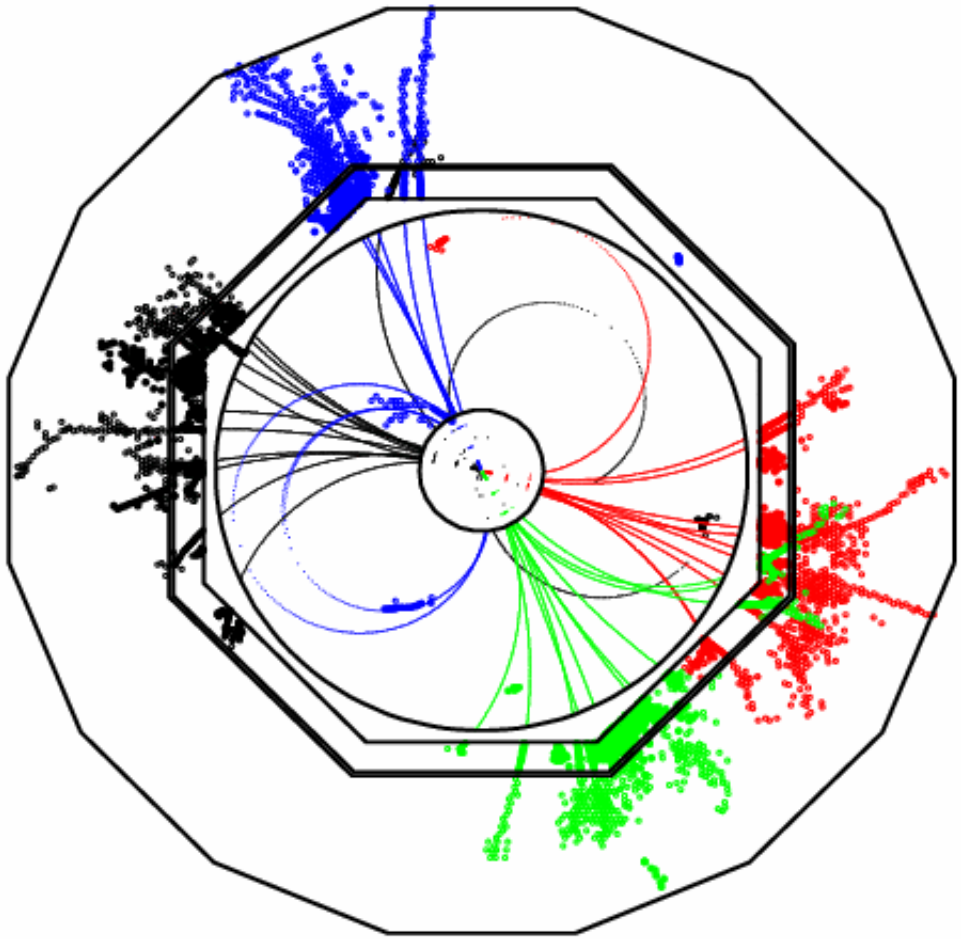


This Talk:

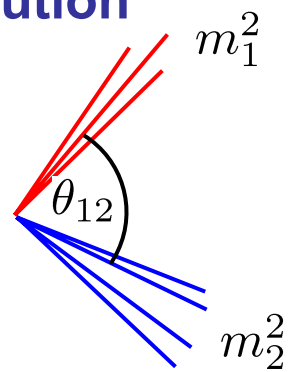
1. PFA Goals
2. Status at LCWS07
3. From LCWS to Zeuthen
4. LDC00 → LDC01_05Sc
5. Gaps
6. Summary/Outlook

❶ PFA Goals

★ **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

★ **Assuming a single jet energy resolution of normal form**

$$\sigma_E/E = \alpha(E)/\sqrt{E(\mathrm{GeV})}$$

$$\sigma_m/m \approx \alpha(E_j)/\sqrt{E_{jj}(\mathrm{GeV})}$$

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

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

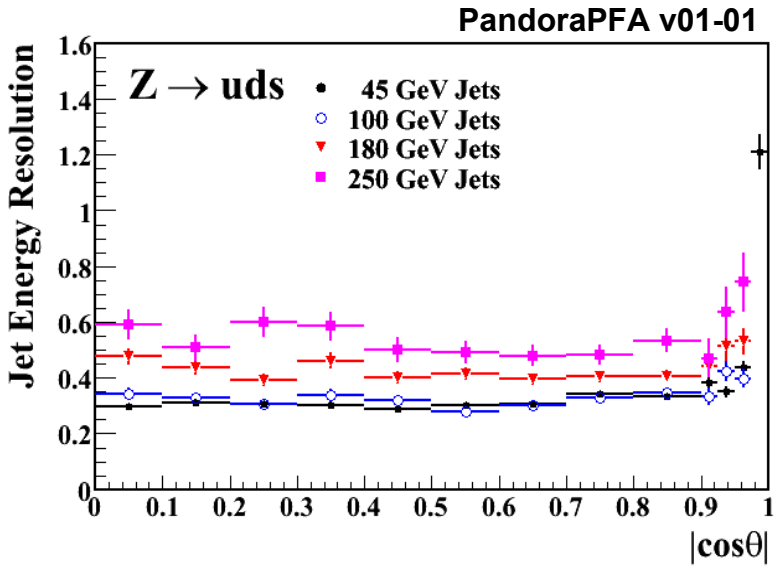
★ **Typical di-jet energies at ILC (100-300 GeV) suggests jet energy resolution goal of** $\sigma_E/E < 0.30/\sqrt{E_{jj}(\mathrm{GeV})}$

❷ Status at LCWS07

★**Full simulation studies using the LDC ILC detector concept with the PandoraPFA algorithm. Use** $Z \to u\bar{u}, d\bar{d}, s\bar{s}$ **decays at rest to benchmark performance**

rms90* 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	3.3 %



★**For jet energies below 100 GeV achieve** $\sigma_E/E < 0.30/\sqrt{E_{jj}(\mathrm{GeV})}$

★**Perhaps more importantly, for jet energies above ~75 GeV achieved**

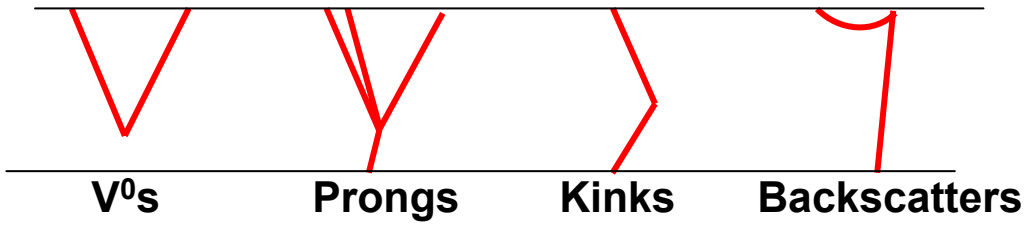
$$\sigma_{E_j}/E_j < 3.8\%$$

★**Post-LCWS emphasis shifted to improving low energy performance, important in likely initial phase of ILC at** $\sqrt{s}$ **~ 200-500 GeV**

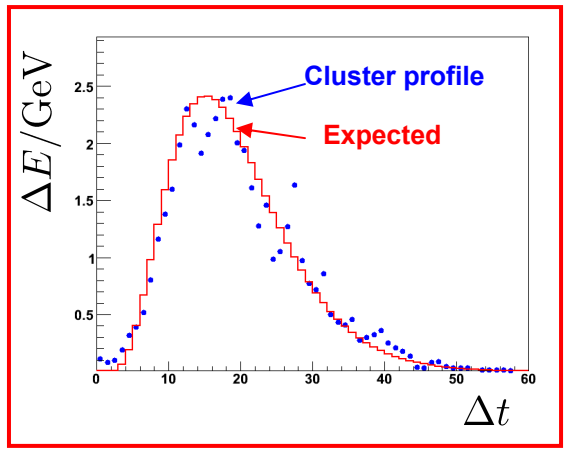
❸ From LCWS to Zeuthen

Step 1: improve low energy performance

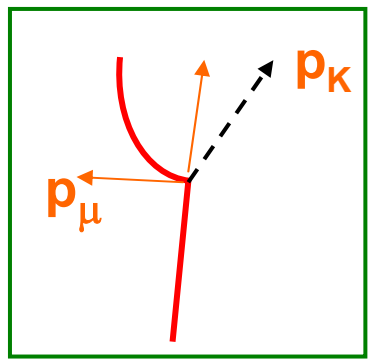
- ★ Technical Improvements/bug fixes
  - ♦ reduced memory footprint (~ factor 2) by on-the-fly deleting of temporary clusters, rather than waiting to event end
- ★ Improved track ID



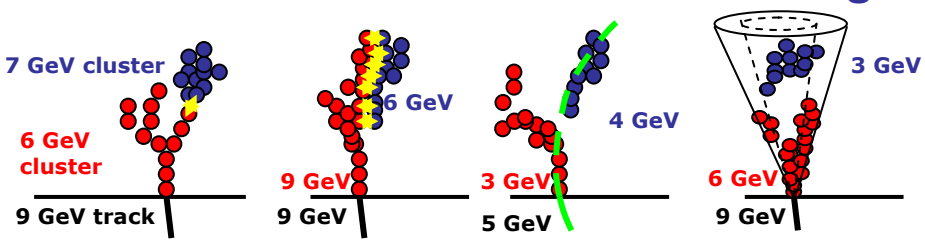
- ★ Much improved photon Identification
  EM shower profile →



- ★ 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 →



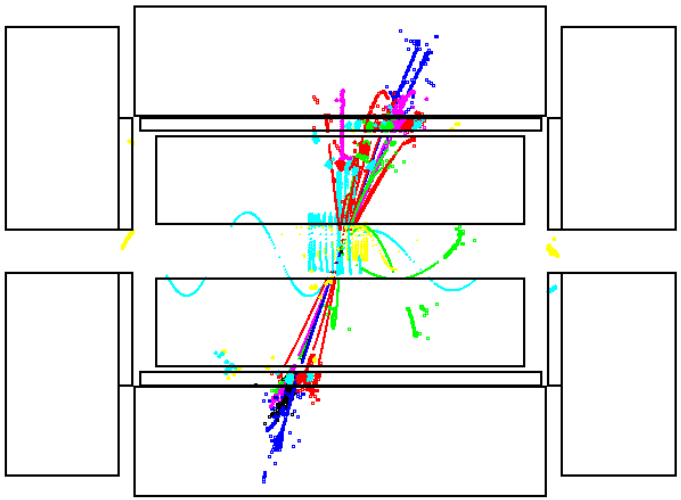
- ★ More sophisticated identification of neutral fragments



From LCWS to Zeuthen cont.

Step 2: increase functionality

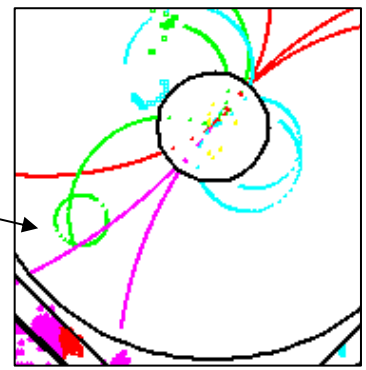
★ Now compatible with digital HCAL and digital ECAL (e.g. MAPs-based)



(PandoraPFAv02 +trackCheater)	E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$
LDC00Sc	100 GeV	29.3 %
LDC00RPC	100 GeV	30.3 %

- very similar performance
- Digitial - not fully optimised…

★ Can now use either **TrackCheater** or **FullLDCTracking**
- required rewrite of V^0 finding + tweaks for **kinks**
- note: FullLDCTracking does not find non-vertex curlers, i.e. reduced kink/V^0 efficiency
- still need to study optimal track quality cuts



Step 3: compatibility with LDC01_05Sc

★ Include LCAL, ECAL Plug. + include MUON hits (read but not yet used)
★ Made more robust – better error/warning reporting
★ Not quite finished – e.g. need to check/tune photon ID but probably OK

LCWS → Zeuthen: LDC00 progress

Cheated Tracks

LCWS07 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	3.3 %

PandoraPFA v02-α

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.226	3.3 %
100 GeV	0.293	2.9 %
180 GeV	0.392	2.9 %
250 GeV	0.534	3.3 %

★ For LDC00:

- Slight degradation when using FullLDCTracking
- Small difference may be due to degraded kink finding
- Track cuts not yet optimised

FullLDCTracking

PandoraPFA v02-01

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.235	3.5 %
100 GeV	0.306	3.1 %
180 GeV	0.427	3.2 %
250 GeV	0.565	3.6 %

Aside : Hadron Shower Models

★First look at dependence on hadron shower model, compare **LHEP & QGSP_BERT** models. Large model differences

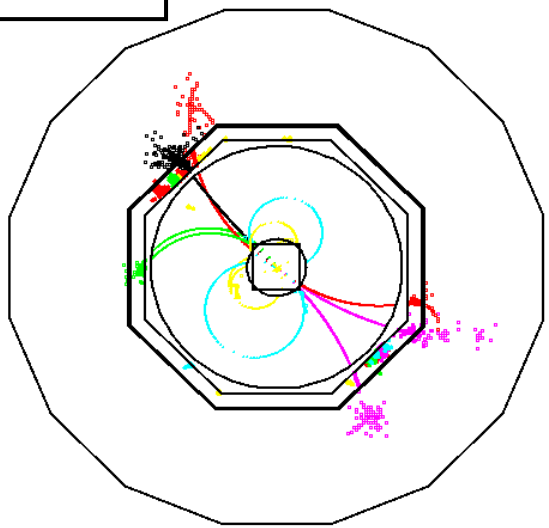
- 30 % in raw energy deposition
- longitudinal/transverse development (see Felix's HCAL talk)

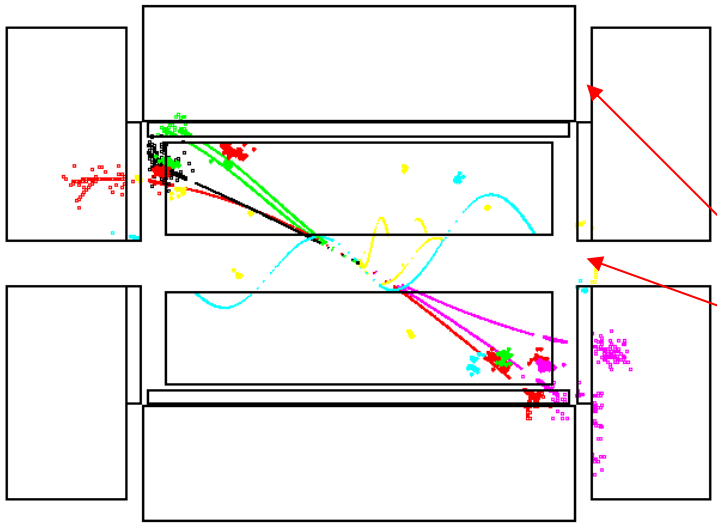
(PandoraPFAv02 +trackCheater)		E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$
LDC00Sc	**QGSP_BERT**	**45 GeV**	**22.6 %**
LDC00RPC	**LHEP**	**45 GeV**	**23.2 %**
LDC00Sc	**QGSP_BERT**	**100 GeV**	**29.3 %**
LDC00RPC	**LHEP**	**100 GeV**	**30.2 %**

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

❹ LDC00 → LDC01_05Sc

LDC00

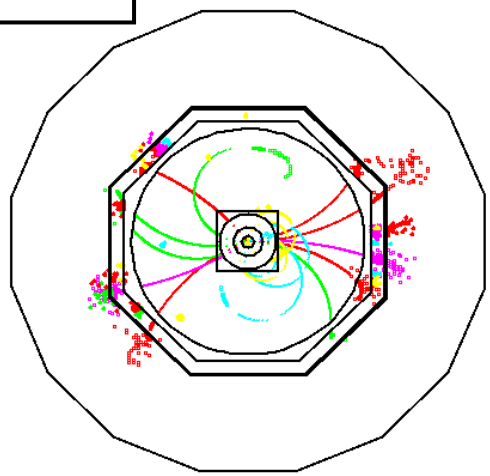


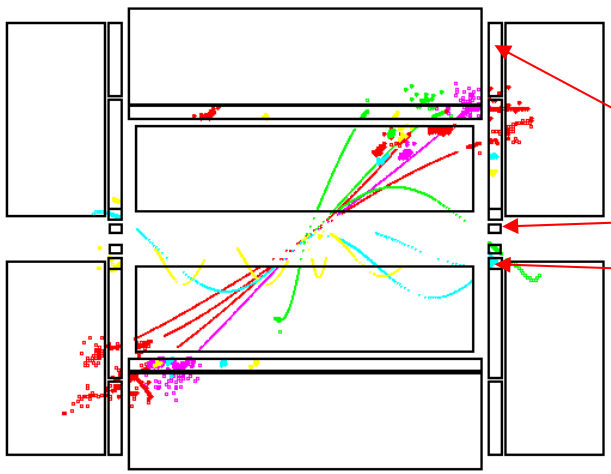


Comments

- ~ Tesla TDR
- Large radius ~1.69 m
- Extended barrel
- No HCAL rings
- Hole in FWD region
- "Baseline" for PFA studies to date

LDC01



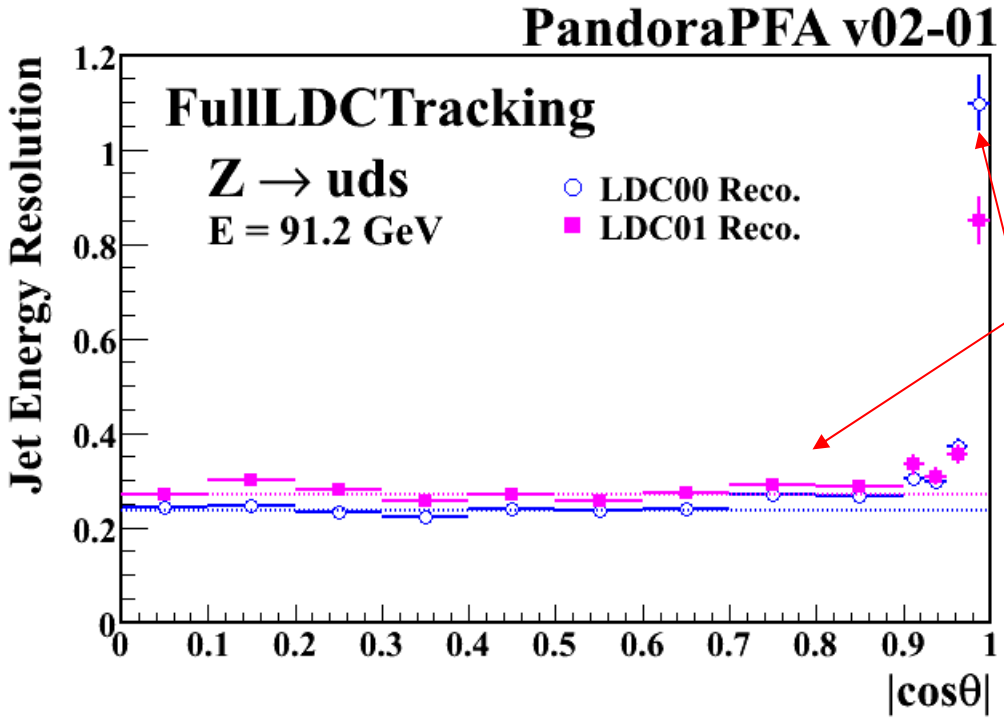


Comments

- Smaller
- TPC radius ~1.58 m
- +HCAL rings
- +LCAL
- +ECAL Plug
- Relatively untested
- Less thick HCAL
  63 → 48 layers

PandoraPFA : LDC00 vs LDC01_05Sc

★ NOTE: so far mostly looked at 91.1 GeV



Comments

★ Barrel performance worse
23.5%/√E ➞ 27.0 %/√E

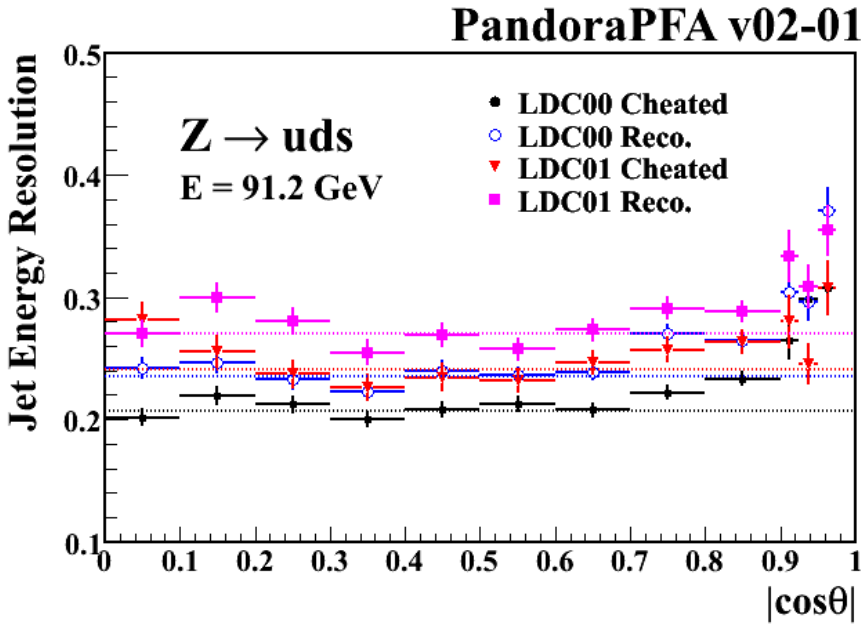
★ Less degradation in Barrel/Endcap overlap region for LDC01
HCAL RING ?

★ Far Endcap region LDC01 better !
LCAL/ECAL Plug

★ For the moment concentrate on degraded performance in barrel
potential implications for detector design…

Origin of degraded Barrel Performance…

★Compare PandoraPFA+LDCTracks with PandoraCheatedPFA+CheatedTracks



★LDC01 has worse performance even at cheated level

} LDC01 Reco & cheated

} LDC00 Reco & cheated

	TrueTracks CheatedPFA	TrueTracks PandoraPFA	LDCTracks PandoraPFA
LDC00	0.207	0.228	0.235
LDC01	0.241	0.269	0.270

Estimated Confusion
0.11
0.12

From reco/cheated differences in quadrature

★ No evidence for PandoraPFA doing a worse job !

★ Is LDC01_05Sc is an intrinsically worse detector for PFA ?

★ If so, what is making the difference in the barrel region ?

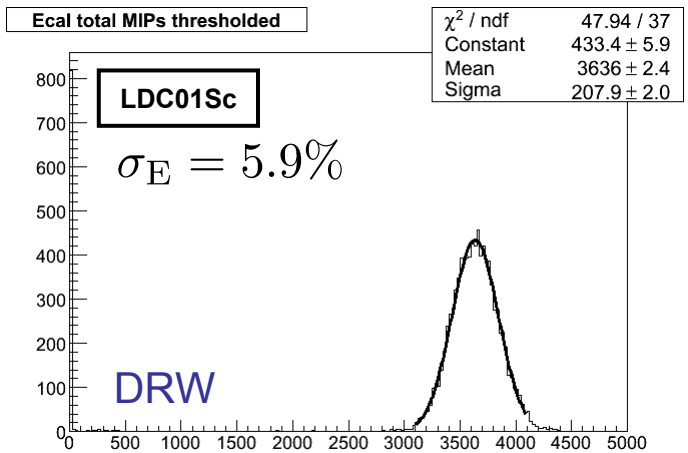
…the ECAL

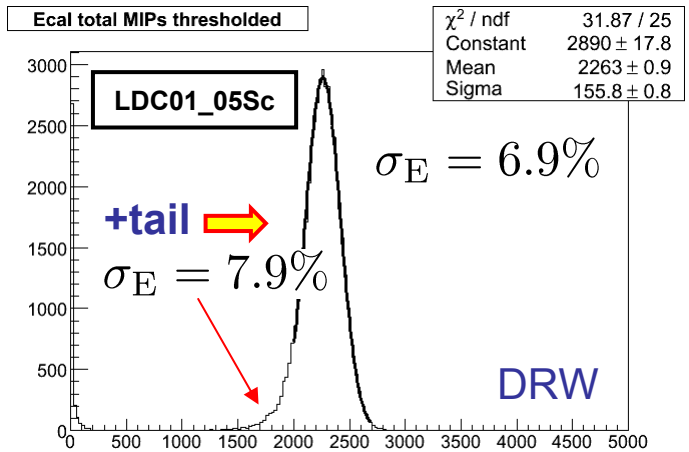
★ **Significant changes to ECAL model between LDC00 and LDC01**

	Layers	Si Thickness	Wafer/Alveolar gaps	$\sigma_E/\sqrt{E}$
LDC00Sc	40	500 μm	no	0.12
LDC01Sc	30	500 μm	no	0.18
LDC01_05Sc	30	320 μm	"realistic"	0.25

★ **LDC01_05Sc ECAL has rather poor energy resolution !**

e.g. 10 GeV photons (all angles)

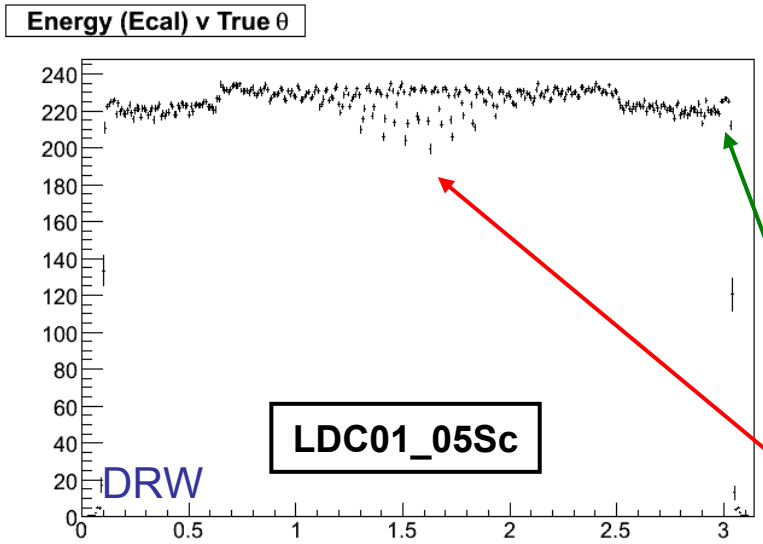


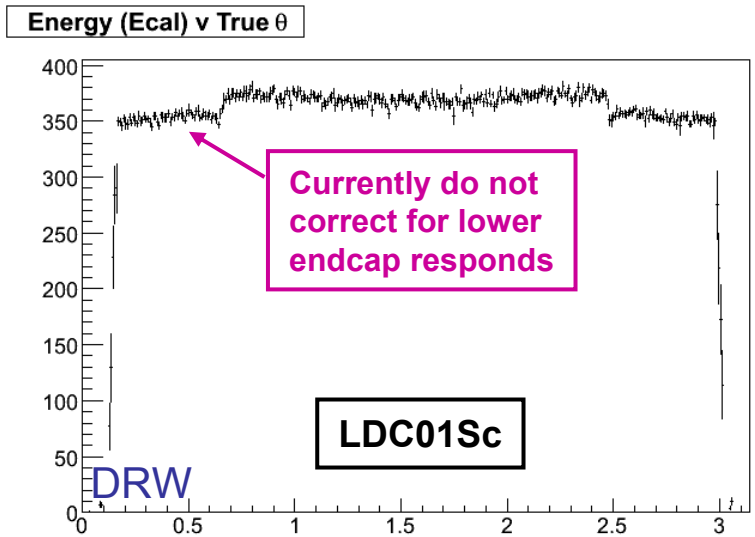


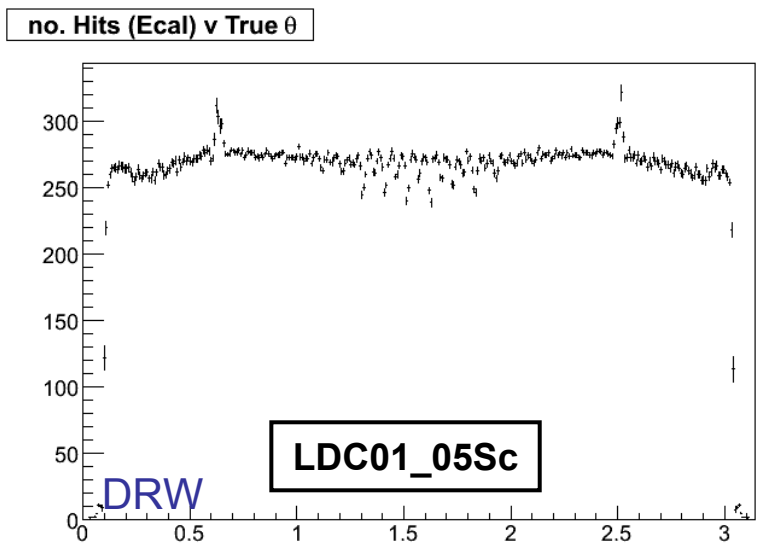
Plots from David Ward

★ **Resolution worse (Si thickness ?) but also problematic tails**

❺ Gaps



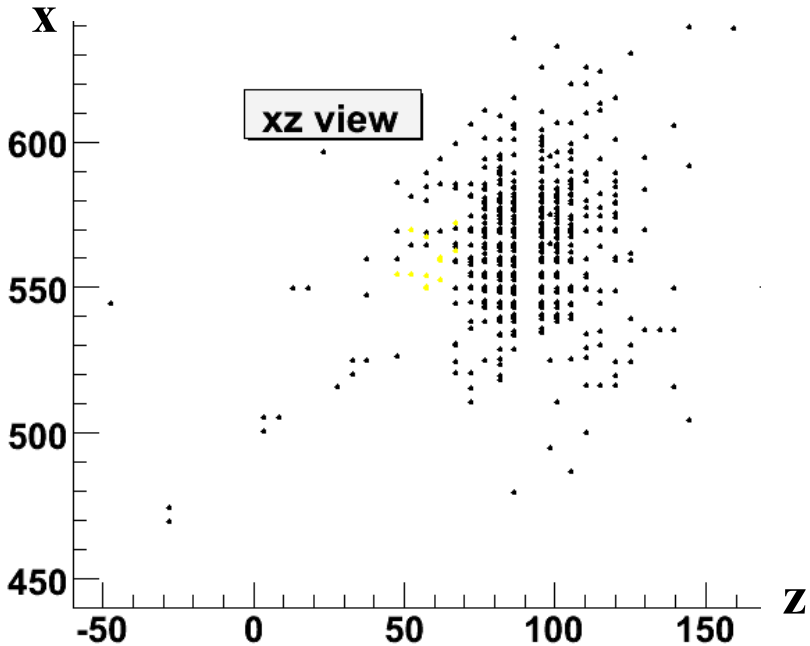




- Structure around $\theta=\pi/2$ caused by inter-wafer gaps (2mm) and inter-alveolar gaps (4mm)
- Beneficial effect of endcap rings.

★ Gaps not small c.f. Moliere radius
★ At small $|\cos\theta|$ gaps line up
★ At the "wrong angle" can miss 30 % of a photon's energy
★ Bad for PFA + impact will increase with energy

e.g. 50 GeV photon reconstructed as 38 GeV



- Here the core of the shower is close to a 4mm gap

- This could be important for PFA - need to address this problem !
- Not trivial: can't simply reconstruct event and then correct energies once position is know – energies used in clustering/reclustering
- **POSSIBLE SOLUTIONS:**
  - adjust hardware model so gaps do not line up
  - mitigate in software, could add "dummy hits" with estimated energy loss in gaps (taken from surrounding hits).

Impact of gaps on PFA

★ Assuming 60% charged particles, 30 % photons, 10 % neutral hadrons, can *estimate* contributions to PFA performance

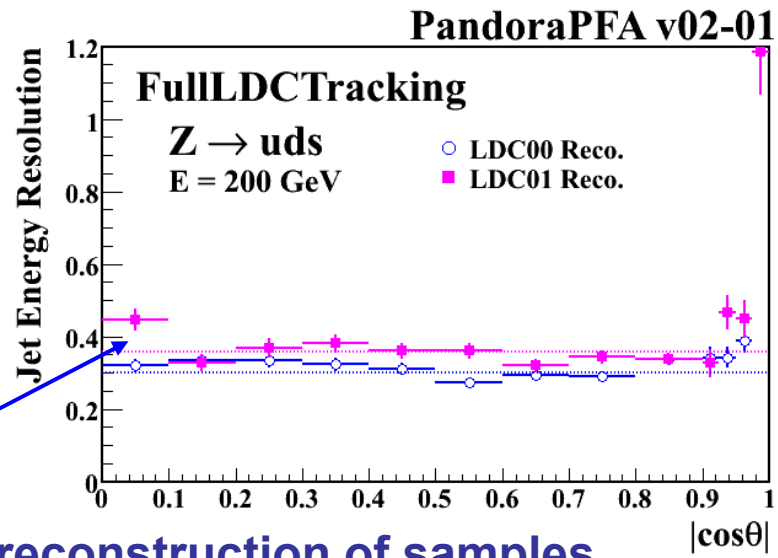
45 GeV jets: $\sigma_E = \alpha\sqrt{E}$

α	ECAL	HCAL	Confusion	Other	Total
LDC00Sc	0.07	0.17	0.11	0.09	0.235
LDC01_05Sc	0.14	0.17	0.12	0.09	0.267

★ For **LDC01_05Sc** ECAL energy resolution is a significant contribution to jet energy resolution !

★ Expect impact of gaps to increase with energy – there is some evidence for this for 200 GeV **Z→uds** events

at small cosθ (where gaps are Most important) degraded performance



★ Ideally address this issue before mass reconstruction of samples.

❻ Summary/Outlook

- ★ **PandoraPFA with FullLDCTracking achieves good performance**

  $\sigma_{E_j}/E_j < 3.6\%$ **for 45-250 GeV jets** **LDC00**

- ★ **v02-01 works with LDC01_05Sc – no indications of problems**
- ★ **However, realistic simulation of ECAL (good) yields worse resolution (Si thickness ?) + effect of gaps is significant**
- ★ **Need to do something about the effect of gaps, ideally before mass reconstruction…**
- ★ **Even then, energy resolution starts to impact PFA performance… Is this due to reduced Si thickness ?**

Short-term Outlook (i.e. to do list):

- ★ **Optimised version for GLD !** **(1 FTE-week ?)**
- ★ **Minor improvements for LDC01**
  - **check update photon ID parameters**
  - **use of muon hits – tagging/tail-catching**
  - **separate calibrations for endcap ECAL**
- ★ **How to handle ECAL gaps…**
- ★ **Optimisation studies… start with HCAL**