Status of PandoraPFA

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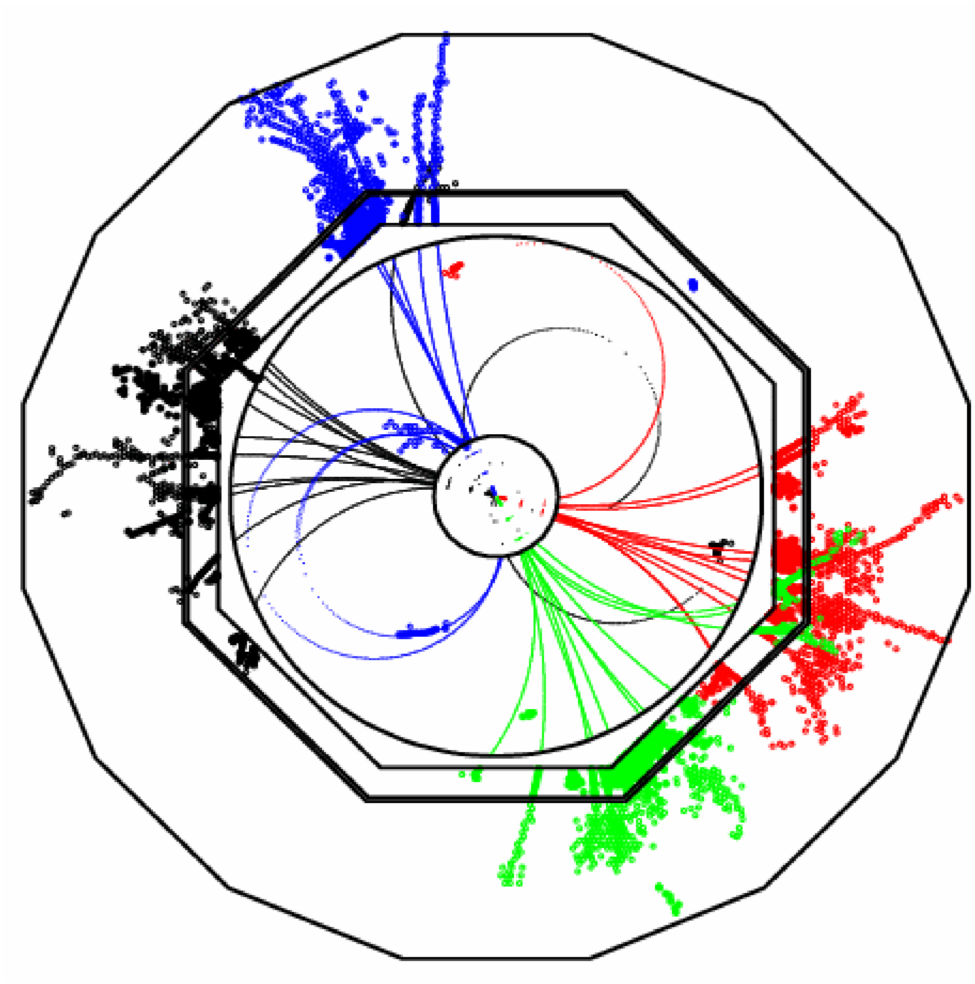


This Talk:

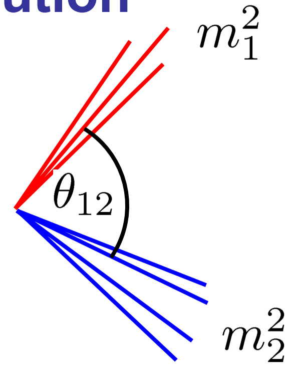
❶ PFA Goals
❷ Status at LCWS07
❸ Recent Improvements
❹ Current Performance
❺ Summary
❻ What next ?

❶ 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 %

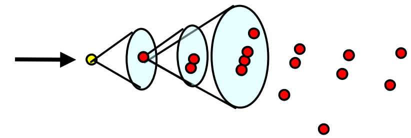
★ Typical di-jet energies at ILC (100-300 GeV) suggests jet energy resolution goal of $\sigma_E/E < 0.30/\sqrt{E_{jj}(\mathrm{GeV})}$

❷ Status at LCWS07

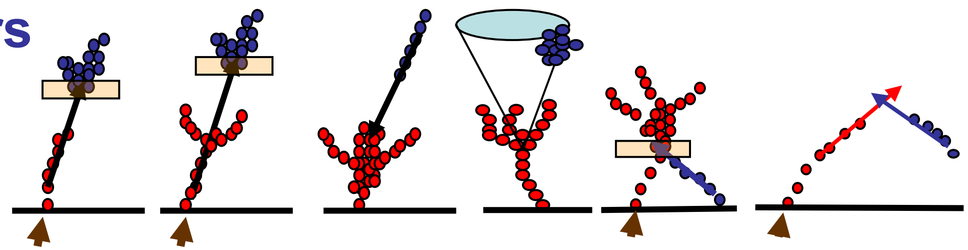
Eight Main Stages:

i. Preparation (isolation cuts etc.)

ii. Loose clustering in ECAL and HCAL

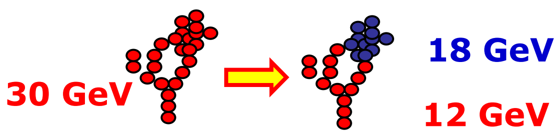


iii. Topological linking of clearly associated clusters

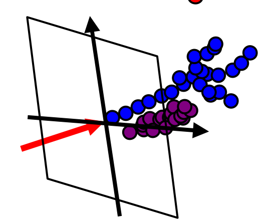


iv. Courser grouping of clusters

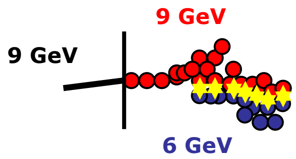
v. Iterative reclustering



vi. Photon Recovery (NEW for LCWS07)



vii. Fragment Removal (NEW for LCWS07)



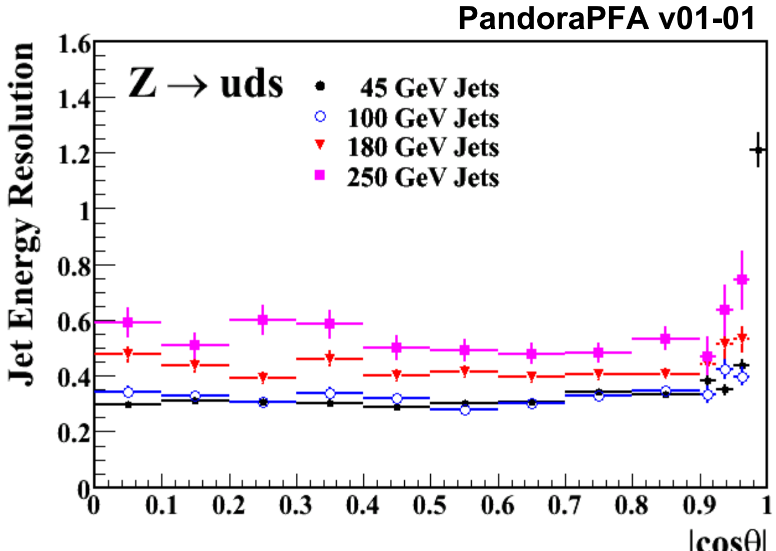
viii. Formation of final Particle Flow Objects

LCWS07 performance

★ 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*

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 achieve

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

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

❸ Recent Improvements

Overview:

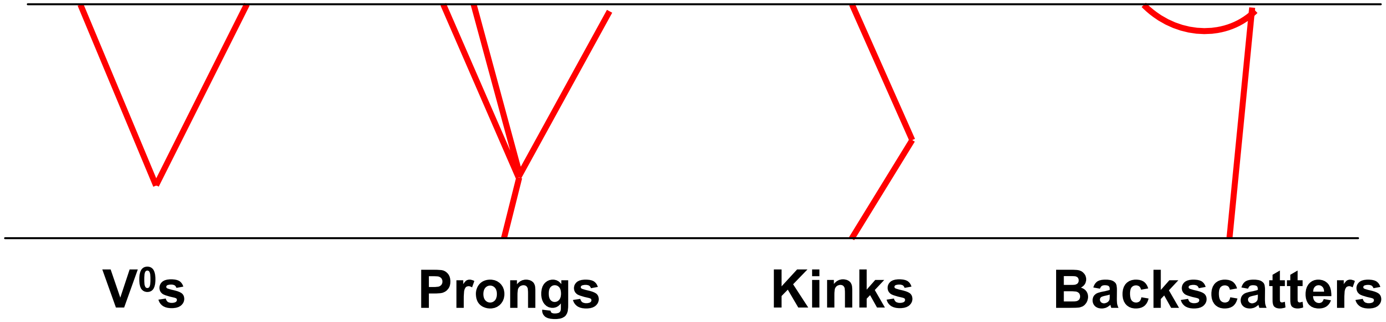
- ★ Technical Improvements
  - ♦ minor bug fixes
  - ♦ reduced memory footprint (~ factor 2) by on-the-fly deleting of temporary clusters, rather than waiting to event end
- ★ Use of tracks (still TrackCheater)
- ★ Photon Identification
  - ♦ EM cluster profile identification
- ★ Particle ID
  - ♦ Much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

① Tracking

- Still based on TrackCheater **Pattern Recognition** with fitted helices for momenta and reconstructed quantities
  - Will move to LDCTracking but want to determine "ideal" performance first
- Previously only used vertex tracks (within 5cm of IP) and kinks + V^0s
- Big effort to use as many tracks in the event as possible
  - helps particularly for lower energy jets
  - motivation I : better energy resolution
  - motivation II : correct measurement of direction
- **TPC-oriented:** take advantage of pattern recognition capability

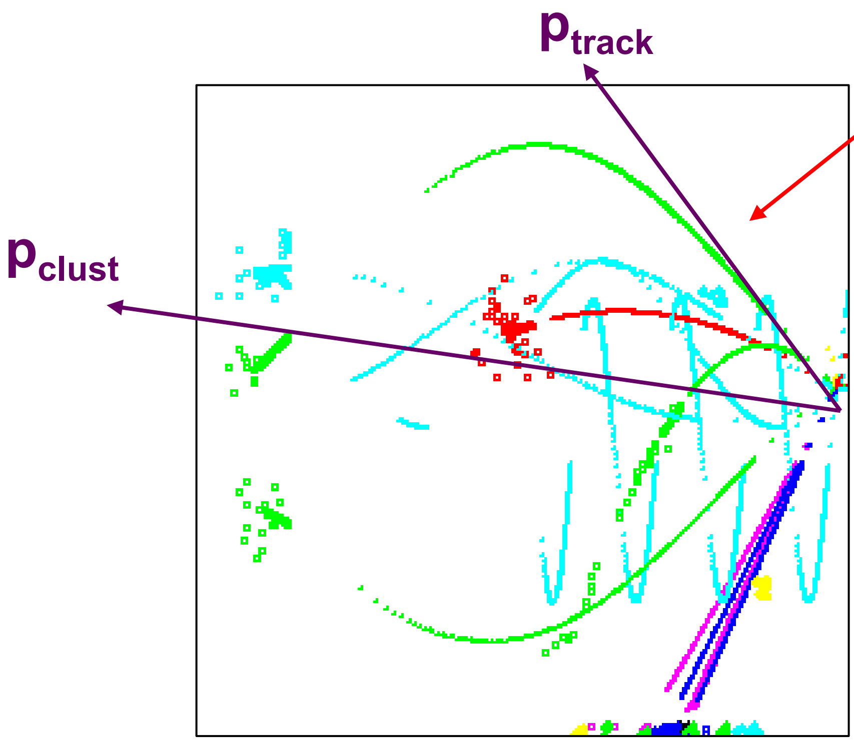
  (some aspects of code would need modification for Si tracker)

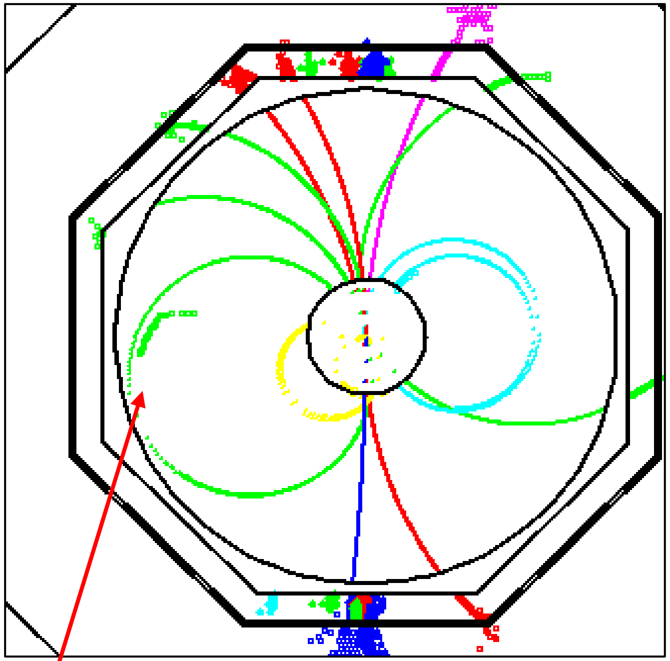
- From cheated tracks identify:



e.g. Tracking I : extrapolation

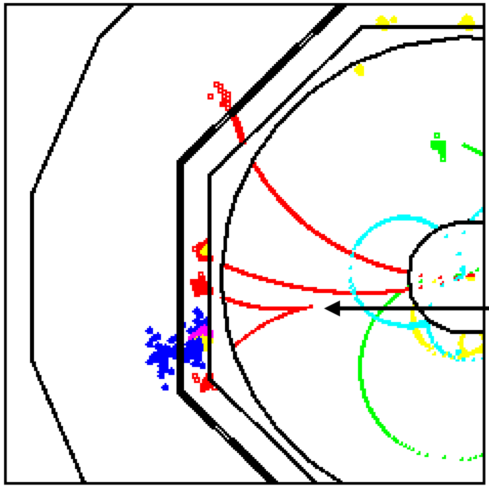
- If a track isn't matched to a cluster – previously track was dropped (otherwise double count particle energy)
- Not ideal – track better measured + <u>direction</u>





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

e.g. Tracking II : V^0s

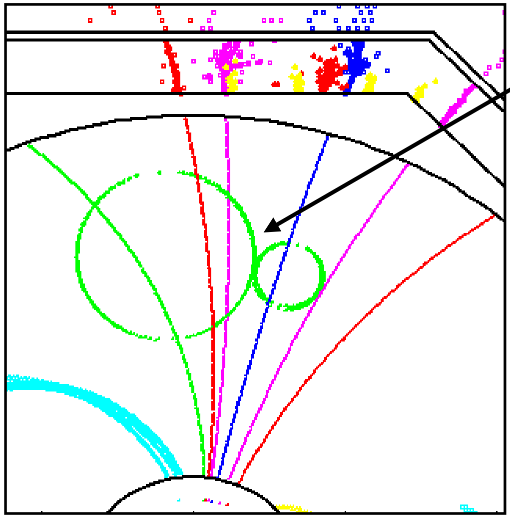


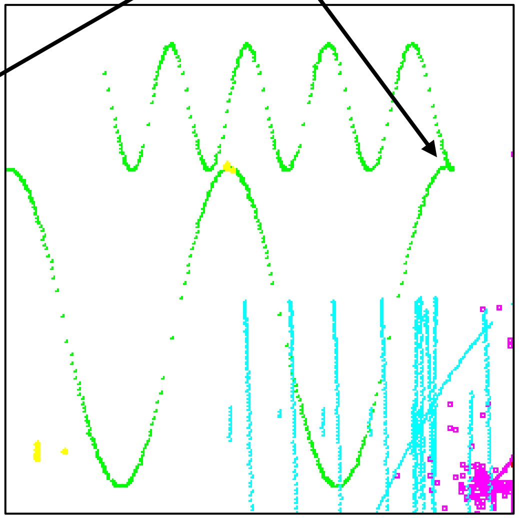
★ V^0 identification helps PFA as track momentum better measured than cluster energy

★ Previously V^0 identification for the main topology

★ Now extended to lower p_T tracks

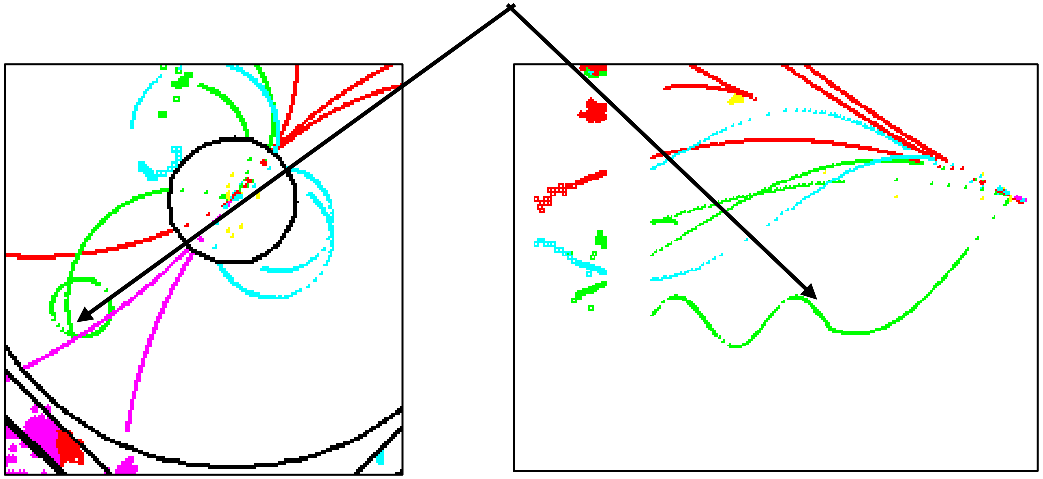
★ Most important for lower energy jets



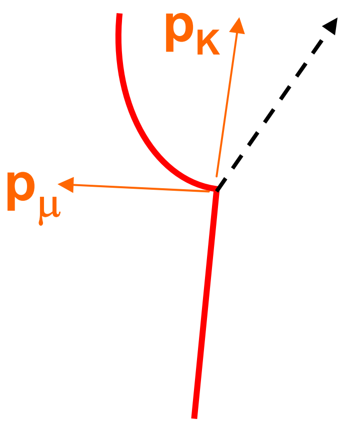


e.g. Tracking III: Kinks

★ Extended Kink finding to "loopers"



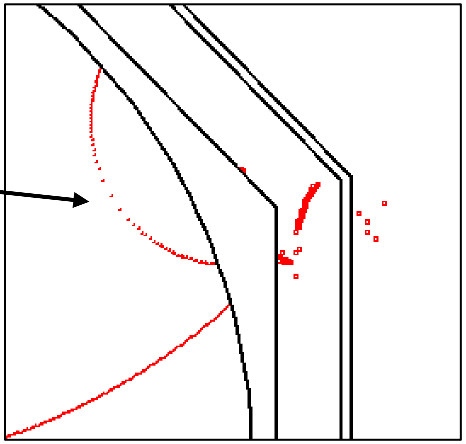
★ Improved (but still fairly crude) reconstruction missing energy



- Consider physics hypothesis, e.g. $K^\pm \rightarrow \mu^\pm \nu$
- Use Helix fits to start and end of tracks to reconstruct missing particle e.g. ν
- Can then reconstruct primary mass
- If consistent with hypothesis, e.g. m_K use primary track for PFO four-momentum

Tracking: Summary

★ Also IDs back-scatters – although not yet used for PFA



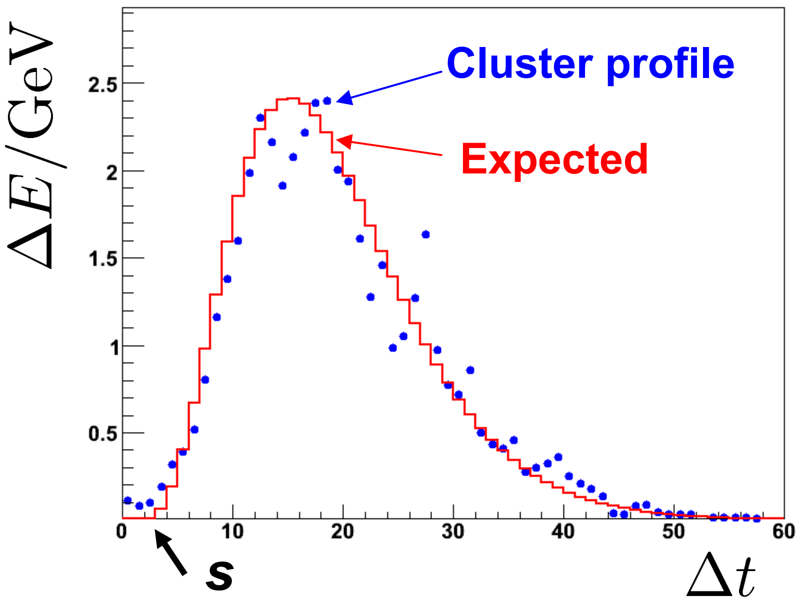
★ Bottom line – most tracks identified as "something" and used appropriately in PFA
★ Mainly affects PFA performance for low energy jets ~1-2% absolute improvement. Will soon quantify this

② Photon ID

- ★ Previously used simple cut-based photon ID
- ★ This is still used in the early (CPU intensive) stages of PandoraPFA
- ★ In the final stages use improved photon ID based on the expected EM longitudinal profile for cluster energy E_0

$$\Delta E = E_0 \frac{(t/2)^{a-1} e^{-t/2}}{\Gamma(a)} \Delta t \qquad a = 1.25 + \frac{1}{2} \ln E_0/E_c$$

- ★ Convert cluster into energy depositions **per radiation length**
  (use cluster to determine the layer spacing, i.e. geometry indep.)



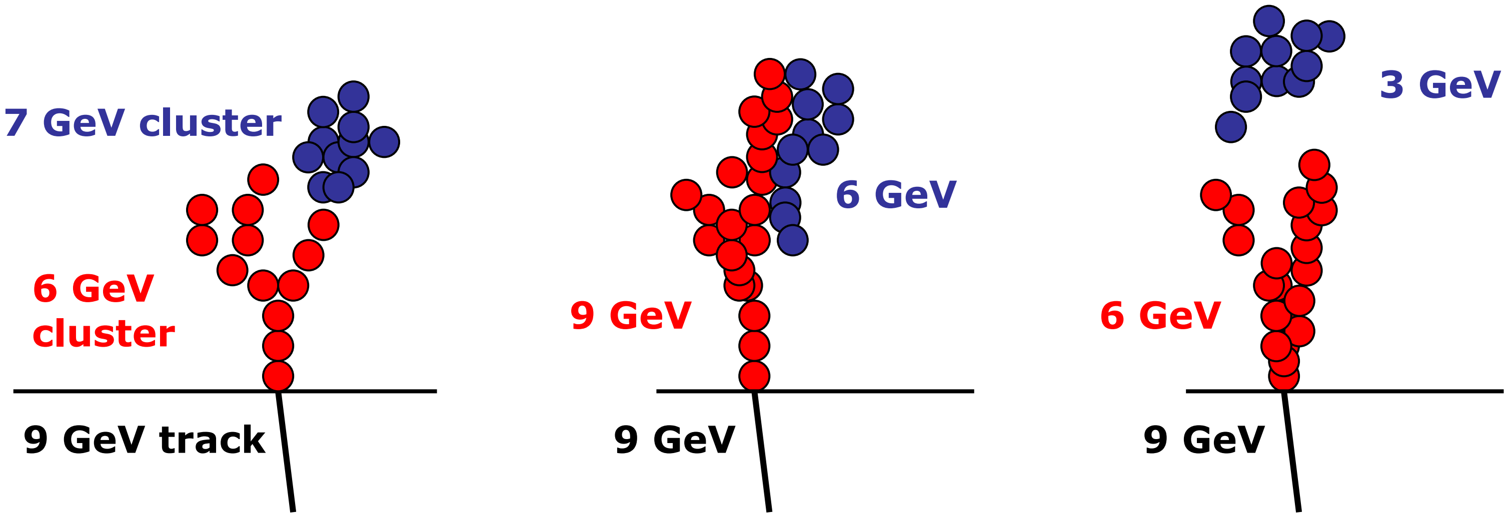
- ♦ Shower Profile fixed by cluster energy
- ♦ But fit for best shower start, ***s***
- ♦ Normalise areas to unity and calc.

$$f = \sum_i |o_i - e_i|$$

- ♦ Gives a measure of fractional
- ♦ disagreement in obs/exp profiles
- ♦ Use ***f*** and ***s*** to ID photons
- ♦ Small improvement in PFA perf.

③ Fragment Removal

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

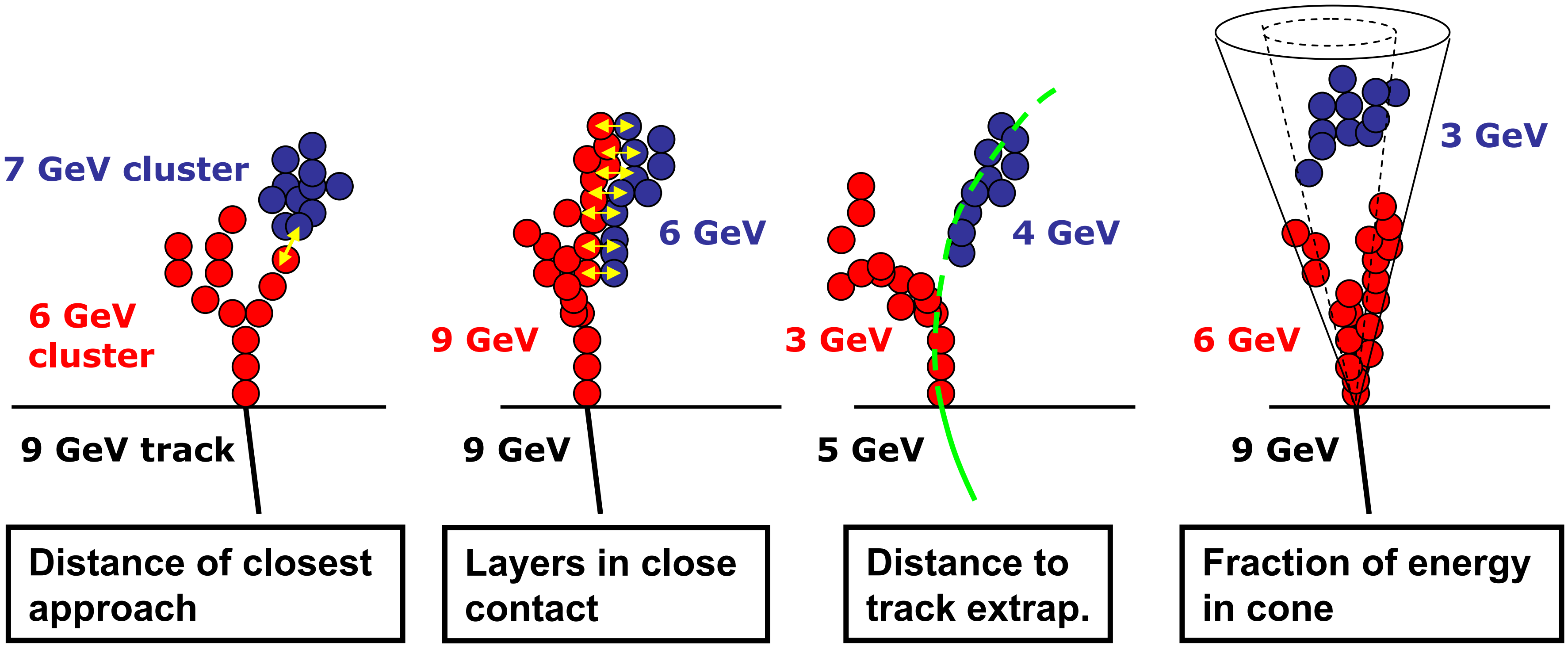


★ Previously the code to do this was **"a bit of a mess"**

★ 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

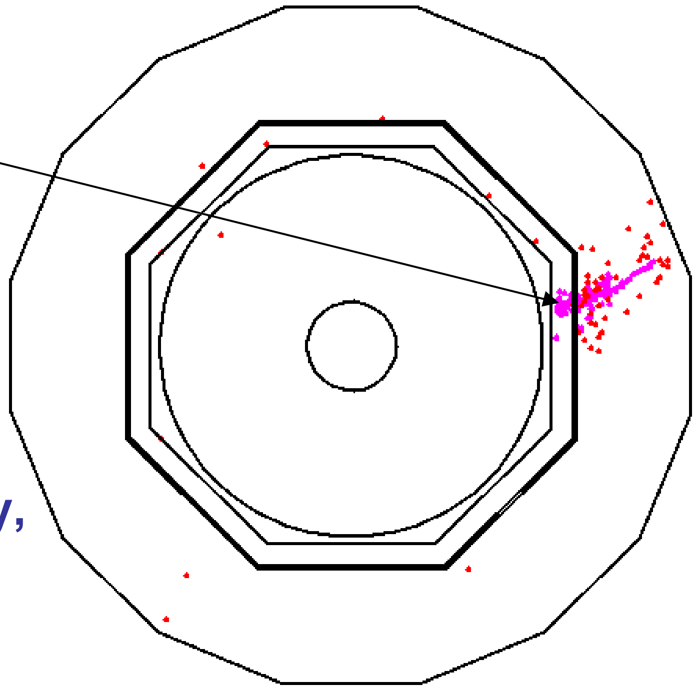
★ Rather *ad hoc* but works well (slight improvement wrt. previous)

④ "Calibration"

- ★ Current benchmark studies with LDC00Sc model
- ★ Wenbiao (see previous talk) pointed out non-linearity in calibration, i.e. energy dependence in E_{PFA}/E_{TRUE} for single K_L, n, …
- ★ Tracked down the origin of this effect to isolation cuts
- ★ PandoraPFA throws away isolated hits, i.e. hits which are not clustered and are > 10 cm from a hit in an existing cluster

<u>e.g. single **10 GeV K_L**</u>

Clustered hits = magenta
Rejected hits = red

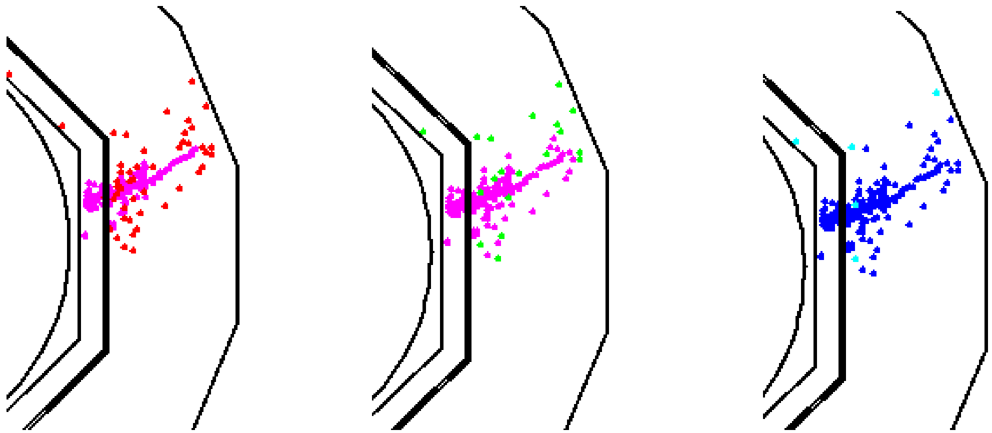


- At some level need to reject isolated hits for PFA as in dense environment not clear to which cluster they are associated
- The larger the cluster, i.e. higher energy, the more chance of picking up the fuzz

⇒ Non-linear response !

“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)

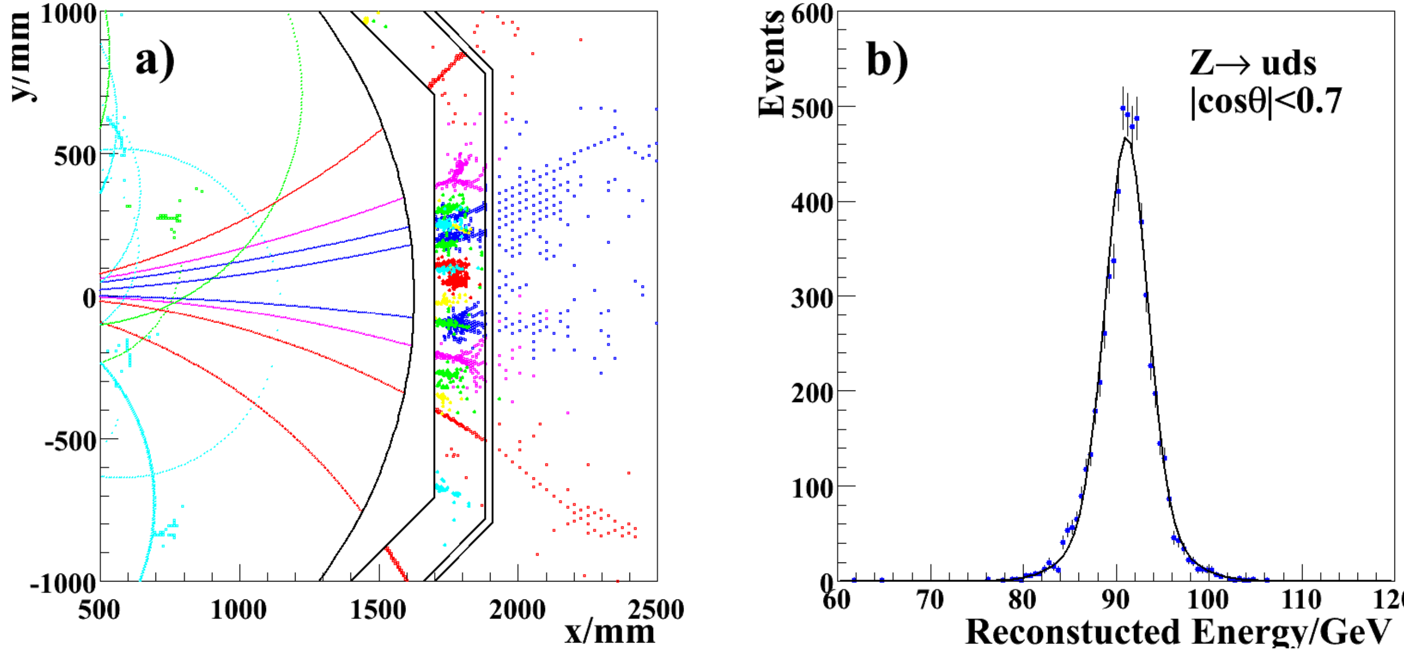
★ Best approach ?

❹ Current Performance

★ As always use barrel **Z → uds** (Mokka 6.1)
★ **LDC00Sc** model with increased 63 layer HCAL
★ **NOTE:** previously used older 91 GeV samples with 40 layer HCAL

★ Significant improvement in performance for low energy jets !

91 GeV Z → uds



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

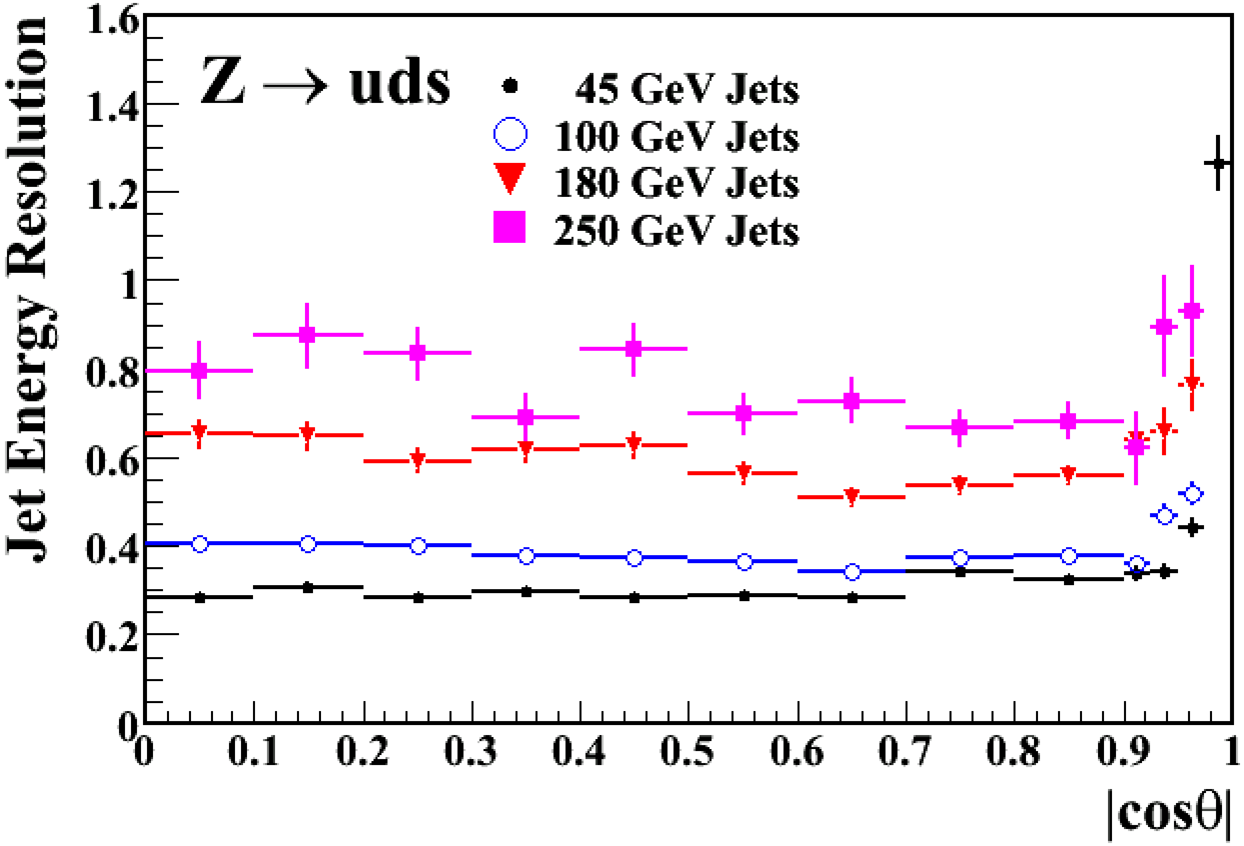
23 % / $\sqrt{E}$

★ For TESLA TDR detector "sweet spot" at just the right place 100-200 GeV jets !

★ However, only modest improvements at higher energy…

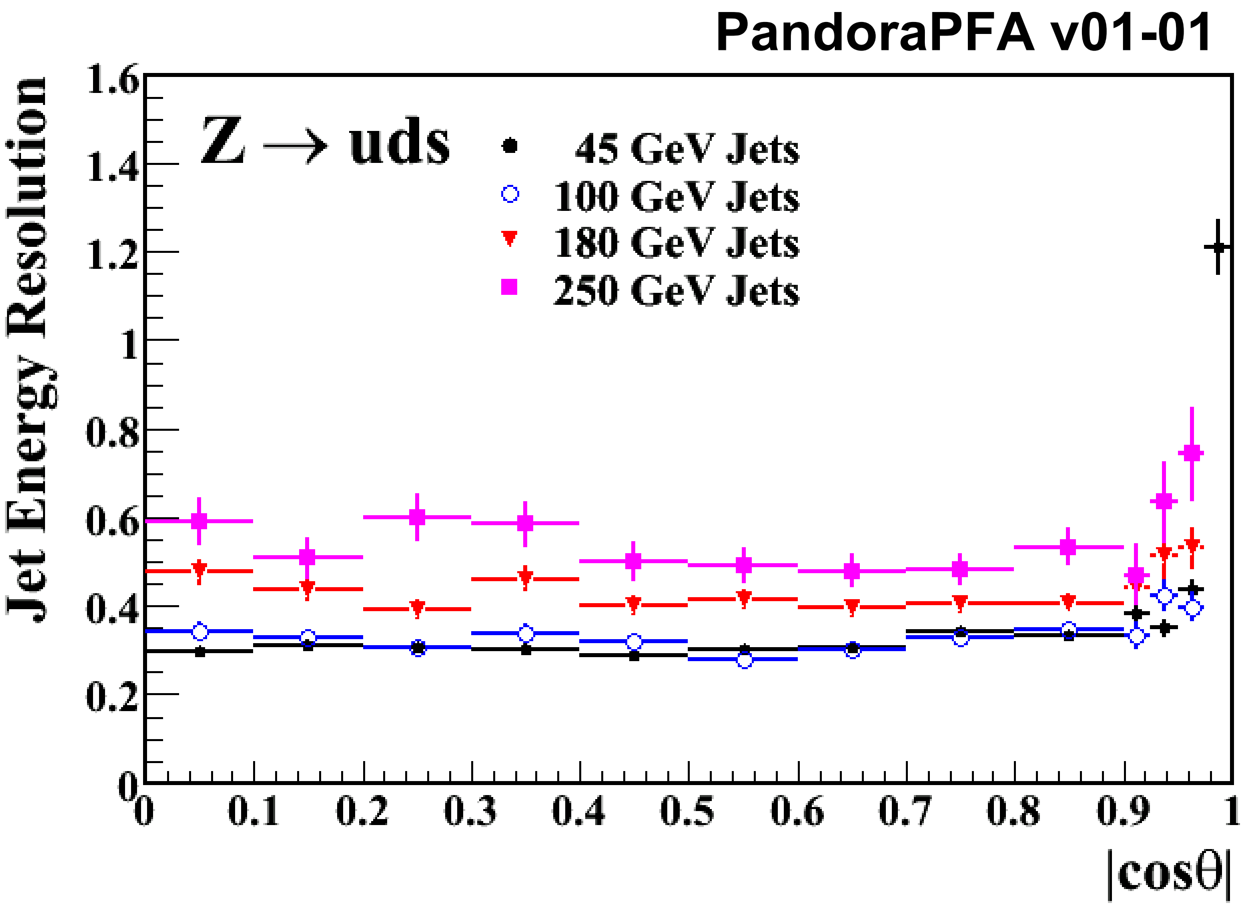
Evolution

PandoraPFA v00-α



09/2006

Evolution



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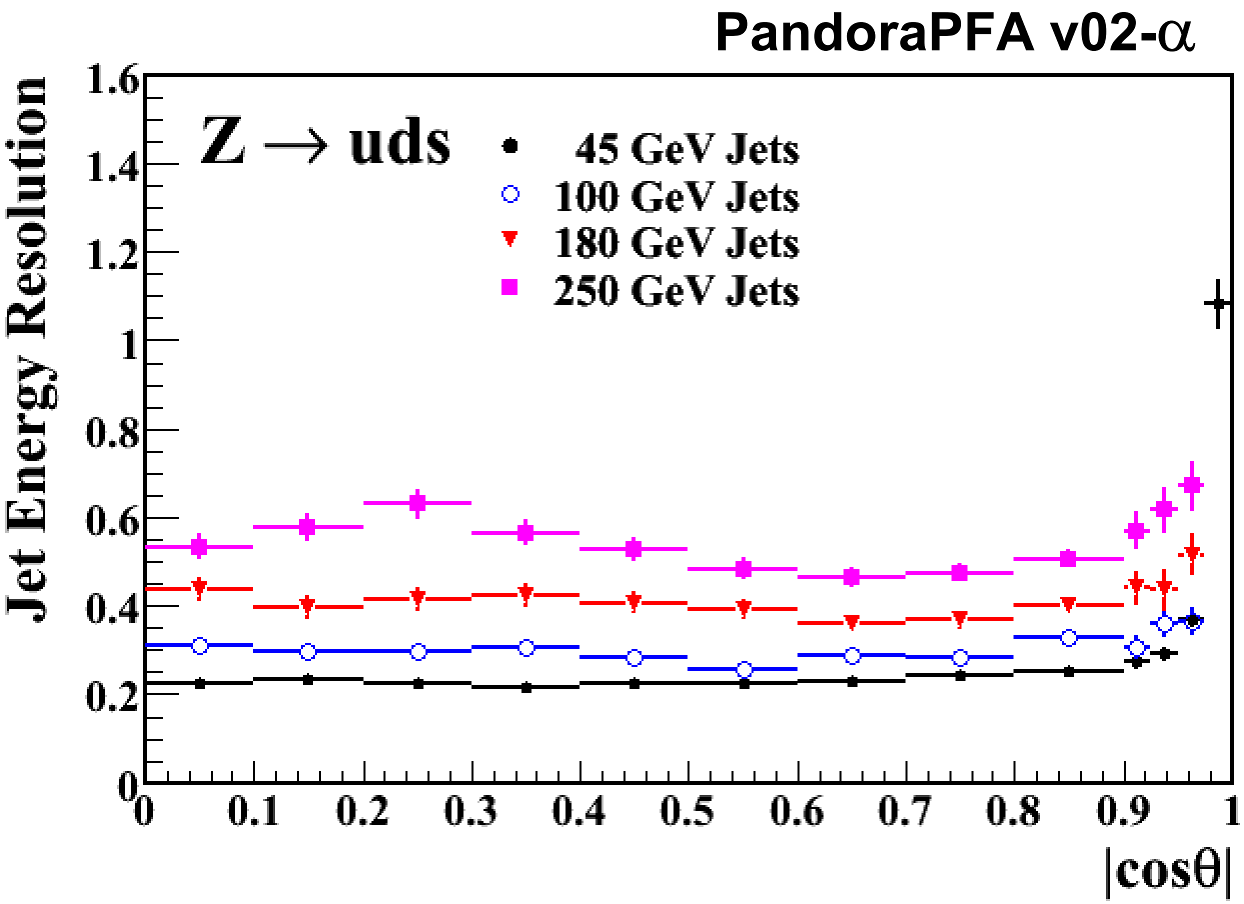
Evolution



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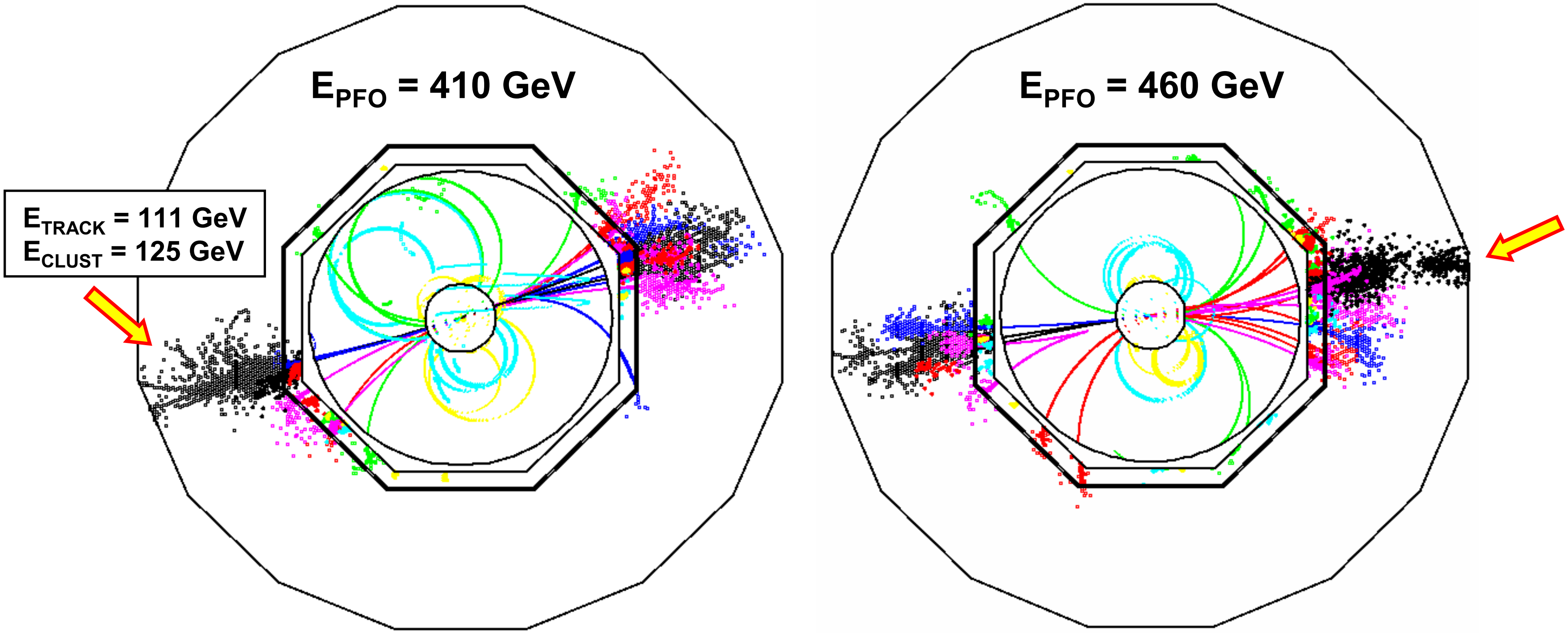
High Energy Performance

- ★ High energy performance stuck at 53%/√E – why ?
- ★ Don't fully understand – but there are some ideas
  - ♦ For 250 GeV jets hadronic showers are large and overlap, different clustering algorithm may help (in reclustering)
  - ♦ Leakage becomes (very?) important



- ★ Plenty of room for improvement – but not trivial

❺ 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)

❻ 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.