A flexible approach to cluster-finding in generic calorimeters of the FLC detector

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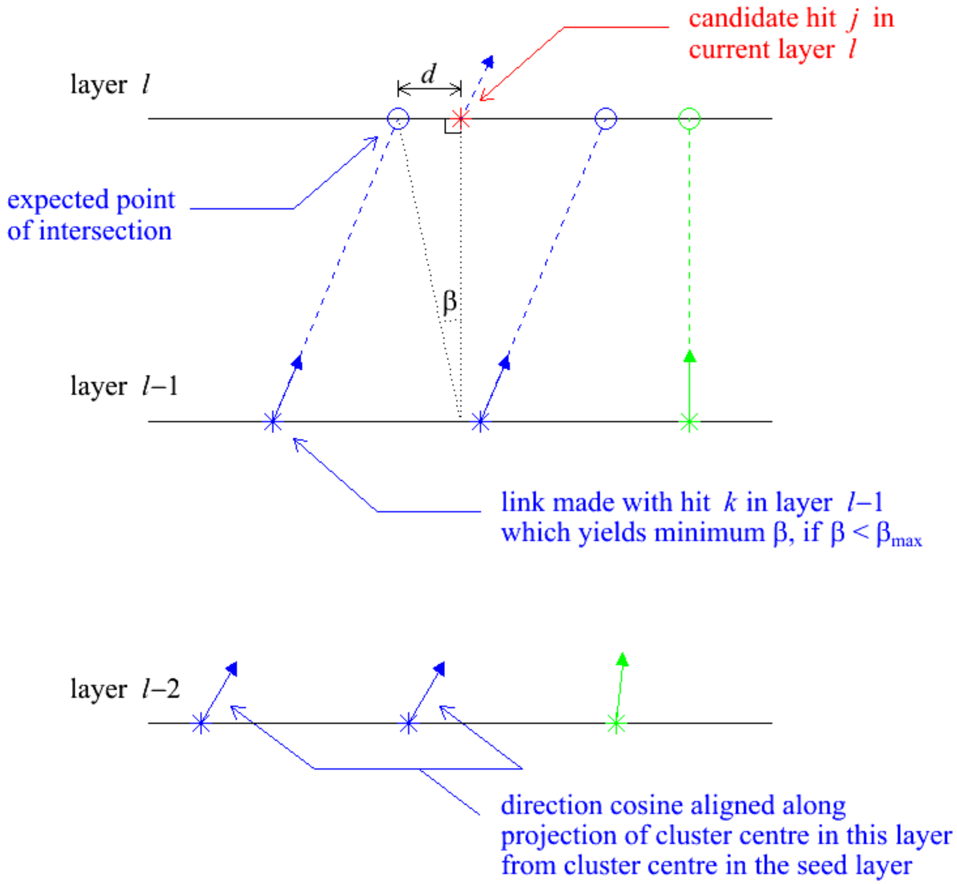
2nd ECFA Workshop: simulation/reconstruction session
1–4 September 2004, Durham, U.K.

Outline

- Tracker-like clustering algorithm: the basis.
- Recap from LCWS ’04 (Paris).
- Progress towards a generalised, geometry-independent, MC-independent framework.
- How it works.
- Event gallery.
- A few words on Minimal Spanning Tree (MST) approach (G.Mavromanolakis).
- Summary and outlook.

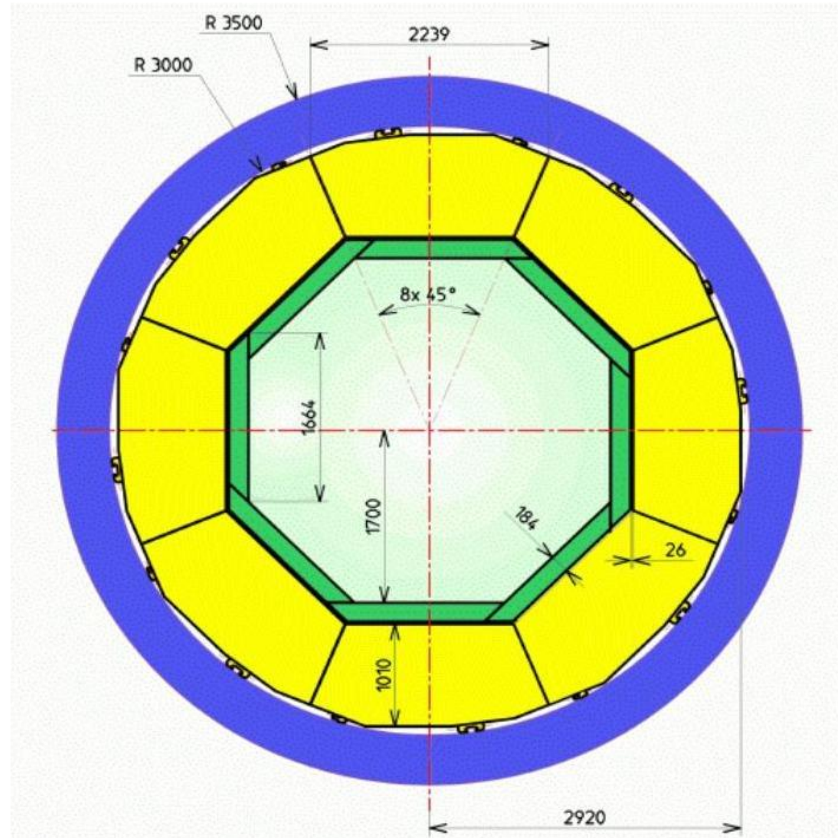
Tracker-like clustering algorithm: the basis



- Sum energy deposits within each cell.
- Retain cells with total hit energy above some threshold (⅓ MIP; adjustable).
- Form clusters by tracking closely-related hits layer-by-layer through calorimeter:
  - for a given hit j in a given layer ℓ, minimize the angle β w.r.t all hits k in layer ℓ-1;
  - if $\beta < \beta_{max}$ for minimum b, assign hit j to same cluster as hit k which yields minimum;
  - if not, repeat with all hits in layer ℓ-2, then, if necessary, layer ℓ-3, etc.;
  - after iterating over all hits j, seed new clusters with those still unassigned;
  - calculate weighted centre of each cluster's hits in layer ℓ (weight by energy (analogue) or density (digital));
  - assign a direction cosine to each hit along the line joining its cluster's centre in the seed layer (or (0,0,0) if it's a seed) to its cluster's centre in layer ℓ;
  - propagate layer-by-layer through Ecal, then Hcal;
  - retrospectively match any backward-spiralling track-like cluster fragments with the forward-propagating cluster fragments to which they correspond using directional and proximity information at the apex of the track.

Recap from LCWS '04 (Paris, 19–23 April)

- Demonstrated application of algorithm to TESLA TDR calorimeters (*barrel* only).
- Relied upon layer index varying smoothly: problems foreseen where it changes abruptly
  - at stave boundaries in Ecal barrel (layers overlap at 45°);
  - at barrel/endcap boundaries in Ecal & Hcal (layers overlap at 90°).
- Clusters tracked layer-by-layer through *each octant of barrel separately* (layers parallel; layer index varies smoothly) ⇒ wasn't designed to cope with cross-talk between octants (just first try!).
- Now need to address cluster-tracking
  - across octant boundaries in barrel;
  - across barrel/endcap boundaries.
- Would like this to be independent of specific geometry, while retaining layer-by-layer approach.



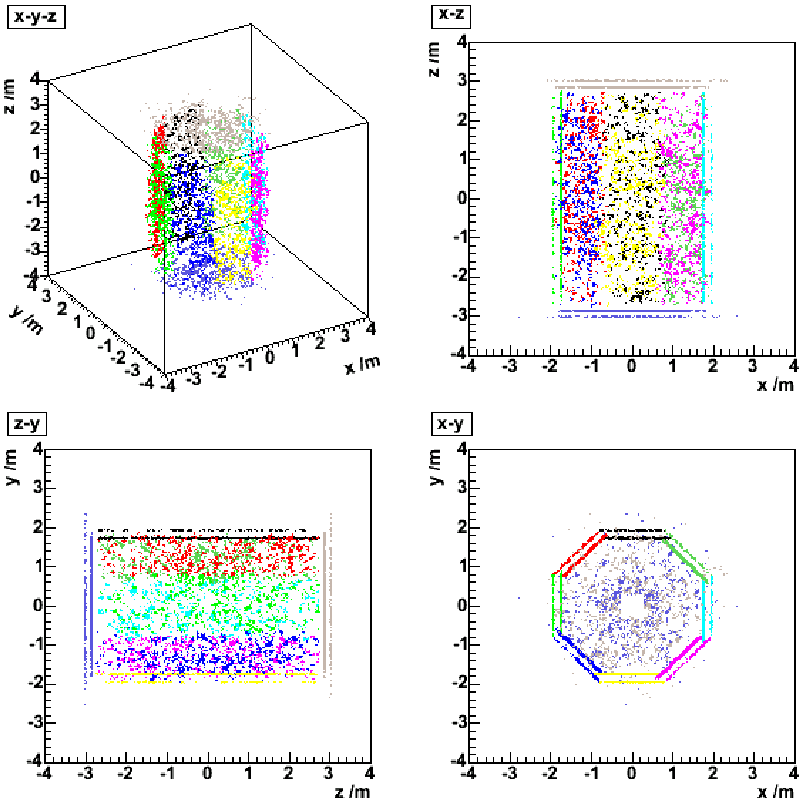
Progress

- Layer indices of hits redefined ("*pseudolayers*") in regions where discontinuities occur (*i.e.* where planes of layers change direction and overlap).
- For TESLA TDR design, hits with same pseudolayer index defined by closed shells of octagonal prisms coaxial with z-axis $\Rightarrow$ pseudolayer index contrived to vary smoothly throughout entire detector (as required).
- Shells located by projected intersections of like-numbered real, physical layers at stave boundaries.
- Pseudolayer index automatically encoded by distances of layers from z-axis (barrel) and $z = 0$ plane (endcaps) *i.e.* idea applicable to *any* likely geometry.
- For general design with an n-fold rotationally symmetric barrel (TESLA: $n = 8$), pseudolayers defined by n-polygonal prisms.

From layers to pseudolayers (TESLA TDR)

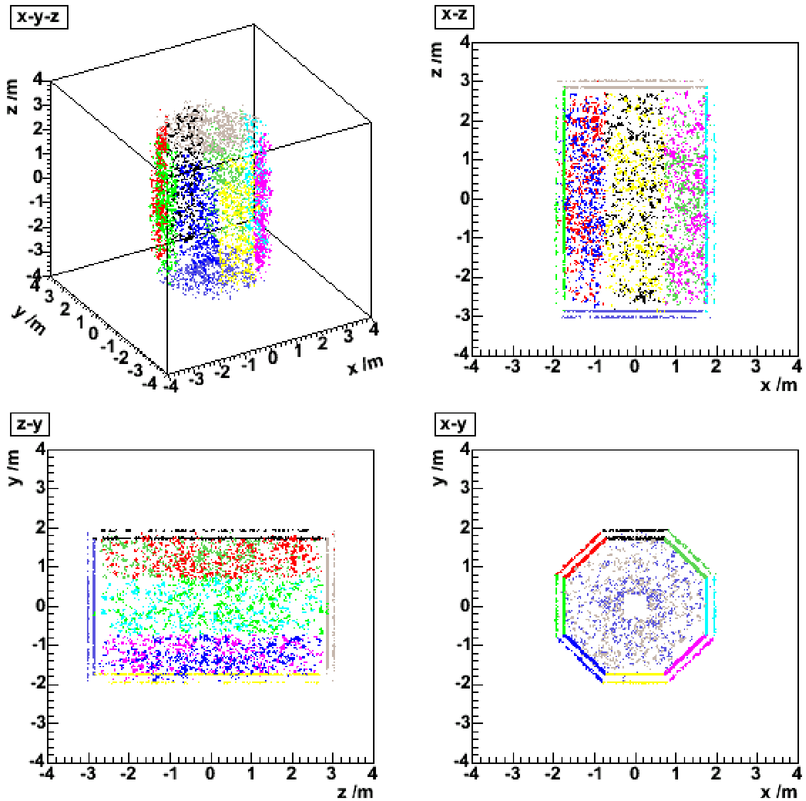
Layers

- Layer index changes discontinuously at:
  (i) stave boundaries in Ecal barrel;
  (ii) barrel/endcap boundaries in Ecal & Hcal.



Pseudolayers

- Define "pseudolayers" as shells of coaxial octagonal prisms ⇒ discontinuities removed; pseudolayer indices vary smoothly.

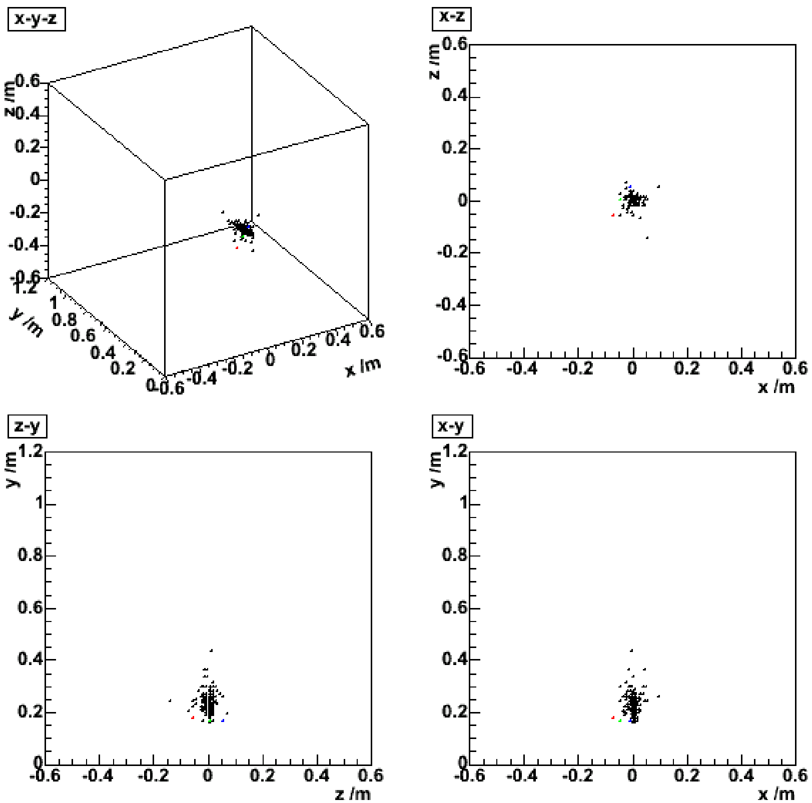


How it works in practice

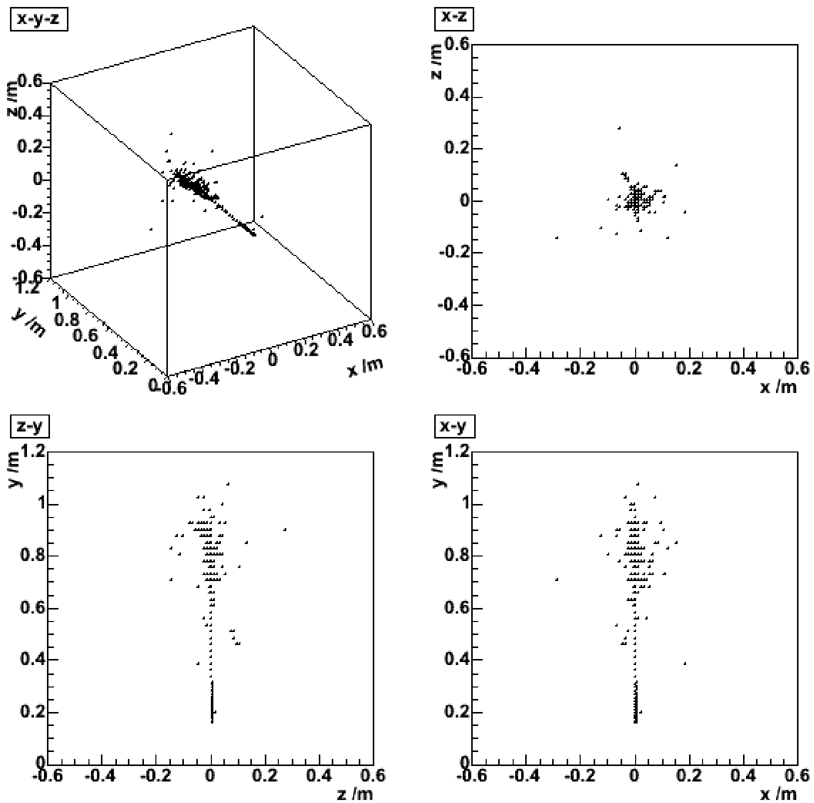
- User free to define degree of rotational symmetry of barrel (*n*), and layer spacings and locations in barrel and (assumed identical) endcaps to study his/her favourite detector design *i.e.* not tied to a particular geometry .
- Pseudolayer indices of hits automatically calculated from (x,y,z) alone, given above geometry definitions.
- Clustering algorithm works as described earlier, with layer indices replaced by pseudolayer indices *i.e.* clusters tracked pseudolayer-by-pseudolayer.
- Various modes (all tested) can be selected (results largely mode-independent):
  - fully analogue (hits weighted by energy in Ecal & Hcal) *e.g.* W/Si Ecal, Fe/scintillator Hcal;
  - semi-digital (hits weighted by energy in Ecal, density in Hcal) *e.g.* W/Si Ecal, rpc Hcal;
  - fully digital (hits weighted by density in Ecal & Hcal) *e.g.* MAPS Ecal, rpc Hcal.
- Independent of Monte Carlo program (tested with Mokka TDR/D09/prototype, Brahms TDR – using LCIO hit output).
- Clusters stored as LCIO (v. 1.1-beta) objects (work in progress).

15 GeV e^-/π^+ events: Mokka prototype

15 GeV e^-



15 GeV π^+



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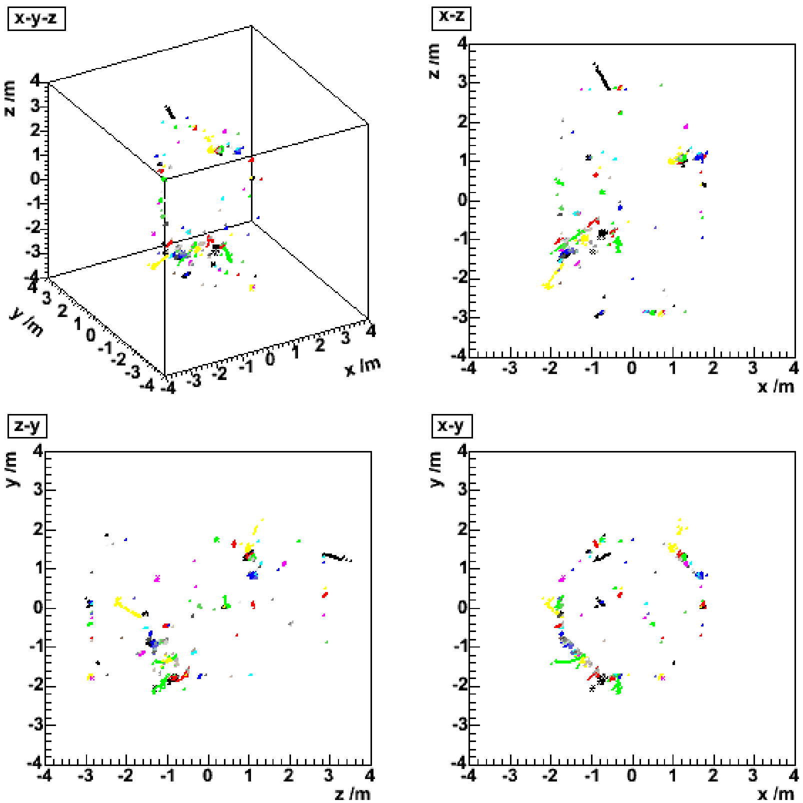
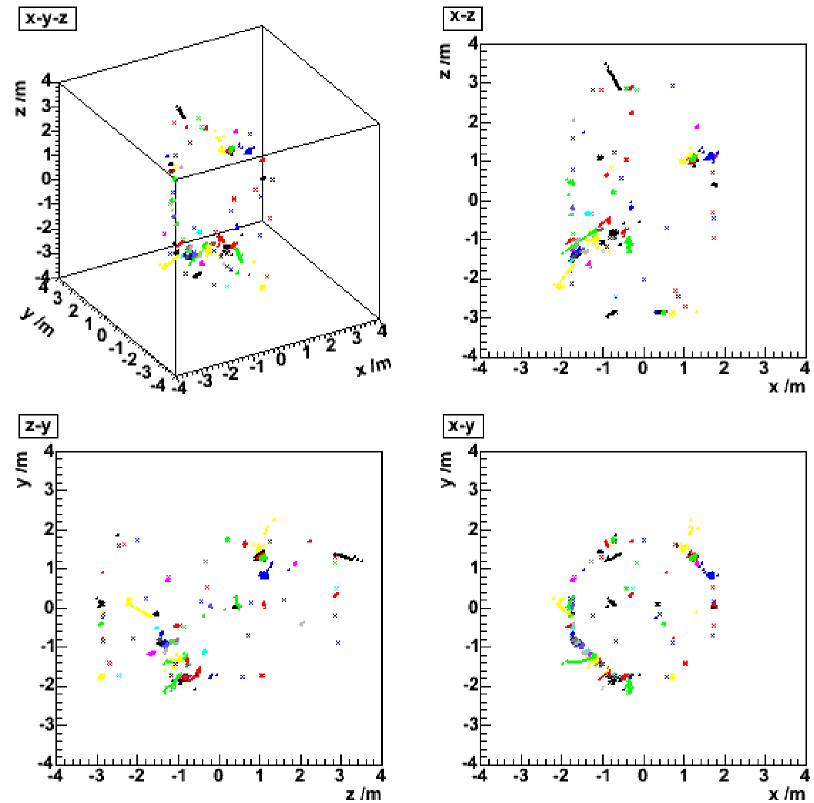
91 GeV Z event: Mokka D09 detector

Reconstructed clusters

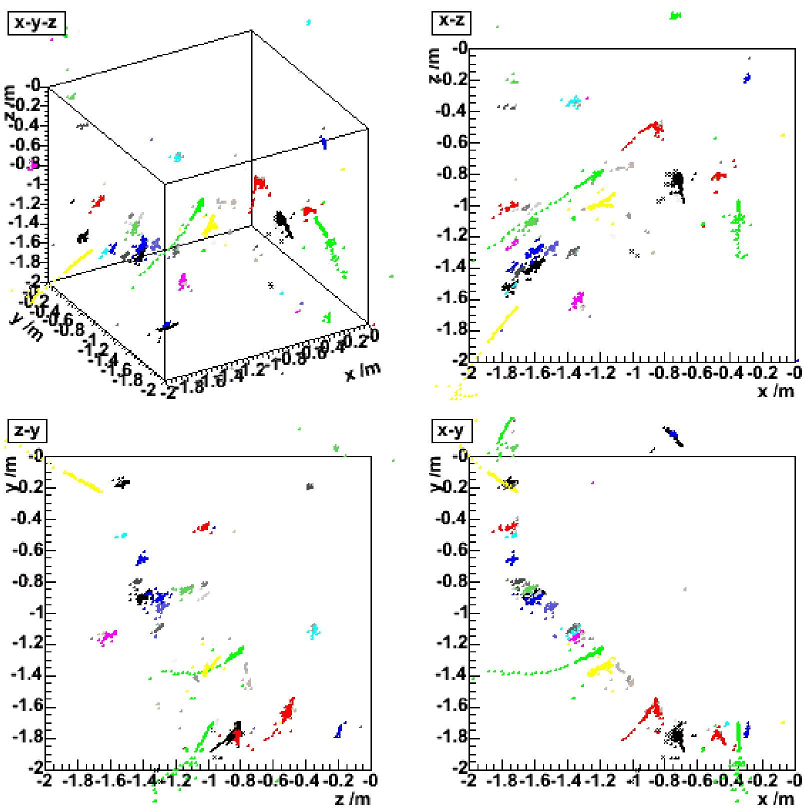


True particle clusters

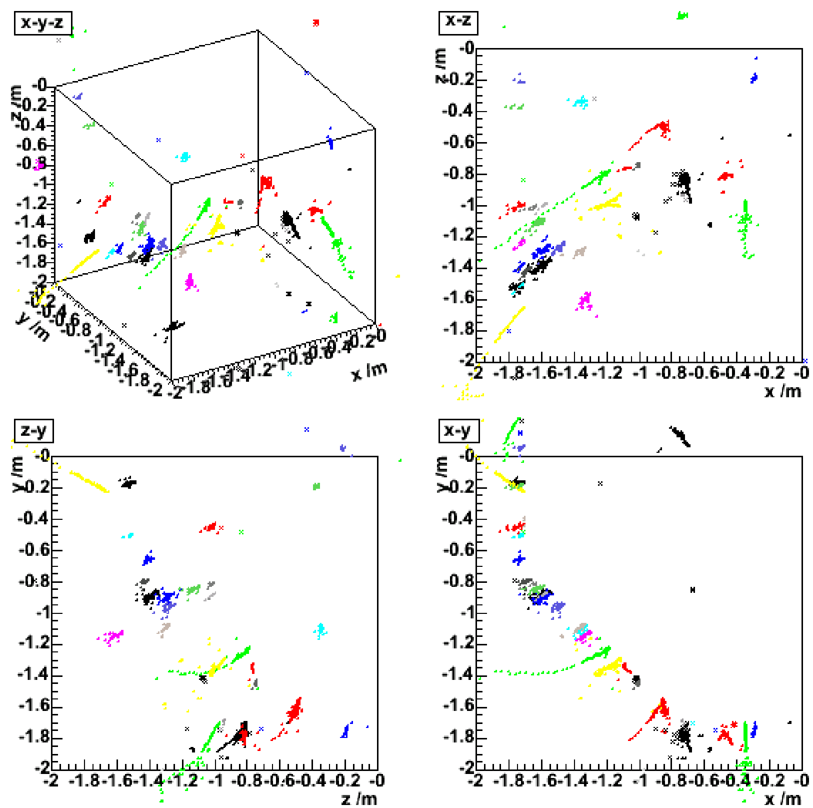


91 GeV Z event: Zoom 1

Reconstructed clusters

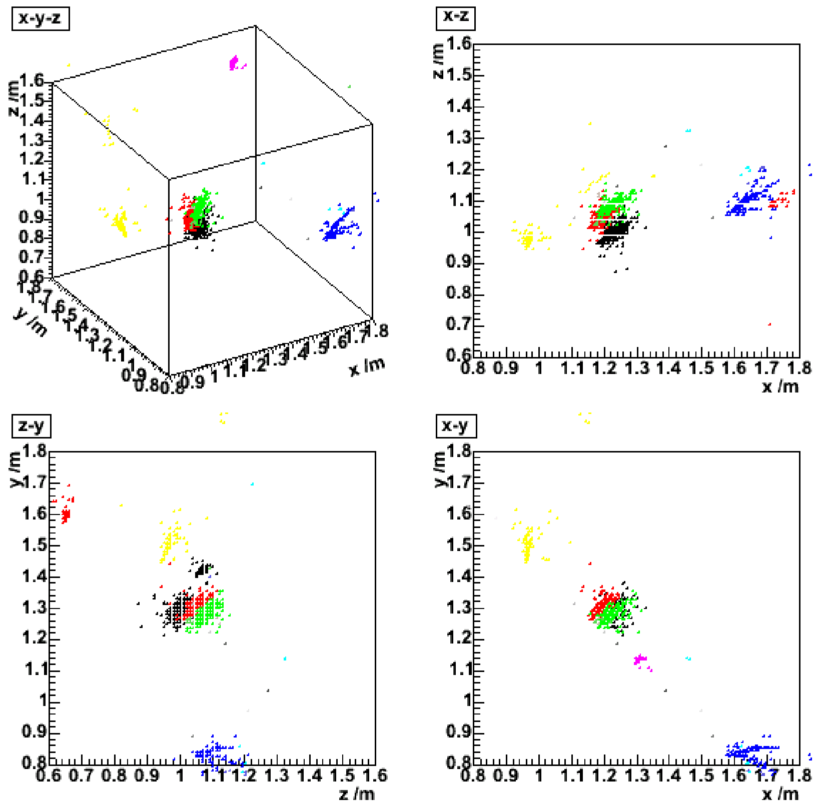


True particle clusters

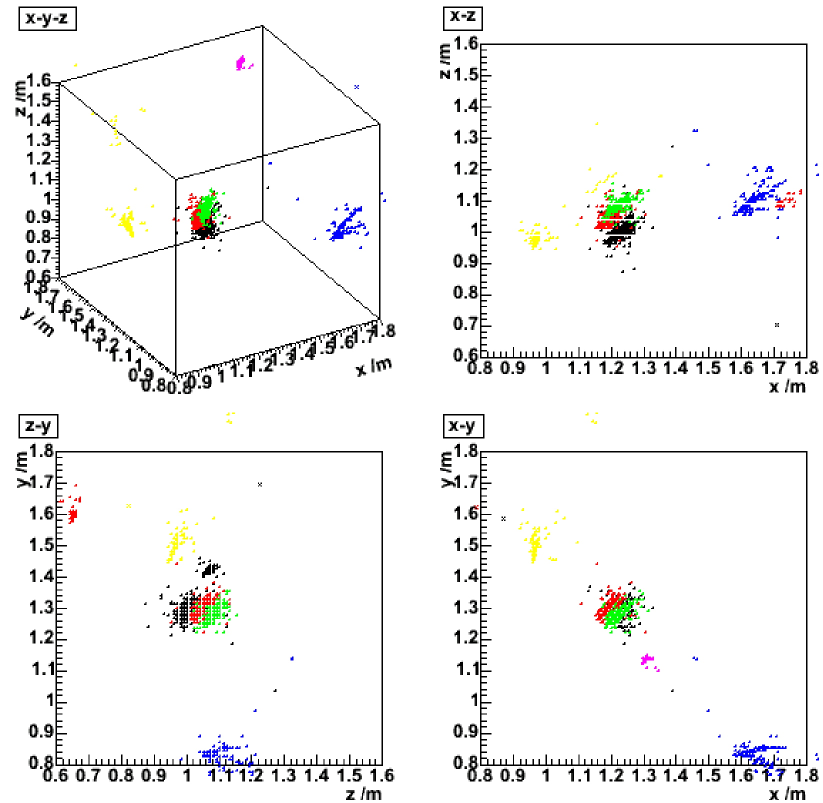


91 GeV Z event: Zoom 2

Reconstructed clusters



True particle clusters



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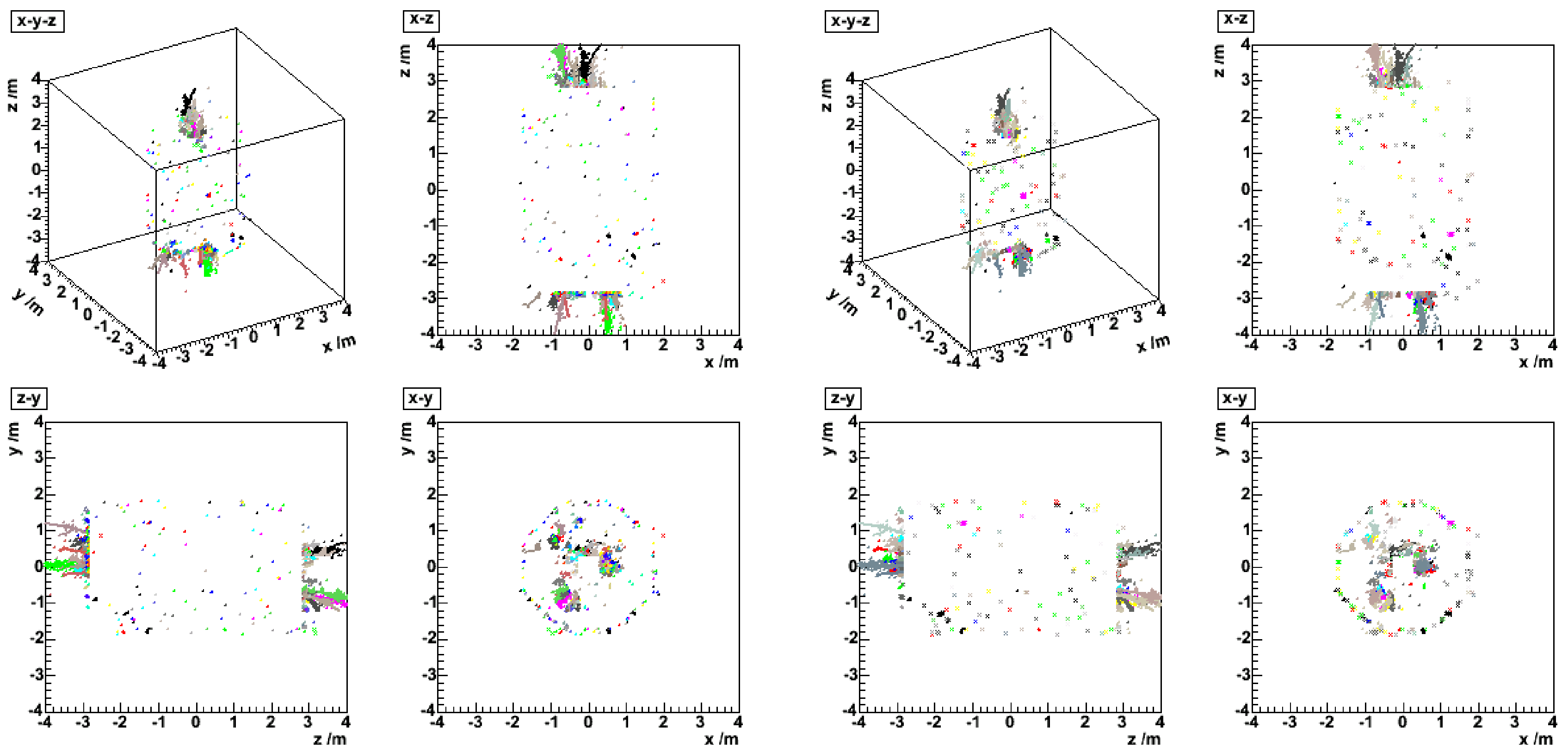
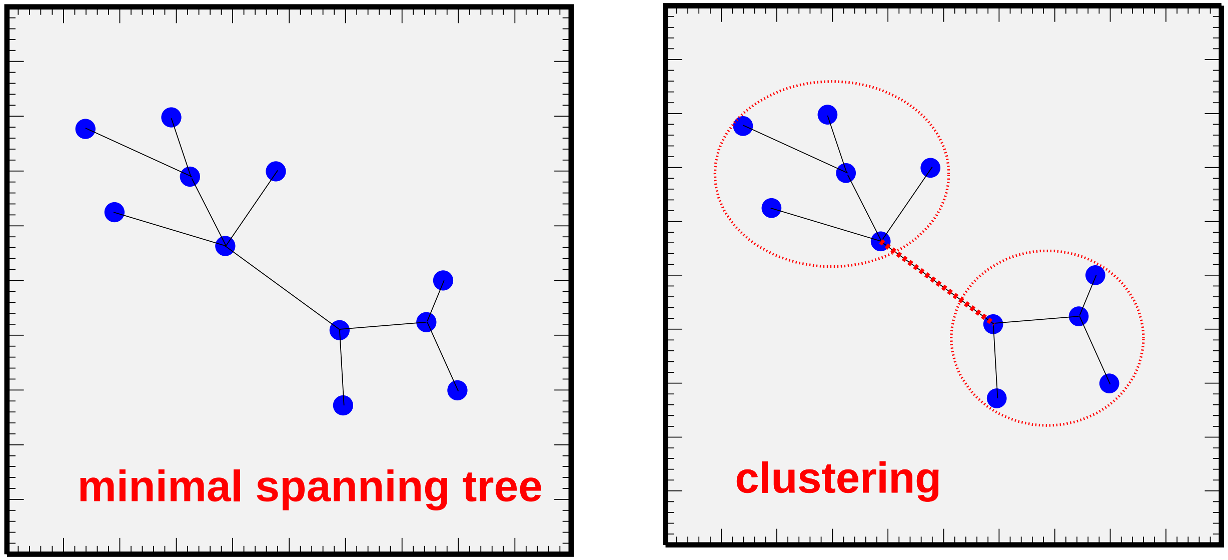
800 GeV W^+W^- event: Mokka D09 detector

Reconstructed clusters | **True particle clusters**



Minimal Spanning Tree approach (G.Mavromanolakis)



- **Minimal Spanning Tree** – a tree which contains all nodes with no circuits, such that sum of weights of its edges is a minimum.
- **Clustering** – algorithm for cutting the MST.

MST (continued)

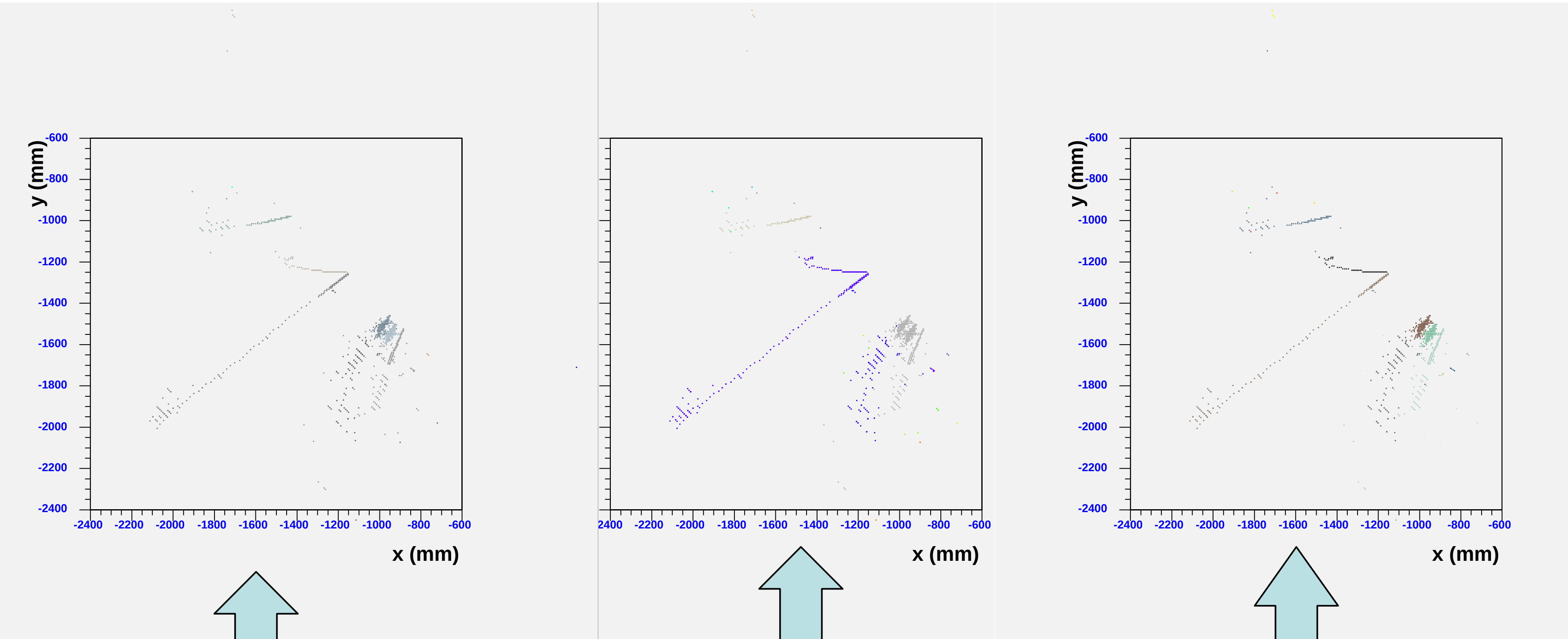
Top-down and then bottom-up clustering

- Use MST algorithm with loose cut to perform coarse clustering (e.g. at the scale of jets?)
- For each MST cluster found, refine using a cone-like clustering approach.

Advantages?

- Speed – preclustering – important for a very granular calorimeter even if occupancy is low.
- Reduced geometry dependence.
- Efficiency (hopefully).

MST clustering in action (Z event)



True clusters

After MST clustering

Final reconstructed clusters

Summary & outlook

- R&D on clustering algorithm for calorimeters at a future LC in progress.
- Approach utilizes the high granularity of the calorimeter cells to "*track*" clusters (pseudo)layer-by-(pseudo)layer.
- Through concept of pseudolayers, can be applied to any likely detector configuration

  $\Rightarrow$ straightforward to compare alternative geometries.
- Tested on prototype and full-detector geometries.
- Reads in hit collections from LCIO (v. 1.1-beta) files; will soon write out LCIO cluster collections, implementing appropriate member functions

  $\Rightarrow$ straightforward to compare alternative algorithms.

The End

That's all folks…

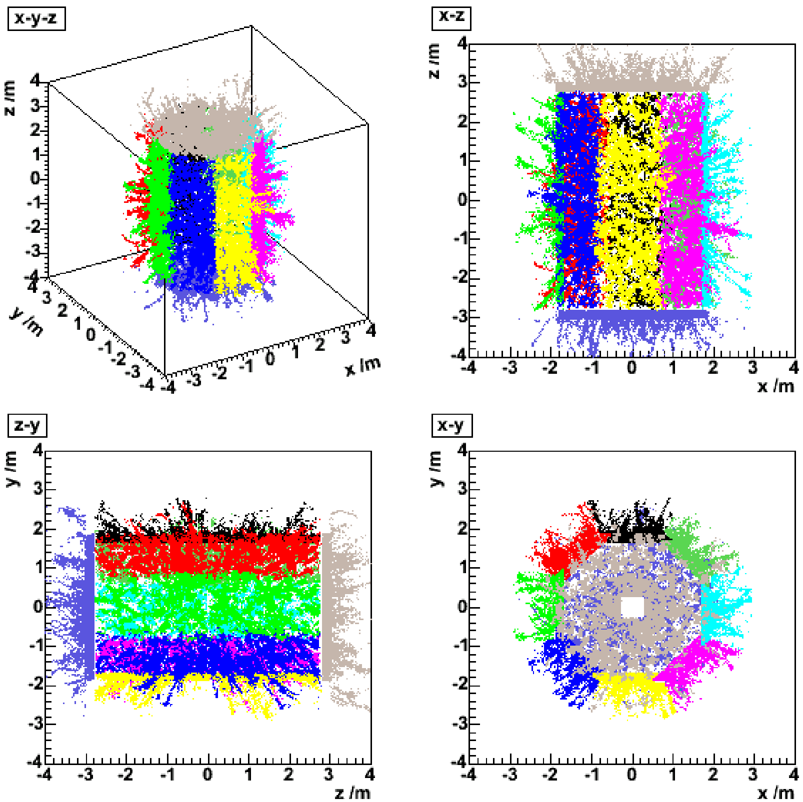
Motivation

- Desire for excellent jet energy resolution at future LC
  - ⇒ calorimeter needs to be highly granular to resolve individual particles within jets;
  - ⇒ calorimeter will have tracker-like behaviour: unprecedented;
  - ⇒ novel approach to calorimeter clustering required.
- Aim to produce a flexible clustering algorithm, independent of ultimate detector configuration and not tied to a specific MC program.
- Develop within an LCIO-compatible framework
  - ⇒ direct comparisons with alternative algorithms can be made straightforwardly.

From staves to pseudostaves (TESLA TDR)

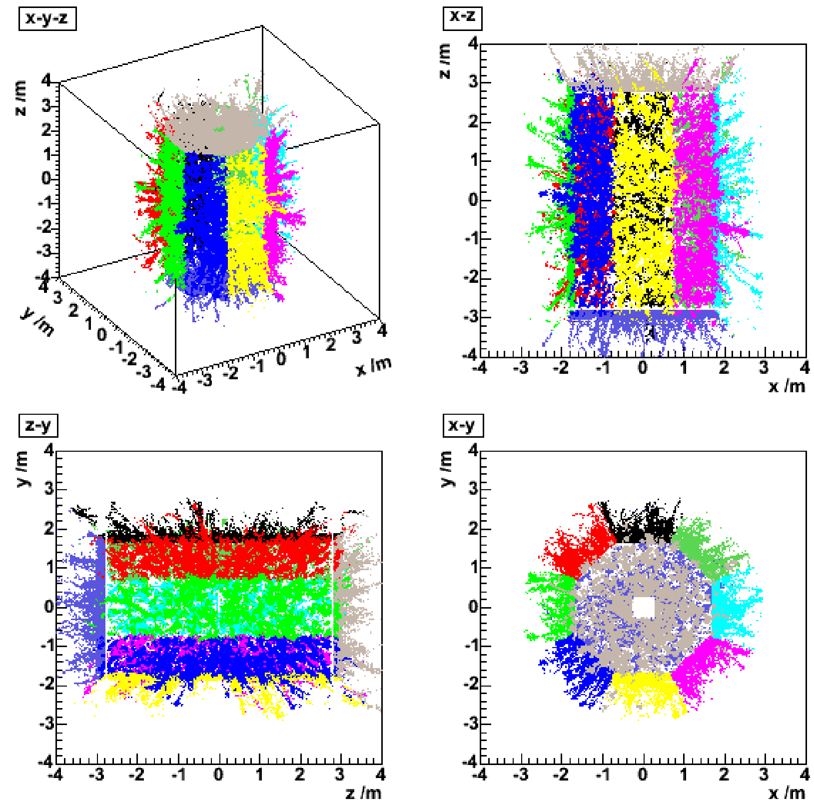
Staves

• Stave = plane of parallel layers



Pseudostaves

• Pseudostave = plane of parallel pseudolayers



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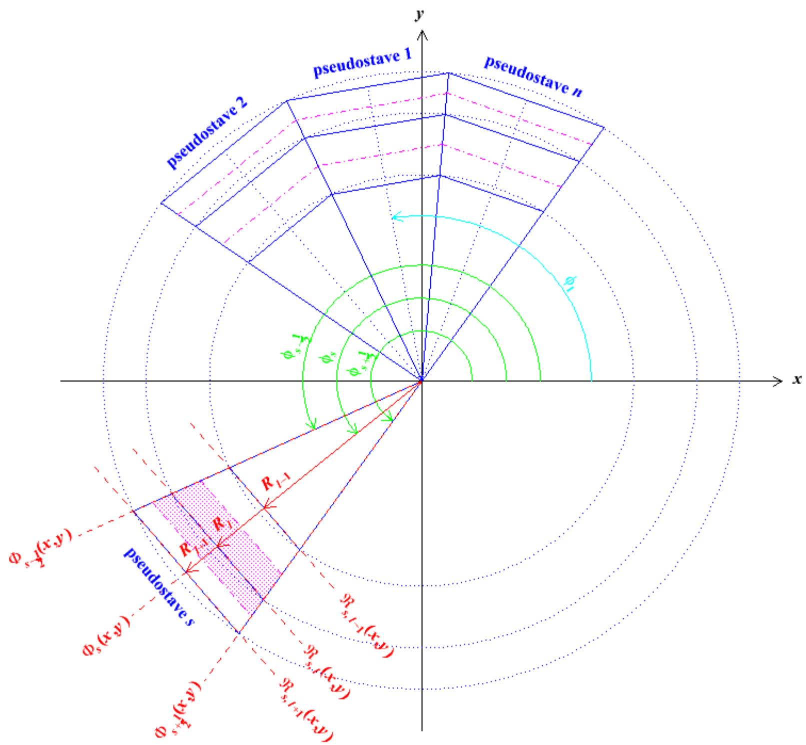
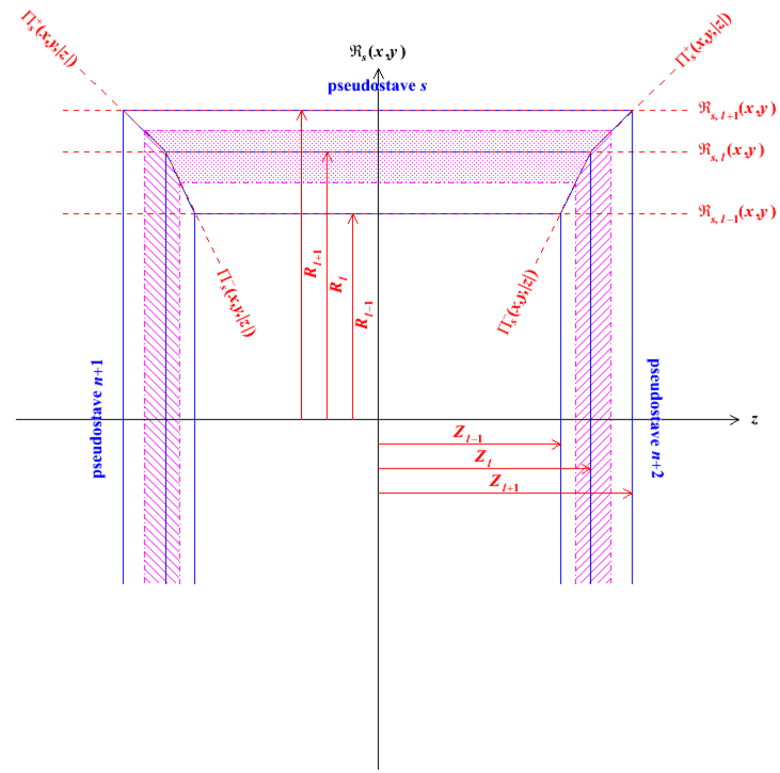
Sections through the generalised detector

Transverse section



Longitudinal section



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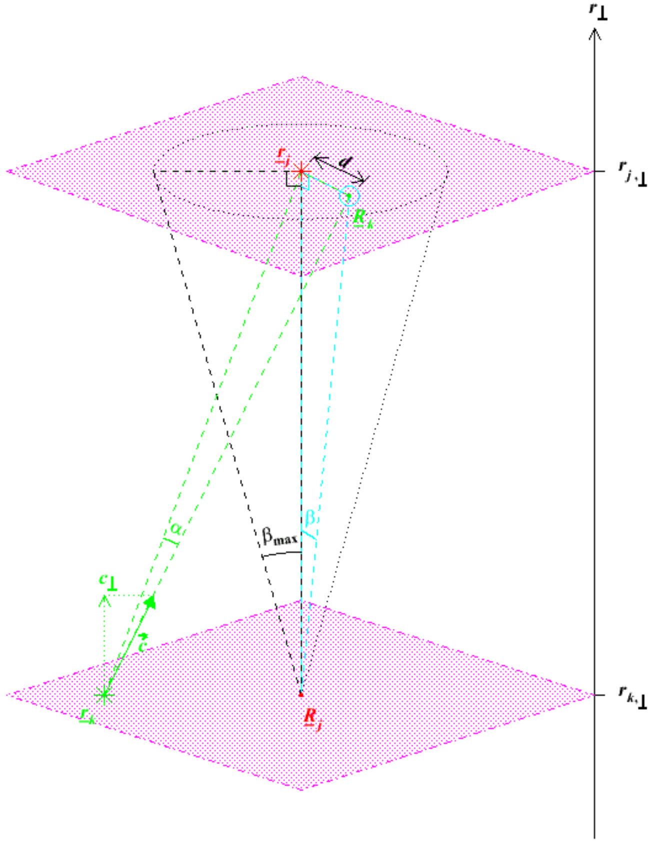
Tracker-like clustering algorithm in 3-D



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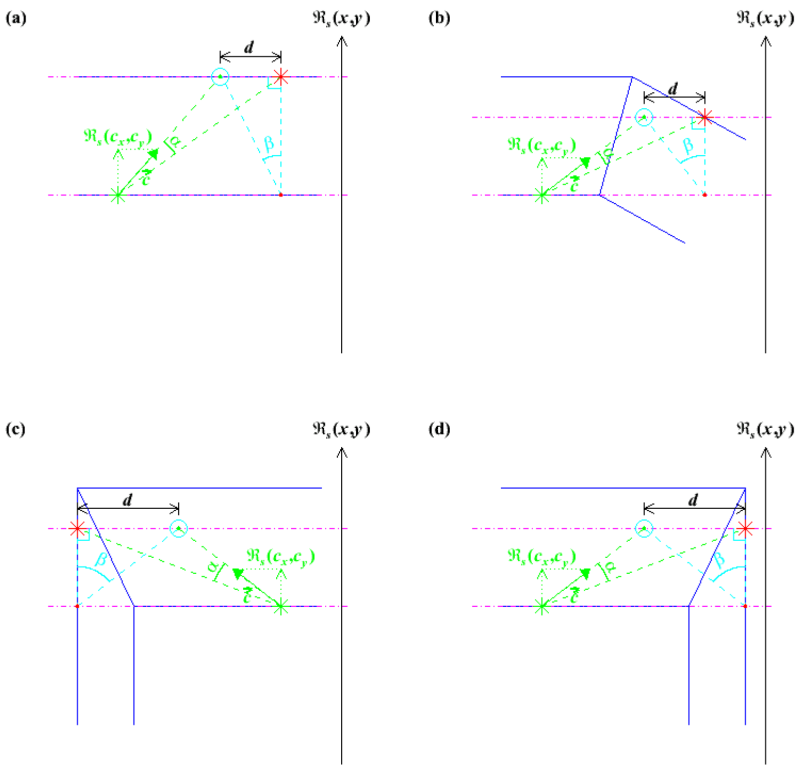
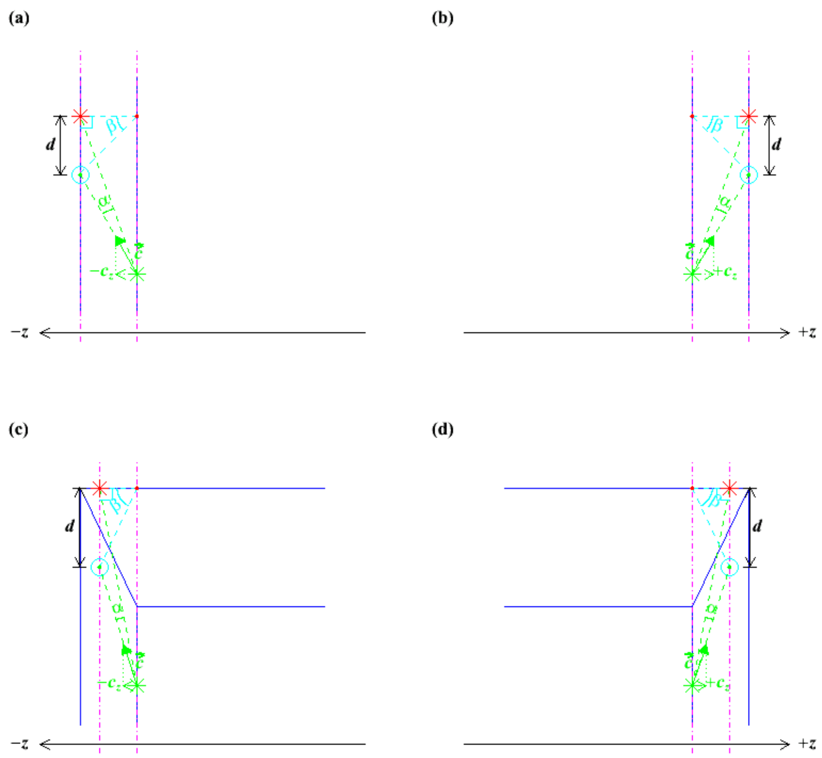
Cluster-tracking between pseudolayers

From the pseudobarrel

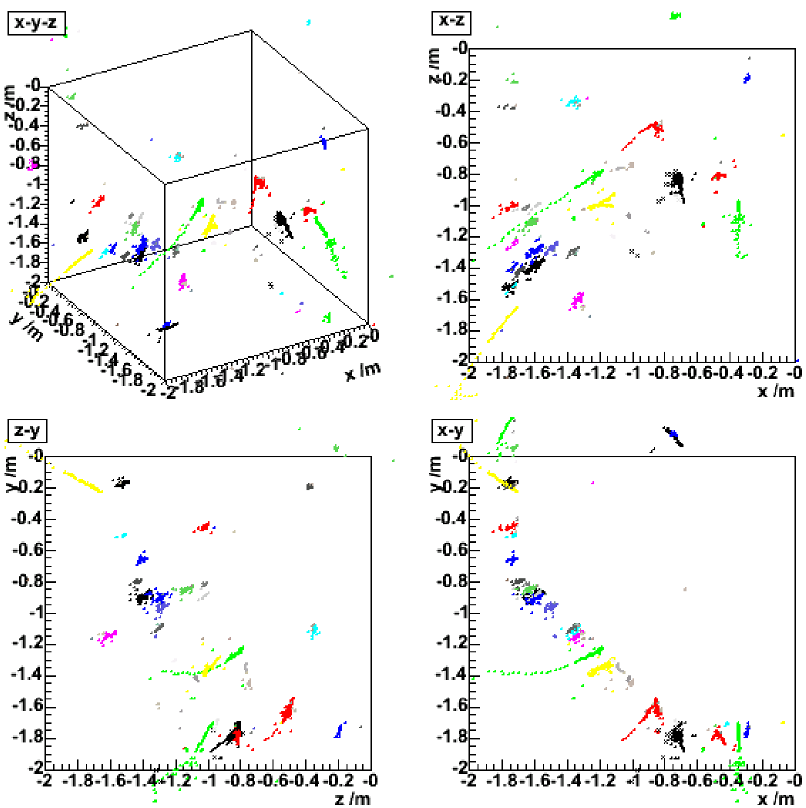


From the pseudoendcap

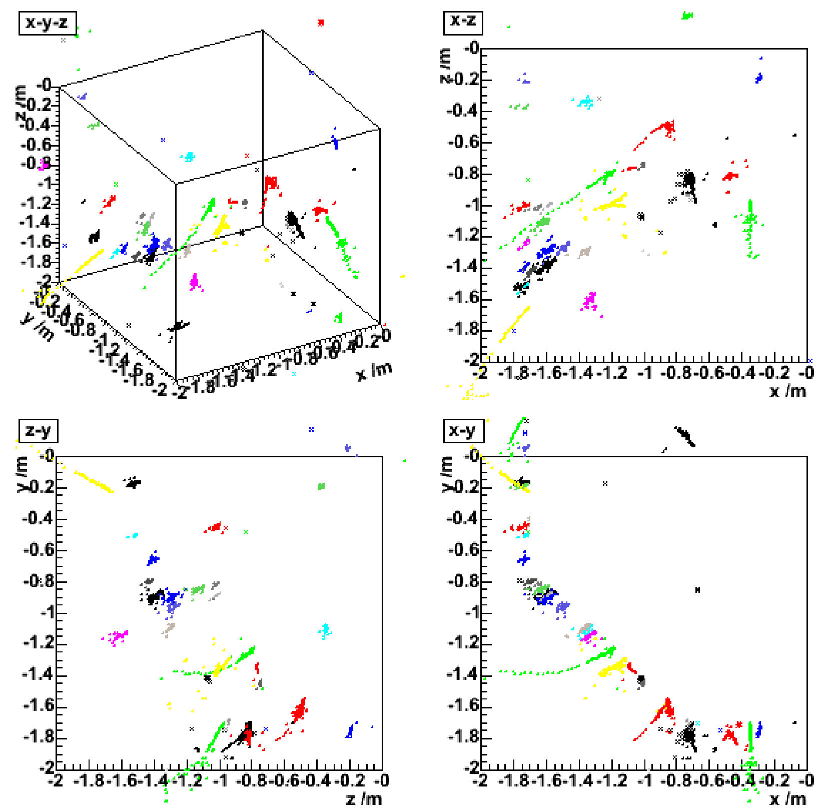


91 GeV Z event: Zoom 1

Reconstructed clusters

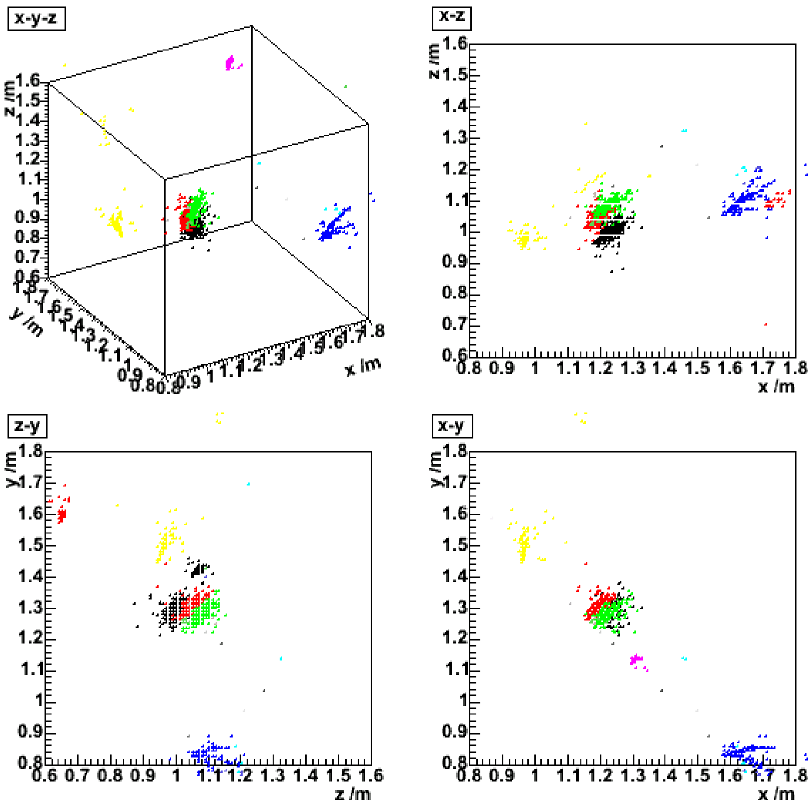


True particle clusters

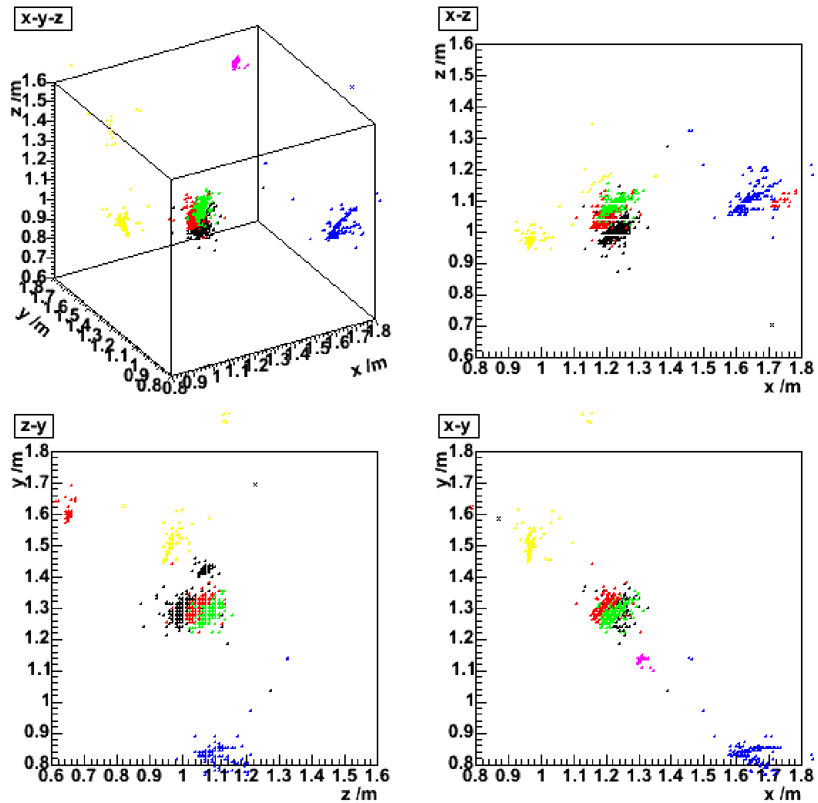


91 GeV Z event: Zoom 2

Reconstructed clusters

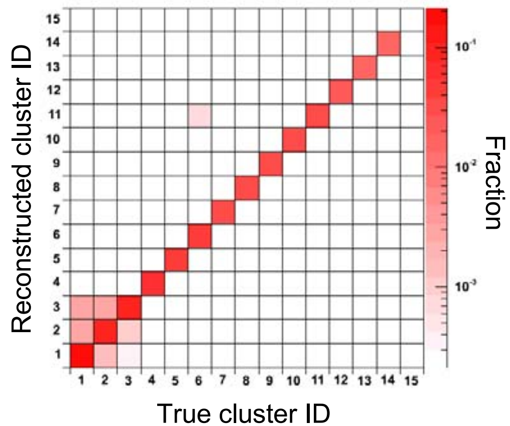


True particle clusters

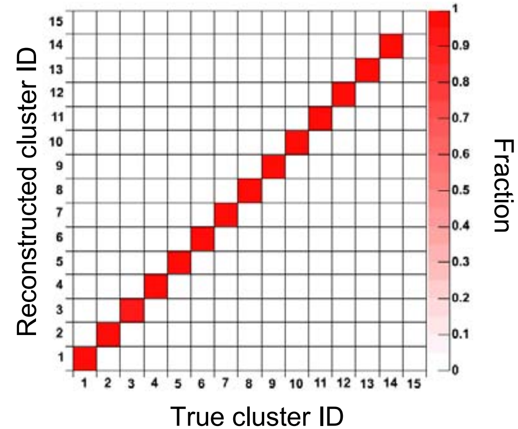


91 GeV Z event: Performance

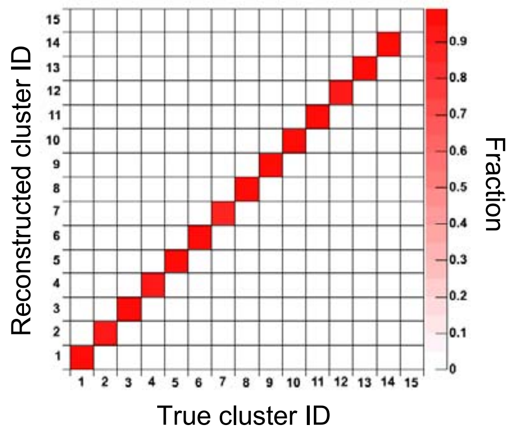
Fraction of event energy in each true-reconstructed cluster pair



Fraction of reconstructed cluster energy in each true cluster



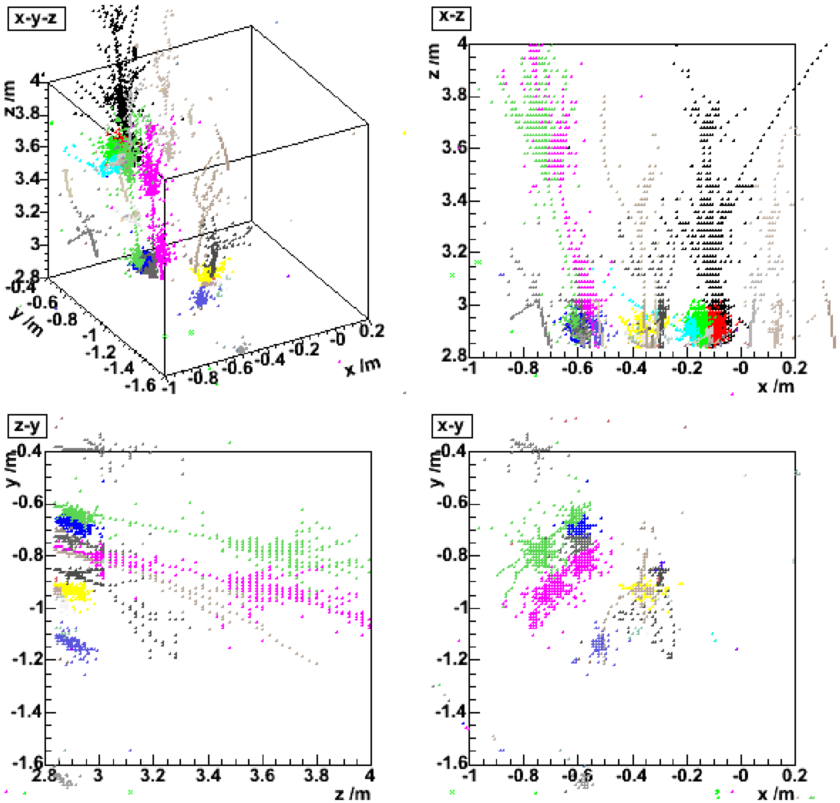
Fraction of true cluster energy in each reconstructed cluster



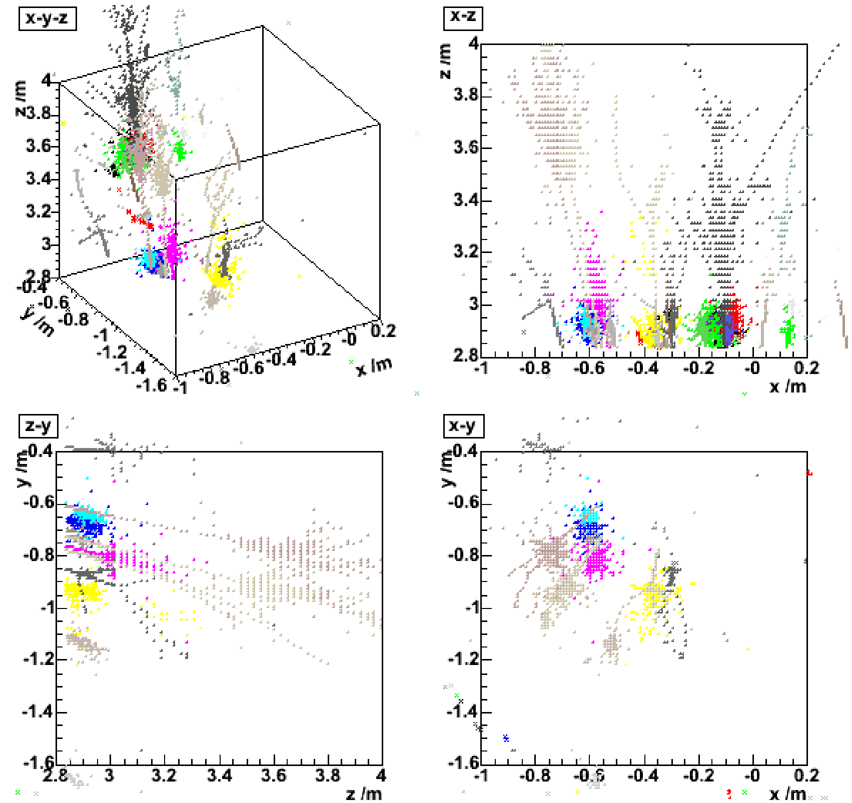
- 15 highest energy reconstructed and true clusters plotted.
- Reconstructed and true clusters tend to have a 1:1 correspondence.
- Averaged over 100 Z events at 91 GeV:
  - 87.7 ± 0.5 % of event energy maps 1:1 from true onto reconstructed clusters;
  - 97.0 ± 0.3 % of event energy maps 1:1 from reconstructed onto true clusters.

800 GeV W^+W^- event: Zoom 1

Reconstructed clusters

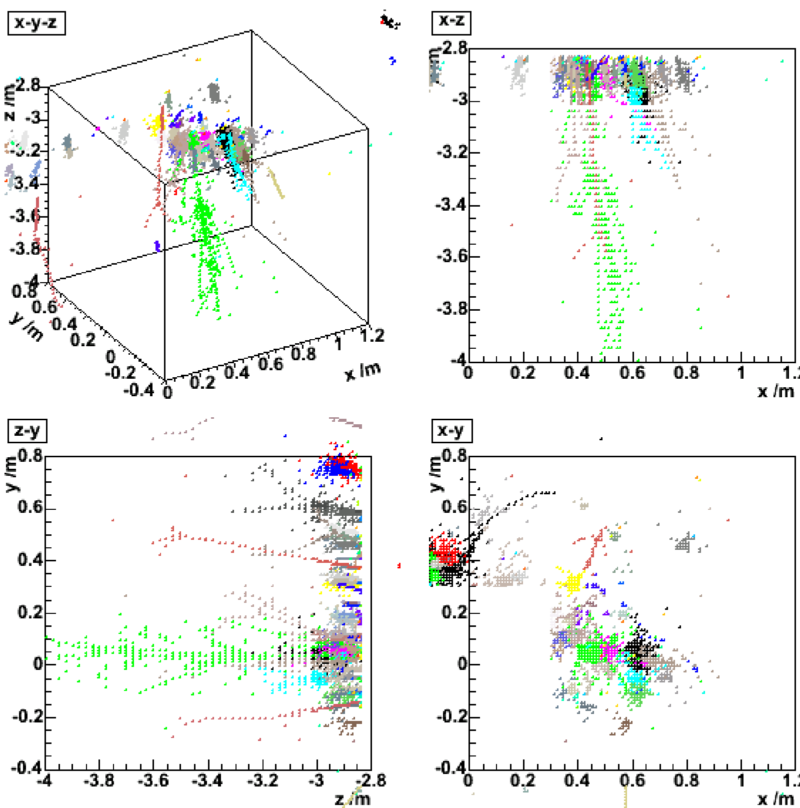


True particle clusters

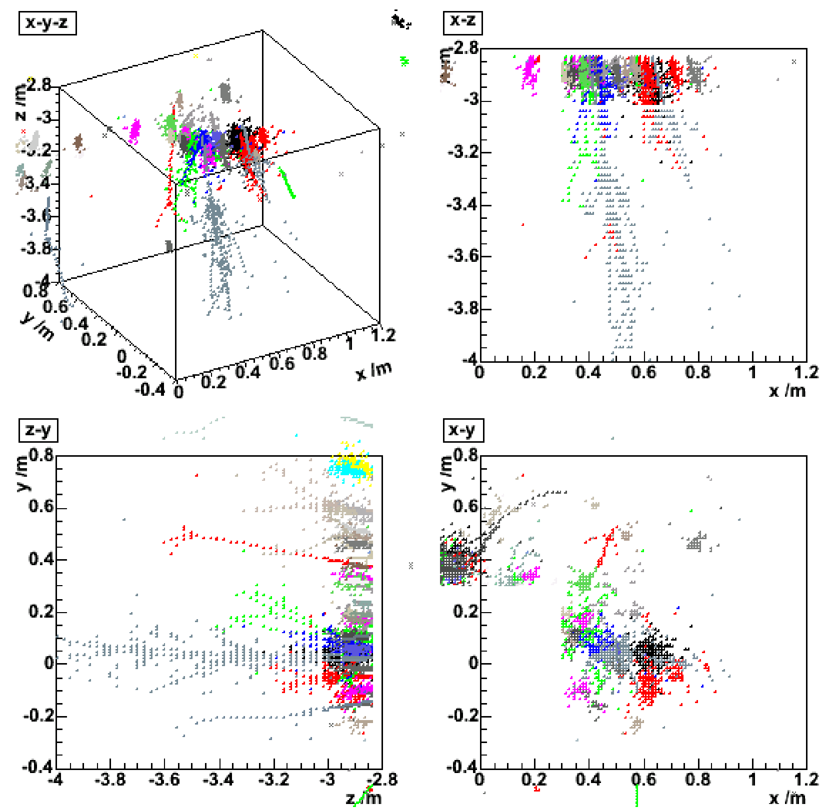


800 GeV W^+W^- event: Zoom 2

Reconstructed clusters

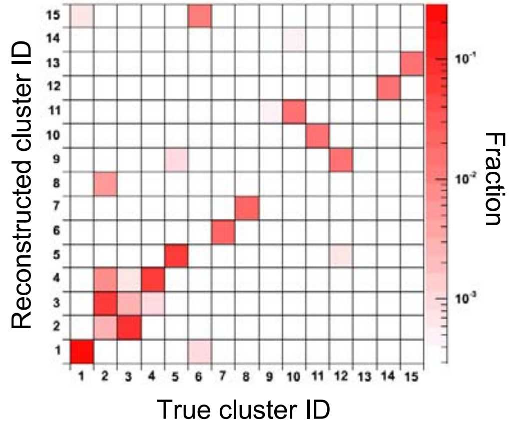


True particle clusters

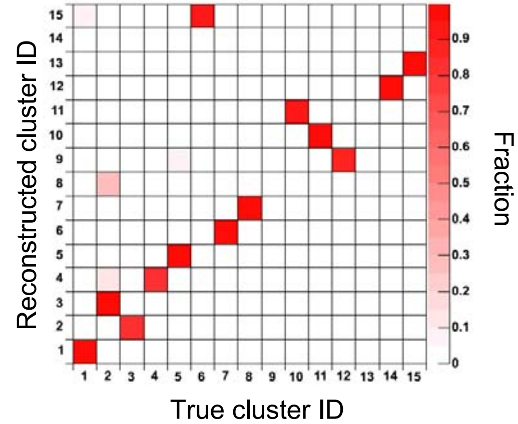


800 GeV W^+W^- event: Performance

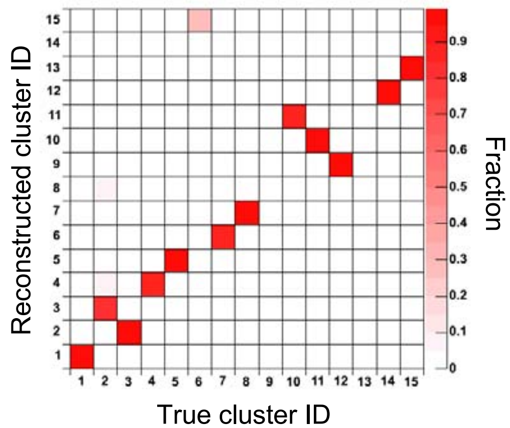
Fraction of event energy in each true-reconstructed cluster pair



Fraction of reconstructed cluster energy in each true cluster



Fraction of true cluster energy in each reconstructed cluster



- 15 highest energy reconstructed and true clusters plotted.
- Reconstructed and true clusters tend to have a 1:1 correspondence.
- Averaged over 100 W^+W^- events at 800 GeV:
  - 83.3 ± 0.5 % of event energy maps 1:1 from true onto reconstructed clusters;
  - 80.2 ± 1.0 % of event energy maps 1:1 from reconstructed onto true clusters.