Two-particle separation studies with a clustering algorithm for CALICE

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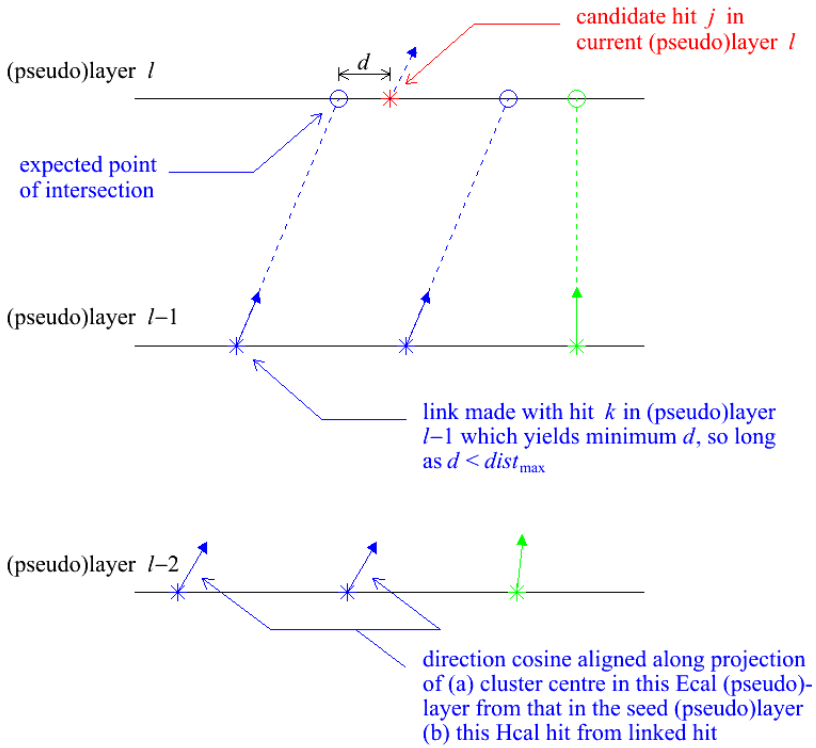
CALICE (UK) meeting
10 November 2004, UCL

Order of service

- Review of the (developing) clustering algorithm.
- How to quantify the two-particle separation capability: a definition of “quality”.
- Quality for single π^+, γ and n events.
- Quality studies with two close-by particles ($\pi^+\pi^+$, $\pi^+\gamma$, π^+n, nn):
  - overview of findings;
  - event gallery.
- Summary.

The algorithm control parameter: dist_max

- Form clusters by tracking closely-related hits (1/3 mip) layer-by-layer through calorimeter:
  - for a given hit j in a given layer l, minimize the distance d w.r.t all hits k in layer l-1;
  - if $d < dist_{max}$ for minimum d, 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., right through to layer 1;
  - after iterating over all hits j, seed new clusters with those still unassigned;
  - if in Ecal, calculate weighted centre of each cluster's hits in layer l (weight by energy (analogue) or density (digital)) and 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;
  - if in Hcal, assign a direction cosine to each hit along the line from the hit to which each is linked (or (0,0,0) if it's a seed) to the hit itself;
  - try to recover backward-spiralling track-like, and low multiplicity 'halo', cluster fragments …



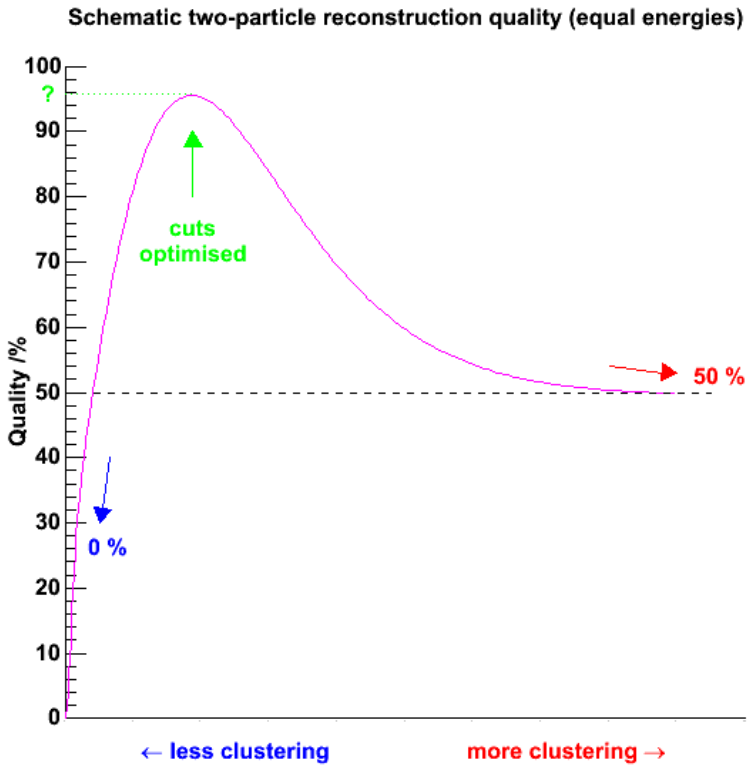
Two-particle separation quality: definition

- Working definition of how well the cluster reconstruction is doing:

  Quality = fraction of event energy that maps in a 1:1 ratio between reconstructed and true clusters.
- Combines "efficiency" (*i.e.* how well the true clusters correspond to the reconstructed clusters) with "purity" (i.e. how well reconstructed clusters correspond to the true clusters) into a single, useful measure.
- With no clustering, each hit is a reconstructed cluster ⇒ quality → 0 (energy spread over multiple reconstructed clusters);

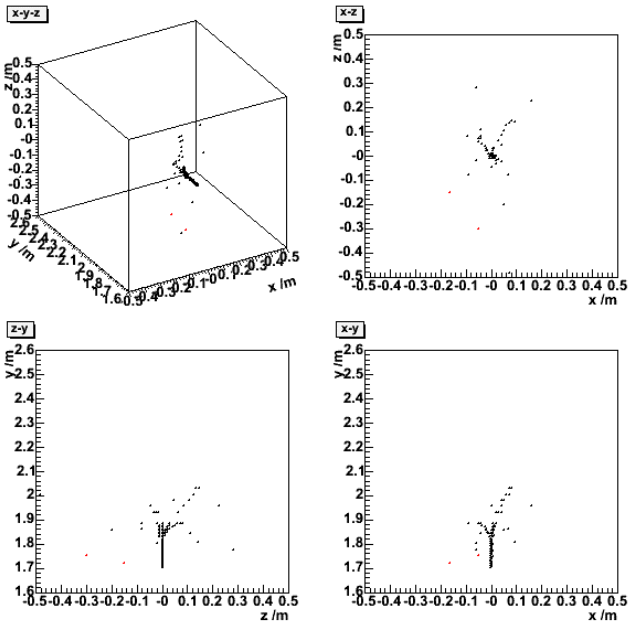
  with maximal clustering, the whole event is one reconstructed cluster ⇒ quality → 50 % (two equal-energy particles; ½ of event energy maps 1:1).
- Would like to find intermediate point where quality is maximised ⇒ look at quality vs clustering cuts vs particle separation.
- Demonstrate principle with snap-shot of algorithm in its current form, varying the `dist_max` cut (D09 detector).
- Energy calibrated according to:

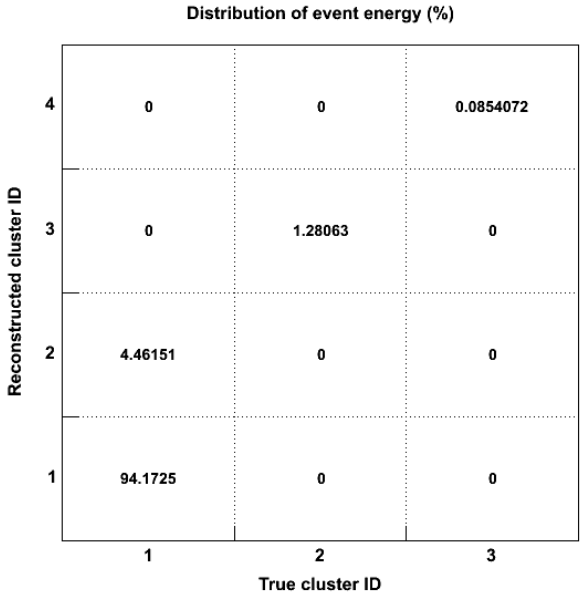
  $E = \alpha[(E_{\text{Ecal; 1-30}} + 3E_{\text{Ecal; 31-40}})/E_{\text{mip}} + 20N_{\text{Hcal}}]$ GeV.



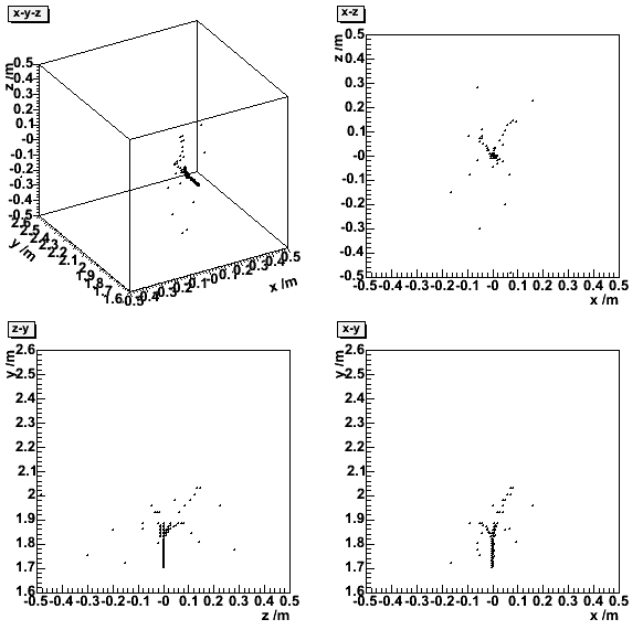
5 GeV single π^+ event

Reconstructed clusters





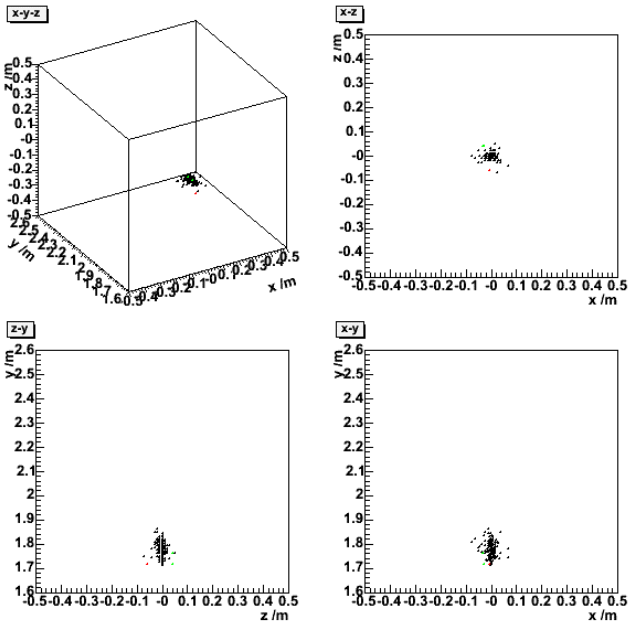
True particle clusters

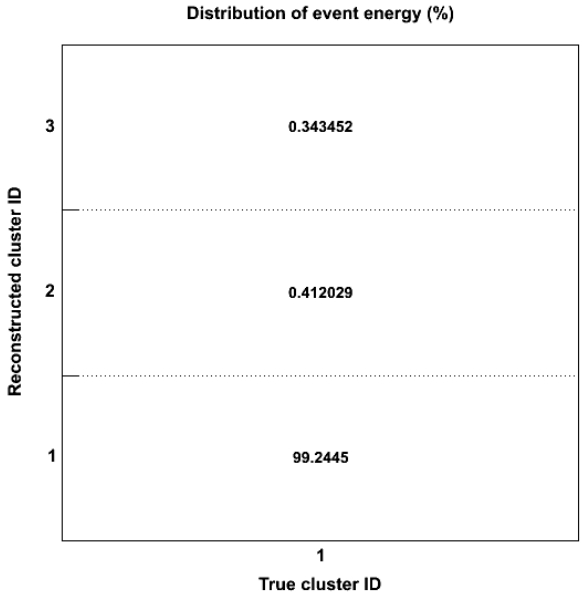


- Quality = 94.2 + 1.3 + 0.1 = 96 %.

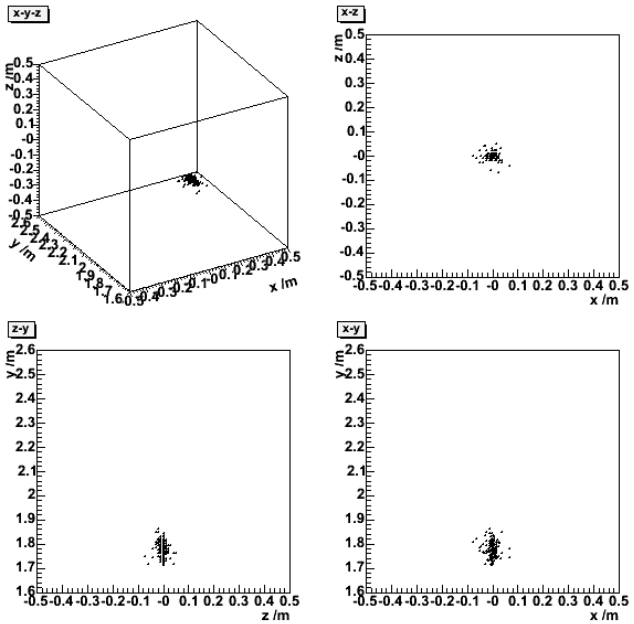
5 GeV single γ event

Reconstructed clusters





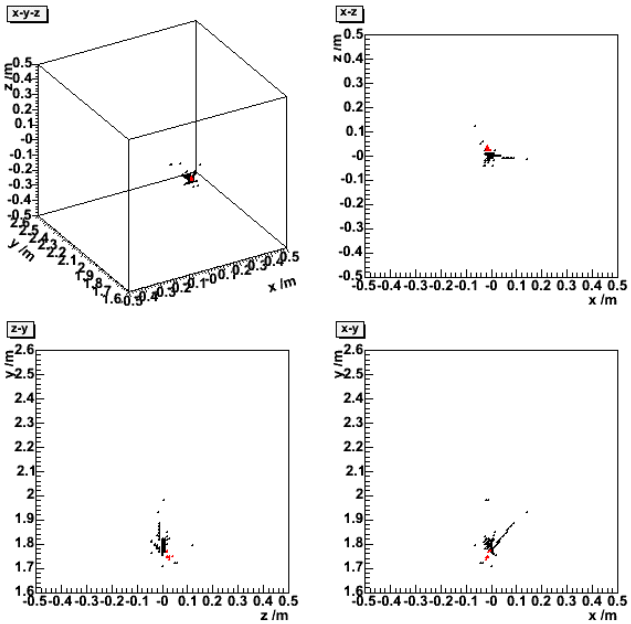
True particle clusters

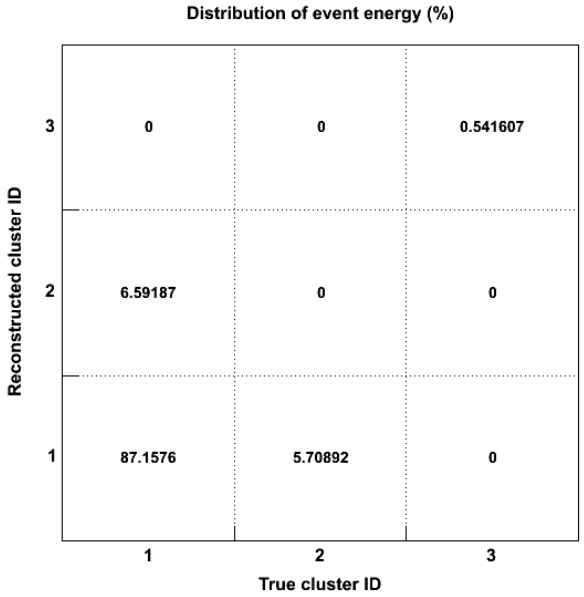


- Quality = 99 %.

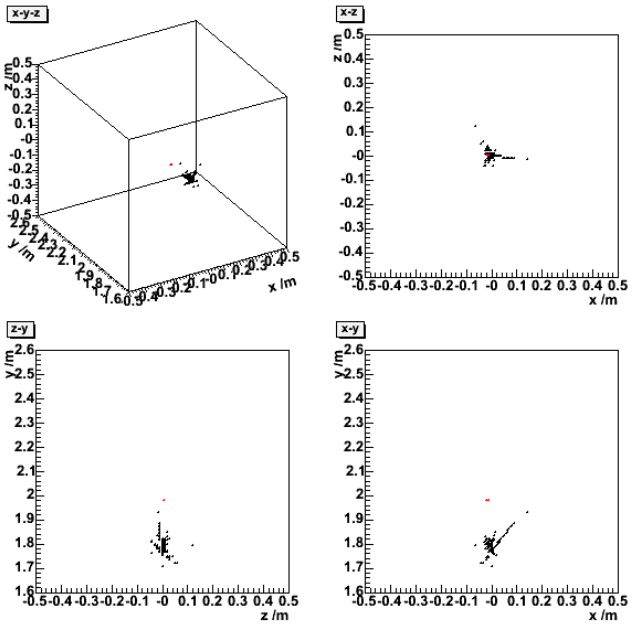
5 GeV single n event

Reconstructed clusters





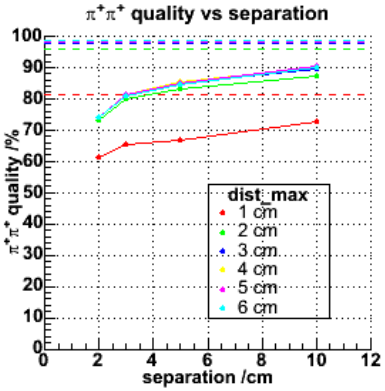
True particle clusters

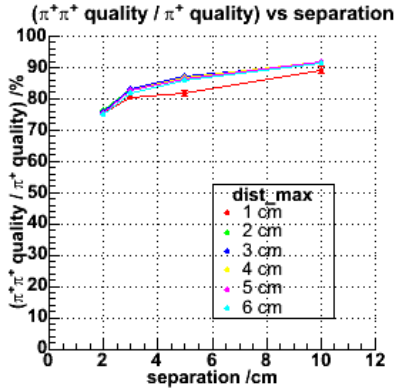


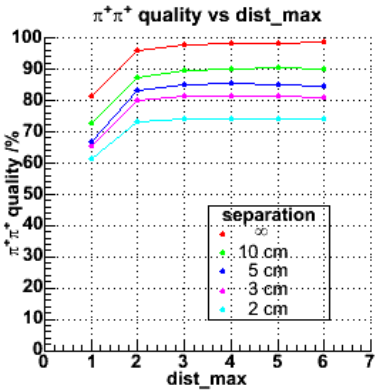
- Quality = 87.2 + 0.5 = 88 %.

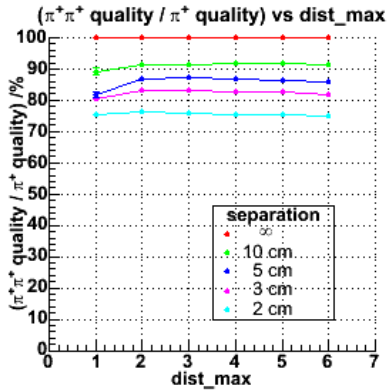
5 GeV $\pi^+\pi^+/\pi^+\gamma$ quality vs separation vs dist_max

$\pi^+\pi^+$

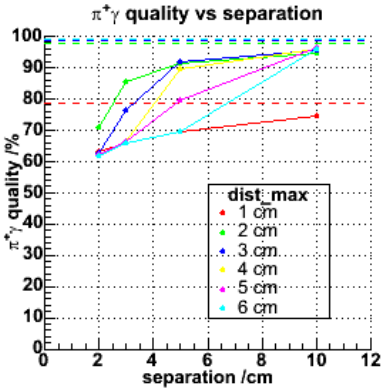


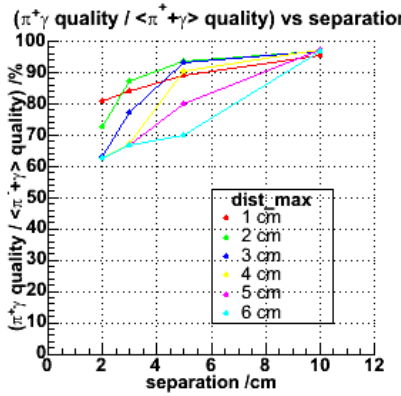


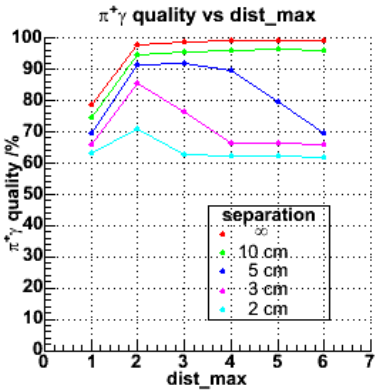


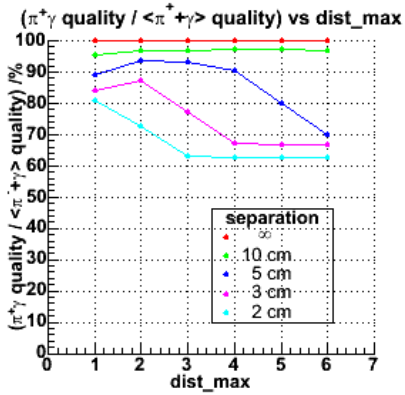


$\pi^+\gamma$





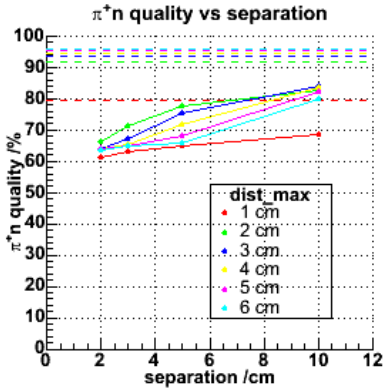


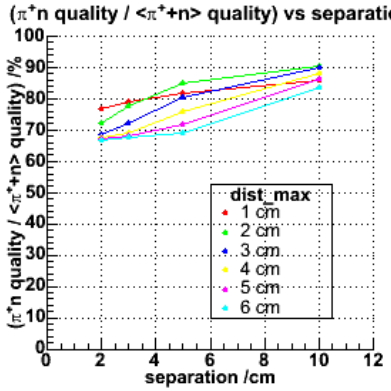


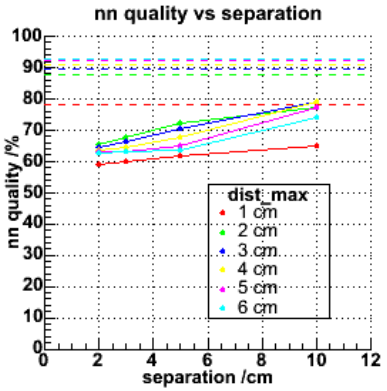
5 GeV π^+n/ nn quality vs separation vs dist_max

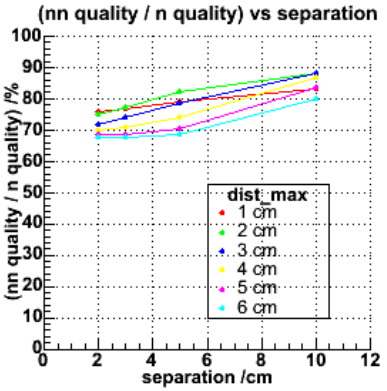
π^+ n

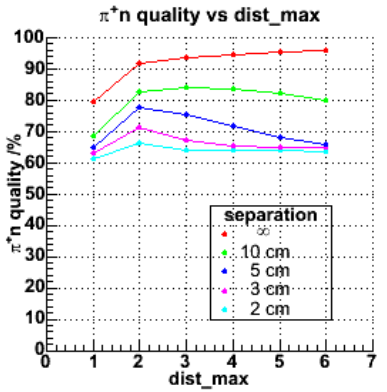
nn

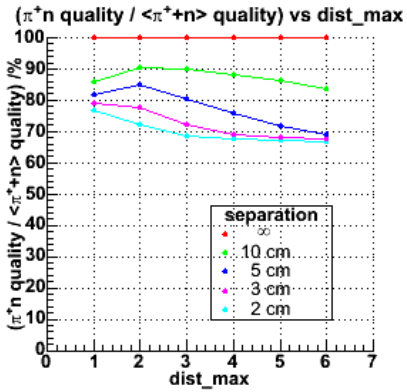


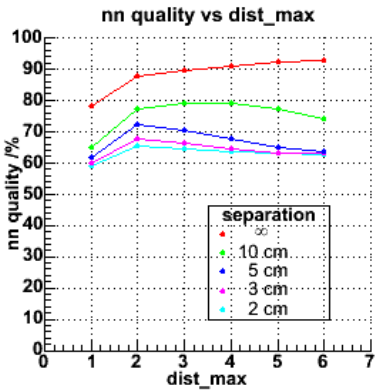


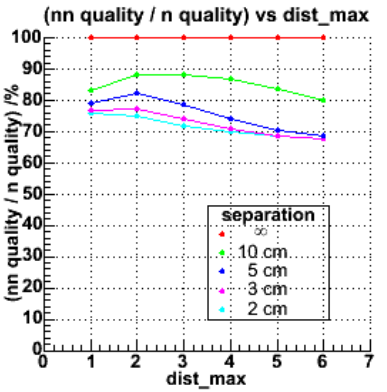






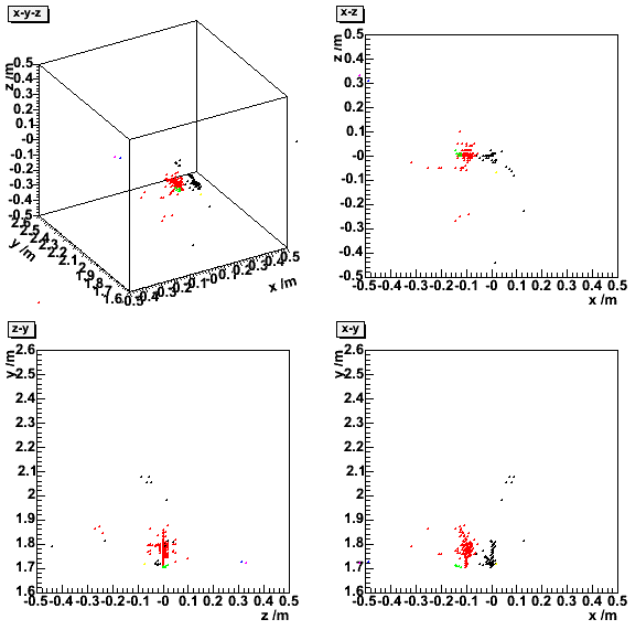






5 GeV $\pi^+\pi^+$ event at 10 cm separation

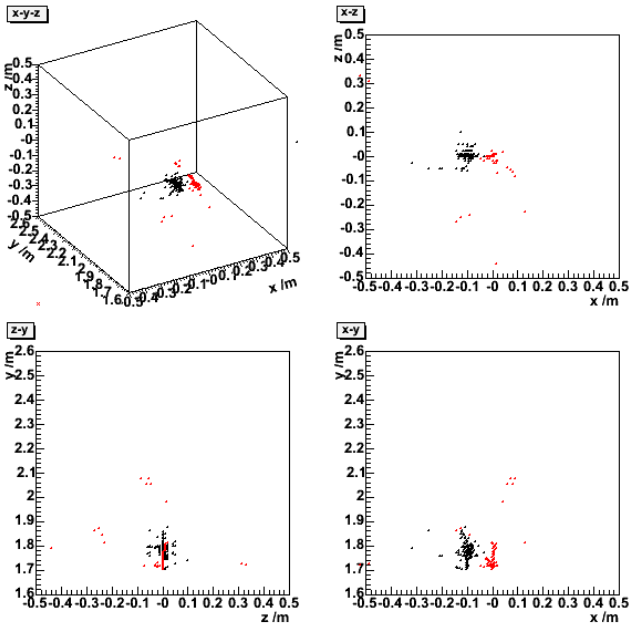
Reconstructed clusters



Distribution of event energy (%)

Reconstructed cluster ID	True cluster ID 1	True cluster ID 2
12	0.0523785	0
11	0	0.0714879
10	0	0.072381
9	0	0.090908
8	0	0.125204
7	0	0.15607
6	0	0.380641
5	1.02958	0
4	0	1.29956
3	3.12519	0
2	43.802	2.12865
1	4.00364	43.6623

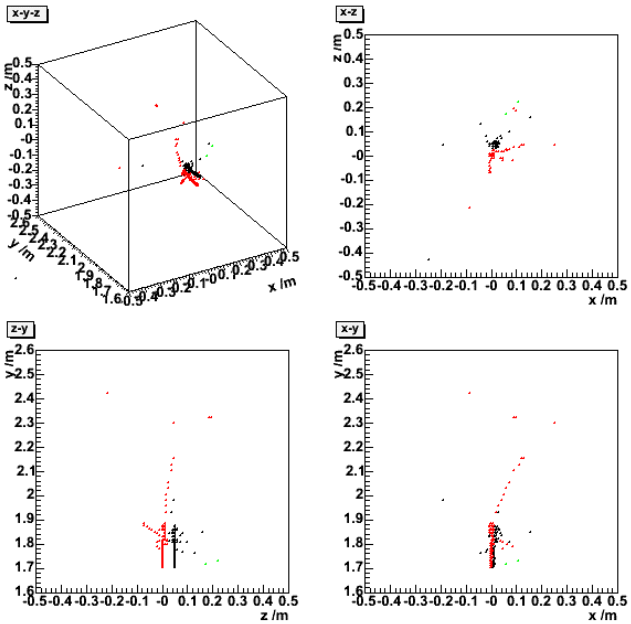
True particle clusters

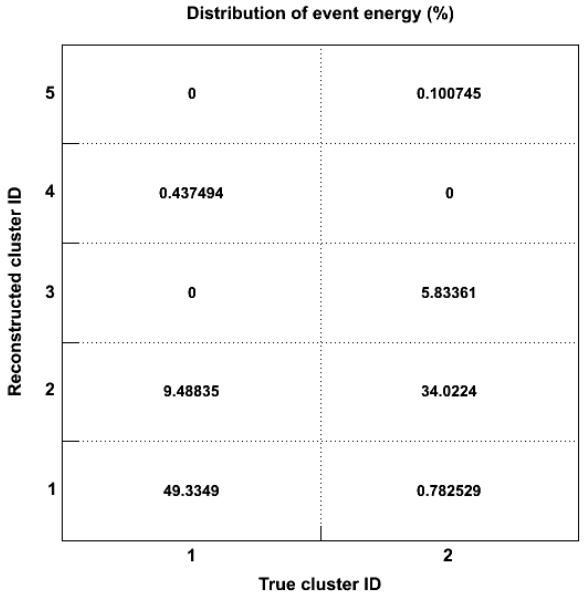


- Quality = 43.8 + 43.7 = 87 %.

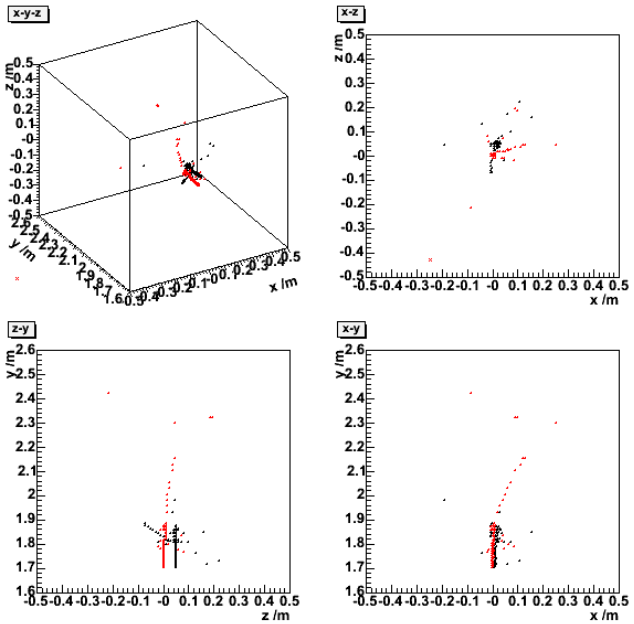
5 GeV $\pi^+\pi^+$ event at 5 cm separation

Reconstructed clusters





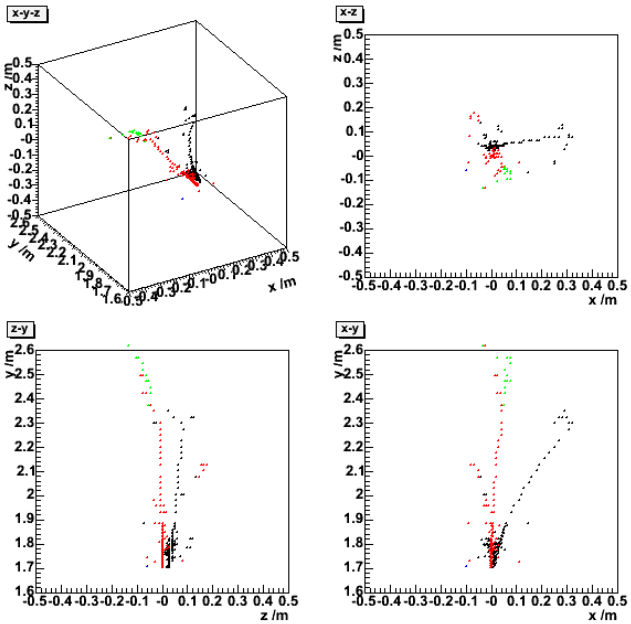
True particle clusters

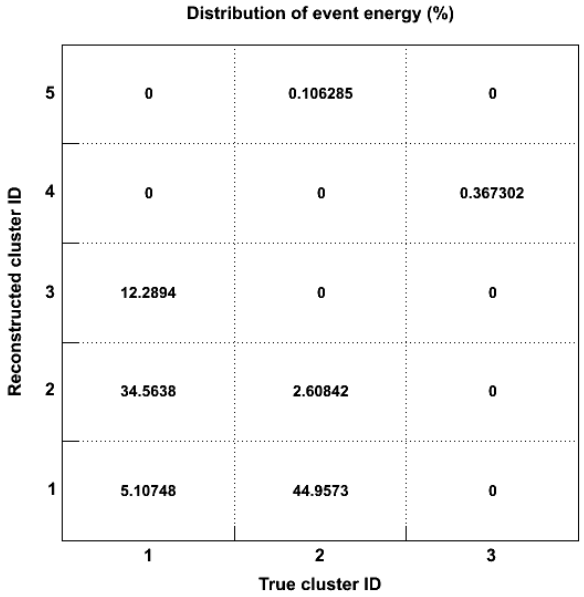


- Quality = 49.3 + 34.0 = 83 %.

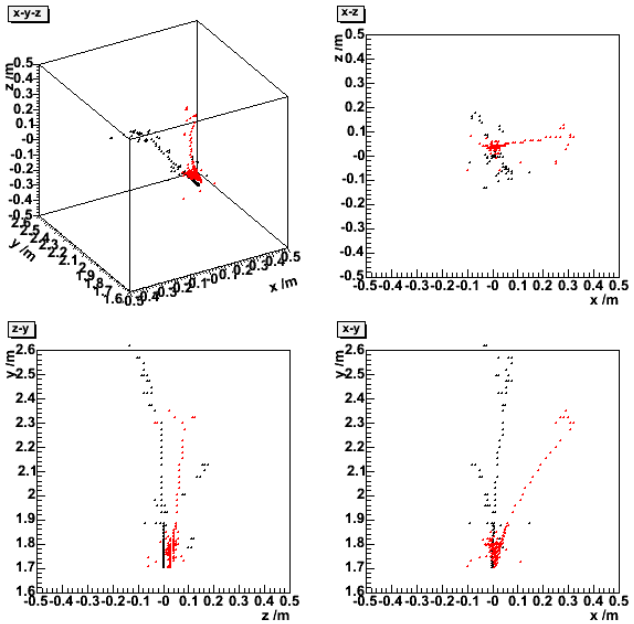
5 GeV $\pi^+\pi^+$ event at 3 cm separation

Reconstructed clusters





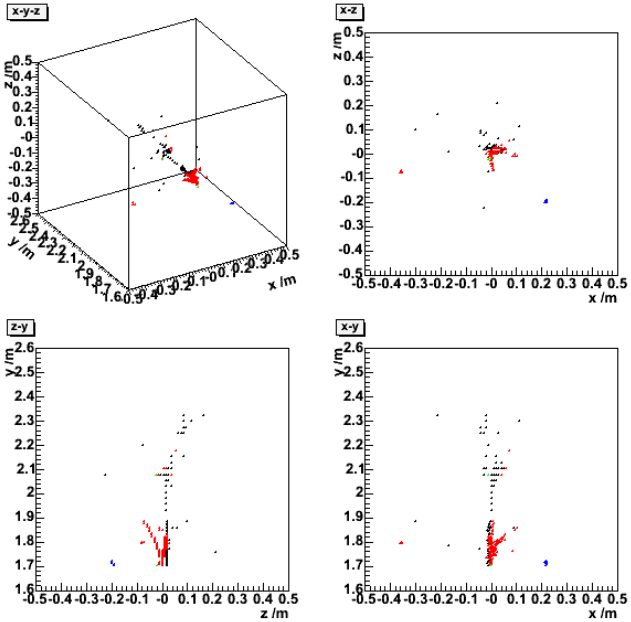
True particle clusters

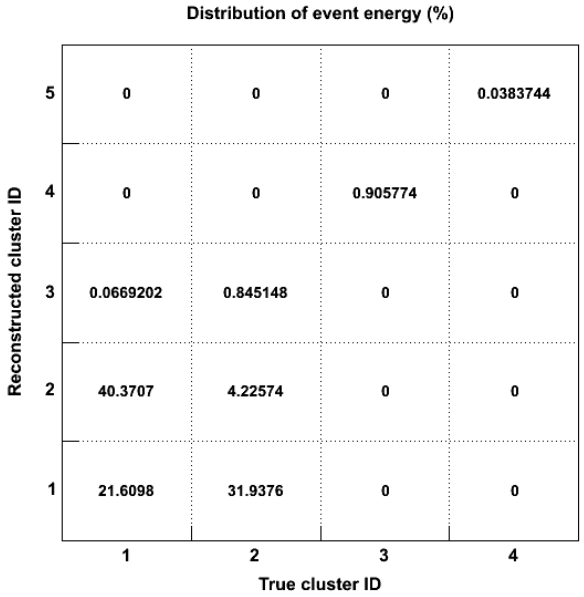


- Quality = 45.0 + 34.6 + 0.4 = 80 %.

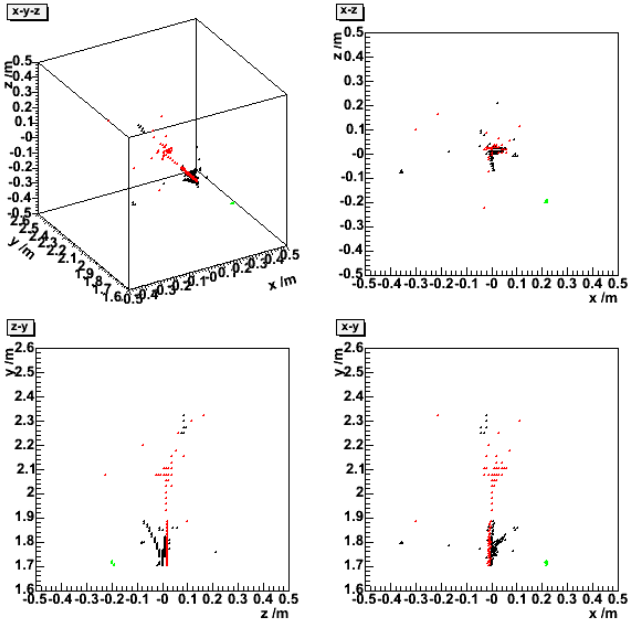
5 GeV $\pi^+\pi^+$ event at 2 cm separation

Reconstructed clusters





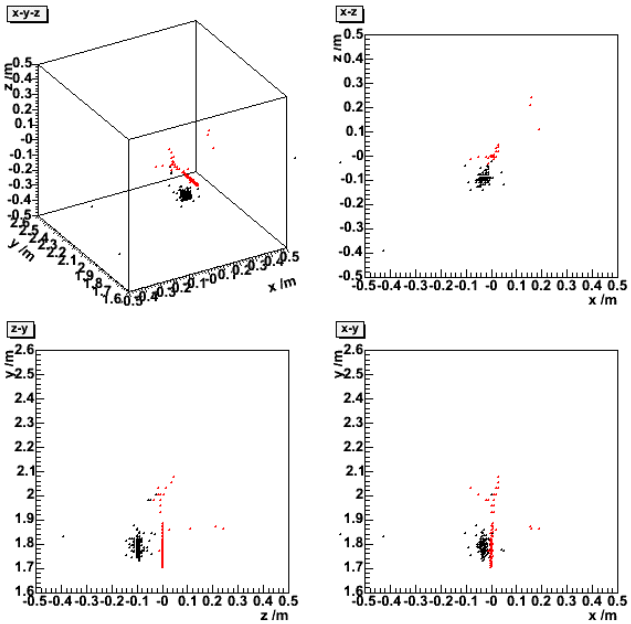
True particle clusters

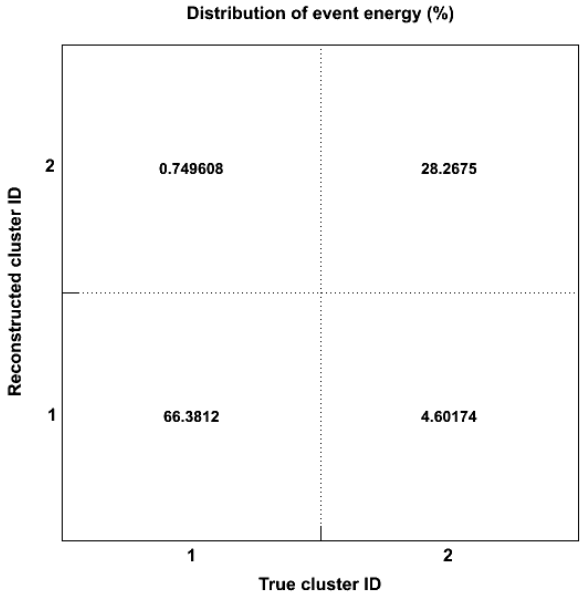


- Quality = 40.4 + 31.9 + 0.9 + 0.04 = 73 %.

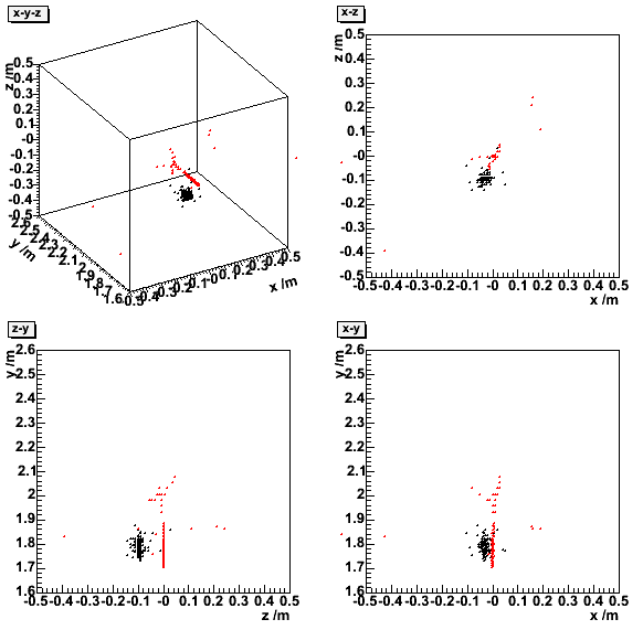
5 GeV $\pi^+\gamma$ event at 10 cm separation

Reconstructed clusters





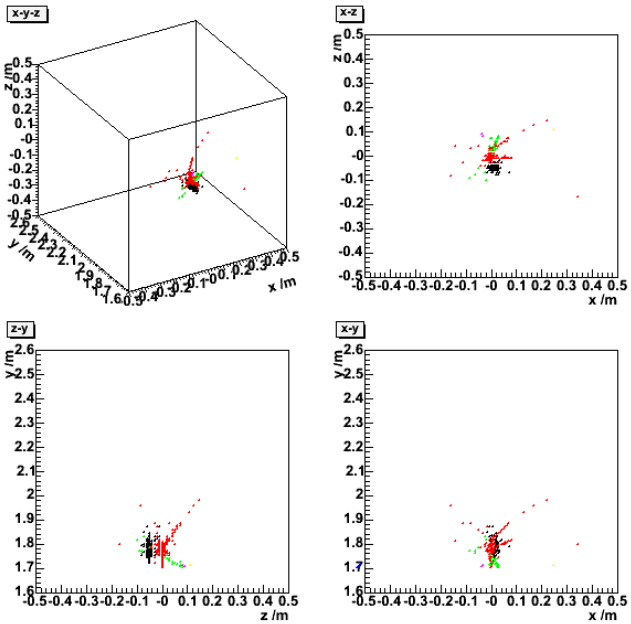
True particle clusters



- Quality = 66.4 + 28.3 = 95 %.

5 GeV $\pi^+\gamma$ event at 5 cm separation

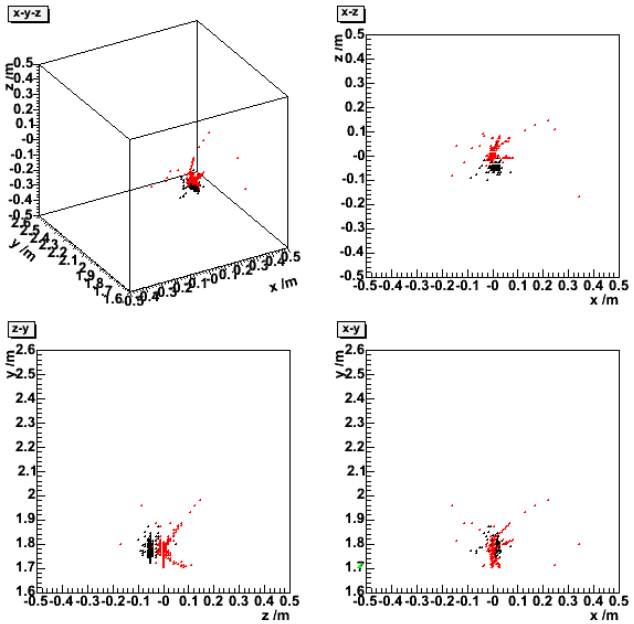
Reconstructed clusters



Distribution of event energy (%)

Reconstructed cluster ID	True cluster ID 1	2	3	4
7	0	0.457841	0	0
6	0	0	0	0.587568
5	0	1.21188	0	0
4	0	0	1.92376	0
3	0.481774	3.14076	0	0
2	2.91315	42.1075	0	0
1	46.6833	0.492326	0	0

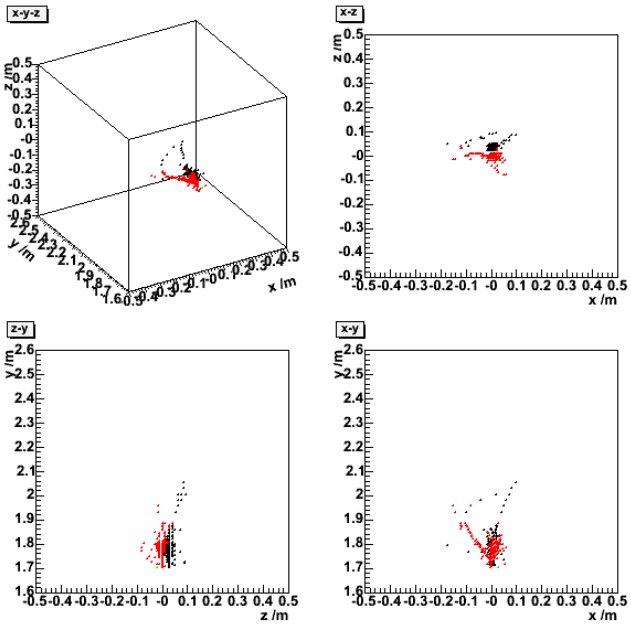
True particle clusters



- Quality = 46.7 + 42.1 + 1.9 + 0.6 = 91 %.

5 GeV $\pi^+\gamma$ event at 3 cm separation

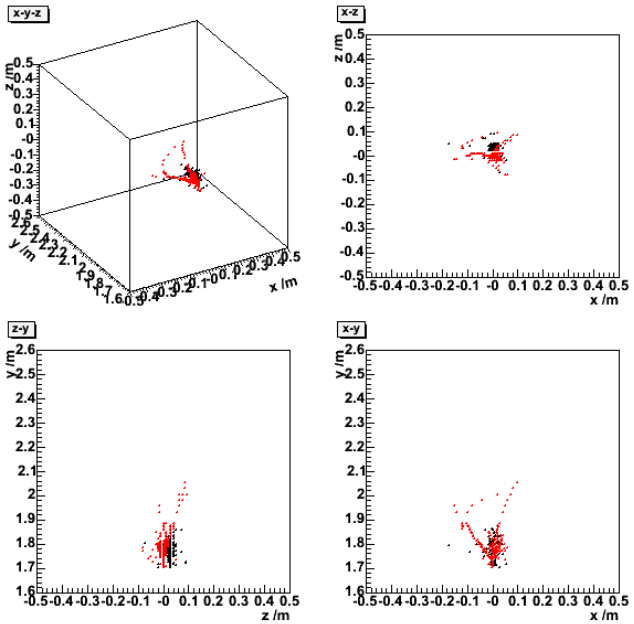
Reconstructed clusters



Distribution of event energy (%)

Reconstructed cluster ID \ True cluster ID	1	2	3	4	5
6	0.116024	0	0	0	0
5	0	0	0	0	0.167232
4	0	0	0	0.170508	0
3	0	0	2.58802	0	0
2	1.10294	31.7472	0	0	0
1	50.6202	13.4879	0	0	0

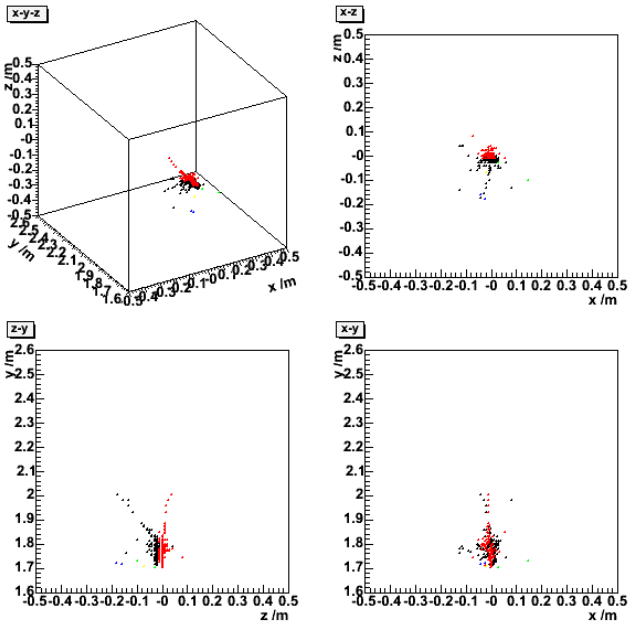
True particle clusters

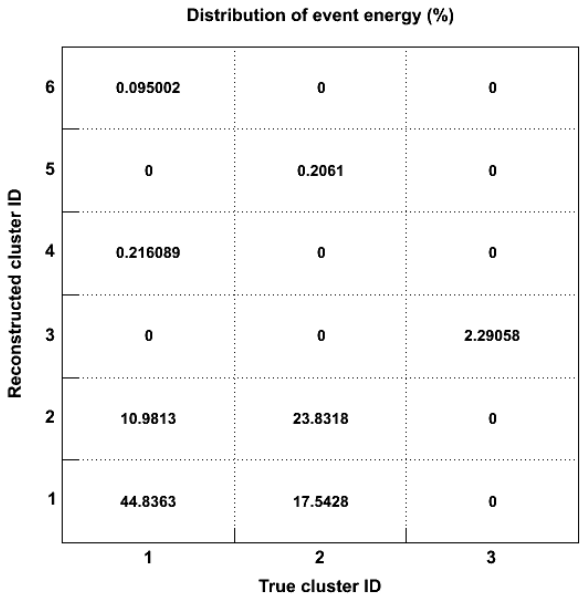


- Quality = 50.6 + 31.7 +2.6 + 0.2 + 0.2 = 85 %.

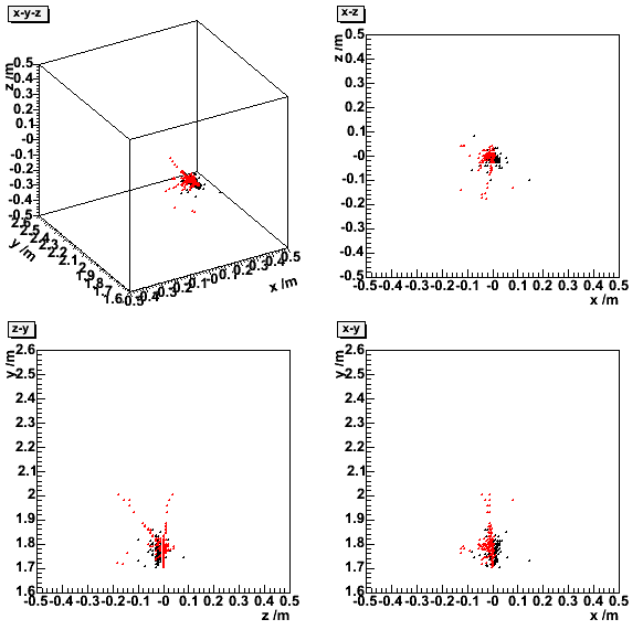
5 GeV $\pi^+\gamma$ event at 2 cm separation

Reconstructed clusters





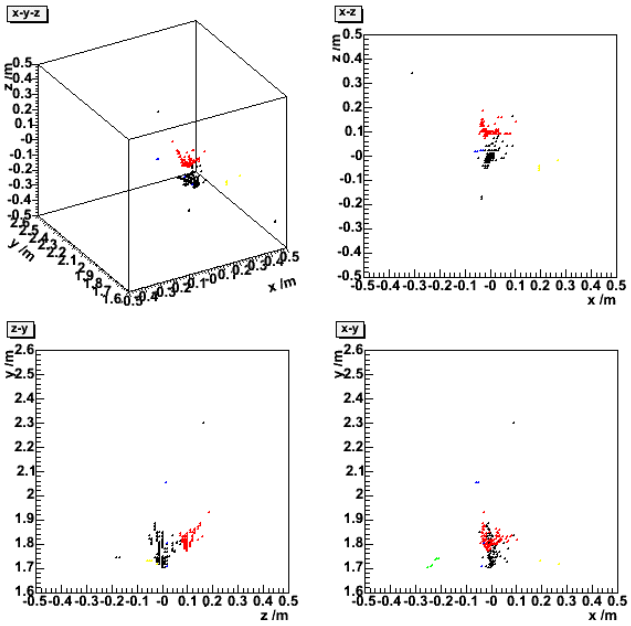
True particle clusters

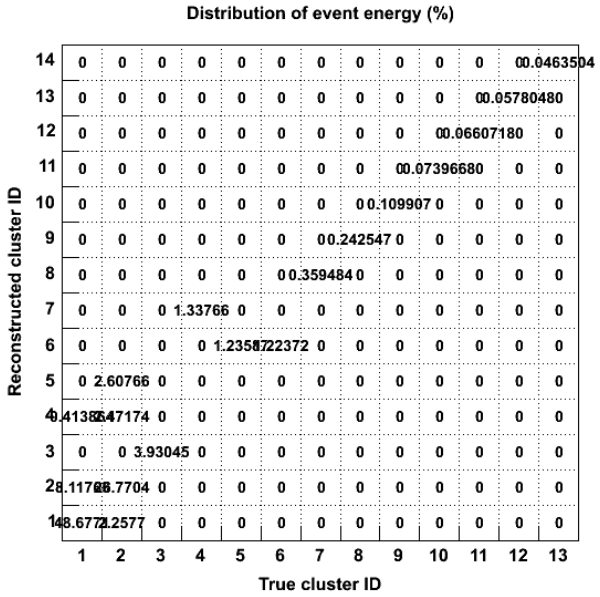


- Quality = 44.8 + 23.8 + 2.3 = 71 %.

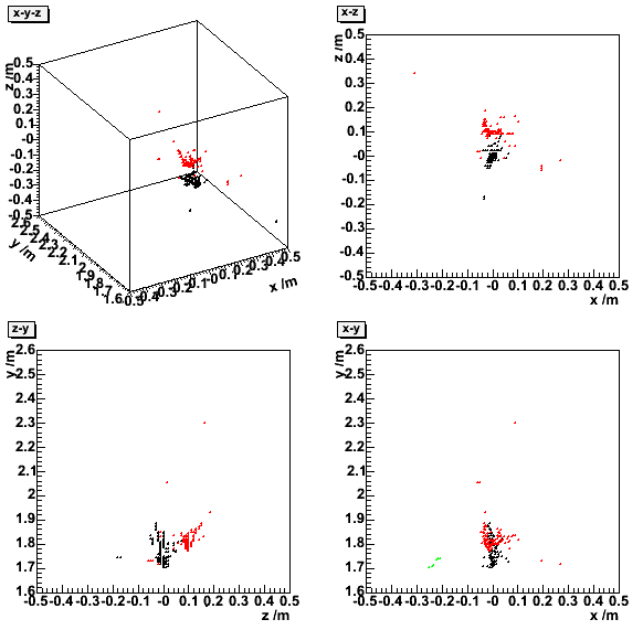
5 GeV π^+n event at 10 cm separation

Reconstructed clusters





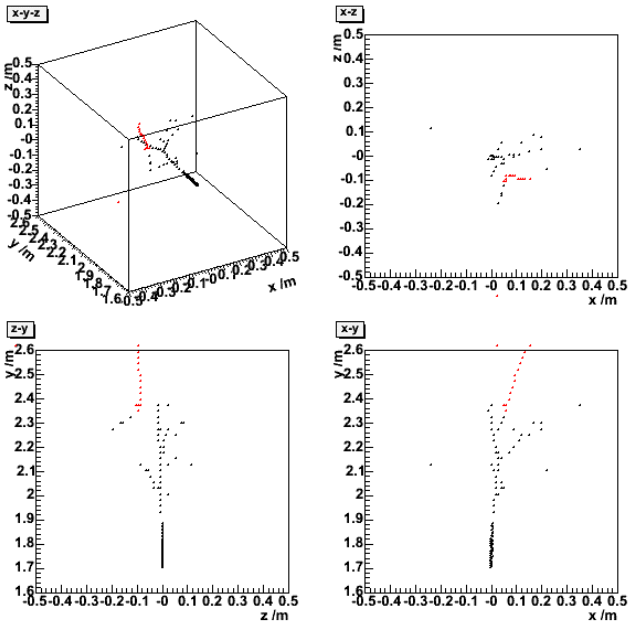
True particle clusters

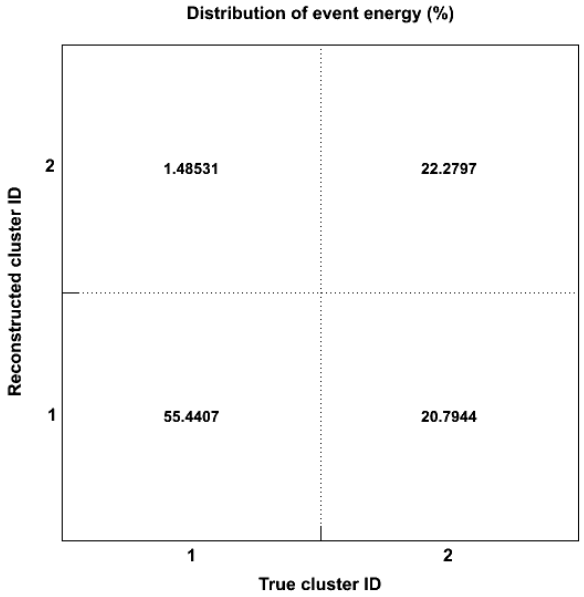


- Quality = 48.7 + 26.8 + 3.9 + 1.3 + 1.2 + 0.4 + 0.2 + … = 83 %.

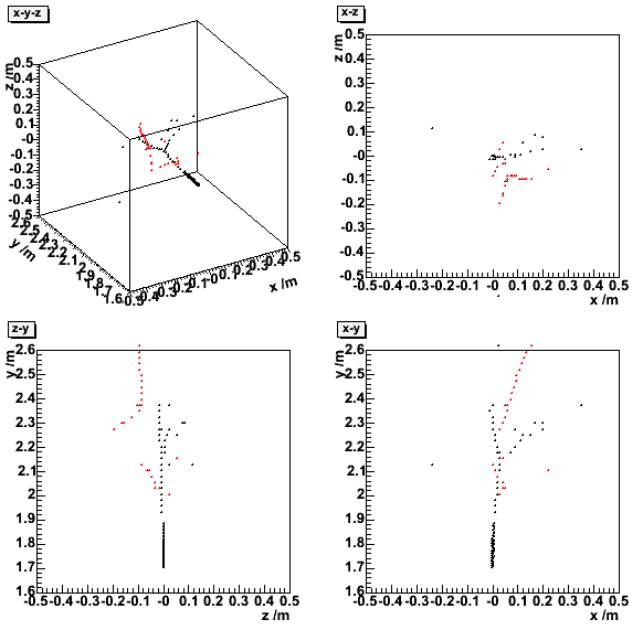
5 GeV π^+n event at 5 cm separation

Reconstructed clusters





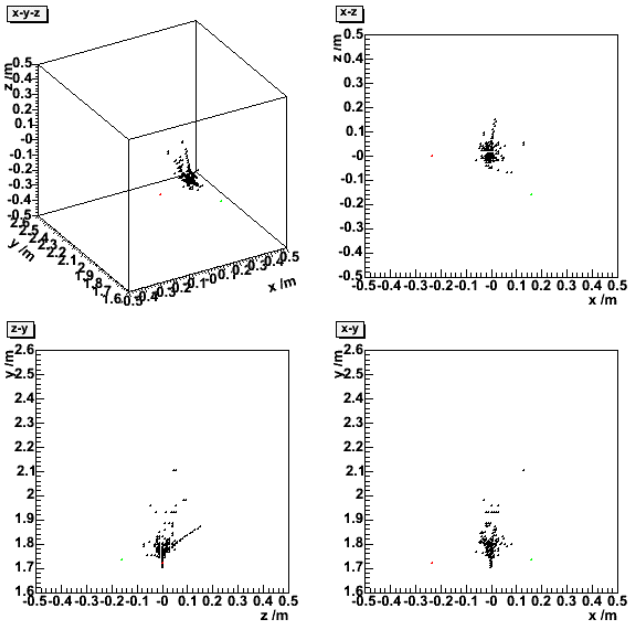
True particle clusters

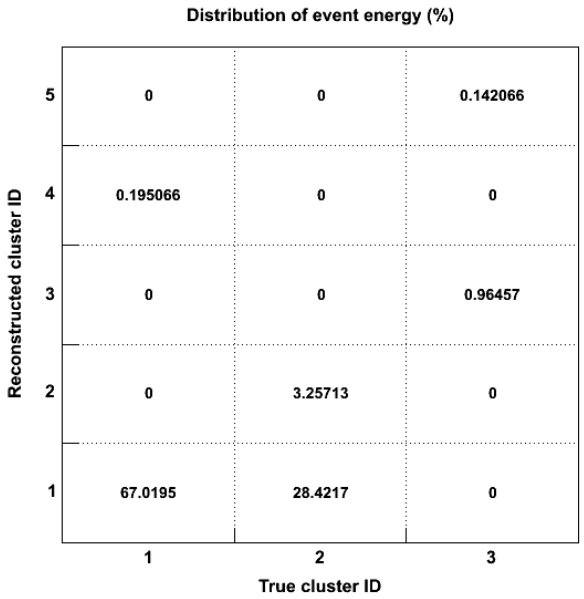


- Quality = 55.4 + 22.3 = 78 %.

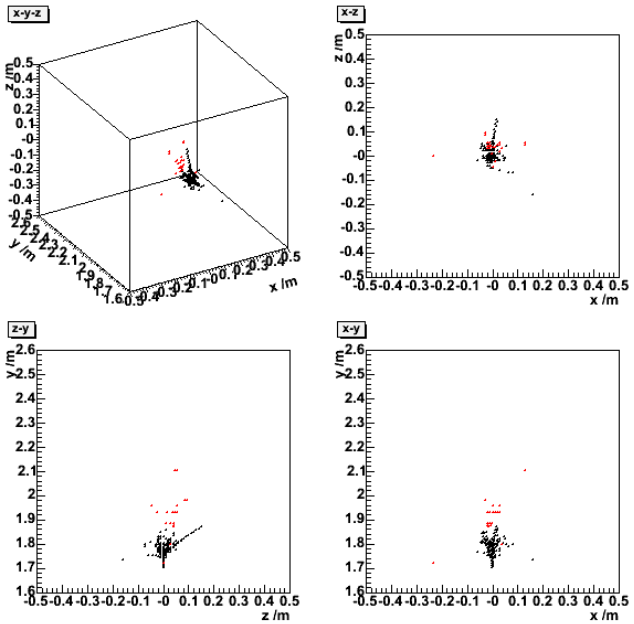
5 GeV π^+n event at 3 cm separation

Reconstructed clusters





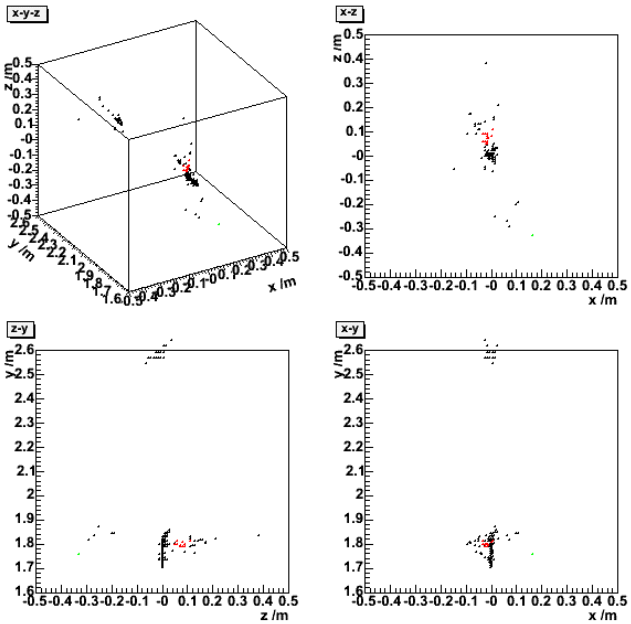
True particle clusters

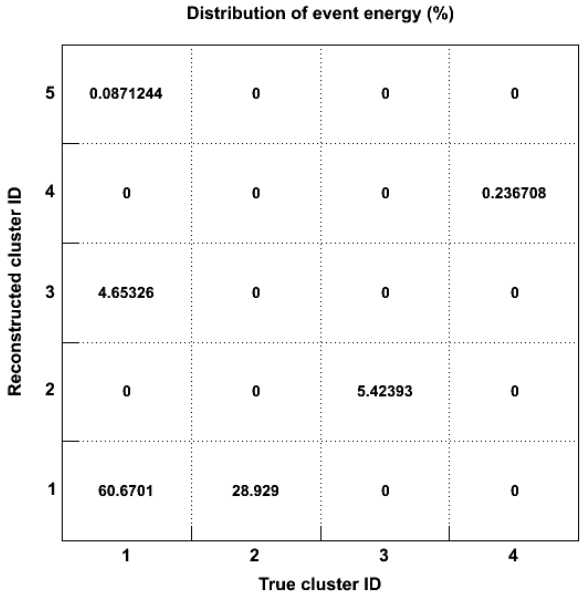


- Quality = 67.0 + 3.3 + 1.0 = 71 %.

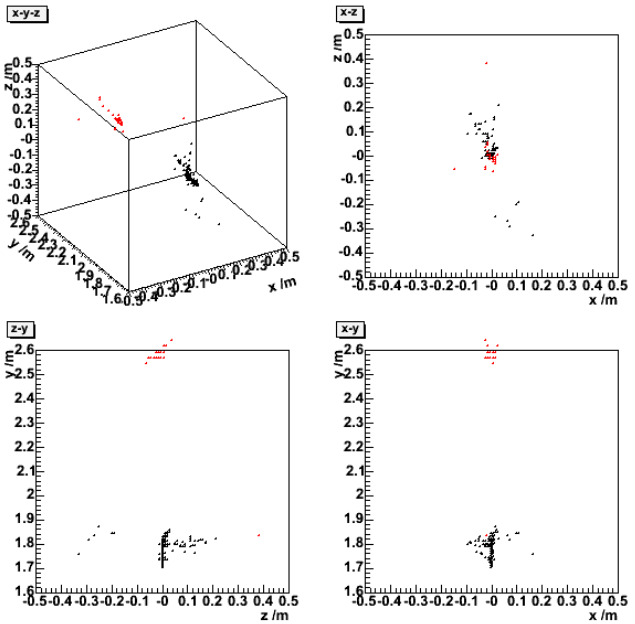
5 GeV π^+n event at 2 cm separation

Reconstructed clusters





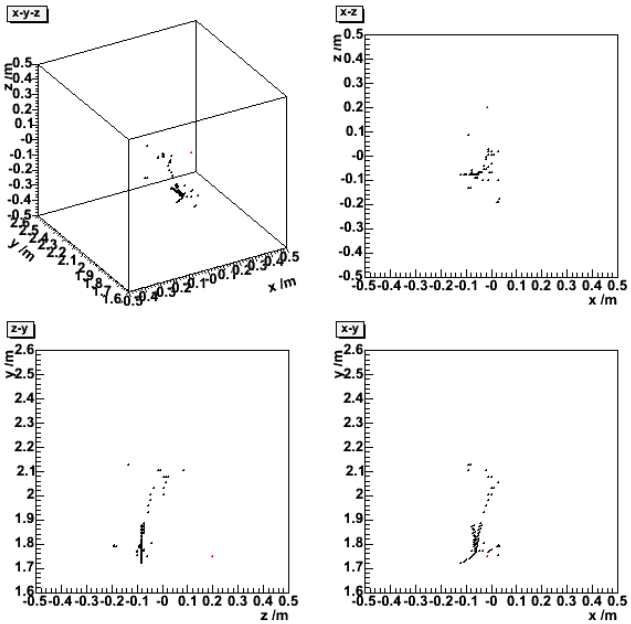
True particle clusters

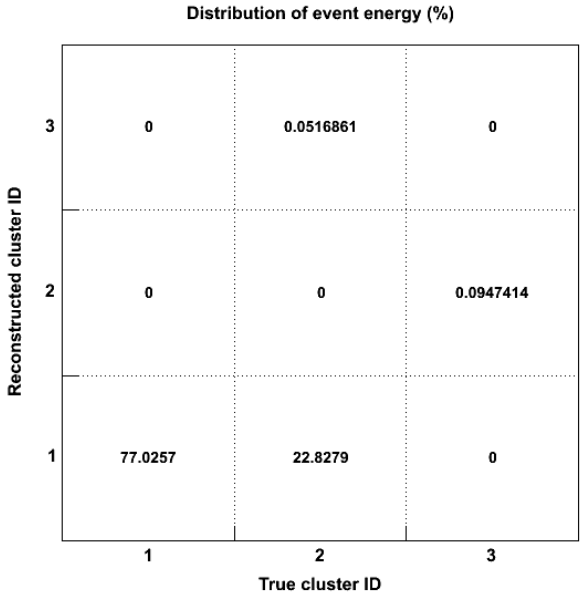


- Quality = 60.7 + 5.4 + 0.2 = 66 %.

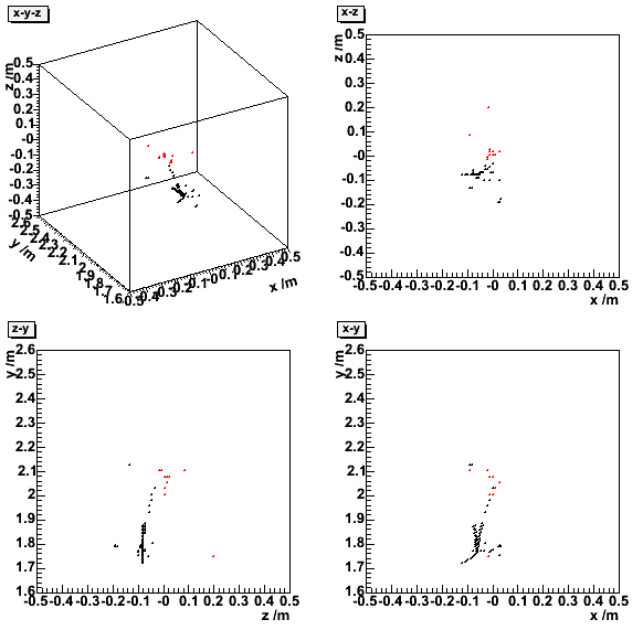
5 GeV nn event at 10 cm separation

Reconstructed clusters





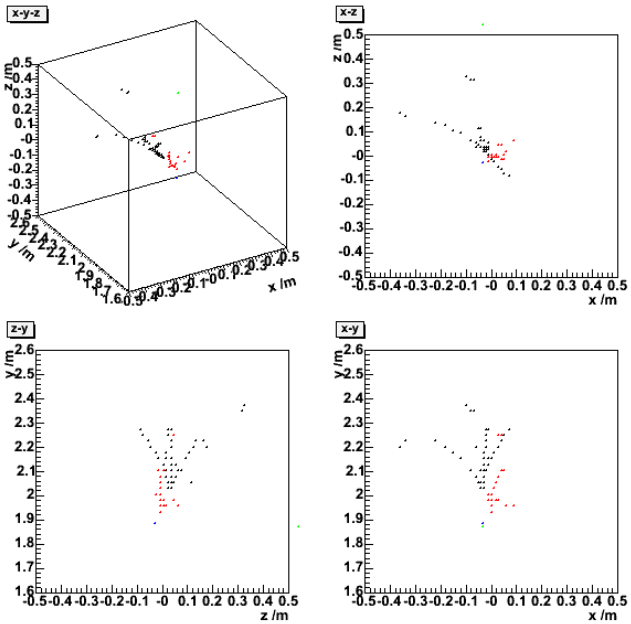
True particle clusters

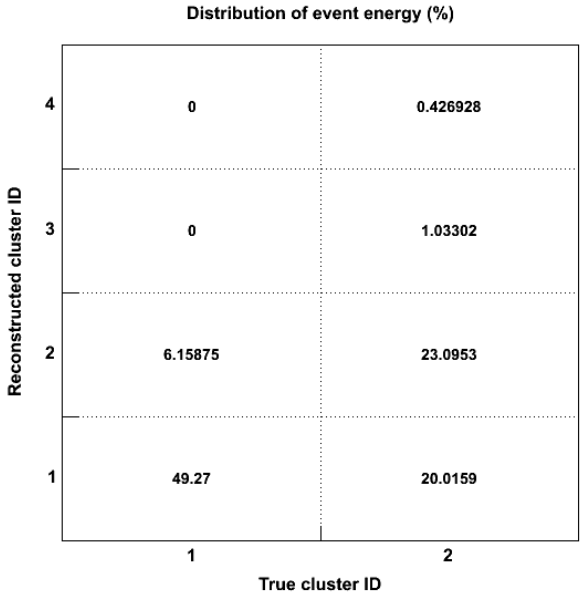


- Quality = 77.0 + 0.1 + 0.1 = 77 %.

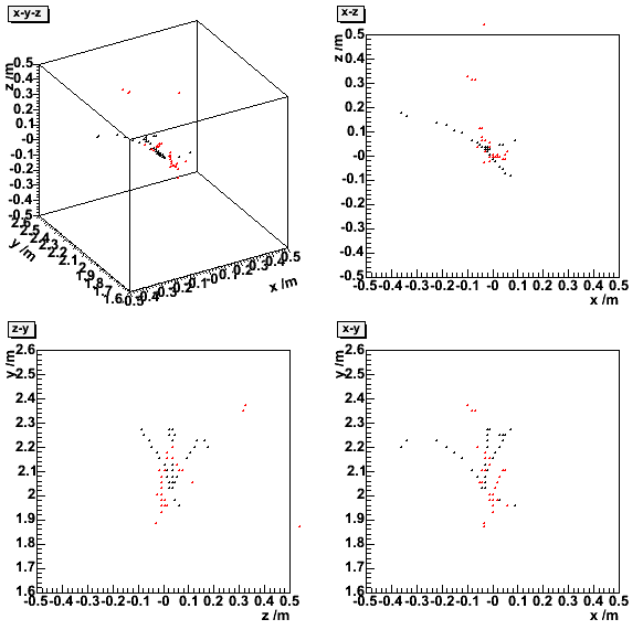
5 GeV nn event at 5 cm separation

Reconstructed clusters





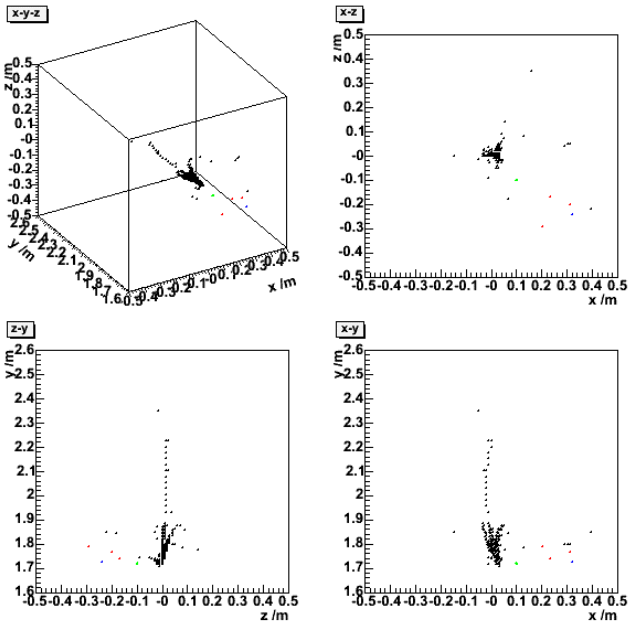
True particle clusters



- Quality = 49.3 + 23.1 = 72 %.

5 GeV nn event at 3 cm separation

Reconstructed clusters



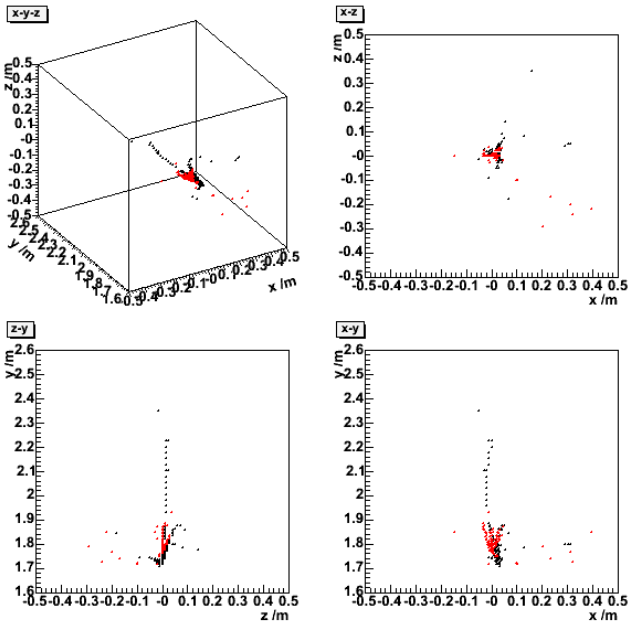
Distribution of event energy (%)

Reconstructed cluster ID

	1	2	3	4	5	6	7	8
9	0	0	0	0	0	0	0	0.0200262
8	0	0	0	0	0	0	0.113786	0
7	0	0	0	0	0	0.143712	0	0
6	0	0	0	0	0.182071	0	0	0
5	0	0.349112	0	0	0	0	0	0
4	0	0.407032	0	0	0	0	0	0
3	0	2.9795	0	0	0	0	0	0
2	0	0	3.00815	2.28172	0	0	0	0
1	61.3559	29.159	0	0	0	0	0	0

True cluster ID

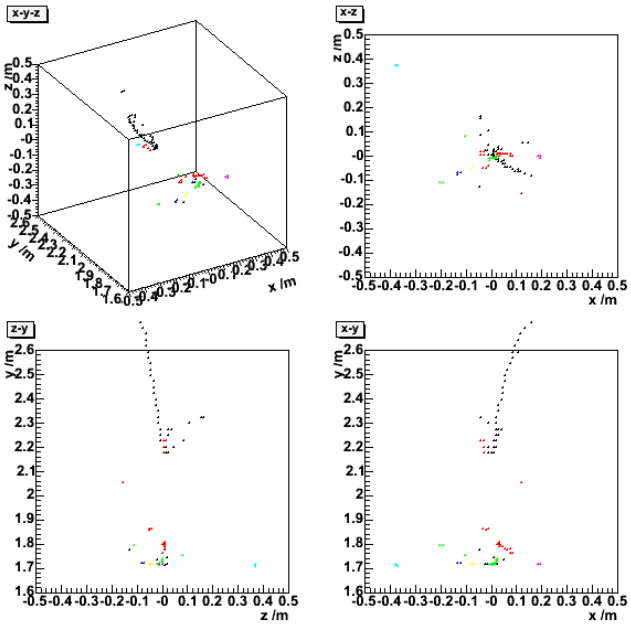
True particle clusters



- Quality = 61.4 + 3.0 + 3.0 + 0.2 + 0.1 + 0.1 + 0.02 = 68 %.

5 GeV nn event at 2 cm separation

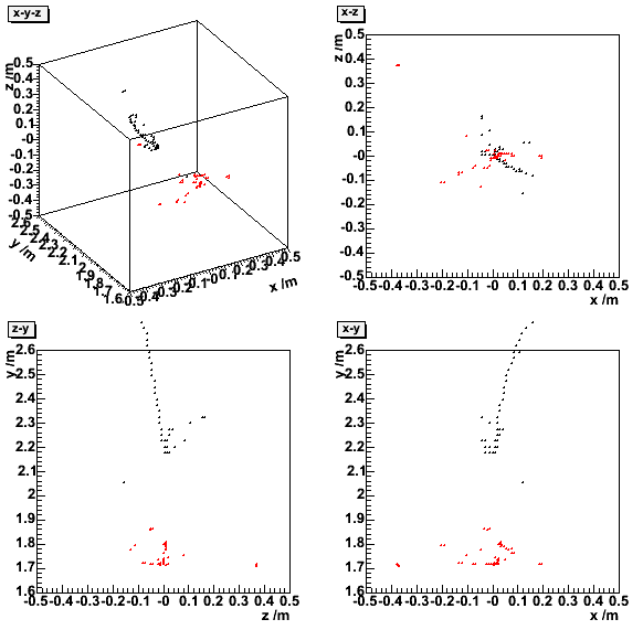
Reconstructed clusters



Distribution of event energy (%)

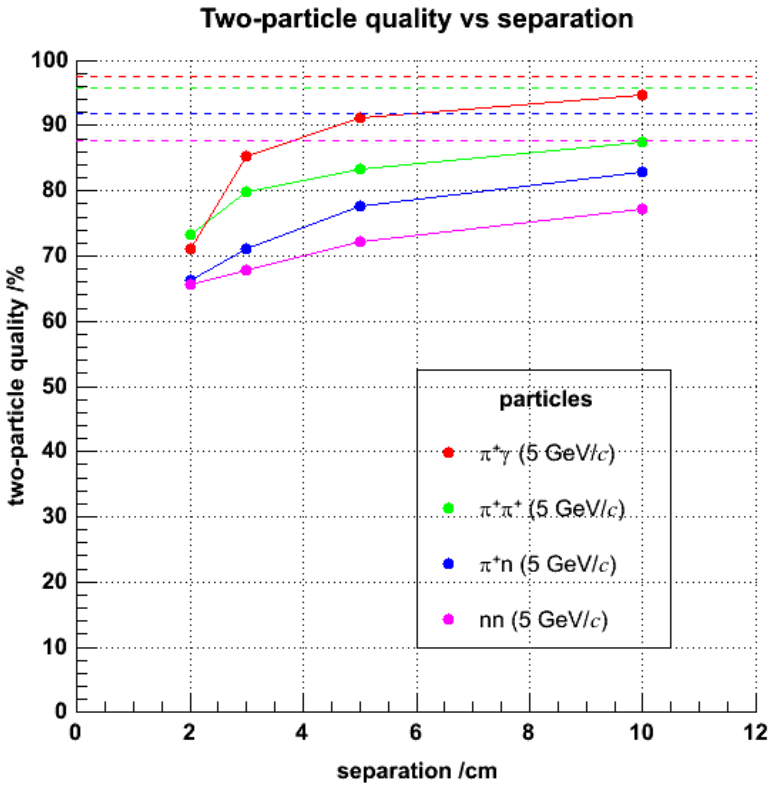
Reconstructed cluster ID \ True cluster ID	1	2	3	4	5	6	7	8
13	0	0	0	0	0	0	0	0.0405264
12	0	0	0	0	0	0	0.0857082	0
11	0	0	0	0	0	0.109765	0	0
10	0	0	0	0	0.122656	0	0	0
9	0	0.396613	0	0	0	0	0	0
8	0	0	0	0.491748	0	0	0	0
7	0	1.01353	0	0	0	0	0	0
6	0	2.76092	0	0	0	0	0	0
5	0	3.45895	0	0	0	0	0	0
4	0	0	4.67787	0	0	0	0	0
3	0	5.97623	0	0	0	0	0	0
2	7.86852	7.57305	0	0	0	0	0	0
1	52.4568	12.9672	0	0	0	0	0	0

True particle clusters



- Quality = 52.5 + 7.6 + 4.7 + 0.5 + 0.1 + 0.1 + 0.1 + 0.04 = 66 %.

Two-particle separation quality: summary



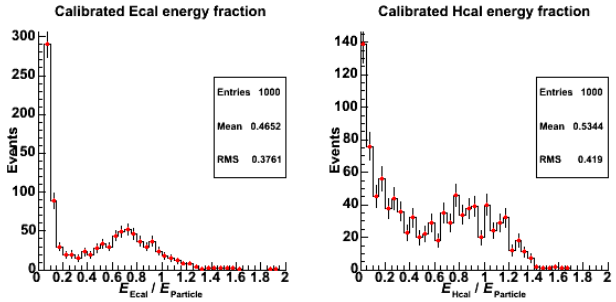
- Goal is to distinguish charged clusters from neutral clusters in calorimeters.
- 'Quality' can be used to optimise the cluster reconstruction and to guide development of algorithm.
- $\pi^+\gamma$ separation already seems to be pretty well under control; π^+n is somewhat tougher (n by itself is tricky).
- $\pi^+\,\pi^+$ and nn separation there for show, but probably not so important in practice.
- Present studies provide a benchmark to make comparisons with other particles, energies, pad-sizes…and, ultimately, detectors and algorithms.

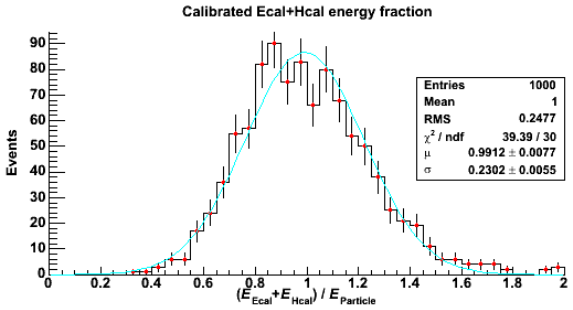
The end

That's all folks…

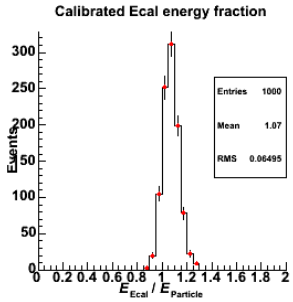
Calibration of π^+, γ and n

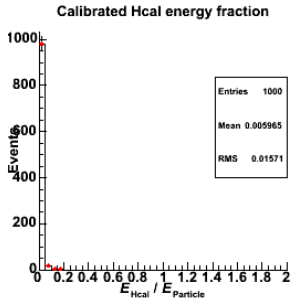
π^+

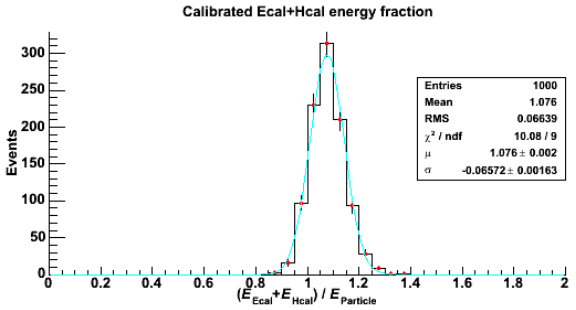




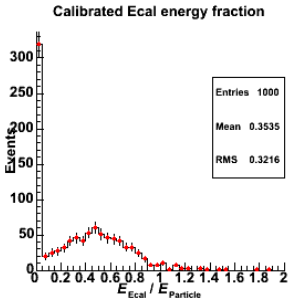
γ

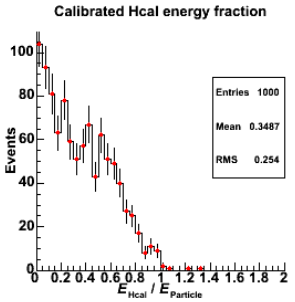


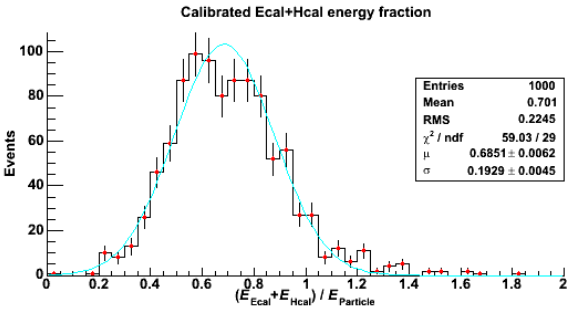




n

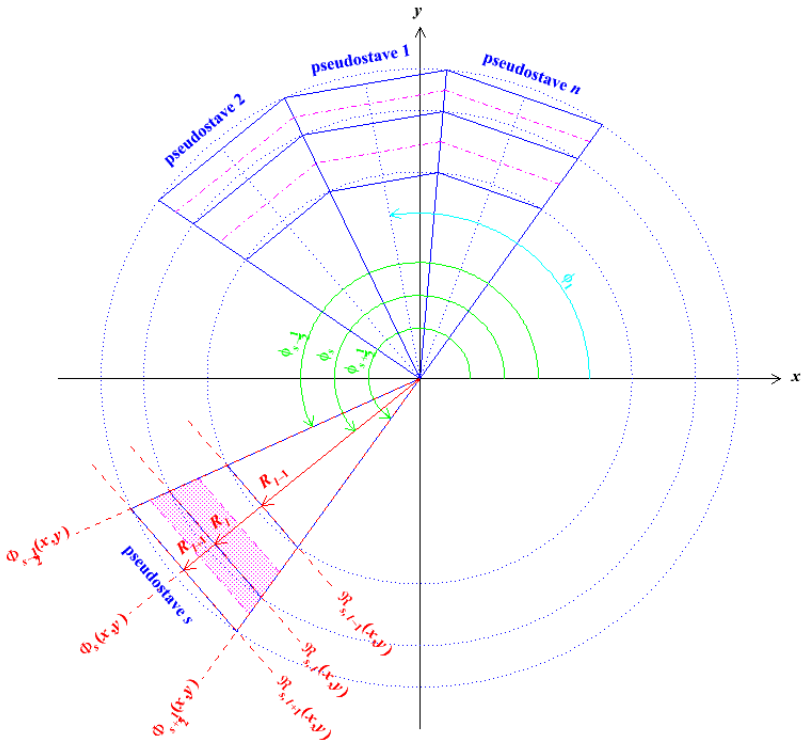




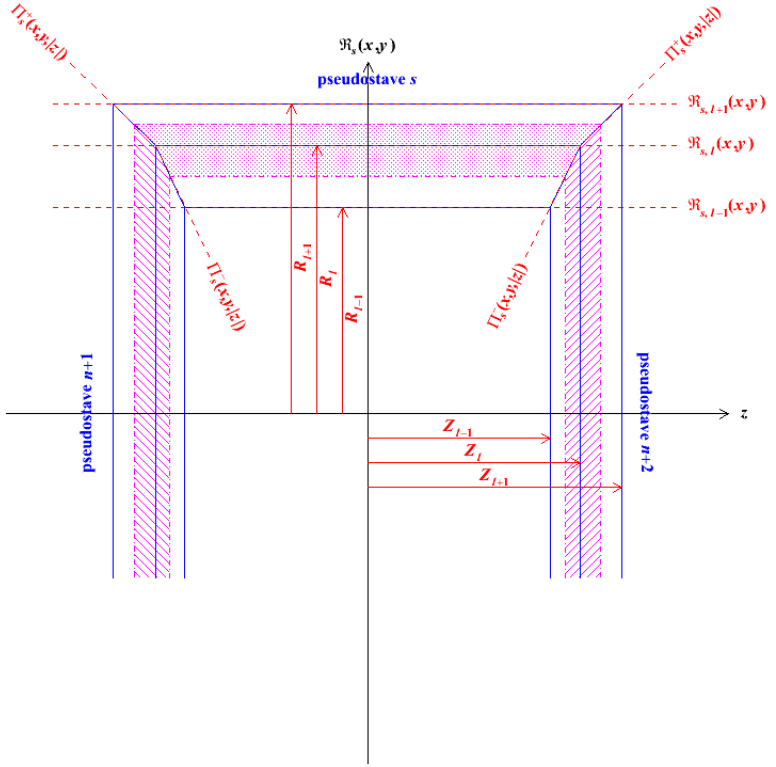


Sections through the generalised detector

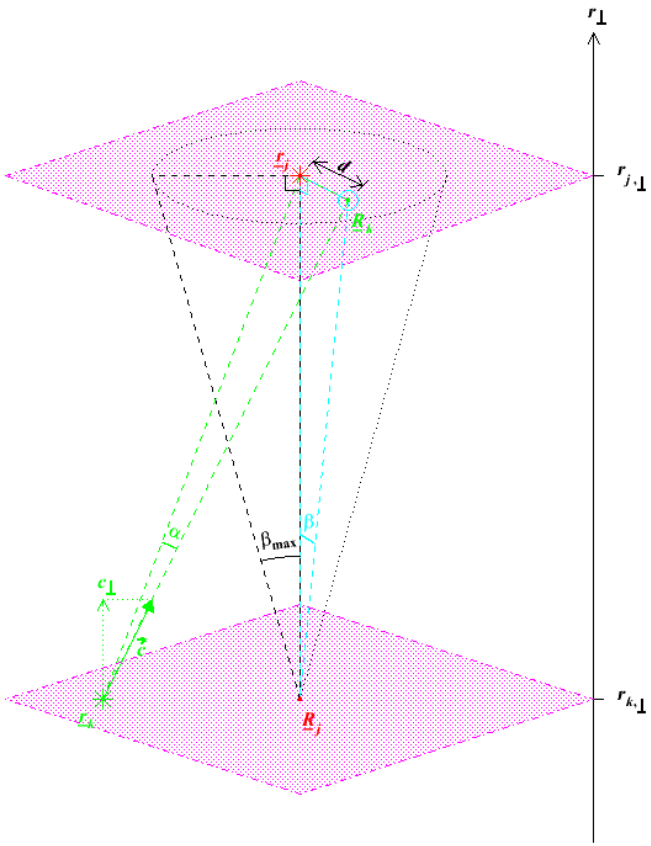
Transverse section



Longitudinal section

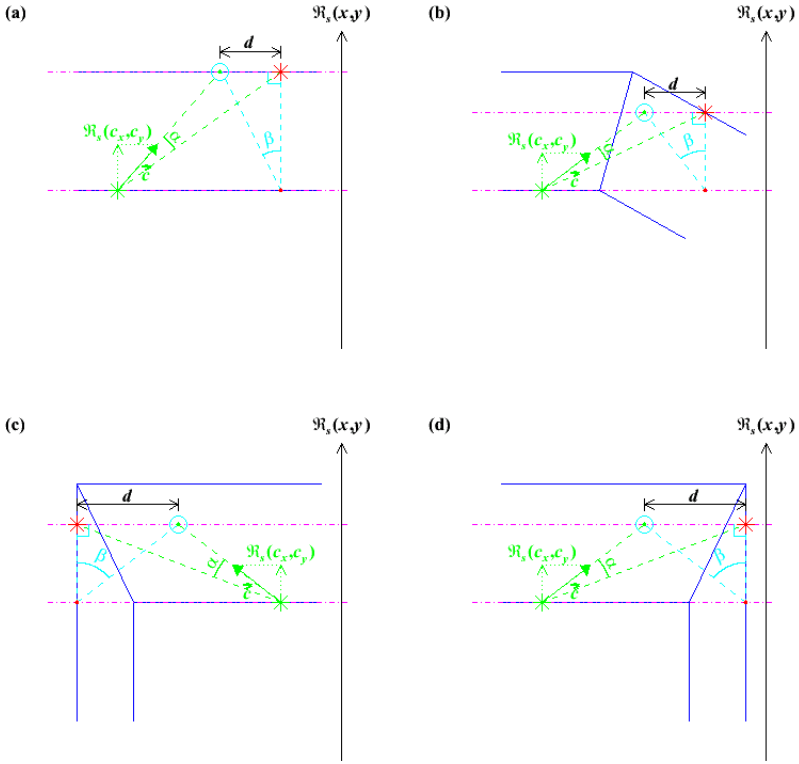


Tracker-like clustering algorithm in 3-D



Cluster-tracking between pseudolayers

From the pseudobarrel



From the pseudoendcap