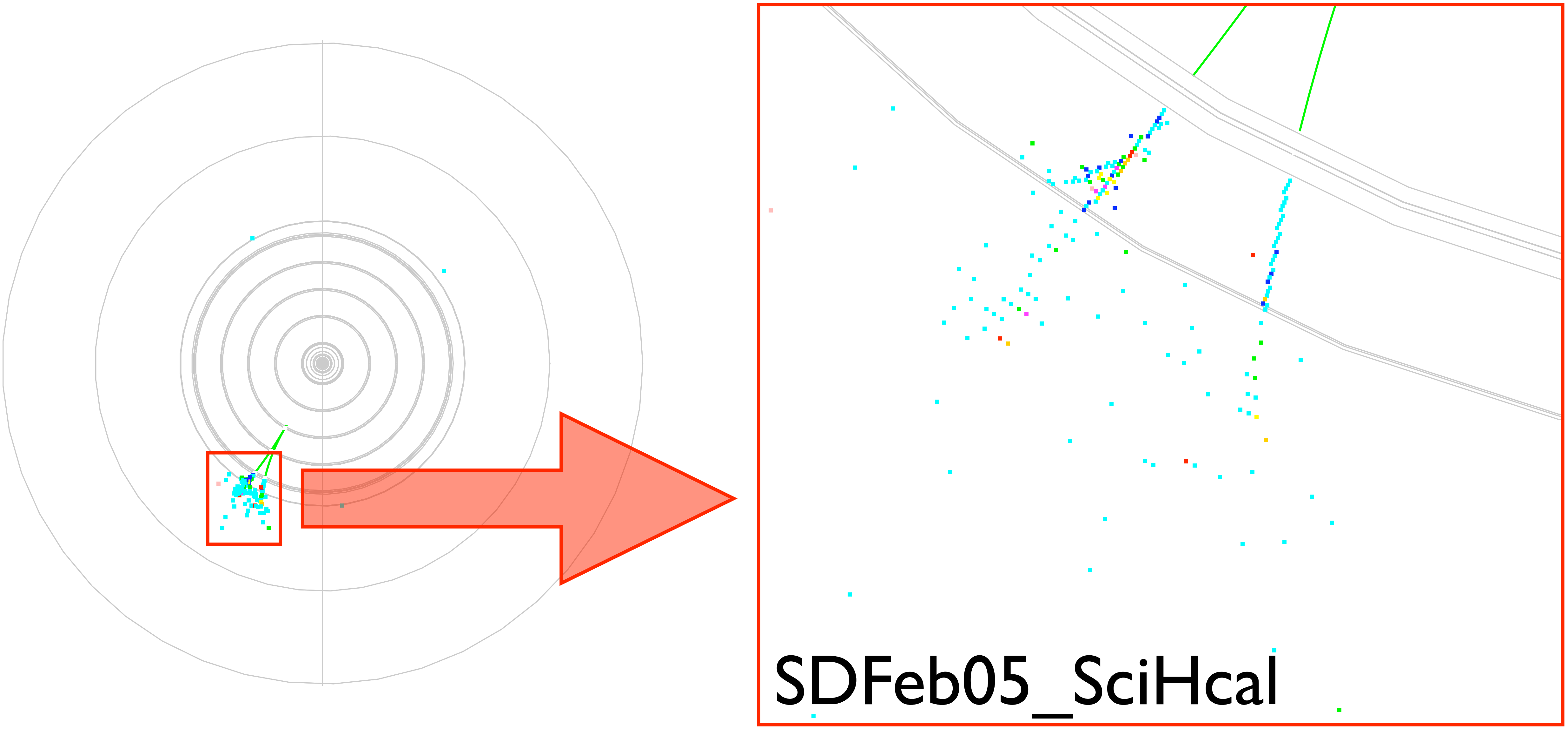
Dissecting the Structure of Hadronic Clusters

Mat Charles, Niels Meyer, Wolfgang Mader, Usha Mallik
The University of Iowa

Introduction, MST recap

- MST algorithm combines hits into clusters if metric(hit1, hit2) < threshold.
- Default metric: simple geometrical distance (similar to nearest-neighbour approach)
- Very effective at picking up contiguous clusters (incl. tendrils that cone algorithms miss)
- ... but doesn't handle close/overlapping clusters gracefully

Example: Ks $\rightarrow \pi^+ \pi^-$



- Clusters are clearly separated by eye...
- But with intermediate hits, they're close enough that MST merges them.

Source: ILC/singleParticle/SDFeb05_SciHcal/sio/lcdg4/K0S_pipi_Theta45-135_5-25Gev.sio

Cluster structure

- Hadronic showers are mostly composed of a few building blocks:
  - Charged track segments
  - Dense clumps following a hard interaction
  - A "halo" of fragments from secondary neutrals, soft tracks, etc.
- Approach:
  - Break cluster down into these pieces
  - See if they should really be linked.

Proof-of-concept algorithm

- Find MIPs that start/end at calorimeter edges — MIPClusterBuilder
- Find large-scale clusters — MSTClusterBuilder
- Within cluster, look for skeleton components:
  - MIPs, track segments — MIPClusterBuilder
  - Dense clumps — MSTClusterBuilder
  - Halo hits (i.e. everything else)
- Link skeleton together
  - Track-clump, with cuts on distance of closest approach (DOCA) and distance between nearest hits
  - Track-track, with cuts on DOCA and distance from nearest hits to point of closest approach (POCA)
- Merge halo hits into nearest clump/MIP

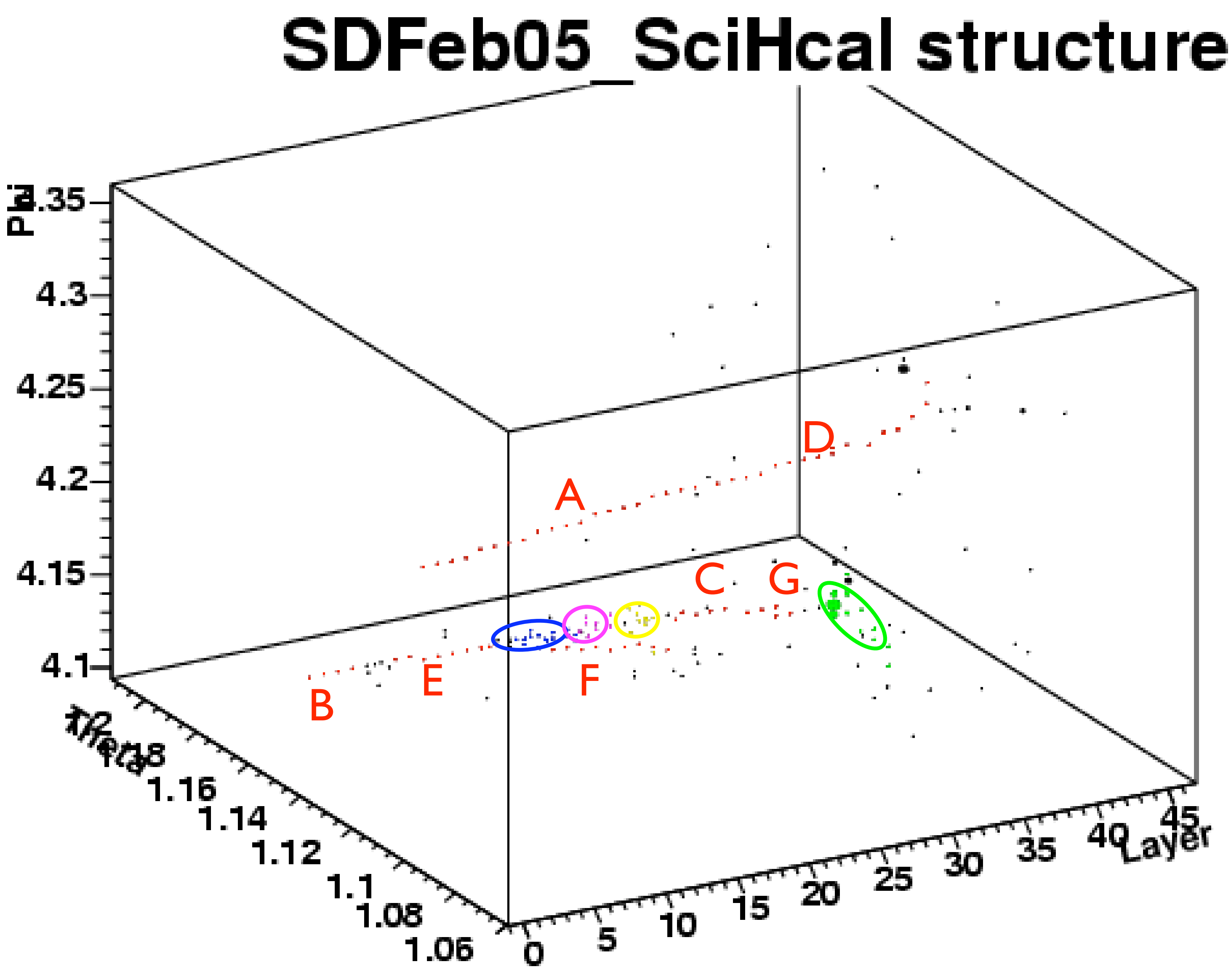
... + details (omitted here)

Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 track segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

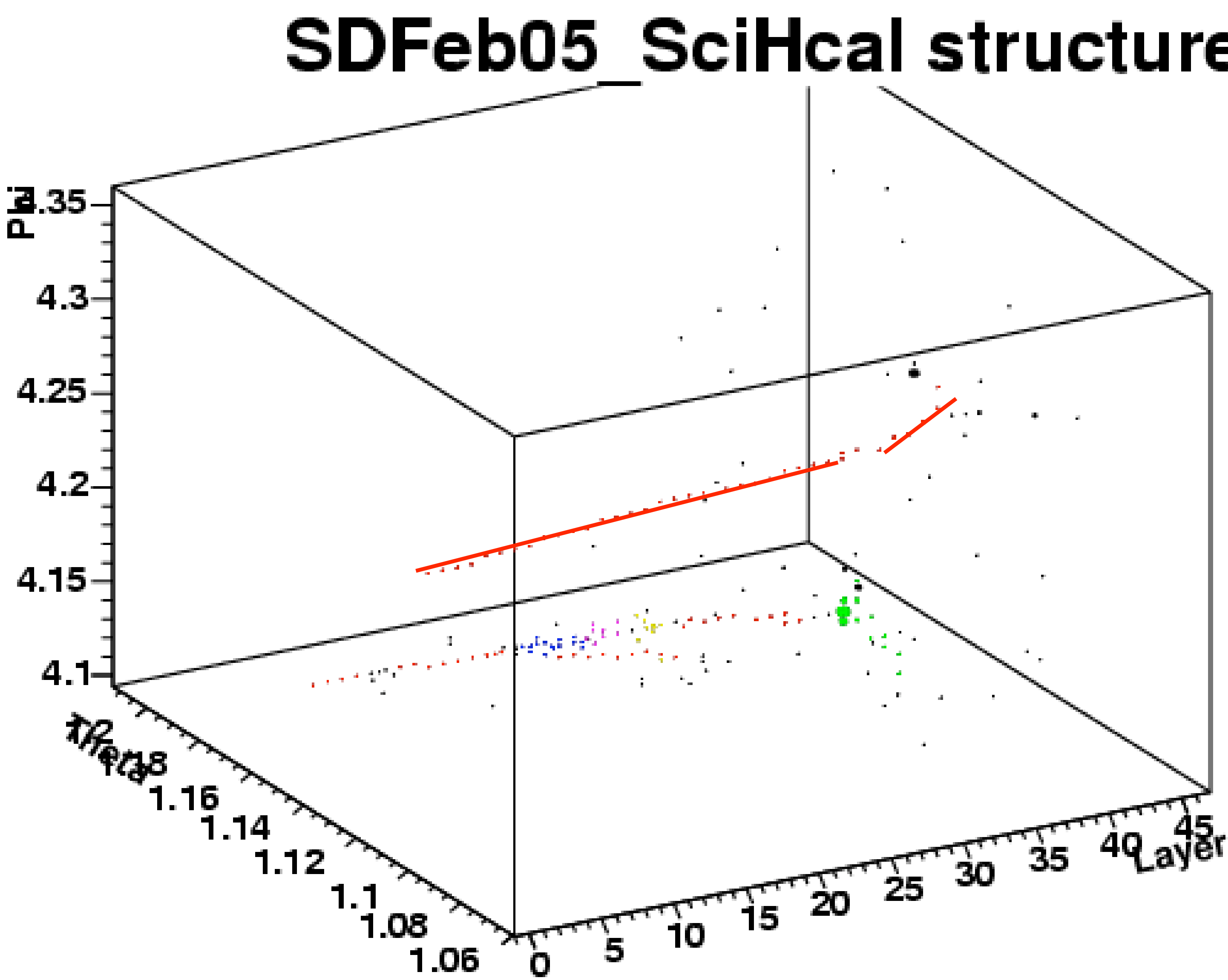
Same event as before.



Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits



DOCA ~ 4.0mm
Hit-hit distance ~ 2.6cm
⇒ Strong link

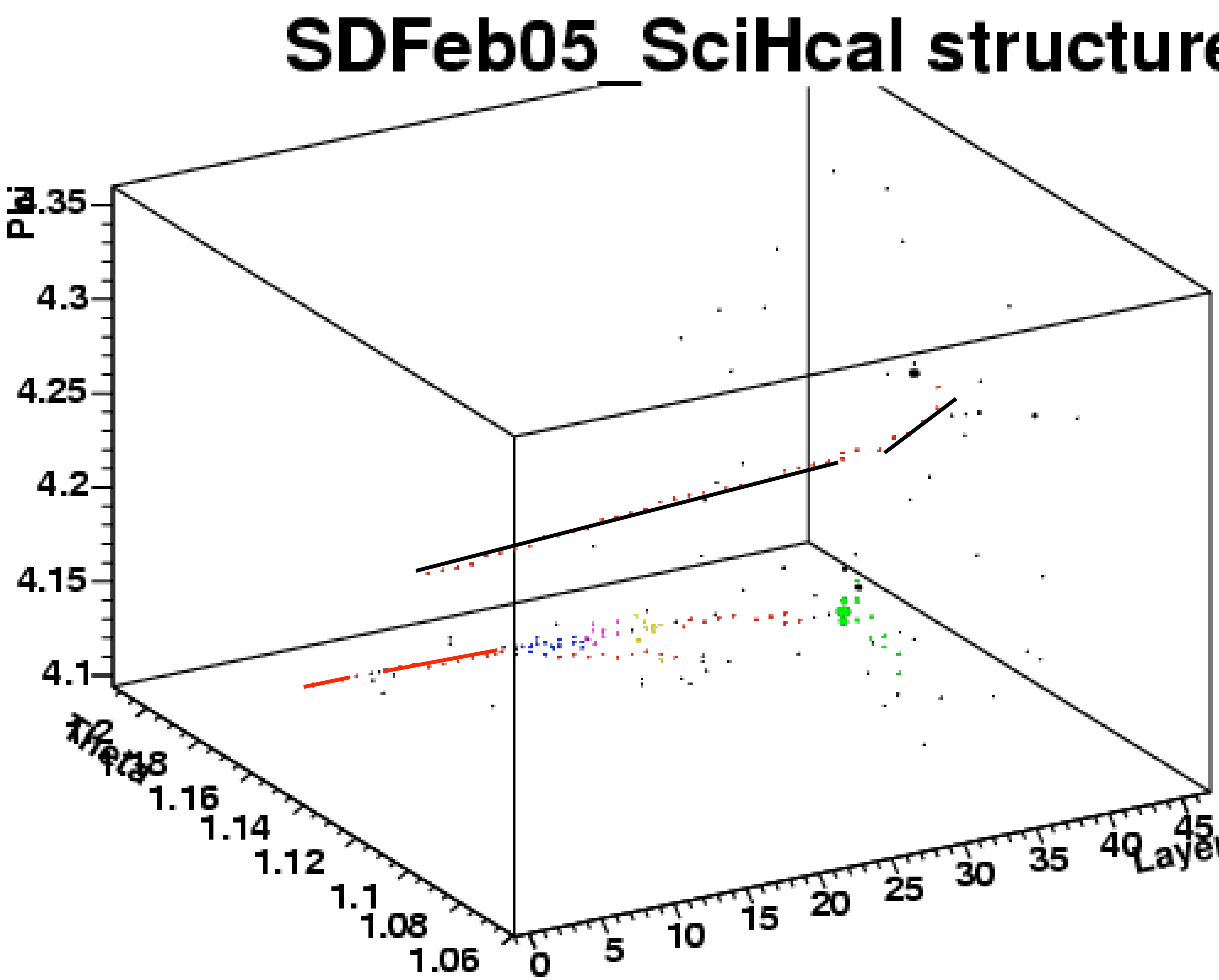
Example: Ks $\rightarrow \pi^{+} \pi^{-}$

4 clumps:

1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:

A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

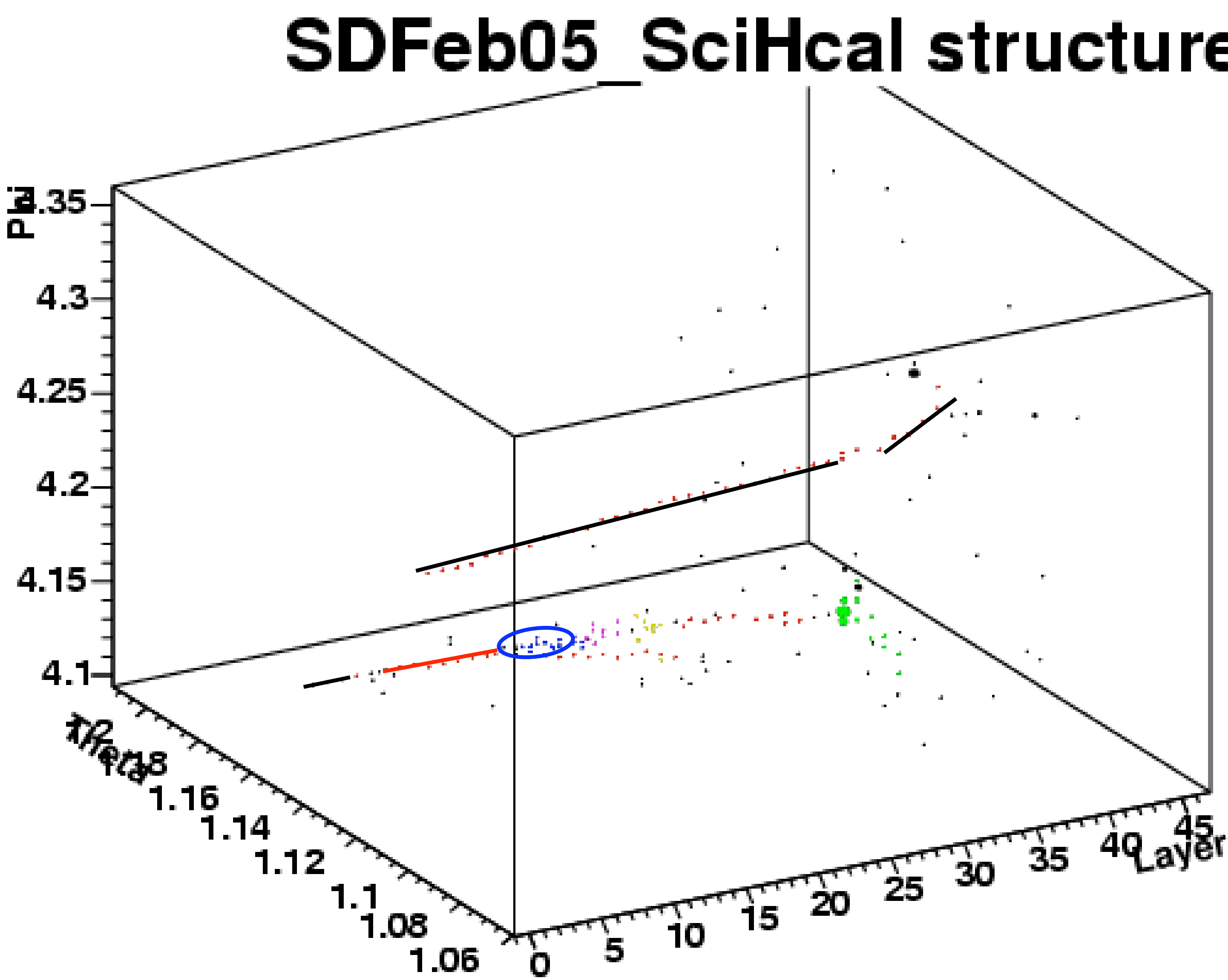


DOCA ~ 2.4mm
Hit-hit distance ~ 1.2cm
⇒ Strong link

Example: Ks $\rightarrow \pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

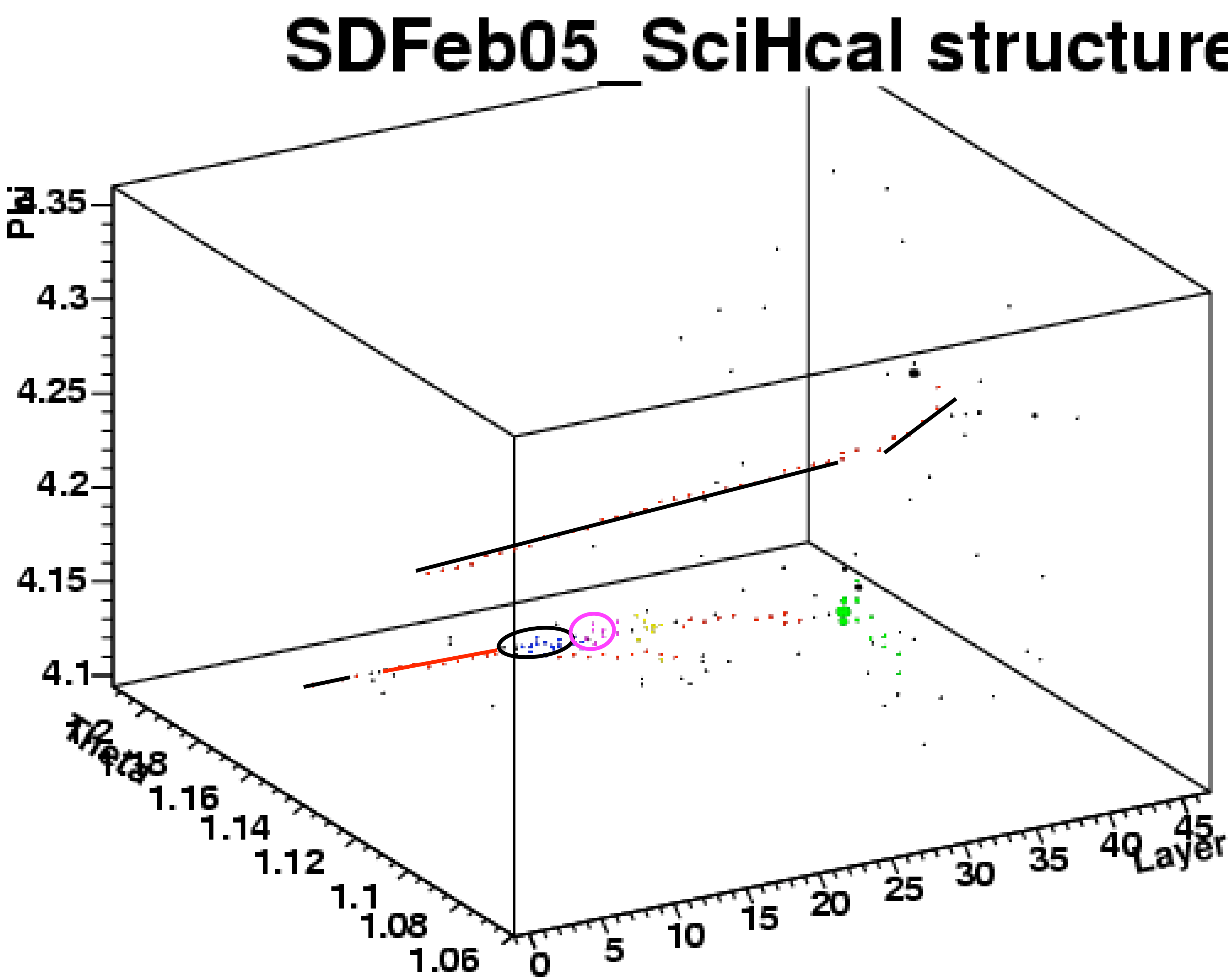


DOCA ~ 3 mm
Hit-hit distance ~ 0.8cm
⇒ Strong link

Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

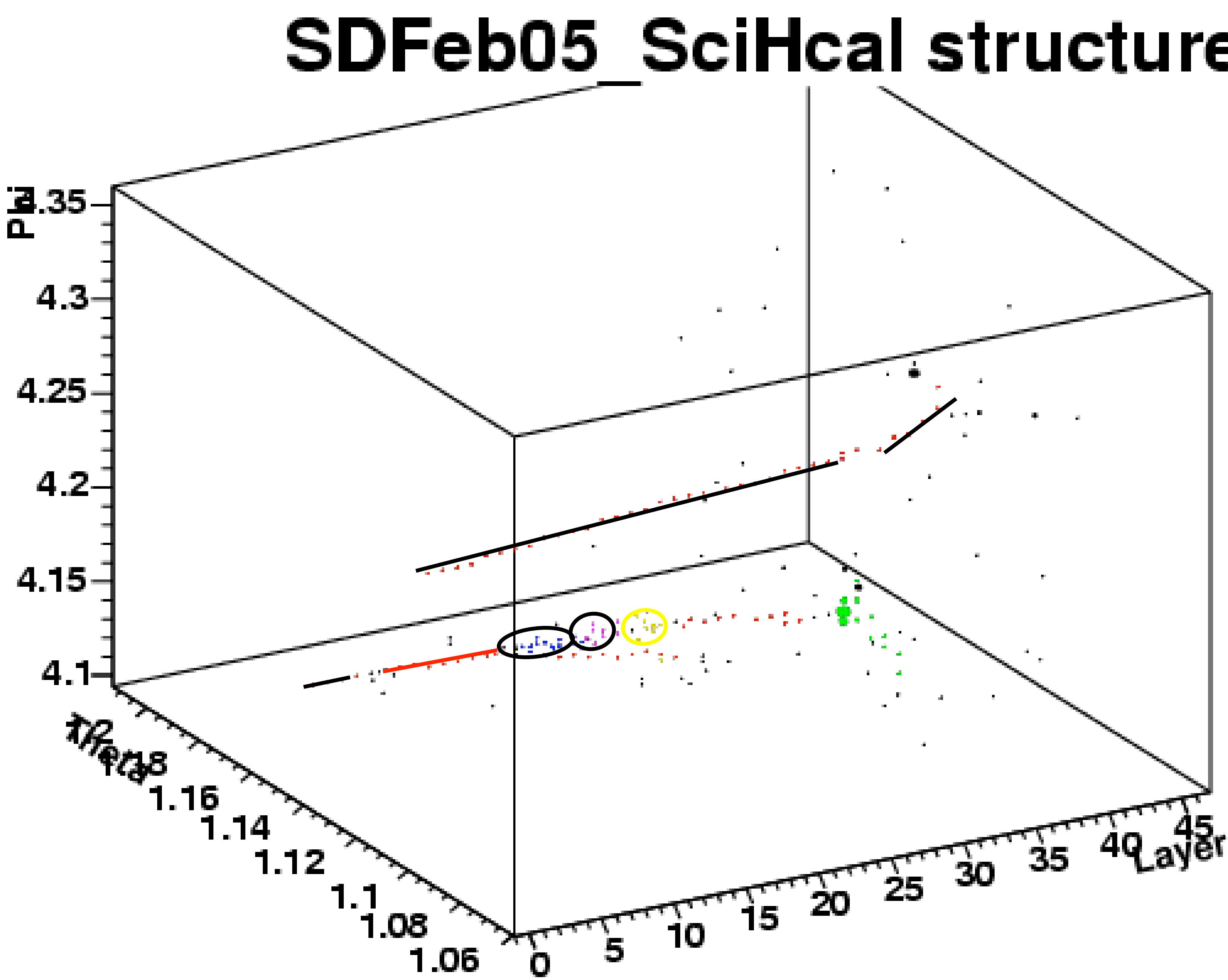


DOCA ~ 10 mm
Hit-hit distance ~ 2.9cm
⇒ Strong link

Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

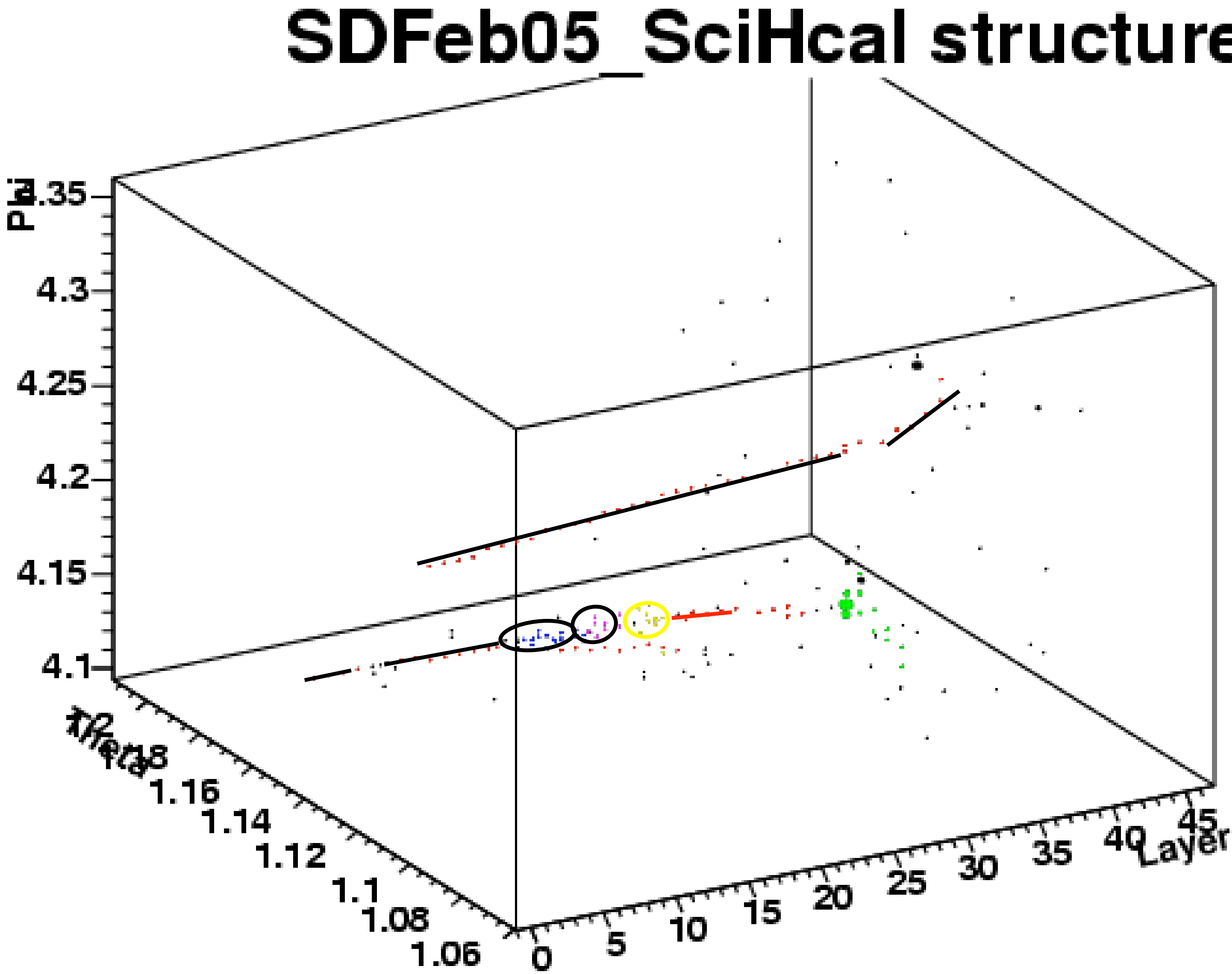


DOCA ~ 10 mm
Hit-hit distance ~ 2.9cm
⇒ Strong link

Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

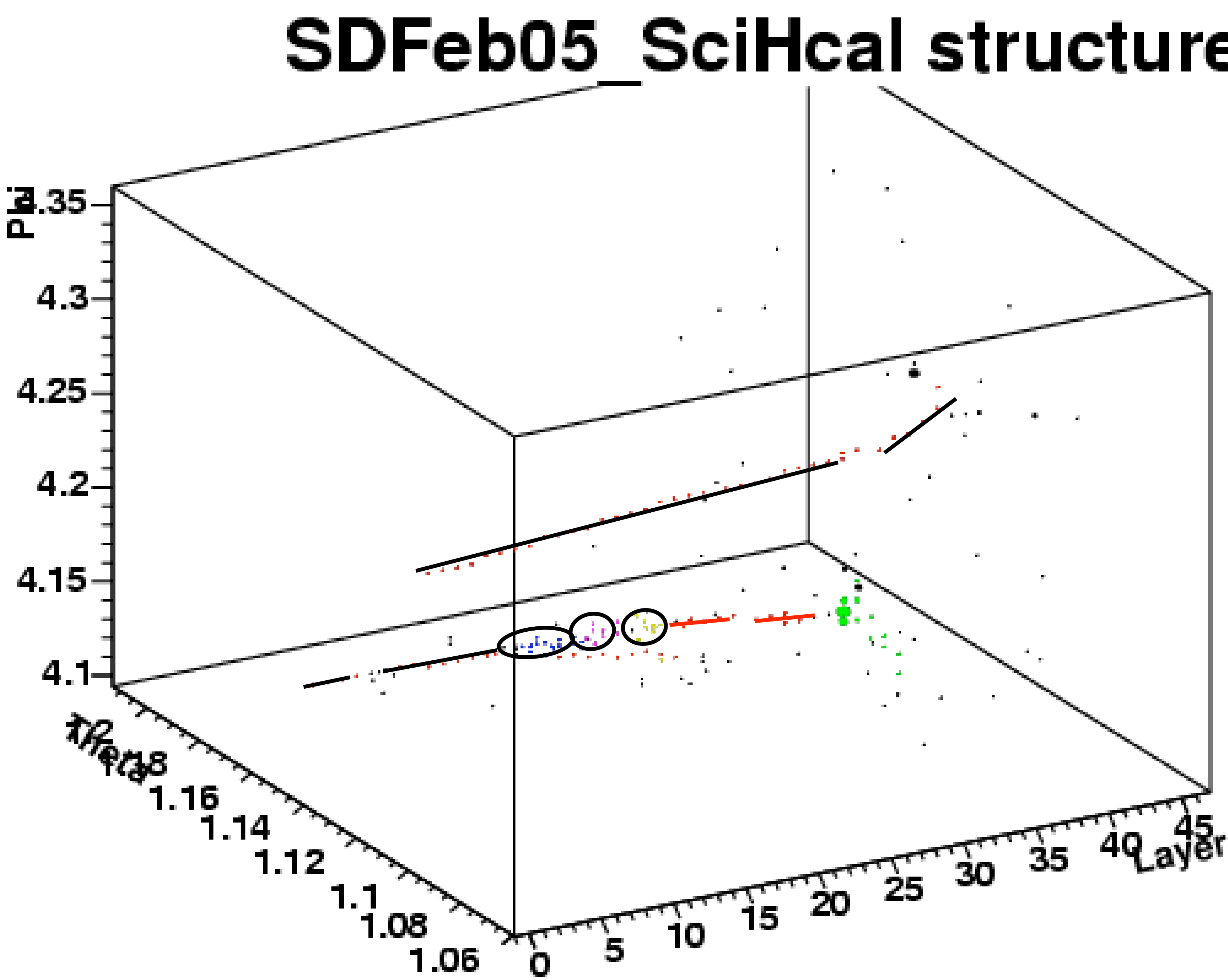


DOCA ~ 12 mm
Hit-hit distance ~ 0.4cm
⇒ Strong link

Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

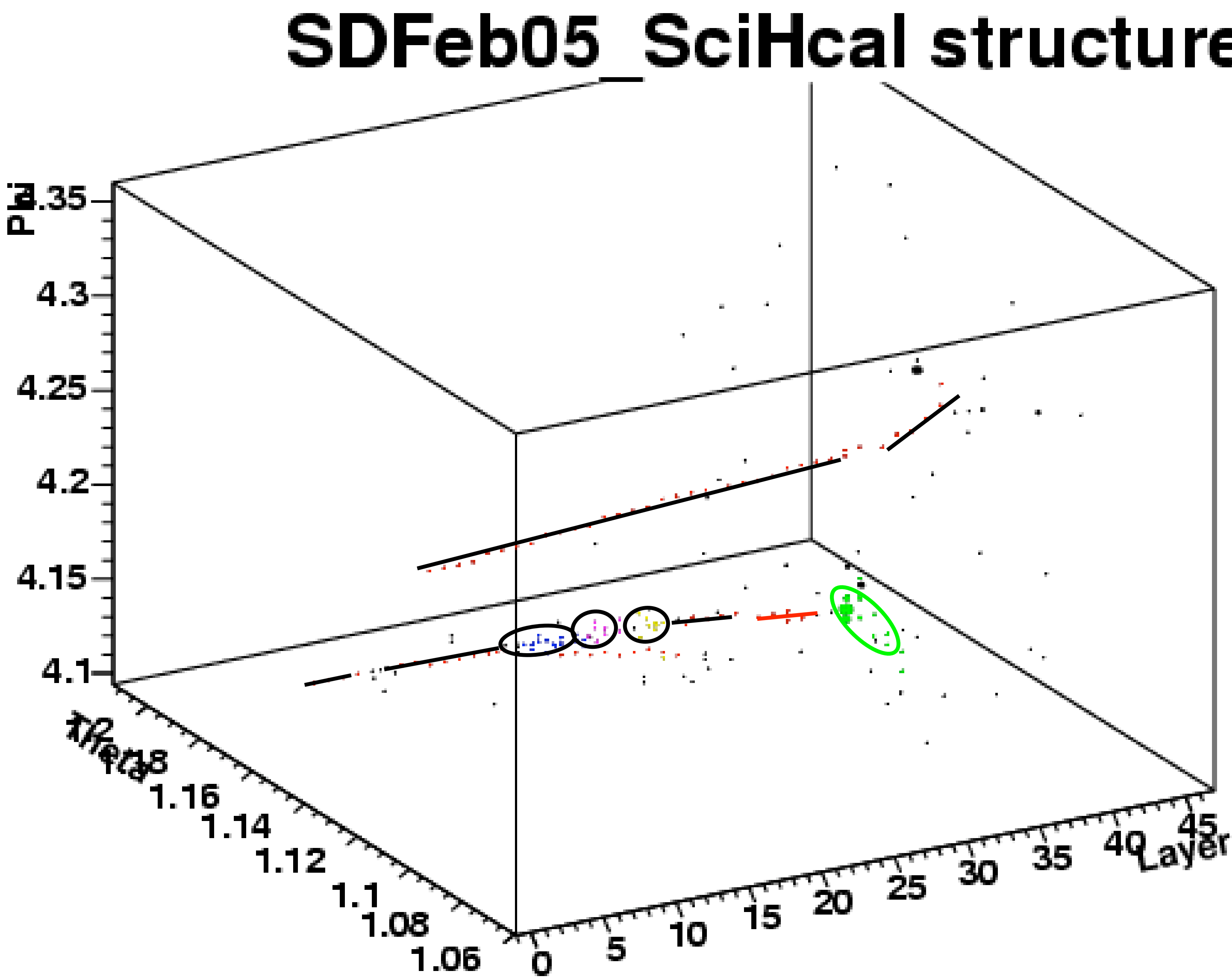


DOCA ~ 1.0 mm
Hit-hit distance ~ 1.6cm
⇒ Strong link

Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

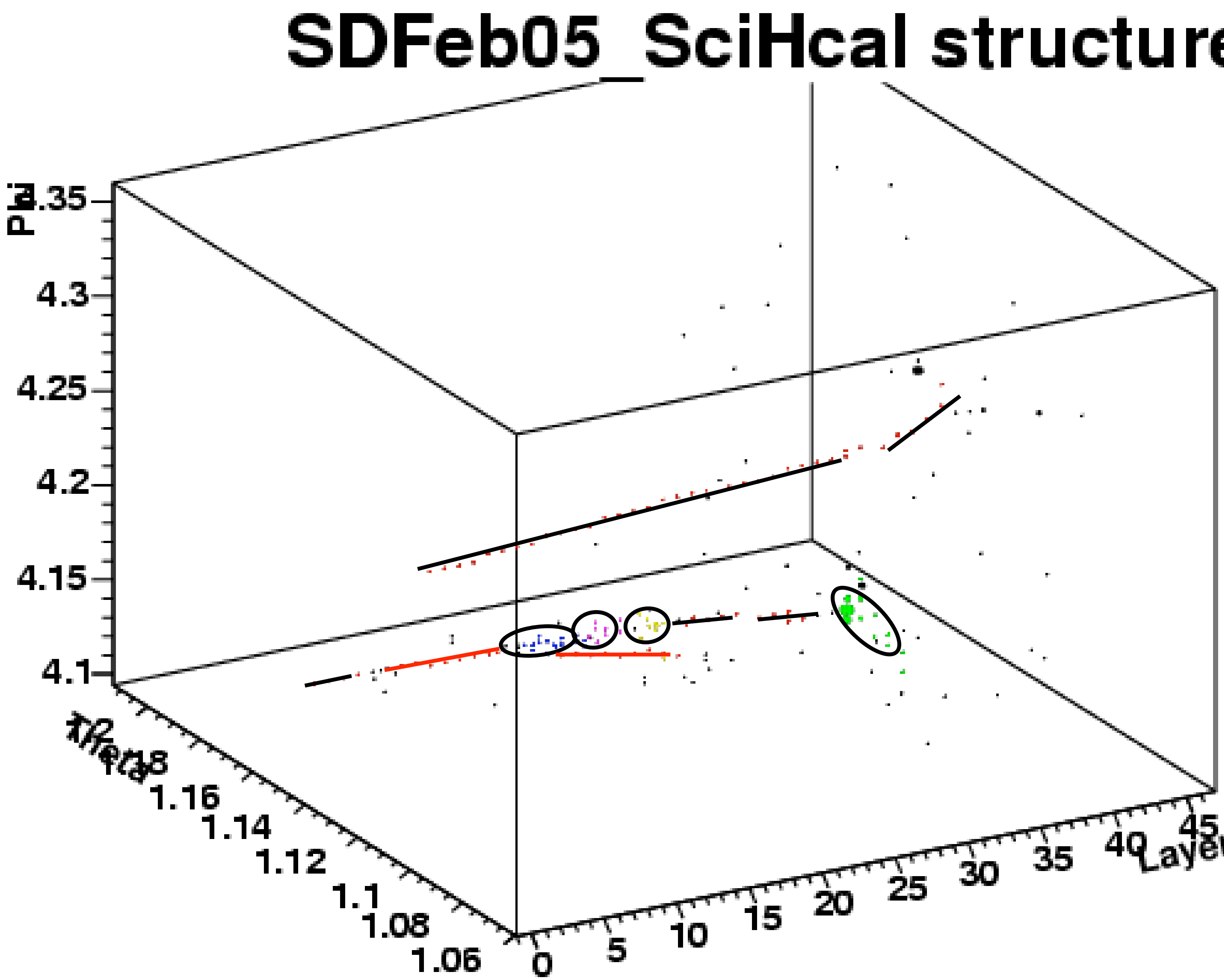


DOCA ~ 5 mm
Hit-hit distance ~ 5.0cm
⇒ Strong link

Example: Ks → $\pi^+ \pi^-$

4 clumps:
1) 15 hits
2) 14 hits
3) 8 hits
4) 9 hits

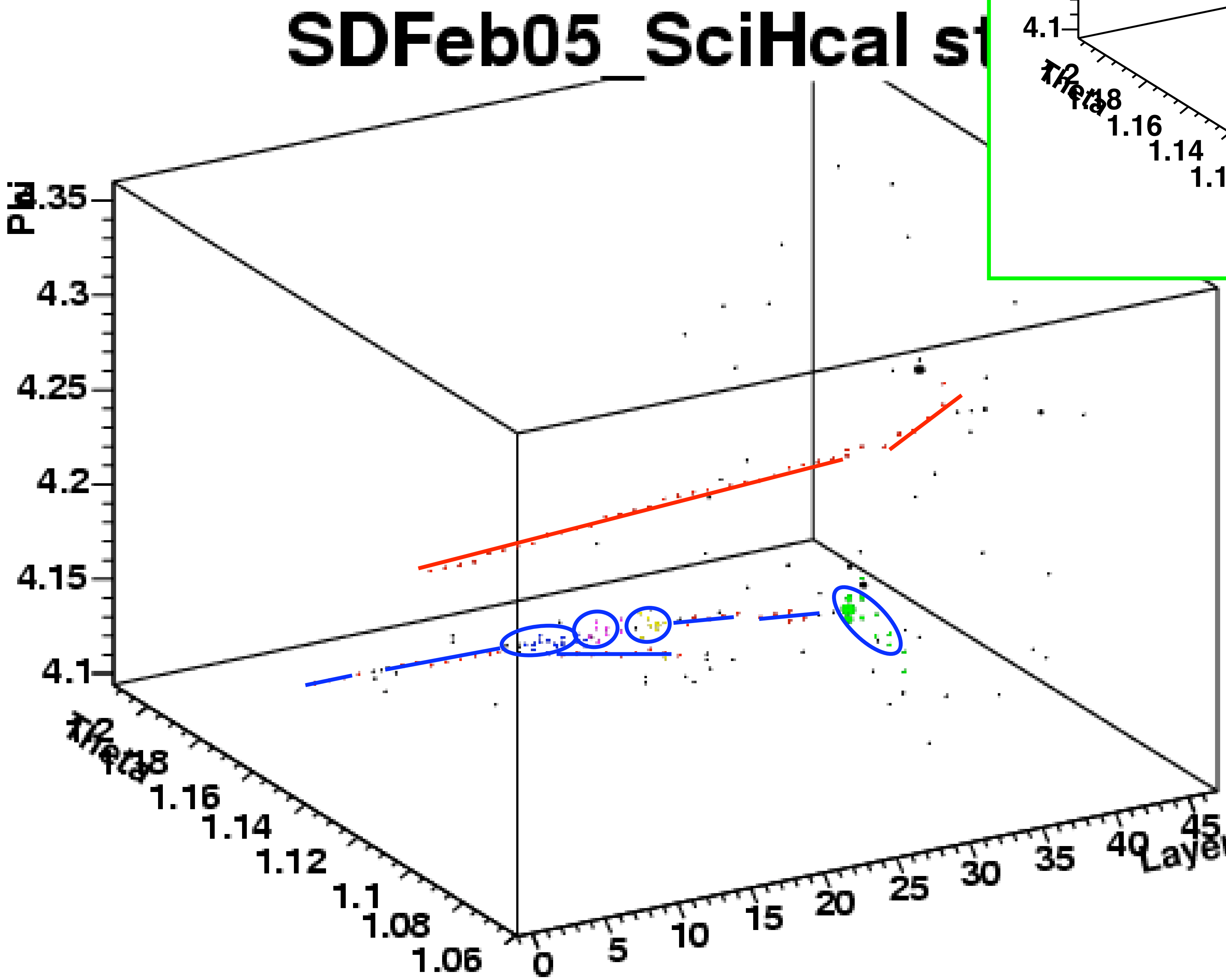
7 MIP segments:
A) 28 hits
B) 4 hits
C) 6 hits
D) 6 hits
E) 9 hits
F) 9 hits
G) 5 hits

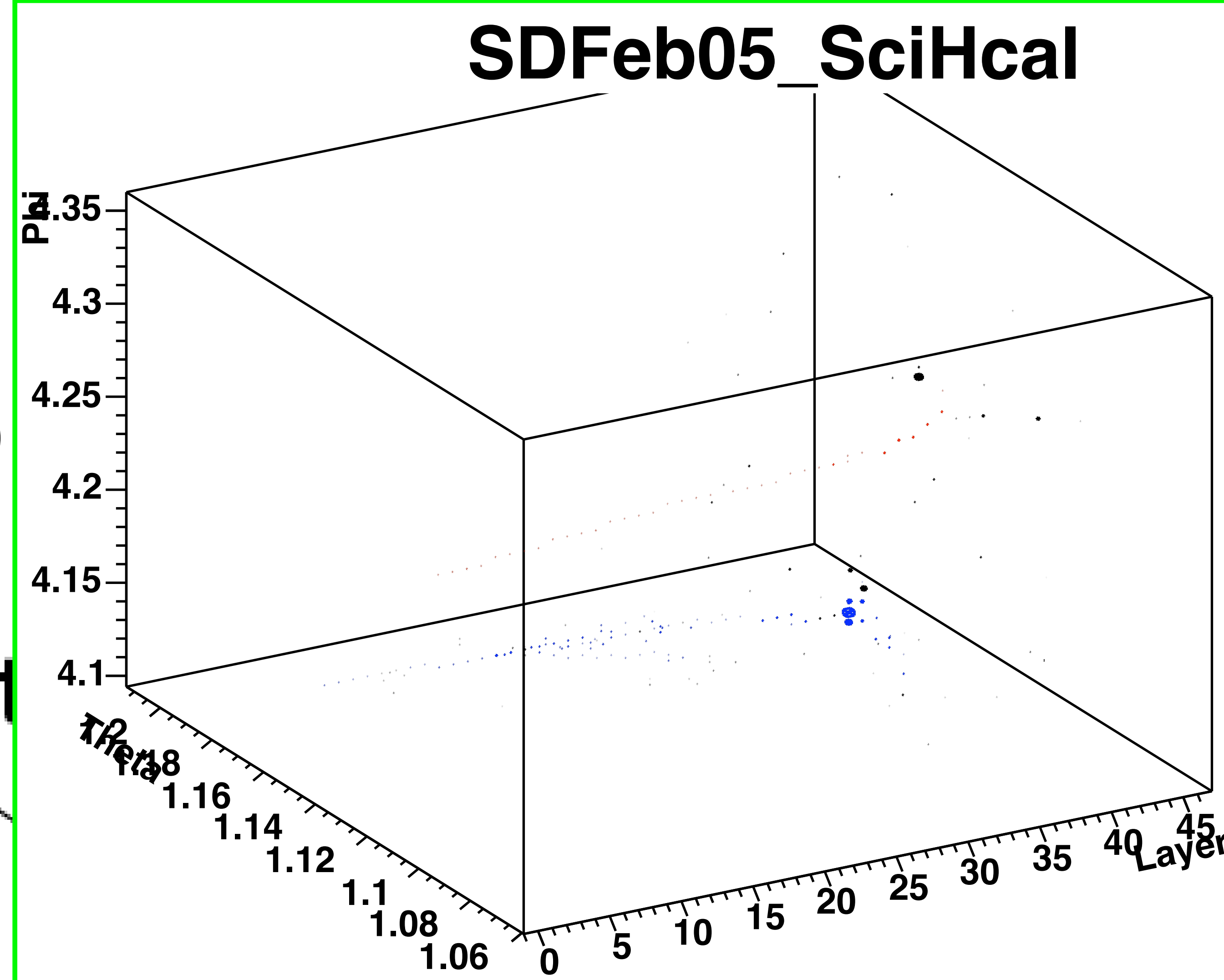


DOCA ~ 0.6 mm
Hit-hit distance ~ 2.1cm
⇒ Strong link

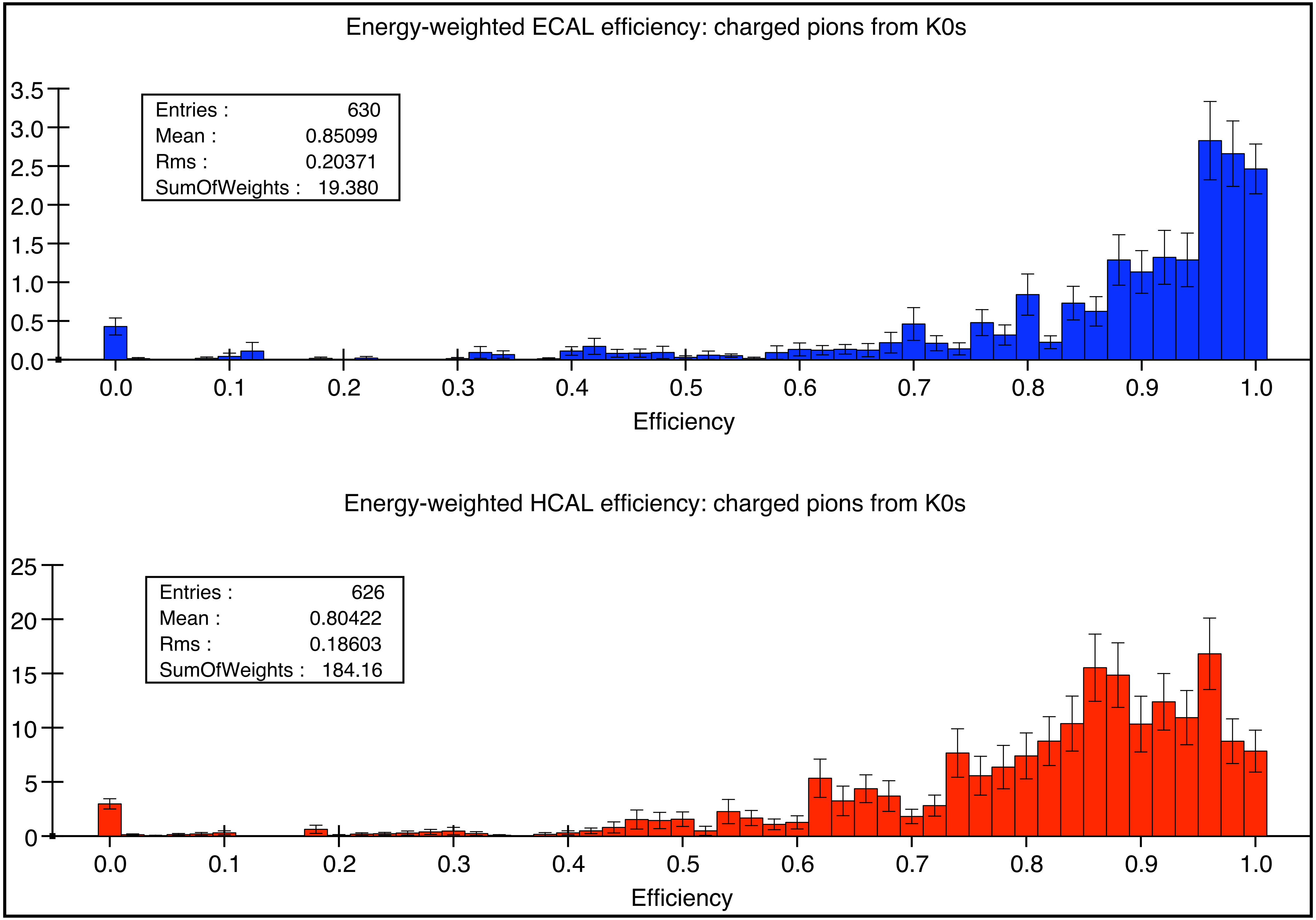
Example: Ks → $\pi^+ \pi^-$

red = first cluster skeleton (π^-)
blue = second cluster skeleton (π^+)
black = halo





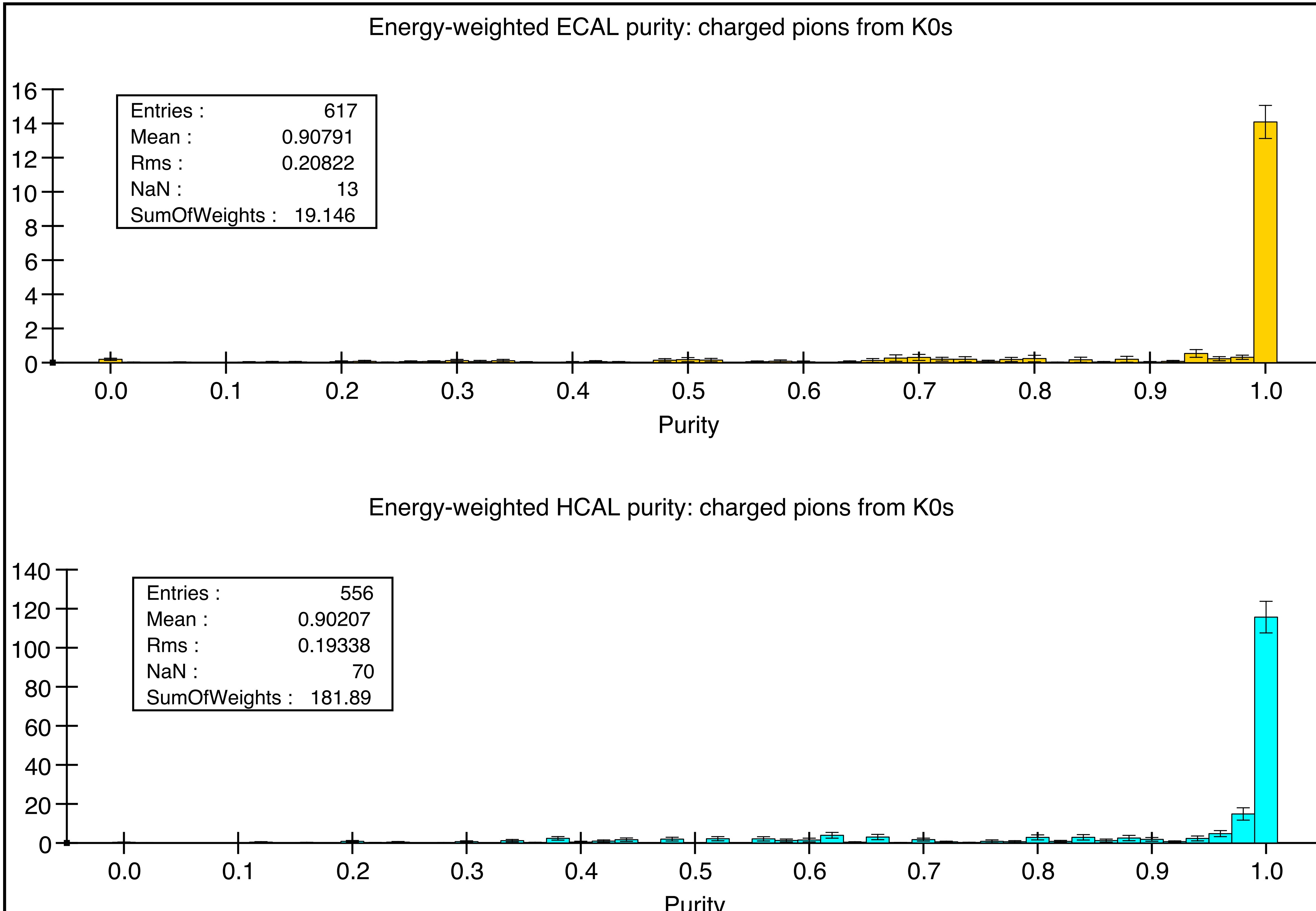
Current performance



Charged pions with p>0.2 GeV/c, produced by K-short decaying at r<120 cm

Source: ILC/singleParticle/SDFeb05_SciHcal/sio/lcdg4/K0S_pipi_Theta45-135_5-25Gev.sio

Current performance



Charged pions with p>0.2 GeV/c, produced by K-short decaying at r<120 cm

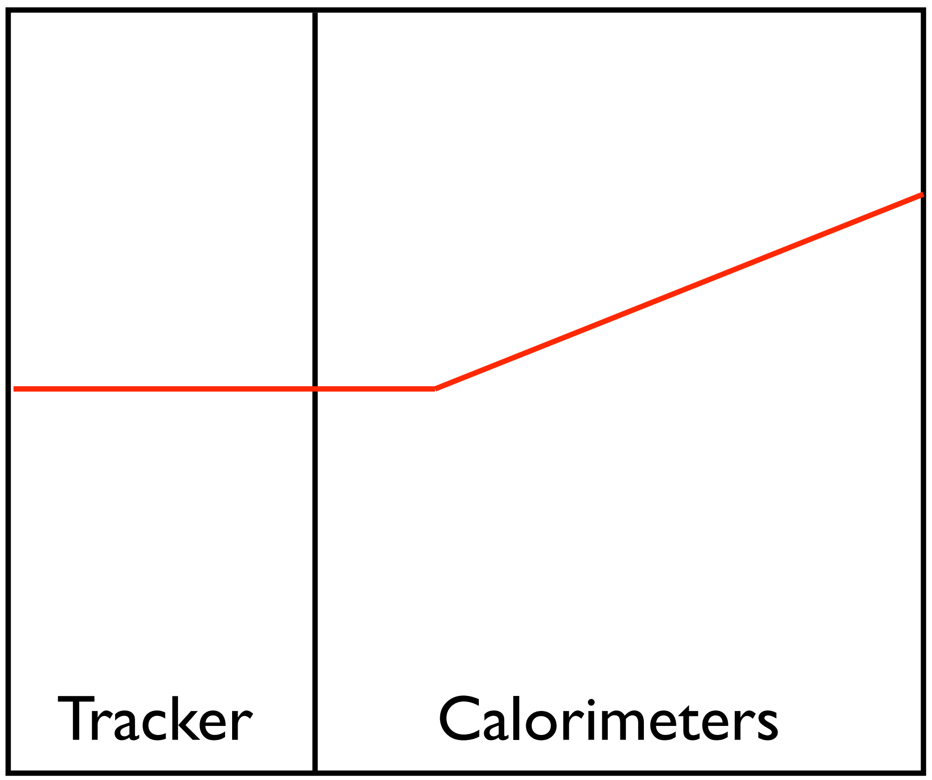
Source: ILC/singleParticle/SDFeb05_SciHcal/sio/lcdg4/K0S_pipi_Theta45-135_5-25Gev.sio

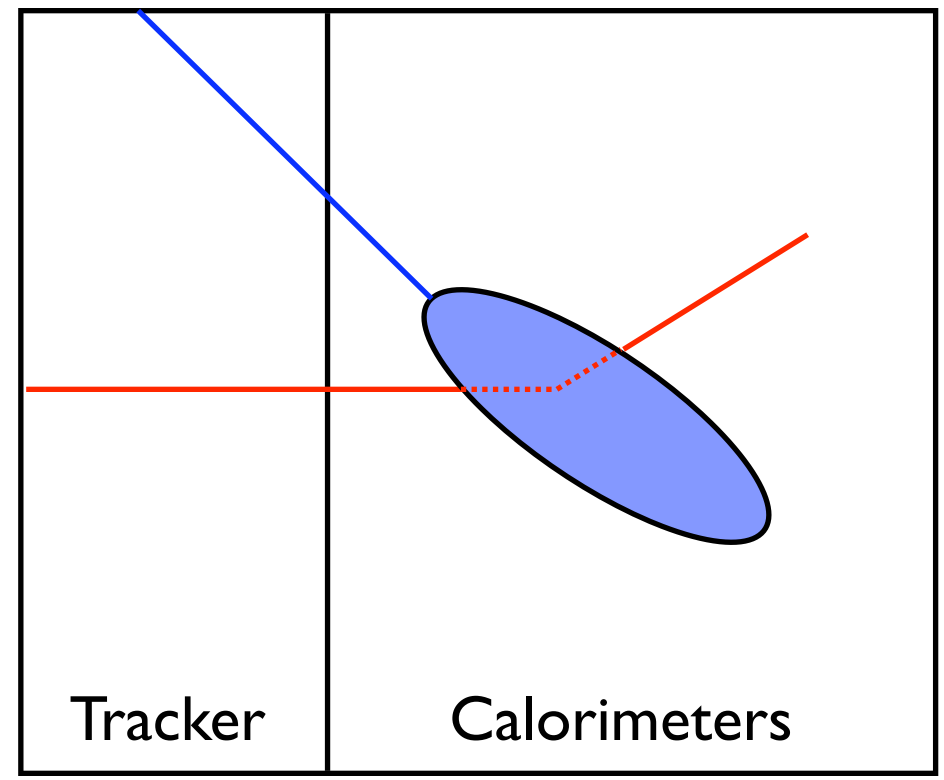
Patterns

- Aggregate statistics are nice but don't tell the whole story.
- Quite often see certain classes of event which confuse the algorithm -- study these "typical events" in more detail.
- Iterative process (fixing one problem can break something else...)

Patterns: Linking tracks

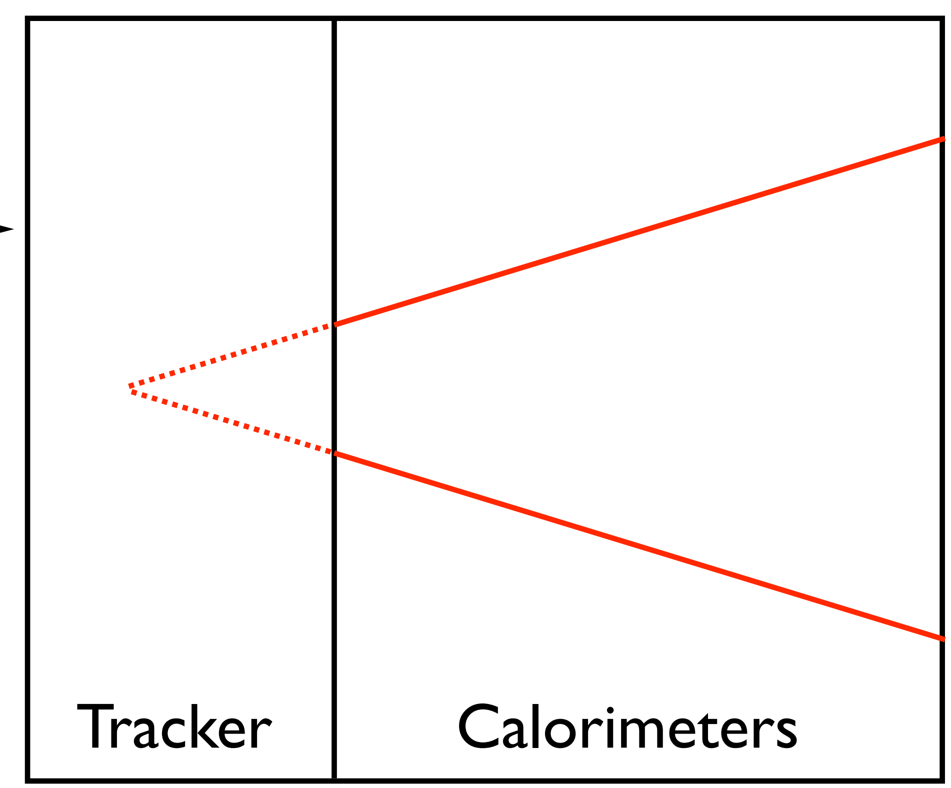
We want to link tracks in cases like these two:





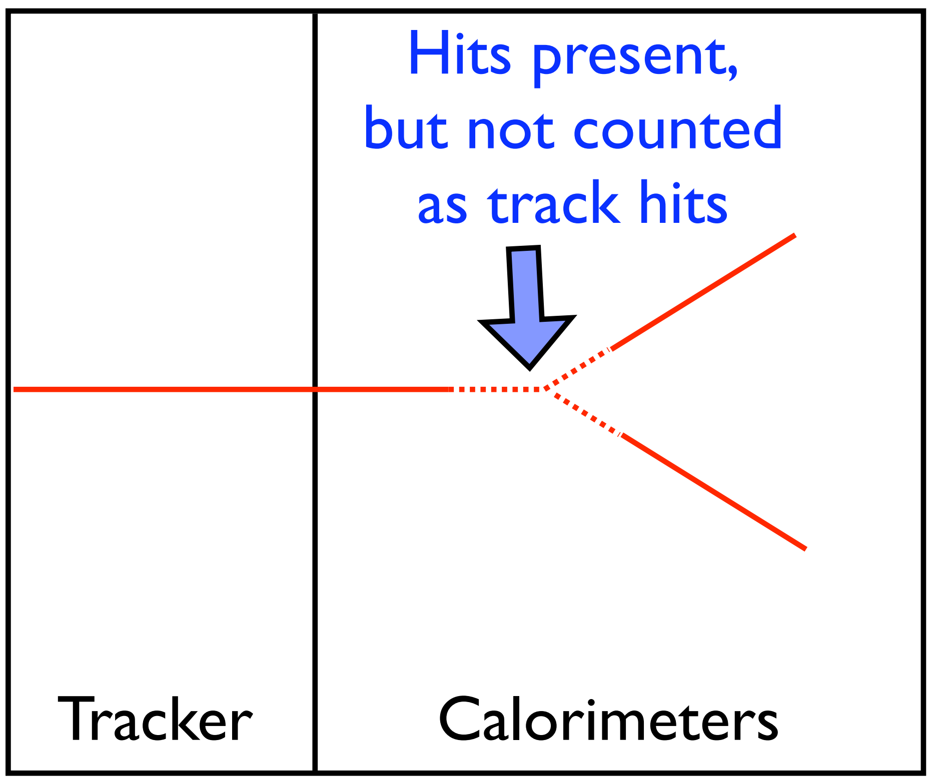
But not in this case:

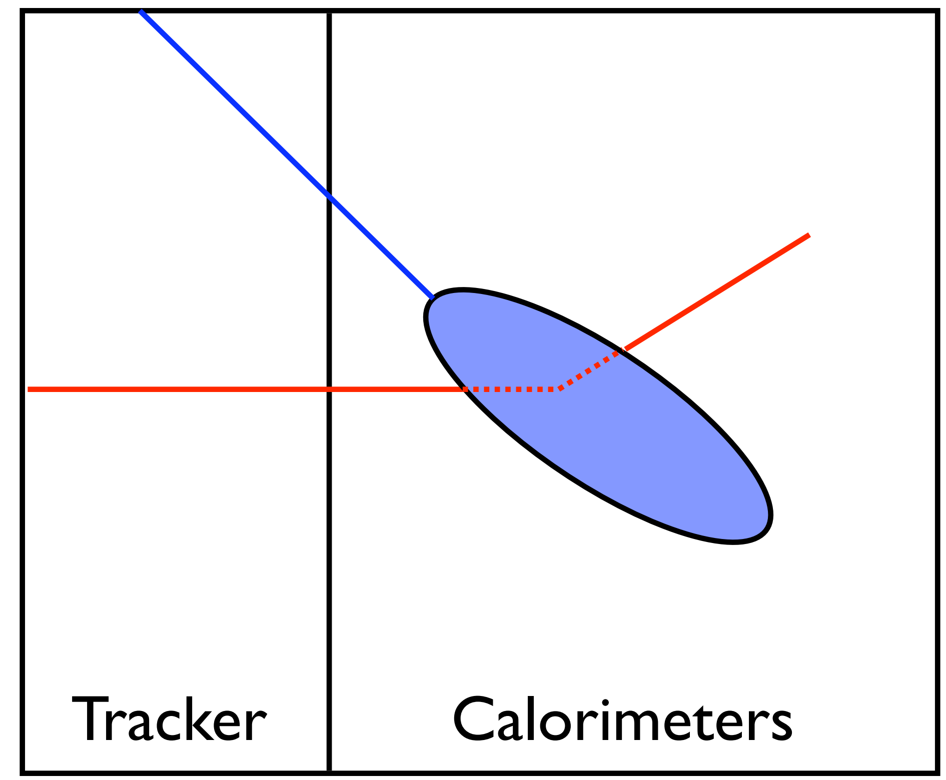
⇒ Require POCA inside calorimeters



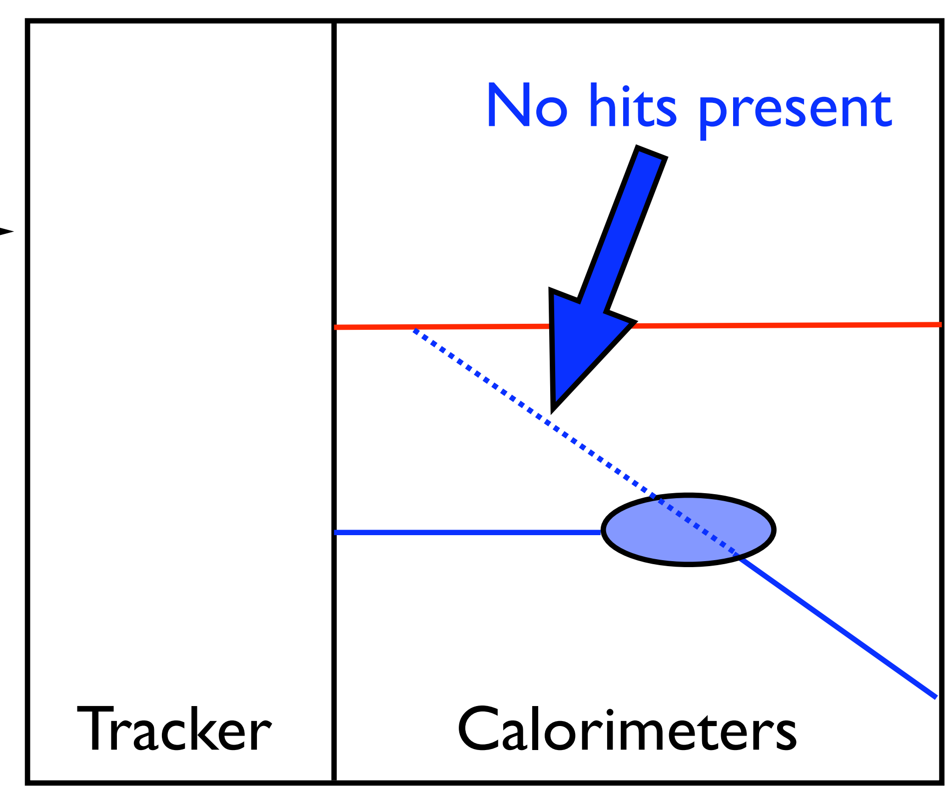
Patterns: Linking tracks

We want to link tracks in cases like these two:





But not in this case:

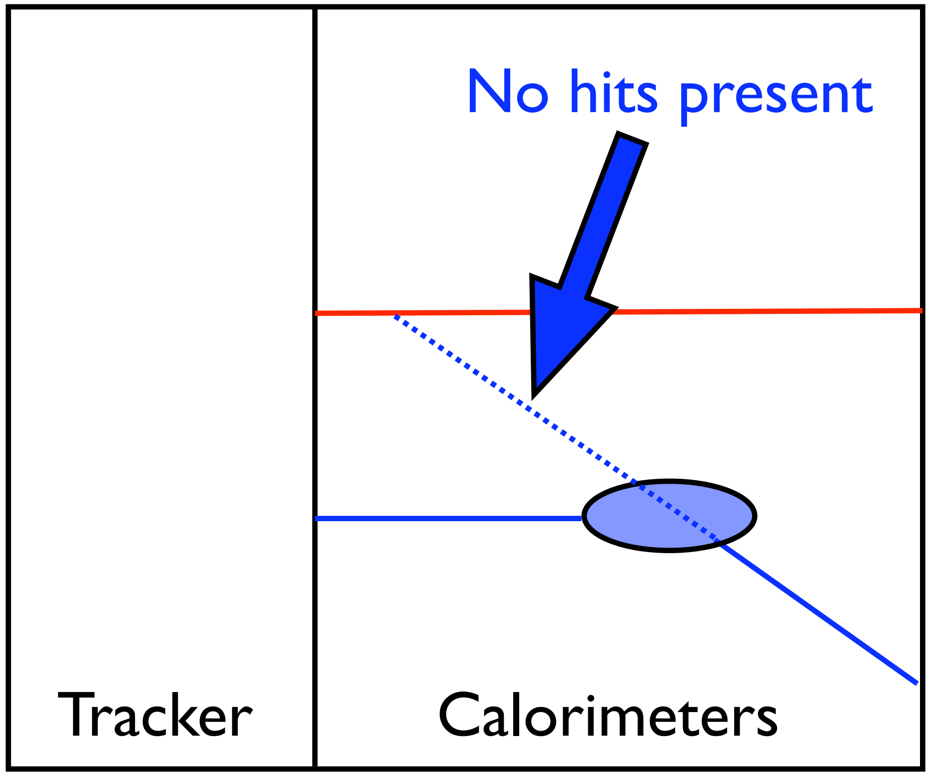


Ideas:

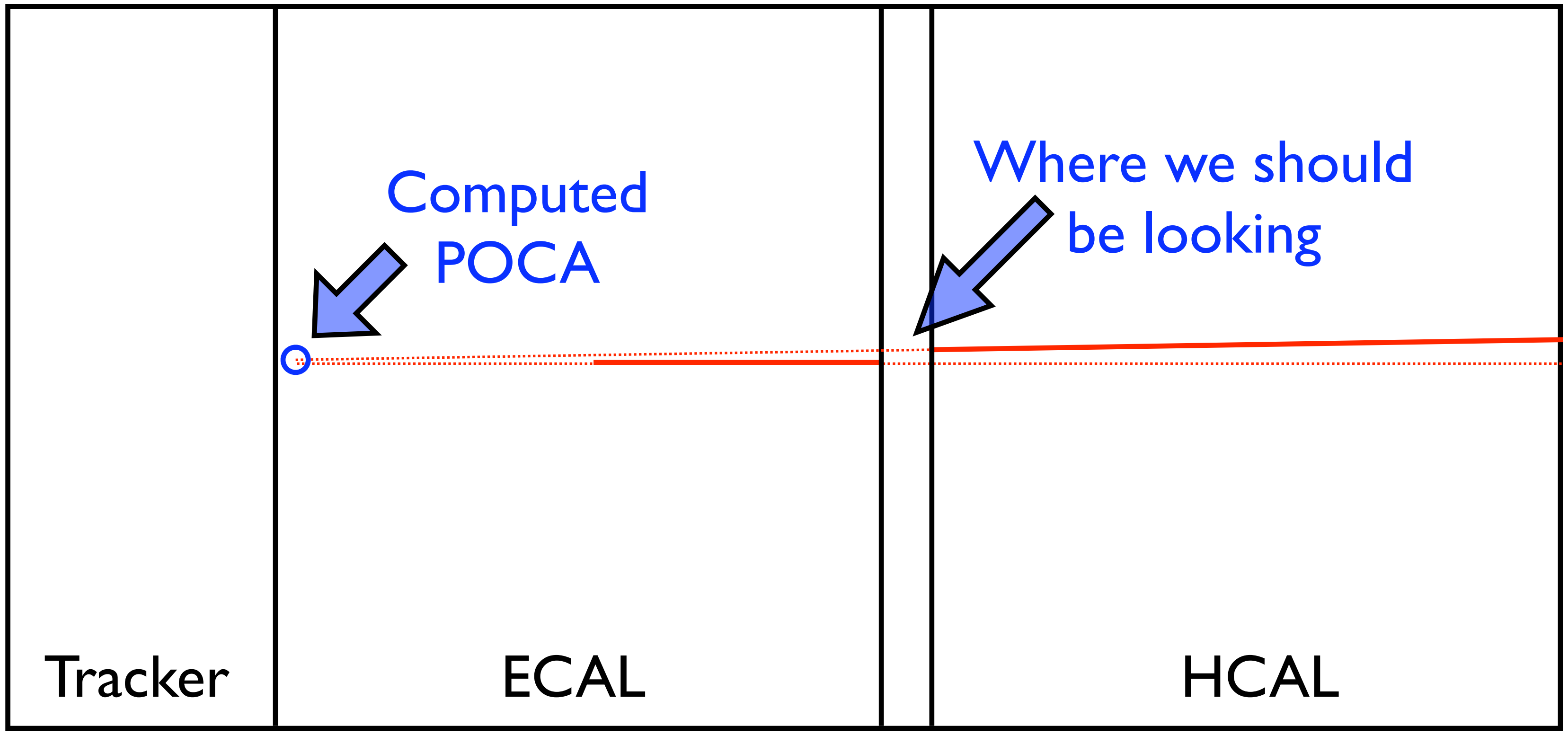
1) Look for intermediate hits
2) Break apart weak links

Patterns: Linking tracks

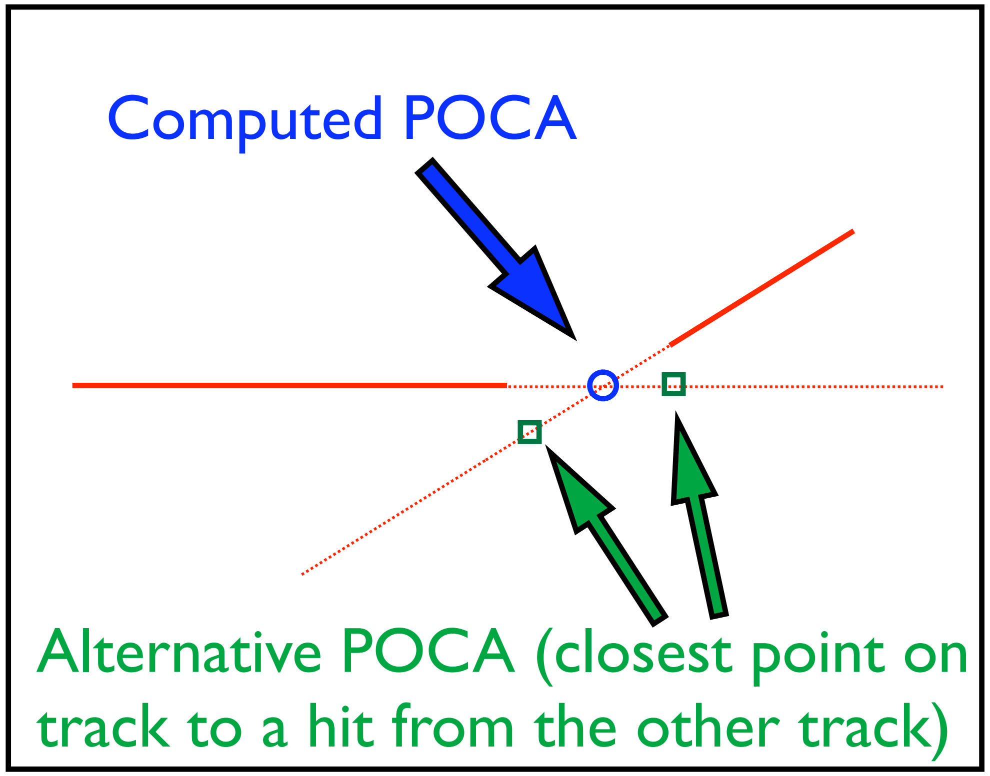
- Look for missing hits
  - Look at gap between track and POCA
  - Real link should have hits along trajectory
- Problem: POCA has large longitudinal uncertainty for near-parallel tracks.



Check for this with alternative DOCA and POCA...



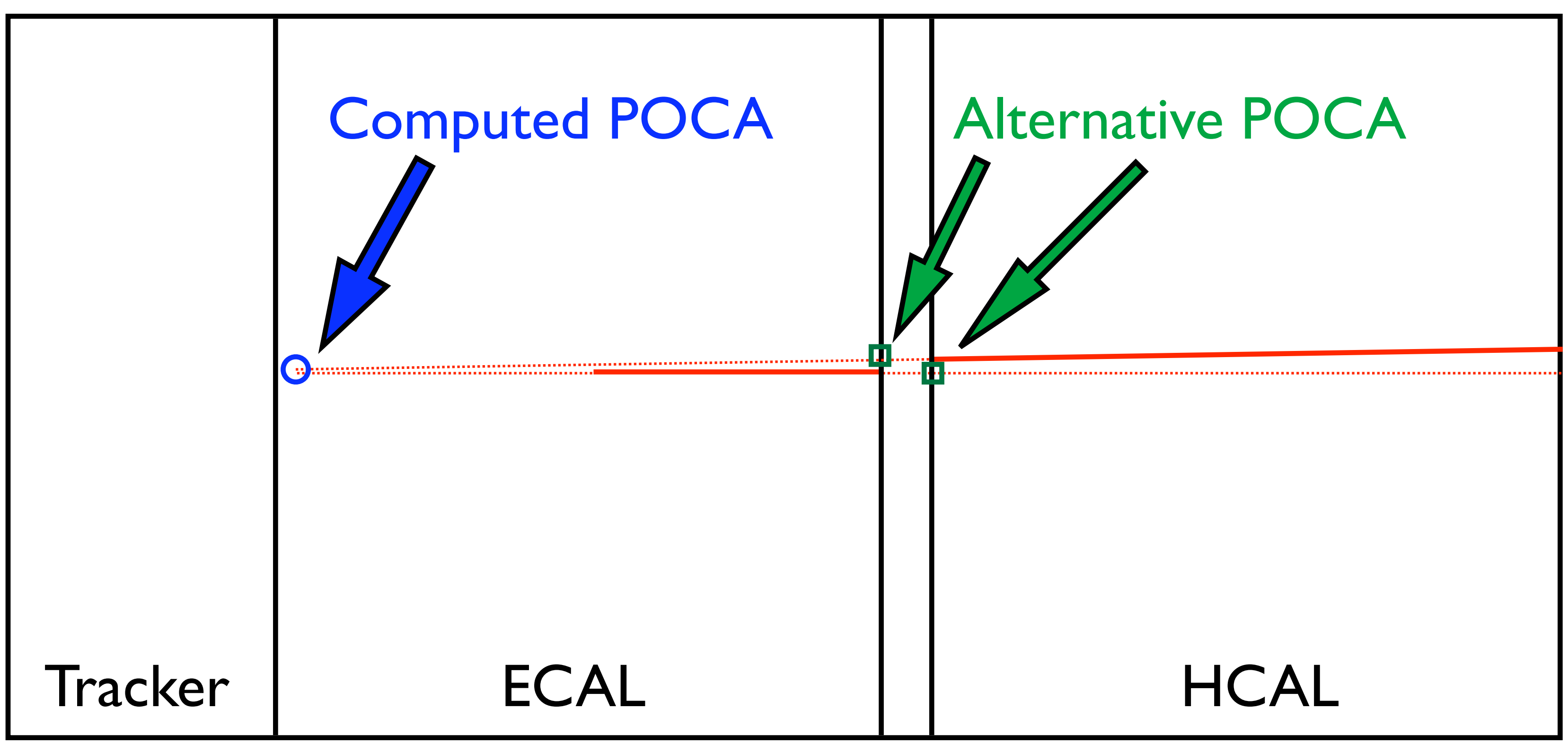
Patterns: Linking tracks



DOCA of tracks to the alternative POCAs >> DOCA to regular POCA

Define D_x = Sum over both tracks of min. distance from a hit to $POCA_x$

$D_{alt1} \sim D_{alt2} \sim D_{regular}$



$DOCA_{alt1} \leq DOCA_{regular}$
$DOCA_{alt2} \leq DOCA_{regular}$

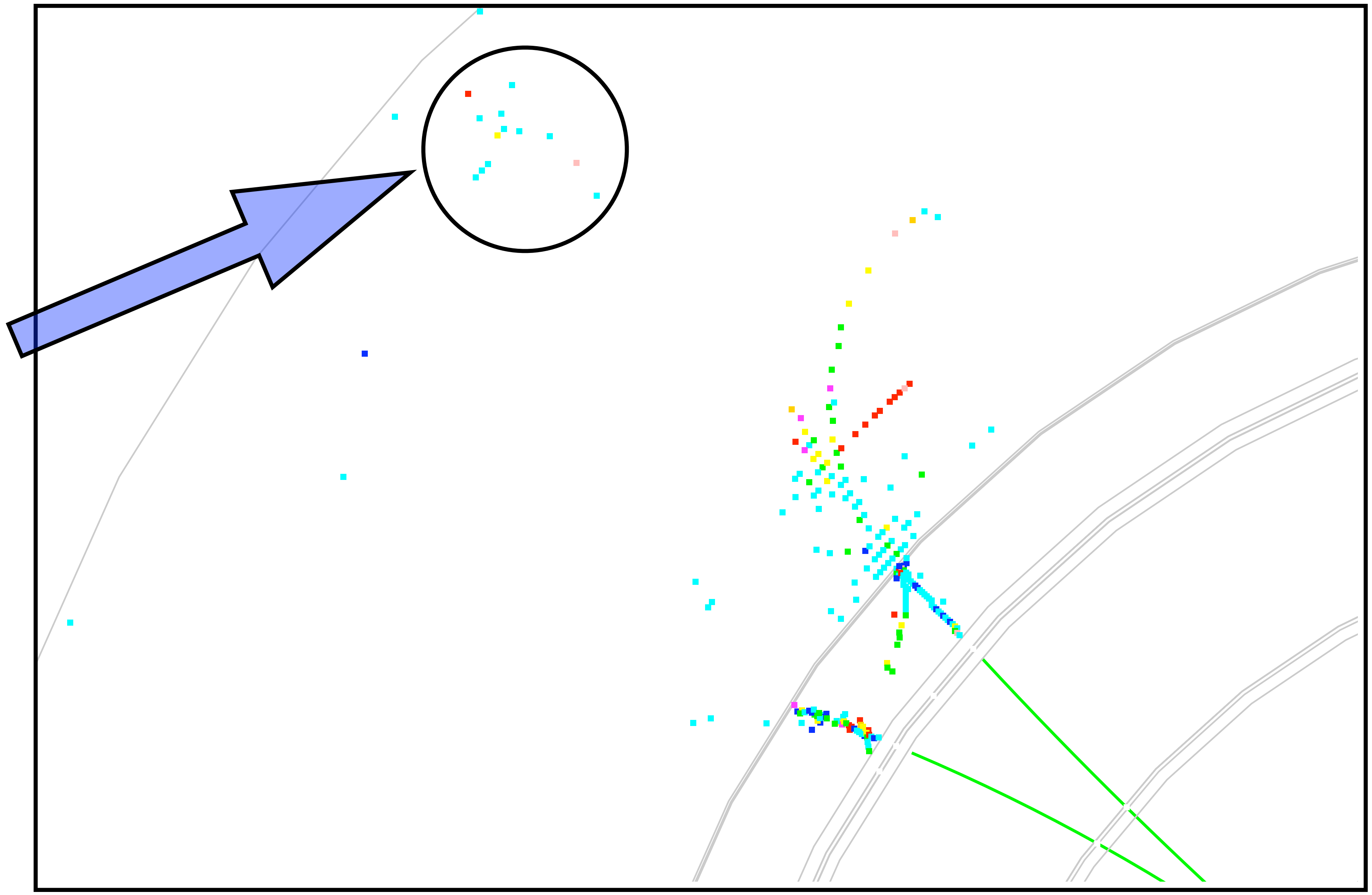
$D_{alt1} << D_{regular}$
$D_{alt2} << D_{regular}$

Use mean of alt. POCAs

Looking for intermediate hits

- So far, linear approximation to tracks sufficient
- But for finding hits, need 1 cell (5 mm) resolution
  - Starting to lose links because track extrapolations don't match up to within a cell.
  - I tried picking up neighbours to compensate
  - ... but then lose discrimination due to false positives
- Probably time to move to a helix fit
  - ESPECIALLY with two segments from the same track

Patterns: Isolated HCAL fragments



MST doesn't handle isolated fragments well
(HCAL threshold is 10cm here)

Probably need an additional step (directional algorithm)

Lots to do...

- Test algorithm performance on more Ks events, taus, neutrons/K-longs, then Z0.
- Switch out or improve components (e.g. helix fit or swimming for tracks; find clumps better)
- Tune DOCA, POCA cuts
- Smarter handling of halo
- Move towards probabilistic approach
  - With likelihood-style tuning, could handle multiple detector designs
- Eventual goal: identifying & separating hadronic showers in calorimeters