TPC Detector Response Simulation and Track Reconstruction

Dan Peterson, Cornell University, Victoria, 29-July-2004

A study of track reconstruction efficiency in a TPC based tracking system,
using the CLEO reconstruction program.

Previous presentations:

* LCWS meeting in Paris, 19-Apr-2004
* ALCPG meeting at SLAC, 07-Jan-2004
* TPC meeting at Berkeley, 18-Oct-2003
* ALCPG meeting at Arlington, 11-Jan-2003

This talk:
- description of the response simulation and hit clustering
- description noise generation
- results on reconstruction efficiency w.r.t. readout segmentation
- discussion of some pathologies
- results on reconstruction efficiency w.r.t. detector size

Refer to the previous talks for:
- more discussion of the motivation
- more description of the track reconstruction algorithm

Goals

optimize the design for a TPC

The Goal of this study is to measure the reconstruction efficiency
for complicated events simulating Linear Collider processes,
w.r.t. design parameters of a TPC based tracking system:
pad size, charge spreading, detector radius, and magnetic field .

Real detector effects are (will be) simulated as much as possible:
track overlap, ionization noise, track decay,
electronic noise, and inefficient pads.

Pattern recognition based on pad level information (as opposed to 3-D space points)
is necessary to be sensitive to hit overlap.

basis for comparing

While this study may be used to optimize a full detector design based on TPC tracking,

it also provides
a comparison with the reconstruction efficiency of a silicon based tracking system.

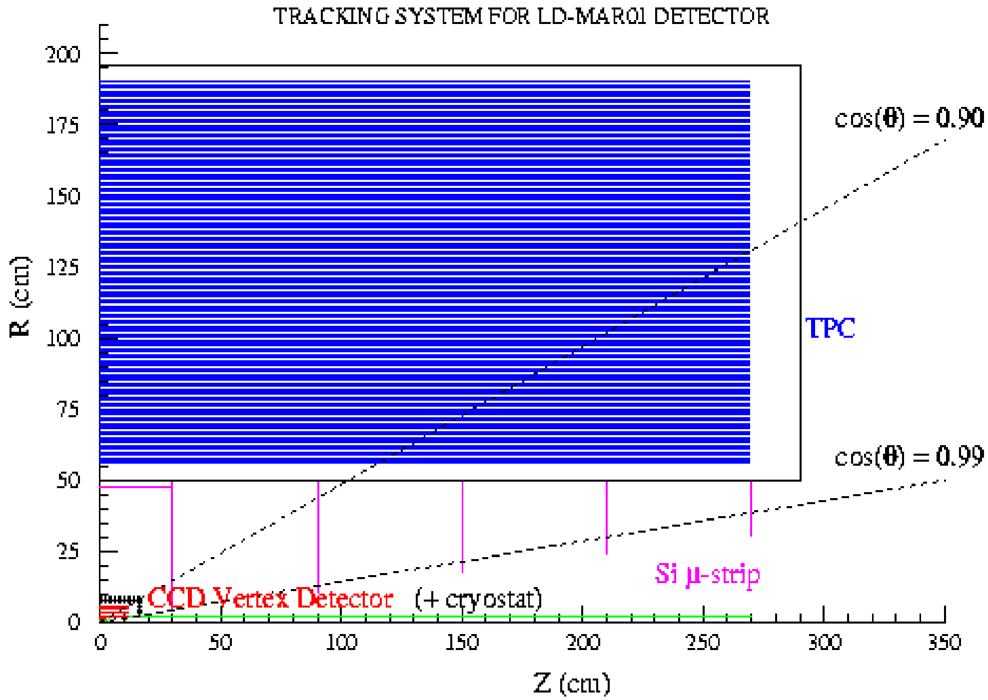
(This study does not provide details on the reconstruction resolution.)

Which TPC ?

This study starts with the "NA Large Detector" design.
Specifically, the TPC outer radius is 1.9 meter.

NA Large Detector:
TPC outer radius: 1.9m
magnetic field: 3T

TESLA Detector
TPC outer radius: 1.6 m
magnetic field: 4 T
cell size: 2mm x 6mm



However, results on readout segmentation and noise tolerance
should apply to a different design with similar **track curvature separation**.
Compare BR^2. "NA large" 1.08 "Tesla" 1.02

The study could also be repeated for a different TPC radius and field with suitable event generation.

Complicated event simulating a Linear Collider Process

A sample event, $e^+ e^- \rightarrow ZH$, from the LCD simulation illustrates the complication due to overlapping tracks.

(All hits are are projected onto one endplate.)

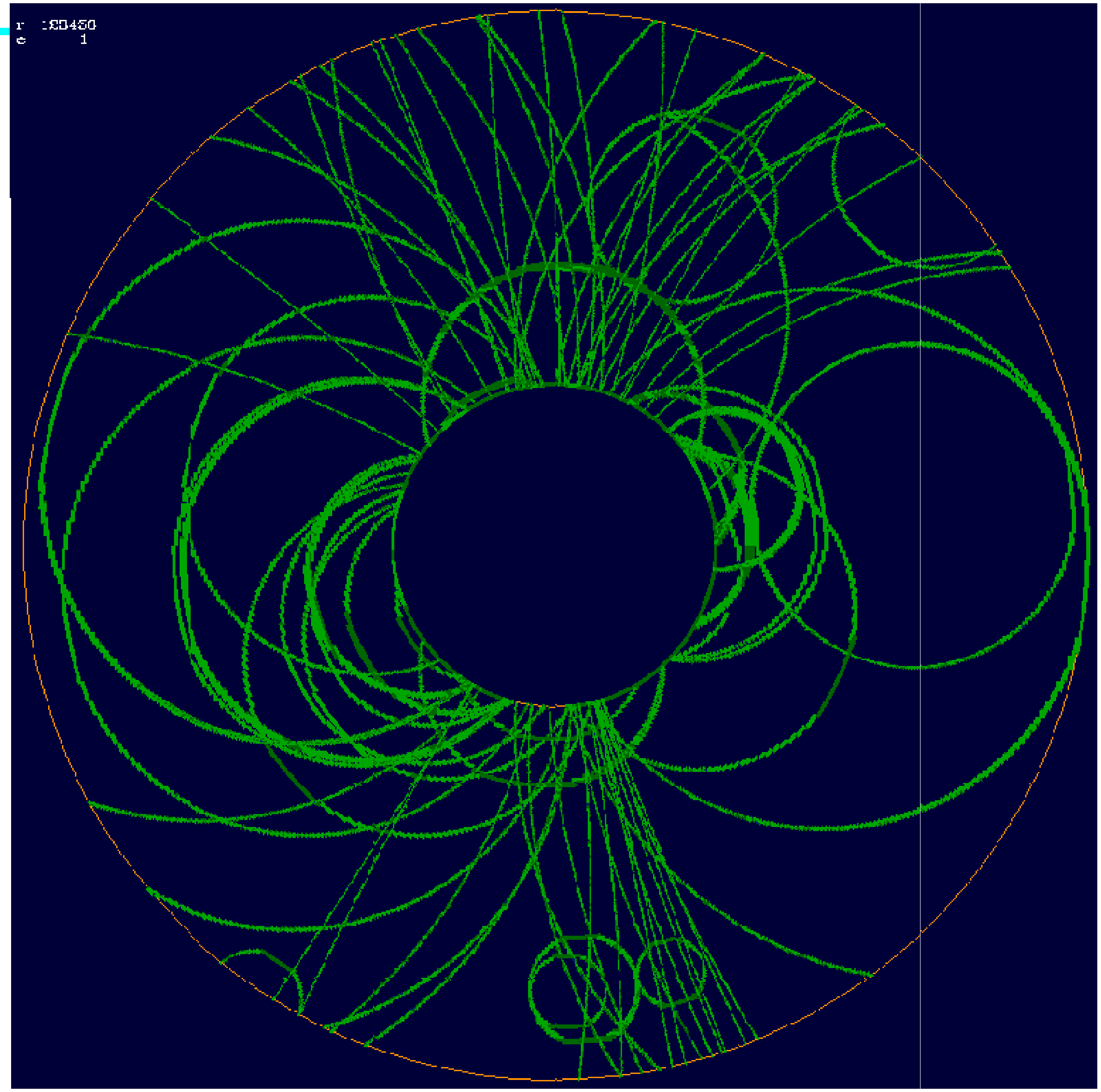
143 layers from 56cm to 190 cm

2 mm wide pads, 1cm radial “height”

- **charge spread is minimal**
- **no noise**

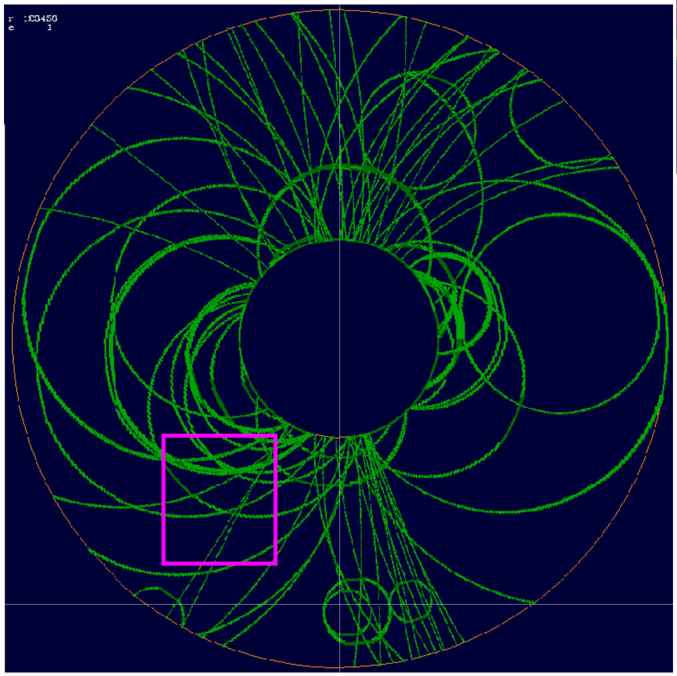
In general, we expect that the overlap can be reduced by taking advantage of z separation.

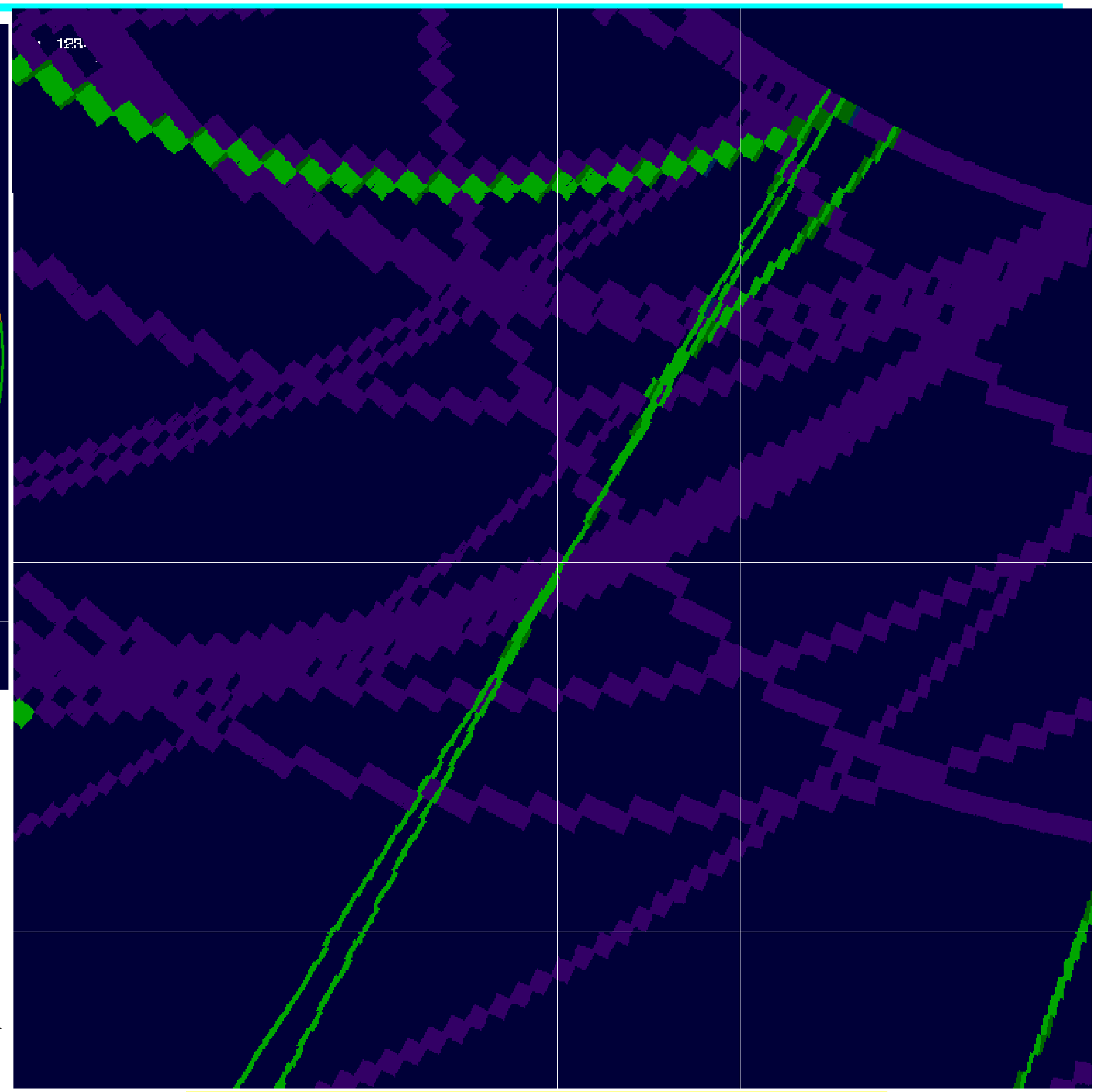
It is not clear from this simple picture if the separation would be sufficient.



Remaining track overlap when taking advantage of Z separation

(Same event, same pad response)





The z separation is often too small to provide straightforward track separation.

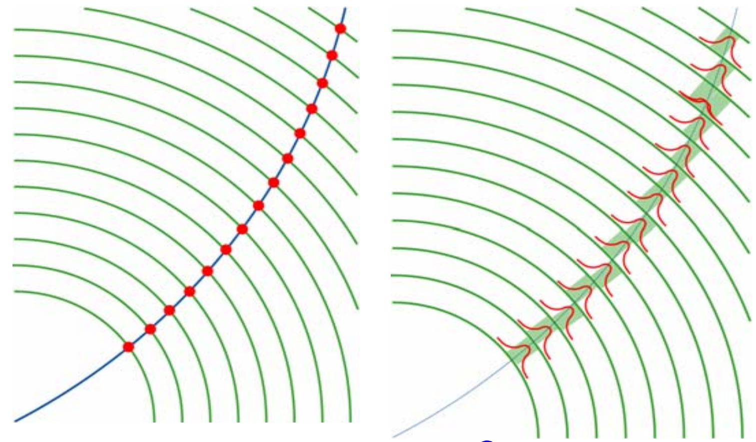
crossing tracks in r-f, and
z-separation = **1 mm** .

Track reconstruction can be efficient for very close tracks by selecting information from those regions where the tracks are isolated, as in the CLEO reconstruction program.

Active cone: Z=[r * (-6 / 40)] +/- 4.7 cm

Detector Simulation: pad response

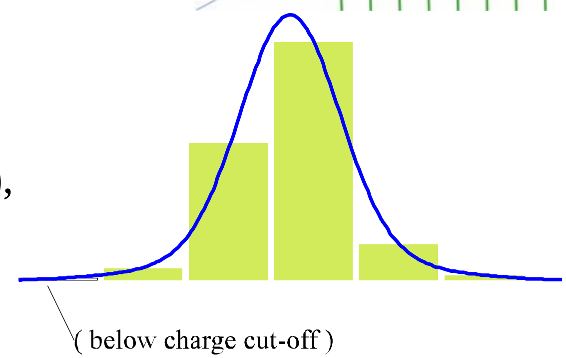
The LCD simulation provides only crossing points; extensions to the simulation have been created within the CLEO reconstruction library.



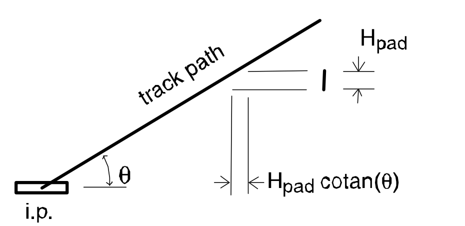
144 crossing points are treated as entries & exits for 143 layers.
143 layers are segmented into pads.

create hits, with time and pulse height, centered on the average position in the cell

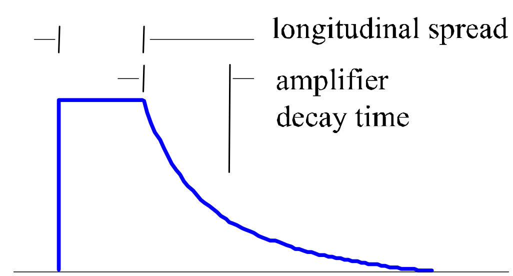
Charge spreading on the pads:
Gaussian width (70% of pad), **cut-off** (~ .002 of min.ion.), charge is renormalized to provide a **total of min. ion**.



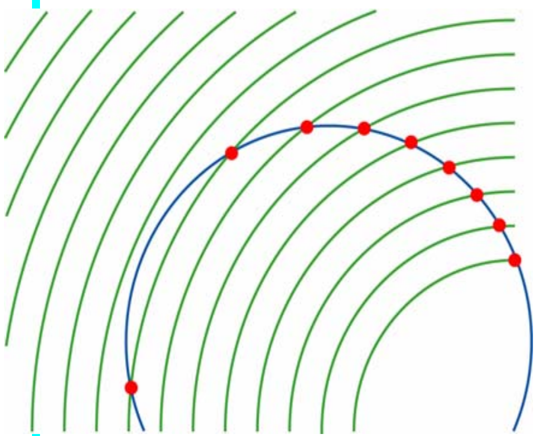
Wave Form to simulate time (= Z) response

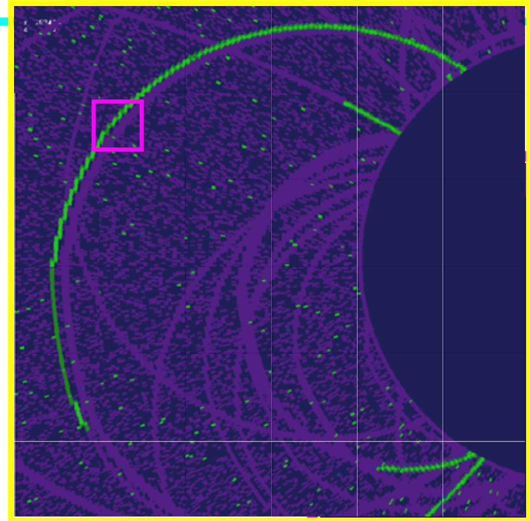


longitudinal spread of track



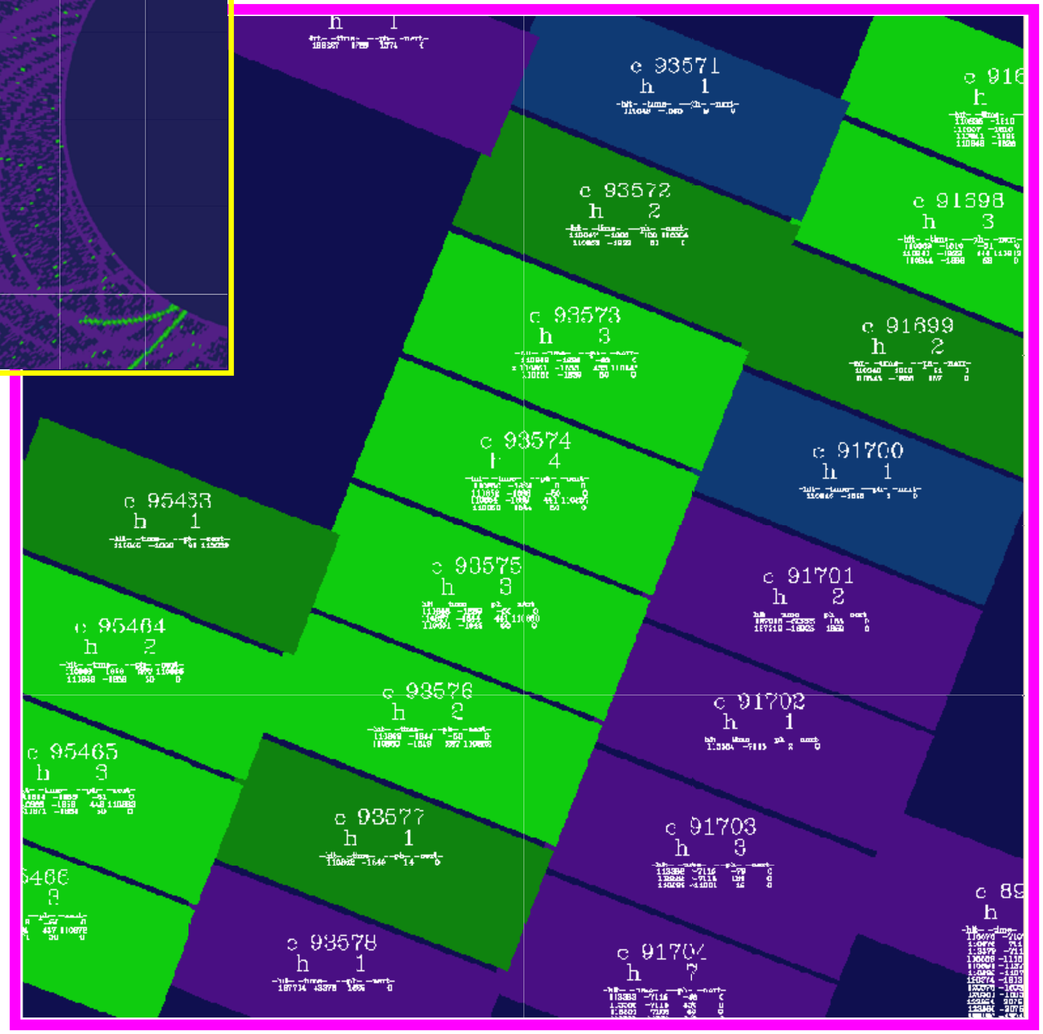
Ionization distribution for large entrance angle





Cell width: 4mm

Active cone: Z=[r * (-3 / 40)] +/- 4.7 cm



While treating the cylinder crossings as layer entry and exit positions, it is easier to identify and properly treat multiple cell crossings.

Ionization is deposited in the cells depending on the path length in each cell.

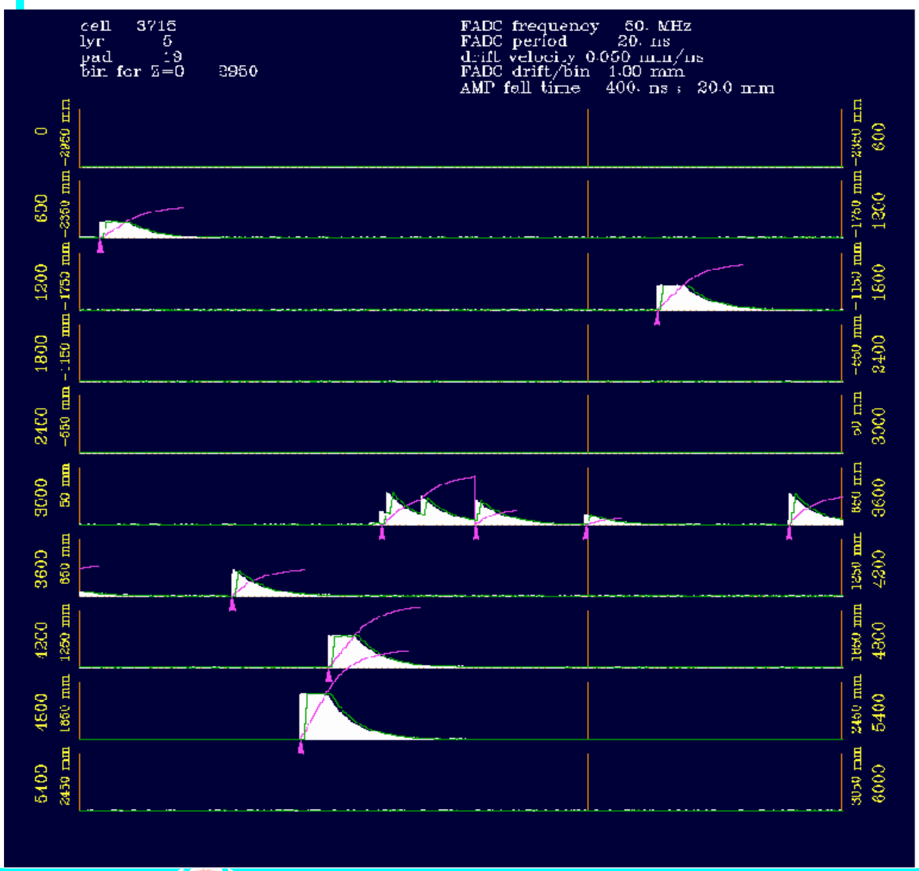
Also shown: The table of numbers on each cell provides information on the hits assigned to that cell.

Detector Response: merging overlapping hits and time pattern recognition

After signals are generated on pads as described in the previous 2 slides,
pads may have overlapping signals that would be merged in the hardware readout.

Each signal, **including noise hits**, is described by a pulse height, time, and duration at max. pulse height.

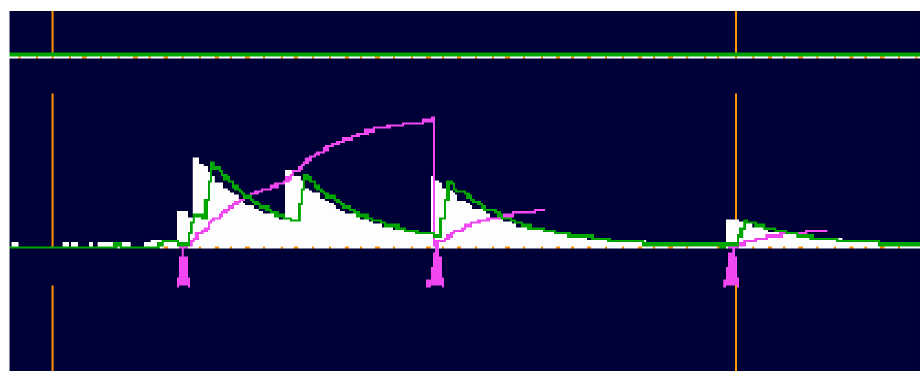
This information is used to simulate a FADC response in which overlapping signals add.



The FADC response is analyzed to determine the *unambiguous threshold crossings* indicated by ( ).

The example shows merged and separated hits.
(Also, note low level noise.)

Threshold crossings found in this procedure replace the original pad signals.

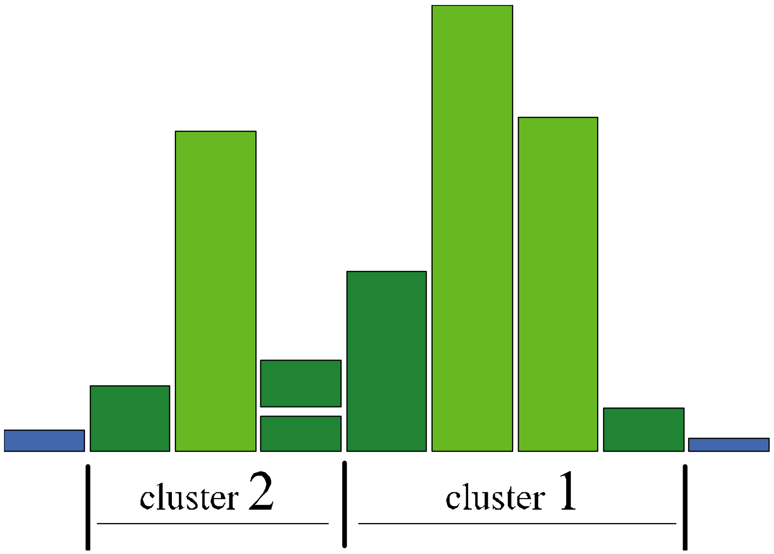


Event reconstruction: pad clustering

Previous slides have described how the generator track crossing of ideal concentric cylinders are converted to FADC signals.

The FADC signals were then processed to recognize "unambiguous" threshold crossings – single pad hits.

Now these single pad hits are clustered in ϕ to locate the significant centers of ionization that can be used by the pattern recognition.



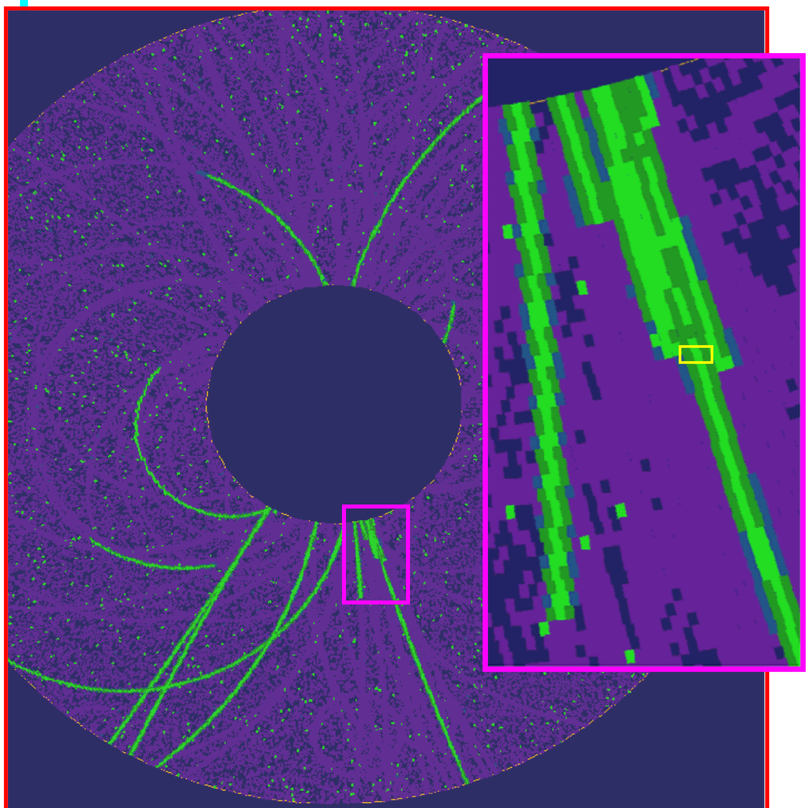
Pads with > 0.51 of the maximum are treated as "core pads".
(a detail of the primary pattern recognition)

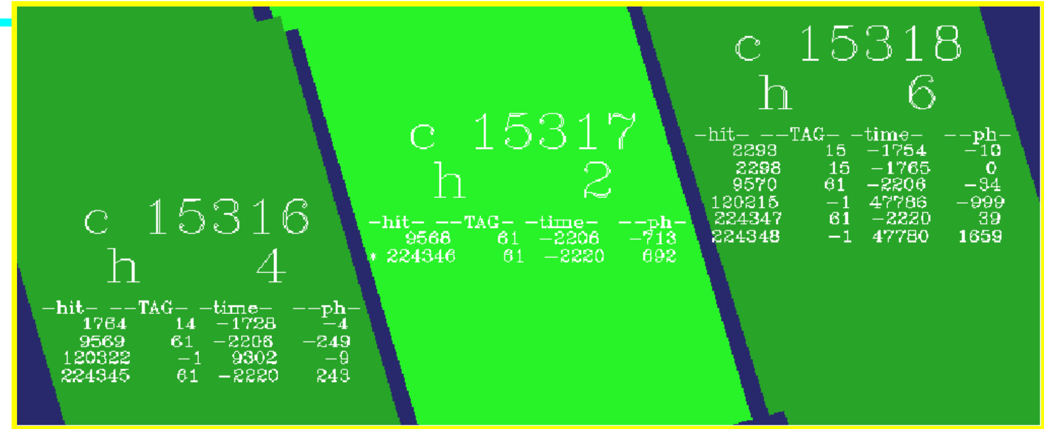
Clustering in r-ϕ

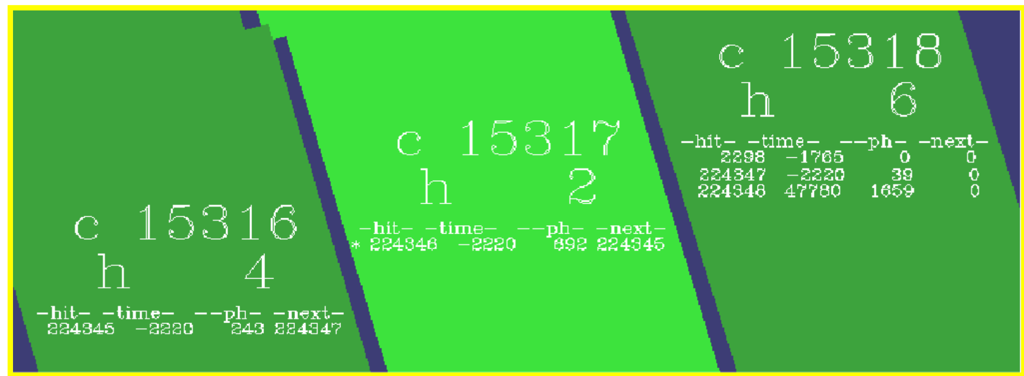
A local maximum, above a threshold, defines a **central pad**.
Adjacent pads, above a lesser threshold are added to the cluster.
Difference in Z of adjacent pads is required to be less than a threshold.
Clusters are **Split** at local minima, less than a fraction of the lesser peak.

Splitting of overlapping cluster **is not precise**.
A pad, which may have contributions from 2 (or more) sources, is assigned to the larger neighbor as shown.
This may lead to non-gaussian smearing of the central position.

Projected hits for event, after detector response simulation and clustering







Active cone: Z=[r * (-7 / 40)] +/- 4.7 cm

Active hits in green

Ignored hits in purple

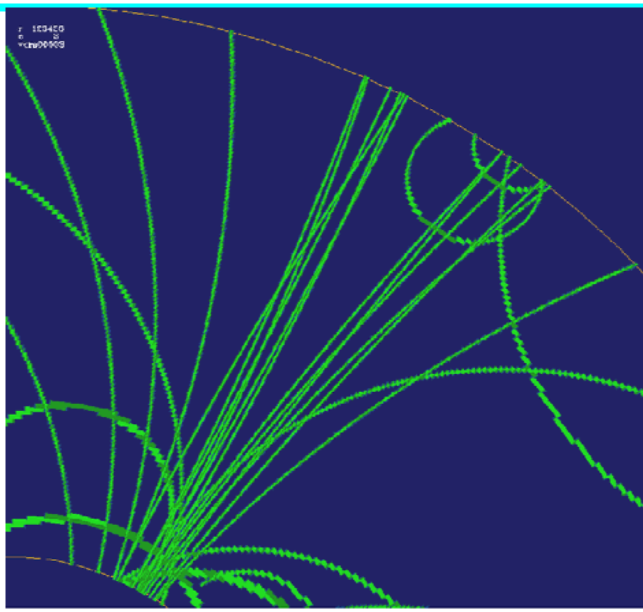
This is the information input to the pattern recognition.

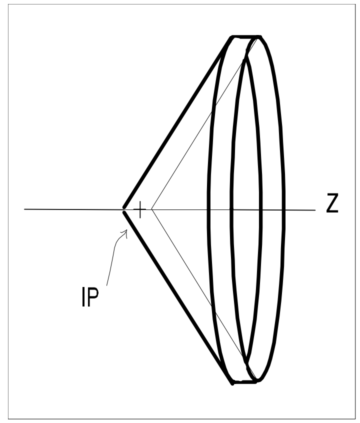
The pad response includes merged hits with time and pulse height information.

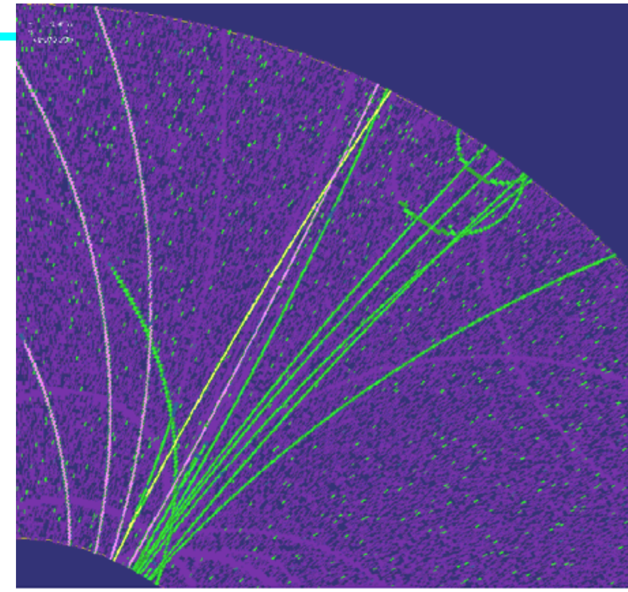
Simple, pre-merged, hits have been “hidden”.

Clustering has been completed for the initial pattern recognition.

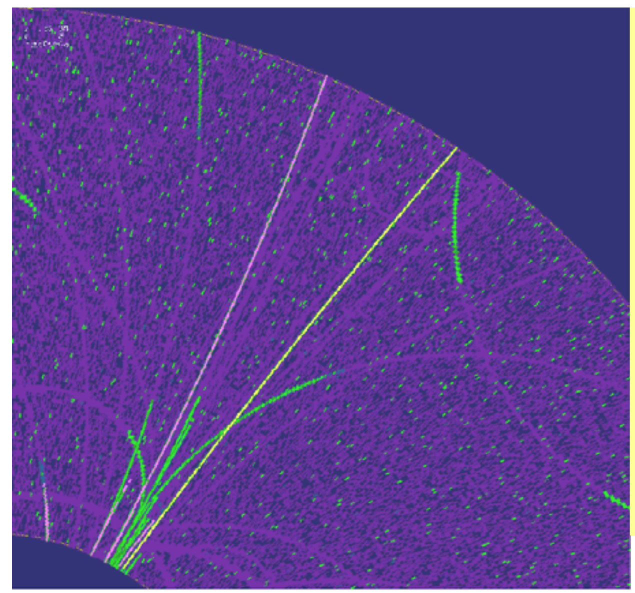
CLEO pattern recognition is modified for use with a 3-dimensional TPC.







Active cone: Z=[r * (-24 / 40)] +/- 4.7 cm



Active cone: Z=[r * (-28 / 40)] +/- 4.7 cm

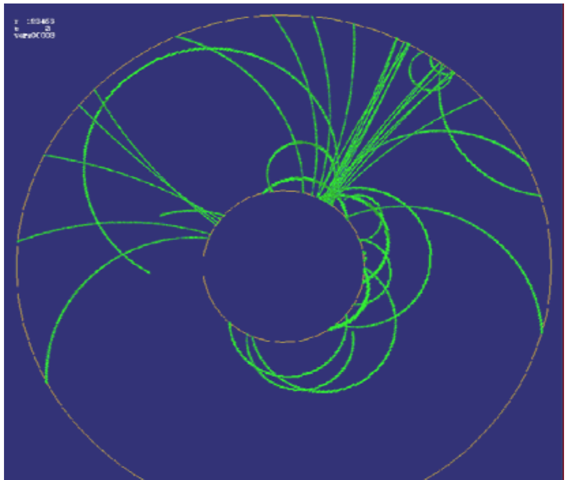
Hits are pre-selected to be in cones projected to the IP
(as already seen in previous slides).

The cones provide a means of isolating tracks in dense jets
(as shown at right).

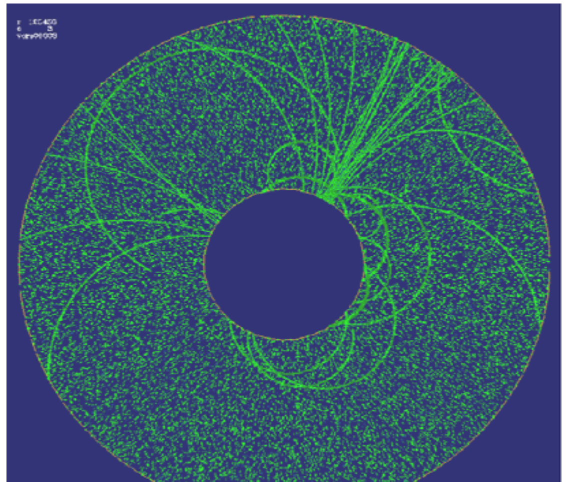
Isolated, clean, track segments are identified in the
1st level of pattern recognition, using only cell positions.

Selected track segments from all cones are
collected and prioritized for a 2nd level, using
precision hit information and local ambiguity resolution

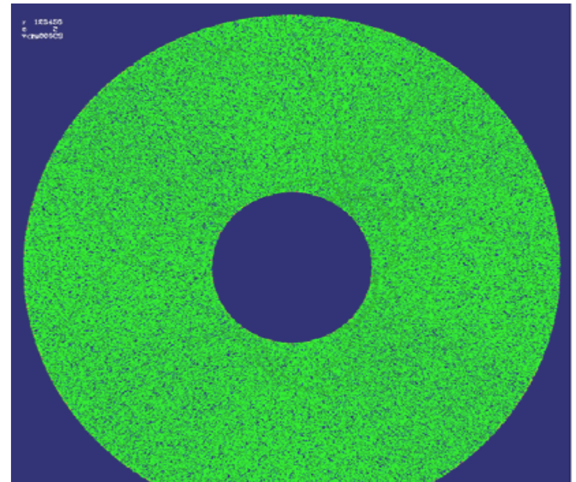
Random Noise: details, occupancy



2 mm cells, no noise



2 mm cells, 30 K noise hits



2 mm cells, 300 K noise hits

Noise is added on single pads in random locations. (Clumped hits might better represent photons.)
The pulse height is 0 to 2 x "minimum ionization".
The time structure has a 2 cm/(velocity) duration plus a tail with 2 cm/(velocity) time constant.

Results shown at the Paris meeting used 300K noise hits per event, independent of cell size.

pad size	*occupancy* (per cell * 4cm readout length)	*affected signals* (signals spread over 3 cells)
2 mm	0.0046	0.014
4 mm	0.009	0.028
10 mm	0.023	0.069

Results shown today will differ because the *occupancy* is 1% for all cell sizes.

MC tracks selected for efficiency studies; the denominator

MC generated track list (not used)

1) $curv_1$, ϕ_1, $impact_1$, $Z0_1$, $COS(\theta)_1$
2) $curv_2$, ϕ_2, $impact_2$, $Z0_2$, $COS(\theta)_2$
3) $curv_3$, ϕ_3, $impact_3$, $Z0_3$, $COS(\theta)_3$

…

…

N) $curv_N$, ϕ_N, $impact_N$, $Z0_N$, $COS(\theta)_N$

MC generated hit list

1) gen. $track_1$, $layer_1$, X_1, Y_1, Z_1
2) gen. $track_2$, $layer_2$, X_2, Y_2, Z_2
3) gen. $track_3$, $layer_3$, X_3, Y_3, Z_3

…

i) gen. $track_i$, $layer_i$, X_i, Y_i, Z_i

…

j) gen. $track_j$, $layer_j$, X_j, Y_j, Z_j

…

M) gen. $track_M$, $layer_M$, X_M, Y_M, Z_M

Sub-list of contiguous generated hits satisfying…

a) same generated track number
b) starts at layer 1
c) increasing layer number
d) truncated if layer number decreases (top of curler)
e) continues through at least 30 layers

TRACK FIT

"Plausible Track" List

1) $curv_1$, ϕ_1, $COT(\theta)_1$, $impact_1$, $Z0_1$

…

n) $curv_n$, ϕ_n, $COT(\theta)_n$, $impact_n$, $Z0_n$

Match $\chi^2 = (\Delta C/.002)^2+(\Delta\phi/.003)^2+(\Delta COT/.002)^2$

Track finding efficiency dependence on pad width and track "curvature".

Require χ < 25 (defined on previous slide.)

Low curvature tracks: defined to NOT curl within the TPC volume.

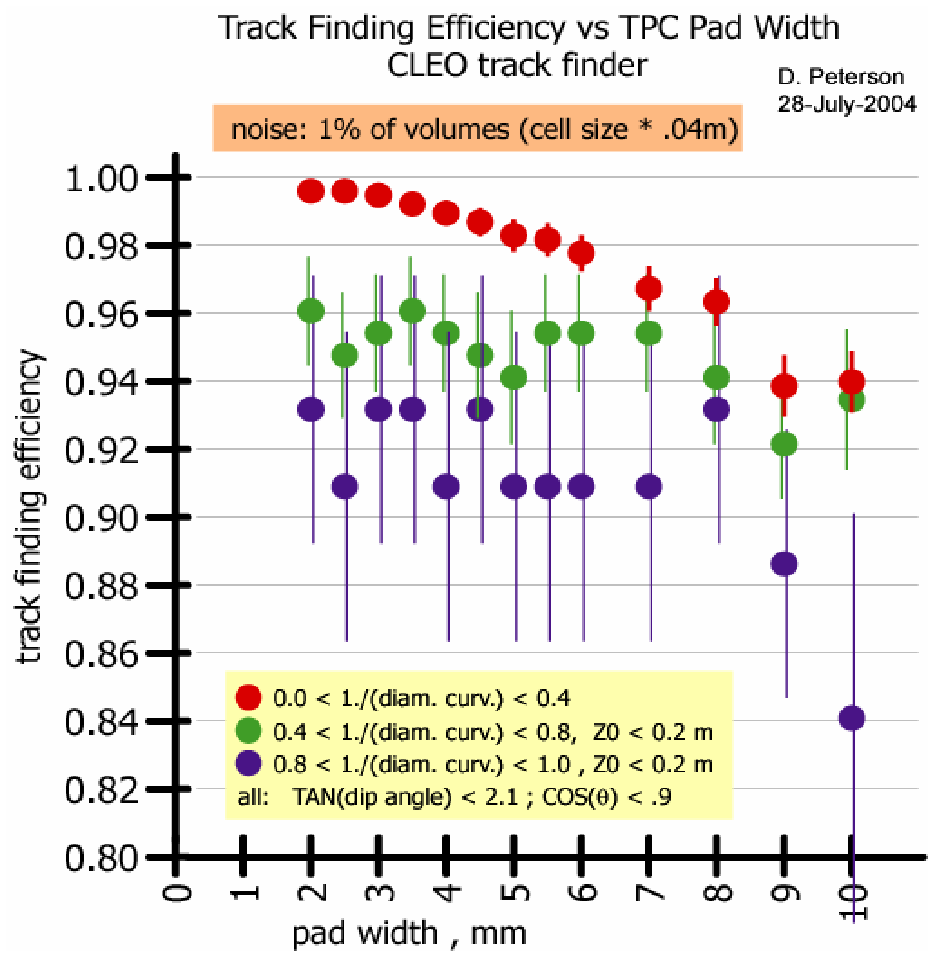
Medium curvature tracks:
curl-over radius: 1.2 to 2.5 meters, $Z_0 < 0.2$m.

High Curvature tracks:
curl-over radius: 1.0 to 1.2 meters, $Z_0 < 0.2$m.
(The inner radius of the chamber is 0.56 m.)

Within error, the efficiency for MED/HIGH curvature tracks is largely independent of pad size; these tracks are spread outside the jets.

Statistical errors larger than the fluctuations indicate that, mostly, the same tracks are lost regardless of pad size.

Efficiencies for MEDIUM and HIGH curvature are consistent: average ~ 94%.



The distribution for LOW curvature is expanded on the next slide.

Efficiency for straight tracks, dependency on noise

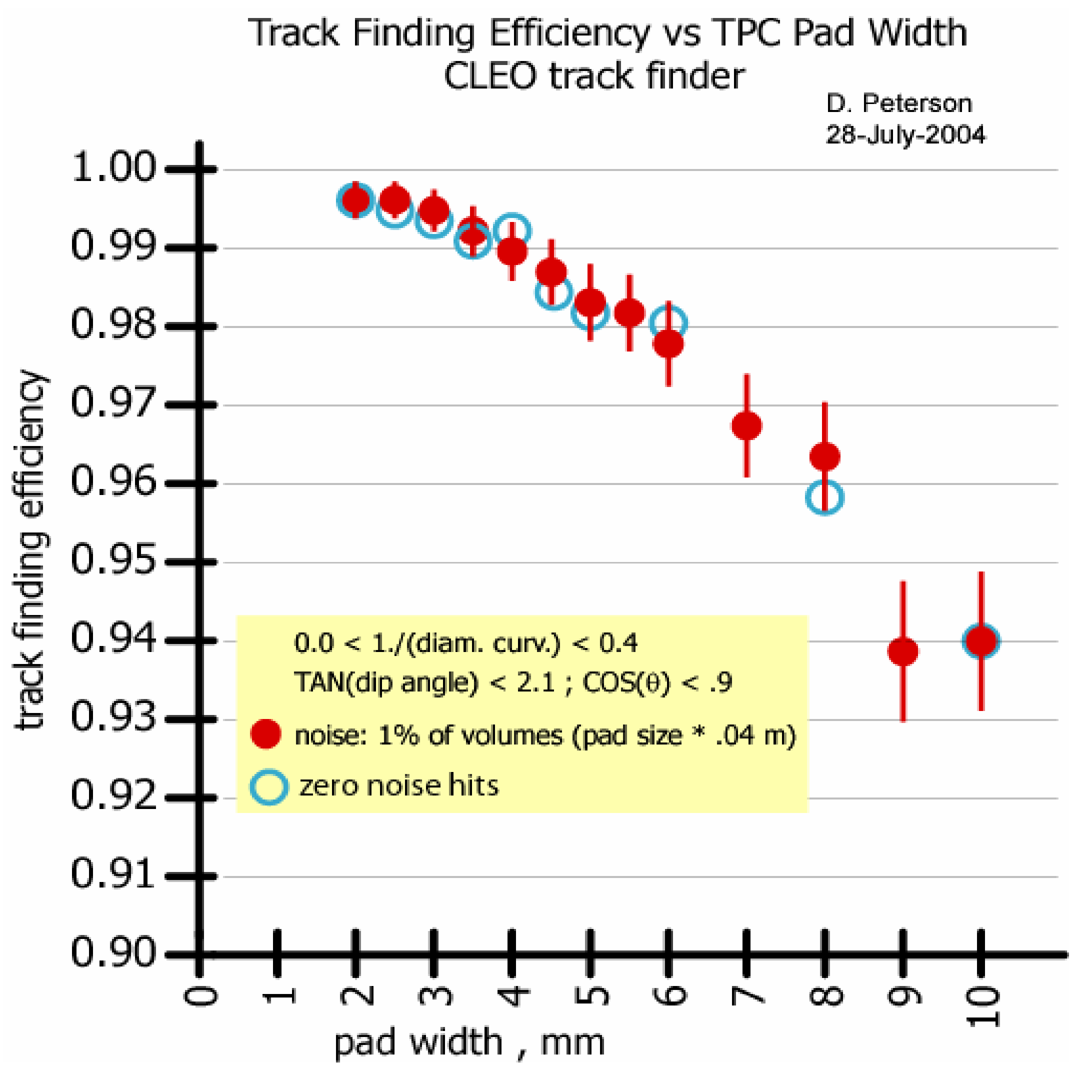
LOW curvature tracks:
efficiency > 99%
for pad width < 4mm,

efficiency ~ 99.5%,
for pad width ~ 3mm.

Efficiency is not affected by random noise up to 1% occupancy.

(The Paris results did show efficiency loss
for pad width > 6mm,
or 1.4 % occupancy)

The efficiency for medium and high curvature tracks has insignificant dependence on noise at 1.4% occupancy.



Pathologies: low curvature

The loss seen at 4mm pad width is dominated by track overlap.

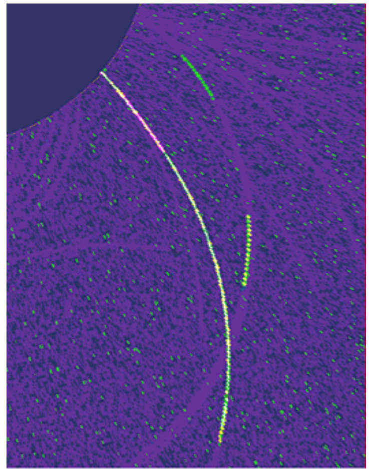
Two tracks that are usually NOT found with smaller pad width are identified as decays-in-flight.

(There are only 766 tracks in the low curvature (straight tracks) sample; this is a large contribution.)

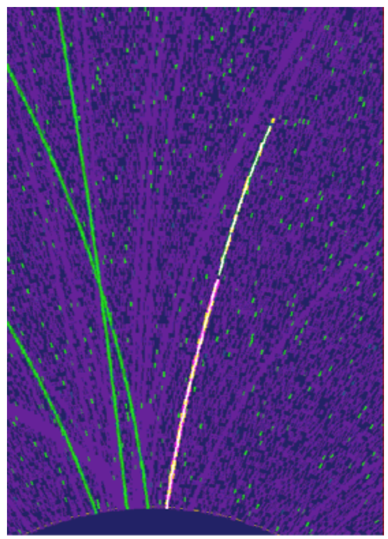
(A change of generator ID number indicates that this is decay rather than hard scatter.)

These tracks can be recovered.

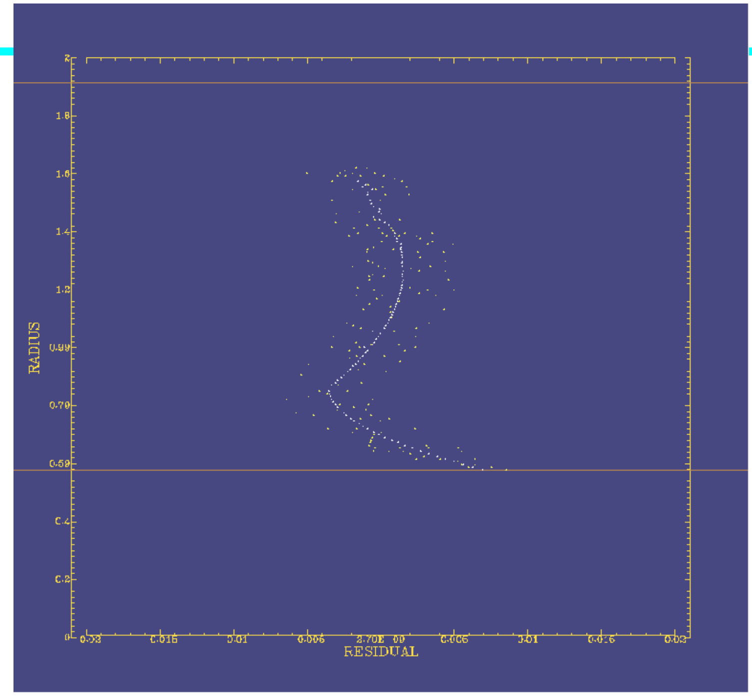
The CLEO reconstruction includes a procedure for recognizing decay-in-flight. This is implemented for CLEOc *where many processes involve low momentum K's. This is not yet implemented for the TPC.*

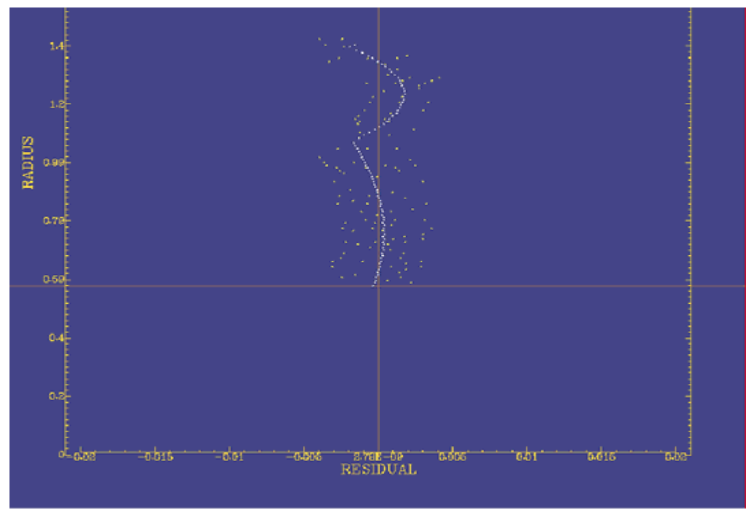


Active cone: Z=[r * (+31 / 40)] +/- 4.7 cm



Active cone: Z=[r * (+30 / 40)] +/- 4.7 cm





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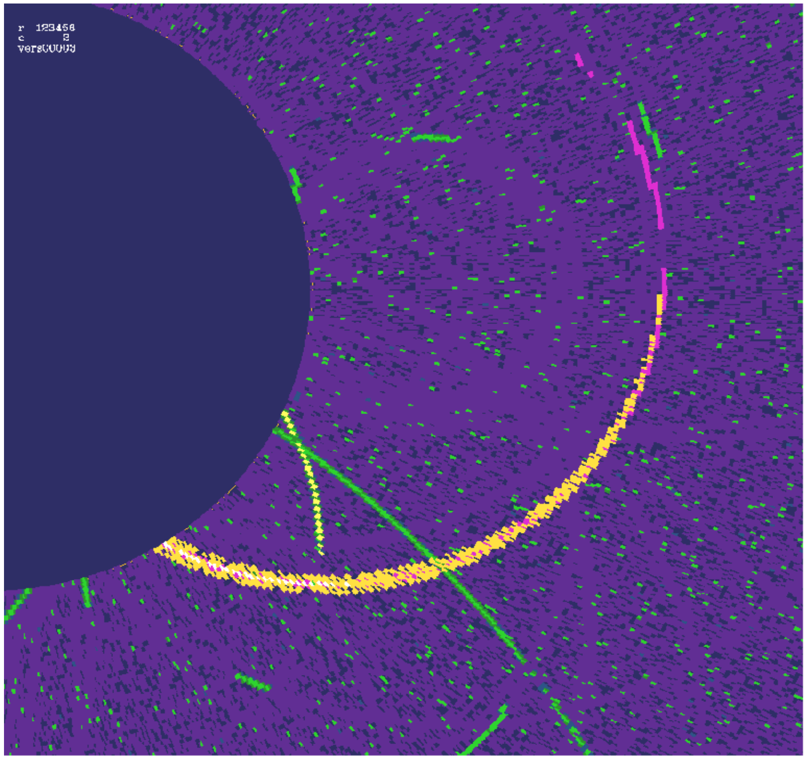
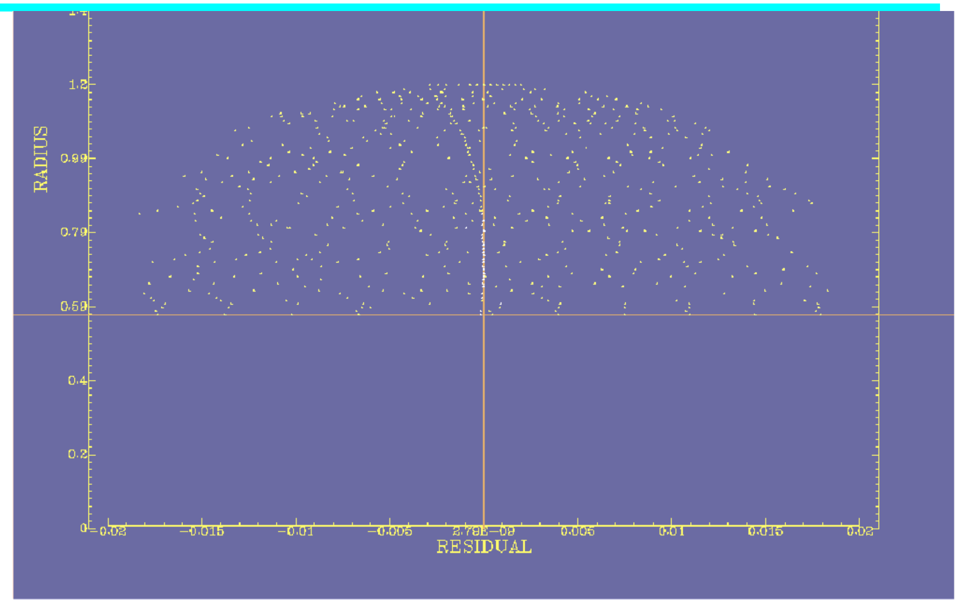
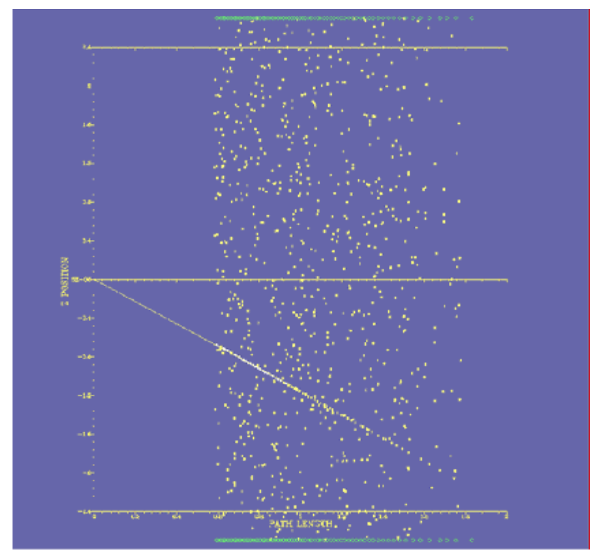
An example of inefficiency in high curvature tracks





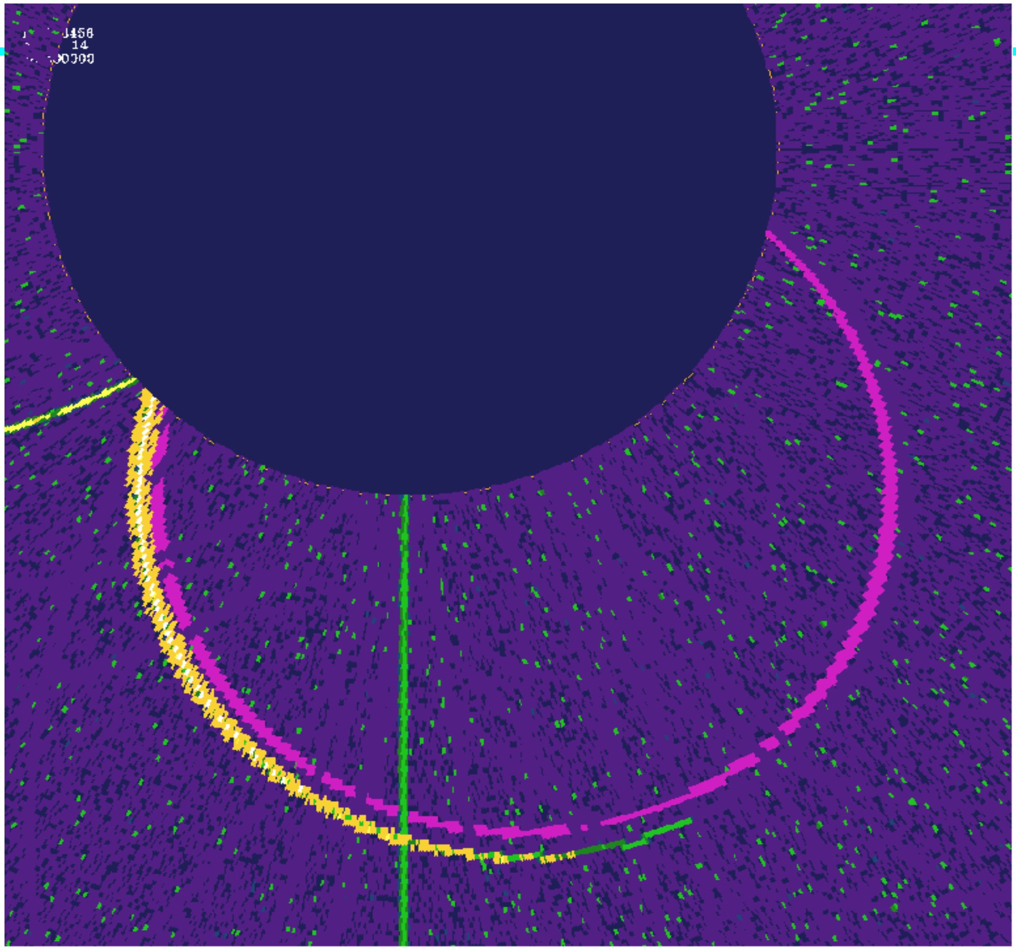


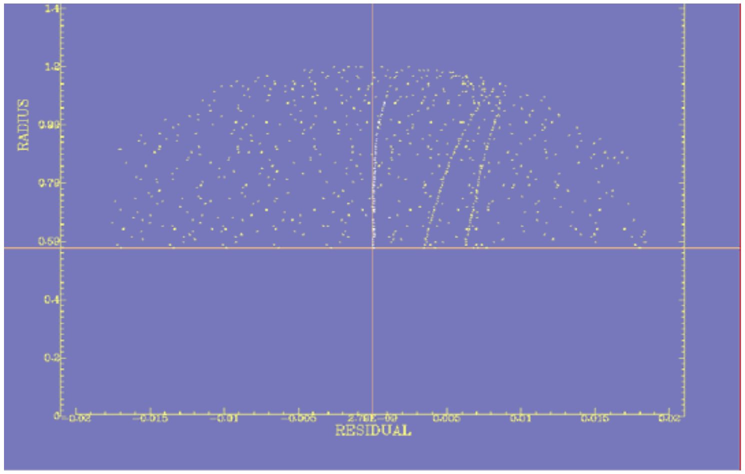
This particle, ~ 450 MeV/c, suffered energy loss after ~ 25 cm.
The track in reconstructed only to the radius of energy loss.

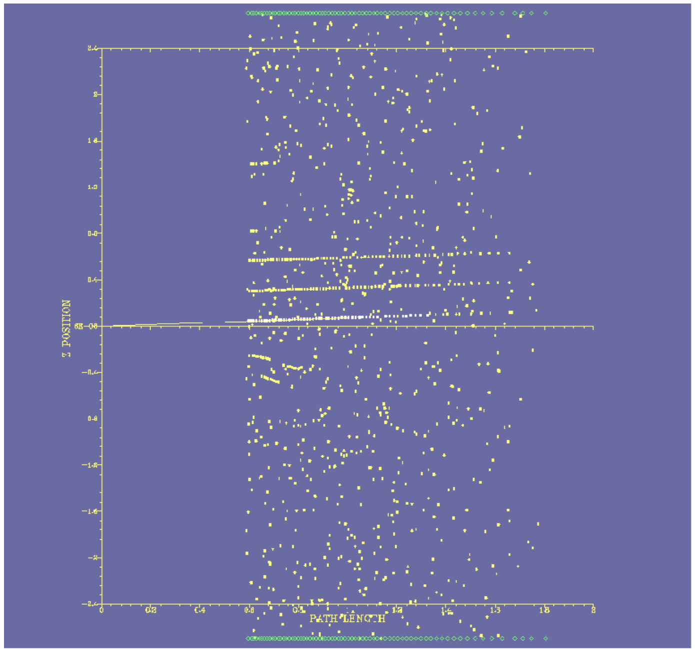
Another (not implemented) procedure in the CLEO reconstruction could extend the hit recognition to the curl-over radius.

Ironically, the found track represents the initial track parameters but not do not match the defined track parameters (slide 13).

An example of multiple loops







The (white) track is the first loop; it is found. It decays.
The missing track (pink) has a changed generator ID number.
There are 2 loops of within a road, ~ 3mm in r-ϕ ; 20cm in z.
Possibly, this pathology could be solved through more optimization of the local ambiguity roads.

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Efficiency dependency on Chamber radius

In a full detector design, chamber radius may be compromised by the calorimetry.

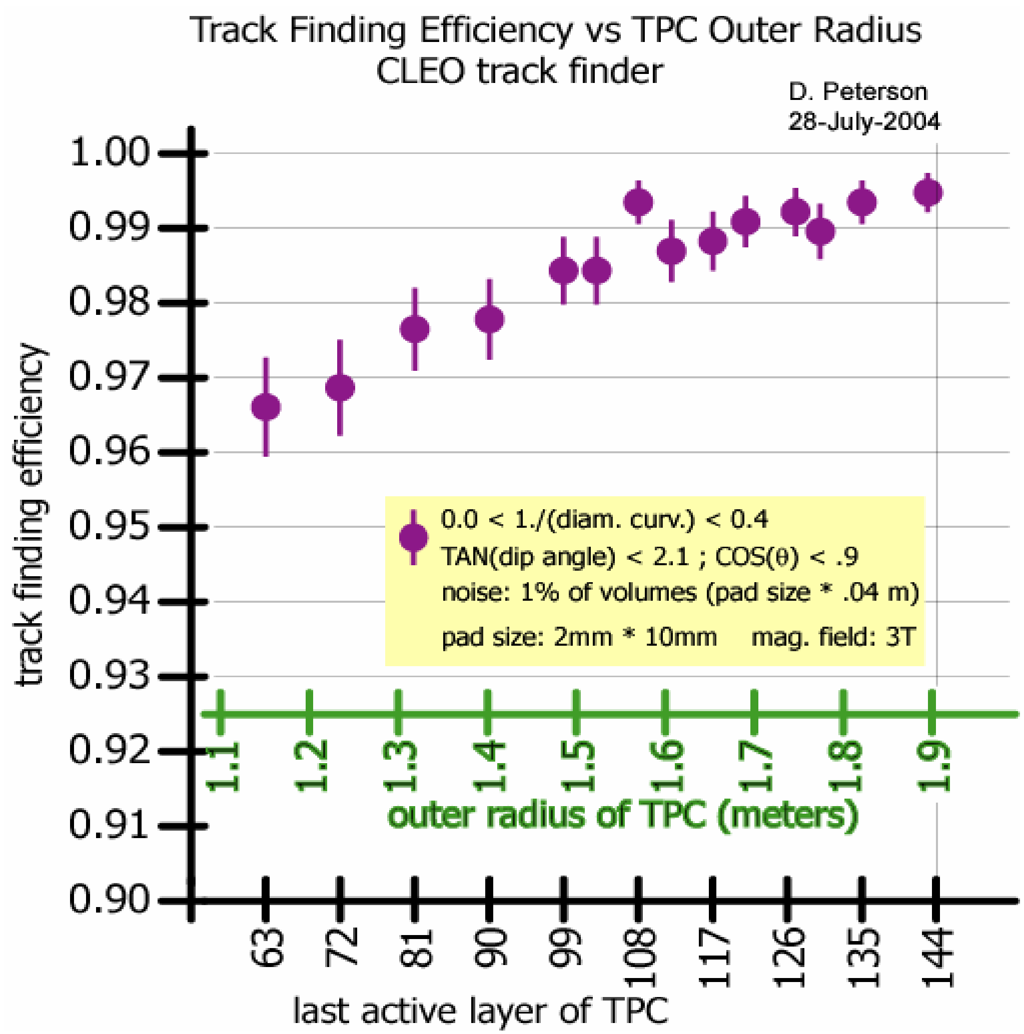
This is the simplest study possible;
cell "height", inner radius, and B field are not adjusted for smaller outer radius.
Hits are not created beyond the selected "last active layer".

The efficiency for low curvature tracks is above 99%
and has only small variation
above 1.7 meter radius (maybe 1.6 m).

High redundancy in the detector provides efficient reconstruction with greatly reduced information.

Small cell height or smaller inner radius (more cells) may improve the efficiency.

Higher B field (more track separation) is expected to improve the efficiency.



Summary, Outlook

The state of the simulation/reconstruction at the ALCPG Victoria meeting:

Simulation of TPC signals and adaptation of the CLEO reconstruction for a TPC are largely complete.
Simulation includes provisions for electronic noise (slide 8) but the volume has not been turned-up.
Time pattern recognition has been revised to allow a floating baseline (for electronic noise and time resolution).
Technology spin-off: the procedure for scanning multiple I.P. pointing cones and the sorting tracks is now used in CLEO for identifying very low momentum tracks in the inner chamber.

Results: (for non curling tracks, within the search volume)

TPC reconstruction efficiency: > 99% for pad size < 4mm.
Noise occupancy up to 1% occupancy causes little change in efficiency.
(This is 1.25 hits/cell. Try that with a drift/jet chamber.)
TPC radius, with B=3T, can be reduced to 1.7 meters with little change in efficiency.

Possible improvements to the study:

Higher electronic noise, Clustered ionization noise, Track background.
Implement the decay-in-flight pattern recognition for the TPC.
Investigate dependence on a parameterization of track isolation.
Quantify the rate of non-removable spurious “found” tracks; this is equally important to energy flow.
Investigate dependence on signal spreading. This could be relevant to, *e.g.*, resistive spreading.
Comment: The study used spreading σ=0.7(pad width), FWHM for 3mm pads is 5mm.

Future:

Mike Ronan and Norman Graf will incorporate the response simulation into the LCD simulation and provide F77 access to simulated hits. (Still) waiting for me to provide the specifications.