TPC Detector Response Simulation and Track Reconstruction

Physics goals at the Linear Collider drive the detector performance goals:

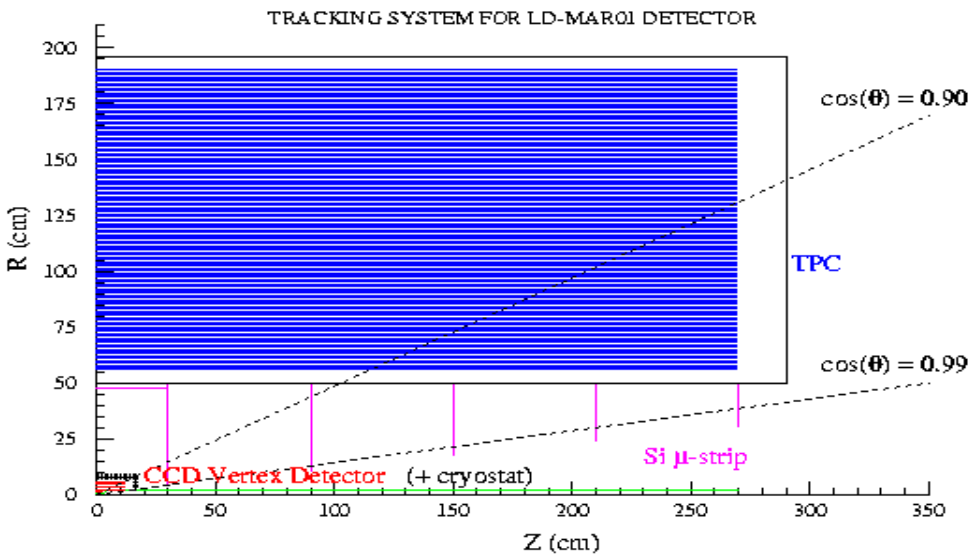
charged particle track reconstruction resolution: $\delta(1/p) = \sim 4 \times 10^{-5}$ /GeV

reconstruction efficiency: 100% within jets for energy flow measurements

Simple simulations, which represent the detector response as smeared space points, show that the track reconstruction resolution can be achieved with the "Large Detector".

For example:

TPC:
2.0 m O.R., 0.5 m I.R., 150 μm spatial resolution
Vertex Detector:
5 layer, 10 μm spatial resolution
Intermediate Tracking Device:
2 layer, r=0.45 m, 10 μm spatial res.
→ $\delta(1/p) = 4.2 \times 10^{-5}$ /GeV



Reconstruction efficiency cannot be easily estimated in the event environment of the Linear Collider, it is dependent on the **non-Gaussian smearing effects: noise and track overlap**.

Reconstruction Efficiency

While reconstruction efficiency is difficult to estimate,

one could achieve the **maximum efficiency** using the **maximum segmentation** possible with a GEM or MicroMegas amplification TPC.

However, the channel count would be excessive (and expensive);

[0.1 cm^2 pads] → 2.4×10^6 multi-hit channels .

To optimize the detector design,
measure the reconstruction efficiency with respect to the detector segmentation,
determine the **minimum segmentation** that provides the "full" efficiency.

A TPC design would be simpler if I can convince you that 0.4 cm^2 pads would be sufficient.

The goal of this work is to measure the reconstruction efficiency and thereby optimize the design
for a TPC in the "Large Detector" design,
incorporating as many real detector effects as possible
(pad size, charge spreading, inefficient pads, noise),
for complicated physics events simulating Linear Collider processes,
and using pattern recognition that starts with pad level information (not space points) .

Many thanks to **Mike Ronan** for wrapping the Cornell reconstruction code in Java
and providing a access to lcd simulation events in .sio format.

Illustration of information provided by the MC: Sample event

Sample event from lcd simulation

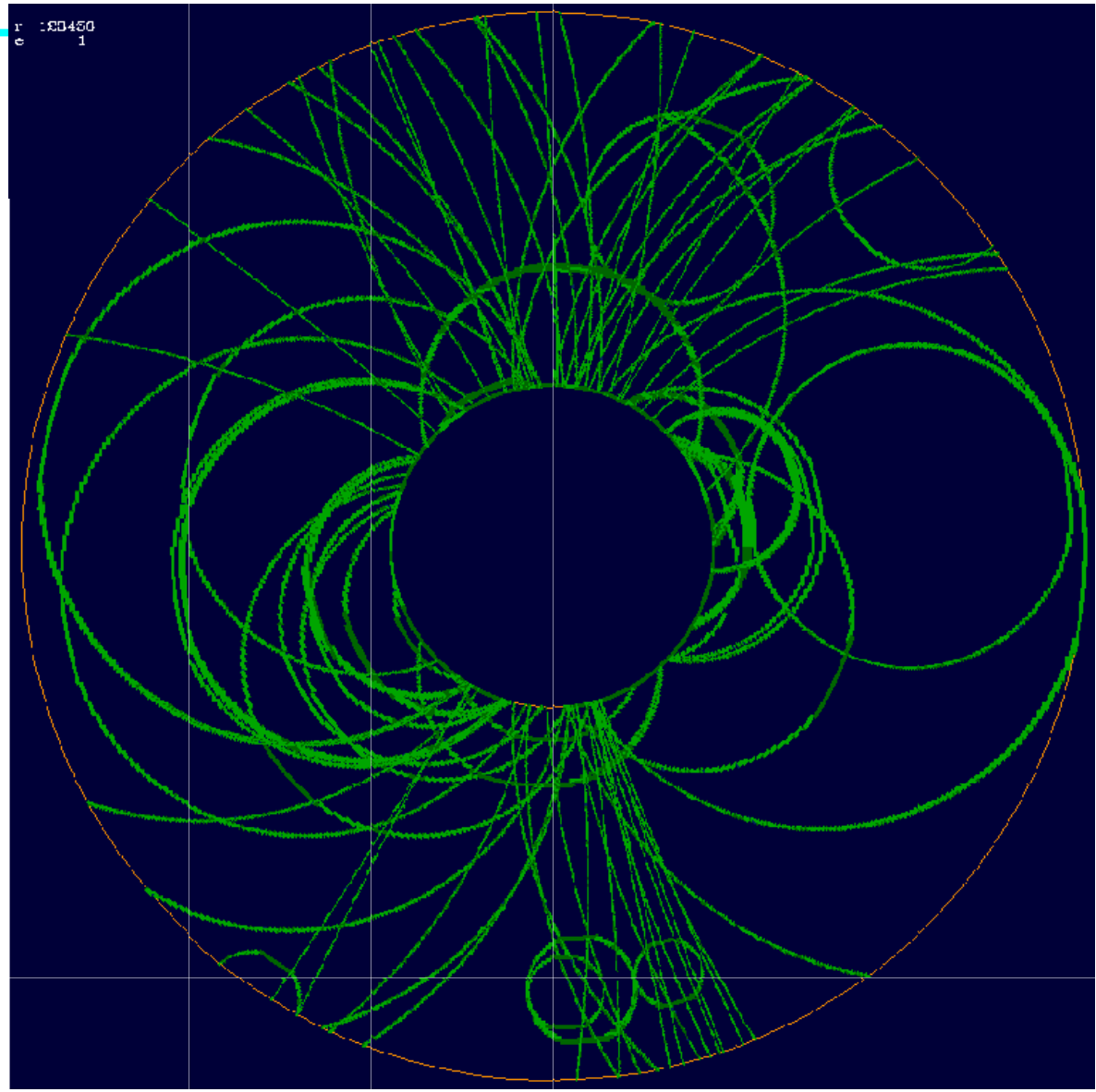
(All hits are are projected
onto one endplate.)

143 layers from 56cm to 200 cm

2 mm wide pads, 1cm radial "height"
(number of pads in layer
is multiple of 8)

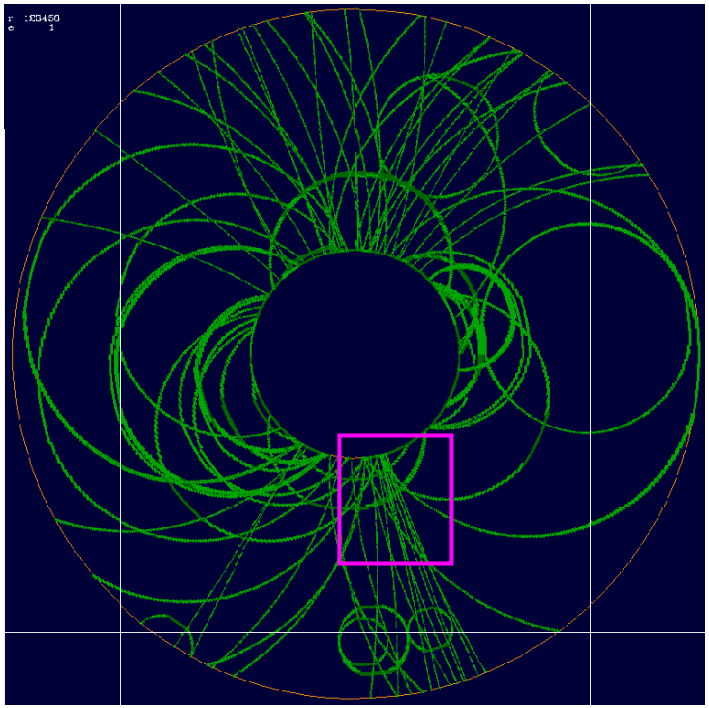
charge spread is minimal
no noise

This would be similar to a situation
with 1 mm pads and
charge spreading to 2 pads,
a very expensive detector.



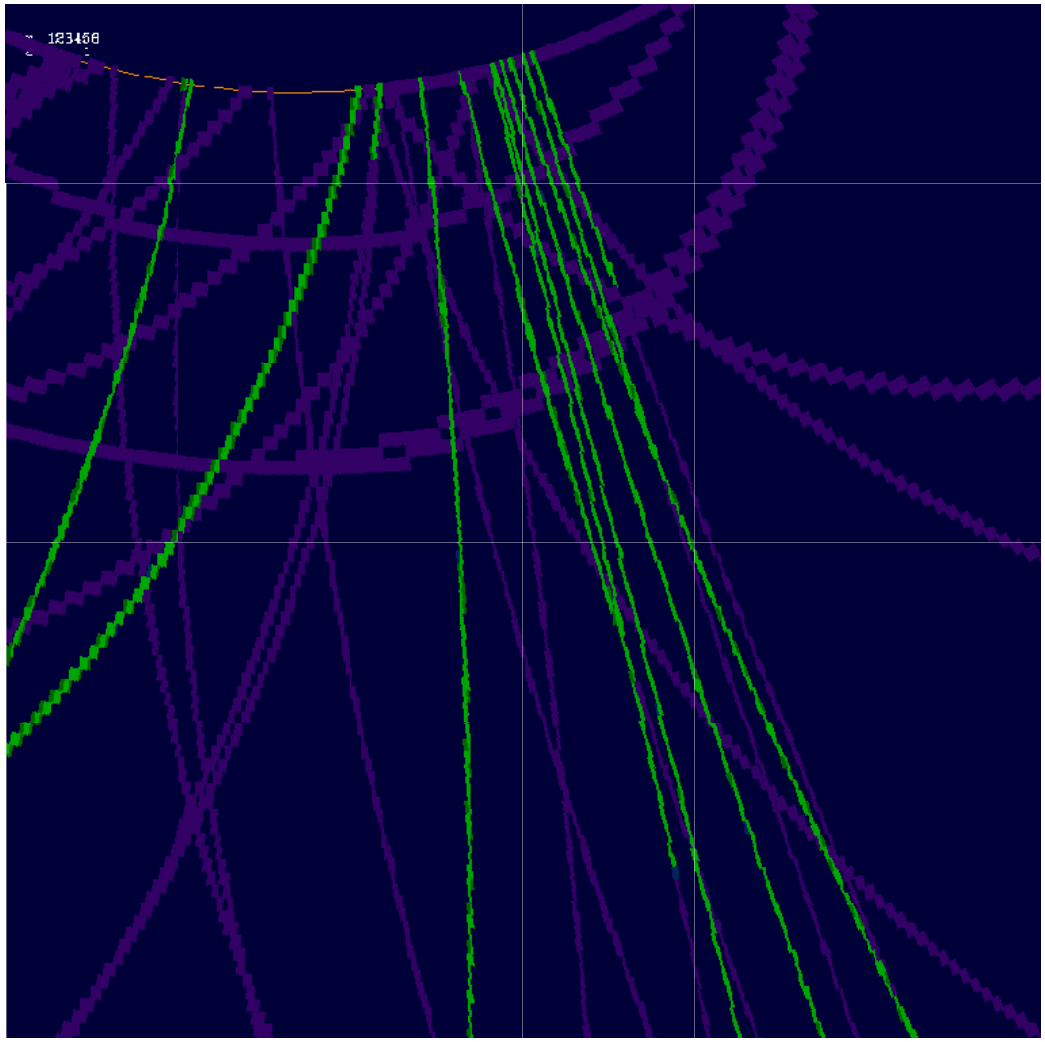
Sample Event: Tracks within a Jet

(Same event, same pad response)



Tracks in a jet are usually separated.

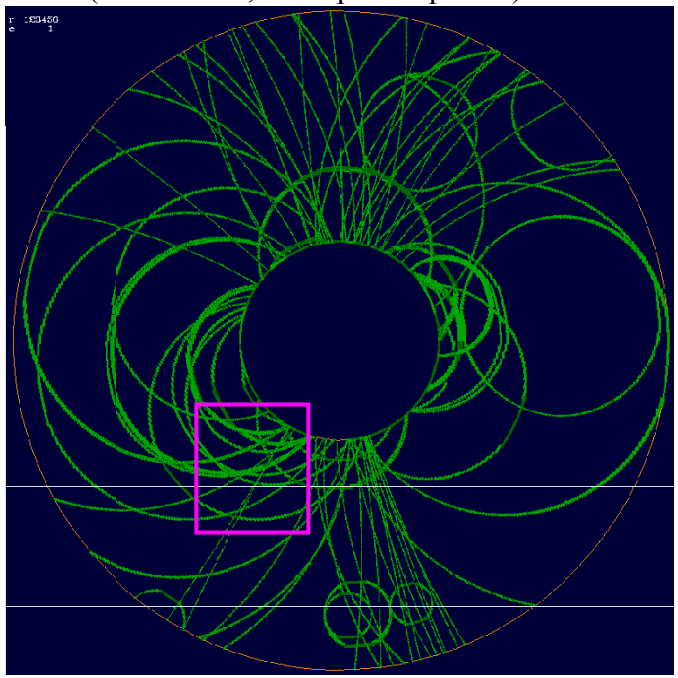
It *appears* that, when
taking advantage of the z separation,
the reconstruction task would be simple.



Active cone: Z=[r * (-6 / 80)] +/- 4.7 cm

Sample Event: Problem with Overlapping Tracks

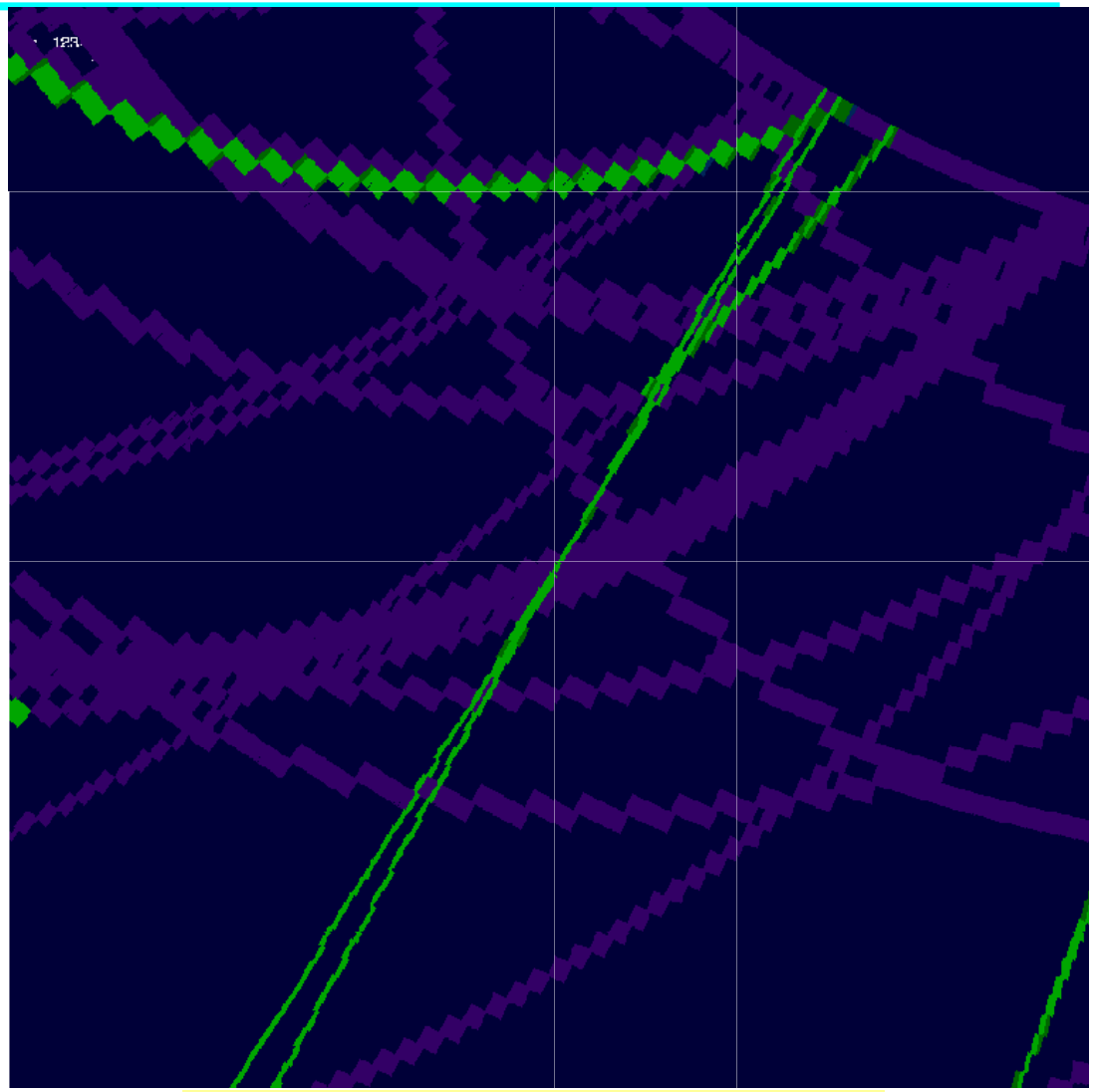
(Same event, same pad response)



However, z separation is often too small to provide track separation.

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

But, track reconstruction can be efficient for very close tracks by using information from regions where the tracks are isolated. This is an advantage of the pat. rec. to be described.

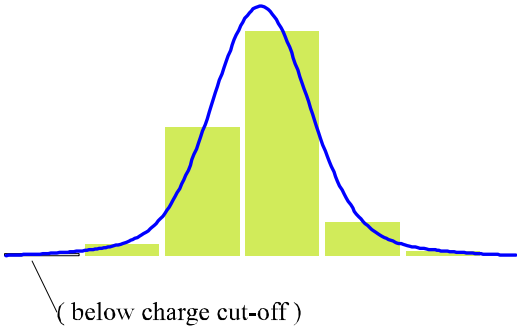


Active cone: Z=[r * (-6 / 80)] +/- 4.7 cm

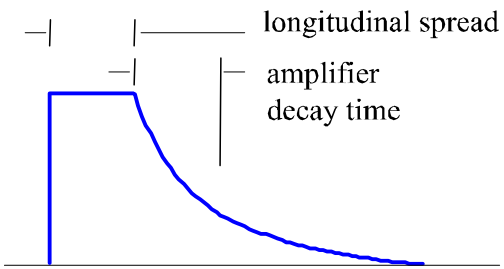
Detector Simulation: Pad Response (and Clustering)

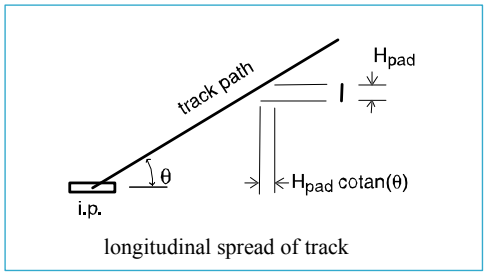
The lcd simulation provides only crossing points; extensions to the simulation are created within the CLEO library.

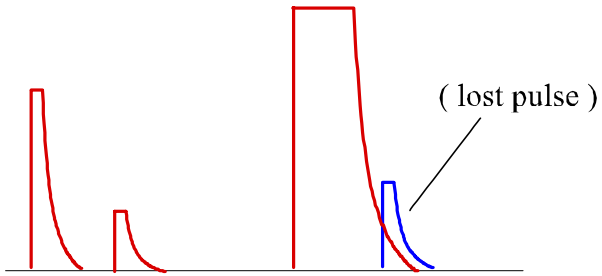
Charge spreading on the pads
Gaussian width, cut-off (~ .002 of min.ion.),
maximum total-number-pads
charge is renormalized to provide a **total of min. ion**.



Wave Form to simulate time (=z) response

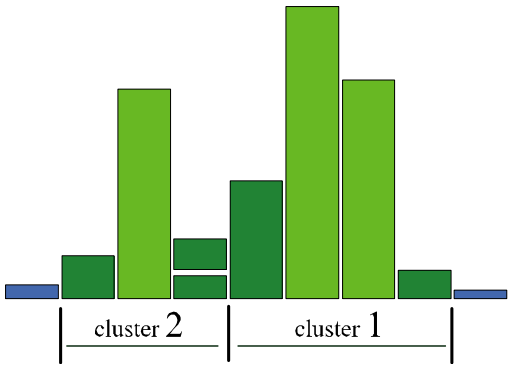






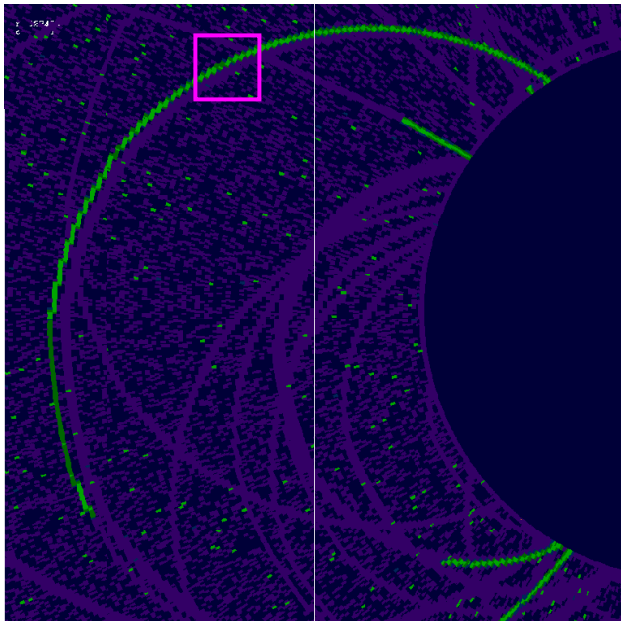
Clustering in r-ϕ
criteria for minimum **central pad** , added **adjacent** pads
splitting at a local minimum,
can lead to pulse height merging and incorrect clustering.

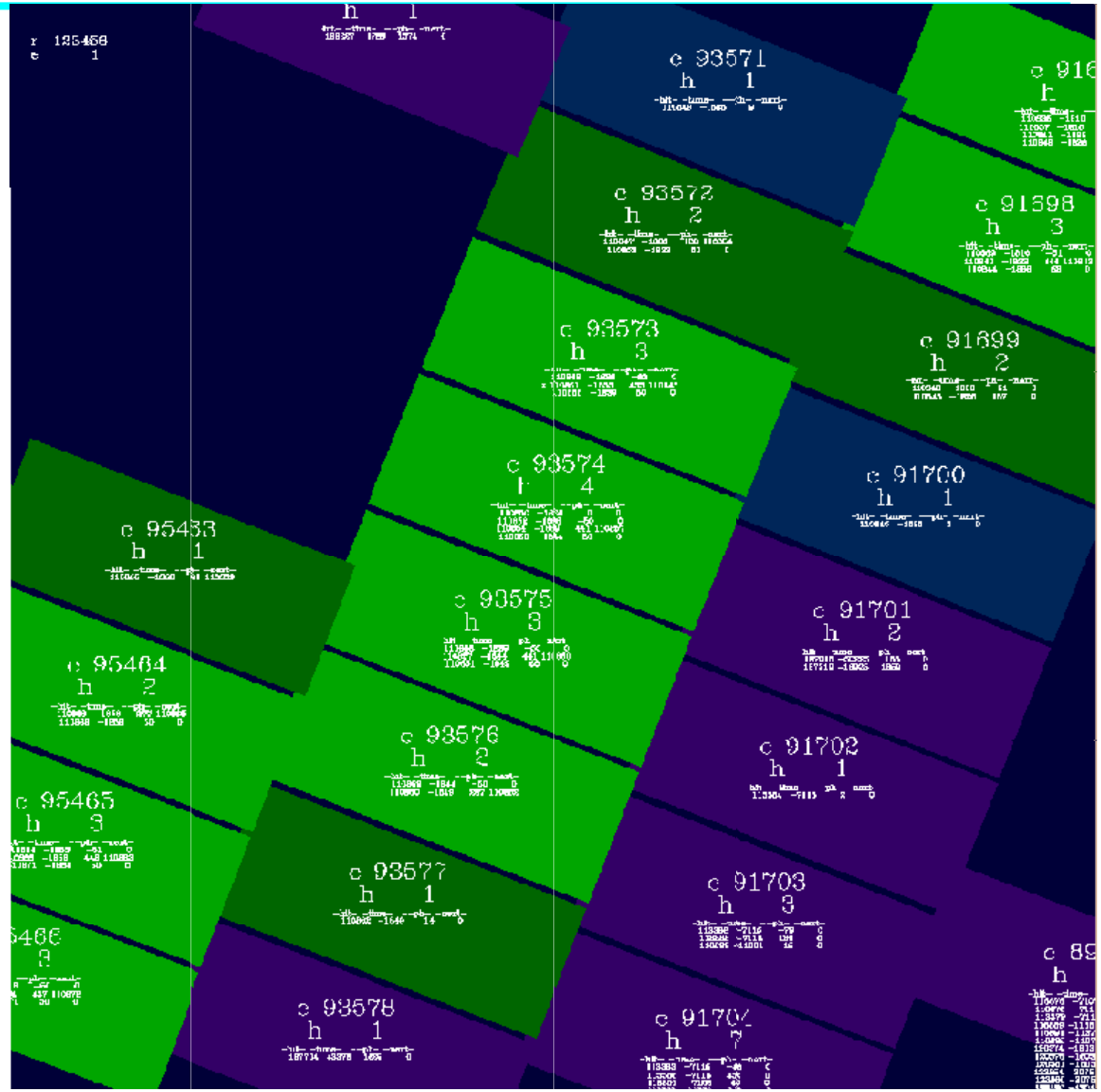
Pads with > 0.51 of the maximum are treated as "core pads".
(a detail of the primary pattern recognition)



New: Ionization distribution at large entrance angle

Cell width: 4mm





Ionization is spread across the cells. Previously, ionization was created only where the track crossed the central radius.

Also shown: multi-hits
clustering

Active cone: Z=[r * (-3 / 80)] +/- 4.7 cm

Track Reconstruction

With a goal of accurately measuring the TPC pad size and spreading that will provide the "full" reconstruction efficiency in Linear Collider physics events,

it becomes important to know what is being measured,

inherent reconstruction efficiency, limited by the track overlap and hit distortion, and NOT an efficiency that is limited by the algorithm.

Require a means to independently determine the root cause of reconstruction failures.

The CLEO reconstruction program include a diagnostics package that provides
internal hit information
and
a graphics interface to the hit assignment,
at intermediate stages in the programs.

This allows
rapid determination the root cause of reconstruction failures (on single tracks) and algorithm development.

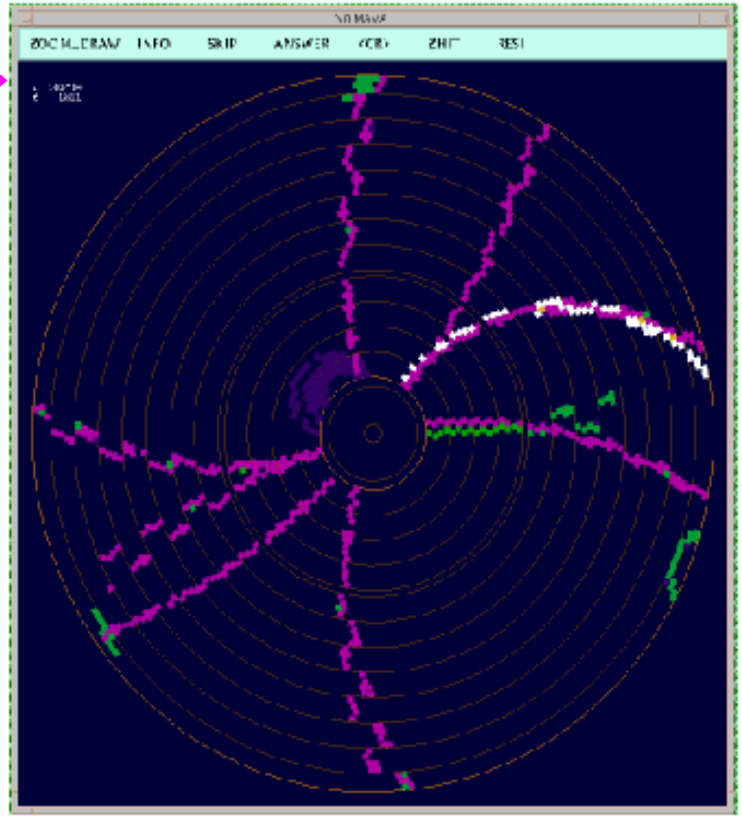
CLEO Track Reconstruction

The current CLEO charge particle track reconstruction

originally written for a drift chamber
(where z information is derived from the track and stereo layers),

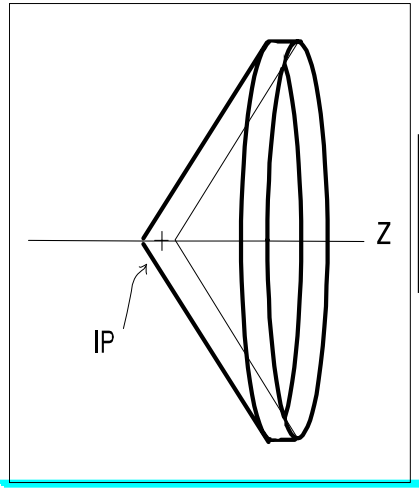
can be adapted to any type of device with dense hit information (like a TPC, but not silicon)
by changing the details of how Z information is derived from the detector signals,

is highly efficient for overlapped tracks
(as shown in the event)
because any region of track separation can be used as a seed,



has 3 stages:

1. clean segment finding
2. initial track finding within the segment road
3. extension to more complicated regions (and other devices).



Segments are found in
pre-selected,
I.P. pointing, cones.

Projected hits for event, after detector response simulation

Same event as slide3

5 mm pads, **3.5 mm** charge spread

Noise: 0.003 occupancy
in 3-d volume
1 cm (r-ϕ) x 2 cm (z) x layer

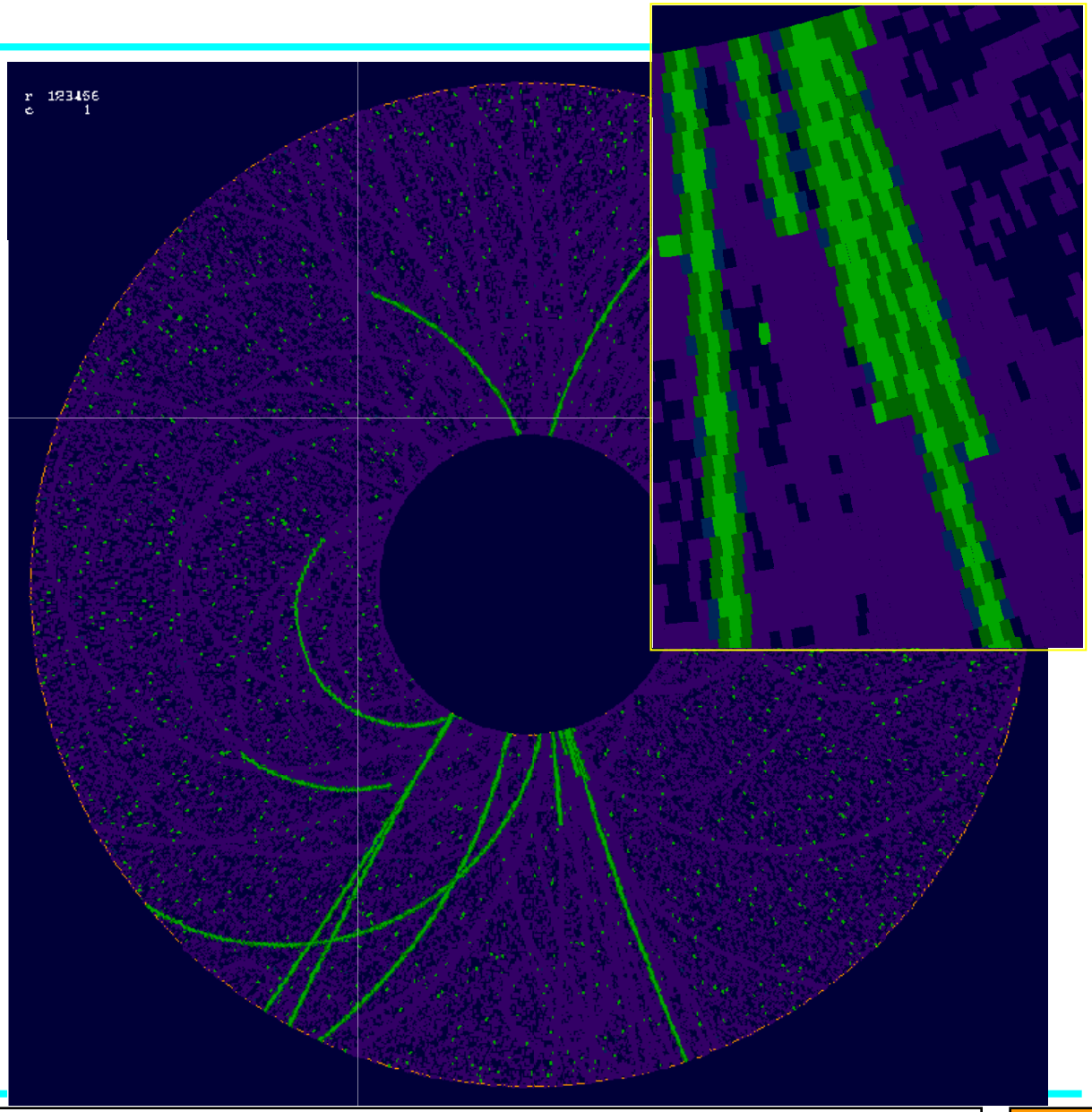
Number of channels (1 side) 222 k
Number of layer crossings 14946
Number of track hits = 137019
(each crossing creating ~ 9.2 hits)

Number of noise hits = 89385

Active hits in green

Ignored hits in purple

Active cone: Z=[r * (-7 / 80)] +/- 4.7 cm



Segment Finding Stage

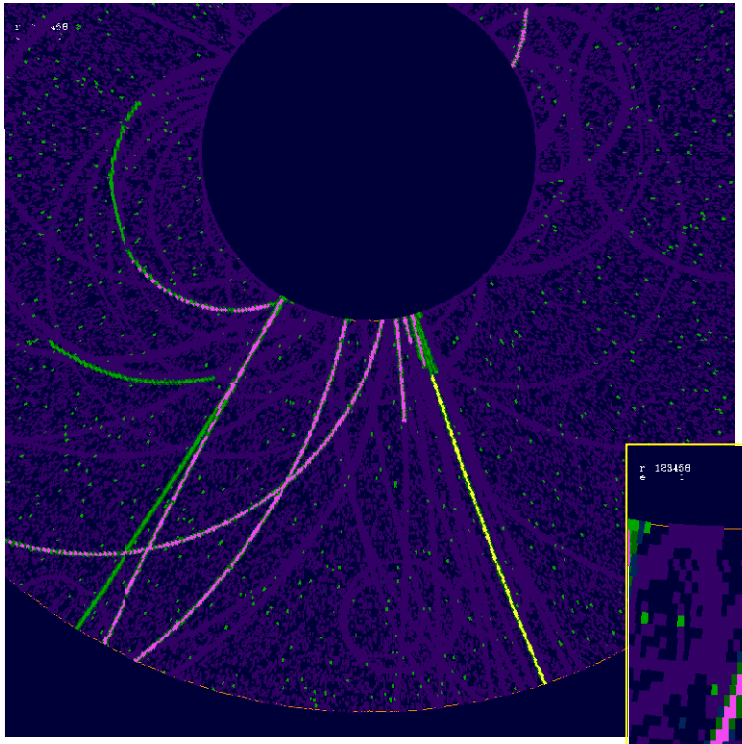
Active hits in green

Ignored hits in purple

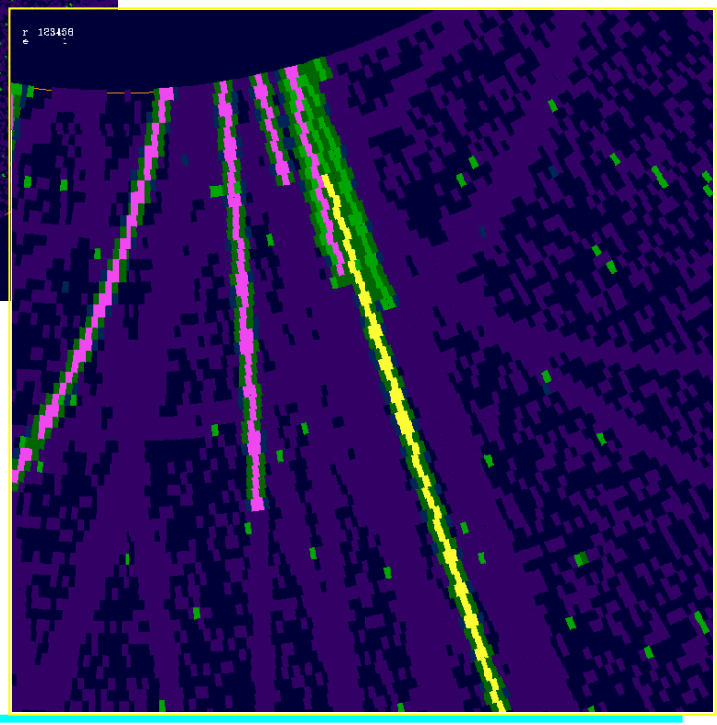
Current isolated segment is shown in **yellow**

Other isolated segments are shown in pink.

At this point, processing for segments is not complete; not all segment are found.



The segment has been extended into the overlap region.



Segments are interrupted in regions of track overlap.

After 2nd Phase, r-ϕ view

Hits in road in orange.

Hits on track in white .

5 mm pads

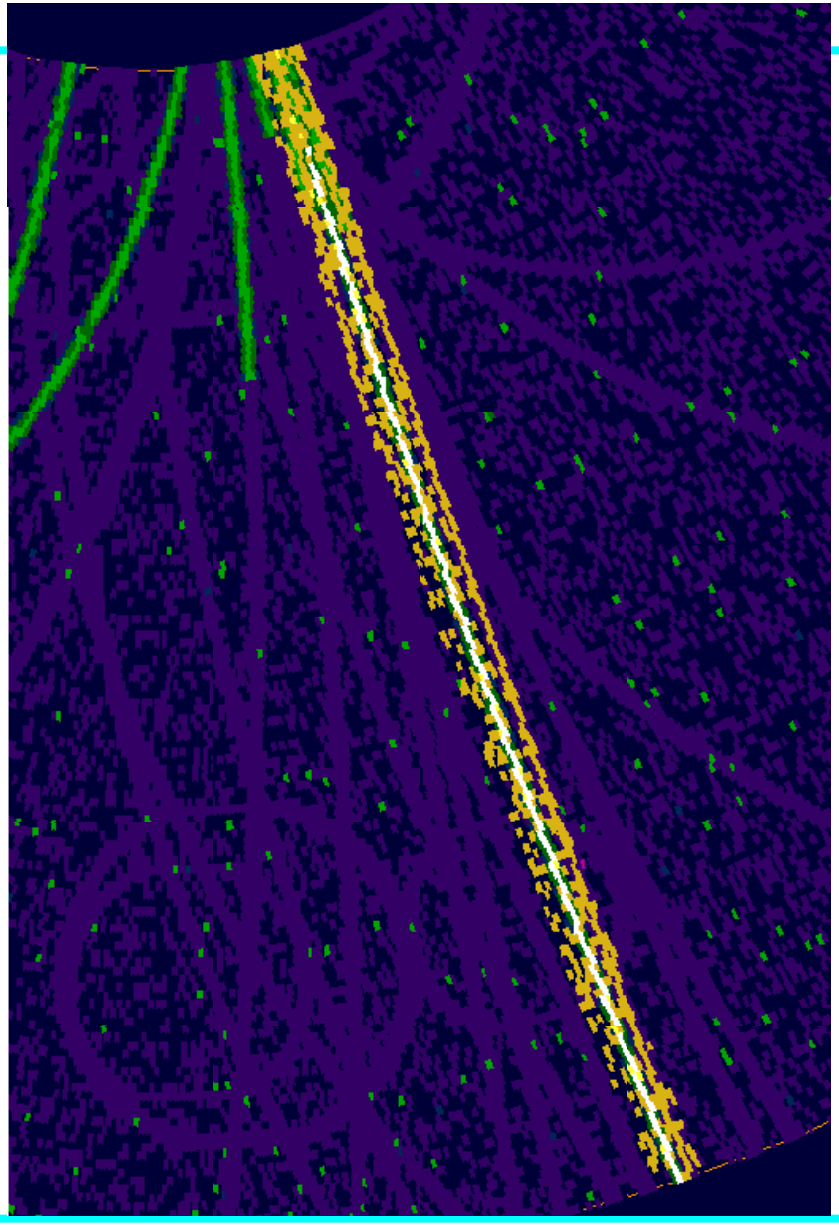
Track does not extend into track overlap region.

r-ϕ impact = 280 μm

χ^2 (of the fit to a track) = 2
with declared hit resolution: 100 μm

This implies that the hit resolution is too good;
hit resolution = 141 μm for 5 mm pads,

Smearing of the pulse heights is incomplete;
requires low-level electronic noise.



After 2nd Phase, residual (r-ϕ) view

PLOT: residual on horizontal
(+/- 0.025 cm at edge)
vs. radius on vertical

2nd phase pattern recognition uses
local residual correlations

(radius is broken up into 16 parts)

In each radial part,
look for correlated hits satisfying

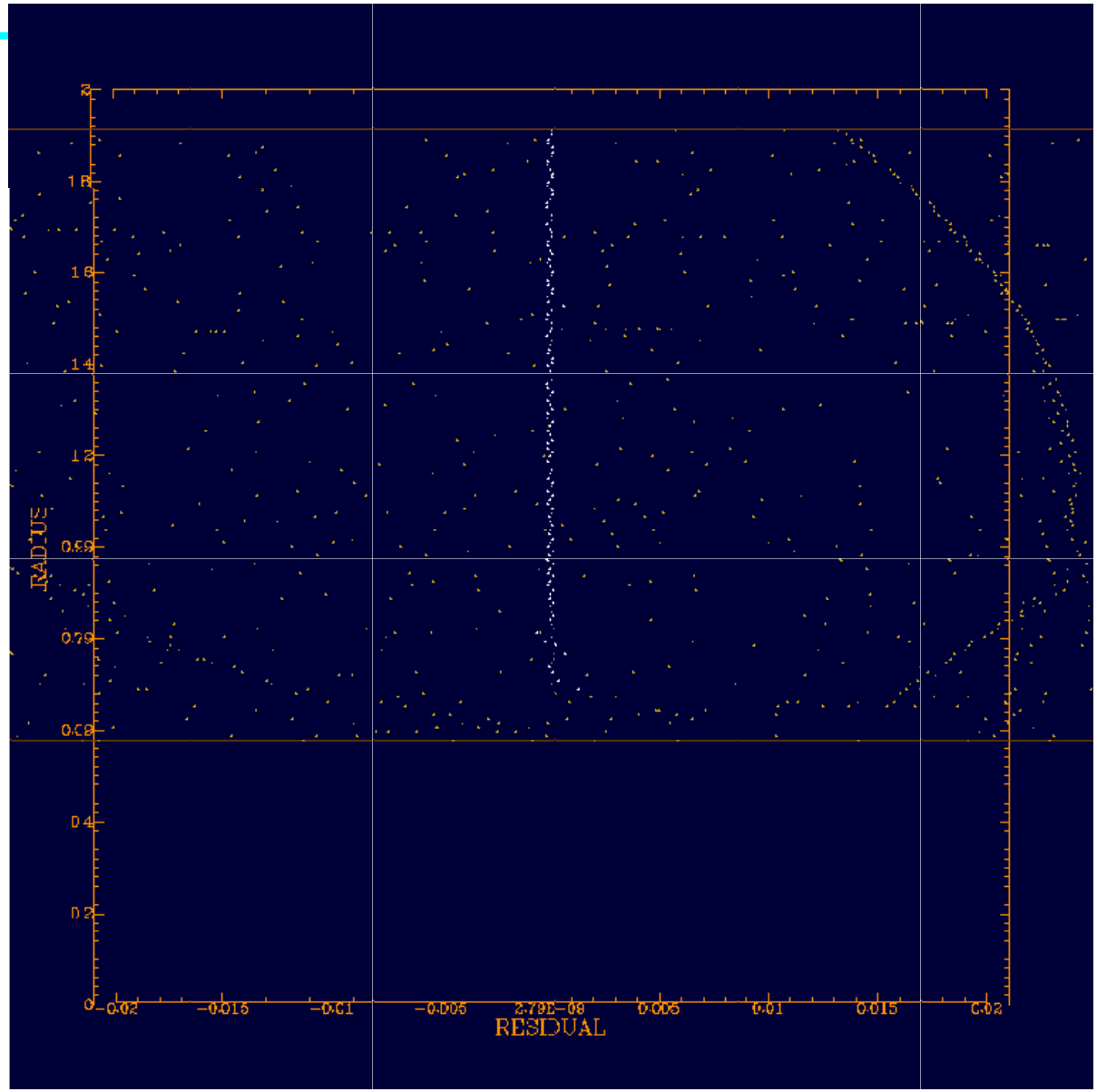
used r-ϕ road < 0.005 m
used z road < 0.10 m .

As will be discussed later, there is only
a weak requirement on the
agreement of the
average z-coordinate of the
solutions in each radial part.

Then,
select best solution in each radial part.

No solutions were found at low radius.

Note: other track.



After 2nd Phase, z view

Hits in road in orange.

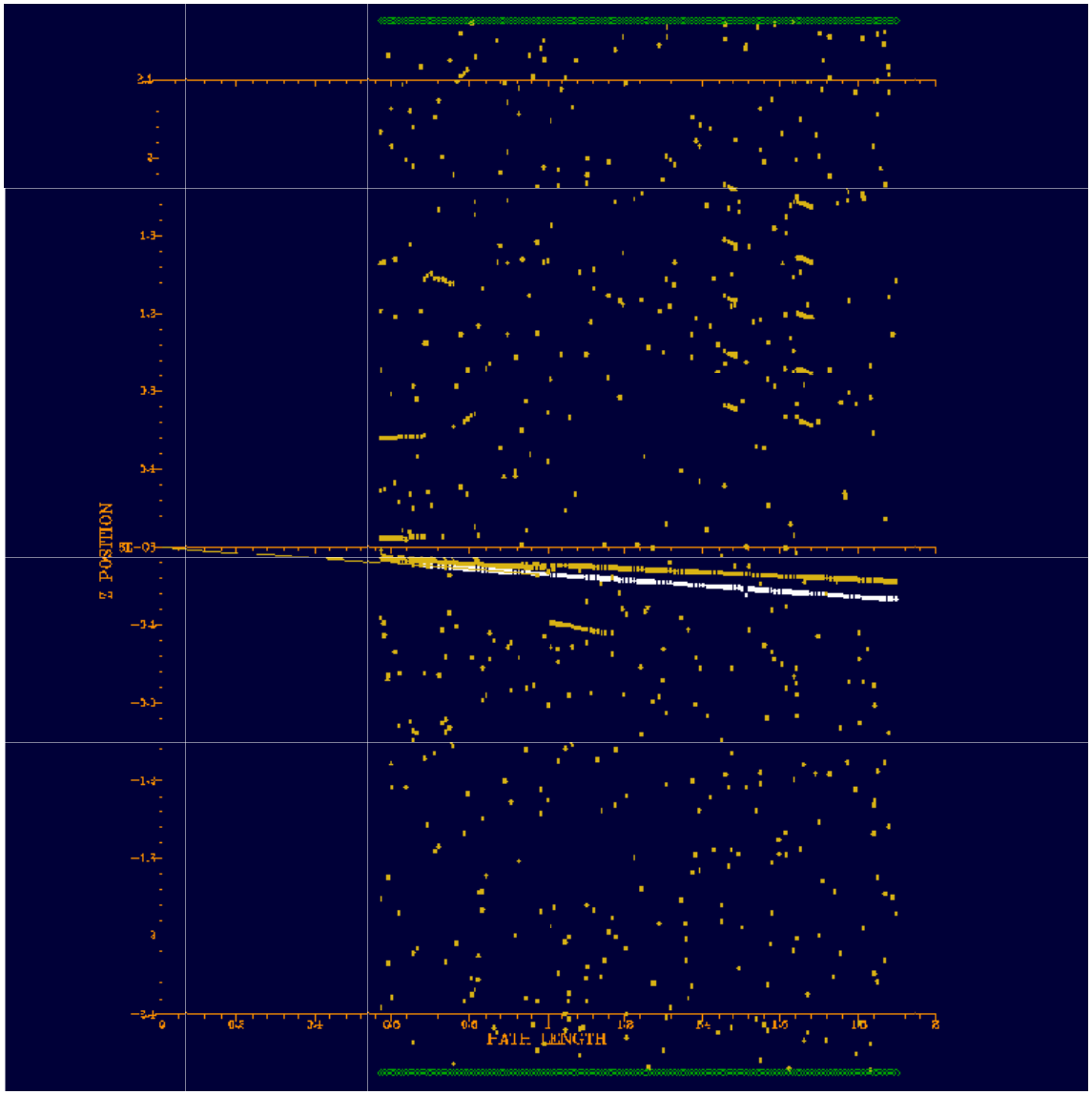
Hits on track in white .

PLOT: Z on vertical
(+/- 2.5 meter)
vs. path length on horizontal

The other track is also very close in Z.

Below .7 meter in arc length,
the hits are merged
and not usable, for either track.

Note:
- other track (interference)
- short tracks that escape the r-ϕ road,
- curler, not completely in the r-ϕ road



MC tracks selected for efficiency studies

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

Preliminary "results"

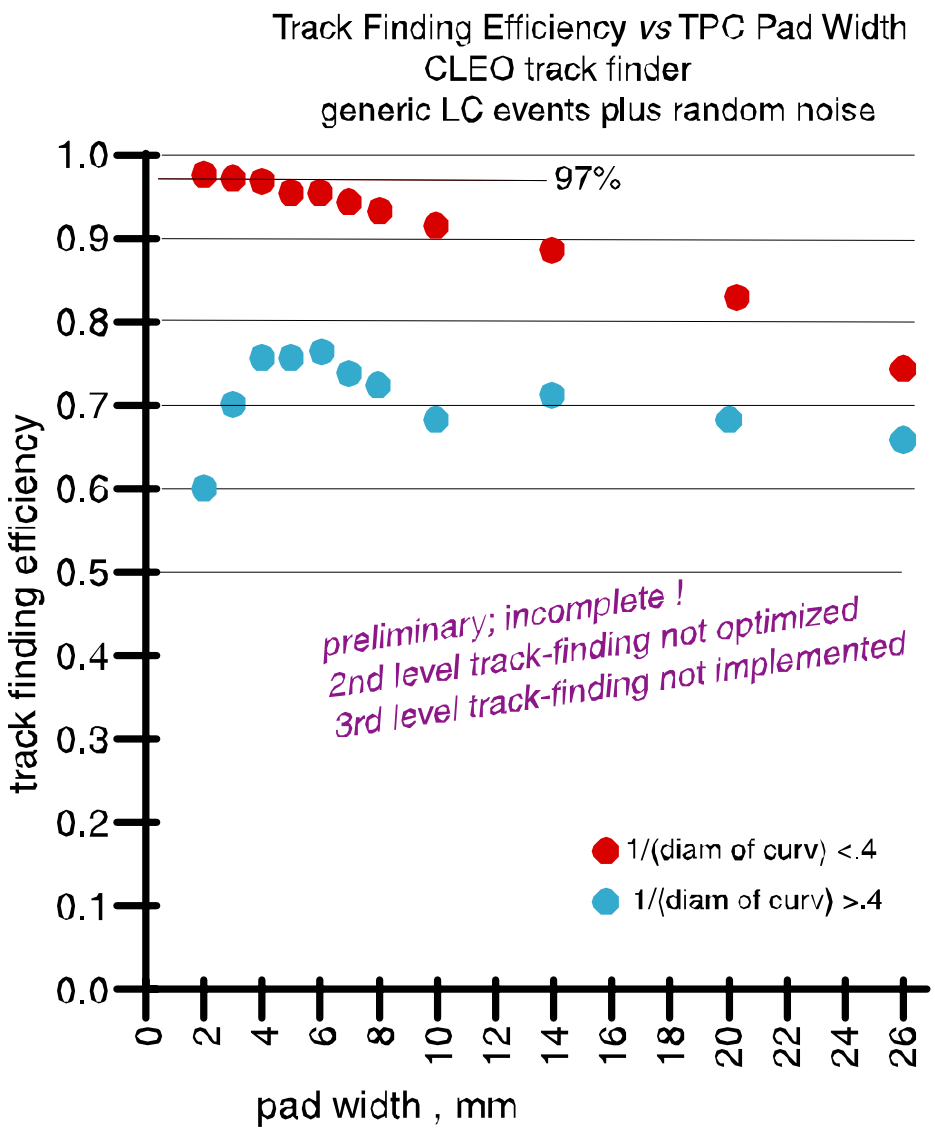
Track finding efficiency
dependence on pad width.

Require $\chi < 25$ (defined on previous slide.)

Efficiency for straight tracks
plateaus at ~ 4mm pad width, at ~ 97%.
(Discussion follows.)

(Recall: Noise: 0.003 occupancy
in 3-d volume
1 cm (r-ϕ) x 2 cm (z) x layer)

Efficiency for curling tracks is worse.
And, the efficiency is worse at the
smallest pad width which can only be
the fault of the pattern recognition.
(Discussion follows.)

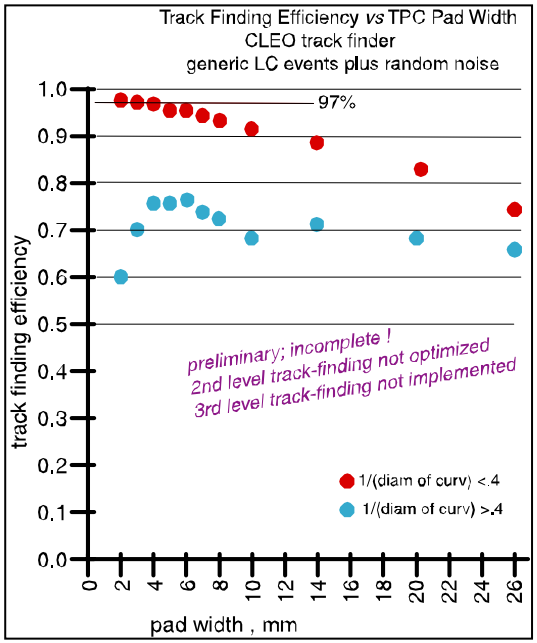


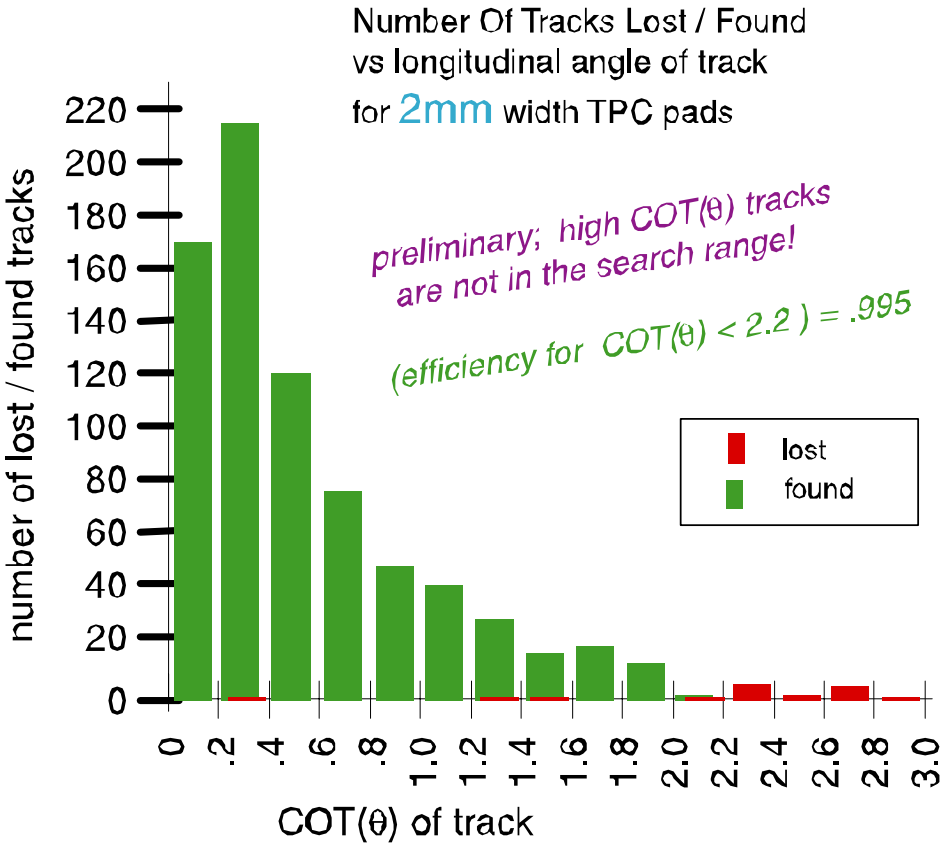
Preliminary "results", discussion

Efficiency for straight tracks plateaus at ~ 4 mm cell width (for this noise level).

Efficiency at plateau: ~ 97% . Reason: track search does not extend beyond COT(θ)>2.

(from slide 16)





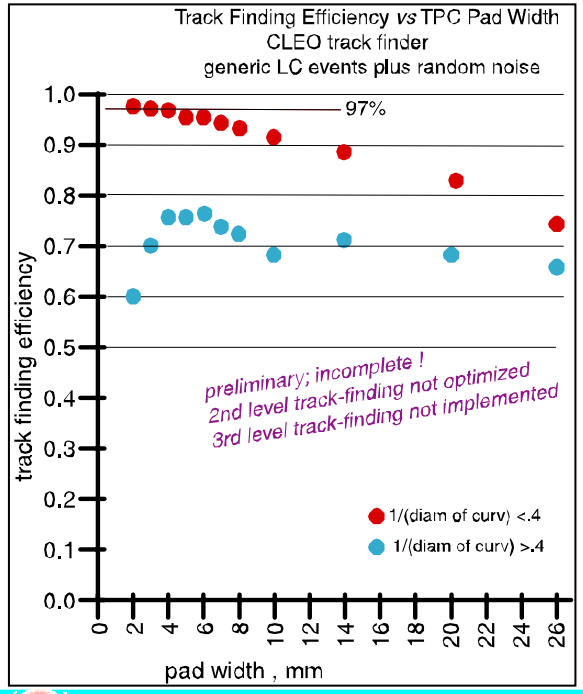
Preliminary "results", discussion

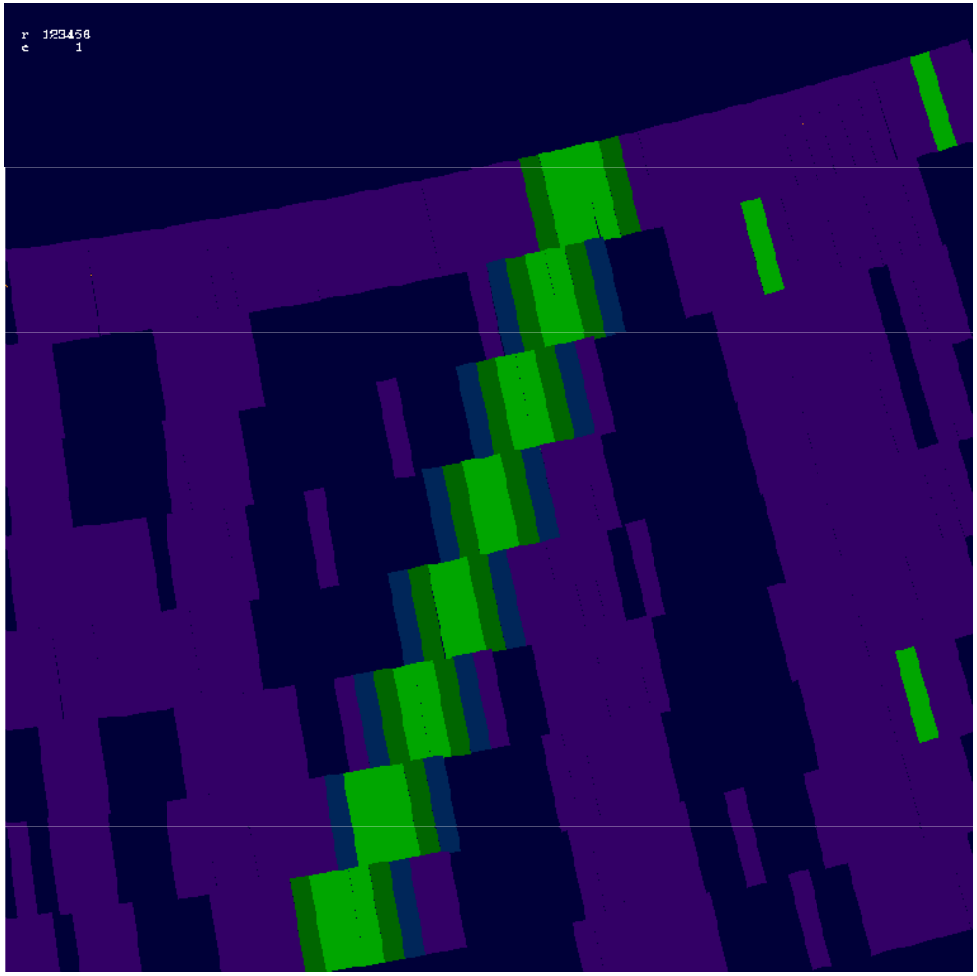
Efficiency for curling tracks extrapolates to ~ 80%.
Anomalous behavior: efficiency decreases for cell size < 4mm.

Curling tracks require more refinement, although improved since Berkeley. Separate treatment for straight and curling tracks may be required.

This will be addressed in the near future.

(from slide 16)



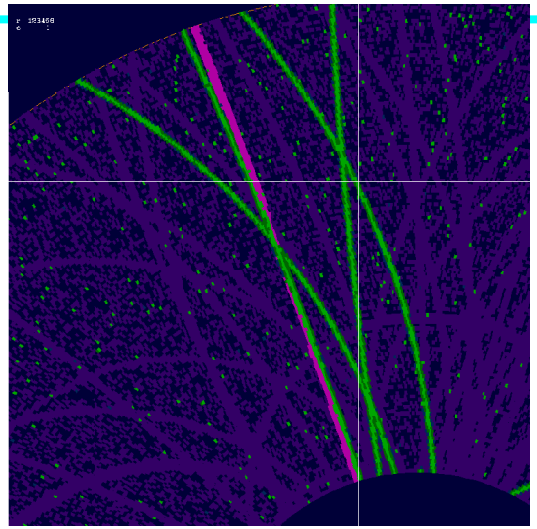


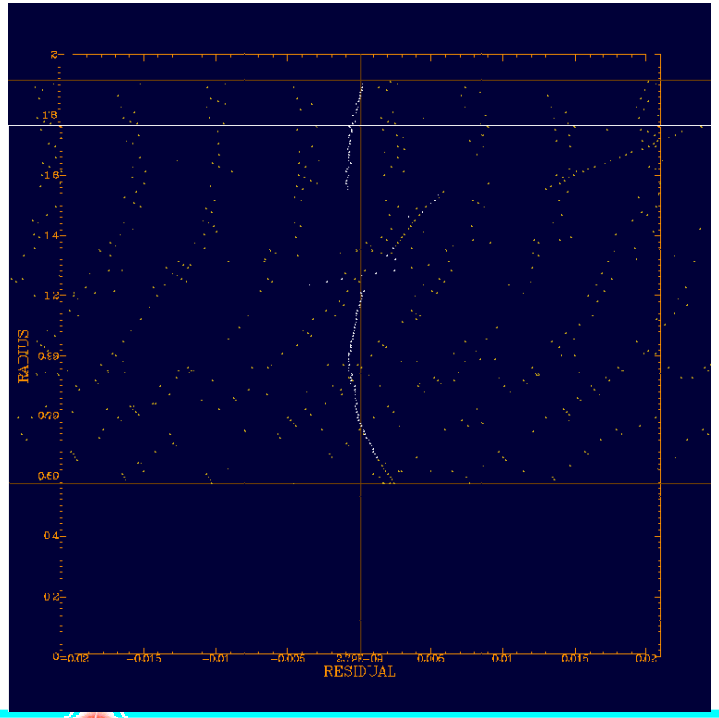
Can the plateau be pushed to 6mm cell width ?

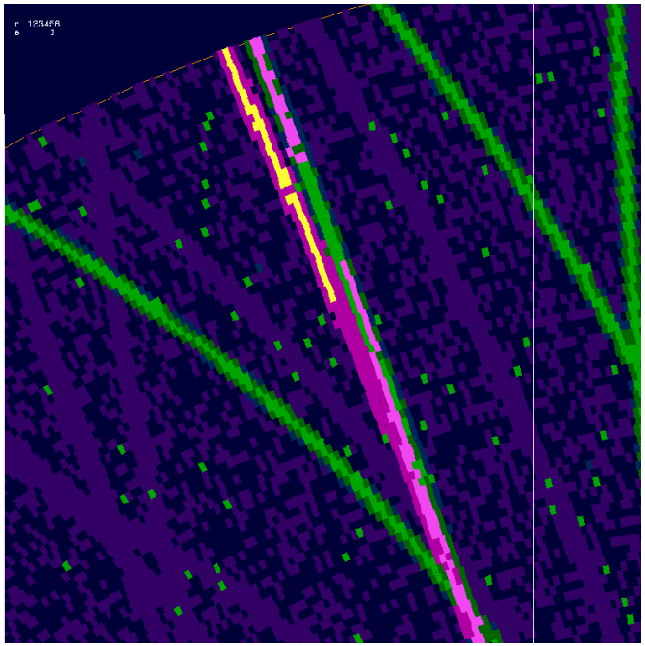
Compare track lists from 2mm and 6mm cell size.
Identify 17 tracks lost with 6mm cell,
out of the 763 tracks found with 2mm cell.
Identify 2 pathologies.

1) large overlap within selection cone.
An isolated segment is found, but the ability to start with any isolated segment and extend is not yet implemented.

Basically, I am using the online version.





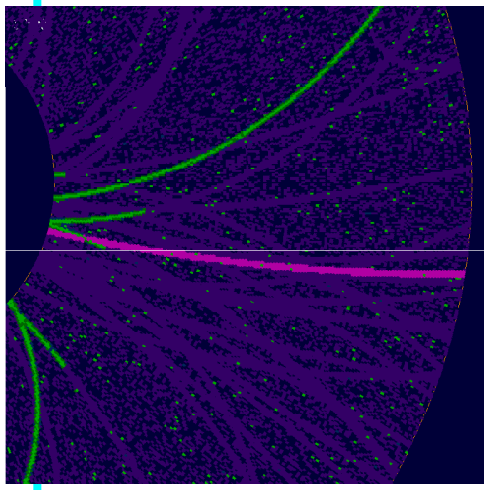


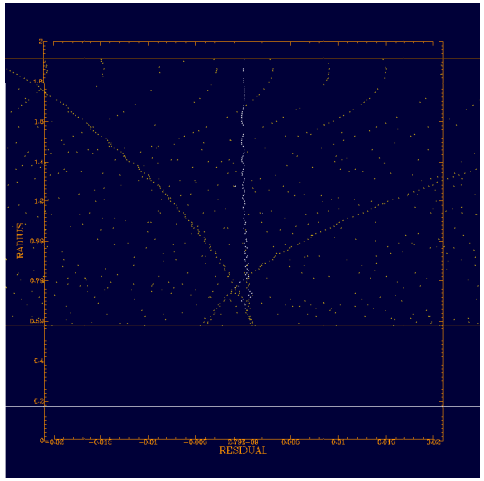
Can the plateau be pushed to 6mm cell width ?

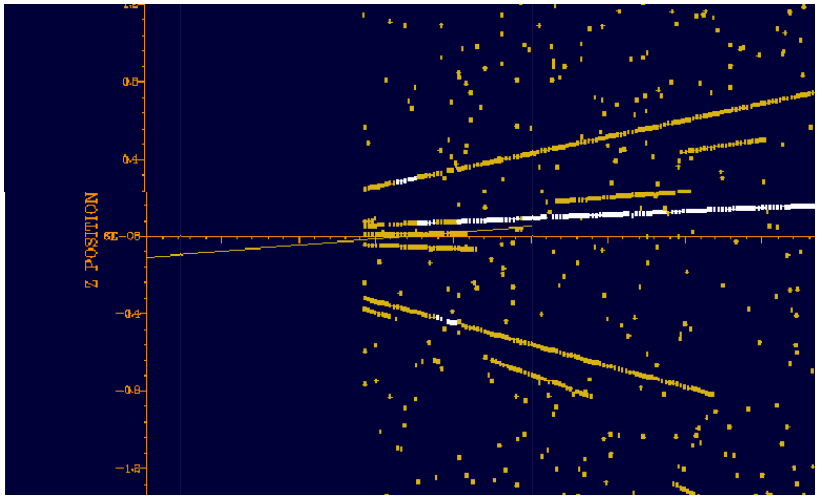
Top: 6 mm cell
Bottom: 2 mm cell

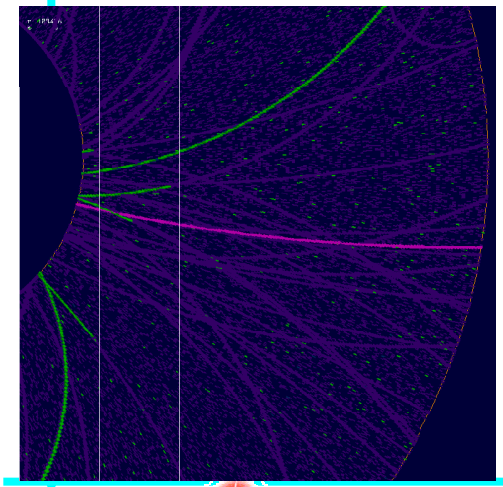
2) overlap at small radius,

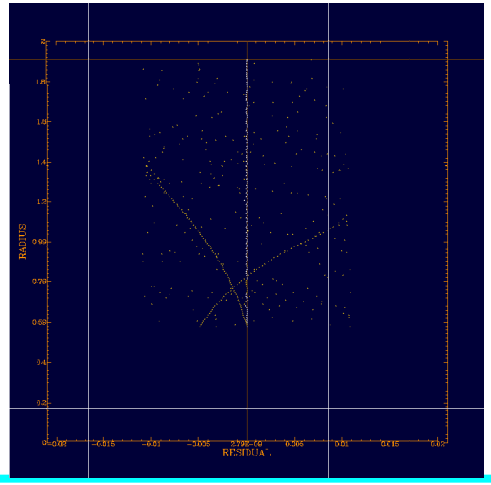
Earlier described that the "best" solution, within a radial group, is selected.
Inconsistency of the Z solutions is observed, but the consistency requirement is not implemented.

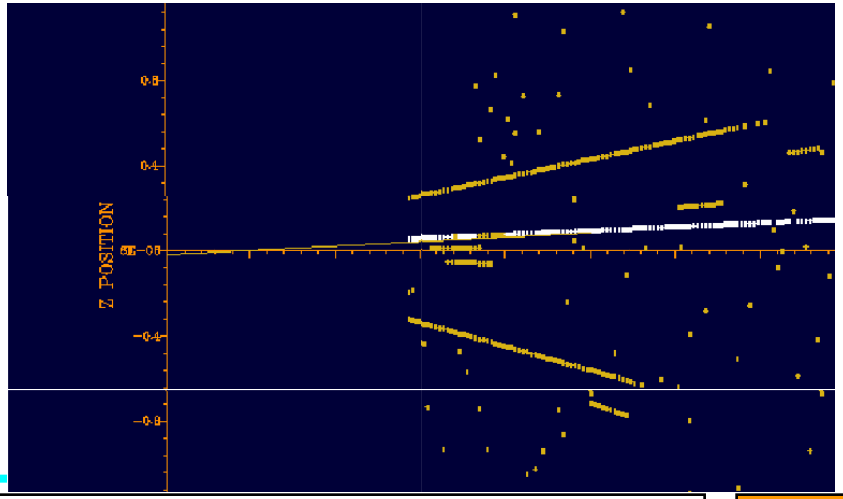












Outlook

"Complete" at the SLAC 2004 ALCPG meeting:

interface to the LCD physics simulation through .sio file (Mike Ronan)
create a TPC geometry, data structure, and detector response simulation
within the Cornell/CLEO reconstruction
create the TPC specific x,y,z hit reconstruction routines
upgrade the reconstruction to handle multi-hit electronics
procedure for scanning through the I.P. pointing cones and sorting tracks
develop a method for identifying tracks that should be found

some optimization of the 1st level pattern recognition for TPC readout

identification of pathologies limiting the efficiency at 6 mm pad width

Needed for efficiency studies: higher statistics

would like to have events with a specific 2 body process, e.g. $Z \rightarrow \mu\mu$.
for resolution: apply **low level noise** to all pulse heights, fraction of min.ion.
implement the full 2nd level pattern recognition to
solve inconsistent z solutions and resolve overlapping tracks
implement the 3rd level pattern recognition to extend overlapping tracks

Result: efficiency vs pad size: efficiency nearly plateaus at 4mm pad size

Future results: **efficiency** and resolution vs. pad size
charge spread , noise level, and 2-track separation, P, and θ