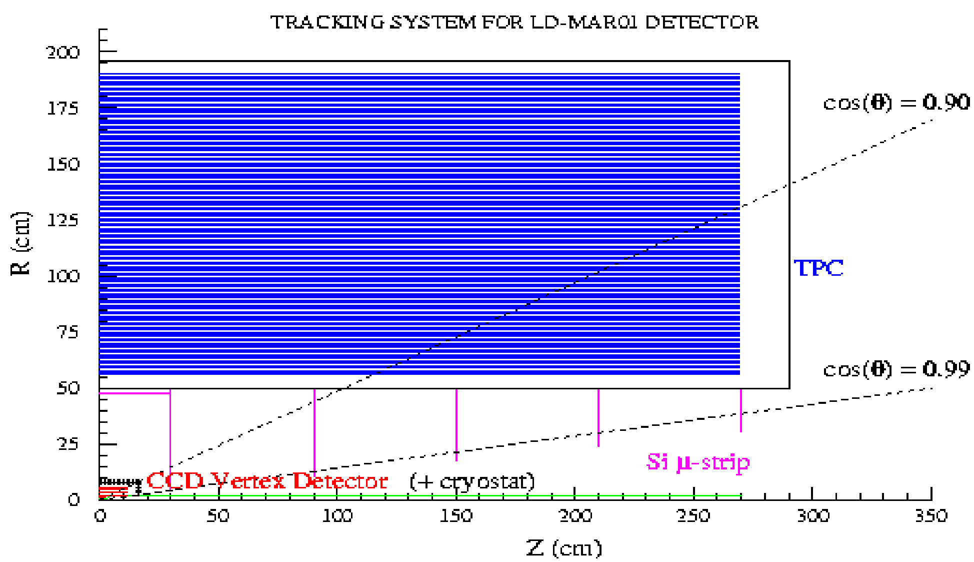
TPC Detector Response Simulation and Track Reconstruction

Physics goals at the Linear Collider drive the detector performance goals:
charged particle track reconstruction resolution: $\delta(1/p)=$ □4 x 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 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.
à $\delta(1/p)= 4.2 \times 10^{-5}$ /GeV



Reconstruction efficiency cannot be estimated so easily 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] à 2.4 x 10^6 multi-hit channels .

To build the optimal detector,

measure the reconstruction efficiency with respect to the detector segmentation,
determine the **minimum segmentation** that provides the “full” efficiency.

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.

Sample event with 2 mm pads

Sample event from lcd simulation

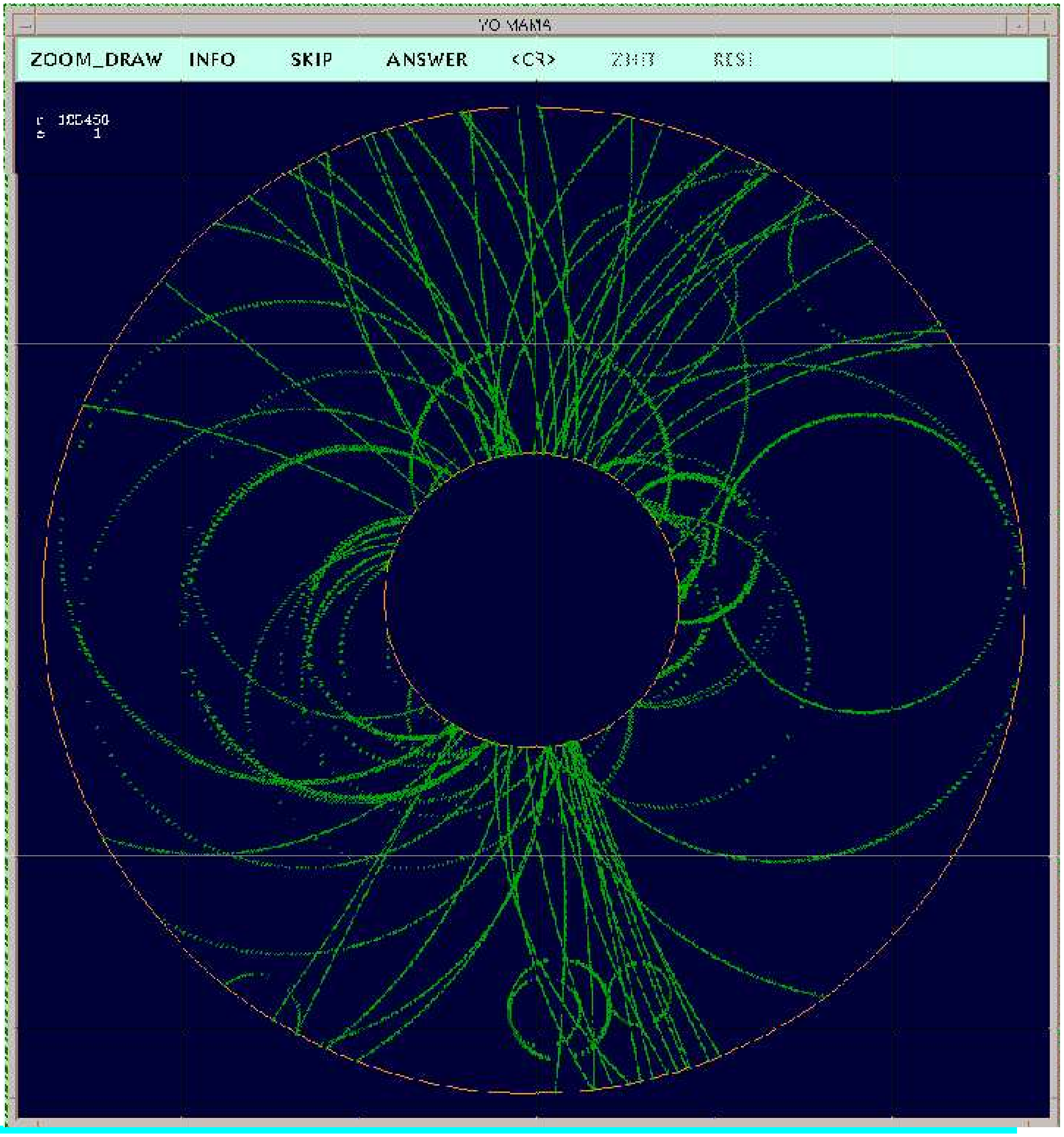
(All hits are are projected onto one endplate.)

144 layers from 56cm to 200 cm

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

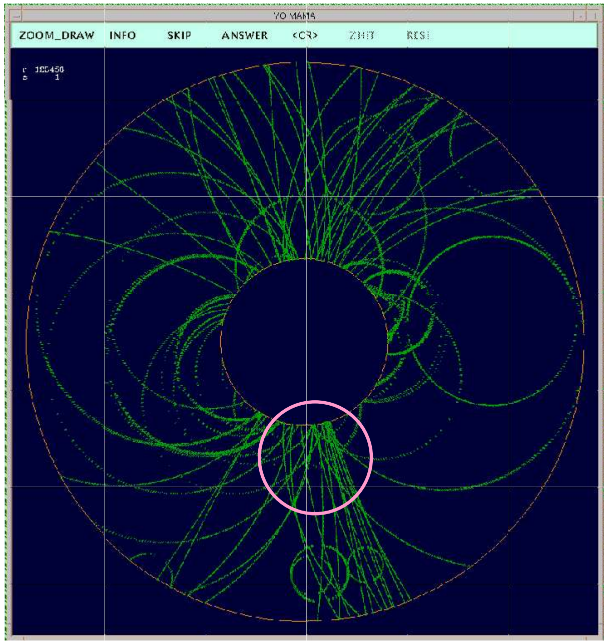
no charge spread
no z overlap
no noise

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



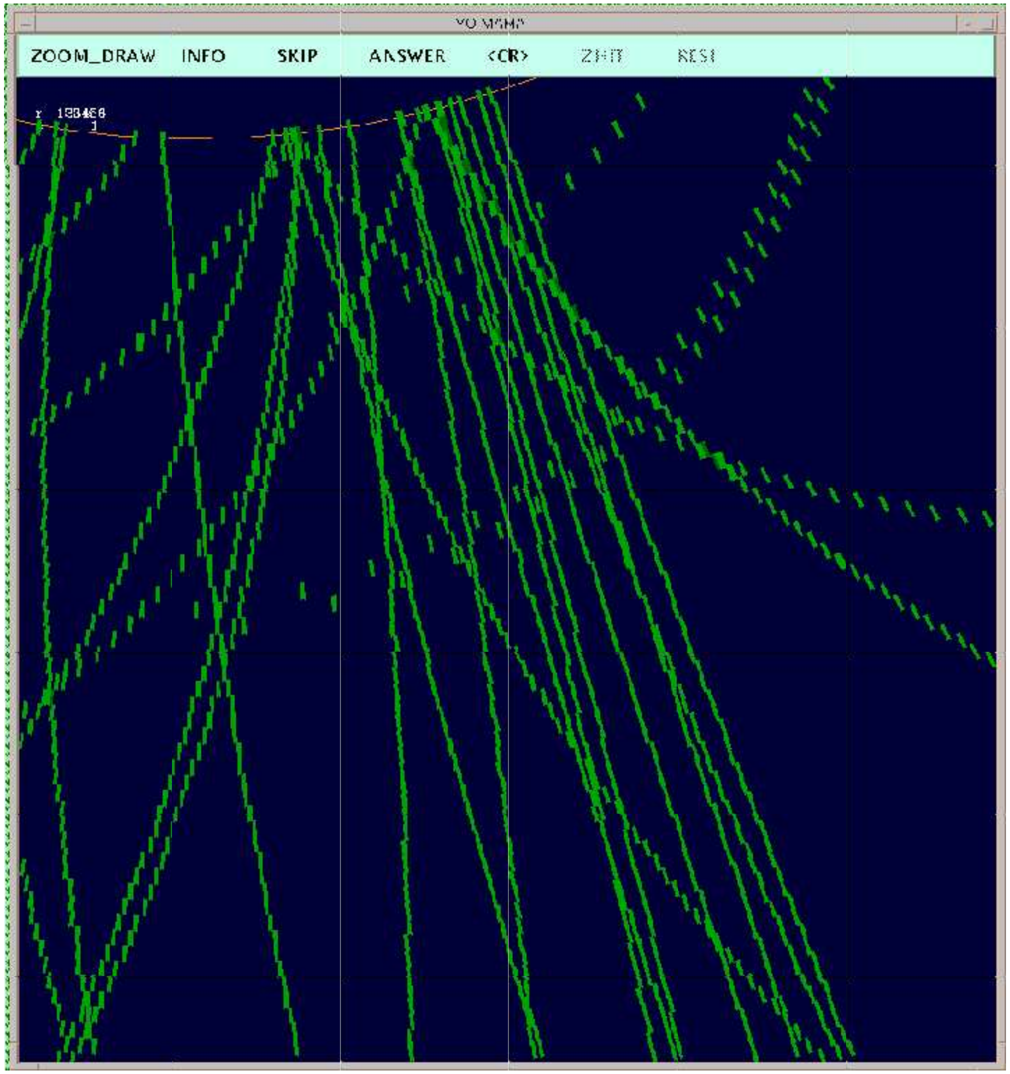
Sample Event, Tracks within a Jet

(Same event, same pad response)



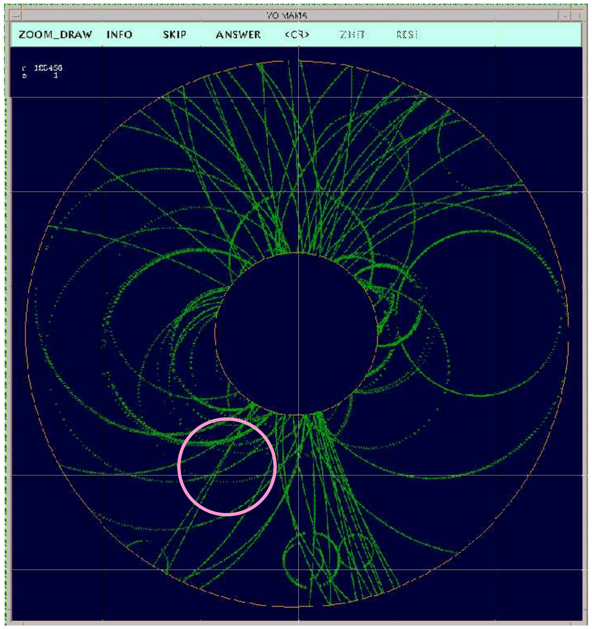
Tracks in a jet are usually separated.

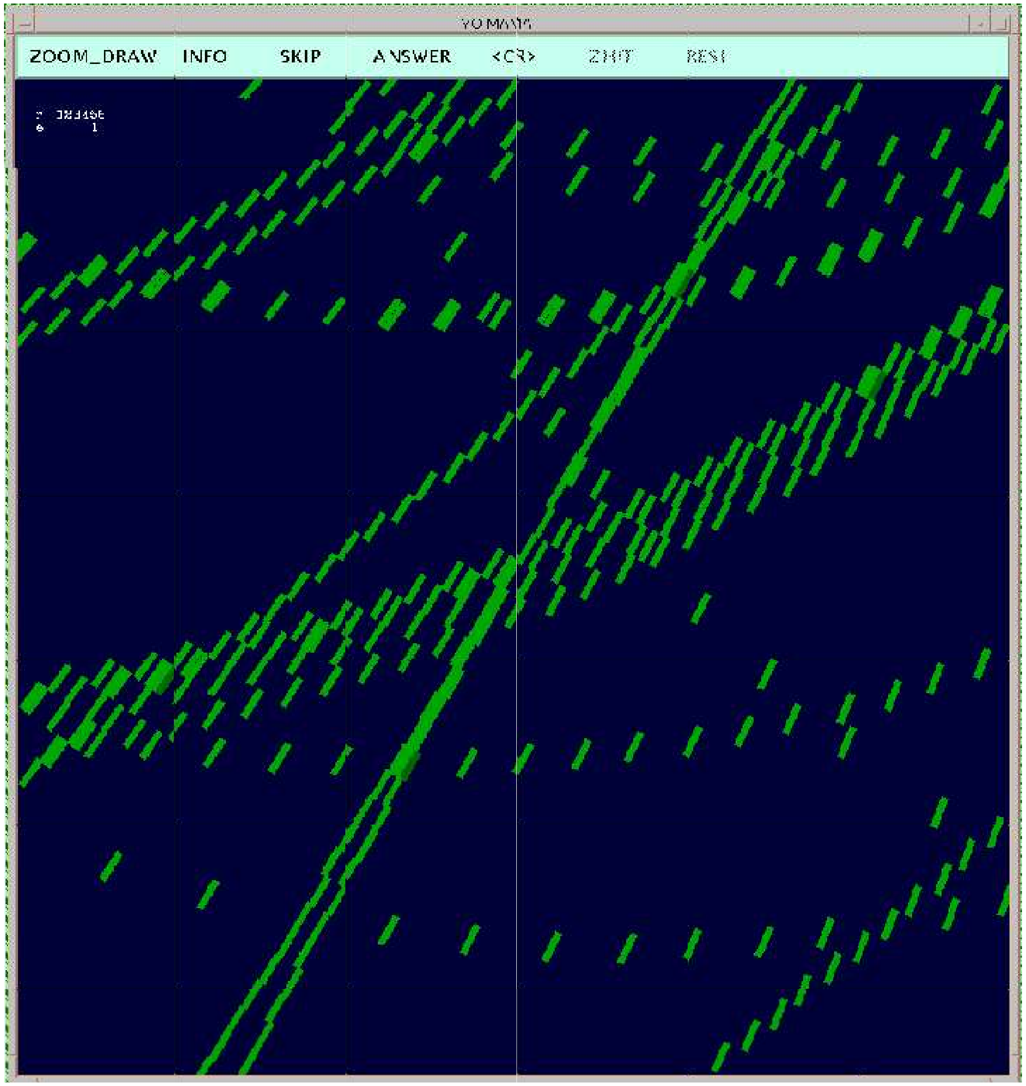
It *appears* that, when
taking advantage of the z separation,
the reconstruction task would be simple.



Sample Event, Problem with Overlapping Tracks

(Same event, same pad response)





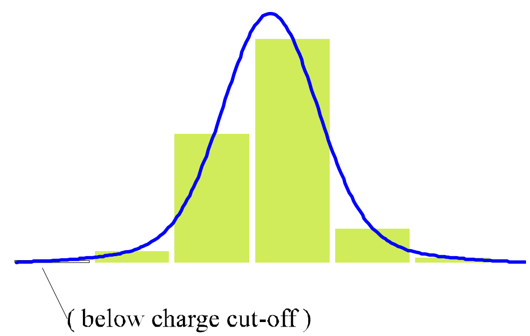
However, z separation is often too small to provide track separation.

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.

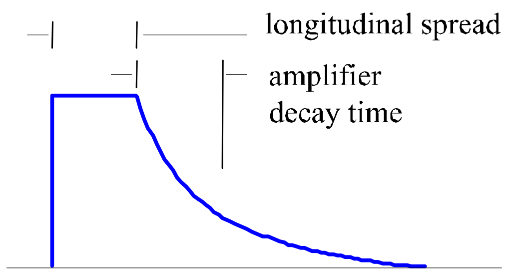
Detector Simulation: Pad Response
(and Clustering)

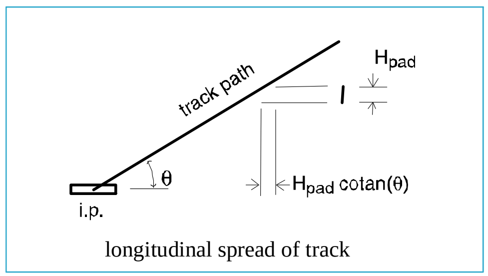
The lcd simulation provides only crossing points;
extensions to the simulation are created within the CLEO library.

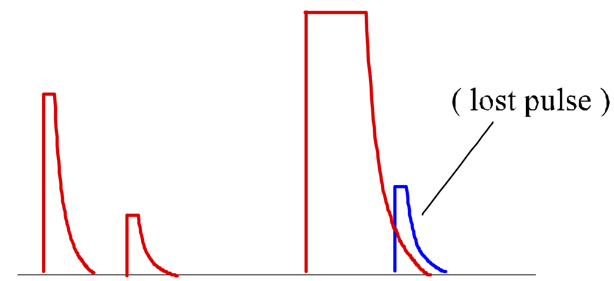


Charge spreading on the pads
Gaussian width, cut-off (~ .002 of min.ion.),
maximum total-number-pads
charge is renormalized to provide a **total of min. ion**.

Wave Form to simulate time (=z) response

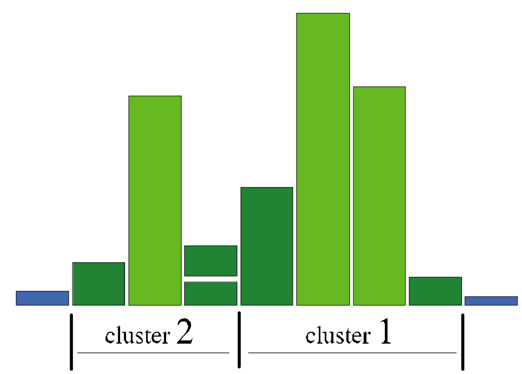






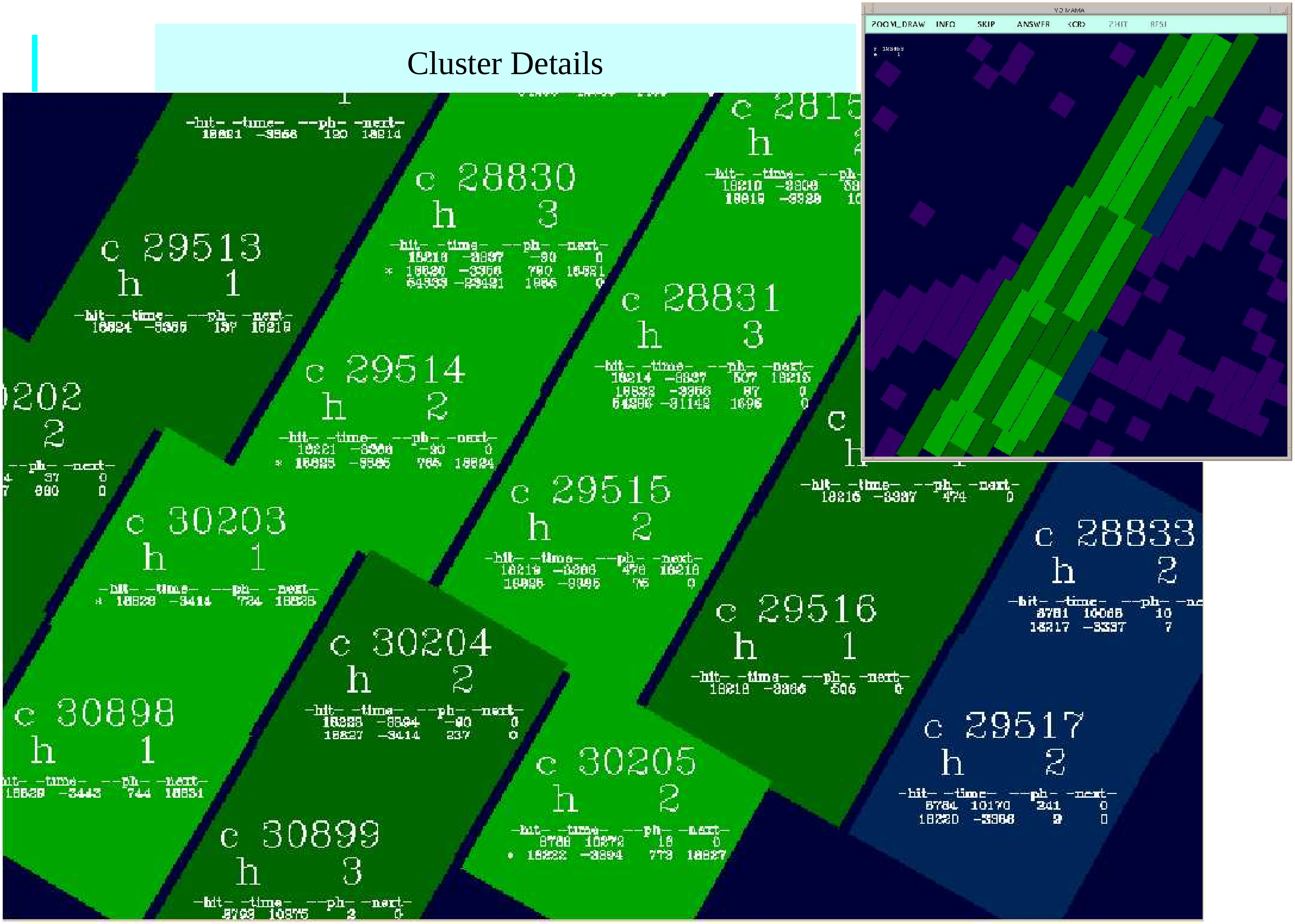
Clustering in r-ϕ
criteria for minimum **central pad** , added **adjacent** pads
splitting at a local minimum,
can lead to pulse height merging and incorrect clustering.

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



CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

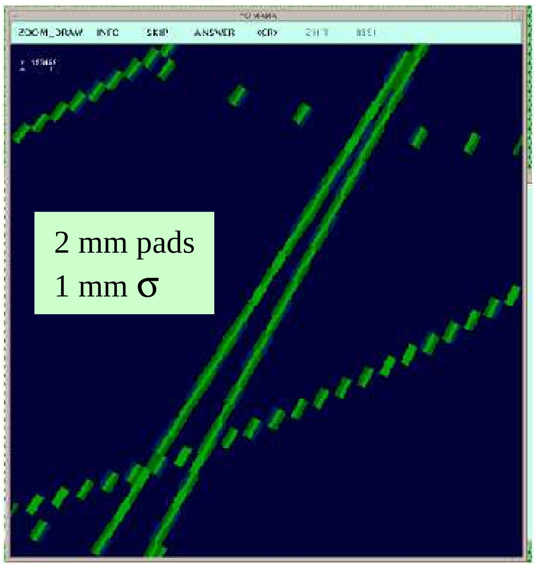
Cluster Details

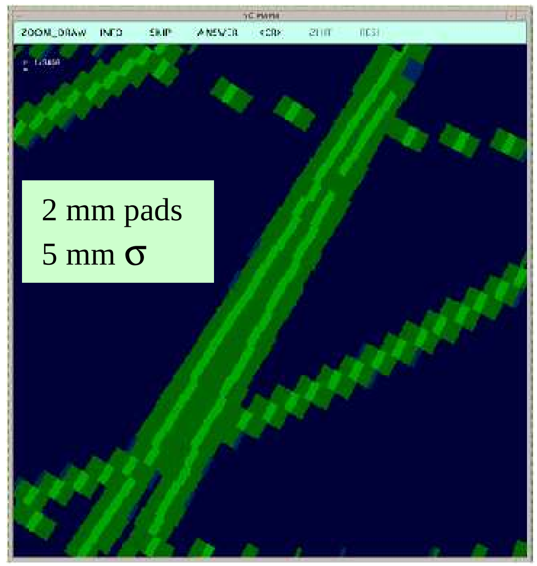


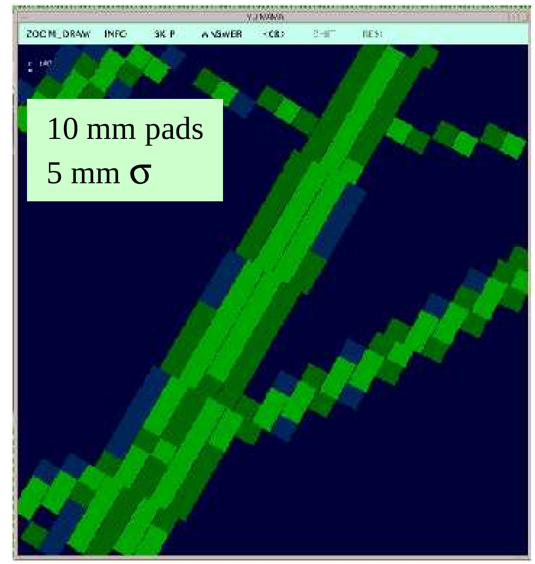
Pad Response:
Examples of Various Pad Width and Charge Spreading Width

The detector pad width and charge spreading create very different conditions for track reconstruction.

(Note: these two tracks are separated by only 1 mm in z.







2 mm pad with **5 mm** spreading would provide **excellent resolution** but it is **not clear** that both these tracks would be **reconstructed**.

10 mm pad with **5 mm** spreading provides **poor resolution** and creates a **challenge for reconstruction**.

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.

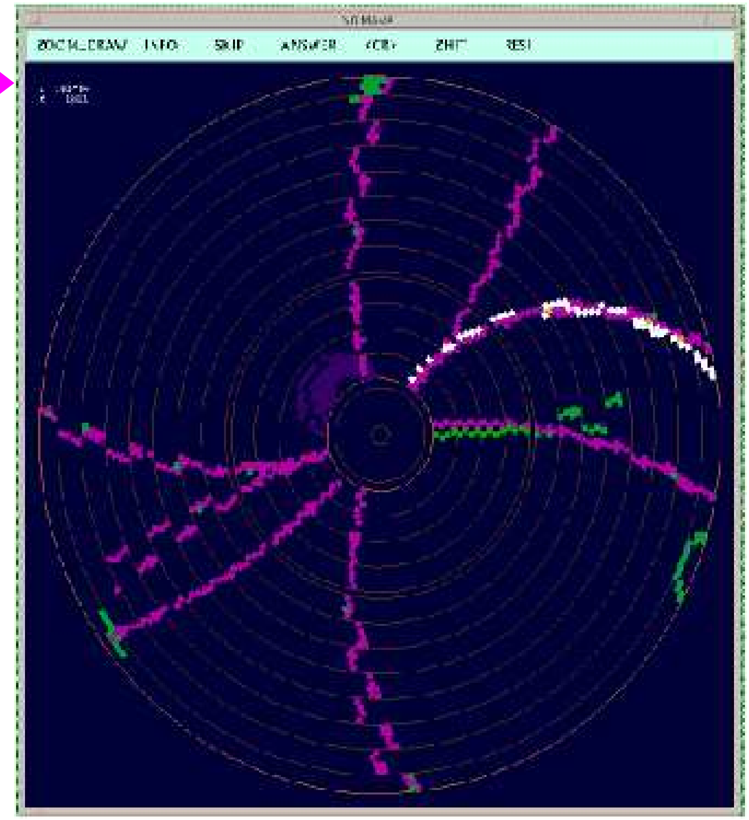
CLEO Track Reconstruction

The current CLEO charge particle track reconstruction

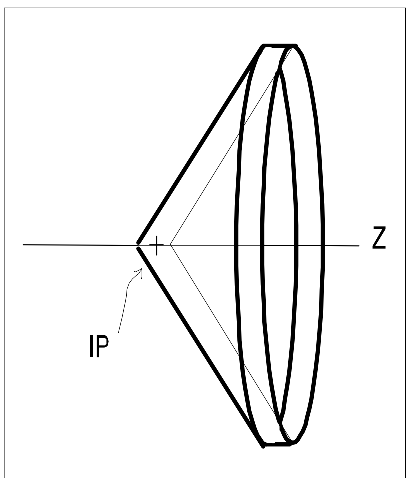
originally written for a drift chamber
(where z information is derived from the track and stereo layers)

can be adapted to any type of device with dense hit information (like a TPC, but not silicon)
(changes, including the treatment of 3-dimensional hit information) are described later

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



a 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

10 mm pads, **7 mm** charge spread

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

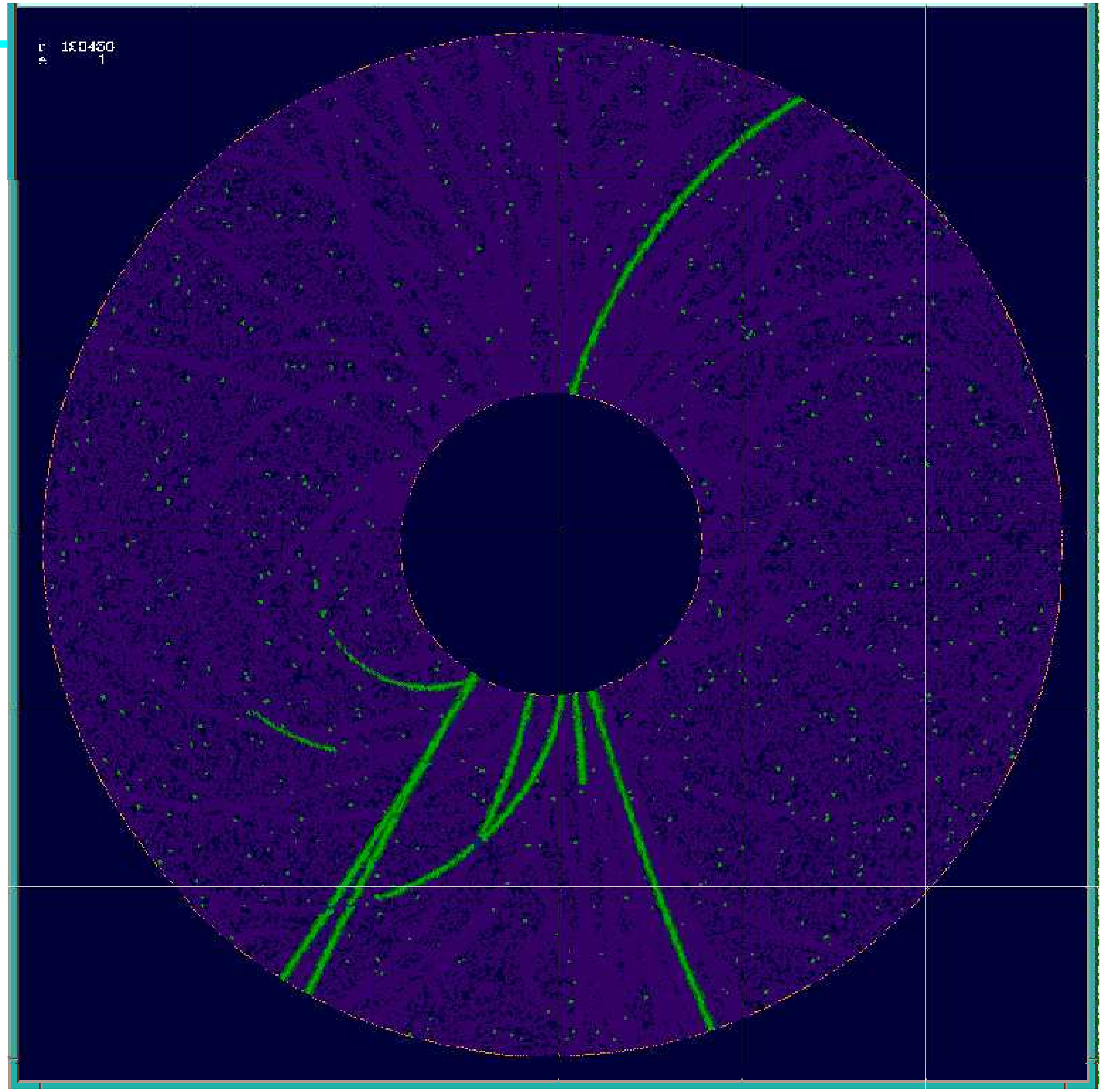
Number of channels (1 side) 112 k
Number of layer crossings 14946
Number of track hits = 51232
(each crossing creating ~ 3.4 hits)

Number of noise hits = 89385

Active cone:
Z=[r * (-6 / 80)] +/- 2.3 cm

Active hits in green

Ignored hits in purple



Segment Finding Stage

Active hits in green

Ignored hits in purple

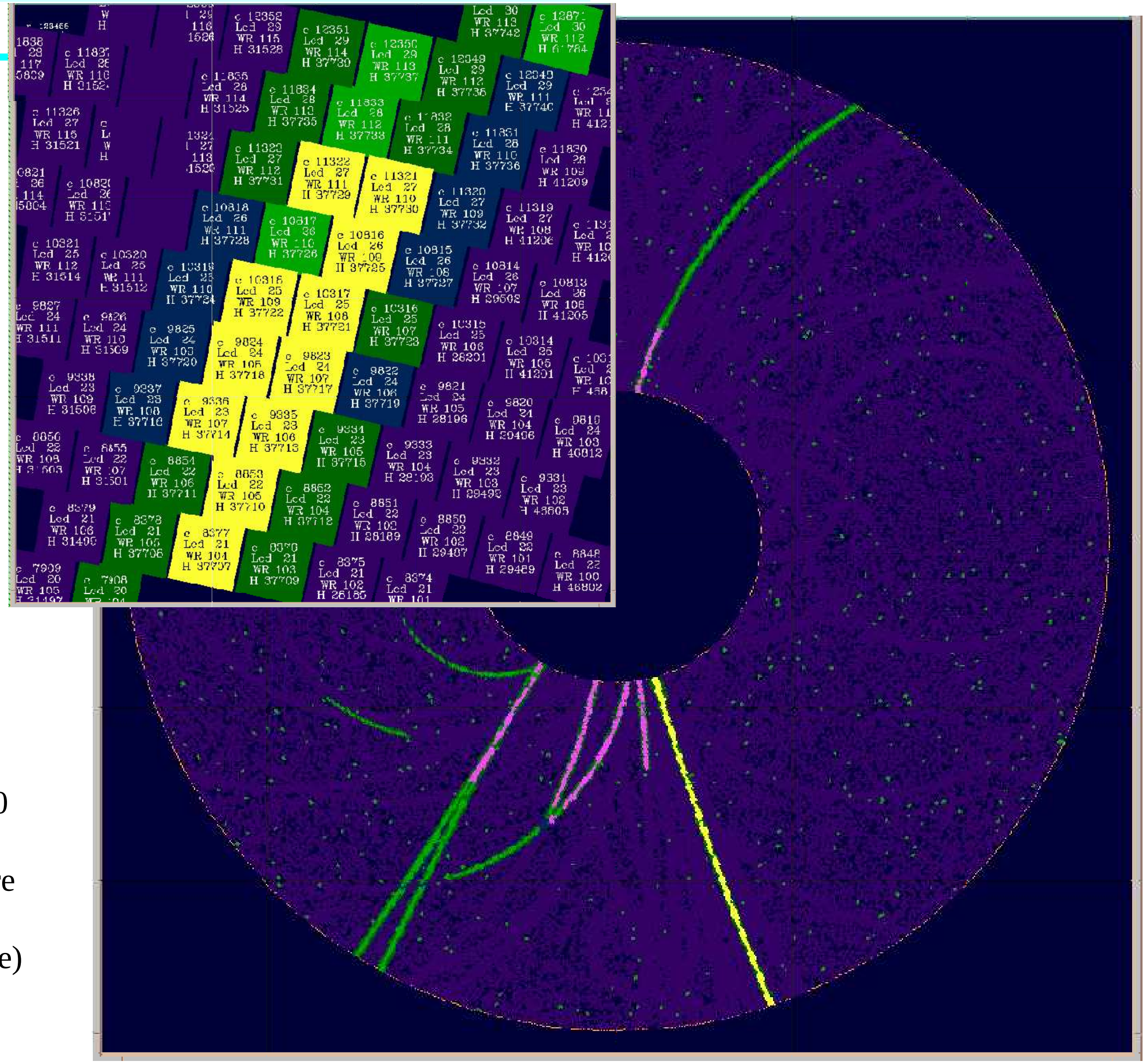
Current isolated segment is shown in yellow

Other isolated segments are shown in pink.

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

Merged tracks (at 7:00) are found as one segment, interrupted when the tracks are ambiguous.

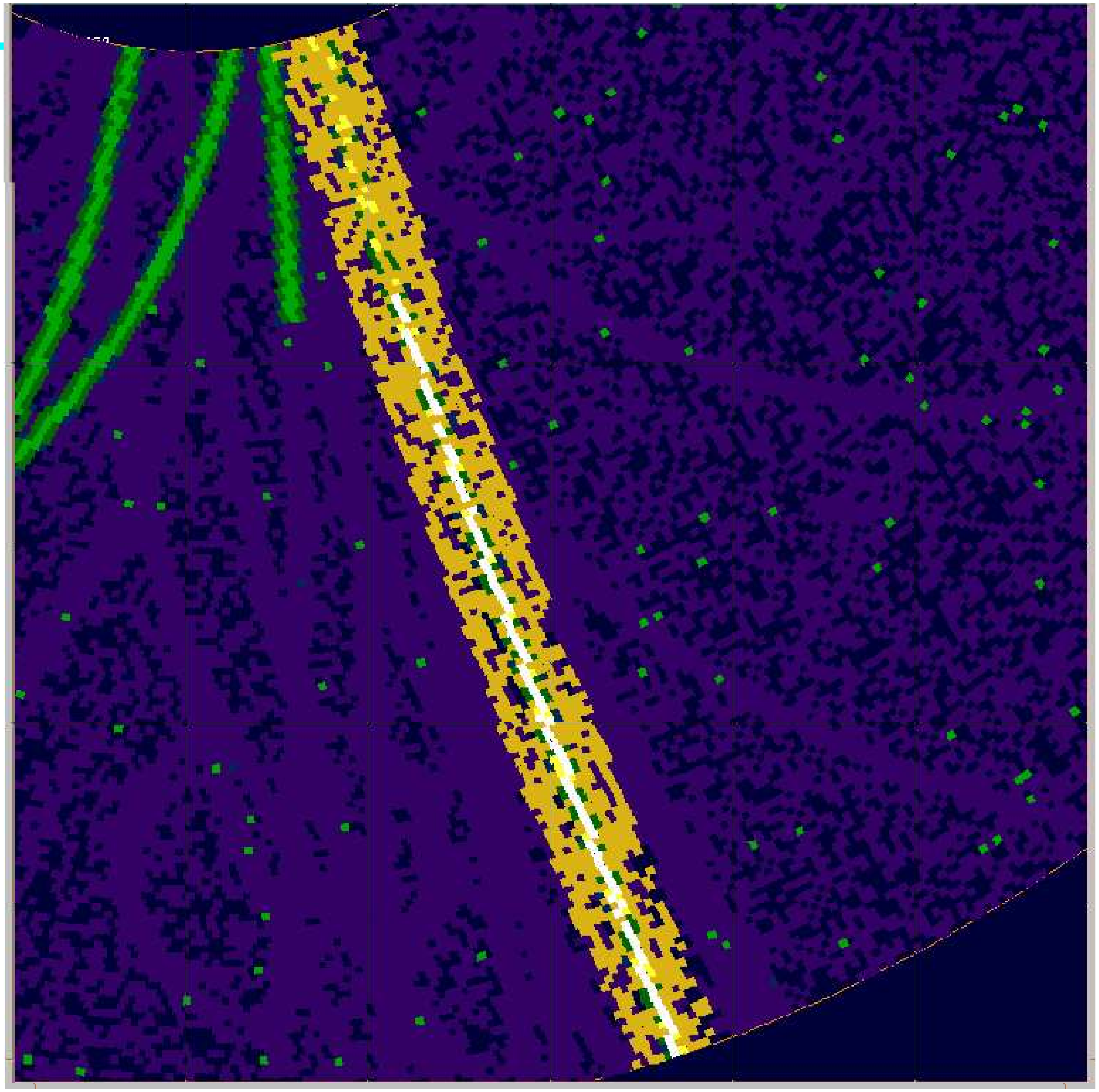
The segment in the track at 1:00 stops prematurely.
From the diagnostics, there are too many double hits.
(segment stage tuning variable)



After 2^{nd} Phase, r-ϕ view

Hits in road in orange.

Hits on track in white .



Although the track
was found to small radius in the
isolated segment stage,

in the 2^{nd} stage,
track is not found at low radius .

r-ϕ impact = 5.6 mm

The χ^2 of the track is actually
too good,
$\chi^2 = 6$.
(hit resolution is 245 μm for
10 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 -

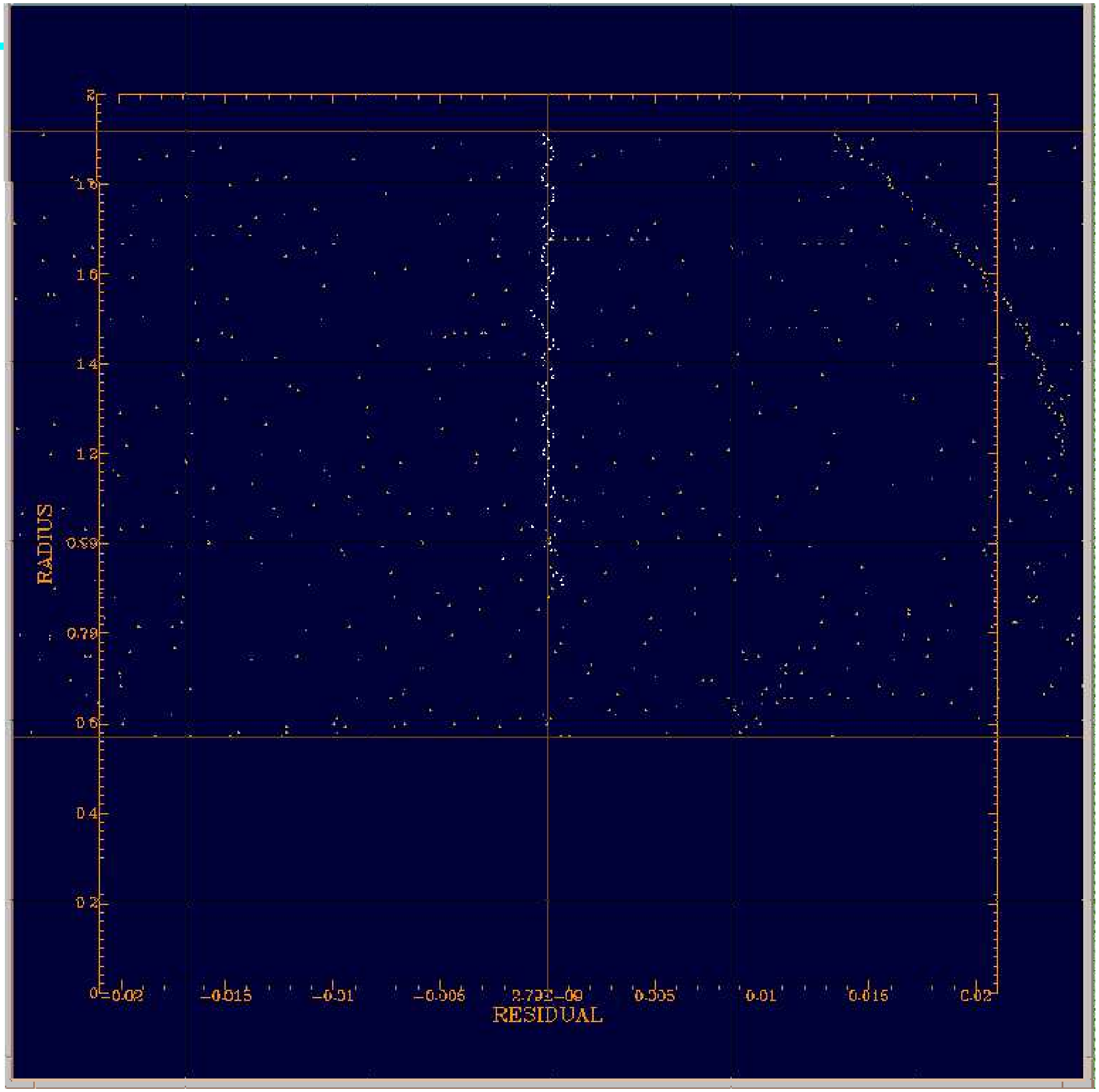
In each radial part,
look for correlated hits satisfying

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

Select best solution in each radial part.

No solutions were found at low radius.

Note:
- other track.



After 2nd Phase, z view

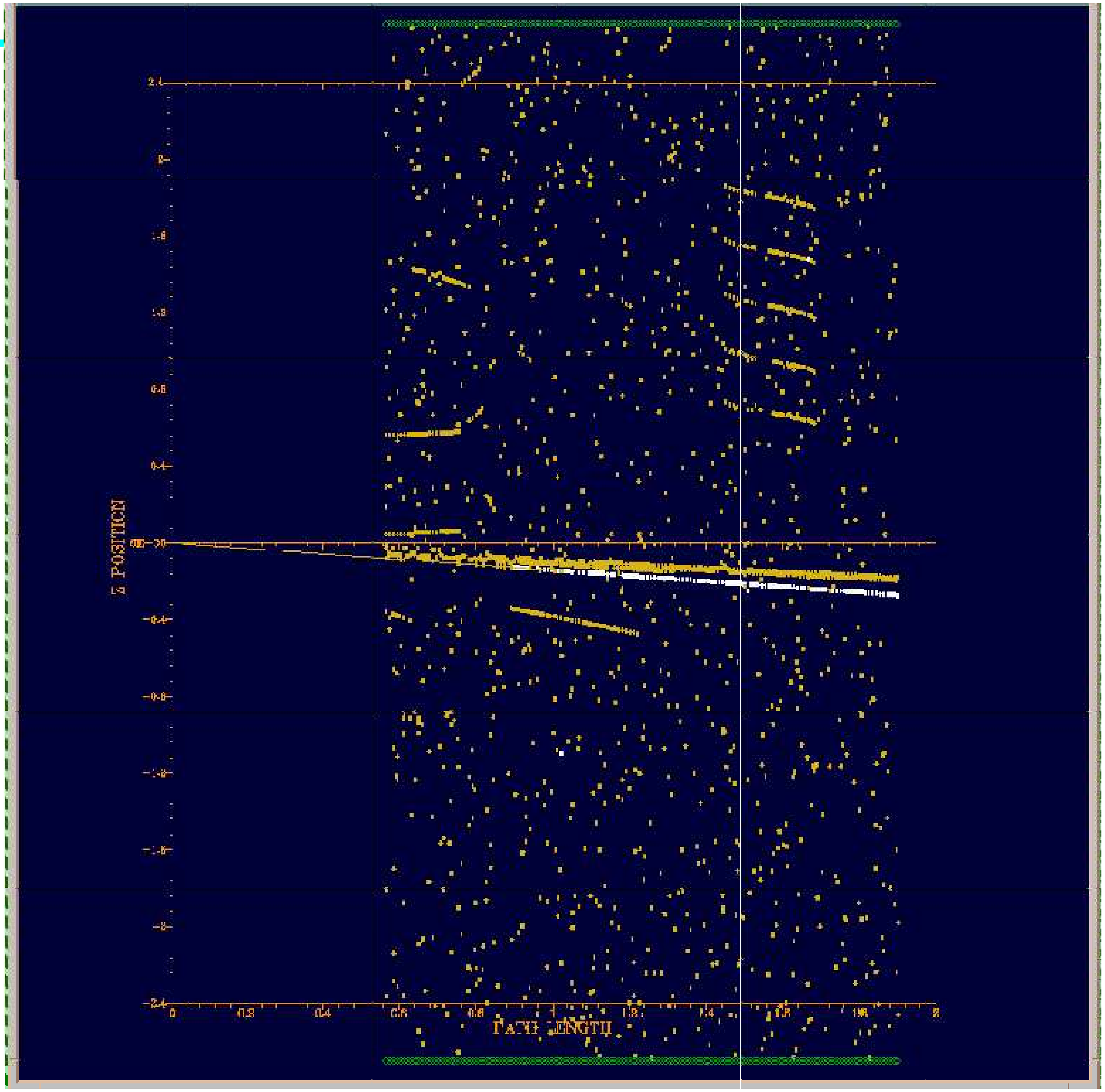
Hits in road in orange.

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 .9 meter in arc length,
the hits are merged
and not usable, for either track,
(at high resolution).



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

After 2nd Phase, r-ϕ view, 5mm pad width

Hits in road in orange.

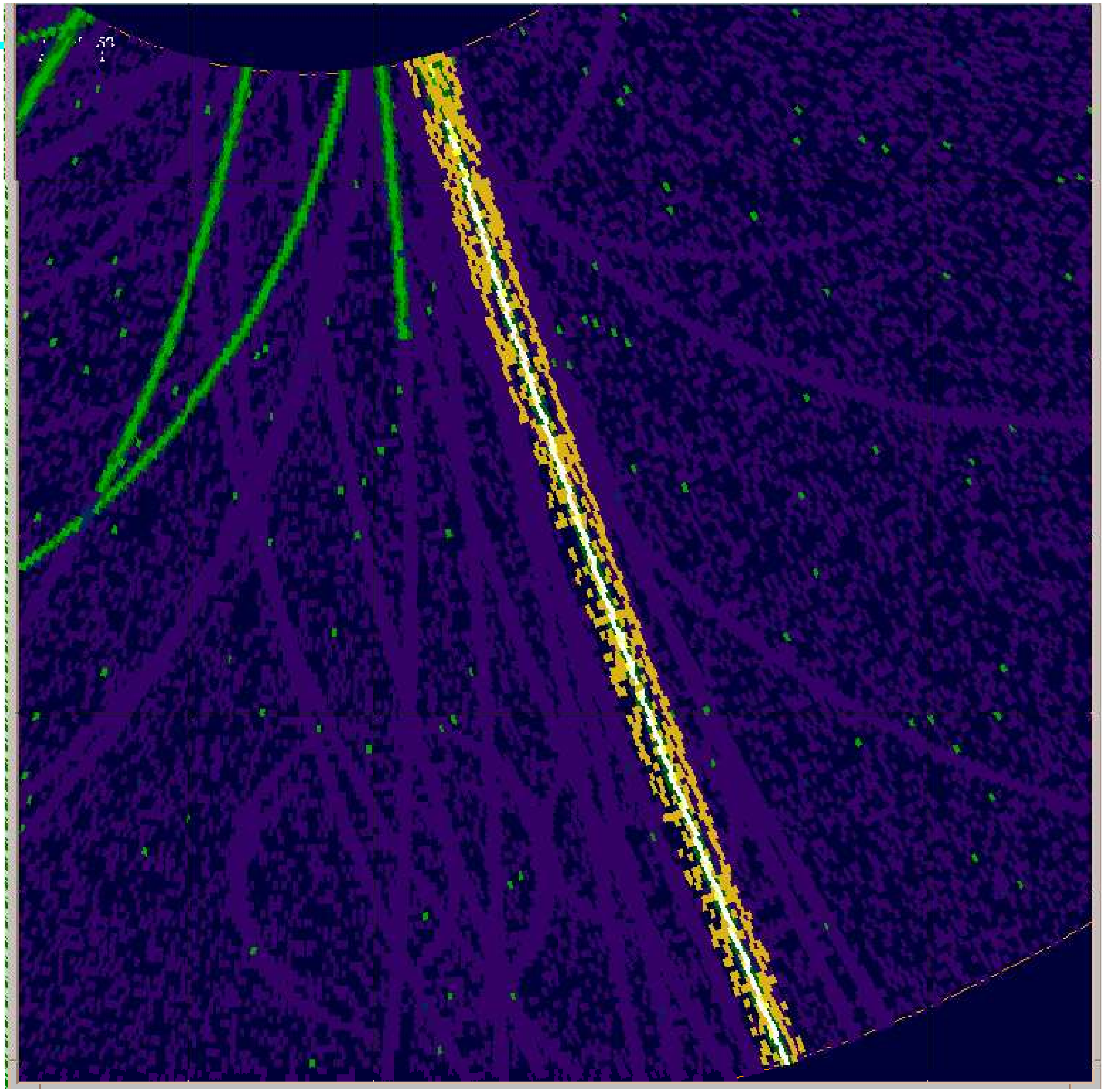
Hits on track in white .

Now repeat the same track with

5mm pads, 3.5 mm charge spread

The track is found extending to lower radius in the 2nd stage.

The χ^2 of the track is still too good,
$\chi^2 = 1.25$
(hit resolution is 111 μm for
5 mm pads.)



After 2nd Phase, residual (r-ϕ) view, 5mm pad width

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

5mm pads, 3.5 mm charge spread

2nd phase pattern recognition

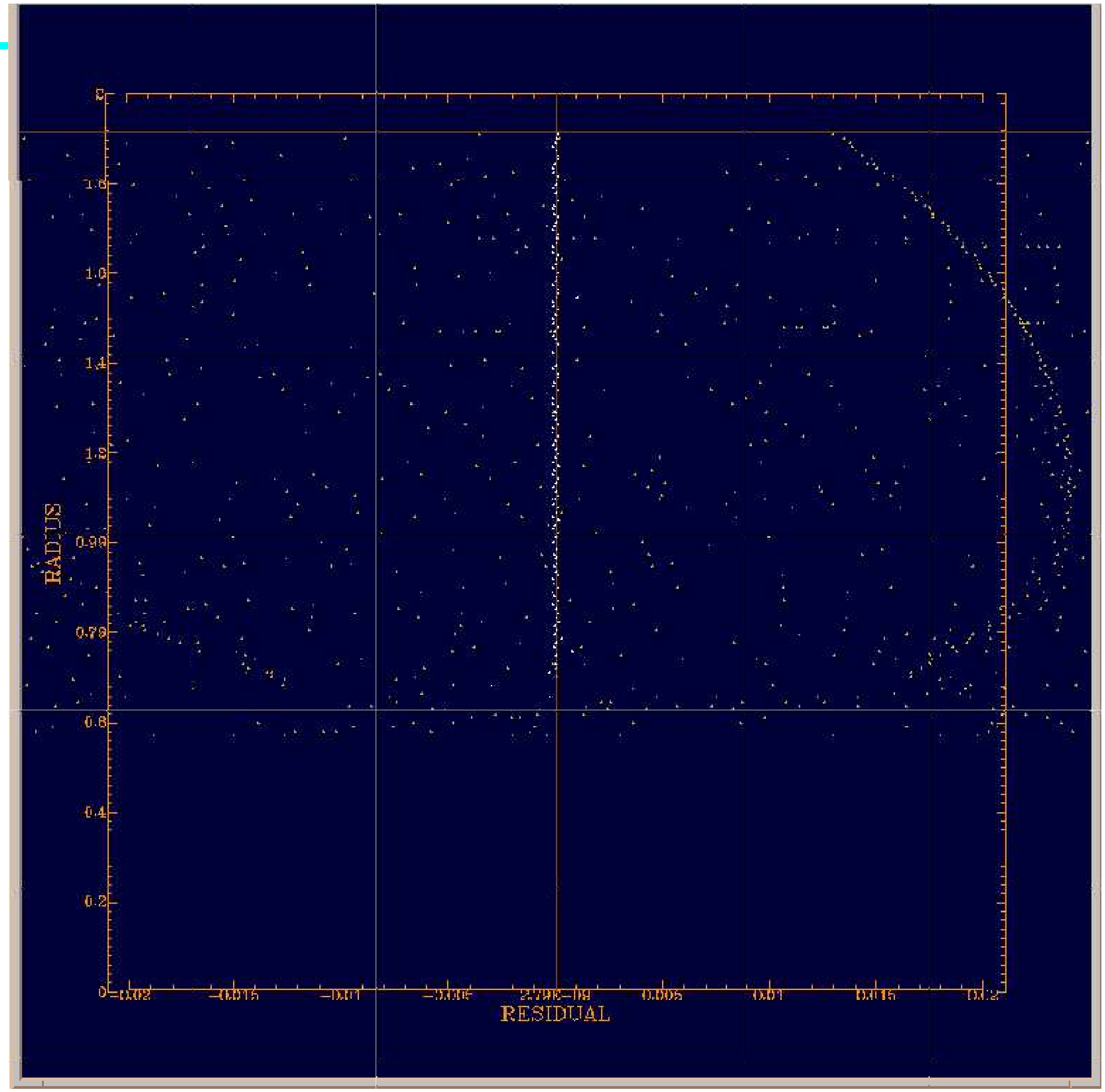
The track extends to lower radius.

(r-ϕ impact = 80 μm)

The other track is more distinct
and also extends inward to the
radius where the two track merge.

Demonstrated sensitivity of reconstruction efficiency to TPC readout characteristics.

For this track only,
10 mm pads is too large,
5 mm pads is sufficient.



Preliminary "results"

Efficiency is calculated relative to
the MC crossing points
rather than
the MC track list.

Define a "plausible track",

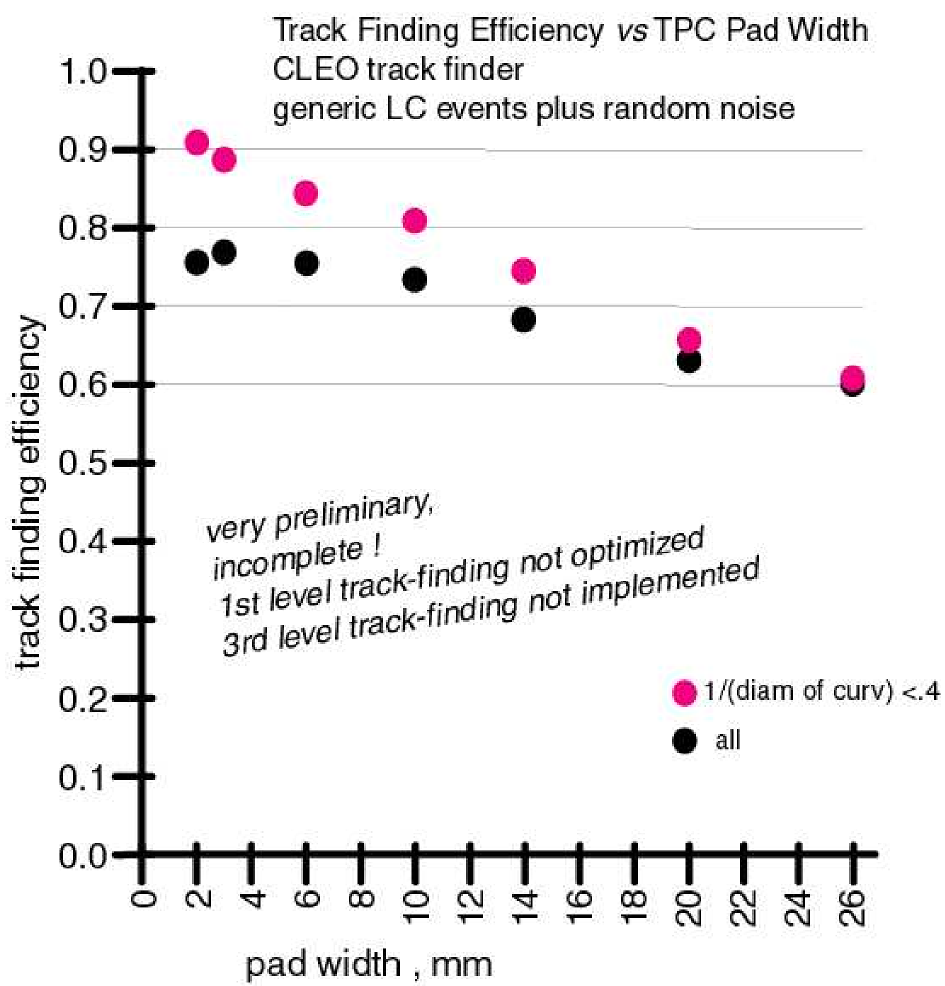
set of of hits pointing to same MC track,

includes crossings in layer 1
through layer 30,

is truncated at top of curler.

Fit the crossing to define the
generated track parameters in the chamber.

Match $\chi^2 = (\Delta C/.002)^2+(\Delta\phi/.003)^2+(\Delta T/.002)^2$
require $\chi < 25$



Outlook

"Complete" at the Arlingtion 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
- initial tune of roads for pattern recognition in TPC data

"Complete" at the Berkeley LC TPC meeting:

- develop a method for identifying tracks that should be found

Needed for efficiency studies:

- optimize the 1st level pattern recognition for TPC readout
- would like to have events with a specific 2 body process, e.g. Z à μμ.
- for resolution: apply **low level noise** to all pulse heights, fraction of min.ion.

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