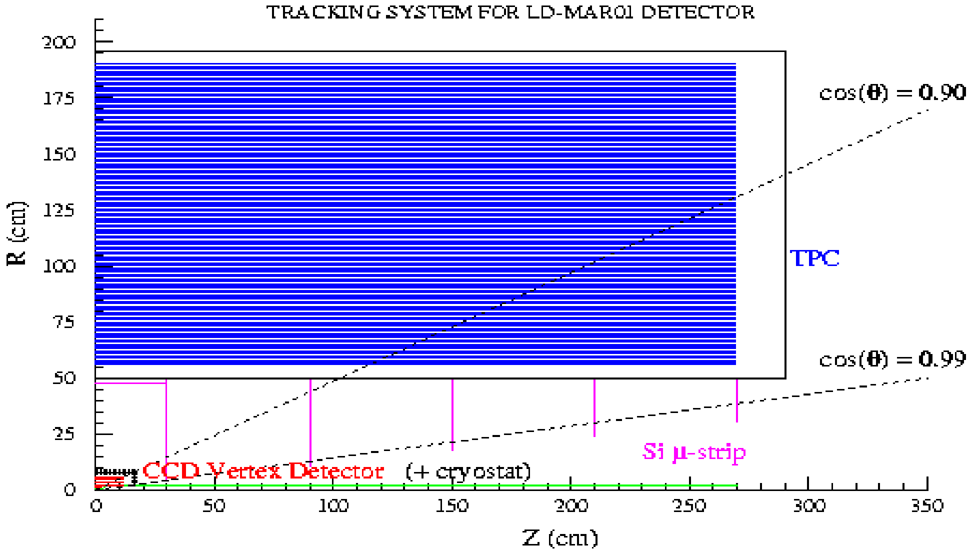
TPC Detector Response Simulation
and
Track Reconstruction

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 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 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 measure,
one could achieve the maximum efficiency with the maximum possible segmentation.

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

[1cm x 1 mm pads] → 2.4×10^6 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 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.

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

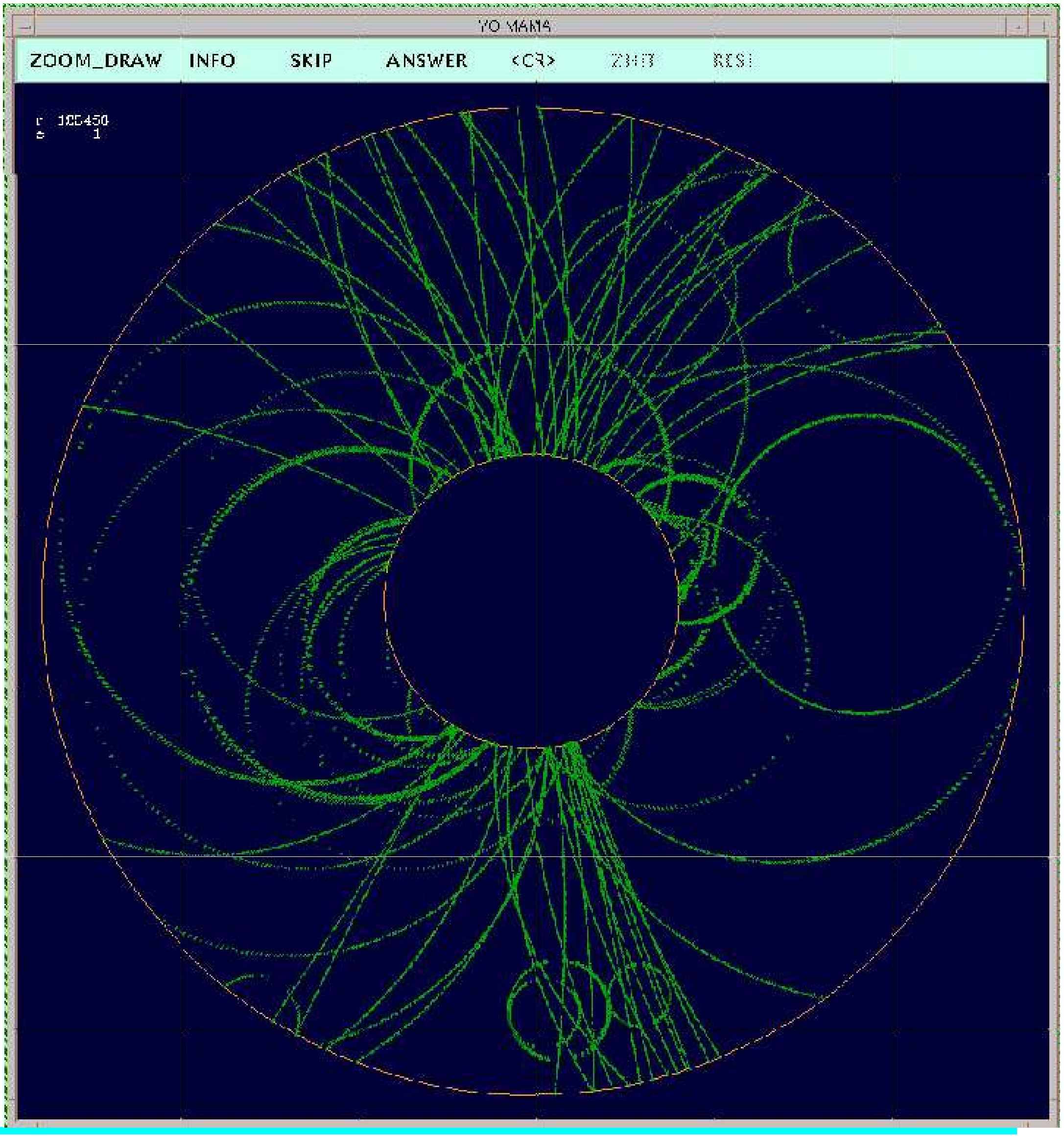
2 mm wide pads
(number of pads in layer is multiple of 8)

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.

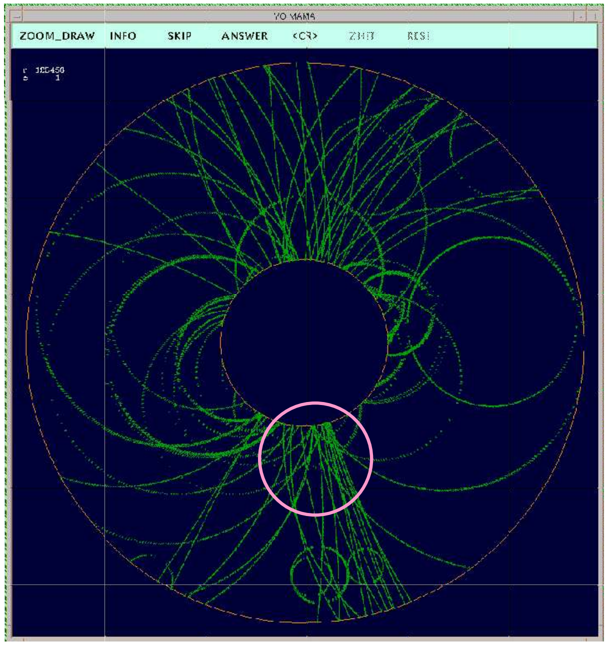
Reconstruction looks almost possible
even
without using z information of the hits.

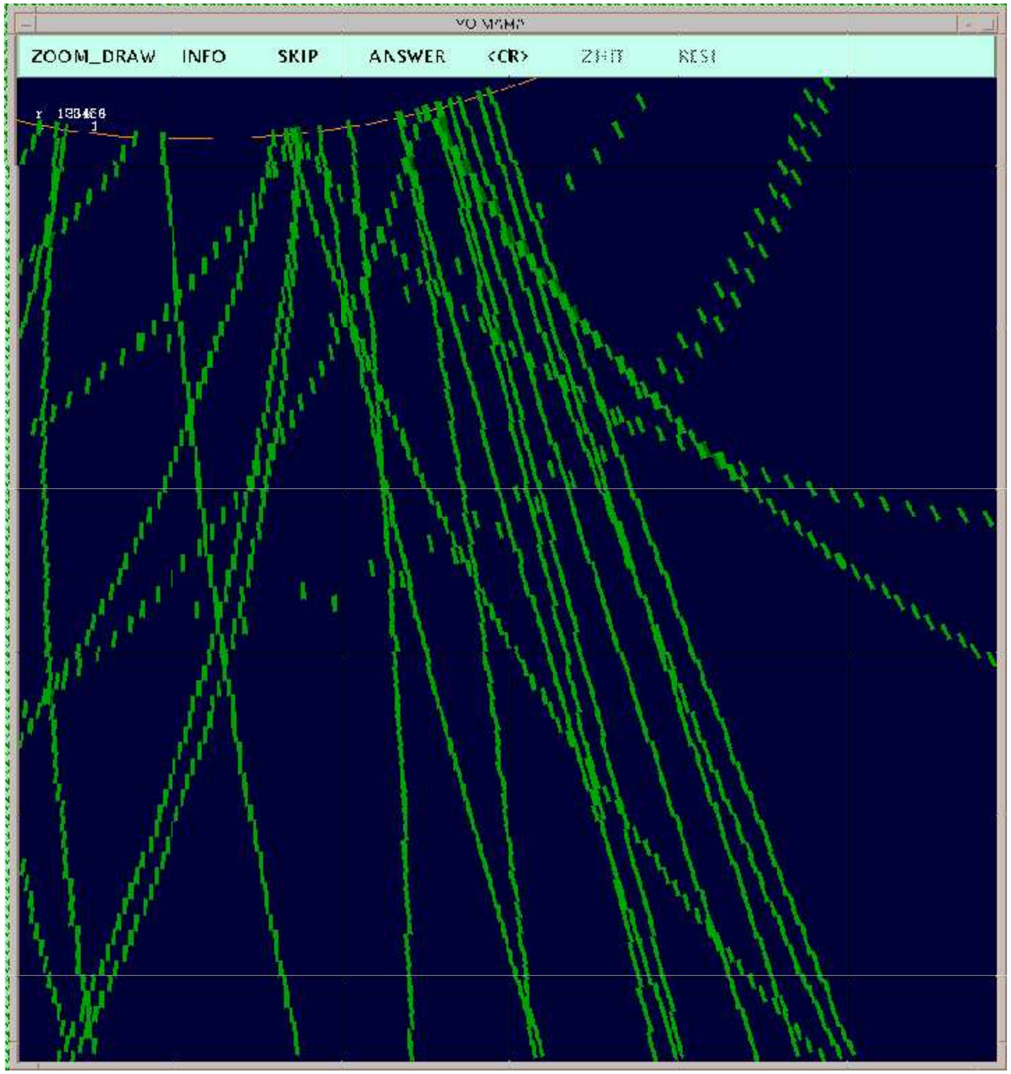
Possibly, when using the z information,
a larger pad size can provide
full reconstruction efficiency.



Sample Event, Tracks within a Jet

(Same event, same pad response)



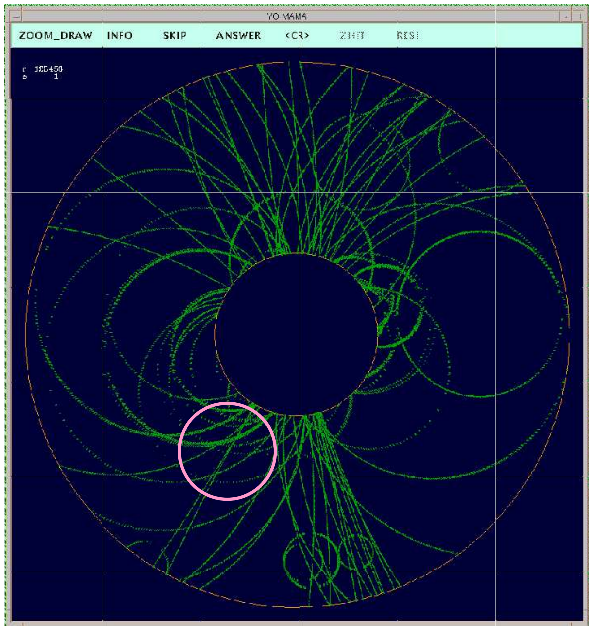


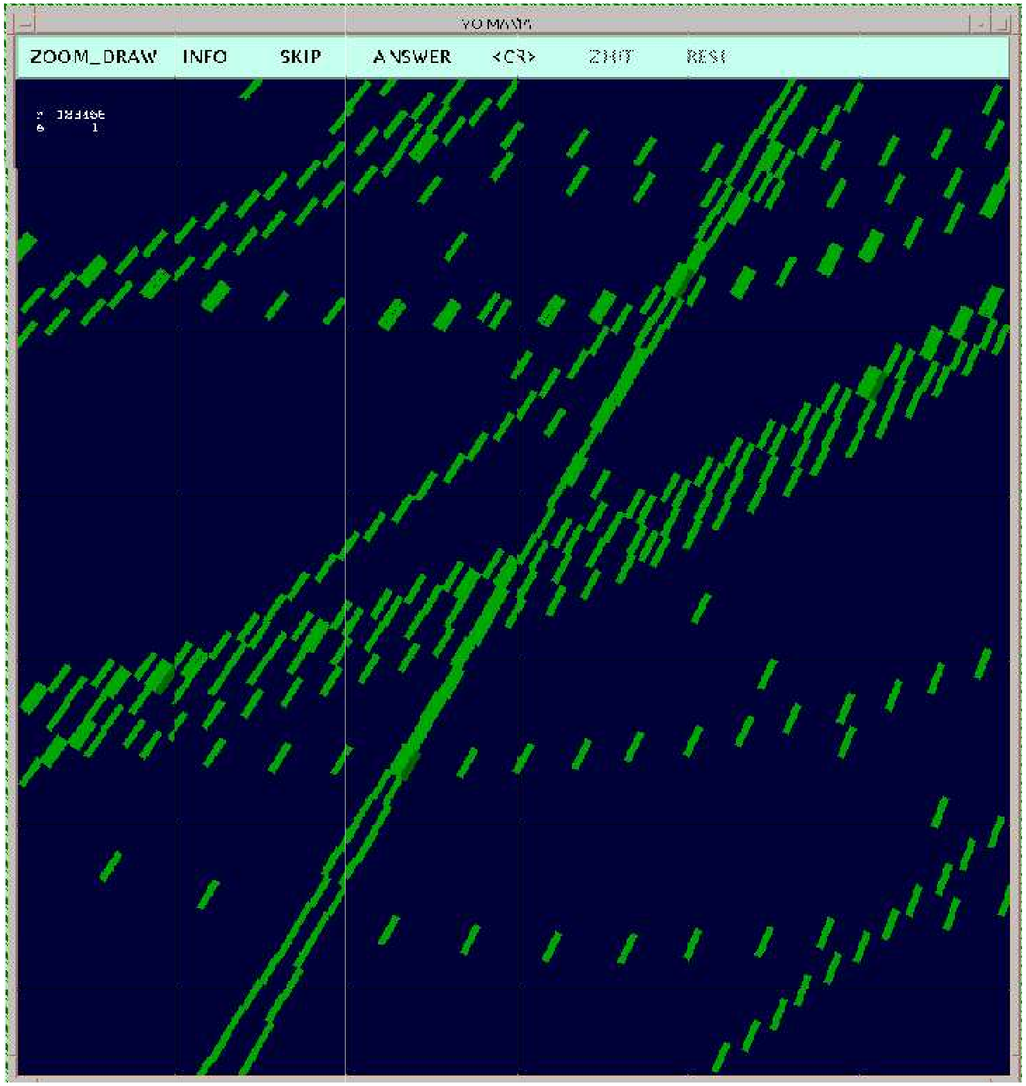
Tracks in a jet are usually separated.

Again, 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 be useful for track separation.

extreme example: for these two tracks
cross in r-f, and
z-separation is only 1mm.

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)

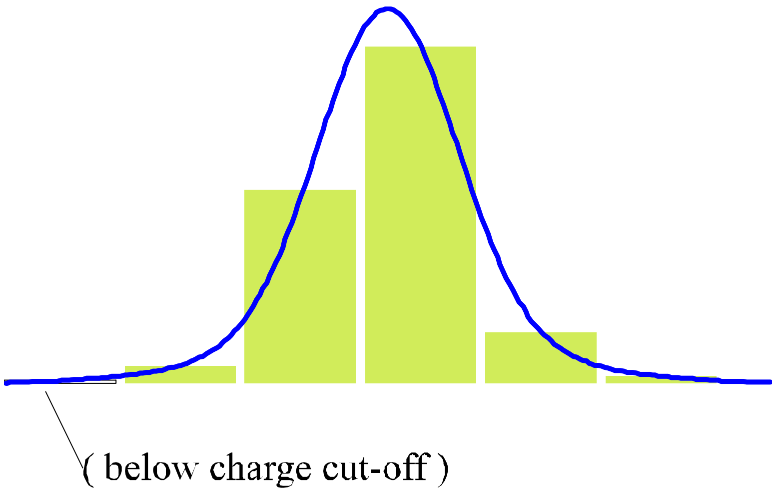
Charge spreading, relative to the lcd crossing point, is defined by parameters in the simulation.

Gaussian width of the charge distribution
pads share the charge sum (miniumum ionizing) in the layer
according to the distance of the pad center
from the crossing point of the track with the layer.
(future: integrate the distribution function across the pad.)

No charge is deposited below a **cut-off** (~ .002 of min.ion.)

There is also a total-number-of-pads maximum.

The charge is renormalized to provide a **total of min. ion**.


(below charge cut-off)

Clusters are formed after determining the time overlap of the pulses.

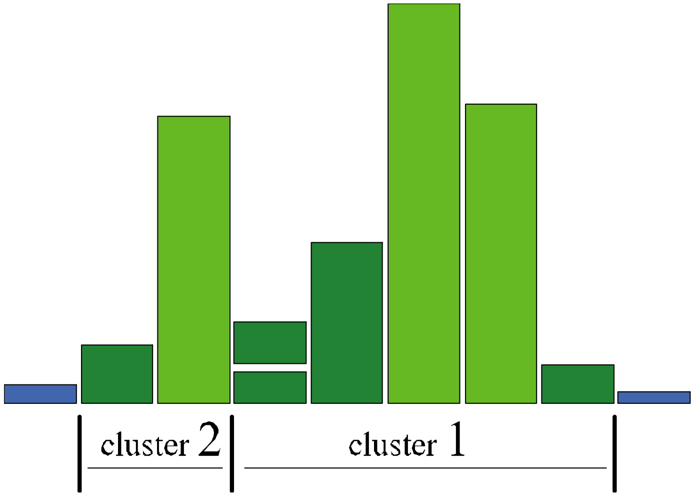
Require **Central pad** with pulse height above (~0.20 min. ion.)

Adjacent pads are added to the cluster, require
pulse height > (~0.01 min. ion.) and Δt < (1 μs (or 5 cm))

Clusters are **split** at a local minimum, require
pulse height (min) < 0.49 of the lesser maxima,

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)



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

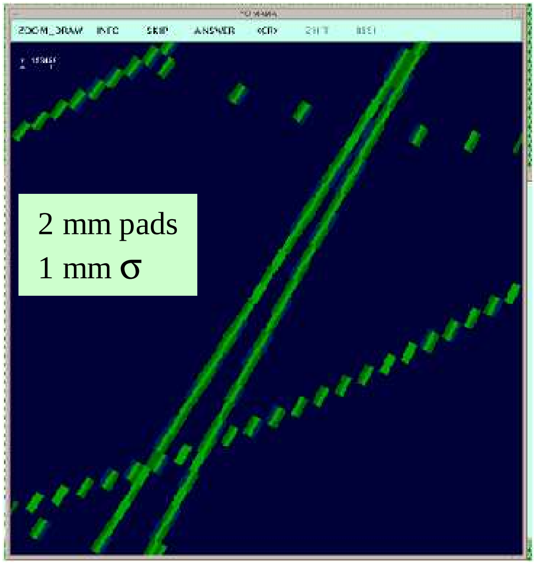
4 figures illustrate the
track separation for various
combinations of the, separately tunable,
pad size and charge spreading.

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

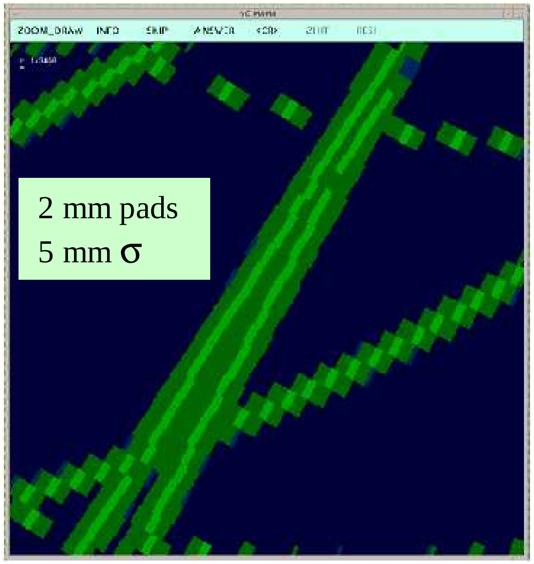
The **2 mm pad with 5 mm** spreading
would provide **excellent resolution**
but
it is **not clear** that both these tracks
would be **reconstructed**.

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

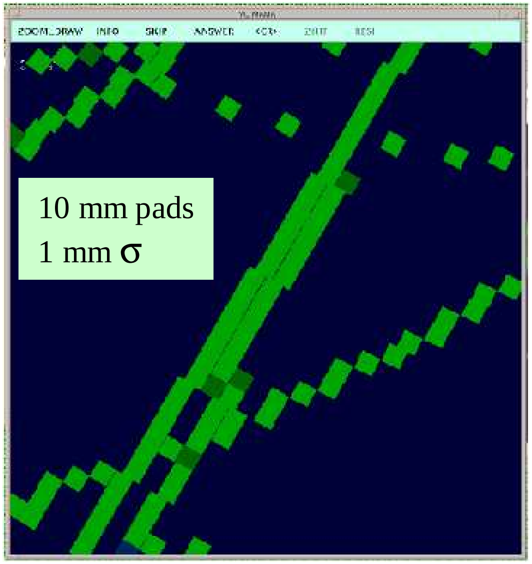
However, this is the configuration
being used for most of the
reconstruction algorithm development.



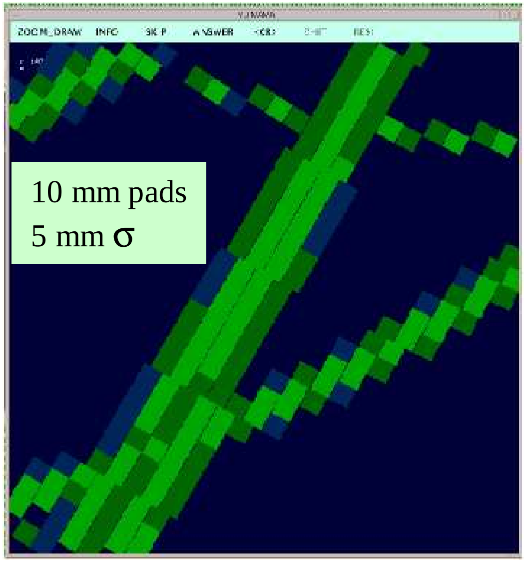
2 mm pads
1 mm σ



2 mm pads
5 mm σ

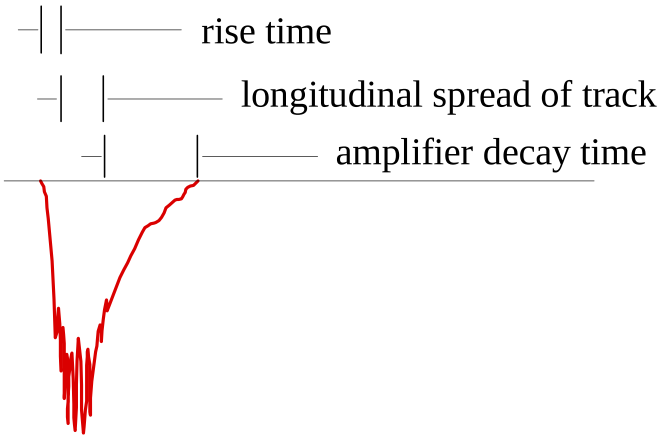


10 mm pads
1 mm σ



10 mm pads
5 mm σ

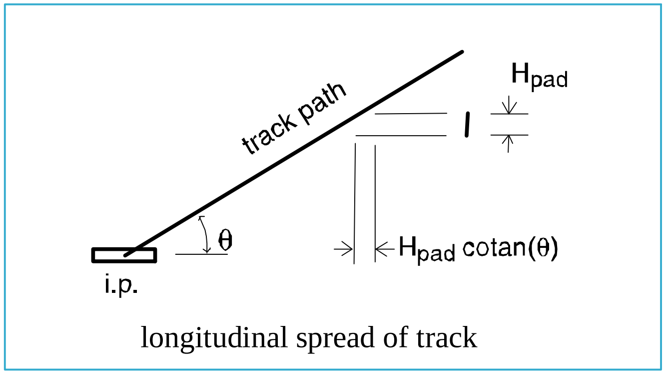
Detector Response: Signal Time Overlap



rise time

longitudinal spread of track

amplifier decay time

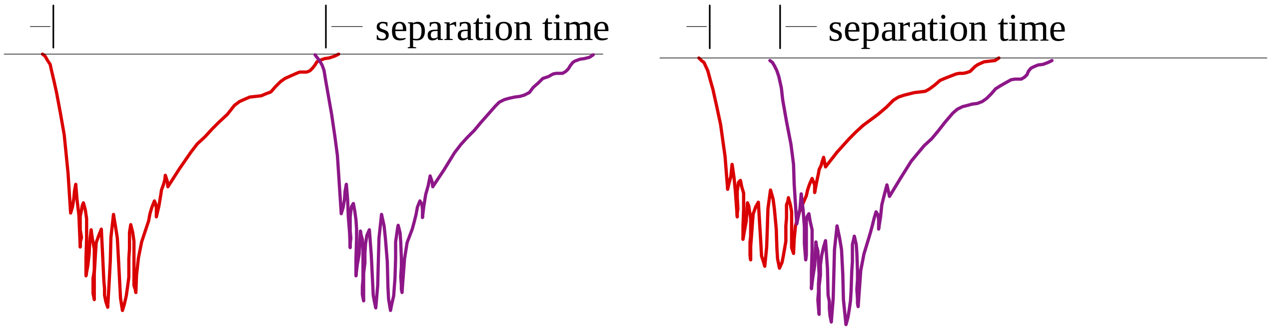


longitudinal spread of track

The TPC signal shape is affected by a **rise time**, and a **decay time** (about 0.4 µs (2 cm at 50 mm/µs.)).
The pulse length has a contribution from the **longitudinal spread of charge** that is collected on a pad.
(1cm width, at cosθ=0.71 , for pads with 1 cm radial spacing) .

Multiple signals on TPC pad will merge if separation is less than ~ 1cm (θ dependent).

Merged signals will result in **lost, or distorted, hits** on tracks.

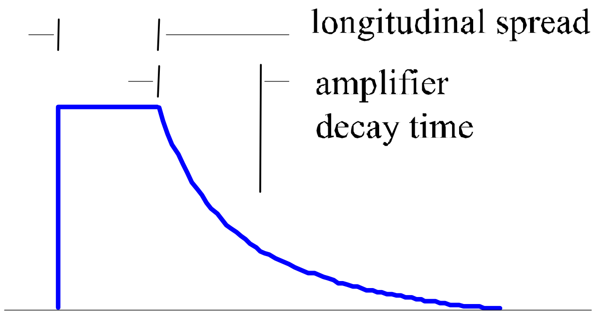


separation time

separation time

Detector Response **Simulation**:
Time Signal Overlap

The basic pad pulse height is determined from the charge sharing of the the available minimum ionization



pulse shape

rise time = 0.

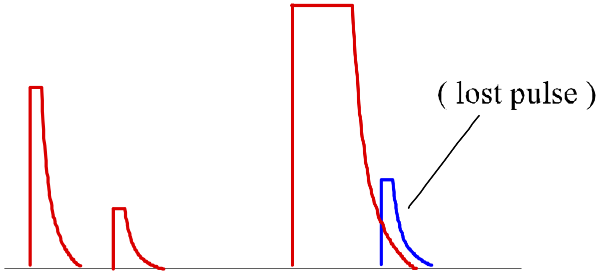
The pulse height is constant at the the basic pad pulse height for a duration corresponding to the longitudinal spread.

(wrong, but treatment as a threshold device delays implementing a wave form analysis.)

(1 cm charge spread, 50 mm/µs ; ~ 200 ns)

The pulse height decays with a characteristic time. (400 ns).

Noise Pulses: duration = 2 cm, and pulse height between 0 and 2 min.ion.



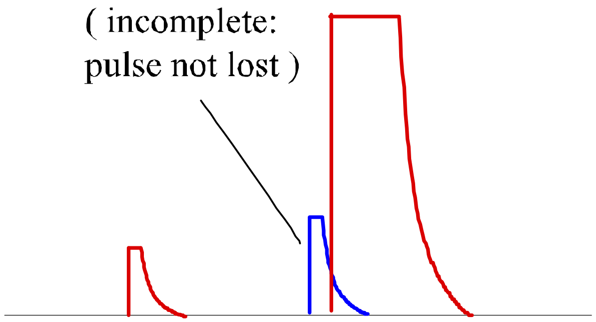
Merging of time overlapped hits on the same pad

Individual signals may be deleted, based on time separation.

Multiple signals are collected on each of the pads.

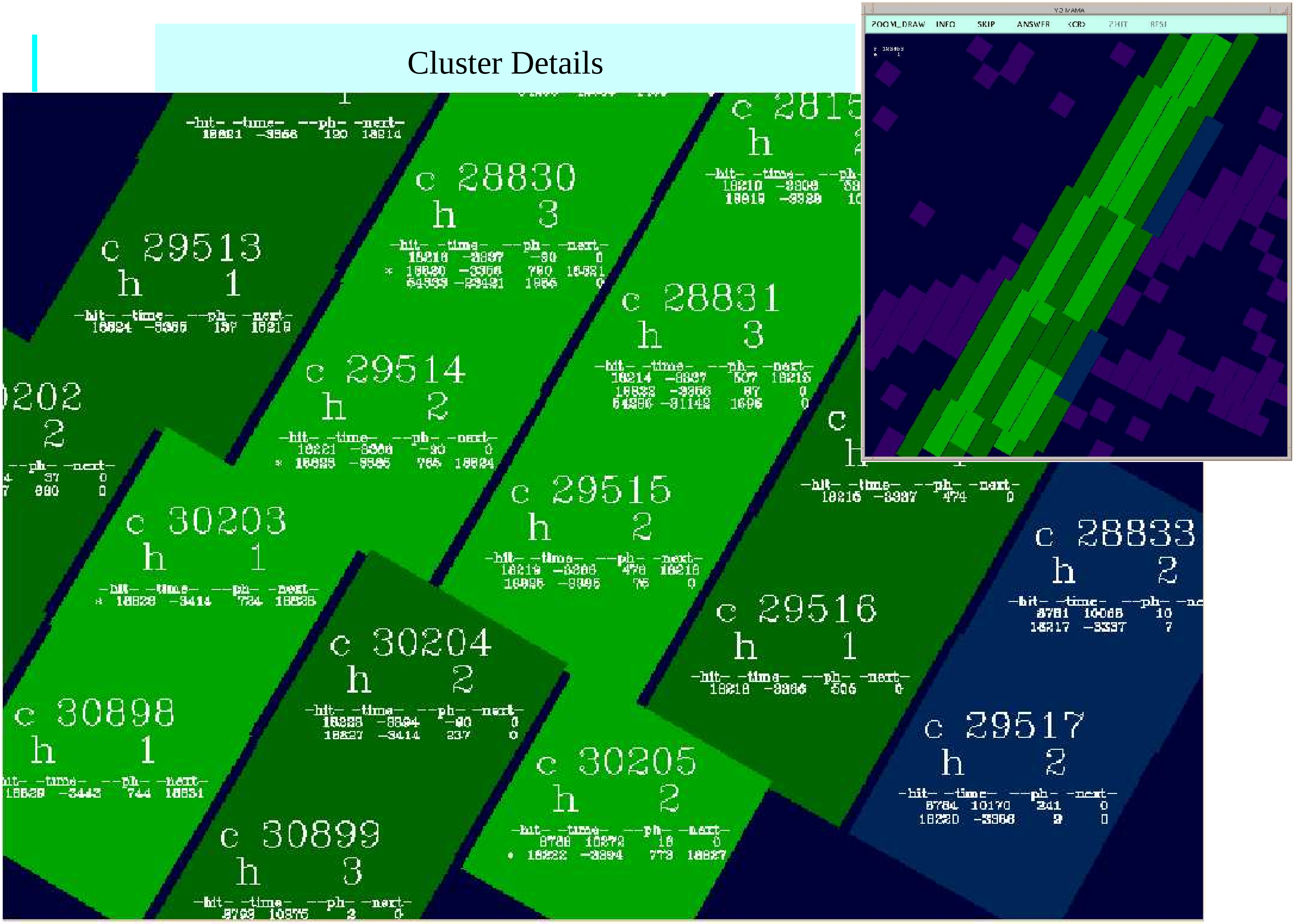
Signals are accepted if the pulse height sum from all earlier signals (the instantaneous pedestal) is less than 0.30 of the candidate signal

(Dirty laundry: This treatment is not yet complete; preceding small signals are not swallowed by larger signals.)



Recorded pulse height of a pad, as used in the r-ϕ clustering, is the basic pulse height, increased by the pedestal.

Cluster Details



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 that what is being measured is

inherent reconstruction efficiency, limited by the track overlap and hit distortion,

and NOT an efficiency that is limited by the algorithm.

Require a means of independently determining 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)

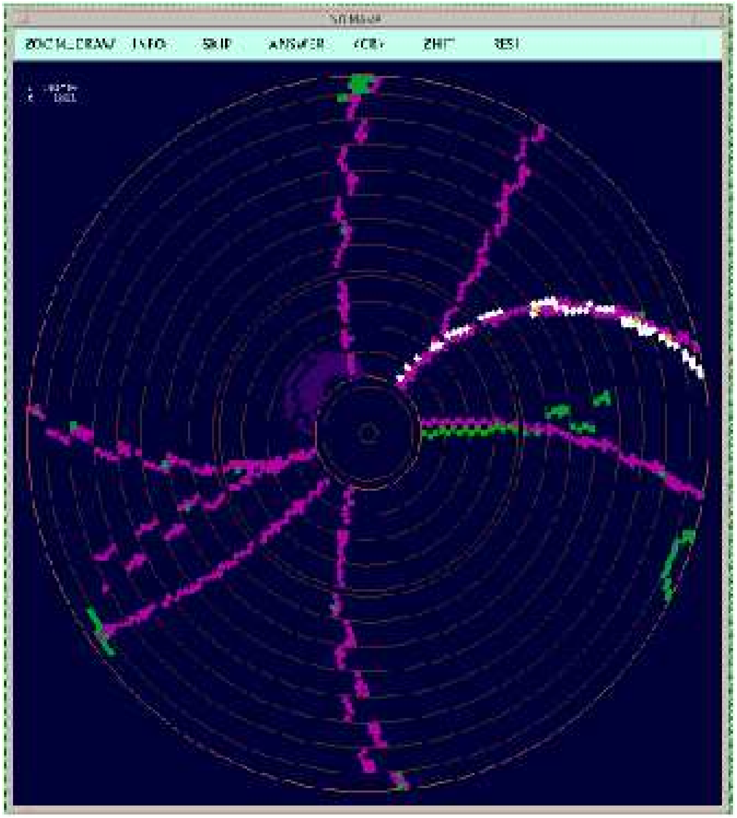
can be adapted to any type of device with dense hit information (like a TPC, but not silicon)
(changes, including the treatment of 3-dimensional hit information) are described later

has been in constant development for 12 years

1999 adapted for an all-stereo drift chamber
(rather than a mostly axial chamber)
March 2002 upgrade treatment of decays-in-flight
Oct 2002 upgrade for long range secondary vertices

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)



CLEO Pattern Recognition,
First Stage for Track Reconstruction

Contrast with the 3-hit-seeded method

3-hit-seeded method:

3 hits are selected, maybe { inner, outer, middle } layers
The 3 hits define a circle in the r-ϕ view, and over-define the z projection.
The seed helix can be qualified by the fit in the z projection.
Hits that match the seed helix are selected inside a road.
A road width is required at this stage with the width determined
by the inherent detector resolution, non-gaussian smearing, track density;
a wide road allows mis-reconstructions, a narrow road limits efficiency.

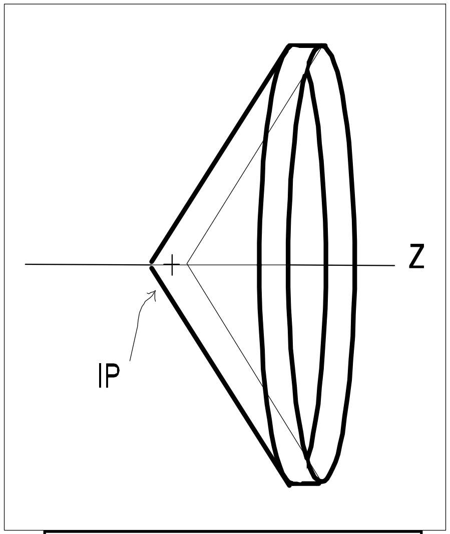
CLEO-segment-finding method:

Tracks are seeded by isolated segments; chains of hits isolated from other segments.

All segments are identified and qualified by length and isolation.
(In the 3-hit-seeded method, seeds are limited those defined in the selected layers.)

in an environment of high track density
use the 3-dimensional information of the hits and
use the characteristic that tracks point to the I.P. in interesting event.

While the 3-hit-seeded method method may be less constrained in z ,
the CLEO-segment-finding method is less constrained by self-selecting the cleanest hit segments.



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

Modifications
to the CLEO Track Reconstruction

The most obvious difference is that the hit information is different;
a program written for a drift chamber is being adapted for a TPC.

Drift chamber hits provide r-ϕ information;
z is derived from stereo layers using the residuals w.r.t. a track hypothesis.

TPC hits provide r-ϕ-z information directly.

The required changes are hidden in the routines that calculate the r-ϕ-z *information for each hit. Once detector-type specific procedures are created, the change is transparent.*

The second difference is that TPC hits must be clustered to create an r-ϕ-z point.

Again, the required changes are hidden in the routines that calculate the r-ϕ-z *information for each hit.*

Most significant modification is to the multi-hit electronics used in a TPC.
(Previous CLEO drift chambers are "small cell" chambers and are, therefore, single hit devices.)

Not an issue in a study using 3-dimensional space points where the concept of a readout channel does not exist
Pattern recognition using an existing track segment to predict other hits requires a mapping from channel to hits.

A mapping between hits on the same electronics channel has been implemented along with the mapping between the hits belonging to a cluster.

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

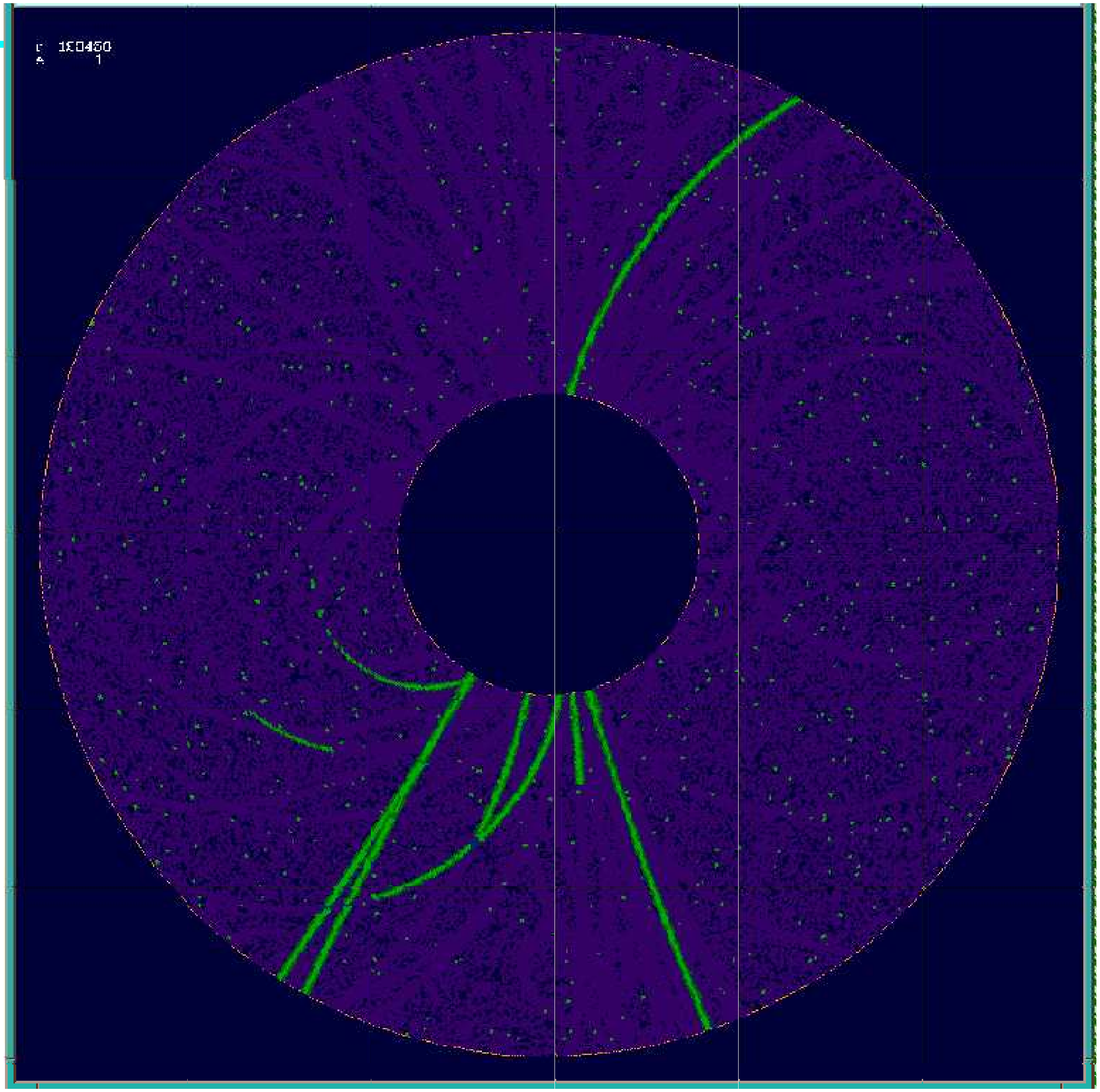
(each crossing creating ~ 3.4 hits)

Number of noise hits = 89385

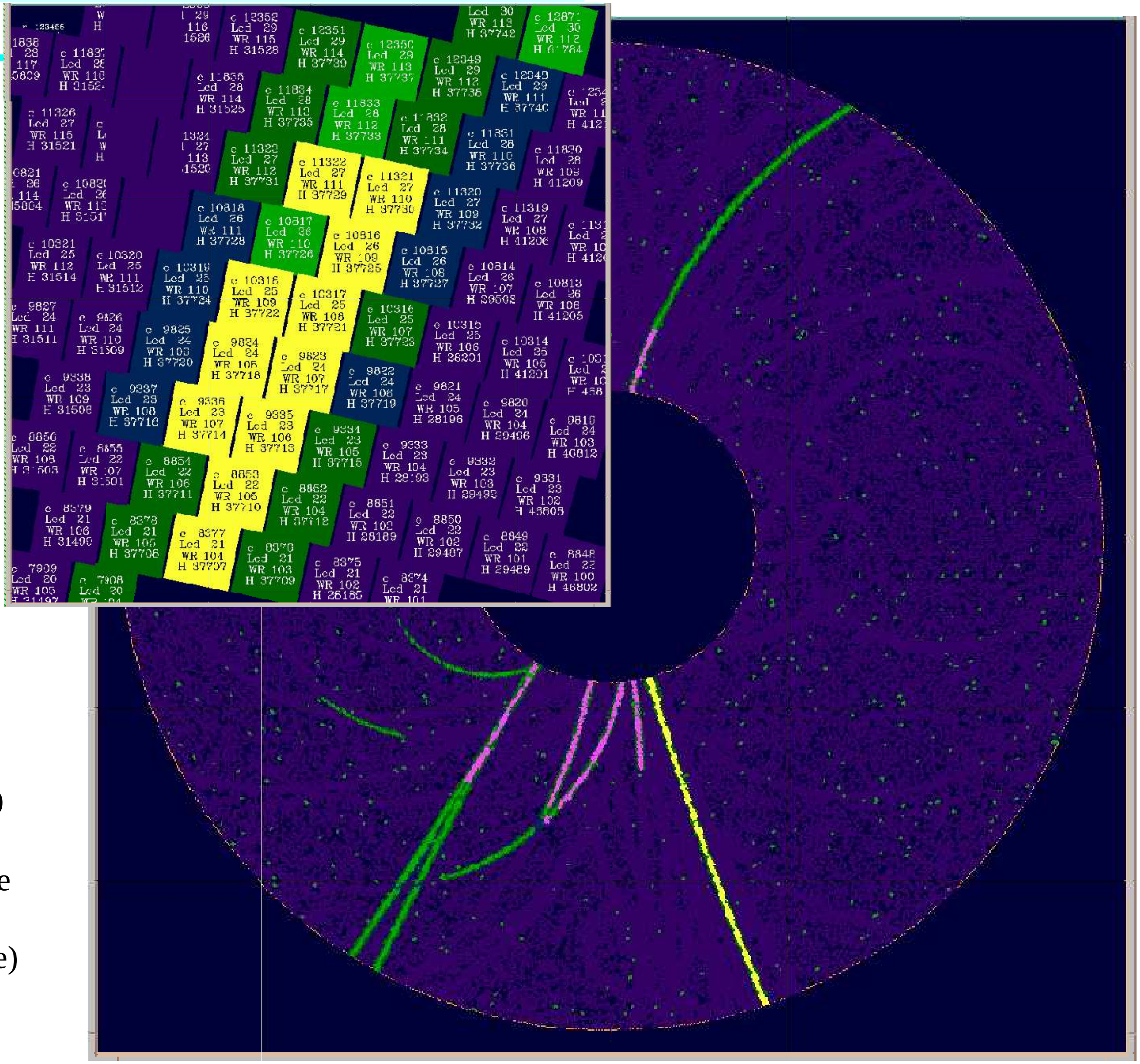
Active cone:
Z=[r * (-6 / 80)] +/- 3 cm
(will use wider cone in future)

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.

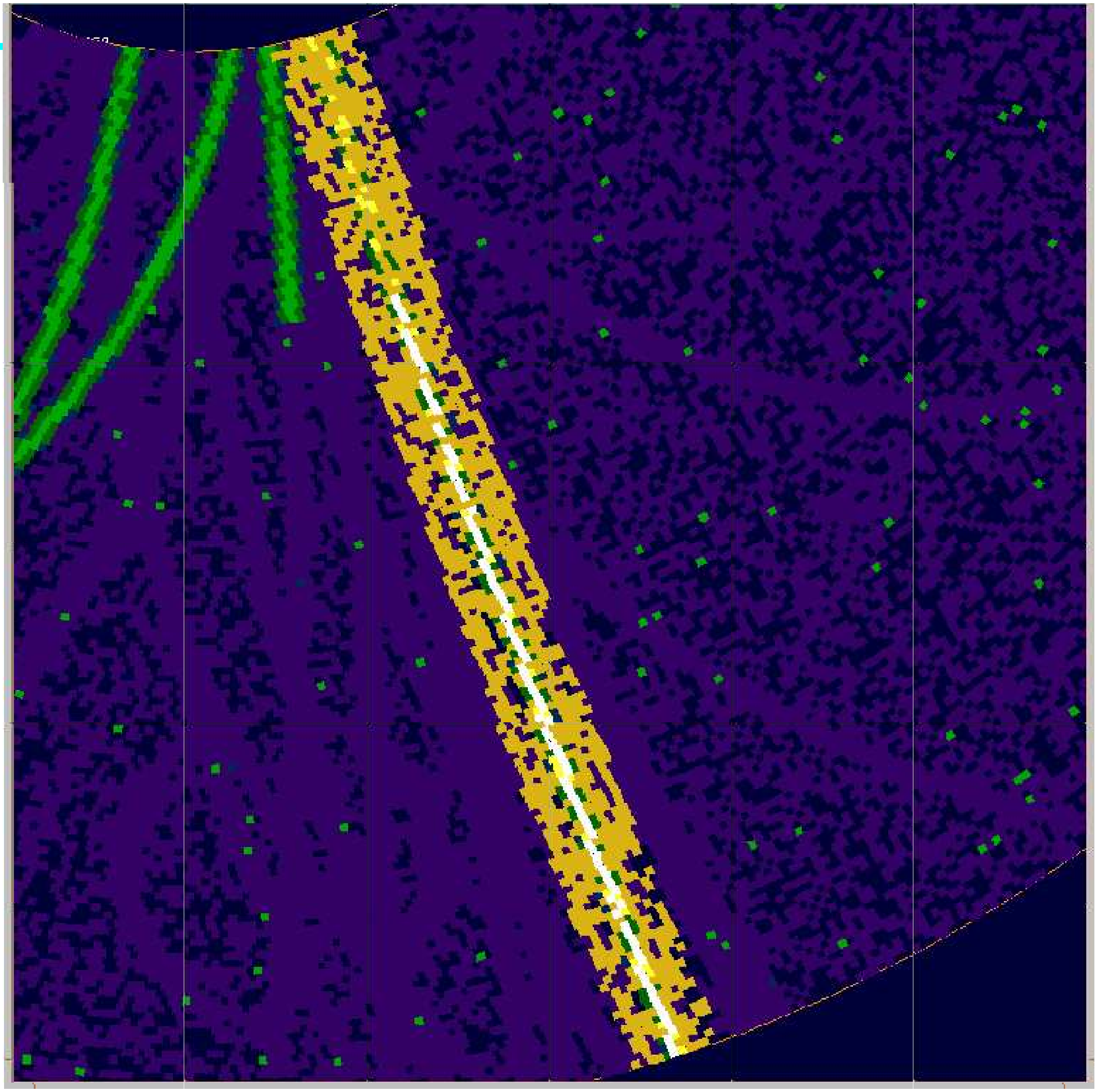
Merged tracks (at 7:00) are found as one segment, interrupted when the tracks are ambiguous.

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.

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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,

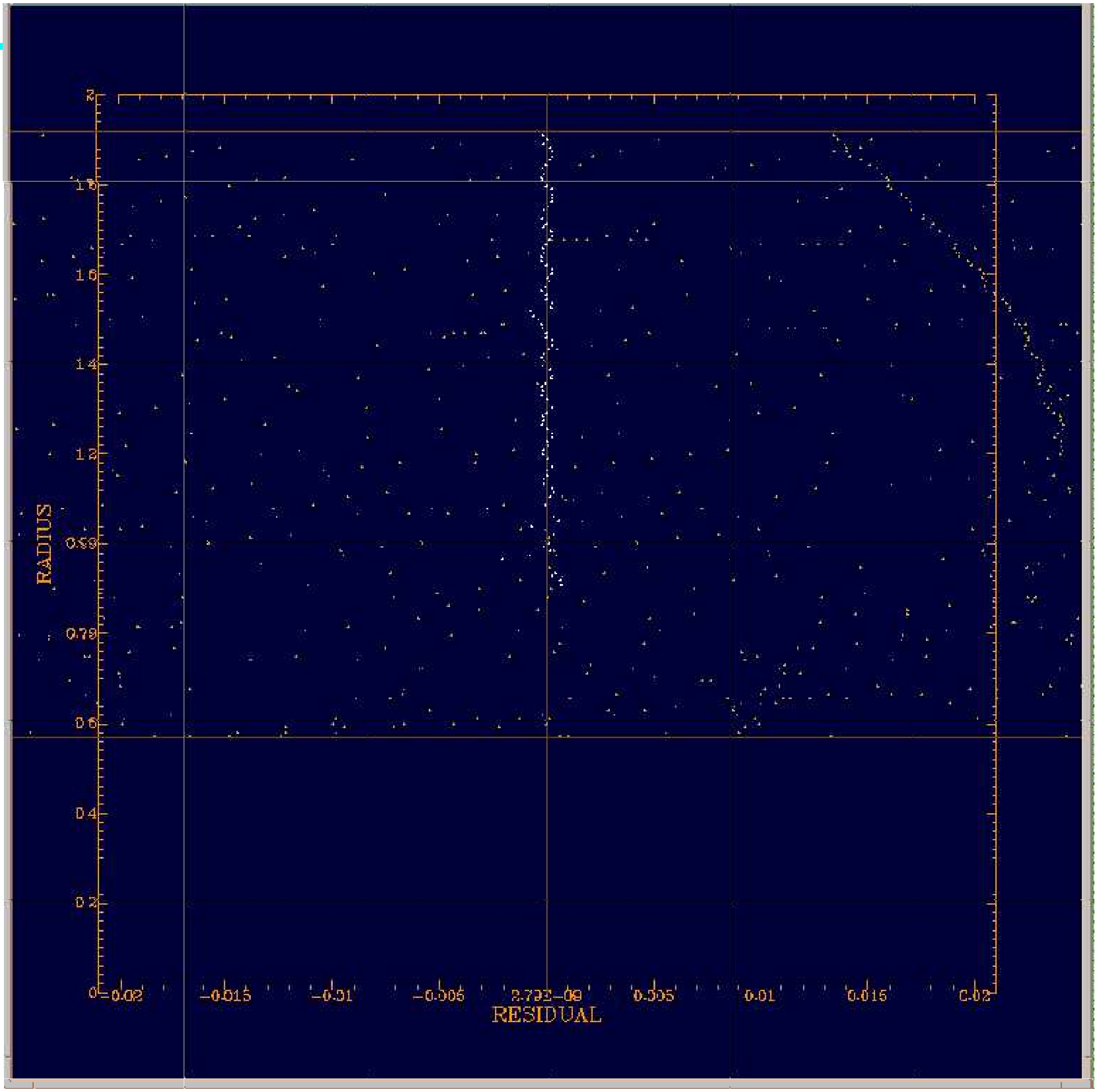
look for correlated hits satisfying

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

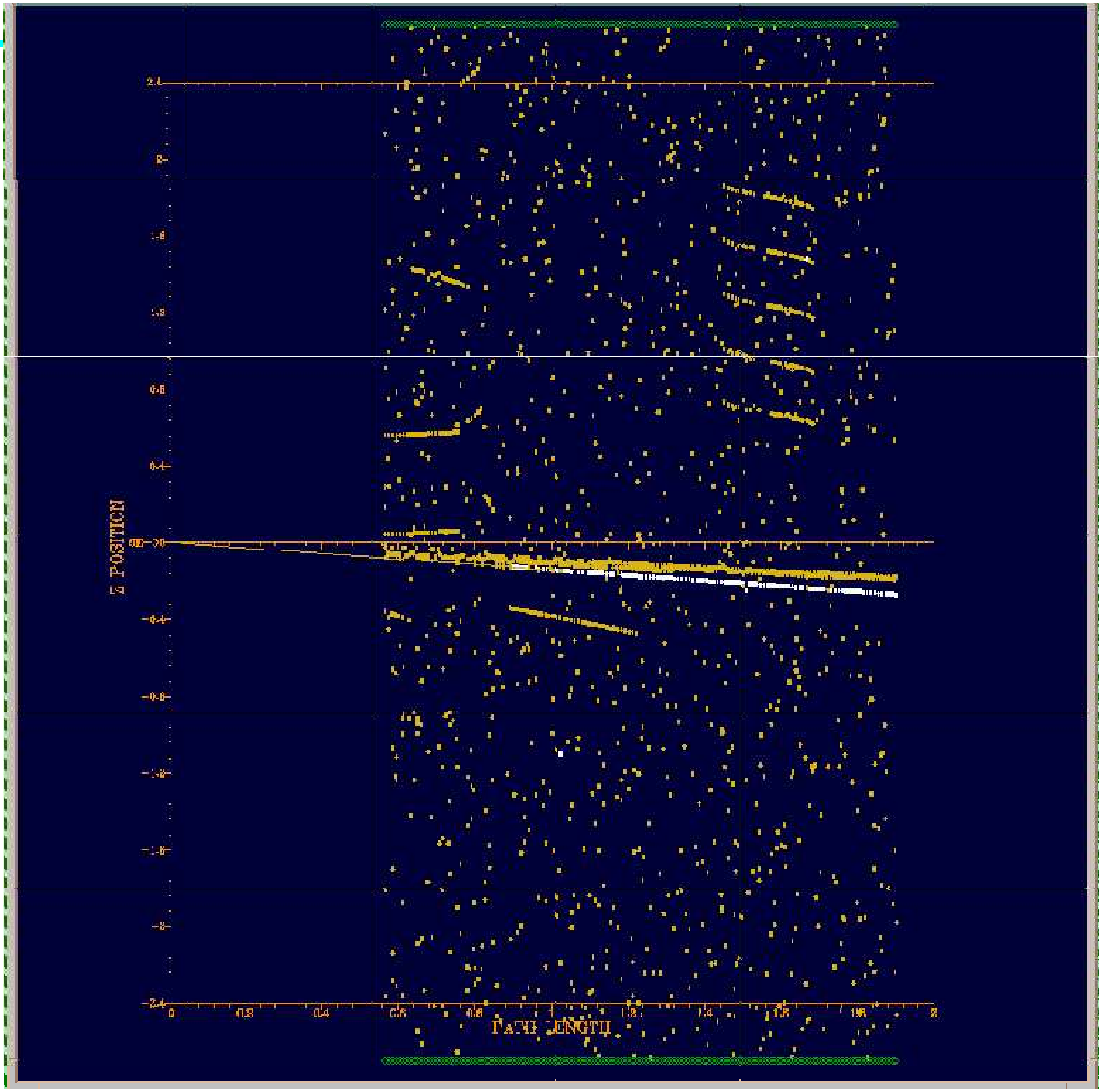
The other track is also very close in Z.

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.

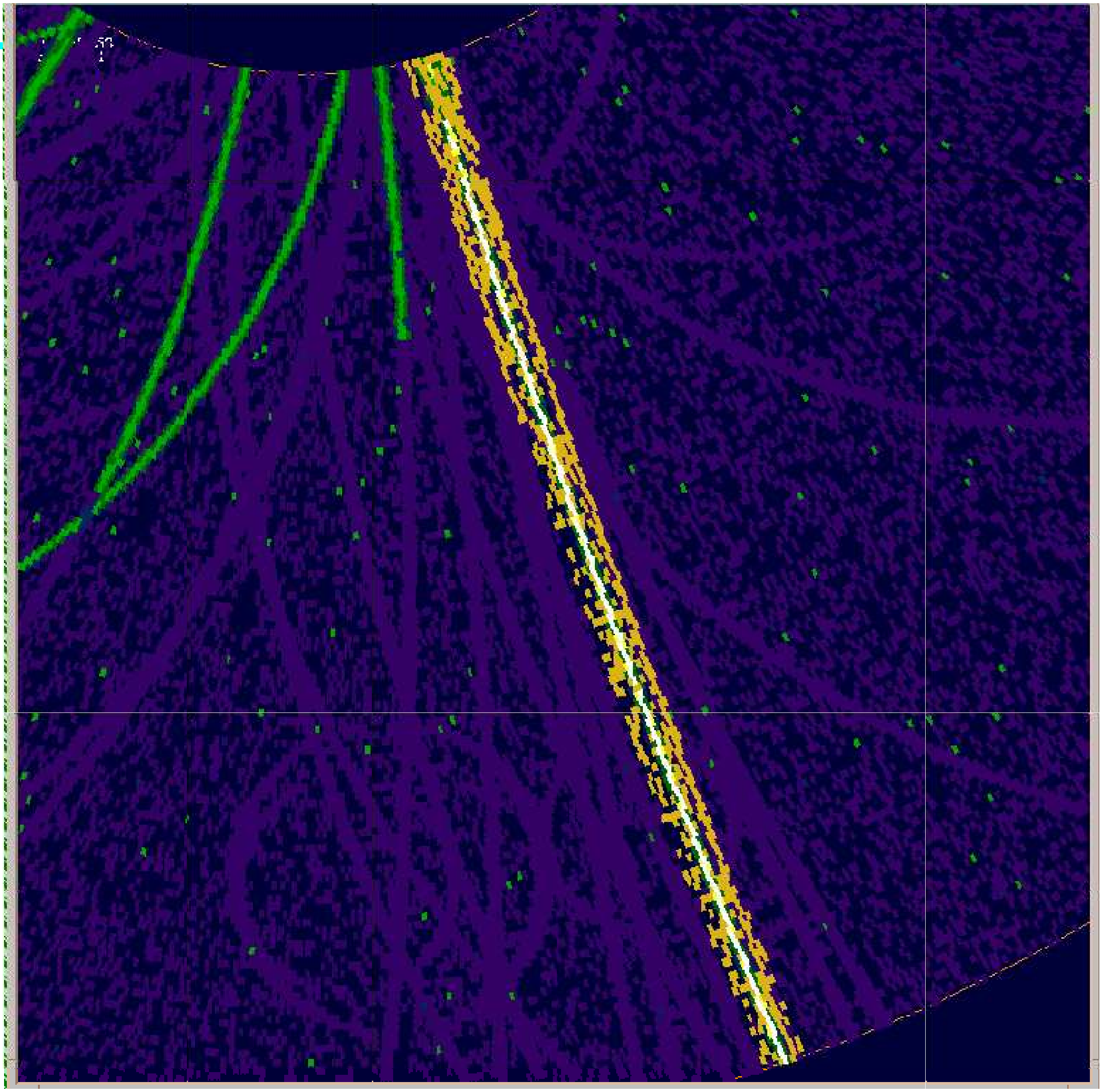
Hits on track in white .

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

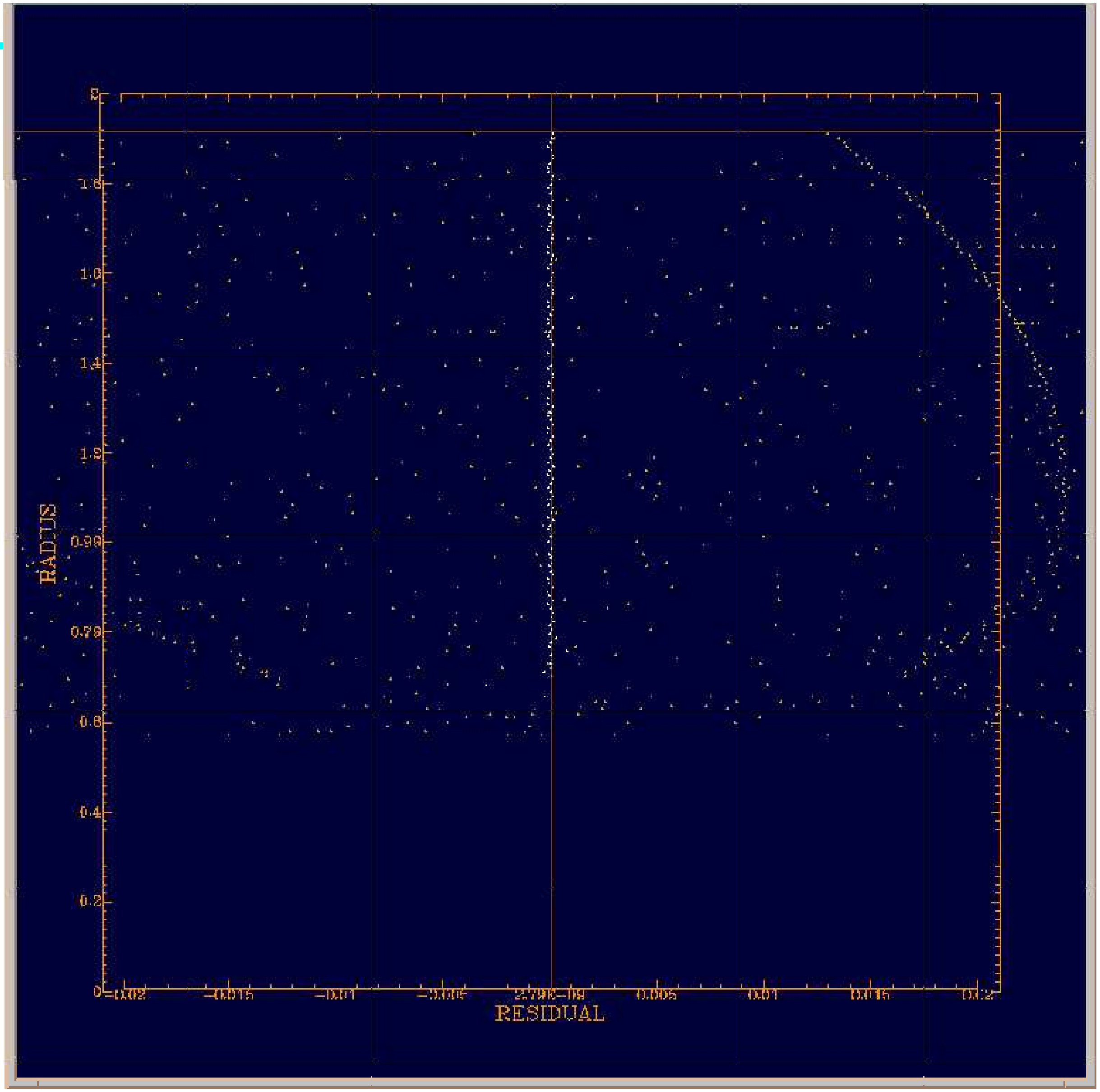
The track extends to lower radius.

(r-ϕ impact = 80 μm)

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

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

Plan:
a statistical study of the relative efficiency
vs.
cell size and charge spread.



Outlook

“Complete”:

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

Needed for efficiency studies:

develop a method for identifying tracks that should be found
- have a list of hits organized by generator track number
- also have generated track in the .sio file
- would like to have events with a specific 2 body process, e.g. Z → 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