

## TPC Detector Response Simulation and Track Reconstruction

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

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

**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  $\mu\text{m}$  spatial resolution

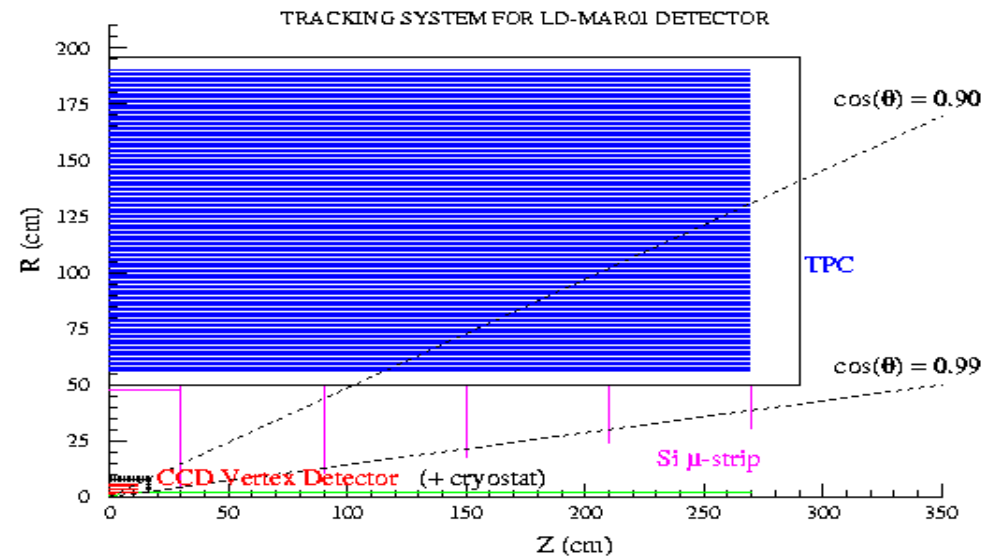
Vertex Detector:

5 layer, 10  $\mu\text{m}$  spatial resolution

Intermediate Tracking Device:

2 layer,  $r=0.45$  m, 10  $\mu\text{m}$  spatial res.

$\rightarrow \delta(1/p) = 4.2 \times 10^{-5} / \text{GeV}$



**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** using the **maximum segmentation** possible with a GEM or MicroMegas amplification TPC.

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

[ 1cm x 1 mm pads ]  $\rightarrow 2.4 \times 10^6$  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 ),

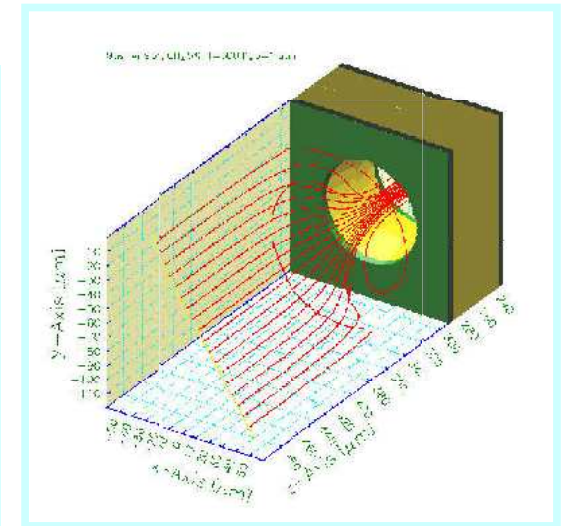
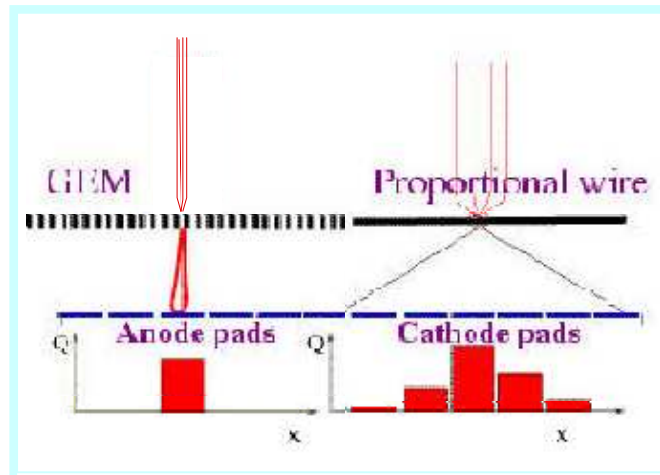
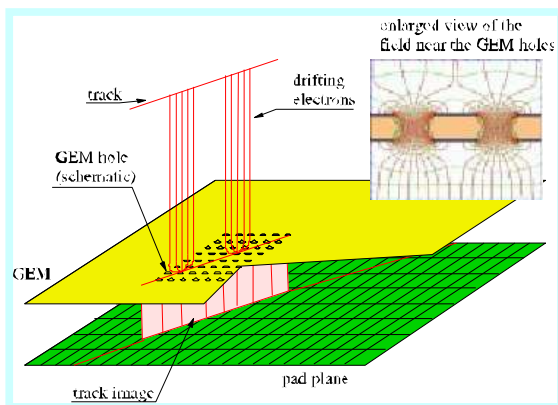
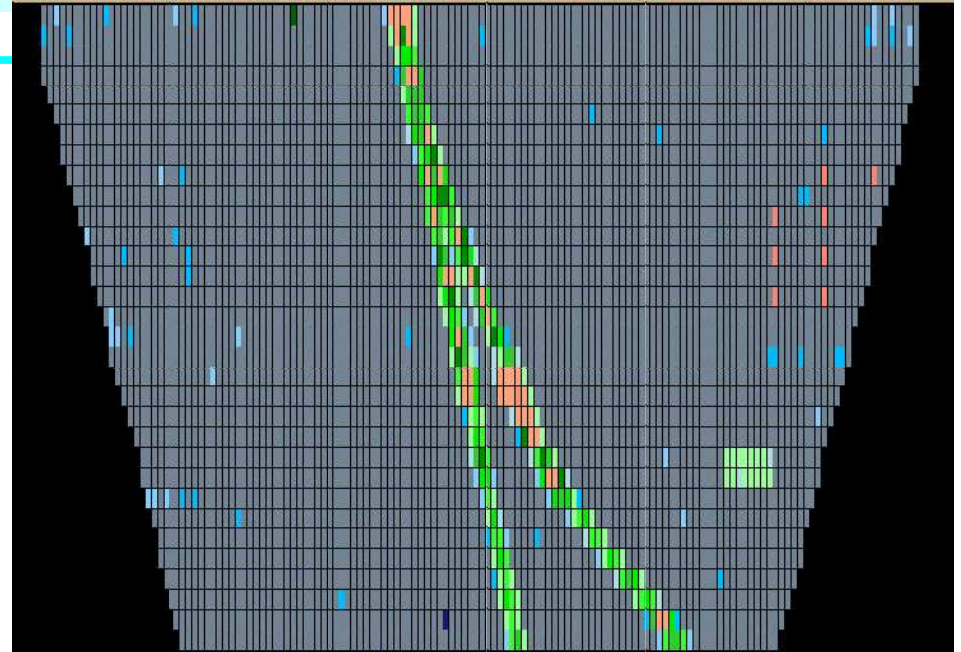
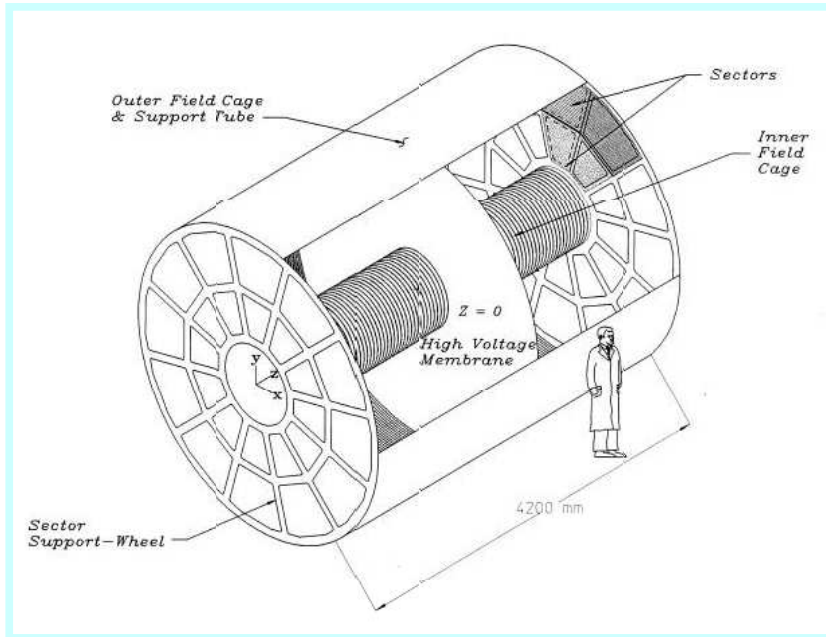
for complicated physics events simulating Linear Collider processes,

and using pattern recognition that starts with pad level information.

Many thanks to **Mike Ronan** for wrapping the Cornell reconstruction code in Java

and providing a access to lcd simulation events in .sio format.

# GEM/MicroMegas Amplification TPCs



## Sample event with 2 mm pads

Sample event from lcd simulation

(All hits are projected onto one endplate.)

144 layers from 56cm to 200 cm

2 mm wide pads

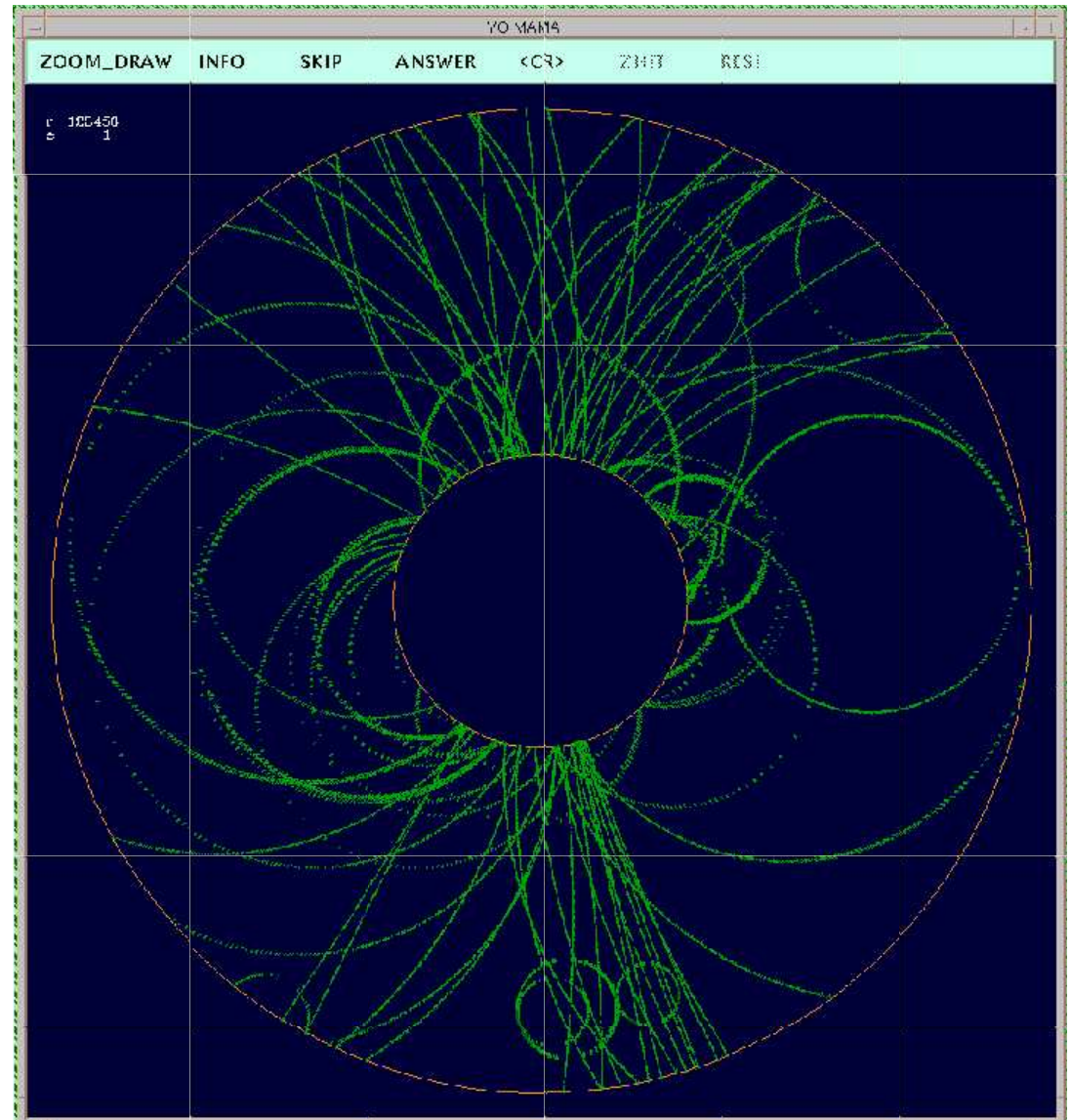
(number of pads in layer is multiple of 8)

no charge spread

no z overlap

no noise

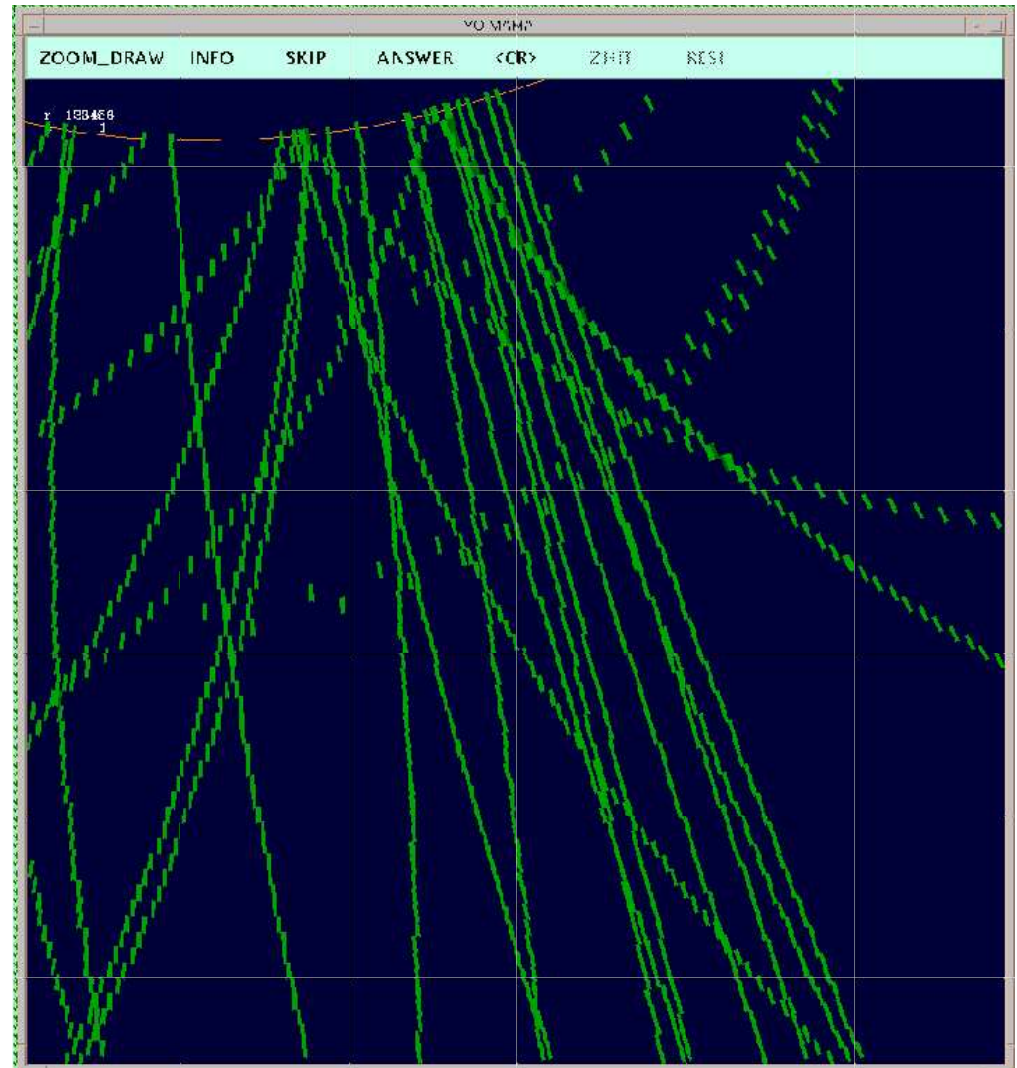
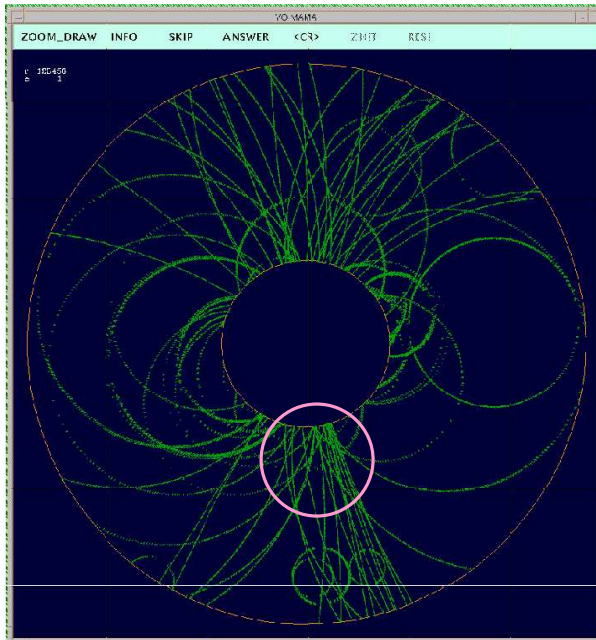
This would be similar to a situation with  
1 mm pads and charge spreading to 2 pads,  
a very expensive detector.





## Sample Event, Tracks within a Jet

(Same event, same pad response )

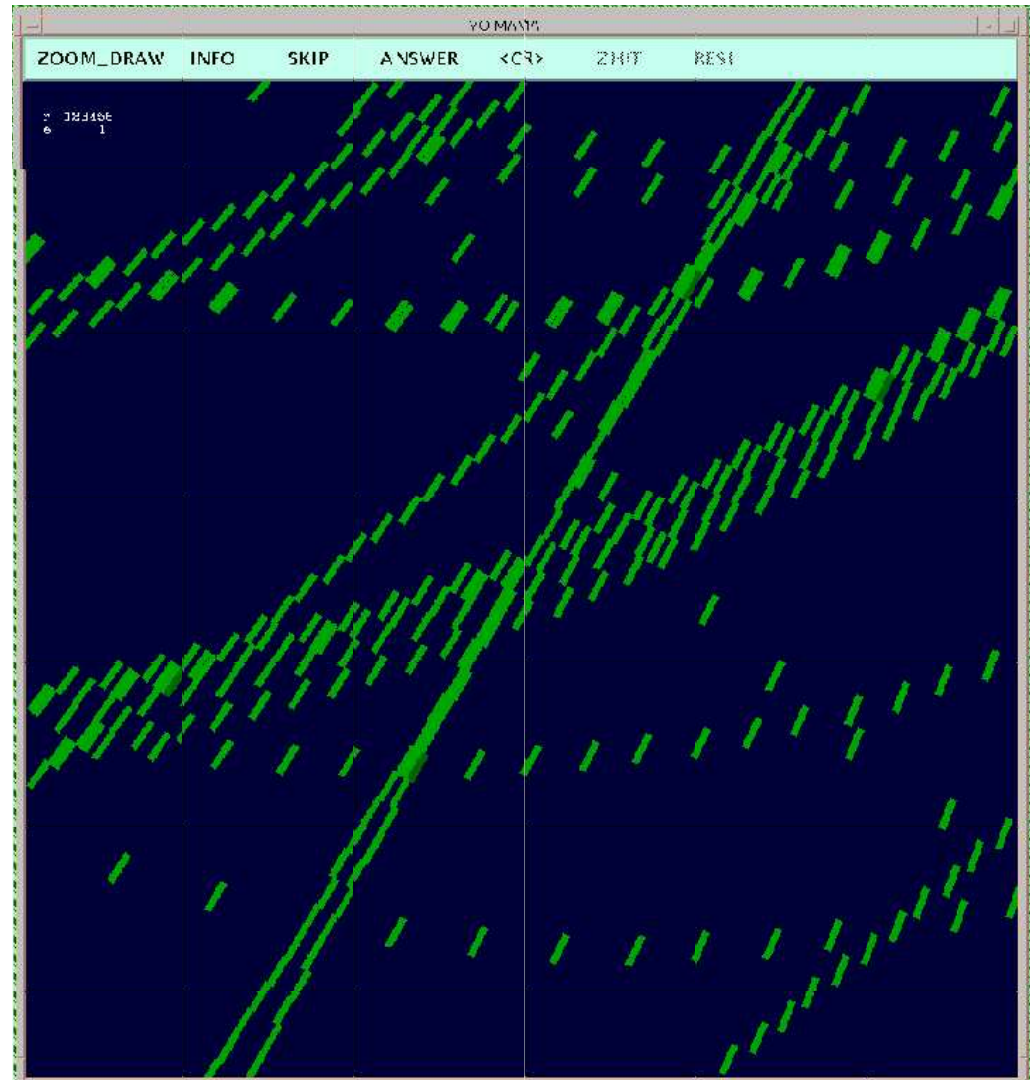
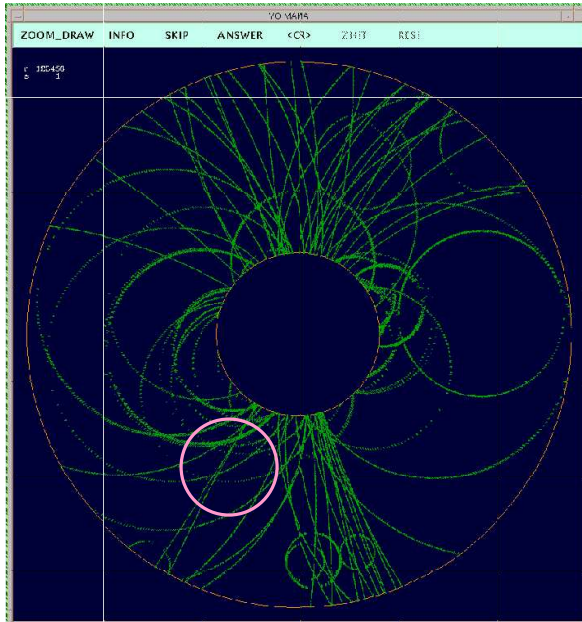


Tracks in a jet are usually separated.

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.

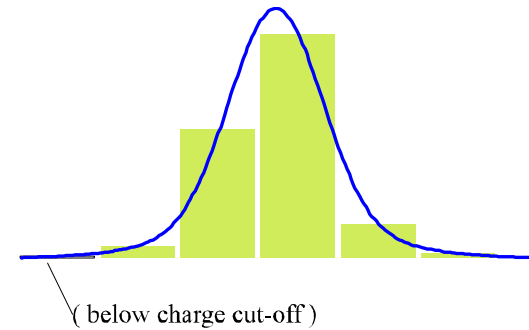
cross in r-f, and  
z-separation = 1mm.

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.

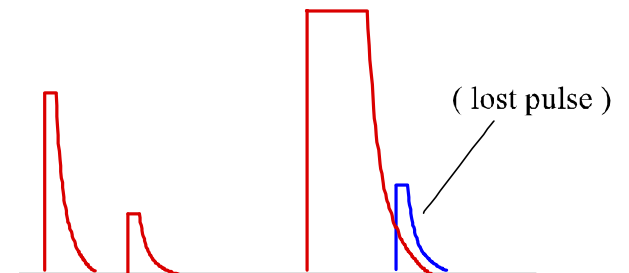
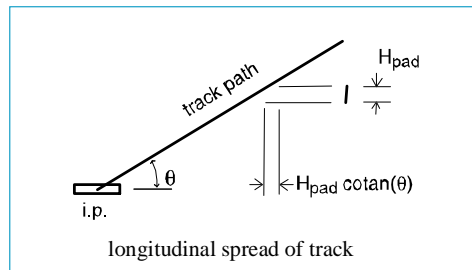
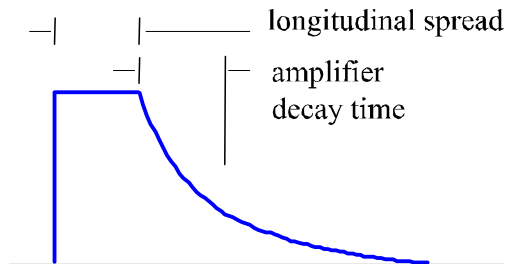
# Detector Simulation: Pad Response ( and Clustering )

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

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

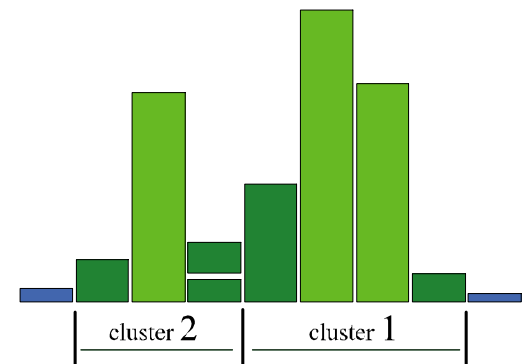


**Wave Form** to simulate time (=z) response



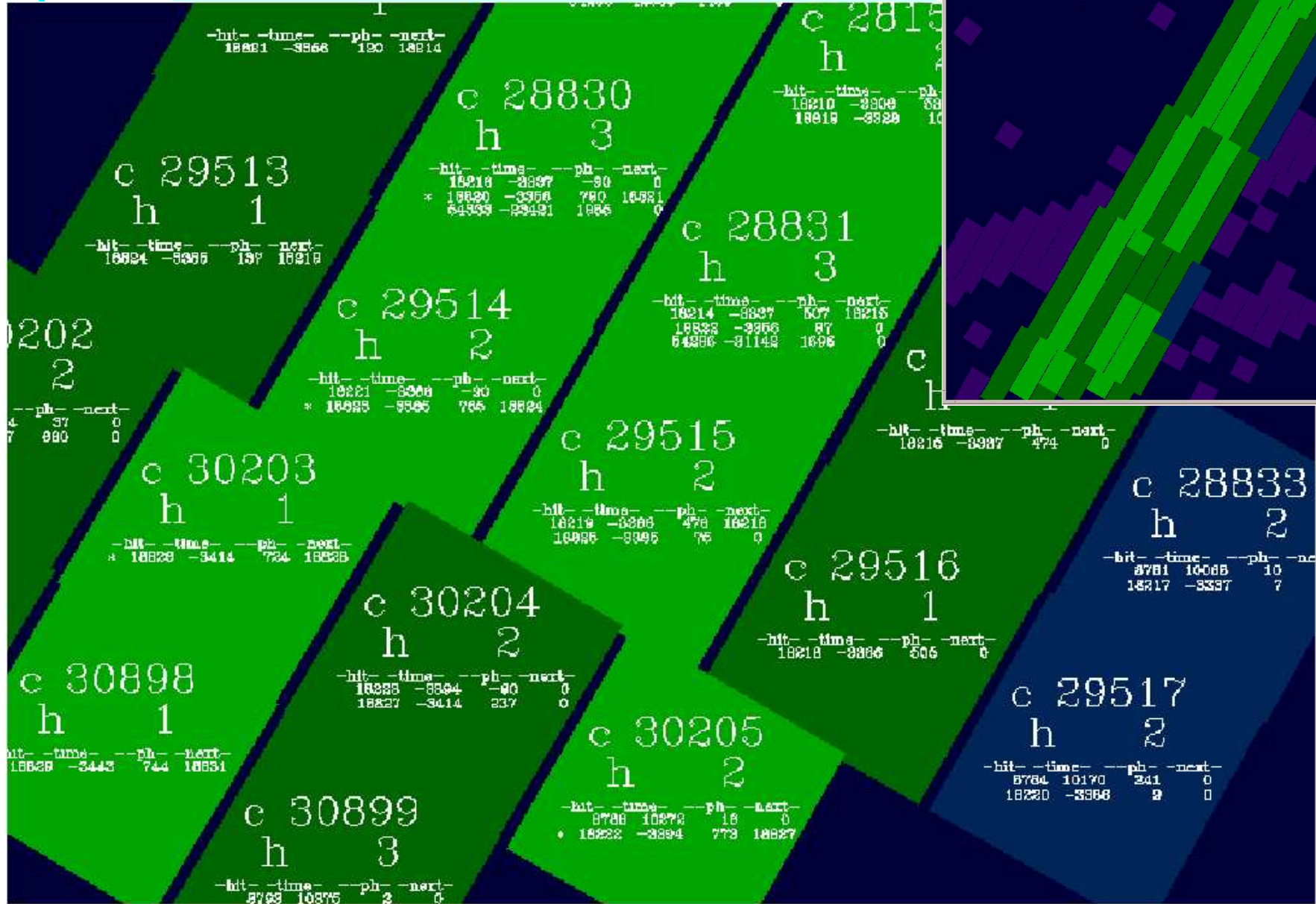
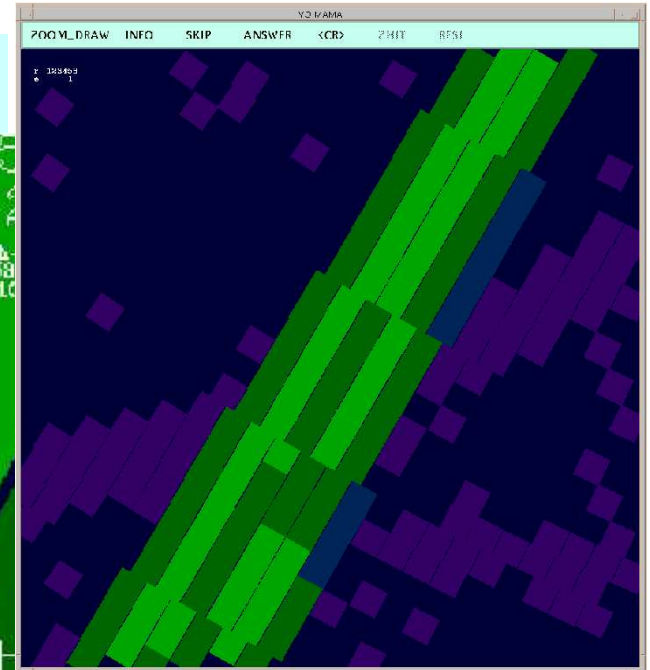
**Clustering** in  $r-\phi$   
criteria for minimum **central pad** , added **adjacent** pads  
**splitting** at a local minimum,  
can lead to pulse height merging and incorrect clustering.

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





# Cluster Details

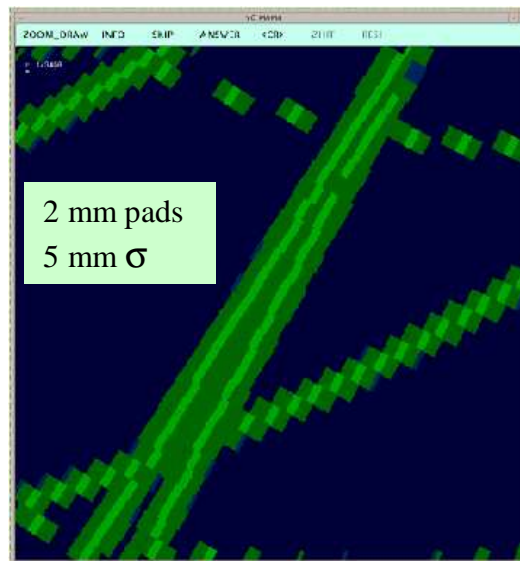
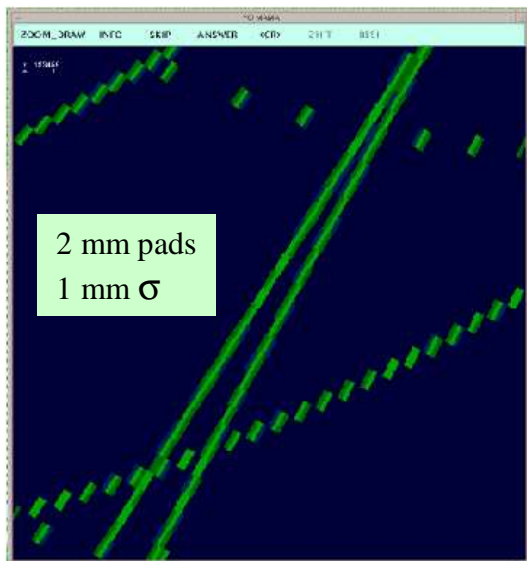




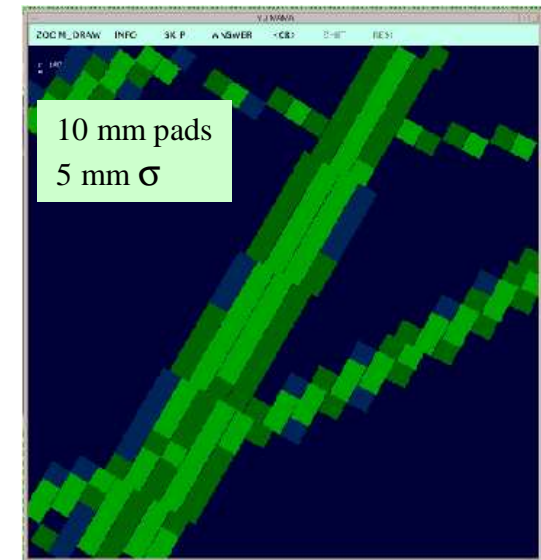
## Pad Response: Examples of Various Pad Width and Charge Spreading Width

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.)



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.

## 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

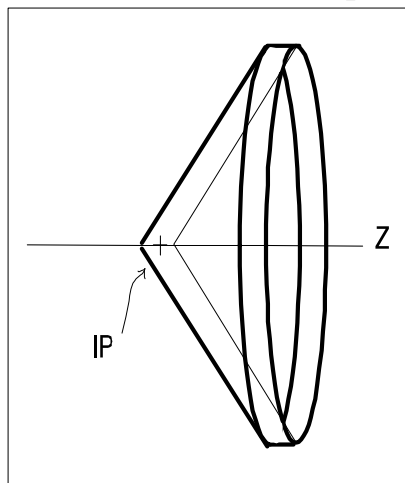
(where z information is derived from the track and stereo layers)

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 3 stages

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

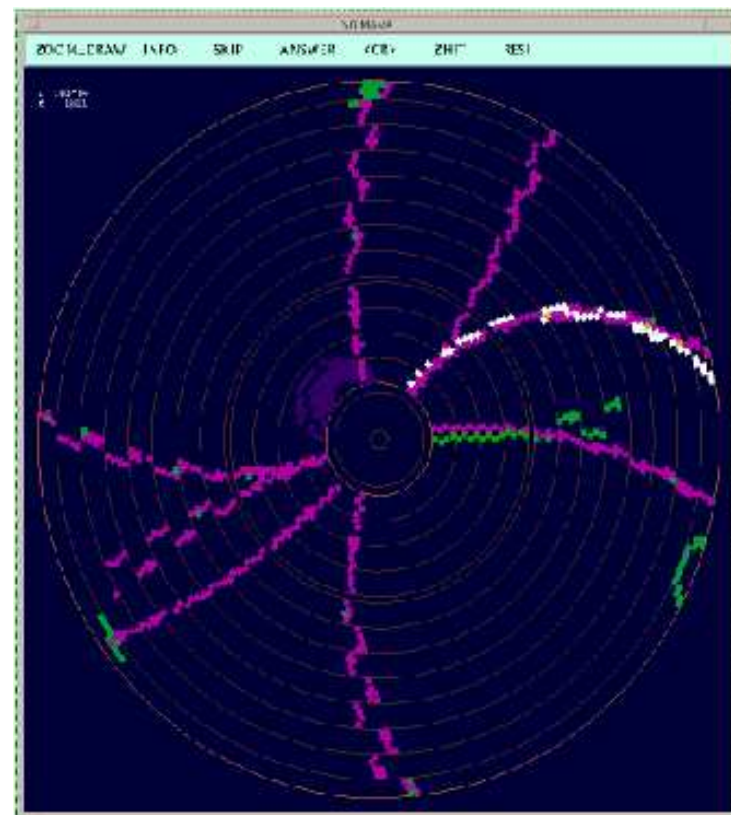


Segments are found in pre-selected, I.P. pointing, cones.

is highly efficient for overlapped tracks

(as shown in the event )

because any region of track separation can be used as a seed





## 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- $\phi$ ) 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)

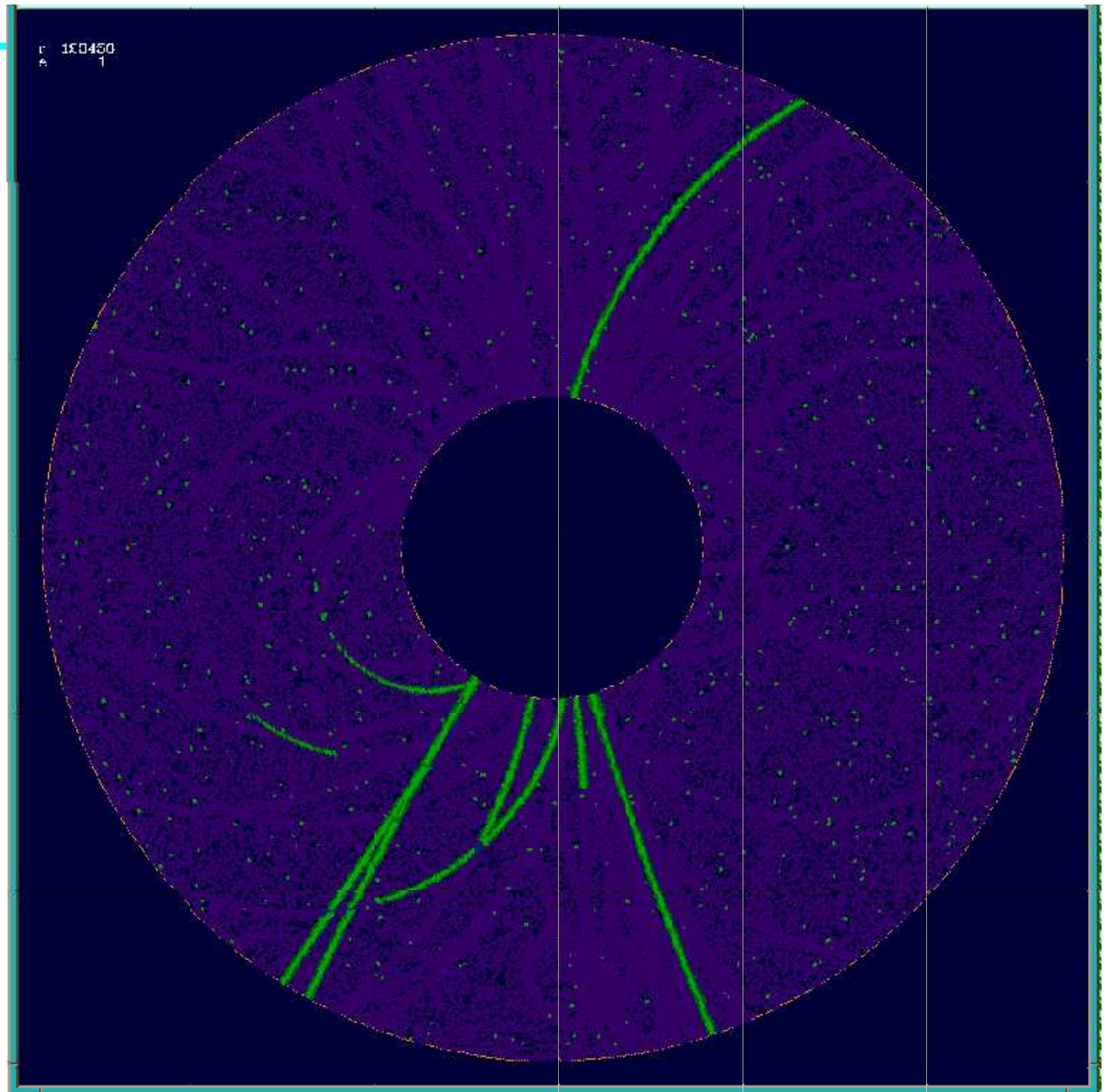
Number of noise hits = 89385

Active cone:

$Z = [ r * (-6 / 80) ] \pm 3 \text{ cm}$   
( 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

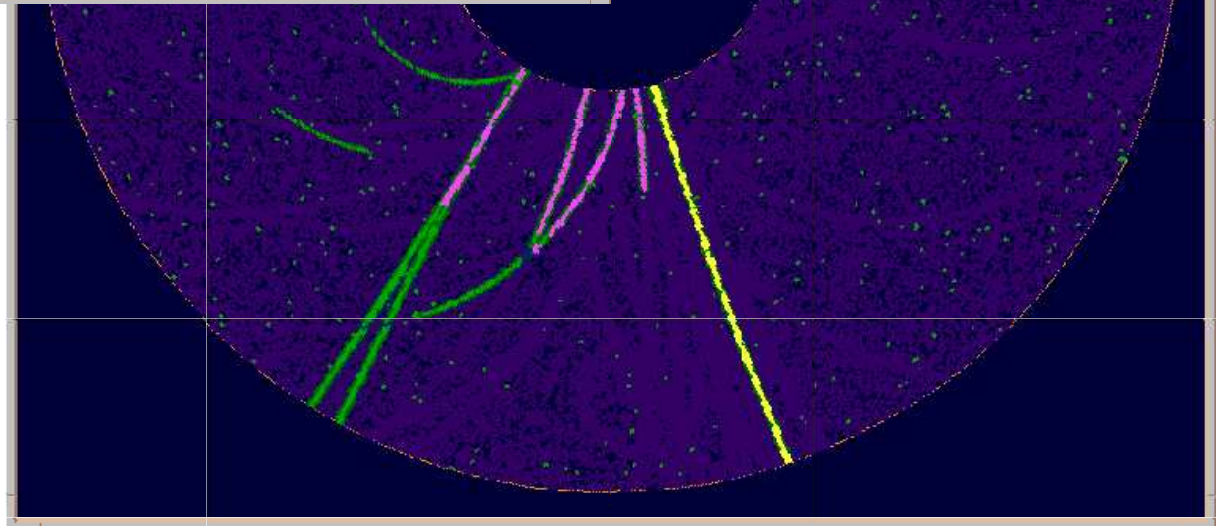
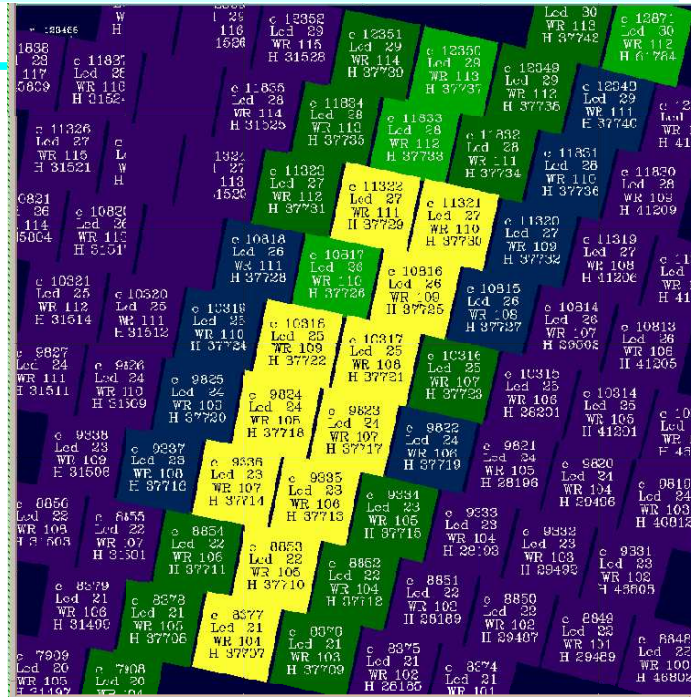
Other isolated segments are shown in pink.

At this point, processing for segments is not complete; not all segments 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<sup>nd</sup> Phase, r- $\phi$ 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<sup>nd</sup> stage, track is not found at low radius .

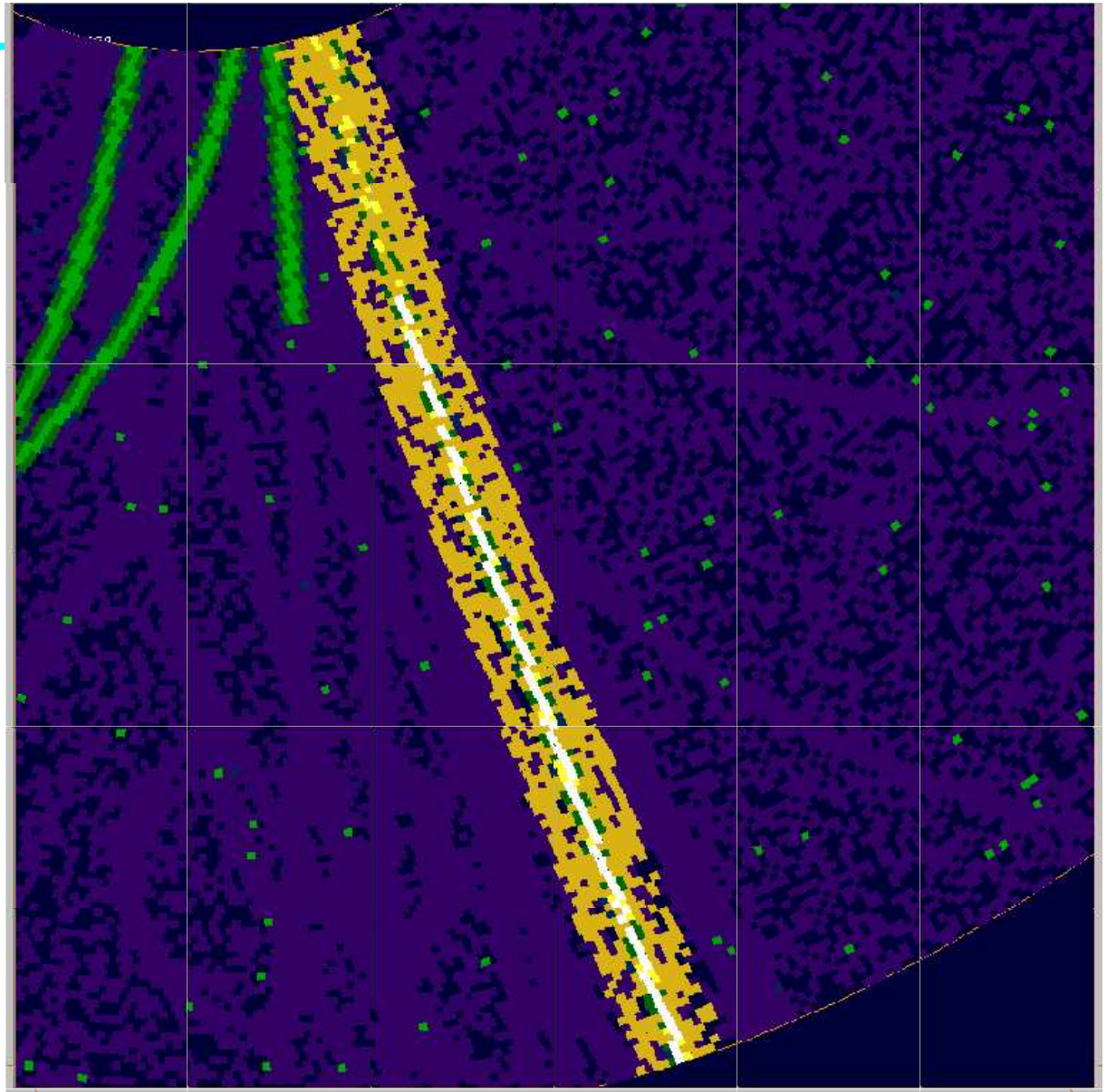
r- $\phi$  impact = 5.6 mm

The  $\chi^2$  of the track is actually too good,

$\chi^2 = 6$ .

( hit resolution is 245  $\mu\text{m}$  for 10 mm pads. )

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





## After 2<sup>nd</sup> Phase, residual (r- $\phi$ ) view

PLOT: residual on horizontal  
( $\pm 0.025$  cm at edge)  
vs. radius on vertical

2<sup>nd</sup> phase pattern recognition uses  
local residual correlations

Radius is broken up into 16 parts

In each radial part,

look for correlated hits satisfying

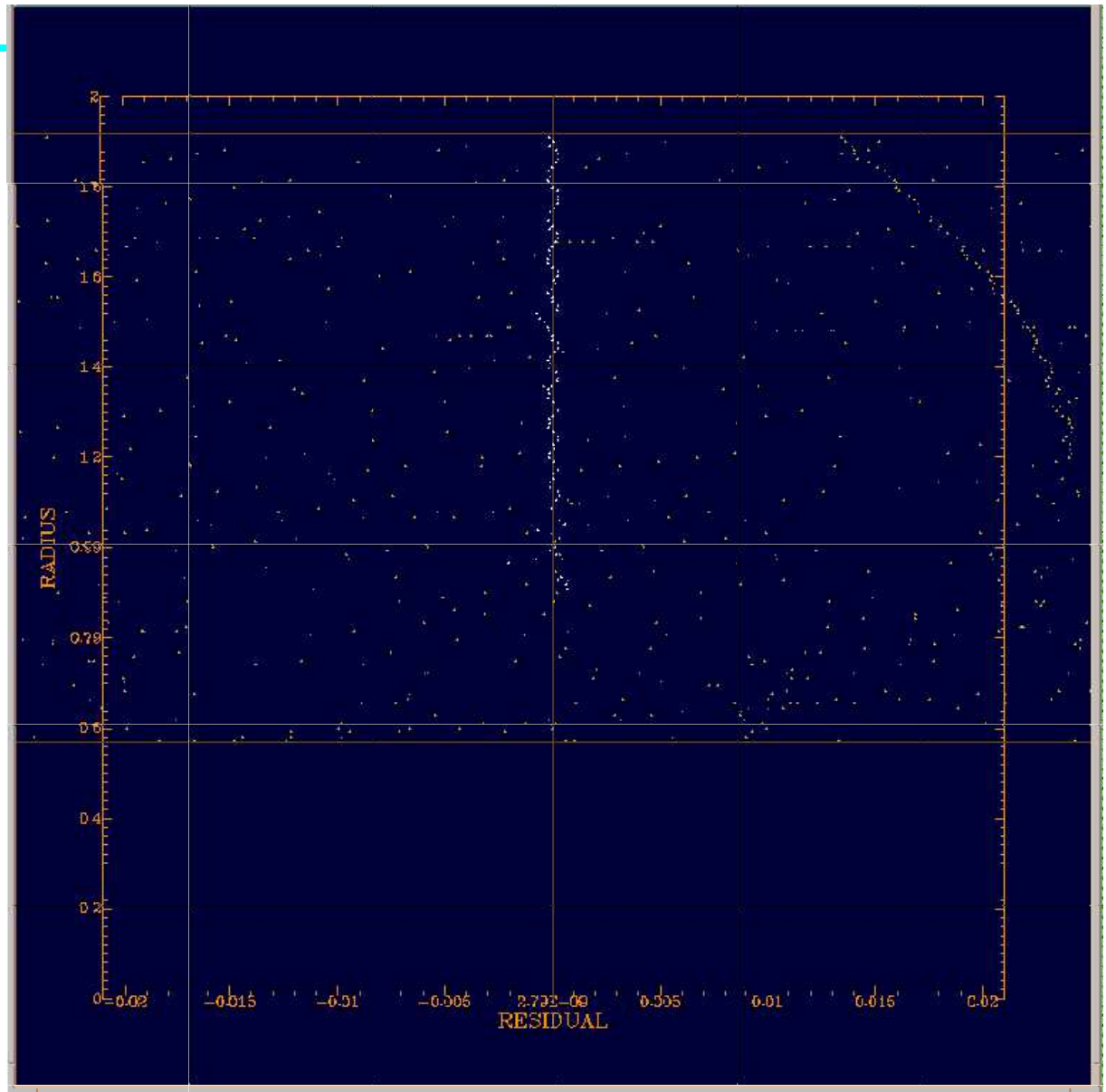
used r- $\phi$  road  $< 0.005$  m

used z road  $< 0.10$  m.

Select best solution in  
each radial part.

No solutions were found at low radius.

Note other track.



## After 2<sup>nd</sup> Phase, z view

Hits in road in orange.

Hits on track in white.

PLOT: Z on vertical  
( $\pm 2.5$  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).**

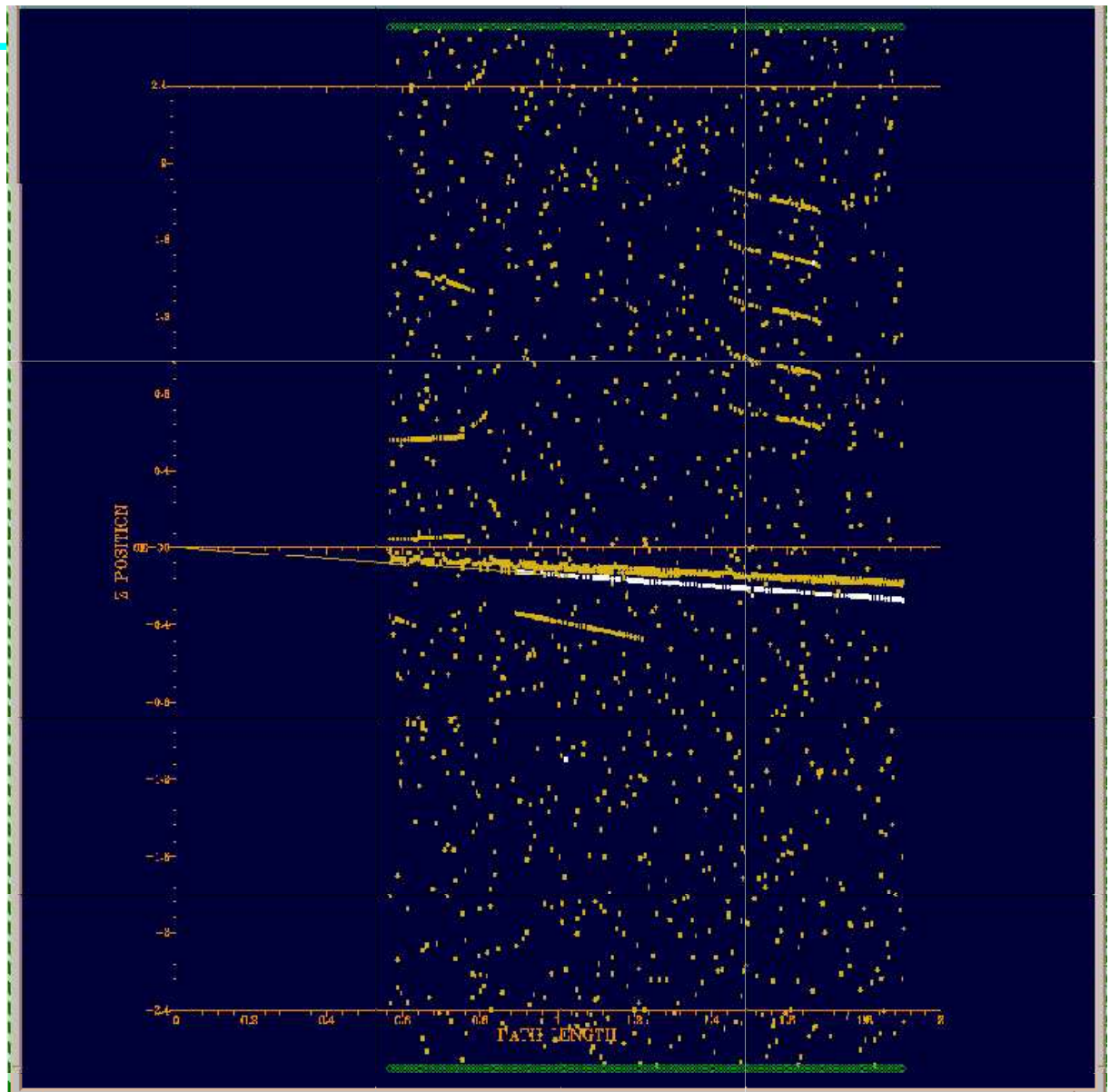
Note:

other track (interference)

short tracks

that escape the  $r$ - $\phi$  road,

curler, not completely in the  $r$ - $\phi$  road



## After 2<sup>nd</sup> Phase, r- $\phi$ view, 5mm pad width

Hits in road in orange.

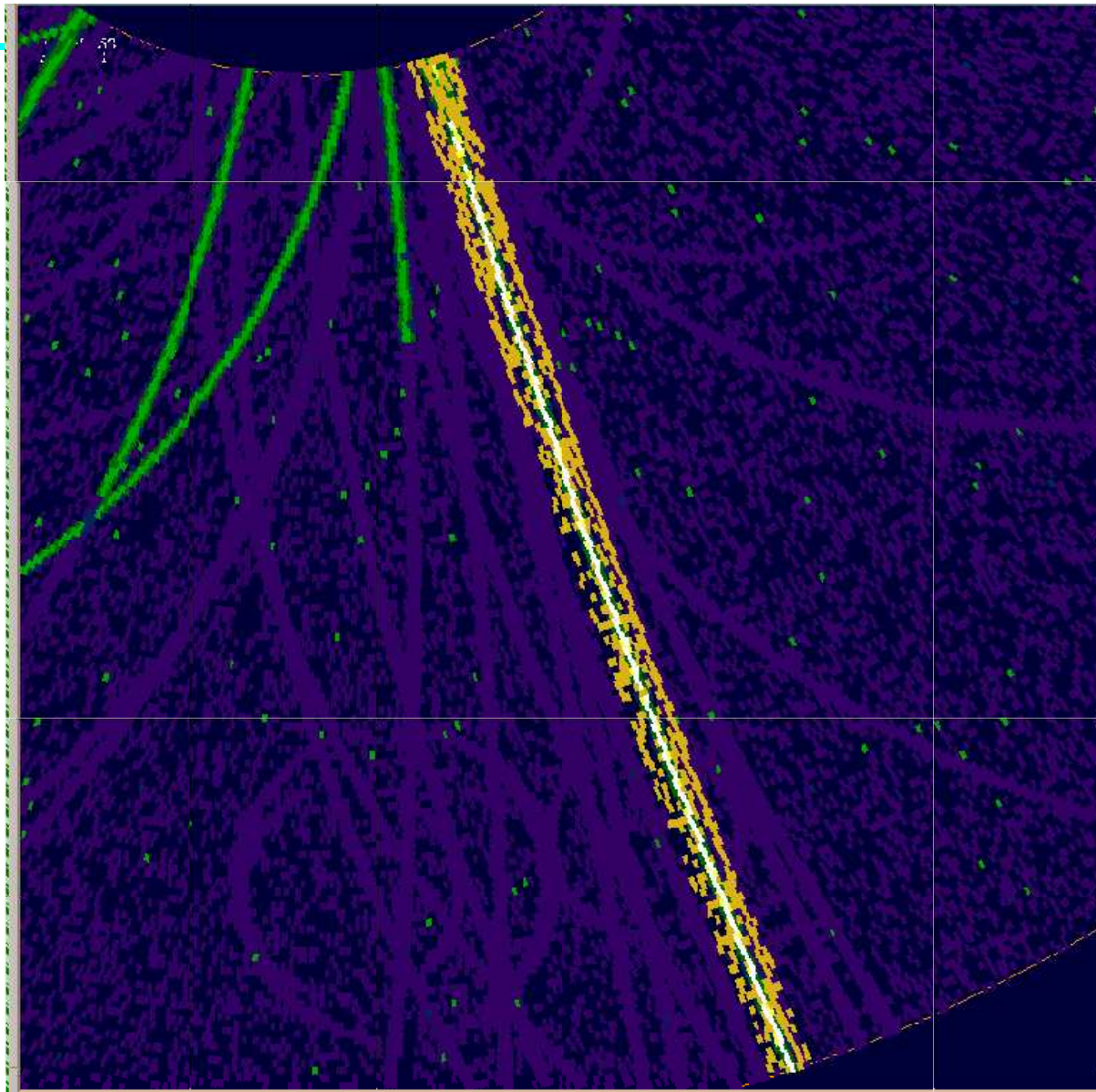
Hits on track in white.

Now repeat the same track with

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

**The track is found extending to lower radius in the 2<sup>nd</sup> stage.**

The  $\chi^2$  of the track is still too good,  
 $\chi^2 = 1.25$   
( hit resolution is 111  $\mu\text{m}$  for  
5 mm pads. )





## After 2<sup>nd</sup> Phase, residual ( $r-\phi$ ) view, 5mm pad width

PLOT: residual on horizontal  
( $\pm 0.025$  cm at edge)  
vs. radius on vertical

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

2<sup>nd</sup> phase pattern recognition

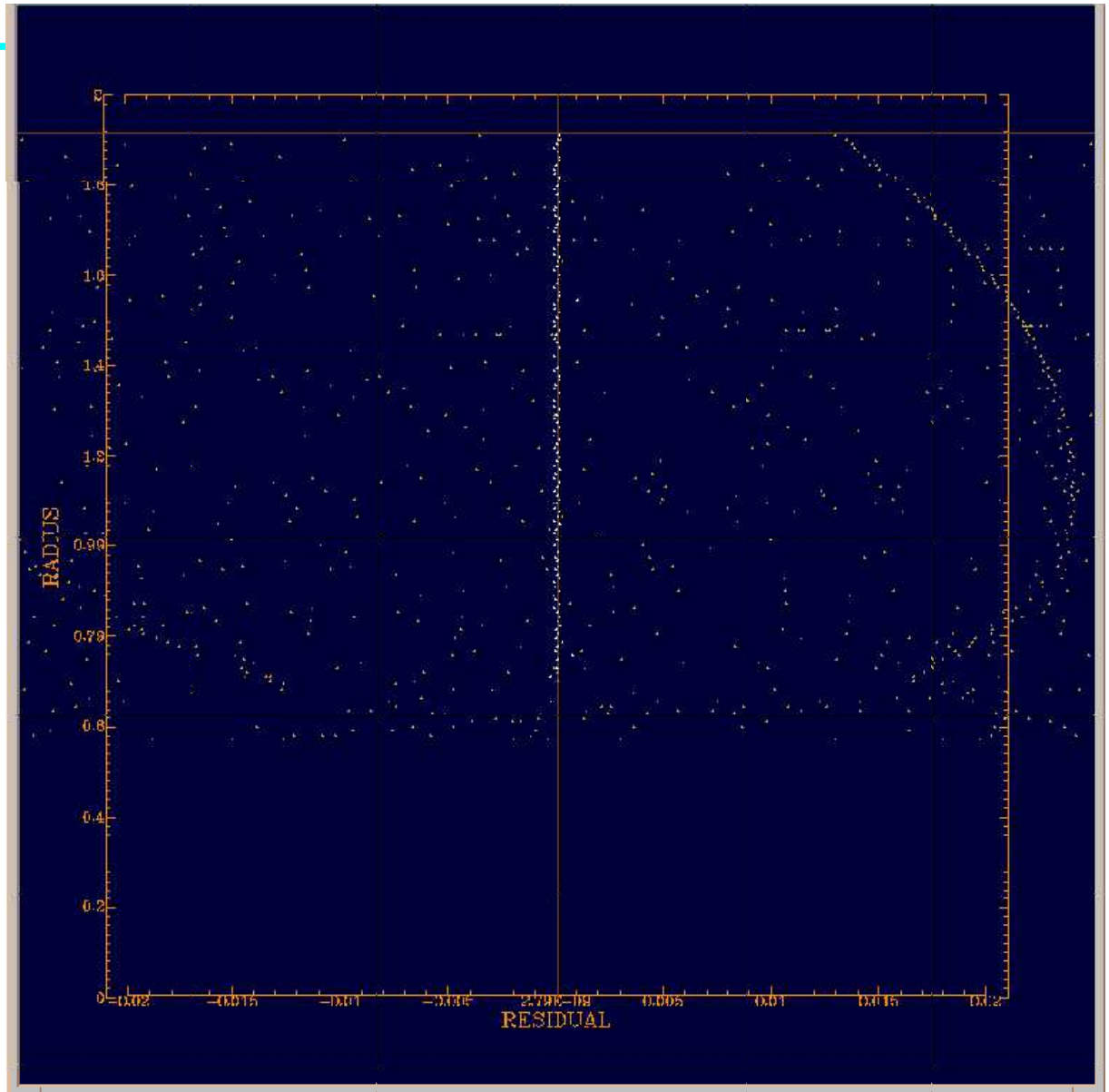
The track extends to lower radius.

**( $r-\phi$  impact =  $80 \mu\text{m}$ )**

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.



## Outlook

“Complete” at the Arlington 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

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.  $Z \rightarrow \mu\mu$ .  
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  $\theta$

