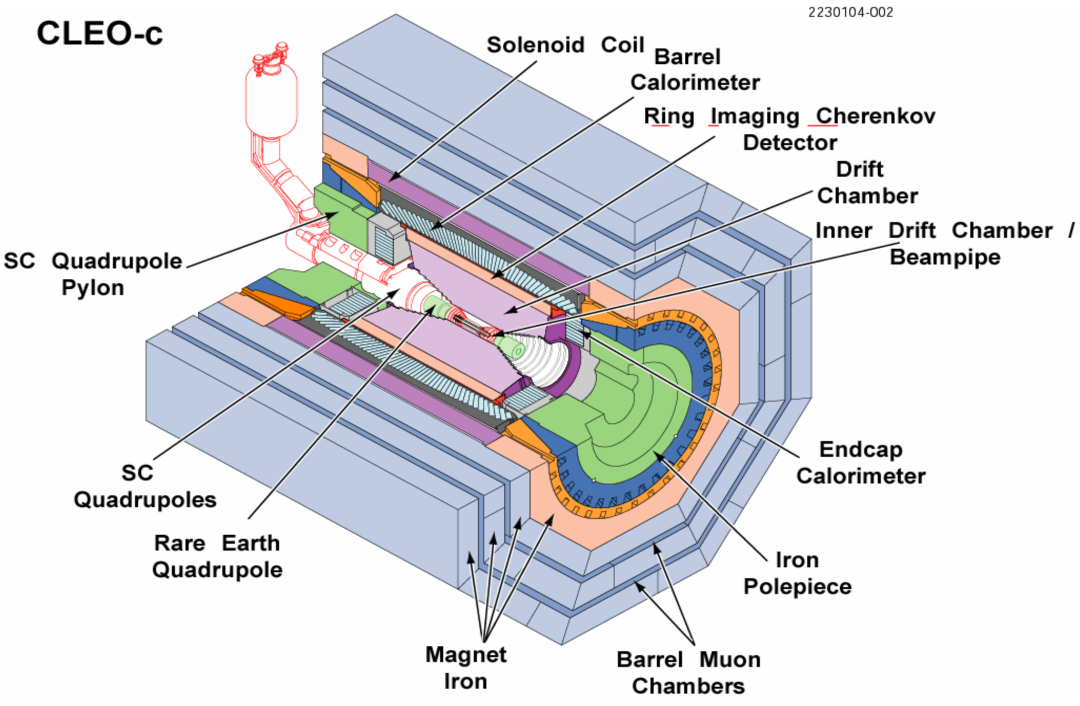
Charged Particle Tracking at Cornell:
Gas Detectors and Reconstruction Software

Dan Peterson, Cornell University



CLEO c

The Cornell group has constructed, operated and maintained the charged particle tracking detectors for CLEO since 1978.

There will be two talks describing the gas tracking chambers in CLEO.

1) (this talk)
chambers, calibration and reconstruction of charged particles

2) (Karl Ecklund) electronics

outline

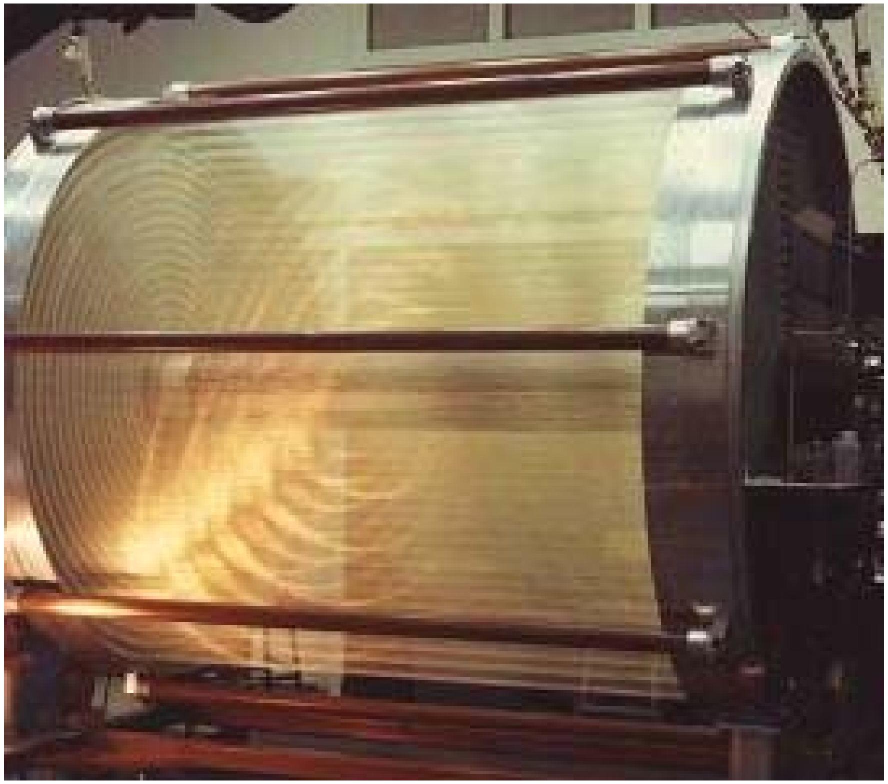
Hardware

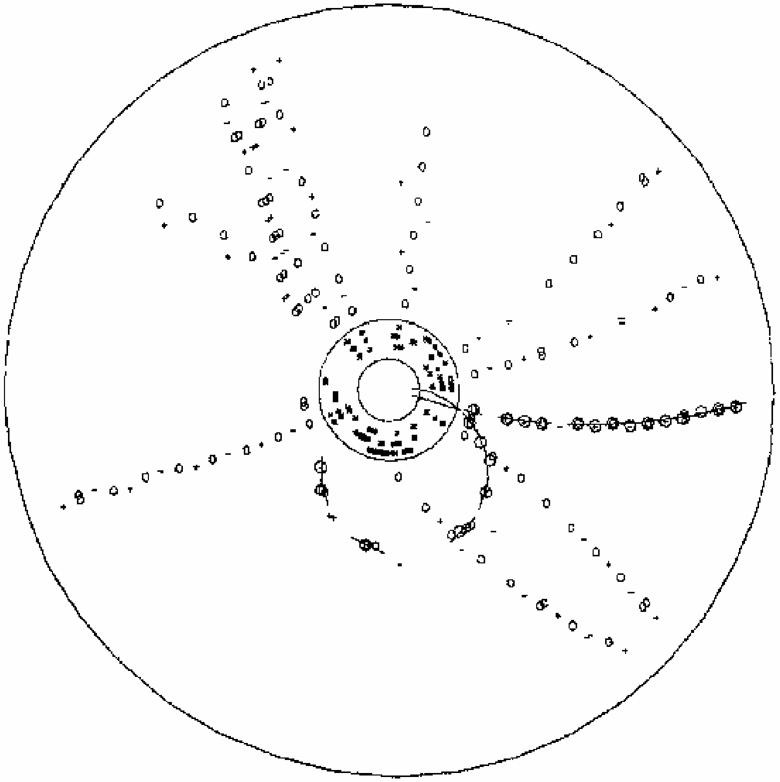
- drift chambers for CLEO I, II, III
- inner chamber for CLEOc
- test chamber / prototyping examples
- future chamber program (International Linear Collider)

Software

- track reconstruction (*ie* pattern recognition)
- fitting
- alignment
- calibration (sketchy)
- and some comments on all-silicon tracking

CLEO I



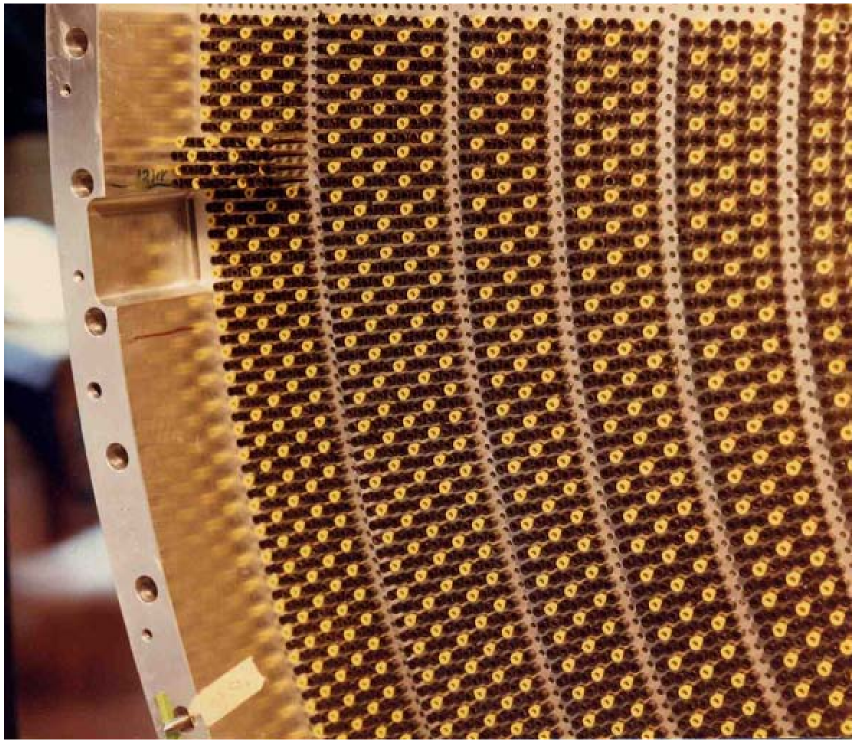


a **sparse chamber** (as seen in the event)
no local-ambiguity resolution
17 layers   [a u a v … a]

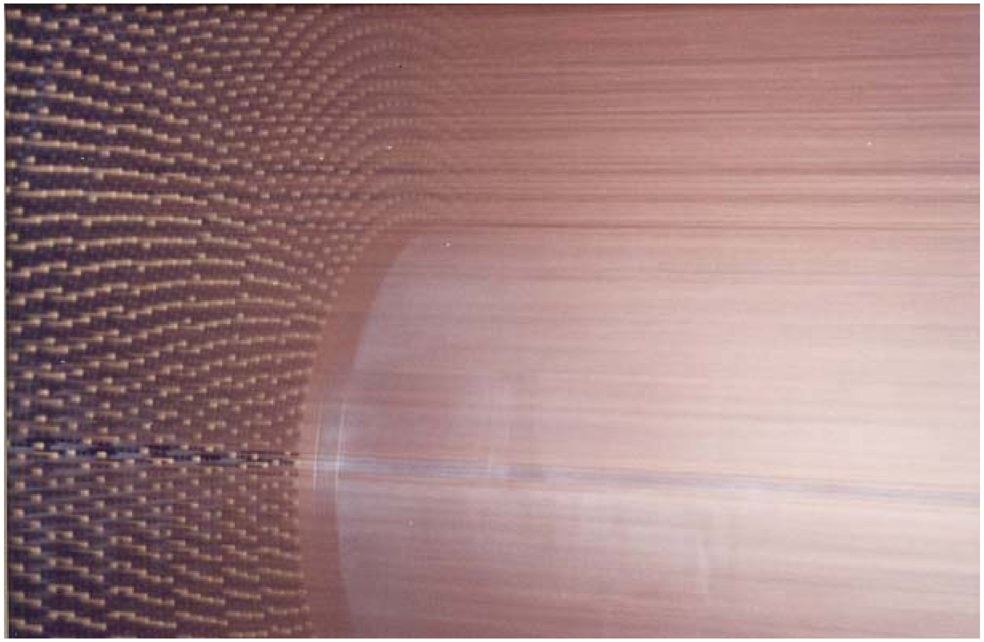
complex track overlap was a problem
limited dE/dX

CLEO I   drift chamber
1979 – 1986
Construction: 1977-1979

CLEO II



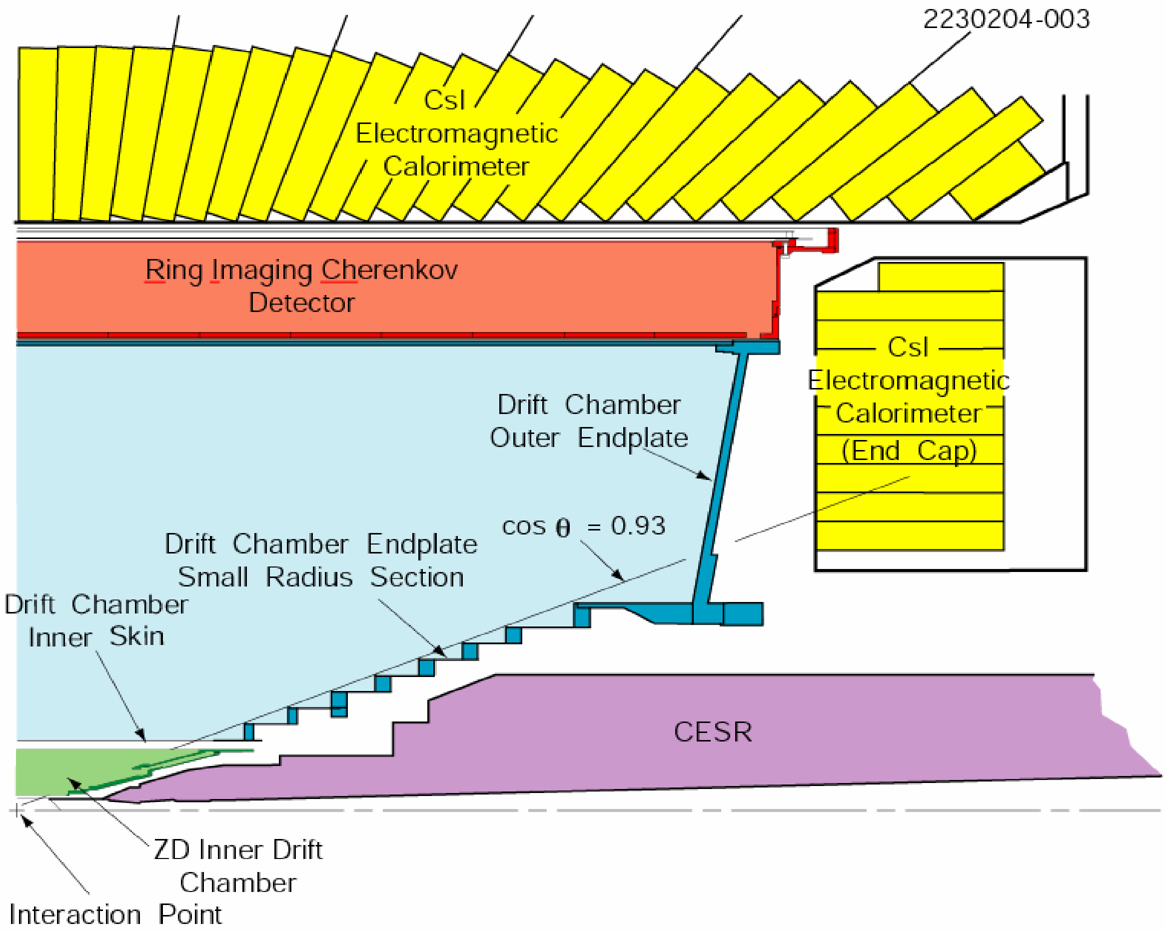
CLEO II drift chamber
1986 – 1998
Construction: 1983 - 1986



51 layers
dense cell design
axial superlayers (bushings shown in photo)
single stereo layers between the axial superlayers
inner and outer cathodes (inner shown in photo)
aluminum field wires
1.25 inch flat endplates (with 1 cm deformation)

The stereo layers were difficult to calibrate;
they were in a non-uniform field cage (vs Z).

CLEO III / CLEO c



integrated design:
space for new machine elements
space for new particle ID

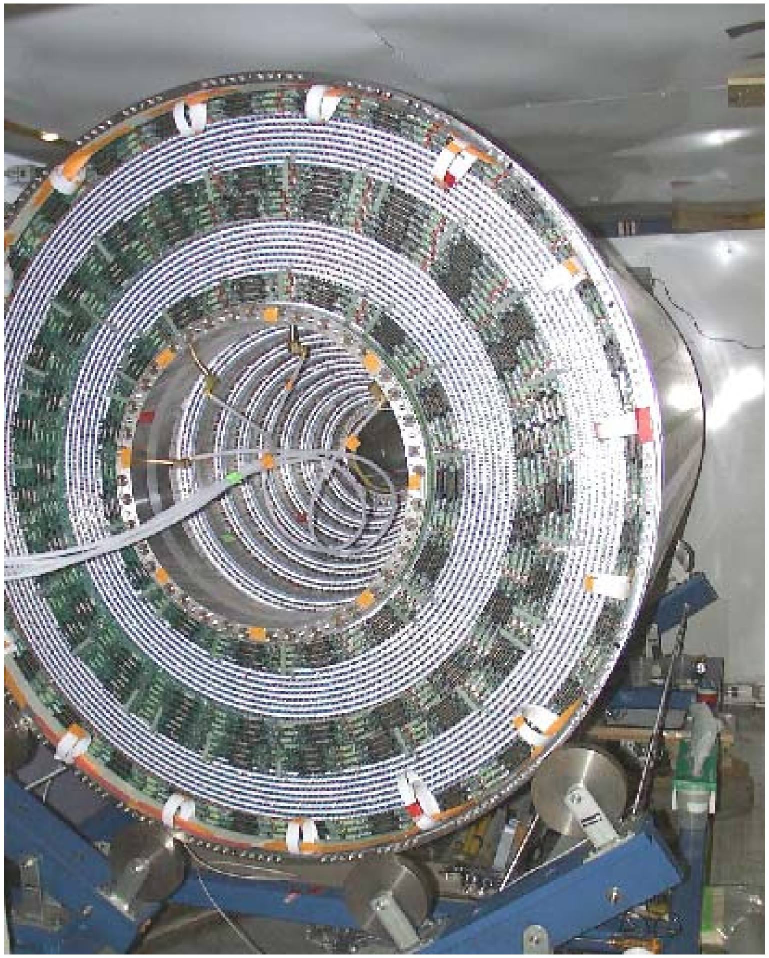
minimal radiating material:
particle ID
end cap CsI calorimeter

momentum resolution
as good at CLEO-II

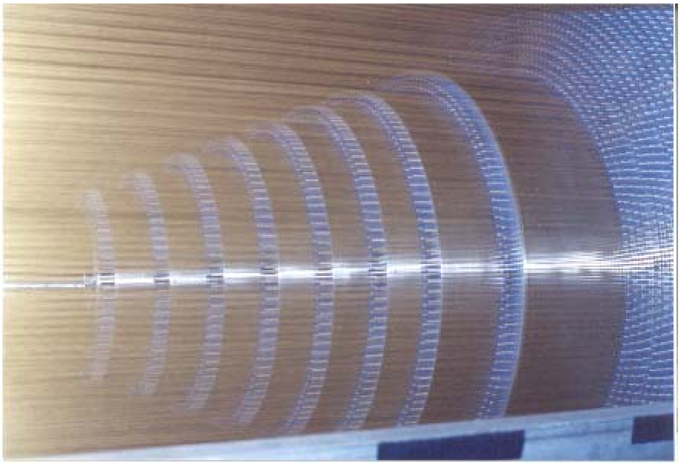
- uninterrupted tracking length
  0.12% X_0 inner wall

- improved spatial resolution
  cell improvements…

DR 3

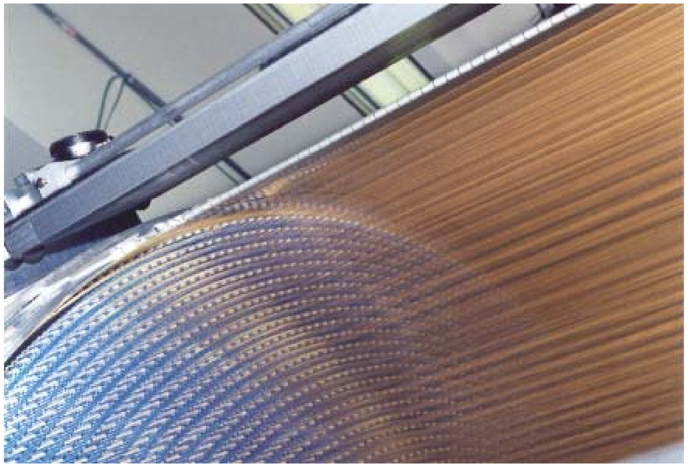


CLEO III/c drift chamber
1999 – present
Design/Construction: 1992 - 1999



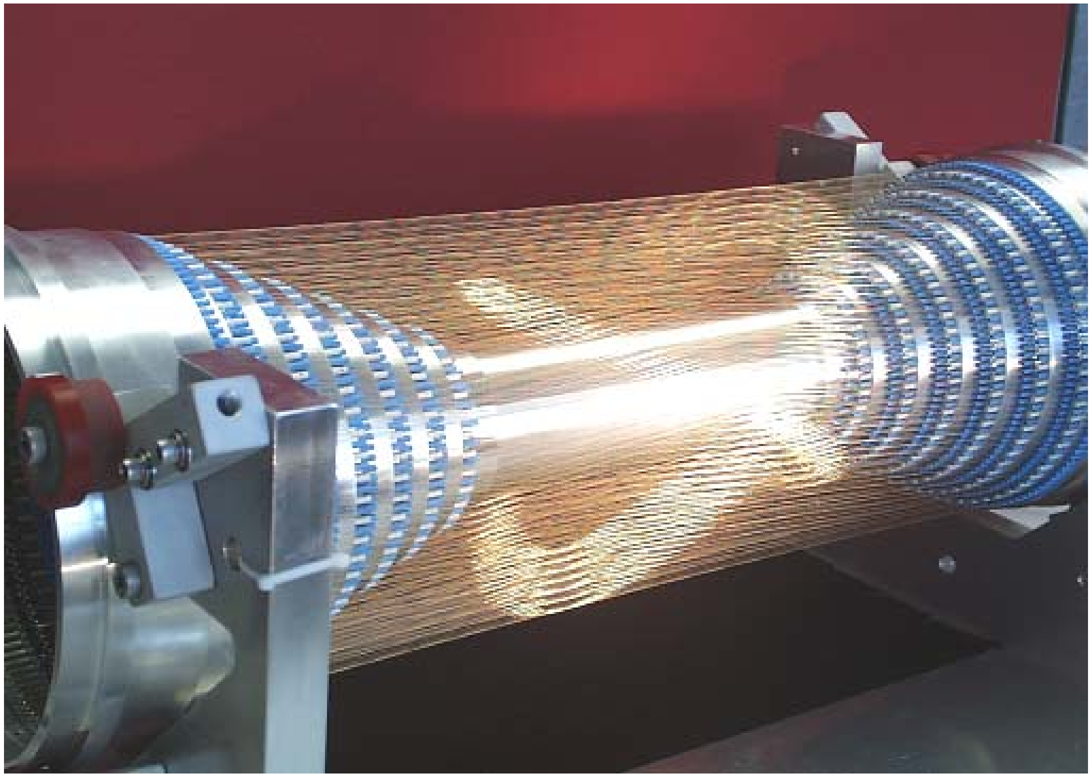
“wedding cake” structure; individual rings and bands

The conical “big” plate deforms < 1mm.



outer cathode

ZD



CLEO c inner drift chamber
2003 – present
Design/Construction: 2001 - 2003

Goals:

momentum resolution, σ_p/p, $p < 1$ GeV,
equivalent to that of DR3 + silicon, 0.33% at 1 GeV

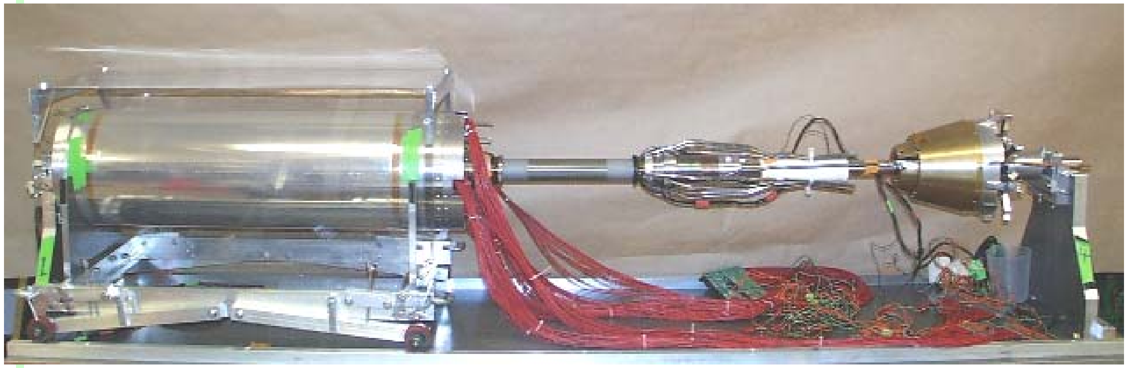
Z_0 resolution consistent with charm physics near threshold: 0.7 mm

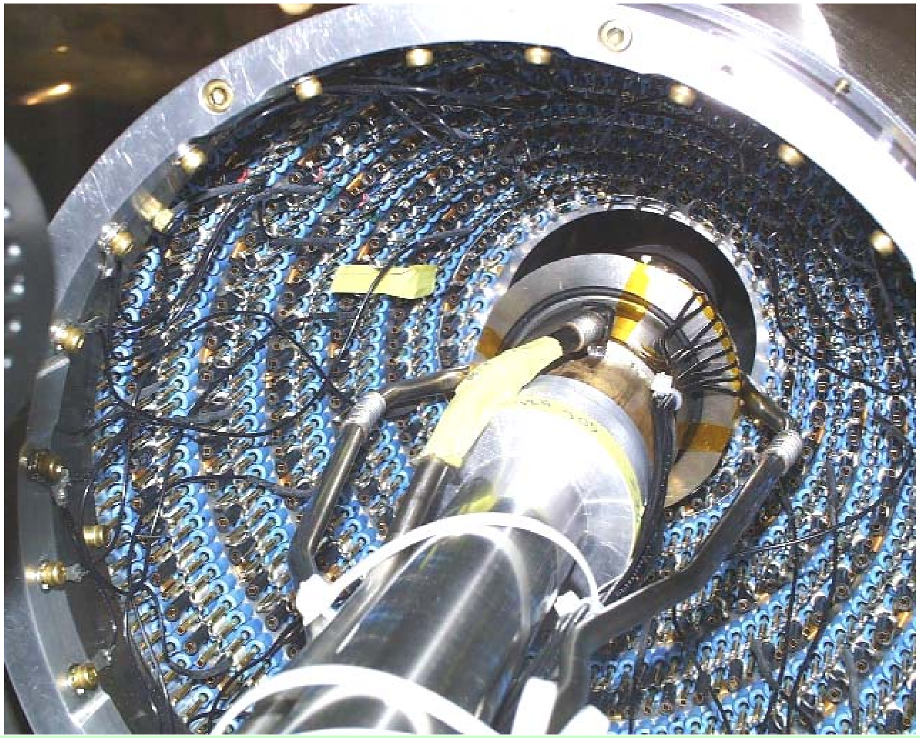
Features:

very large stereo angle: $d(r\phi)/dz = 0.1$
0.01 % X_0 outer wall (0.12 % in DR3 inner wall) provides continuous volume

ZD installation

an integrated assembly involving
tracking and vacuum groups





The interaction vacuum chamber (2 layer beryllium, fluid cooled) was originally designed for installation with the <u>clam-shelled</u> Si-3 detector.

The vacuum chamber was retrofitted into the ZD chamber retaining all

- cooling,
- radiation monitoring, and
- tungsten masking.

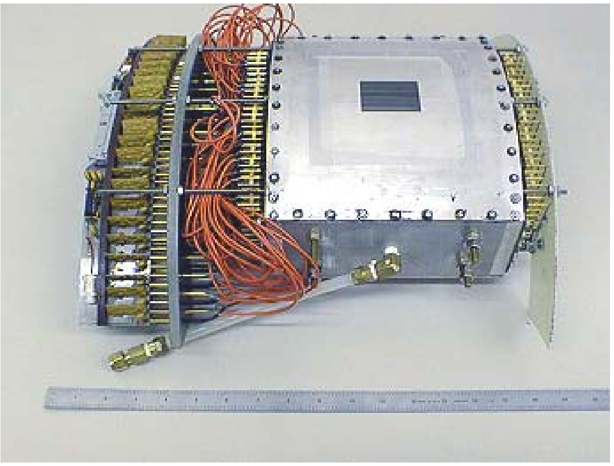
A boat-in-a-bottle problem.

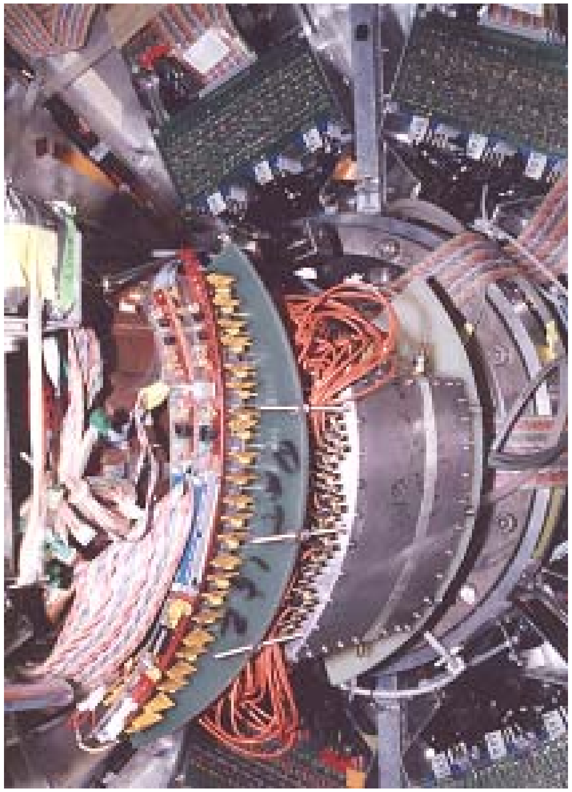
Working with our **drafting dept.,** down-time was reduced by 3-D modeling the installation steps.

Test Chambers

several test chambers; this shows two

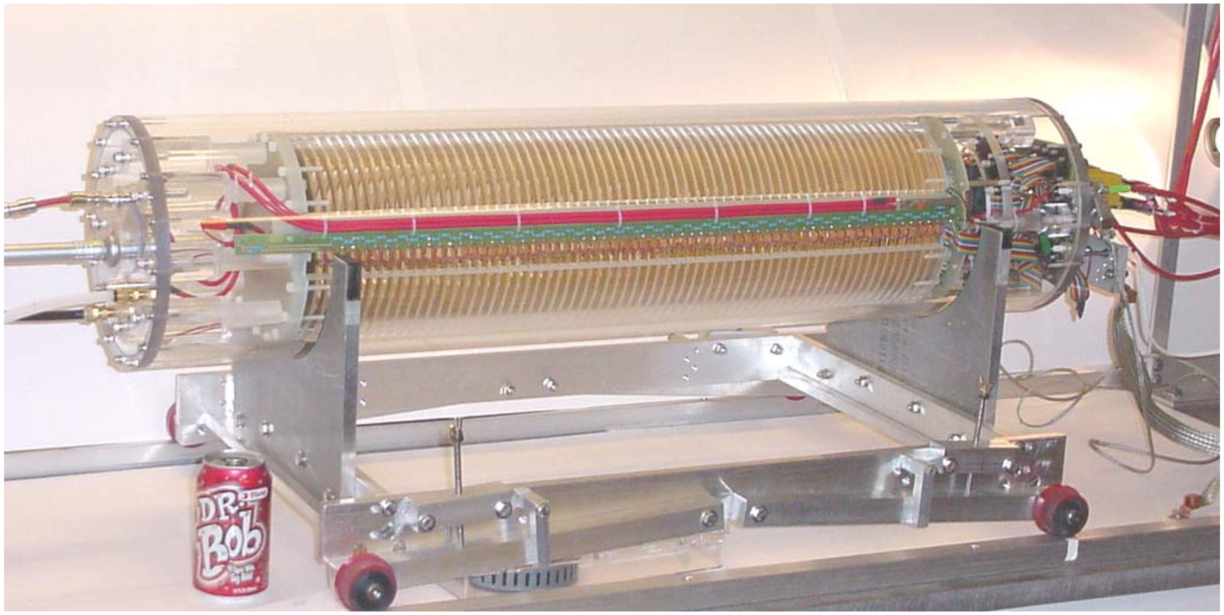
10-layer device for
measuring helium based gasses in the CLEO B-field
fitted in the endcap, strapped to the final quadrupole
3:1 square and 3:1 hexagon chamber were tested

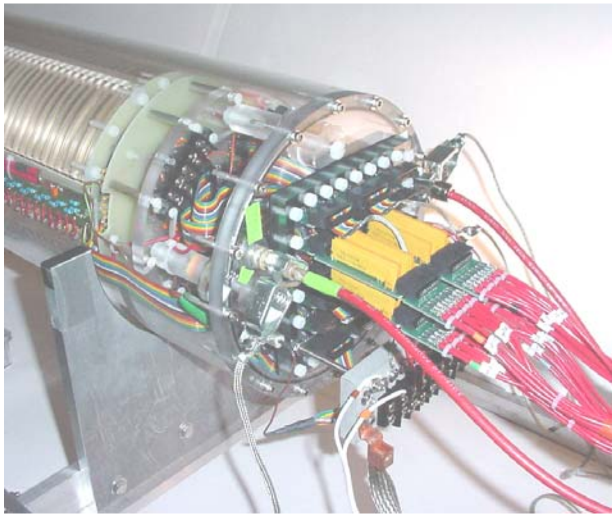




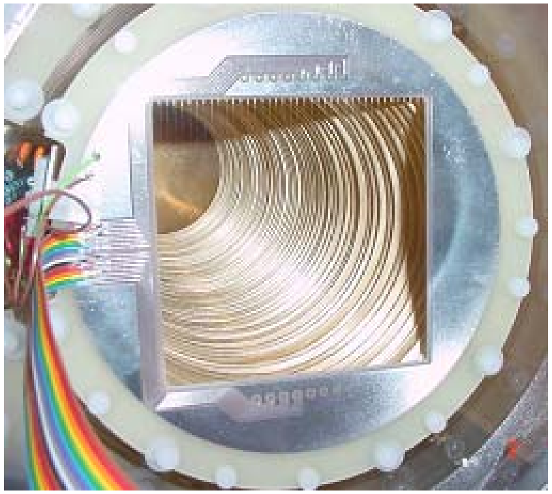
3-layer device to measure the ability
to control beam backgrounds at very low radius
inserted inside the, then, existing beam pipe ↓

Linear Collider TPC R&D

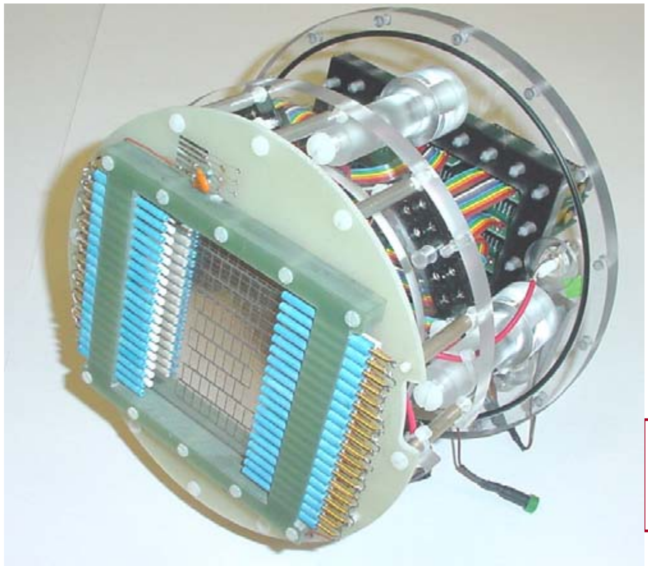




TPC field cage, 64 cm, 20KV



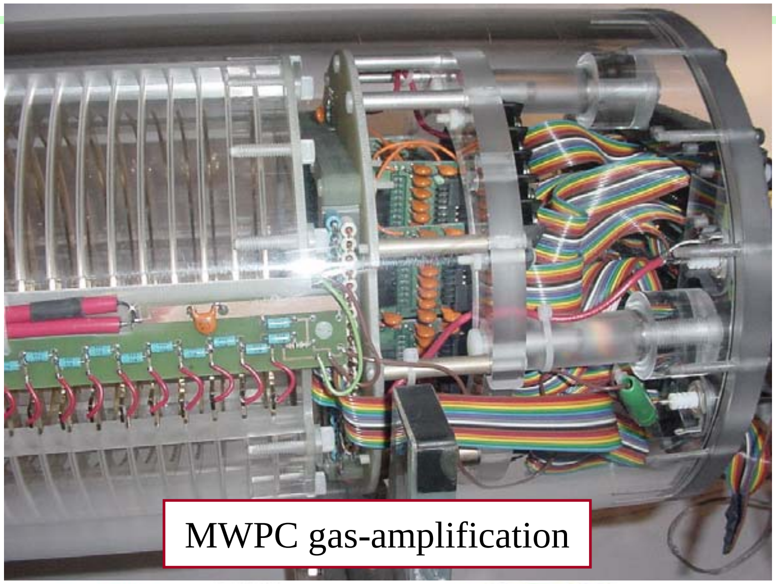
field cage termination, wire grid

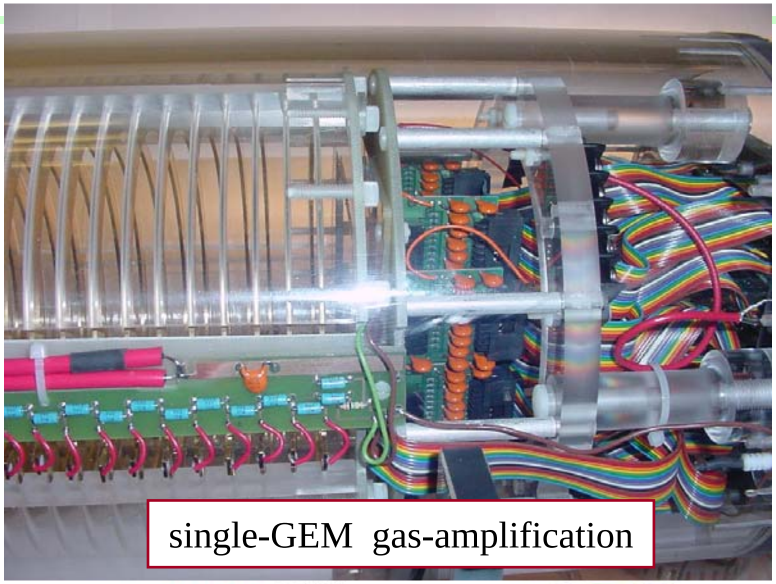


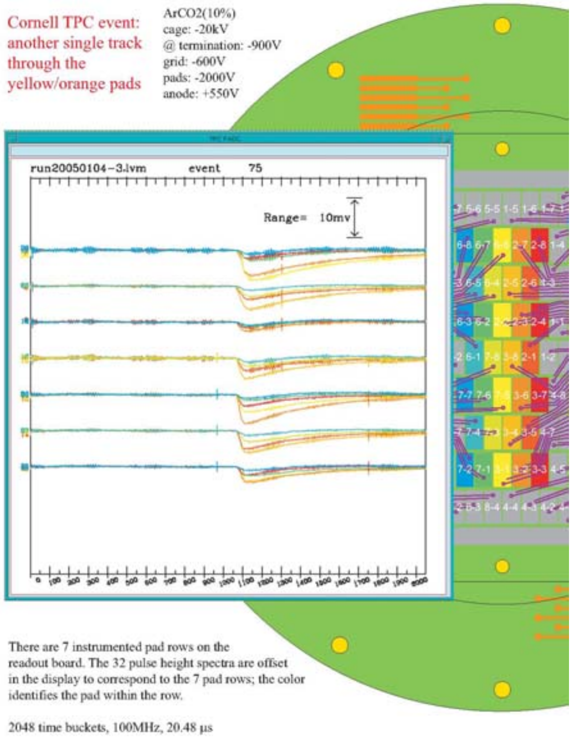
wire gas-amplification stage, readout pads

TPC R&D is in collaboration with Ian Shipsey's group at Purdue who will provide the MPGD (GEM and MicroMegas) avalanche stages.

Linear Collider TPC R&D


MWPC gas-amplification


single-GEM gas-amplification


Cornell TPC event:
another single track
through the
yellow/orange pads

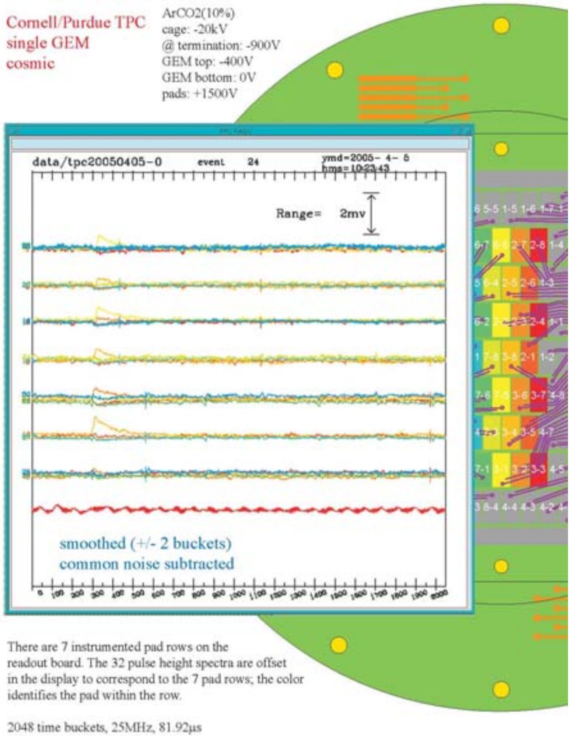
ArCO2(10%)
cage: -20kV
@ termination: -900V
grid: -600V
pads: -2000V
anode: +550V

run20050104-3.lvm event 75

Range= 10mv

There are 7 instrumented pad rows on the readout board. The 32 pulse height spectra are offset in the display to correspond to the 7 pad rows; the color identifies the pad within the row.

2048 time buckets, 100MHz, 20.48 µs


Cornell/Purdue TPC
single GEM
cosmic

ArCO2(10%)
cage: -20kV
@ termination: -900V
GEM top: -400V
GEM bottom: 0V
pads: +1500V

data/tpc20050405-0 event 24 ymd=2005- 4- 5 hms=10:23:43

Range= 2mv

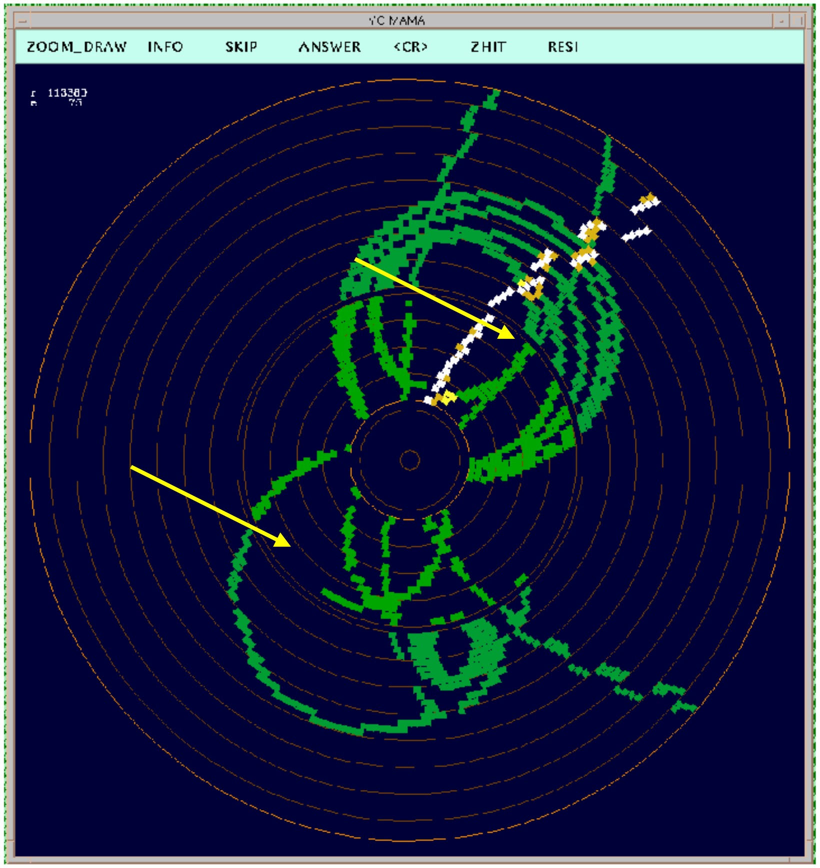
smoothed (+/- 2 buckets)
common noise subtracted

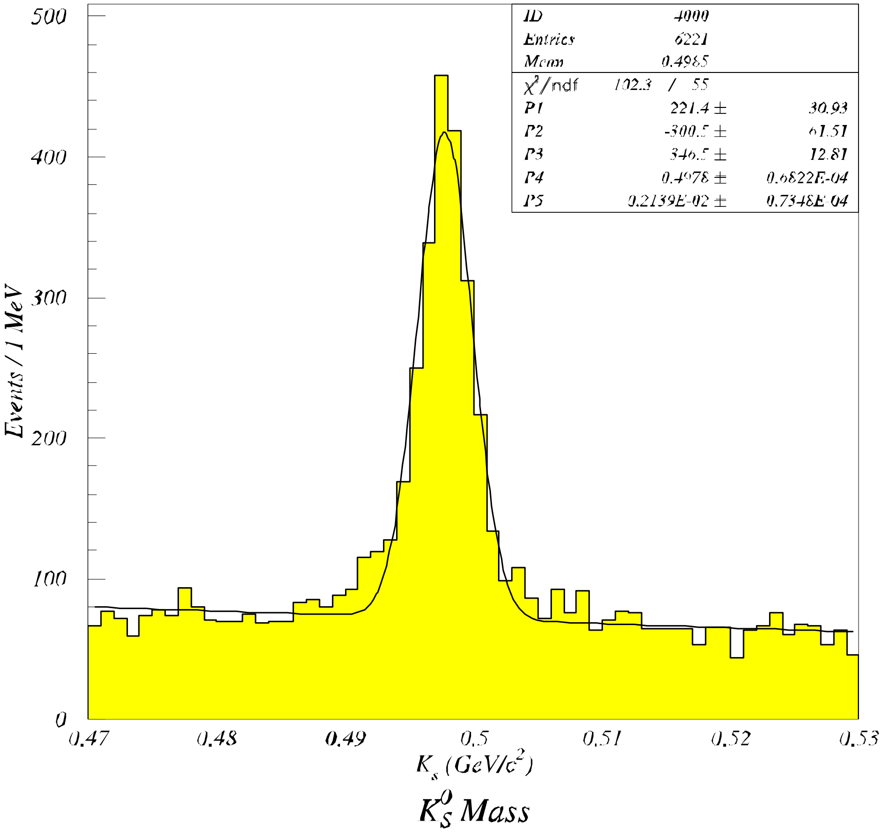
There are 7 instrumented pad rows on the readout board. The 32 pulse height spectra are offset in the display to correspond to the 7 pad rows; the color identifies the pad within the row.

2048 time buckets, 25MHz, 81.92µs

Track Reconstruction

How to we transform the hardware signals
(times and pulse heights, threshold discriminated)
to a product that provides some insight into a physical process ?





Pattern recognition

Various methods:

Some depend on intrinsic resolution, at some level requiring 3 points define circle (globally or locally).

This will probably be the case for the LHC pixel detectors; layer-layer spacing >> track separation.

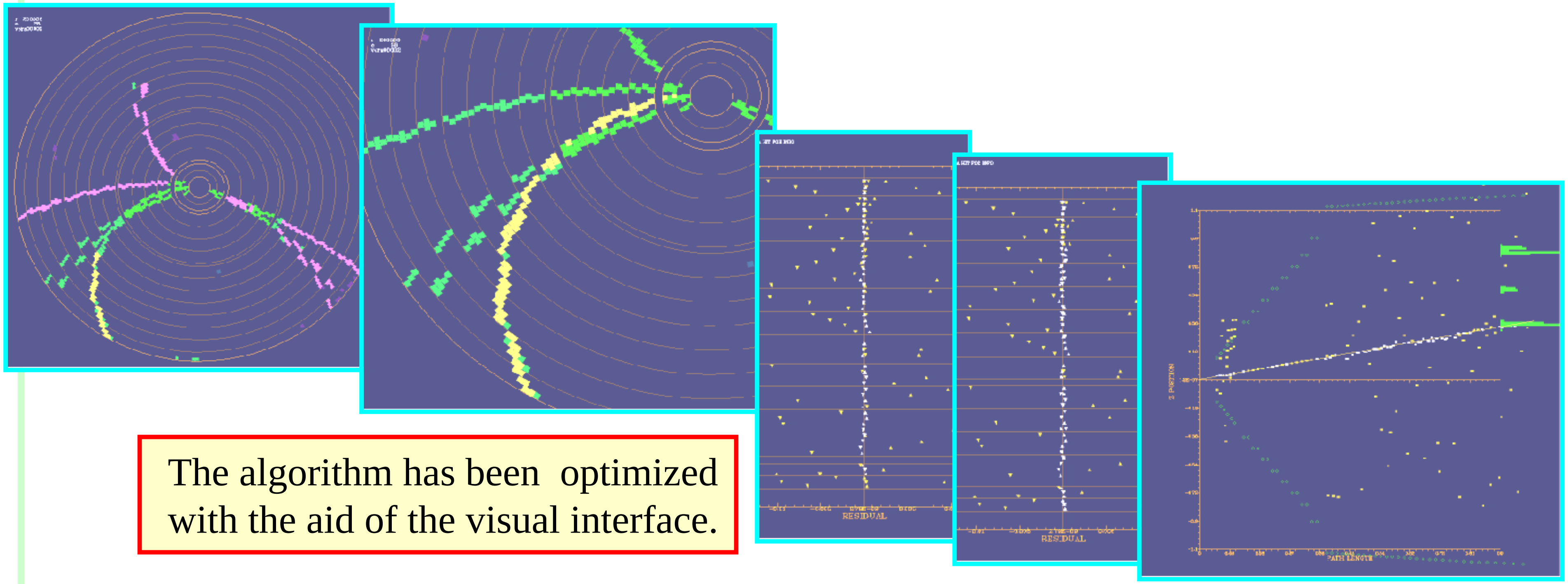
Our current method does not depend on intrinsic resolution to seed the track.

The method uses local chains of isolated hits at cell level,

extends into noisier regions,

then applies local-ambiguity-resolution using the precision information,

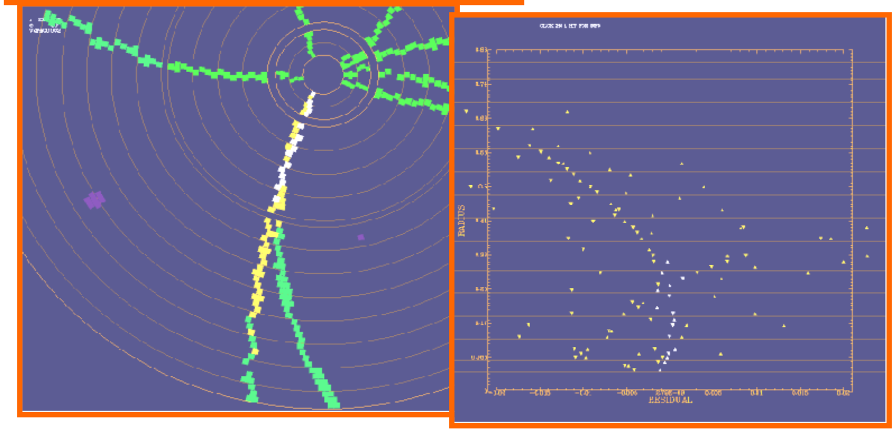
extends and adds still unidentified hits, now using precision information.



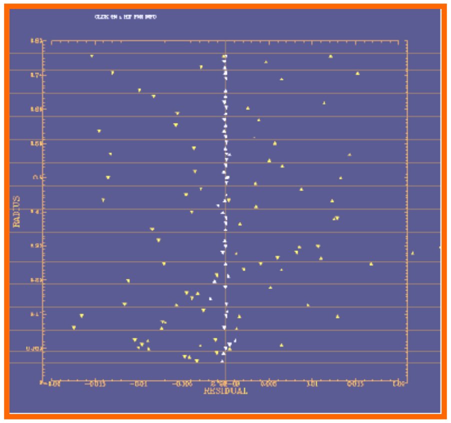
The algorithm has been optimized with the aid of the visual interface.

Pattern recognition pathologies, some examples

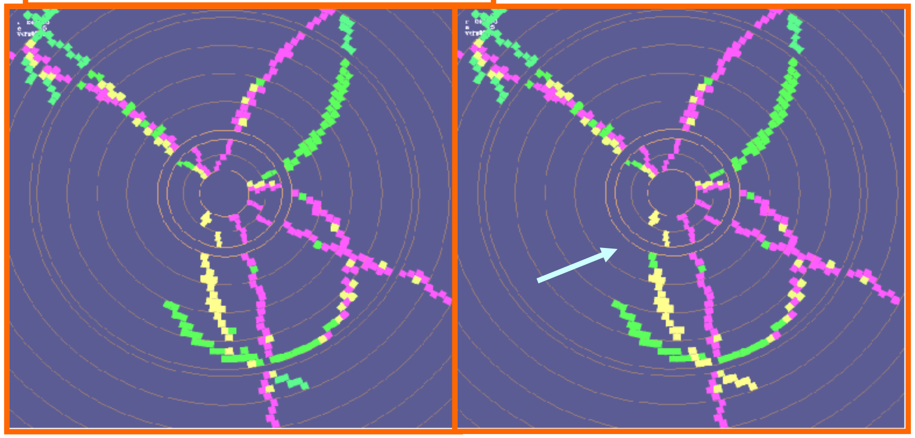
a) significant track overlap



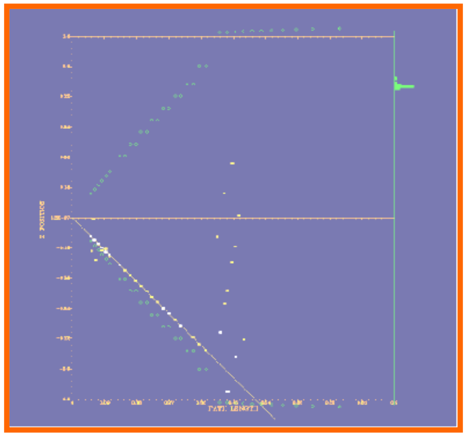
Loop:
initiate the
local-ambiguity-resolution
with a range of
dZ hypotheses.



b) complexity in the ZD

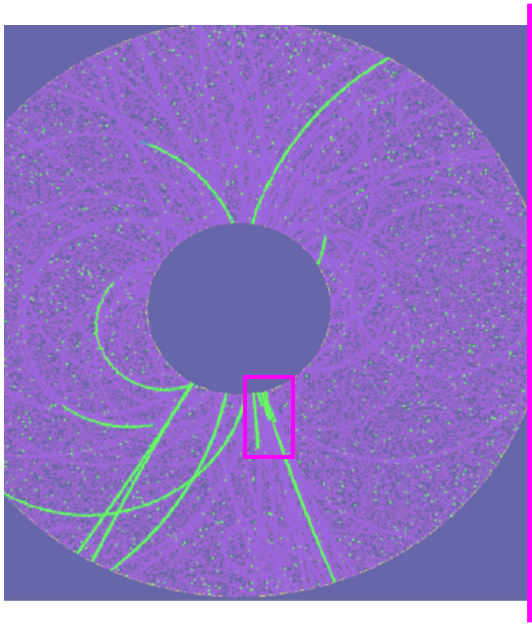


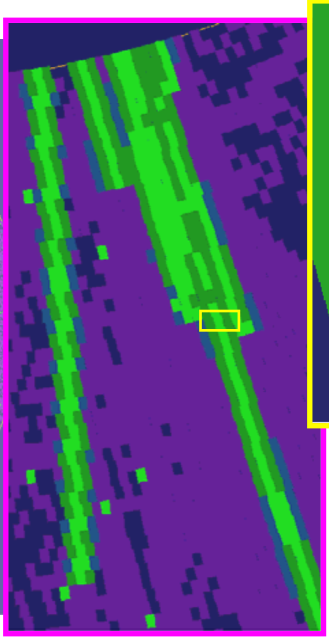
Loop:
initiate the
chain-finding
with a range of
dZ hypotheses.

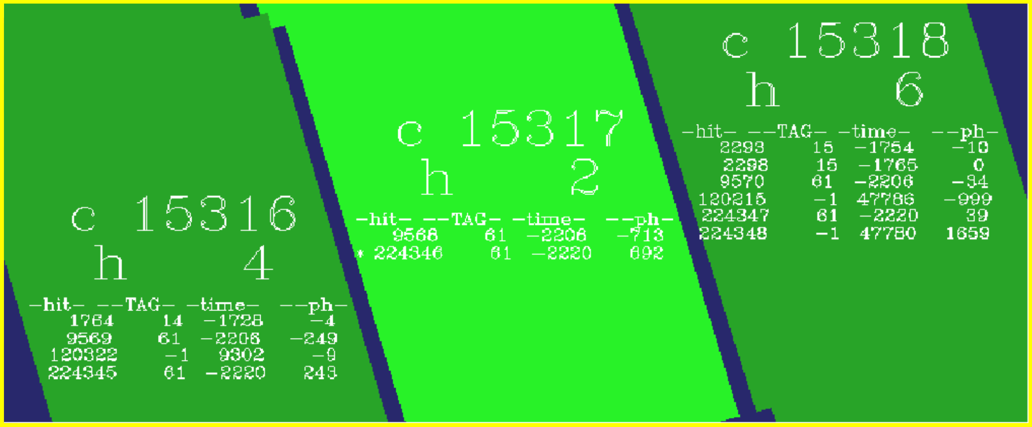


c) decays in flight: use tests with artificially shortened chamber radius, require decreased χ^2

CLEO pattern recognition, application to a Linear Collider TPC

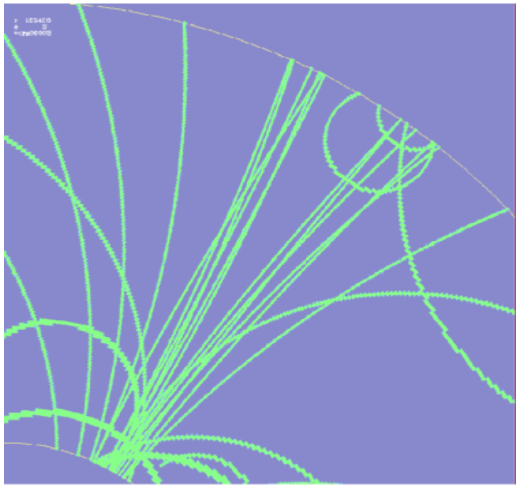






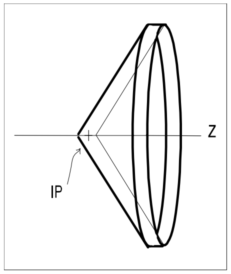
```
c 15316
h     4
-hit- --TAG- -time- --ph-
  1764    14  -1728    -4
  9569    61  -2206  -249
120322    -1   9302    -9
224345    61  -2220   243

c 15317
h     2
-hit- --TAG- -time- --ph-
  9568    61  -2206  -713
* 224346  61  -2220   692

c 15318
h     6
-hit- --TAG- -time- --ph-
  2293    15  -1754   -10
  2298    15  -1765     0
  9570    61  -2206   -34
120215    -1  47786  -999
224347    61  -2220    39
224348    -1  47780  1659
```

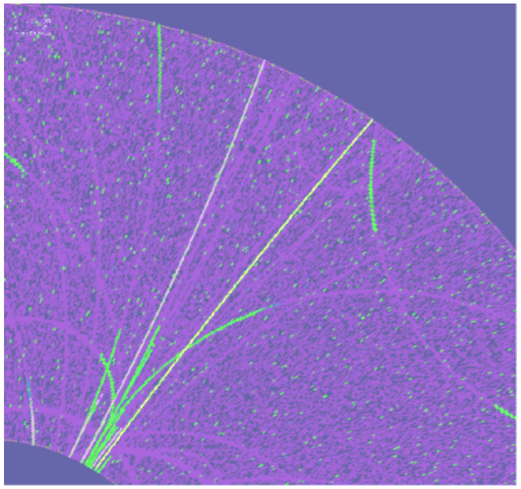
Cell count and track density are greatly increased.
Cells are multi-hit; time provides the z information.
At the cell level, pattern recognition is similar.
Only the means of extracting precision x,y,x
information is different.



Scanning initial Z assumptions
greatly reduces
event complexity.

The program structure for the
scan was first developed for
the TPC,
then applied to the ZD scan (prev. slide).





Kalman Fitting

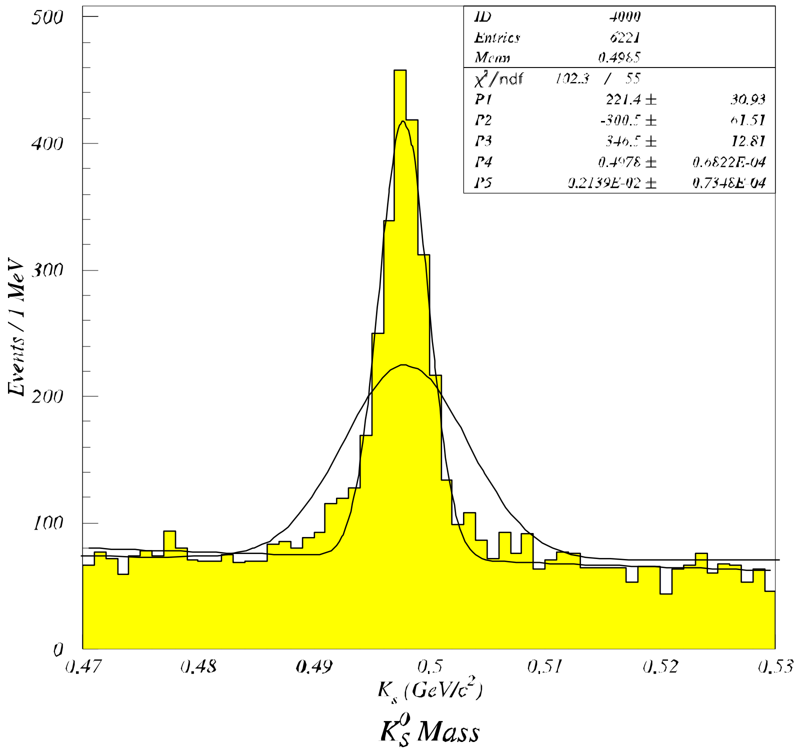
The Kalman fit

compensates for
- energy loss
- degradation of information due to scattering.

This is the CLEO final fit and, therefore, includes
- calibration,
- alignment,
- fitting weights, and hit deletion.

Our implementation also provides utilities to
delete non-physical hits in a neutral decay hypothesis
and refit.

One of the authors (Ryd) of the original CLEO II program
and the sole author (Sun) of the CLEO III/c program
are current members of the Cornell group.



Resolution improvement: (CLEO III)

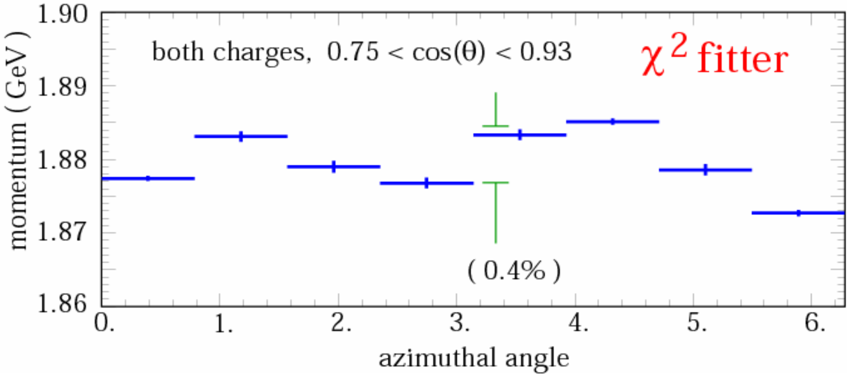
Using tracks from the finder (χ^2 fits in projections, corrected to vertex): K^0 resolution is $\sigma \simeq 5$ Mev.

After Kalman fitter: K^0 resolution is $\sigma \simeq 2$ Mev.

Kalman Fitting

The Kalman fit

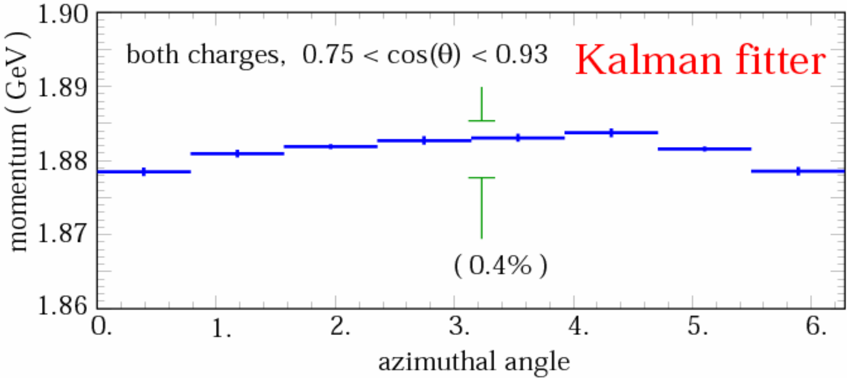
is a transport method and, therefore,
inherently allows
application of a magnetic field map.



CLEO III (c) has a
1.5 (1.0) Tesla solenoid field.

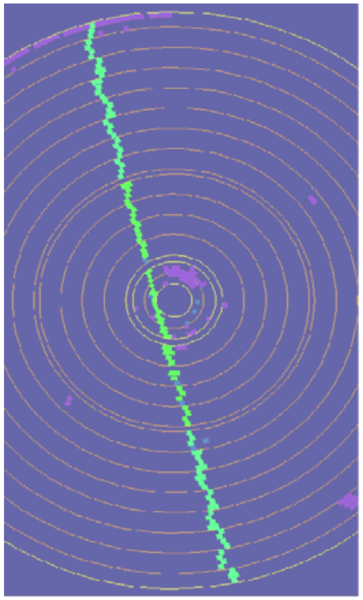
The magnetic field is distorted by the
fringe field of the final focus quadrupoles (slide 5)
causing a 2-cycle momentum dependence.

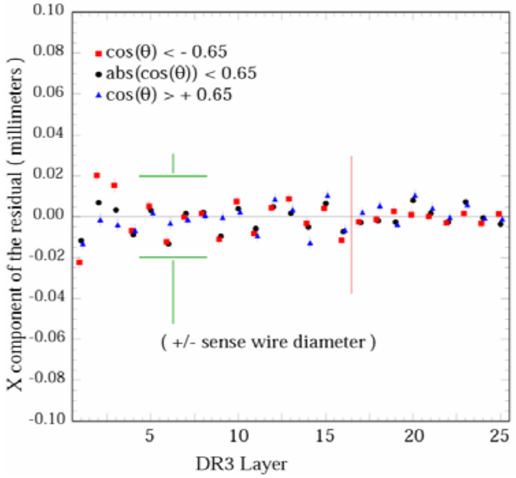
This is corrected in the Kalman fit.

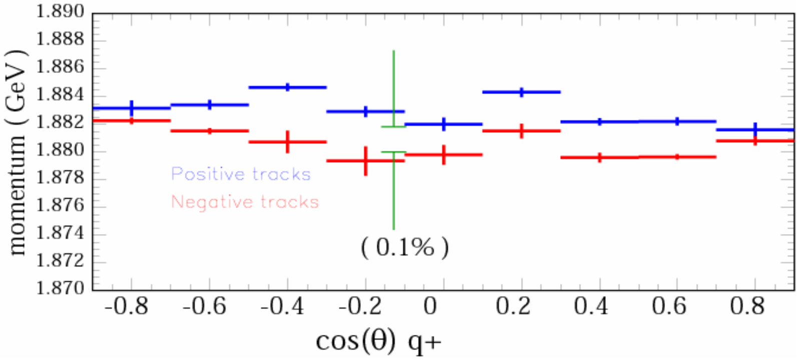


(The residual 1-cycle momentum dependence
is due to the crossing angle)

alignment







many parameter problem:

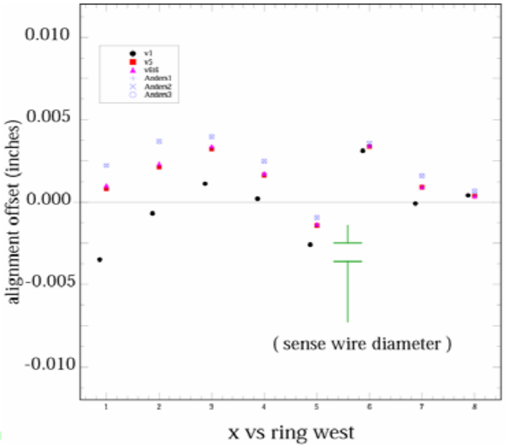
2 ends - big plates, 8 small plates, ZD plates

3 variables: δx, δy, $\delta\phi_z$

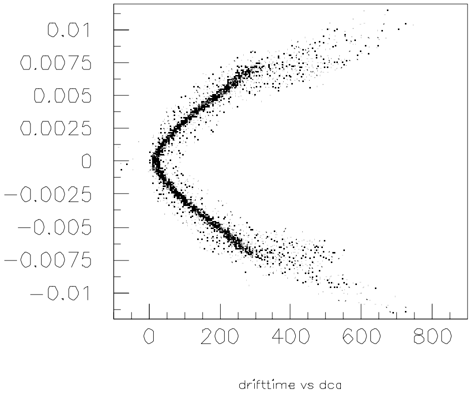
start with precision optical measurements before stringing
finish with clean data: Bhabha and mu pairs, cosmics.

sensible constraints: optical survey, mechanical tolerances
for example: big-plate-to-big-plate twist ,
the optical measure is superior to track measures

decoupled from calibration as much as possible;
use symmetric drift region.



Calibration, Spatial Resolution



Residuals: time-measured hit position are compared to the fitted position.

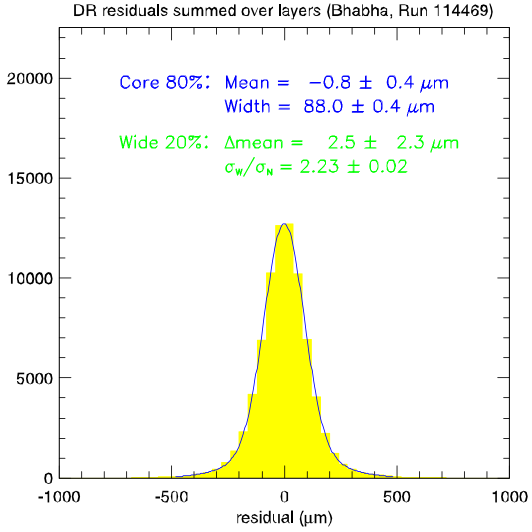
Parameterized as double gaussian with fixed 80% fraction in narrow component.

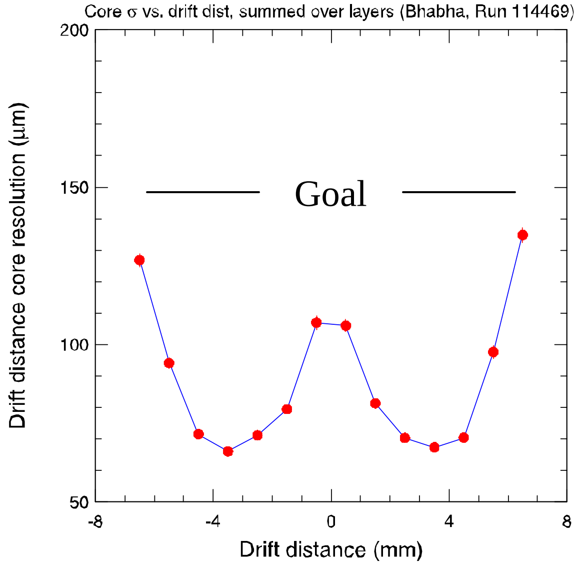
Narrow component:

σ=88 μm (average over entire cell)

wide component: 200 μm

average : 110 μm (Goal: 150 μm)





Narrow component of resolution
w.r.t drift distance

65 μm minimum: due to calibration

135 μm at cell edge: due to cell improvements

Silicon Reconstruction Issues

Our experiences in track-finding and alignment have been within the context of a drift chamber tracking system.

(As is the case with most groups, except for specialty VD tracking.)

The track finding is aided by having closely spaced hits; this allows us to not rely on the intrinsic resolution.

The silicon hit identification has been done by extrapolating the drift chamber track into the silicon.

Similarly, silicon alignment was aided by using the drift chamber to define a line parallel to, but not necessarily through, the silicon hits.

The all-silicon trackers* present new challenges.

(* including ILC SiD)

Within a dense jet,

track-finding will rely on the intrinsic resolution.

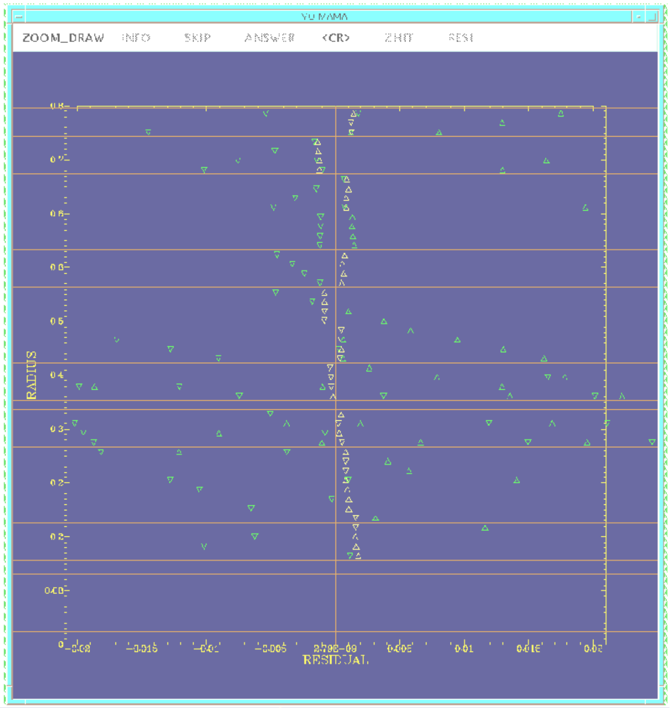
But, **alignment correction $\gtrsim$ intrinsic resolution** .

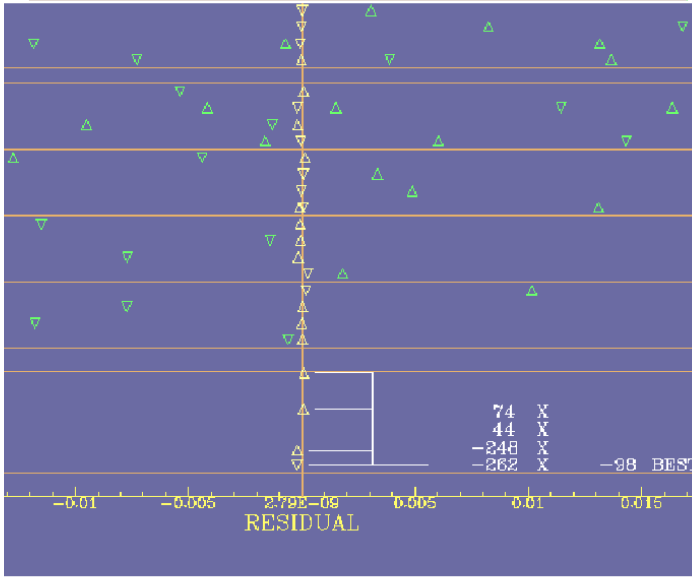
θ_{ms} * extrapolation distance ?>? intrinsic resolution

track separation $\lesssim$ intrinsic resolution .

Success requires **(several)** new approaches from several groups.

A visual interface to the algorithms could expedite that success.





in conclusion …

We have a successful program in charged particle tracking

We are **involved in every aspect** of tracking:
hardware, commissioning, reconstruction, fitting, calibration, alignment .

We approach **calibrations and alignment** with **hardware** experience.
(It is the same people.)

We have implemented a **visual interface** to **resolve pathologies**
in track-reconstruction, this optimizing the efficiency.

We have benefited by **working closely with the machine group** for
an integrated hardware design
an understanding of backgrounds.

We have extensive **technical support**,
both with our **in-house** mechanical and electronics shops,
and due to our experience working with **outside vendors**.