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

Two talks will describe the chambers, electronics, calibration and reconstruction of charged particles in CLEO.
components

Detector hardware
Readout electronics
Online calibration Thresholds, maintenance
Beam bunch resolving
Offline calibration
Detector alignment
Reconstruction Pattern recognition
Reconstruction fitting
physics
CLEO I drift chamber
1979 – 1986
Construction: 1977-1979

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
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).
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…
“wedding cake” structure; individual rings and bands
The conical “big” plate deforms < 1mm.

CLEO III/c drift chamber
1999 – present

outer cathode
In a magnetic field, a non-uniform up-down electric field would be rotated into a left-right asymmetry.

Adjust the sense wire position to compensate for non-uniform field wire density. Drift cells are then electrically symmetric in the “r” direction (up-down) direction.

Left-right asymmetries are greatly reduced; calibration is simplified. Field wire phase is not important.
Layer Design

Maximize number of measurements:
AXIAL-STEREO interfaces, which require separate field layers or create distorted cell geometry, are limited by grouping stereo layers together.

47 layers
16 axial layers in stepped section
  arranged in 8 groups of 2 layers
  constant number of cells,
  half-cell-stagger

31 stereo layers in outer section
  arranged in 8 super-layers,
  constant number of cells,
  half-cell-stagger
  \( d(r\phi)/dz \sim 0.02 - 0.03 \), alternating sign,
  nearly constant hyperbolic sag

Cell shape constant over the length of the chamber
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:
\[ \sigma = 88 \, \mu m \text{ (average over entire cell)} \]
wide component: 200 \, \mu m
average: 110 \, \mu m \text{ (Goal: 150 \, \mu m) }

Narrow component of resolution w.r.t drift distance
65 \, \mu m minimum: due to calibration (next talk)
135 \, \mu m at cell edge: due to cell improvements
Goals:
  momentum resolution, $\sigma_p/p$, $p < 1$ 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 clam-shelled 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.
Cornell Influence

ZEUS:
- drift chamber design: influenced by CLEOII
- crimp pins: copied design and (Swiss) vendor

BaBar:
- general advice:
- endplate manufacture:
  
  *Cornell is aggressive in pursuing vendors and working with vendors to develop processes to meet our requirements.*

  BaBar had their drift chamber endplate fabricated at the commercial machine shop trained by Cornell.

  (Photo shows DPP measuring the BaBar endplate at the commercial machine shop.)

BESIII:
- design of inner endplate cone
- crimp pins: copied design and (US) vendor
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 avalanche stage, readout pads
readout end assembly, incl. feedthroughs

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

significant track overlap

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

decays in flight: use tests with artificially shortened chamber radius, require decreased $\chi^2$

complexity in the ZD

Loop: initiate the chain-finding with a range of dZ hypotheses.
CLEO pattern recognition, application to a Linear Collider TPC

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,z information is different.

Scanning of the Z assumption greatly reduces event complexity.

The program structure for the scan was first developed for the TPC, then applied to the ZD scan.
Kalman Fitting

The Kalman fit compensates for energy loss degradation of information due to scattering.

Transport method inherently allows application of a magnetic field map.

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

One of the authors of the original CLEO II program and the author of the CLEO III program are current members of the Cornell group.
many parameter problem:

2 ends - big plates, 8 small plates, ZD plates
3 variables: $\delta x, \delta y, \delta \phi_z$

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. (This is a large region due to cell.)
Last Slide!

Successful program in charged particle tracking

We are involved in every aspect of tracking.

Hardware designs are influenced by our calibration experience.
We approach calibrations and alignment with hardware experience.
It is the same people.

Track reconstruction is developed using a visual interface to quickly resolve pathologies.

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

We have extensive technical support.
But, when a job is beyond our machine shops, we work with vendors.
“Visit your vendors early and often.”