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  
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
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…
CLEO III/c drift chamber
1999 – present

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

outer cathode
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: $d(\phi)/dz = 0.1$
- 0.01 % $X_0$ outer wall (0.12 % in DR3 inner wall) provides continuous volume
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.
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

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

field cage termination, wire grid

wire gas-amplification stage, readout pads
Linear Collider TPC R&D

MWPC gas-amplification

There are 7 instrumental 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.

D. Peterson, tracking presentation to CMS representatives 15-April-2005
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,

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 $\chi^2$
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 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 (χ² fits in projections, corrected to vertex): K⁰ resolution is $\sigma \approx 5$ Mev.

After Kalman fitter: K⁰ resolution is $\sigma \approx 2$ 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: $\delta x$, $\delta y$, $\delta \phi_z$

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.
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
135 \, \mu m 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 \( \approx \) 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.