Alignment experience at CDF
Aart Heijboer
University of Pennsylvania

for the CDF tracking group
many thanks to Raymond Culberston (fnal)
Overview of CDF

tracking system:
- pretty good approximation
- COT measures the curvature
- Si measures the impact Parameter
COT

- 30K sense wires, 96 layers,
- r=41cm to 135cm, drift chamber
- 12-wire cells, tilted for Lor. angle
- \( \frac{1}{2} \) are 2° stereo
- \( \sigma(p_T) = 0.15\% \ p_T^2 \)
COT alignment

starting point:
- assembly specifications, plus
- finite element analysis to model
  - end plate distortion
  - 1.6” aluminium with 5040 slots for wire planes and sheets
  - wires and field sheets under tension: 36 Tons of force
  - deformations of 0.6 cm
- effects of gravity and electrostatic forces on wire positions modeled

E = 2.4 kV/cm
Amplitude = 117 microns
Offset = 84 microns
COT alignment

- cosmics: fit single helix to both in and out-going legs
- For each cell, fit:
  - fwest, feast
  - tilt of wires in the cell

residual along track direction

\[ \Delta Y (\mu m) \]

compare to hit-resolution of \(~140 \mu\)
COT alignment

'false curvature' correction
- r-dependent offset
- compare E/p for e^+ e^- and derive correction

recently: better understood
- additional z-dependence
- new COT alignment used for W-mass analysis (has smaller false curvature correction)

also: many tests done with J/ψ to derive a posteriori corrections
CDF Silicon Detector

- **Run II Silicon**
  - 7-8 Silicon Layers
  - 722,432 Channels / 1008 Ladders / 5456 Chips
  - 6 m² of Silicon
  - Designed to last for 2-3 fb⁻¹

- Silicon detector comprised of three (mechanically) separated
  - Layer-00
  - SVX II
  - Intermediate silicon layer: ISL
SVX II

- The core of the CDF Silicon Detector
- 2.5 to 10.6 cm in radius
- 5 layers of double-sided silicon
  - 3 layers with axial & $90^\circ$ stereo strips (1,2,4)
  - 2 layers with axial & $1.2^\circ$ stereo strip (3,5)
- Strip pitch from 60$\mu$m to 140$\mu$m
- highly symmetric: 12 wedges x 3 barrels

360 Ladders / 3168 chips
Intermediate Silicon Layer (ISL)

- small angle stereo,
- One central layer (|\(\eta|<1\))
  - Links tracks from SVX to Wire-Chamber (COT)
- Two forward layers (1<|\(\eta|<2\))
  - Allows tracking at high \(\eta\)
- Strip Pitch:
  - 112\(\mu\)m (axial & stereo)
Layer-00

- Precision position measurements
  - 2x25 µm effective strip pitch
  - Low Mass: 0.6%-1.0% $X_0$
  - Mounted directly on Be beam-pipe
- Actively cooled
- Rad-Hard Silicon
  - Can be biased to 500V
  - Likely to outlive inner most SVXII layer

300µm installation clearance

72 Ladders / 108 chips
'online' alignment / positioning
Silicon Vertex Trigger (SVT)

- For the first time, a silicon detector is used in the online (L2) trigger
- The SVT takes data directly from the SVX
  - Does fast track reconstruction using a set of templates
  - Looks for displaced vertices
  - Great for heavy quark tagging
- Uses 4/5 ladders in one SVX wedge
- Requires good SVX alignment
  - 100 $\mu$rads with respect to beam line

- Trigger on events with two displaced ($d>120 \ \mu m$) tracks
- Foundation for large part of b-physics program
- Takes data directly from SVX
- Si track reconstruction at L2 trigger
- Pattern search requires
  - straight SVX positioning wrt beamline (100 $\mu$rads)
  - no wedge-crossers -> keep beam in middle

- Very fast reconstruction of silicon data at L2 (20$\mu$s latency) by dedicated hardware: SVT
Active positioning system

- Mission: Keep silicon tracker aligned parallel with beam full scale ~ 20micron
  - active movement
  - clamping mechanism
- supported weight:
  - designed for 50-80kg Silicon
  - actual weight: 110 kg + 70 from cables
- system cannot handle the weight
- Successfully used to move Si to coincide with Tevatron beam in 2001 with some manual help to take weight off). Crucial for displaced track trigger.
- Since then, not operated anymore, but still **passively** supporting Si
Real time monitoring system (RASNIK)

- 17 systems deployed throughout tracking volume
- Some not anymore operational due to line of sight blocked by cables during shutdown ;-(
- Not used much anymore
  - not needed: detector is quite stable
  - some false 'alarms' due to movement of projector

- Maintaining expertise is becoming an issue here too.
'offline' alignment
Assembly and survey data

- Surveys performed at each stage of assembly:
  - ladders measured before/after they were put on barrels
  - barrel-to-barrel measurements
  - ISL vs SVX vs L00
- Ladder survey showed:
  - ladders bowing & 'kinking' at wafer boundaries.
    - solution: align at wafer-level
  - individual wafers not flat either
  - additional DOFSs in database:
    - wafer warp: wafer height vs z, rφ (quadratic par.)
- Wafer warps are only numbers that remain from survey data all other dofs have been remeasured offline.
- Survey data gave us excellent starting point: *pattern recognition works*.
  - but not used as constraint.
SVX Internal alignment

- Start from assembly.
  - was very good
  - 10 μ in rφ, / 40 μ in r

Philosophy:
- make ntuples with hit information
- store residuals wrt to track fit
  - simple, fast refits on residuals
  - different fit possible
    - Fix curv from COT, fix track at layer 5 hit and SVX beamline
    - N-1 unbiased tracks
    - COT tracks / biases tracks etc

- simple algorithm
  - 'one thing at a time'
    - wafer -> ladder -> wedge, global
    - db design follows this
  - need to iterate a few times
    - for pattern recognition & non-linearities & ....
SVX alignment algorithm

Define local coordinates at wafer center: r, z, φ

\[ \Delta = -T_\phi + \tan(\alpha)T_r + zA_\phi + \tan(\alpha)zA_\phi - \tan(\alpha)\phi A_z \]

ϕ residual to first order given by:

χ² minimisation → inversion of 5x5 matrix consisting of simple sums of the residuals.
Alignment Algorithm

matrix inversion boils down to...

$T_\phi = \langle \Delta \rangle$

$R_z = \langle \phi \Delta \rangle$

$T_r = \langle \tan(\alpha) \Delta \rangle$
Remaining degrees of freedom

Basically some as internal, using $\Delta \phi$ wrt COT tracks
- rotation about z-axis
  - compare fitted $\phi$ of SVX and COT tracks
- venetian blind
  - compare fitted $\phi$ of SVX and COT tracks
    as function of $\phi$
- overall scale
  - again SVX vs COT $\phi$ as function of $\phi$
  - overlap residuals... tricky
    - overlap region very small in all but 2 layers
    - residuals behave differently (i.e. weird)
      very close to edge.
  - not fully consistent with internal alignment
    (e.g. z-dependence conflicts with rotation
    measurement of individual wafers)
  - understood to $O(10 \mu)$
  - lifetime measurements compute systematic on r-scale
    by scaling all Si by $50 \mu$ -> very small effect ($50 \mu/10 \text{cm}<10^{-3}$)
Z-alignment

- Align the 90 deg layers to each other
  - track trough L1 and L4, fit L2
- Small-angle stereo
  - found that stereo angle was wrong: variable outside specs and offset
  - z-scale fixed by measuring distance between barrels (could also use COT, but COT z-scale very well known)

- typical residuals now: 10µ in 90°
  - 100µ in SAS
ISL & L00 alignment:

- Using fits to residuals from tracks from SVX and COT
- Tracks cross only 1 or 2 ISL layers => no 'internal' ISL alignment
- Similar algorithms to SVX internal alignment
- Layer-00: only $\phi$ layer: residuals can be set = 0.
Final residuals

Why are not not all 0?
- In MC they are (nothing wrong with algorithm)
- degrees of freedom that are not understood?
- good enough = good enough
  - people doing physics want workable alignment fast.
  - people doing alignment want to do physics. i.e. we have very limited manpower, spending most time now on validating/monitoring, little on going after hard problems that might by us a few micron improvement.
- Making (even small changes) has some overhead: reprocessing of data, Monte Carlo, revalidating.

- typical $r\phi$ residuals seen:
  - 5$\mu$ in ISL micron
  - couple $\mu$ in SVX
  - 1$\mu$ in L00
Overall accuracy

- same un-understood effects are at few µm level
- small compared to IP resolution
stability over time
Stability of SVX

Alignment tasks now mostly monitoring of stability.
- SVX internal alignment observed to be very stable over time
- beginning 2005, Si temp. was lowered from -6°C to -10°C no difference seen
- Same goes for internal z-residuals
Stability of Layer-00

- Layer-00 mounted on the beampipe
- Susceptible to shaking during detector work
  - Misalignments seen, up to 20 μ, after each shutdown
  - Most important layer for IP: want residuals < few μ
- Some spontaneous drift also seen
- => Layer-00 requires realignment every few months

![Graph showing stability of Layer-00](image)
Global alignment of SVX wrt COT

- Measure beam-line using
  1) only COT information
  2) SVX information
- compare positions to align SVX wrt COT
- compare measured slopes for global rotation

- beamlines are needed for physics anyway.
  - automatically generated for each run

  crosschecked with SVX residual using COT tracks.
The silicon is slowly sinking at an average rate $\sim 50\mu$/year
- Remember those overloaded inchworms I told you about?
- No indication for horizontal movement
- Beamline slopes show no indication of rotation (agreement few 10$\mu$rad)
Stability global positioning

Also seen by RASNIK monitoring system

- Periodically correct the global alignment of the Si to keep misalignment w.r.t COT within ~20µm.
concluding...
“lessons learned”

- Personpower is limited, spend it on
  - getting alignment out fast: physics analyses do not like to wait for it.
  - checking with different datasets (J/Ψ+Z mass/cosmics/ magnet-off), understanding discrepancies, *documentation* rather than
  - using many different algorithms that are fundamentally equivalent i.e. many different ways of looking at the same residuals

- An alignment scheme based on the symmetries of the detector was easier than a global inversion strategy.

- Moving targets will slow you down
  - Si clustering / Tracking / Vertexing / preferred datatsets and *bugs* all changed often
  - Plan for a partial, changing detector, chips/ladders/wafers come and go

- Flexible database/code structure: we found several unexpected DOF's (waver bows, stereo angles – modif'ing db+interface was painful)
“lessons learned”

some more opinions from CDF alignment people.

- Construction was excellent
  - important to get going. Finally ~everything done on data.
  - in case of conflicts, you'll always choose to go with the data

- Retaining expertise & software compatibility is becoming an issue, especially for little-used systems (inchworms & rasniks)

- *Data is much more “squirrelly” than Monte Carlo*
  - MC is good to test methods, but...
    - Some inconsistencies still not resolve
    - Couldn't get below ~2-5 μ in general

- We did not really think about alignment until the data were there. This workshop already shows LHC is in better shape.
Summary

- Positioning tolerance of Si determined by displaced track-trigger
  - Active positioning and monitoring system not used much because of stable conditions (very fortunate)
  - SVT works beautifully
- Survey data very important.. but finally overruled by data
- Si alignment understood at level of few-microns
  - because very hard to make more progress
  - Alignment not nearly dominant contribution to resolution

Displaced track trigger (SVT)+
Great momentum resolution (COT) +
excellent vertexing resolution  \[\ldots\]
**Summary**

- Positioning tolerance of Si determined by displaced track-trigger
- Active positioning and monitoring system not used much because of stable conditions (very fortunate)
- SVT works beautifully
- Survey data very important, but finally overruled by data
- Si alignment understood at level of few-microns because very hard to make more progress
- Alignment not nearly dominant contribution to resolution

---

Displaced track trigger (SVT) +
Great momentum resolution (COT) +
excellent vertexing resolution (SVX+L00)
CDF Run II Preliminary \[ L = 1.00 \text{ fb}^{-1} \]

\[ B_s \rightarrow D_s^* (3)\pi^+ \]

\[ \langle \sigma_{cl} \rangle = 25.9 \mu \text{m} \]

osc. period at \( \Delta m_s = 18 \text{ ps}^{-1} \)