Alignment experience at CDF

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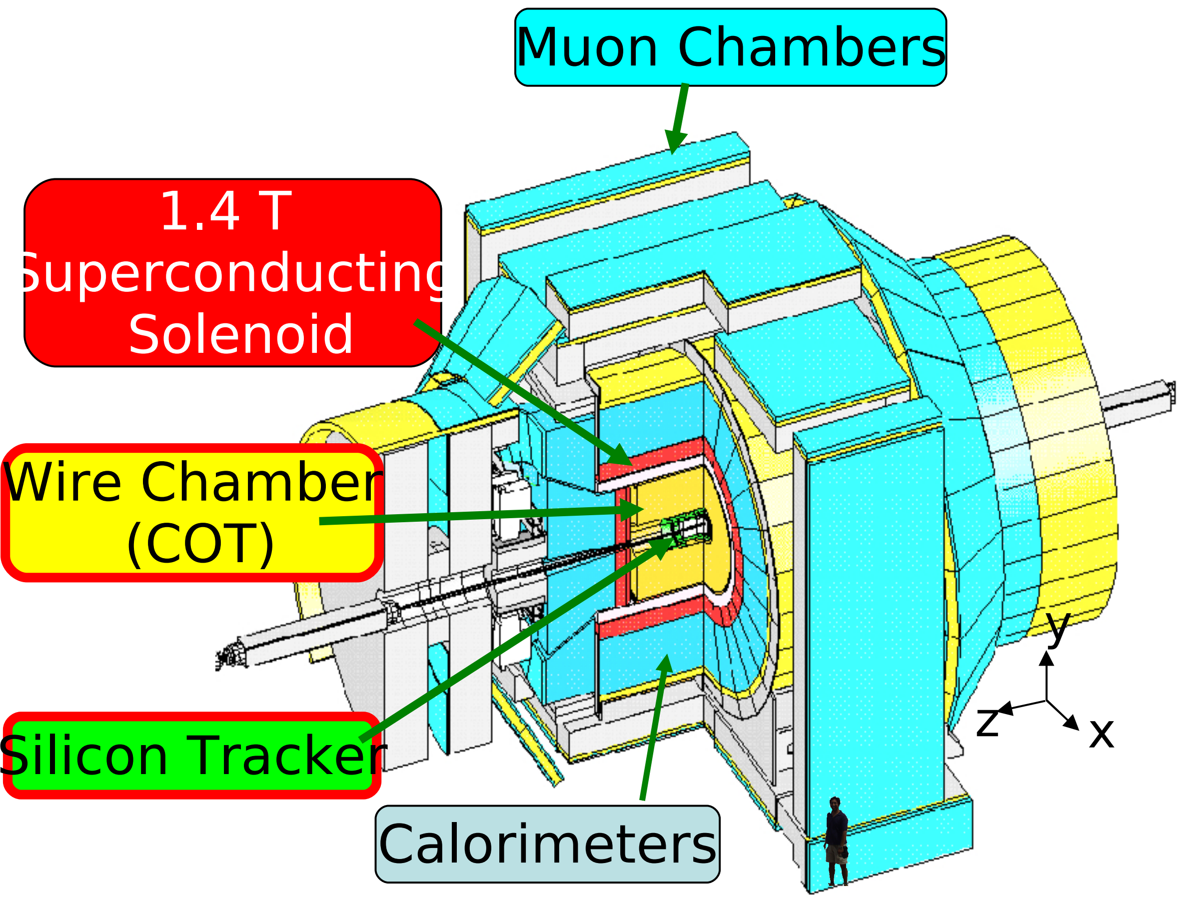
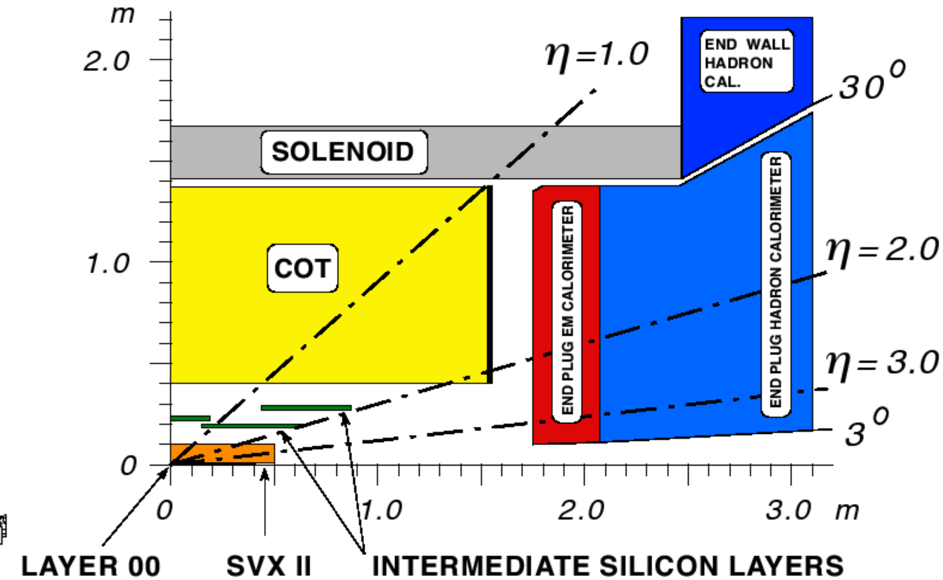
for the CDF tracking group

many thanks to Raymond Culberston (fnal)

Overview of CDF



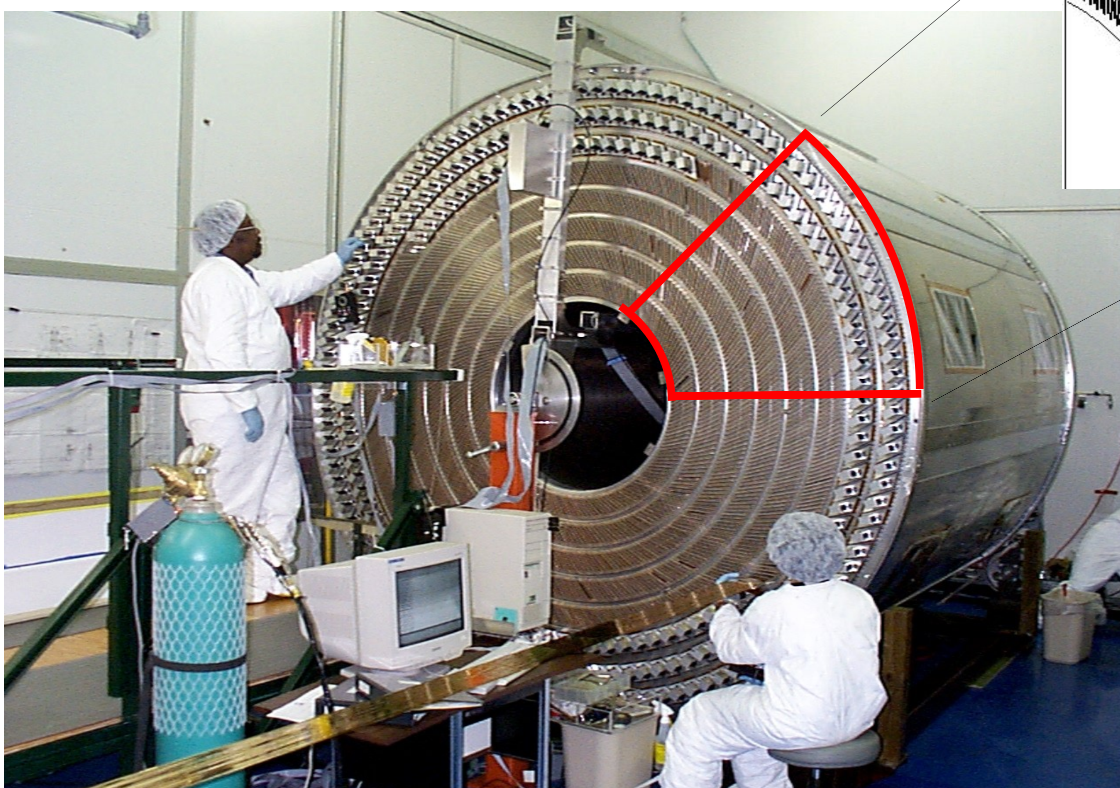


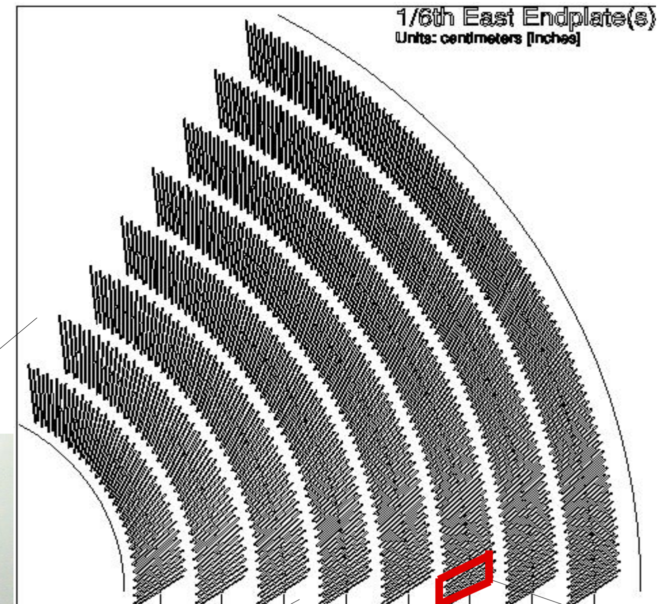
tracking system:
pretty good approximation

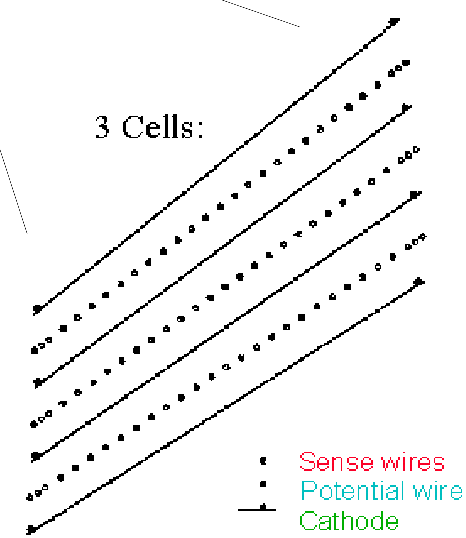
- COT measures the curvature
- Si measures the impact Parameter

COT

- 30K sense wires, 96 layers,
- r=41cm to 135cm, drift chamber
- 12-wire cells, tilted for Lor. angle
- ½ are 2° stereo
- $\sigma(p_T) = 0.15\%\ p_T^2$



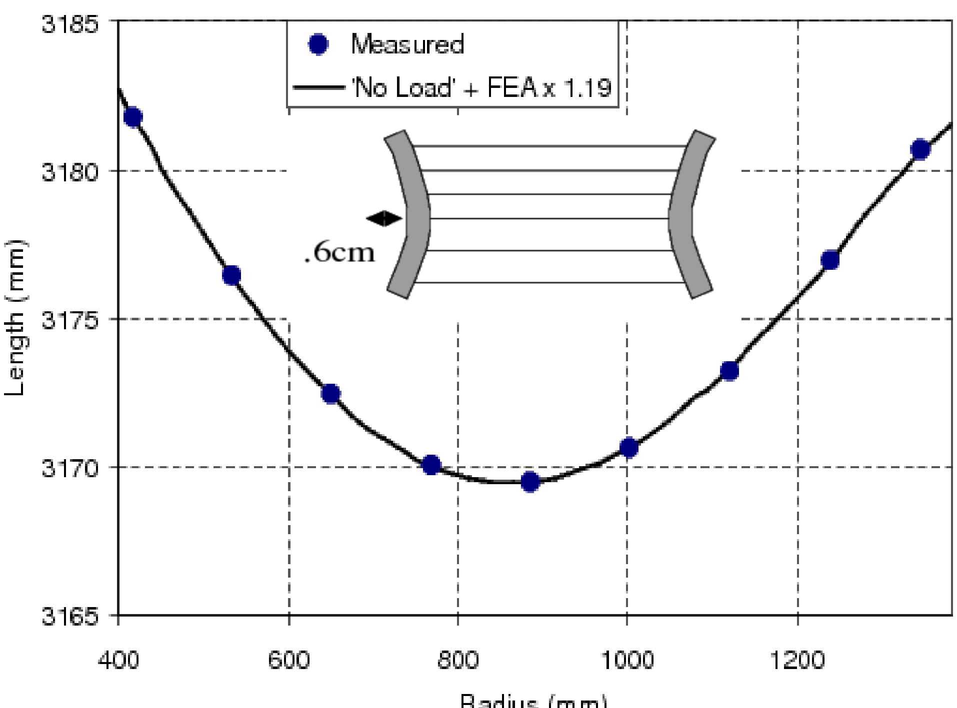


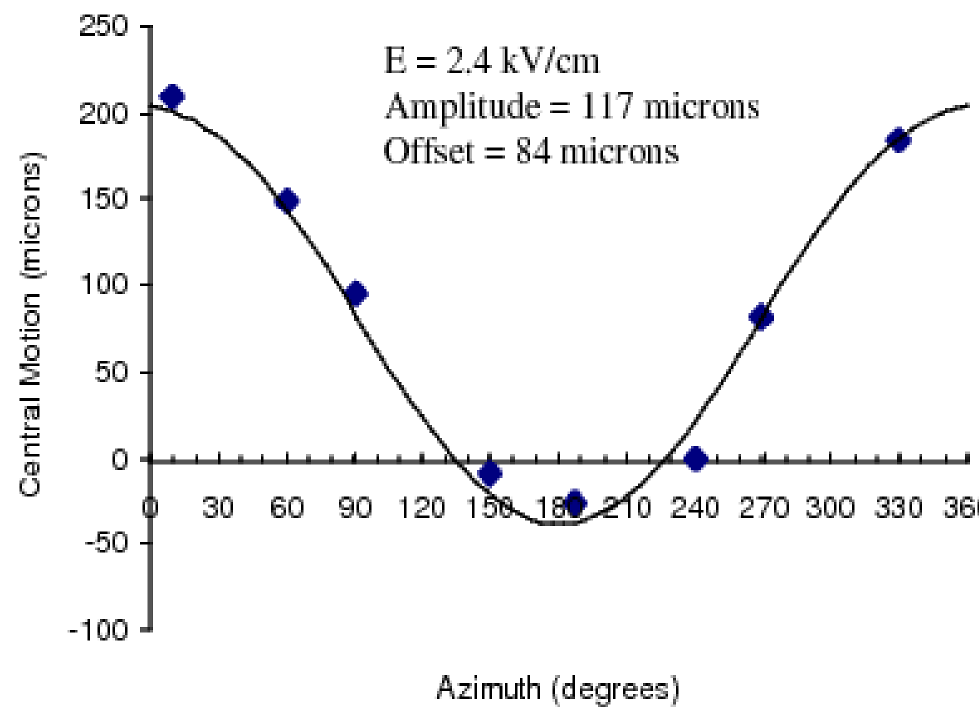


COT alignment

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

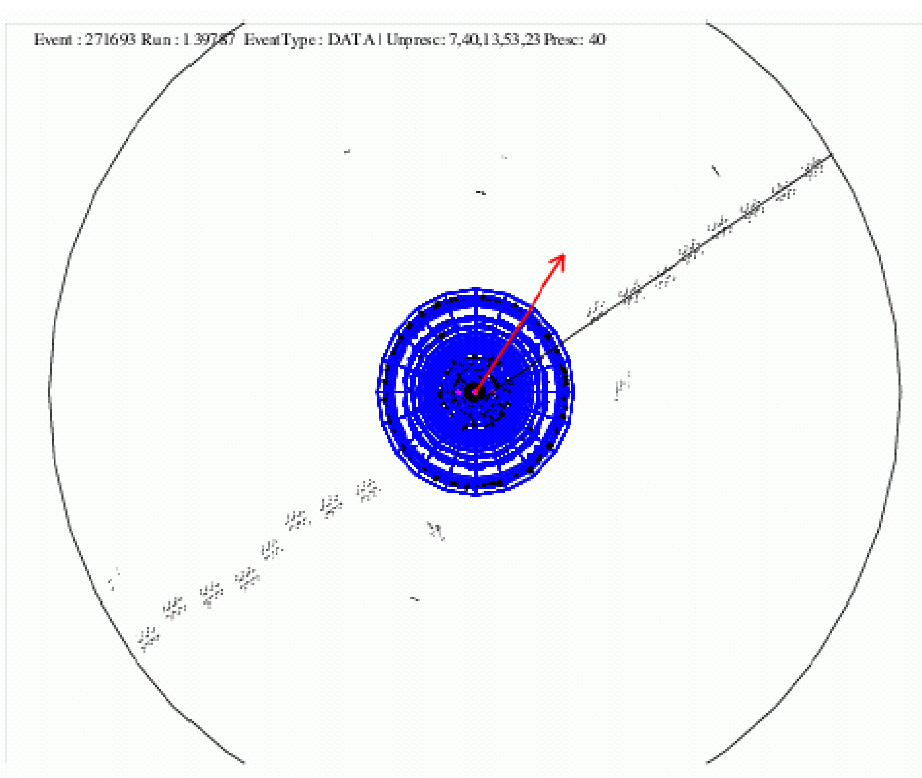




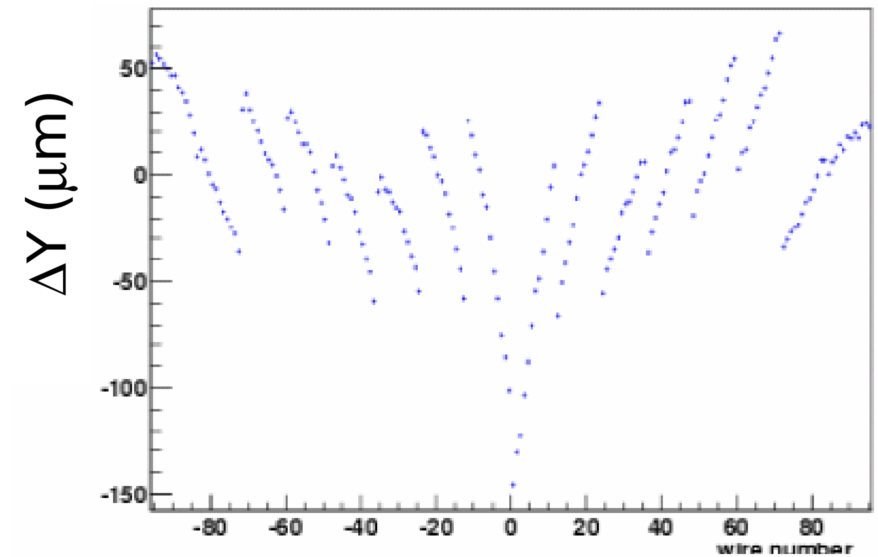
COT alignment

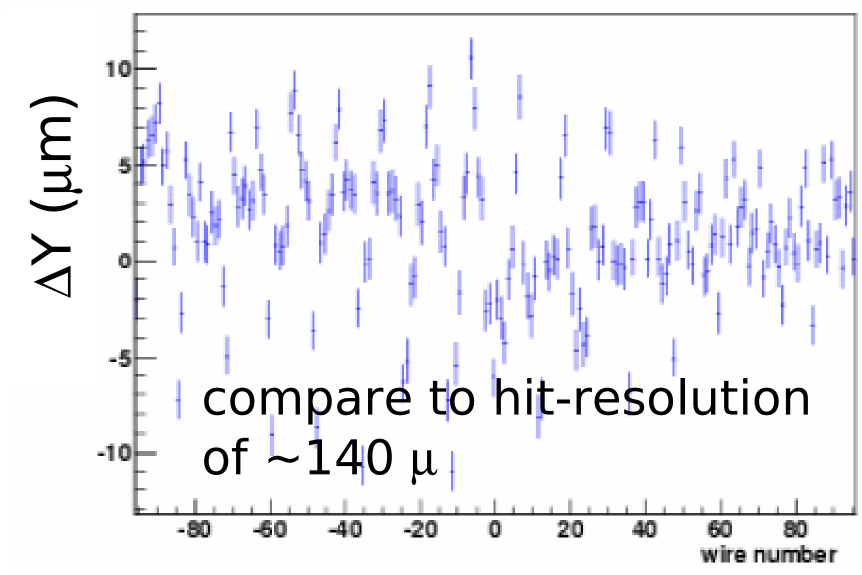
cosmics:

- 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



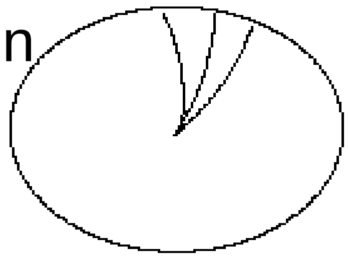


compare to hit-resolution of ~140 μ

COT alignment

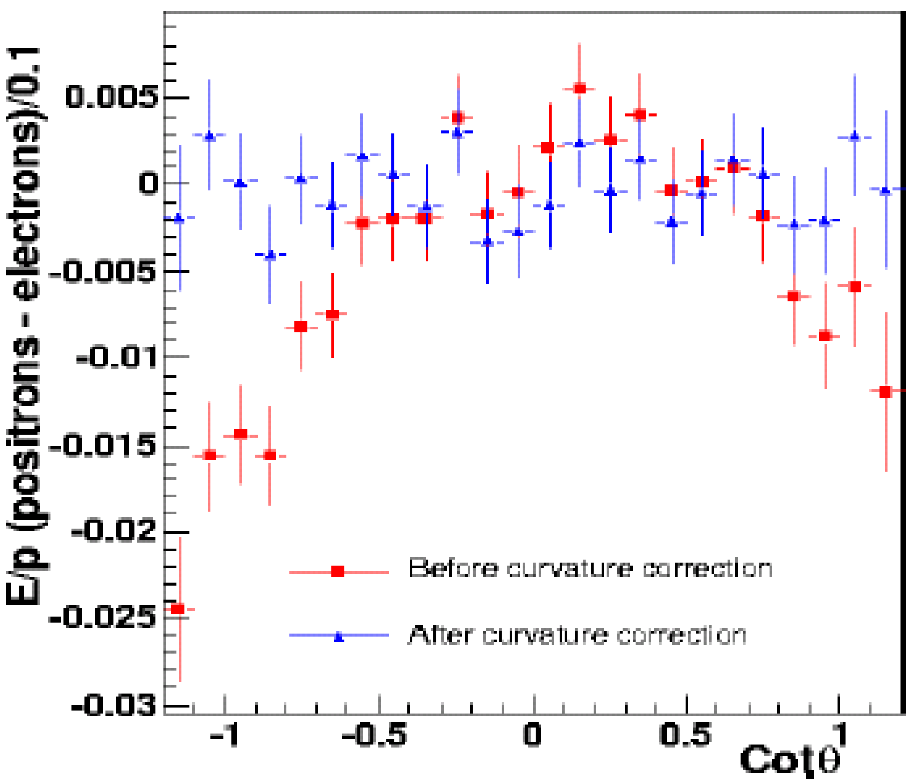
'false curvature' correction

- r-dependent f offset
- compare E/p for e^+ e & derive correction



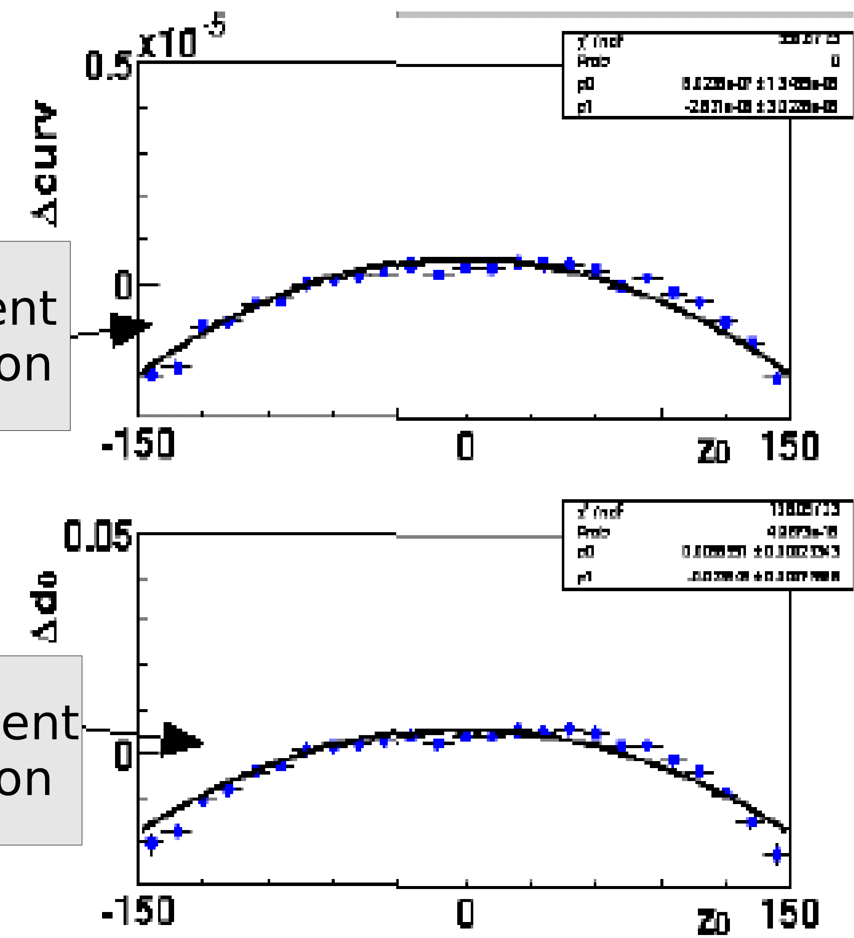
recently: better understood

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



r dependent wire motion

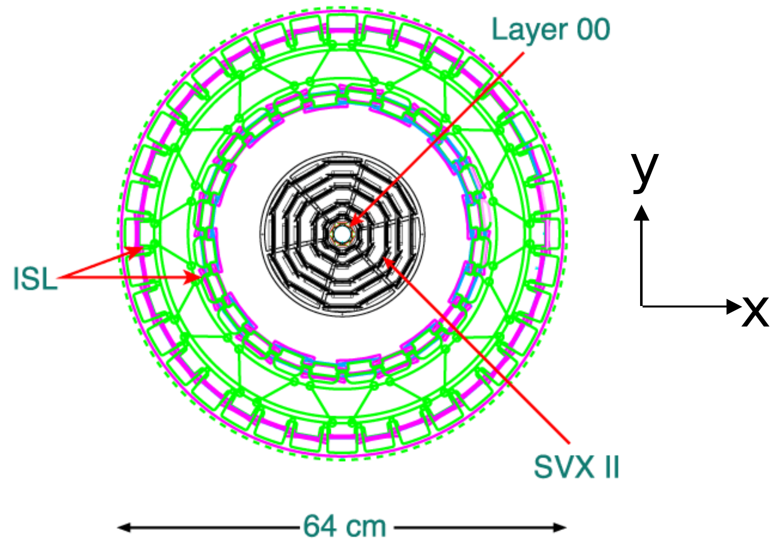
r independent wire motion

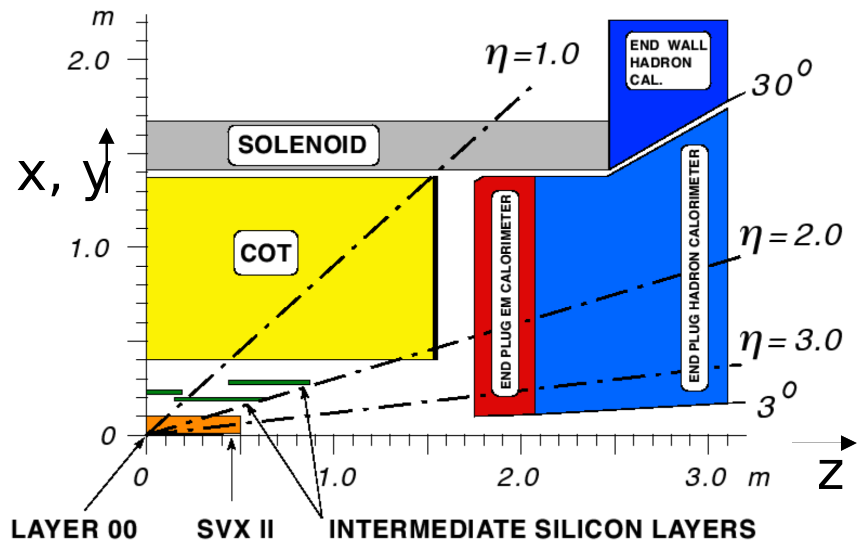


also: many tests done with J/ψ to derive a posteriori corrections

CDF Silicon Detector

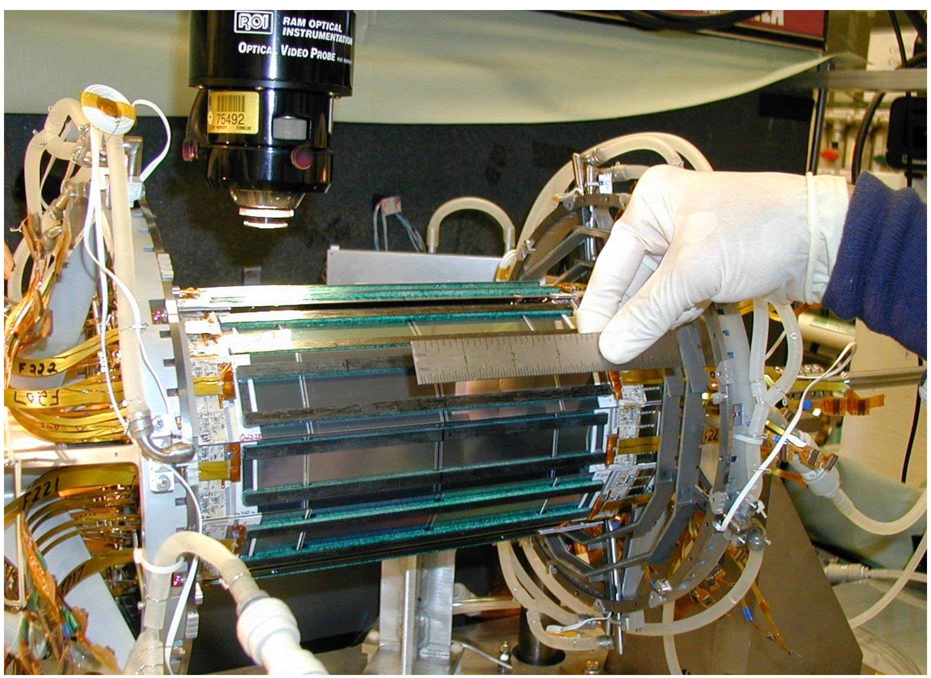
- Run II Silicon
  - 7-8 Silicon Layers
  - 722,432 Channels / 1008 Ladders/ 5456 Chips
  - 6m^2 of Silicon
  - Designed to last for 2-3fb^{-1}
- Silicon detector comprised of three (mechanically) separated
  - Layer-00
  - SVX II
  - intermediate silicon layber : ISL

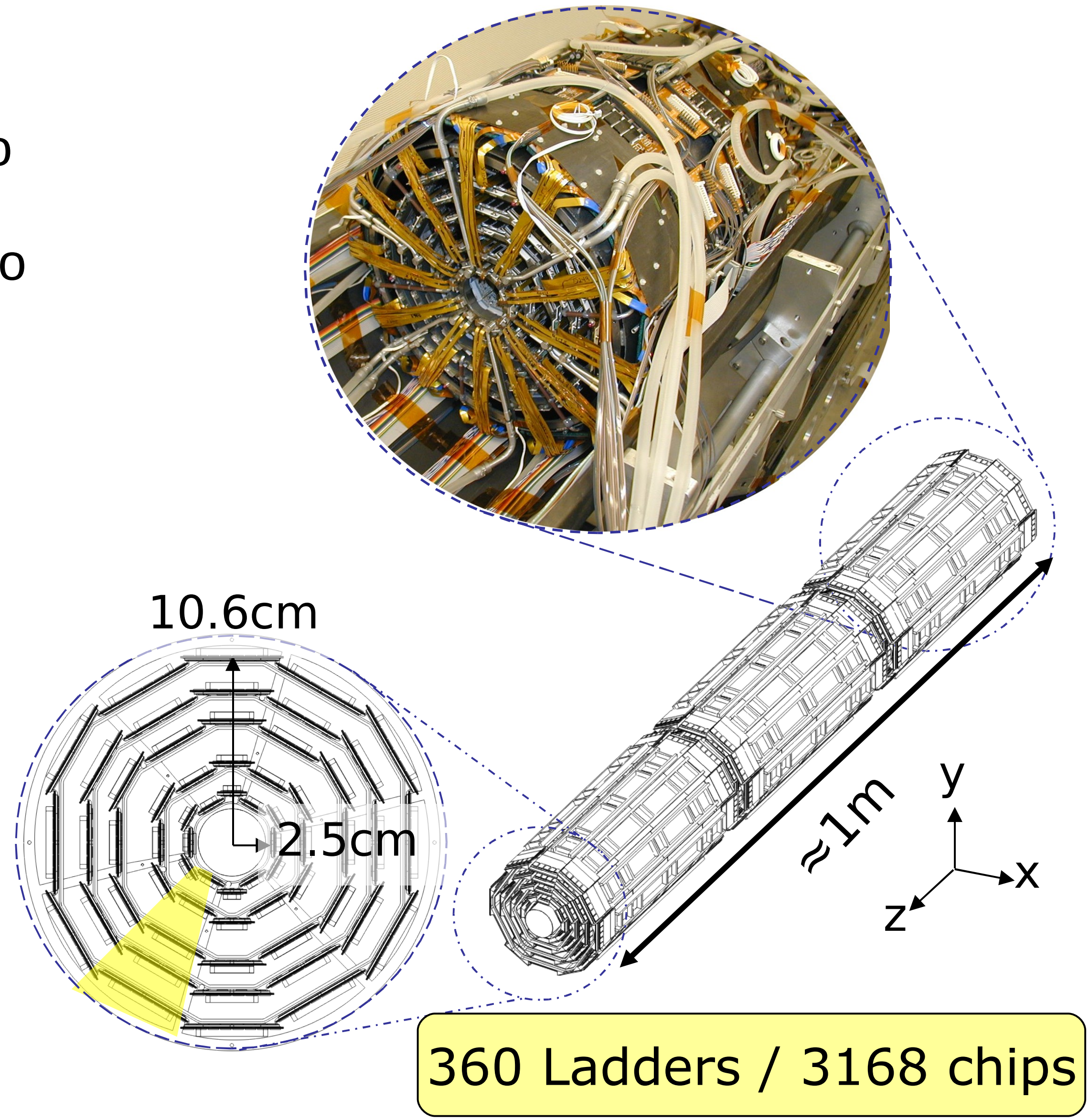




SVX II

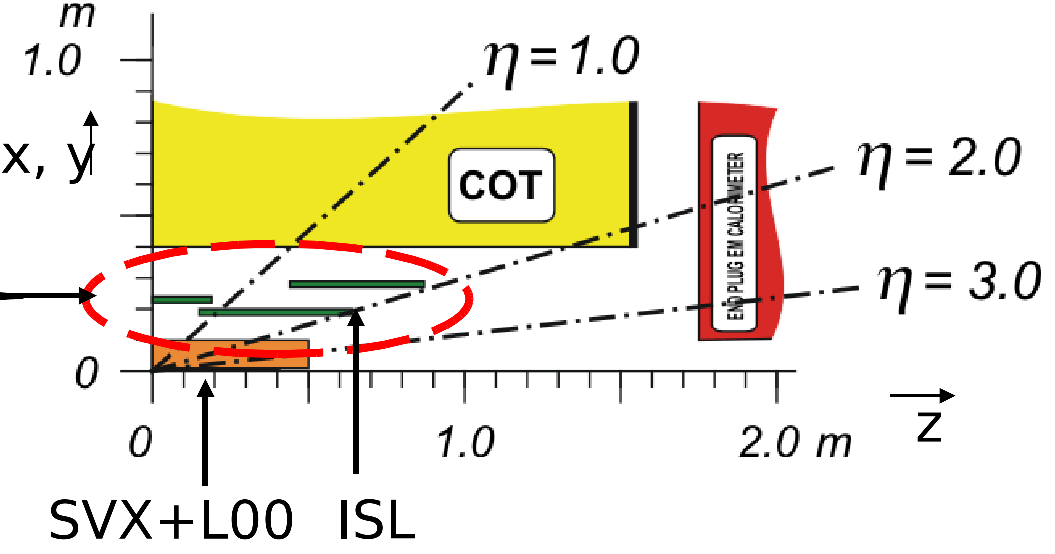
- The *core* of the CDF Silicon Detector
- 2.5 to 10.6 cm in radius
- 5 layers of double-sided silicon
  - 3 layers with axial & 90^0 stereo strips (1,2,4)
  - 2 layers with axial & 1.2^0 stereo strip (3,5)
- Strip pitch from 60µ to 140µ
- highly symmetric: 12 wedges x 3 barrels

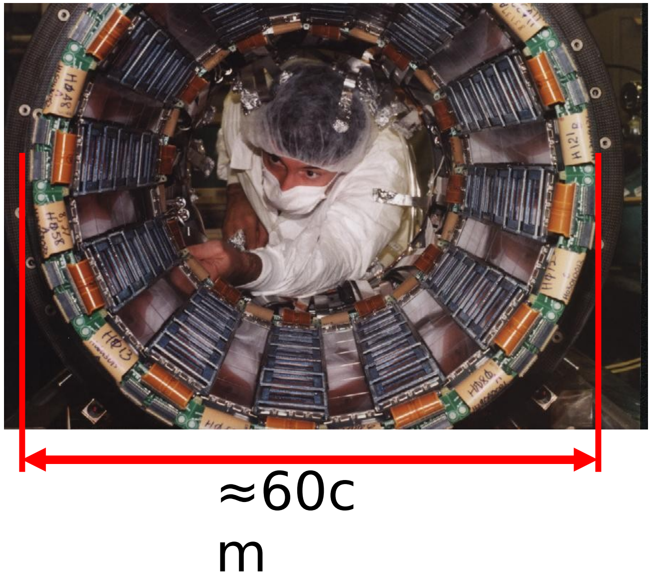


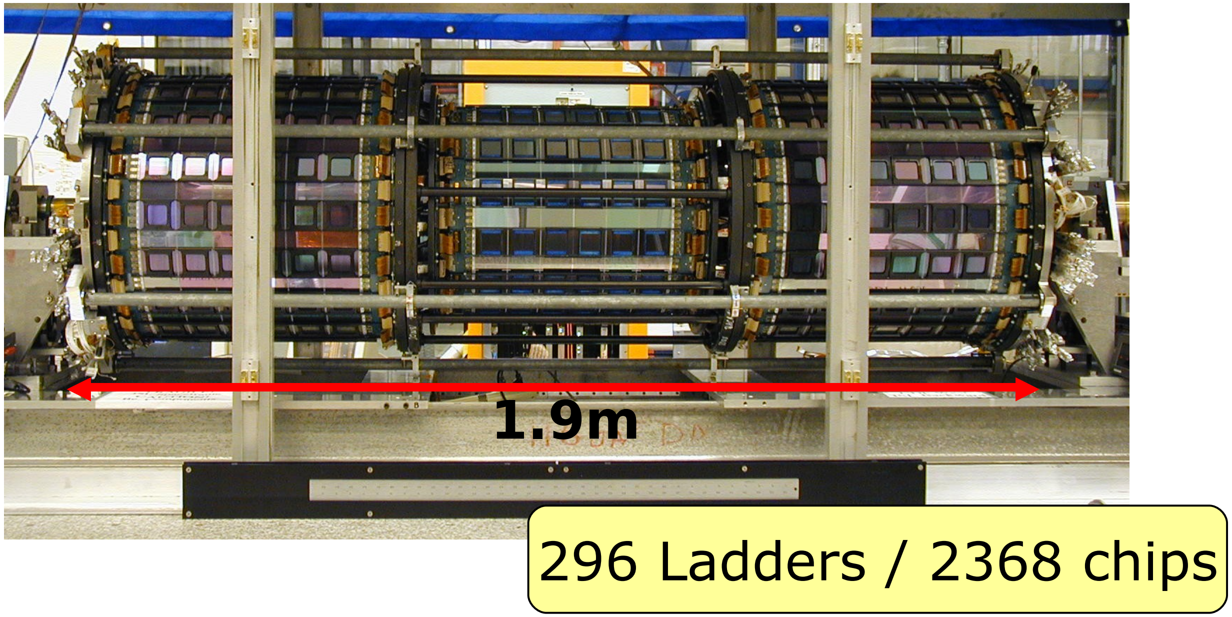


Intermediate Silicon Layer (ISL)

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



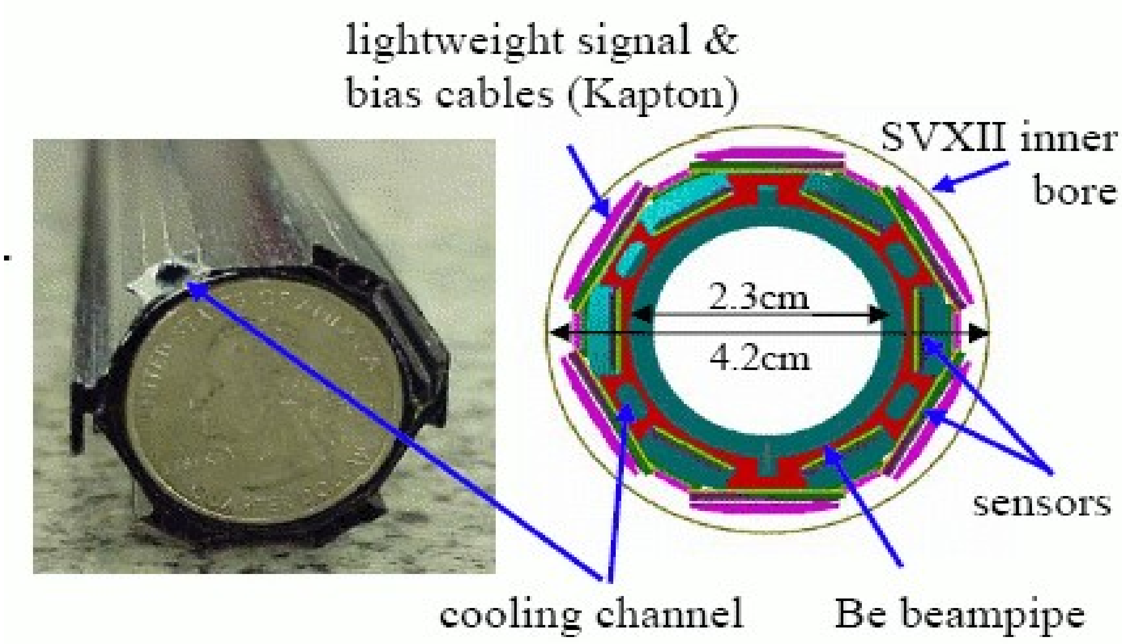




Layer-00

- 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

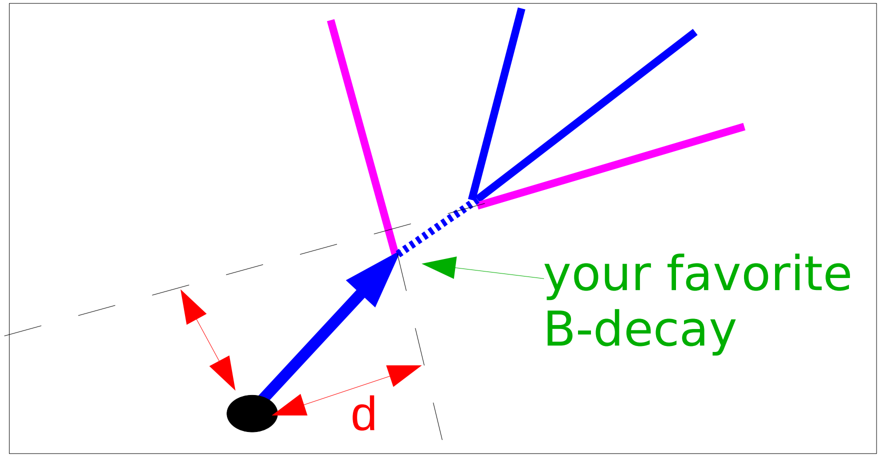
72 Ladders / 108 chips



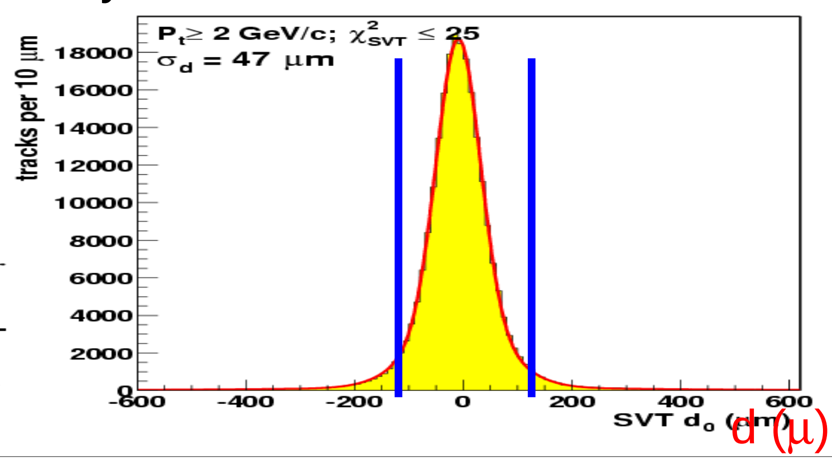
'online' alignment / positioning

Silicon Vertex Trigger (SVT)

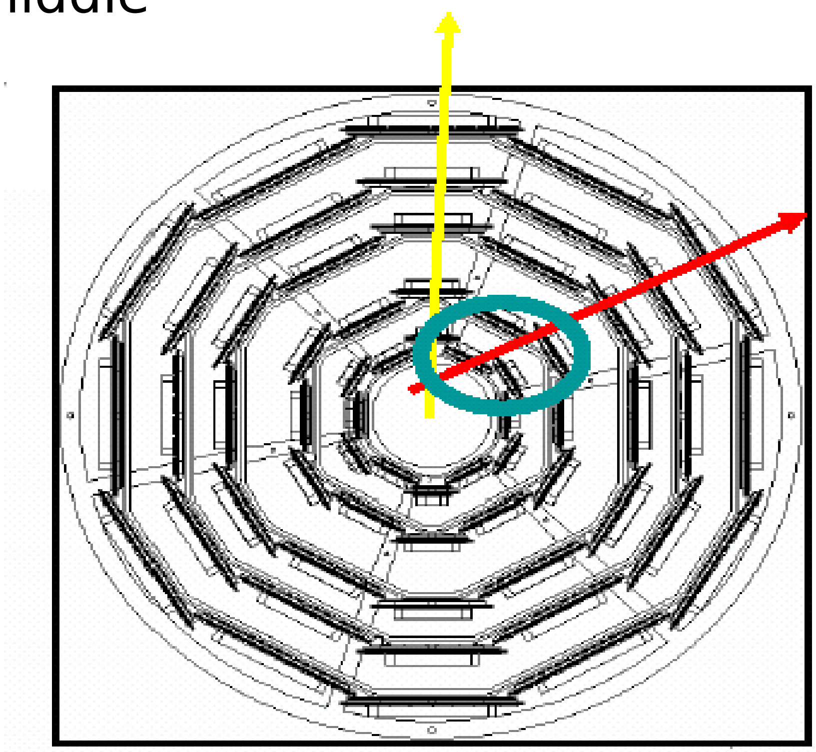
Trigger on events with two displaced (d>120 μm) tracks



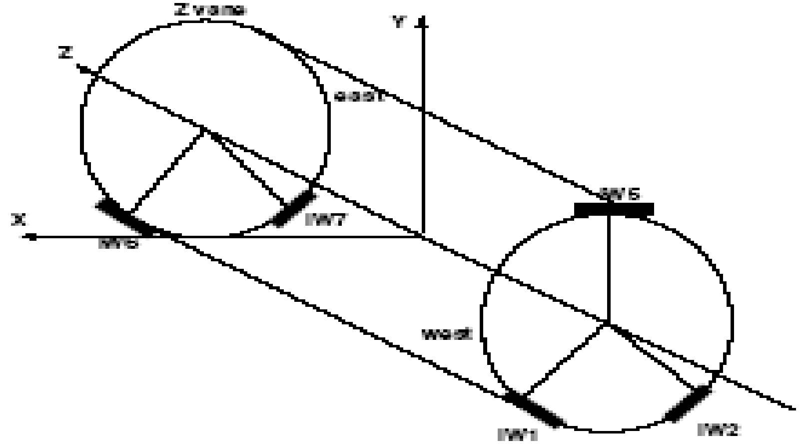
very fast reconstruction of silicon data at L2 (20μs latency) by dedicated hardware: SVT

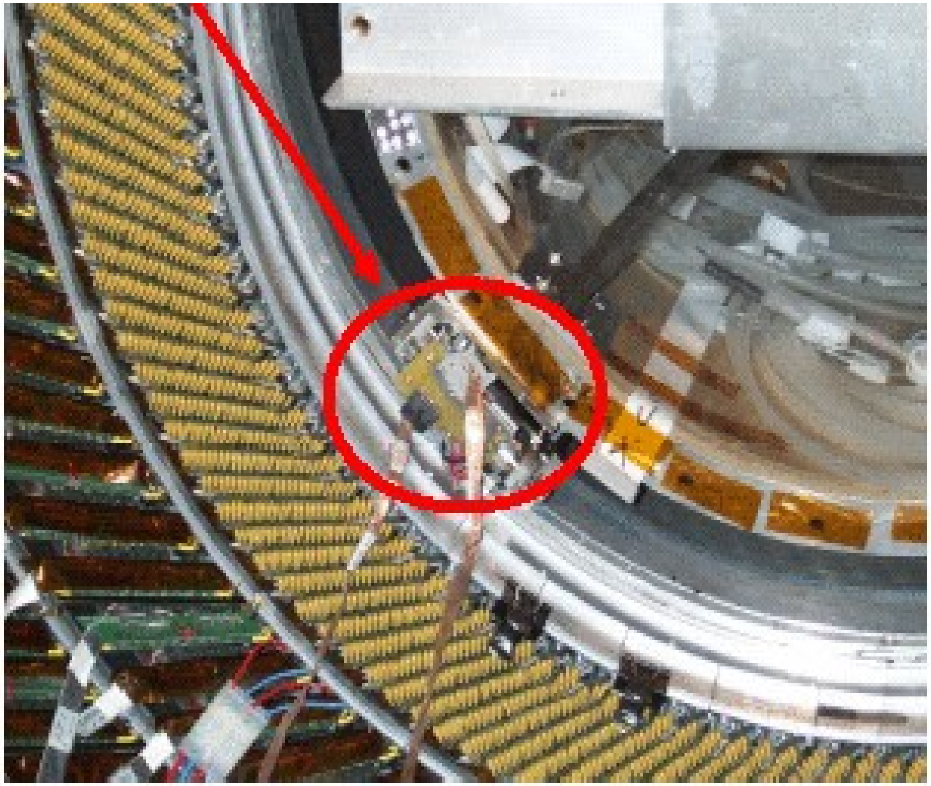


- Foundation for large part of b-physics program
- takes data directly from SVX
- Si track reconstruction at L2 trigger
- Pattern search requires
  - straight SVX positioning wrt beamline (100 μrads)
  - no wedge-crossers -> keep beam in middle



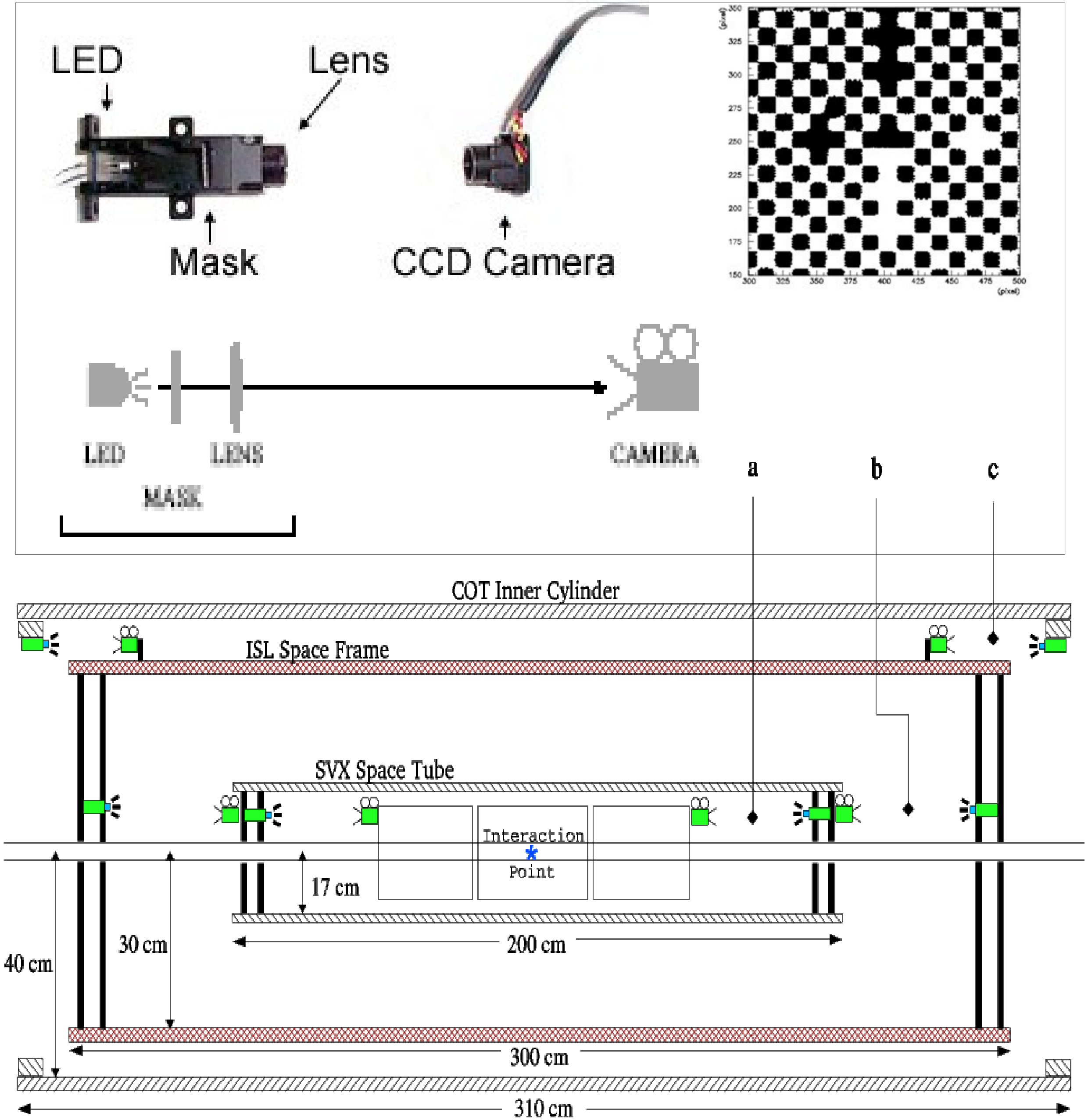
Active positioning system





- 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)



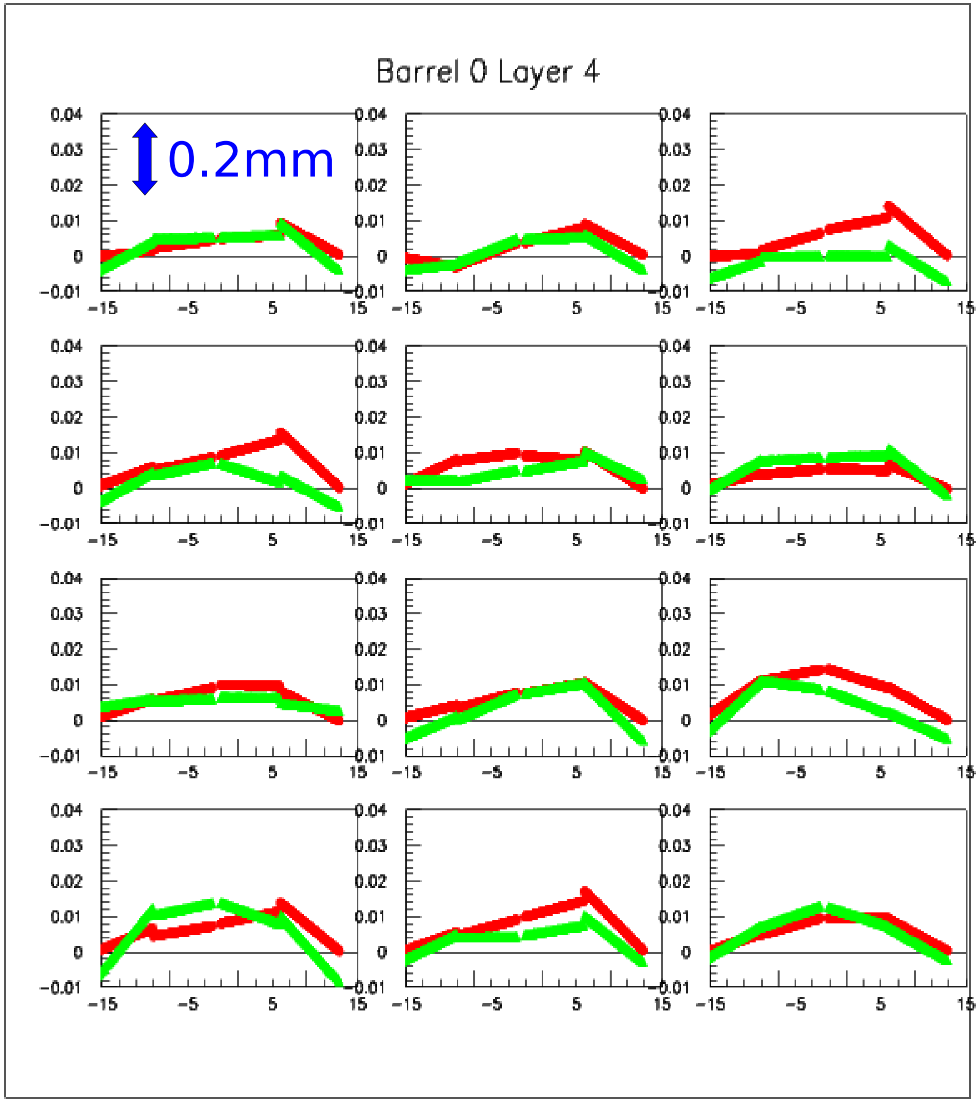
- 17 systems deployed throughout tracking volume
- Some not anymore operational due to line of sight blocked by cables during shutdown ;-(
- Not used much anymore
  - not needed: detector is quite stable
  - some false 'alarms' due to movement of projector

- Maintaining expertise is becoming an issue here too.

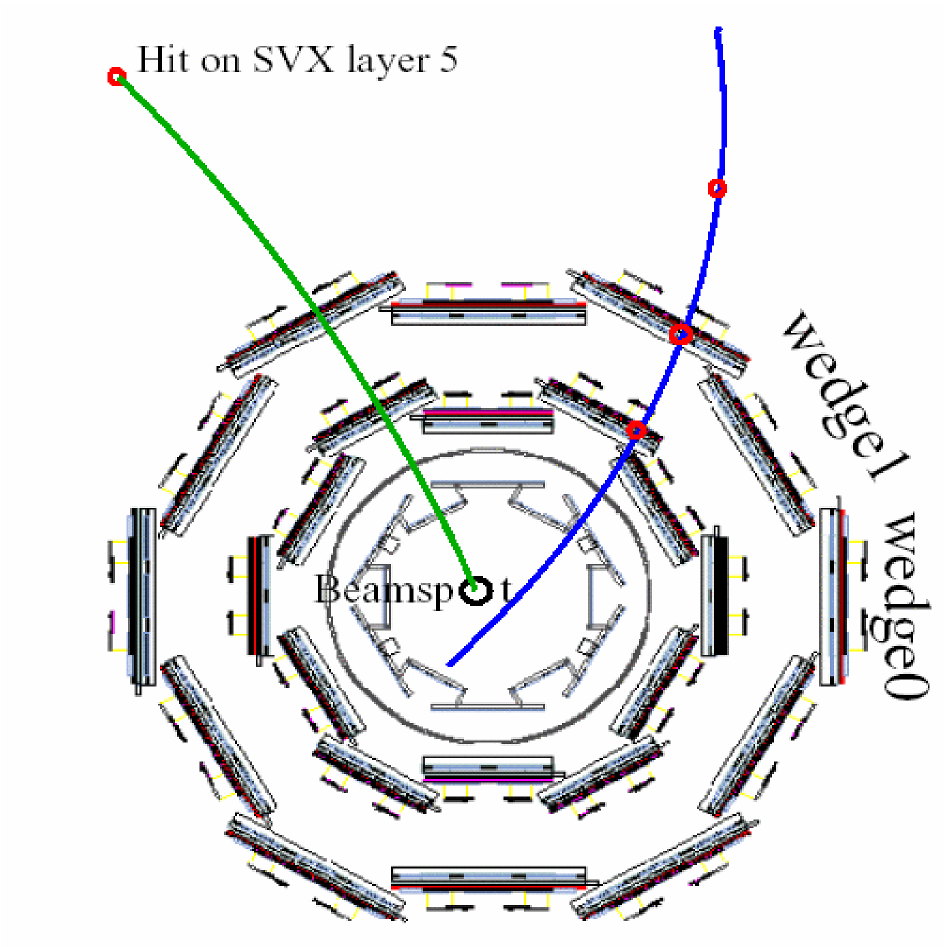
'offline' alignment

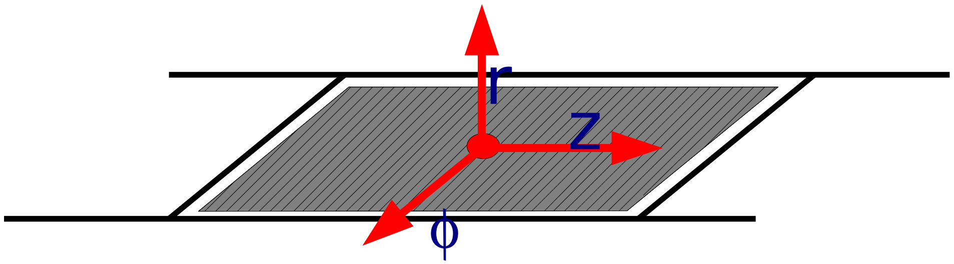
Assembly and survey data

- Surveys performed at each stage of 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**

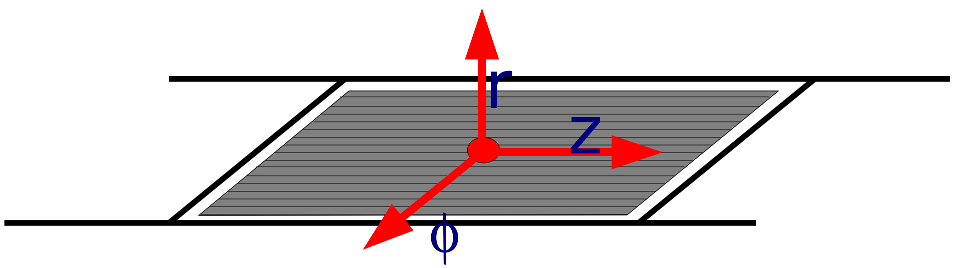
Philosophy:

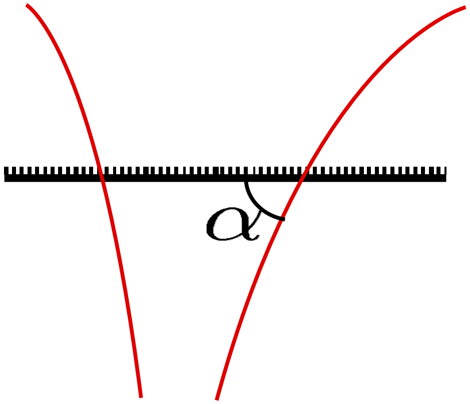
- **make ntuples with hit information**
- **store residuals wrt to track fit**
  - **simple, fast refits on residuals**
  - **different fit possible**
    - **Fix curv from COT, fix track at layer 5 hit and SVX beamline**
    - **N-1 unbiased tracks**
    - **COT tracks / biases tracks etc**

- **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





ϕ residual to first order given by:

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

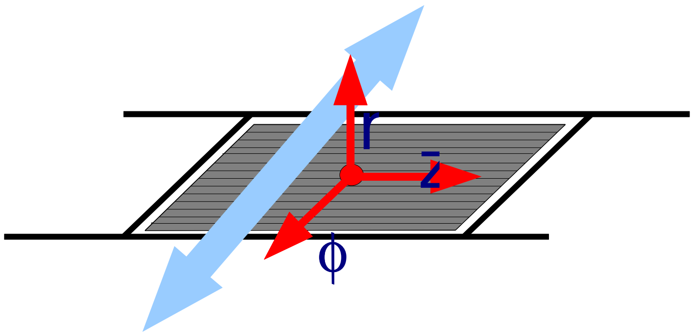
translation

rotation

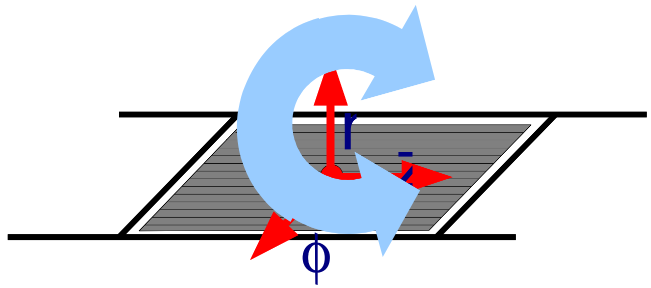
χ^2 minimisation $\rightarrow$ inversion of 5x5 matrix consisting of simple sums of the residuals.

Alignment Algorithm

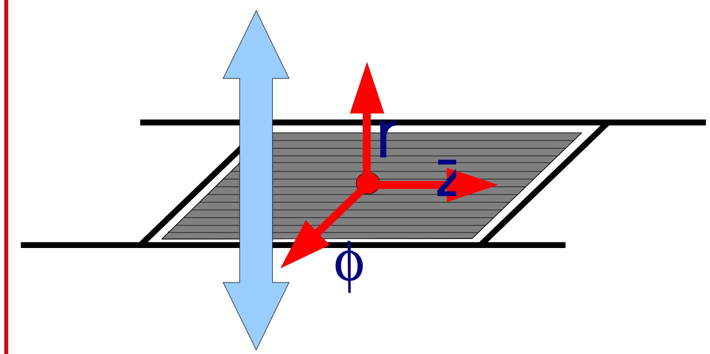
matrix inversion boils down to...



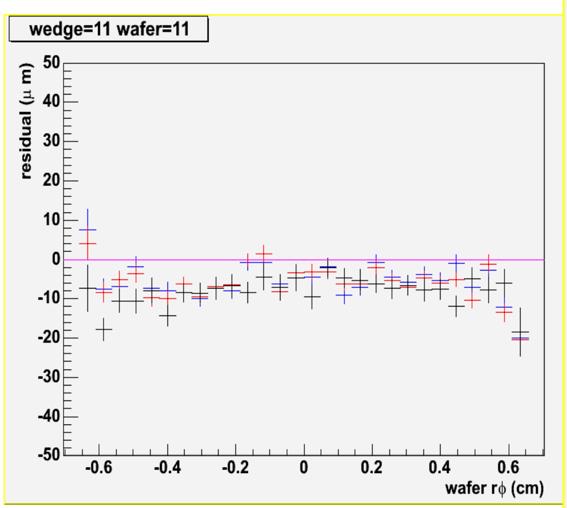
$$T_\phi = < \Delta >$$

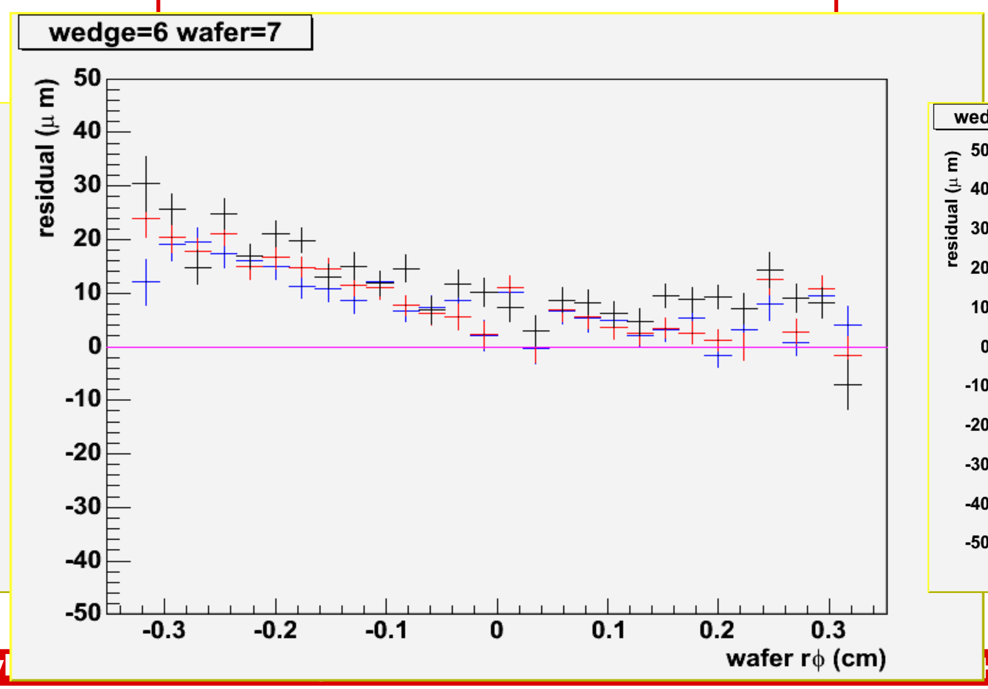


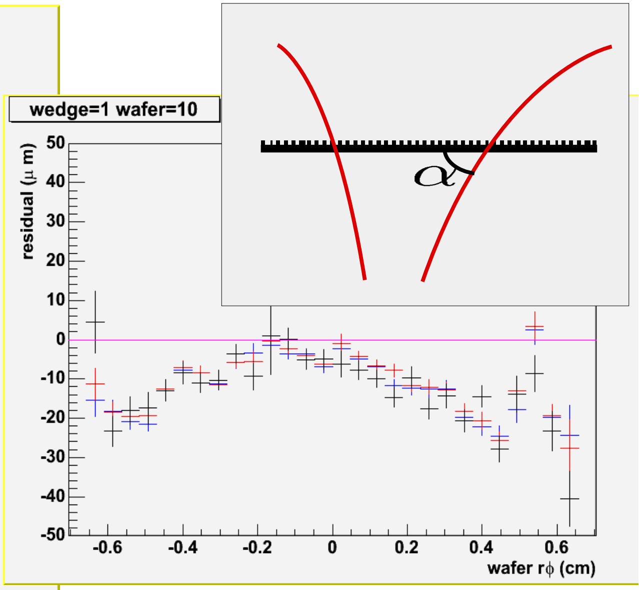
$$R_z = < \phi\Delta >$$



$$T_r = < \tan(\alpha)\Delta >$$



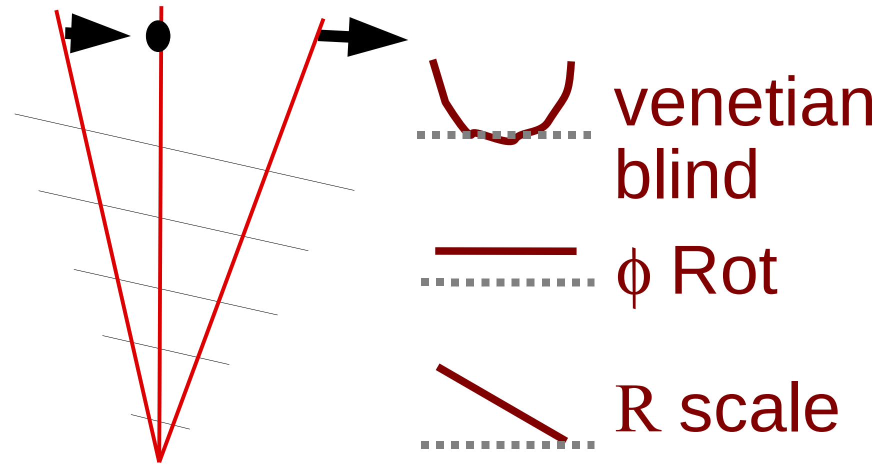


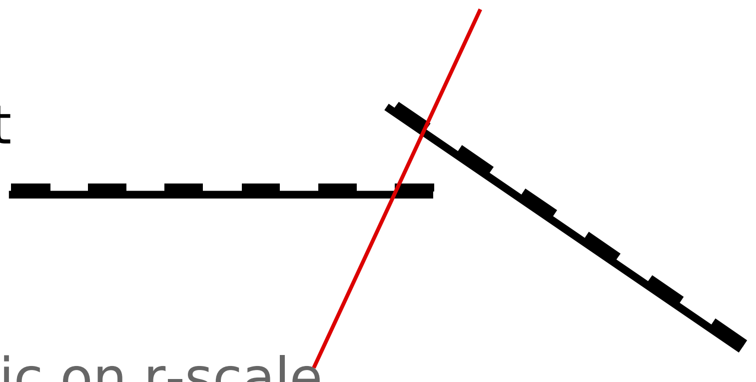


Remaining degrees of freedom

basically some as internal, using $\Delta\phi$ wrt COT tracks

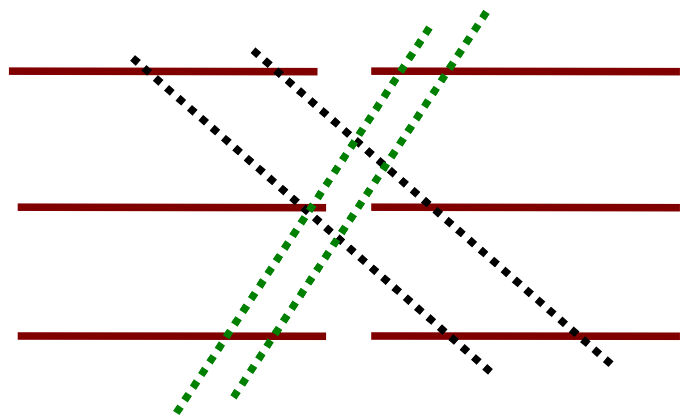
- rotation about z-axis
  - compare fitted ϕ of SVX and COT tracks
- venitian blind
  - compare fitted ϕ of SVX and COT tracks as function of ϕ
- overall scale
  - again SVX vs COT ϕ as function of ϕ
  - Overlap residuals... tricky
    - overlap region very small in all but 2 layers
    - residuals behave 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(10μ)
    - lifetime measurements compute systematic on r-scale by scaling all Si by 50μ -> very small effect (50μ/10cm<10^{-3})



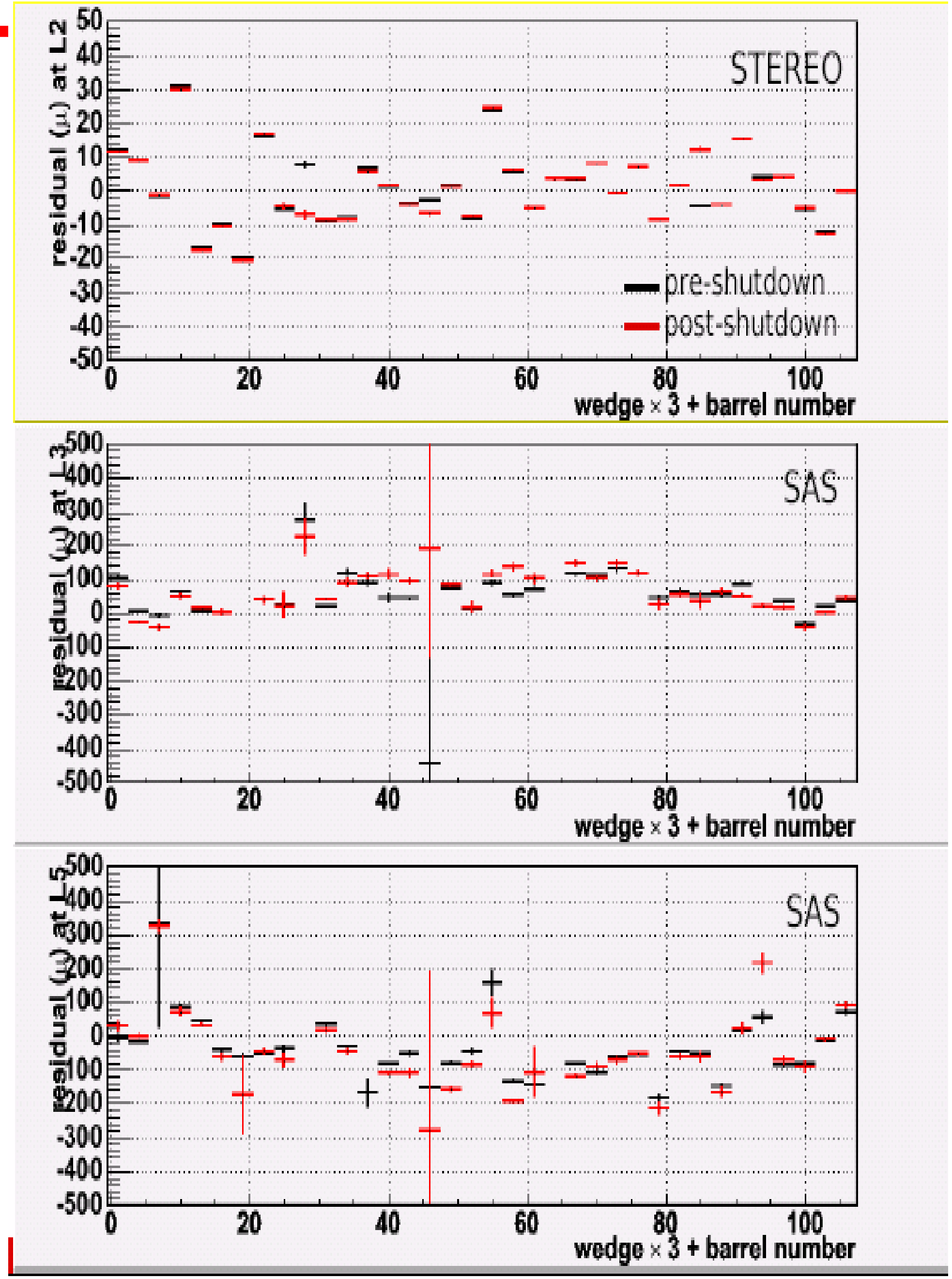


Z-alignment

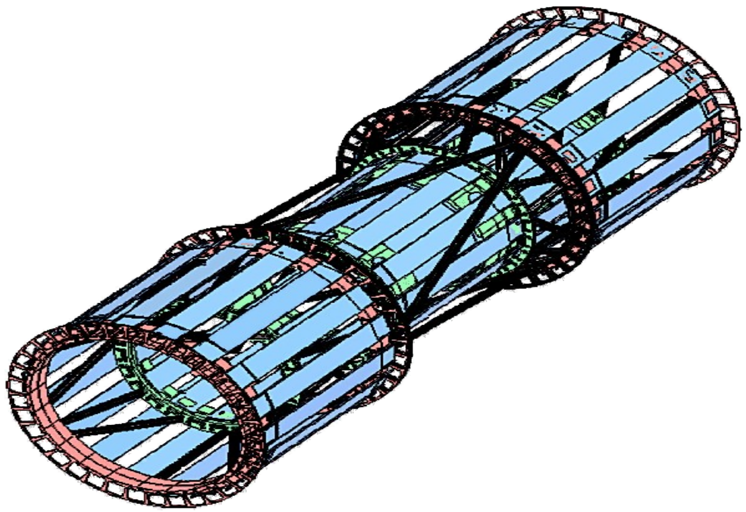
- Align the 90 deg layers to each other
  - track trough L1 and L4, fit L2
- Small-angle stereo
  - **found that stereo angle was wrong: variable outside specs and offset**
- z-scale fixed by measuring distance between barrels (could also use COT, but COT z-scale very well known)

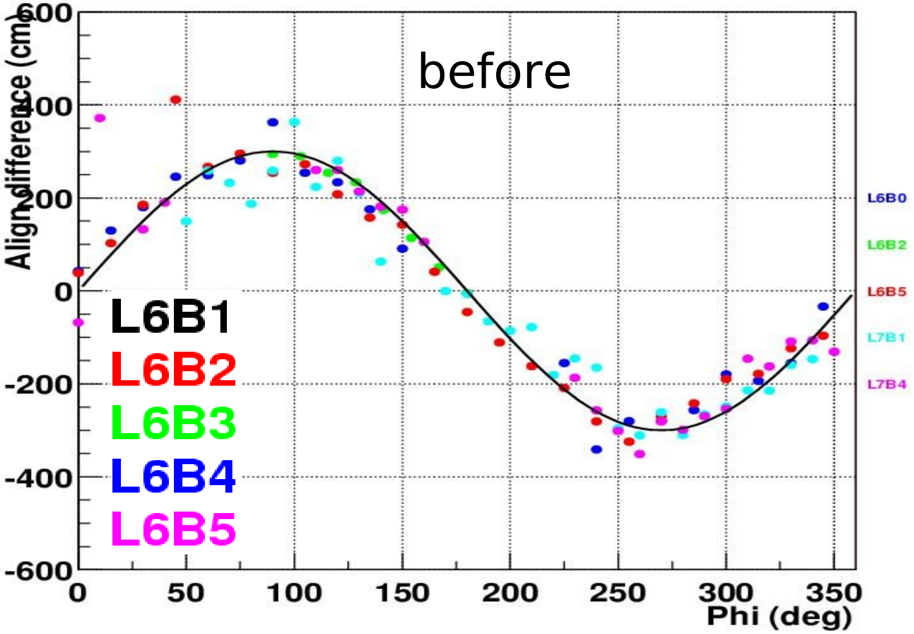


typical residuals now: 10μ in 90o
100μ in SAS



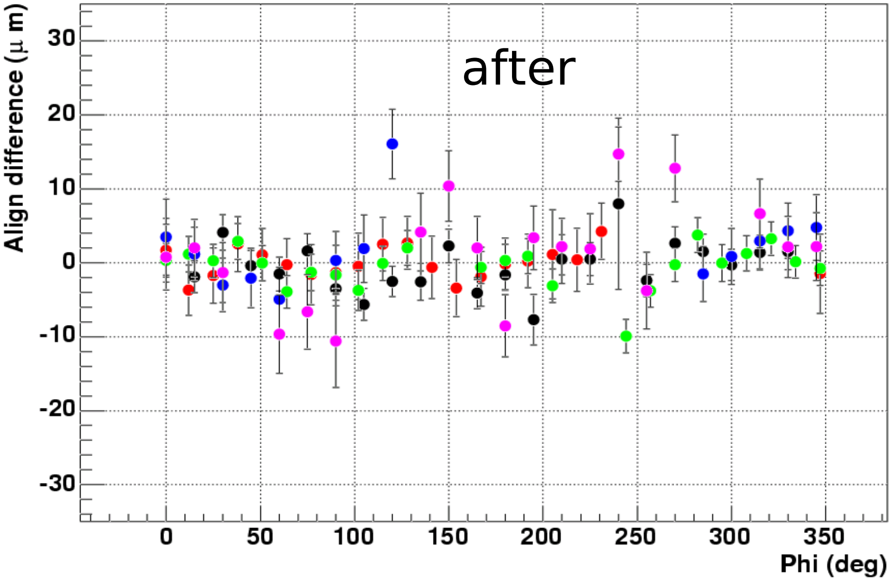
ISL & L00 alignment :





- 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

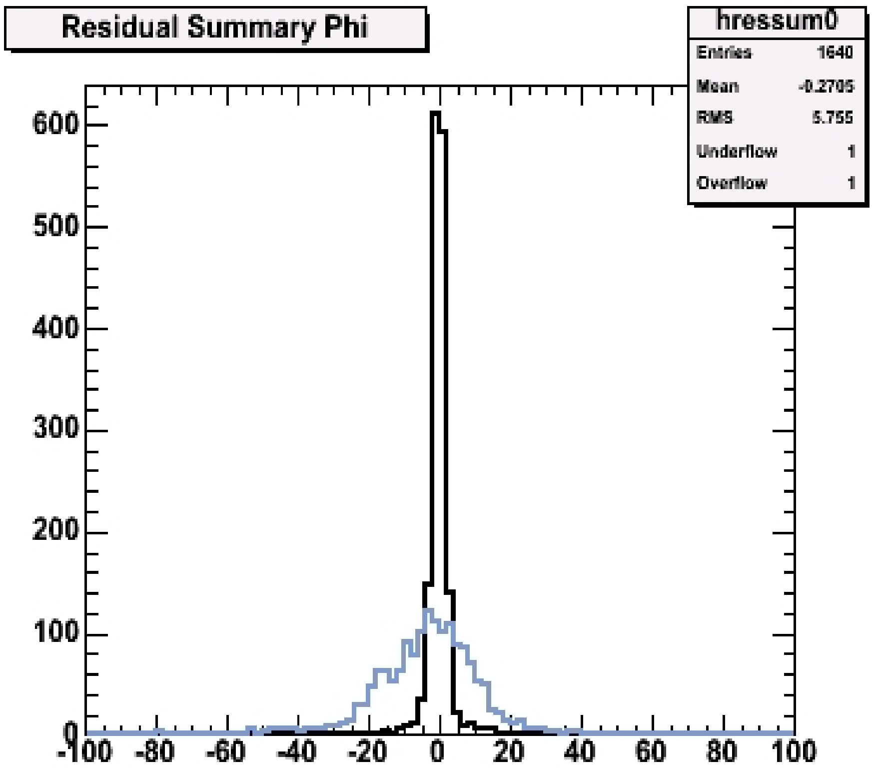
- Layer-00: only ϕ layer: residuals can be set=0.



Final residuals

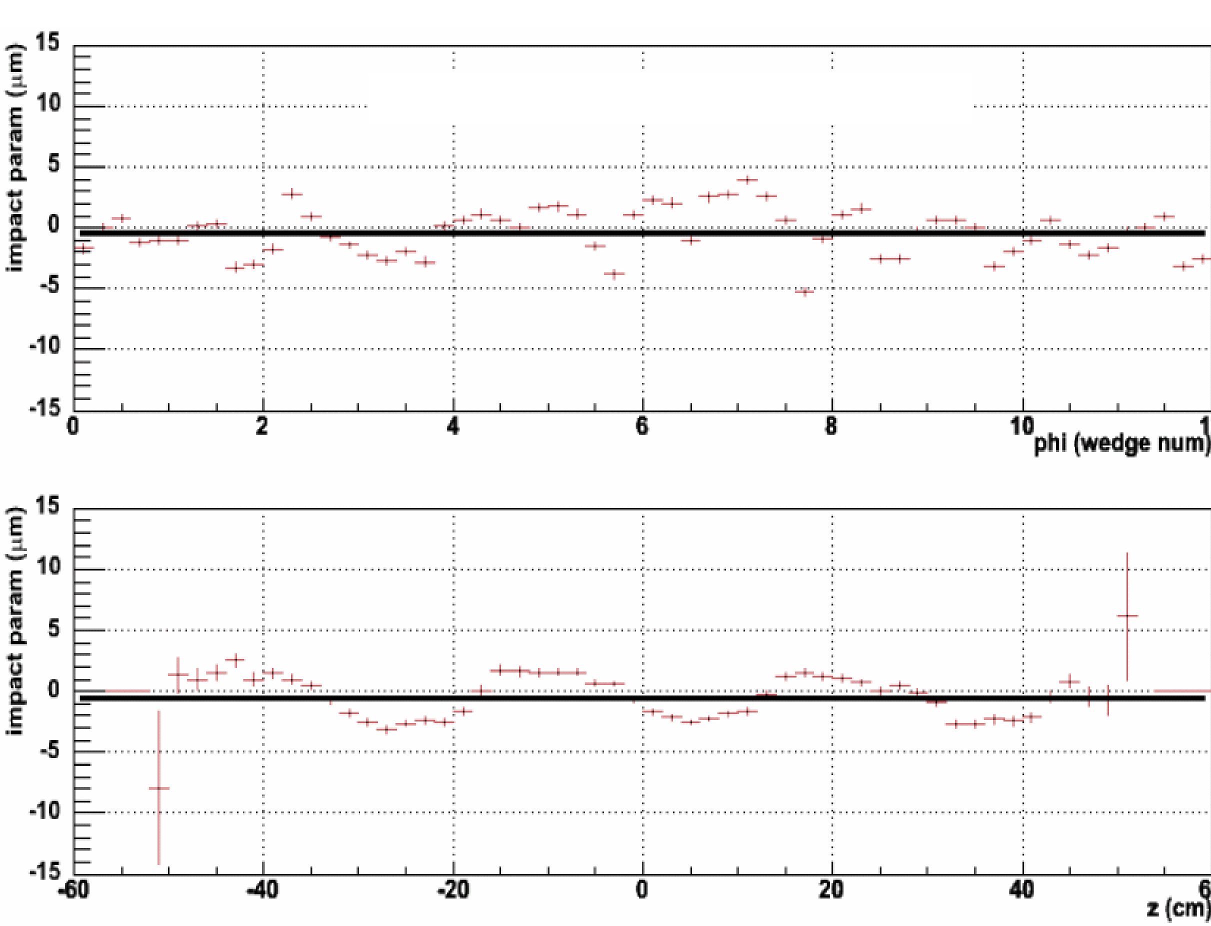
Why are not not all 0?

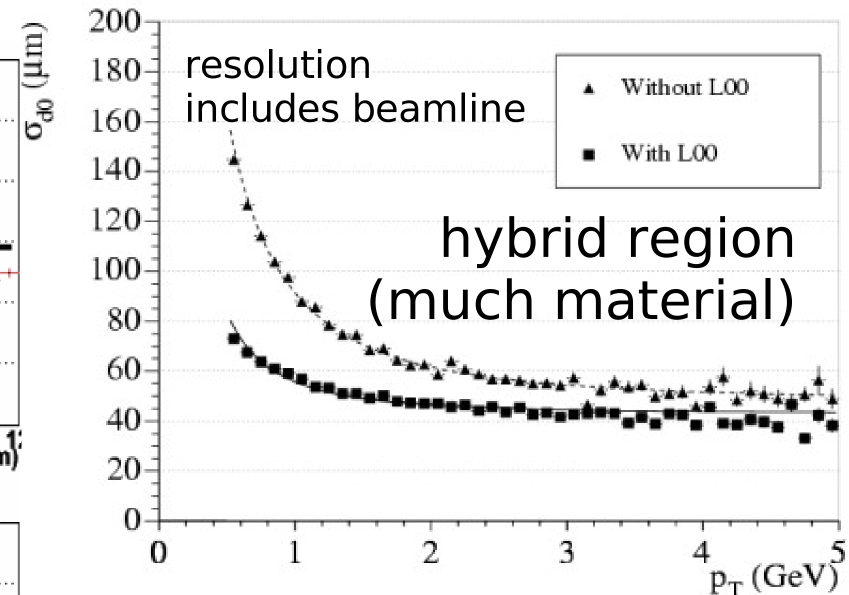
- In MC they are (nothing wrong with algorithm)
- degrees of freedom that are not understood?
- good enough = good enough
  - people doing physics want workable alignment fast.
  - people doing alignment want to do physics. i.e. we have very limited manpower, spending most time now on validating/monitoring, 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.

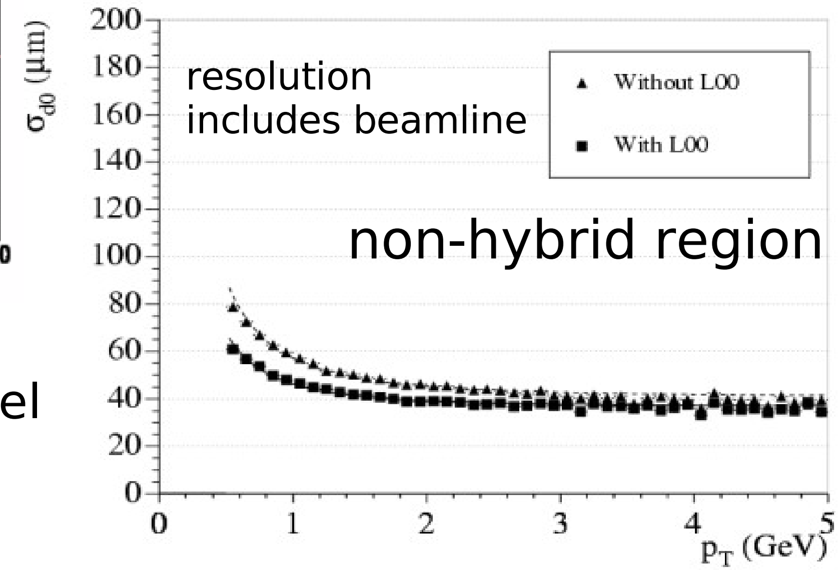


- typical rϕ residuals seen:
  - 5μ in ISL micron
  - couple μ in SVX
  - 1μ in L00

Overall accuracy







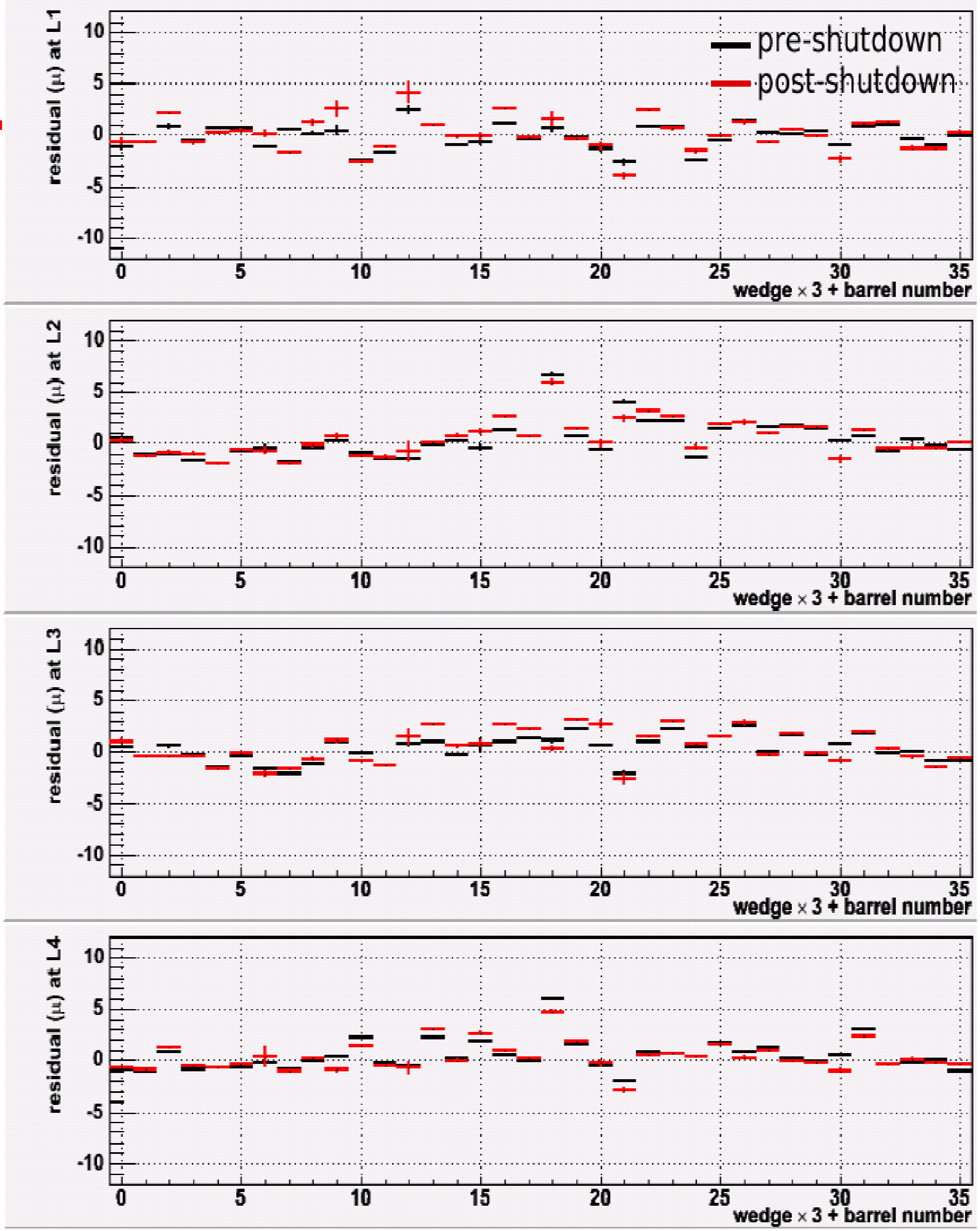
- same un-understood effects are at few μm level
- small compared to IP resolution

stability over time

Stability of SVX

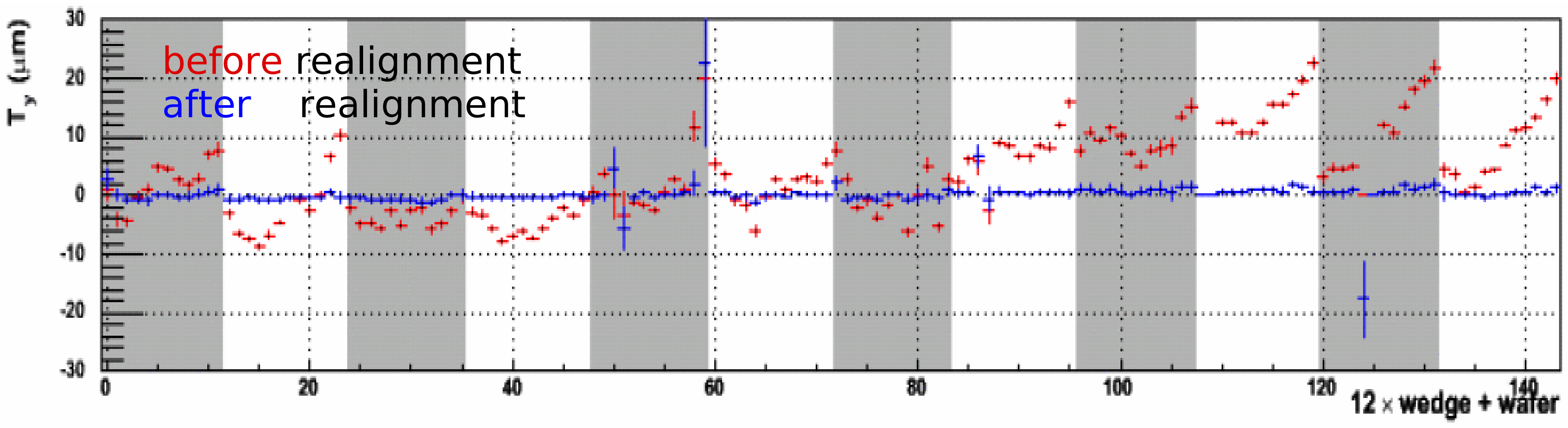
Alignment tasks now mostly monitoring of stability.

- SVX internal alignment observed to be very stable over time
- beginning 2005, Si temp. was lowered from -6ºC to -10ºC 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, upto 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*

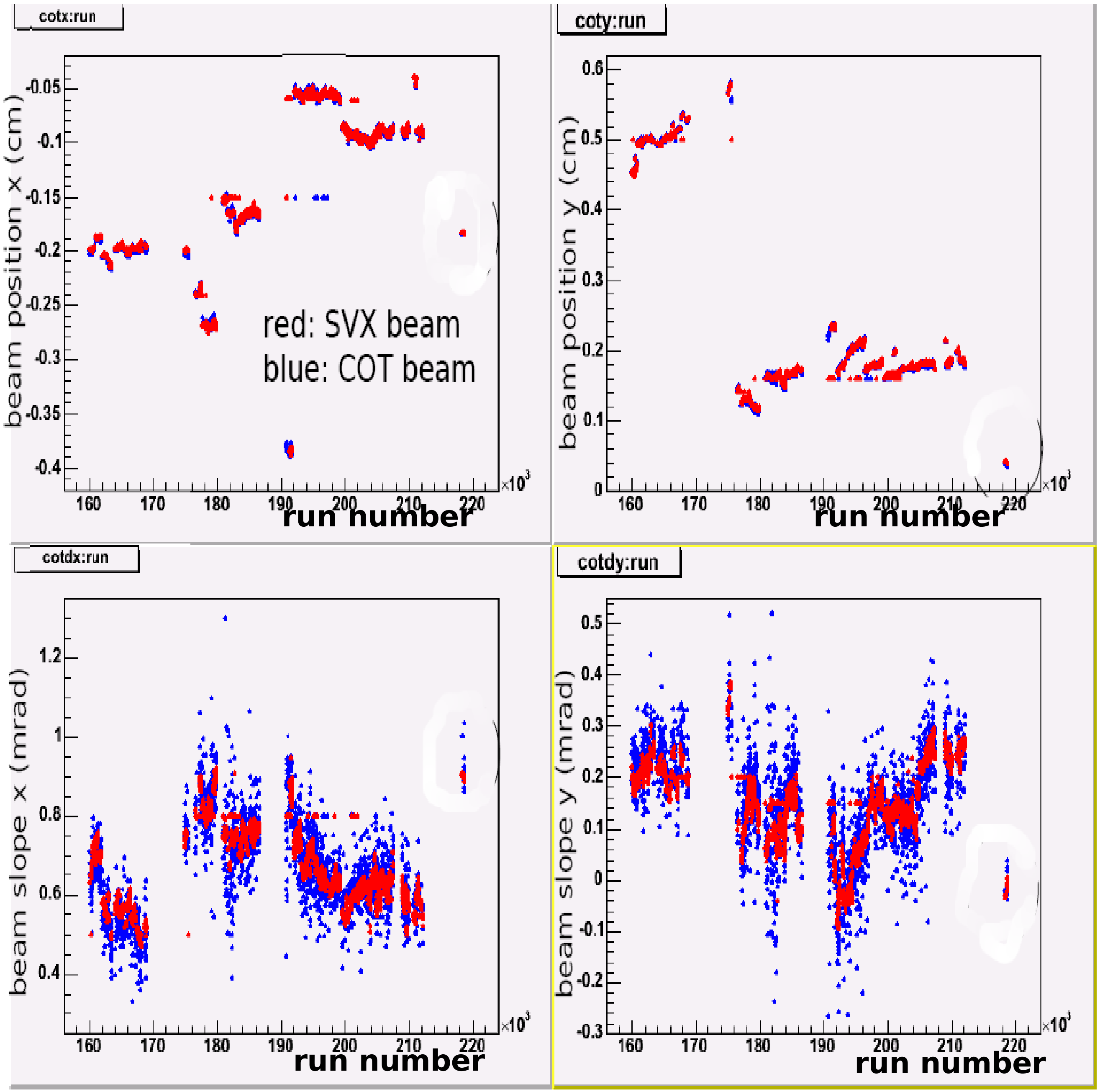


Global alignment of SVX wrt COT

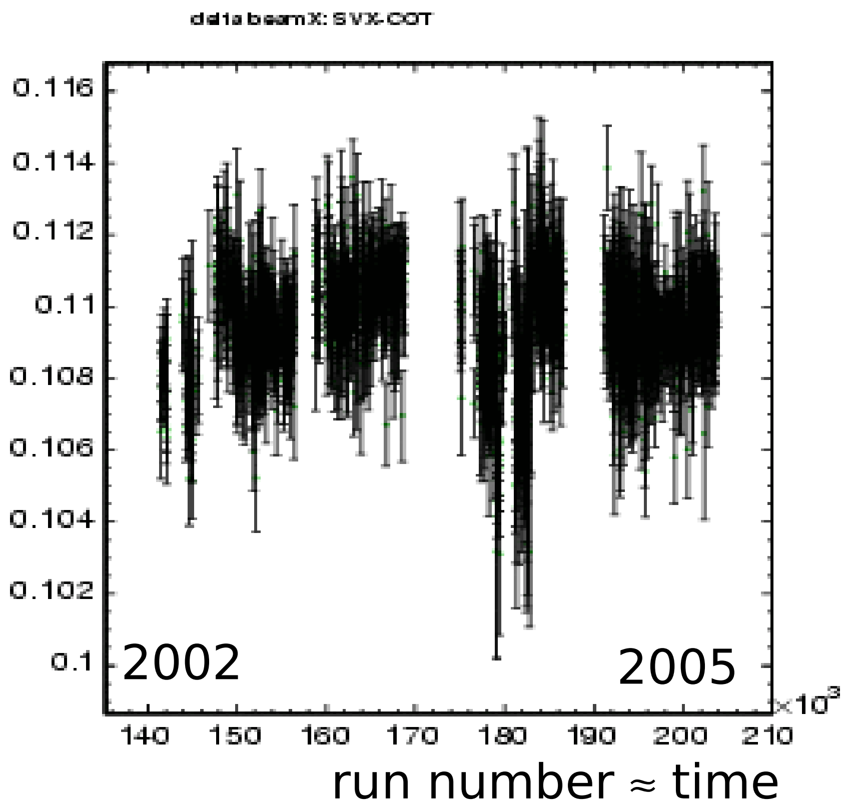
- Measure beam-line using
  - 1) only COT information
  - 2) SVX information
- compare positions to align SVX wrt COT
- compare measured slopes for global rotation

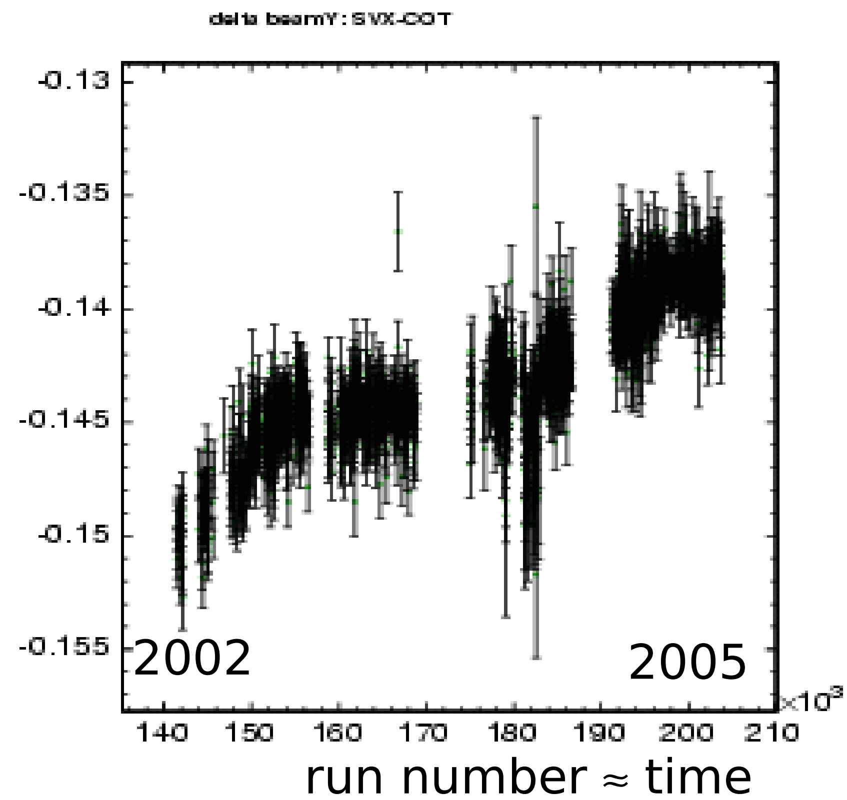
- beamlines are needed for physics anyway.
  - automatically generated for each run

crosschecked with SVX residual using COT tracks.



Stability global positioning

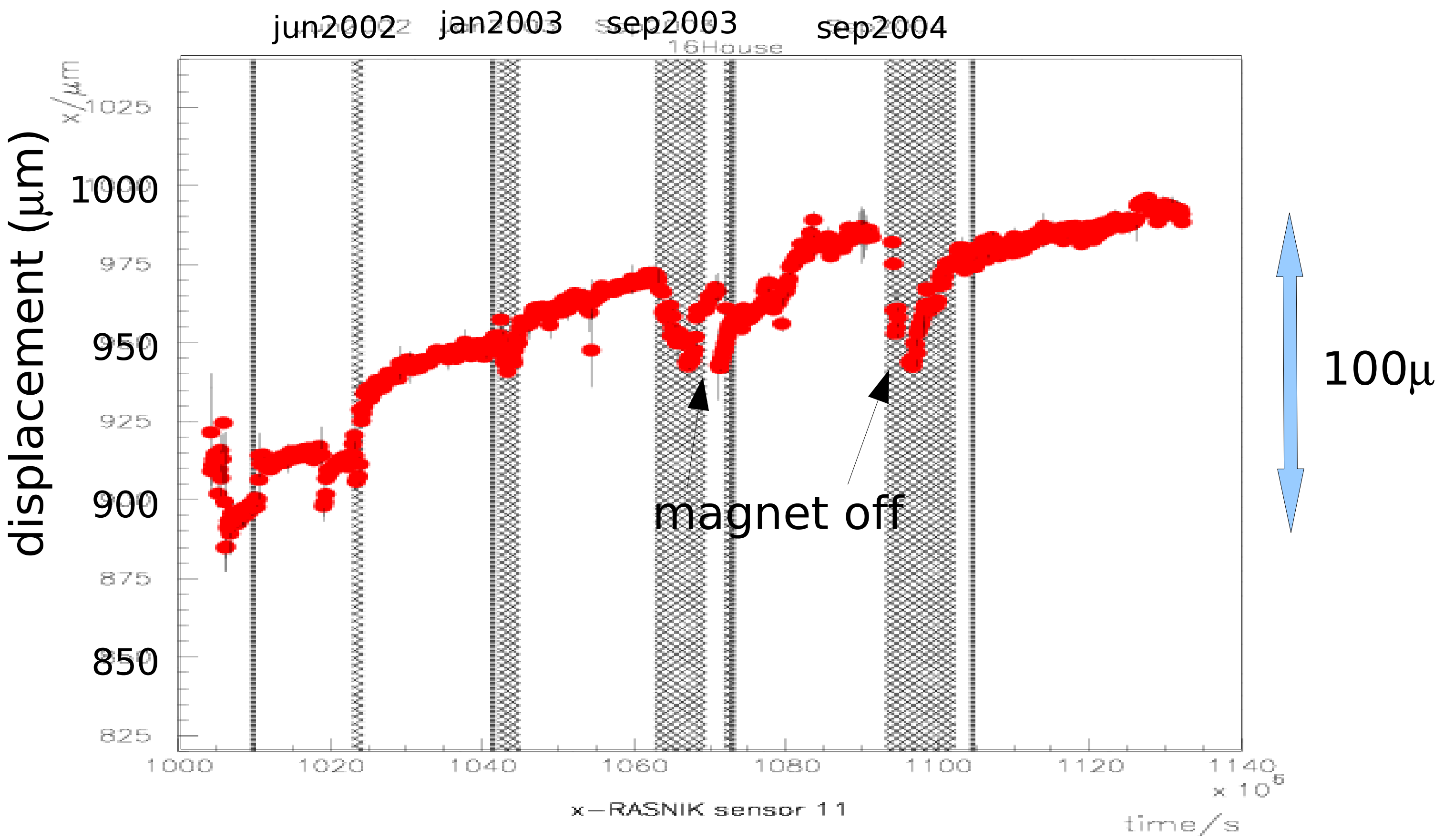




- The silicon is slowly sinking at an average rate ~ 50μ/year
  - Remember those overloaded inchworms I told you about?
- No indication for horizontal movement
- Beamline slopes show no indication of rotation (agreement few 10μrad)

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”

some opinions from CDF alignment people.

- Personpower is limited, spend it on
  - getting alignment out fast: physics analyses do not like to wait for it.
  - checking with different datasets (J/Psi+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 isue, especially for little-used systems (inchworms & rasniks)

- *Data is much more “squirrely” 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

=

....

Summary

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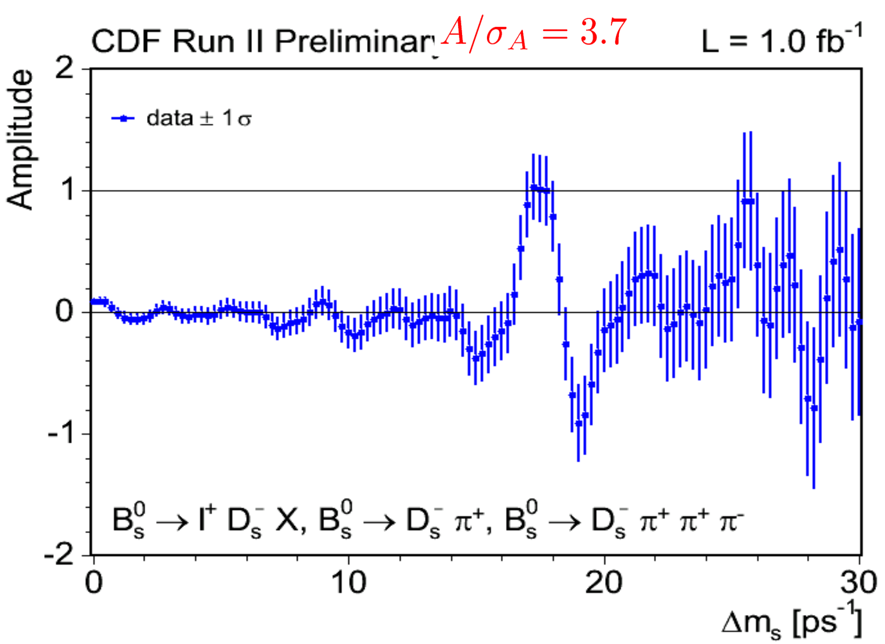
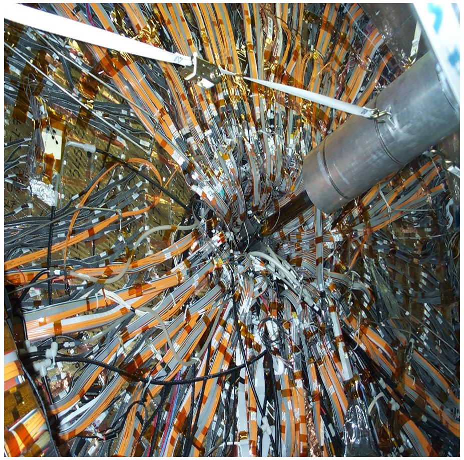
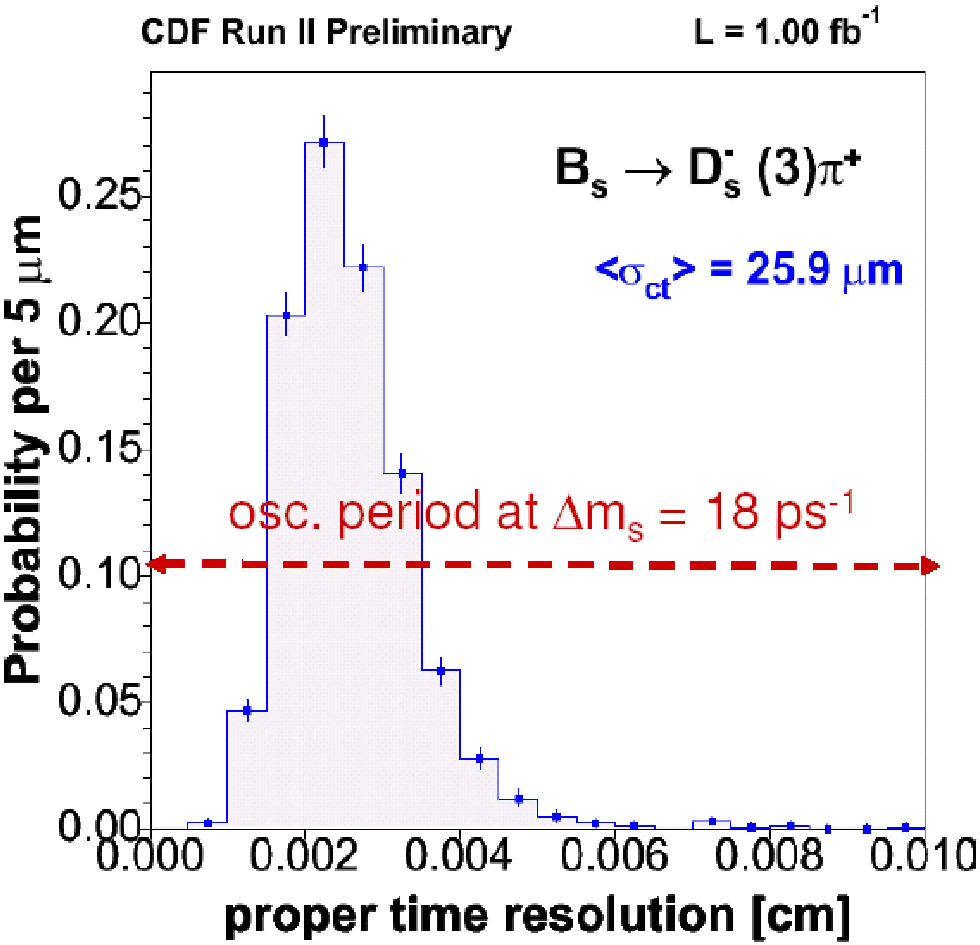
Displaced track trigger (SVT)+
Great momentum resolution (COT) +
excellent vertexing resolution (SVX+L00)

=







CDF Run II Preliminary
L = 1.00 fb^{-1}
$B_s \to D_s^- (3)\pi^+$
$<\sigma_{ct}>$ = 25.9 μm
osc. period at Δm_s = 18 ps^{-1}
Probability per 5 μm
proper time resolution [cm]
0.00
0.05
0.10
0.15
0.20
0.25
0.000
0.002
0.004
0.006
0.008
0.010