HFT Alignment Procedures

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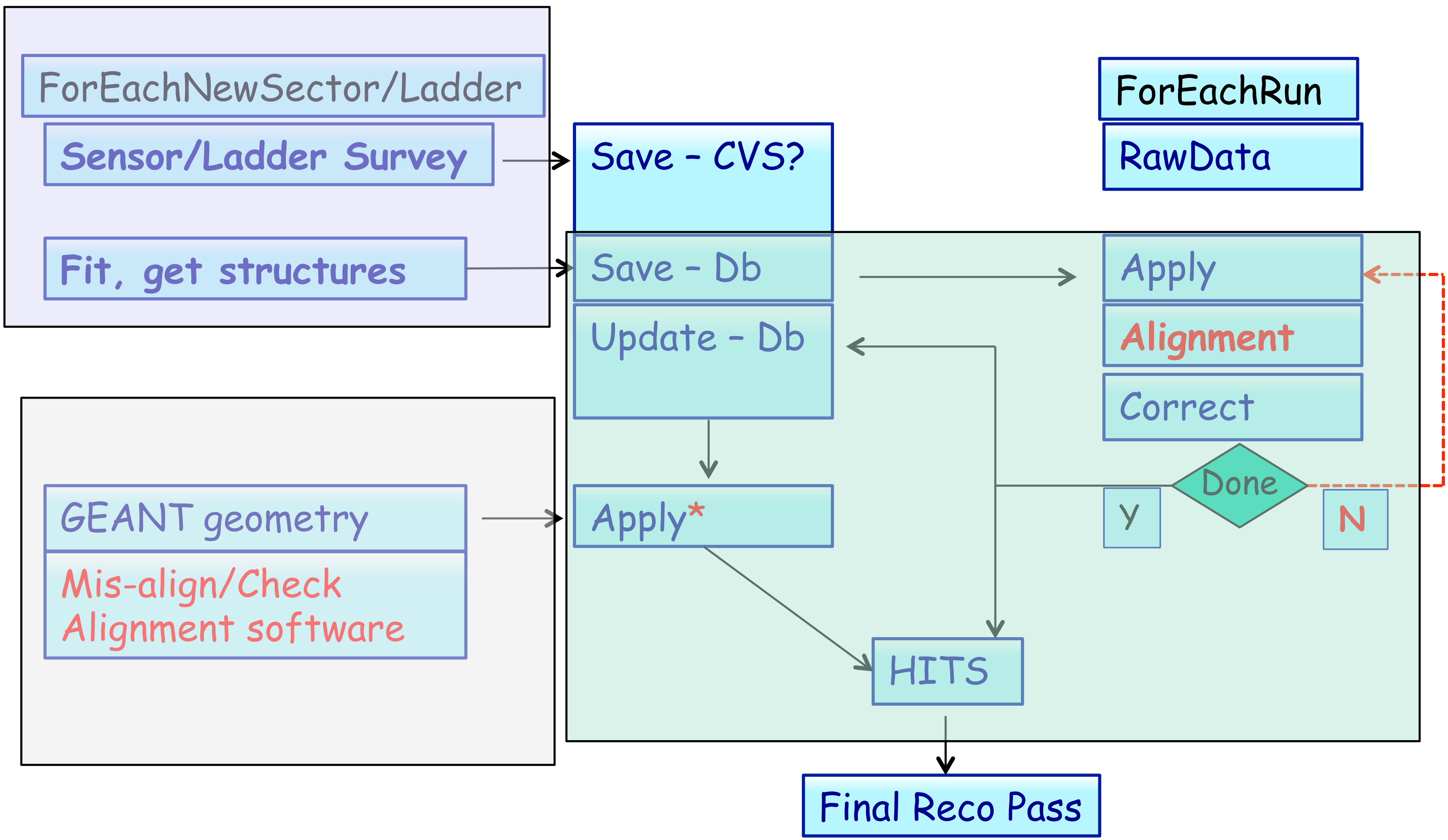
- Introduction
- HFT Configuration – System hierarchy
- (thoughts on) Proposed procedures
- Tools/Implementation (Jonathan)
- Plans, Timeline and Issues
- Summary

Flowchart of Geometry/Survey/Alignment



* VMC, STV ready

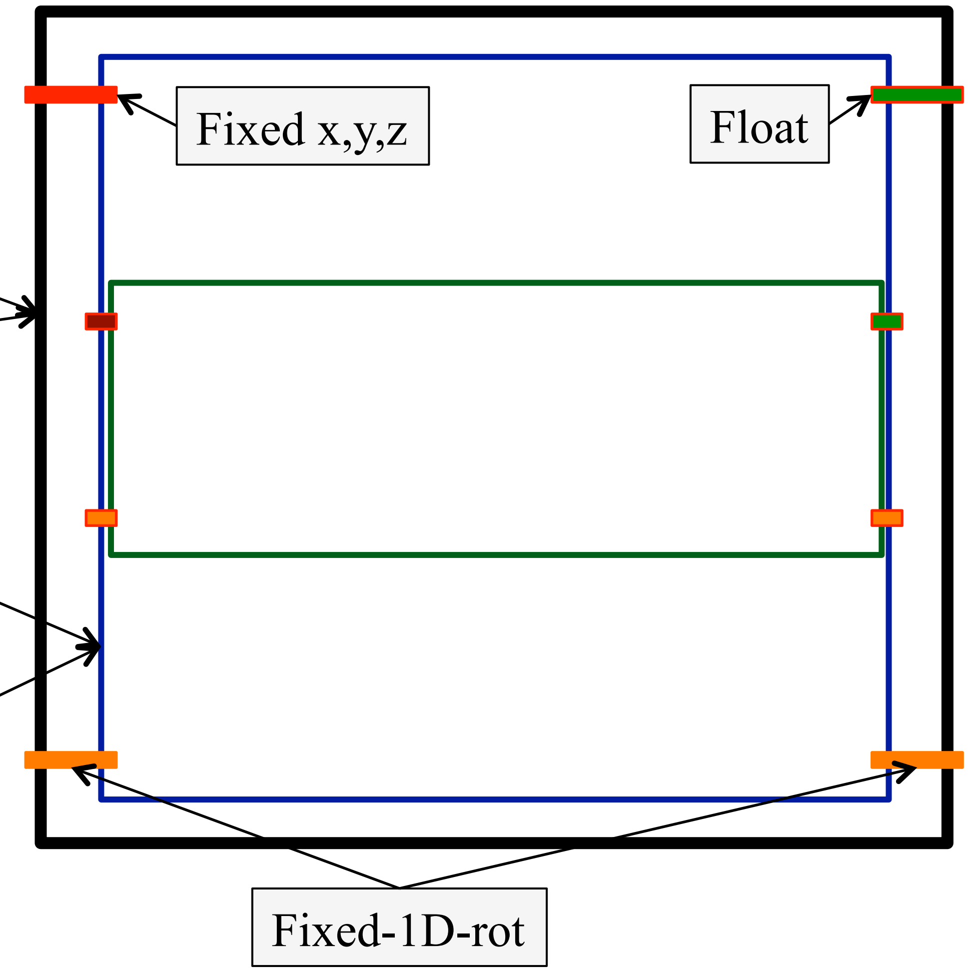
Introduction

- Anything we build or touch or use needs Modeling, Survey and in-situ Alignment
  - i.e. versioning

- Survey will freeze position of sensors on sectors (PXL). Help also with sector on hemisphere (PXL?). For SSD/IST will freeze position of sensors on ladder and ladder shape

- For each yearly Run the in-situ position of major detector elements needs to be rechecked

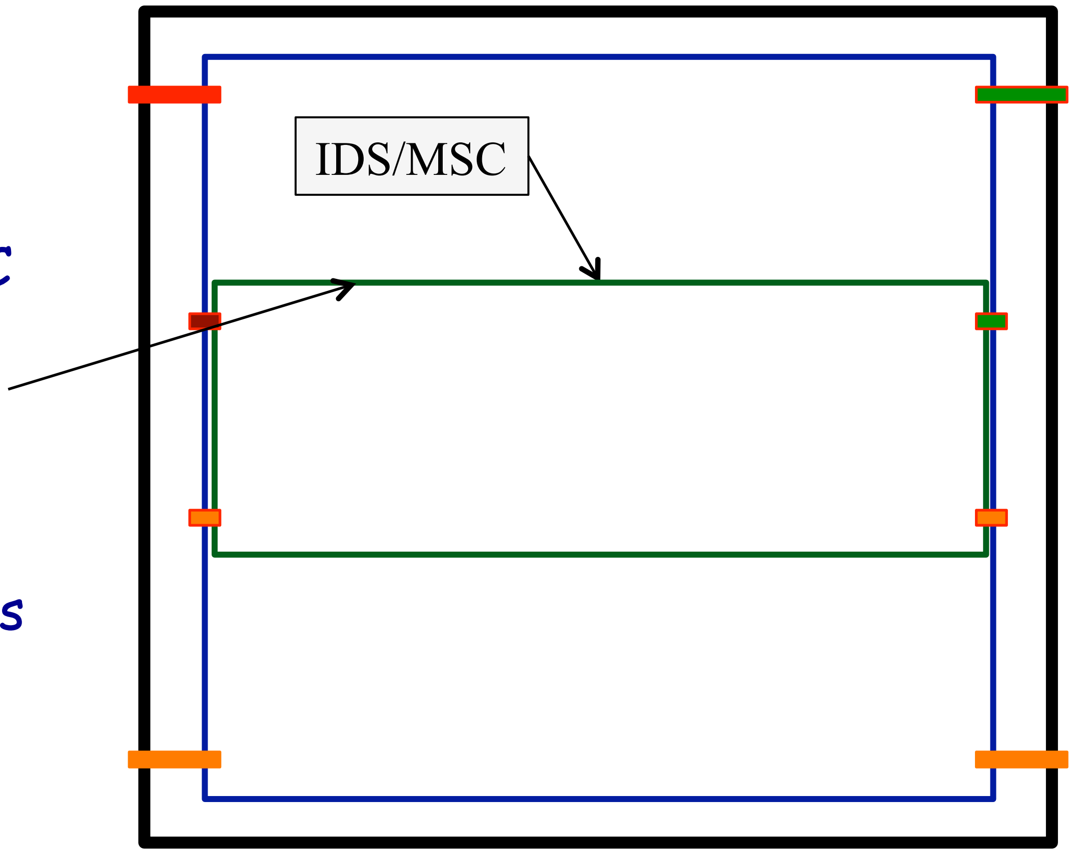
Reference System Hierarchy



- Star Magnet defines overall system (Field map)
- TPC is the first important system for HFT (relative positioning), attached to Magnet

- **ESC/WSC** attached to TPC wheel. It defines the HFT system's relation (as a whole) to TPC system

- See next slides for systems inside the HFT complex

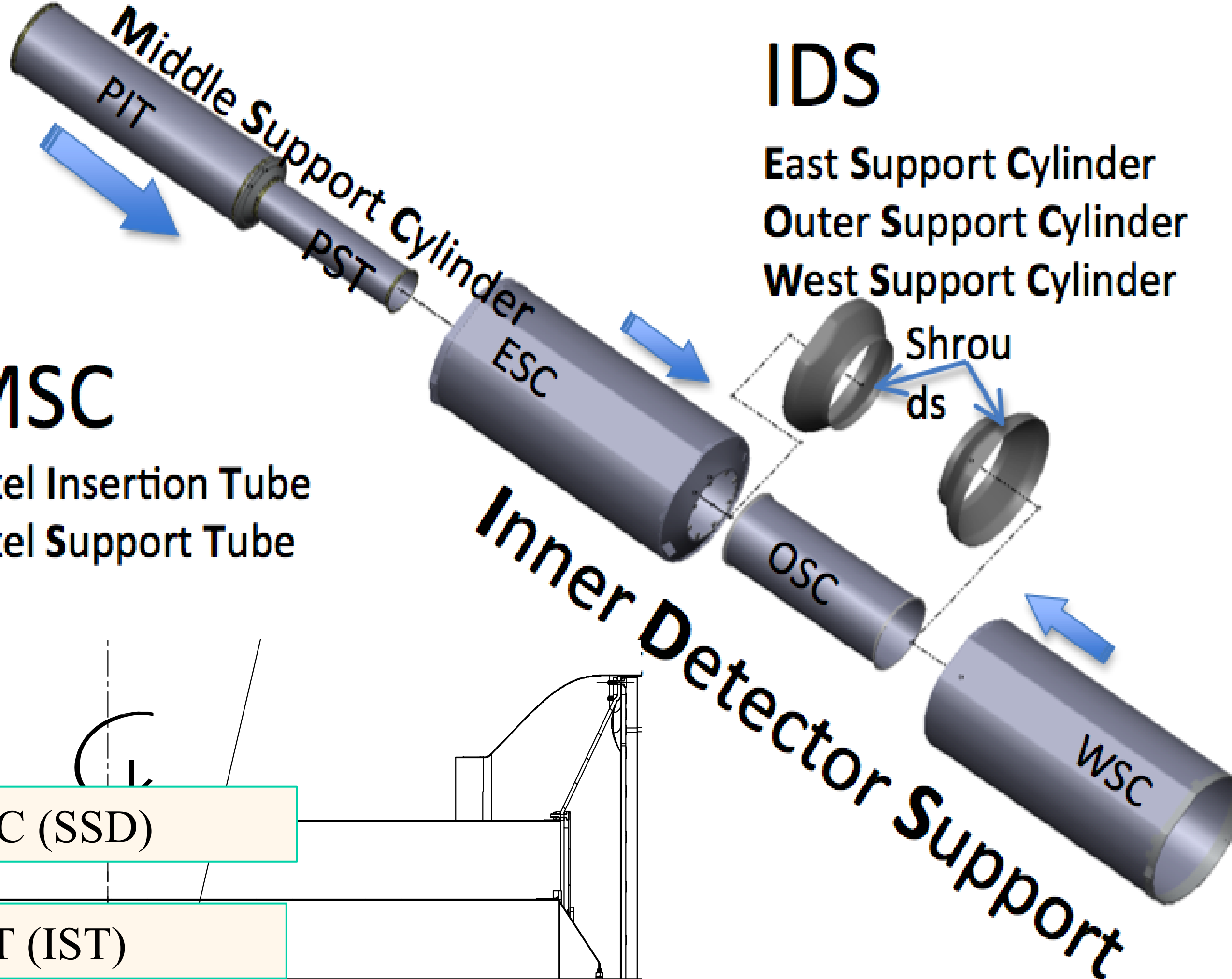


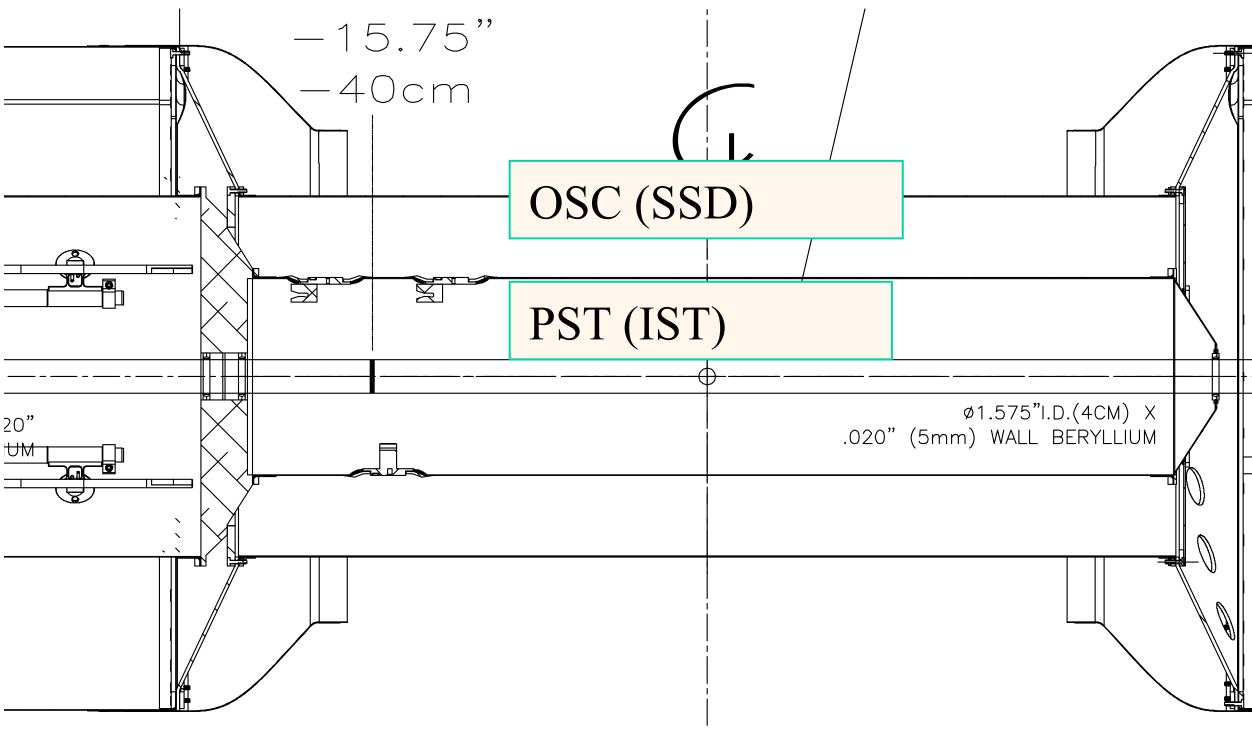
IDS

East Support Cylinder
Outer Support Cylinder
West Support Cylinder

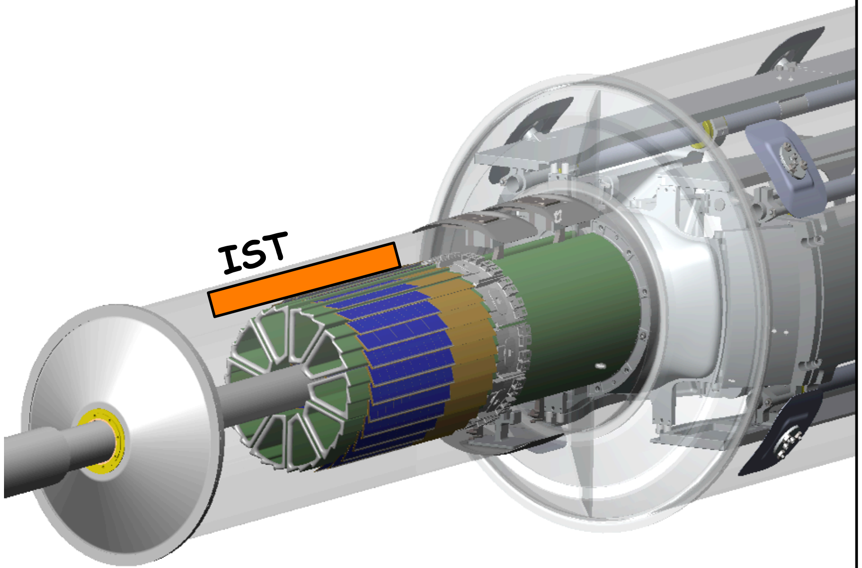
MSC

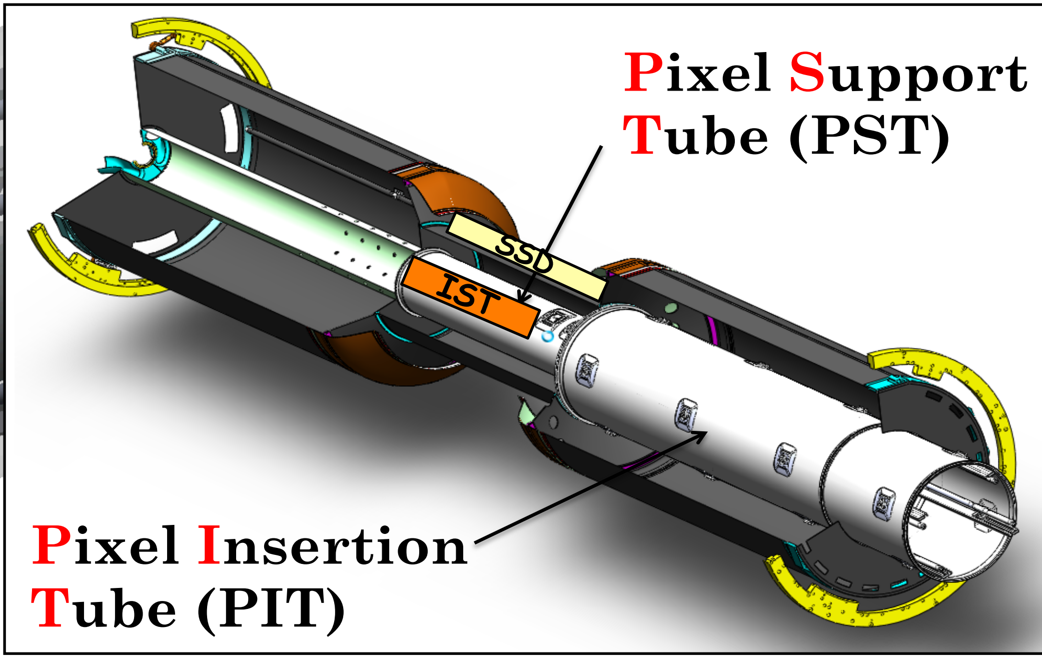
Pixel Insertion Tube
Pixel Support Tube

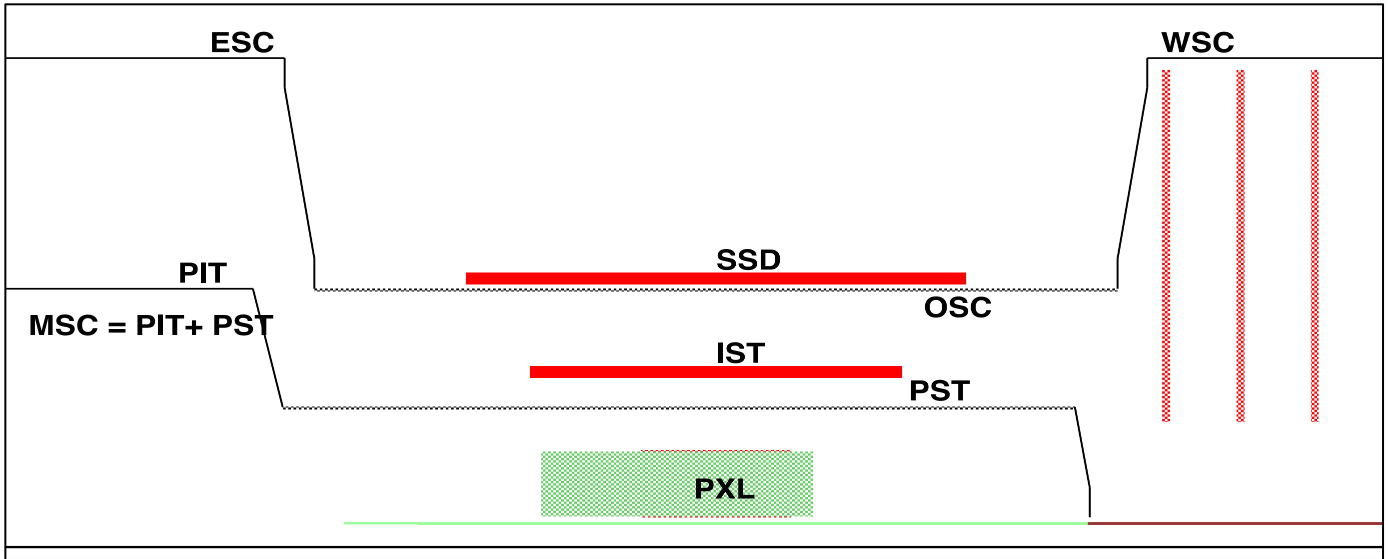




General Layout







Reference systems - comments

- In general survey accuracy of critical components (relative pixel and/or sensor positions) expected to be better than acceptable values

- Will soon need surveyed positions of IDS targets
  - to build 'ideal' position Db
  - Sub-millimeter accuracies acceptable -> Tracks will fix them

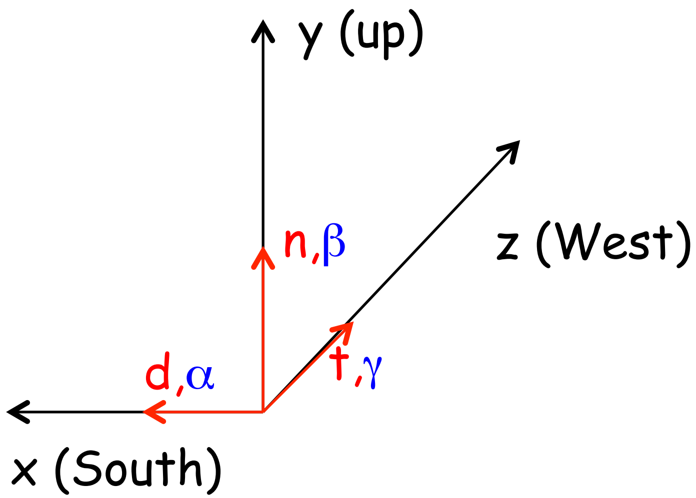
- All this information is represented as matrices (position/orientation) of their center-of-gravity. These matrices are used to define Local to Global transforms

GEANT geometry can/should be synchronized with Realistic Volume hierarchy instead of the current 'patch-the-hit' scheme

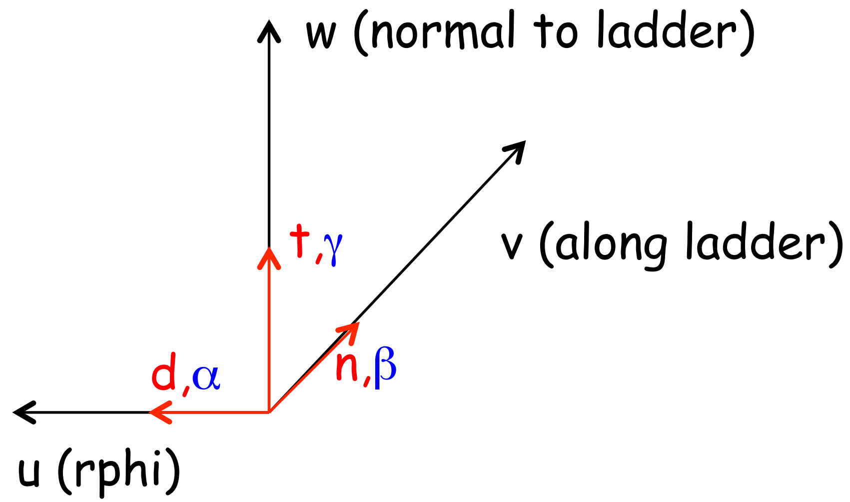
- VMC environment will facilitate this

Definitions

Global Coordinates



Local Coordinates



- Local v (along ladder) is fixed and along global z
- Local w (normal to wafer plane) is fixed (points away from the interaction point
- Local u (rphi on wafer plane) varies so it forms a RHS with v-ww

Offline use of Geometry Info

- Local-to-Global transforms are done in terms of **TGeoHMatrix**
- This can be e.g. the center of a sensor or a pixel.
- n,d,t are unit vectors and β,α,γ the corresponding rotation angles, RHS

TGeoHMatrix definition

$$\begin{pmatrix} x_G \\ y_G \\ z_G \\ 1 \end{pmatrix} = \begin{bmatrix} \hat{d}_x & \hat{n}_x & \hat{t}_x & d_x \\ \hat{d}_y & \hat{n}_y & \hat{t}_y & d_y \\ \hat{d}_z & \hat{n}_z & \hat{t}_z & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x_L \\ y_L \\ z_L \\ 1 \end{pmatrix}$$

Transform example

$$x_G^i = R \cdot x_L^i + T^i$$

$$x_G = \left(\hat{d}_x \cdot x_L + \hat{n}_x \cdot y_L + \hat{t}_x \cdot z_L\right) + d_x$$

Local <-> Global transforms

OLD SSD

WG = Tpc2Global * GL * SG * LS * WLL;
WaferInGlobal=Tpc2Magnet *SsdinTpc*SectorInSSD*LadderInSector*WaferInLadder

HFT SSD

WG = Tpc2Global * GL * LO * WLL;
WaferInGlobal=Tpc2Magnet *IDS2Tpc*Ladder2IDS*WaferInLadder

HFT IST

WG = Tpc2Global * GL * PI *LO * WLL;
WaferInGlobal=Tpc2Magnet *IDS2Tpc*PST2IDS*Ladder2PST*WaferInLadder

HFT PXL

PG = Tpc2Global *GL * PI *DP * SD * WLL;
PXLInGlobal=Tpc2Magnet*IDS2Tpc*PXL2IDS*DShell2PXL*Sector2DShell*(Pxl-Sector)

Alignment methods (outline only)

- There are 'Global' and 'Self' Alignment methods
  - Global uses mostly 'external' track information
  - Self uses mostly 'internal' track information
  - For HFT we propose a mix (more Self !)
- We have successful 'Global' methods already in place (SVT/SSD)
  - TPC distortions, t0, 'track tof' etc is a problem
- In HFT system we have significant sensor overlap to make use of 'Self' alignment methods. We also have high precision PXL info with excellent sector rigidity, survey info, placement.
- We need to use this advantage

We lack a hardware monitoring system. Once detectors are installed we rely on survey and alignment software

The hit-track residual Δx in the direction perpendicular to the axial strips is given by

$$\Delta x \equiv x_{track} - x_{hit} = \delta x + z \sin\beta + \tan\phi(\delta y + z\sin\alpha + x\sin\gamma) - f(\vec{B}, \phi) \qquad (1)$$

and for the direction parallel to the axial strips (in double sided ladders)

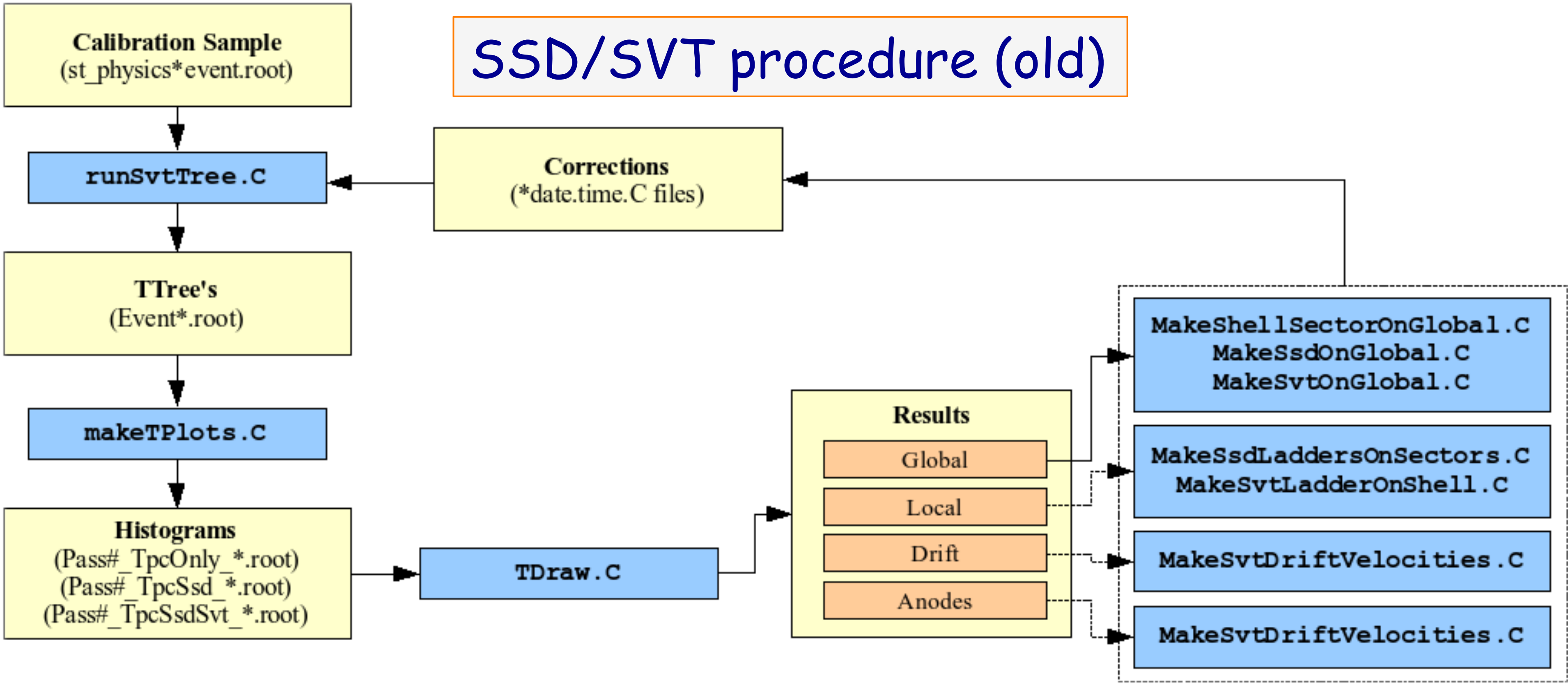
$$\Delta z \equiv z_{track} - z_{hit} = \delta z + x \sin\beta + \tan\theta(\delta y + z\sin\alpha + x\sin\gamma) \qquad (2)$$

The simplest approach to determining the alignment parameters is to use the means of the following histograms(for the Δx case):

1. the distribution of residuals integrated over y, z, and ϕ, which gives δx directly,
2. the residual vs. z which gives $\sin\beta$,
3. the residual vs. $\tan\phi$ which gives δy,
4. the residual/$\tan\phi$ vs. x which gives $\sin\gamma$,
5. and the residual/$\tan\phi$ vs. z which gives $\sin\alpha$.

D.Chakraborty, J.D.Hobbs, D0 note Oct.13, 1999

SSD/SVT procedure (old)



The sequence to be followed for each detector is:

1) **SSD Alignment**: (TPC tracks Only)
   Global - SSD on Global and Sectors on Global;
   Local - SSD Ladders on Sectors;
2) **SVT Alignment**: (TPC+SSD hits on tracks)
   Global - SVT on Global and Shells on Global;
   Local - SVT Ladders on Shells; (Drift Velocities);
3) **Consistency Check**: (TPC+SSD+SVT hits on tracks)
   Global;Local (ladders);Drift Velocities;

- For alignment we use "good" (well defined) tracks fitted with the primary vertex. (e.g. NFP, pt cuts)
  - Use of primary tracks significantly improves precision of track predictions in HFT and reduces influence of systematics.
  - Good statistics is a must (up to a point)(see example in Jonathan's talk)(50-100K hits per wafer/sensor)

- In order to minimize TPC space-charge distortions, tracking errors (mismatches) and PXL pileup we will need to use low luminosity and low-medium multiplicity data as the alignment sample

- Method is iterative since it is precise for small deviations

HFT Proposed Procedure:

Remember: PXL detector is a big asset (c.f. TPC)

1. Global Alignment of PXL
   - Relative alignment of PXL sectors and halves using overlap region AND halves using Event vertex found by each half
   - Relative alignment of PXL and TPC [TPC primary tracks]
     - Iterative->(PXL, PXL half, sector)
   - Exact sequence/interplay needs to be determined

2. Primary tracks with TPC+PXL hits
   - Alignment of IST ladders with respect to PXL

3. Primary tracks with (All – SSD) hits
   - Alignment of SSD ladders

4. Check

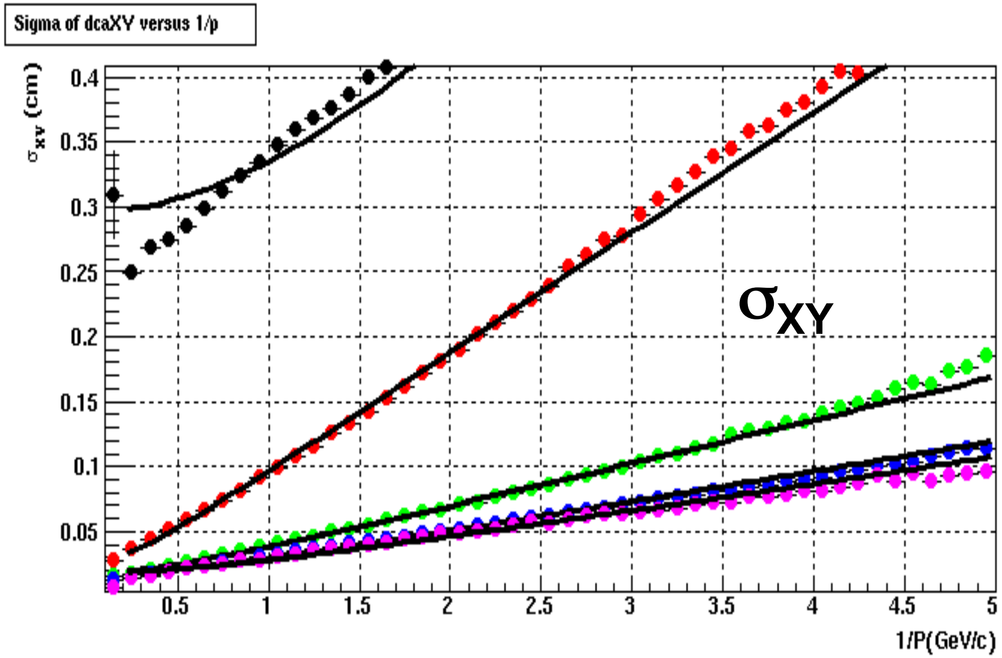
- We assume that sensors on ladder and ladders on sectors are pre-surveyed to specs

Precision requirements for HFT alignment

- Pointing accuracy is ultimate figure of merit: DCA resolution (in bending XY $\equiv r\phi$ plane: σ_{DCA}), and resolution in non-bending plane: σ_z
  - $\sigma^2_{DCA} = \sigma^2_{vertex} + \sigma^2_{track} + \sigma^2_{MCS}$ (the same for non-bending plane)
  - primary vertex resolution: $\sigma_{vertex} \sim 3\mu m + (120\ \mu m / \sqrt{N_{ch}})$; for central Au+Au collisions turns out to be ~5 μm
  - track pointing resolution: $\sigma_{track} \sim 1.5\ \sigma_{XY}$ [in our case, where σ_{XY} is intrinsic detector precision (~10μm)] $\oplus$ alignment errors
  - multiple scattering (MCS): $\sigma_{MCS} \sim 20\mu m / \beta p$ (GeV/c) (for thin PXL)

Overall mis-alignments of < 10 μm or <MCS are acceptable

DCA resolution



- SVT/SSD example

- With increasing no. of fitted Si points it is improved by ~ order of magnitude.
- Contribution from tracking (constant term) is comparable with MCS @ 1 GeV/c

Number of Silicon Points fitted to track	σ_{XY} @1GeV/c (μm)
0 - ● TPC only	3350
1 - ● TPC+SSD	967
2 - ● TPC+SSD+SVT	383
3 - ● TPC+SSD +SVT	296
4 - ● TPC+SSD +SVT	281

Tasks

- Need to finalize the PXL sensor representation in Db (prototype sector)
- Need to setup Data formats, code to deliver matrices etc
- Need to know/map the (realistic) error of every survey step
- Need to start simulations to determine alignment software performance
- Need to rework GEANT geometry synchronization (STV, VMC)
- Need to finalize SSD procedures and initialize/define IST ones
- Need to include gravitational sagging in SSD and IST (?) model
- Need to keep/use expertise around

Plans/Timeline

Some of these efforts need to go in parallel

- It will take about a month or two to setup the chain and clean up the code for all HFT subsystems (current environment)
  - Includes software, Db structures, Hit, conventions
- We can do (some) tests in current environment or begin porting to VMC (with help)
- By the end of the year we would need to have defined and have established working interfaces to Survey for PXL
- Full chain ready to work with cosmics/data when available

Only then, when done, we can start looking at other packages

Summary

- The building up of a working chain is coming along
- All 3 needed efforts are moving along (Geo, Sur, Al)
- Benefited enormously from previous experience as we hope to benefit from current experience
- A lot still needs to be done
- Target to have a working chain for data beginning of the year is not unrealistic

Backup

References

1. “The STAR time projection chamber a unique tool for studying high multiplicity events at RHIC”, M.Anderson et al., NIM A499: 652,2003.
2. “The laser system for the STAR time projection chamber”, J. Abele et al., NIM A499: 692,2003.
3. “Correcting for distortions due to ionization in the STAR TPC”, G. Van Buren et al.,NIM A566:22-25,2006.
4. “The STAR Silicon Vertex Tracker” A large area Silicon Drift Detector”, R.Bellwied et Al., NIM A499: 640, 2003.
5. “The STAR silicon strip-detector (SSD)”, L.Arnold et al., NIM 2003 A499: 652, 2003.
6. “Alignment Strategy for the SMT Barrel Detectors”, D.Chakborty, J.D.Hobbs, October 13, 1999. D0 Note (unpublished)
7. “Sensor Alignment by Tracks”, V.Karimaki et al.,CMS CR-2004/009 (presented at CHEP 2003)
8. http://phys.kent.edu/~margetis/STAR/HFT/Survey/SVTSmallScaleSelfAlignment.pdf
9. http://phys.kent.edu/~margetis/STAR/HFT/Survey/SVT_Alignment_JPCSL.pdf

Small Scale Self-Alignment with the SVT

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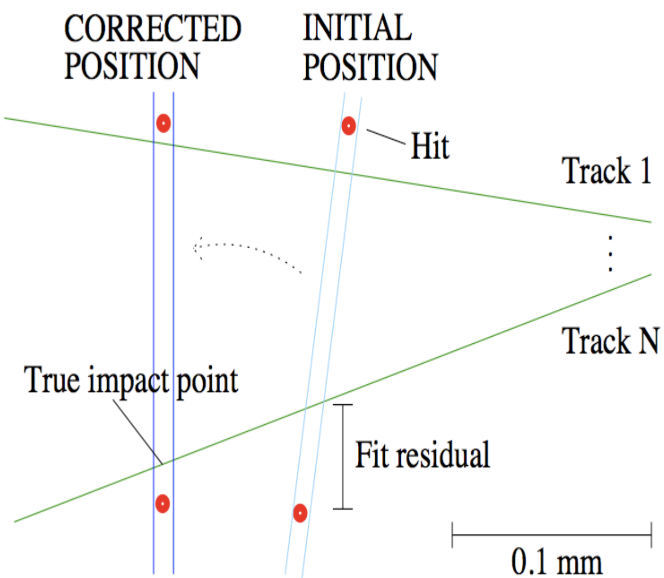

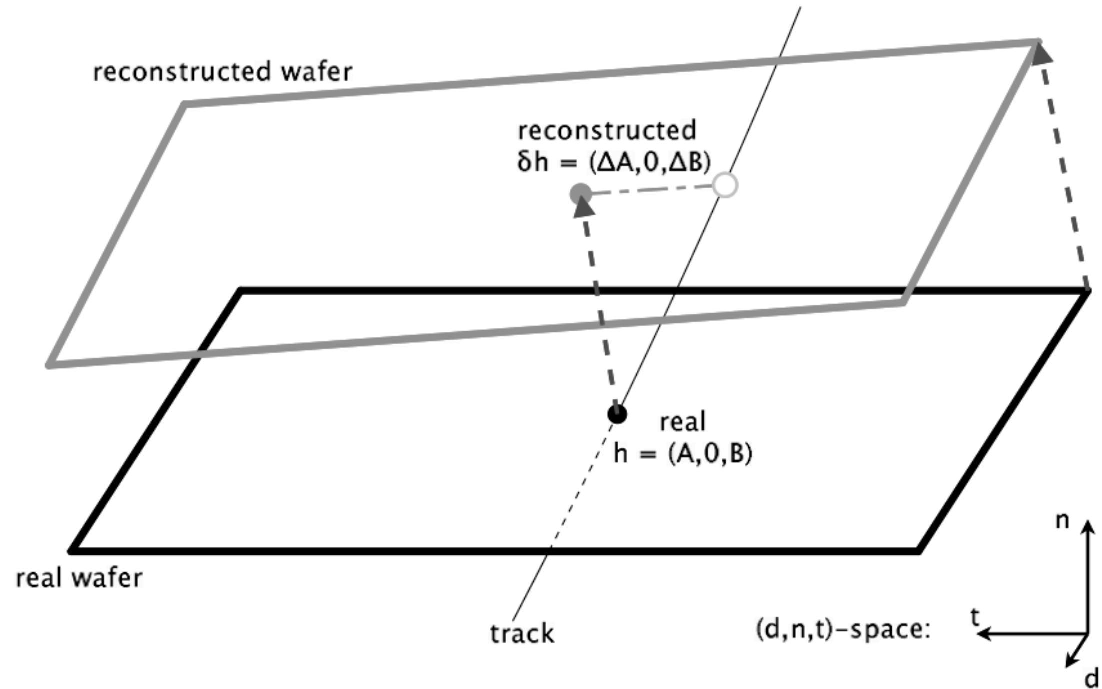

$$\Delta A = -B\delta\phi_n - \delta x_d + v_{dn}[A\delta\phi_t - B\delta\phi_d + \delta x_n]$$
$$\Delta B = A\delta\phi_n - \delta x_t + v_{tn}[A\delta\phi_t - B\delta\phi_d + \delta x_n]$$

http://drupal.star.bnl.gov/STAR/comp/calib/svt/selfalign

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$$\Delta B = A\delta\phi_n - \delta x_t + v_{tn}[A\delta\phi_t - B\delta\phi_d + \delta x_n]$$

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D.Chakraborty, J.D.Hobbs, D0 note Oct.13, 1999

A. Appendix. Jacobian of measured hit position deviation from predicted track ones with respect to misalignment parameters.

1. *Misalignment of the detector in Global Coordinate System (GCS)*

- $\vec{j} = (j_x,\, j_y,\, j_z)$ - track direction cosinuses in GCS on measurement plane,
- $\vec{x} = (x,\, y,\, z)$ - track prediction in GCS on measurement plane,
- $\vec{x}_{hit} = (x_{hit},\, y_{hit},\, z_{hit})$ - hit position in GCS on measurement plane,
- $\vec{v} = (v_x,\, v_y,\, v_z)$ - direction of perpendicular to measurement plane in GCS,
- $\vec{\Delta} = (\Delta_x,\, \Delta_y,\, \Delta_z,\, \Delta_\alpha,\, \Delta_\beta,\, \Delta_\gamma)$ - misalignment parameters: shift and rotation with respect to X,Y,Z axises, respectively.
- $\vec{x}_{hit} - \vec{x} = \mathbf{G} \cdot \vec{\Delta} =$
$$\begin{pmatrix} -1 + j_x v_x & j_x v_y & j_x v_z & j_x(-v_y z + v_z y) & -z + j_x(v_x z - v_z x) & y + j_x(-v_x y + v_y x) \\ j_y v_x & -1 + j_y v_y & j_y v_z & z + j_y(-v_y z + v_z y) & j_y(v_x z - v_z x) & -x + j_y(-v_x y + v_y x) \\ j_z v_x & j_z v_y & -1 + j_z v_z & -y + j_z(-v_y z + v_z y) & x + j_z(v_x z - v_y x) & j_z(-v_x y + v_y x) \end{pmatrix} \vec{\Delta}$$

2. *Misalignment of the detector in Local Coordinate System (LCS)*

- $\vec{u} = (u,\, v,\, w \equiv 0)$ - track prediction in LCS on measurement plane.
- $(t_u,\, t_v)$ - track direction tangenses in Local Coordinate system (LCS) on measurement plane.
- $\vec{u}_{hit} = (u_{hit},\, v_{hit})$ - hit position in LCS on measurement plane,
- $\vec{\delta} = (\delta_u,\, \delta_v,\, \delta_w,\, \delta_\alpha,\, \delta_\beta,\, \delta_\gamma)$ - misalignment parameters, shift and rotation with respect to local u,v,w axises, respectively.
- $$\vec{u}_{hit} - \vec{u} = \mathbf{L} \cdot \vec{\delta} = \begin{pmatrix} -1 & 0 & t_u & t_u v & -t_u u & v \\ 0 & -1 & t_v & t_v v & -t_v u & -u \end{pmatrix} \vec{\delta}$$
- $(u_{hit} - u) = -\delta_u + t_u(\delta_w + v\delta_\alpha - u\delta_\beta) + v\delta_\gamma;$
  $(v_{hit} - v) = -\delta_v + t_v(\delta_w + v\delta_\alpha - u\delta_\beta) - u\delta_\gamma;$