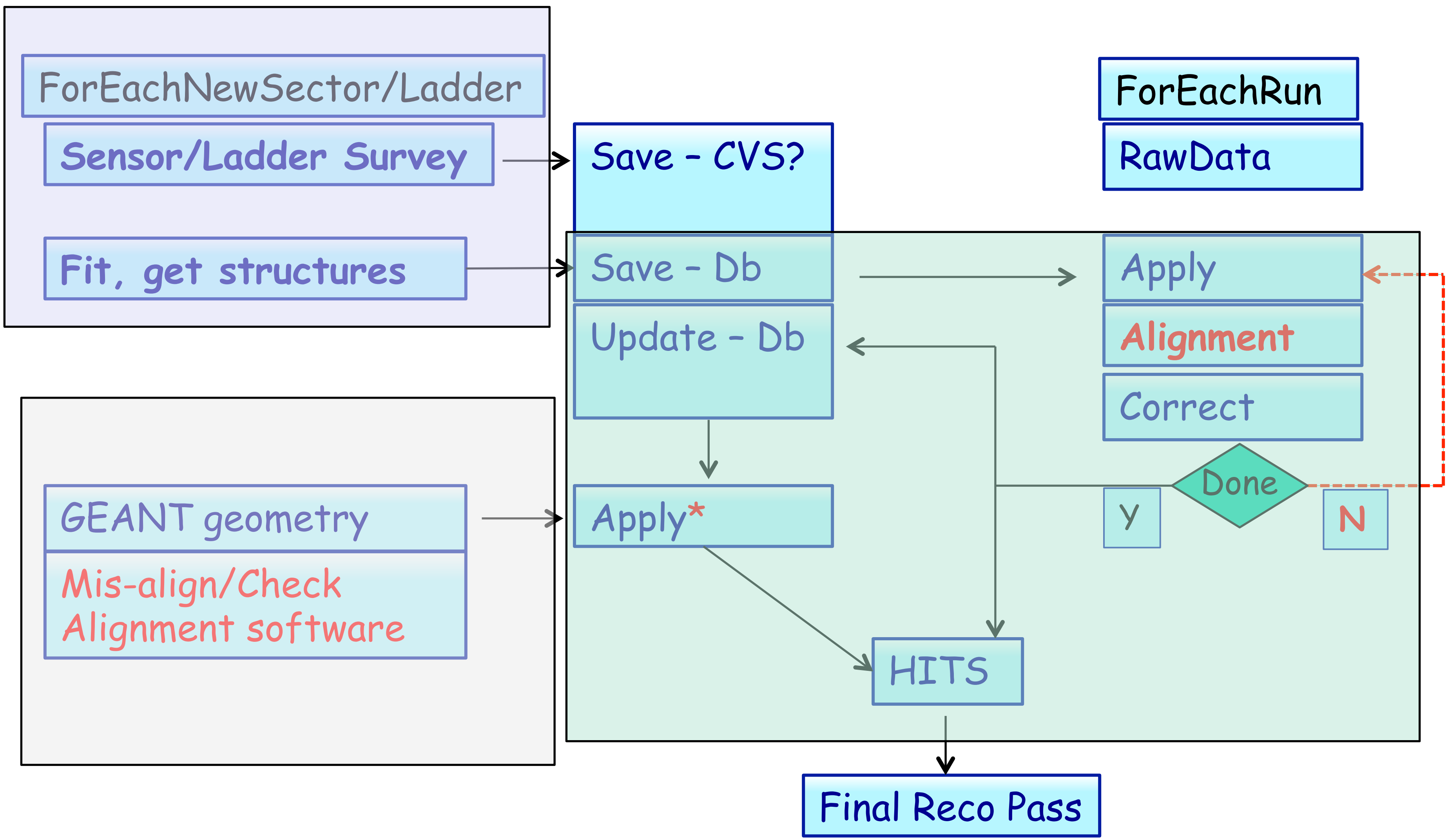
HFT Alignment Procedures

S. Margetis, KSU

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

Flowchart of Geometry/Survey/Alignment



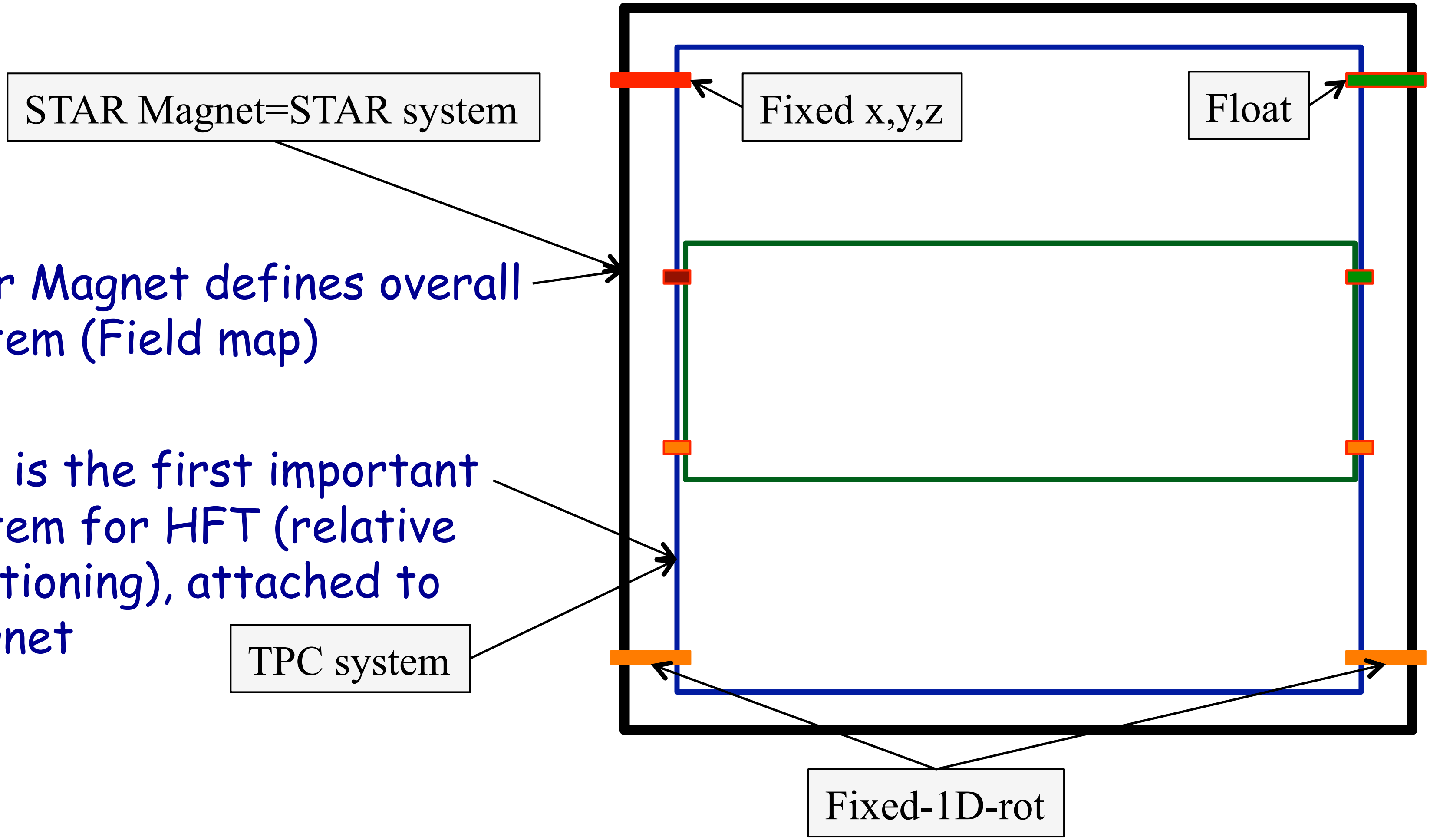
* VMC, STV ready

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

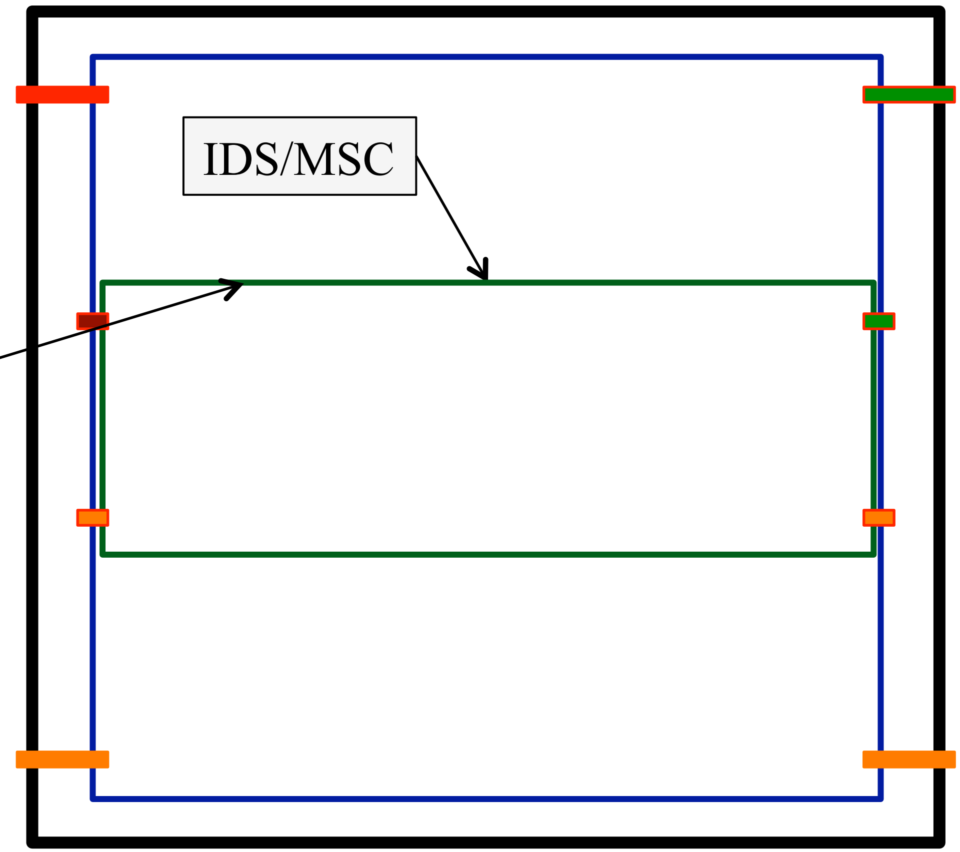
Reference System Hierarchy

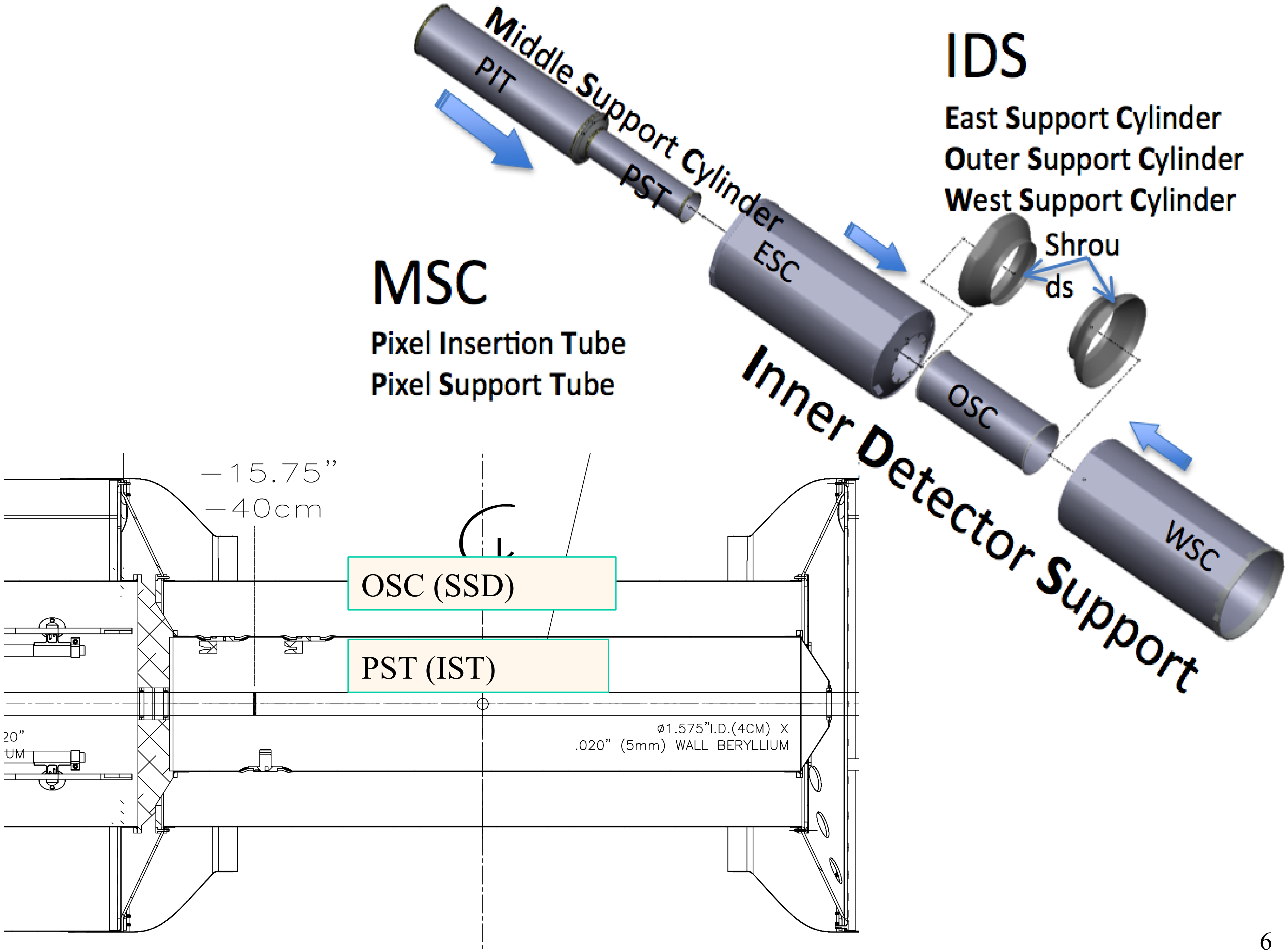
- Star Magnet defines overall system (Field map)
- TPC is the first important system for HFT (relative positioning), attached to Magnet



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

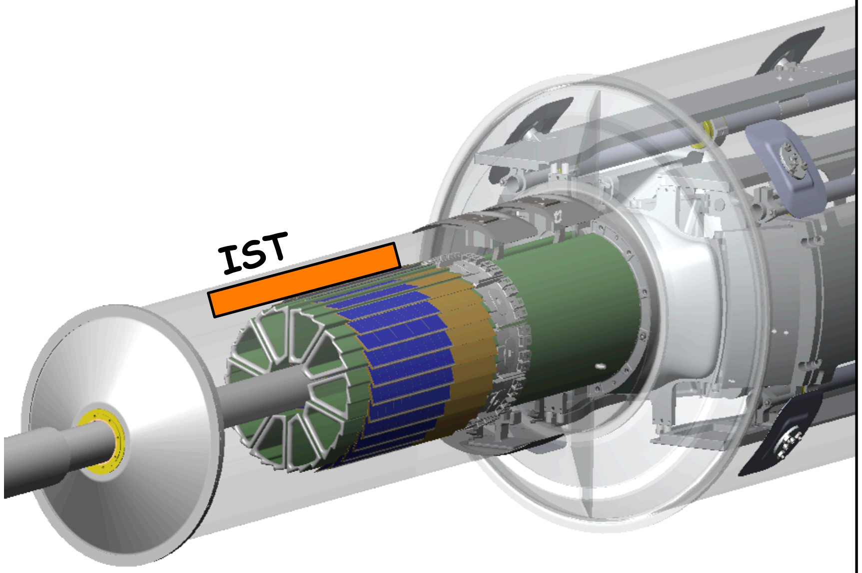
- See next slides for systems inside the HFT complex

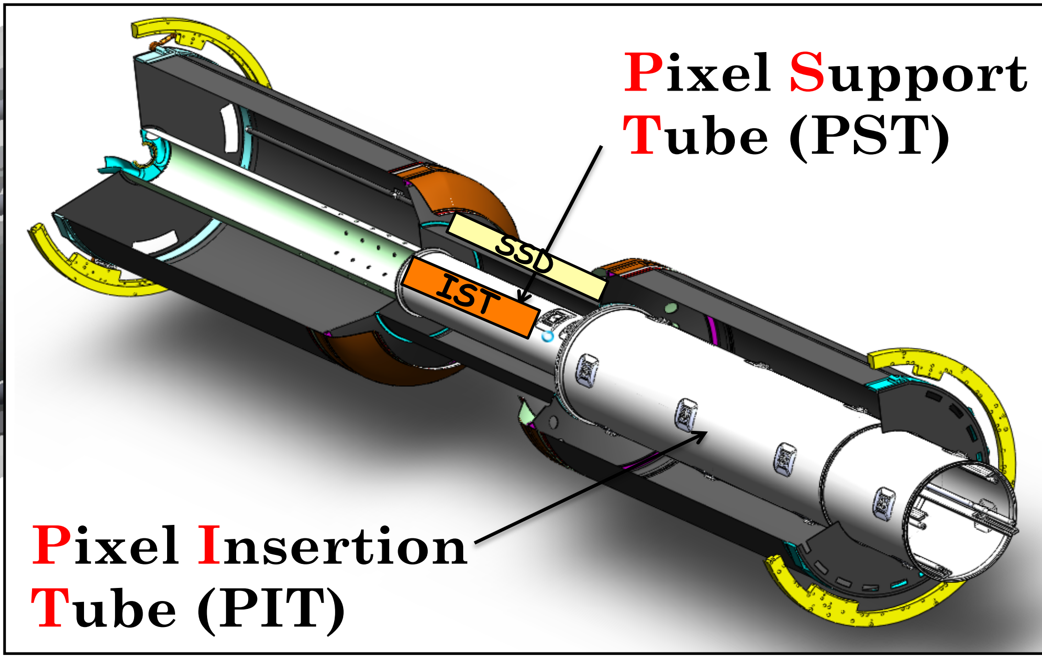


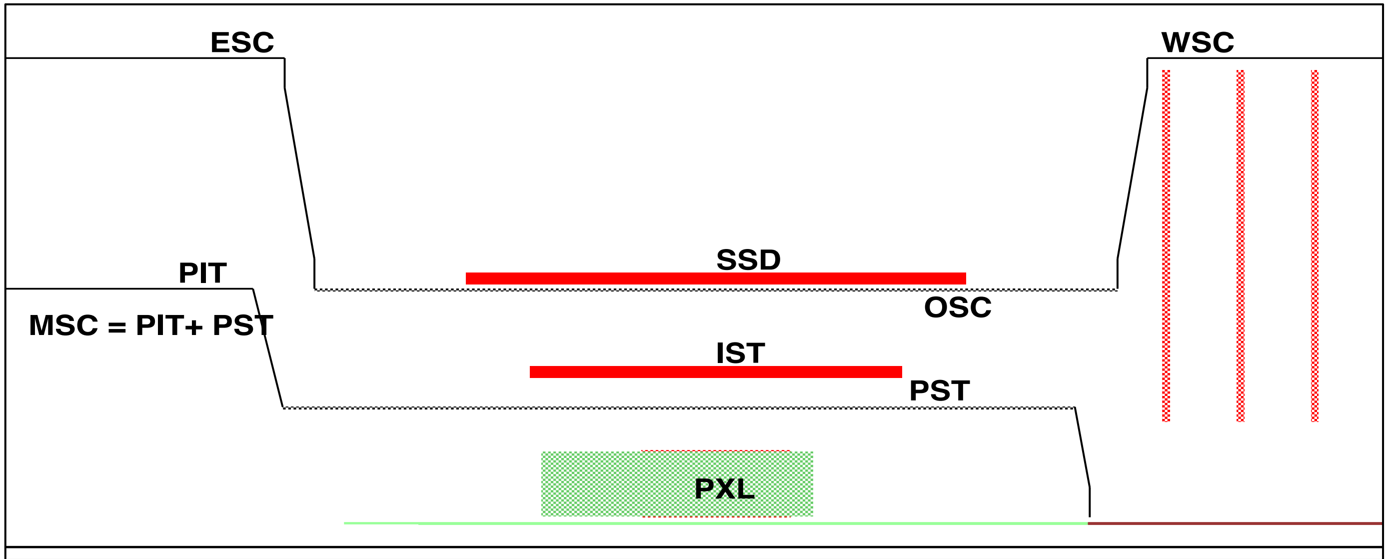


MSC
Pixel Insertion Tube
Pixel Support Tube
IDS
East Support Cylinder
Outer Support Cylinder
West Support Cylinder
Middle Support Cylinder
PIT
PST
ESC
Shrou
ds
OSC
WSC
Inner Detector Support
−15.75”
−40cm
OSC (SSD)
PST (IST)
ø1.575”I.D.(4CM) X
.020” (5mm) WALL BERYLLIUM

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

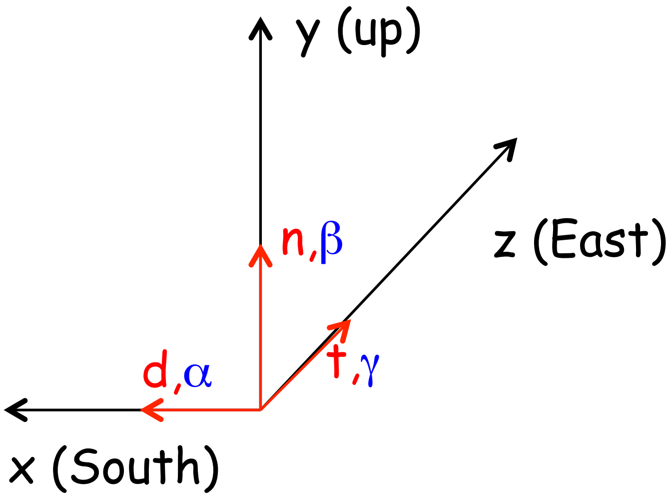
- All this information is represented as matrices (position/orientation) of their center-of-gravity. These matrices are used to define Local to Global transforms

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

- VMC environment will facilitate this

Offline use of Geometry Info

Definitions



- 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

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

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

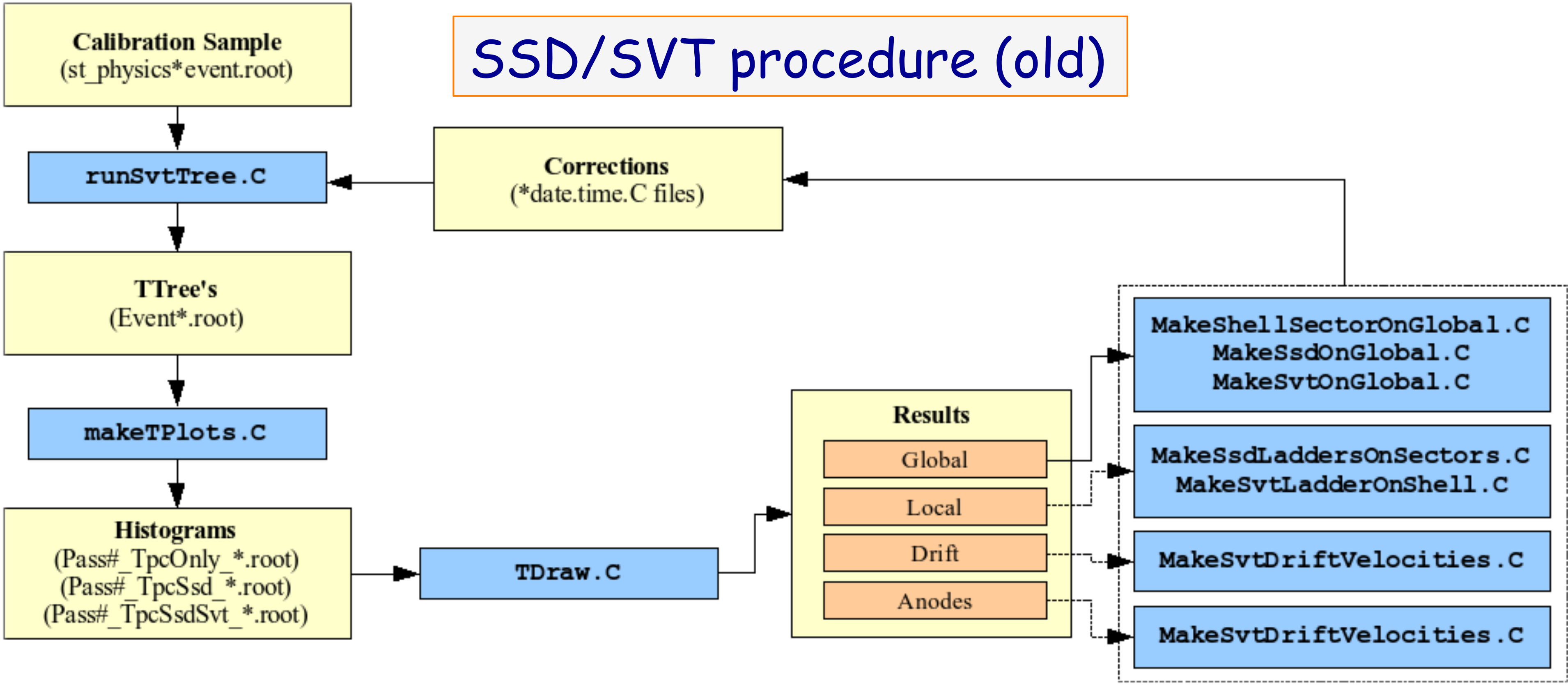
$$\Delta z \equiv z_{track} - z_{hit} = \delta z + x \sin\beta + \tan\theta(\delta y + z \sin\alpha + x \sin\gamma) \quad (2)$$

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)

- 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

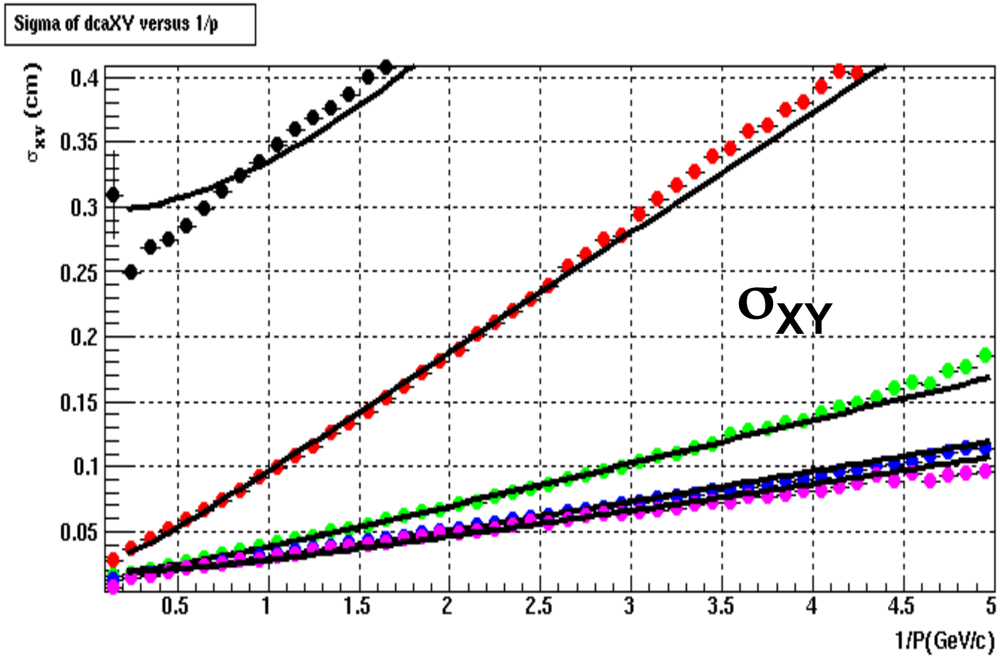
- We assume that sensors on ladder and ladders on sectors are pre-surveyed to specs

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

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

- 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

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
- Need to rework/prioritize Software Summer activities

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

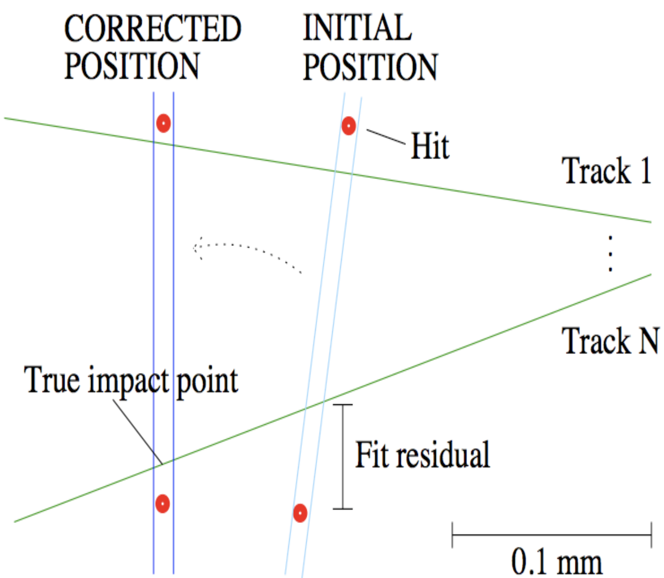
Backup

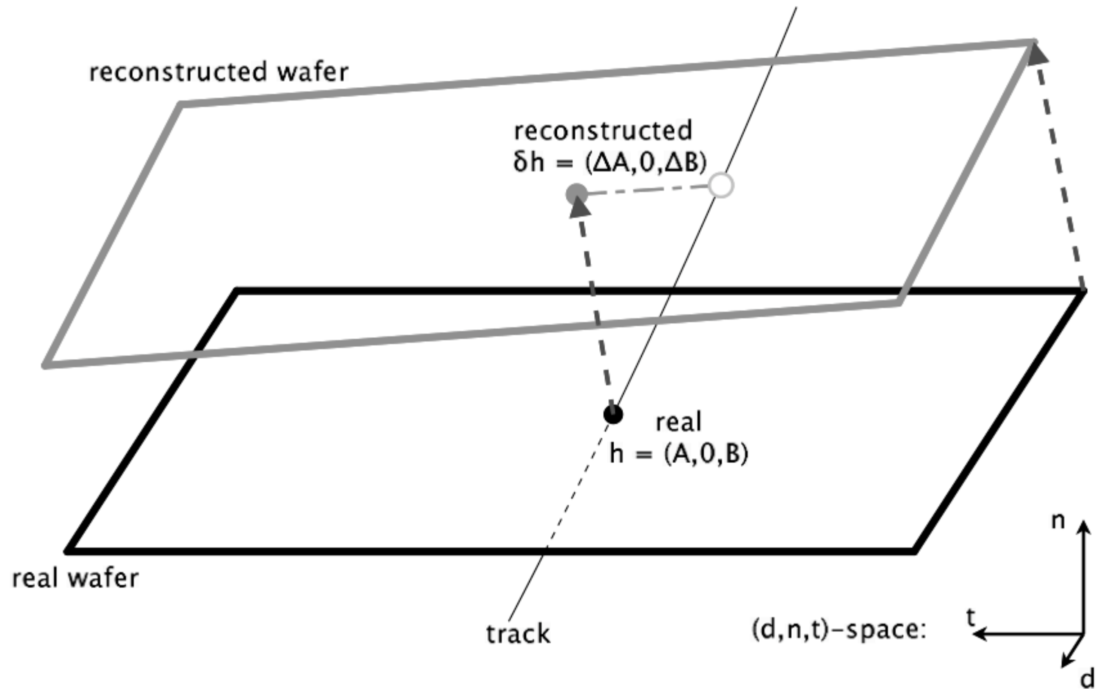
References

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

G. Van Buren†, Y. Fisyak†, S. Margetis‡, V. Perevoztchikov†
†Brookhaven National Laboratory, Upton, New York 11973
‡Kent State University, Kent, Ohio 44242





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

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

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

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)

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

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

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

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.
-
$$\vec{u}_{hit} - \vec{u} = \mathbf{L} \cdot \vec{\delta} = \begin{pmatrix} -1 & 0 & t_u & t_u v & -t_u u & v \\ 0 & -1 & t_v & t_v v & -t_v u & -u \end{pmatrix} \vec{\delta}$$
- $(u_{hit} - u) = -\delta_u + t_u(\delta_w + v\delta_\alpha - u\delta_\beta) + v\delta_\gamma;$
  $(v_{hit} - v) = -\delta_v + t_v(\delta_w + v\delta_\alpha - u\delta_\beta) - u\delta_\gamma;$