# SVT Alignment - Status / To Do

PF

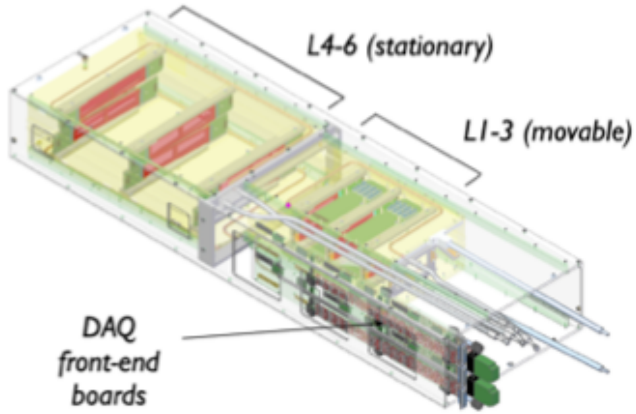
11/16/2021

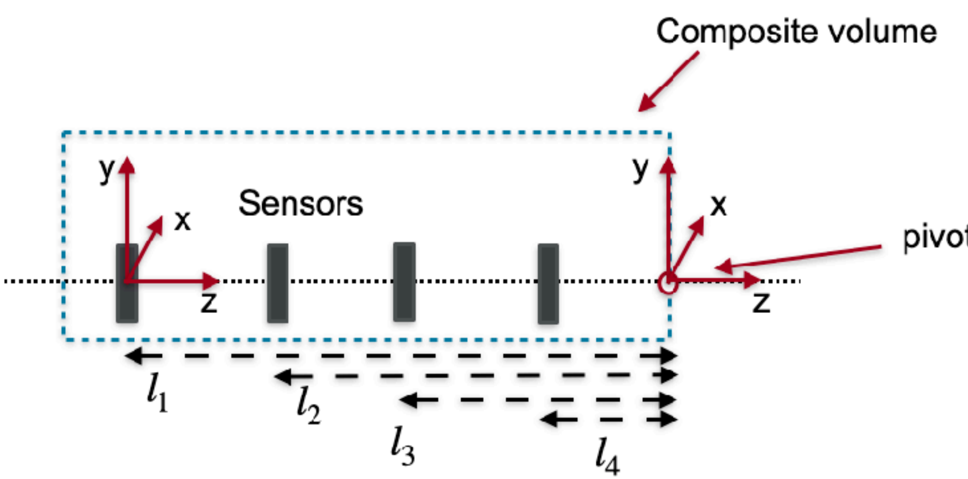
U.S. DEPARTMENT OF ENERGY | Stanford University
SLAC NATIONAL ACCELERATOR LABORATORY

# Track Based alignment of the SVT Detector

GBL + MPII

- The HPS track-based alignment framework is based on the General Broken Lines (GBL) and Millepede II (MPII)
- HPS Tracker Geometry split in:
  - 4 U-Channels structures
  - 7 Modules structures
  - 20 Single sensors structures
- Each structure location and orientation is defined by 6 DoF:
  - 3 Translations : $T_x, T_y, T_z$
  - 3 Rotations : $R_x, R_y, R_z$
- Global $\chi^2$ minimisation technique
- Weak mode constraints employed:
  - Momentum constraint
  - Beamspot location constraint



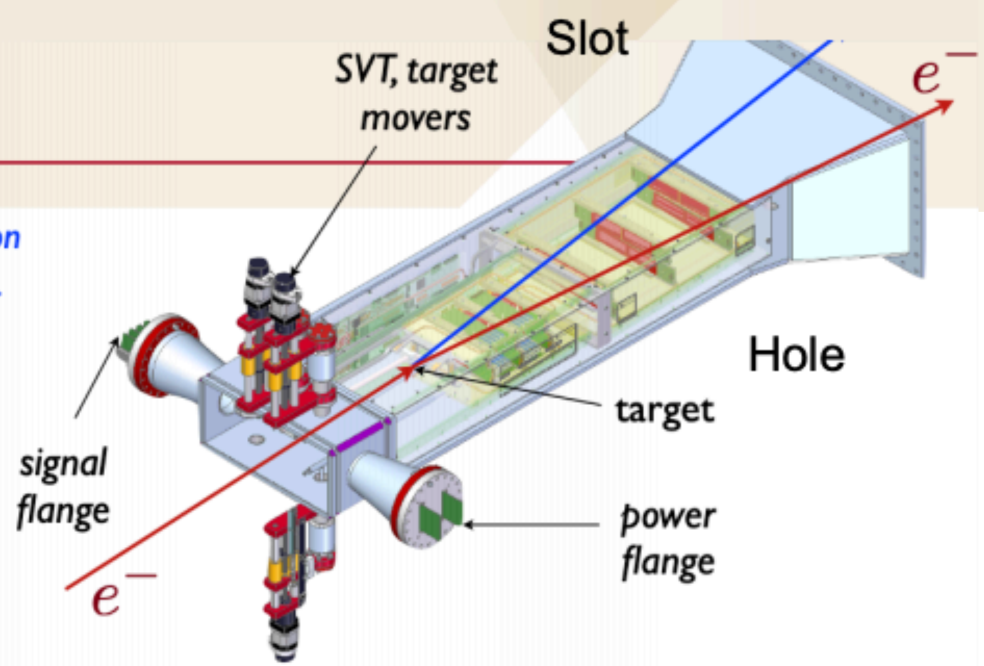



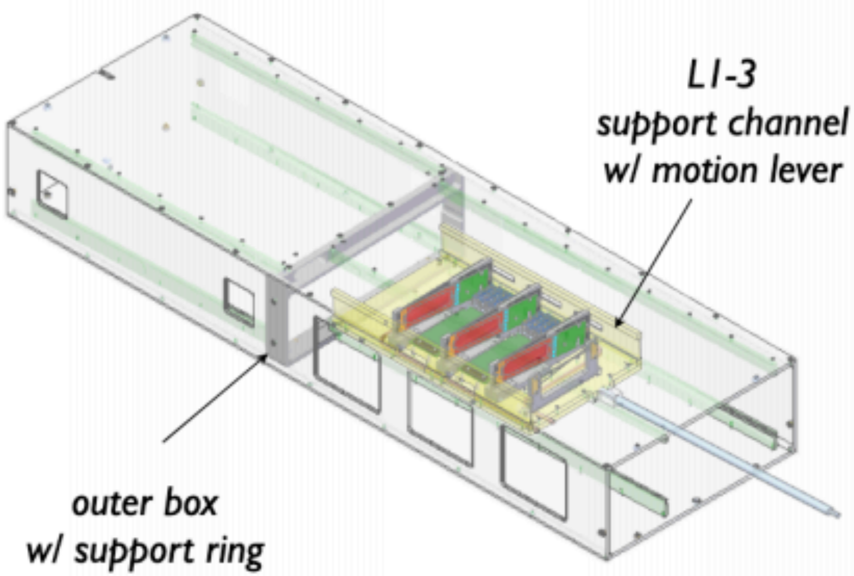
# The HPS SVT

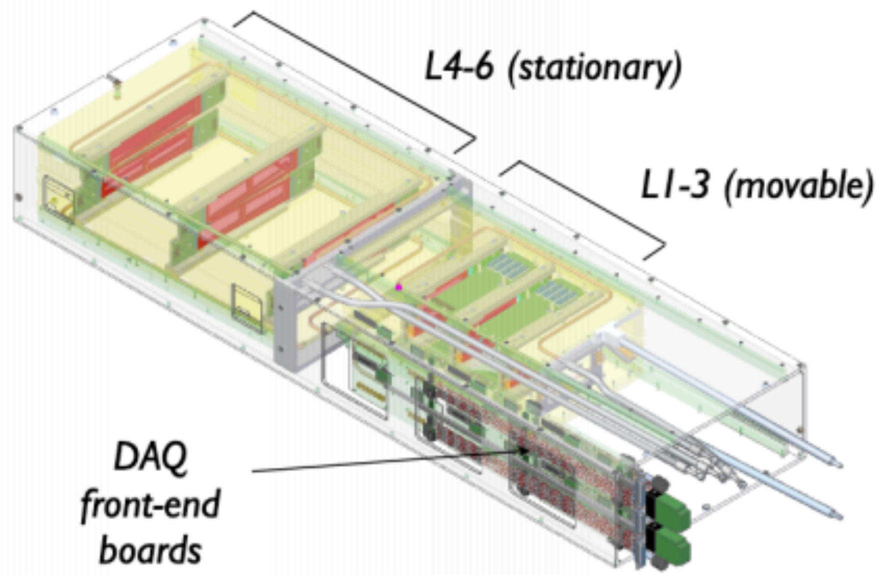
*7 double-layers of silicon strips, each plane measures position (~6-10 μm) and time (~2 ns) with ~0.2% – 0.35% $X_0$/hit.*

*Operates in an extreme environment:*

- beam vacuum and 1.5 Tesla magnetic field
  ⇒ constrains materials and techniques
- sensor edges 0.5 mm from electron beam in L1
  ⇒ must be movable, serviceable
- sensors see large dose of scattered electrons
  ⇒ must be actively cooled to -20 ˚C
- 24528 channels can output >100 gb/sec
  ⇒ requires fast electronics to process data

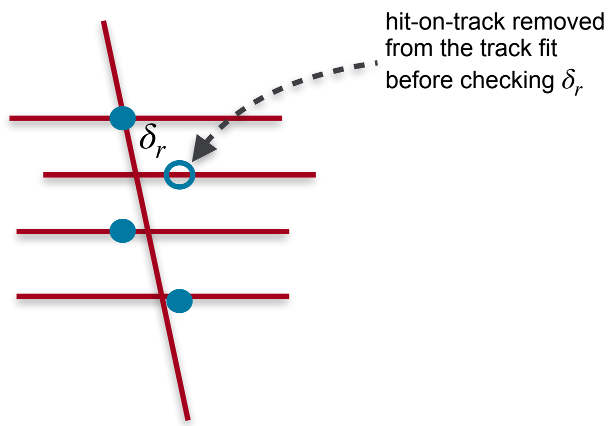


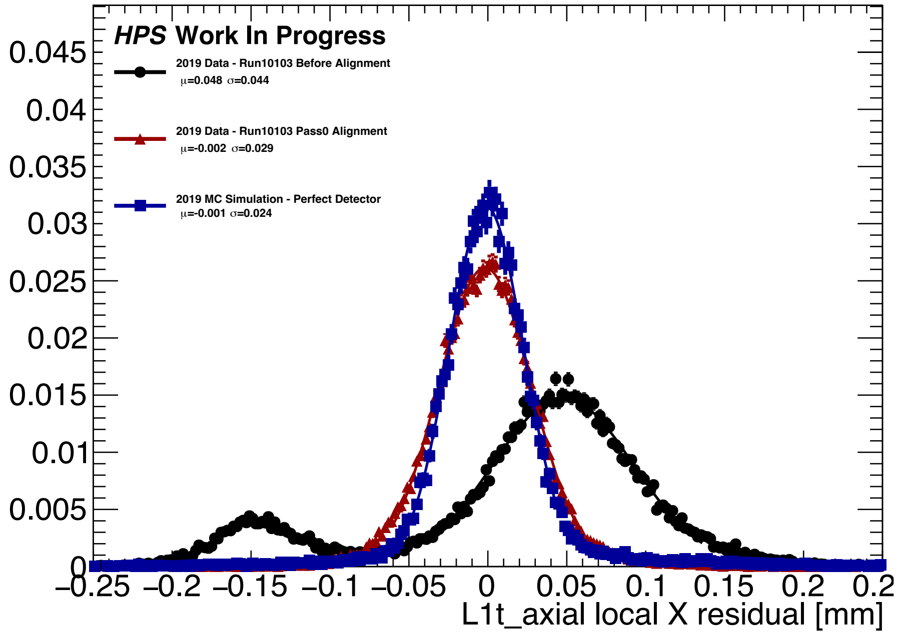



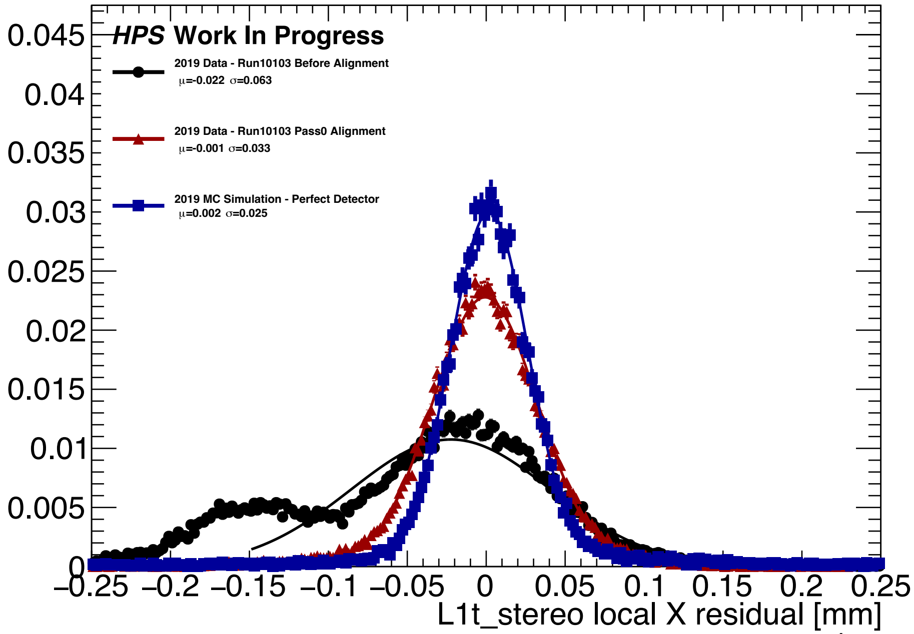



# Alignment performance - Unbiased Residuals

- Checked alignment solution quality by evaluating unbiased residuals distributions
- Mean linked to the residual position misalignment
- Large improvement in the newly placed thin-sensors
- Resolution to be improved to get closer to ideal geometry (from perfect MC)



# Alignment performance - Unbiased Residuals

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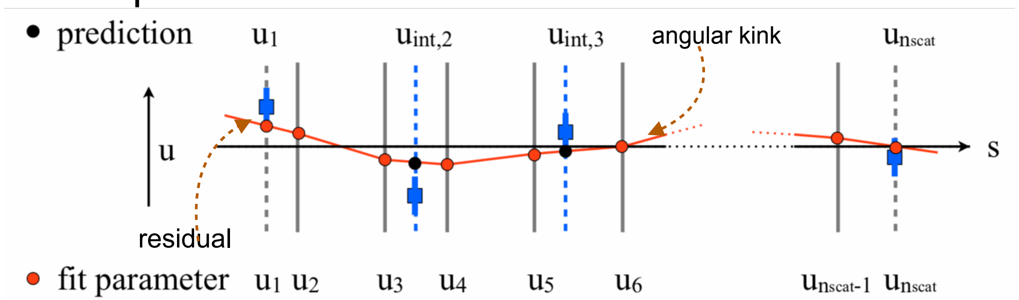
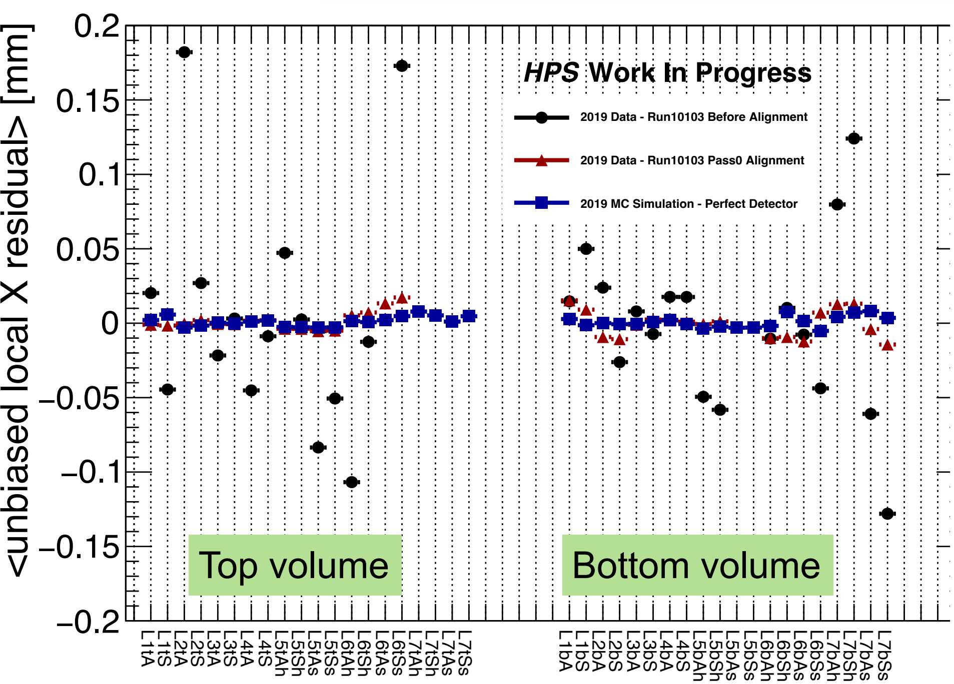
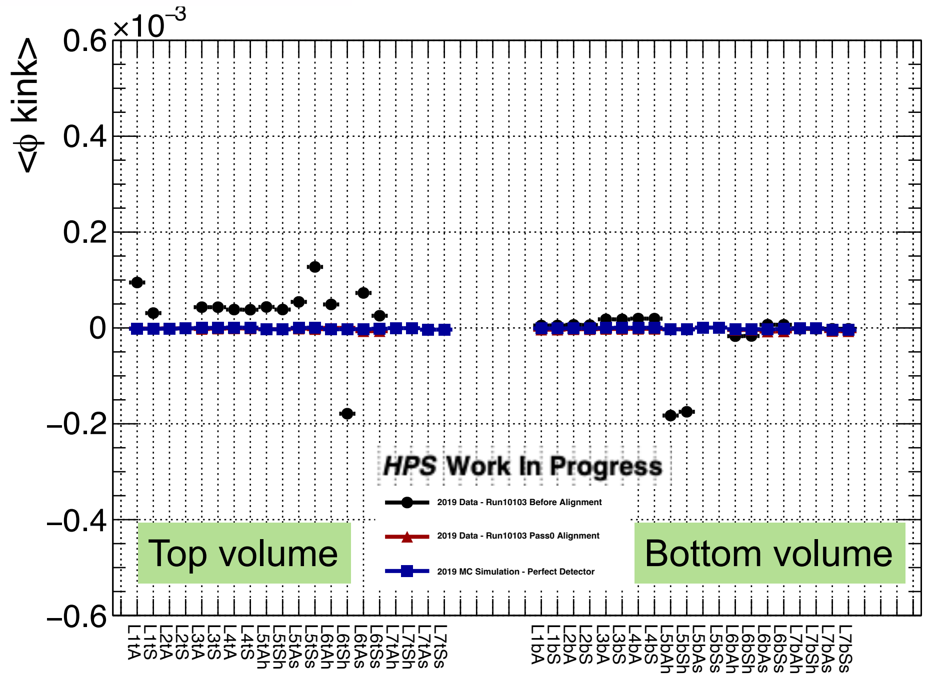
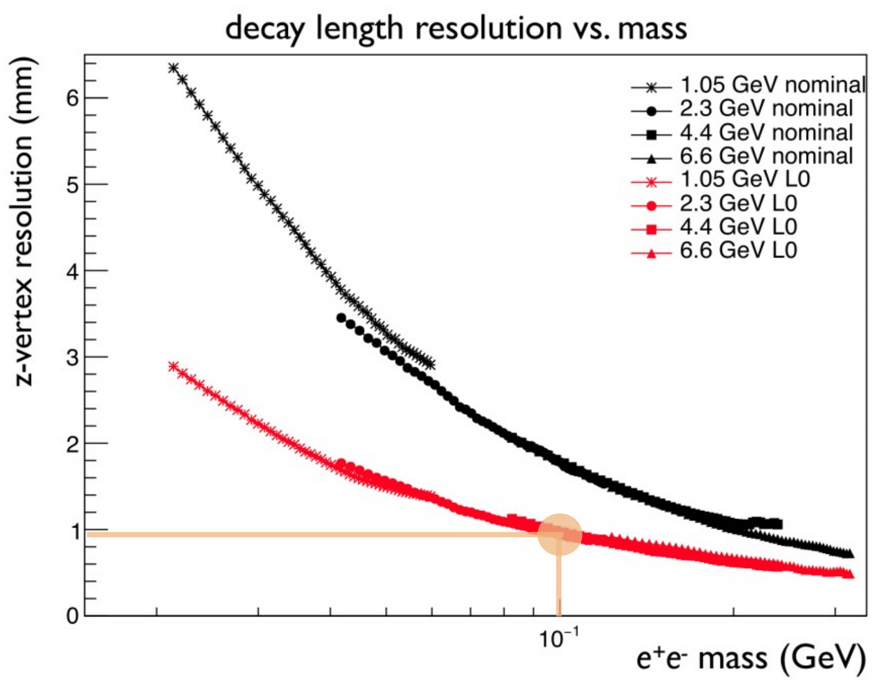
- Initial misalignments up to 200um recovered by current alignment procedure across all detector
- Residual misalignment from first calibration pass ~ 10um, work in progress
- Angular kinks as expected from MC ideal simulation

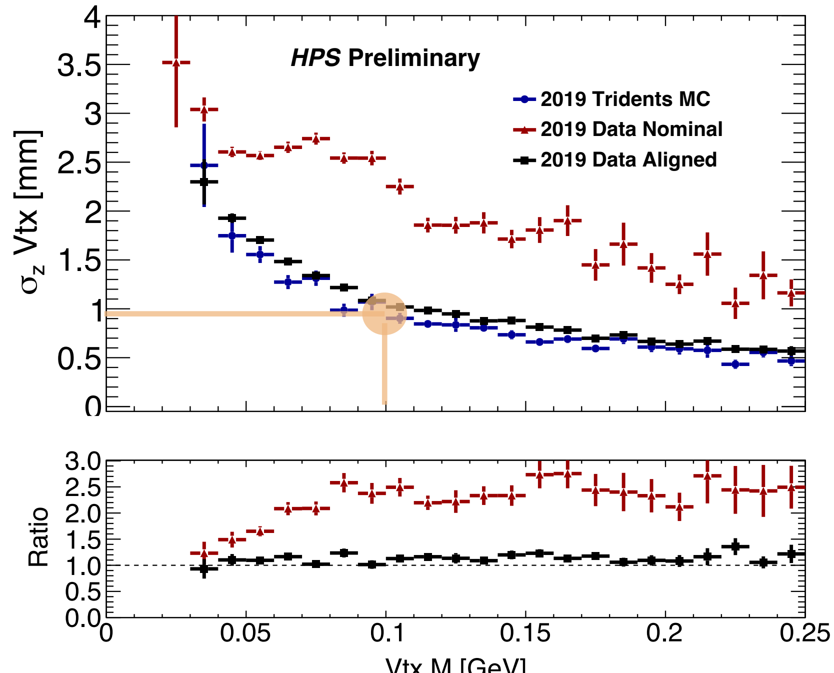


# Detector performance - Vertexing




- Preliminary alignment show that HPS reconstruction is able to achieve simulated design performance
- Resolution extracted from gaussian fit on the core of the vertex distribution
- In these results *optimistic* MC simulation has been used (no beam background / pileup included). A simulation that would have similar conditions of data should cover up residual resolution difference

# SVT Performance - Momentum Scale and Resolution

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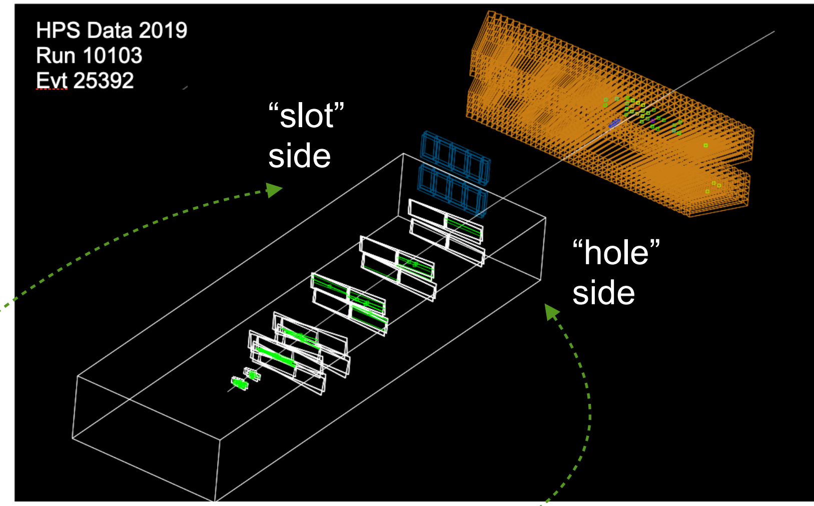
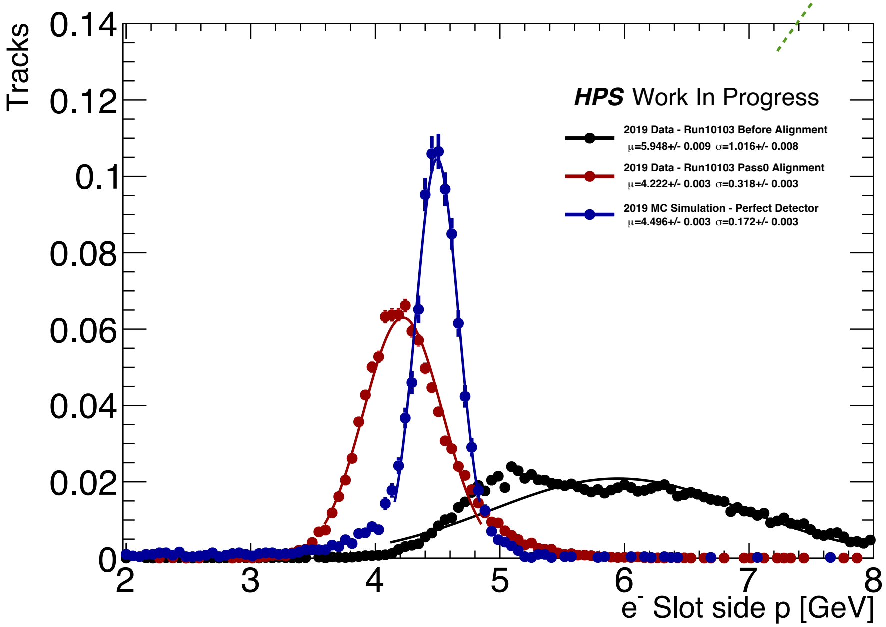
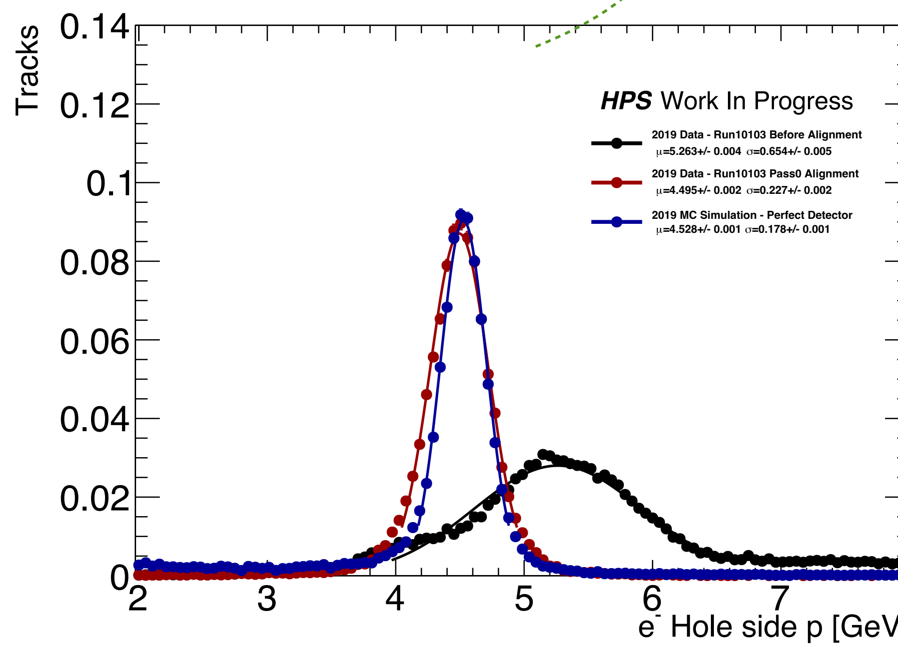
- Elastically beam scattered electrons are used to align the SVT with momentum scale constraint
    - Clean event selected by **single high-energy cluster in calorimeter**
    - **Known track momentum for weak-mode suppression**
    - **Only one side of the detector illuminated**:
      - Asymmetry detector halves alignment performance
      - Slot side momentum scale suffers of hole-on-track (one missing working layer for bottom)
- Momentum calibration for positrons/electrons is checked using E/p method



# News from last Collab meeting

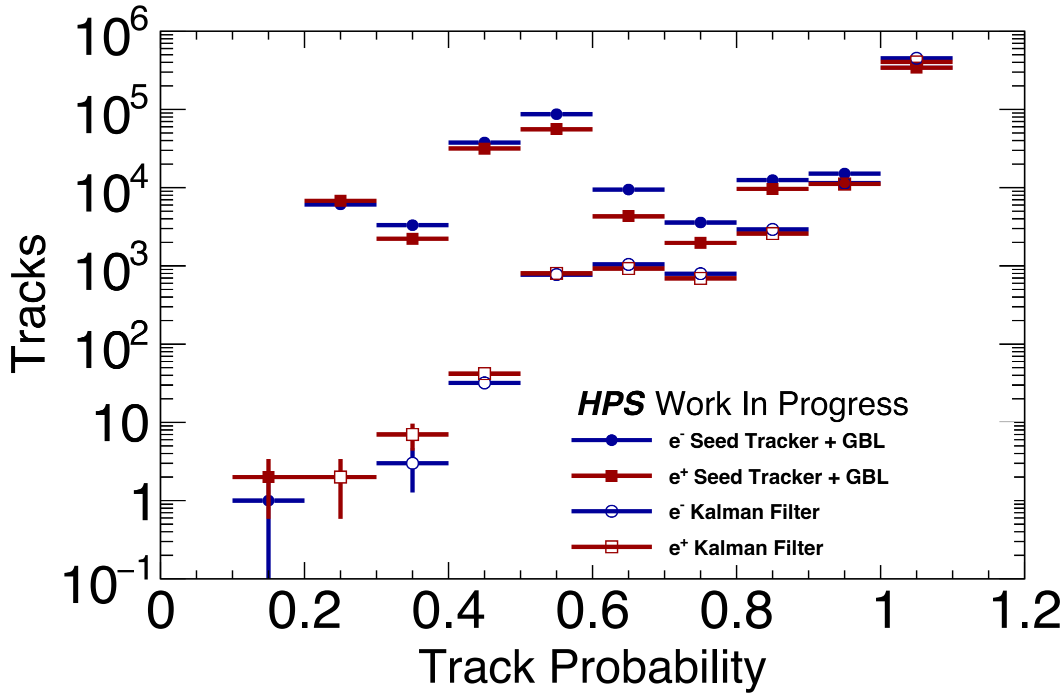
- **Alignment Framework Updates**
  - Integrated KF tracks into the Alignment framework:
    - Possible to run alignment with those tracks now
    - Faster turn-around of results, better pattern recognition
  - Developed a full hierarchical alignment with volumes in the centre of mass of the sensors (or other structures)
    - Alignment constants are always saved at sensor level so it can be integrated in current framework
  - Momentum discrepancy between two halves of detector:
    - Indications of Rotations wrt GlobalX / Global Y
    - Current performance
  - V0 alignment using e+ - e-
    - Ongoing

# New Tracking - Hit-On-Track association

- The **hit on track association performance** of the new tracking algorithms is assessed using MC Simulation
- Hits and reconstructed tracks are associated to generated particles using truth information
- **Track Probability** defined as the ratio:

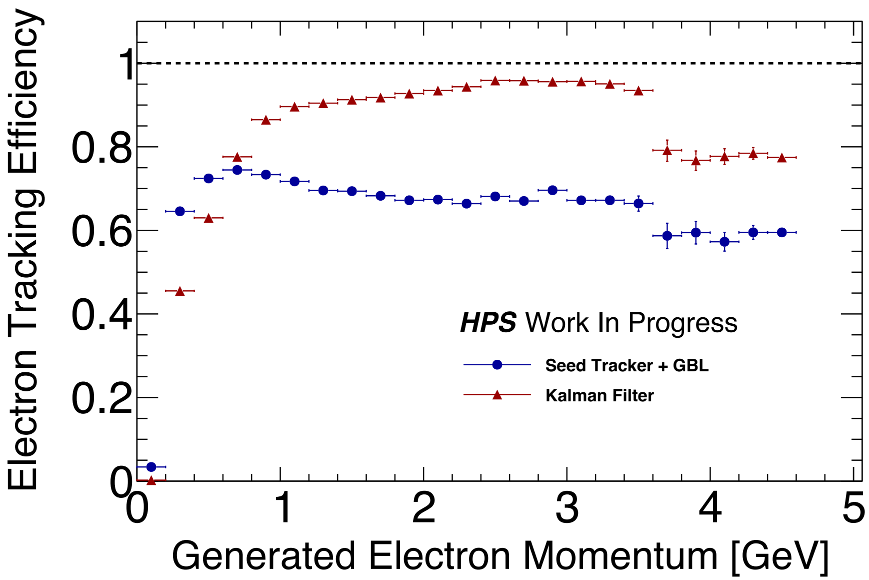
$$TrackP = \frac{N_{hits}^{truth}}{N_{hits}^{track}}$$

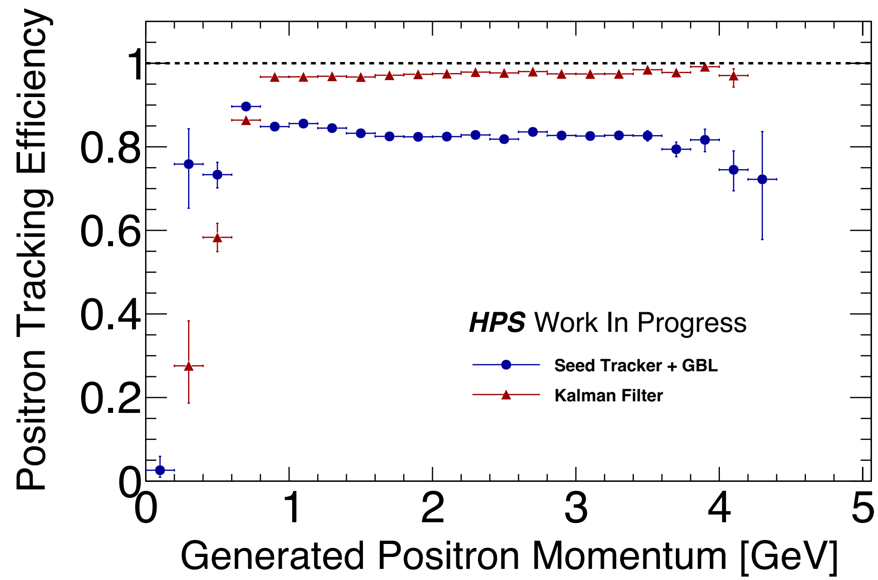
where $N_{hits}^{truth}$ are the hits matched to the generated particle




- The lower the TrackP the higher is the chance of mis-associated hits
- Tracks with <0.5 TrackP are likely to be formed by random hit combinations
- Large improvement expected on mitigating mis-associated hits-on-track for displaced vertex analysis.

# New Tracking - MC Simulation Distributions




$$\epsilon(p_{truth}) = \frac{N^{recoTrack}_{matched}(p_{truth})}{N_{trackableMCP}(p_{truth})}$$

- $N^{recoTrack}_{matched}$ are the tracks required to have TrackP > 0.8
- The efficiency to find "high-quality" tracks is up to **>85% (>95%) for $e^-$ ($e^+$)** across the physics range. Legacy tracking ranges between **70-75% (~85%) for $e^-$ ($e^+$)**.
- Drop close to beam energy for $e^-$ due to large fraction of generated beam scattered electrons hardly reconstructable at high-purity

# Updates to Alignment Framework

- **Kalman Tracks**
  - Alignment framework now fully supports Kalman Tracks
  - GBL Trajectories are formed from Kalman Tracks (no need to refit)
  - Possible to switch between KF Tracks and ST tracks by a flag
  - GBL is invoked via JNA and Original C++ library
  - Residuals and derivatives have been checked and are in agreement with the ST ones.

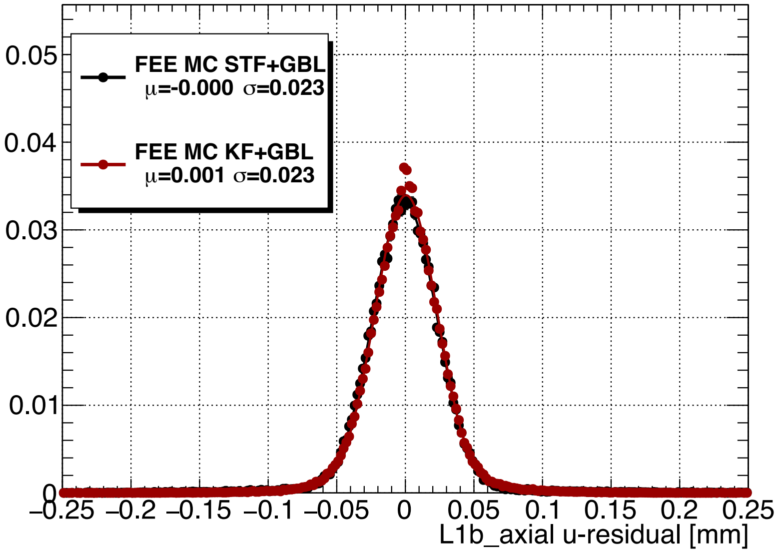
## KF + GBL

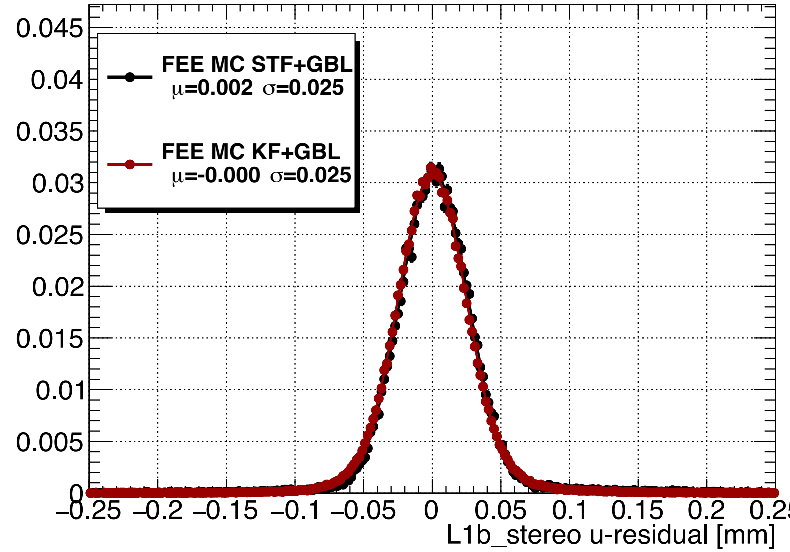
- Simple MC Particles (no beam Bkg)
  - Up to 400 Hz
- FEE Data (with beam)
  -
- Tri-trig (no Beam Bkg)
- Tri-trig + beam

## SeedTracker+GBL

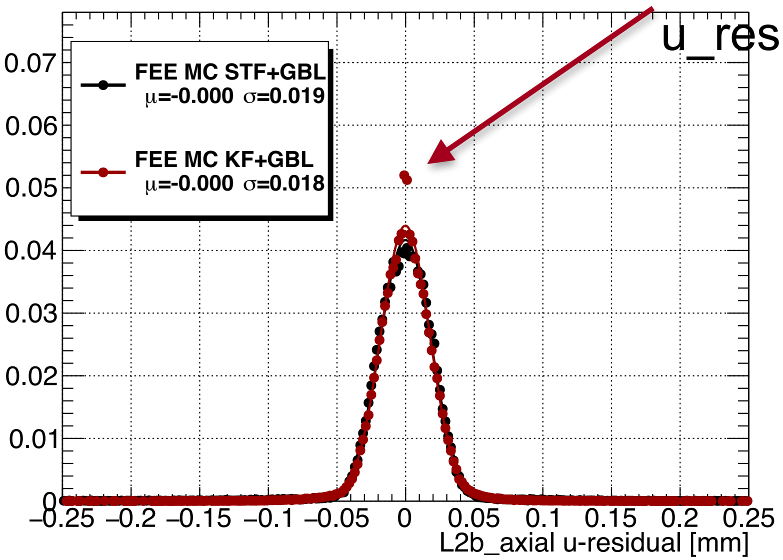
- Simple MC Particles (no beam Bkg)
  - Up to ~420 Hz
- FEE Data (with beam)
  -
- Tri-trig (no Beam Bkg)
- Tri-trig + beam

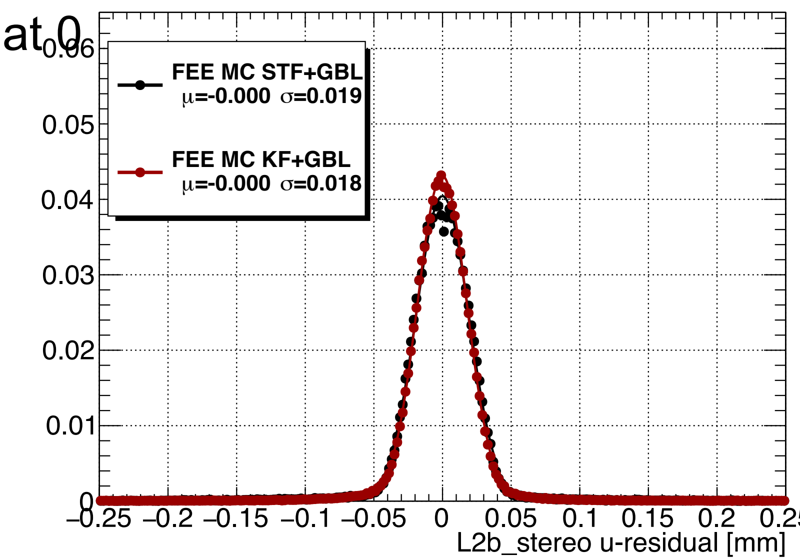
# Check on perfect aligned geo - FEE MC



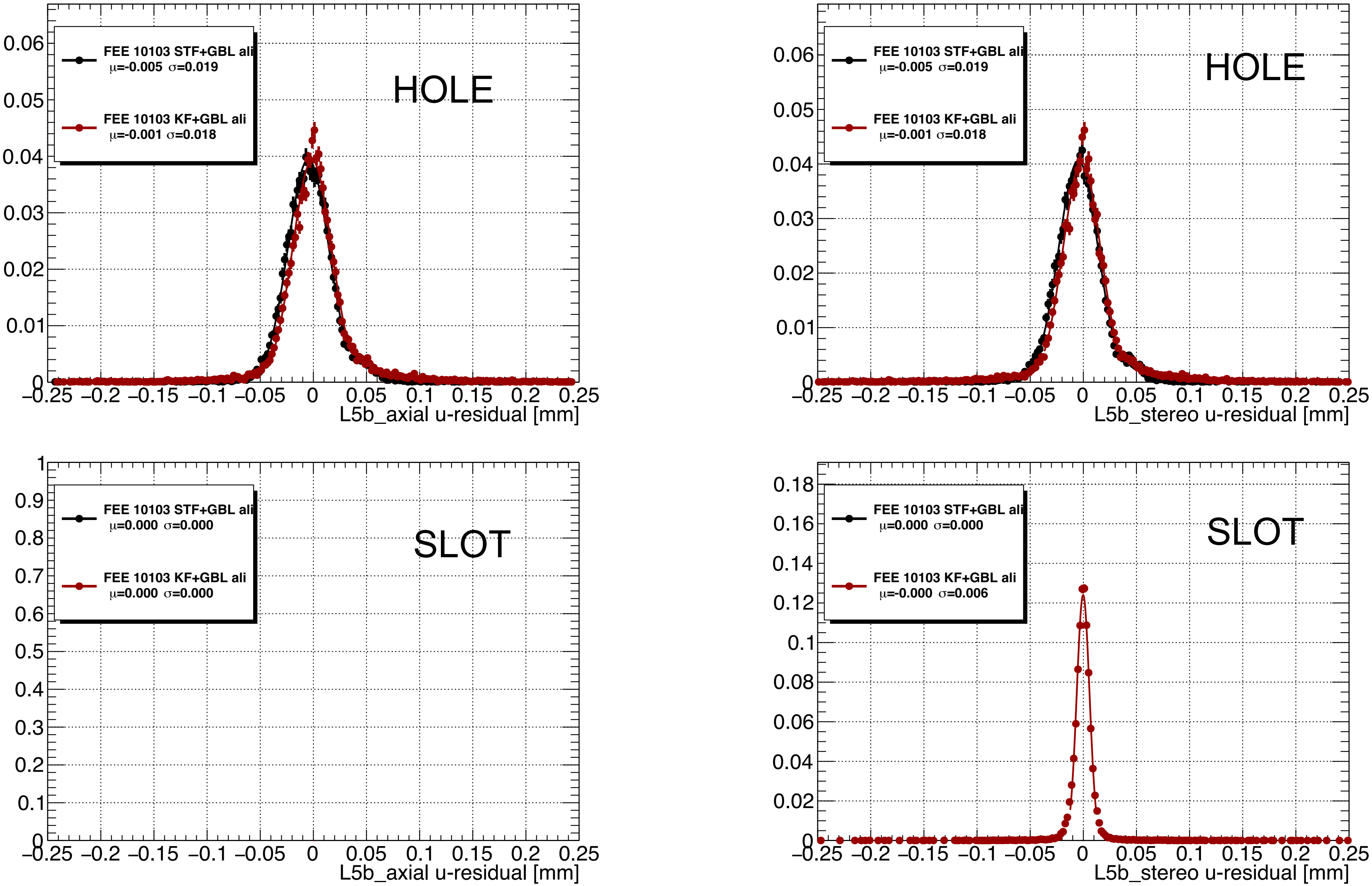




No cut on Nhits => low DoF =>
u_res spike at 0



# Check on 10103 - recovered hits on the L5b stereo slot side



# More alignment Framework developments

- **Alignment Framework Updates**
  - Developed a full hierarchical alignment with volumes in the centre of mass of the sensors (or other structures)
    - Alignment constants are always saved at sensor level so it can be integrated in current framework
  - AligmentStructuresBuilder: Create a tree with all the alignment structure in the Centre of Mass
  - SimpleGBLTrajAliDriver.java: Simple flag to switch to this type of Hierarchical Alignment structure
  - MisalignmentTool.py: Tool to create custom misalignment, such as Volume movements, double sensors misplacements, UChannel Movements, all in the SVT frame (decoupled beam rotation angle)
  - DerivativeConverter.py: Tool to convert global alignment structures into single sensors corrections
    Whole structures movements can be applied on top of current alignment and on top of any survey measurements correctly.
  - **Functionality still under study on MC samples:**
    **- Important to study effect of momentum scale from whole Volume opening angles (old discussion with John)**

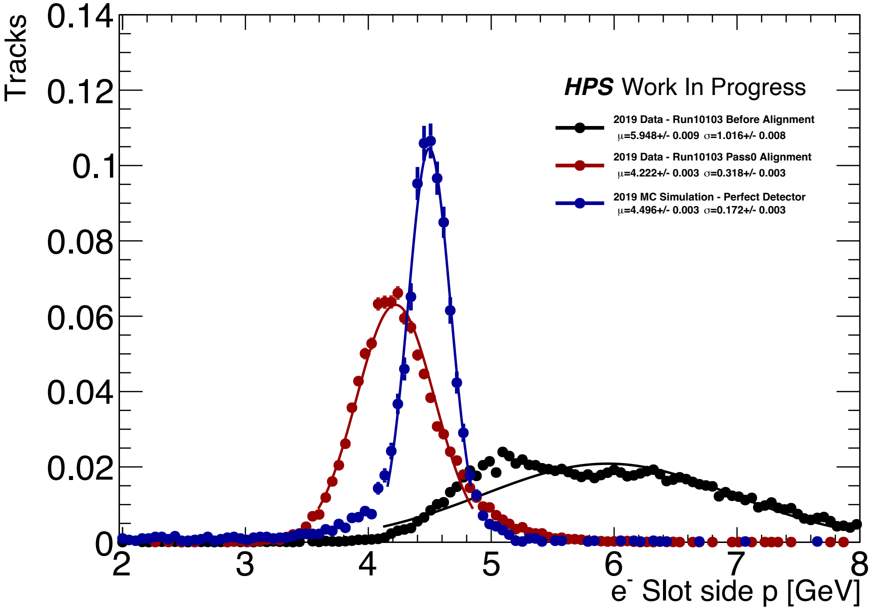
# Current issues

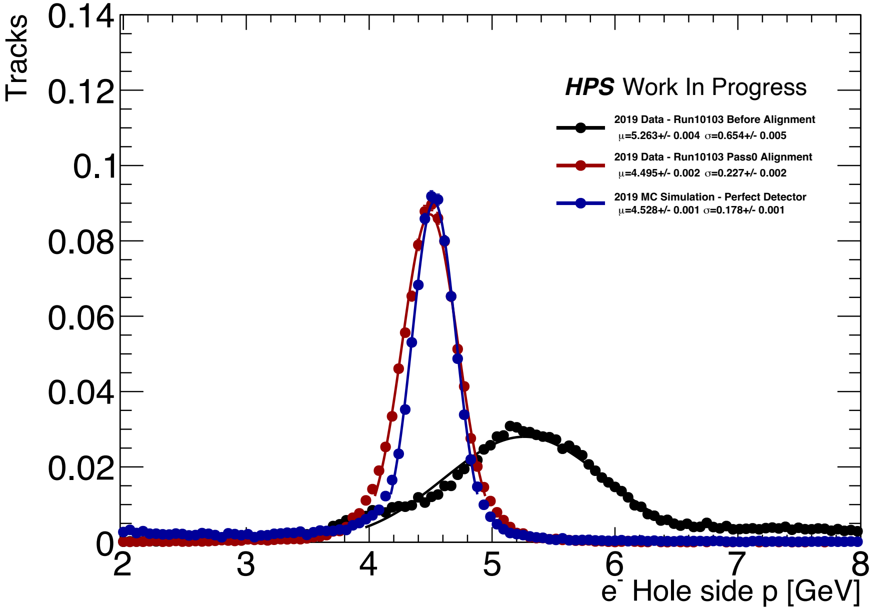
- **Major current alignment issues**
  - Top Volume momentum scale is too high
    - To be understood
  - There is a large asymmetry between hole-slot side
    - Expected wrong rotations wrt global Y axis
  - There is a dependence of momentum from tanLambda, especially in top Volume
    - Expected wrong rotations wrt global X axis
  - Ran Kalman-Filter based alignment on 2021 but found different results with respect to Seed Tracker based alignment
    - In particular: no convergence of the alignment corrections

# Current issues



- **Major current alignment issues**
  - There is a large asymmetry between hole-slot side momentum
  - A possible reason could be a rotation of some sensors along global Y axis
  - This would create a side with closer hits and a side with further hits wrt the other layers



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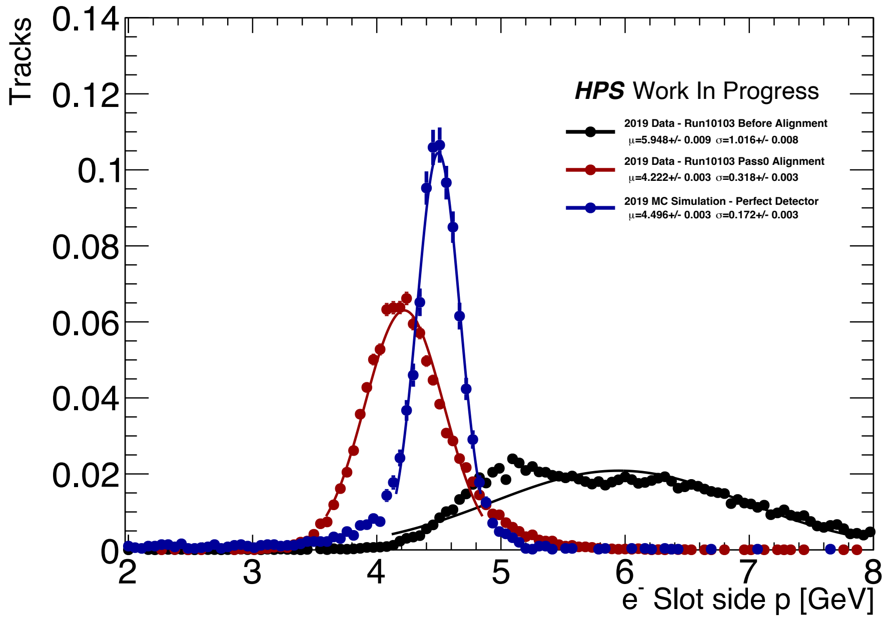
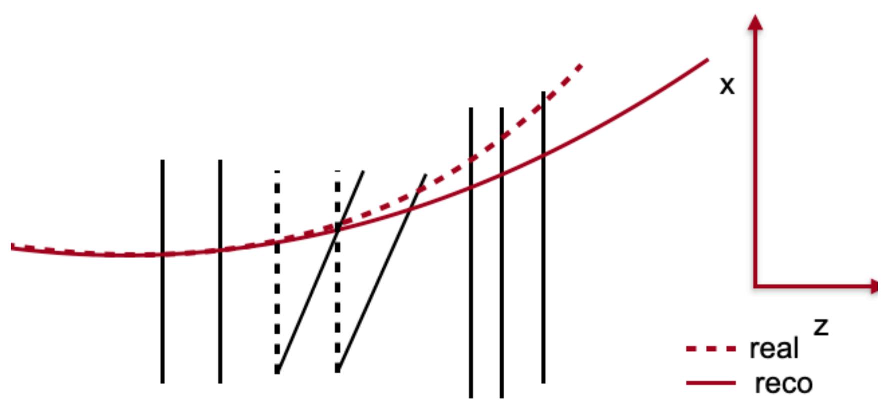
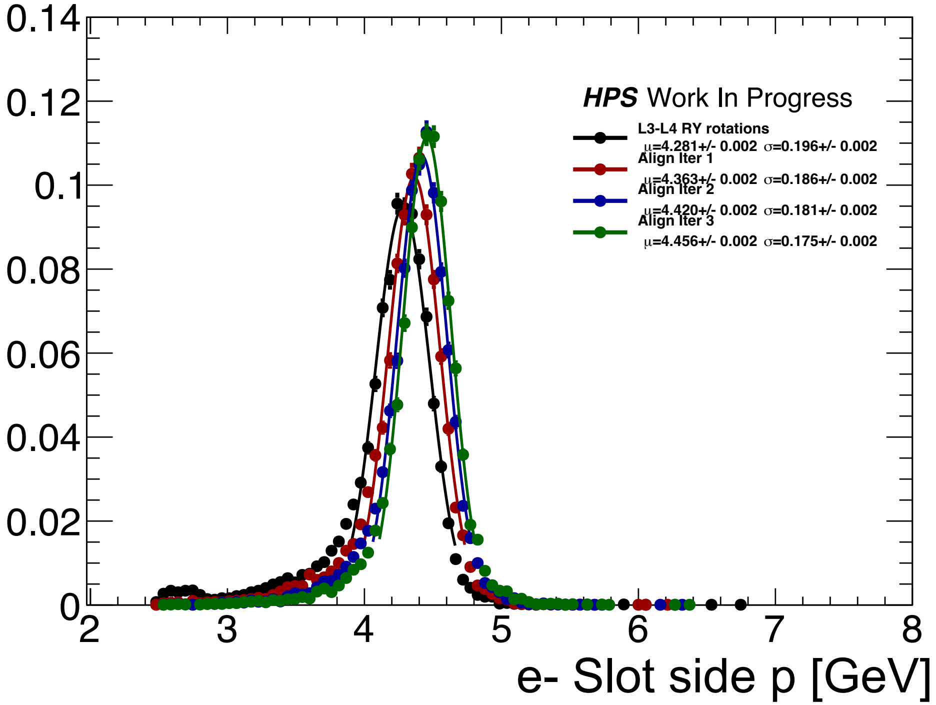
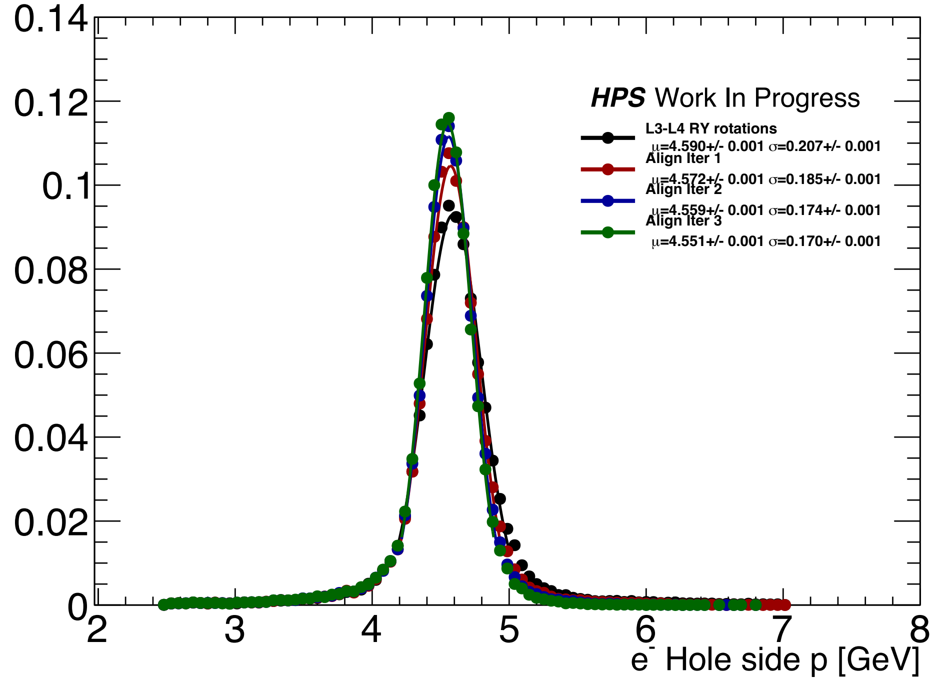


# Current issues

- **Major current alignment issues**
  - Hole - Side asymmetry might generate from rotations around Y
  - Tested in the perfect MC
  - Seen that improves the resolution for momentum in the hole side, but scale is maintaned, Slot side shows that alignment can recover this effect.
  - => Working in progress on Data



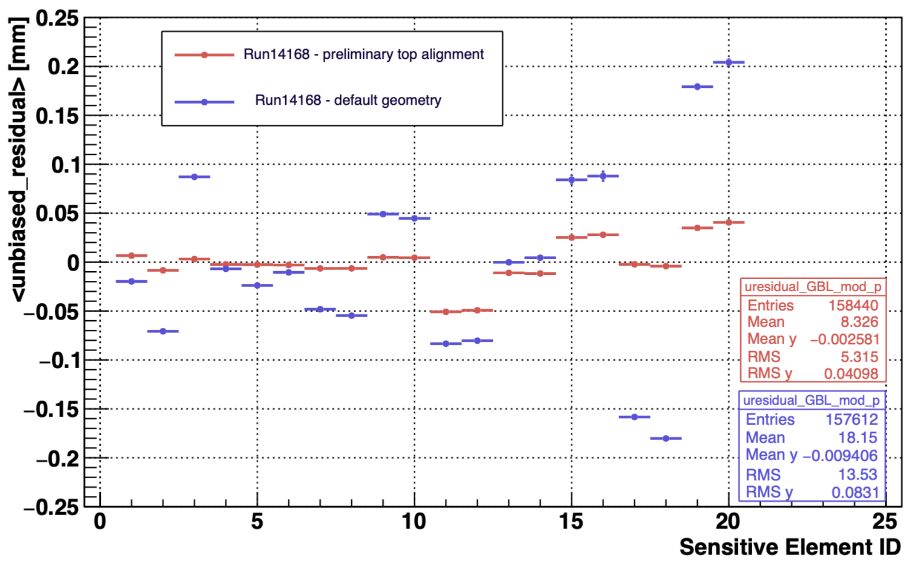
# 2019 Alignment plans

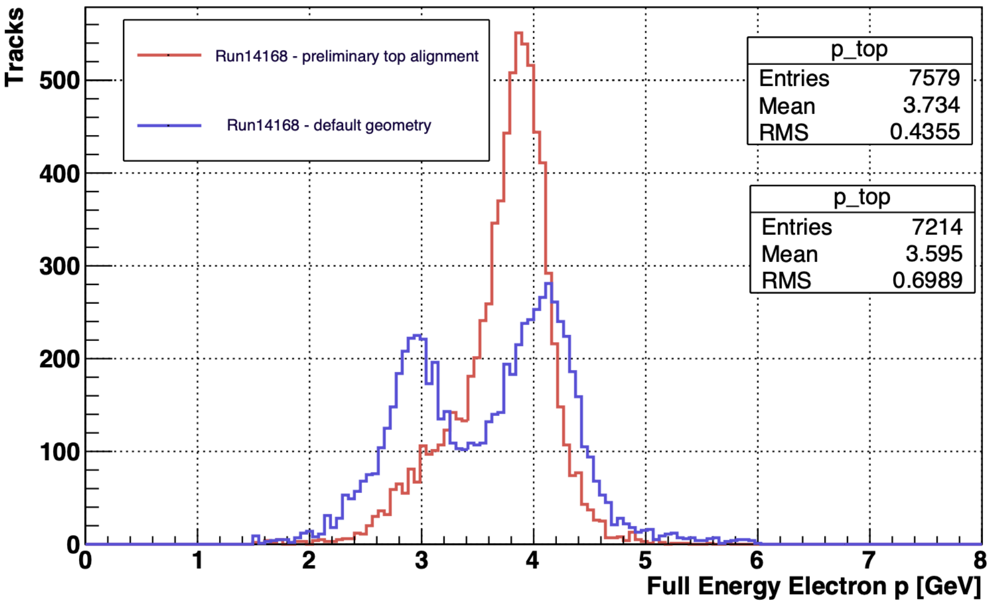
SLAC

- **I'll focus on Top Volume momentum scale correction for 2019 data**
  - Tighten up the momentum constraint using FEEs
    Will try to free additional degrees of freedoms for alignment of global structures or single modules
    Will try to use additional samples for momentum calibration which are not FEEs
- **Pass over some tools to Cameron and Norman**
  - Both expressed interest to help with the machinery for 2019 and 2021. A collection of available updated and validated tools is reported in slide 14
- **Check the discrepancy between ST+GBL and KF+GBL using MC and Data samples**
  - I will try to nail down why the two algorithms produce different final results and convergence behaviour
- **Investigate issues with survey constants for front UChannels in 2019**
  - 2021 Survey showed that structures such as UChannels should be placed quite precisely where expected from 2016. However geometry code changed for those structures and the past survey constants do not produce the same result: will try to fix that in the geometry code.

# 2021 Current Alignment

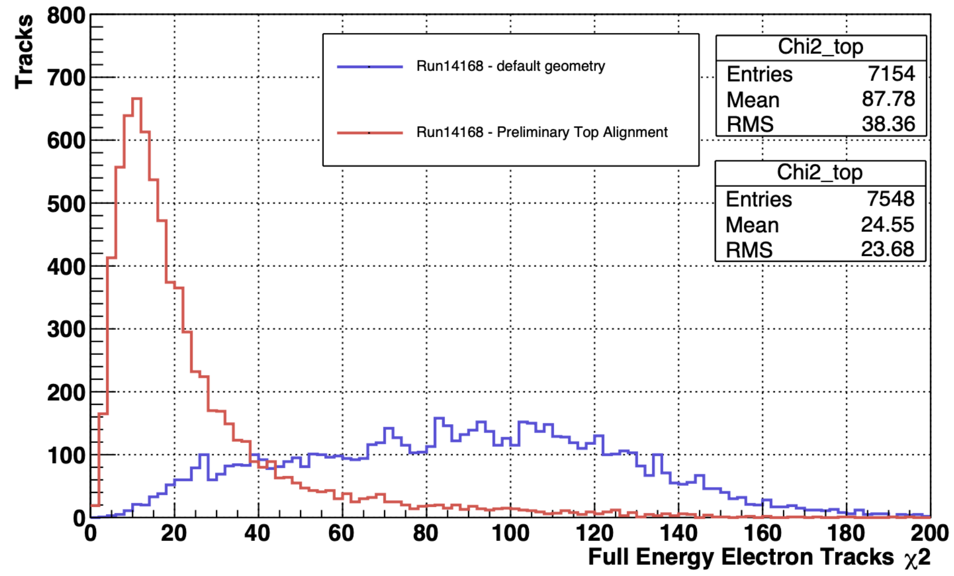
- **Ran a preliminary alignment on the top volume for 2021 Data taking run**
  - I've done this at the beginning of the data taking and only for the top volume
  - Used one of the early FEE runs 14168. Improved the momentum of FEE electrons, showing momentum peak at ~3.73GeV
  - Mostly focused on front of the detector alignment: back of the detector should be improved (as shown on top right plot) where mean of the residuals is still tenths of um

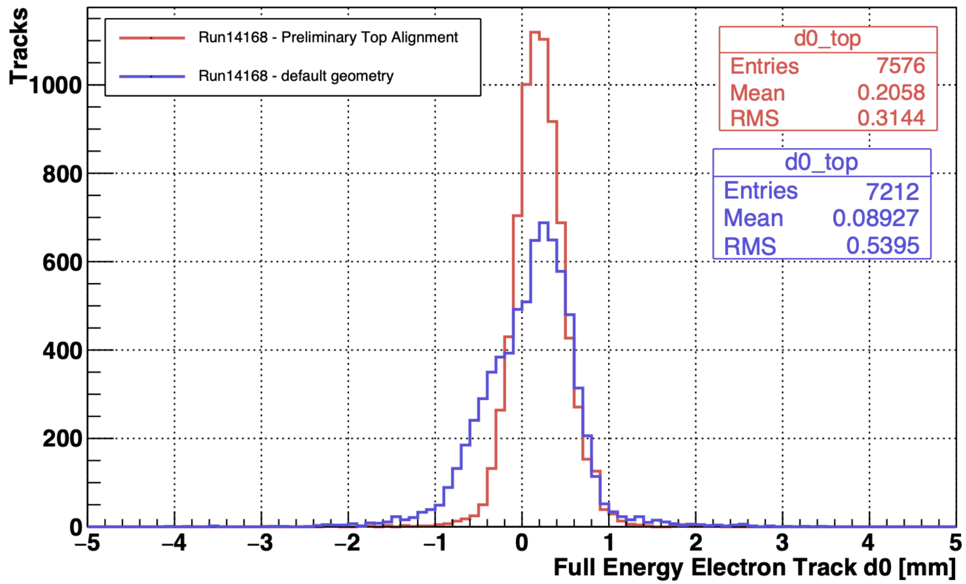


# 2021 Current Alignment

- **Ran a preliminary alignment on the top volume for 2021 Data taking run**
  - I've done this at the beginning of the data taking and only for the top volume
  - Used one of the early FEE runs 14168.
  - Chi2 largely improved and d0 shows improvement



# 2021 Alignment - First steps

- **Need to focus on bottom volume alignment**
- More difficult due to initial very bad momentum calibration and with a hole on track on ly5
- **Need to recover the 2021 survey constants**
  - Currently no survey information is added into the compact detector for 2021
  - All is at nominal location from reconstruction geometry code, which might not coincide with global structure locations.
  - First step would be to put the 2021 survey constants in for
    - Global structures, UChannels, SVT Box..
    - Single Sensors

# BACKUP

# Refit of Kalman Tracks using the GBL algorithm

SLAC

```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,      1.0000]
 HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
 HPS tracking system W=[    -0.99954,   -0.030429, -9.9954e-05]
 HPS tracking system Track direction=[     0.98746,     0.14696,    0.057743]
 phi=  0.147738, lambda=  0.057776
 Arc length 2D=  38.85172 mm,  Arc length 3D=  38.91665 mm
 Measurement =   -5.11500 +-  0.01588 mm
 Track intercept in sensor frame = [     -5.1223,      5.6505,  9.9954e-06]
 RMS projected scattering angle=  0.000109

SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=2, scatterOnly=0
 HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
 HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
 HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
 HPS tracking system Track direction=[     0.98753,     0.14643,    0.057743]
 phi=  0.147210, lambda=  0.057776
 Arc length 2D=  46.40196 mm,  Arc length 3D=  46.47951 mm
 Measurement =   -4.07047 +-  0.01588 mm
 Track intercept in sensor frame = [     -4.0698,     -6.2055, -9.9954e-06]
 RMS projected scattering angle=  0.000109
```

DEFAULT COMPUTATION

GBLStripClusterData computed by the seedTracker + gbl.MakeGBLTrack

```
KalmanInterface.printGBLStripClusterData: cluster ID=1, scatterOnly=0
  HPS tracking system U=[ -0.00010000,  6.1357e-17,      1.0000]
  HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
  HPS tracking system W=[    -0.99954,   -0.030429, -9.9954e-05]
  HPS tracking system Track direction=[     0.98747,     0.14687,    0.057737]
  phi=  0.147648, lambda=  0.057770
  Arc length 2D=  40.64545 mm,  Arc length 3D=  40.71338 mm
  Measurement =   -5.11500 +-  0.01143 mm
  Track intercept in sensor frame = [     -5.1175,      5.6337,  5.0143e-05]
  RMS projected scattering angle=  0.000110

KalmanInterface.printGBLStripClusterData: cluster ID=2, scatterOnly=0
  HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
  HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
  HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
  HPS tracking system Track direction=[     0.98754,     0.14637,    0.057737]
  phi=  0.147150, lambda=  0.057769
  Arc length 2D=  48.16848 mm,  Arc length 3D=  48.25156 mm
  Measurement =   -4.07047 +-  0.00986 mm
  Track intercept in sensor frame = [     -4.0669,     -6.1878,  -0.0021116]
  RMS projected scattering angle=  0.000110
```

COMPUTATION FROM KF

GBLStripClusterData computed by KalmanInterface

# Crosschecks of the GBLStripClusterData

```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
 HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
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 Measurement =   -5.11500 +-  0.01143 mm
 Track intercept in sensor frame = [     -5.1175,      5.6337,  5.0143e-05]
 RMS projected scattering angle=  0.000110
```

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 HPS tracking system U=[  -0.0031373,    0.099787,      0.99500]
 HPS tracking system V=[    0.030267,    -0.99454,     0.099836]
 HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
 HPS tracking system Track direction=[     0.98754,      0.14637,     0.057737]
 phi=  0.147150, lambda=  0.057769
 Arc length 2D=  48.16848 mm,  Arc length 3D=  48.25156 mm
 Measurement =   -4.07047 +-  0.00986 mm
 Track intercept in sensor frame = [     -4.0669,     -6.1878,  -0.0021116]
 RMS projected scattering angle=  0.000110
```

- The UVW (local frame) system matches between the two computations (OK)
- The track direction in $\phi$ and $\lambda$ is in agreement (OK)

# Refit of Kalman Tracks using the GBL algorithm

```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
 HPS tracking system V=[    -0.030429,     0.99954, -3.0429e-06]
 HPS tracking system W=[     -0.99954,   -0.030429, -9.9954e-05]
 HPS tracking system Track direction=[     0.98746,      0.14696,     0.057743]
 phi=  0.147738, lambda=  0.057776
 Arc length 2D=  38.85172 mm,  Arc length 3D= 38.91665 mm
 Measurement =   -5.11500 +-  0.01588 mm
 Track intercept in sensor frame = [      -5.1223,       5.6505,  9.9954e-06]
 RMS projected scattering angle=  0.000109

SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=2, scatterOnly=0
 HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
 HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
 HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
 HPS tracking system Track direction=[     0.98753,      0.14643,     0.057743]
 phi=  0.147210, lambda=  0.057776
 Arc length 2D=  46.40196 mm,  Arc length 3D=  46.47951 mm
 Measurement =   -4.07047 +-  0.01588 mm
 Track intercept in sensor frame = [      -4.0698,      -6.2055, -9.9954e-06]
 RMS projected scattering angle=  0.000109
```

```
KalmanInterface.printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
 HPS tracking system V=[    -0.030429,     0.99954, -3.0429e-06]
 HPS tracking system W=[     -0.99954,   -0.030429, -9.9954e-05]
 HPS tracking system Track direction=[     0.98747,      0.14687,     0.057737]
 phi=  0.147648, lambda=  0.057770
 Arc length 2D=  40.64545 mm,  Arc length 3D=  40.71338 mm
 Measurement =   -5.11500 +-  0.01143 mm
 Track intercept in sensor frame = [      -5.1175,       5.6337,  5.0143e-05]
 RMS projected scattering angle=  0.000110

KalmanInterface.printGBLStripClusterData: cluster ID=2, scatterOnly=0
 HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
 HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
 HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
 HPS tracking system Track direction=[     0.98754,      0.14637,     0.057737]
 phi=  0.147150, lambda=  0.057769
 Arc length 2D=  48.16848 mm,  Arc length 3D=  48.25156 mm
 Measurement =   -4.07047 +-  0.00986 mm
 Track intercept in sensor frame = [      -4.0669,      -6.1878,  -0.0021116]
 RMS projected scattering angle=  0.000110
```

- There is a difference (~5%) between the arcLength computed from the origin to the first measurement state.
- I made this computation myself using helix approx. I will check the lines of code with Robert.
- I also noticed that the two algorithms provide a slightly different momentum for this same track:
  - 4.43 GeV for seedTracker + GBL
  - 4.38 GeV for KF
  (and therefore radius and phi), which also relates to that.

# Refit of Kalman Tracks using the GBL algorithm

```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
 HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
 HPS tracking system W=[    -0.99954,   -0.030429, -9.9954e-05]
 HPS tracking system Track direction=[     0.98746,      0.14696,     0.057743]
 phi=  0.147738, lambda=  0.057776
 Arc length 2D=  38.85172 mm,  Arc length 3D=  38.91665 mm
 Measurement =   -5.11500 +-  0.01588 mm
 Track intercept in sensor frame = [      -5.1223,       5.6505,   9.9954e-06]
 RMS projected scattering angle=  0.000109

SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=2, scatterOnly=0
 HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
 HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
 HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
 HPS tracking system Track direction=[     0.98753,      0.14643,     0.057743]
 phi=  0.147210, lambda=  0.057776
 Arc length 2D=  46.40196 mm,  Arc length 3D=  46.47951 mm
 Measurement =   -4.07047 +-  0.01588 mm
 Track intercept in sensor frame = [      -4.0698,      -6.2055, -9.9954e-06]
 RMS projected scattering angle=  0.000109
```

```
KalmanInterface.printGBLStripClusterData: cluster ID=1, scatterOnly=0
  HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
  HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
  HPS tracking system W=[    -0.99954,   -0.030429, -9.9954e-05]
  HPS tracking system Track direction=[     0.98747,      0.14687,     0.057737]
  phi=  0.147648, lambda=  0.057770
  Arc length 2D=  40.64545 mm,  Arc length 3D=  40.71338 mm
  Measurement =   -5.11500 +-  0.01143 mm
  Track intercept in sensor frame = [      -5.1175,       5.6337,   5.0143e-05]
  RMS projected scattering angle=  0.000110

KalmanInterface.printGBLStripClusterData: cluster ID=2, scatterOnly=0
  HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
  HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
  HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
  HPS tracking system Track direction=[     0.98754,      0.14637,     0.057737]
  phi=  0.147150, lambda=  0.057769
  Arc length 2D=  48.16848 mm,  Arc length 3D=  48.25156 mm
  Measurement =   -4.07047 +-  0.00986 mm
  Track intercept in sensor frame = [      -4.0669,      -6.1878,  -0.0021116]
  RMS projected scattering angle=  0.000110
```

- Notice the measurement on sensor
- The measurement location is the exactly the same in the two computations (OK), the error used in Kalman is smaller (which might be an indication of a possible source of the larger $\chi^2$ we see in Kalman Tracks).
- I think this has been noticed and presented by Robert already

# Refit of Kalman Tracks using the GBL algorithm

SLAC

```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
 HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
 HPS tracking system W=[    -0.99954,   -0.030429, -9.9954e-05]
 HPS tracking system Track direction=[     0.98746,     0.14696,    0.057743]
 phi=  0.147738, lambda=  0.057776
 Arc length 2D=  38.85172 mm,  Arc length 3D=  38.91665 mm
 Measurement =   -5.11500 +-  0.01588 mm
 Track intercept in sensor frame = [     -5.1223,      5.6505,  9.9954e-06]
 RMS projected scattering angle=  0.000109

SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=2, scatterOnly=0
 HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
 HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
 HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
 HPS tracking system Track direction=[     0.98753,     0.14643,    0.057743]
 phi=  0.147210, lambda=  0.057776
 Arc length 2D=  46.40196 mm,  Arc length 3D=  46.47951 mm
 Measurement =   -4.07047 +-  0.01588 mm
 Track intercept in sensor frame = [     -4.0698,     -6.2055, -9.9954e-06]
 RMS projected scattering angle=  0.000109
```

```
KalmanInterface.printGBLStripClusterData: cluster ID=1, scatterOnly=0
  HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
  HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
  HPS tracking system W=[    -0.99954,   -0.030429, -9.9954e-05]
  HPS tracking system Track direction=[     0.98747,     0.14687,    0.057737]
  phi=  0.147648, lambda=  0.057770
  Arc length 2D=  40.64545 mm,  Arc length 3D=  40.71338 mm
  Measurement =   -5.11500 +-  0.01143 mm
  Track intercept in sensor frame = [     -5.1175,      5.6337,  5.0143e-05]
  RMS projected scattering angle=  0.000110

KalmanInterface.printGBLStripClusterData: cluster ID=2, scatterOnly=0
  HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
  HPS tracking system V=[    0.030267,    -0.99454,    0.099836]
  HPS tracking system W=[     0.99954,    0.030429,  9.9954e-05]
  HPS tracking system Track direction=[     0.98754,     0.14637,    0.057737]
  phi=  0.147150, lambda=  0.057769
  Arc length 2D=  48.16848 mm,  Arc length 3D=  48.25156 mm
  Measurement =   -4.07047 +-  0.00986 mm
  Track intercept in sensor frame = [     -4.0669,     -6.1878,  -0.0021116]
  RMS projected scattering angle=  0.000110
```

- The track prediction in the sensor frame is very similar
- These are single particles samples, so I expect very clean events and well defined tracks. Is good to see that the two fits work in a similar fashion in ideal conditions.

# Refit of Kalman Tracks using the GBL algorithm

SLAC

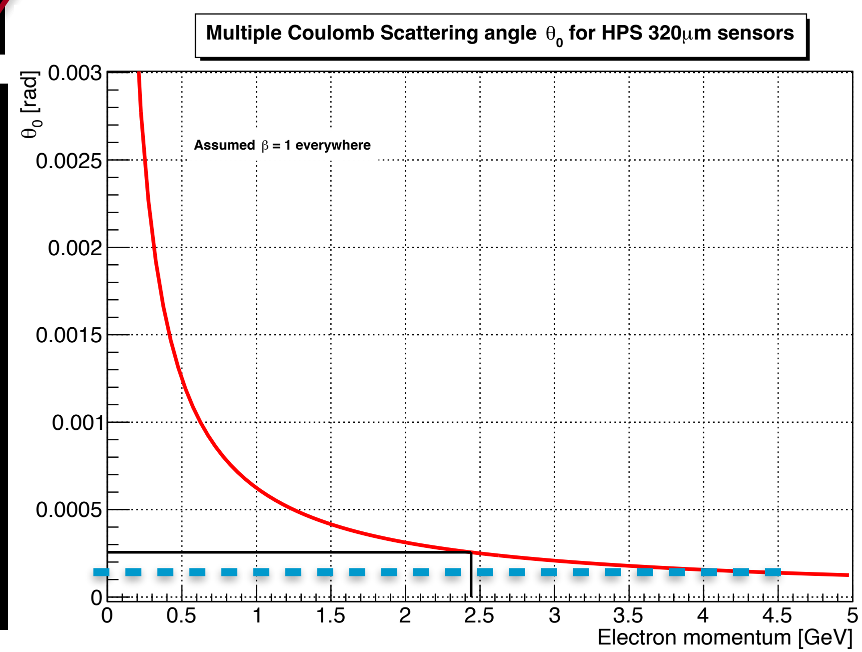
```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
 HPS tracking system V=[    -0.030429,     0.99954, -3.0429e-06]
 HPS tracking system W=[     -0.99954,   -0.030429, -9.9954e-05]
 HPS tracking system Track direction=[     0.98746,       0.14696,     0.057743]
 phi=  0.147738, lambda=  0.057776
 Arc length 2D=  38.85172 mm,  Arc length 3D=  38.91665 mm
 Measurement =    -5.11500 +-  0.01588 mm
 Track intercept in sensor frame = [        -5.1223,       5.6505,  9.9954e-06]
 RMS projected scattering angle=  0.000109

SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=2, scatterOnly=0
 HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
 HPS tracking system V=[     0.030267,    -0.99454,    0.099836]
 HPS tracking system W=[      0.99954,    0.030429,  9.9954e-05]
 HPS tracking system Track direction=[     0.98753,       0.14643,     0.057743]
 phi=  0.147210, lambda=  0.057776
 Arc length 2D=  46.40196 mm,  Arc length 3D=  46.47951 mm
 Measurement =    -4.07047 +-  0.01588 mm
 Track intercept in sensor frame = [        -4.0698,      -6.2055, -9.9954e-06]
 RMS projected scattering angle=  0.000109
```

```
KalmanInterface.printGBLStripClusterData: cluster ID=1, scatterOnly=0
  HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
  HPS tracking system V=[    -0.030429,     0.99954, -3.0429e-06]
  HPS tracking system W=[     -0.99954,   -0.030429, -9.9954e-05]
  HPS tracking system Track direction=[     0.98747,       0.14687,     0.057737]
  phi=  0.147648, lambda=  0.057770
  Arc length 2D=  40.64545 mm,  Arc length 3D=  40.71338 mm
  Measurement =    -5.11500 +-  0.01143 mm
  Track intercept in sensor frame = [        -5.1175,       5.6337,  5.0143e-05]
  RMS projected scattering angle=  0.000110

KalmanInterface.printGBLStripClusterData: cluster ID=2, scatterOnly=0
  HPS tracking system U=[  -0.0031373,    0.099787,     0.99500]
  HPS tracking system V=[     0.030267,    -0.99454,    0.099836]
  HPS tracking system W=[      0.99954,    0.030429,  9.9954e-05]
  HPS tracking system Track direction=[     0.98754,       0.14637,     0.057737]
  phi=  0.147150, lambda=  0.057769
  Arc length 2D=  48.16848 mm,  Arc length 3D=  48.25156 mm
  Measurement =    -4.07047 +-  0.00986 mm
  Track intercept in sensor frame = [        -4.0669,      -6.1878,   -0.0021116]
  RMS projected scattering angle=  0.000110
```

- MS Scattering angle are also in agreement (after bug fix)
- And in agreement with expected computations



# Refit of Kalman Tracks using the GBL algorithm

```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=15, scatterOnly=0
 HPS tracking system U=[ -1.3394e-16,  2.8328e-16,     -1.0000]
 HPS tracking system V=[    0.030479,    -0.99954, -2.8701e-16]
 HPS tracking system W=[    -0.99954,   -0.030479,  1.2525e-16]
 HPS tracking system Track direction=[     0.99314,     0.10170,    0.057743]
 phi=  0.102047, lambda=  0.057776
 Arc length 2D= 691.80963 mm,  Arc length 3D= 692.96587 mm
 Measurement =  -10.80000 +-  0.00866 mm
 Track intercept in sensor frame = [     -10.780,     -16.762, -3.0680e-12]
 RMS projected scattering angle=  0.000141

SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=16, scatterOnly=0
 HPS tracking system U=[  -0.0015233,    0.049956,     0.99875]
 HPS tracking system V=[    0.030440,    -0.99829,    0.049979]
 HPS tracking system W=[     0.99954,    0.030479, -2.1858e-16]
 HPS tracking system Track direction=[     0.99319,     0.10119,    0.057743]
 phi=  0.101532, lambda=  0.057776
 Arc length 2D= 699.16396 mm,  Arc length 3D= 700.33249 mm
 Measurement =   14.57960 +-  0.00866 mm
 Track intercept in sensor frame = [      14.570,     -16.623, -2.1233e-12]
 RMS projected scattering angle=  0.000141
```

```
KalmanInterface.printGBLStripClusterData: cluster ID=15, scatterOnly=0
  HPS tracking system U=[ -1.3394e-16,  2.8328e-16,     -1.0000]
  HPS tracking system V=[    0.030479,    -0.99954, -2.8701e-16]
  HPS tracking system W=[    -0.99954,   -0.030479,  1.2355e-16]
  HPS tracking system Track direction=[     0.99317,     0.10141,    0.057739]
  phi=  0.101760, lambda=  0.057771
  Arc length 2D= 689.91479 mm,  Arc length 3D= 691.07823 mm
  Measurement =  -10.80000 +-  0.00256 mm
  Track intercept in sensor frame = [     -10.800,     -16.670,   -0.055430]
  RMS projected scattering angle= 0.000143

KalmanInterface.printGBLStripClusterData: cluster ID=16, scatterOnly=0
  HPS tracking system U=[  -0.0015233,    0.049956,     0.99875]
  HPS tracking system V=[    0.030440,    -0.99829,    0.049979]
  HPS tracking system W=[     0.99954,    0.030479, -2.2111e-16]
  HPS tracking system Track direction=[     0.99322,     0.10089,    0.057734]
  phi=  0.101236, lambda=  0.057766
  Arc length 2D= 697.29890 mm,  Arc length 3D= 698.47450 mm
  Measurement =   14.57960 +-  0.00256 mm
  Track intercept in sensor frame = [      14.586,     -16.536,    0.054415]
  RMS projected scattering angle= 0.000143
```

- For completion, I also report the last two hits
- Apart from the differences already discussed, the rest all agree.
- After having confirmed that KF algorithm finds (at least) the same tracks found by the seedTracker and after having confirmed that the translation from the KF measurementSites is ~ OK, I can feed these points to the GBL refitter I re-wrote.
- This allows to use Kalman-Tracks for alignment purposes as the global derivatives will be available

# Millepede Binary File comparison

SLAC

## KF + GBL

```
-g- meas.  1 21101 2 18 0.00122682831716 0.0158771332353
local   array('i', [4, 5])
local   array('f', [0.09736587107181549, -0.9953923225402832])
global  array('i', [21101, 21201, 21301, 22101, 22201, 22301, 21161, 21261, 21361, 22161, 22261, 22361,\
21180, 21280, 21380, 22180, 22280, 22380])
global  array('f', [1.0, -2.3147618697705056e-20, 0.016910819336771965, -0.11080228537321091, -0.114006\
67577981949, 6.552153587341309, 0.9950041770935059, 0.0998334139585495, -0.016910819336771965, -0.884289\
3838882446, -14.147073745727539, -135.5476837158203, 0.09927047789096832, 0.019951412454247475, -0.99500\
41770935059, -363.2969970703125, 131.65892028808594, -33.60577392578125])
```

## SeedTracker+GBL

```
-g- meas.  1 21101 2 18 0.00136008707341 0.0158771332353
local   array('i', [4, 5])
local   array('f', [0.09735807776451111, -0.9953941106796265])
global  array('i', [21101, 21201, 21301, 22101, 22201, 22301, 21161, 21261, 21361, 22161, 22261, 22361\
, 21180, 21280, 21380, 22180, 22280, 22380])
global  array('f', [1.0, 3.9990818964526124e-20, 0.016970820724964142, -0.11099298298358917, -0.113879\
2559504509, 6.540224552154541, 0.9950041770935059, 0.0998334139585495, -0.016970820724964142, -0.891931\
95104599, -14.150341987609863, -135.53575134277344, 0.09926864504814148, 0.020011385902762413, -0.99500\
41770935059, -363.3003845214844, 131.64688110351562, -33.597747802734375])
-g- meas.  2 21102 2 18 0.0114786094055 0.0158771332353
```

Residual and sigma on sensor 21101
Local derivatives labels and values
Global derivatives labels and values

No appreciable difference between ST+GBL and KF+GBL => same derivatives, expected same alignment solution