SVT Alignment - Status / To Do

PF

06/20/2021

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

Disclaimer

- **Disclaimer**
  - Due to personal reasons and other work duties I had really little time to prepare for this talk today, my apologies
  - This talk will be mostly a snapshot of where I am now and a note of what I should try next to improve the SVT alignment
  - It will be mostly a list of available tools, current results and next-steps in a short time scale.

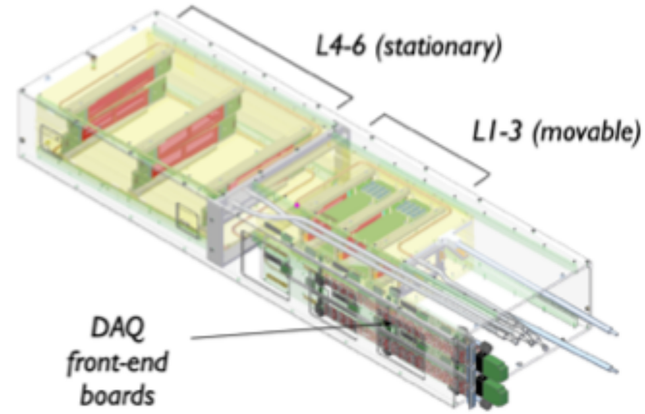
Track Based alignment of the SVT Detector

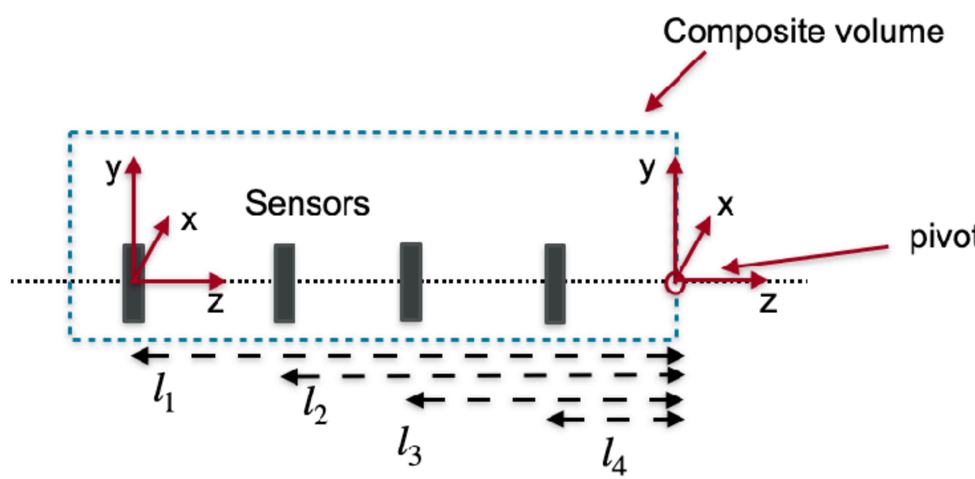
GBL + MPII

- 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 χ^2 minimisation technique
- Weak mode constraints employed:

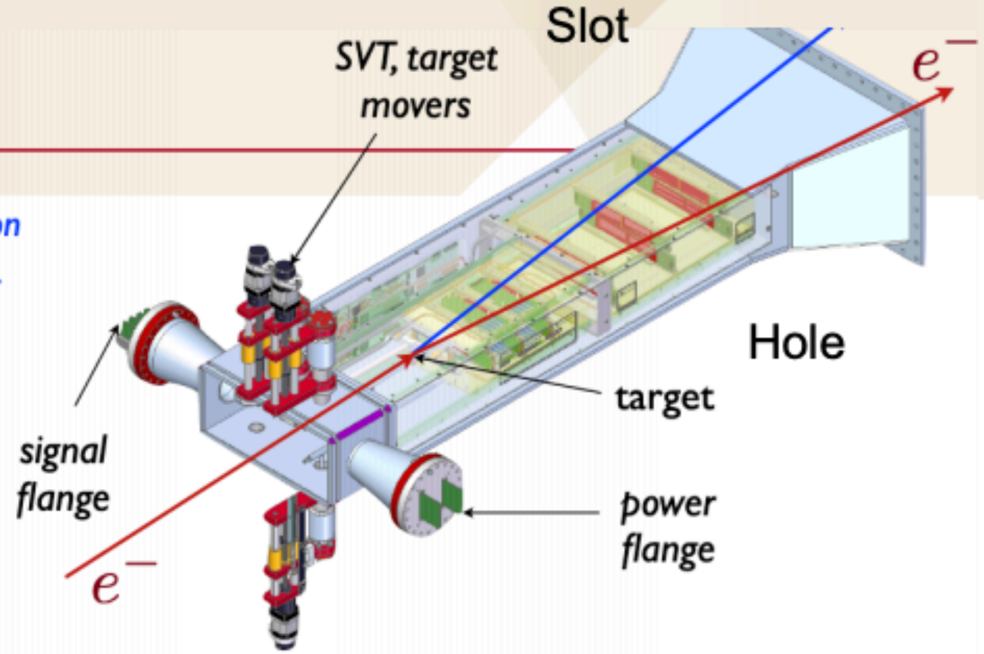
  - Momentum constraint

  - Beamspot location constraint





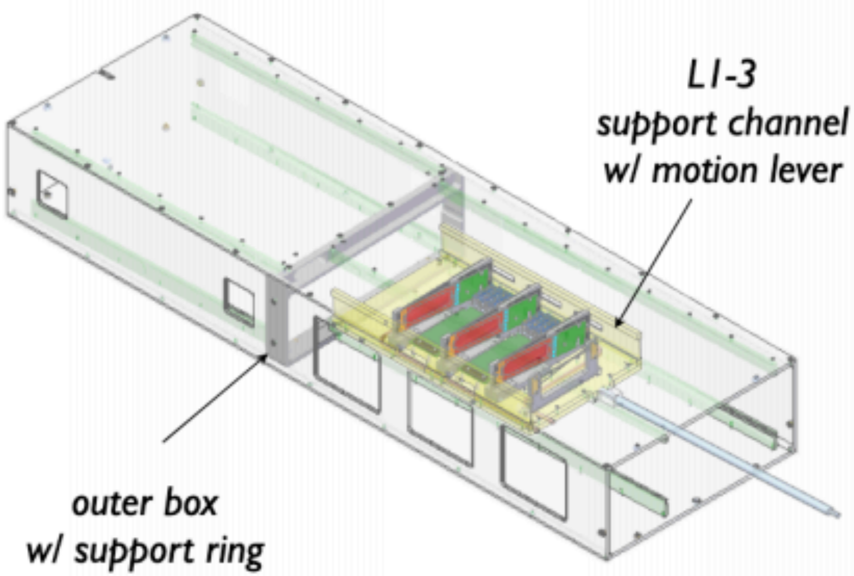
The HPS SVT

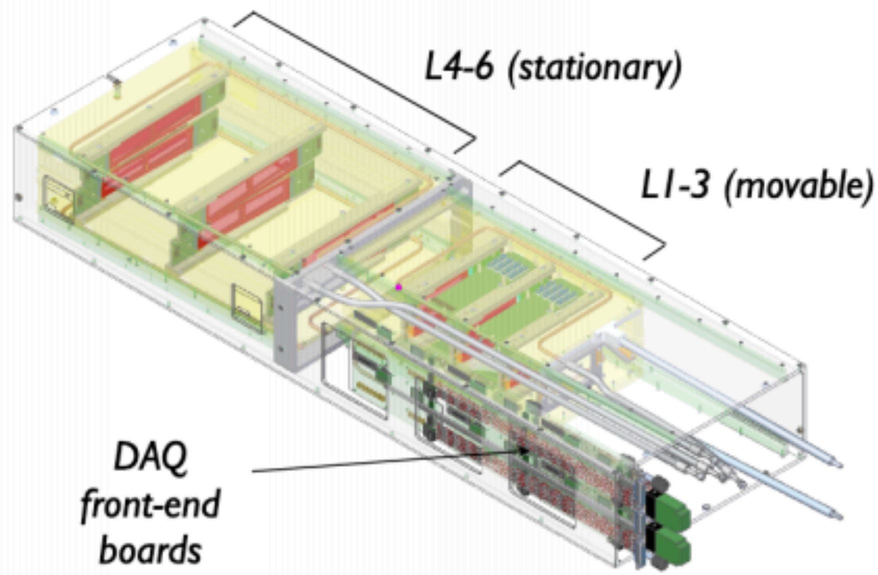


7 double-layers of silicon strips, each plane measures position (~6-10 μm) and time (~2 ns) with ~0.2% – 0.35% X_0/hit.

Operates in an extreme environment:

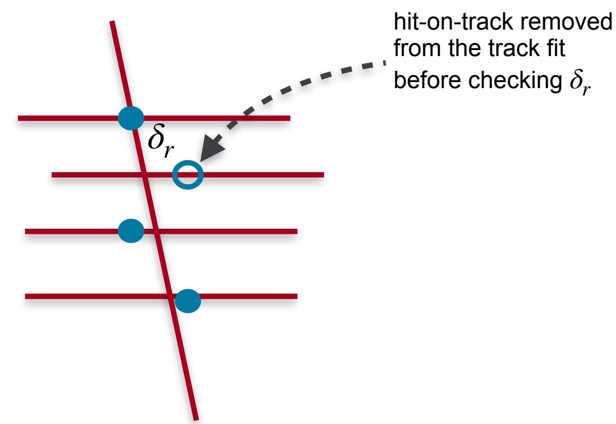
- beam vacuum and 1.5 Tesla magnetic field
  ⇒ constrains materials and techniques
- sensor edges 0.5 mm from electron beam in L1
  ⇒ must be movable, serviceable
- sensors see large dose of scattered electrons
  ⇒ must be actively cooled to -20 ˚C
- 24528 channels can output >100 gb/sec
  ⇒ requires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

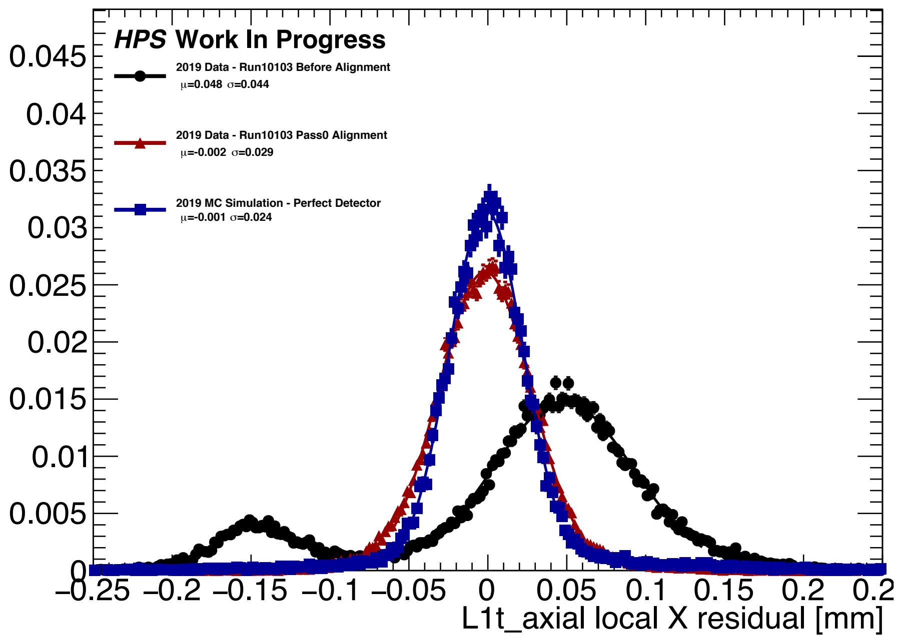


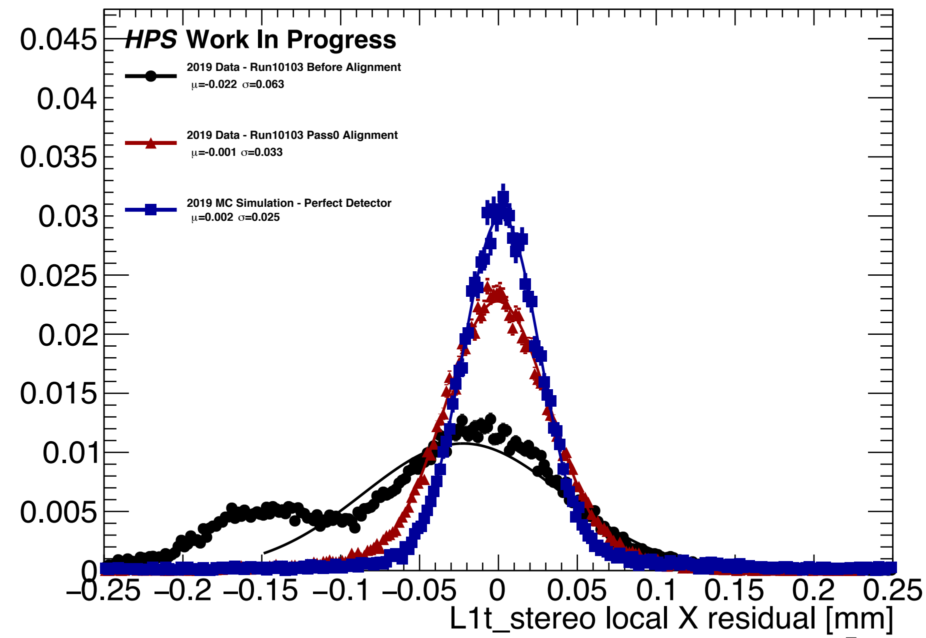


Alignment performance - Unbiased Residuals

- 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)

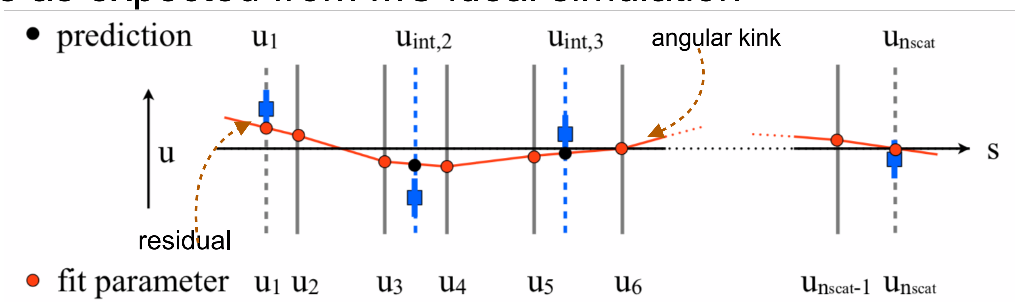


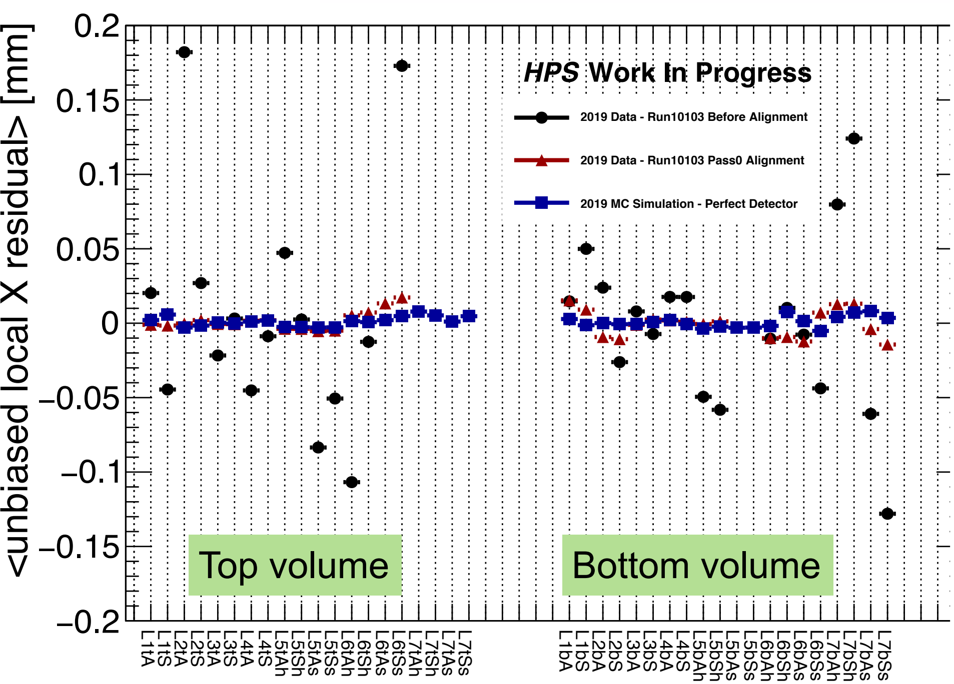


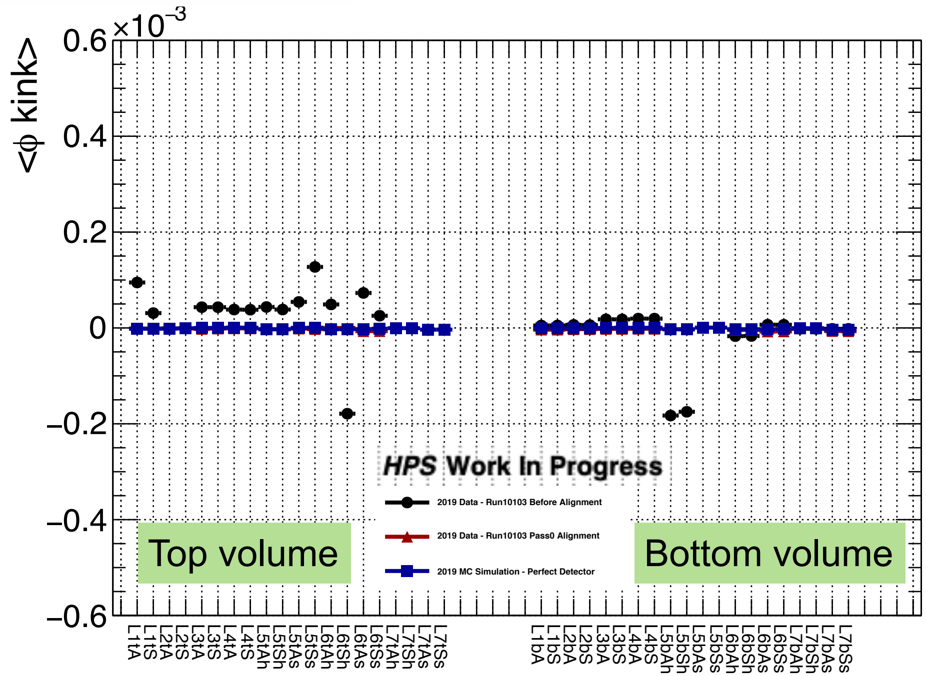


Alignment performance - Unbiased Residuals

- 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

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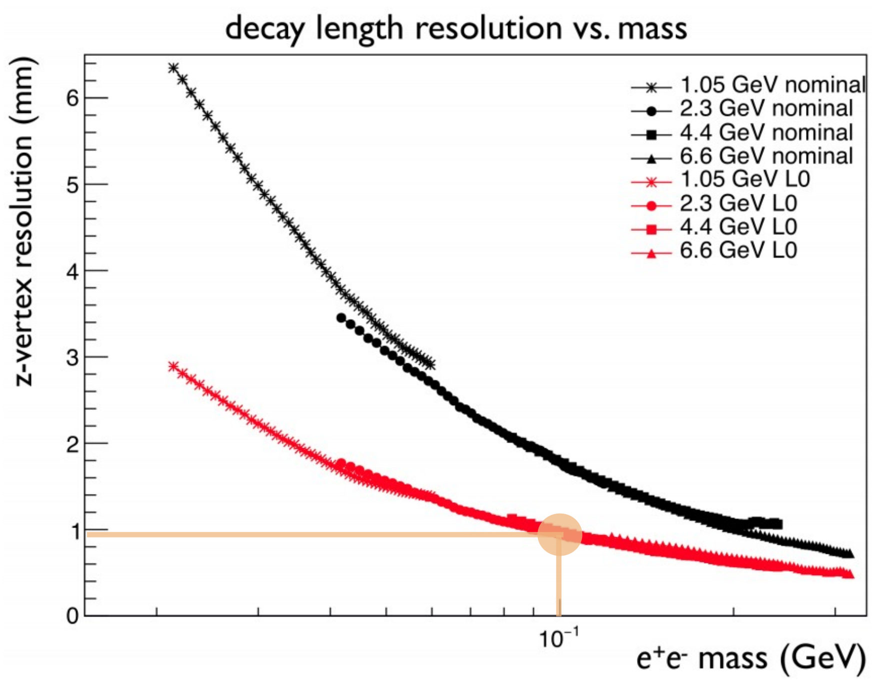
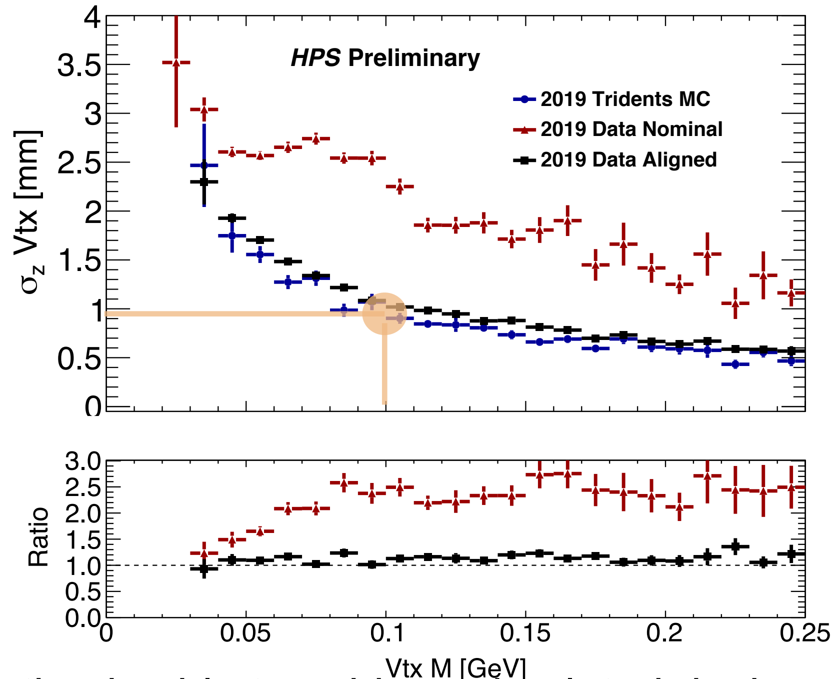
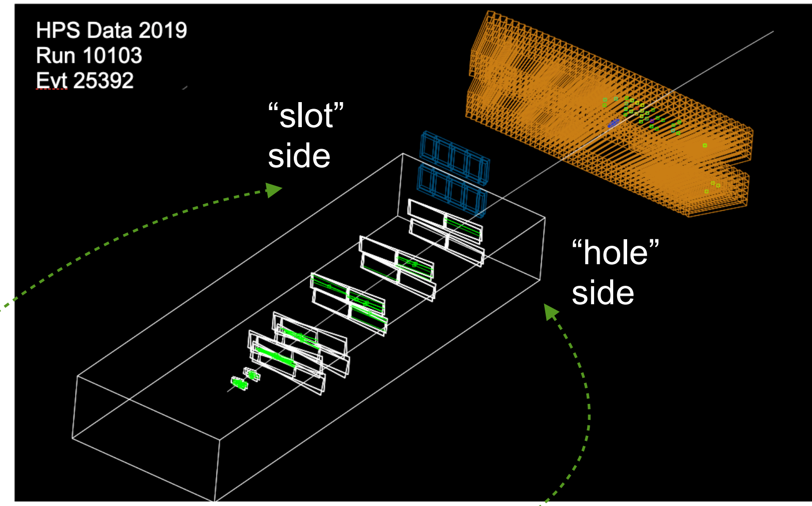


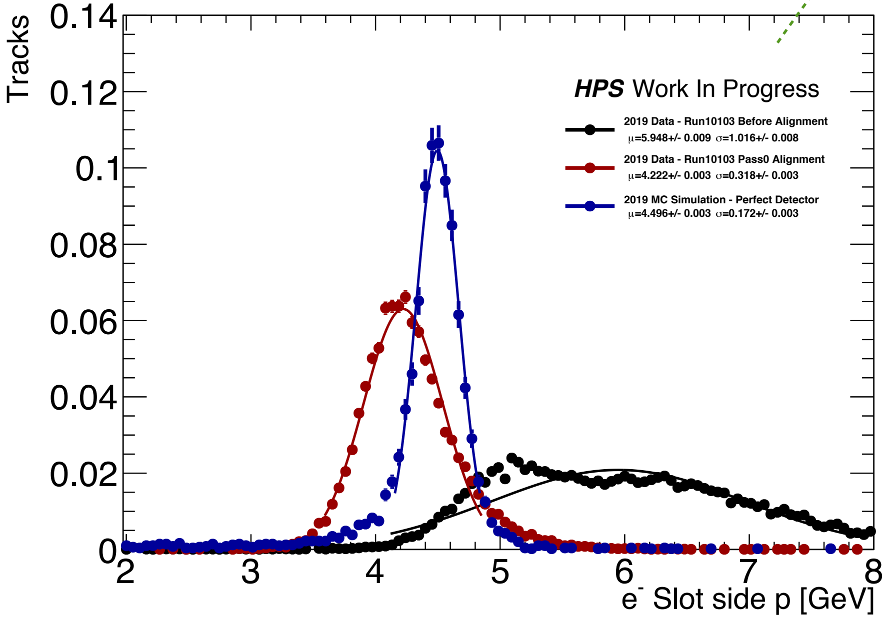


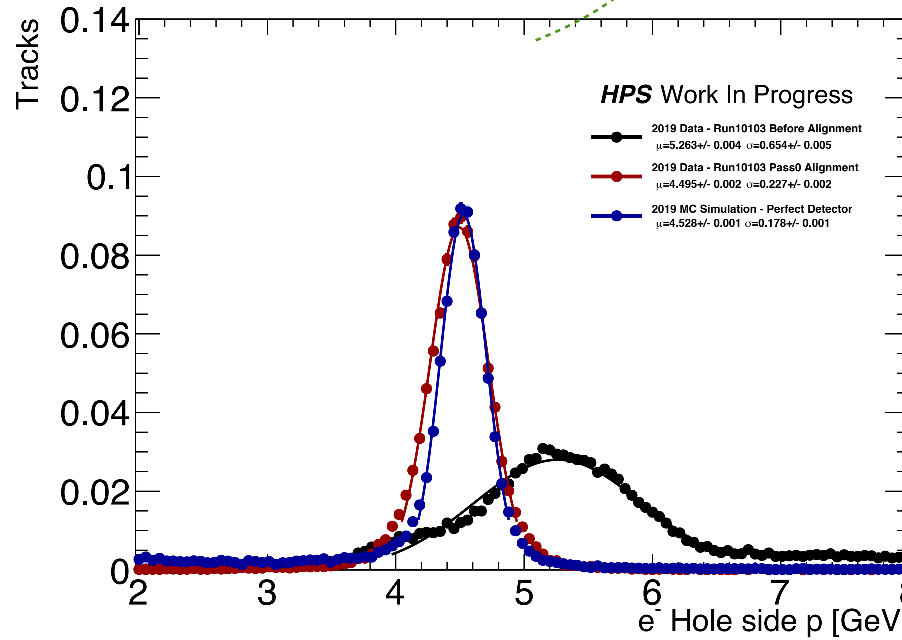
- Preliminary alignment show that HPS reconstruction is able to achieve simulated design performance
- Resolution extracted from gaussian fit on the core of the vertex distribution
- In these results *optimistic* MC simulation has been used (no beam background / pileup included). A simulation that would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

SVT Performance - Momentum Scale and Resolution

- 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

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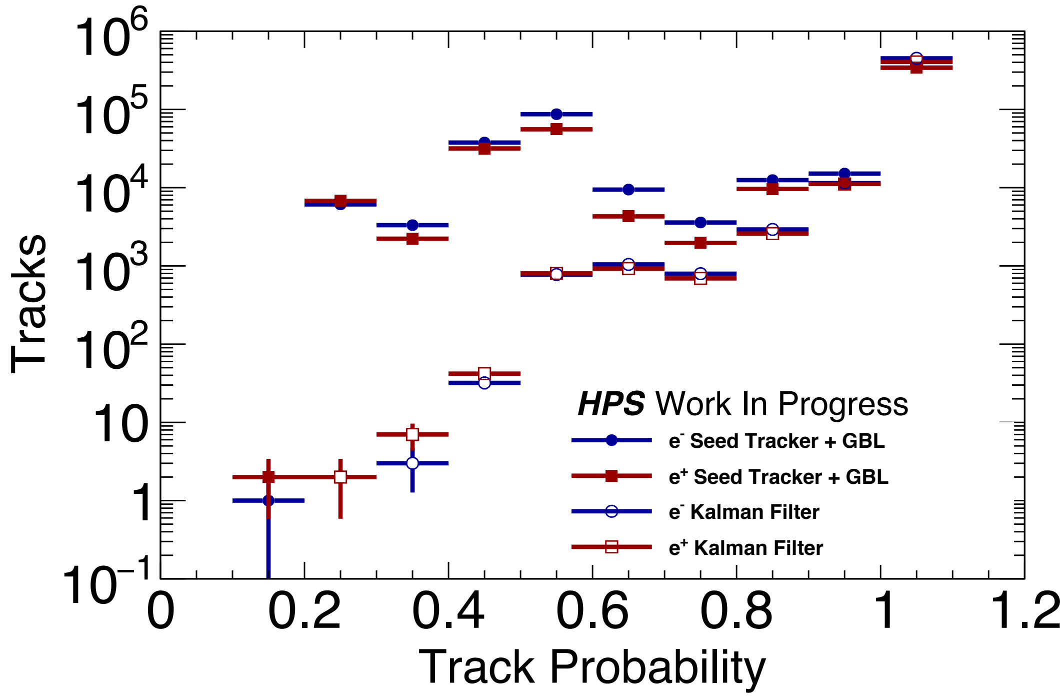
- **Alignment Framework Updates**
  - Integrated KF tracks into the Alignment framework:
    - Possible to run alignment with those tracks now
    - Faster turn-around of results, better pattern recognition
  - Developed a full hierarchical alignment with volumes in the centre of mass of the sensors (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:

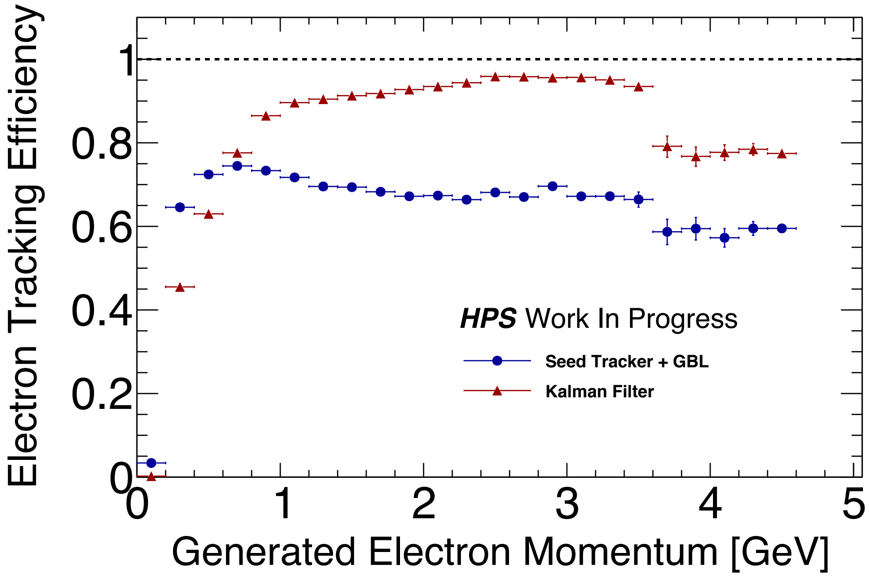
$$TrackP = \frac{N_{hits}^{truth}}{N_{hits}^{track}}$$

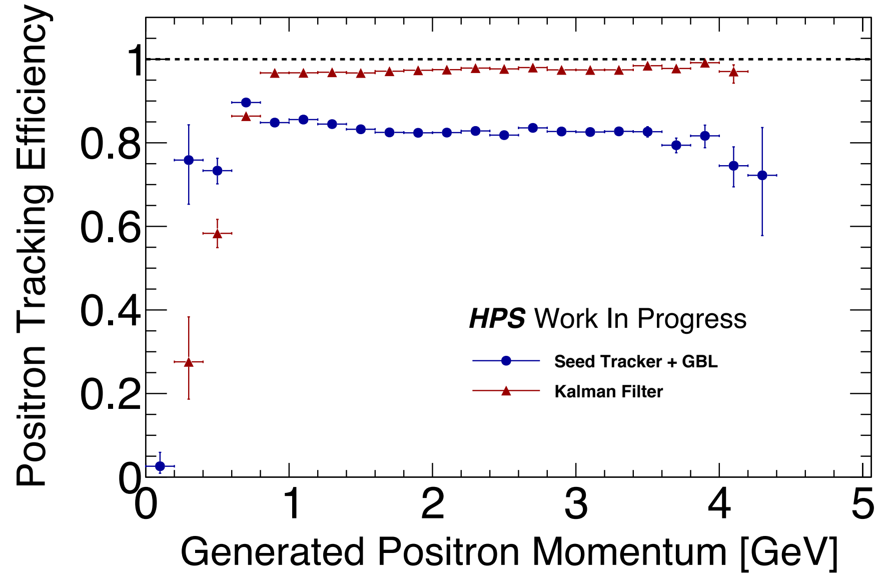
where N_{hits}^{truth} are the hits matched to the generated particle



- 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

Refit of Kalman Tracks using the GBL algorithm

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```
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]
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```

DEFAULT COMPUTATION

GBLStripClusterData computed by the seedTracker + gbl.MakeGBLTrack

```
KalmanInterface.printGBLStripClusterData: cluster ID=1, scatterOnly=0
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  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

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  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
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COMPUTATION FROM KF

GBLStripClusterData computed by KalmanInterface

Crosschecks of the GBLStripClusterData

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- The UVW (local frame) system matches between the two computations (OK)
- The track direction in ϕ and λ is in agreement (OK)

Refit of Kalman Tracks using the GBL algorithm

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- 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.

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```

- 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 χ^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

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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

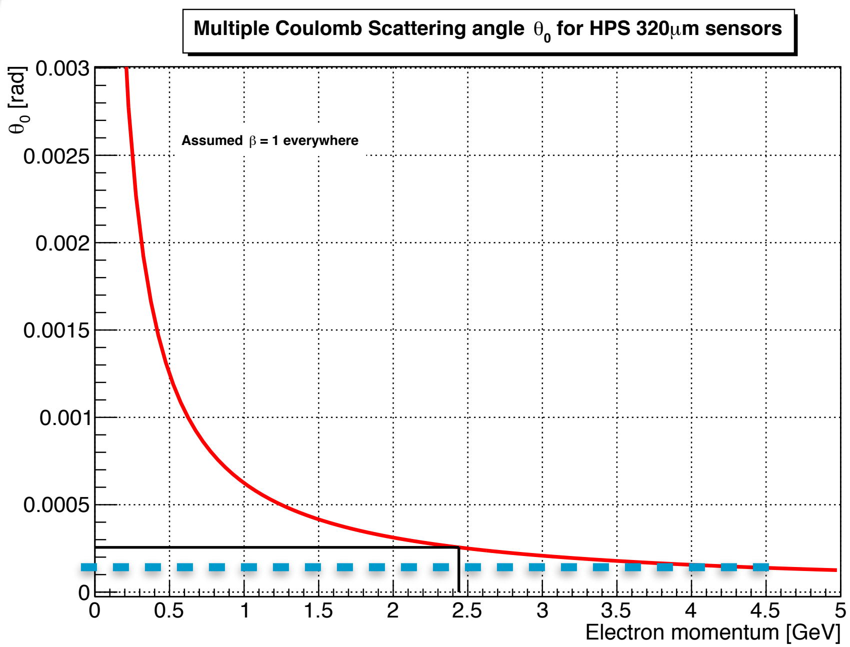
```
SimpleGBLTrajAliDriver - printGBLStripClusterData: cluster ID=1, scatterOnly=0
 HPS tracking system U=[ -0.00010000,  6.1357e-17,       1.0000]
 HPS tracking system V=[   -0.030429,     0.99954, -3.0429e-06]
 HPS tracking system W=[    -0.99954,   -0.030429, -9.9954e-05]
 HPS tracking system Track 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 = [     -4.0659,     -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

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
```

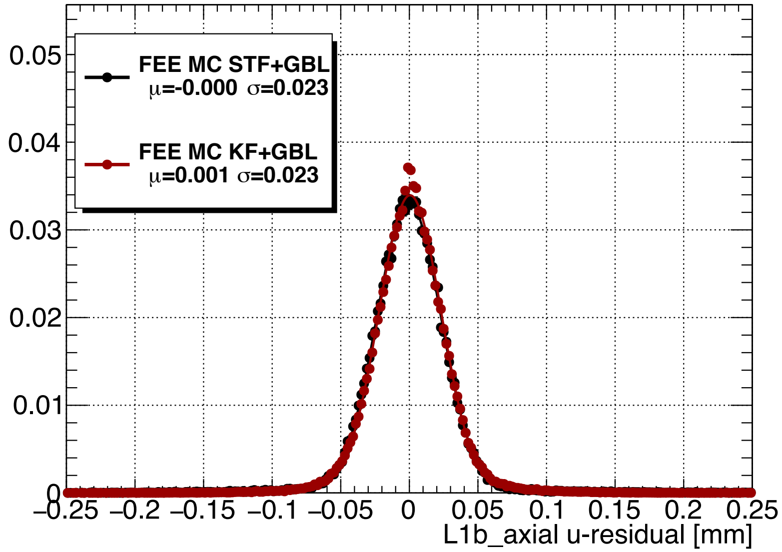
Residual and sigma on sensor 21101

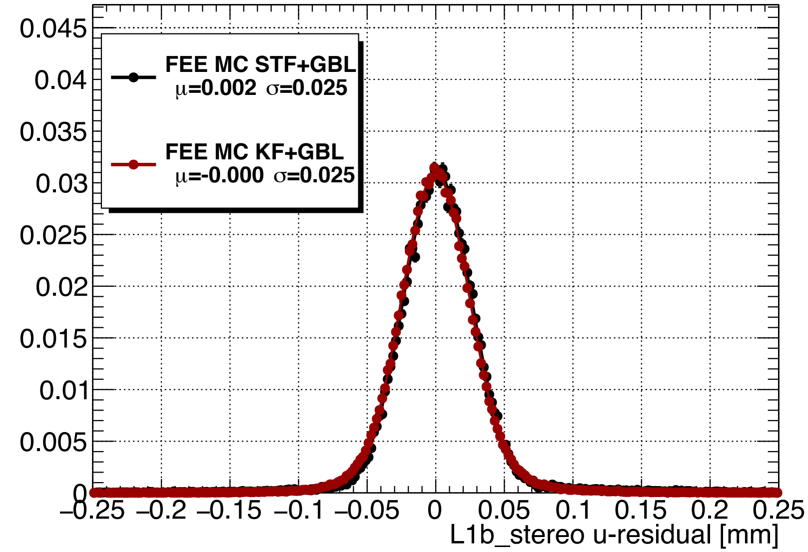
Local derivatives labels and values

Global derivatives labels and values

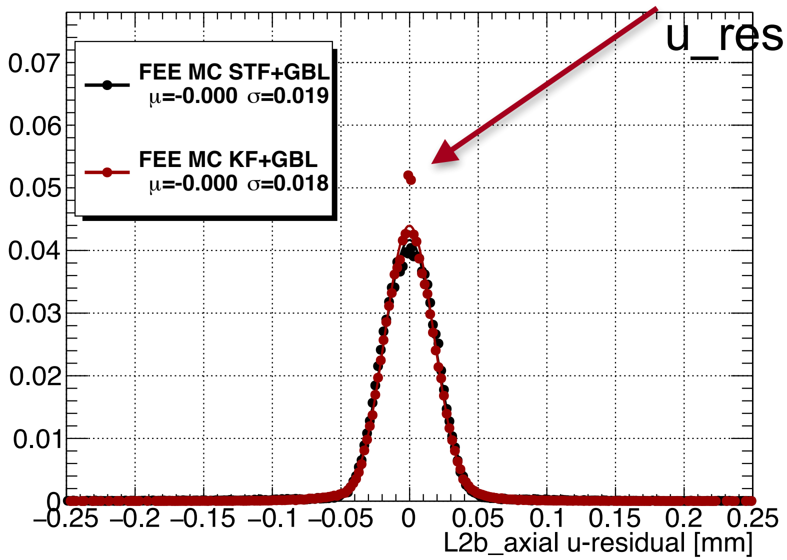
No appreciable difference between ST+GBL and KF+GBL => same derivatives, expected same alignment solution

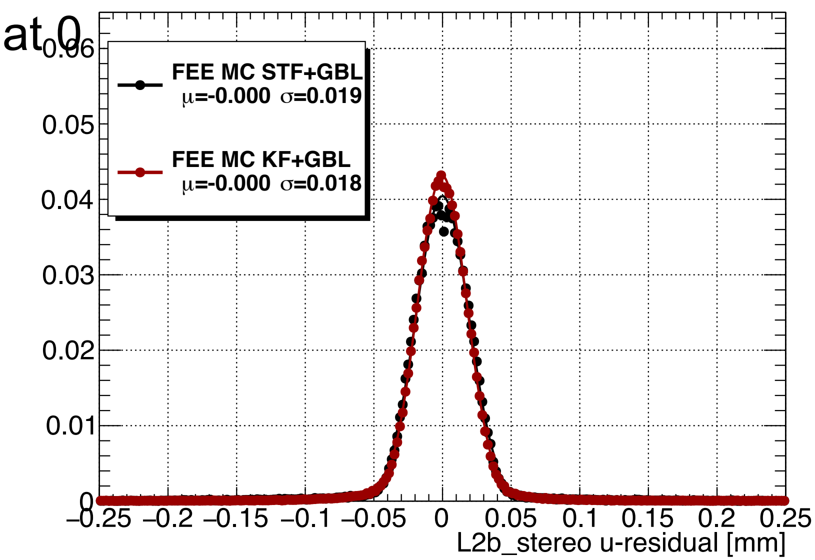
Check on perfect aligned geo - FEE MC



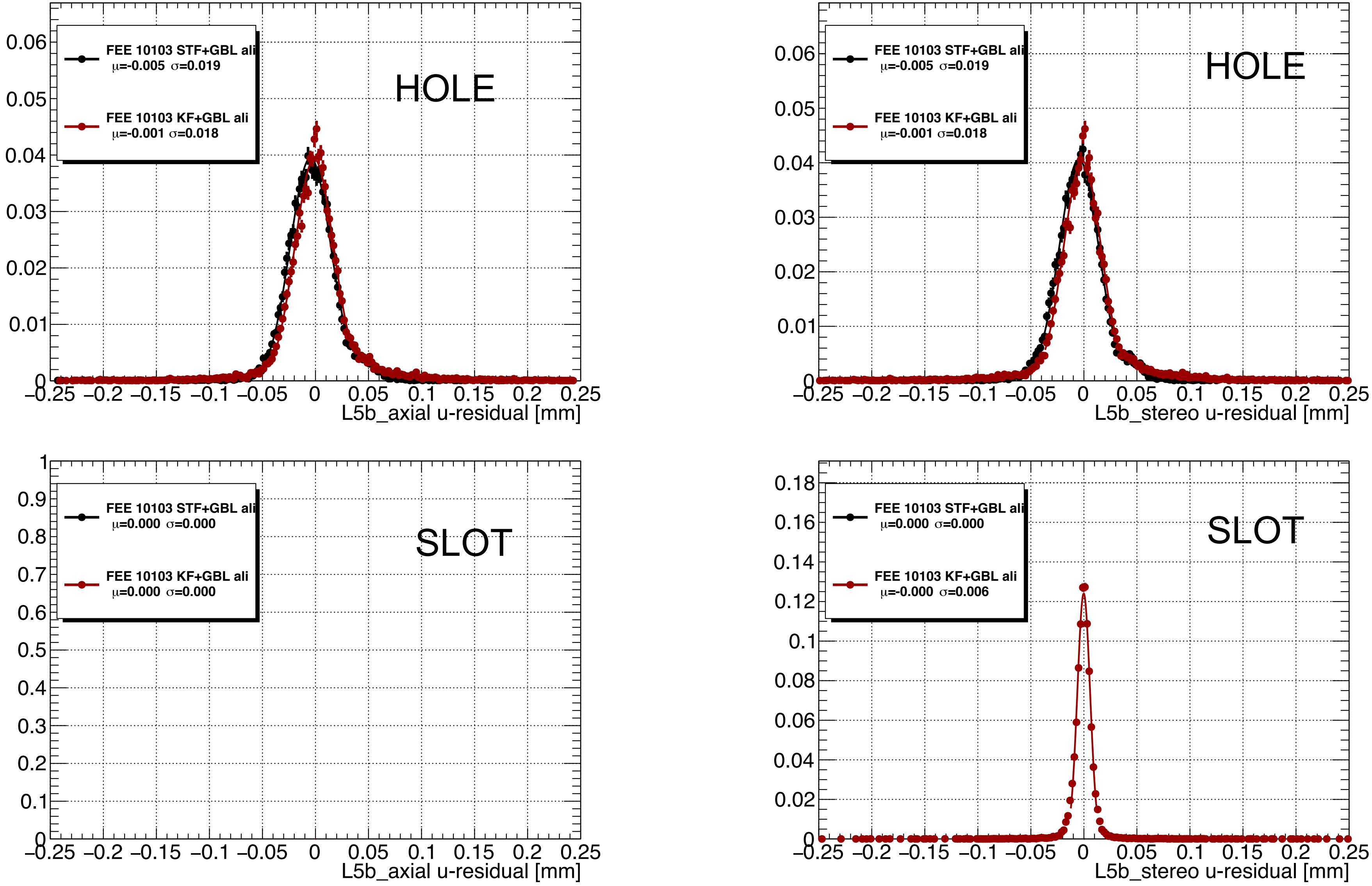


No cut on Nhits => low DoF => u_res spike at 0





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



More alignment Framework developments

SLAC

- **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)

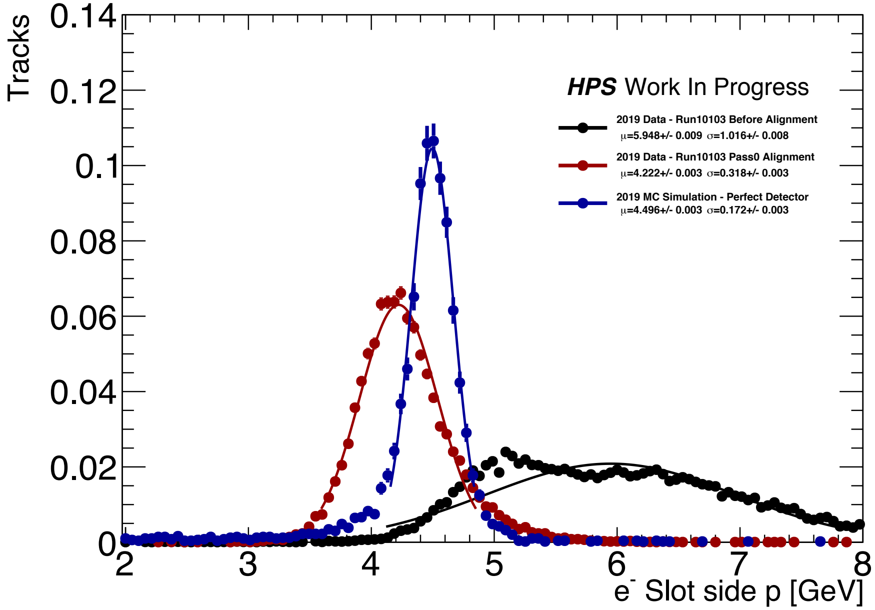
Current issues

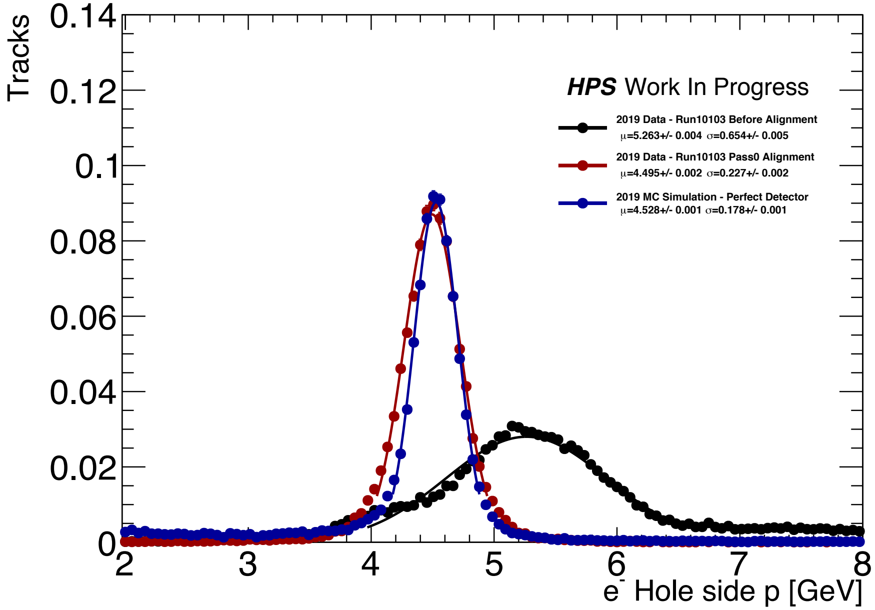
SLAC

- **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

Current issues

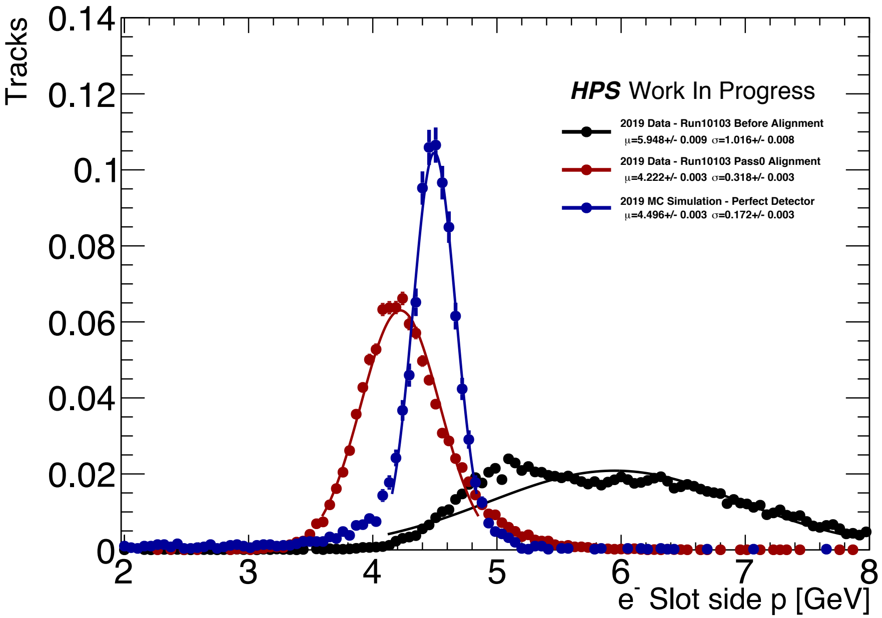
- **Major current alignment issues**
  - There is a large asymmetry between hole-slot side momentum
  - A possible reason could be a rotation of some sensors along global Y axis
  - This would create a side with closer hits and a side with further hits wrt the other layers

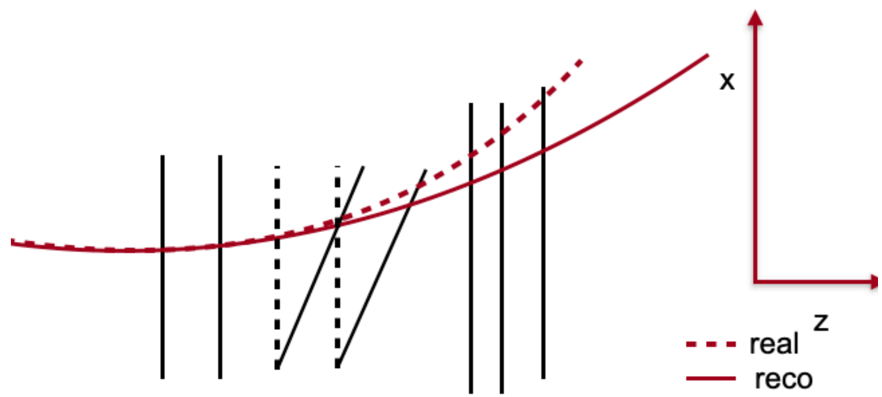




Current issues

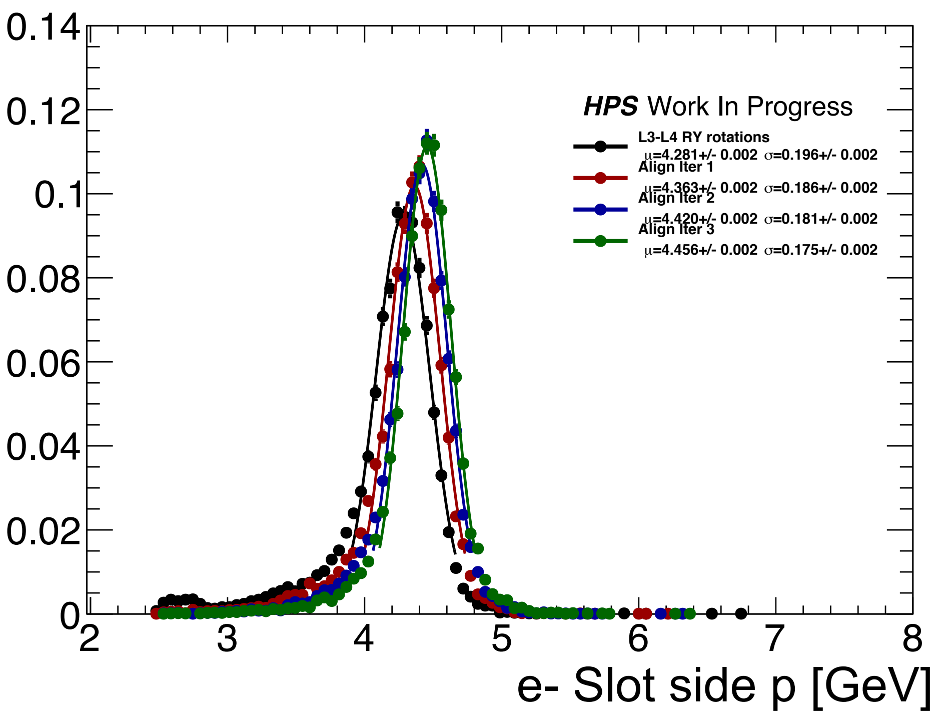
- **Major current alignment issues**
  - There is a large asymmetry between hole-slot side momentum
  - A possible reason could be a rotation of some sensors along global Y axis
  - This would create a side with closer hits and a side with further hits wrt the other layers

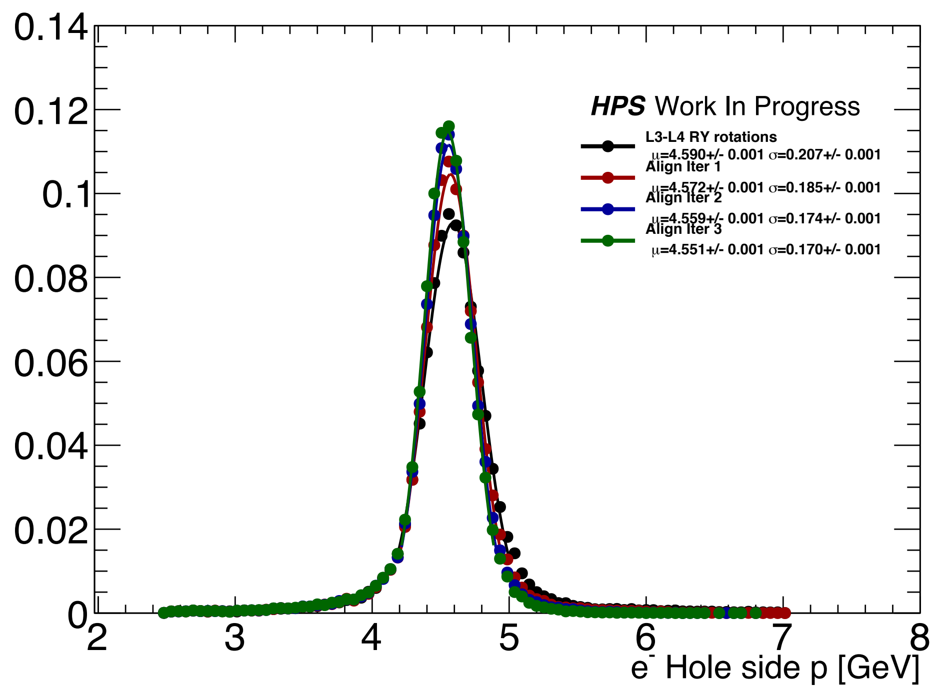




Current issues

- **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





Summary

- Kalman Tracks can now be used for alignment
- Alignment framework now includes all possible structures including:
  - Full Volumes
  - Half sensors
  - …
- Studying the effect of correcting some Rotation DoFs to improve momentum scale and resolution => Work in progress
- I had to shift to DAQ so I don’t have much progress on this topic the past month
  - Happy to pass over if people want to help with this task while I’m busy with run preparations.

BACKUP