2019 SVT Alignment Status

PF

12/04/2023

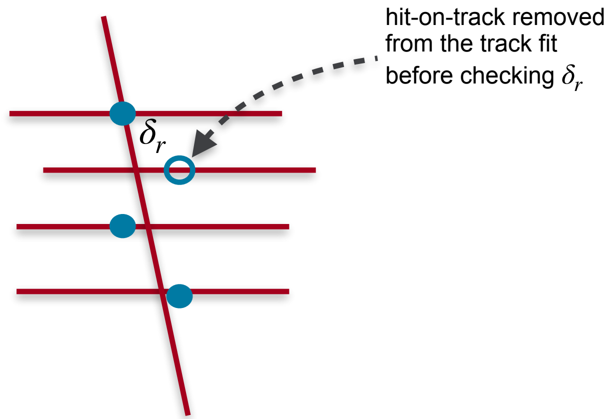
Introduction

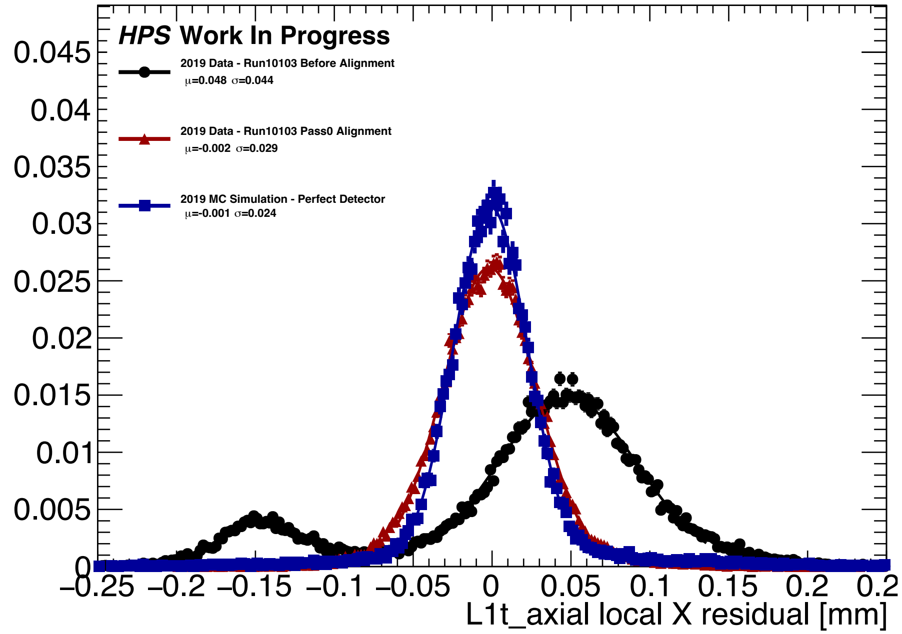
- **Proposed new baseline for alignment for 2019**
  - Details of the new procedure, iterations and corrections: focus on transparent and complete documentation and motivations
  - Comparison with the current FEE-based alignment in hps-java compact
- **Performance of 2019-baseline alignment**
  - Residuals (PF), some FEEs
  - FEE and Vertexing (see Norman's talk)
- **Study of distortions of the detector and their effects**
  - Implementation of in-plane collective distortions (twists)
  - Study of out-of-plane distortions (telescope elongation, module separation, out-of-plane bowing)
- **Move forward**
  - What is missing and how to move forward
- **Newly developed Tools**
  - For monitoring and collective distortions.
  - Applications to Moellers for 2021

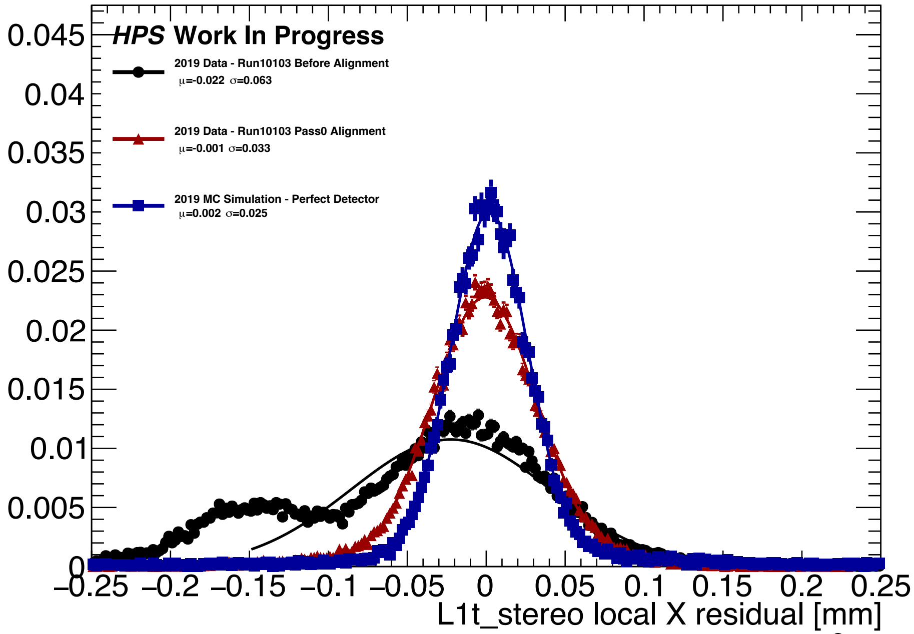
2019 Alignment performance - Unbiased Residuals

SLAC

- 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)

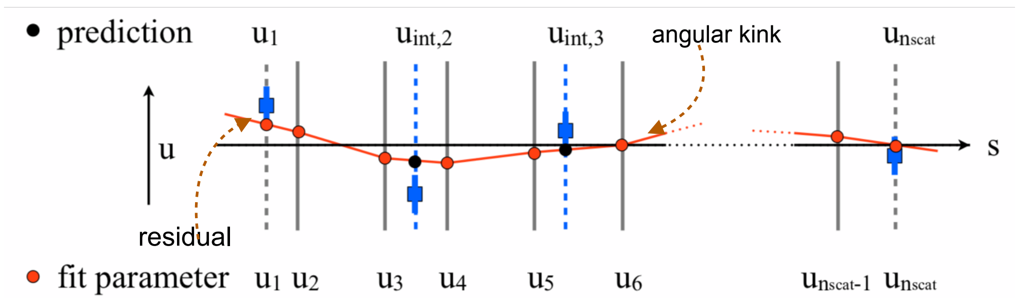


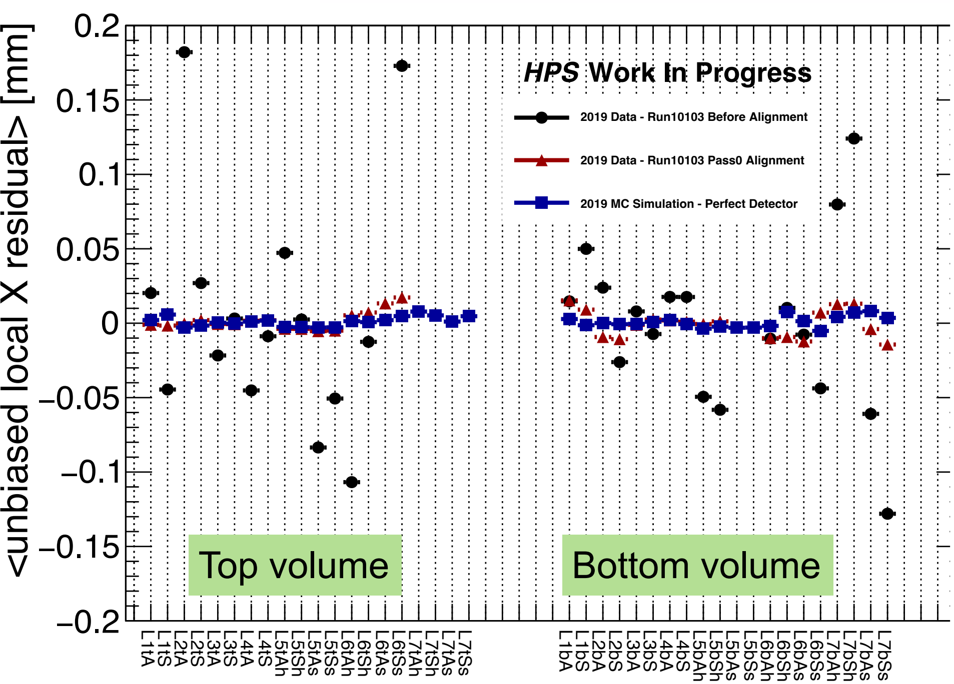


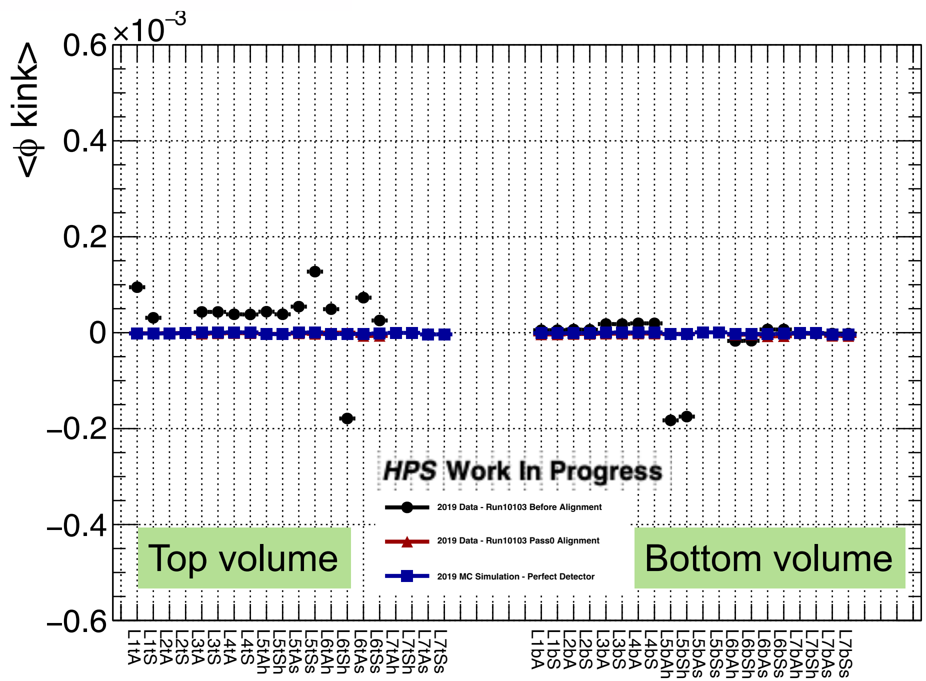


2019 Alignment performance - Unbiased Residuals

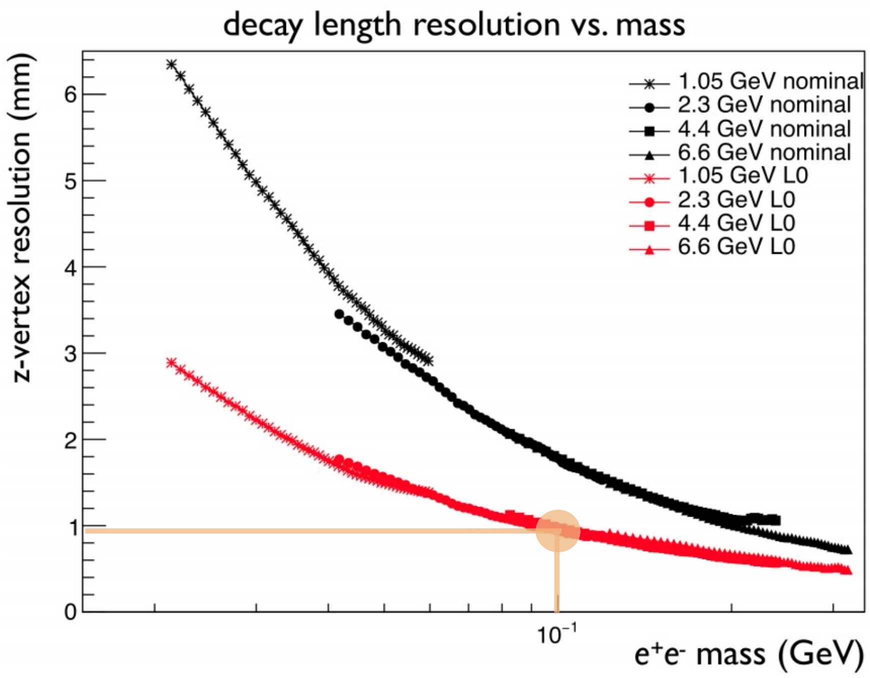
SLAC

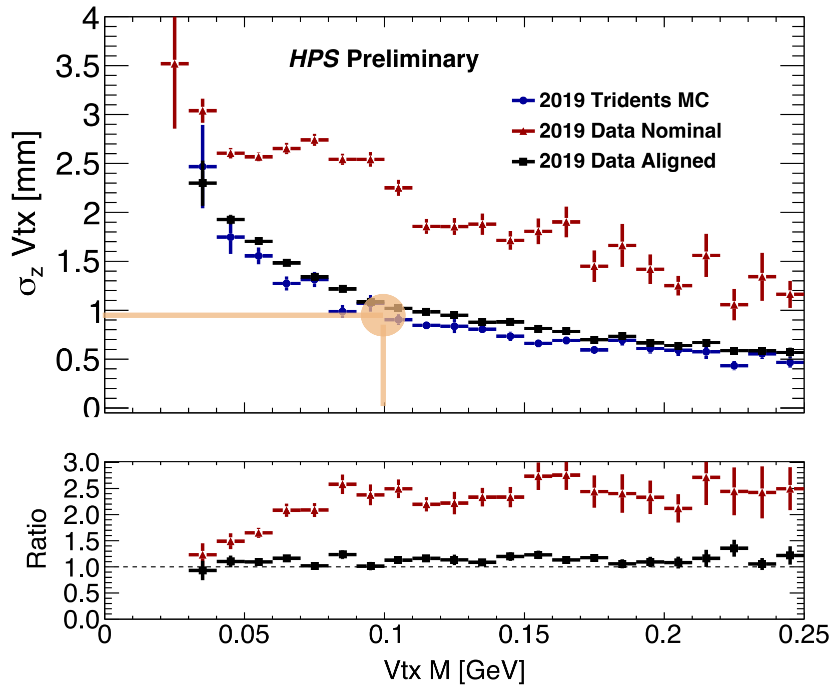






2019 Detector performance - Vertexing

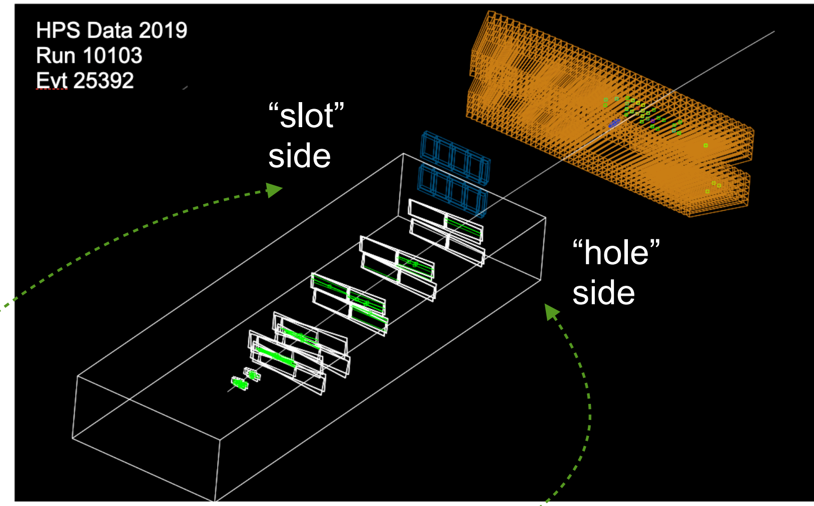


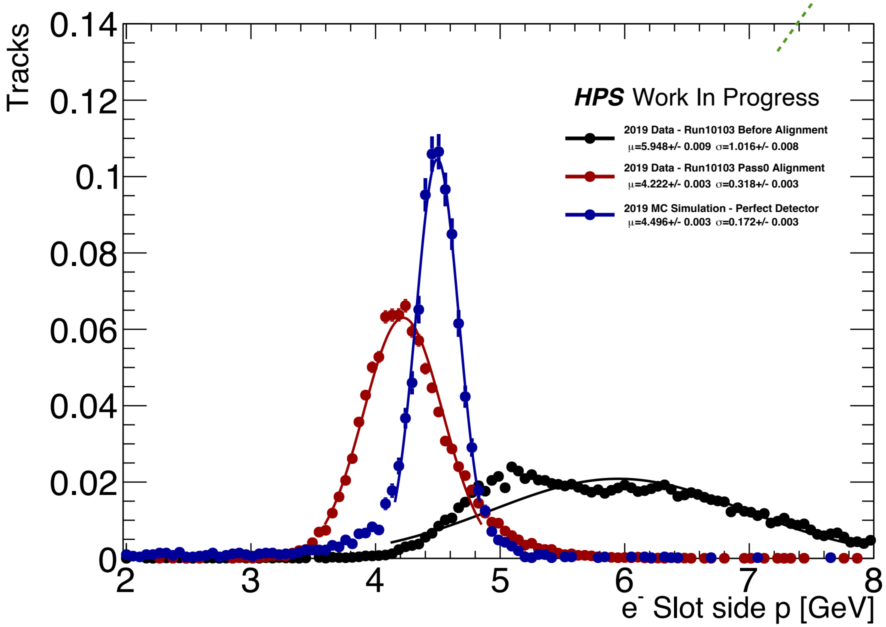


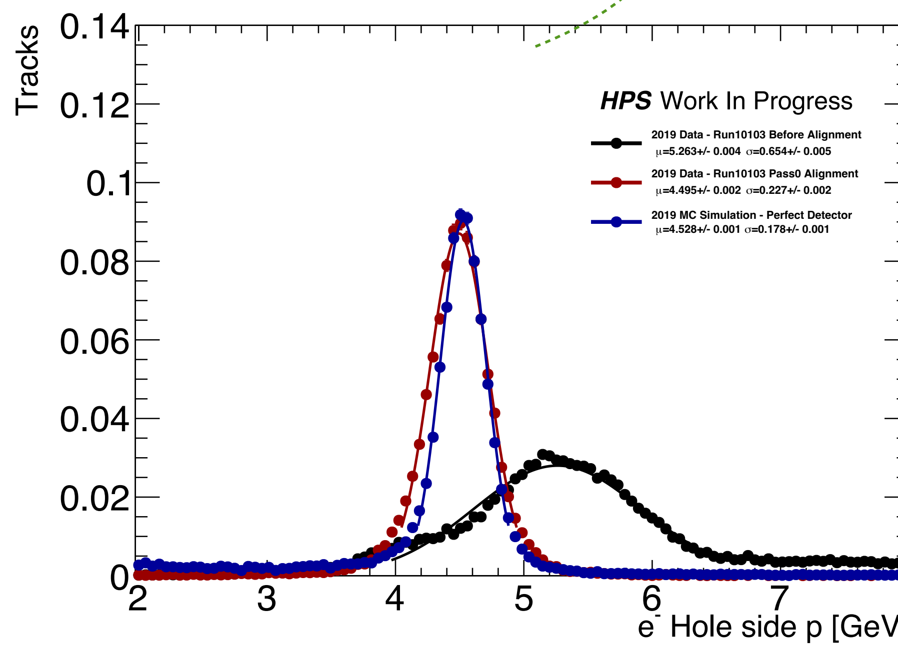
2019 SVT Performance - Momentum Scale and Resolution

SLAC

- 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

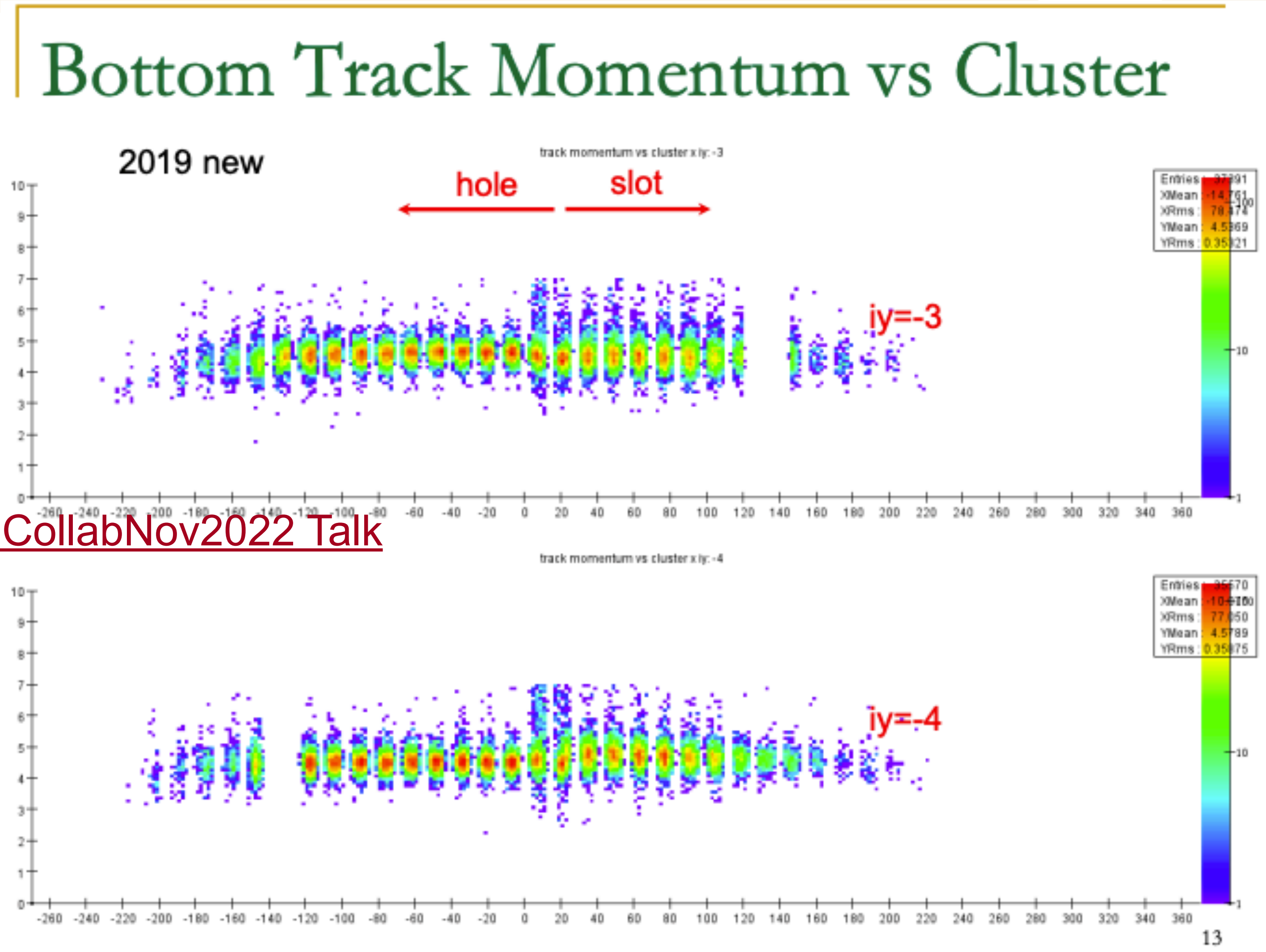






Brief reminder on current 2019 alignment performance

SLAC



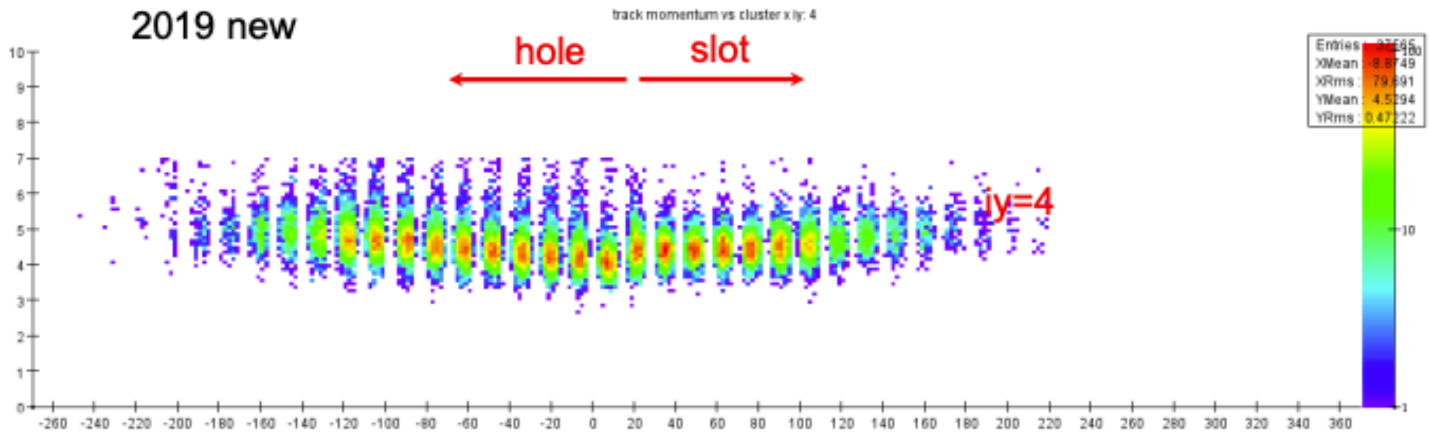
[Norman's CollabNov2022 Talk]

- Followed up and improved p dependence from phi

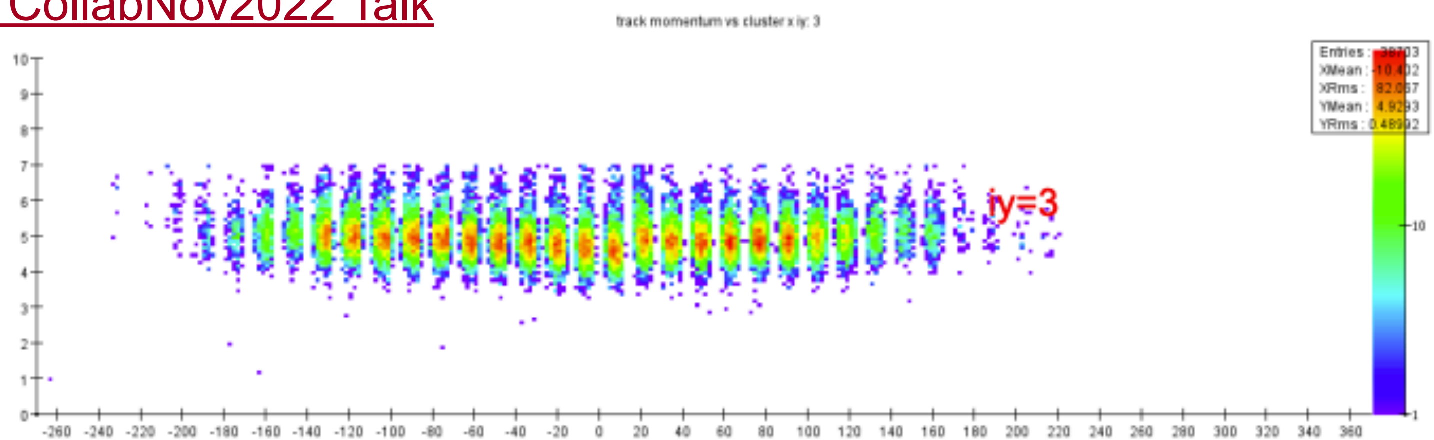
Brief reminder on current 2019 alignment performance

SLAC

Top Track Momentum vs Cluster x



[Norman's CollabNov2022 Talk]



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- Followed up and improved p dependence from phi

Brief reminder on current 2019 alignment performance

SLAC

- Motivations for a new alignment procedure for 2019
  - Received multiple comments to use 2016-like procedure that led to acceptable performance in previous analysis
  - Using FEEs doesn't illuminate properly the slot side and led to poor performance in tracking in that region
  - Order of corrections lost during many iterations
  - Size of corrections of global structures large and un-expected

New starting point: HPS 2019 geometry design

- During several passes checking the geometry we found few inconsistencies between the geometry from HPS design and what was returned by the hps-java geometry classes
- Tim, some time ago, produced a full dump of the sensor x-y-z positions "as designed", available here
  2019 Geometry Design
- 2016 survey measurements are stored in the Pass-2 compact from 2016 analysis:
  HPS-Physics2016-Pass2 compact
- I've created a new detector compact, called HPS_TimDesign_iter0 that matches the position of the sensors in 2019 Geometry to the design.
  - The orientation of the UChannels are taken from the 2016 compact (so top and bottom volumes are not exactly at 30.5 mrad) wrt beam axis

New starting point: HPS 2019 geometry design

- Additionally I've been requested to perform a check using 2016 alignment strategy
- I performed a new alignment pass without usage of external constraints (BS or momentum) and used only e+/e- tracks from run 10031
- Not easy to really apply the same procedure in 2019 so I kept 2 main ideas:
  - **Keep fixed first and last sensor and align everything in between**
  - **Align the innermost sensors when the rest is fixed**

test #	start from #	floats	Delta p (T-B) MeV/c	chi2 res top	chi2 res bot	mean chi2 tot
0	**-**	**-**	**40**	**33.62**	**71.77**	**20.14**
1	0	tu 3+4+5 T&B	81	11.01	31.97	7.9
2	0	tu 2+3+4+5 T&B	20	9.7	31.9	7.59
3	2	tu 3+4 T&B	3	3.58	8.14	2.44
4	3	tu+tw 3+4 T&B	7	2.76	2.62	1.37
5	4	ru+rv+rw 3+4 T&B	23	4	3.73	1.63
6	5	tu 2+3+4+5 T&B	30	3.75	7.92	2.88
7	5	tu+tw 3+4 T&B	38	3.34	2.77	1.83
8	0	tuw 4+tuw3+tuw 2 T&B 3 steps in row	101	351.7	422.3	150.8
9	0	as 8 curved tracks only	-	-	-	-
10	0	tuw 4TB + tuw 3 + 2 tuw T&B	95	13.8	20.96	8.78
11	0	tu 2+3+4+5 T&B curved only	101	41	7.95	11.4
12	**4**	**tu 1+6 T&B**	**0**	**0.56**	**2.13**	**0.7**
12F	**4**	**" with new fieldmap**	**3**	**0.56**	**2.15**	**0.7**
13	12	global alignment (check compact)	153			14.7
14	12	ru+rv+rw 3+4 T&B	9	0.59	4.17	1.06
15	14	tu 3+4 B + rurvrw 4HB	33	0.56	4.18	1.08
16	15	rurvrw 4H+5H B	33	0.56	2.77	0.86
17	15	ru+rv+rw 3+4H B	26	0.56	2.5	0.82
17F	15	" with new fieldmap	26	0.56	2.48	0.81
18	15	ru+rv+rw 3+4S B	30	0.56	0.57 8 dof	1.48
19	12	tw 4B new fieldmap	5	0.56	0.46	0.49
20	**19**	**ru+rv+rw 4T hole+ 4B**	**10**	**0.56**	**0.99**	**0.49**
21	20	d0 , z0 global centering	1	1.86	1.35	0.73
22	21	d0 , z0 global centering	5	1.88	1.36	0.74
23	22	tu+tw 1+2+3 T+B	6	0.61	0.86	0.46
24	23	d0, z0 global centering	6	0.57	0.73	0.43
25	24	tu+tw 6T+6B	10	0.45	0.62	0.39

Alessandra's Talk in 2018

- The actual internal alignment corrections performed in 2016 seems to be described in the 2016 compact:

This is an X correction and only for bottom

```
Global +1 mm shift in y
Correction on top and bottom Layers 1-3 opening angle
Millepede internal alignment
(iterations: 3-4-5TB tu + 2TB tu + 3-4TB tu + 3-4TB rw +1-6TB tu + 3-4TB tu+rw)
Corresponds to version #31
```

Some caveats

- Tracing back the actual iterations that made their way in is not clear.
- The final constants seem to be relative to v31 (not present in the table)
- Stored in the 2016_Pass2_Compact
- Checks are ongoing to understand if 2016 dataset has been reconstructed with the constants in the database or in the compact.
- We can say that compact has the expected performance (and was consistently used for all comparison studies done in the past 3 years)

test #	start from #	floats	Delta p (T-B) MeV/c	chi2 res top	chi2 res bot	mean chi2 tot
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4	3	tu+tw 3+4 T&B	7	2.76	2.62	1.37
5	4	ru+rv+rw 3+4 T&B	23	4	3.73	1.63
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7	5	tu+tw 3+4 T&B	38	3.34	2.77	1.83
8	0	tuw 4+tuw3+tuw 2 T&B 3 steps in row	101	351.7	422.3	150.8
9	0	as 8 curved tracks only	-	-	-	-
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11	0	tu 2+3+4+5 T&B curved only	101	41	7.95	11.4
12	**4**	**tu 1+6 T&B**	**0**	**0.56**	**2.13**	**0.7**
12F	**4**	**" with new fieldmap**	**3**	**0.56**	**2.15**	**0.7**
13	12	global alignment (check compact)	153			14.7
14	12	ru+rv+rw 3+4 T&B	9	0.59	4.17	1.06
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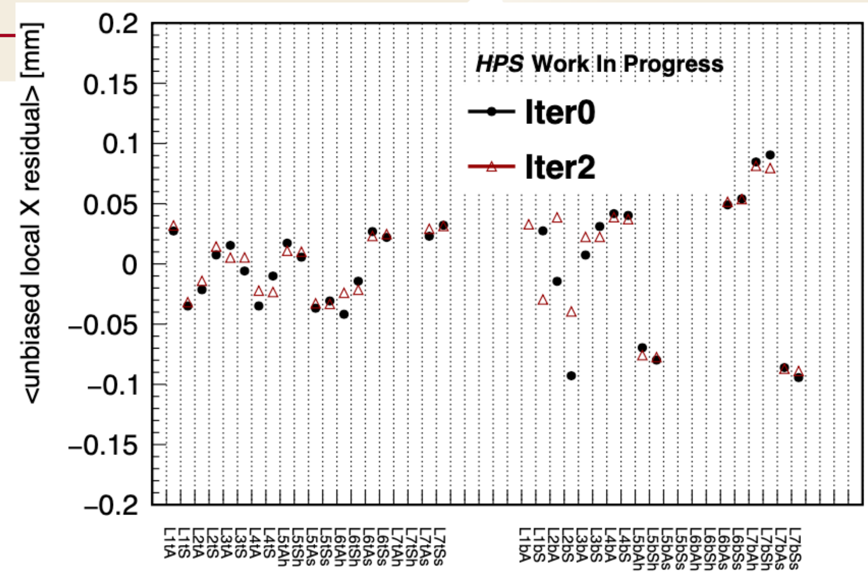
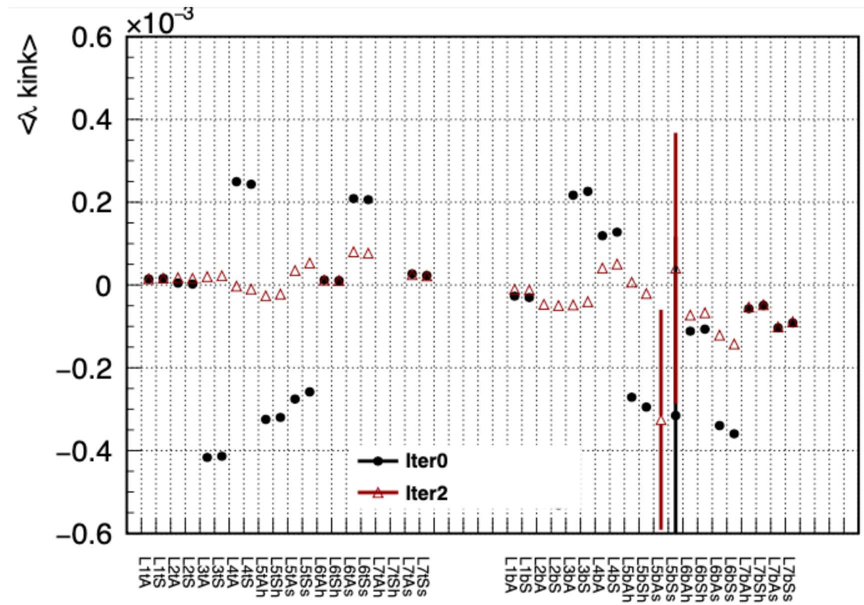
Alessandra's Talk in 2018

Starting point - Iter1 + Iter2

- First 2 iterations aligned Tu of the modules (axial+stereo) pairs
- I kept fixed L1A+S and L7A+S to provide the global Y scale of the volumes
  - For top L7S only
- Mostly fixes the lambda-kinks
  - To be checked again opening angle
- I used e+/e- pairs, no constraints, only chi2 alignment
- **Iter2 is another iteration of these DoFs (~um level corrections)**

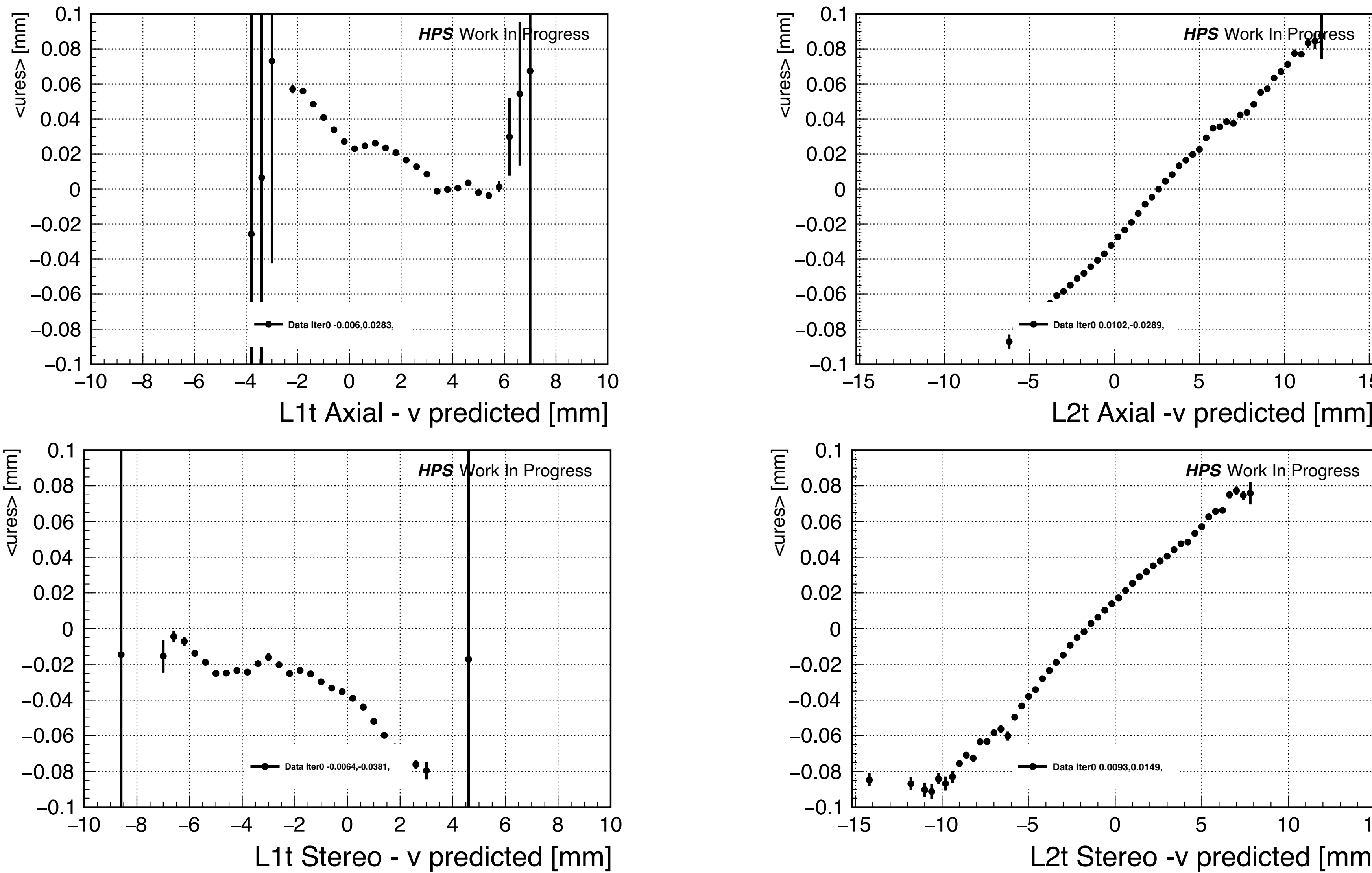




module_L2t_fullmodule	0.027033	+-	0.000067	11162
module_L3t_fullmodule	0.089035	+-	0.000155	11163
module_L4t_fullmodule	0.053068	+-	0.000211	11164
module_L5t_fullmodule	0.093002	+-	0.000258	11165
module_L6t_fullmodule	0.005489	+-	0.000254	11166
module_L2b_fullmodule	-0.077149	+-	0.000074	21162
module_L3b_fullmodule	-0.005823	+-	0.000168	21163
module_L4b_fullmodule	-0.021870	+-	0.000221	21164
module_L5b_fullmodule	-0.100210	+-	0.000255	21165
module_L6b_fullmodule	-0.065507	+-	0.000217	21166

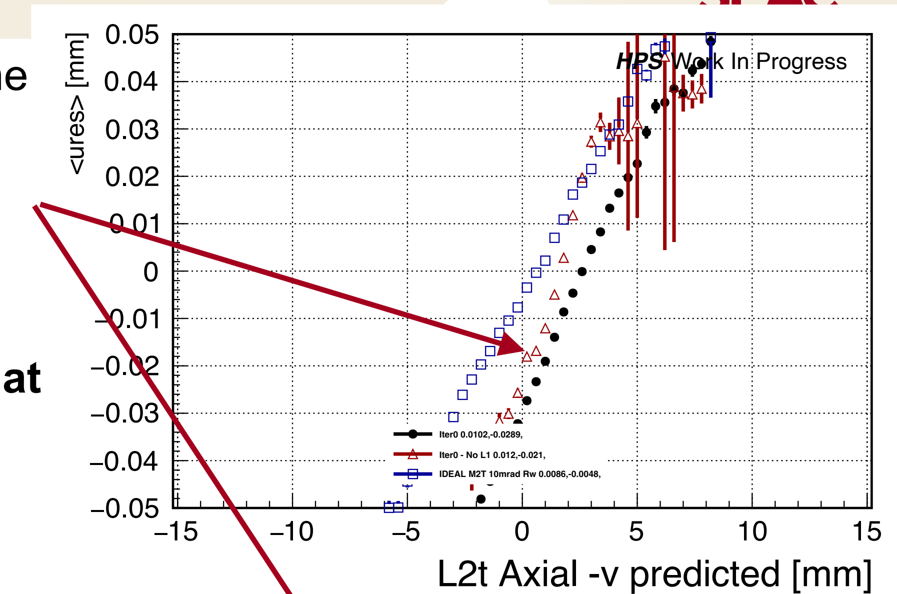
Study of the innermost sensors Rw

- Observed large rotation in L2Top sensor and somewhat different L1Top rotation - Why?



Study of the innermost sensors Rw

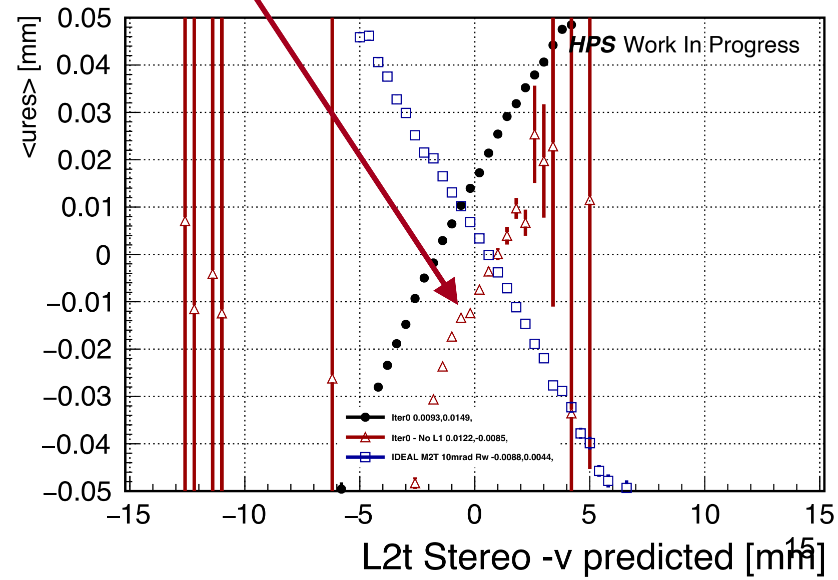
- The trends are present in similar form in both the tracks found with and without L1top
  - **Slope also present when L1 is removed**
- **It cannot be a full module Rw as previously suggested:**
  - **Opposite slopes for Stereo and Axial in that case**
  - Tested on ideal MC + 10mrad Rw of M2T module



2019 corrections. Stereo sensor ~ 8-10mrad rotation

```
<millepede_constant name="12301" value="0.0 - -0.002500 - -0.001700" />
<millepede_constant name="12302" value="0.0 - -0.004700 - -0.001600" />
<millepede_constant name="12303" value="0.0 - -0.008000 - -0.000200" />
<millepede_constant name="12304" value="0.0 - -0.008000 - -0.000900" />
```

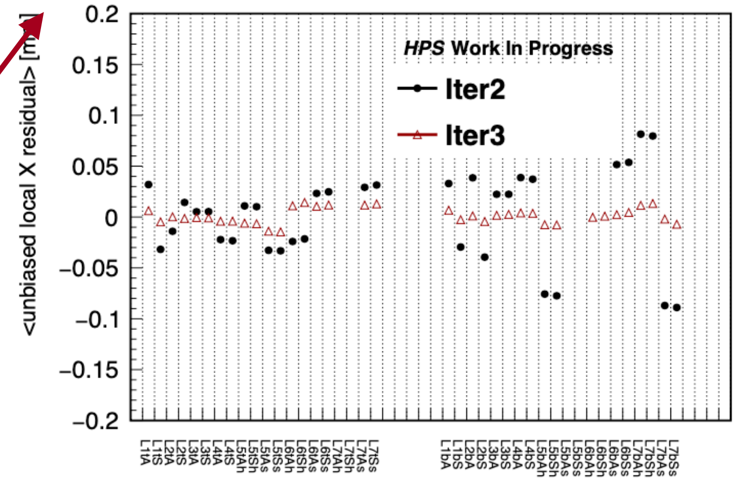
```
<millepede_constant name="22301" value="0.0 - -0.008033 - -0.001779" />
<millepede_constant name="22302" value="0.0 - 0.003447 - 0.001482" />
<millepede_constant name="22303" value="0.0 - -0.011274 - -0.001217" />
<millepede_constant name="22304" value="0.0 - 0.005886 - 0.001047" />
```

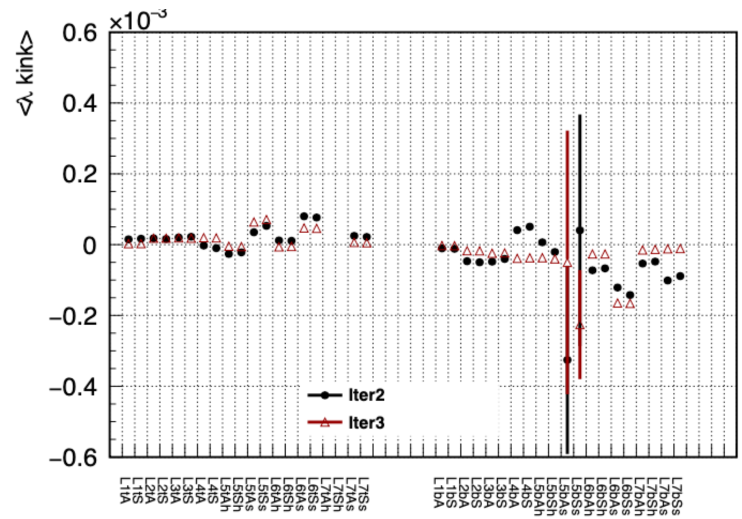


Iter3

- The beam-spot location at Iter2 is close to 0-0 in X-Y
- **Correcting the Rw of the stereo sensors doesn't move the beam-spot much in transverse plane but has large effect in Z**
- Keep L1 fixed and align tu of the Axial and Stereo for L2-3-4-5
  - Similar to 2016 pass
  - Could not align L6 at the same time because of weak mode
  - L5 Axial and Stereo is aligned at double-sensor level

(iterations: 3-4-5TB tu + 2TB tu





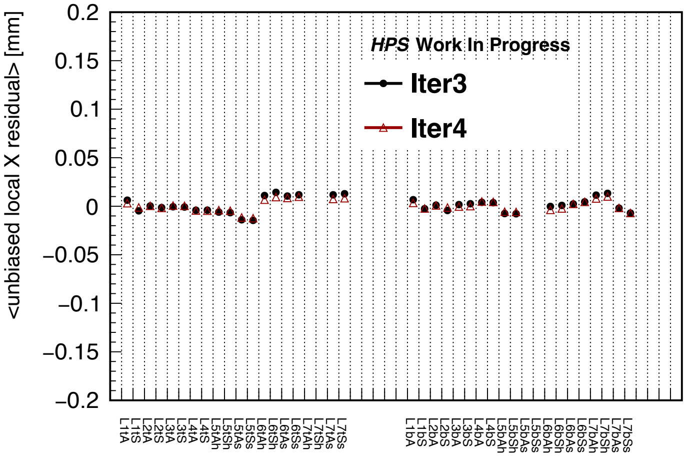
Iter3 Details

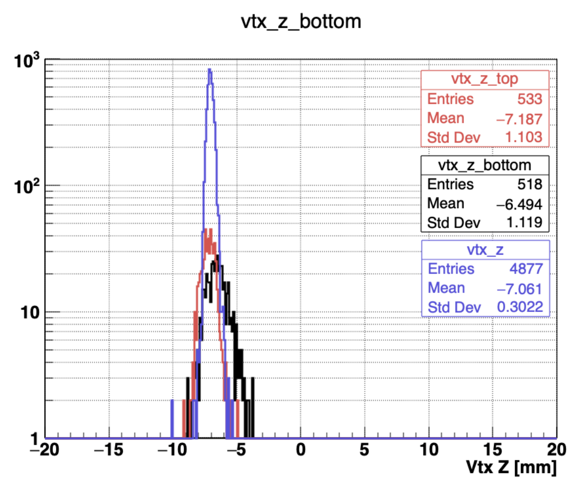
```
module_L2t_halfmodule_axial  -0.017278 +-   0.000064 11103  (change  -0.017278)
module_L2t_halfmodule_stereo   0.029812 +-   0.000070 11104  (change   0.029812)
 module_L3t_halfmodule_axial   0.000110 +-   0.000123 11105  (change   0.000110)
module_L3t_halfmodule_stereo  -0.027430 +-   0.000143 11106  (change  -0.027430)
 module_L4t_halfmodule_axial  -0.000882 +-   0.000150 11107  (change  -0.000882)
module_L4t_halfmodule_stereo  -0.041955 +-   0.000178 11108  (change  -0.041955)
   doublesensor_axial_L5_top   0.014500 +-   0.000123 11171  (change   0.014500)
  doublesensor_stereo_L5_top  -0.009749 +-   0.000129 11172  (change  -0.009749)
module_L2b_halfmodule_stereo  -0.012576 +-   0.000076 21103  (change  -0.012576)
 module_L2b_halfmodule_axial  -0.010649 +-   0.000072 21104  (change  -0.010649)
module_L3b_halfmodule_stereo   0.073986 +-   0.000146 21105  (change   0.073986)
 module_L3b_halfmodule_axial   0.027108 +-   0.000136 21106  (change   0.027108)
module_L4b_halfmodule_stereo   0.080968 +-   0.000180 21107  (change   0.080968)
 module_L4b_halfmodule_axial   0.041723 +-   0.000162 21108  (change   0.041723)
   doublesensor_axial_L5_bot  -0.011886 +-   0.000145 21171  (change  -0.011886)
  doublesensor_stereo_L5_bot  -0.015878 +-   0.000147 21172  (change  -0.015878)
```

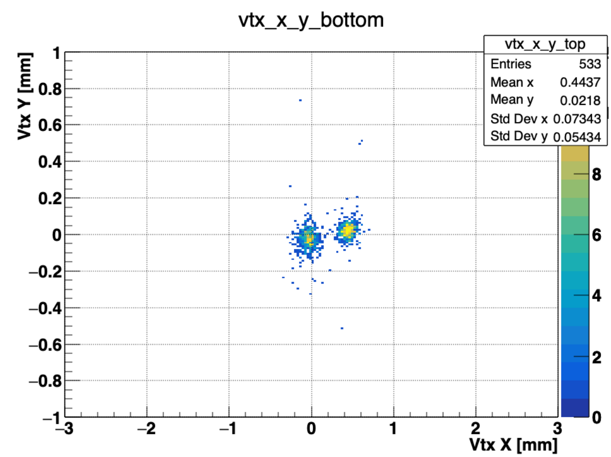
- Largest corrections are for Ly3 and Ly4 Stereo in bottom volume:
  - 74 and 81um respectively
- Majority of corrections are between 10-30um at this stage

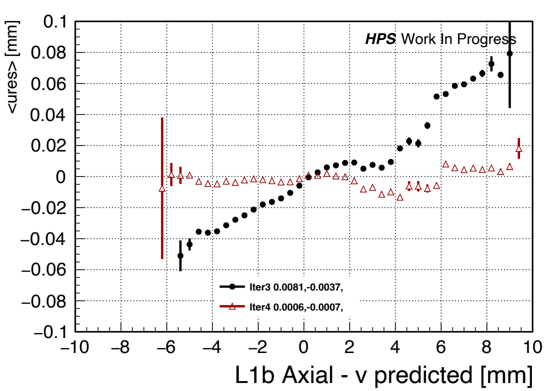
At this point correct for innermost sensors.

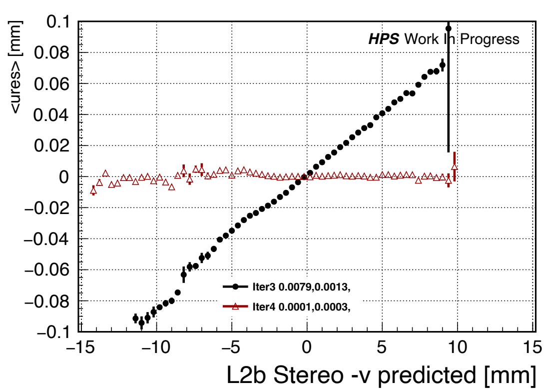
- Corrected L1-L2
  - Tu and Rw
- Kept the rest of the detector fixed

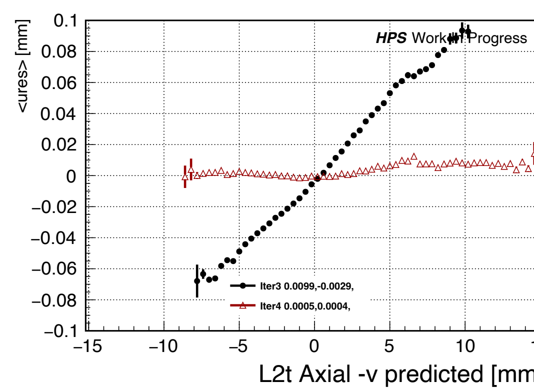












Iter4 corrections - Details

```
module_L1t_halfmodule_axial     0.003546 +-   0.000144 11101
module_L1t_halfmodule_stereo   -0.015911 +-   0.000142 11102
module_L2t_halfmodule_axial    -0.016434 +-   0.000092 11103
module_L2t_halfmodule_stereo    0.008687 +-   0.000093 11104
module_L1t_halfmodule_axial     0.006074 +-   0.000085 12301
module_L1t_halfmodule_stereo    0.008630 +-   0.000074 12302
module_L2t_halfmodule_axial     0.008560 +-   0.000025 12303
module_L2t_halfmodule_stereo    0.009370 +-   0.000024 12304
module_L1b_halfmodule_stereo    0.072912 +-   0.000157 21101
module_L1b_halfmodule_axial    -0.037993 +-   0.000152 21102
module_L2b_halfmodule_stereo    0.056571 +-   0.000106 21103
module_L2b_halfmodule_axial    -0.049155 +-   0.000102 21104
module_L1b_halfmodule_stereo    0.007146 +-   0.000076 22301
module_L1b_halfmodule_axial     0.001001 +-   0.000065 22302
module_L2b_halfmodule_stereo    0.011262 +-   0.000028 22303
module_L2b_halfmodule_axial    -0.004122 +-   0.000025 22304
```

- Rotations (in bold) of the stereo sensors are of the order of 10mrad
  - In agreement with what extracted from MC studies.
- Translations are maximum 55um (for L2b Stereo)
  - Notice how L2b stereo moves together with axial: it is actually 50um movement of a full module in Y

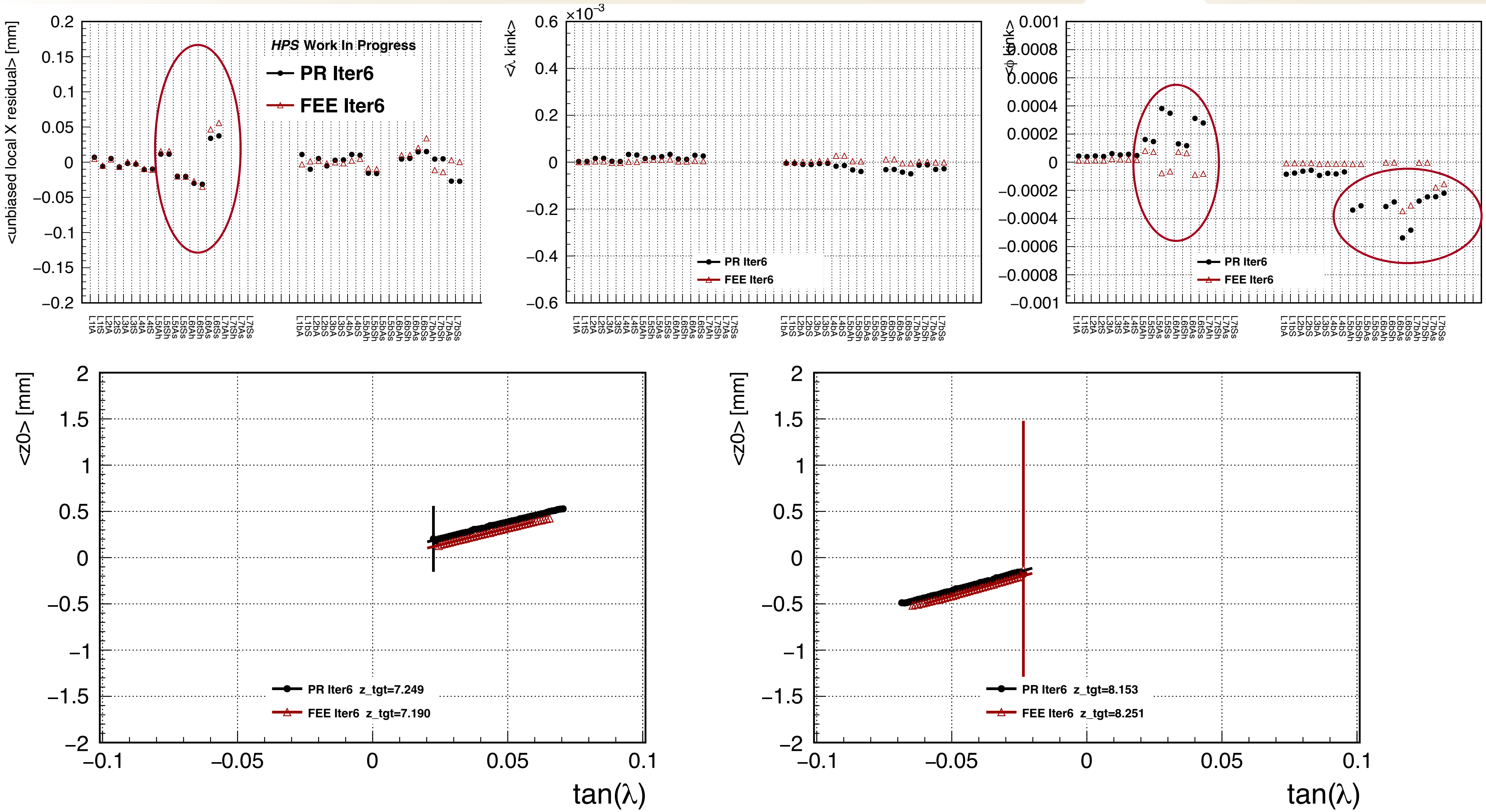
Final iterations and Summary

- At this point, 2 more iterations are performed to finish aligning the detector in Tu and Rw
  - Iter5 is an iteration of the back of the detector as double sensors:
    L5-L6-L7 Top Double sensors Tu + Rw
  - Iter6 is an iteration aimed to align most of the left over alignment DoF
    L3-L4 AS L5AS-HS L6AS-HS Tu+Rw

	Free	DoF	Comment
Iter1	M2-M3-M4-M5-M6	Tu	Full modules
Iter2	M2-M3-M4-M5-M6	Tu	Full modules
Iter3	L2AS-L3AS-L4AS-D5AS	Tu	Front sensors and L5 double sensors
Iter4	L1AS-L2AS	Tu+Rw	Innermost sensors
Iter5	D5AS-D6AS-D7AS	Tu+Rw	Back as double sensors
Iter6	L3-L4-L5-L6	Tu+Rw	Front (L3-L4) and back as single sensors

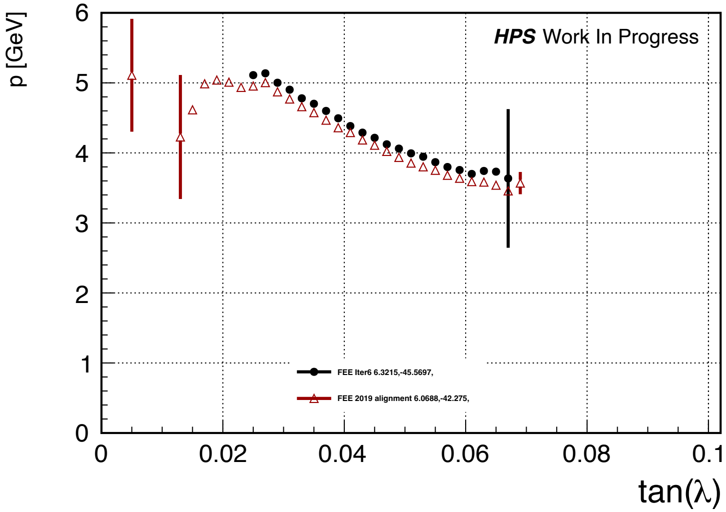
Brief performance snapshot (more from Norman)

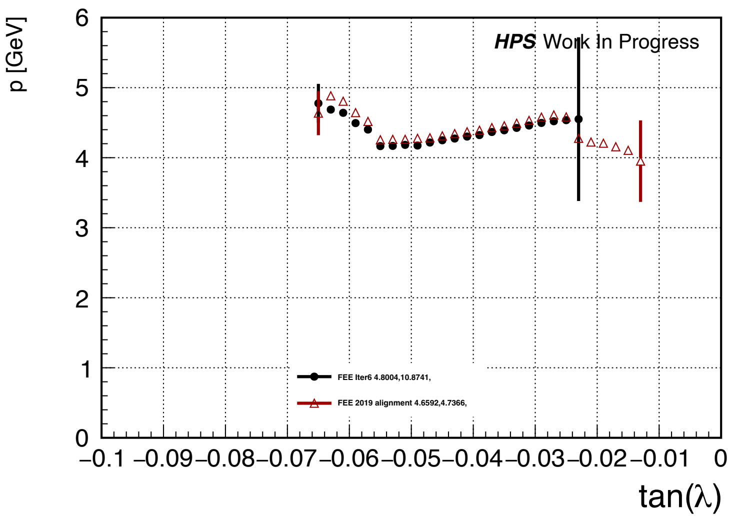
SLAC



- Some work should be done still for the back of the detector. However last corrections with just Chi2 minimization are small (um level)

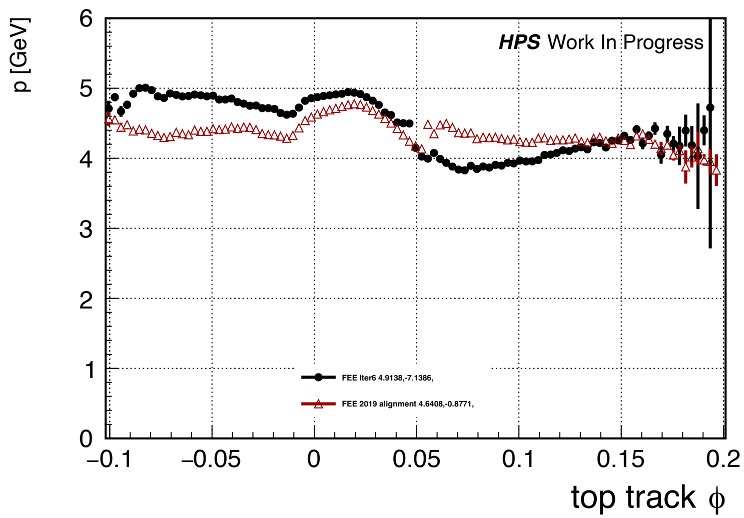
Brief performance snapshot (more from Norman)

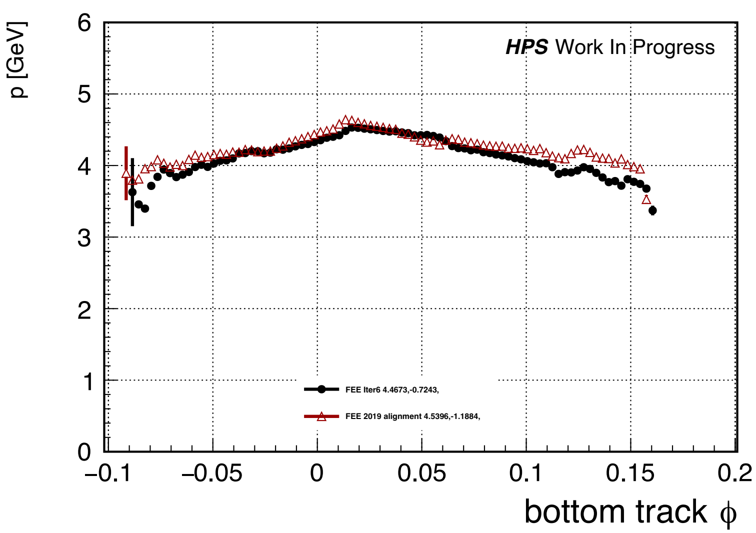




- A different alignment procedure with e+e- tracks, no external constraints and no global structure alignment produce momentum shapes as function of tanLambda very similar between the two runs
- In the bottom the step <-0.06 is due to the transition from having hit in ly7 or not
- **Any of these procedures doesn't cure the tanL dependence**

Brief performance snapshot (more from Norman)





- The track dependence wrt phi is similar in bottom volume, slightly worse in top
- That can be corrected using constraints (as shown in the Red points showing the 2019 alignment in the current hps-java version)
- **Correcting the phi dependence doesn't have a sizable impact on p vs tanL**

Work ongoing on alignment

- My ongoing goal is to understand what misalignments can affect
  - Momentum distributions: I do not see a clear path using tu-rw to correct for the momentum distributions in 2019.
  - Discrepancy between z0_tanL and 3D-Vertexing in bottom volume
  - Discrepancy between top and bottom volume vertex location in Z

Work ongoing on alignment

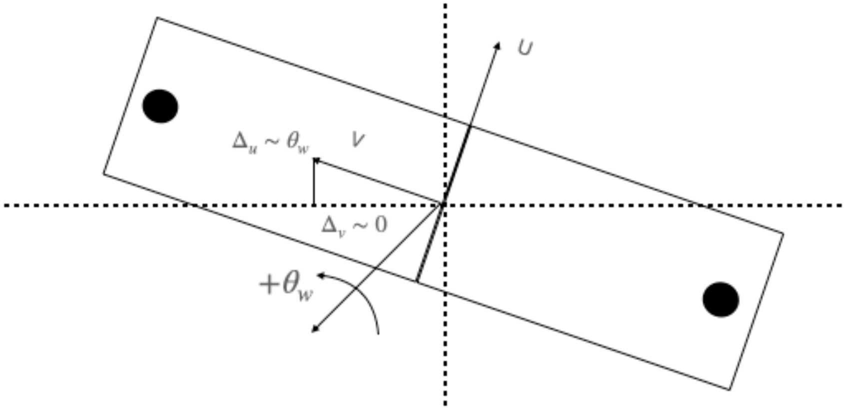
SLAC

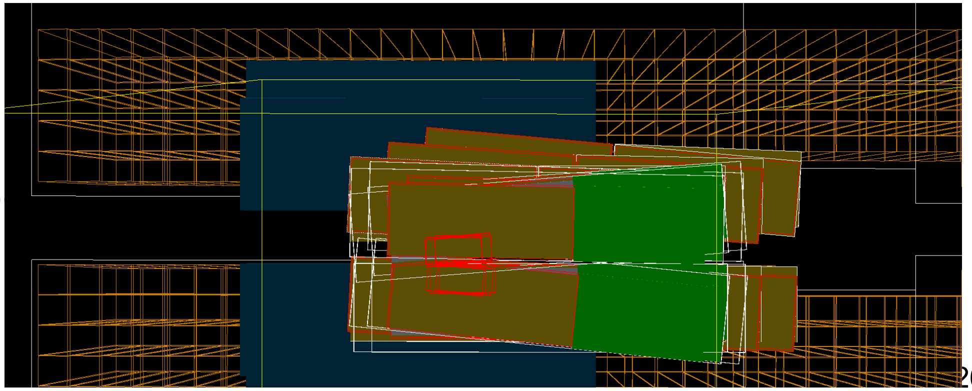
- My ongoing goal is to understand what misalignments can affect
  - Momentum distributions: I do not see a clear path using tu-rw to correct for the momentum distributions in 2019.
  - Discrepancy between z0_tanL and 3D-Vertexing in bottom volume
  - Discrepancy between top and bottom volume vertex location in Z

- **Studied some collective movements (Twists)**
- **And out of plane distortions** (telescope elongations, see Sarah's talk)
- Possible bowing, studied with residuals as function of u-v position on the sensor

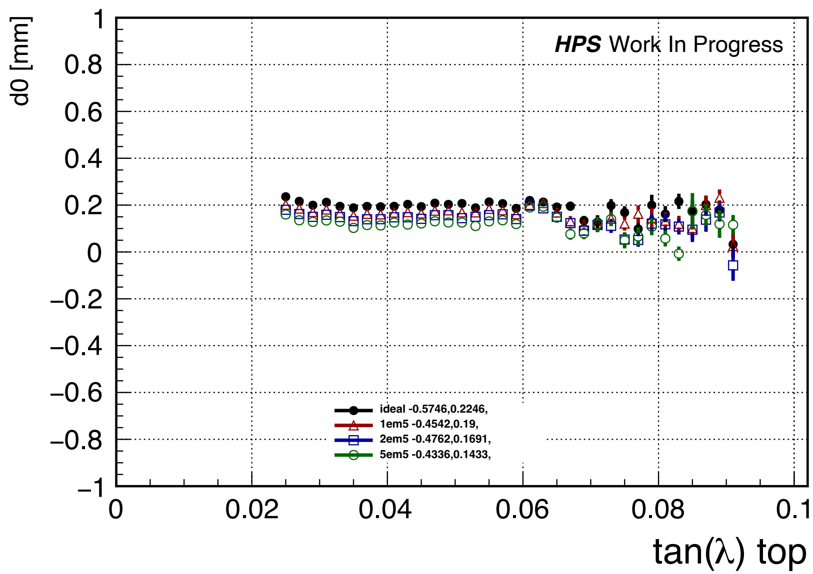
Detector Twist

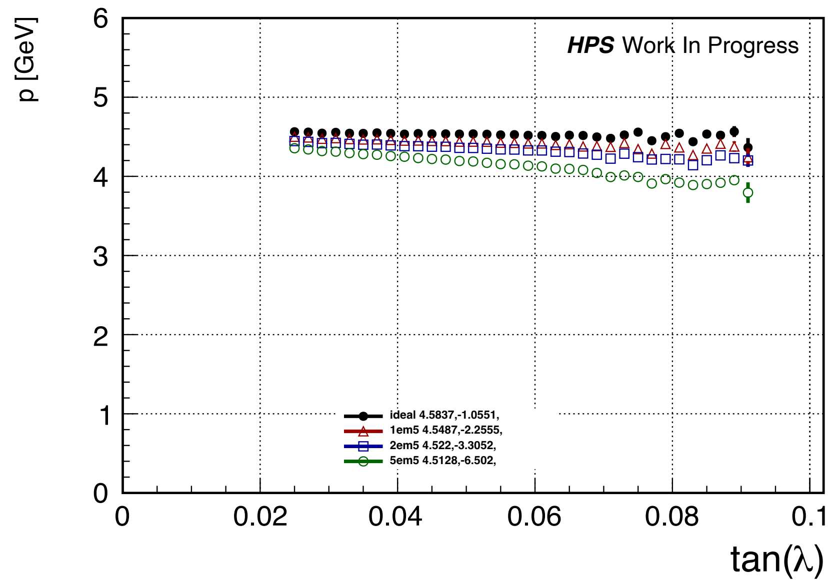
- A detector twist, i.e. rotation of the detector with an angle that is proportional to the Z location of the modules, might cause a momentum that depends on the dip angle
- **Implemented as rotation of modules with respect to the beam axis**
  - This development is also useful to insert rolls of the detector with respect to the beam axis to correct Norman's observation in Moeller events





Effects

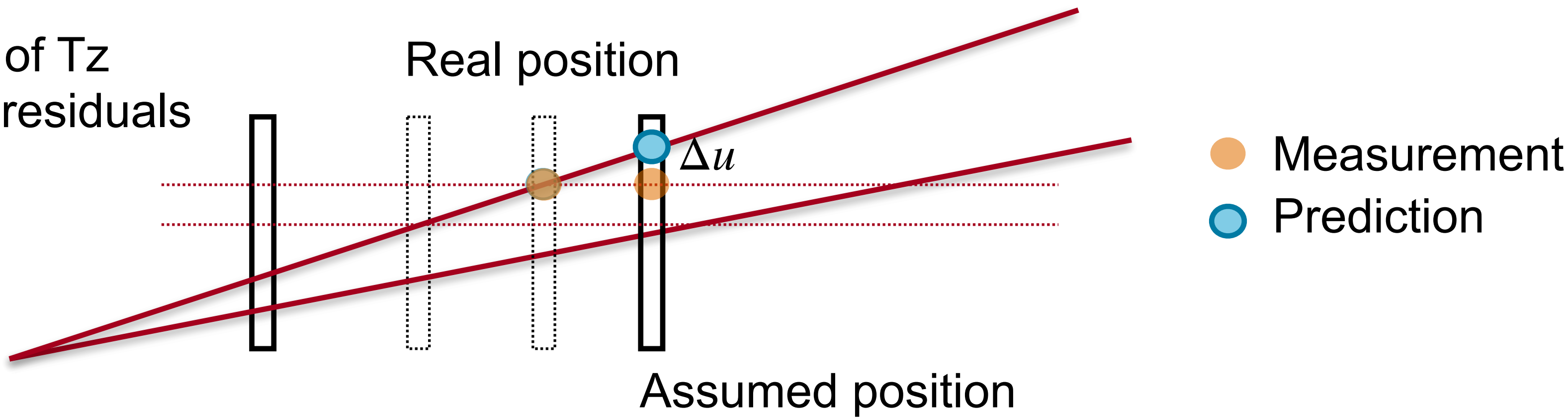




- Required twist for appreciable p vs tanL in FEEs: 5e-5
- This means O(30mrad) Rw and O(mm) of Tu of the back layers
  - Considered too large
- Also tested effect on only Stereo sensors with not appreciable change
  - I do not think that a twist (alone) can account for this effect

Out of plane distortions

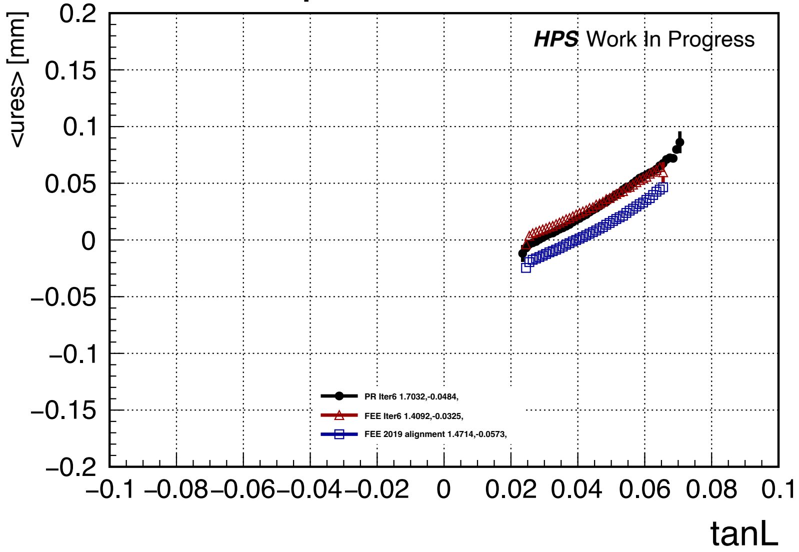
Example of Tz effect on residuals

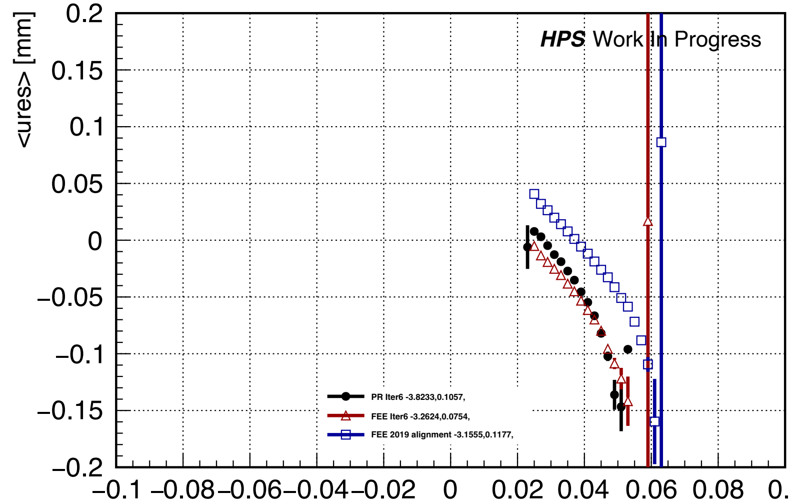


- Out of plane distortions can give res-u vs u linear shapes
- If one plots the residuals vs tanLambda, then $\Delta_u = \tan\lambda \cdot T_z$, so the slope of that shape is the inferred Tz correction to be applied
- Additionally, if we assume that there is no Tz of the modules, then we can interpret those shapes under a global $\tan\lambda$ correction
- These effect are present in 2019 dataset, largely independent between PR and FEE runs, not dependent on the alignment procedure so far
- **The inferred corrections are of the order of 1-2mm in Tz: expected to be too large**

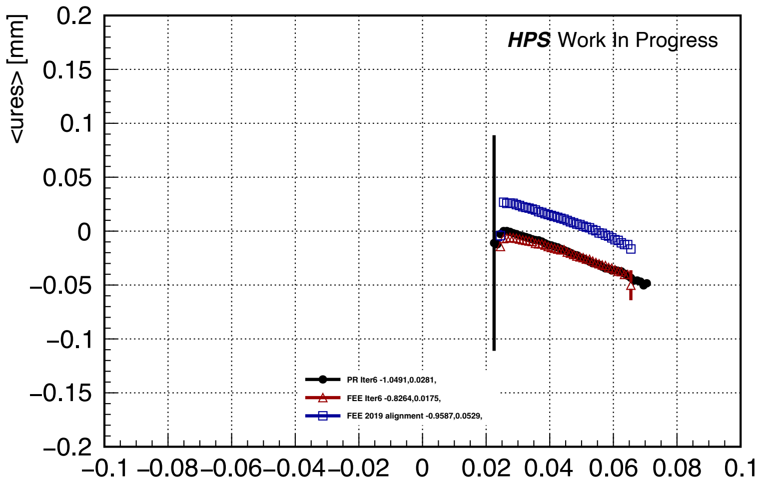
Out of plane distortions - PR/FEE Iter6 and FEE 2019

L5 Top Stereo Hole

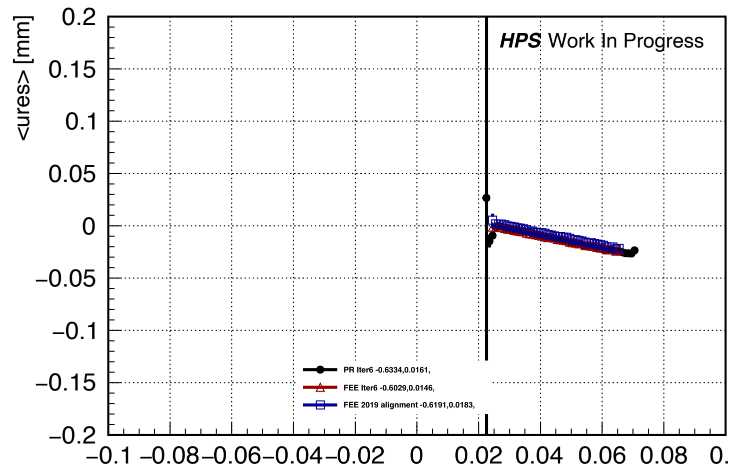




L6t Stereo hole - tanL



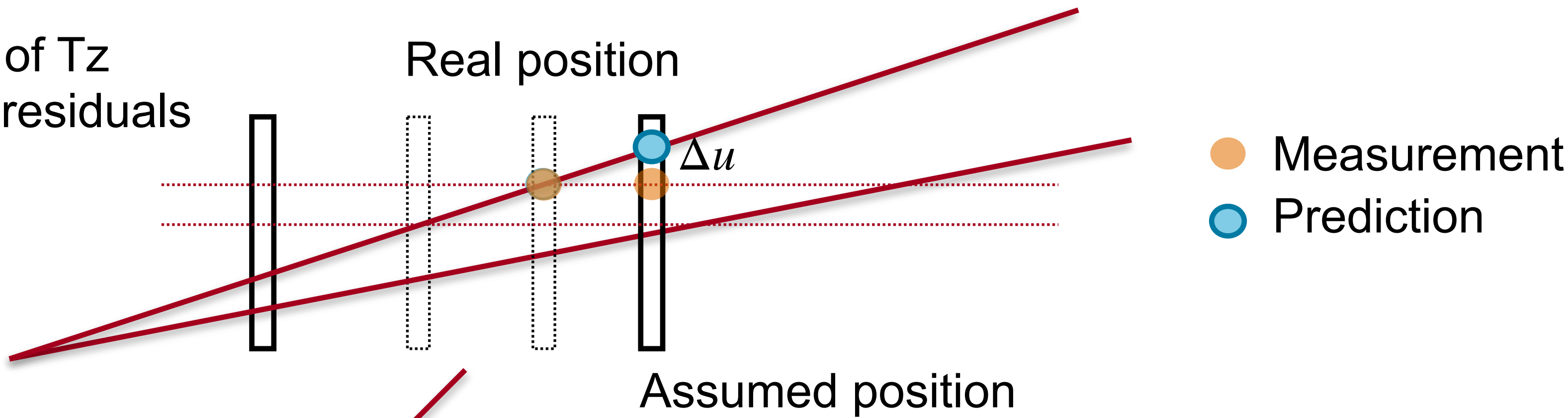
L4t Stereo - tanL

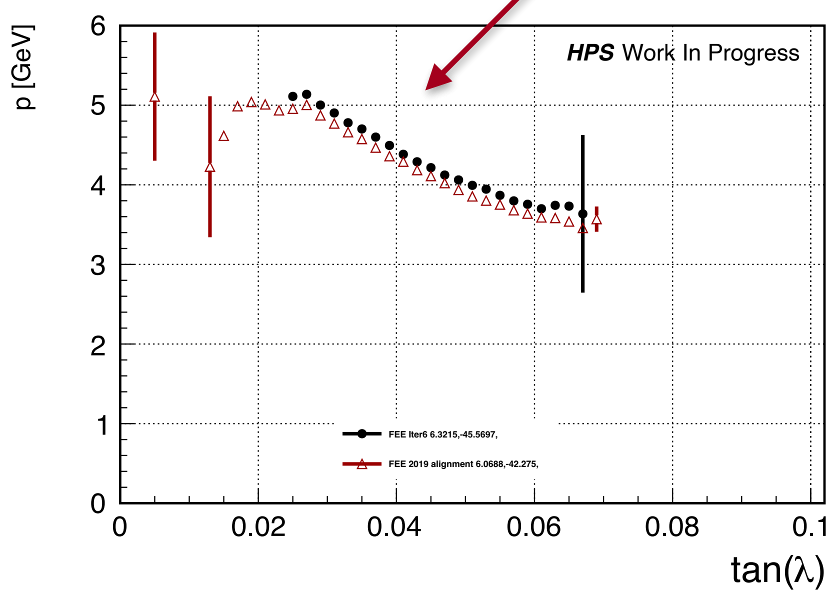


L2t Stereo - tanL

Out of plane distortions - PR/FEE Iter6 and FEE 2019

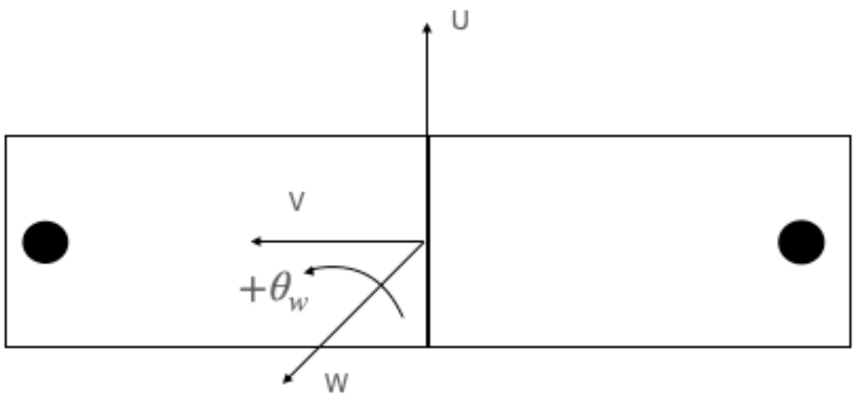
Example of Tz effect on residuals



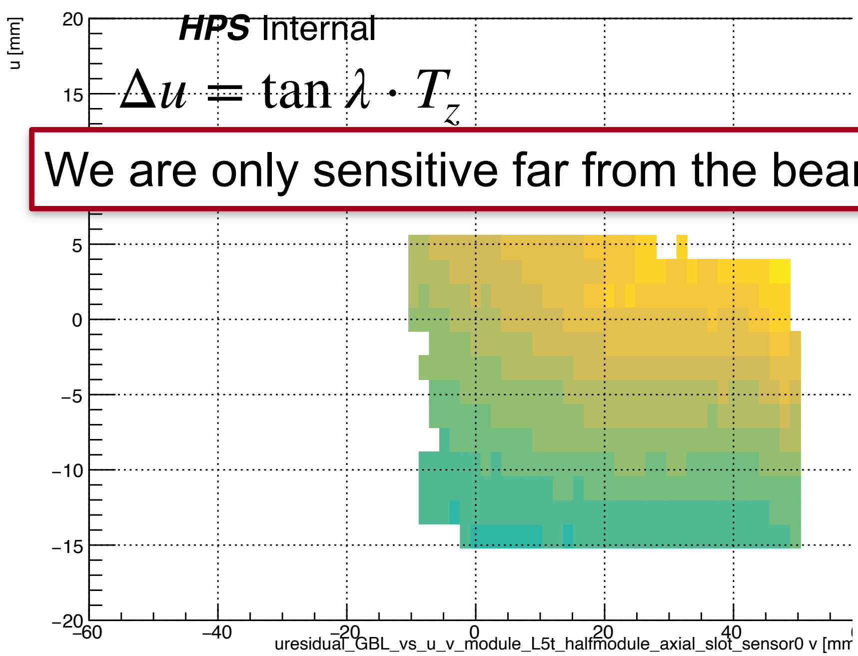


- If stereo u fit position depend on tanLambda, there is a bias in global-X of the hit depends on tanL in the track fit
- If this happens in the back of the detector there is a bias in curvature as function of tanL=> momentum that depends on tanLambda

Out of plane distortions: looking as maps

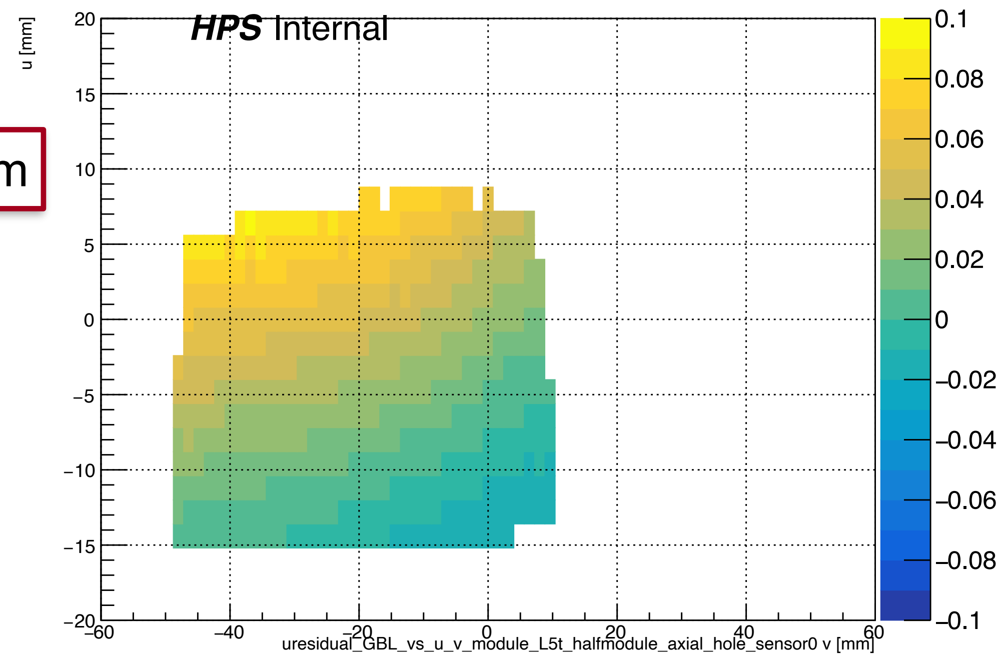


- Computed the residuals in bins of u-v using e+/e- tracks
- Arranged the shape as a double sensor
- We can see a “bulge” in the center of the sensor and less distortion on the side of the sensors
- **Possible bowing of the double sensors: 1-2mm could be possible.**



$$\Delta u = \tan\lambda \cdot T_z$$

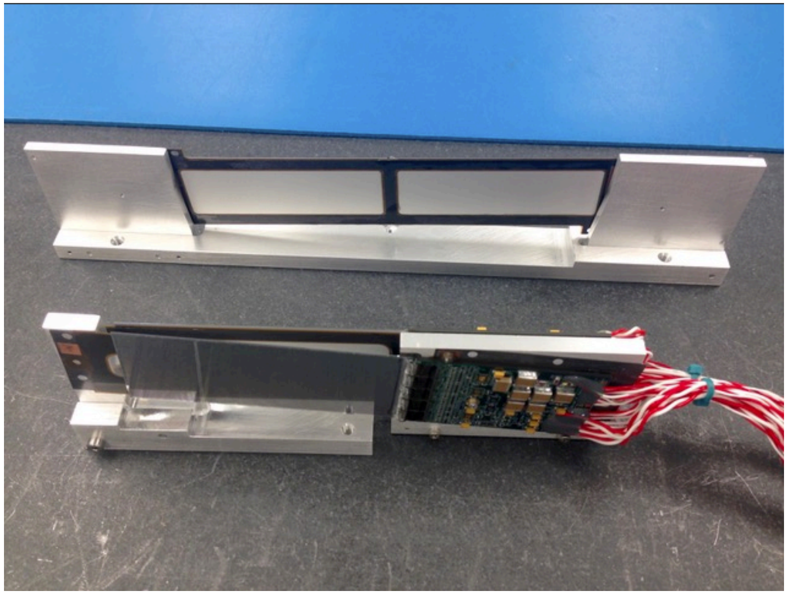
We are only sensitive far from the beam

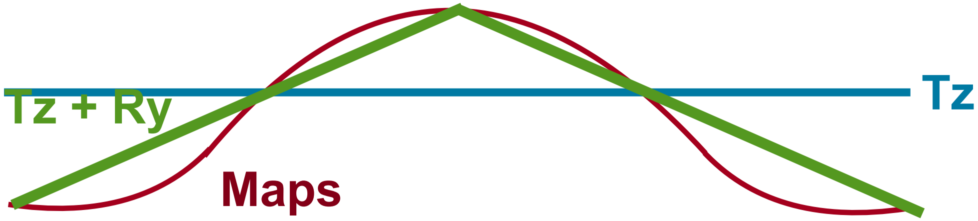


Out of plane distortions: looking as maps

- It could be a bulge of the sensor in the central region
- The sides would be at Tz=0 due to the fixation at the hybrids
- 1mm plausible over a 200mm double sensor
- This can affect modules in different way
- It can be time dependent:
  - No effect in 2016 as “fresh” modules but can affect 2019/2021 after years of operation
  - Modules are swapped, they can affect 2019-2021 differently
- First ideas:

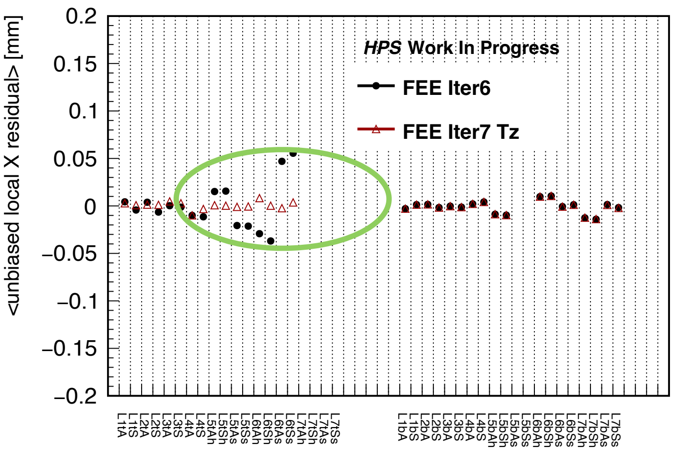
  - **O(0) correction, simple Tz**
  - **O(1) correction, Ry + Tz**
  - **O(2) correction, apply Δu from residual maps as function of u/v**

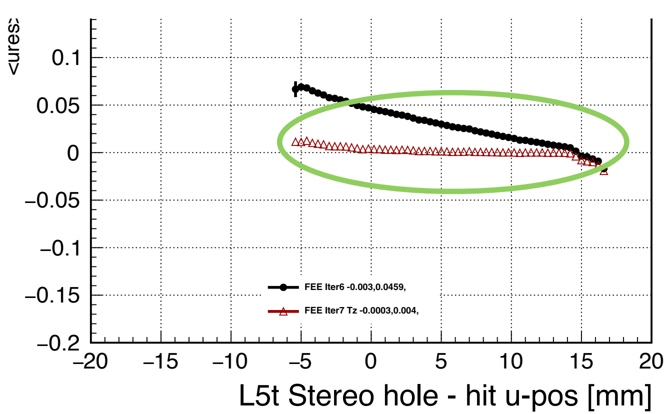


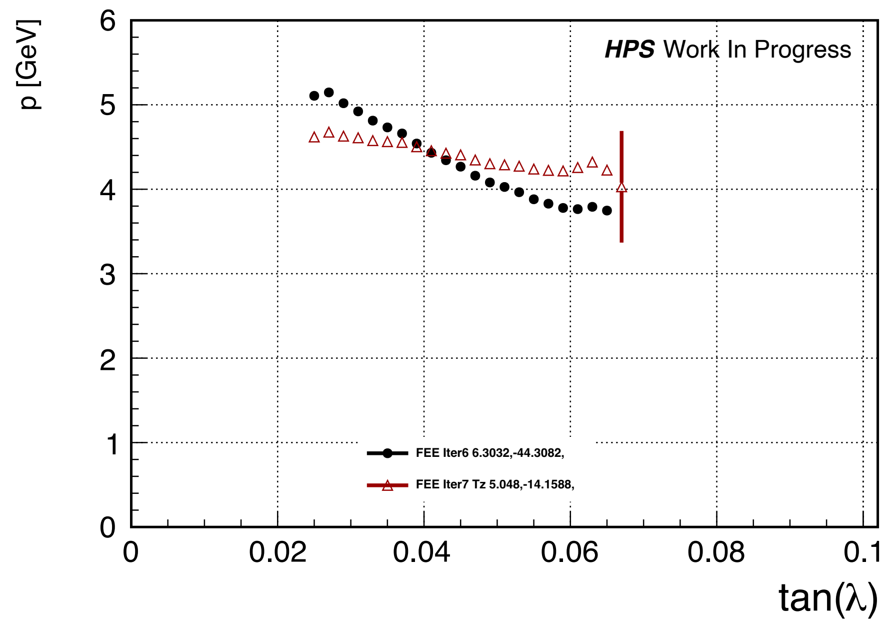


Iter7 - Correcting Tzs

- The only correction I found that fixes p vs tanL and the residuals vs tanL is allowing Tz to be aligned
- While before the corrections were considered too large, with a bowing hypothesis we could think about a Tz+Ry and have a first order correction.
- At second order we can apply the corrections extracted from the residual maps







Summary and conclusions

- Re-derived corrections for 2019 detector using a 2016-like procedure
  - Simpler, more compact and gives similar performance results
    - Norman will give a better overview
- Reported *in full* the steps and corrections applied to avoid future confusion
  - It's not fully completed as there are still some corrections that can be done with external constraints
- Concentrating on momentum biases on the top volume
  - I am able to interpret the biases as out-of-plane distortions of some form
  - Tried to interpret as correlated distortions without success
    - Machinery still useful for global corrections given observations in Moellers by Norman.
- A bowing of the back sensors could explain the magnitude of the necessary corrections as well as time-dependence, "random placing" due to module swapping and different performances
- At first order could be corrected with an Ry + Tz at the hybrid location, (if the bulge is not too steep in the center)

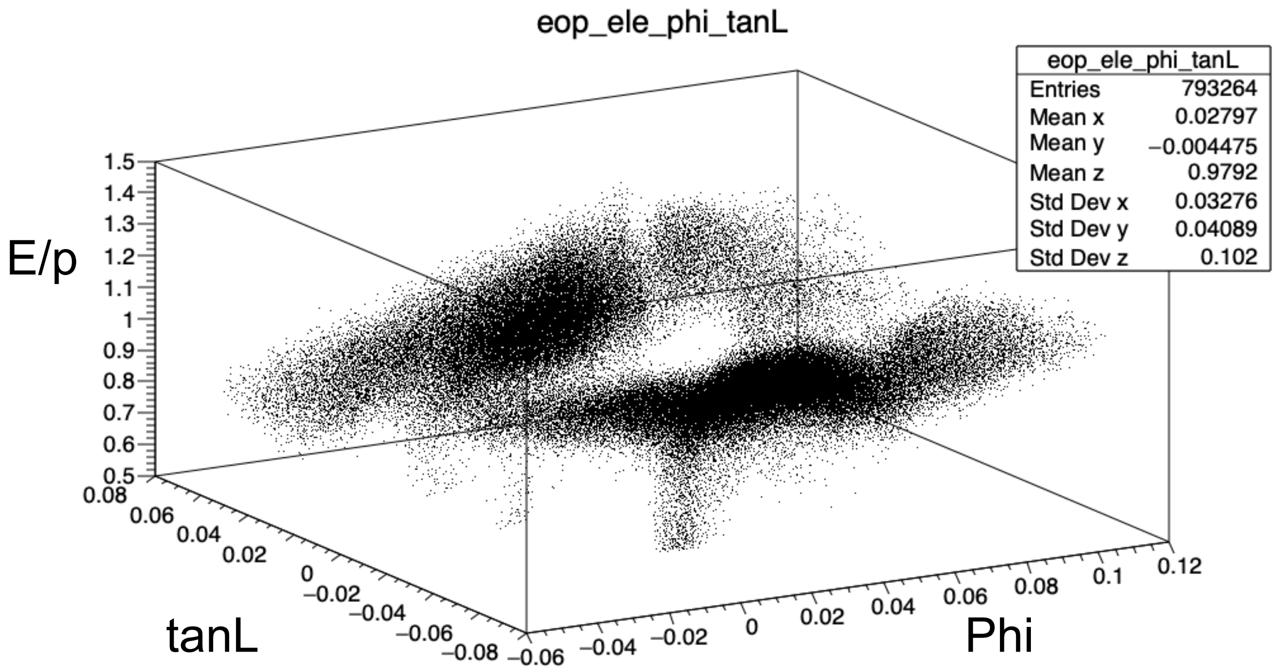
New tool: rootjna

- I wrote a new tool, rootjna https://github.com/pbutti/rootjna
- This tool contains the C wrappers to call via java JNA basic root functionalities
  - Open / Close TFiles
  - Fill, store, retrieve and get content of TH1D, TH2D, TH3D
- The tool can be written better, I only care about the functionality.
  - Happy if a student is willing to improve it.
- I wrote the java classes in the gbl package

- This is not a sw proposal, I'm just saying what I did

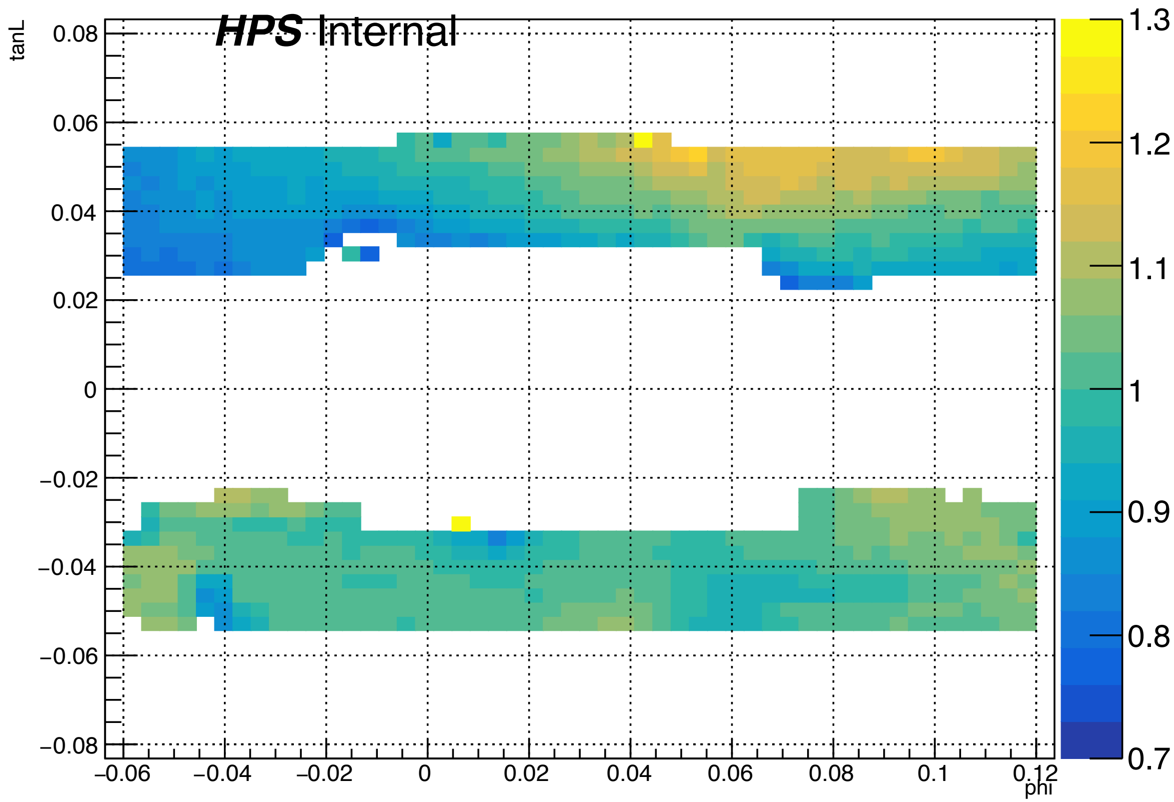
Status

- Started from the detector HPS_TimDesign_iter4
  - Extensive detail of the detector + corrections can be found in the talk at the SLAC Meeting on the 22Nov2022.
  - The slides are attached here in backup as well.
- Used 10104 FEEs
- New driver [RootMapsDriver.java]() to only produce these maps on top of FinalStateParticles



Status

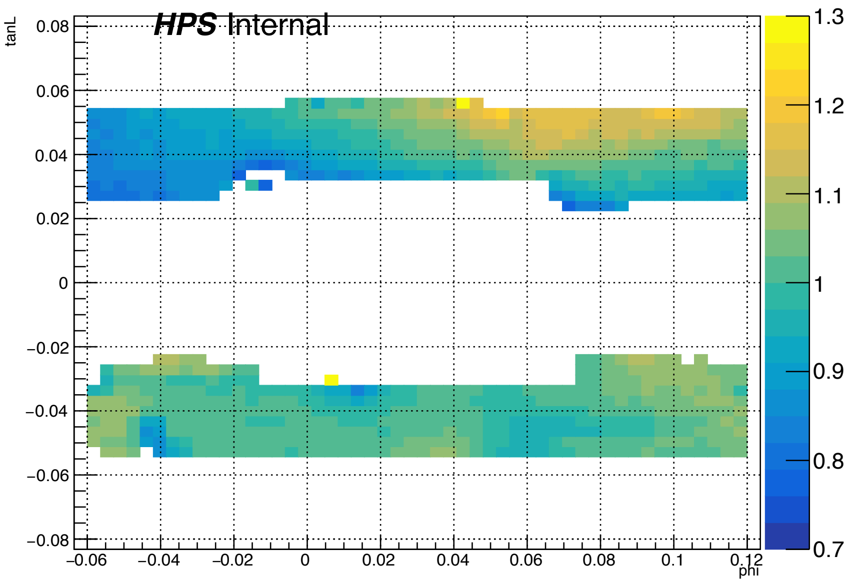
- Maps are fit with a CrystalBall in each bin
  - An iterative gauss fit in +/-2 sigma from mu gives very similar results
- Interesting diagonal trend in the top volume in E/p



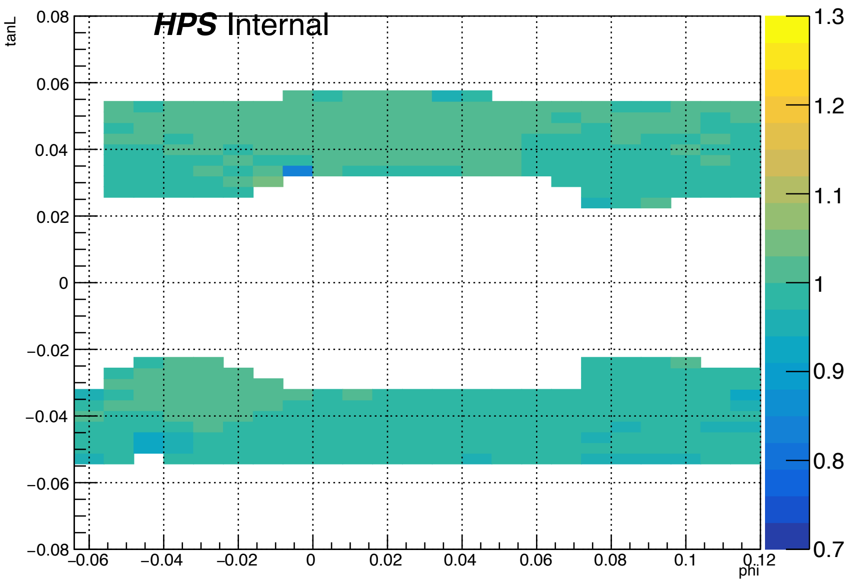
Refit tracks with E/p maps constraints

- Closure test on the machinery is done by loading the map in hps-java
- Refitting the track using the constraint from previous iteration map
- This method should work fine to constrain tracks for electrons and positrons
- It’s important to have the correct Energy of the calorimeter

Original

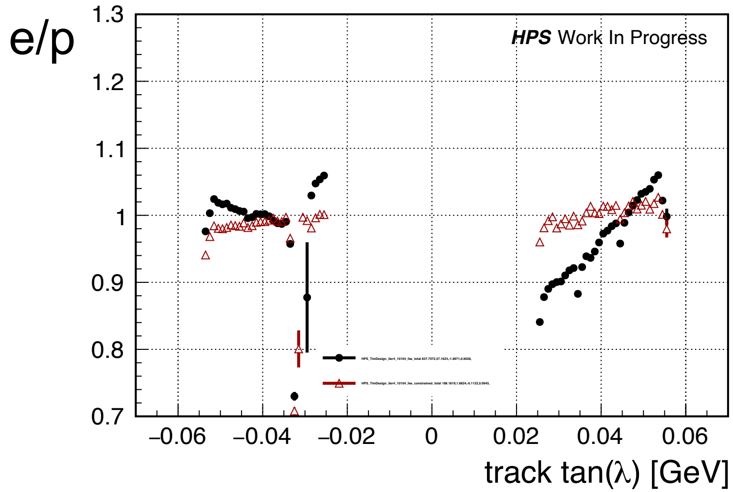


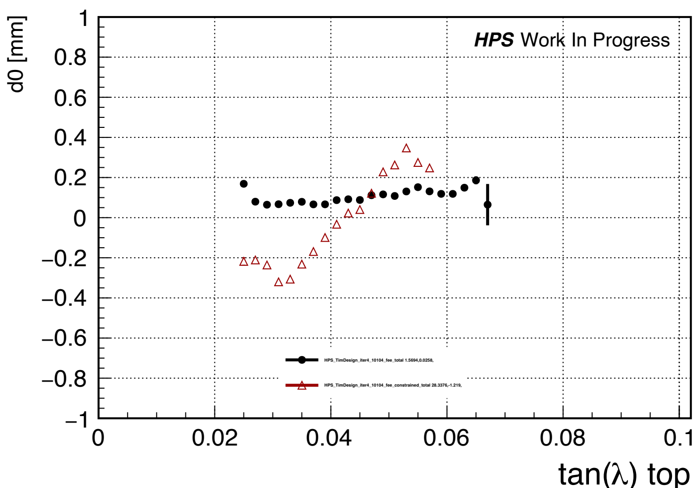
Refit with constraint

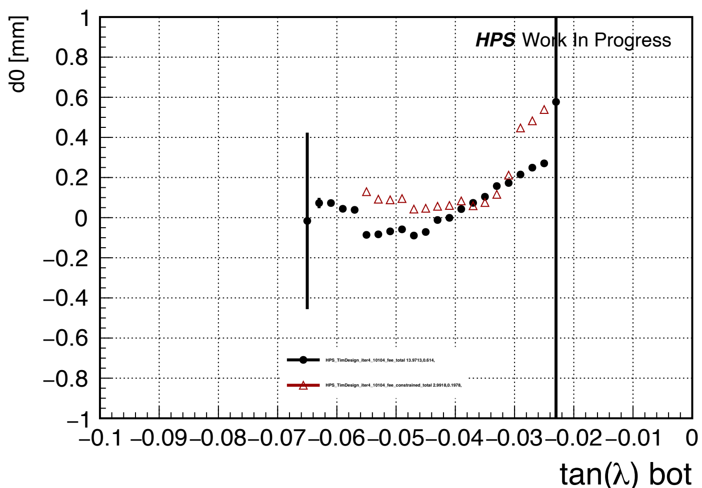


Effects on other track parameters

- Track parameters are correlated. Especially bending plane
- Top d0 distribution flat vs tanL (expected) before constrain
  - Trend in tanL is "passed" to impact parameter

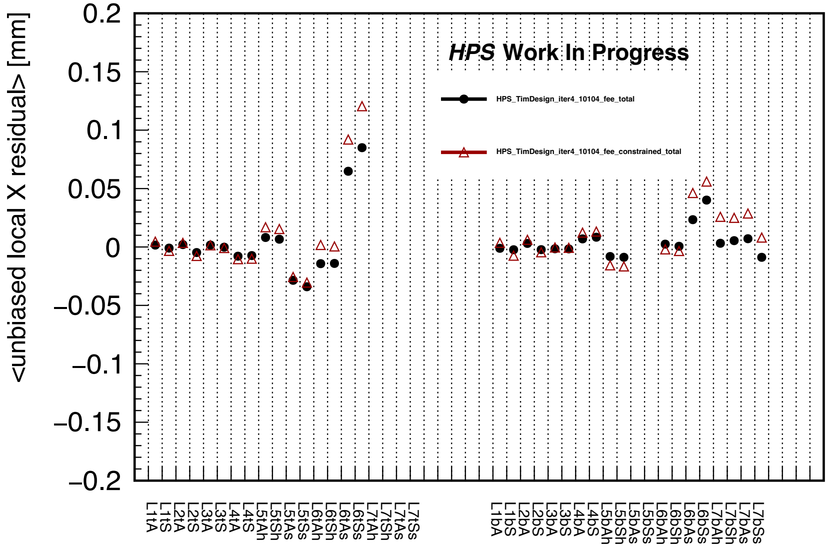


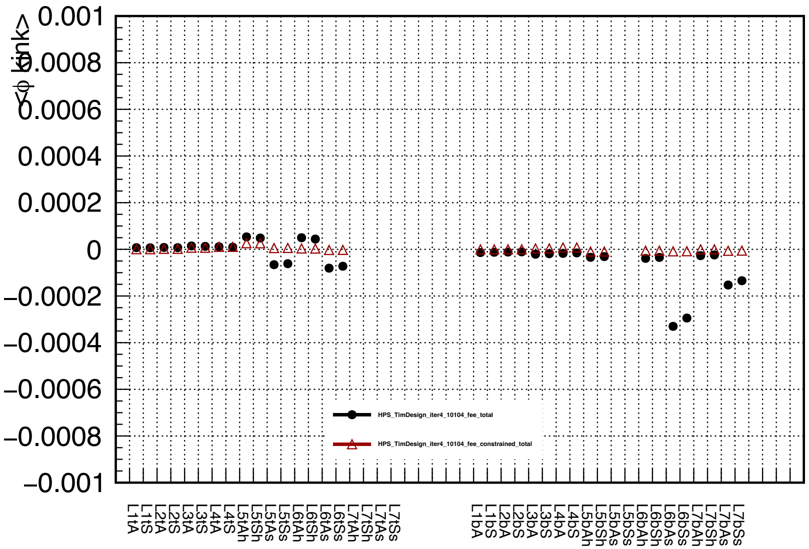


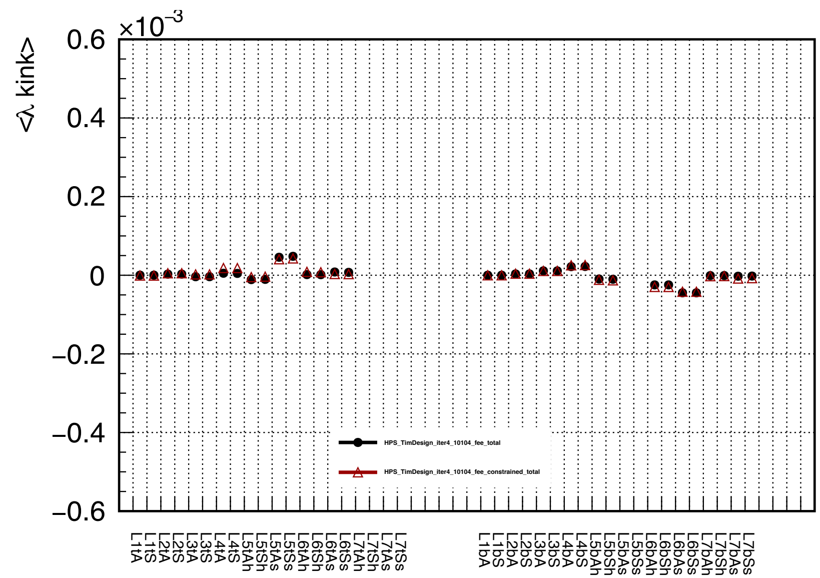


Residuals

- We can also monitor the unbiased residuals on the refitted tracks as well as the kinks



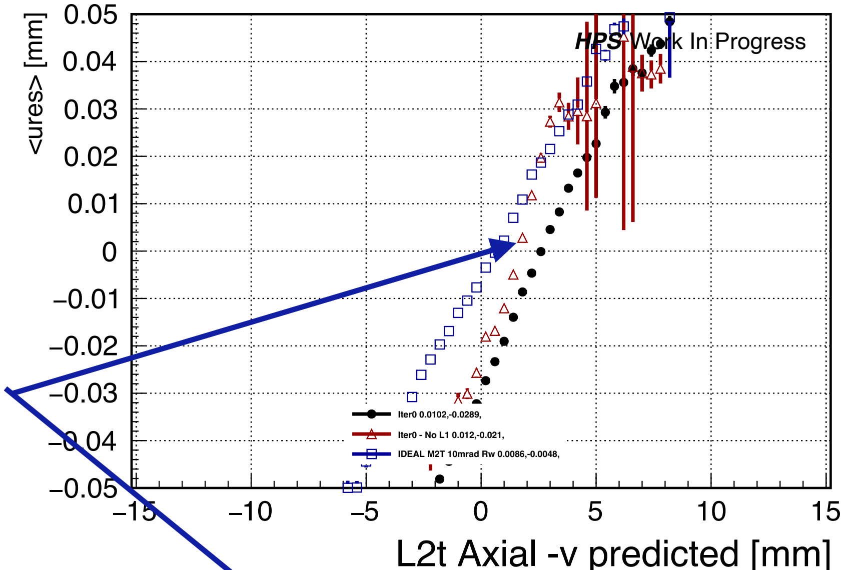


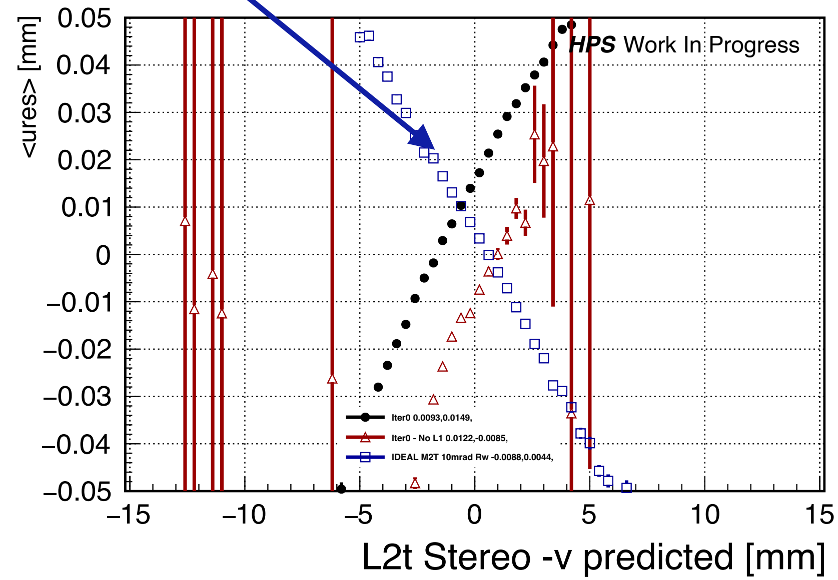


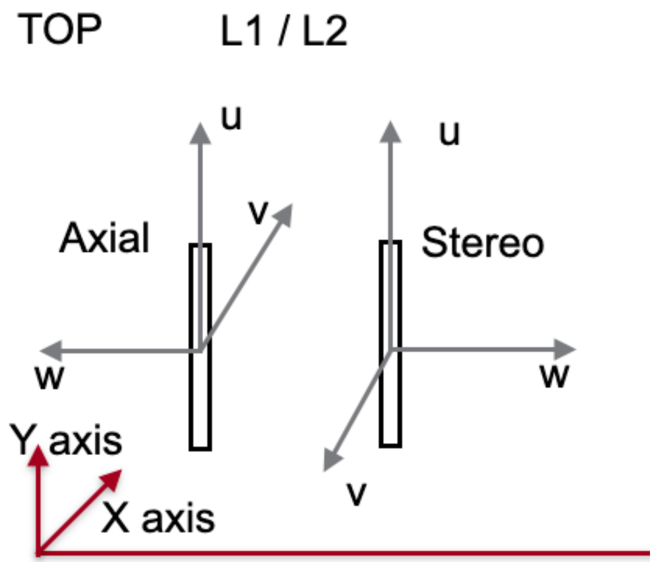
BACKUP

Study of the innermost sensors Rw

- The trends are present in similar form in both the tracks found with and without L1top
  - **Slope also present when L1 is removed**
- **It cannot be a full module Rw as previously suggested:**
  - **Opposite slopes for Stereo and Axial in that case**
  - **Tested on ideal MC + 10mrad Rw of M2T module**

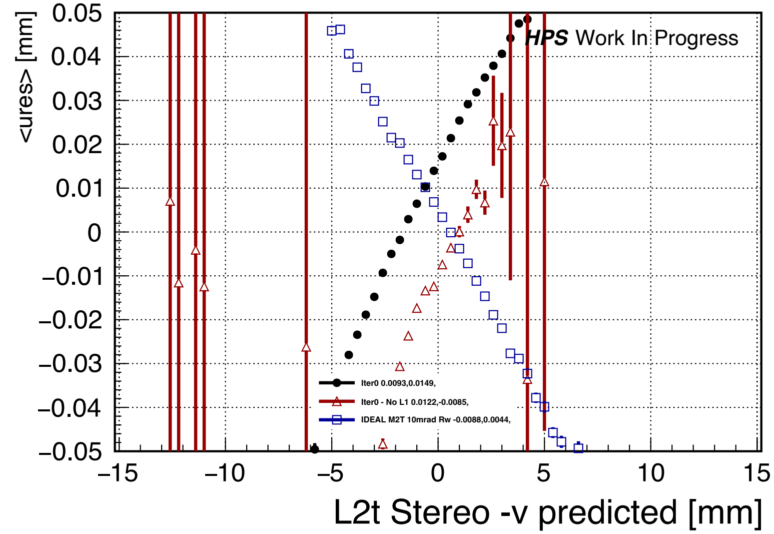


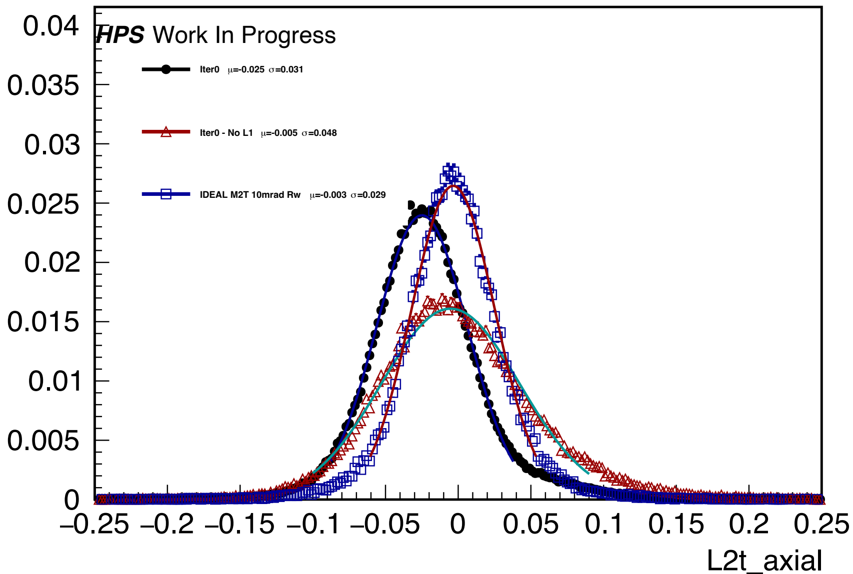


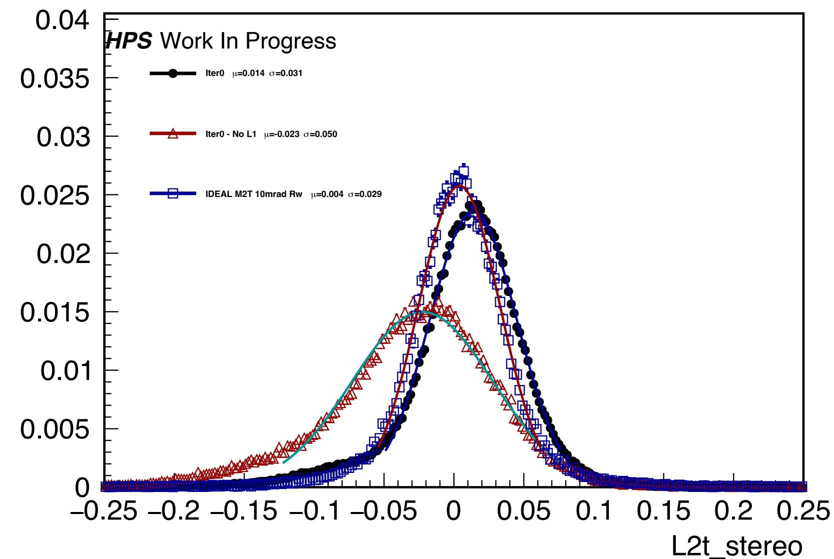


Study of the innermost sensors Rw

- The module rotation misalignment has been applied to the module defined as center of mass of the axial-stereo pair
- Notice how the mean of the unbiased residuals are only very mildly affected (*) - expected
  - In the plot below, **blue** is the misaligned MC with only **~3um displacement of the mean**
  - **(*)** A small displacement is due to the fact that the Module center of mass is not in the pivot of the single sensor rotations

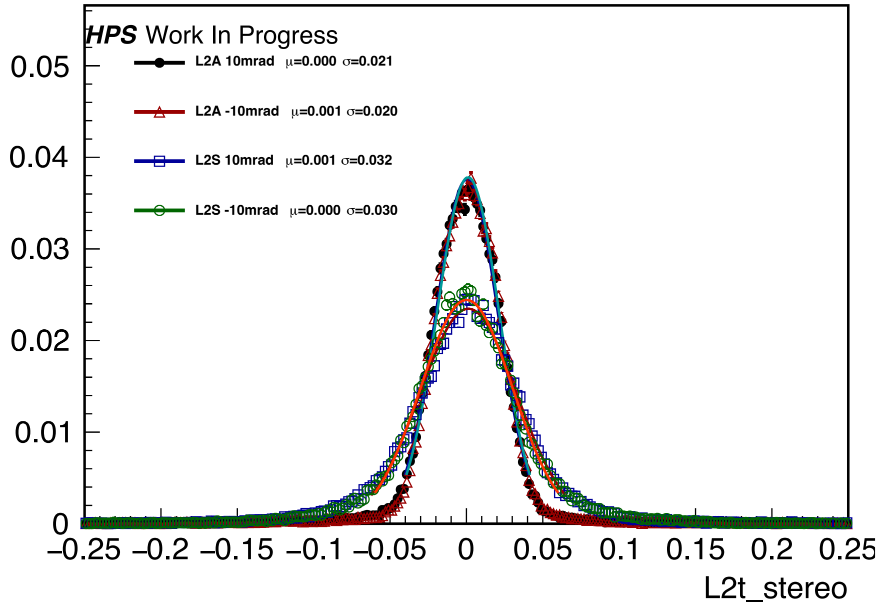


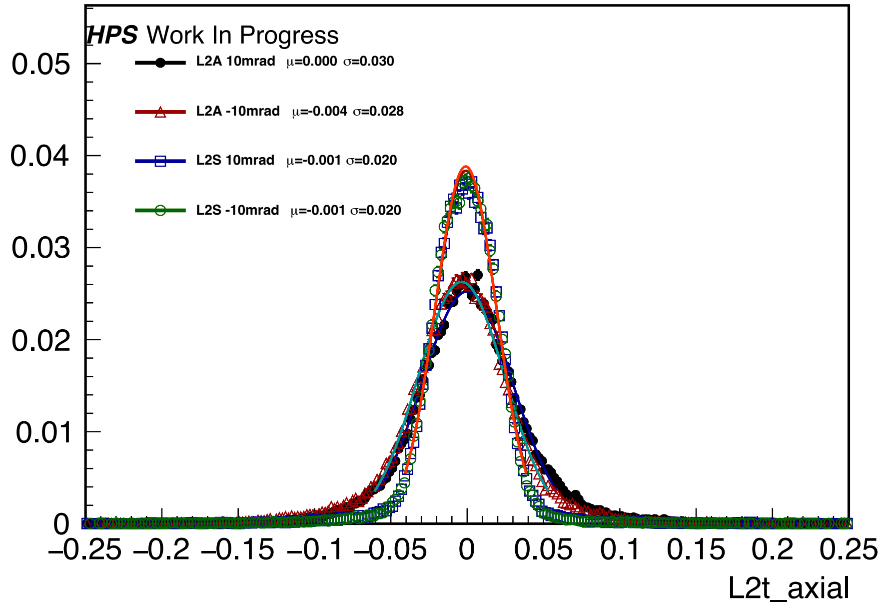




Study of the innermost sensors Rw

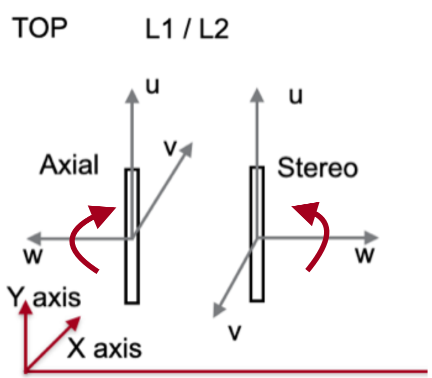
- Studied the effect of rotating the single sides by 10mrad
  - Rotations are now applied to Axial and Stereo sensors separately
- Mean of the residuals not affected
- Only resolution affected

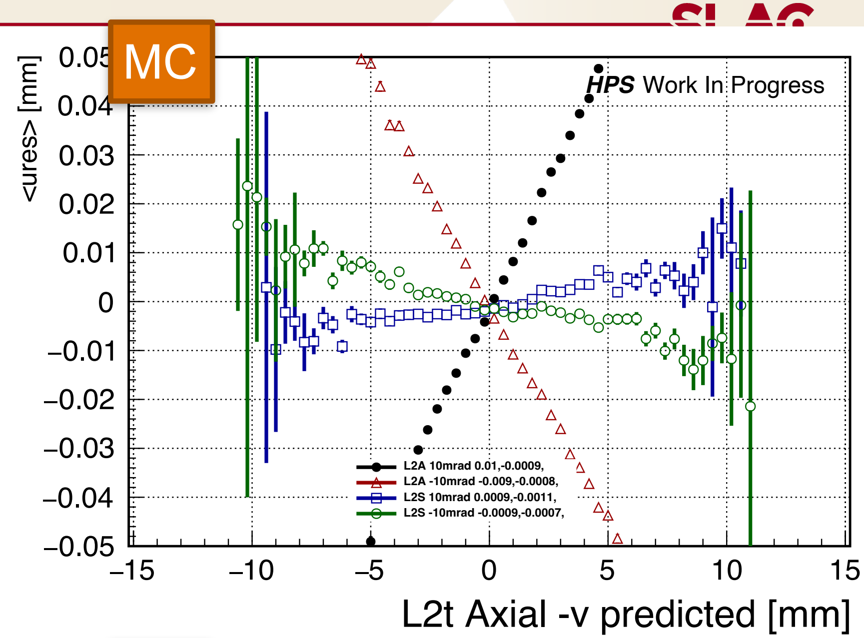


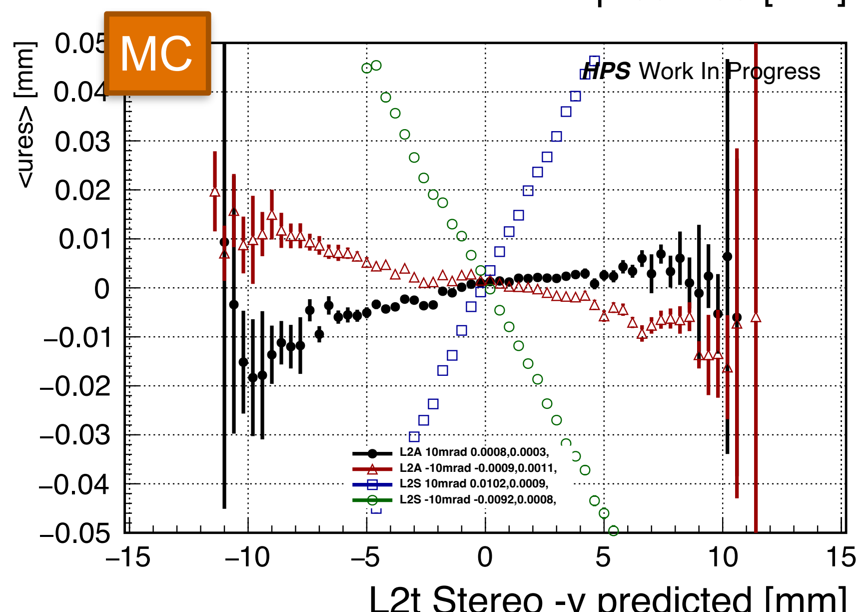


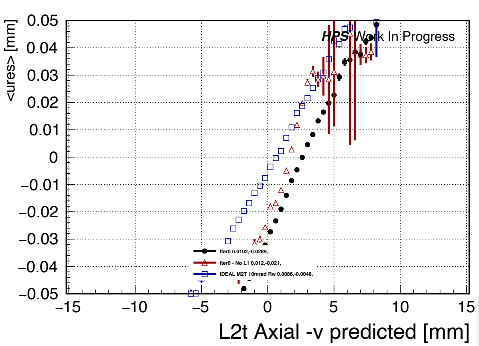
Study of the innermost sensors Rw

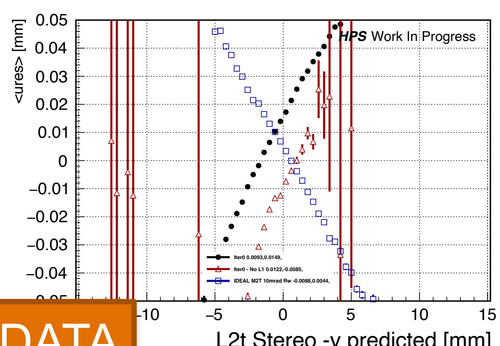
- Studied the effect of rotating the single sides by 10mrad
- Single side rotation has a reflection effect on the opposite side
- The reflection emulates a ~10 smaller rotation on the other side of the module
- **In data, we see a slope in the same direction.**
  - Axial and Stereo are rotated by the similar amount around their w axes => **cannot be a single side rotation only**







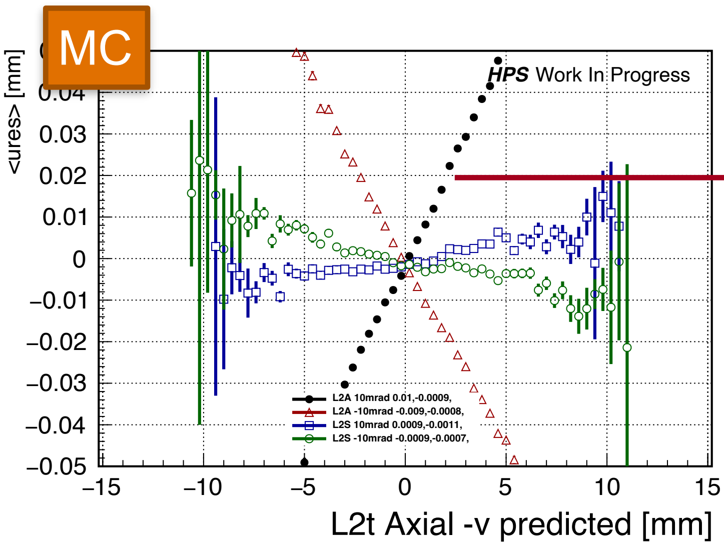




DATA

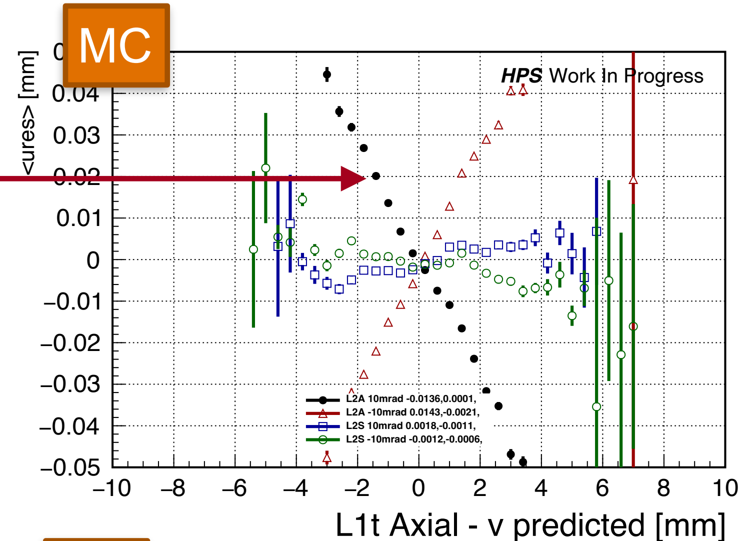
Study of the innermost sensors Rw - L1L2 coupling

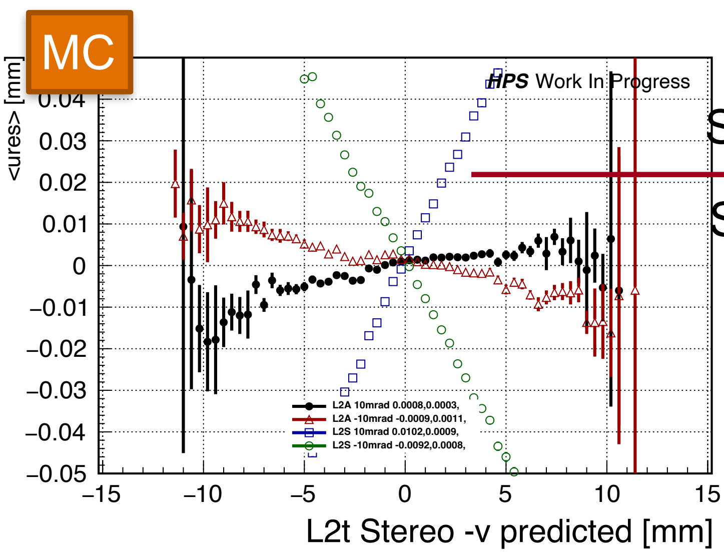
- Alternated reflection on layers next to the misaligned one



Axial to axial

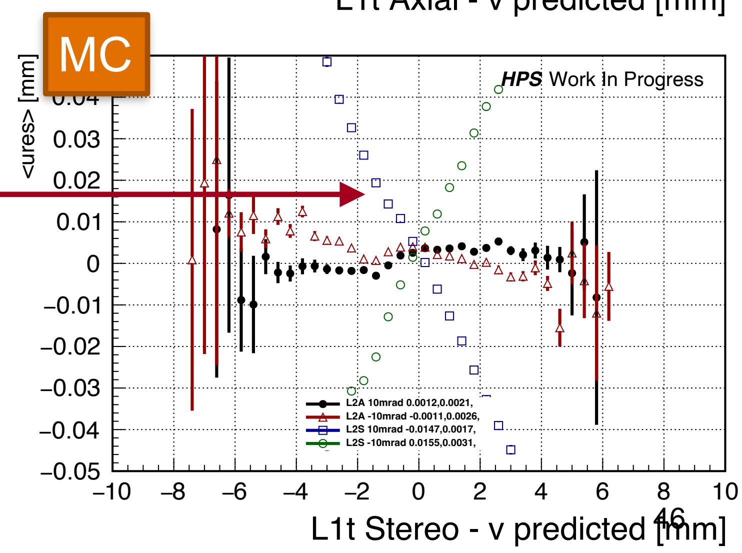
Strong coupling





Stereo to stereo

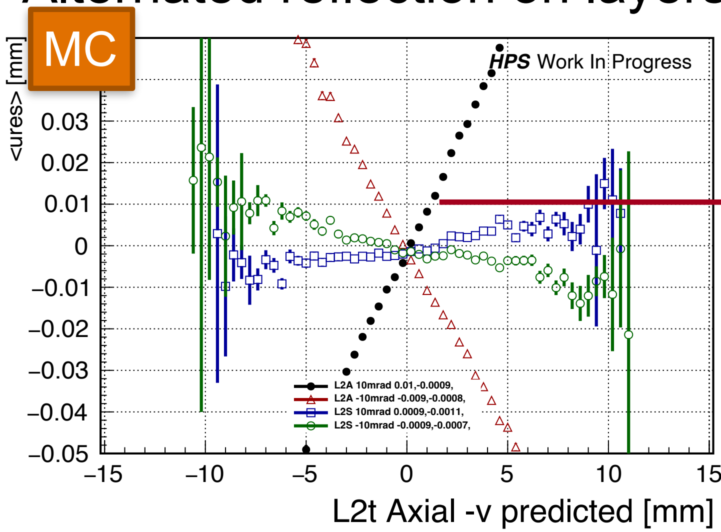
Strong coupling



Study of the innermost sensors Rw - L2L3 coupling

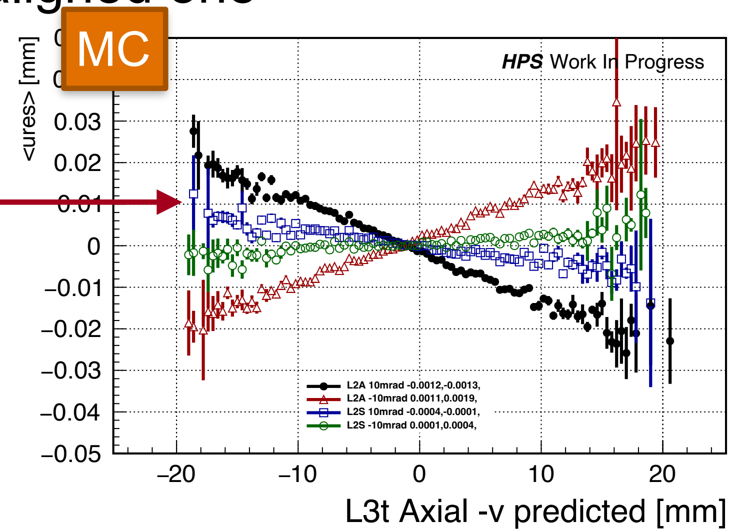
SLAC

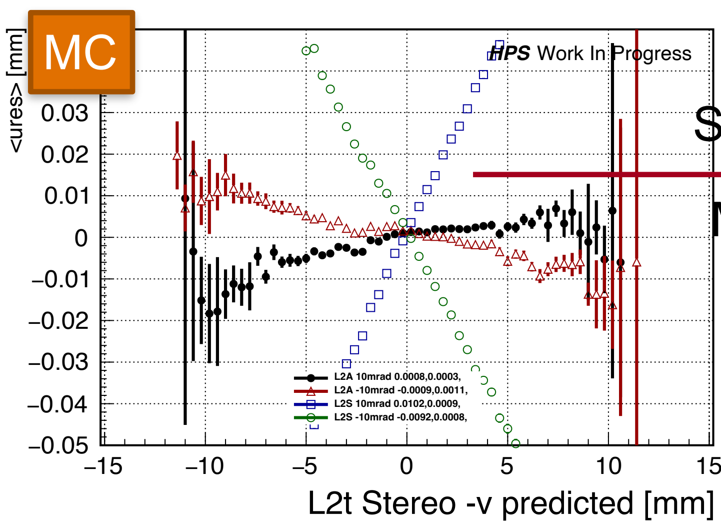
- Alternated reflection on layers next to the misaligned one



Axial to axial

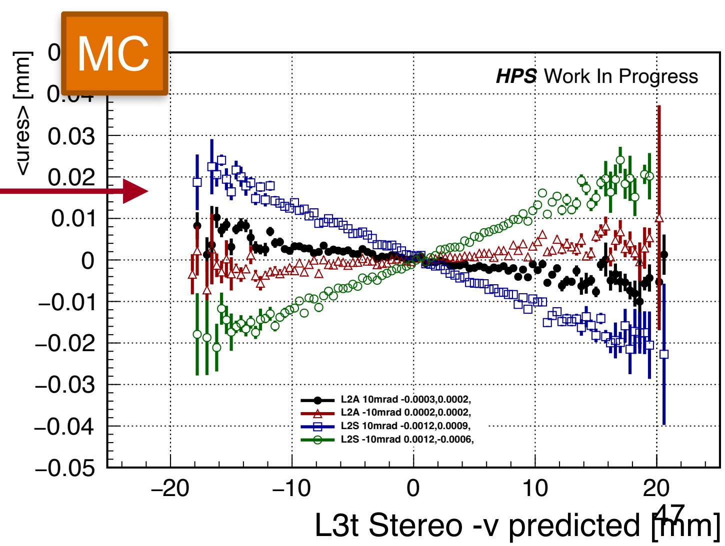
Milder coupling





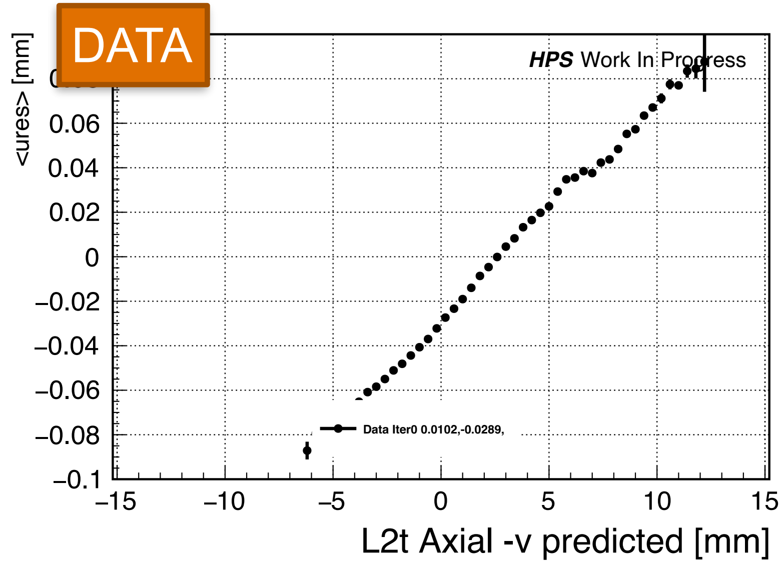
Stereo to stereo

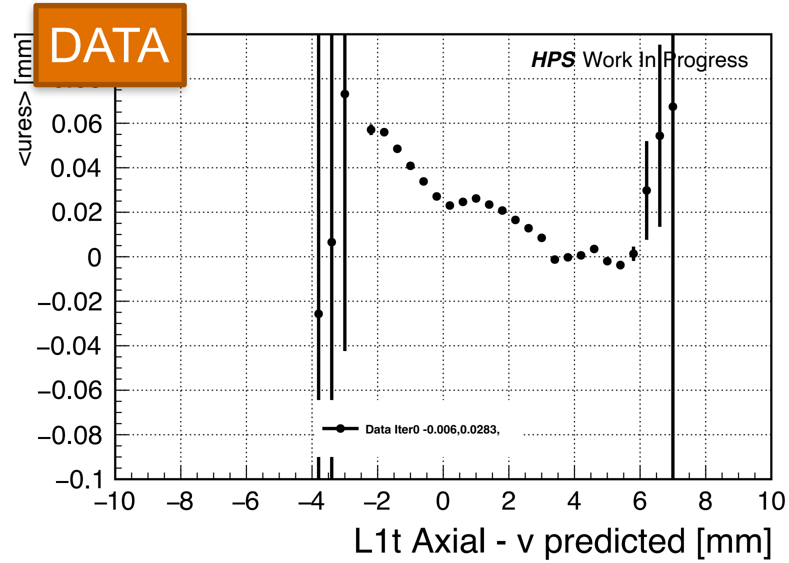
Milder coupling

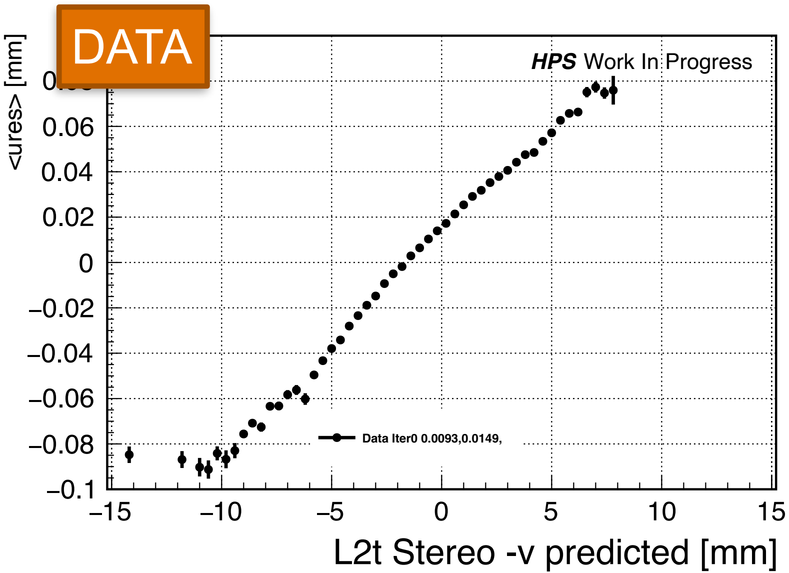


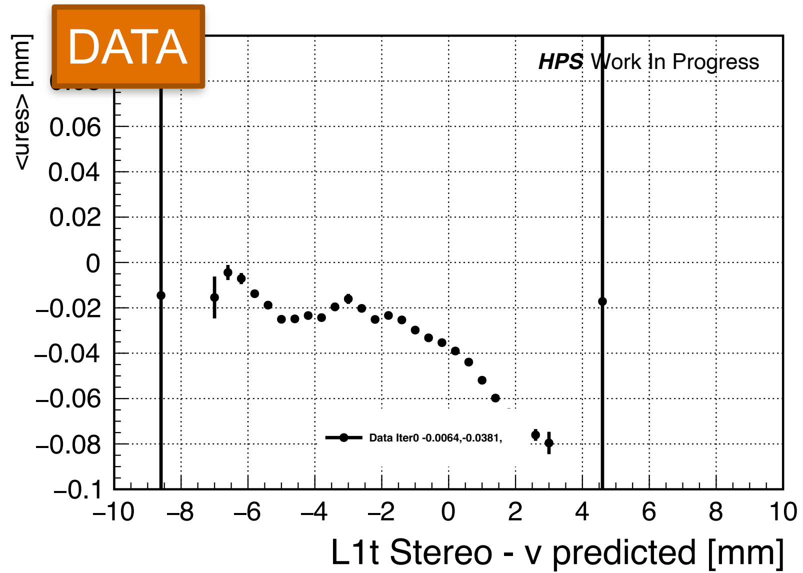
Study of the innermost sensors Rw

- What's the case in data? Both rotated or one reflection on the other ?



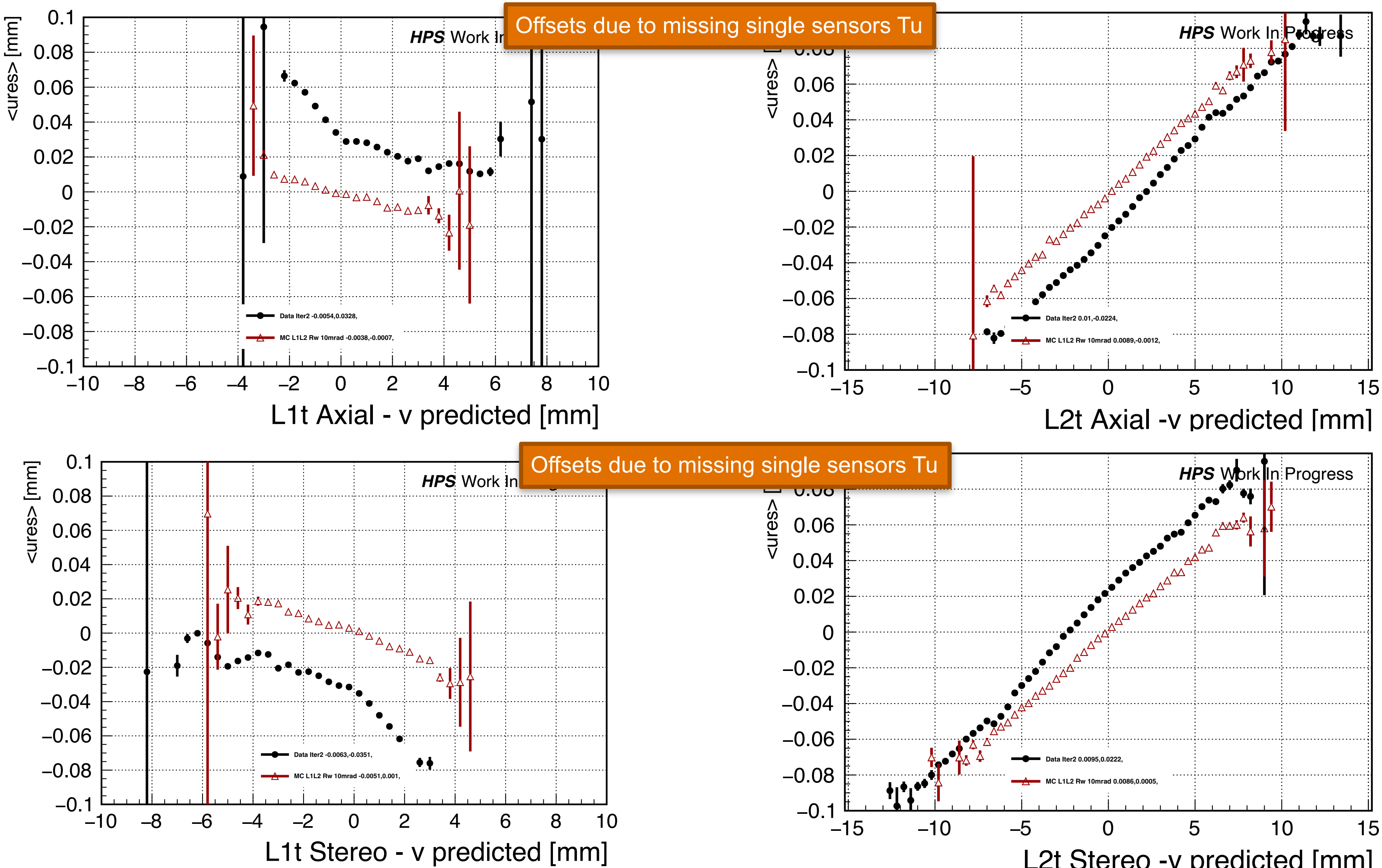






Inserting 10mrad Rw in IDEAL MC - Good modeling L1L2

- Check on IDEAL MC + misalignment L1A/S and L2A/S 10mrad Rw

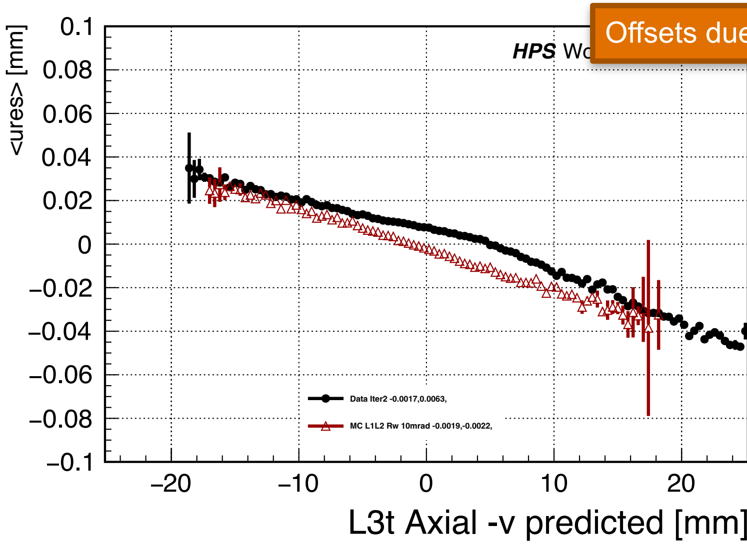


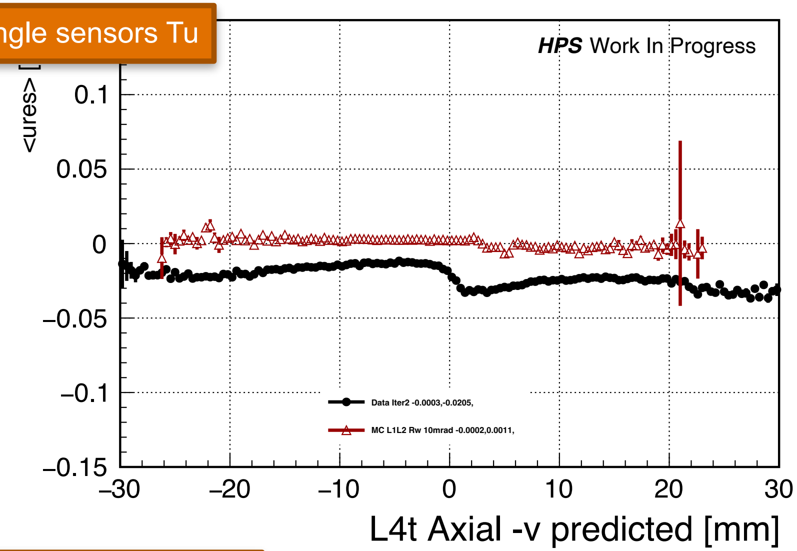
Inserting 10mrad Rw in IDEAL MC - Good modeling L3L4

SLAC

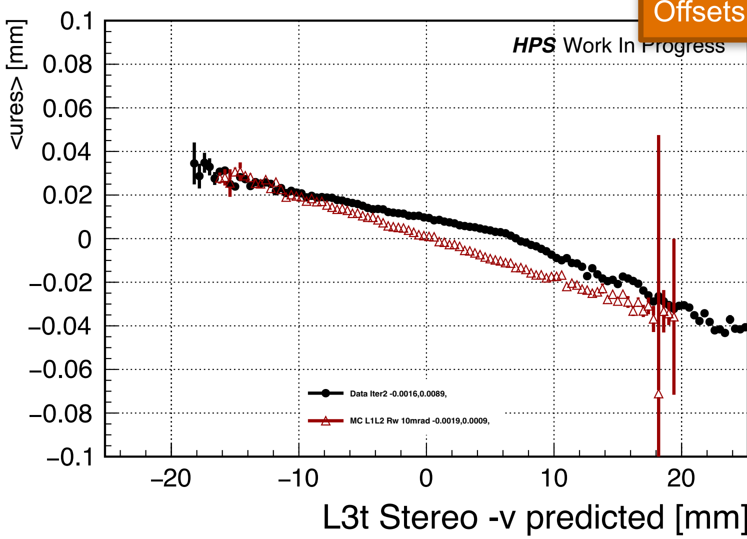
- Check on IDEAL MC + misalignment L1A/S and L2A/S 10mrad Rw

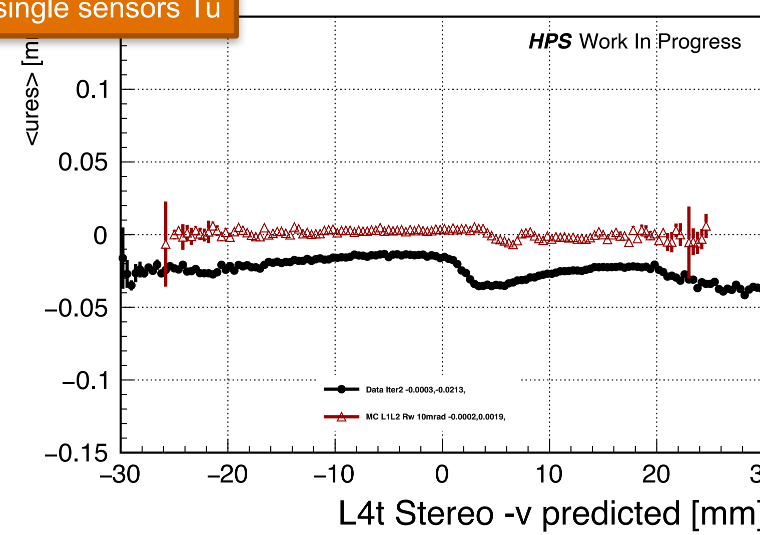
Offsets due to missing single sensors Tu





Offsets due to missing single sensors Tu





Check on bottom volume

SLAC

- Ideal + L1L2 Rw rotation misalignment of 10mrad reproduces well the data
- Analysis of effects on Ly3 and Ly4 corroborates that most of the rotation effect is in the innermost layers only
- Running **single iteration** MPII with 6 hits on tracks finds about 9mrad for the stereo and between the 5-8mrad in the axial
  - Subito mode: not precise

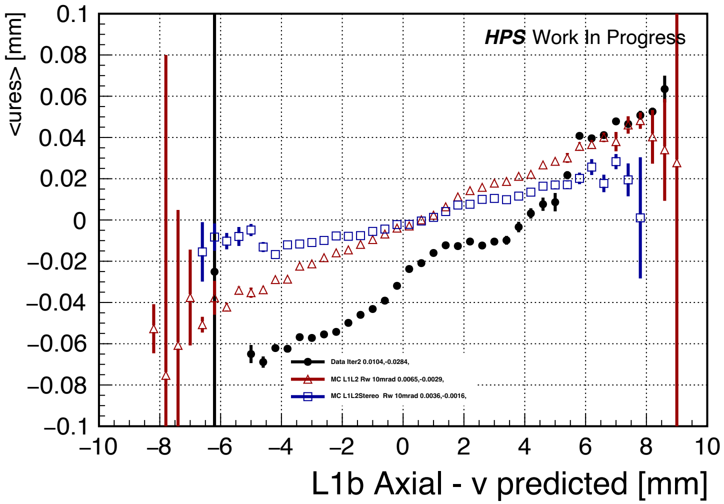
```
 module_L1t_halfmodule_axial    0.010403 +-    0.000144 11101
module_L1t_halfmodule_stereo   -0.022224 +-    0.000142 11102
 module_L2t_halfmodule_axial   -0.011726 +-    0.000092 11103
module_L2t_halfmodule_stereo    0.001439 +-    0.000093 11104
 module_L1t_halfmodule_axial    0.004811 +-    0.000085 12301
module_L1t_halfmodule_stereo    0.009504 +-    0.000074 12302
 module_L2t_halfmodule_axial    0.007905 +-    0.000025 12303
module_L2t_halfmodule_stereo    0.009370 +-    0.000024 12304
```

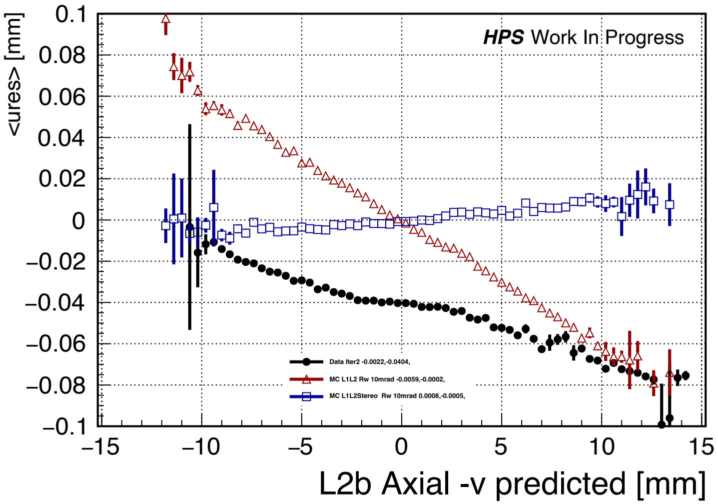
- Finding the same rotations in L1 and L2 makes sense:
  - Modules are built with the same frame
- Bottom sensors show similar distortions
  - Different order of the layers might change a bit the effects

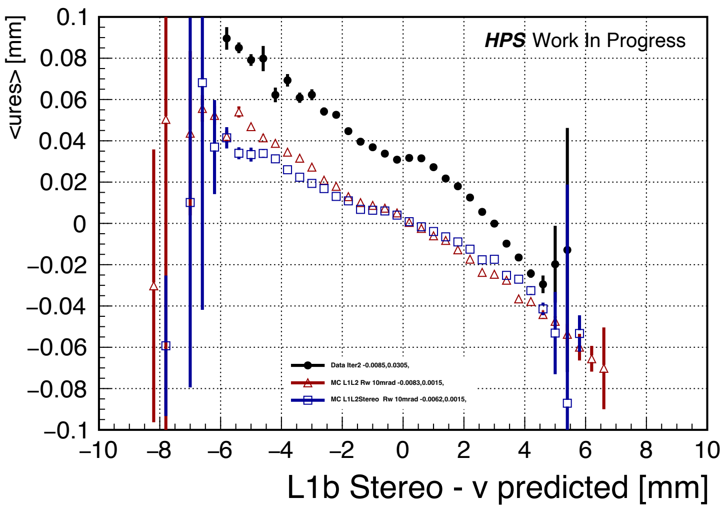
Study of the innermost sensors Rw - Bottom

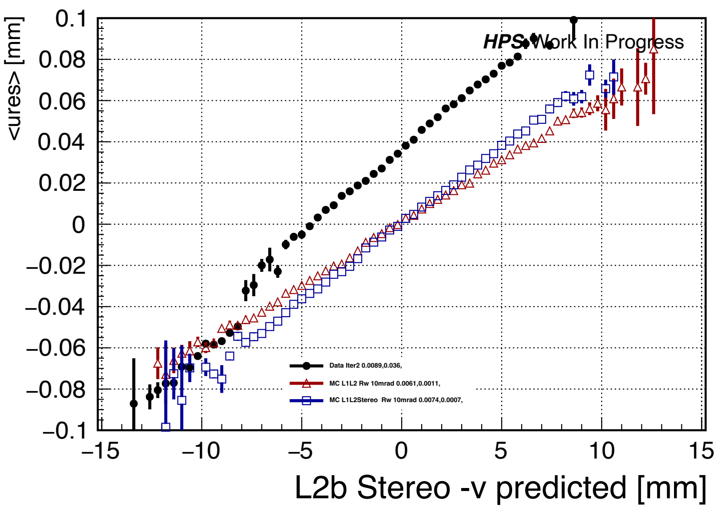
SLAC

- Check on IDEAL MC + misalignment L1A/S and L2A/S 10mrad Rw **(Red)**
- Added misalignment with 10mrad Rw only for Stereo sensors **(Blue)**



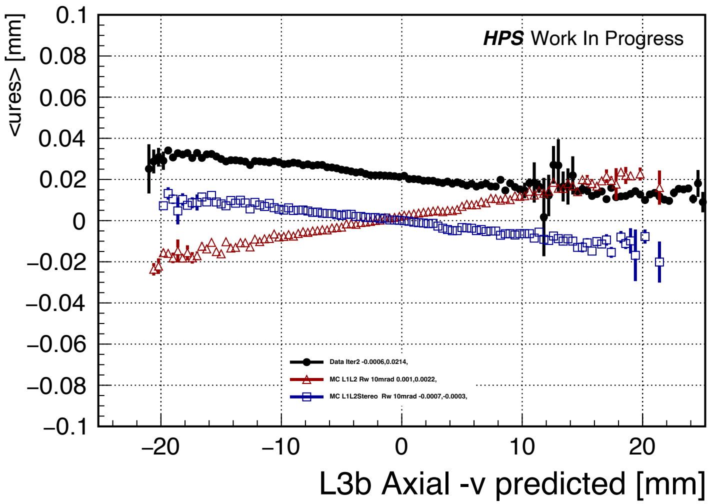


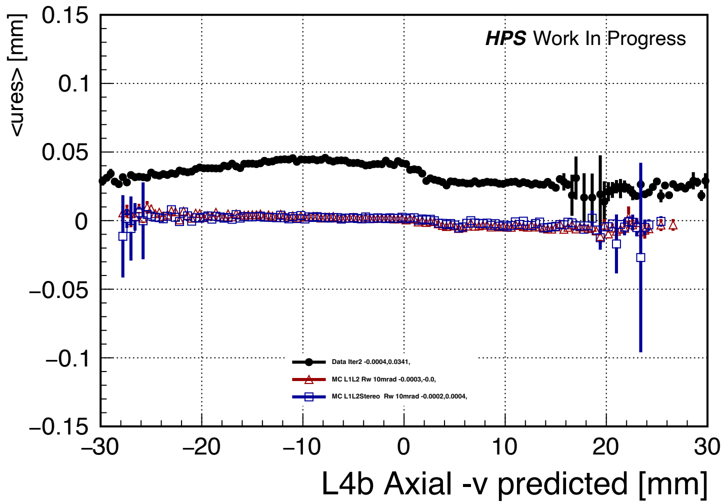


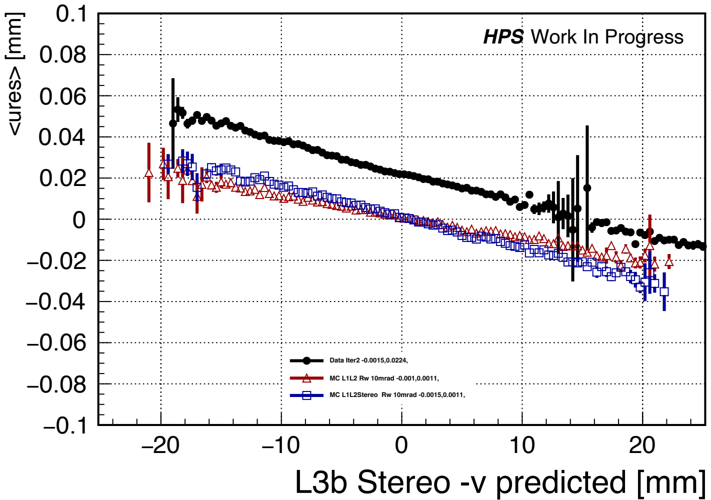


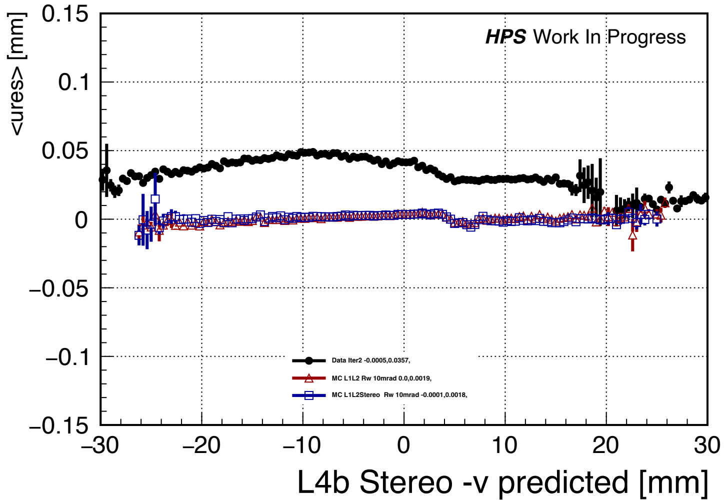
Study of the innermost sensors Rw

- Check on IDEAL MC + misalignment L1A/S and L2A/S 10mrad Rw **(Red) -> Axial rotation too large on Ly3b**
- Added misalignment with 10mrad Rw only for Stereo sensors **(Blue)**









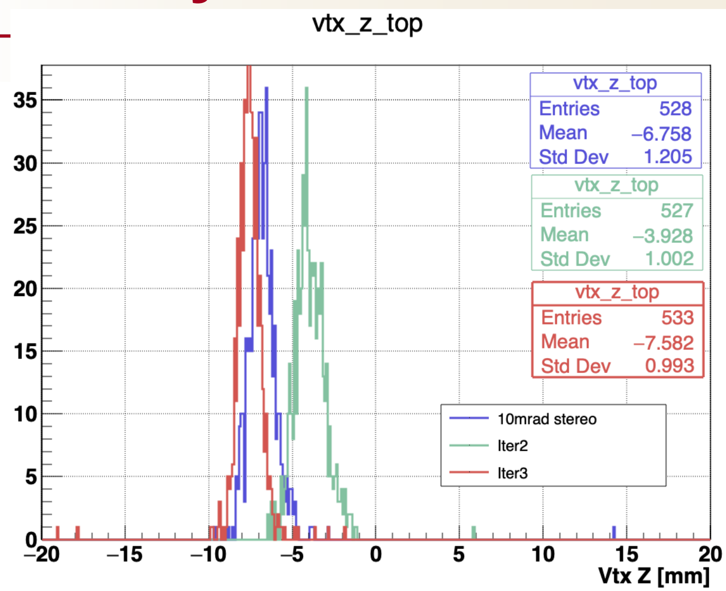
Full MPII solution

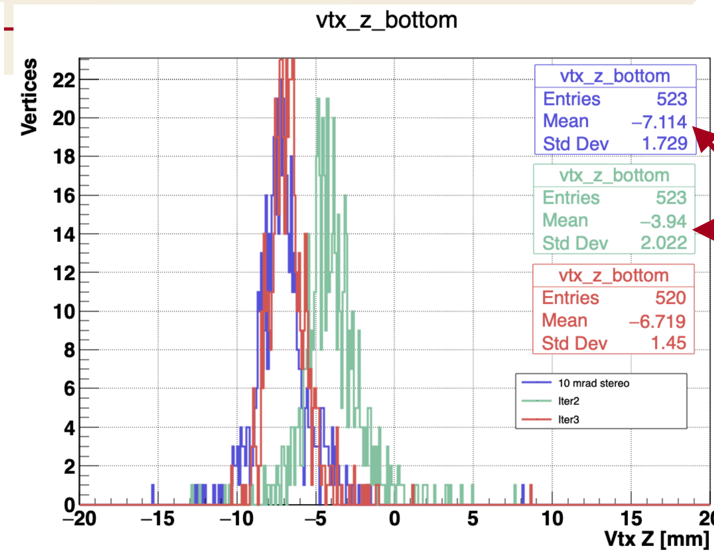
- I think a rotation of ~10mrad of stereo angle, consistent across all the innermost layers (top and bottom) is real
  - Sytematically correlated because of same mounting frame
- Axial sensor rotations do not have a consistent rotation between top and bottom
  - From MC misalignment analysis is expected to be of few mrad only

I performed a MPII alignment of the innermost sensors only in Tu / Rw and found similar results

```
module_L1t_halfmodule_axial     0.003546 +-    0.000144 11101
module_L1t_halfmodule_stereo   -0.015911 +-    0.000142 11102
module_L2t_halfmodule_axial    -0.016434 +-    0.000092 11103
module_L2t_halfmodule_stereo    0.008687 +-    0.000093 11104
module_L1t_halfmodule_axial     0.006074 +-    0.000085 12301
module_L1t_halfmodule_stereo    0.008630 +-    0.000074 12302
module_L2t_halfmodule_axial     0.008560 +-    0.000025 12303
module_L2t_halfmodule_stereo    0.009370 +-    0.000024 12304
module_L1b_halfmodule_stereo    0.072912 +-    0.000157 21101
module_L1b_halfmodule_axial    -0.037993 +-    0.000152 21102
module_L2b_halfmodule_stereo    0.056571 +-    0.000106 21103
module_L2b_halfmodule_axial    -0.049155 +-    0.000102 21104
module_L1b_halfmodule_stereo    0.007146 +-    0.000076 22301
module_L1b_halfmodule_axial     0.001001 +-    0.000065 22302
module_L2b_halfmodule_stereo    0.011262 +-    0.000028 22303
module_L2b_halfmodule_axial    -0.004122 +-    0.000025 22304
```

Study of the innermost sensors Rw

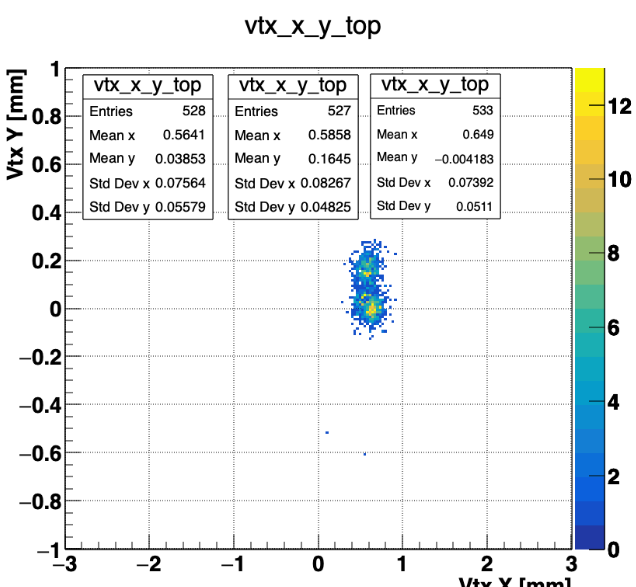




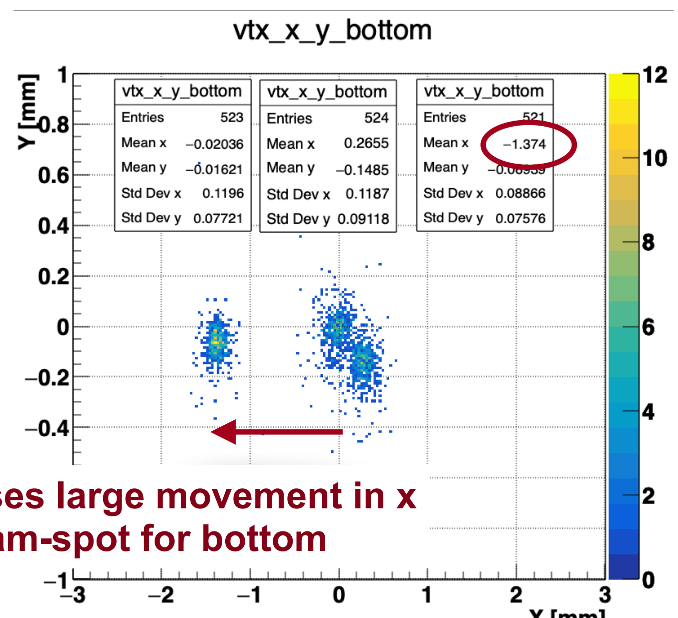
Just correcting the rotations bring the beam-spot ~ -7.mm

Most of the Z change due to fixing orientation of the sensors more than their displacement

10mrad stereo Iter2 Iter3



10mrad stereo Iter2 Iter3

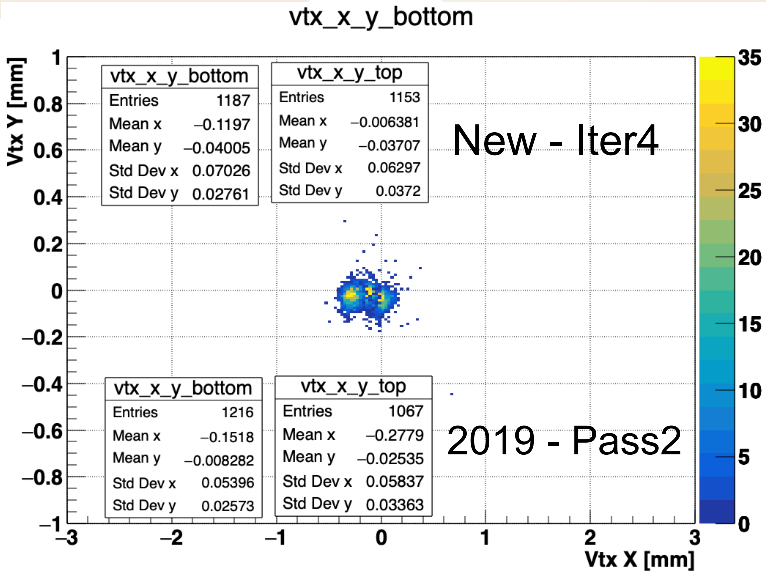


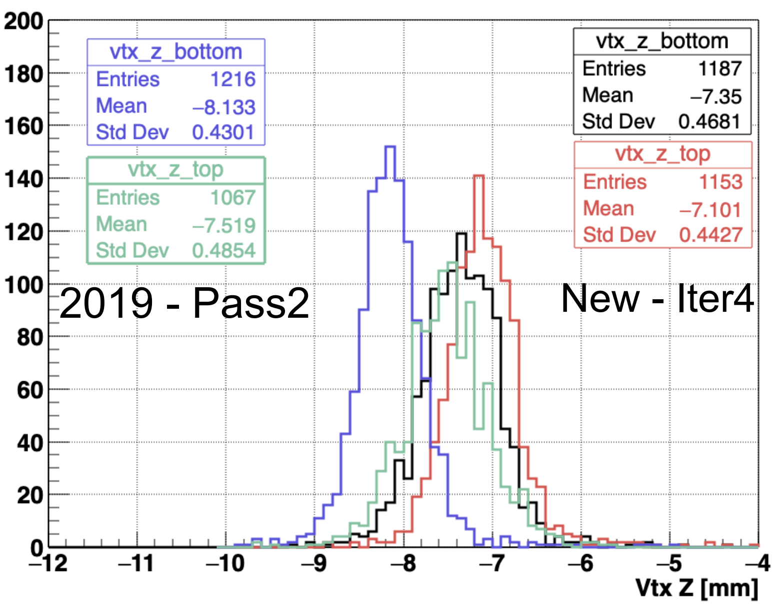
Iter3 causes large movement in x of the beam-spot for bottom

Checking the performance on FEE sample too

Beamspot in split - FEEs

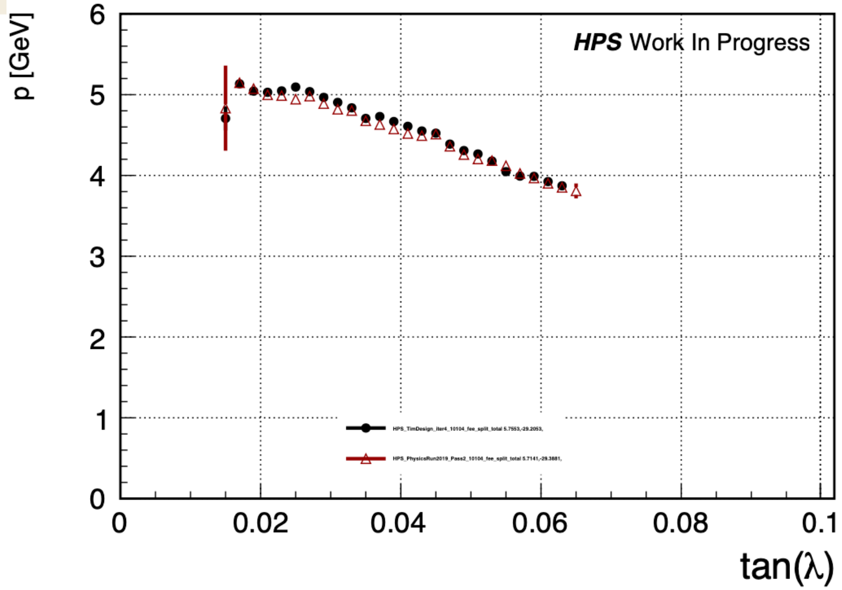
- Without the usage of beam-spot constraint we can get the X-Y location of the beam-spot to agree between top and bottom in FEEs
- Z distributions are also within 200um between top and bottom
  - Better with respect to the other iteration
  - Probably due to more careful corrections of the Rws of innermost sensors (large impact on z location of Vtx)

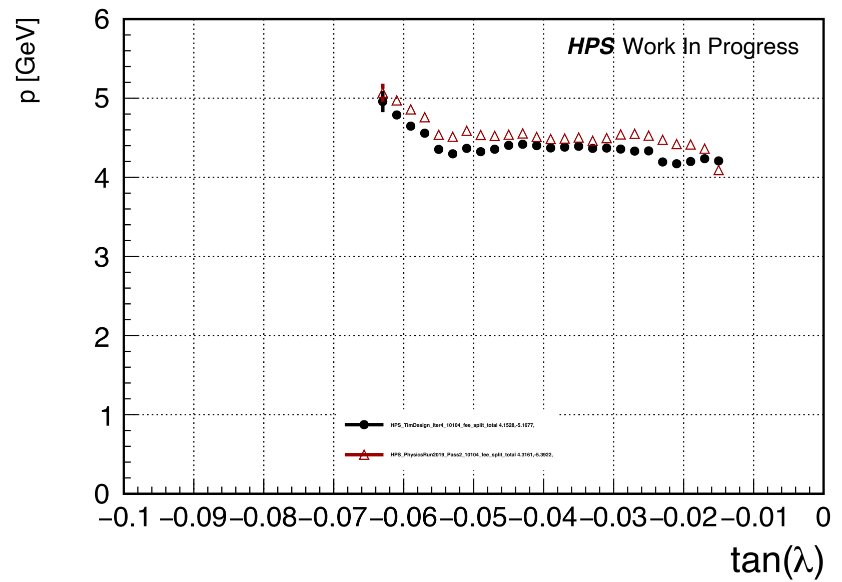




Momentum in split Fee

- No smoking gun here:
  the tanL dependence is still present in the same form and shape with same sub-structures.
  - **Not surprising as the DoF aligned won't fix this problem**
- Difference in scale can be fixed with momentum constraint
- At this point only minor differences in procedure are present in 2019 and 2016
  - **Only last major difference is missing ly7 for 2019**

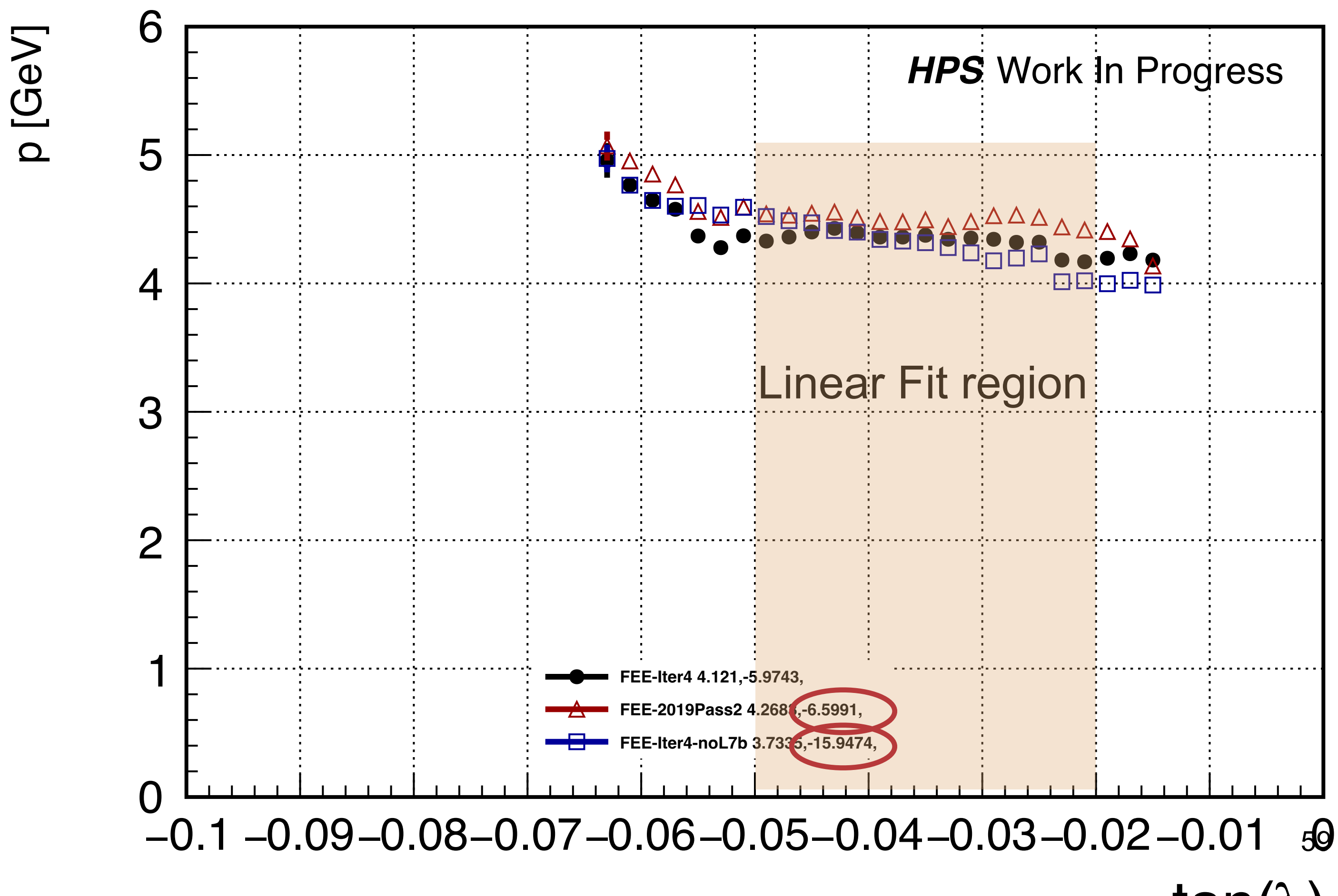




Momentum in split Fee - bottom volume

- I re-ran track finding and reconstruction on FEEs removing the last layer in bottom volume
  - This is to mimic the absence Ly7 in the top volume
  - We can observe that a p vs tanL slope in the reconstructed dataset without Ly7 appears with the same alignment constants

- I believe that part of the issue we see in 2019 slope is due to the lack of measurement in the last layer.



Summary

- I re-ran some of the alignment passes using a strategy close to 2016
  - No external constraints
  - Similar passes used in 2016, with some adaptations to 2019 data
  - Used “perfect” design geometry + orientations of the UChannels coming from Survey measurements
- Found:
  - Most of the Z of the vertex in PR comes from fixing the rotations of the innermost sensors
    - Seem to be O(5-10mrad) rotations of the stereo innermost sensors that need to be corrected
  - Possible to have a Beamspot close to (0,0) in the transverse plane without the need of a 1mm correction that was inserted in 2016 (after all doesn’t seem to really matter)
  - Very similar momentum performance for FEEs observed in top and bottom volume
    - Same shapes of momentum vs tanL even if following a much different strategy.
  - Removing Ly7b hits introduces a visible slope in pvsTanL in the bottom volume too

Iter1+2 corrections

```
module_L2t_fullmodule   0.027033 +-   0.000067 11162
module_L3t_fullmodule   0.089035 +-   0.000155 11163
module_L4t_fullmodule   0.053068 +-   0.000211 11164
module_L5t_fullmodule   0.093002 +-   0.000258 11165
module_L6t_fullmodule   0.005489 +-   0.000254 11166
module_L2b_fullmodule  -0.077149 +-   0.000074 21162
module_L3b_fullmodule  -0.005823 +-   0.000168 21163
module_L4b_fullmodule  -0.021870 +-   0.000221 21164
module_L5b_fullmodule  -0.100210 +-   0.000255 21165
module_L6b_fullmodule  -0.065507 +-   0.000217 21166
```

Iter2 not reported here but is an iteration of module level TUs
=> um movements so basically stable

Iter3 corrections

```
module_L2t_halfmodule_axial  -0.017278 +-   0.000064 11103  (change  -0.017278)
module_L2t_halfmodule_stereo   0.029812 +-   0.000070 11104  (change   0.029812)
 module_L3t_halfmodule_axial   0.000110 +-   0.000123 11105  (change   0.000110)
module_L3t_halfmodule_stereo  -0.027430 +-   0.000143 11106  (change  -0.027430)
 module_L4t_halfmodule_axial  -0.000882 +-   0.000150 11107  (change  -0.000882)
module_L4t_halfmodule_stereo  -0.041955 +-   0.000178 11108  (change  -0.041955)
   doublesensor_axial_L5_top   0.014500 +-   0.000123 11171  (change   0.014500)
  doublesensor_stereo_L5_top  -0.009749 +-   0.000129 11172  (change  -0.009749)
module_L2b_halfmodule_stereo  -0.012576 +-   0.000076 21103  (change  -0.012576)
 module_L2b_halfmodule_axial  -0.010649 +-   0.000072 21104  (change  -0.010649)
module_L3b_halfmodule_stereo   0.073986 +-   0.000146 21105  (change   0.073986)
 module_L3b_halfmodule_axial   0.027108 +-   0.000136 21106  (change   0.027108)
module_L4b_halfmodule_stereo   0.080968 +-   0.000180 21107  (change   0.080968)
 module_L4b_halfmodule_axial   0.041723 +-   0.000162 21108  (change   0.041723)
   doublesensor_axial_L5_bot  -0.011886 +-   0.000145 21171  (change  -0.011886)
  doublesensor_stereo_L5_bot  -0.015878 +-   0.000147 21172  (change  -0.015878)
```

Iter4 corrections

module_L1t_halfmodule_axial	0.003546	+-	0.000144	11101
module_L1t_halfmodule_stereo	-0.015911	+-	0.000142	11102
module_L2t_halfmodule_axial	-0.016434	+-	0.000092	11103
module_L2t_halfmodule_stereo	0.008687	+-	0.000093	11104
module_L1t_halfmodule_axial	0.006074	+-	0.000085	12301
module_L1t_halfmodule_stereo	**0.008630**	**+-**	**0.000074**	**12302**
module_L2t_halfmodule_axial	0.008560	+-	0.000025	12303
module_L2t_halfmodule_stereo	**0.009370**	**+-**	**0.000024**	**12304**
module_L1b_halfmodule_stereo	0.072912	+-	0.000157	21101
module_L1b_halfmodule_axial	-0.037993	+-	0.000152	21102
module_L2b_halfmodule_stereo	0.056571	+-	0.000106	21103
module_L2b_halfmodule_axial	-0.049155	+-	0.000102	21104
module_L1b_halfmodule_stereo	**0.007146**	**+-**	**0.000076**	**22301**
module_L1b_halfmodule_axial	0.001001	+-	0.000065	22302
module_L2b_halfmodule_stereo	**0.011262**	**+-**	**0.000028**	**22303**
module_L2b_halfmodule_axial	-0.004122	+-	0.000025	22304

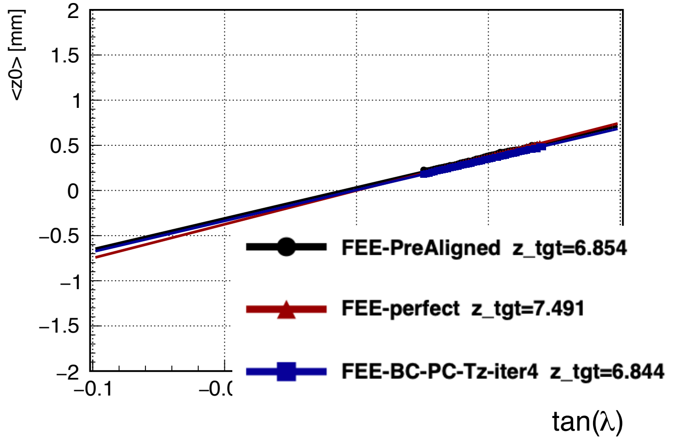
Iter5 corrections

```
 doublesensor_axial_L5_top  -0.003342 +-   0.000083 11171  (change  -0.003342)
doublesensor_stereo_L5_top   0.009833 +-   0.000087 11172  (change   0.009833)
 doublesensor_axial_L6_top  -0.005086 +-   0.000183 11173  (change  -0.005086)
doublesensor_stereo_L6_top   0.017448 +-   0.000204 11174  (change   0.017448)
 doublesensor_axial_L7_top   0.038751 +-   0.000474 11175  (change   0.038751)
doublesensor_stereo_L7_top   0.019724 +-   0.000521 11176  (change   0.019724)
 doublesensor_axial_L5_top   0.000053 +-   0.000001 12371  (change   0.000053)
doublesensor_stereo_L5_top  -0.000163 +-   0.000001 12372  (change  -0.000163)
 doublesensor_axial_L6_top   0.000070 +-   0.000002 12373  (change   0.000070)
doublesensor_stereo_L6_top  -0.000077 +-   0.000002 12374  (change  -0.000077)
 doublesensor_axial_L7_top   0.001095 +-   0.000007 12375  (change   0.001095)
doublesensor_stereo_L7_top   0.000099 +-   0.000007 12376  (change   0.000099)
 doublesensor_axial_L5_bot  -0.015013 +-   0.000302 21171  (change  -0.015013)
doublesensor_stereo_L5_bot  -0.003758 +-   0.000306 21172  (change  -0.003758)
 doublesensor_axial_L6_bot  -0.021399 +-   0.000072 21173  (change  -0.021399)
doublesensor_stereo_L6_bot   0.018069 +-   0.000072 21174  (change   0.018069)
 doublesensor_axial_L5_bot   0.000106 +-   0.000004 22371  (change   0.000106)
doublesensor_stereo_L5_bot   0.000087 +-   0.000004 22372  (change   0.000087)
 doublesensor_axial_L6_bot   0.000158 +-   0.000001 22373  (change   0.000158)
doublesensor_stereo_L6_bot  -0.000181 +-   0.000001 22374  (change  -0.000181)
```

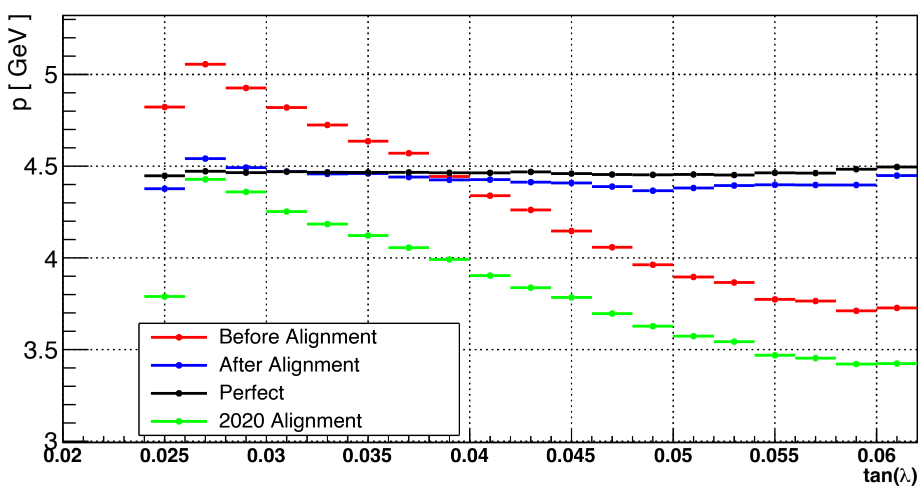
Iter6 Corrections

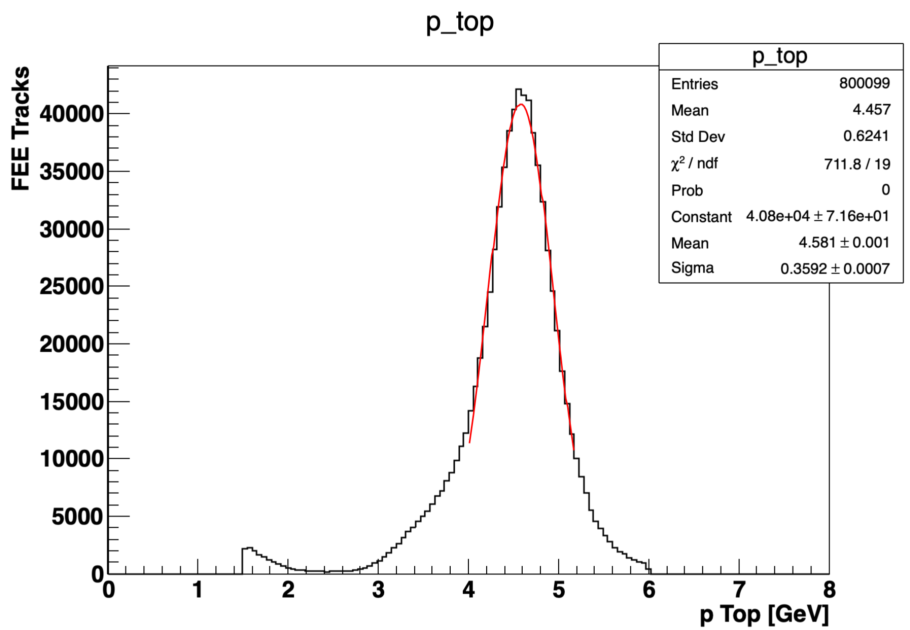
```
      module_L3t_halfmodule_axial   0.002008 +-   0.000070 11105  (change   0.002008)
     module_L3t_halfmodule_stereo   0.002266 +-   0.000095 11106  (change   0.002266)
      module_L4t_halfmodule_axial   0.001778 +-   0.000098 11107  (change   0.001778)
     module_L4t_halfmodule_stereo   0.004298 +-   0.000144 11108  (change   0.004298)
 module_L5t_halfmodule_axial_hole  -0.001939 +-   0.000216 11109  (change  -0.001939)
module_L5t_halfmodule_stereo_hole   0.004565 +-   0.000214 11110  (change   0.004565)
 module_L5t_halfmodule_axial_slot  -0.009324 +-   0.000264 11111  (change  -0.009324)
module_L5t_halfmodule_stereo_slot   0.002079 +-   0.000258 11112  (change   0.002079)
 module_L6t_halfmodule_axial_slot  -0.002096 +-   0.000188 11115  (change  -0.002096)
module_L6t_halfmodule_stereo_slot  -0.000999 +-   0.000187 11116  (change  -0.000999)
 module_L5t_halfmodule_axial_hole   0.000031 +-   0.000006 12309  (change   0.000031)
module_L5t_halfmodule_stereo_hole  -0.000065 +-   0.000006 12310  (change  -0.000065)
 module_L5t_halfmodule_axial_slot   0.000243 +-   0.000008 12311  (change   0.000243)
module_L5t_halfmodule_stereo_slot  -0.000163 +-   0.000008 12312  (change  -0.000163)
 module_L6t_halfmodule_axial_slot   0.000079 +-   0.000008 12315  (change   0.000079)
module_L6t_halfmodule_stereo_slot  -0.000138 +-   0.000008 12316  (change  -0.000138)
     module_L3b_halfmodule_stereo   0.000442 +-   0.000107 21105  (change   0.000442)
      module_L3b_halfmodule_axial  -0.003287 +-   0.000076 21106  (change  -0.003287)
     module_L4b_halfmodule_stereo   0.004427 +-   0.000169 21107  (change   0.004427)
      module_L4b_halfmodule_axial  -0.006425 +-   0.000114 21108  (change  -0.006425)
module_L5b_halfmodule_stereo_hole   0.002272 +-   0.000352 21109  (change   0.002272)
 module_L5b_halfmodule_axial_hole   0.006835 +-   0.000344 21110  (change   0.006835)
module_L6b_halfmodule_stereo_hole   0.001592 +-   0.000272 21113  (change   0.001592)
 module_L6b_halfmodule_axial_hole   0.007406 +-   0.000264 21114  (change   0.007406)
module_L6b_halfmodule_stereo_slot  -0.010130 +-   0.000229 21115  (change  -0.010130)
 module_L6b_halfmodule_axial_slot   0.012797 +-   0.000220 21116  (change   0.012797)
module_L5b_halfmodule_stereo_hole   0.000086 +-   0.000009 22309  (change   0.000086)
 module_L5b_halfmodule_axial_hole  -0.000418 +-   0.000009 22310  (change  -0.000418)
module_L6b_halfmodule_stereo_hole   0.000054 +-   0.000009 22313  (change   0.000054)
 module_L6b_halfmodule_axial_hole  -0.000708 +-   0.000009 22314  (change  -0.000708)
module_L6b_halfmodule_stereo_slot   0.000511 +-   0.000012 22315  (change   0.000511)
 module_L6b_halfmodule_axial_slot  -0.000629 +-   0.000011 22316  (change  -0.000629)
```

SVT Performance TOP - Possible to improve via Tz ?

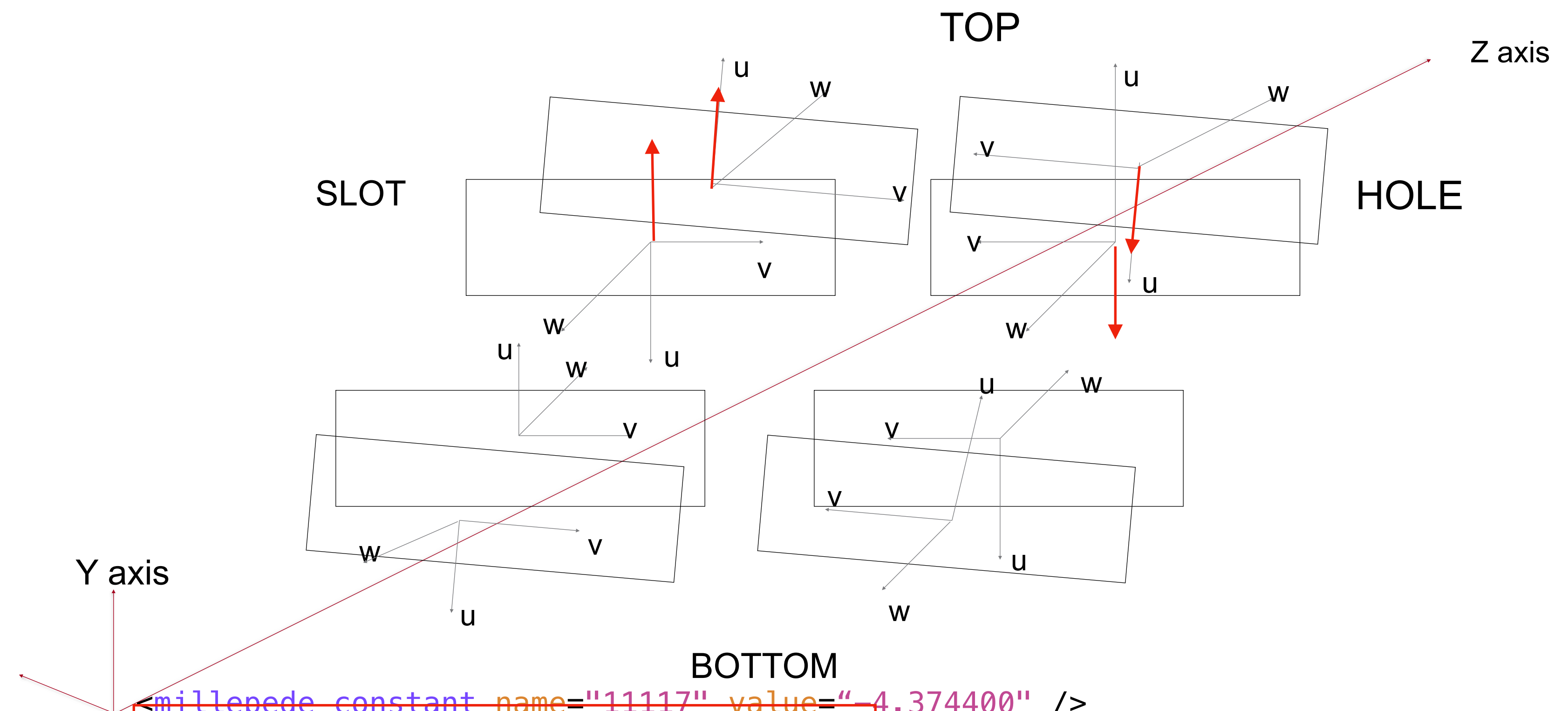


- This iteration
  - Fixes ures vs u/v dependence in large amount
  - Fixes PvsTanLambda
  - Keeps the BC at 0,0 in x/y with internal constraint at -6.9 mm
  - Fixes hole/slot dependence on momentum
  - Worth pursuing further? Combine with lower momenta tracks with more curvature?





```
11117 module_L7t_halfmodule_axial_hole
11118 module_L7t_halfmodule_stereo_hole
11119 module_L7t_halfmodule_axial_slot
11120 module_L7t_halfmodule_stereo_slot
```

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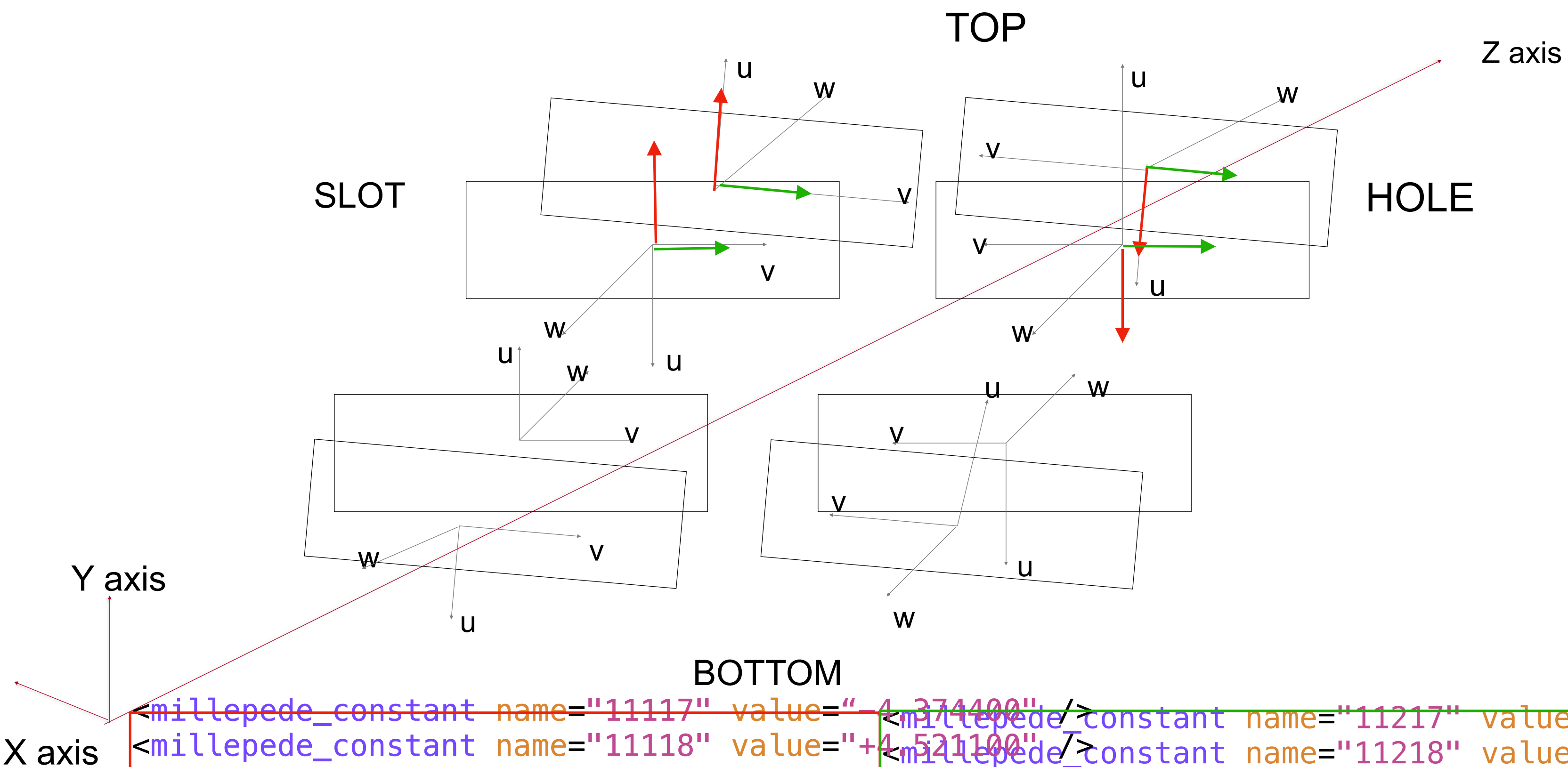
<millepede_constant name="11120" value="+4.489400" />
```

```
11117 module_L7t_halfmodule_axial_hole
11118 module_L7t_halfmodule_stereo_hole
11119 module_L7t_halfmodule_axial_slot
11120 module_L7t_halfmodule_stereo_slot
```

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```
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<millepede_constant name="11220" value="+ 2.913500"
```

```
11117 module_L7t_halfmodule_axial_hole
11118 module_L7t_halfmodule_stereo_hole
11119 module_L7t_halfmodule_axial_slot
11120 module_L7t_halfmodule_stereo_slot
```

```
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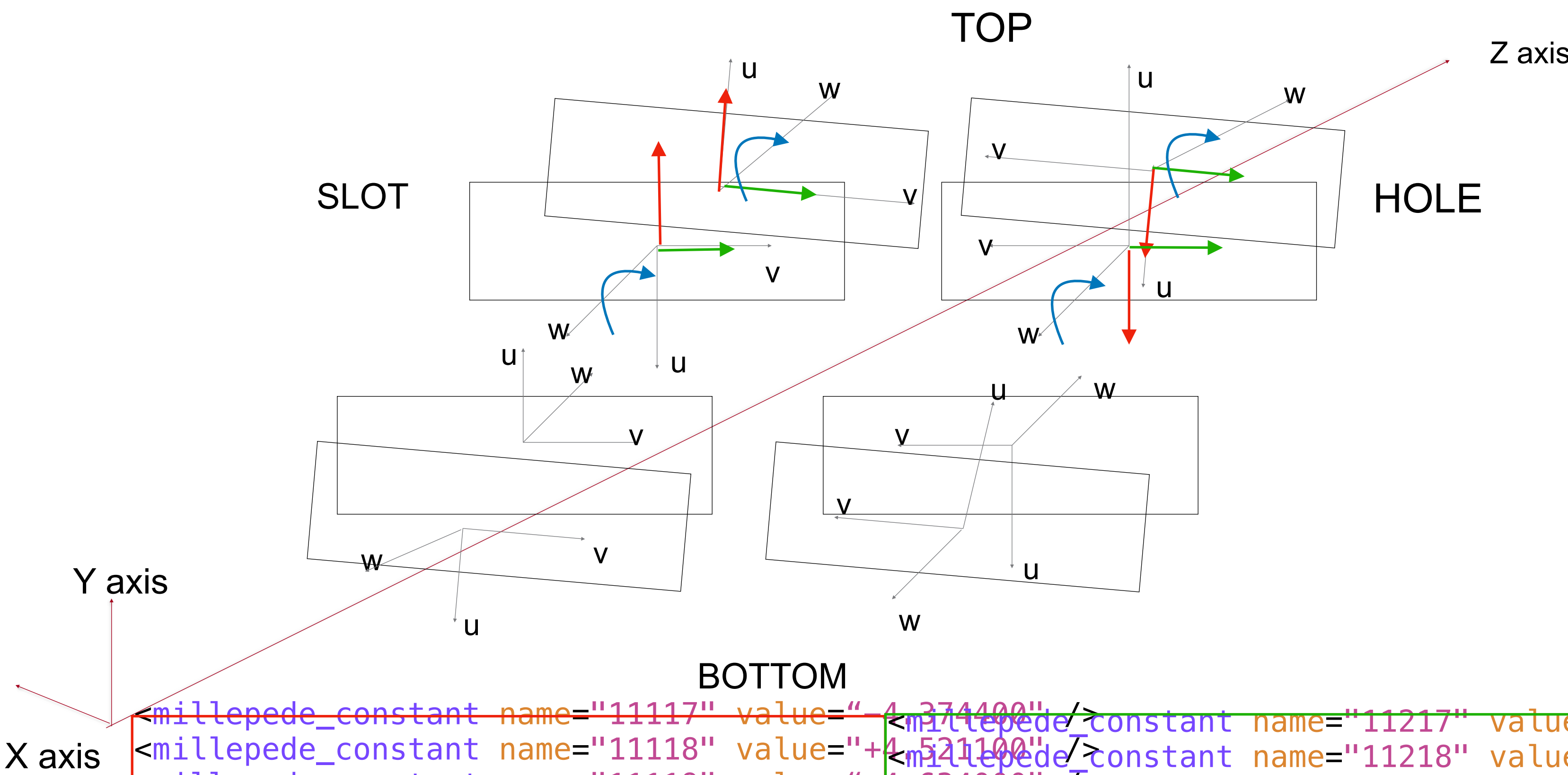


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```

```
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```