2019 Alignment Status

PF

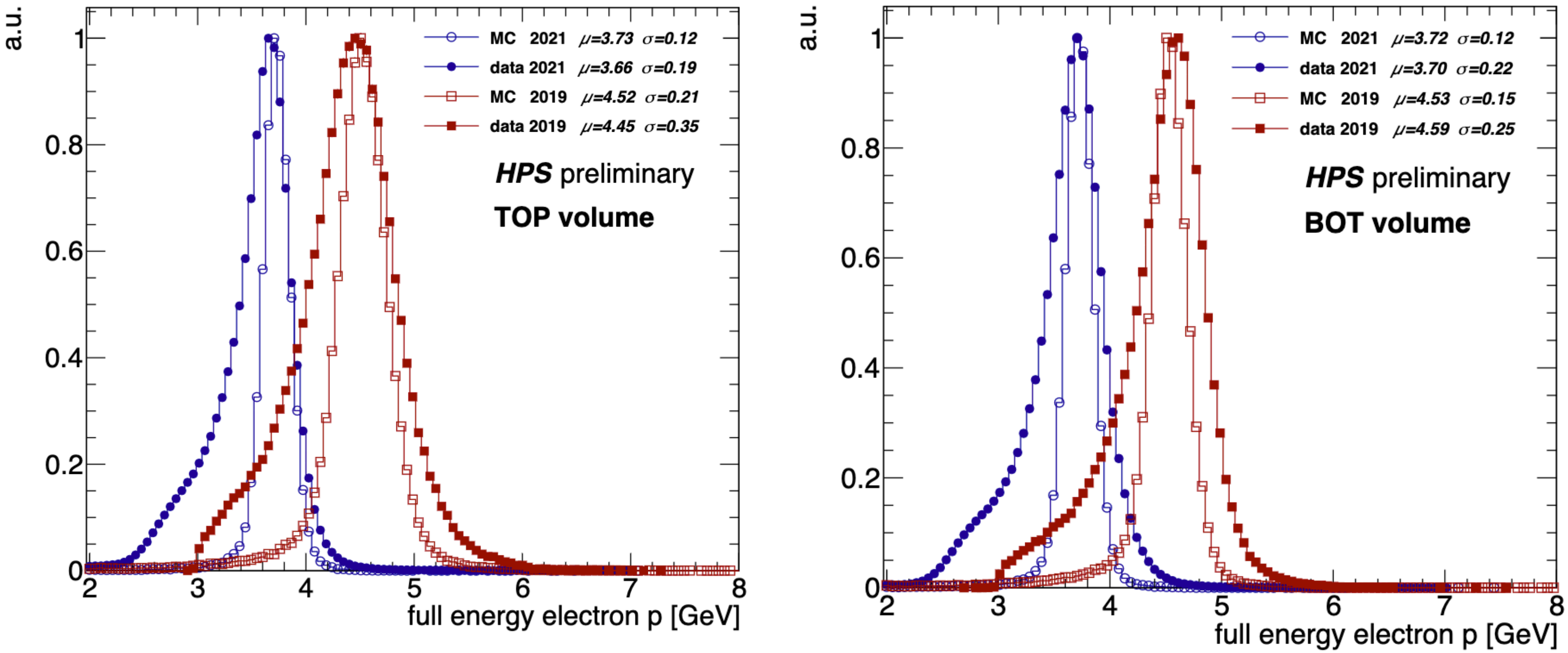
11/14/2023

Recap from last collaboration meeting

- Presented new baseline constants for 2019 dataset
  - Documented procedure and motivation for each step
- General performance of 2019 alignment on FEEs
  - Crosschecks with 2016 biases

- Today:
  - Recap of last results
  - Current status of the work done on top of previous solution
  - Ongoing issues
  - Some ideas on how to proceed

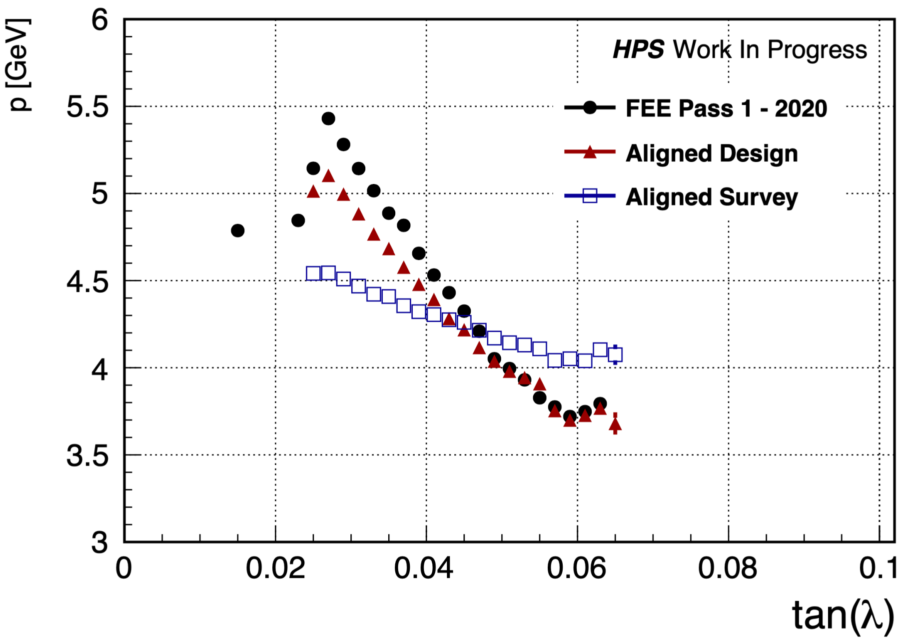
Snapshot from jeopardy

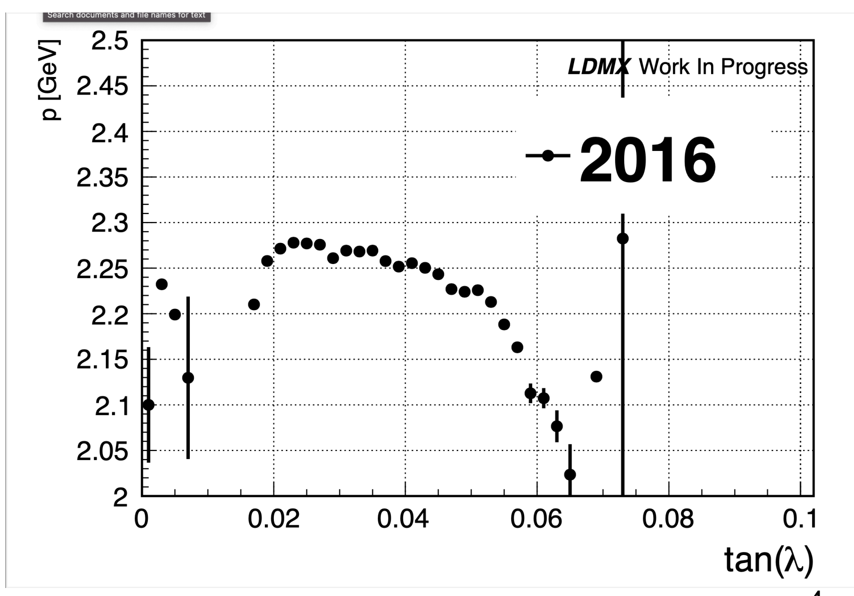


- 2019:
  - Top (Bottom) bias -2% (+0.8%), resolution 7.7% (5.5%)
  - Top, missing ly7
- 2021:
  - Top (Bottom) bias -2% (+0.5%), resolution 5.1% (5.8%)

Momentum Biases

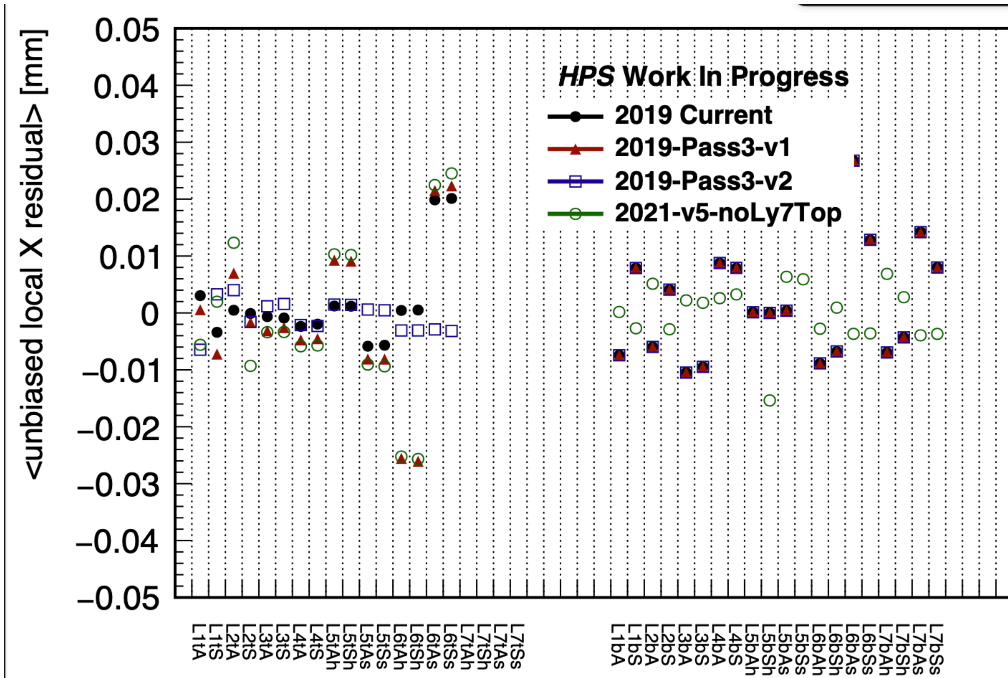
- After the re-alignment procedure on Surveyed detector the momentum bias due to tanL is of the order of **~10% in [0.025, 0.06]** interval [4.5 to 4]
  - **FEE Pass 1 - 2020 was ~50%, ~30% in Aligned Design**
  - A dedicated look to 2016 run7800 shows ~6% [2.28 to 2.15]
- There is a left-over bias that can removed by simple translation of stereo sensors.





Checks on e+/e- sample

- Used e+/e- to improve current 2019 alignment for top volume
  - Focus on residual mean and E/p metrics
  - Run 10031
- Not straightforward solution:
  - Minimizing residuals doesn’t necessarily brings best momentum resolution performance
- Bottom not improved yet
- Compared to 2021 v5 performance (run14770)



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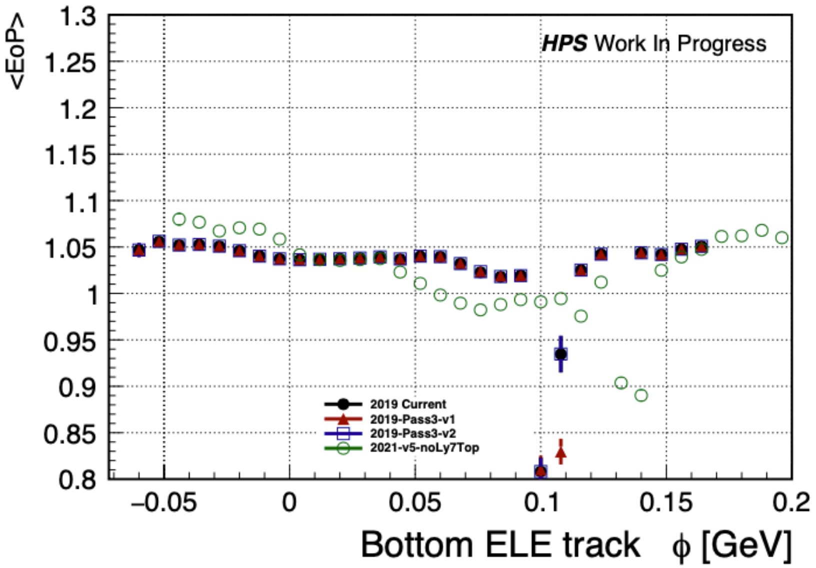
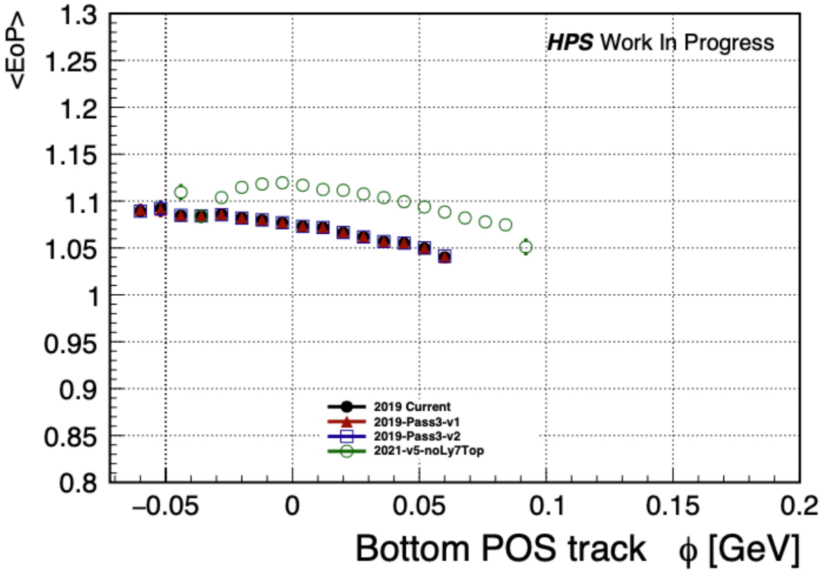
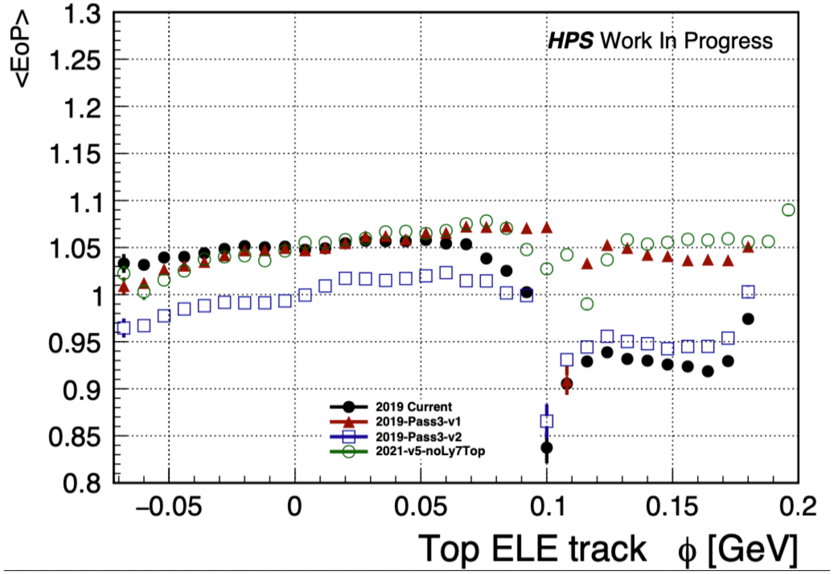
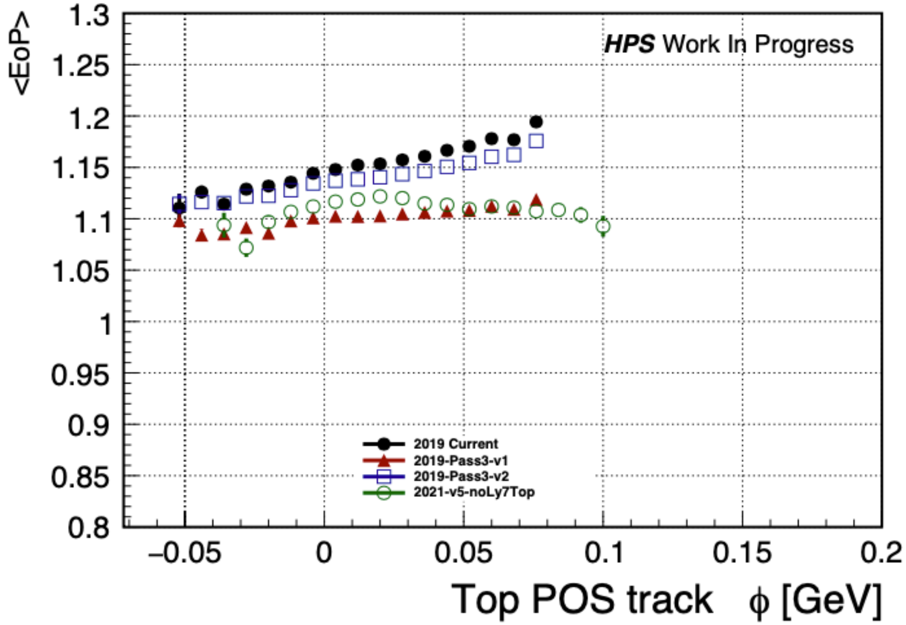




- Bottom volume for 2019 doesn’t seem worse than 2021 current performance
  - Did not focus on 2019 bottom.

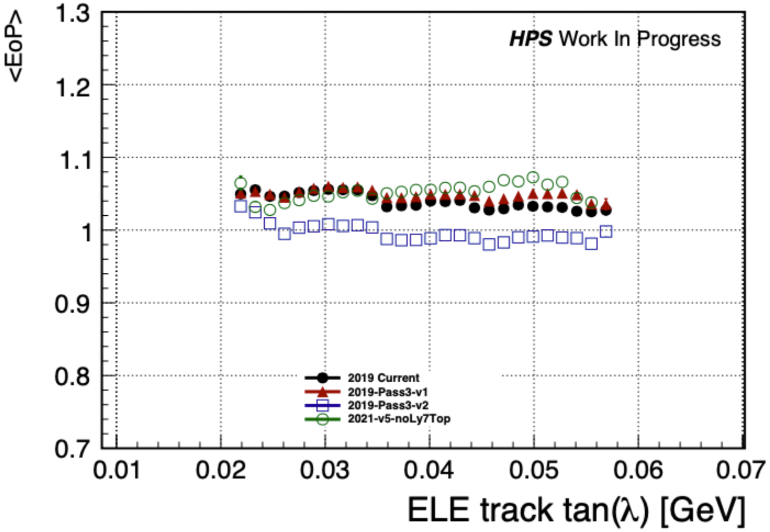
Checks on e+/e- sample

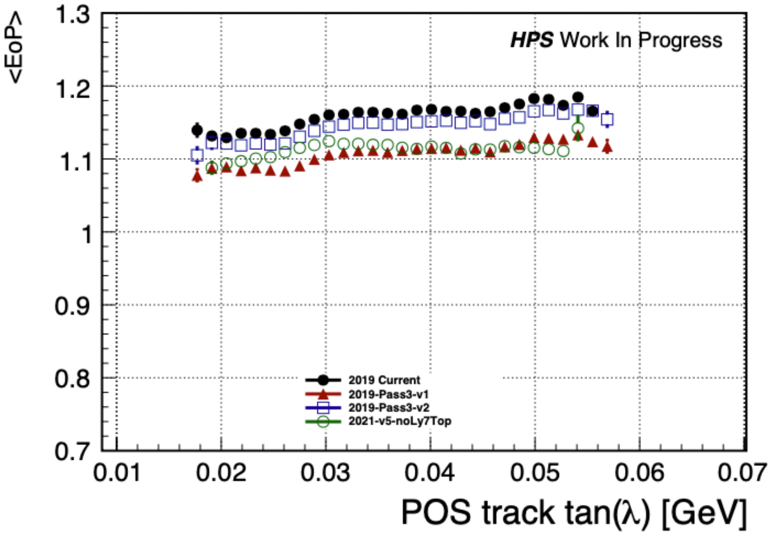




- Improved momentum bias on hole side (Pass3-v2) bit at cost of slot side
- Pass3-v1 has similar performance of 2021 for both e+ and e-
  - Improvable

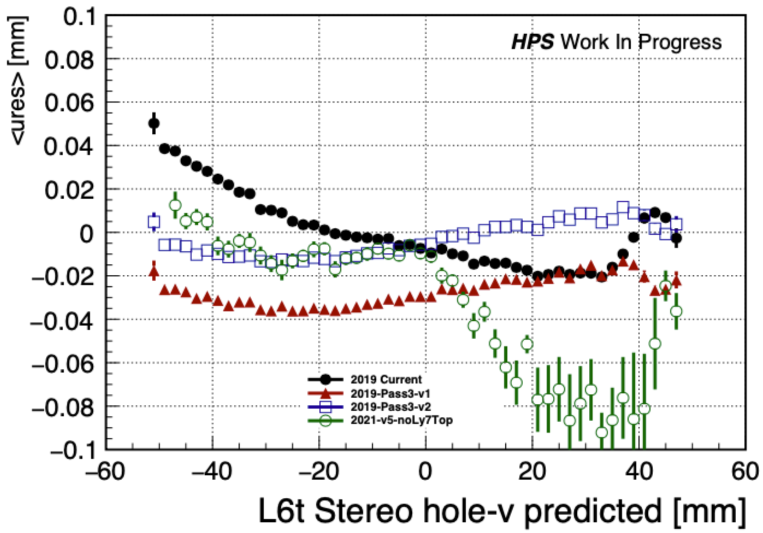
Checks on e+/e- sample

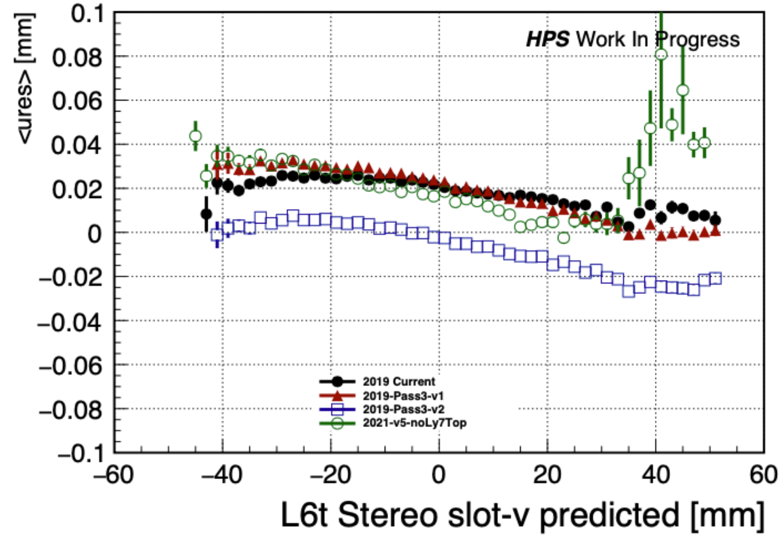




- Few % of trends in E/p vs tanL
- Similar in 2019 and 2021
- Scale corrected for electron side (Pass3-v2) and can be improved in positron side.
  - Difficulty seems to rely in getting both at the same time
  - Little bit more on this later

Residuals in the back of the detector



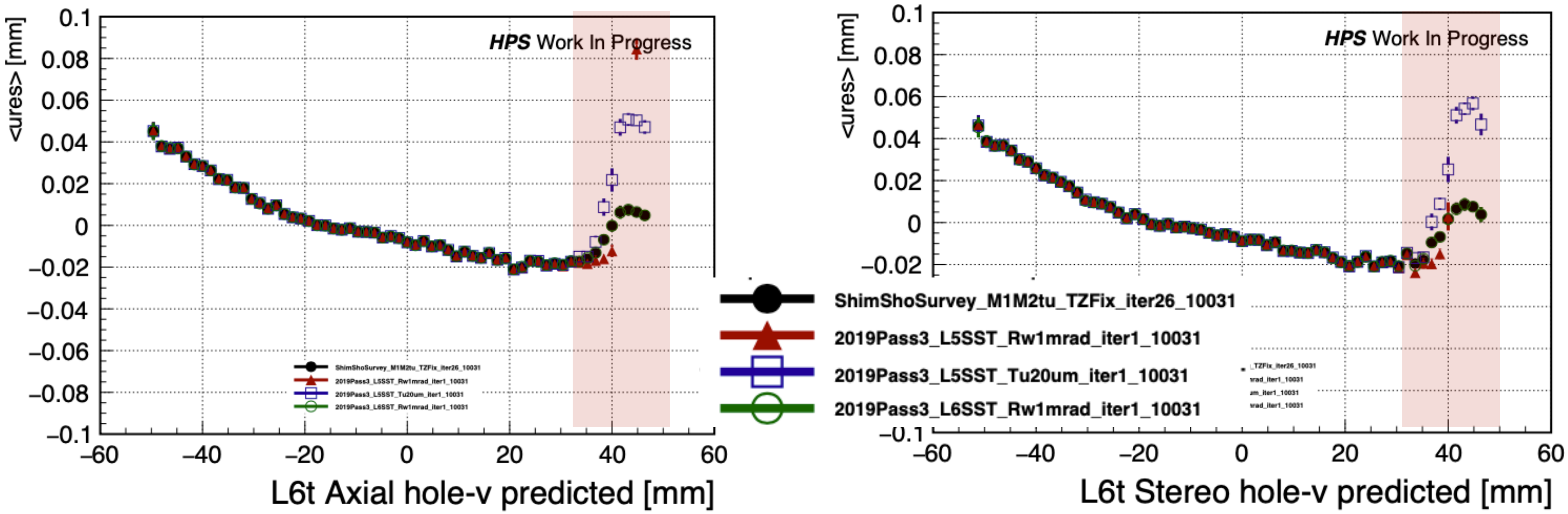


- Residual in the back can be improved by removing structures as function of v
  - More on that later
- Improvement observed in 2019
- 2021 shows sub-optimal alignment in “cross-regions”, i.e. where tracks with hit on Ly6 in the hole (slot) side have hit in slot (hole) side in layer 5
  - Low stat in the profile seems to imply loss of track fits

Some studies on residuals

- I’ve tried to study and characterize effects of movements on residuals
- “cross-side” effects
- Some of my organized studies have been added to the backup of this talk

- **<u>The step in the red region of Ly6 Hole Side can be corrected via Tu of Ly5 Stereo Slot.</u>**



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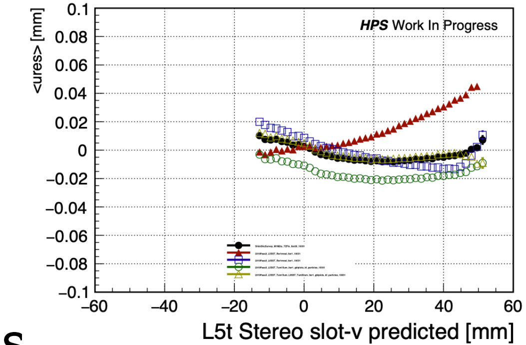
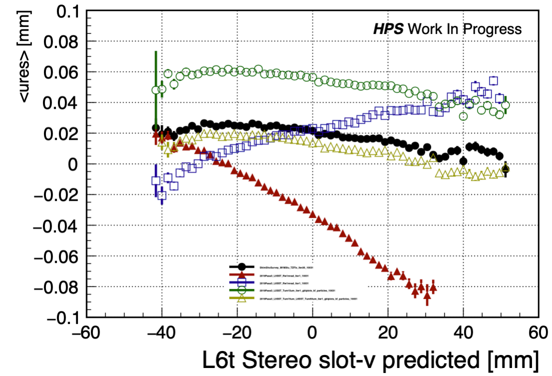
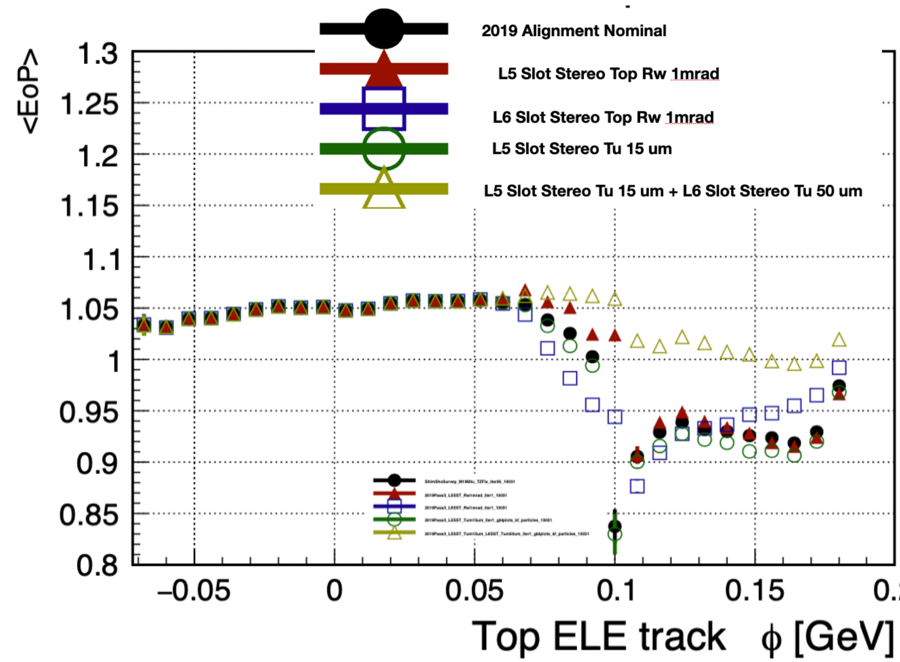


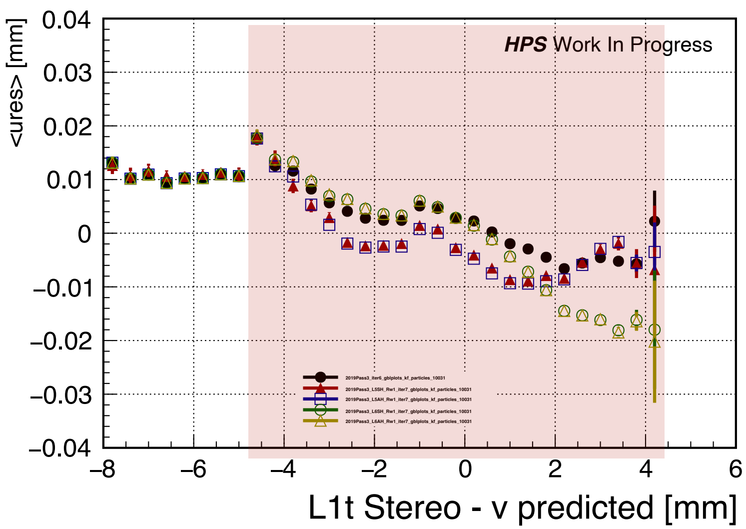


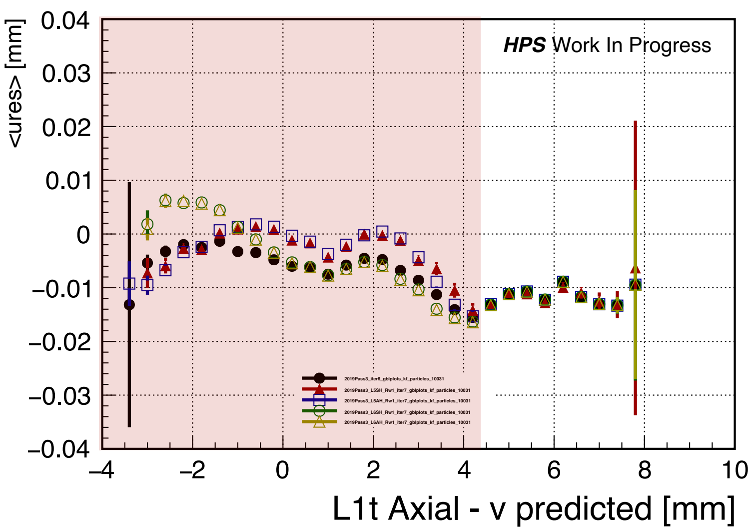


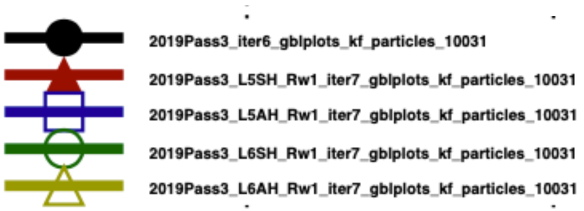
- Movements of the back slot side have an effect on Electron E/p at high phi values
  - Tu = Flat rise,
    Rw = Linear trend
- In a detector where Ly7 is missing:
  - Tu < 0 in Ly5 leads to lower E/p on the high phi region. Flat correction
    Rw > 0 in Ly6 creates a trend in large phi with positive slope, .i.e. E/p increases with phi = > momentum decreases with phi

Some studies on residuals

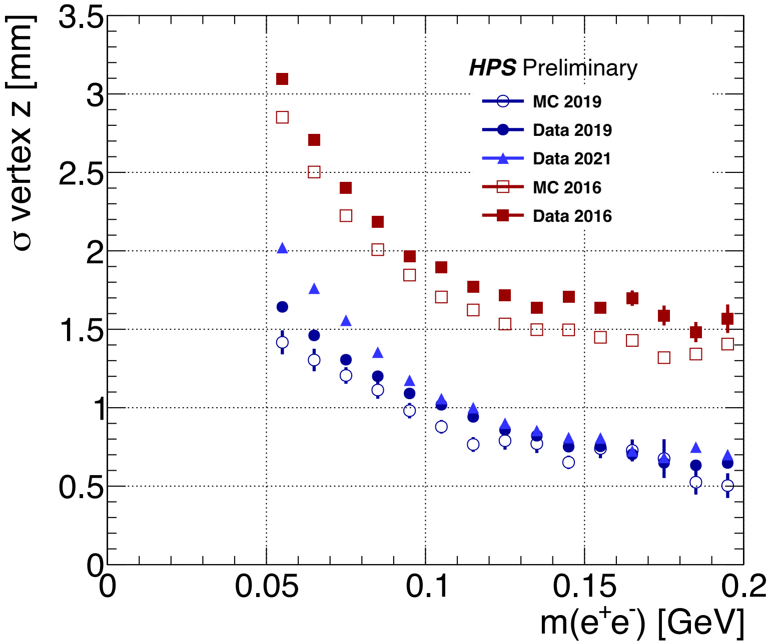
- Front layers show structures in the residuals that are hard to characterize by single sensor movements in the back
- Releasing all sensors that have an effect on MPII doesn't provide the correct solution
  - Even with constraints
- Improving these residuals might improve VTX resolution and structures in momentum resolution

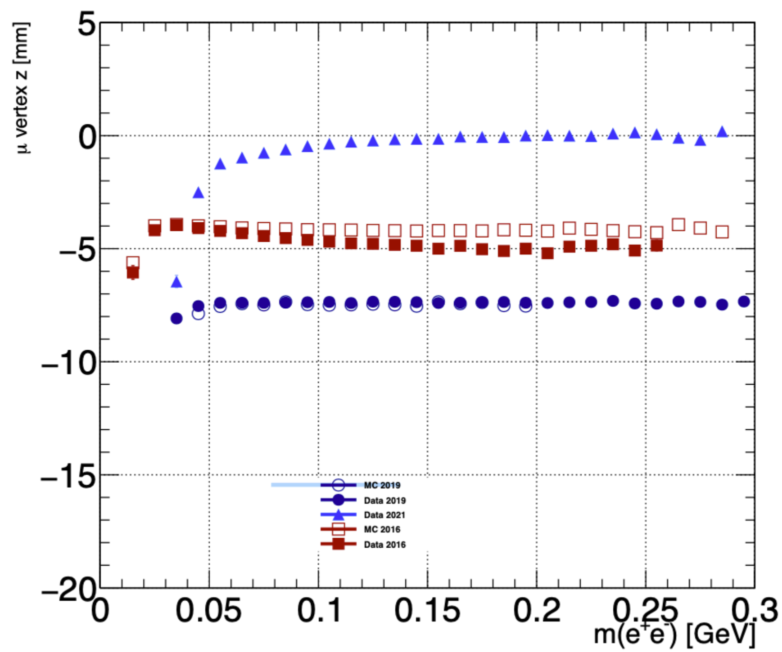






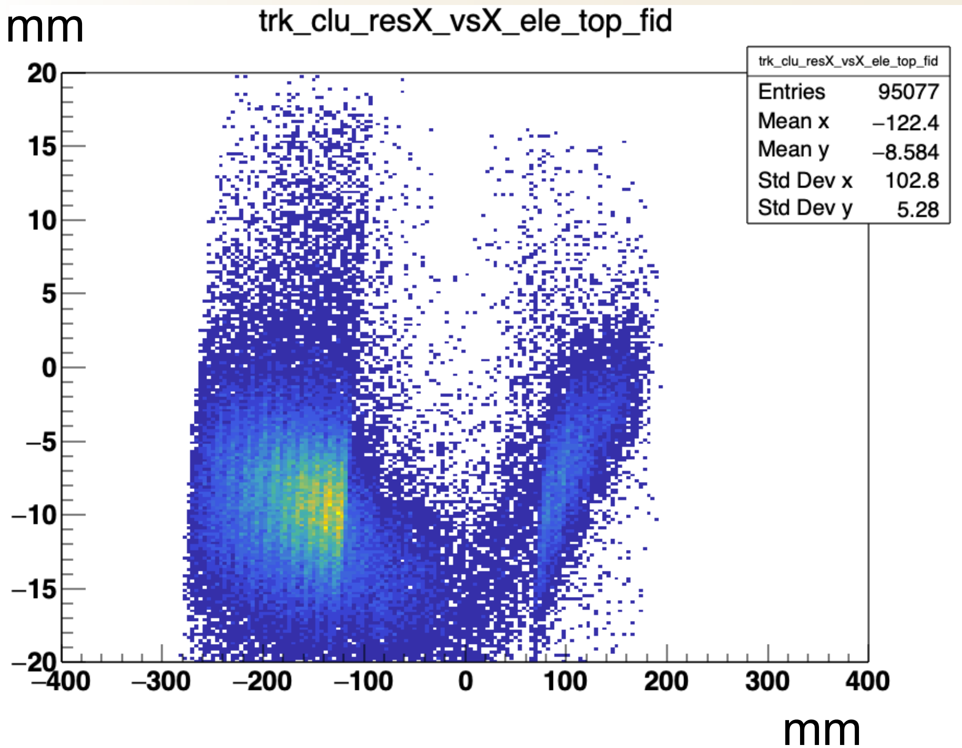
Vertexing side

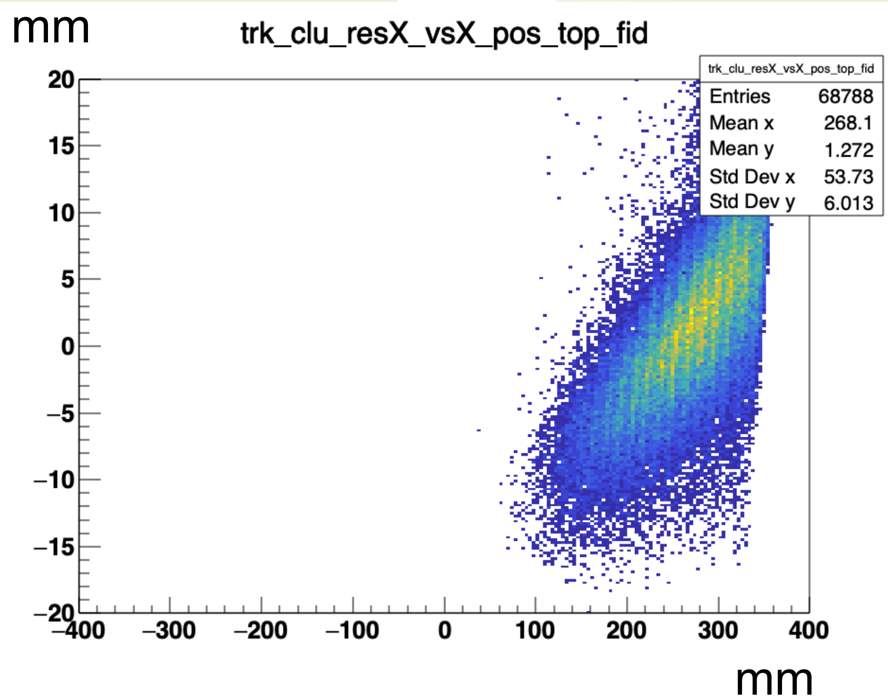




- 2019 shows good agreement in terms of resolution and mean of the distribution wrt to MC
  - Low mass drift at lower mean in data seems in agreement with MC simulation
  - Expected to be due to L1L1 hit requirement effects and not misalignments
- 2021, shows flat behavior at high masses, steep drift in mean at low masses.
  - To be investigated in principle, not a problem if we don't focus in that region.
- 2021 MC not present in vertexing resolution plot due to un-expected good resolution (couldn't find the plot but procedure to reproduce is fully documented here
- 2019 MC has low statistics and would be important to check these plots with higher stat for PAC in July.

Calorimeter side





- Track - cluster matching still shows issues in all the 2019 tags
- Here shown Pass3-v1
- Observed in e+/e-, with different biases

Current left-over issues and some (personal) ideas

- **Current open issues in 2019 detector**
  - **Dedicated pass on bottom volume**
    - Mostly focused on top volume as that expresses worse momentum resolution performance.
    - However doesn't look worse than 2021 dataset when compared without last sensitive layer
  - **Improve residual shapes for top volume**
    - Potentially improve vtx and E/p resolution
  - **Check time stability**
    - Has been shown that the detector is stable for the full run in 2021
    - Time dependence of the solution wasn't checked in 2019, we should do it
  - **Tracks to cluster residuals**
    - Detector still exhibits biases in track to cluster matching for 2019, this is even after correcting the extrapolation to ECAL
    - Could add ECAL cluster position to track fit and get derivatives, tricky but feasible, or just correct in the matching tool
- **Current procedure issues for both 2019 and 2021**
- **Investigate why MPII minimization provides wrong results**
  - Running MPII on sensors that cause innermost layers residual structures doesn't fix the biases. This shouldn't happen in principle and the source of this issue is not clear
  - A possible cause is strongly non-uniform illumination of the sensors:
    - Define procedure to accept tracks that illuminate uniformly our sensors could be a possibility to remove this effect. (Tim)
      - Get first the on-sensor hit distribution
      - Load the distribution in hps-java and throw a random number accordingly
      - Throw away tracks according to 1./ pdf
- **2016 didn't suffer of some of the effects observed in 2019/2021 alignment**
  - New addition are the innermost layers. Maybe try an alignment removing the innermost layers from the track finding and once alignment of mid-back is done, re-introduce them one by one.

Conclusions

- Presented snapshot of recent work on 2019 alignment compared with 2021
- In few of the metrics reached comparable performances
- Some issues remain such as:
  - Time dependence, cluster-track matching still has biases, bottom residuals to be improved, shapes in the residuals still showing internal misalignments…
- Vertex resolution and mean in agreement with MC simulation
- Vtx pSum for 2019 dataset should be re-checked for July PAC with new alignment tag

Conclusions

- Presented snapshot of recent work on 2019 alignment compared with 2021
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- Vertex resolution and mean in agreement with MC simulation
- Vtx pSum for 2019 dataset should be re-checked for July PAC with new alignment tag
- Unfortunately I do not expect to be involved much (at all?) in the coming efforts regarding these endeavors.

- I feel privileged to have worked with you all and thankful for having had the opportunity to meet you and get to know this experiment and collaboration

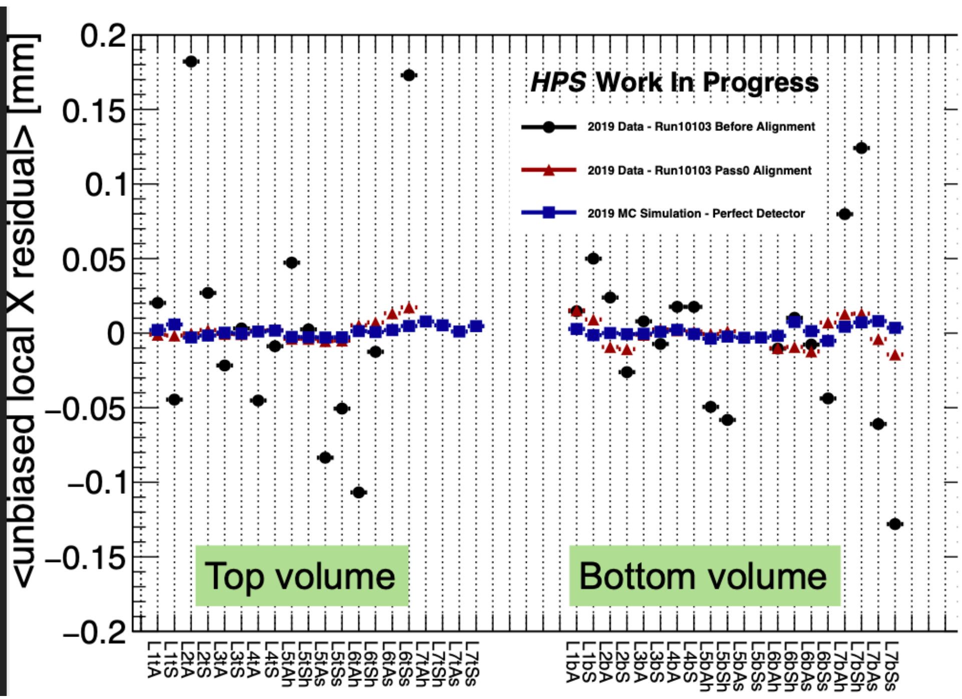
BACKUP

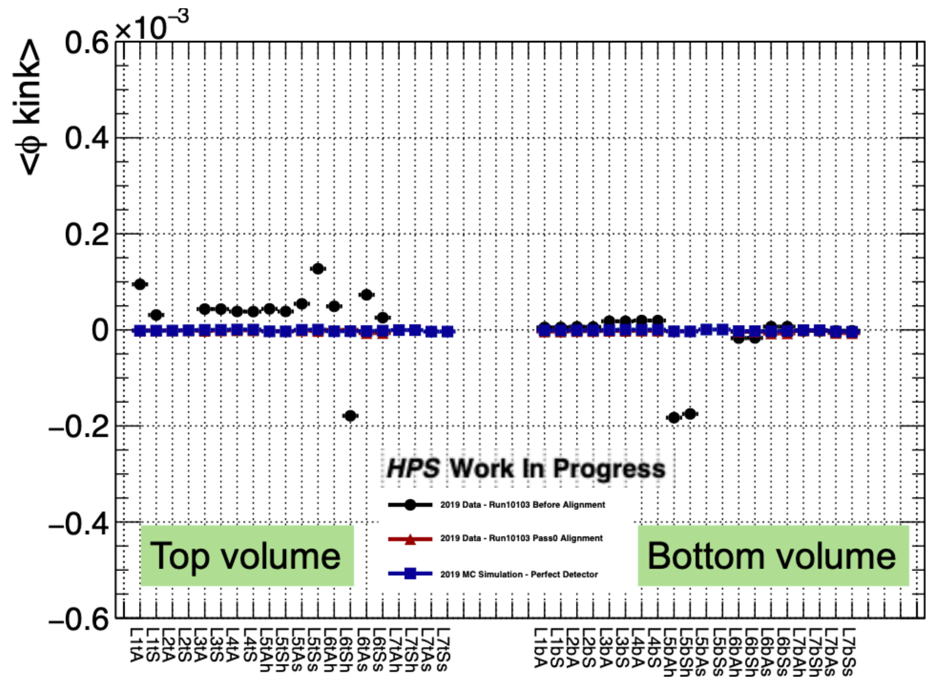
Introduction

- Proposal of new baseline constants for 2019 dataset
  - Focus on procedure documentation and motivation for each step
  - Comparison with current alignment tag, May 2019 constants
- General performance of 2019 alignment on FEEs
  - Did not have time to produce plots for e+/e- for today
  - If people agree with the reasoning behind today's presentation, will do next days
- Move to 2021 dataset

Recap of the general performance of "official" tag

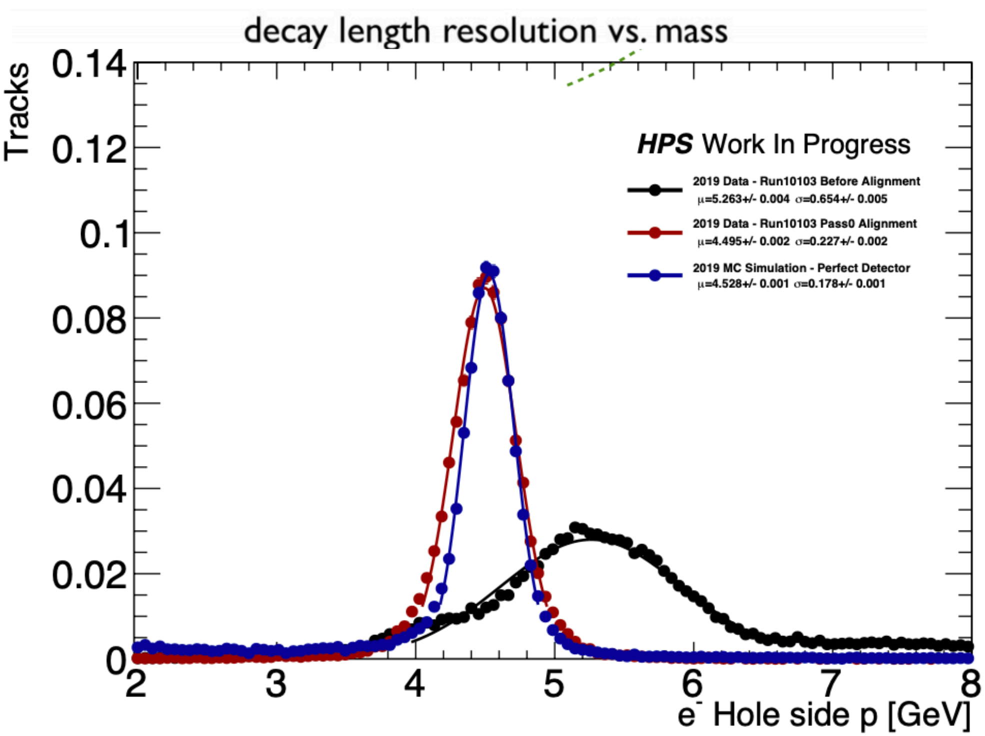
- The "official" tag, i.e. what is in hps-java and can be used out of the box has been derived in 2020 from FEEs (mostly) with some corrections for e+/e- data
- Provides an aligned detector in terms of residuals / kinks.

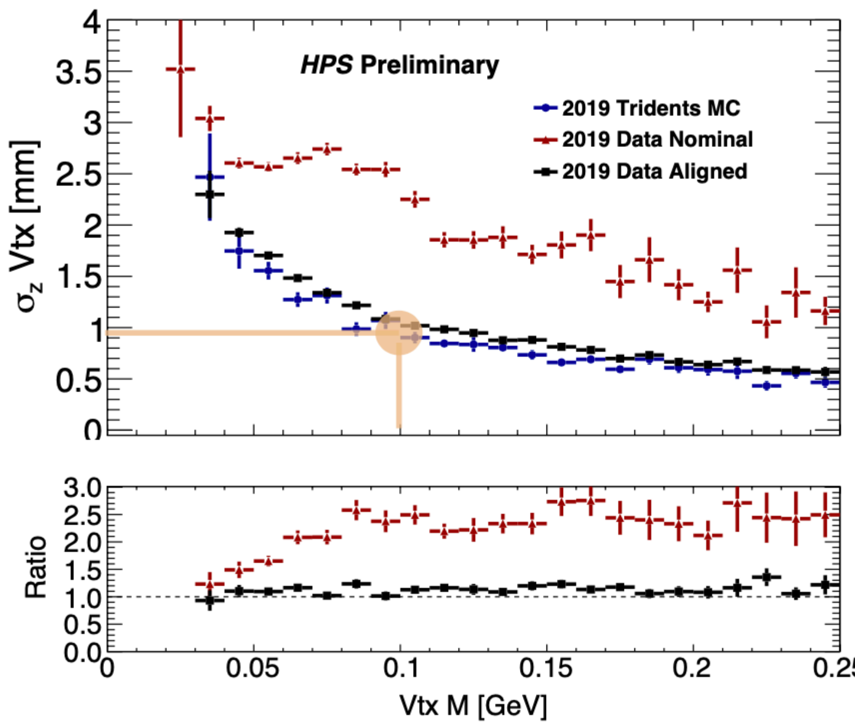




Recap of the general performance of “official” tag

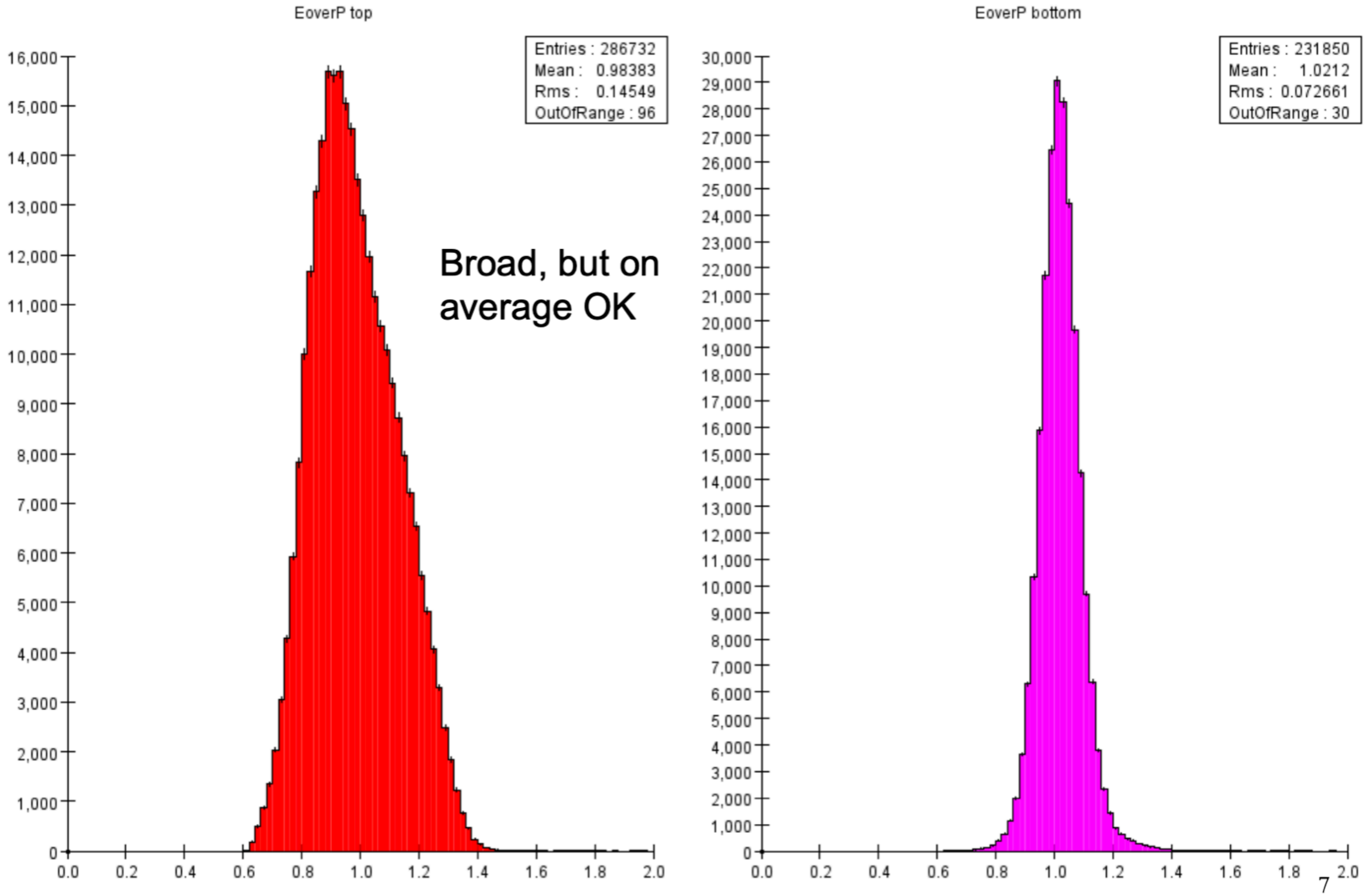
- Provides almost the expected resolution on vtx_z from MC (within 10%)
- As well as close resolution in momentum wrt MC simulation





Recap of the general performance of "official" tag

- However characterized by bad momentum resolution in the top volume
- 2% bias / 7% resolution Bottom volume, 2% bias / 14% resolution top



Recap of the general performance of "official" tag

- Such resolution is considered unsuitable for analysis and need to be corrected
- This lead to the efforts in improving the alignment constants for top volume in the past several months

- We followed few strategies:
  - **Change of alignment starting point**:
    - Dedicated revisit of the HPS design and create a geometry that carefully reproduces that (**HPS_TimDesign_iter0**)
    - Revisit / crosscheck and recomputation of the survey constants for 2019 (Summarized by Sarah) to produce a new geometry starting point (**HPS_ShimShoSurvey_iter0**)
  - Multiple alignment **procedural changes** including reproduction of 2016 steps, different / mixture of FEE + e+/e- datasets, hierarchical alignment from global structures first

Re-Alignment strategy for 2019

- From 2020 alignment tag 2 new starting points have been used to re-align 2019 data
  - Nov ’22: As Design detector
  - ~Sep’ 23: Surveyed detector
- A summary of the procedures is given

Re-Alignment strategy for 2019

SLAC

- 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
```

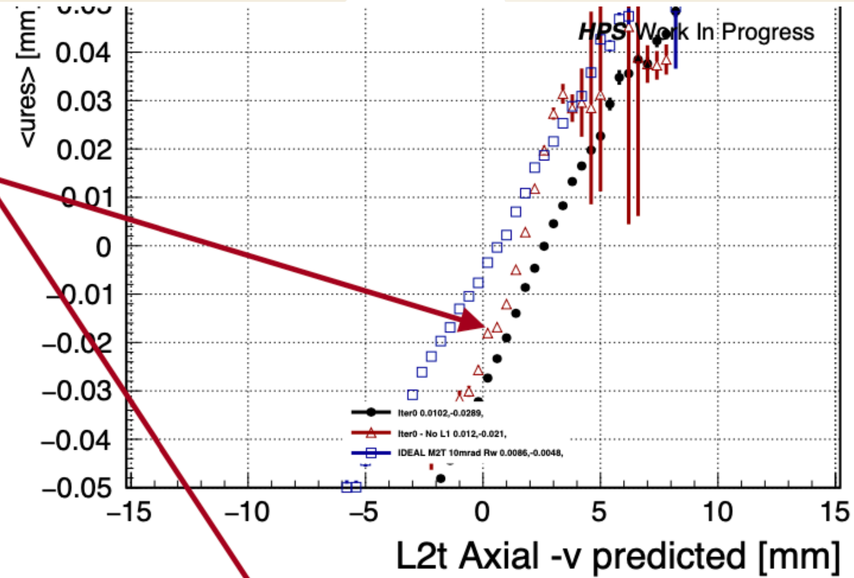
Rotations of Innermost sensors

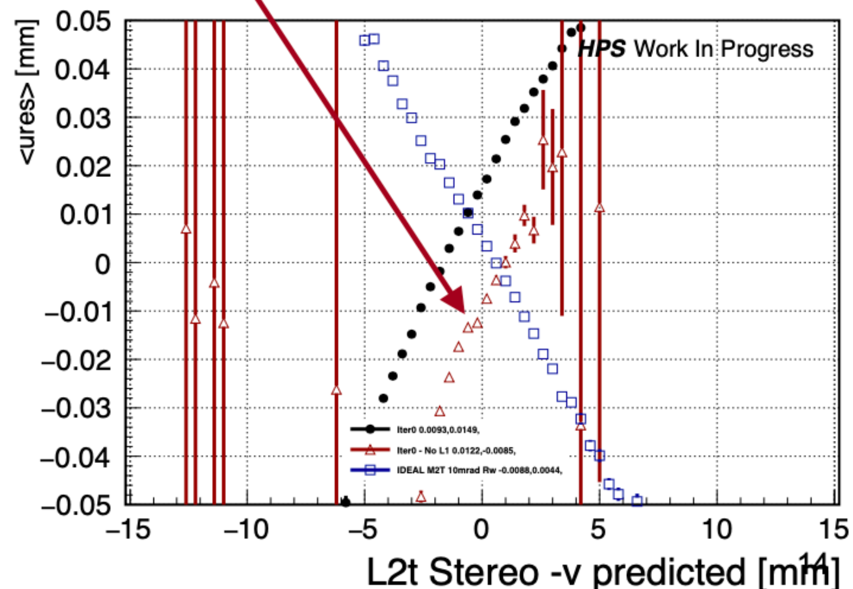
- The trends are present in similar form in both the tracks found with and without L1top
  - **Slope also present when L1 is removed**
- **It cannot be a full module Rw as previously suggested:**
  - **Opposite slopes for Stereo and Axial in that case**
  - Tested on ideal MC + 10mrad Rw of M2T module

2019 corrections. Stereo sensor ~ 8-10mrad rotation

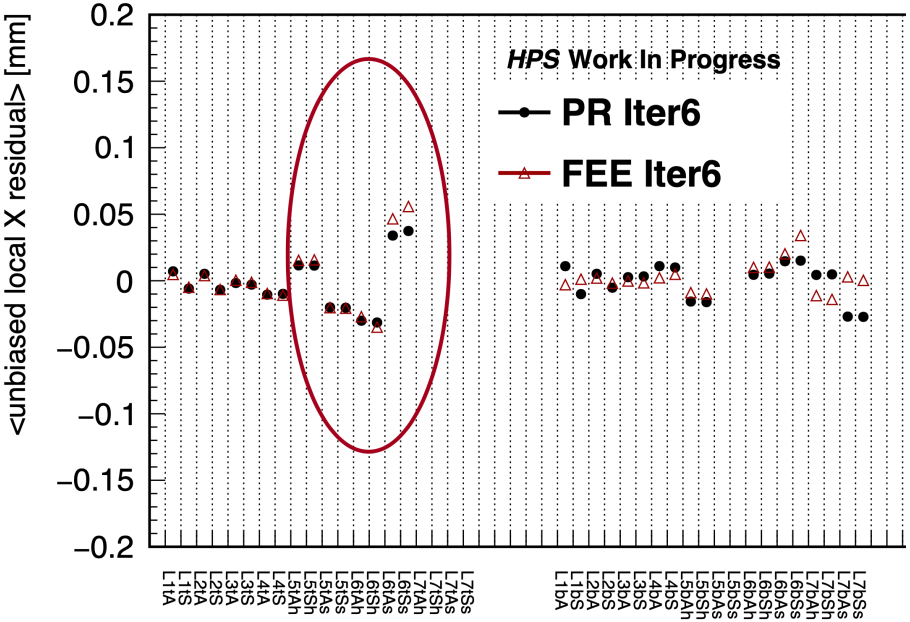
```
<millepede_constant name="12301" value="0.0 - -0.002500 - -0.001700" />
<millepede_constant name="12302" value="0.0 - -0.004700 - -0.001600" />
<millepede_constant name="12303" value="0.0 - -0.008000 - -0.000200" />
<millepede_constant name="12304" value="0.0 - -0.008000 - -0.000900" />
```

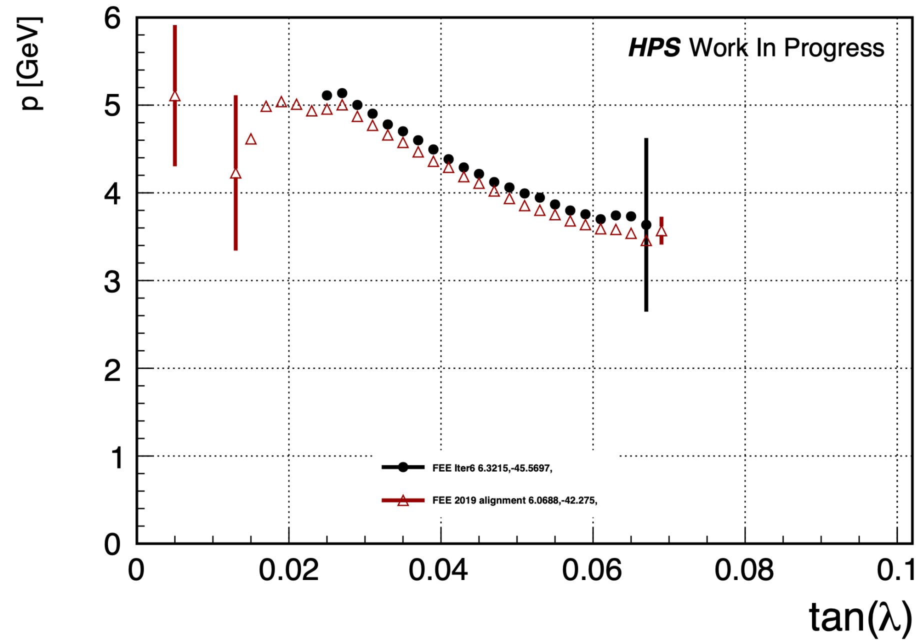
```
<millepede_constant name="22301" value="0.0 - -0.008033 - -0.001779" />
<millepede_constant name="22302" value="0.0 - 0.003447 - 0.001482" />
<millepede_constant name="22303" value="0.0 - -0.011274 - -0.001217" />
<millepede_constant name="22304" value="0.0 - 0.005886 - 0.001047" />
```





Results from Design

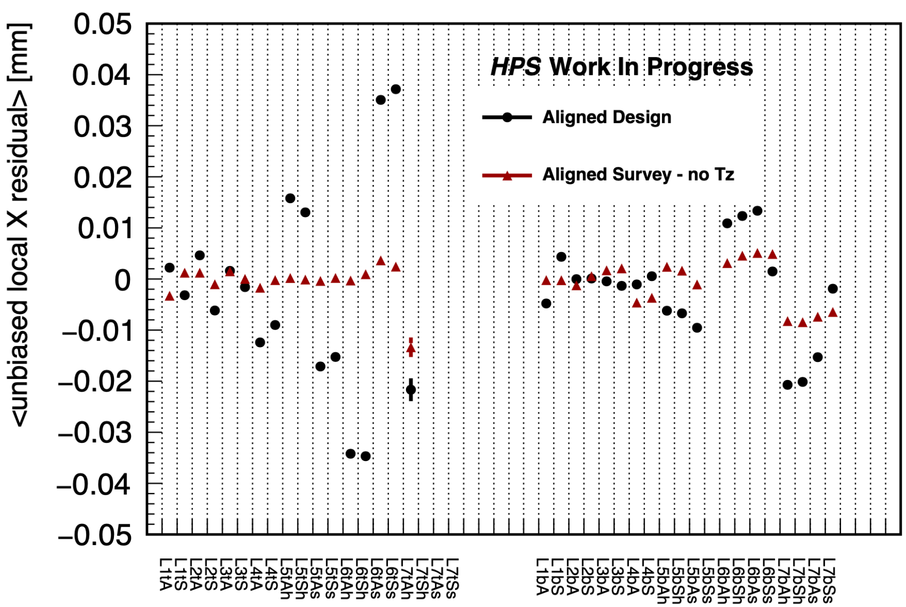


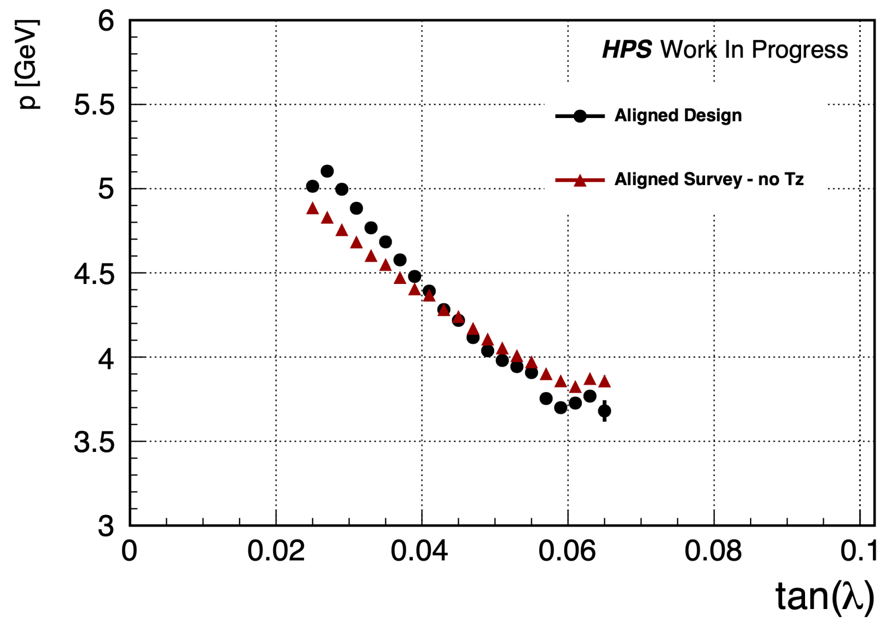


- A Full report on the procedure given in May Collab Meeting
- Residuals are due to resu vs tanL dependence
- **No sizeable improvement on previous iteration re-using 2020 constants.**

Re-alignment from Survey

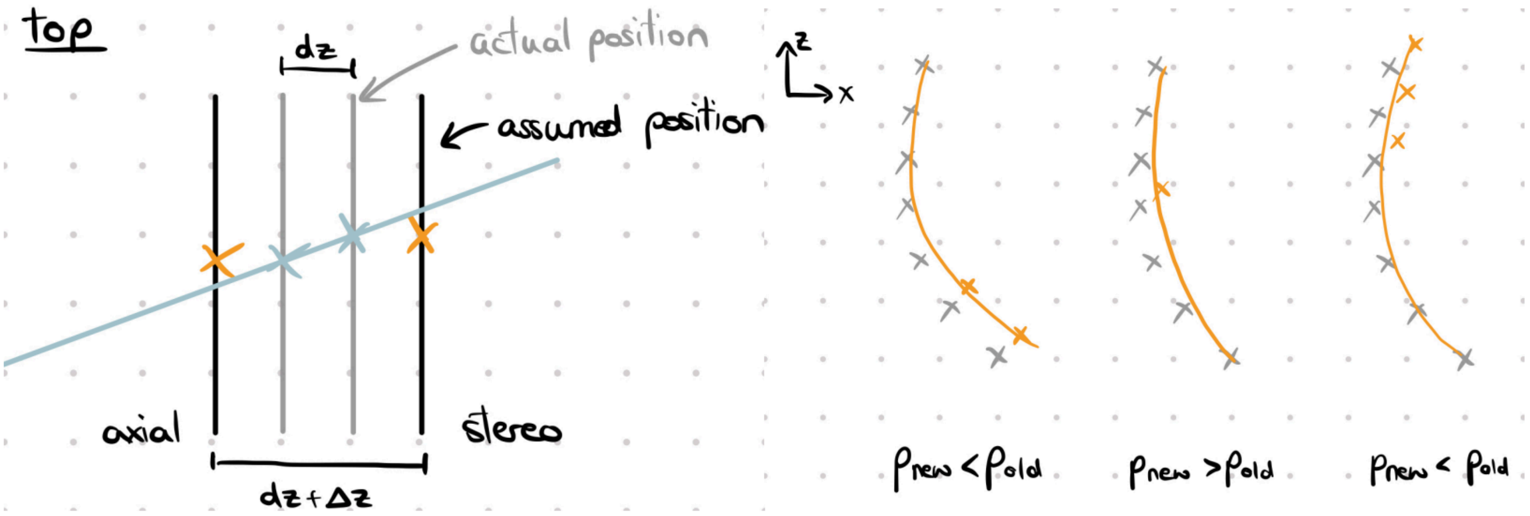
- The re-alignment on survey focuses on the fact that survey sensors positions are known and Innermost Sensors positions are largely unknown.
- Perform alignment of innermost sensors first, then move to back sensors
  - Improve detector residuals and track parameters with BS + MomC
- **Perfect residuals in top volume, marginal improvement on momentum slope**





Effects of increased sensor separation on curvature

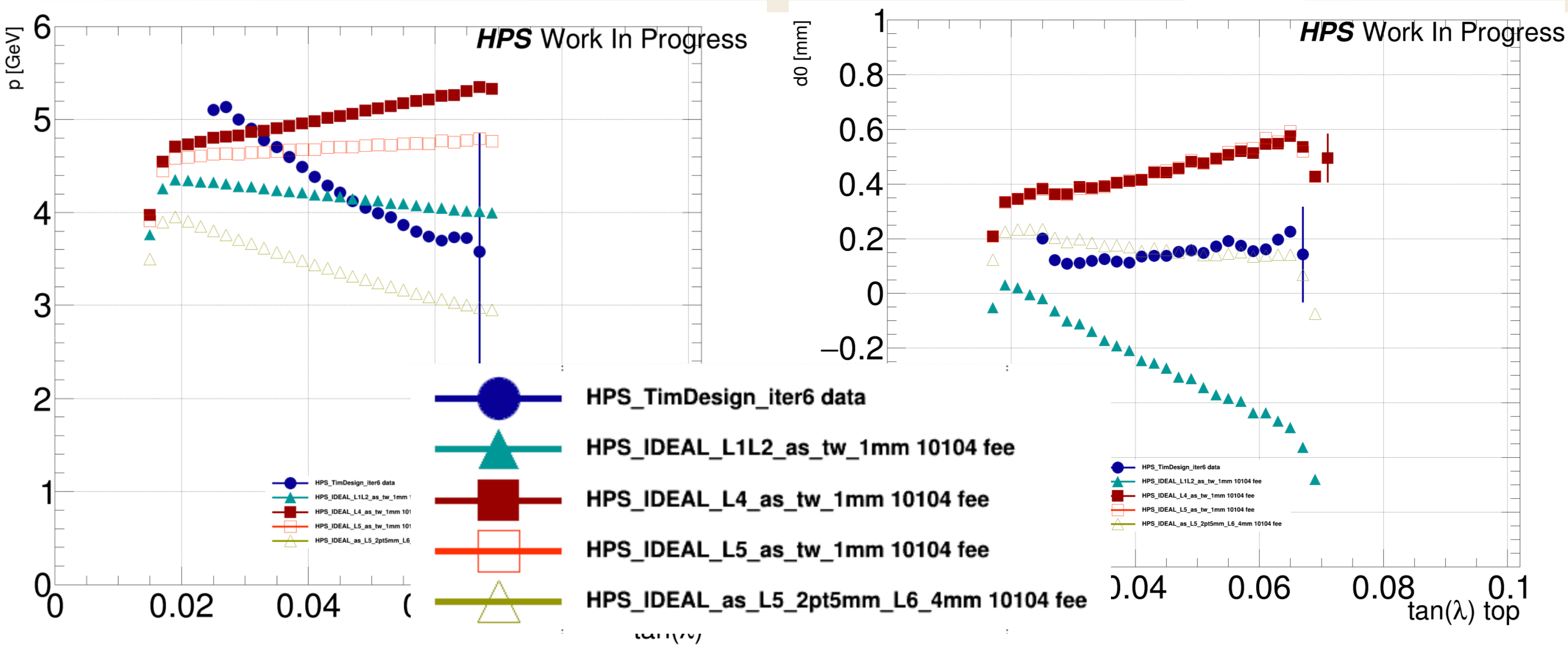
SLAC



Sarah

- Actual position of sensors and hits (grey and blue) and reconstructed position with misaligned detector (black and orange)
- Decrease of reconstructed $\|\tan\lambda\|$ and ϕ
- Movements in front and back $\rightarrow$ increase of curvature, movements in middle $\rightarrow$ decrease of curvature

Effects of increased sensor separation on curvature

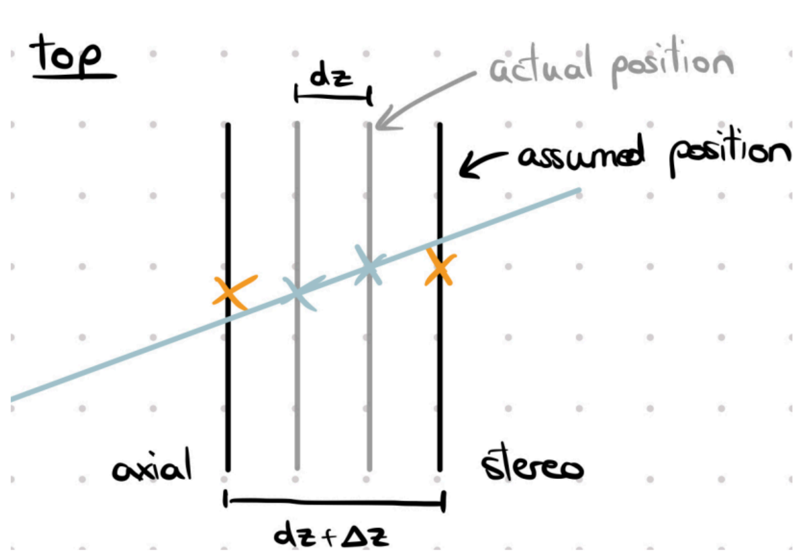


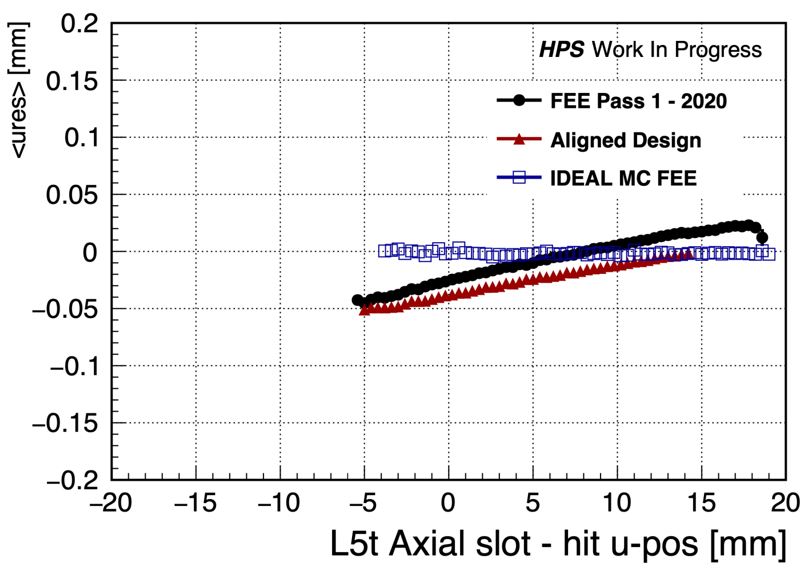
- Movements out of plane will have effects on curvature as well as d0 as function of tanL
- Rotations in rW of stereo sensors do not produce the same results
  - O(4mrad) Rotations of L1L2 stereo do not produce similar d0 vs tanL (backup)
  - O(mrad) Rotations of L5L6 in rw do not produce similar p vs tanL (backup)

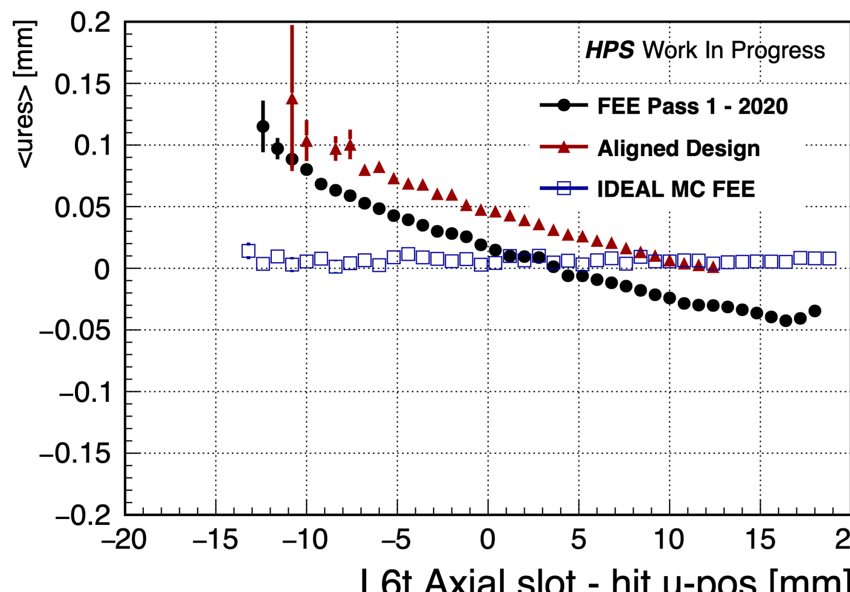
Additional evidence of out of plane misalignments

SLAC

- Additional evidence for out of plane misalignment is given by the presence of residual trends as function of tanL (or hit measured position on layers)







Difficulty to align out of plane

- Our tracks are basically perpendicular to the sensors
  - tanL ~ 0.02
- This means that dR/dTw ~ tanL << 1, leading to large possible corrections
- A large Tw will have minimal impact on Chi2: definition of weak mode
- Additionally releasing multiple sensors at once free the telescope scale resulting in ~ singular matrix in the linear system

- Chi2 approach
- Symmetric real matrix, always diag
  - Eigenvectors correspond to coherent movements of sensors
- In this example I moved all the back layers from L3-L6 in u/w

```
Store              3 : low-value end of eigenvalues
      stored n-tuples:              16
          1    1.000000        0.7091320E+10
          2    2.000000        0.6890340E+10
          3    3.000000        0.2592552E+10
          4    4.000000        0.2048553E+10
          5    5.000000        0.7688589E+09
          6    6.000000        0.1521045E+09
          7    7.000000        0.4009384E+08
          8    8.000000         3264373.
          9    9.000000         539056.9
         10    10.00000         524527.5
         11    11.00000         204057.8
         12    12.00000         153961.9
         13    13.00000         60010.82
         14    14.00000         12762.64
         15    15.00000         3774.473
         16    16.00000         401.6375
```

- Eigenvalues span across 8 orders of mag
- **Eigenvector 12 poorly constrained**
  - **Weak mode, corrections unreliable**
  - $\sigma_{corr} \sim 1/\lambda_{corr}$

Difficulty to align out of plane

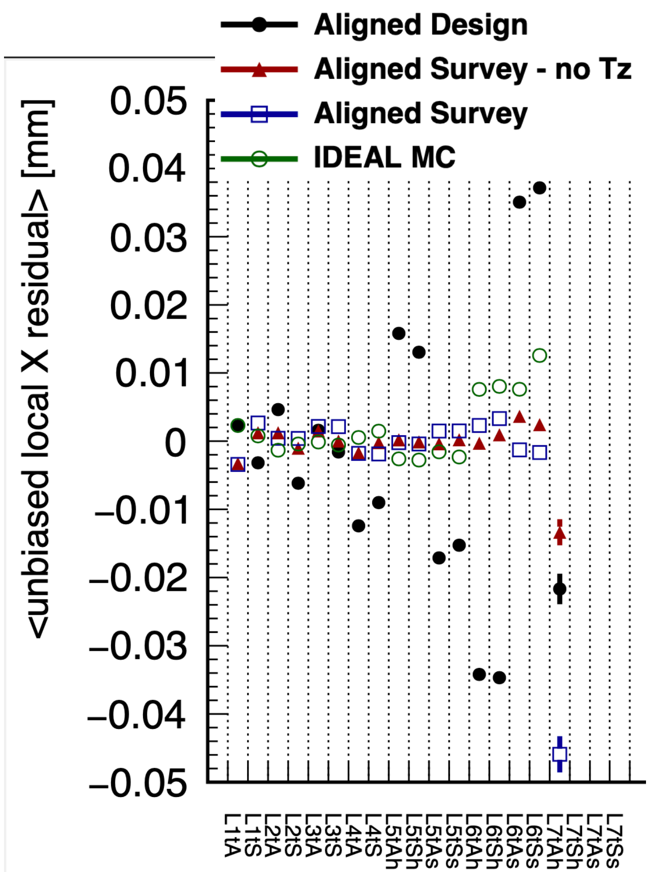
- **Challenge in 2019 alignment:**
  - No strong mode Tu/Rw or linear combination of those across many modules provides complete correction of observed track parameter biases
    - **But again, I might have overlooked.**
  - Residuals strongly depend on tanL:
    - Physics and FEEs will have different residuals as they illuminate the detector differently in tanL
    - Indication of sizeable of plane distortions.
  - Not possible to align in one go out of plane due to weak modes
    - Even with Vtx / momentum constrain. Better with e+/e- but too low tanL anyway.

Procedure I followed

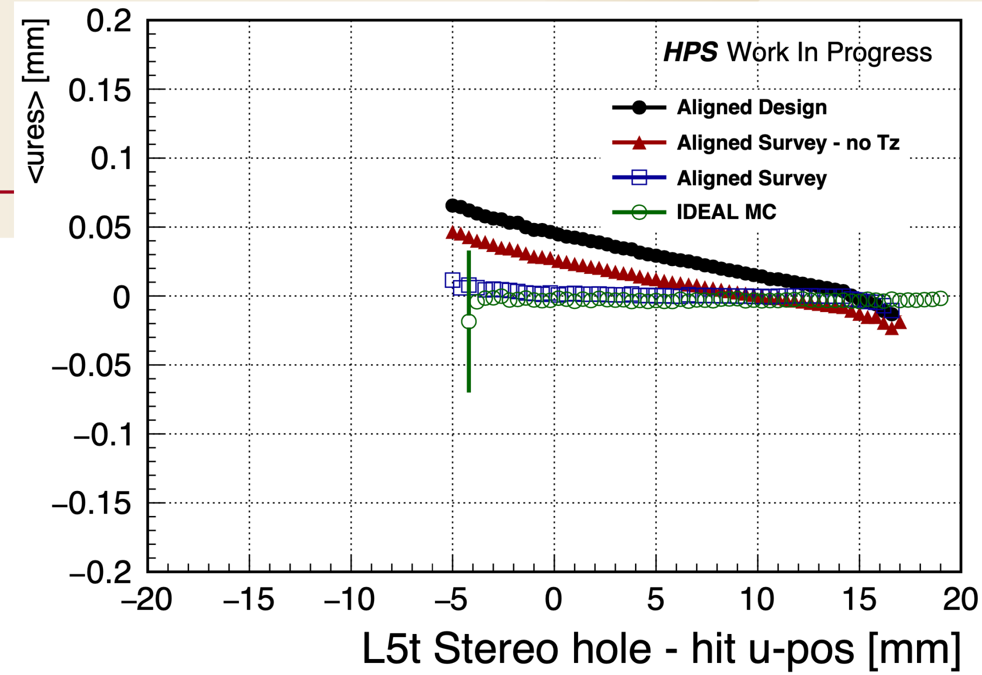
- **Used BS and P constraint assuming 4.55 GeV and -7.5 target**
- 1 - tu/rw/tw of L1-L2
  - This causes d0 vs tanL bias in Top
- 2 - tu/rw/tw of L4-L5
  - Use L123 and L6 to constraint Z scale
- 3 - tu/rw/tw of L5S + L6
  - Improve momentum
- 4 - tu/rw/tw of L1-L2
  - Reduce d0 bias (it takes out corrections from 1)

- **Final Tz corrections in backup**
  - **Up to 1mm in Stereo correction at ly6 (~1 / 700 correction to z scale)**
  - **Kept it as small as possible, doesn't fully correct the biases**

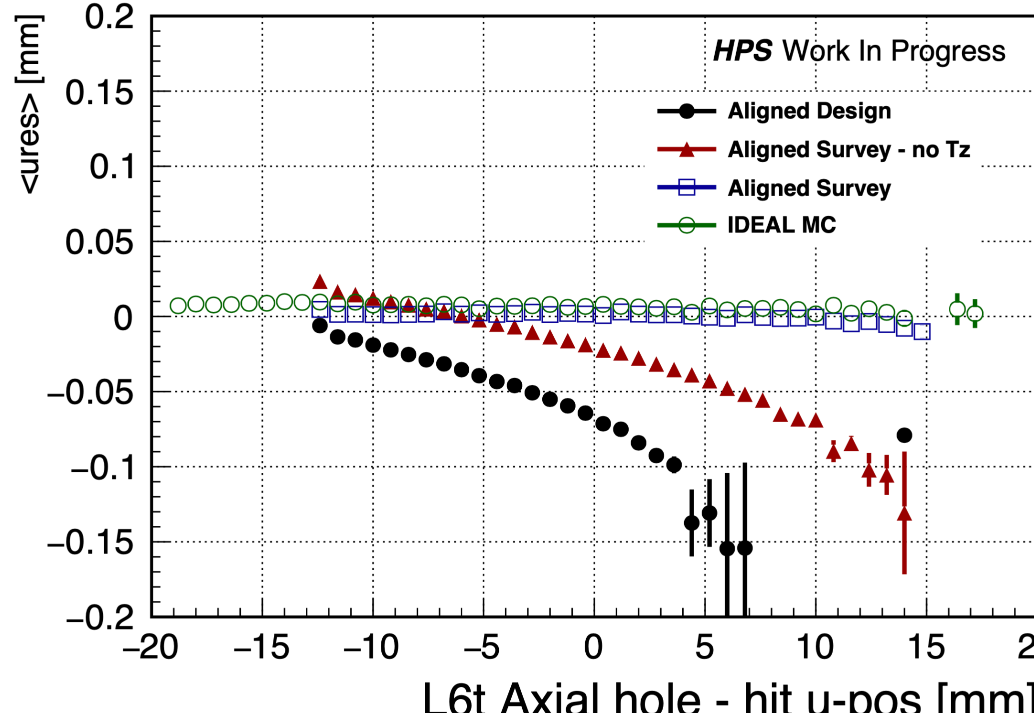
Results



Aligned Design
Aligned Survey - no Tz
Aligned Survey
IDEAL MC
<unbiased local X residual> [mm]
0.05
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
−0.04
−0.05
L1tA
L1tS
L2tA
L2tS
L3tA
L3tS
L4tA
L4tS
L5tAh
L5tSh
L5tAs
L5tSs
L6tAh
L6tSh
L6tAs
L6tSs
L7tAh
L7tSh
L7tAs
L7tSs

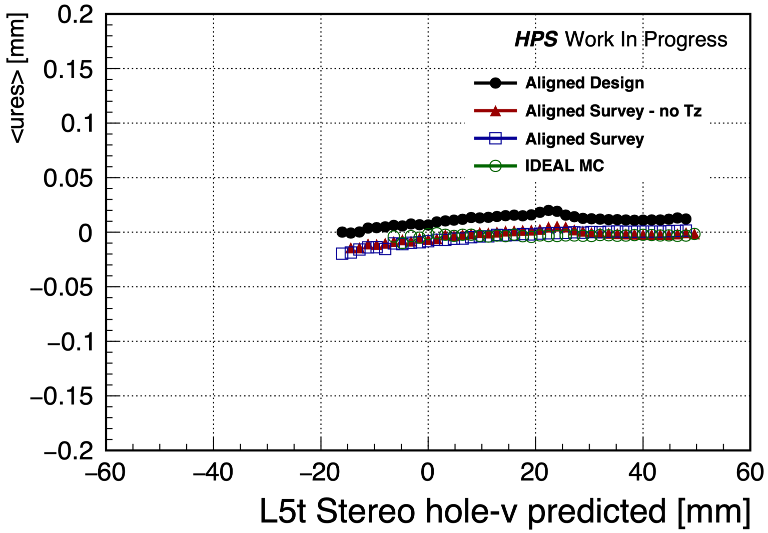


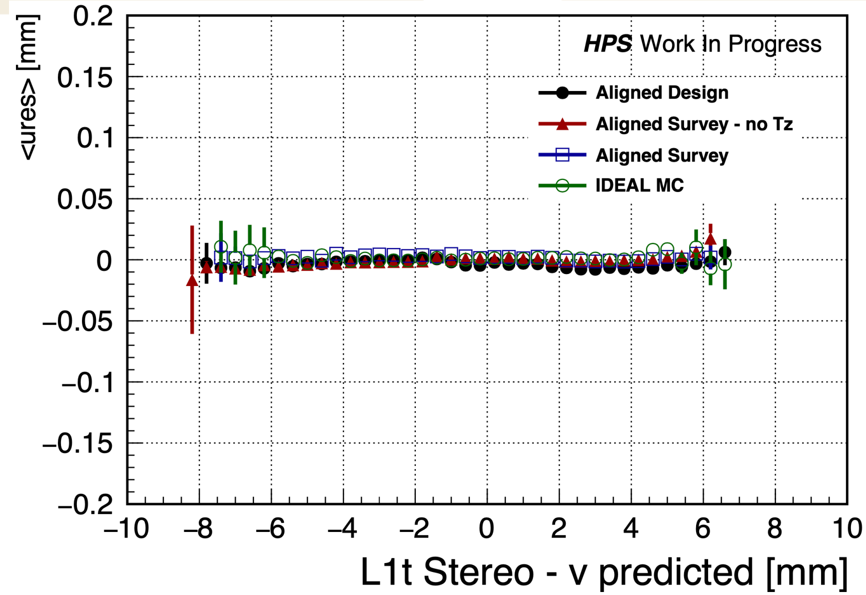
HPS Work In Progress
Aligned Design
Aligned Survey - no Tz
Aligned Survey
IDEAL MC
<ures> [mm]
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−20
−15
−10
−5
0
5
10
15
20
L5t Stereo hole - hit u-pos [mm]

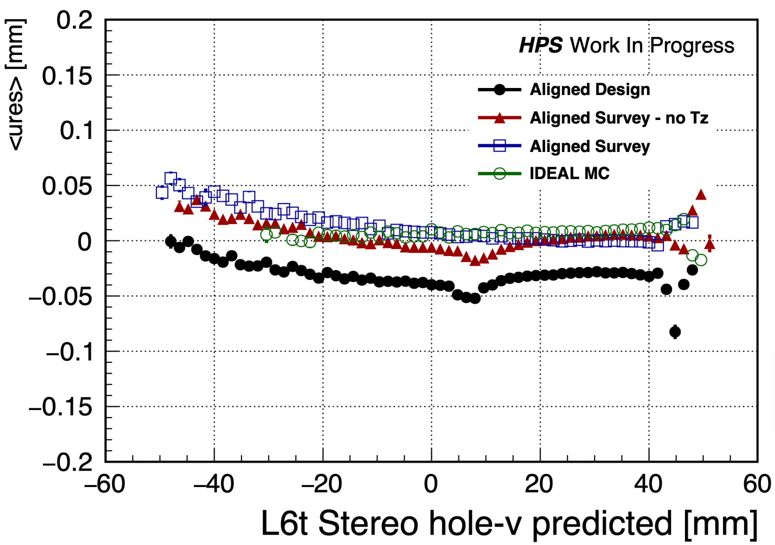


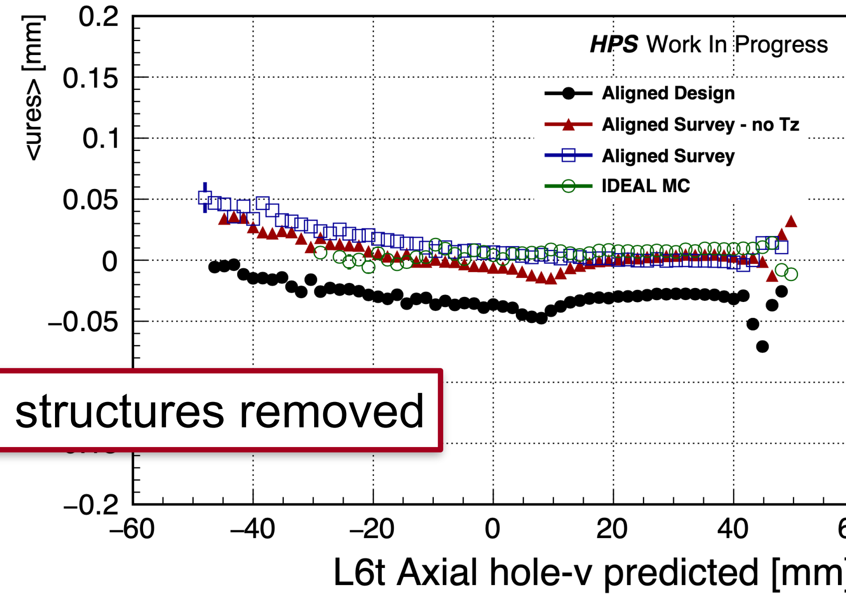
HPS Work In Progress
Aligned Design
Aligned Survey - no Tz
Aligned Survey
IDEAL MC
<ures> [mm]
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−20
−15
−10
−5
0
5
10
15
20
L6t Axial hole - hit u-pos [mm]

Results





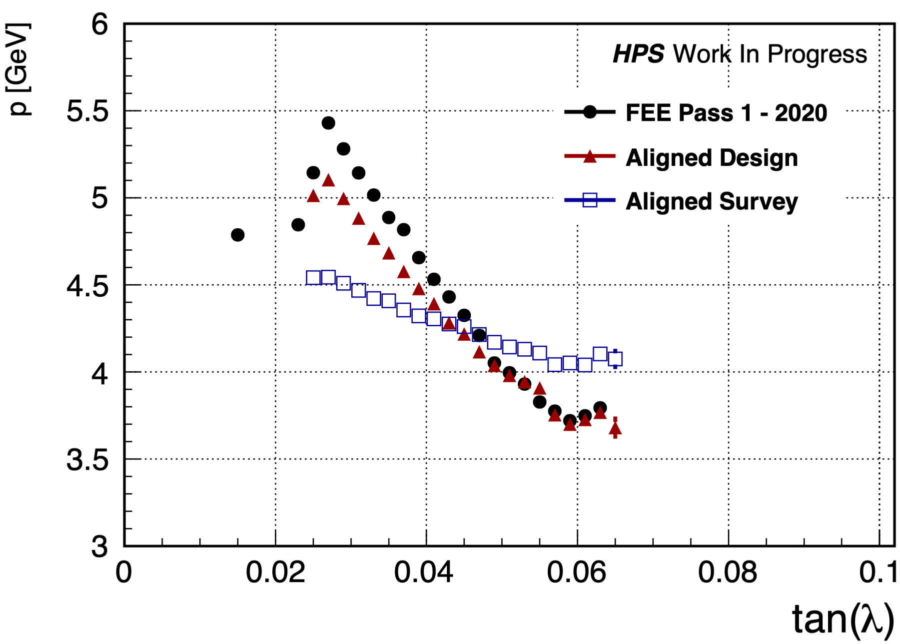


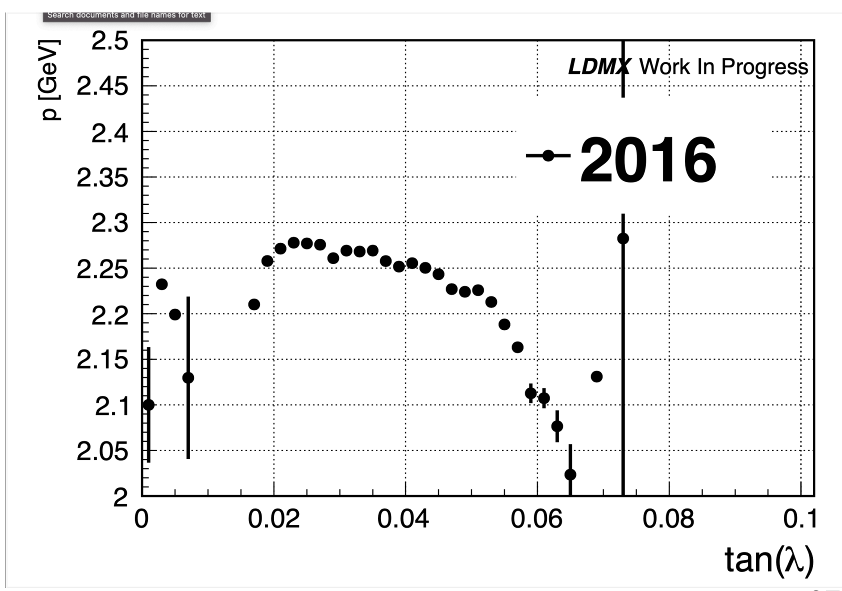


V shape structures removed

Momentum Biases

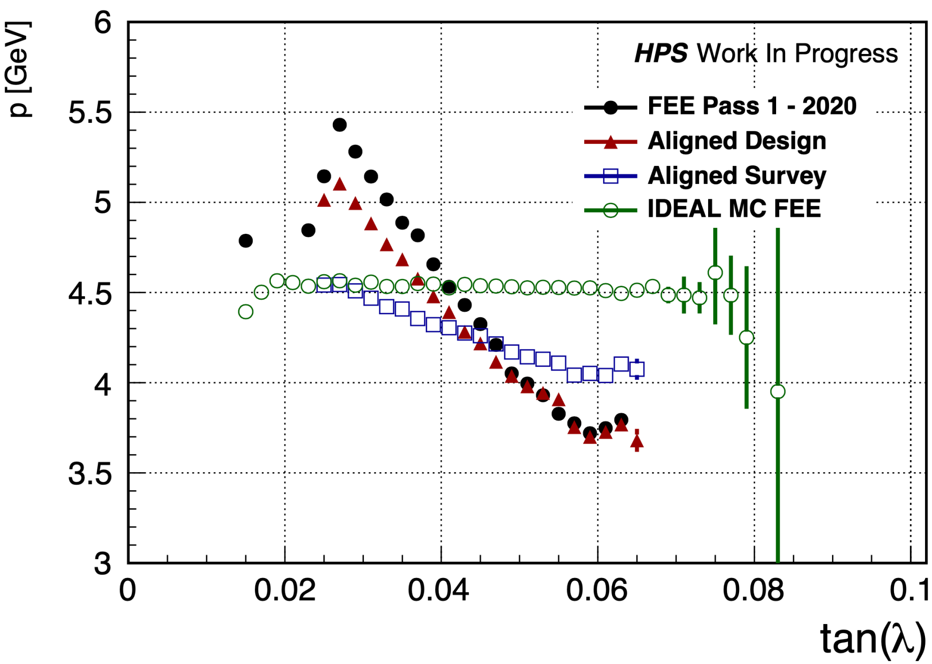
- After the re-alignment procedure on Surveyed detector the momentum bias due to tanL is of the order of **~10% in [0.025, 0.06]** interval [4.5 to 4]
  - **FEE Pass 1 - 2020 was ~50%, ~30% in Aligned Design**
  - A dedicated look to 2016 run7800 shows ~6% [2.28 to 2.15]
- There is a left-over bias that can removed by simple translation of stereo sensors.

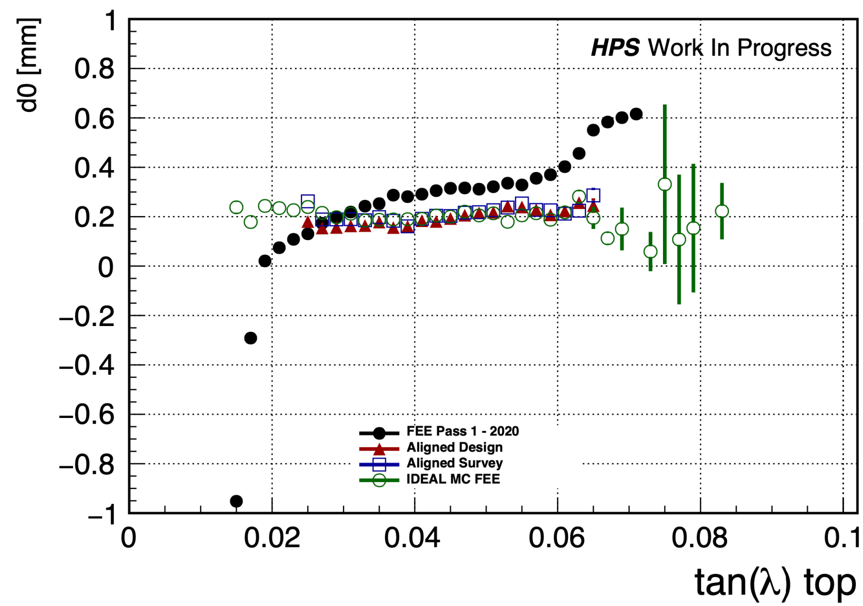




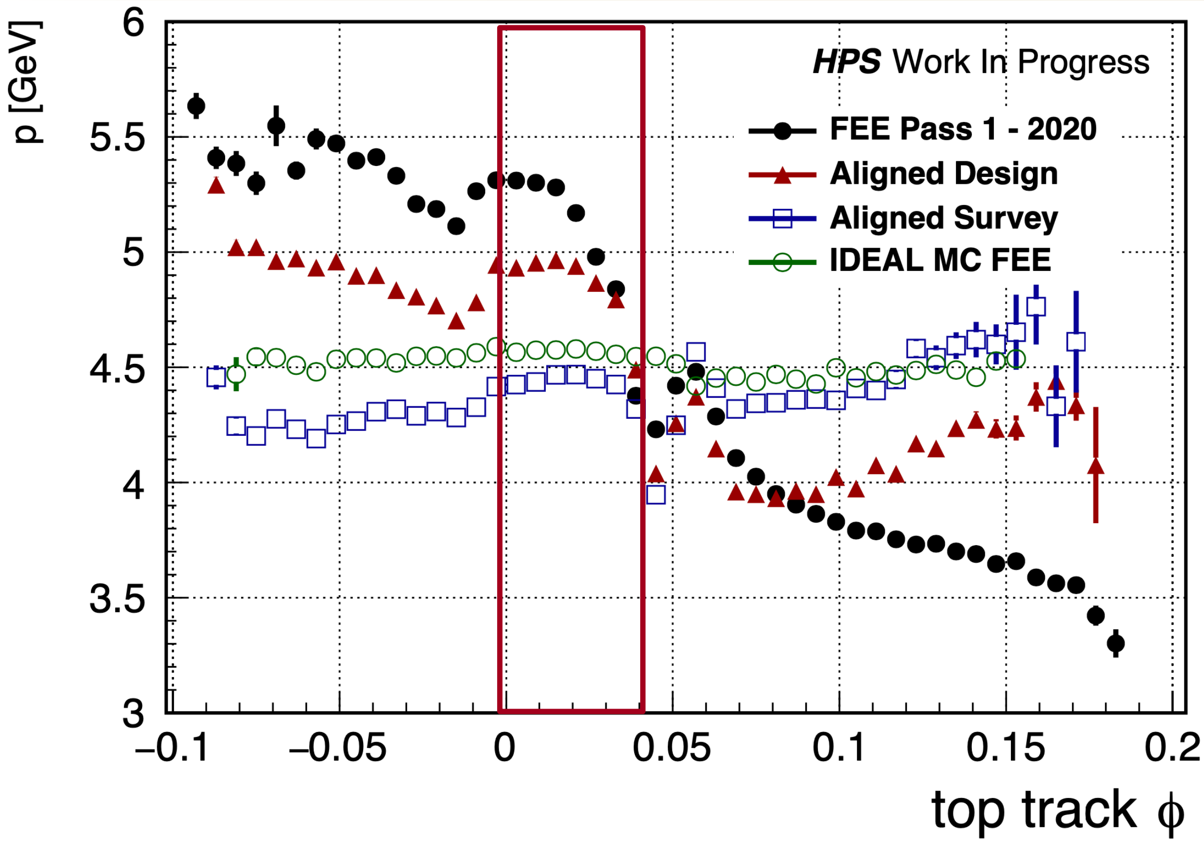
Momentum Biases

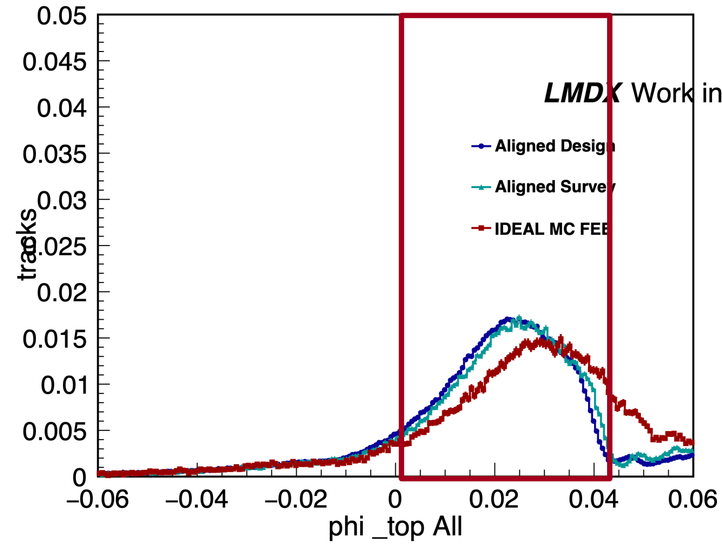
- There is some tension between p and d0
- As discussed it can be eliminated by moving stereo sensors in the front in w
- The **d0 is flat at 200um** corresponds to a target at -7.5 mm as shown by FEE MC. Momentum vs tanL is completely flat in MC.





Momentum Biases



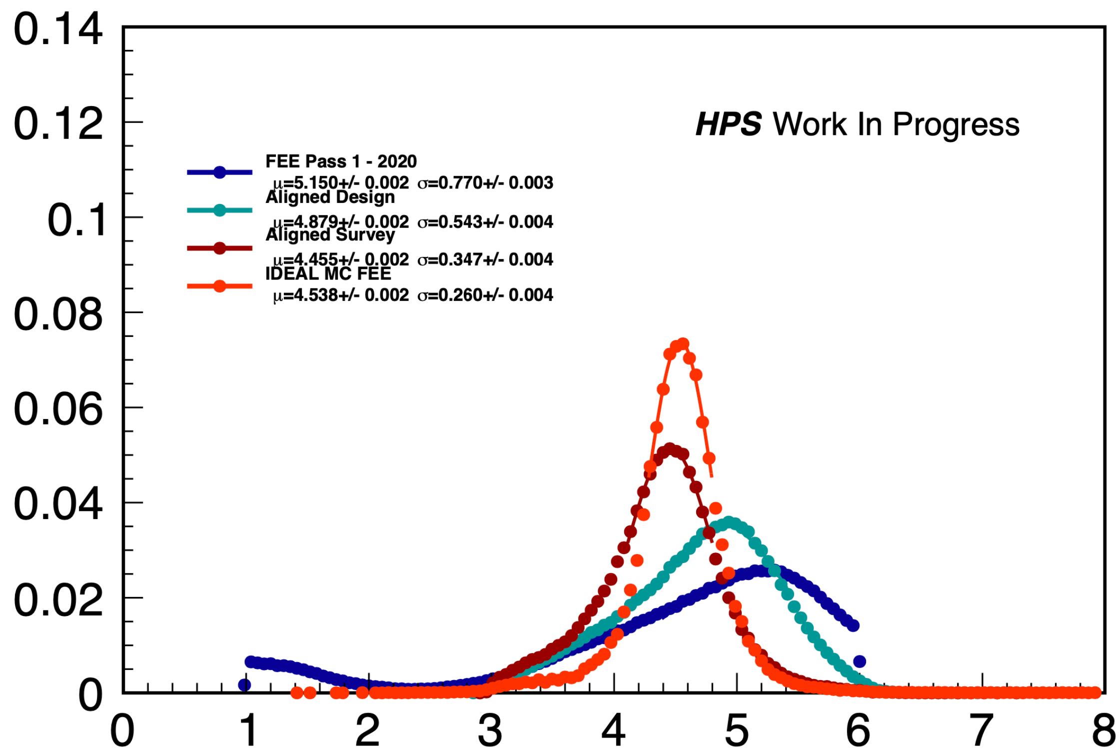


- Most of FEEs are central, phi biases don't matter too much in this study

- Phi dependence largely improved sensors wrt previous iterations
- Smoother MC at phi~0.05 due to >= 5 hits requirement instead of ==6
- Can be improved a bit in Data with additional work, or corrected in analysis by tanL/phi bias map.

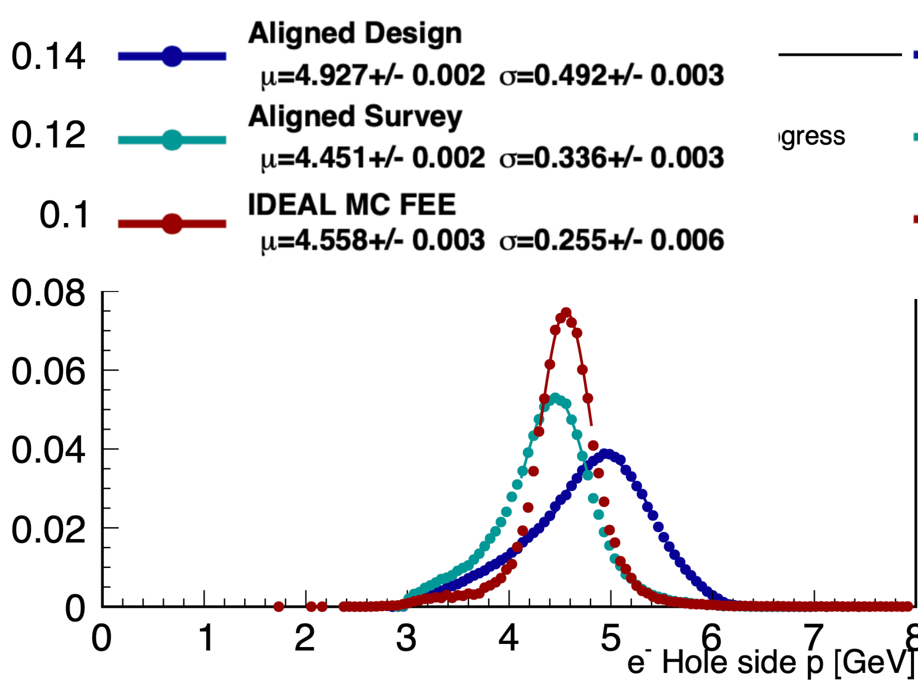
Momentum Resolution

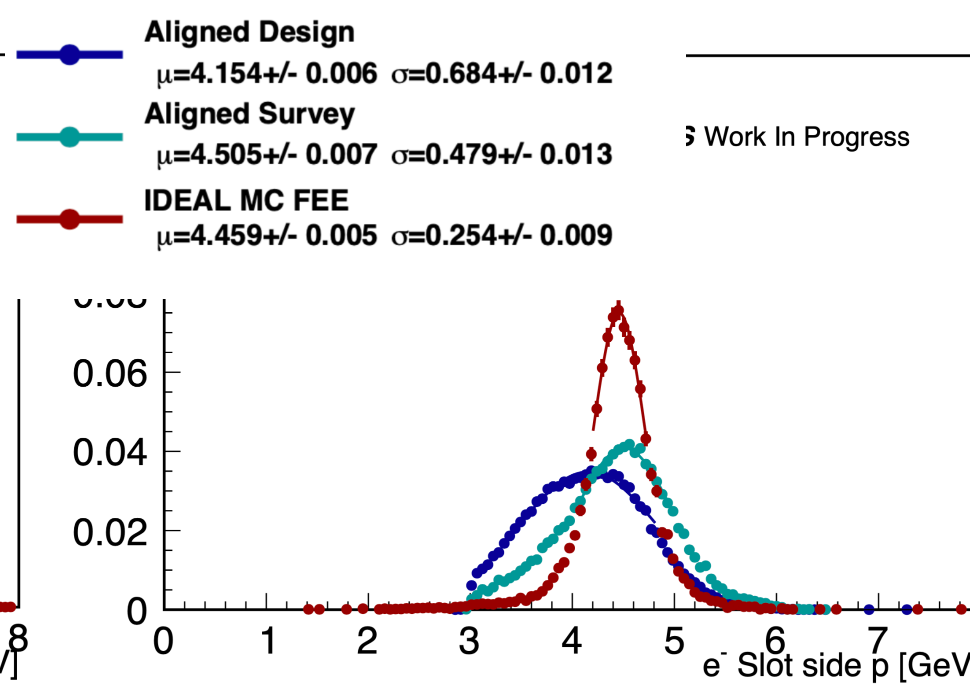
- Momentum resolution improved from 770 MeV to 350 MeV **(7.7% @ 4.55 GeV vs 5.7% in perfect MC)**
  - Data 35% worse resolution than MC, 50% in 2016.
    - Not fair comparison, different kinematic regimes and sources of uncertainties as discussed yesterday.
  - Known dependence from tanL can be removed during analysis.
- **2% bias wrt perfect MC can be removed by back layer translations**



SLOT / HOLE Momentum

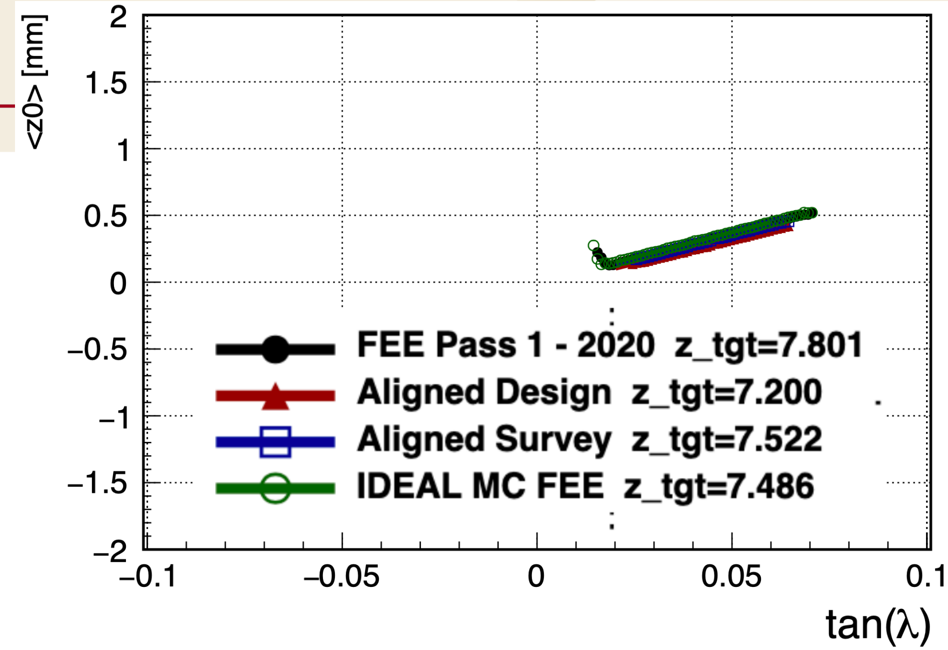
- Momentum scale compatible between Hole and slot side
- Resolution could be improved.
  - More difficult than hole side due to stat. More driven by phi dep than hole side
  - E/p on e+ probably helps

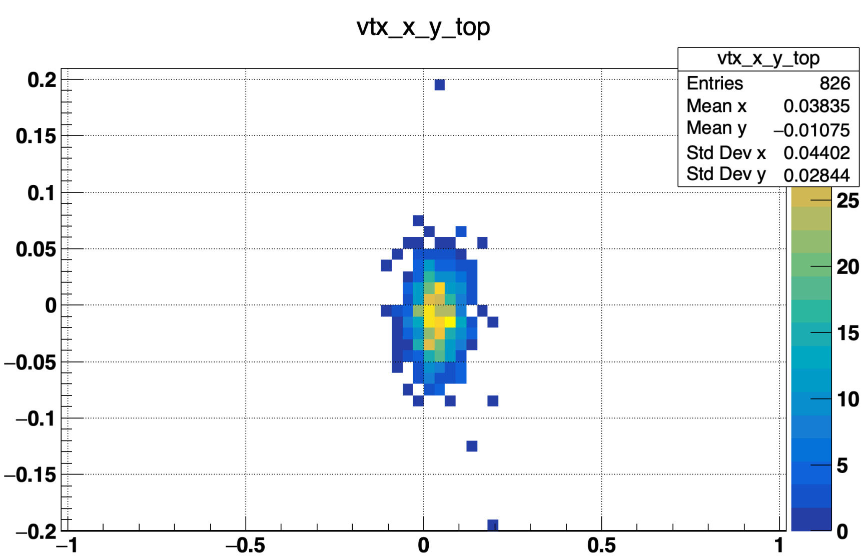


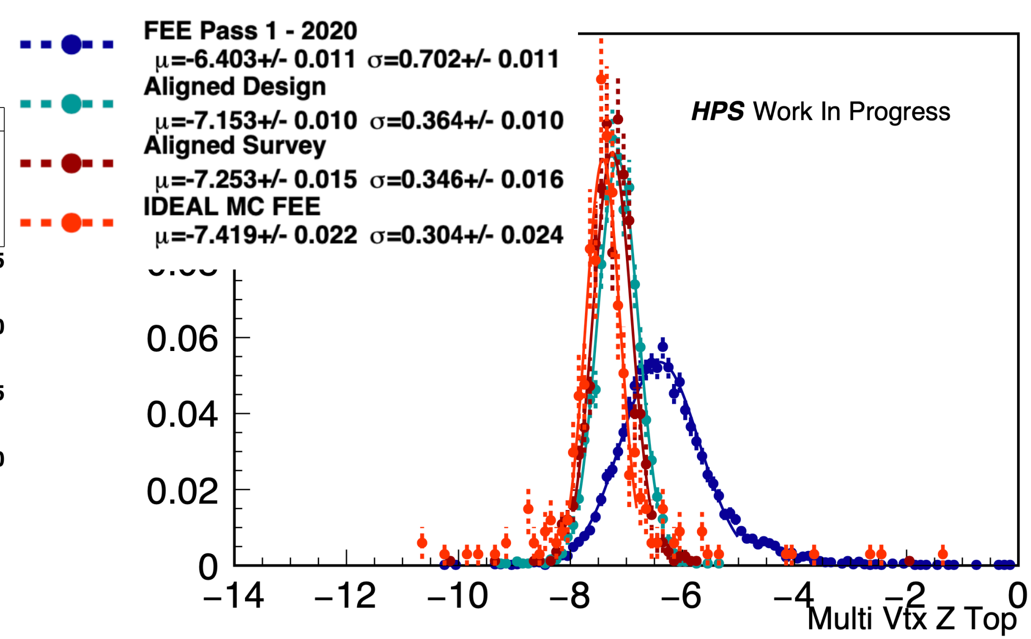


Vertex location

- Z0 vs TanL and multiVtx location provide compatible locations to the Z target
  - Discrepancy up to O(700-800um) between the methods observed in the past







Summary

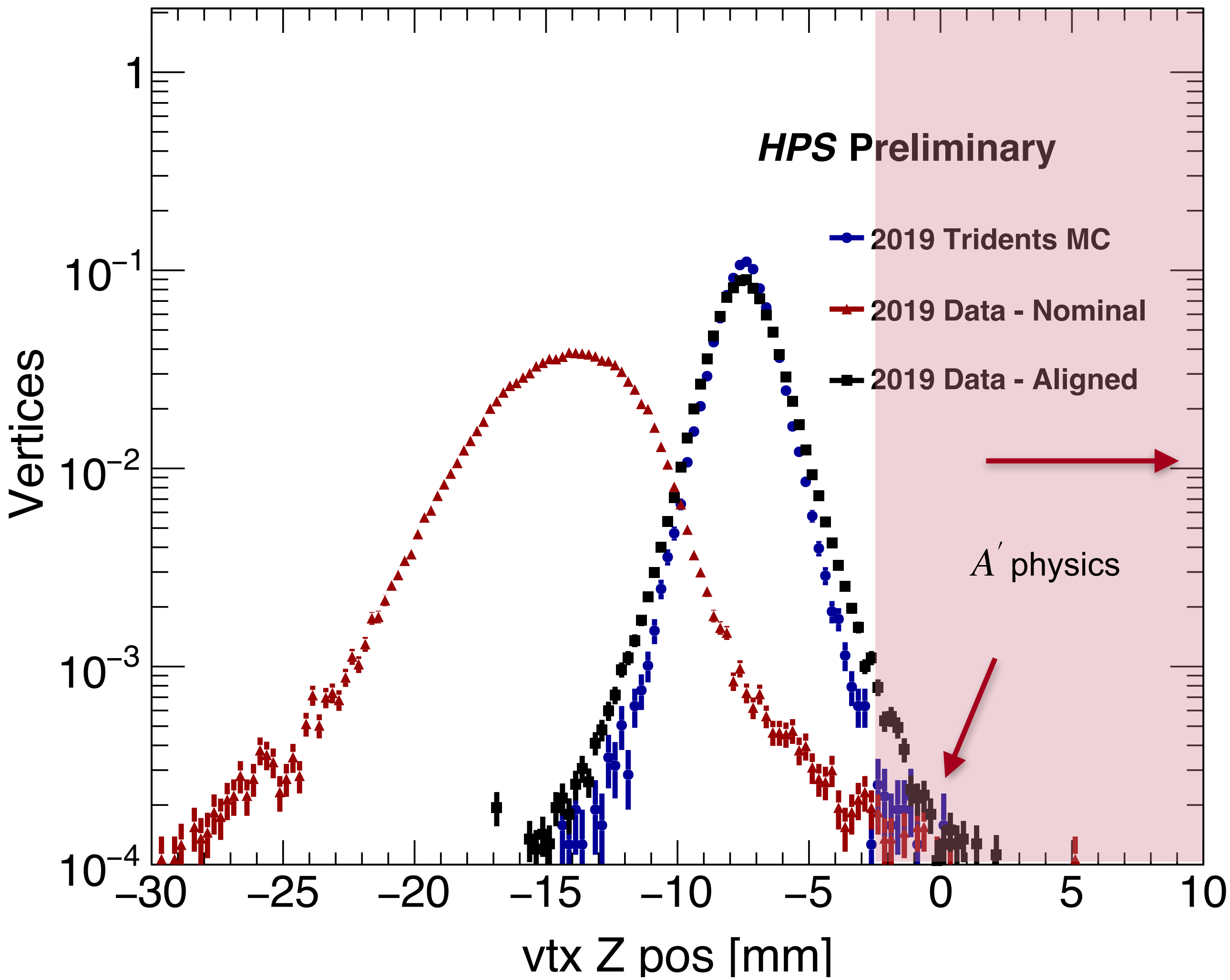
- The p vs tanL in 2019 seems like it's a pretty though bias to be removed
- Difficult detector deformation that could be :
  - **Real**: Some misalignment of the detector arisen at a certain point or sensors out-of-plane deformations
  - **Fictitious**: Introduced by our reconstruction or all single alignment procedures followed in the past years (I lost count how many I did)
- I am arriving at the exhaustion of my ideas
  - Larger corrections can be done to fully recover the bias if wanted
- Solution found provides not perfect, but in my view, acceptable performance as well as a procedural approach on how to improve it further
  - Fixes can be done also from analysis side.
- **Necessary next steps:**
  - **Validate on e+/e-**
  - **Apply same approach to bottom**
- **Release, some run-by-run studies, move to 2021**

Some personal thoughts

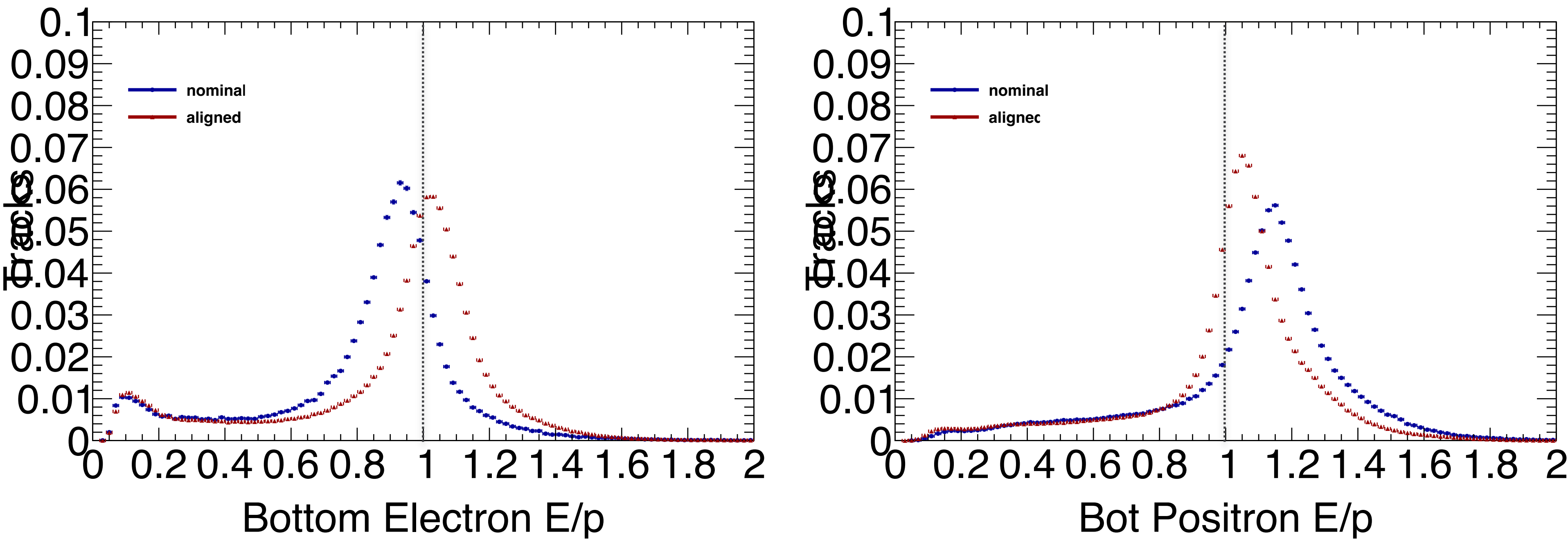
- I found the HPS detector difficult to align to a satisfactory degree of performance using standard minimization procedures.
  - Of course, this might just be me

- Things that can be improved in advance wrt 2025
  - 2019 alignment was performed concurrently with major changes in reconstruction code and suffered of loss of continuity with previous iterations
  - Simulation studies before jumping on trying to solve the pressing issue
  - Better calibration / standardized samples
    - Norman worked in this direction but I think we could do better.
      - **Multi run e+/e- sample with flat tanL distribution would be useful**
  - Poor degree of trust on relative axial-stereo measurements
    - Would benefit to have that so modules can be aligned as composite structures (providing 3D point info).
  - Other experiments will be tackling this challenge (sPhoenix, ATLAS Itk, FASER..) we should share tools more
  - **Document things in an useful and comprehensive way**
    - A special mention to Sarah and Tom here.

2019 - Vertex distribution

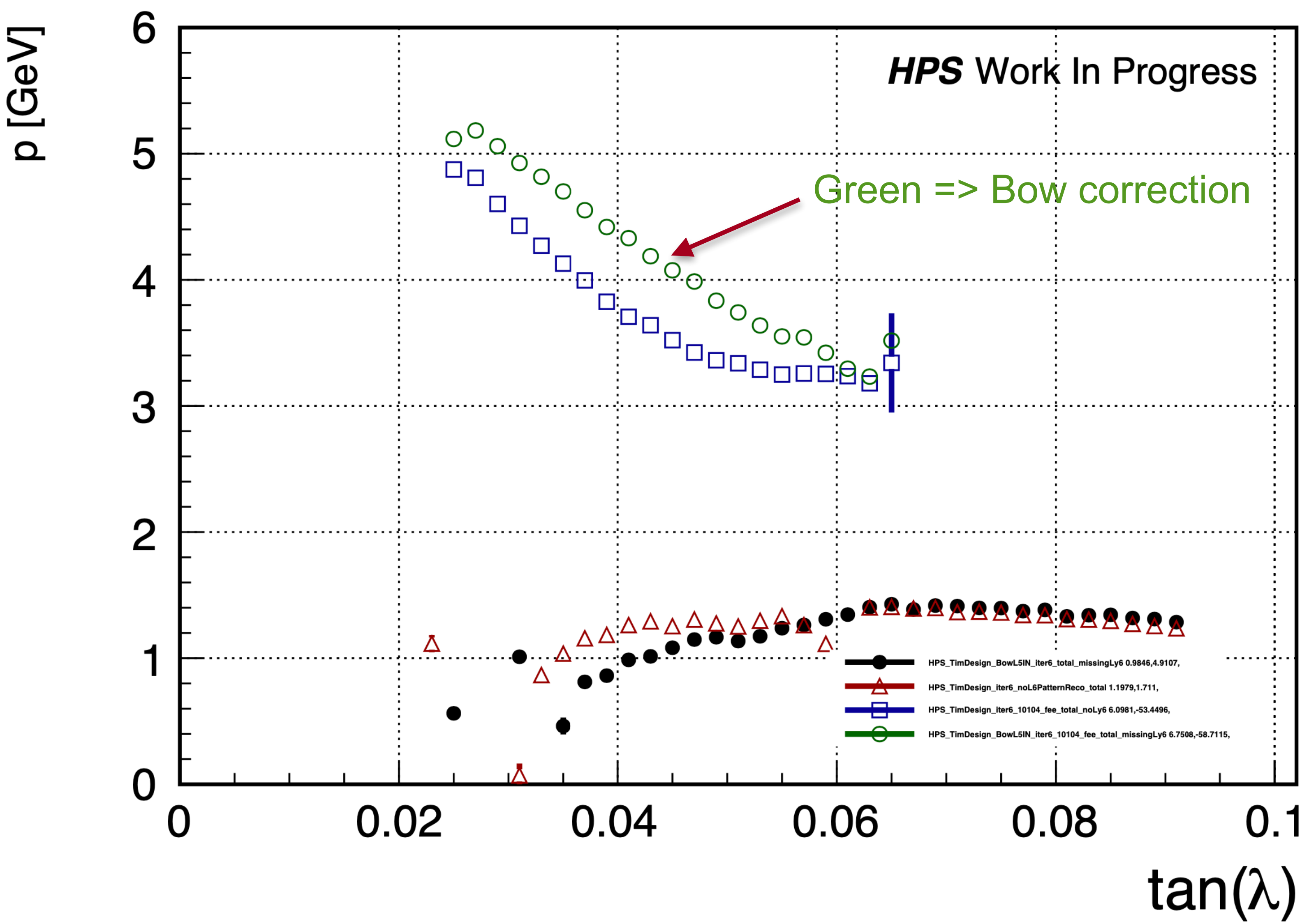


2019 - E/p from tridents



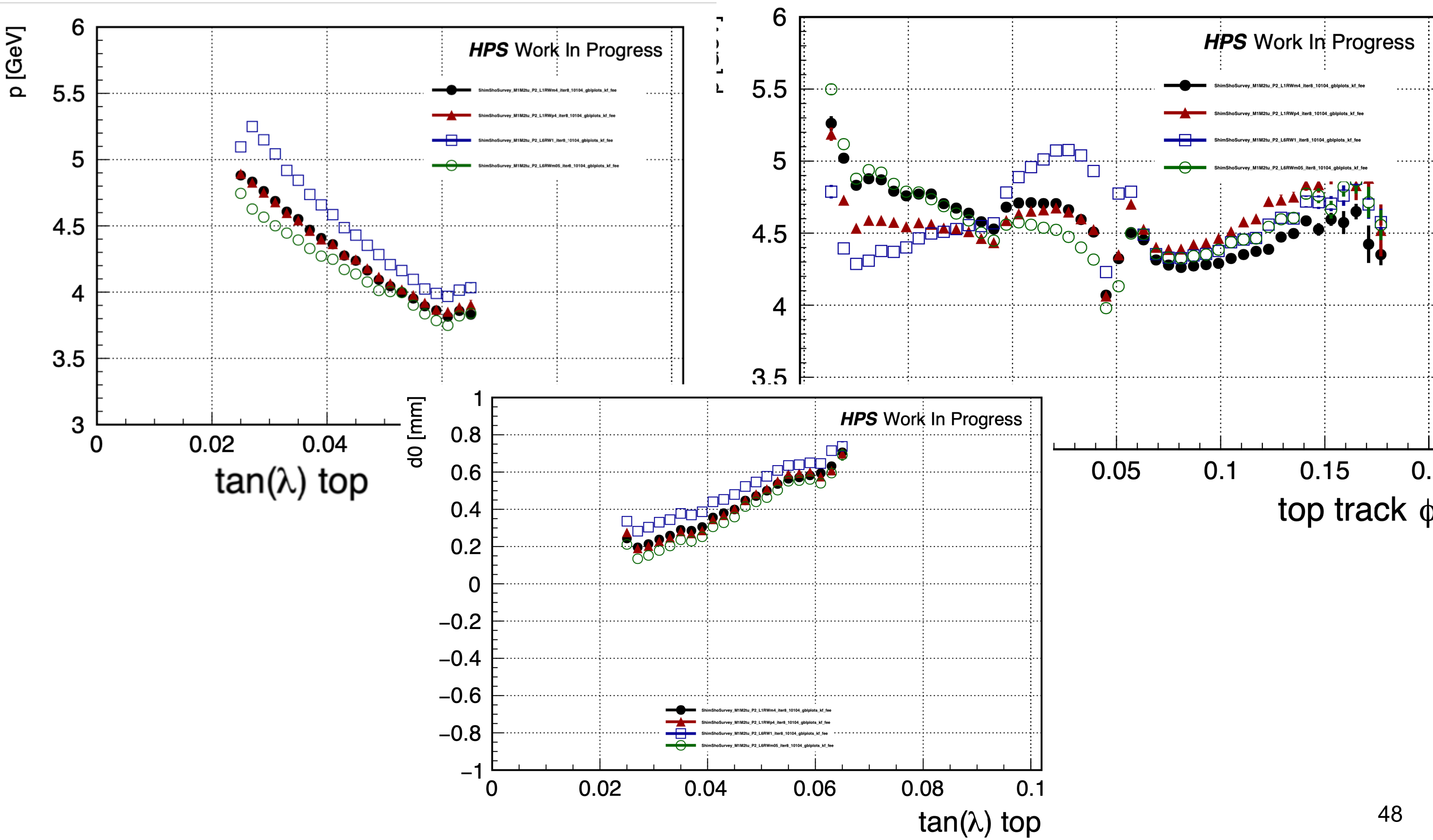
- Inclusive trident sample
- Checked Tracker vs Ecal calibration by checking tracks matched to Ecal clusters

2019 Momentum



2019 d0/Momentum - Rotations of L1 (4mrad) and L6 (1mrad)

- Starting point is detector on data before any Tz, which presents the slope itself.



2019 Tz corrections

```
<millepede_constant name="11301" value="0.0 + -0.017800 + 0.033900" />
<millepede_constant name="11302" value="0.0 + -0.798400 + 0.516400 + 0.1 + 0.1" />
<millepede_constant name="11303" value="0.0 + 0.013000 + 0.077800" />
<millepede_constant name="11304" value="0.0 + -0.773600 + 0.508100 + 0.1 + 0.1" />
<millepede_constant name="11305" value="0.0 + 0.371600" />
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<millepede_constant name="11315" value="0.0 + -0.000100 + 0.000200 + -0.298400" />
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```
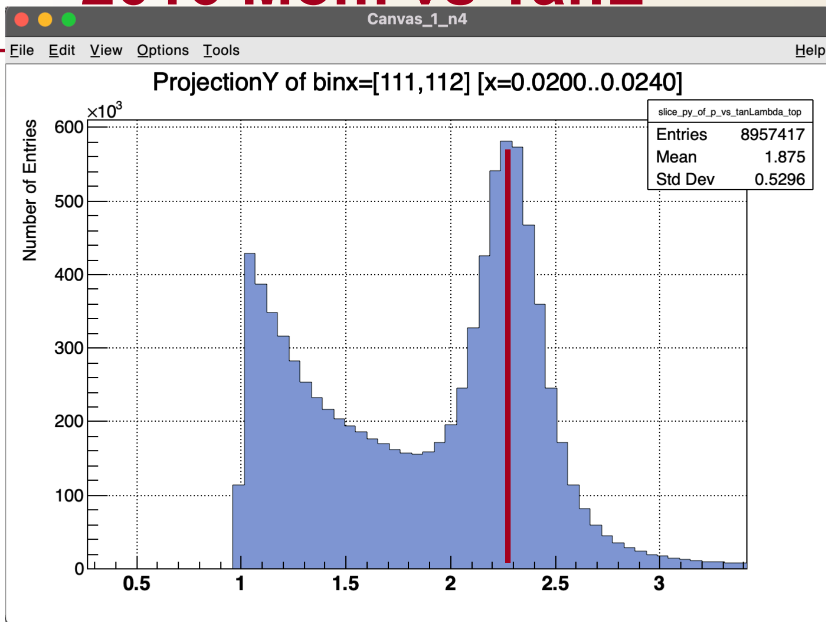
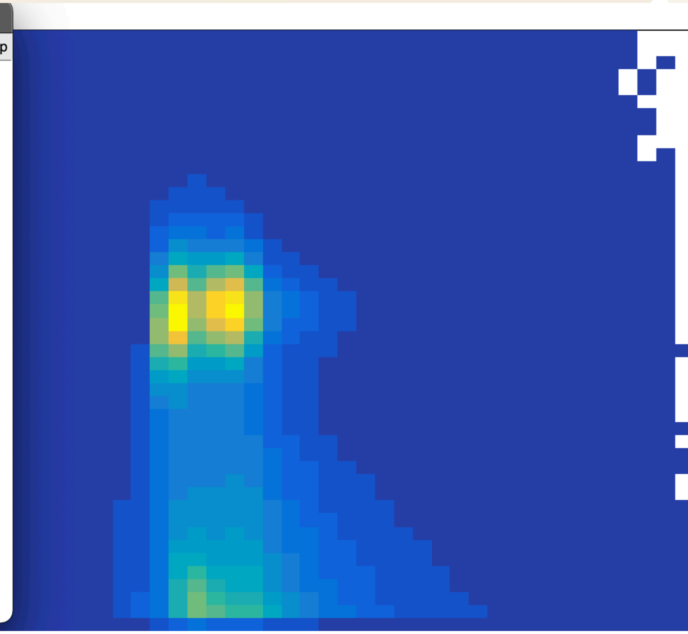
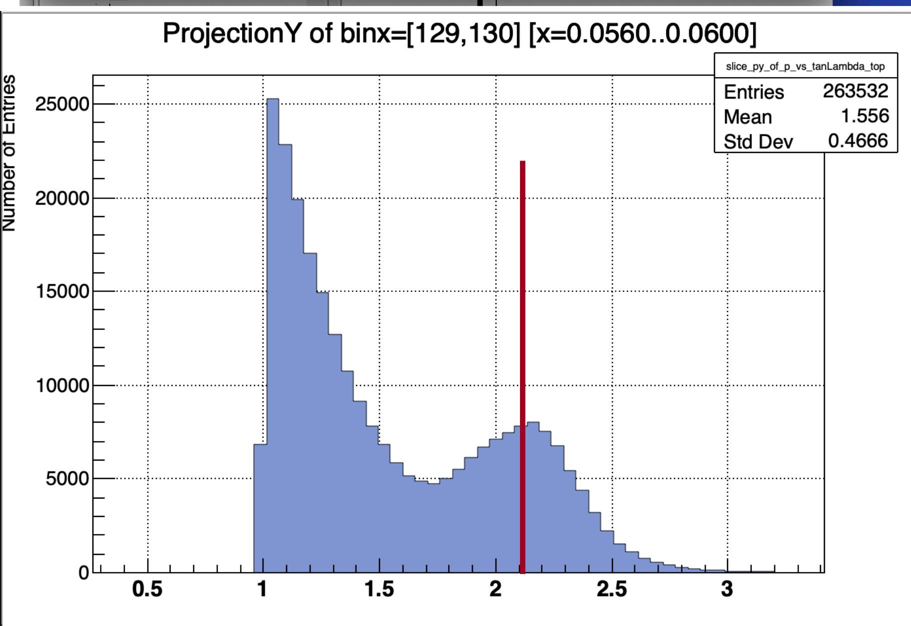
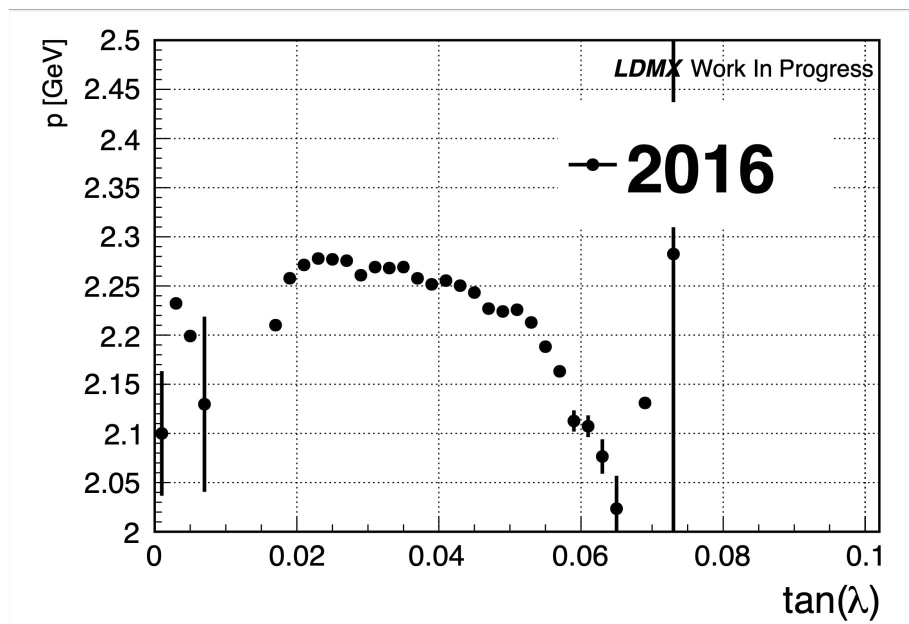

2016 Mom vs TanL

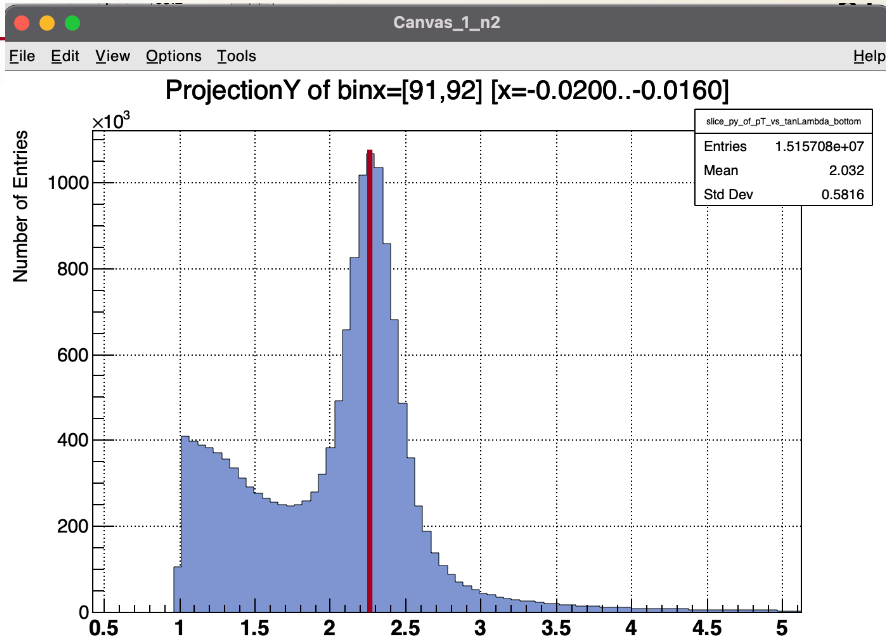


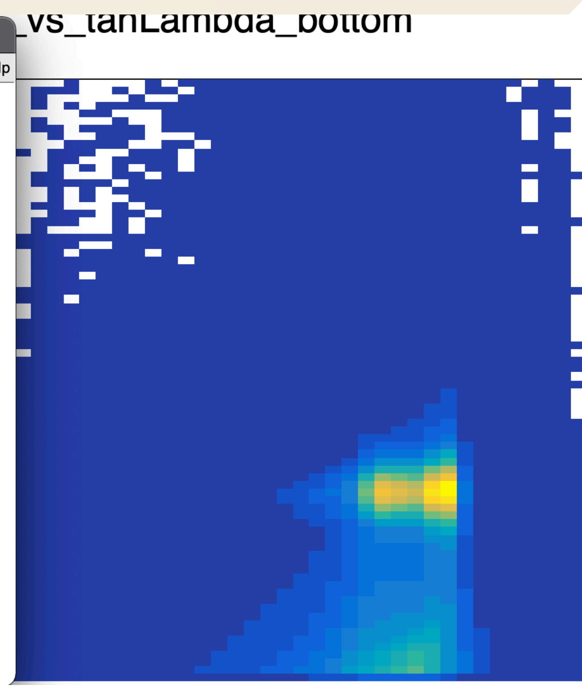


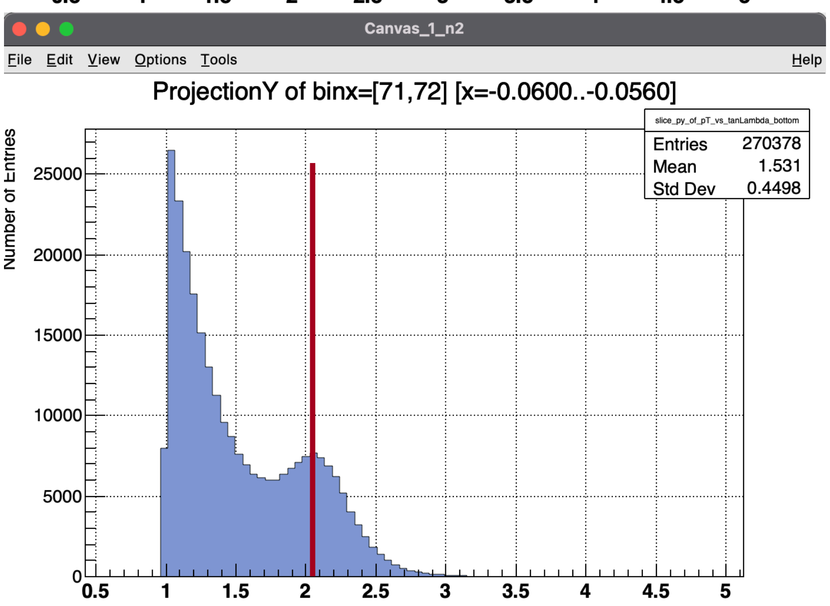


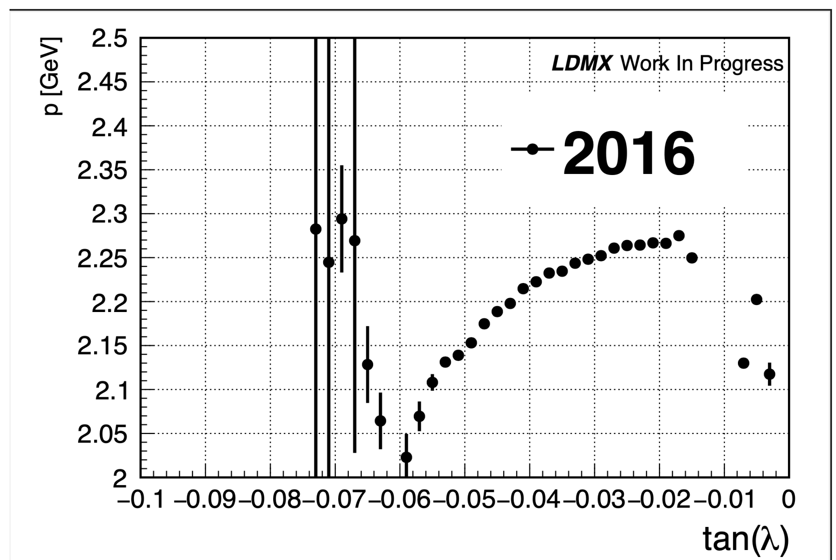


2016 Mom vs TanL







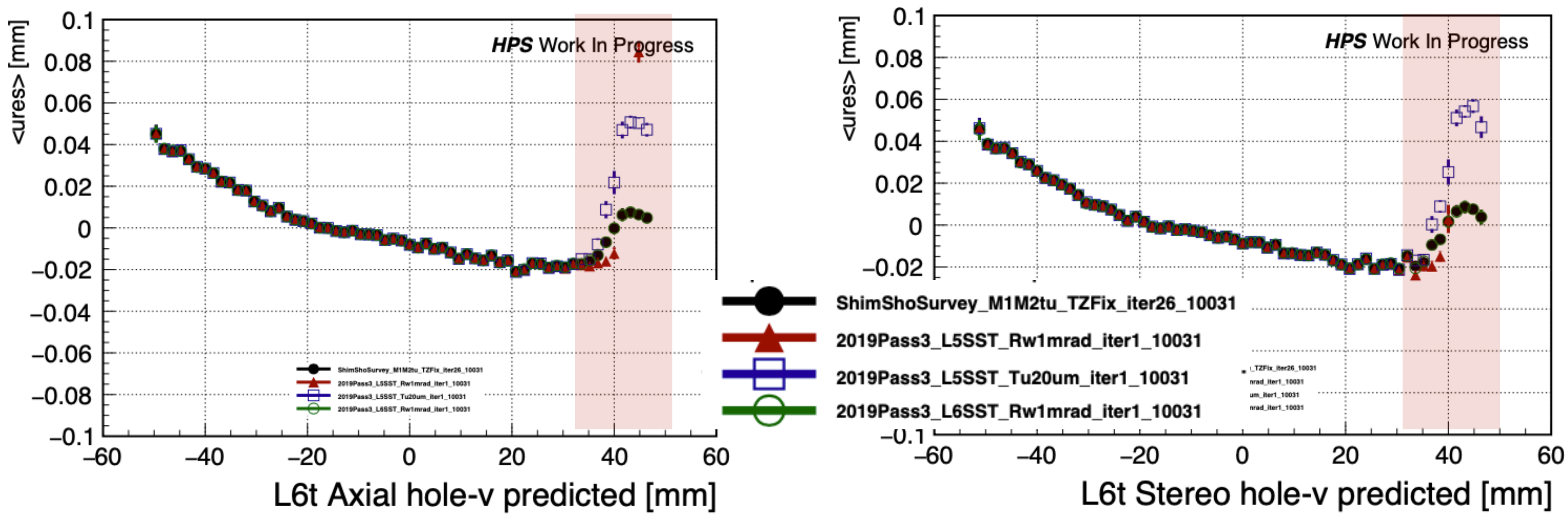


Study of impact of single sensor movements

- Used trig-trig + beam data
    - Removed Ly7Top from 10031 to simulate later detector conditions
- The idea is to study the impact of moving single sensors on
    - Unbiased residuals
    - E/p distributions
- With the aim to understand and correct observed biases in the reconstruction

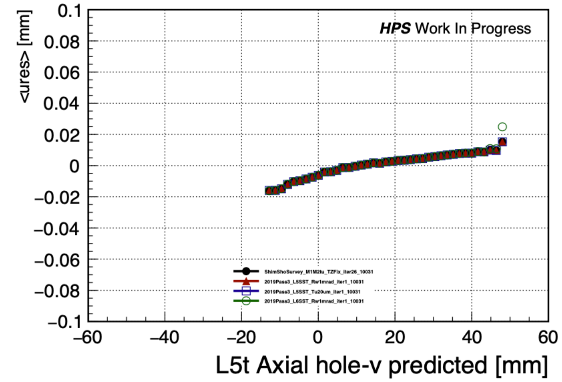
Step structure in the vs-v hole residuals

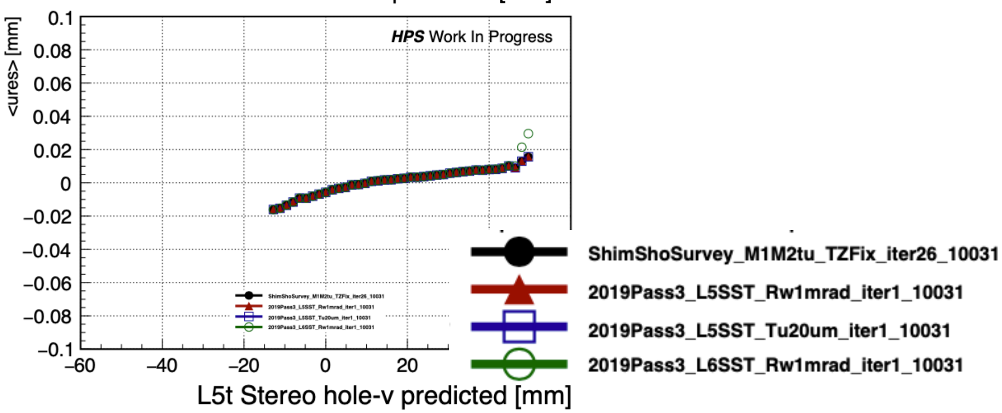
- Black - Current best detector for 2019 Top Volume
- We observe a step structure in the residuals vs v in ly6 in the hole side
  see area in red
- Tested 2 movements:
  - Rotation Rw=1mrad of Ly5 Stereo Slot of 1mrad ==> Kills tracks in that region, no effect outside
  - Translation Tu=20um of Ly5 Stereo Slot ==> Moves residuals in that region, no effect outside
- **<u>The step in the red region of Ly6 Hole Side can be corrected via Tu of Ly5 Stereo Slot.</u>**



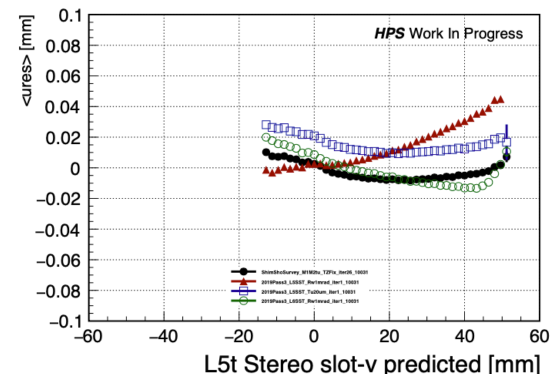
Step structure in the vs-v hole residuals

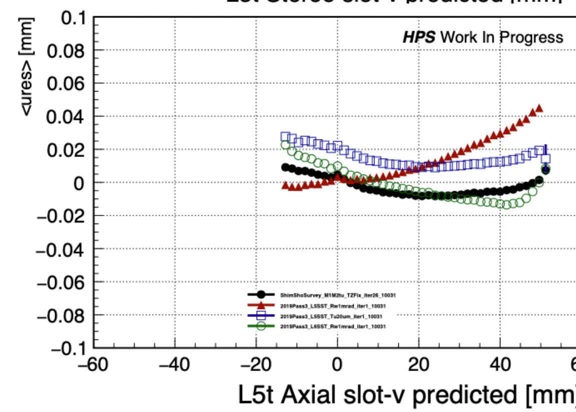
- Effect on Ly5
    - No effect on Hole side (as expected)





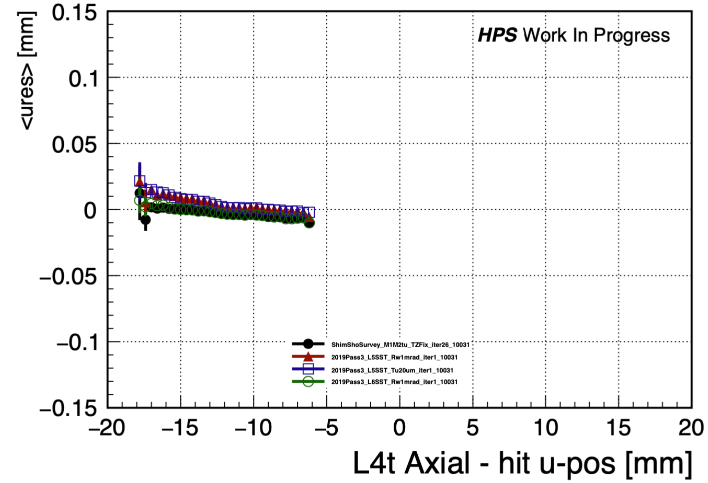
- Effect on Ly5
    - Large effects on Slot side

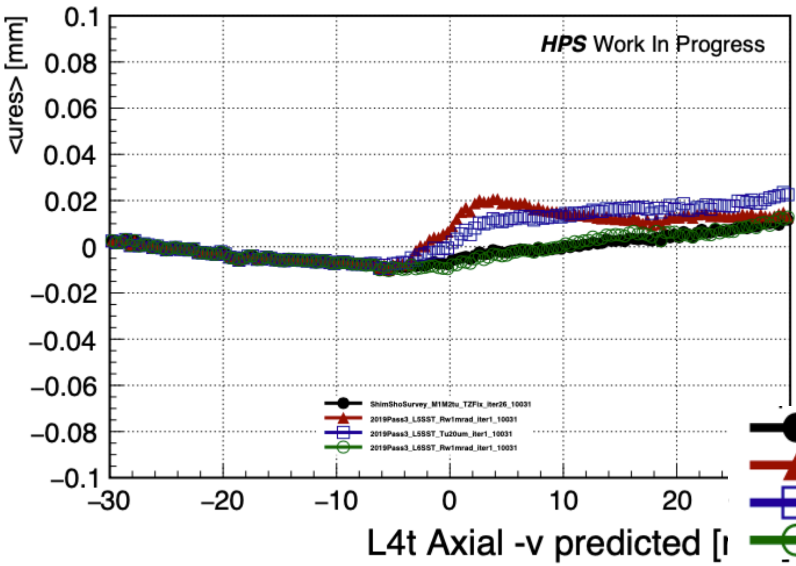


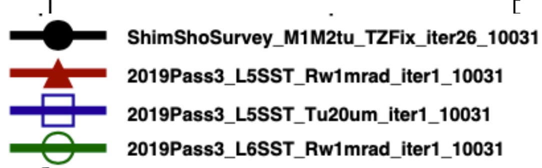


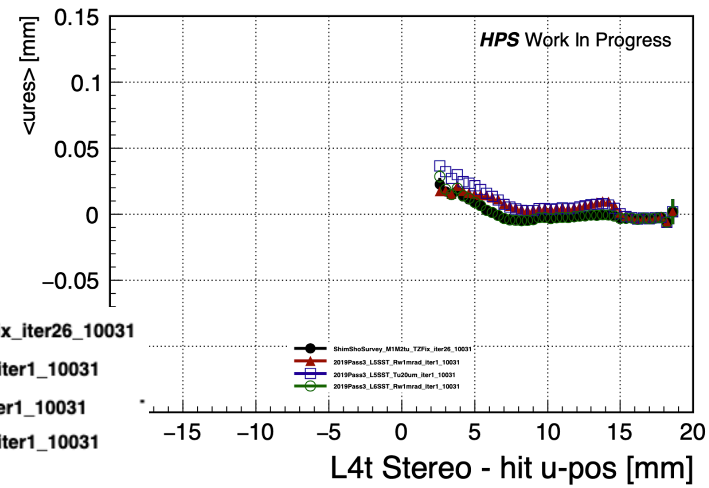
Step structure in the vs-v hole residuals

- Clear effects on Ly4 in both vs v and vs u residuals.
- The vs v Axial and Stereo look the same. The vs u has less effect on the axial and could mimic a Z movement of this sensor.



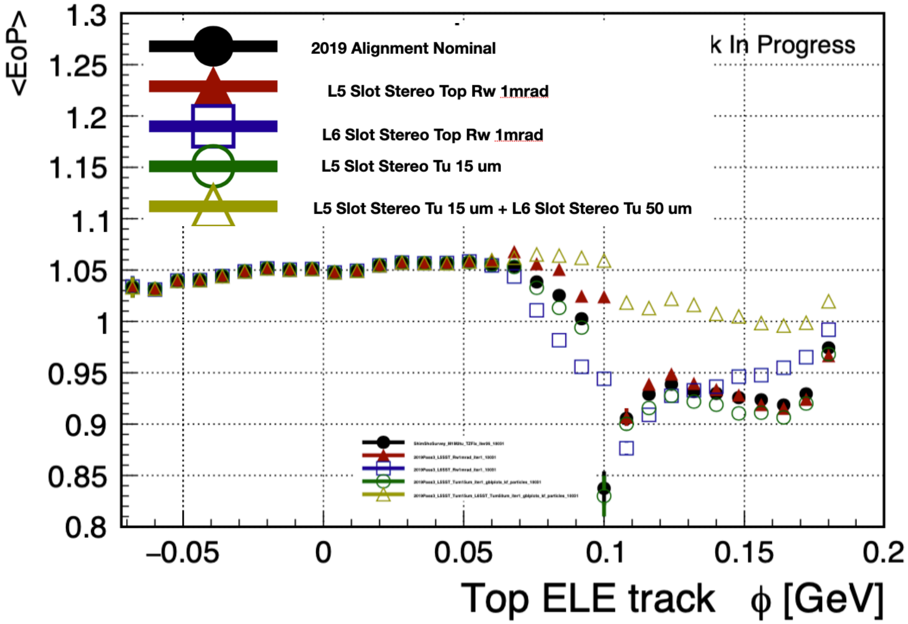


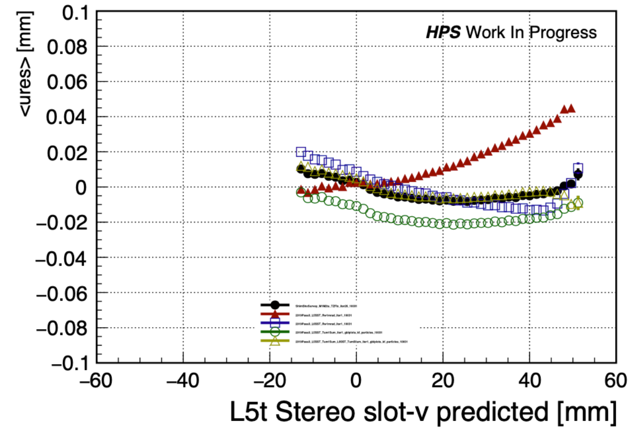


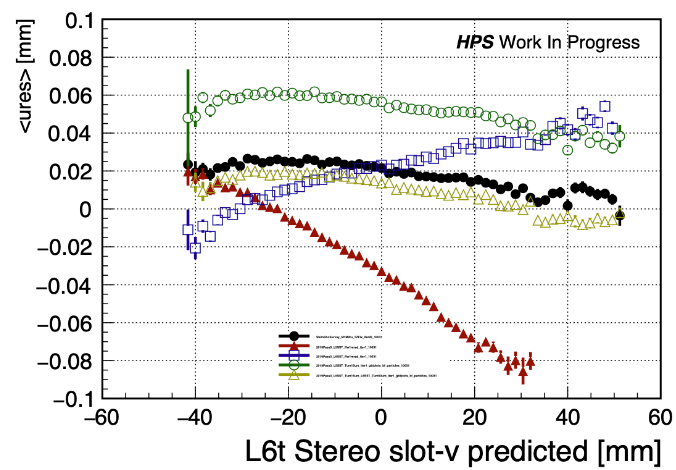


EoP effects of back layers Tu / Rw - ELECTRONS

- Movements of the back slot side have an effect on Electron E/p at high phi values
  - Tu = Flat rise,
    Rw = Linear trend
- In a detector where Ly7 is missing:
  - Tu < 0 in Ly5 leads to lower E/p on the high phi region. Flat correction
    Rw > 0 in Ly6 creates a trend in large phi with positive slope, .i.e. E/p increases with phi = > momentum decreases with phi

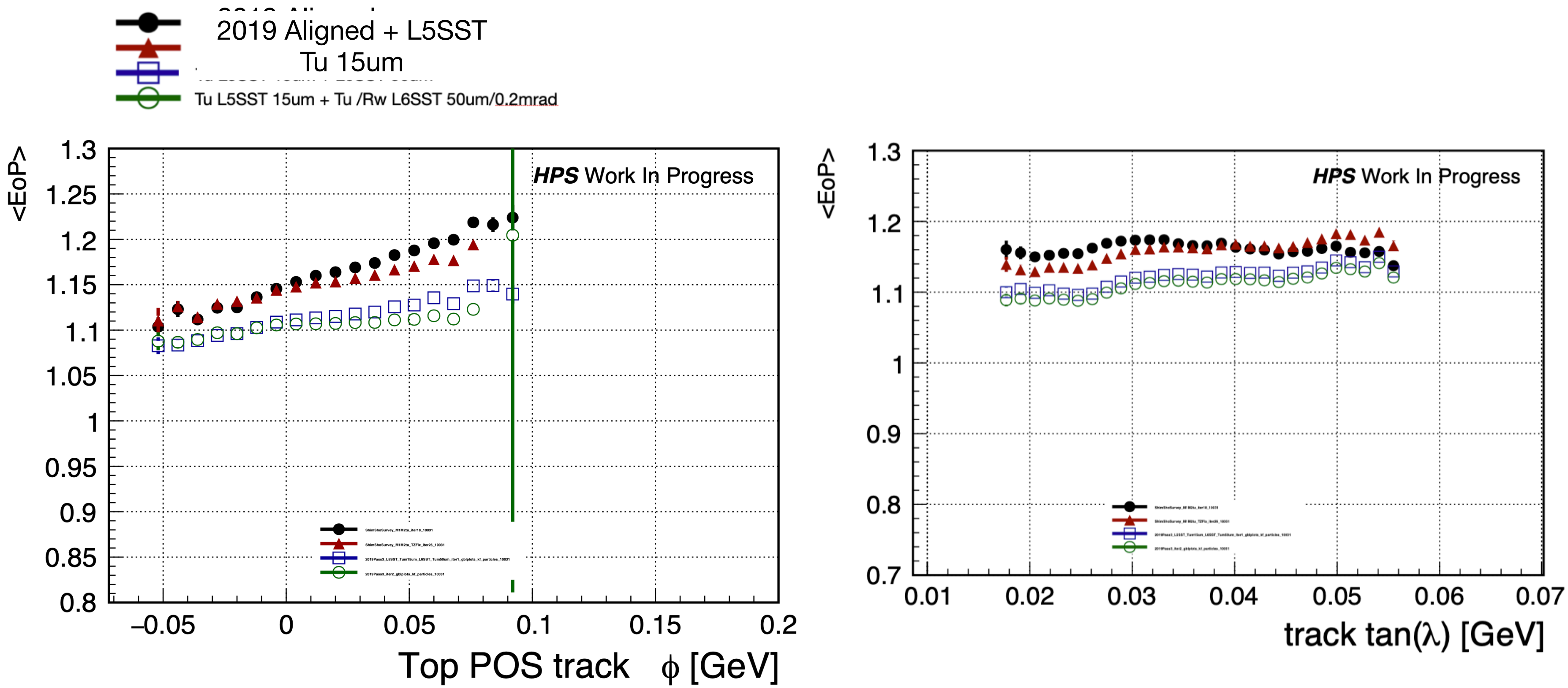






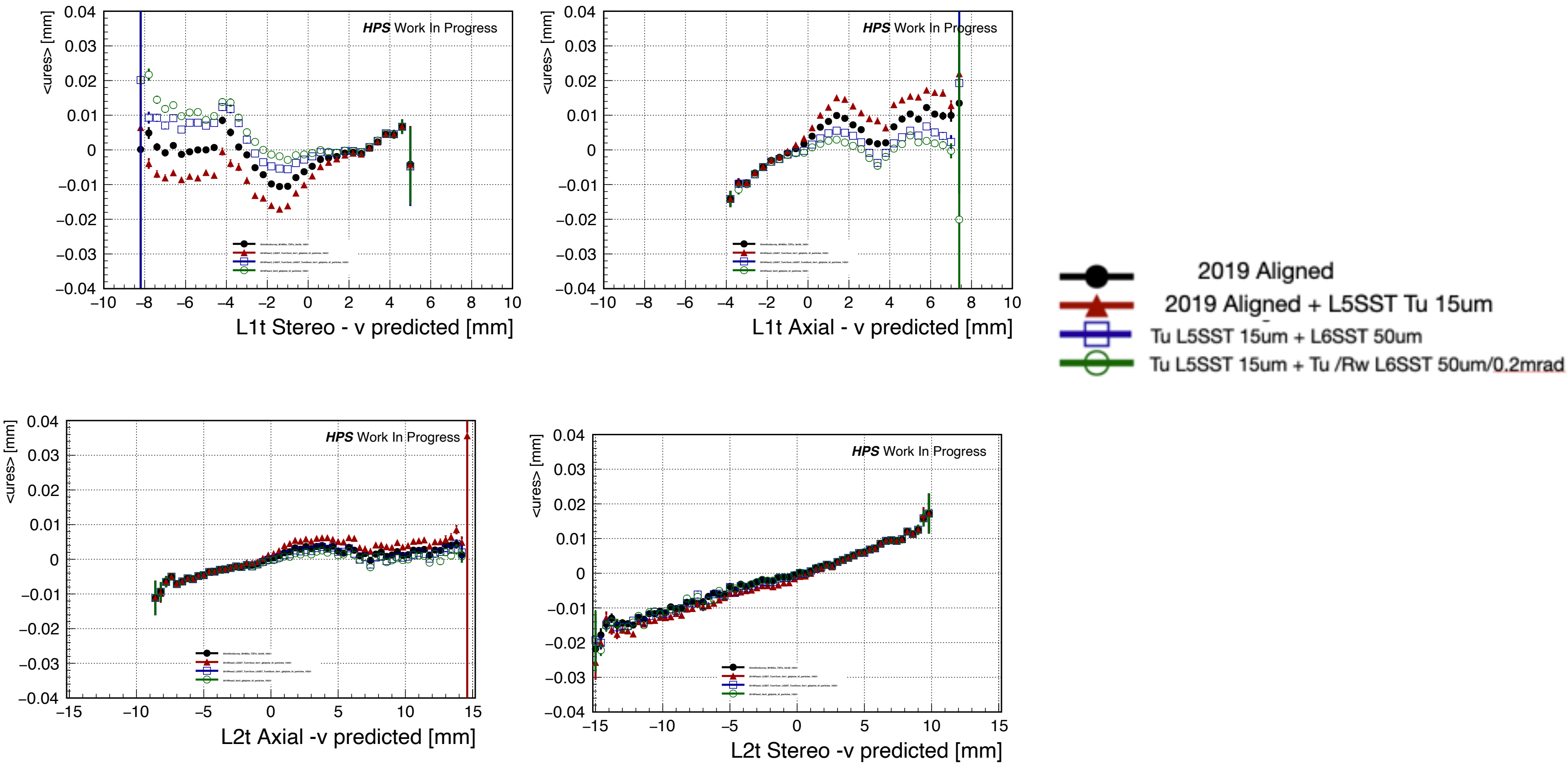
EoP effects of back layers Tu / Rw - POSITRONS

- 15um Correction L5SlotStereo Tu, L6 SlotStereo Tu60um + Rw0.4 mrad



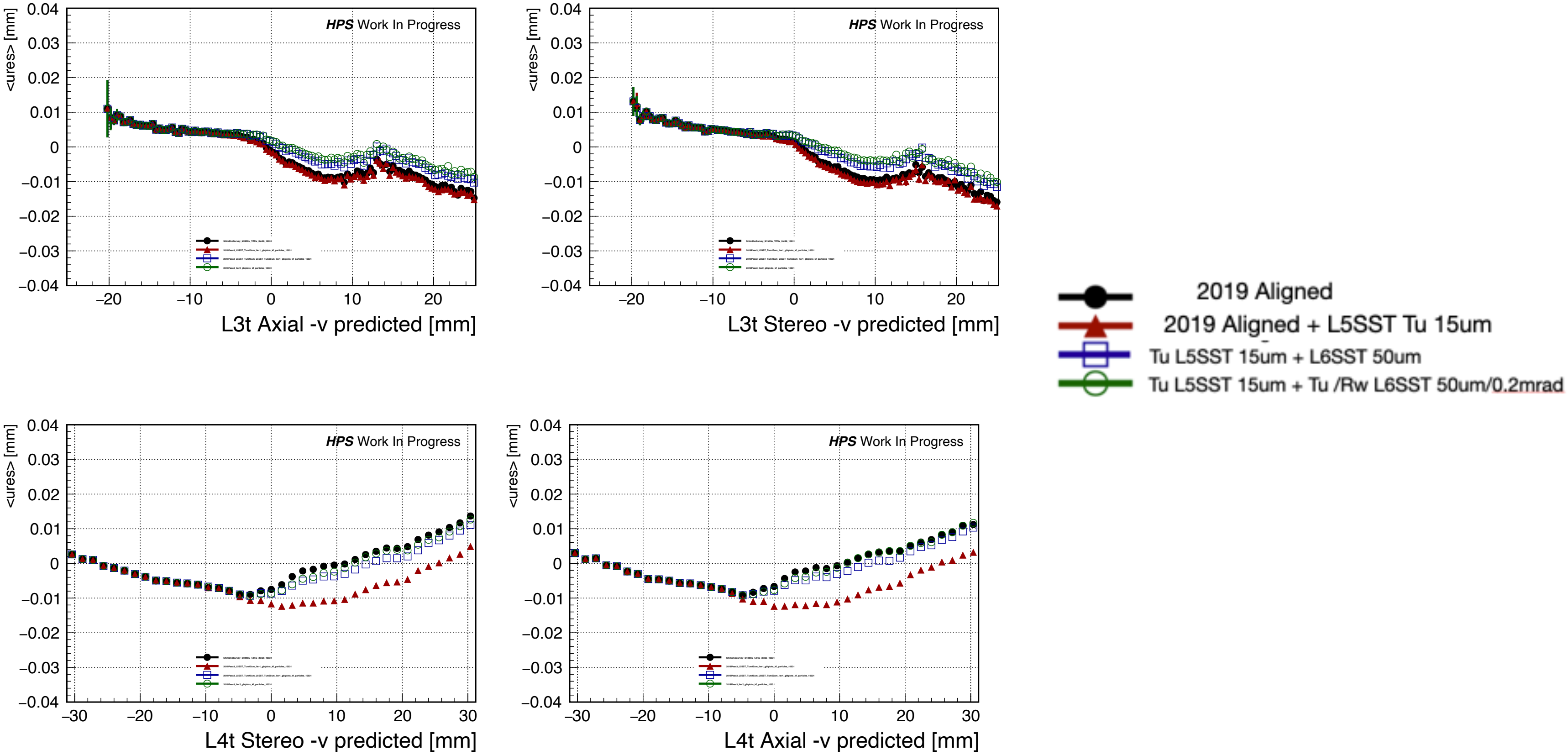
Effects on front of the detector

- 15um Correction L5SlotStereo Tu, L6 SlotStereo Tu60um + Rw0.4 mrad



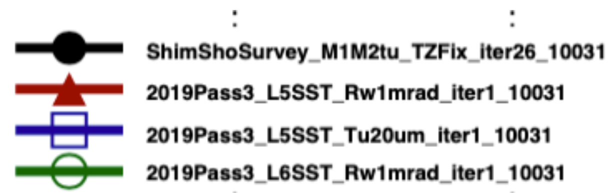
Effects on front of the detector

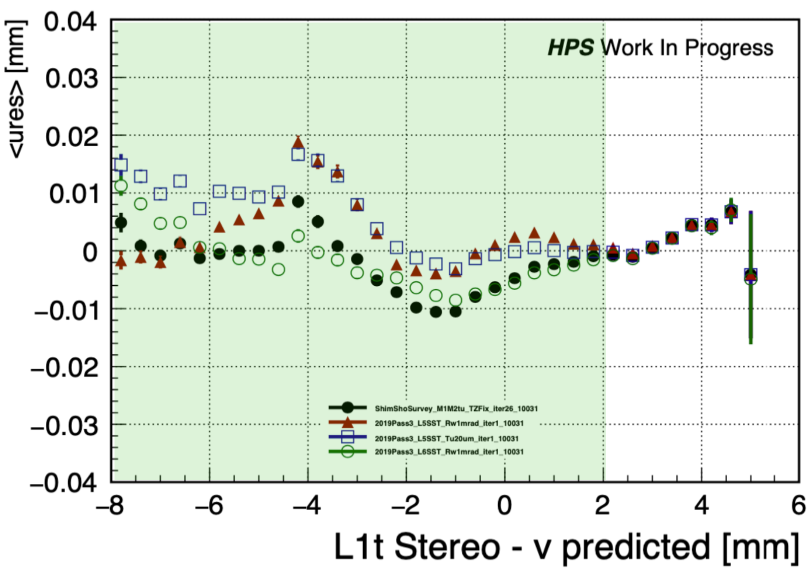
- 15um Correction L5SlotStereo Tu, L6 SlotStereo Tu60um + Rw0.4 mrad

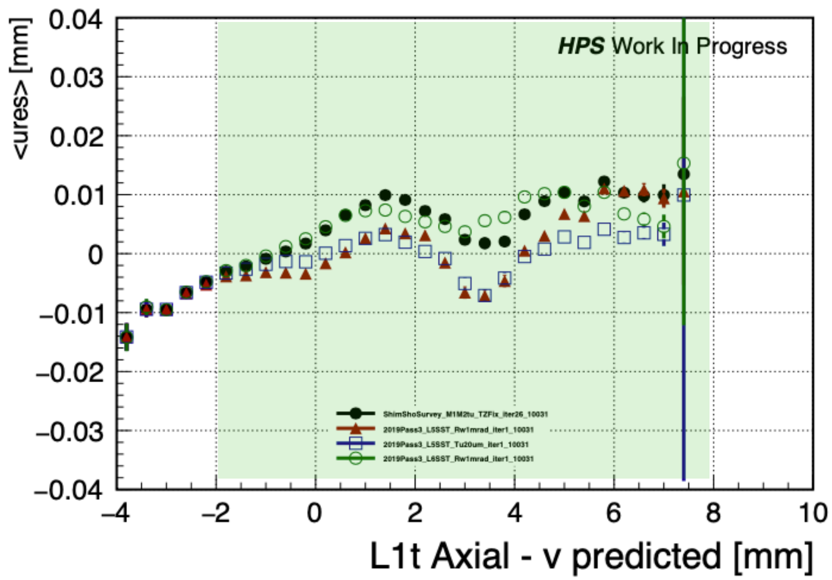


Effects on Ly1

- The structures on the front layer are correlated on the back of detector movements.
- Complicated, piece-wise structures linked to Tu/Rw
- Green area only affected by SLOT side

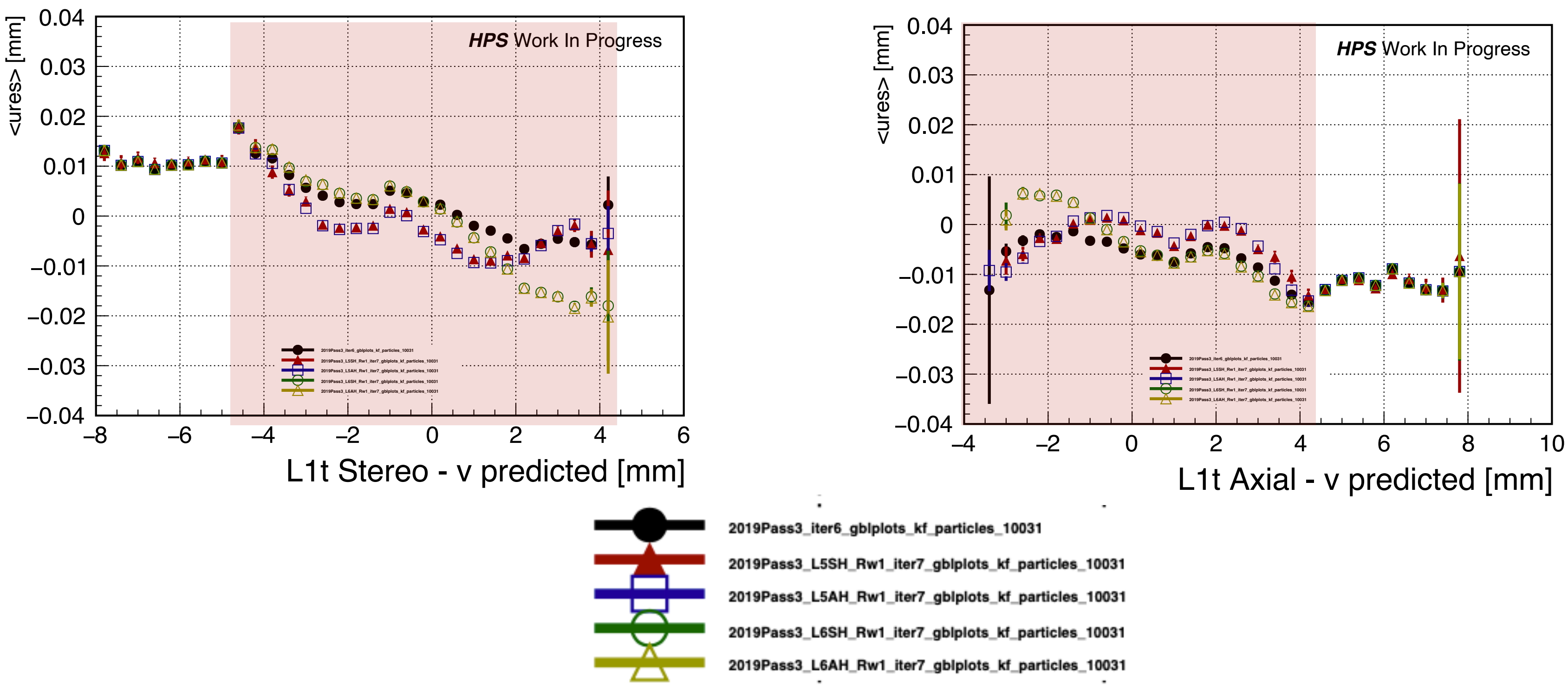






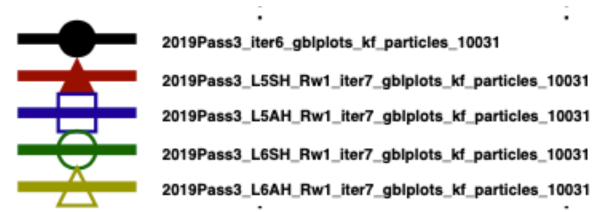
Effects on Ly1

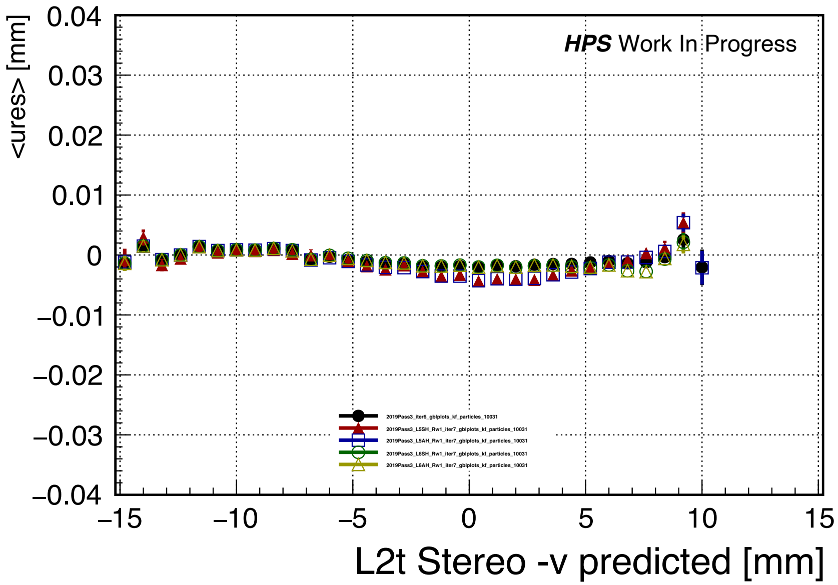
- The structures on the front layer are correlated on the back of detector movements.
- Complicated, piece-wise structures linked to Tu/Rw
- Red area only affected by HOLE side
- Axial-Stereo is degenerate: only worth changing one.

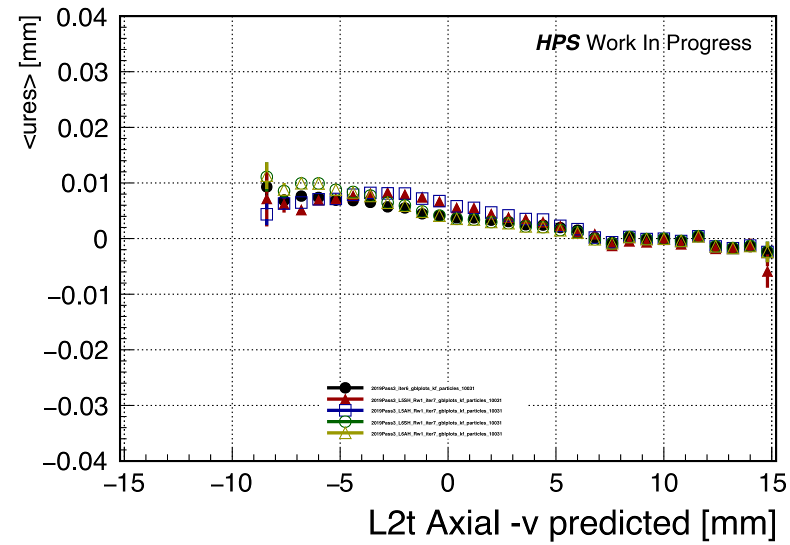


Effects on Ly2

- The structures on the front layer are correlated on the back of detector movements.
- Complicated, piece-wise structures linked to Tu/Rw
- Red area only affected by HOLE side
- Axial-Stereo is degenerate: only worth changing one.

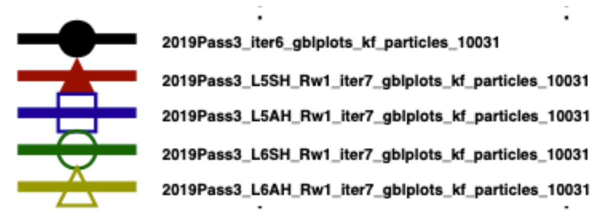


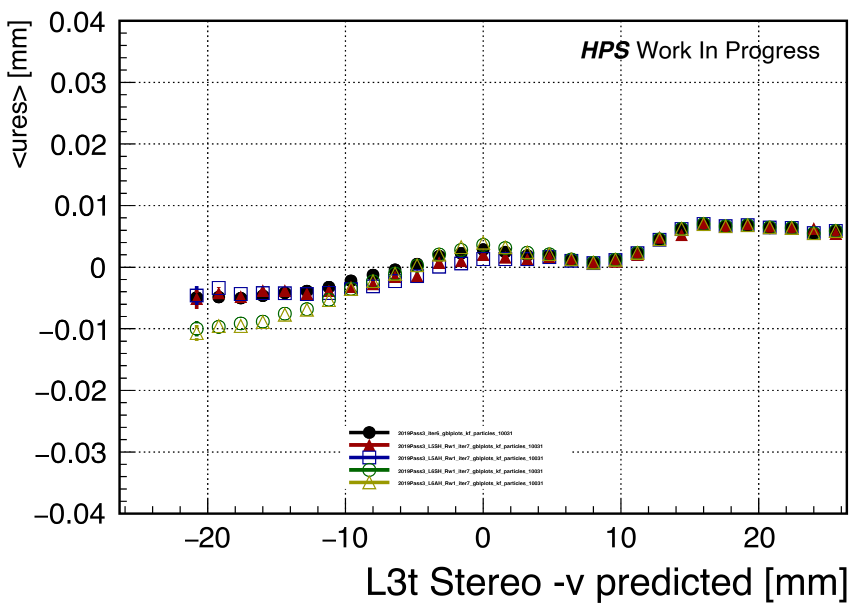


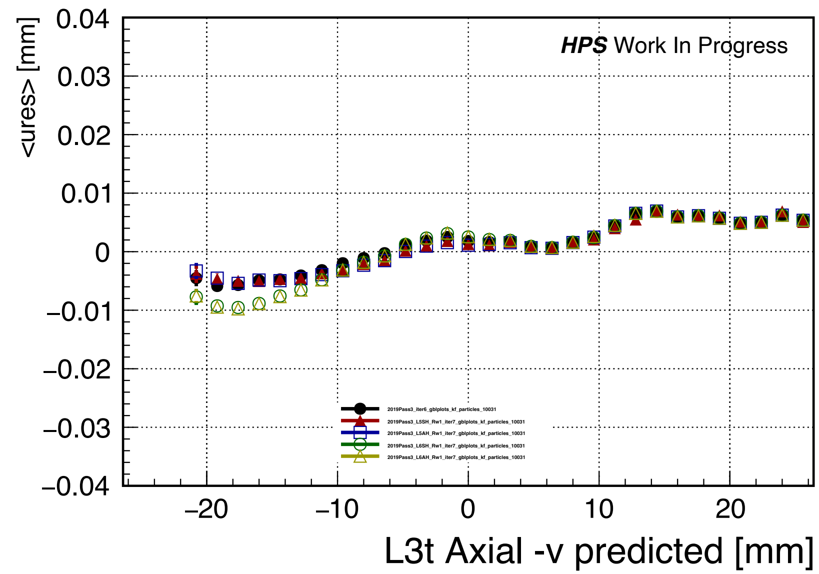


Effects on Ly3

- The structures on the front layer are correlated on the back of detector movements.
- Complicated, piece-wise structures linked to Tu/Rw
- Red area only affected by HOLE side
- Axial-Stereo is degenerate: only worth changing one.

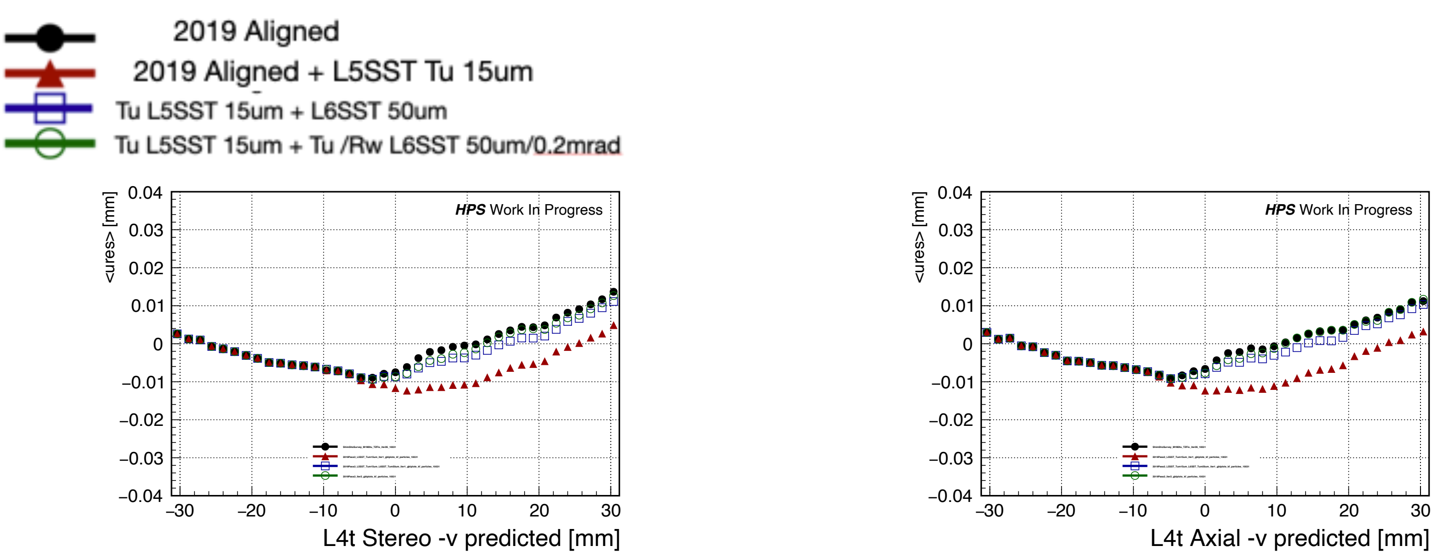






Concentrate on Ly4Top

- We see no effects in the trend in Ly4Top, right side, where the slot stereo L5 is moved
- **These v shapes seems to be strongly linked to L5 Axial rotations for the top volume.**
    - I've tested the effects of aligning the stereo side but that has very small effect on these shapes. I suppose because the axial side kind of "washes" the effect out.
    - Additionally, I've already taken out the relative rotations in the slot side as discussed before between Ly5 and Ly6, so those shouldn't depend on this sensor much
    - Finally, there is no simple movement of Ly4 that can produce this V shape and Ly5 Top Axial is the closest one.

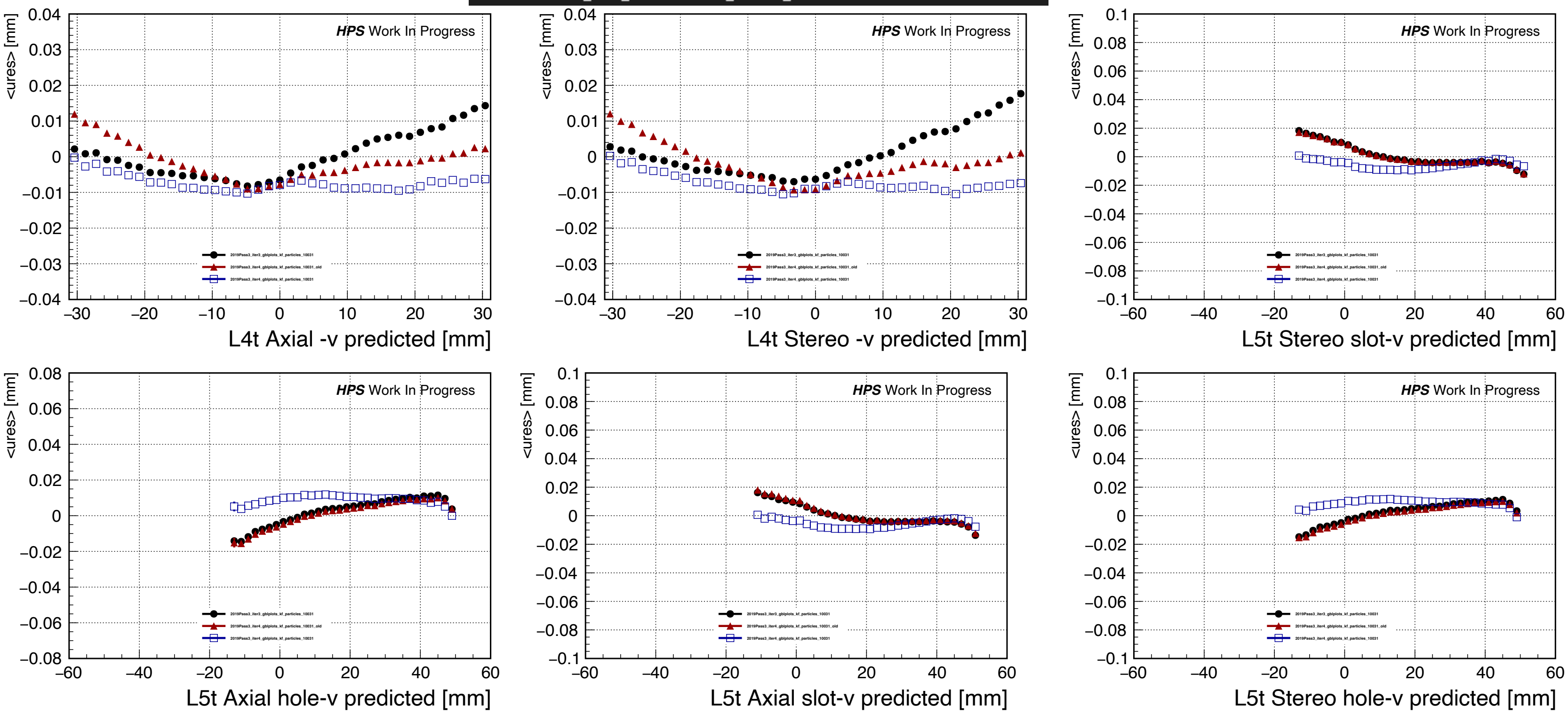


Concentrate on Lv4Top

- Alignment strat

```
     module_L2t_halfmodule_stereo   0.004079 +-   0.000033 11104  (change   0.004079)
      module_L3t_halfmodule_axial   0.013253 +-   0.000033 11105  (change   0.013253)
     module_L3t_halfmodule_stereo  -0.018434 +-   0.000037 11106  (change  -0.018434)
 module_L5t_halfmodule_axial_hole  -0.014911 +-   0.000081 11109  (change  -0.014911)
 module_L5t_halfmodule_axial_slot   0.015405 +-   0.000063 11111  (change   0.015405)
     module_L2t_halfmodule_stereo  -0.000098 +-   0.000013 12304  (change  -0.000098)
      module_L3t_halfmodule_axial  -0.000413 +-   0.000005 12305  (change  -0.000413)
     module_L3t_halfmodule_stereo  -0.000369 +-   0.000005 12306  (change  -0.000369)
 module_L5t_halfmodule_axial_hole   0.000391 +-   0.000003 12309  (change   0.000391)
 module_L5t_halfmodule_axial_slot  -0.000363 +-   0.000003 12311  (change  -0.000363)
```

VERY GOOD
FOR L4 AND L5 STRANGE
STRUCTURES!



Concentrate on Lv4Top

- Alignment strat

```
    module_L2t_halfmodule_stereo   0.004079 +-   0.000033 11104  (change   0.004079)
     module_L3t_halfmodule_axial   0.013253 +-   0.000033 11105  (change   0.013253)
    module_L3t_halfmodule_stereo  -0.018434 +-   0.000037 11106  (change  -0.018434)
module_L5t_halfmodule_axial_hole  -0.014911 +-   0.000081 11109  (change  -0.014911)
module_L5t_halfmodule_axial_slot   0.015405 +-   0.000063 11111  (change   0.015405)
    module_L2t_halfmodule_stereo  -0.000098 +-   0.000013 12304  (change  -0.000098)
     module_L3t_halfmodule_axial  -0.000413 +-   0.000005 12305  (change  -0.000413)
    module_L3t_halfmodule_stereo  -0.000369 +-   0.000005 12306  (change  -0.000369)
module_L5t_halfmodule_axial_hole   0.000391 +-   0.000003 12309  (change   0.000391)
module_L5t_halfmodule_axial_slot  -0.000363 +-   0.000003 12311  (change  -0.000363)
```

VERY GOOD
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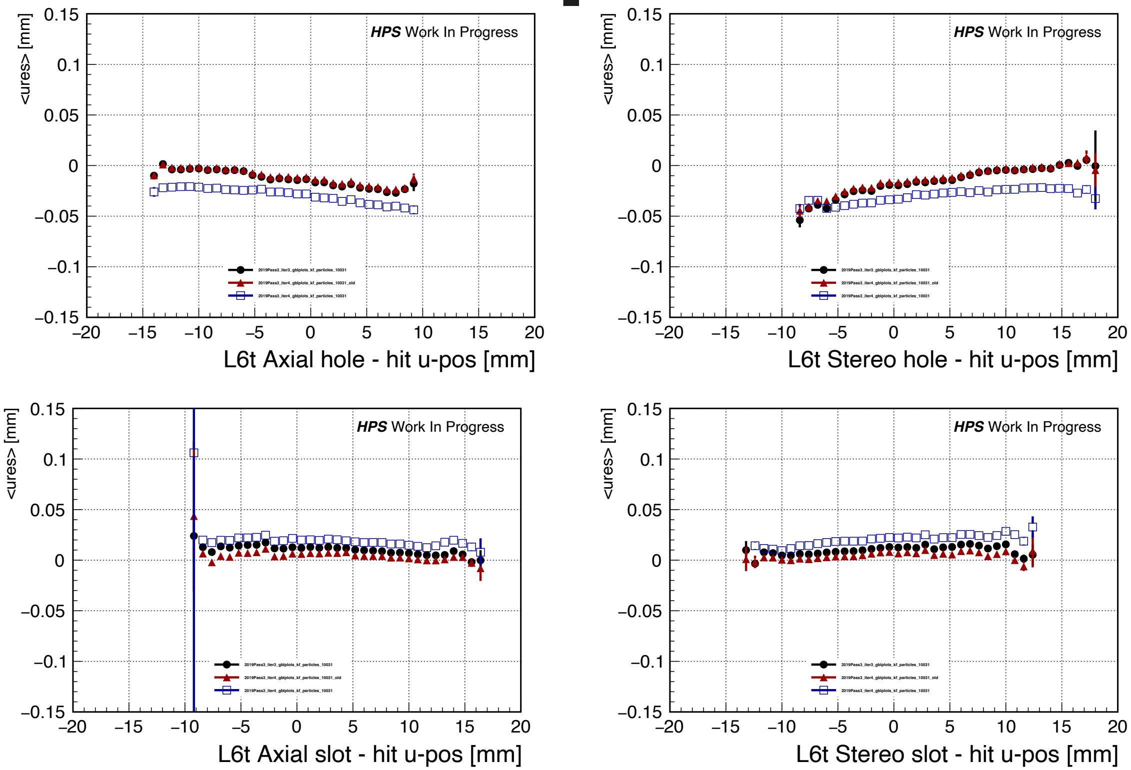
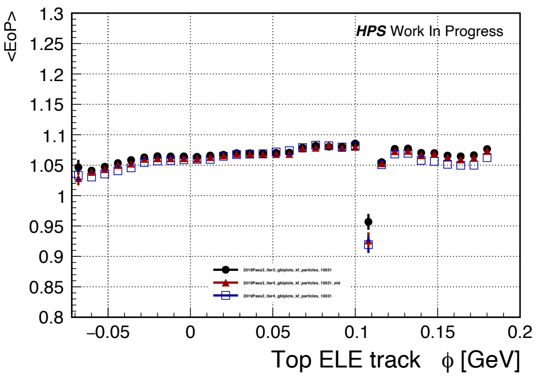
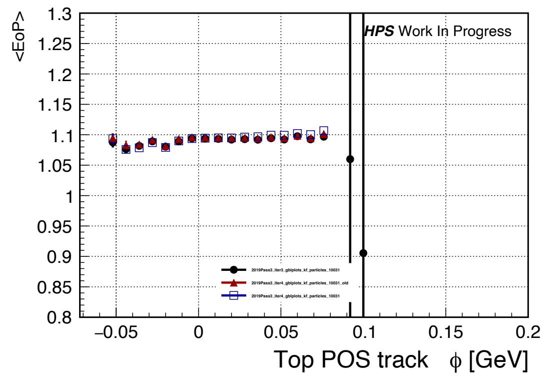
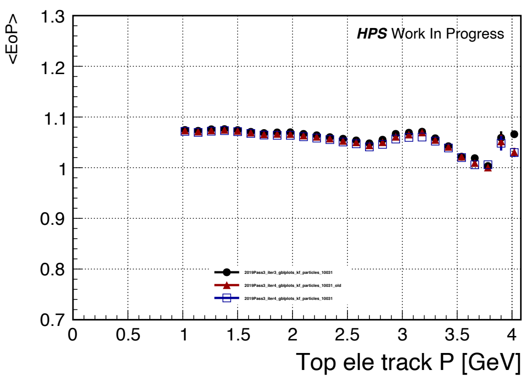


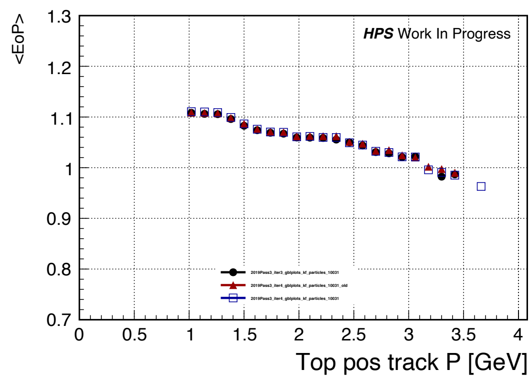
Concentrate on Ly4Top

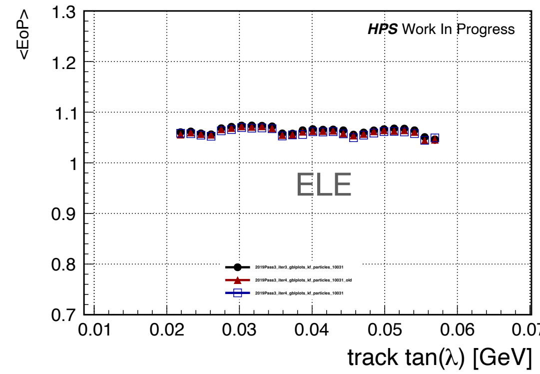
- Alignment strategy:

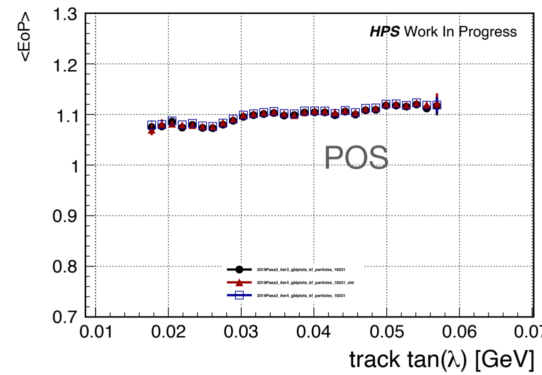






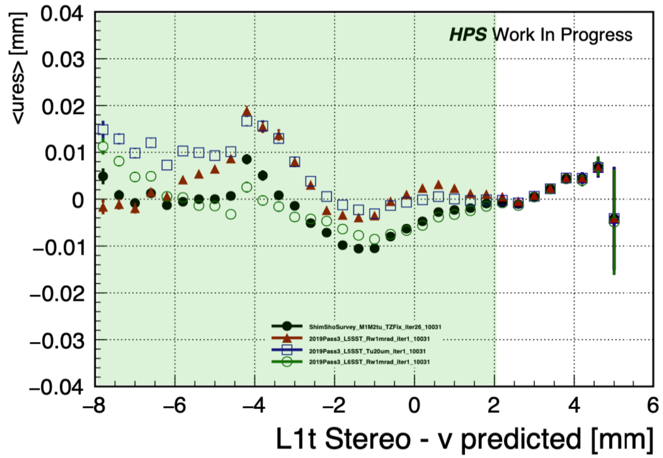


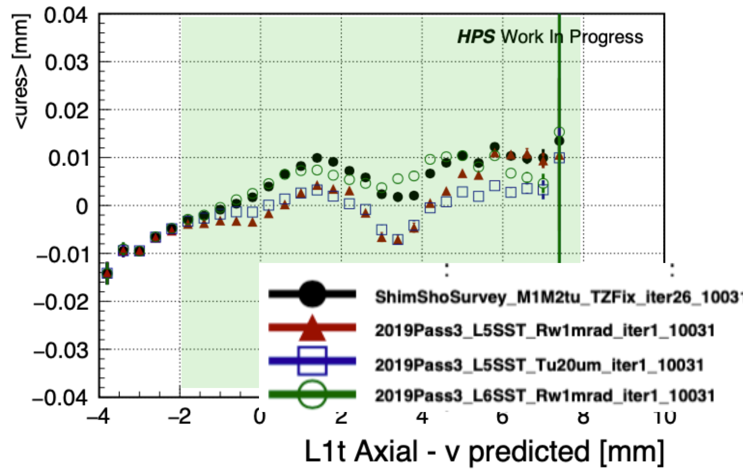


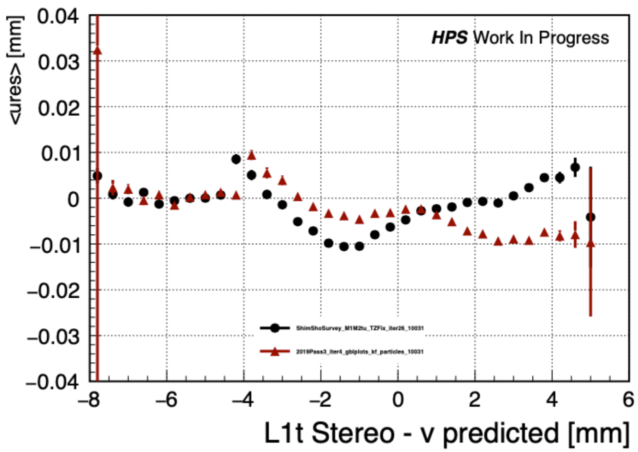


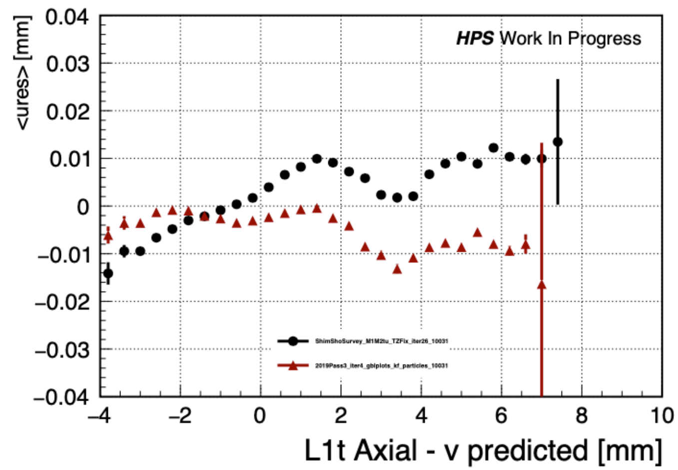
Basically no effect on momentum distributions across parameters

Let’s go back to the front and check the effects









EoP electron trends as function of Ly6S Rw

- Check the effect of plain Rw