Alignment of 2021 Detector

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Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

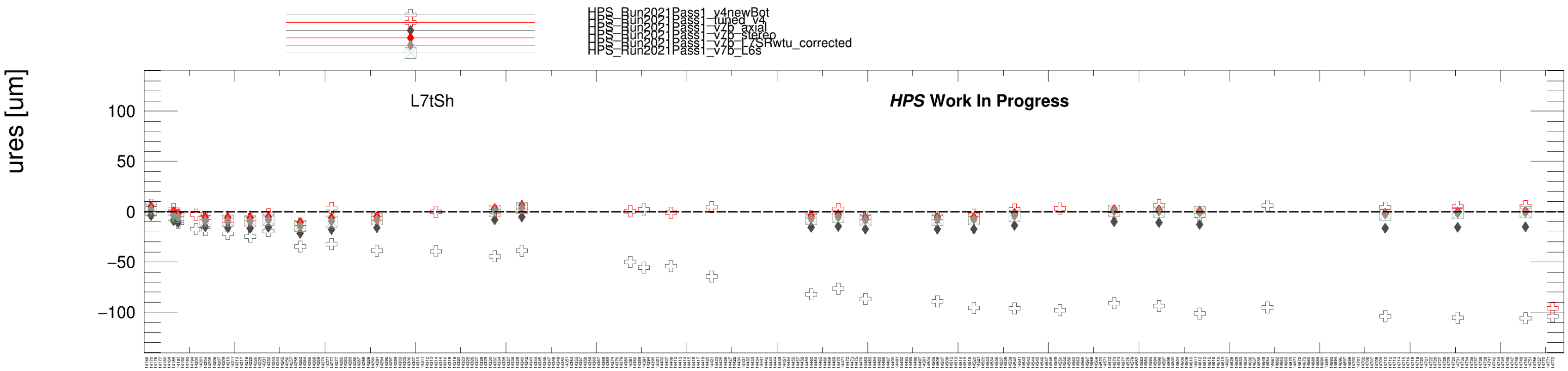
General alignment strategy

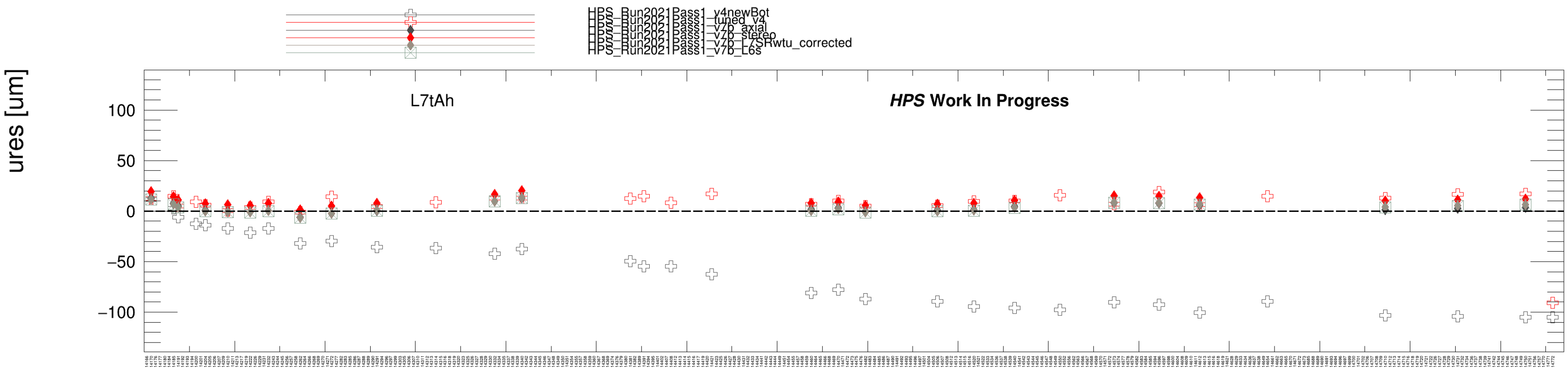
- *Local alignment* of the detector using data from early run
- Perform *global movements* to align top/bottom detectors
  - Translational movements to align vertex positions
  - Calibrate opening/closing of top and bottom detectors to theoretical Moller mass
- Capture time dependent movements of the (top) detector with *run-by-run millepede corrections*
  - Obtained from a subset of the dataset and interpolated to all runs using simple polynomial fit
  - Most notably, large tu movements needed in the outer most tracking layers. Some small Rw also applied in v7

Alignment 2021 efforts

- Alignment progressed through several iterations in last year:
  - **v6 alignment model:**
    - First attempt at run-by-run parameterization above v4
    - Used for 1% pass over Christmas holiday
  - **v7 alignment model:**
    - Built upon v6 “template model” (no run-by-run)
    - Global translations and opening/closing of detector to align top/bottom vertex (x,y) and target z-position
    - Additional run-by-run iterations to improve momentum scale
    - Used for ~0.3% pass in April 2025
  - **v8 alignment model:**
    - Aiming to improve momentum scale and impact parameter resolution across entire detector

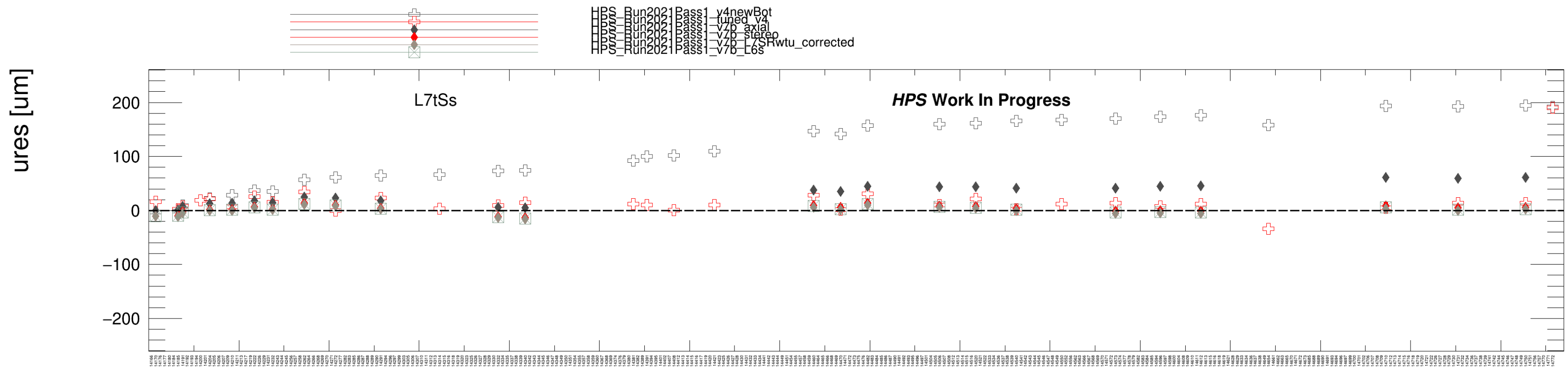
Run-by-run tu: L7 hole side

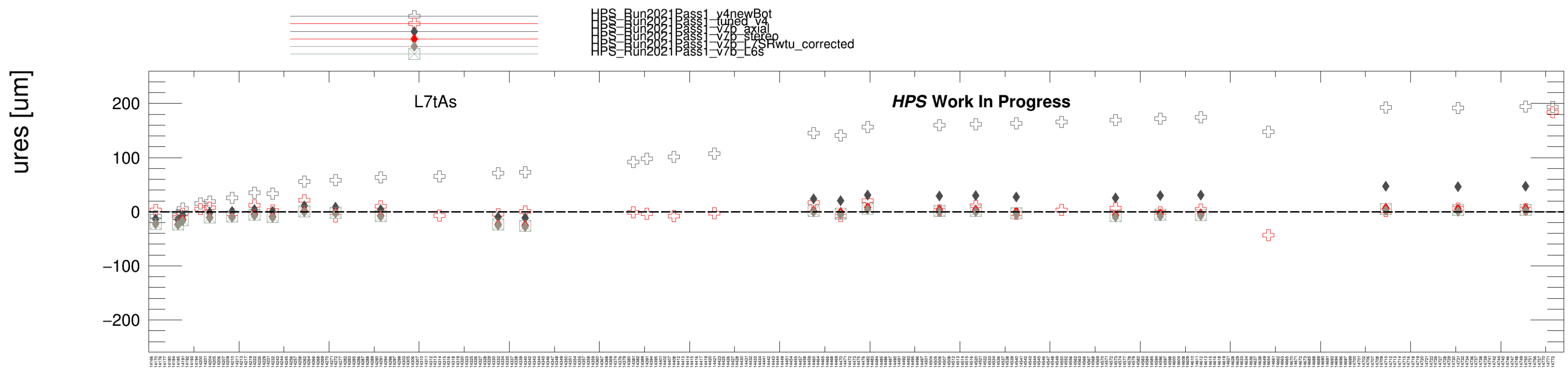




Large tu corrections needed in the outer layers

Run-by-run tu: L7 slot side





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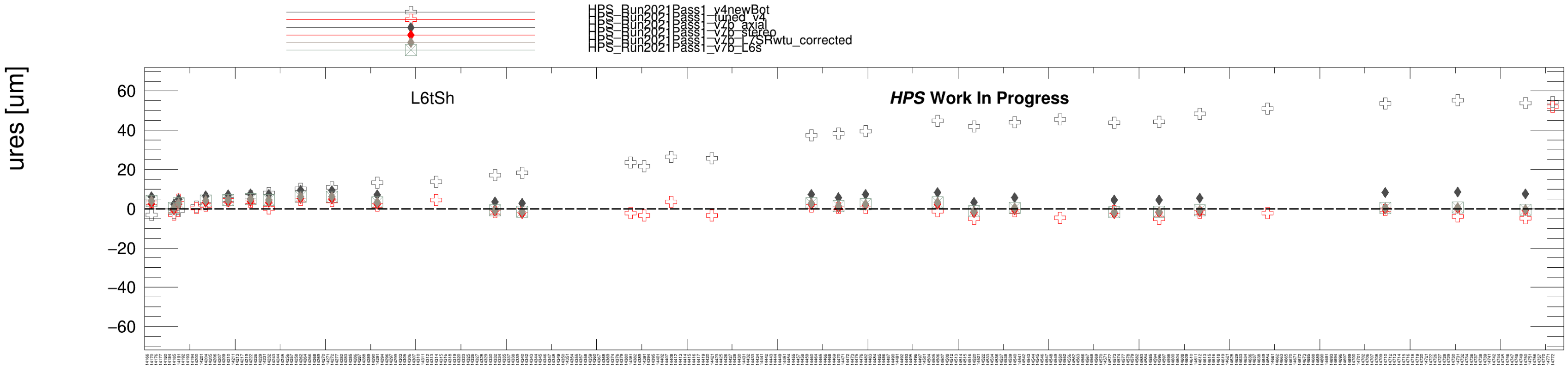

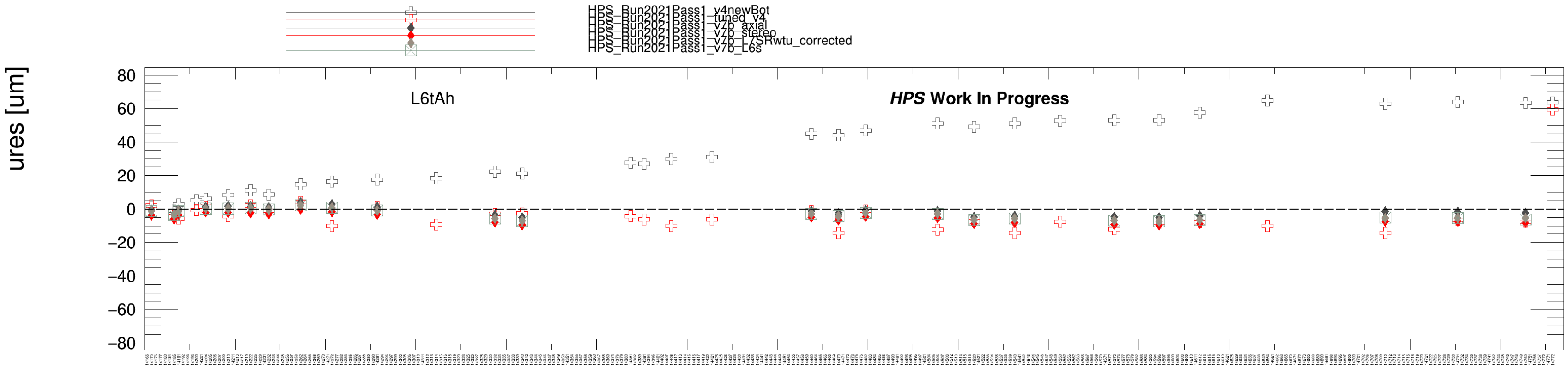

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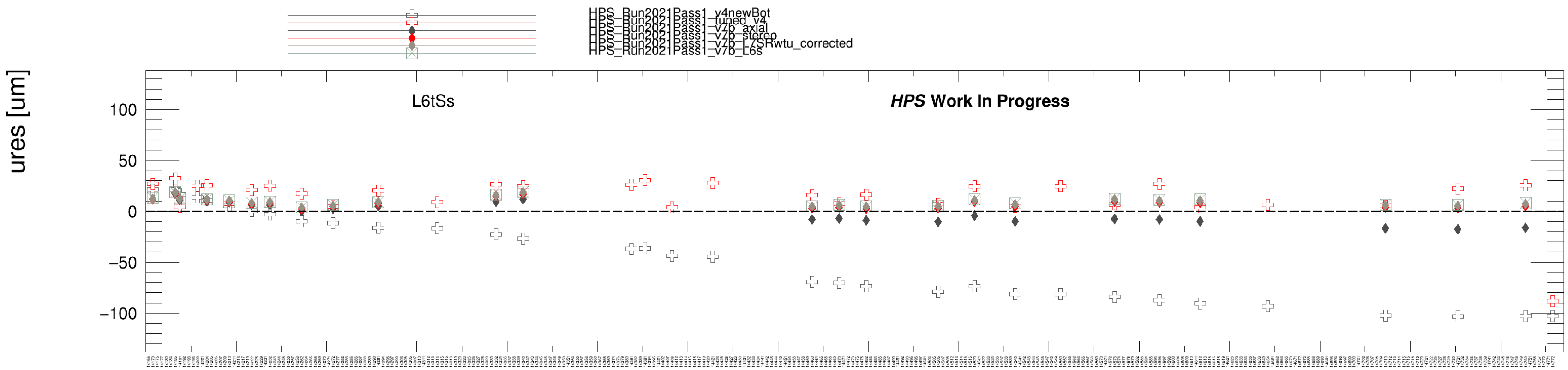

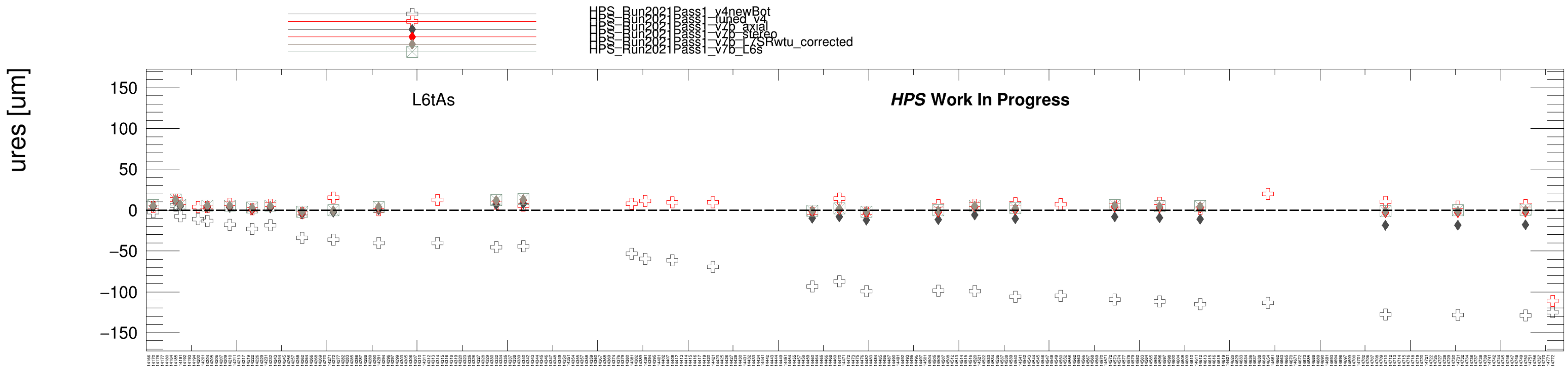

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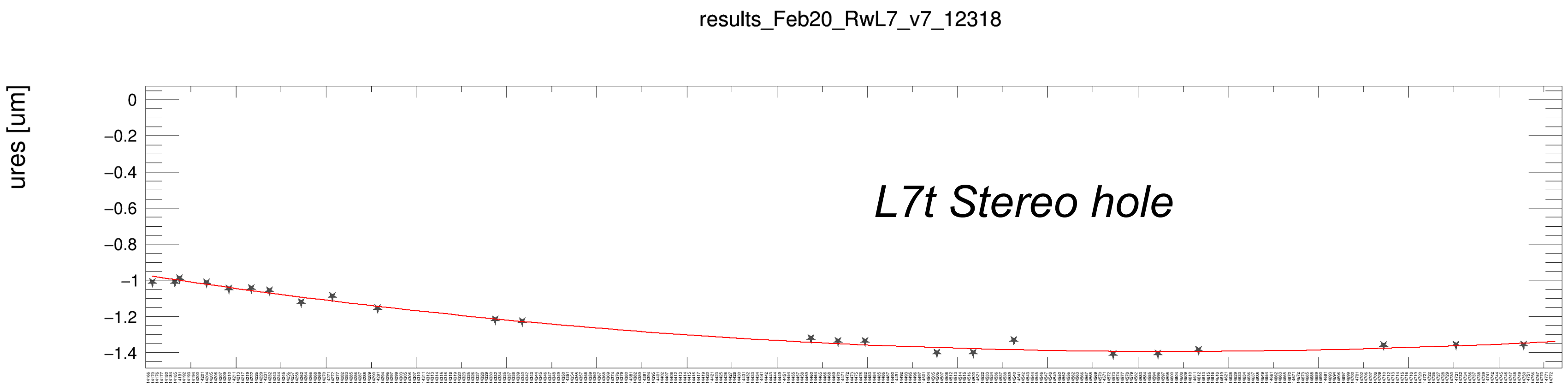
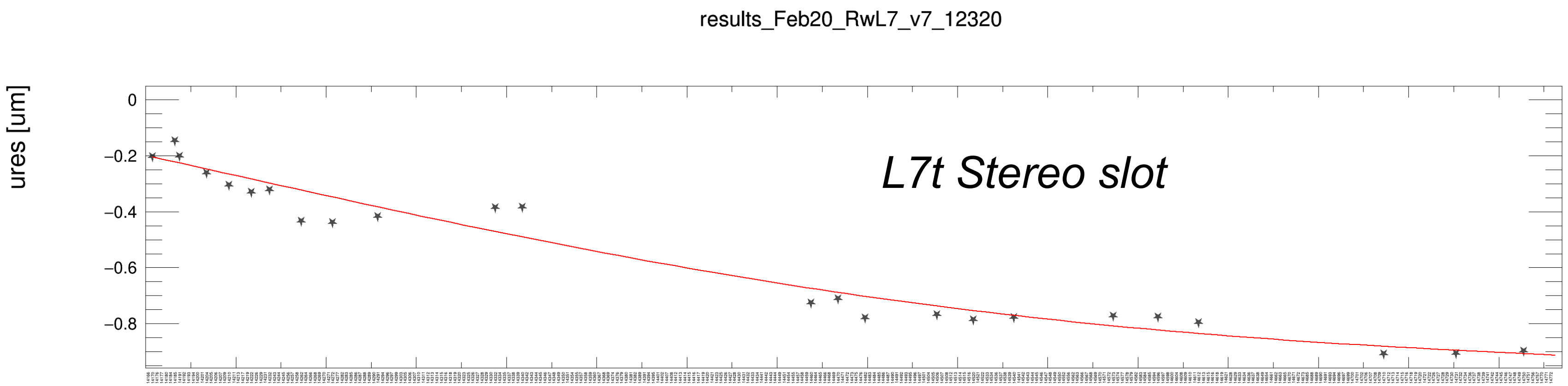
Run-by-run tu: L7 Rw corrections

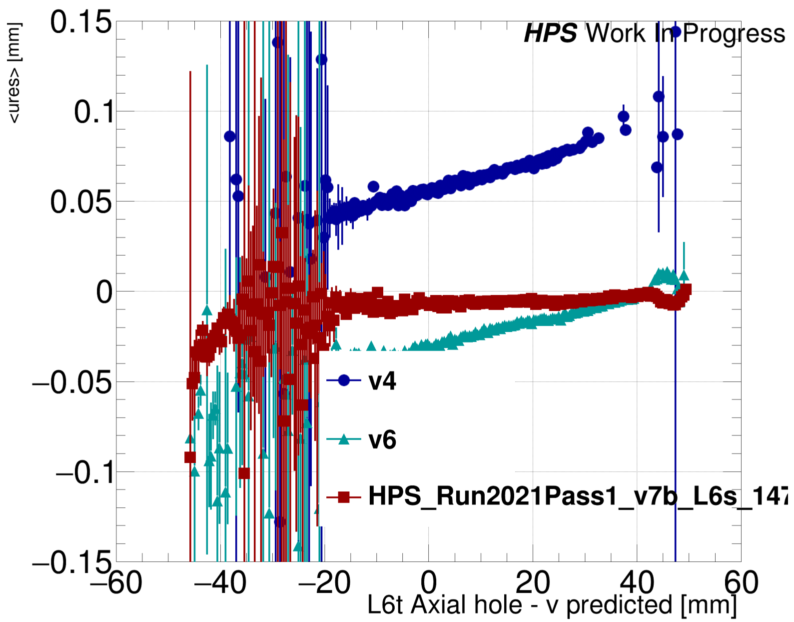


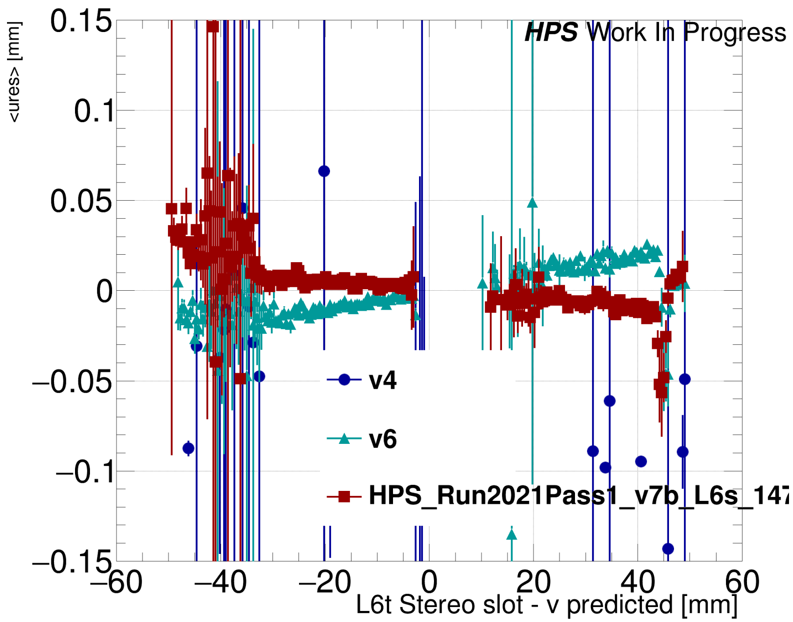


Some small Rw run dependency

Rw movements in v7 alignment

- Additional Rw movements in L6 and L7 to fix v-slopes
  - One of the last runs — heavily relying on extrapolated millepede constants and performing well!





Red squares: v7 alignment model

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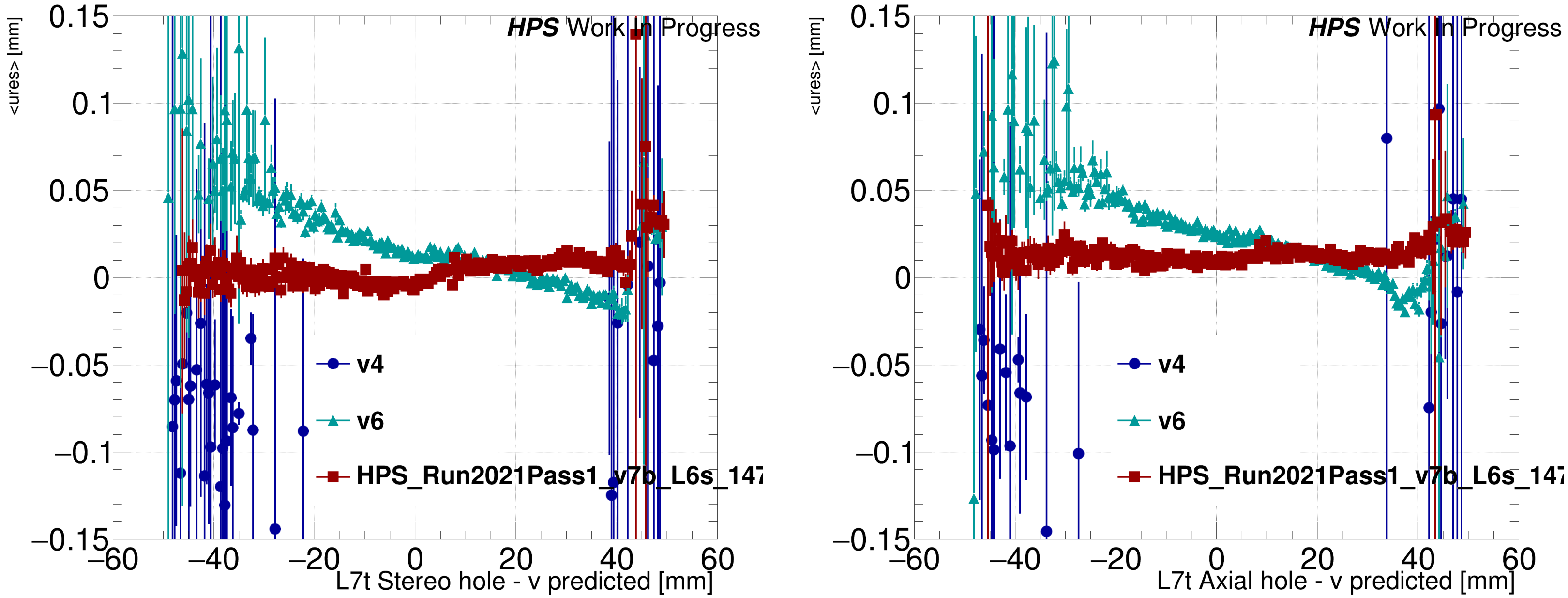


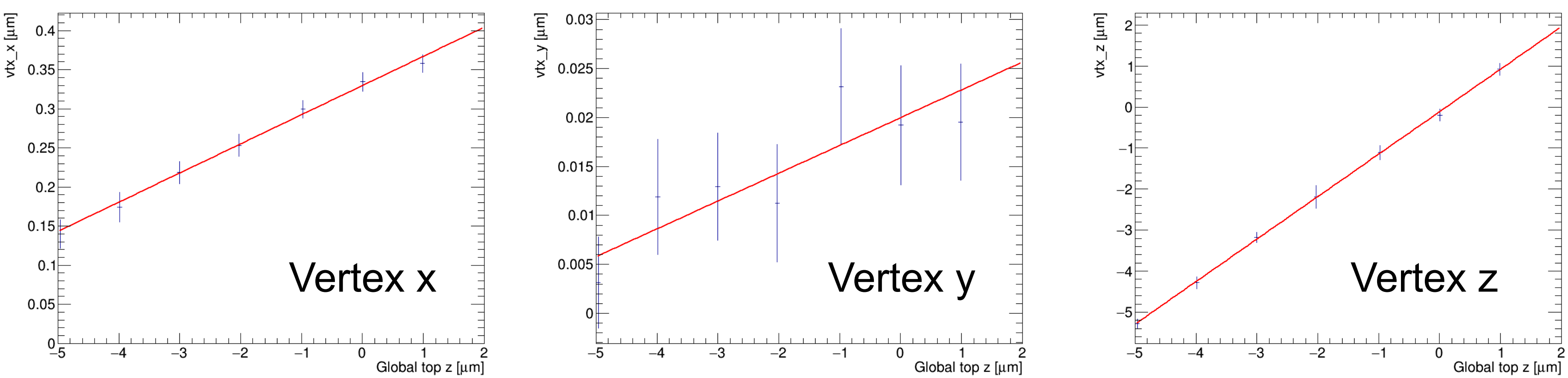
Red squares: v7 alignment model

Global movements in matrix representation

- Aligning top and bottom detectors to a common vertex position need to take into account correlations
- Relate the vertex position to these global distortions:

$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \begin{bmatrix} m_{xx} & m_{xy} & m_{xz} \\ m_{yx} & m_{yy} & m_{yz} \\ m_{zx} & m_{zy} & m_{zz} \end{bmatrix} \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix} + \begin{bmatrix} v_x^0 \\ v_y^0 \\ v_z^0 \end{bmatrix} \longrightarrow \vec{g} = M^{-1}\left(\vec{v} - \vec{v^0}\right)$$

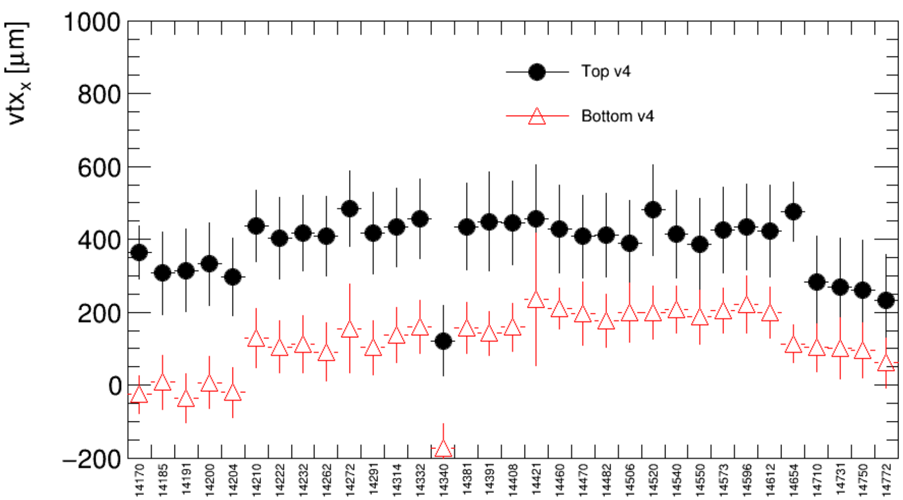
Desired vertex position — *Slope vtx vs distortion* — *Distortion* — *Vertex position no distortions* — *Invert to solve for distortions that give desired vertex position v*



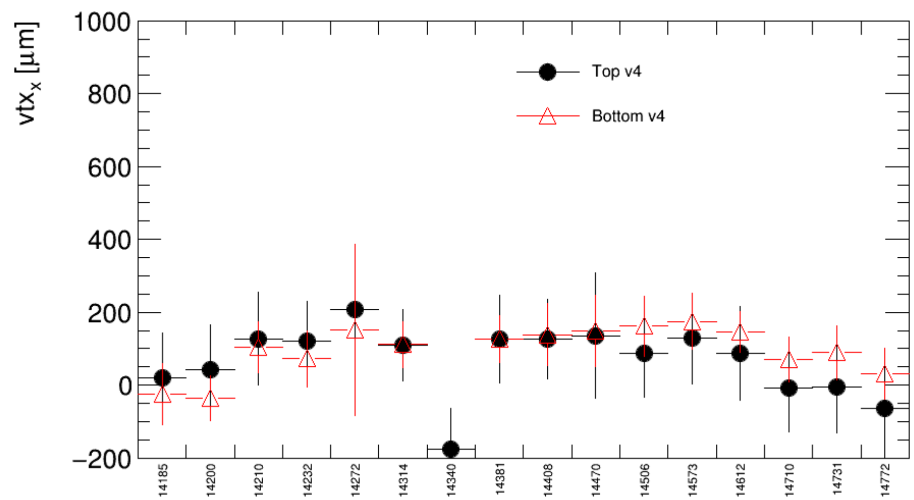
Global movement along z-axis

Comparisons: vertex x-coordinate

- Using multi-track vertex fits to get (x,y,z) positions
- Demonstrated method by moving vertex to (0,0,0)
  - Global movements derived using run 14185
  - Works well with agree between top/bottom across runs



Nominal v4



After global movements

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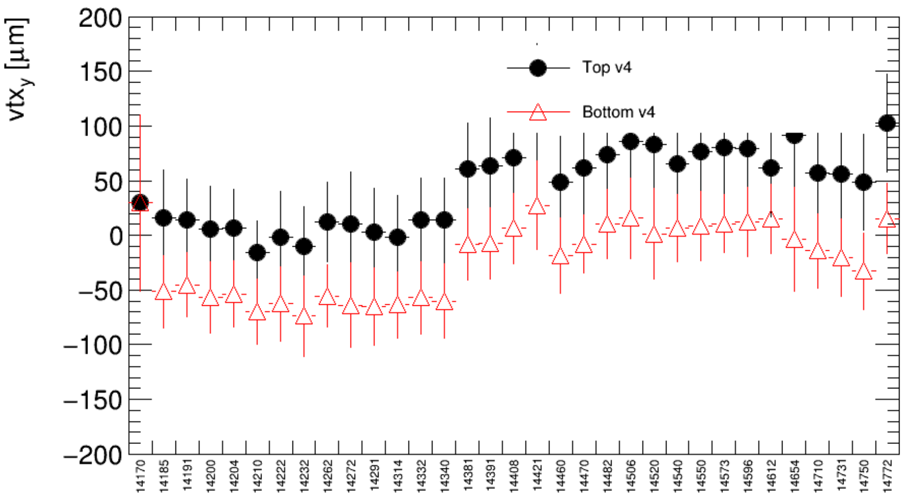
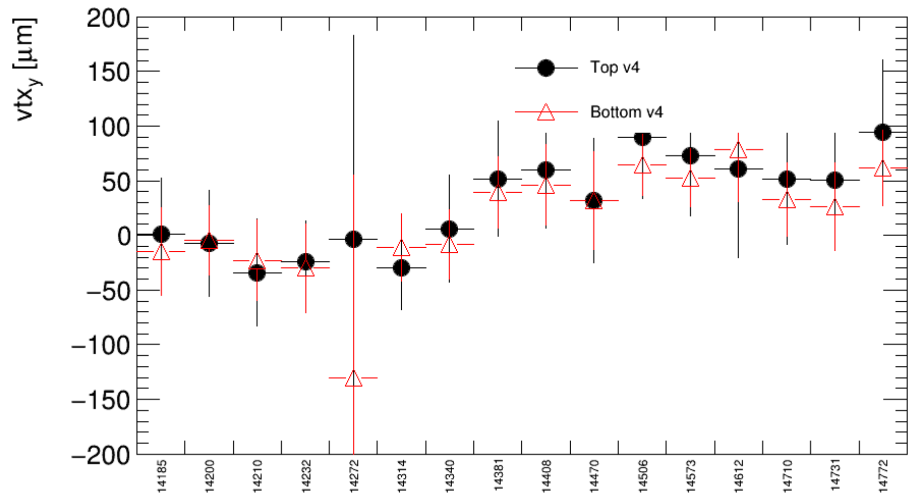


Nominal v4



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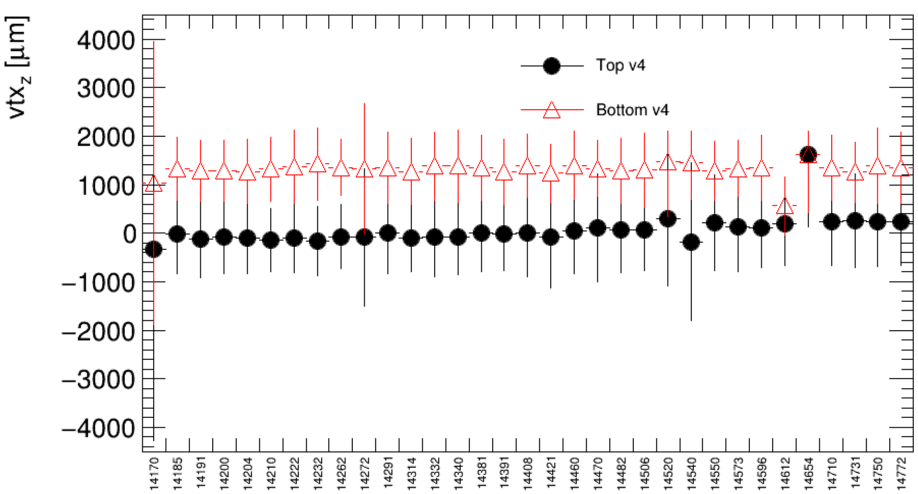

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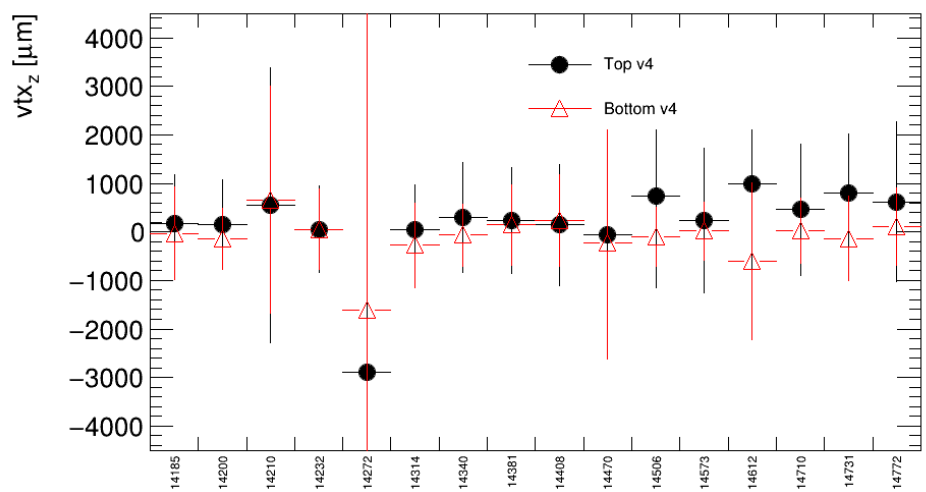

After global movements

Calibrating to correct Moller Mass

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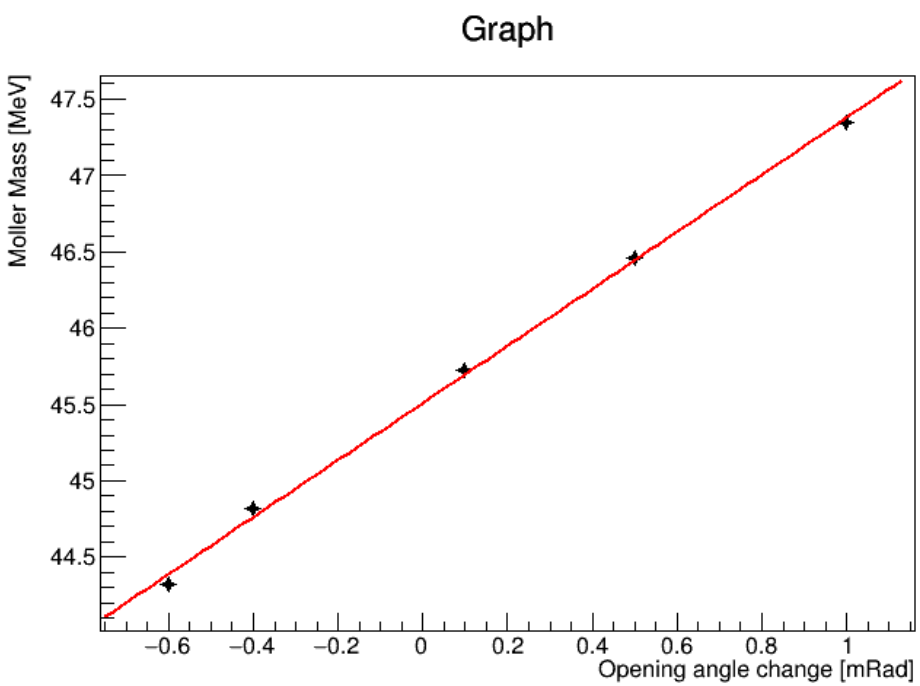
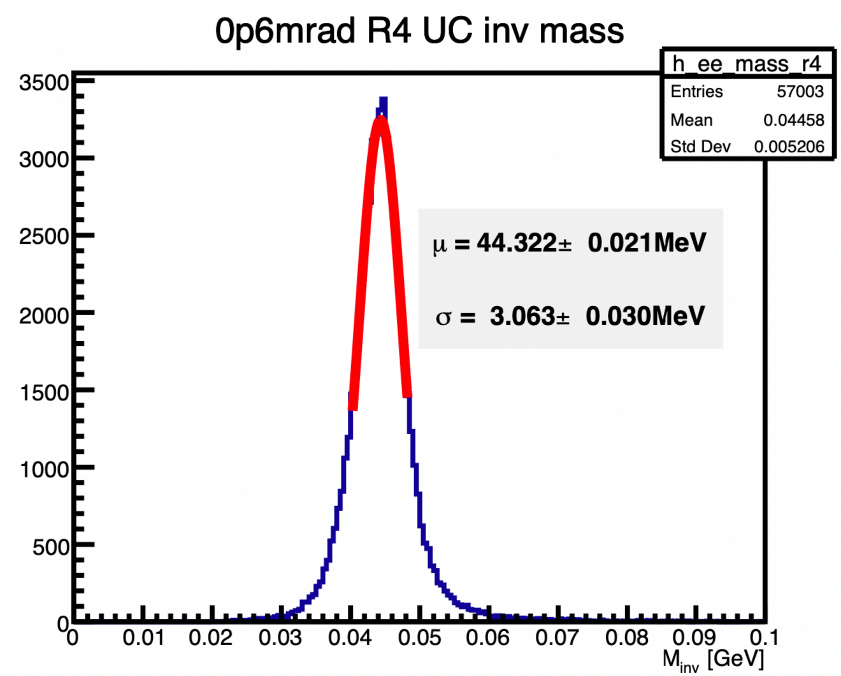
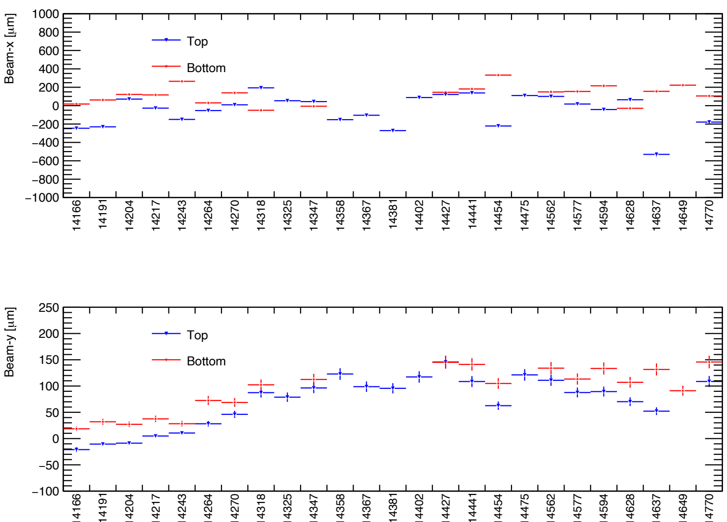
- Perform opening/closing of detector around beam spot
  - Does not affect residuals or vertex positions (see back up slides)
- Adjusted opening angle of detector (by 0.6mRad) to give theoretical predicted Moller mass of 44.3 MeV



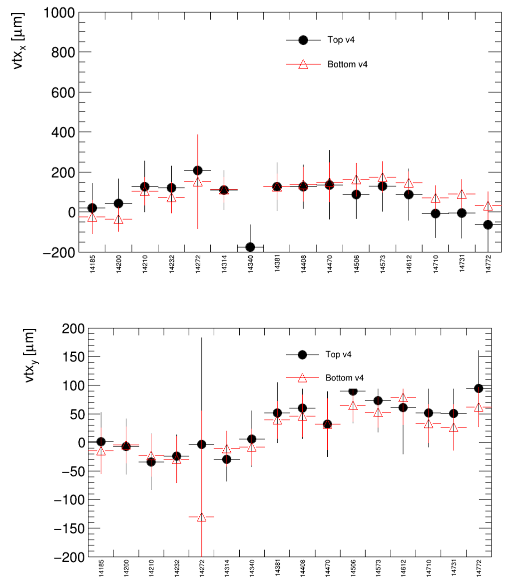


Revisiting vertex position

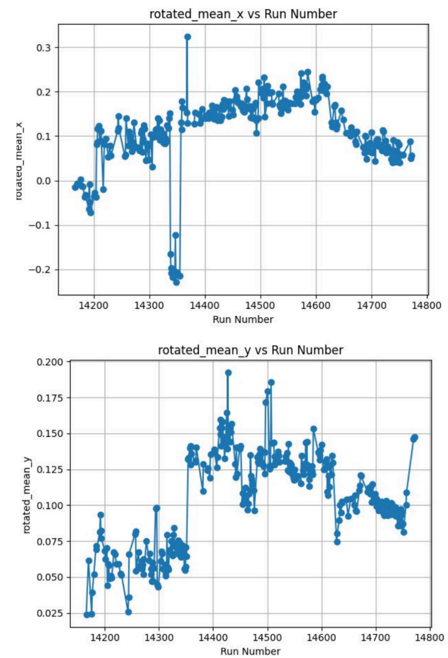
- Aside from obtaining top-bottom agreement, thought should be given on where to move the final vertex
- The (x,y) position is informed by wire-scan data and agrees well between v0, multi-track and wire-scan data



Wire scan data



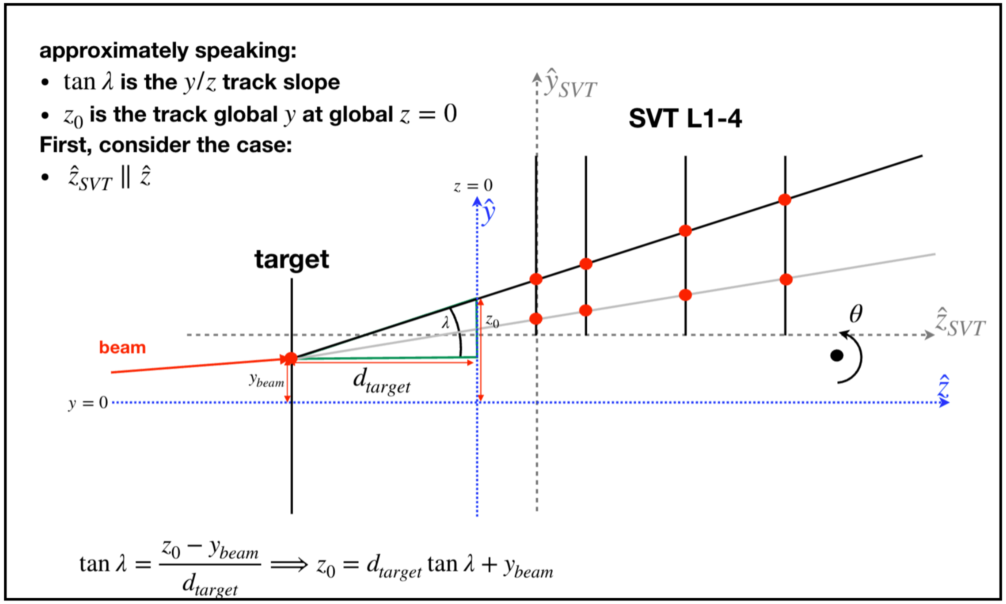
Multi-track vertex



V0 (v7 data)

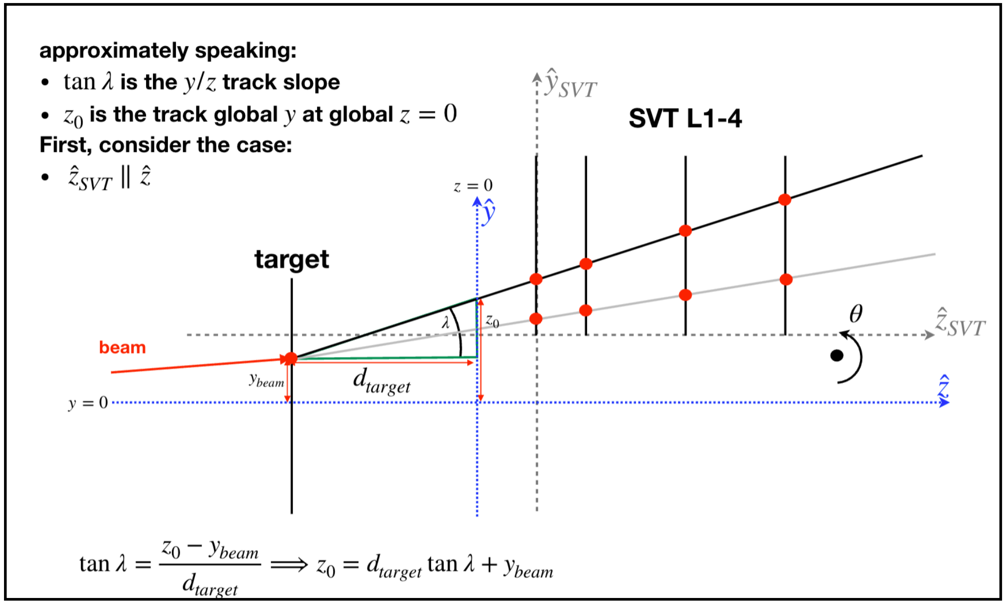
Revisiting vertex position

- However, no measurement for target z-position, but several methods can be used to cross-check each other
  - Multi-track vertex fits & **“z0 vs tanL” method**



Revisiting vertex position

- However, no measurement for target z-position, but several methods can be used to cross-check each other
  - Multi-track vertex fits & **"z0 vs tanL" method**
  - From MC studies, extracting target position from z0 vs tanL method accurate to ~1mm



z-target from tritrig MC

	Top	Bottom
Z = -7.5 mm	7.35 +/- 0.05	7.82 +/- 0.09
Z = 0.0 mm	-0.55 +/- 0.06	0.4 +/- 0.1
Z = +7.5 mm	-8.48 +/- 0.06	-7.61 +/- 0.07

Effect of (top)mis-alignments for 0mm

	Top	Bottom
Nominal	-0.55 +/- 0.06	0.4 +/- 0.1
L1tS tu +20um	-0.668,0.061	0.397,0.089
L1tA tu +20um	-1.227,0.058	0.397,0.089
L2tS tu +20um	-0.214,0.055	0.397,0.089
L2tA tu +20um	-0.273,0.052	0.397,0.089
Middle run (det)	-0.654,0.063	0.397,0.089
End run (det)	-0.668,0.061	0.397,0.089

Revisiting vertex position

- Aside from obtaining top-bottom agreement, thought should be given on where to move the final vertex
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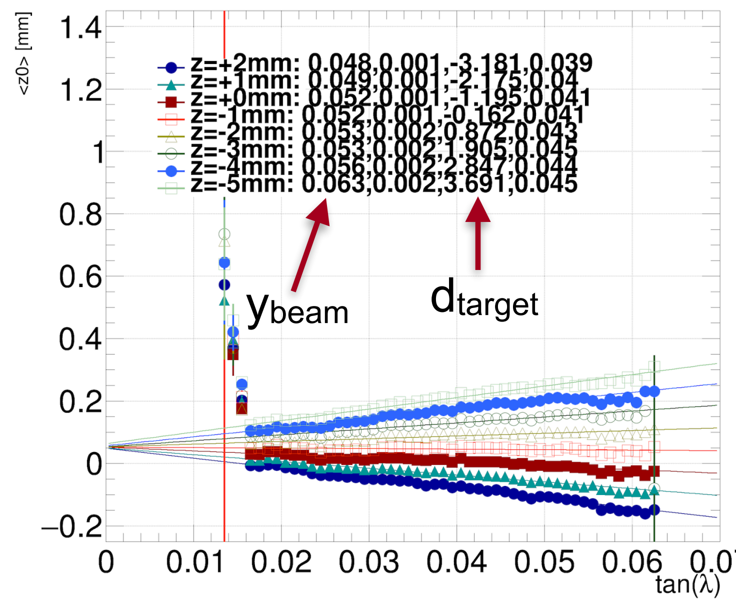
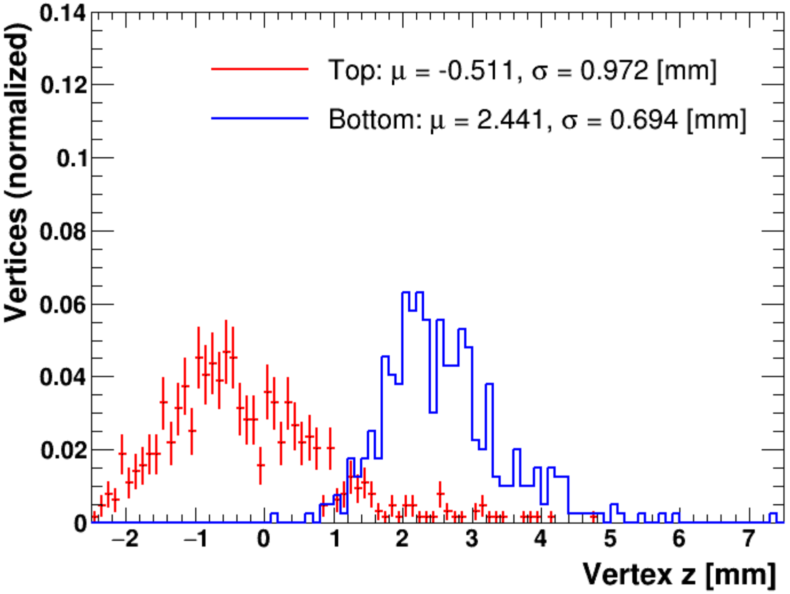
Replace these coefficients with those extracted from z0 vs tanL method



Updates to z0 vs tanL method

- For the v7 alignment, the z0 vs tanL method coefficients were used to perform the global movements
  - Long standing issue: introduces (but previously there) tension between top/bottom multi-track fits
- The two methods rely on very different information
  - Z0 vs tanL axial view
  - Multi-track vertex fits will incorporate curvature
- Issue is likely a combination effects relating to global movements and momentum scale



Z0 vs tanL issues

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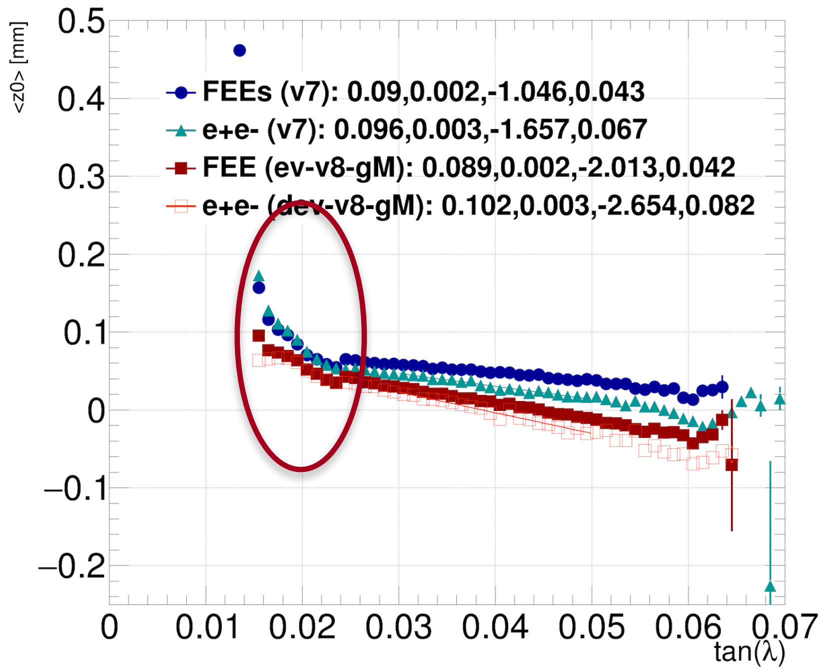
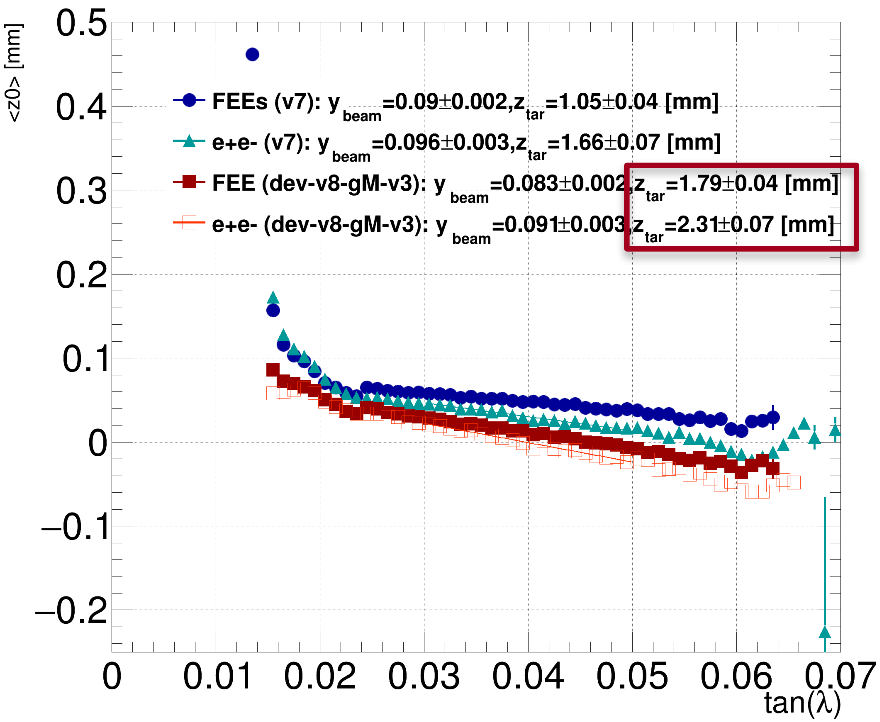
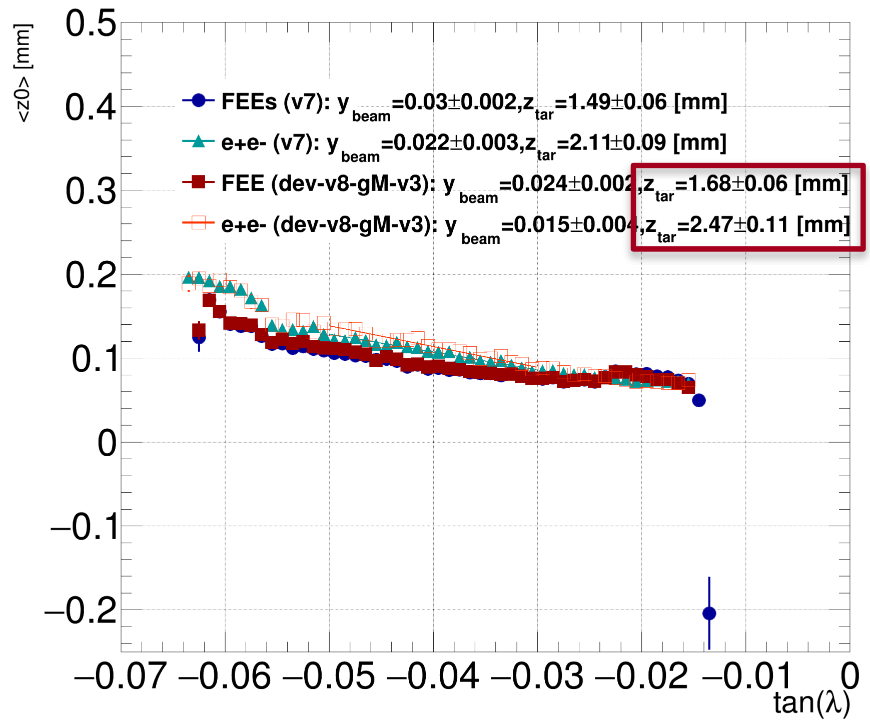
- Small issue with the implementation of z0 vs tanL method that were only realized in the last week…
- Z0 vs tanL slope is not linear across entire region
  - In particular, at low tanL has a very steep slope
  - Assuming this is related to acceptance effects and/or misalignments in L1/L2
  - Moreover, acceptance effects could be different for top bottom detectors, due to y-beam offset (~90um)



Updates to z0 vs tanL method

- For now, fitting between tanL [0.025,0.05]. This moves the predicted target position a bit lower than tuned in v7
  - Decided to shift the top detector a bit more (z+800um) as part of v8 efforts to improve agreement ("dev-v8-gM-v3")





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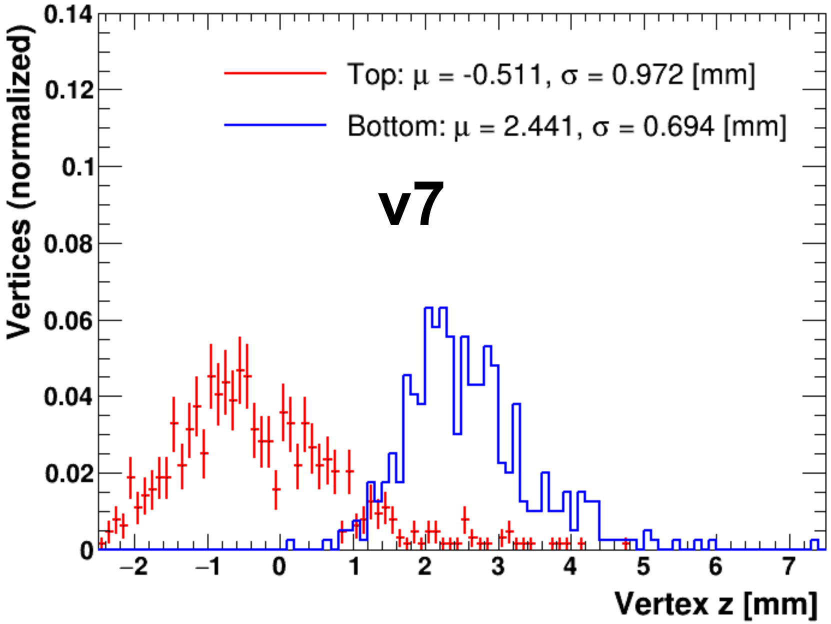
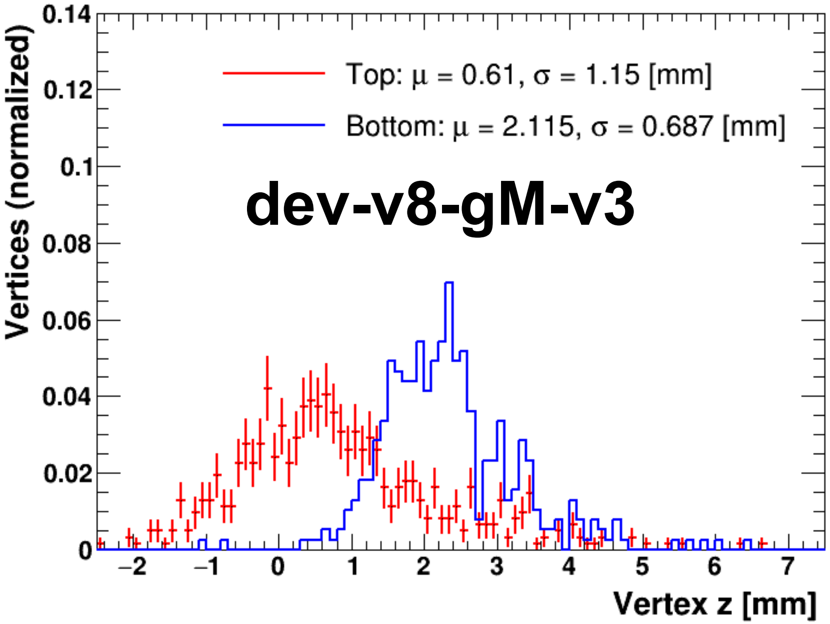
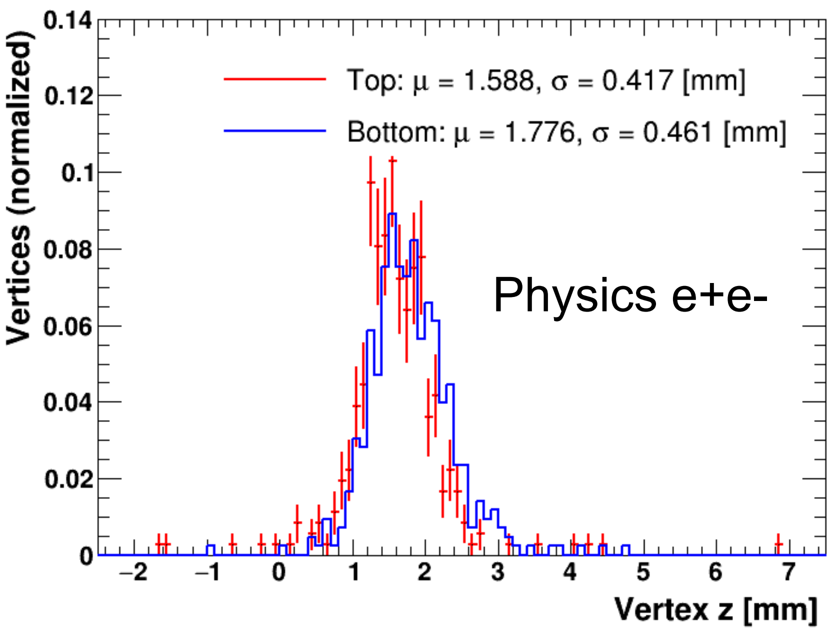


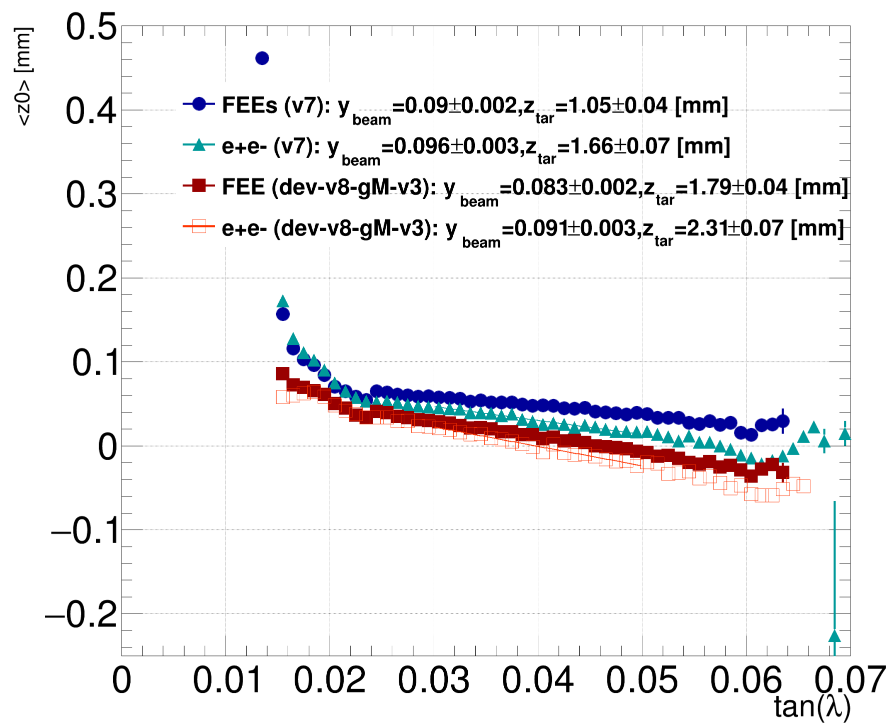


Beam spot constrained vertex alignment

- Improvement of vertex location: start using beam-spot constrained vertex alignment tools developed by PF
- Used (x-y) vertex information V0 and z-target at 1.8mm



BSC with target at 1.8mm
Top & Bottom agree well!



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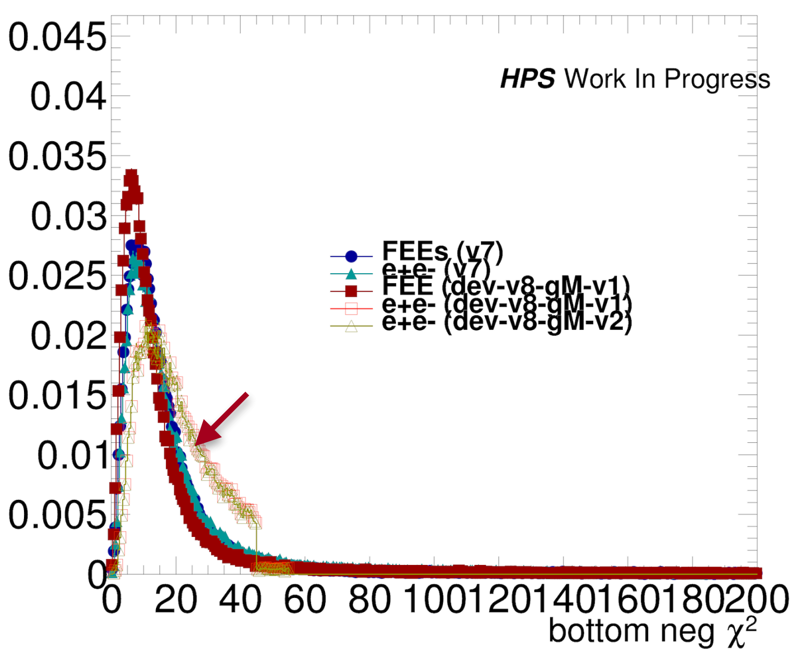
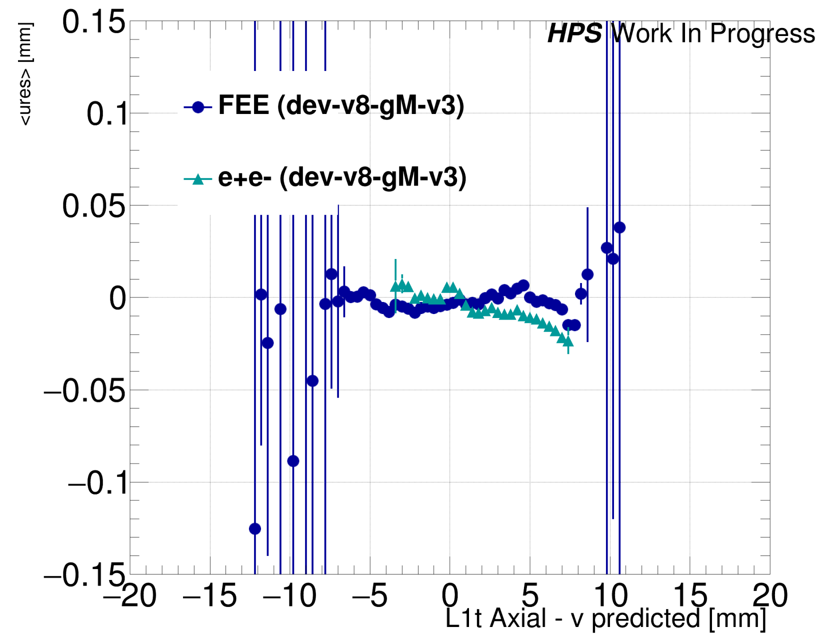
- However, obtain large chi2 when including BS along track, so can't tune using millepede yet…





Vertex locations: Summary

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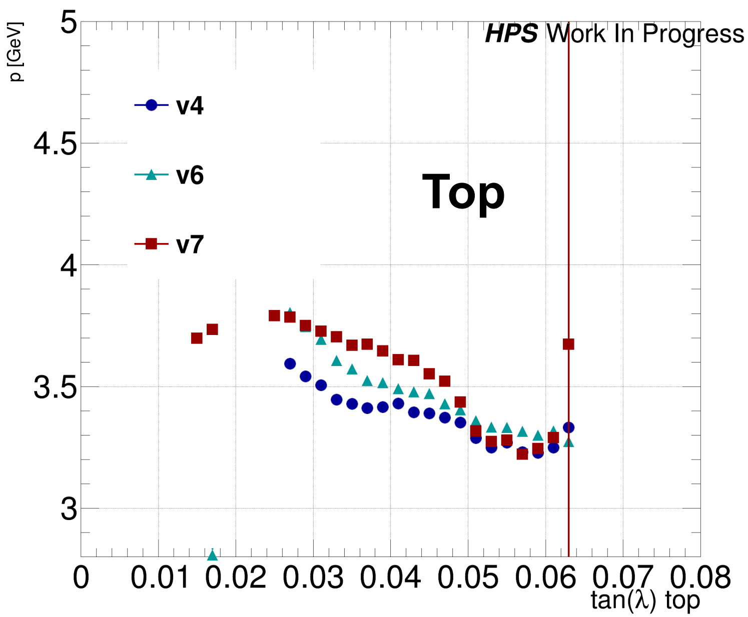
- Latest status of vertex locations in dev-v8
- Agreement across the two different methods and event streams is around 0.5 to 1mm
  - Notable outlier is the top multi-track for FEEs. Depends more strongly on track curvatures, and momentum scale is (again) currently too high in v8

	Z0 vs tanL [mm]		**Multi-track [mm]**	
	Top	*Bottom*	*Top*	*Bottom*
Physics (BSC)	2.31	2.47	1.59	1.78
FEE (PC)	1.79	1.68	0.61	2.16

Momentum scale vs tanL

- Clear trend in the momentum vs tanL for top detector
  - Momentum slope in region of tanL 0.025-0.05
  - Significantly lower (but flat) scale tanL>0.05



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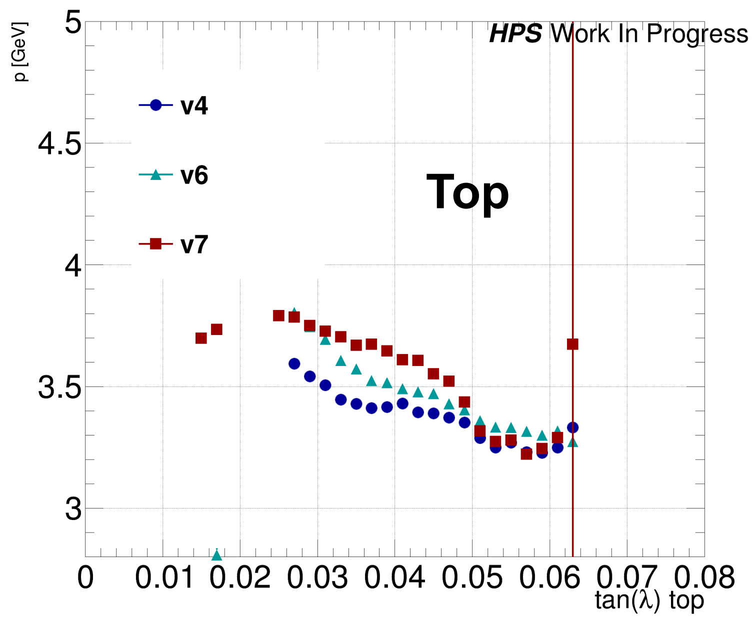

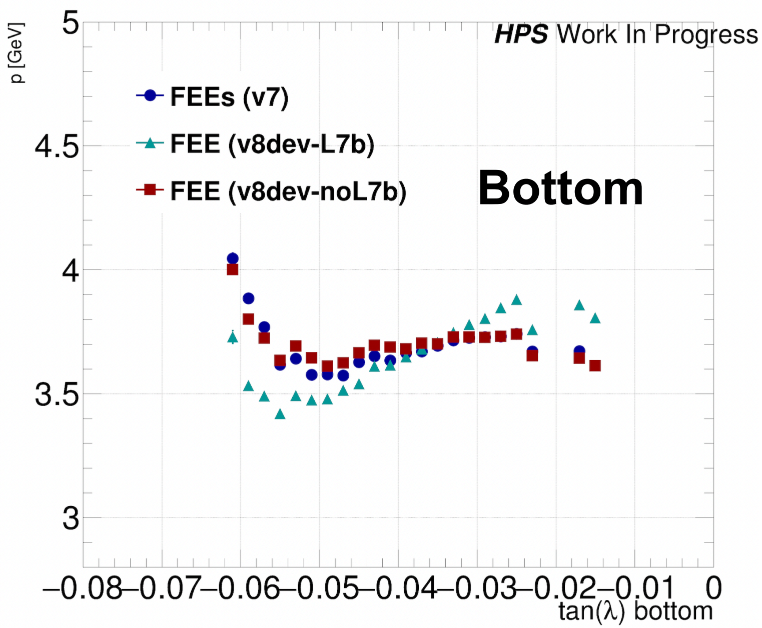

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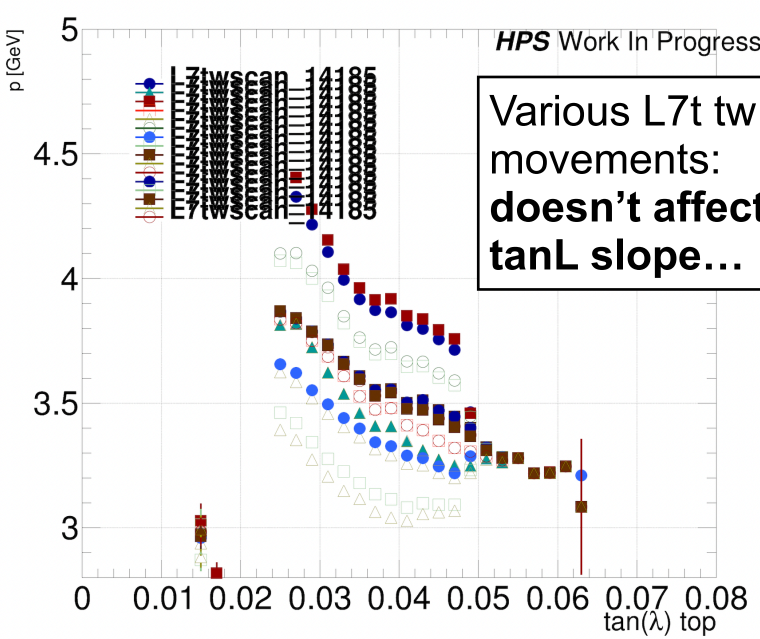
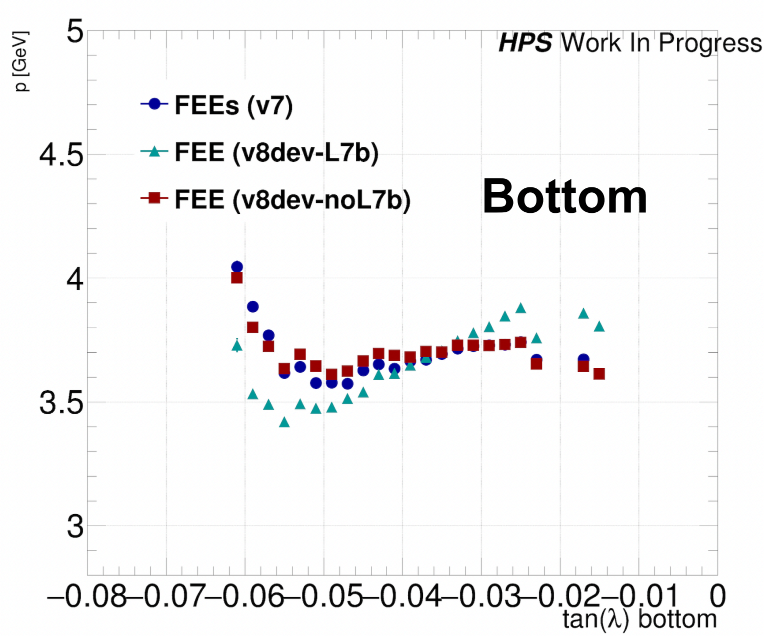
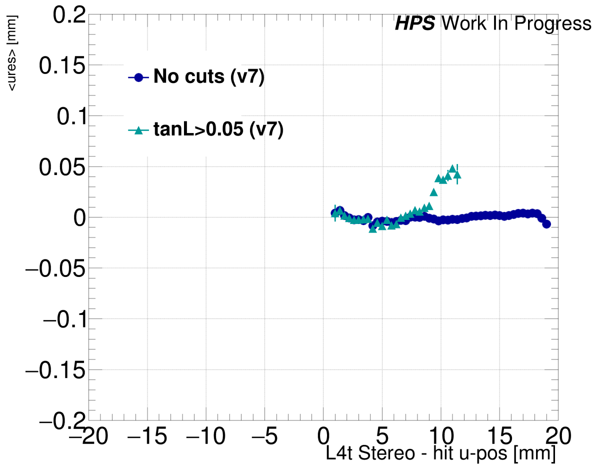
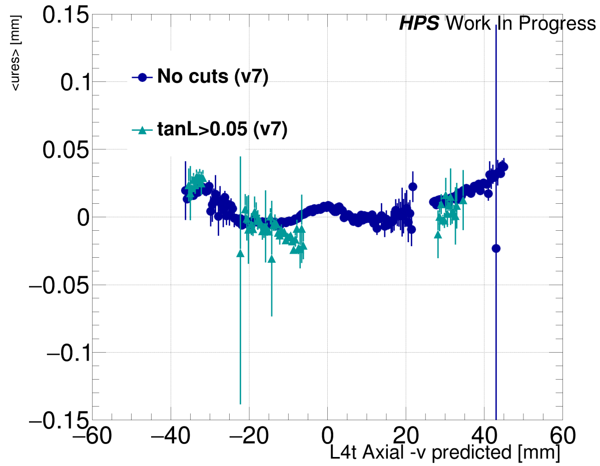


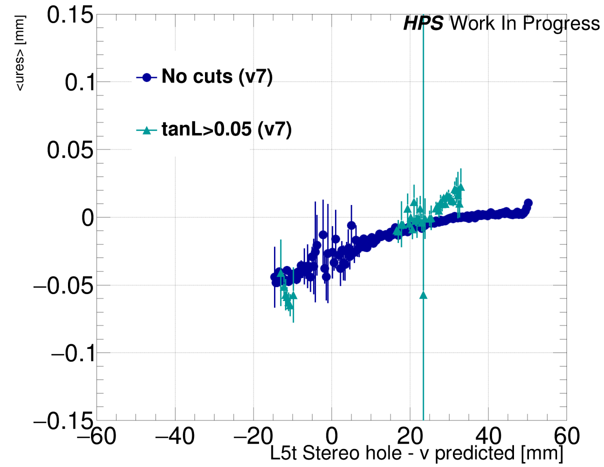


Selecting High tanL

- Studying residuals with explicit tanL>0.05 requirement:
  - Tracks do not leave hits in L7 and very few in L6
  - Strange trend in L4 residuals as tracks loose outer layers
  - Evidence of a L5 Rw but in tension with “inclusive” selection







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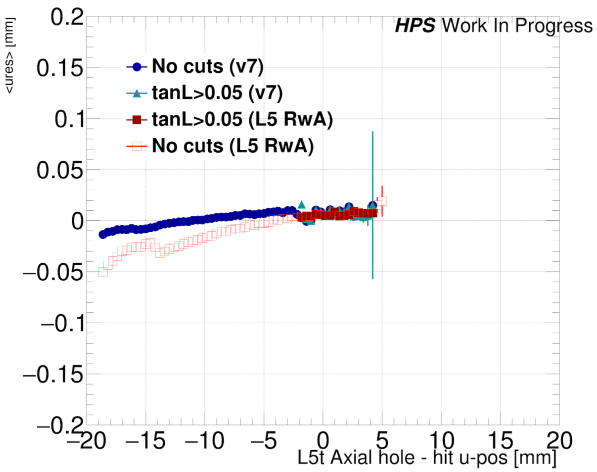
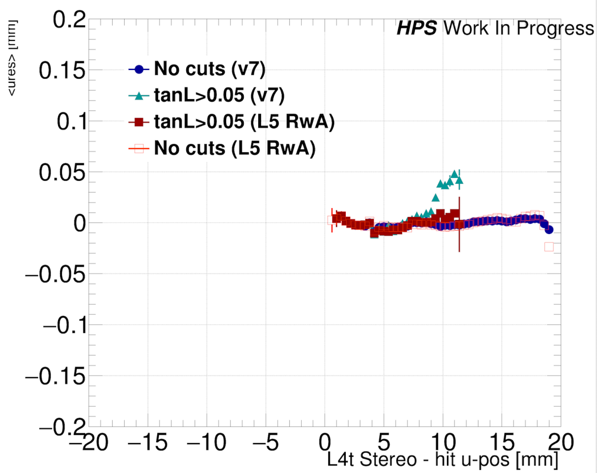
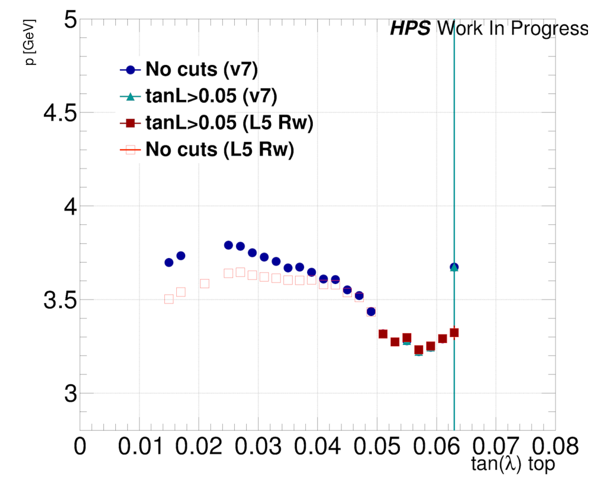
  - Strange trend in L4 residuals as tracks loose outer layers
  - Evidence of a L5 Rw but in tension with “inclusive” selection
- Ran millepede L5 Rw (and few others) fits in tanL>0.05
  - Fixes weird features and flatten momentum scale for tanL ~ 0.02-0.05, but introduce bigger issues into residuals…

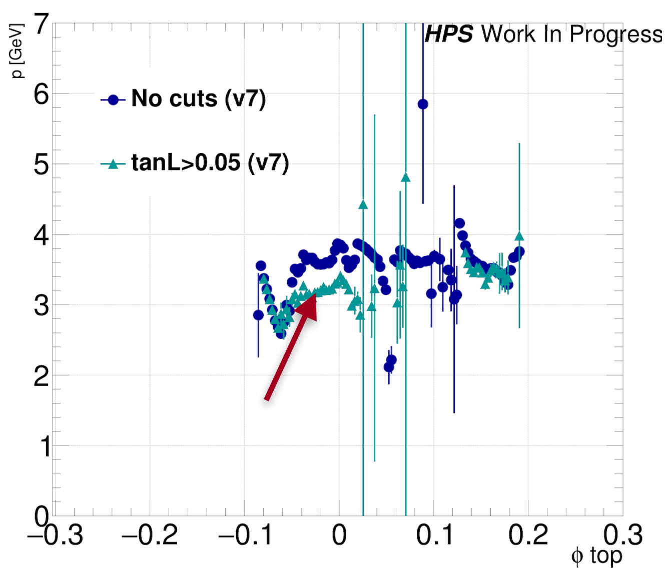


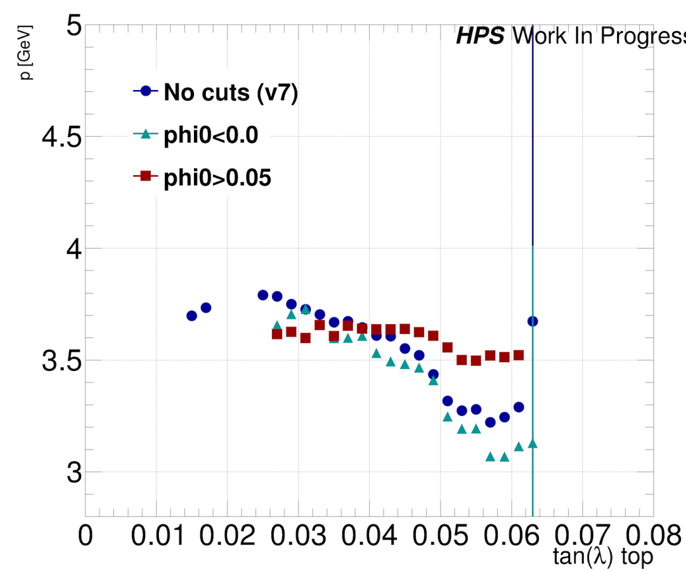




Decomposing high tanL further…

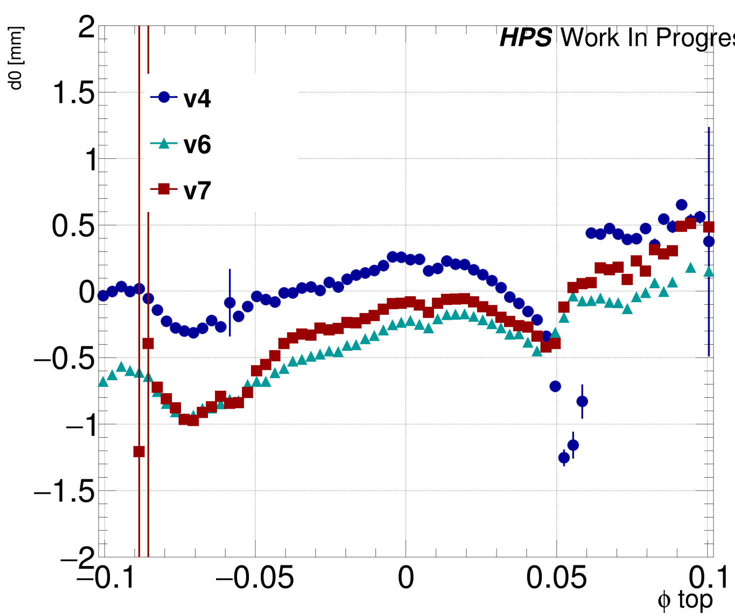
- Negative phi0 in tanL>0.05 region responsible for slope and the low momentum scale scale
  - From early studies, majority of tracks originating at -phi0 and tanL>0.05 cross from slot (L5) to hole (L6) side
  - Current line of thinking is that the z-scale is incorrect for this configuration (L5 slot/hole side have different tw)

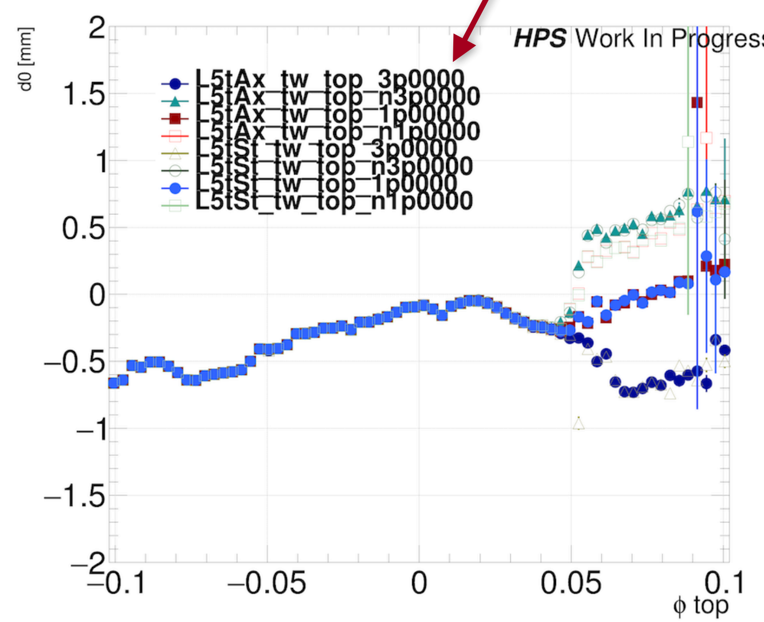




d0 bias issue

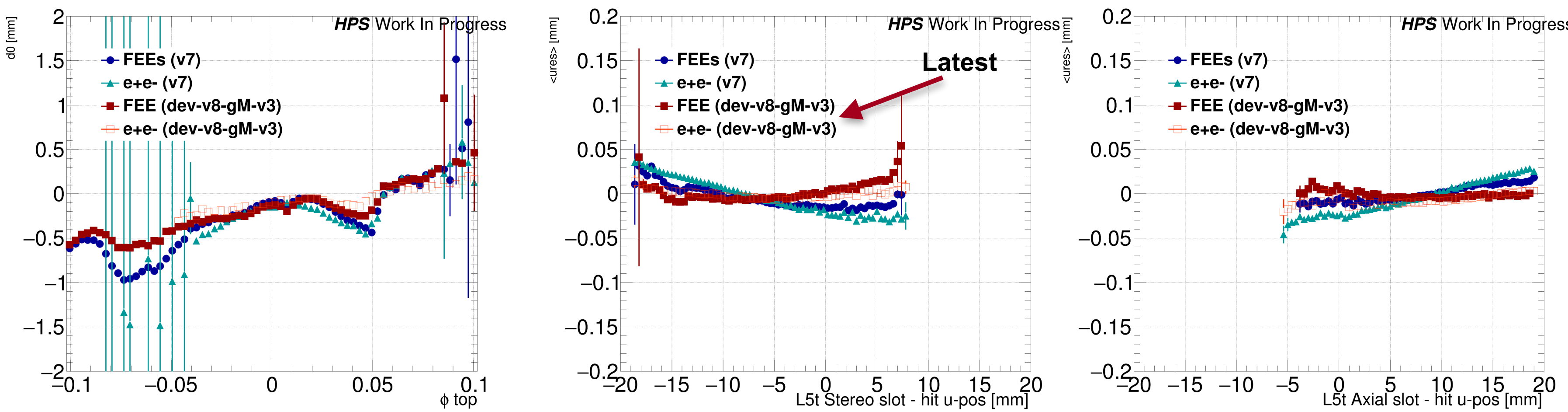
- Top detector suffers from many unique features in d0
  - Some improvements achieved from local alignment (these are included into the tw variations on right)
  - Sensitive to out-of-plane tw movements on slot side, which haven't been the focus with FEEs





d0 bias issue

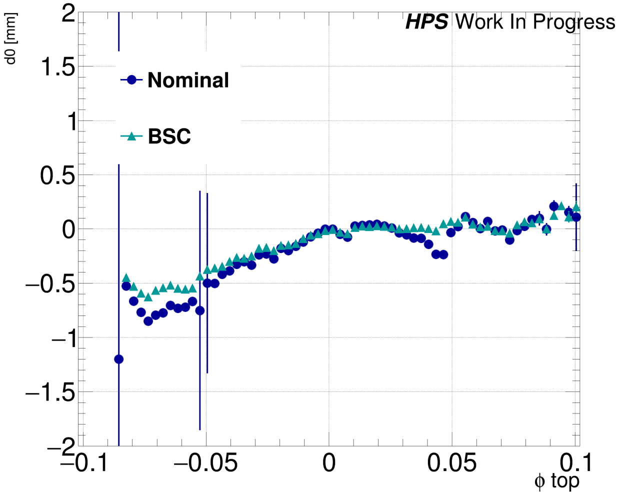
- Top detector suffers from many unique features in d0
  - Some improvements achieved from local alignment (these are included into the tw variations on right)
  - Sensitive to out-of-plane tw movements on slot side, which haven't been the focus with FEEs
  - Started incorporating physics e+e- data into alignment procedure, and clear need for additional slot side work

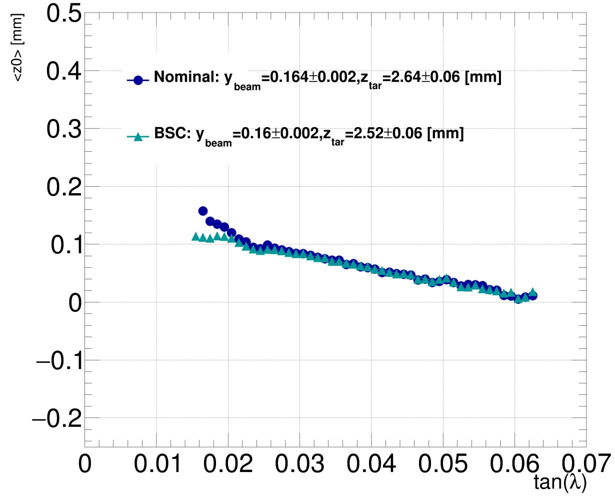


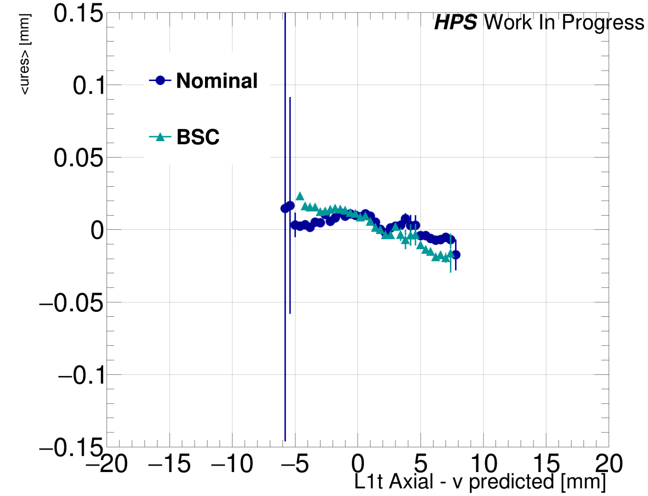
PC vs BSC

SLAC

- d0 bias is also sensitive to global movements (see backup)
  - Top and bottom alignment based on multi-track z-vertex checked (labelled “Nominal” in plots)
- Beam spot constraint removes the dip at phi0 ~0.05 and reduces z0 vs tanL slope at small tanL
  - Rw movement needed in L1t axial layer?







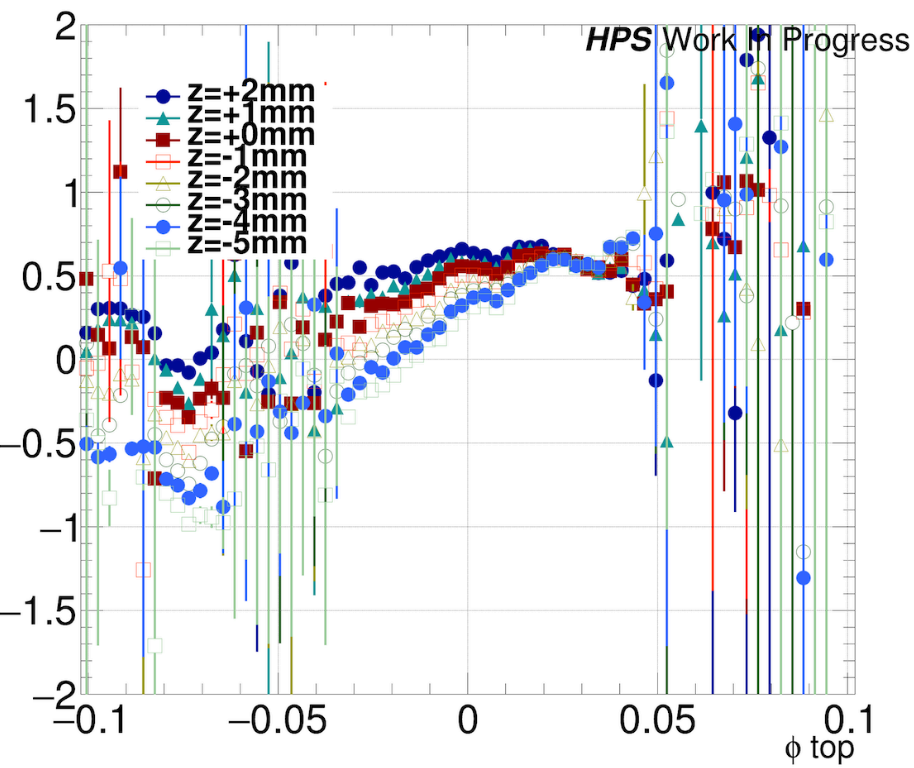
Conclusions

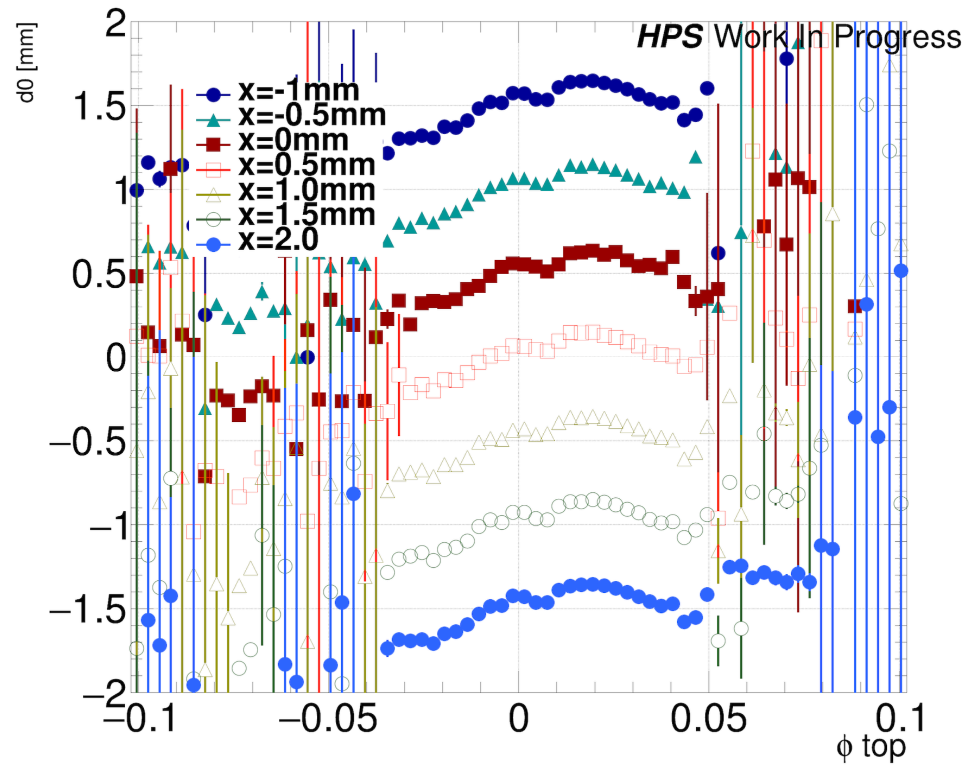
- Lots of studies on the 2021 alignment model beyond v7
  - Improved tuning in the outer most layers (top&bottom)
  - Global movements to align top and bottom detectors
  - Improved understanding of vertex locations and first usage of beam spot constrained alignment driver
  - Narrowing in on origins of several features and movements that impact d0, z0, and tanL biases
- Strong need to solve BSC alignment driver Chi2 “issue”
- Optimistic to have a v8beta detector in the next month
  - But, would like to revisit initial tw movements made in v6 with focus on d0 and momentum biases in phi0 and tanL

Questions

d0 bias issue: global movements

- Also sensitive to global motions of the SVT detector
  - Z-movements cause a slope on negative side
  - Movements along the x-axis scale effect to d0





Note: v6 study with relatively low stats