Wedge Analysis

Longitude Problems

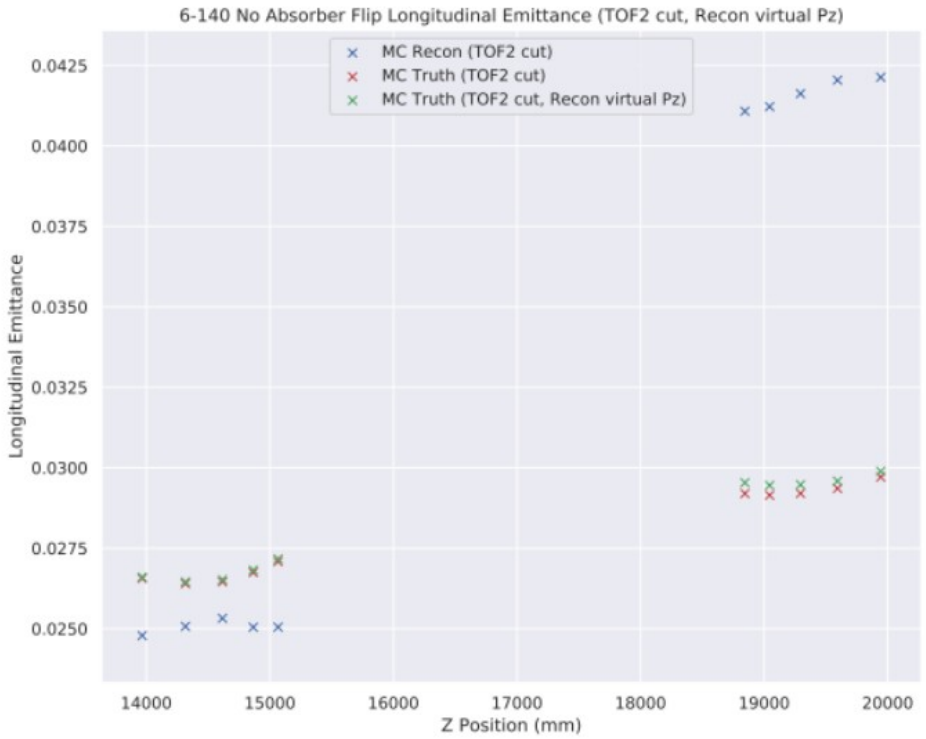
Previously

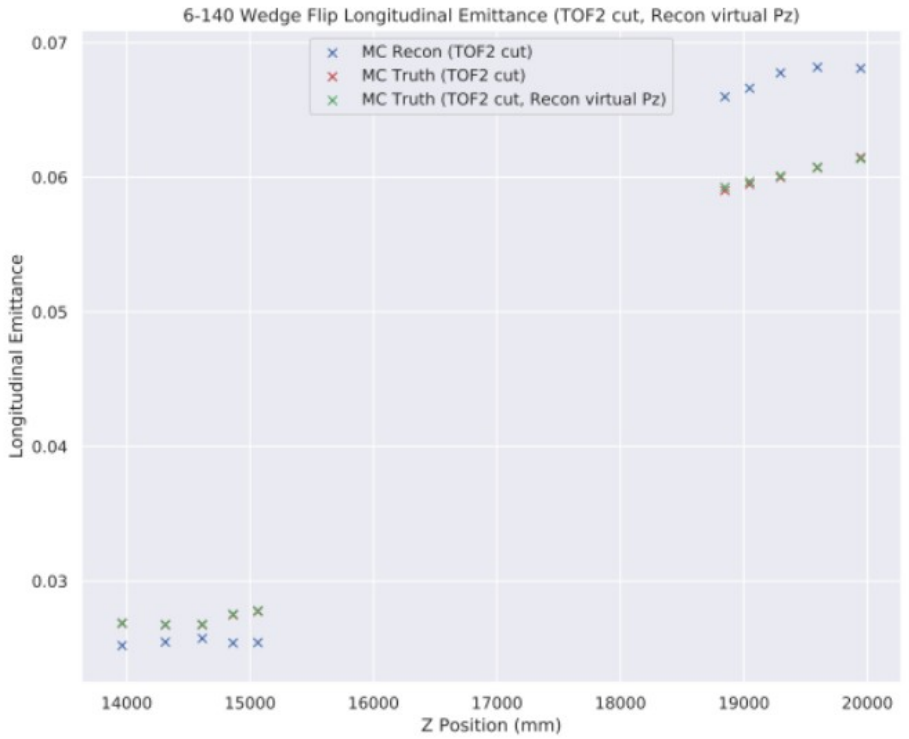
- Showed Emittance, Amplitude and Density all had Longitudinal and 6D Problems in MC Recon but not in MC Truth
- MC Truth showed 6D Density Conservation, little change in Amplitude and small change in Emittance (non-linearities) when no absorber is present. Wedge case showed dispersion effects that still need a correction
- Showed Pz is a problem by substituting Pz Truth by Pz Recon

- Gave back of envelope calculation of why Pz bias could be there, will show some more plots about it

Longitudinal Emittance

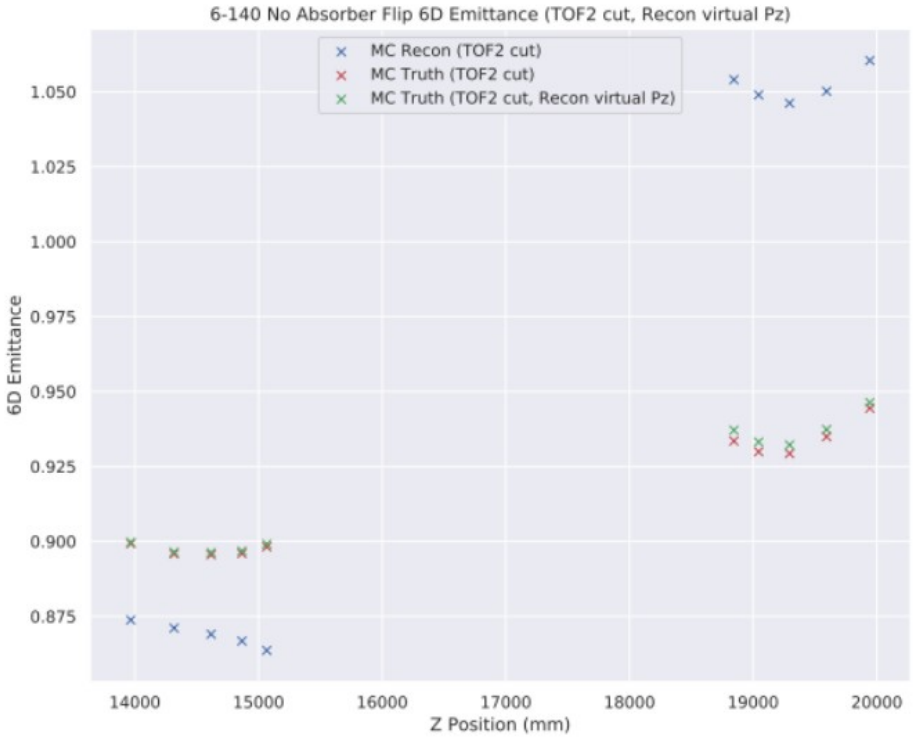
- Green is same as Truth except Time has been reconstructed using Truth Pz
- Recon shows larger discrepancies (Resolution effect)
- No Absorber Longitudinal Emittance shows small change, but Wedge Longitudinal Emittance doubles between TKU and TKD

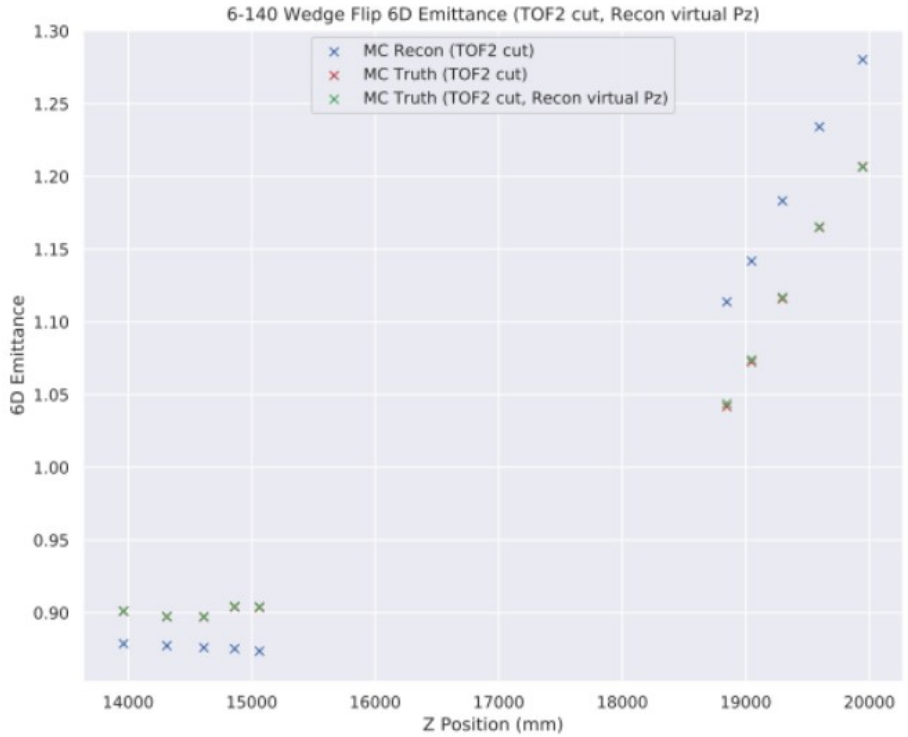




6D emittance

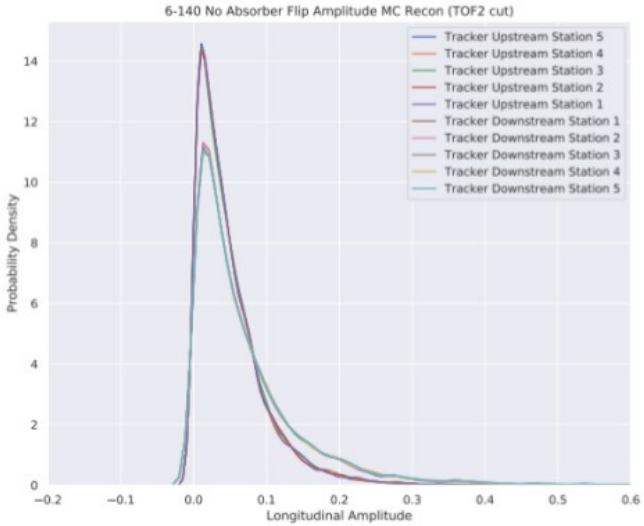
- Green is same as Truth except Time has been reconstructed using Truth Pz
- Recon shows larger discrepancies (Resolution effect)
- Could take larger momentum bite, but would then need to correct transverse components. Probably need to in Wedge case due to dispersion downstream

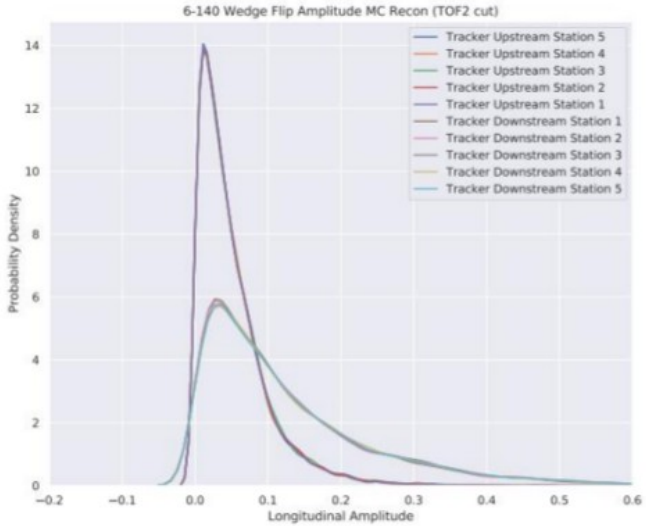


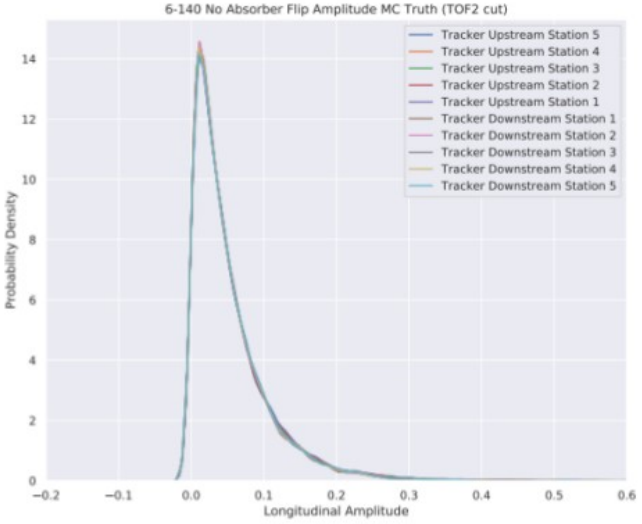


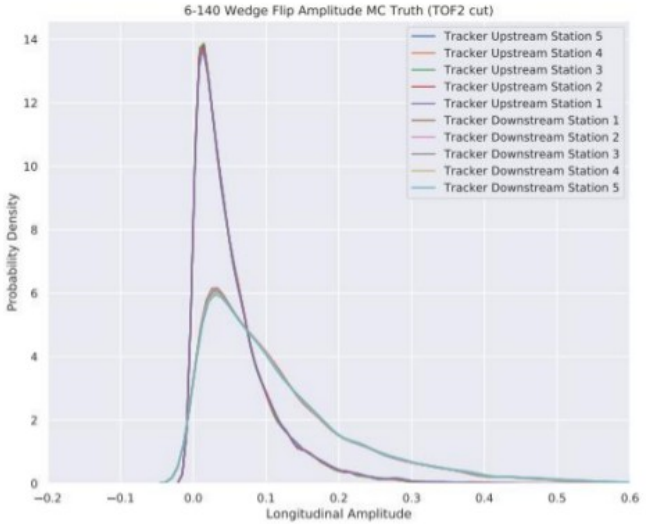
Longitudinal Amplitude

- MC Truth shows conservation between TKU and TKD for No Absorber
- Growth for Wedge
- Recon is off due to the Pz being reconstructed differently in TKU and TKD



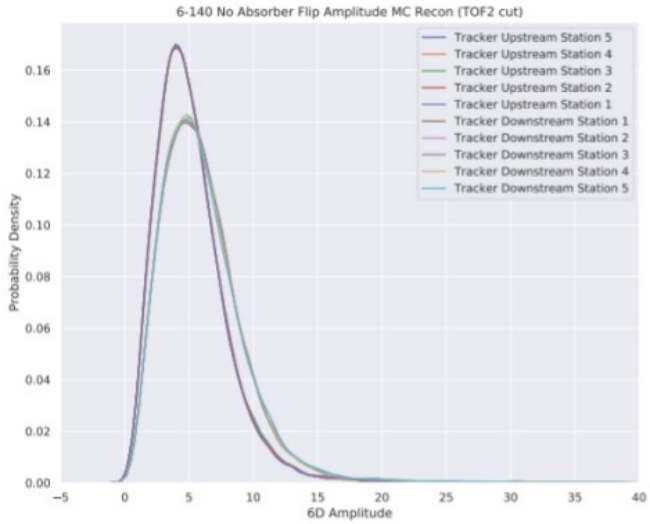


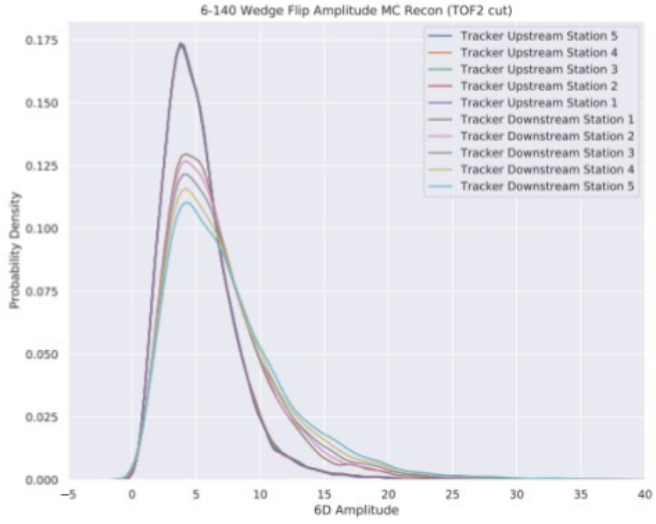


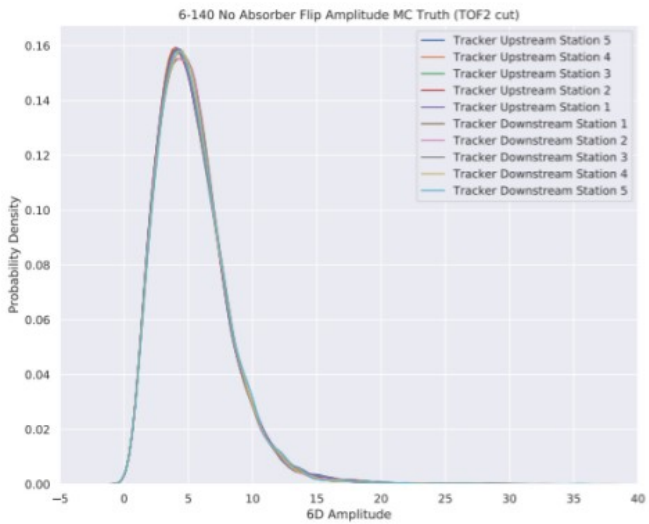


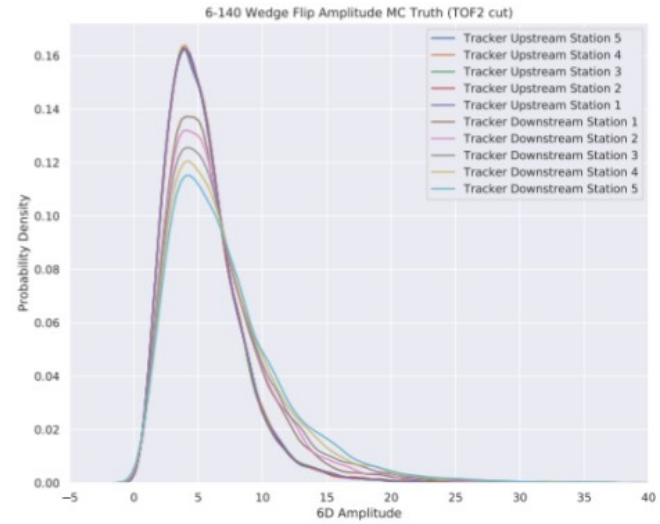
6D Amplitude

- Truth shows 6D conservation for No Absorber case
- Wedge shows change between TKU and TKD and within TKD due to dispersion
- Likely need to correct Transverse components for extra rotation
- Makes separation of 6D into Transverse and Longitudinal components tricky



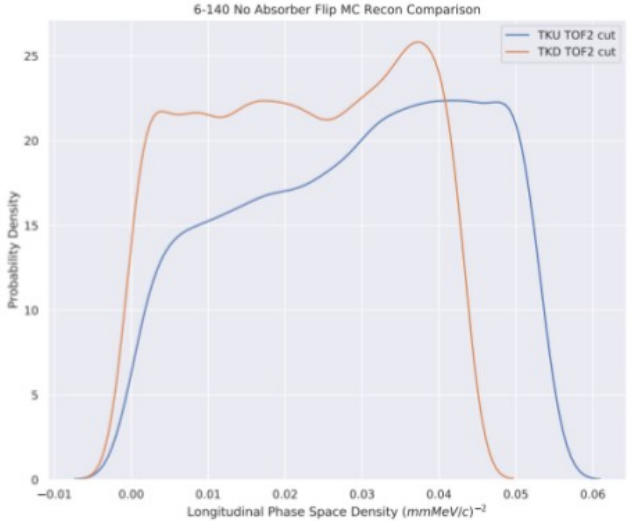


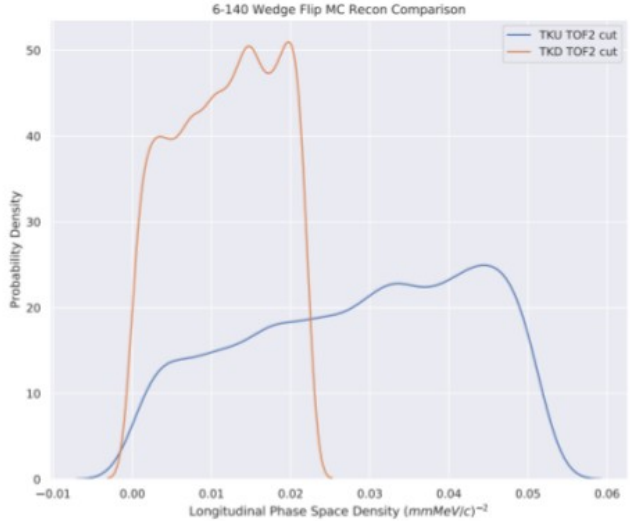


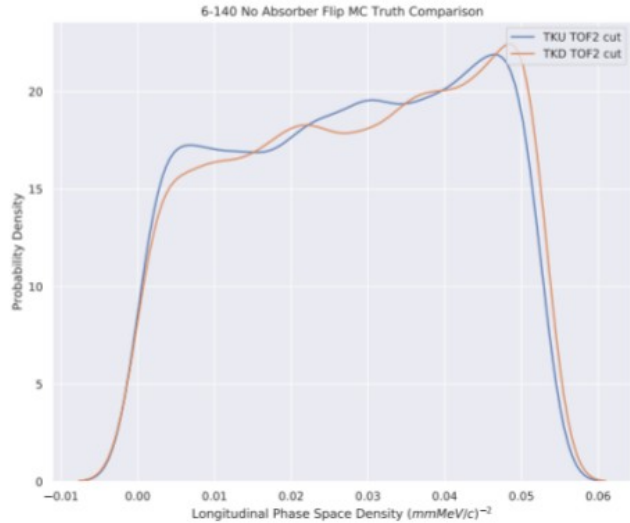


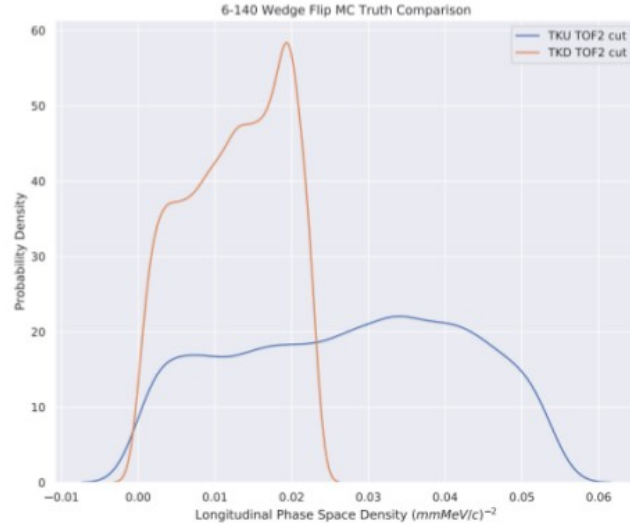
Longitudinal Density

- See similar effects for longitudinal density as for Amplitude
- Truth conserves No Absorber density and halves Wedge density of beam.
- Wedge density shape change indicates some edge effect



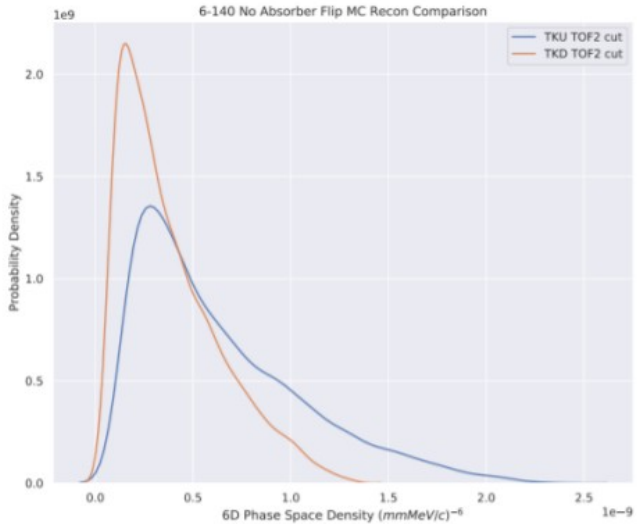


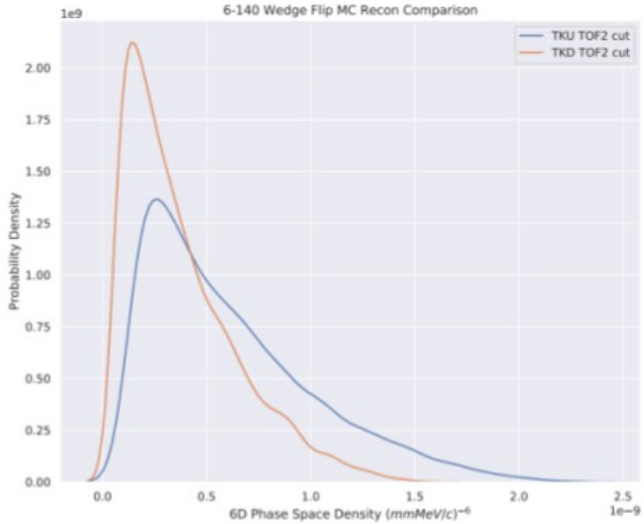


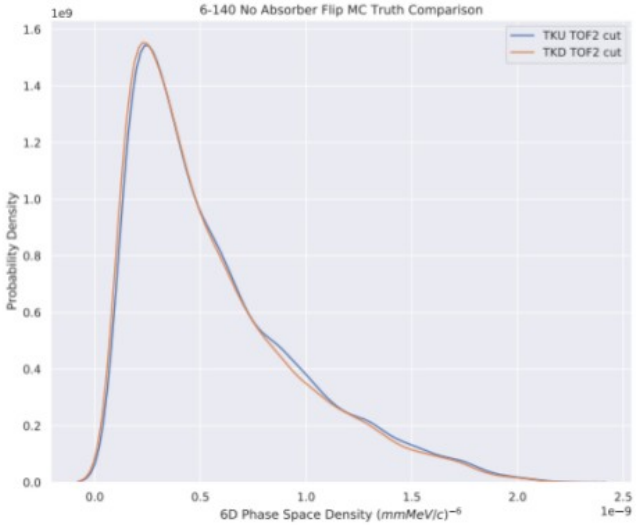


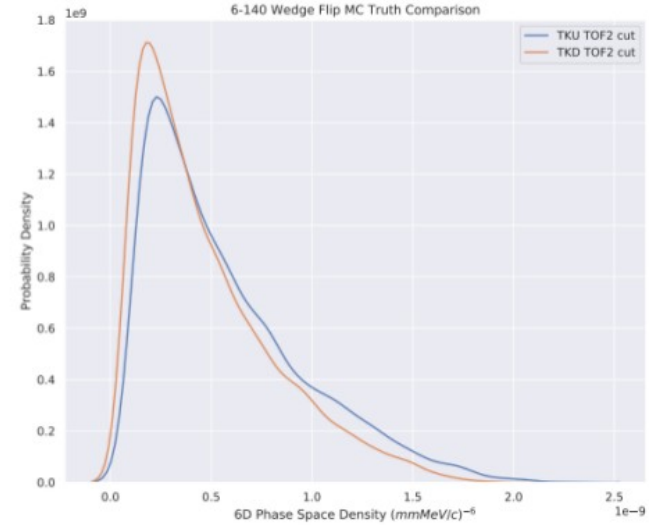
6D Density

- 6D density is also similar to 6D Amplitude
- It also has same effect through TKD -> Transverse Components need correction









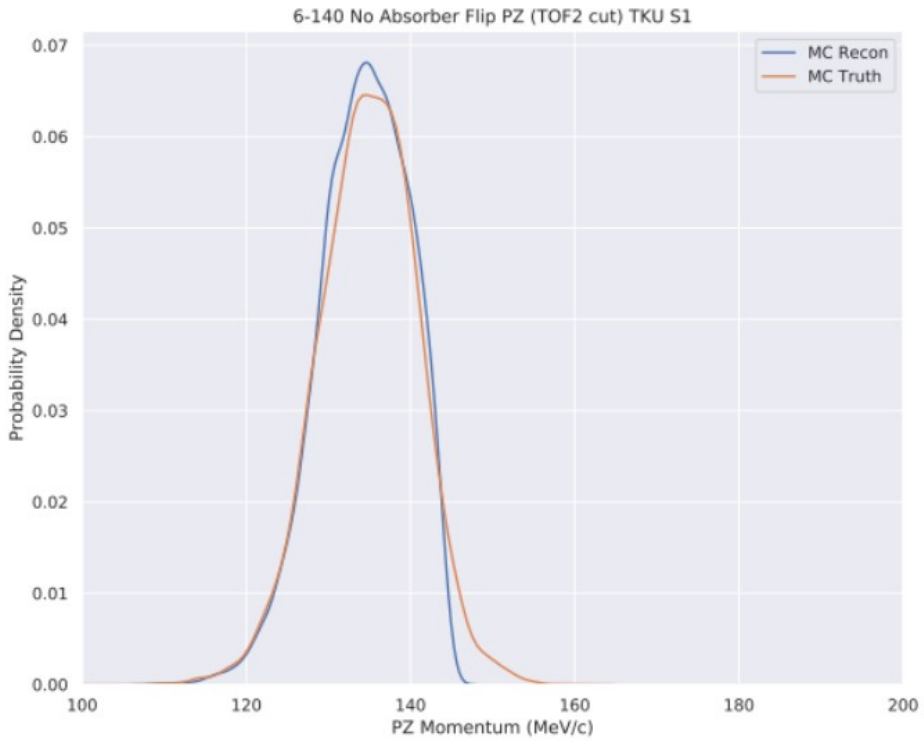
Pz Bias

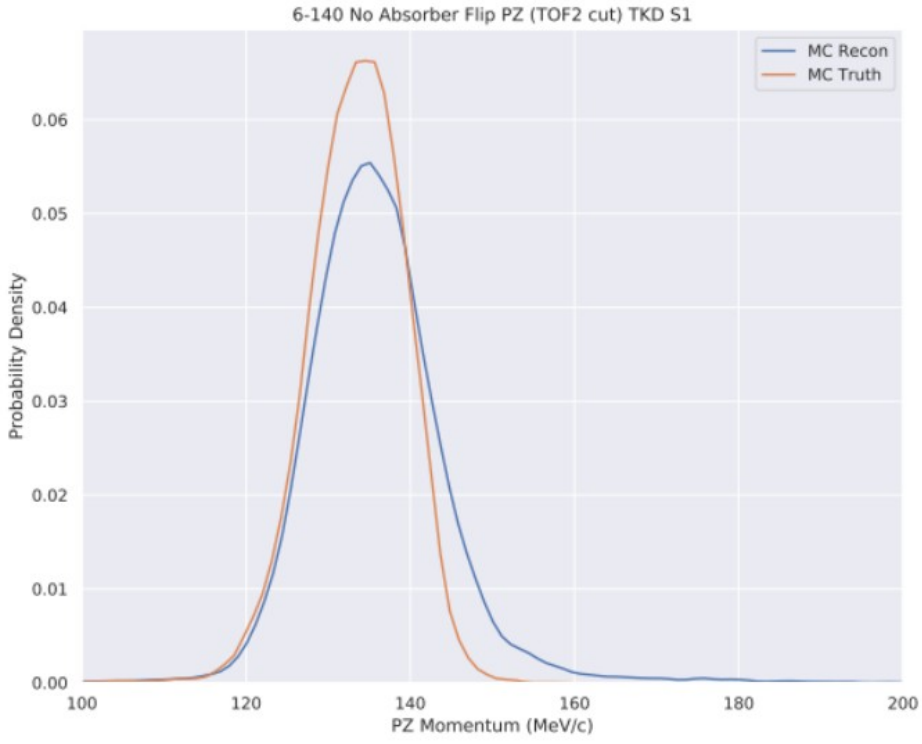
- Difference becomes obvious when one looks at Pz distribution and Residuals
- Clear difference in Mean and RMS between TKU and TKD
- i.e. Energy is being added to the particle between TKU and TKD as a result of the Reconstruction, but that amount varies depending on the particle

- Low/High Pt, Pz, radius, Bz and other parameters affect the amount of bias
- The Recon phase-space volume becomes distorted from the Truth phase-space volume (e.g. a cube whose sides become more concave/convex). The distortion is also different between the trackers.
- For example a low Pz particle will have a different Residual compared to a high Pz particle. The distribution and Phase-space volume is stretched differently depending on Pz. Similiarily the other parameters also have similar effects. They are also not necessarily linear.

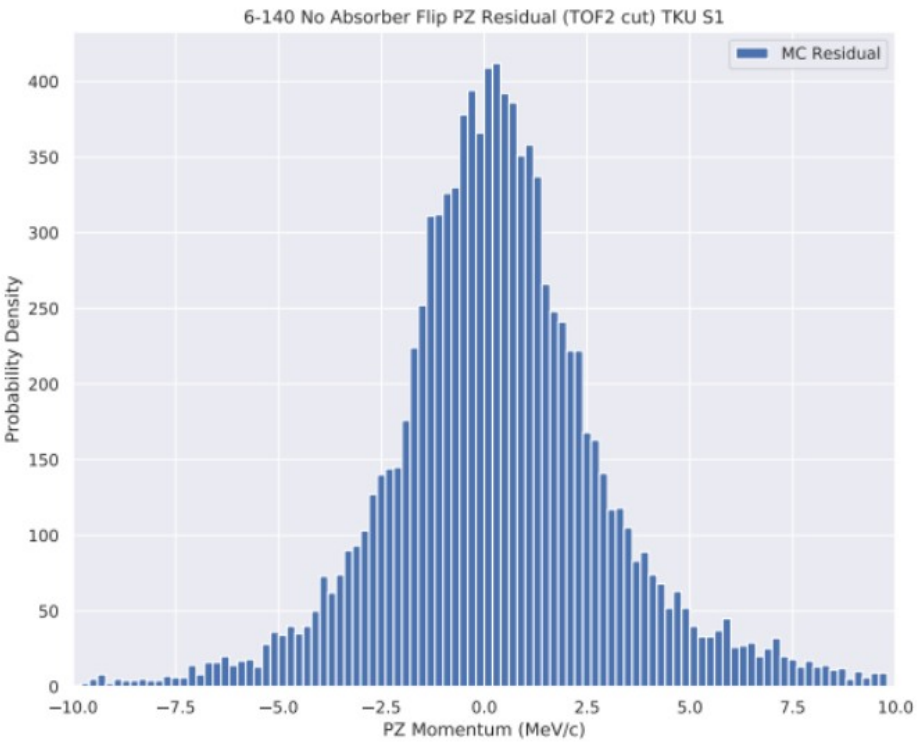
Pz Distribution at Reference Planes

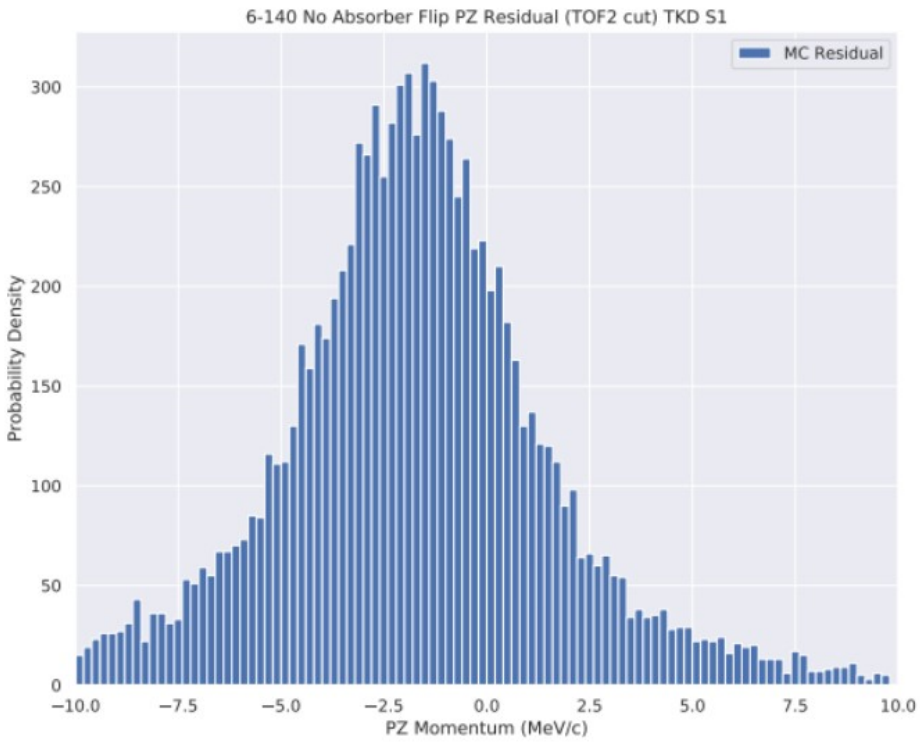
- TKU: Recon Probability Distribution is narrower and taller
- TKD: Recon Probability Distribution is broader and smaller
- Trackers are not identical in their reconstruction -> systematic bias





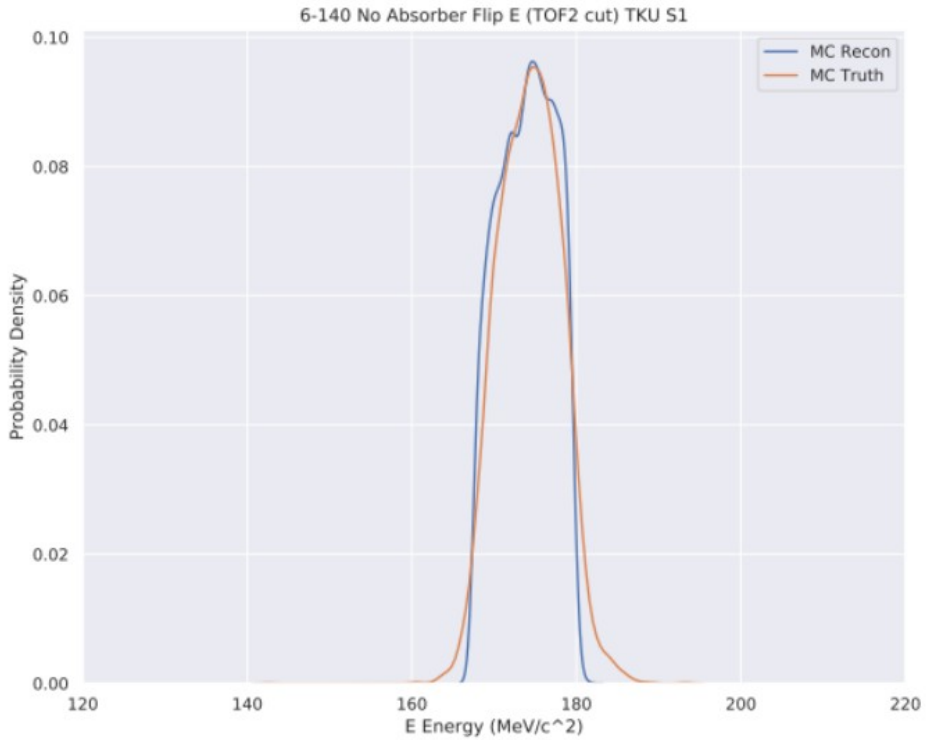
Pz Residuals at Reference Planes

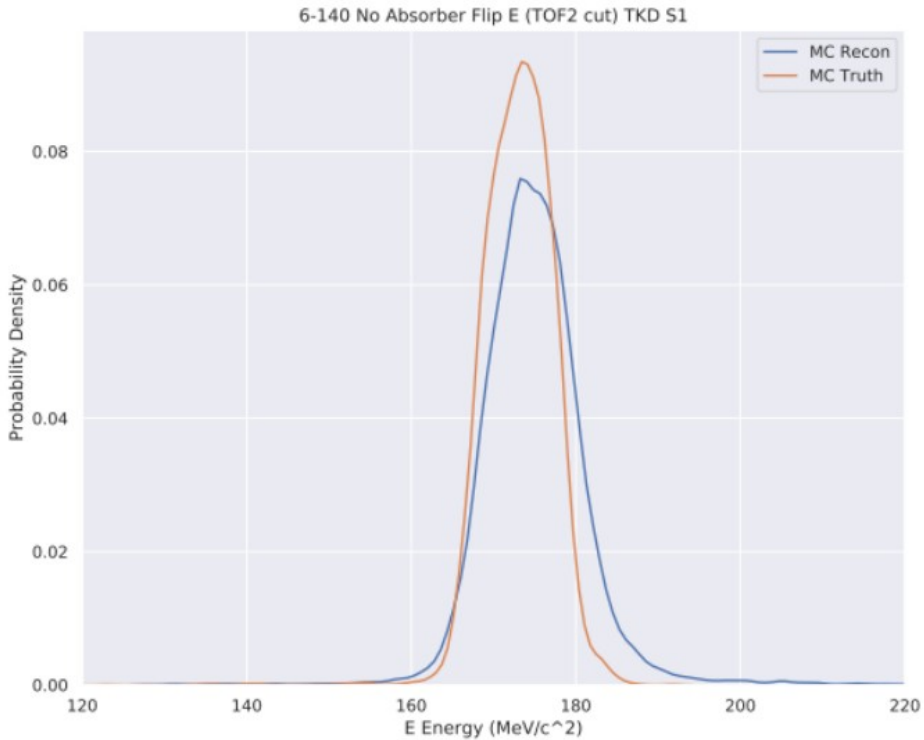




Energy distribution at Reference Planes

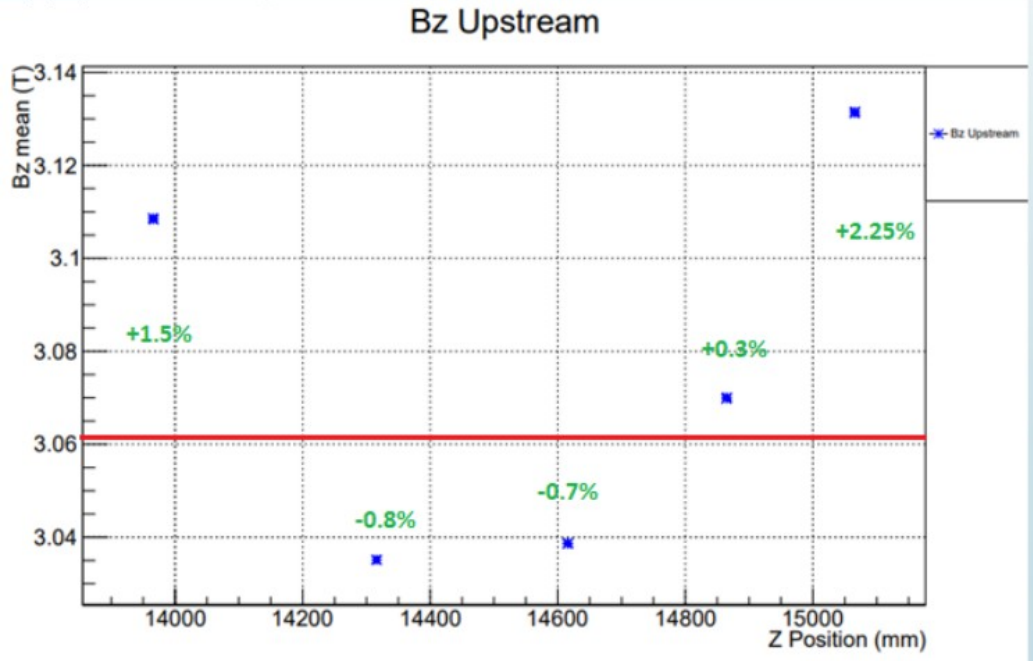
- Similar to Pz

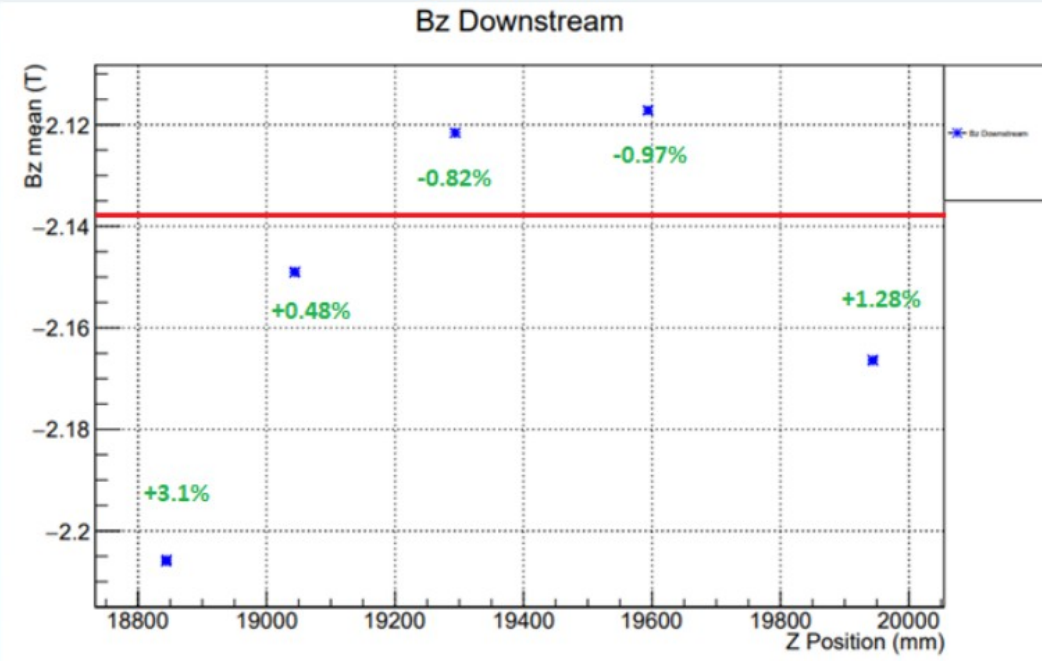




My ideas for why Pz is biased

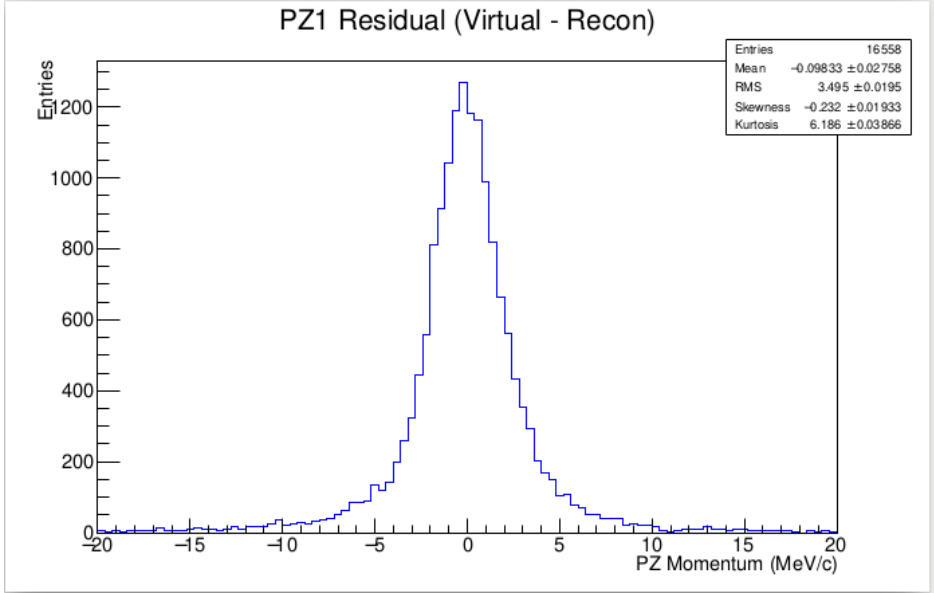
- Non-homogenity of the magnetic field
- Misalignments
- Energy Loss in Tracker doesn’t account for helix deformation

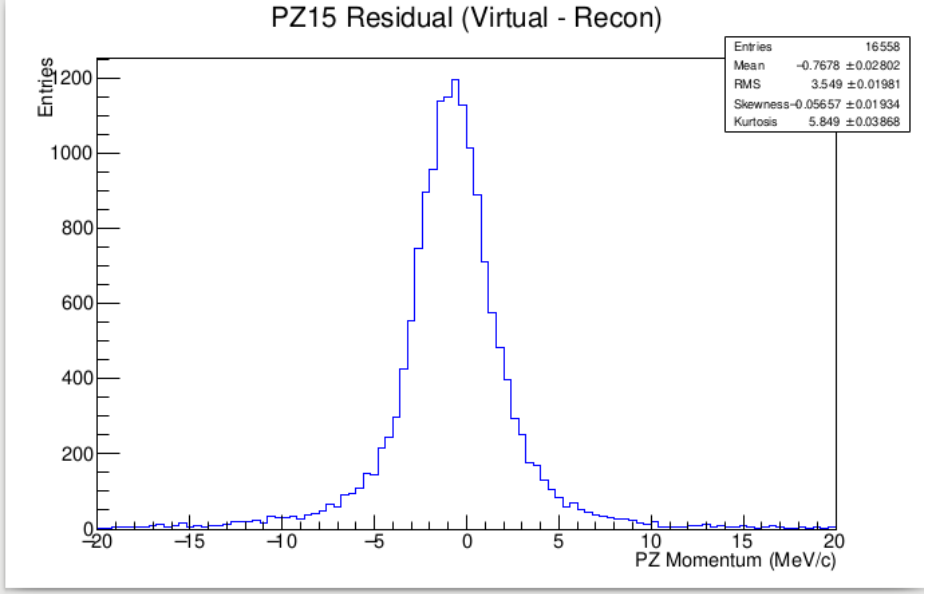


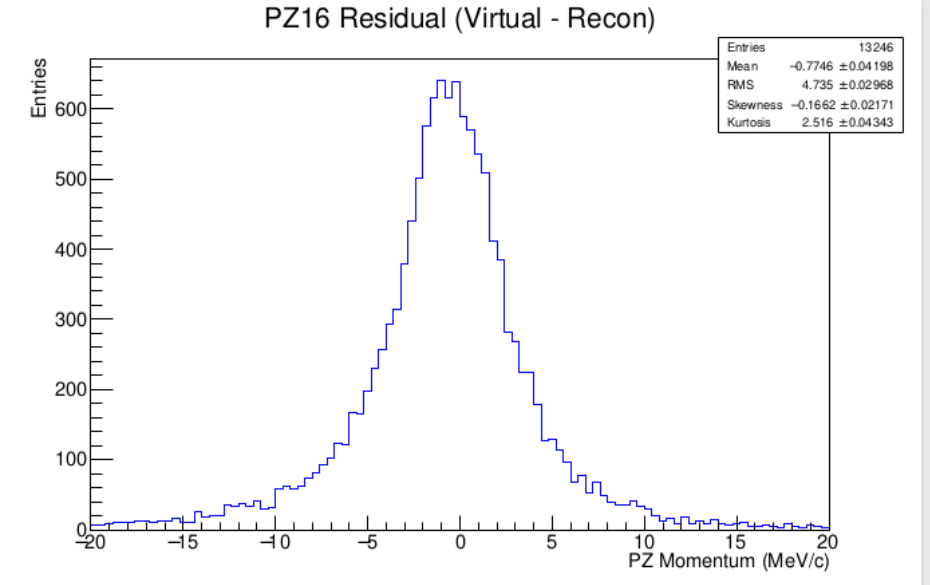


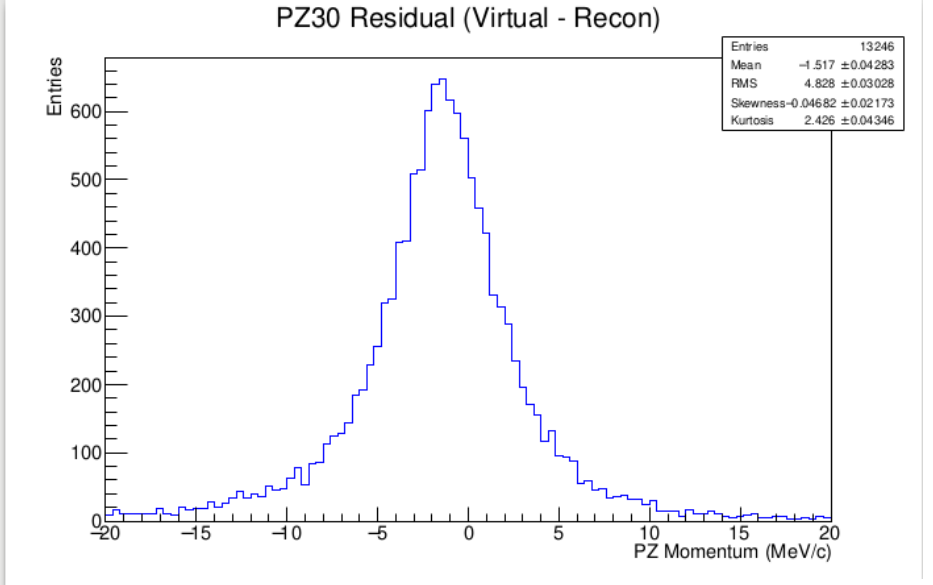
Non-homogenity of Magnetic field

- Know there is a Pz bias
- It changes both in the tracker and between the trackers
- Will compare it to a constant field solenoid
- Will look at the effect of scaling the field


PZ1 Residual (Virtual - Recon)
Entries 16558
Mean −0.09833 ±0.02758
RMS 3.495 ±0.0195
Skewness −0.232 ±0.01933
Kurtosis 6.186 ±0.03866
Entries
PZ Momentum (MeV/c)

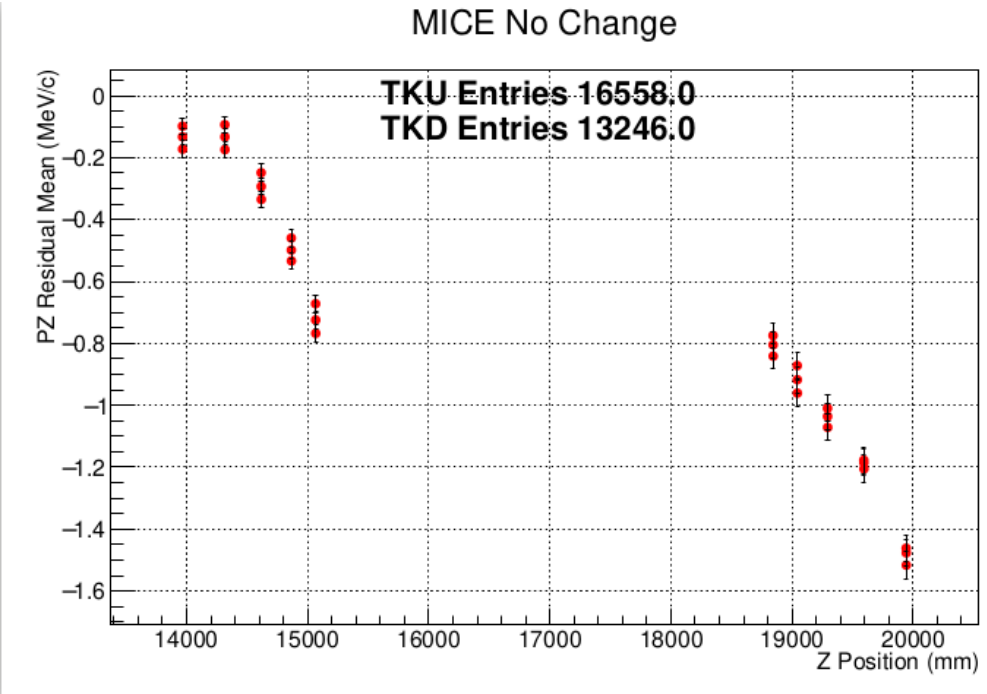

PZ15 Residual (Virtual - Recon)
Entries 16558
Mean −0.7678 ±0.02802
RMS 3.549 ±0.01981
Skewness −0.05657 ±0.01934
Kurtosis 5.849 ±0.03868
Entries
PZ Momentum (MeV/c)

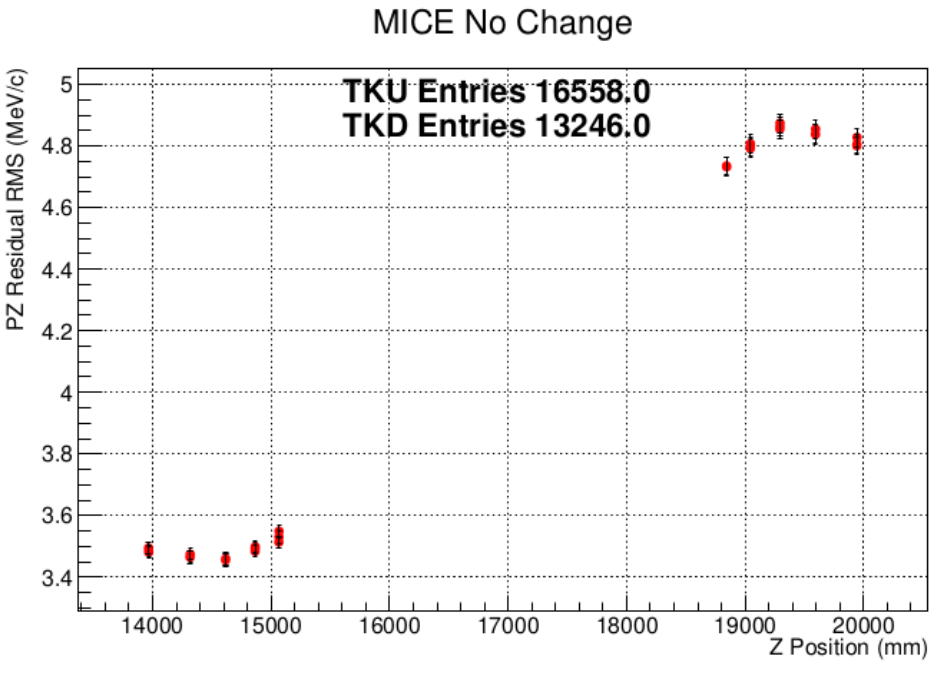

PZ16 Residual (Virtual - Recon)
Entries 13246
Mean −0.7746 ±0.04198
RMS 4.735 ±0.02968
Skewness −0.1662 ±0.02171
Kurtosis 2.516 ±0.04343
Entries
PZ Momentum (MeV/c)


PZ30 Residual (Virtual - Recon)
Entries 13246
Mean −1.517 ±0.04283
RMS 4.828 ±0.03028
Skewness −0.04682 ±0.02173
Kurtosis 2.426 ±0.04346
Entries
PZ Momentum (MeV/c)

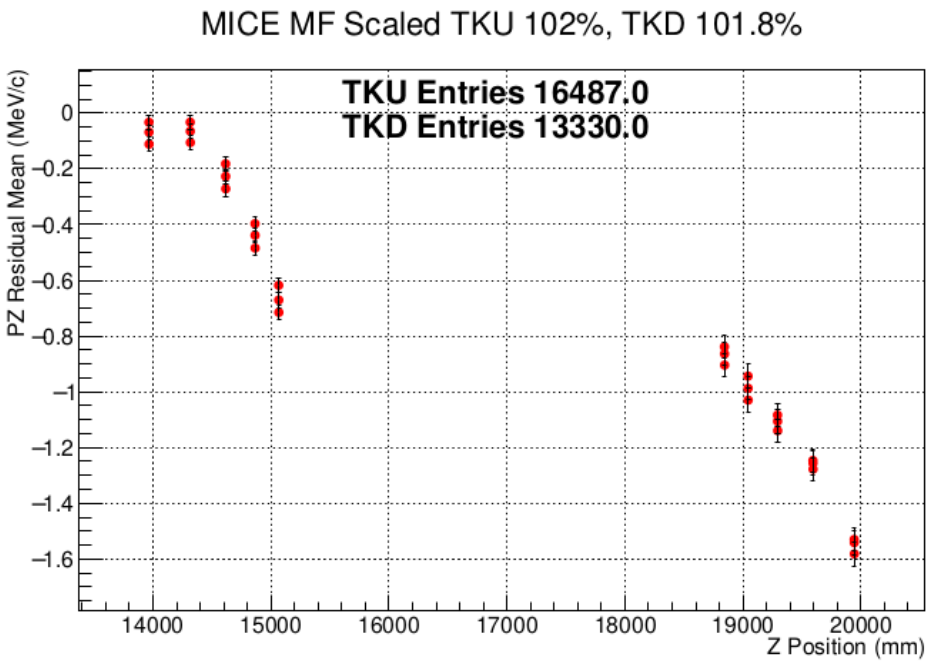
Non-homogenity of MICE Magnetic Field

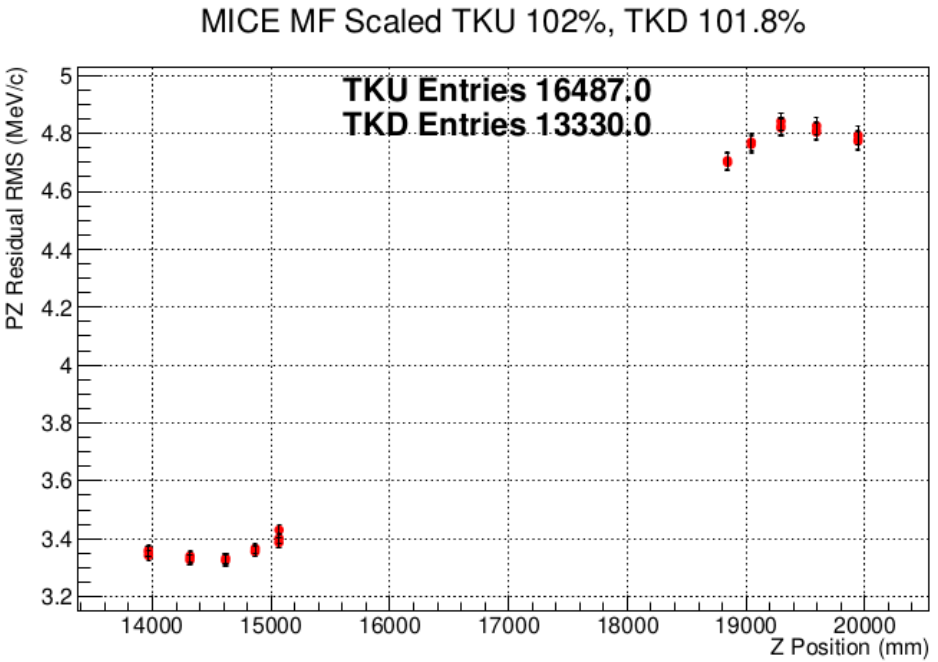
- Pz Residual Mean: Grows in and between trackers
- Pz Residual RMS: Constant in tracker, different between trackers (perhaps due to 3T vs 2T field)



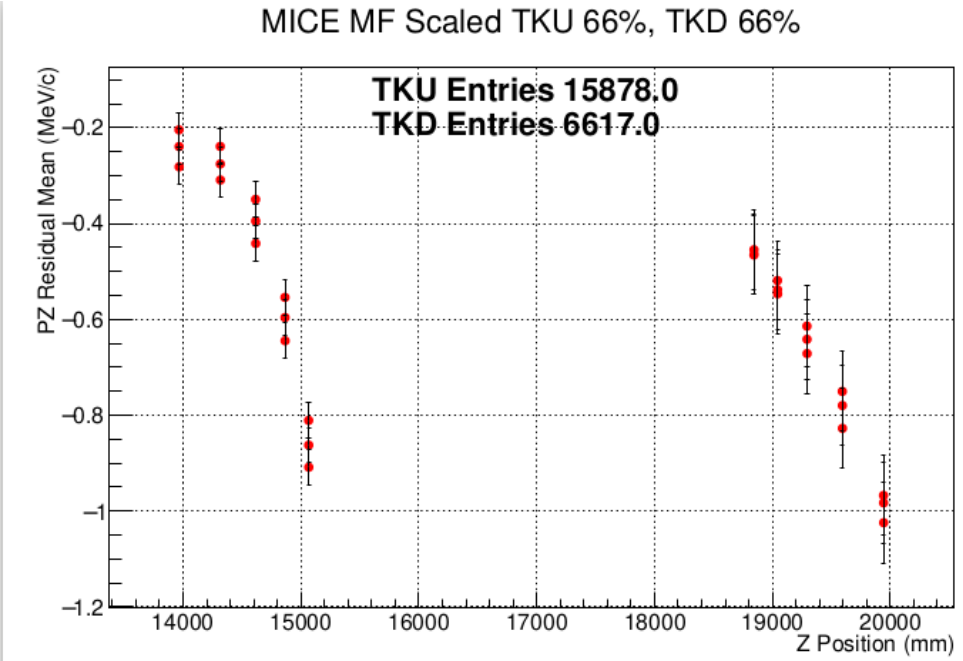


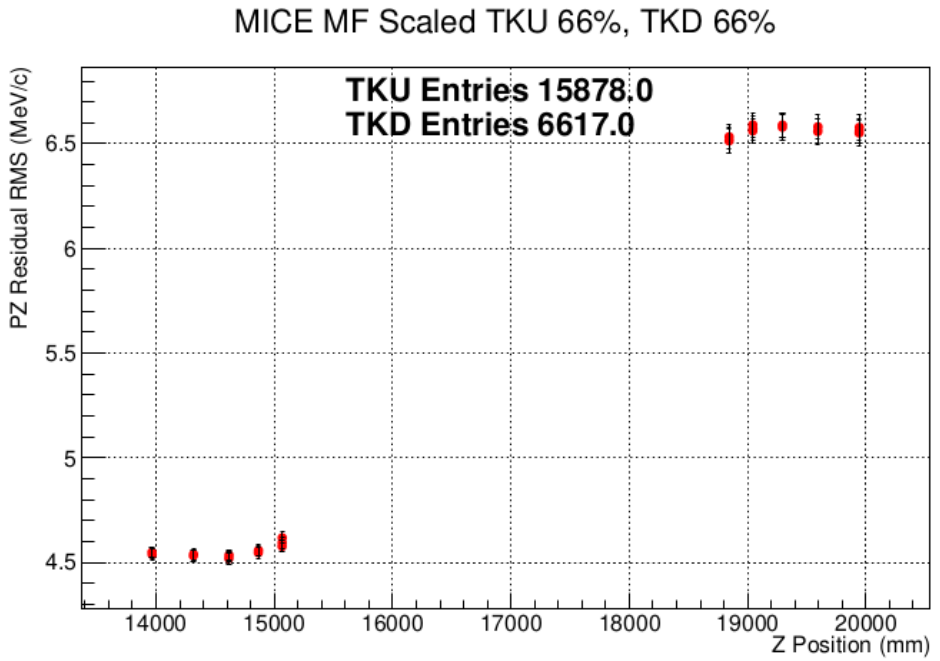
- MICE field scaled as in MAUS, 2% TKU, 1.8%TKD



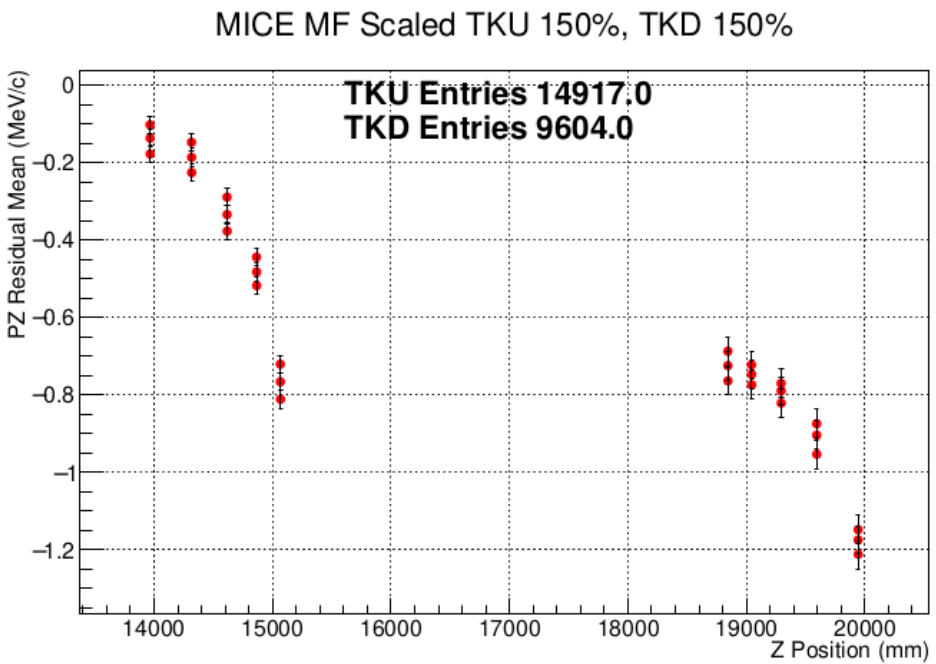


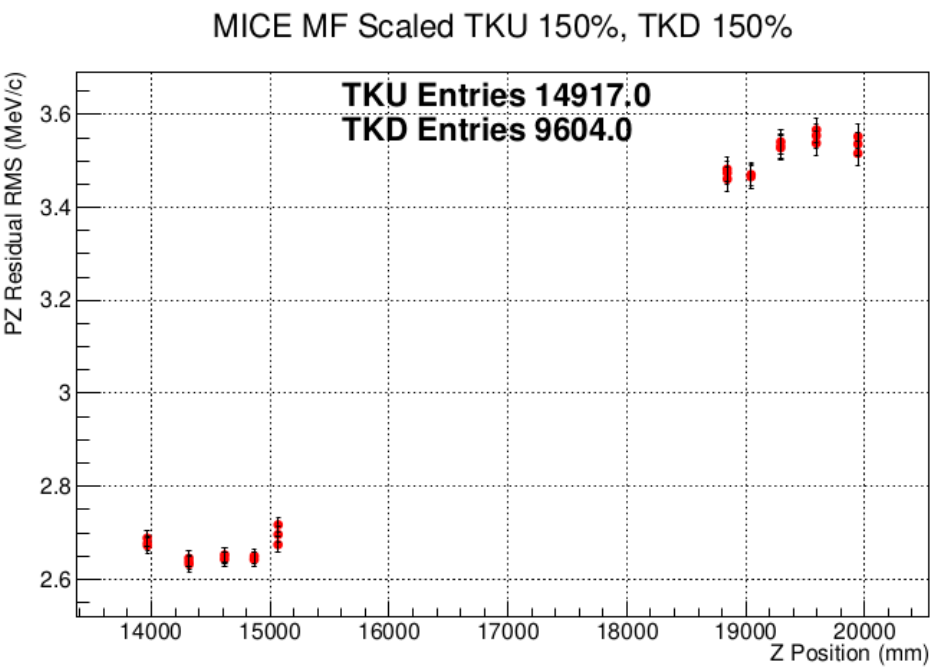
- Magnetic field in Trackers scaled to 2/3 value
- i.e. ~ 2T in TKU, ~1.33T in TKD





- Magnetic field in Trackers scaled to 3/2 value
- i.e. ~4.5T in TKU, ~3T in TKD

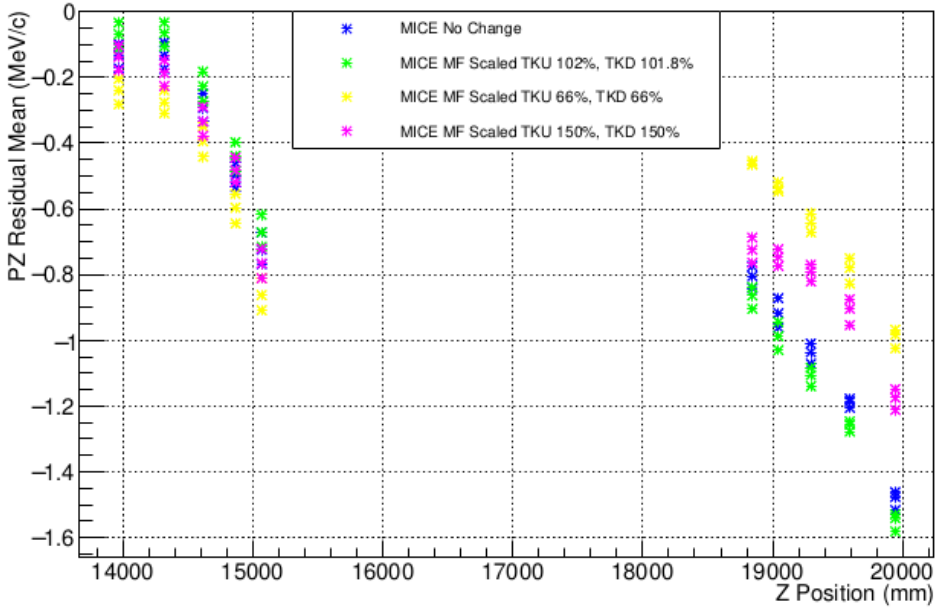




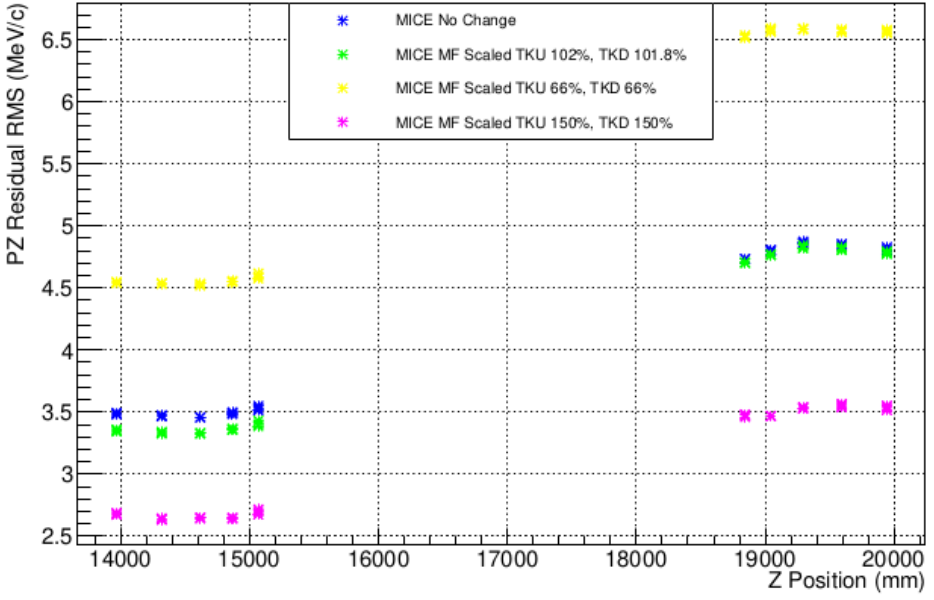
Higher Fields improve RMS, when fields at similar strength in TKU and TKD then RMS similar

- Mean PZ Residual changes, but appears more of a transmission effect

Mean PZ Residual



RMS PZ Residual

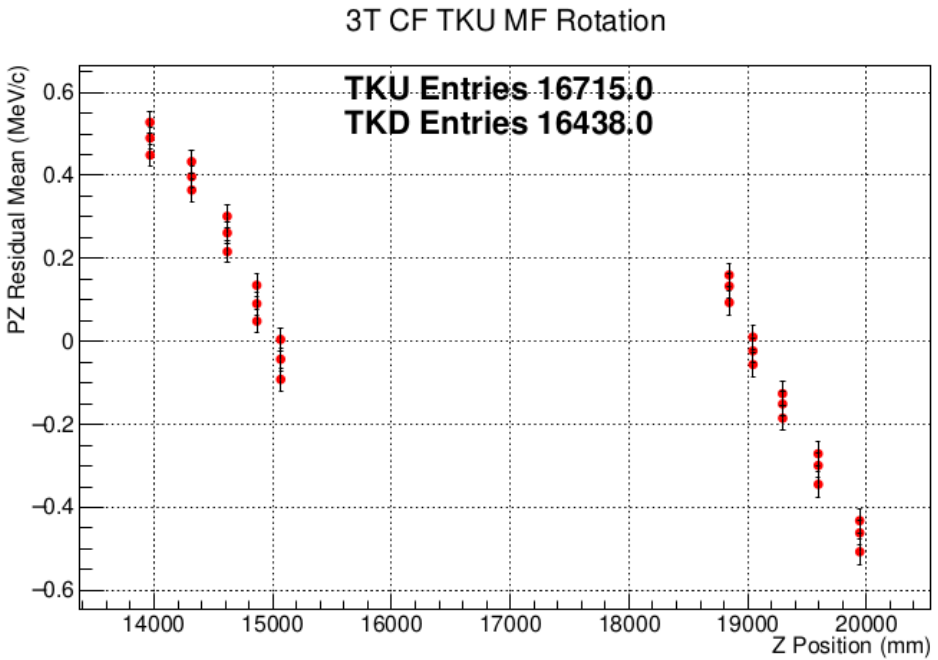


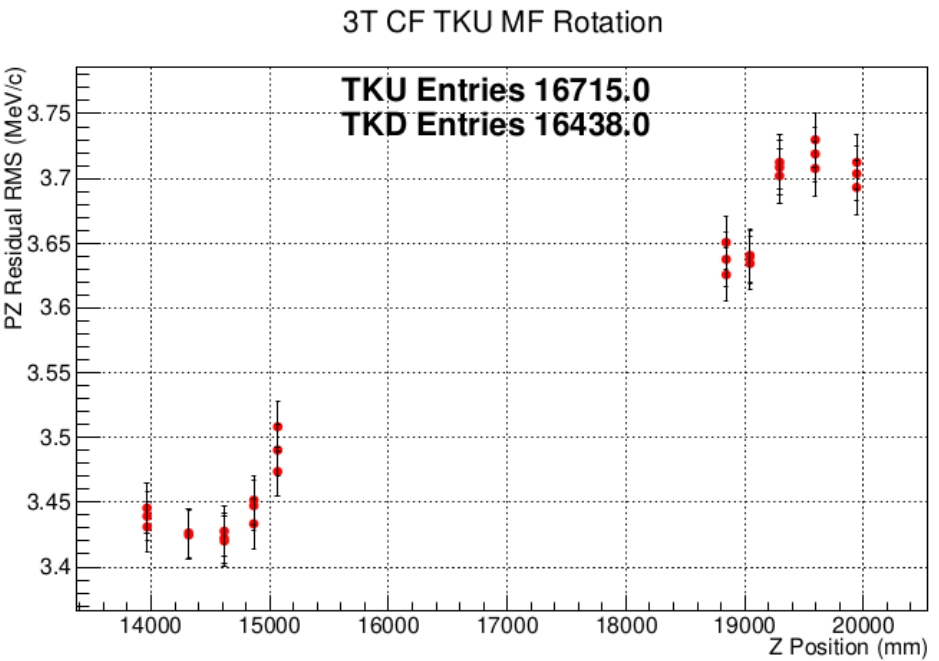
Non-homogenous to homogenous

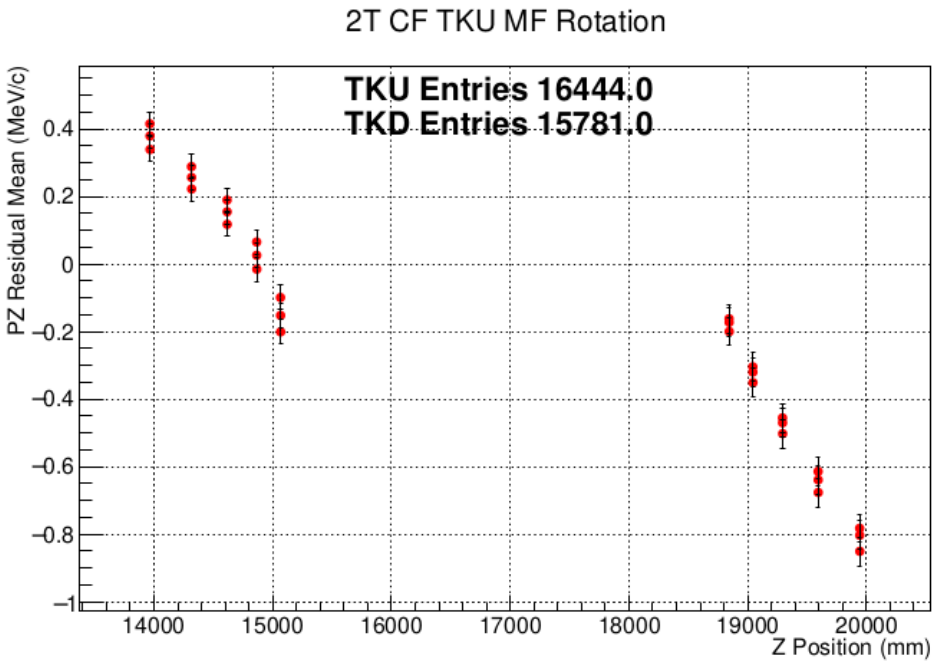
- Will remove all the MICE Fields and replace it by a long constant solenoid field centred at the absorber and covering both trackers
- The same particles are propagated as previously
- All start at a virtual plane just before first plane of TKU. These candidate particles were extracted at that plane from MC run 247 at that plane.

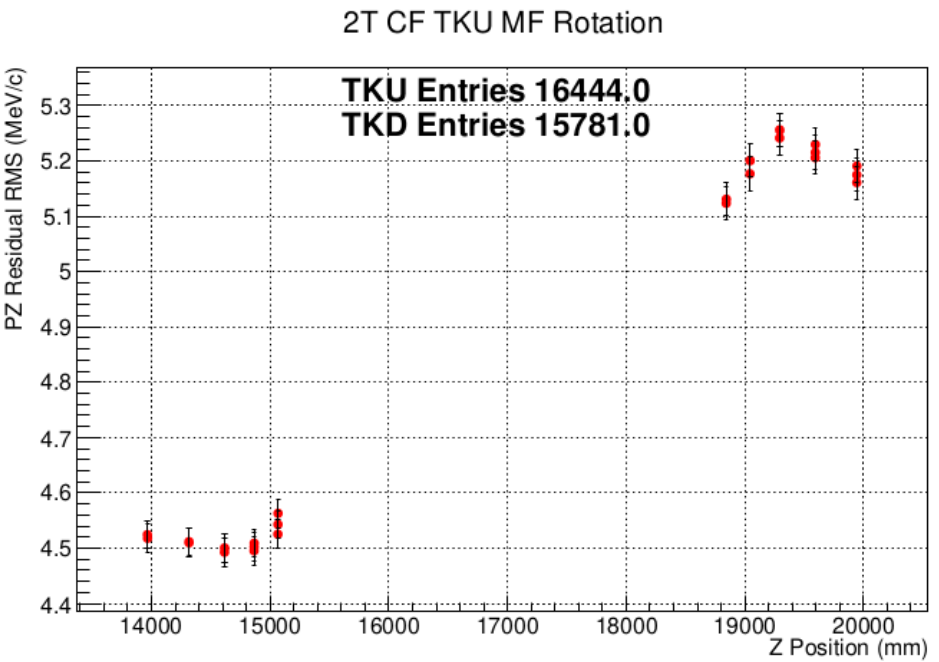
Homogenous Constant 3T Solenoid Field

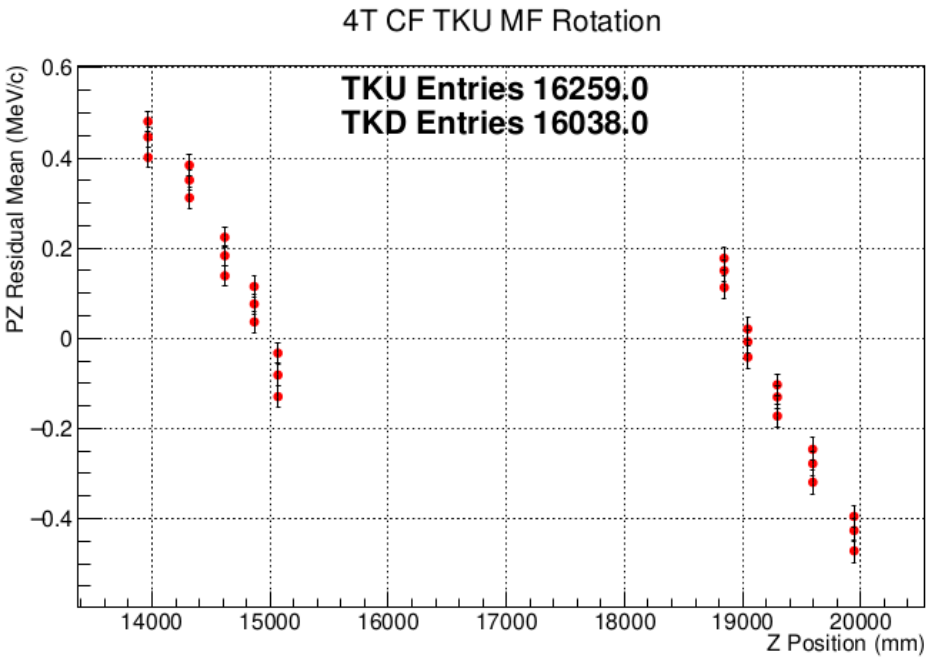
- Pz Residual Mean: the mean bias is improved, but it shows similar growth within the tracker
- Pz Residual RMS: similar TKU, reduced in TKD

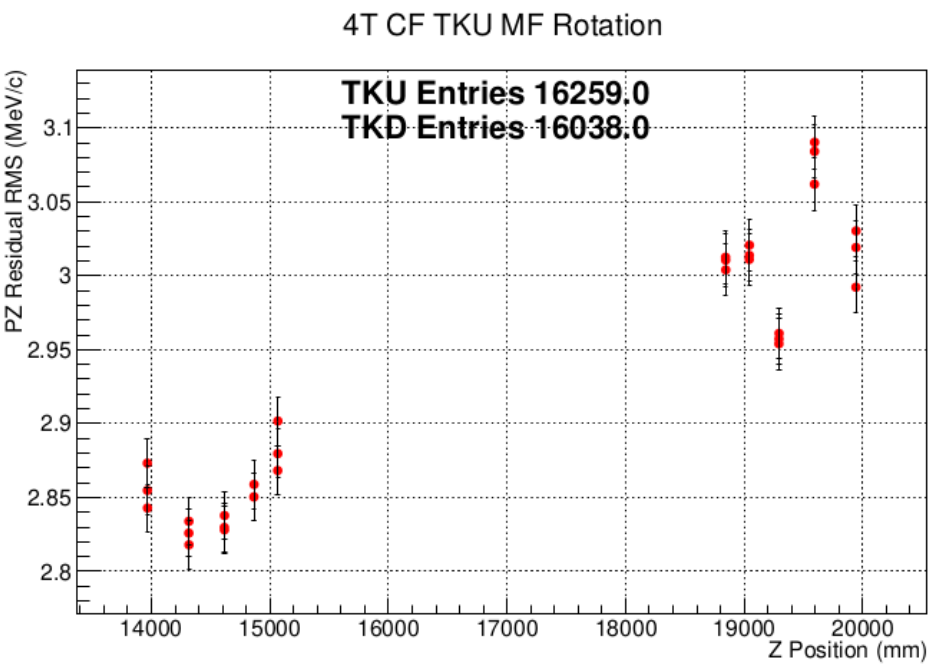





2T CF TKU MF Rotation
TKU Entries 16444.0
TKD Entries 15781.0
PZ Residual Mean (MeV/c)
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)


2T CF TKU MF Rotation
TKU Entries 16444.0
TKD Entries 15781.0
PZ Residual RMS (MeV/c)
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
4.4
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

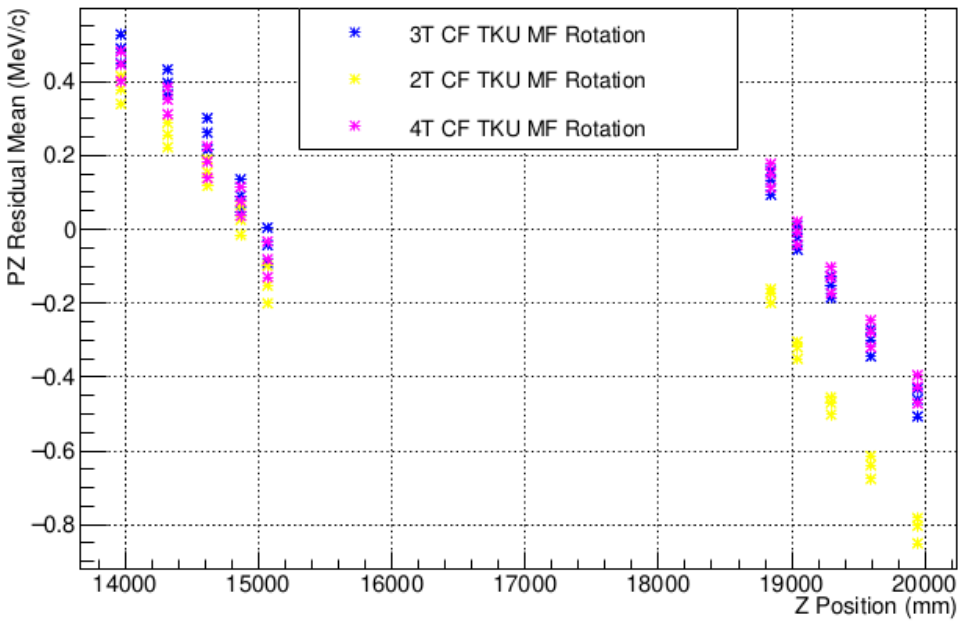

4T CF TKU MF Rotation
TKU Entries 16259.0
TKD Entries 16038.0
PZ Residual Mean (MeV/c)
0.6
0.4
0.2
0
−0.2
−0.4
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)


4T CF TKU MF Rotation
TKU Entries 16259.0
TKD Entries 16038.0
PZ Residual RMS (MeV/c)
3.1
3.05
3
2.95
2.9
2.85
2.8
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

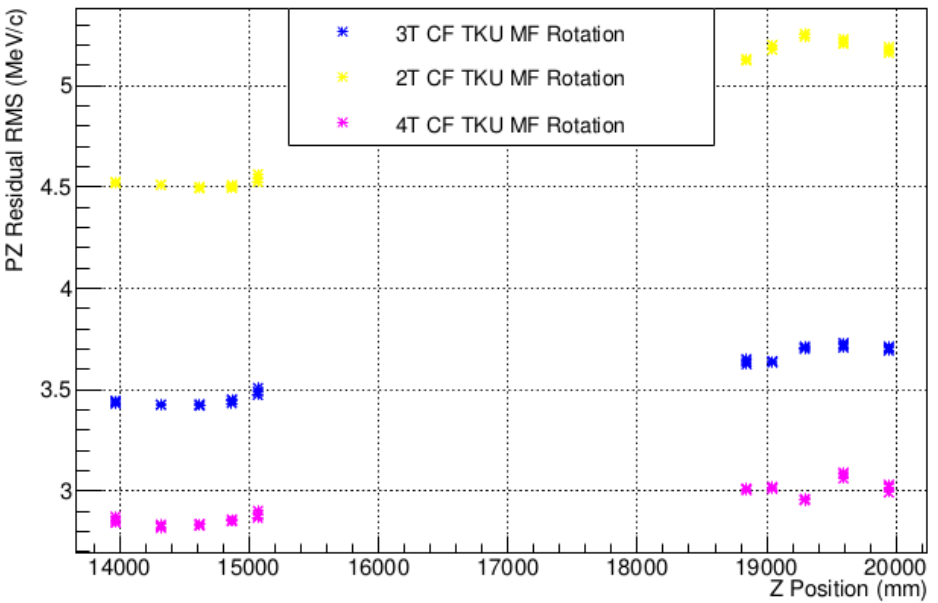
Higher fields - > Better RMS

- Residual in tracker decreases linearly

- Mean PZ Residual



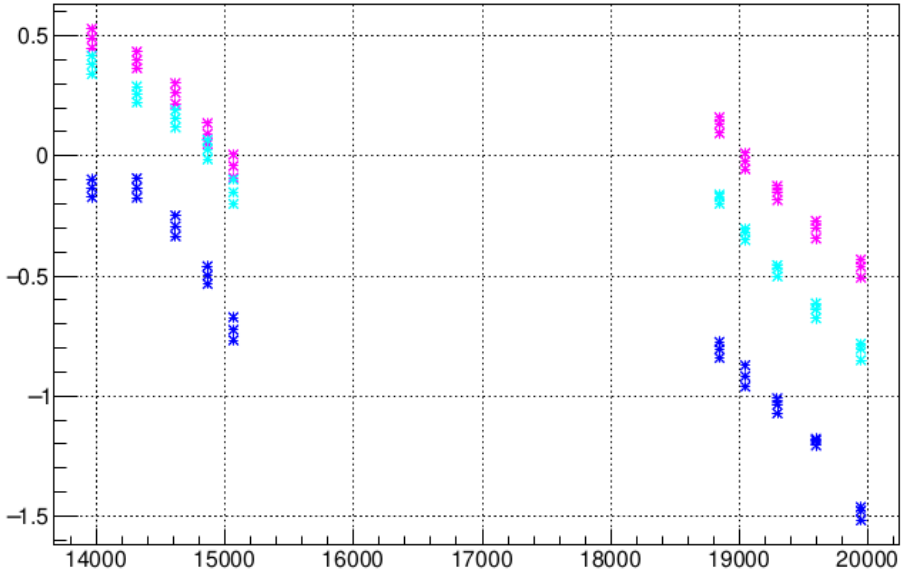
RMS PZ Residual



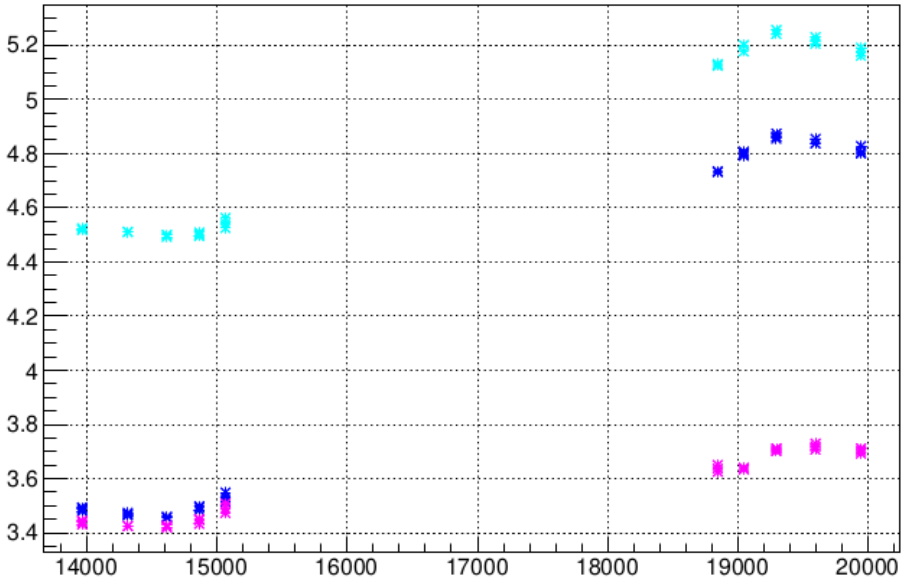
Blue = MICE field No Change
Cyan = Constant Field 2T
Magenta = Constant Field 3T

PZ Bias depends on magnetic field

Mean PZ Residual

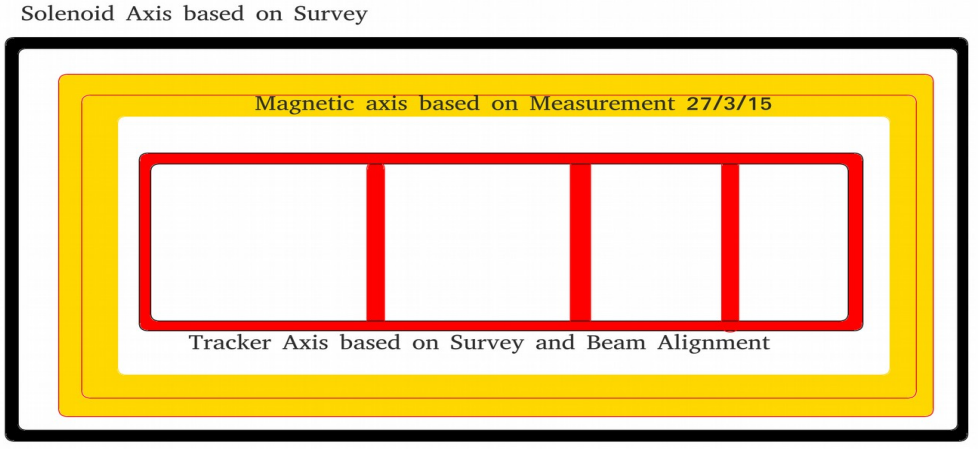


RMS PZ Residual



Misalignments

- Dependencies on Francois Beam Alignment, Surveys of the Positions of the Solenoids, and measurement of the magnetic field misalignment
- Not clear how they worked (to me), but a little clearer now
- Assumed Parent Geometry File contained the individual misalignments, but actually has sum of misalignments
- It starts with the MICE information and Alignment gdml's
- From here a number of xsl files transform the modules to the required locations.
- So what is the misalignment based on?



Misalignments

- MAUS information gdml file sets the solenoid position based on the survey measurements
- The magnets contained hard-coded numbers are offset from the survey measurements by a fixed rotation (mostly).
- I assume those numbers would be based on Blackmore and Cobb magnetic alignment data. Can’t get numbers to match yet, may be some other rotation I do not know of yet (still working on it).
- Finally there is a misalignment between the tracker and the solenoid. Those numbers change when there is a new Beam Alignment correction, although the values used are not clear to me yet

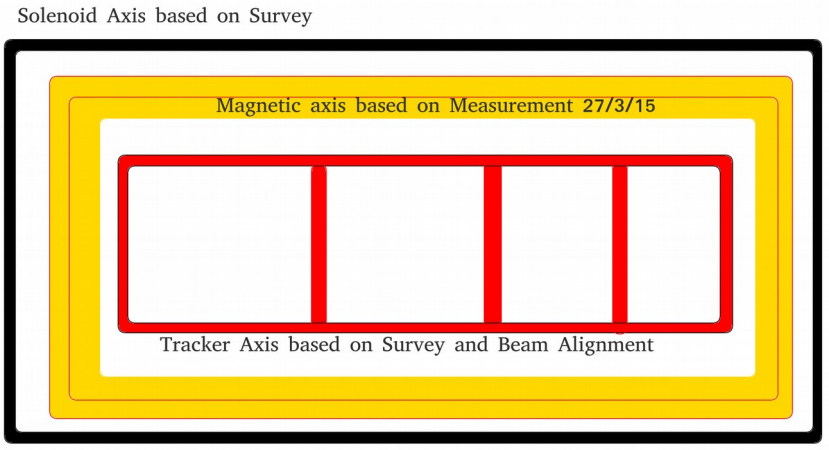
```
#10318
        <file name="/home/craig/MAUS-v3.3.0/files/geometry/download/Tracker0.gdml"/>
        <position name="DEVICE-MOUNTED-DETECTORS_Part__Feature_pos" unit="mm" x="-0.7472" y="0.4492" z="-426.8969"/>
        <rotation name="DEVICE-MOUNTED-DETECTORS_Part__Feature_rot" unit="degree" x="-0.0188" y="180.0029" z="0.0"/>

        <file name="/home/craig/MAUS-v3.3.0/files/geometry/download/Tracker1.gdml"/>
        <position name="DEVICE-MOUNTED-DETECTORS_Part__Feature001_pos" unit="mm" x="-1.1021" y="1.0462" z="426.695163991"/>
        <rotation name="DEVICE-MOUNTED-DETECTORS_Part__Feature001_rot" unit="degree" x="-0.0002" y="-0.0975" z="0.0"/>

                    Module /home/craig/MAUS-v3.3.0/files/geometry/download/Tracker0.dat
                    {
                     Position -0.86511378119 3.64859277401 14515.836783 mm
                     Rotation 0.196047193 179.985234111 0.0 degree
                    }

                    Module /home/craig/MAUS-v3.3.0/files/geometry/download/Tracker1.dat
                    {
                     Position -2.40241422181 11.4022303071 19393.7675747 mm
                     Rotation 0.409400974 -0.147030316 0.0 degree

                    Module /home/craig/MAUS-v3.3.0/files/geometry/download/ssu_virtuals.dat
                    {
                     Position 0.013710418 1.878772135 14942.73 mm
                     Rotation -0.177247193 -0.017665889 0.0 degree

                    }

                    Module /home/craig/MAUS-v3.3.0/files/geometry/download/ssd_virtuals.dat
                    {
                     Position -1.669178516 7.305682432 18967.09 mm
                     Rotation 0.409600974 -0.049530316 0.0 degree

</physvol><physvol name="SolenoidUS_phys"><file name="/home/craig/MAUS-v3.3.0/files/geometry/download/SolenoidUS.gdml"/>
<position name="SolenoidUS_pos" unit="mm" x="0.013710418" y="1.878772135" z="14942.73"/>
<rotation name="SolenoidUS_rot" unit="degree" x="-0.177247193" y="-0.017665889" z="0.0"/>

</physvol><physvol name="SolenoidDS_phys"><file name="/home/craig/MAUS-v3.3.0/files/geometry/download/SolenoidDS.gdml"/>
<position name="SolenoidDS_pos" unit="mm" x="-1.669178516" y="7.305682432" z="18967.09"/>
<rotation name="SolenoidDS_rot" unit="degree" x="0.409600974" y="-0.049530316" z="0.0"/>
```

- From SolenoidUS/DS.gdml, based on Francois, shows rotation between Tracker and Solenoid
- From ParentGeometryFile.dat, virtuals have survey alignment, Trackers have survey alignment combined with rotation between Tracker and Solenoid from above
- From MAUS_infromation.gdml, shows Misalignment of Solenoids based on Surveys

	Date	Z up	Xup	Y up	Z down	X down	Y down								
TKU	06/09/17	13567.24	0.39	4.25	16486.21	0.33	-2.74		13572.78	1.26	-0.57	16225.69	-0.7	-0.93	
TKD	06/09/17	17430.12	-3.75	-3.9	20345.23	0.54	14.93		17640.16	-2.36	-2.43	20315.11	-2.97	1.61	
	Z Center	Distance	Z Length	X Length	Y length	X dist	Y dist	X Offset	Y Offset		Rotations (radian)		Rotations (milliradian)		
TKU	14941.46	1544.75	2918.97	-0.06	-6.99	-0.031752639	-3.699182417	0.361752639	0.959182417		-2.05552E-05	-0.002394685	-0.020555196	-2.394684893	
TKD	18968.16	1377.07	2915.11	4.29	18.83	2.026554847	8.895111368	-1.486554847	6.034888632		0.001471644	0.006459537	1.471643642	6.45953734	
											-0.001177726	-0.137205338	Rotations (degrees)		
											0.08431897	0.370104227			
	29/11/17	13568.51	-0.41	6.13	16487.48	0.49	-2.9		13574.05	0.46	1.31	16226.96	-0.62	-0.9	
	29/11/17	17427.62	-3	-3.7	20342.71	-0.48	17.14		17637.66	-1.74	-2.09	20312.6	-3.97	3.8	
	14942.73	1544.75	2918.97	0.9	-9.03	0.476289582	-4.778772135	0.013710418	1.878772135		0.000308328	-0.003093567	0.308327947	-3.093566842	
	18967.09	1375.62	2915.09	2.52	20.84	1.189178516	9.834317568	-1.669178516	7.305682432		0.000864468	0.007149129	0.864467522	7.1491292	
											0.01766589	-0.177248324			
											0.049530341	0.40961493			

From surveys to MICE misalignments, uses Flange measurements in TKU and TKD

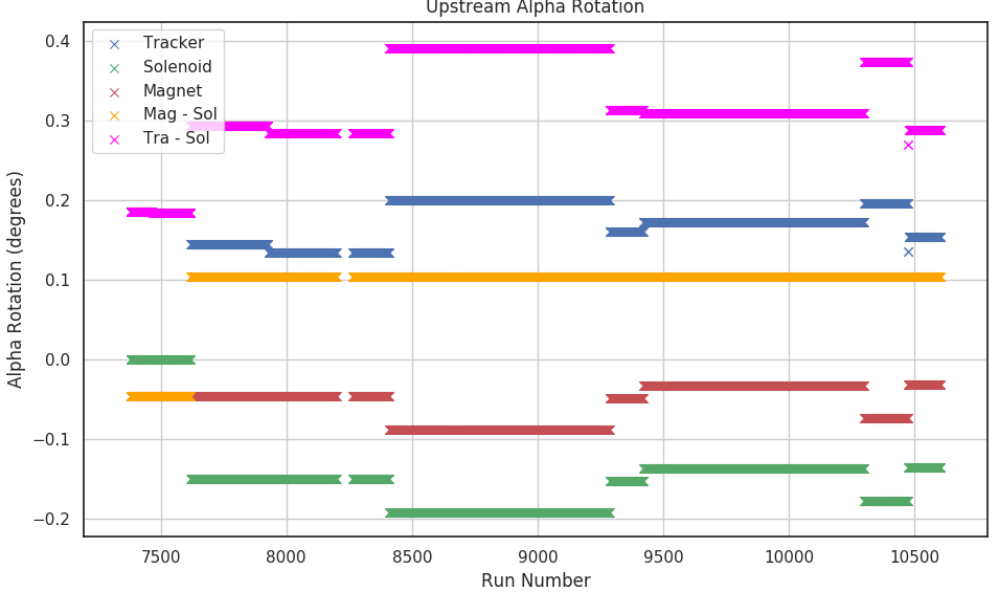
Misalignments

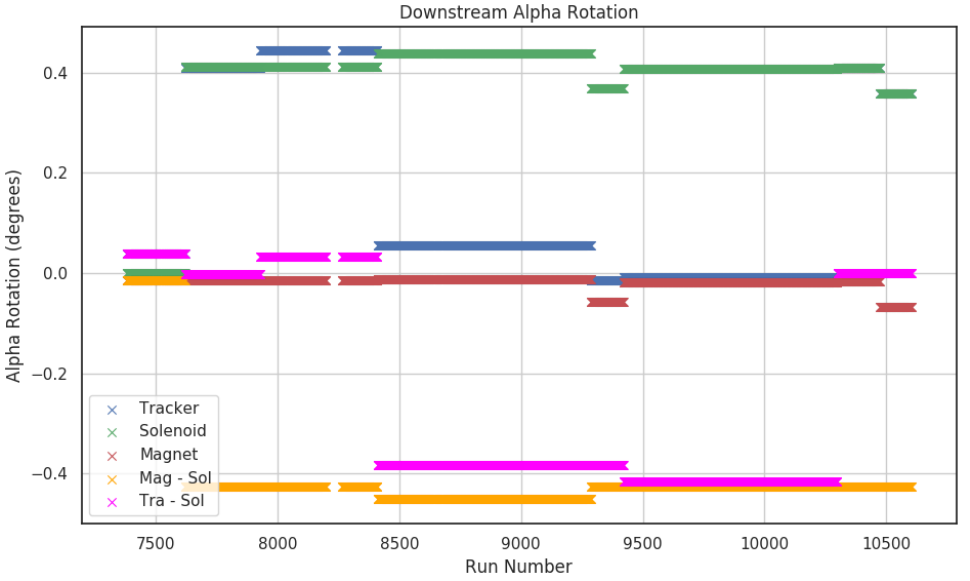


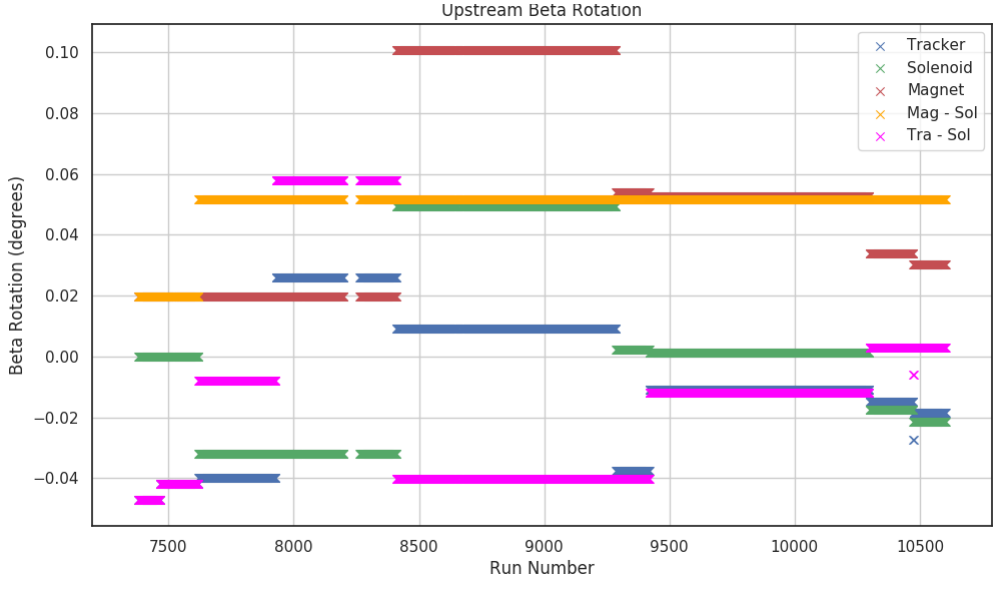
- Know how the survey alignment works in MAUS
- Not sure about Francois and Magnet alignment numbers (but magnet is fixed rotation)

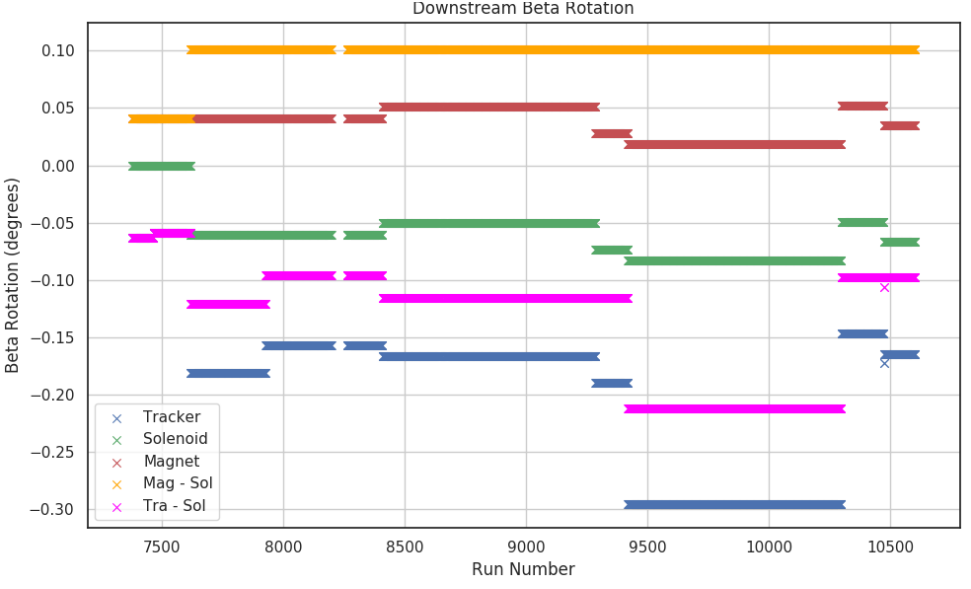
- Know what Parent Geometry File has now – a combination of survey alignments combined with solenoid to tracker misalignments
- Know which parameters to change for MC, may not know exactly where each comes from, but can estimate if/when it becomes a problem

- In following alpha and beta refer to rotations around the X and Y axis


Upstream Alpha Rotation
Alpha Rotation (degrees)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol


Downstream Alpha Rotation
Alpha Rotation (degrees)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol


Upstream Beta Rotation
Beta Rotation (degrees)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol


Downstream Beta Rotation
Beta Rotation (degrees)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol

Misalignmets

SSU	M1 [mm]	M2 [mm]	E1 [mm]	CC [mm]	E2 [mm]
z	3449.22	3013.39	2613.39	1863.39	1113.39
z'	16106.55	15670.49	15270.29	14519.90	13769.50

Table 3.7 Table of centre positions in z and z' for all of SSU's coils. Coloured cells are those that are calculated from the method described above.

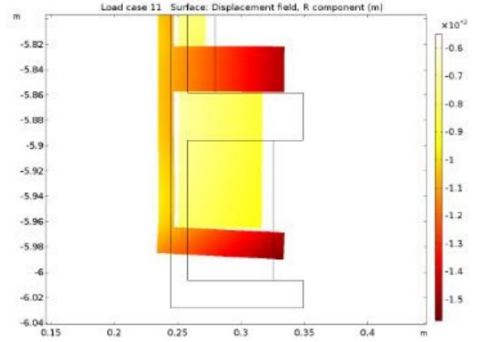
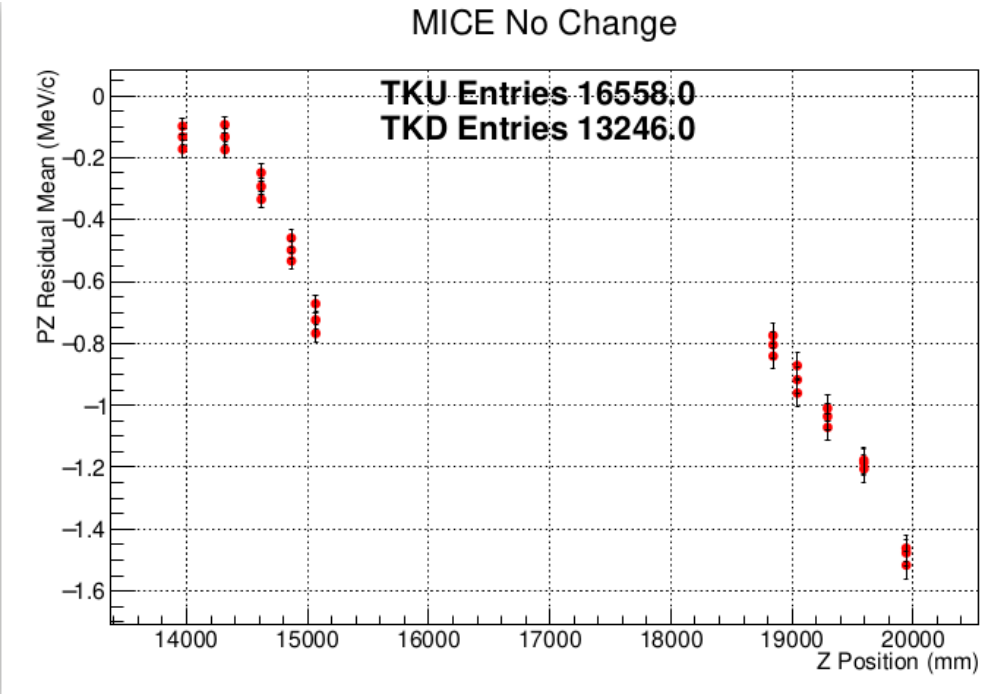
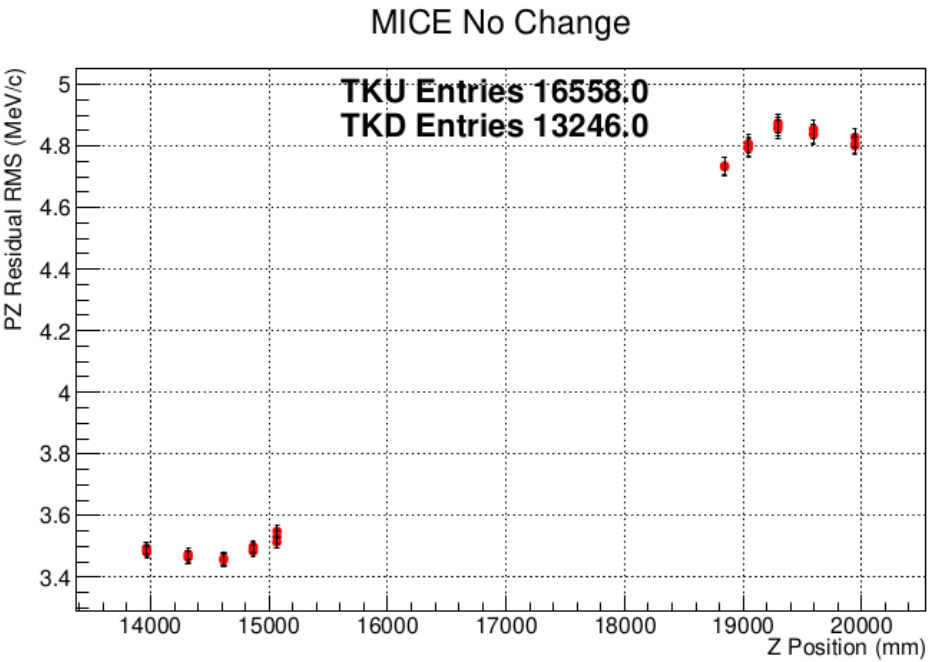


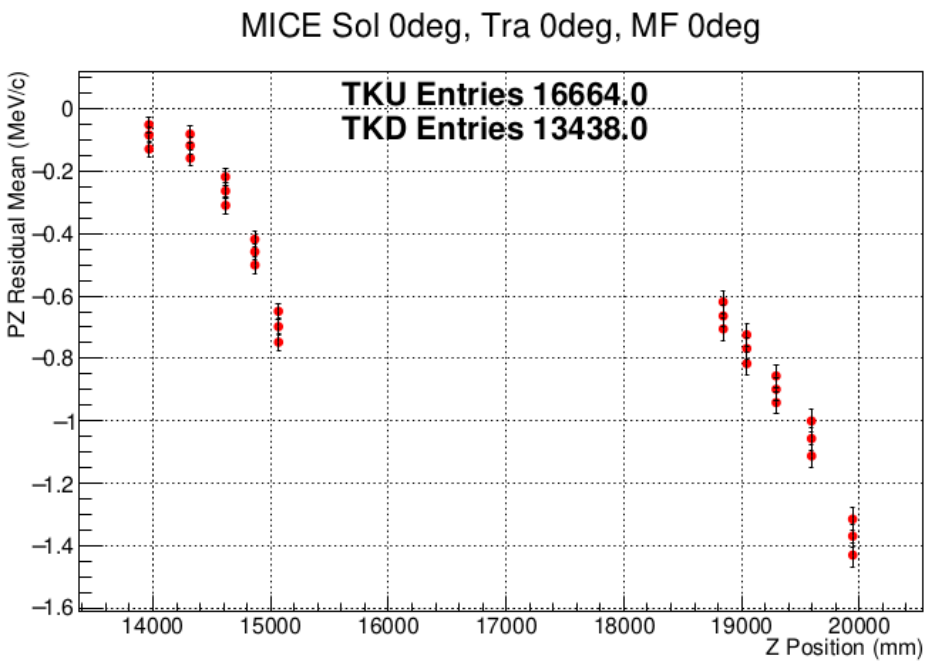
Fig. 3. Deformation plot of the E2 coil and the bobbin (deformation ten times amplified). The colour indicates the radial displacement.

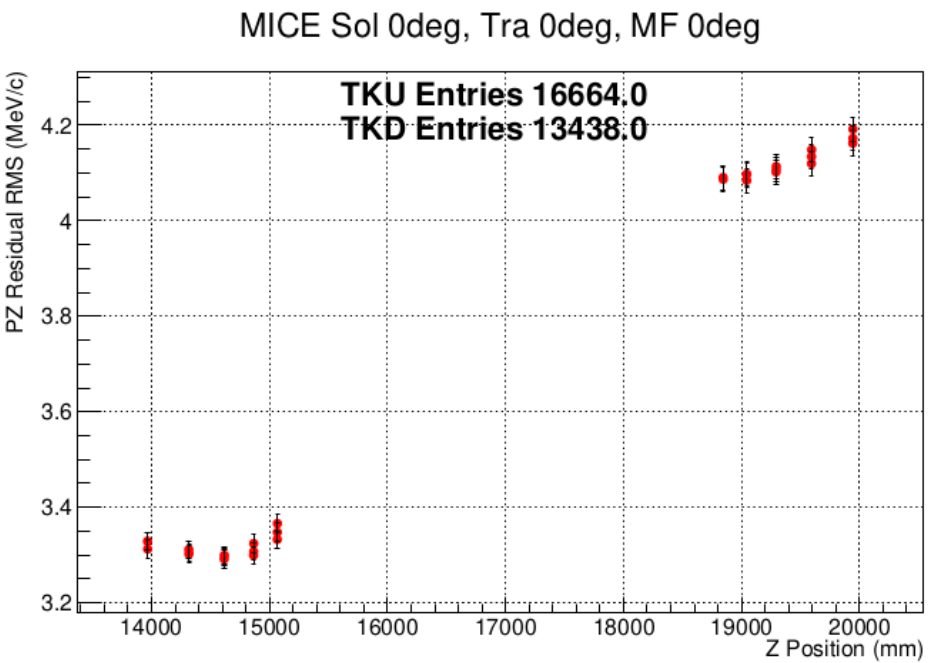
- Note, have only dealt with warm bore position misalignments
- But that suffices for understanding the PZ bias between MC Truth and MC Recon

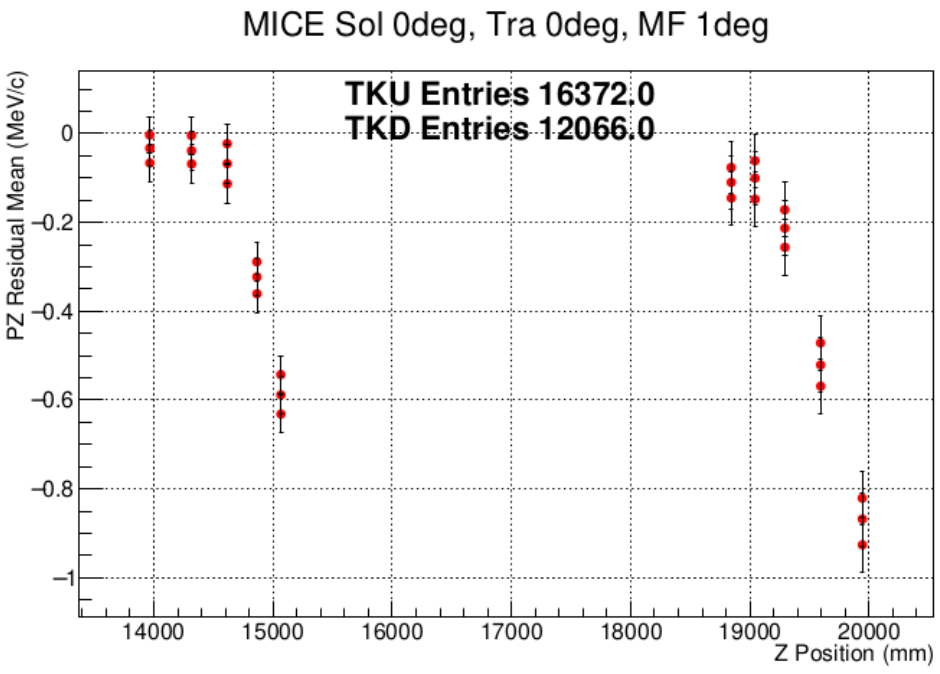
- Know the magnets cool down and that there are forces between them causing deformations in the expected magnetic field
- These would be differences between MC Recon and Data, likely beyond scope to solve but can run MC to see if/when such deformations become problematic

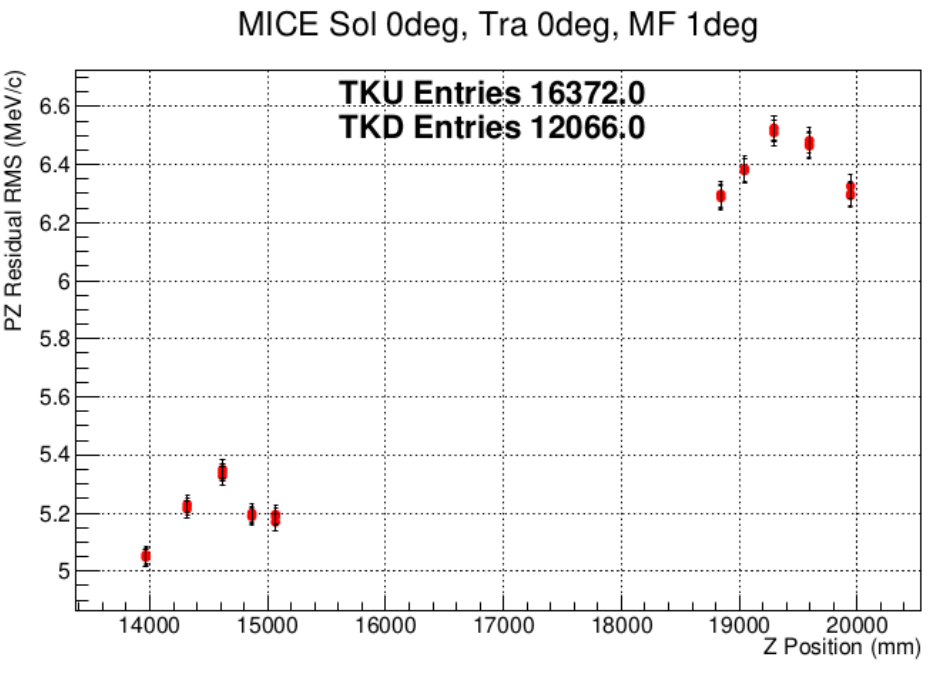

MICE No Change
TKU Entries 16558.0
TKD Entries 13246.0
PZ Residual Mean (MeV/c)
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

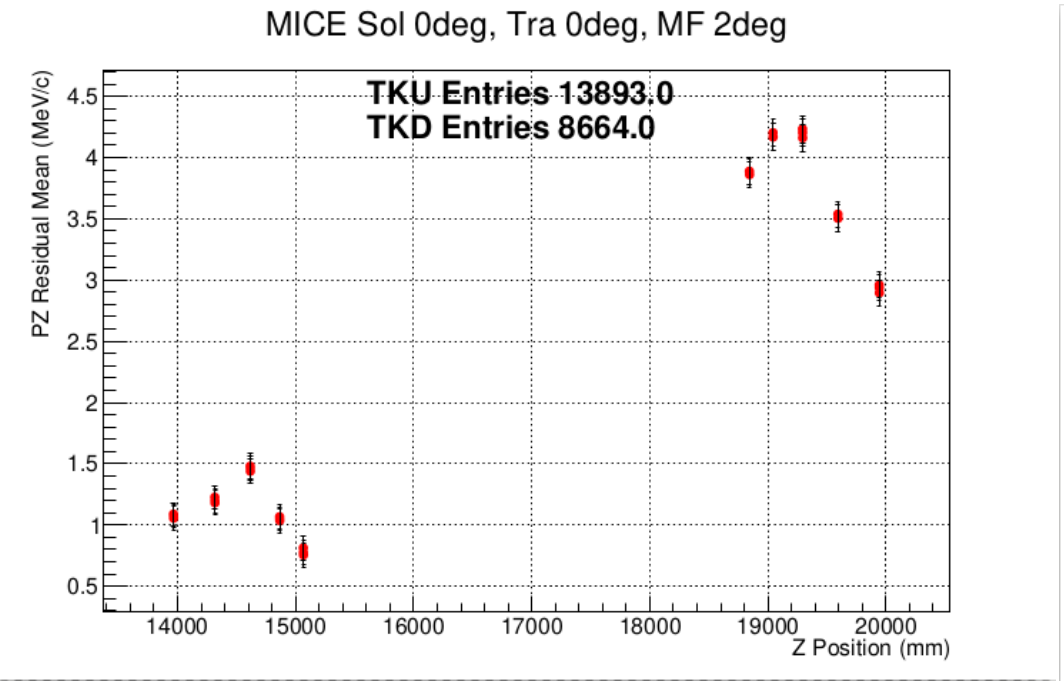

MICE No Change
TKU Entries 16558.0
TKD Entries 13246.0
PZ Residual RMS (MeV/c)
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

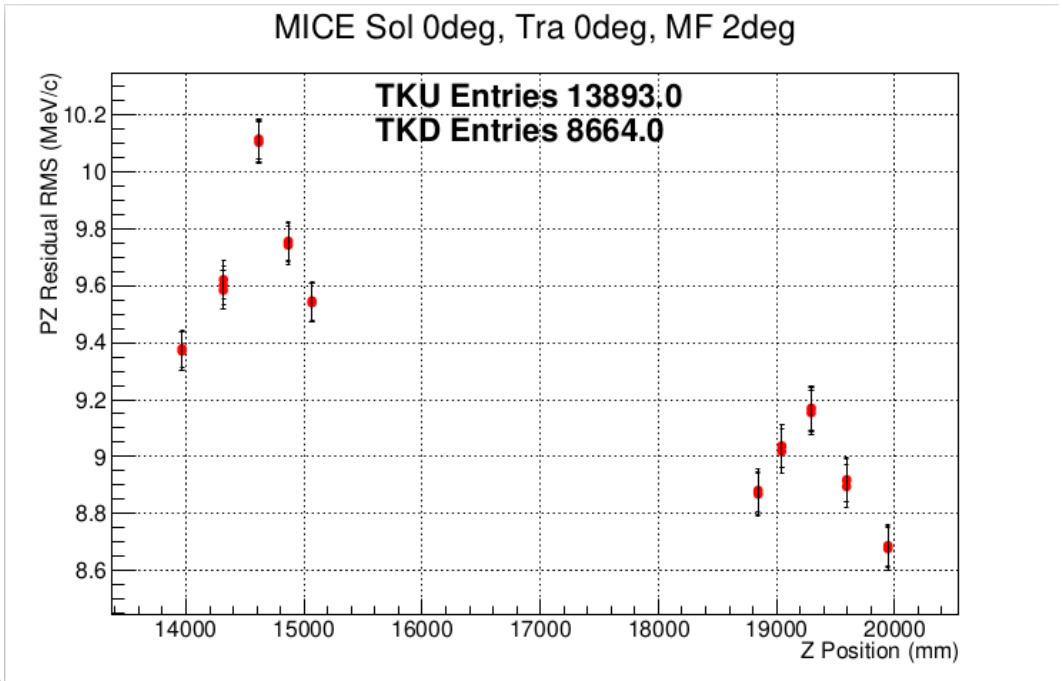

MICE Sol 0deg, Tra 0deg, MF 0deg
TKU Entries 16664.0
TKD Entries 13438.0
PZ Residual Mean (MeV/c)
Z Position (mm)
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
14000
15000
16000
17000
18000
19000
20000


MICE Sol 0deg, Tra 0deg, MF 0deg
TKU Entries 16664.0
TKD Entries 13438.0
PZ Residual RMS (MeV/c)
Z Position (mm)
4.2
4
3.8
3.6
3.4
3.2
14000
15000
16000
17000
18000
19000
20000

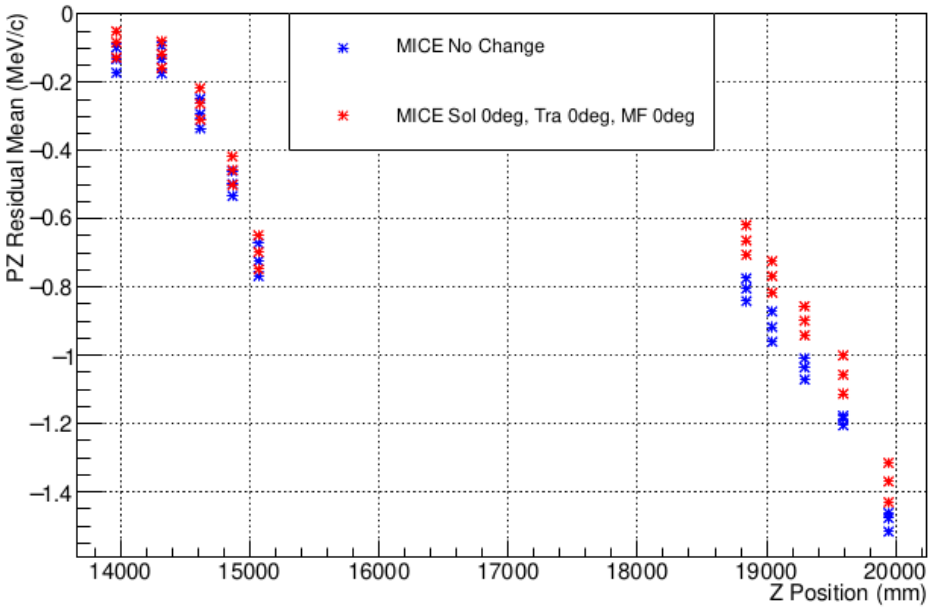

MICE Sol 0deg, Tra 0deg, MF 1deg
TKU Entries 16372.0
TKD Entries 12066.0
PZ Residual Mean (MeV/c)
0
−0.2
−0.4
−0.6
−0.8
−1
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

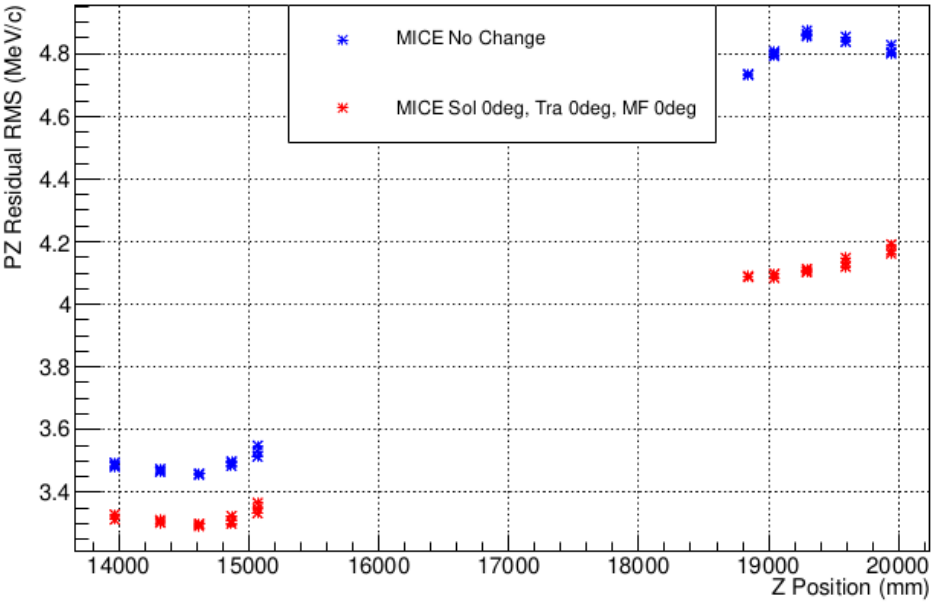

MICE Sol 0deg, Tra 0deg, MF 1deg
TKU Entries 16372.0
TKD Entries 12066.0
PZ Residual RMS (MeV/c)
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
5
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)


MICE Sol 0deg, Tra 0deg, MF 2deg
TKU Entries 13893.0
TKD Entries 8664.0
PZ Residual Mean (MeV/c)
Z Position (mm)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
14000
15000
16000
17000
18000
19000
20000


MICE Sol 0deg, Tra 0deg, MF 2deg
TKU Entries 13893.0
TKD Entries 8664.0
PZ Residual RMS (MeV/c)
Z Position (mm)
10.2
10
9.8
9.6
9.4
9.2
9
8.8
8.6
14000
15000
16000
17000
18000
19000
20000

- Perfect Alignment - > Pz Residual Mean and RMS improve
- Pz Mean Residual difference between TKU and TKD is greater however

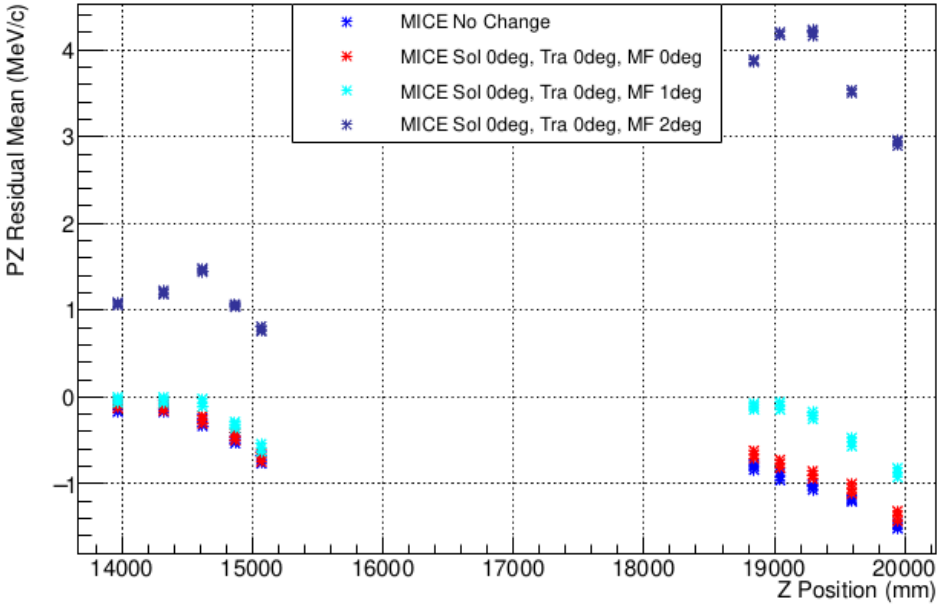




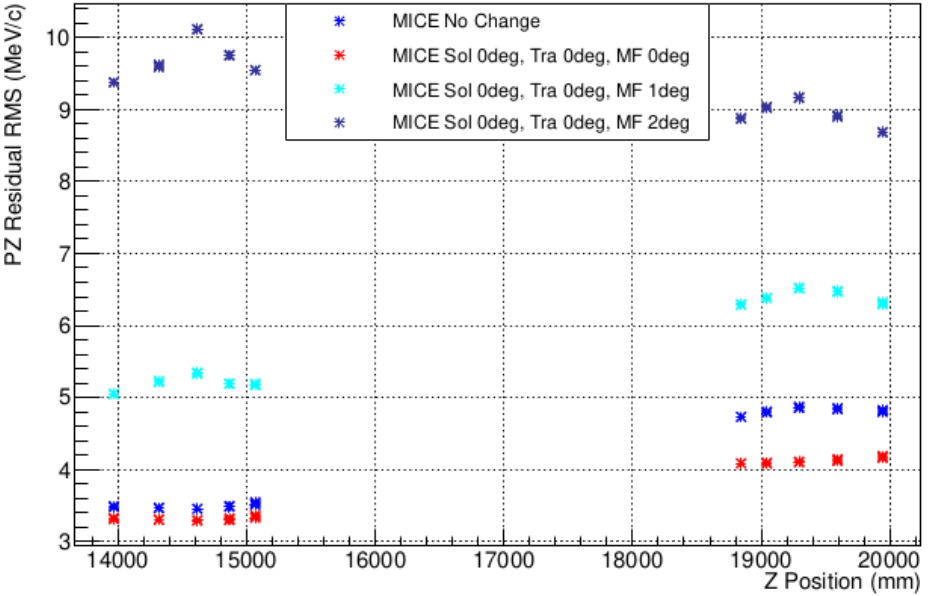
Rotating MF in TKU and TKD alters Mean and RMS Residual significantly

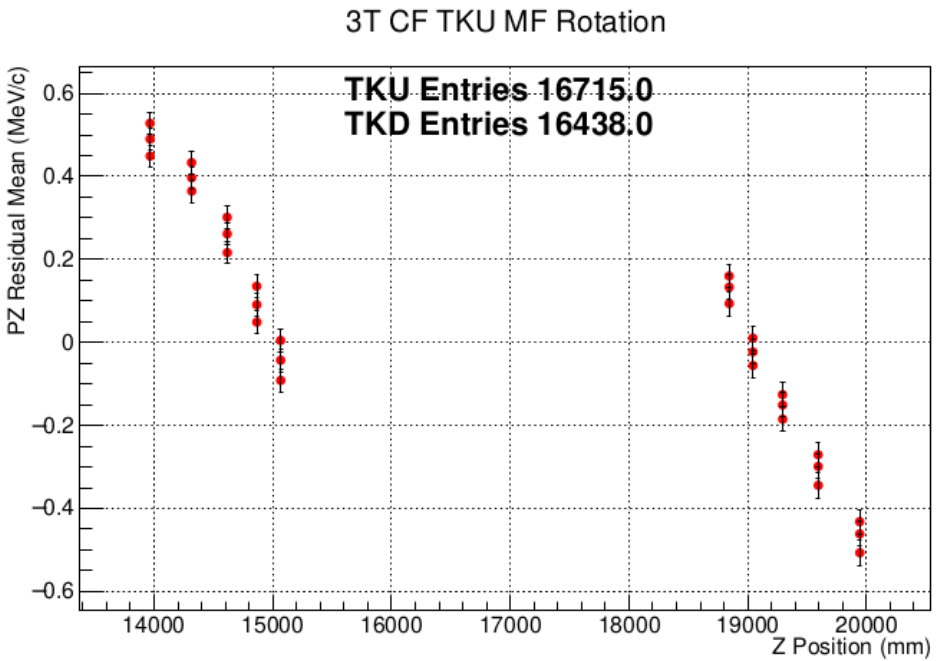
- Transmission also is affected – Data transmission can act as guide for what is reasonable (1deg = 17.45 mrad)

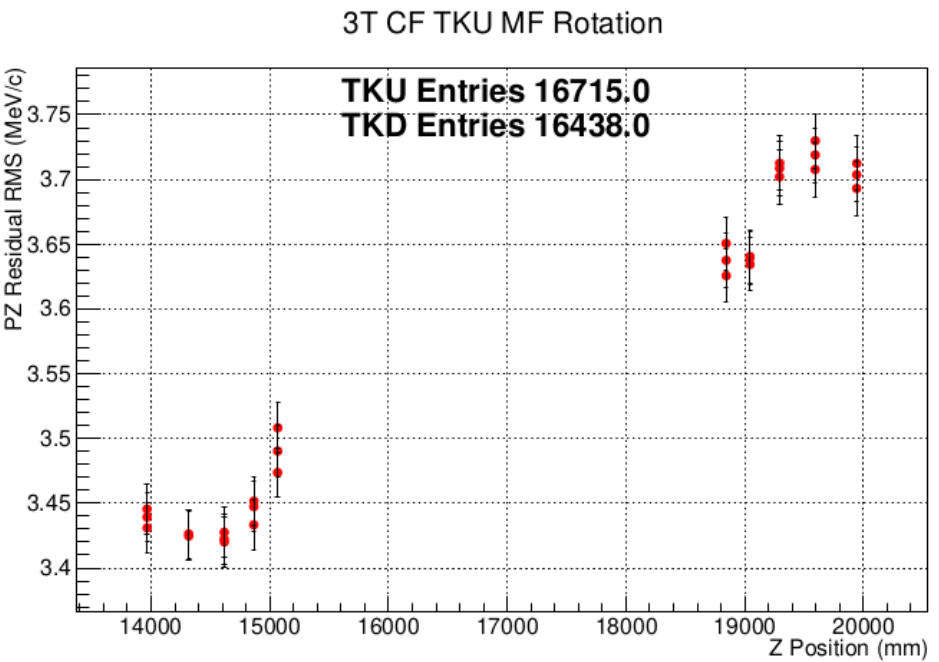
Mean PZ Residual

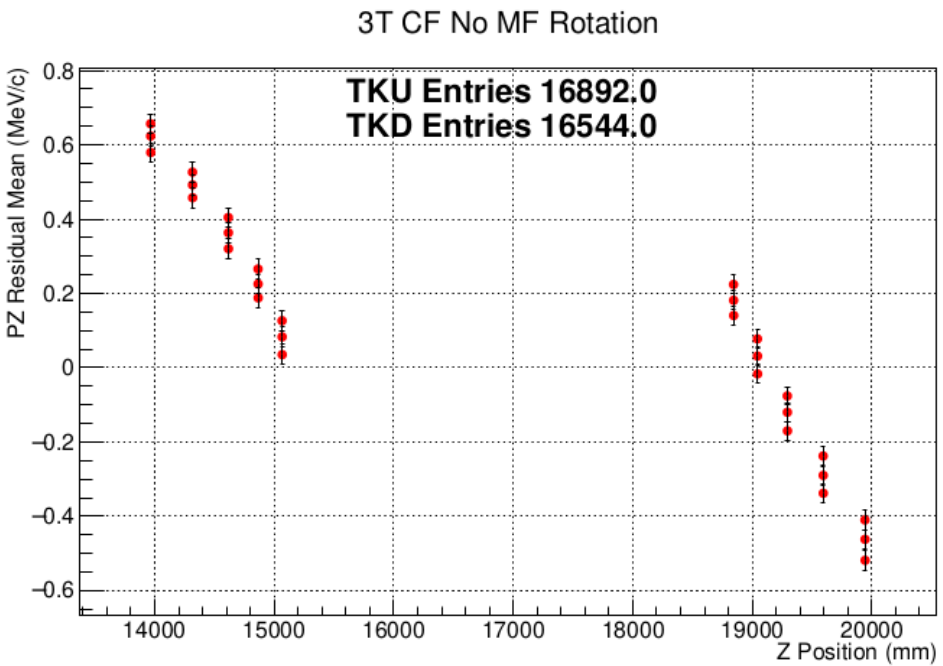


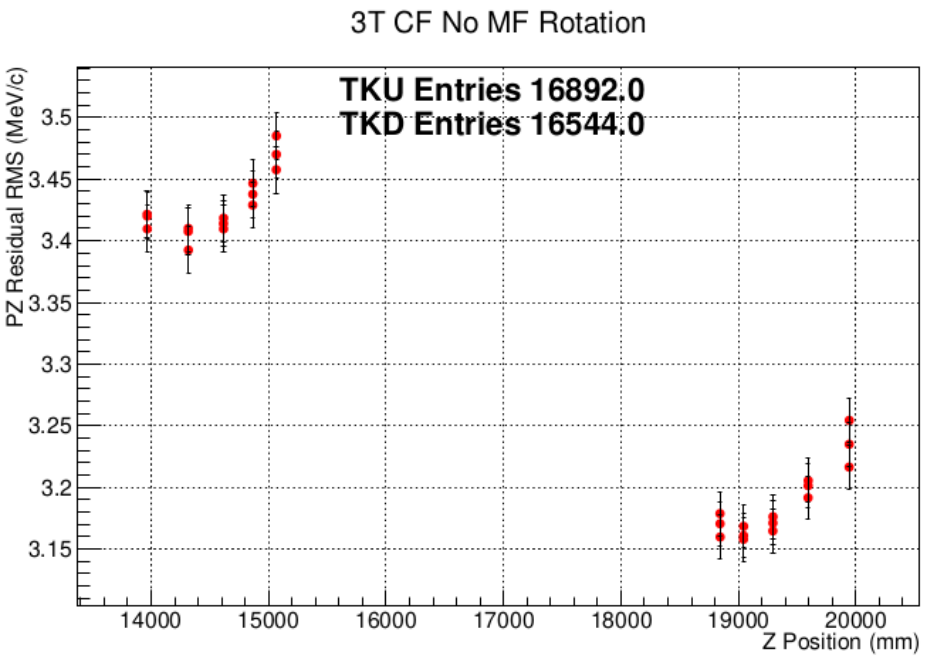
RMS PZ Residual

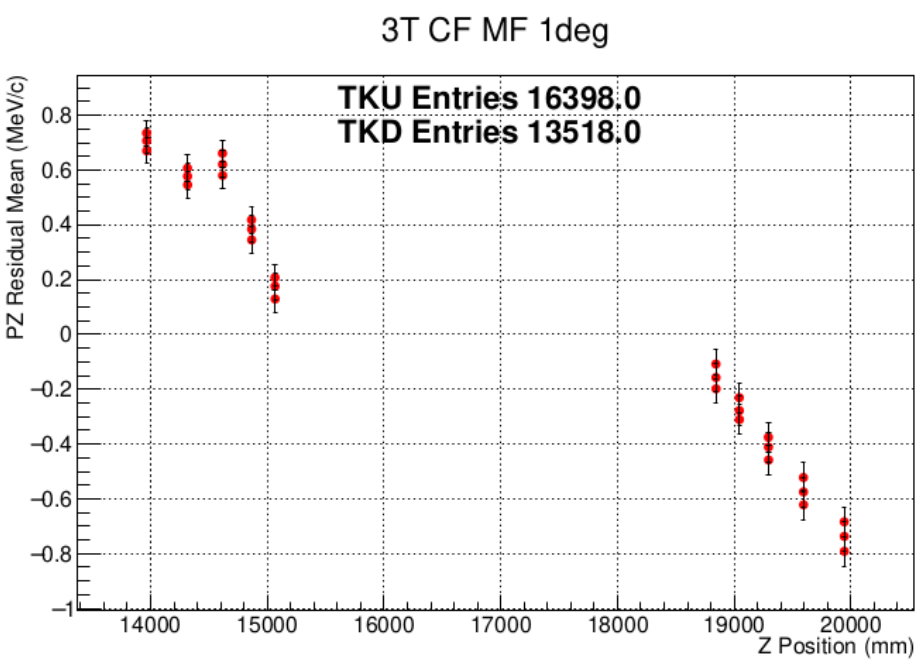


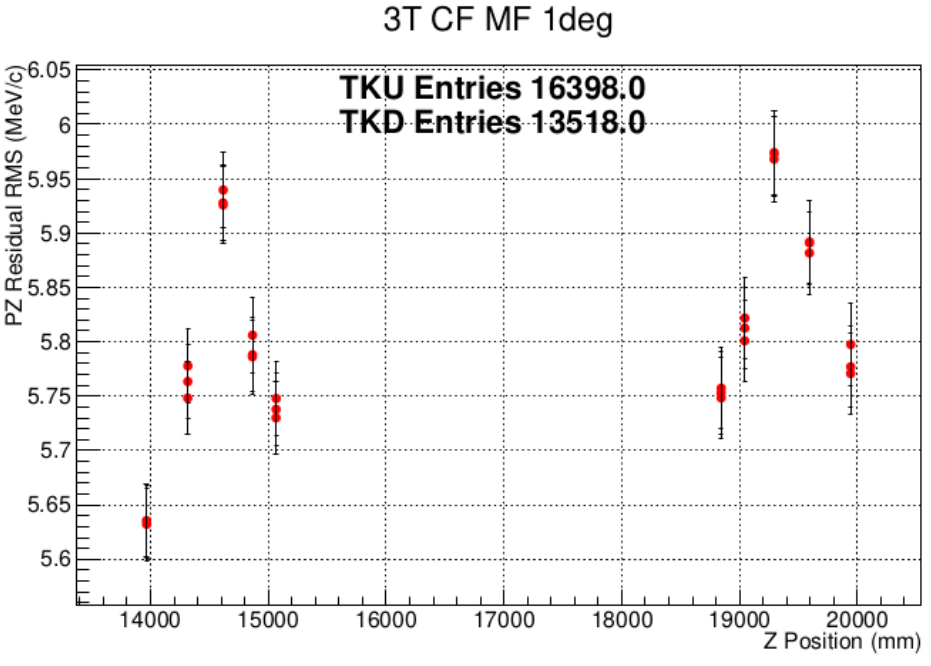

3T CF TKU MF Rotation
TKU Entries 16715.0
TKD Entries 16438.0
PZ Residual Mean (MeV/c)
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

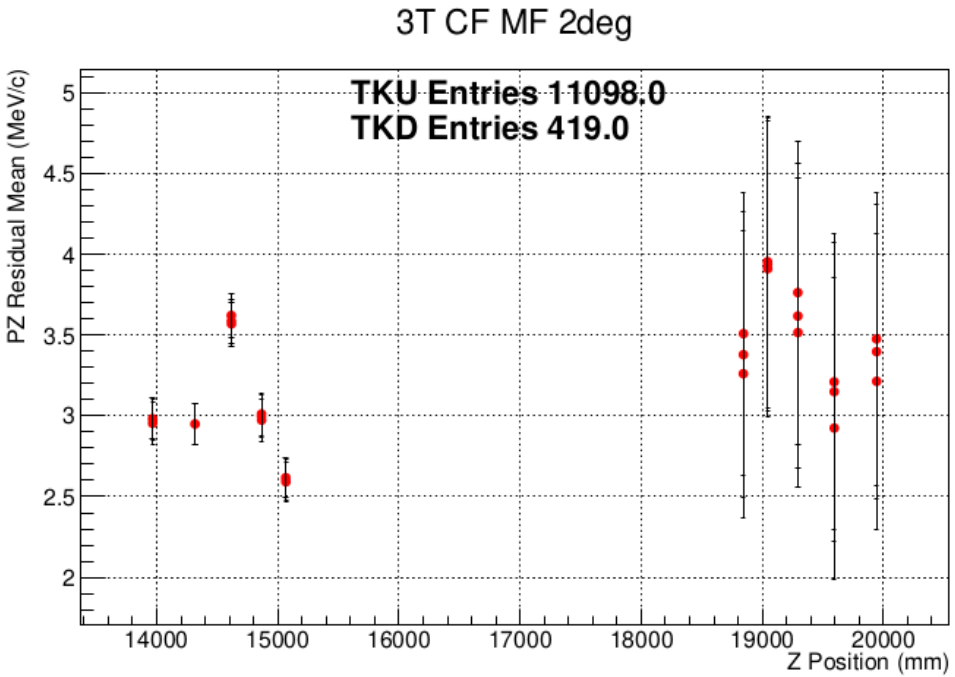

3T CF TKU MF Rotation
TKU Entries 16715.0
TKD Entries 16438.0
PZ Residual RMS (MeV/c)
3.75
3.7
3.65
3.6
3.55
3.5
3.45
3.4
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

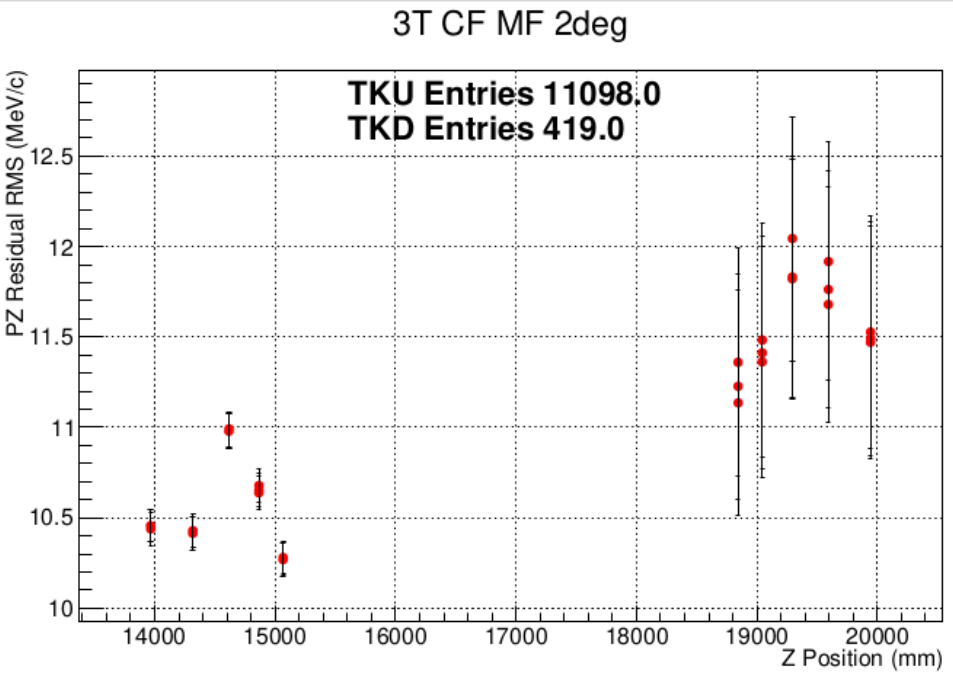

3T CF No MF Rotation
TKU Entries 16892.0
TKD Entries 16544.0
PZ Residual Mean (MeV/c)
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)


3T CF No MF Rotation
TKU Entries 16892.0
TKD Entries 16544.0
PZ Residual RMS (MeV/c)
3.5
3.45
3.4
3.35
3.3
3.25
3.2
3.15
14000
15000
16000
17000
18000
19000
20000
Z Position (mm)

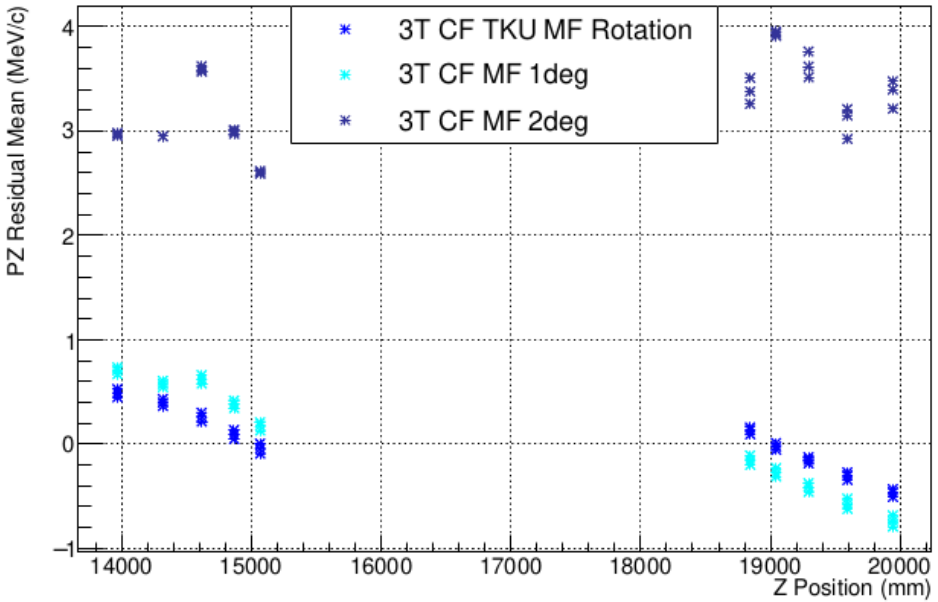

3T CF MF 1deg
TKU Entries 16398.0
TKD Entries 13518.0
PZ Residual Mean (MeV/c)
Z Position (mm)

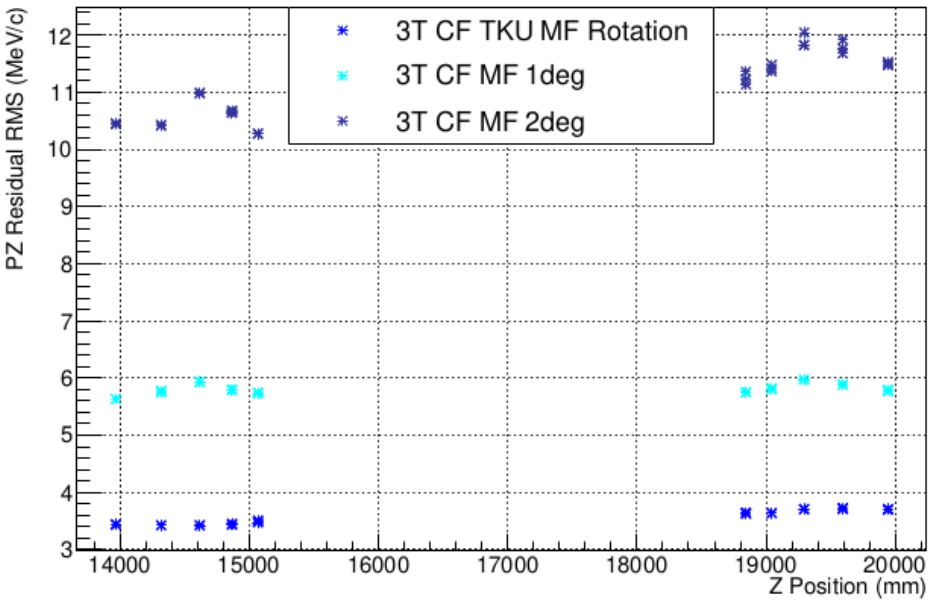

3T CF MF 1deg
TKU Entries 16398.0
TKD Entries 13518.0
PZ Residual RMS (MeV/c)
Z Position (mm)


3T CF MF 2deg
TKU Entries 11098.0
TKD Entries 419.0
PZ Residual Mean (MeV/c)
Z Position (mm)


3T CF MF 2deg
TKU Entries 11098.0
TKD Entries 419.0
PZ Residual RMS (MeV/c)
Z Position (mm)

- Main Effect from Magnetic field misalignment is increasing Pz Residual RMS

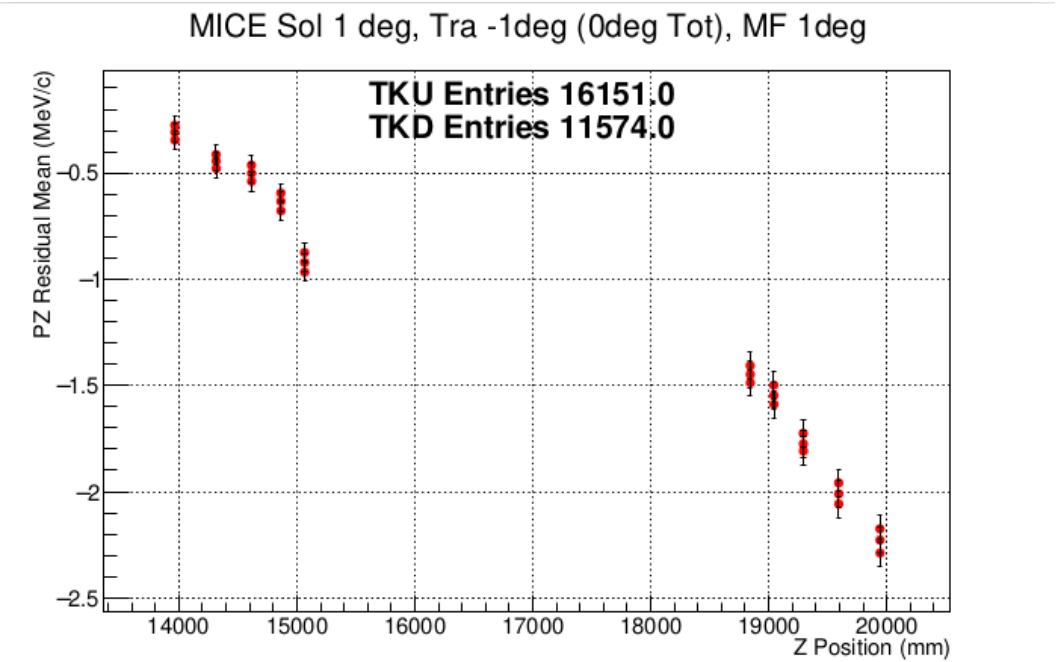


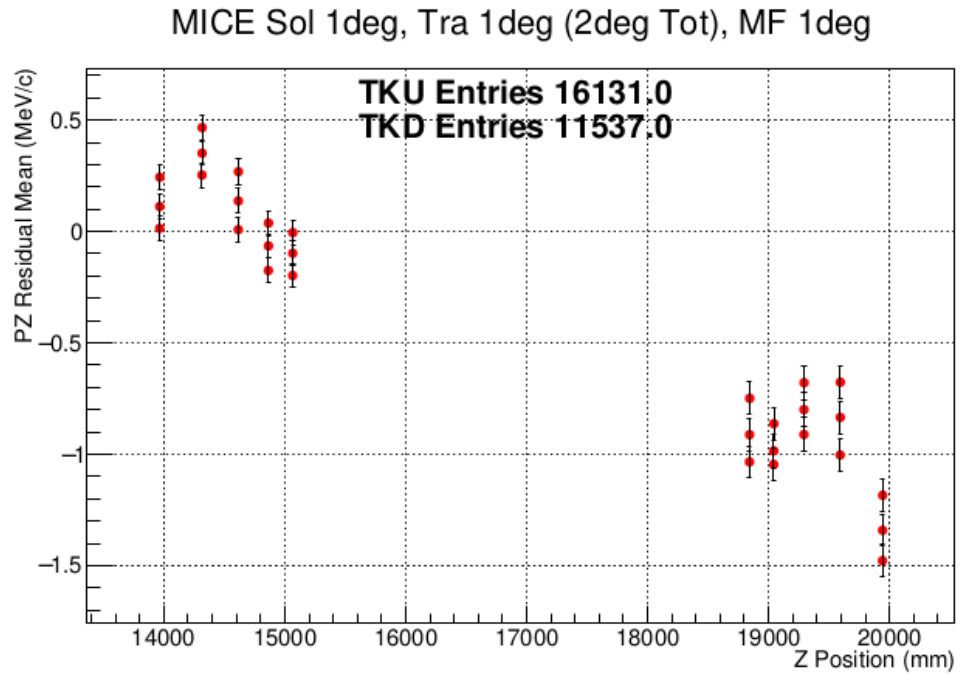


Misalignments

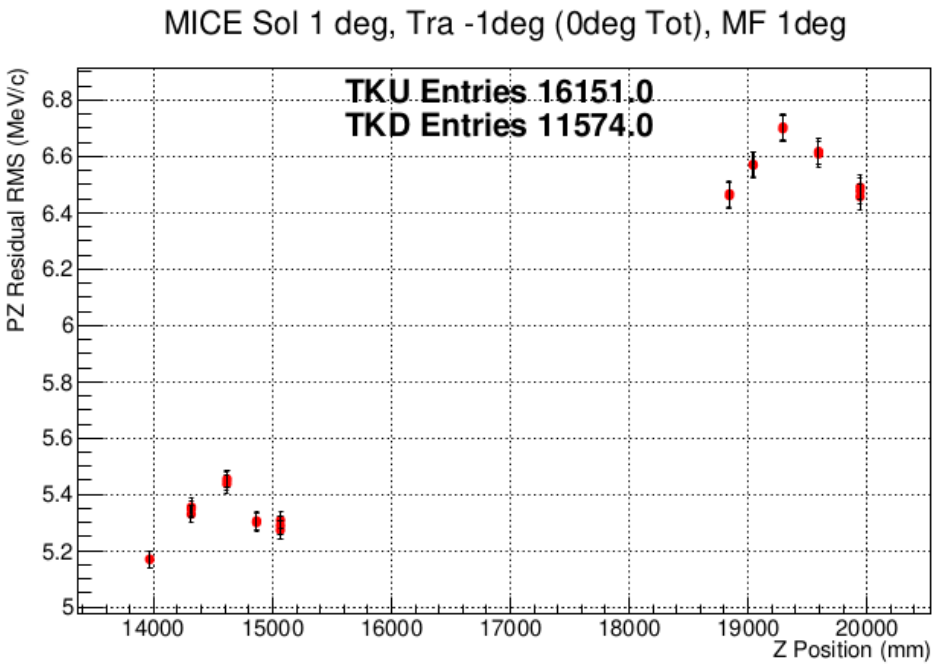
- Magnetic Misalignment up to 0.5 deg in MAUS
- Tracker and Solenoid Misalignments will also have effects
- Haven’t fully thought out implications, so will only pick out some plots

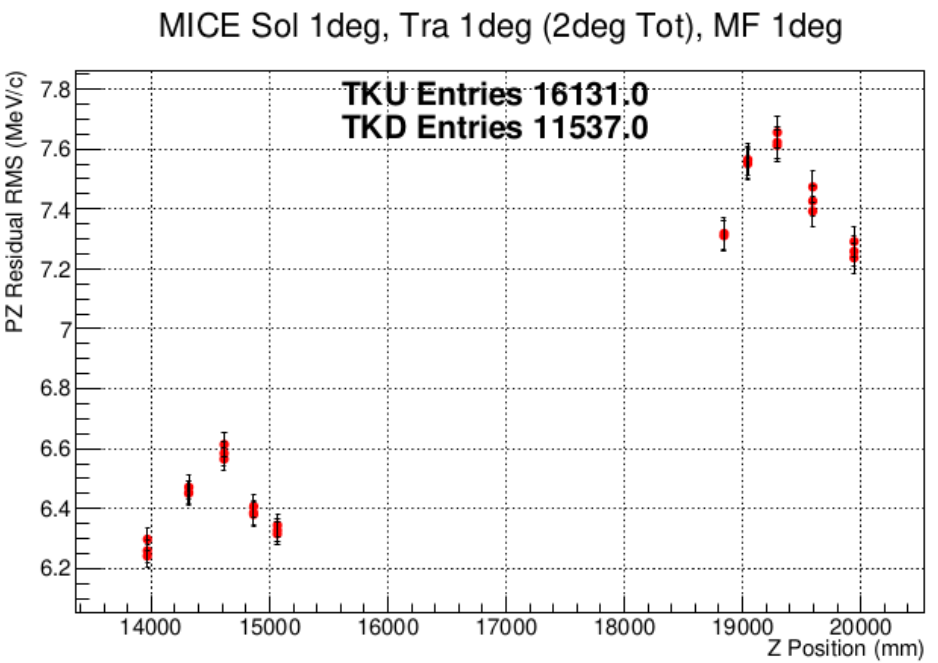
- Solenoid and Magnetic field have same misalignment
- Only changed Tracker alignment by +/-1 degree from solenoid
-



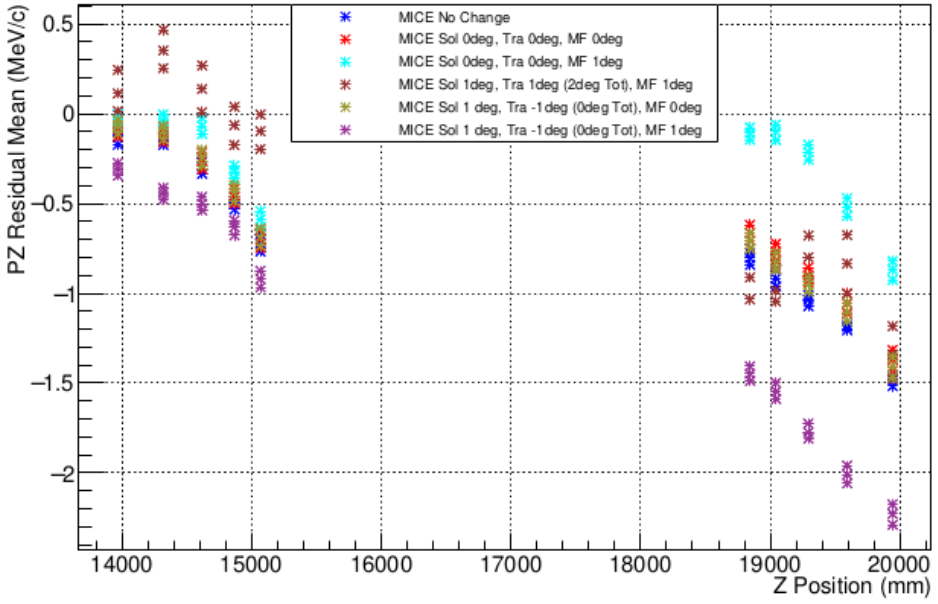


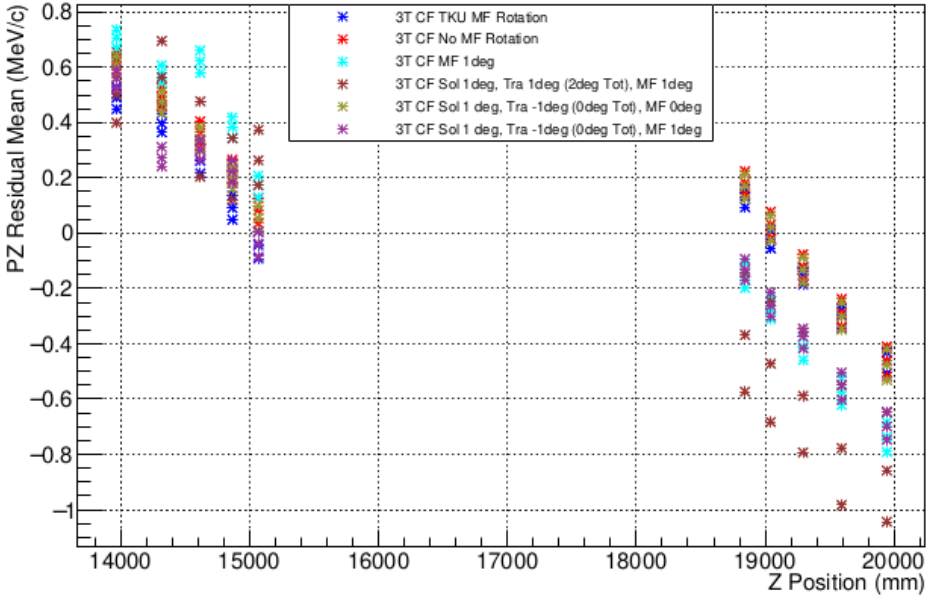
- Corresponding RMS of Pz Residuals
- Trajectory of particles hasn’t changed, only where it hits the tracker has



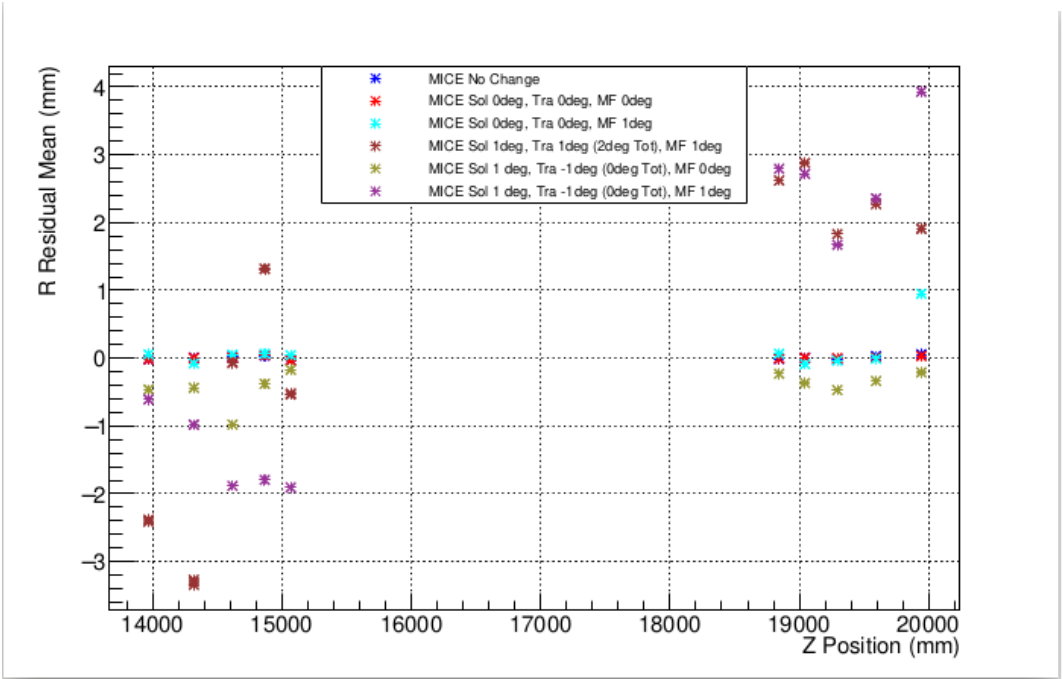


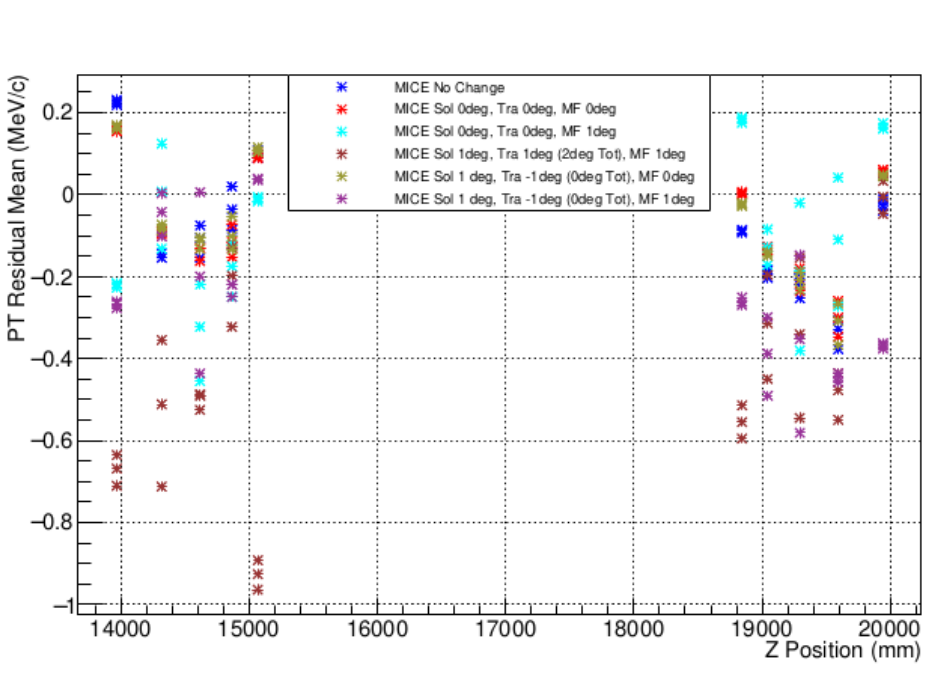
- Misalignments cause changes in the Pz Residuals
- Should we be trying to match them at reference planes?
- - > Reconstruction is susceptible to misalignments





- Can see similar effects for transverse components, albeit on a smaller scale
- Reconstuction may lead to under/overestimating cooling effect
- We don’t have any errors due to misalignments, how sure are we about them?





Misalignments and Recon

- How may the data be misaligned
- Solenoids should be well known from Surveys (unless they move)
- Trackers known from Francois Straight Track Beam Alignment (implementation of values in MAUS unclear)
- Magnetic field based on Alignment from 27/3/2015 (survey not in MICE notes) Implementation into MAUS also unclear

SSU	M1 [mm]	M2 [mm]	E1 [mm]	CC [mm]	E2 [mm]
z	3449.22	3013.39	2613.39	1863.39	1113.39
z'	16106.55	15670.49	15270.29	14519.90	13769.50

Table 3.7 Table of centre positions in z and z' for all of SSU's coils. Coloured cells are those that are calculated from the method described above.

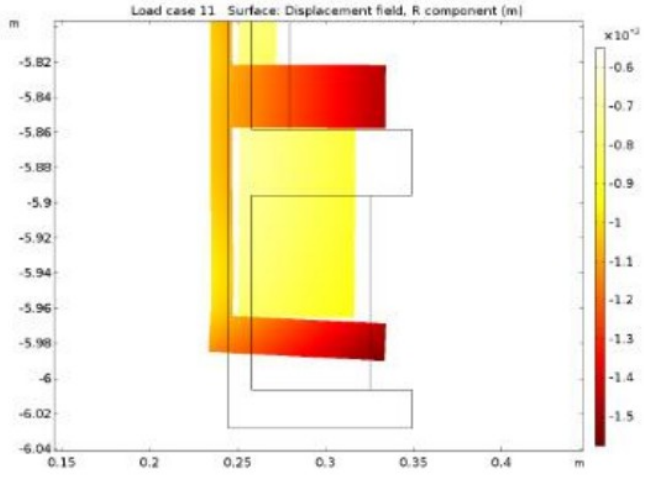


Fig. 3. Deformation plot of the E2 coil and the bobbin (deformation ten times amplified). The colour indicates the radial displacement.

Misalignments and Recon

SSU	M1 [mm]	M2 [mm]	E1 [mm]	CC [mm]	E2 [mm]
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Table 3.7 Table of centre positions in z and z' for all of SSU's coils. Coloured cells are those that are calculated from the method described above.

- Reconstruction and Monte Carlo uses warm bore dimensions
- FEA (H. Witte) suggests cooling and forces deform and move magnets
- Langlands showed M1 to M2 distance measurement contracts
- Measured 435.83mm vs 440mm in MAUS (1% effect)
- Contraction/movement may be similar for other coils – May mean magnetic field changes/ moves longitudinally relative to the trackers

Can also look at draw wires to see if solenoids move

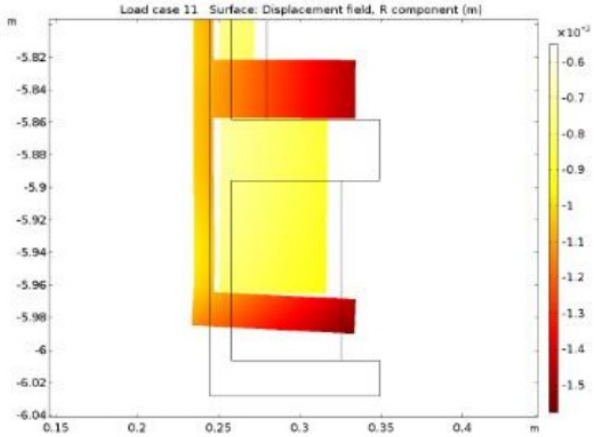
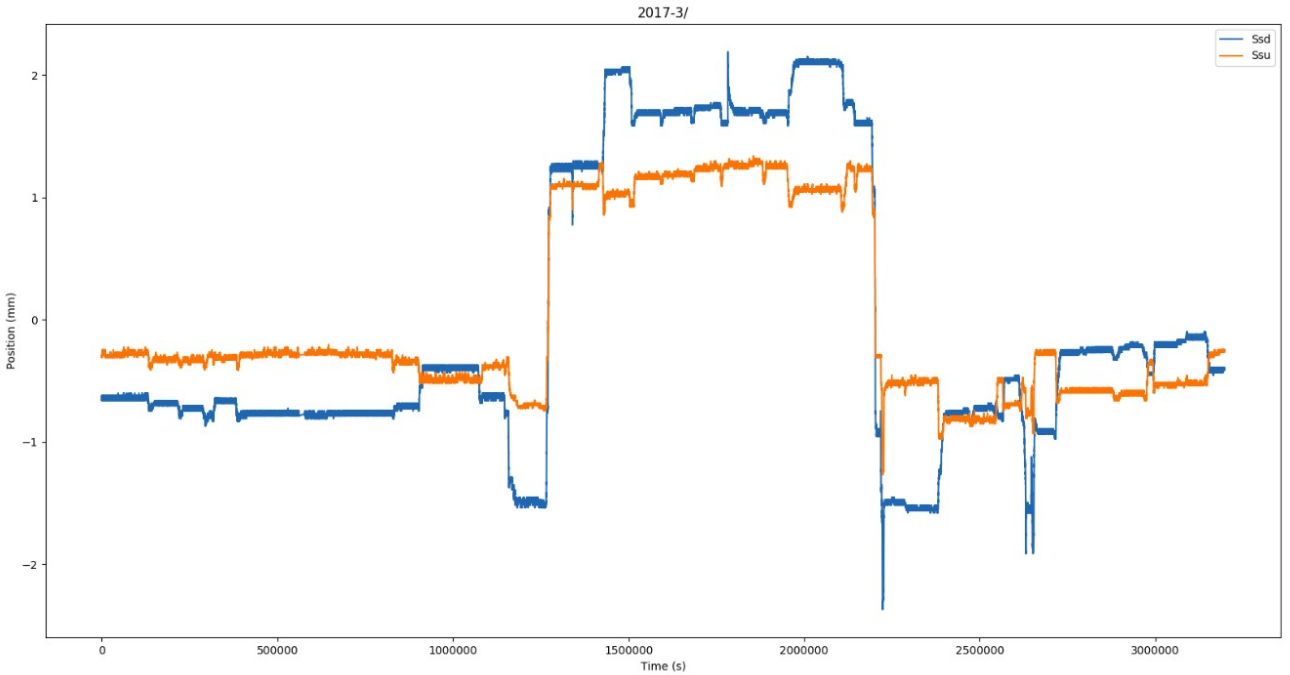
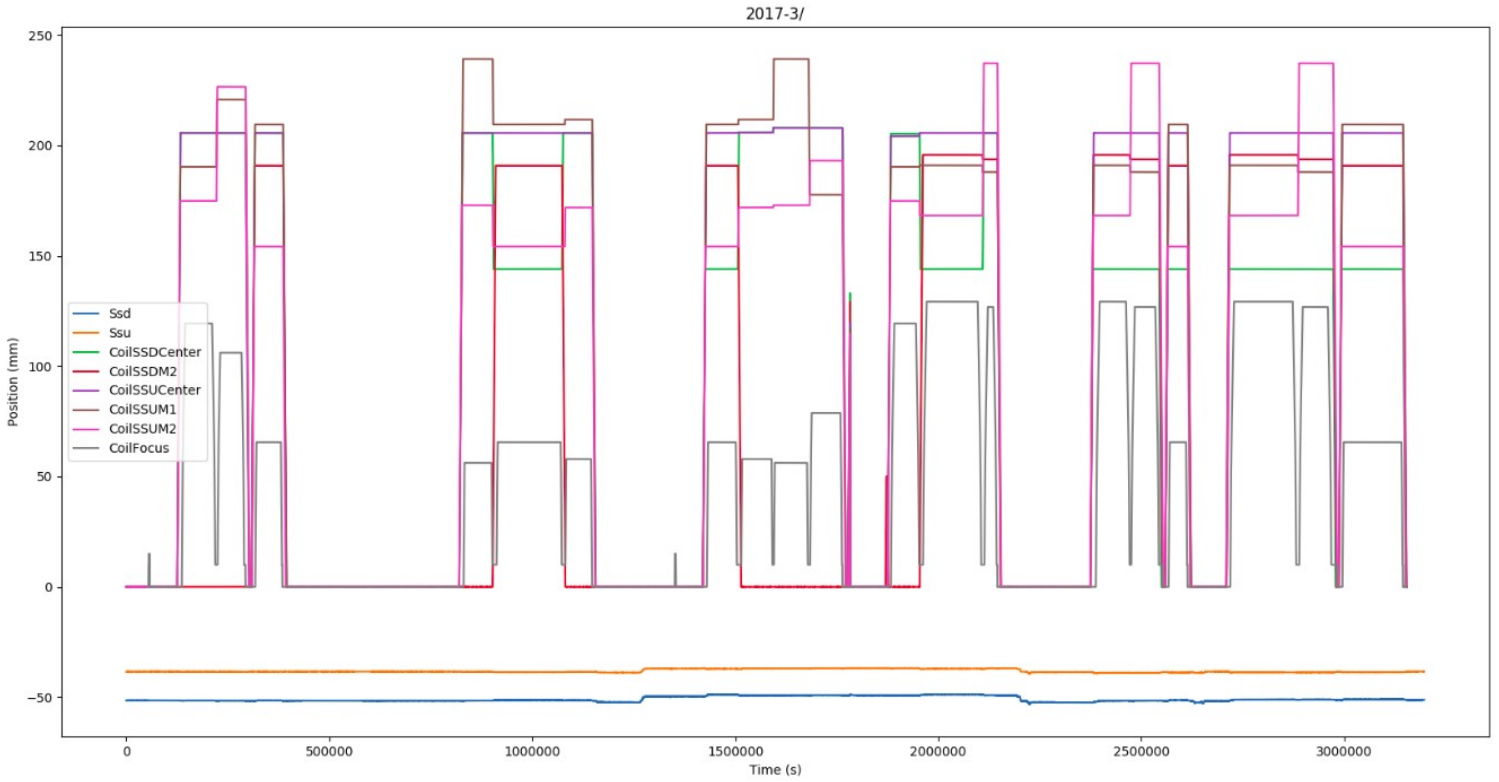


Fig. 3. Deformation plot of the E2 coil and the bobbin (deformation ten times amplified). The colour indicates the radial displacement.

- Change from Mean position of the SSU and SSD draw wires during ISIS cycle 2017/3
- Movements by up to 4mm, unclear if Transverse, longitudinal or mixed component
- First large change 28/11 with LH2 empty vessel removed to no absorber
- Second spike 9/12, inserting LiH, 3rd spike 14/12, inserting Wedge
- Difference of SSU and SS
  wedge



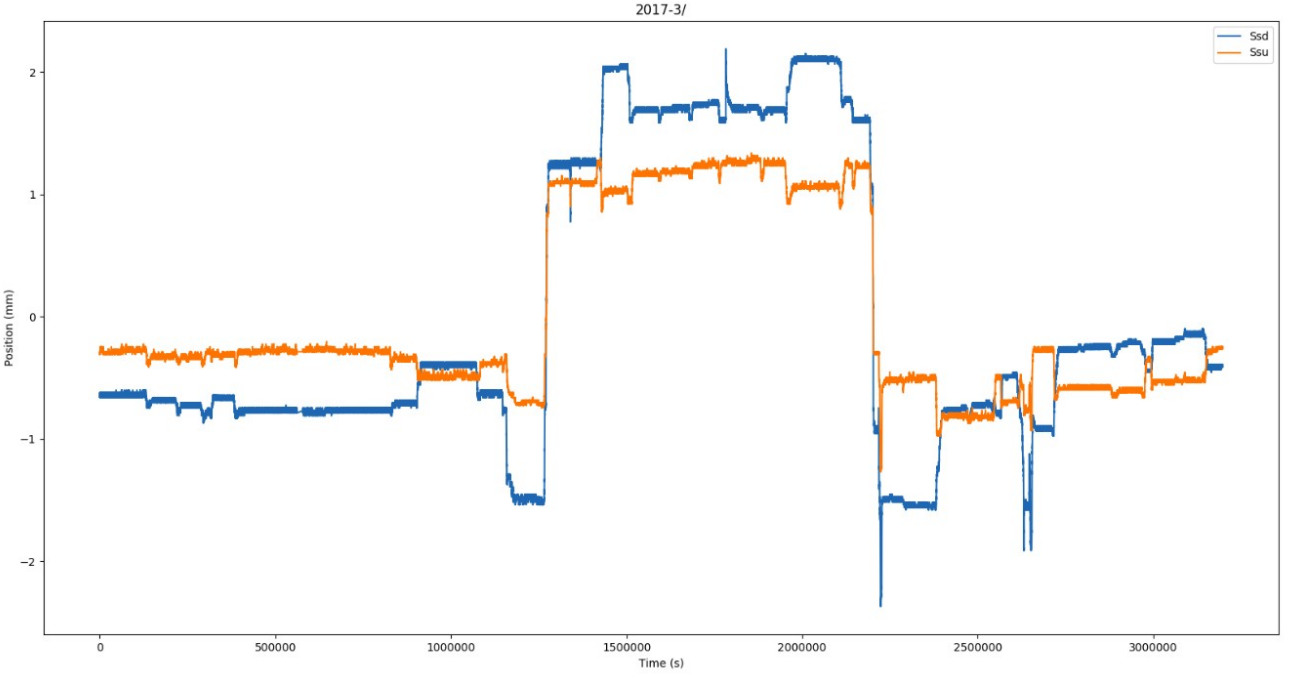
- SSU and SSD draw wire position and coil magnet currents are plotted.
- No appreciable magnetic field effect, due to absorber changes



Draw wires - survey comparison

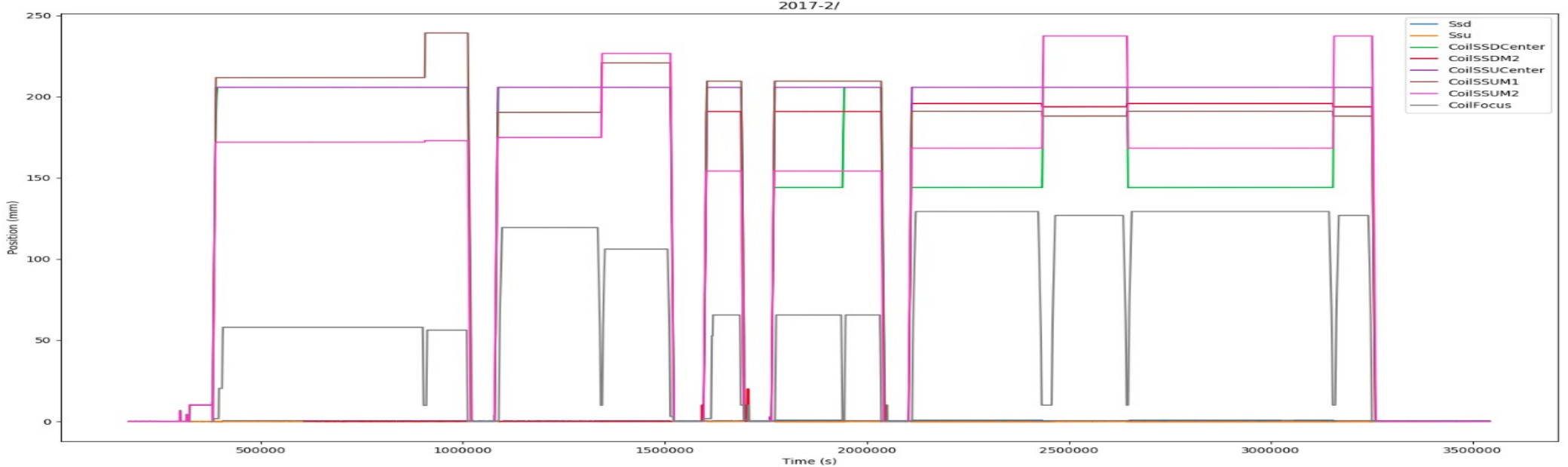
- SSU/SSD based on Survey (except wedge, based on LiH survey)
- Tracker 0,1 based on Survey plus Beam Alignment
- Draw wires show greater movement than surveys
- Beam-based alignment shows large transverse movement (albeit different longitudinal position)
- Comparison difficult without d

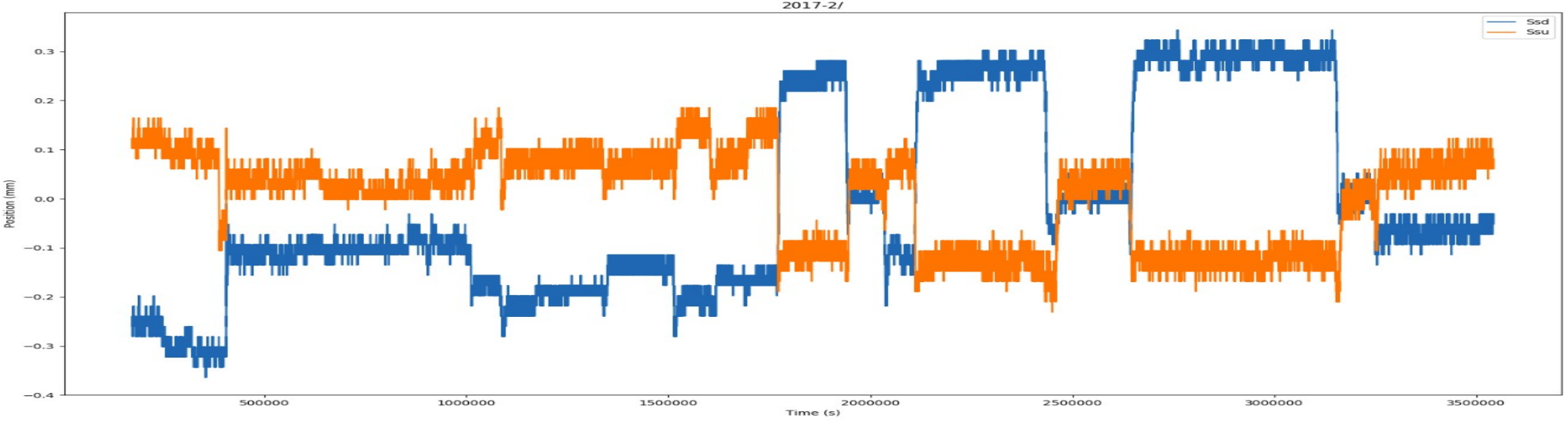
Tracker 0	x	y	z
LH2→No	1.337641401	-5.244120038	-1.2810226
No → LiH	-1.30886485	1.281436368	3.2174675
LiH → Wedge	0.747199948	-0.449198095	-0.0013378
Tracker 1	x	y	z
LH2→No	-0.580031803	-5.970735252	-1.2546227
No → LiH	1.475489441	-2.75944736	2.3889188
LiH → Wedge	-0.37339019	1.713259855	-2.3836467
SSU	x	y	z
LH2→No	0.348042222	-0.919589715	-1.27
No → LiH	-0.589449582	0.517802135	3.215
LiH → Wedge	0	0	0
SSD	x	y	z
LH2→No	-0.006941484	0.373037568	1.07
No → LiH	-0.244778516	1.337182432	-2.38
LiH → Wedge	0	0	0



Other cycles may be different

- Next is cycle 2017/2
- Movement is less than a millimetre, but it does show magnetic field dependence occasionally
- Draw wire data goes back to June 2016. Can’t see changes from when magnetic field alignment was done in March 2015

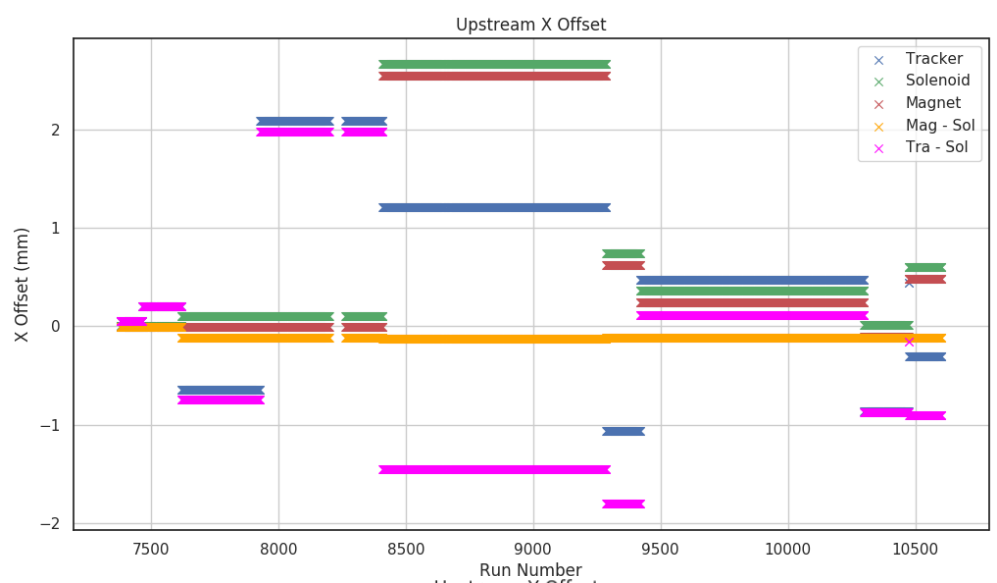

2017-2/
Ssd
Ssu
CoilSSDCenter
CoilSSDM2
CoilSSUCenter
CoilSSUM1
CoilSSUM2
CoilFocus
Position (mm)
Time (s)

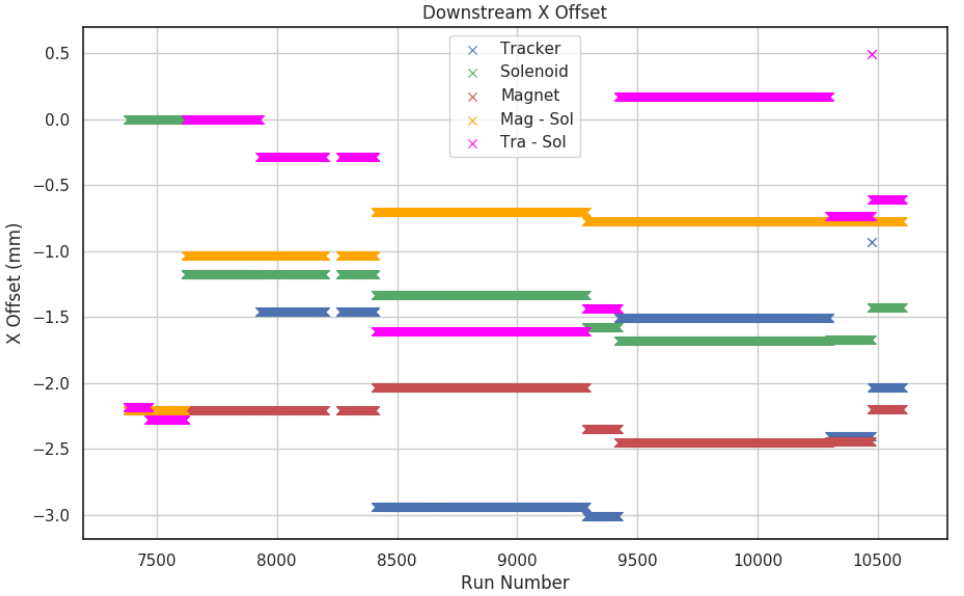

2017-2/
Ssd
Ssu
Position (mm)
Time (s)

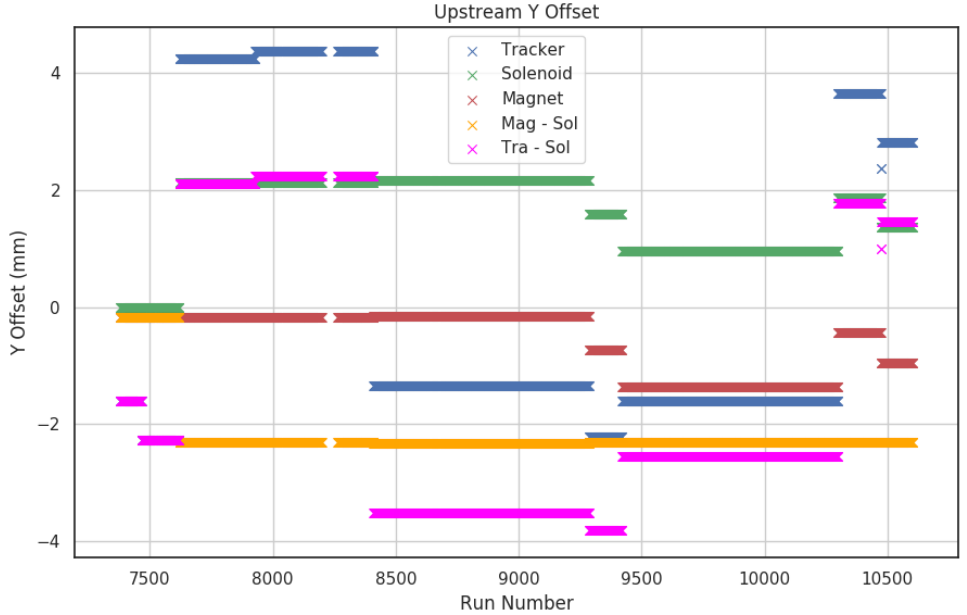
Energy Loss and Helix deformation

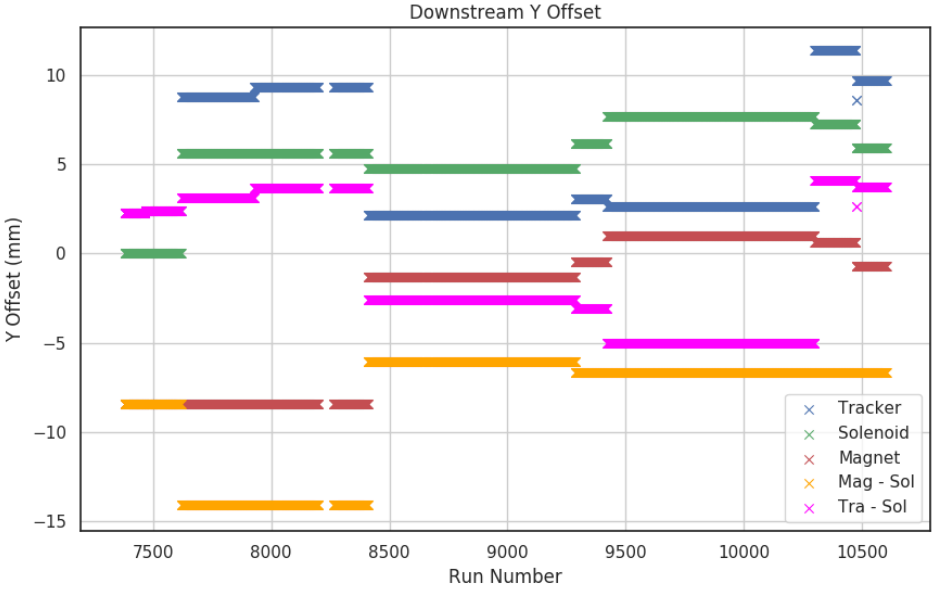
- Still working on it
- Need Recon to work without Energy Loss
- Can then show all three effects separately
- Perhaps enough to allow a correction procedure

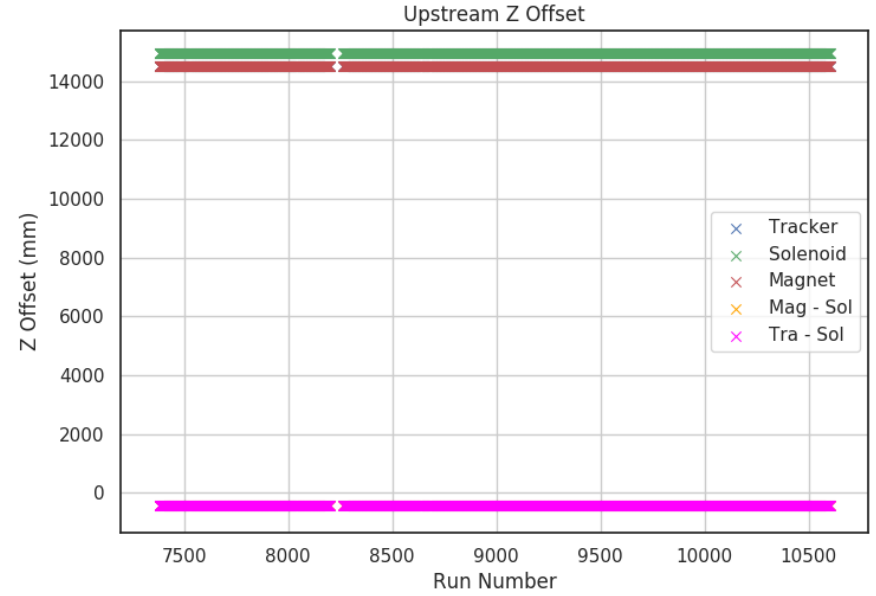
THE END

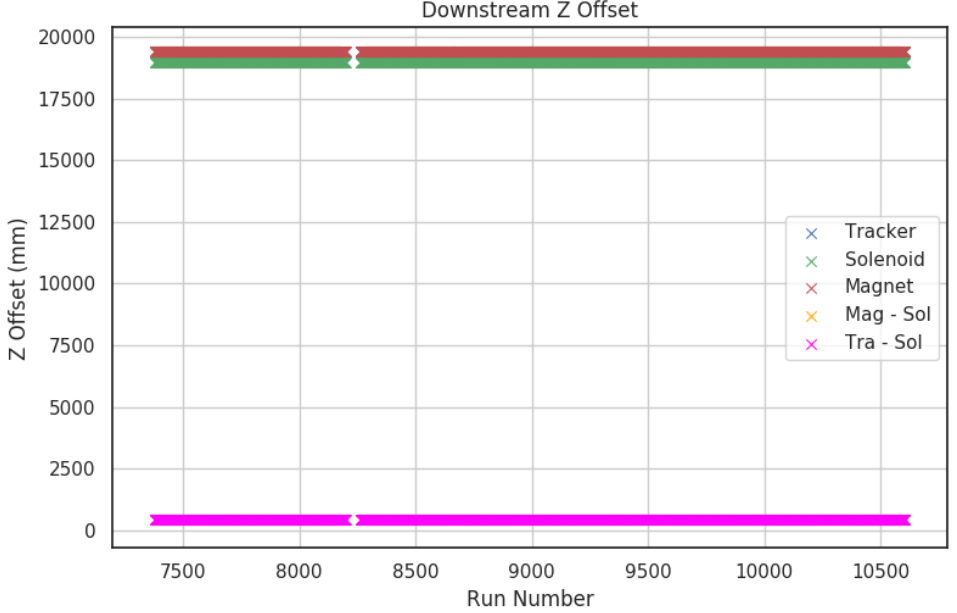

Upstream X Offset
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol
X Offset (mm)
Run Number

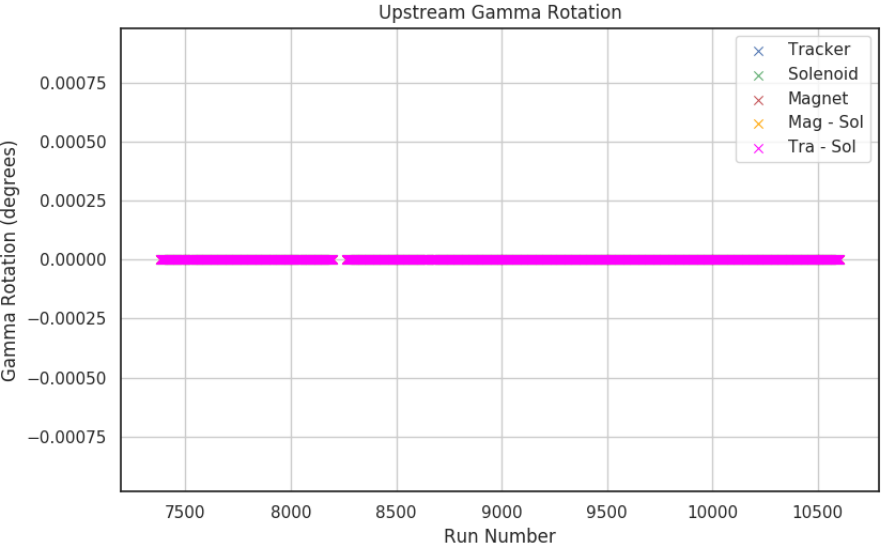

Downstream X Offset
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol
X Offset (mm)
Run Number

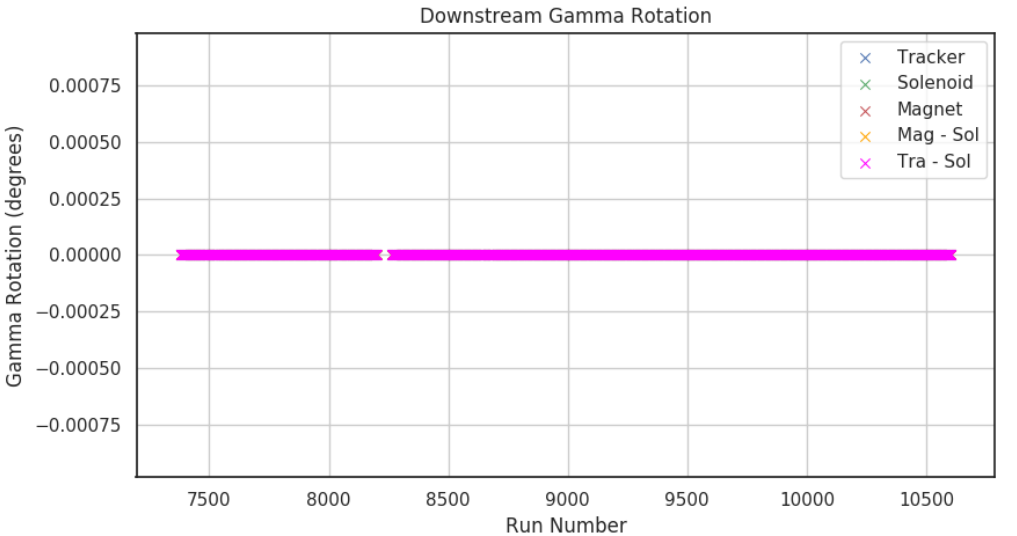

Upstream Y Offset
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol
Y Offset (mm)
Run Number


Downstream Y Offset
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol
Y Offset (mm)
Run Number


Upstream Z Offset
Z Offset (mm)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol


Downstream Z Offset
Z Offset (mm)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol


Upstream Gamma Rotation
Gamma Rotation (degrees)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol


Downstream Gamma Rotation
Gamma Rotation (degrees)
Run Number
Tracker
Solenoid
Magnet
Mag - Sol
Tra - Sol