# Reconstruction WG Summary

PF

03/04/2024

U.S. DEPARTMENT OF ENERGY | Stanford University

SLAC NATIONAL ACCELERATOR LABORATORY

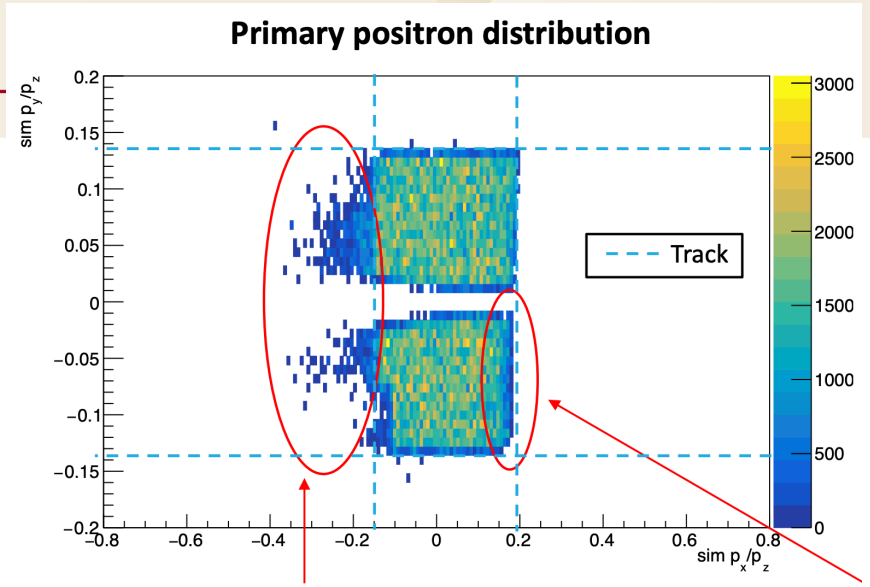
# Introduction

- Update on
  - Track Extrapolation to ECAL issue
  - Alignment stability as function of time in 2021 dataset

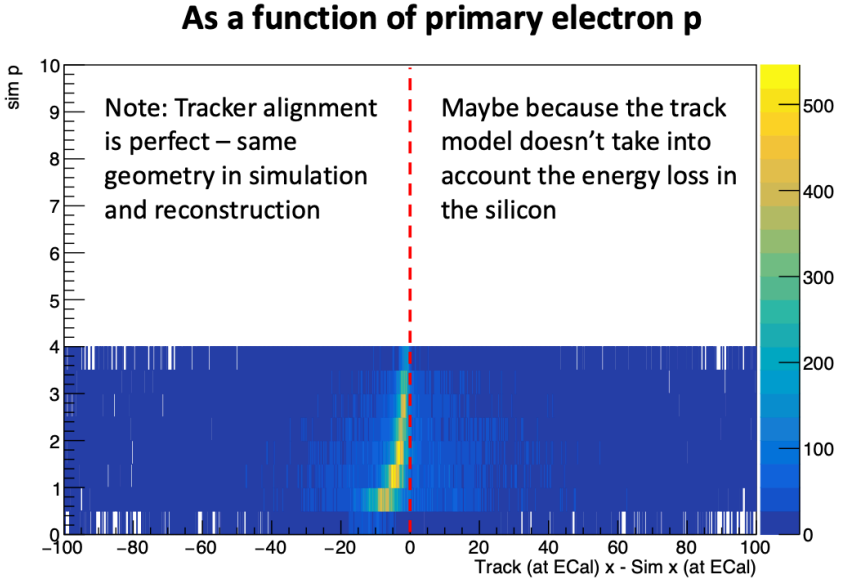
# Track Extrapolation to ECAL

- Dedicated study of the HPS acceptance in SVT / Ecal by **Abishek / Cam**
- Single e+/e- particle gun using GPS
  - Isotropically generated from point source with uniform energy distribution

- During studies on MC observed bias in the $\Delta(Track_X^{ECAL}, SimHit_X^{ECAL})$ residuals at the face of the ECAL
  - Increases for low momenta tracks




- Mainly coming from low momentum primaries
- Mainly at low tan($\lambda$)



# Track Extrapolation to ECAL

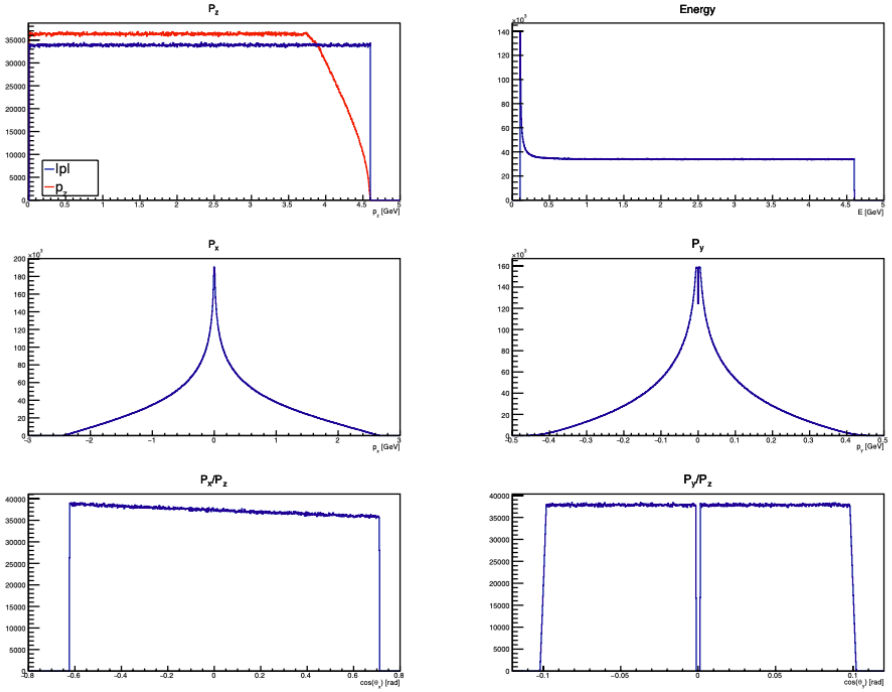


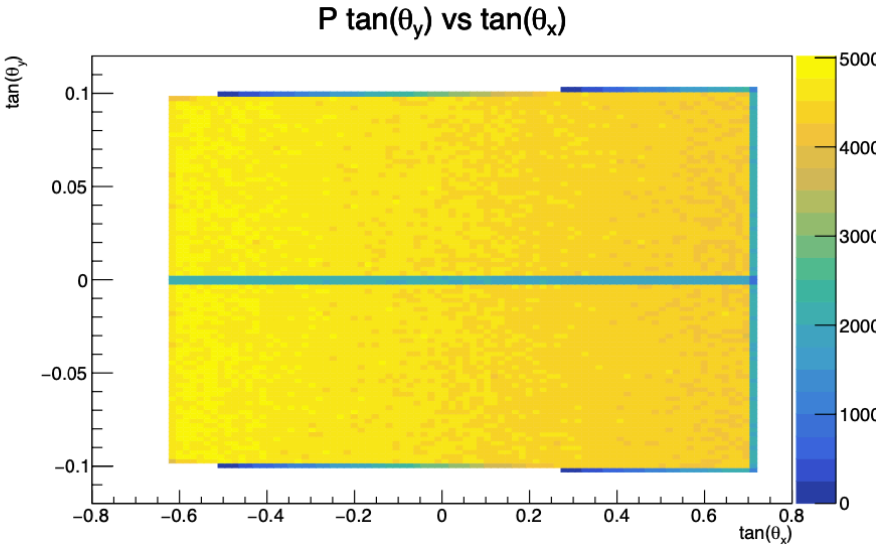
- This problem was already reported by Alic and Norman some time ago 4.21.2021-Weekly

- **Lewis and Maurik** dove into this problem to characterized the source of the possible issues
- Together we checked:
  - **If it's a tracking related problem**, i.e. track fit is poor and so extrapolation is poor
  - **If it's an integration problem**, i.e. RK4 is wrongly setup to integrate the particle path in the fringe field
  - **If it's an extrapolation problem**, i.e. tracks and RK4 are fine but there is a bug somewhere in the extrapolation.

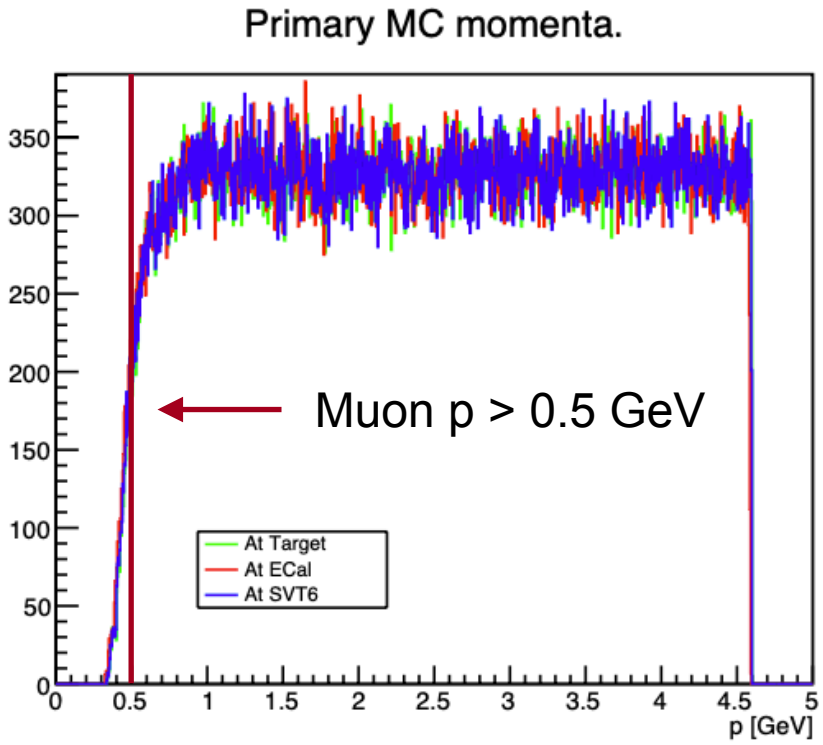
# Dataset used

- As shown before by Lewis: a single negative muon is thrown per event by flat distribution in momentum and $\tan(\theta_x)$, $\tan(\theta_y)$.



# Muons

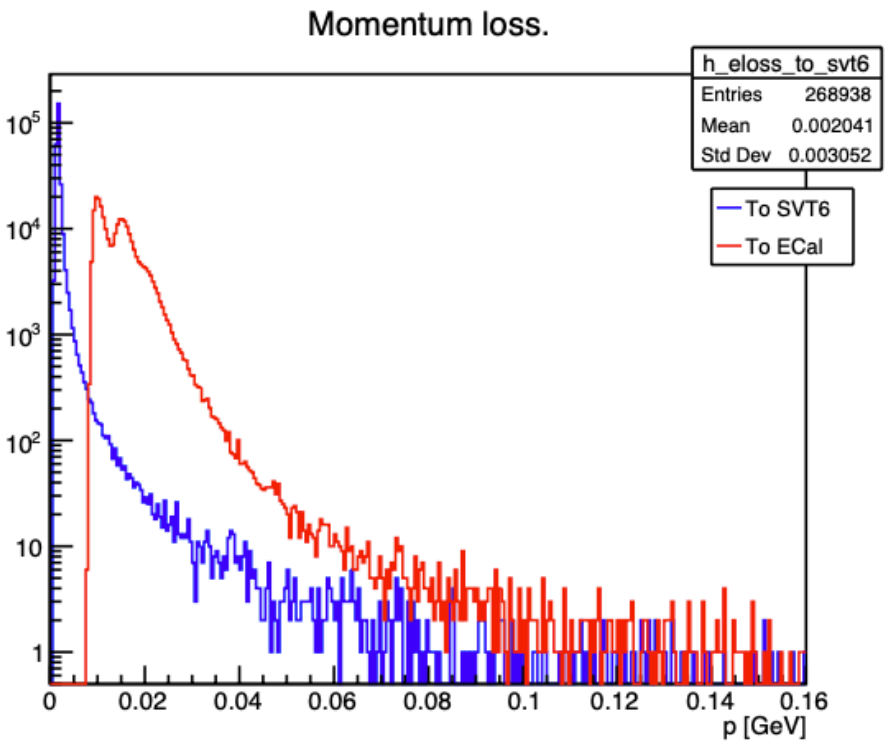



A fairly flat distribution in momentum of the muon all the way to the ECAL

There are strict cuts on this data:

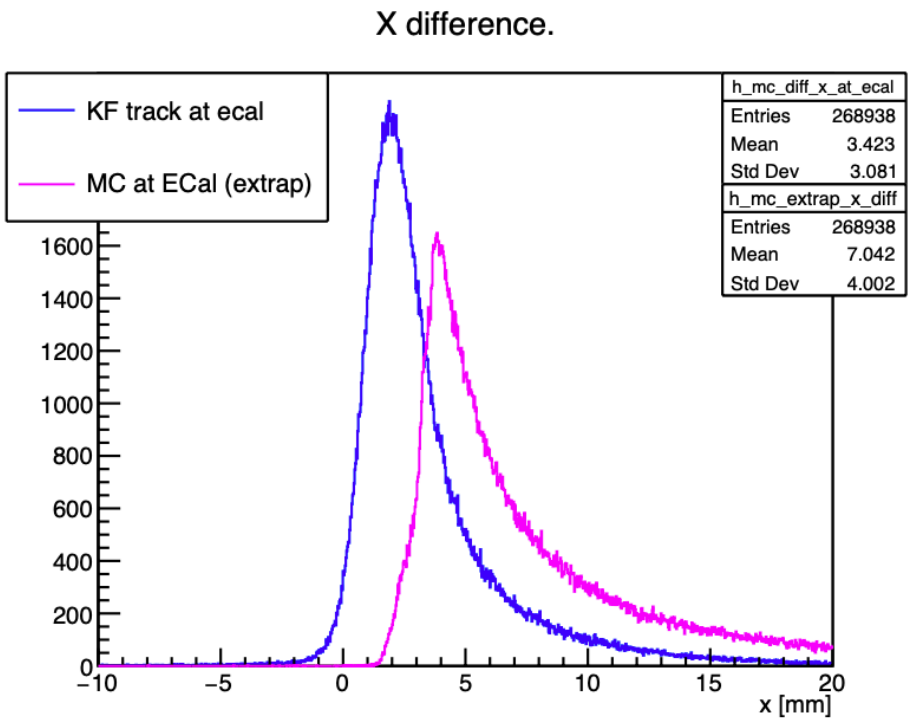
```
Select only 1 Primary MC particle: pass=2560892    all=4999900    -- eff=51.22 % cumulative eff=51.22 %
Select only 1 KF or GBL track.:    pass=1017929    all=2560892    -- eff=39.75 % cumulative eff=20.36 %
Select only 1 MC particle at ECal: pass=858624     all=1017929    -- eff=84.35 % cumulative eff=17.17 %
Select only 1 ECal cluster:        pass=441478     all=858624     -- eff=51.42 % cumulative eff=8.83 %
Select only 1 MC particle at SVT6: pass=268938     all=441478     -- eff=60.92 % cumulative eff=5.38 %
```

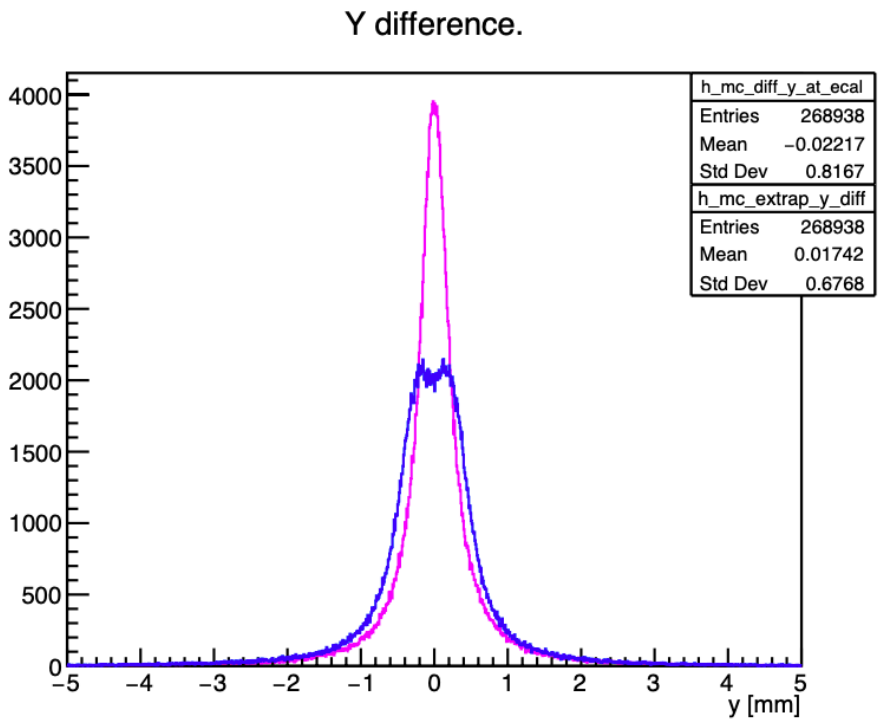
This causes subtle structure in the position distributions.




Not much momentum lost due to multiple scattering.
From last layer of the SVT to the ECal the vacuum exit plate is the main contribution to energy loss, and the production of secondaries.

# Results

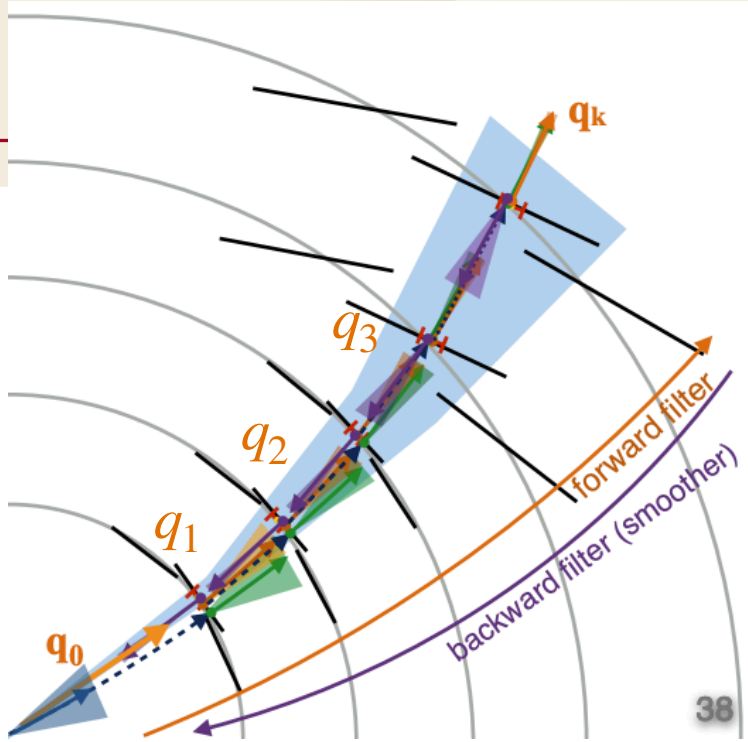


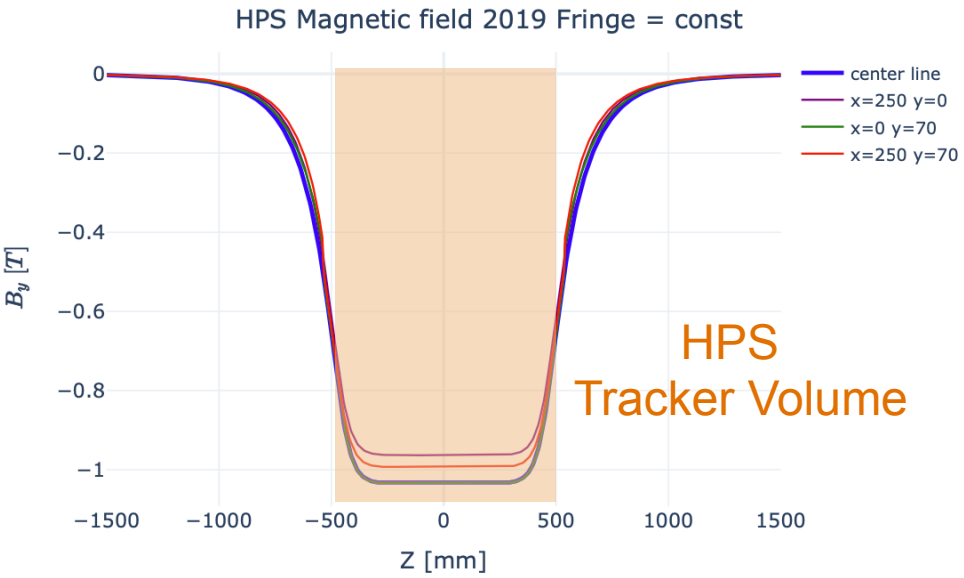




- **Maurik / Lewis** reproduced the X extrapolation bias using single muons
- Not apparent in non-bending direction (Y)
- Blue shape is the $\Delta(TrackX, SimHitX)_{ECAL}$ using our reconstruction
- Pink shape is linear extrapolation from last SVT layer (can be disregarded here)

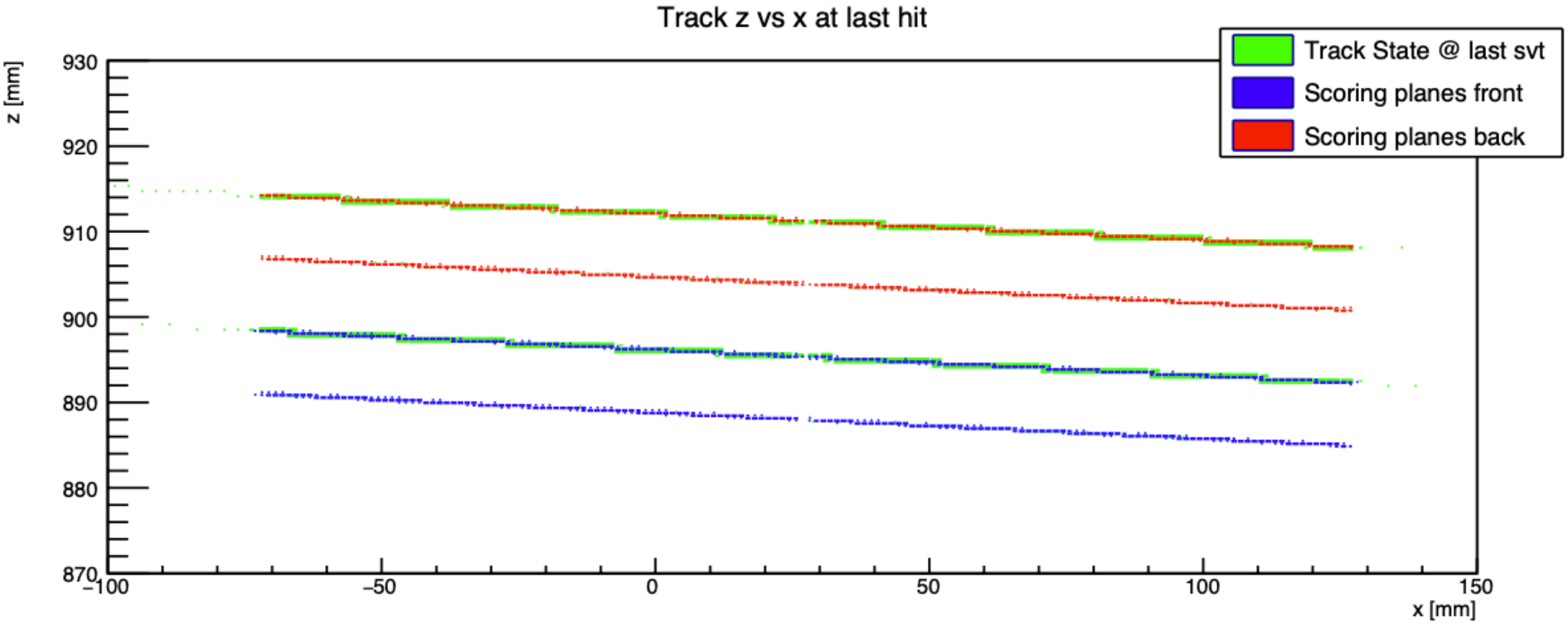
# KF Tracking recap

- Forward filtering, backward smoothing
- KF formalism provides track states, for example $q_i = (loc_0, loc_1, \phi, tan\lambda, q/p)$, at each surface that describe the trajectory of a particle between measuring surfaces
- In HPS each track state is stored as an helix, $q_i = (d_0, z_0, \phi, tan\lambda, \omega)$ with reference to 0.0.0 (very impractical)
- Extrapolation outside the tracker volume should be done with closest measurement,
  - For example to the calorimeter in HPS, should use state qk.
- Extrapolation outside the tracker volume should be done using the non-uniform BField Map
- Internally to HPS tracker, helix propagation between measurements is used (and that's ~ fine)



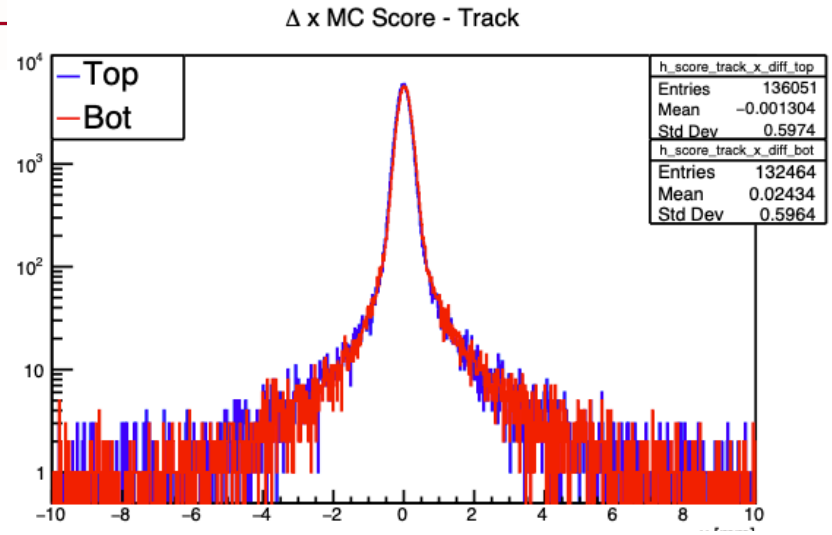



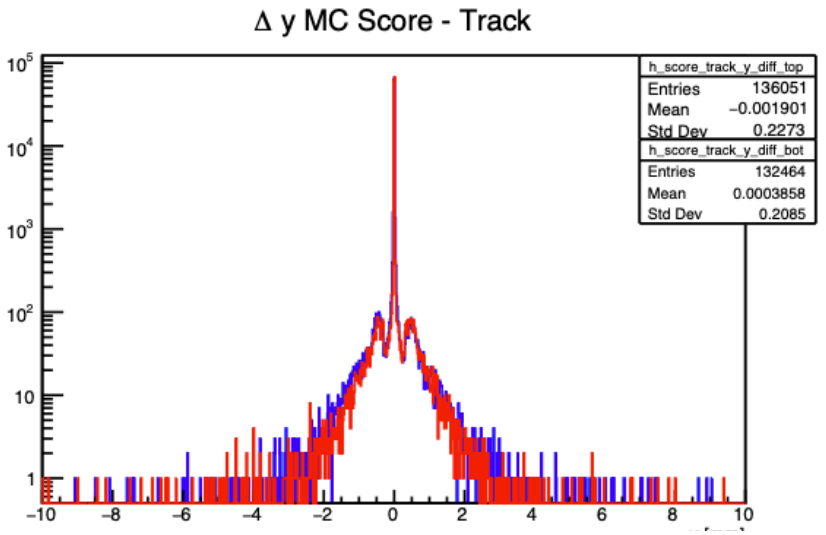
# Last track state checks

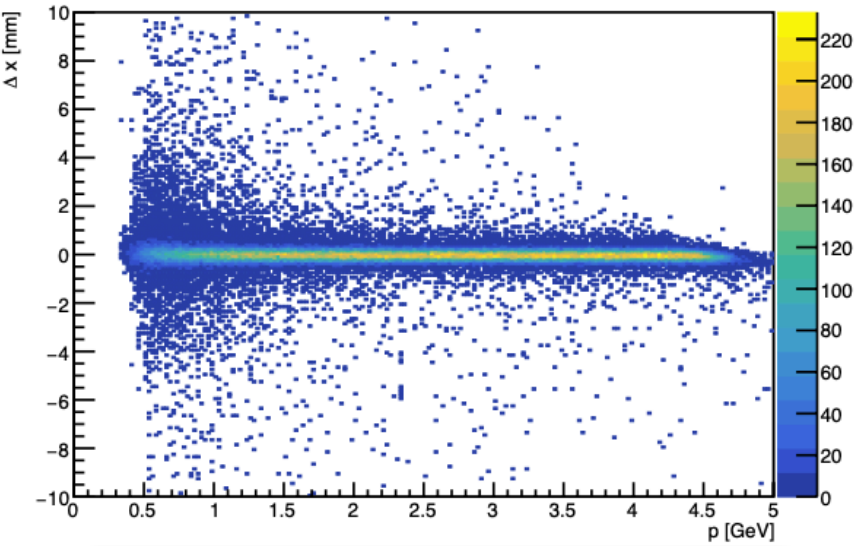


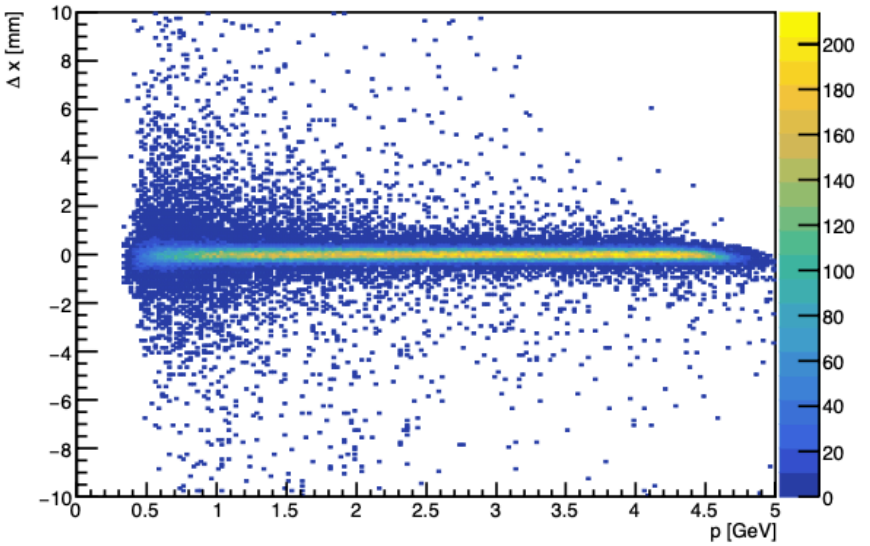

- Track state **qk** at SVT6 layer was checked against truth information
- Truth information is obtained via a scoring plane located at last sensitive surface (2 surfaces: 1 for top and 1 for bottom)

# X-Y positions at last state



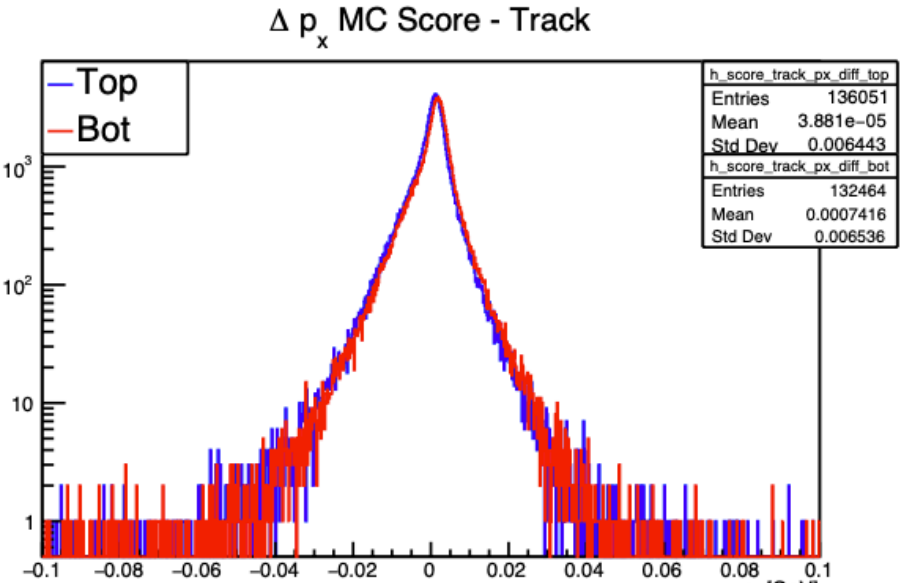



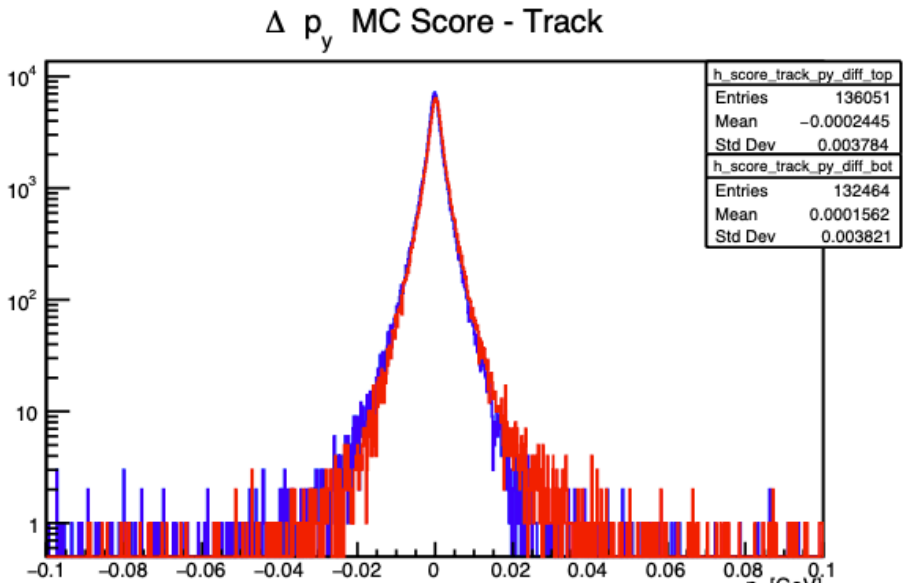



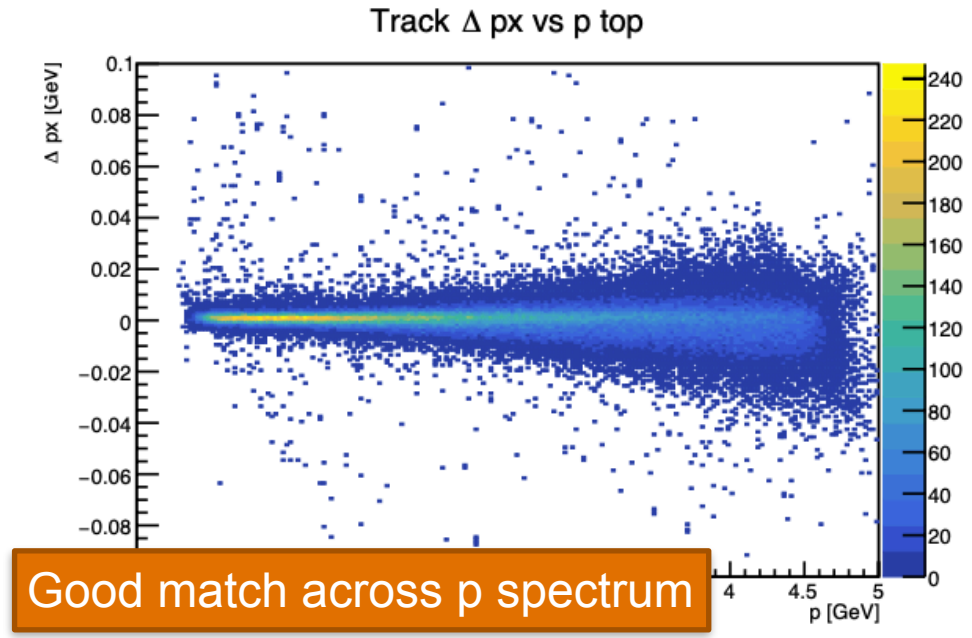



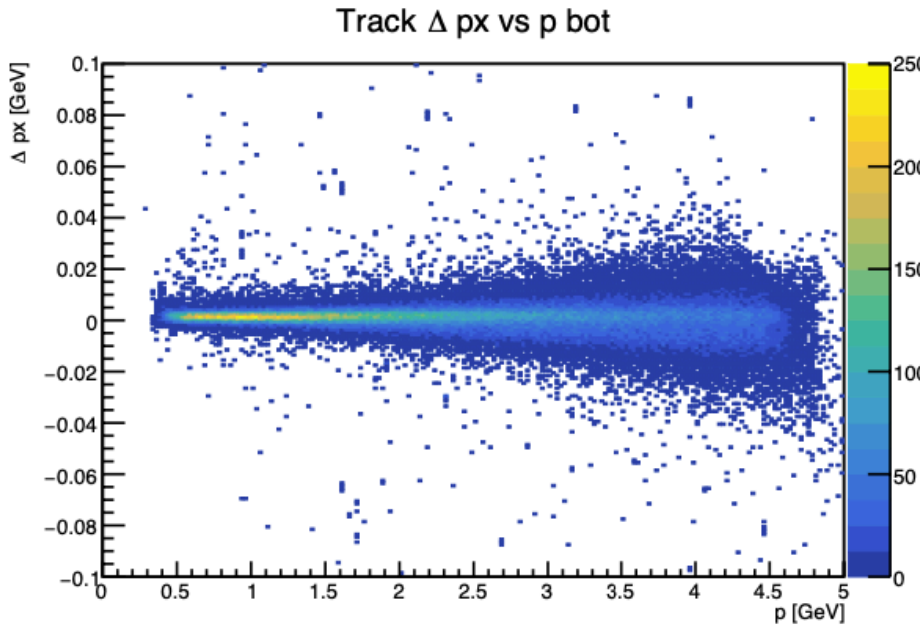

Good match across p spectrum

# Px Py momentum at last state




Good match across p spectrum

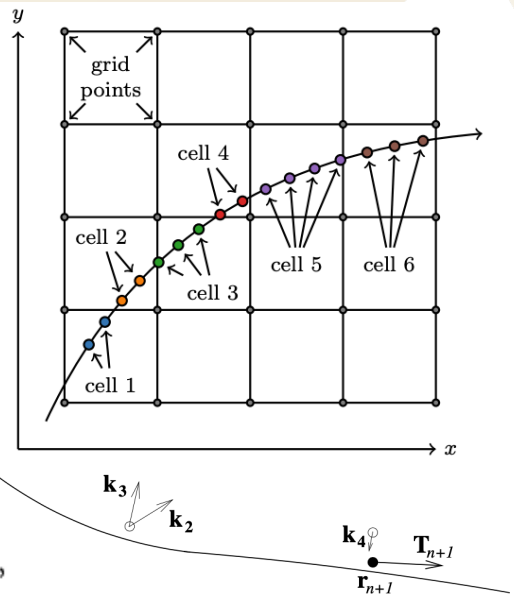
# Extrapolation in non-uniform field

- The equation of motion can be written as

$$\frac{d^2\boldsymbol{r}}{ds^2} = \frac{q}{p}\left(\frac{d\boldsymbol{r}}{ds} \times \boldsymbol{B}(\boldsymbol{r})\right) = \lambda(\boldsymbol{T} \times \boldsymbol{B}(\boldsymbol{r}))$$

$$\frac{d\vec{r}}{ds} = \frac{d\vec{r}}{vdt} = \frac{\vec{v}}{v} = \vec{T}$$

$$\frac{d\vec{T}}{ds} = \frac{q}{p}(\vec{T}x\vec{B})$$

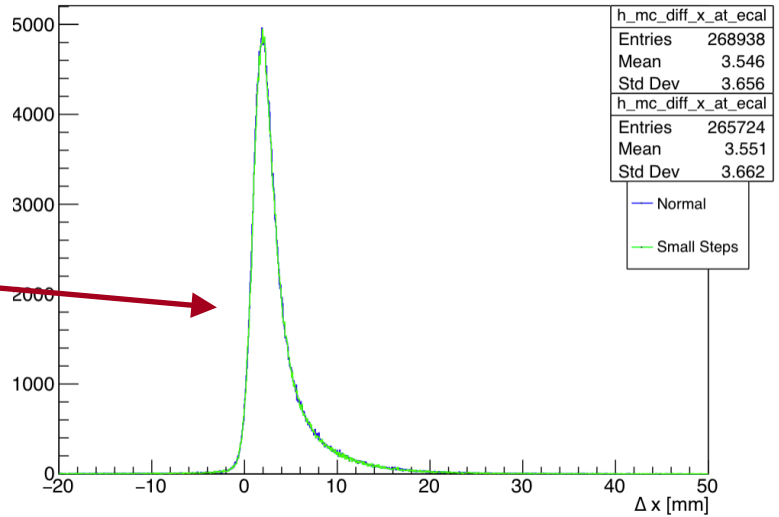



$$k_1 = f(t_n, y_n),$$
$$k_2 = f\left(t_n + \frac{h}{2}, y_n + h\frac{k_1}{2}\right),$$
$$k_3 = f\left(t_n + \frac{h}{2}, y_n + h\frac{k_2}{2}\right),$$
$$k_4 = f(t_n + h, y_n + hk_3).$$

$$y_{n+1} = y_n + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4),$$
$$t_{n+1} = t_n + h$$

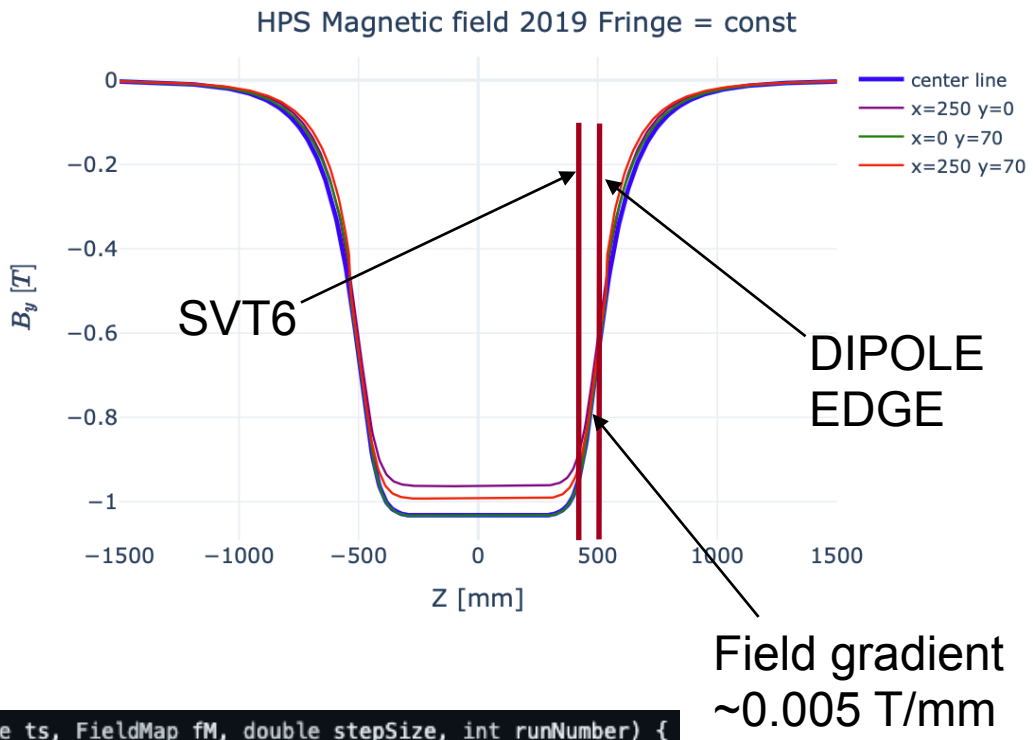
- RK4 (see above) can be used to integrate provided the initial (**r0**, **p0**), the starting point
- Quality depends on the step h
  - We tried to reduce stepping size of x10 with no improvement
  - **RK integration seems fine/good enough**

X difference.



# A possible issue

- We ruled out tracking issues in the tracking volume
- We ruled out issues in RK4 stepping size
- We confirmed that the track state at the last layer is correct wrt MC particle
- **But the hps-java extrapolation starts from a different location: DIPOLE EDGE at 997mm**
- **The (r0,p0) are obtained by helical extrapolation from SVT6 to the DIPOLE EDGE**
  - **Wrong due to fringe field**




```
public static BaseTrackState getTrackExtrapAtEcalRK(TrackState ts, FieldMap fM, double stepSize, int runNumber) {

    double zAtEcal = BeamlineConstants.ECAL_FACE;
    if (4441 < runNumber && runNumber < 8100)
        zAtEcal = BeamlineConstants.ECAL_FACE_ENGINEERING_RUNS;

    Hep3Vector startPos = extrapolateHelixToXPlane(ts, BeamlineConstants.DIPOLE_EDGE_ENG_RUN);
    Hep3Vector startPosTrans = CoordinateTransformations.transformVectorToDetector(startPos);
    double distanceZ = zAtEcal - BeamlineConstants.DIPOLE_EDGE_ENG_RUN;
    double charge = -1.0 * Math.signum(getR(ts));
```

# Corrected

Smoothed qk at SVT6

SLAC

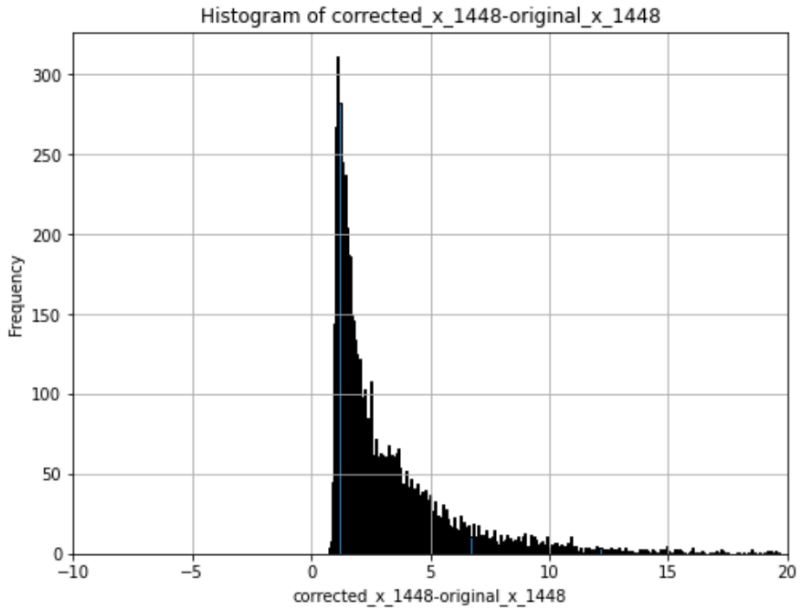
- I've corrected hps-java to use the (r0,p0) directly from the KF state qk on SVT6

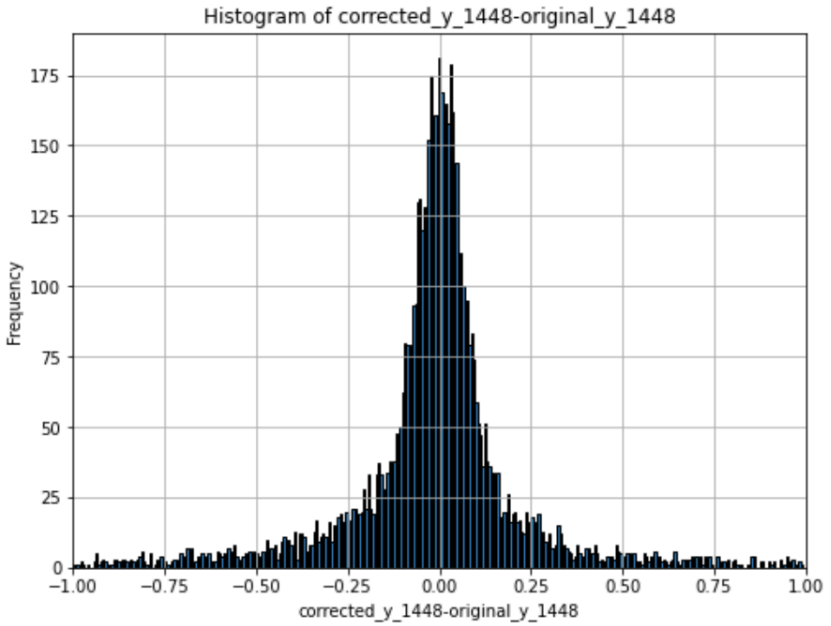
hps-java rk_fix branch

```
Vec localIntersection = sv.helix.atPhi(0.);
Vec localMomentum = sv.helix.getMom(0.);

// Global position and momentum
Vec intGlb = helixState.toGlobal(localIntersection);
Vec momGlb = helixState.Rot.inverseRotate(localMomentum);
```

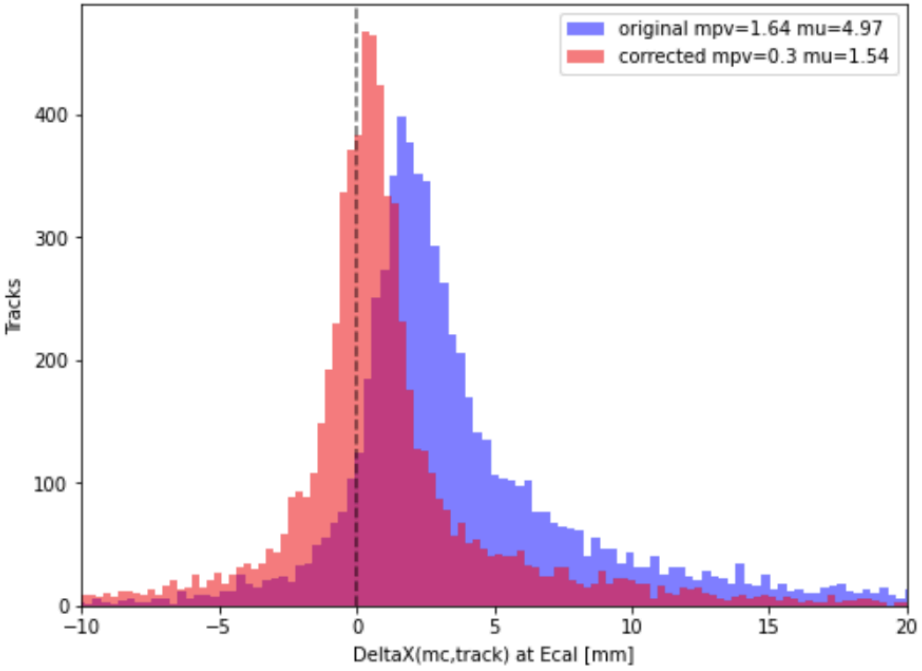
- I've corrected hps-java to use the (r0,p0) directly from the KF state qk on SVT6
- Checked the effect extrapolation to ECAL 1448 mm

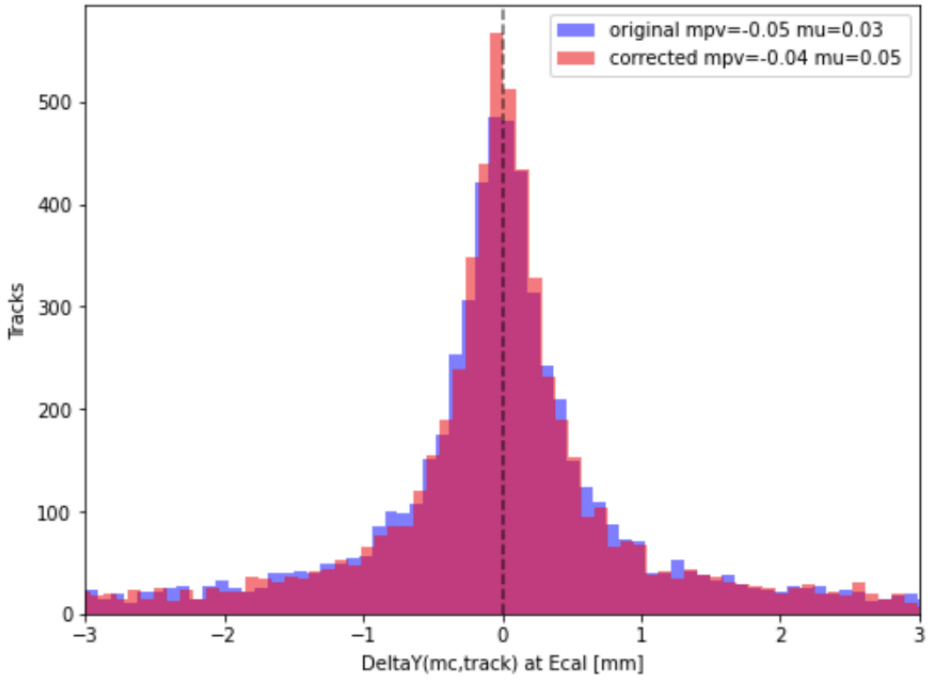


# Results

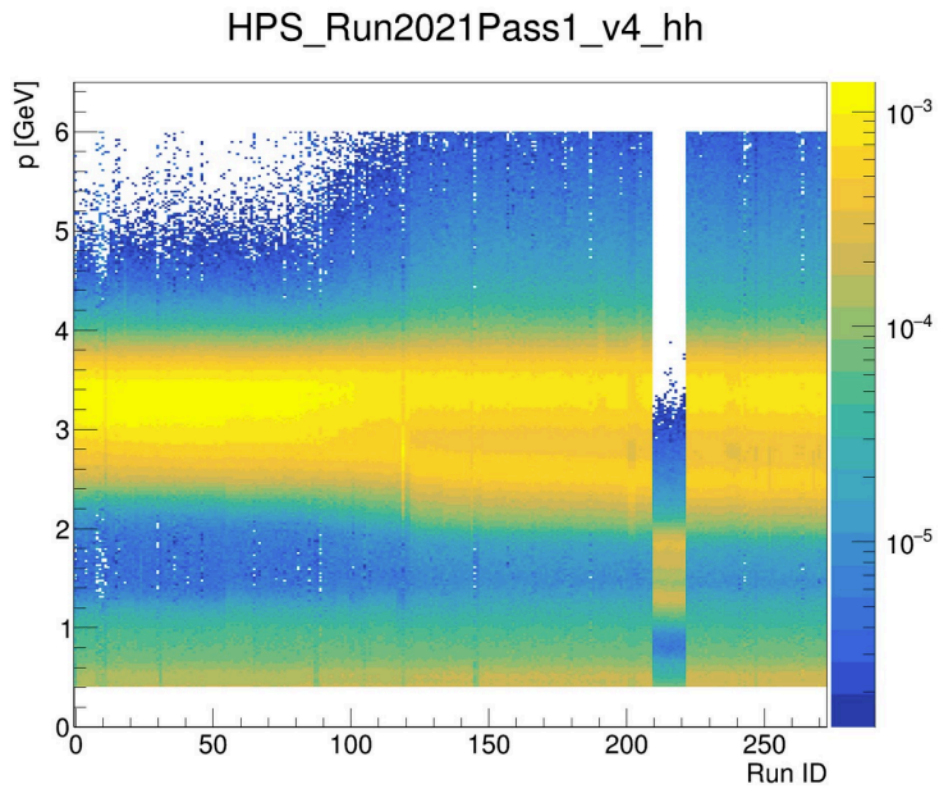
- I’ve corrected hps-java to use the (r0,p0) directly from the KF state qk on SVT6 and checked the extrapolation at ECAL vs MC Truth
- **Much improved in terms of MPV, mean, width.**
  - Residual source of discrepancy:
    - Not perfect SVT6 starting point
    - RK4 doesn’t always arrive at the ECAL face.
      A correction is applied if that is the case and I haven’t checked if it’s fully correct.
    - Not sure if 0.3mm of bias justifies the need of additional checks.
- **Will deploy this in hps-java with PR**

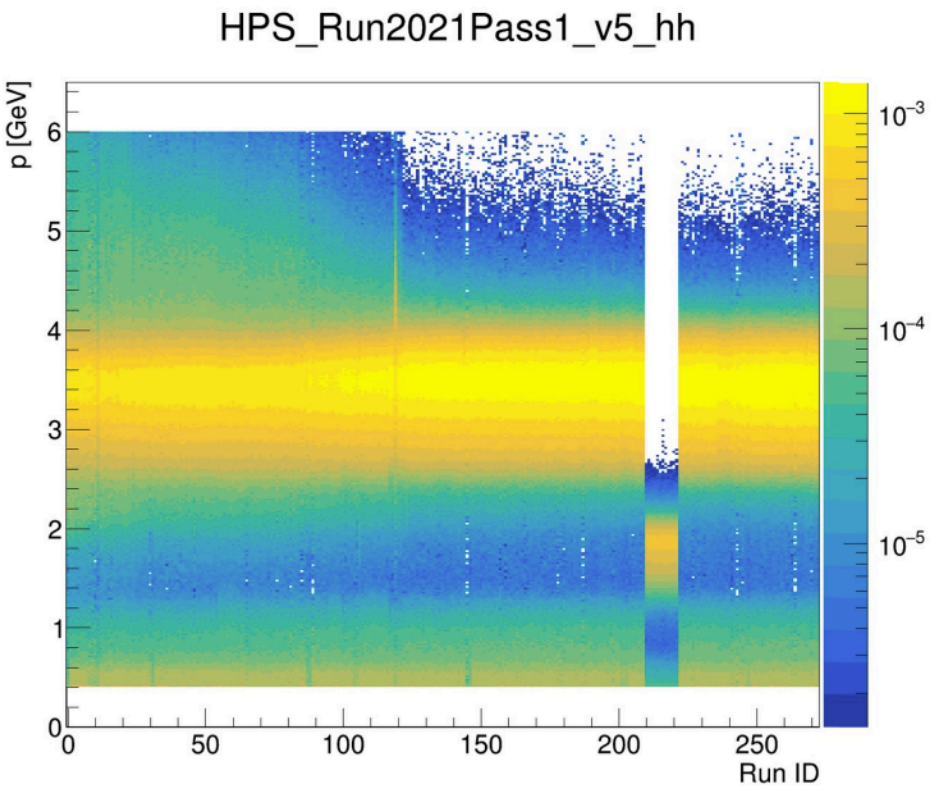


# Alignment 2021 - Status update

SLAC




- Indication of time-dependent misalignment
- Alignment from later run doesn't lead to bifurcation when going back in time
- Developing set of plots as function of runID to identify which run-chunks need specific realignment
- Bottom detector would need another re-alignment before doing run-dependent alignment of the dataset

# Summary and Conclusions

SLAC

- Track to ECAL extrapolation bias largely corrected using more appropriate extrapolation track state.
  - It seems to be mostly due to an extrapolation error (see slide 4)
  - Identified thanks to the work of few people involved
- Some level of discrepancy remains. I haven't investigated it further

- These studies lead to a discussion if it would make sense to change our track states to something more useful.
  - Debatable due to the impact on people needing these details for specific analysis, e.g. hit-killing, propagation back to target/beamspot location. Needs a bit of discussion

# Muons

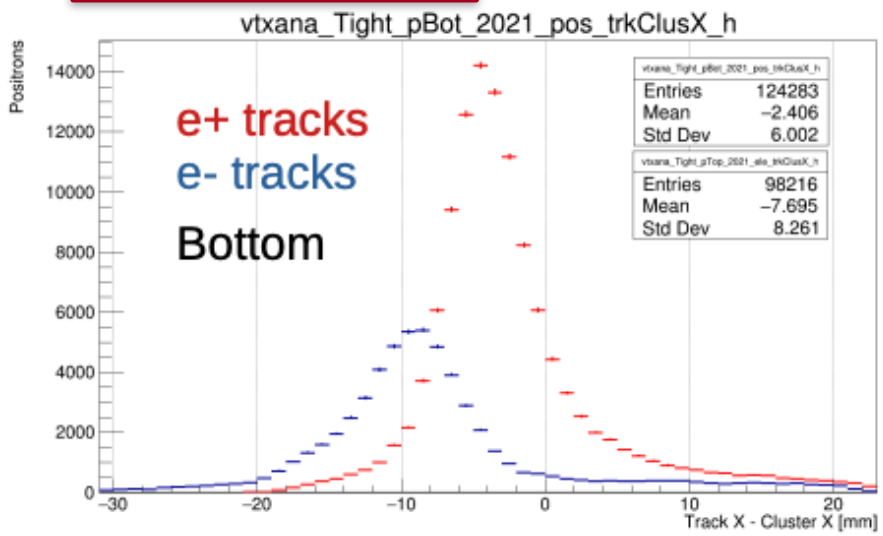
# Alignment 2021 Status

SLAC

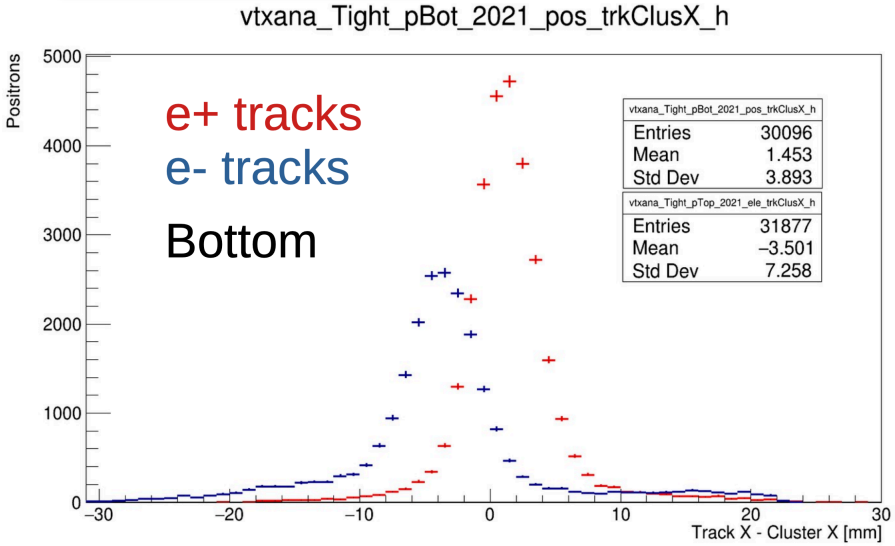
Cam's 14th Nov 2023 Talk

- Extrapolation to ECAL face in bottom volume improved by coherent movement of back stereo sensors
- In better agreement between top and bottom volumes, e+/e- tracks

Before Correction




After Correction

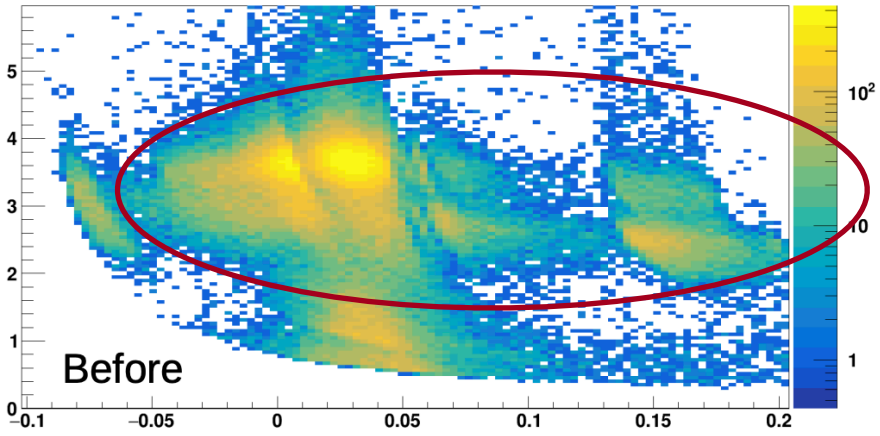


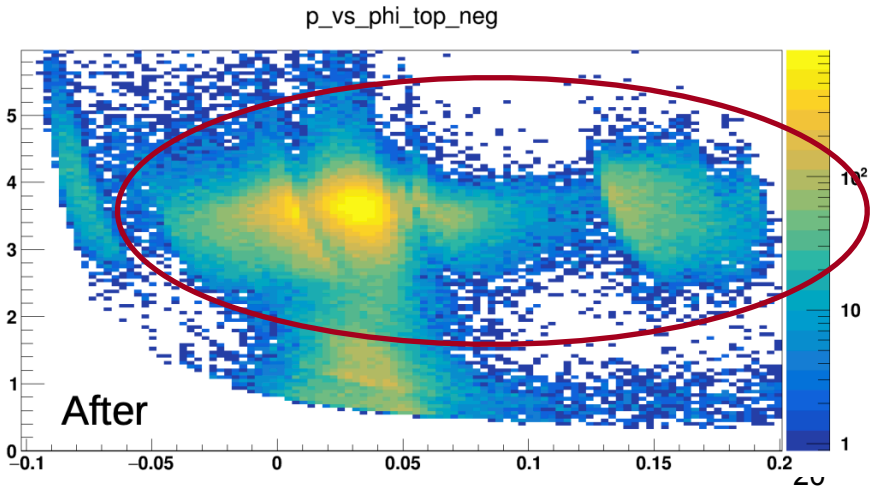
# Alignment 2021 Status

SLAC

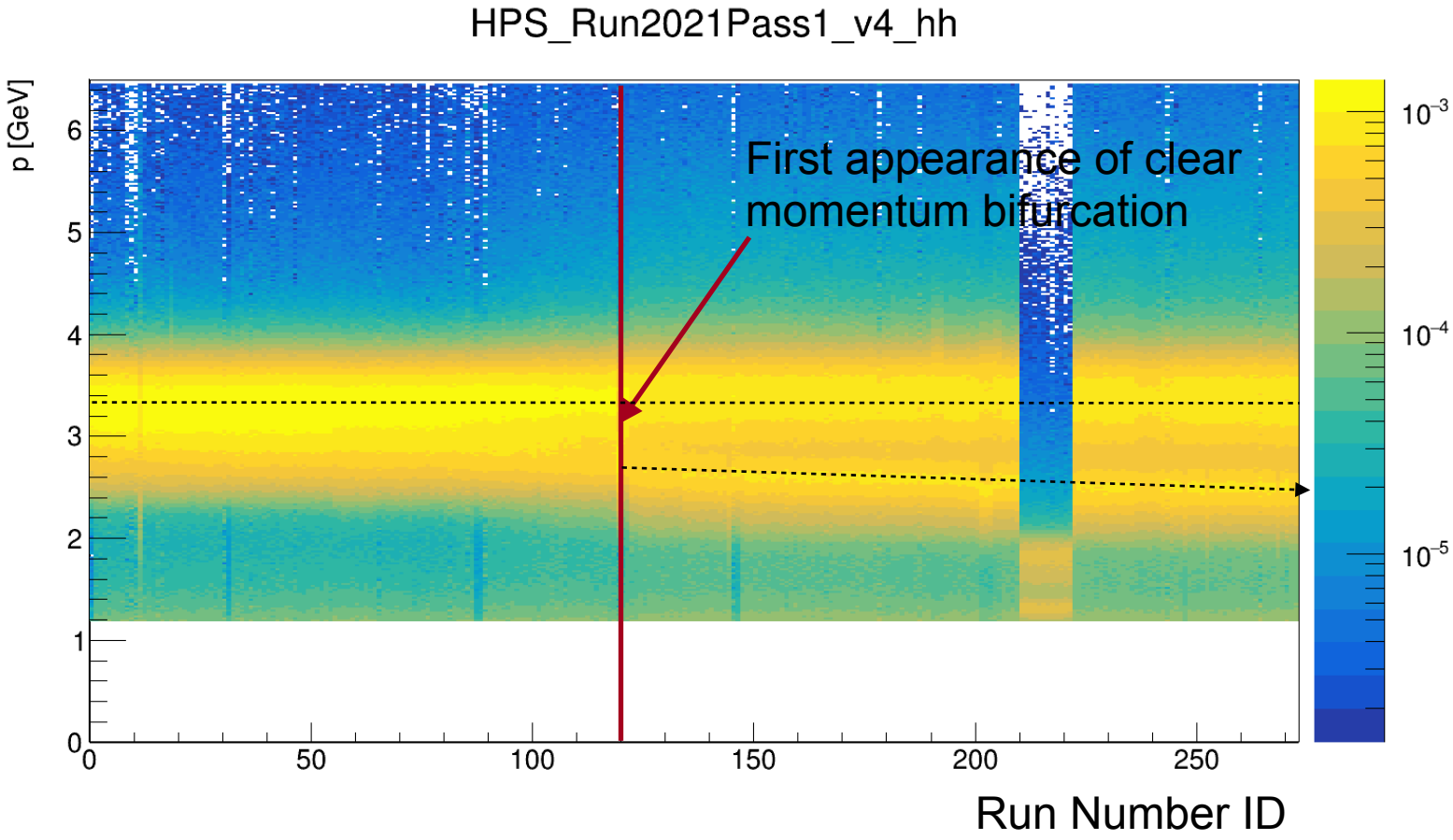
Cam's 9th Jan 24 Talk

- While a good detector was found for the first part of 2021, evidence for time-dependent movements was observed in later runs
- Progress has been made to improve late-2021 performance
- Identified large Rw in Ly6
- Plan to do 1% of 2021 with new geometry and determine if other runs need dedicated detectors



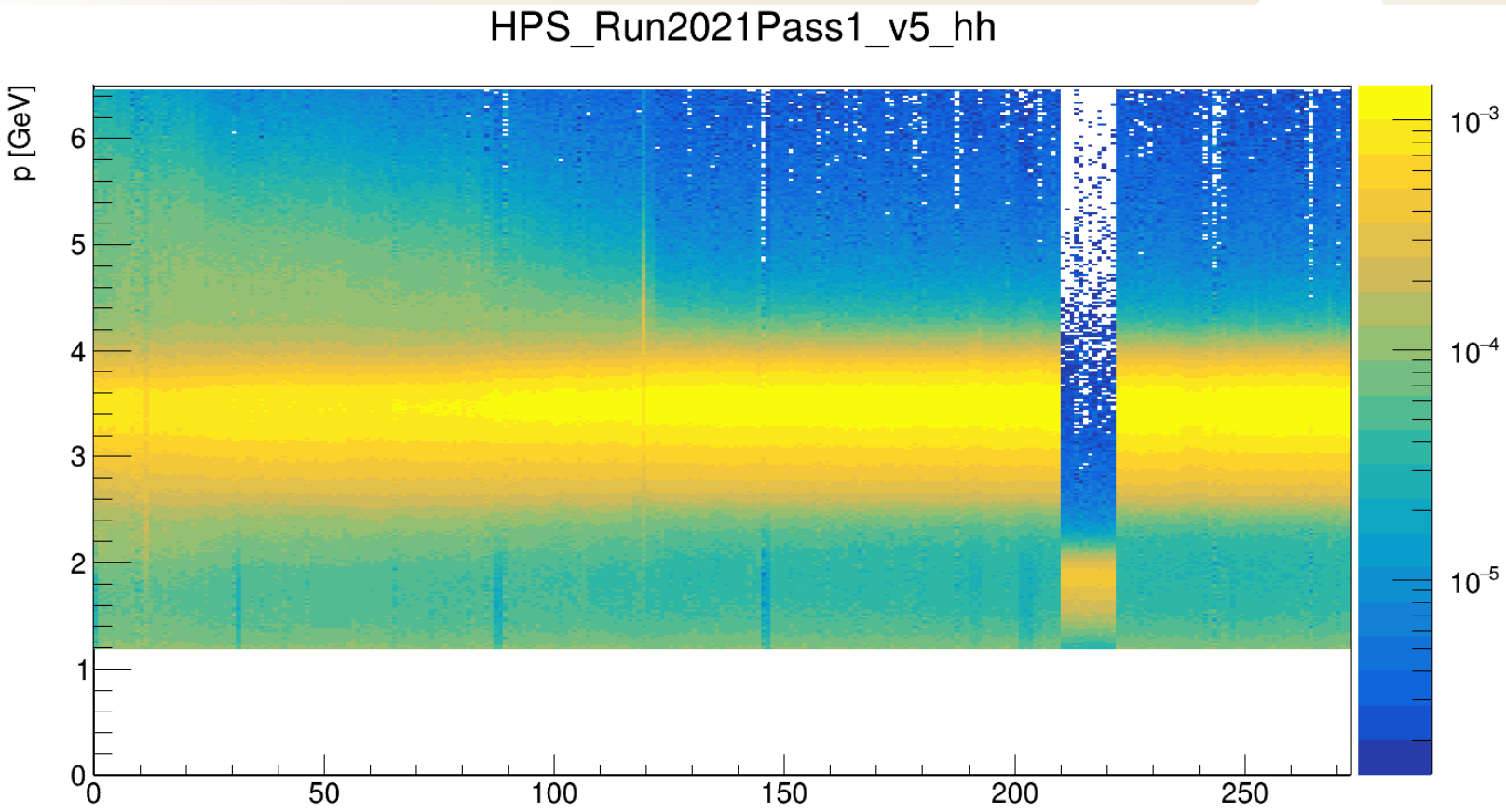



# Detector movements during 2021 run



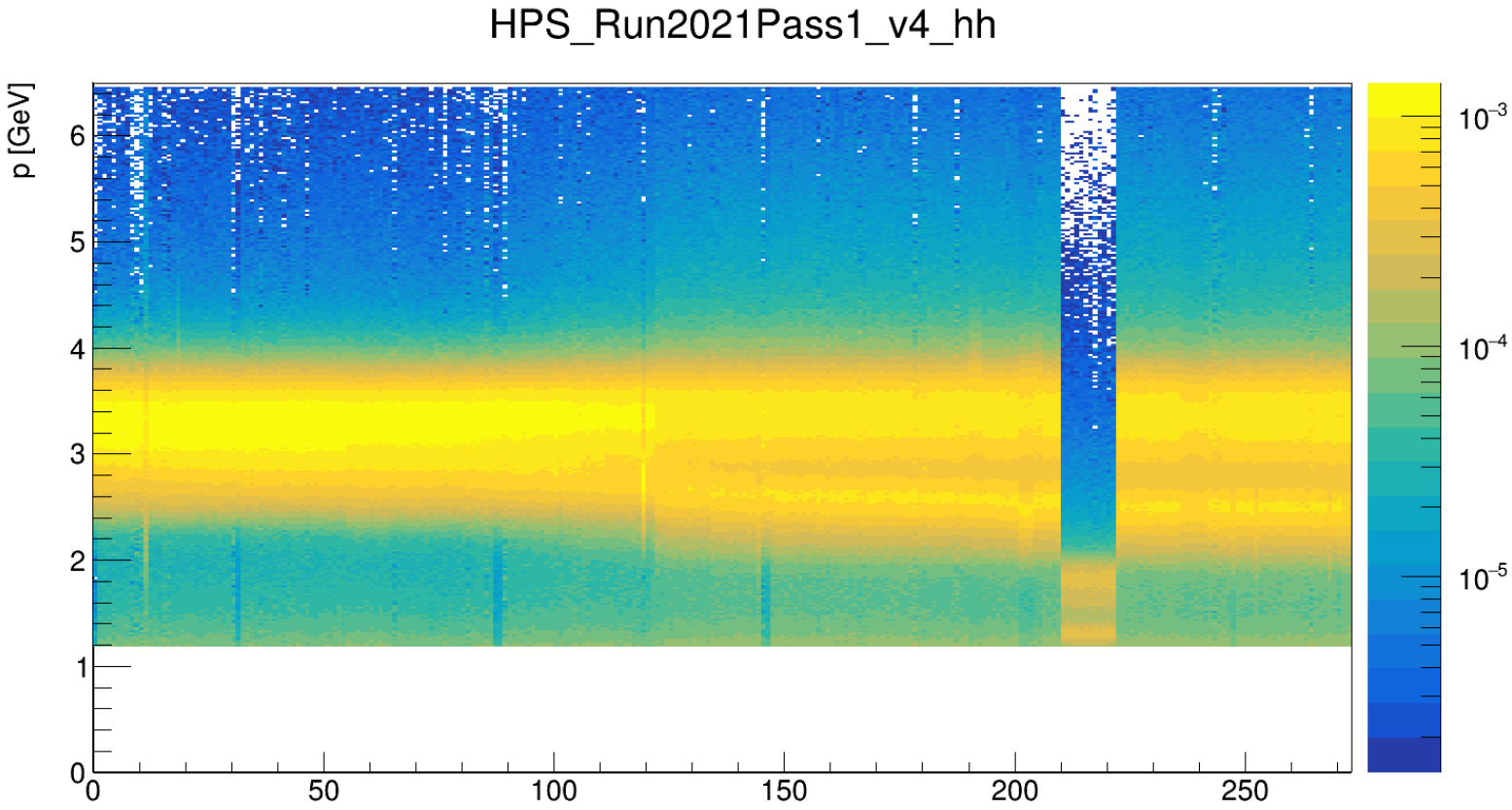

- Few studies reported already this problem in the past
- More detailed check on run number dependence showed clear appearance of momentum bifurcation

# Detector movements during 2021 run




- Bifurcation improved by systematic translation in sensitive direction (Tu) of ly5 - ly6 Stereo sensors.

# Detector movements during 2021 run



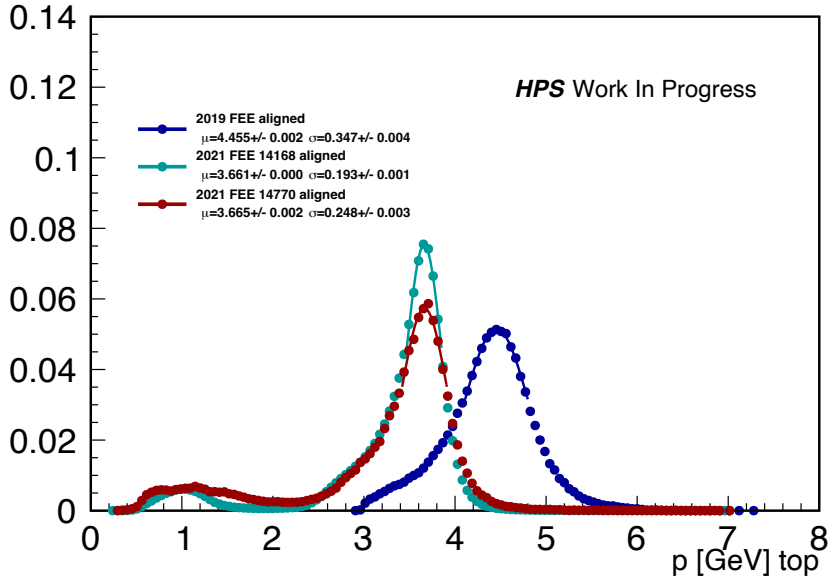

- This investigation could be extended to pin the causes of these effects to understand better our detector stability with time:
  - Possible to correlate with detector conditions, e.g. chiller failures
  - Correlate with detector movements, e.g. by using unbiased residuals or systematic alignment corrections values from a baseline geometry

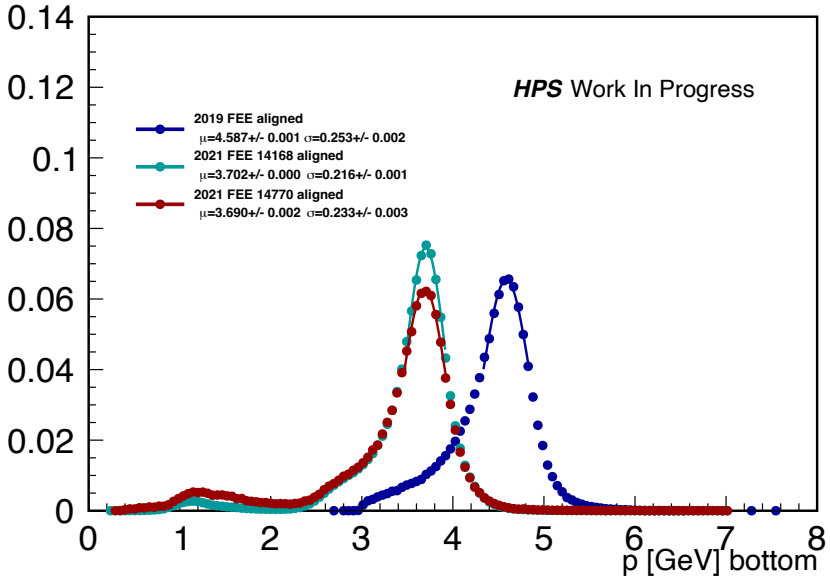
# Comparison between 2019 / 2021 alignment

SLAC

- A summary of the 2019/2021 alignment has been given at the HPS Fall ’23 collaboration meeting
- I will report a some extracts of a comparison between the two alignments
  - Reminder: for 2019 top volume has a more developed alignment
  - Detector conditions between 2021 and 2019 are slightly different
    - 12 (14) hits on track for 2019 (2021) TOP volume
    - 14 (13) hits on track for 2019 (2021) BOT volume
    - Different target location
  - Lack of harmonization in alignment monitoring selection in the two runs
    - However some major figures of merit should be stable, e.g. momentum, unbiased residuals, track as well as internal consistency between the volumes.

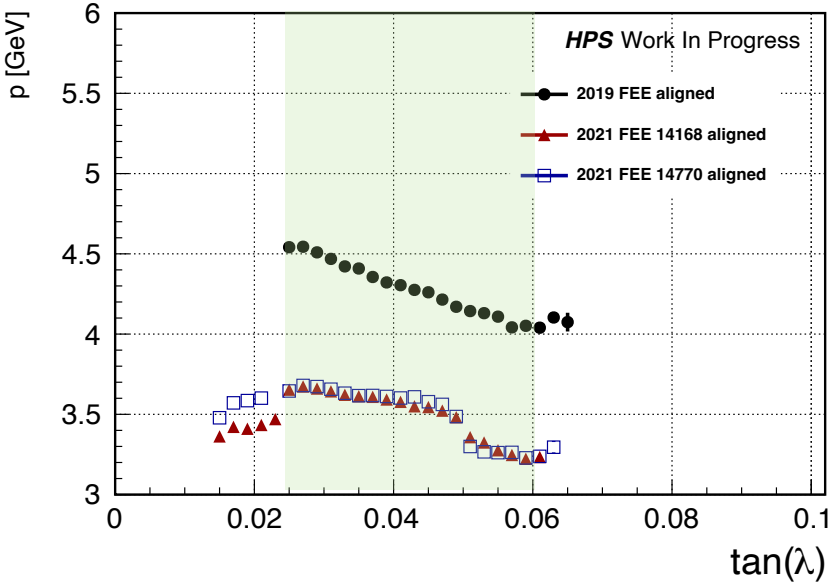
# Track Momentum 2019/2021

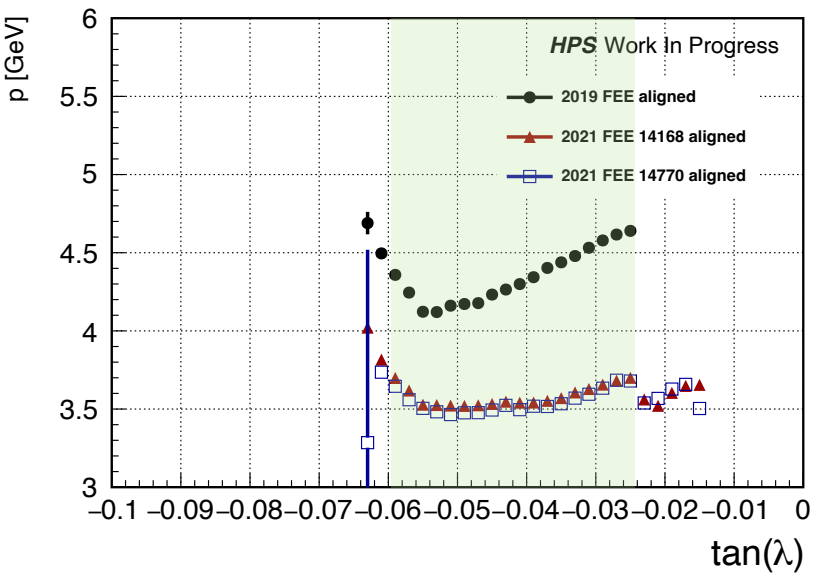


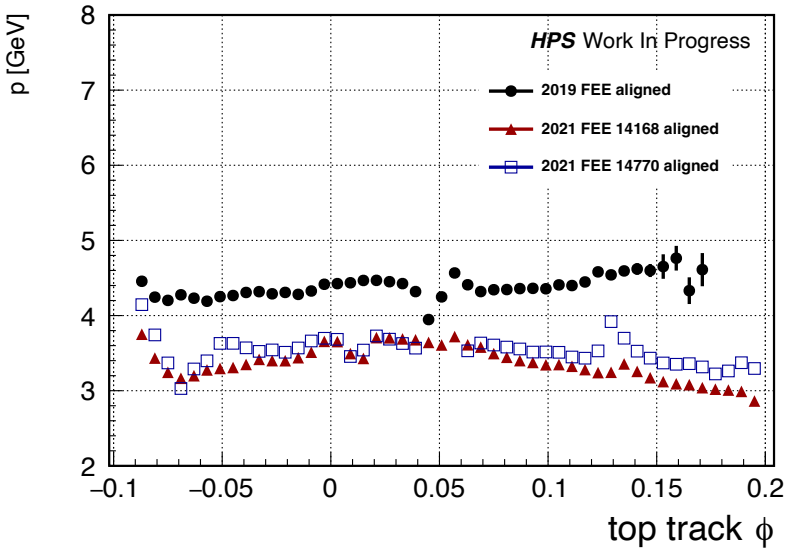



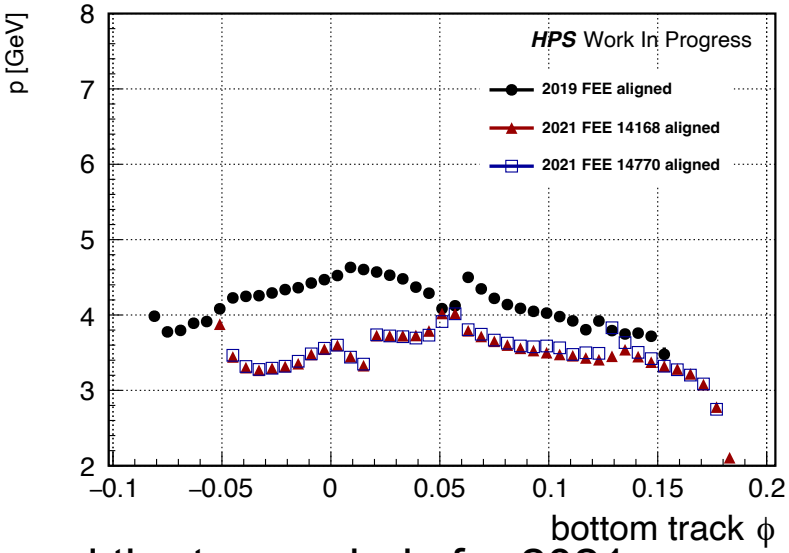

- Momentum distributions between top / bottom volumes are:
  - **7.8% (5.2 / 6.8%) for 2019 (early/late 2021) for Top volume**
- - **5.6% (6.1 / 6.3%) for 2019 (early/late 2021) for Bot volume**
- Consider:
  - Missing layer7 in 2019 as well as higher momentum (sigma_p / p ~ p)
  - Missing layer5 hit in 2021 bottom volume
- MC resolutions for 2019 conditions: 5.7% (3.5%) for TOP (BOT) @ 4.55 GeV
- Projecting 2019 DATA (MC) resolution to 2021 conditions, I'd expect ~4.6% (~3%) resolution @ 3.7 GeV

# Track Momentum 2019/2021



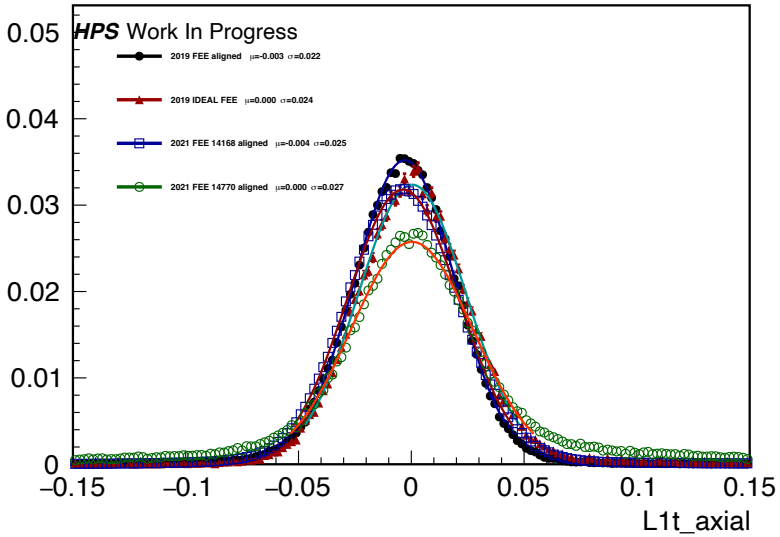



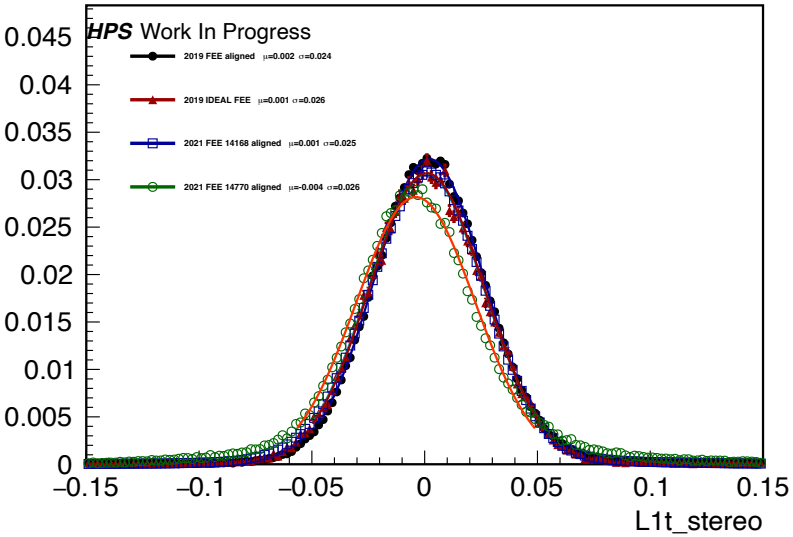



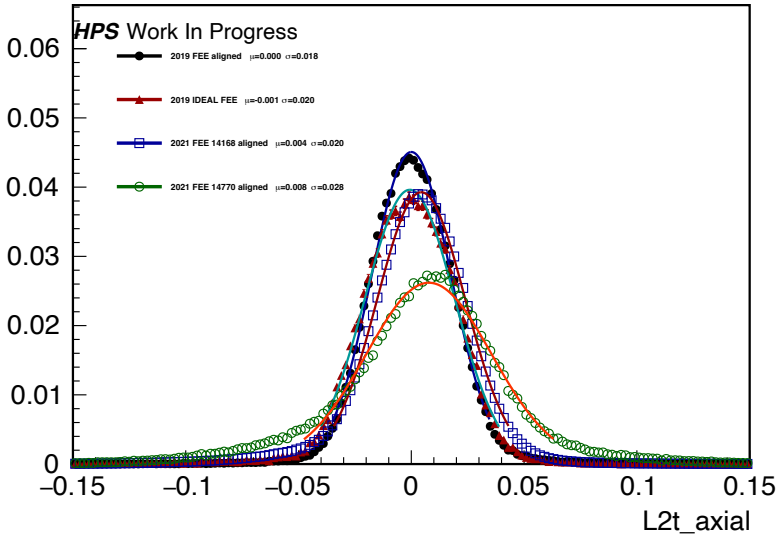



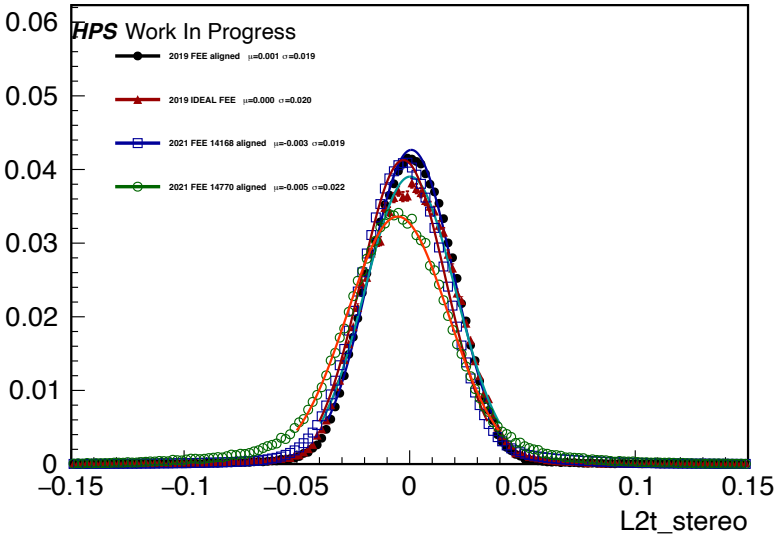

Qualitatively similar trends through the two runs and the two periods for 2021

# Unbiased residuals - General distributions



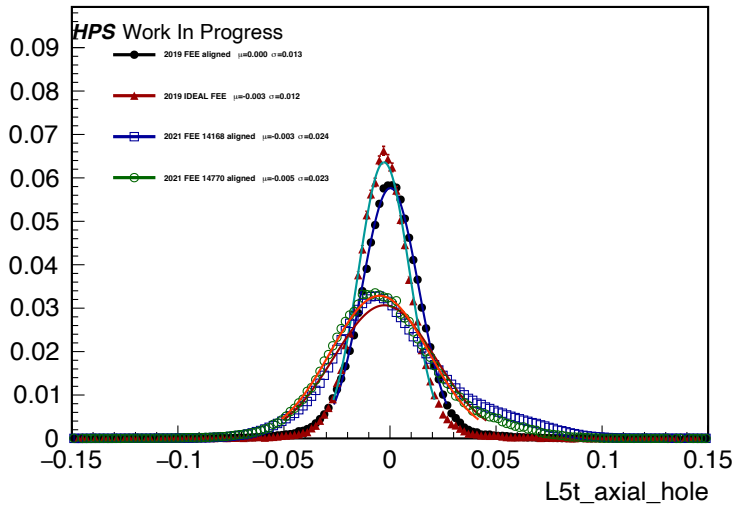



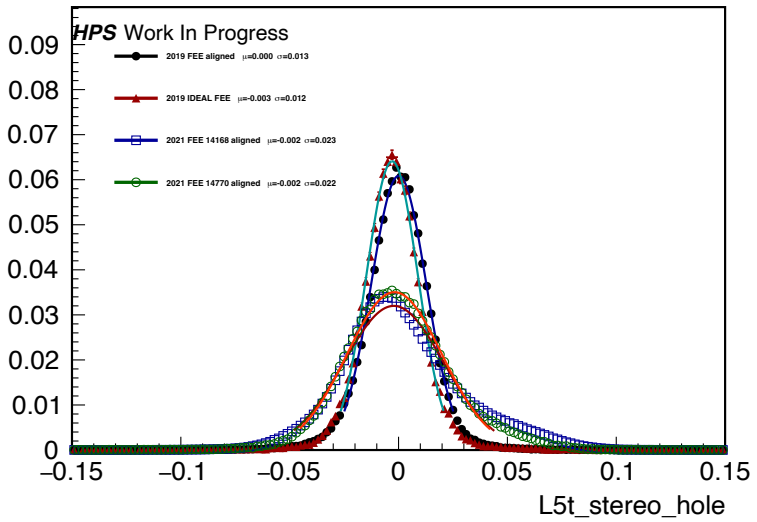



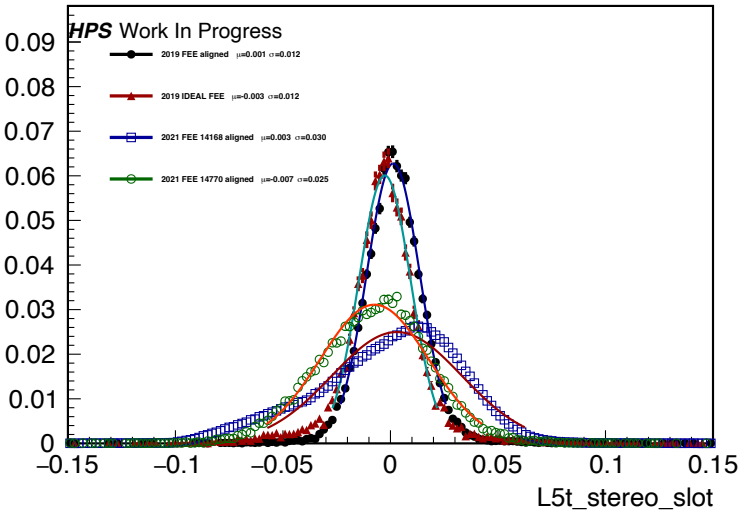



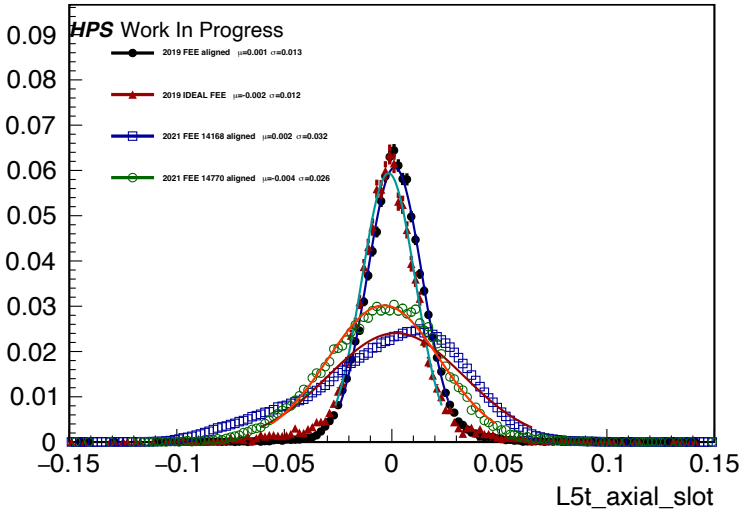

- 2019 / early 2021 close to ideal MC unbiased resolution.
- Late 2021 shows residual degradation in the innermost sensors

# Unbiased residuals - General distributions




- 2019 Closer to ideal hit-on-track resolution
  2021 early/late runs show possible room for improvement for back detector = > expected impact on track Chi2

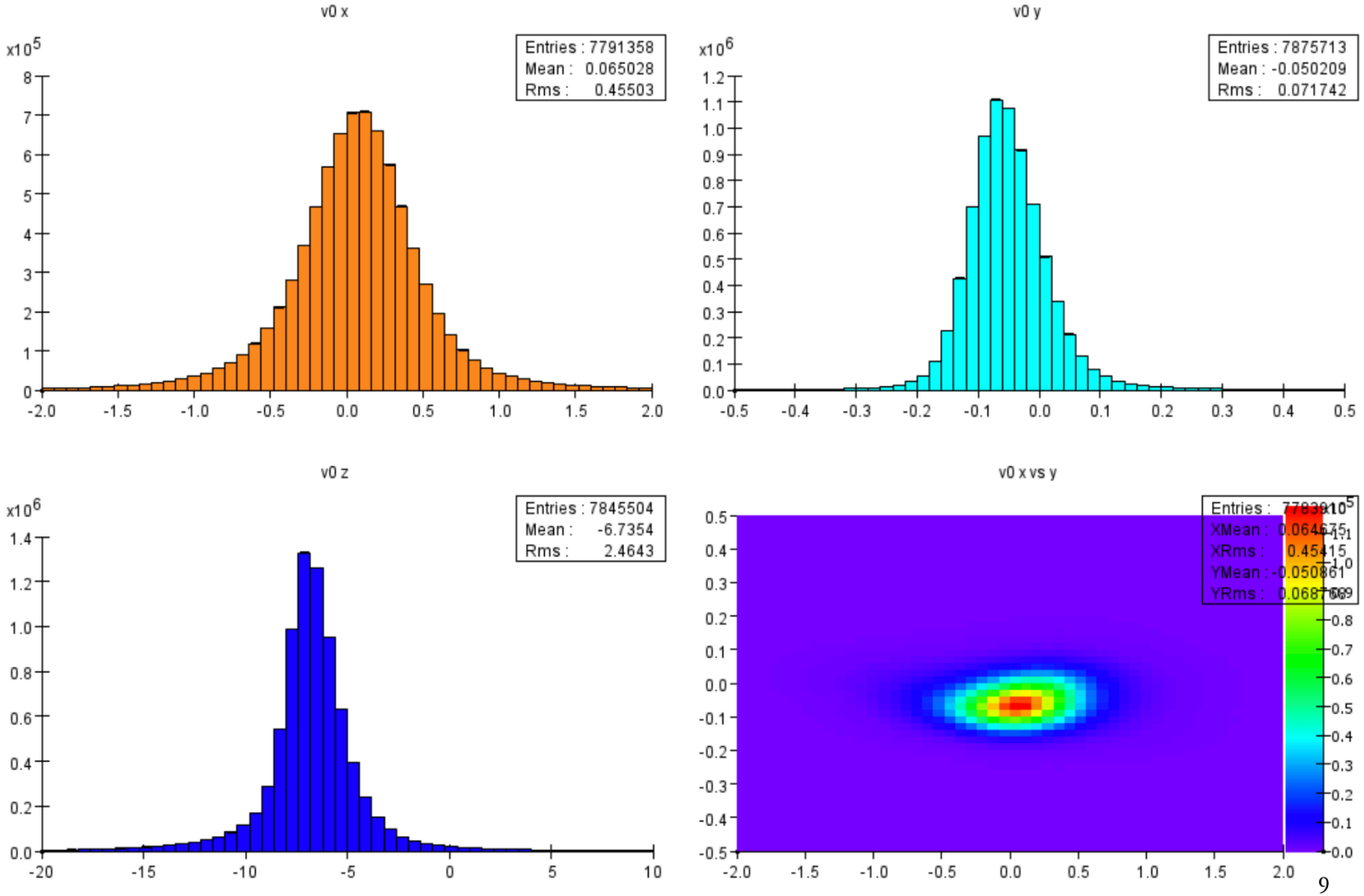
# Backup

# Status summary
# V0s

# General status of 2019 alignment from Pass0 - NG/PF

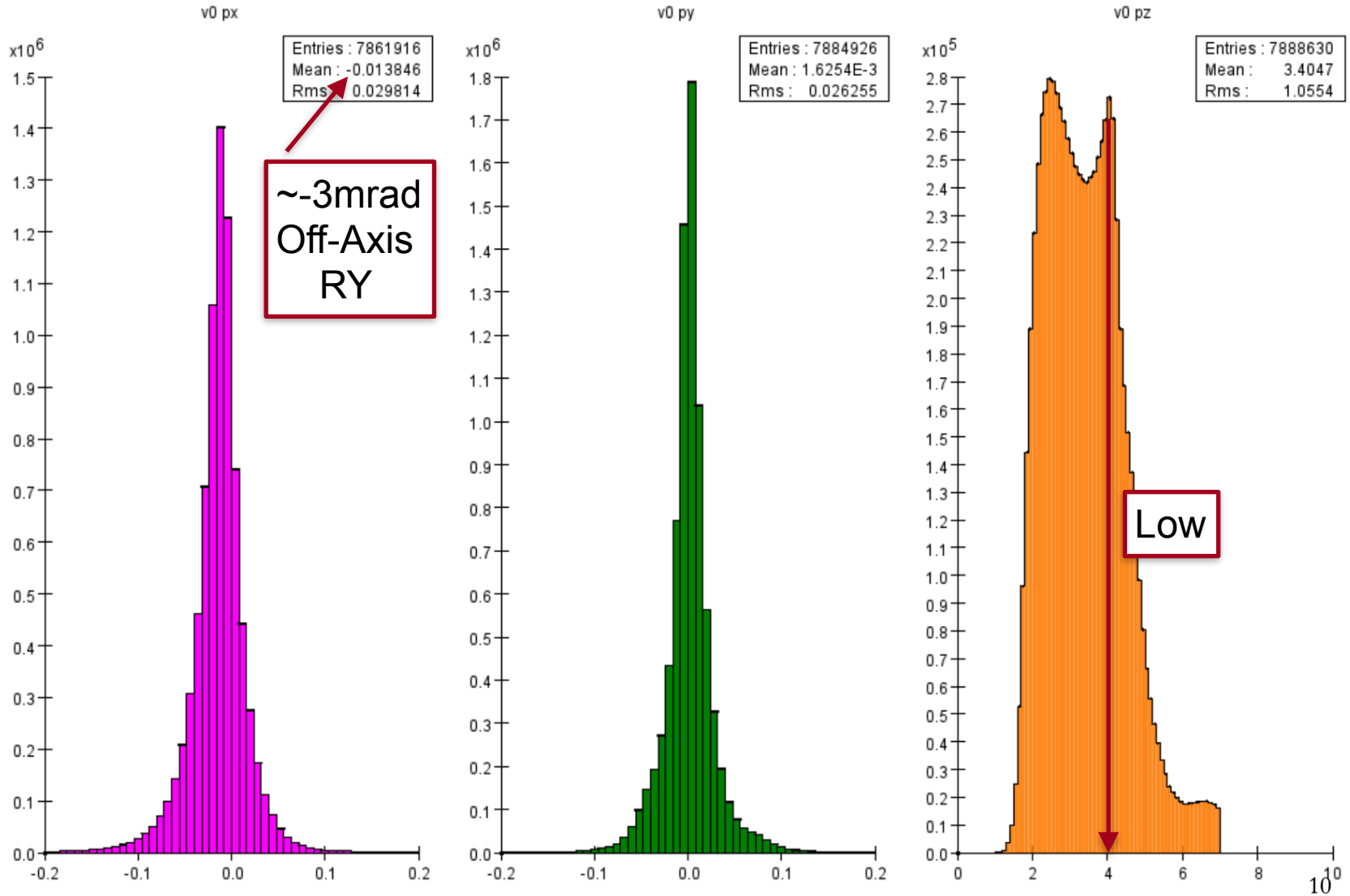
SLAC

## V0 Vertex Positions 2019



# General status of 2019 alignment from Pass0 - NG/PF

SLAC

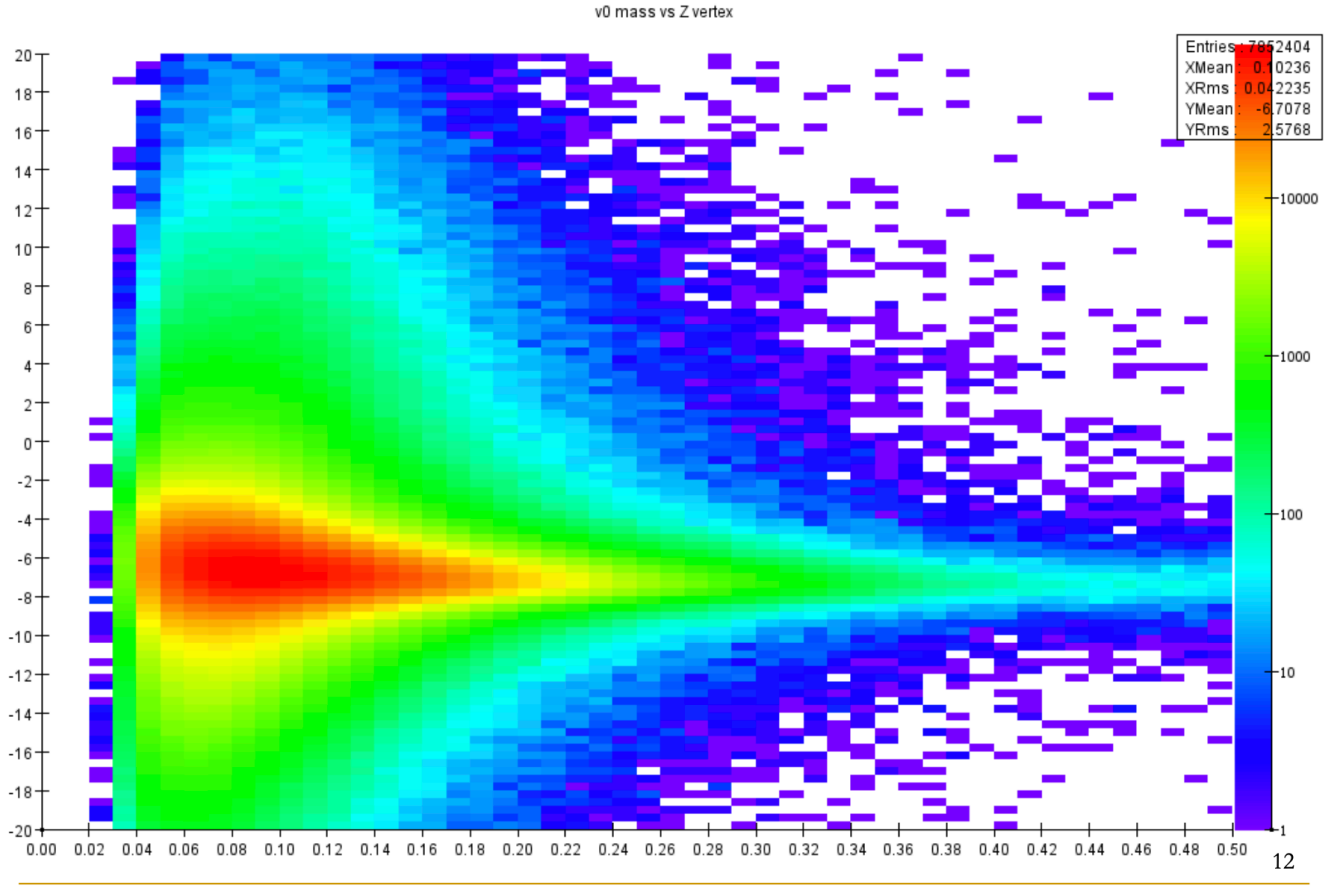


# General status of 2019 alignment from Pass0 - NG/PF

SLAC

- **Slight tilt -> to be confirmed with a profile plot**

## V0 Vertex Mass vs Vertex Z 2019

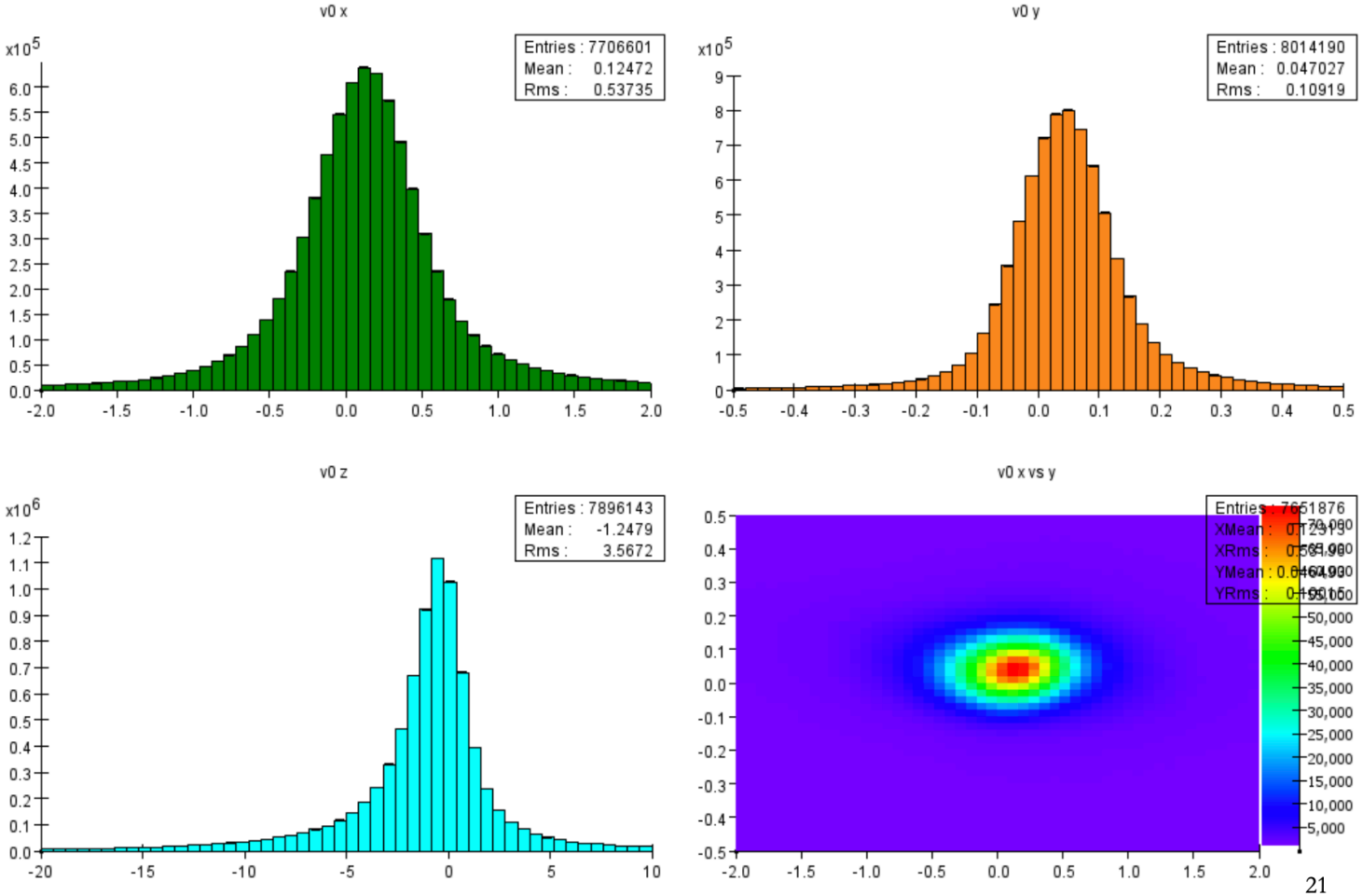



12

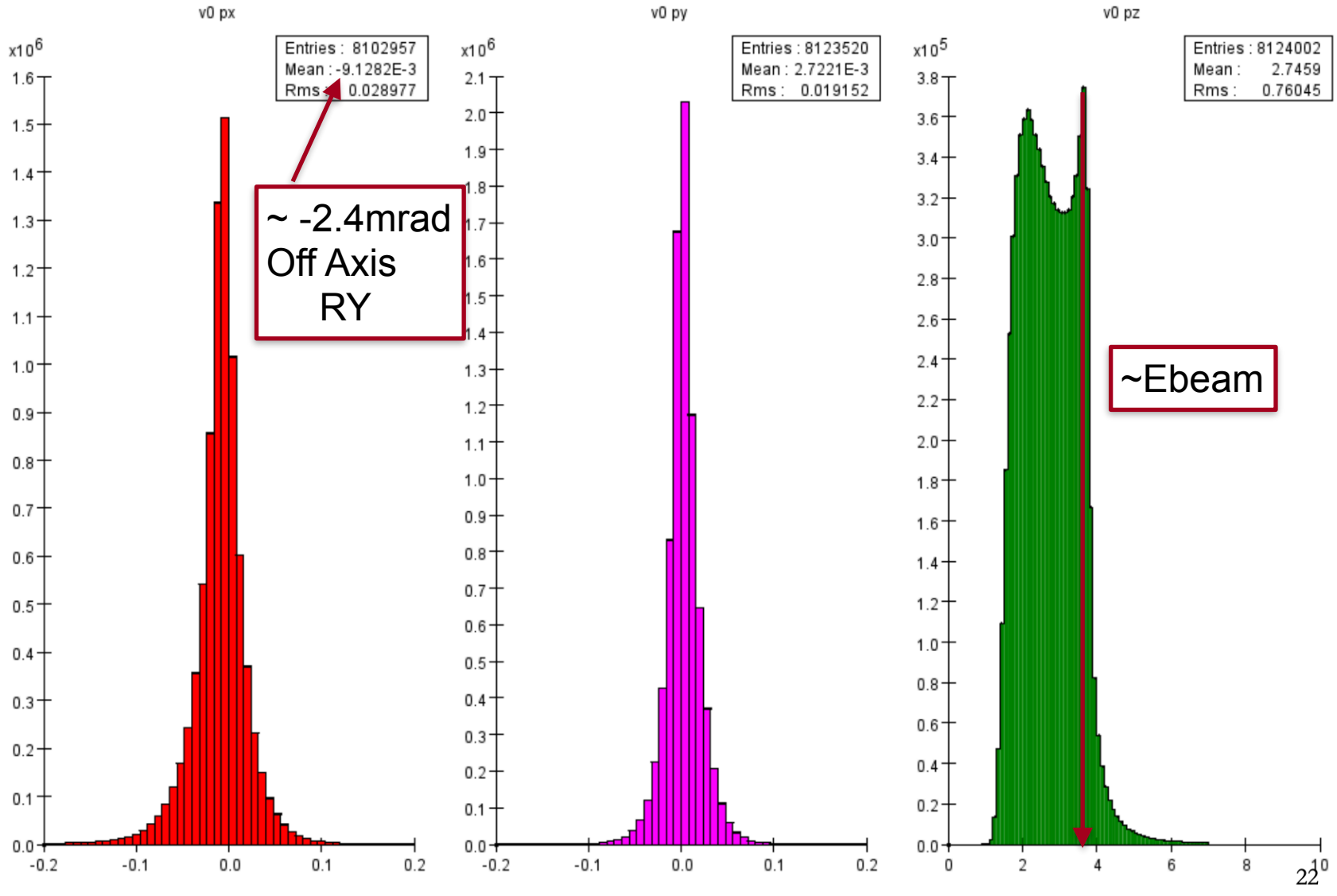
# General status of 2021 alignment from Pass0 - NG/CB

SLAC

## V0 Vertex Positions 2021



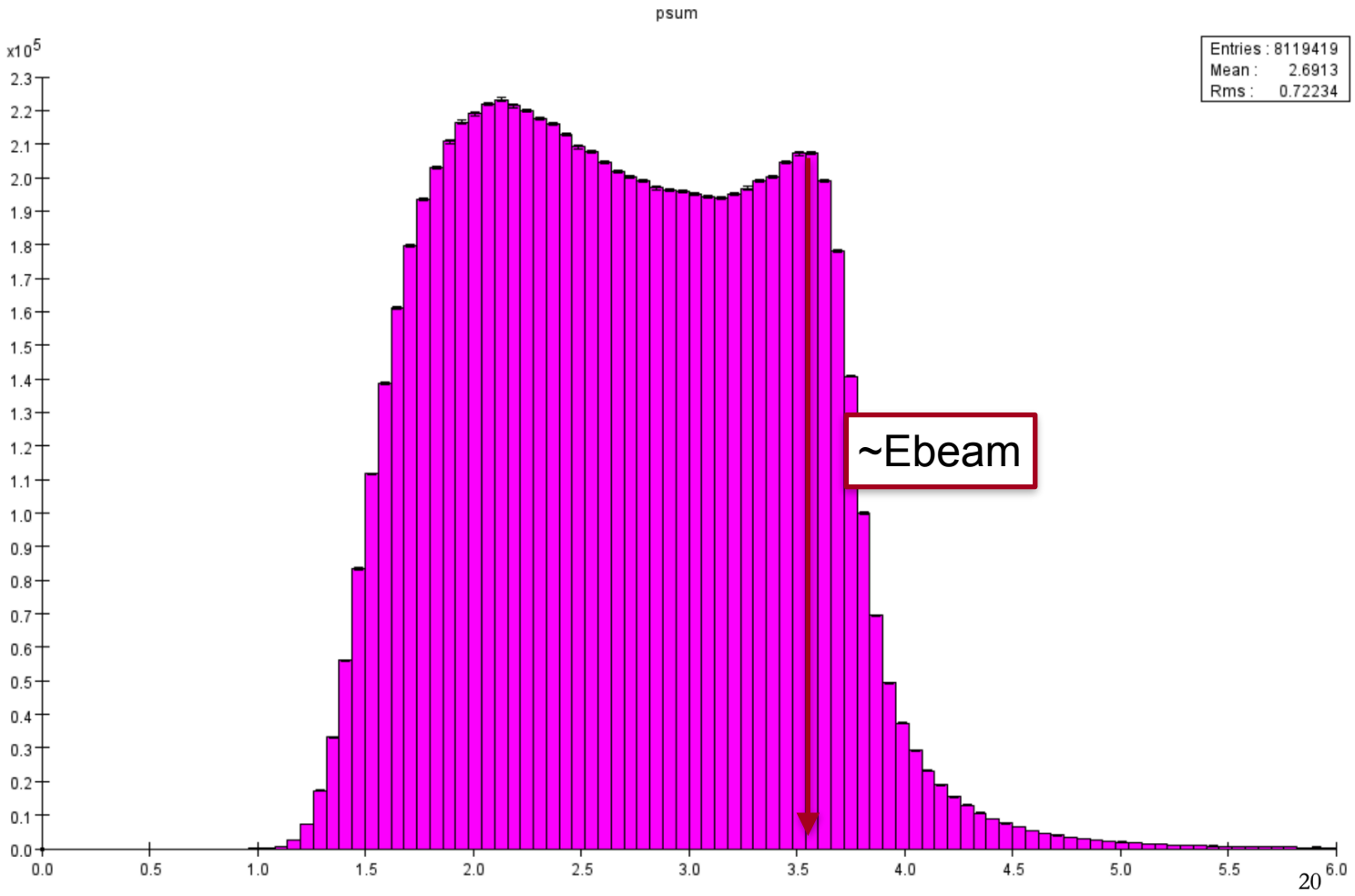
# General status of 2021 alignment from Pass0 - NG/CB



# General status of 2021 alignment from Pass0 - NG/CB

SLAC

## Psum 2021

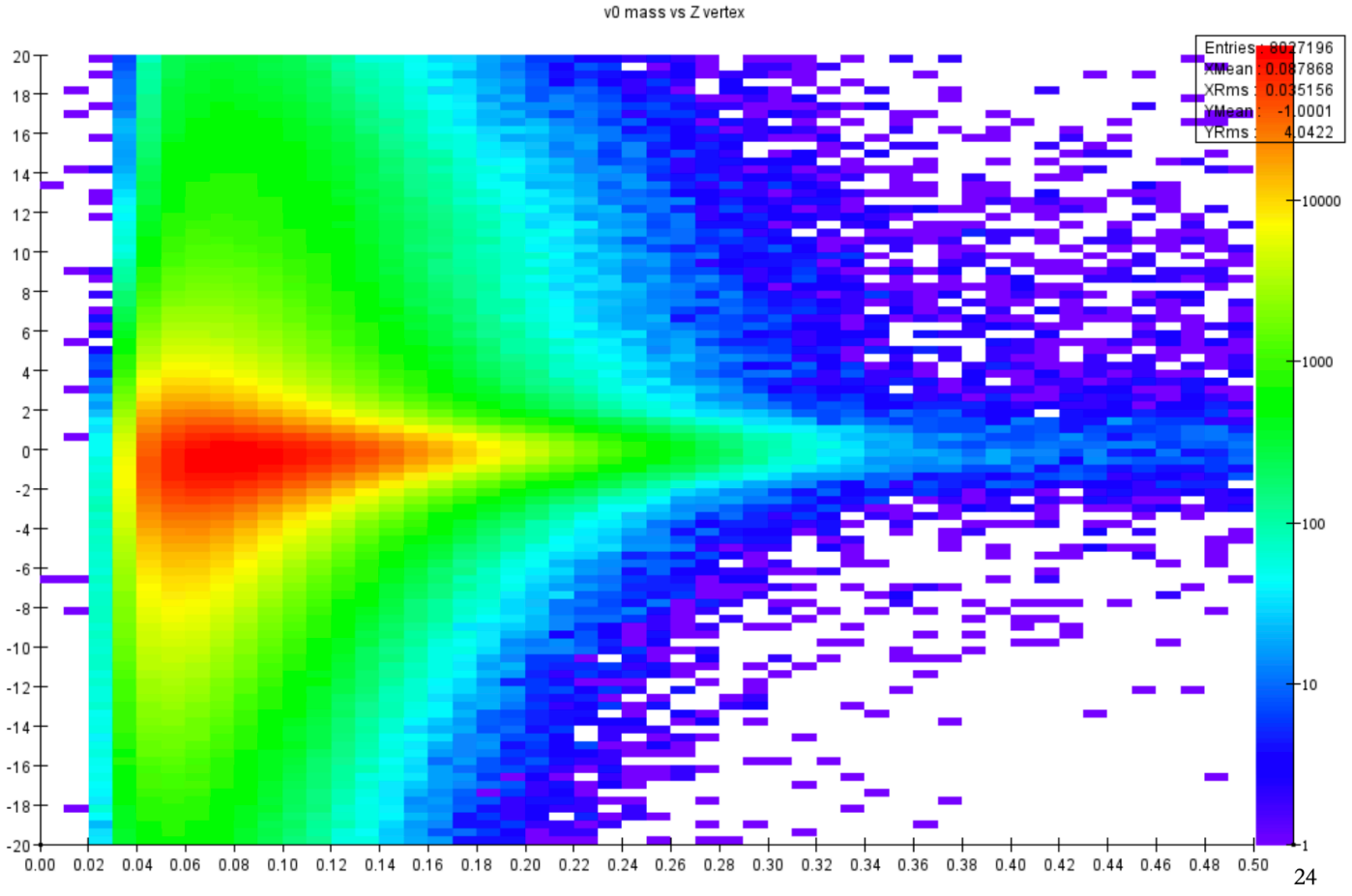


# General status of 2021 alignment from Pass0 - NG/CB

SLAC

- **Slight turn-on effect -> to be confirmed with profile**

## V0 Vertex Mass vs Vertex Z 2021




24

# General status of 2021 alignment from Pass0 - NG/CB

SLAC

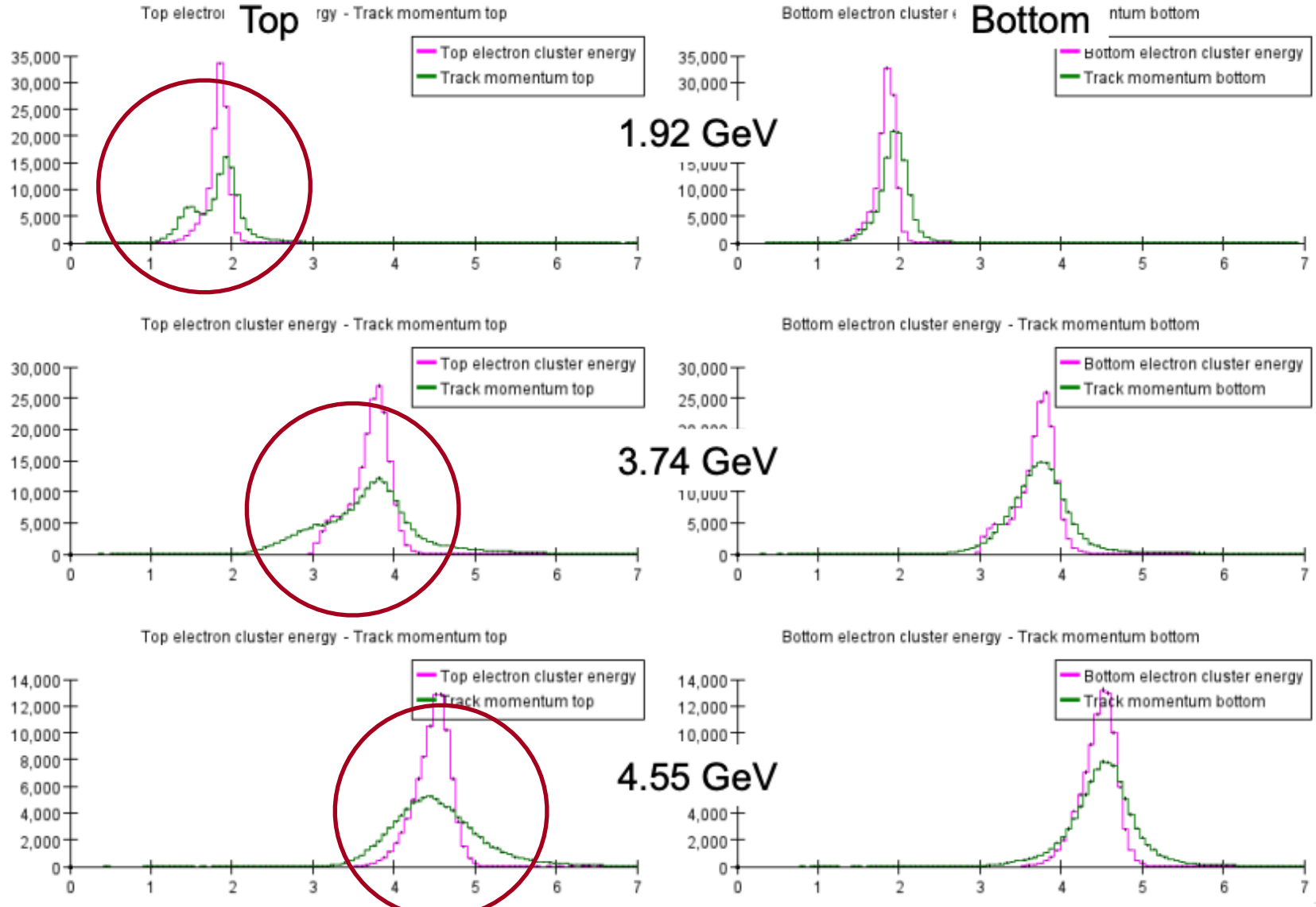
- **A preliminary check on V0 events show:**
  - A reasonable beamspot determination for 2019/2021 dataset in pass0
  - A reasonable Psum for vertex distribution (high peak 10% low for 2019, <5% low for 2021)
  - A rotation of the volumes wrt beam axis of O(2-3mrad) - to be confirmed by crosscheck on FEEs
- **Stability of the constants has been checked across multiple runs**
  - Norman reported checking the Beamspot location across multiple runs on the sample partitions - stable determination of the beamspot and agreement with recorded beam movements
- **Track efficiency observed to decrease as function of time during 2019 / 2021**
  - **To be followed up.**

# Current activities

# FEE Momentum Summary vs FEE energy 2019 and 2021

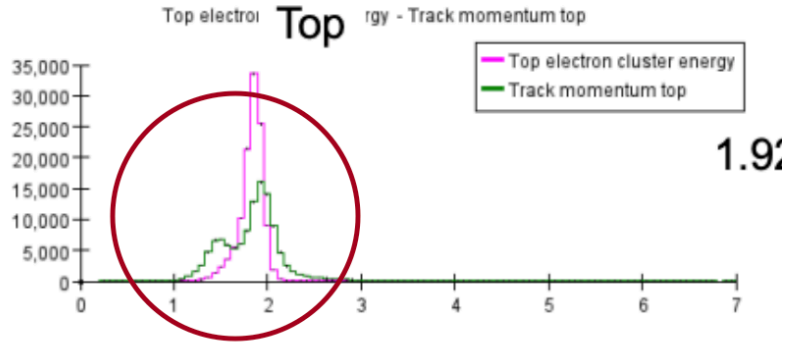
Norman/Cam/PF

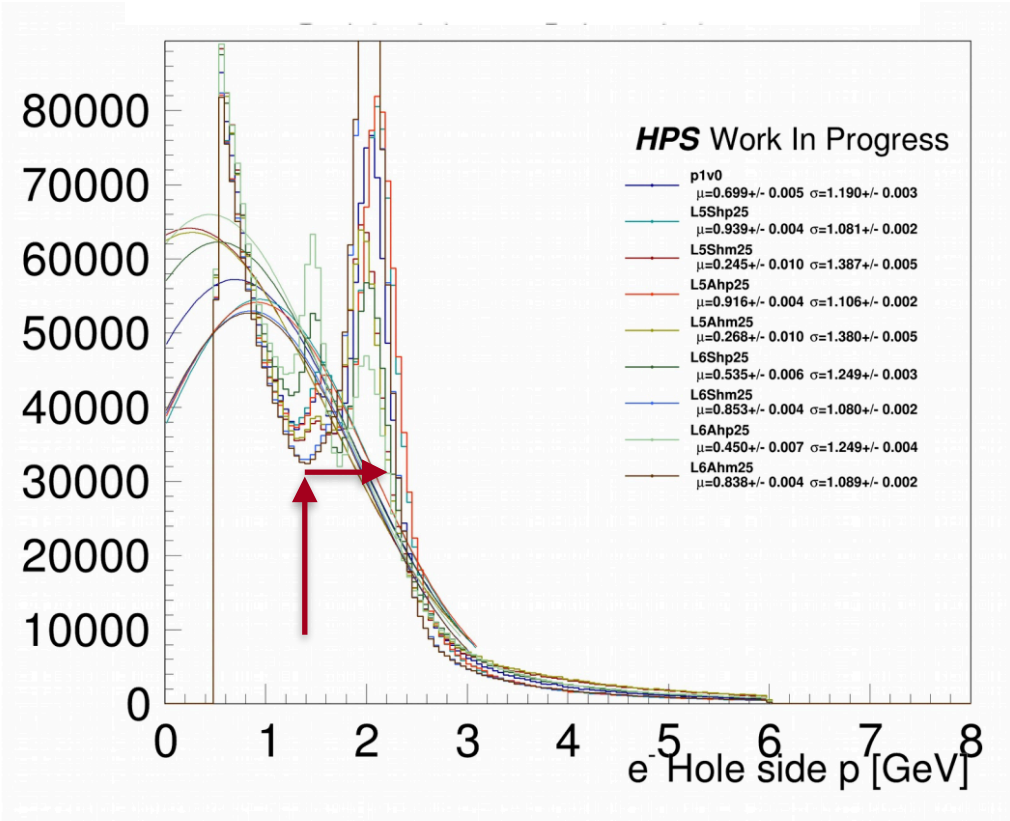
SLAC



# Momentum bifurcation in top Volume

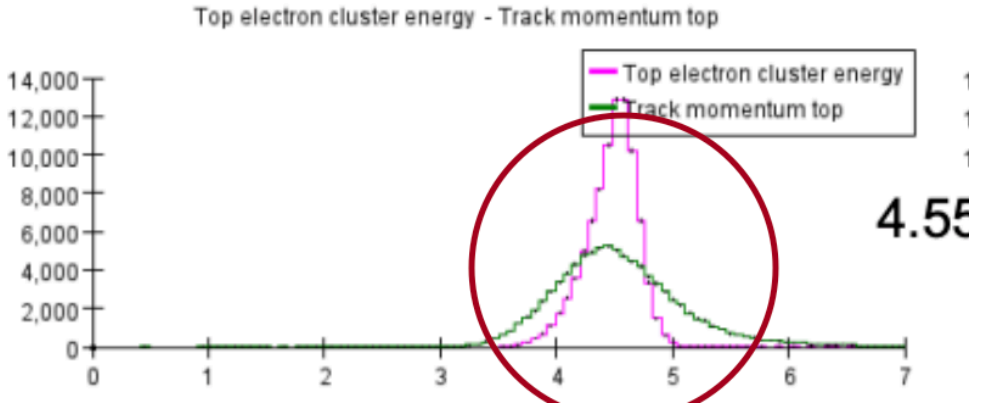
- **Observed momentum bifurcation in top Volume in the 1.96 GeV dataset**
  - Cameron presented a new detector at the AW to address that problem
- Approached by systematically move layer 5 and 6 stereo sensors in Tu
- **A combination of local corrections has been found to remove the momentum bifurcation**
  - The detector is still work in progress and need to be validated / evaluated over V0 / FEE samples
- A similar effect might affect 3.74 GeV sample
- **Lot of work is ongoing to improve alignment in top volume for 2021 using similar approach**

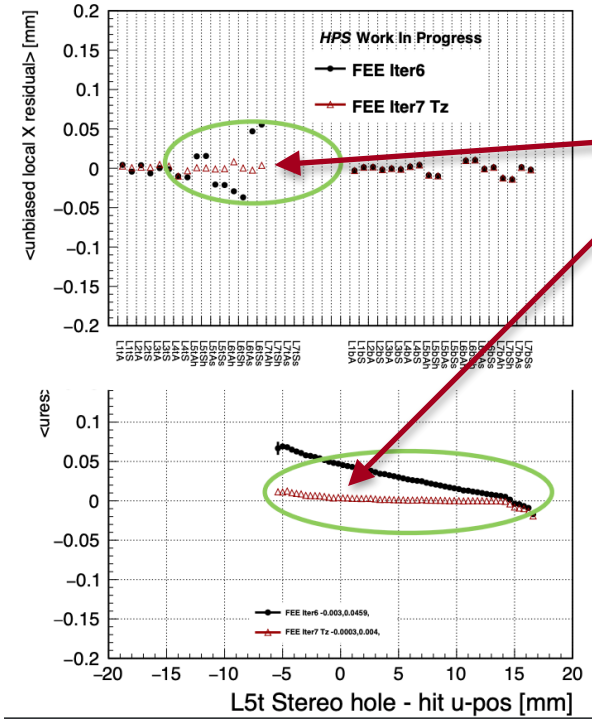


# Top Momentum in 2019

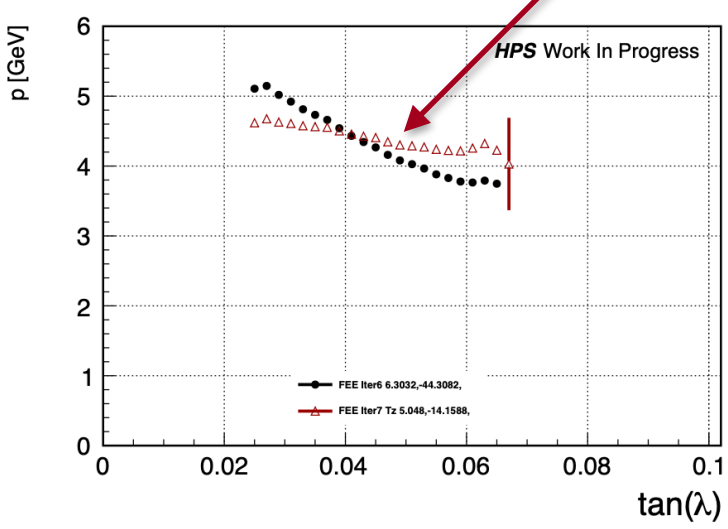
- Top momentum resolution is un-acceptable compared to MC expectation (even when dropping Ly6 hits)
- Only solution found so far is aligning freeing out of plane movements (Tz) with momentum constraint in FEE sample



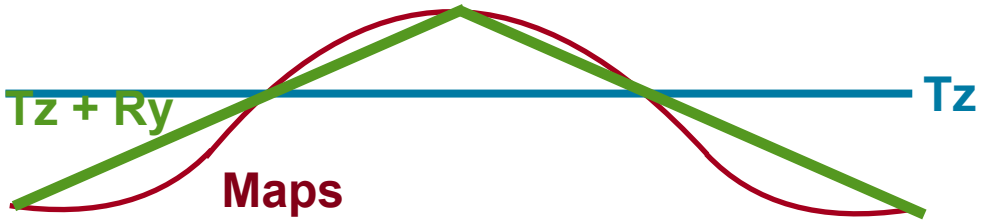

Fix residual shapes

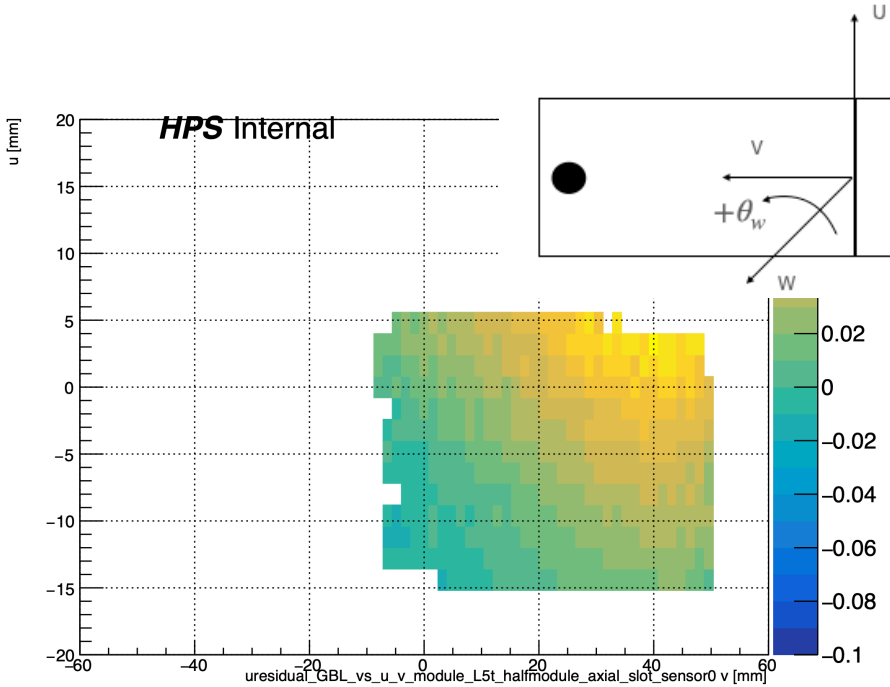
Improved momentum

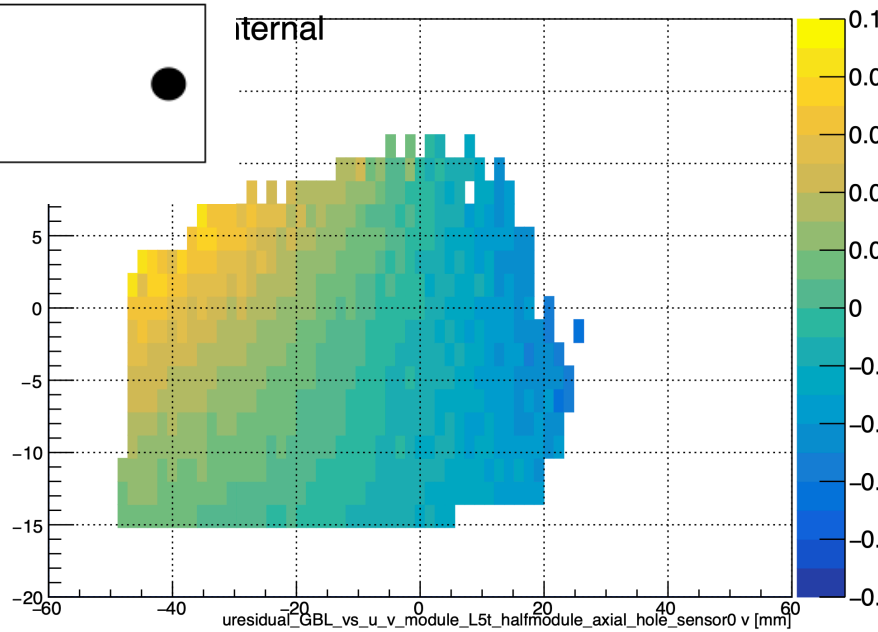


# Top Momentum in 2019

- However, very large distortions and expected to be un-physical
- Checked in detail residuals as function of u-v on the sensors
- Observed a “bulge” / “sink in”

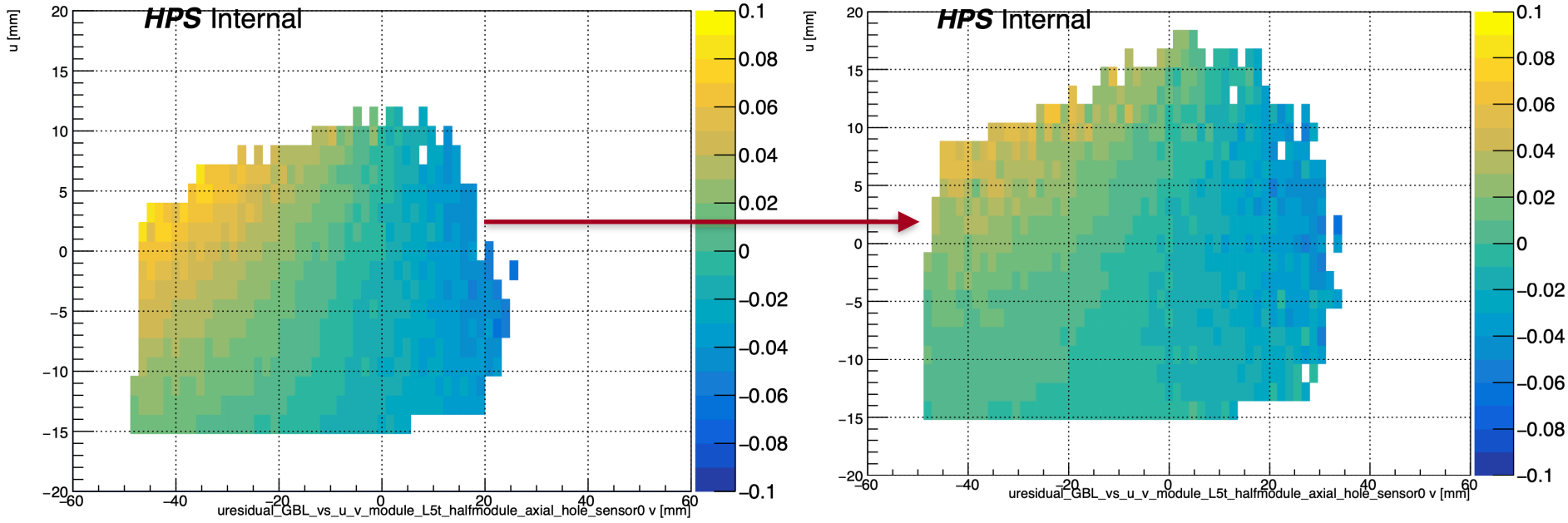


# Top Momentum in 2019

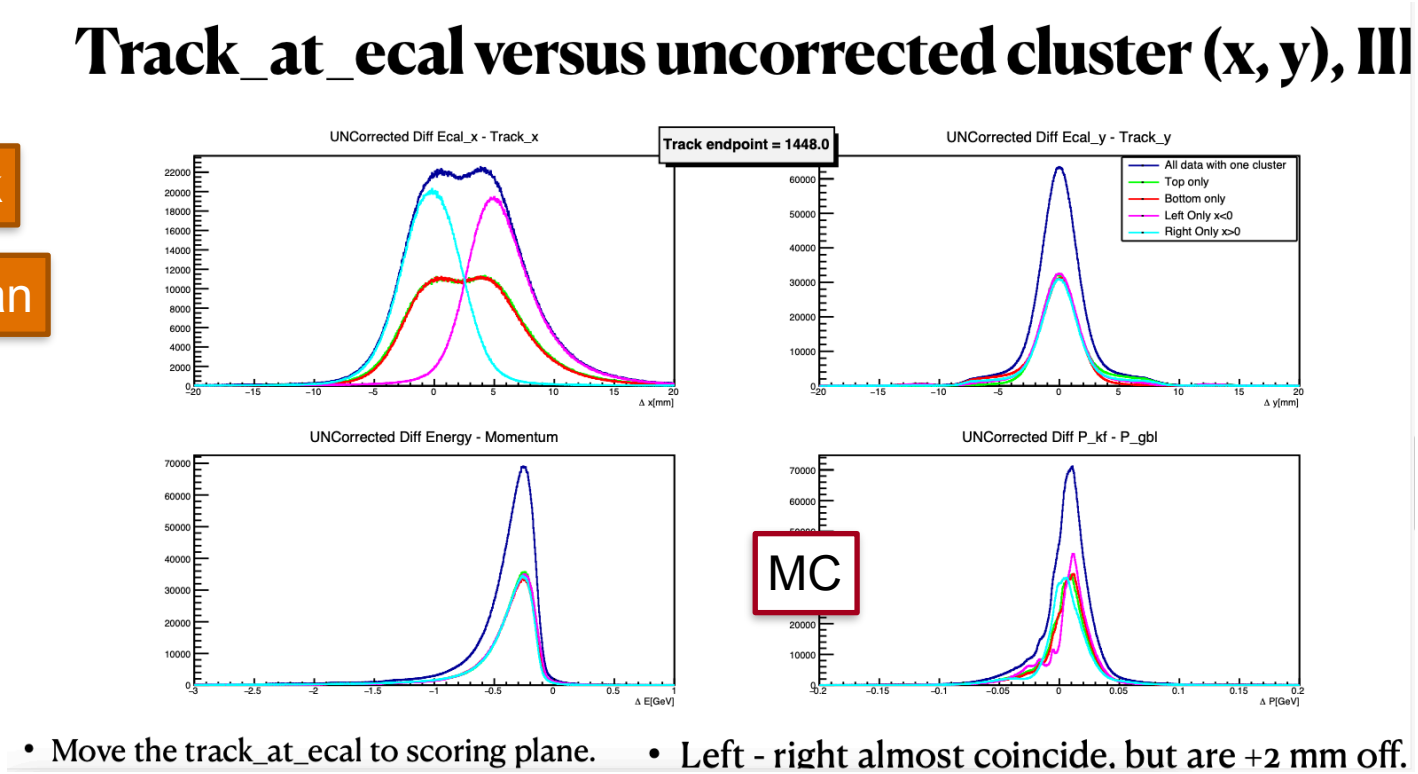
- First correction approach: triangular shape Tz+Ry (-0.5mm / -10mrad) improves.
  - This is a single movement, need to be done together with Tu/Rw
- It's a bowing-in movement, not a bowing out
- Momentum in the top is not corrected yet (backup) -> studies continue.



# Cluster-Track studies in MC

Maurik

Norman




- Found and corrected by Norman by PR #982
- Ecal position not properly picked up in different runs / data periods

# Students Report: Sarah / Tom

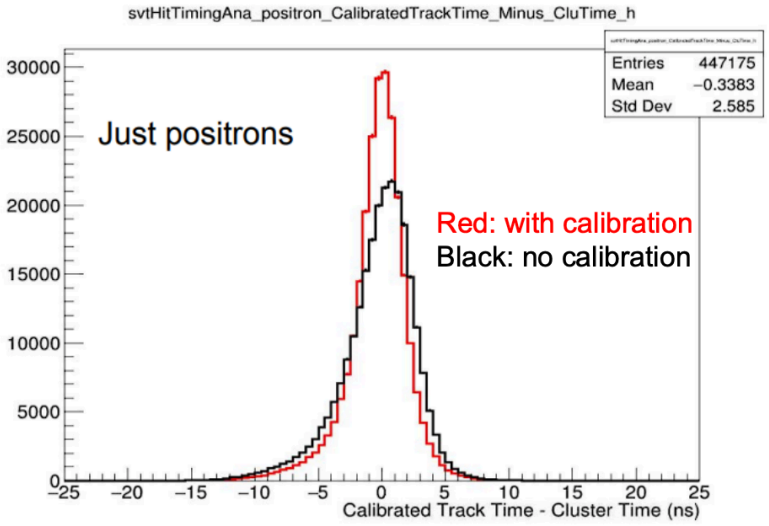
SLAC

- Tom: Validation of KF alignment on 2016 dataset
  - Start from 2016 surveyed compact and run KF alignment to check if KF-based alignment provides a good solution
  - Start from 2016 aligned compact: Use KF-based alignment with BS/Momentum constraints to improve performance of 2016 detector
  - Lot of progress done in software and infrastructure as well as alignment iteration automatization and simplification

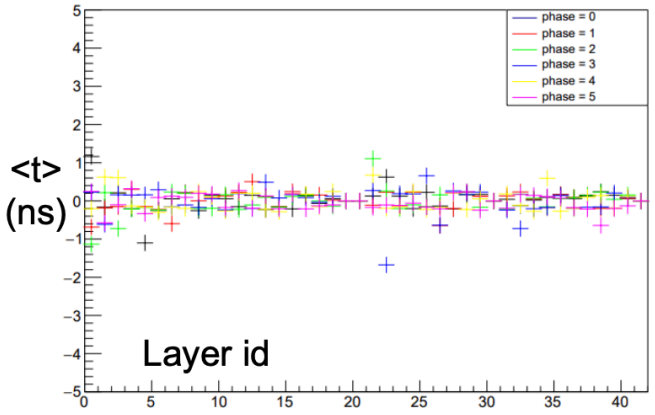
- Sarah: MC based studies for misalignments and MC production
  - Produce MC samples for tri-trig + beam using hps-mc
  - Systematic studies of misalignments
    - Out-of-plane and collective in-plane (twists, rolls, global yaws) movements.
- Progress also made in improving plotting library for alignment monitoring

# Hit Timing studies: MattG

## Workshop summary: Cluster Time Calibration & Track Times




- MG showed layer- and phase-dependent calibrations using (hit-cluster time) to line things up
- There is definitely some improvement to track-time distributions…nothing huge and we still don't seem that we are as good as we should be
- Code is in hps-jave to read in constants either from db or resource file. Will look at run-dependence and decide which one to use.




Work on hit-timing also ongoing by Cam/Rory. Please check the AW talk for comprehensive information

# Summary take-away

SLAC

- 2 Alignment tags have been released for 2019 and 2021
- Large improvements with respect to the nominal detector have been provided
  - A first look on V0s has been presented, constants seem stable across multiple runs, performance is reasonable for starting designing analysis while improvements are being made
- Work ongoing to fix some outstanding issues:
  - Possible out-of-plane distortions in 2019 / 2021
  - Momentum / track parameter biases vs tanL
  - Vertexing consistency between z0_vs_tanL method and 3DVertexing for bottom volume.
- Hit Timing studies ongoing
  - A procedure is being developed to improve hit timing information and hit-to-track association

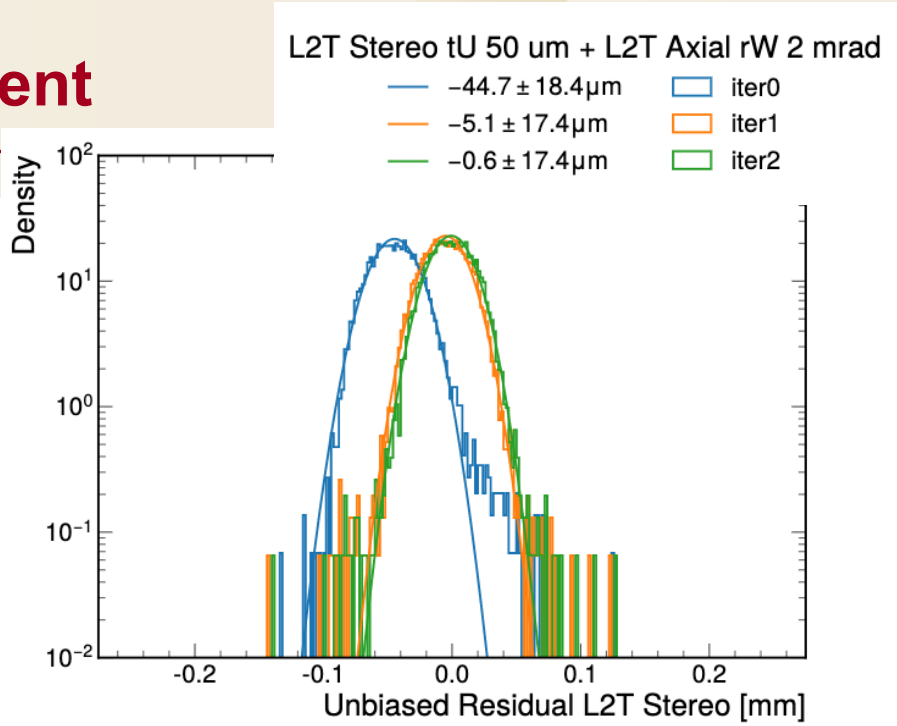
# Work ongoing

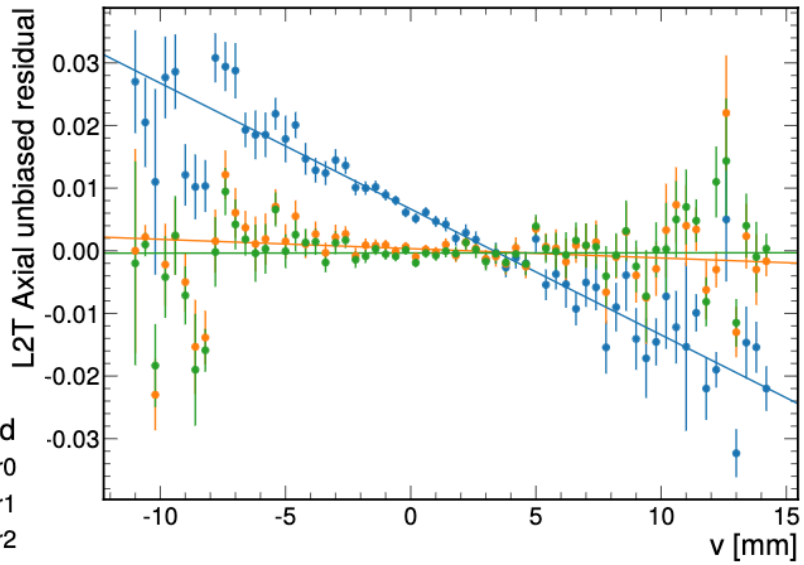
# KF based alignment development

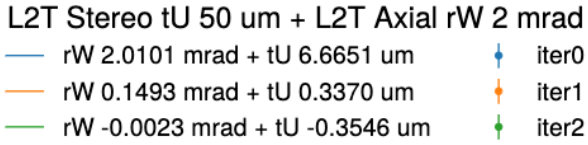
- As we updated the tracking reconstruction from SeedTracker and GBL refit to Kalman Filter we need to update the MPII inputs evaluation
- General workflow:
  - Find a track using KF pattern recognition
  - Provide the list of hits and initial track fit to GBL re-fitter
  - Build a trajectory and extract alignment derivatives
- Tested sensor translations and tilts
- Constraints to be tested
- To be validated on 2016 data

Basic functionality validated on MC

Tom



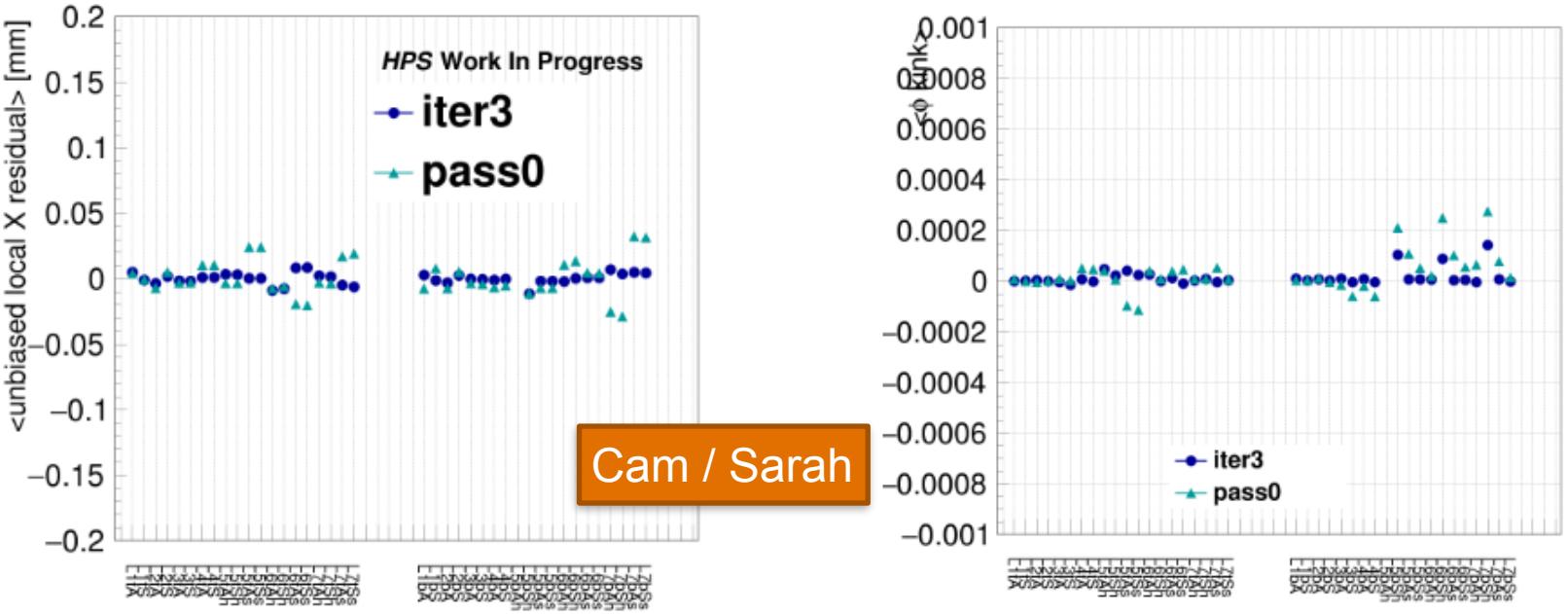



# Application to 2021

- First application of KF-based alignment on 2021 dataset
  - Goal is to recover hits on single side sensors and improve track quality
- Done a 3-iteration pass using plain (no-external constraints) minimization floating tu-rw on all sensors in back of the detector

Improvement of the hit-on-track residuals
and angular kinks -> better Chi2



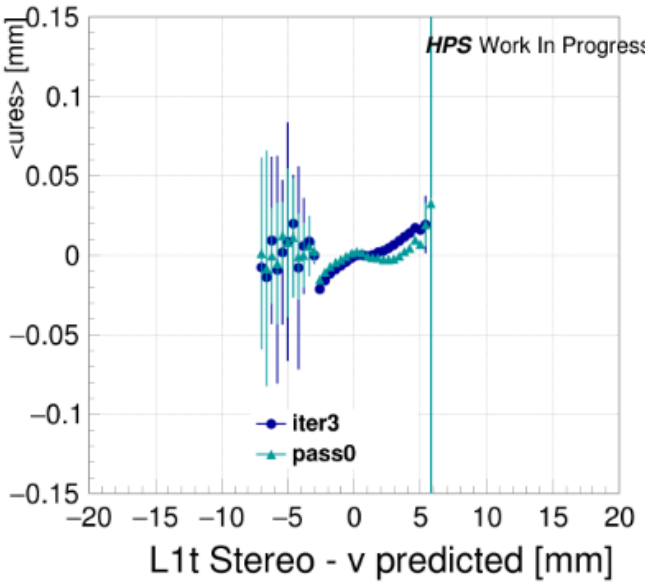

Cam / Sarah

# Application to 2021 - Some future steps

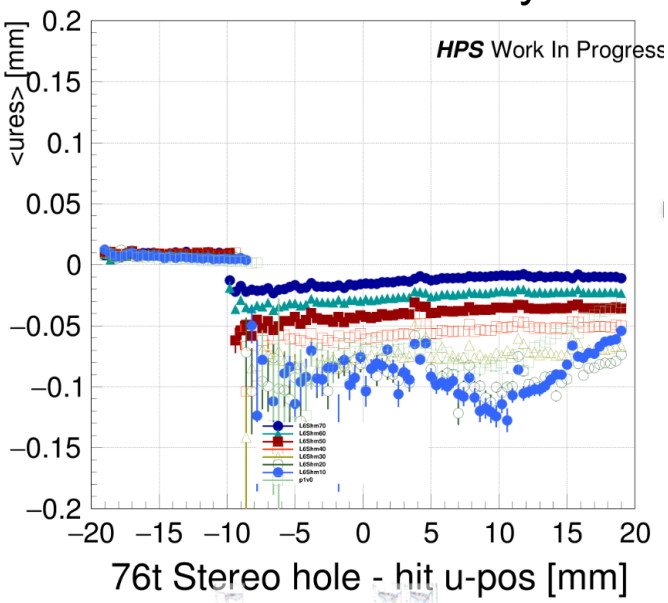
- Current work in progress:
  - Additional passes in the front of the detector
  - Investigation of momentum bifurcation in the FEEs
    - **Scan over possible positions of single sensors to guide next iterations**
  - Investigation of large Chi2 tail when removing hits on tracks

Cam / Norman

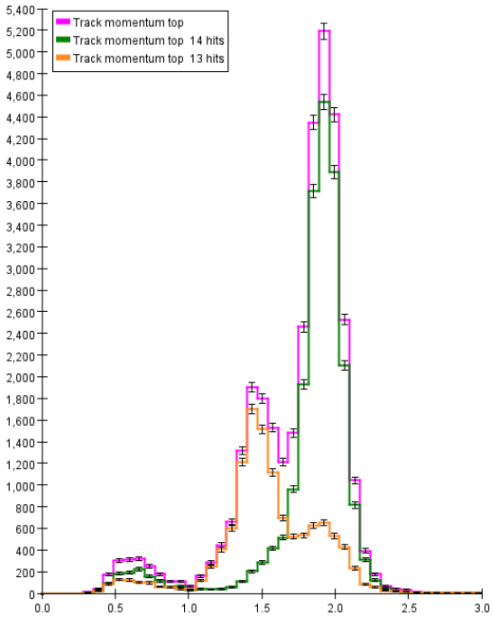
Rotations to be corrected




Scan over L6t stereo position
Check effect on other layers

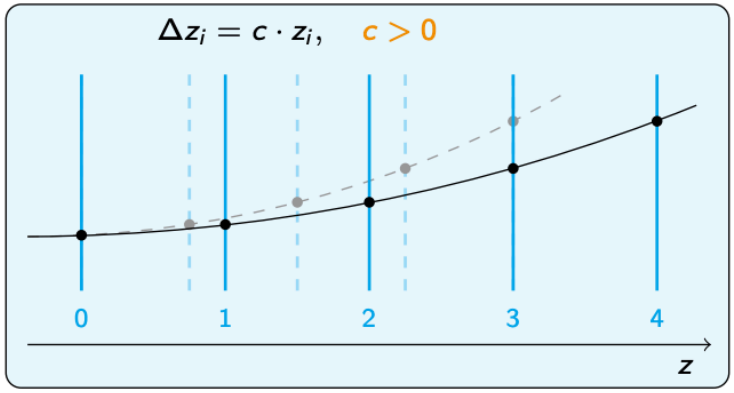



Investigation ongoing on FEE momentum bifurcation

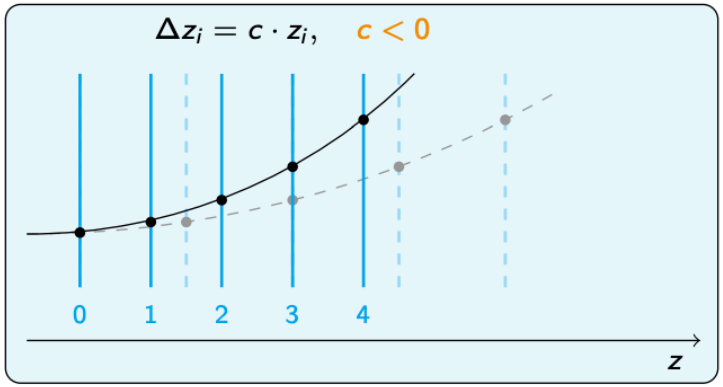


# MCBased misalignment - Out of plane distortions

- As discussed, we observed some features in data alignment plots that are not being solved by releasing tu and rw of the sensors (as done in 2016)
- In particular we want to study telescope contraction/elongation modes
- Out of plane distortions would imply dependence of track parameters on tanL (such as momentum/d0)



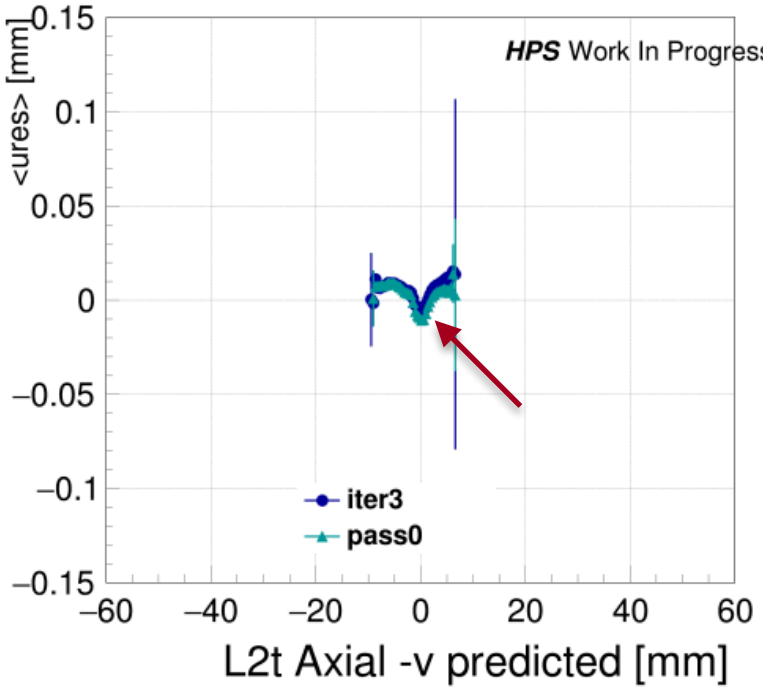

Telescope elongation/contraction
Will have an impact on track parameters such as momentum



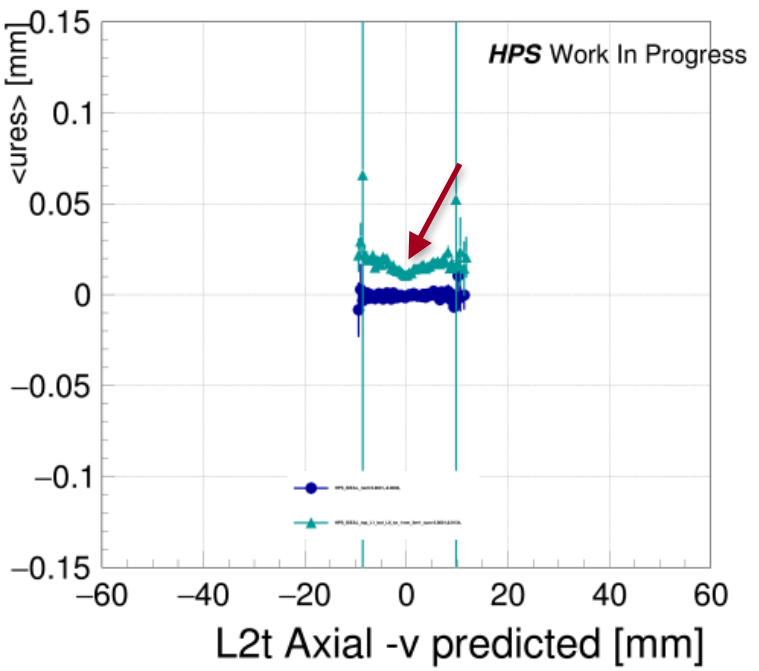
# MCBased misalignment

- Using FEE MC, Sarah is studying the effect of out of plane distortions on residuals and track parameters
  - Different scenarios under investigation
- Comparison with 2021 data
  - With different alignment of tu - rw iterations

Cam/Sarah




2021 data



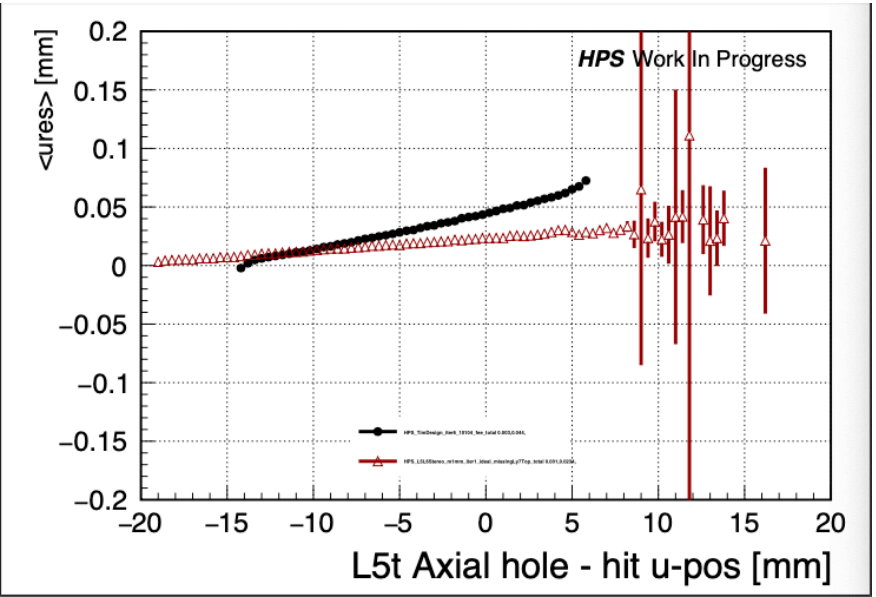

MC L1 1 mm tw

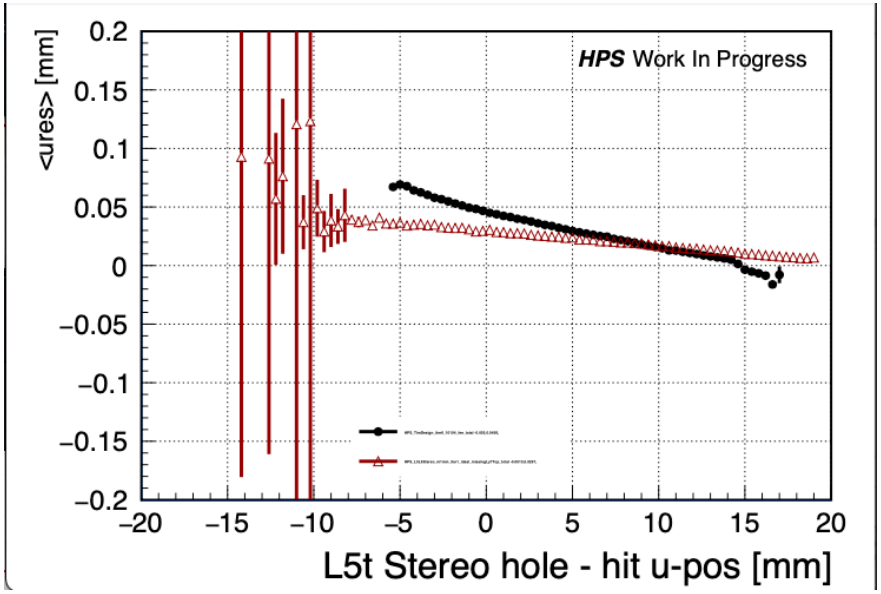
# MCBased misalignment

- Using FEE MC, Sarah is studying the effect of out of plane distortions on residuals and track parameters
  - Different scenarios under investigation
- Comparison with 2019 data
  - With different tu-rw iterations
- We are able to interpret those effects under the assumption of out-of-plane distortions
  - Only separation between Axial-Stereo pairs fix it
  - Large displacement of each side O(mm) necessary
- **We are currently investigating other in-plane correlated movements, such as twists and rolls with respect the beam axis**

Cam/PF/Sarah

## MC L5-L6 Stereo movements of -1mm
## 2019 FEE Data



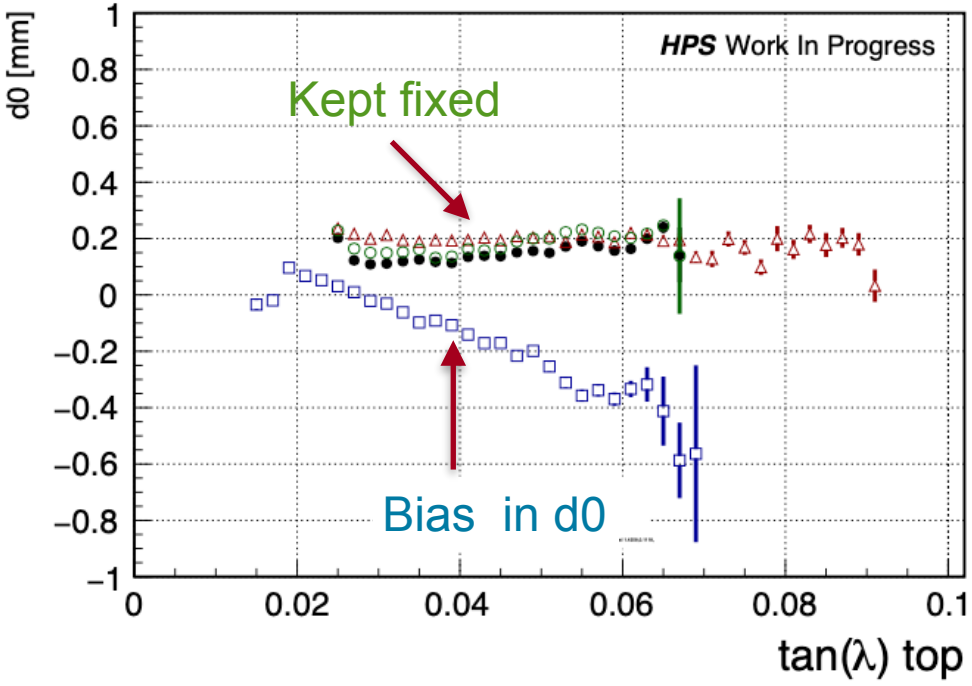



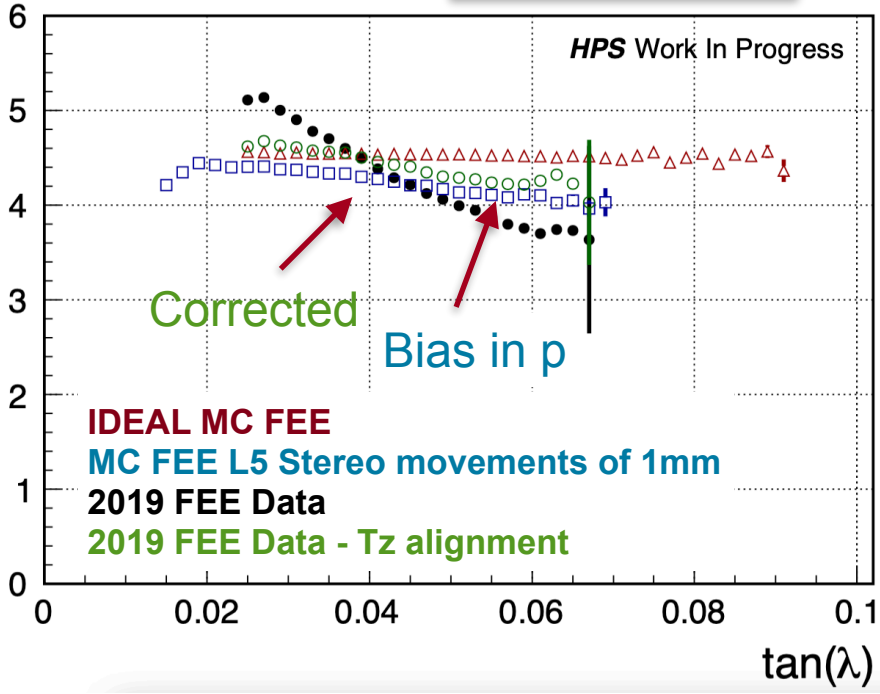
# Re-alignment using out of plane distortions

SLAC

- Alignment of the out-of-plane distortions is not easy as it is affected by telescope Z-scale weak-mode
- It is one of the misalignment that could explain p_vs_tanL dependency
  - Others are under study
- First pass done, and study on other data sets (such as low-p tracks, WABs, tridents) is ongoing

Cam/PF/Sarah



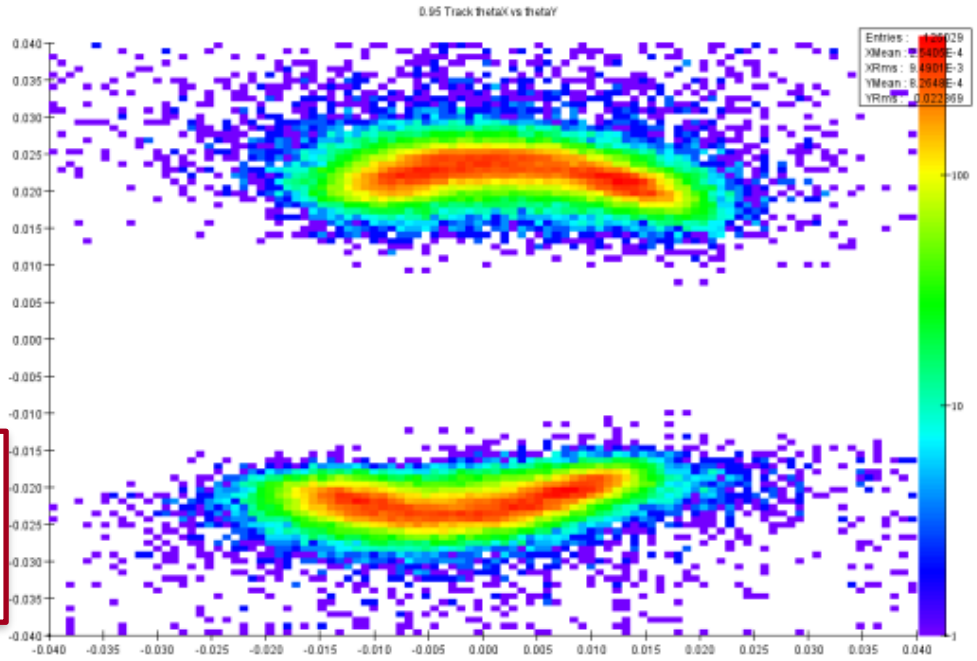



# Global alignment - Moellers



- Tight cuts require maximum number of hits on track (13 or 14, depending on top or bottom).
- Select narrow momentum slice, plot $\theta_X$ vs $\theta_Y$
  - should give circle centered at (0,0)

Norman




Need to extract the needed correction value to test it

# Summary

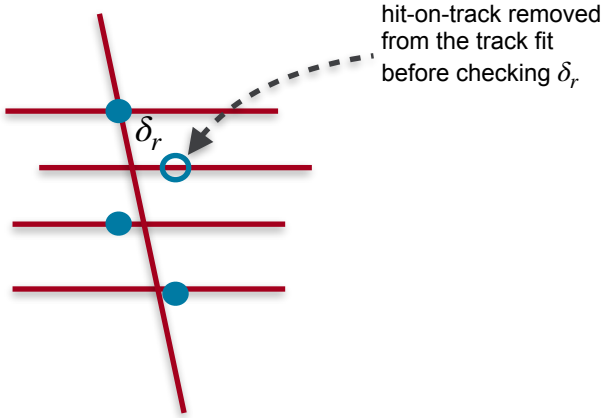


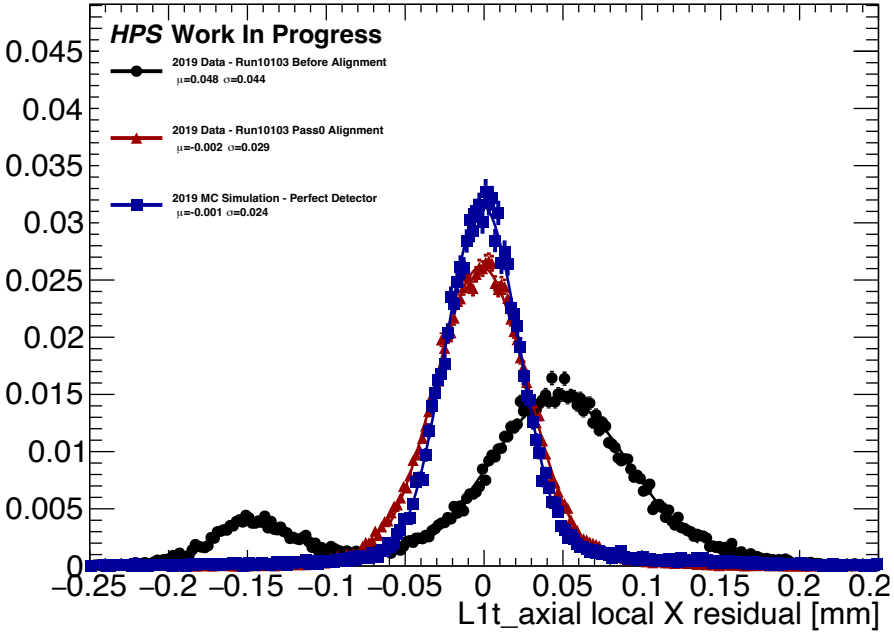
- Preliminary tags have been published end of last year for processing
  - Lot of work being done on assessing momentum scale and resolution
  - We should start working toward vertexing quality too (I only have plots for 2019)
- While large improvements have been made toward a better calibration several items are under study:
  - Momentum scale and biases
  - Track quality improvement
  - MC-based studies to understand seen distortions
  - Improvement to reconstruction software with the addition of improved functionalities (hard to summarize)
- We aim to have an improved tag by beginning of April
  - But this shouldn't stop analysis group to start looking toward some physics analysis design

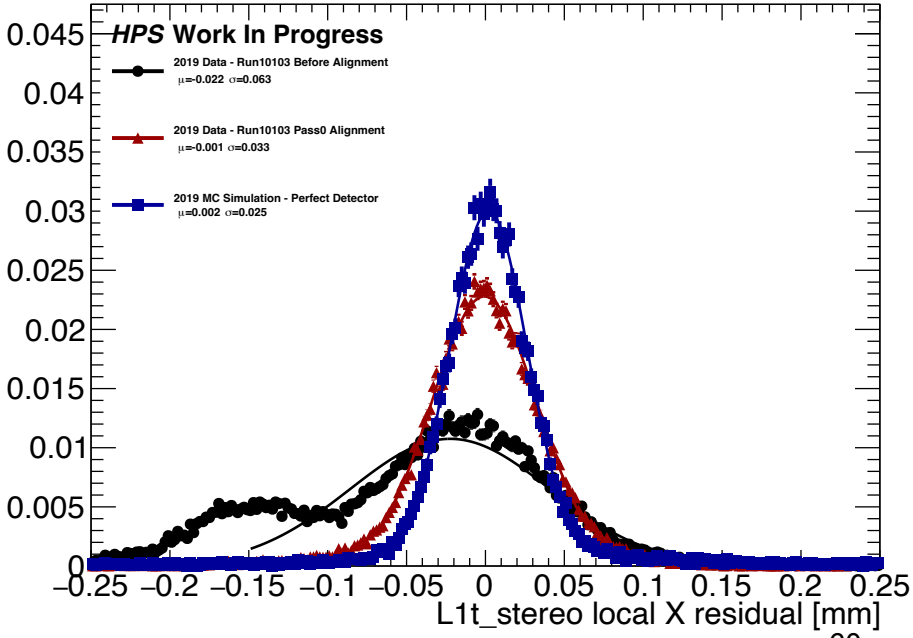
# BACKUP

# Alignment performance - Unbiased Residuals

- Checked alignment solution quality by evaluating unbiased residuals distributions
- Mean linked to the residual position misalignment
- Large improvement in the newly placed thin-sensors
- Resolution to be improved to get closer to ideal geometry (from perfect MC)

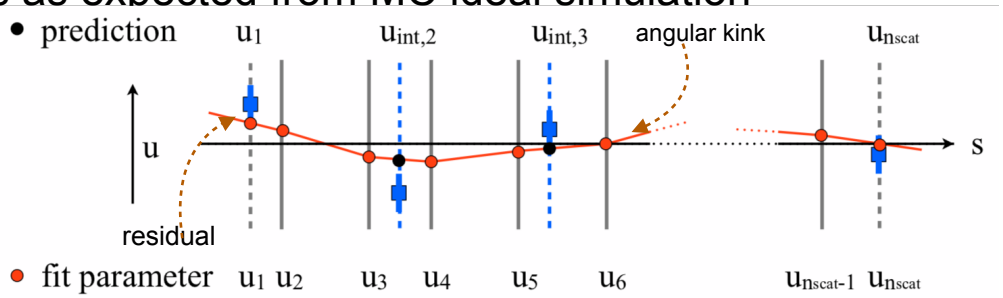


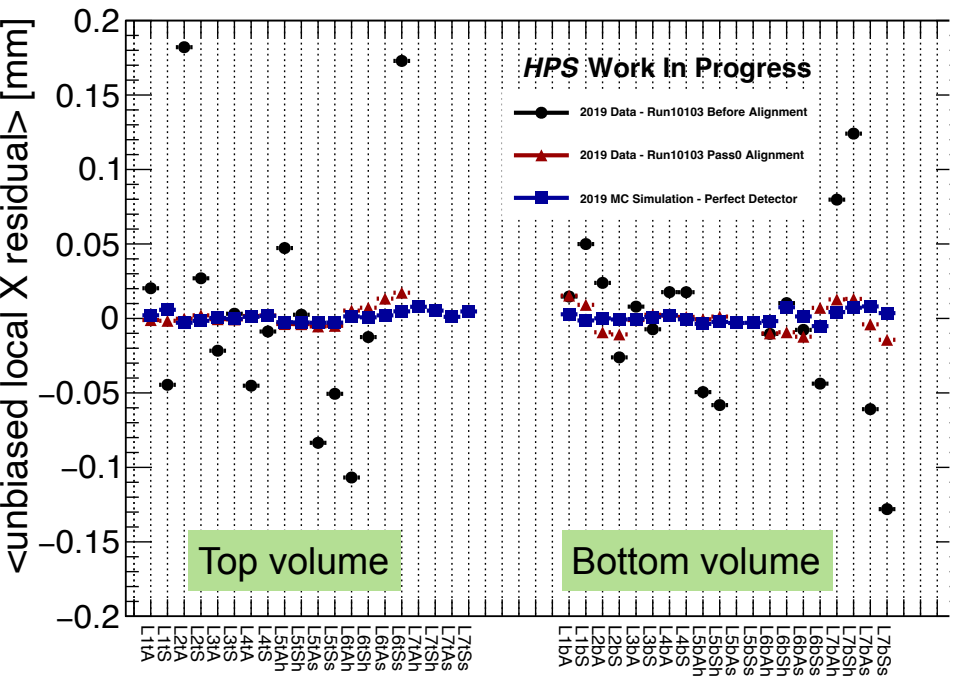



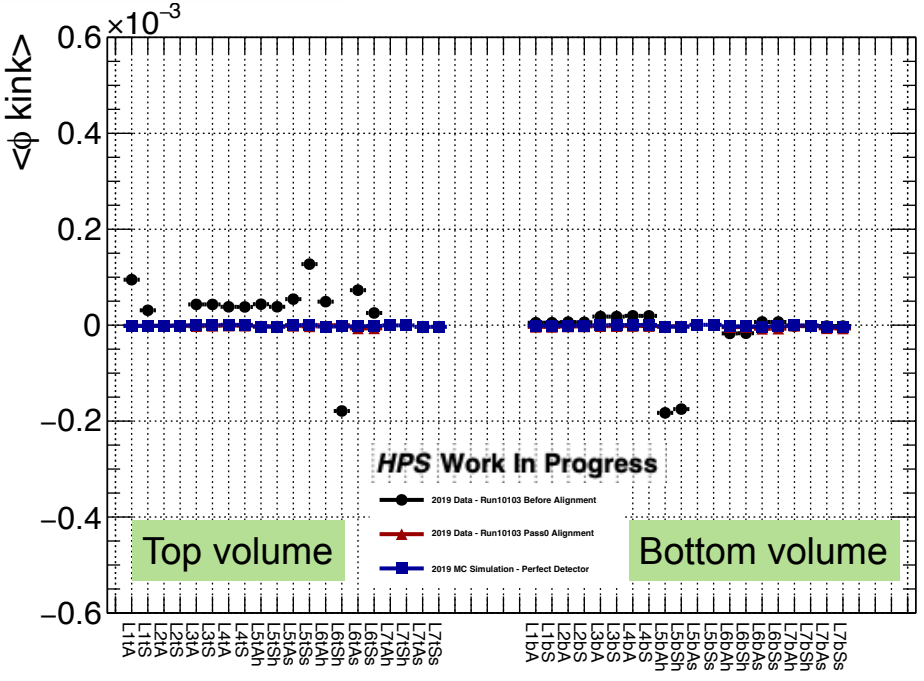



# 2019 Alignment performance - Unbiased Residuals

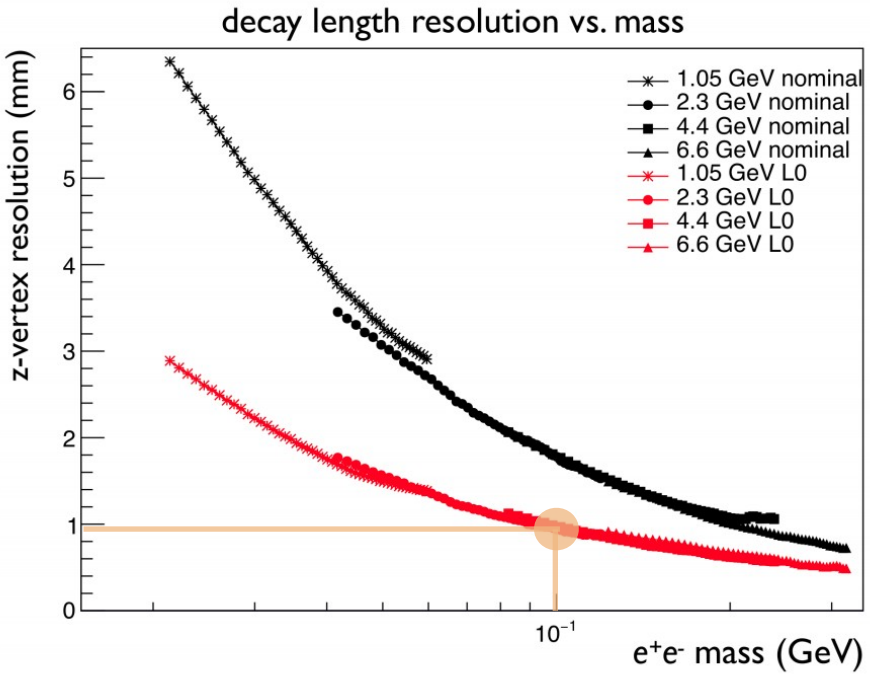
- Initial misalignments up to 200um recovered by current alignment procedure across all detector
- Angular kinks as expected from MC ideal simulation

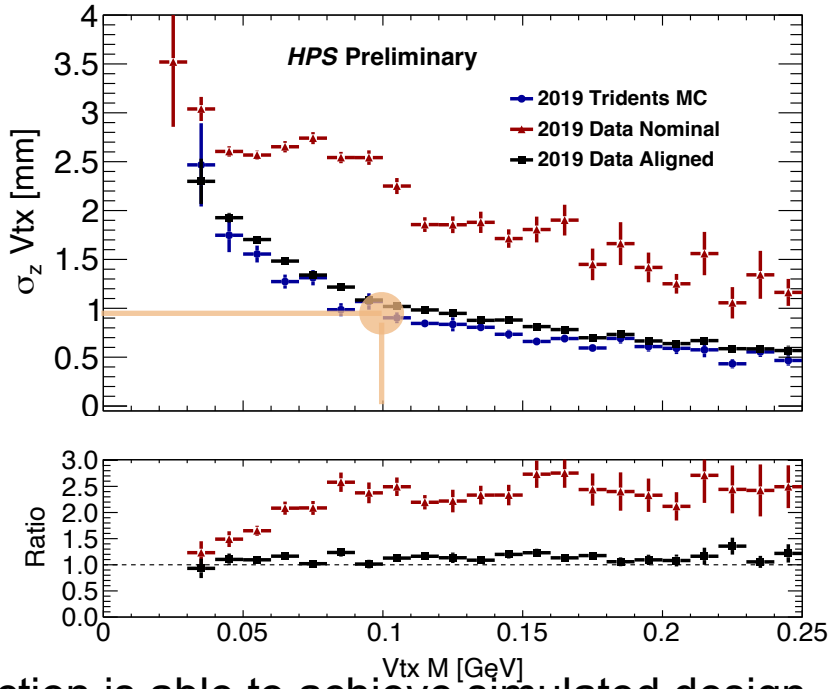


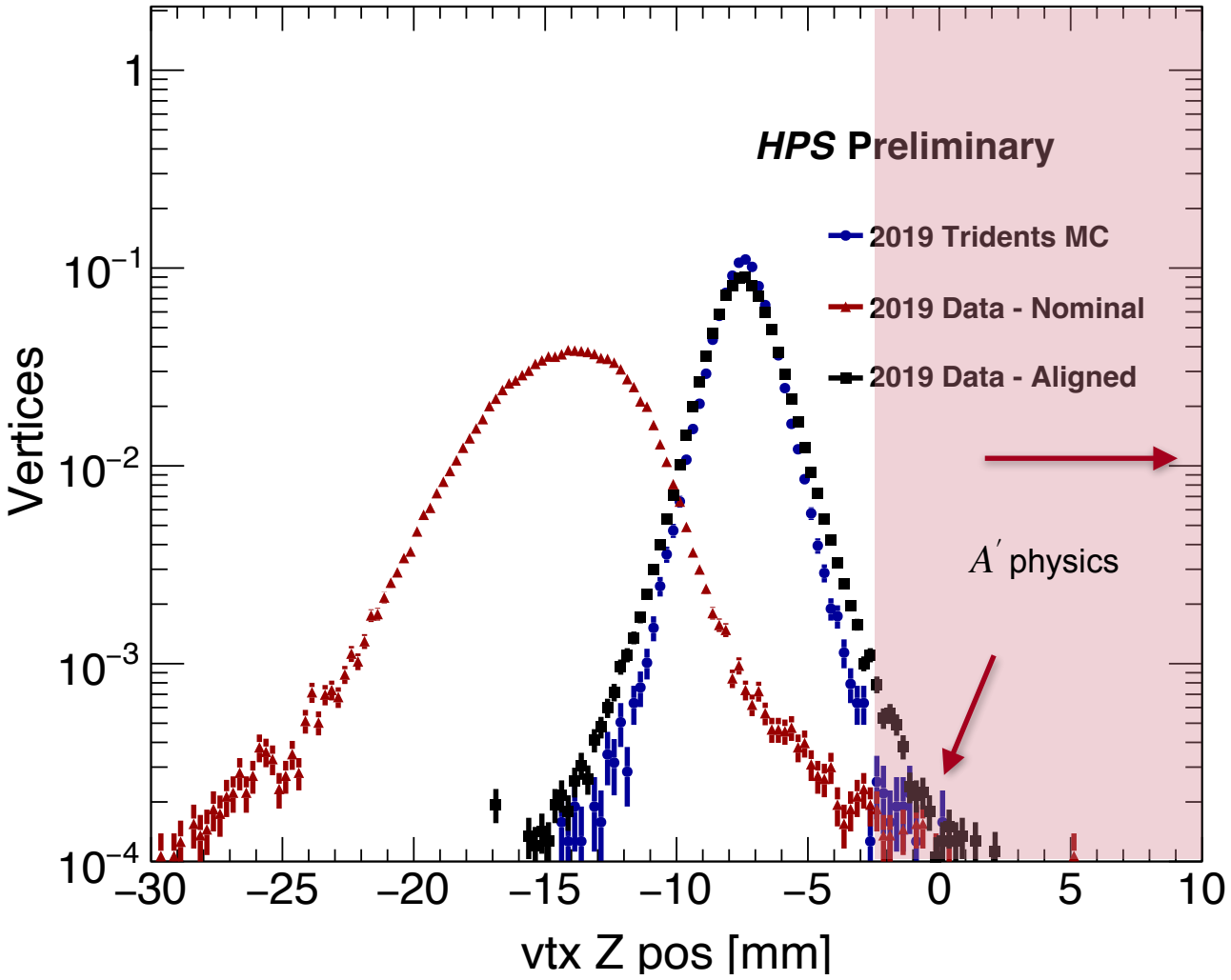
# 2019 Detector performance - Vertexing



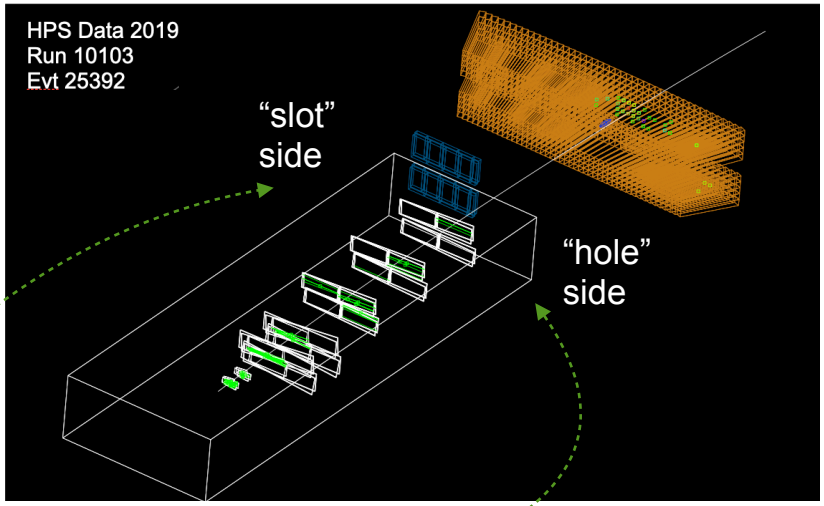

- Preliminary alignment show that HPS reconstruction is able to achieve simulated design performance
- Resolution extracted from gaussian fit on the core of the vertex distribution
- In these results *optimistic* MC simulation has been used (no beam background / pileup included). A simulation that would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

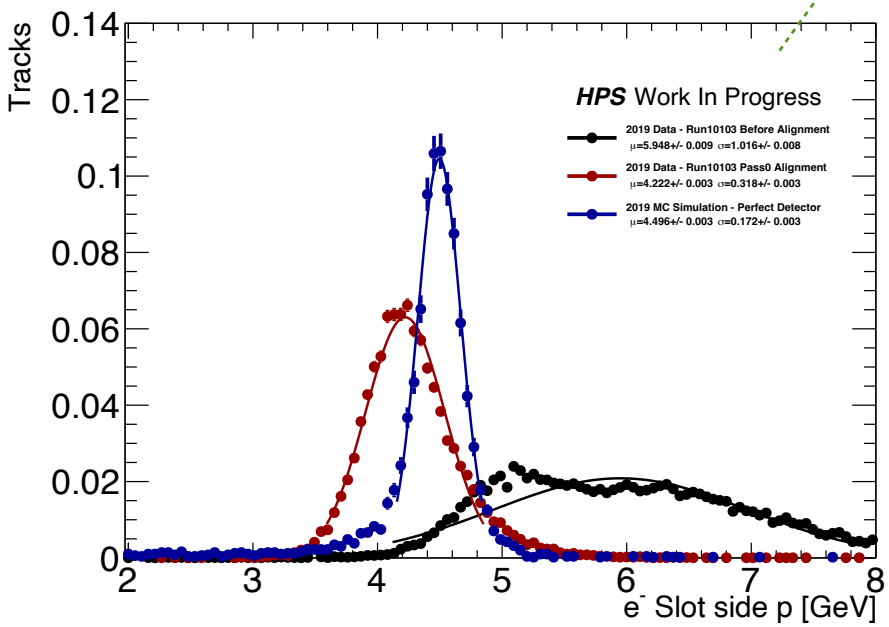
# 2019 - Vertex distribution

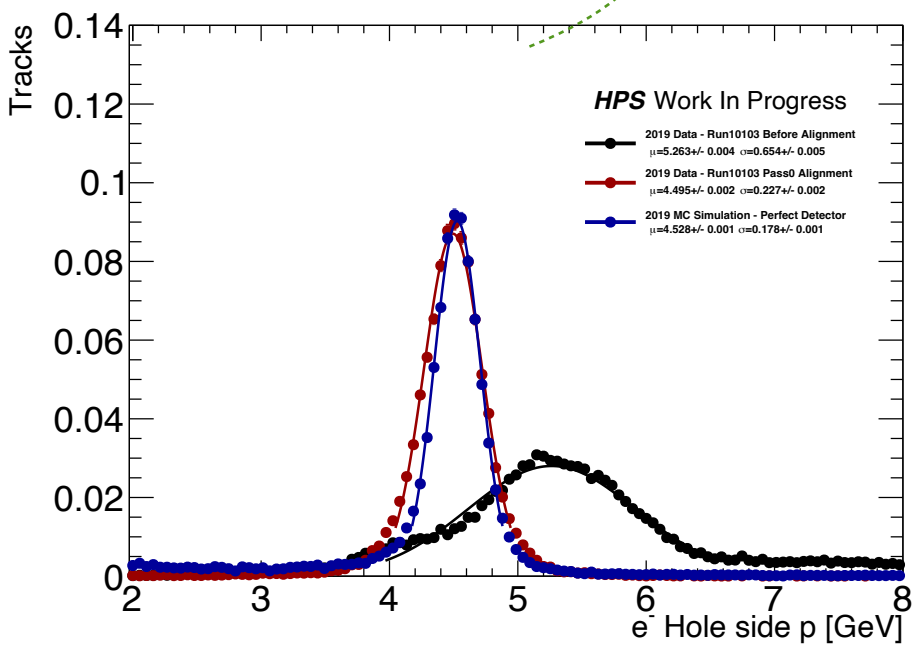


# SVT Performance - Momentum Scale and Resolution

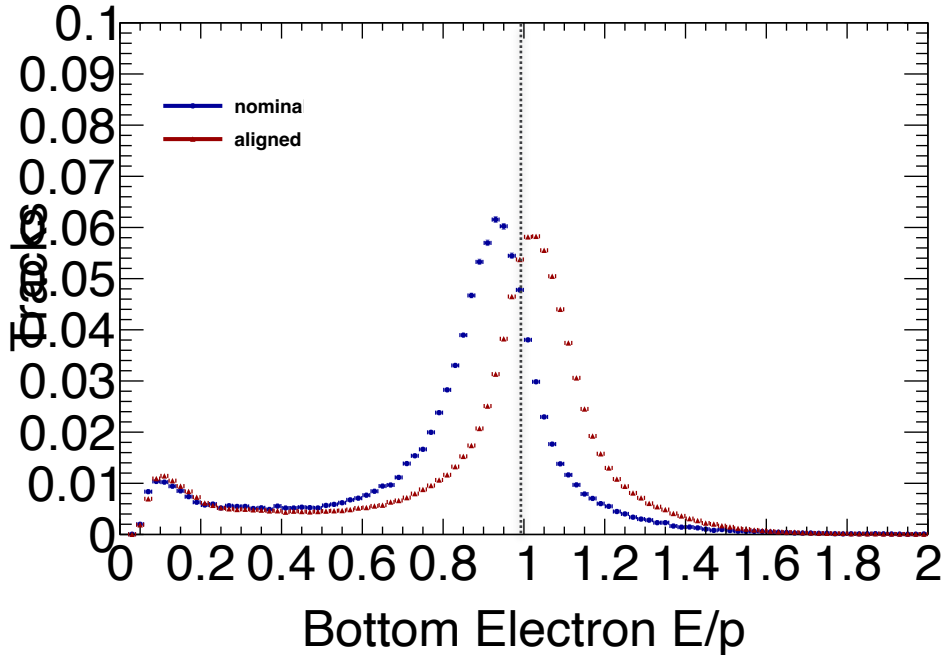
- Elastically beam scattered electrons are used to align the SVT with momentum scale constraint
  - Clean event selected by **single high-energy cluster in calorimeter**
  - **Known track momentum for weak-mode suppression**
  - **Only one side of the detector illuminated**:
    - Asymmetry detector halves alignment performance
    - Slot side momentum scale suffers of hole-on-track (one missing working layer for bottom)
- Momentum calibration for positrons/electrons is checked using E/p method

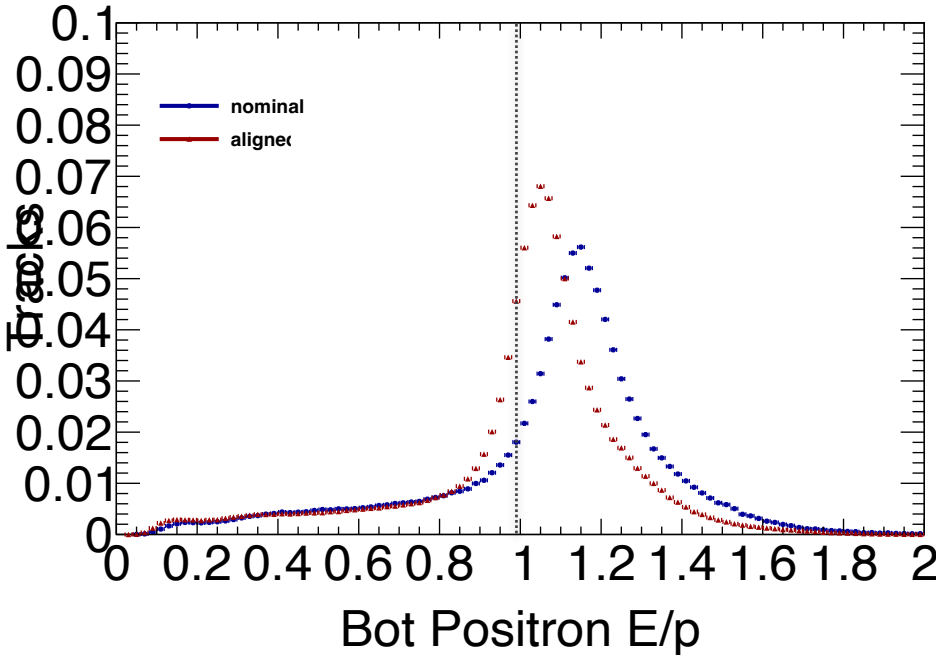


# 2019 - E/p from tridents




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

# SVT Reconstruction Group

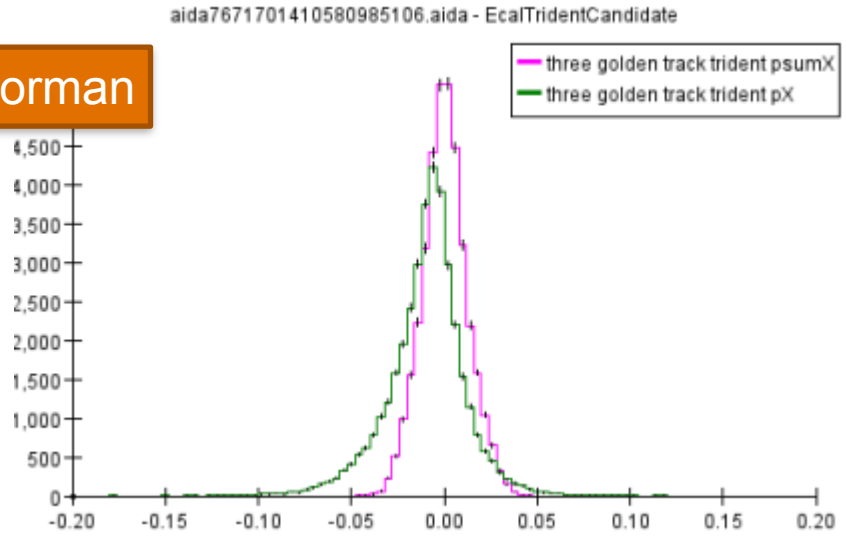
SLAC

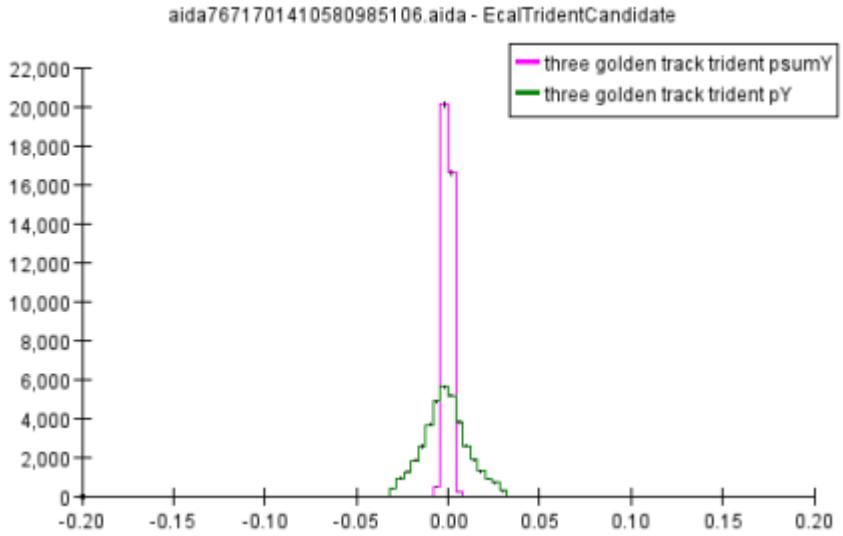
| | Activity focus | FTE % |
|---|---|---|
| **PF** | 2019 Alignment, sw/infr dev, MC misalignment studies | 50% |
| **Cameron** | 2021 Alignment, MC misalignment studies, SVT Hit Calib, sw/infr dev | 50% |
| **Norman** | 2019-2021 Global/internal Alignment performance | 75% |
| **MattG** | Hit timing calibration | 25% |
| **Rory (QT)** | SVT hit Calibration | 50% |
| **Sarah (QT)** | MC-based misalignment studies, sw/infr | 50% |
| **Tom (QT)** | sw/infr dev, KF-based alignment validation | 75% |
| **Omar** | sw/infr dev | 10% |

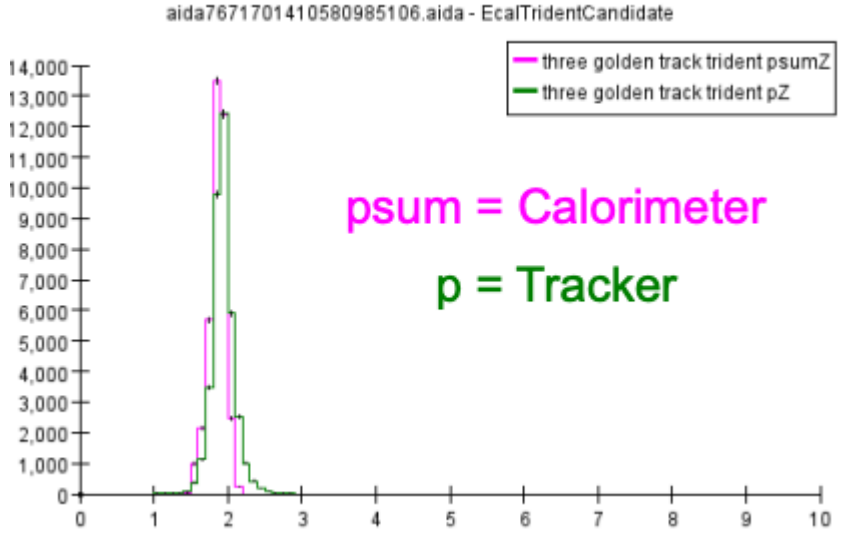
# Tridents candidate four momentum in 2021

Run 014661 at 1.92GeV

Norman

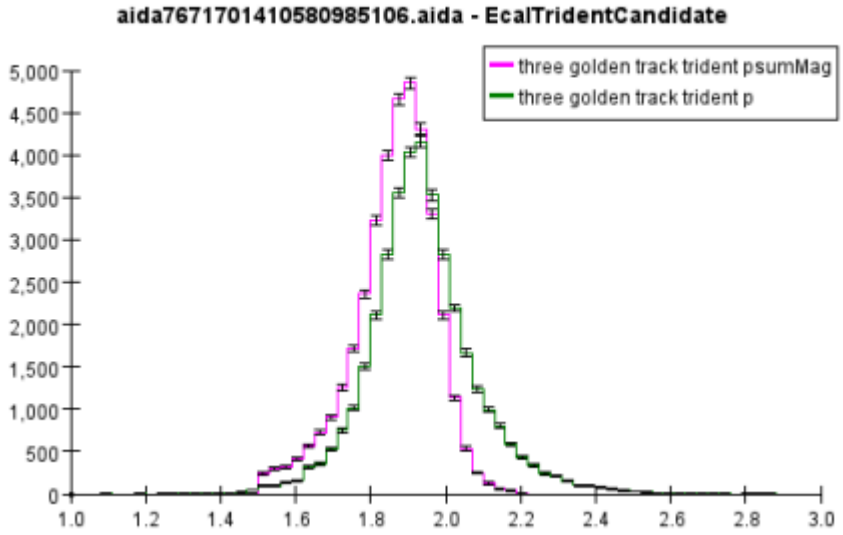


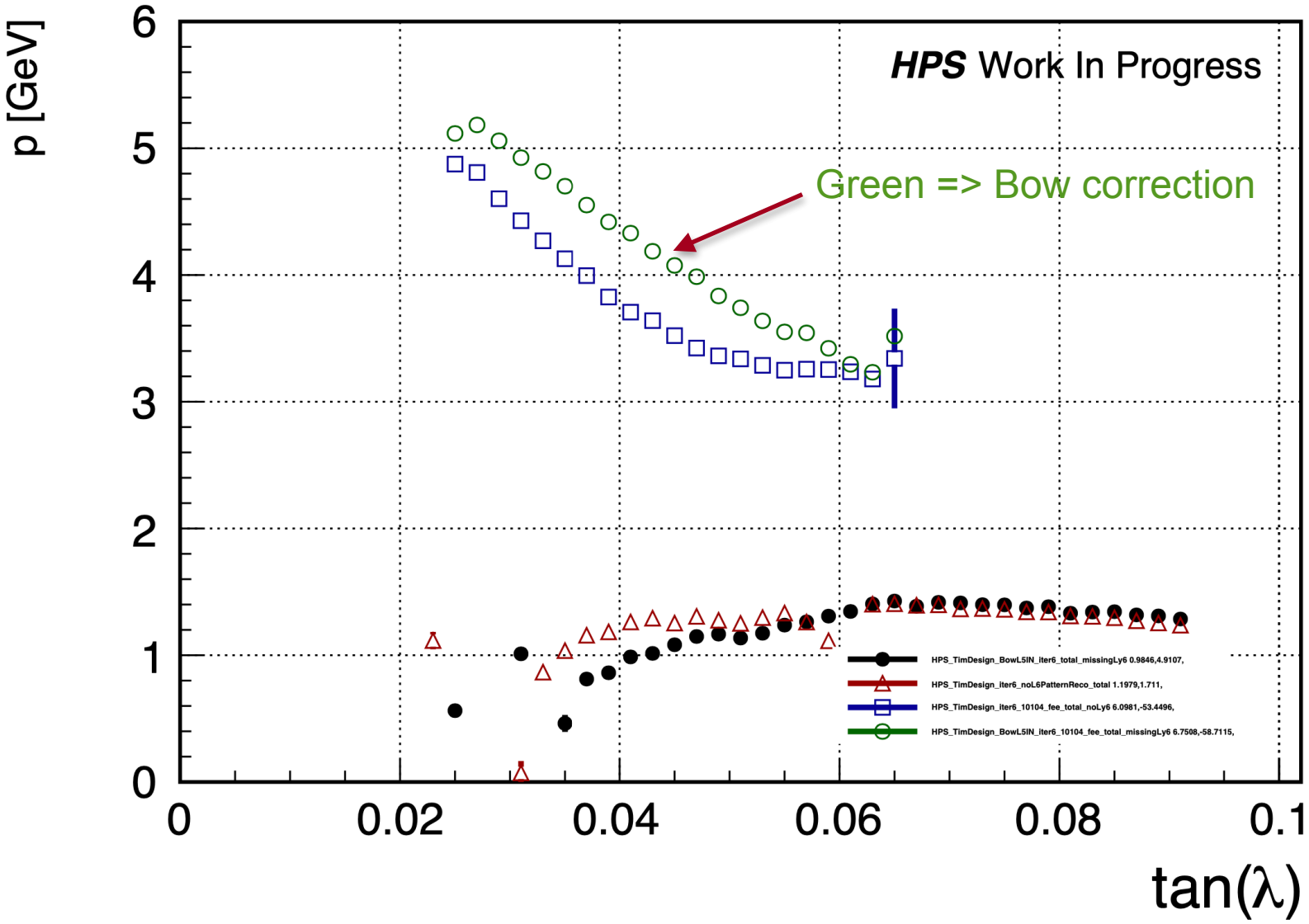




psum = Calorimeter

p = Tracker



# 2019 Momentum



# Cluster-Track position at ECAL in 2021

Norman

Misalignment between SVT and Ecal
Bimodal on top
Difference between top and bottom