



Track Extrapolation to the ECal

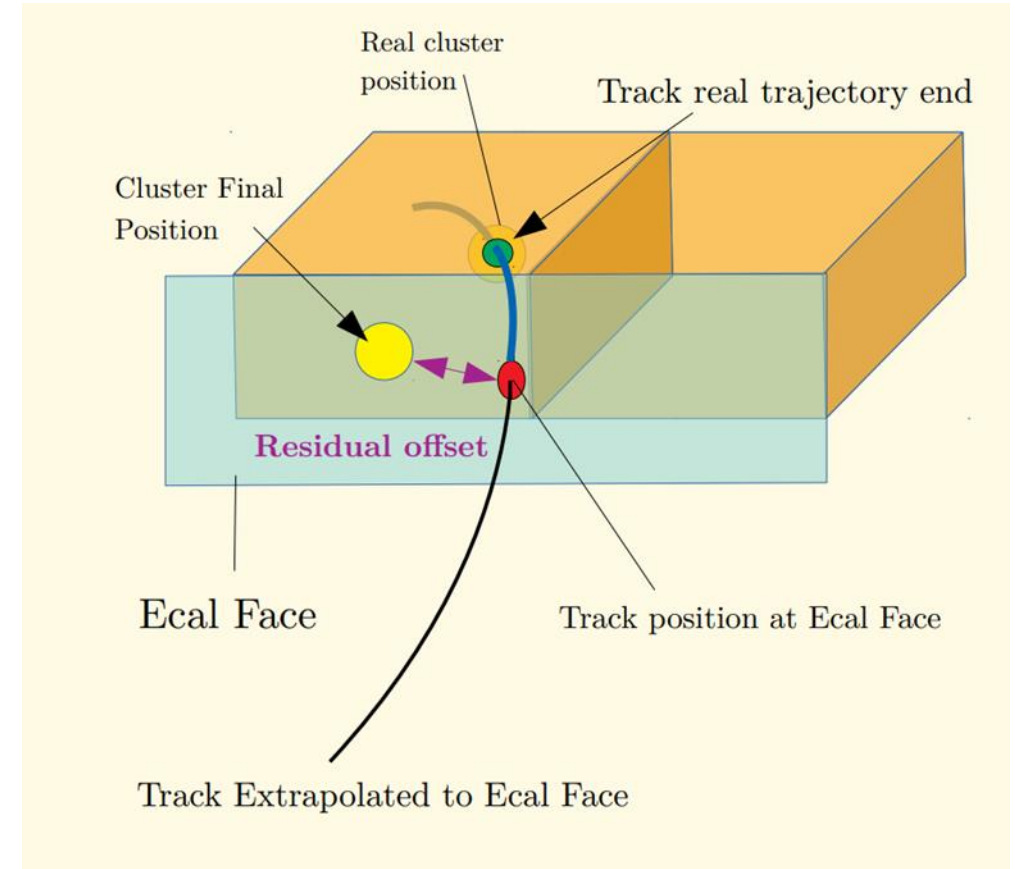
Lewis Wolf

HPS Spring Collaboration Meeting

6/4/24

Motivation

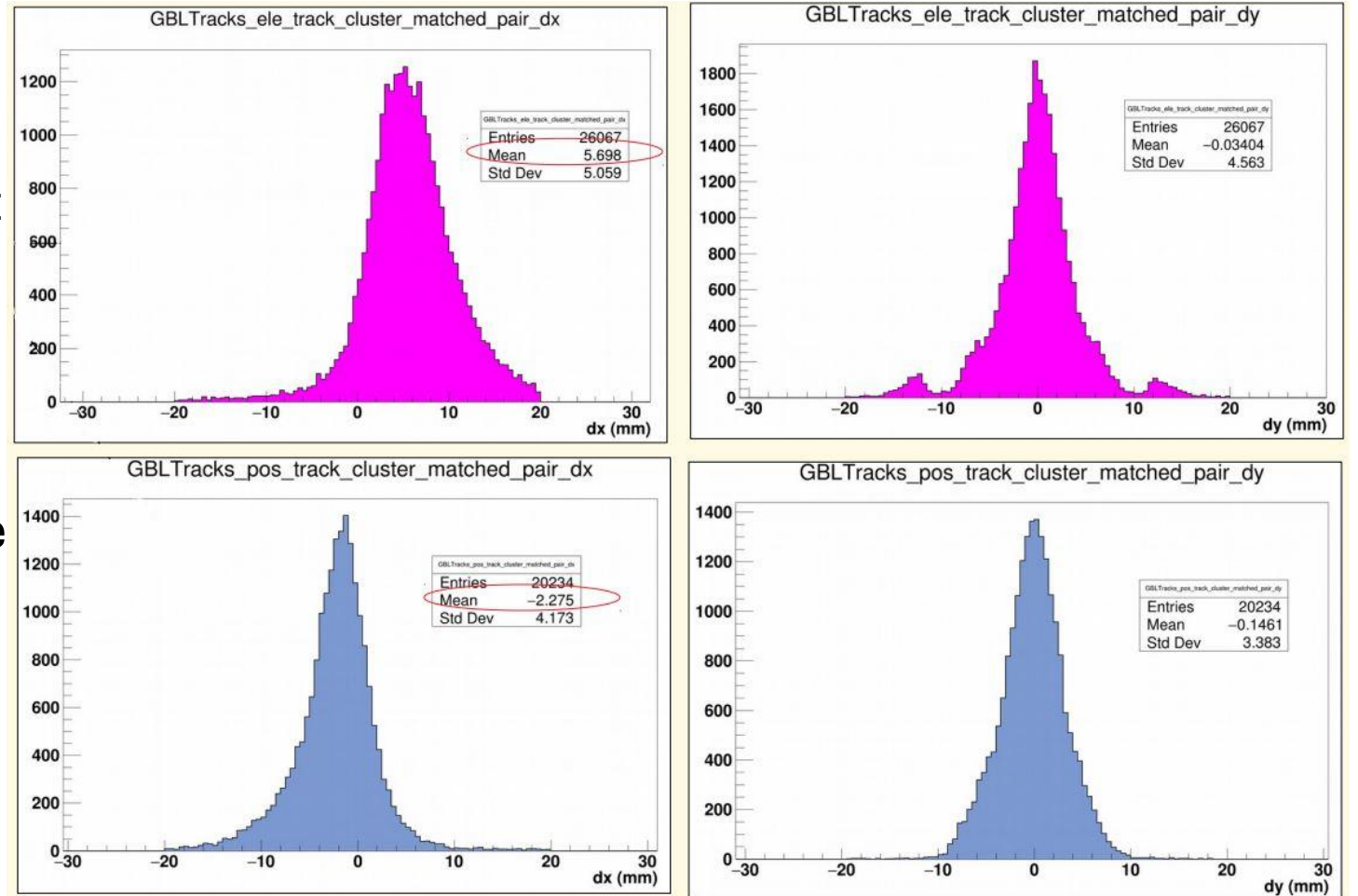
- A consistent discrepancy between Ecal hit and extrapolated-to-ECal track positions has been observed for quite some time.
 - Reported by Norman and Alic within 2016 data set in 2021
- This discrepancy persists, even after accounting for shower depth or comparing to the MC scoring plane in front of the ECal
- As a test, this discrepancy was reproduced and investigated with MC Muons, which interact less than electrons.



From Alic's weekly 3/29/21

Motivation

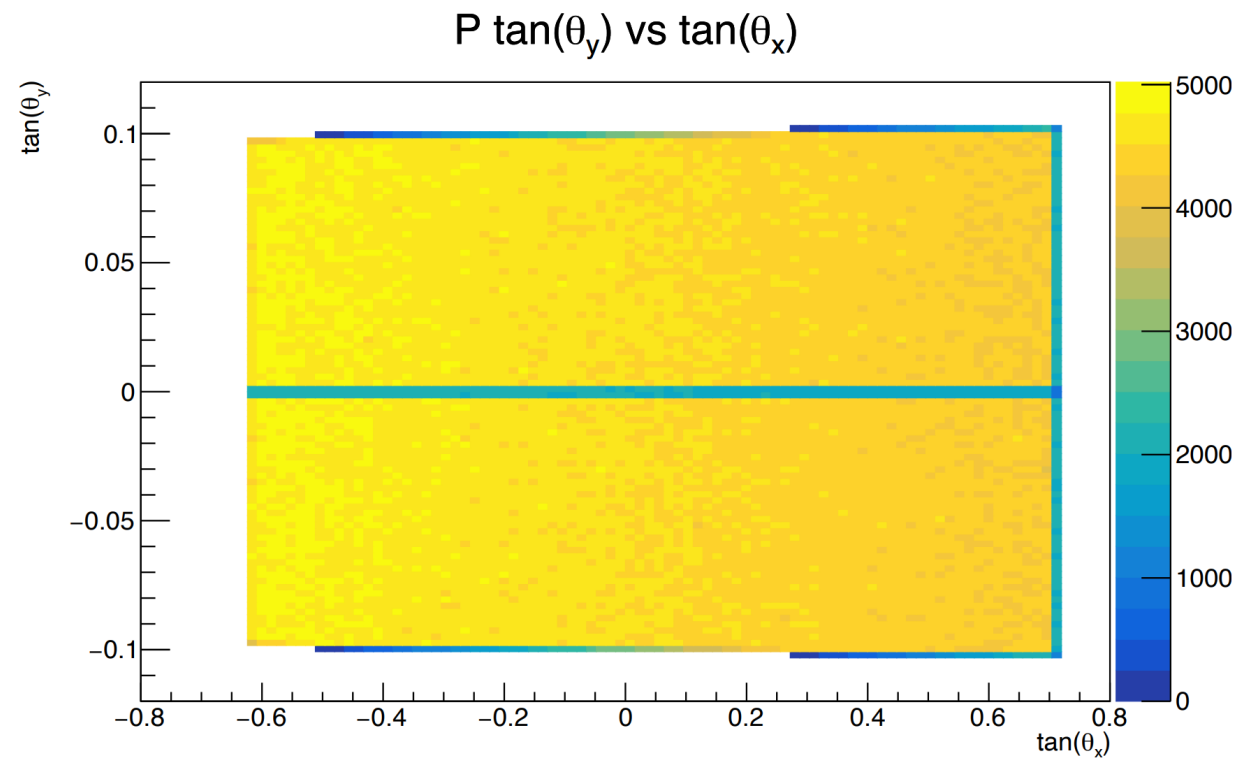
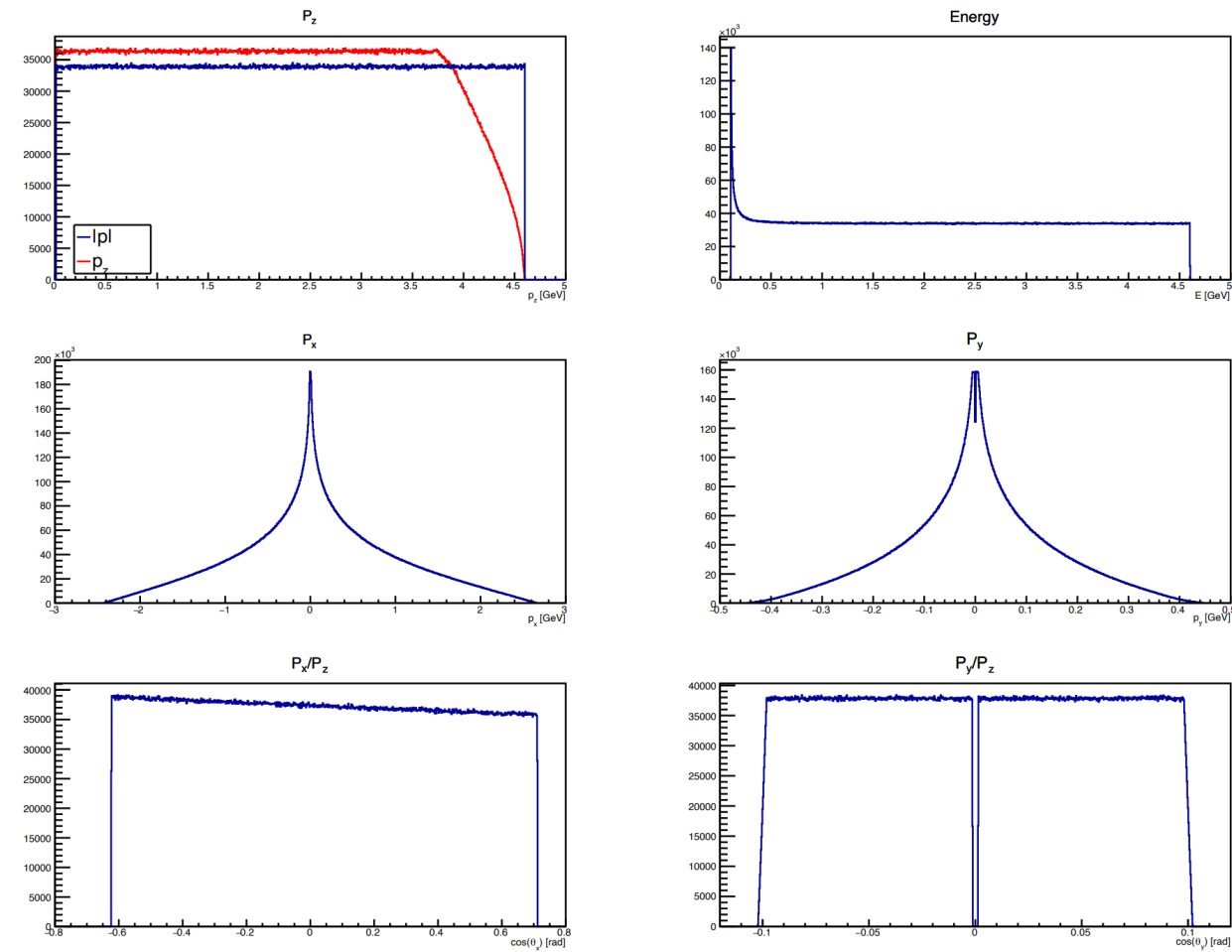
- Original discrepancy first noted with GBL tracks in 2016, but also present in KF tracks.
- It is important to minimize this residual because we are now considering using the location of the ECal cluster with the KF tracking, so being as precise as possible is necessary for accurate tracks



From Alic's weekly 3/29/21

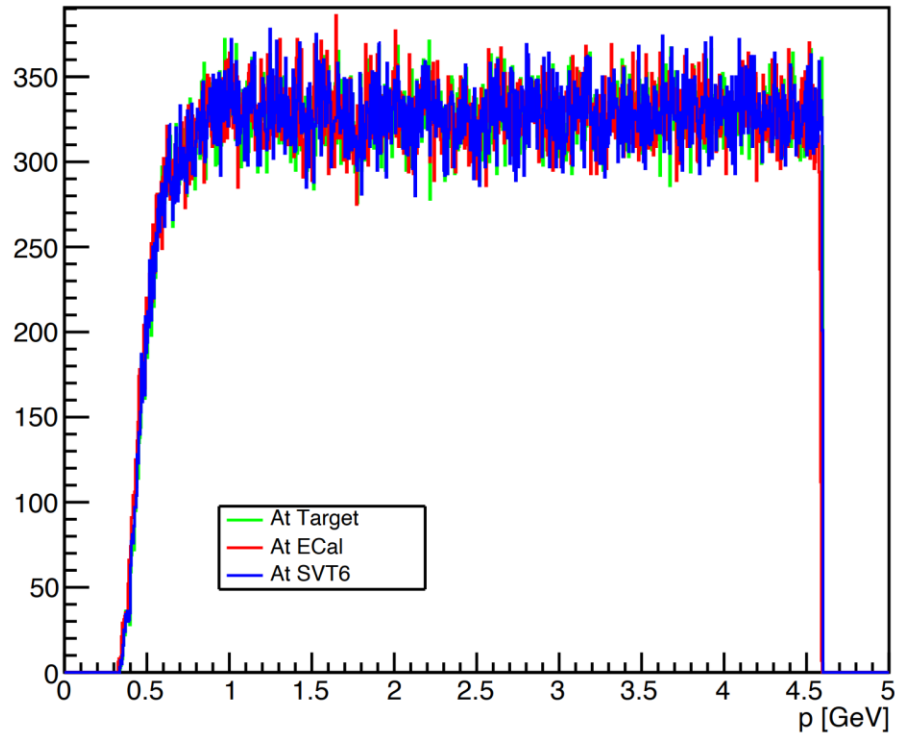
Input Muon Distribution

Muons were thrown with flat momentum, $\tan(\theta_x)$, and $\tan(\theta_y)$ distributions; one muon per MC event.



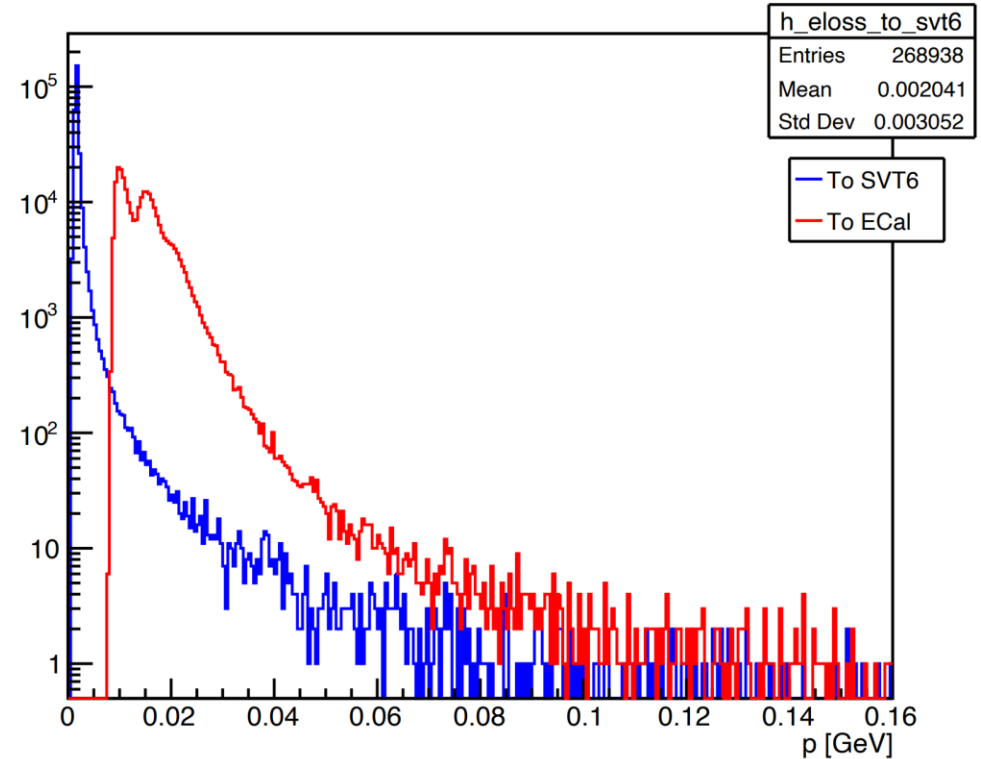
Input Muon Distribution

Primary MC momenta.



Flat distribution of momentum from target to ECal.

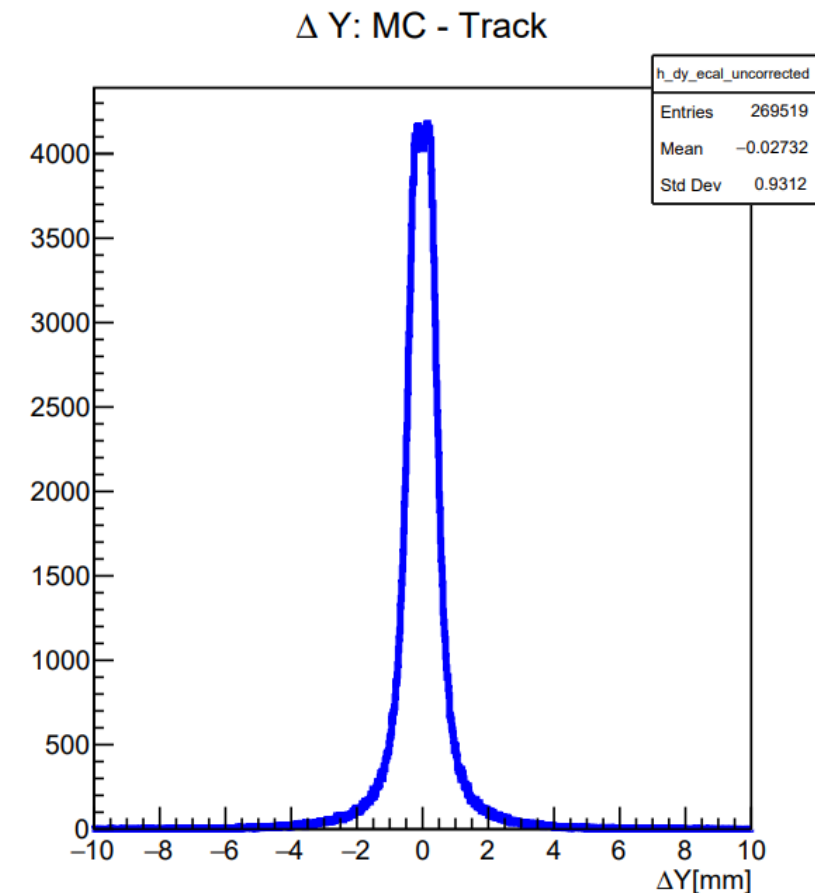
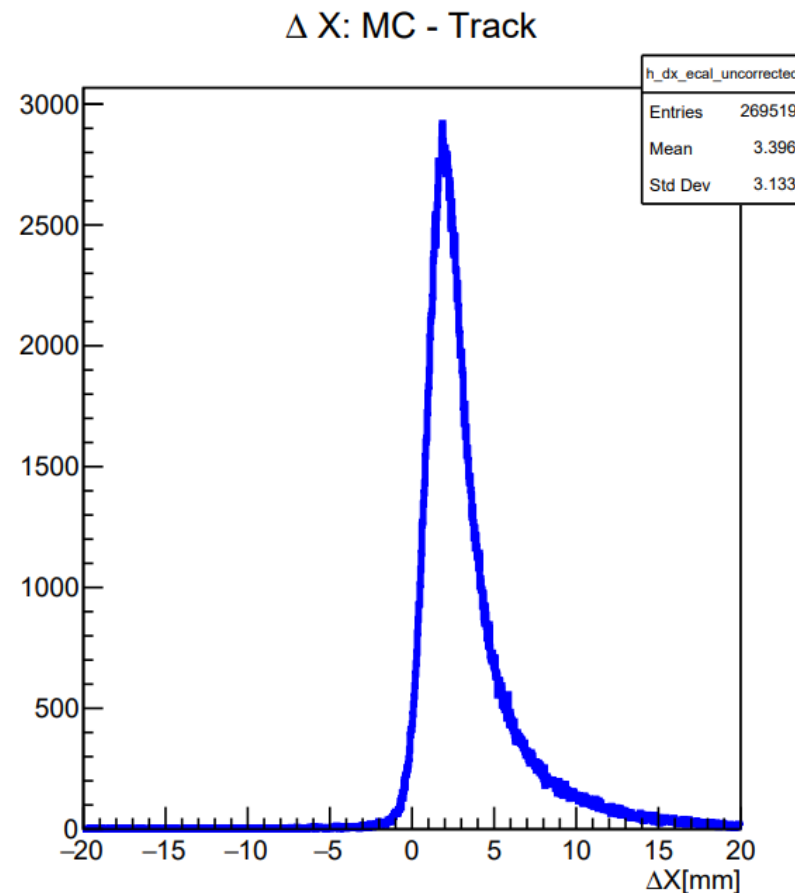
Momentum loss.



Not much energy loss on the way to the ECal. The difference between last tracking layer (SVT6) and the ECal is due to muons passing through the vacuum exit plate and creating secondary particles.

Comparing Track and MC positions at ECal

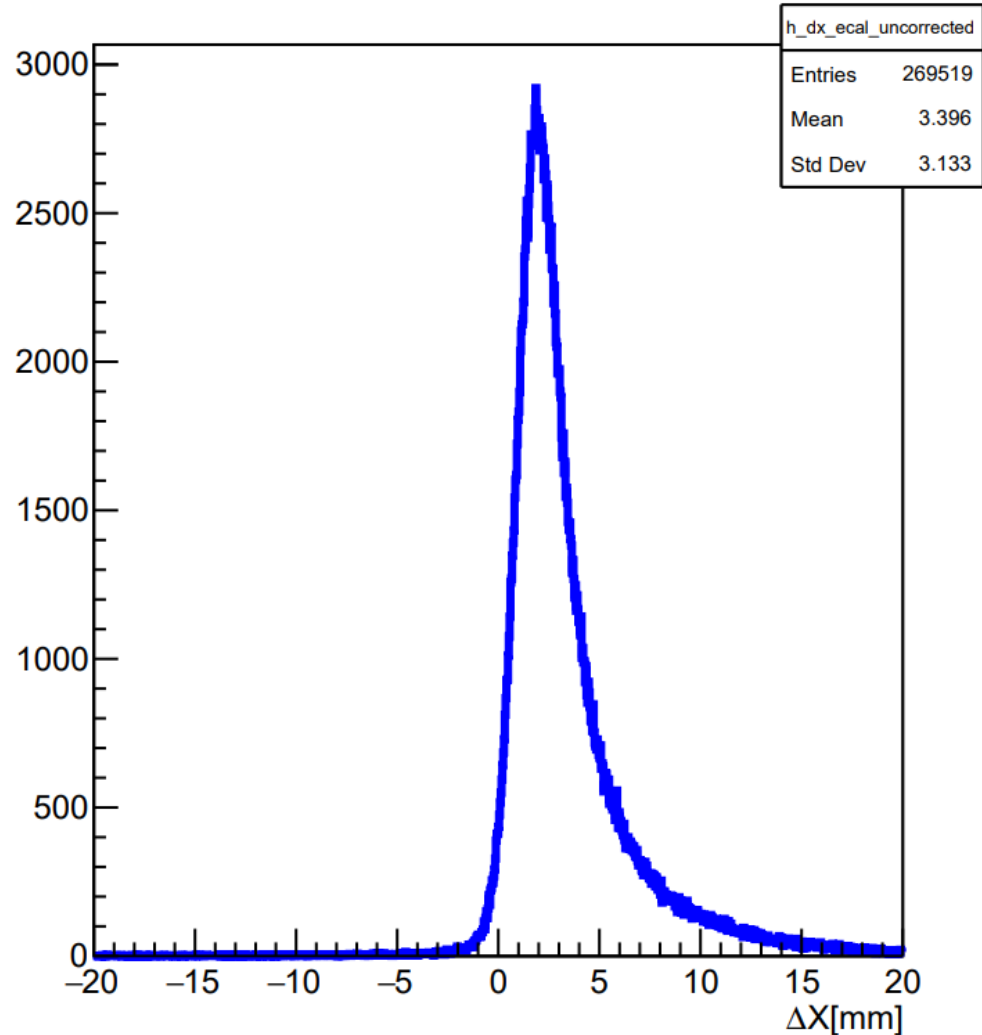
- MC data used here is filtered significantly to trace single MC muons through the detector to ensure we are accurately comparing values.
- Initial comparison between MC position at ECal scoring plane and KF Track position at Ecal Scoring plane showed a >3mm discrepancy in X and much less disagreement in Y.



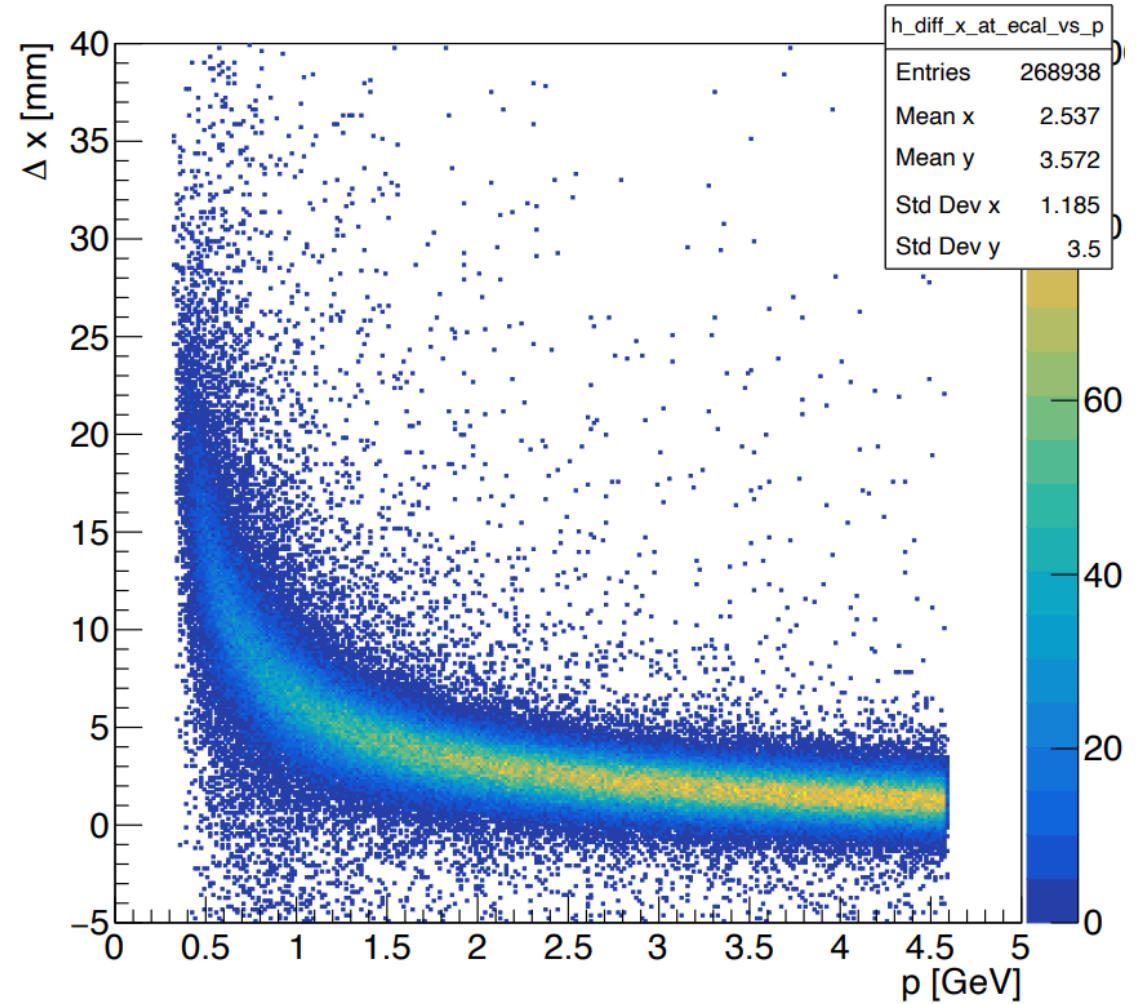
Select only 1 Primary MC particle:	pass=2560892	all=4999900	-- eff=51.22 % cumulative eff=51.22 %
Select only 1 KF or GBL track.:	pass=1017929	all=2560892	-- eff=39.75 % cumulative eff=20.36 %
Select only 1 MC particle at ECal:	pass=858624	all=1017929	-- eff=84.35 % cumulative eff=17.17 %
Select only 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 %

Comparing Track and MC positions at ECal

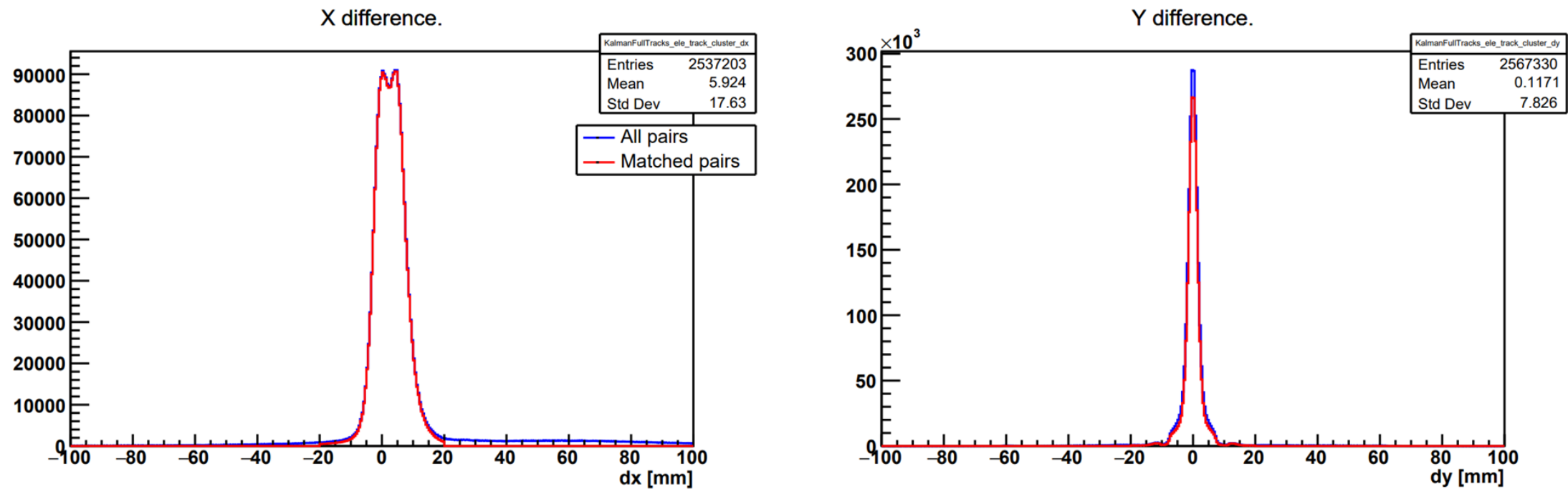
ΔX : MC - Track



KF Track Δx vs p



Comparing Track and MC positions at ECal

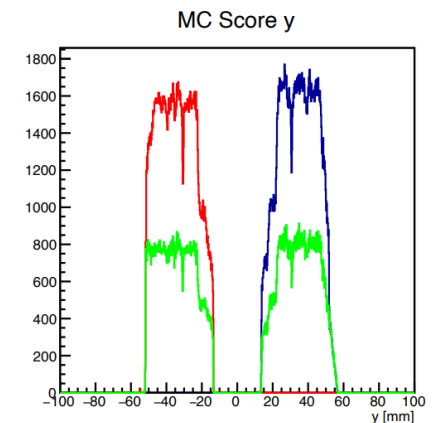
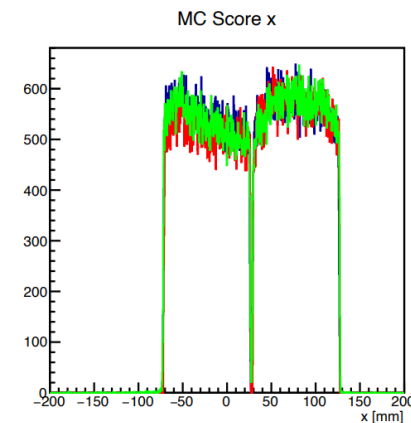
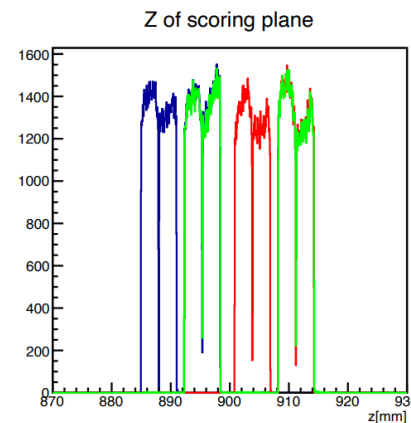
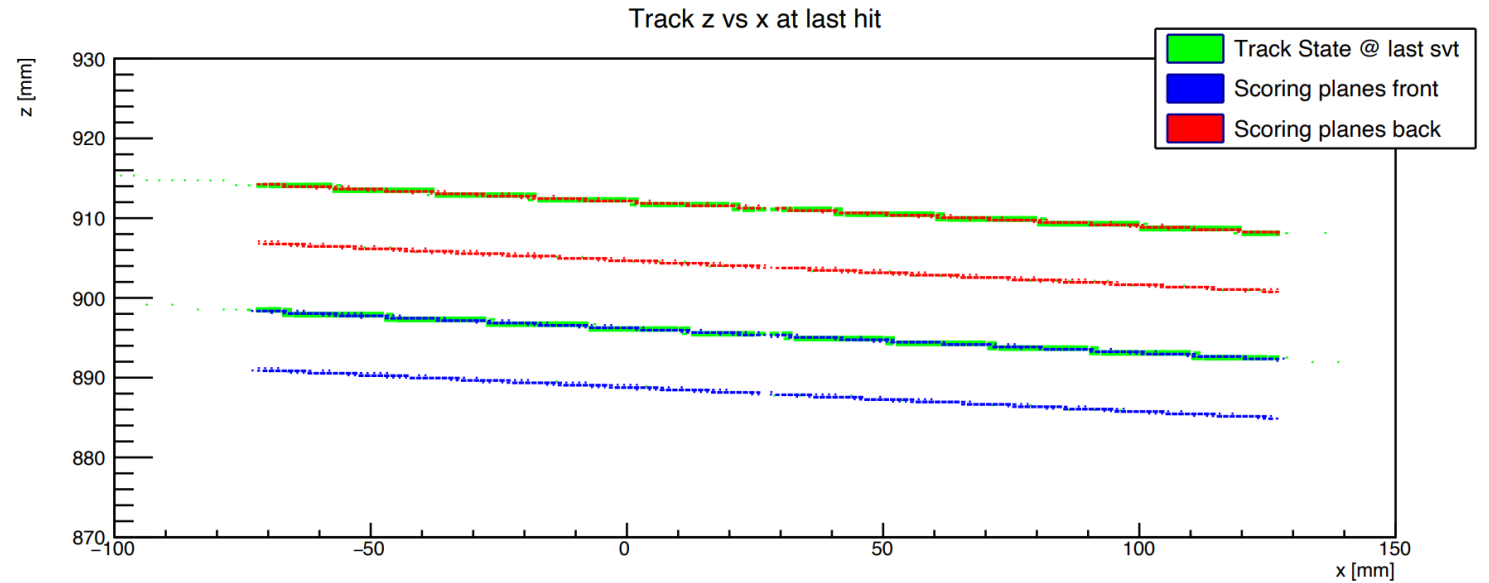


- This was also seen within the HPS Java (trackClusterMatcherMinDistance.java) code when throwing only negatively charged muons. Also pointed out by Alic in 2021
- Maybe the B field between the last SVT layer and the Ecal is causing some error in the track extrapolation?

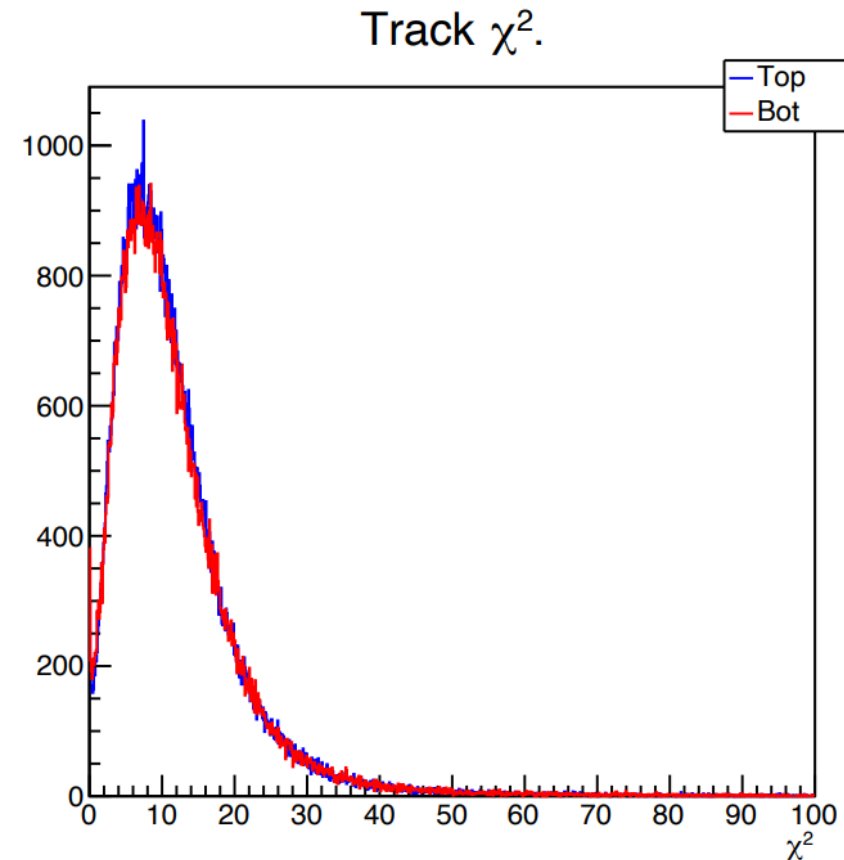
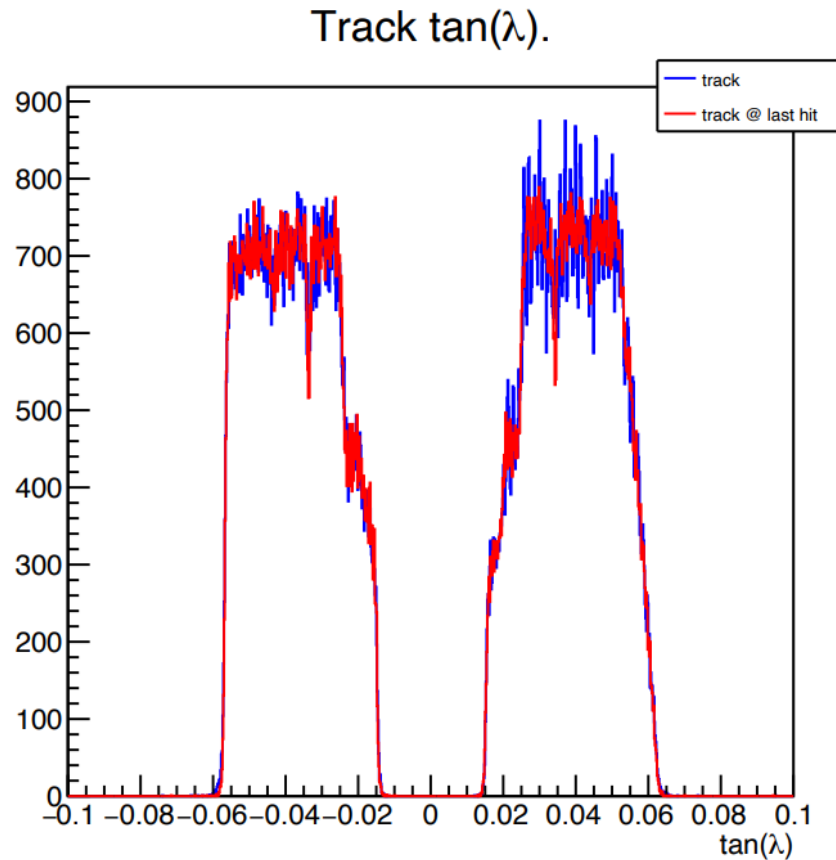
Track state at last SVT layer

After the various truncated fields didn't fix the discrepancy at the ECal scoring plane, the next place to look was the last SVT layer to see if the issue was here as well.

There are 4 scoring planes at lasthit: two for the top tracker and two for the bottom. The second of each is what the track_at_lasthit to, which are highlighted in green.



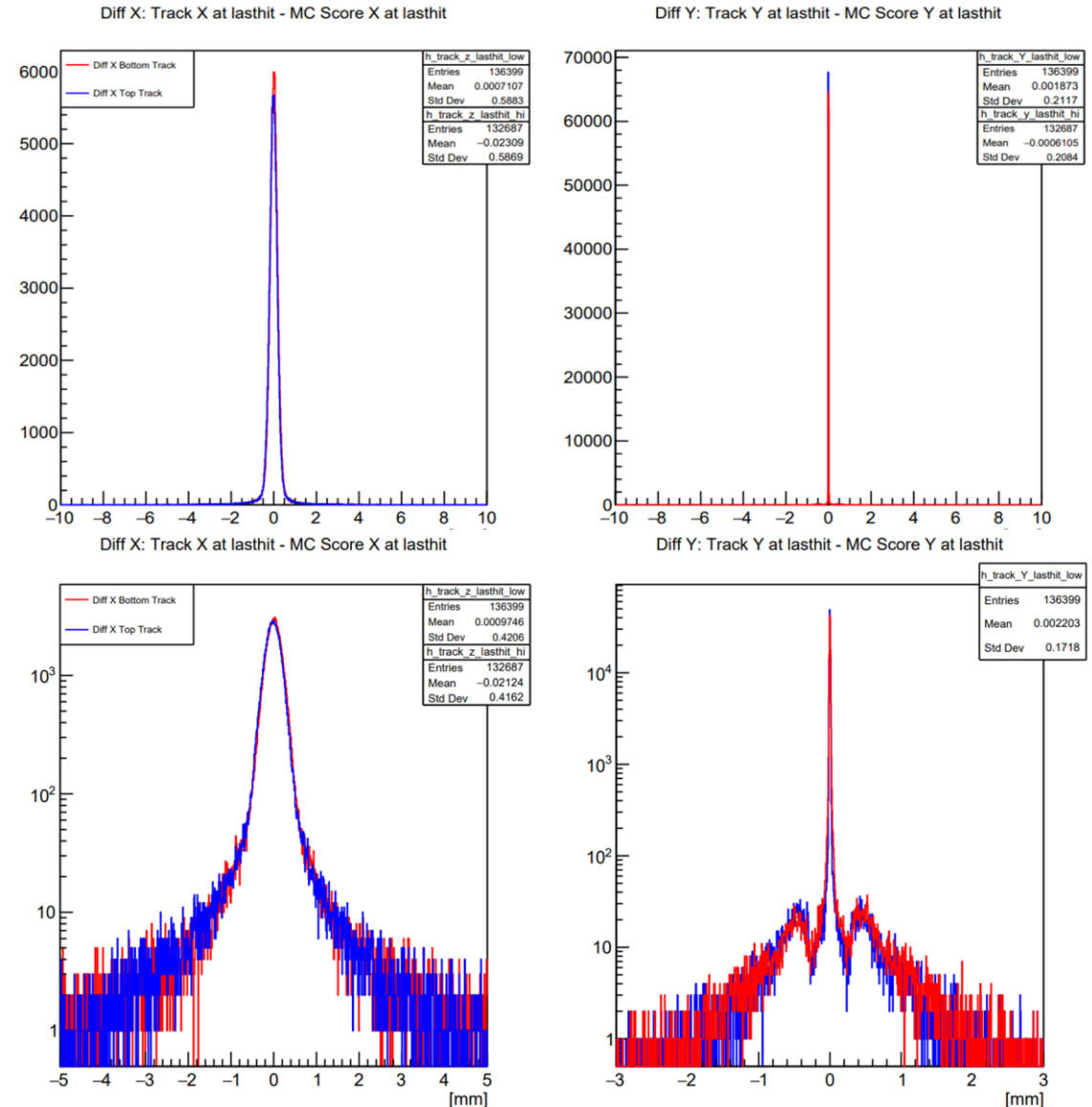
Discrepancies at last SVT layer



- Tracks after filtering are very clean.

Discrepancies at last SVT layer

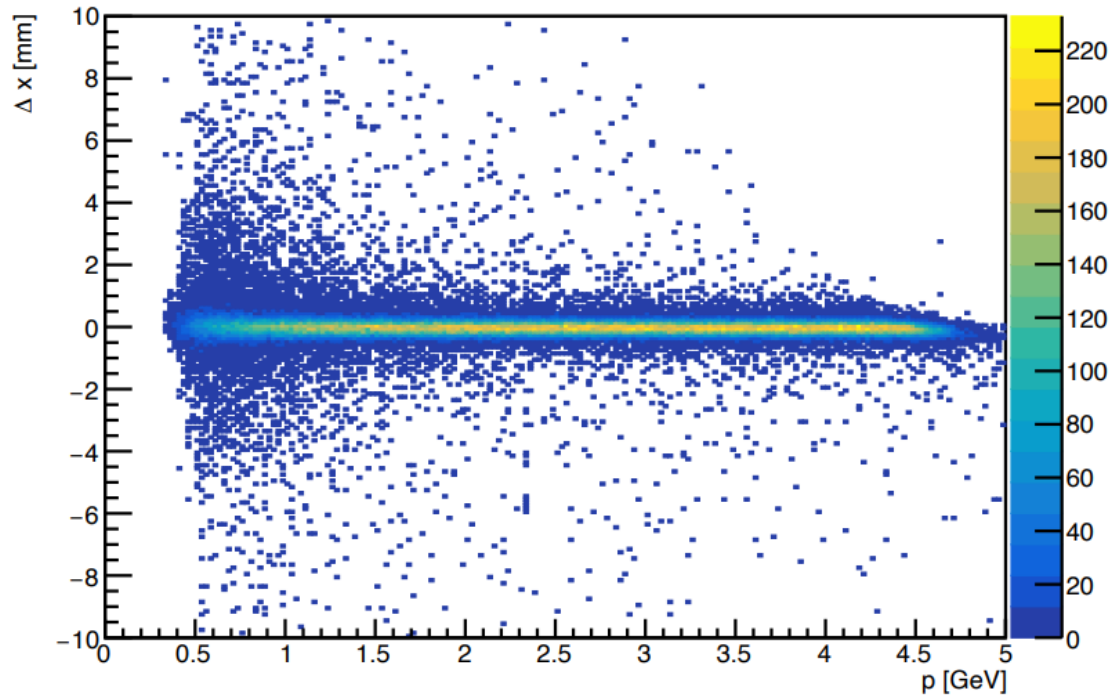
- The next thing to investigate were the position and momentum residuals at the last SVT layer. Not having the same issue here would serve as evidence that something is going wrong in the extrapolation code.
- Top and bottom tracks separated and show agreement. The discrepancy here is very small and exhibits a bit of strange behavior in Y visible in the log-scale plot.
- Because these are in quite good agreement, the discrepancy must be sourced somewhere in the track extrapolation code



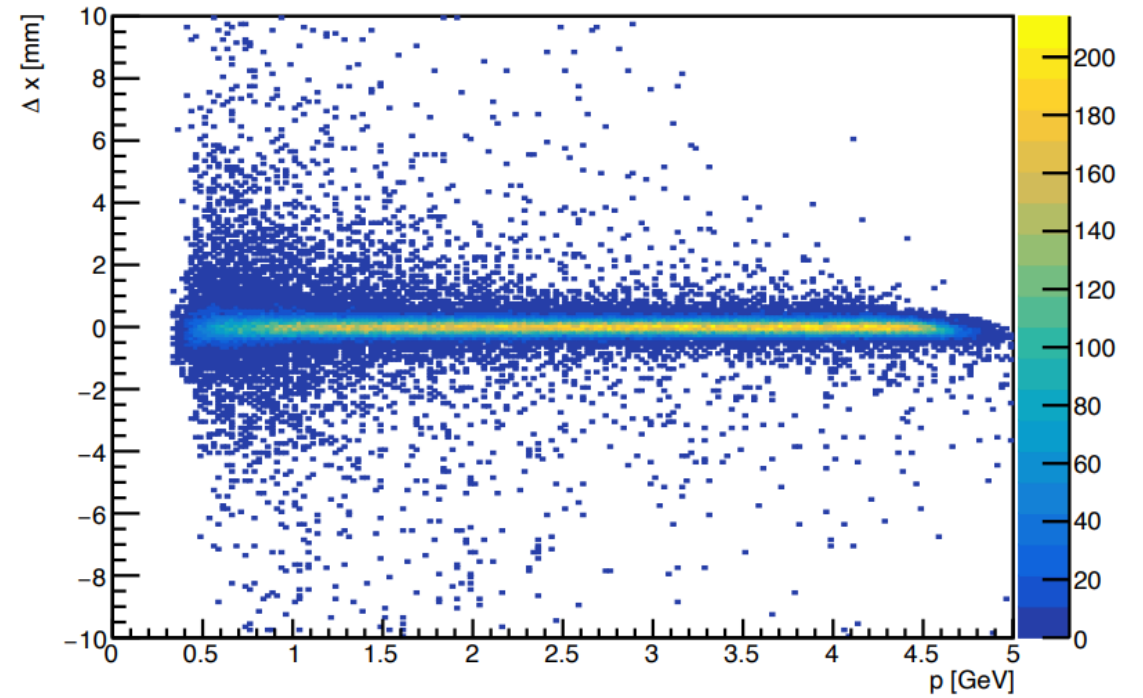
Track state at last SVT layer



Track Δx vs p top



Track Δx vs p bot



- No momentum dependence in the x residual seen at the last tracking layer

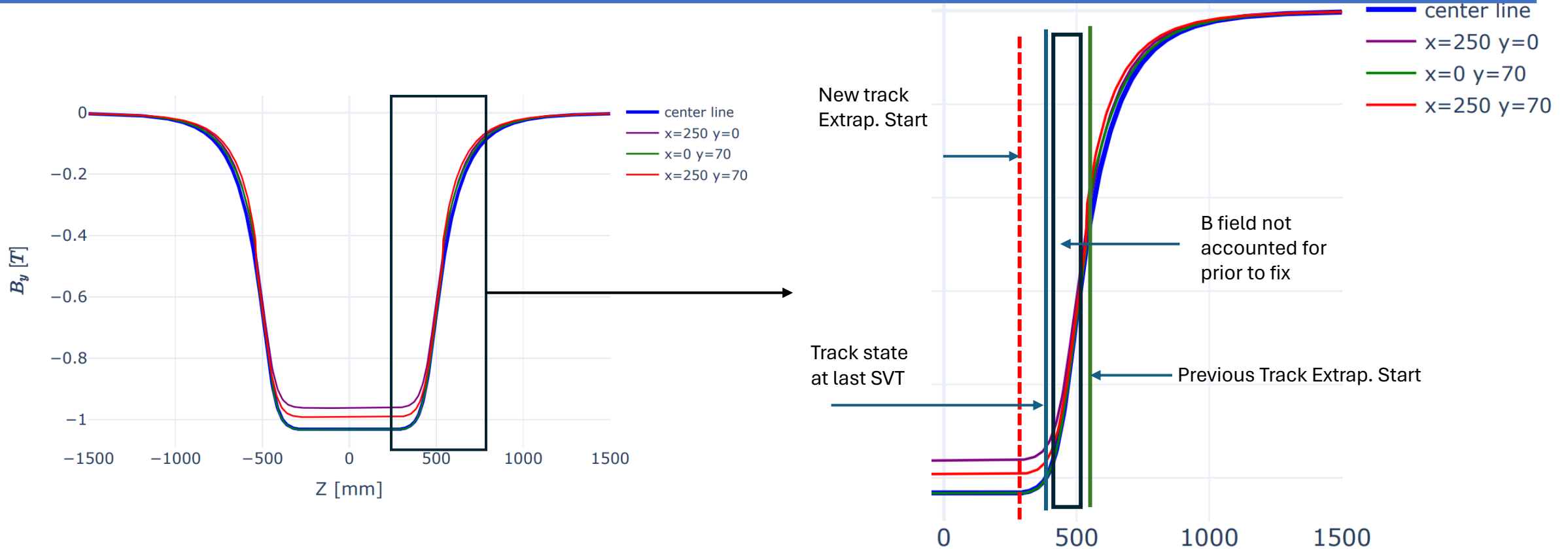
- In a long zoom session with PF at CERN, Maurik in Maine, and myself at UNH we stepped through HPS java with a debugger
- One result of the debugging session: b field is retrieved correctly, Runge-Kutta stepping appears to be functioning as intended.
 - 10x total steps resulted in no change in discrepancy

Largest sources of the discrepancy

- Ecal z position scoring plane originally located at 1443mm, moved to 1448mm
- Largest fix: starting the track extrapolation at the true last SVT tracker plane and *not* at the end of the tracking volume
 - Ecal_track_extrapolation_start_z = 800 in TrackUtils.Java

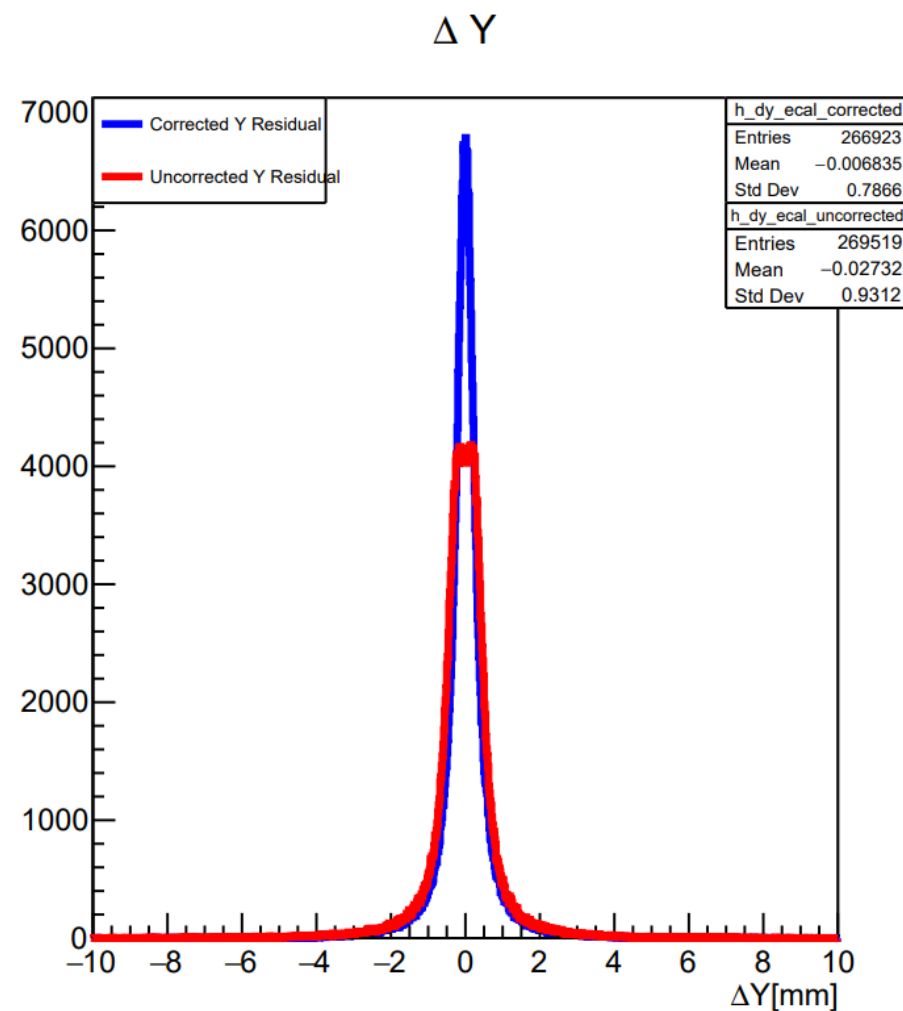
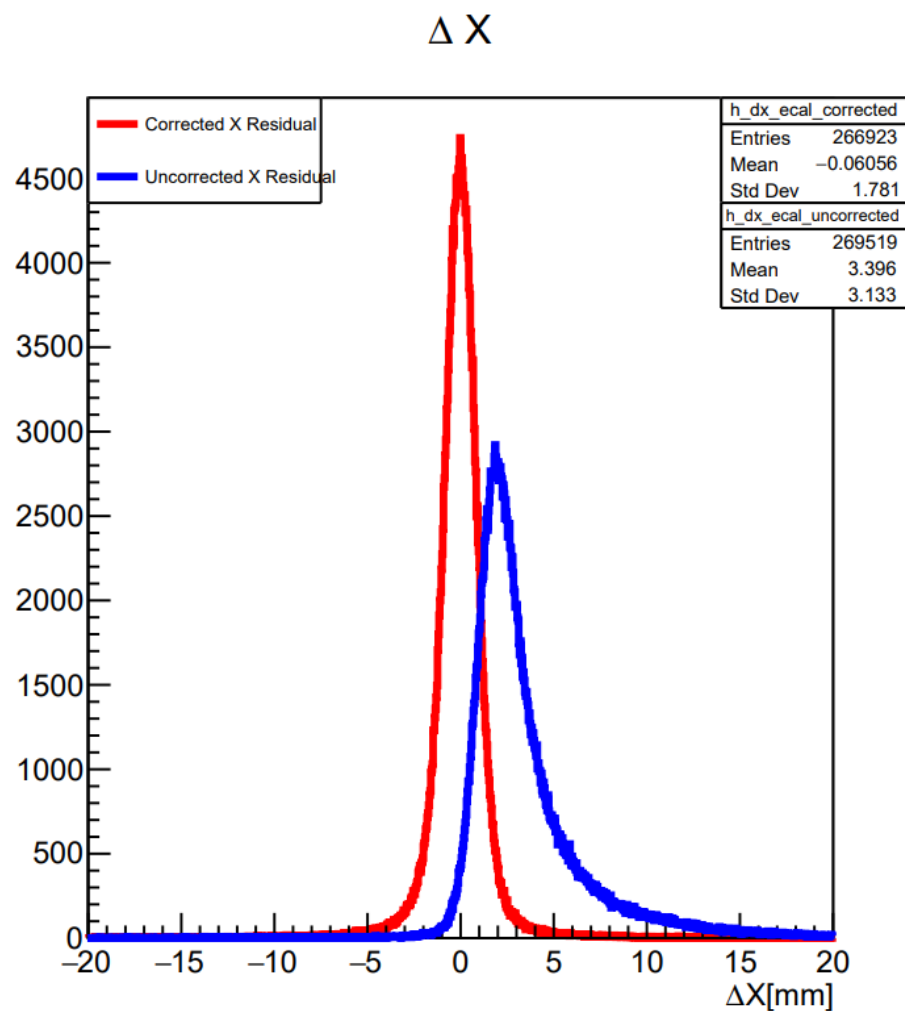
```
public static final double DIPOLE_EDGE_ENG_RUN = 457.2 + 1080 / 2;  
+ public static final double ECAL_TRACK_EXTRAPOLATION_START_Z = 800; // Starting point for track  
extrapolation to ECAL -- MWH 2024/4/15  
+
```

Largest sources of the discrepancy



- The previous z coordinate where the extrapolation of the track was using the information at the last track status at the last SVT layer but starting the extrapolation at too high of a z and *not* accounting for the B field in between.
- The fix sets the extrapolation to start at the same z value as the last SVT track status and then steps through all of the present field with Runge-Kutta

Confirmation of the fix

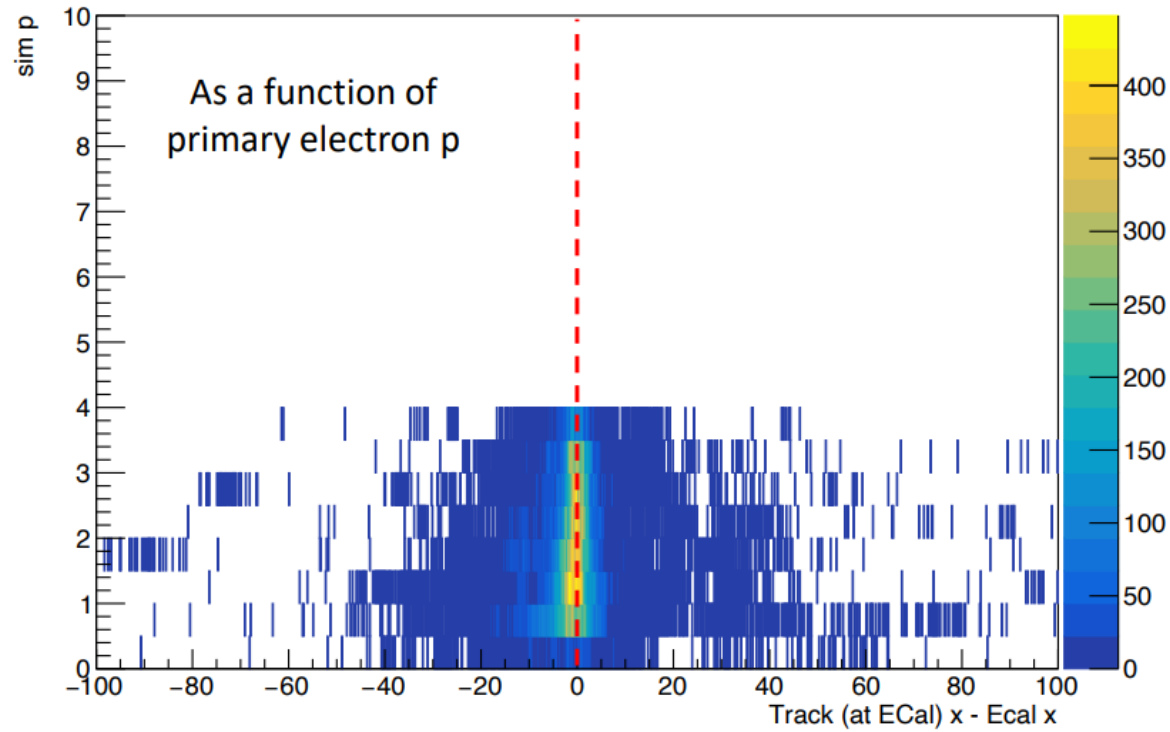


- Residuals are much smaller now with same MC muon input distribution

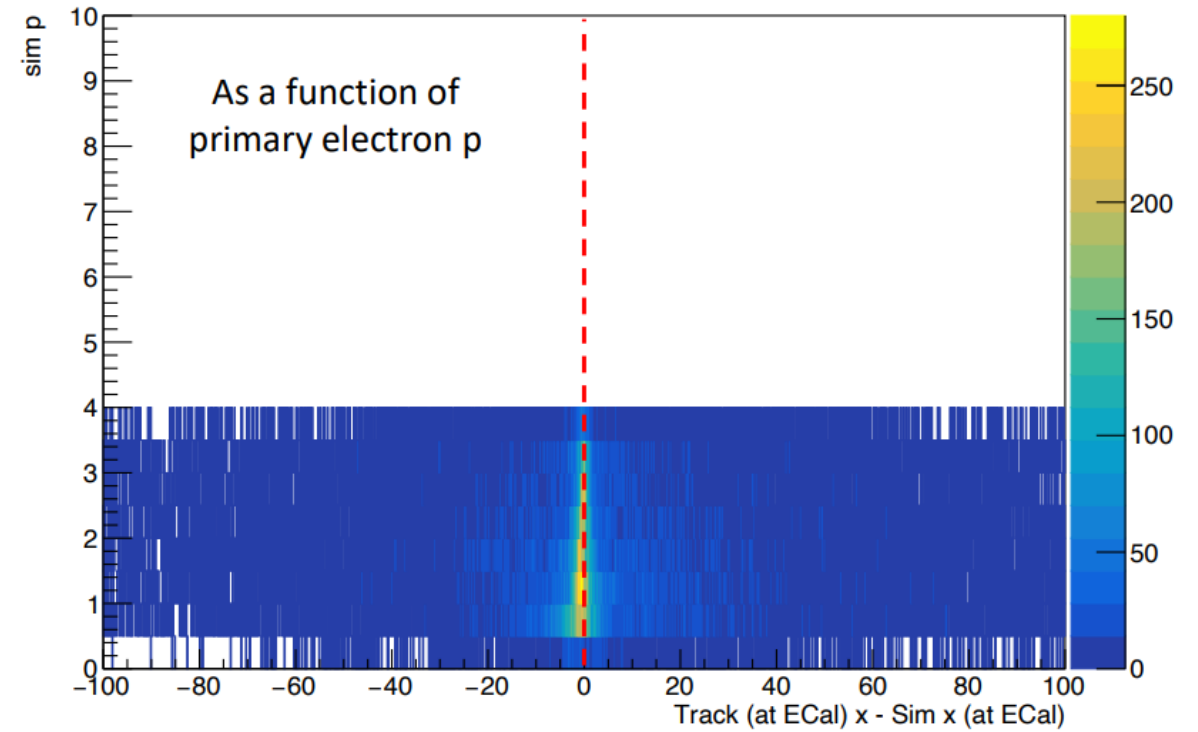
Fix also confirmed by Abhisek

Events with **exactly 1 Primary electron, 1 KF track and 1 ECal cluster**

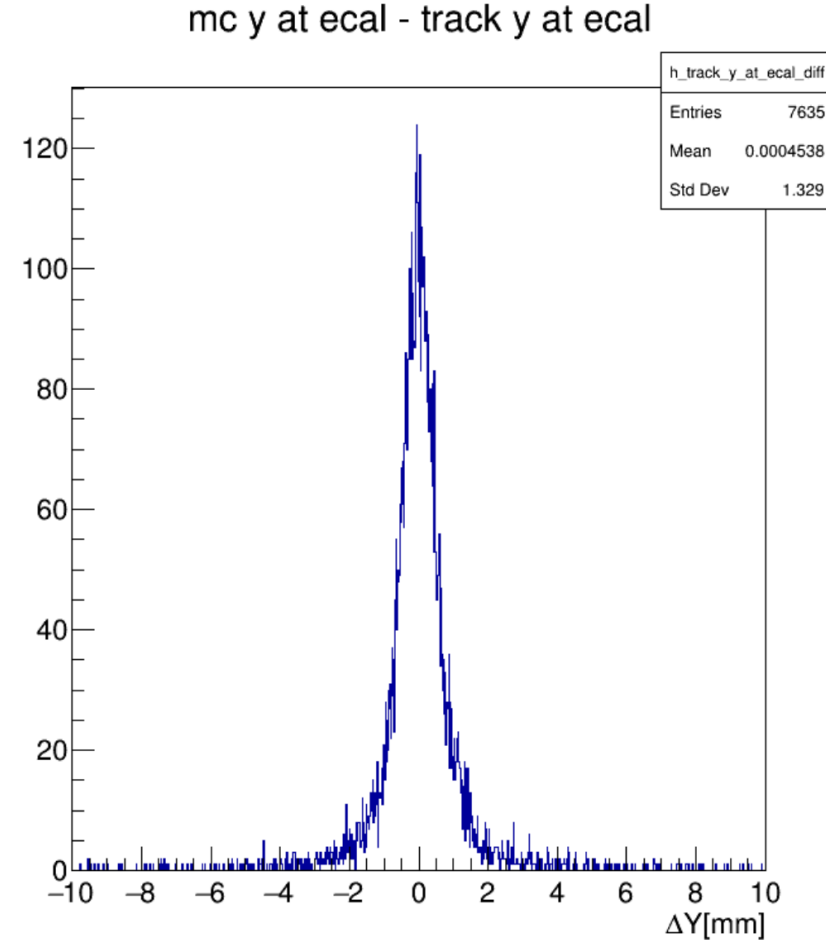
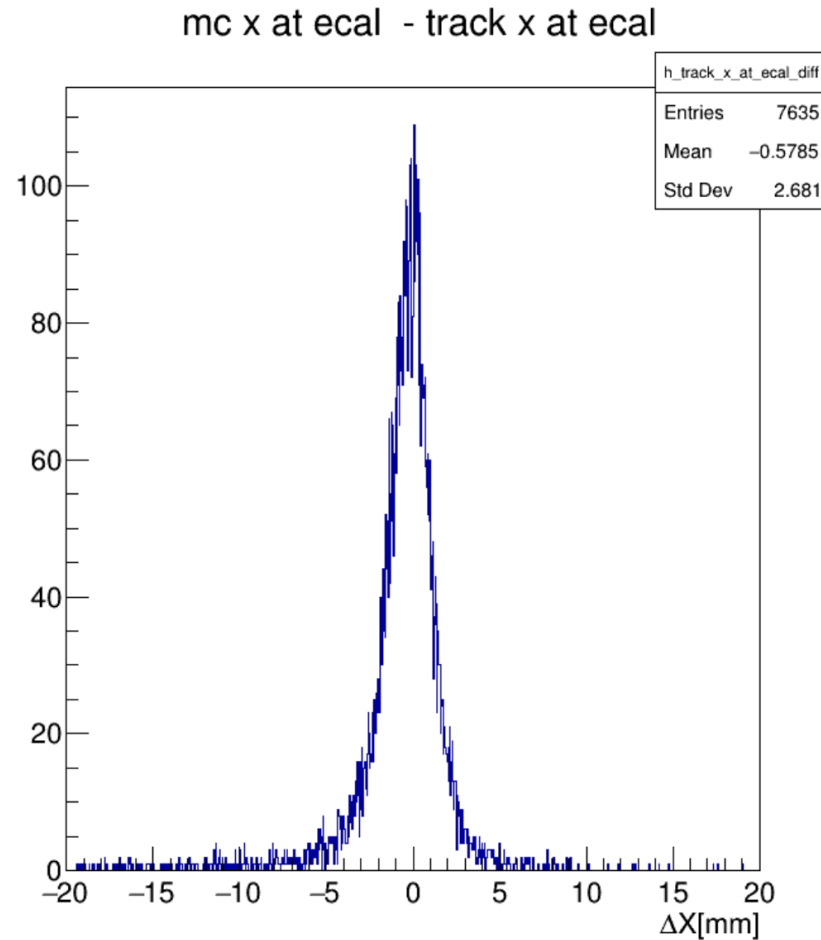
Track x at ECal – ECal Cluster x



Track x at ECal - MC Tracker Hit x at ECal



Fixed Extrapolation Code with Electrons



- Electrons still exhibit a small discrepancy due to fringe field; ECal flange $z = 1221\text{mm}$ relative to target or 763.8mm relative to magnetic field center

Summary and further ECal Plans

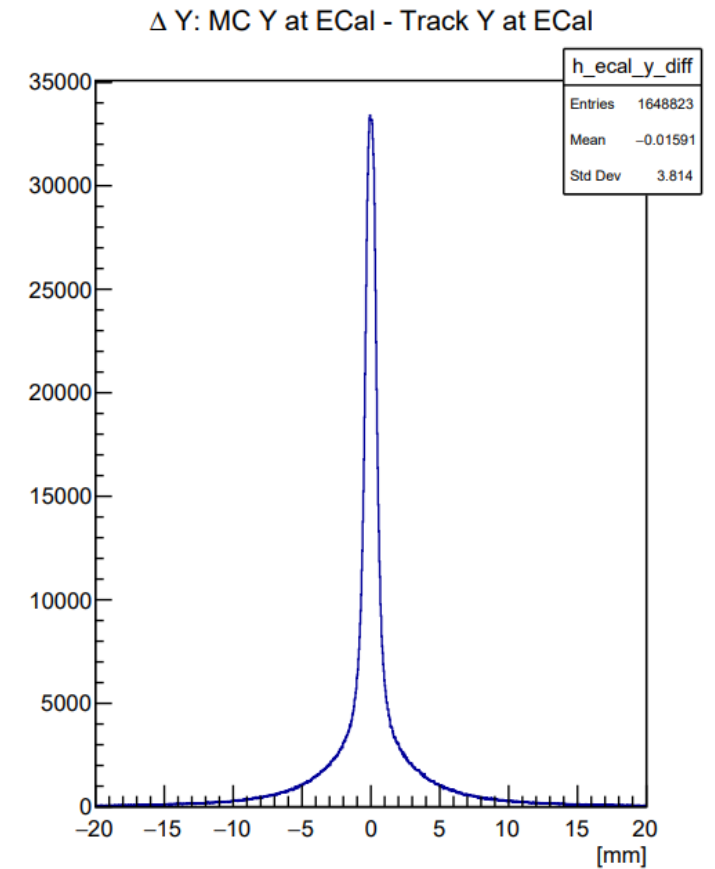
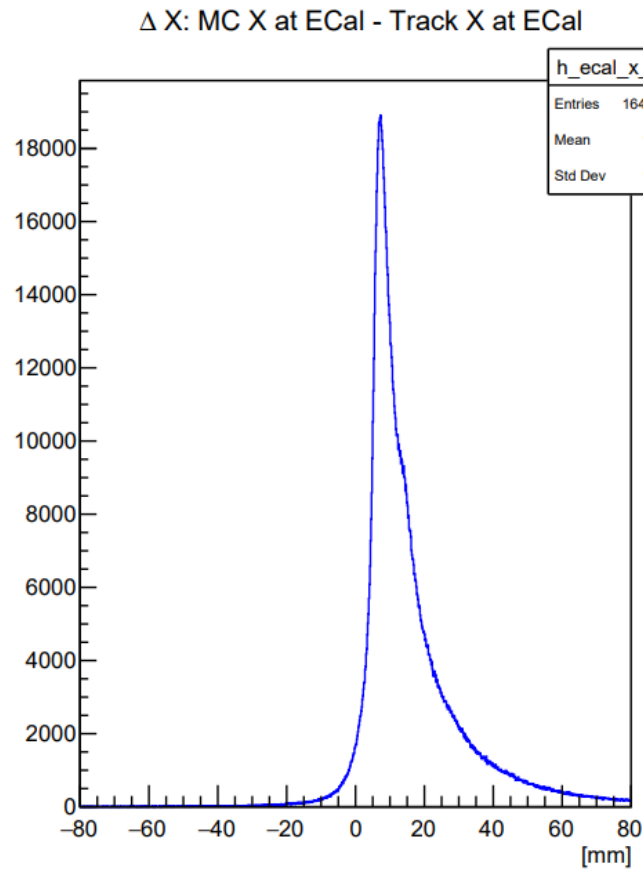
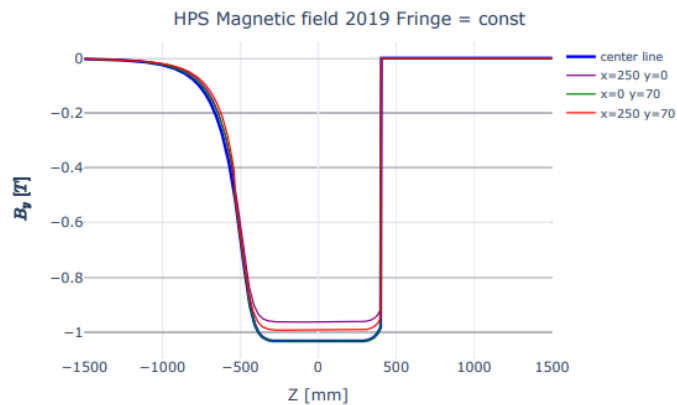
- The fix is introduced in HPS-Java – iss1026_fix_track_extrapolation
 - Z position of Ecal scoring plane moved from 1443mm → 1448mm
 - Track extrapolation start z moved from: DIPOLE_EDGE_ENG_RUN → Ecal_track_extrapolation_start_z = 800
- Look at ECal position corrections
 - The current corrections use the ECal scoring plane at 1443, not 1448 where it is now located with the updated code. Corrections will change very little
- Revisit using ML to improve ECal calibration and use information outside of fiducial region
- What else?

Backup

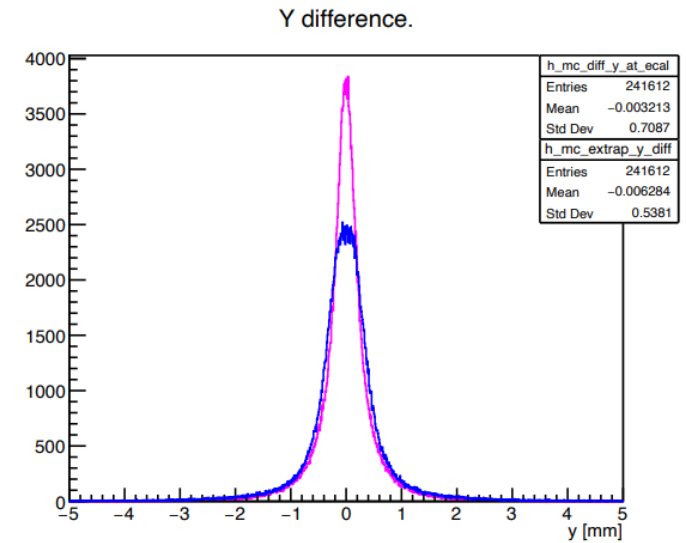
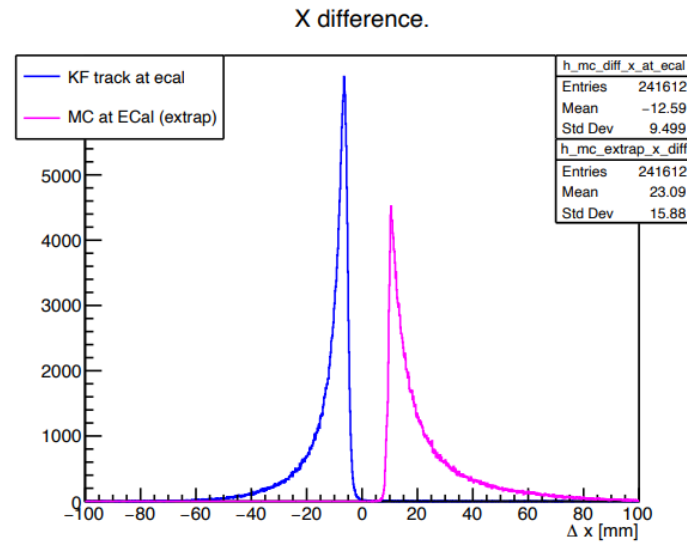
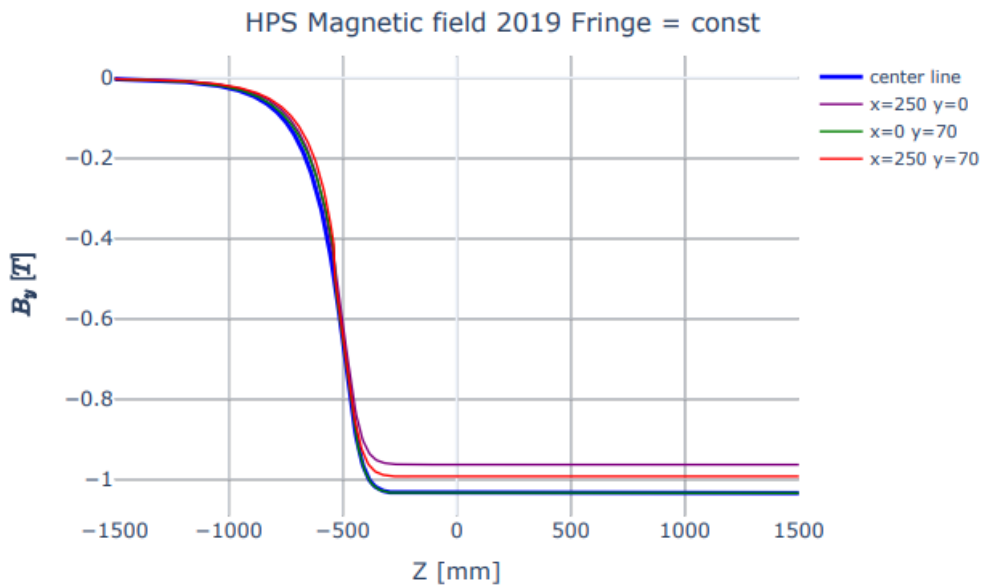


Truncating B Field at lasthit: dx gets worse

- Discrepancies at Ecal scoring plane using MC Muon sample with the B field truncated after the last SVT layer with zeros, not just left as undefined.



Truncating B Field at lasthit: dx gets worse



Position Distributions of MC Sample

