Tracking Update

Norman Graf (SLAC)

HPS Spring Collaboration Meeting

JLab, May 23, 2018

Tracking-specific talks @ this meeting

- SVT upgrade (Tim)
- Software update (Maurik)
- Update on MC (Takashi)
- Beam position and tilt (Bradley)
- SVT Alignment (Alessandra)
- Track top-bottom asymmetry(Miriam)
- Update on Kalman filter (Robert)

- Why yet another tracking talk?

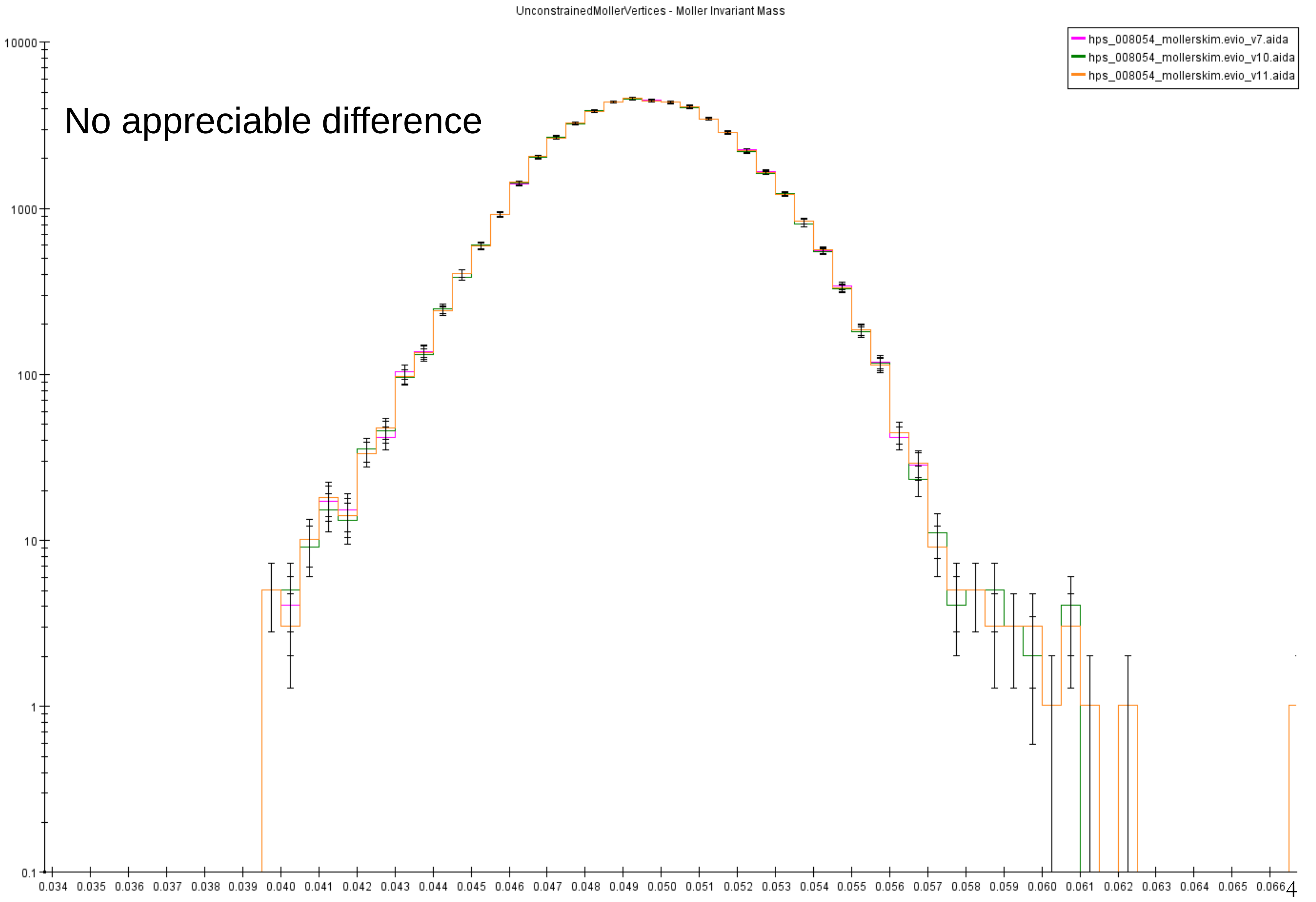
Alignment

- Alessandra and Mariangela have developed several alignments using various combinations of field-on and field-off data and various strategies to internally align detector planes.
  - Using millepede for internal relative alignment, then forcing d0 and z0 to be centered to zero.

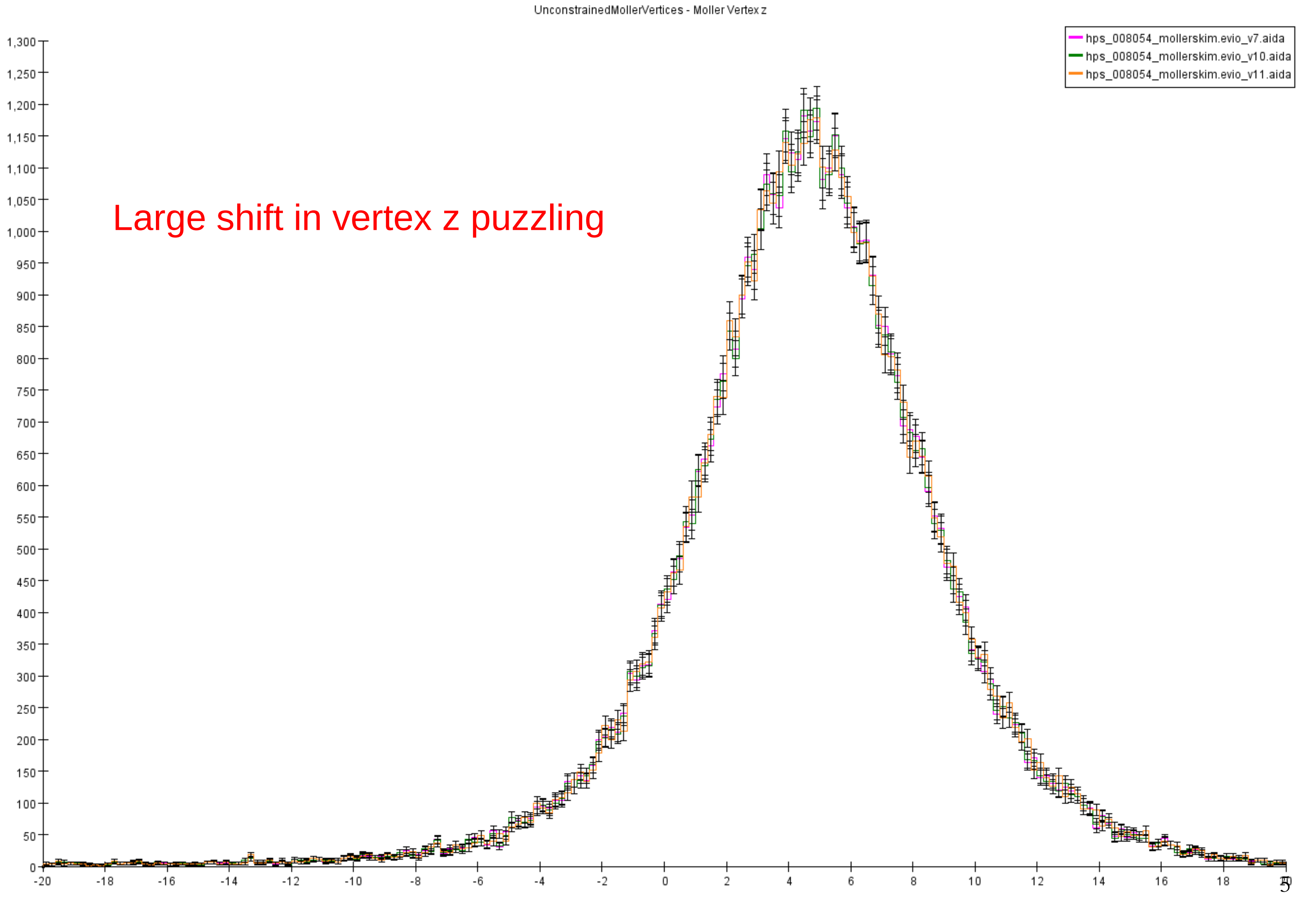
- Use Møller events to characterize/qualify the SVT alignment.

- Reconstruct some number of Møller events using these detectors and see whether there are any metrics to decide between them.

Møller Invariant Mass



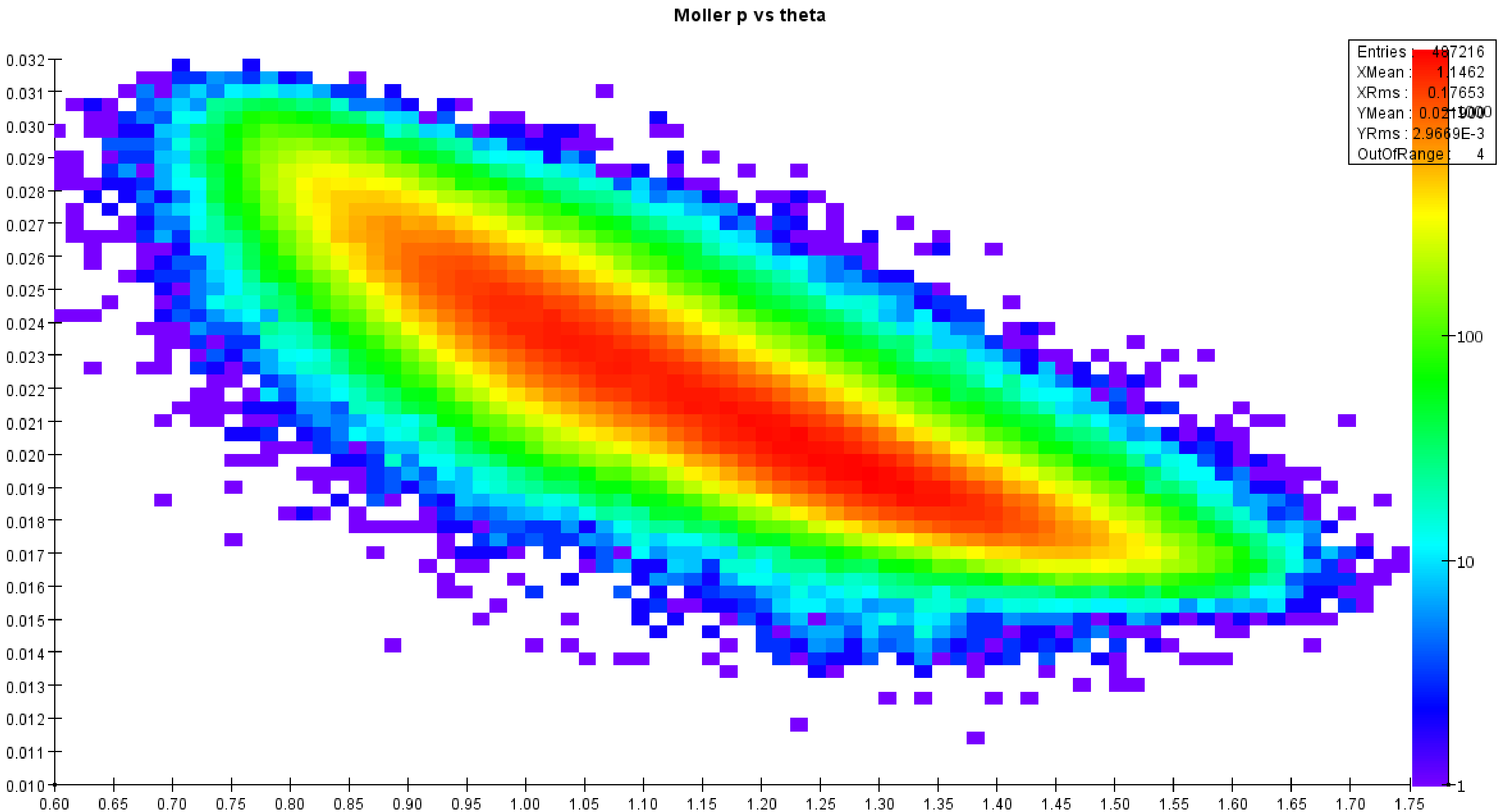
Møller Vertex Z Position



Detector alignment

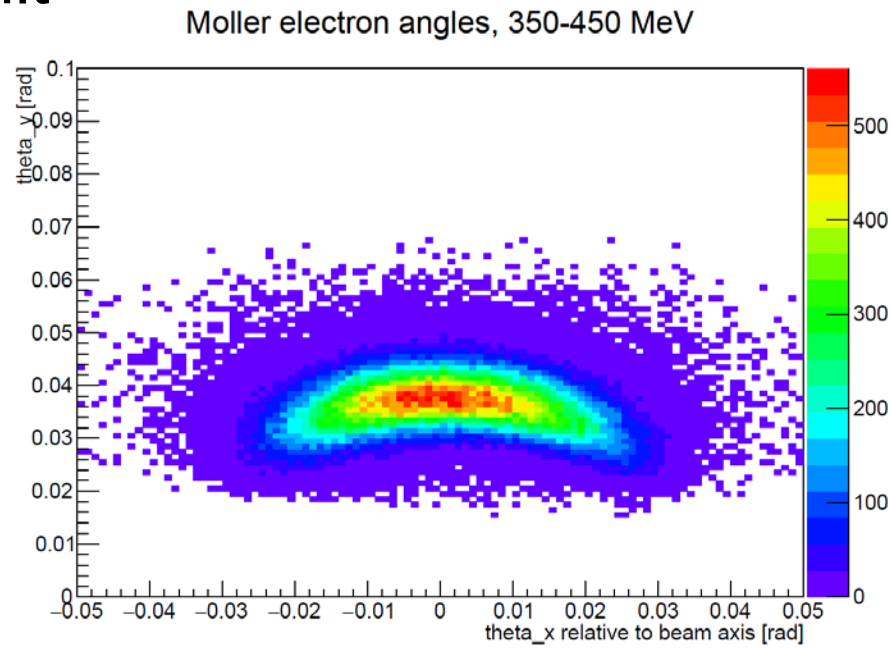
- No smoking guns to select between detectors, but fact that target position has moved so much is cause for concern.
  - Z of target is NOT one of the millepede constraints.
- Use other kinematic constraints such as momentum vs theta. We know what the functional form should be, so now exploring how best to utilize this to introduce global constraints.
- Work in progress.

Møller momentum vs theta



Moller Theta-momentum

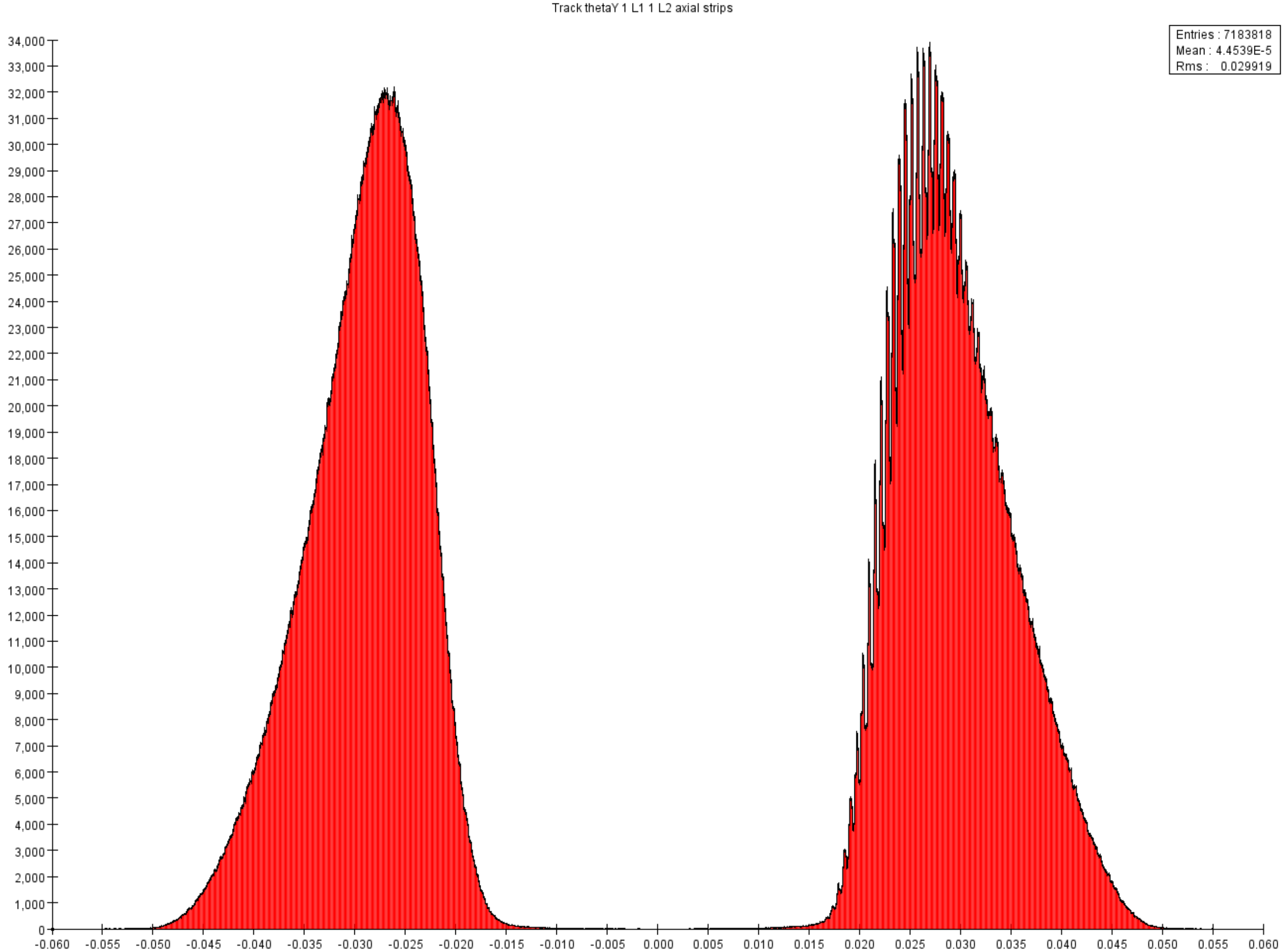
- Take slices in momentum, plot theta-x vs theta-y
  - Fit to circle gives information on possible upper or lower SVT tilt



  - Used by Sho to develop tweak pass6 corrections
  - Work in progress to repeat/reproduce.

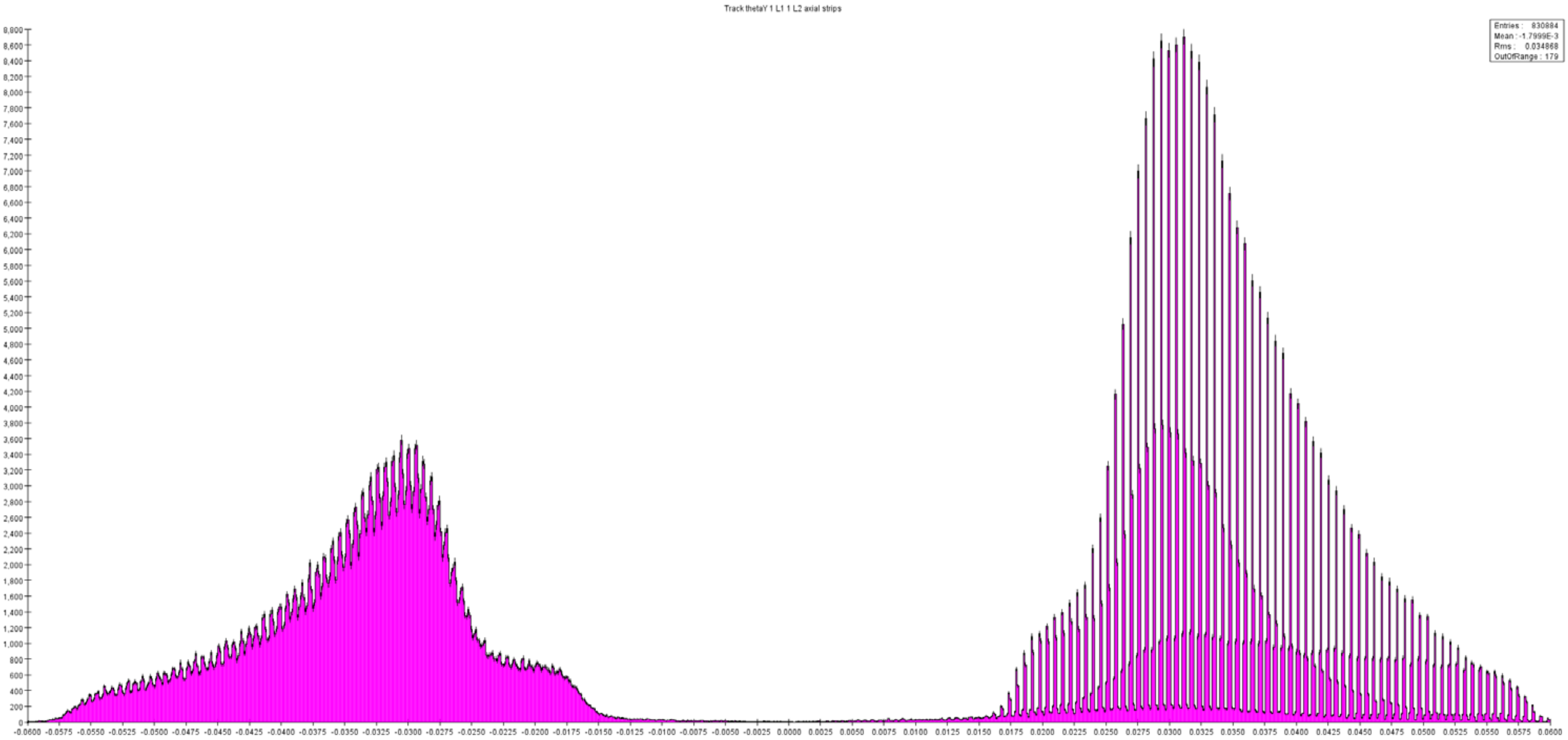
Theta_Y

- Simply plotting Theta_y shows interesting difference between top and bottom:



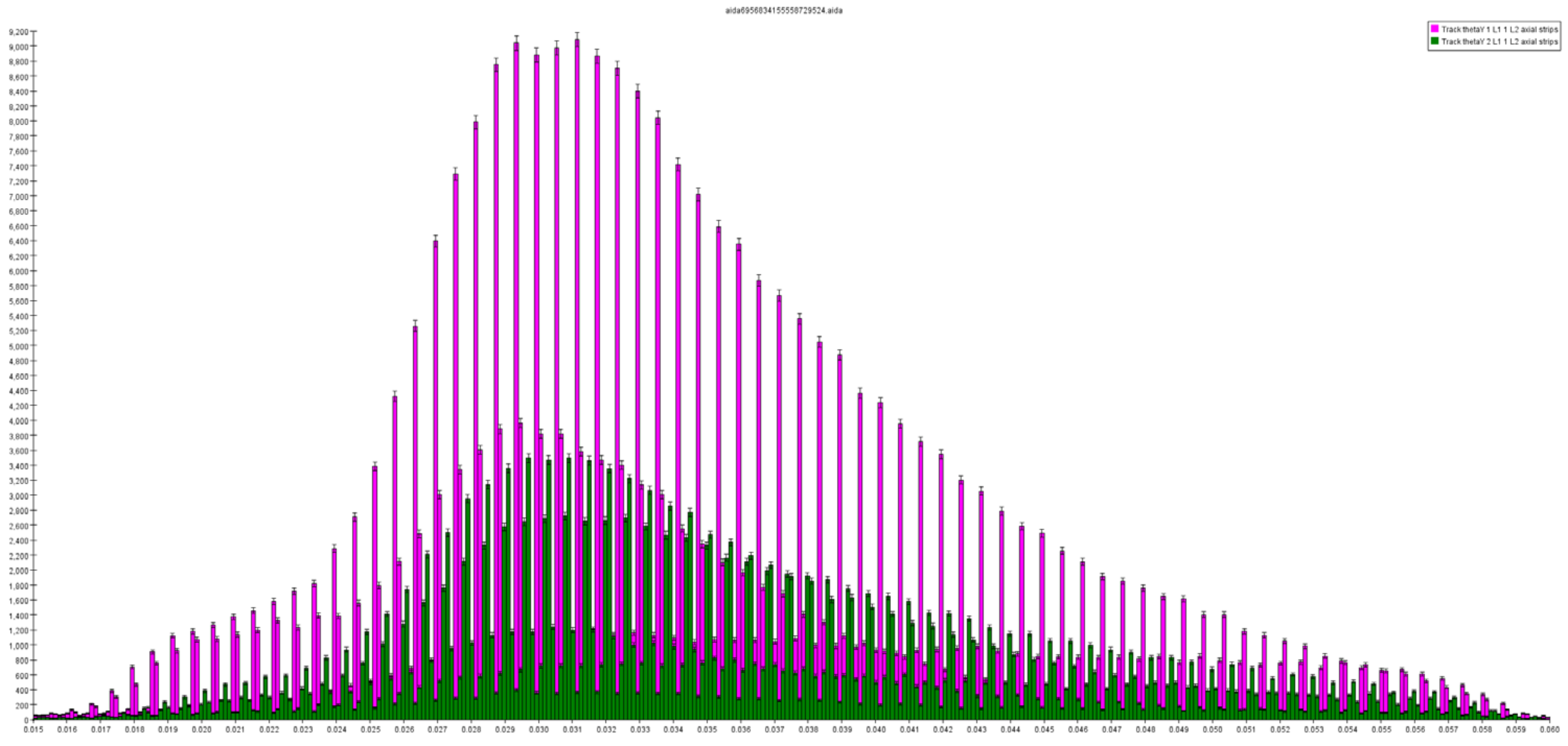
Theta_Y

- Selecting single-strip clusters in axial layers 1 & 2 accentuates this difference.

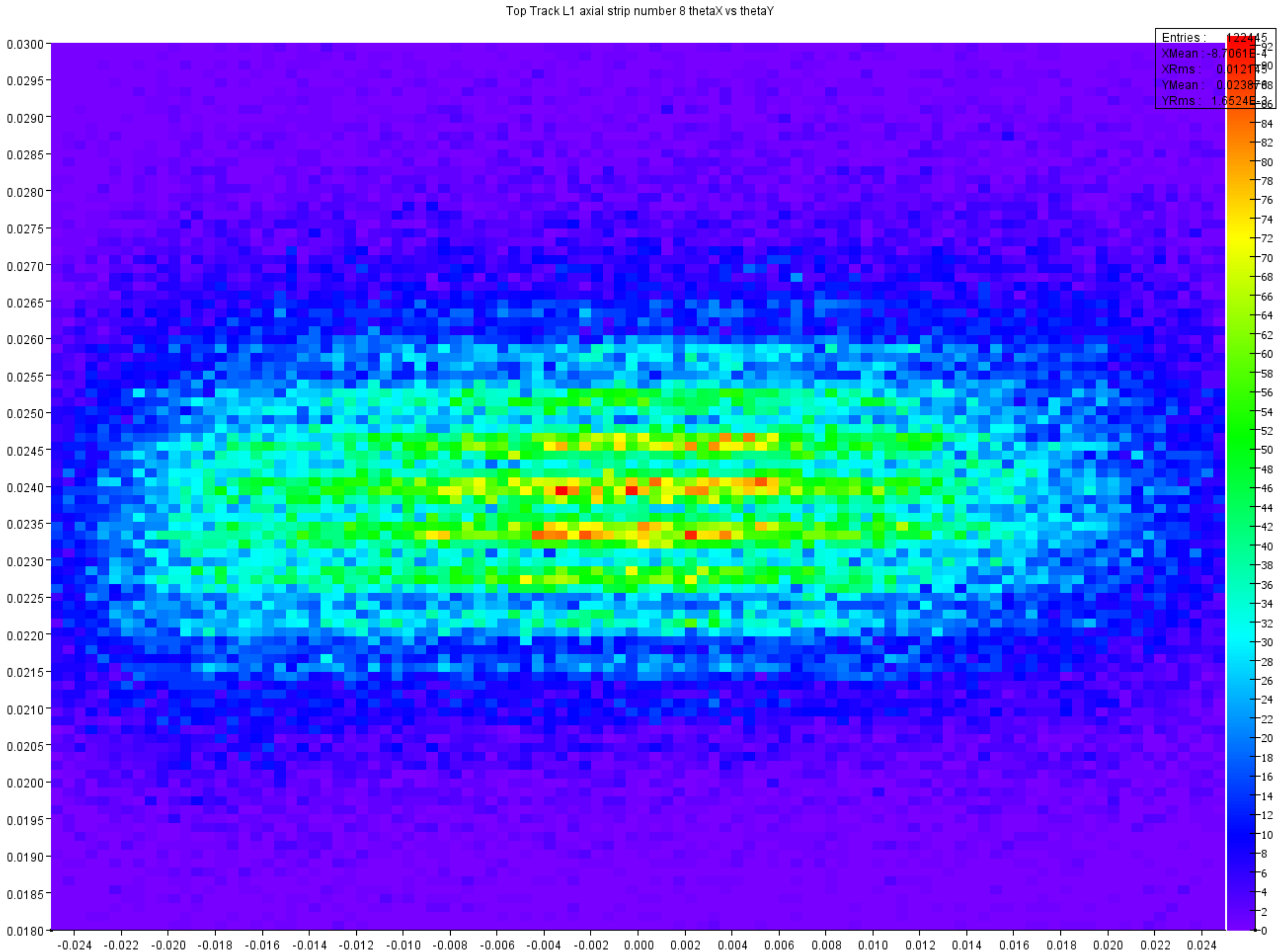


Theta_Y

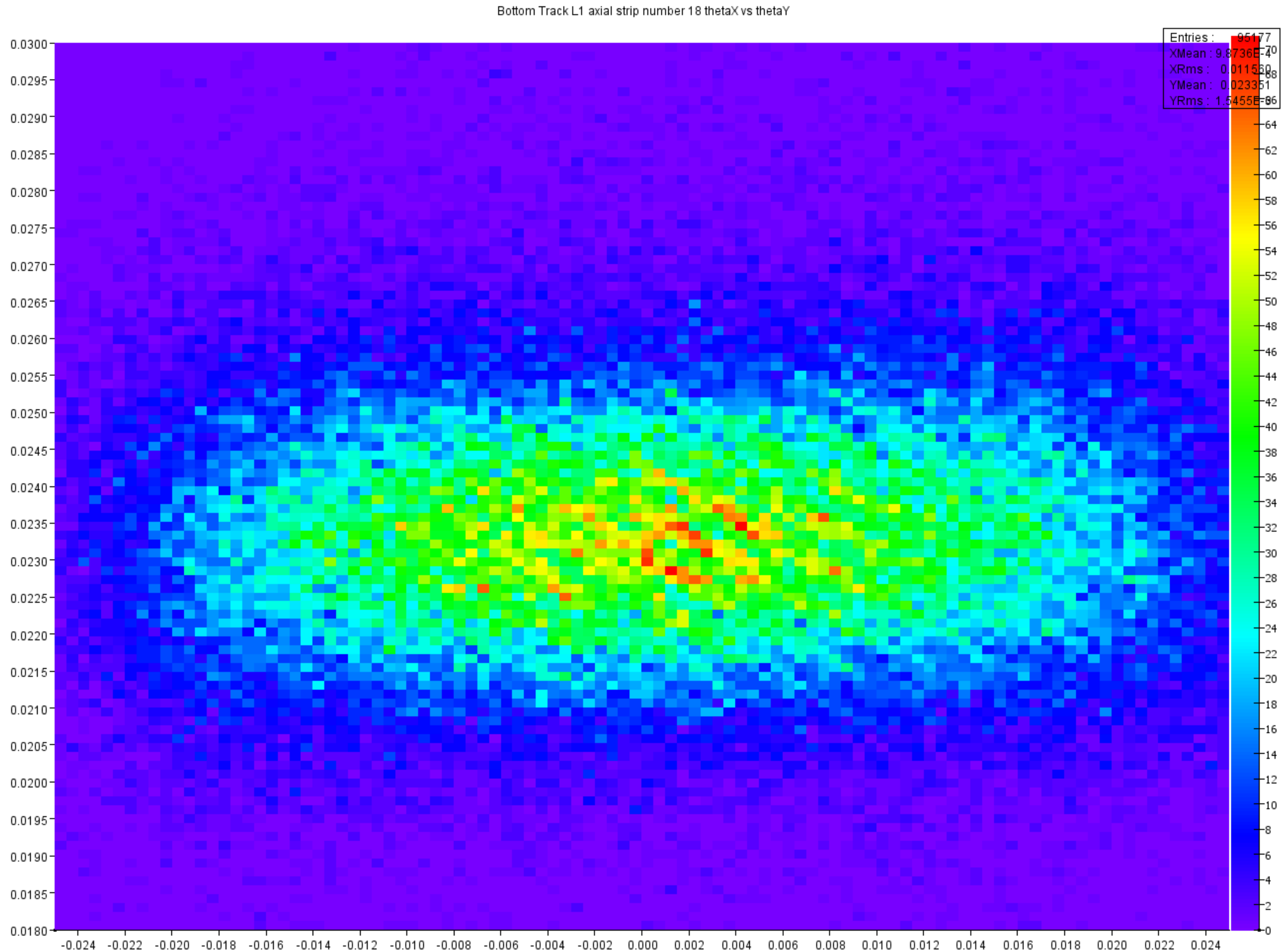
- Selecting double-strip clusters in axial layers 1 & 2 accentuates this difference, with comb offset.
- Classic digital “shadowing effect” (MWPCs)



Top ThetaX vs ThetaY



Bottom ThetaX vs ThetaY

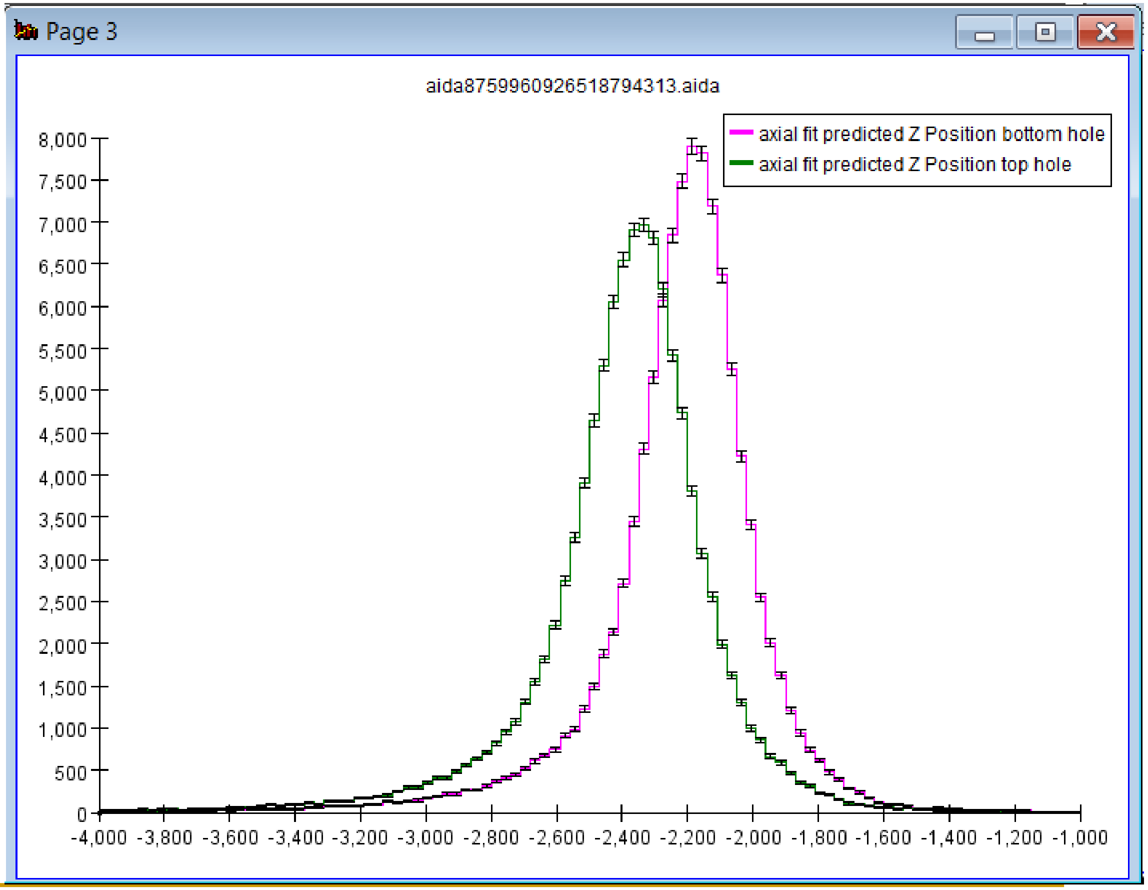


Alignment Moving Forward

- Include beam spot (and ECal?) into alignment procedure using single-track
- Include vertex constraint for multiple track events
- Include vertex and mass constraint for Møller events
- Ties SVT coordinate system to HPS lab system
- Couples top and bottom halves of detector
- Constrains(?) weak (momentum) mode
- (Some ad-hoc corrections to deal with some of these issues were introduced into tweakpass6)
- Robustify, streamline and automate(?) procedures
- Find new manpower to take over effort for 2019

Field-Off Straight Tracks

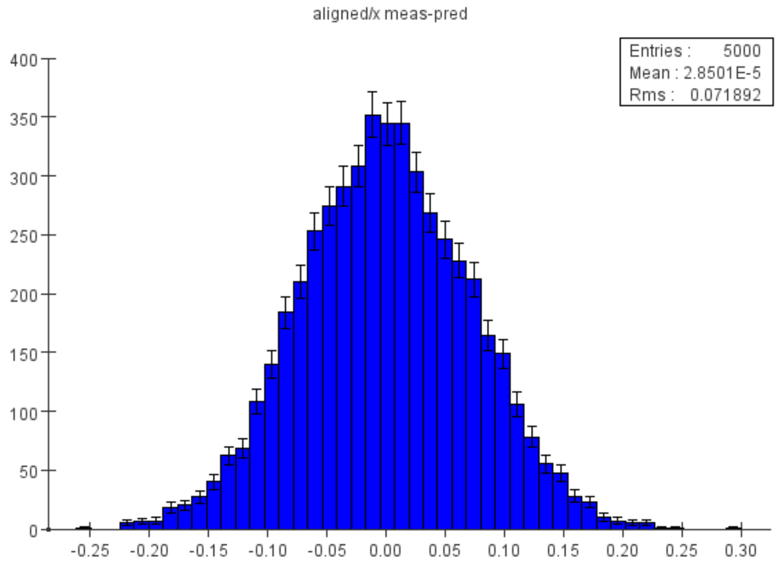
- Project tracks found in both top and bottom SVT back to intersection with X-Z plane (y=0)
- Plot value of Z at intercept
- Top z = -2346
- Bottom z = -2180
- σ ~ 150

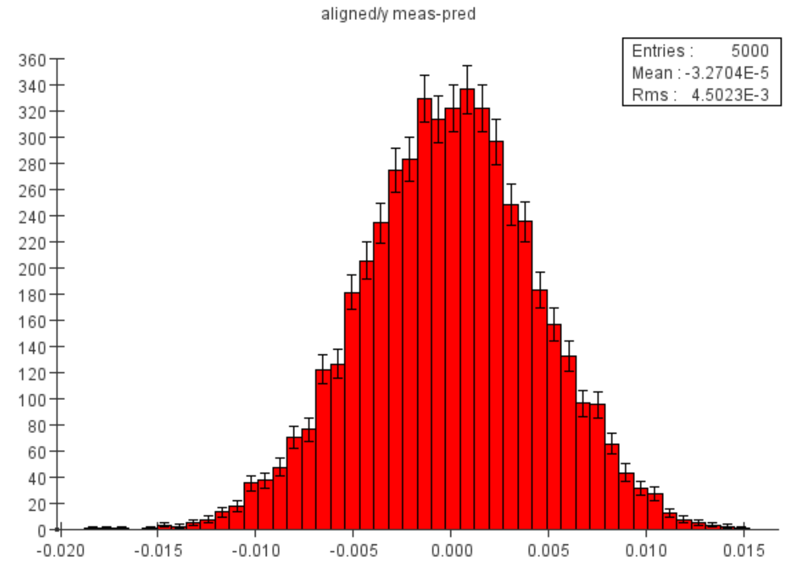


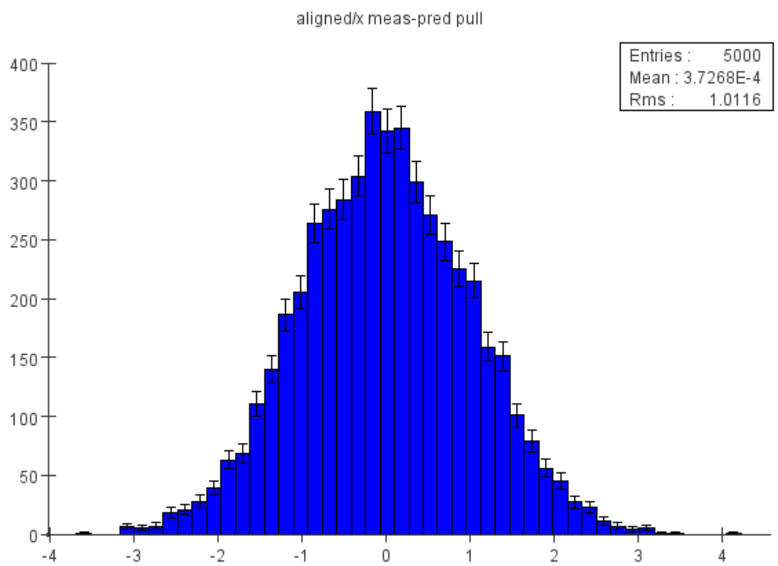
Field-Off alignment

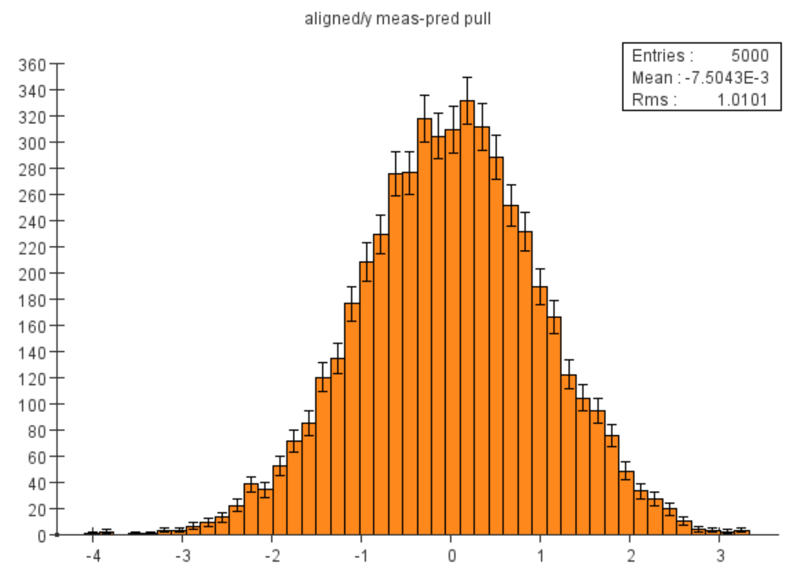
- I'm developing code to perform a least-squares alignment independent of millepede.
- Code written to fit tracks to 1D strips in arbitrarily-oriented planes, propagate straight tracks to planes, introduce arbitrary 6-parameter misalignments and the least-squared code to derive the 6 position + orientation parameters.
- Currently works (with no MCS) if I introduce misalignments and then align those mis-aligned planes.
- Moving from stand-alone to hps-java
  - Will first use MC, then try field-off data
- Using this to develop strategies for not know which planes are misaligned.

Position Alignment (res & pull)

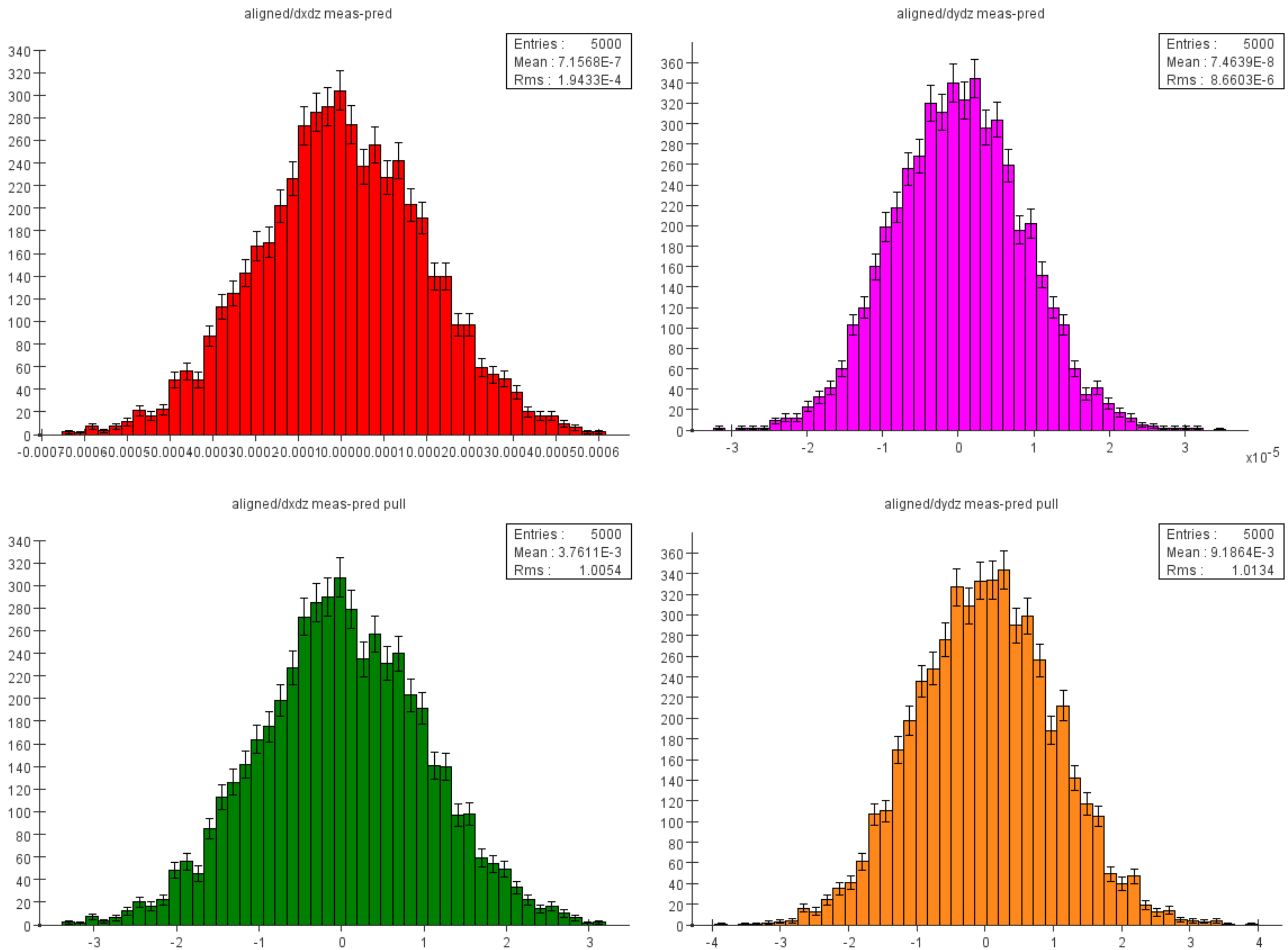




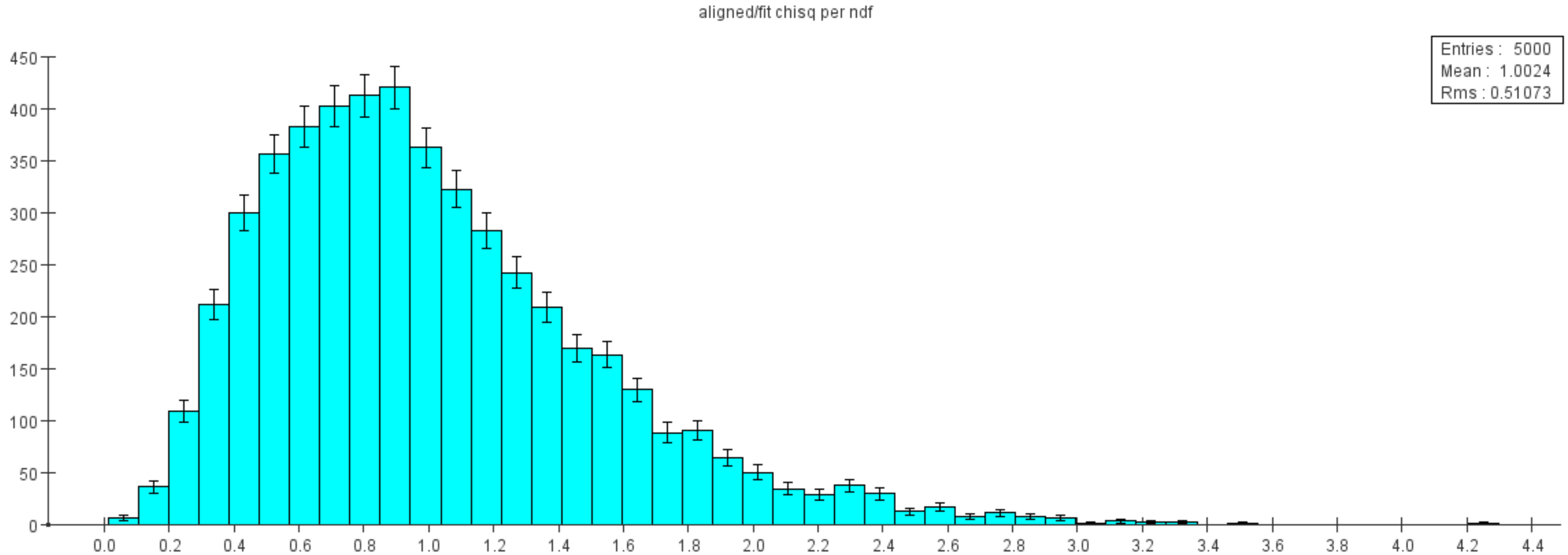


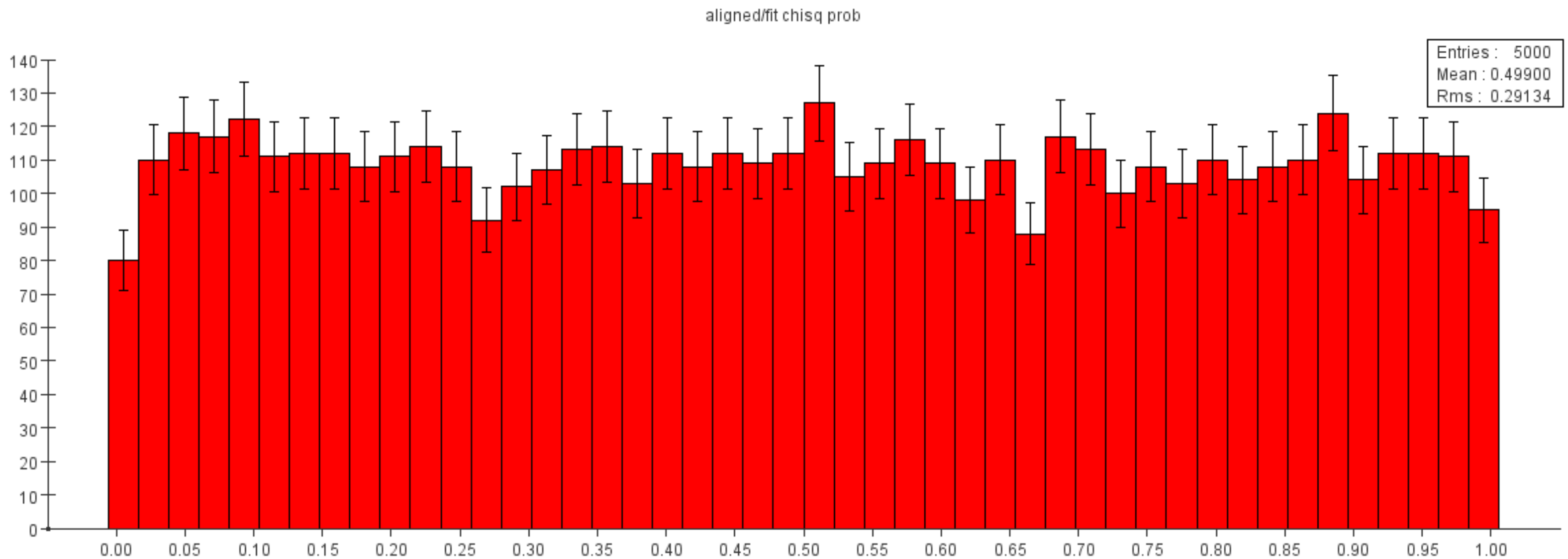


Rotation Alignment (res & pull)



Aligned track chi-squared





Integration Tests

- Have selected calibration events from run 5772 (2015) and 7796 (2016)
  - FEE (Full Energy Electrons) 10k events top/bottom
  - Møller Candidates 10k events
  - V0 Candidates 10k events
- Have skimmed off the events in evio format
- Integration tests over these samples as part of the release or manually.

Testing the software 2015

- Running from the master branch:

```
> java
  -cp hps-distribution-3.11-SNAPSHOT-bin.jar
  org.hps.evio.EvioToLcio
  -x /org/hps/steering/recon/EngineeringRun2015FullRecon.lcsim
  -r -d HPS-EngRun2015-Nominal-v6-0-fieldmap
  -DoutputFile=TestFile
  /path/to/evioFile
```

Testing the software 2016

- Running from the master branch:

> java

-cp hps-distribution-3.11-SNAPSHOT-bin.jar

org.hps.evio.EvioToLcio

-x
/org/hps/steering/recon/PhysicsRun2016FullRecon.lcsi
m -r -d HPS-PhysicsRun2016-v5-3-fieldmap_globalAlign

-DoutputFile=TestFile

/path/to/evioFile

Analysis

- Each test sample has a dedicated analysis Driver which analyzes events and writes the output histograms to an aida and a root file.
- Comparison Driver then runs which compares the output to a known, standard set of histograms.
  - Differences are flagged, assertions thrown if necessary.

org.hps.test.it

- Targets:
  - EngRun2015FeeRecon (Analysis Driver)
  - EngRun2015FeeReconTest

  - EngRun2015MollerRecon (Analysis Driver)
  - EngRun2015MollerReconTest

  - EngRun2015V0Recon (Analysis Driver)
  - EngRun2015V0ReconTest

- After building hps-java, run test target:
  - cd integration-tests
  - mvn verify -Dit.test=EngRun2015FeeReconTest

Input Data Samples

- http://www.lcsim.org/test/hps-java/calibration
  - hps_005772_feeskim_10k.evio
  - hps_005772_mollerskim_10k.evio
  - hps_005772_v0skim_10k.evio
- Will be downloaded from the web, then cached for later re-use

Test Output

- integration-tests /target/test-output/
  - EngRun2015FeeReconTest
    - EngRun2015V0ReconTest.aida, .root, .slcio
  - EngRun2015MollerReconTest
    - EngRun2015MollerReconTest.aida, .root, .slcio
  - EngRun2015V0ReconTest
    - EngRun2015V0ReconTest.aida, .root, .slcio

Fee Histograms

- Bottom 5 Hit Track Momentum
- Bottom 5 Track dEdx
- Bottom 6 Hit Track Momentum
- Bottom 6 Track dEdx
- Bottom Track Chisq Prob
- Bottom Track Chisq per DoF
- Bottom Track Momentum
- Bottom Track Number of Hits
- Bottom Track X0
- Bottom Track Y0
- Bottom Track Z0
- Bottom Track theta
- Top 5 Hit Track Momentum
- Top 5 Track dEdx
- Top 6 Hit Track Momentum
- Top 6 Track dEdx
- Top Track Chisq Prob
- Top Track Chisq per DoF
- Top Track Momentum
- Top Track Number of Hits
- Top Track X0
- Top Track Y0
- Top Track Z0
- Top Track theta

- Separately for Top and Bottom Tracks

Møller Histograms

- Moller Bottom Track Momentum
- Moller Invariant Mass
- Moller Momentum
- Moller Top Track Momentum
- Moller Track Chisq Prob
- Moller Track Chisq per DoF
- Moller Track Momentum
- Moller Track Number of Hits
- Moller Vertex Chisq
- Moller Vertex x
- Moller Vertex y
- Moller Vertex z
- Moller p top vs p bottom
- Moller p vs theta
- Moller p1 vs p2
- Moller theta1 vs theta2
- Moller vertex X vs Y
- Moller x Momentum
- Moller y Momentum
- Moller z Momentum

- Separately for each Vertex Collection
  - BeamspotConstrained
  - TargetConstrained
  - Unconstrained

V0 Histograms

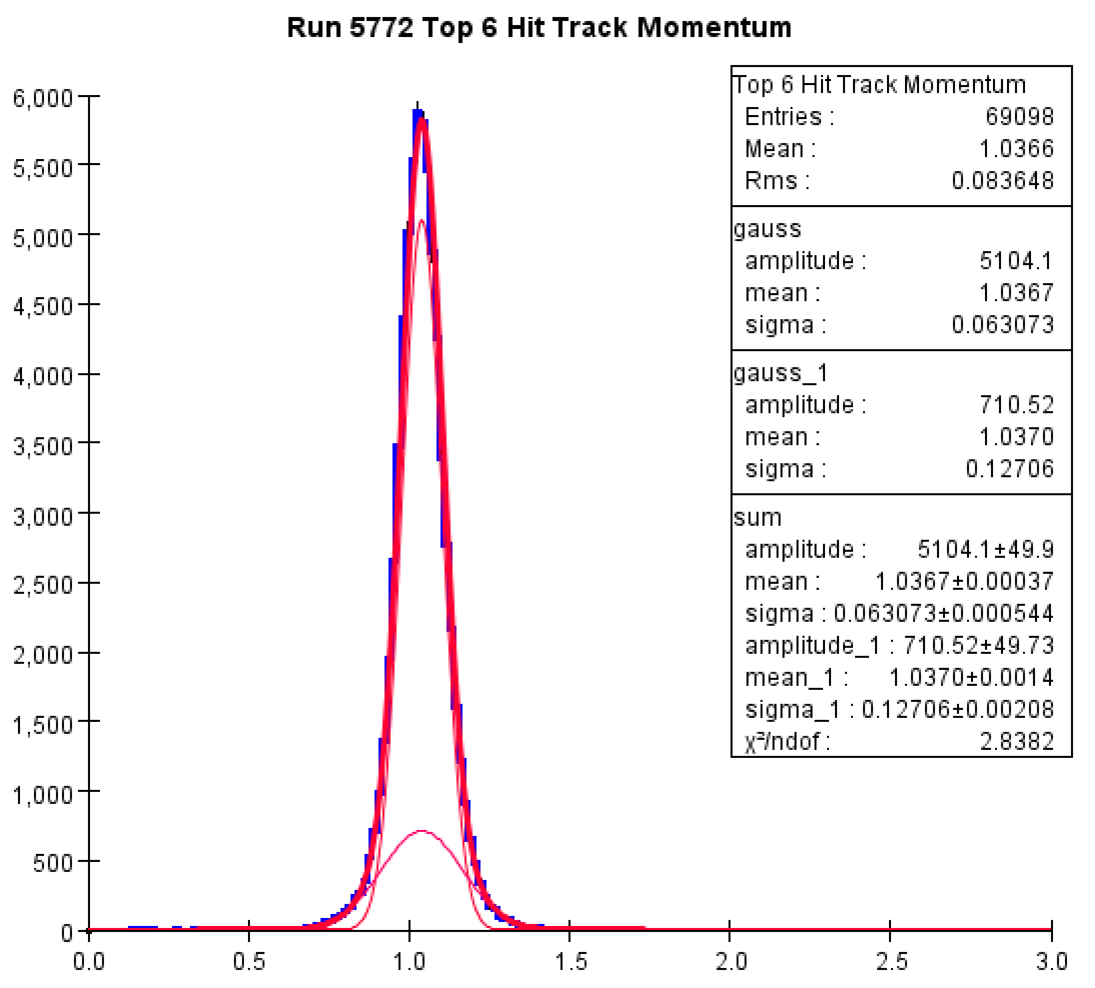
- V0 Bottom Track Momentum
- V0 Invariant Mass
- V0 Momentum
- V0 Top Track Momentum
- V0 Track Chisq Prob
- V0 Track Chisq per DoF
- V0 Track Momentum
- V0 Track Number of Hits
- V0 Vertex Chisq
- V0 Vertex x
- V0 Vertex y
- V0 Vertex z
- V0 Vertex z L1L1
- V0 p top vs p bottom
- V0 p vs theta
- V0 p1 vs p2
- V0 theta1 vs theta2
- V0 vertex X vs Y
- V0 x Momentum
- V0 y Momentum
- V0 z Momentum

- Separately for each Vertex Collection
  - BeamspotConstrained
  - TargetConstrained
  - Unconstrained

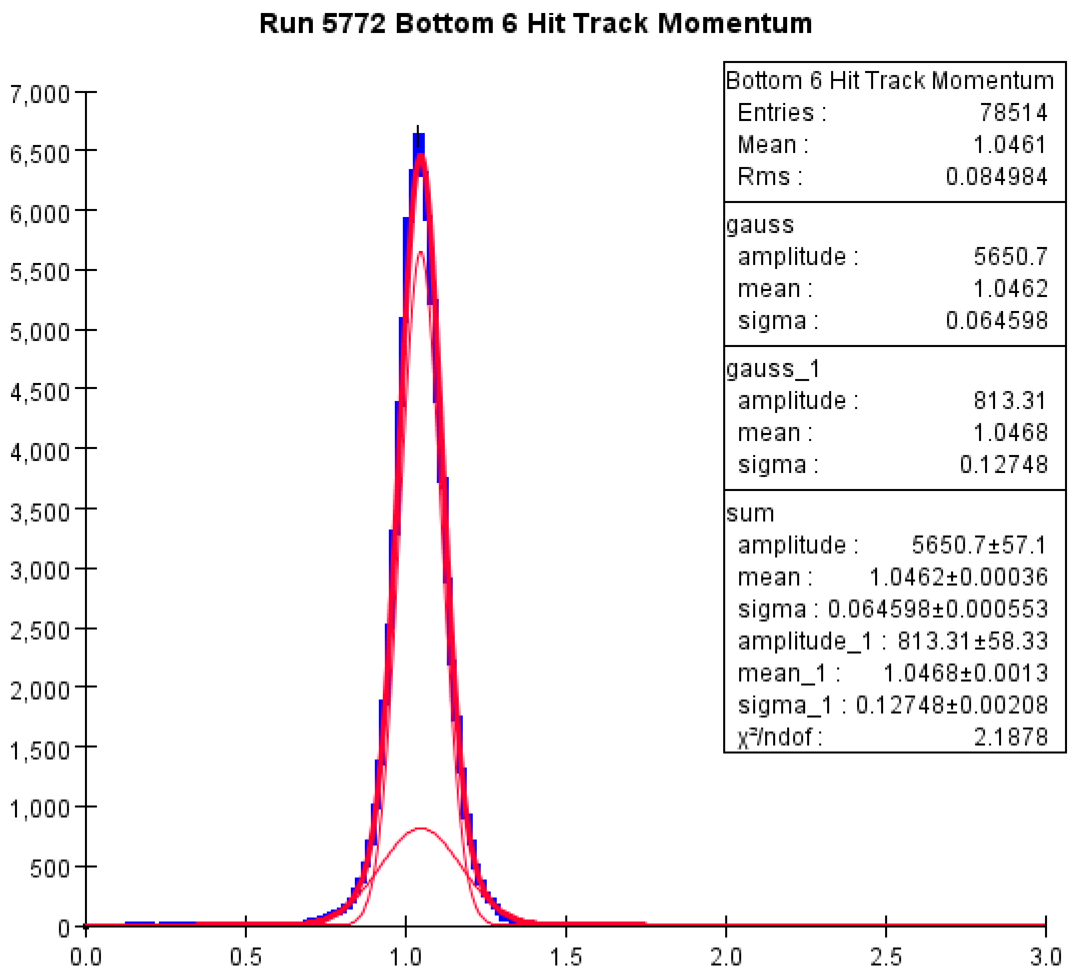
Status

- Event samples identified and events skimmed and available in evio format.
- Integrated tests processing the evio files finished
- Analysis Drivers and first pass at histograms finished.
- Histogram comparisons need to be improved.
- Feedback needed on selection of performance metrics to be analyzed and procedures for comparing output.
- Histograms available on the web.
  - Handy resource if you're just interested in looking at a snapshot of where we are.
- Note being prepared

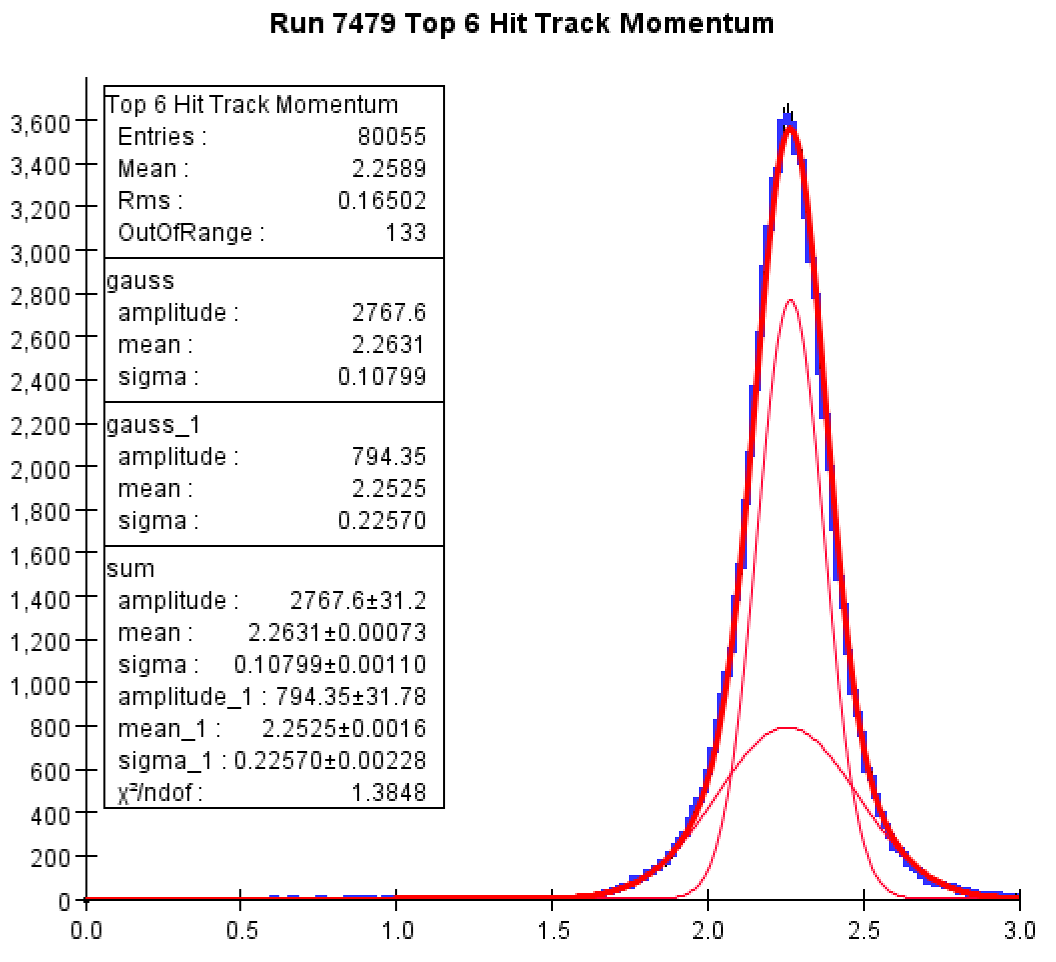
Momentum Calibration FEE



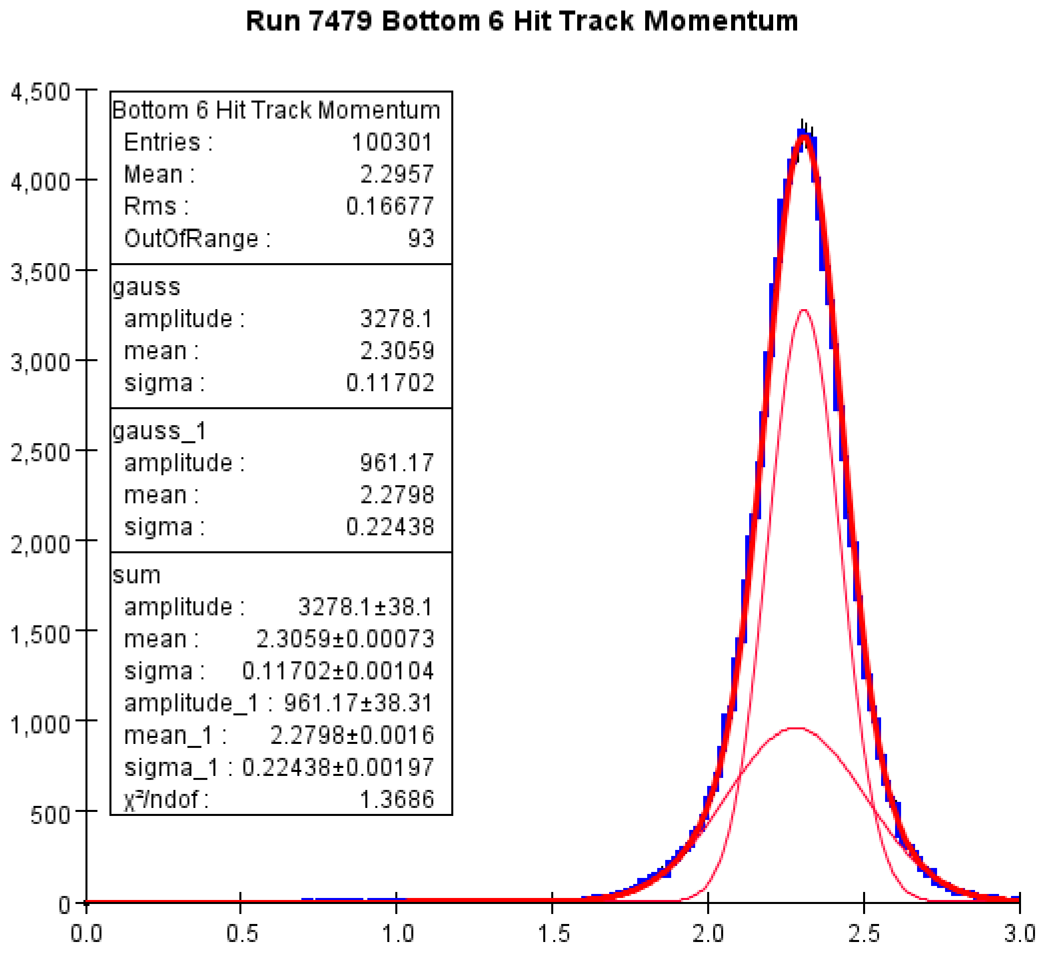
Momentum Calibration FEE



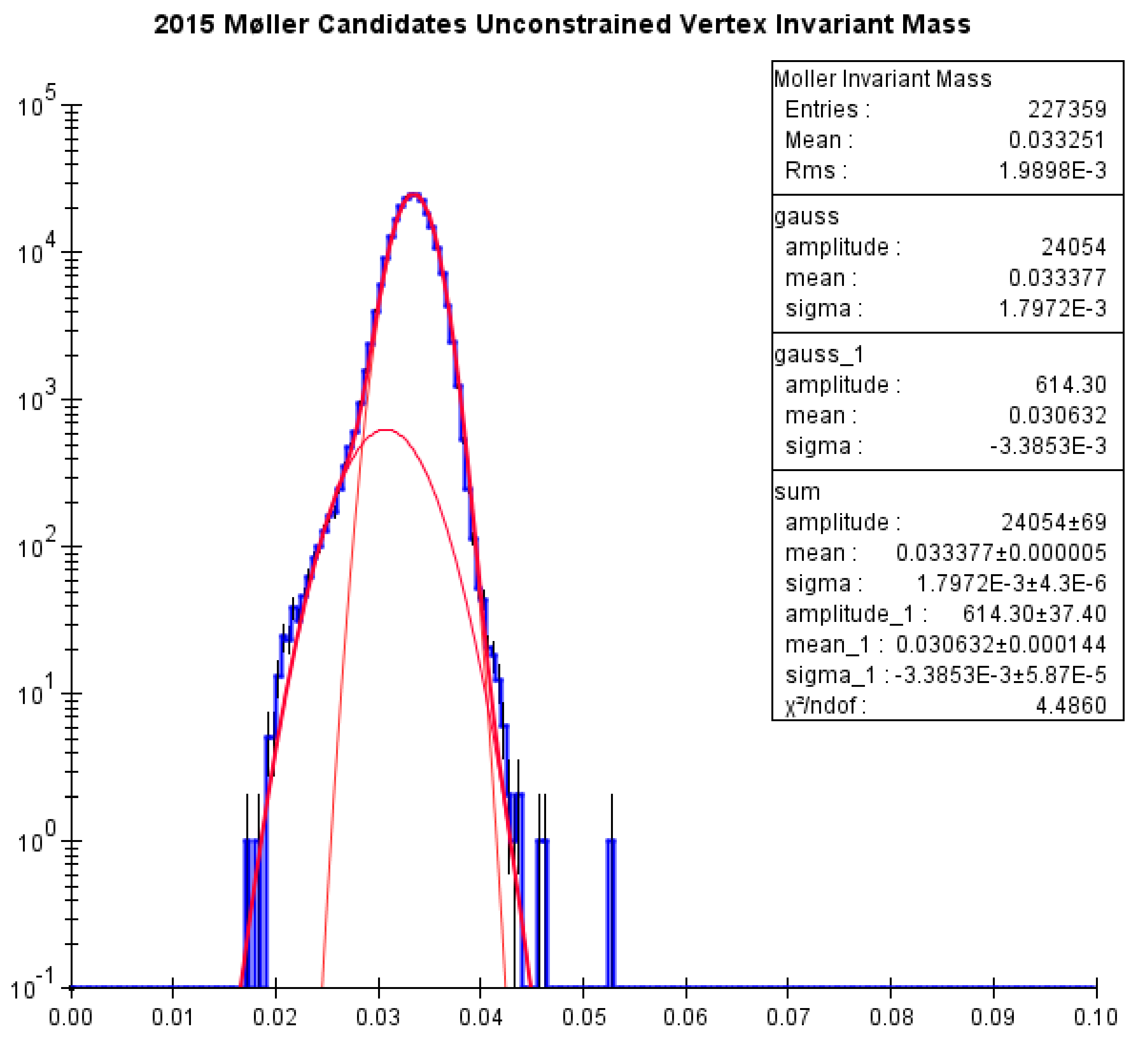
Momentum Calibration FEE



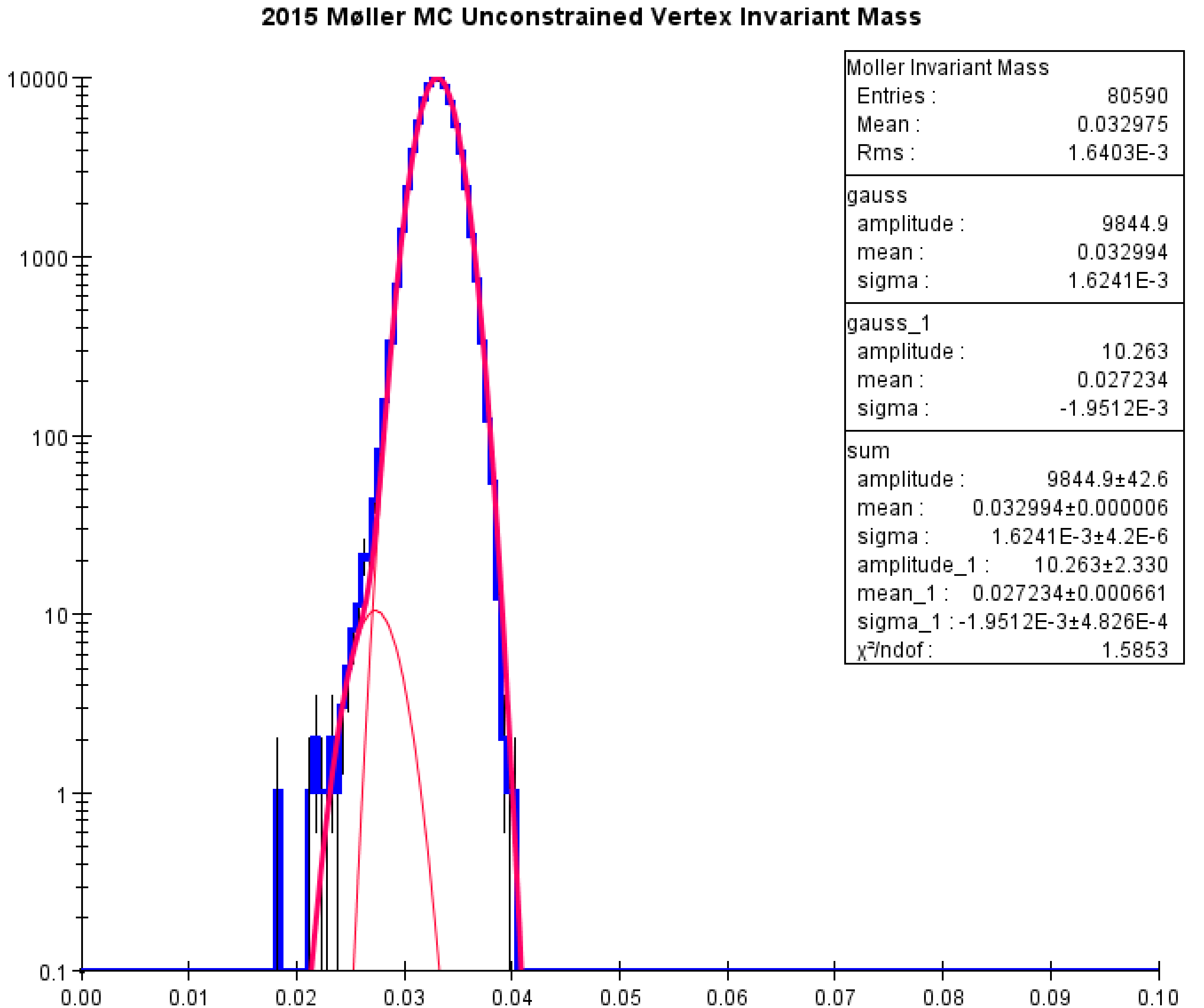
Momentum Calibration FEE



Mass calibration: 2015 Møllers



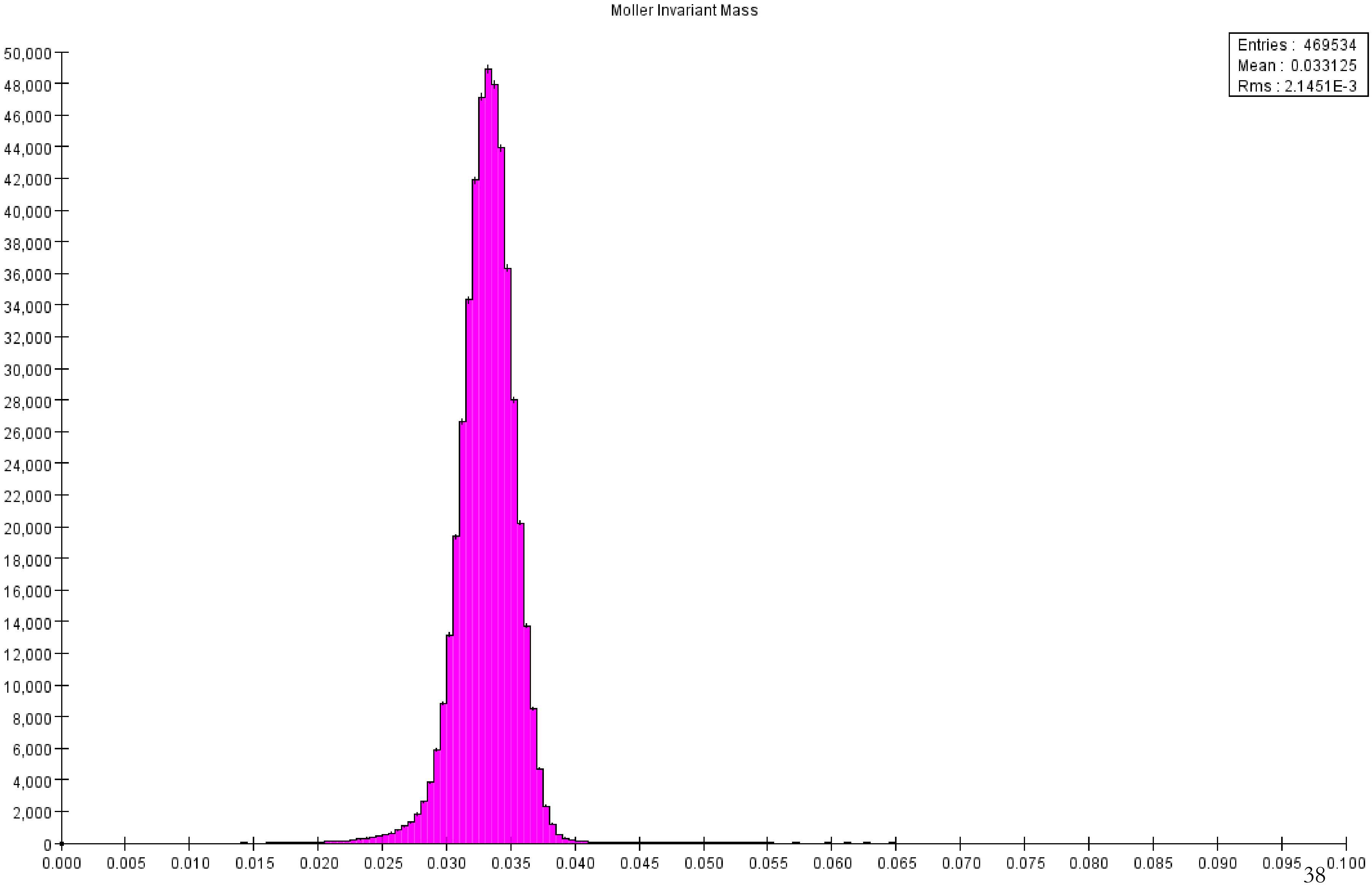
Mass calibration: 2015 MC Møllers



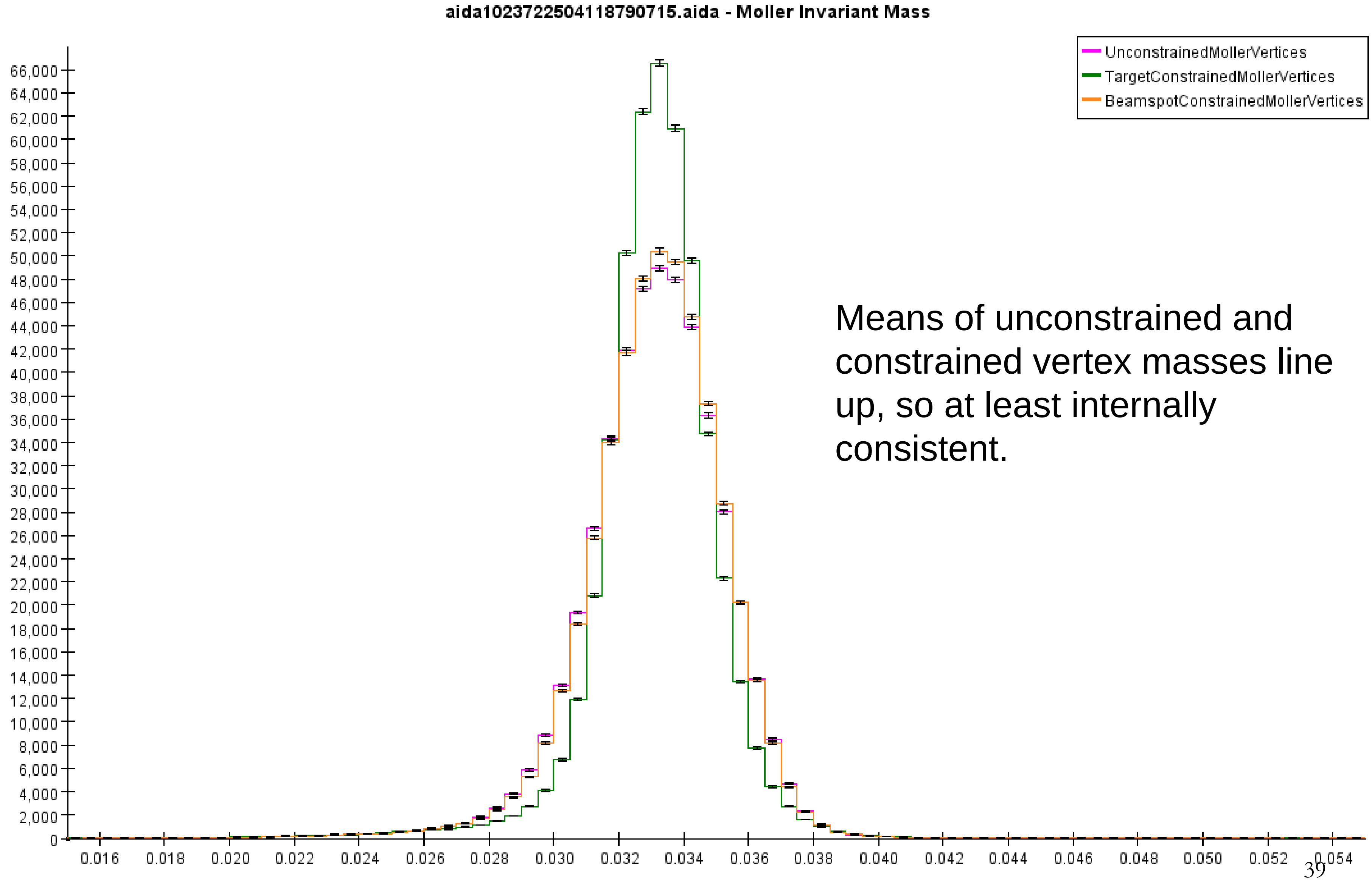
Where's the Beam? Where's it going?

- Use Møller events to determine beam position and beam direction with respect to the SVT.
- 2015 5772 pass8
- 2015 7804 pass1

2015 Møller Mass (unconstrained)

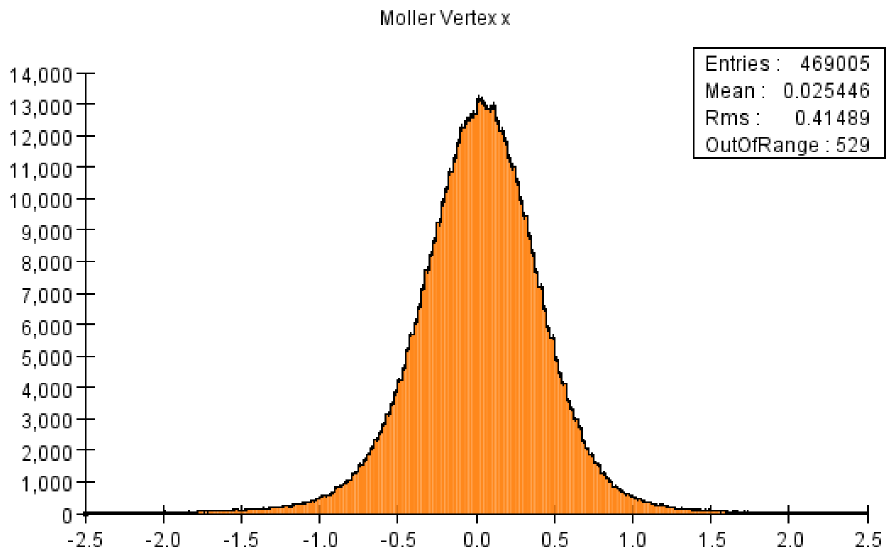


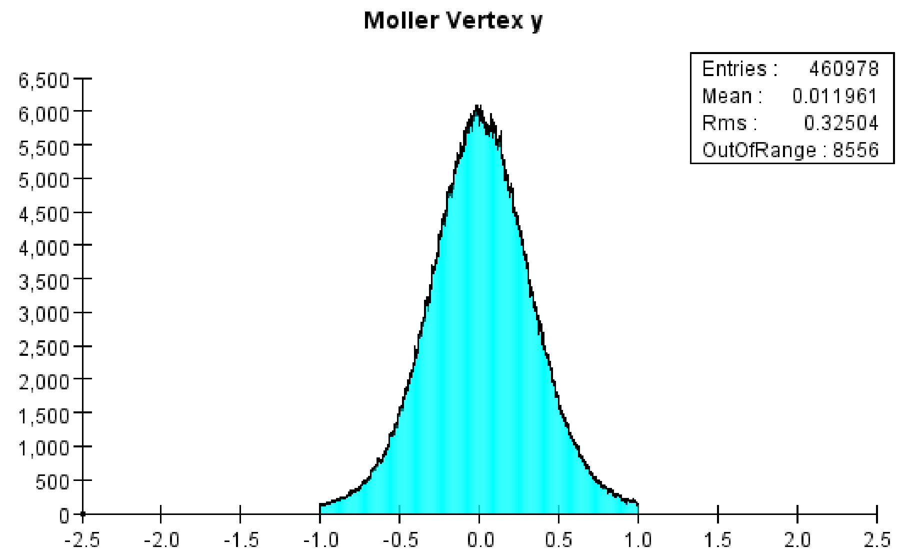
2015 Møller Mass (all)

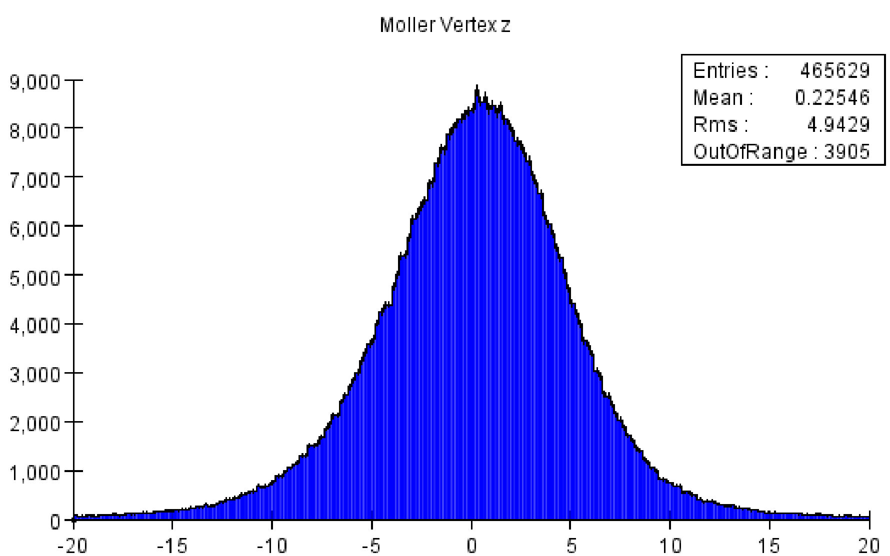


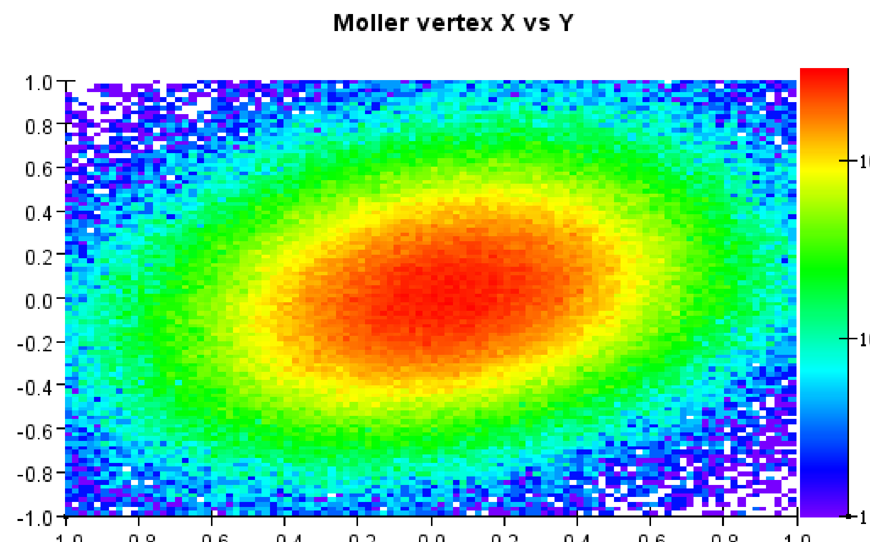
Means of unconstrained and constrained vertex masses line up, so at least internally consistent.

2015 Møller Vertex pos.(unconstrained)

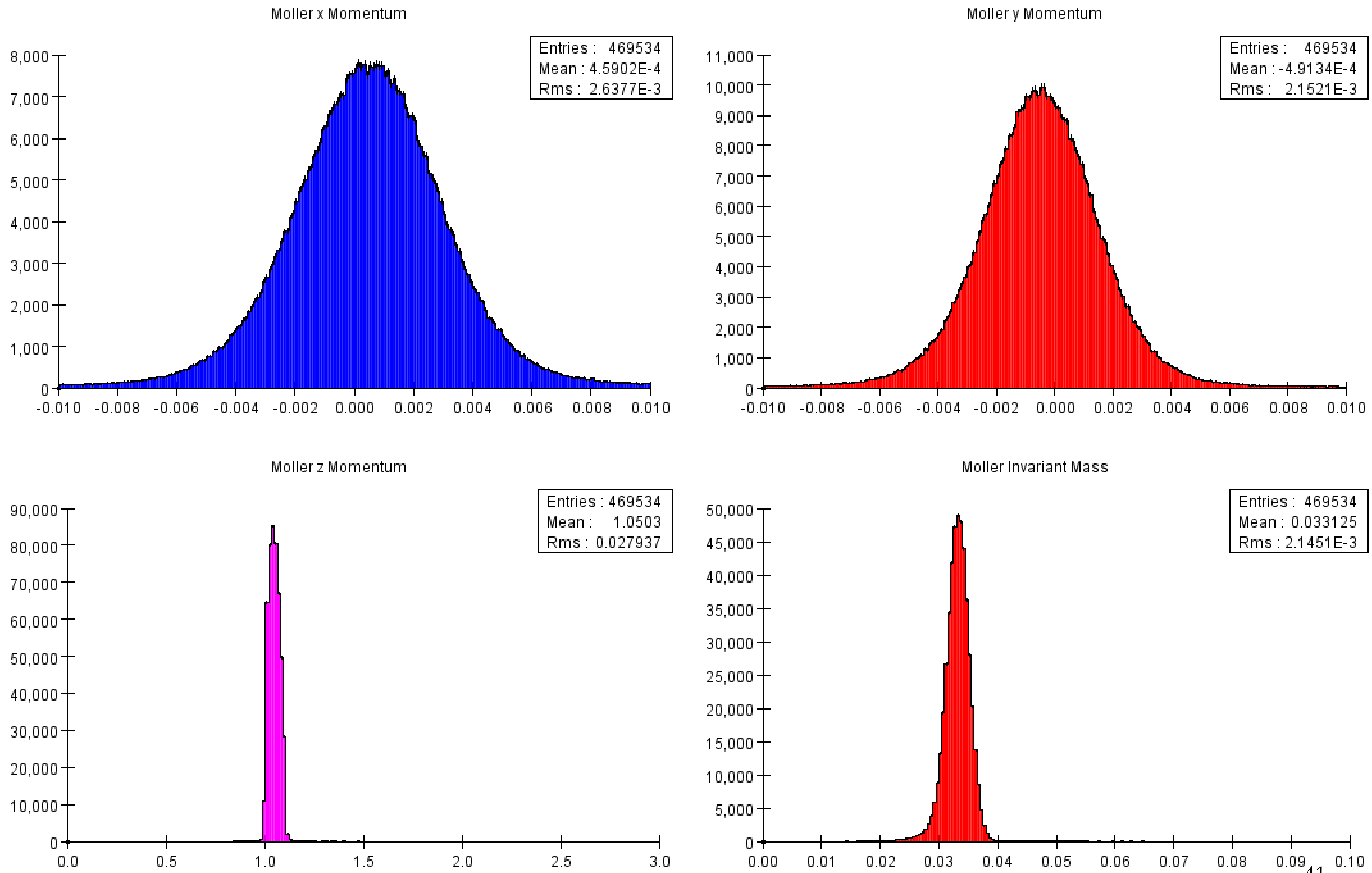




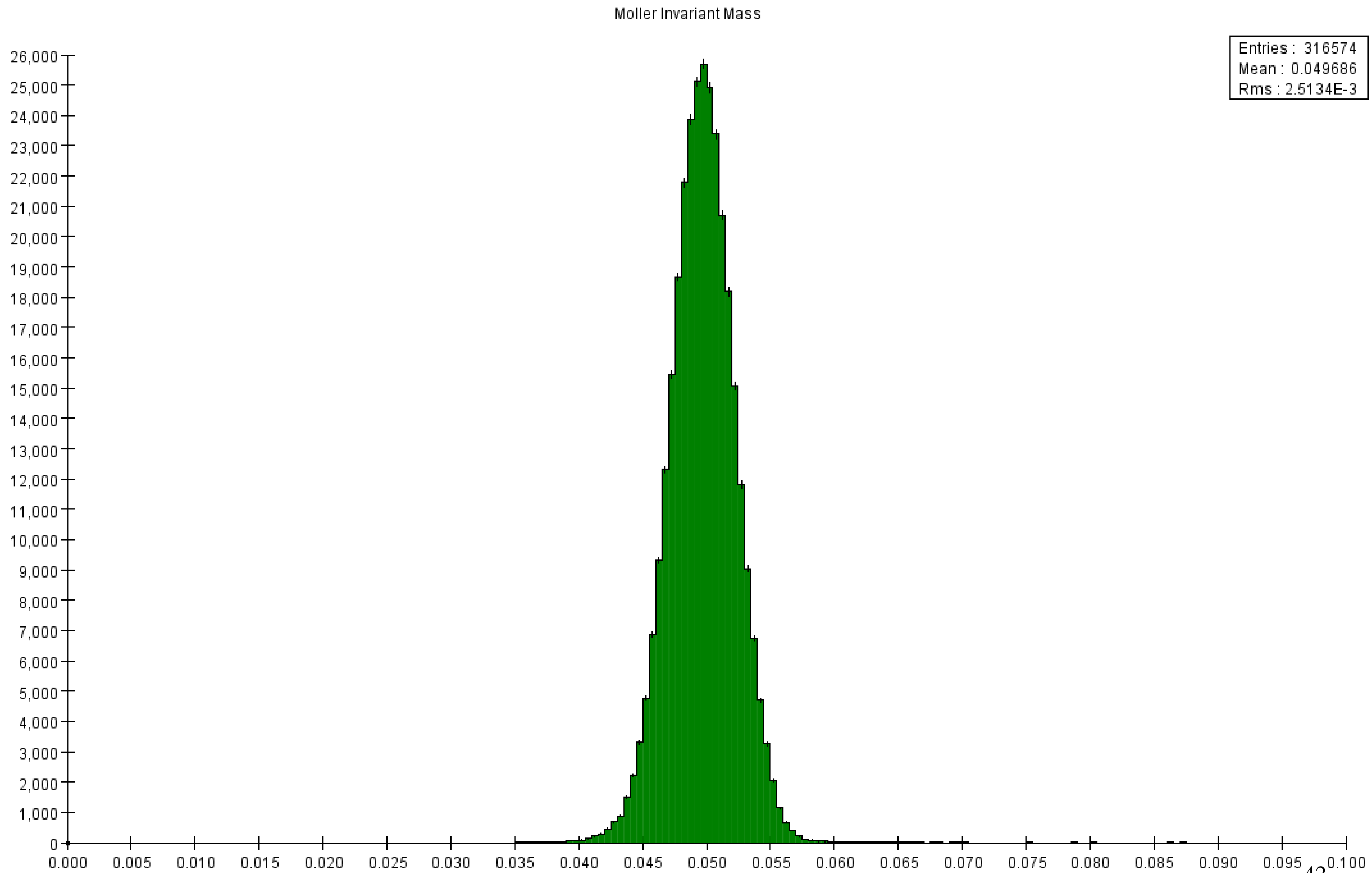




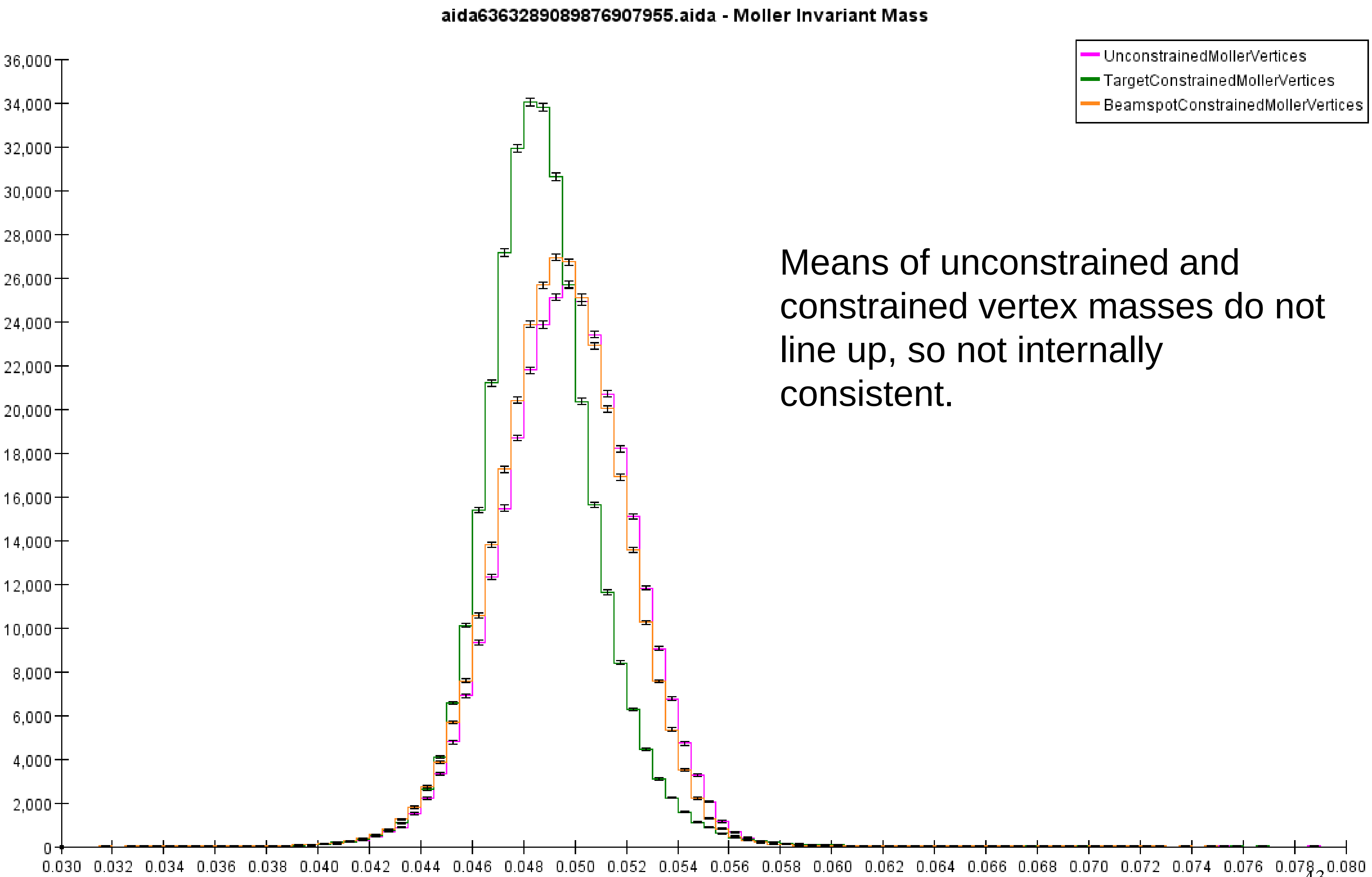
2015 Møller Momenta (unconstrained)



2016 Møller Mass (unconstrained)

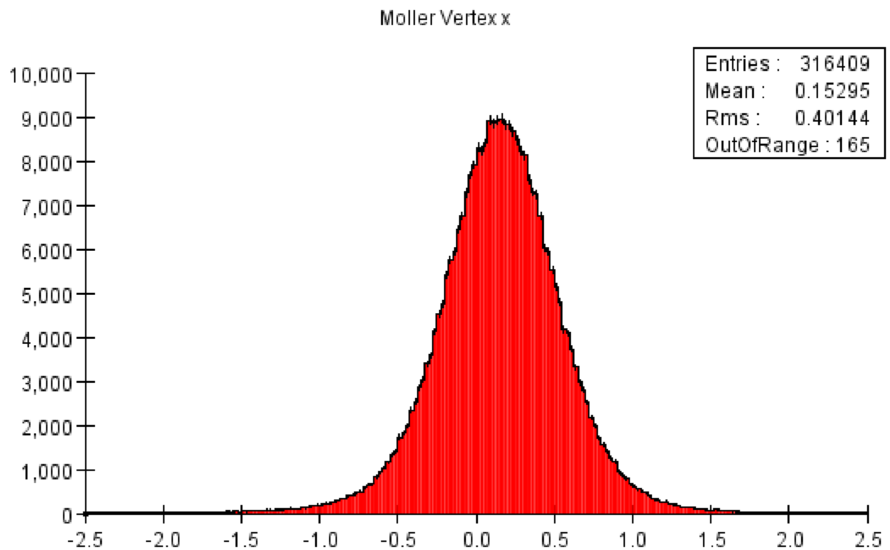


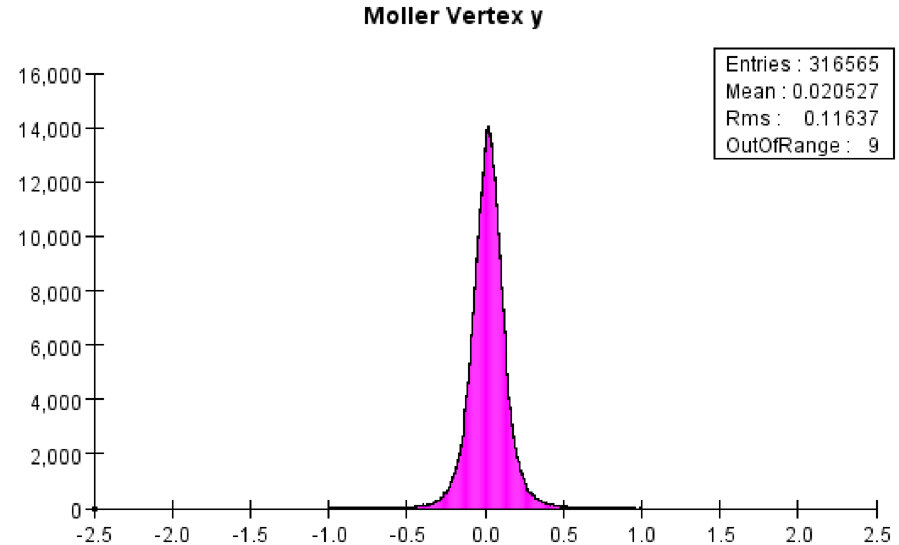
2016 Møller Masses (all)

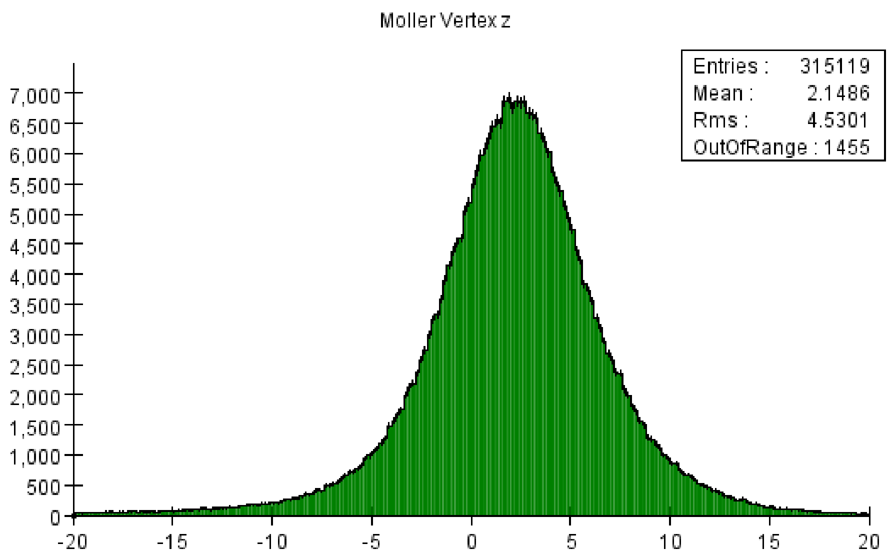


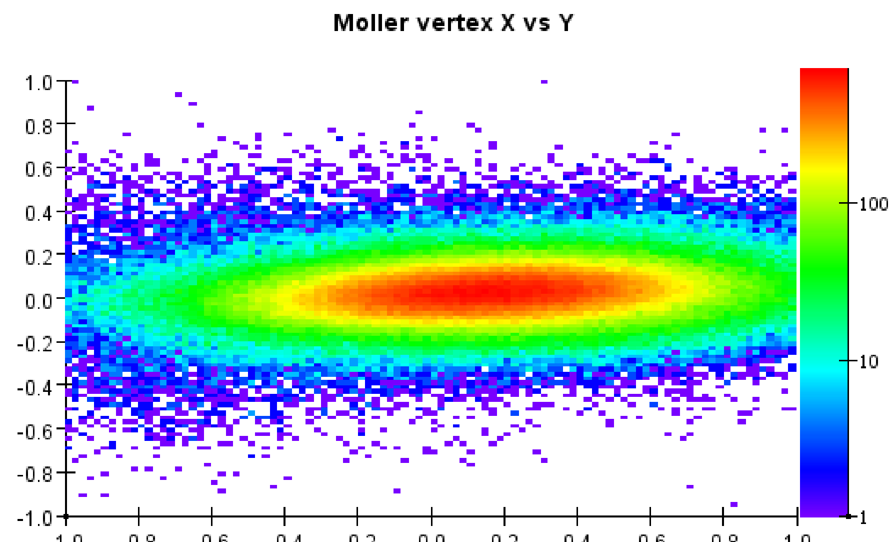
Means of unconstrained and constrained vertex masses do not line up, so not internally consistent.

2016 Møller Vertex Position

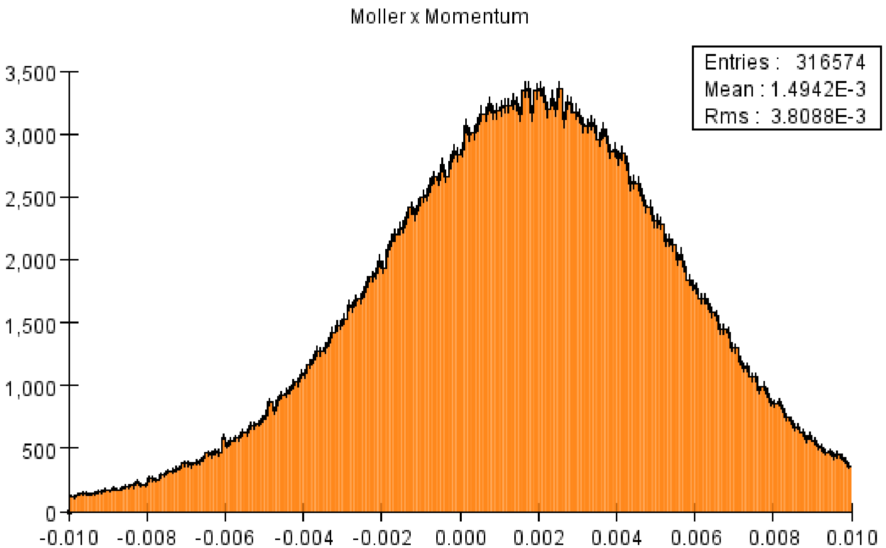


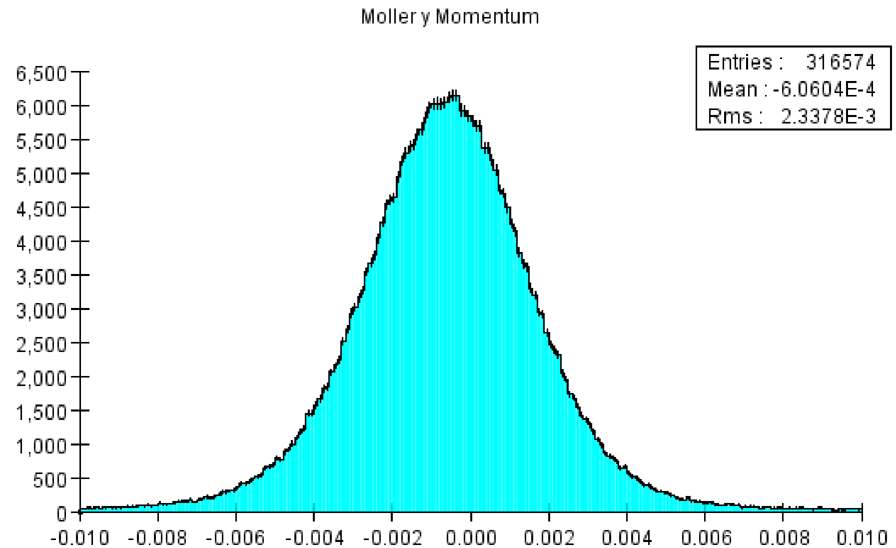


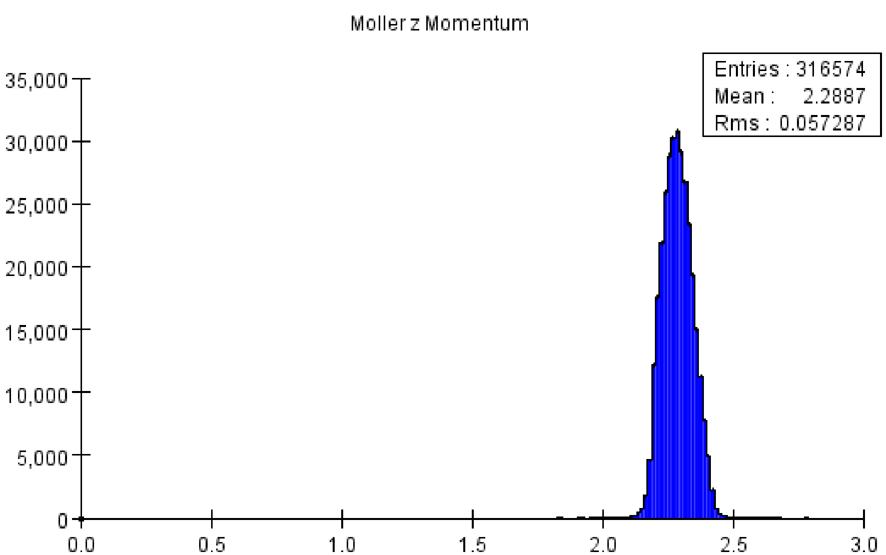


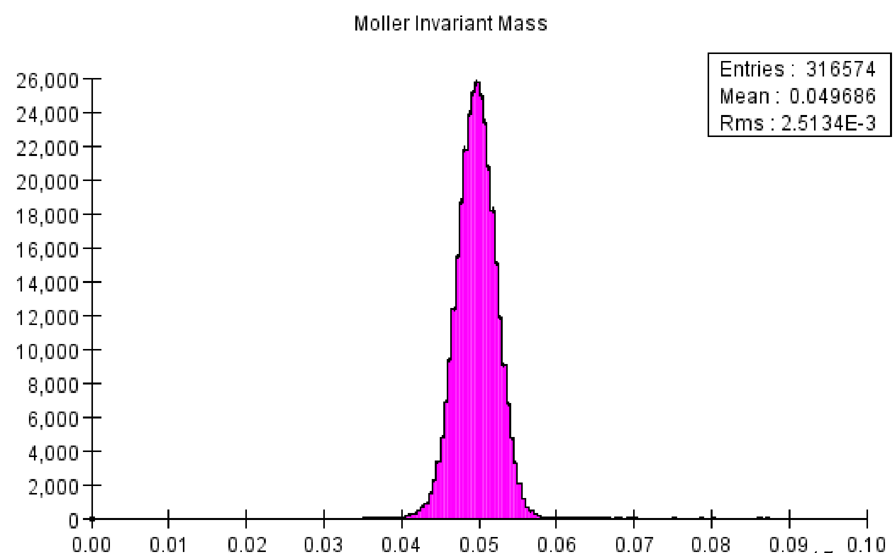


2016 Møller Vertex Momentum









Situation

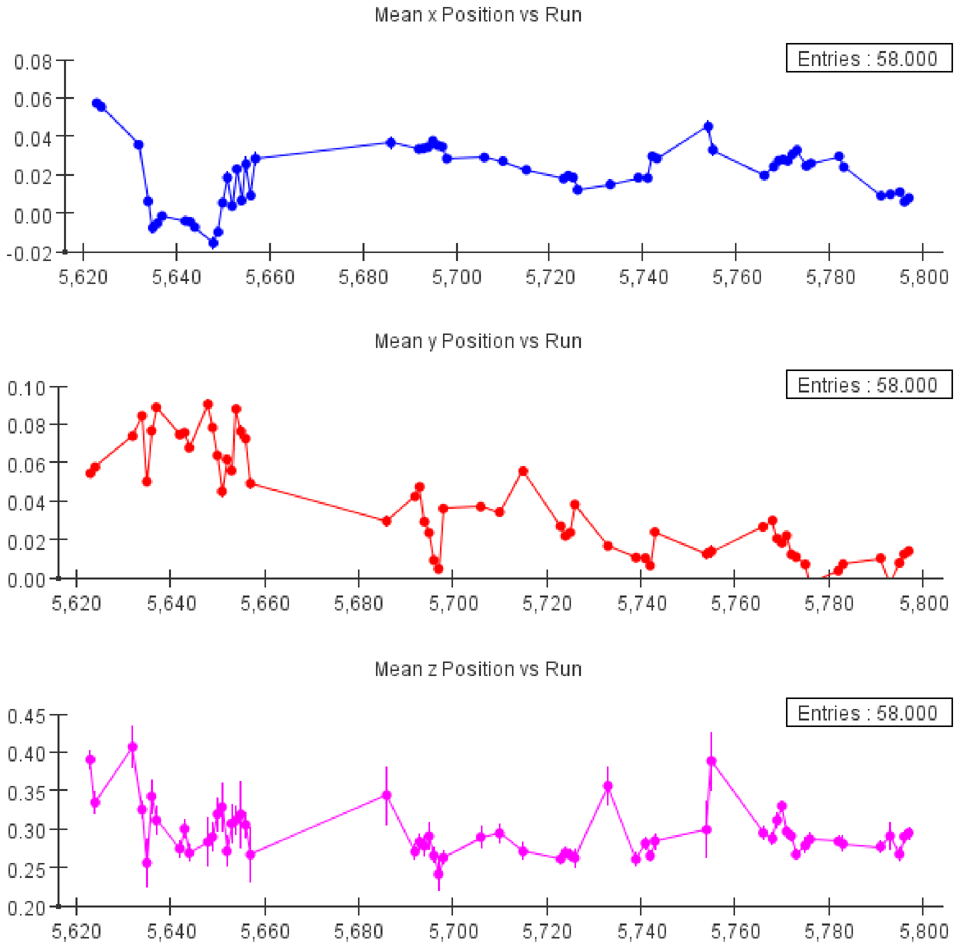
- 2015 alignment appears to be OK.
  - e.g. the target-constrained mass agrees with the unconstrained.
- Beam Position : (0.025, 0.012) mm
- Beam Direction (0.43, -0.46) mr (px/pz, py/pz)
- 2016 alignment needs more work
  - e.g. the target-constrained mass disagrees with the unconstrained.
- Beam Position : (0.15, 0.02)* mm
- Beam Direction (0.65, -0.26)* mr (px/pz, py/pz)
- Work ongoing.

Constrained Vertex Fits

- The Beamspot- and Target-constrained vertex fits use the beam and target positions.
  - These had been fixed numbers hard-coded
- Can derive beam (x,y) and (px/pz, py,pz) at the target from unconstrained Møllers.
- Get σ_x, σ_y from SVT wire scans
- Monitor changes with HARP scans.
- Beam tilt in (x,y) from data or HARP scans.

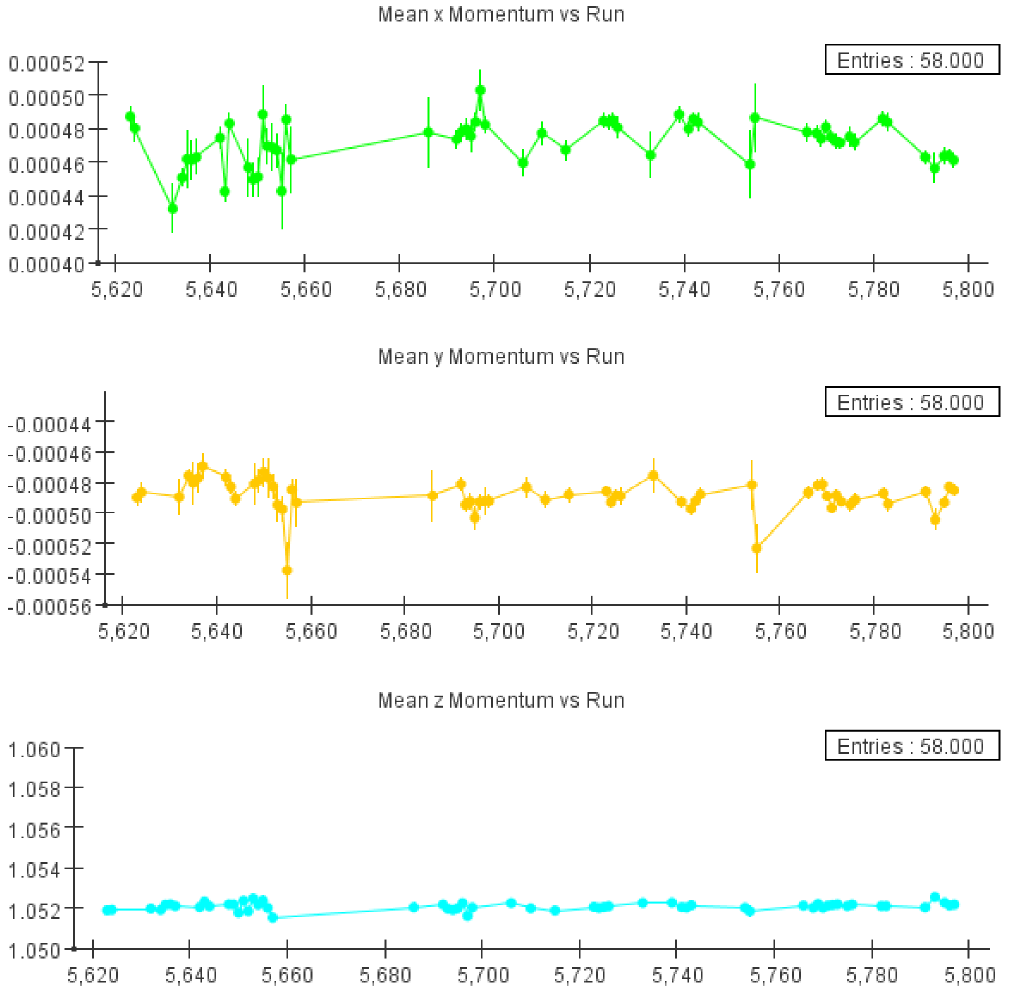
2015 Beam Position Variability

- Check variability in the beam position (and rotation?) as a function of time. X vs Y distribution of the unconstrained vertices from the pass8 Møller skims.



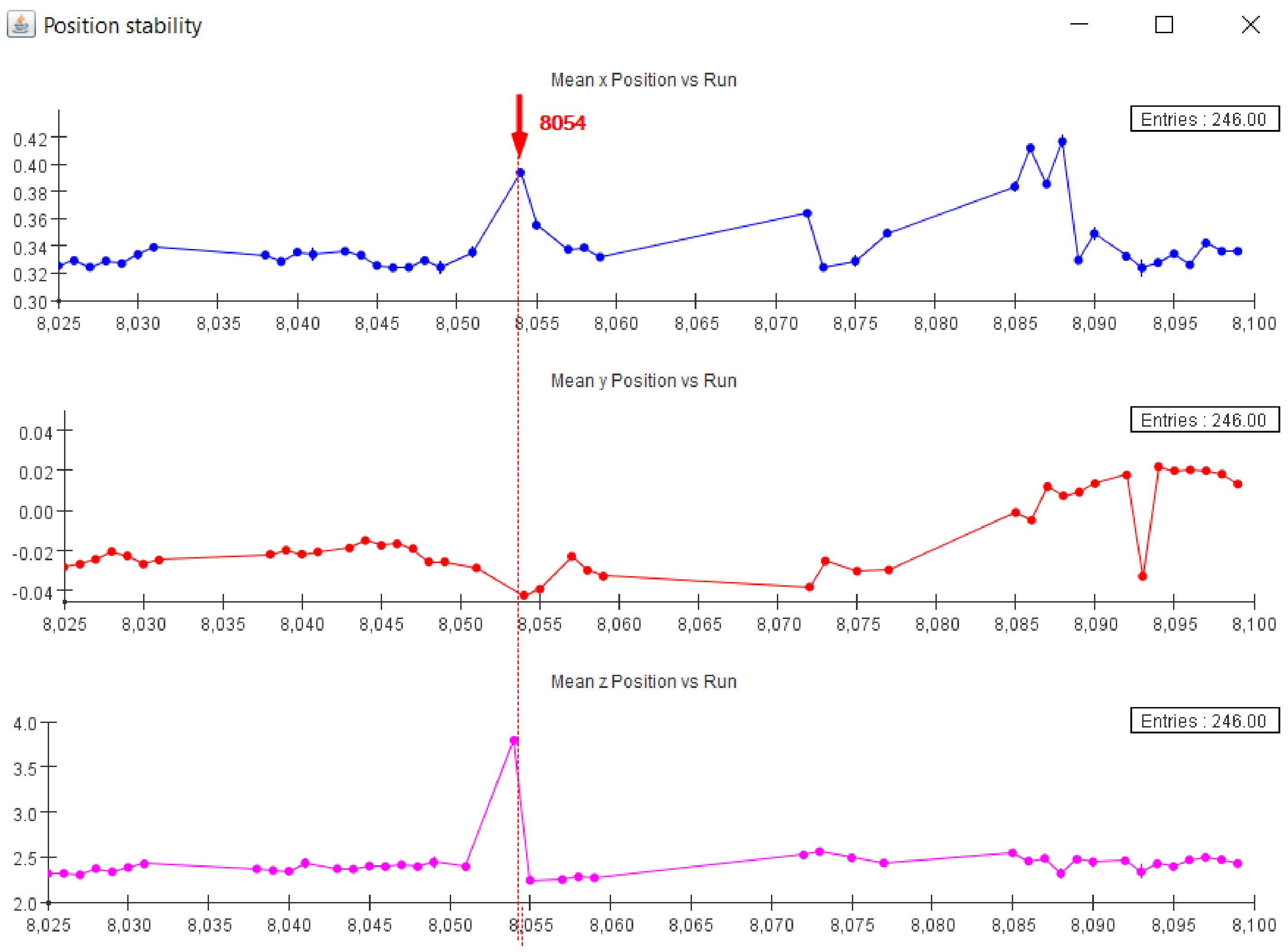
2015 Beam Direction Variability

- Check variability in the beam direction as a function of time. pX and pY distribution of the unconstrained vertices from the pass8 Møller skims.



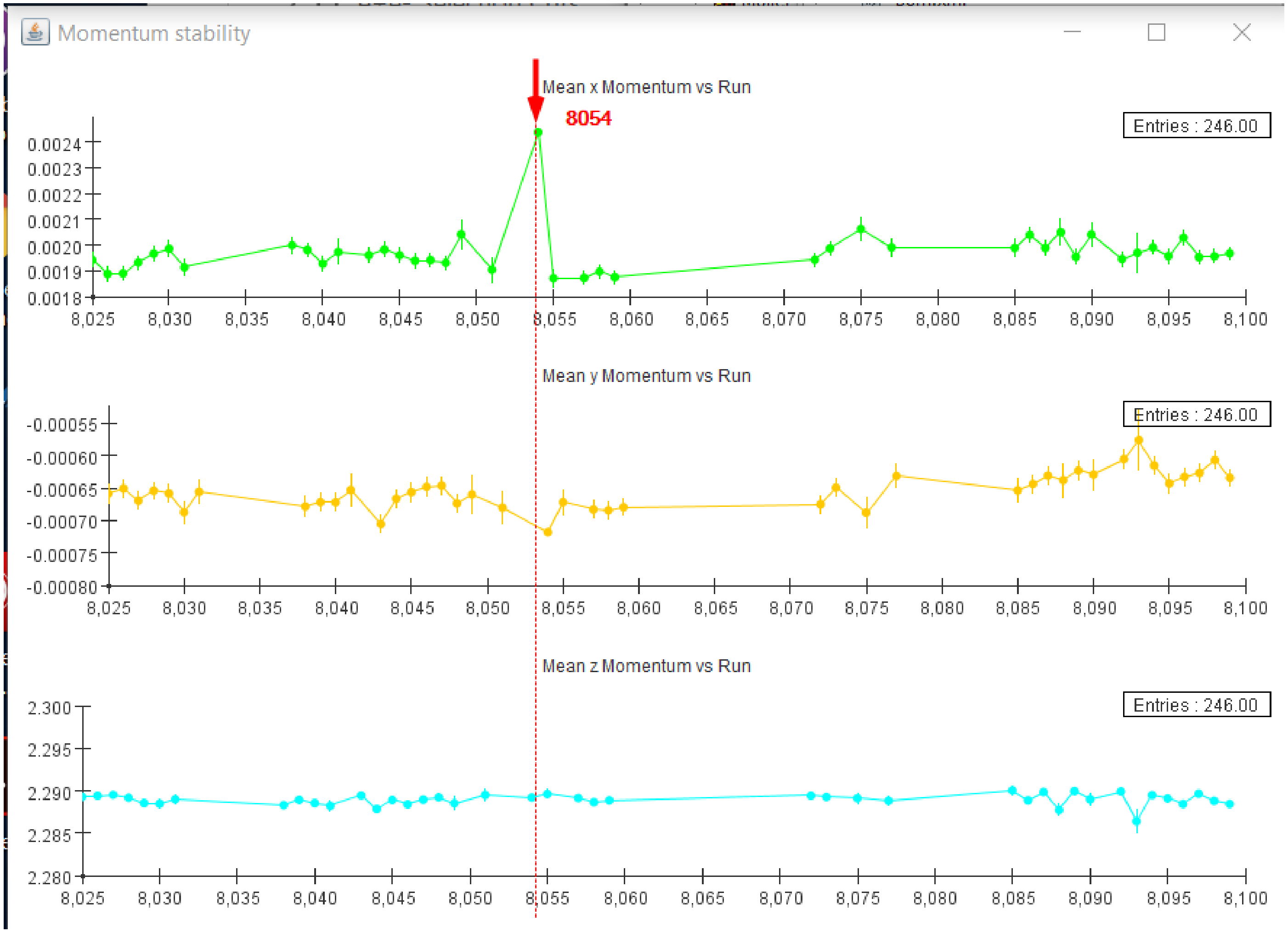
2016 Beam Position Variability

- Check variability in the beam position (and rotation?) as a function of time. X vs Y distribution of the unconstrained vertices from the pass1 Møller skims.



2016 Beam Direction Variability

- Check variability in the beam direction as a function of time. pX and pY distribution of the unconstrained vertices from the pass1 Møller skims.



Beam Position in reco

- Beam Position is used in the reconstruction for the beamspot-constrained and target-constrained vertices. Seem stable enough to use fixed values for each run. Input via steering file, not through database/conditions system, viz.

```
<driver name="ReconParticleDriver“
type="org.hps.recon.particle.HpsReconParticleDriver" >
      <ecalClusterCollectionName>EcalClustersCorr</ecalClusterCollectionName>
      <trackCollectionNames>GBLTracks</trackCollectionNames>
      <beamPositionX> 0.0 </beamPositionX>    data
      <beamSigmaX> 0.125 </beamSigmaX>     HARP scan + SVT wire
      <beamPositionY> 0.0 </beamPositionY>    data
      <beamSigmaY> 0.030 </beamSigmaY>     HARP scan + SVT wire
      <beamPositionZ> 0.5 </beamPositionZ>     data
   </driver>
```

n.b. currently do not use beam tilt in (x,y) plane in vertex constraints.

Software CPU Performance

- Our tracking software is SLOW!
  - Not currently an issue, but will definitely become critical during long 2019 run
  - Maurik has shown timing breakdown, Miriam has made good progress, but more need to be done.
  - Overall CPU budget dominated by tracking, primarily track-finding/fitting, followed by raw hit-fitting
    - Fix what we have
    - Start over
- Fitting readout samples to determine hit time and pulse height
  - Currently using generic minuit fit
  - Need to evaluate possible gains from a dedicated fitter

Pattern Recognition

- Possible improvements:
  - Improved axial/stereo matching (L4-L6)
  - Improved and/or more strategies using 3D points
    - Needed for L0 in any case
  - Cluster-seeded tracking
    - ECal cluster position and energy define a trajectory which originates from the beam-spot (HPS Note 2015-006).
    - Find tracks consistent with that hypothesis.
  - Implement pattern recognition based on 1D strip hits.
    - No “ghost” hits, or parallax issues
    - Could see increased efficiency by not requiring hits in both axial and stereo layers per station.
    - See Robert’s talk.

Track Fitting

- Track fit quality is not chi-squared distributed
- Discrepancy between data and MC
- Resolution of issues complicated by:
  - Strip cluster position
  - Module position (alignment)
  - Track extrapolation (non-uniform field)
  - Multiple scattering and energy loss
- GBL refit could benefit from external review
- Kalman fit might expose issues
- Whole chain needs better documentation
  - Javadoc on what the code is expected to be doing
  - Documentation on procedure, algorithm, math

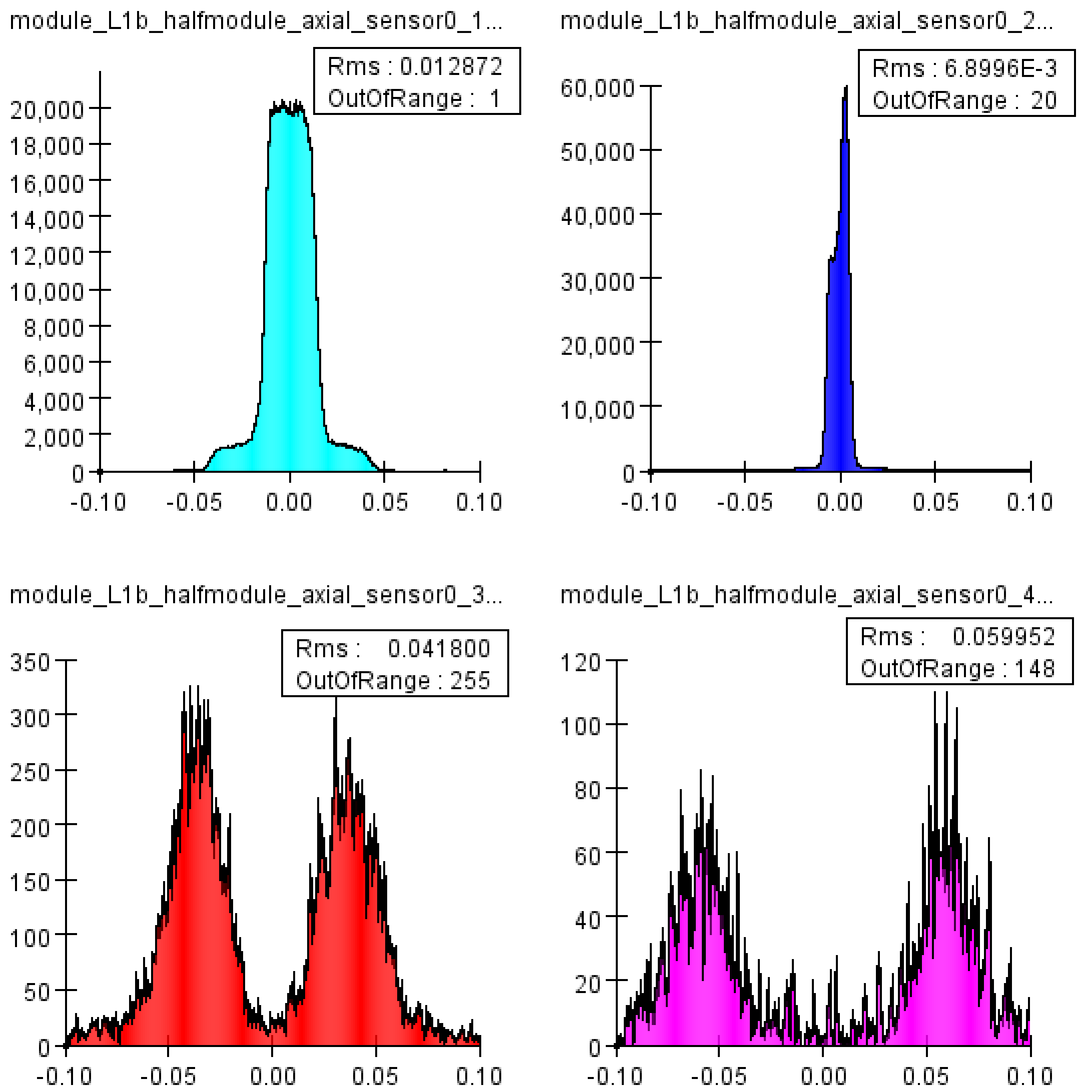
Tracking Down Tracking

- My quest to understand our track reconstruction has led me back to hits.
  - Recall that our track fit metric is not χ^2 distributed.
- Analyze MC hits to check our input to track fitting.
- Analyze latest set of tri-trig-wab-beam events.
- Compare measurement (u) of strip cluster hits to the SimTrackerHit position as a function of sensor as well as number of hits in the strip cluster.

Hit Residuals (measured-predicted)

1 strip

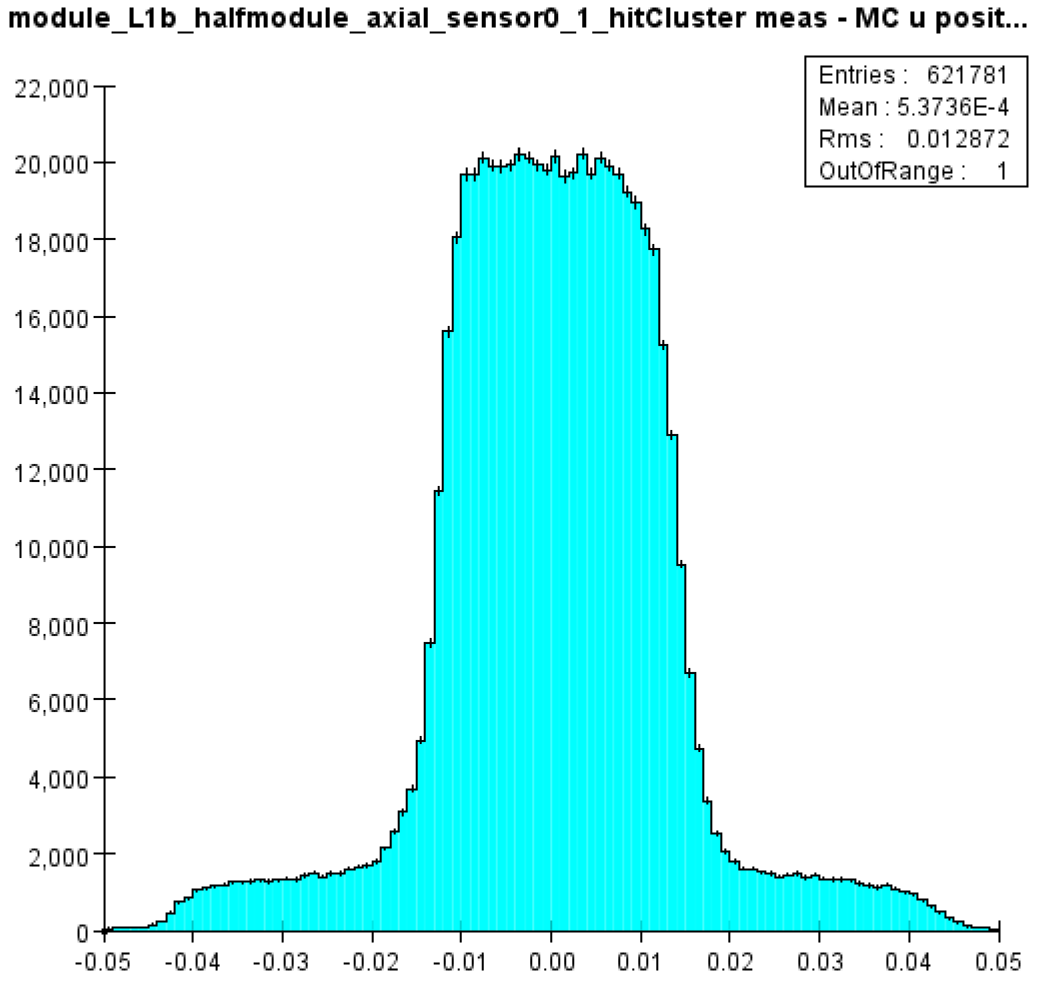
2 strip



3 strip

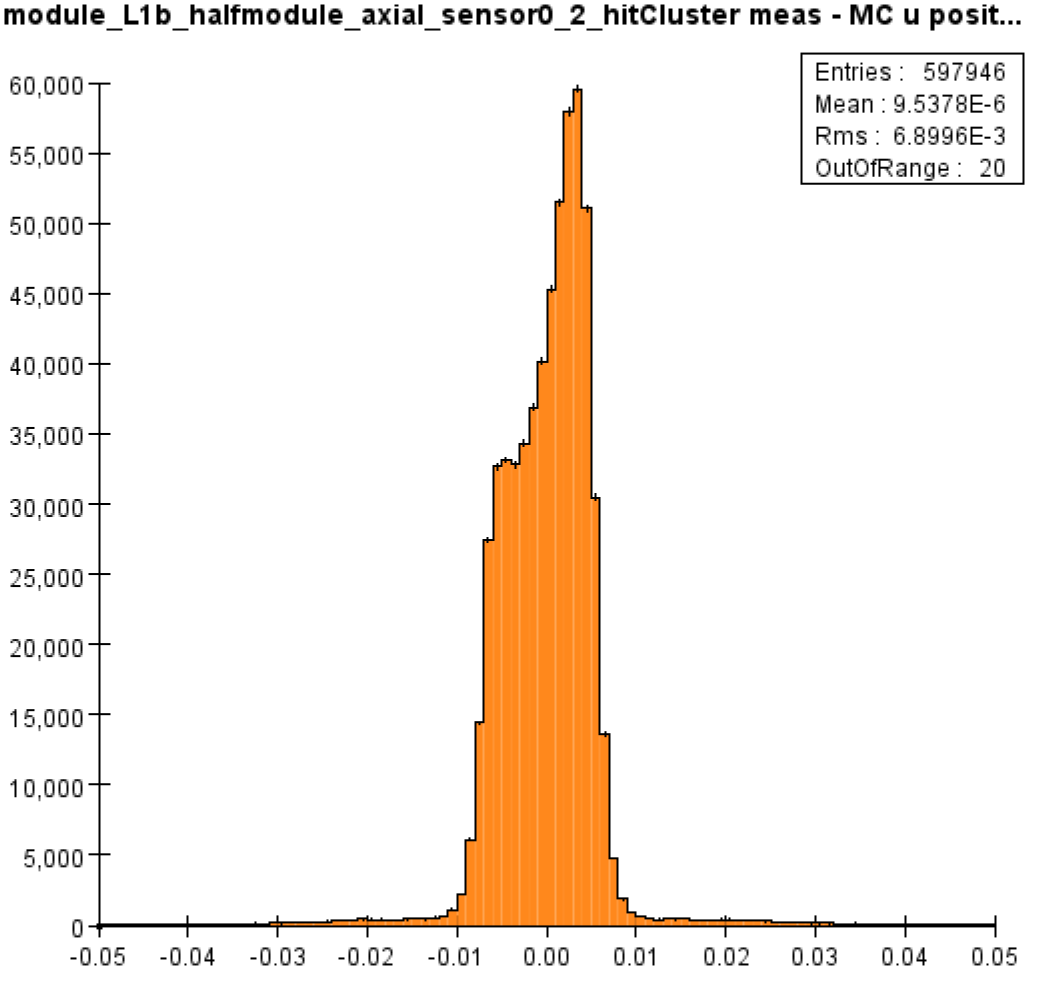
4 strip

1 Strip



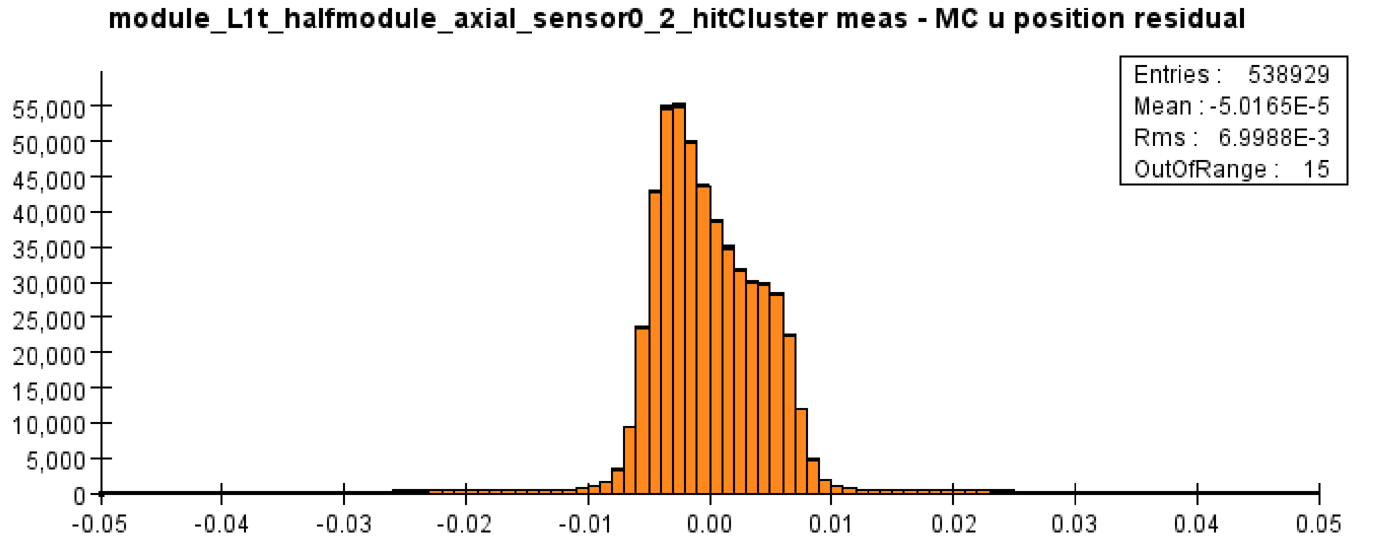
module_L1b_halfmodule_axial_sensor0_1_hitCluster meas - MC u posit...
Entries : 621781
Mean : 5.3736E-4
Rms : 0.012872
OutOfRange : 1
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-0.05
-0.04
-0.03
-0.02
-0.01
0.00
0.01
0.02
0.03
0.04
0.05

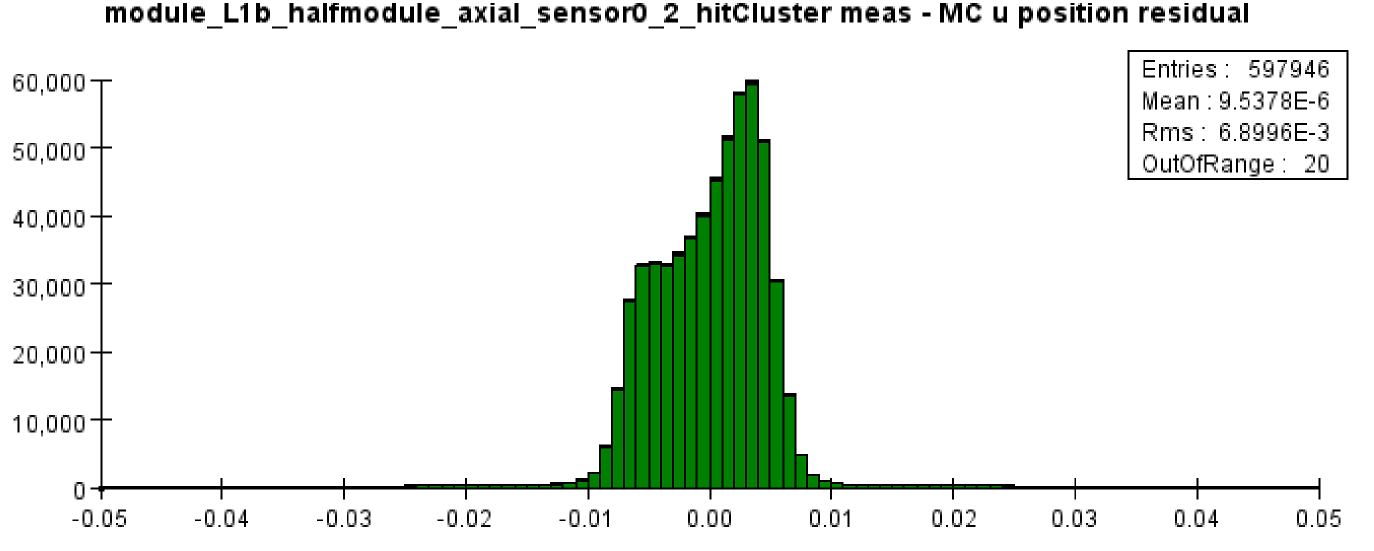
2 Strip



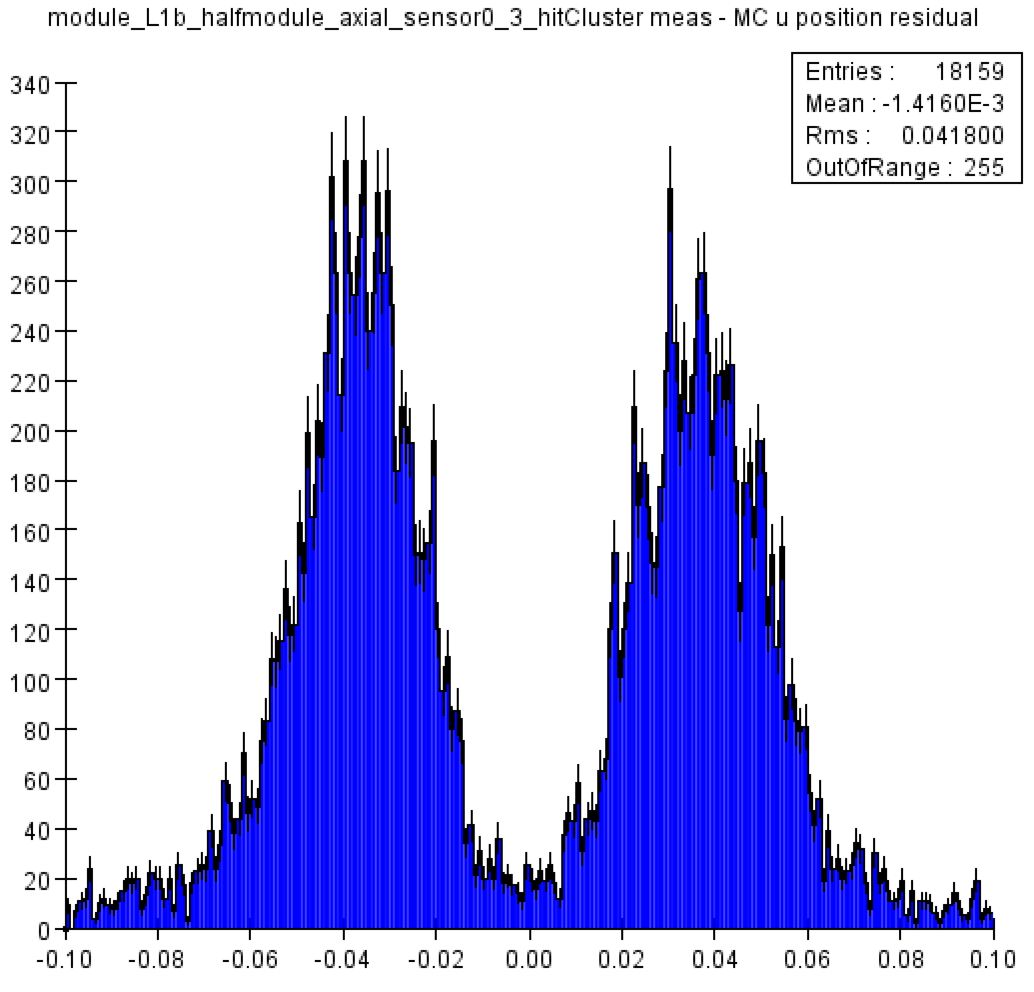
module_L1b_halfmodule_axial_sensor0_2_hitCluster meas - MC u posit...
Entries : 597946
Mean : 9.5378E-6
Rms : 6.8996E-3
OutOfRange : 20
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
-0.05
-0.04
-0.03
-0.02
-0.01
0.00
0.01
0.02
0.03
0.04
0.05

2 Strip (top vs bottom)



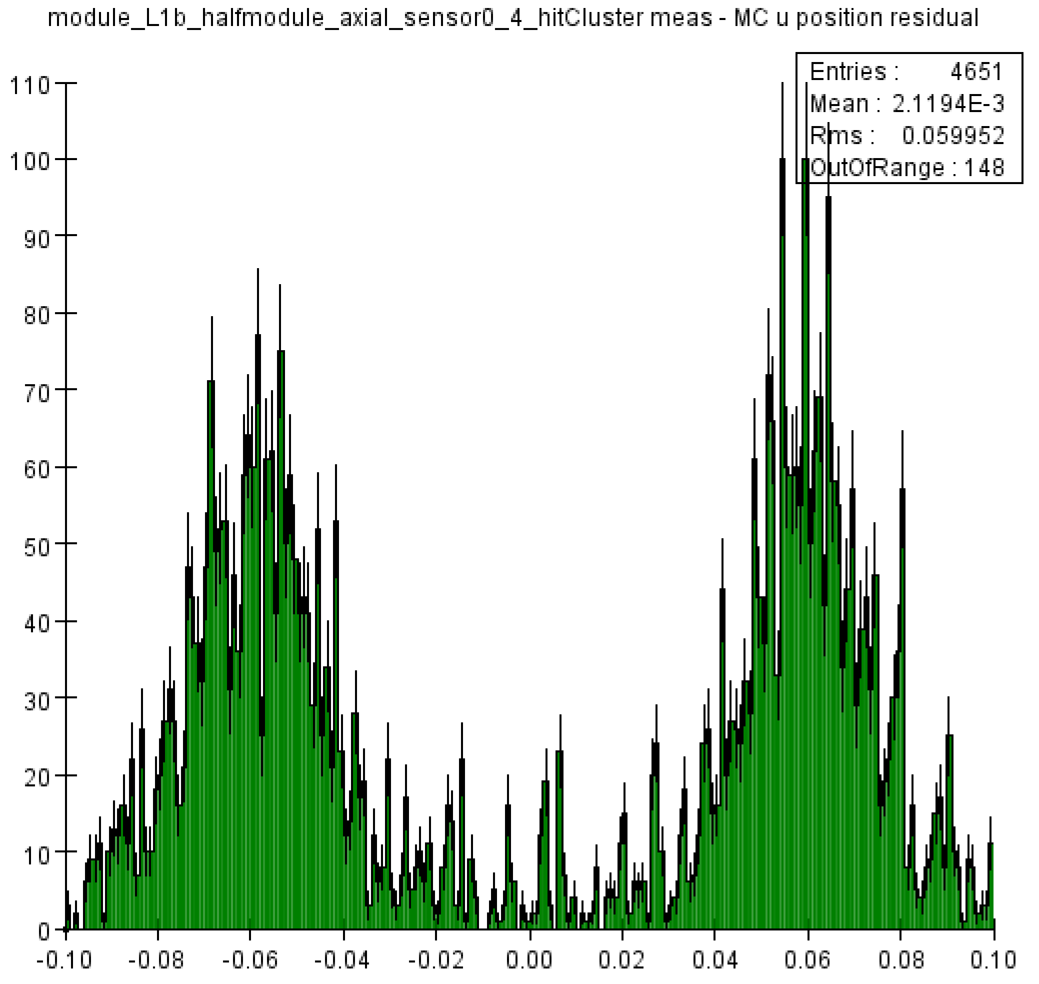


3 Strip



module_L1b_halfmodule_axial_sensor0_3_hitCluster meas - MC u position residual
Entries : 18159
Mean : -1.4160E-3
Rms : 0.041800
OutOfRange : 255
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-0.10
-0.08
-0.06
-0.04
-0.02
0.00
0.02
0.04
0.06
0.08
0.10

4 Strip



module_L1b_halfmodule_axial_sensor0_4_hitCluster meas - MC u position residual
Entries : 4651
Mean : 2.1194E-3
Rms : 0.059952
OutOfRange : 148
110
100
90
80
70
60
50
40
30
20
10
0
-0.10
-0.08
-0.06
-0.04
-0.02
0.00
0.02
0.04
0.06
0.08
0.10

MC Hit Summary

- No resolution (yet) to the resolution
- Single strip clusters seem to be OK
- Two-strip clusters are asymmetric
- Recall that the majority of hits in data are split roughly 50-50 between 1- and 2-strip hits.
- Three- and four-strip clusters are bimodal
- Currently looking into both the charge drift and diffusion code as well as the clustering.
- Also looking at unbiased hit residuals to see if there is evidence of this in the data (although MCS dominates).
- Could we improve our millepede alignment by analyzing only 2-strip hits in the planes that we are floating? Will factor of 2 better in resolution make up for factor of 2 worse in statistics?

Tracking in 2019

- If all goes well, we will not have the luxury of spending years aligning and calibrating our detector and reconstructing our data from scratch as often as we have.
- Need to come up with a run plan that enables us to quickly align and calibrate what is essentially a new tracking detector.
- Need to worry about data storage and reconstruction time.

Run Plan

- Would be nice to have some limited exposure to beam for calibration purposes prior to going DC for 8 weeks:
  - To allow us to commission the detector with downtime that does not cost us PAC days
  - At lower energies to get Moller events
  - With field-off to get straight-throughs
  - With dedicated FEE triggers to give us large angle scatters that populate the edges of the detector.

Recon Plan

- Need to intensify our efforts (start?) to improve the performance of our tracking reconstruction
  - Speed up hit wave-form extraction with dedicated fitter
  - Speed up / improve pattern recognition
  - Push recoil-electron track finding/fitting/vertexing
  - Reduce our output LCIO file size
    - e.g. drop raw SVT wave-forms after fits, eliminate duplicate tracks, clusters, etc.
  - Implement "smart" strategies for pass-N re-reconstruction, e.g.
    - Re-run over lcio, not evio
    - Don't re-calculate hit pulse heights and times
    - Don't re-run pattern recognition, simply re-fit tracks with new, better geometry, re-associate tracks with ecal clusters, …

Documentation

- Tim is leading the effort to prepare the SVT writeup.
  - Draft is in progress, intend to submit to NIM.
    - In github
      - git clone https://git.overleaf.com/12905342sjjwjbxhwwwb svt_nim
    - On Overleaf
  - Current effort aimed at performance plots, which are being assembled online.
- Track Reconstruction Note in preparation
  - On Overleaf

Meetings & Results Pages

- Weekly meetings to discuss both hardware and software tracking issues
  - Subscribe to mailing list
- 2015 Performance Studies
  - Confluence page with task list and performance plots related to analysis of the 2015 data
- 2016 Performance Studies
  - Confluence page with task list and performance plots related to analysis of the 2015 data

Summary

- Current code and algorithms are working, but…
- Improvements to the Alignment, Calibrtion, Tracking and Vertexing feed directly into improvements in the bump-hunt and vertex analyses and our discovery reach
- Major changes are unlikely for the analysis of data already taken, but will be necessary for physics run in 2019.
  - We have a little over a year to get ready.
    - + Much can be done in that time
    - - Much needs to get done in that time
- Great opportunities for new contributors