2021 Data Reconstruction: Calibration / Analysis First Look

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HPS Collaboration Meeting
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2021 Offline Data Reconstruction

- Software development for the 2021 run should be done on git branch Run2021.
- Reconstruction Version
  - hps-java 5.1 snapshots on Run2021 branch
- Detector
  - HPS_Run2021Pass1Top
- Steering File
  - PhysicsRun2021_pass0_recon_evio.lcsim
    - n.b. this runs only the Kalman Filter track finding & fitting

2021 Data Samples

- A few special runs (e.g. FEE & Møller trigger runs) and sample partitions from other runs have been processed and made available for analysis.
- /volatile/hallb/hps/production/physrun2021/recon/HPS_Run2021Pass1Top/
  - 14* : physics runs, ten partitions 40-49
  - 14168: FEE run
  - 14362, 14364: Møller special runs at 3.74 GeV
  - 14652, 14653: Møller special runs at 1.92 GeV
  - 14753, 14754 SVT positioning wire target
  - 14764, 14768 Field-off (2H02 HARP, collimator wire target)
- Not an exhaustive list, but representative of the various data sets available for calibration and alignment.

Calibration Current Status

- Ecal is using the correction factors derived for the 2019 data
  - Corrections for the 2021 data are being worked on
    - Will skim the FEE trigger events from the 2021 data and perform the iterative crystal-by-crystal corrections and any run-dependent corrections (e.g. temperature, radiation exposure)
    - MC samples of single electrons, positrons and photons at a number of energies for the 1.92 and 3.7 GeV runs have been generated and will be used to determine the "sampling fraction" corrections
    - Please contact Andrea Celentano for details and to offer your assistance.
- SVT top has had an initial alignment pass performed on the SVT top sensors using FEEs
  - Will extend this to bottom sensors
  - Will use positrons as well as electrons
  - Will use lower-energy matched clusters as momentum constraint once Ecal is calibrated.
  - See PF's presentation for details

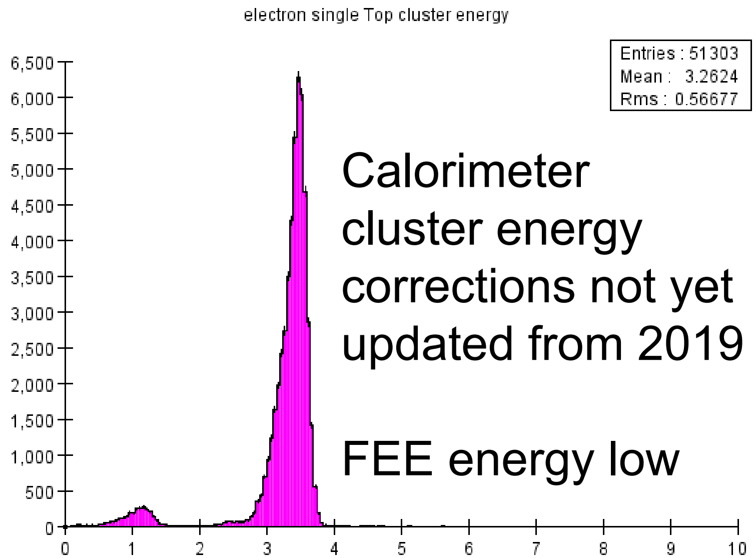
Ecal Calibration Data 2021

- Reconstruction Version
  - hps-java 5.1, Run2021 branch
- Detector
  - HPS_Run2021Pass1Top
- Steering File
  - PhysicsRun2021_pass0_recon_evio.lcsim
- FEEs
  - Run 14168
  - One and only one fiducial cluster
  - Seed energy > 1.9 GeV
- WABs
  - Skim events containing two and only two clusters in the fiducial region of the calorimeter
  - Clusters in diagonally opposite quadrants
  - Cluster times within 2ns
  - Cluster Esum > 2 GeV
- Tridents
  - Select events with three Ecal clusters with one cluster on the positron side and two clusters on the electron side.
  - Require sum pY ~ 0. GeV
  - Require esum > 2 GeV

Ecal Calibration Samples

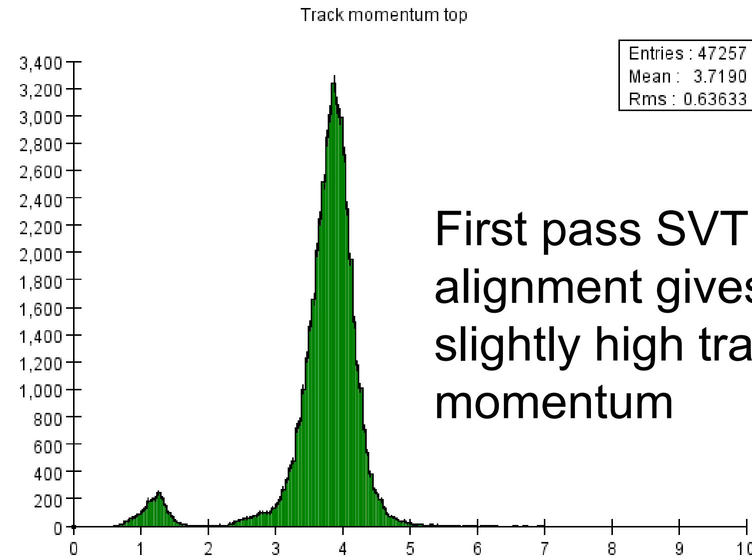
- FEE samples will provide crystal by crystal corrections to the readout channels at both 1.92 and 3.7 GeV by requiring single cluster energies to equal the beam energies.
- WAB samples will be used to test the “sampling fraction” corrections for both electrons and positrons at lower cluster energies by requiring that the energy sum of electron + photon clusters equals the beam energies
- Three-prong tridents will be used to test the “sampling fraction” corrections for positrons by requiring the energy sum of the two electrons and one positron to equal the beam energies.

FEE 12 or more hit Tracks

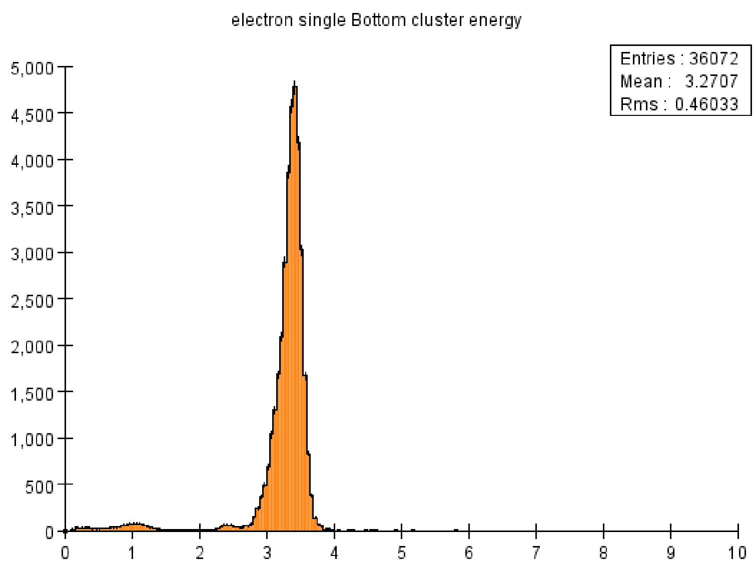


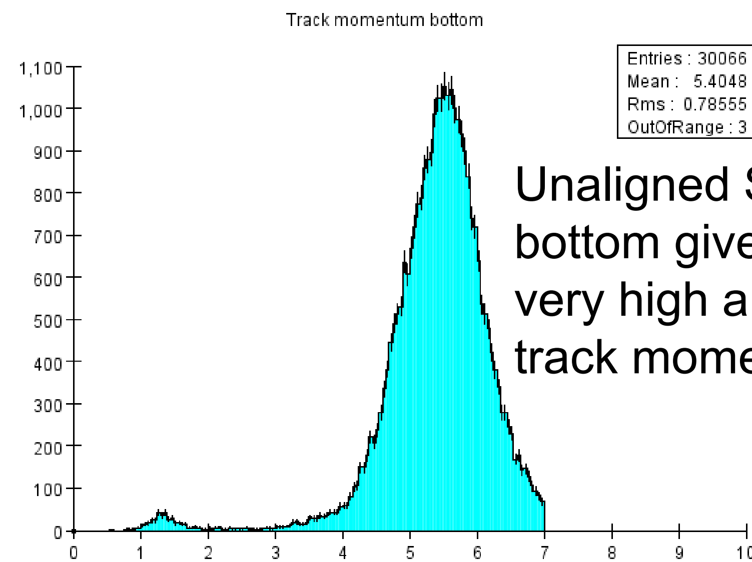
Calorimeter cluster energy corrections not yet updated from 2019

FEE energy low



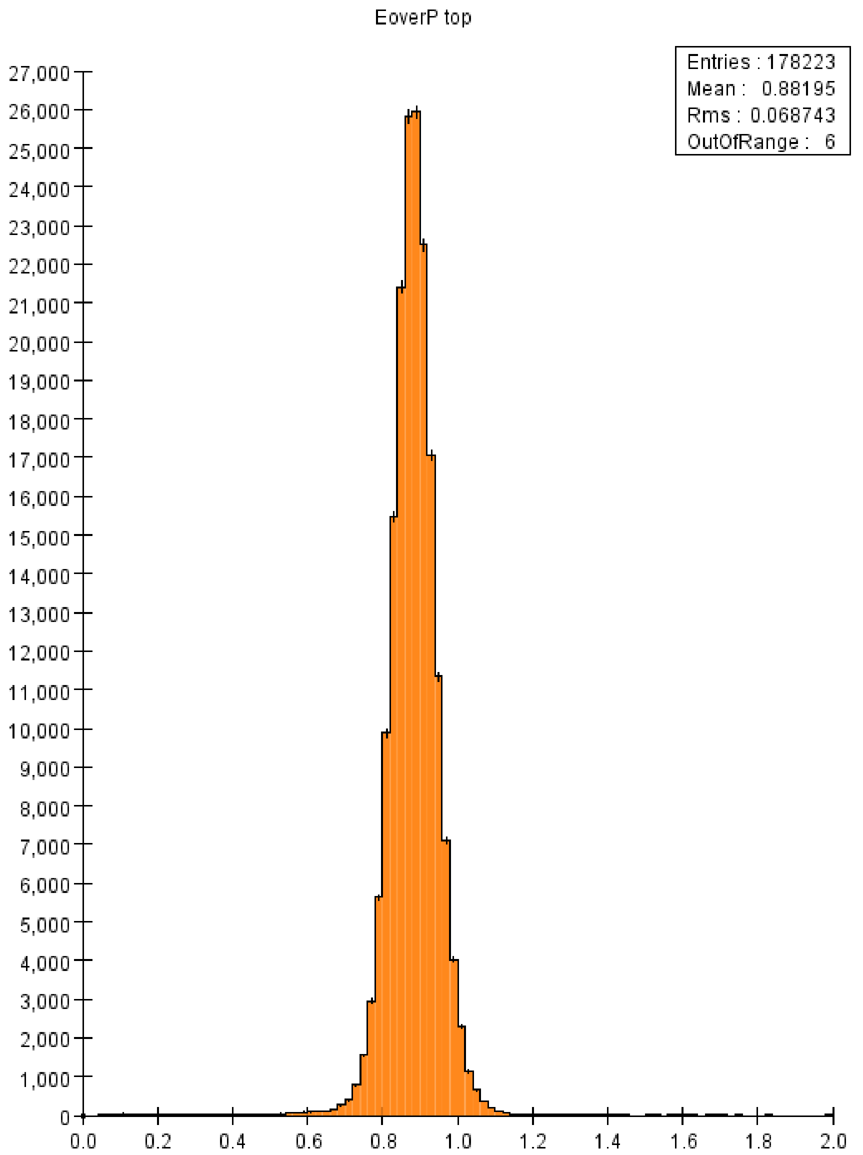
First pass SVT top alignment gives slightly high track momentum

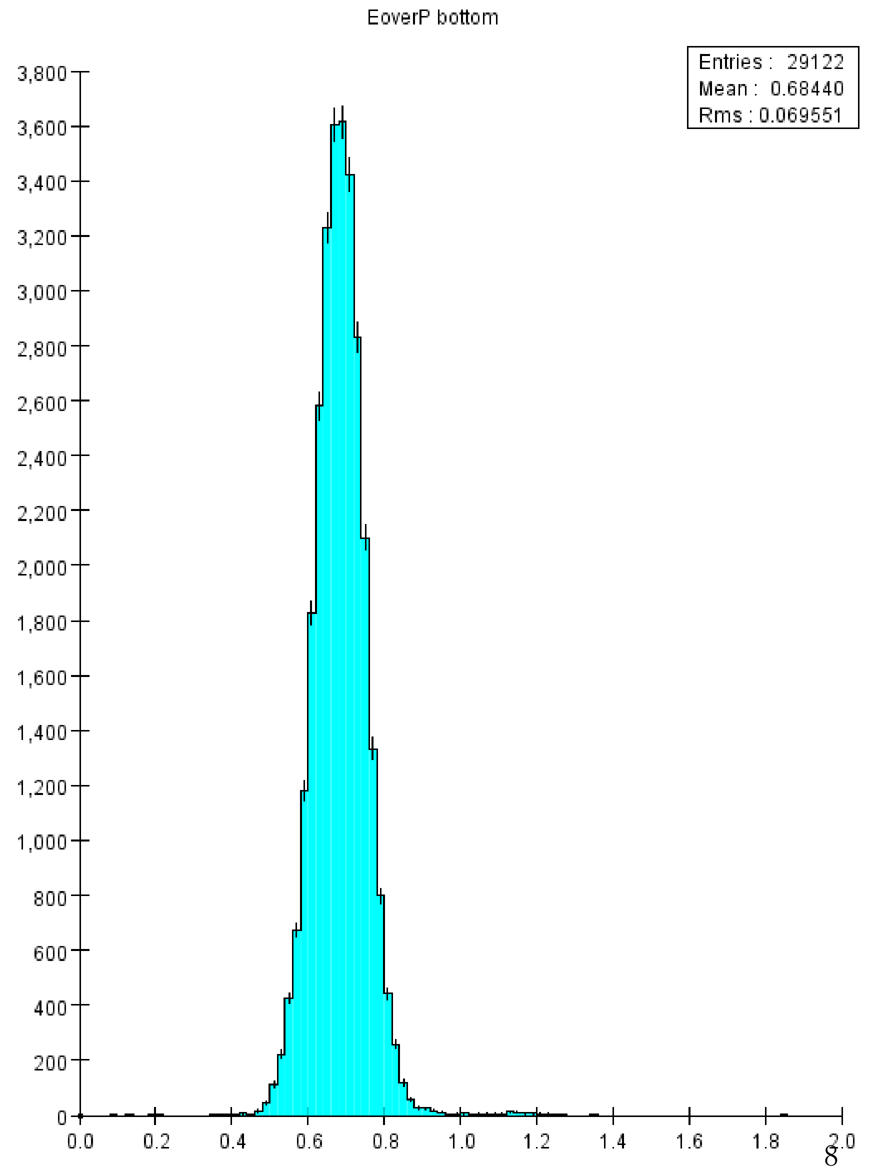




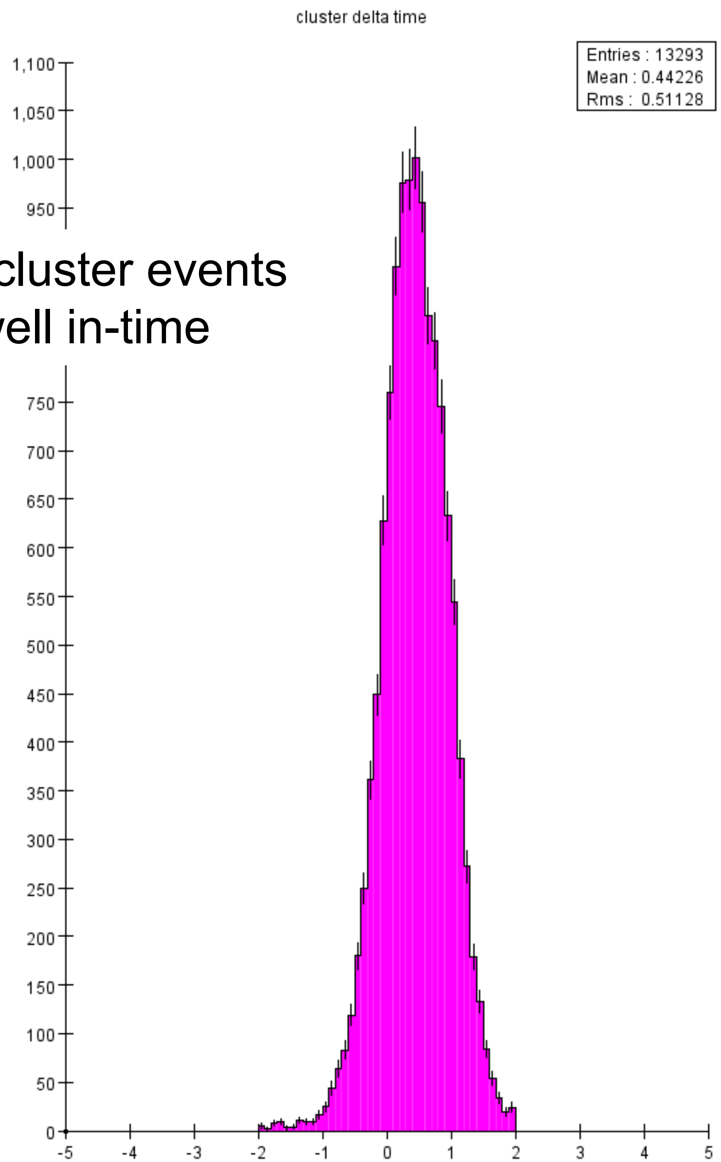
Unaligned SVT bottom gives very high and broad track momentum

FEE E/p

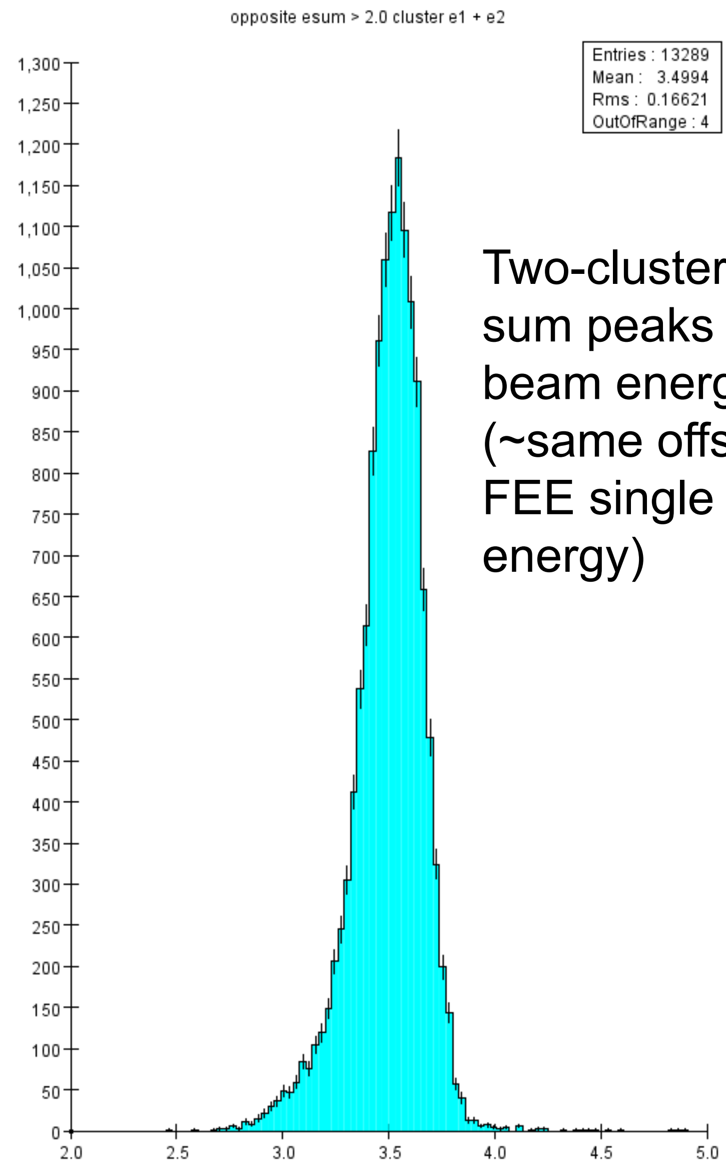

EoverP top
Entries : 178223
Mean : 0.88195
Rms : 0.068743
OutOfRange : 6
27,000
26,000
25,000
24,000
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0


EoverP bottom
Entries : 29122
Mean : 0.68440
Rms : 0.069551
3,800
3,600
3,400
3,200
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

WAB two-cluster dt and esum

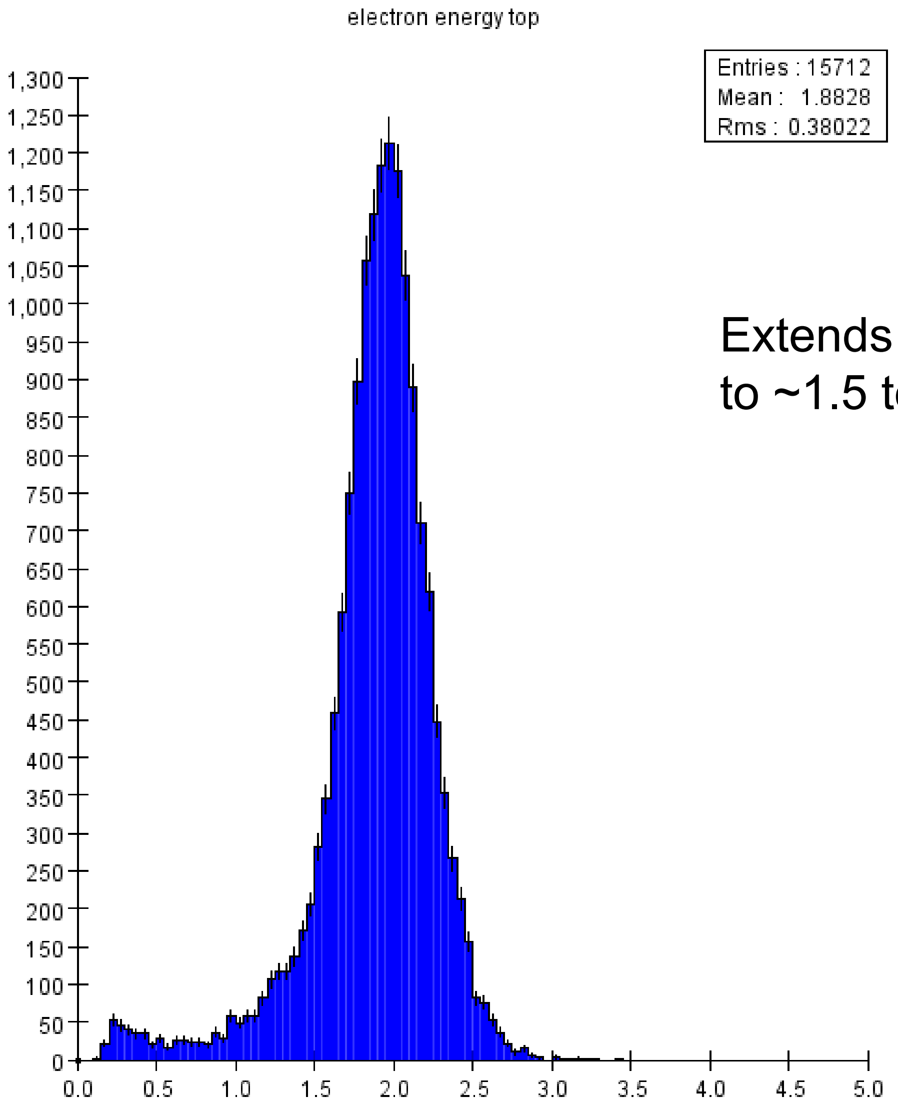


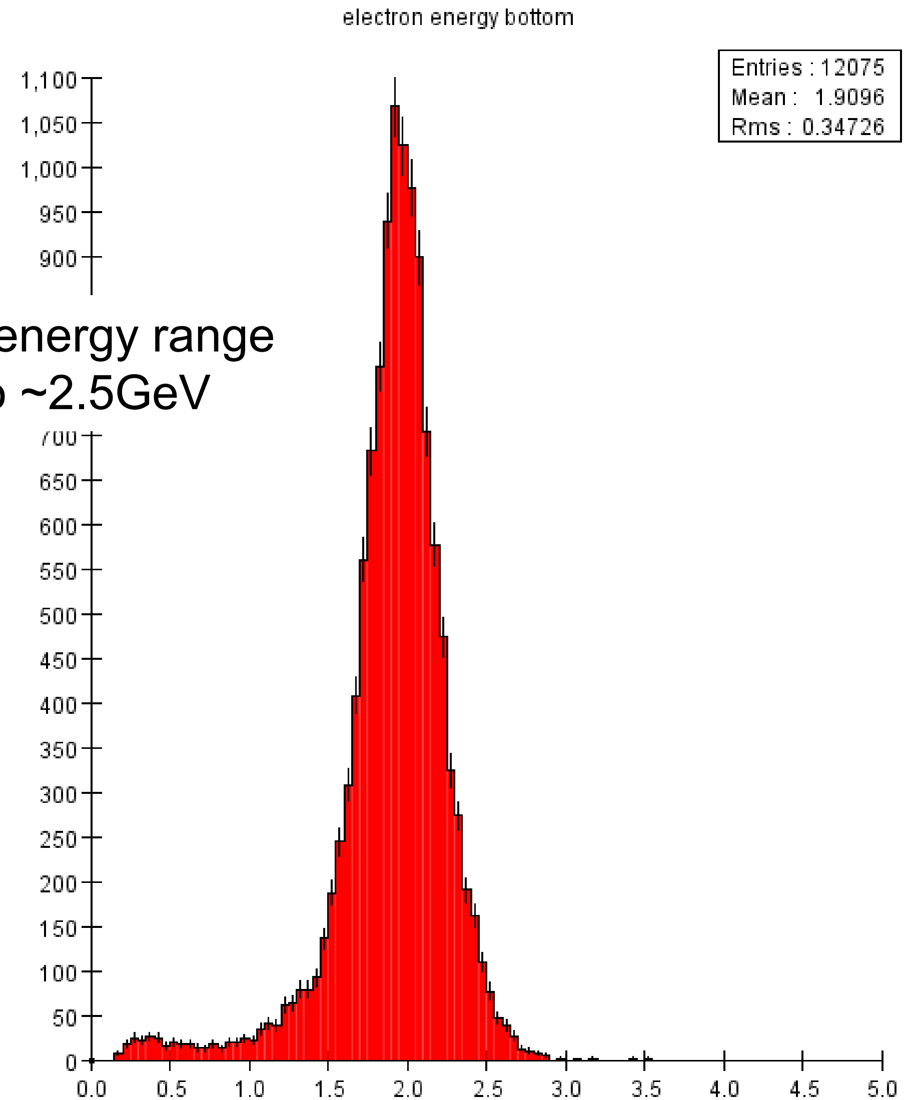
Two-cluster events are well in-time



Two-cluster energy sum peaks close to beam energy (~same offset as FEE single cluster energy)

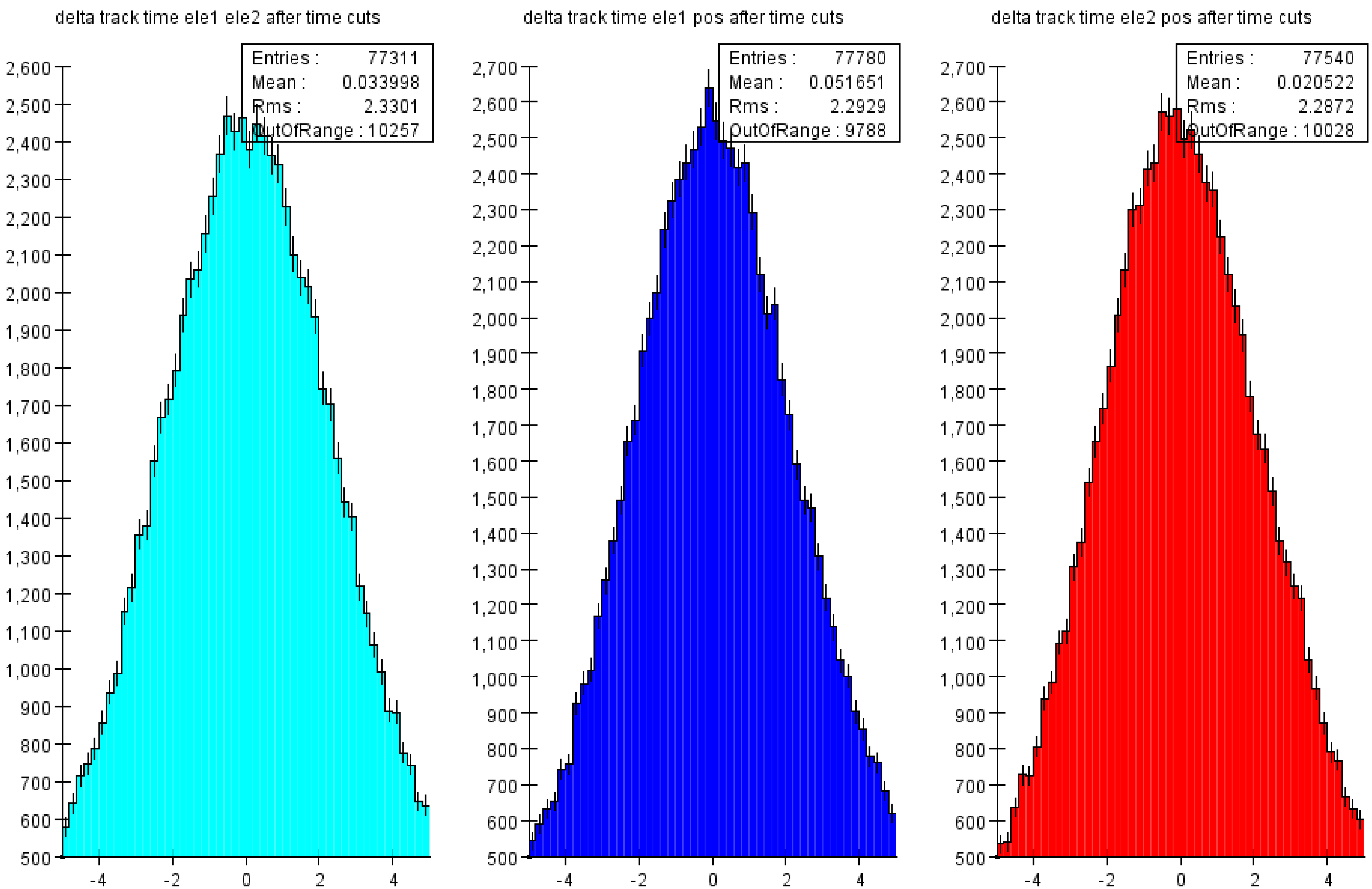
WAB Candidate Cluster Energy





Extends energy range to ~1.5 to ~2.5GeV

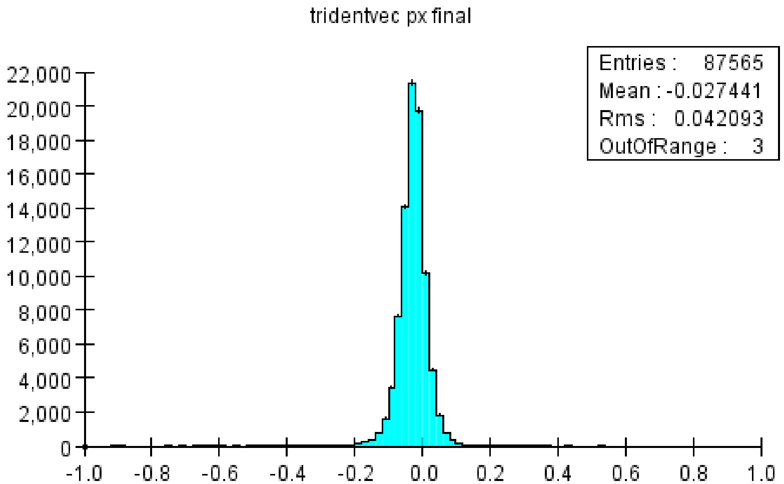
$e^+e^-e^-$ Trident delta Track Times

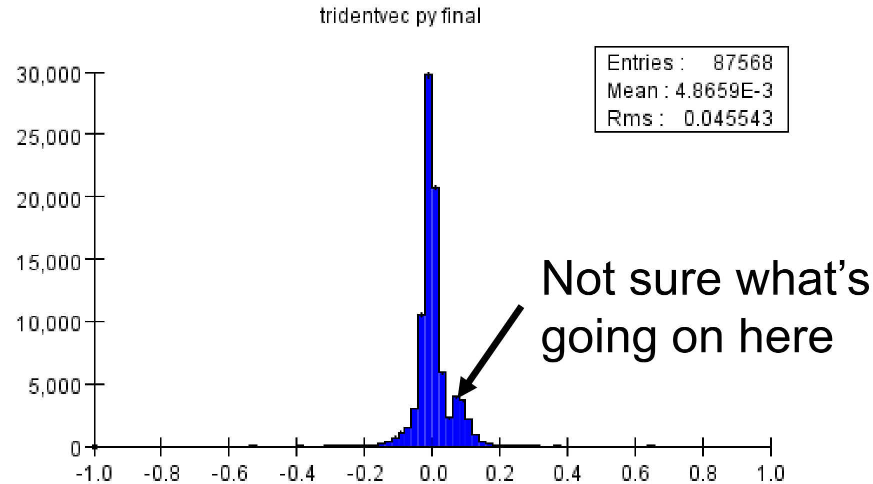


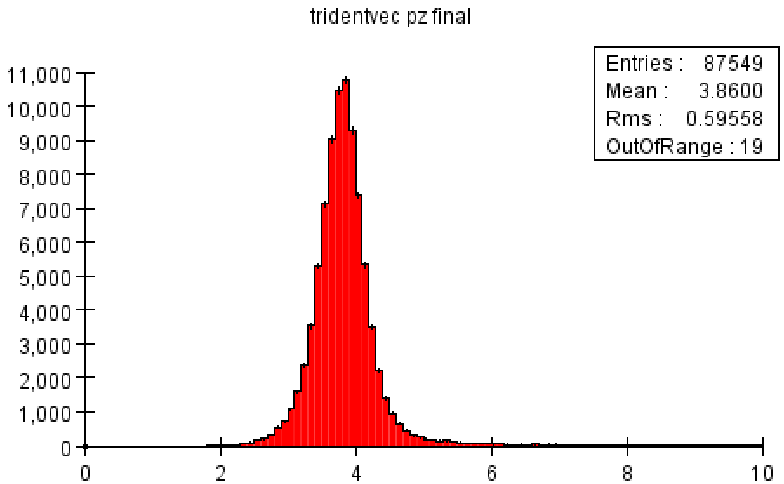
Three-cluster events are well in-time

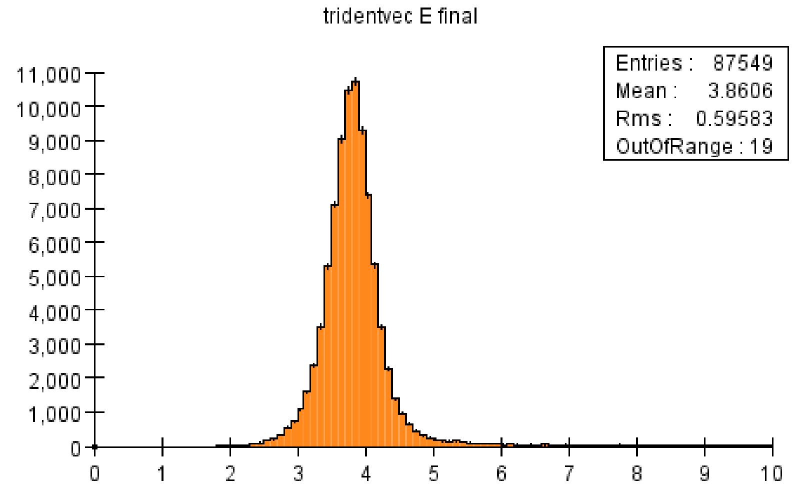
Track-time is good proxy for cluster time, albeit with worse resolution

$e^+e^-e^-$ Trident Four Vector



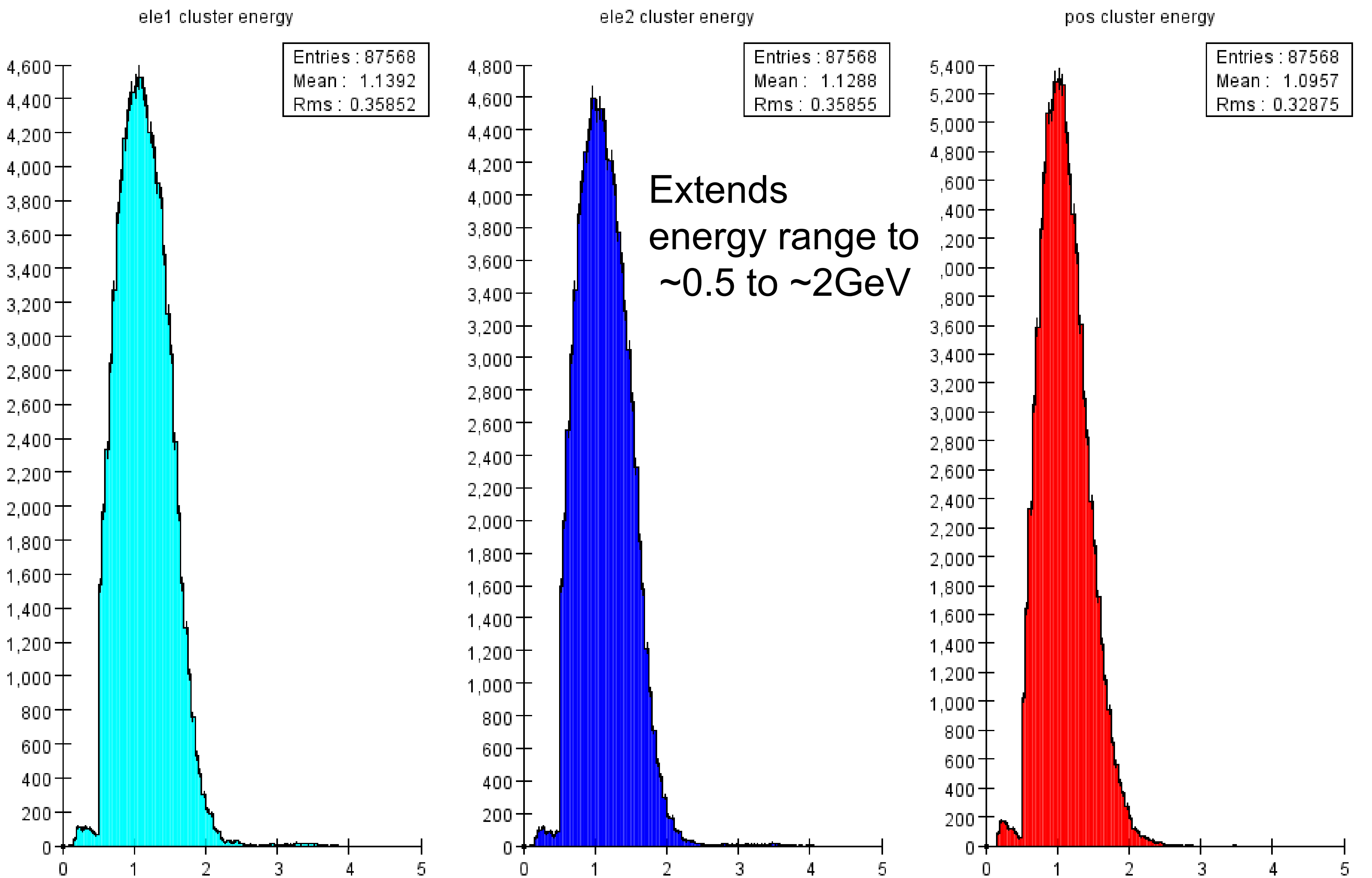






Three-cluster four-vector is commensurate with incoming beam
Once fully calibrated, can be used to determine beam direction wrt HPS

$e^+e^-e^-$ Trident Cluster Energies



Extends energy range to ~0.5 to ~2GeV

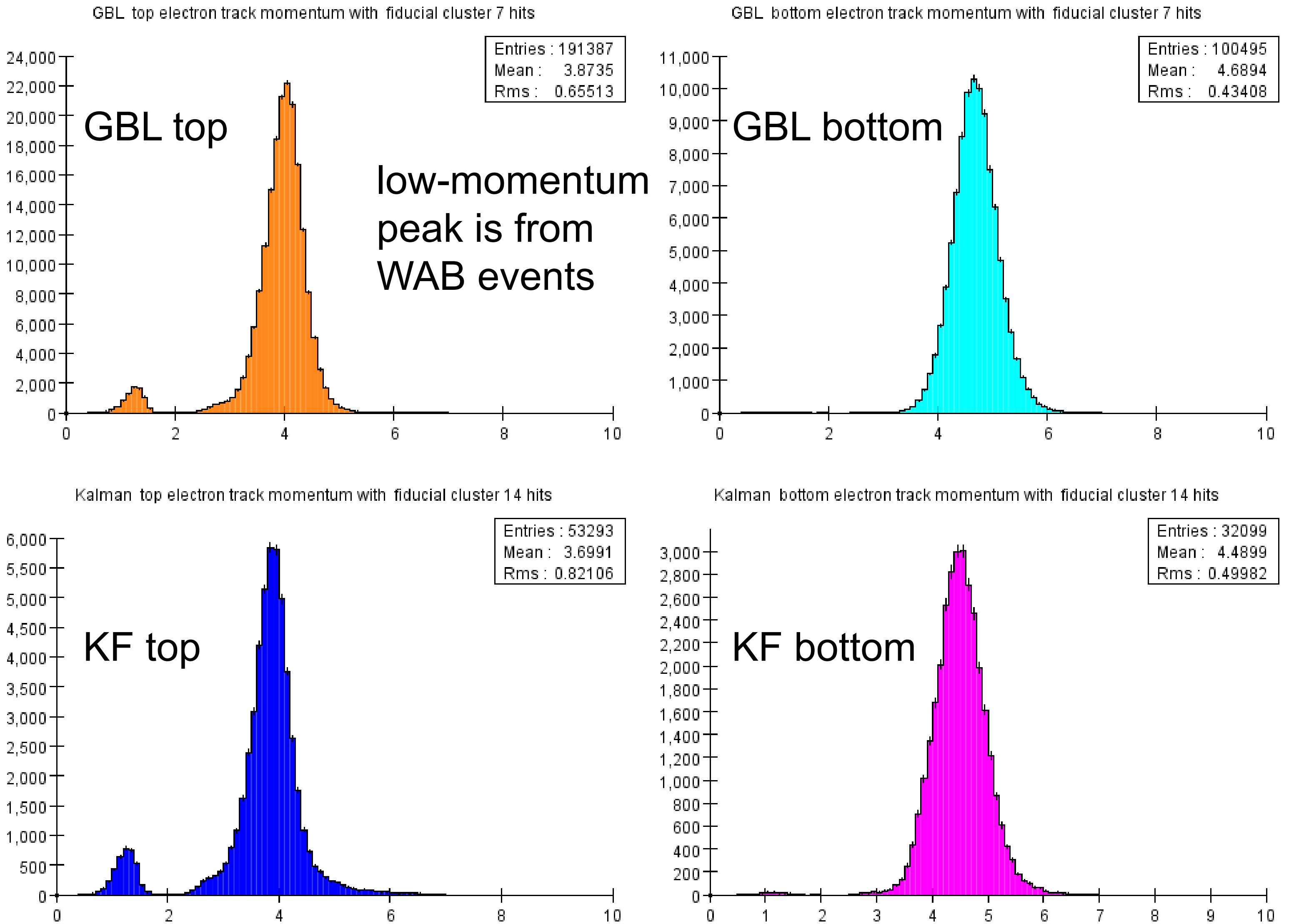
FEE, WAB and Tridents

- Several issues to note:
- Calorimeter-only selection cuts provide us with clean samples of events which will allow us to study track-finding efficiencies, tracker alignment and tracker momentum scale and resolution
- Calorimeter cluster corrections have not yet been derived for the 2021 run. We are using those developed for the 2019 run.
  - Efforts are underway to derive corrections appropriate for the 2021 data
- Calorimeter Cluster Energy is low
    - FEE cluster energy ~ 93% of beam energy
- Track momentum scale is high
  - ~3.9GeV (top)
  - ~4.9GeV (bottom)
- Track momentum resolution in bottom is poor.
- Track timing, although worse than calorimeter cluster timing, can be used to reject backgrounds
- Calorimeter-only selection cuts provide clean event samples that can be used to momentum-constrain the SVT alignment from 0.5GeV to 3.74 GeV

SVT Alignment with FEEs

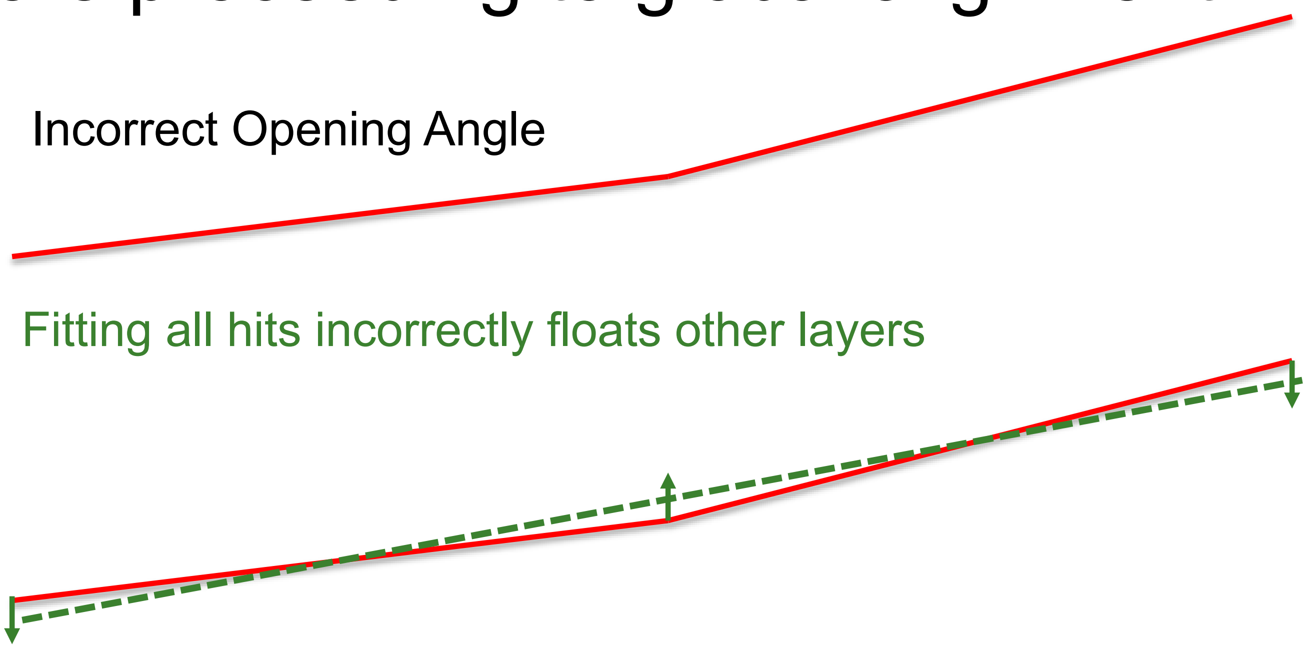
- Using the FEE events to align/calibrate the SVT.
  - highest-energy tracks have lowest multiple-scattering
- Select FEE events with tracks having hits in all layers (7 for GBL, 14 for KF).
- Break tracks associated with FEE clusters into two parts: front four sensors & back three sensors
- Fit each segment separately and extrapolate to the z of the SVT hinge.
- Compare slopes and intercepts to measure "opening angle" and offsets.

FEE track momenta



SVT "Opening Angle"

- Currently working to correct for opening angle before proceeding to global alignment.



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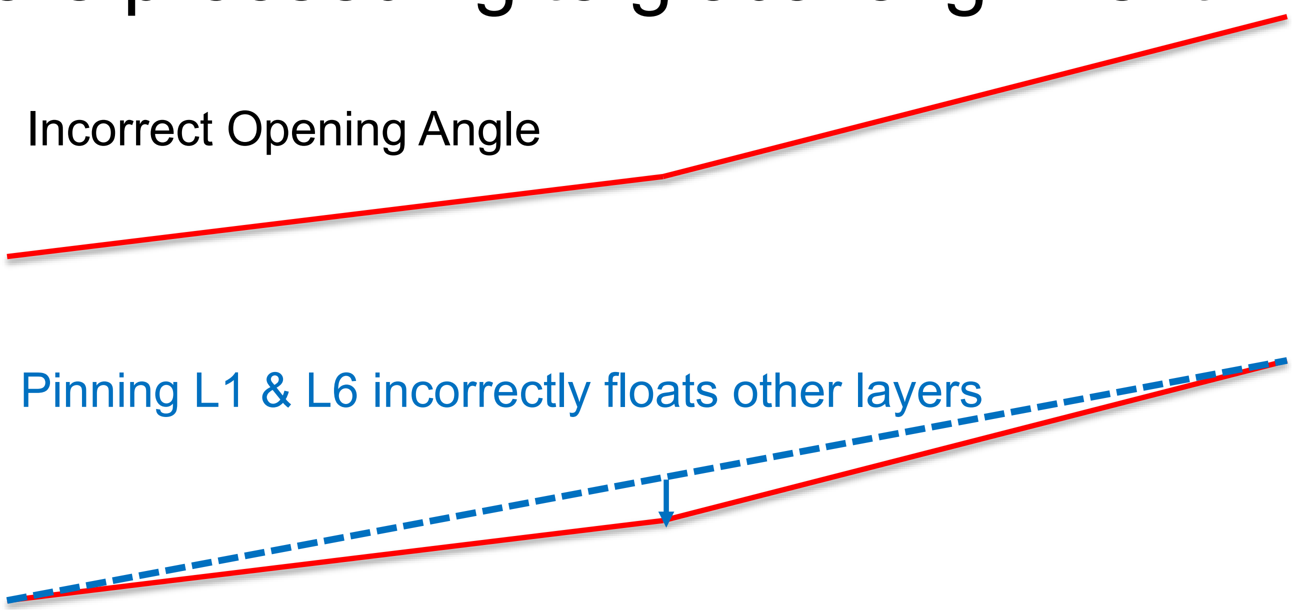

SVT "Opening Angle"

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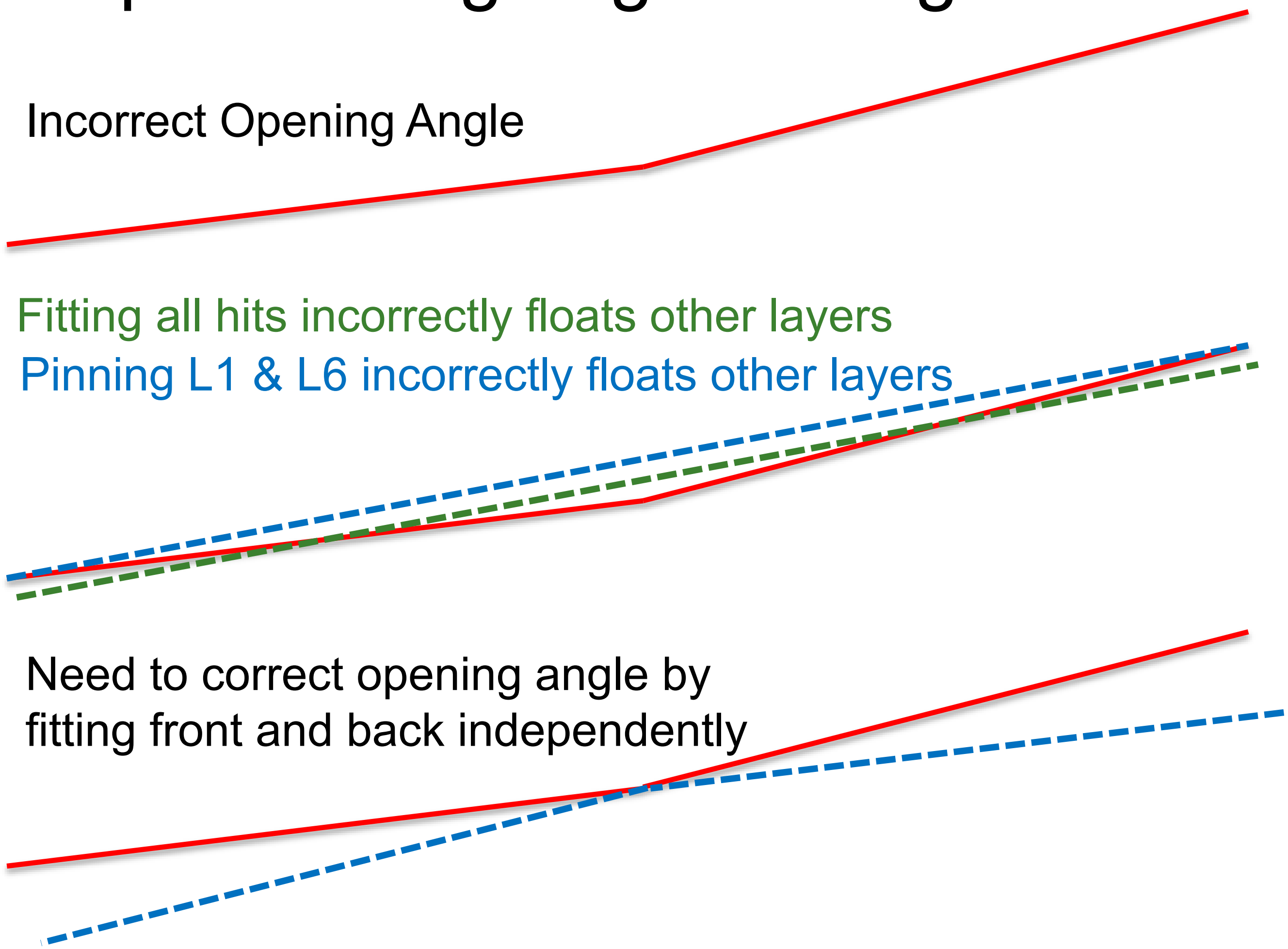
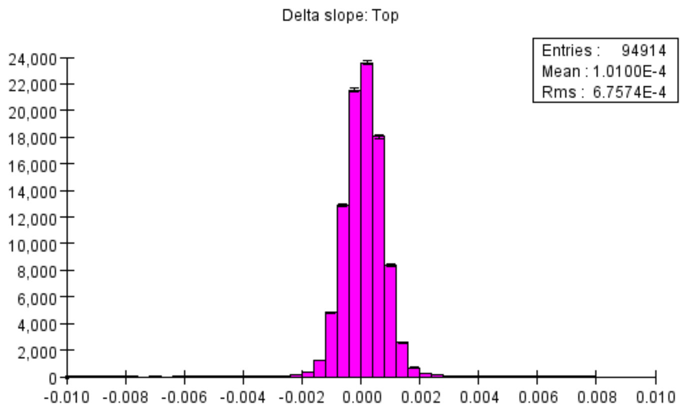
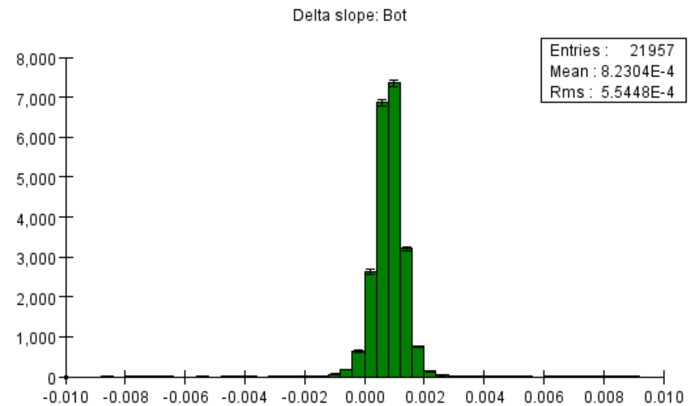
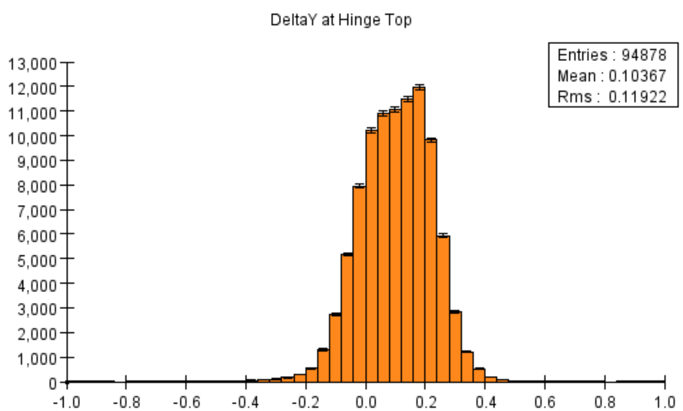


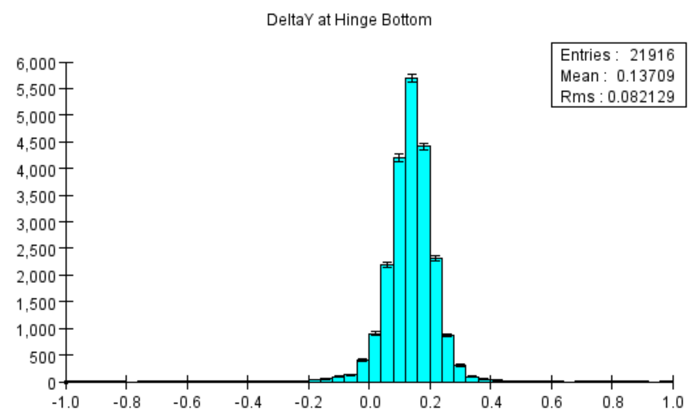
HPS_Run2021Pass1Top Detector

- Differences in slopes and intercepts noted in both top and bottom.
- Top “opening angle” appears commensurate with zero, whereas bottom appears to require some correction
- Broadness of difference in intercept in top may point to a rotation about z axis, whereas bottom may be resolved with a simple offset





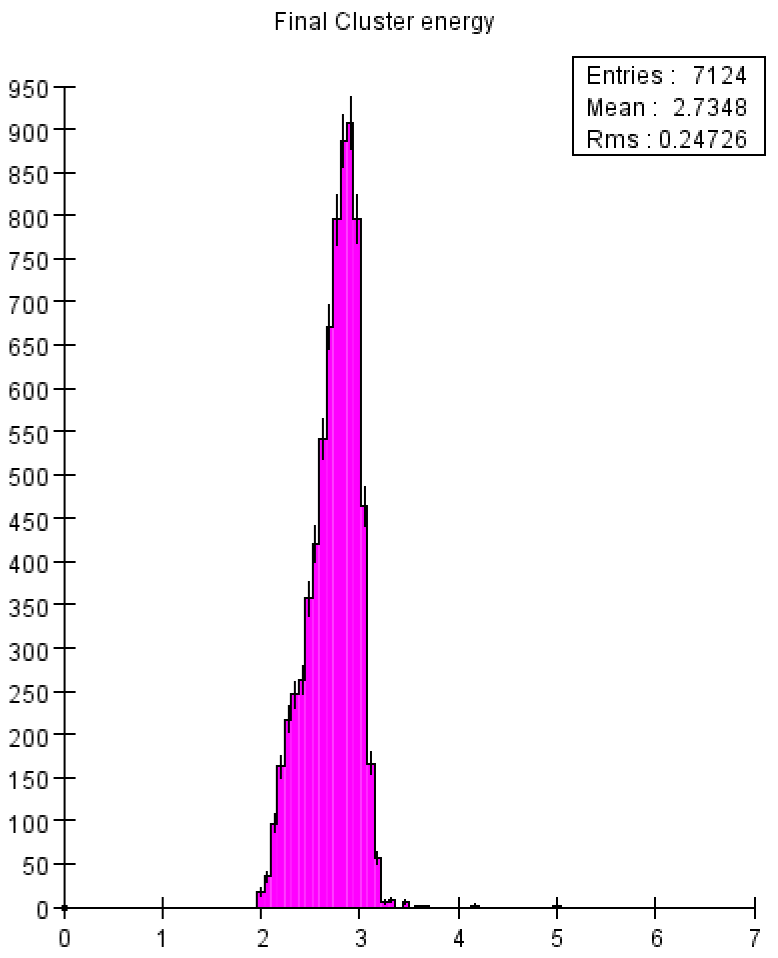


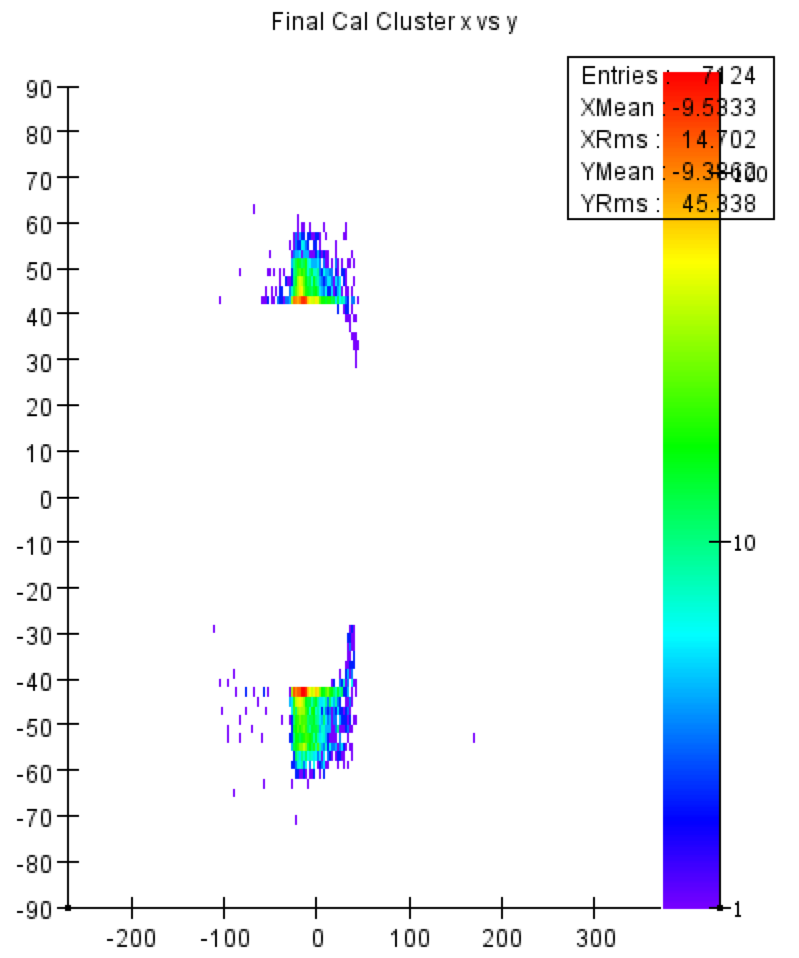


Field-Off Data

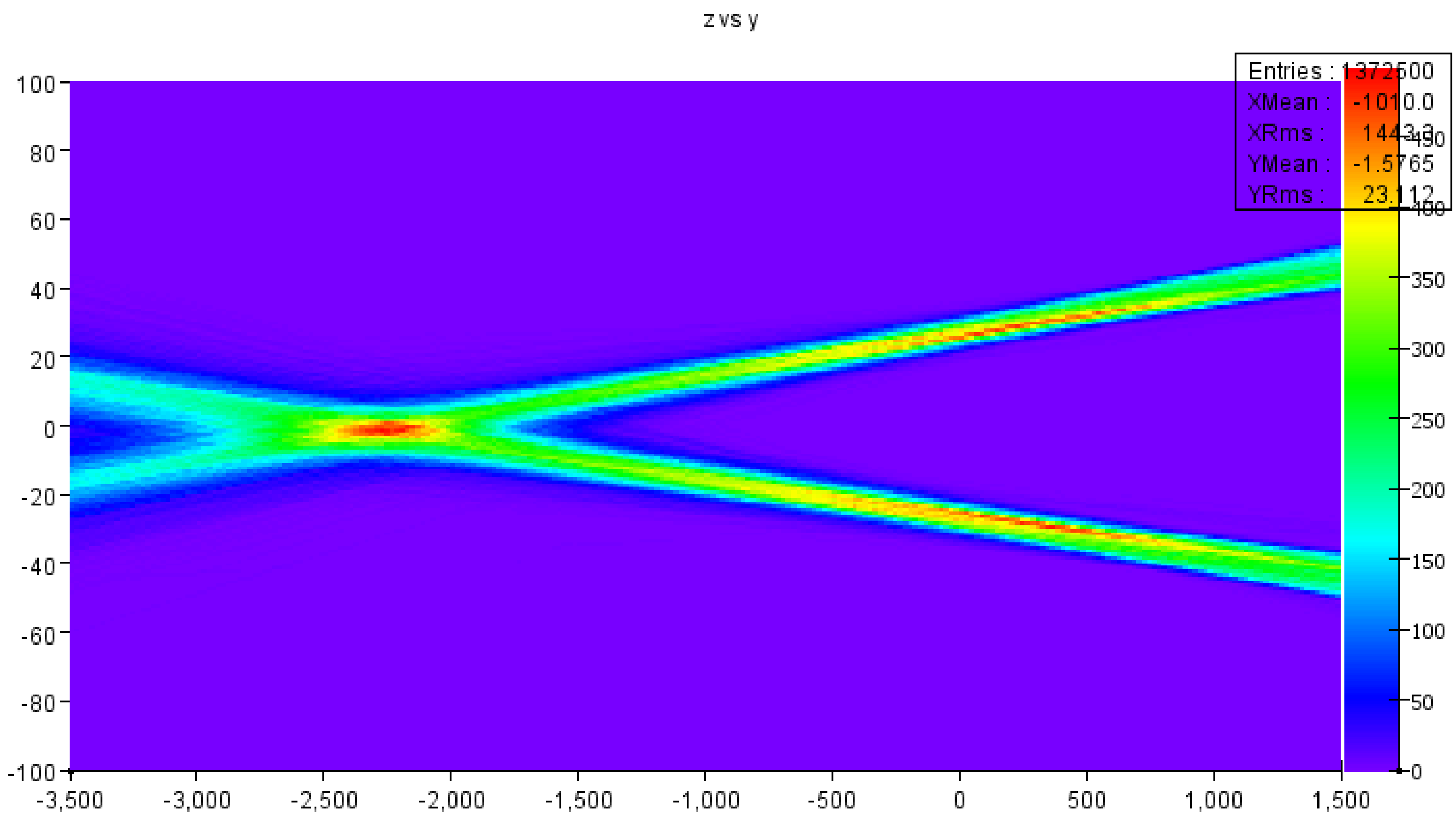
- Use straight tracks from the field-off runs.
- Run 14764 used 2H02 Harp wire as target
  - ~ -2270mm upstream
- Run 14768 used 2H02 collimator wire as target
  - ~ -3080mm upstream
- Have implemented code to perform straight-track fits to 1D strip cluster hits in the field-off data
- Pattern Recognition
  - Connect Ecal cluster position to the 2H02 harp or collimator wire
  - Look for 1D hits in sensors in the road
- Fit 1D hits to track
- Fit n-1 hits to determine unbiased residuals for each sensor

Field-Off Data



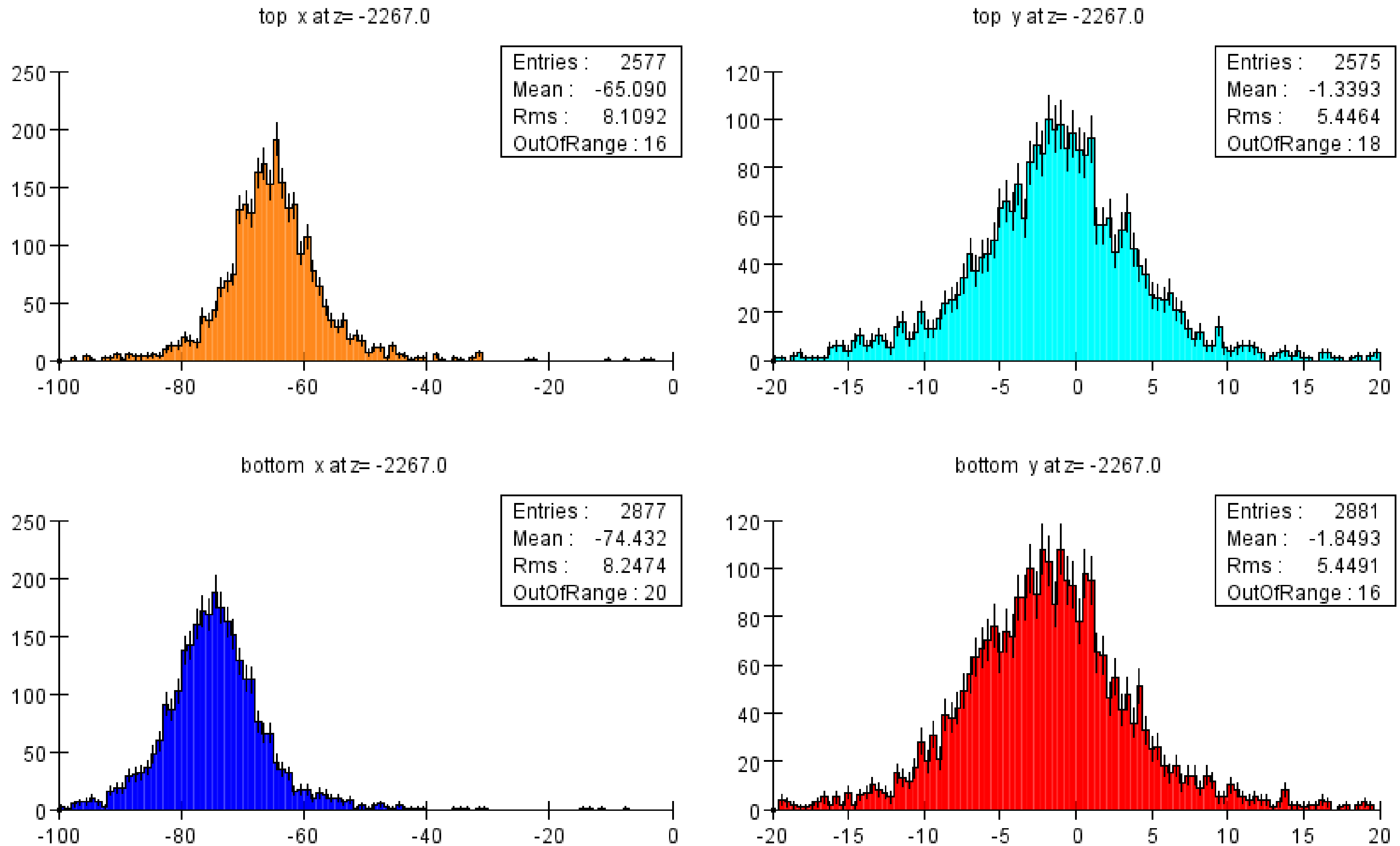


Field-Off Data



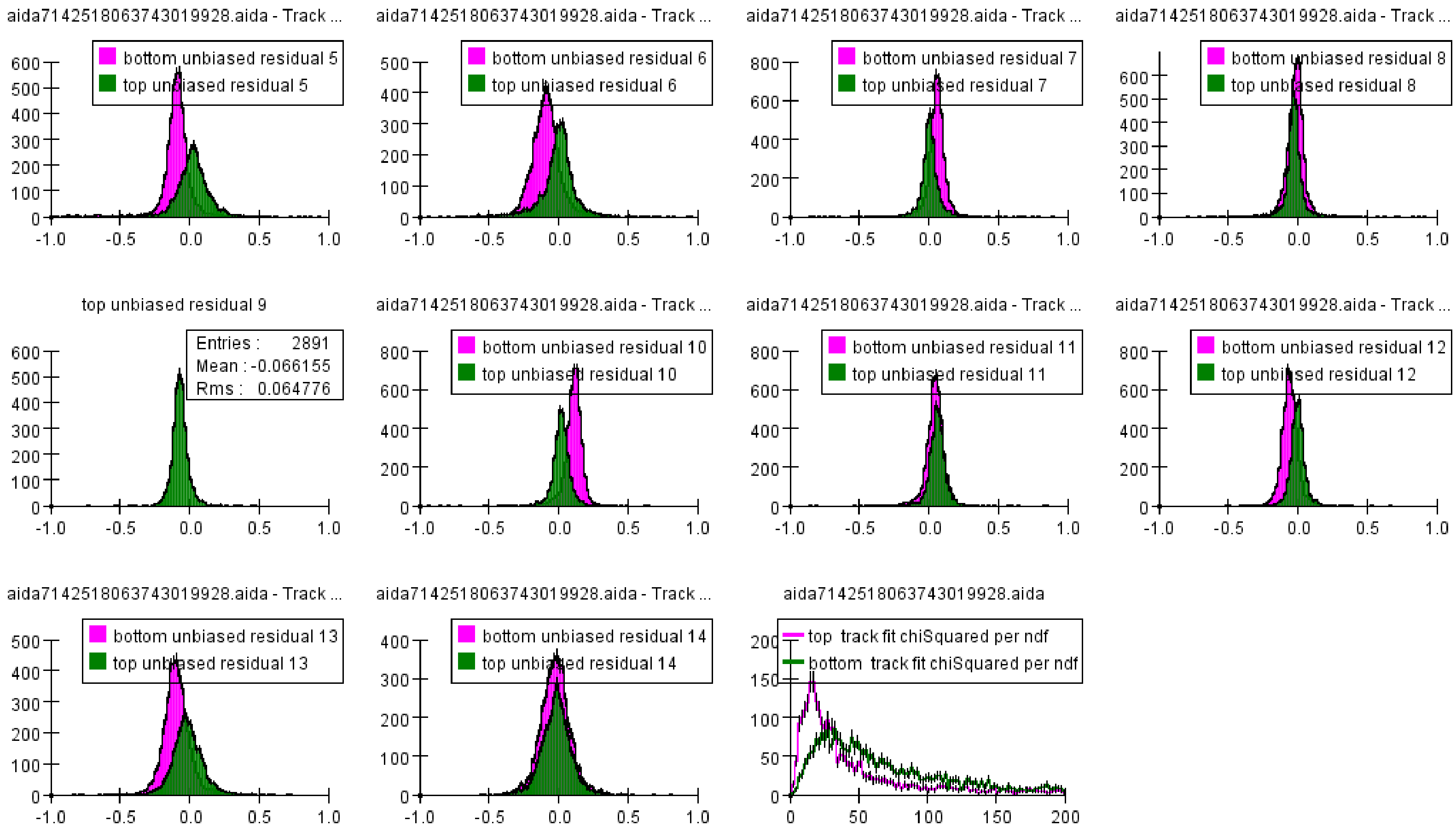
Track extrapolations from top and bottom converge roughly at the location of the 2H02 harp wire in z.

Field-Off Data



Differences in the top and bottom are not unexpected, as the top sensors have been subjected to a first alignment iteration whereas the bottom sensors have not yet been aligned.

Field-Off Data Unbiased Residuals



Unbiased residuals for bottom sensors and track-fit chi-squared show much larger means than those in the top, as expected.

Field-Off Data Alignment

- Will attempt to align the individual sensors using the beamspot at the wire locations as a constraint
- Will compare the corrections to those derived via the canonical alignment procedures
- Will then use these alignment parameters as input to the global SVT alignment procedure
- Alternatively, will use the aligned detectors derived via alternate methods to check positions and slopes at the wire targets.

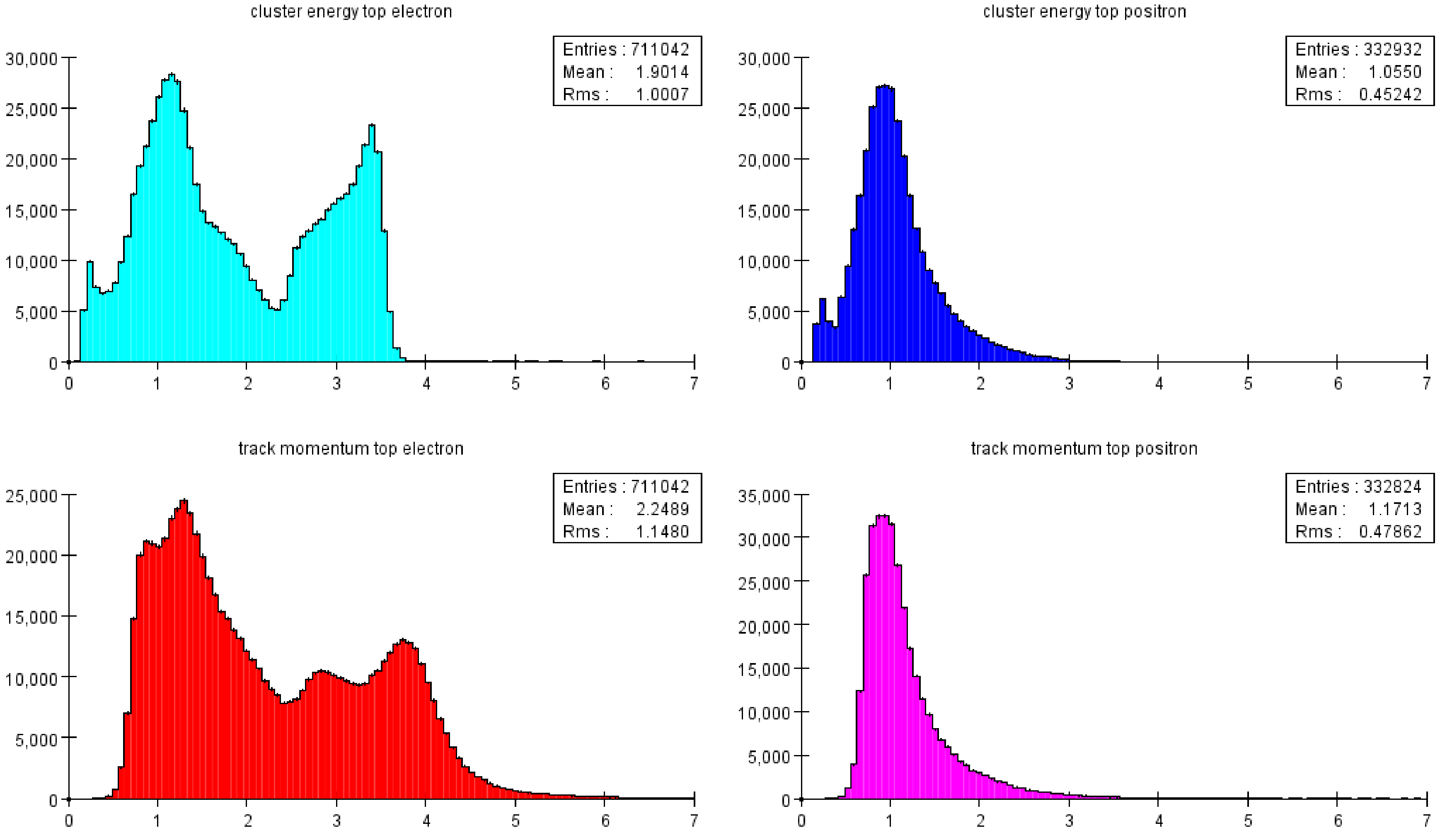
SVT Positioning Wire Targets

- Use SVT positioning wires as target
- 14753, SVT bottom wire as target, 10.2M events
  - DAQ configure: hps2021_v2_3_SVT_WIRE_RUN.trg.
  - Bottom wire-to-beam: 0.105 mm
  - layer0-to-beam: -7.205 mm
  - angle: 0.019 rad.
- 14754, SVT top wire as target, 10.3M events
  - DAQ configure: hps2021_v2_3_SVT_WIRE_RUN.trg.
  - Top wire-to-beam: 0.074 mm
  - layer0-to-beam: 7.602 mm
  - angle: 0.0189 rad.

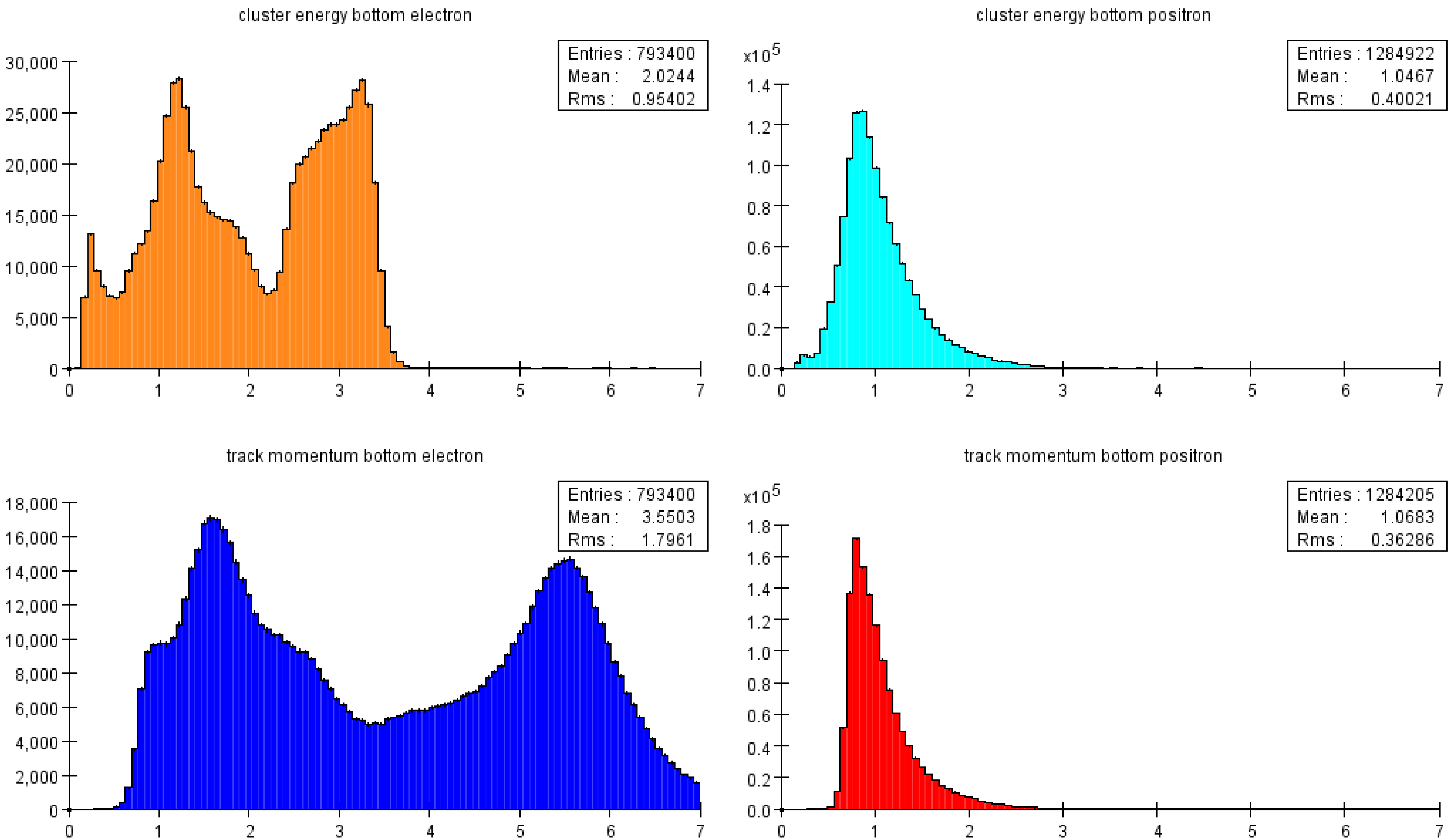
SVT Positioning Wire Targets

- Events reconstructed using default 2021 detector
  - should be OK for half of the detector at a time
    - i.e. top tracks should be OK for bottom wire target and *vice versa*
- First look at the data indicates that the events behave as expected, viz.
  - bottom wire gives more electron tracks in the top
  - top wire gives more electron tracks in the bottom
- Vertex same-side electron and positron tracks from different events to generate vertices composed of top-only and bottom-only tracks

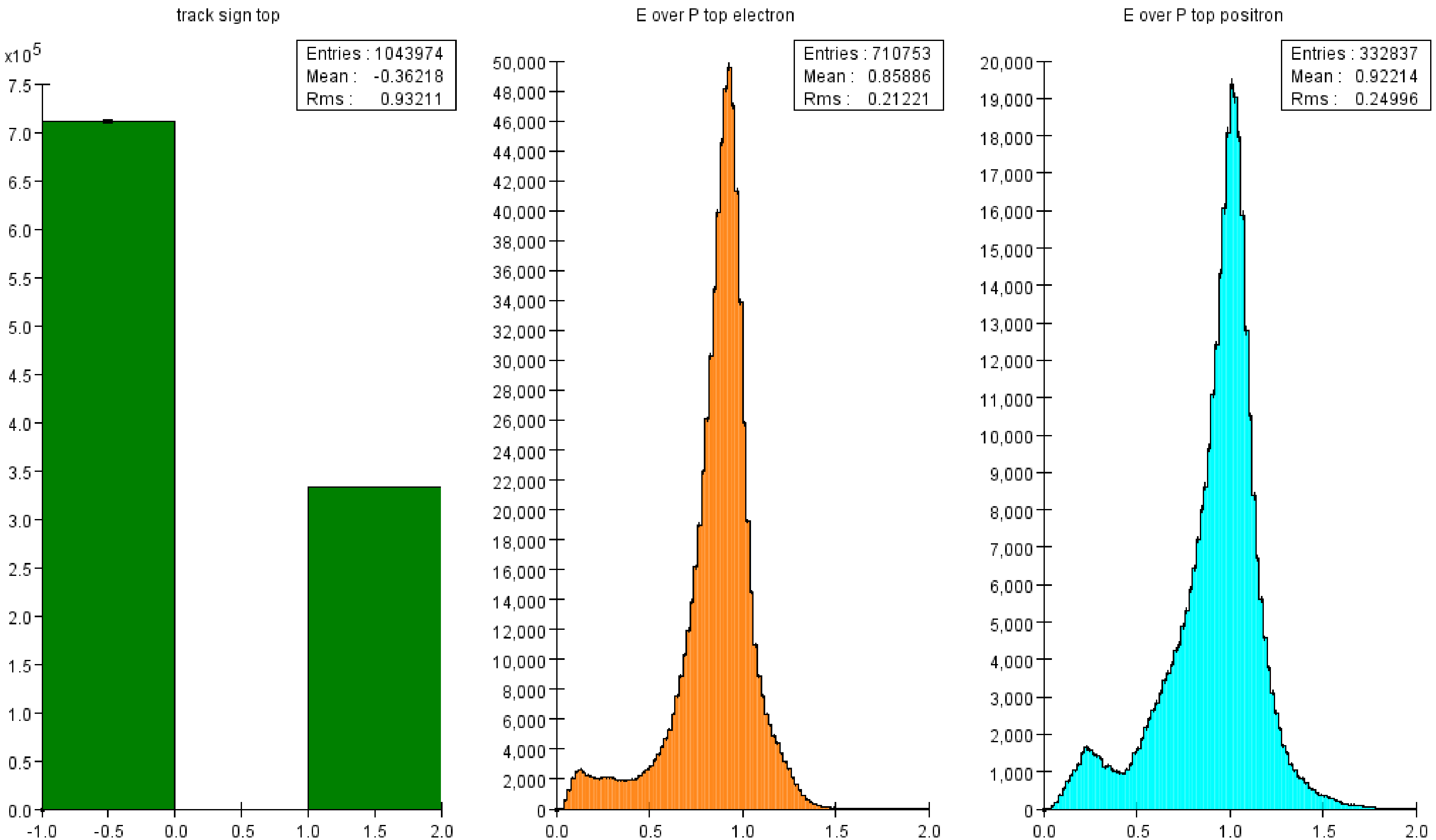
Bottom Wire as Target



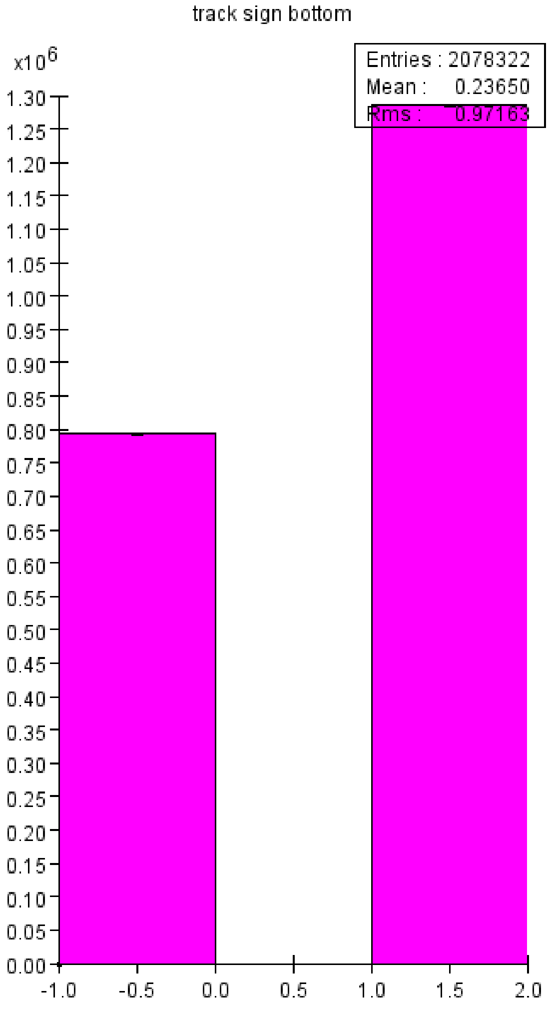
Top Wire as Target

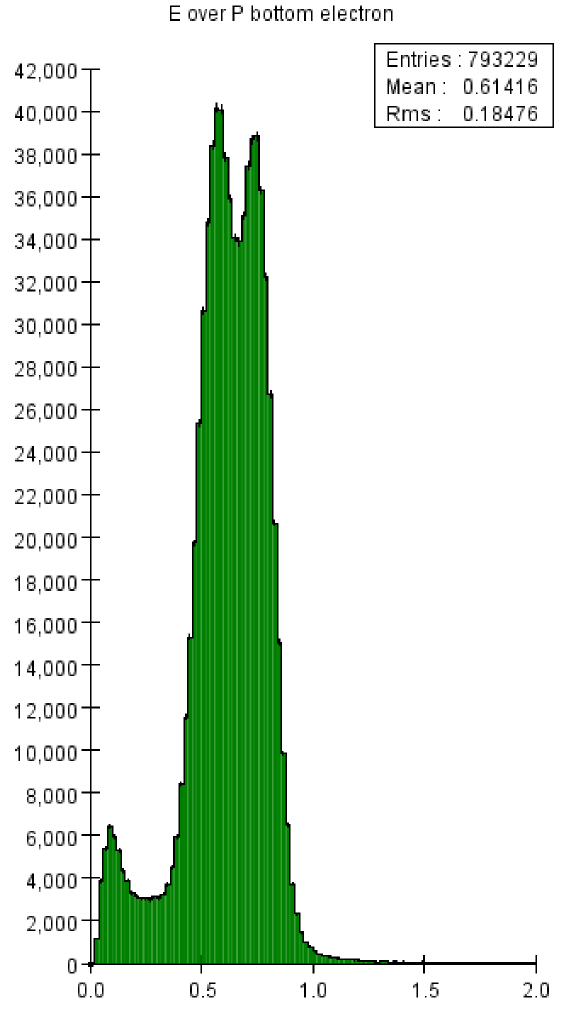


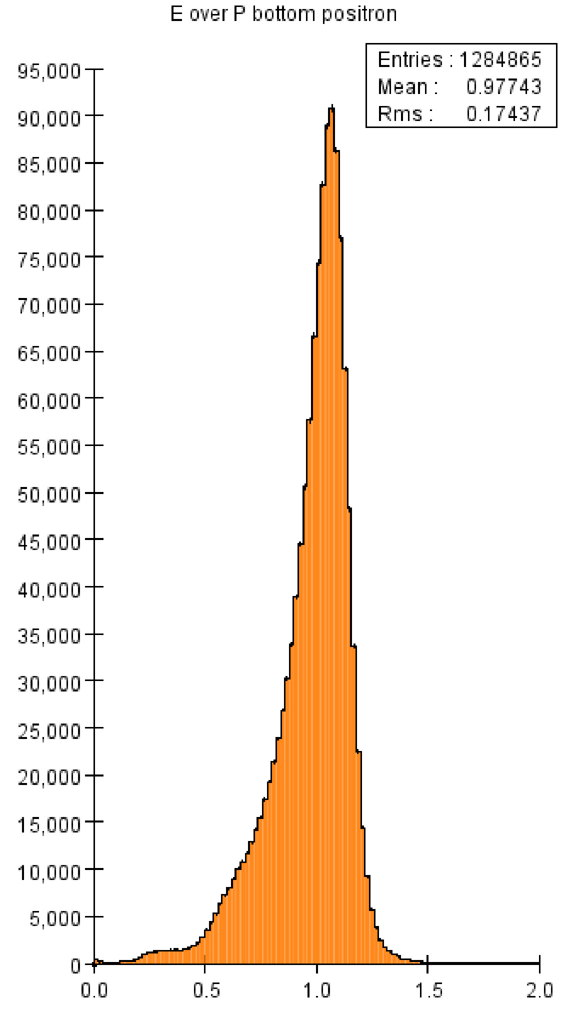
Bottom Wire as Target



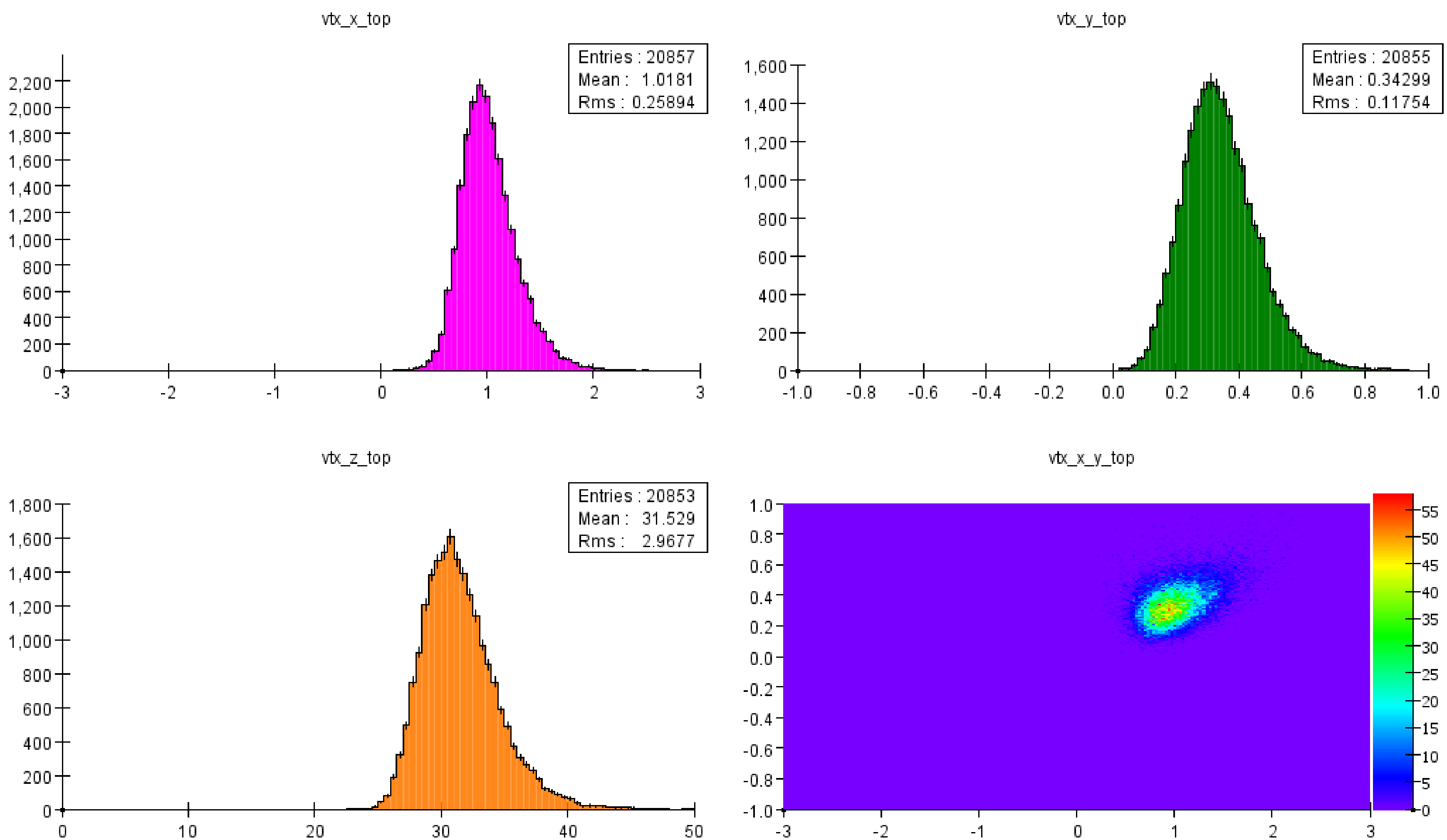
Top Wire as Target



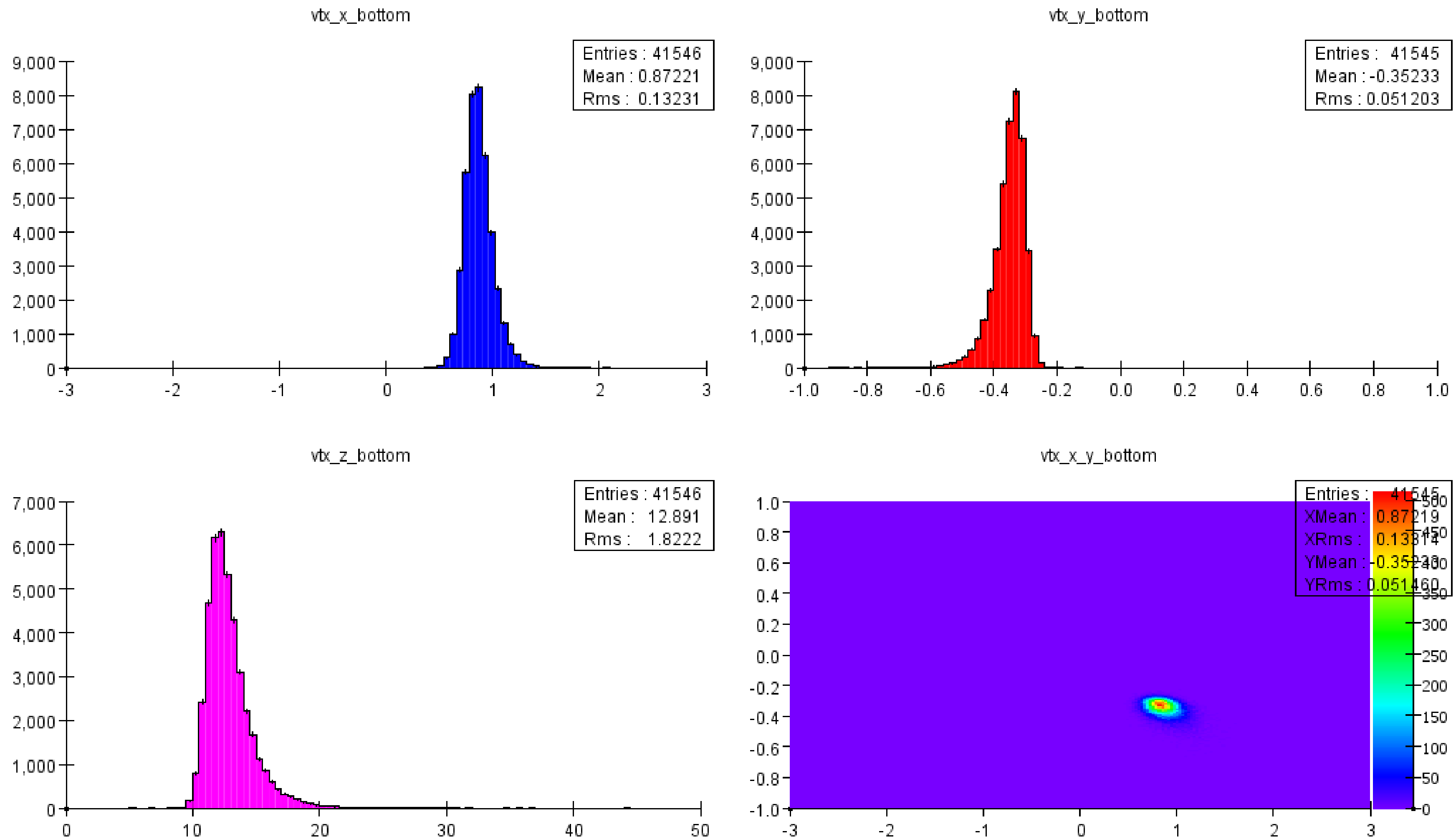




Bottom Wire as Target



Top Wire as Target



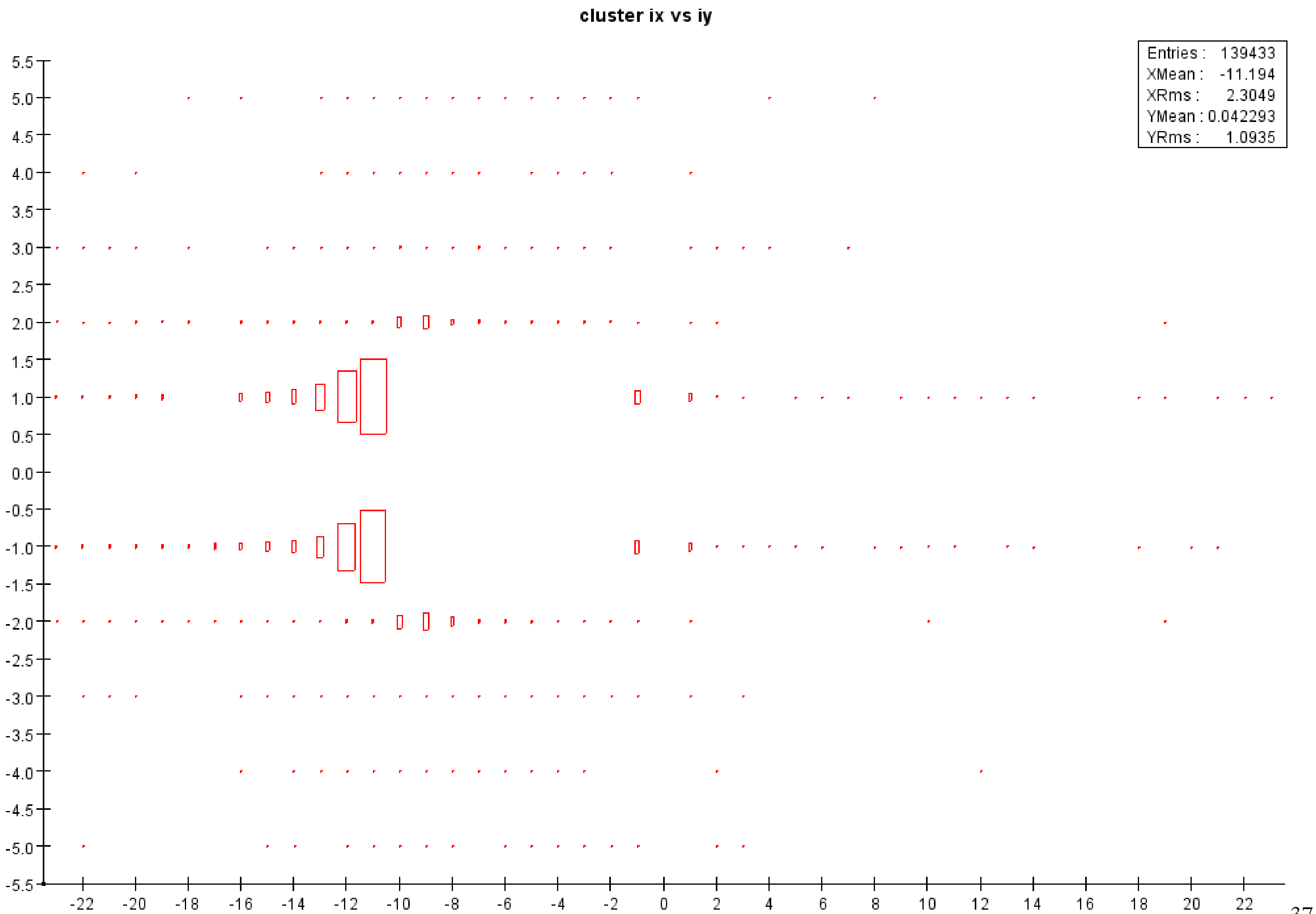
SVT Positioning Wire Targets

- There is a LOT of structure in these plots
- Will take some time to understand differences between the two data sets
  - top vs bottom track
  - top vs bottom wire targets.
- Will want to generate two new detectors with correct positions of the SVT halves.
- Good test-bed to check "opening angle" determination.
- In principle could use well-known(?) positions of the wires as a measurement point in the track fitting and alignment procedure.

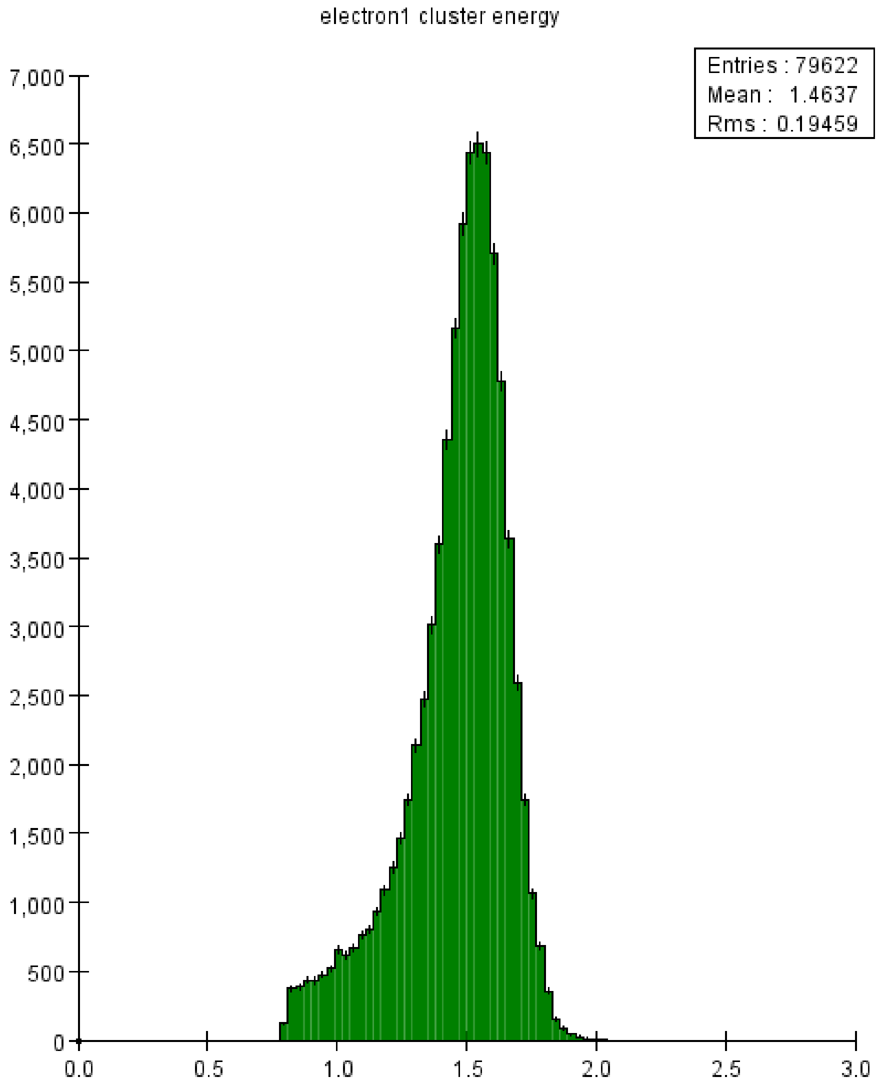
Møllers

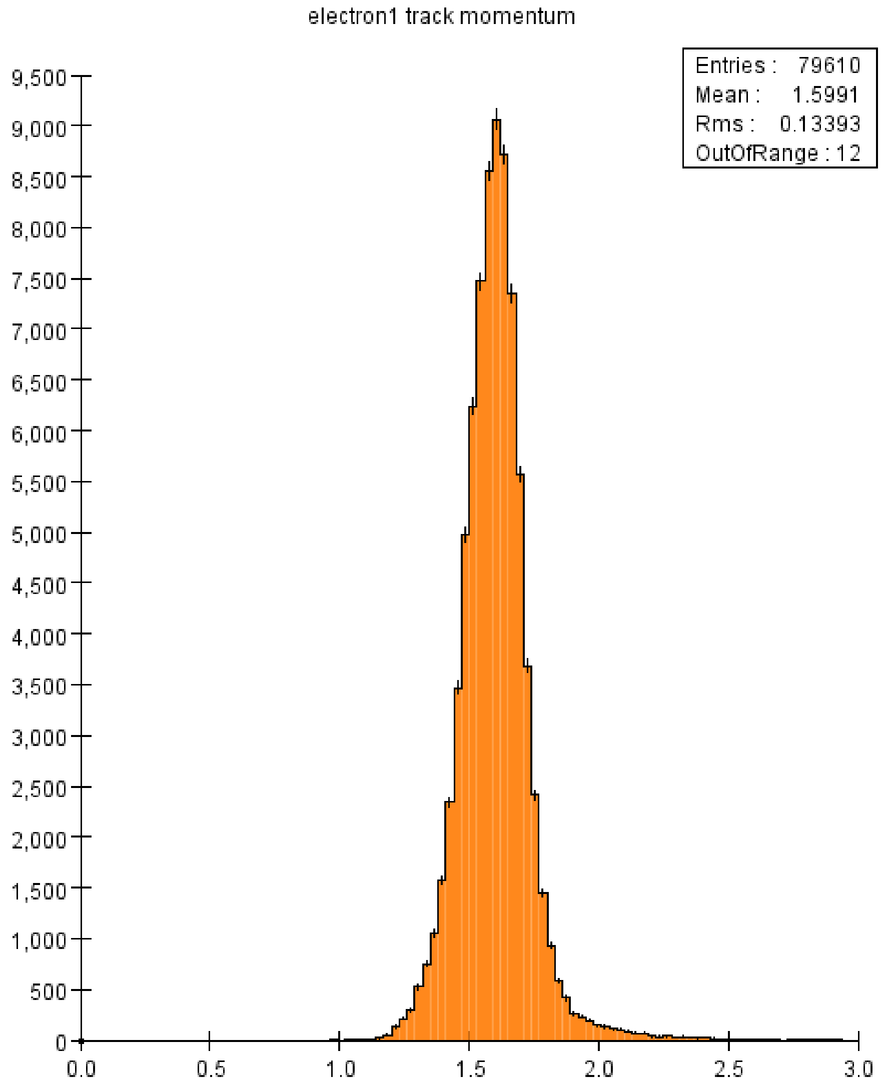
- We expect only one leg of Møller scatters to impact the calorimeter in the 3.7GeV runs.
- Signature in 2021 3.7GeV data would be one electron with an Ecal cluster in the Møller trigger region and another negatively-signed track in the gap on the opposite half of the detector.
- Tongtong has generated a number of Møller MC events to develop the trigger.
  - Use these untriggered pure Møller samples to develop offline analysis selection cuts.

Møller MC Cluster IX vs IY

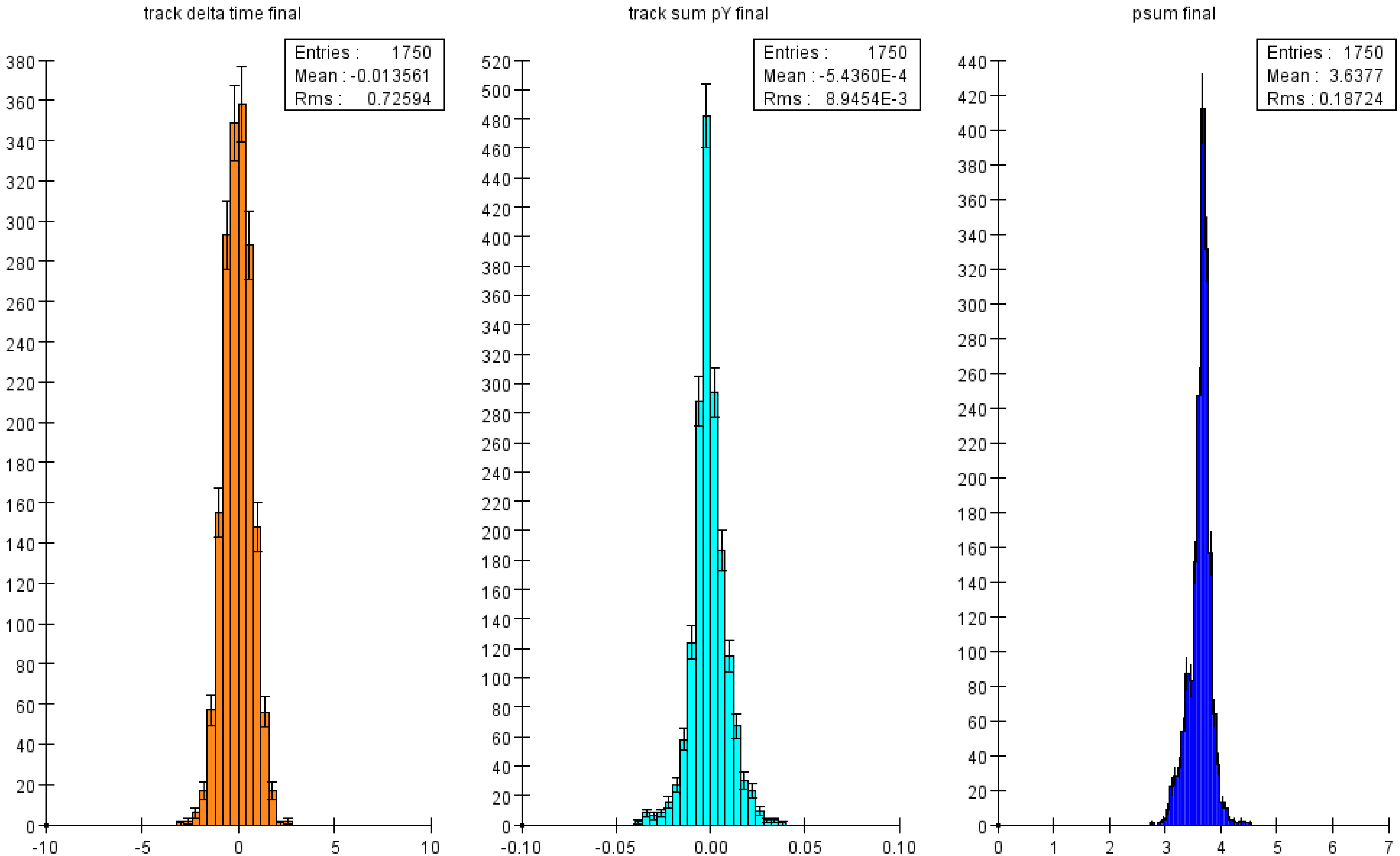


Møller MC Energy / Momentum

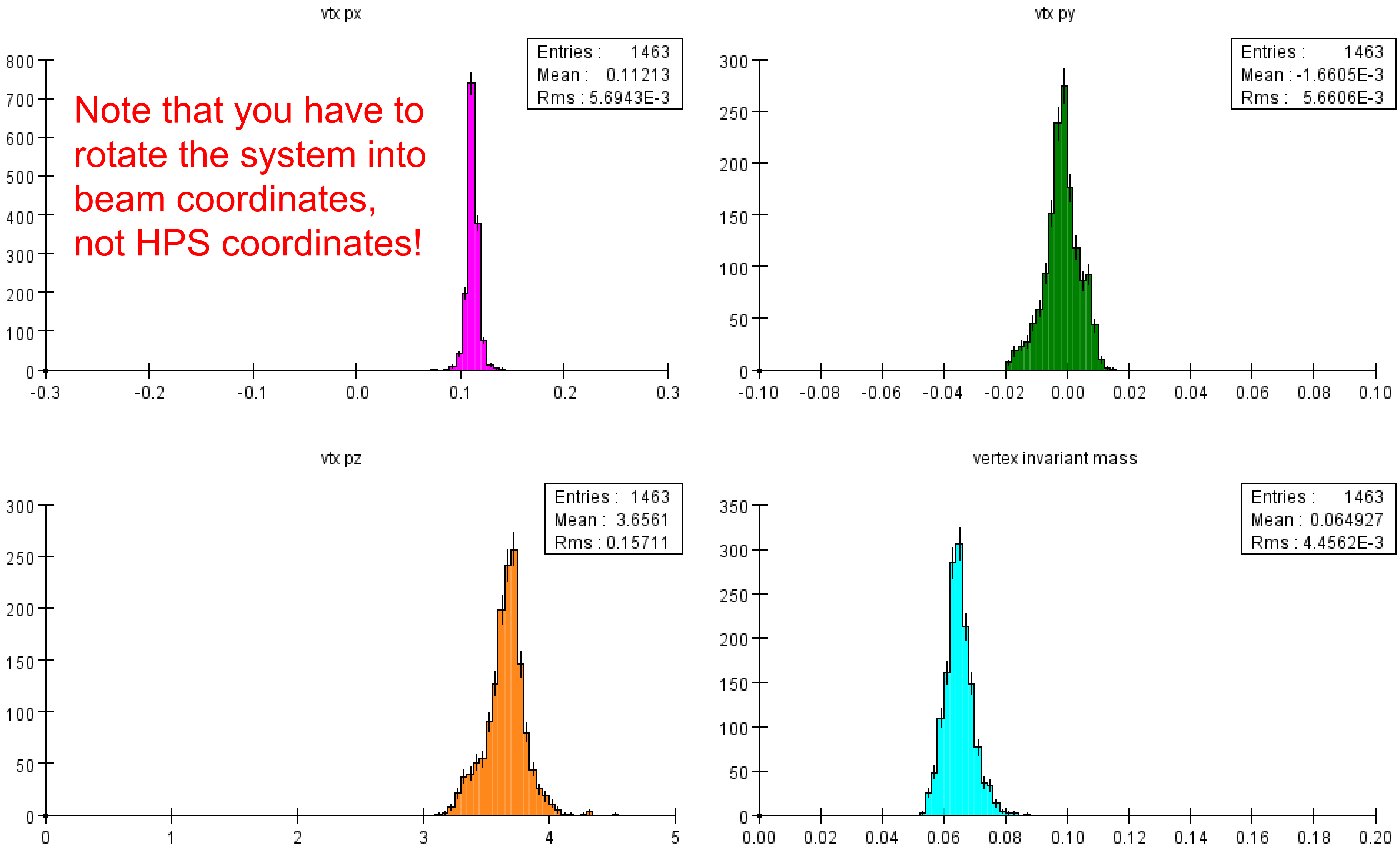




Møller MC Selection Cuts



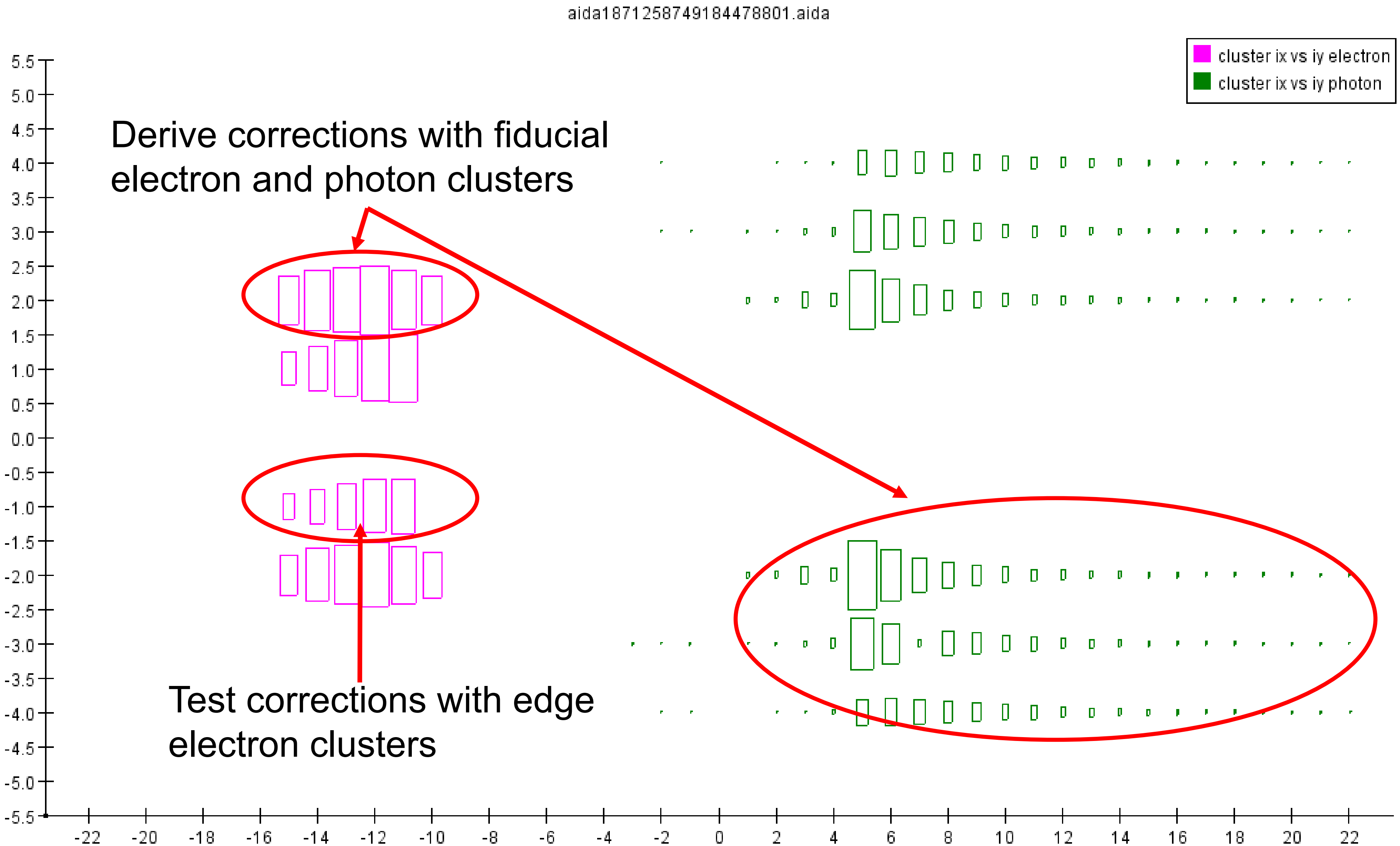
Møller MC pX, pY, pZ, mass



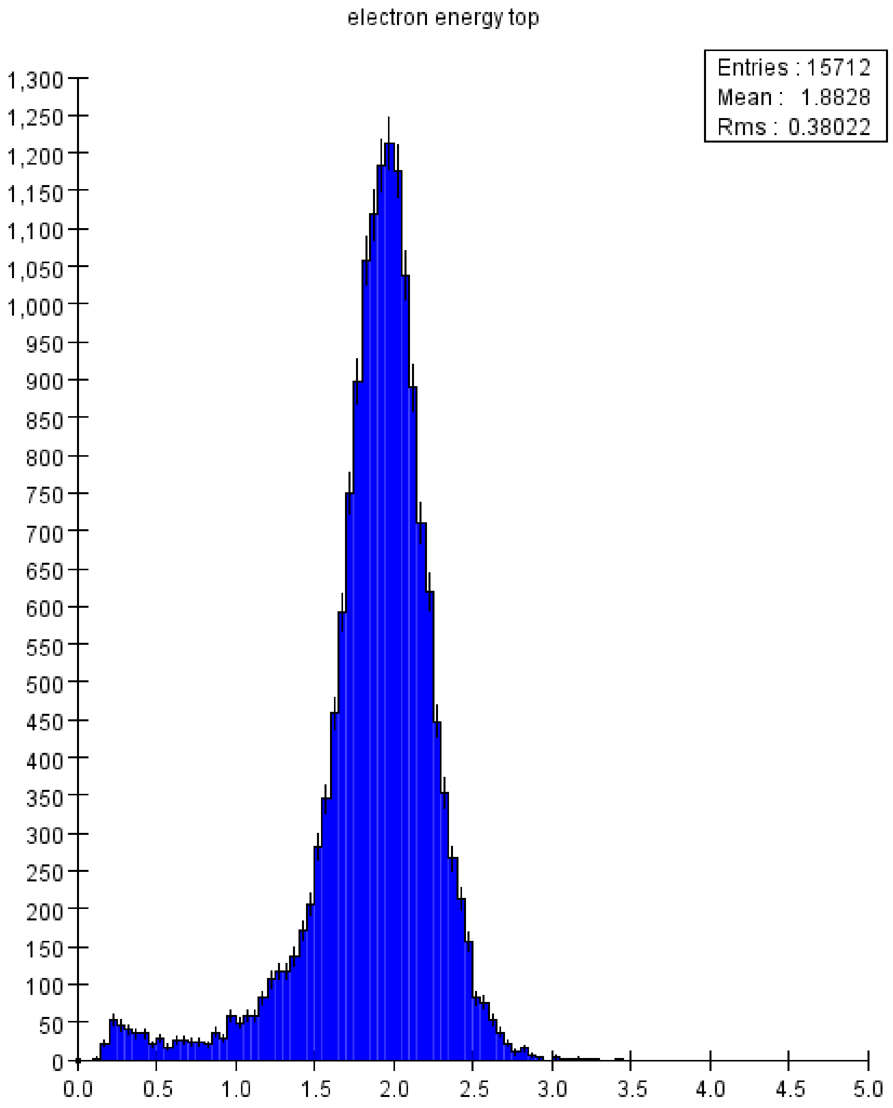
Data Calibration with WABs

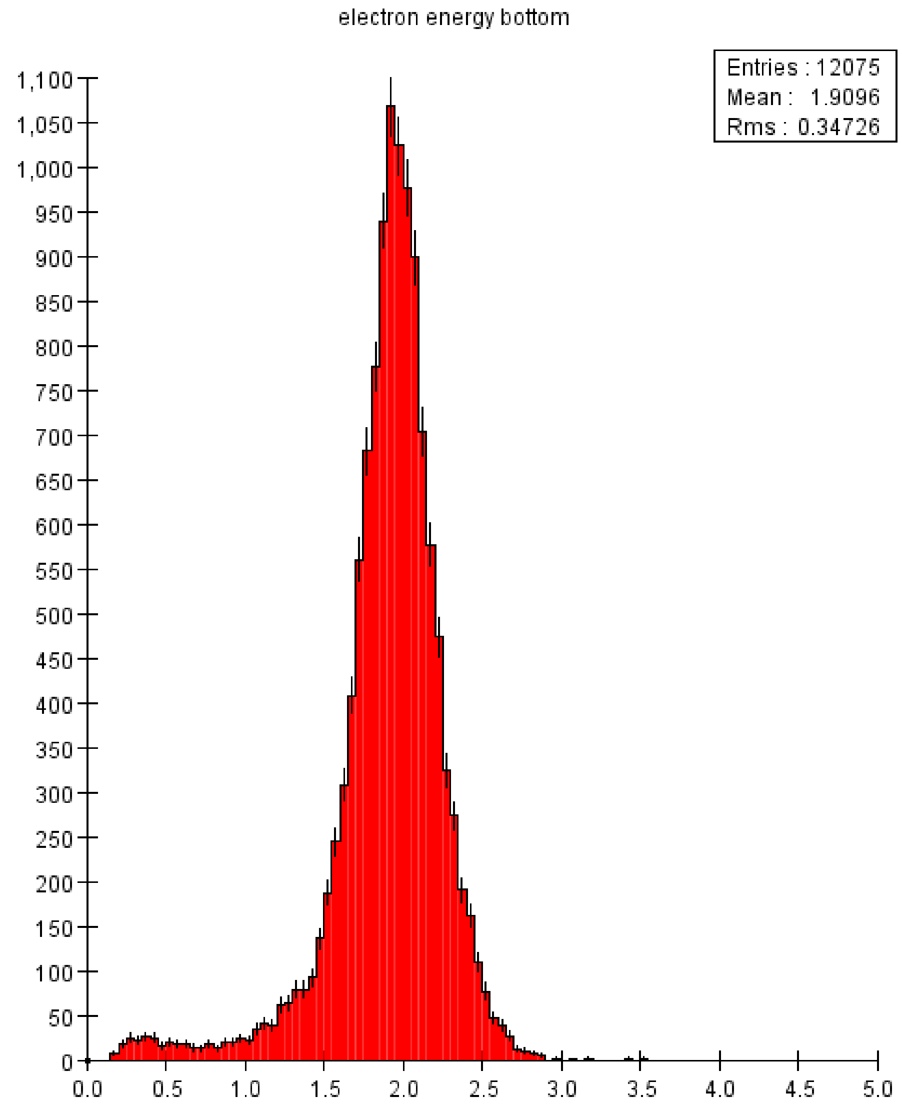
- Note that WAB-candidate electrons are a good proxy for the Møller electrons that trigger.
- Select WAB candidate electrons to perform energy and momentum calibration in the data.
  - two and only two clusters in the event, in-time and in diagonal quadrants
  - One electron with cluster in the Møller trigger region
    - abs(iy) <= 2 && ix > -16 && ix < -9
  - One photon in the calorimeter fiducial region
- Use E/p for fiducial clusters to correct track momentum to cluster energy
- Correct cluster energy to agree with beam energy
- Check procedure with sum of electron track momentum and photon energy.

WAB Electron and Photon IX vs IY

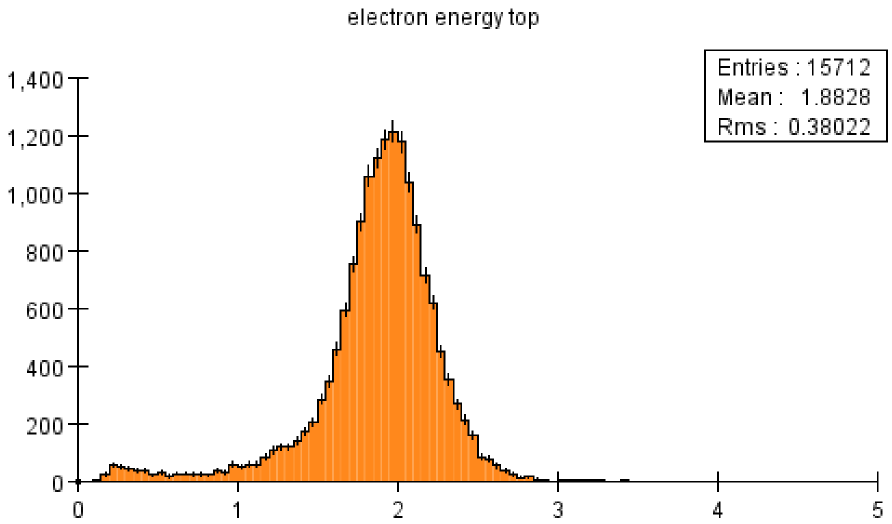


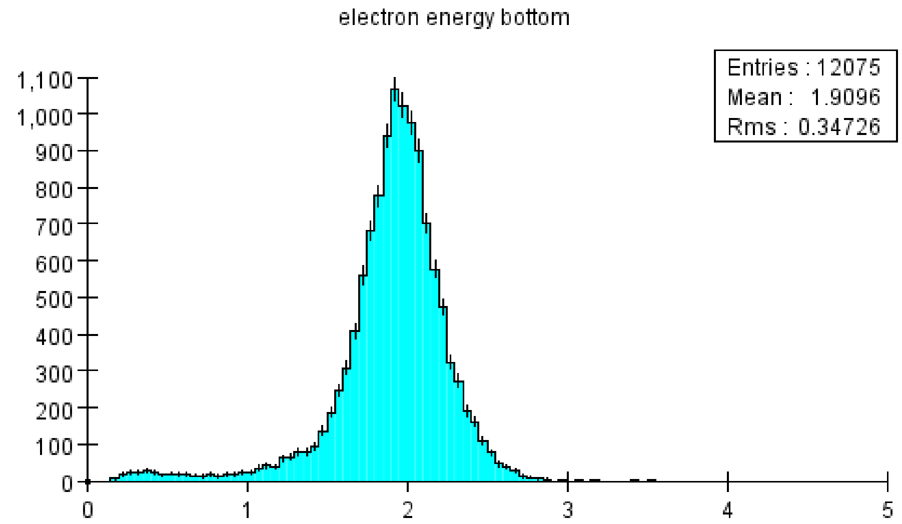
WAB Electron Cluster Energy

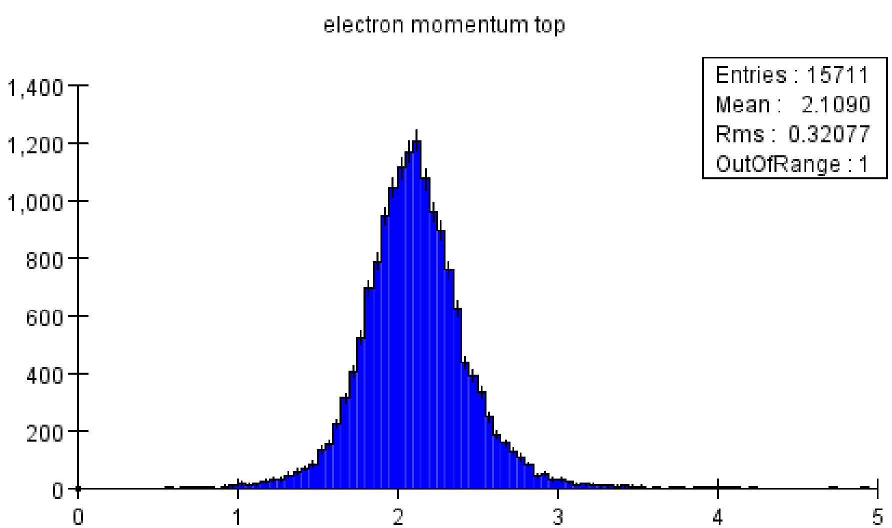


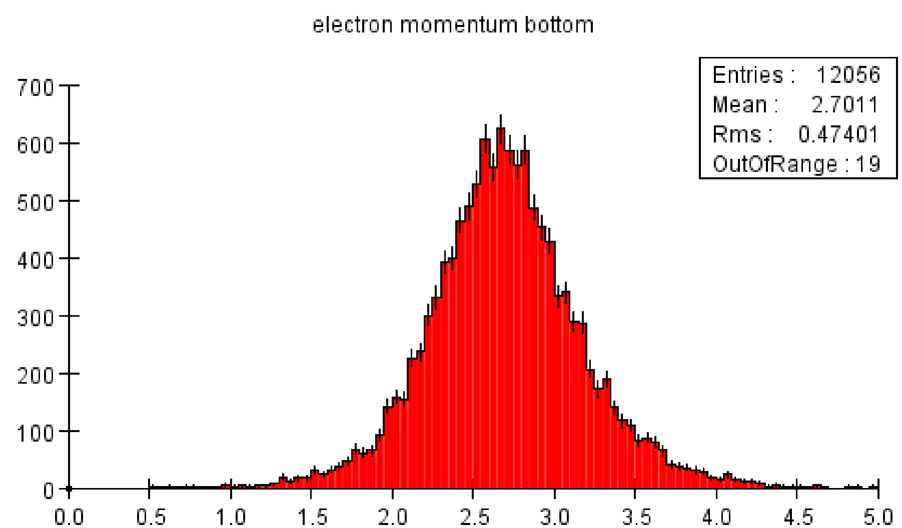


WAB Electron Energy and Momentum

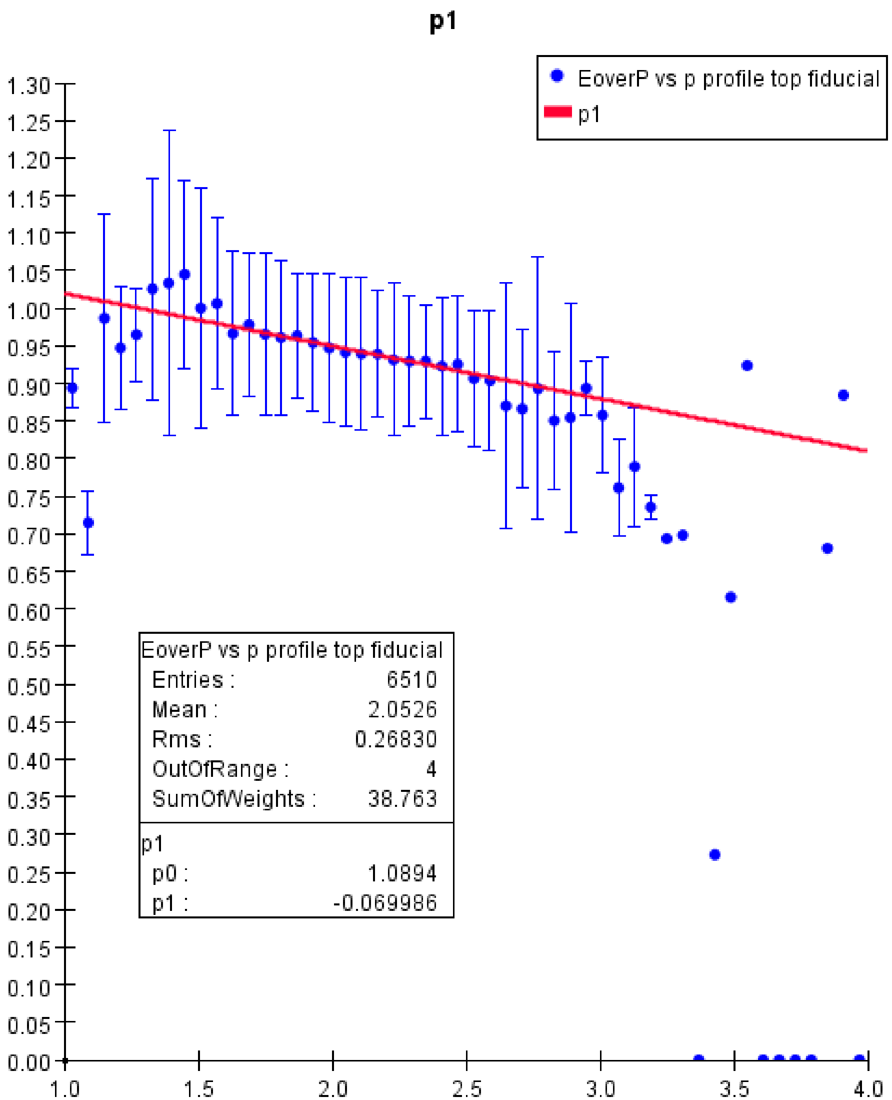


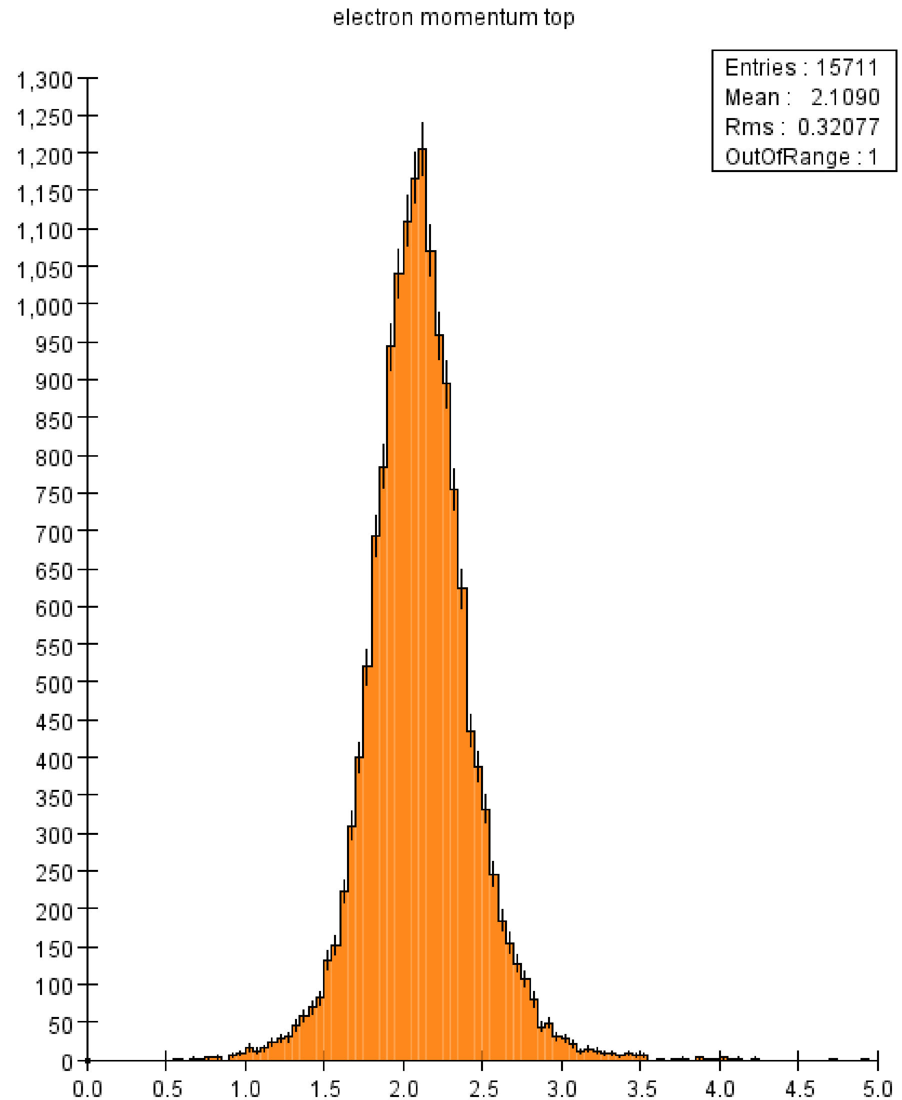




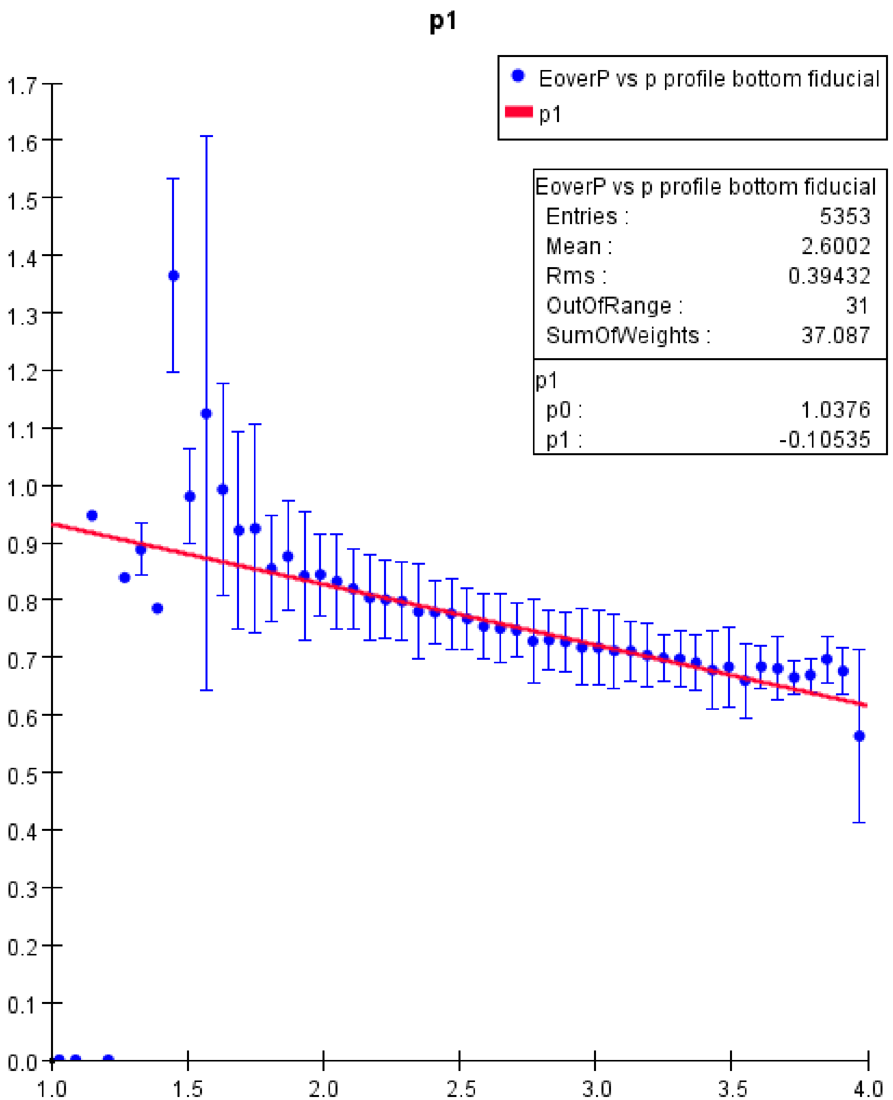


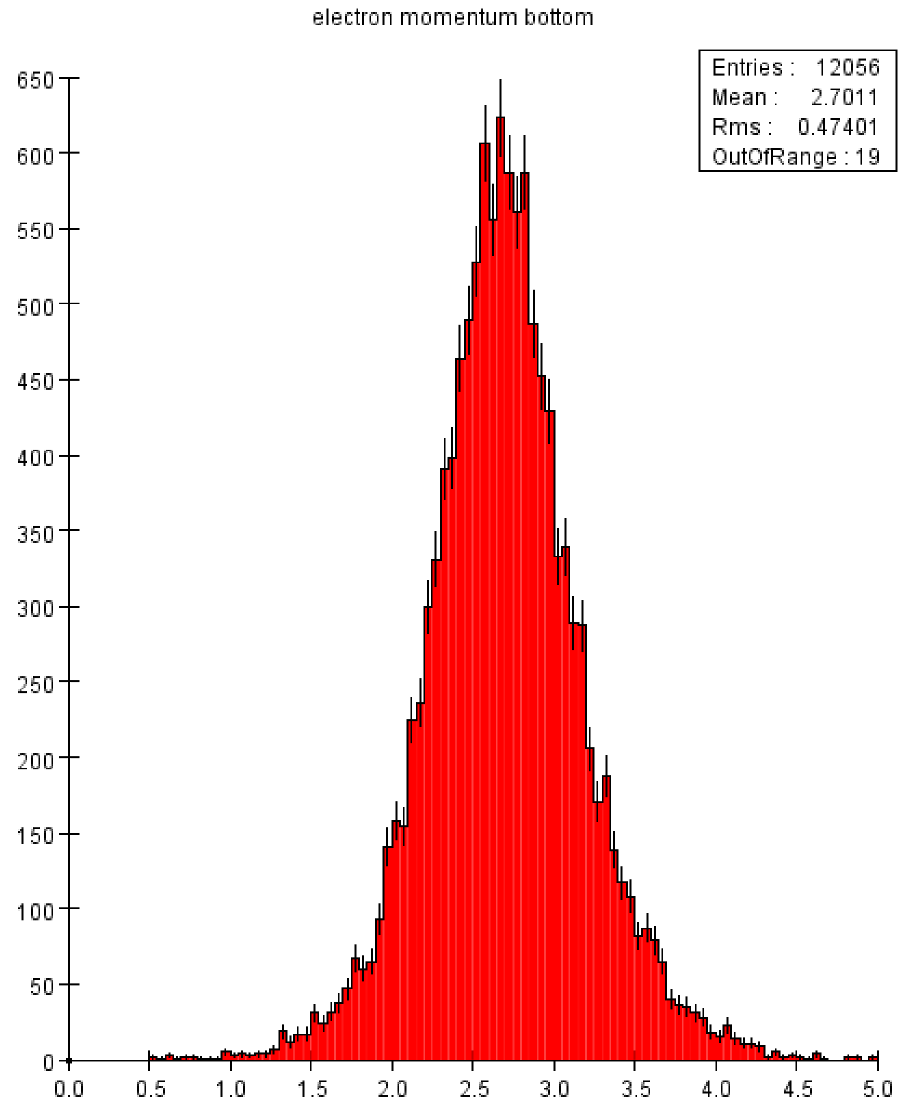
Electron E/p Top



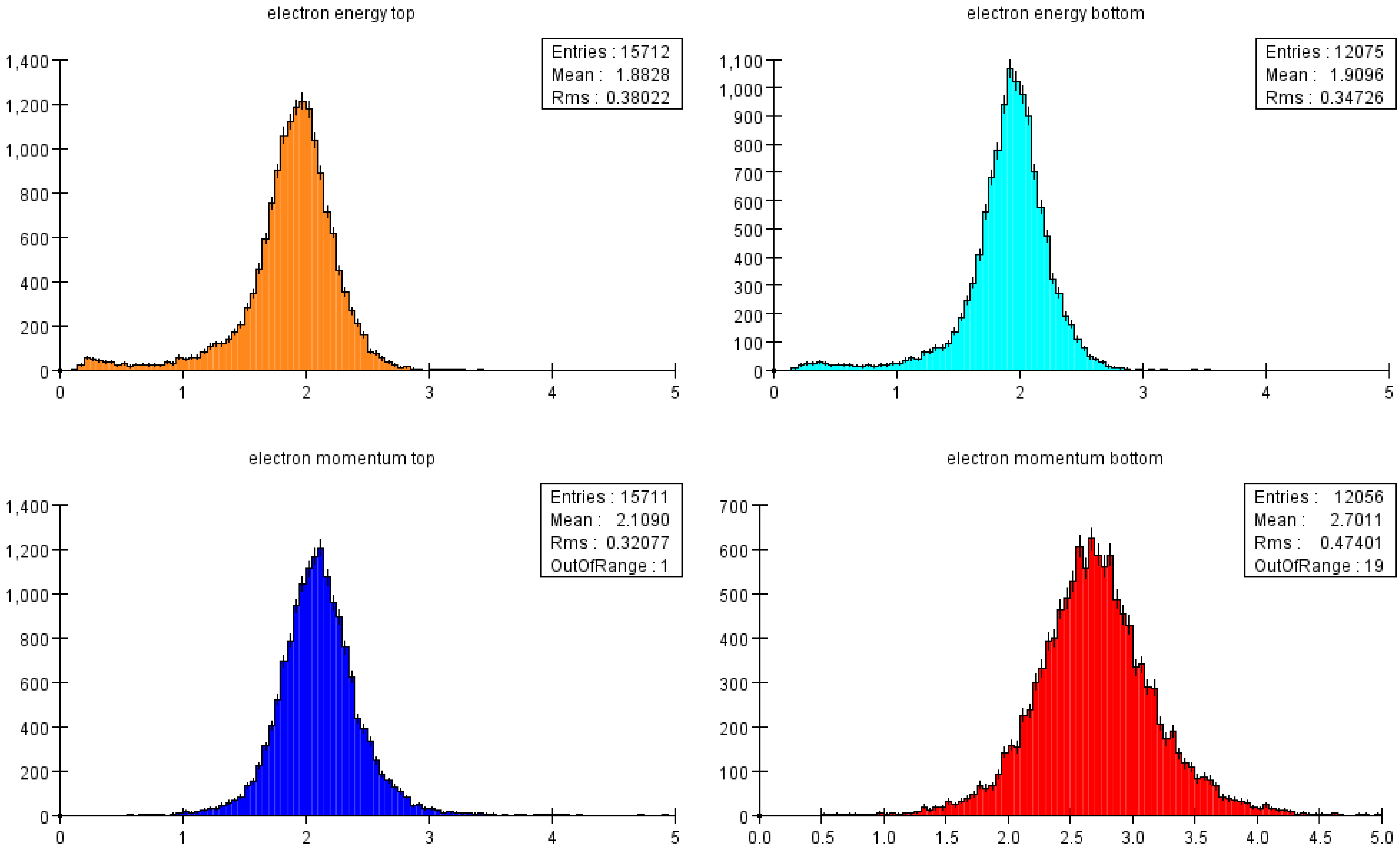


Electron E/p Bottom

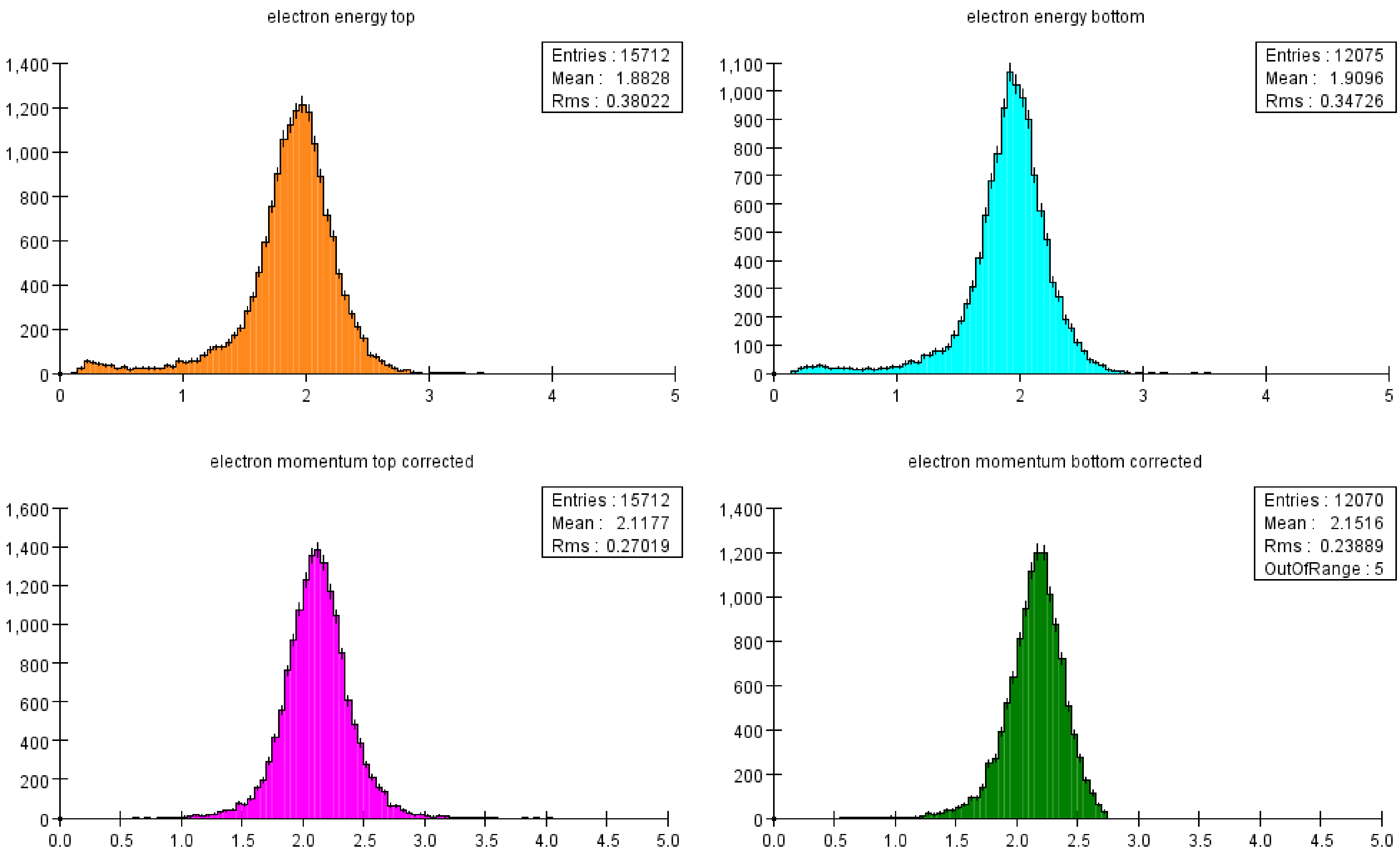




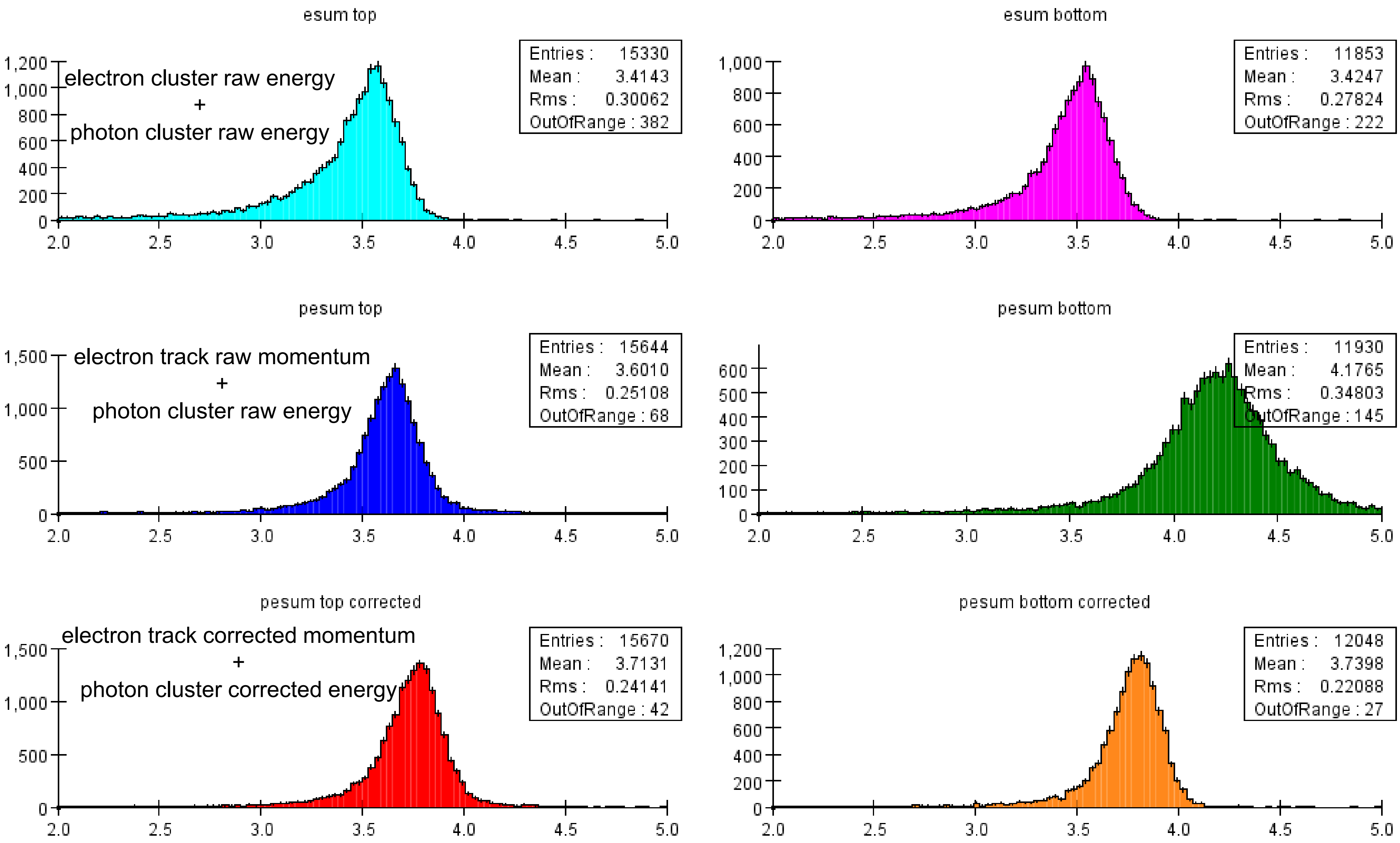
WAB Electron Energy and Momentum



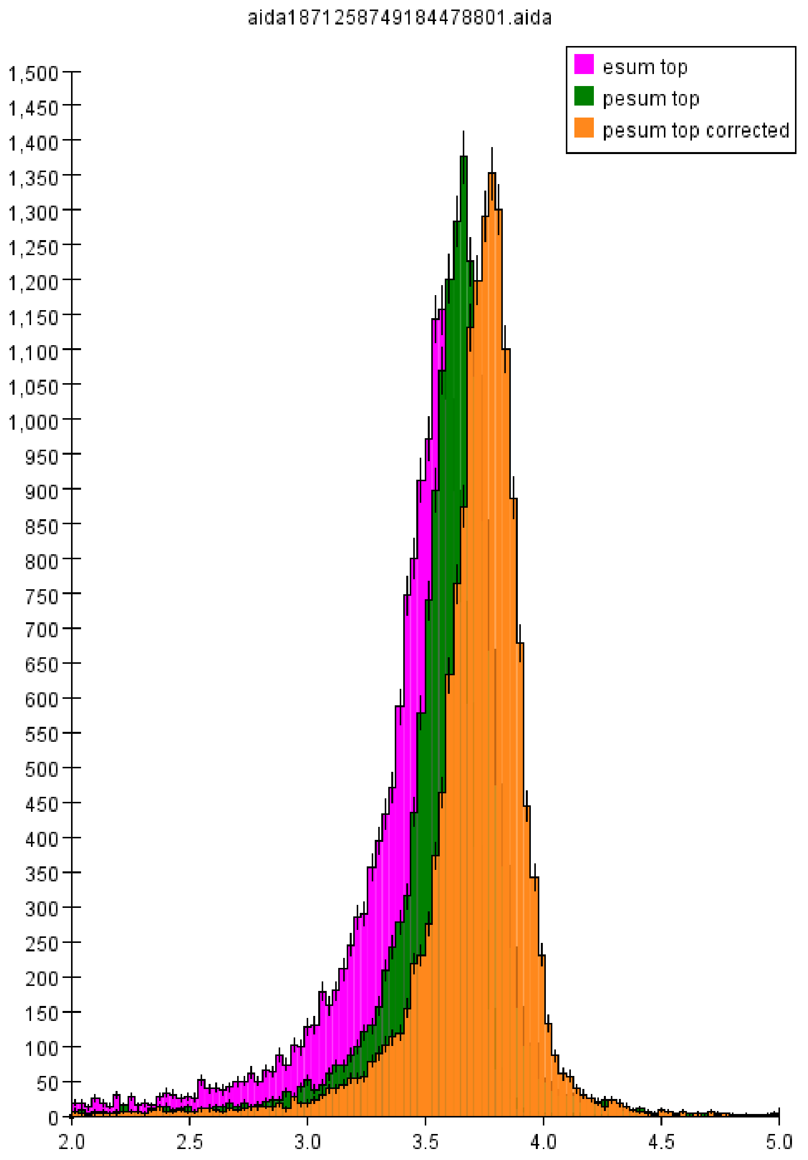
WAB Electron E & p Corrected

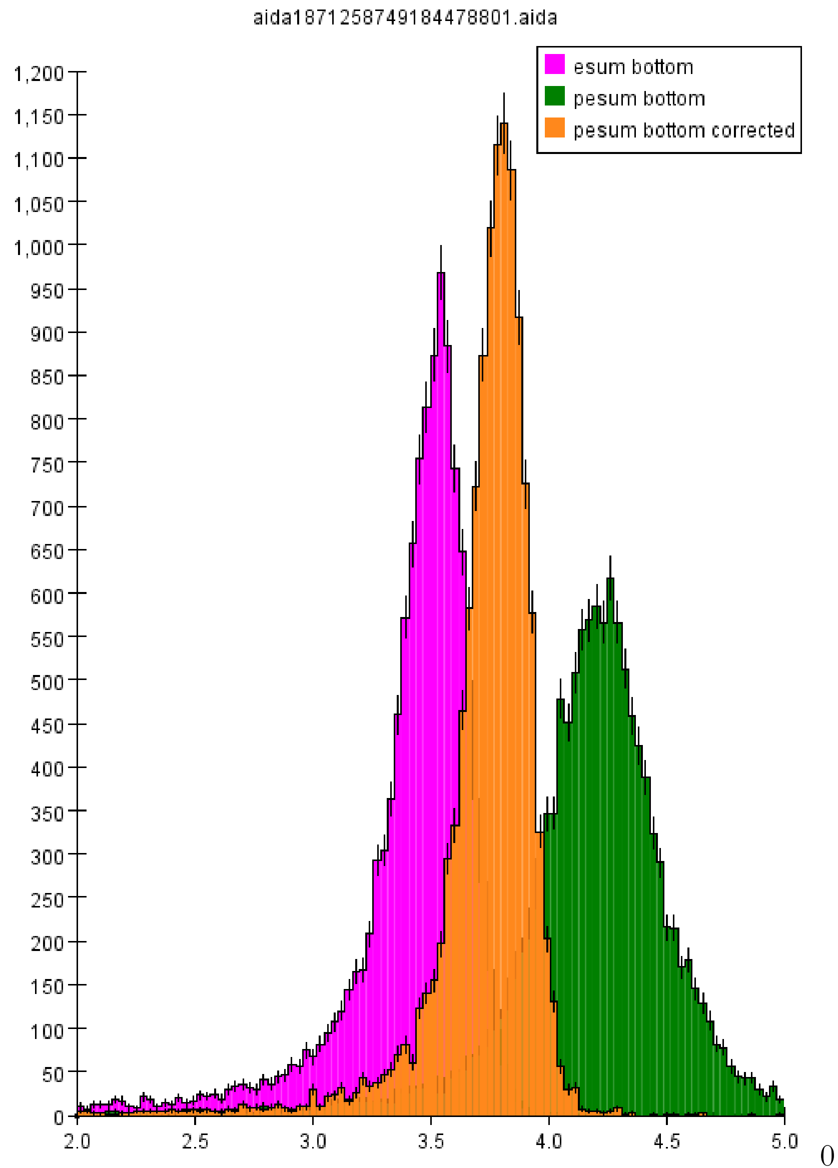


WAB sumEE, sumEP, sumEP_corr

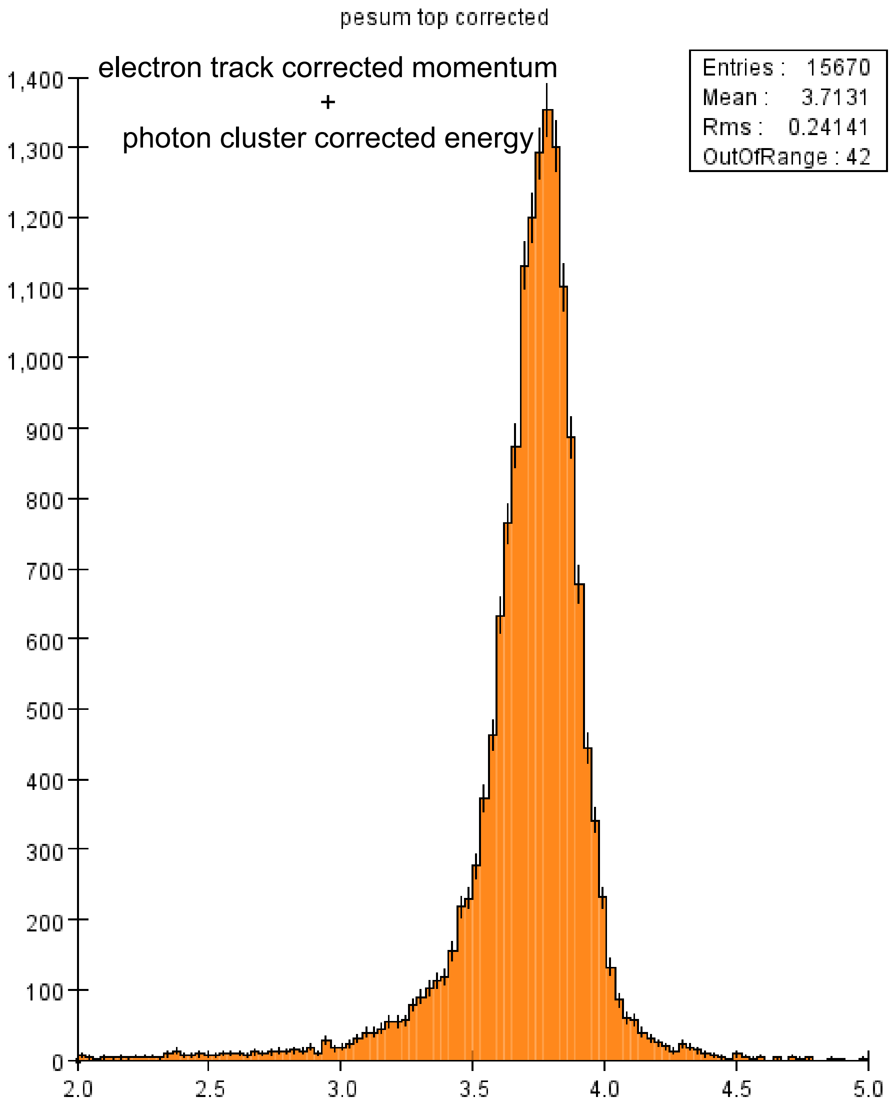


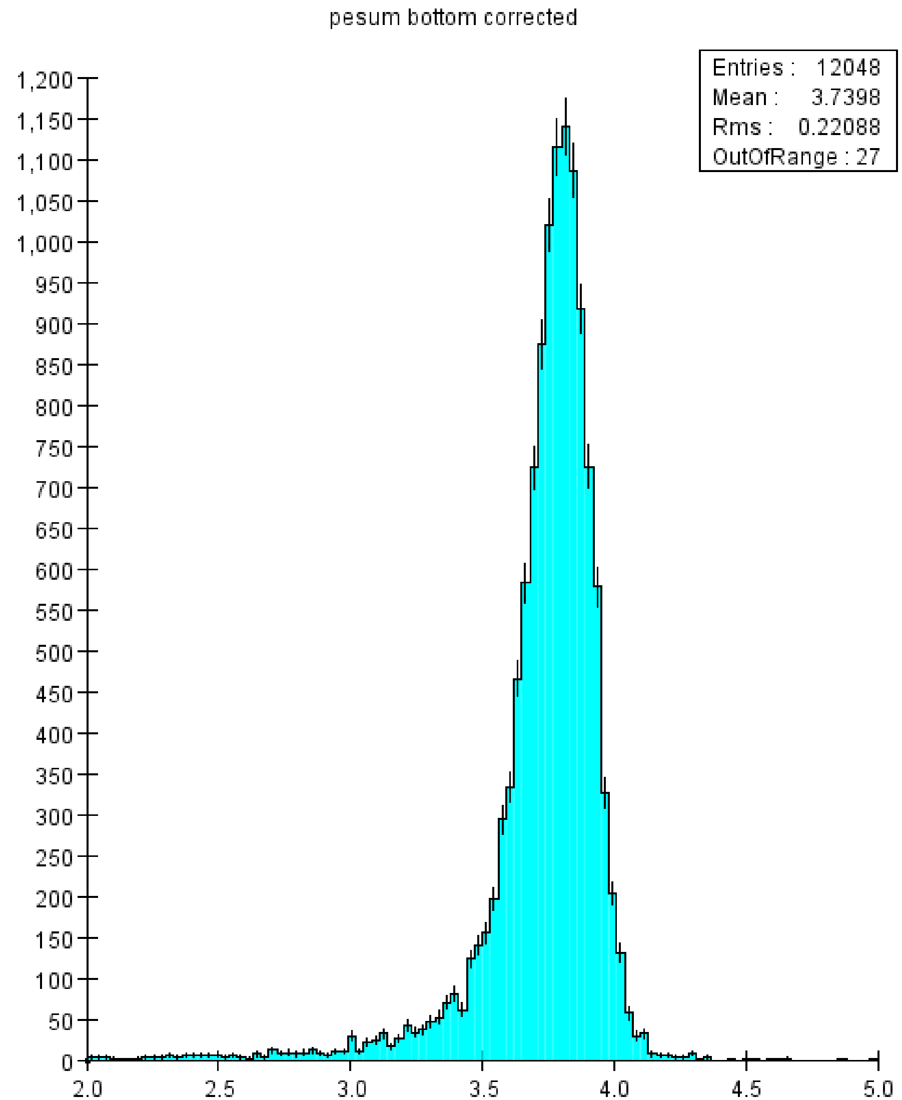
WAB sumEE, sumEP, sumEP_corr





WAB sumEP_corr





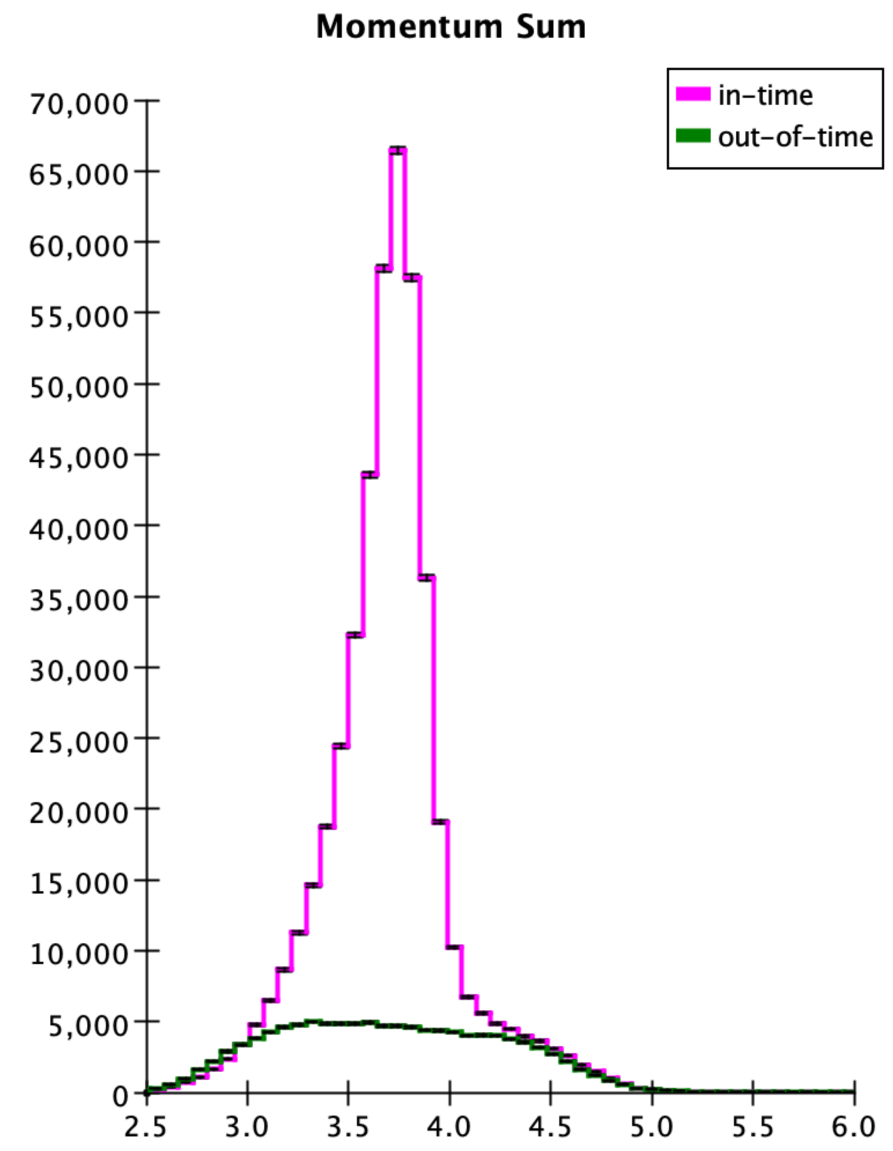
WAB corrections

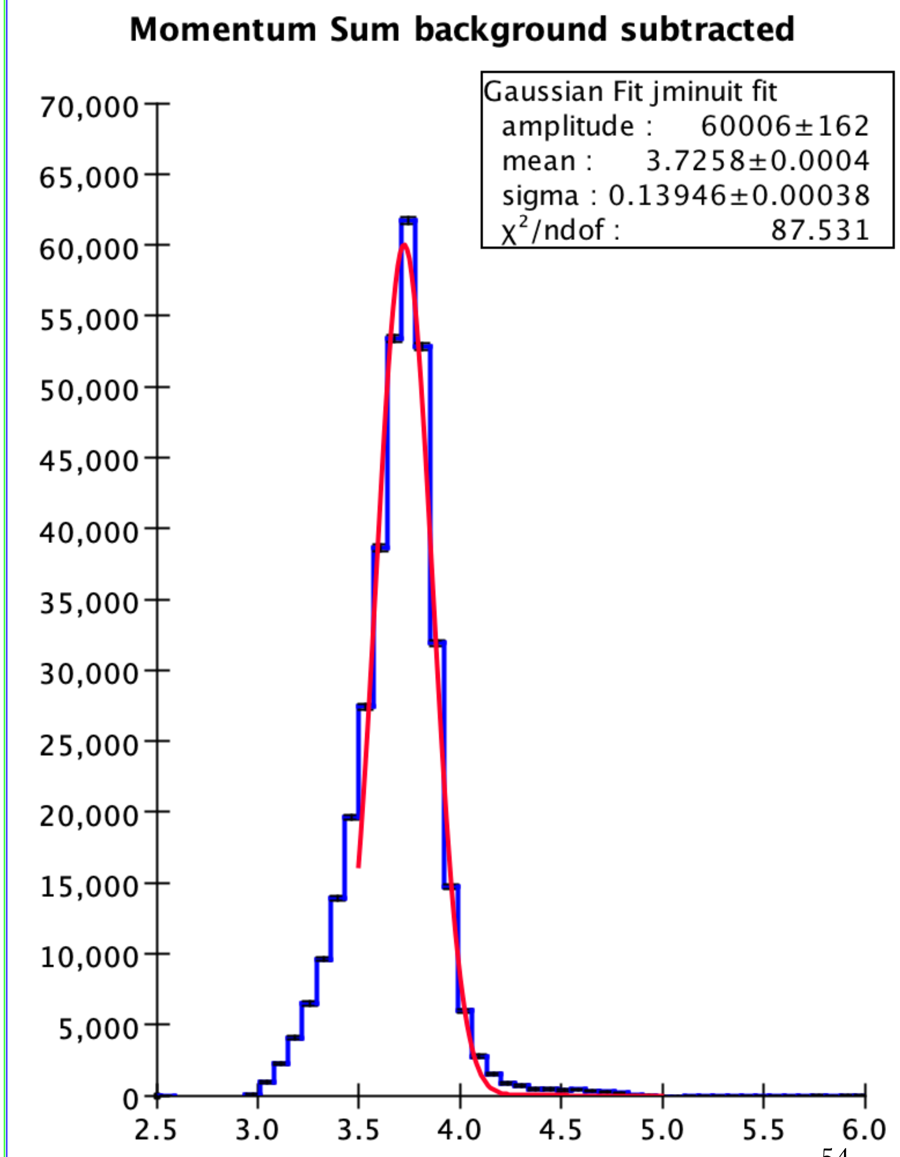
- Momentum and energy corrections derived from WAB sample result in sharply-peaked distribution of the sum of electron track momentum and photon cluster energy.
- Top and bottom electron track momenta agree
- Will apply energy and momentum corrections to electrons in Møller candidate sample.

Møller Analysis of the Data

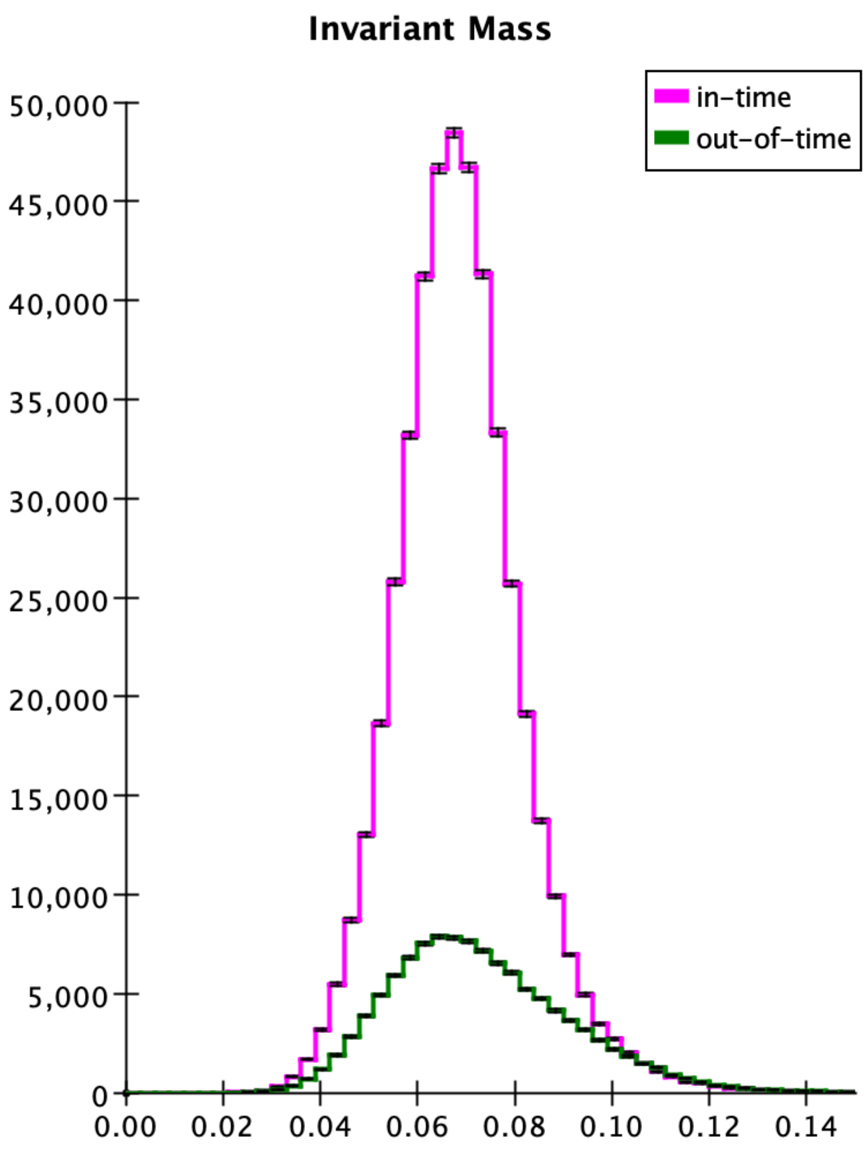
- Took dedicated Møller runs 14362, 14364 at 3.74 GeV
- Require an Ecal cluster in the region:
  - |iy|=1, -14<=ix<=-10
- Require electron track match to trigger-region cluster
  - 11 or more hits on track
- Require additional electron in other detector half
  - 11 or more hits
  - delta track time < 2 ns
  - pY sum < 0.02
  - psum>3.25
- Apply WAB-derived energy and momentum corrections
- Use out-of-time tracks to check background contributions

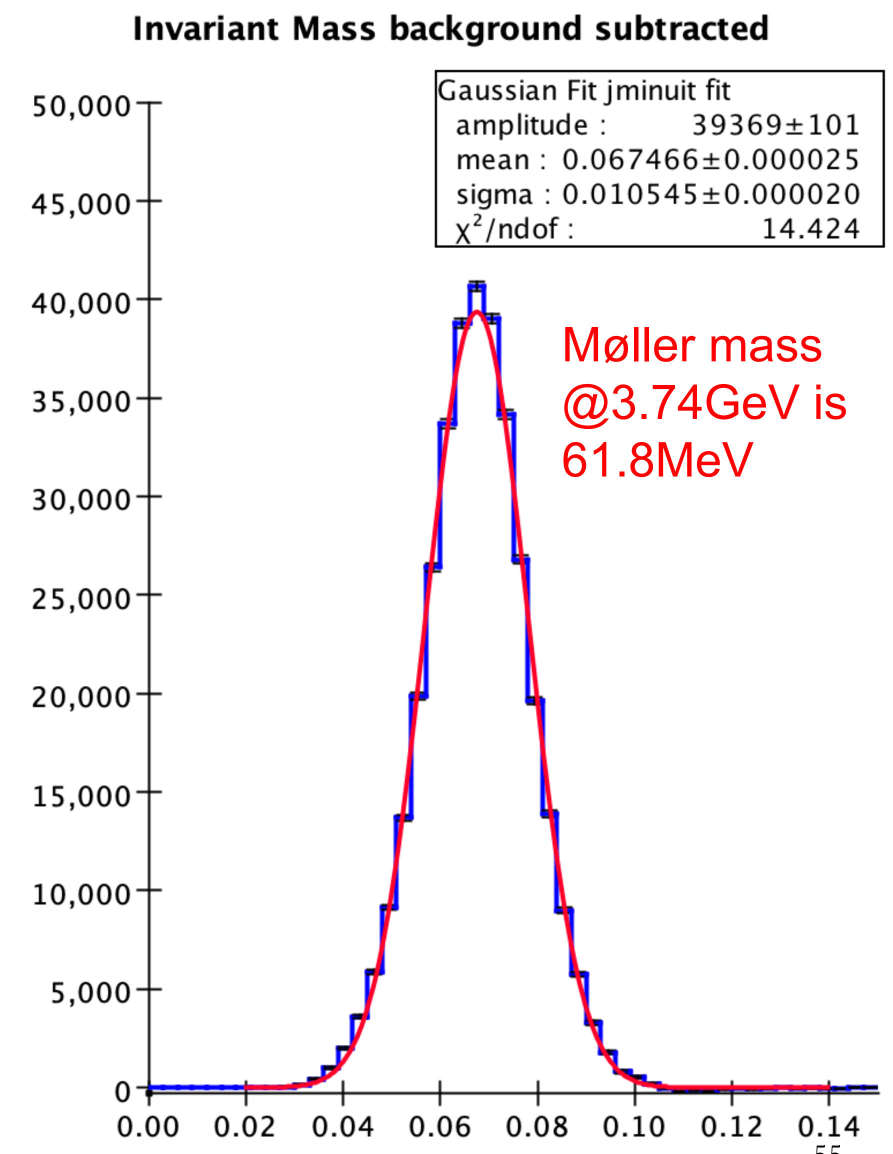
Møller Candidate psum





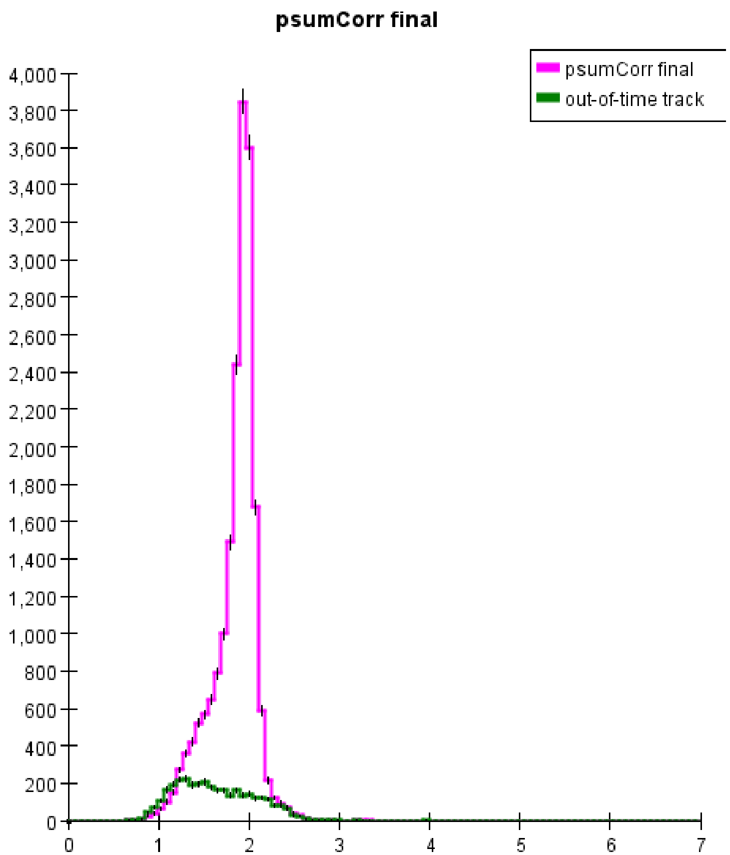
Møller Candidate Invariant Mass

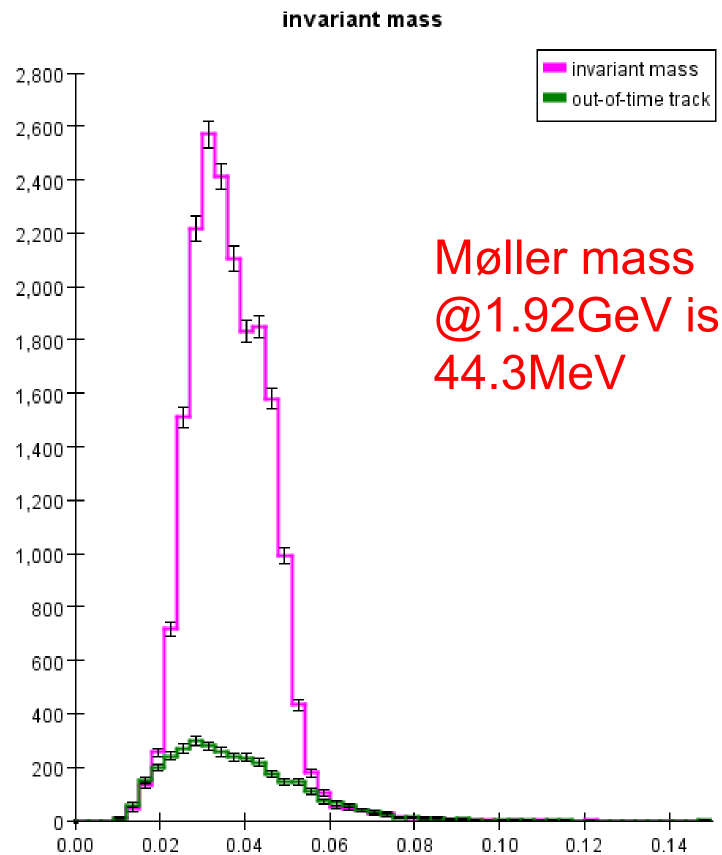




Møller Analysis of the 1.92 GeV Data

- Dedicated Møller runs 14652, 14653 at 1.92 GeV
  - Use similar selection cuts
  - Use out-of-time tracks to check background contributions





Møller Analysis of the Data

- A number of *ad hoc* (but data-derived) corrections have been applied *in lieu* of proper alignments and calibrations, but nevertheless it appears that we have a clear Møller signal in the data.
- Momentum-angle correlation can be used to align the SVT
- Møller four-vector can be used to determine beam direction with respect to HPS coordinates
- Agreement between unconstrained and target-constrained masses can be used to determine target z position
- Ultimately will be used to derive the mass resolution at both 44.3 and 61.8 MeV

Action Items

- Skim the FEE, Møller and di-muon triggers
  - Represents ~5% of the data
  - But we need to stage ~ 1PB
- Derive the Ecal calibrations
  - Crystal-by-crystal corrections from the FEE data
    - available at 1.92 and 3.74 GeV
  - “Sampling Fraction” corrections from MC
    - MC single-particle e^-, e^+, γ samples at various energies are available
  - Run-dependent corrections from the data
  - Procedure is well-established and well-documented and I am sure Andrea would welcome volunteers
- Align the SVT
  - Huge amount of effort from PF has gone into developing the tools and infrastructure to support this effort
  - Huger amount of effort is needed to actually align and calibrate the tracker
  - Numerous data samples are available to study/constrain this effort
    - FEEs, WABs, three-prong Tridents provide momentum-constrained tracks for sensor alignment
    - Møllers at both 1.92 and 3.74 GeV provide strong momentum-angle constraints for global alignment
    - Tracks from two different z locations (SVT positioning wires on top and bottom)
    - Straight tracks at two different z locations (2H02 Harp and collimator wires)
- Please get involved!

Summary

- FEE, WAB and three-prong trident (or converted WAB) samples have been selected using calorimeter-only cuts
- Samples are available for Ecal and SVT calibration and alignment and tracking efficiency, scale and resolution studies once the SVT has been aligned.
- Initial Møller analyses look promising
  - Four-momentum replicates the beam
  - Invariant mass peaks reasonably close to that expected but is higher and broader than anticipated
    - Presumably a mixture of alignment, calibration and backgrounds
    - Momentum has *ad hoc* corrections, but no changes to opening angle
  - Samples available at both 1.92 and 3.74 GeV
- Ecal calibration procedure is well-established and well-documented. Please contact Andrea Celentano to volunteer in this effort.
- Need to concentrate on tracker alignment to understand momentum scale and resolution.
  - PF has devoted a large amount of time and effort to develop the infrastructure to perform the SVT alignment and to perform the initial alignment iteration
  - Please contact PF to volunteer for this effort.
- **Get involved! This is your data!**