NOvA Test Beam detector calibration

Technical Note

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Abstract

What is this about and what will I describe in here

Contents

1 Introduction

TO DO:

- Divide the motivation to abstract (why do we care about test beam calibration, what did we do and how did we do it. What are the results)
- and introduction (brief history of test beam calibration, maybe a bit more detail into why is test beam calibration imporant)

Why is Test Beam? "The idea, as with any test beam experiment, is to expose a detector to a beam of very well-characterized particles, so that we can improve our understanding our how the detector responds to such particles. We make use of upstream detectors to collect data on the beam particles before they interact in the NOvA detector. For example, we will be able to see what a 1 GeV proton actually looks like in our detector, without having to simulate it, and we can test how well we would have reconstructed the energy using our existing techniques. We may find we are able to make improvements to our tools to better match what we see in the detector with how we reconstruct it. Or we may find we already do a pretty good job. Either way, with a full cross-comparison like this, we can be more confident in our analysis of the data and reduce the level of uncertainty we consider are associated with the relevant measured quantities. Ultimately, the aim will be to reduce the level of uncertainty on the neutrino oscillation analyses and to make even better, more accurate measurements of the Standard Model."Why is Test Beam calibration done:

- To be able to directly compare TB to the standard detectors
- To be able to verify our calibration procedures using TB data
- To study the particle response as a function of energy
- To determine an energy resolution
- To compare currently used energy scales to data and understand if we can use TB data for absolute energy scale in all NOvA detectors

For DeltaM2: By increasing exposure, total syst. error decreases by (+) 18.5For sin2Th23: Difference by reducing calib syst.: (+) 10.8Statement: “The NOvA Test Beam will improve the total systema6c error on the final measurement of the oscilla6on parameters Dm232 and sin2Th23 by 10Potential Test Beam impacts: Check modeling of hadronic interacOons in detector (check GEANT systemaOcs), Using Test Beam data as “single-parOcle MC” to train CVN prong-like algorithms, GeneraOve Adversarial Networks for MC improvements using Test Beam data, Check ND calibraOon procedure to try and understand causes of 3-5

- Hadronic response and comparison with MC modeling
  - response as a function of energy
  - establishing of an absolute energy scale
  - determination of energy resolution
  - studies of topological features and resolution

    * pion tracking and showers
    * proton tracking and showers
  - studies of timing features and resolution

- Electromagnetic response and comparison with MC modeling
  - response as a function of energy
  - establishing of an absolute energy scale
  - determination of energy resolution
  - studies of topological features and resolution
    * electron signatures
    * gamma signatures
  - studies of timing features and resolution
  - studies of π^0 from π^- charge-exchange

- Muon response and comparison with MC modeling
  - comparison with detailed optical simulations
  - determination of energy resolution
  - studies of topological features and resolution
  - cross-talk studies
  - comparison to cosmic ray muons (requires a special trigger)
  - studies of the muon calibration protocol

- Light yield and response studies as a function of particle type and detector configuration
  - understanding the Cherenkov light contribution
  - vertical and horizontal responses and comparison with simulations
  - data with selected planes rotated by 45 and 90 degrees
  - slanted (angle) plane response (and subset of programs as above)
  - fiber attenuation studies
  - Birks' constant studies

- Near / Far readout comparison

- Gather large libraries of particles at known energies and multiple angles of incidence to help develop a CNN prong ID. Also allows training of a particle-based CVN-like PID.

Also use information from:

- NOvA Test Beam Technical Statement of Work

- NOvA Test Beam program (paper for DOE) [docdb:25074]

- NOvA Test Beam task force report [docdb:15750]
- Overview presentation of NOvA Test Beam [docdb:20495]
- Test Beam support document [docdb:22172]
- NOvA Test Beam program proceedings [docdb:55808]

Mike's proceedings from ICHEP 2020 [**?**].

2 Overview of the Test Beam detector

The NOvA Test Beam detector is a scaled down version of the Near and Far Detectors shown on figure 1. It is placed in the MC7b enclosure of the Fermilab Test Beam Facility in the path of the MCenter beamline with a variety of beamline detectors to measure and identify a range of particles with various momenta [**?**].

Maybe also mention the specific times Test Beam detector was operational.

Majority of the Test Beam detector and it's instrumentation is identical to the other NOvA detectors, but there are a few differences, including size, scintillator oil used, readout electronics, or environmental controls, that we're discussing in this section.

General parameters

The NOvA Test Beam detector consists of two 31-plane blocks, each beginning and ending with a vertical plane, with an additional horizontal plane glued inbetween them to preserve the alternating arrangement [**?**]. Each plane consists of 2 modules side-by-side and each module is made up of 32 cells. Each cell has an inner (without the PVC) depth and width of 5.9 cm and 3.8 cm respectively, same as for the other NOvA detectors, and a length of 2.6 m. This brigns the final dimensions of the Test Beam detector to 63 planes $\times$ 64 cells, or $2.6 \times 2.6 \times 4.1\,\mathrm{m}^3$.

The 63 planes are numbered from 0 to 62, with even numbers corresponding to vertical planes and odd numbers to horizontal planes. Cells are numbered 0 to 63, going from bottom to top for horizontal planes and left to right, when facing the front of the detector, for vertical planes.

The detector coordinate system is illustrated on figure 1. It is centered with $(0,0,0)$ in the centre of the first plane [**?**]. The x axis runs left to right when facing the front of the detector, y axis bottom to top, and z axis goes along the beam direction from front to the back of the detector. The exact geometry of the Test Beam detector from several alignment surveys is saved in gdml files and used in our analyses [**?**].

In the past we encountered an issue when aligning the Test Beam detector with the beamline measurements broke several assumptions within the Test Beam geometry [**?**], which manifested as uncalibrated cells in the back of the detector [**?**]. This was fixed by realigning both the detector and the beamline based on the last alignment survey and implemented in the production tag R23-04-05-testbeam-production.a and there after [**?**].

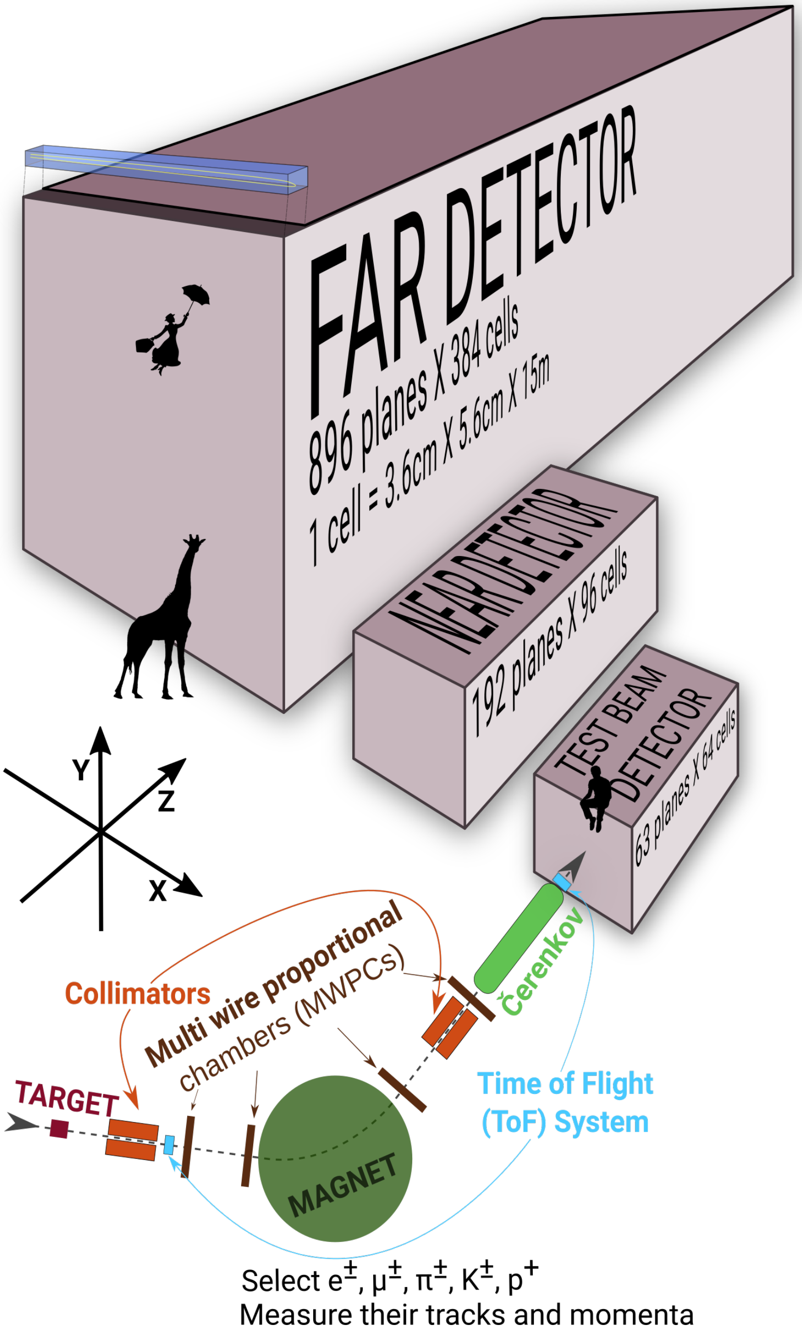


Figure 1: Comparison of Test Beam detector scale to the Near and Far NOvA detectors (and a man, giraffe, or Mary Poppins). Also shown are the Test Beam beamline detectors and components (not to scale), with arrows showing the direction of the beam. The three black arrows show the orientation fo the detector coordinate system.

Scintillator

The Test Beam detector is filled with (more than) three different versions of the NOvA scintillator, which differ mainly in the way they were stored since the filling of the near and far detectors. This is illustrated on figure 2.

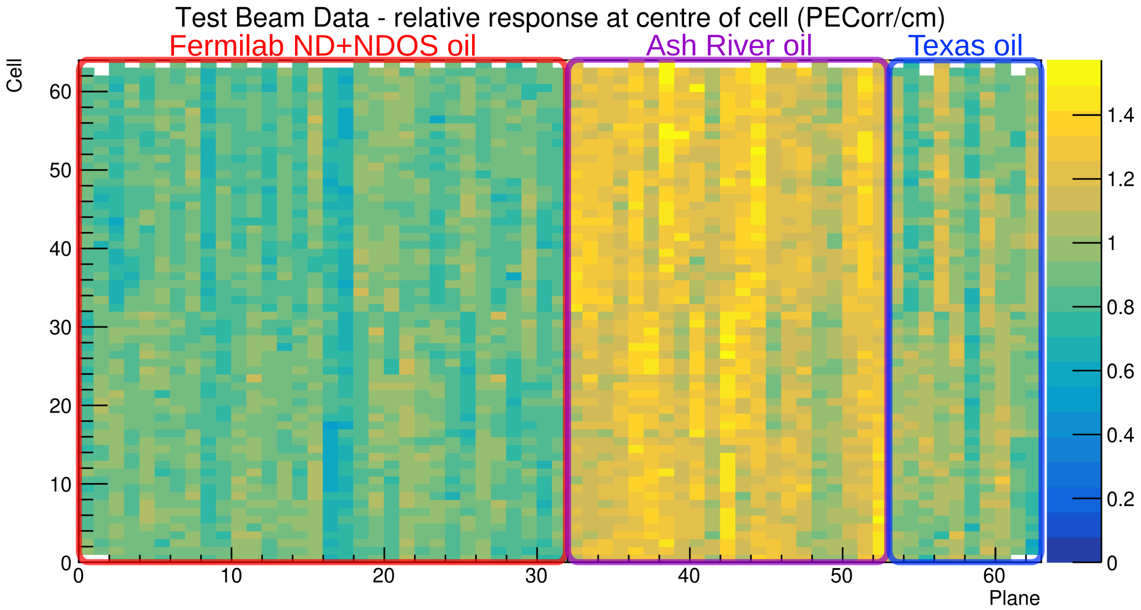


Figure 2: Uncorrected energy response in the centre of cells across the Test Beam detector showing a clear distinction between the different scintillator oils.

The original plan [?] was to use the scintillator from a tanker and one of the tanks located outside in Fermilab. First tests showed acceptable results and the tanker oil was used to fill out almost the entirety of the first block of the detector (first 32 planes) [?]. However, when we loaded the oil from tank two into the tanker, it became extremely cloudy and unusable, possibly due to contamination with water accumulated at the bottom of the tanks, which was mixed with oil by the pump. The rest of the first block was the topped up with high quality scintillator from NDOS, which has been stored inside in barelles at MiniBooNE [?]. This is labeled as "Fermilab ND+NDOS oil" on figure 2.

Even before the extreme cloudiness was discovered, it was known that the oil from the tanks has lost much of its original light yield properties. Reasons vary from water contamination to insects and dirt contamination [?]. Yet it was still decided to use the tank 2 oil [?]. It was also decided not to mix the various oils (tanker/tank/NDOS/Ash River) as studying energy deposition in different types of oils could lead to some interesting insights [?].

The first 21 planes of the second block (planes 32 to 52) were filled with the Far Detector production scintillator shipped in from Ash River [?]. This oil has been stored in "totes" inside a building and under several layers of black plastic [?]. Also used a little (70 gallons) scintillator from NDOS to fill these planes (compared to 1900 gallons from Ash River) [?].

The last 10 planes (planes 53 to 62) [?] were filled with scintillator drained from NDOS stored in Texas A&M University and University of Texas at Austin [?, ?]. This scintillator has higher light yield than the one from the tanker, but lower than the Ash River one [?].

In total the Test Beam detector is filled with 5418 gallons of scintillator oil with a weight of approximately 28.6 tons [?].

Readout

The Test Beam detector uses in total 126 front end boards (FEBs), each reading out signal from 32 cells (half of a plane) [?]. The readout is located on the top and right (looking on the front) side of the detector. 118 FEBs are version 4.1, same as in the Far Detector, and 8 FEBs, located on planes 16, 17, 48 and 49, are version 5.2, same as in the Near Detector. The Near Detector FEBs are designed to read out data in a fester rate and we used a mix of FEB types to study the difference in their response and to validate both versions in the same environment [?].

Environment

Unlike the near and the far detector, the Test Beam detector does not have any overburden to shield it from cosmic particles.

Temperature very stable during winter months (heaCng is installed at MC7). However, dew point went over 10C ND shutdown threshold several times.

Underfilled cells issue

The Test Beam detector is slightly tilted around the Z axis by about 0.7° towards the readout. This caused the top cells of both modules of all the horizontal planes (cells 31 and 63) to be underfilled, creating an air bubble on the left side of the detector and severly affecting the energy response in those cells [?]. This has been fixed [?] by adding extensions to the filling ports and overfilling the horizontal cells with the NDOS scintillator stored in drums Fermilab (not the scintillator store in a tanker or tanks). This scintillator was also used in the first half of the detector (Fermilab ND+NDOS oil on figure 2), but is different from the "Ash River oil" used in part of the second half of the detector (bright part of figure 2). The overfilling was done in April 2021 in 3 stages in between the full operation of the Test Beam detector.

3 The NOvA calibration process

Test Beam is intentionally following the same calibration procedures as the standard NOvA detectors. This section intends to provide a brief overview of the general NOvA calibration process and introduce basic utilities used.

At some point I could also list all the important variables and their description. Define PE, PECorr, MEU, w...

Maybe also talk that generally calibration is trying to get the GeV response from the original ADC signal and write an equation of how is this done.

Describe that the results of the calibration process are store in csv tables and loaded during processing of each event.

Talk about fiber brightness, what it is and why do we have 12 fb bins and how do we get them now. Why are we doing a consolidated planes for simulation.

Give links to other calibration technotes so that people can go take a look if they want more information. This should be just a general overview, stating the facts, no really describing how we got to where we are.

from Calibration_Meta_READFIRST.pdf pclist = list of **pre-calibrated** hist; these have a position and PE count pcliststop = pclist files only containing events that look like stopping muons

Should I talk about the timing calibration? This is done prior to the attenuation when making the pclist/pcliststop files. How do you go from the APD/ADC signal and TDU signal into PE? How do we calculate PE? The timing calibration itself serves to make each detector use the same time...

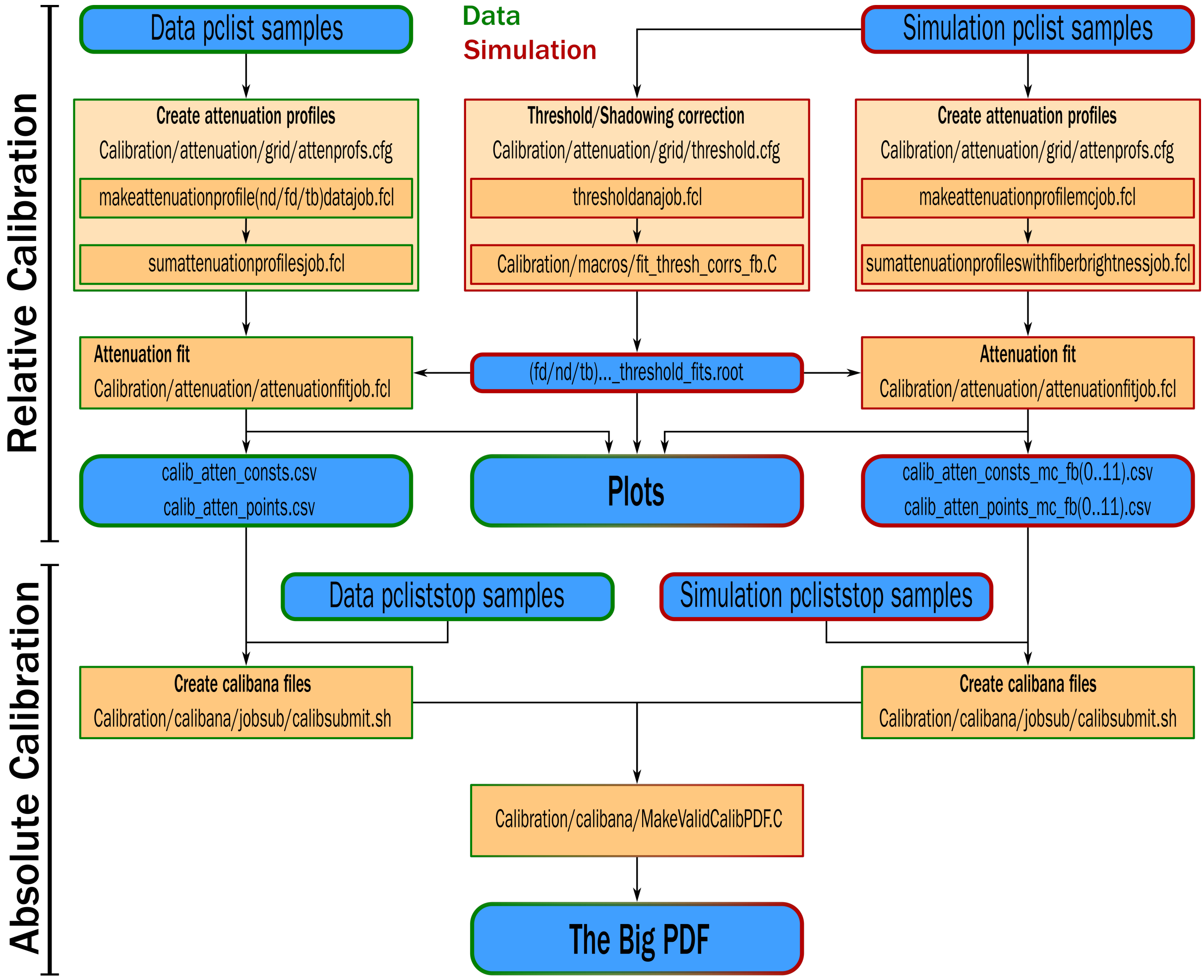


Figure 3: Flow chart showing the jobs (orange background) and files (blue background) needed and produced during the full NOvA calibration process. The left chain is showing the data calibration process (with green border) and is applied to every data calibration sample separately (periods or epochs). The center and right chains are showing the simulation calibration proces, which is redone only if there's a change to the detector simulation. The absolute calibration at the bottom combines data and simulation. The entire process is done separately for each NOvA detector.

3.1 Creating calibration samples

How do we create the calibration samples and what cuts are applied?

Mention exactly the name and the location of the fcl files to create the TB pclist/pcliststop files. (Or should I only do this in the next section when mentioning the TB calibration?)

What are the main variables that are in the calibration samples? Specifically the PE and such.

When should I talk about the ADC to PE conversion? Here?

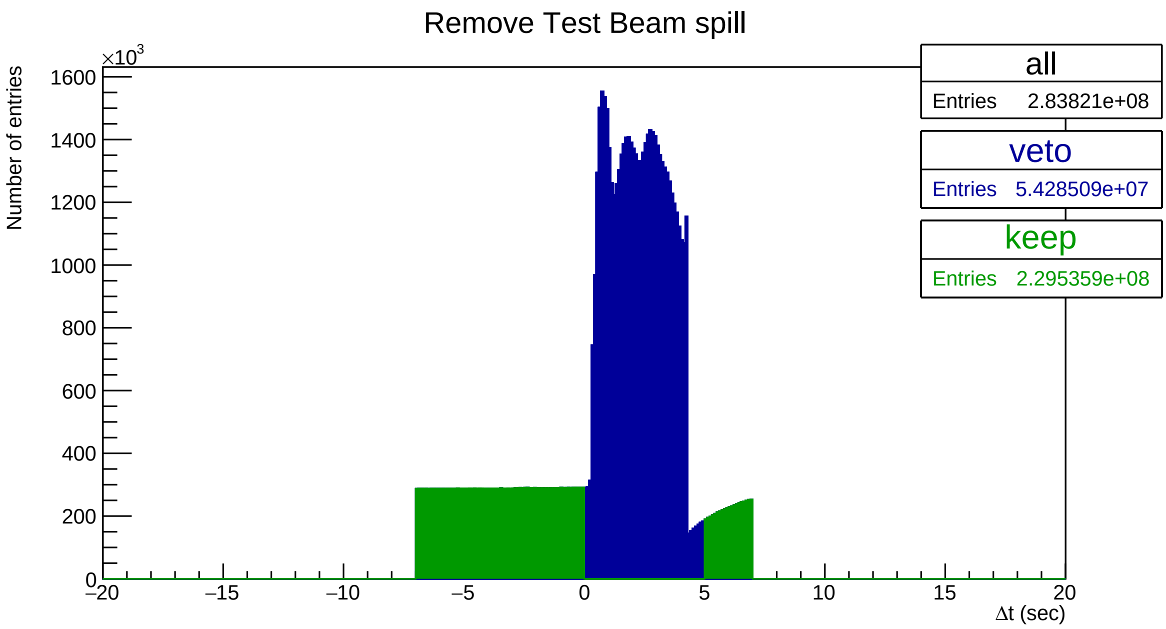


Figure 4: Test Beam beam spill events removed from the calibration samples. Test Beam beam spill is 4.2 seconds long and we remove events (in blue) within a 5 seconds window from the start of the beam spill. The remaining events (green) should mostly consist of cosmic particles. This example and the numbers of entries are for the full period 4 Test Beam sample.

Tricell condition

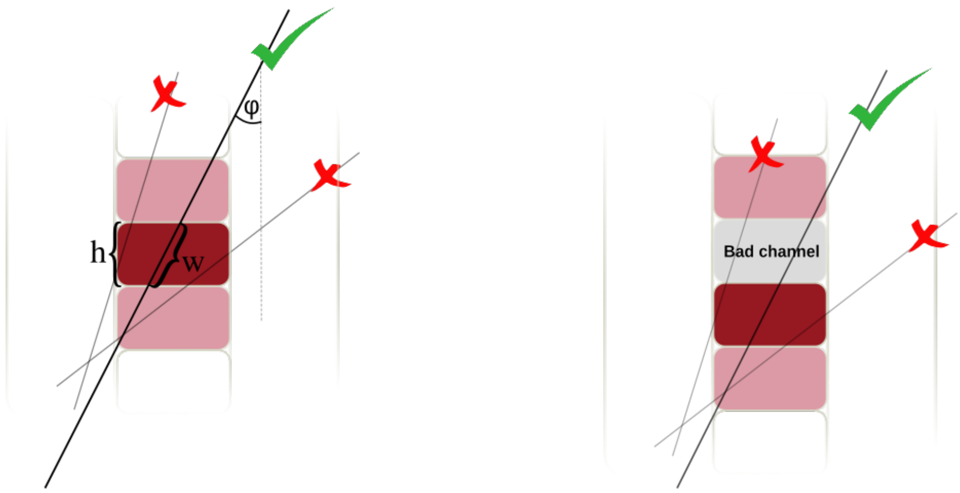
Adding the underfilled cells to the bad channels which are automatically skipped for the tricell condition

3.2 Relative calibration

Detailed description can be found in the "Instructions for the Attenuation Calibration Job" technote from Prabhjot from docdb:13579 (list of all calibration technotes).

Relative calibration/attenuation correction (the exact commands are shown on figure 5.

1. Create the threshold/shadowing corrections
2. Create profile histograms of PE/cm over w for each cell in each plane. The job is `makeattenuationprofileXjob.fcl`, where `X` is `nddata`, `fddata`, `tbdata`, or `mc`.
3. Analyse the calibhist files and draw the histograms
4. Do the attenuation fit using the `attenuationfitjob.fcl`



(a) (b)

Figure 5: Illustration of the tricell condition (a). We only use hits that have two surrounding hits in the same plane to be used in the NOvA calibration. This is to ensure a good quality of the pathlength (w) reconstruction, which is calculated from the known cell height (h) and the reconstructed track angle (φ). In case the hit is next to a bad channel (b), we ignore this bad channel and require a hit in the next cell over.

Create attenuation profiles Attenutation profiles have a constant binnin fNBins=100 (in w), same for ND, FD and TB. This results in an effectively finer binning for TB compared to ND and FD. For FD w = (-900,+900), ND: (-250,+250), TB: (-150,+150). TB: 3cm/bin, ND: 5cm/bin, FD: 18cm/bin. What effect could this have on the relative calibration results? Particularly on the calibration shape?

Apply the threshold/shielding correction.

Do the fit. What exact fits are we using and in what order? Exponential, fit to residuals...

Now we have the relative calibration done and the constants saves. What are the const and points files that we get? What do they mean?

3.3 Absolute calibration

Apply cuts and get an average PECorr response for each epoch/period individually and for each view. Get an average over the two views.

Save the results.

3.4 Calibration uncertainties

4 NOvA Test Beam detector calibration

4.1 Overview

History of TB calibration. What led to the final version of TB calibration. What can be done next.

Dates and times when the data taking occured.

From Calibration_Meta_READFIRST.pdf: Validations of any calibration correction take the same basic form:

1. What deficency are you correcting for? (For Test Beam this would be the difference between the different scintillators, also the faulty FEBs, distribution of w is not flat, especially in the overfilled cells. The energy response between the different cells and planes is not the same. Maybe I should talk about this for each period separately when I have the calibhist plots which show the non-linearities. Also the PhotonTransport plots don't really show the PECorr but the PE/cm itself but with the fit!!!

2. What correction factors/scales have you found? Show them in plot form. (This is basically the PhotonTransport plots for the relative calibration and the pecorrcm distributions for the absolute calibration)

3. Now generate the same plots as in (1) but with the corrections applied. Technically this is the absolute calibration validation plots. Does this mean that the PE/cm plots from the absolute calibration should be/are exactly the same as the calibhist plots? Not entirely as those are only for the stopping muons, whereas the calibhist are for the through-going muons. Does it mean I should maybe generate the calibhist plots with the relative calibration applied?

4. Ratios of plots in (3) to (1) to highlight any patterns or difficult-to-spot discrpancies between what we think should happen when the constants are applied, and what does happen. But what does this tell us? It's basically just an average of the attenuation correction...

Period naming, possibly epochs (for P3). List of data samples, plus MC samples that were used and pointer to the data-based simulation technote.

Specific running conditions: - maybe enough to mention this in the individual descriptions of the test beam periods Underfilled cells Faulty FEBs (Period 2 and Period 3)

Why do we do the calibration generally and why do we need to do in for Test Beam specifically - probably in the introduction

Temperature study (small overview)

From Teresa's thesis Along with setting the energy scale of the detector, we need to calibrate the timing of the readout system for the detector. The Data Concentrator Modules (DCMs) responsible for collating the data from multiple FEBs get their timing information via a daisy chain originating at the detector TDU. Each DCM in the chain has a timing offset relative to the DCM before it, with the last DCM having the earliest ti. Following the procedure described in [66], I used timing information from hits on cosmic ray muon tracks that pass through multiple DCMs to determine the relative offsets between DCMs, shown in Figure 3.20.

4.1.1 Definitions

List all final data and simulation definitions used.

From Teresa's thesis: "For Test Beam, we have three beam-based triggers, one pulsed trigger, and two data-driven triggers. The data-driven triggers are both activity-based triggers. The first is intended to record cosmic ray induced events for use in calibrating the detector.

4.2 Detector Brightness

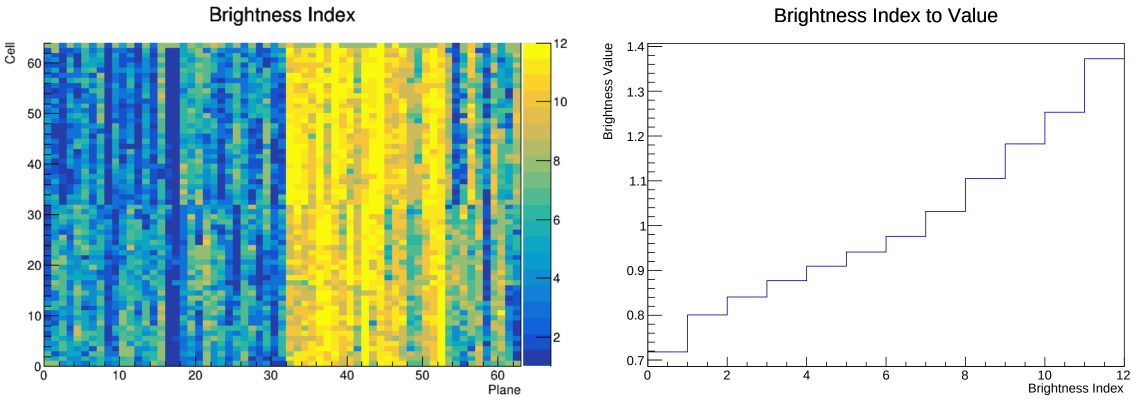


Figure 6: The Test Beam detector is (like the standard NOvA detectors) divided into 12 brightness bins (left plot), each representing a relative difference in energy response (right plot) due to different brightnesses of the fibers, scintillators, or readout.

4.3 Simulation

We originally used Teresa's calibration MC sample, but after we saw disagreement, we developed a new MC based off of the period 3 data, which we ended up using for both period 2 and period 3. For fibre brightness we are also using the same MC from period 3 data as it represents the detector in its best condition.

We used a data-based simulation of cosmic muons for the Test Beam detector calibration. The details are described in the technote XXX. We used this and this data as a basis and this and this data for the fiber brighness file.

4.3.1 Relative calibration results

4.4 Period 1

Only a month of data, only first half of detector filled, primary/secondary beam halo, or oversaturation leading to FEB shutoffs [docdb:38349 and 41331]. Only used for comissioning, not used for any data analysis or calibration.

4.5 Period 2

What was done for the period 2 tb calibration, short overview of what has been done: test beam data were calibrated all at the same time without splitting them to separate epochs. See figures 10,11 and 12.

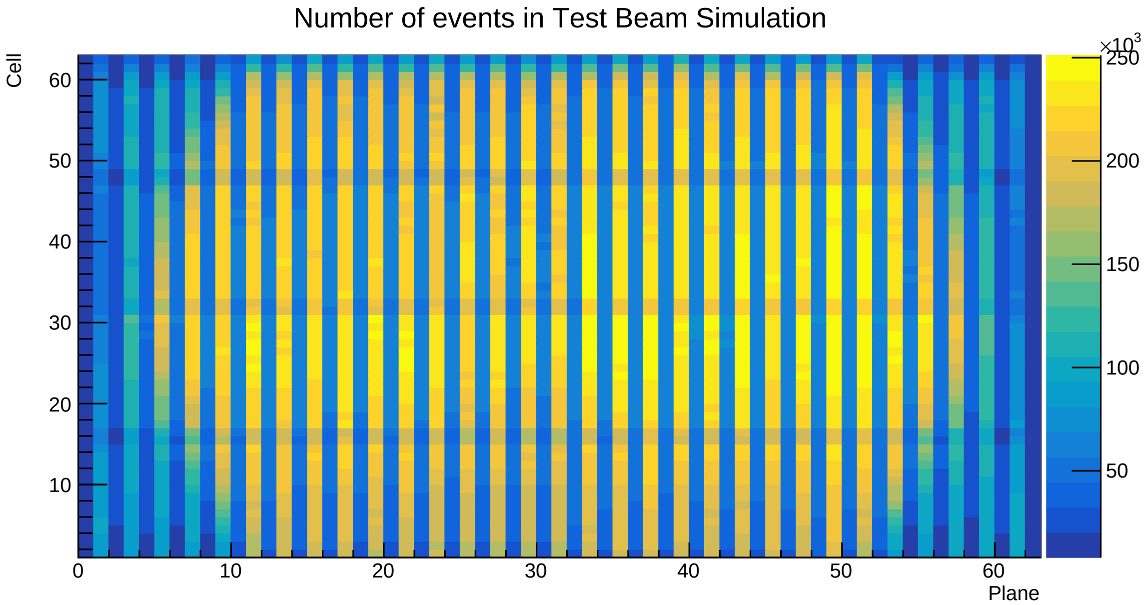


Figure 7: Distribution of events in the Test Beam simulation calibration sample.

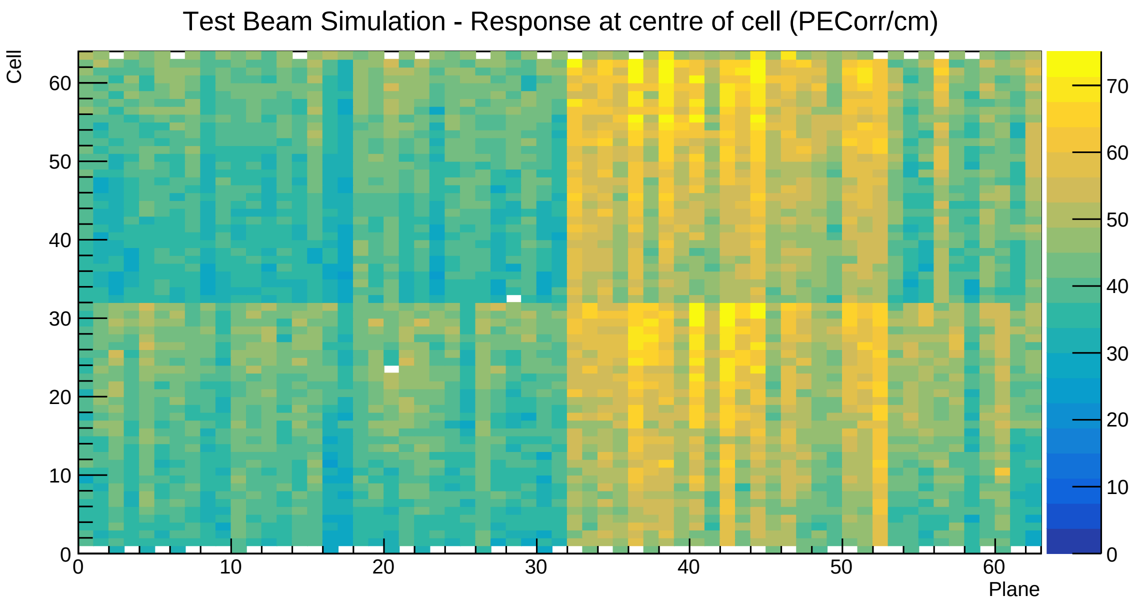


Figure 8: Overview of the relative calibration results for the Teast Beam detector simulation. Each cell is represents the average corrected energy response (in PECorr/cm) in the centre of each cell. The blank cells are uncalibrated.

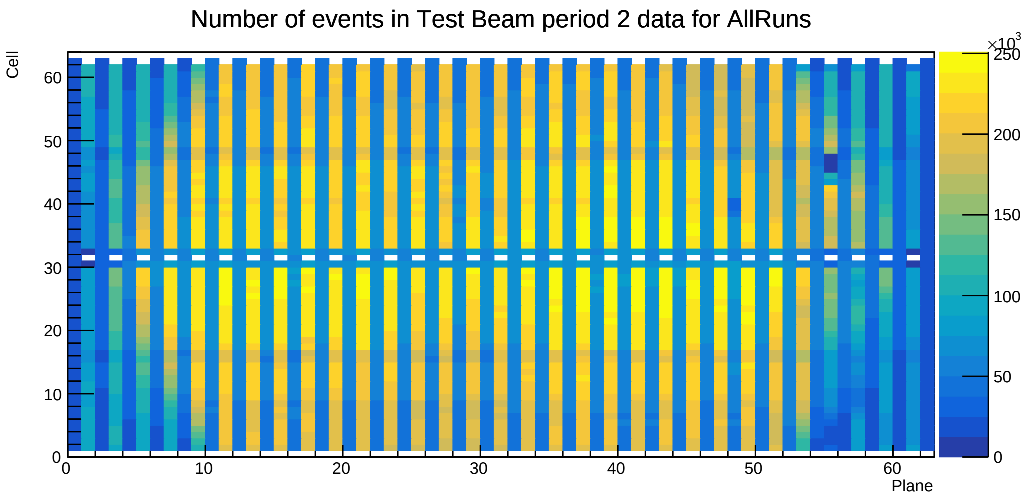


Figure 9: Distribution of events in the period 2 Test Beam data calibration sample.

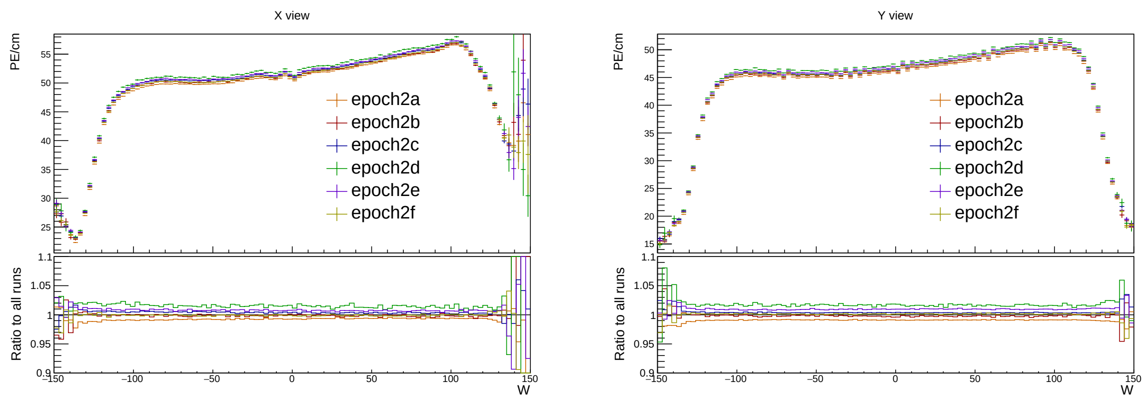


Figure 10: Uncorrected average energy response as a function of the position within a cell (w) for epochs in period 2. It is clear that there is no significant difference between the various epochs.

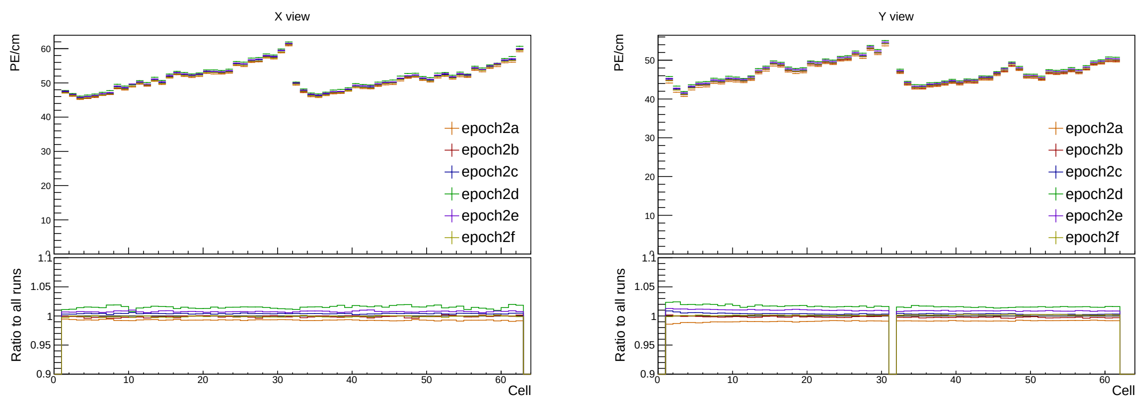


Figure 11: Uncorrected average energy response as a function of cells for epochs in period 2.

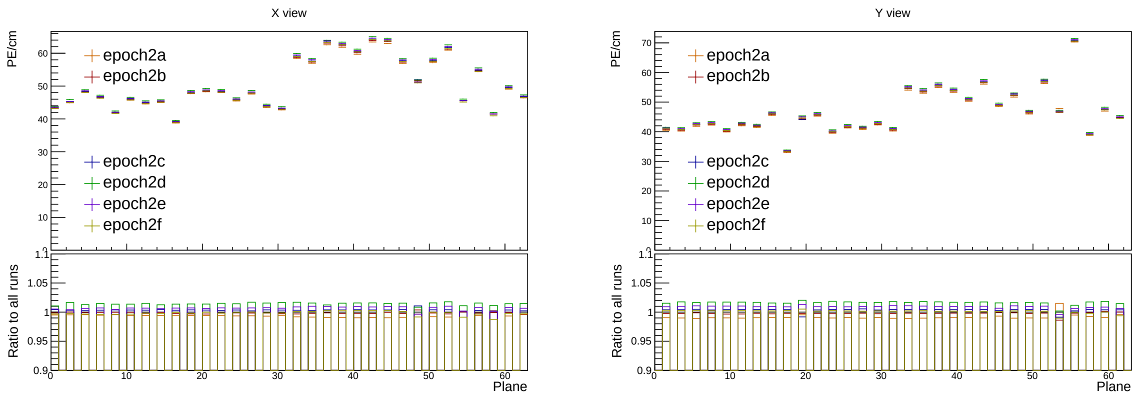


Figure 12: Uncorrected average energy response as a function of planes for epochs in period 2.

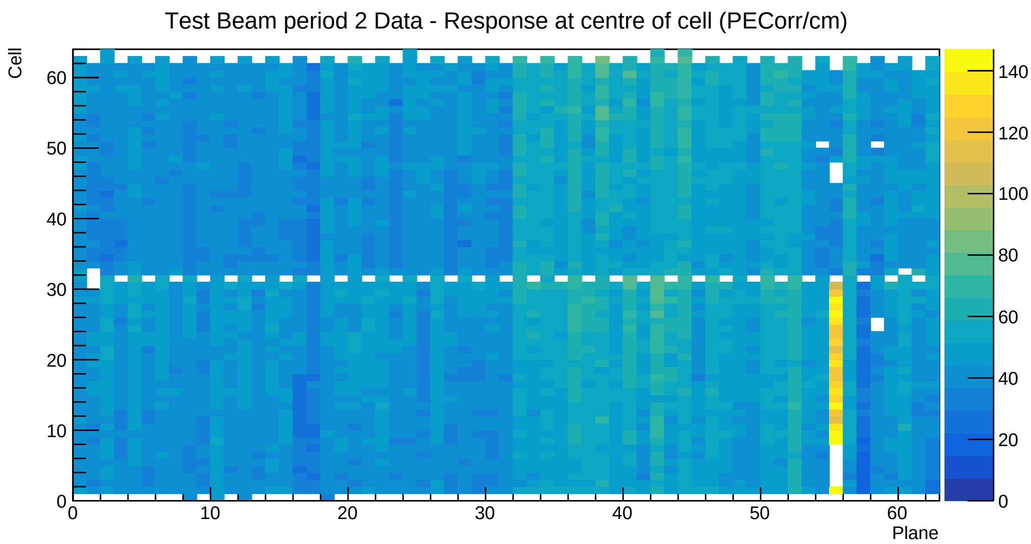


Figure 13: Overview of the relative calibration results for the Teast Beam detector period 2 data. Each cell is represents the average corrected energy response (in PECorr/cm) in the centre of each cell. The blank cells are uncalibrated.

4.5.1 Relative calibration results

4.6 Period 3

Separation of Period 3 data into different epochs based on the running conditions (include plot of the running conditions). We are separating data into pre- and post- filling states. We're using only the fully-refilled post-FEB swap data from period 3 as a basis for the simulation creation.

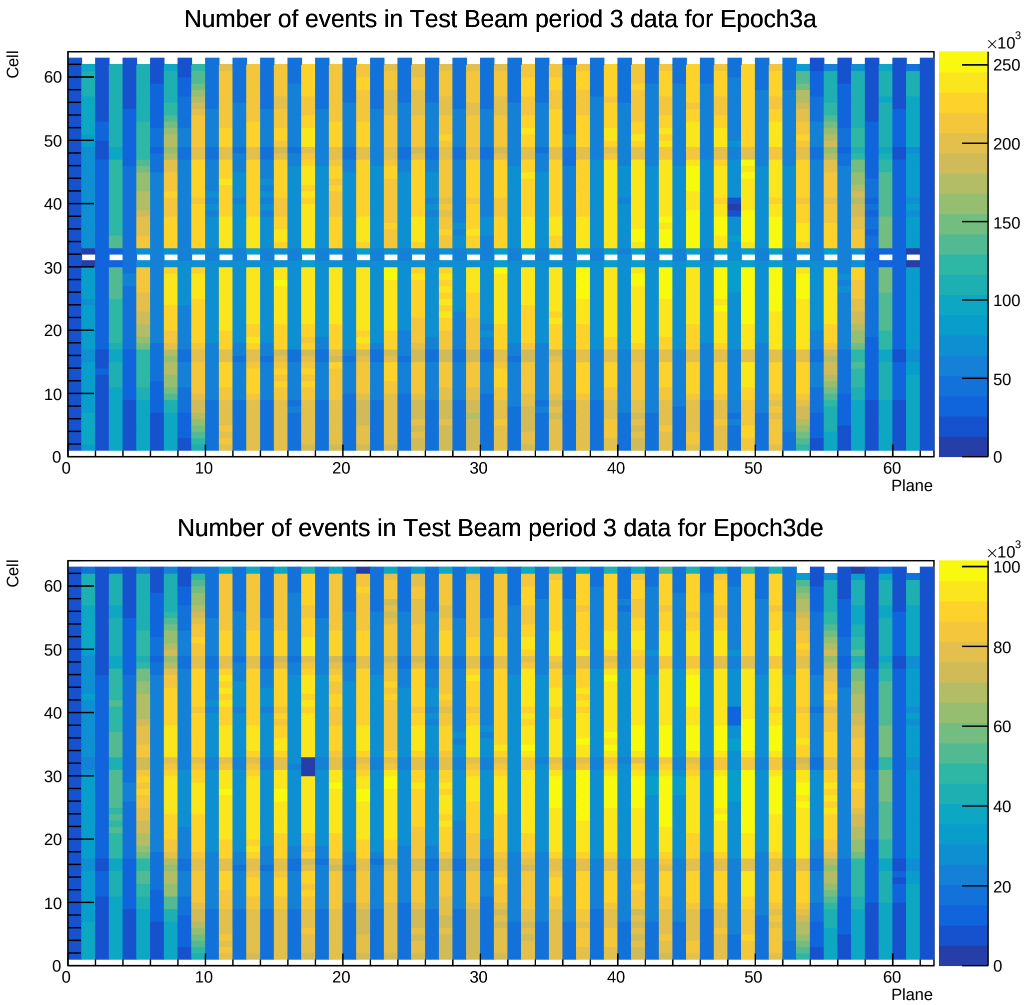


Figure 14: Distribution of events in the period 3, epoch 3a Test Beam data calibration sample.

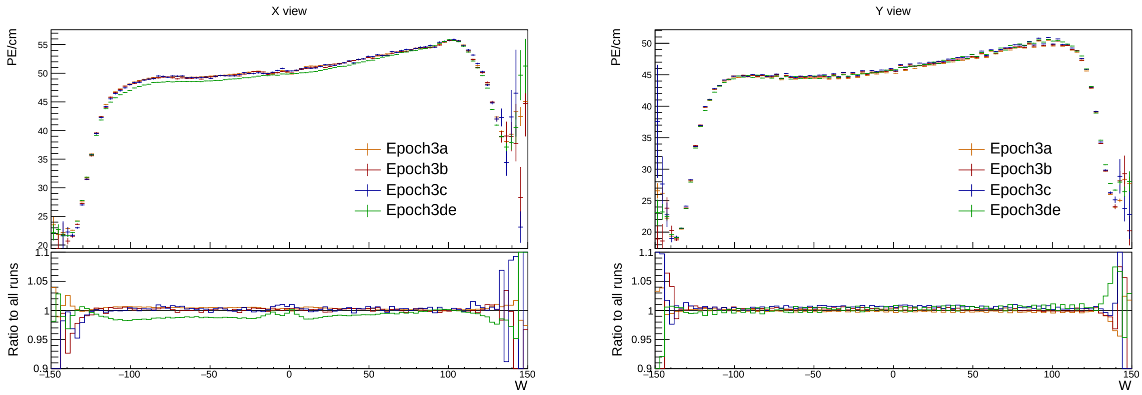


Figure 15: Uncorrected average energy response as a function of the position within a cell (w) for epochs in period 3.

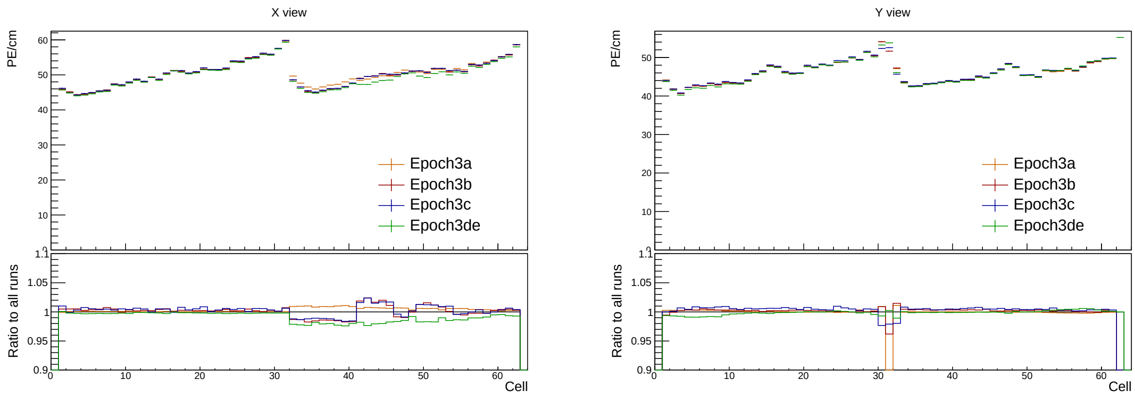


Figure 16: Uncorrected average energy response as a function of cells for epochs in period 3.

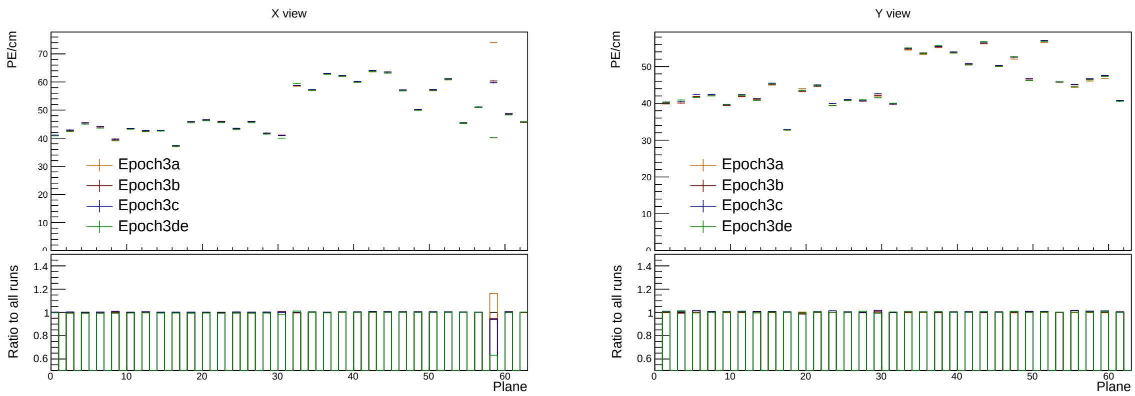


Figure 17: Uncorrected average energy response as a function of planes for epochs in period 3.

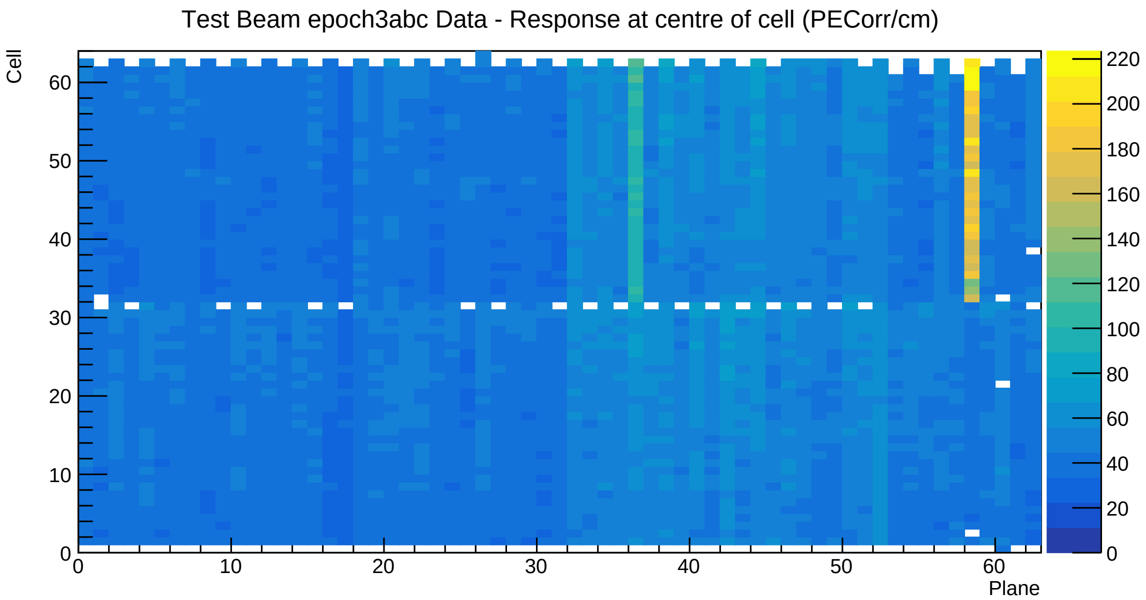


Figure 18: Overview of the relative calibration results for the Teast Beam detector period 3, combined epochs 3a, 3b and 3c data. Each cell is represents the average corrected energy response (in PECorr/cm) in the centre of each cell. The blank cells are uncalibrated.

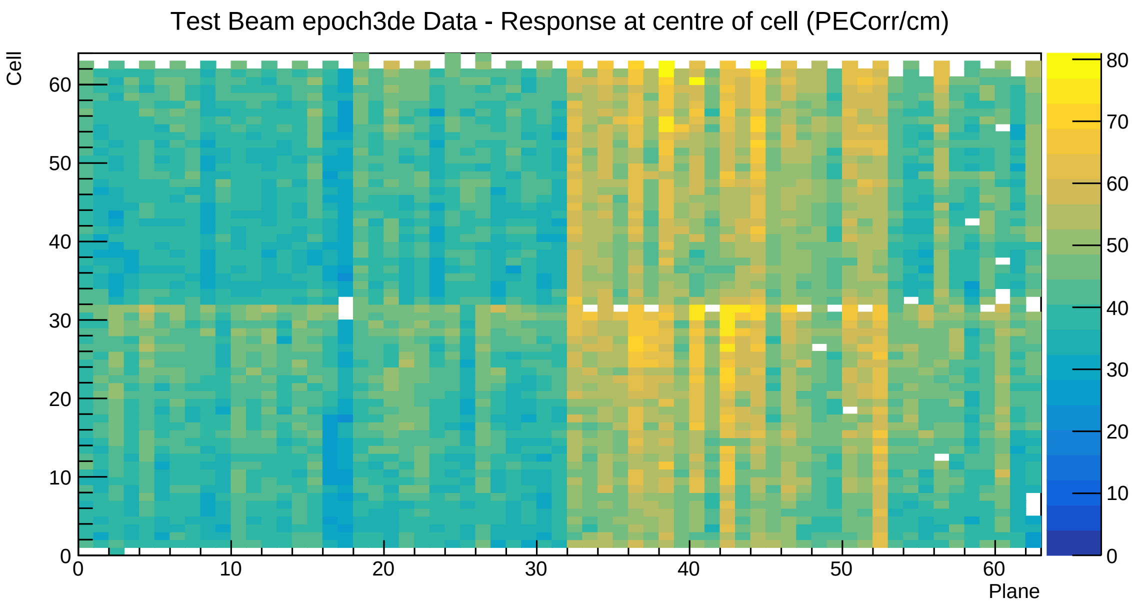


Figure 19: Overview of the relative calibration results for the Teast Beam detector period 3, combined epochs 3d and 3e data. Each cell is represents the average corrected energy response (in PECorr/cm) in the centre of each cell. The blank cells are uncalibrated.

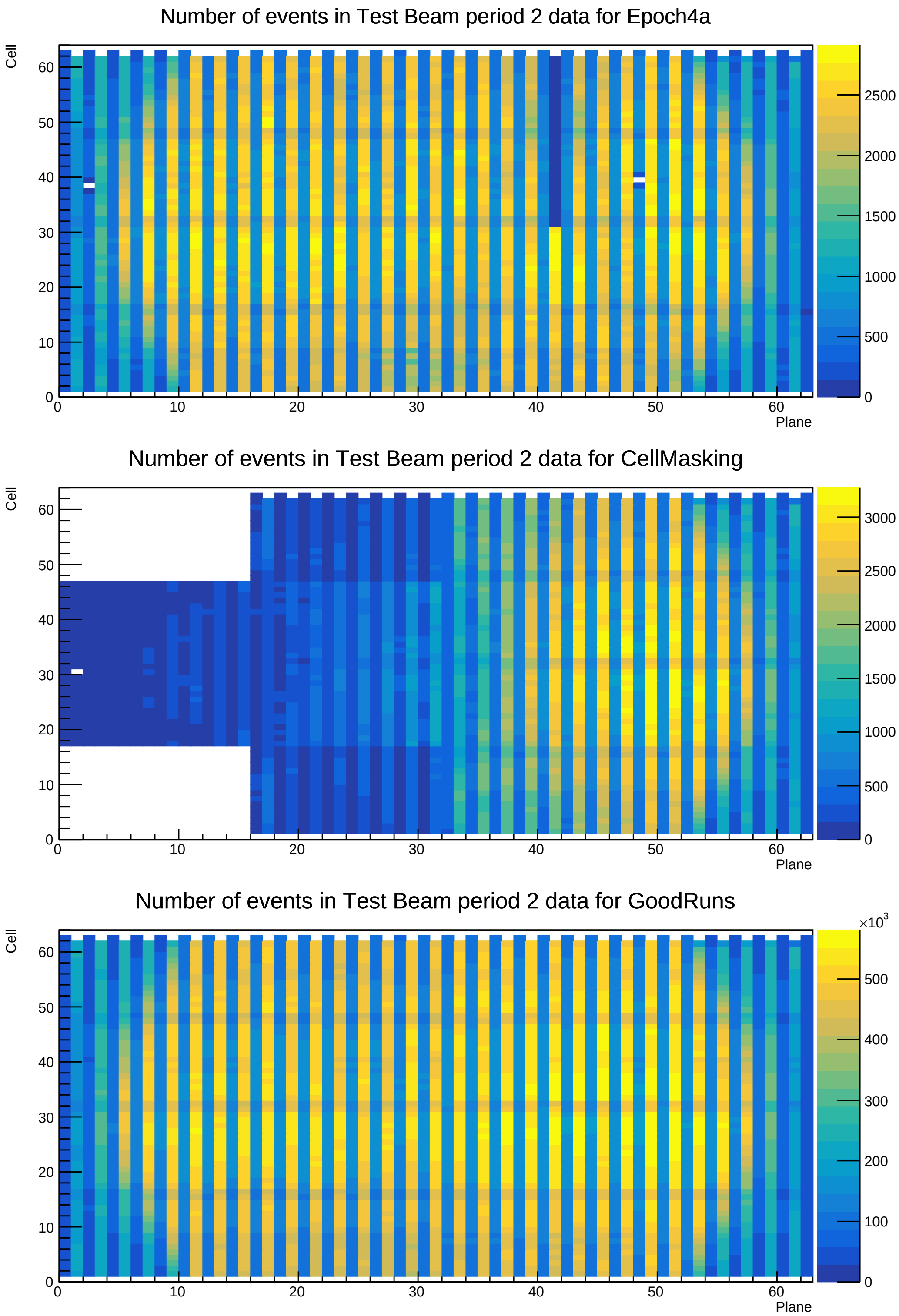


Figure 20: Distribution of events in the Test Beam period 4 data calibration sample. The top plot shows the first three comissioning runs, the middle plot the status of the detector during the Cell Masking studies and the bottom plot shows the rest.

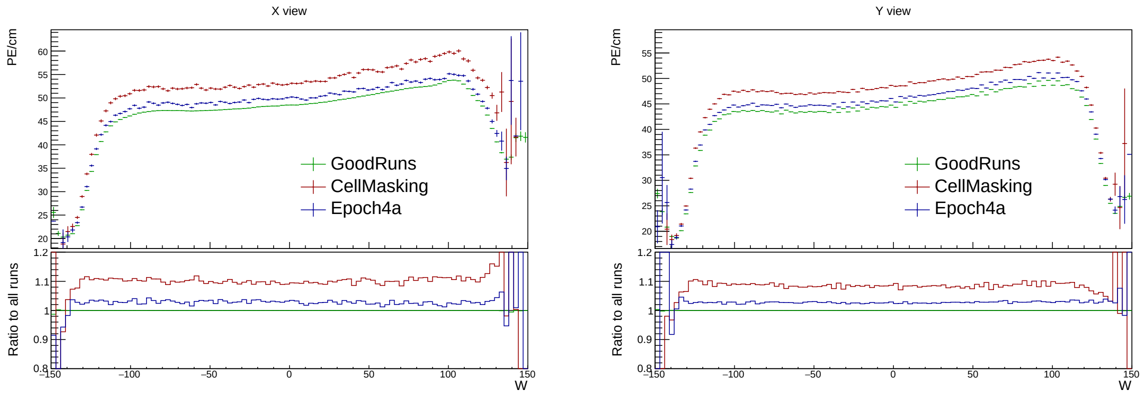


Figure 21: Uncorrected average energy response as a function of the position within a cell (w) for epochs in period 4.

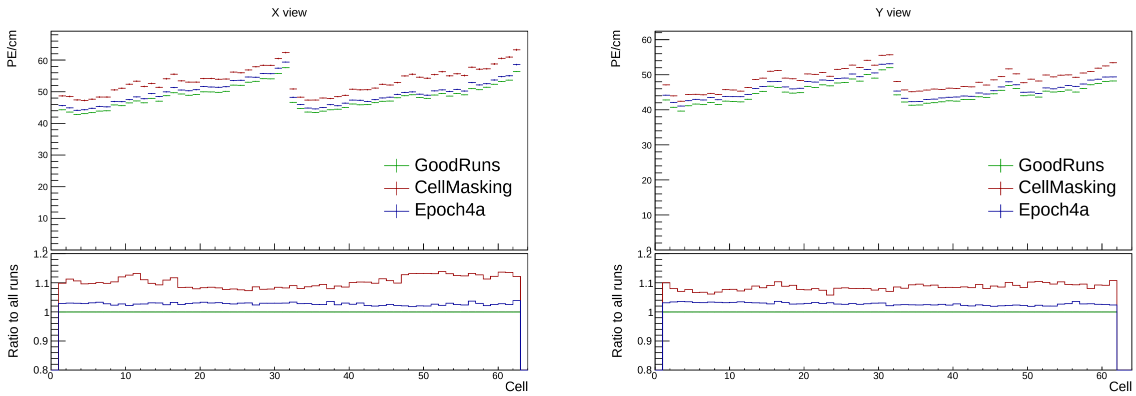


Figure 22: Uncorrected average energy response as a function of cells for epochs in period 4.

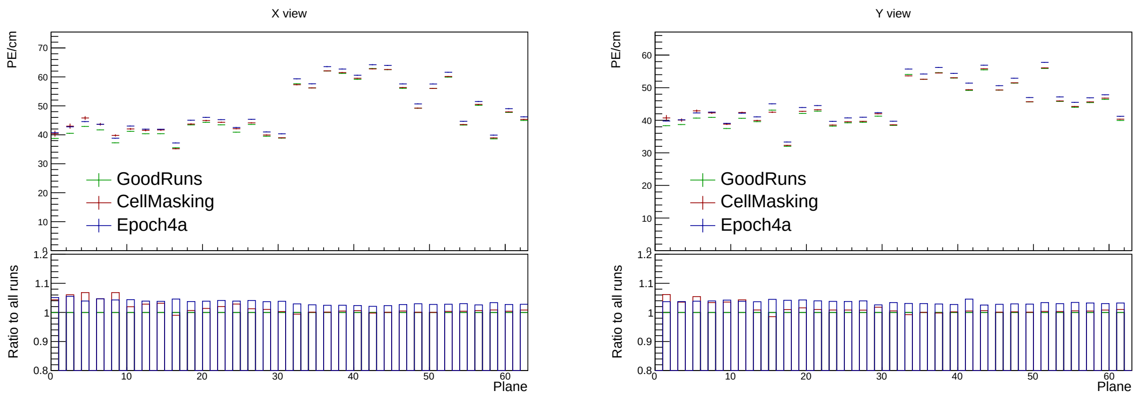


Figure 23: Uncorrected average energy response as a function of planes for epochs in period 4.

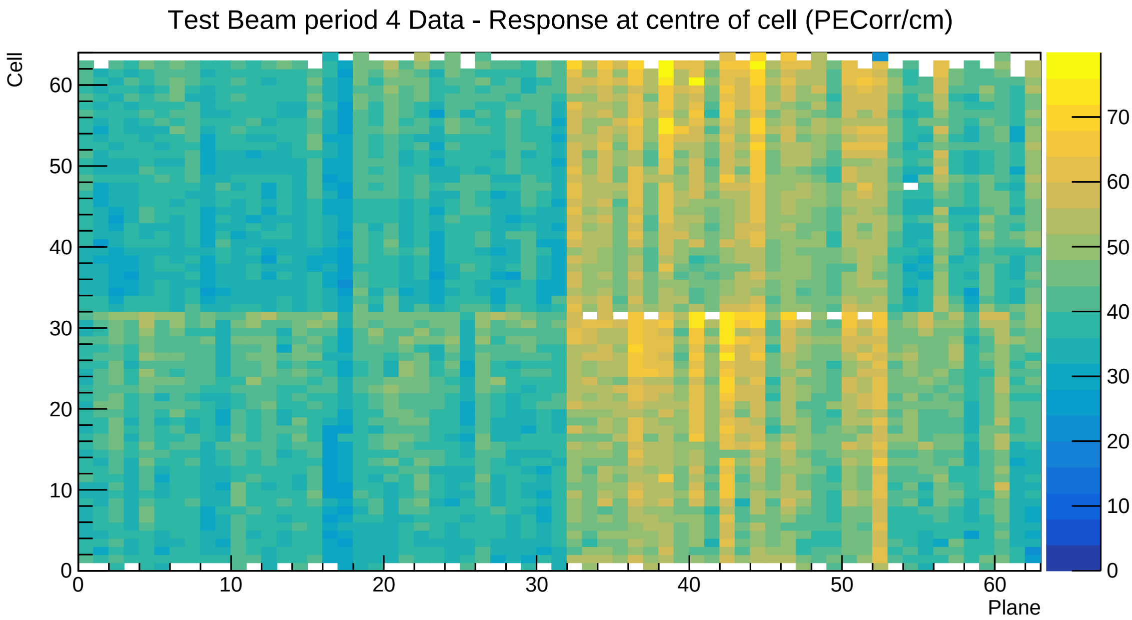


Figure 24: Overview of the relative calibration results for the Teast Beam detector period 4 data. Each cell is represents the average corrected energy response (in PECorr/cm) in the centre of each cell. The blank cells are uncalibrated.

4.6.1 Relative calibration results

Combined epochs 3a, 3b and 3c

Combined epochs 3d and 3e

4.7 Period 4

4.7.1 Relative calibration results

4.8 Absolute calibration results

Standard absolute calibration cuts: track window, flat-response W, positive pe, pecorr, and pathlenght reco

Sample	NHits$x$	MEUx	NHits$y$	MEUy	MEU	MEU Err	TrueE/dx	tE/dx Err
epoch 3abc data	2.638e+05	38.49	1.621e+06	39.4	38.94	0.006758	1.772	0.000238
epoch 3de data	1.049e+05	38.63	6.725e+05	39.42	39.02	0.01048	1.772	0.000238
period 2 data	2.322e+05	38.7	1.413e+06	39.4	39.05	0.007252	1.772	0.000238
period 4 data	5.268e+05	38.63	3.316e+06	39.4	39.01	0.004703	1.772	0.000238
simulation	2.829e+05	40.17	1.842e+06	39.93	40.05	0.006418	1.772	0.000238

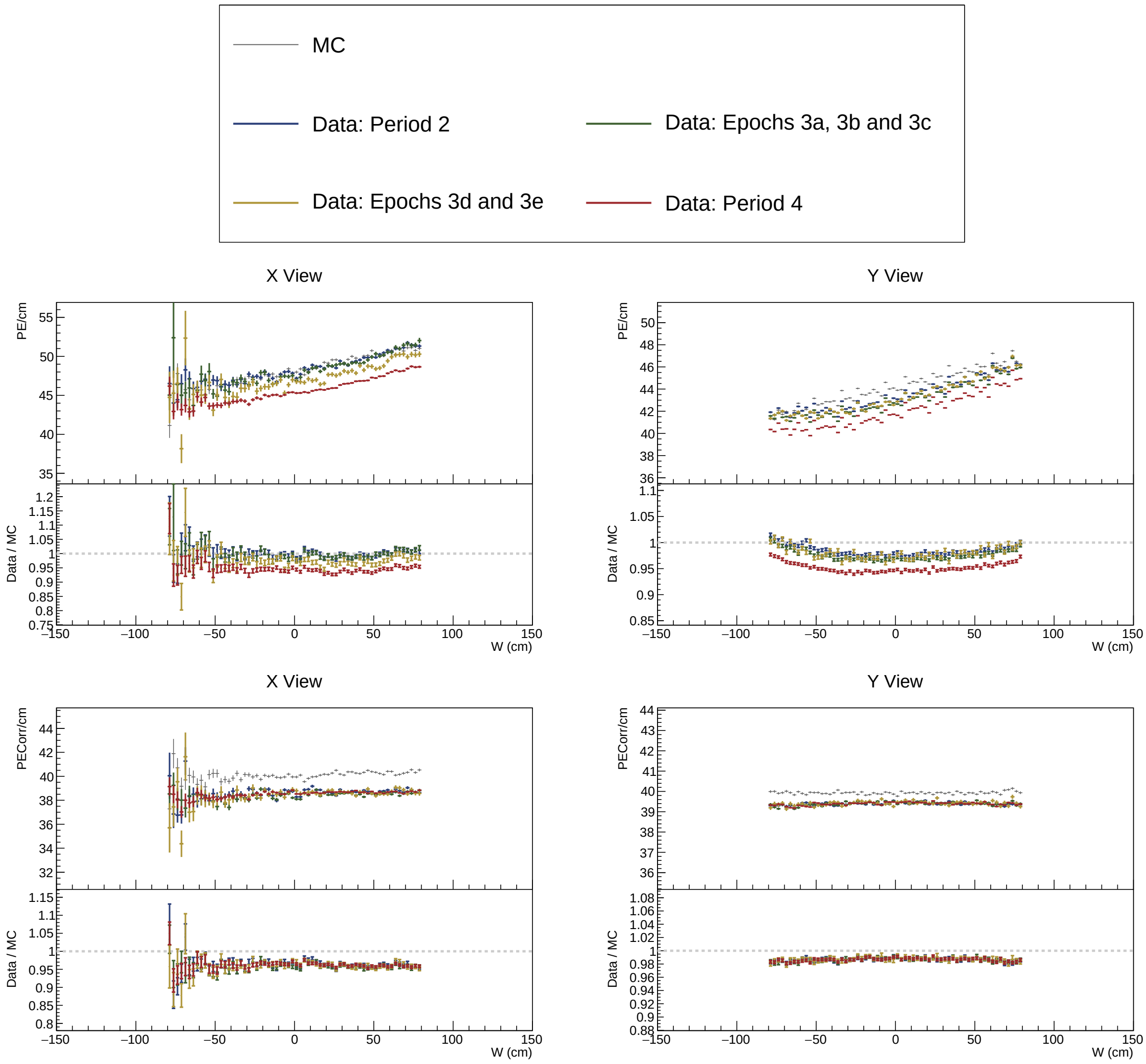


Figure 25: ...

316 ## 4.9 Drift in TB data

317 ## 4.10 Results

318 Table of final results. Final CSVs are locate in the `/nova/ana/testbeam/calibration` and
319 they have been included in the vXX.XX calibration tag.
320 Plots of absolute calibration results

321 ## 4.11 Validation

322 Comparisons with older version of calibration and maybe with the FD and ND

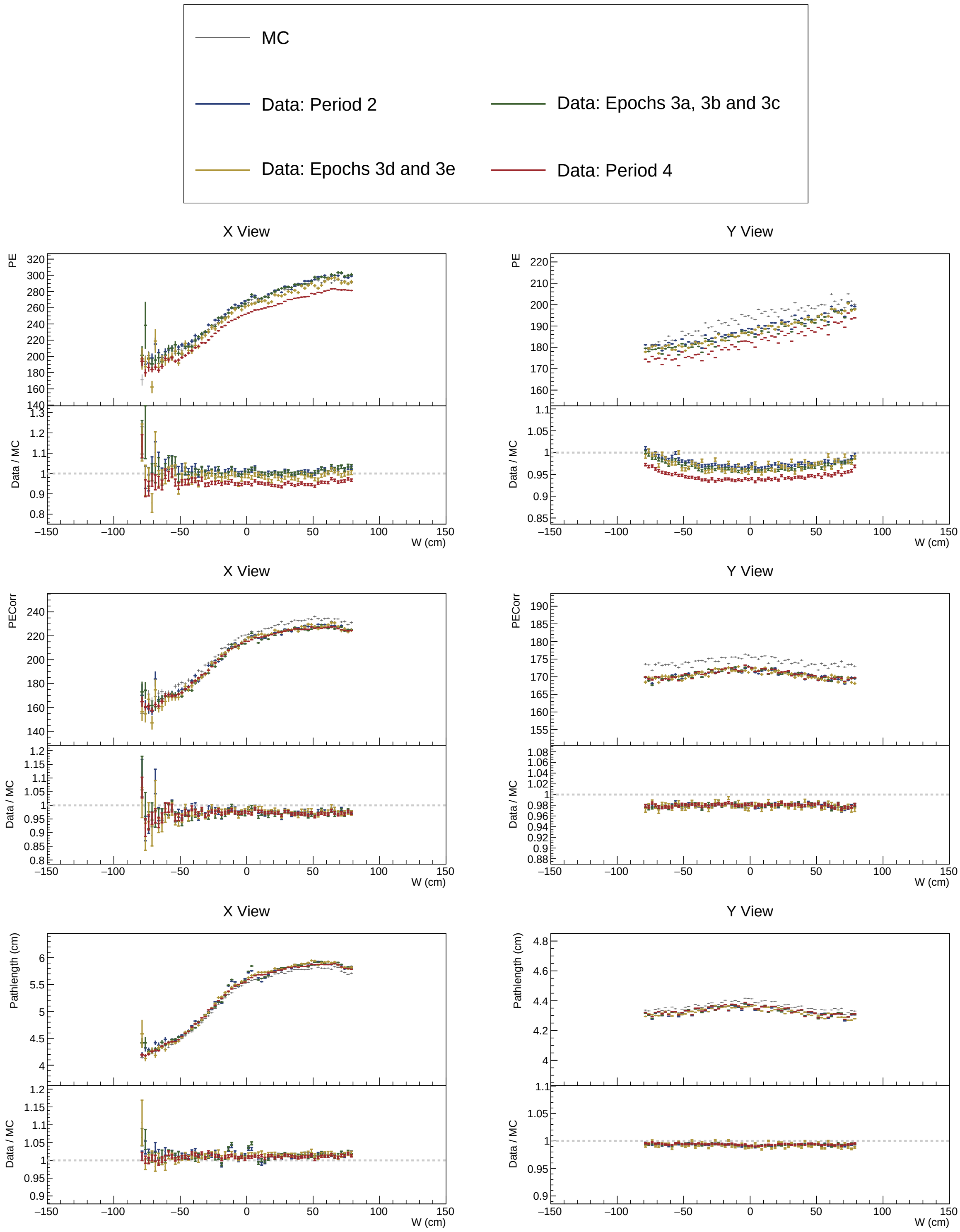
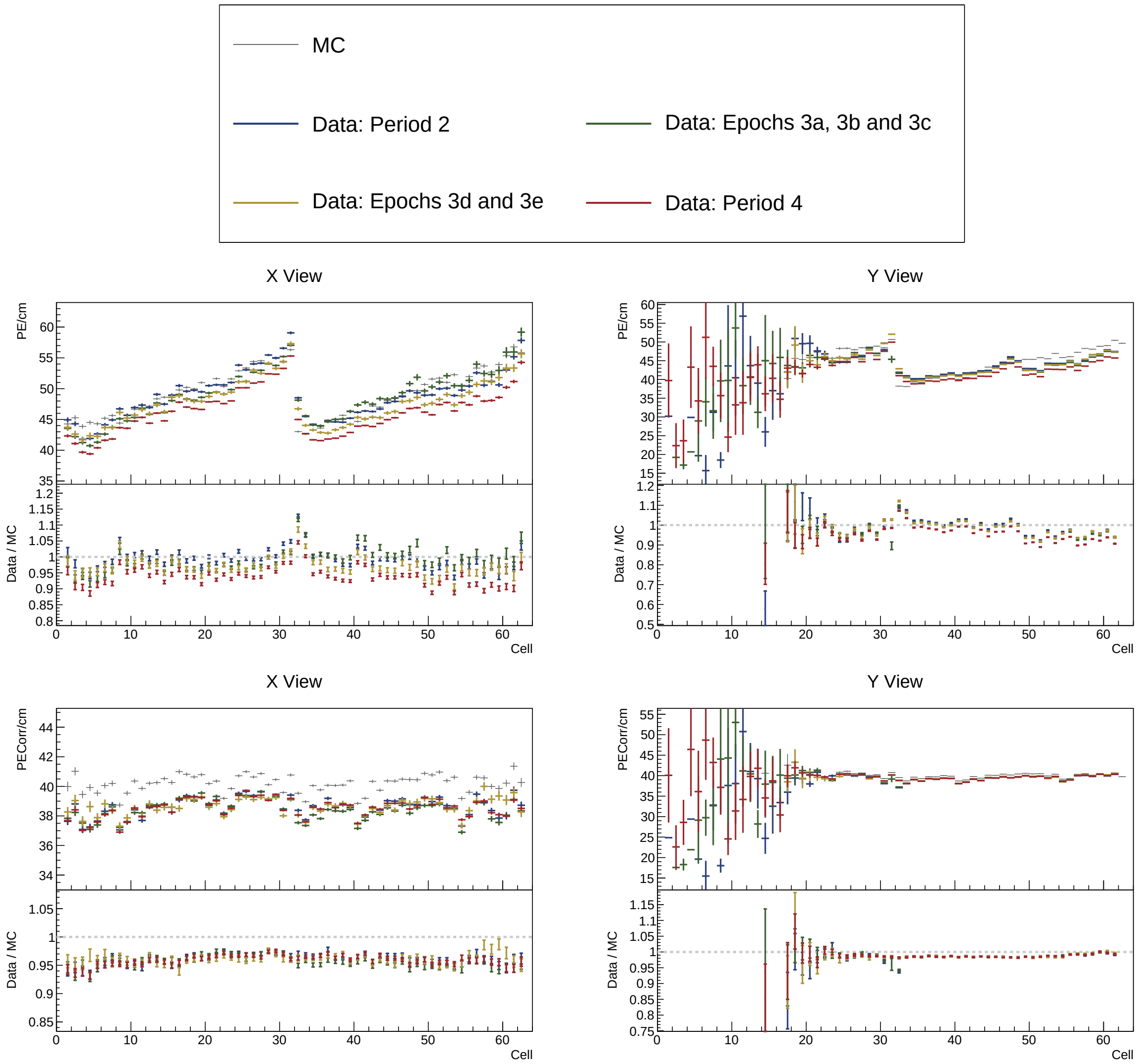

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X View
Y View
PE
PECorr
Pathlength (cm)
Data / MC
W (cm)

Figure 26: ...



MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X View
Y View
PE/cm
PECorr/cm
Data / MC
Cell

Figure 27: ...

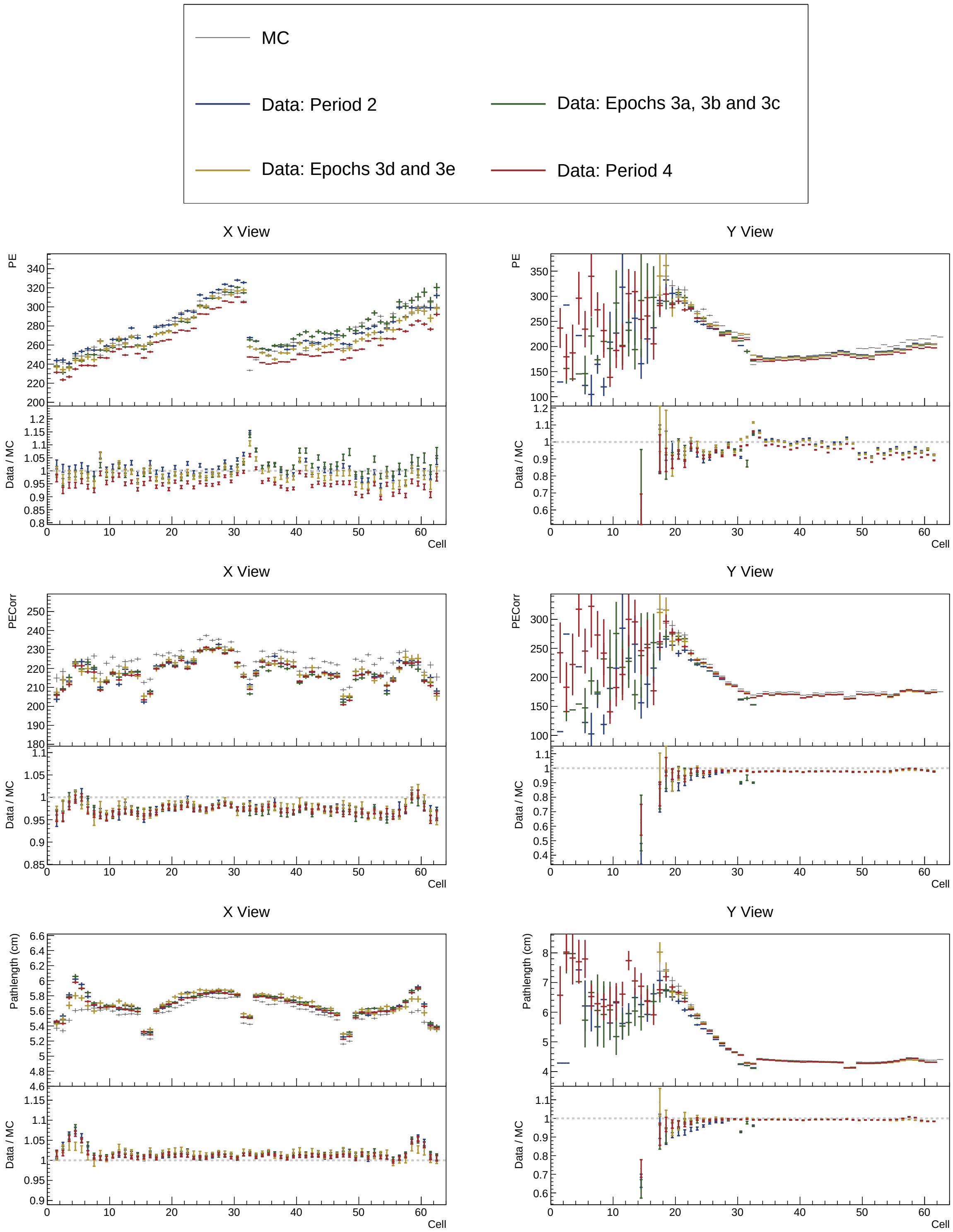
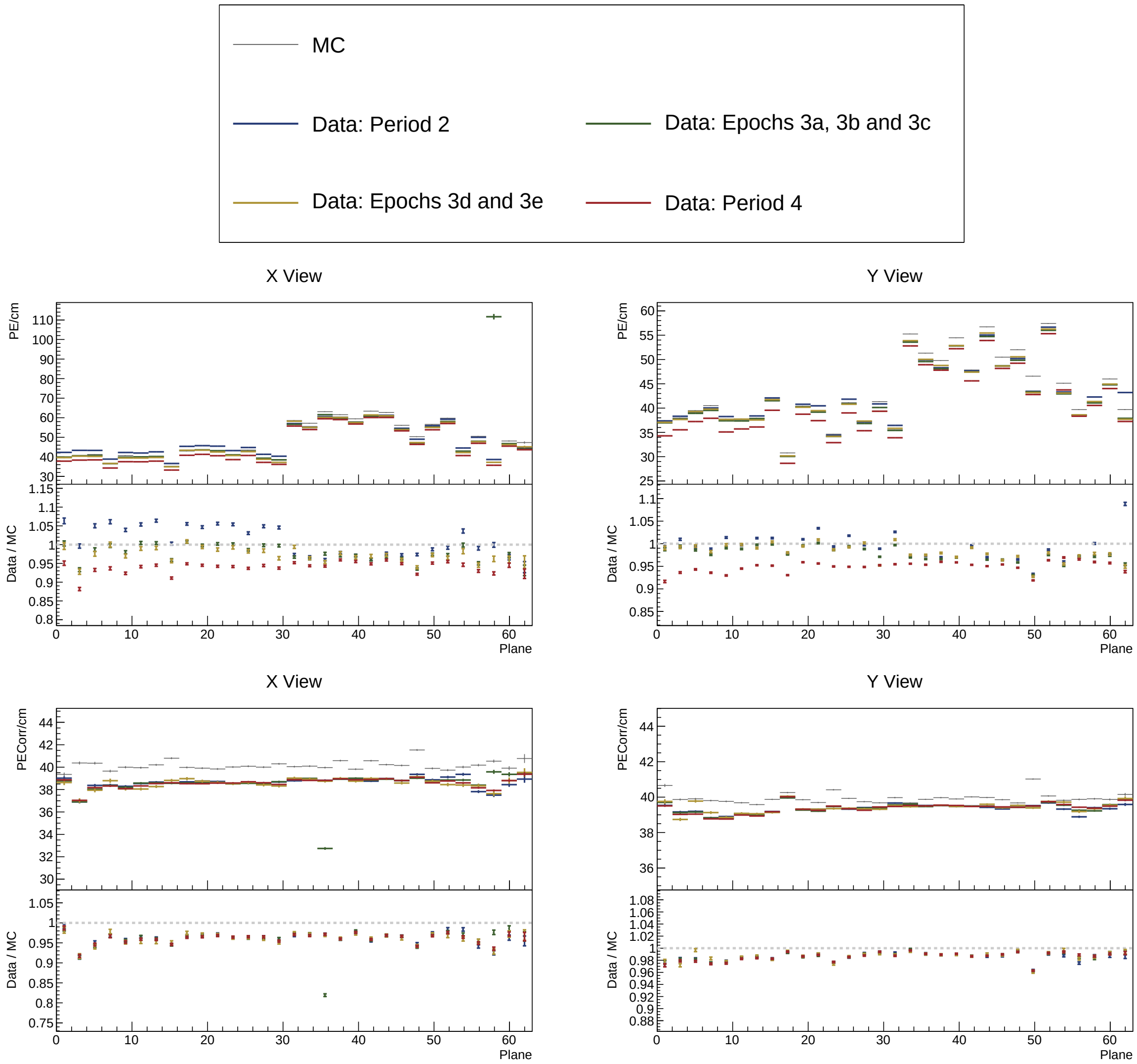

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X View
Y View
PE
PECorr
Pathlength (cm)
Data / MC
Cell

Figure 28: ...



MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X View
Y View
PE/cm
PECorr/cm
Data / MC
Plane

Figure 29: ...

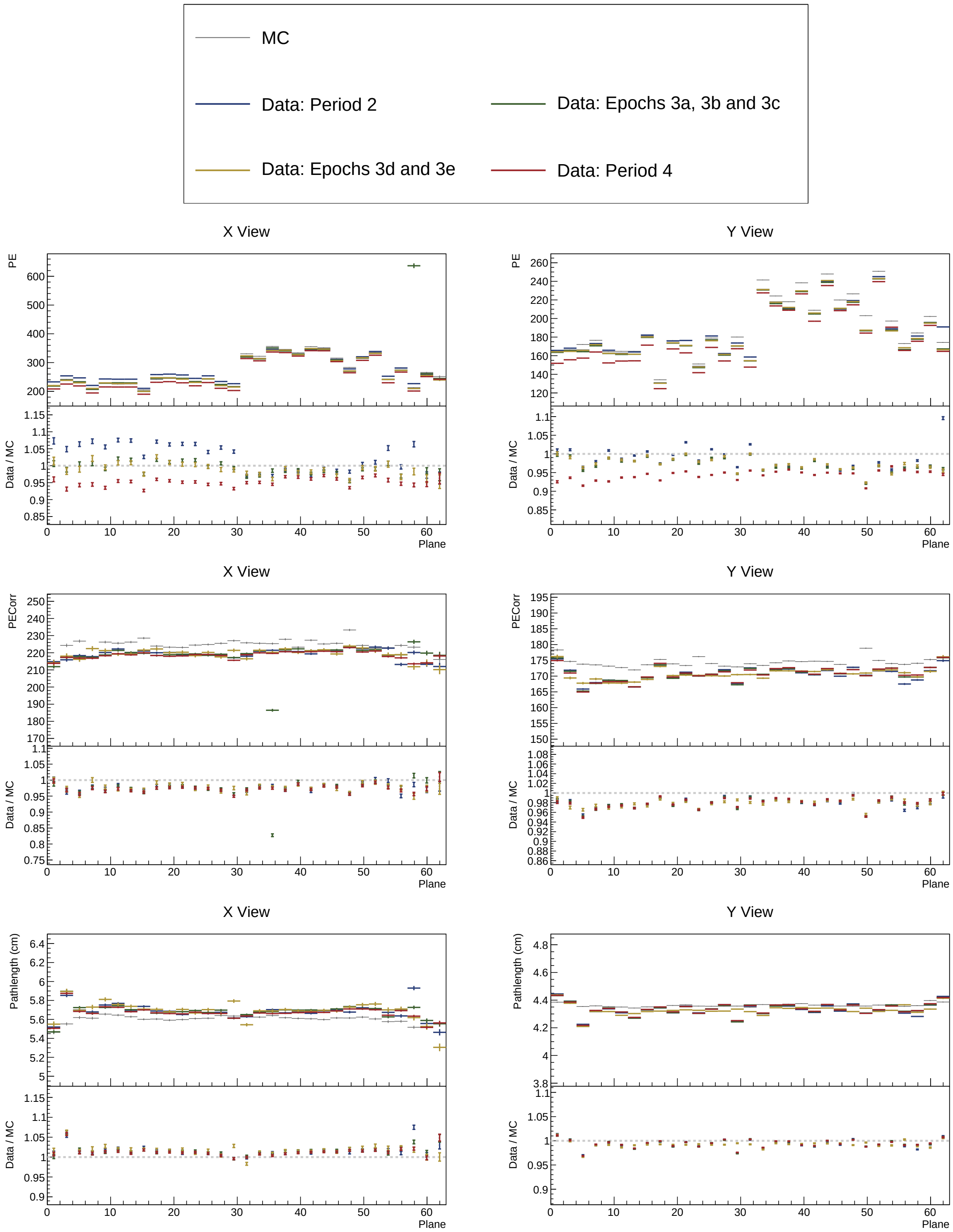

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X View
Y View
PE
PECorr
Pathlength (cm)
Data / MC
Plane

Figure 30: ...

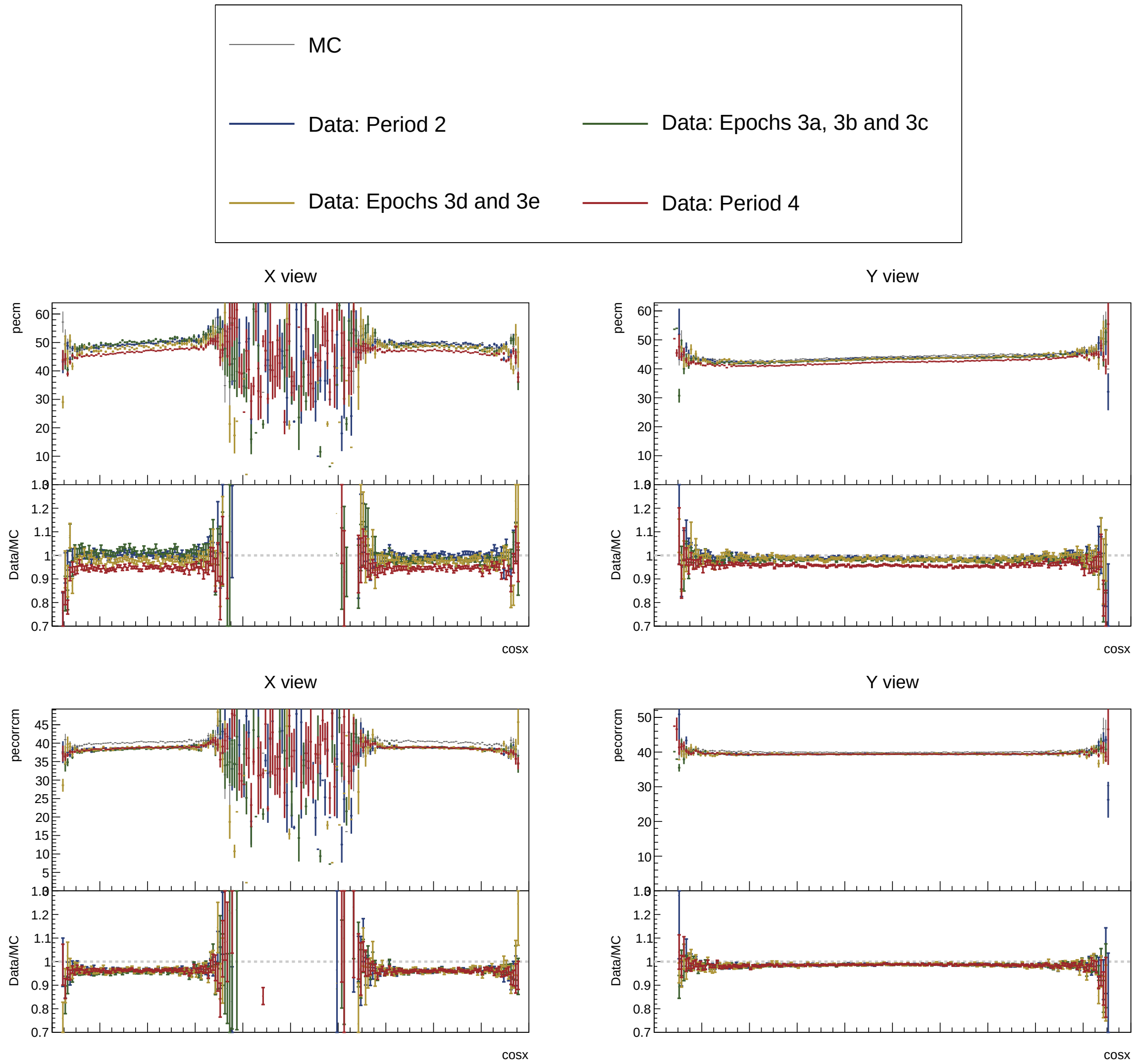

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X view
Y view
pecm
pecorrcm
Data/MC
cosx

Figure 31: ...

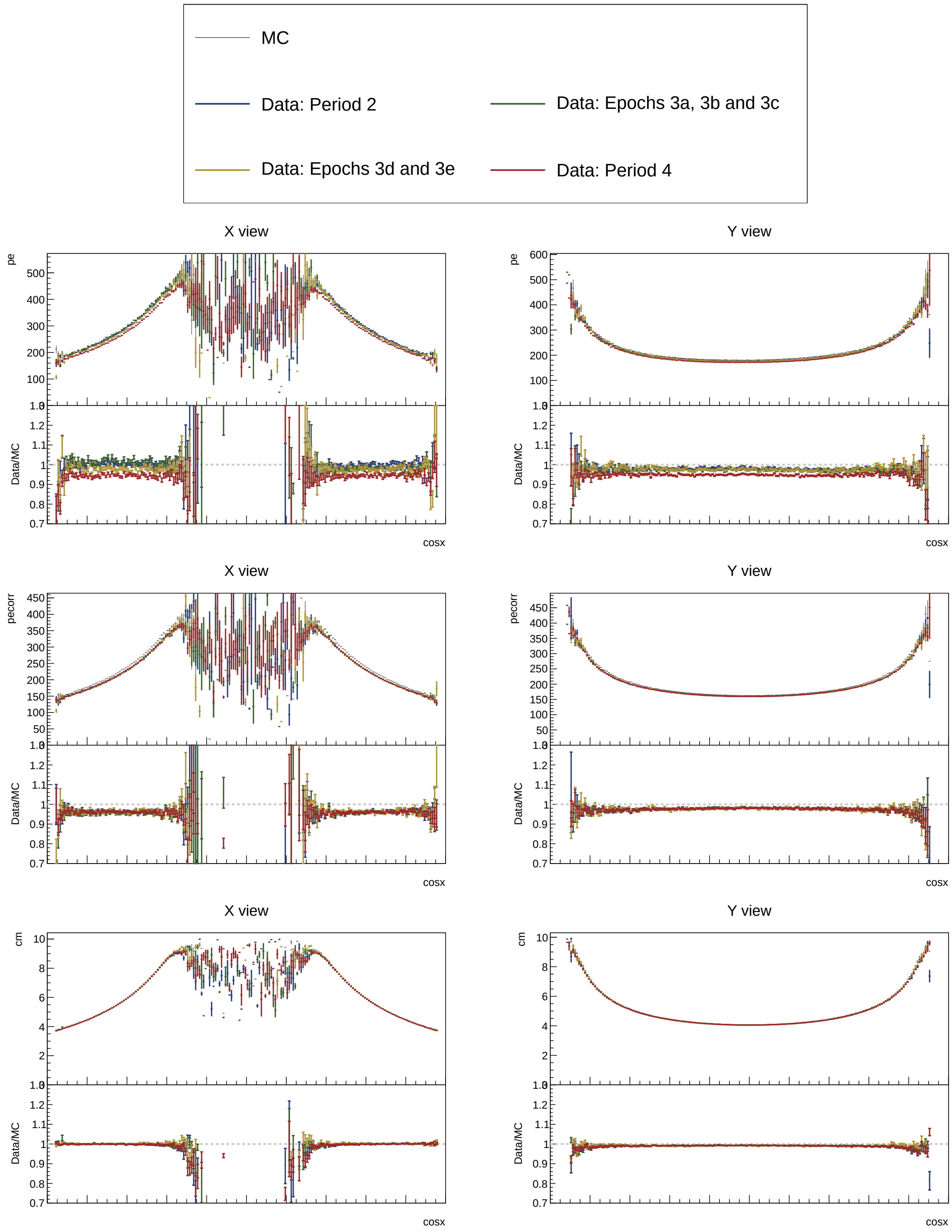

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X view
Y view
pe
pecorr
cm
Data/MC
cosx

Figure 32: ...

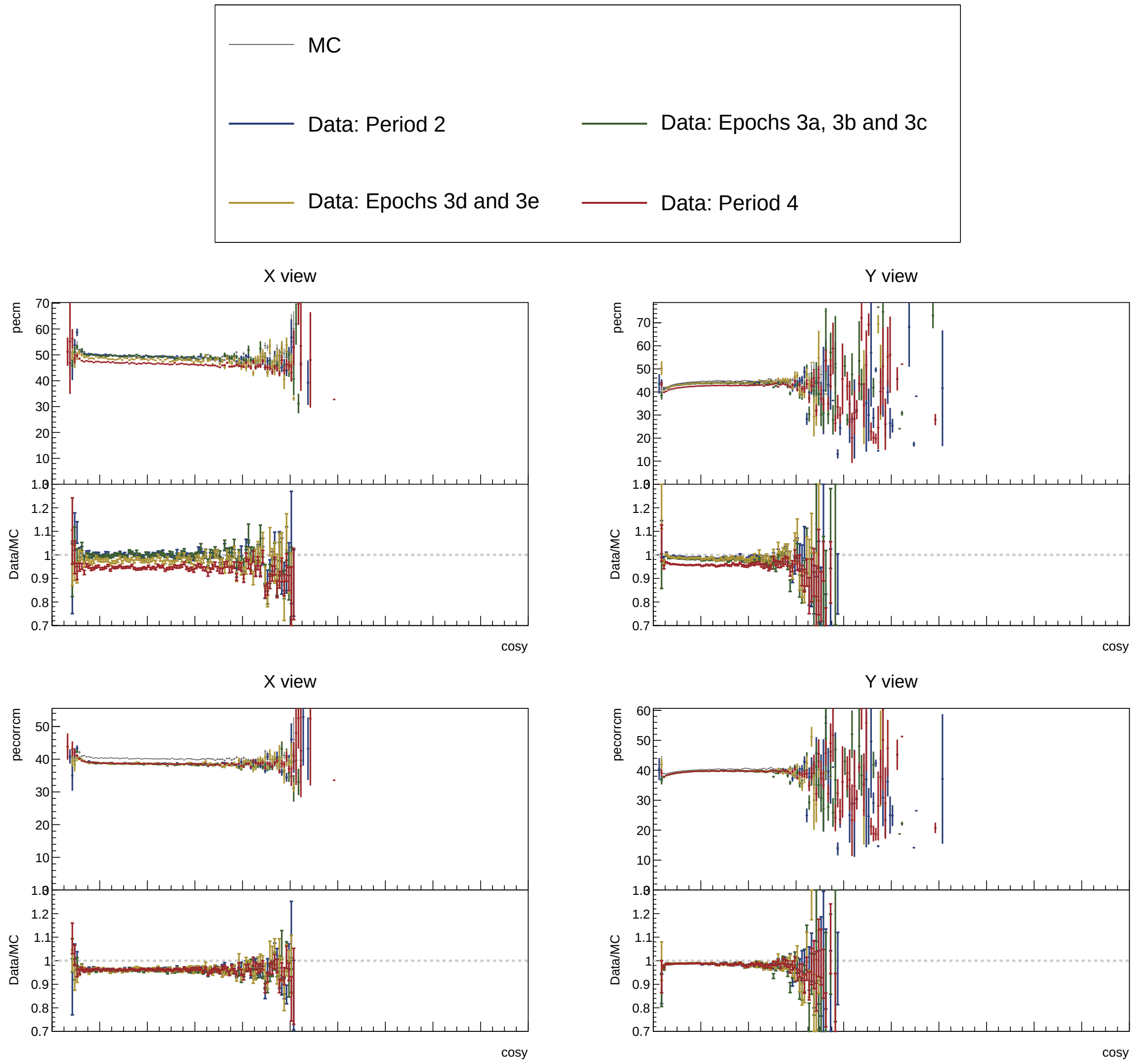

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X view
Y view
pecm
pecorrcm
Data/MC
cosy

Figure 33: ...

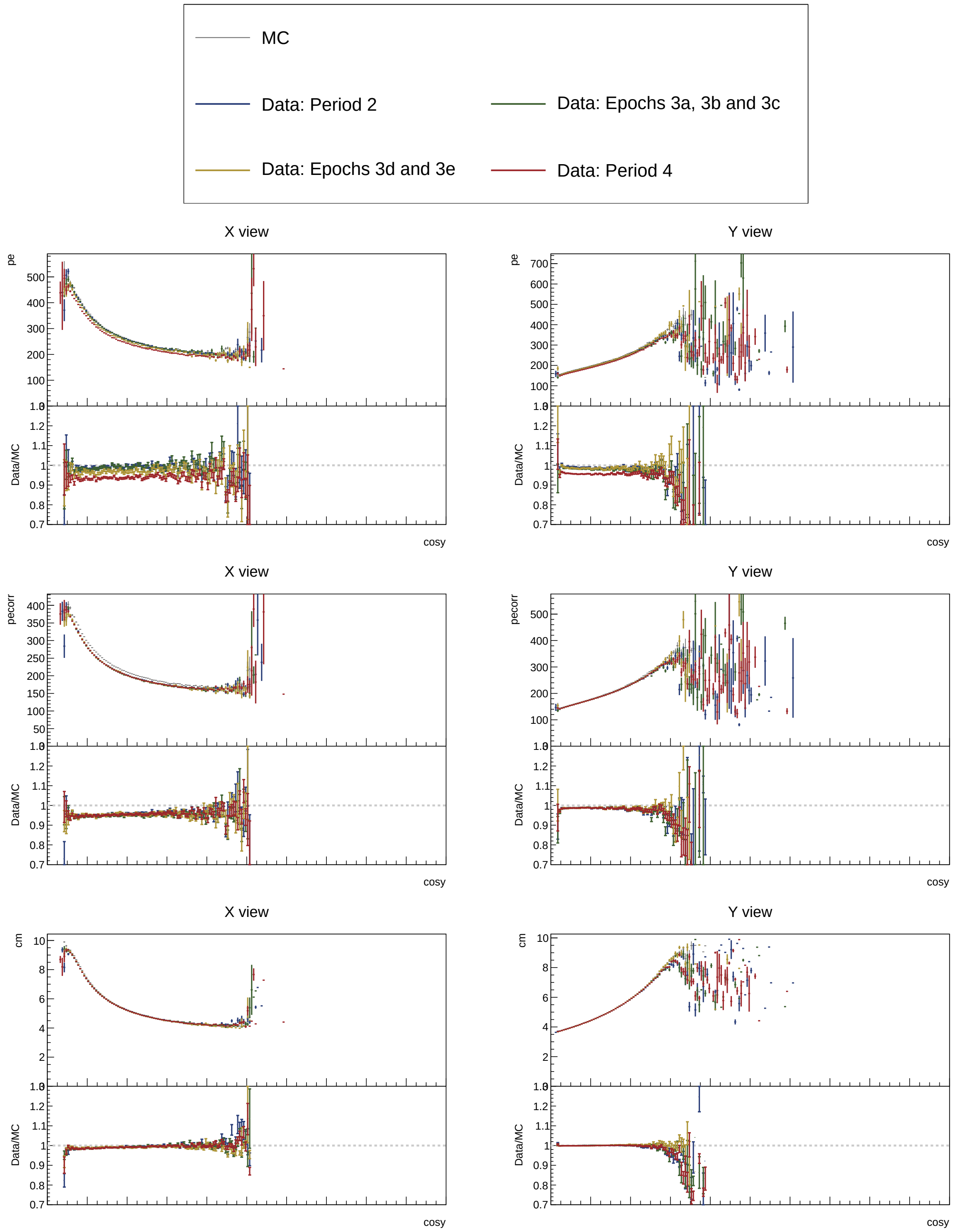

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X view
Y view
pe
pecorr
cm
Data/MC
cosy

Figure 34: ...

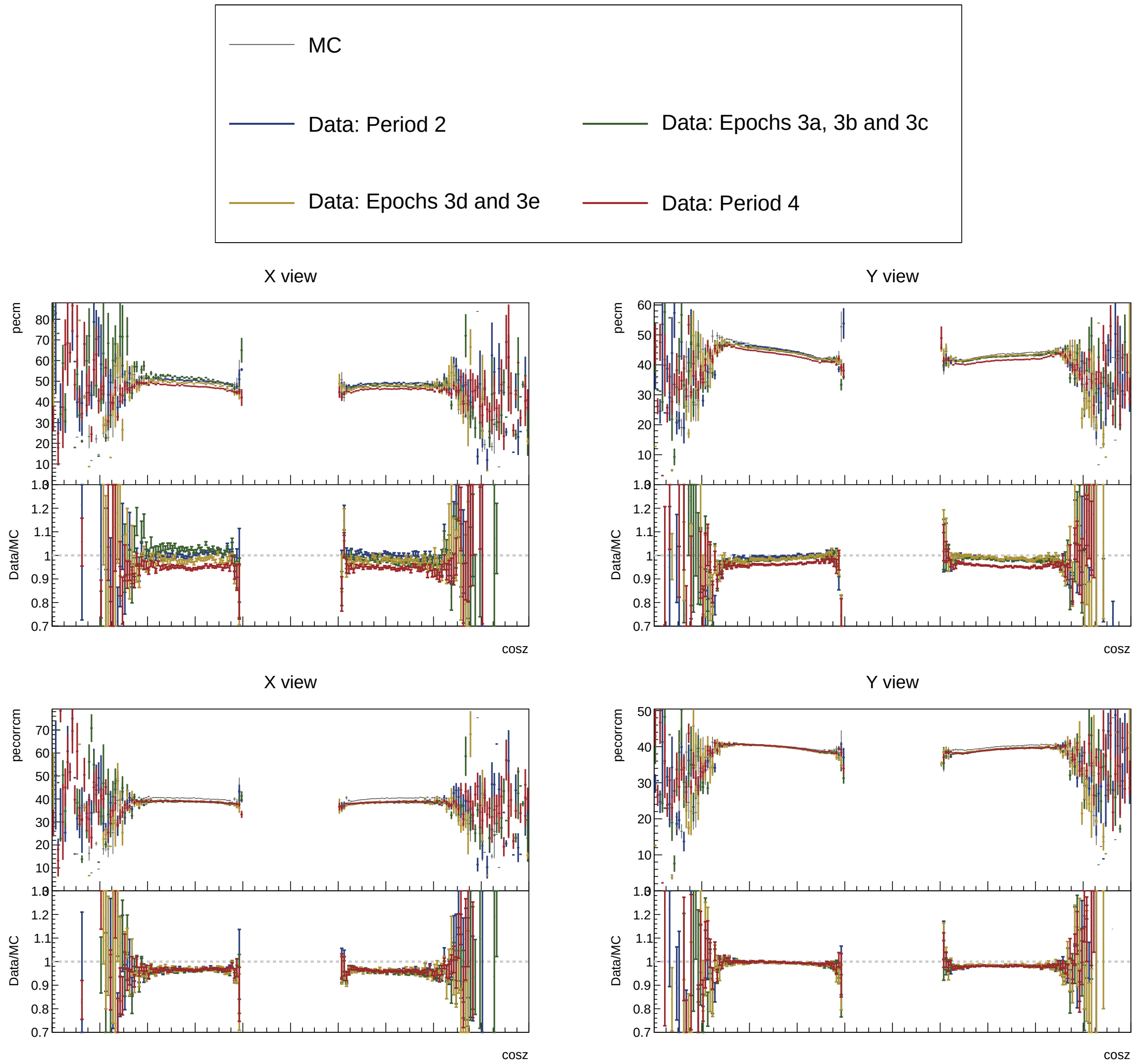

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X view
Y view
pecm
Data/MC
cosz
X view
Y view
pecorrcm
Data/MC
cosz

Figure 35: ...

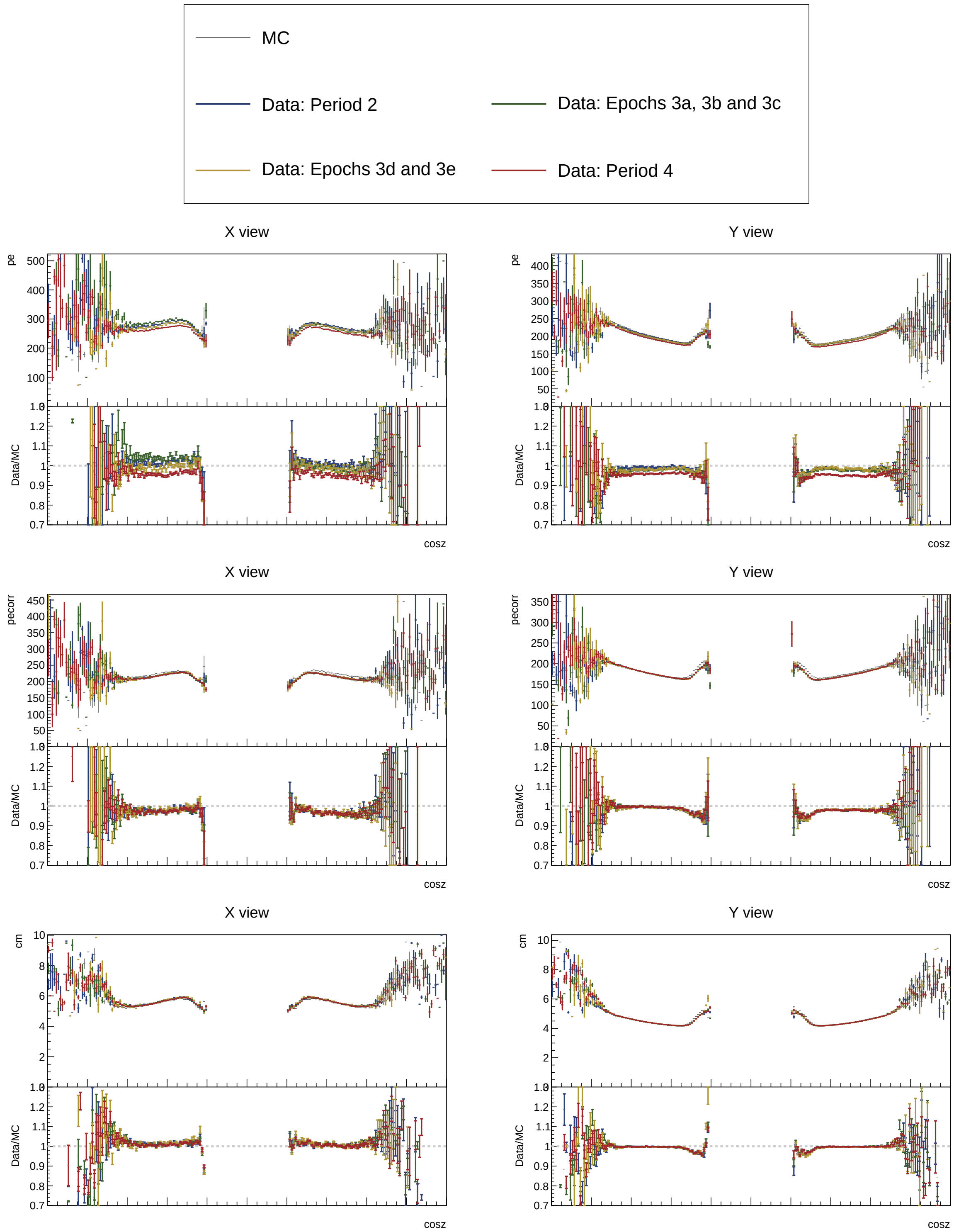

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X view
Y view
pe
pecorr
cm
Data/MC
cosz

Figure 36: ...

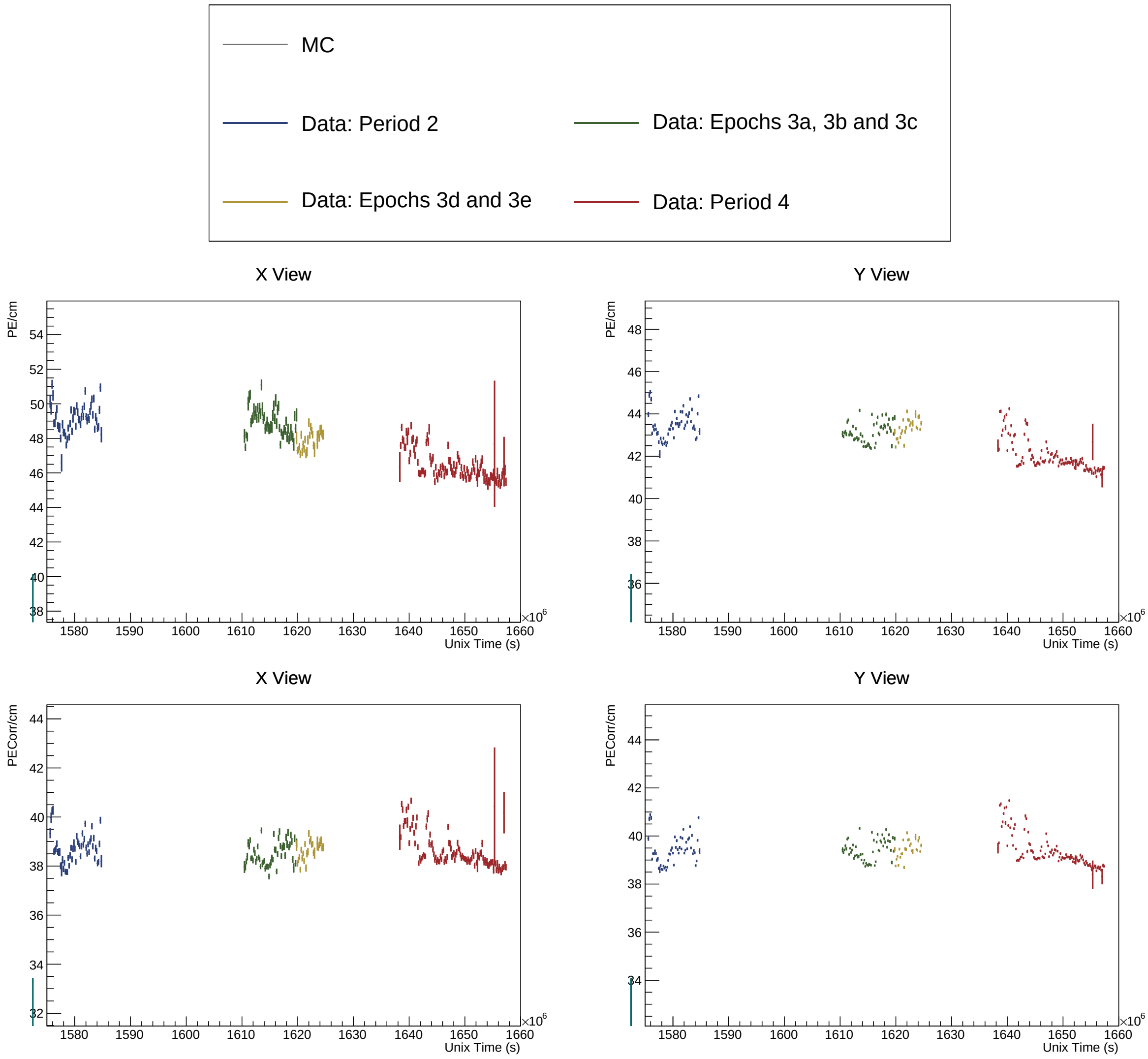

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X View
Y View
PE/cm
PECorr/cm
Unix Time (s)
×10⁶

Figure 37: ...

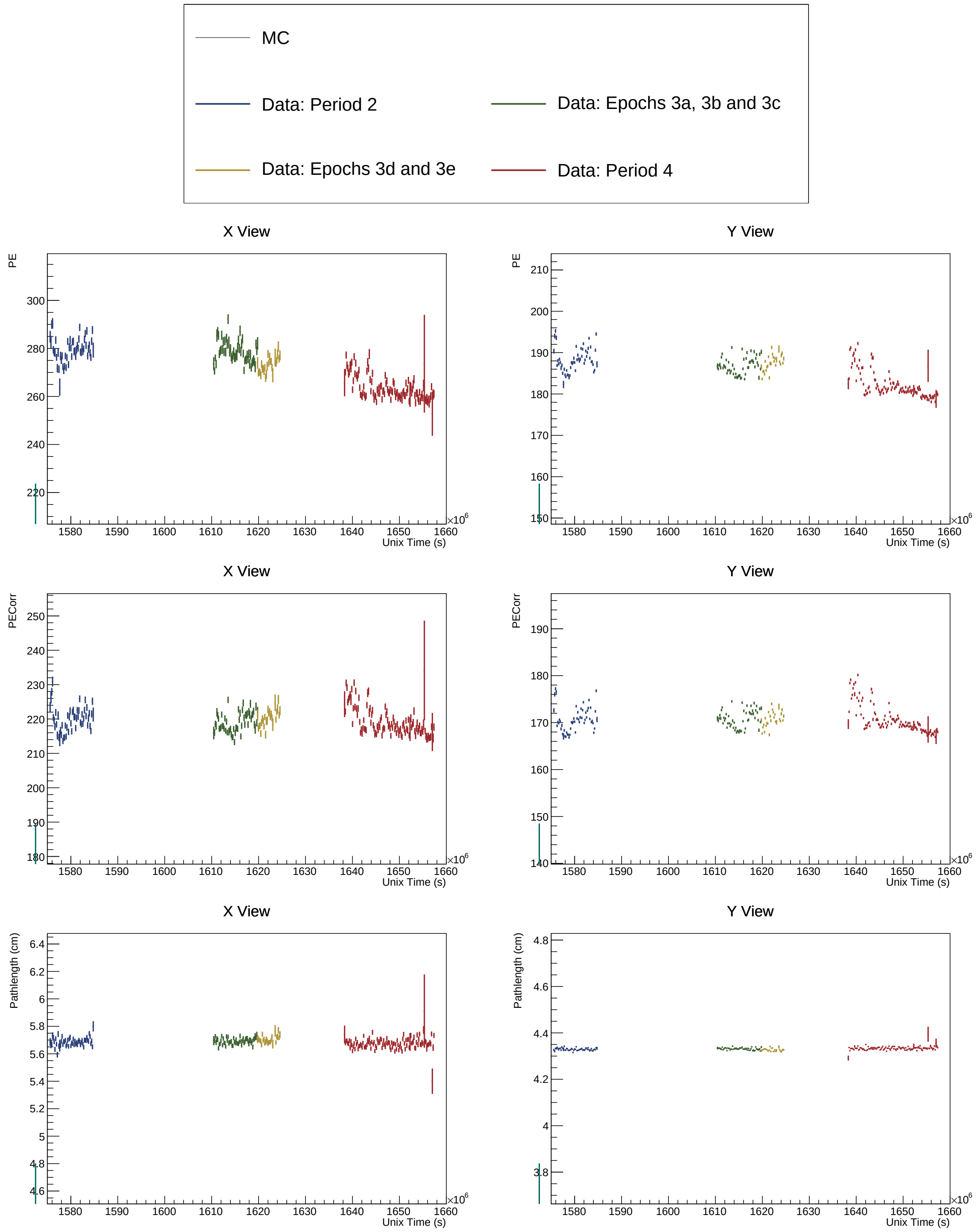

MC
Data: Period 2
Data: Epochs 3a, 3b and 3c
Data: Epochs 3d and 3e
Data: Period 4
X View
Y View
PE
PECorr
Pathlength (cm)
Unix Time (s)
×10^6

Figure 38: ...