2S Module Simulation and Alignment Stability Study

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2S Module Simulation

->There are differences between MC and data

-> The aim : To modify the geant4 simulation of 2S modules to improve the Data – MC comparison

The modifications:

->Implementation of delta rays

->Increasing the sampling throughout the silicon

->Changing the active thickness

->Adding timing effects

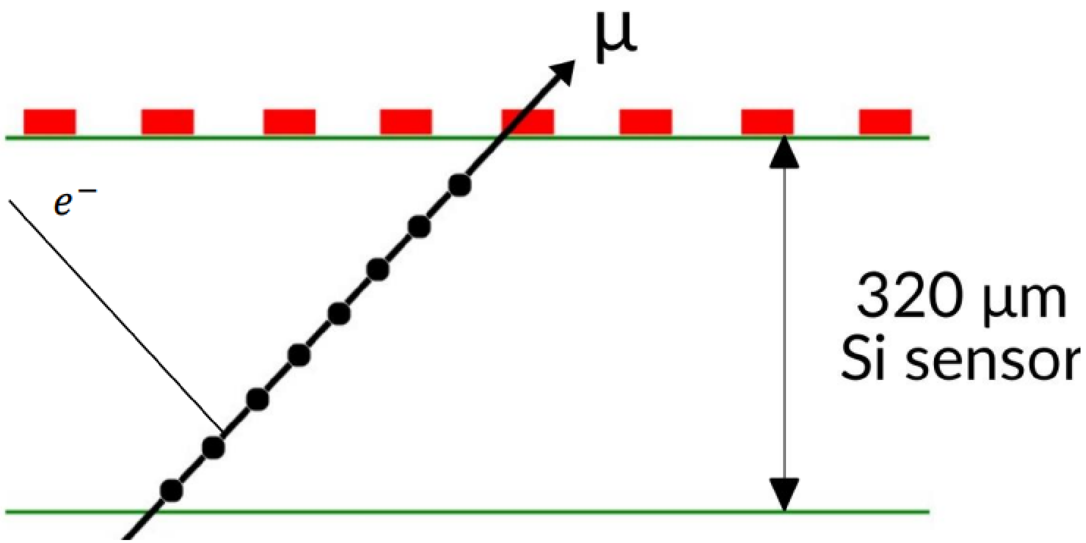
1. How the delta rays are simulated and how we can improve it :

by adding a production cut that allows more low energy secondary particles to be generated

Currently : the range cut in the silicon for electrons is 2.3cm & energy threshold : 9.7MeV

After : the range cut in the silicon for electrons was changed to -> 10 µm & energy threshold : 31.7 keV

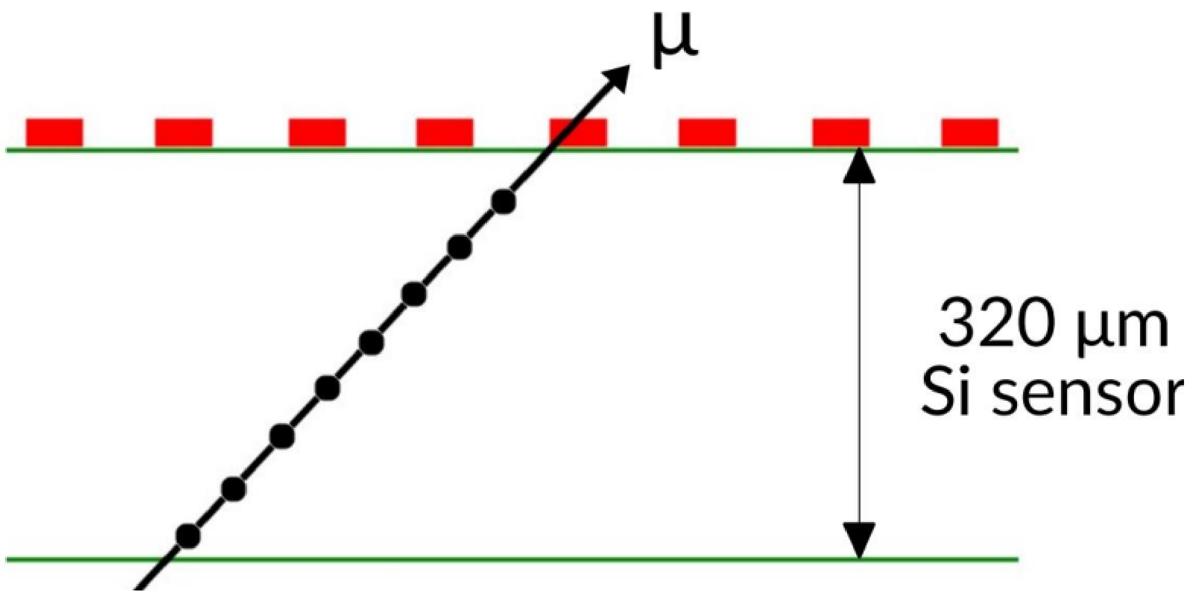
By changing the range cut to be 10 microns rather than 2.3 cm the particles that were not generated before due to having too low an energy are now present.



Increasing Sampling

- Currently FairMUonE saves only the entering position into the silicon sensor and the exiting position.
  If a particle made more than one step in the silicon, this was neglected and only the exiting position of the sensor is used.

- By adding more steps through the silicon in the simulation, this will increase the sampling and we will be more precise with having the landau fluctuations over smaller paths.



The step length can be set to any length but the step length that has been used for these studies is 10 microns.

Active Thickness of Sensor

- There was a study done by CMS where they evaluated what active thickness would be best for the phase 2 upgrade → they found the best option was 290um of active thickness and 30 um inactive.
- To implement this , the way the tracker points are saved was changed.

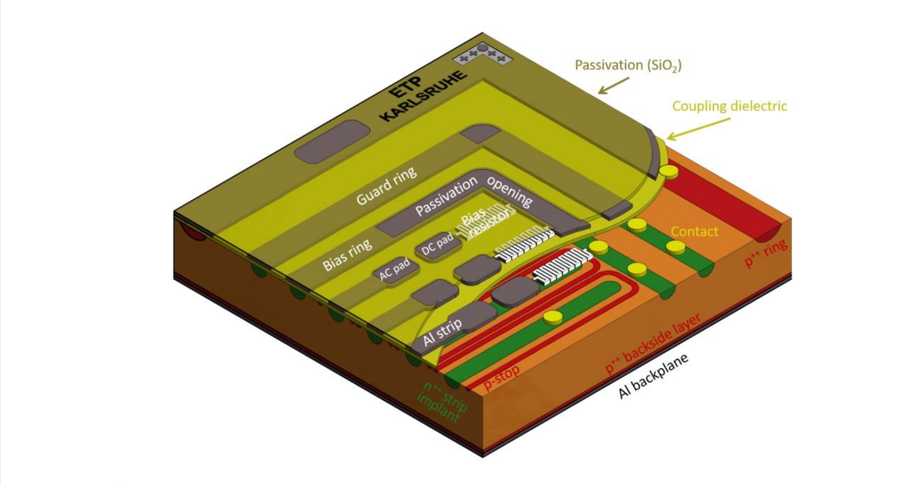
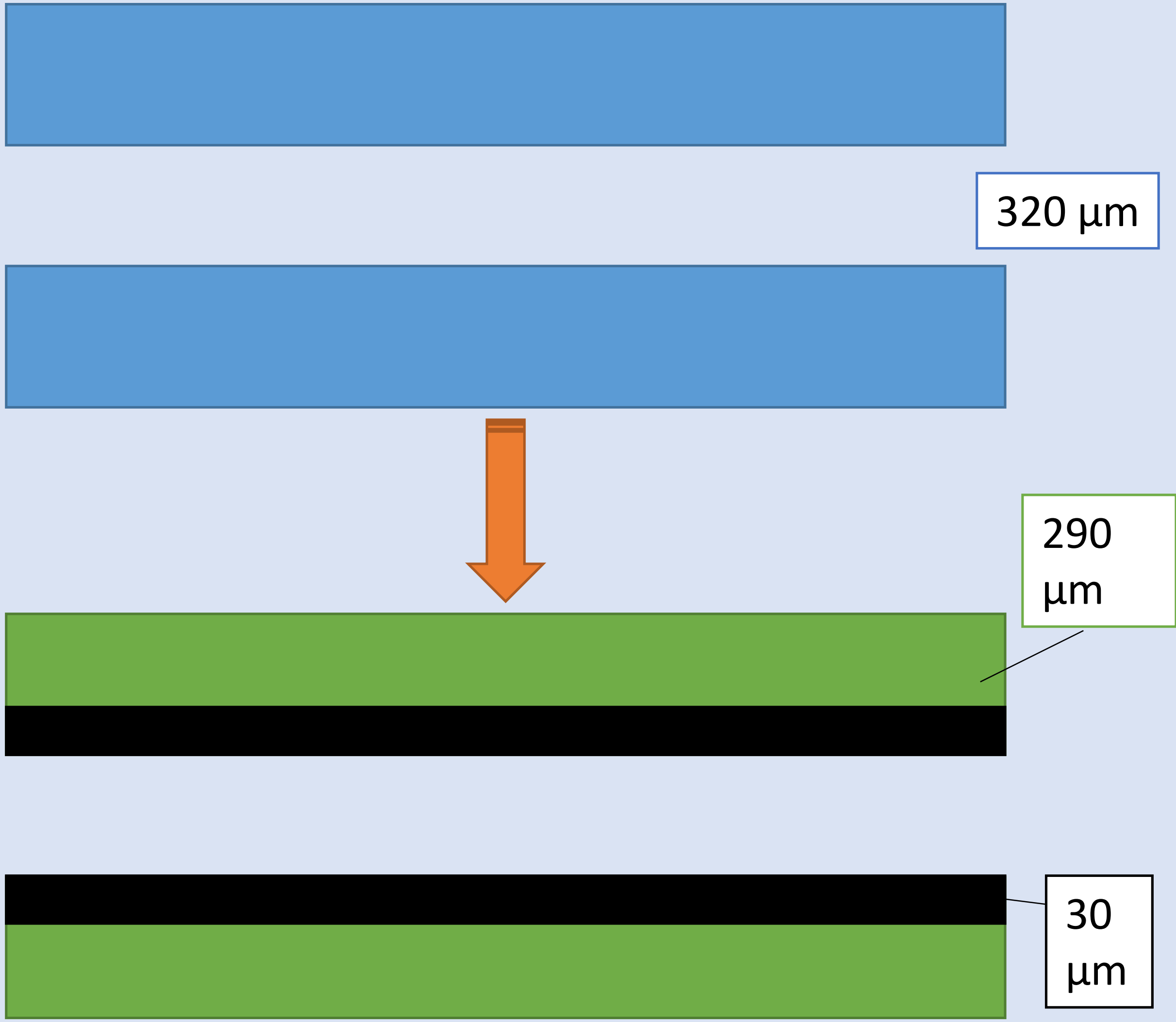


Figure 3. Schematic drawing of a portion of a p-type, AC coupled strip sensor similar to the ones used for the CMS Phase-2 Outer Tracker (after ref. [12]).



Implementation of timing effects

- Currently in FairMUonE the 2S modules are perfectly synchronised and particles are in time with the DAQ clock
- To change this two offsets were added

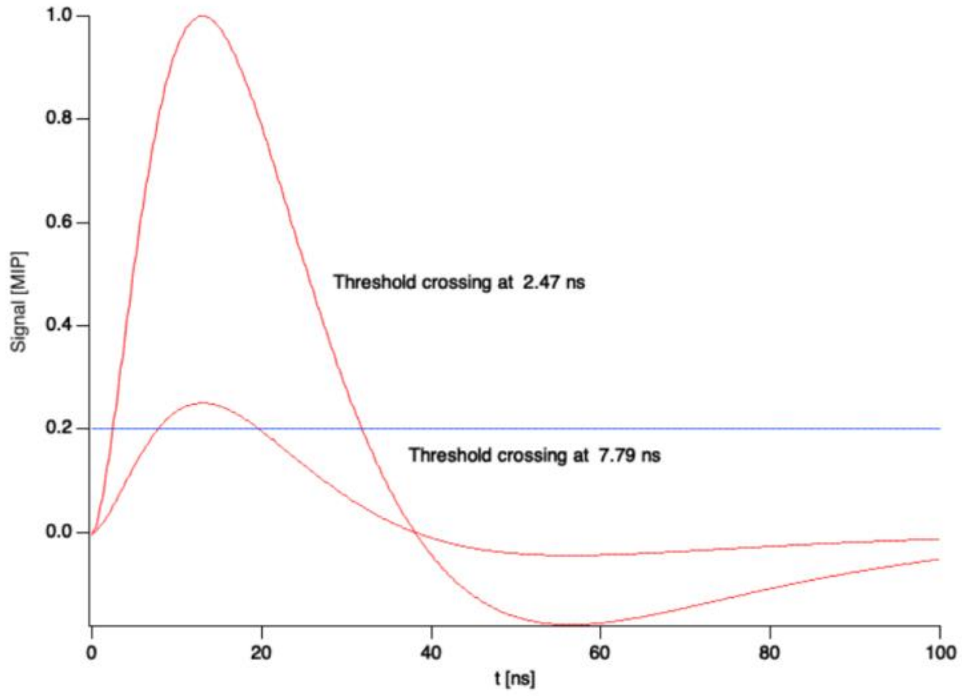
1. We expect muons to be uniformly distributed over a clock cycle, so an offset was added to every hit in an event so that a random time of arrival with respect to the DAQ clock is implemented.
2. The second offset was added to change the synchronisation of the 2S modules, the gaussian offset is applied to each module which is kept for the whole simulation.

CBC Pulse Shape

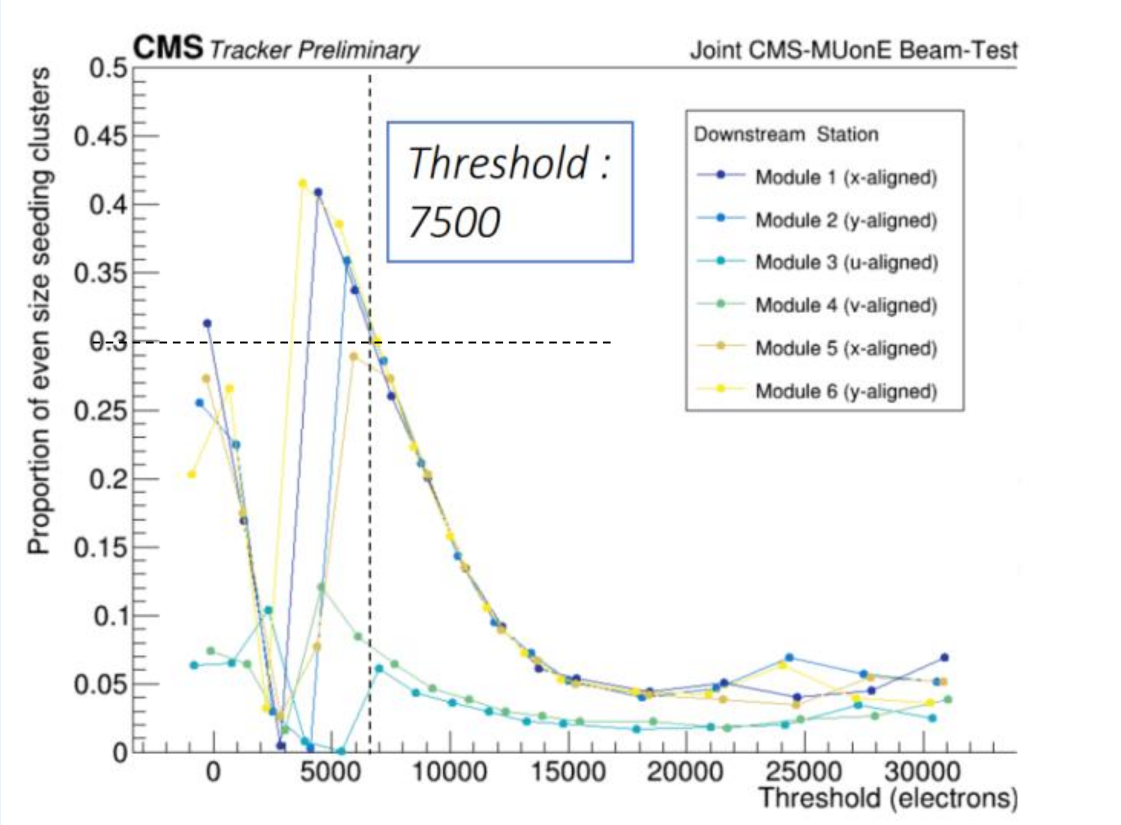
$$f(t) = Ae^{-at} + Be^{-bt} + Ce^{-ct} + De^{-dt}$$

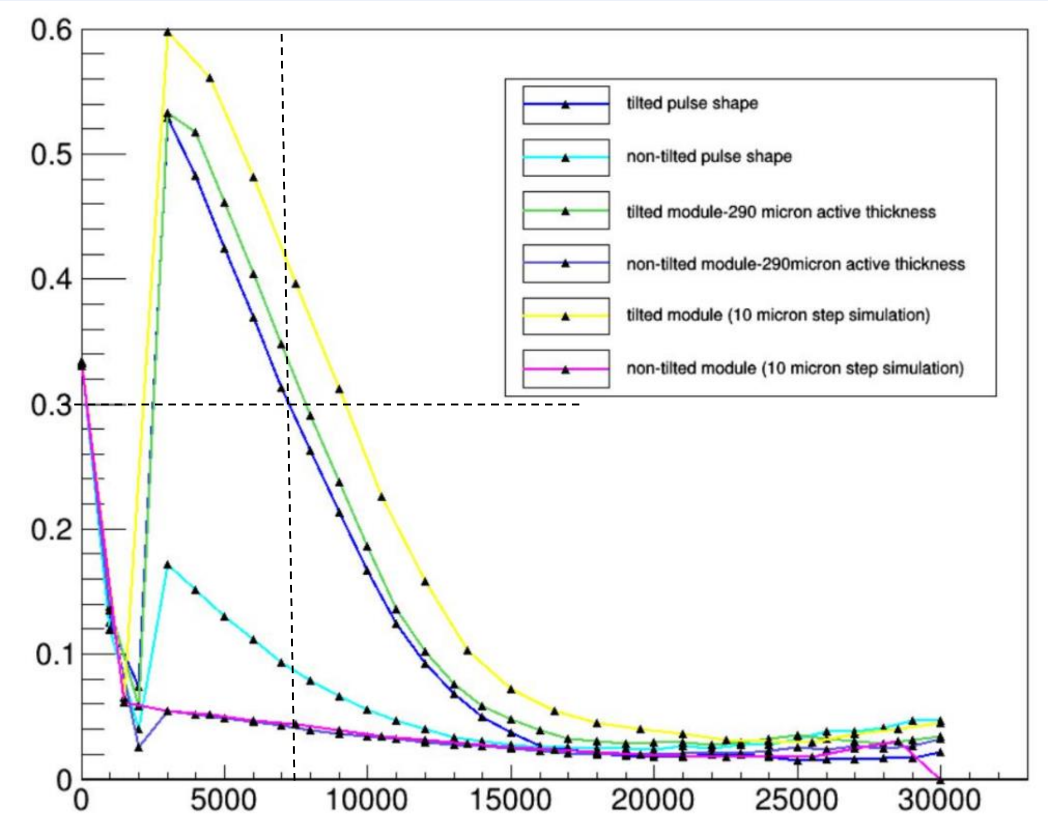
- In previous implementation we just look at if the signal is larger than the threshold
- The time when a signal is over the threshold depends on the charge of the signal

- By adding in the pulse shape function into the digitization we calculate the time it takes for a particle to surpass the stripThreshold



Results of this Study





-> The changes that were applied have made the simulation of the 2S modules closer to what happens in data!

Alignment Stability Study

->The alignment of the modules is important so that we can measure the angles of the particles to the precision that we require.

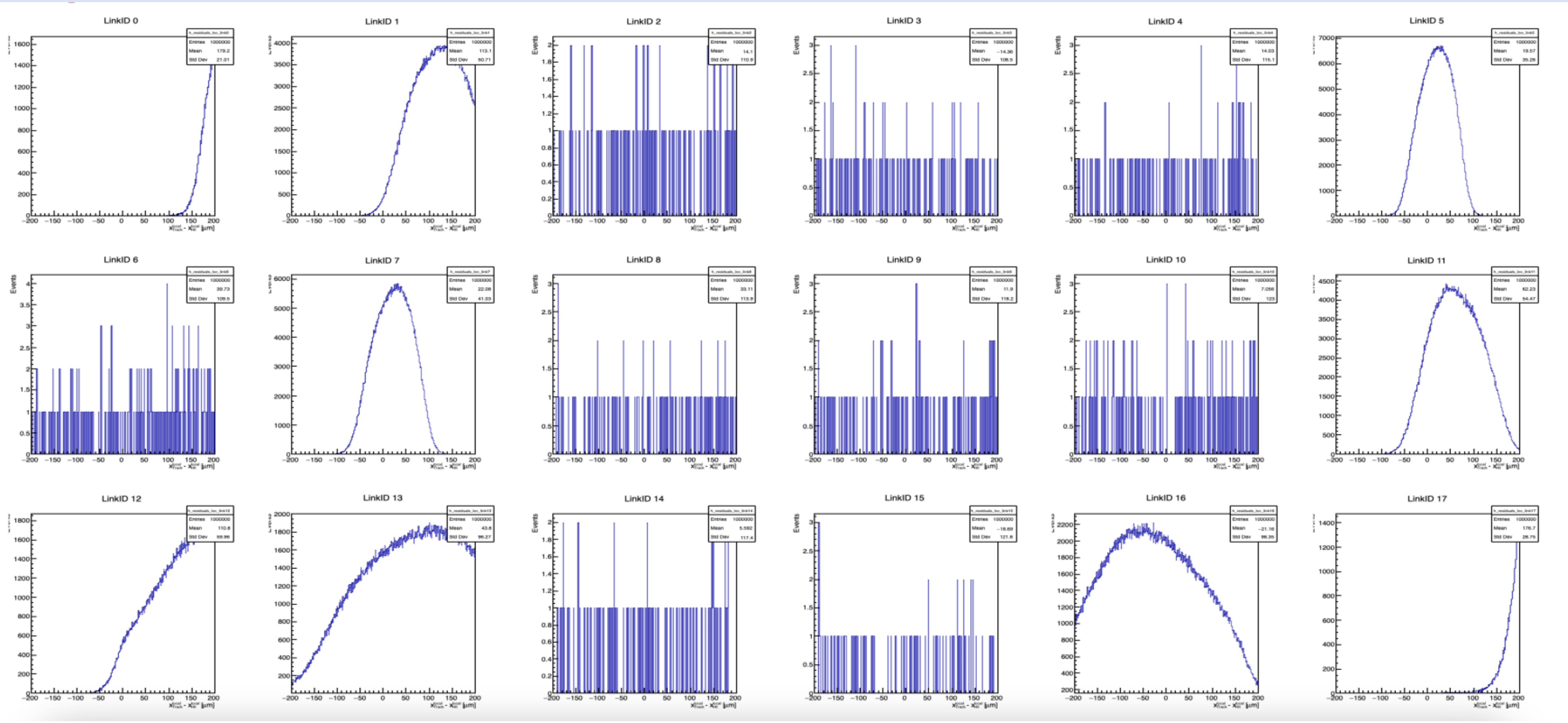
-> The alignment for MUonE takes the first 100 files of a run and runs the alignment on this portion until it has 1 million events to be able to run.

->For this study the alignment was run on different parts of the run:
The first 100 events, the second 100 events,the middle 100 events and then the last 100 events

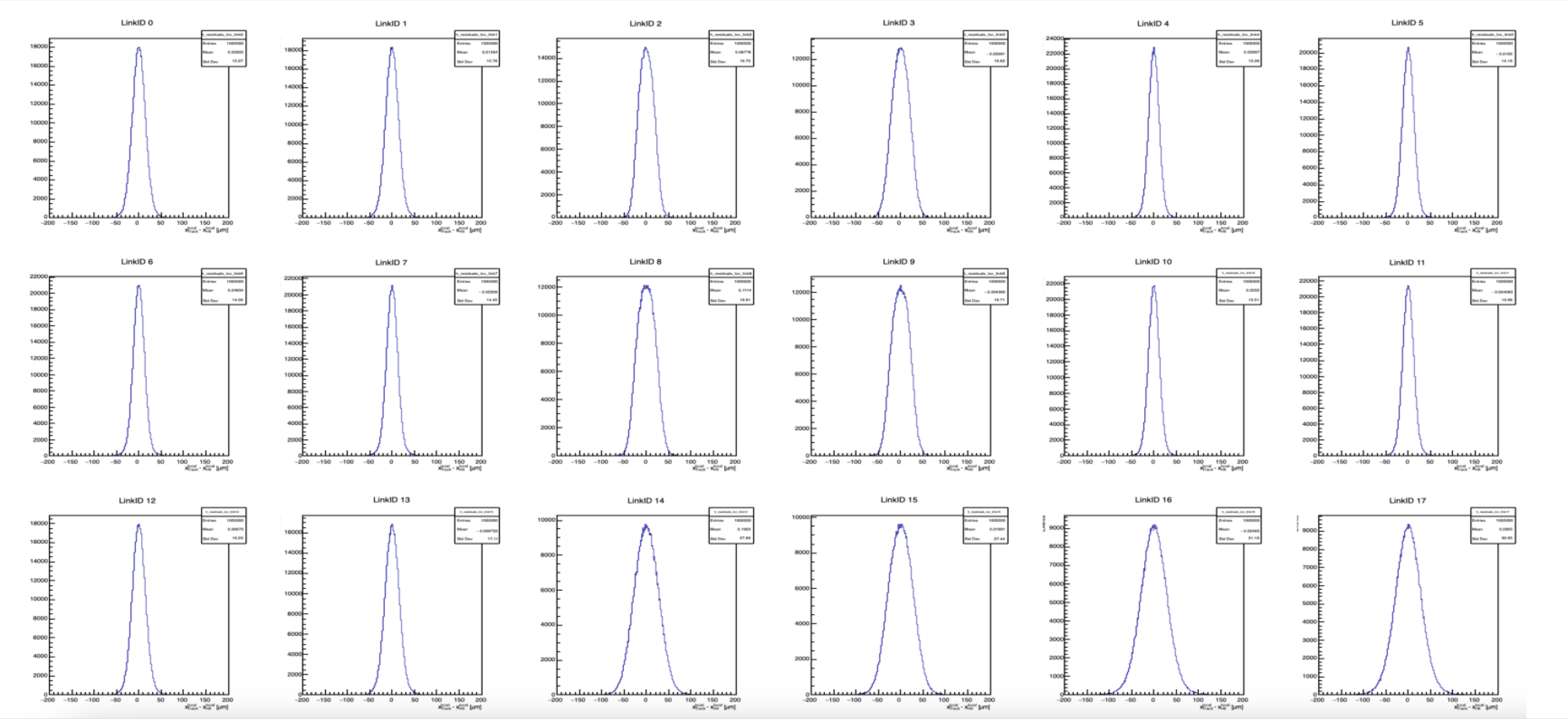
-> This is so that we can look at the final alignment parameters at each point and see if and by how much they have varied.

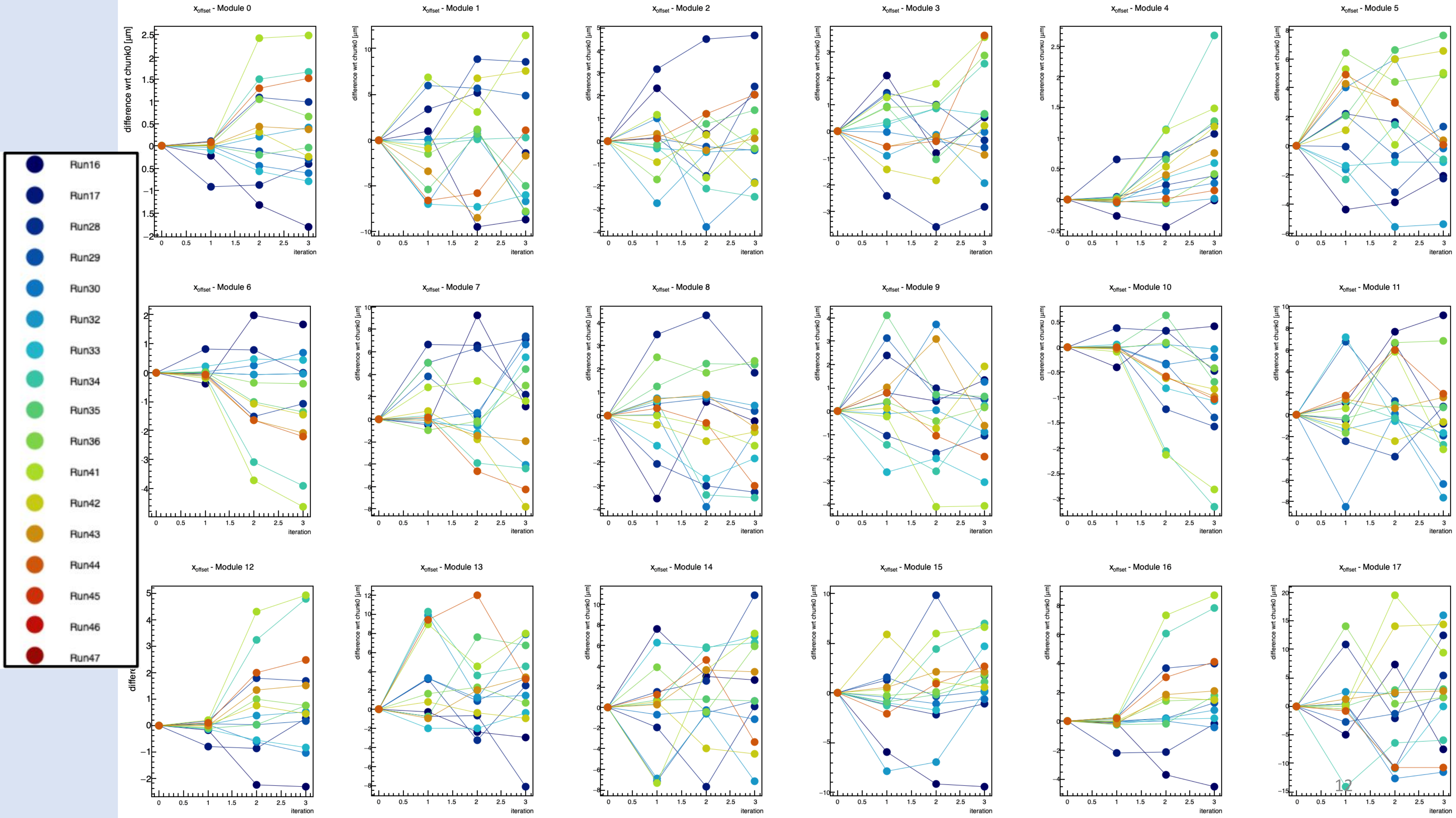
-> This was done on a selection of 16 different runs from the 2025 test run

Before Alignment

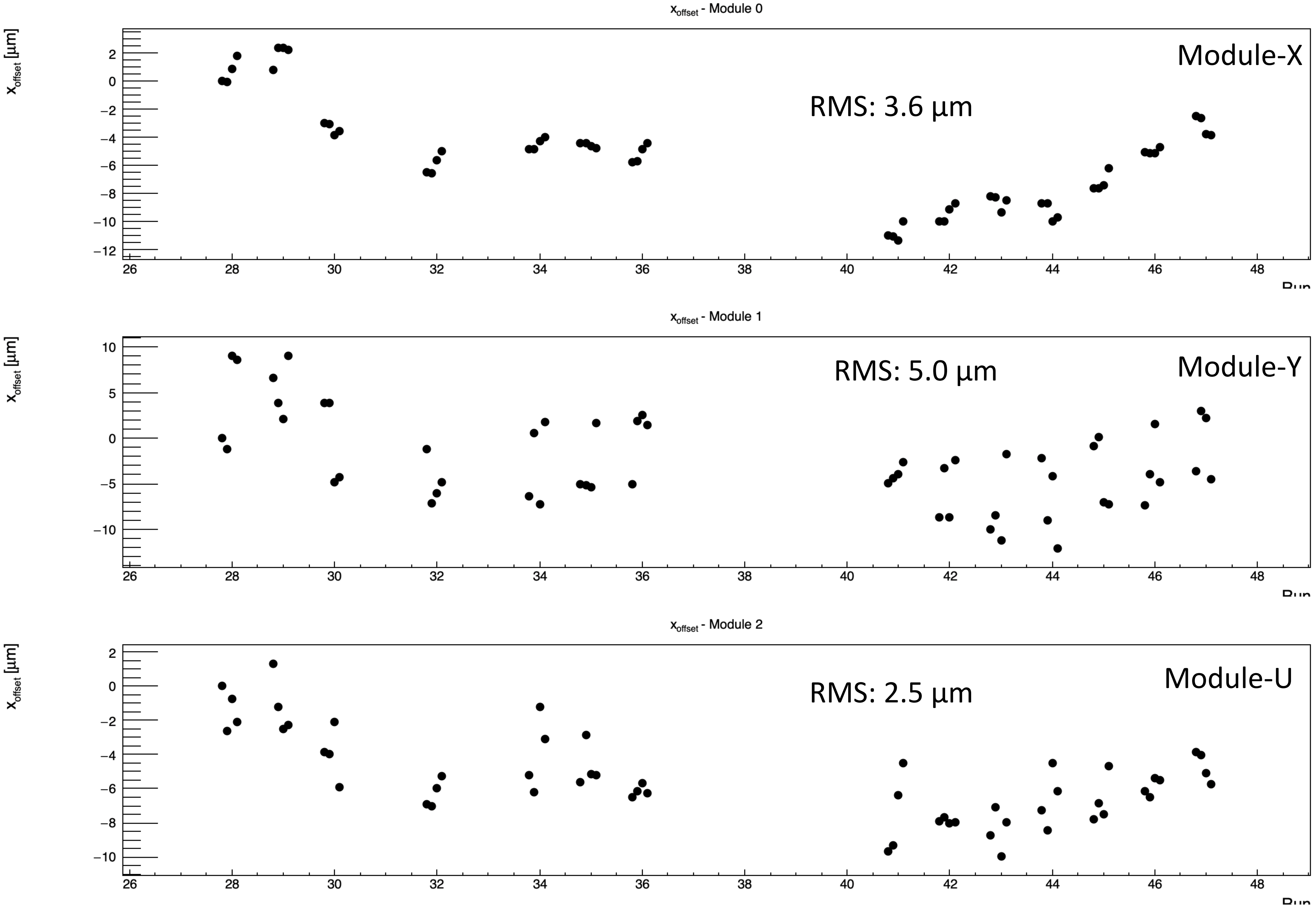


After Alignment




x_offset - Module 0
x_offset - Module 1
x_offset - Module 2
x_offset - Module 3
x_offset - Module 4
x_offset - Module 5
x_offset - Module 6
x_offset - Module 7
x_offset - Module 8
x_offset - Module 9
x_offset - Module 10
x_offset - Module 11
x_offset - Module 12
x_offset - Module 13
x_offset - Module 14
x_offset - Module 15
x_offset - Module 16
x_offset - Module 17
difference wrt chunk0 [µm]
iteration
Run16
Run17
Run28
Run29
Run30
Run32
Run33
Run34
Run35
Run36
Run41
Run42
Run43
Run44
Run45
Run46
Run47

-> To look at things more closely (and clearly) the next plots show the difference between the alignments wrt the first 100 file alignment of run28 as a function of the run.



x_{offset} - Module 0
Module-X
RMS: 3.6 µm
x_{offset} - Module 1
RMS: 5.0 µm
Module-Y
x_{offset} - Module 2
Module-U
RMS: 2.5 µm
x_{offset} [µm]

Conclusions

-> We improved the 2S module simulation including the timing effects.
   Which will improve the Data MC comparison.

-> The larger differences we see in the initial plot of over 10 microns in the y modules probably due to the CIC alignment which is known to be about 10 microns

-> Seems that behaviour is separated between the two halves of runs used
This is to be investigated

Thank you for Listening !