

Detector Simulations & Analysis *from the 2025 test run*

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HEP Annual Meeting

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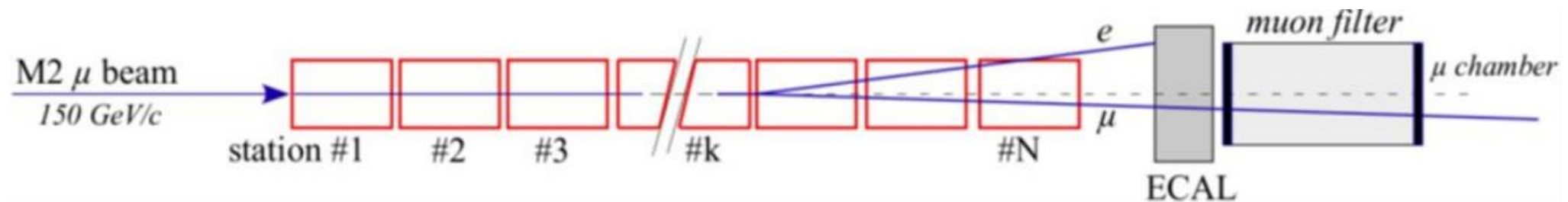
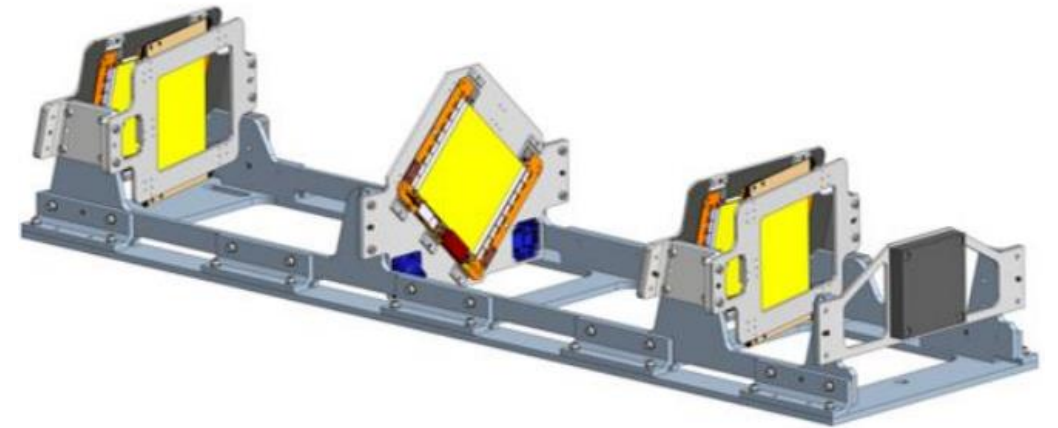
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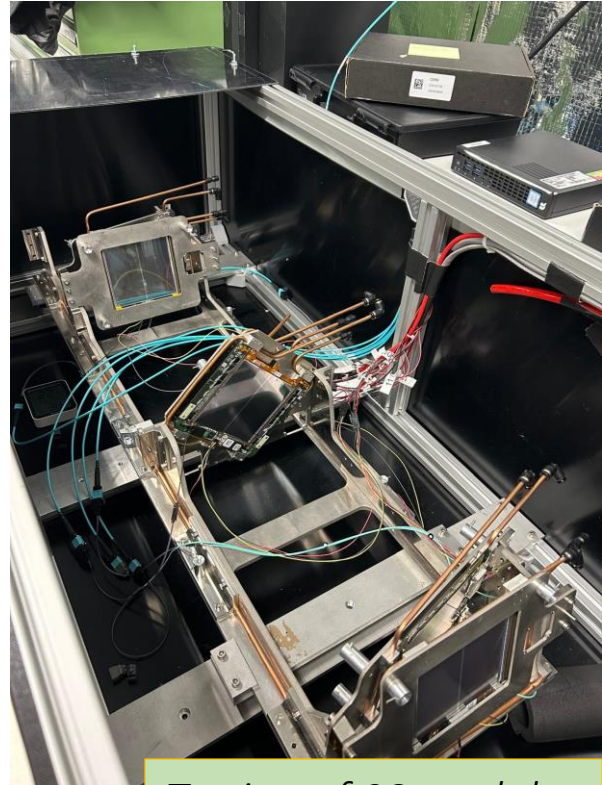
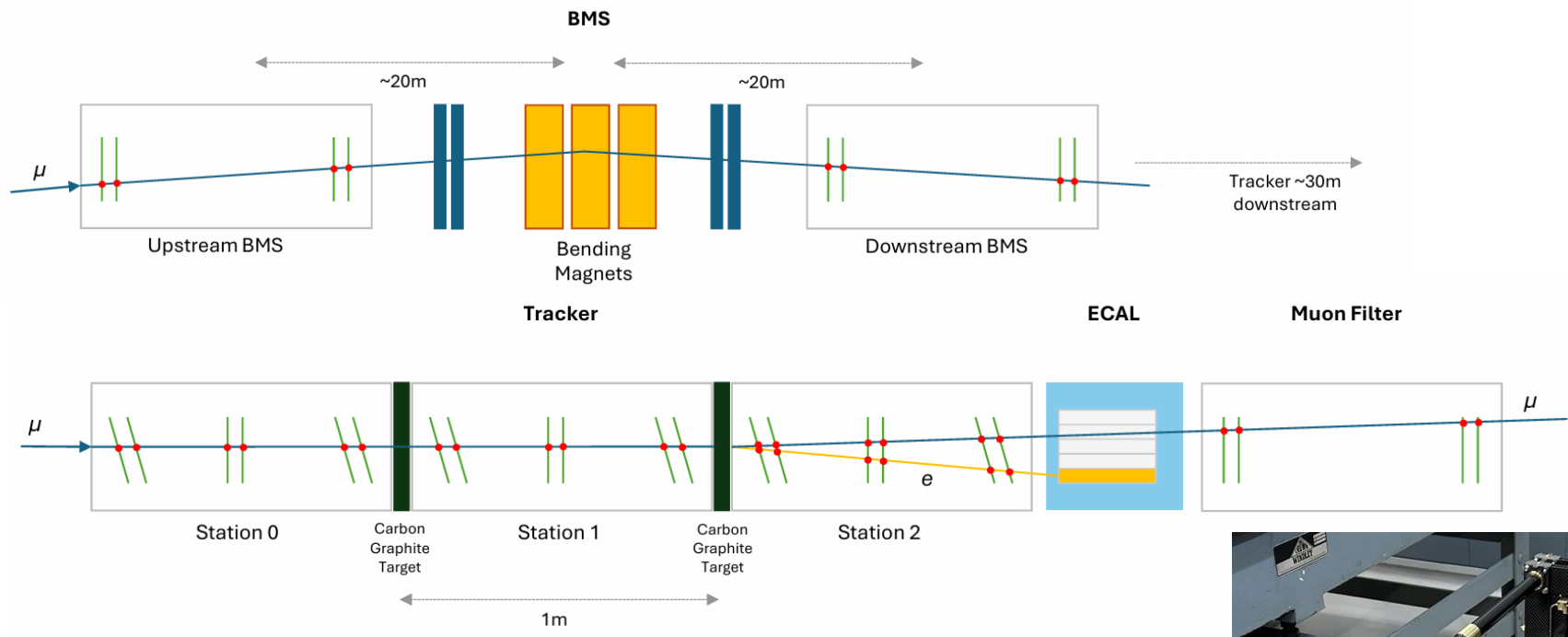
The MUonE Experiment

- MUonE is a μ -e scattering experiment
- Providing an independent method of calculating a_{μ}^{HLO}
- Taking place at the M2 beamline at CERN
- It is a modular experiment made up of repeating 1m long station . Each with its own target and tracking system.
- One station is made up of 6 2S modules, developed for the CMS phase 2 upgrade
- Before the stations there will be a beam momentum spectrometer (BMS) and a muon filter and calorimeter for PID

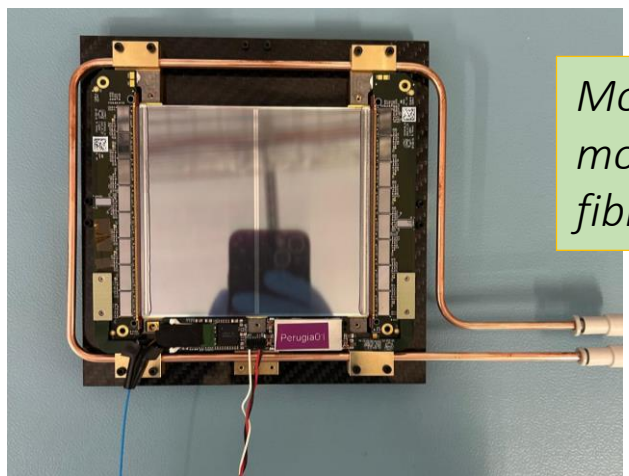


2025 Test Run

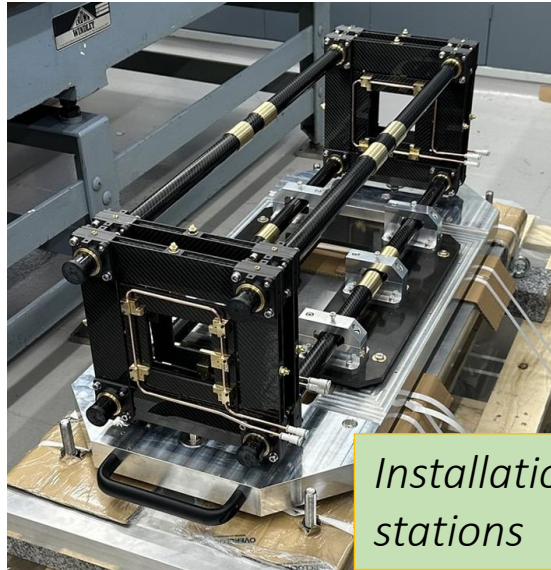
Setup of the test run



Testing of 2S modules



Mounting of 2S module on carbon fibre frame



Installation of BMS stations

Motivations

Detector Simulations

The intrinsic resolution is one of the main systematic effects for our measurement.

There is ~30% difference in the hit resolution of 160 GeV μ between data and MC.

Alignment Stability Study

MUonE uses an iterative alignment procedure, the alignment parameters were studied.

They need to be consistent to keep the measurement of the angles at the required precision.

BMS analysis

The BMS allows us to measure the energy of individual incoming muons before they reach the tracker.

This information can be used to determine very precisely the variations of the beam energy during the data taking.

Detector Simulations



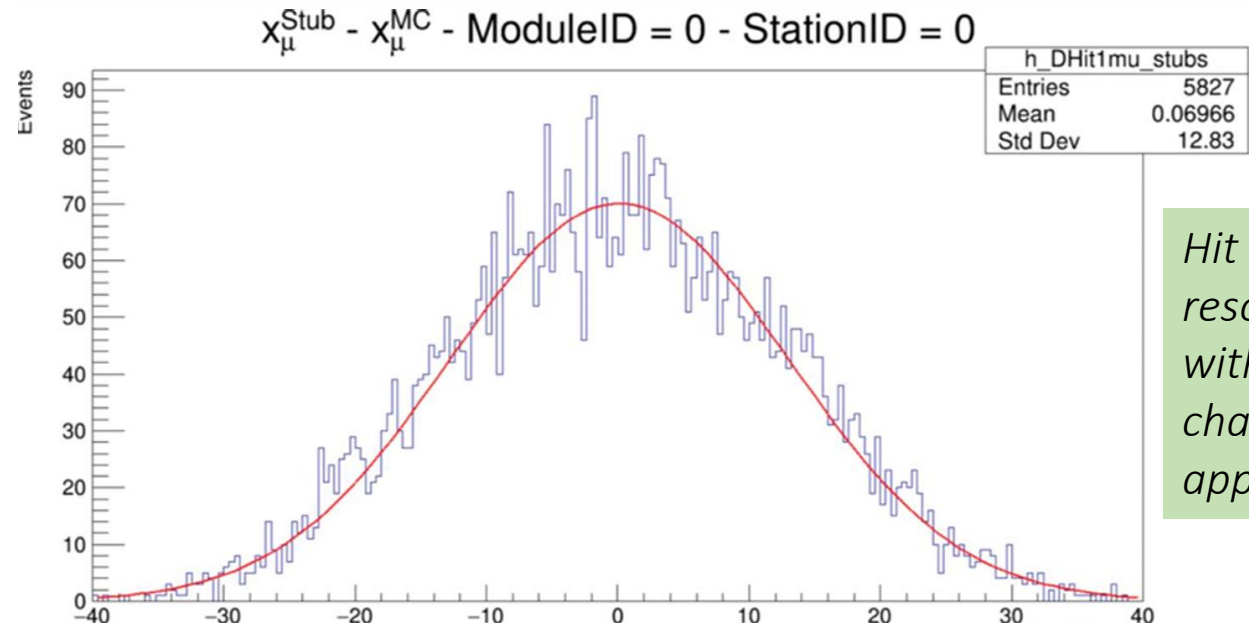
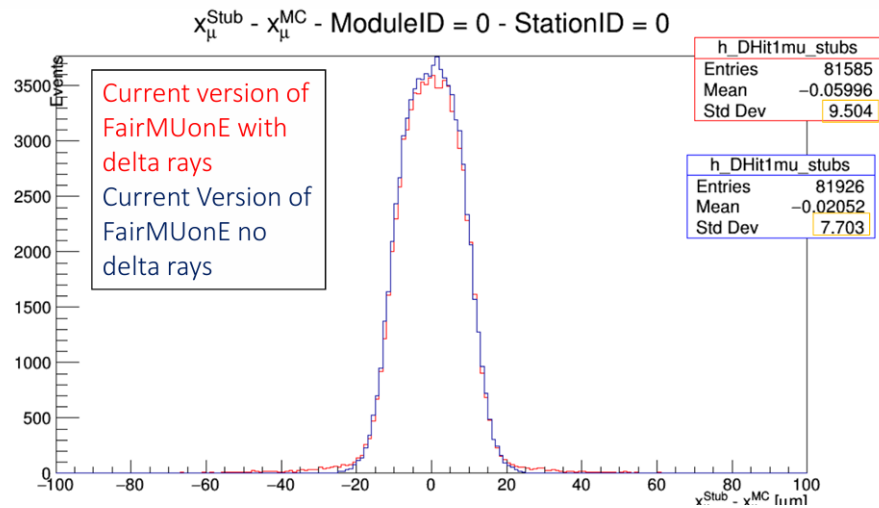
Changed a range cut in order to generate lower energy particles.

- Std dev of hit resolution increased by 2 μm

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

- increase in the standard deviation of 1 μm

Hit resolution in data : 11.59 μm

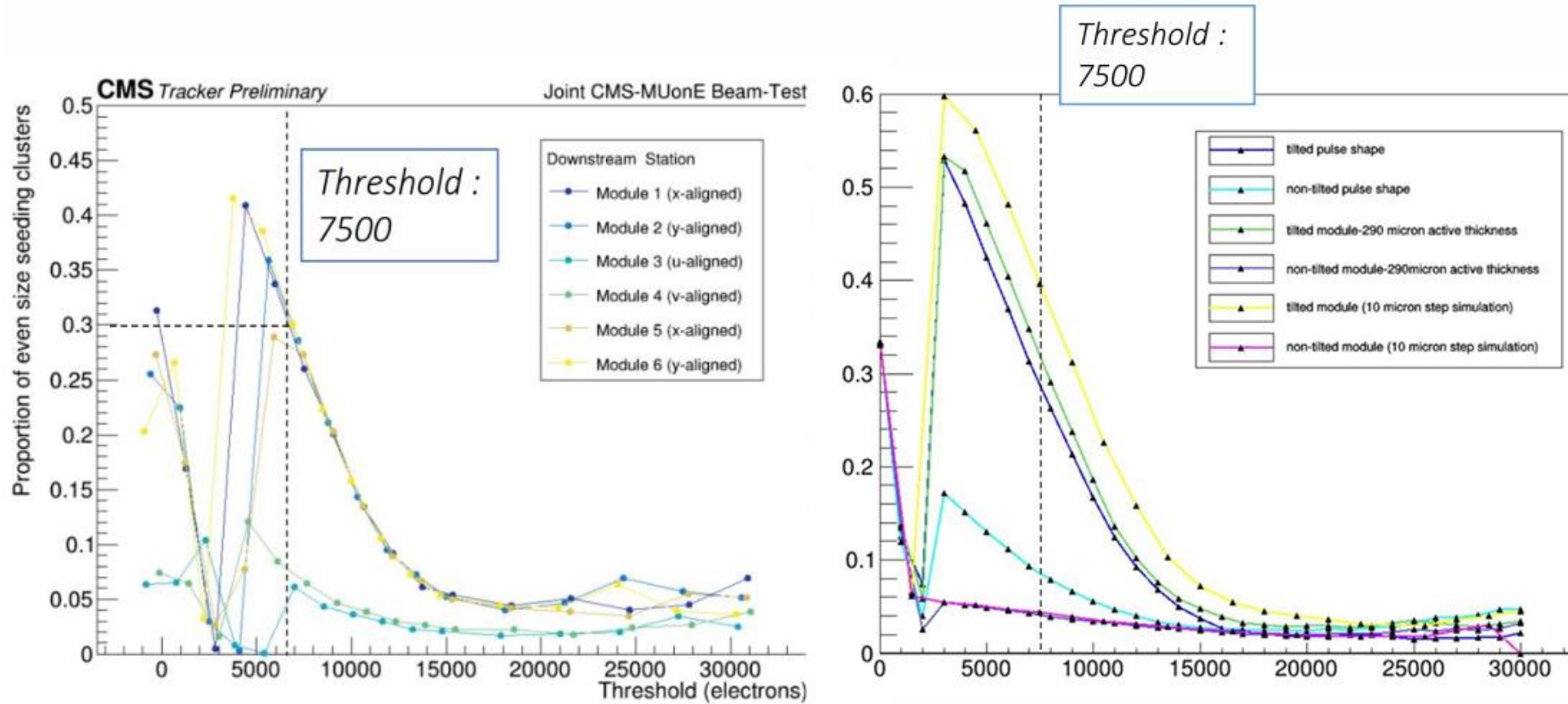


Hit resolution with all changes applied !

The sensors active thickness in the simulation was changed to represent the sensors better

The muon beam is asynchronous with the DAQ clock : timing offsets were added to represent this
The time when a signal is over the threshold depends on the charge of the signal
By adding in the CBC pulse shape function into the digitization we calculate the time it takes for a particle to surpass the Strip Threshold

Detector Simulations



Largest change in peak came after changing the active thickness

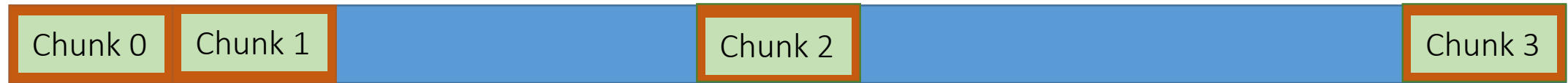
Adding in the timing effects and the CBC pulse shape enabled us to be sensitive to the peak at around 3000 e- in non tilted modules

Through the various changes that had been made changes were also seen in threshold scans that were made at each point.

While we are not achieving the same results we can definitely say that the results are closer

Alignment Study

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



This was carried out on a selection of 16 runs.

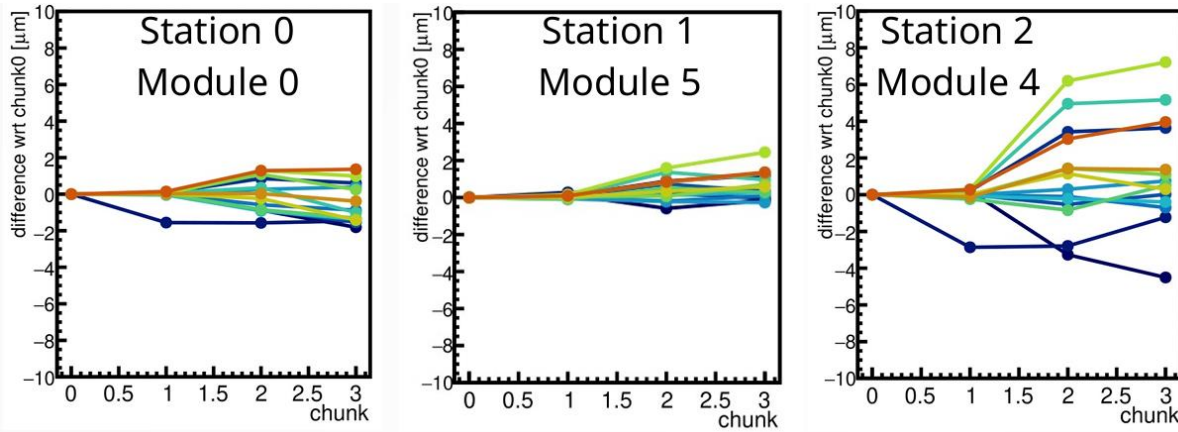
difference between a given alignment parameter A in a given chunk relative to chunk 0

$$\Delta A_i = A_{\text{chunk}-i} - A_{\text{chunk}-0}$$

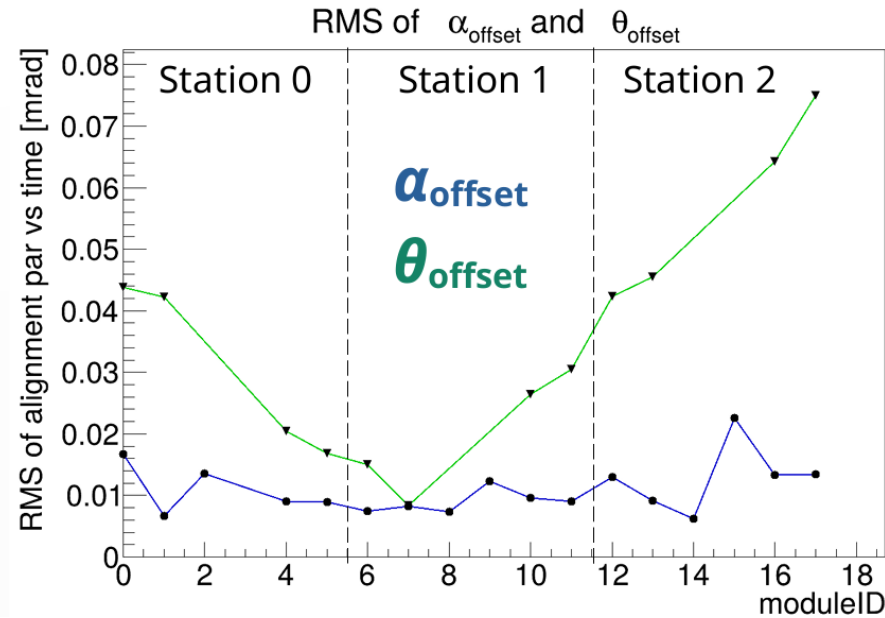
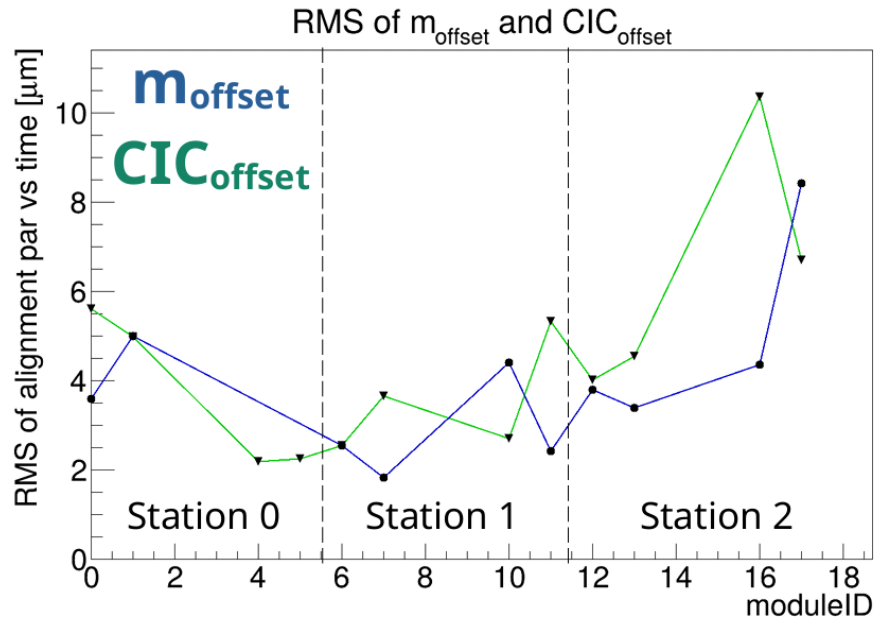
Alignment Study



moffset = alignment parameter along the direction measured by a 2S module

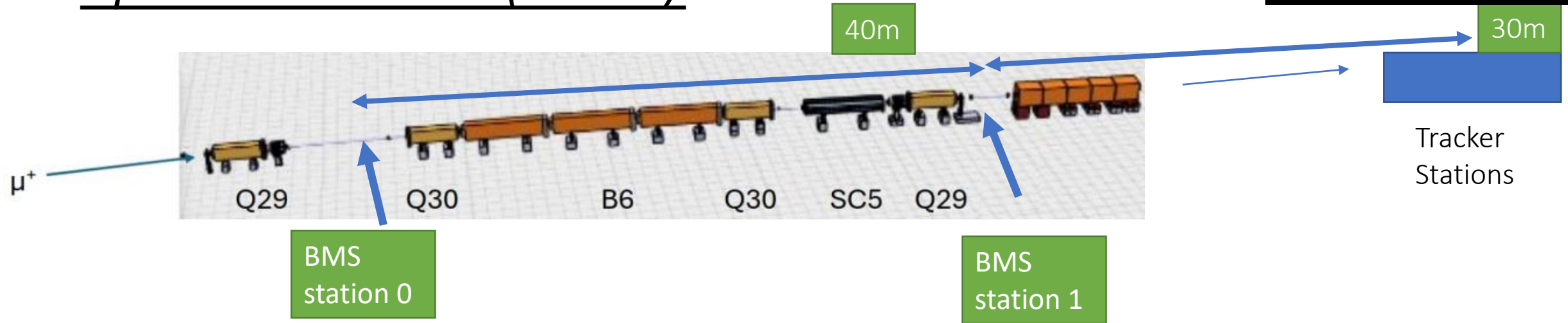


Agreement < 5 μm for all the modules (Station 2 Module 4: < 10 μm)



CICoffset = alignment parameter along the direction orthogonal to measured one
alphaoffset = correction on the rotation angle around the beam axis
thetaoffset = correction on the tilt angle

The Beam Momentum Spectrometer (BMS)



- B6 : bending magnet made up of 3 magnets that are each 5m
~30mrad vertical deflection of the beam
Power = 16 T.m
- Q29-30 : quadrupoles each one is 3m
field mapping of the quadrupoles is required for final precision

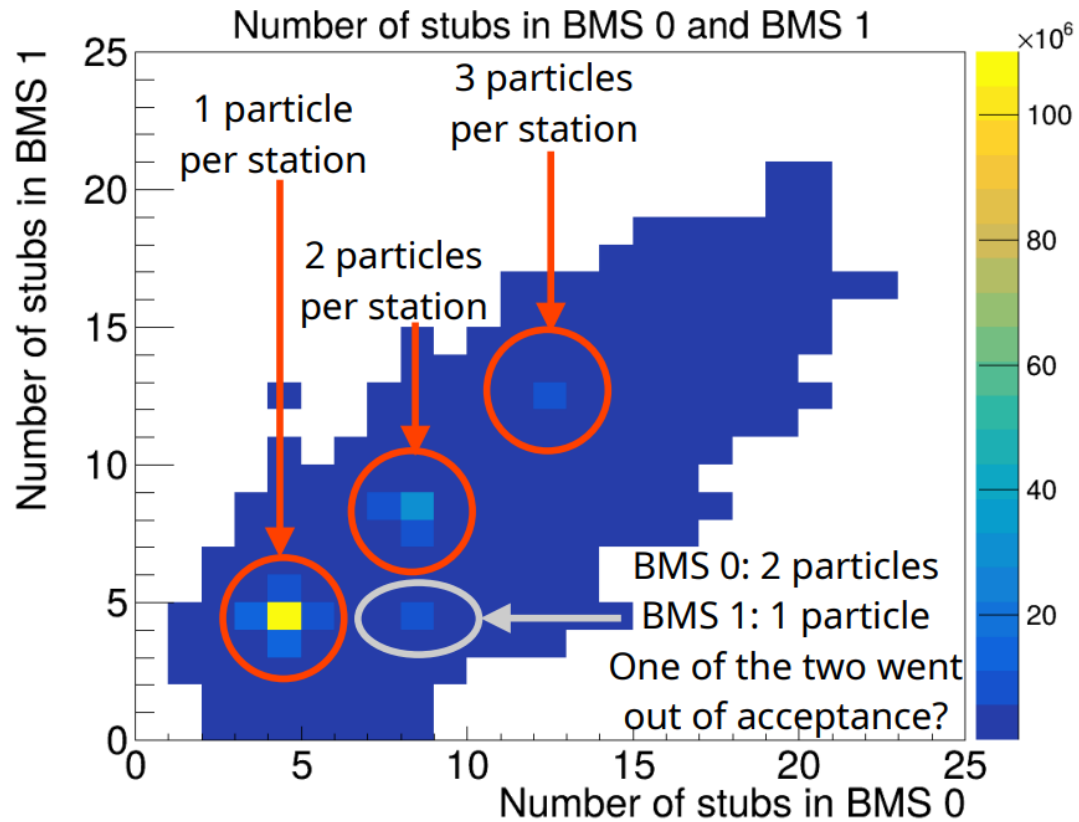
- The knowledge of the beam energy is one of the main sources of systematic error
- The BMS allows us to measure the energy of individual incoming muons before they reach the tracker.
- This information is needed for the analysis of data in the tracking stations.
- The aim is to have knowledge of event-by-event μ -momentum at <0.5%



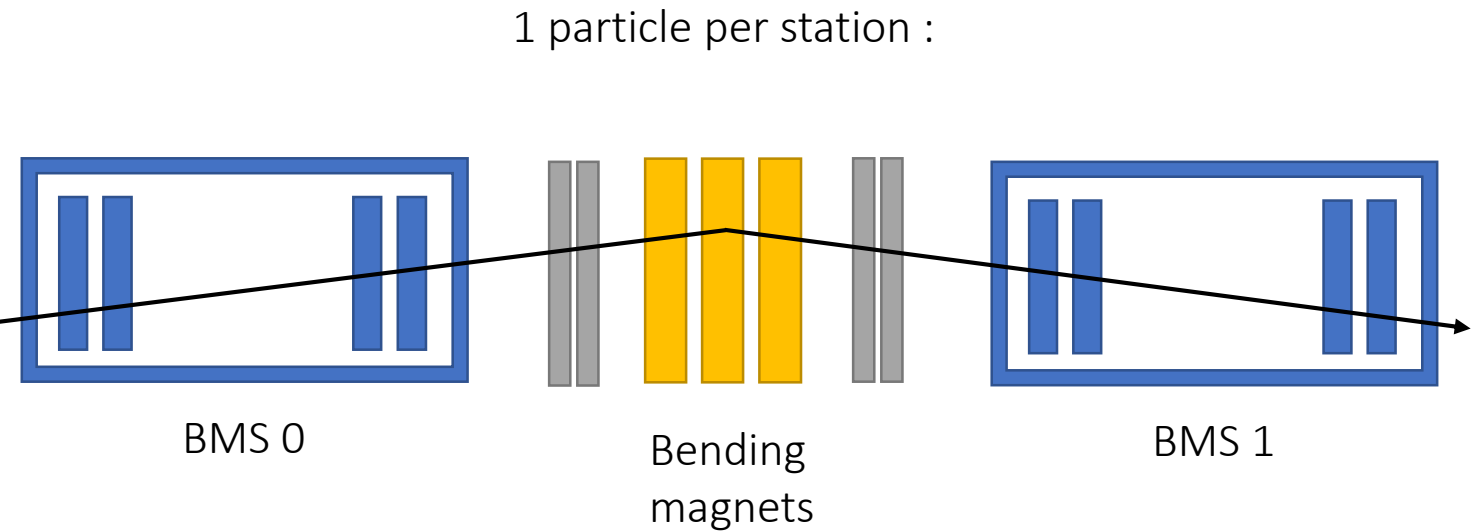
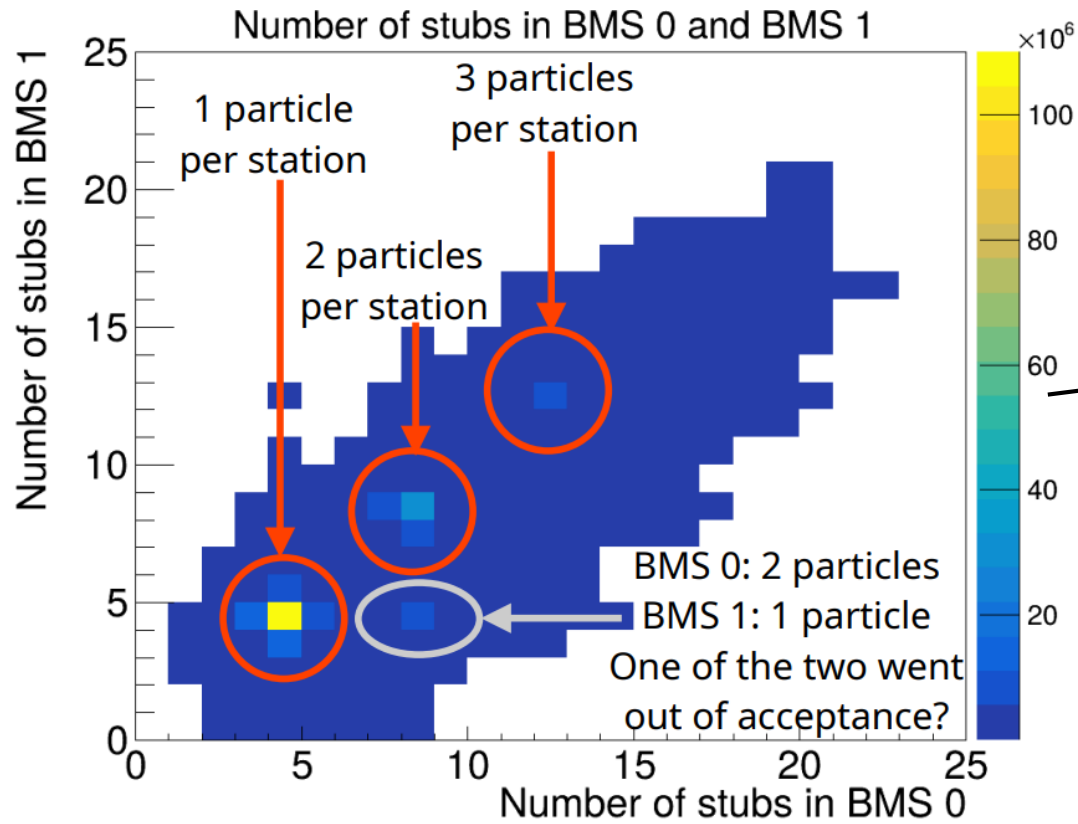
Preliminary BMS analysis from 2025 test run

- In the 2025 test run the BMS was composed of two stations, each with four 2S modules.
- The first step was to look at the number of particles detected in the BMS stations and compare to what we are seeing in the tracker stations
- Then, the slopes of the trajectory of the particles in the BMS stations was looked at to see the bending effect of the magnetic field

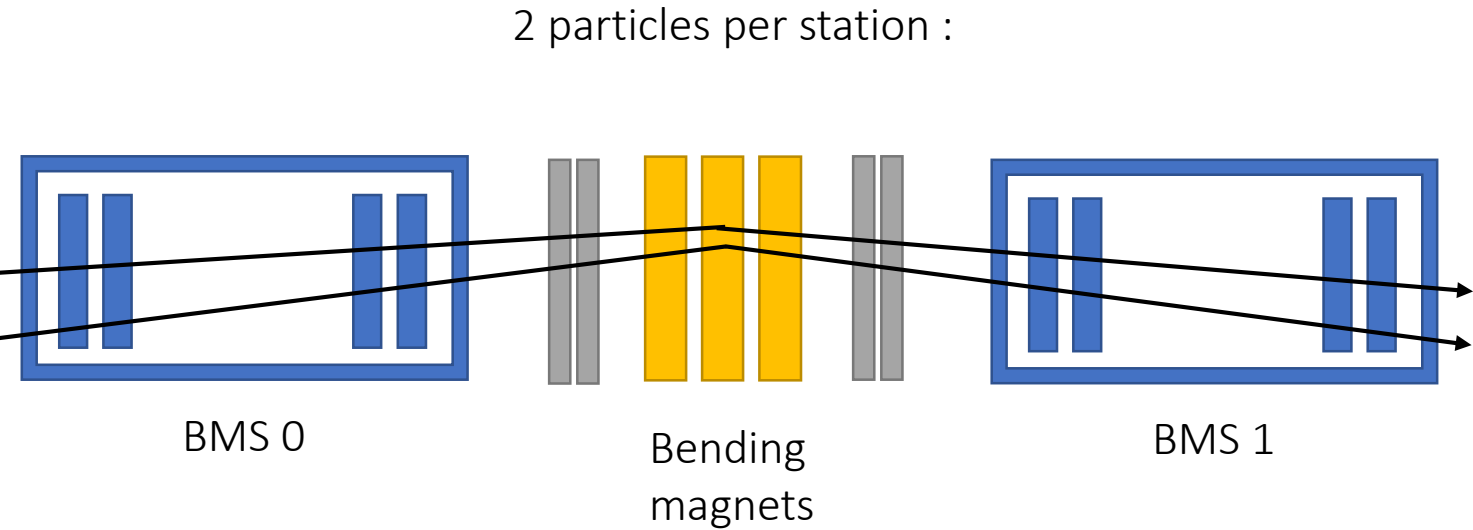
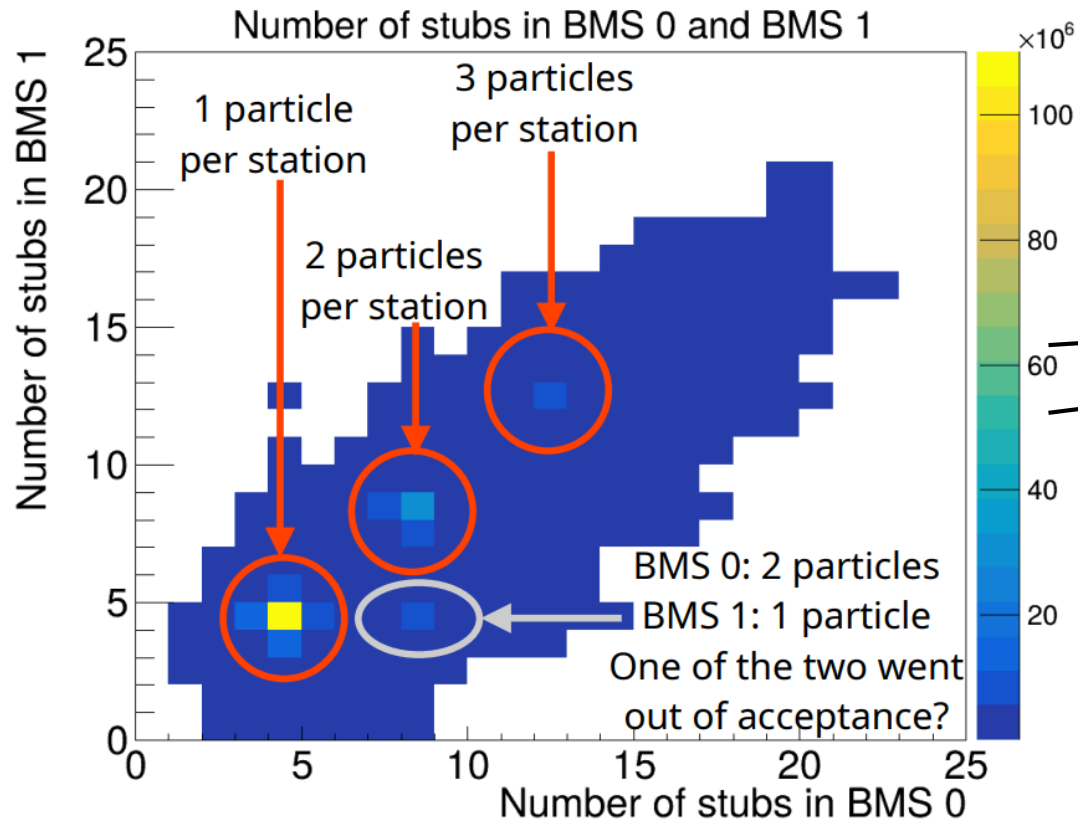
BMS0-BMS1 stub correlations



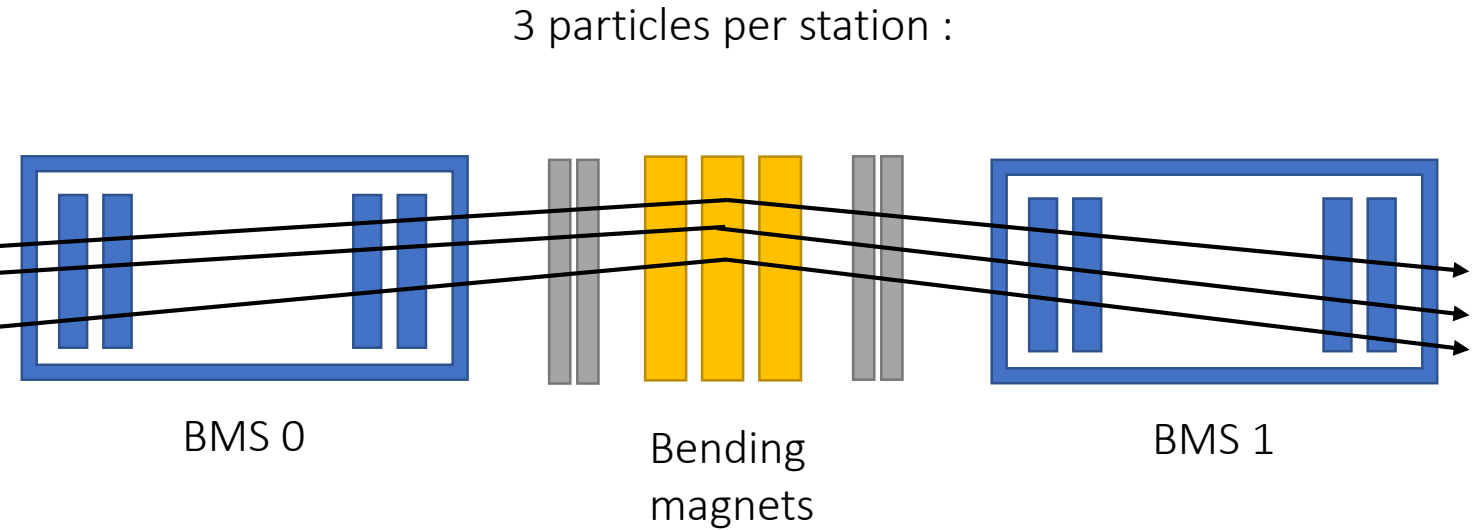
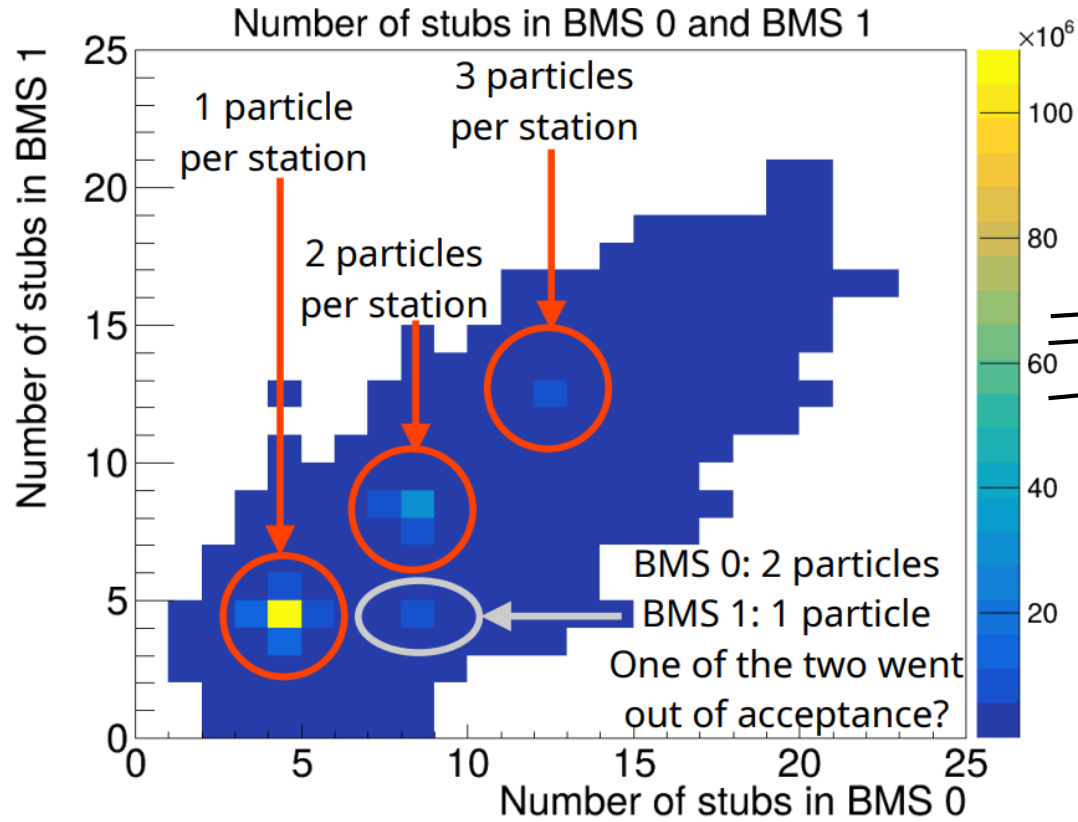
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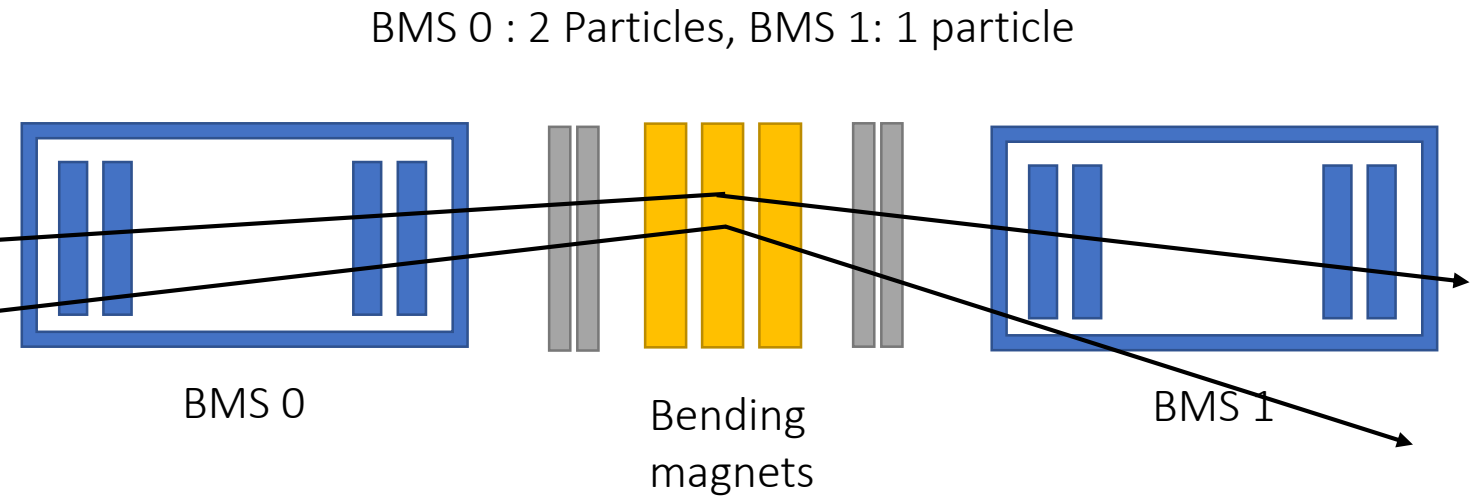
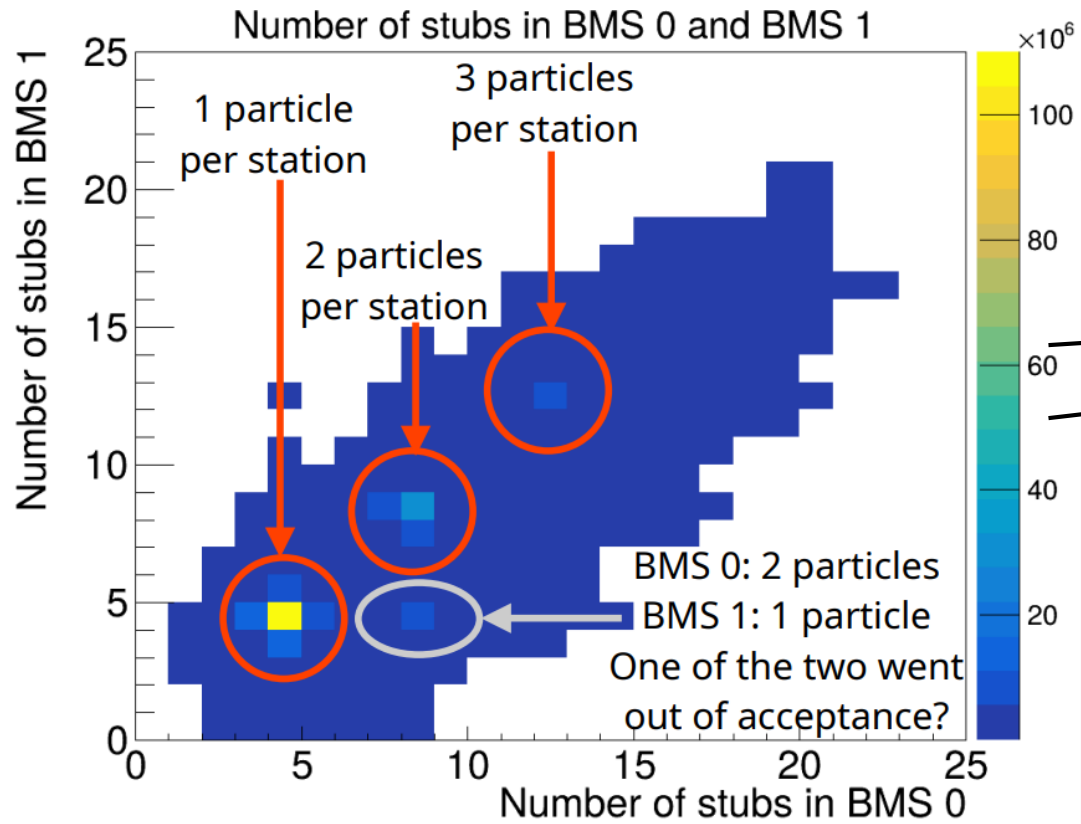
BMS0-BMS1 stub correlations



BMS0-BMS1 stub correlations



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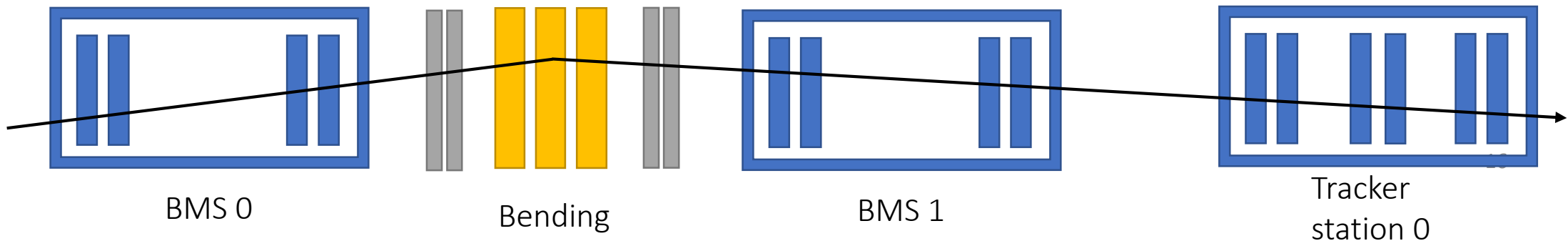
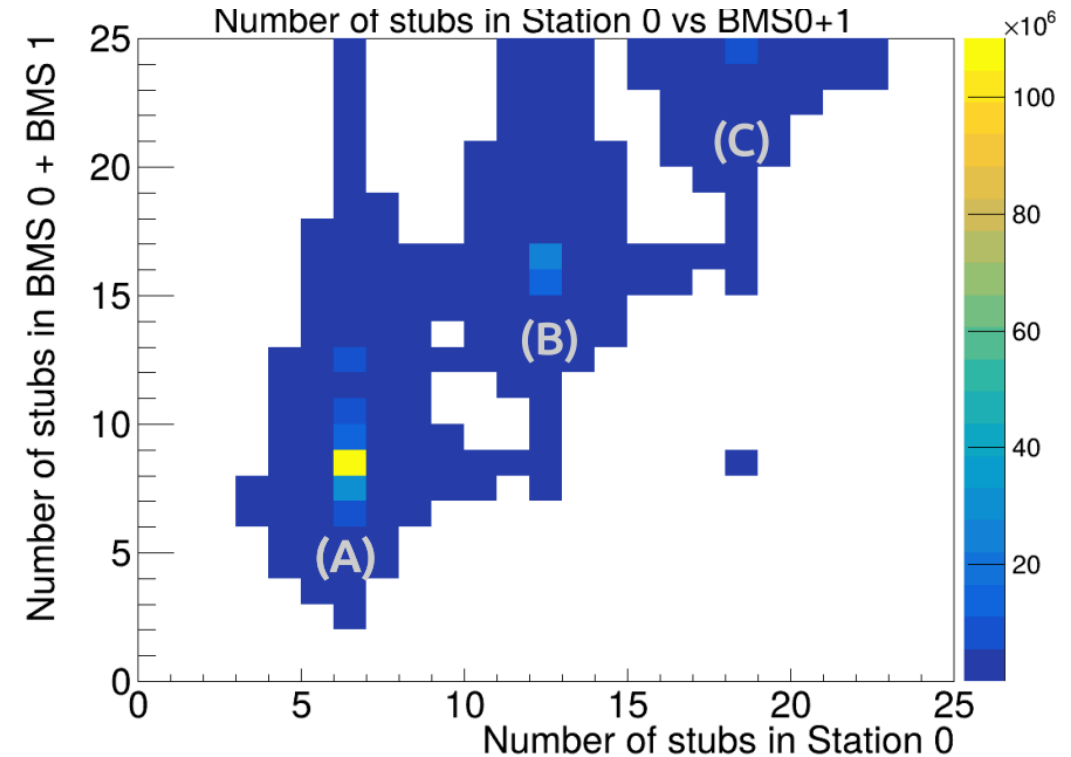
Tracker-BMS stub correlations

There are 3 structures visible :

(A) 1 particle in Station 0 of the tracker and 1 particle in the BMS

(B) 2 particles in Station 0 of the tracker and 2 particles in the BMS

(C) there is a smaller amount of 3 particle in station 0 of the tracker and 3 particles in the BMS



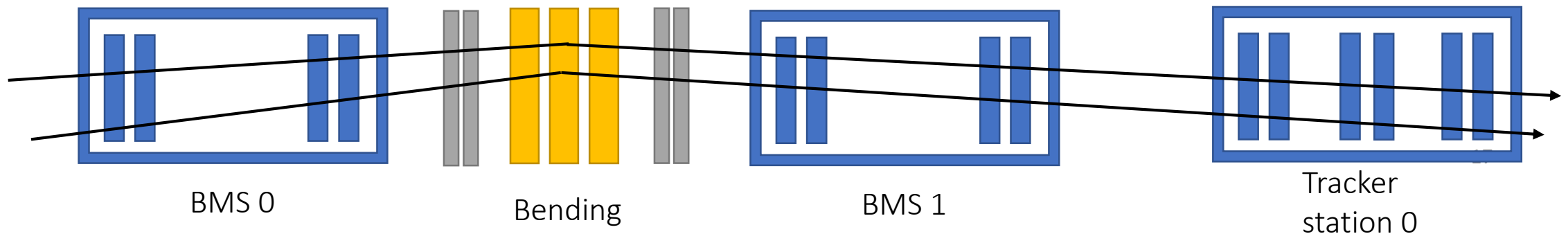
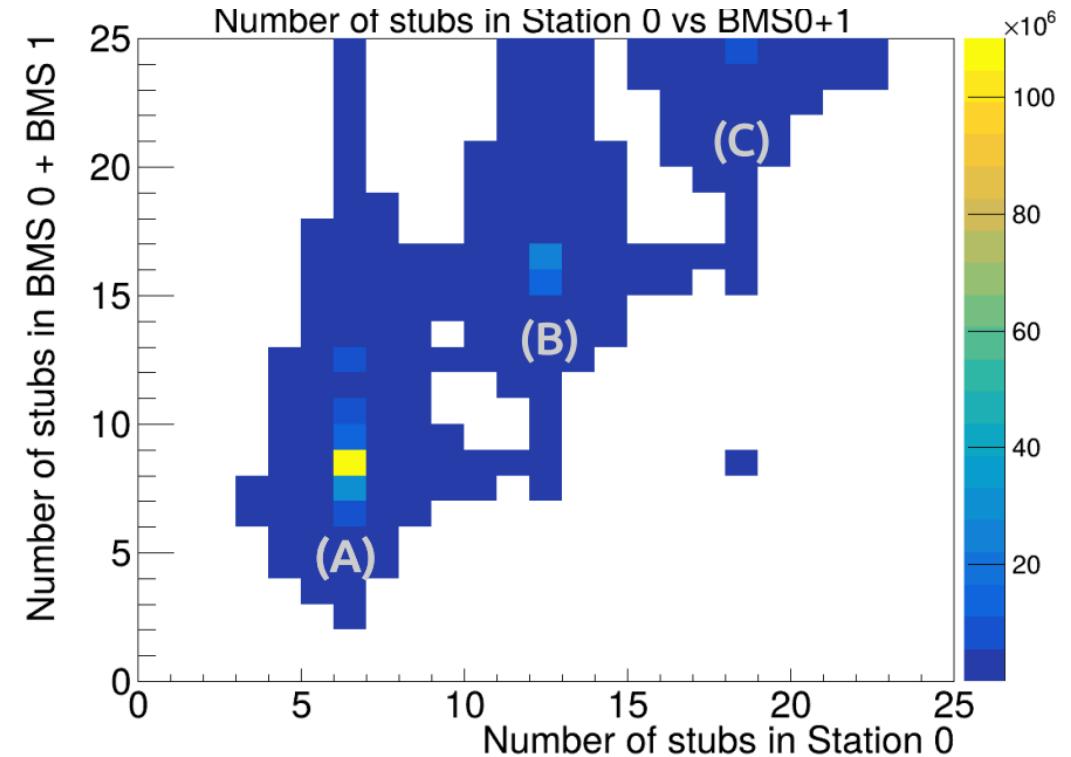
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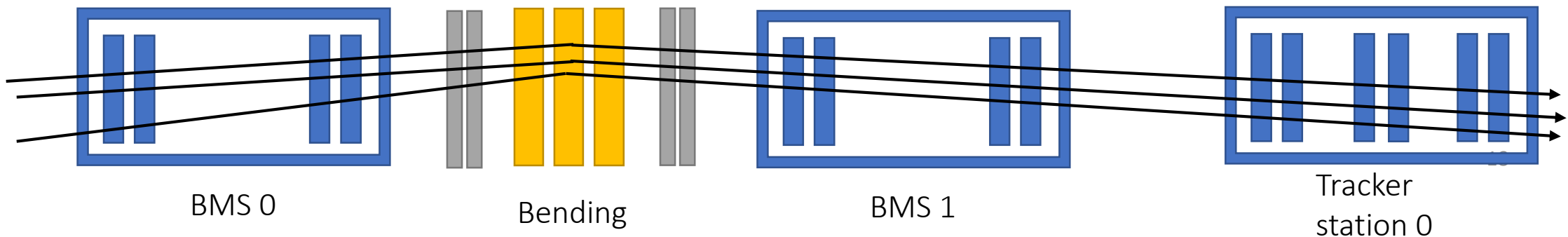
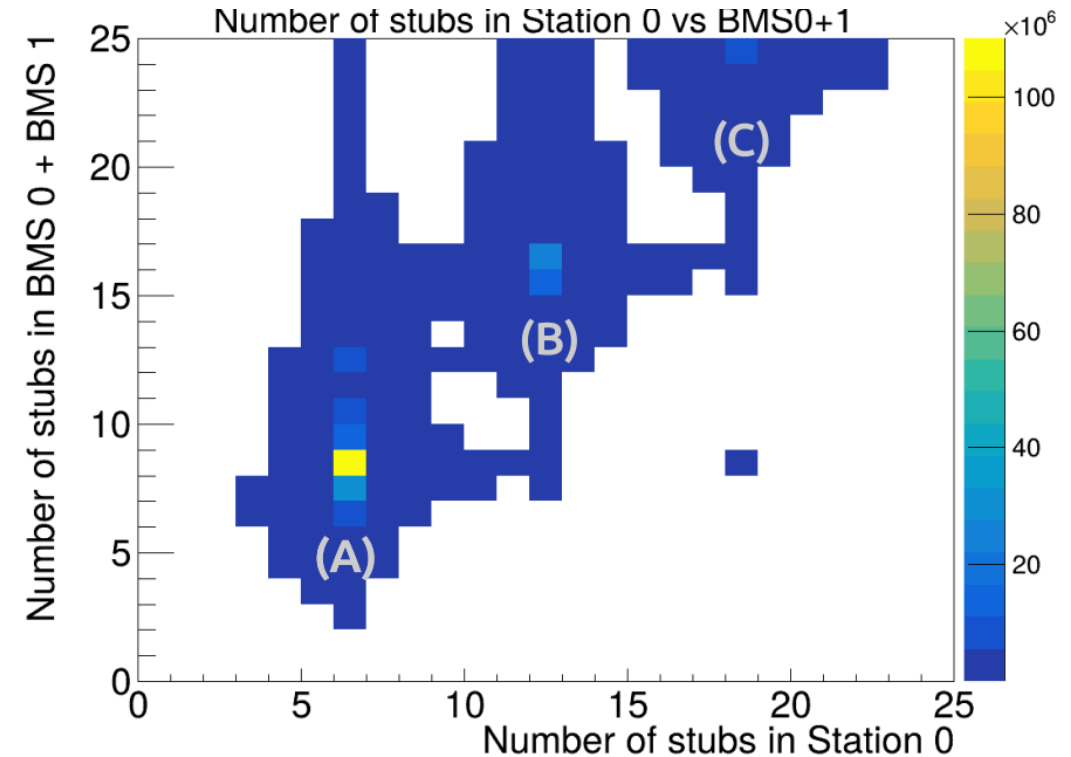
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Tracker-BMS stub correlations

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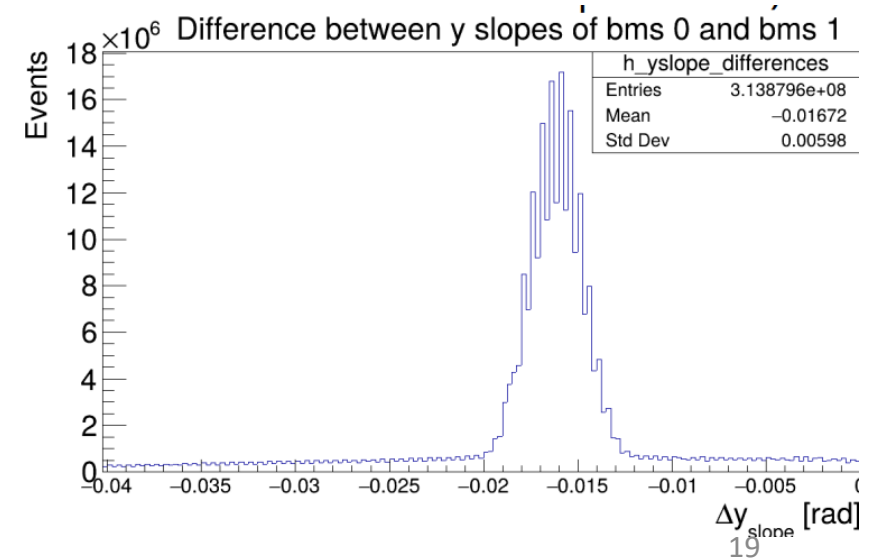
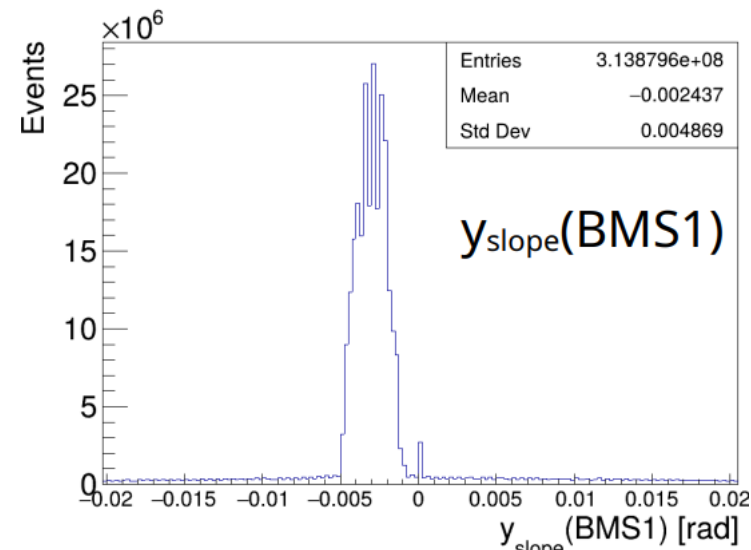
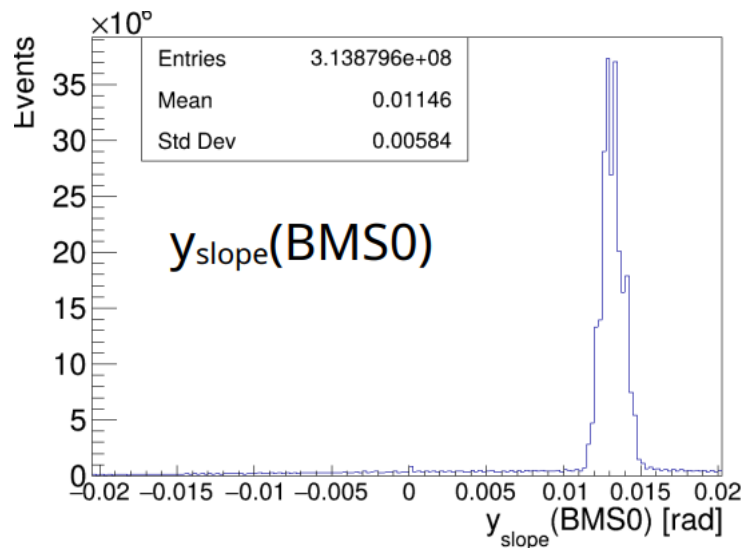
- (A) 1 particle in Station 0 of the tracker and 1 particle in the BMS
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Y slopes

The plots below show the slopes of particles in the BMS station in the y directions .

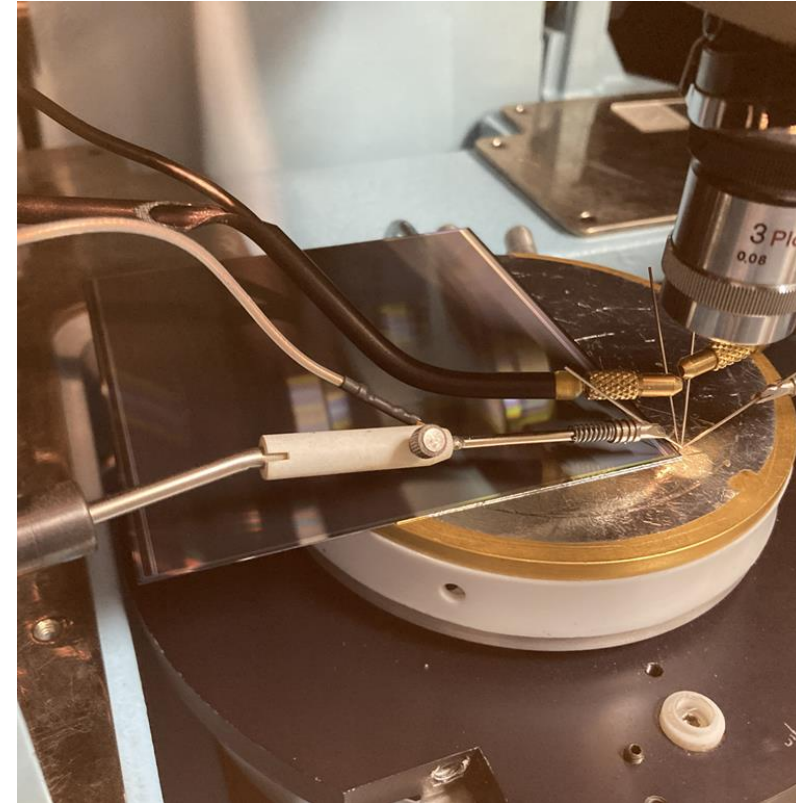
To give full interpretation of these results a full metrology is needed as the two slopes are calculated in the local systems of their respective stations



Summary



- The progress on the simulation improvements has brought us closer to data and now all that is being worked on is the tuning of some of the parameters.
- The study of the alignment parameters is complete and I have also produced the alignment files for all the runs for the 2025 test run
- A full metrology is needed to have a complete beam momentum measurement , the analysis of this is ongoing.
- I have also been working with Alan in the clean room to test some new silicon strip sensors

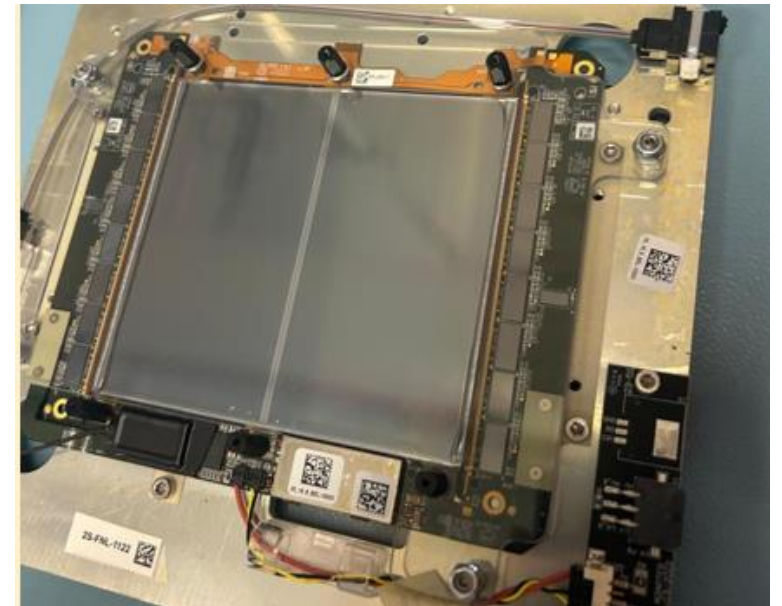


Thank you for listening !

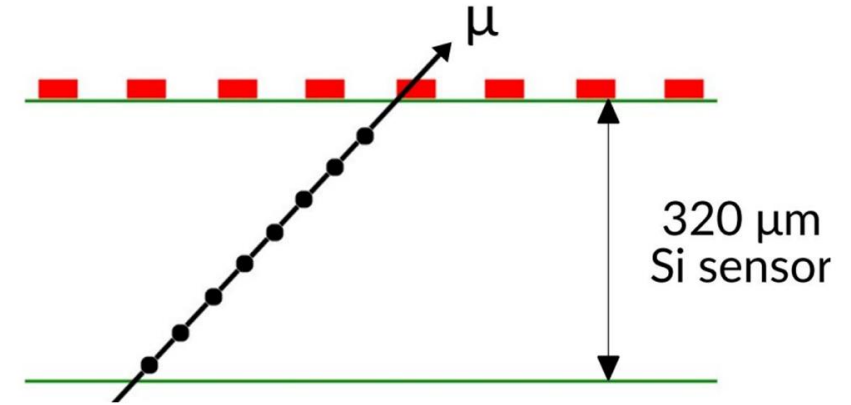
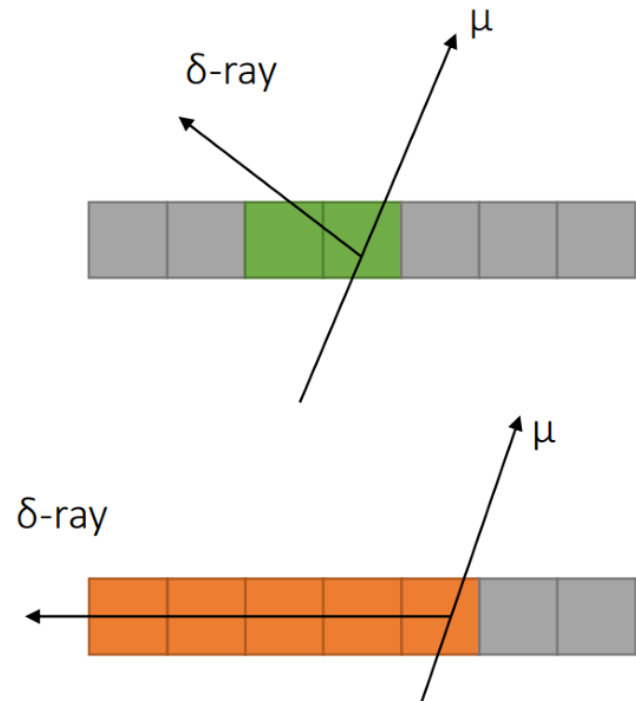
Backup

2S Modules

- 2 silicon strip sensors of 320 μm thickness that are reading the same coordinate
- The two sensors are separated by 1.8mm
- The sensors are read out by CMS Binary Chips (CBC), there are 16 CBC's on each module
- They suppress background of single sensor hits
- Reject large angle tracks
- Pitch : 90 μm
- Readout rate : 40MHz
- Area : $10 \times 10 \text{cm}^2$



We expect delta rays to travel in the silicon and be emitted at large angles. 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.

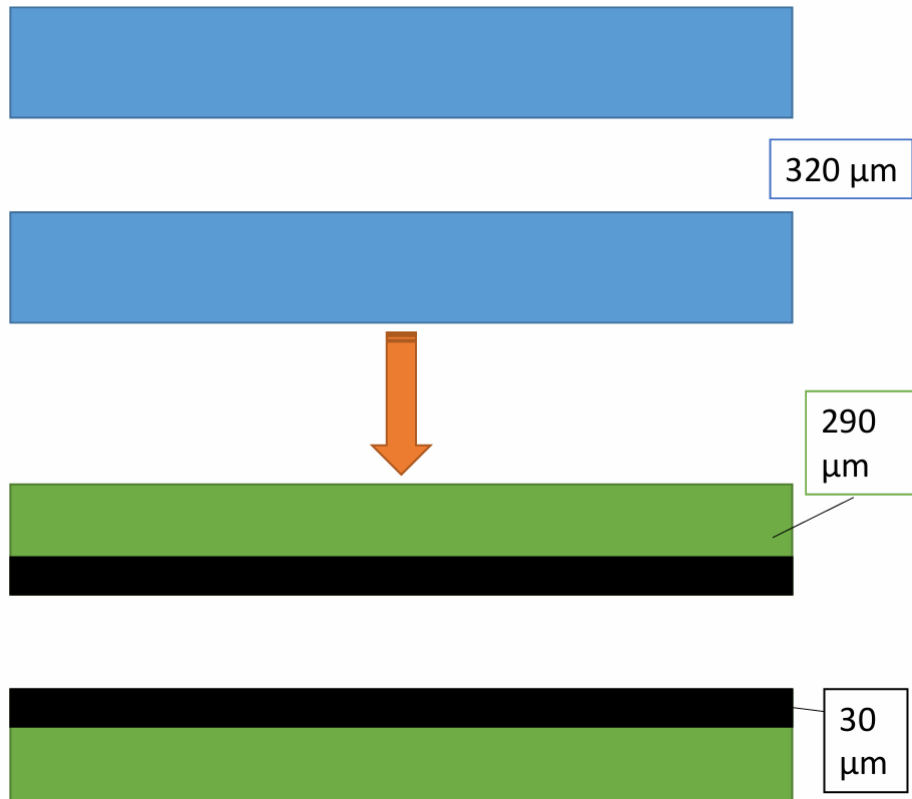


Currently FairMUonE saves only the entering position into the silicon sensor and the exiting position.

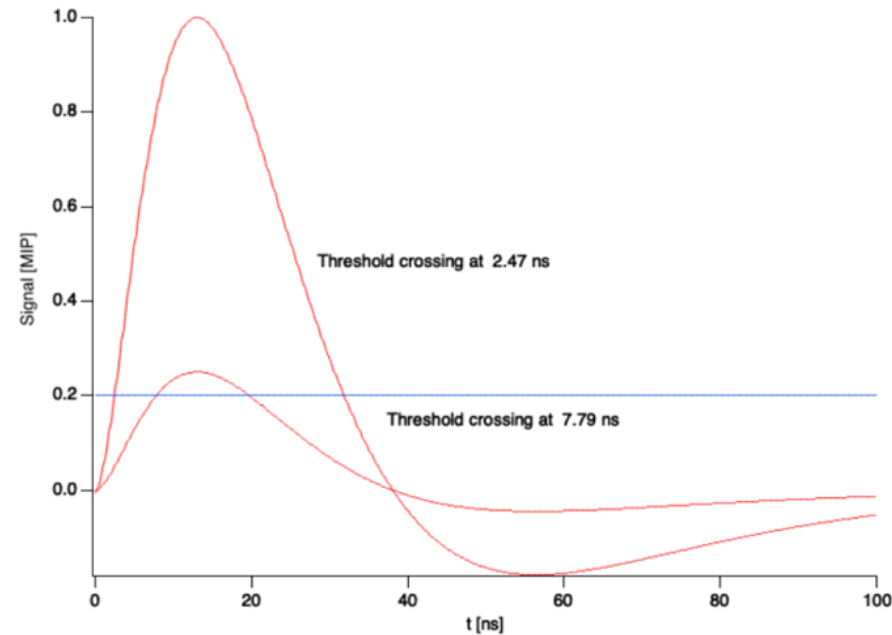
Then in the digitization the energy deposit is divided into 10 micron segments.

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 2S modules have 290 μm of active thickness but FairMUonE had 320 μm



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



The muon beam is asynchronous with the DAQ clock but this is not reflected in FairMUonE

- Two offsets were added to reflect these timing effects
- The time when a signal is over the threshold depends on the charge of the signal
- By adding in the CBC pulse shape function into the digitization we calculate the time it takes for a particle to surpass the Strip Threshold