The Beam Momentum Spectrometer Stations for the MUonE experiment

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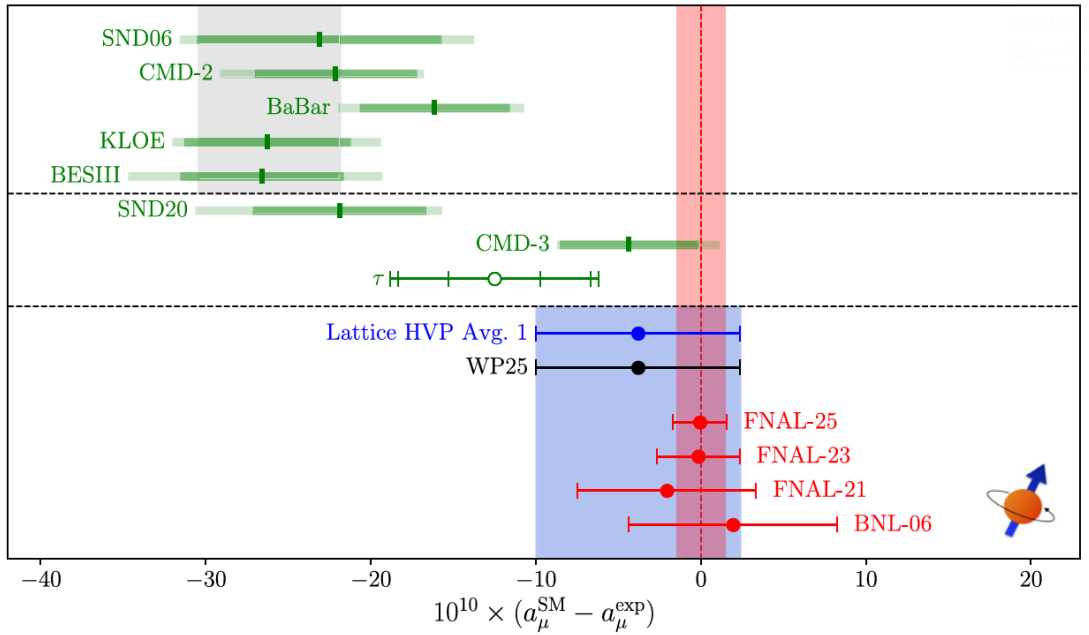
The anomalous magnetic moment of the muon

- Tension between data-driven and lattice determinations of SM prediction of a_μ
- a_μ^{HLO} is the largest source of uncertainty on the theoretical determination as it cannot be calculated using perturbation theory.

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HLO}$$



Motivation of MUonE

$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 dx(1-x)\Delta\alpha_{had}[t(x)]$$

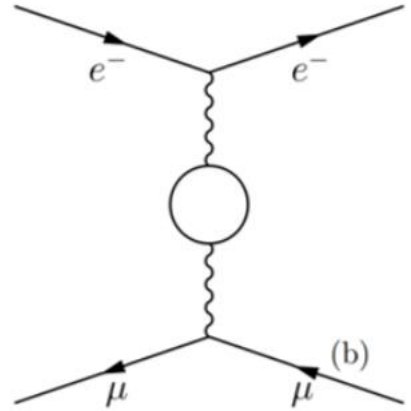
$$t(x) = \frac{x^2 m_\mu^2}{x-1} < 0$$

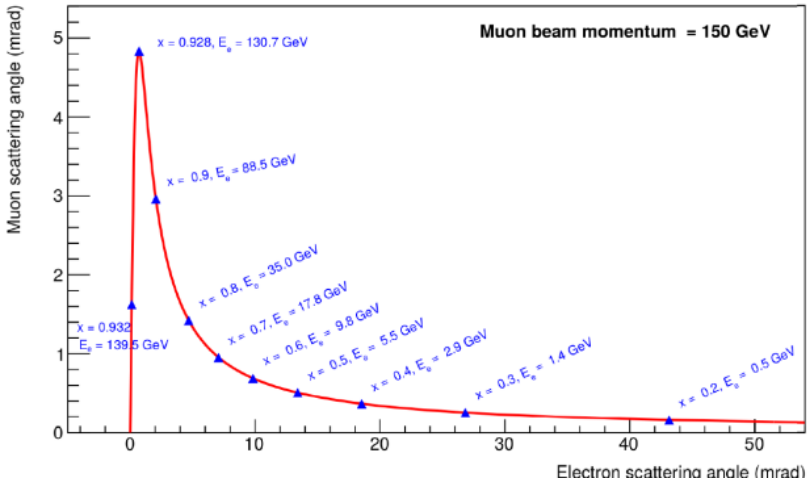
MUonE is a μ-e scattering experiment

o It will provide an independent method of calculating the hadronic vacuum polarisation contribution to the muon anomaly, a_μ^{HLO}.

o The challenge of MUonE is on the precision of the experiment.

- The goal is to have a statistical uncertainty of 0.3% and a similar systematic uncertainty. Such precision is predicted to take 3 years of data taking.
  This corresponds to the statistical error on the shape of the cross section being 10ppm





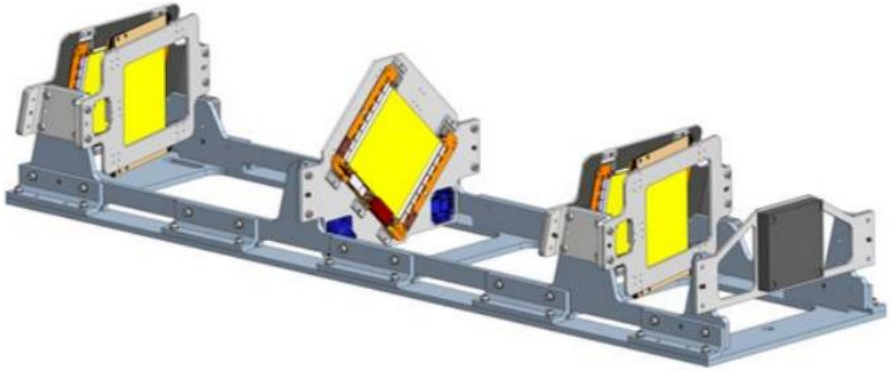
Experimental Setup

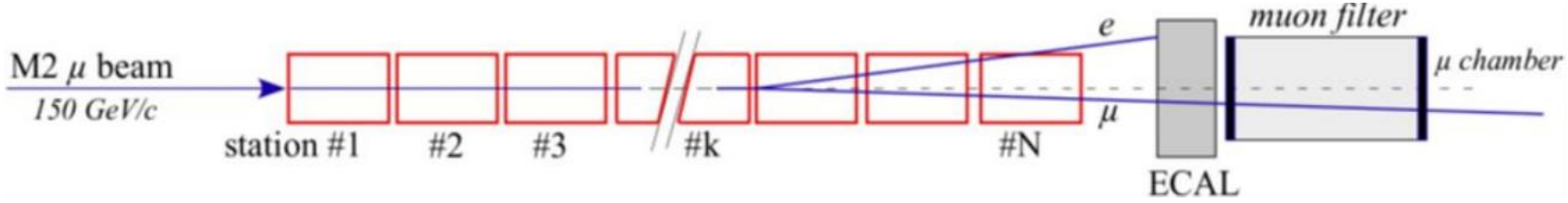
MUonE will take place at the M2 beamline at CERN.

It is a modular experiment made up of repeating 1m long station . Each with its own target and tracking system.

The station is made up of 6 2S modules which have been developed for the CMS phase 2 upgrade . Test beam with 2 stations in 2023 and a first run with 3 stations was completed in 2025.

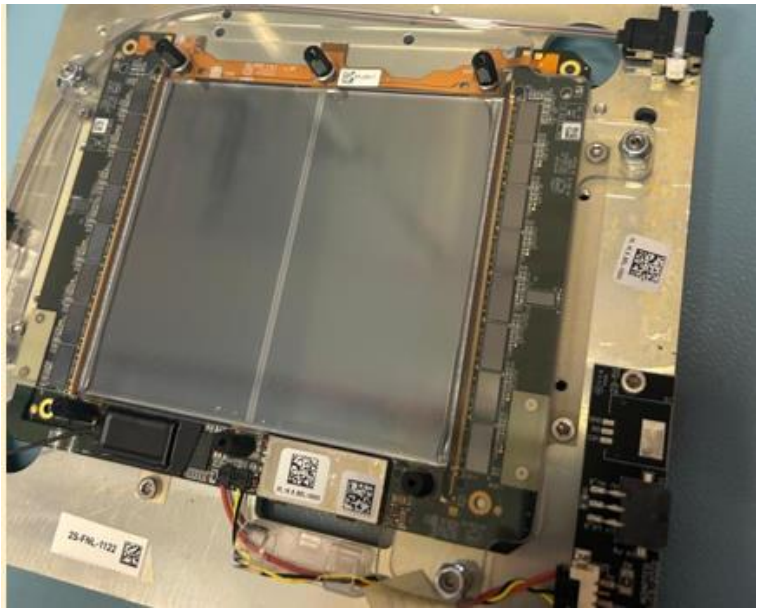
Before the stations there will also be a beam momentum spectrometer (BMS) and afterwards a muon filter and calorimeter for PID.





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 :$10x10cm^2$



Why we need the BMS

The knowledge of the beam energy is one of the main sources of systematic error on the extraction of a_μ^{HLO}

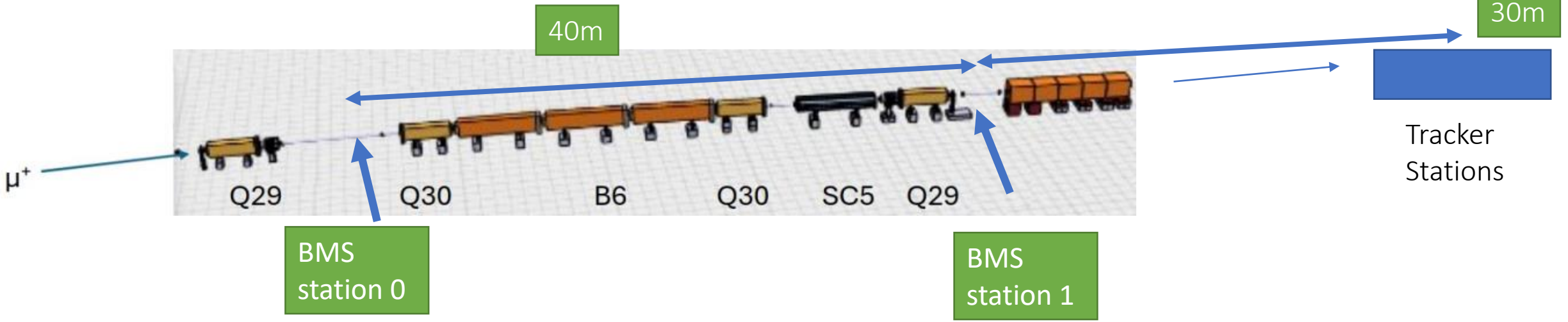
The BMS allows us to measure the energy of individual incoming muons before they reach the tracker.

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

Which is important information to know for the analysis of data taken from the tracker stations

The aim is to have knowledhe of event-by-event μ-momentum at <0.5%

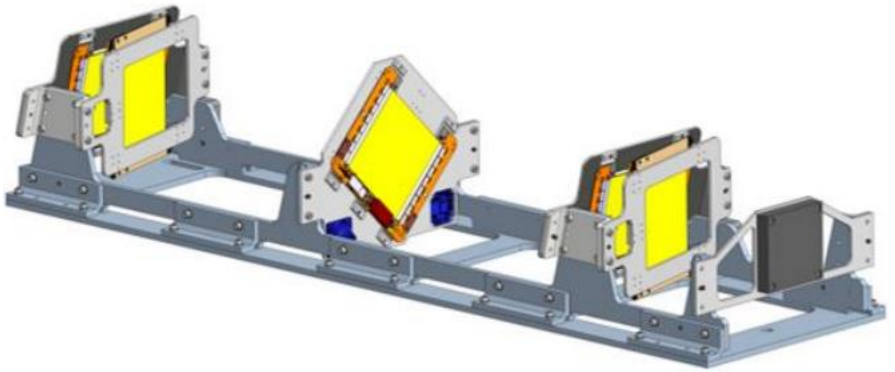
The Beam Momentum Spectrometer (BMS)



- 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 requires for final precision

Support structure of MUonE

- The support structure of the tracker stations is made of Invar which is an expensive and heavy material that is difficult to machine.
- Tests were carried out to find an alternative to construct the support structure for the BMS
- The support structure needs to have a low coefficient of thermal expansion to maintain the precision of the experiment
- This precision is achieved if the systematic error on the shape of the differential cross section is kept at 10ppm,which is equivalent to 10µm in the z direction of a station.

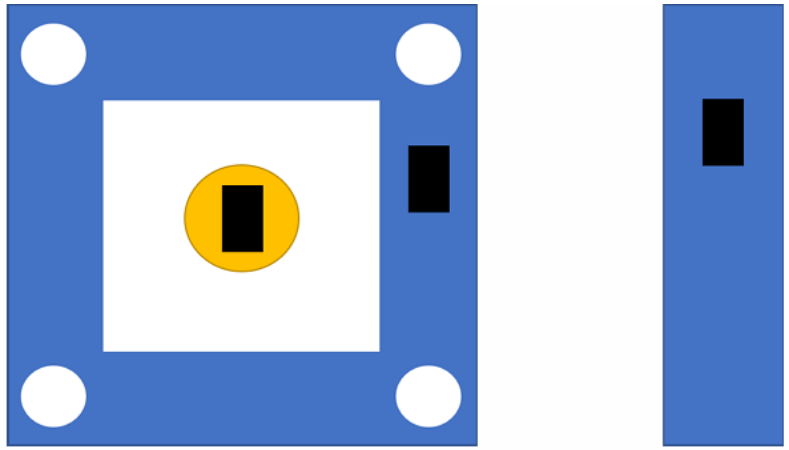


Carbon Fibre CTE Tests

Two types of carbon fibre were tested : One is a frame using a high strength carbon fibre sheet and the other is a carbon fibre composite M55J.

3 strain gauges were attached to a carbon fibre frame and on reference material titanium silicate.

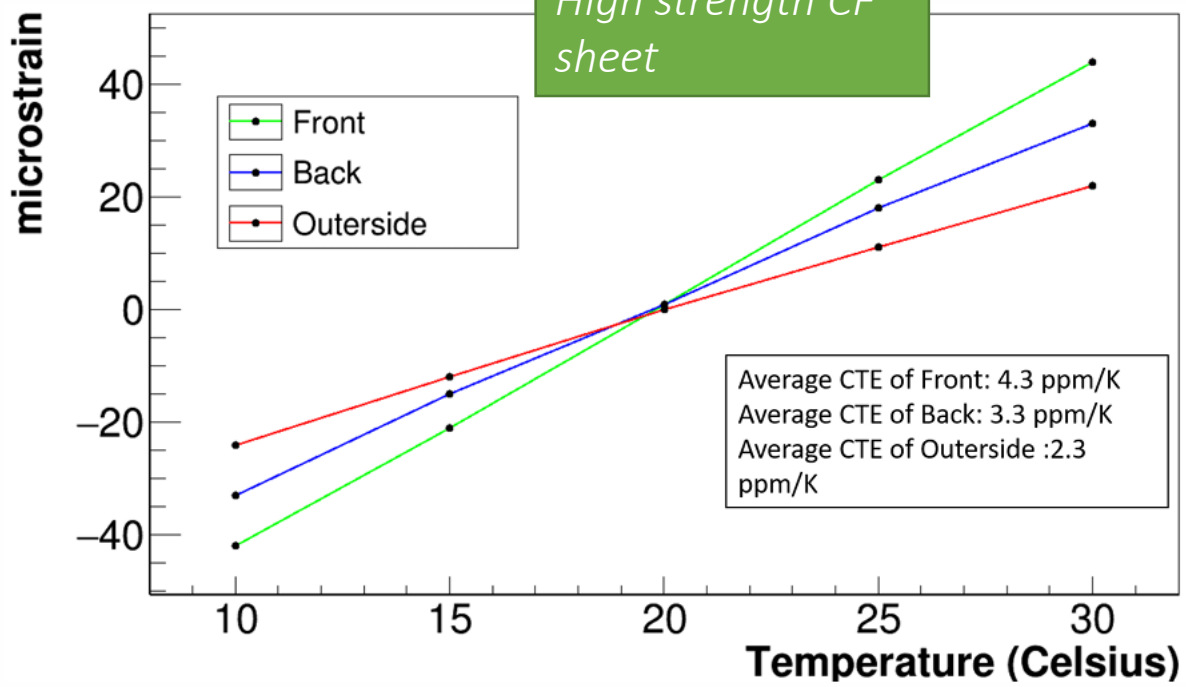
A thermal cycling chamber was used to cycle through a range of temperatures to get measurements of the strain of the material as a function of the changing temperature



CTE Results

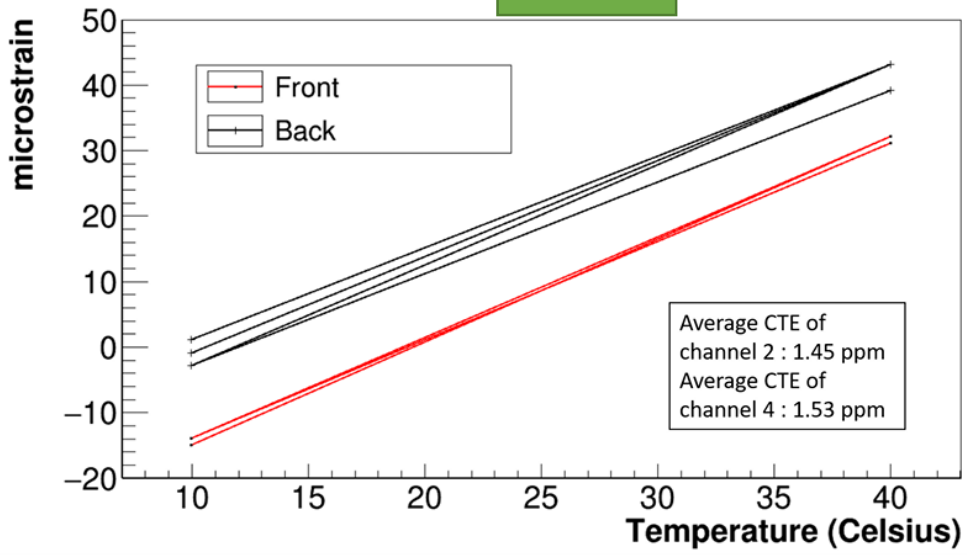
- The CTE is found by taking the gradient of the true strain against the temperature.
- True strain is strain from the sensor with subtracted strain from the TiS.
- Average CTE of 3.8ppm/K.
- Which is around 3 times larger than the CTE of Invar.
- Bending due to the front and back sensors having different CTE's

High strength CF sheet



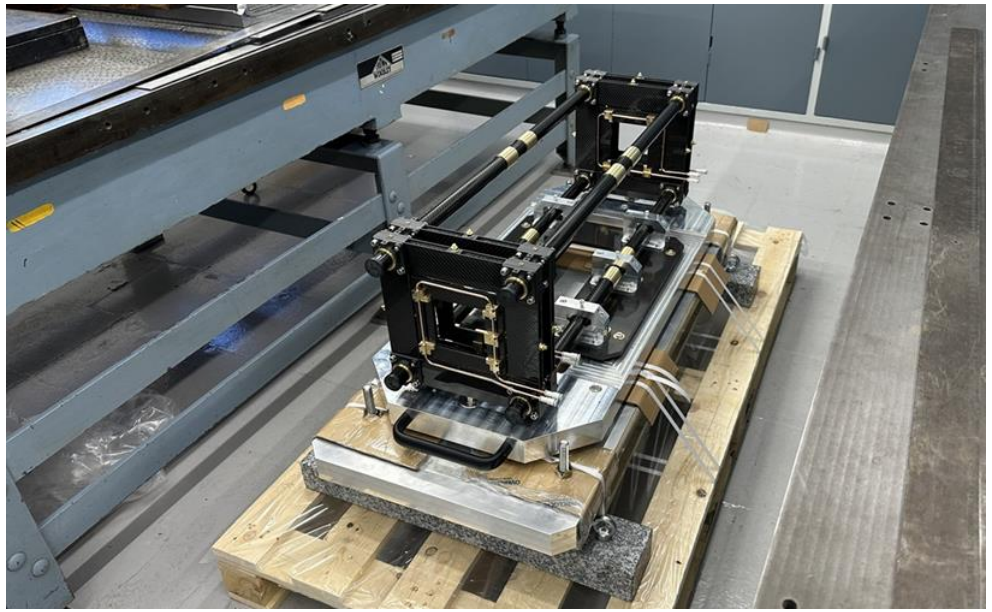
- CTE of M55J was found by doing a scan with large temperature jumps.
- This allows less time for the readings of the strain to drift in other sensors which took less time to stabilise than the TiS.
- An average CTE of 1.5ppm/K was found

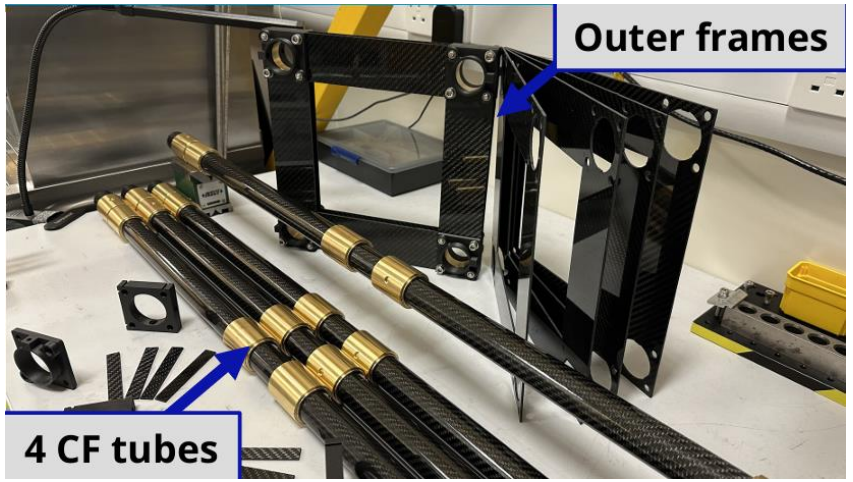
M55J

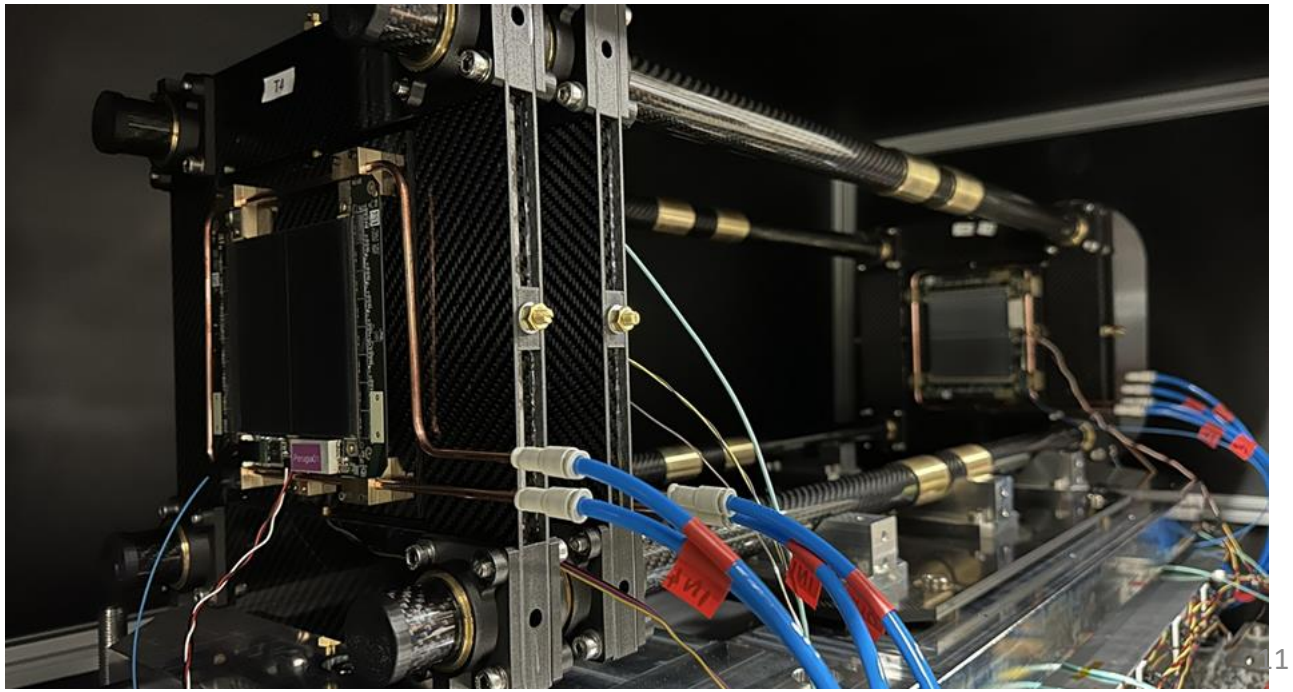


Temp (˚C)	CH2	CH4
40	39	32
10	-3	-15
40	43	32
10	-1	-14
40	43	31
10	1	-14

The BMS Carbon Fibre Structures for the 2025 test run



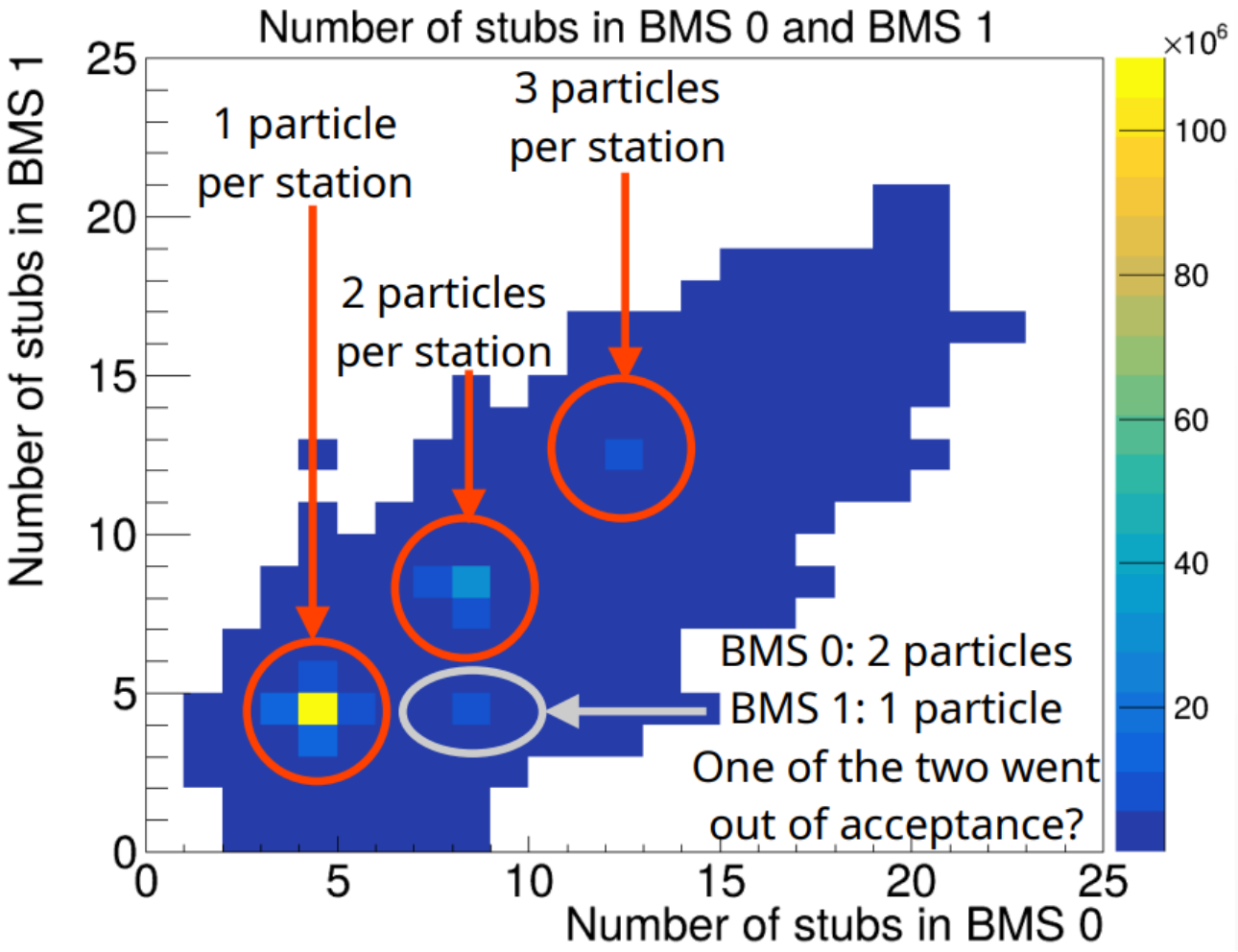




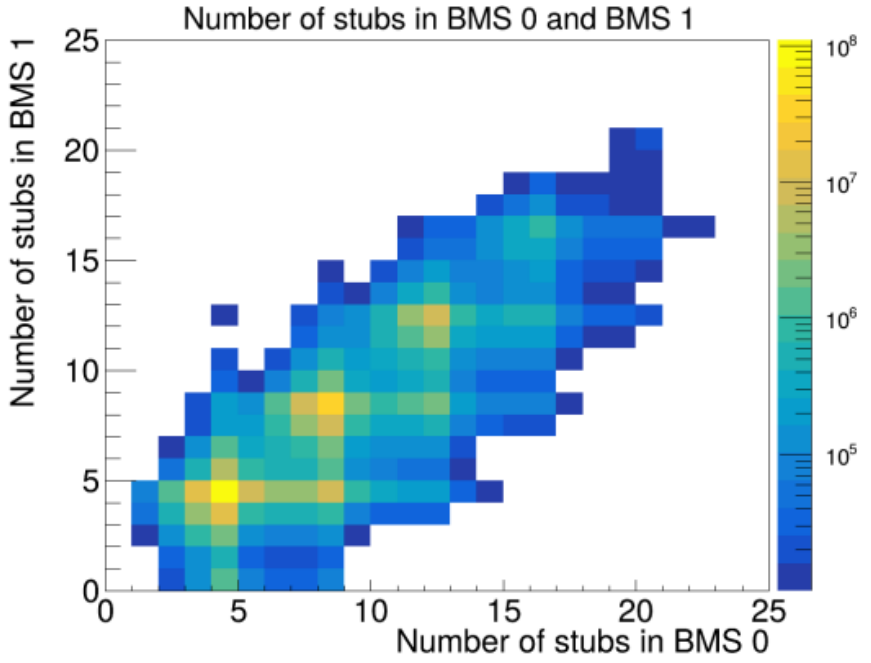
Preliminary BMS analysis from 2025 test run

- In the 2025 test run the BMs was composed of two station with four 2Smodules.
- 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



Same plot but the z axis is in the log scale



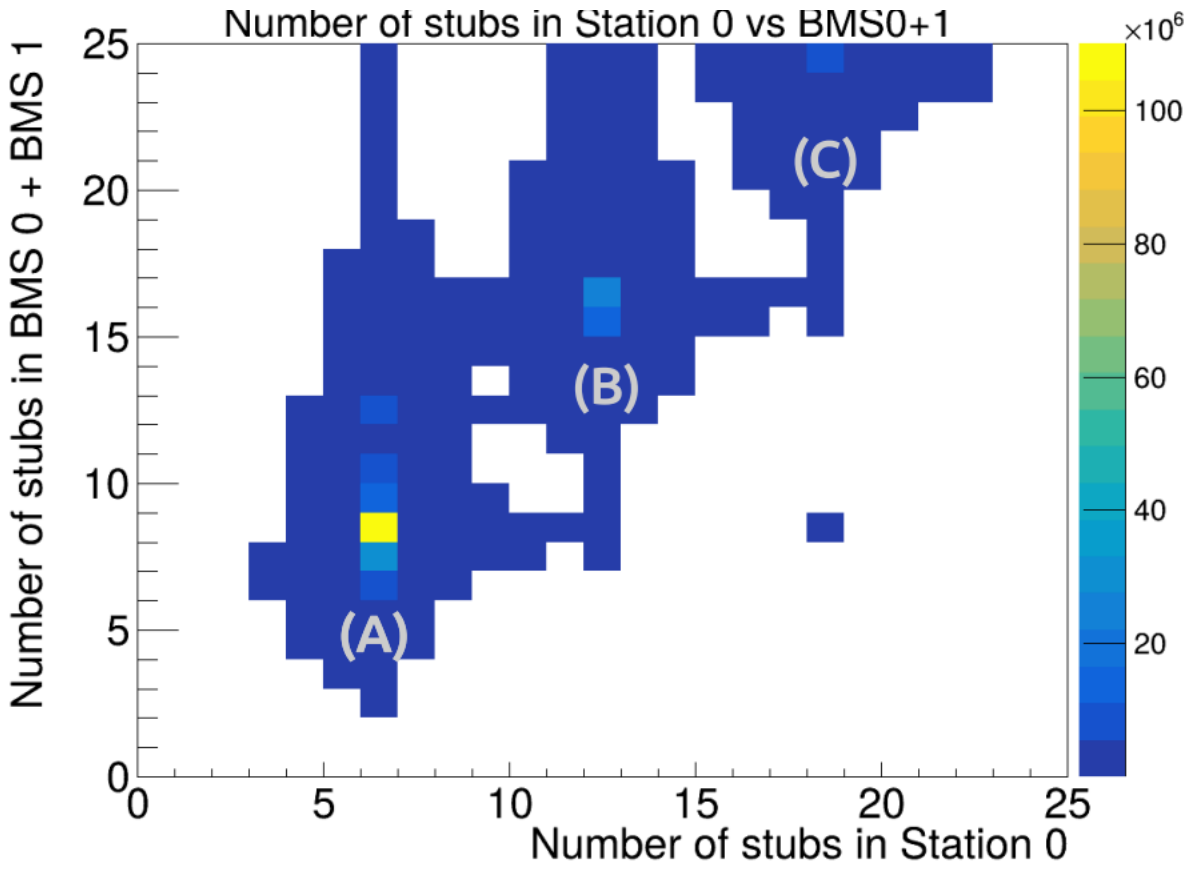
Tracker-BMS stub correlations

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



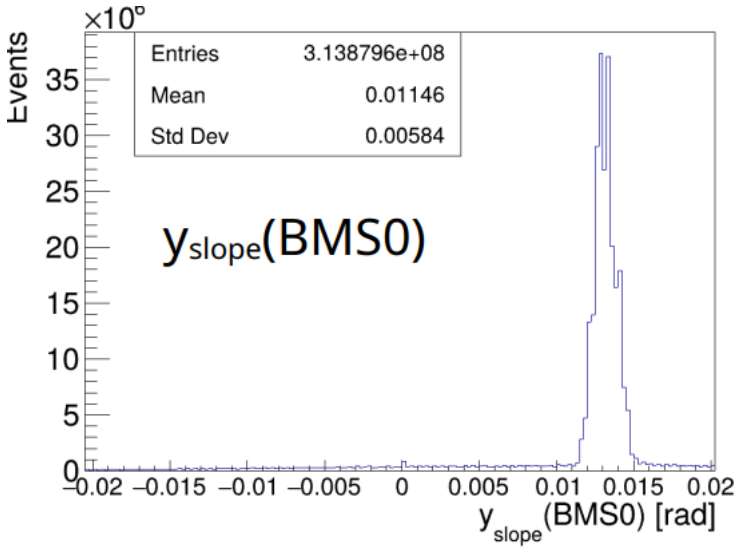
Y slopes

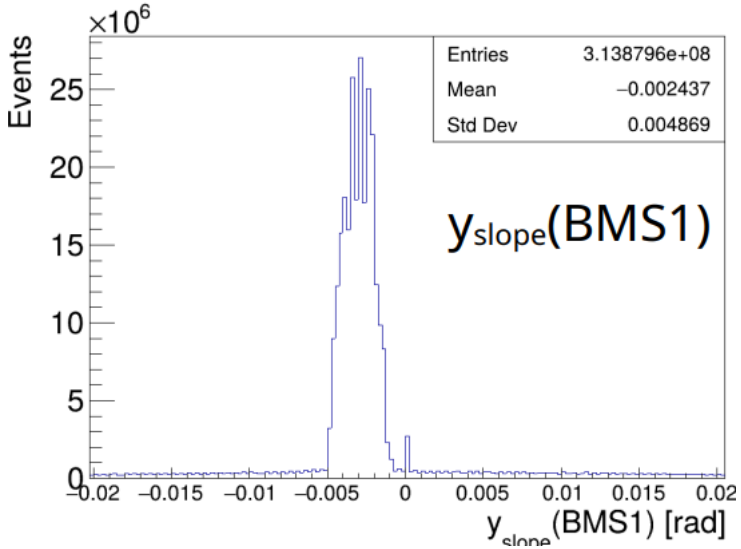
The plots below show the slopes of particles in the BMS station in the y directions .

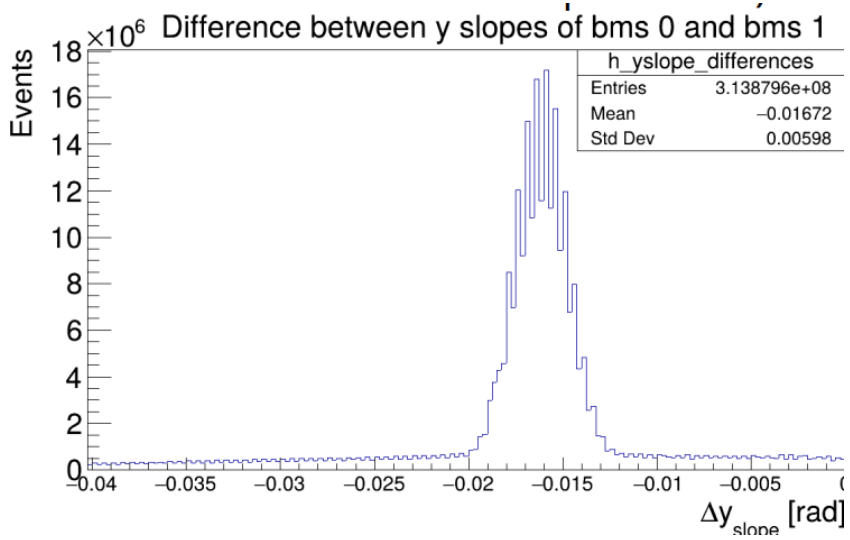
This was done taking the position at y0 and y1

We can see here there are peaks over the background of hits

To give full interpretation of these results a full metrology is needed as the two slopes are calculated in two different reference systems





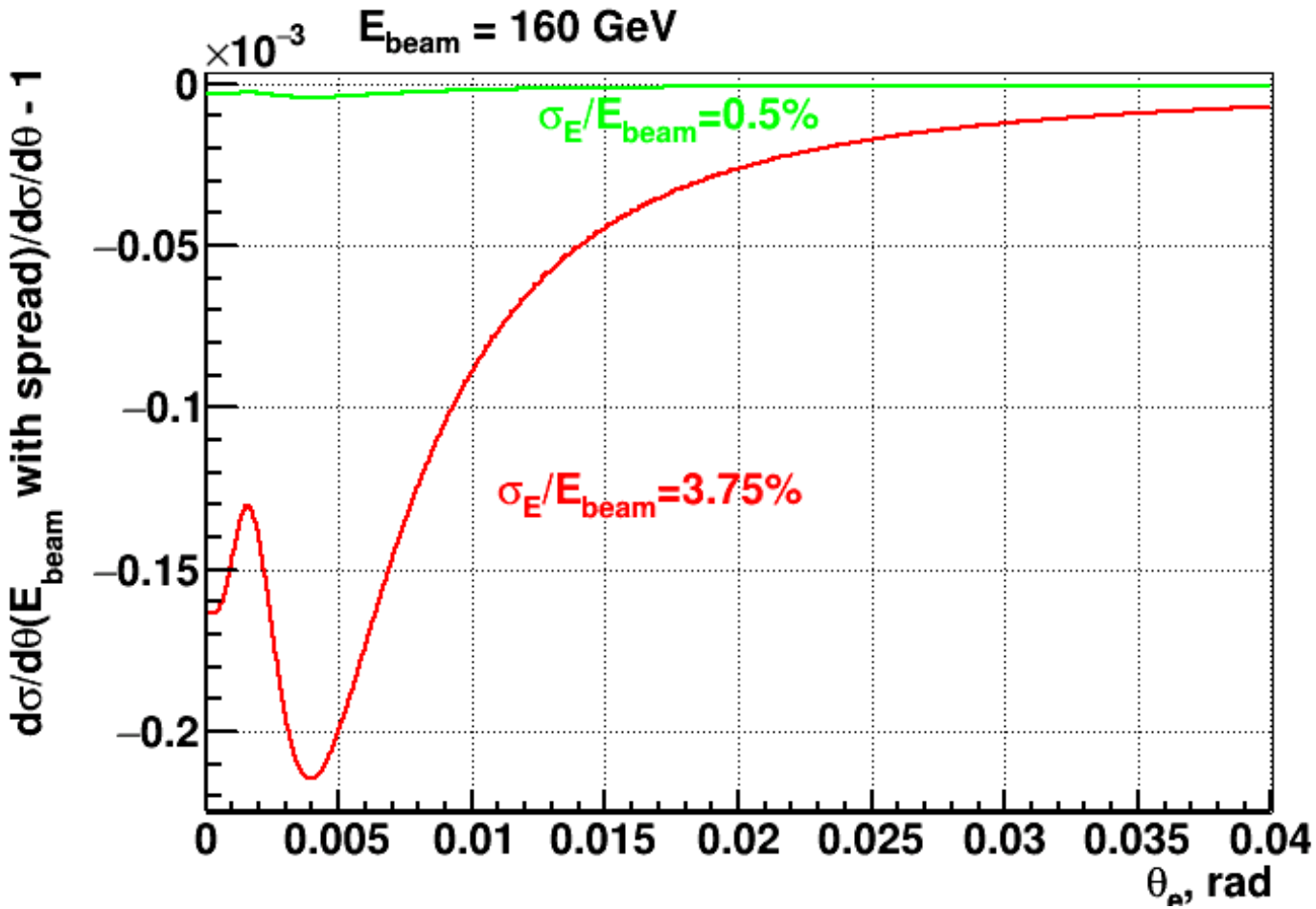


Conclusion

- M55J was found to have a CTE of 1.5 ppm/K
- This material was used for the BMS stations in the 2025 test run
- Preliminary results of the analysis of the BMS were shown
- The full metrology is needed to have a complete beam momentum measurement , the progress on this is ongoing.
- The full metrology will be made up of a laser survey which allows us to place the two BMS stations in a common reference system and a 3D scanner photogrammetry which tells us the modules positions inside a station

Thank you for listening !

backup


E_beam = 160 GeV
×10^−3
0
−0.05
−0.1
−0.15
−0.2
σ_E/E_beam=0.5%
σ_E/E_beam=3.75%
dσ/dθ(E_beam with spread)/dσ/dθ - 1
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
θ_e, rad

X slopes

From the x slope shown below we can see peaks over the background of hits