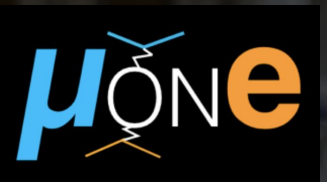
# Performance of MUonE DAQ in the Test Run 2023

David Monk

*09/11/2023*




Northwestern University

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# Overview

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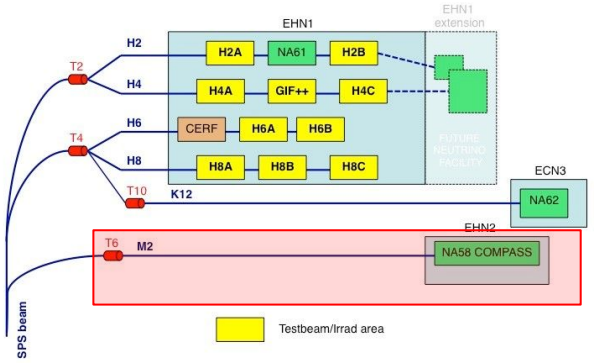
- Hardware Track Finding
- Conclusions

# 2023 Test Run

# Introduction

- The MUonE experiment in collaboration with CMS has conducted several beam tests in the last two years to develop and test its DAQ system, most recently August/September 2023

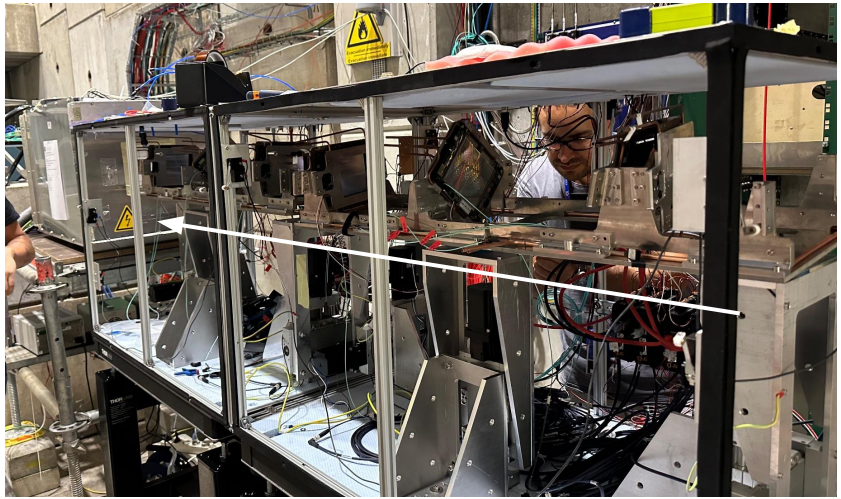



- CERN M2 beamline
  - Secondary beam generated from SPS (T6 target)
  - Up to $2 \times 10^8$ muons per spill, 50 MHz asynchronous rate
  - 160 GeV muons or 40 GeV electrons (lower intensity)

# Experimental Setup I - Stations

- 12 2S modules, housed in 2 ‘stations’
  - 6 modules per station
  - 2S module mounted on custom Invar plates, each chilled to within +/- 0.5℃ (18℃ inlet)
  - Dry environment (< 3% RH)

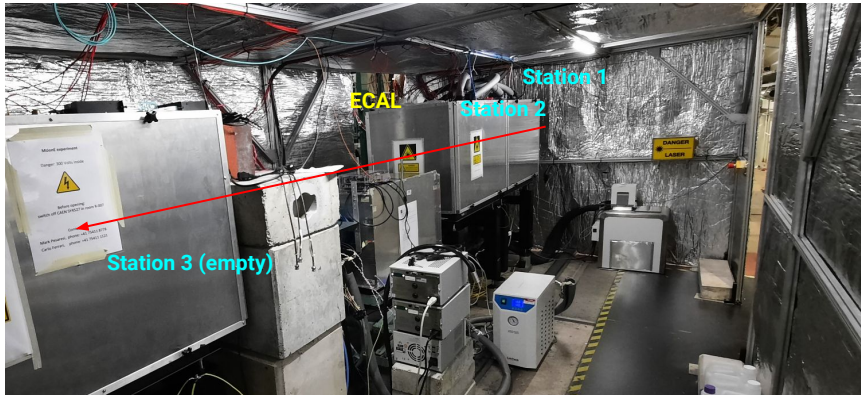
| | Module ID | lpGBT | CIC | Comments |
|---|---|---|---|---|
| Station 1 | 2S_18_5_IPG-00001 | v0 | CIC2 | I2C patch |
| | 2S_18_5_IPG-00002 | v0 | CIC2 | |
| | 2S_40_6_BEL-00005 | v0 | CIC2 | |
| | 2S_18_5_BEL-00003 | v0 | CIC2 | |
| | 2S_18_5_IPG-00005 | v1 | CIC2 | |
| | 2S_18_6_FNL-00004 | v0 | CIC2 | HV patch |
| Station 2 | 2S_18_5_KIT-00001 | v0 | CIC2 | |
| | 2S_18_5_BRN-00010 | v1 | CIC2 | |
| | DAQ/DPS (CERN#9 - 4mm) | v0 | CIC2 | |
| | DAQ/DPS (2S_18_5_KIT-00003) | v0 | CIC2 | |
| | 2S_18_5_KIT-00002 | v0 | CIC2 | |
| | 2S_18_6_BRN-00011 | v1 | CIC2 | |

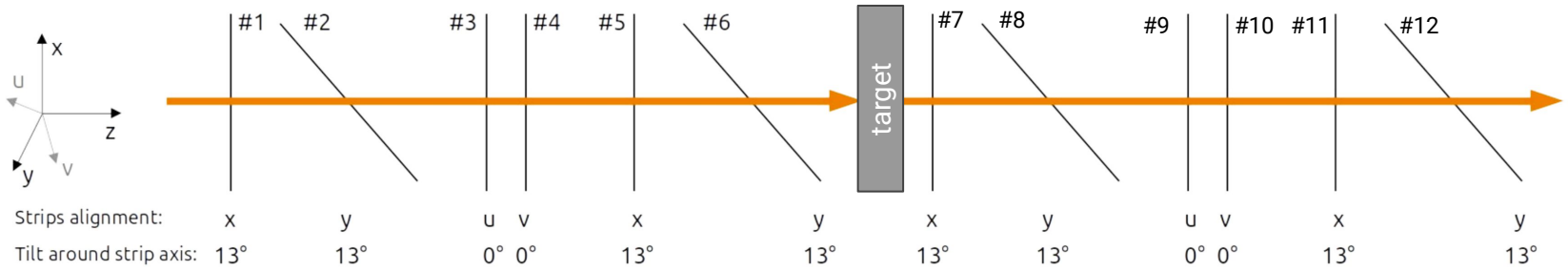


*1 station*

# Experimental Setup II - Additional Components

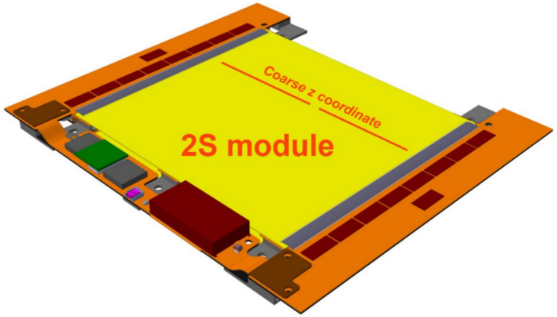
- Complete setup included:
  - A 3rd station for additional modules
  - ECAL for PID
  - Removable 2/3cm carbon graphite target between stations
  - Entirely enclosed in a tent + ventilation for environmental stability

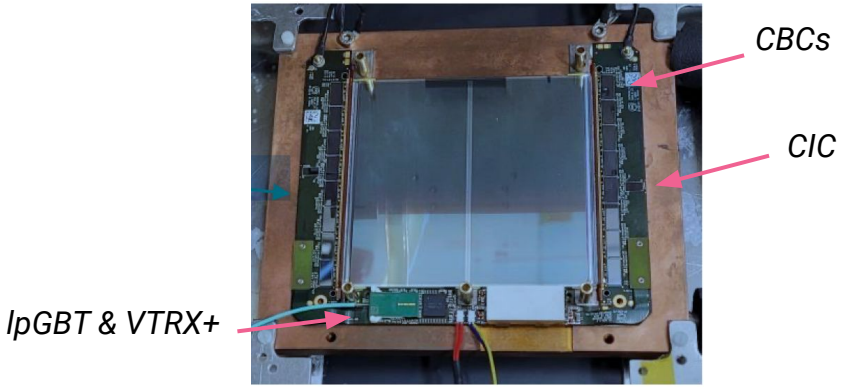


# Experimental Setup III - FE Hardware

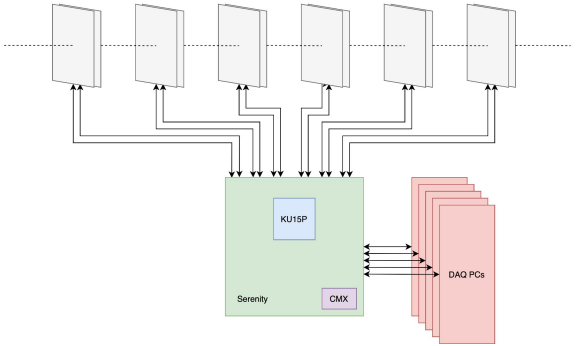
- 2S modules have been developed for the CMS Phase-II Tracker upgrade, composed of 2 layers of silicon strip sensors, whereby hits in the two layers are correlated to form a “stub”
- 10cm x 10cm active area, composed of 2 columns of 1016, 90 µm pitch, strips per layer
- Makes use of CERN-developed lpGBT+VTRx for optical readout at 5 Gbps
- Operates at “LHC” clock rate of 40 MHz
  - Asynchronous to M2 beam
  - Intended for CMS L1 trigger

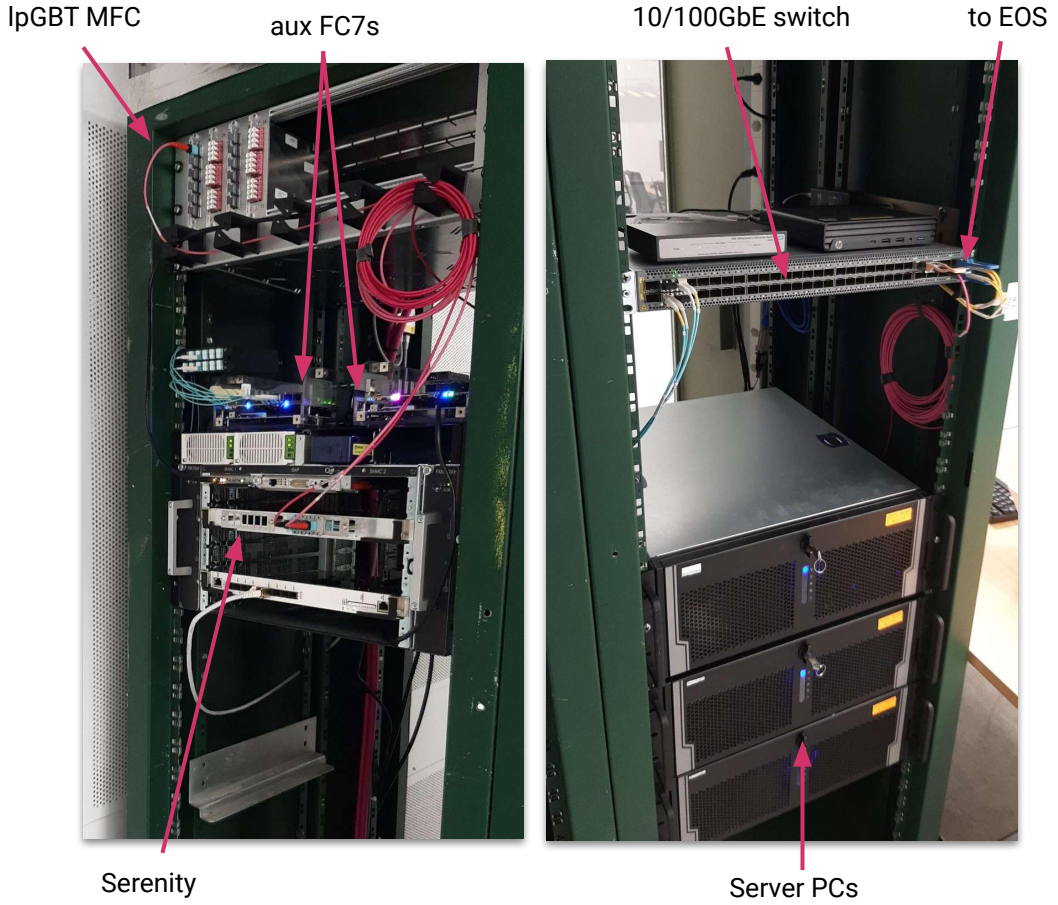


# Experimental Setup IV - Back End Electronics

- Serenity prototype processing card
  - AMD-Xilinx KU15P FPGA
  - Up to 36 lpGBT links (12 used)
  - Multiple 10GbE links to DAQ
  - Intel-based COM-Express SoM for management
- DAQ PCs receive 10GbE data
  - Buffering, packaging, DQM, and ship
  - 100GbE link direct to EOS



# Operations

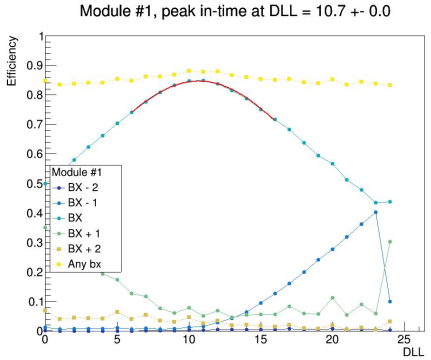
- 23 data taking runs recorded
  - 350 TiB of raw data
  - 24 trillion stubs!
- Live histogramming in firmware at 40MHz to monitor beam and DAQ status in real time
  - Beam profiles
  - Link occupancy
  - Error flags and counts
- All monitoring data aggregated and displayed using Prometheus/Grafana

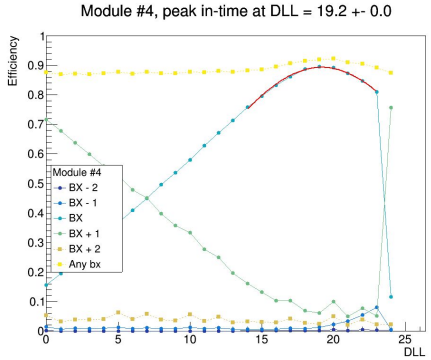
*Zero transient sync/SEU-type errors observed - over 1 month operation!*

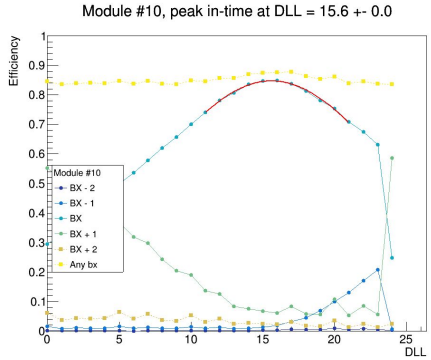
# Commissioning

# Commissioning: synchronisation

- Successful synchronisation of stub data across 12 modules to within 1ns
  - Using (asynchronous) beam



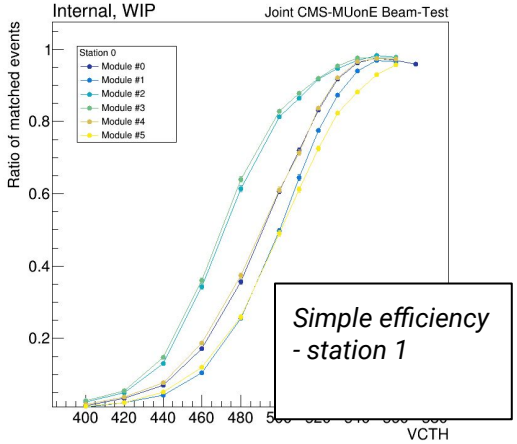



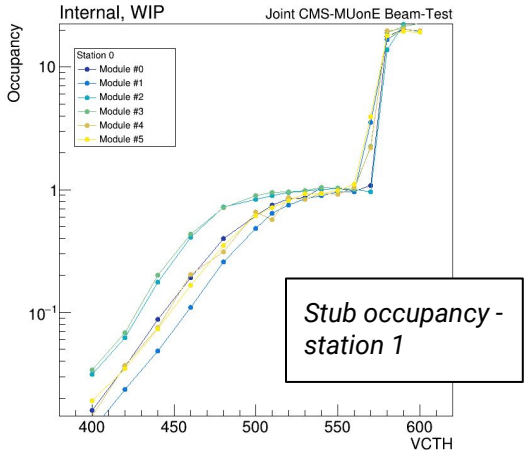

*DLL scans for three example modules*

- Remove ToF and other intrinsic delays wrt module 0
  - DTC shows lpGBTv1 latency is improved by ~1 BX
  - Synchronisation achieved using:
    - FastCommand delays first (BX resolution)
    - CBC DLL tuning (~1ns resolution)

# Commissioning: threshold tuning

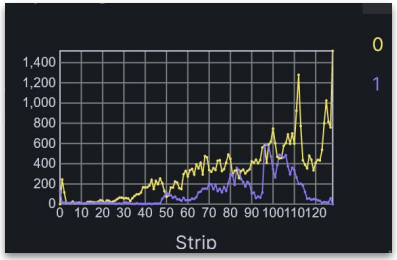
- Threshold scans taken both with and without beam
- When commissioning 2S modules, possible to optimise for efficiency, noise or resolution
  - Not all at the same working point
  - Decision must be taken as to which measurable is most important
- Possible in future to tune individual CBCs on each module to equalise gain differences

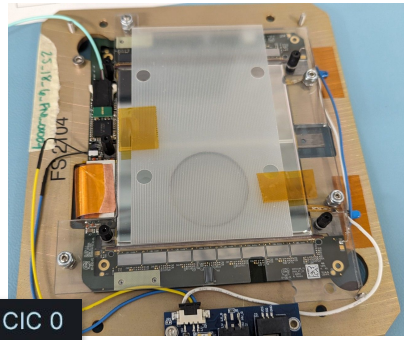


# Commissioning: noise issues

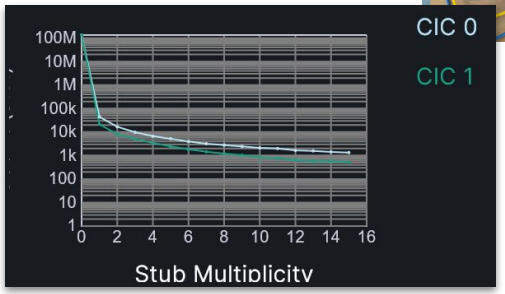
*Module #6*



- Module #6 (FNL_00004) suffered from unexplained noise
  - Not detected using standard offset tuning & noise scan in Ph2ACF
  - Visible from stub data accumulated online ➔ low rate (~4kHz)
  - External (to station) sources ruled out
  - Module arrived with patch to HV - assumed related

- Except module #2 (IPG_00002) spontaneously developed a similar problem towards end of BT
  - No obvious explanation for sudden change
  - Obvious from on/offline data ➔ high rate (~36kHz)
  - Multiplicity quite flat…
  - External (to station) sources ruled out




*Module #2*

- Modules back in lab for further investigations

# Initial Results

R. Pilato

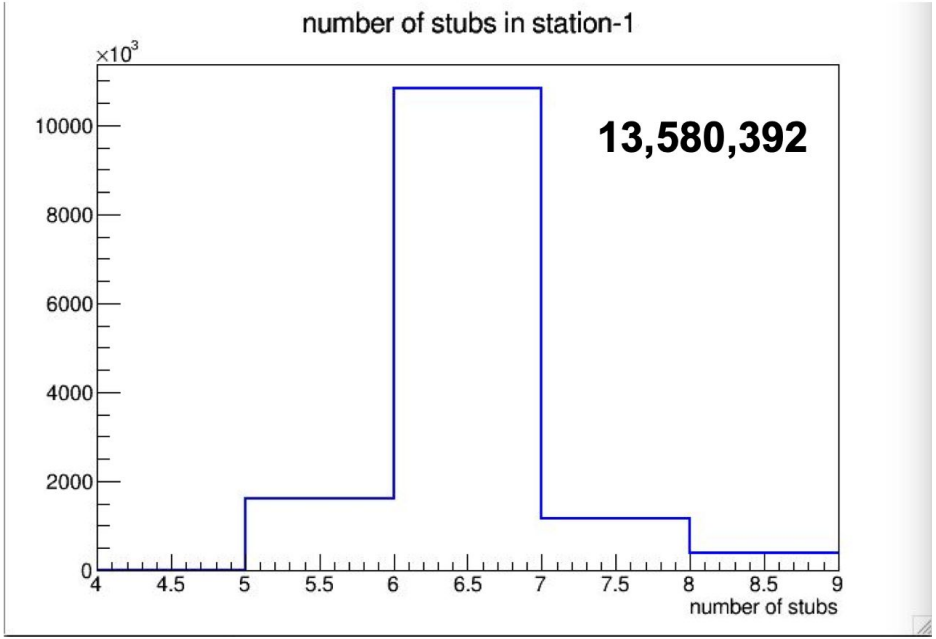
# Initial Results I - Module Efficiency

- Analysis ongoing, strange effects still observed in data
  - All 12 modules show loss of efficiency at high intensity
  - Correlated with beam profile
  - Some worse than others
- No obvious explanation yet
  - CBC truncation ruled out
  - CIC truncation is too small an effect (no evidence so far)
- Plenty of analysis to do here
  - Needs some attention

U. Marconi

# Initial Results II - System-wide Efficiency

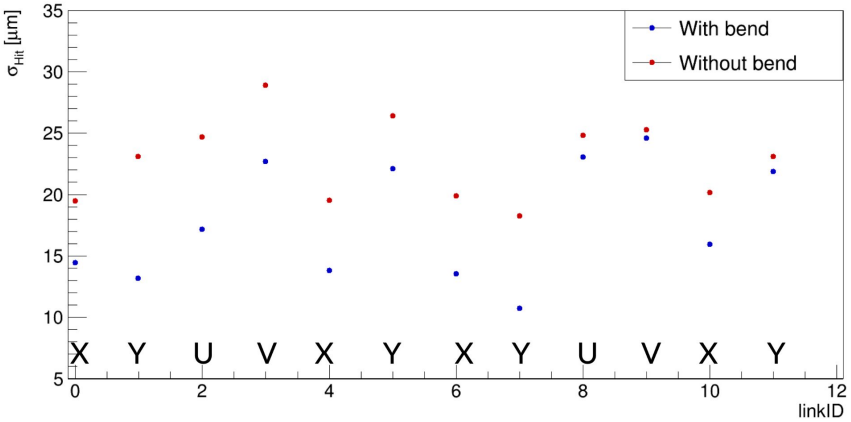
- Simple stub counting seems to show good overall efficiency, suggesting module efficiency measurements are not independent
- Promising result when considering future proposals and timescales
- Studies must now be extended to more complex track reconstruction



R. Pilato

# Initial Results III - Resolution

- Resolution measurement in good agreement with previous CMS beam tests
- Expect ~26 µm for un-tilted modules, less for tilted
- Significant improvement seen when using bend information
- Resolution not consistent between modules in same class - alignment effects?

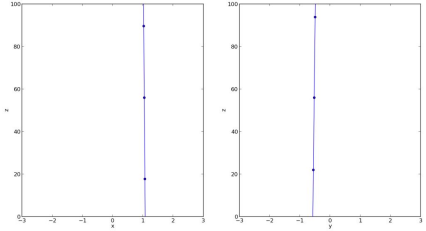



| LinkID | $\sigma_{Hit}$, Bend [µm] | $\sigma_{Hit}$, without Bend [µm] |
|---|---|---|
| 0 | 14.4 | 19.5 |
| 1 | 13.2 | 23.1 |
| 2 | 17.2 | 24.7 |
| 3 | 22.7 | 28.9 |
| 4 | 13.8 | 19.5 |
| 5 | 22.1 | 26.4 |
| 6 | 13.6 | 19.9 |
| 7 | 10.7 | 18.3 |
| 8 | 23.0 | 24.8 |
| 9 | 24.6 | 25.3 |
| 10 | 16.0 | 20.2 |
| 11 | 21.9 | 23.1 |

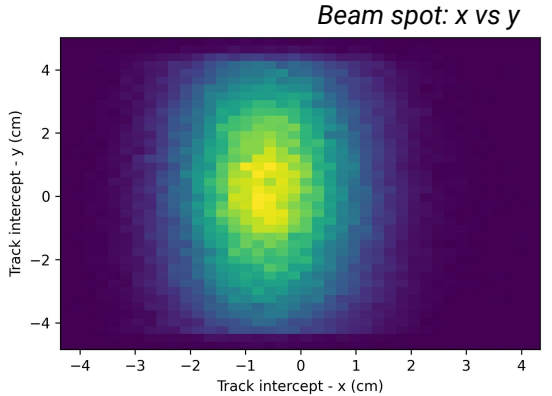
# Landmark Result

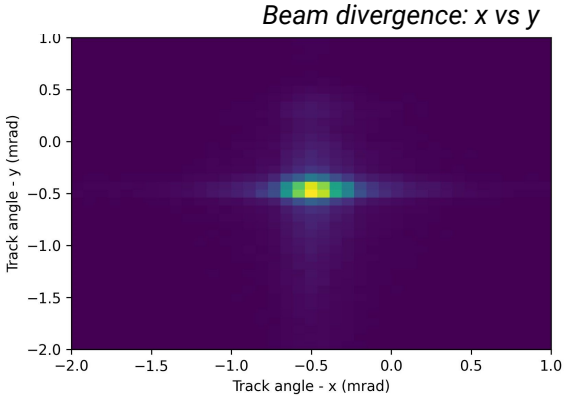
# Online tracking

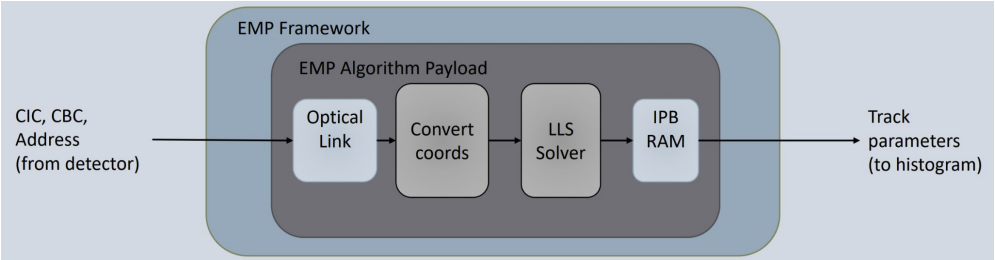
- Online selection of single muon events
  - 1 stub per module per event
  - Separate stream to main DAQ
- HLS based track fitter included in firmware
  - Based on Linear Least Squares (LLS) fit
- First demonstration of online 3D tracking with 2S modules!
  - Track parameters histogrammed in firmware
  - Necessary for future online event selection to limit readout bandwidth



*Event display: single $\mu$*



# Conclusions

# Conclusion

- MUonE and CMS have sustained the 40 MHz readout of Phase-II Tracker modules in several joint test beams
  - 350 TiB of stub data live-streamed to EOS = 24 trillion stubs
  - Strong proof of concept for final DAQ design
- Data quality looks good, efficiency is high for the overall system
- Many candidate events identified, likelihood of extracting “physics” is high!

# Additional Content

- Detailed talk on DAQ for MUonE

- Strategy for hardware event selection

# Backup

# Beam Profiles