40MHz Readout of CMS Silicon Modules in a High Intensity Beam

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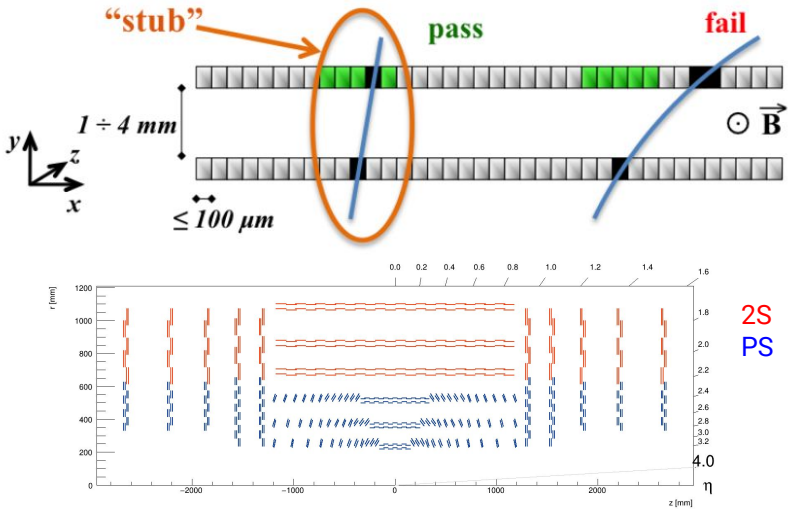
Contents

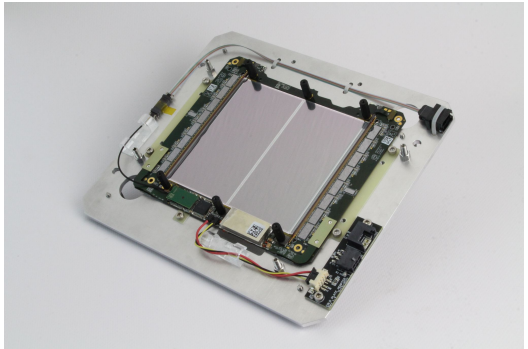
CMS Tracking in HL-LHC

As the LHC moves to a high intensity regime ($\sim 2\times10^{34} \rightarrow 7.5\times10^{34}$ $cm^{-2}s^{-1}$), it will be necessary to include tracking information to the Level-1 trigger of CMS.

Two Strip (2S) modules have been developed for the CMS Phase-II Tracker upgrade, comprising 2 layers of silicon strip sensors, whereby hits in the two layers are correlated to form a “stub”. Stubs are transmitted to the Level-1 trigger system at the 40 MHz LHC clock.

The sensor has a 10 cm x 10 cm active area, composed of 2 columns of 1016, 90 µm pitch, strips per layer.





See Anna’s talk

MUonE

See Anna's poster

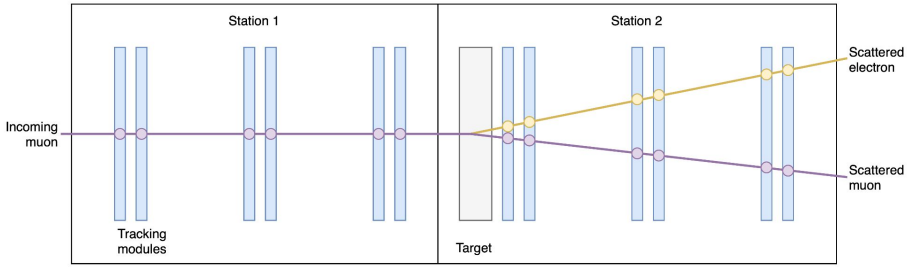
MUonE is a proposed experiment to directly measure the running hadronic contribution to the anomalous magnetic moment of the muon (a_μ^{HLO}).

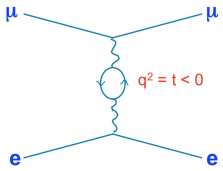
It will be a precision measurement, thus will require accurate tracking and high statistics; 2S modules are proposed to form the tracker of the experiment.

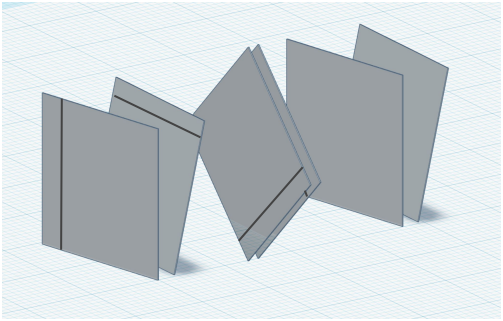
- High resolution
- Capability to readout hit data at 40 MHz

Final experiment will be made up of 40 individual "stations":

- Six tracking planes per station
- Thin target upstream of tracker
- Self-contained unit: manages cooling, power and optical readout of modules







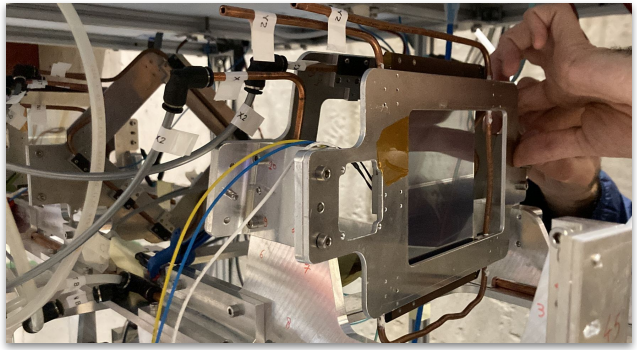
Modules are tilted to increase resolution. Strips are oriented in "x" and "y" directions for outer pairs and rotated by 45° for middle pair ("u" and "v").

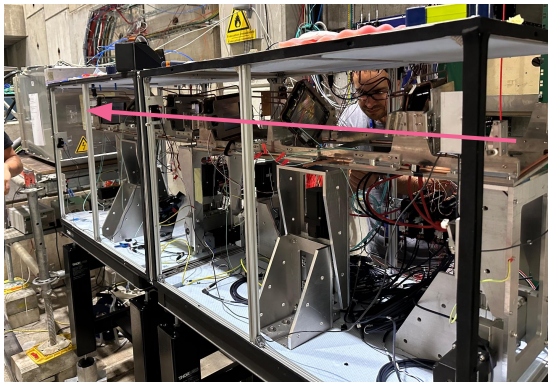
Joint Test Beam 2023 I - Experimental Apparatus

Multiple test beams have been conducted for MUonE, each expanding the capability of the system.

2023 saw 12 2S modules placed in the M2 beamline at CERN:

- Two fully-equipped stations, 2 cm graphite target in between to generate scattering events
- High intensity muon beam, with peak rate of ~50 million muons/second, 5 second spills





Beam direction

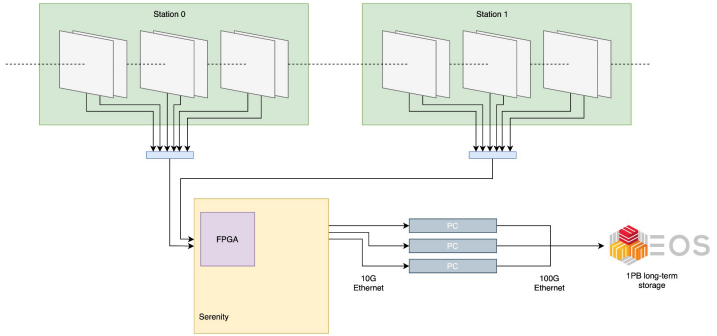
Joint Test Beam 2023 II - DAQ System

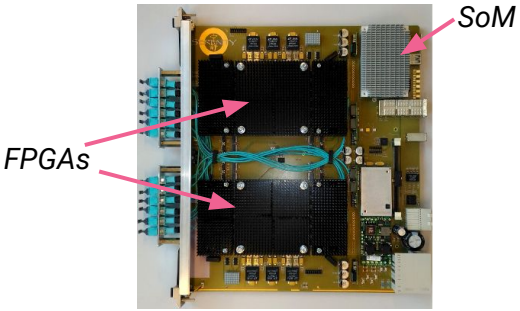
Readout system used for test beam was representative of that which will be used in final system for CMS:

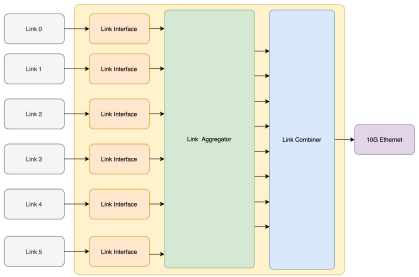
- Used the Serenity prototype card, designed for CMS - two AMD-Xilinx KU15P FPGAs, up to 144 optical transceivers
- Firmware took stubs and formed them into collections based on event ID

Stub data sent at full line rate to PCs over 10 Gbps ethernet:

- Data collected into larger chunks (~1.2 GB) and transferred over 100G ethernet to EOS.
- **Triggerless** - all data saved to disk from every event
- 350 TiB raw data saved to disk = >1.5 trillion stubs







Online Monitoring

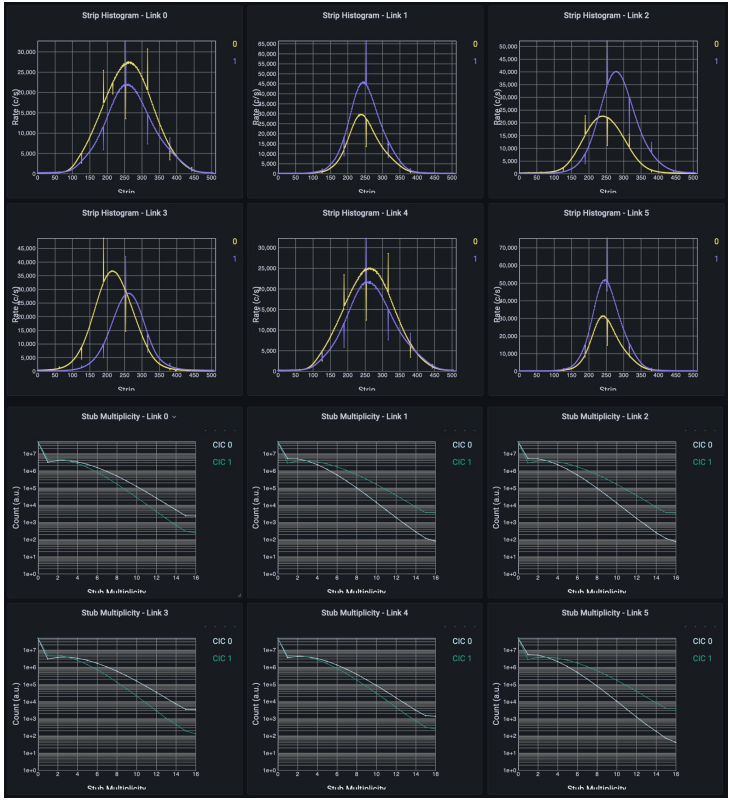
Possibility to make use of both FPGA and SoM on BE processing card for monitoring of DAQ in real-time

Two histogramming firmware blocks integrated into design:

- **Stub Address:** Provides real-time beam profile, generated from every stub sent from FE modules.
- **Packet size**: number of stubs histogrammed for every packet received. Useful for estimating truncation in FE modules.

Histograms are readout to the SoM via IPBus, then exposed as a web page to be scraped by Prometheus instance and plotted in Grafana.

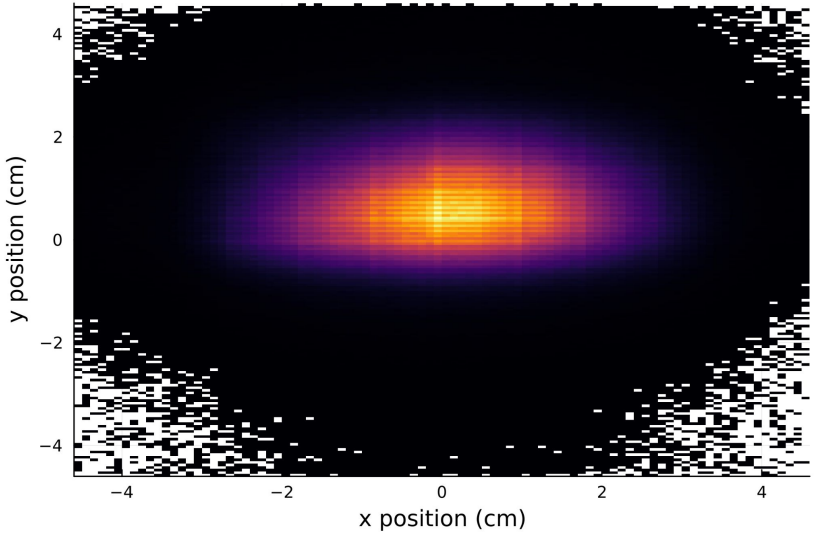
Temperature, humidity sensors also connected as well as CAEN power supply.



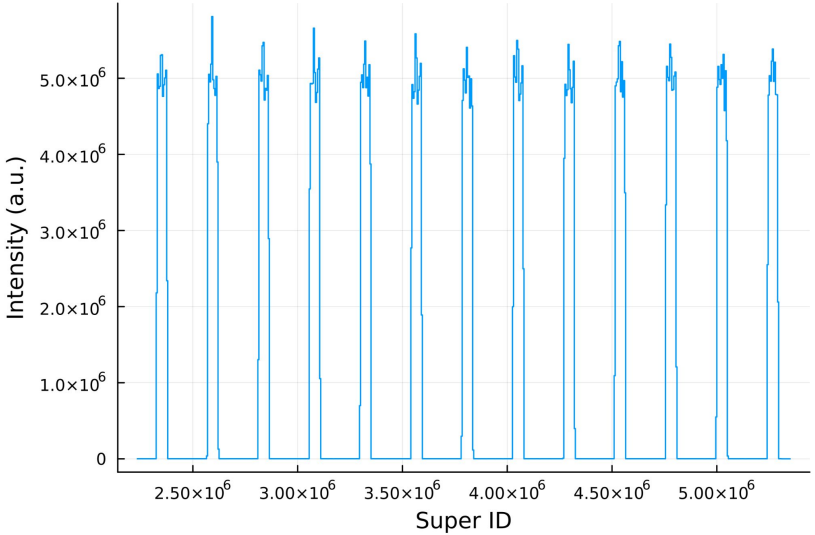
Test Beam Results

Overview

Beam profile



Time series

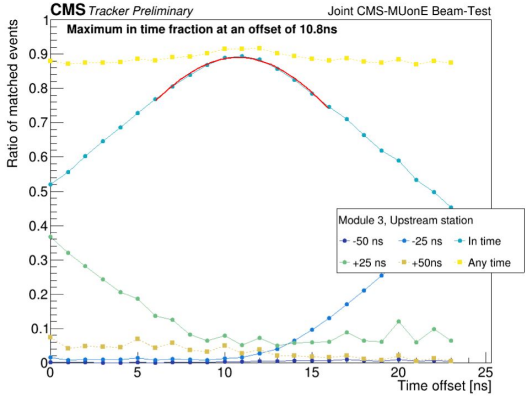


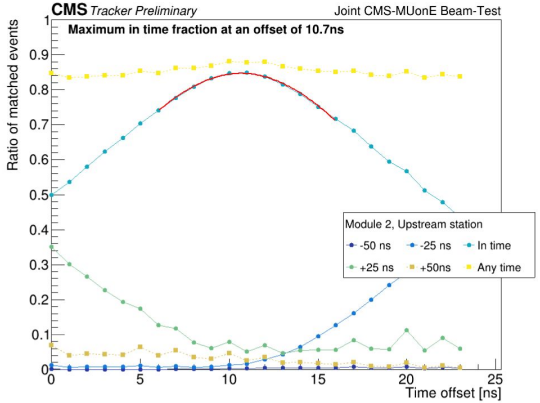
Timing Scans

A synchronised detector is a crucial first step in any tracking system. A DLL in each module allows for the sampling clock to be adjusted in 1ns steps across the 25ns sampling window.

Reference plane set at DLL = 12, other modules scanned between 0 - 25.

Value at which highest fraction of matched events are in time is taken for future configurations.



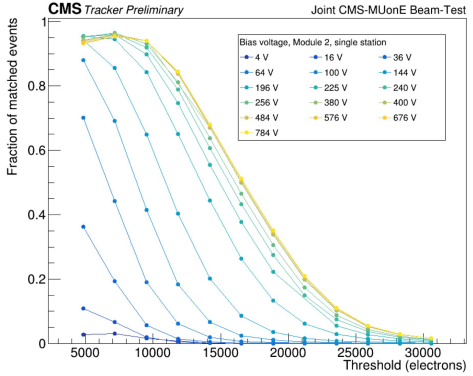


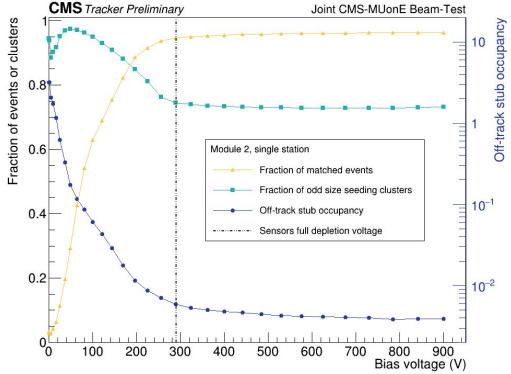
Efficiency vs Threshold

The efficiency of a modules was tested against the binary threshold in the readout electronics and bias voltage applied across the sensor.

Results show complete depletion is achieved above approximately 275V.

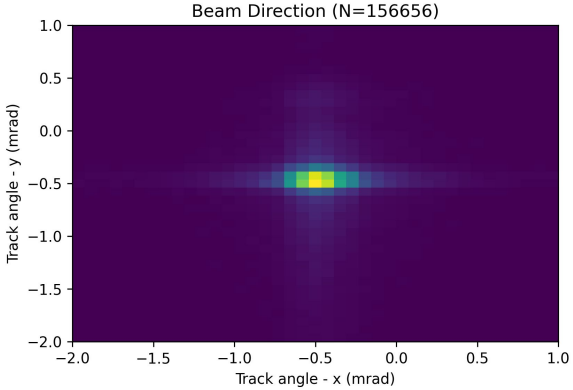
Threshold working point calculated to be ~7500 elections. Below this, the module readout is dominated by noise.

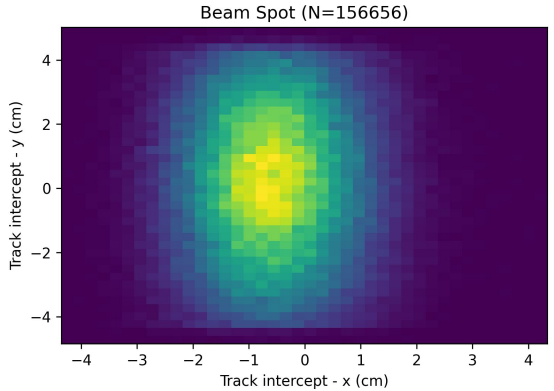




Online Tracking

- Landmark result for the test beam: first achievement of online tracking with CMS Phase-II modules. Demonstrates the concept for CMS.
- Ran on FPGA using High Level Synthesis (HLS) design.
- Simplified linear fit used for straight line, no magnetic field to bend particles.
- Good agreement seen between online and offline distributions of track parameters.





A Look to the Future

CMS

The CMS tracker is now entering the preproduction phase, with over 7500 2S modules planned on being assembled before the end of 2026.

Large scale structures of the tracker will be tested at the Tracker Integration Facility (TIF) at CERN, cosmic rays used to generate hits in the sensors.

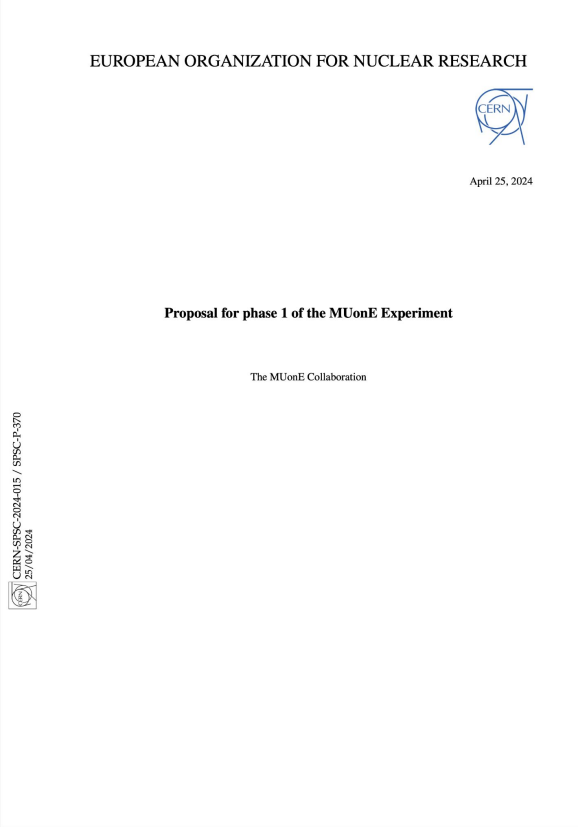
Continued test beams at M2 this year and next will provide the only opportunity for large-scale, high intensity stress tests of the DAQ chain.

MUonE

The MUonE collaboration recently submitted a formal proposal to CERN for its experiment, under review until September this year.

If accepted, the experiment will receive extended running in 2025, 4+ weeks, to perform physics measurements.

Apparatus for 2025 will contain at least 4 stations, doubling the number of modules to be readout by the DAQ system, continuing to push the scale of the tests.


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN

April 25, 2024

Proposal for phase 1 of the MUonE Experiment

The MUonE Collaboration

CERN-SPSC-2024-015 / SPSC-P-370
25/04/2024

Conclusions

To achieve the physics goals of CMS during HL-LHC, the addition of tracking into the Level-1 trigger will be critical. Through the development of the novel 2S modules, this looks set to be achievable.

In test beams such as the M2 test in 2023, the readout of these modules at the full 40 MHz LHC rate has been demonstrated, with the modules showing excellent performance in both time and efficiency.

Both experiments must now expand towards their final systems, with further tests scheduled in the next years to verify the system at scale.