Advancements in the Silicon Tracking System of the CBM experiment: Module series production, testing, and operational insights

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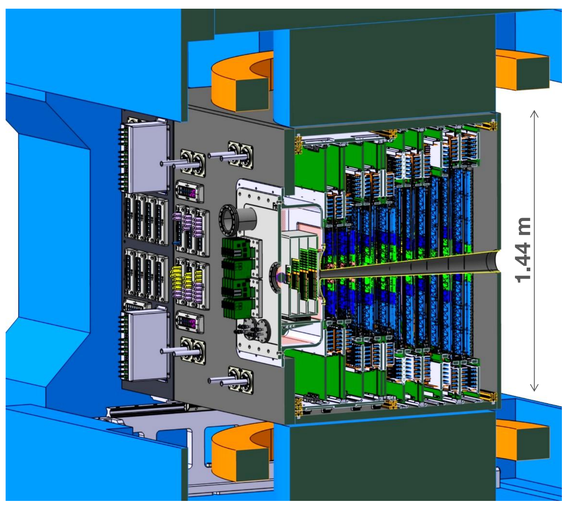
Silicon Tracking System (STS) for the CBM experiment



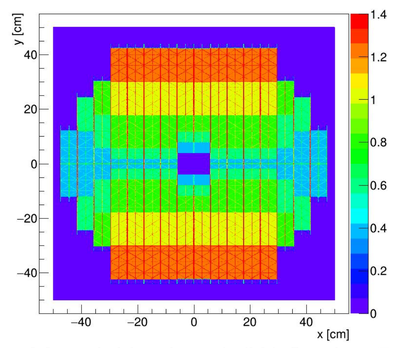
STS inside CBM superconducting magnet

Requirements:

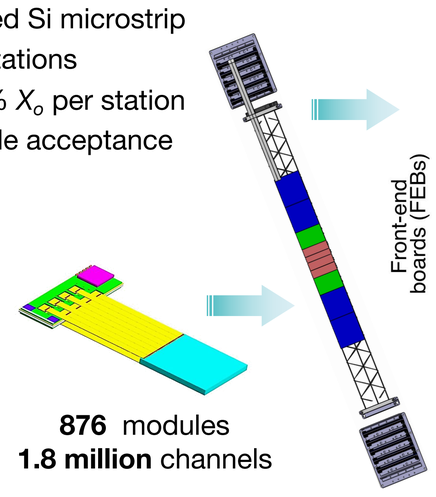
- Space point determination in high-rate collision environment: 10^5 – 10^7/s (A+A), up to 10^9/s (p+A)
- Hit spatial resolution ≈ 25 µm
- $\Delta p/p \approx 1.8\%$ (p > 1 GeV/c, 1 Tm field)
- Hit and track (p > 1 GeV/c) reconstruction efficiency 98% and 96%
- Physics aperture : 2.5° ≤ Θ ≤ 25°
- Self-triggering front-end electronics with free streaming readout
- Online tracking and event selection

Large area, light weight detector assembly

- Approx. 4 m² of double-sided Si microstrip sensors built in 8 tracking stations
- Light-weight: ≈ 0.4% – 1.4% X_o per station
- Front-end electronics outside acceptance

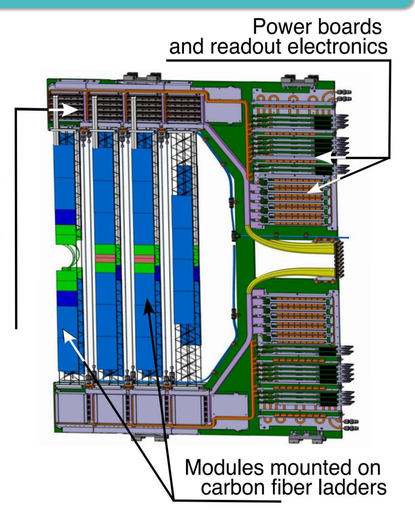


Material budget (x/X_o) Station 7



876 modules
1.8 million channels

106 Ladders



20 half-units

STS detector modules

→ **Large area double-sided, double-metal Si sensors:**

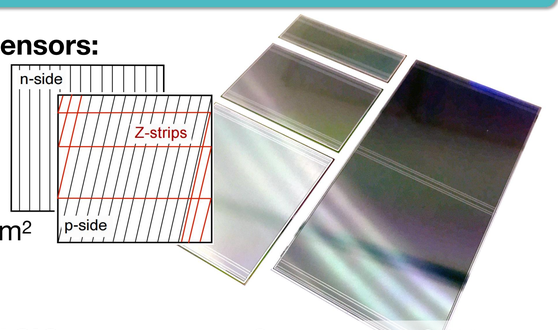
- Thickness: ~300 µm
- 1024 strips/side, 58 µm pitch
- Strip length 2/4/6/12 cm
- 7.5° stereo angle for p-side strips
- Radiation tolerance: 1 × 10^{14} n_{eq} (1 MeV) /cm²

→ **Light weight polyimide microcables**

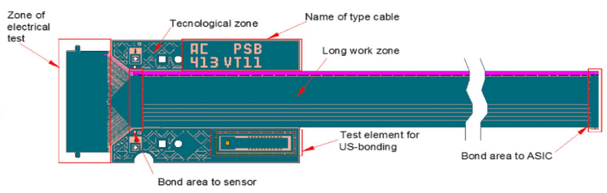
→ **2 Shielding layers**

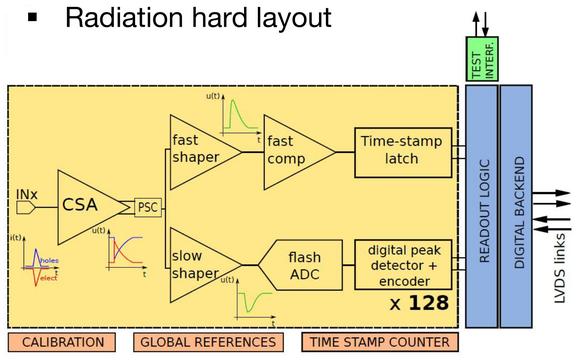
→ **2 Front-end boards (FEB) carrying 16 SMX ASIC:**

- 128 channels operating in both signals polarity
- Time resolution < 5 ns
- 5 bit flash ADC/channel (15 fC dynamic range)
- Power consumption: < 10 mW/channel
- From 1 to 5 data uplinks (9.41 Mhits/s per link)
- Radiation hard layout

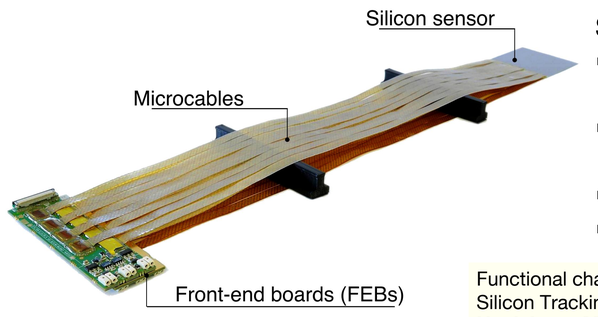


Large area Si sensors for CBM:
2×6 cm², 4×6 cm², 6×6 cm², 12×6 cm²



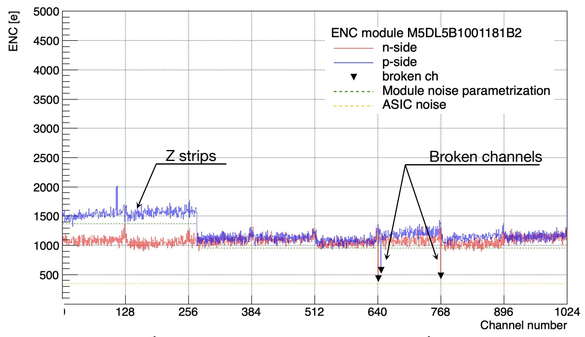


Block diagram of the SMX ASIC



Functional characterization of STS modules

Low noise: essential for the free-streaming detector operation



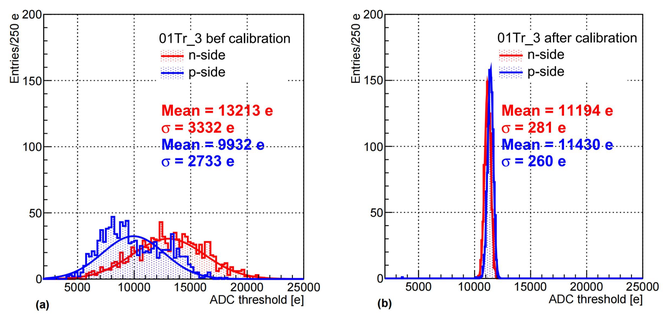
$$ENC[e] = \left[\underbrace{L_{sensor} \cdot 1.02 \frac{pF}{cm}}_{sensor} + \underbrace{L_{cable} \cdot 0.38 \frac{pF}{cm}}_{microcable} \right] \cdot 25 \frac{e}{pF} + \underbrace{350\ e}_{ASIC}$$

ENC parametrization based on the estimated channel's capacitance

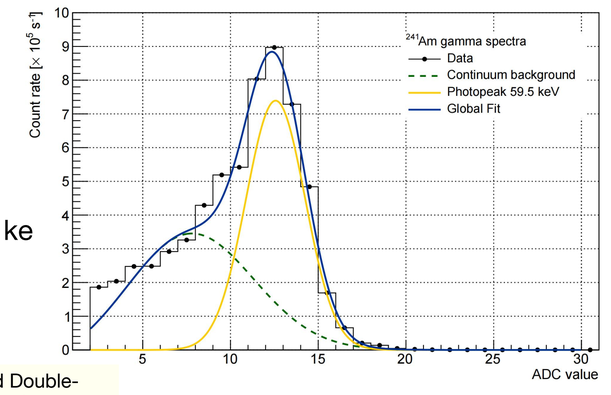
Signal amplitude measurement:

- ^{241}Am gamma spectra reconstructed using a high resolution calibration of the ASIC 5-bit flash ADC.
- Charge collected under the 59 keV photopeak ~ 16 ke (smaller than MIP signals in CBM ~24 ke)
- Charge collection effiency > 96%
- Signal to noise ratio ~15

Calibration of the SMX measuring circuits



Procedure ensures homogenous response among all channels in the module. Channel-to-channel spread reduced by a factor 10.



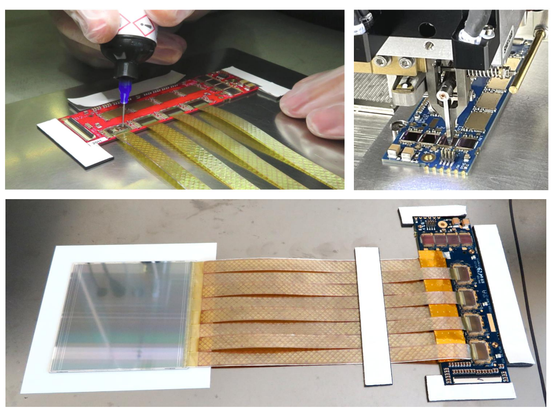
Functional characterization of modules for the Silicon Tracking System of the CBM experiment, **Nucl. Instr. Meth. Phys. Res. A1059 (2024)**

From 3D to 5D tracking: SMX ASIC-based Double-Sided Micro-Strip detectors for comprehensive space, time, and energy measurements, **arXiv:2311.02140v1**

Series production since May 2023

Common effort between two assembly centers: GSI, Darmstadt & KIT, Karlsruhe

MODULE ASSEMBLY



Fully automatized quality control checks during the different stages of the module assembly:

- Testing ASIC functionalities
- Quality of the bonding process by checking the electrical connectivity
- Monitoring the FEBs power consumption

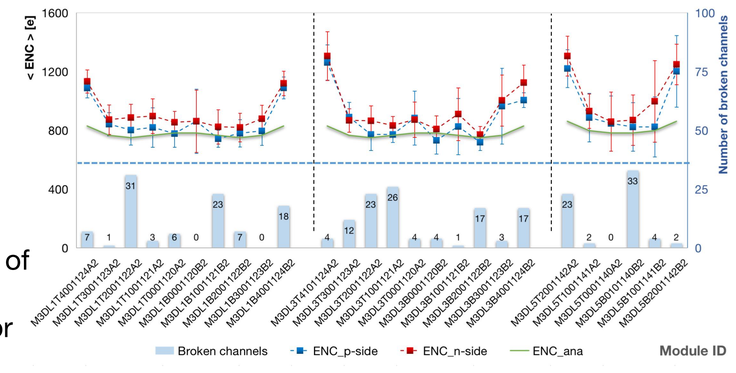
STATUS
30.06.2024

- ☑ **PRODUCED: 190**
- ☑ **TESTED: 83**
- ☑ **ON LADDER: 26**

MODULE TESTING

Two steps procedure:

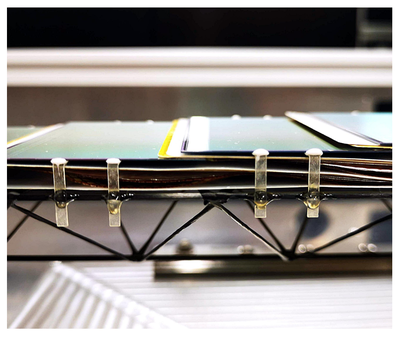
1. Functional characterization of each module
2. Thermal stress test:
   - Thermal cycling between -20°C and 13°C
   - Performance evaluation and reliability check of components and the thermal interface
   - Multiple power-ups reproducing real detector operation

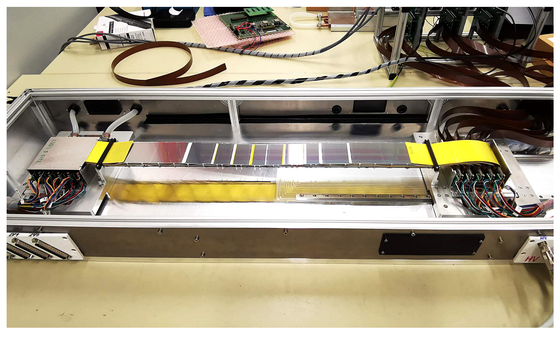


Performance of the first 26 STS modules before assembling onto the ladder

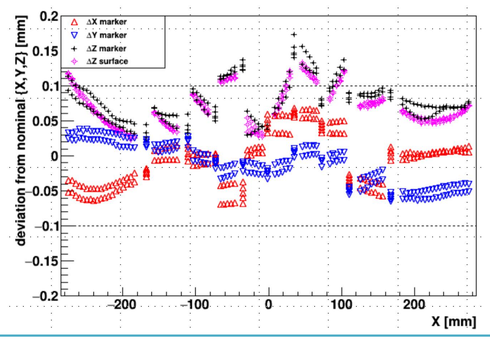
LADDER ASSEMBLY

Mounting of modules onto low-mass carbon-fiber structure





Metrology: High precision required for detector assembling (< 100 µm)

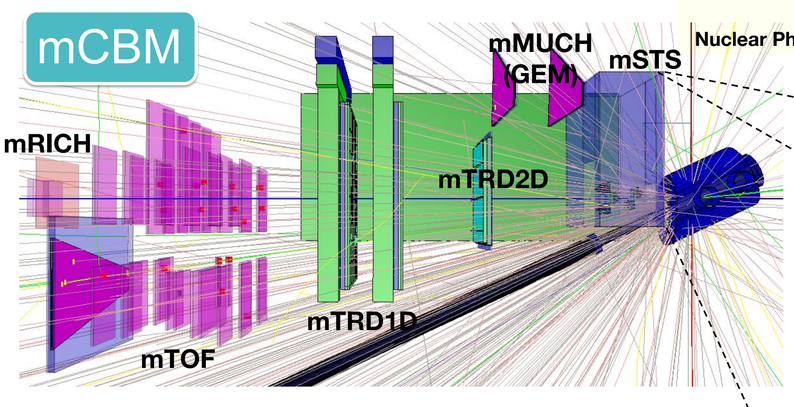


mCBM at SIS18

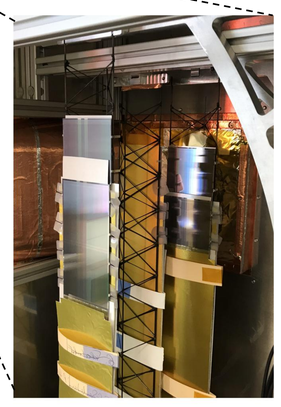
CBM full testing setup for high rate, nucleus-nucleus collisions at GSI/FAIR SIS18

Goals:

- Verification of CBM free streaming read-out and data transport
- Test of prototype and pre-series detectors: connection scheme, hardware test, achieved occupancies
- Demonstrator for full CBM operation, data taking and online analysis



First Λ Baryons for CBM
Nuclear Physics News, 33(2), pp. 36–37

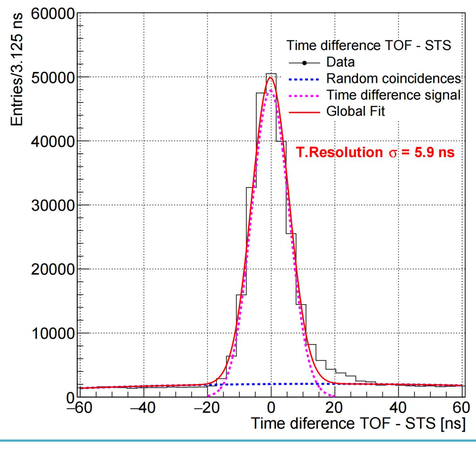


mSTS at mCBM:

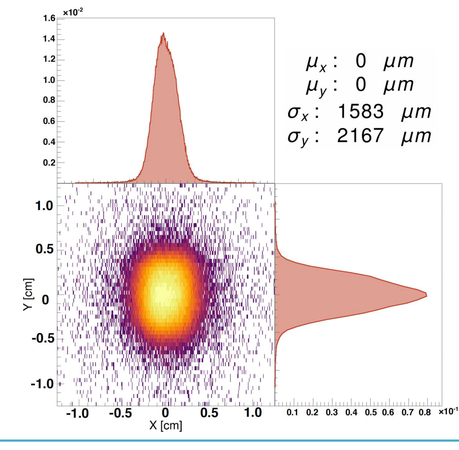
- 3 tracking stations built from 12 detector modules
- More than 20 000 readout channels (1.3% of full STS)
- Operation up to readout saturation rates

Vertex reconstruction and tracking performance of the STS detector with the mCBM setup at SIS18, **PoS, vol VERTEX2023 (2024), pp. 064**

STS time resolution **~6 ns** (relative to ToF detector, after time-walk correction)



Ni + Ni 1.93 GeV/u (May 2022)
Event vertex reconstruction combining multiple detectors: mSTS, mTRD & mTOF



STS Project:

Key participant institutes:

- Germany: GSI *Darmstadt,* Univ. Tübingen, Univ. Frankfurt, KIT *Karlsruhe*
- Poland: AGH *Krakow,* JU *Krakow,* WUT *Warsaw*
- Ukraine: INR, *Kyiv*
- Japan: KEK (assoc.)

Timeline:

- Production Readiness: Jun. 2019
- Detector construction: 2023 – 2026
- Ready for installation into CBM: from 2026

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