Recent developments in the Silicon Tracking System of the CBM experiment towards starting system assembly

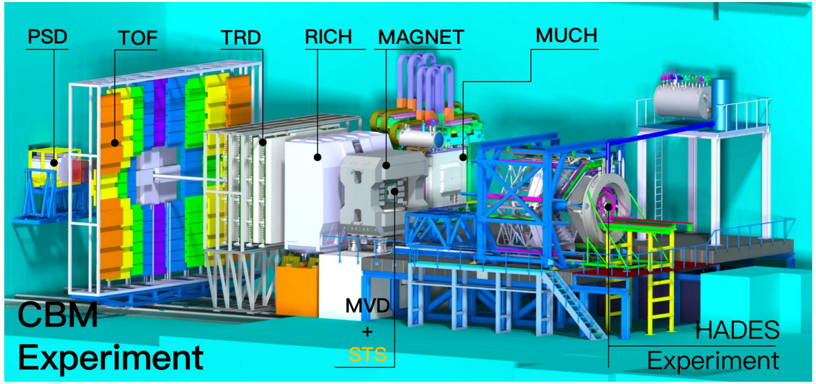
Adrian Rodríguez Rodríguez (a.rodriguezrodriguez@gsi.de), GSI Helmholtzzentrum, *for the CBM Collaboration*

ABSTRACT:

The Silicon Tracking System (STS) is the main tracking detector of the CBM experiment. It is designed to reconstruct trajectories of charged particles with high efficiency, to achieve momentum resolution better than 2% inside a 1 Tm magnetic field, and to be capable of identifying complex decay topologies. The main STS functional building block is the detector module. It consists of a double-sided silicon sensor connected through a stack of low-mass microcables to the custom-developed readout ASICs on two front-end electronics boards. 876 modules are arranged in 8 tracking stations, where 1.8 million channels are read out with self-triggering electronics, matching the experiment's data streaming and online event analysis concept.

Currently, the construction of the STS detector advances on multiple fronts: finalizing and testing the mechanical design, testing of the cooling concept via a thermal demonstrator, and the assembly of 3 ladders comprising 30 modules with the final components and procedures for the so-called pre-series production phase. The latter task is essential for testing the assembly concept of the final detector and requires a thorough quality control to ensure reliable performance of the modules and a high production yield. For this purpose, multiple quality control steps have been implemented before and during the assembly of the components and the necessary hardware and software has been developed. This work will present an overview of the results of systematic testing of the STS modules and components, and the most significant achievements and challenges in the detector mechanical assembly and integration.

THE COMPRESSED BARYONIC MATTER (CBM) EXPERIMENT



Fix target experiment

Triggerless, free-streaming readout chain:
- Self-triggered Front-end electronics
- Powerful computing farm for 4D (x, y, z, t) tracking and online event reconstruction.

- **GOAL:** to explore the QCD phase diagram at high net-baryon densities and moderate temperatures, searching for:
  - Equation of state of nuclear matter at high densities
  - First-order phase transition from hadronic to partonic matter and critical point
  - Signatures of chiral symmetry restoration
- **UNIQNESS:** high interaction rates (10^5-10^7 Hz); ideal for systematic, high precision studies of high-density nuclear matter.
- **ENERGY RANGE @ SIS100**
  - ions: 10^9/s, 2-14 GeV/u, $\sqrt{s_{NN}}$= 1.9 - 4.5 GeV
  - protons: 10^{11}/s up to 29 GeV

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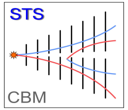
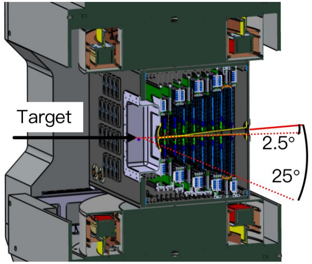
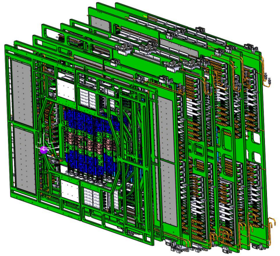


THE SILICON TRACKING SYSTEM

Tracking and reconstruction of high multiplicity collisions



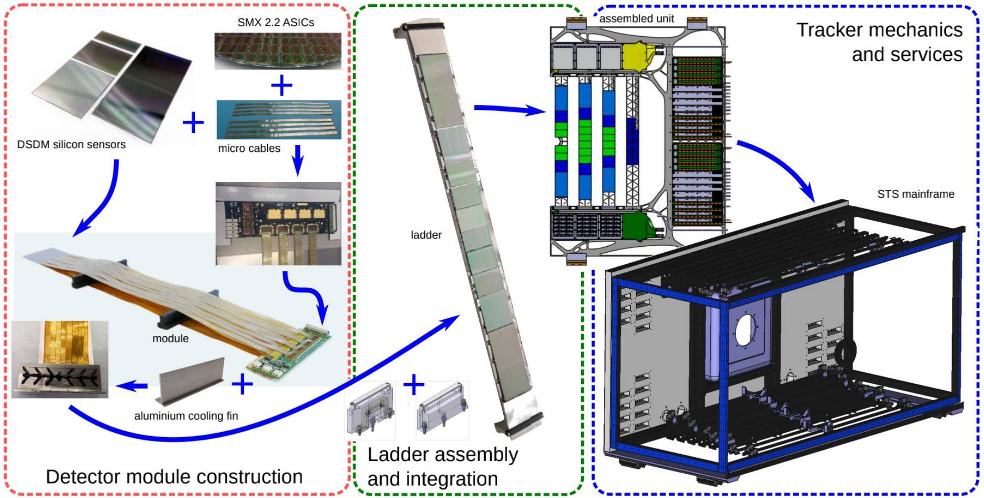
- 8 trackingsStations built with double-sided microstrip silicon sensors;
- Physics aperture: 2.5° ≤ Θ ≤ 25°
- Low material budget design, front-end electronics out of the physics acceptance;
- high efficiency ~97% for p > 1 GeV/c;
- excellent momentum resolution <2%;
- radiation hard: withstand up to 10^{14} 1 MeV n_{eq} cm^2.



Detector module as a functional unit:

- Double-sided silicon sensor.
- Stack of Al-polyimide readout cables (length up to 50 cm).
- 2 front-end boards (2 × 8 ASICs).
- 2 Al shielding layers operated at high potential.

ASSEMBLY SEQUENCE & STRUCTURE



STS in numbers:

- 876 modules, 106 ladders, & 14 000 r/o ASICs, & 7 000 LDOs
- Large number of unique components: 199 module variants, 38 ladder types

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MODULE ASSEMBLY COMPONENTS:

Double-sided Si microstrip sensors

- 1202 sensors were received and inspected
- Optical and Electrical quality grades were given according to the test results

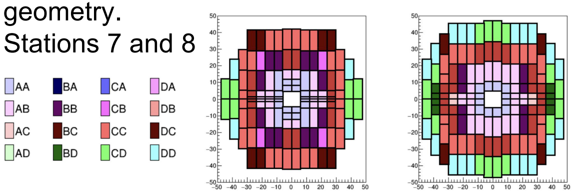
QC Electrical tests

Sensor size	Grade A	Grade B	Grade C	Grade D
22 mm	99	3	4	0
42 mm	267	20	50	0
62 mm	256	28	44	21
124 mm	222	37	84	47

QC Optical tests

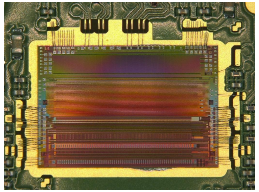
Sensor Size	Grade A	Grade B	Grade C	Grade D
22 mm	93	13	2	0
42 mm	296	50	3	0
62 mm	185	144	19	5
124 mm	114	125	107	35

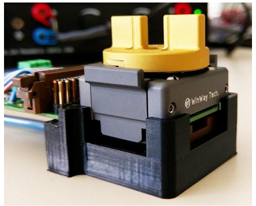
Electrical + Optical results projected on STS geometry.
Stations 7 and 8



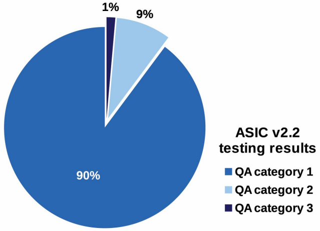
STS front-end electronics

- SMXv2.2 produced in Q4 2020
- Pilot production ~ 2000 pieces available since December 2020.
- ASICs tested and characterized before module assembly using a pogo-prober station.
- E-FUSED with unique ID number.
- Very good production yield (~90% good).



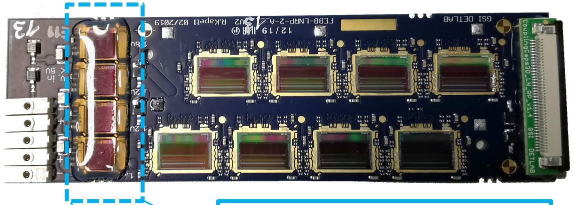


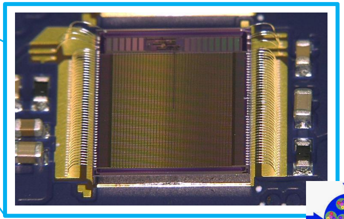
Pogo–prober station for ASIC test



Front-end boards (FEBs) and LDOs

- Final prototypes of FEB-8_2 (2 LVDS uplinks/ASIC) in production
- 2 flavours of FEB-8_5 (5 LVDS uplinks/ASIC) first prototype in production.
- LDO 1.2 and 1.8 V: full production done





Linear Voltage regulator used in FEB8

QM QUARK MATTER KRAKÓW 2022

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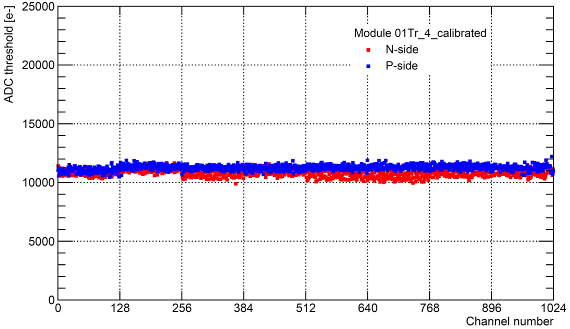
QUALITY CONCEPT FOR MODULE TESTING & CHARACTERIZATION:

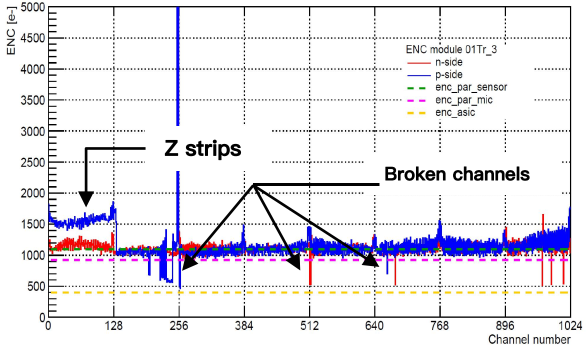
SEQUENTIAL TEST (Time ~4 hours)

- Connect & Power up
- Communication
- ASICs configuration / LV Current measurement / Write/Read ASICs registers
- Analog response check
- HV biasing / Sensor IV measurement
- Calibration of the measuring circuits
- ENC measurement / Check of calibration parameters
- Full data stream read out

THERMAL TESTS



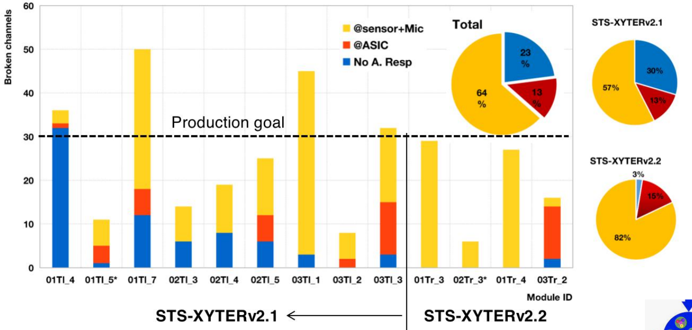
Threshold distribution for a module after calibration



ENC distribution across all channels in the module

KEY POINTS:

- Threshold homogeneity achieved for both polarities (channels spread reduced 10 times after calibration)
- Design goal of 1000 e- ENC is achievable.
- Broken channel milestone (below 1.5%) is also in our grasp.
- The ESD structure in the front-end electronics brings a significant improvement to the channel's protection.



Broken channels distribution for multiple produced modules

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CHALLENGES OF THE STS COOLING CONCEPT:

POWER DISSIPATION:

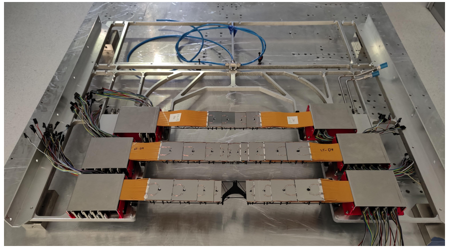
- 40 kW from front-end electronics.
- 10 kW from the LV power cables and through the walls of an insulation box.
- Up to 6 mW/cm^2 from irradiated sensors.

ELECTRONICS COOLING – MONOPHASE 3M NOVEC 649

- Coolant (NOVEC 649) temperature at -40° C.

SILICON SENSOR COOLING – AIR COOLING

- Perforated carbon fiber tube running along the sensors.
- Sensors cooled down to below -7° C to avoid thermal runaway

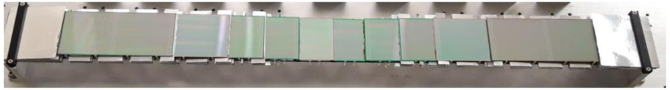


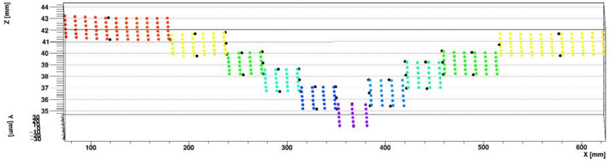
RECENT DEVELOPMENT:

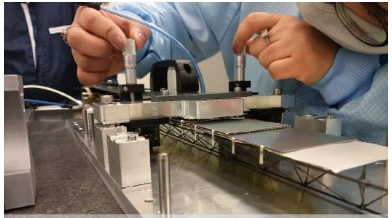
Thermal demonstrator under construction to experimentally prove the feasibility of STS concepts in realistic boundary conditions

LADDER ASSEMBLY ASPECTS:

- Every module after testing is mounted on the light-weight carbon structures: ladder.
- From 8 to 10 detector modules installed on one ladder.
- Optical metrology performed in a dedicated setup (table with camera) and measured precision in O(10µm).







Positioning the Sensorholder, here: mSTS

MECHANICAL INTEGRATION ASPECTS:

- 876 modules, 106 ladders, ~14 876 modules, 106 ladders, ~14000 r/o ASICs, and 7000 LDOs
- Large number of unique components: 166 module variants, 38 ladder types