The high count-rate self-triggering Silicon Tracking System of the CBM experiment at FAIR – *design, series assembly, upgrade options* –

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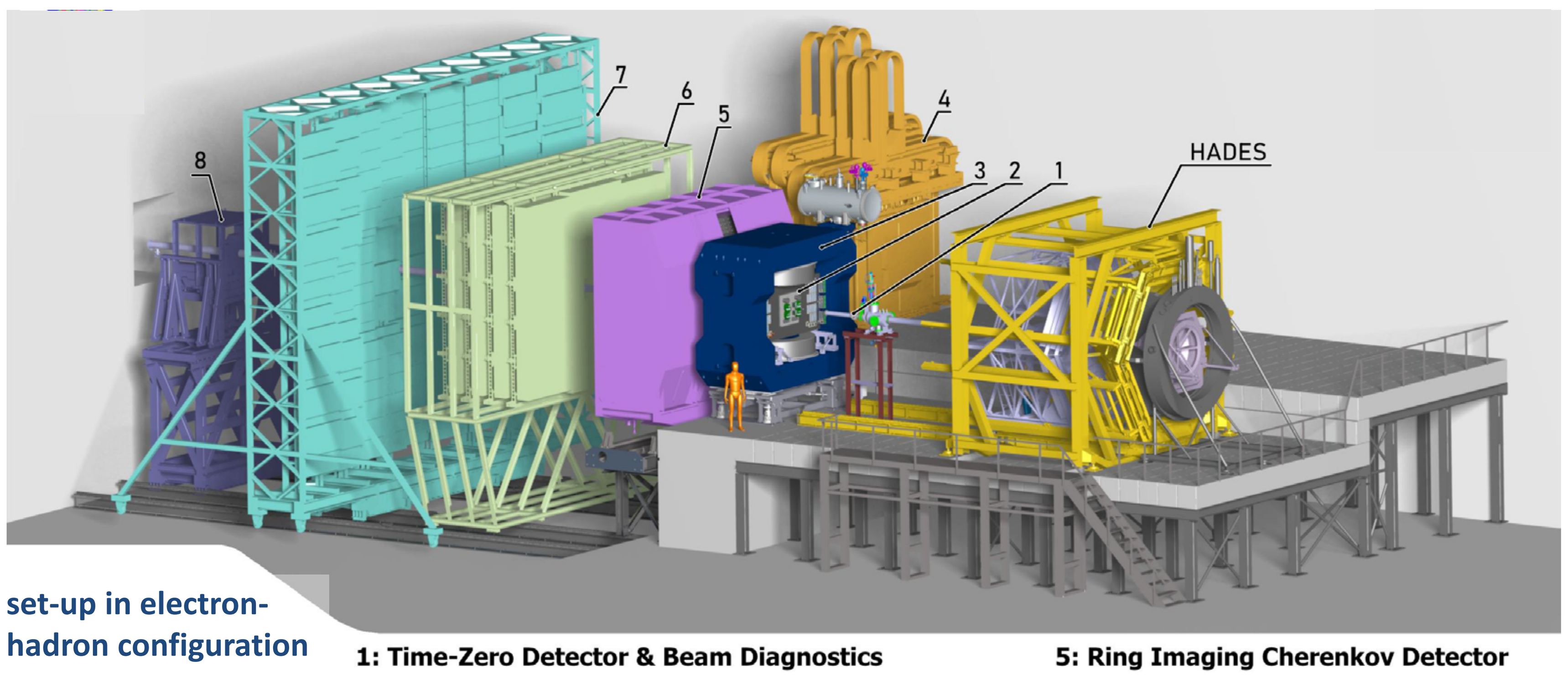
The Compressed Baryonic Matter (CBM) experiment at FAIR



set-up in electron-hadron configuration

HADES detector for separate running

1: Time-Zero Detector & Beam Diagnostics
2: Silicon Tracking System / Micro Vertex Detector
3: Superconducting Dipole Magnet
4: Muon Chambers
5: Ring Imaging Cherenkov Detector
6: Transition Radiation Detector
7: Time of Flight Detector
8: Forward Spectator Detector

Physics aim

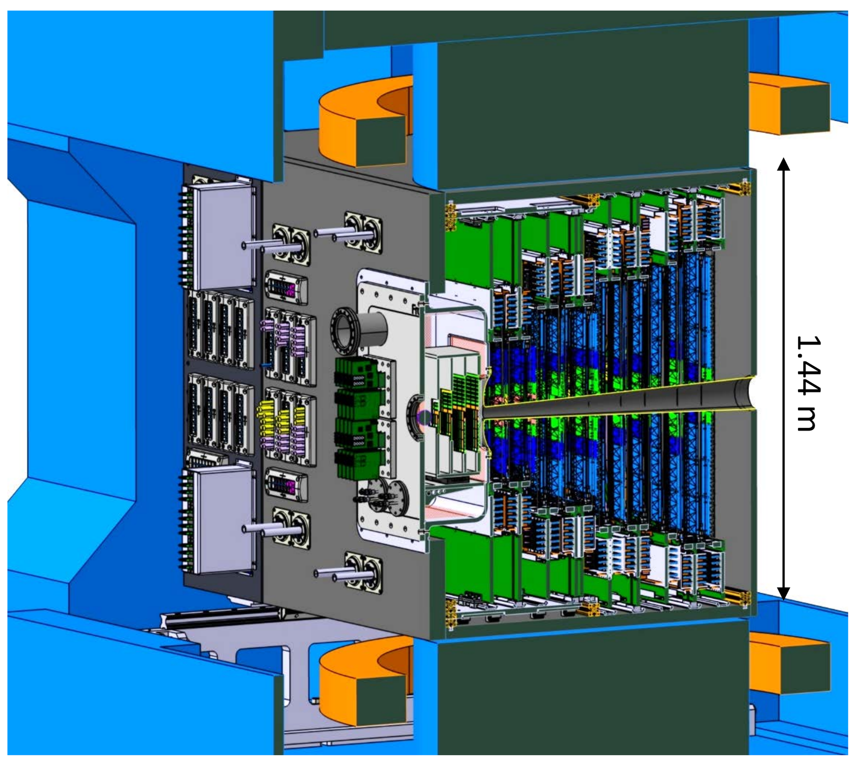
- Exploration of the QCD phase diagram at high net baryon densities and moderate temperatures
- Starting with SIS100 projectile energies: 2 ÷ 11 GeV/nucleon ≡ $\sqrt{s_{NN}}$ = 2.7 ÷ 4.9 GeV, protons up to 29 GeV

Observables

- Hadrons, electrons, muons, photons
- Particle yields and multi-differential cross-sections
- Rare diagnostic probes: strange mesons, light vector mesons (ρ, ω, ϕ), charm production

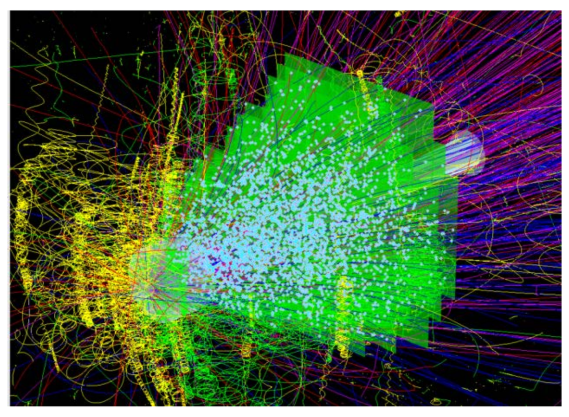
Challenges in QCD matter physics – The scientific programme of the CBM experiment at FAIR
Eur. Phys. J. A 53, 60 (2017), https://doi.org/10.1140/epja/i2017-12248-y

The Silicon Tracking System (STS)

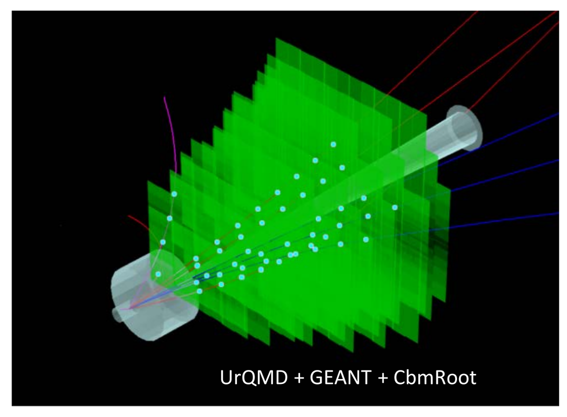


STS in the gap of the superconducting dipole magnet

- pile-up free track point determination in high-rate collision environment: 10^5 – 10^7/s (A+A), up to 10^9/s (p+A)
- physics aperture: 2.5° ≤ Θ ≤ 25°
- 8 tracking stations in 1 Tm dipole magnetic field, distance from target: 0.3 m ÷ 1.0 m
- hit spatial resolution ≈ 15 µm
- self-triggering front-end electronics, data streaming to compute farm for on-line track and event determination
- time-stamp resolution ≈ 5 ns
- material budget: 0.3% X_0 ÷ 1.4% X_0 per station
- momentum res.: Δp/p ≈ 1.8% (p > 1 GeV/c)



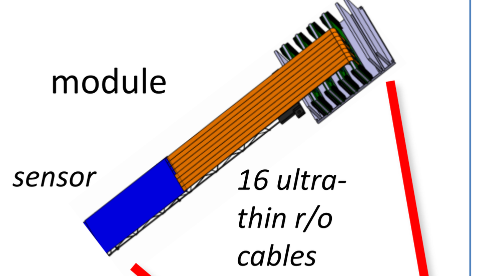
central Au+Au, 8 GeV/nucleon
~ 350 charged particles/collision
10^5 – 10^7 collisions/s



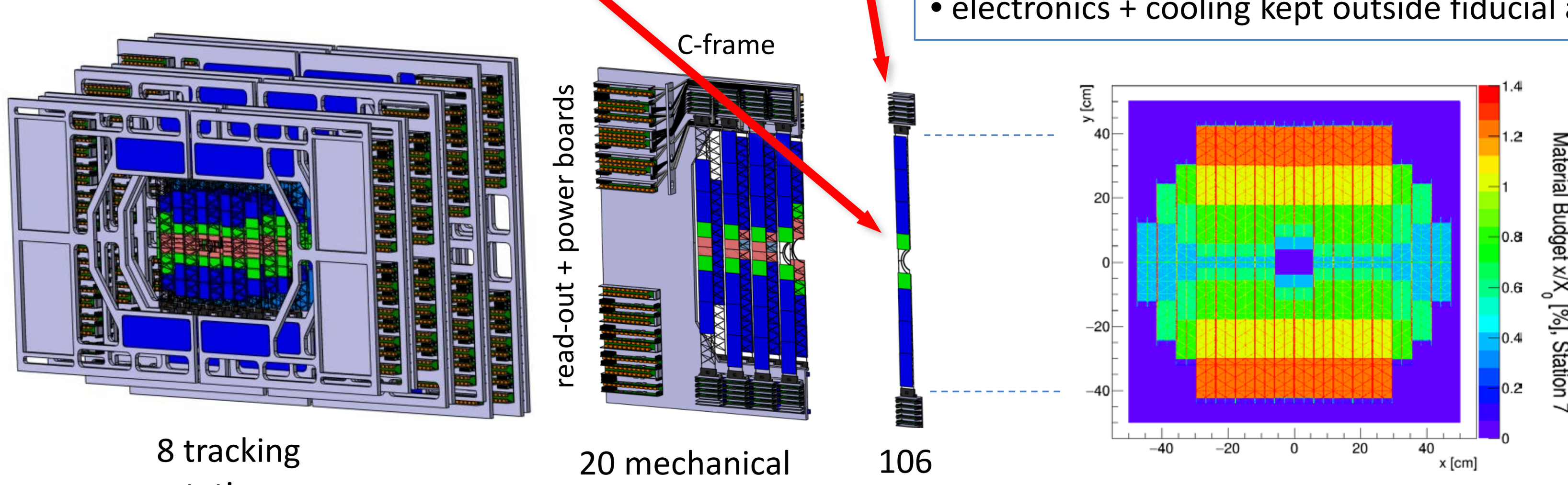
p+C, 29 GeV
few charged particles/collision
up to 10^9 collisions/s

Design and Integration

- 876 detector modules
  - double-sided, double-metal Si microstrip sensor
  - 2 FEE boards with 2× 8 STS-XYTER ASICs, 2048 ch.
  - 16 ultra-thin r/o cables, Al-Polyimide, 5÷50 cm long

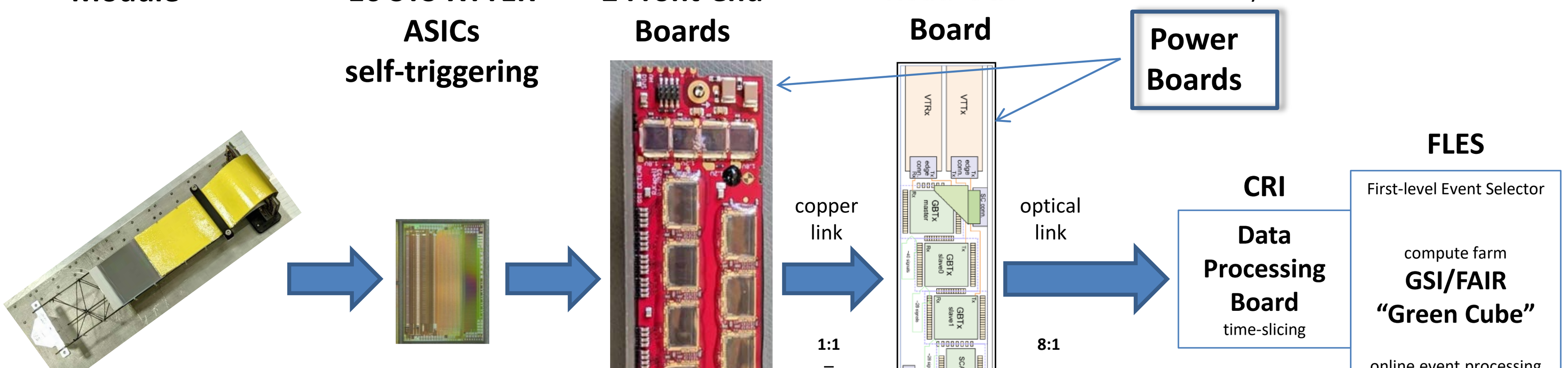


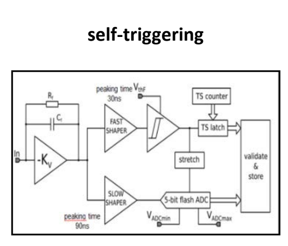
- 106 detector ladders with 8/10 modules
- integration on 20 half-units / 8 tracking stations
- mounting into thermal enclosure
- power dissipation: ≈ 40 kW
  - electronics: liquid cooling (NOVEC)
  - sensors: dry air cooling
- sensor operation at T ≥ 0° C
- electronics + cooling kept outside fiducial area



8 tracking stations | 20 mechanical half-units | 106 ladders

Read-out Electronics, Data Acquisition Chain





STS-XYTER ASIC	*v2.2 (produced 2020/22)* **2016 JINST 11 C02024**
CMOS process	*UMC 180 nm*
channels	128, polarity +/-
noise	< 1ke⁻ at 20-50 pF load
ADC range	linear up to12 fC, 5 bit
clock	250 MHz
power	< 10 mW/channel
timestamp	~5 ns resolution
out interface	5 × 500 Mbit/s LVDS

8 STS-XYTER, 4 LDO

STS-XYTER ASICs
à 1/2/5 LVDS E-links out
time-stamped data

GBTx chip-set (CERN):
3 GBTx, 1 VTRx, 1 VTTx, 1 SCA
42 E-links à 320 Mb/s
3 GBT optical uplinks à 4.48 Gb/s

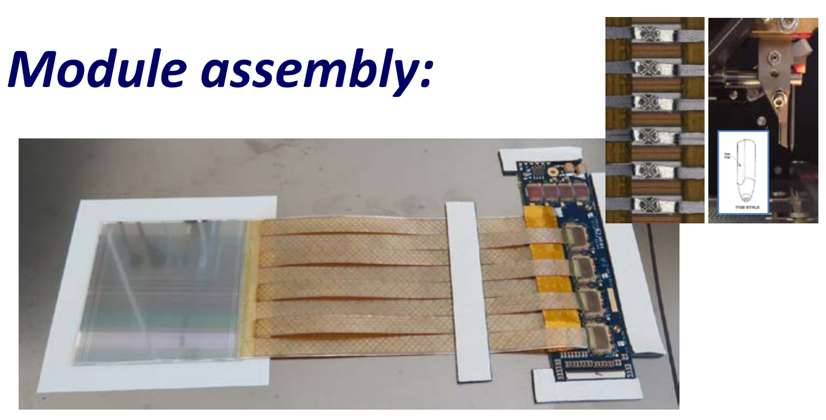
prototype free-streaming DAQ system

CROB prototype available, ROB under development

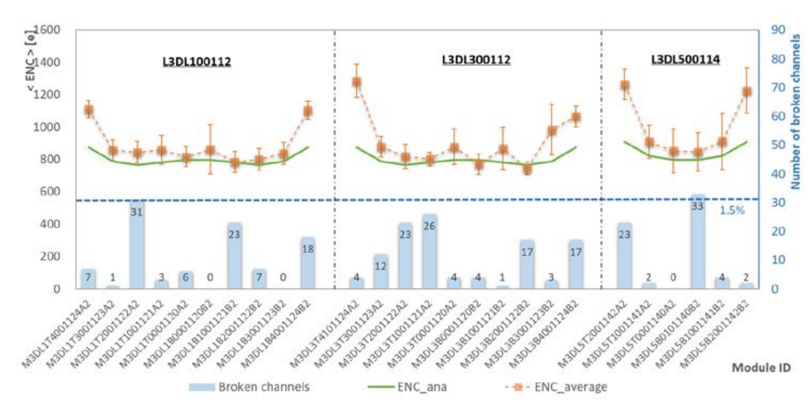
operating in beam at mCBM

Modules and Ladders – Series Assembly

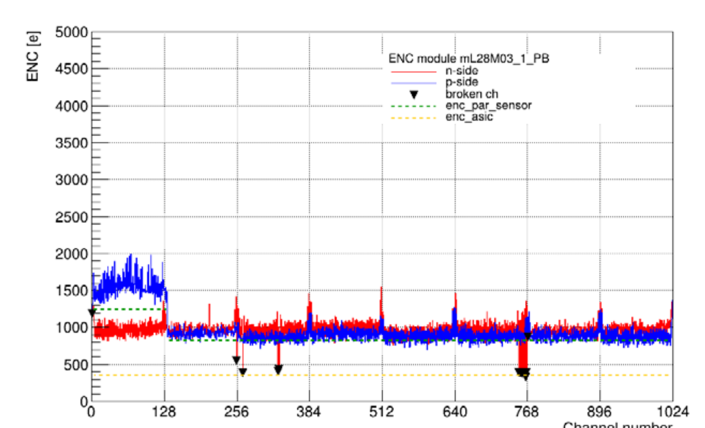
Module assembly:



tab-bonding of Al-polyimide micro cables between sensor and ASICs/front-end boards



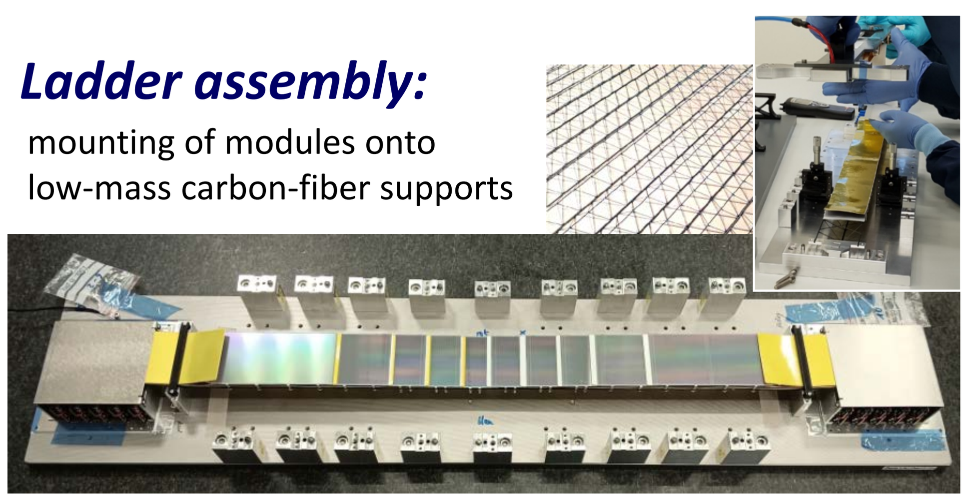
performance of 26 modules, first three series ladders



qualification test

Ladder assembly:

mounting of modules onto low-mass carbon-fiber supports



Functional characterization of modules for the Silicon Tracking System of the CBM experiment,
Nucl. Instr. Meth. Phys. Res. A1059 (2024), https://doi.org/10.1016/j.nima.2023.168813

mSTS Demonstrator in mCBM @ SIS18

mSTS
(1% of full STS)

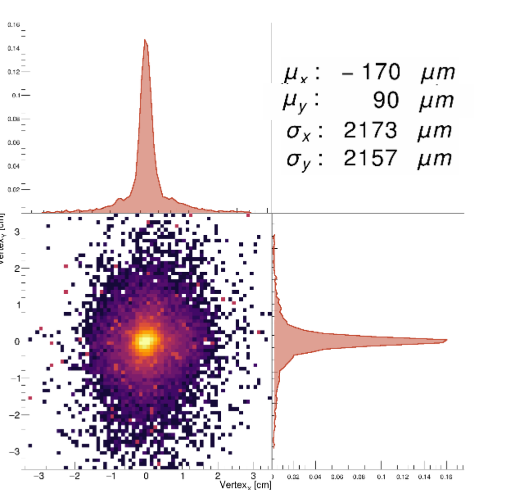
- *12 modules on 6 detector ladders*
- *arranged on 5 mechanical units*
- *forming a system of 3 tracking stations*

mCBM

full-system demonstrator with prototype/pre-series CBM components: BMON,STS, MUCH, TRD, TOF, RICH, FSD, DAQ/FLES

(prototype) components meet specifications:

- *time resolution 4.8 - 9.2 ns*
- *hit spatial resolution 10 µm*
- *hit reconstruction efficiency > 97%*



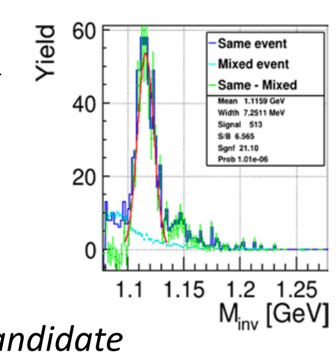
event vertex reconstruction

mSTS (2022) with 2 tracking stations

mCBM benchmark
rare signal reconstructed: Λ → p π⁻

Ni+Ni 1.93 GeV/u (May 2022),
10^9 collisions, 400 kHz av. coll. rate

- *all detector systems involved*
- *secondary vertex detection*
- *velocity windows for p and π⁻ candidate*



"First Λ Baryons for CBM."
Nuclear Physics News, 33(2), pp. 36–37
https://doi.org/10.1080/10619127.2023.2198920

Upgrade Options

The STS system design with its largely independent upstream and downstream construction blocks

- allows for facilitated maintenance + repair
- or to upgrade e.g. the higher irradiated detector parts after the nominal end-of life criterion of 10^{14} $n_{equiv.\ 1\ MeV}$ cm^{-2}

Detailed requirements are to be determined by CBM physics workgroups. Candidate detector technologies for running beyond the baseline program are, e.g.:

- monolithic active pixel sensors
  - self-triggering
  - time-resolution and data throughput same or better than the current STS
  - system integration compatibility with large-area coverage

STS Project

Timeline:

- 2013 – Technical Design Report
- 2019 – 2021 Sensor Production
- 2020 – 2023 FEE Production
- 2024 – 2025 Production of Mechanics
- 2023 – 2026 STS Detector Construction
- 2026 – Ready for installation into CBM

Institutes:

Germany:	GSI-FAIR, Tübingen Univ., Goethe Univ., KIT
Poland:	AGH, JU, WUT
Ukraine:	KINR
Japan:	KEK (assoc.)

Assembly Centers: GSI-FAIR, KIT

CBM FAIR GSI

presented at
PISA2024 – 16th Pisa Meeting on Advanced Detectors, La Biodola - Isola d'Elba, Italy, 26 May – 1 June 2024