System Integration Issues with the Silicon Tracker of the CBM Experiment at FAIR

I. CBM experiment at FAIR

II. Silicon Tracking System

III. Integration: status and issues

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for the CBM Collaboration

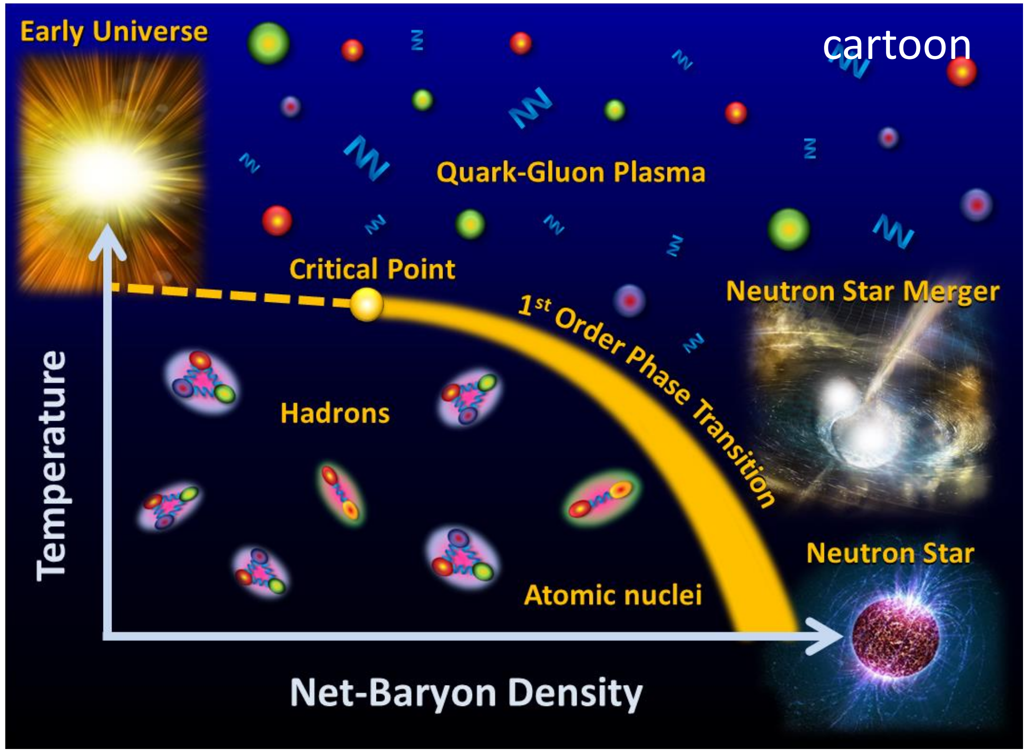
Forum on Tracking Detector Mechanics 2019, Cornell University, Ithaca NY, USA

Compressed Baryonic Matter

The phase diagram of strongly interacting matter

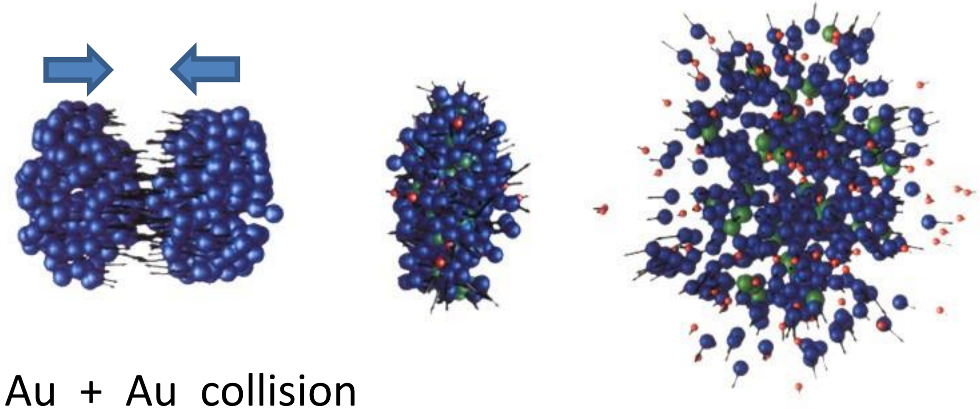
$\Rightarrow$ focus on high-density matter:

Compressed **B**aryonic **M**atter



in the **laboratory**: nucleus-nucleus collisions

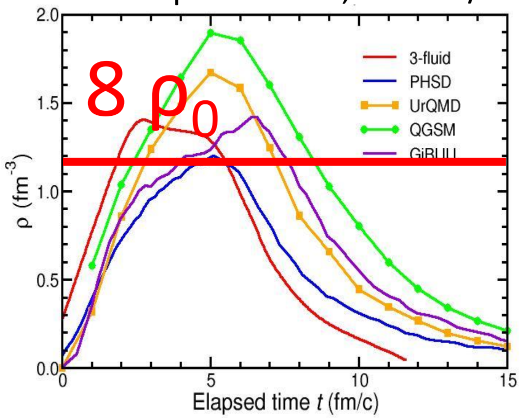
FAIR: the proper energy regime !



Au + Au collision

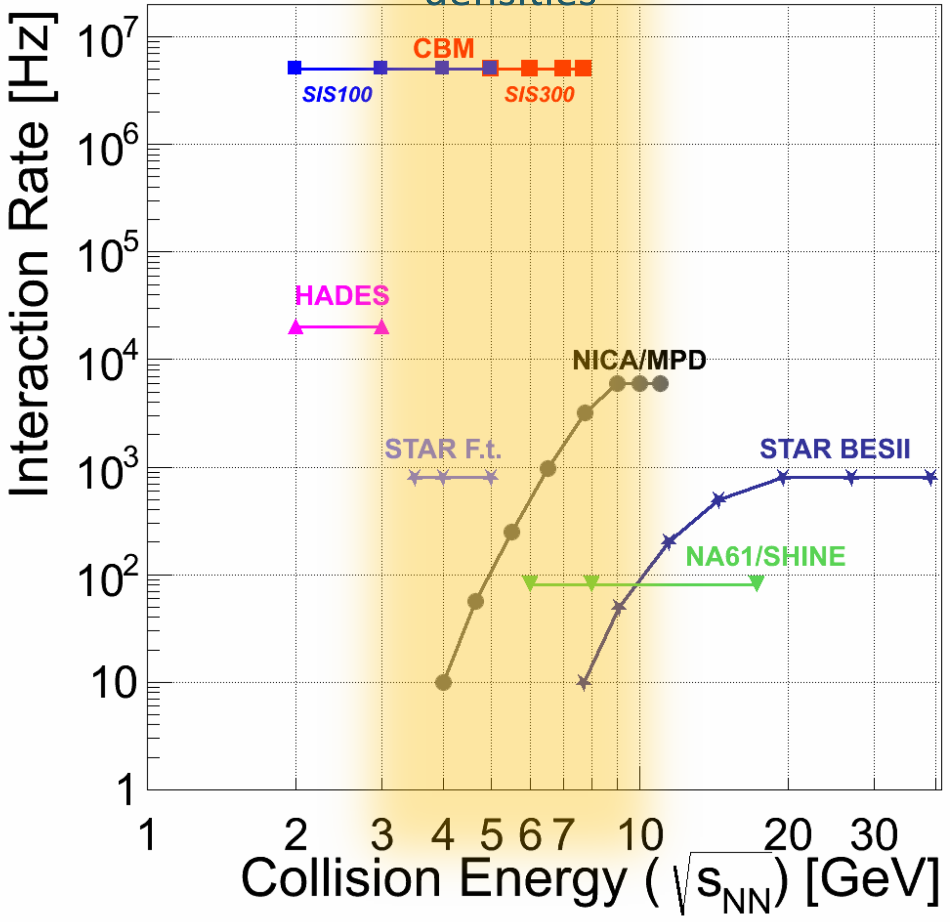
temperature	T < 120 MeV
density	$\rho > 8\,\rho_0$
reaction time	$t \sim 10^{-23}$ s

model predictions, 10 GeV/u

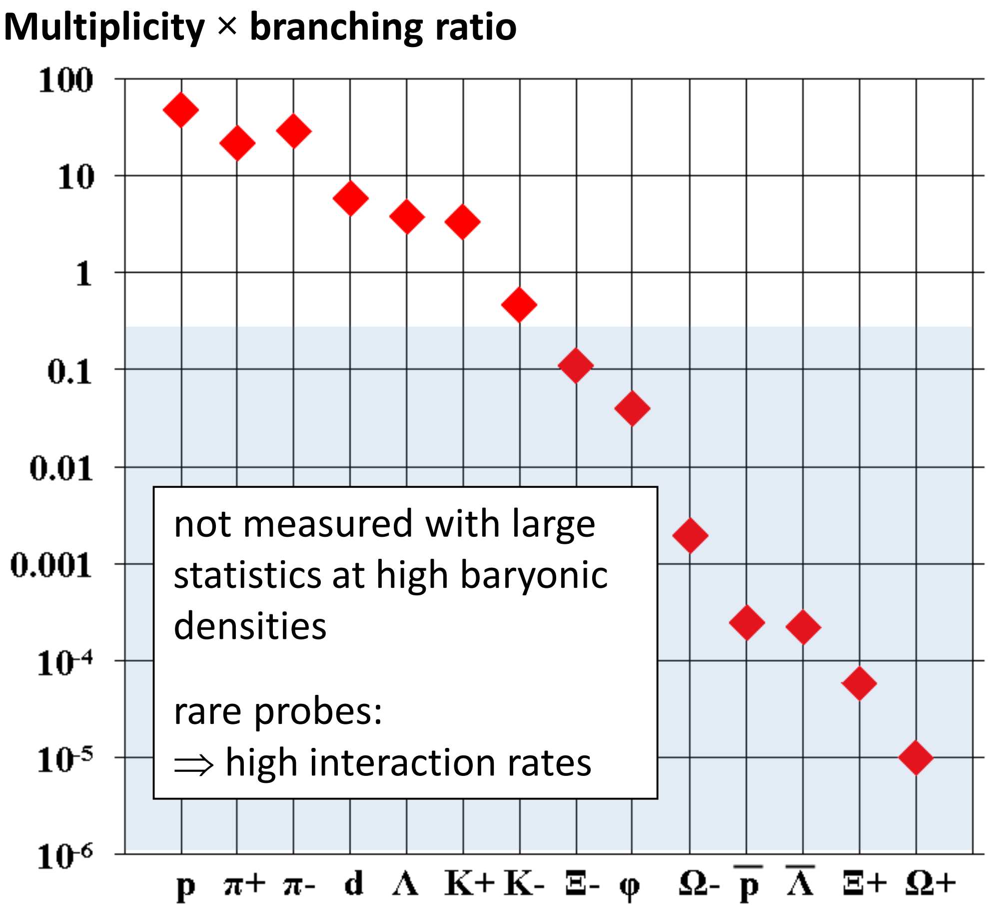


Compressed Baryonic Matter

high
net-baryon
densities

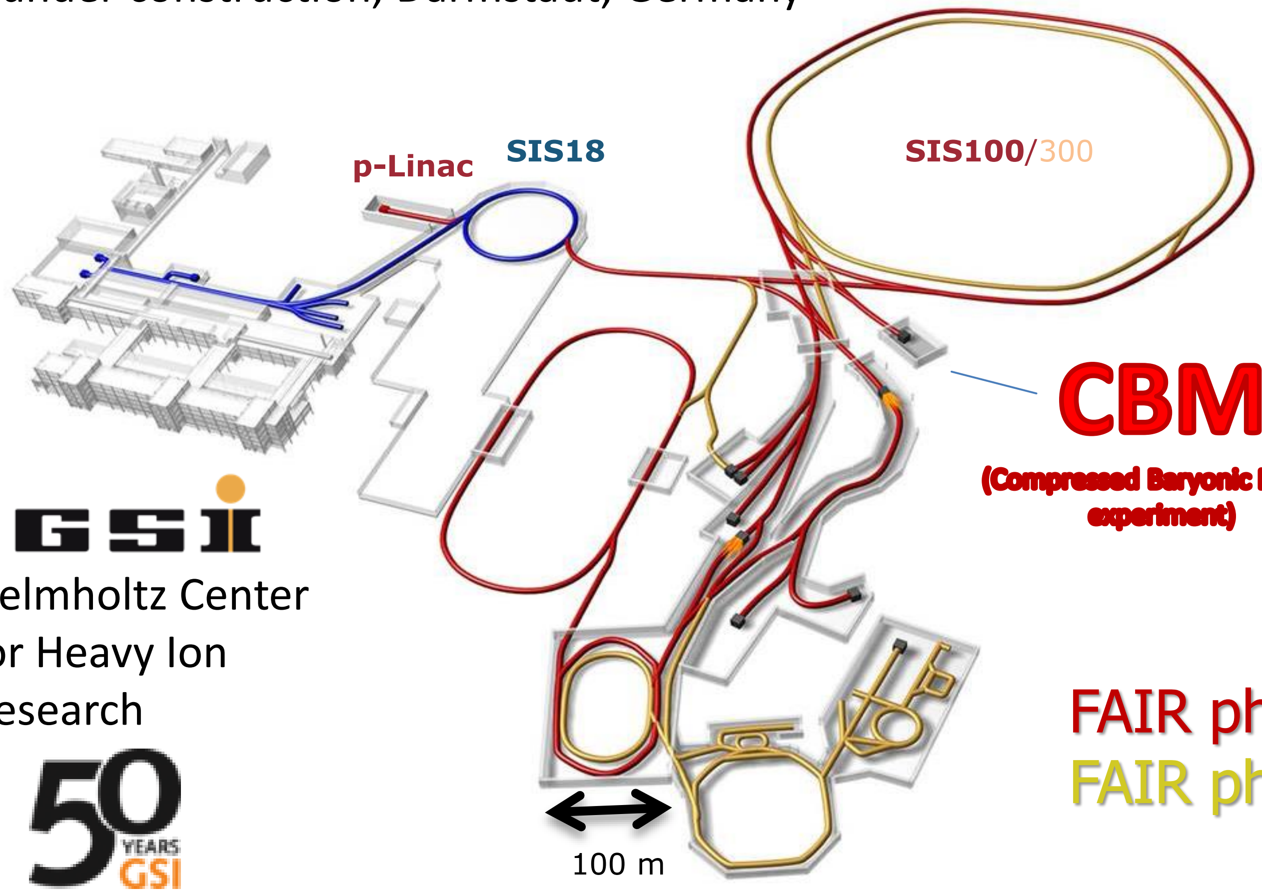


Particle yields in central Au+Au 4 A GeV



Facility for Antiproton and Ion Research

- new international research laboratory to explore the nature and evolution of matter in the Universe
- under construction, Darmstadt, Germany



CBM

(Compressed Baryonic Matter experiment)

GSI Helmholtz Center for Heavy Ion Research

FAIR phase 1
FAIR phase 2

CBM beams at 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
  - target: typically 1% λ_I

current completion date, first beams: 2025

Facility for Antiproton and Ion Research

https://fair-center.eu/

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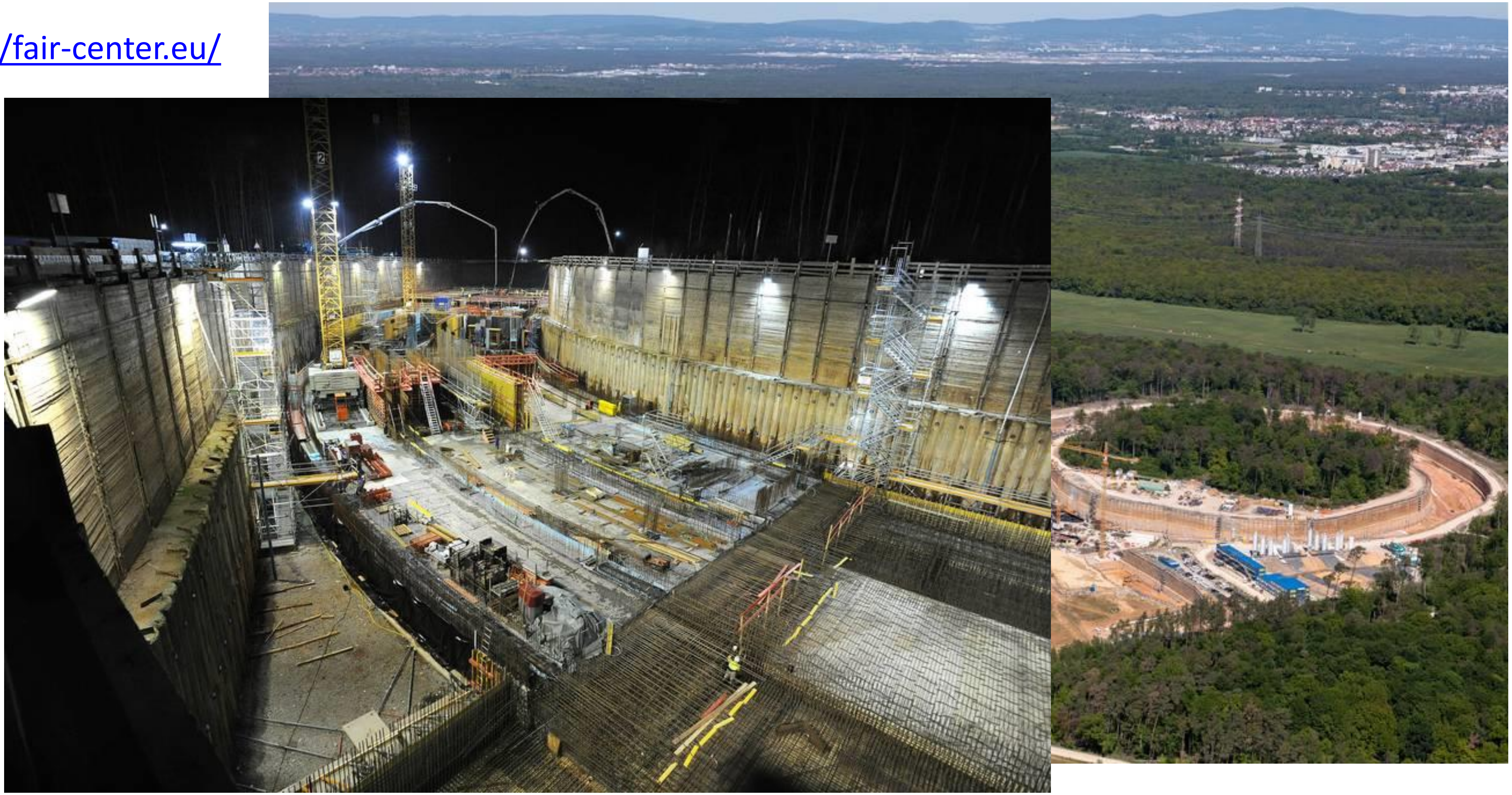

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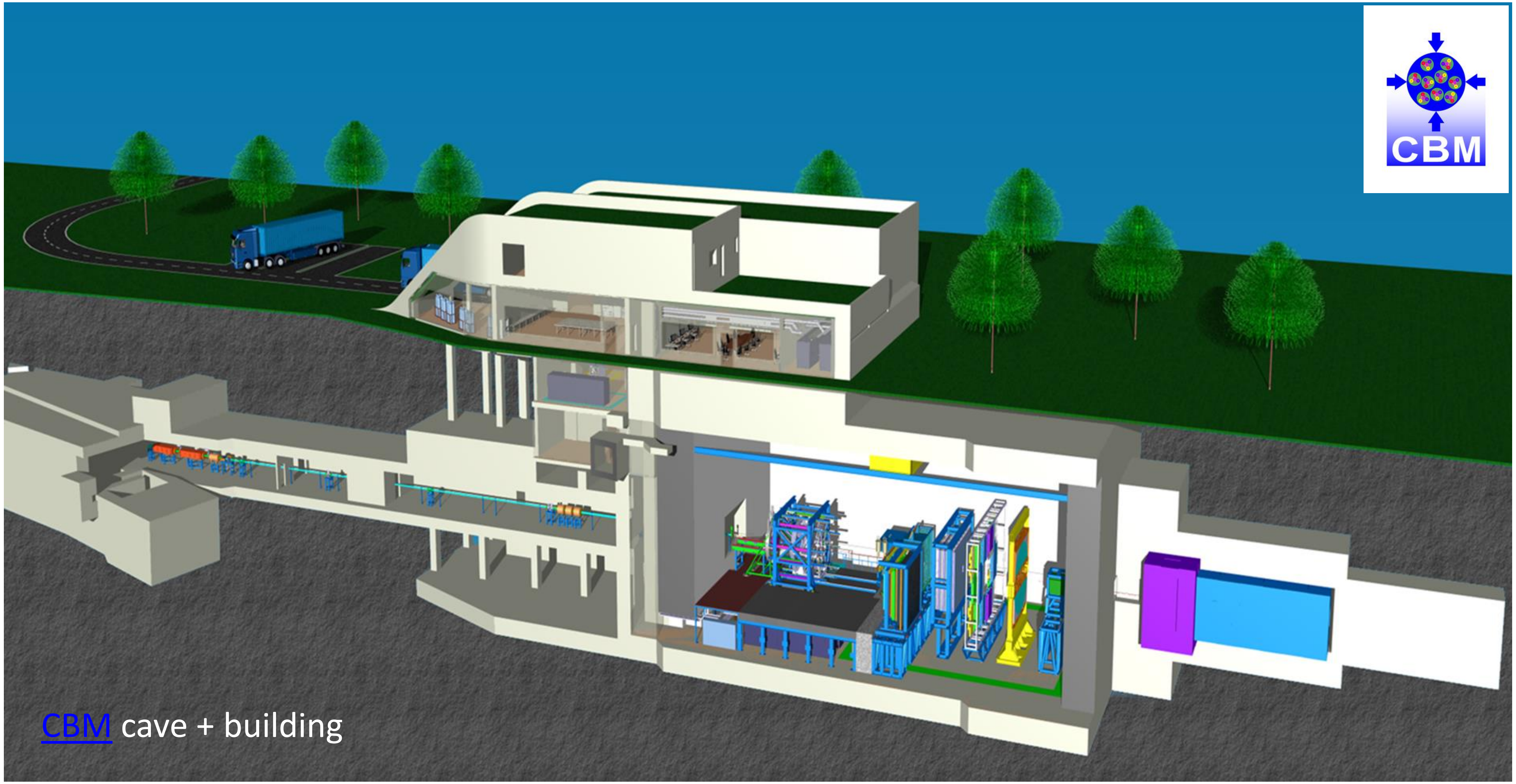
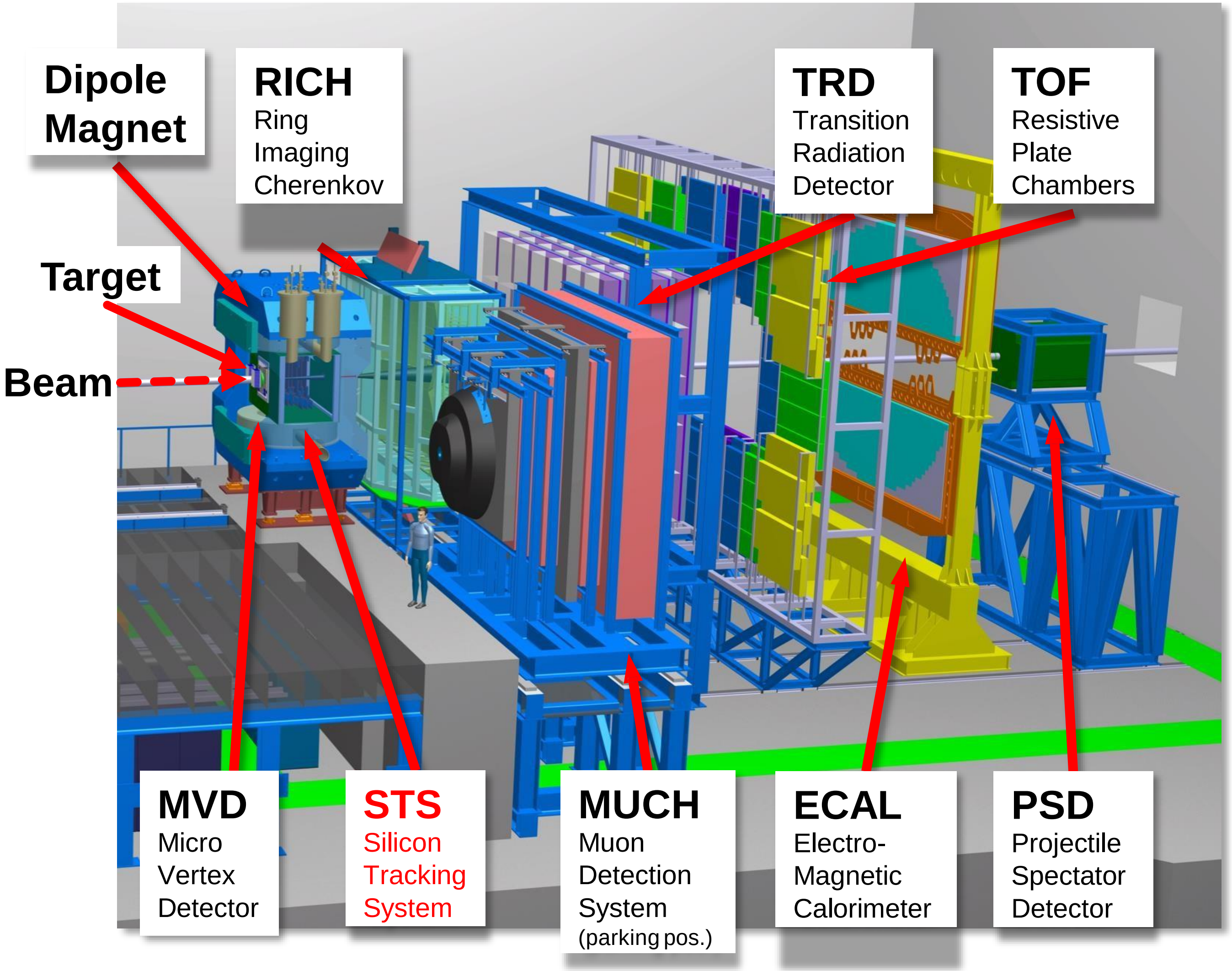
Compressed Baryonic Matter Experiment



Compressed Baryonic Matter Experiment



- Tracking acceptance:

  $2.5° < \theta_{lab} < 25°$

- Free streaming DAQ

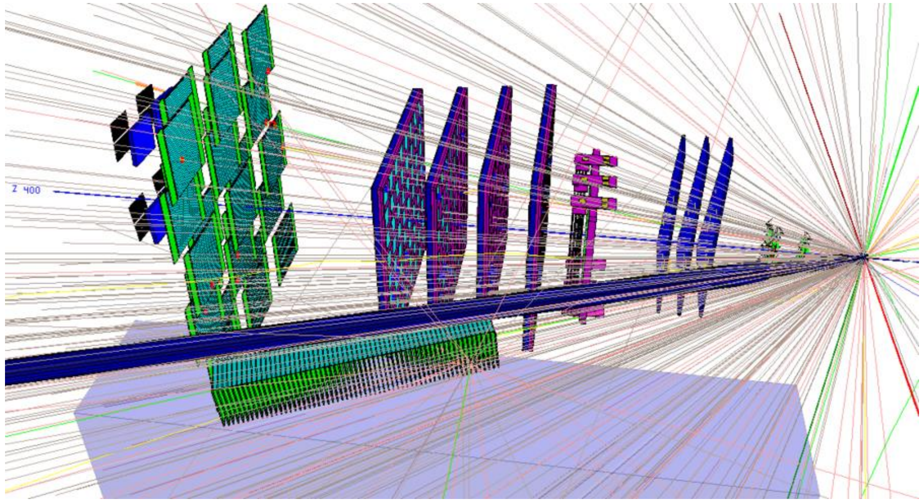
  R_{int} = 10 MHz (Au+Au)

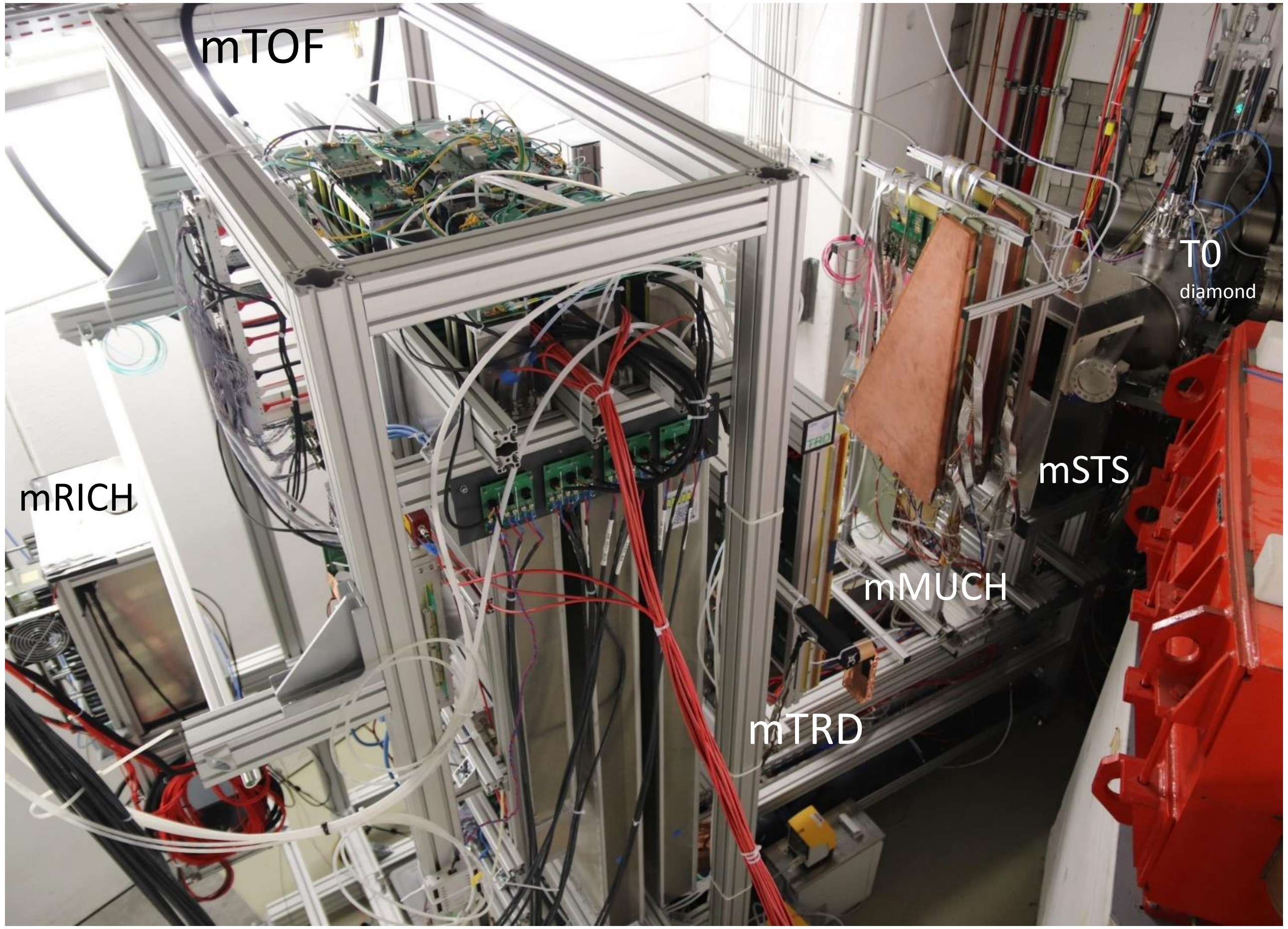
  with
  R_{int} (MVD) = 0.1 MHz

- Software based event selection

mCBM test experiment

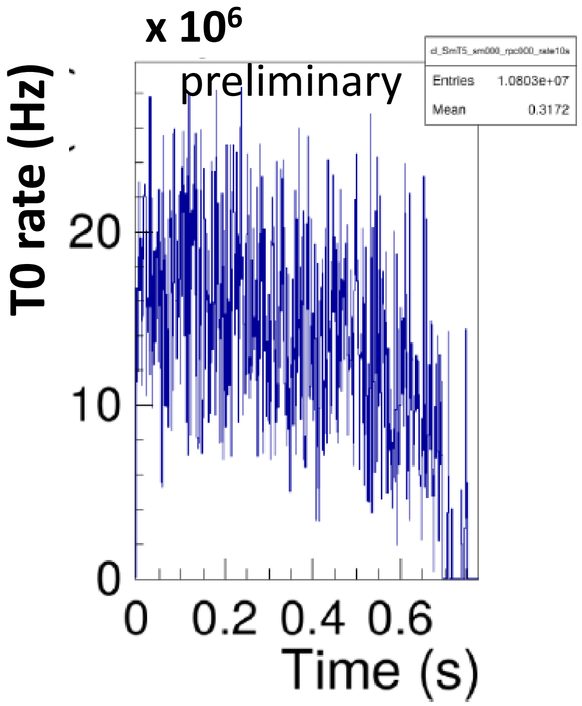
mCBM@SIS18 - a CBM full system test-setup
for high-rate nucleus-nucleus collisions at GSI/FAIR





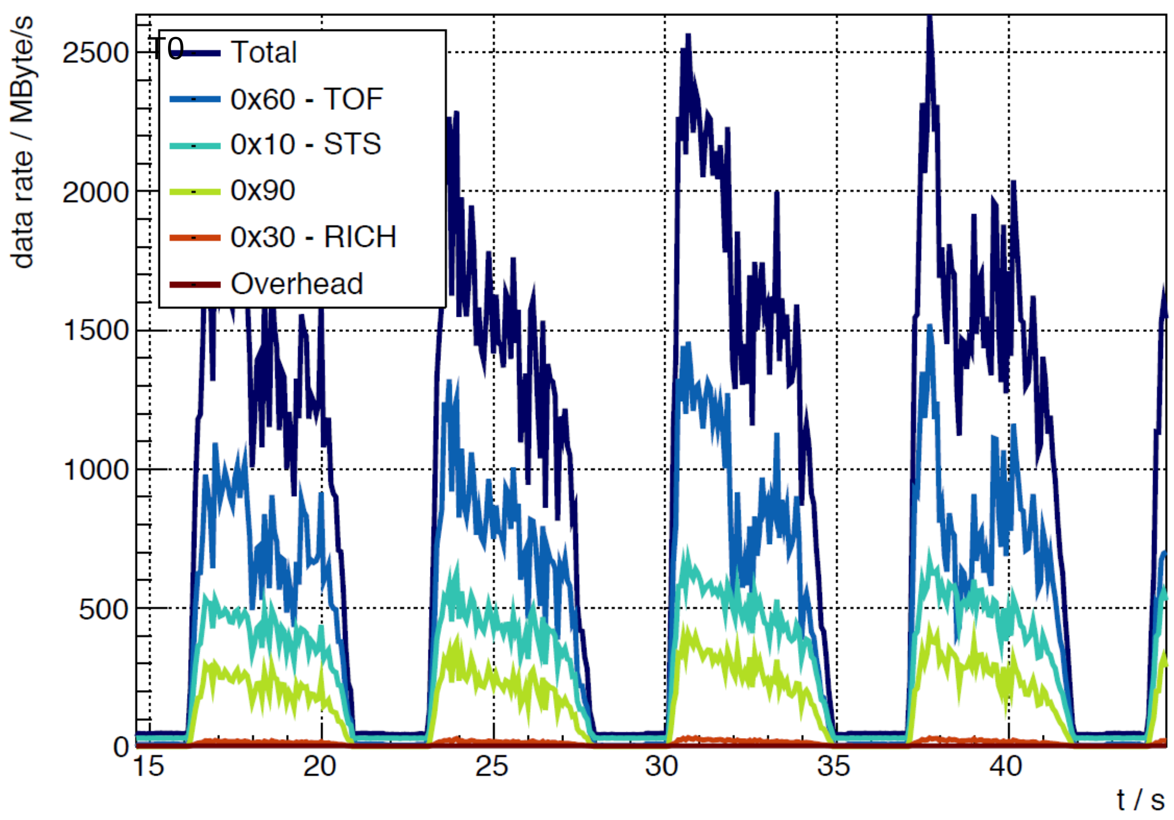
- CBM prototype detector systems
- free-streaming read-out and data transport to the mFLES
- online event reconstruction and selection
- up to 10 MHz collision rate
- first successful commissioning with beam 12/2018 and 3/2019

mCBM test experiment



March 30, 2019:
beam intensity ≈ 10^8 Ag ions / s
interaction rates 10^6 … 10^7 /s (preliminary)

March 30, 2019 – run 175
(approx.) 10^8 Ag ions/s (1.58 GeV/u) + Au (2.5mm)



Silicon Tracking System

Central CBM detector: charged-particle tracking + momentum measurement

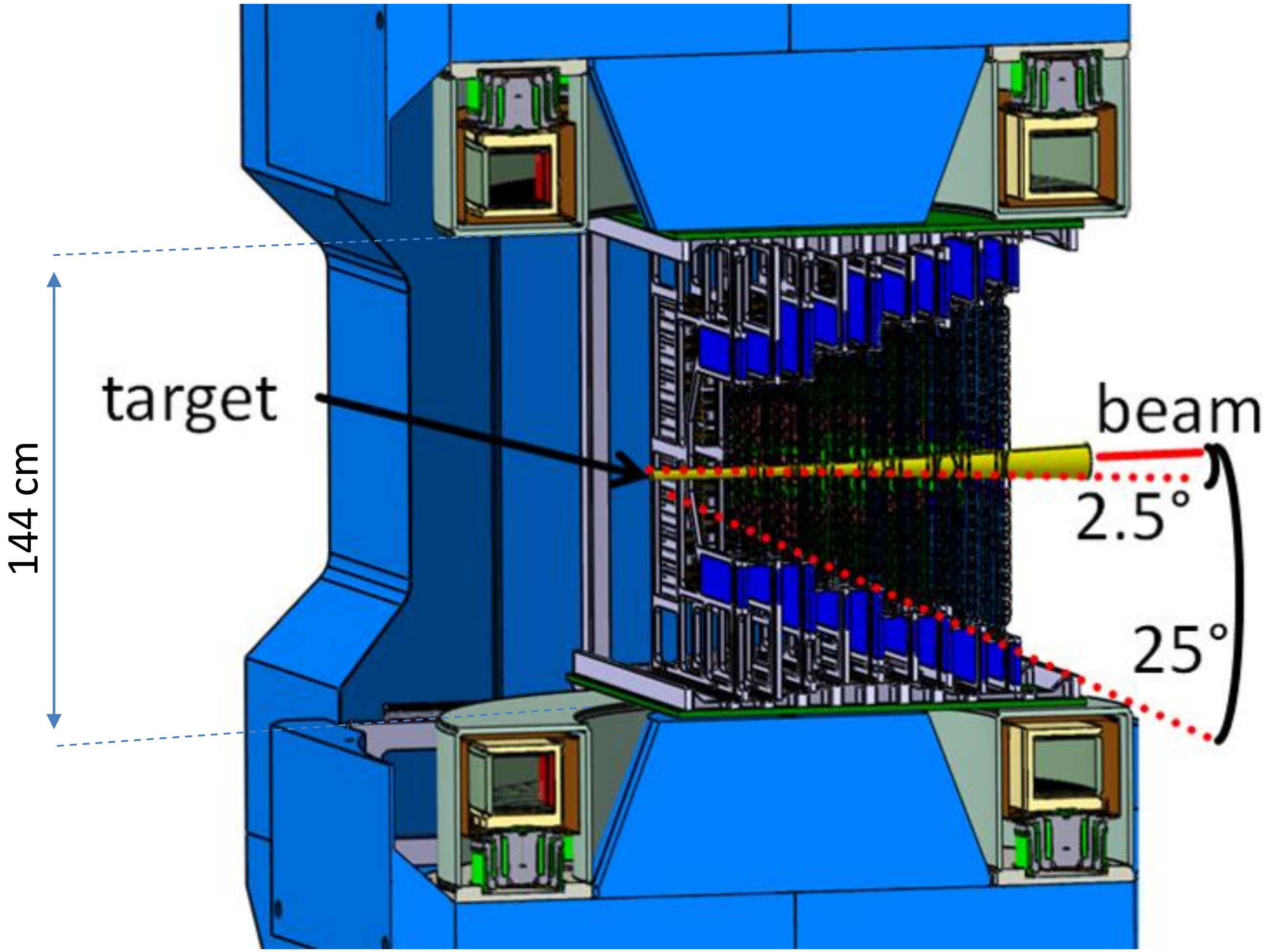
Requirements/challenges:

- up to ~ 700 charged particles per heavy-ion collision → high granularity
- $10^5 - 10^7$ heavy-ion collisions per second → radiation tolerant
- pile-up free streaming of hit data to online computing → fast electronics
- mechanical precision: transversal to beam ≈ 100 µm, less along beam

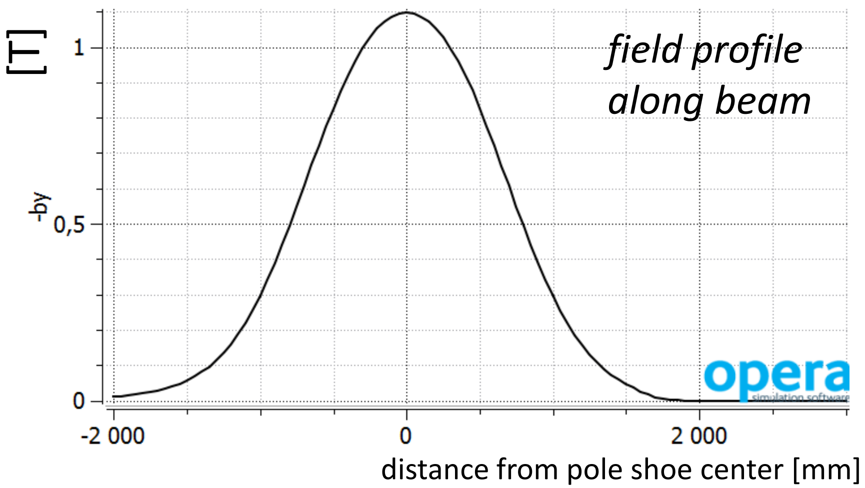
Approach:

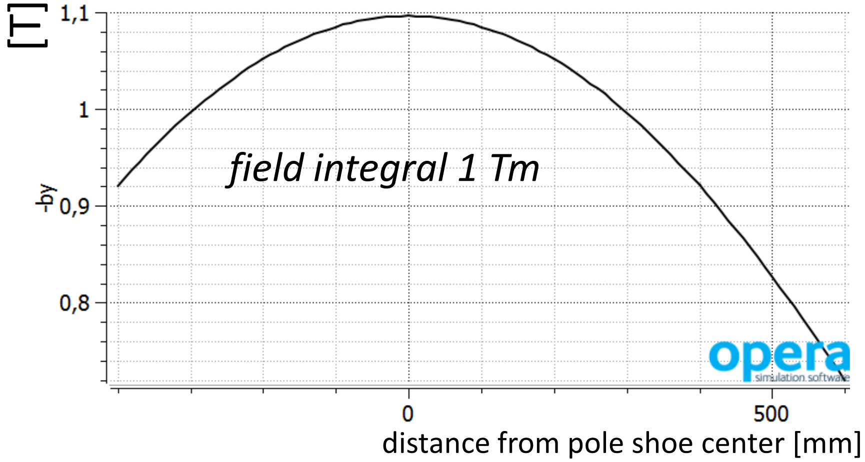
- 8 tracking stations, 0.3 – 1.0 m downstream target
  - *≈ 4 m^2 area, ≈ 3.5 m^3 volume, 896 modules, 106 ladders, 1.8 M channels*
- double-sided silicon microstrip sensors
  - *hit spatial resolution ≈ 25 µm*
  - *life time rad. tol. up to 10^{14} n/cm^2 (1 MeV eq.)*
  - *operation at T < -10 °C*
- self-triggering electronics
  - *time-stamp resolution ≈ 5 ns*
  - *radiation tolerance > 30 Mrad*
  - *power dissipation ~ 40 kW*
- low-mass detector modules/ladders:
  - *electronics/cooling outside physics aperture*
  - *material budget per station: ≈ 0.3% – 2% X_0*

Silicon Tracking System

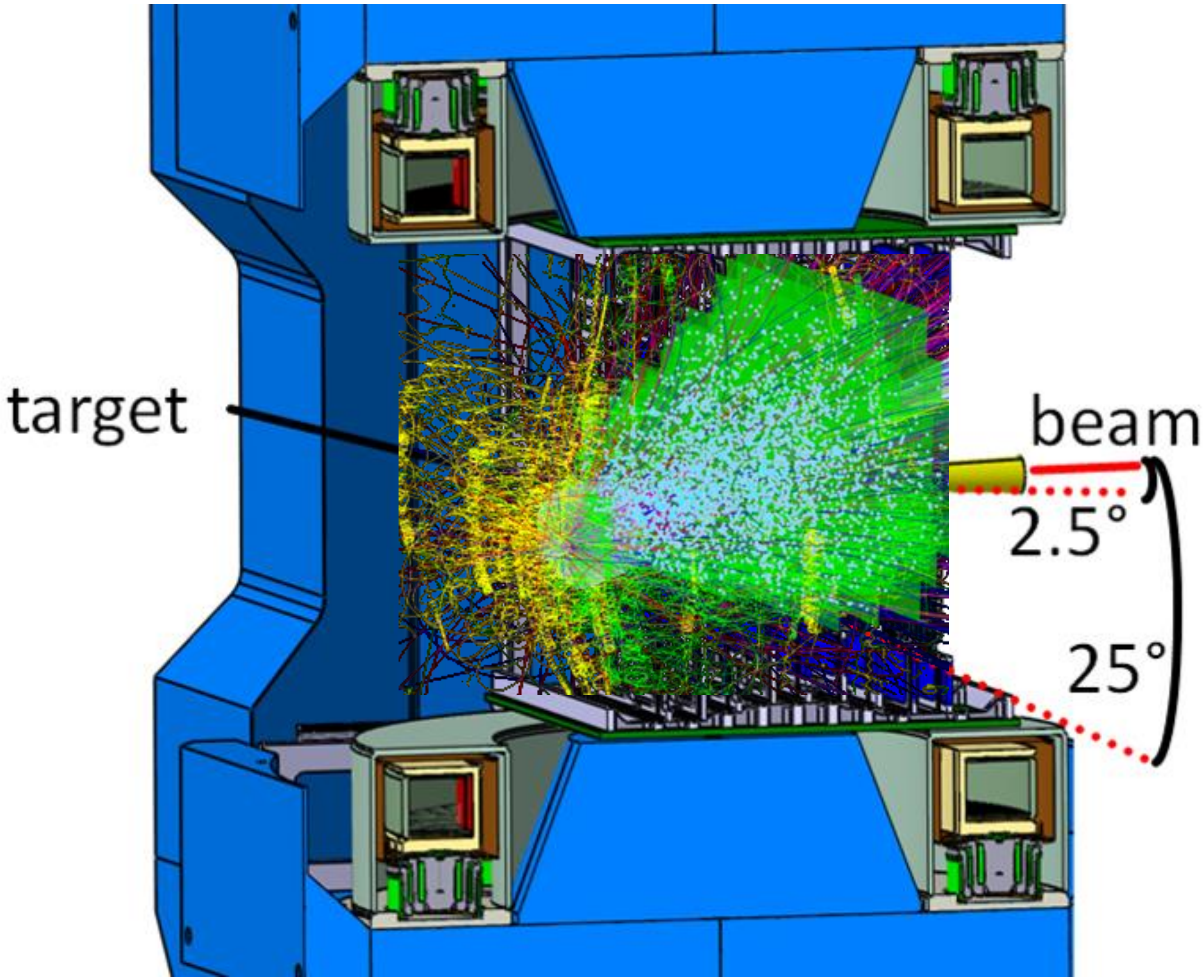


superconducting dipole magnet





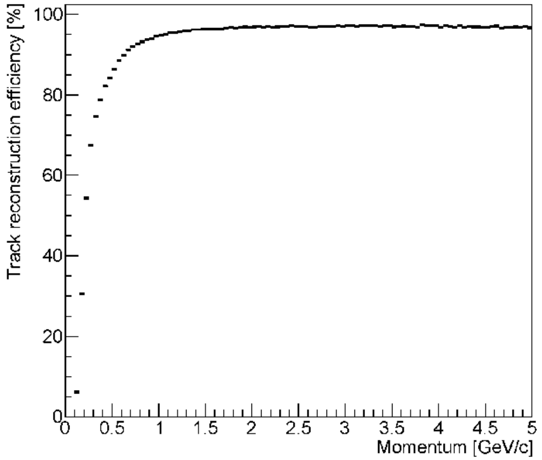
Silicon Tracking System



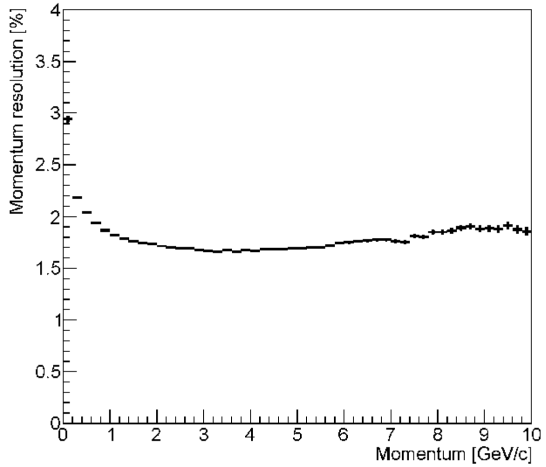
central collision, Au-Au, 10 GeV/u

- 700 charged particles in aperture
- track reconstruct. efficiency: > 96 %
- momentum resolution: ~ 2%

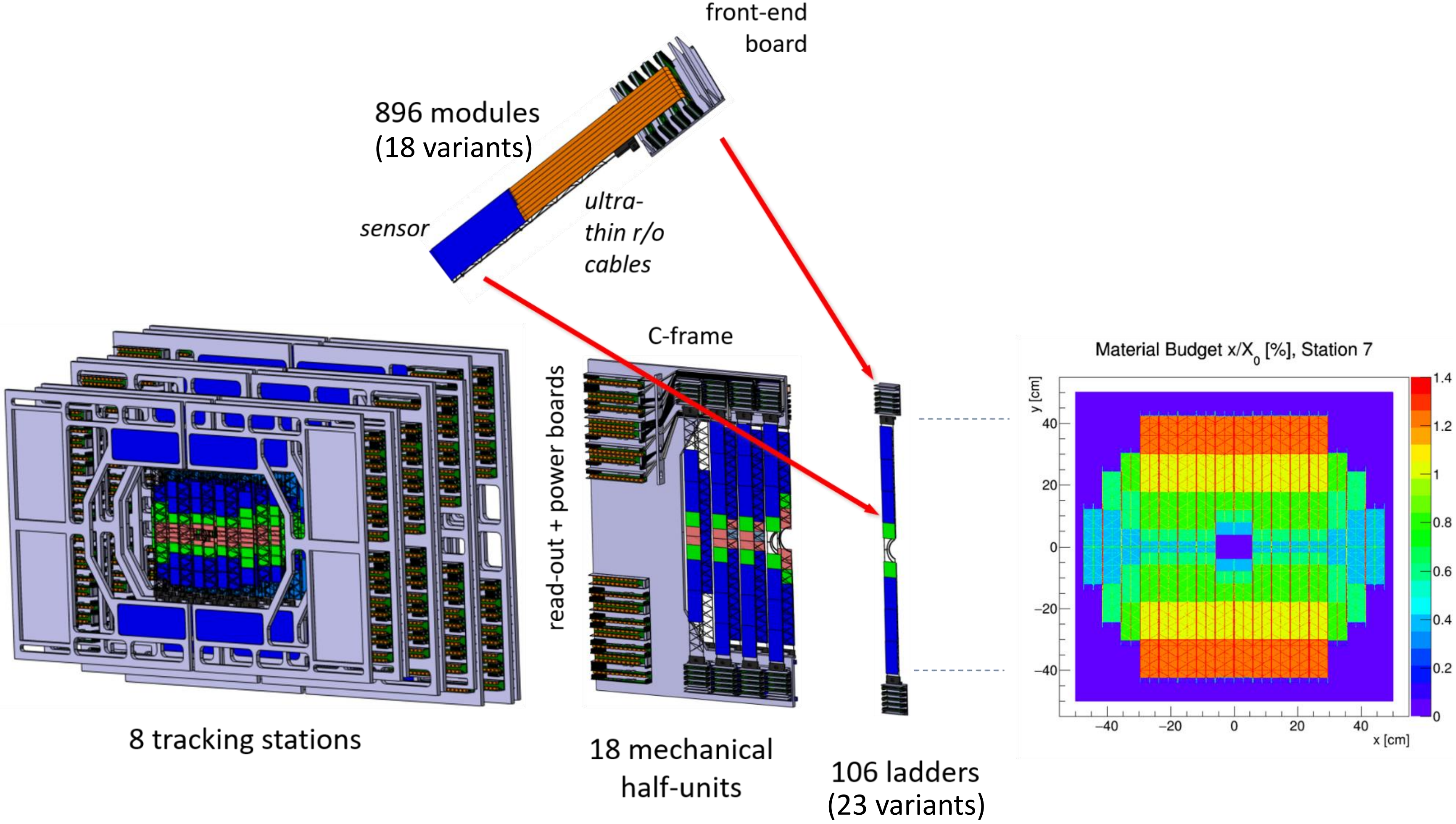
track reconstruction efficiency



momentum resolution

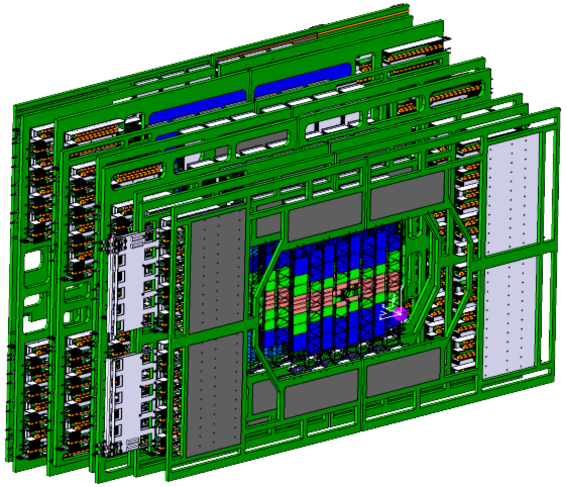


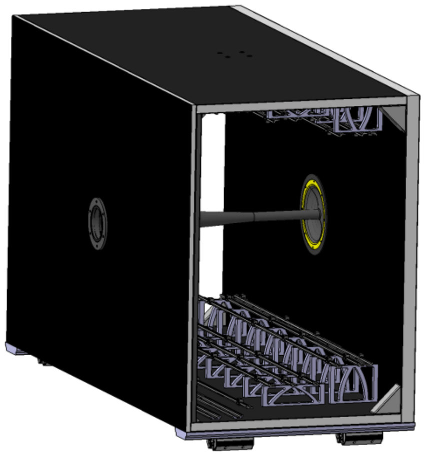
STS – composition

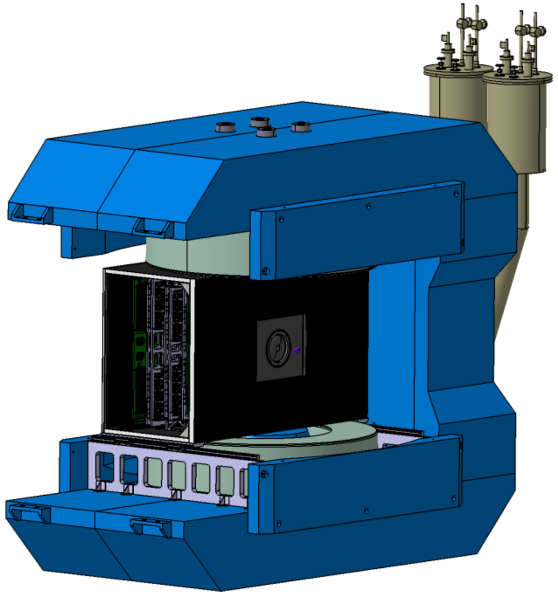


System engineering

details on construction in:
O. Vasylyev, FTDM 2017







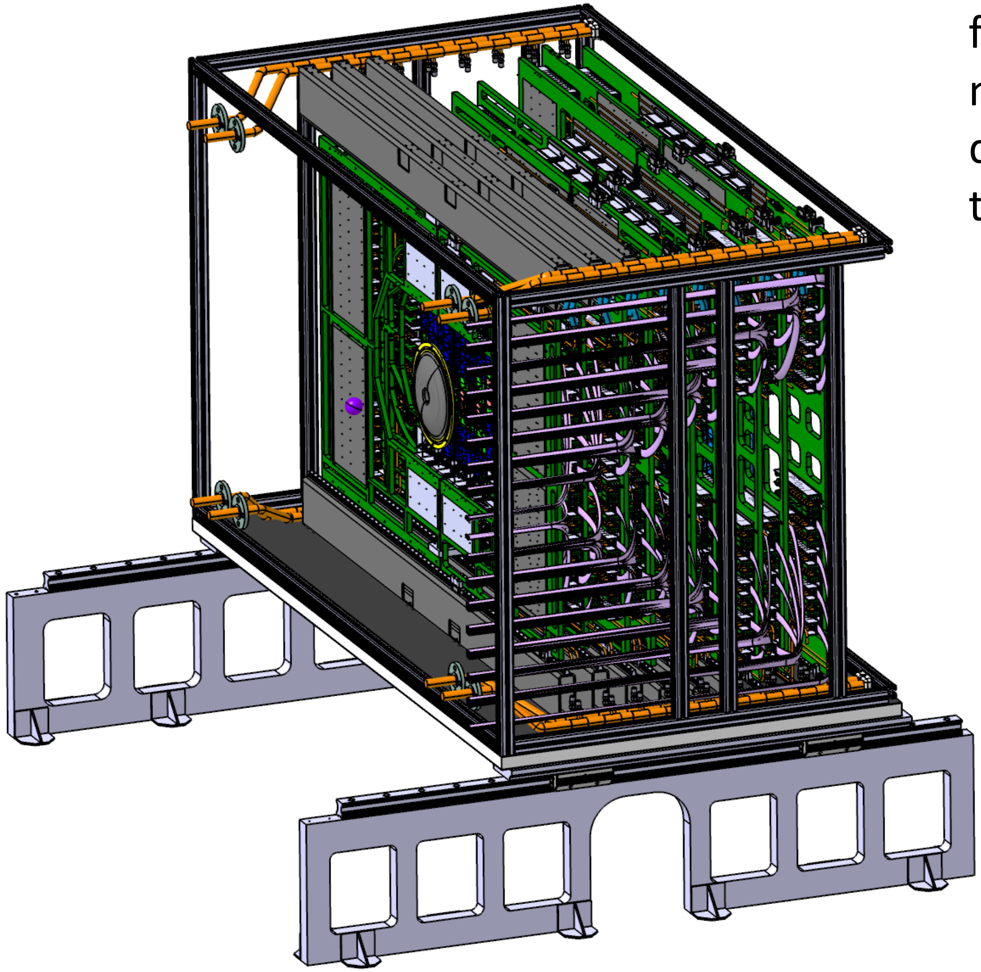
Consistent design being detailed. Current issues:

Mechanical frames:
- Material
- Rail system
- Positioning / adjustment
- Cooling plate shape
- Sensor cooling
- Cabling

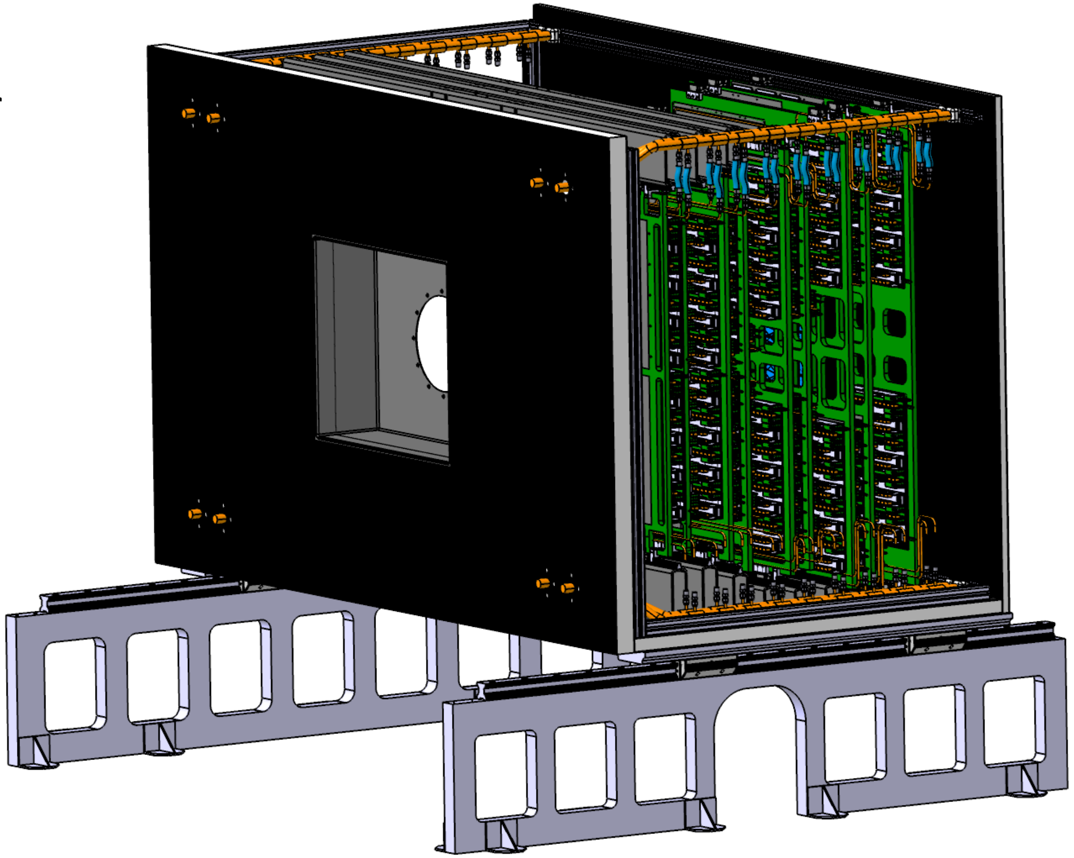
Thermal enclosure:
- Sealing
- Panel connections
- Material budget rear panel
- Overall stiffness
- Service / support mechanics
- Overall assembly procedure

Global system aspects:
- STS services, rail supports and details of
  - Cabling, patch panels
  - Cooling
  - Positioning
  - Safety / emergency systems
  - Integration upstream and downstream
  - vibrations / structural analysis

System engineering



full-scale
mechanics
demonstrator
to be set-up



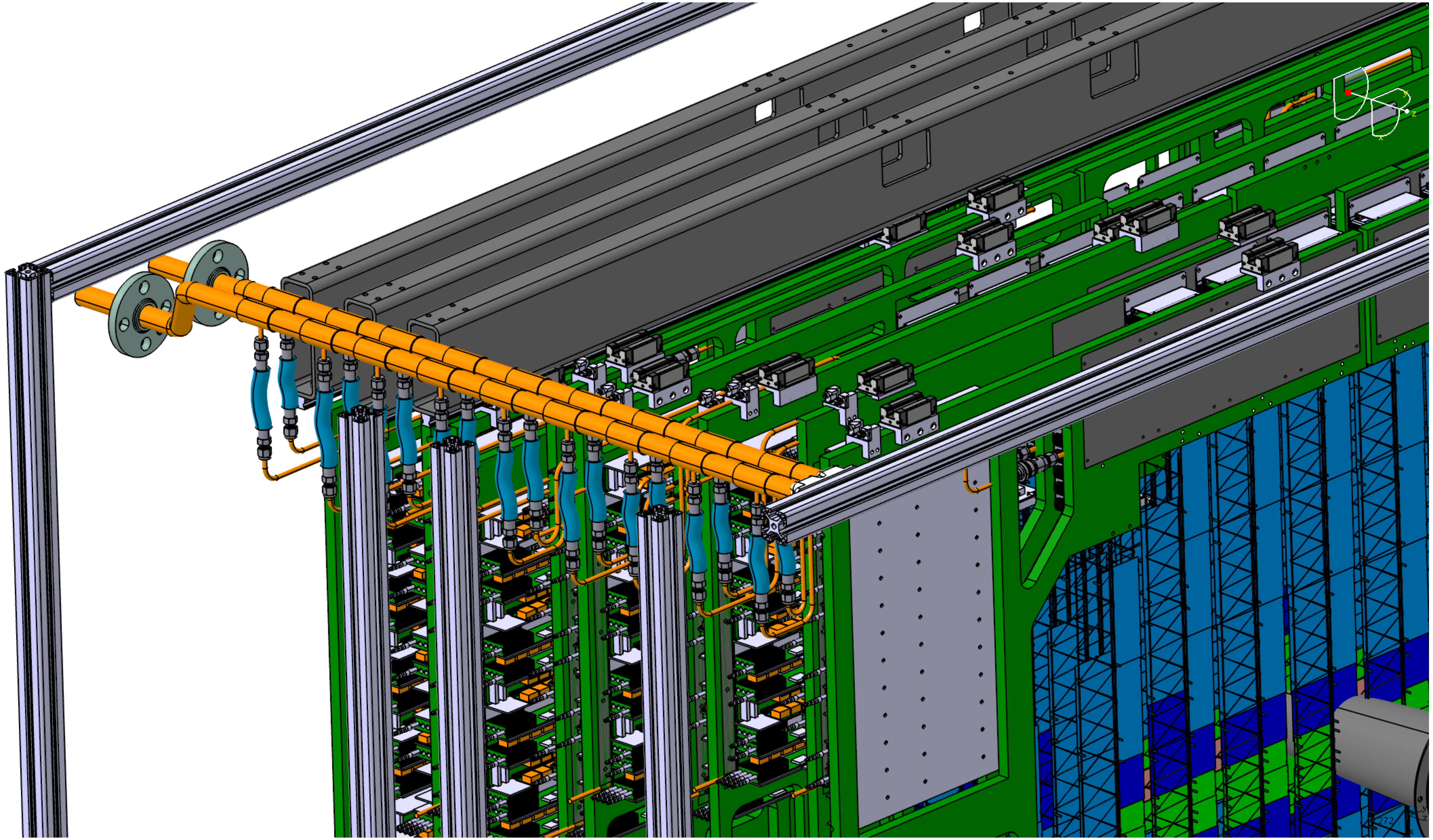
System engineering

cooling concept:

- *liquid distribution for electronics cooling*
- *gas flow for sensor cooling*

thermal demonstrator under set-up

details in:
K. Agarwar,
FTDM 2019



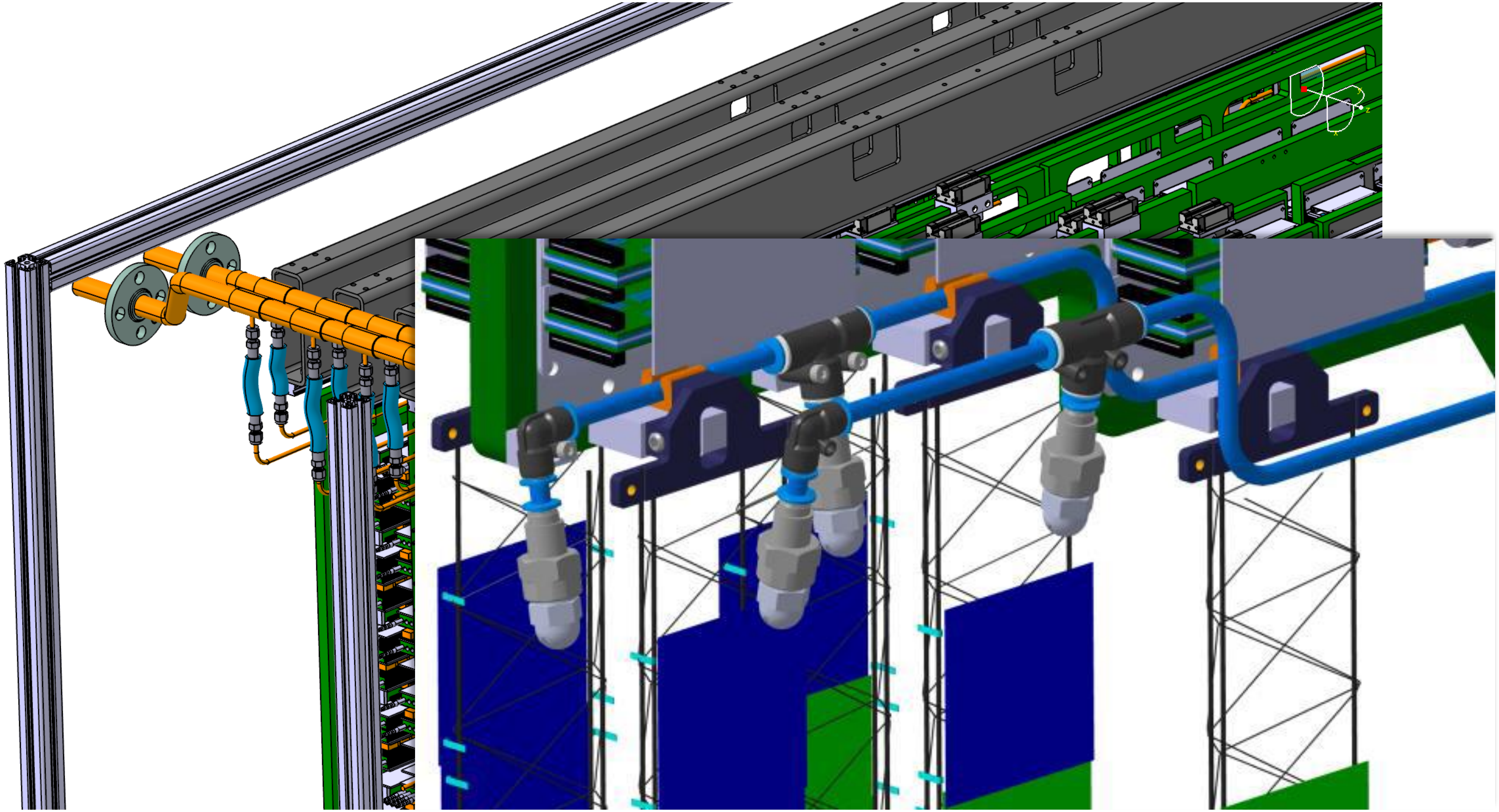
System engineering

cooling concept:

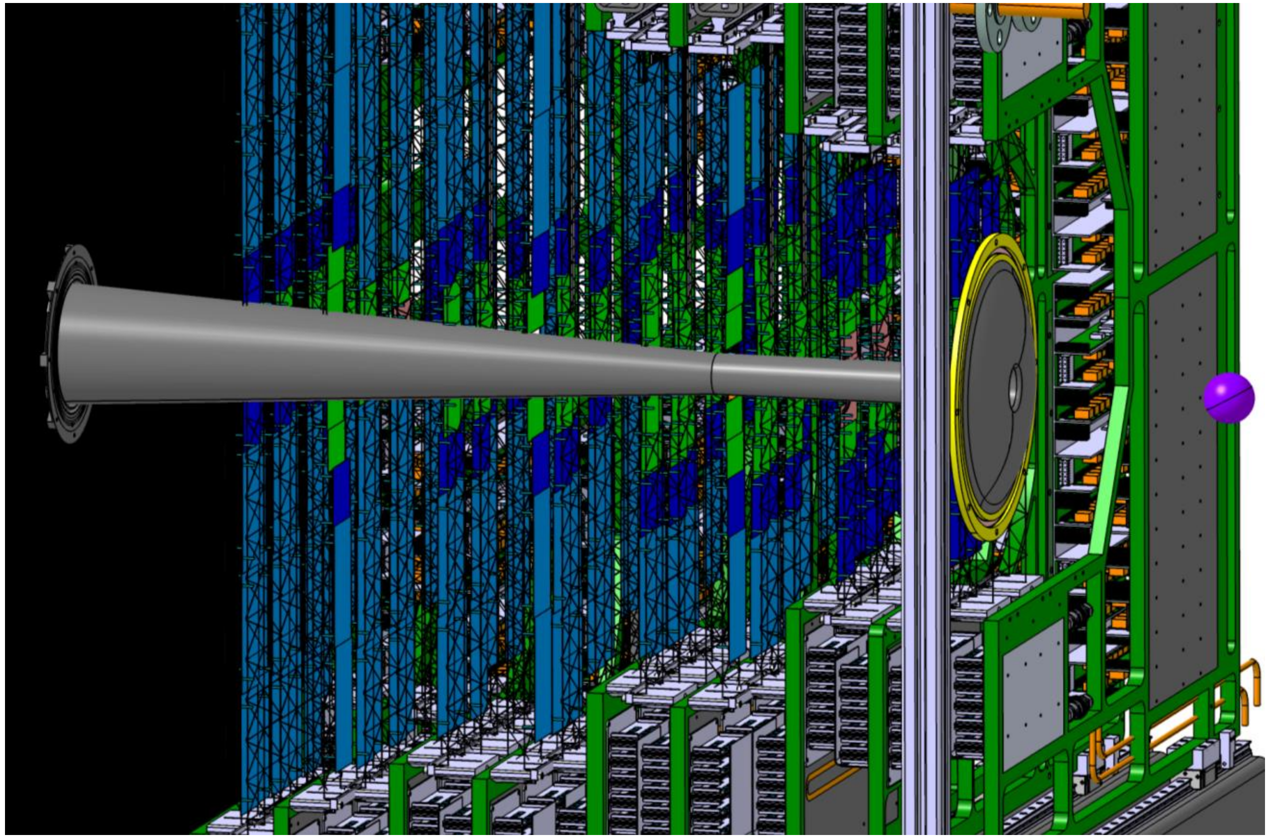
- *liquid distribution for electronics cooling*
- *gas flow for sensor cooling*

thermal demonstrator under set-up

details in:
K. Agarwal,
FTDM 2019



Beam pipe



0.5 mm carbon fiber prepreg on a hub, foil embedded

- *window to target vacuum*
- *pipe*

first prototype made in industry

vacuum stability test failed

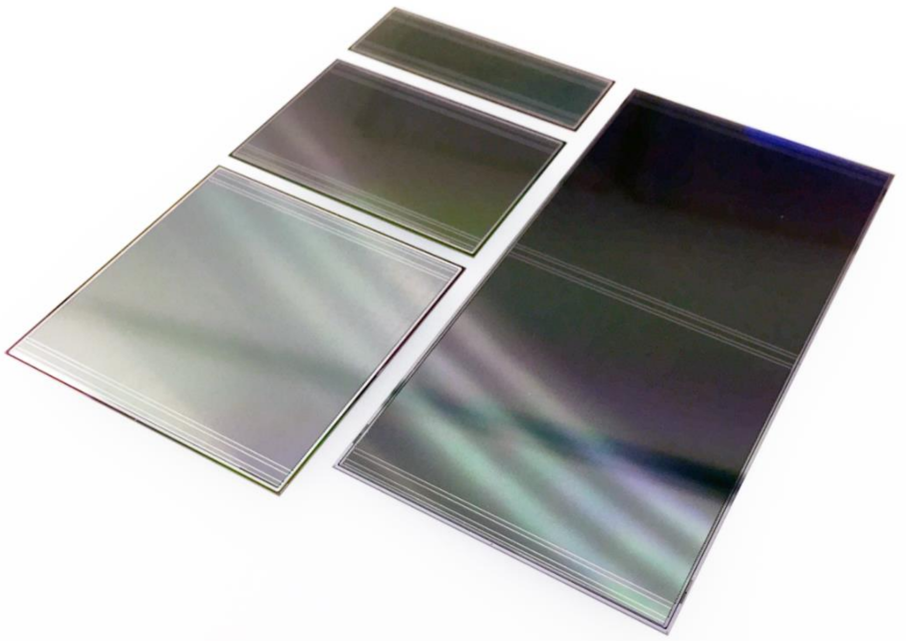
- *collapse in transition area to conical part*

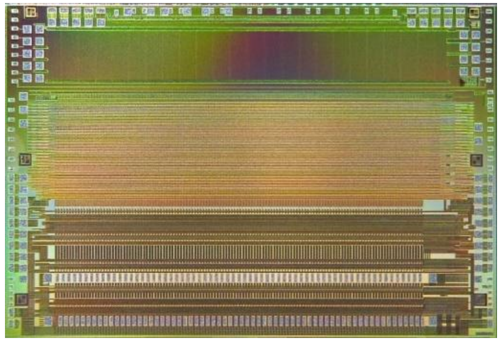
new trial pending

- *thicker carbon fiber layer for pipe: 0.8 mm*

Module assembly

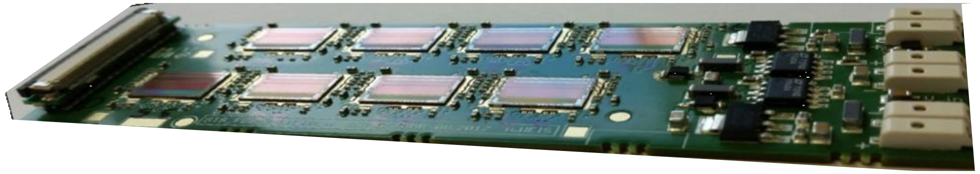
- *double-sided microstrip sensors*
- *1024 strips of 58 μm pitch*
- *320 μm thick*
- *4 variants/strip lengths*



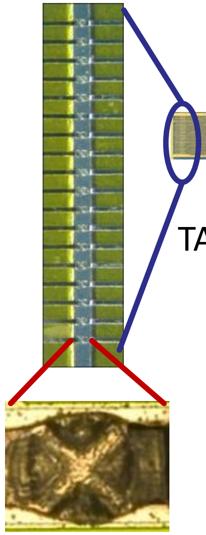


STS-XYTER v2.1

128 channels
self-triggering
5 bit ADC, time resolution < 5 ns

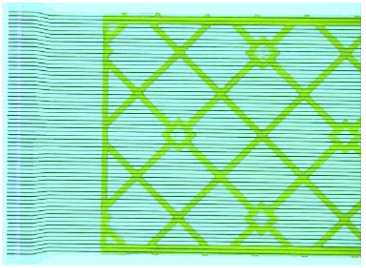


Front-end electronics board FEB-8



signal layer:
64 Al lines of 116 μm pitch, 30 μm wide, 14 μm thick on 10 μm polyimide

TAB bonding
(Al width
45 μm) *)

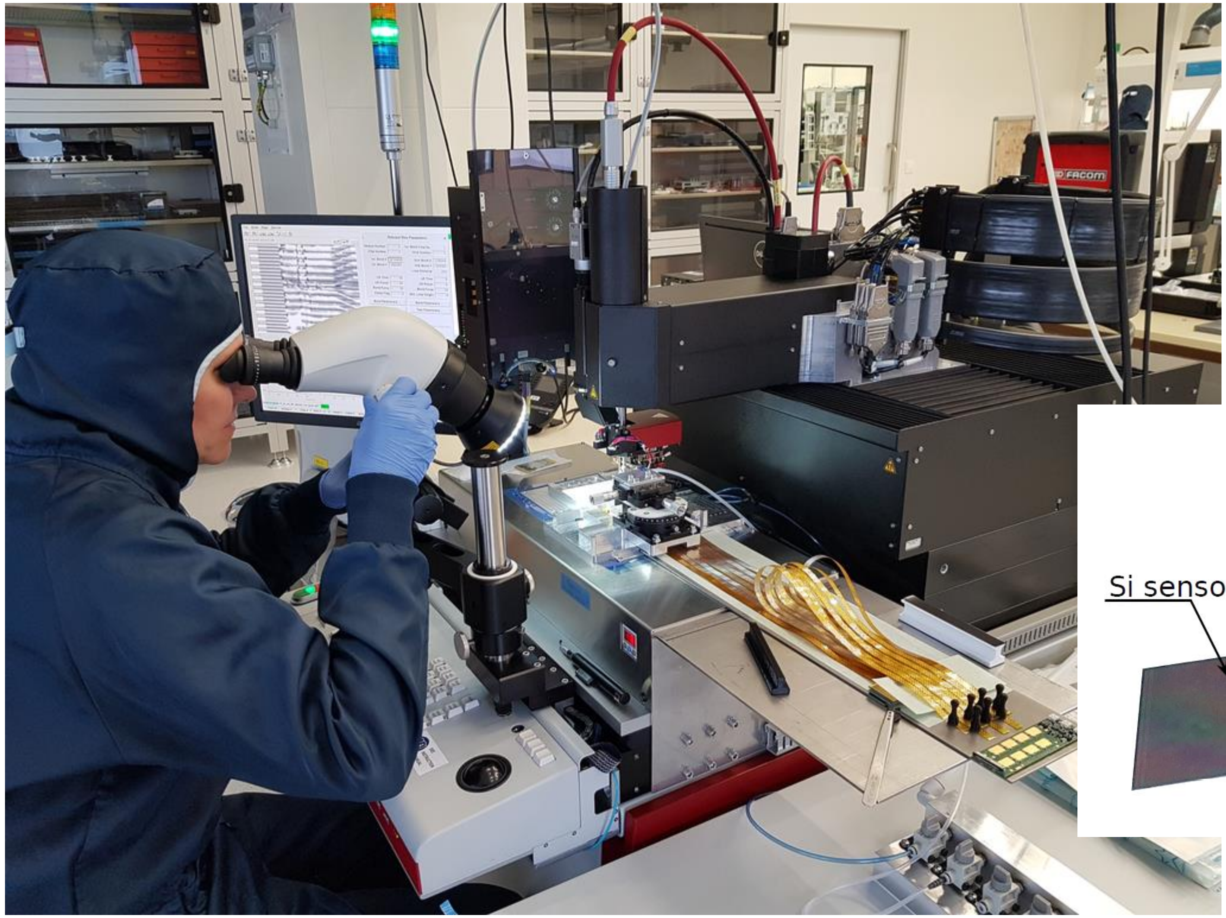


- trace lengths 5 - 55 cm
- trace capacitance 0.45 pF/cm

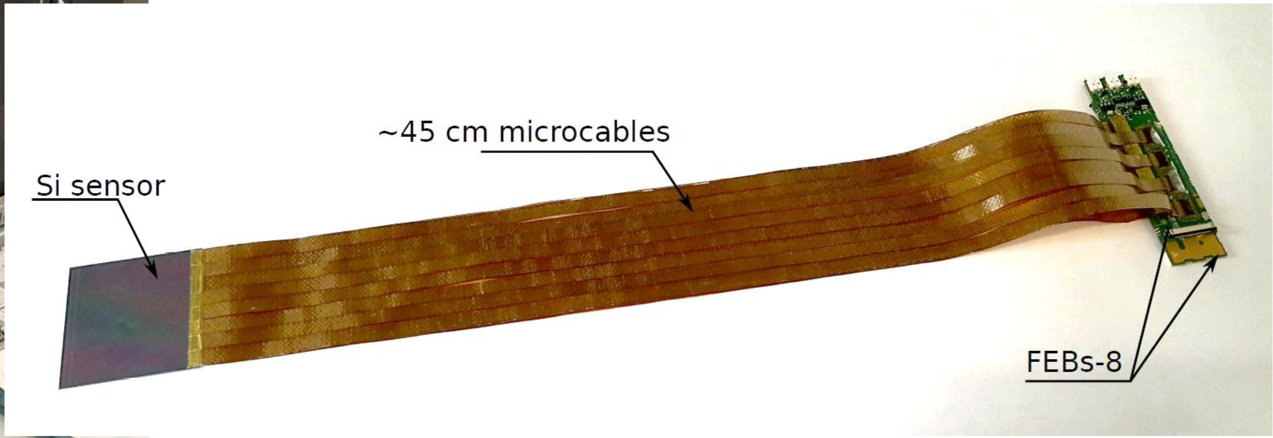
cable stack: with shielding, spacers
thickness ~ 800 μm / 0.23% X_0

*) alternative Cu cable/interconnect technology under study

Module assembly



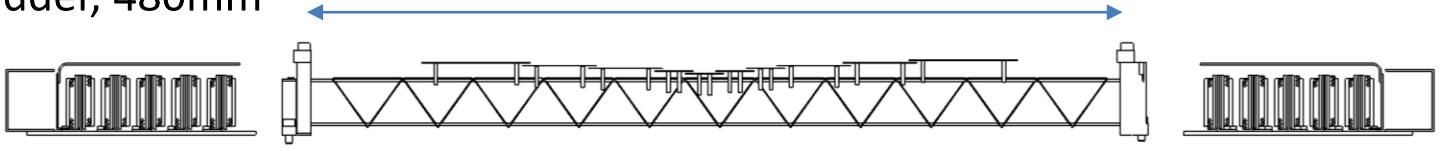
longest module variant
for mSTS



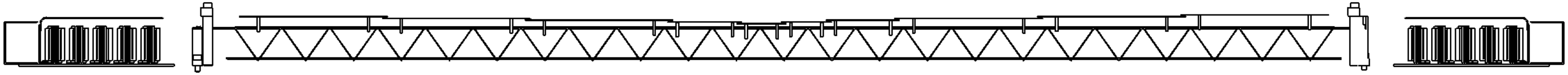
Ladder assembly

carbon fiber supports

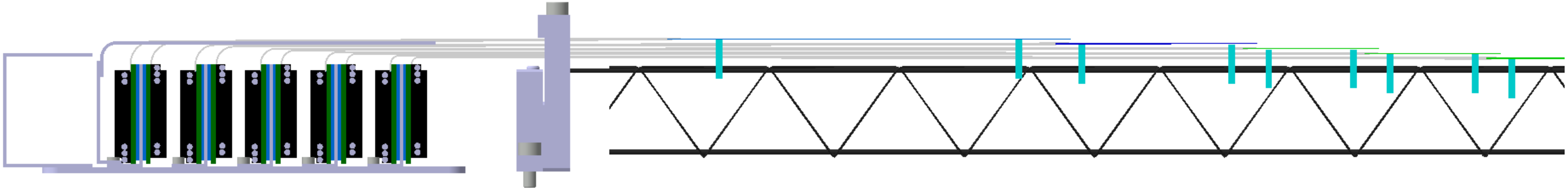
shortest ladder, 480mm



longest ladder, 970mm



FEE box, microcable routing, sensor attachment

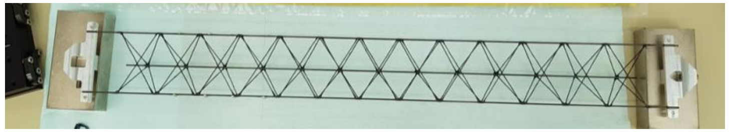


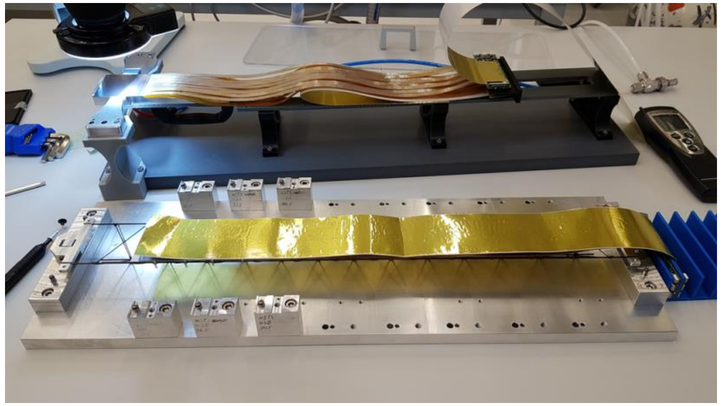
transition-fits:
pin to C-frame, pin to bearing

Ladder assembly

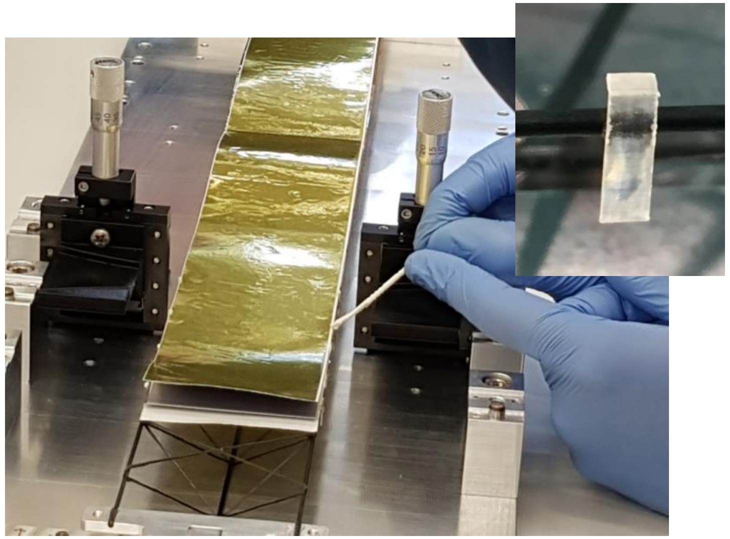
half-ladder #0 for mSTS demonstrator

carbon fiber ladder with bearings



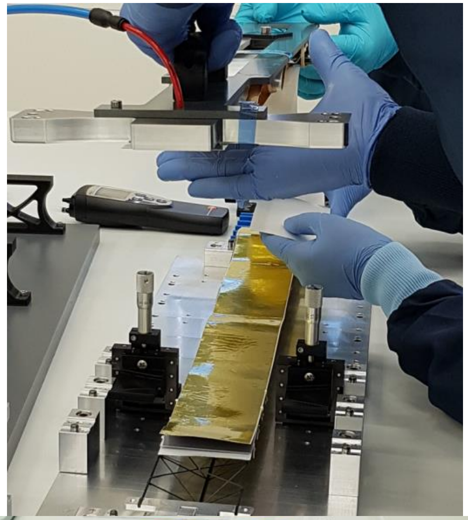


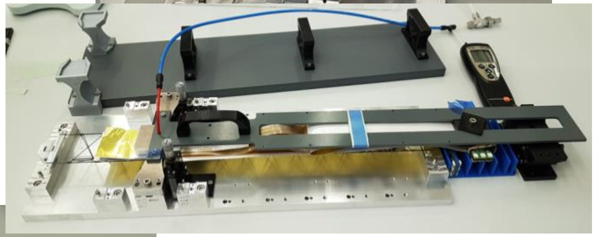
module #0 installed on ladder;
module #1 on transfer tool

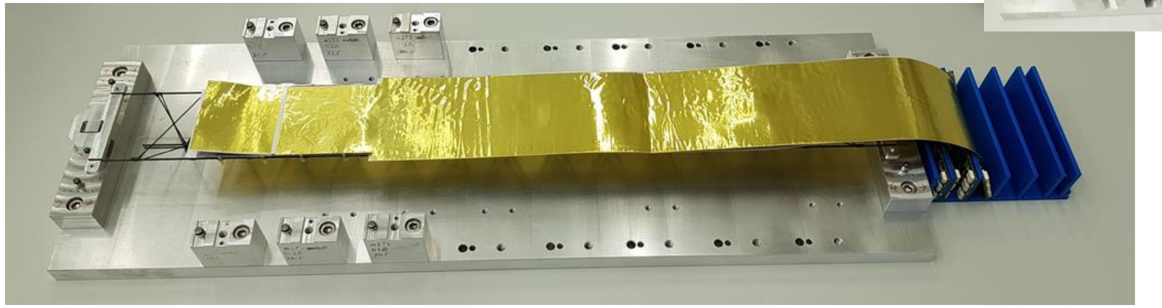


application of glue onto L-legs

transfer of module
#1 to ladder







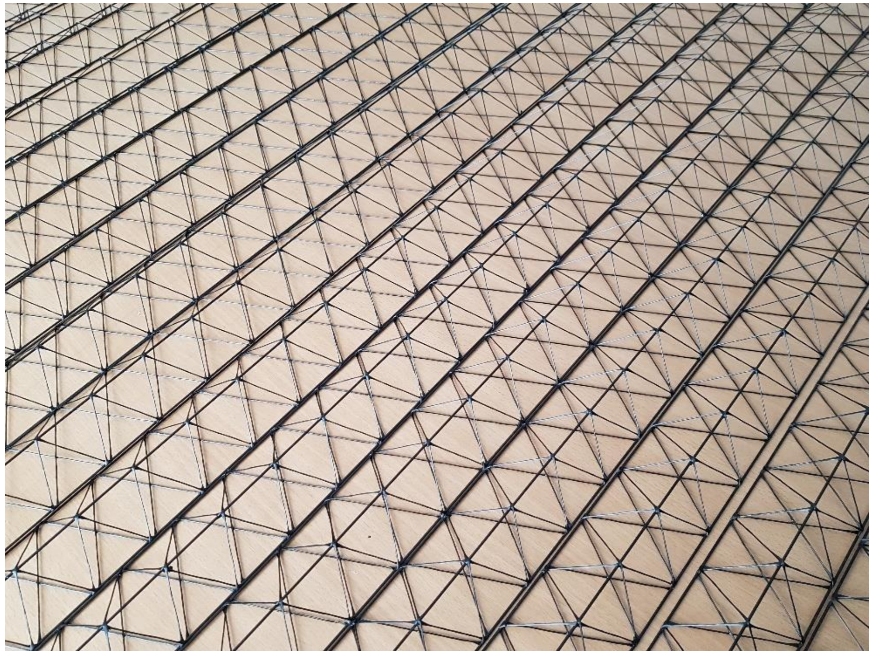
module #1
transferred, fixed
during curing of glue

Carbon fiber ladders

derived from ALICE-ITS for production in a company

winding core (prototype – Al, final – steel)

- carbon tube, 1.5/0.7mm ∅
- carbon fiber,
  Tenax, HTA40 E13, 3K, 200tex,
  three rovings, twisted
- EP resin

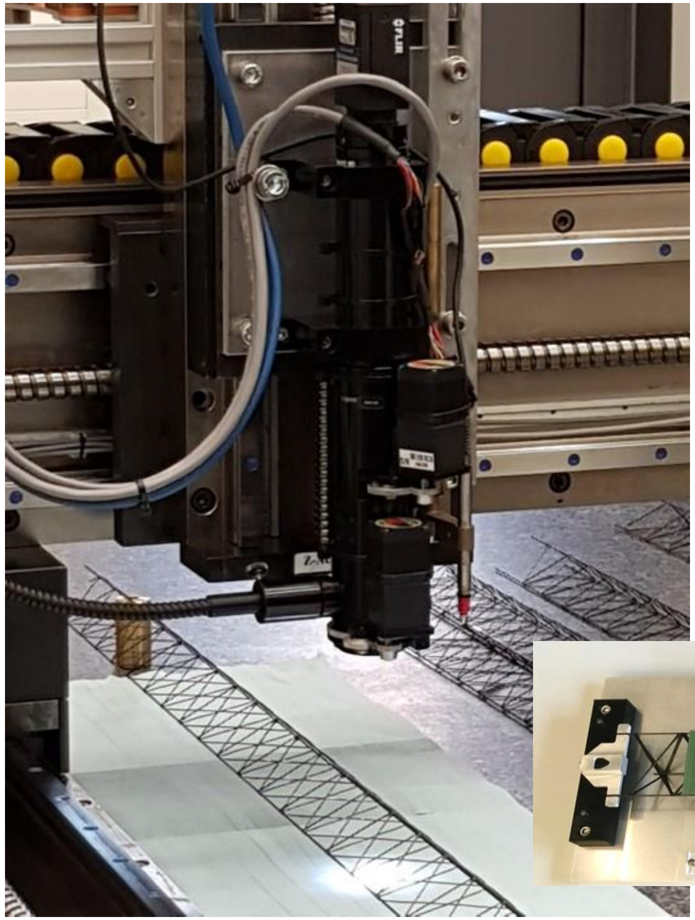


prototypes produced in company

length 120 cm, weight 14.8 g

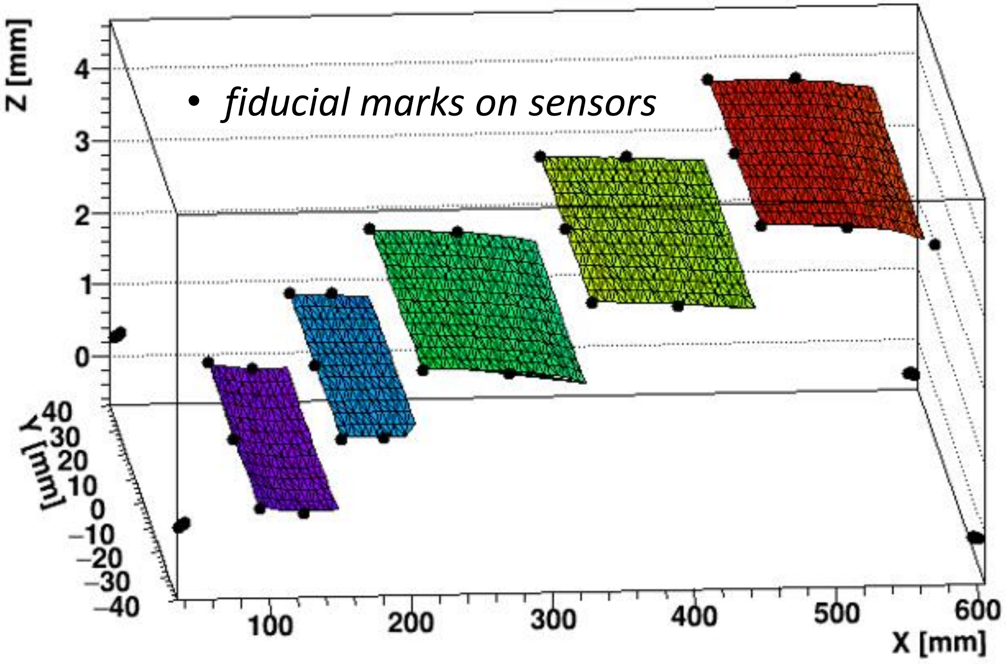
Optical metrology

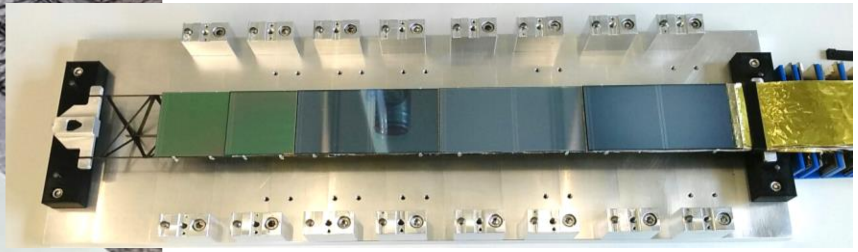
conceived for silicon microstrip QA,
adapted to ladder metrology:



– fiducial mark survey
– focus: surface height
– edge detection

10 µm position resolution



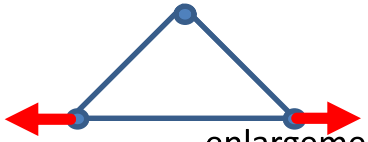


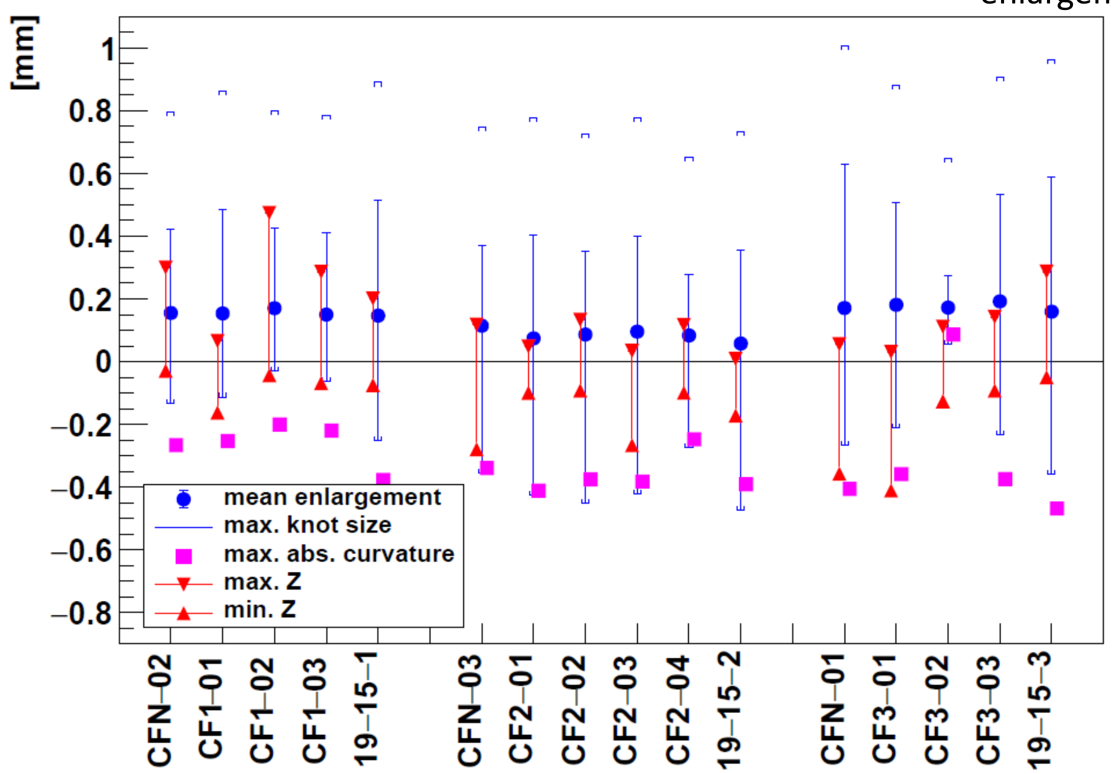
- mSTS mechanical dummy half-ladder
- demonstration of assembly technique
- sensor warp and other effects
- module placement achieved within target ± 200 µm (z), 100 µm rms (xy)

Survey of carbon fiber ladders

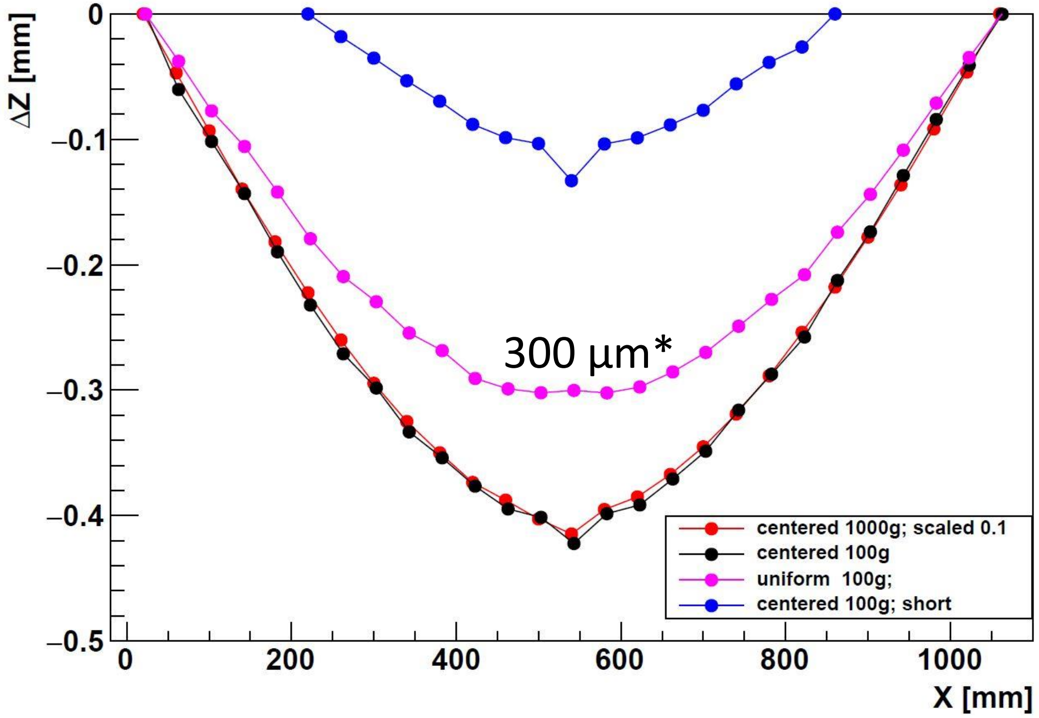
** at simultaneous load; with module mounting starting from center of ladder: expect ≈ 100 µm*

ladder shapes – 16 prototypes





ladder sag under load

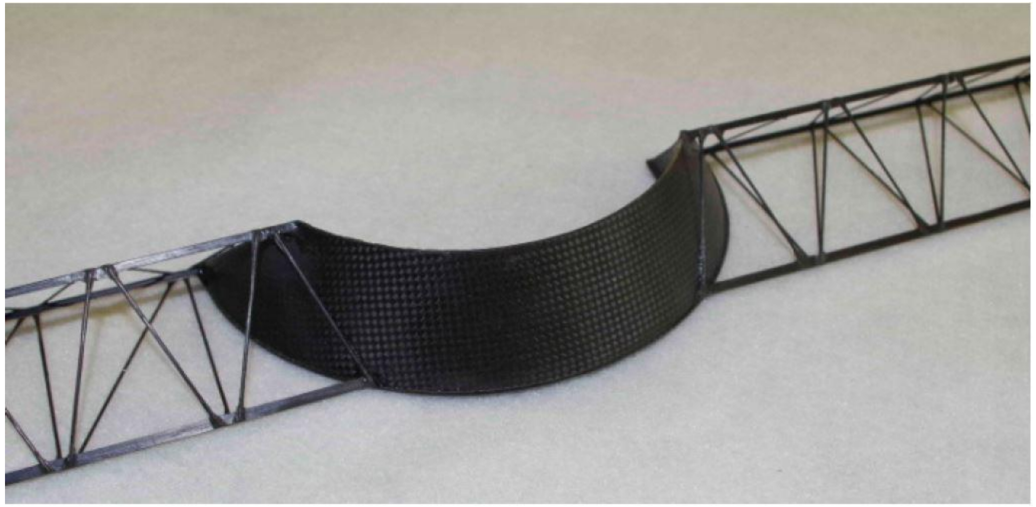


quality uniform, slightly larger tolerances needed – longer L-legs

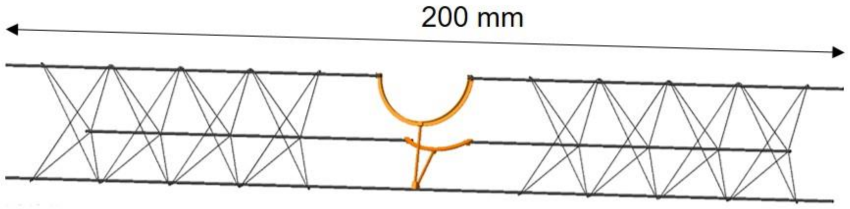
vibrational analysis ?

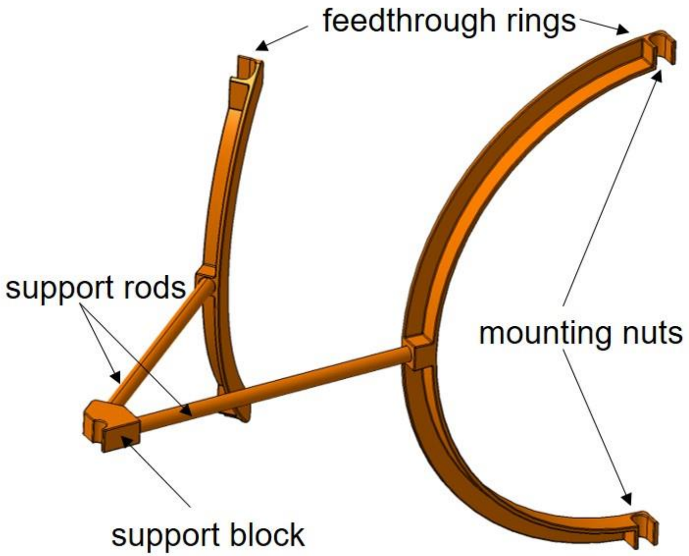
Central ladders

Concepts of modification to the carbon fiber ladders for the beam pipe intersection:



Hollow carbon fiber cone added to a ladder (ALICE-ITS style frame).
Turned out presenting too much material in CBM-STS geometrical arrangement.





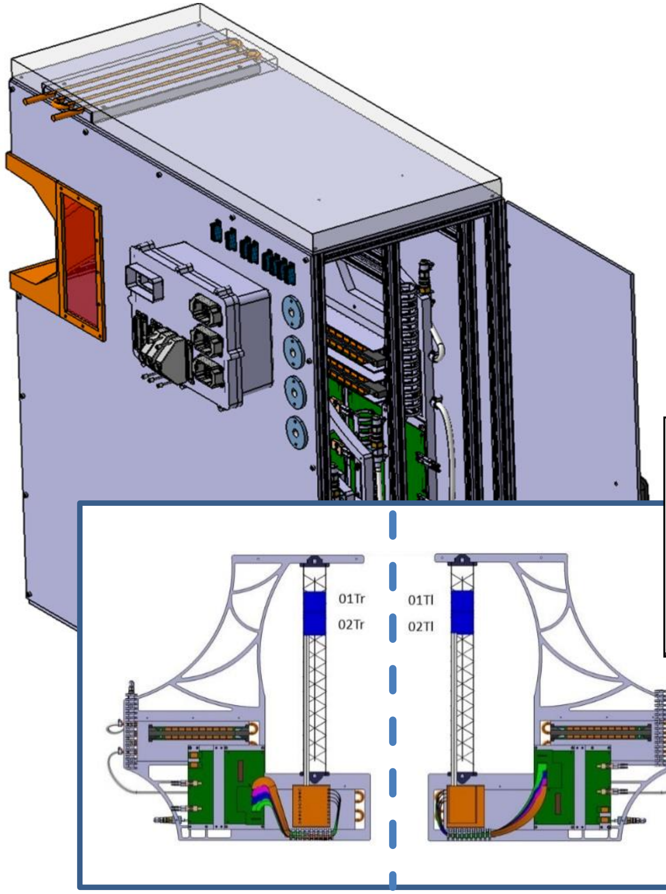
Low-mass ribs in the cut-out. To be prototyped.

mSTS demonstrator

mSTS – demonstration of:

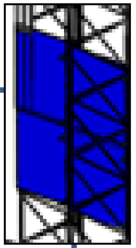
- C-frame and ladder mounting mechanics
- module and ladder assembly
- LV + HV powering
- liquid cooling of electronics (water)
- module performance, data streaming

no sensor cooling, operation at ``room'' temperature



station #0: C-frames #0 and #1

station #0
area 12 x 12 cm^2



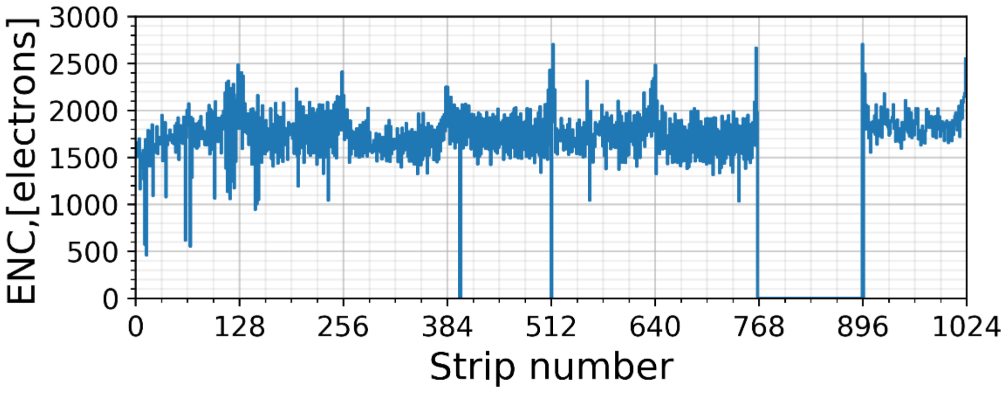
Issues seen with modules

module assembly yield

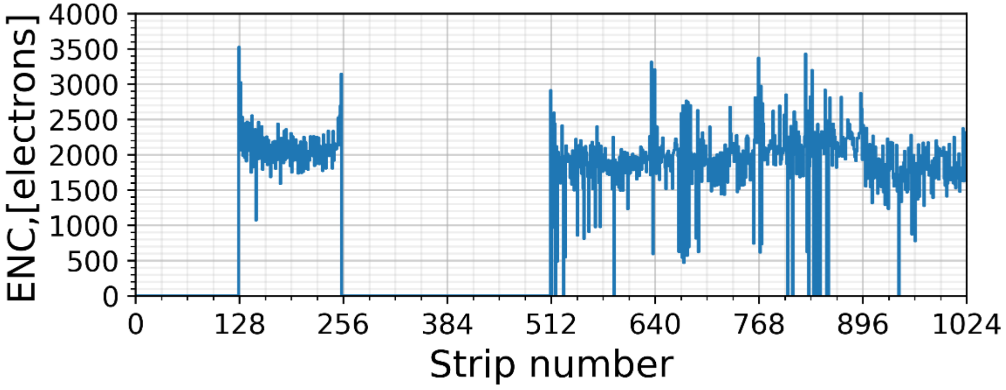
- all tested components
- microcable attachment yield high
- FEB 8 assembly/operation yield too low on the first prototypes
  - under systematic study
  - new FEB design, custom designed rad. tol. LDO, …

noise in longest modules too high

- in test box: ≈ 1300 e OK
- in mSTS: ≈ 3000 e ⇒ S/N ≈ 8-12 threshold high *(preliminary)*
  - under systematic study
  - powering scheme, filtering



P-side, Vbias = 100V



N-side, Vbias = 100V

Issues with STS system integration summarized

modules:

- understand and improve FEB assembly yield
- improve with respect to final noise in system

ladders:

- full length assembly to be done
- central ladders to be prototyped

vibration analysis:

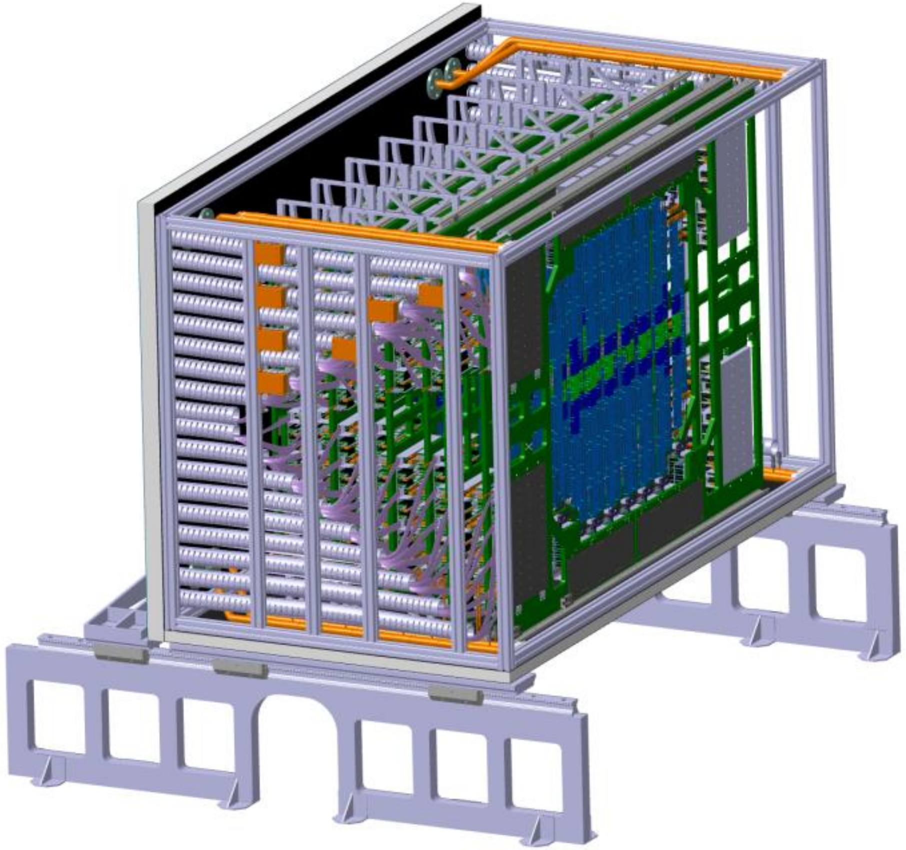
- how to identify sources?   cooling: N2 stream, liquid pump, …
- apply to which components, measure? ladders, pipes, C-frames, …

beam pipe:

- prototype based on carbon fiber, not yet approved

system integration:

- optimization of FEB box design with respect to cooling properties and space/cabling requirements



CBM-STS project teams

Germany

- *Helmholtz Center (GSI), Darmstadt*
- *Karlsruhe Institute of Technology (KIT), Karlsruhe*
- *Eberhard Karls University (EKU), Tübingen*

Poland

- *University of Science and Technology (AGH), Krakow*
- *Jagiellonian University (JU), Krakow*
- *Warsaw University of Technology (WUT), Warsaw*

Russia

- *Joint Institute for Nuclear Research (JINR), Dubna*

Ukraine

- *Institute for Nuclear Research (KINR), Kiev*

Japan

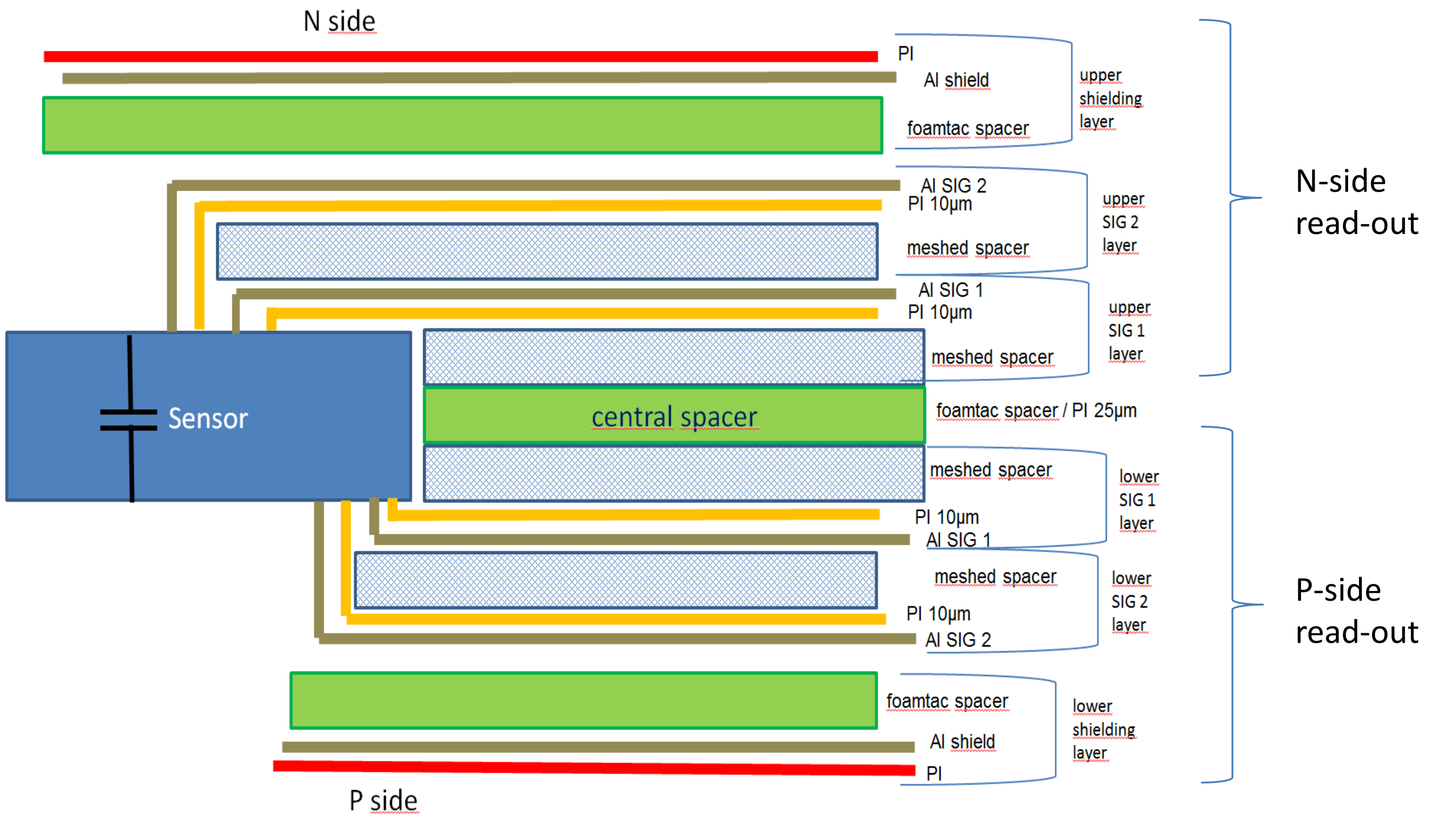
- *High Energy Accelerator Research Organization (KEK), Tsukuba (associate member)*

STS timeline:

Construction: 2019 – 2024
Installation: 2025
First beams: in 2025

Backup

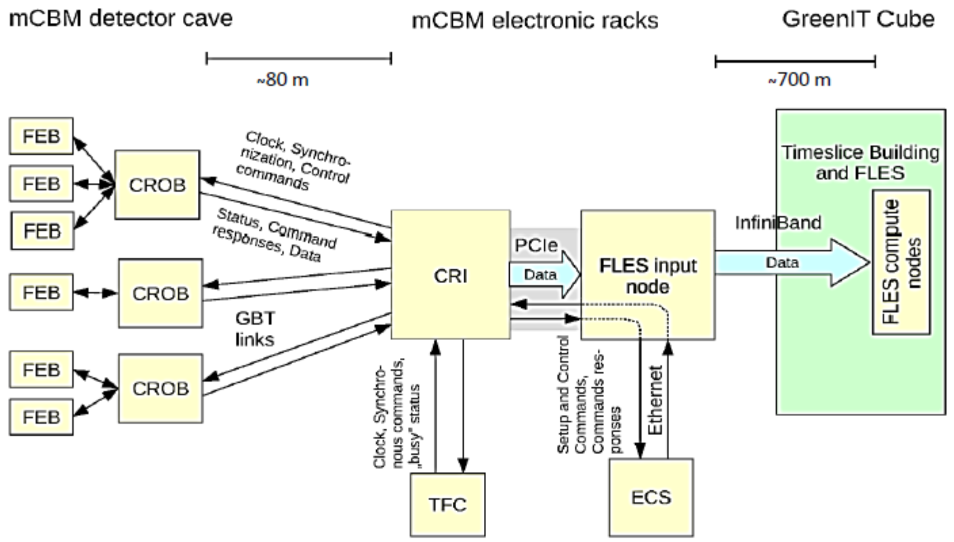
Module microcable stack



cable stack:

- thickness ≈ 800 µm, 0.23% X_0
- trace capacitance 0.45 pF/cm
- trace lengths 5 - 55 cm

Read-out chain



Block diagram of the STS readout chain

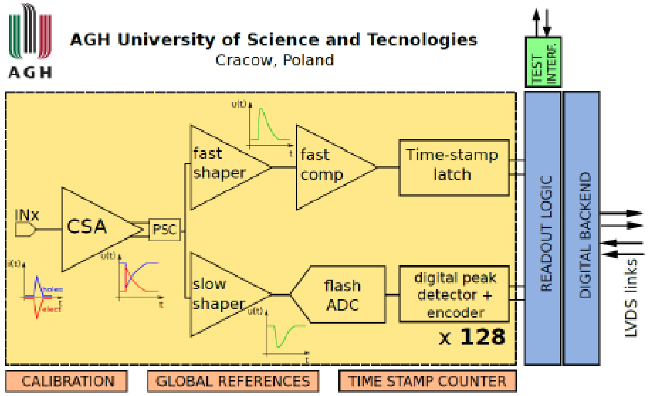
High performance, free-streaming readout chain
Main components:

FEB: Front-end boards
ROB: Readout board
CRI: Common readout interface
TFC: Timing and fast control
ECS: Experiment control system
FLES: First level event selector

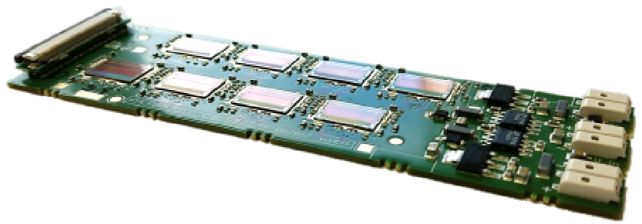
Front-end electronics

STS-XYTER ASIC
STS + X, Y coordinates + Time and Energy Resolution

- 128 readout channels + 2 test channels
- expected total capacitance: Up to 40 pF
- both signals polarity
- time resolution < 5 ns
- 5 bit flash ADC/channel (15 fC dynamic range)
- hit rate/channel: >250 kHz
- radiation hard layout
- digital backend compatible with the CERN-GBTx data concentrator



Block diagram of the STS-XYTER ASIC

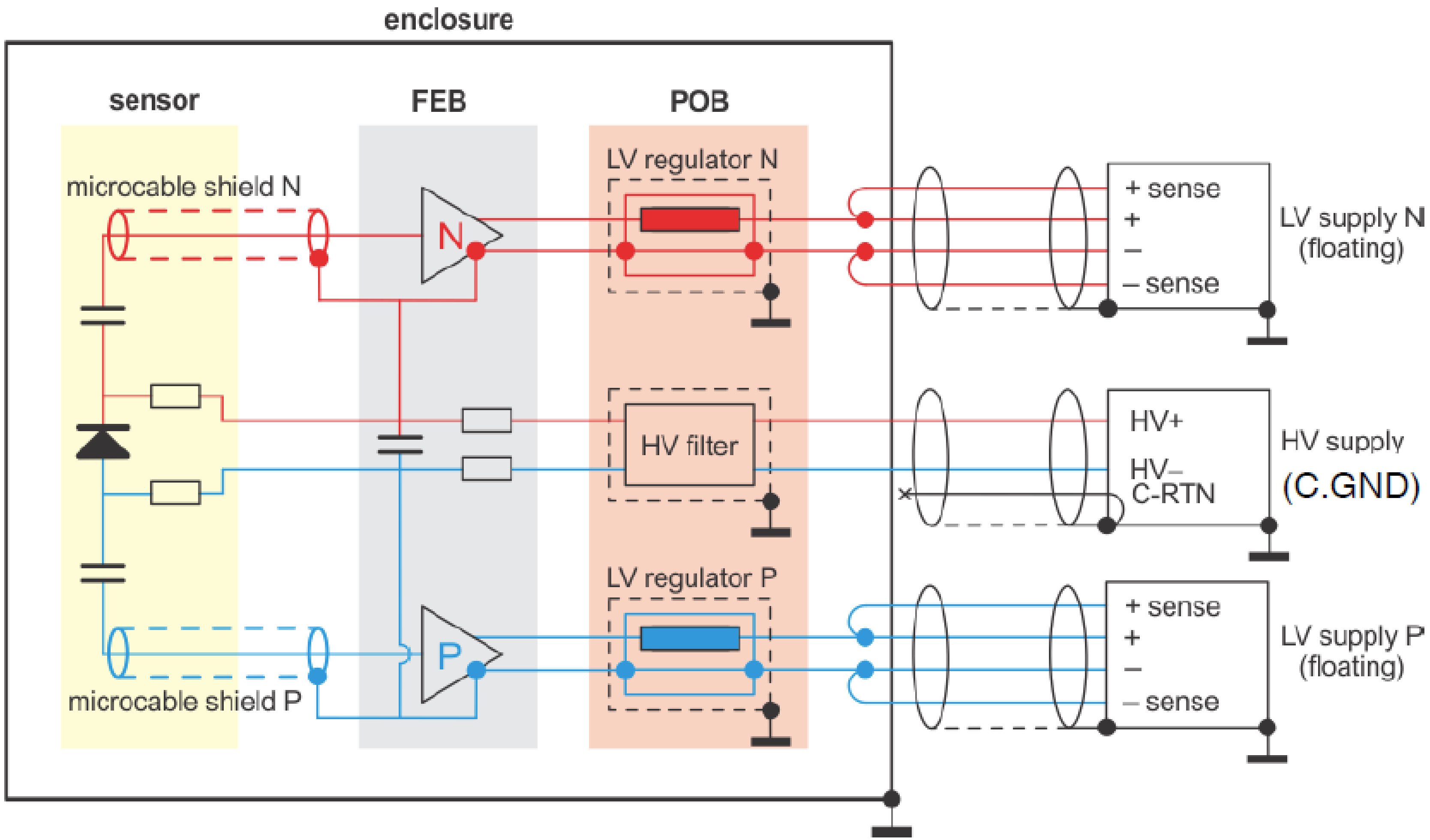


Prototype of the STS front-end board carrying 8 STS-XYTER ASICs

Front-end Board

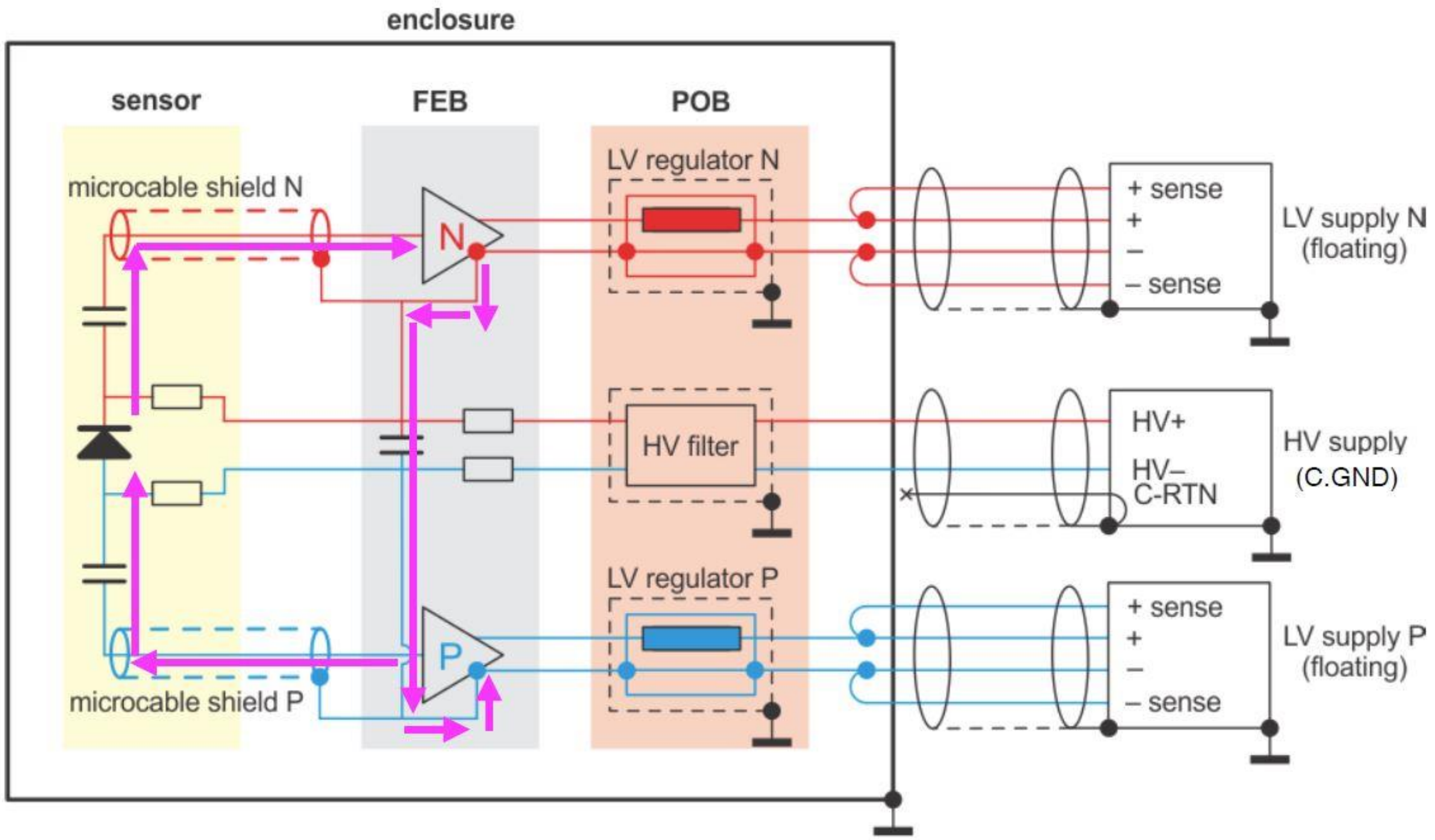
- part of a functional module
- high-level integration board with 8 STS-XYTER ASICs and up to 5 data links per ASIC
- connected via microcables to the Si sensors

mSTS powering scheme



- Floating LV supplies are referenced to the P- and N-side potentials.
- Microcable shields are connected to the respective FEB grounds.
- HV common return is not connected to the mSTS enclosure.
- Enclosure is grounded at all times; electrically insulated from the mounting table

Detector signal path



- Return path capacitor must be placed close to the FEBs.
- Blocking resistors prevent signal "escape" into the filter and HV power supply.