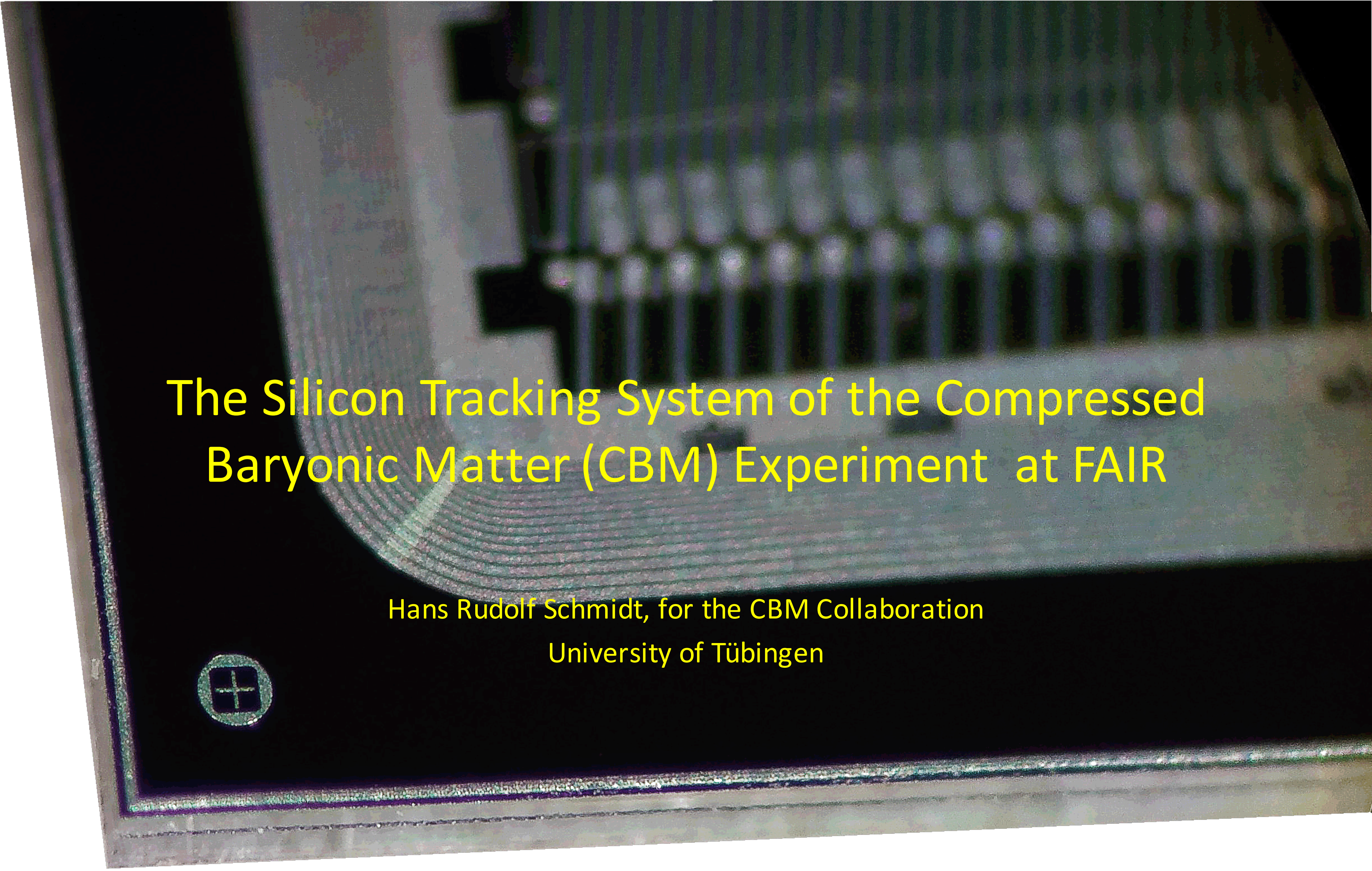


The Silicon Tracking System of the Compressed Baryonic Matter (CBM) Experiment at FAIR

Hans Rudolf Schmidt, for the CBM Collaboration
University of Tübingen

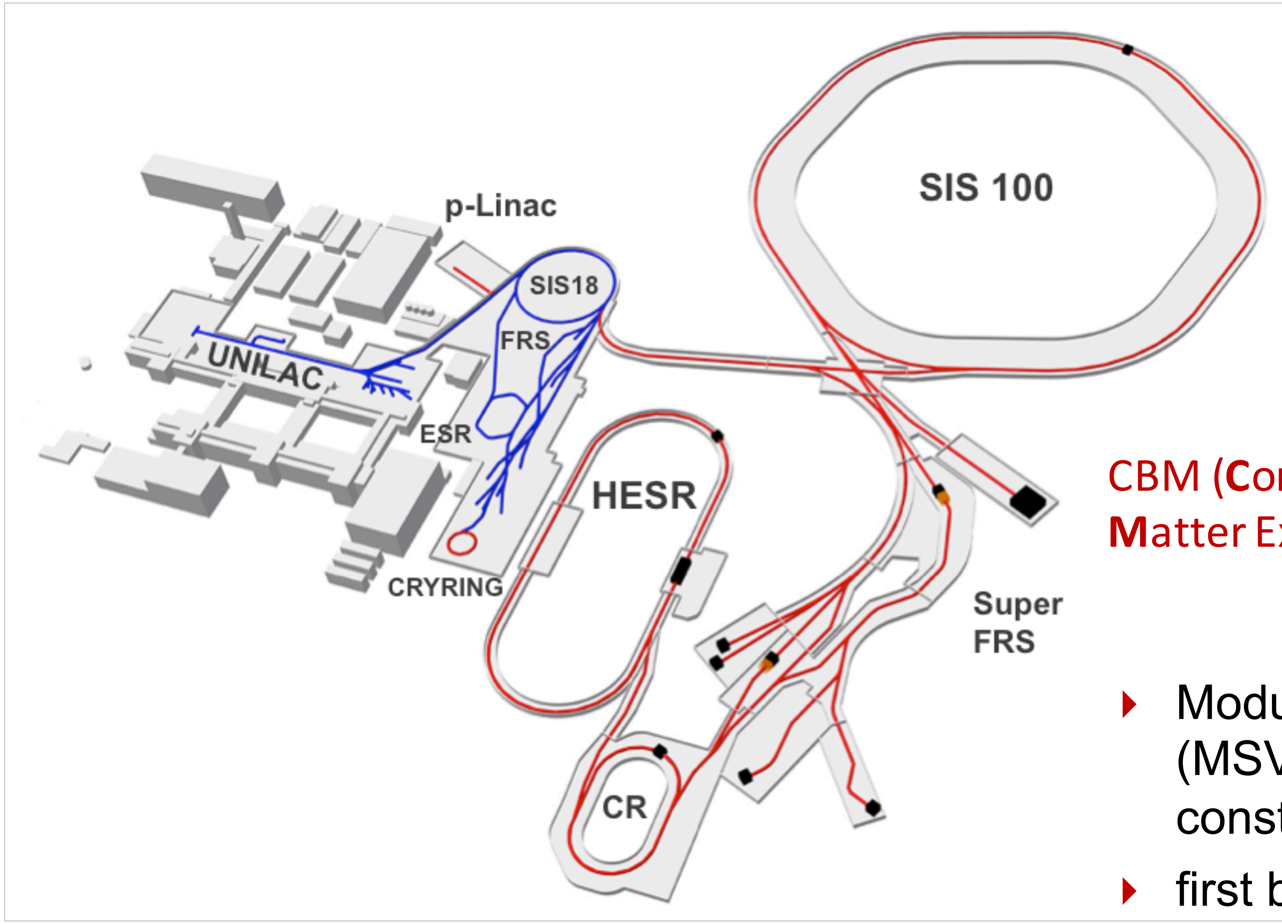
CBM

FAIR

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Frontier Detectors for Frontier Physics
14th Pisa Meeting on Advanced Detectors
May 27 – June 2 2018 • La Biodola, Isola d'Elba (Italy)

FAIR @ Darmstadt



CBM (**C**ompressed **B**aryonic **M**atter Experiment)

- Modularized Start Version (MSV) of FAIR currently under construction
- first beams (p,…, U) expected 2024
- E_{beam} = 11 - 29 AGeV

FAIR Construction Site

- areal view

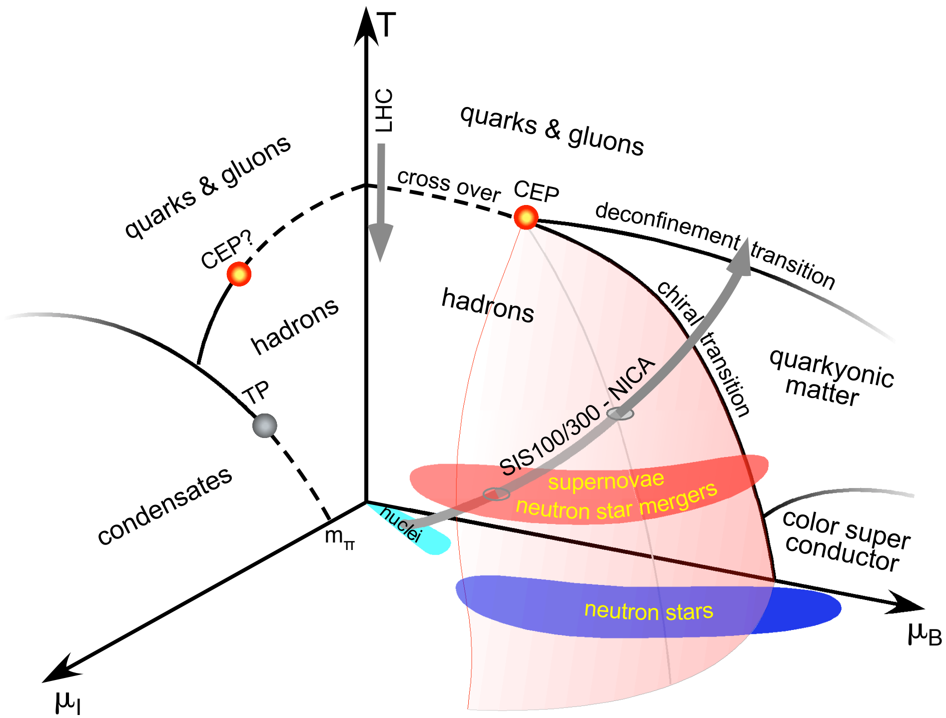
FAIR Construction Site

- excavation of the SIS100 tunnel

FAIR Construction Site

- excavation of the SIS100 tunnel (May 2018)

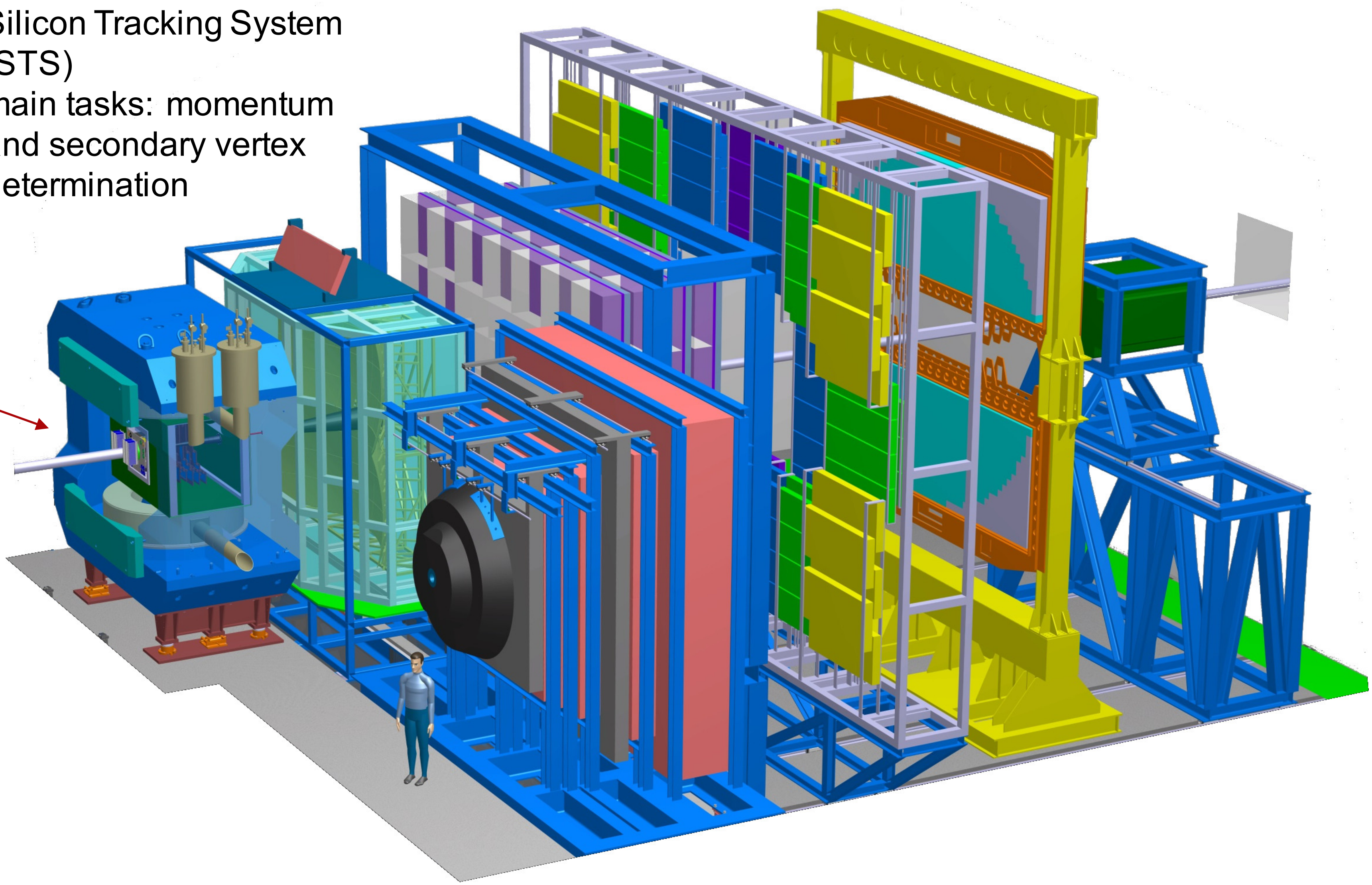
CBM Physics Mission



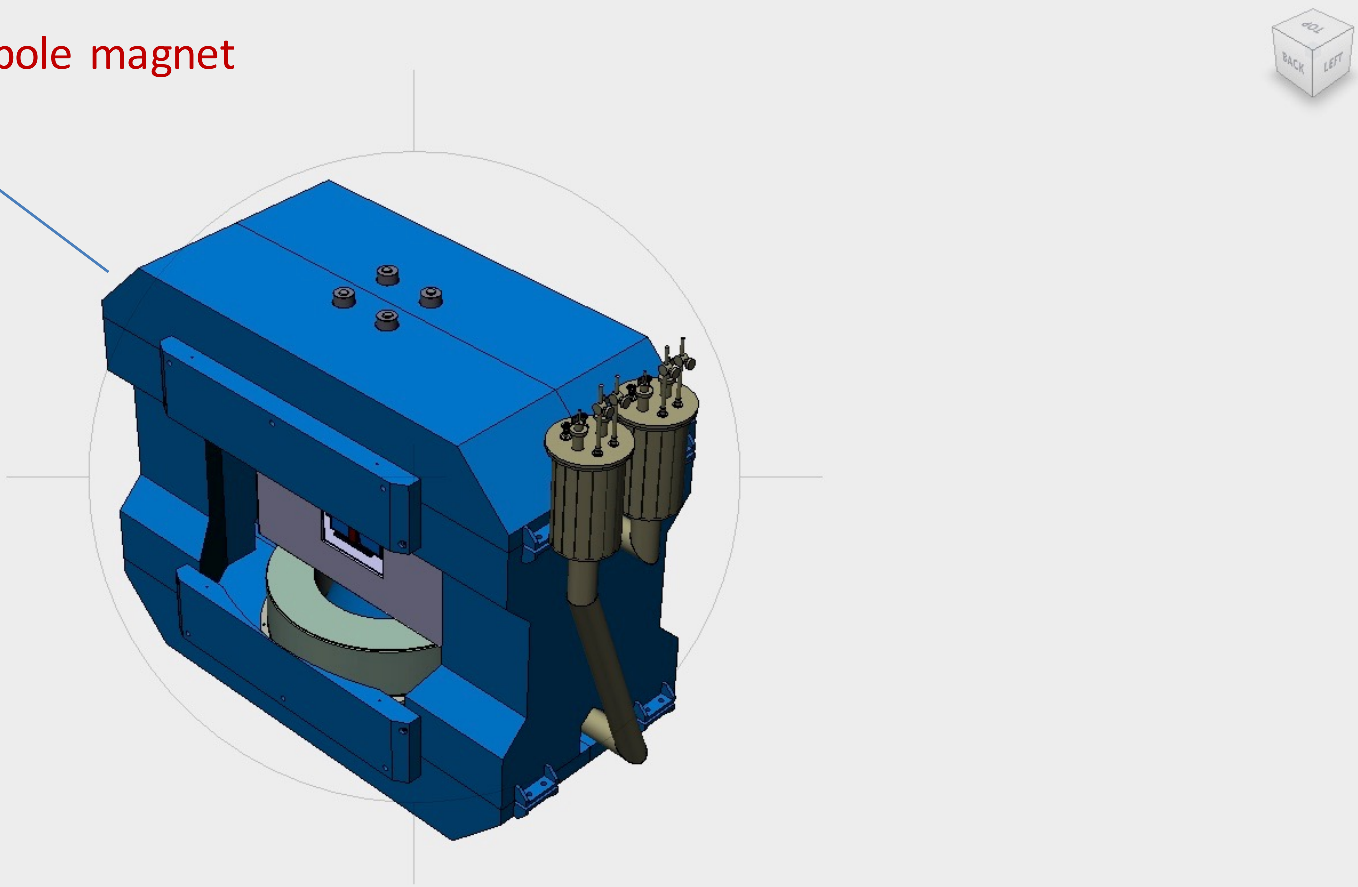
- Exploration of the QCD phase diagramm at high μ_B and moderates temperatures
  - de-confinement and chiral transitions
  - equation-of-state relevant for neutron stars and neutron star mergers
    - utilizing rare probes: di-lepton, multi-strangeness
- Note: this is generally low-p_t physics
- CBM sub-detectors must be capable to measure at rel. low momentum but at high interaction rates ($\sim 10\ Mhz$)

CBM Fixed Target Detector Setup

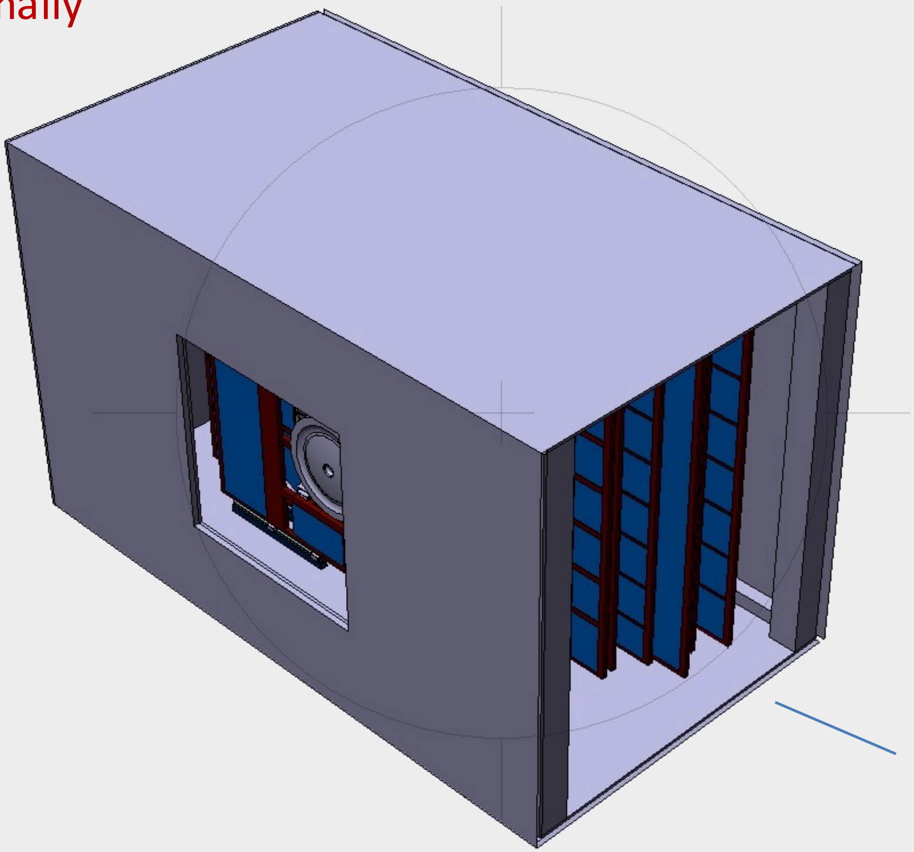
- Silicon Tracking System (STS)
- main tasks: momentum and secondary vertex determination



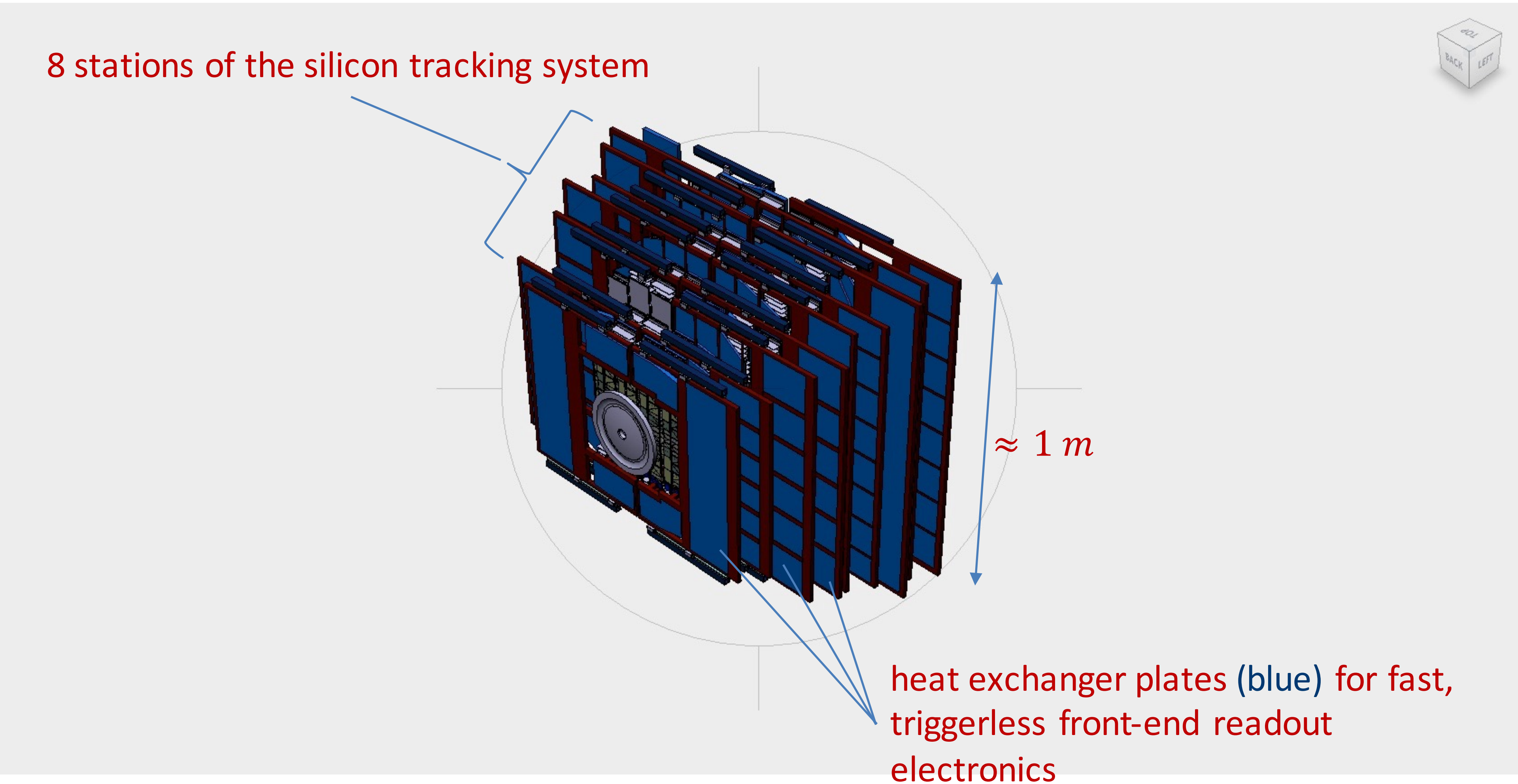
1 Tm superconducting dipole magnet

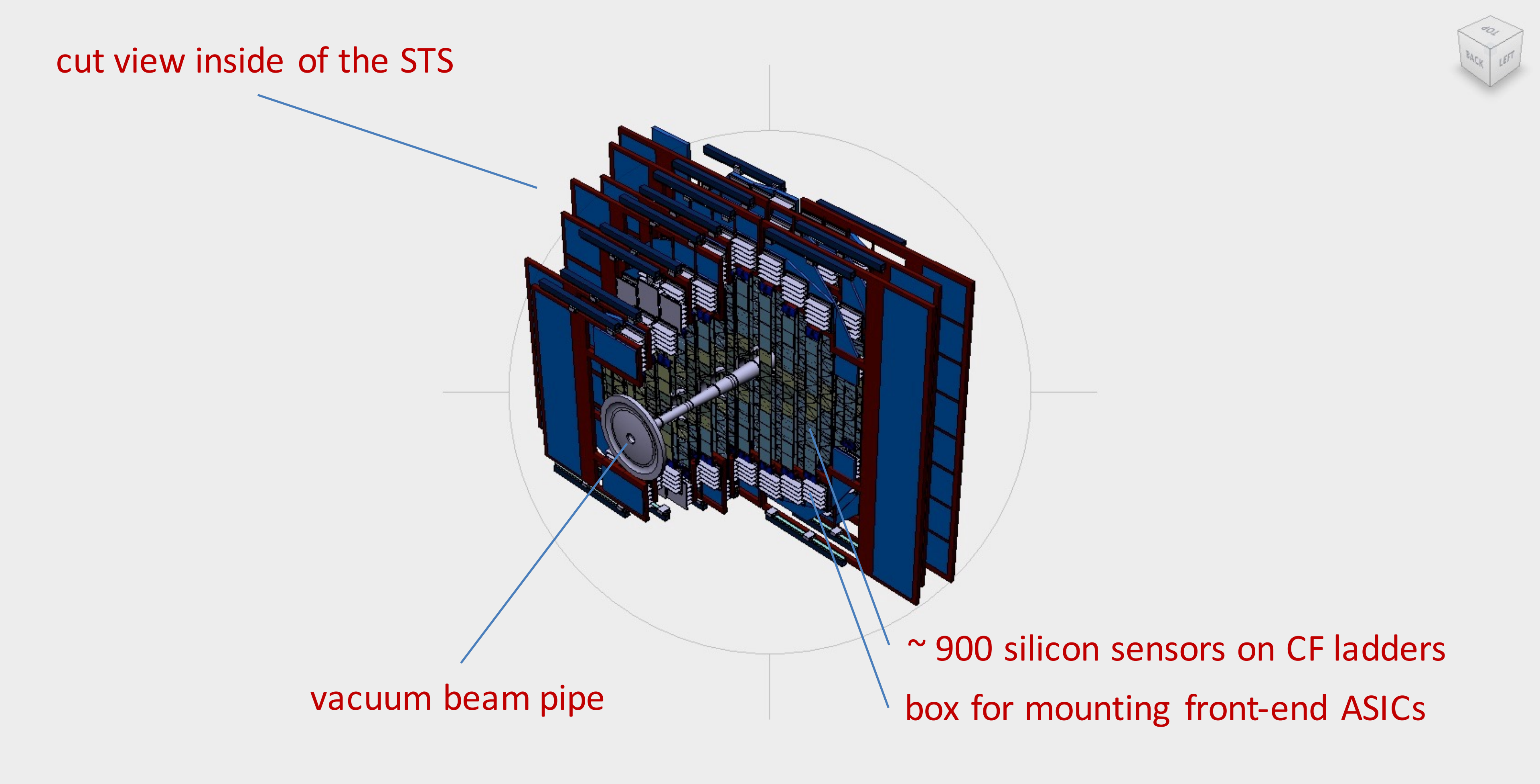


inside magnet: thermally insulating box



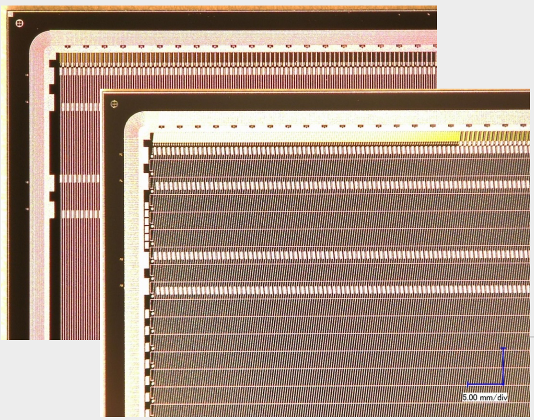
side walls removable for maintenance


8 stations of the silicon tracking system
$\approx 1\ m$
heat exchanger plates (blue) for fast, triggerless front-end readout electronics

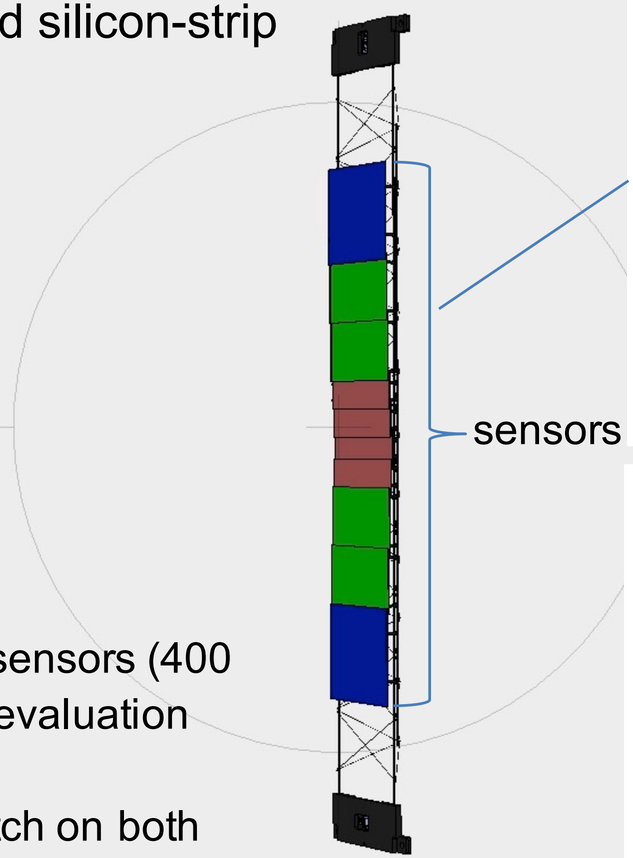

cut view inside of the STS
~ 900 silicon sensors on CF ladders
vacuum beam pipe
box for mounting front-end ASICs

CF Ladder with Sensors

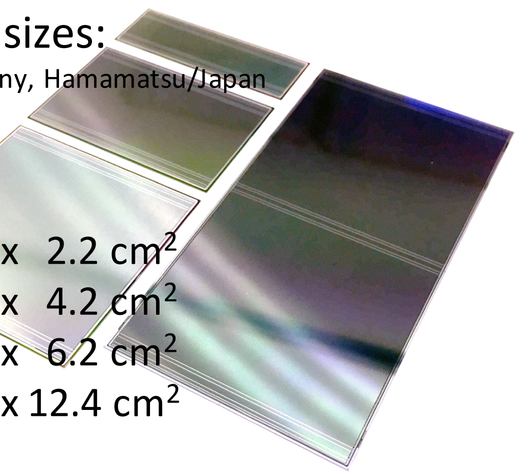
sensor type: double-sided silicon-strip



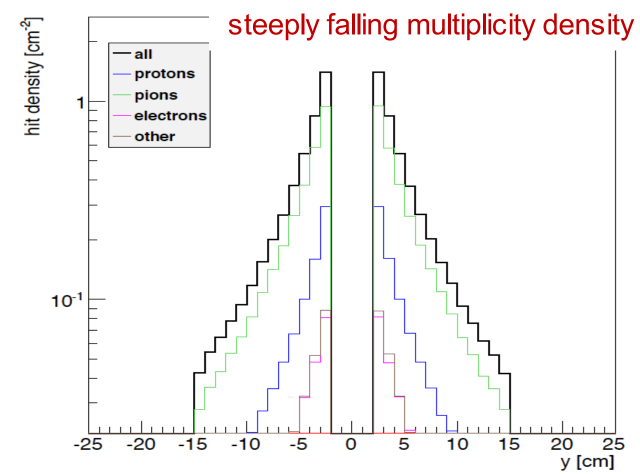
- 285/320 ± 15 µm thick
  - impact of thicker sensors (400 or 500 µm) under evaluation
- n-type silicon
- 1024 strips of 58 µm pitch on both sides
- angle front/back: 7.5°/0°



sensor sizes:
CiS/ Germany, Hamamatsu/Japan



- 6.2 x 2.2 cm^2
- 6.2 x 4.2 cm^2
- 6.2 x 6.2 cm^2
- 6.2 x 12.4 cm^2



station 1

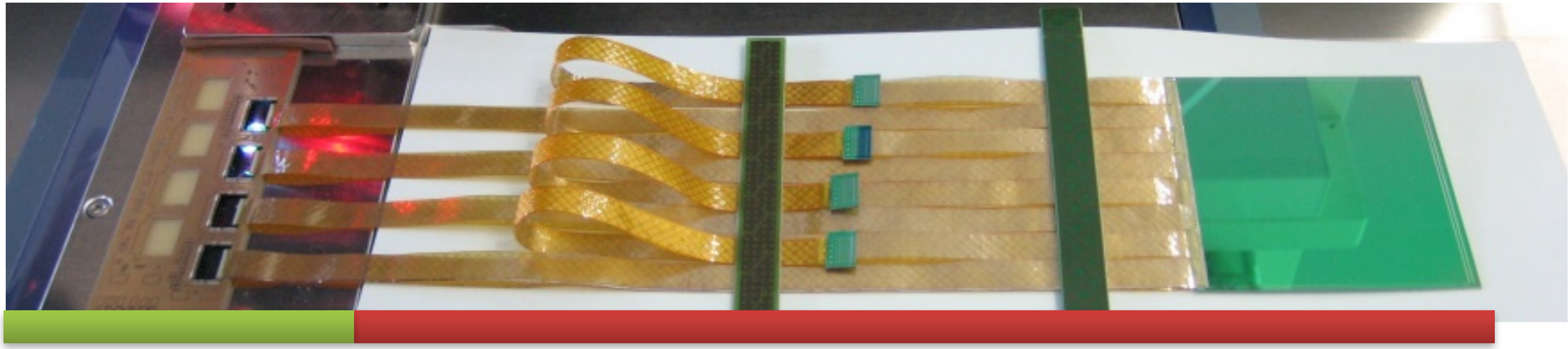
Challenges I: Material Budget

- best possible momentum resolution at low momenta

$\Rightarrow$ minimize multiple scattering $\Theta_m = \frac{13.6MeV}{\beta \cdot c \cdot p} \cdot \sqrt{\frac{X}{X_0}}$ $\Leftrightarrow$ minimize material budget

- basic functional unit is a module, consisting of:

FEB with r/o ASICs **ultra-thin micro cables** sensor

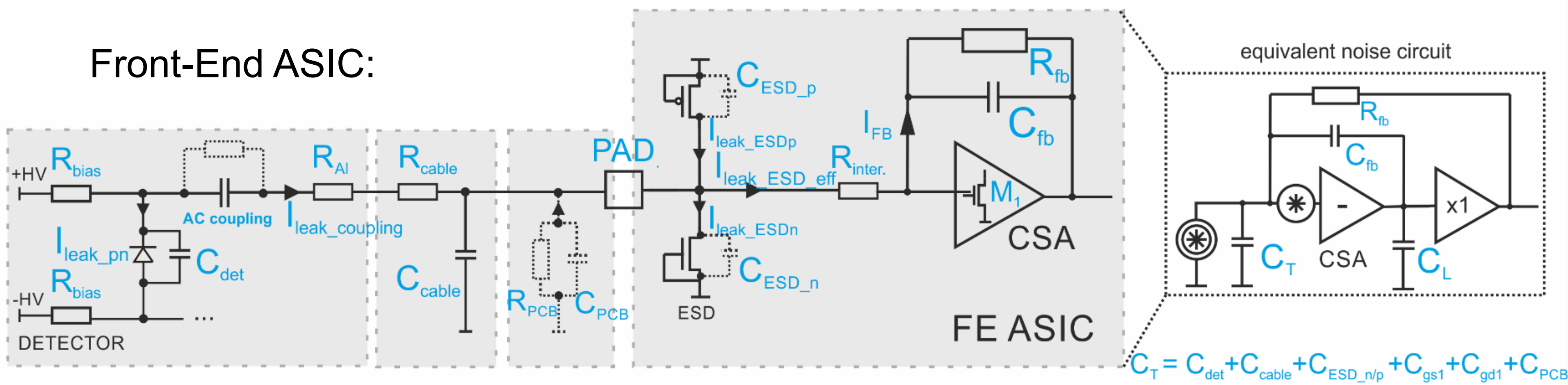


FEE outside of acceptance inside of acceptance

- geometry/multiplicity density dictates 18 different module types!
  - different sensor, different cable, different bandwidth of r/o

Challenges II: Signal/Noise

- Design goal: ENC_{total} < 1000e RMS
- ENC_{FEE} < 500e RMS (complex, many contributions)



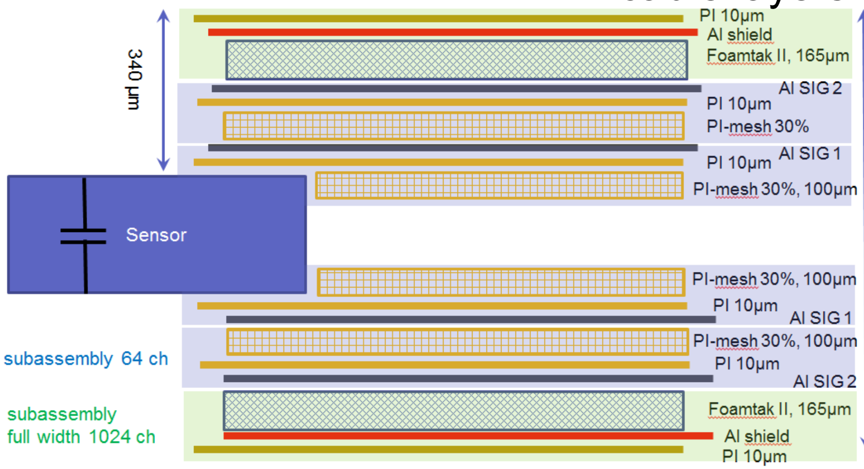
- Noise scales with total capacitance:
  - $C_T = C_{det} + \mathbf{C_{cable}} + C_{ESD\_n/p} + C_{gs1} + C_{gd1} + C_{PCB}$

⇒ careful design of µ-cables to minimize capacitance

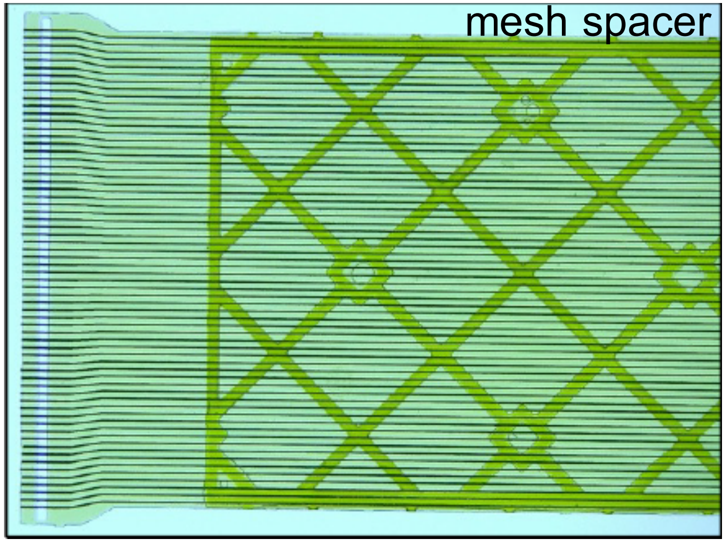
Read-out Cables

- main design constraints: capacitance, bonding scheme, production yield
- signal layer: 64 lines - 116 µm pitch, 14 µm thick, on 10 µm polyimide
  - 32 cables/sensor
  - mesh layer between signal and ground layer to decrease capacitance
- alternative mounting schemes:
  - Aluminum-Polyimide technology, tab bonding (LTU Ltd, Kharkov, Ukraine)
  - Copper-Polyimide technology, stud bonding (KIT, Karlsruhe)

cable layers



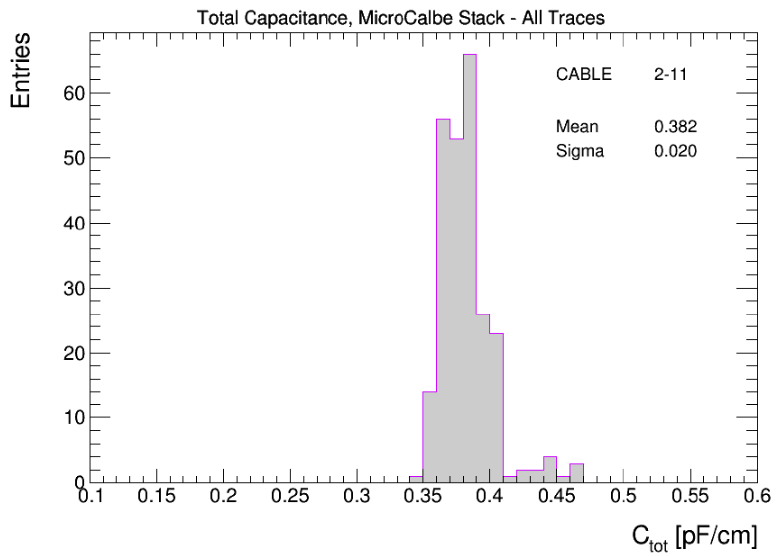
mesh spacer

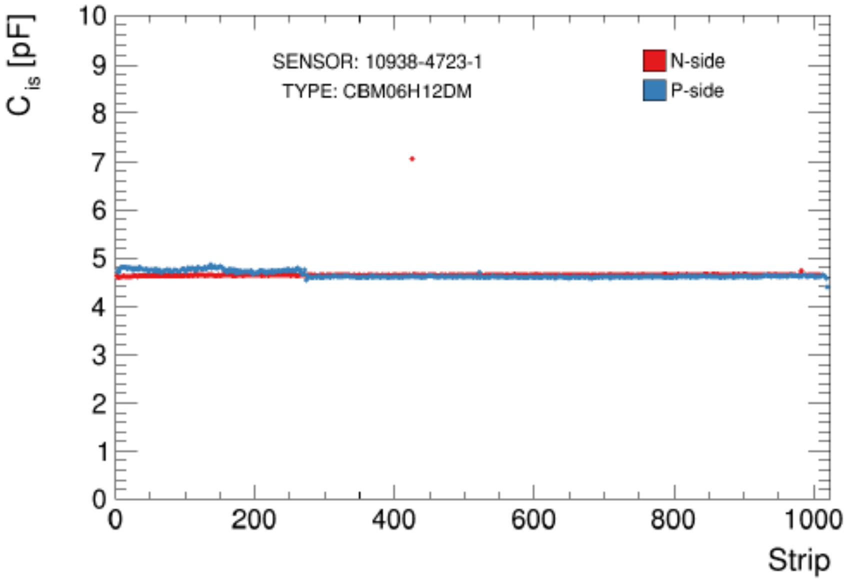


Measured Cable and Sensor Capacitances

- cable total capacitance
  C_{cable} = 0.382 ±0.020 pF/cm

- sensor interstrip capacitance
- 12 cm sensor (Hamamatsu)
  $C_{interstrip}$ = 0.38±0.2 pF/cm

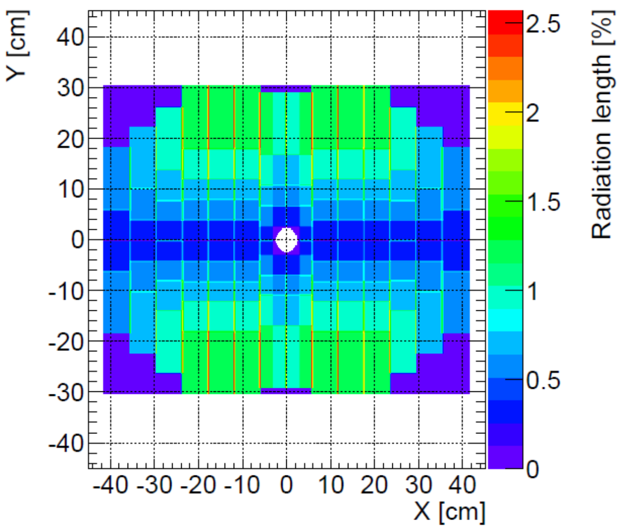




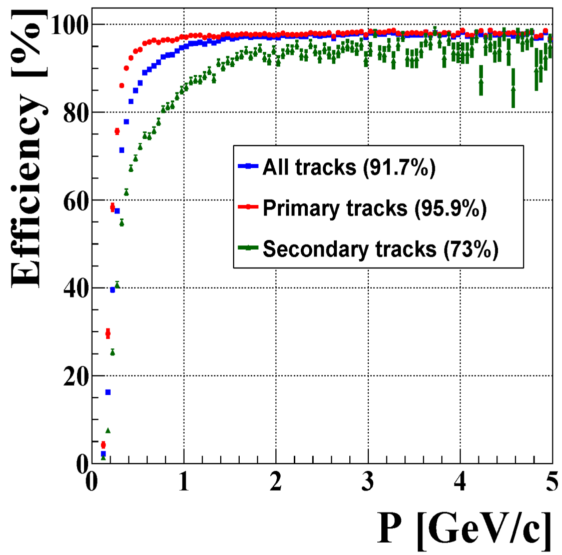
- design goal: cable capacitance/cm² should not exceed interstrip value of sensor
- cable length up to 55 cm!

Material Budget & Simulation Results

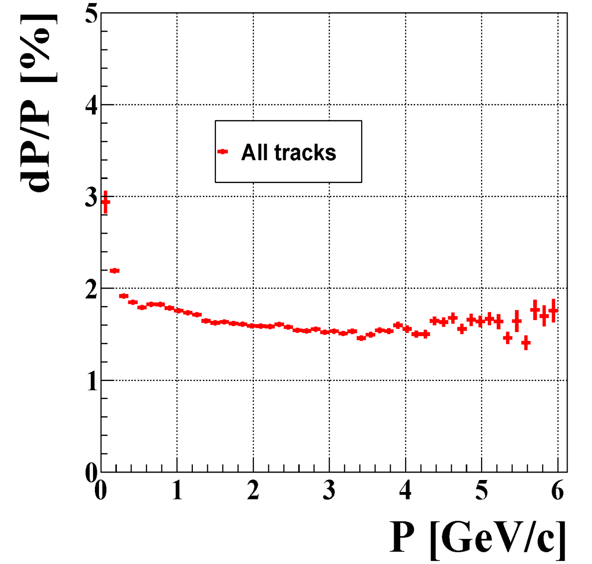
mateal budget/station



reconstruction efficiency



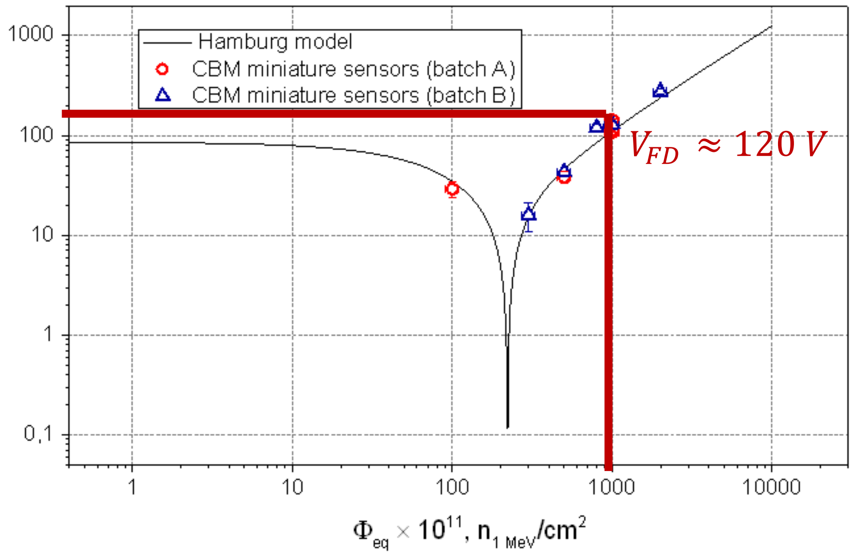
momentum resolution



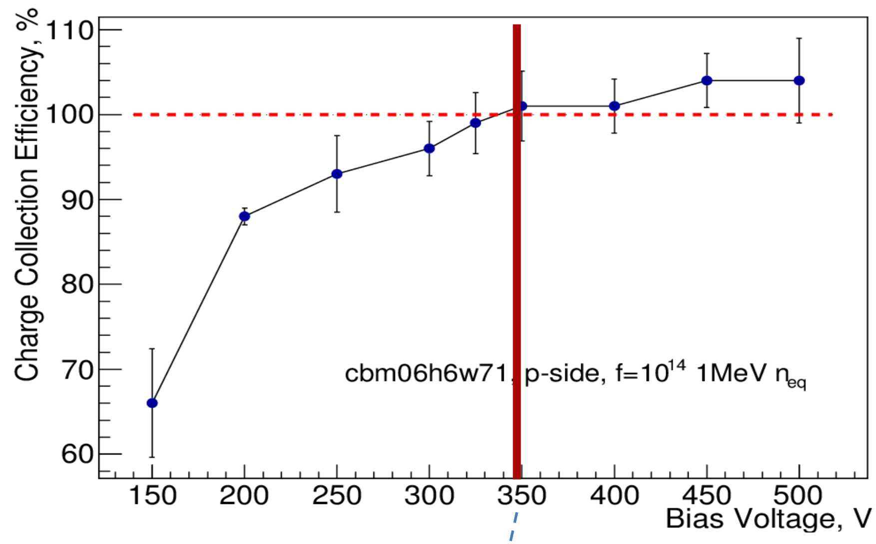
- material budget ranges from $X/X_0 = 0.3$ (sensor only) to $X/X_0 = 1-1.5\%$ (sensors + cables) resulting in:
  - reconstruction efficiency (simulation): $\epsilon \approx 98\%$
  - momentum resolution (simulation): $\frac{\delta p}{p} \approx 1.5-2\%$

Challenges III: Radiation Tolerance

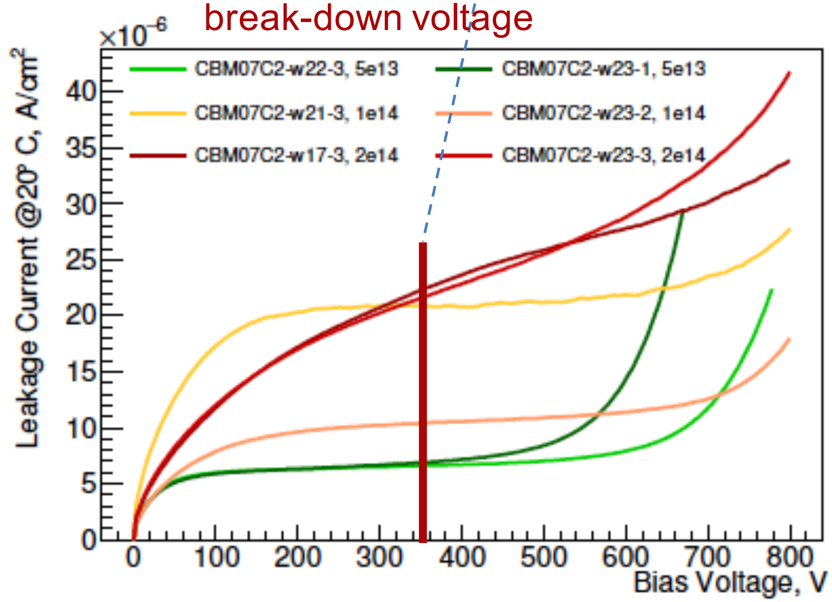
type inversion with fluence



charge collection efficiency irradiated sensors



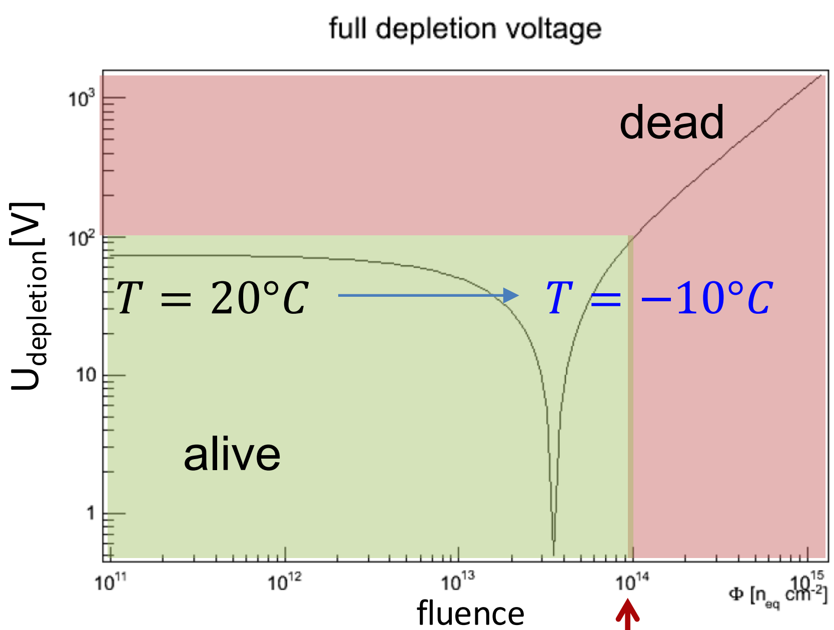
break-down voltage



- life time fluence: $\Phi_{eq} = 10^{14}_{n_{1MeV}}\ cm^{-2}$
  - 5-10 month of running at 10 MHz
- corresponding full depletion voltage: $V_{FD} \approx 120\ V$
- to recover charge collection eff.: $V_{FD} > 350\ V$
- high current or breakdown essentially sets limit to the lifetime

Challenges IV: Cooling

- effects in high radiation environment:



$$I_{leak}(V,\Phi) = \alpha V \Phi$$

$$I_{leak}(T) = I_{leak,293}\left(\frac{T}{293}K\right)^2 \exp\left(-\frac{E_{gap}(T)}{2k_B}\right)\left(\frac{1}{T} - \frac{1}{293K}\right)$$

- leakage current increase with fluence V, Φ and temperature T

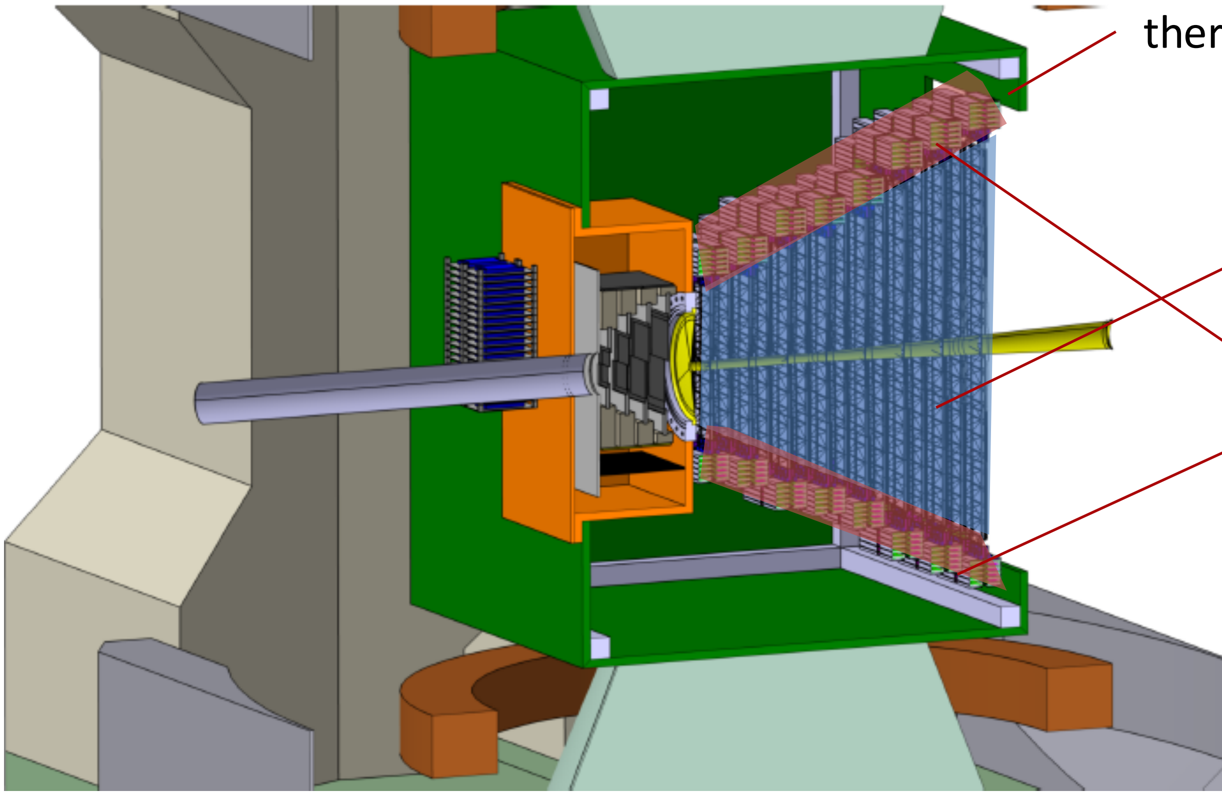
⇒ sensor cooling mandatory to avoid thermal runaway

⇒ keep sensors permanently at $T = -10°C$

up tp 6 mW/cm² at end of life time ($\Phi_{eq} = 10^{14}_{n_{1MeV}}\, cm^{-2}$)

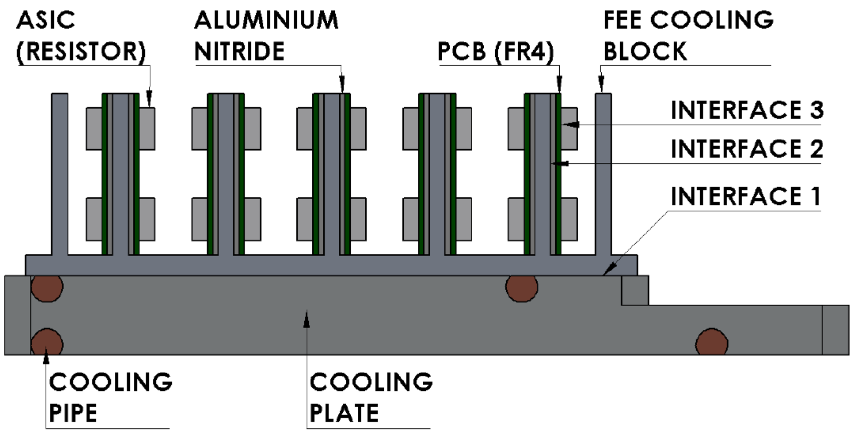
Cooling Requirements

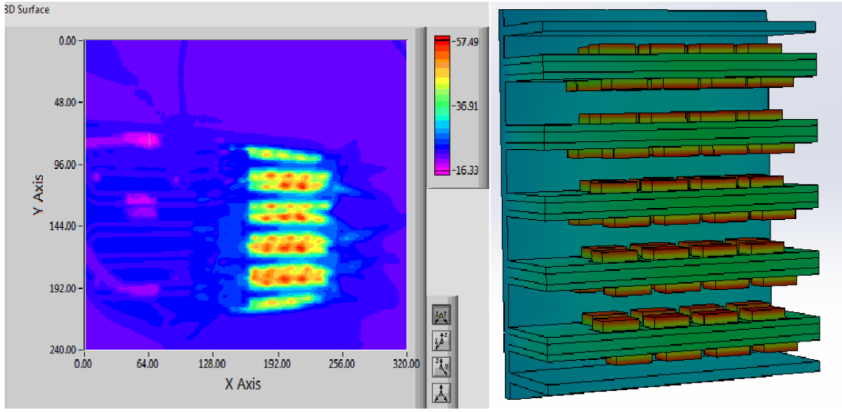
- fast readout electronics produces 40 kW thermal power within insulation volume

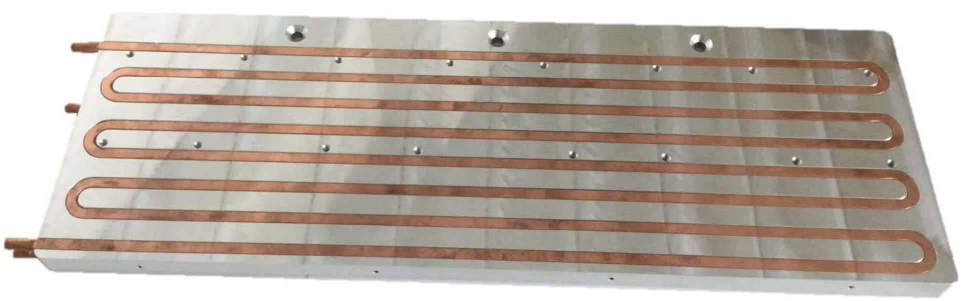


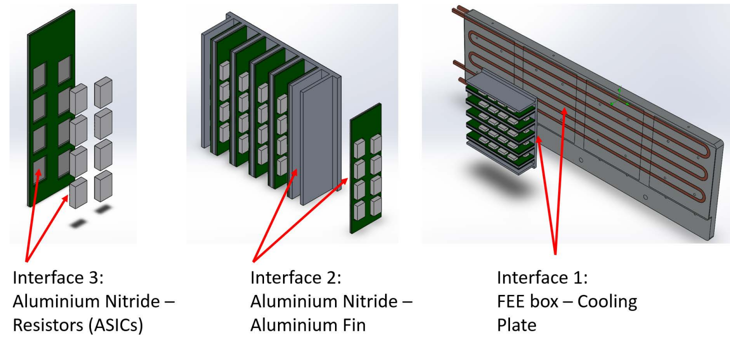
- Efficient high power CO_2 cooling system under development to neutralize 40 kW thermal power from r/o electronics!
- but: innermost sensors produce up to 6 mW/cm^2 – cooling by forced N_2 convection??

Cooling R&D







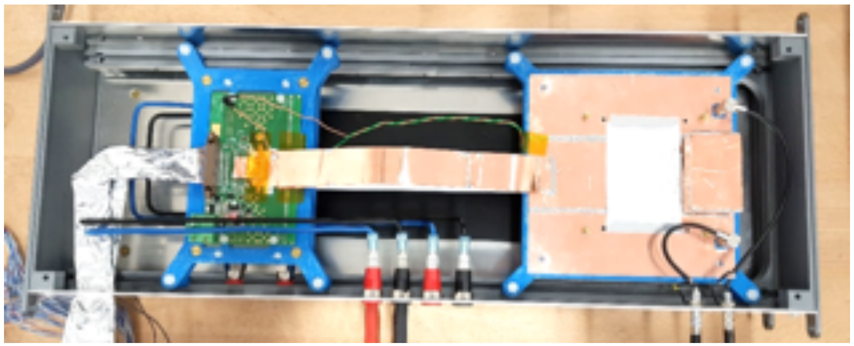


- optimization of:
  - heat exchanger (P=120 bar)
  - thermal interfaces
- large scale cooling demonstrator

see poster by Kshitij Agarwal

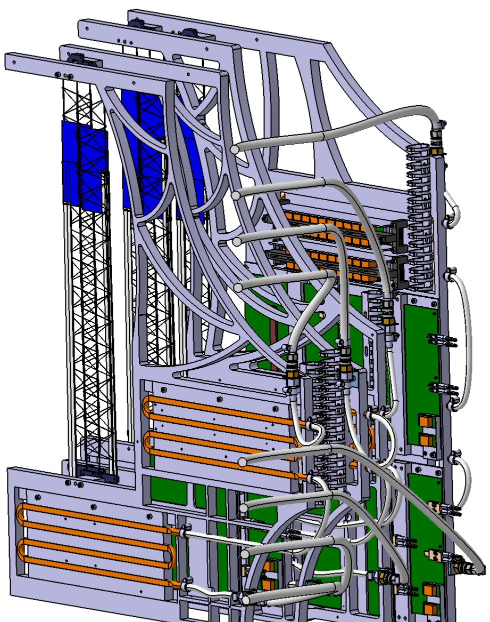
STS Functional Demonstrators

single module



- module test at COSY, Feb. 2018
  - proton beam, 1.7 GeV/c
  - 128 channels /side read out
  - microcable 25 cm long
- design parameters verified
  - ENC = 1090 ±150 e (n)
  - ENC = 1350 ±200 e (p) (?)
  - signal-to-noise: 15±3

miniSTS



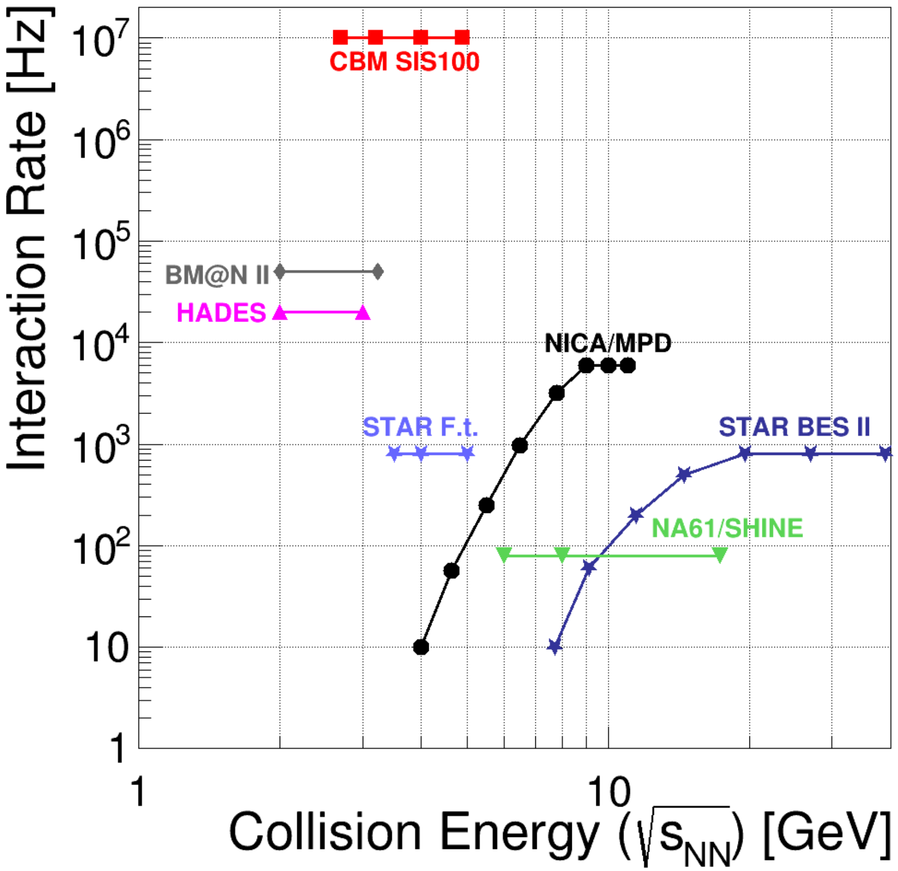
- miniSTS in demonstrator experiment miniCBM at GSI/SIS18 in 2018/19
  - up to 4 layers of silicon
  - full system test including streaming readout

Summary

- CBM STS design optimized wrt
  - material budget and radiation tolerance
    - sensor R&D finished
  - sophisticated QA methods developed (see poster by E. Lavrik)
  - cooling R&D ongoing
- sensor production readiness review (April 2018)
  - ready for tendering
  - sensor purchasing & module production 2019-2020
- participating laboratories
  - GSI Darmstadt (QA, assembly, integration)
  - JINR Dubna (QA, assembly)
  - University of Tübingen (QA, cooling)
  - KIT Karlruhe (cables, assembly)
  - AGH, Cracow (readout ASICs)
  - JU, Cracow (readout)
  - WUT, Warsaw (readout)

backup

Interaction Rates

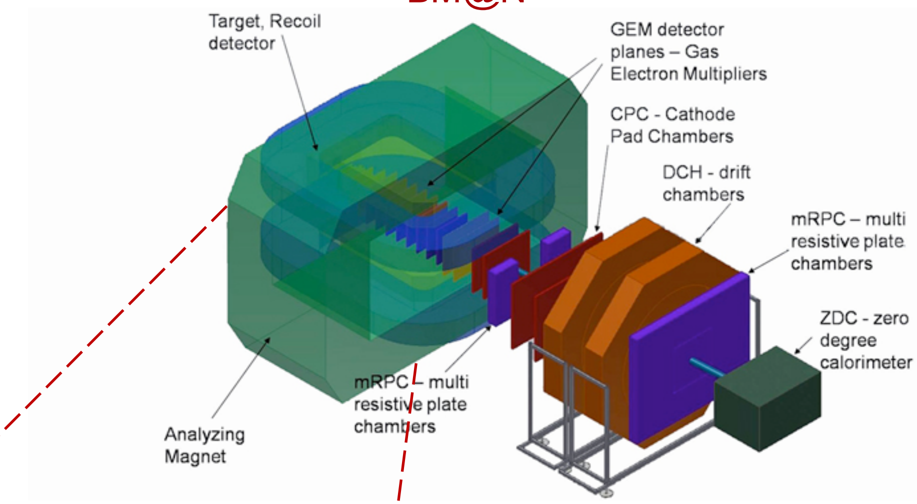


- utilizing rare probes requires high luminosity (high interaction rates)
- R_{int}= 10 MHz, several OoM higher than at colliders at comparable collision energies
- CBM sub-detectors must be capable to measure at rel. low momentum but at high rates

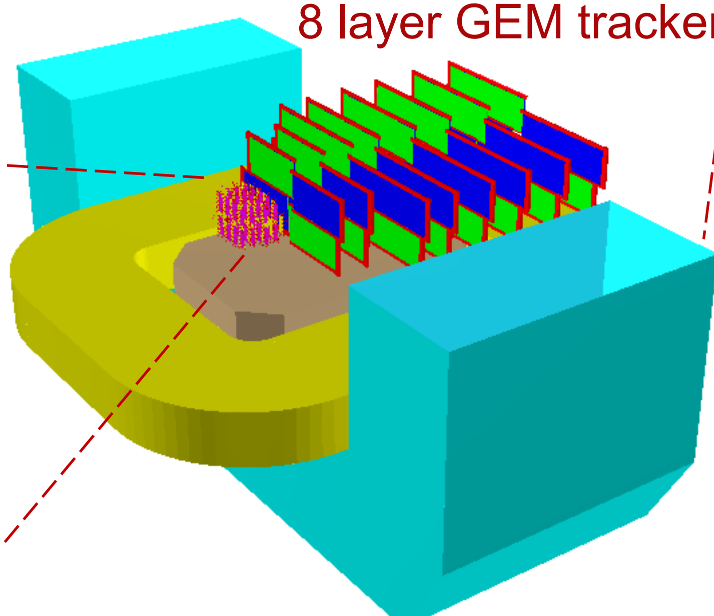
STS Large Demonstrator II

- Mutual interest by CBM groups from Germany and Russia to install, commission and use 4 CBM-like Silicon Tracking Stations in BM@N in 2019 – 2021
- Au beams up to 4.5 GeV/u

BM@N



8 layer GEM tracker



4 layer STS