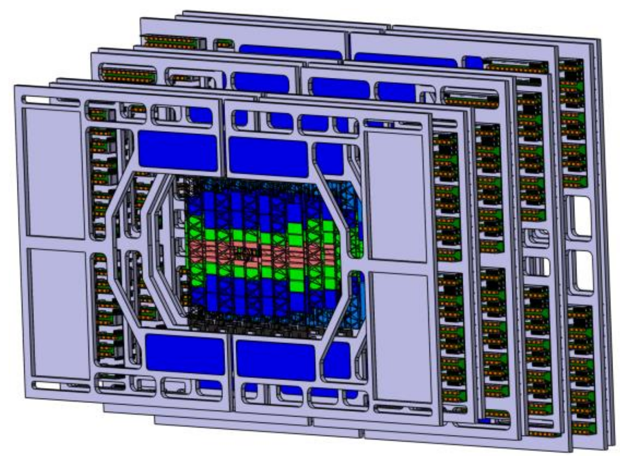
The Silicon Tracking System of the CBM experiment at FAIR

Johann M. Heuser,
GSI Helmholtz Center for Heavy Ion Research,
Darmstadt, Germany

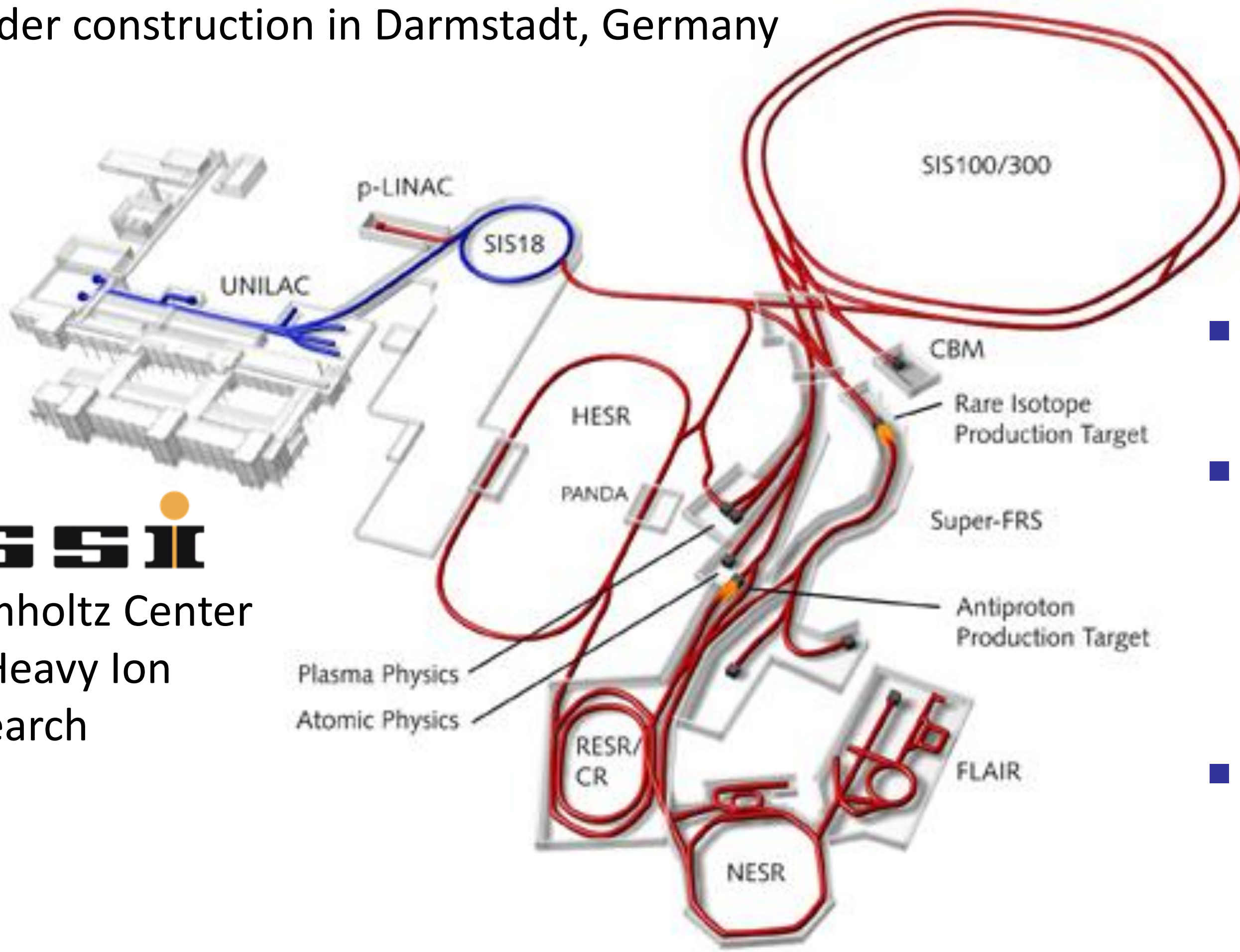


Workshop on the Future of Silicon Detector Technologies

CiS Forschungsinstitut für Mikrosensorik GmbH
Erfurt, Germany, 6 March 2018

Facility for Anti-Proton and Ion Research

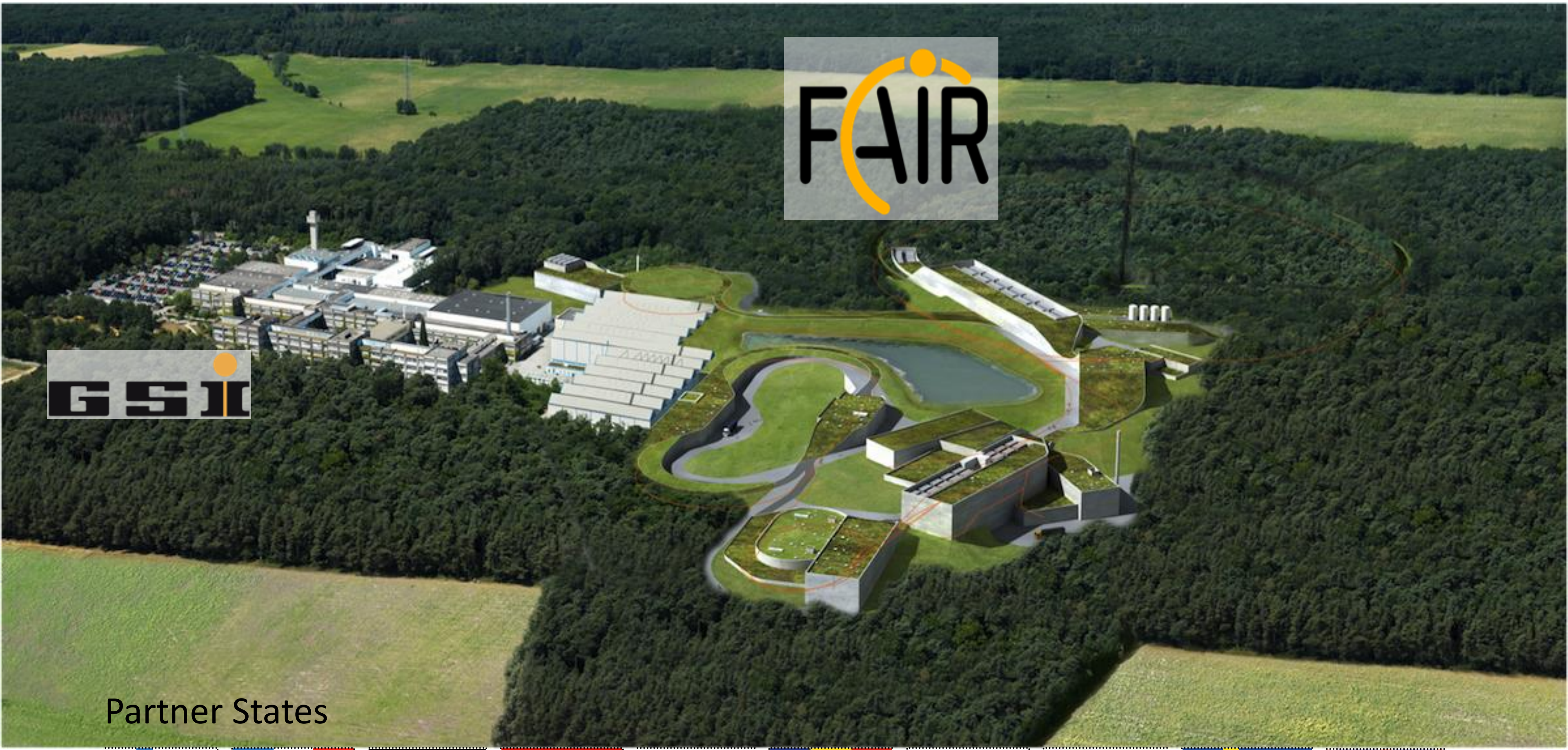
- new international research laboratory to explore the nature and evolution of matter in the Universe
- under construction in Darmstadt, Germany



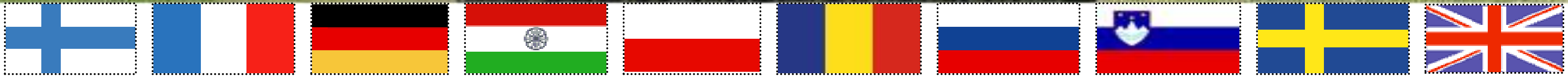
Helmholtz Center for Heavy Ion Research

- ***Protons:***
  2 - 29/89 GeV
- ***Ions:***
  2 – 14 GeV/u (SIS100)
  10 – 45 GeV/u (SIS300)
  $\sqrt{s_{NN}}$= 1.9 - 4.5 GeV
  $\sqrt{s_{NN}}$= 4.2 - 9 GeV
- ***Intensities:***
  10^{12}/s @ Super-FRS,
  10^{9}/s @ CBM

Facility for Anti-Proton and Ion Research

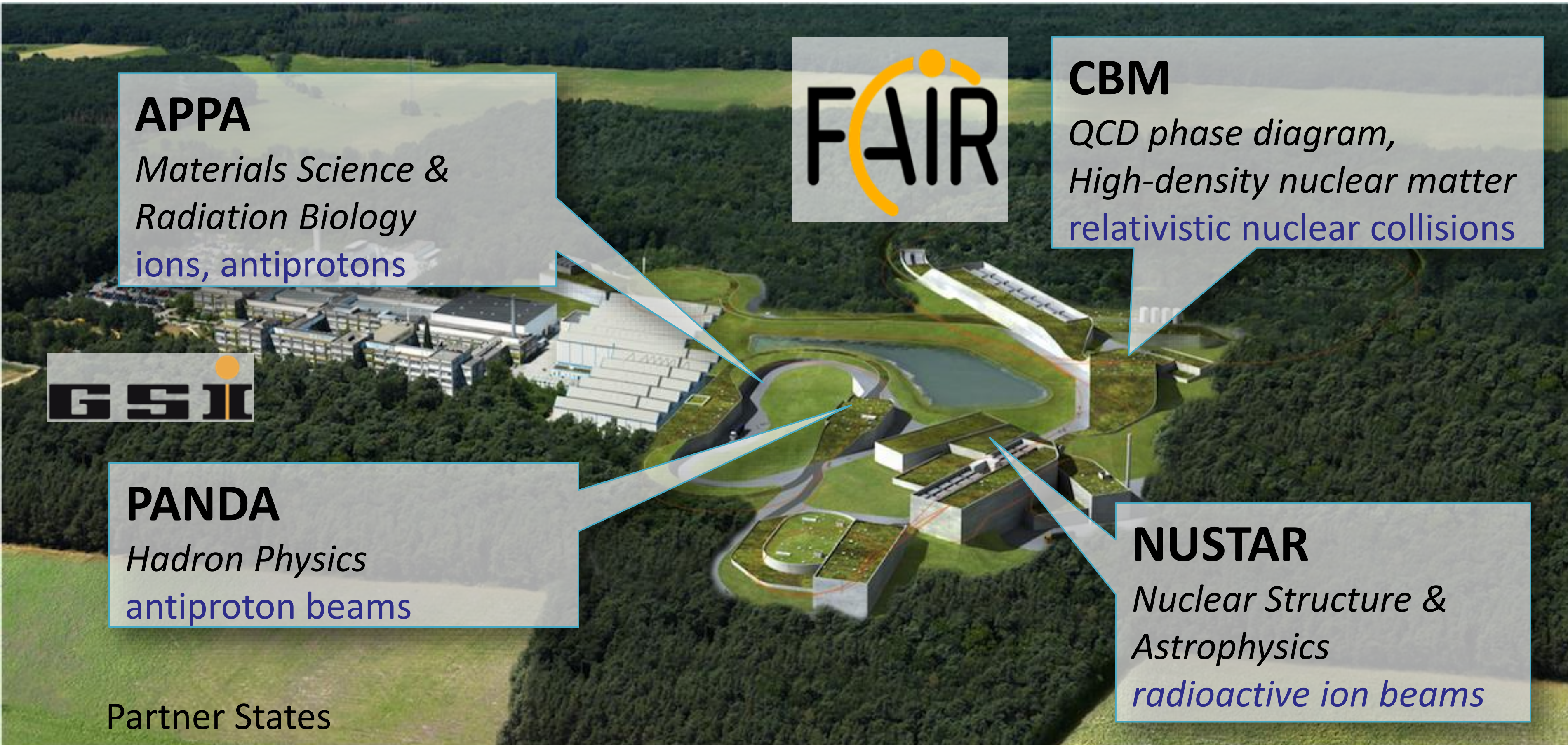


Partner States



Finland France Germany India Poland Romania Russia Slovenia Sweden UK

Facility for Anti-Proton and Ion Research

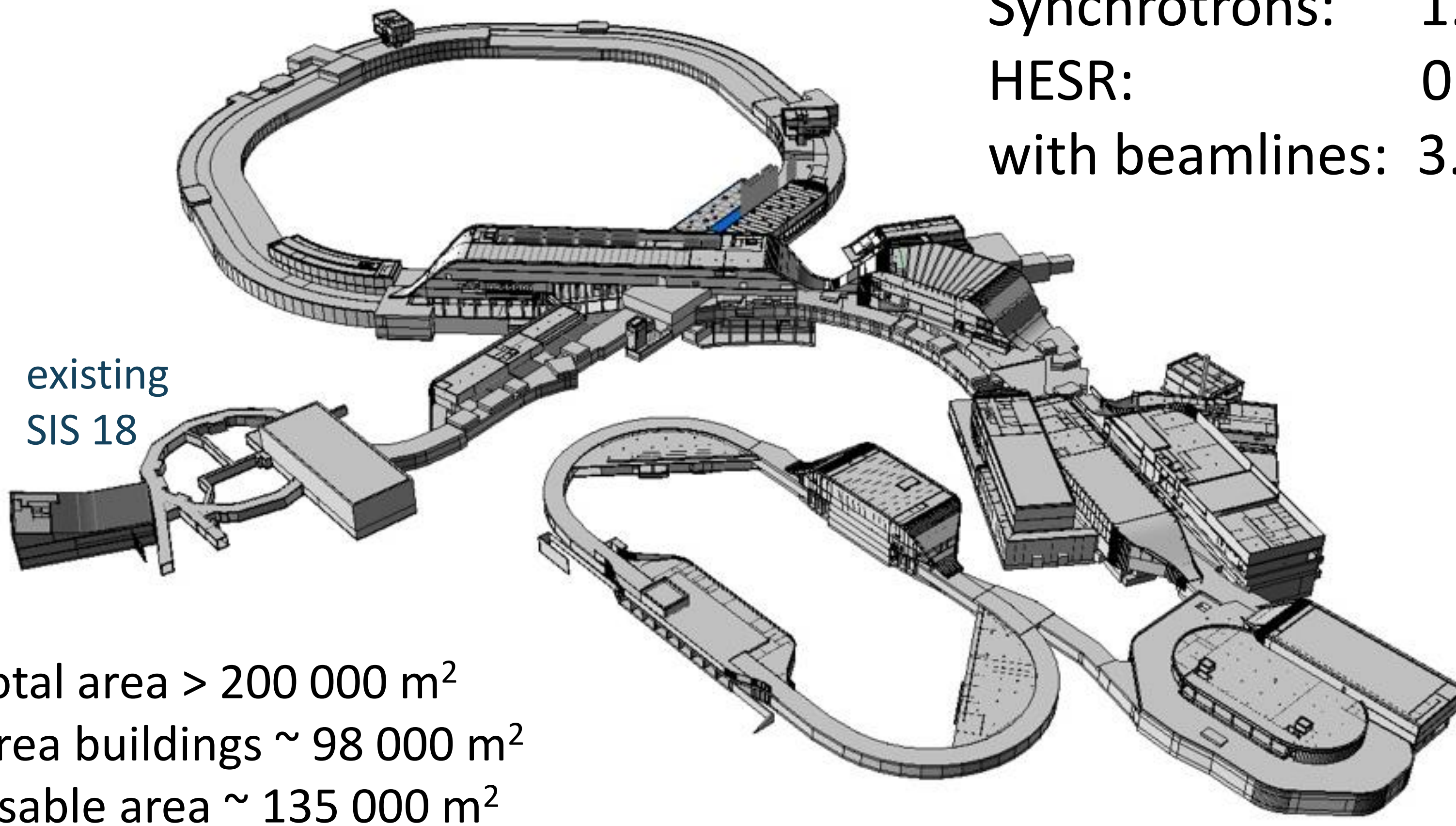


Partner States

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

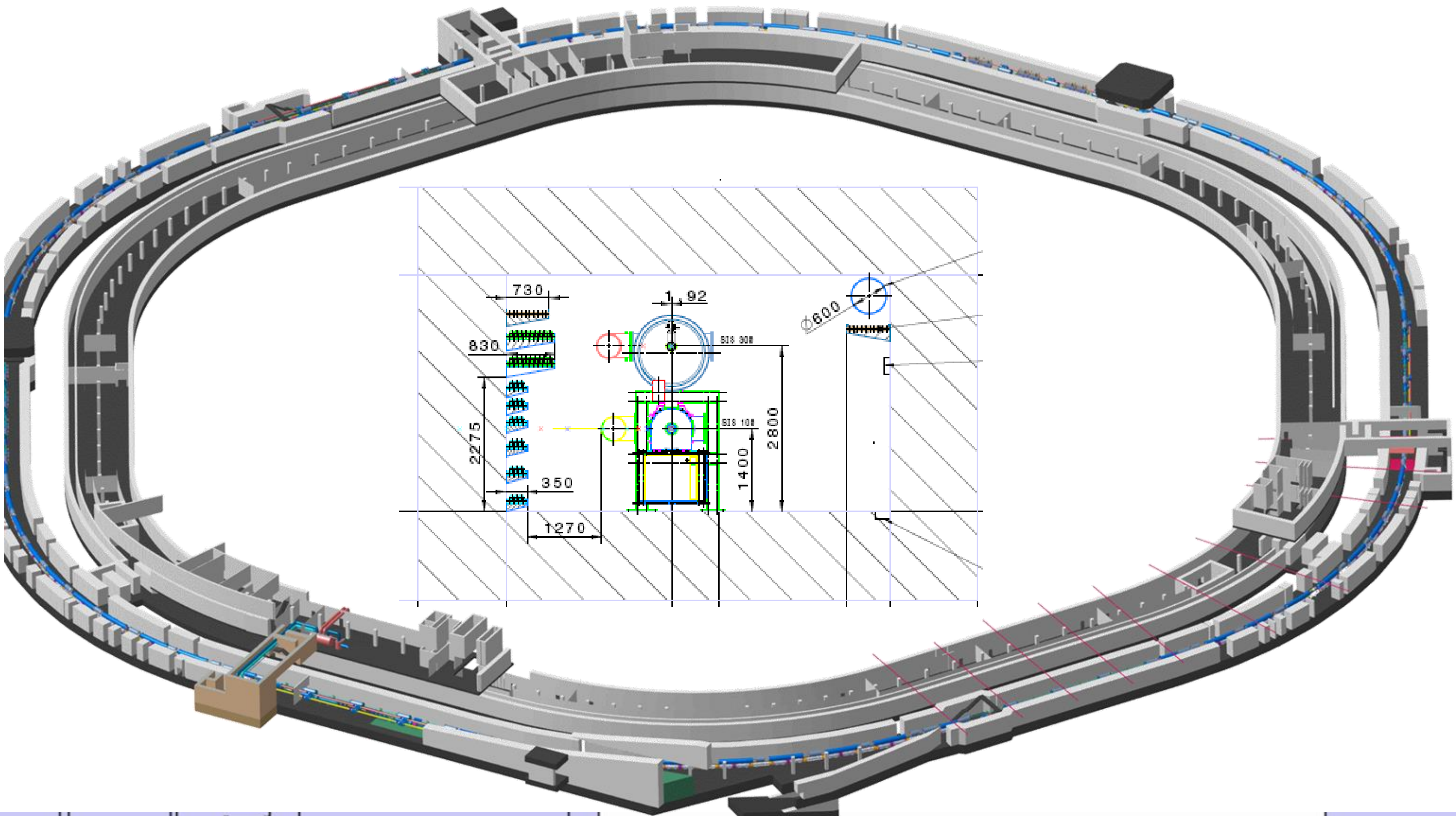
FAIR Civil Construction

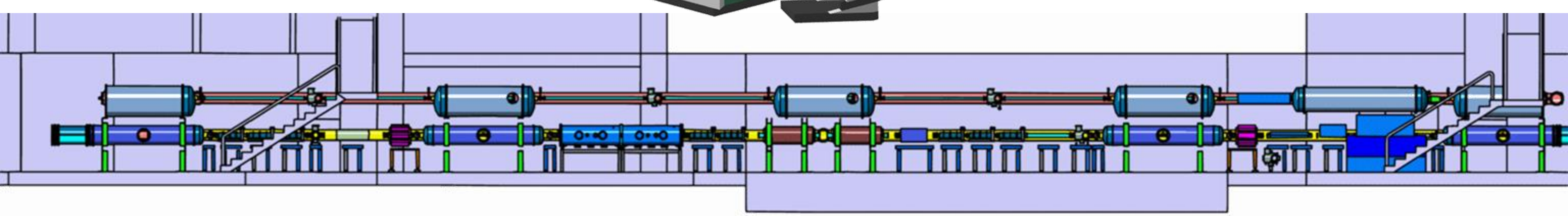
Synchrotrons: 1.1 km
HESR: 0.6 km
with beamlines: 3.2 km



Total area > 200 000 m^2
Area buildings ~ 98 000 m^2
Usable area ~ 135 000 m^2
Volume of buildings ~ 1 049 000 m^3
Substructure: 1350 pillars, 60 m deep

Tunnel for SIS100/SIS300





Facility for Anti-Proton and Ion Research

Civil construction (Status 2014)

The four most powerful drilling machines worldwide put down 1350 reinforced concrete pillars of 60 m depth and 1.2 m diameter.

FAIR Project Status 2018

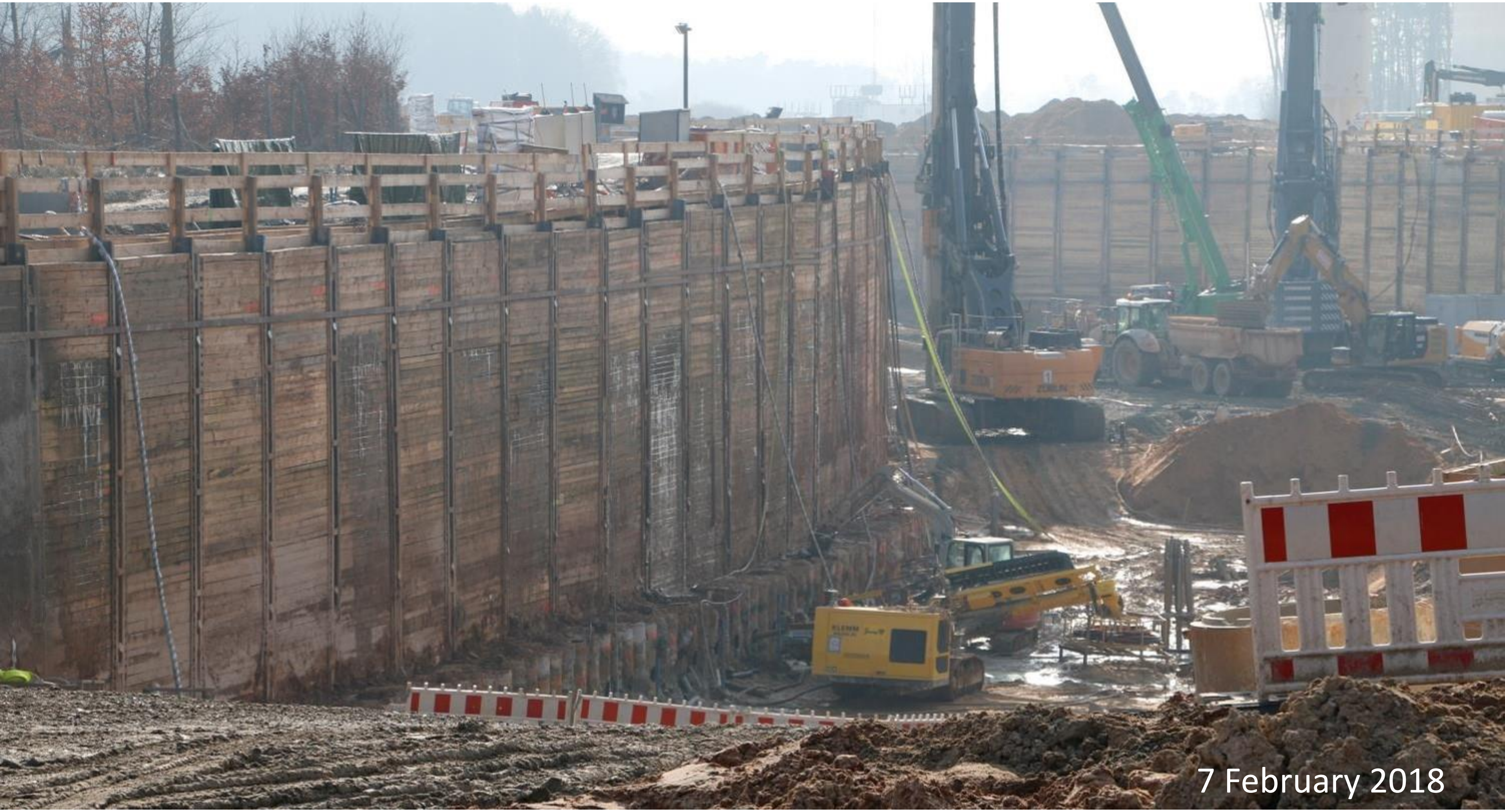
- Successful restart in 2015 and 2016 after new construction requirements
- Start of excavation and trench sheeting in July 2017
- Civil construction Area North, i.e. SIS-100 tunnel plus adjacent buildings including the CBM building, has been awarded on January 29th 2018.
- Shell construction will start mid 2018.
- Completion of all buildings by 2022
- Full integrated planning for construction and commissioning of the entire project: Completion of the full FAIR facility by 2025.

Ground breaking - 4 July 2017

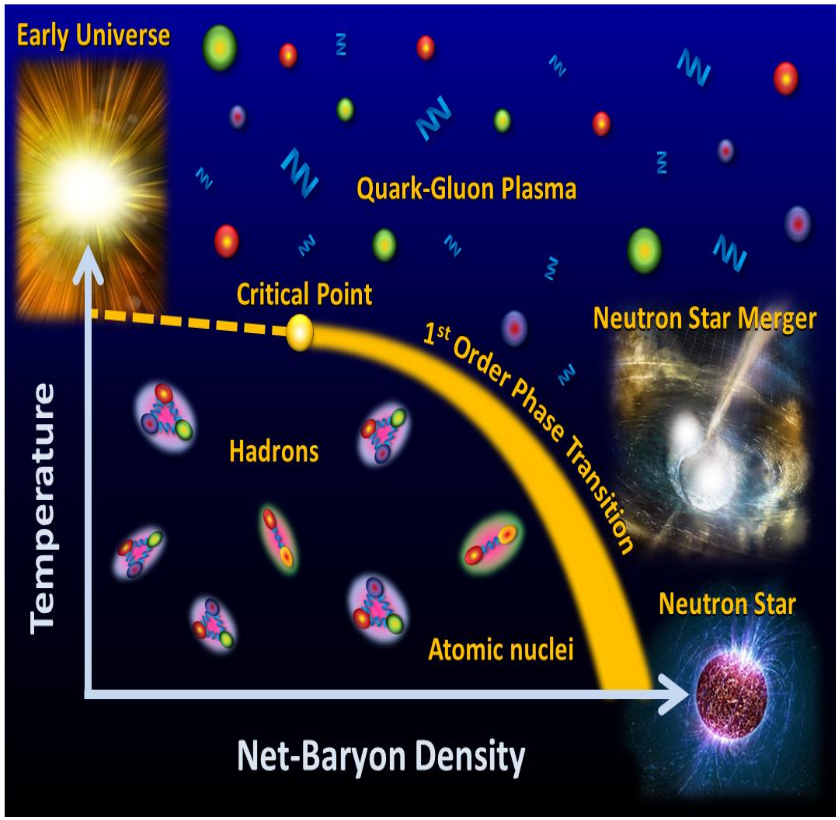
Excavation SIS100 tunnel - Nov 2017

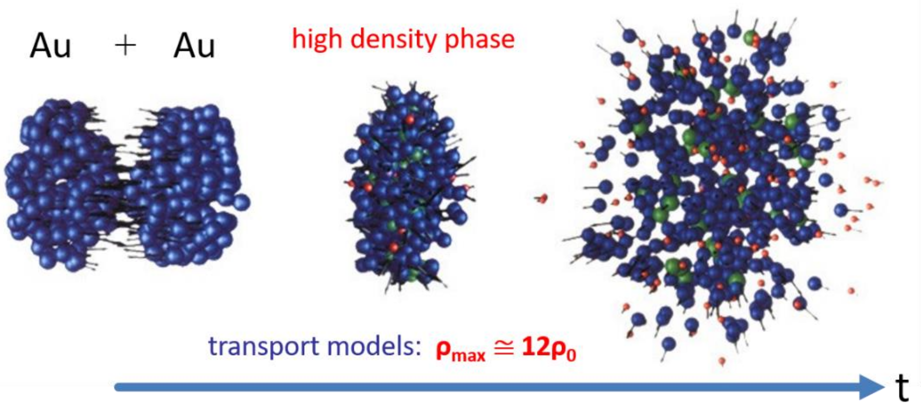
FAIR Construction Area North

FAIR Construction Area North



Compressed Baryonic Matter



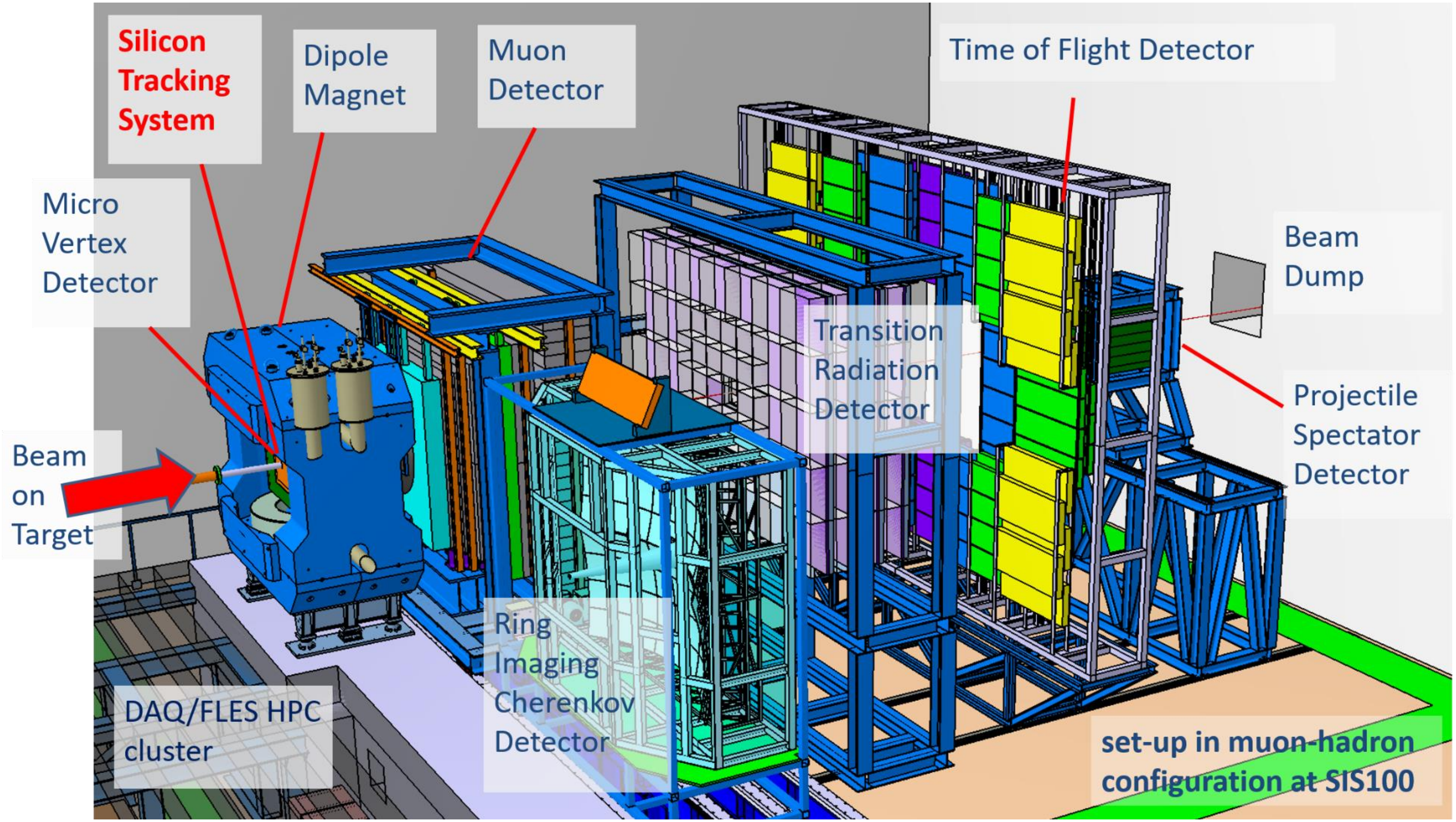


high density and high temperatures reached on a very short time scale:
t ≈ 10^{-22} s (10 fm/c), ρ = $3.4 \cdot 10^{16}$ g/cm^3, T = 10^{12} K

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

CBM Experiment



CBM Experiment

CBM – Collaboration: 55 institutions, 470 members

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang
Chongqing Univ.

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IPHC Strasbourg

Germany:
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
Frankfurt Univ. ICS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
KIT Karlsruhe
Münster Univ.
Tübingen Univ.
Wuppertal Univ.
ZIB Berlin

India:
Aligarh Muslim Univ.
Bose Inst. Kolkata
Panjab Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
IOP Bhubaneswar
IIT Kharagpur
IIT Indore
Gauhati Univ.

Korea:
Pusan Nat. Univ.

Poland:
AGH Krakow
Jag. Univ. Krakow
Warsaw Univ.
Warsaw TU

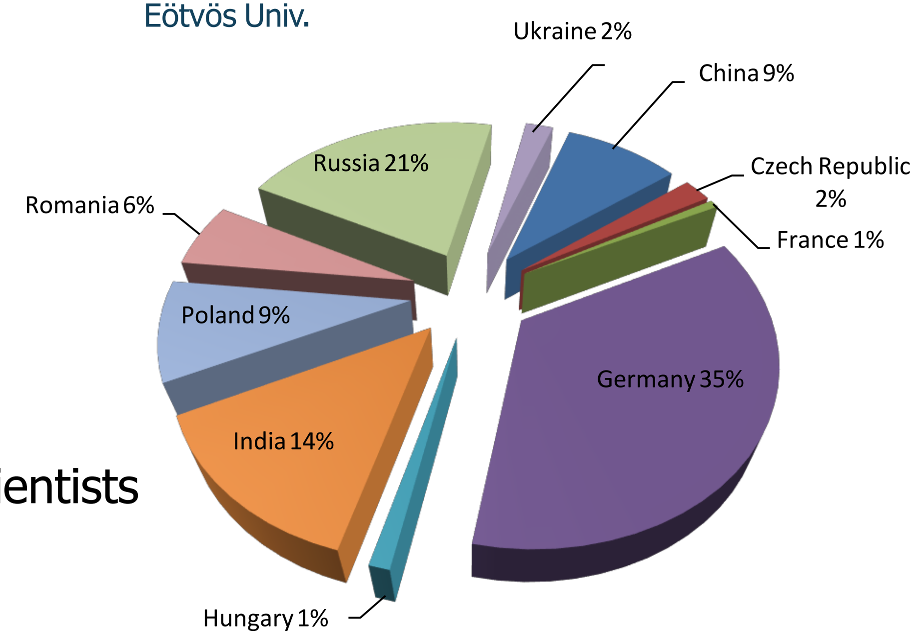
Romania:
NIPNE Bucharest
Univ. Bucharest

Hungary:
KFKI Budapest
Eötvös Univ.

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
VBLHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
PNPI Gatchina
SINP MSU, Moscow

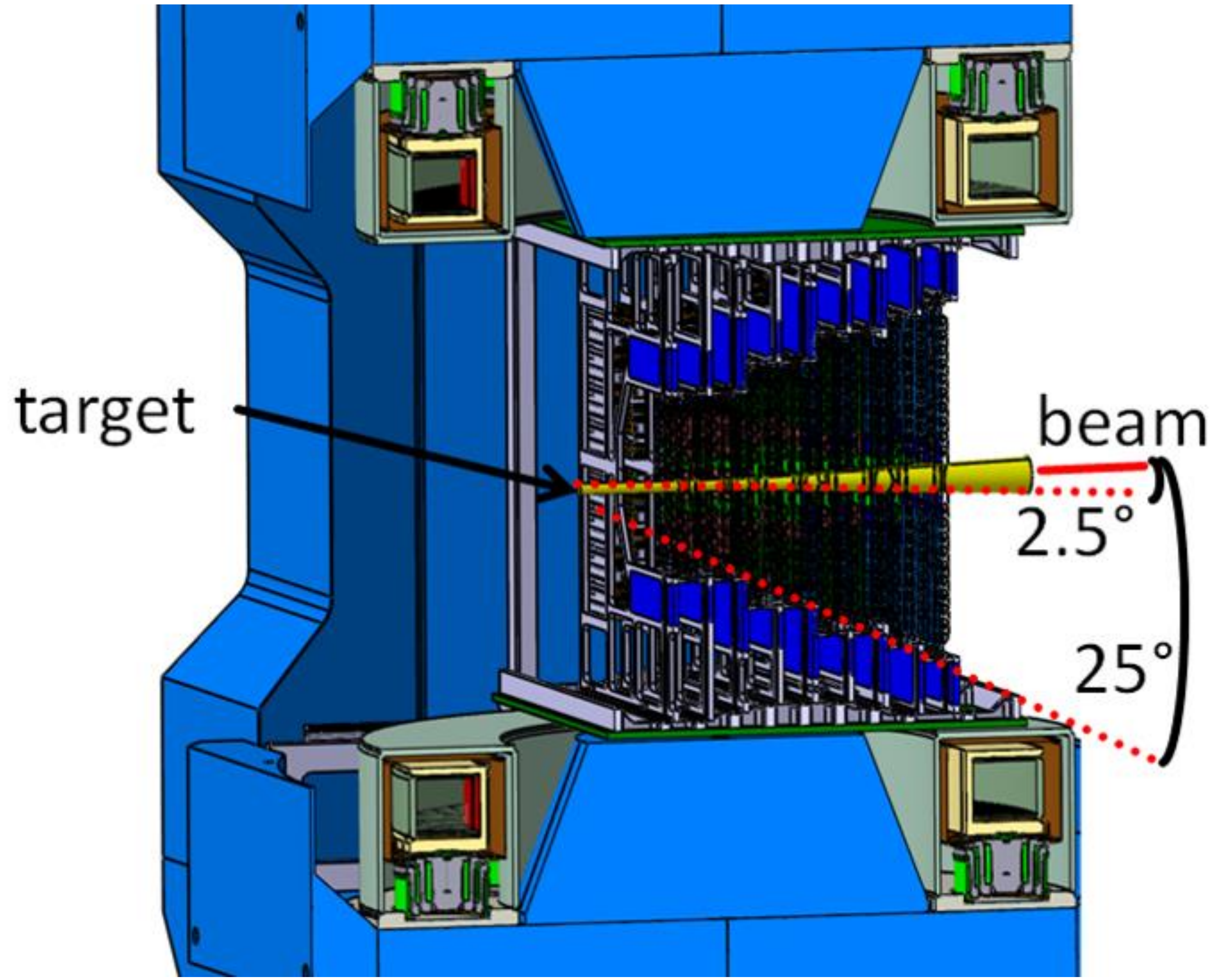
Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research

http://www.fair-center.eu/for-users/experiments/cbm.html

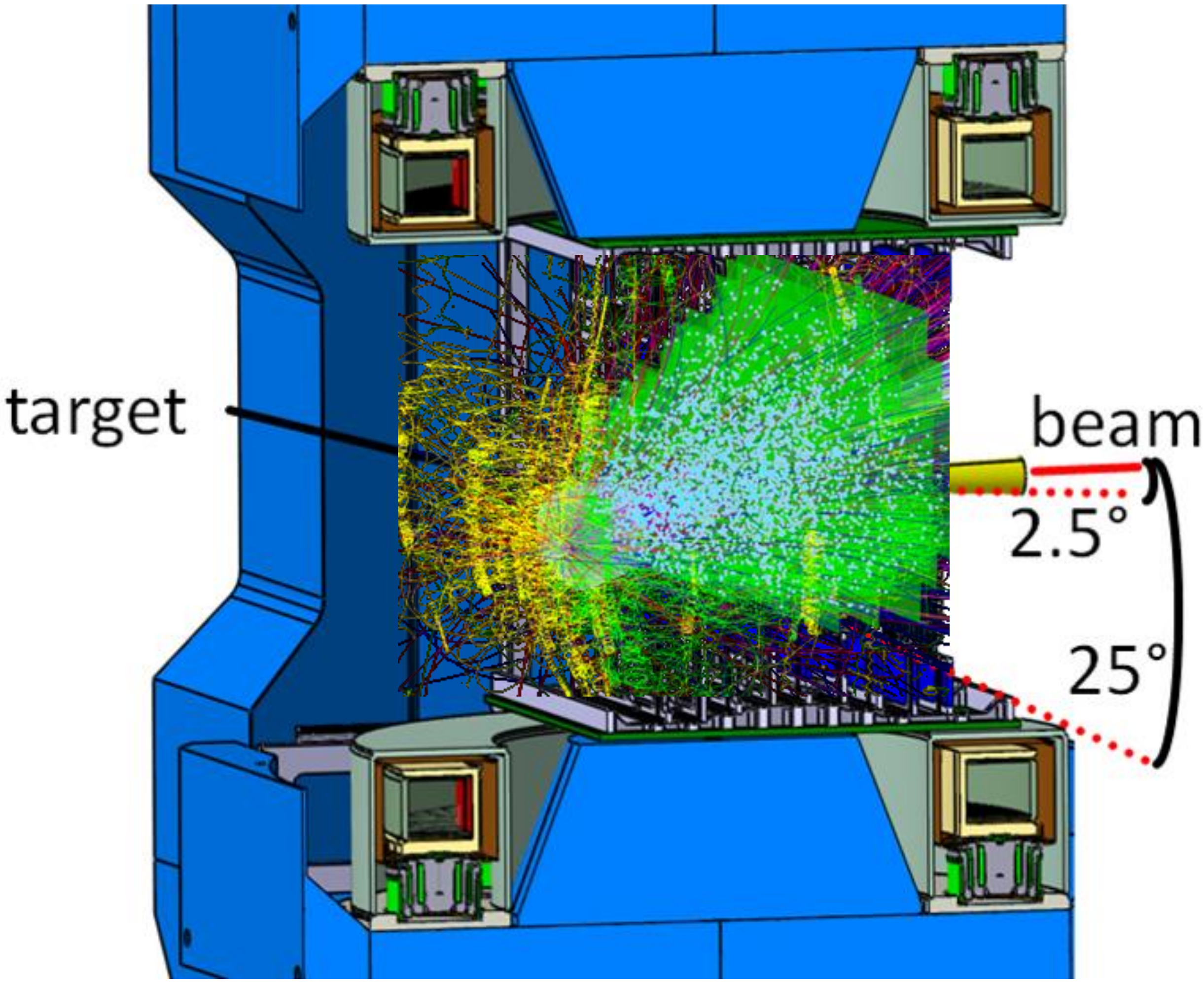


CBM Scientists

Silicon Tracking System



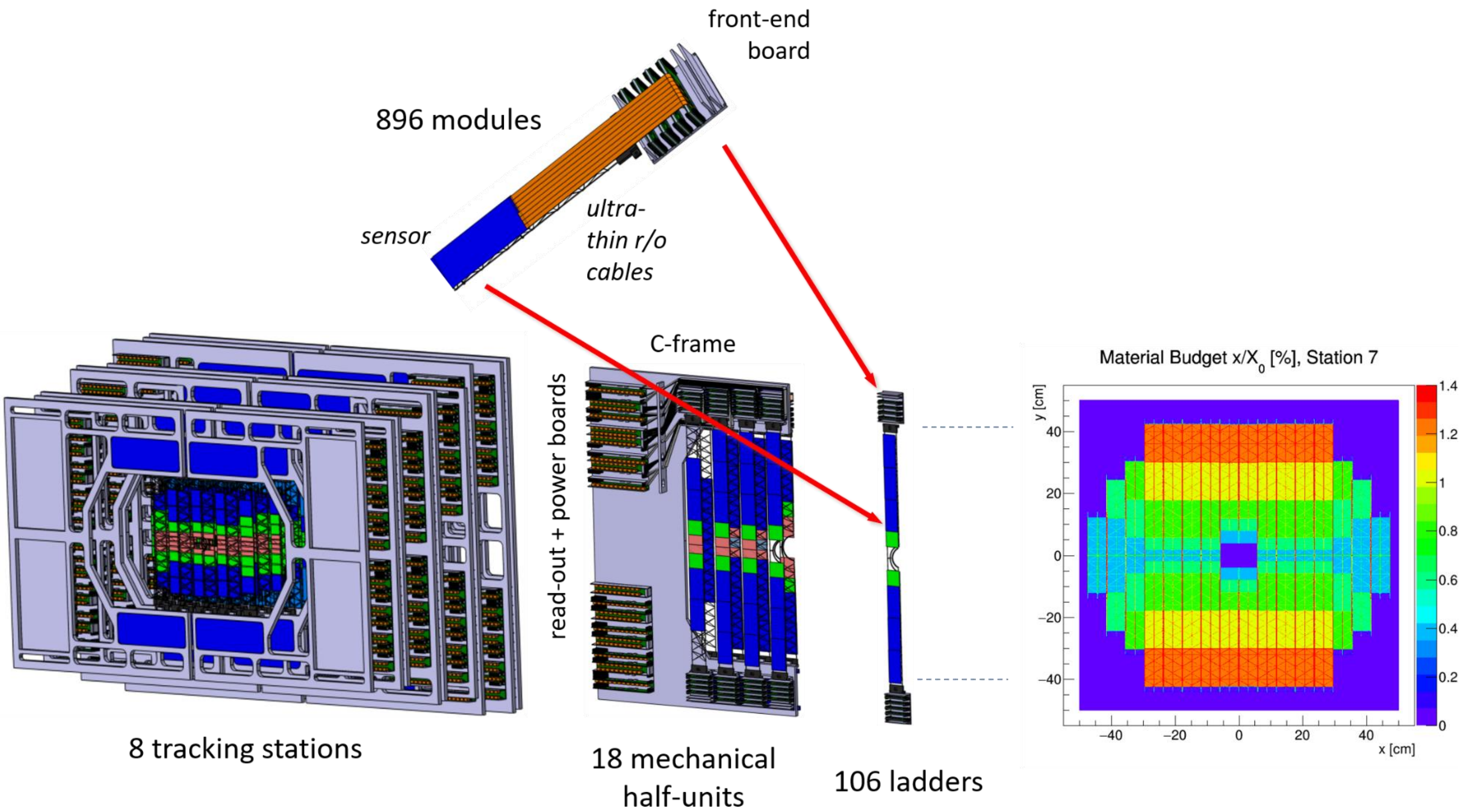
Silicon Tracking System



STS – charged-particle tracking

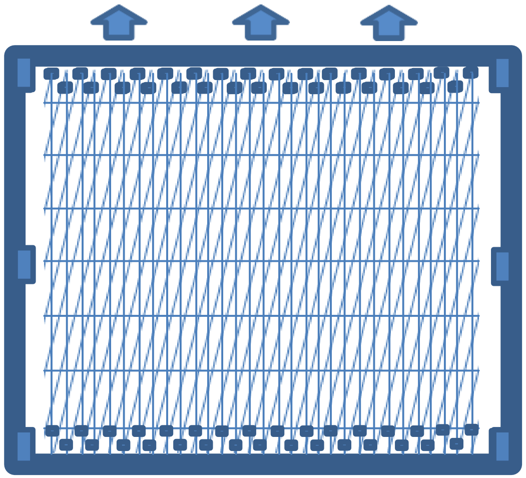
- pile-up free track point determination
  in high-rate collision environment: $10^5 - 10^7$/s (A+A), up to 10^9/s (p+A)
- physics aperture : $2.5° \leq \Theta \leq 25°$, $0.3\ \text{m} \leq z \leq 1.0\ \text{m}$
- 8 tracking stations, $\approx 4\ \text{m}^2$ total area, 896 detector modules, 106 ladders
- double-sided silicon microstrip sensors
- hit spatial resolution ≈ 25 µm
- self-triggering front-end electronics (throughout CBM experiment)
- time-stamp resolution ≈ 5 ns (up to 10 MHz beam-target interactions)
- material : ≈ 0.3 % – 1% X_0 per station
- momentum resolution: $\Delta p/p \approx 1.8\%$ ($p > 1$ GeV/c, 1 Tm field)
- identification of decay topologies within STS aperture

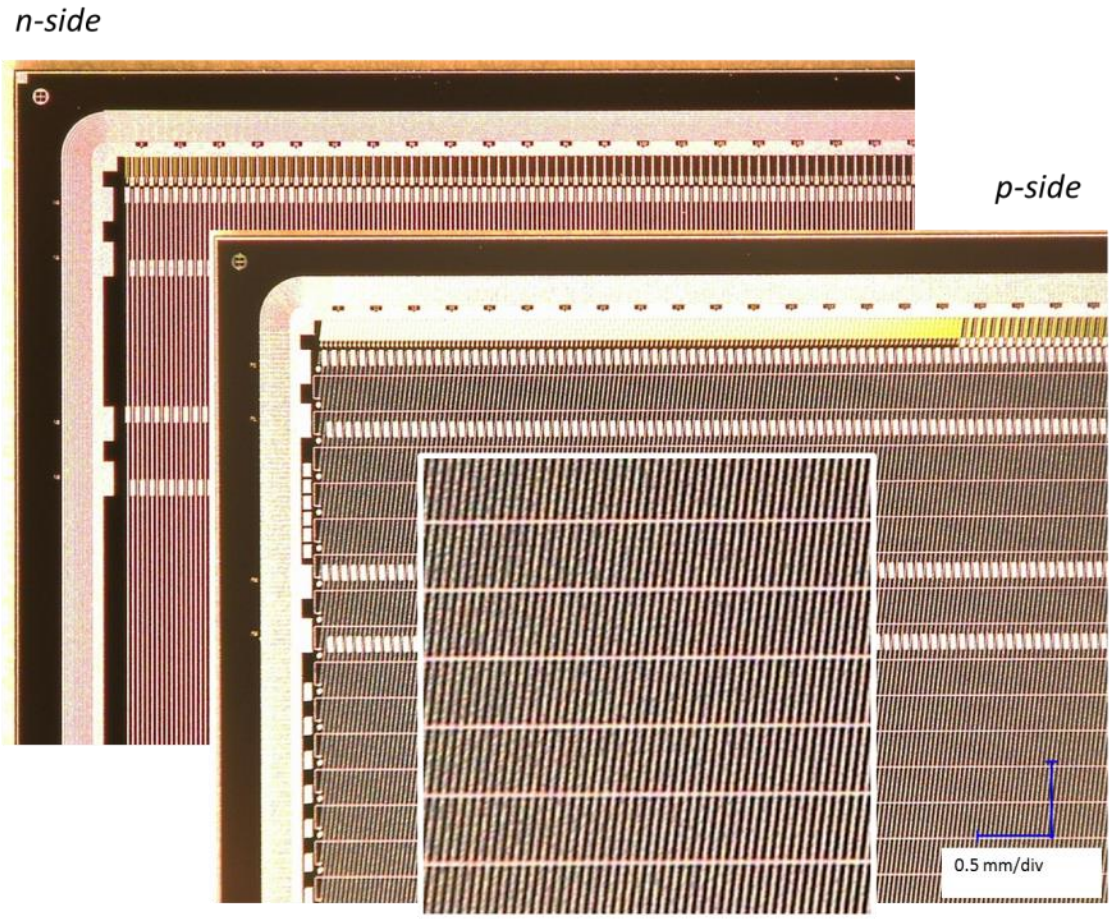
STS integration model



Microstrip sensors

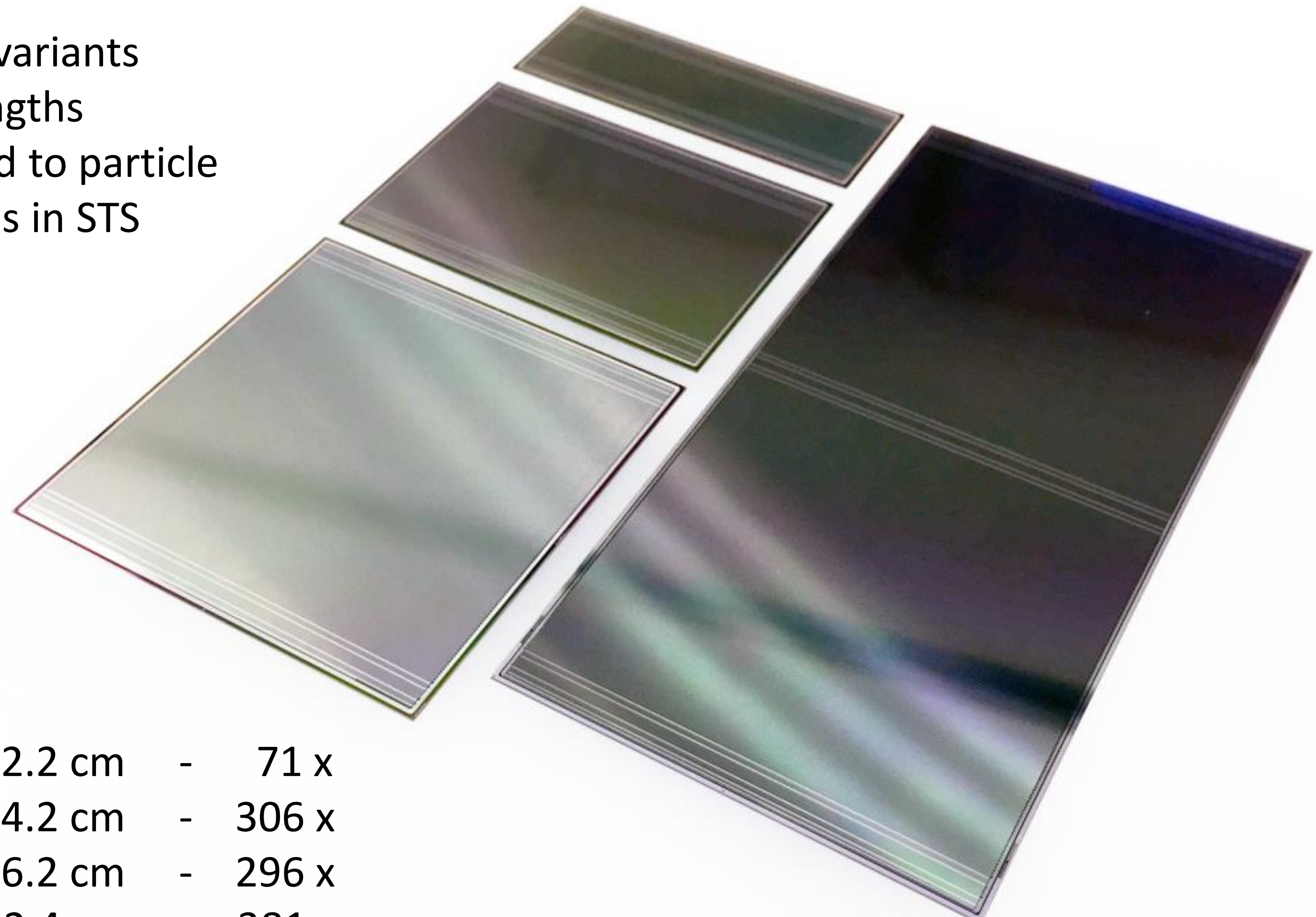
- 285/320 ± 15µm thick
- n-type silicon
- double-sided segmentation
- 1024 strips of 58 µm pitch
- strip length 2/4/6/12 cm
- angle front/back: 7.5°/0°
- read-out from top edge
- double-metal routing on p-side





Microstrip sensors

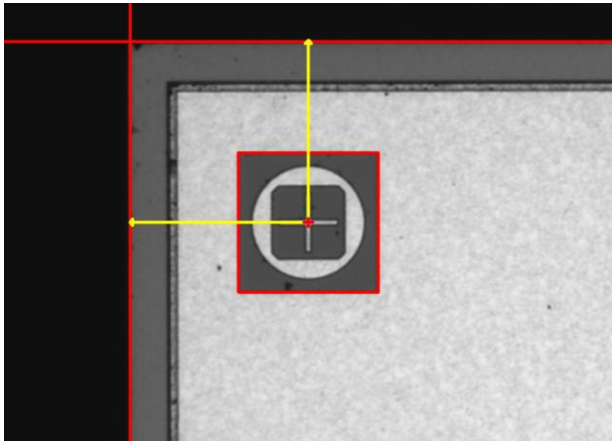
- 4 main variants
- strip lengths matched to particle densities in STS



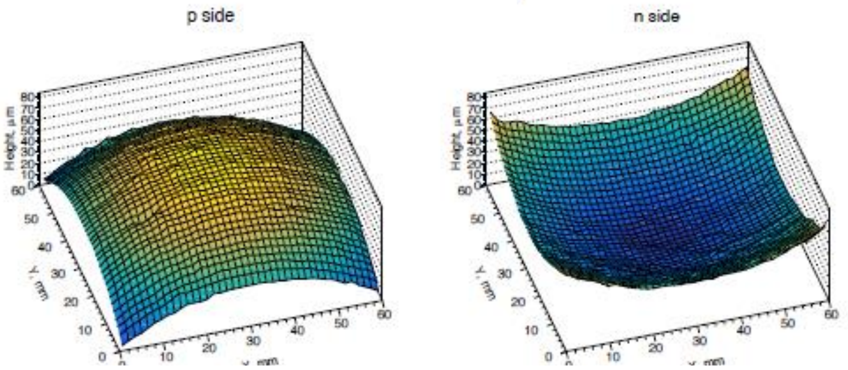
6.2 cm x 2.2 cm	-	71 x
6.2 cm x 4.2 cm	-	306 x
6.2 cm x 6.2 cm	-	296 x
6.2 cm x 12.4 cm	-	381 x

Camera-based optical inspection

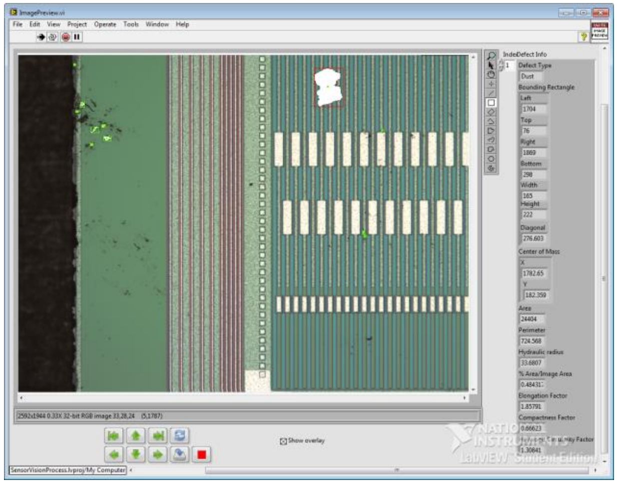
edge parallelism

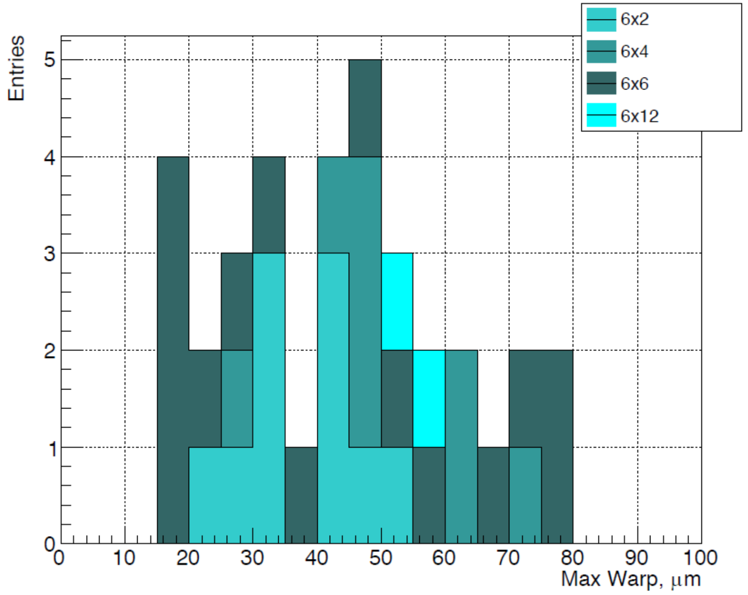


warp



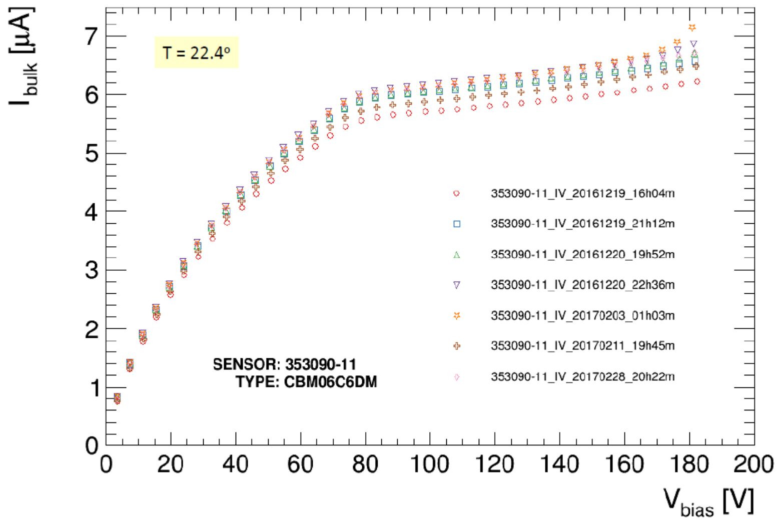
defects/shorts/interruptions



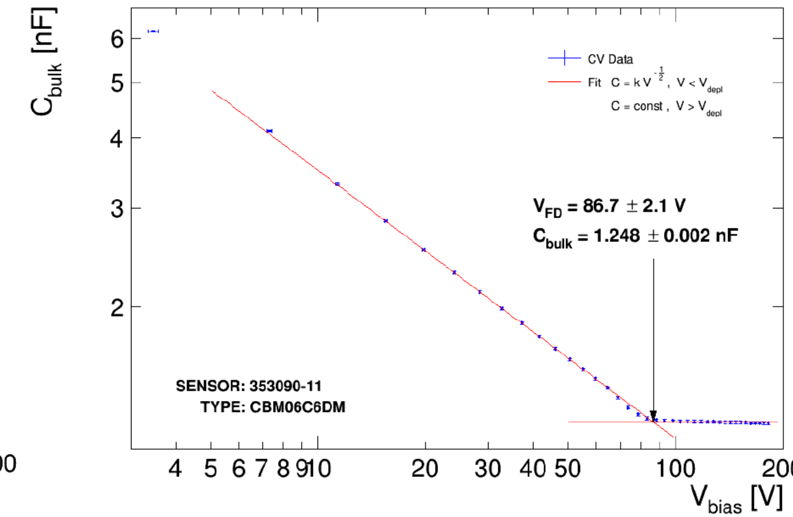


Bulk and strip performance

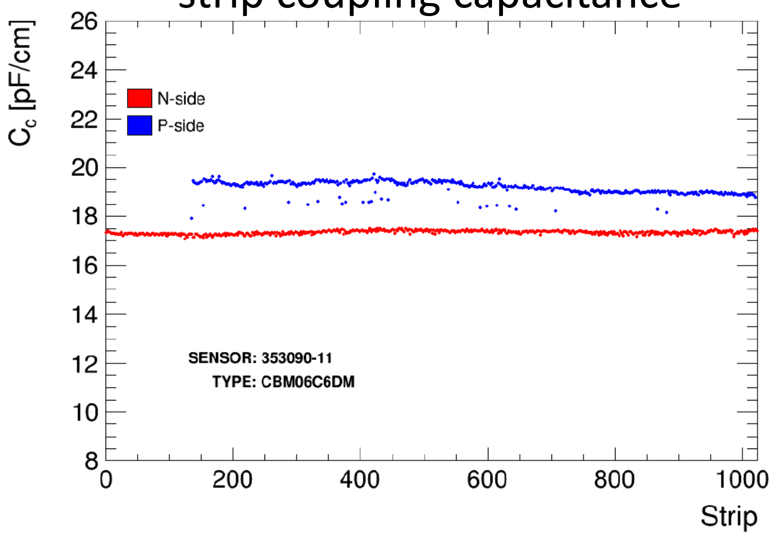
IV characteristic



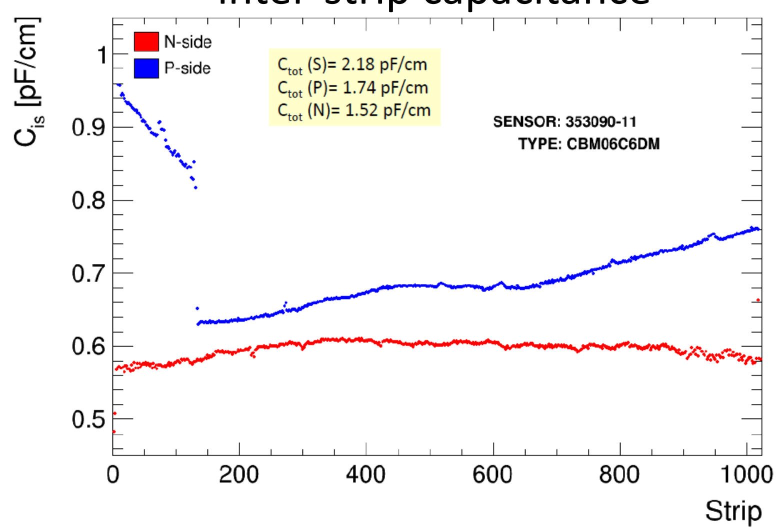
CV characteristic



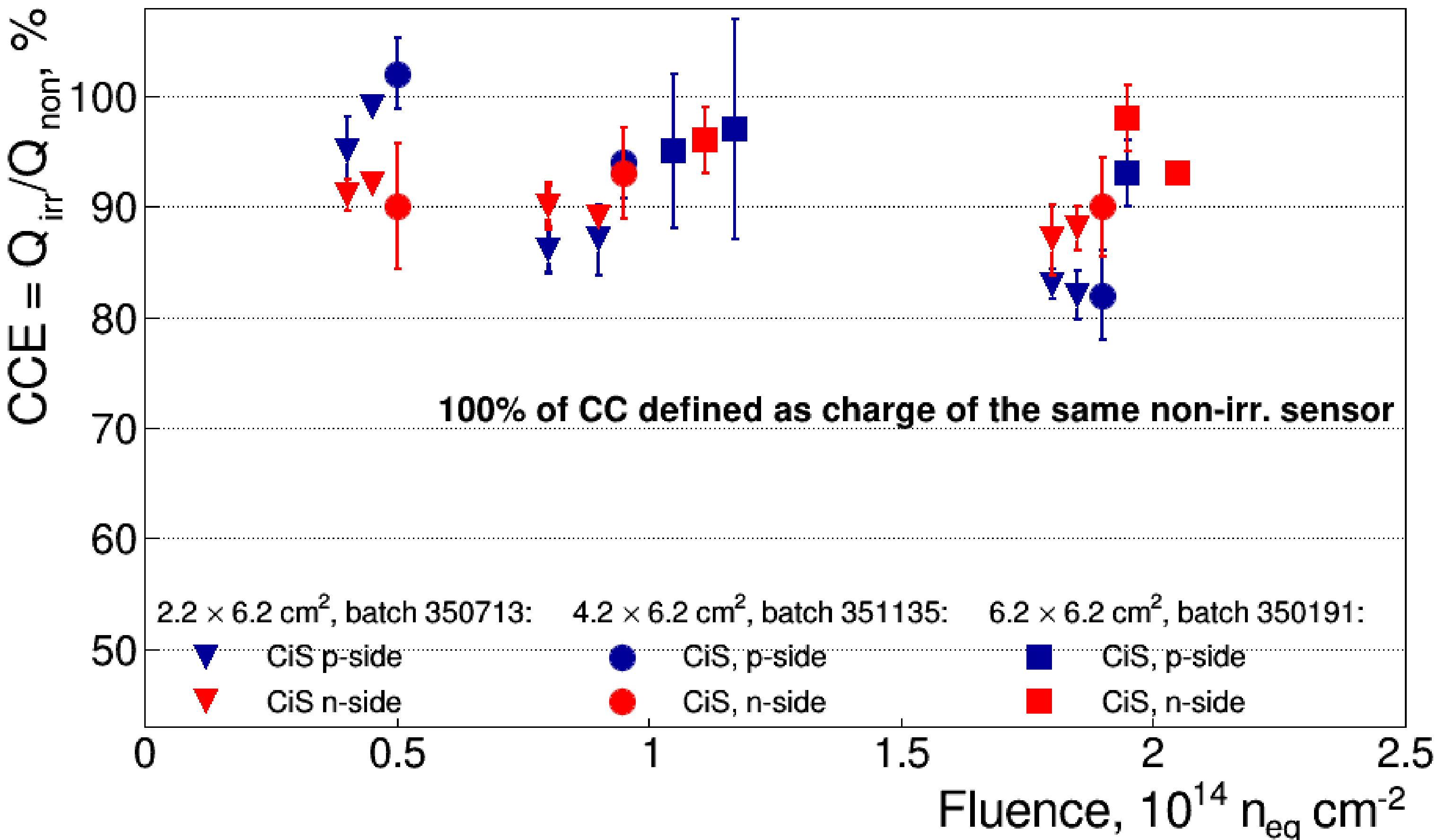
strip coupling capacitance



inter-strip capacitance

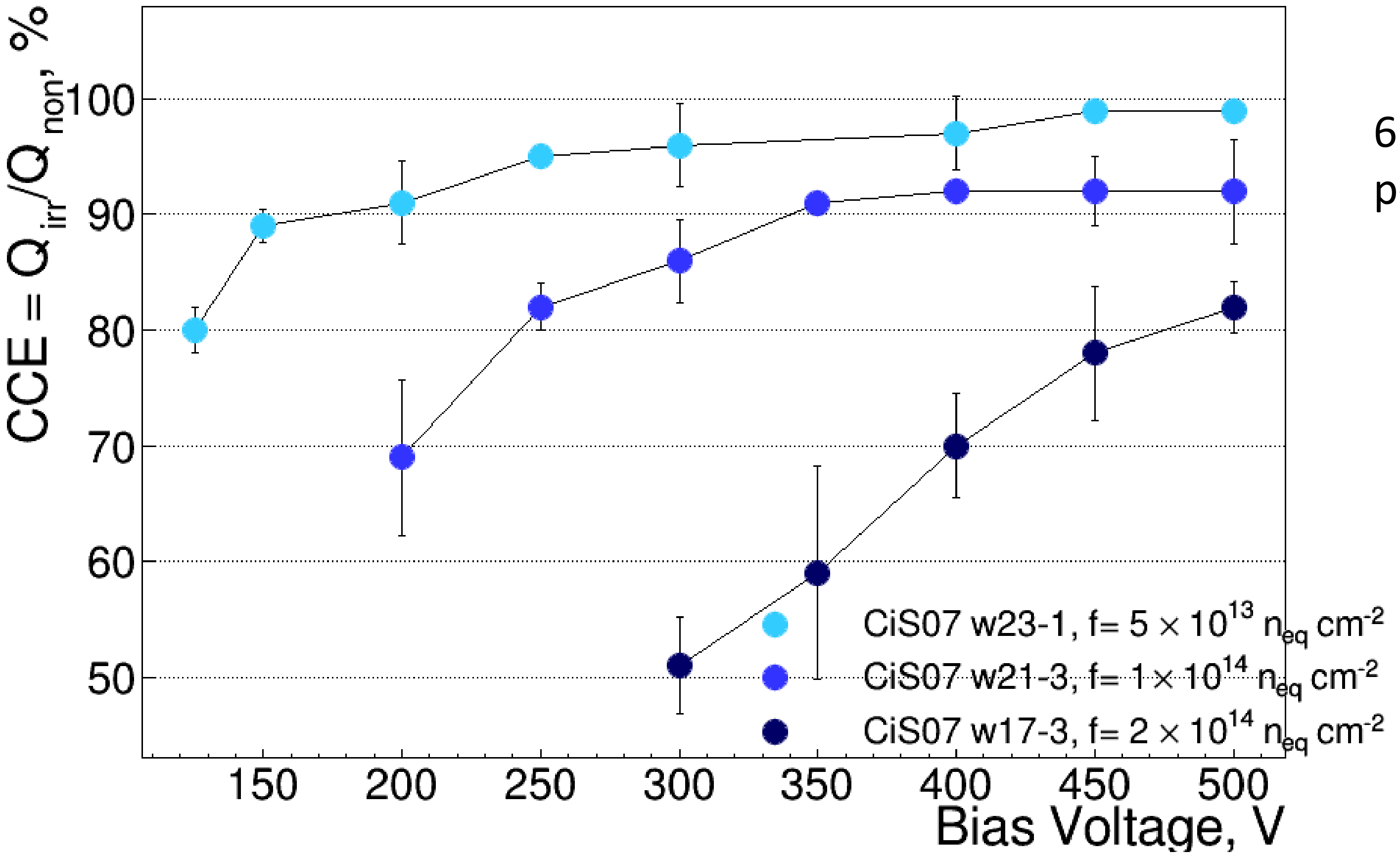


Irradiation studies



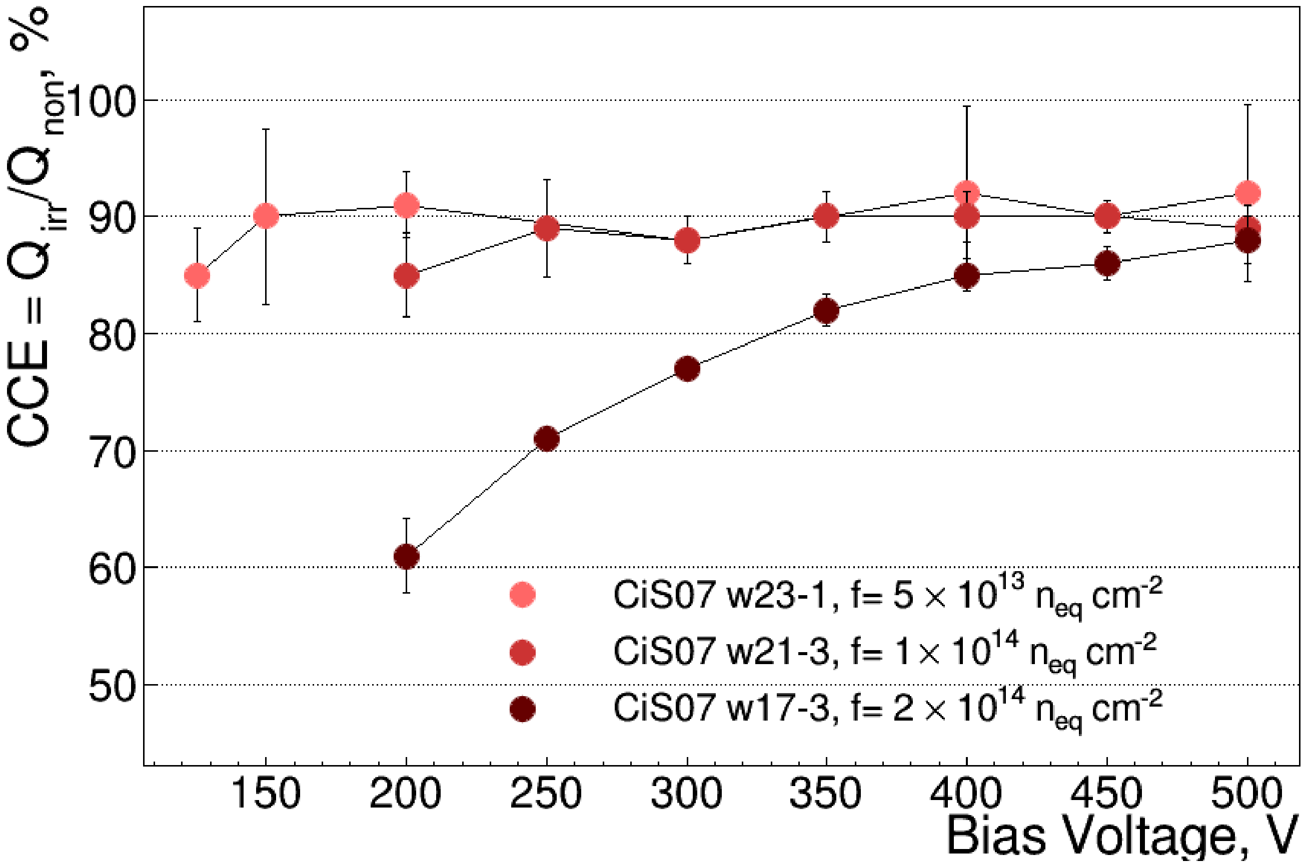
23 MeV proton beam at KIT

Irradiation studies



6 x 2 cm^2
p-side

Irradiation studies



6 x 2 cm^2
n-side

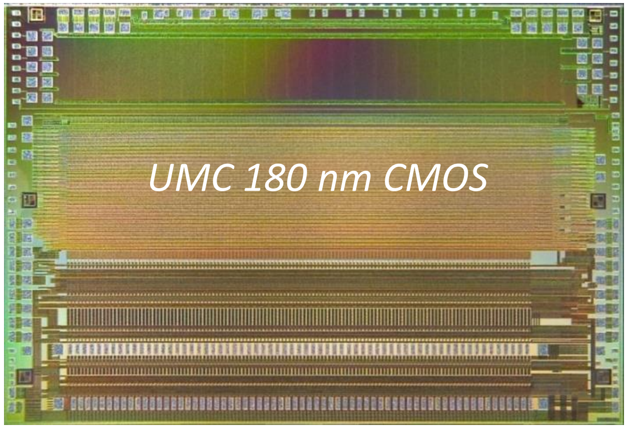
Status of microstrip sensors

Final prototype sensors developed:

- layout optimized for STS and module assembly
- 4 main variants
- prototypes from CiS, Hamamatsu
- QA: bulk/strip-by-strip at vendor, electrical/optical QA at CBM
- radiation tolerance demonstrated
- tested in prototype module
- technical specifications and quality criteria fixed
- Production Readiness Review 4/2018
- call for tender in Q2/2018.

Read-out ASIC "STS-XYTER"

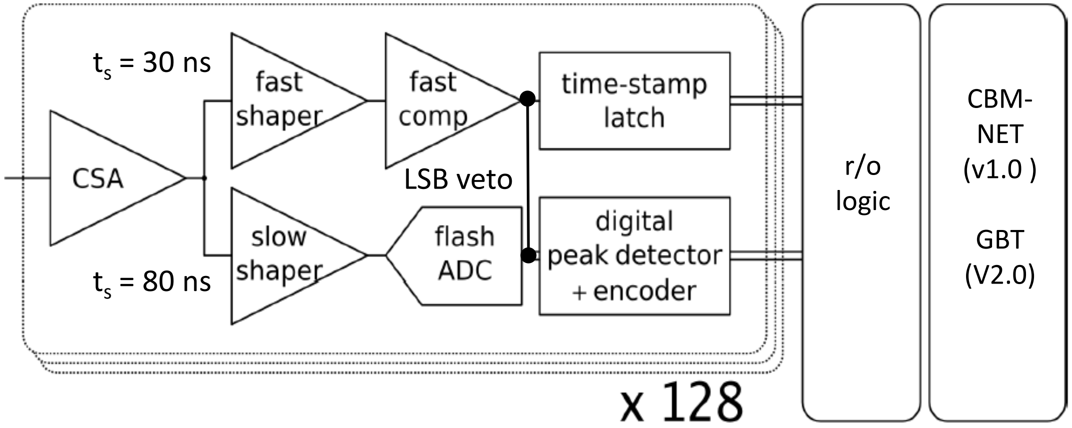
- *purely data driven read-out*
- *time-stamped data elements*
- *few hundred kHz per channel*



channels	128, polarity +/-
noise	ASIC only: < 400 e, in module: < 1000 e
ADC range	15 fC, 5 bit
clock	160 MHz
power	< 10 mW/channel
timestamp	< 5 ns resolution
out interface	5 × 320 Mbit/s LVDS

for every channel:

- fast branch: time-stamp
- slow branch: signal height digitization (energy)



noise minimization in self-triggering system:

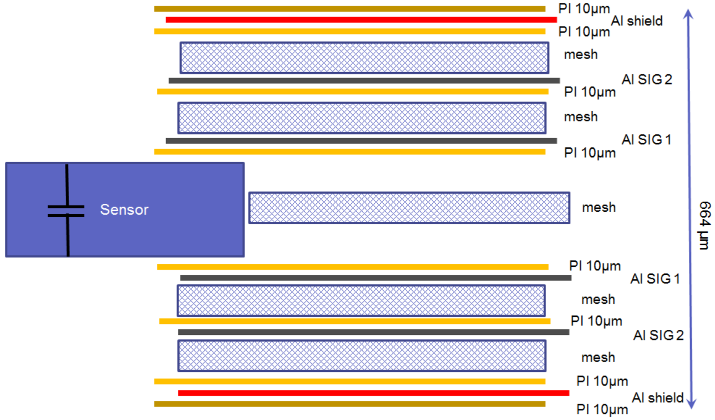
- effective two-level discrimination
- trigger to timestamp latch vetoed if no ADC-LSB

2016: STS-XYTER 2.0, GBTx-eLink-readout , STS protocol

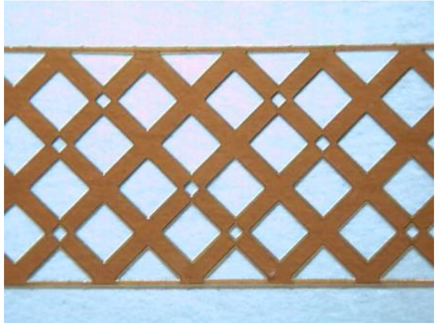
2018: STS-XYTER 2.1 AFE modifications, DBE fixes/new features prior to large production

Read-out cables

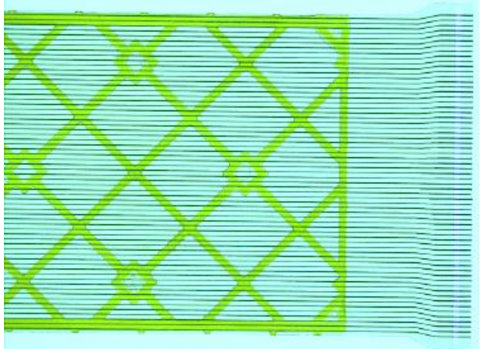
cable stack: *thickness 0.230 % X_0*



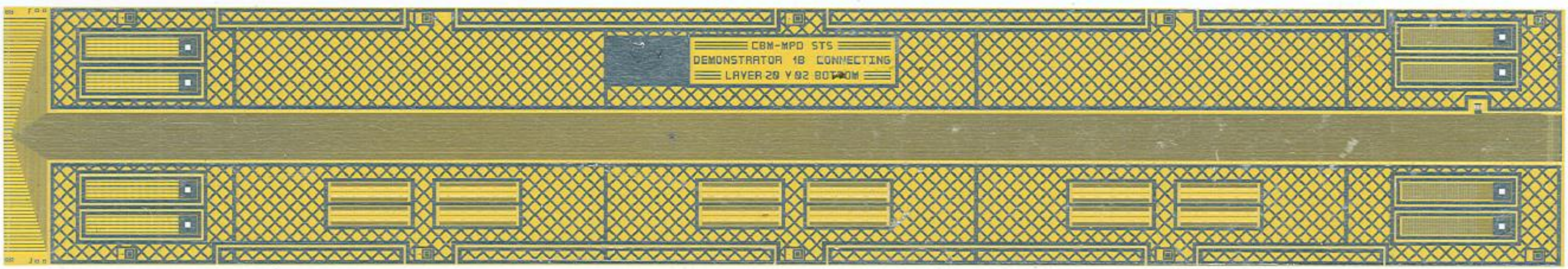
spacer layer



64 traces per cable



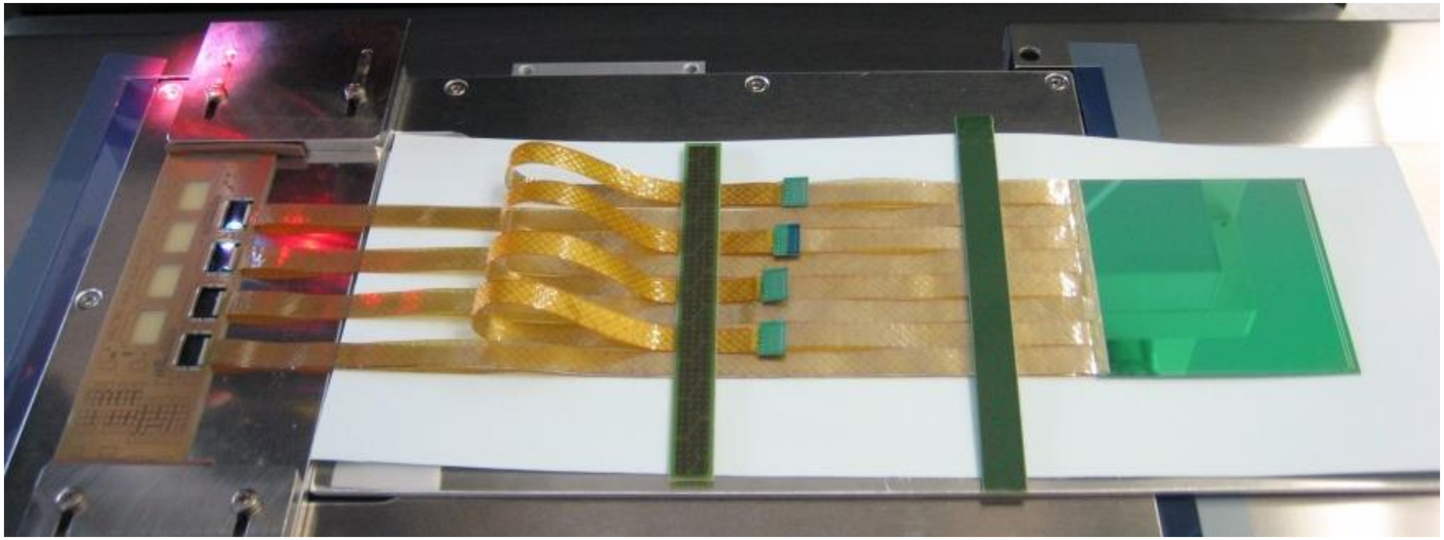
signal layer: *64 Al lines of 116 µm pitch, 10 µm thick on 14 µm polyimide, lengths up to 55 cm*



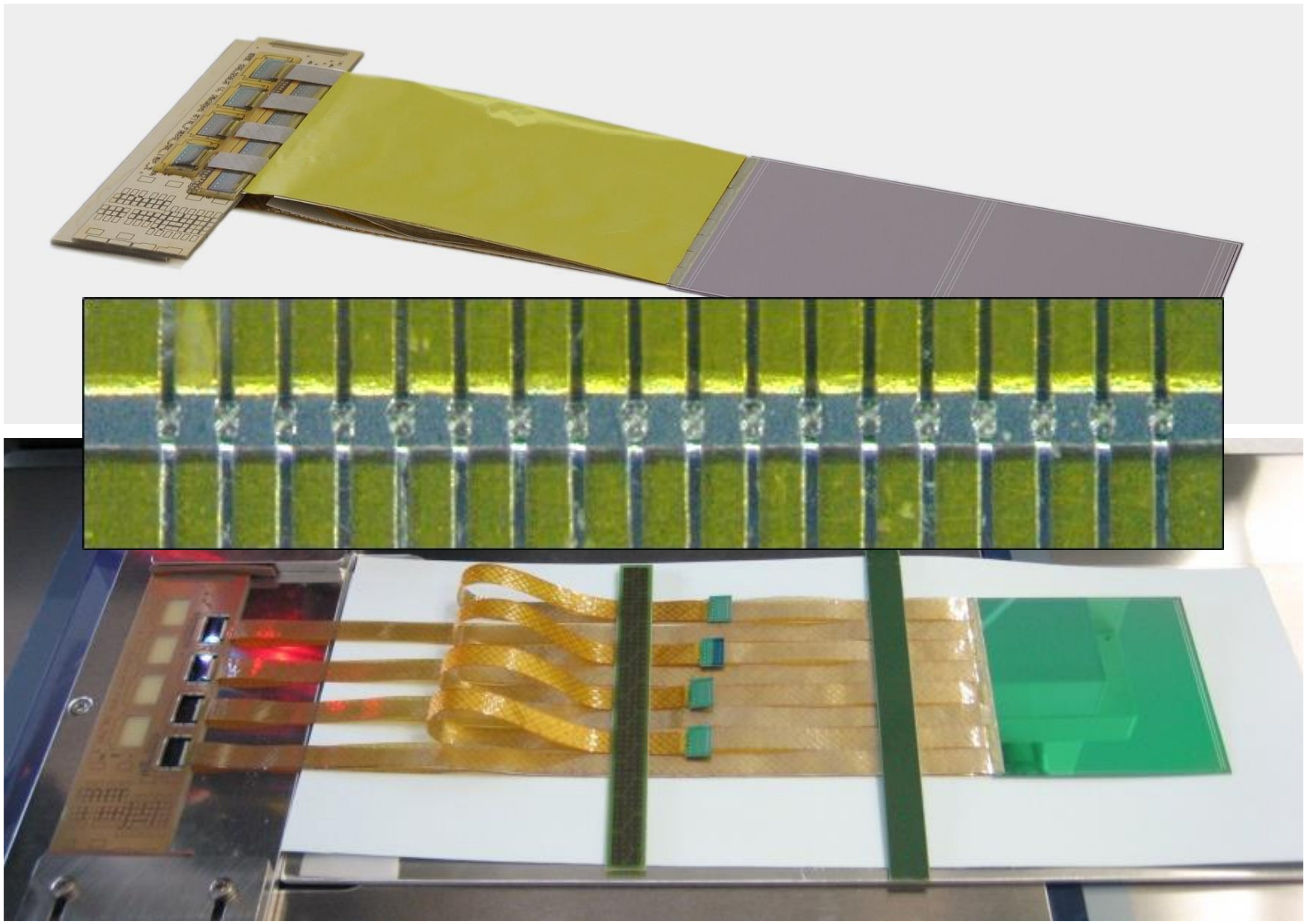
Important:
trace capacitance < 500 fF/cm

Challenge: production yield of up to 50cm long cables.
Alternative under investigation: Cu-polyimide.

Modules assembly



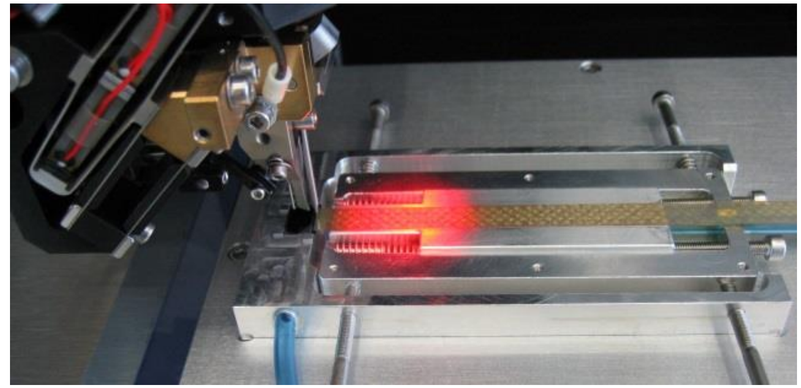
Modules



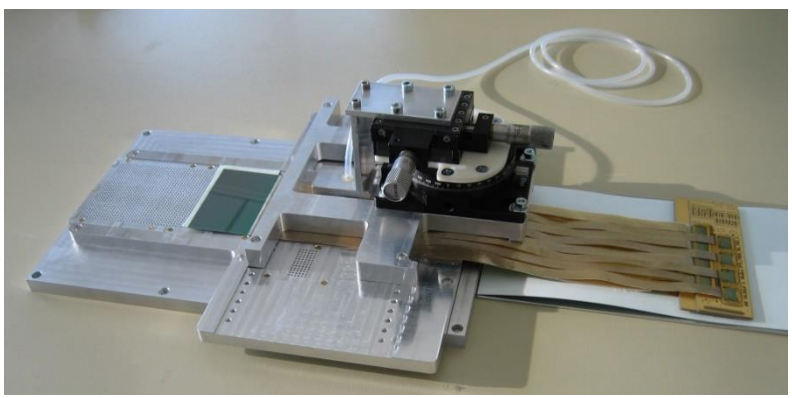
tab bonding

Module assembly

(1) ASIC-test in socket (Pogo pins)



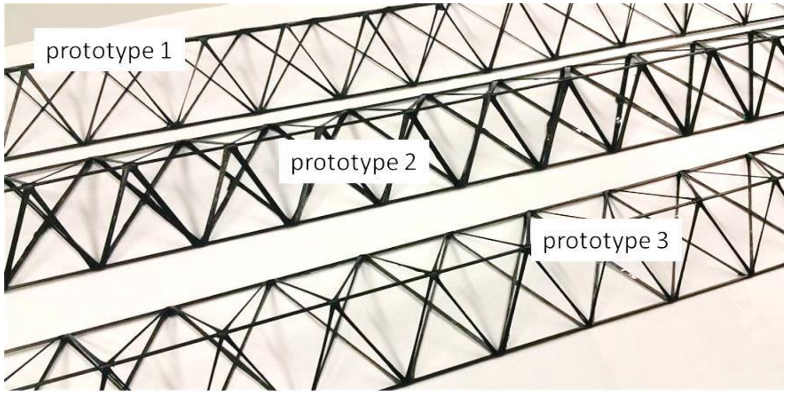
(2) ASIC-to-micable TAB bonding

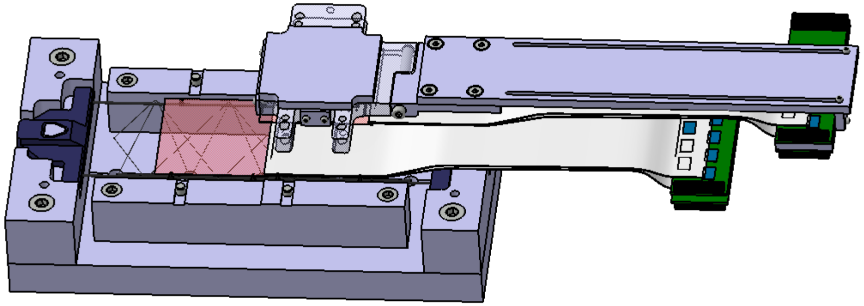


(3) microcable-to-sensor TAB bonding
(4) die- and wirebonding of ASICs to FEB-PCB

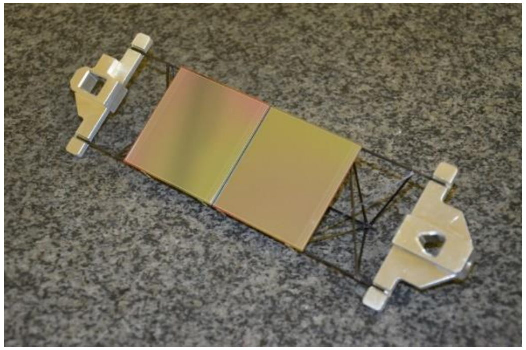
(5) glueing of shielding layers and spacers
(6) repeat for reverse module side

Ladder assembly





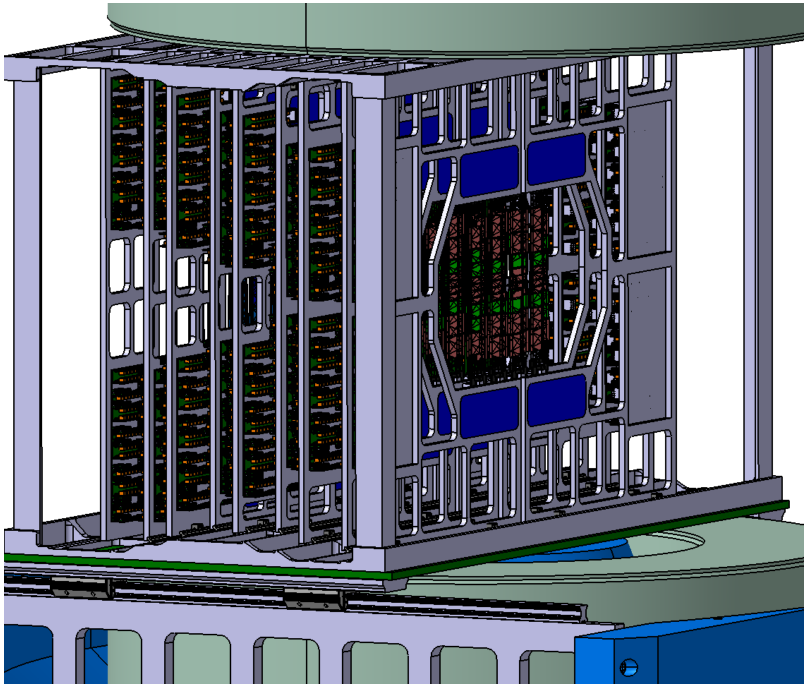
module placement tooling

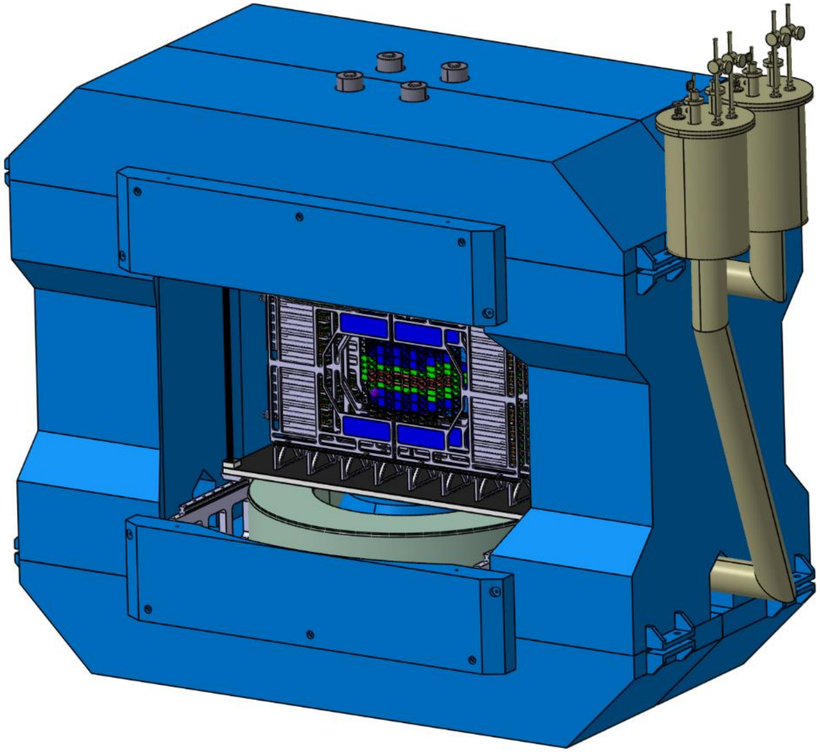


pre-series carbon-fiber ladders made in industry

positioning within ± 35 µm (optical survey) demonstrated

System Integration

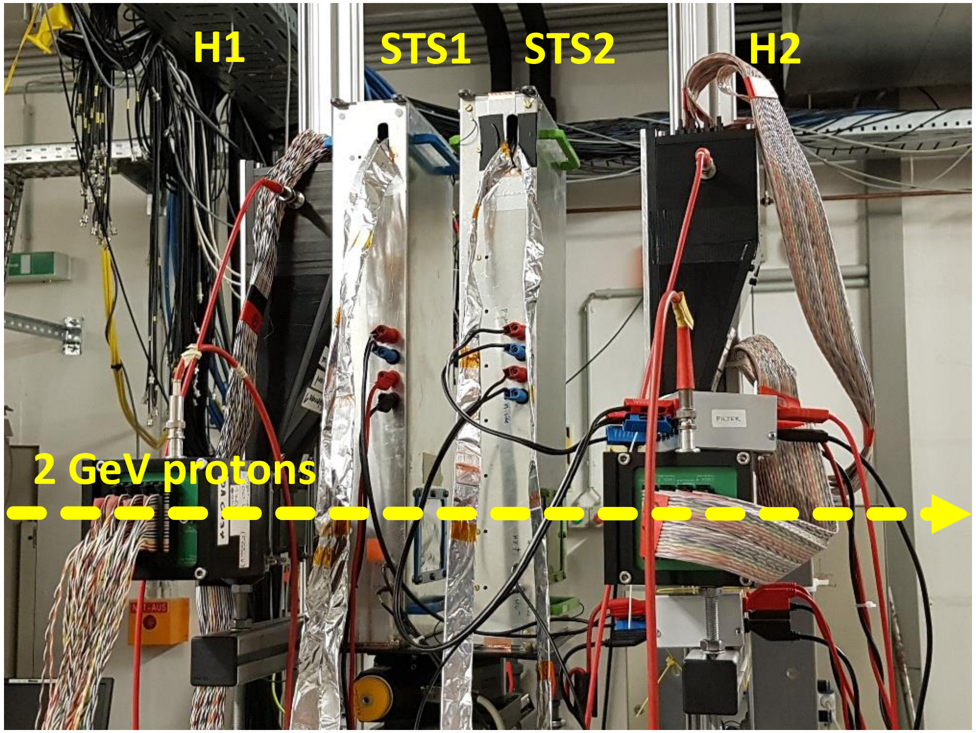


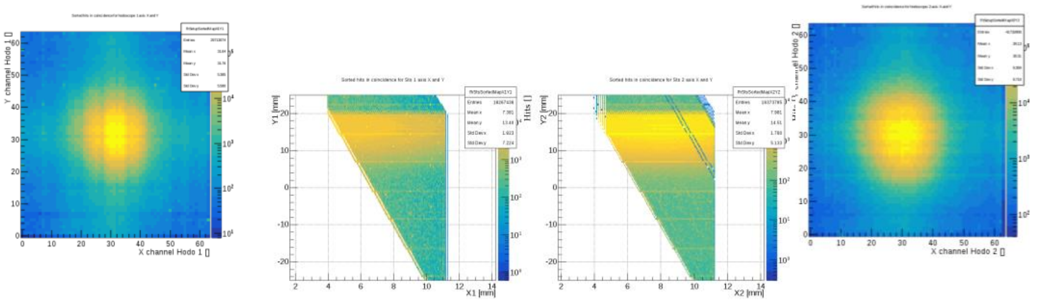


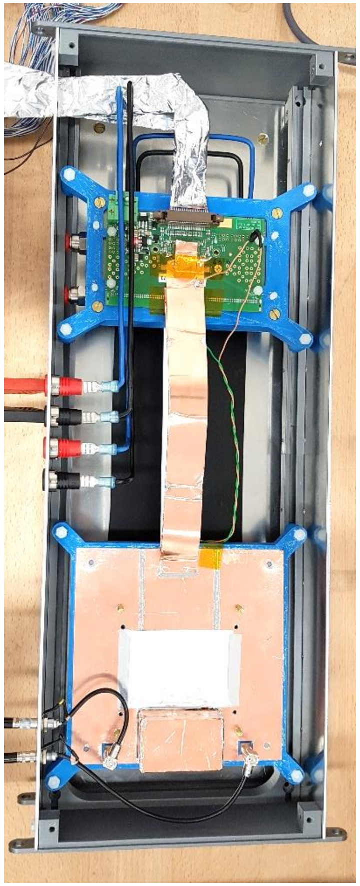
- mechanical construction:
  ladders, mechanical units, beam pipe,
  main-frame, rail system in magnet

- component installation
- cabling and powering
- thermal insulation, cooling

STS in-beam test, COSY, 26.2. - 5.3.2018







prototype
STS module

STS-XYTERv2.0
on FEB-B
- 128 chs p-side
- 128 chs n-side

microcables

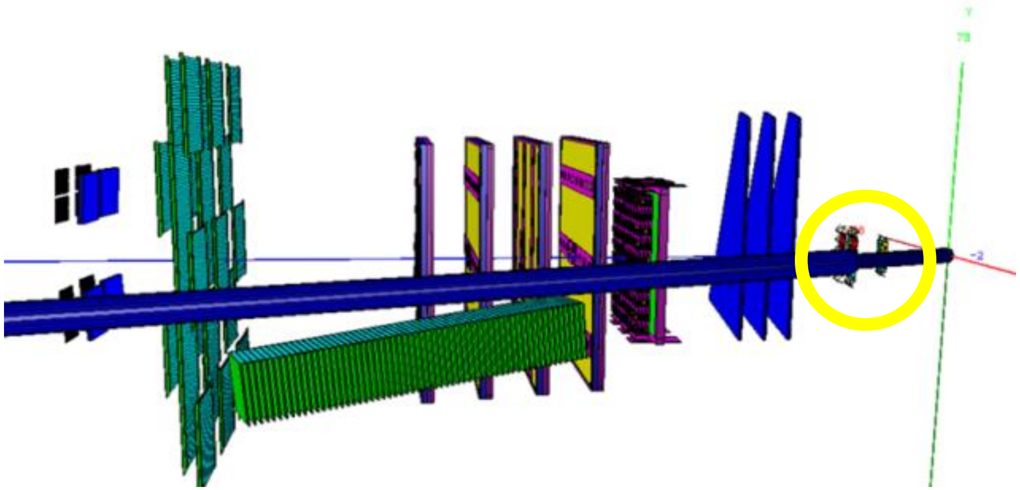
6 x 4 cm^2
microstrip
sensor

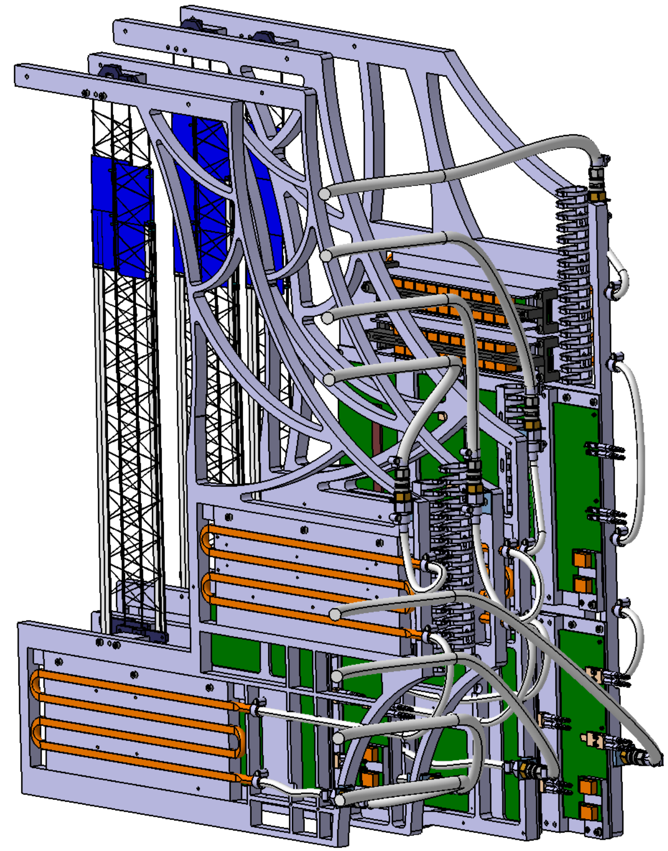
+ prototype
free-streaming
DAQ

mSTS demonstrator

mCBM experiment at SIS18/GSI:

- prove data transport/event building
- 2018/2019 technical, 2020/21 physics runs
- realistic input from prototype detectors
- ion collisions on target





cave, beamline, detectors under construction.

mSTS:
– *2 small stations with 2 and 3 ladders (4 and 9 modules)*
– *tracking with time-based hit data*
– *test STS-XYTER ASIC with realistic particle load*

CBM-STS Project Timeline

- Technical Design Report approved – 2013
- Production Readiness of components – 2018
  - *silicon microstrip sensors*
  - *tendering in Q2/2018*
- Test experiments 2018 – 2021
- Production of components and

  STS system assembly – 2019 – 2022
- Installation in CBM magnet – 2023
- Beam delivery starting – 2024

http://repository.gsi.de/record/54798

The future

- upgrade of CBM silicon tracking with pixel detectors
- provided (and expecting) that monolithic devices become as radiation hard and fast as hybrid systems today
- interest in technology exploration now:
  - detectors
  - module
  - system integration