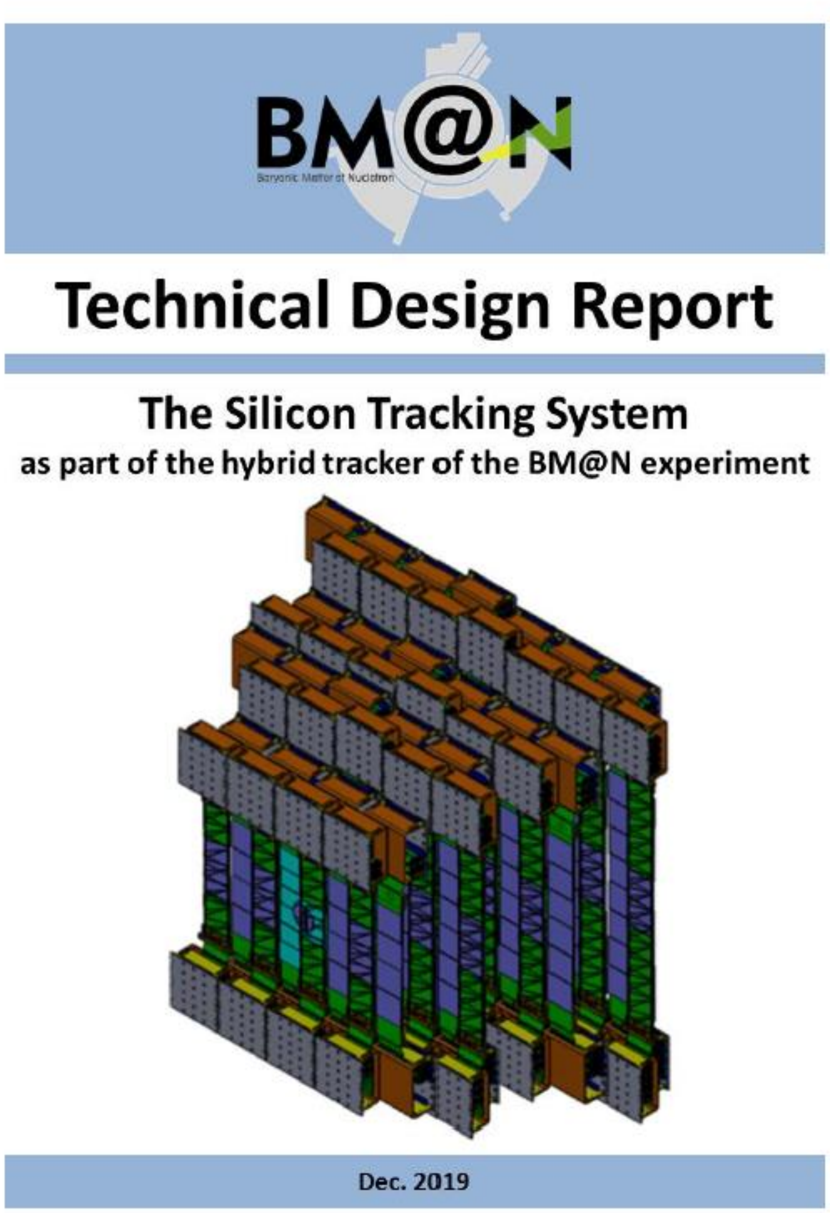

STS TDR and hardware status

D. Dementiev and P. Senger for BM@N STS group:

A. V. Baranov[4], D. Dementev[1], V. Elsha[1], J. Heuser[2], P. I. Kharlamov[1,4], I. M. Kovalev[4], A. Kolzhvari[1], I. A. Kudryashov[4], A. A. Kurganov[4], E. Lavrik[3], V.V. Leontyev[4] T. Lygdenova[1], M. M. Merkin[4,1], Y. Murin[1], M. Protsenko[1], C. J. Schmidt[2], H. R. Schmidt[2,5], A. Sheremetev[1], A. Sheremeteva[1], A. Senger[2], P. Senger[2,6], N. Sukhov[1], M. Shitenkov[1], A. Voronin[1], A. G. Voronin[4], W. Zabolotny[7], A. Zinchenko[1]

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[2] GSI Helmholtzzentrum, Darmstadt, Germany
[3] FAIR Darmstadt, Germany
[4] SINP MSU, Moscow, Russia
[5] University Tübingen, Germany
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[7] Warsaw University of Technology, Warsaw, Poland

STS TDR content

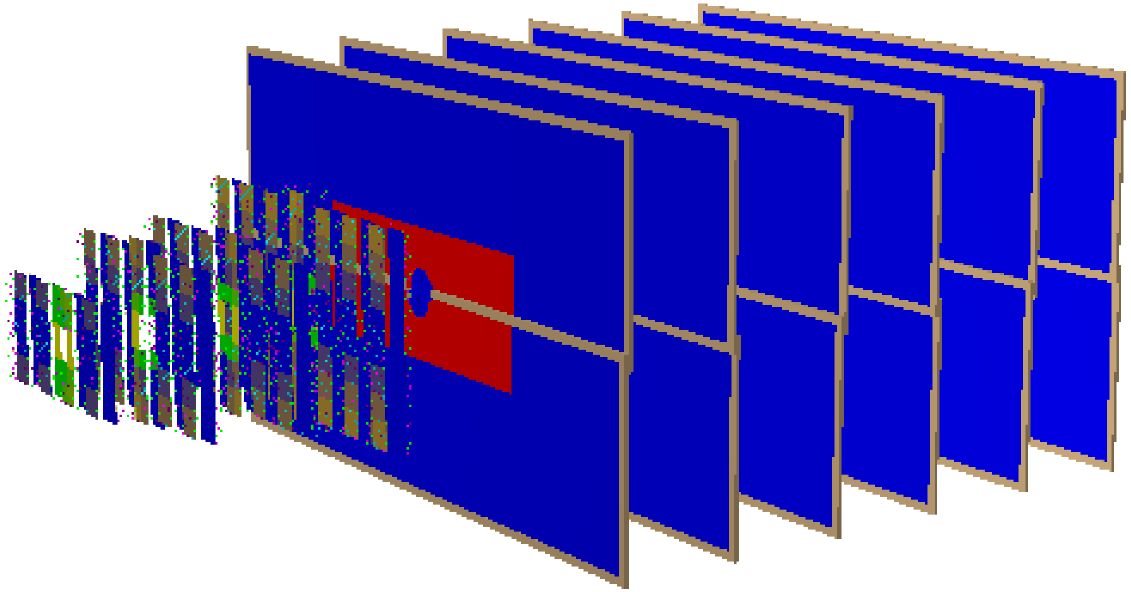
1. **The research Program of the upgraded BM@N experiment**
2. **Physics performance simulations of the hybrid tracking system (STS+GEM)**
3. **Radiation environment**
4. **The Silicon Tracking System**

    1. Layout of the Silicon detector stations and system components
    2. Double-sided microstrip sensors
    3. Readout cables, evaluation and optimization
    4. The DAQ system
    5. Cooling system
    6. STS Module Assembly
    7. Ladder Assembly
    8. Support frames and system integration
    9. Quality assurance of module assembly
    10. Low and High Voltage powering scheme for STS
    11. Project organization and time lines

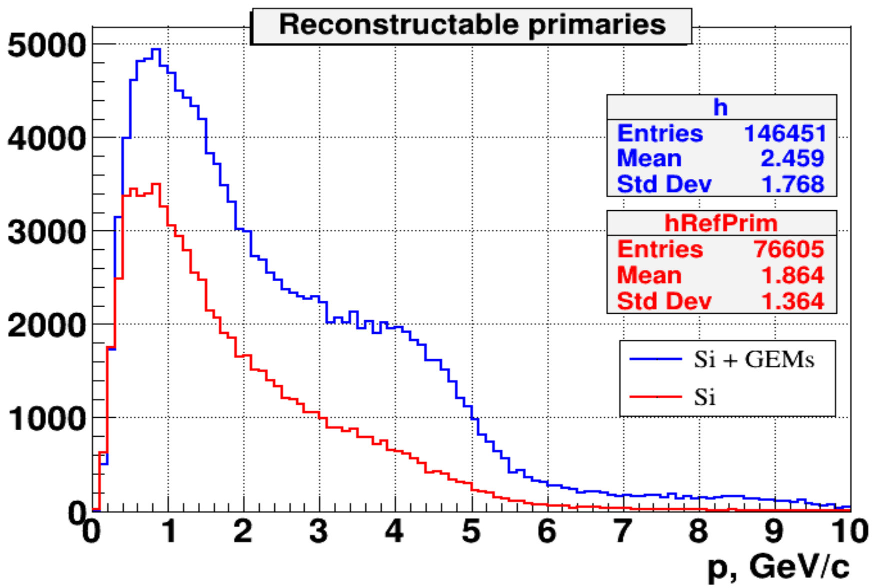
2. Physics performance simulations of the hybrid tracking system (STS+GEM)

The BM@N hybrid tracking system comprises the 4 silicon stations and 6 GEM stations. The silicon stations are located at 30 cm, 50 cm, 70 cm, and 90 cm downstream the target, followed by the GEM detectors at 120 cm up to 270 cm, with a gap of 30 cm between the stations

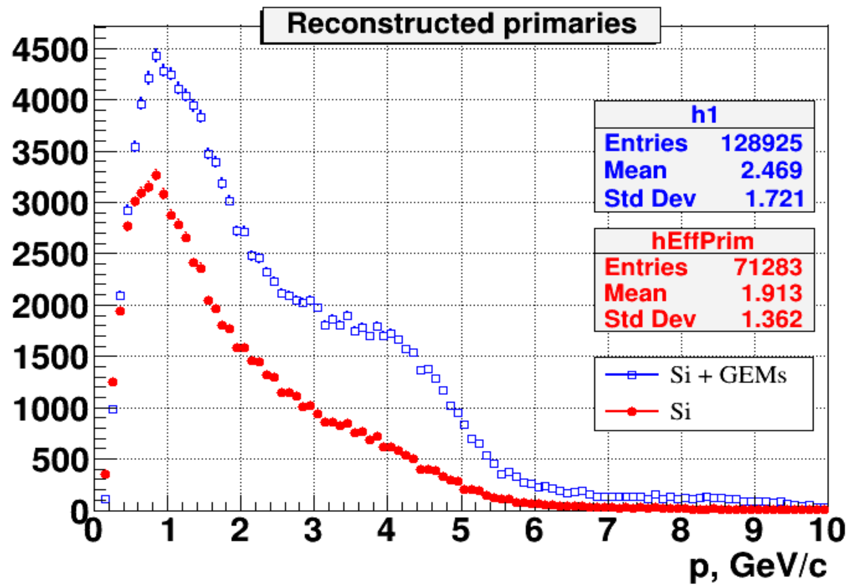
Simulations have been performed with the event generator DCM-QGSM



Track reconstruction efficiency



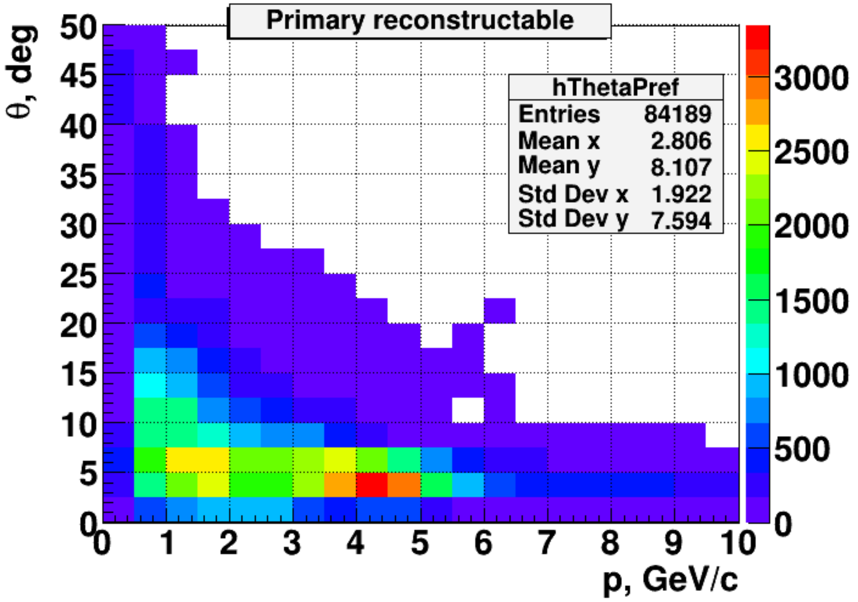
Re-constructible (4 or more hits) primary tracks as function of momentum found in 1000 central Au+Au collisions at a kinetic beam energy of 4A GeV



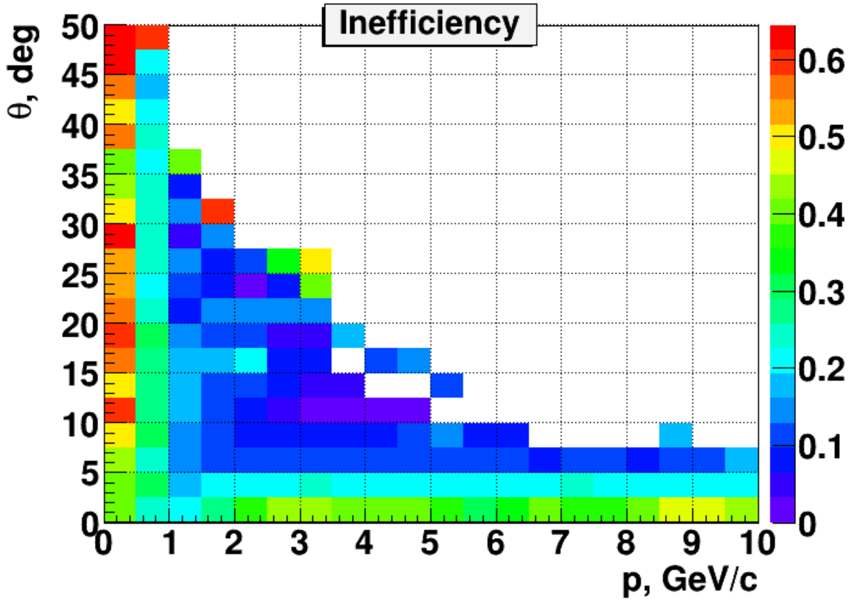
Reconstructed primary tracks as function of momentum found in 1000 central Au+Au collisions at a kinetic beam energy of 4A GeV

- Almost twice as much primary tracks are re-constructible using the hybrid system, as compared to the silicon stations only;
- About 88% of the re-constructible tracks have been found in the hybrid detector, compared to 93% for the tracks producing hits in the silicon stations only

Track reconstruction efficiency



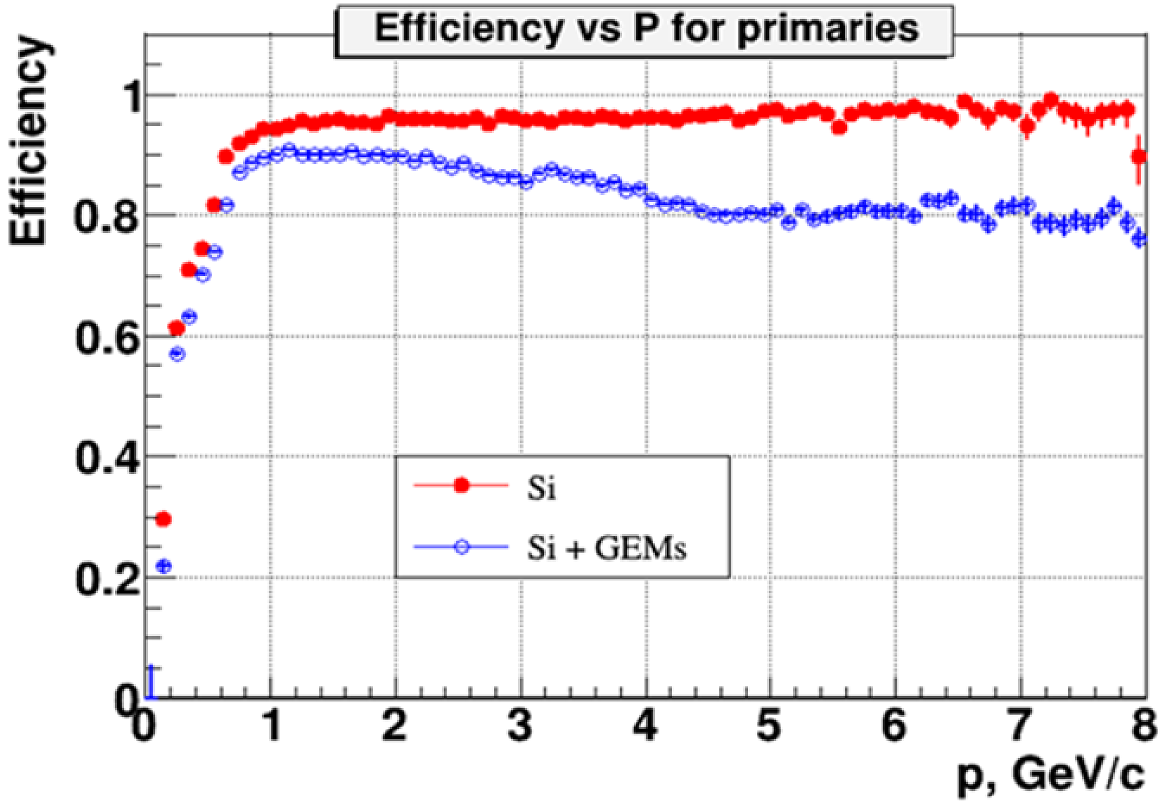
Phase space of primary particles re-constructible in the STS+GEM setup, but not re-constructible in the STS.



Phase space distribution of the particles which are not reconstructed by the four STS stations

Tracks which are emitted at polar angles around 5° and smaller miss the 1st STS station, which has an inner hole with a diameter of about 6 cm, corresponding to an emission angle of 5.7°. In addition to the tracks with small emission angles also tracks with very low momenta are not accepted

Track reconstruction efficiency

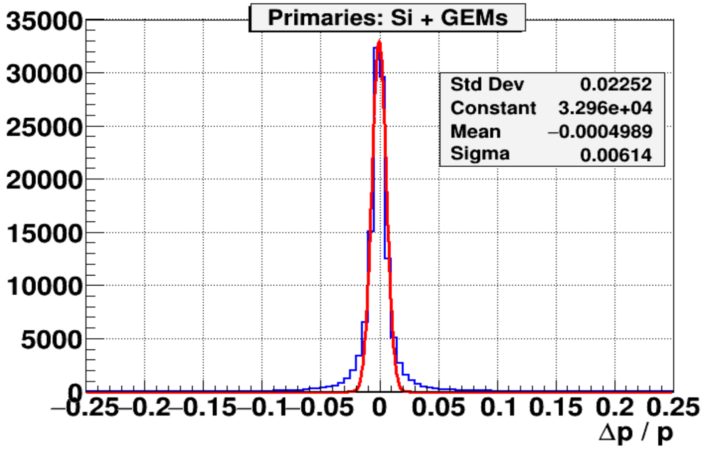


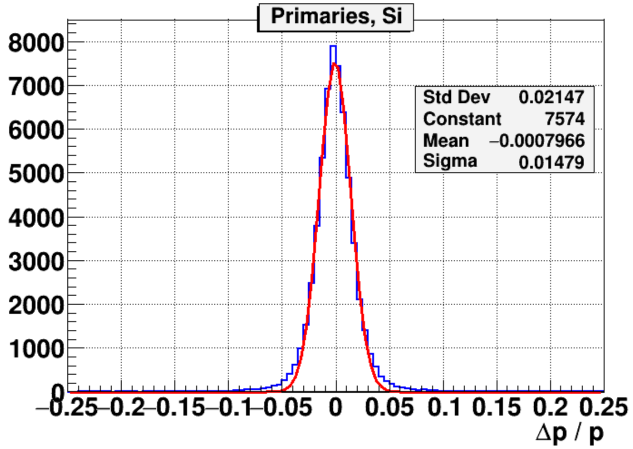
Reconstruction efficiency as function of momentum for primary tracks with minimum 4 hits in the STS stations only (red histogram), and in STS + GEM stations (blue histogram)

- STS only: efficiency >90% for the momentum > 0.6 GeV/c
- STS+GEM: efficiency >90% for the momentum of about 1-2.5 GeV/c and 80% for the momentum >4 GeV/c

The reason for the lower efficiency of the STS+GEM system is the low granularity of the GEMs, which leads to a large number of clone hits being misinterpreted as real hits.

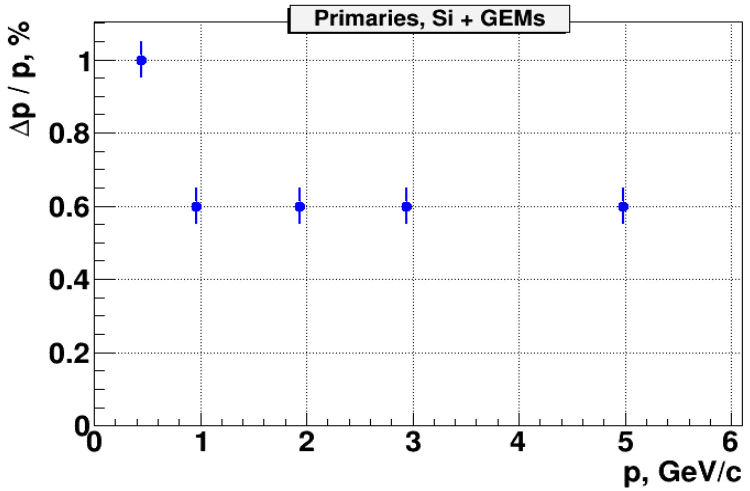
Momentum resolution





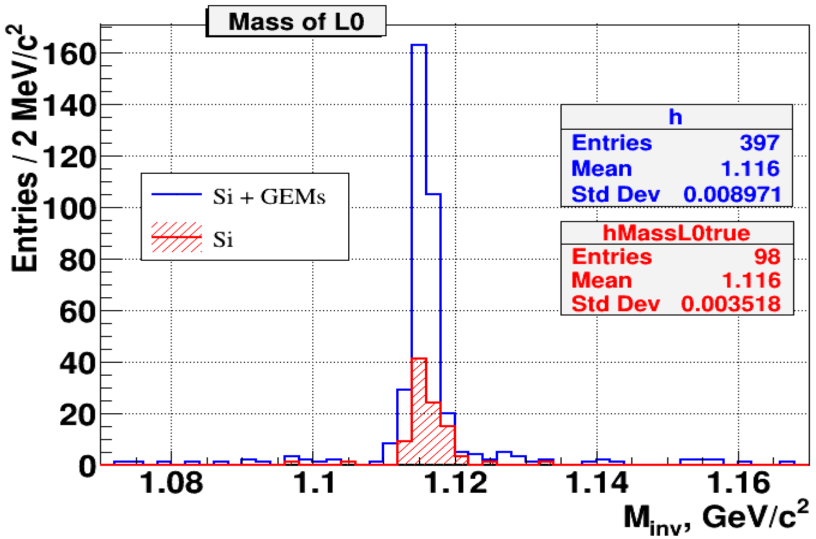
- STS only: $\Delta p/p = 0.015$
- STS + GEM: $\Delta p/p = 0.006$

Momentum resolution for primary tracks emitted in central Au+Au collisions at a beam kinetic energy of 4A GeV reconstructed in the STS+GEM setup (left), and in the STS (right).



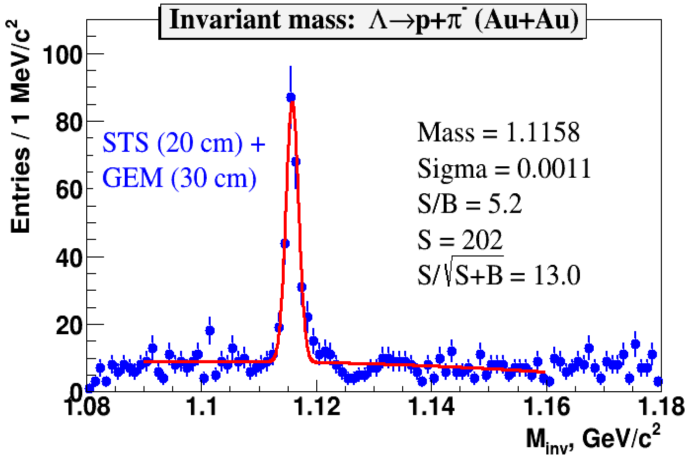
Momentum resolution for primary tracks emitted in central Au+Au collisions at a beam kinetic energy of 4A GeV reconstructed in the STS+GEM setup as function of momentum

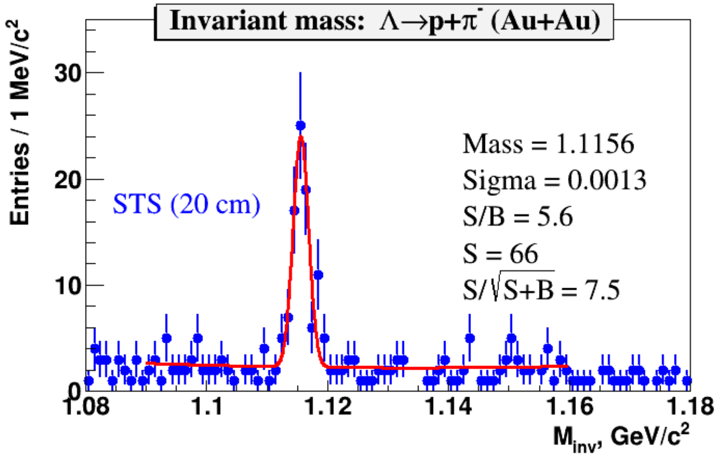
Lambda reconstruction



Lambda reconstruction efficiency is slightly above 10 % for the STS+GEM
And about 2.6% for STS only

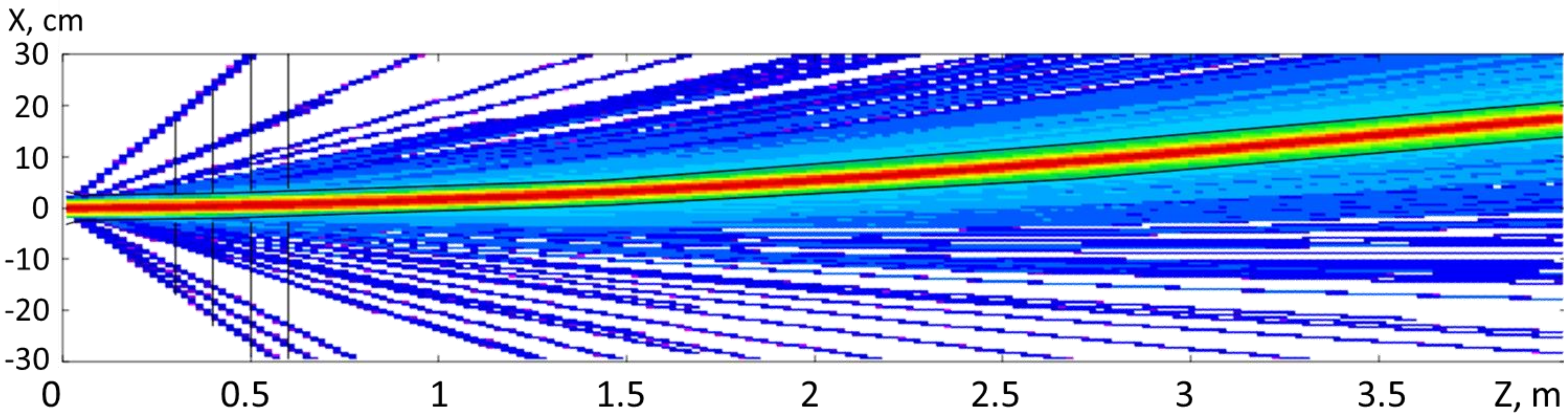
Number of reconstructed lambdas using 4 silicon stations only (red), and using the 4 STS + 6 GEM stations (blue).





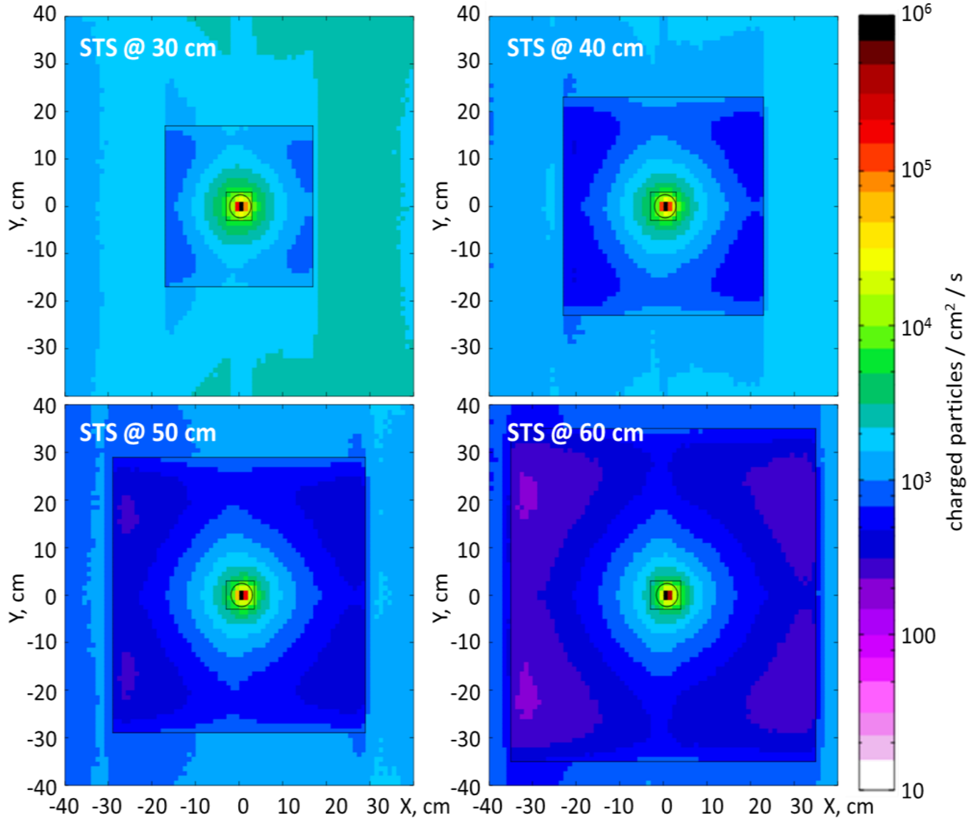
Proton-pion invariant mass spectra using 4 silicon + 6 GEM stations (left), and using 4 silicon stations only (right).

3. Radiation environment



Projection of the Au ions into the X-Z plane illustrating the beam deflection. Results of FLUKA calculations for an Au beam with a kinetic energy of 4.5A GeV, a profile with a width of σ = 3.5 mm, and a divergence of 1mrad

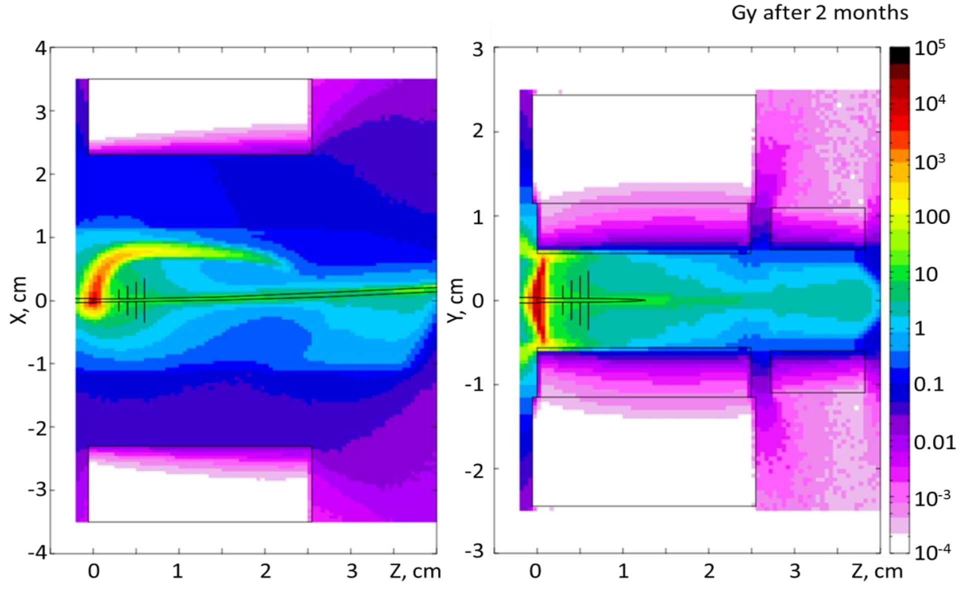
Radiation level in the detector regions



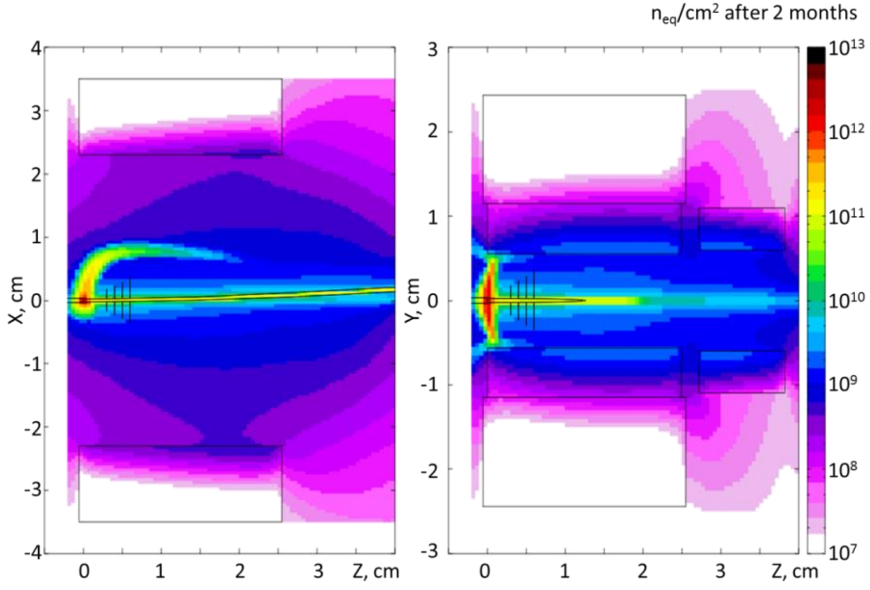
Distributions of rate densities for charged particles hitting the four silicon stations in minimum bias Au+Au collisions at a beam kinetic energy of 4.5A GeV and an intensity of $2 \cdot 10^6$ ions/s.

Channel inefficiencies for the STS are $1.5 \cdot 10^{-5}$ for the majority of the sensors and $1.5 \cdot 10^{-4}$ for the sensors close to the beam pipe.

Radiation level in the detector regions



Ionizing dose in Gray

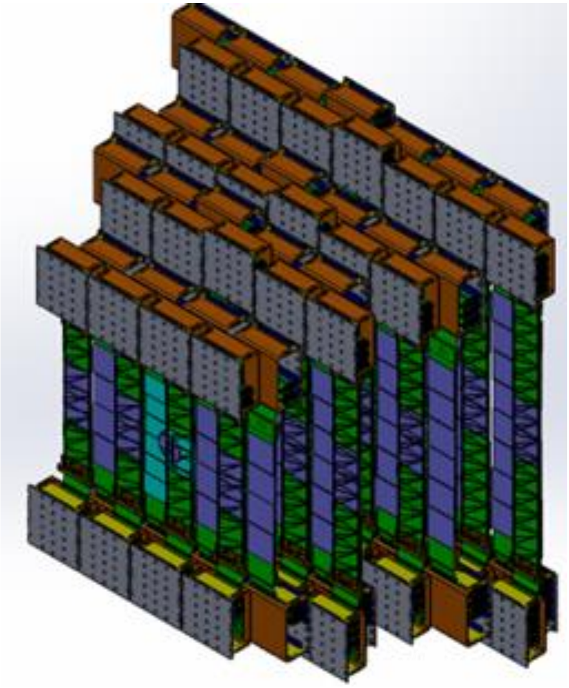


Equivalent neutron fluence n_{eq}/cm^2

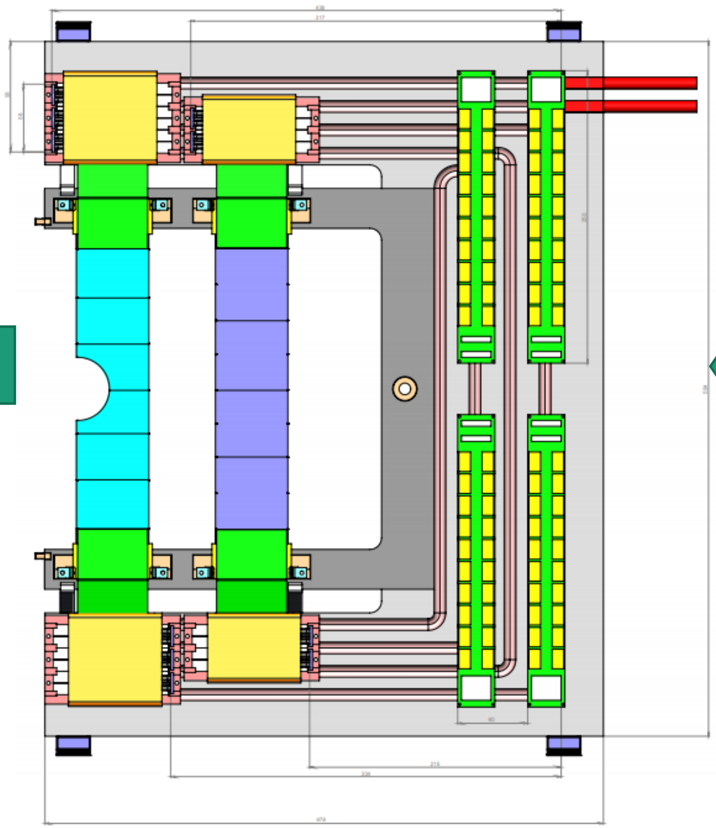
For STS: the ionizing dose ~10 Gy after 2 month, lifetime dose ~ 100 Gy => mild damage of the central sensors. The equivalent neutron fluence is below 10^{10} n_{eq}/cm^2 after 2 months, life time fluence of 10^{11} n_{eq}/cm^2, which is well within the radiation tolerance of the sensors.

For GEM: the ionizing dose ~1 Gy after 2 month of beam on target, corresponding to a life time dose of 10 Gy. The equivalent neutron fluence is below 10^{10} n_{eq}/cm^2 after 2 months, corresponding to a life time fluence of 10^{11} n_{eq}/cm^2. Both values can be tolerated by the GEM detectors.

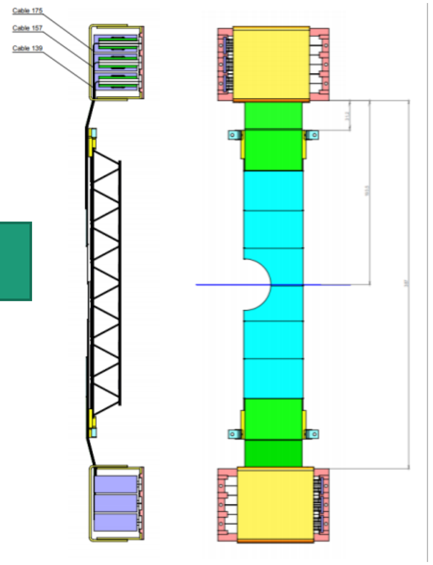
4. The Silicon Tracking System



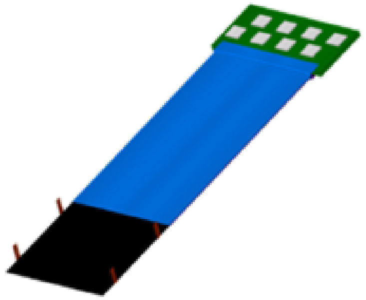
4 Stations



16 Quarter-Stations

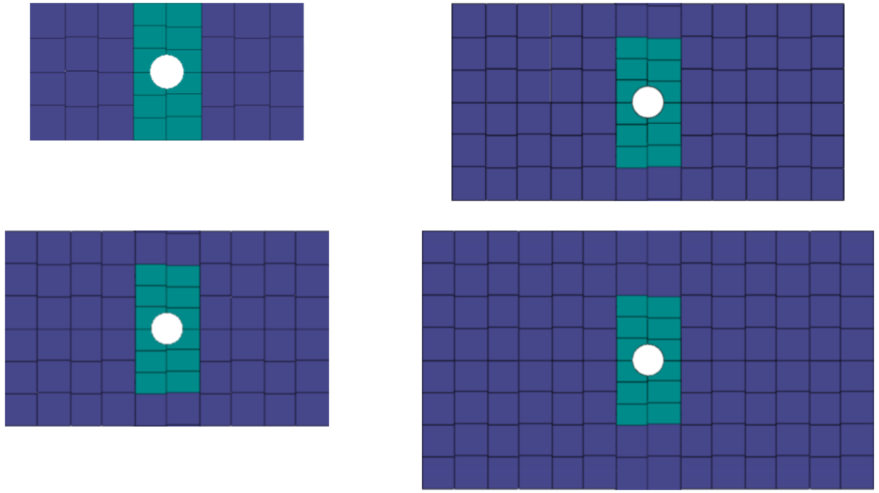


34 ladders

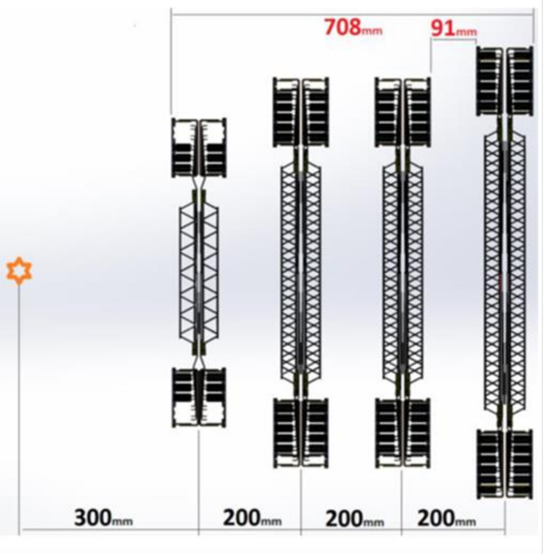


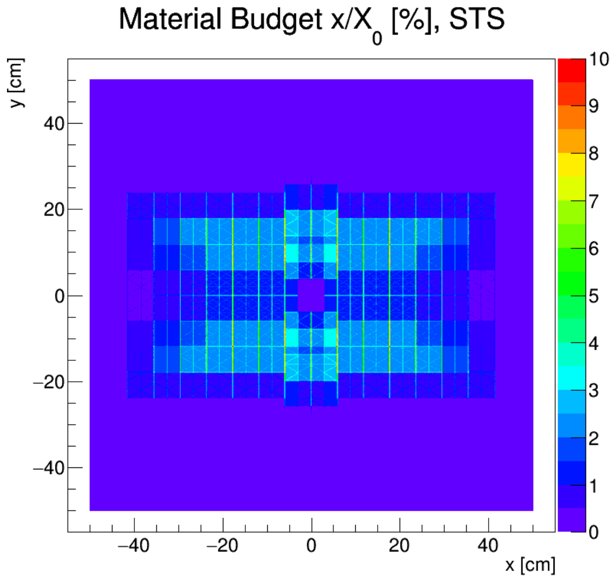
292 modules

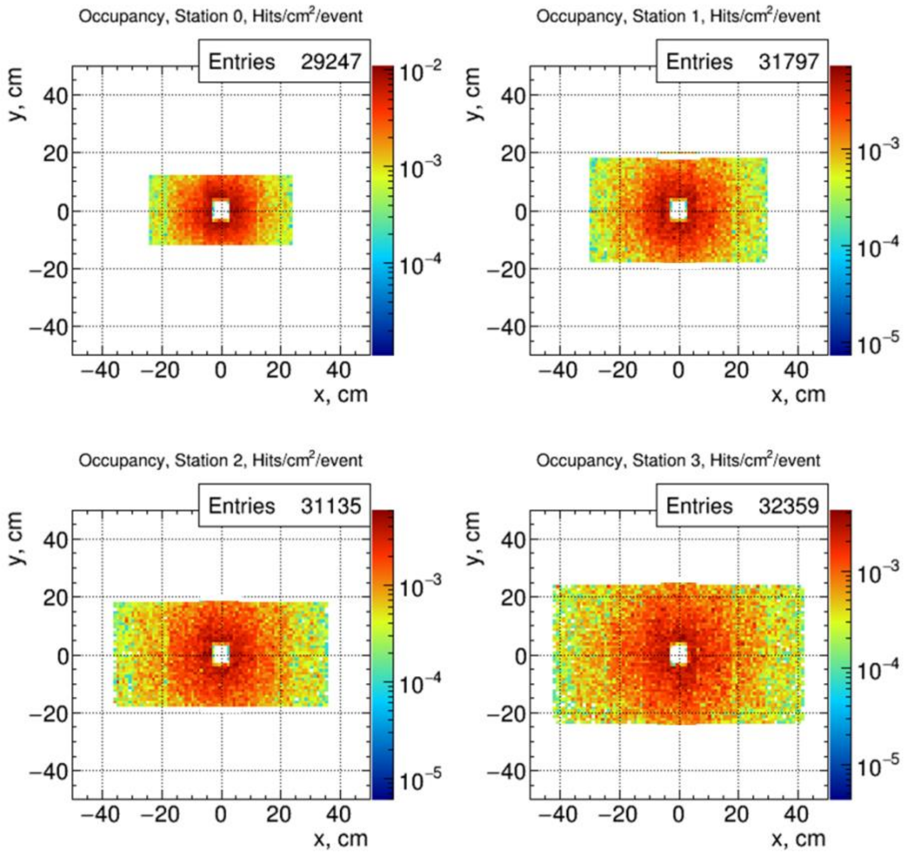
Layout of the Silicon detector stations



Layout of the STS with sensors 42 x 62 mm² (green) and 62 x 62 mm² (blue)



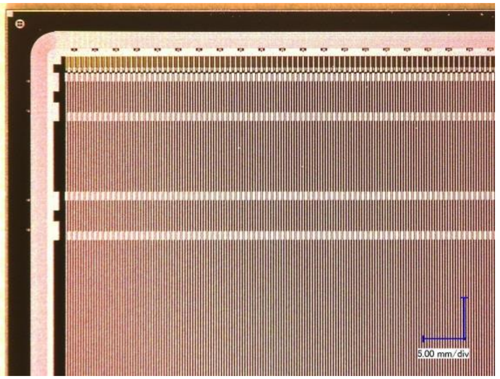




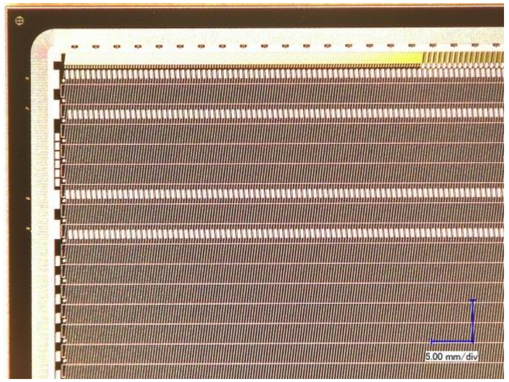
Hit density per cm² and event in the four STS stations

The hit density is below 0.02 hits/cm²/event. For an inner sensor of size 42 x 62 mm² this value corresponds to a strip occupancy of about $5 \cdot 10^{-4}$ per event.

Double-sided sensors



n-side



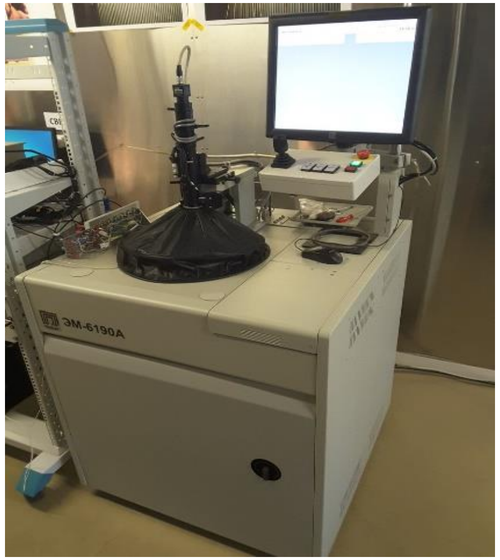
p-side

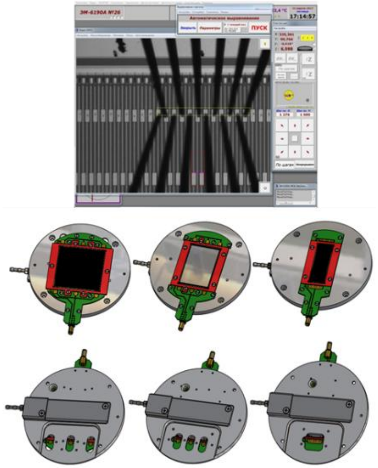
Current status of sensors:
Most of the sensors are already delivered to the JINR assembly site and tested.

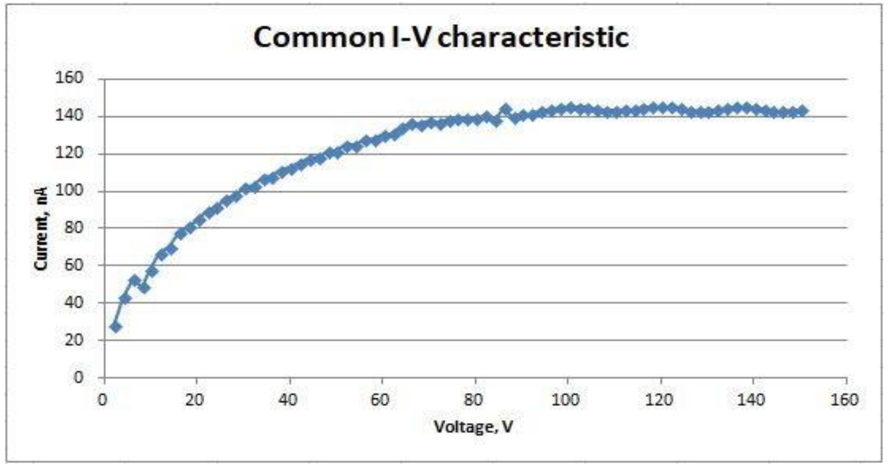
Design of the central sensors with a round cut for the beam-pipe is now being developed by SINP MSU
Sensors will be ordered at CiS in 2020

- Vendors: CiS (Germany) and Hamamatsu (Japan)
- Double-sided sensors with 1024 strips per side
- Three different geometries: 42*62mm², 62*62mm² and central sensors with round cut 42*62mm²
- Pitch of one strip: 58 µm
- Thickness: 300 µm (285 µm at CiS and 320 µm at Hamamatsu)
- Stereo angle: 7.5°

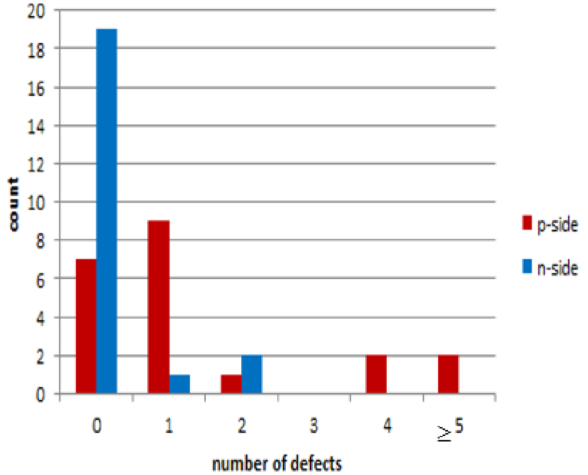
QA tests of the sensors

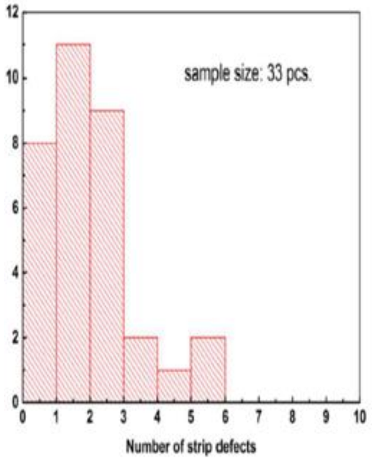




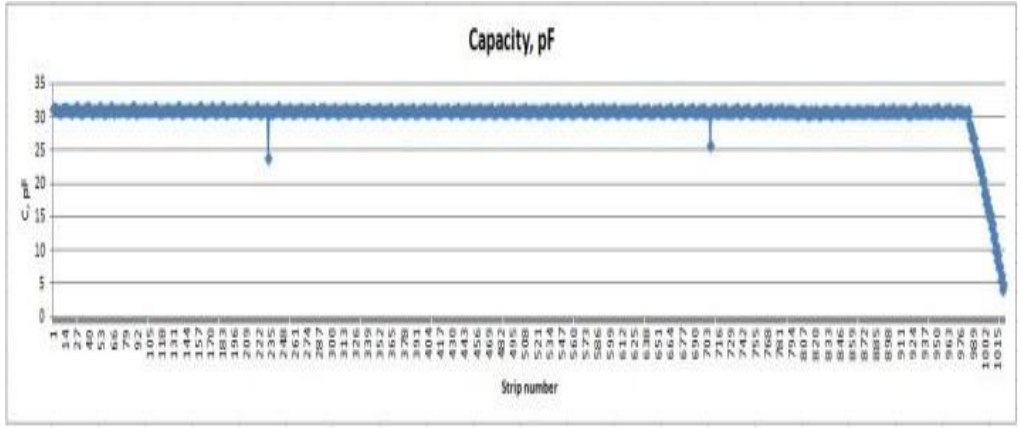


Current-Voltage characteristic of a sensor of 6.2 by 6.2 cm at room temperature



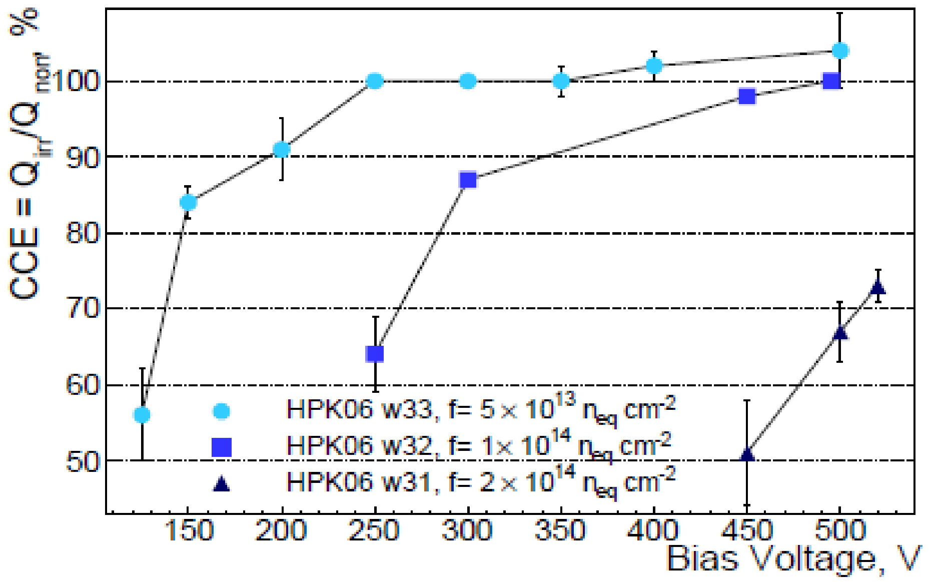


Statistics of strip defects on a number of 6.2 by 6.2 cm sensors from CiS (left) and Hamamatsu (right)

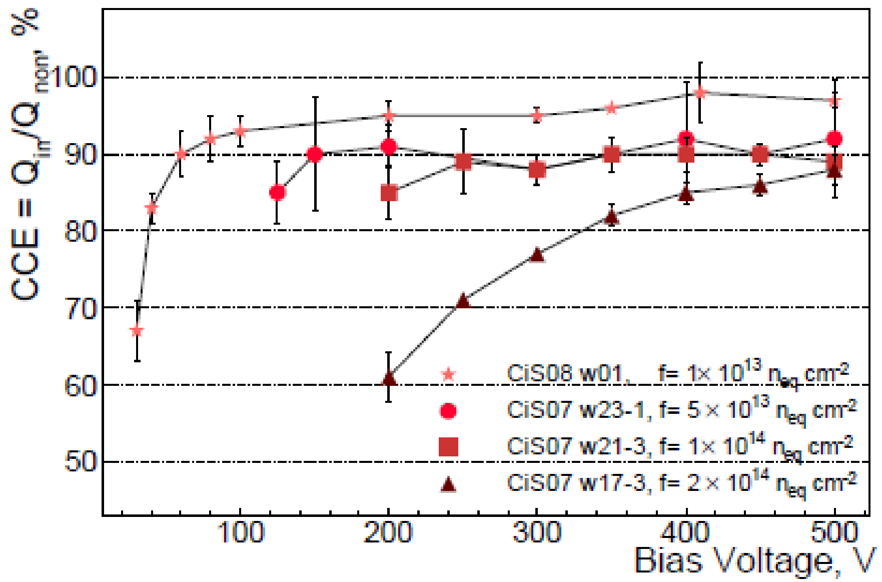


Strip-by-strip measurement of capacitance to its neighboring strips reveals potential short circuits or breaks

Sensor performance after irradiation



Hamamatsu sensors

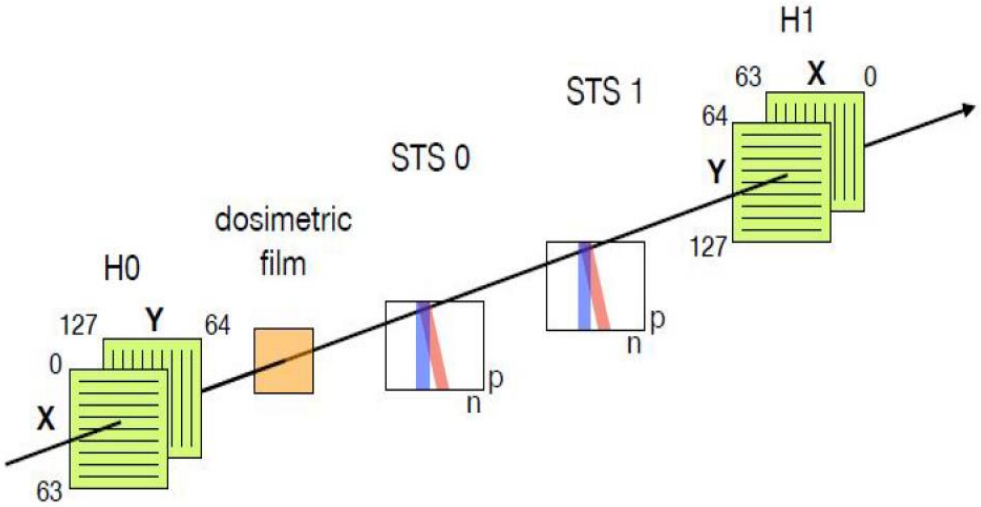


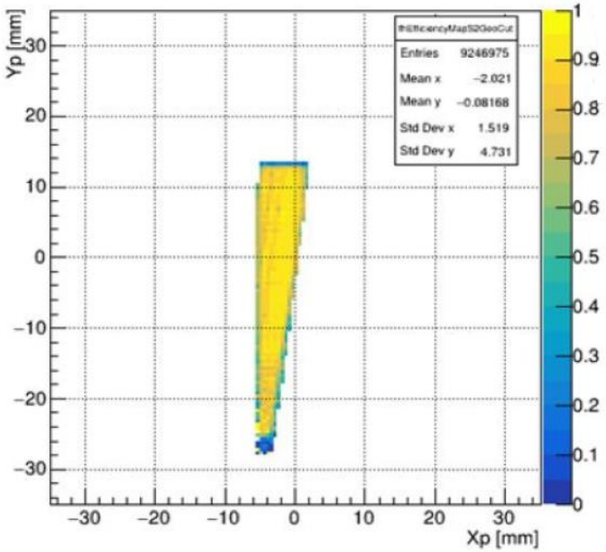
CiS sensors

Measurements of charge collection efficiency (ratio of detected charge in irradiated to non-irradiated sensors) for samples of Hamamatsu and CiS sensors

CiS and Hamamatsu allow operating the sensors up to 2×10^{14} neutrons/cm^2 fluence

Hit reconstruction efficiency with a STS module



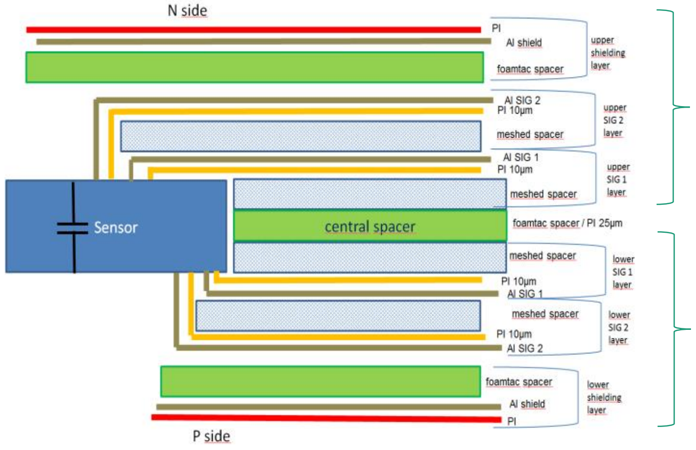


In-beam experiment with a test module structure to determine the hit reconstruction efficiency from proton-beam induced signals in a prototype silicon micro-strip sensor coupled to self-triggering prototype front-end electronics of the CBM-STS.

Measured hit reconstruction efficiency is more > 95%
(1.7 GeV/c proton beam)

Readout micro-cables

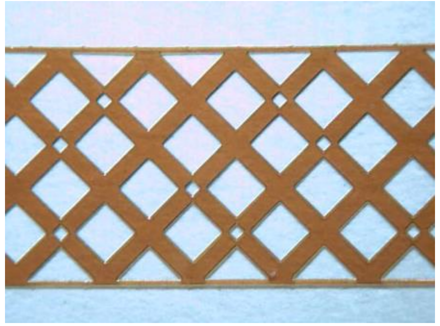
cable stack: *thickness ~ 800 µm / 0.23% X_0*



N-side read-out

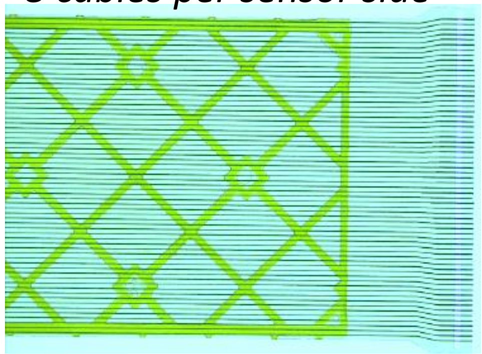
P-side read-out

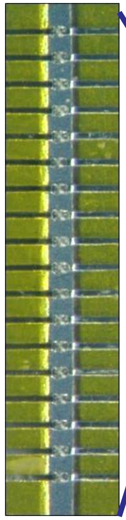
meshed spacer layer



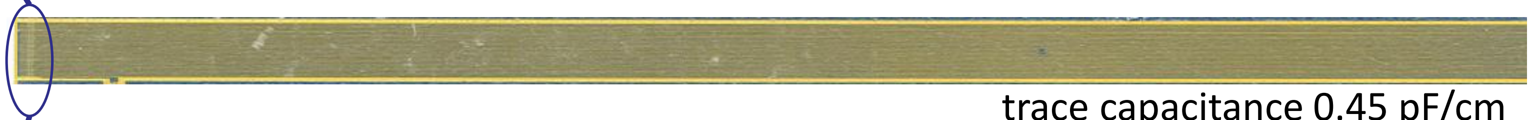
(foam spacers also)

64 traces per signal layer
2 signal layers per cable
8 cables per sensor side



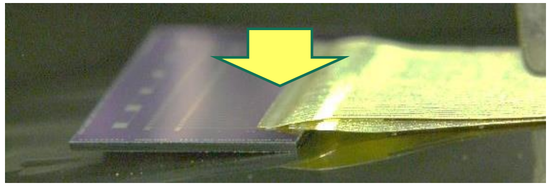


signal layer: *64 Al lines of 116 µm pitch, 14 µm thick on 10 µm polyimide*



trace capacitance 0.45 pF/cm

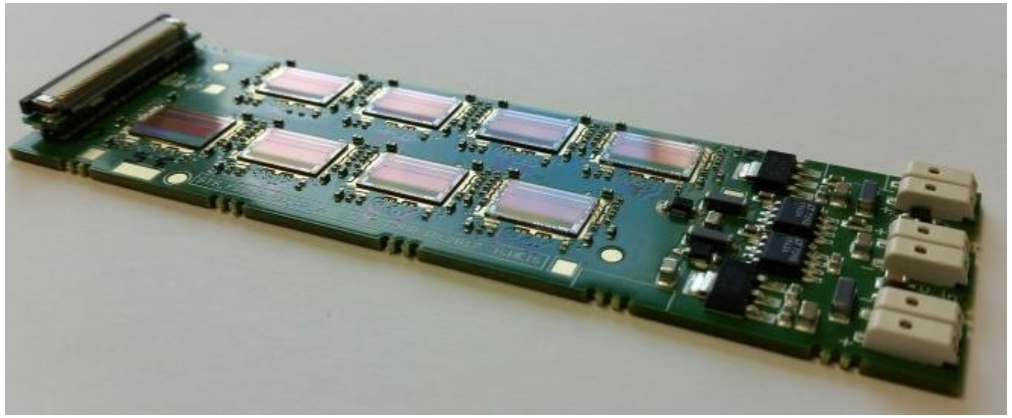
trace lengths 11 - 30 cm



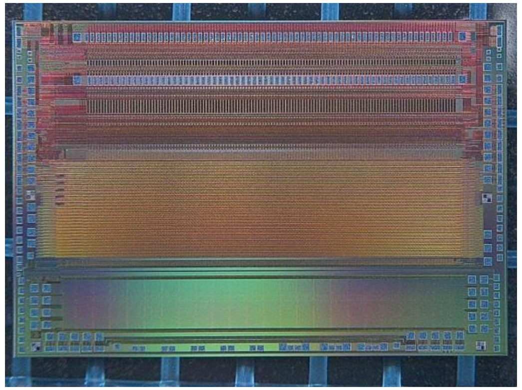
tab-bonding of 2 signal layers to Al pads on ASIC and sensor

Current status of micro-cables:
Most of the micro-cable sets for the pilot version of STS are already produced and will be delivered to the JINR assembly site in Feb 2020. Microcables for the central ladders will be produced in 2020

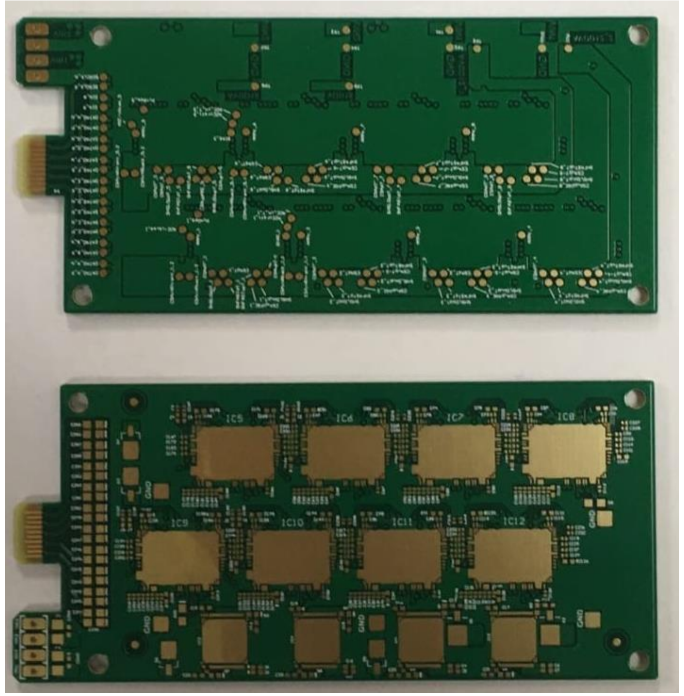
Front-end electronics



Front-end board with 8 STSxyters (CBM type)



STSxyter ASIC



Front-end board with 8 STSxyters adopted for the integrational requirements of BM@N

Each STS-XYTER is capable of delivering data of up to 50 MHits. The FEB-8 to be employed for BM@N will have connectivity for 10 MHits per chip. The FEB may be operated at lower clock speeds down to 40 MHz. In such a mode of operation the maximum hit rate for a module is then 2,5 MHits per second.

According to the simulations the hit rate per ASIC will be lower than 0,08 Mhits/s

Module assembly

TAB-bonding of the microcables to the STS-XYTER-ASIC´s

⇩

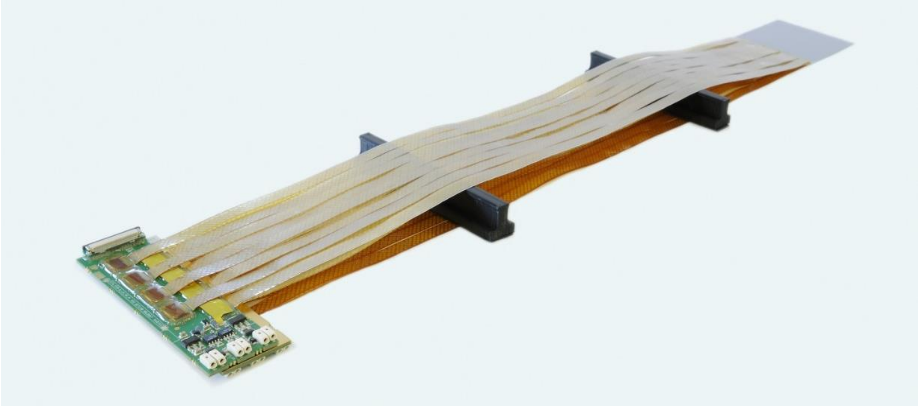
TAB-bonding of the microcables to the silicon sensor

⇩

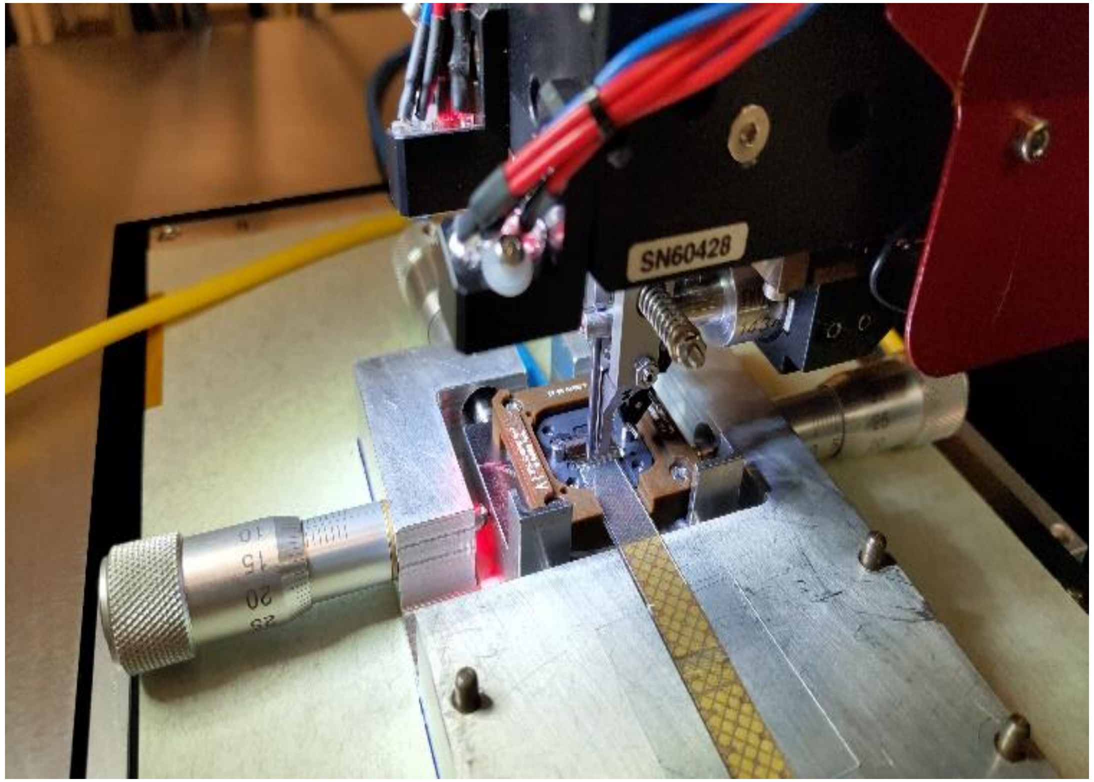
die- and wirebonding of the STS-XYTER-ASIC´s to the PCB-rows

⇩

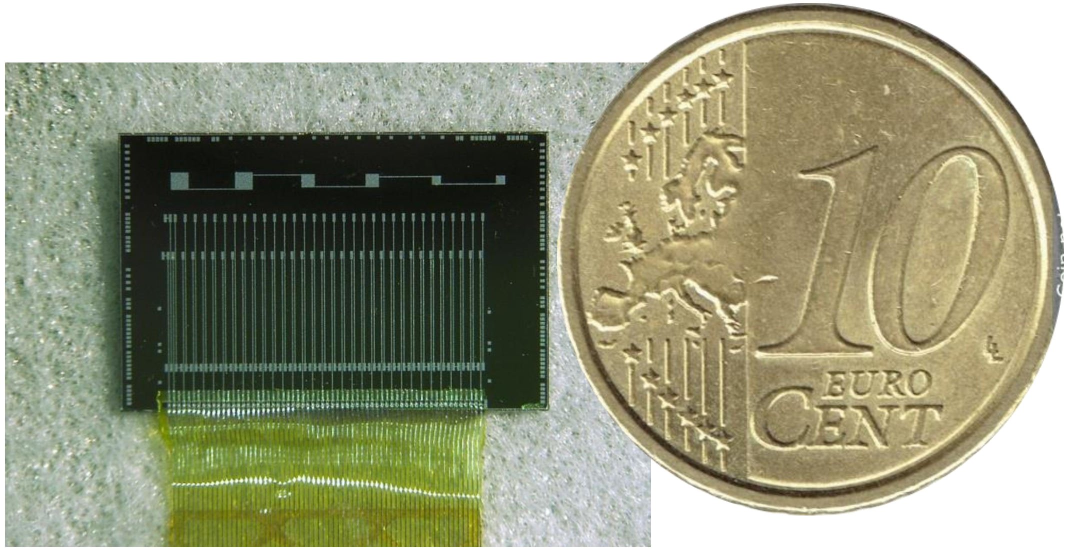
glueing of shielding- layers and spacers



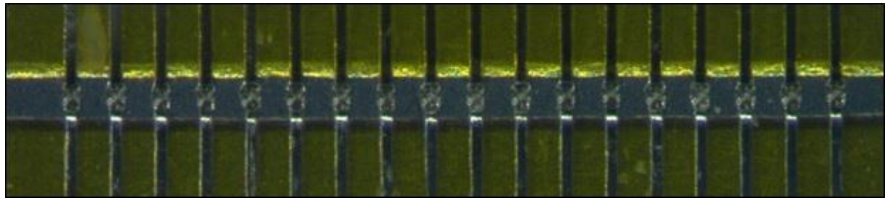
Module assembly: Tab-bonding



Tab bonding of the microcables to the ASIC

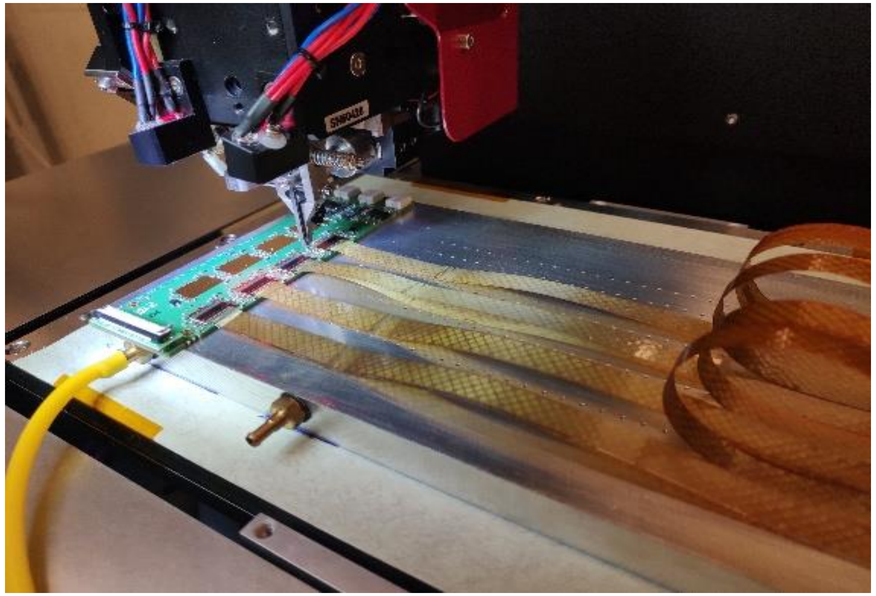


microcable TAB-bonded to a dummy-ASIC

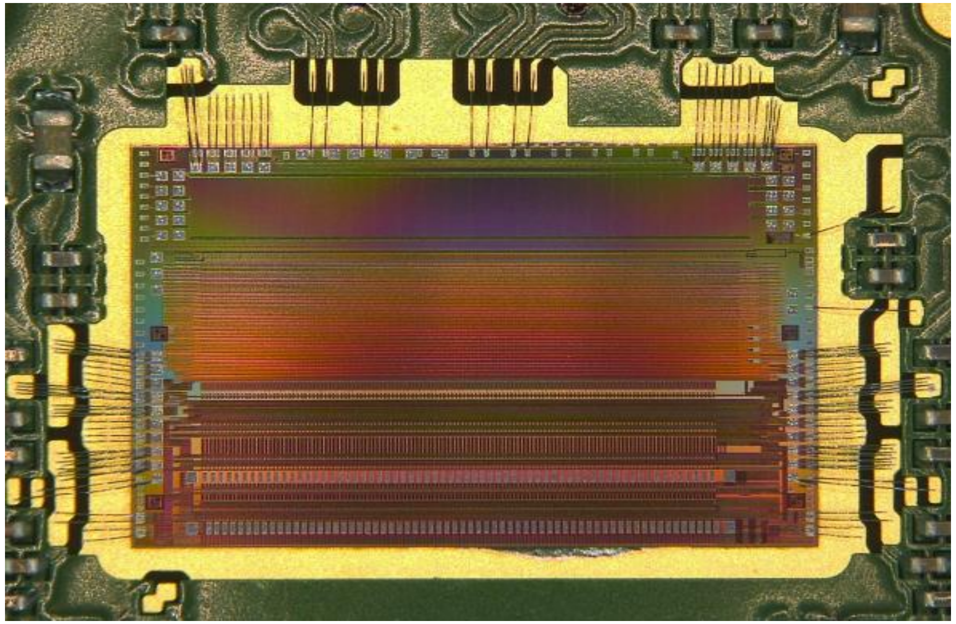


row of TAB-bonds

Module assembly: Wire-bonding

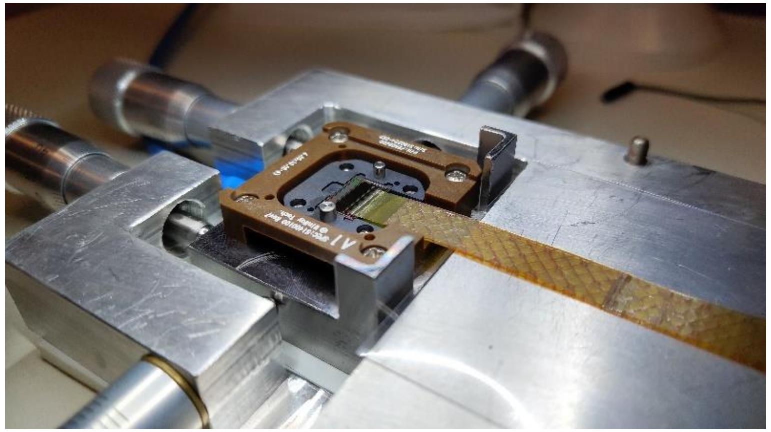


The wire-bonding of STSXYTER on the FEB

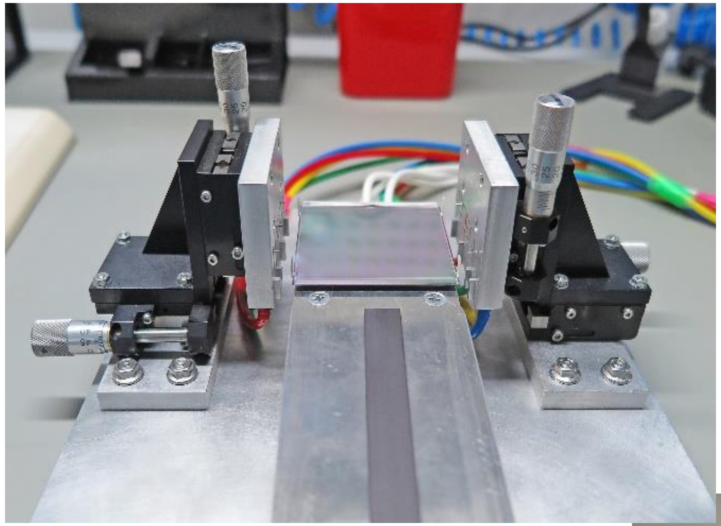


A wire-bonded STSXYTER

Module assembly: fixtures



Jig for the Tab bonding of the
ASIC to micro-cables



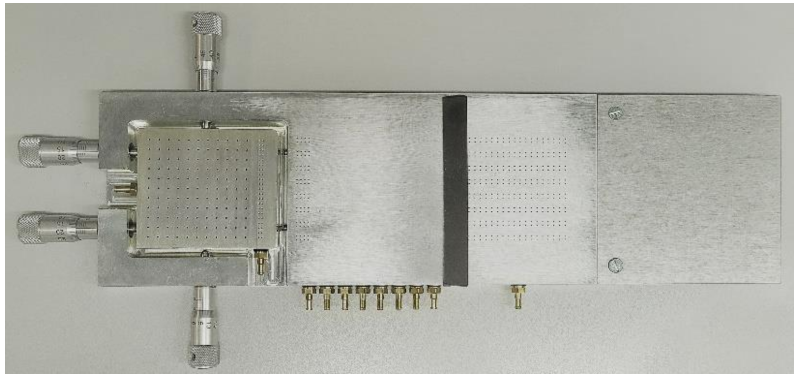
Jig for the gluing of L-legs to
the sensor

Current status of jigs:

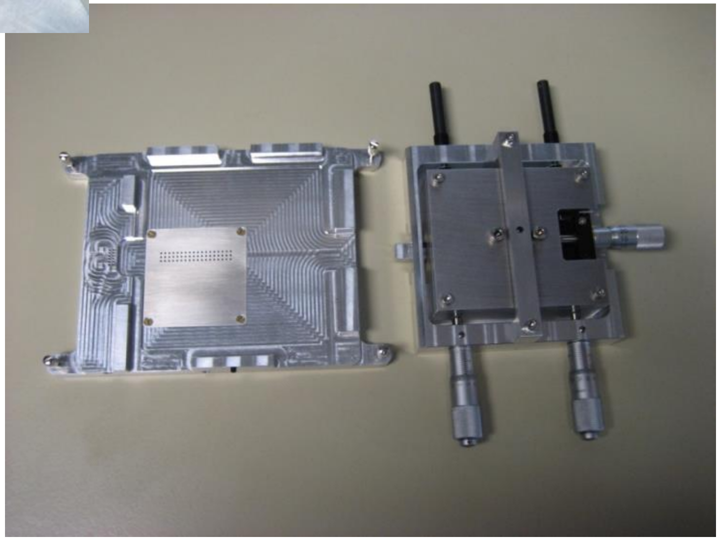
All jigs were developed, produced and tested

However, minor upgrades should be done for the new FEB geometry.

New parts will be produced in Mar 2020



Jig for the Tab bonding of the
sensor to micro-cables



GSI fixture for the tab-bonding of the
microcables to the ASICs

Module assembly: glues

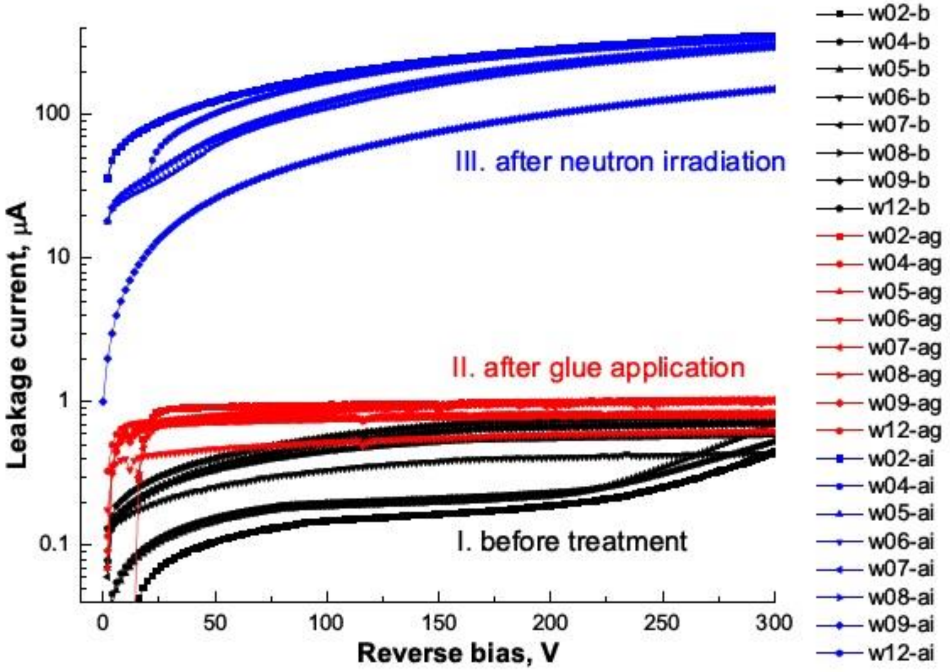
Adhesives play an important role for the STS module assembly for

- Fixing of microcables on the sensor and ASIC;

- Protecting of the Tab-bonds on the STSXYTER ASIC and the sensor;

- Protecting of the wire-bonds on the ASIC: with Glob top dam & fill;

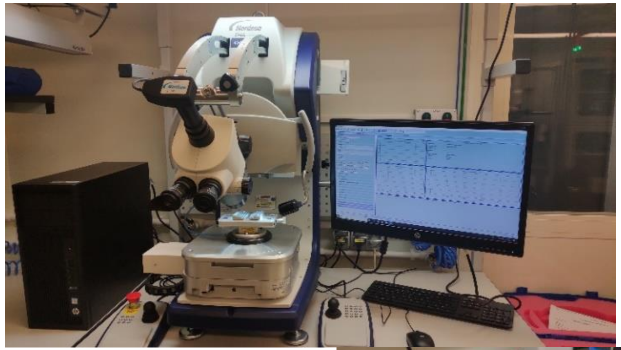
- Die-bonding of the ASICs to PCB.



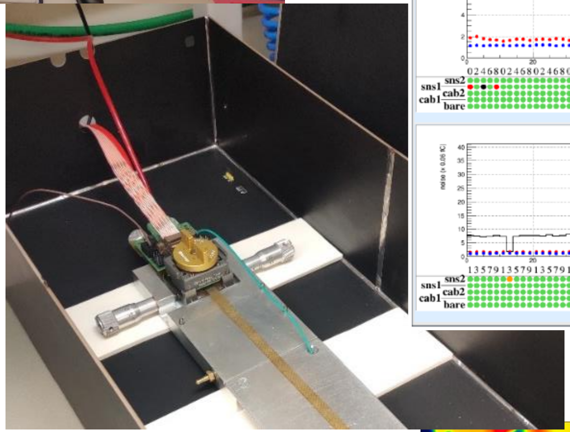
To test the radiation hardness of the glues and their influence on the leakage current of the sensors, we applied different glues on Baby-sensors.

The leakage currents were measured before and after application of glue and after irradiation

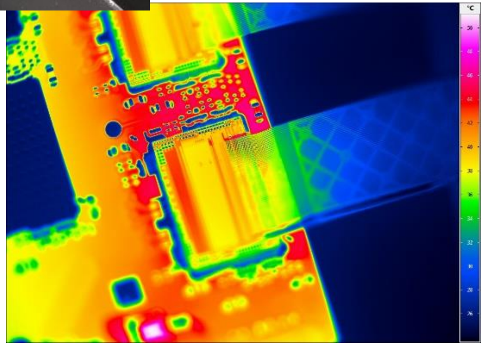
QA of the modules



1. Tests with a Pull-test machine for the accurate setting of the bonding parameters

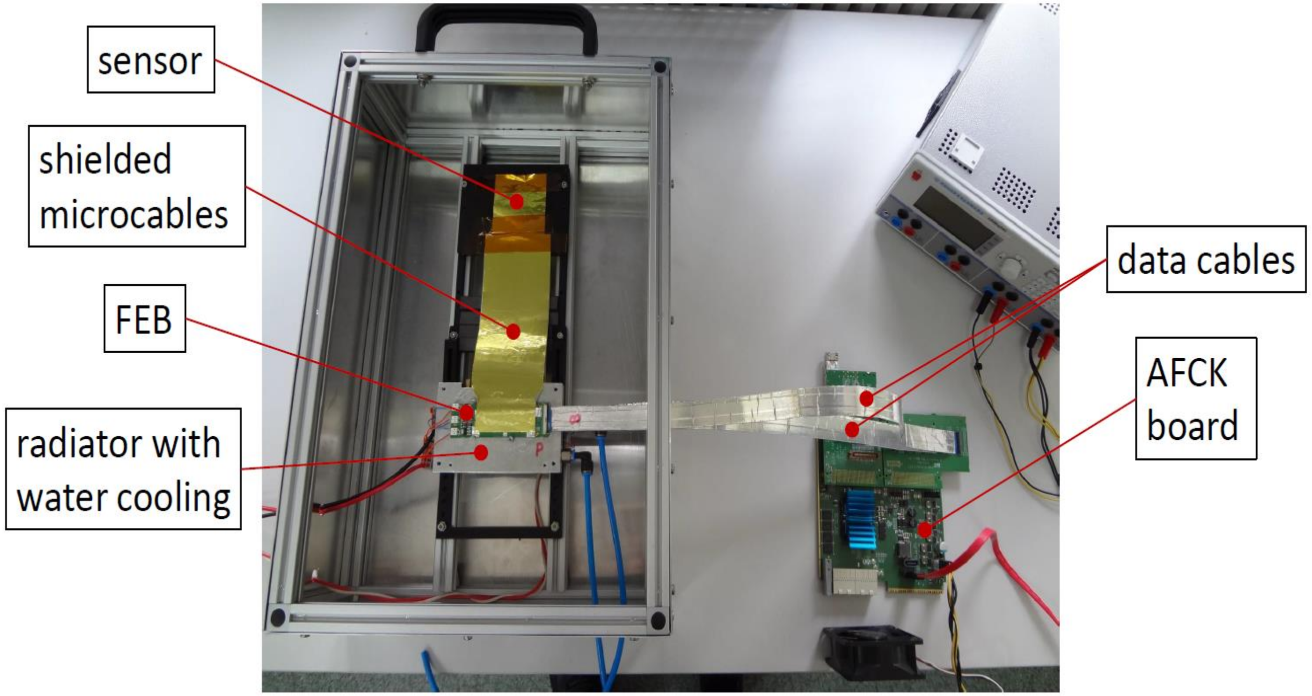


2. Bonding quality tests with Pogo-pin test circuit



3. Electrical and optical tests of the wire-bonds

Characterization of the modules



Test bench for the module prototypes

performance:

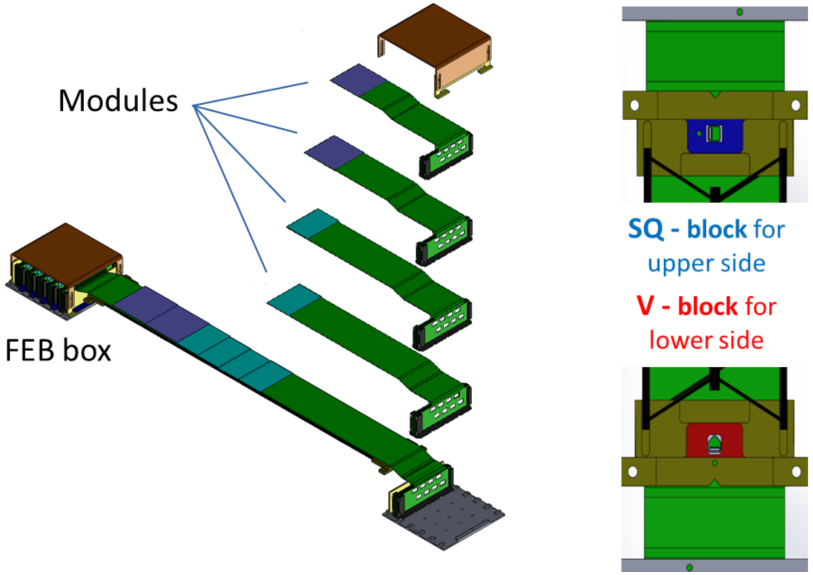
- noise:
  - 1090 ±150 e (n)
  - 1350 ±200 e (p)
- r/o threshold:
  - 7000 e
- signal mean:
  - 16720 e (n)
  - 20300 e (p)
- signal-to-noise: 15±3
- hit detection eff.: > 95%

Summary on the module assembly

Assembly procedure was developed and tested on 5 assembled modules. Module assembly procedure was improved with the aim to minimize the number of not-operable channels (less than 3%)

- It was demonstrated that the value of 1.5% of not operable channels is achievable, however the jigs should be modified
- Assembly workflow should be finalized together with the GSI assembly center (*17-18 Feb 2020: STS Module & Ladder Assembly Retreat meeting*)
- Production DB is being developed

Ladder assembly

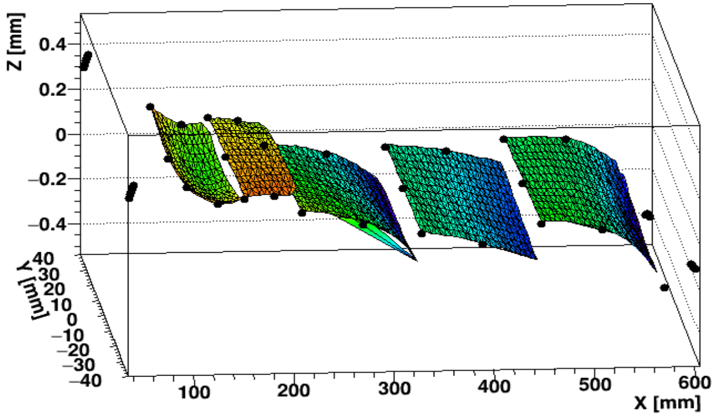


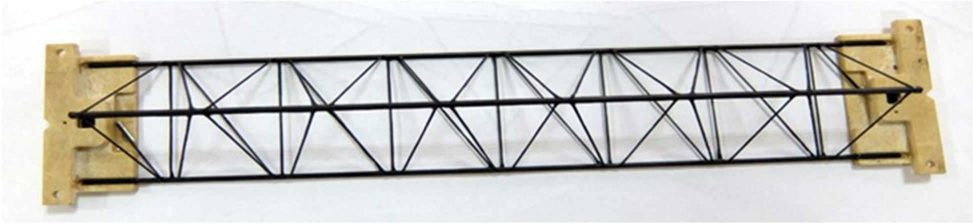
Exposed view of the ladder

Ladder assembly device

LAD should provide the following accuracy of the sensor positioning:

X coordinate	±15µm on a 1200 mm base
	±12 µm on 180 mm base
Y coordinate	±50 µm
Z coordinate	±50 µm

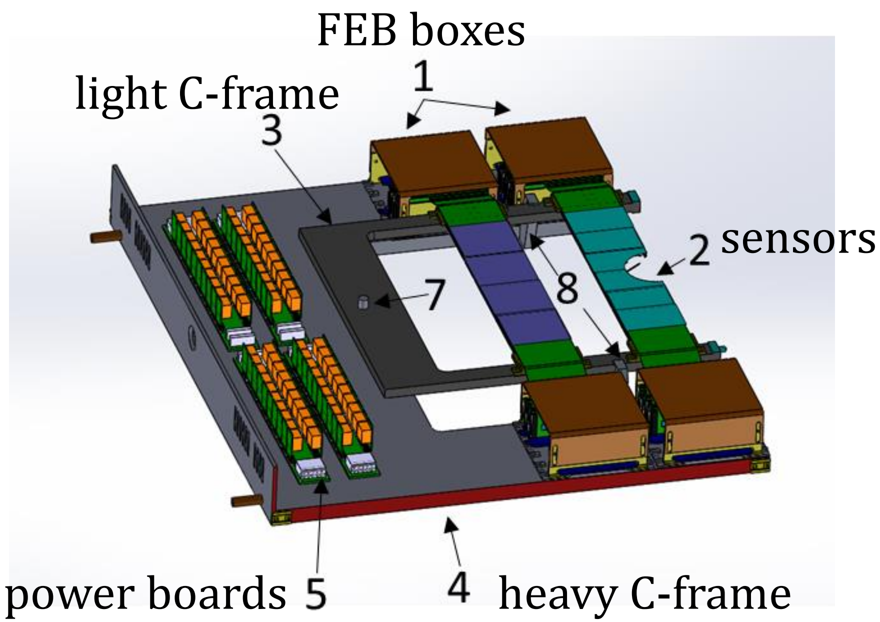




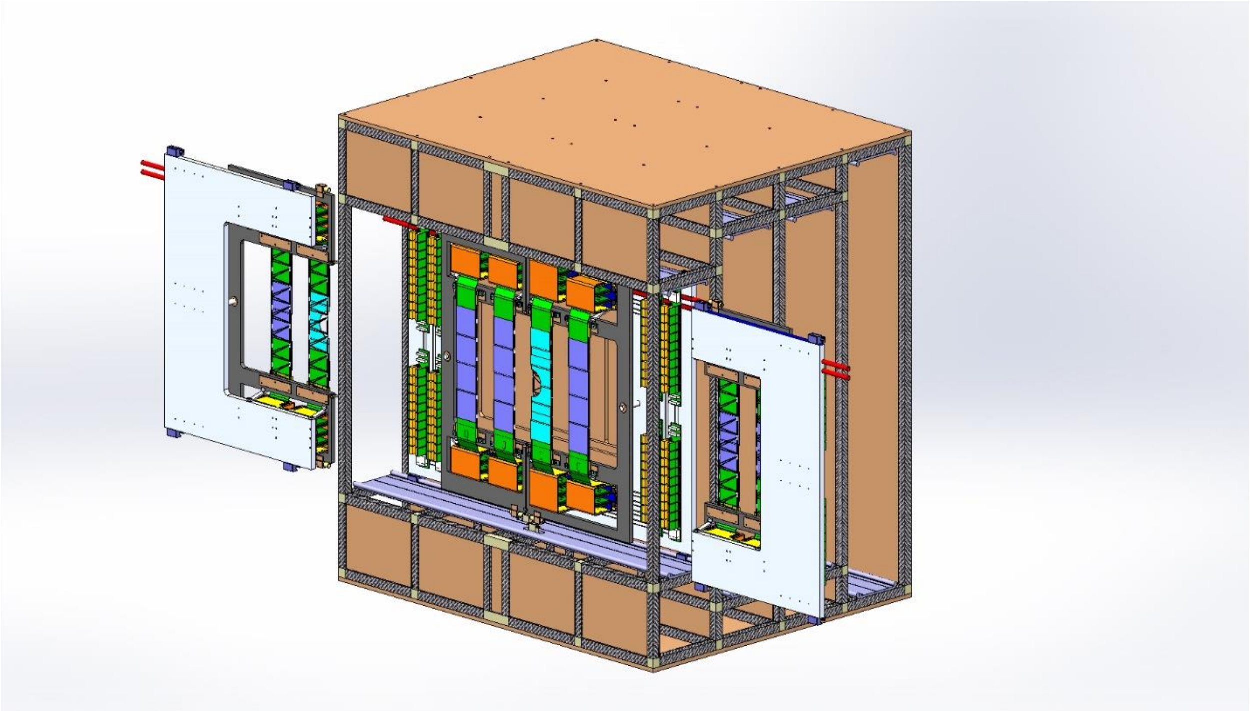
CF truss with mounting blocks on both sides.

- CF trusses for BM@N STS are already produced
- LAD has been delivered to JINR in Dec 2019
- Upgrade of the software and fixtures is needed
- First dummy ladder is being assembled

Support frames and system integration



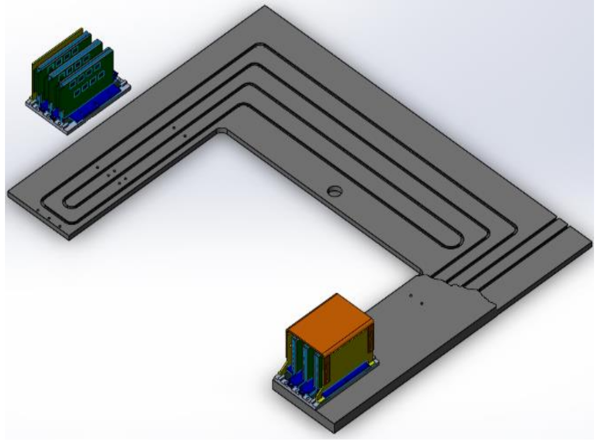
Schematic view of the quarter of the 1st Station



STS Mainframe with the 1st Station installed

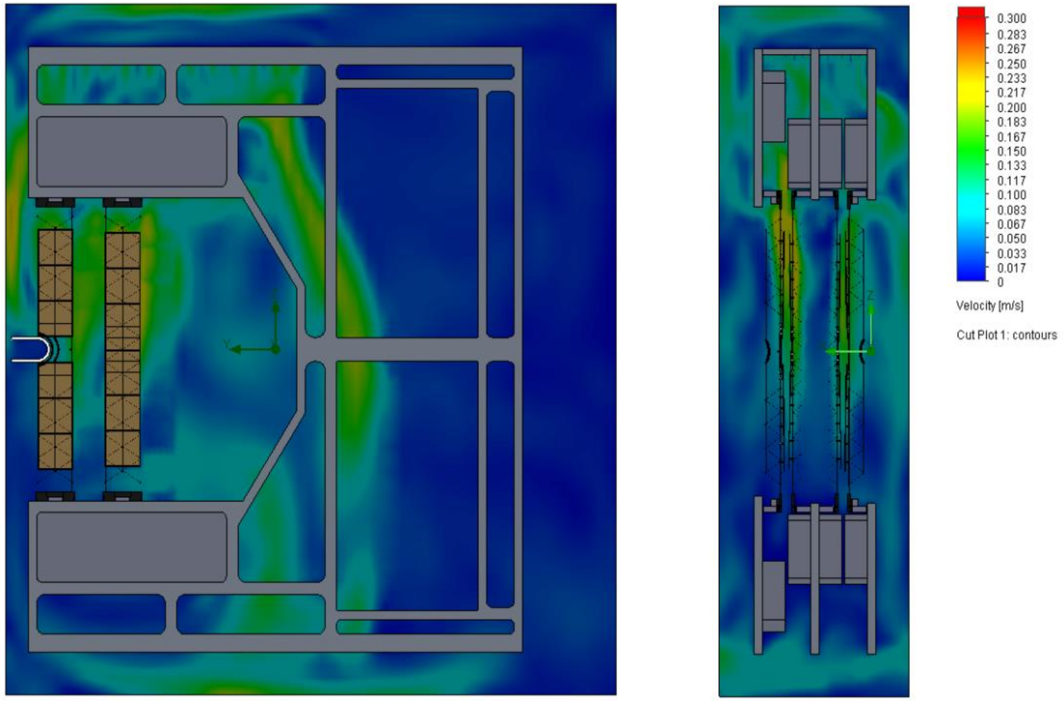
- Two versions of the mainframe will be produced: for the Pilot version of STS and for the Full configuration.
- Preliminary design of the first two stations is ready
- To be approved by S. Igolkin in Apr 2020

Cooling system

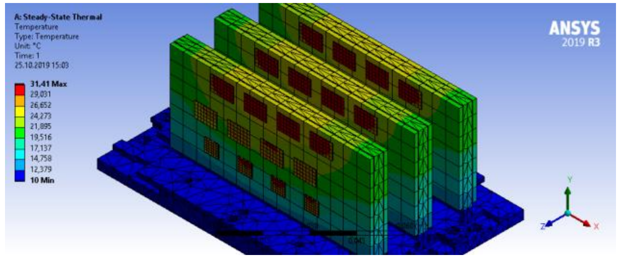


Schematic view of the thermal path from the heat producing ASICs mounted onto a FEB to the heat exchanger plate.

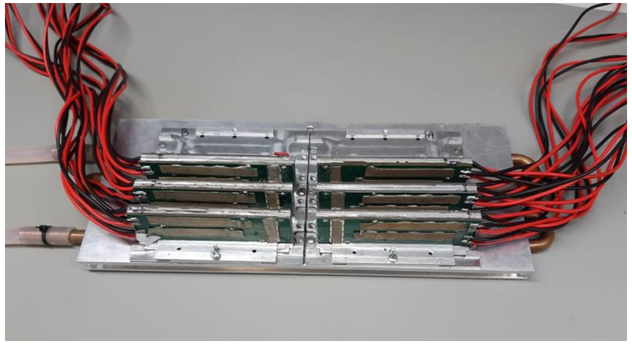
Prototype of the heat exchanger for the 1st Station



Cut plot contours of the gas flow in terms of velocity for the CBM-type STS station.



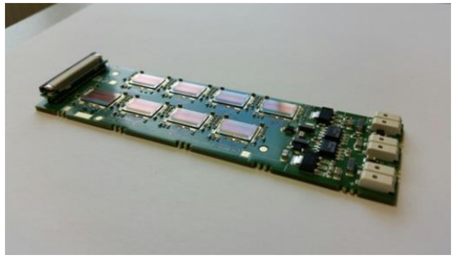
Thermal simulations of the FEB box

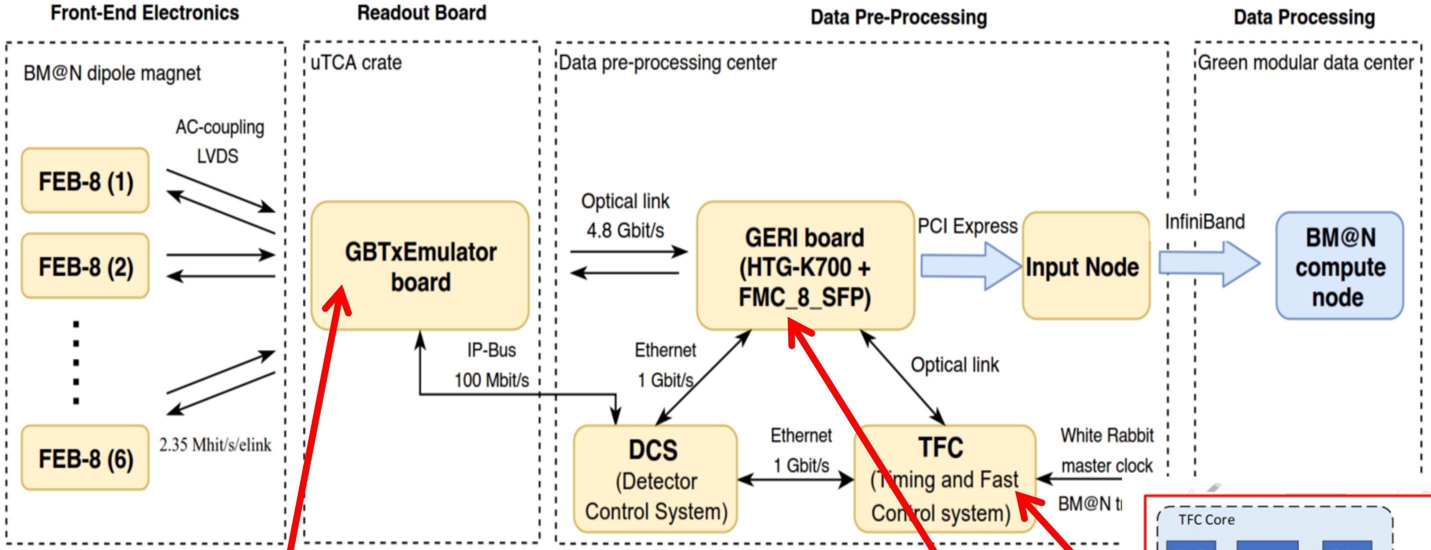


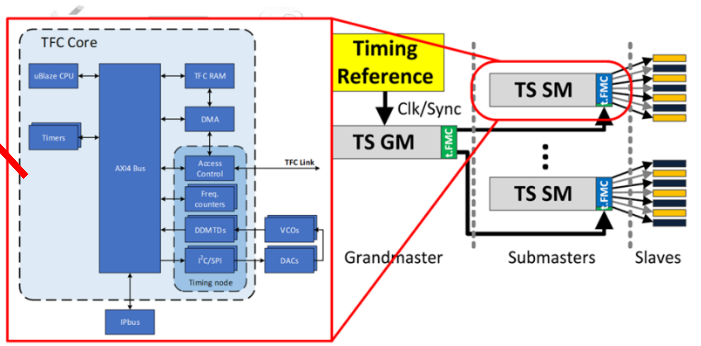
Thermal mockup

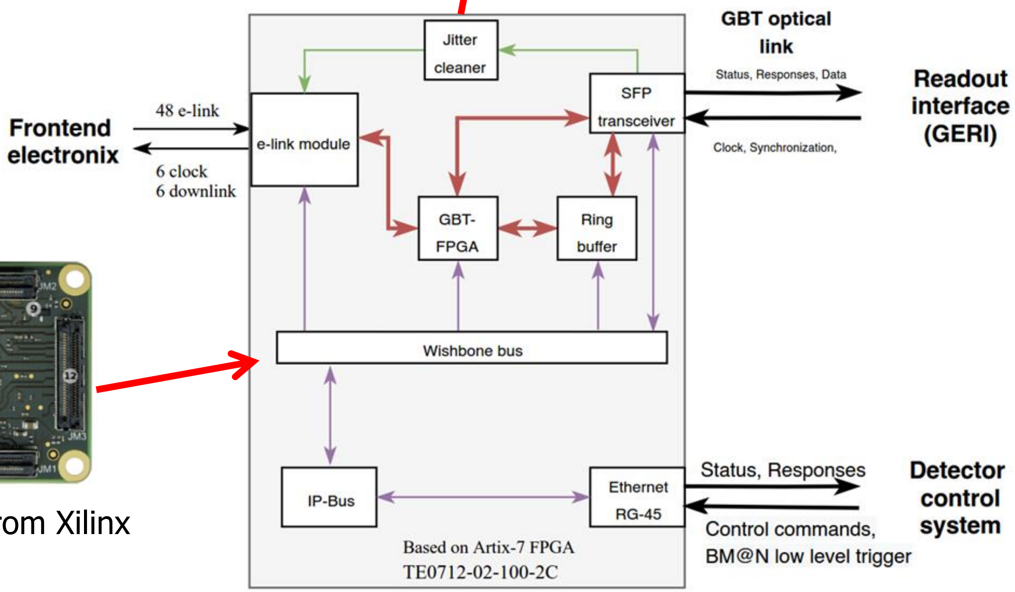
- Thermal interfaces between ASICs and heat exchanger plate were opted
- 2* 14 kW chillers are already delivered
- Design of the cooling system will be performed by the company

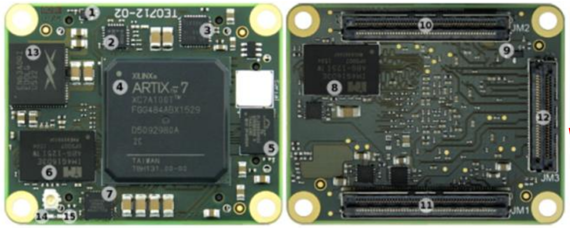
DAQ chain



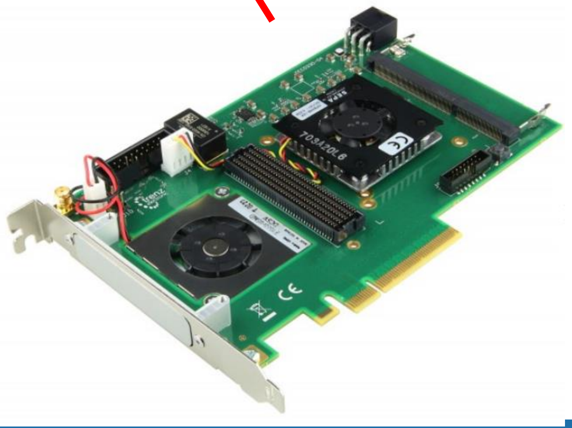






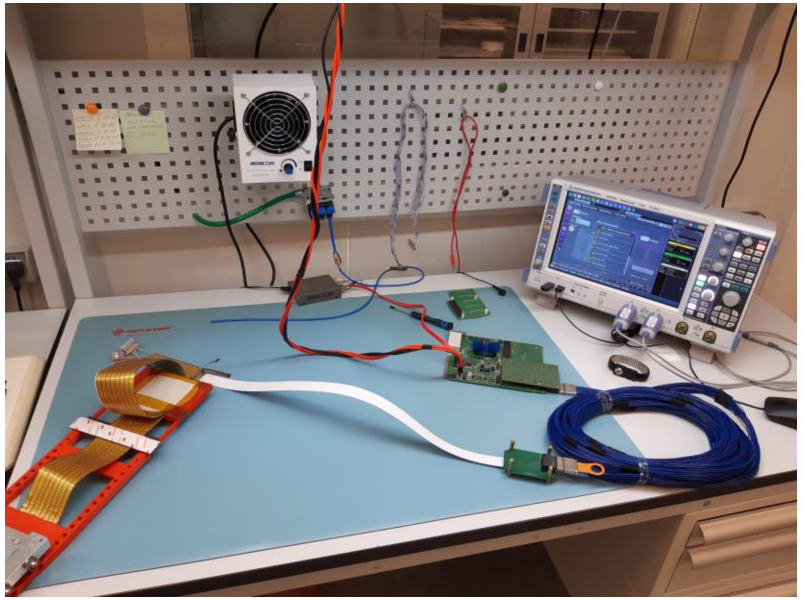


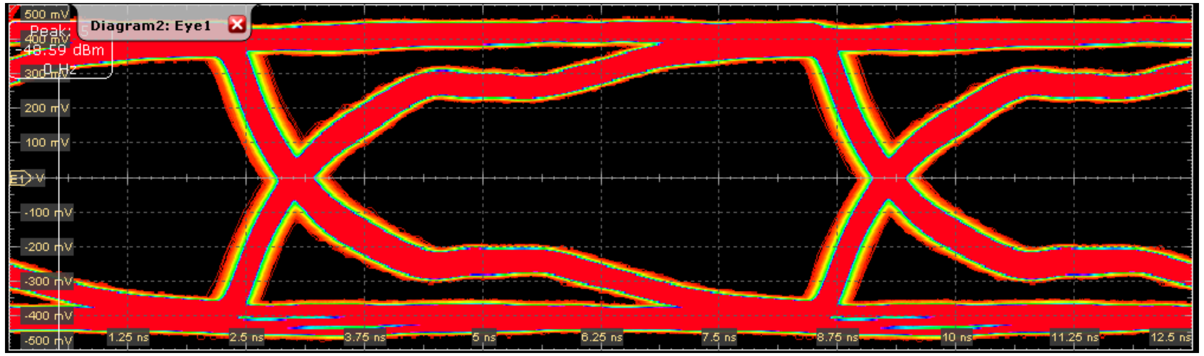
Trenz TE0712-02-100-2C platform from Xilinx



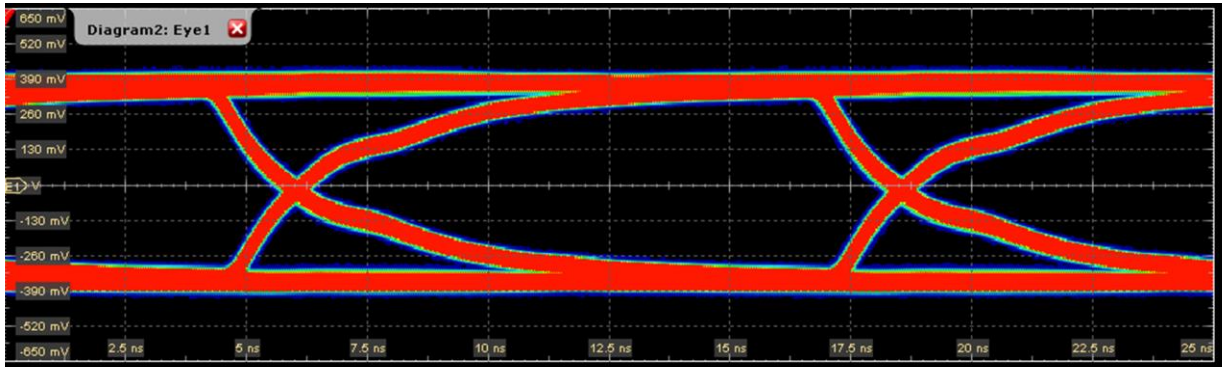
H/w: GSI
F/w: WUT

SI tests of the data cable connection between FEB and GBTxEMU board

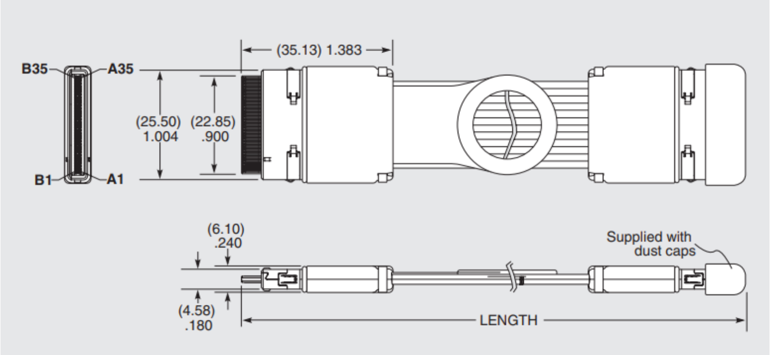




Eye diagram of the Dwn-link signal at 160 MHz Clck



Eye diagram of the Dwn-link signal at 80 MHz Clck



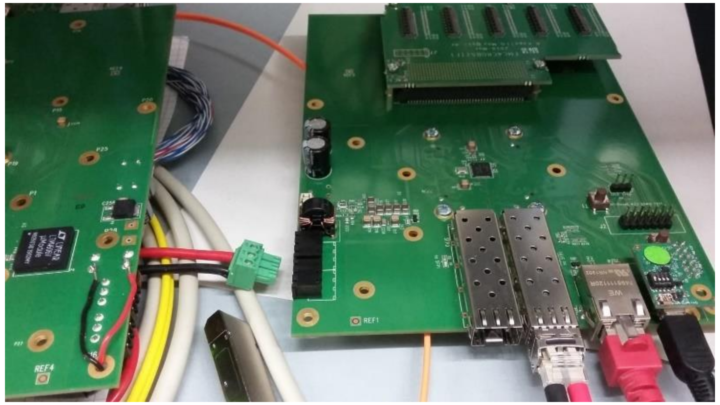
Samtec HDLSP twinax cable

10 m data cable connection was tested with different types of the cables

Samtec HDLSP twinax cable was opted

It is capable to transmit data even at speed of 320 Mbit/s

GBTxEMU board status

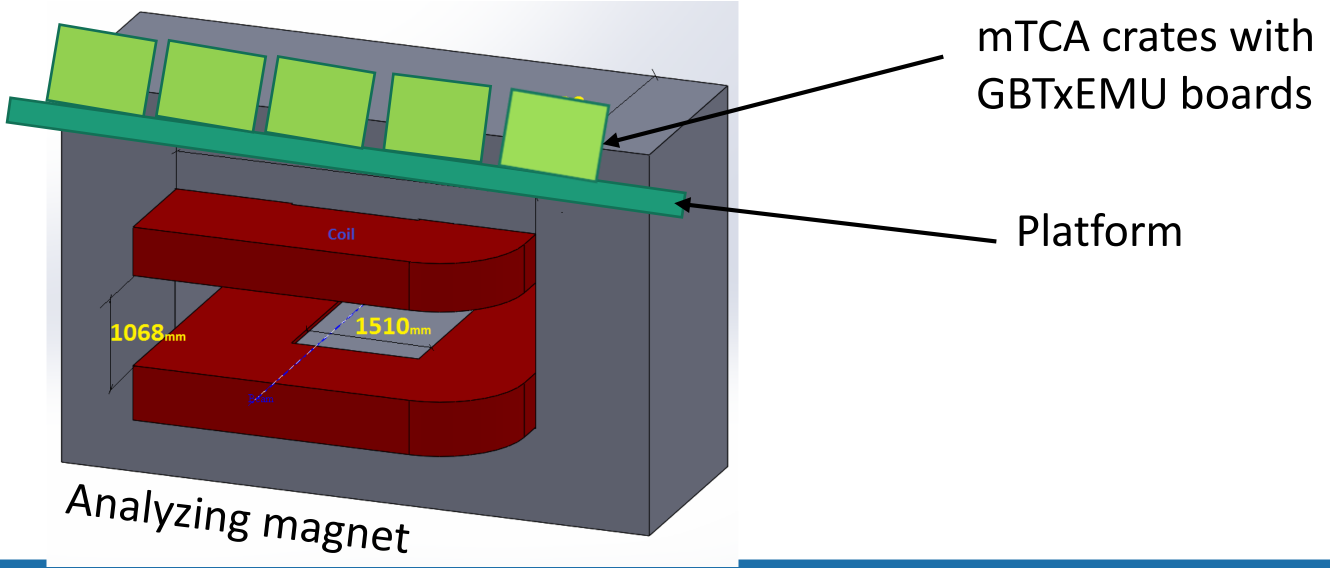


Test bench with GBTxEMU

- Prototype of the GBTxEMU board was produced by GSI;
- Firmware was developed and tested at 80 MHz clock;
- Modifications of the blocks responsible for the communication with the ASICs are needed to operate at 40 MHz;
- Routines for the configuration of the ASICs have to be canged
- A new version of the board adopted for the mTCA crate will be produced by GSI in 2020
- The Full DAQ chain expected to be ready till the end of 2020

For the pilot version: 2* mTCA crates
For the full version 5* mTCA crates

F/w Designed by W. Zabolotnyi (WUT)



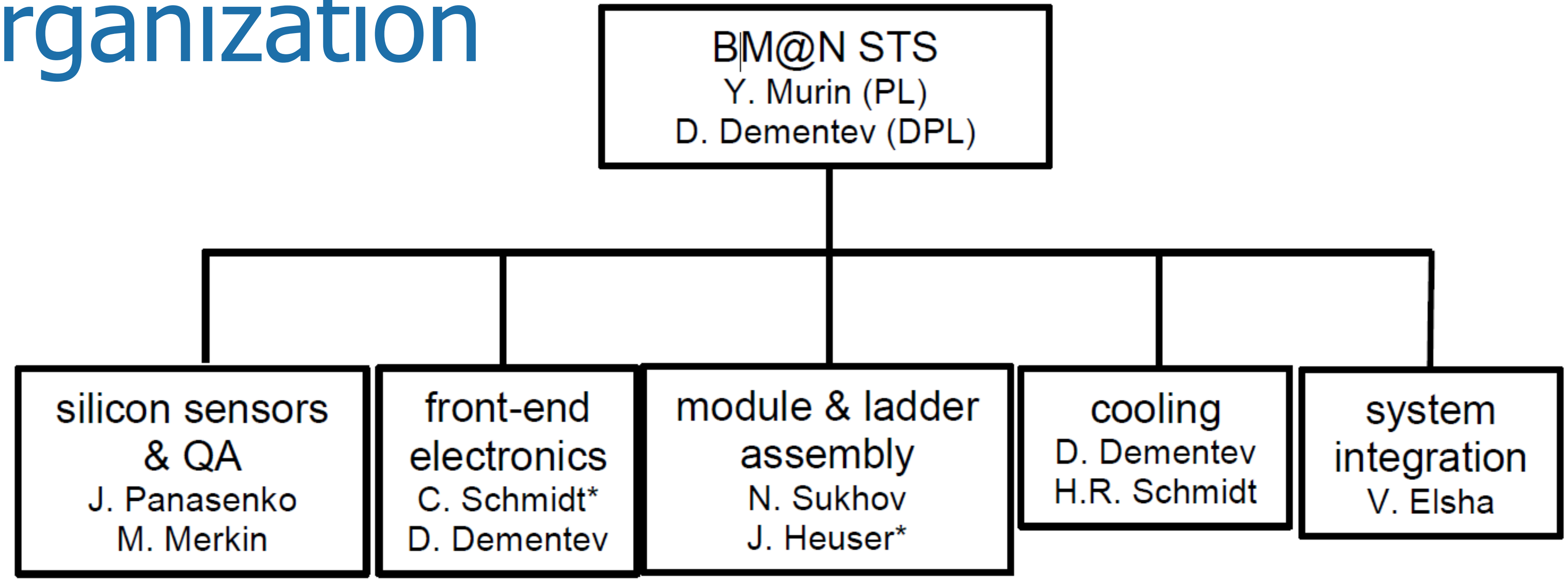
GERI board status

TRENZ TEC0330-4 PCIe Gen2 Interface Board

F/w Designed by W. Zabolotnyi (WUT)

- F/W blocks for the data processing in a data driven mode were already developed and tested on another h/w platform
- Now those blocks are implemented on a new platform
- Trigger mode of the operation is now the first priority and expected to be ready till the end of 2020

Project organization



The participation of GSI experts in the construction of the BM@N-STS is based on the legal validity of the Russian-German Roadmap, which still has to be signed by the Russian side. Likewise, the time line is valid under the condition, that the Roadmap will be signed in the first half of 2020, and the German effort is focused on the module assembly. If this is not the case, the duration of the project will increase by 12 months.

Tasks	2019	2020	2021	2022	2023
Module assembly and QA	Tool development	Station 1+2	Station 3+4		
Ladder assembly	Tool development	Station 1+2	Station 3+4		
Micro cables	Production station 1+2	Production station 3+4			
ASICSs	Production	Production			
FEBs	Production	Production			
HV, LV	Development	Production	Production		
CF mainframe	Development	Production station 1+2	Production station 3+4		
Cables, fibres	Design	Production	Production		
Cooling	Design	Production	Production		
Read-out chain	Design	Production	Production		
System integration			Station 1+2	Station 3+4	
Commissioning				Station 1+2	Station 3+4
Data taking					Station 1+2 Station 3+4

Thank you for your attention!