Status of the Silicon Tracking System of BM@N experiment (BM@N STS)

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For BM@N STS group

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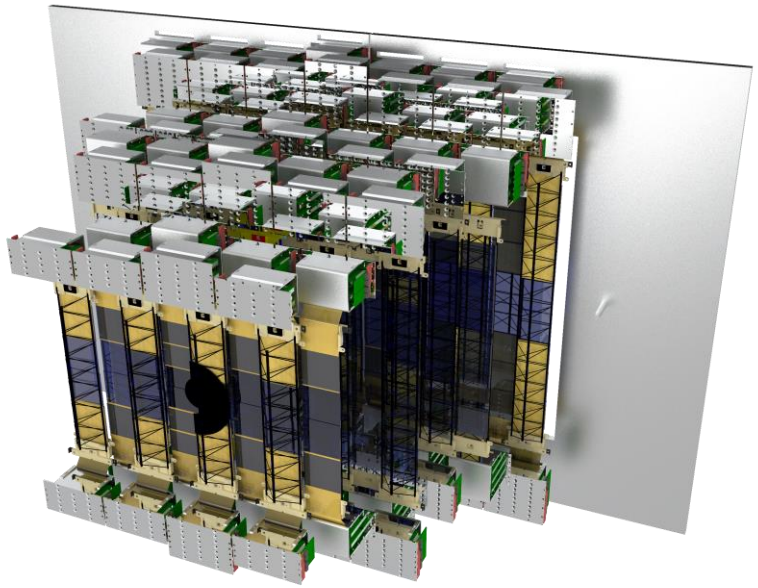
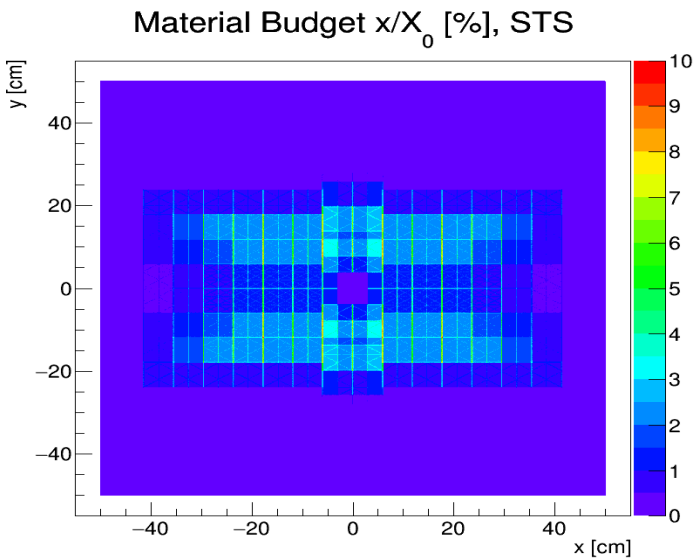
Outline

- STS **modules**: performance and assembly status;
- STS **ladders**: test results and assembly status;
- STS **readout electronics** and integration into the global BM@N DAQ;
- STS **beam-pipe**;
- **Power supply system**;
- Conclusions and outlook

Silicon Tracking System (STS)





STS material budget

4 x STS stations

34 x Ladders

292 x Modules

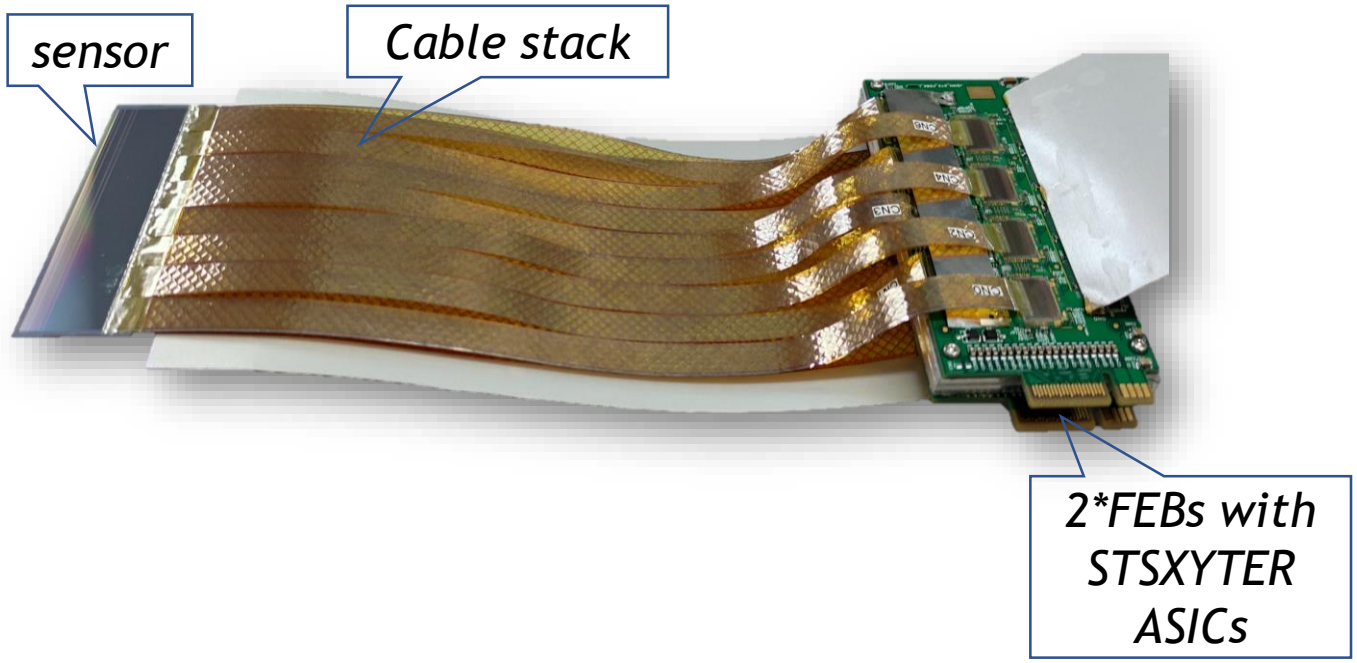
STS team

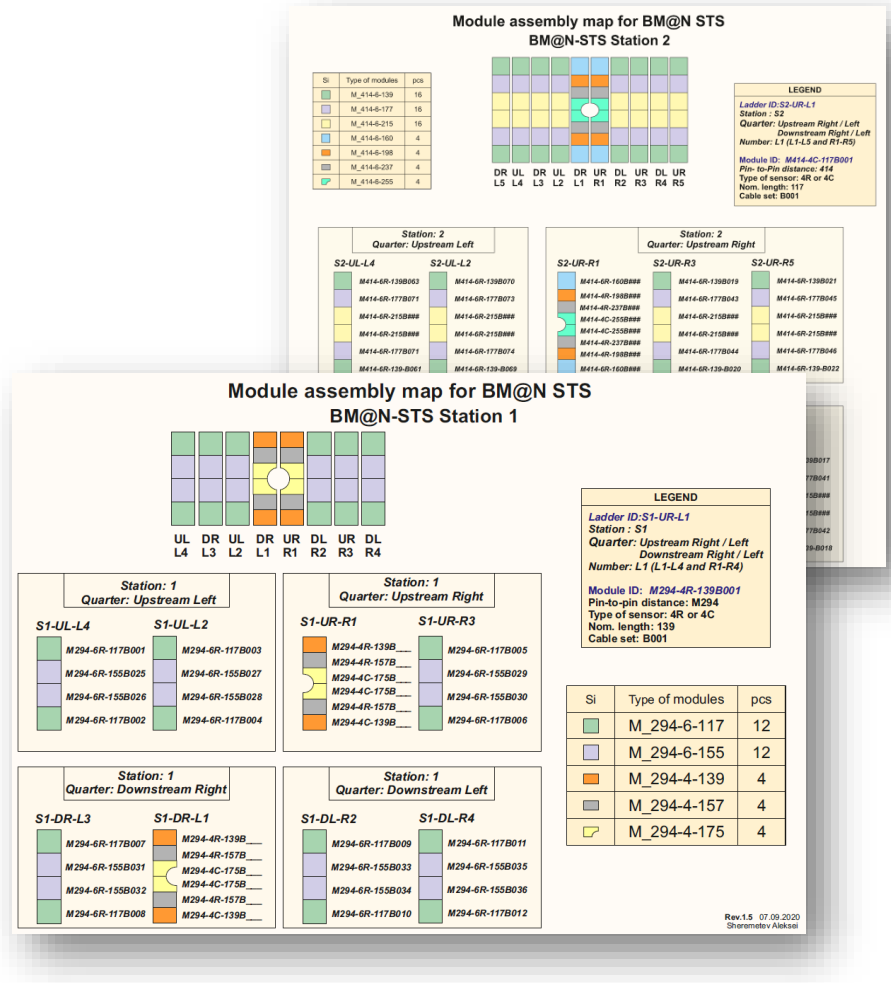
Technical solutions:

- double-sided silicon microstrip sensors
  - hit spatial resolution ≈ 25 μm
  - material budget per tracking station: ≈ 0.3% - 2% X_0
  - radiation tolerance up to 1 × 10^{14} n/cm^2 (1 MeV equivalent)
- self-triggering front-end electronics, time-stamp resolution ≈ 12,5 ns
- low-mass detector modules/ladders

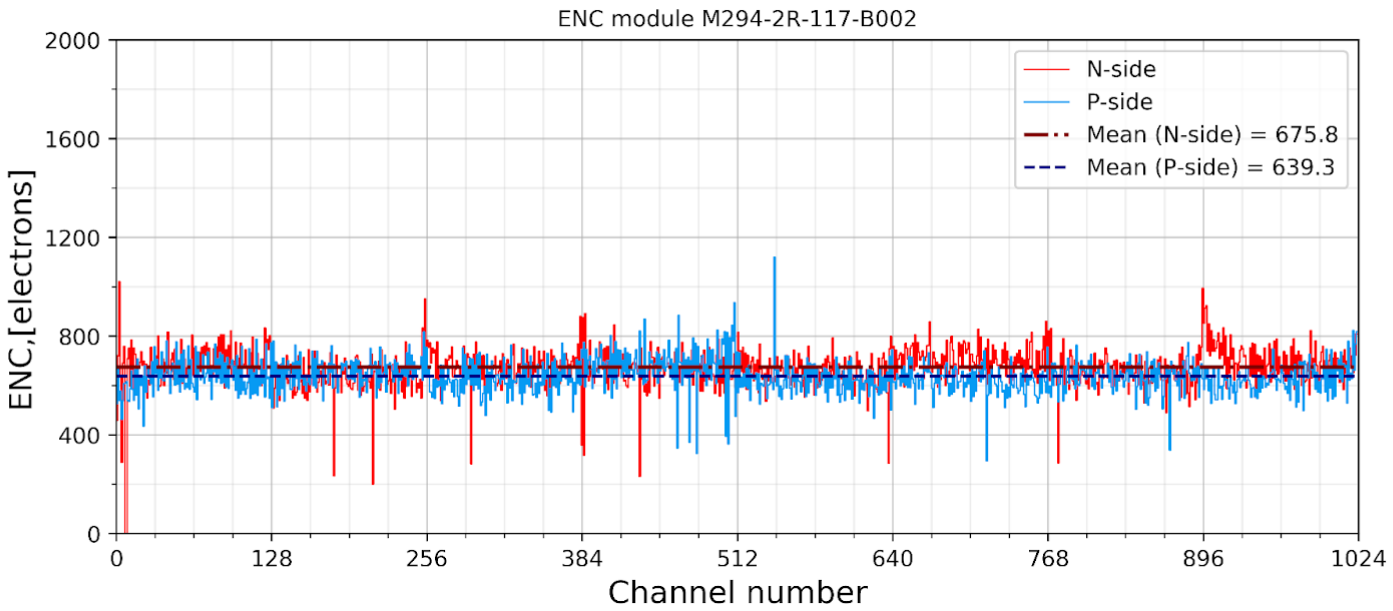
The project is being implemented as a joint effort of CBM and BM@N STS teams under the GSI-JINR Roadmap Agreement

STS Modules

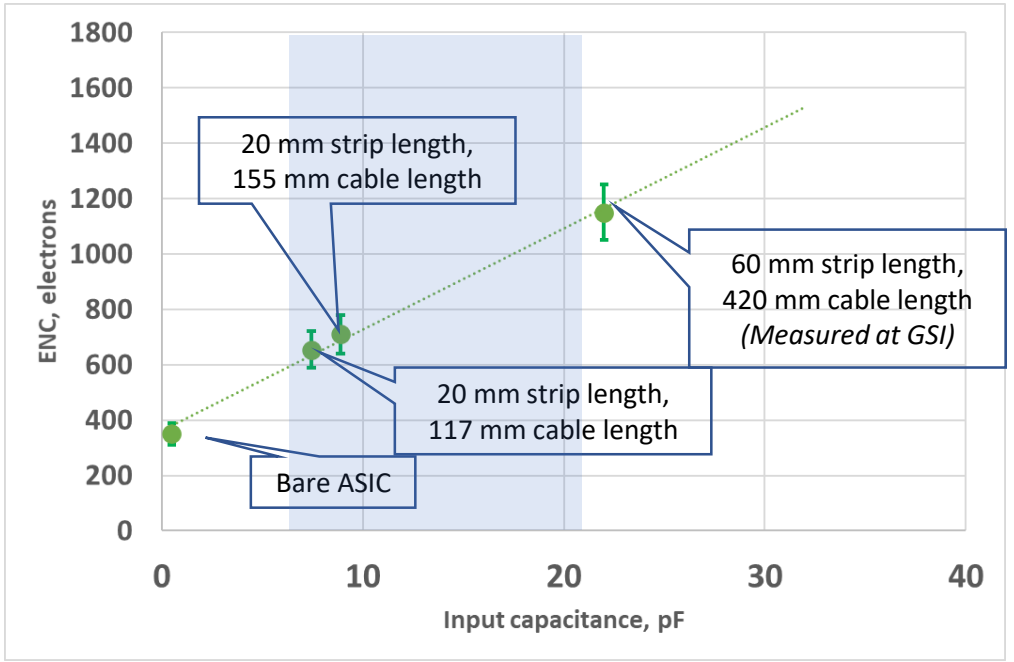

sensor
Cable stack
2*FEBs with STSXYTER ASICs


Module assembly map for BM@N STS
BM@N-STS Station 2
Module assembly map for BM@N STS
BM@N-STS Station 1
LEGEND
Ladder ID:S1-UR-L1
Station : S1
Quarter: Upstream Right / Left
Downstream Right / Left
Number: L1 (L1-L4 and R1-R4)
Module ID: M294-4R-139B001
Pin-to-pin distance: M294
Type of sensor: 4R or 4C
Nom. length: 139
Cable set: B001
Si | Type of modules | pcs
M_294-6-117 | 12
M_294-6-155 | 12
M_294-4-139 | 4
M_294-4-157 | 4
M_294-4-175 | 4
Station: 1 Quarter: Upstream Left
Station: 1 Quarter: Upstream Right
Station: 1 Quarter: Downstream Right
Station: 1 Quarter: Downstream Left
Station: 2 Quarter: Upstream Left
Station: 2 Quarter: Upstream Right

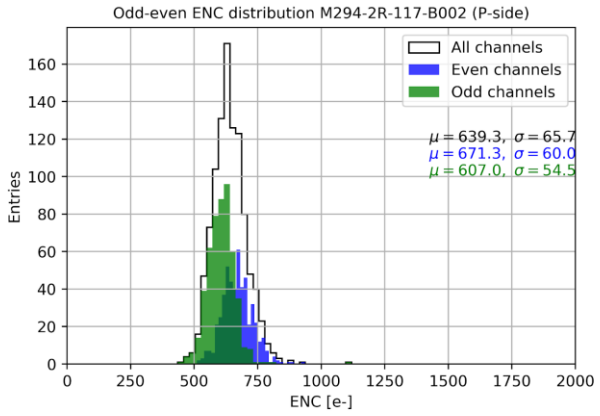
Module performance: noise



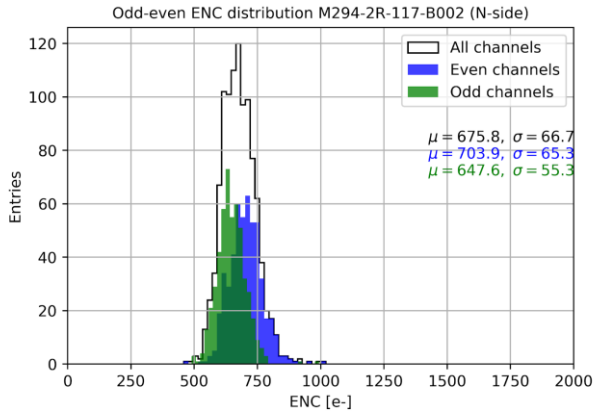
Noise per channel distribution



Noise level depending on the type of the module (sensor size and cable length)



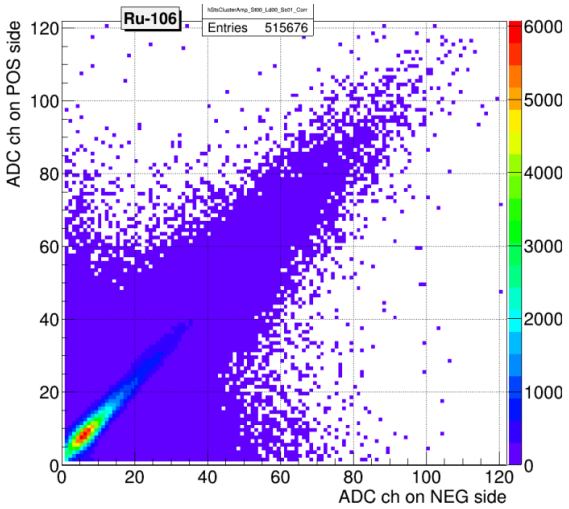
Noise distribution for the P- side

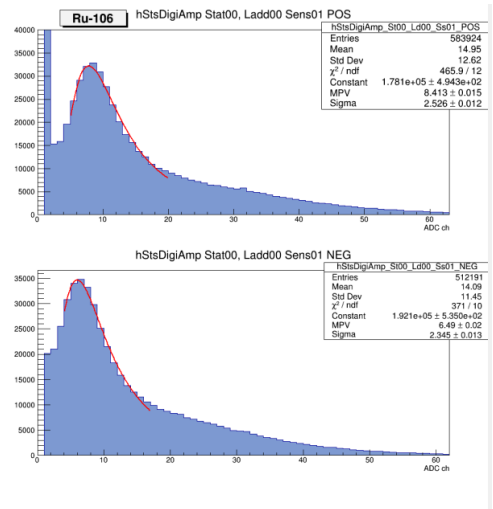


Noise distribution for the N- side

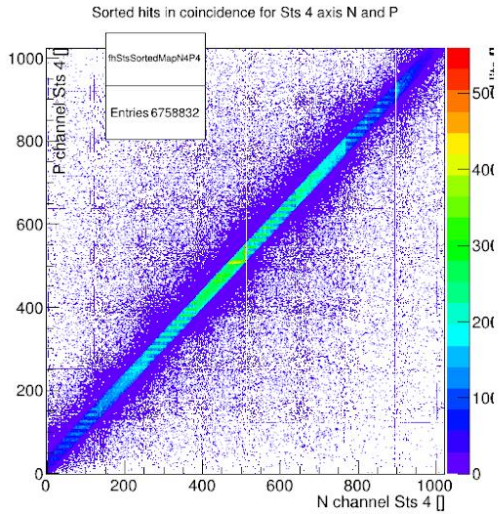
Noise level depends on the module type (size of the sensor and length of the cables)
For BM@N modules ENC~ 600- 1200 electrons

Tests with Ru-106

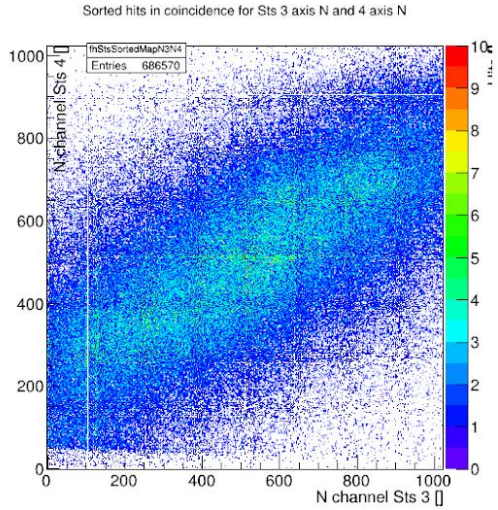




Cluster amplitudes on the P- and N- sides



Correlations between P- and N-sides of the same sensor

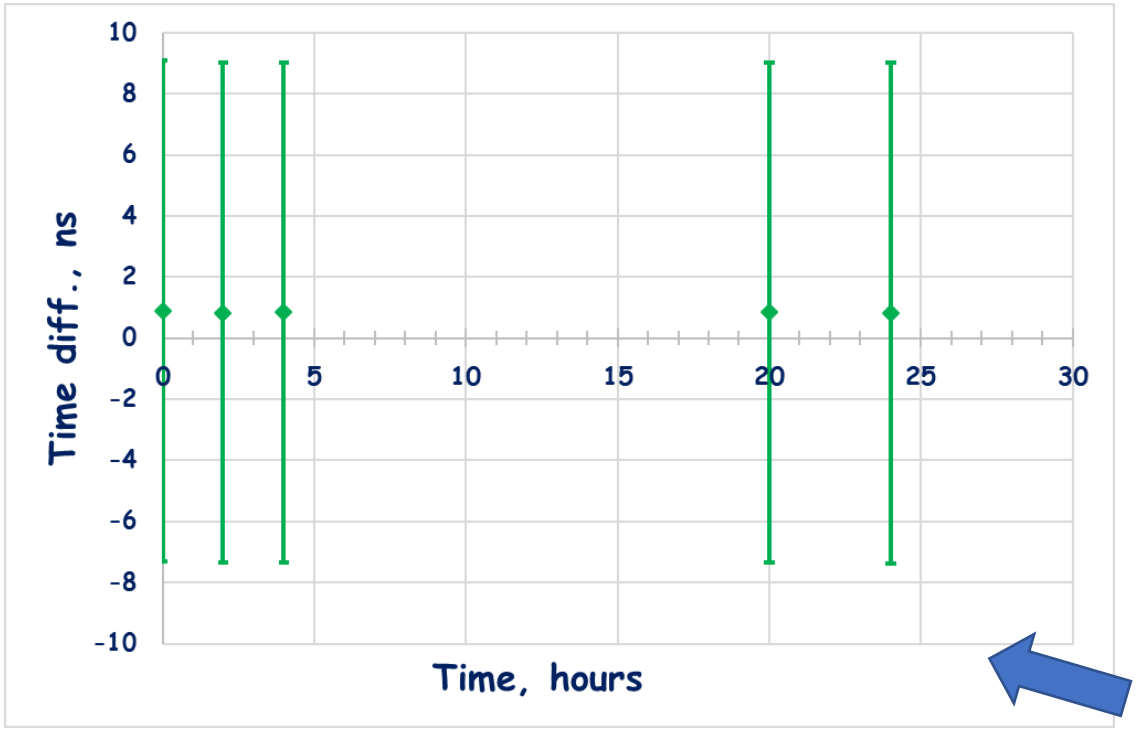


Correlations between two sensors

Measured signal

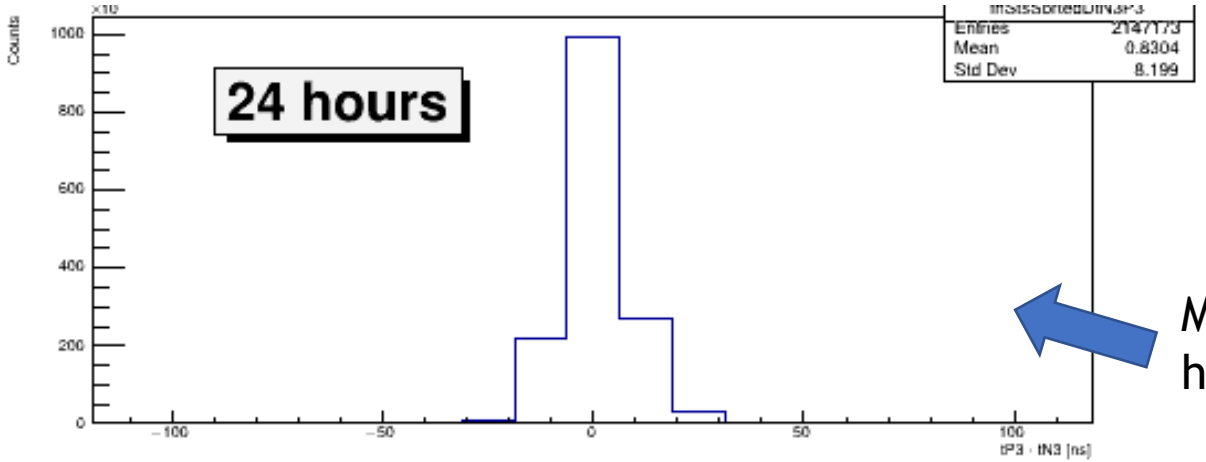
- On the P-side: 22 700 ± 1 523 e^-;
- On the N side: 22 200 ± 1 478 e^-;
- Up to 10% reduction of the CCE for the irradiated sensors

Long-term tests



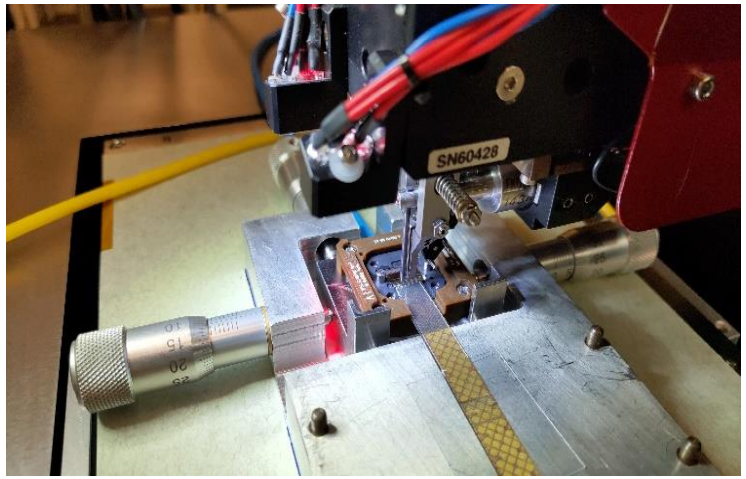
- Power and thermal cycling tests;
- Tests of the stability of the time synchronization between readout ASICs;
- Tests of the EMI immunity

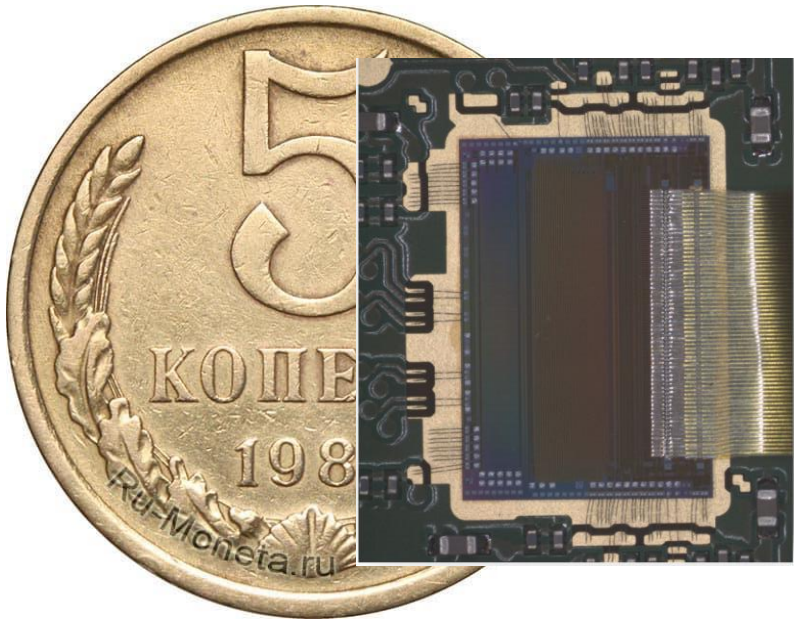
Evolution in time of the synchronization quality between ASICs for a single module

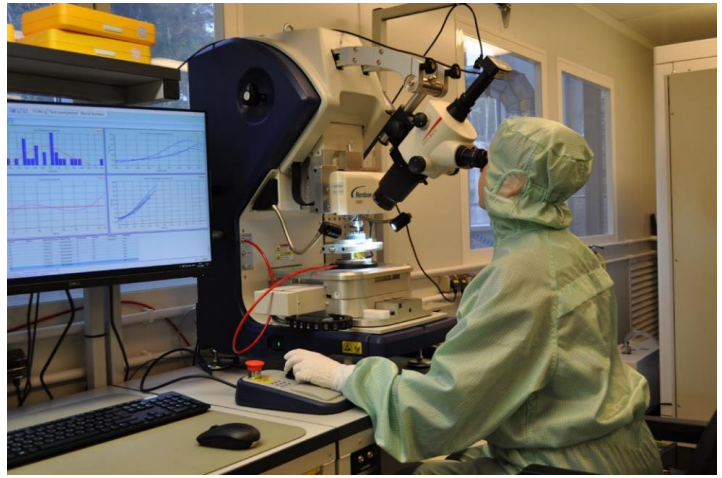


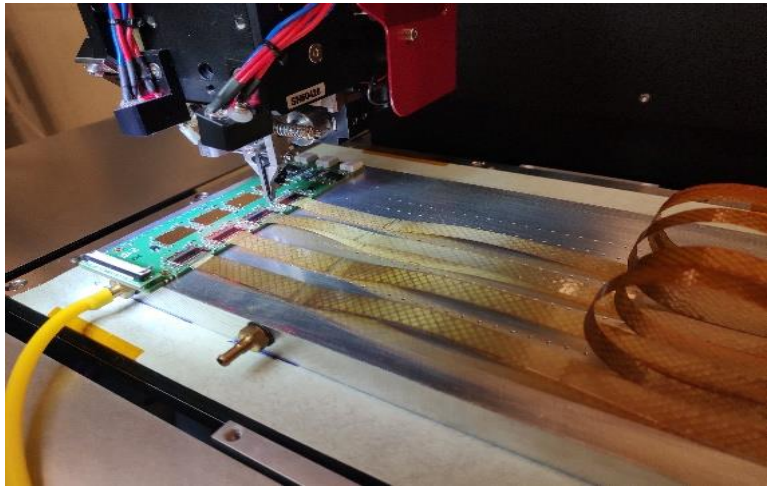
Measured time difference in *ns* between hits on the P and N sides of the sensor

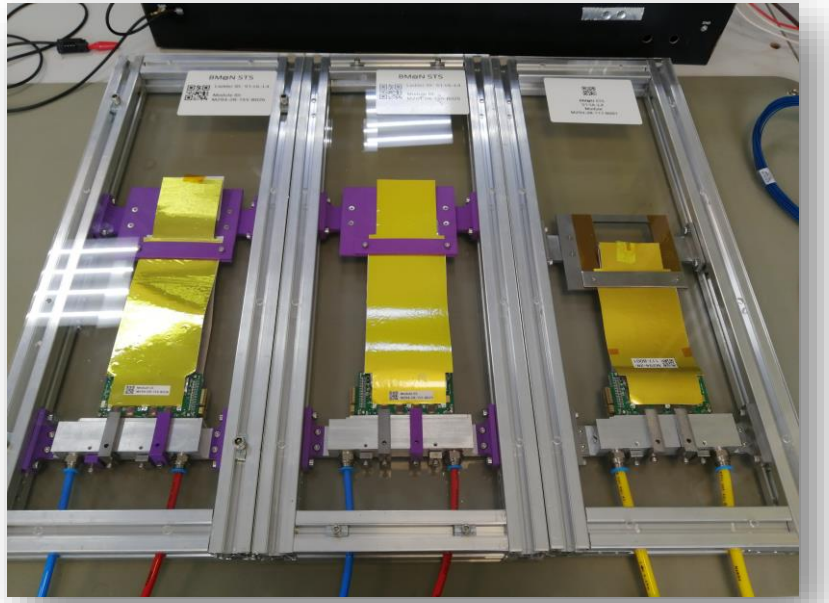
Module assembly







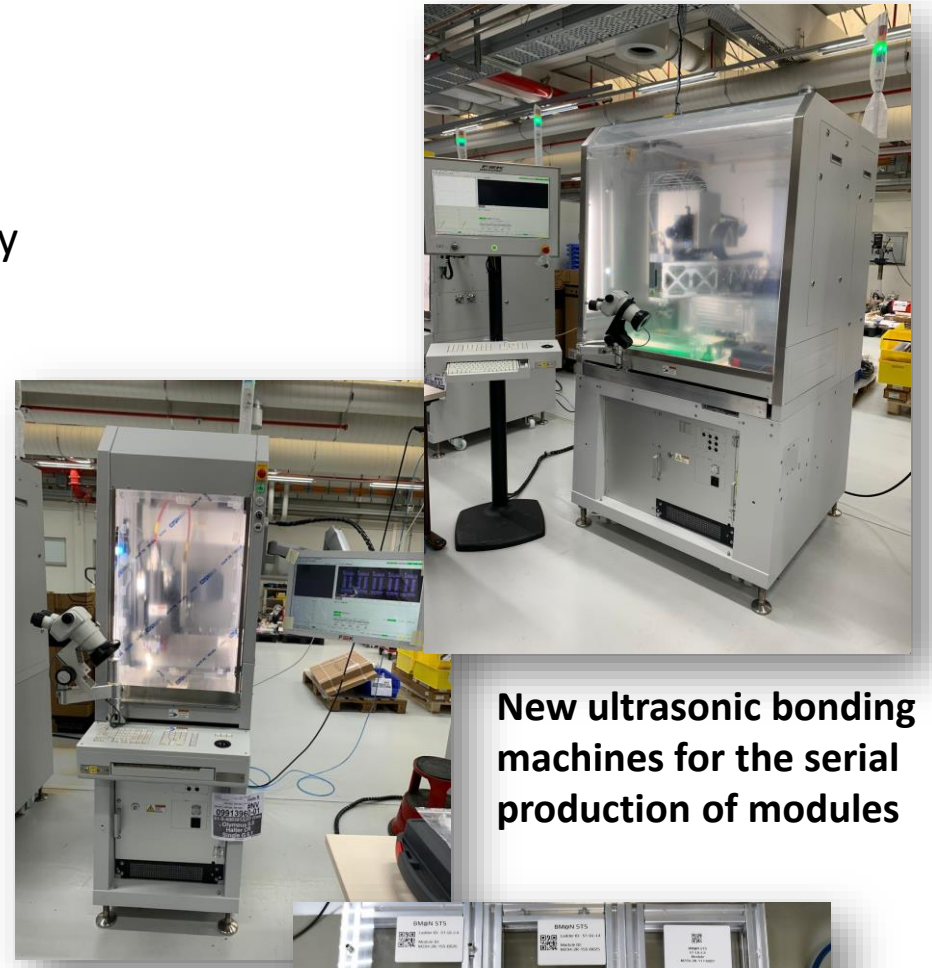




Module assembly status

Status:

- Eight modules were assembled and tested with the aim to tune the assembly workflow and tooling;
- Modified set of assembling jigs was produced for the serial production. New jigs will provide the possibility to assemble up to 4 modules in parallel;
- Assembly site is being extended to be ready to house series production of the BM@N STS modules *(additional Delvotec bonding machines to be received soon):*
  - Civil construction works is over (Bldg.2016 #103);
  - Installation of the climatic equipment has started;
- Two more technicians joined the team in September 2021 and are now being trained.



New ultrasonic bonding machines for the serial production of modules

Perspective:

Start of the pre-serial (30 pcs) module production for BM@N as soon as all needed components will be delivered

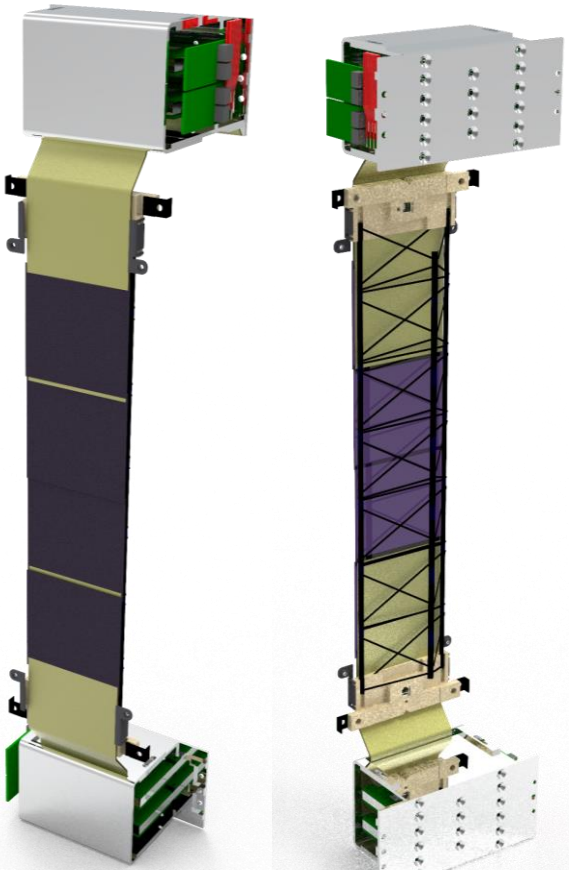
Problems identified:

Delays in the delivery of the components due to the Covid

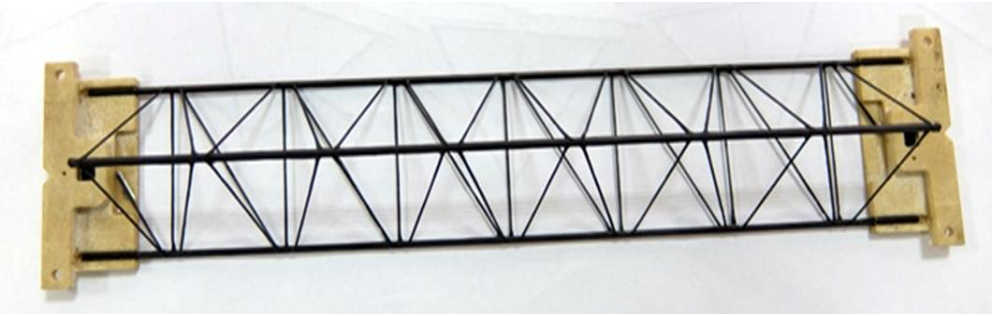
First assembled modules

Funding source: CremlinPlus EC Grant & GSI-JINR Roadmap Agreement

STS ladder

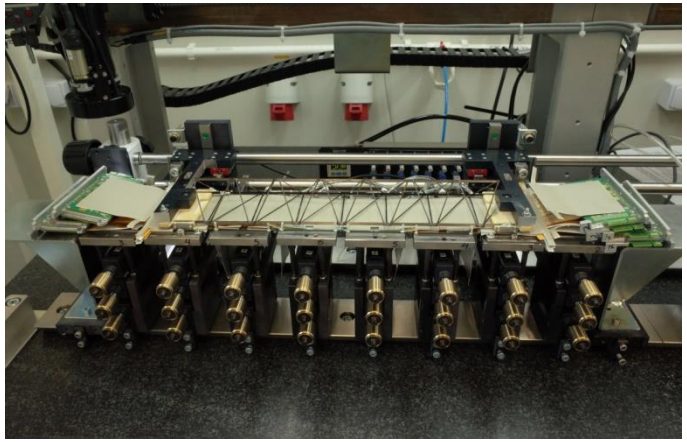


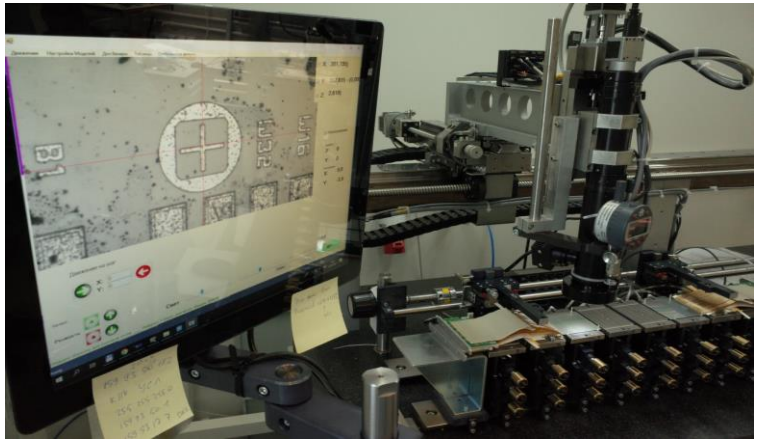
Ladder assembly device

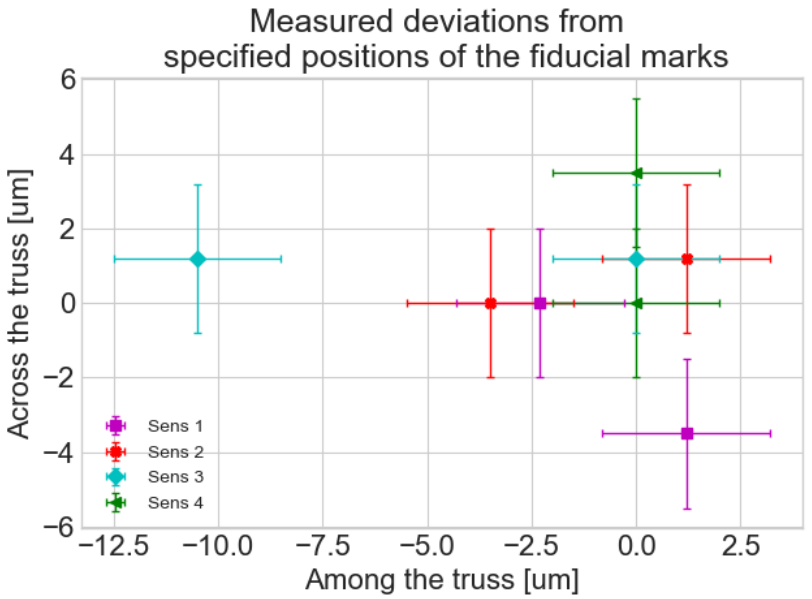


CF-truss with bearings

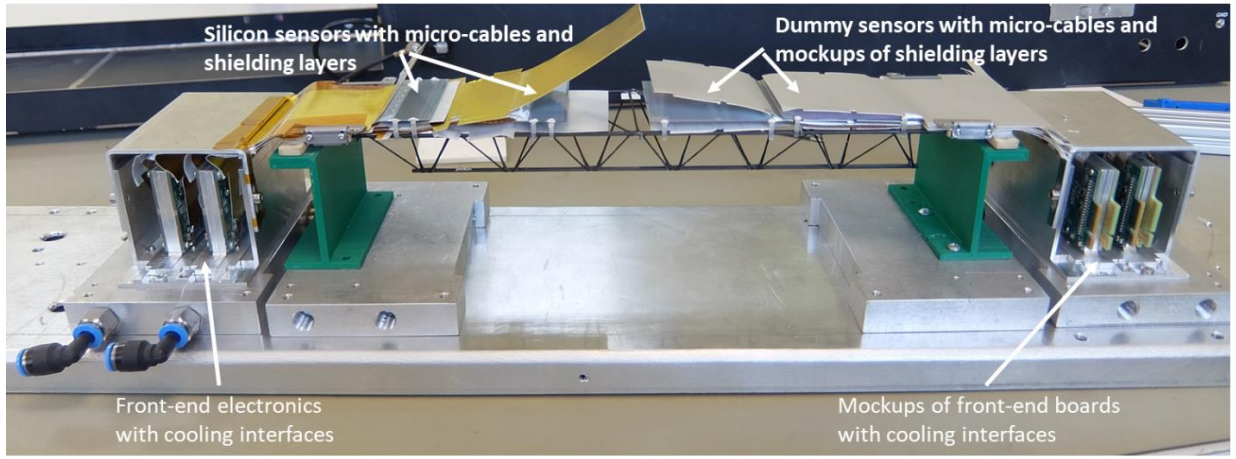
Ladder assembly

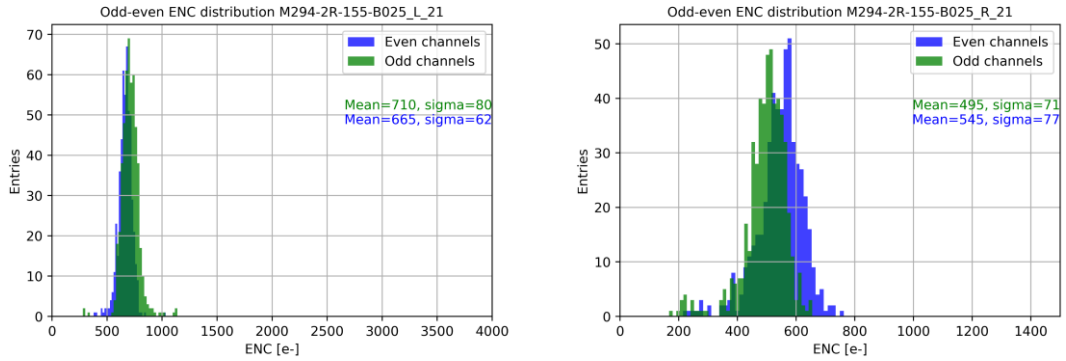






Each sensor has fiducial marks on its surface. Position of each mark is specified for each module on a specific ladder.
Deviation of the measured position of the fiducial from the specified one are shown on the right plot.

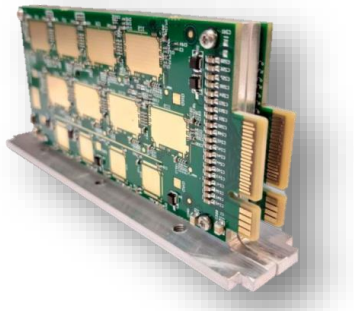


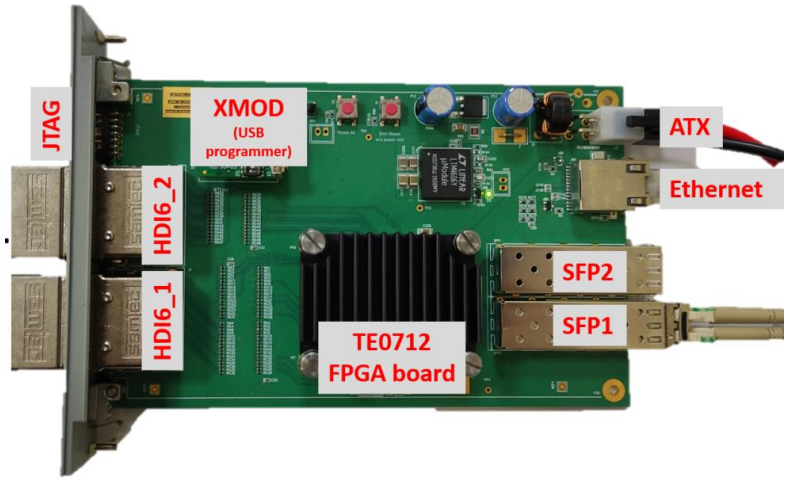


Measured noise per channel distribution for the module on ladder

Signal/Noise > 25

Readout electronics





TFC
Timing and Fast
Control

Computing System

FEB-8
FEE

elinks
2.35 MHit/s/elink

Data,
Synch,
commands

GBTxEMU

FPGA based
emulator of CERN
GBTx
serializer and data
combiner chip
48 x 80 Mbit/s
to 3.84 Gbit/s optical

48 e-links
3 x Sensors

Gbit opt.

Data,
Synch,
commands

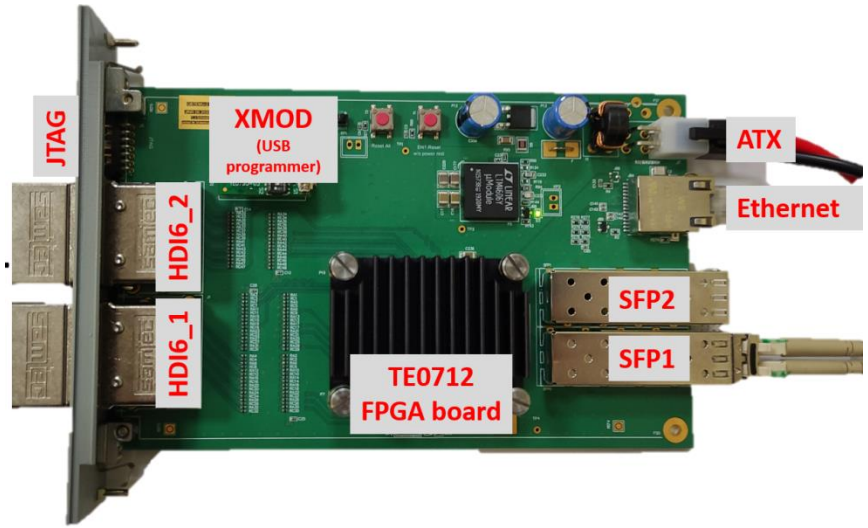
GERI-Board
FPGA based
PCIe Interface to
computer system

BM@N
Data center

GBTxEMU status

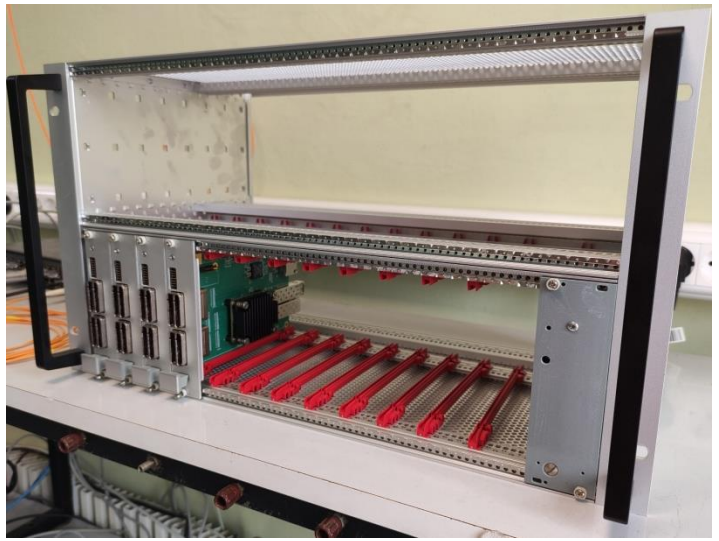
The GBTxEMU board is prepared as a controller and data concentrator of BM@N STS module readout chain

- The GBTxEMU board is used for tests of STS readout components performed in JINR.
- The GBTxEMU firmware is improved based on tests performed in JINR.
- The new, 3U EuroCard compatible board for GBTxEMU has been designed in JINR, successfully manufactured and tested (picture on the right).



Problems identified:

- SEUs induced in the programmable logic devices by the neutron flux may become a problem at maximum interaction rate of the BM@N.
  Radiation tests of the device are needed. Depending on the results, modifying the firmware may be necessary to increase its radiation resilience for high-intensity beams.



GERI status

The commercially available Trenz TEC0330 board has been selected as GERI prototype.

The first blocks of the firmware for GERI have been developed:

- The GBT-FPGA core needed for GBTxEMU communication has been successfully ported;
- The initial version of the PCIe core including the DMA engine has been implemented and used for throughput tests;
- Test bench with a GERI board was installed at JINR;

TRENZ TEC0330-4 Interface Board

Certain problems requiring hardware modifications have been identified, the required modifications have been introduced and successfully tested.

- Providing the recovered clock feedback for jitter cleaner;
- Replacement of fixed frequency crystal oscillator with VCXO.

Delivery of GERI boards is delayed till May 2022 due to 'silicon crisis'

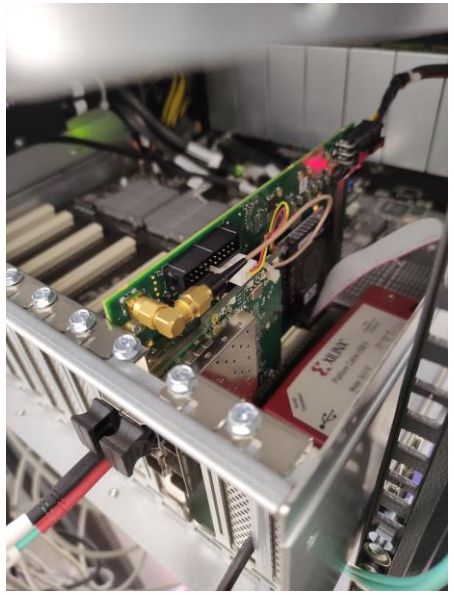


Photo of the GERI test bench at JINR

Integration in the global BM@N DAQ

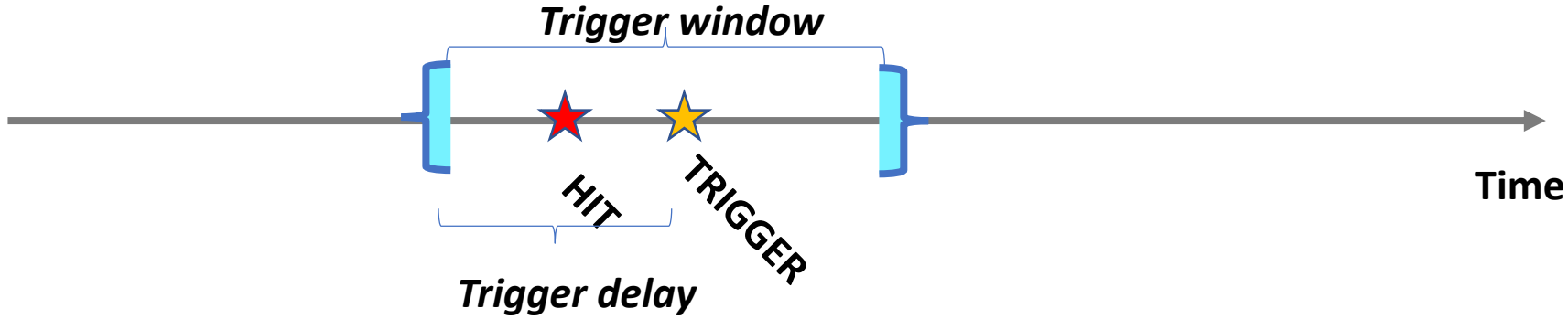
1. **Integration of the free streaming STS readout in the triggered data acquisition system of BM@N**
   - The concept of the triggered acquisition for the current version of the firmware is elaborated and implemented;
   - Triggered acquisition was tested on the laser test bench with a full STS-module readout chain;
   - Parameters of the trigger window (*delay, window size*) could be set within the range defined by the BM@N DAQ group

2. **Synchronization of the STS clock system with the WR network used in BM@N**
   - The concept of using 10 MHz clock and PPS signal from WR switch as a reference for the STS clock domain was elaborated and tested;
   - It was approved that the proposed solution allows to achieve the quality of the synchronization between STS and WR clock systems on the level <1ns;
   - The first blocks of the firmware for TFC module have been developed;

3. **Integration of the STS data stream in the BM@N DAQ**
   - The prototype version of the PCIe-based engine for high-performance data transport is prepared;
   - The software application for the transmission of the incoming STS data via 1Gb Ethernet to the BM@N data processing center is being implemented

Concept of the triggered readout for BM@N STS

- The front-end readout electronics of STS operates only in the self-triggered mode therefore the data filtering according to the trigger decision is implemented in the GERI;
- Due to the free-streaming readout scheme GERI provides the functionality of the time-based data sorting. The sorters store the data for the sufficient amount of time (up to 96 μs) and thus provides the possibility to implement also trigger-based data filter.



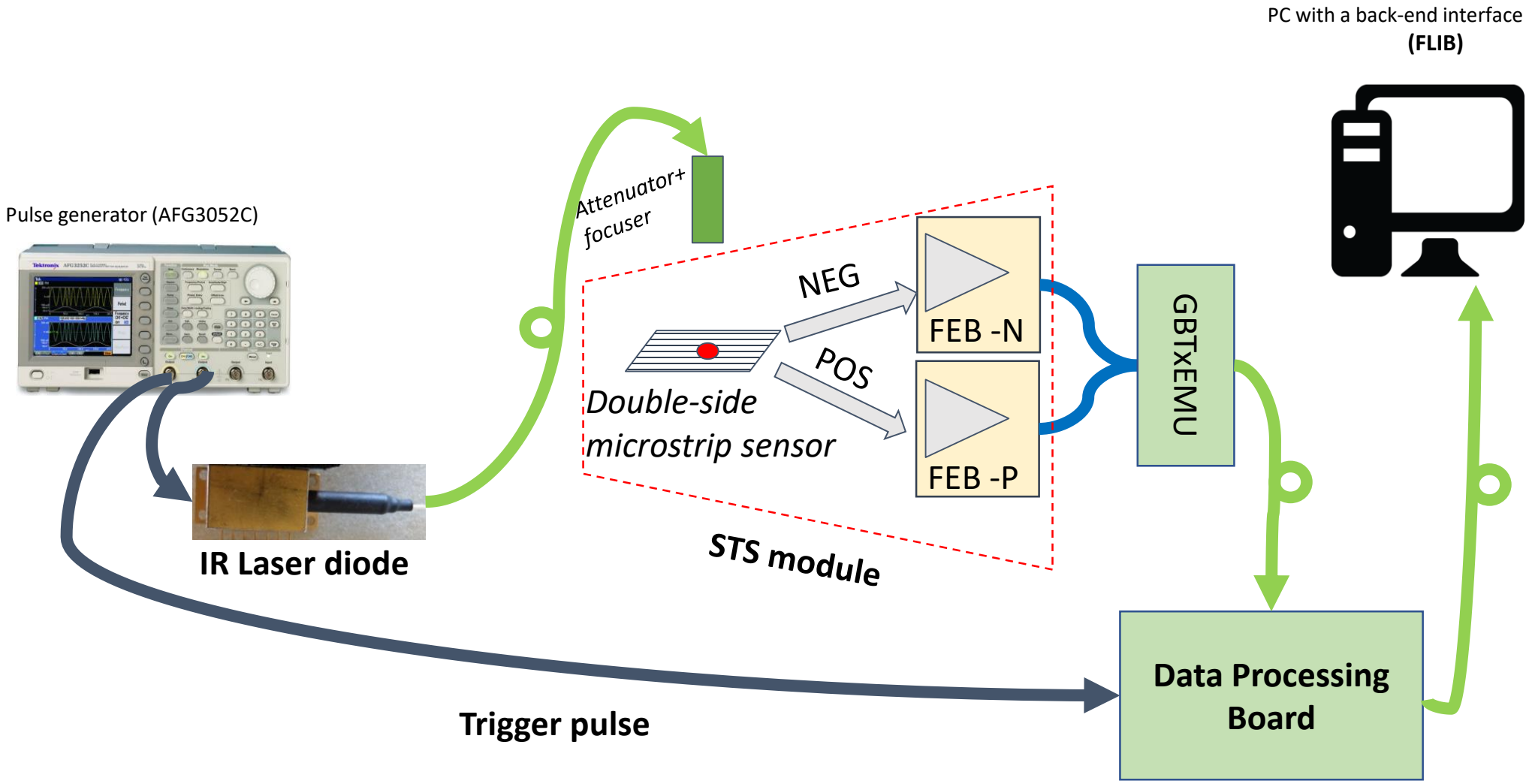
Trigger window and trigger delay parameters could be configured within the specified range:

- *Trigger latency <= 7 us;*
- *Trigger window <= 7 us;*
- *Min time between triggers: 20 us.*

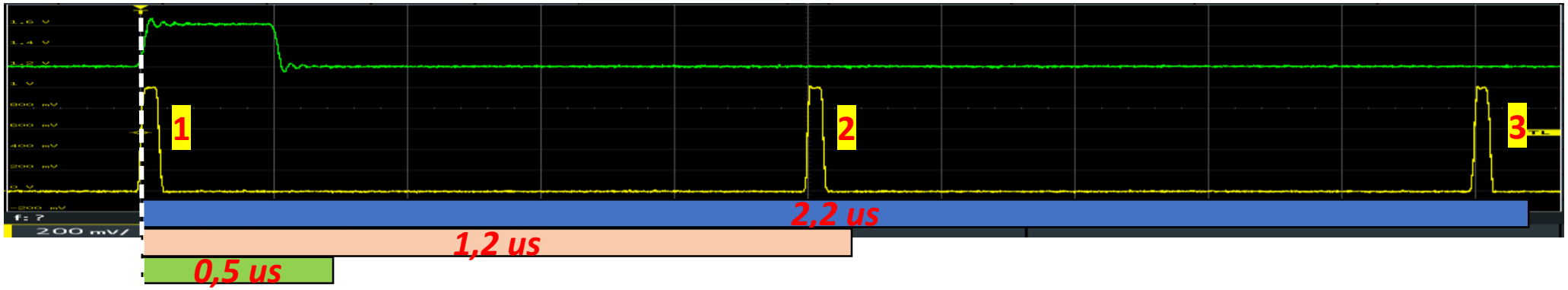
(from the discussion with the BM@N DAQ group)

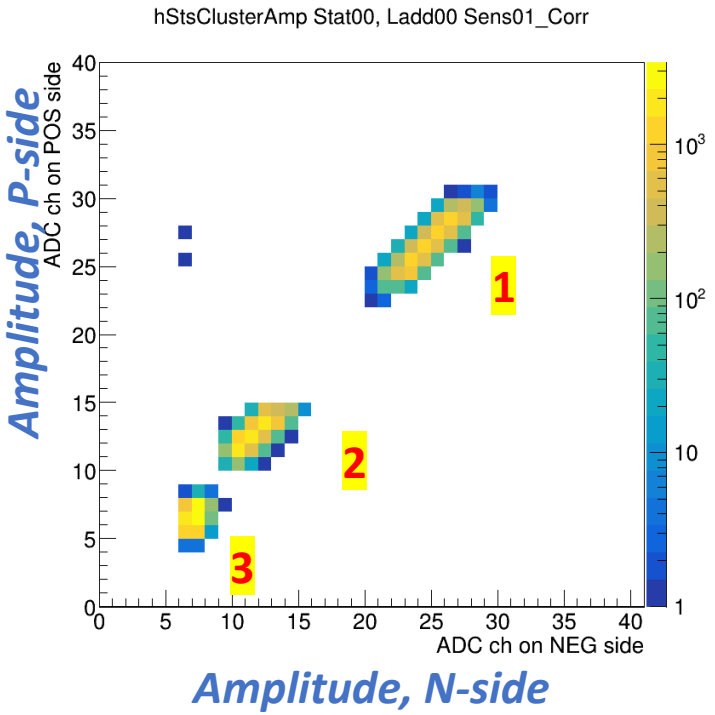
The concept was tested on the laser test bench

Laser test bench

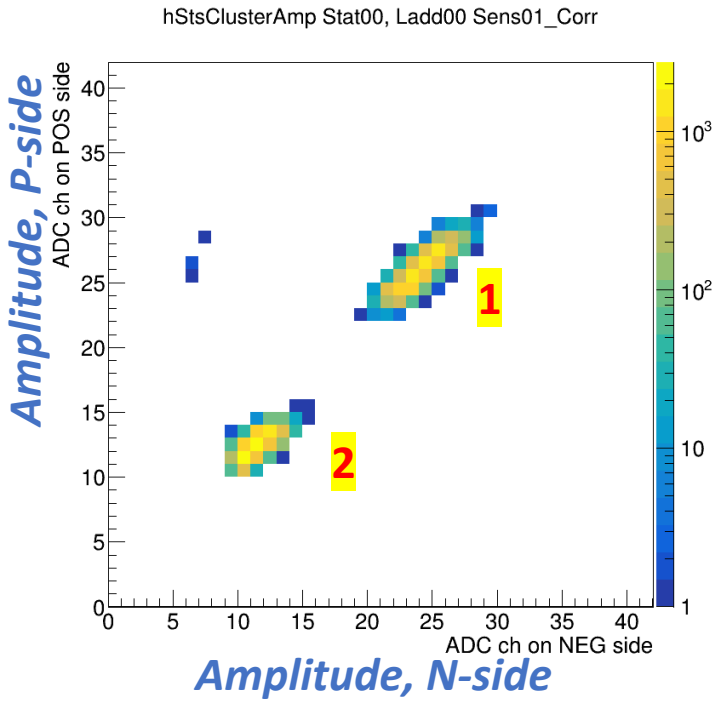


Demonstration of the concept

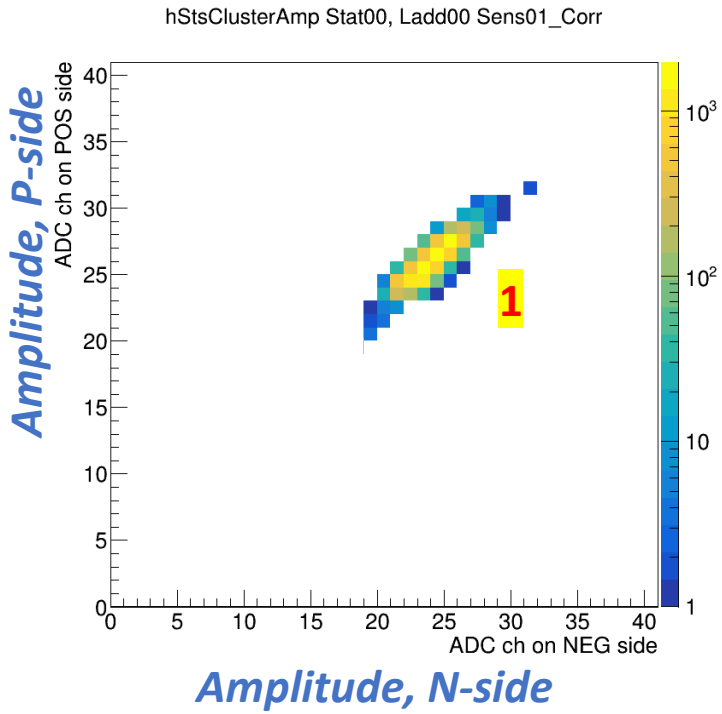




Trigger window = *2,2* us

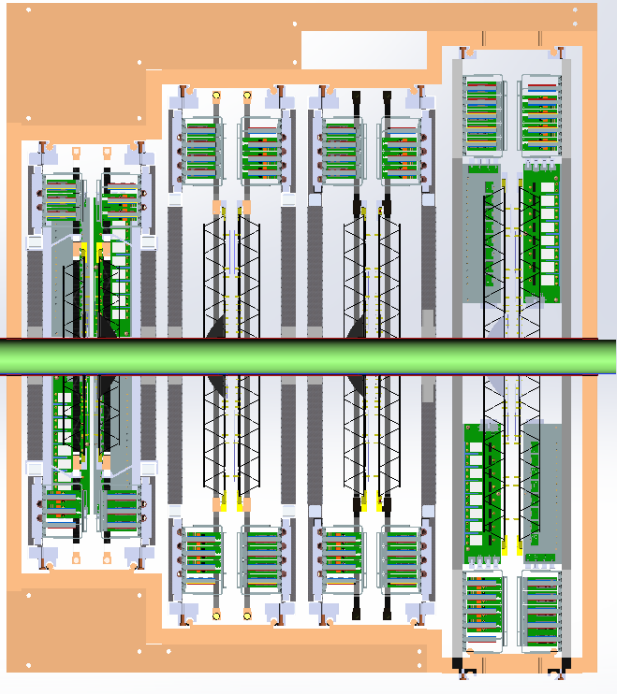


Trigger window = *1,2* us

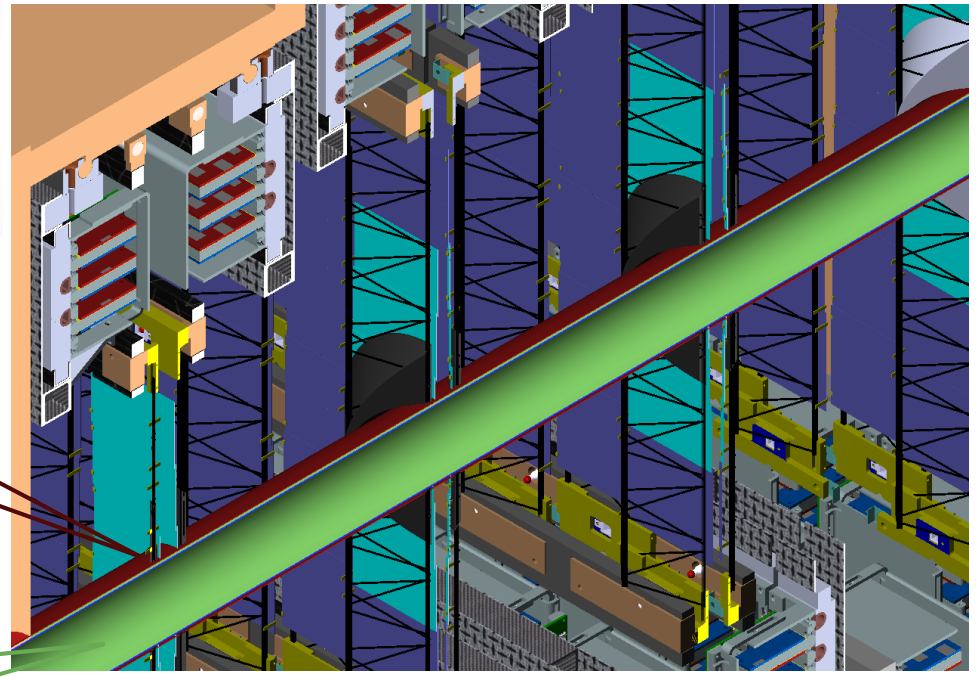


Trigger window = *0,5* us

STS beam-pipe



- Cutout diameter in the central sensors: 55 mm;
- Mainframe integrated sleeve for the beam pipe: wall thick. 0.5 mm; inner diameter 53 mm;
- STS Beampipe max diameter: 52 mm;



Advantages and disadvantages for beam-pipe sleeve

Advantages:

- Beam pipe is not biased to the STS mainframe;
- Variety of the hybrid tracker configurations

Disadvantages:

- Extra material especially for the particles with low scattering angles;
- Absence of the thermal insulation;

Proposal:

To foresee upgrade of the STS beampipe section for the 2nd stage (4 stations) of STS:

To have the new beam pipe section as a part of the Mainframe of STS.

LV and HV Power Supply system

STS power supply system

Features:

- comprises 448 HV channels (pos & neg) and 360 LV channels;
- Custom designed power supply modules;

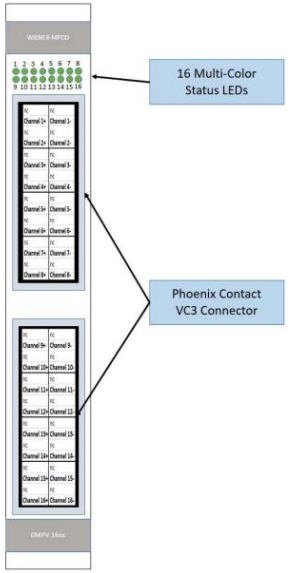
Status:

- Is funded by GSI-JINR Roadmap Agreement;
- Tendering procedure for the CBM and BM@N power supply systems was finished in Dec 2021;
- System will be produced by two vendors: Wiener and ISEG;

Integration:

- Place for the power racks was already defined outside of the BM@N cave in the radiation safe environment;
- System comprises 108 power cables, the weight of the cable stack is ~25 kg/m/ So, special cable supporting structure is needed.

HV module



LV module

Summary (1 of 2)

Work Package	Status	Next Steps	Risks / Issues
Module Assembly	▪ MA workflow was established and tested, ▪ Waiting for the module components in batches	• Proceed with productivity increase actions • Proceed with data collection, reporting and analysis improvements	Timely reception of module components from Germany
Ladder Assembly	• LA workflow was established and tested, • waiting for the module production.	• Receive the upgraded shields, • proceed with LA once the required modules are produced	
Read-out electronics	Integration into the Global Read-out BM@N system: • the concept of the triggered acquisition was implemented and tested, • the concept of the STS clock system was elaborated, • the prototype version of the engine for STS data stream integration was elaborated, • further developments are in-progress.	• Proceed with firmware for TFC module, • Proceed with software development for STS data stream integration, • Proceed with analysis / testing once the components are received	World-around “Silicon crisis” causing delays of shipment of components for backend controller GERI, etc.

Summary (2 of 2)

Work Package	Status	Next Steps	Risks / Issues
Mechanical integration and cooling	• Conceptional design of the mainframe is completed. CD documentation and procurement are in-progress, • conceptional design of the cooling system is being clarified. Simulations are in-progress, • production of central ladders is being planned.	• Complete CD documentation and start production, • Finalize Cooling System concept, • Proceed with production of central ladders once all composition parts are received	Multiple and not well known integration issues to be resolved on the way

- 2x - Stations;
- 18x - Ladders;
- 100x – STS modules.

• Targeting for 2023

- 4x - Stations;
- 44x - Ladders;
- 292x - STS modules.

• Targeting for 2024

Thank you for your attention!