Silicon tracking station with a free-streaming readout system as a part of the BM@N tracking system

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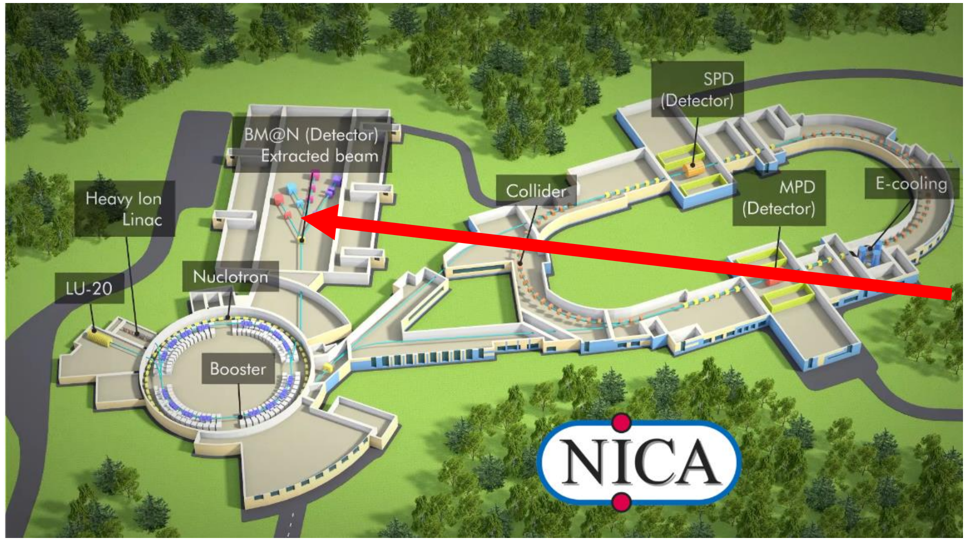
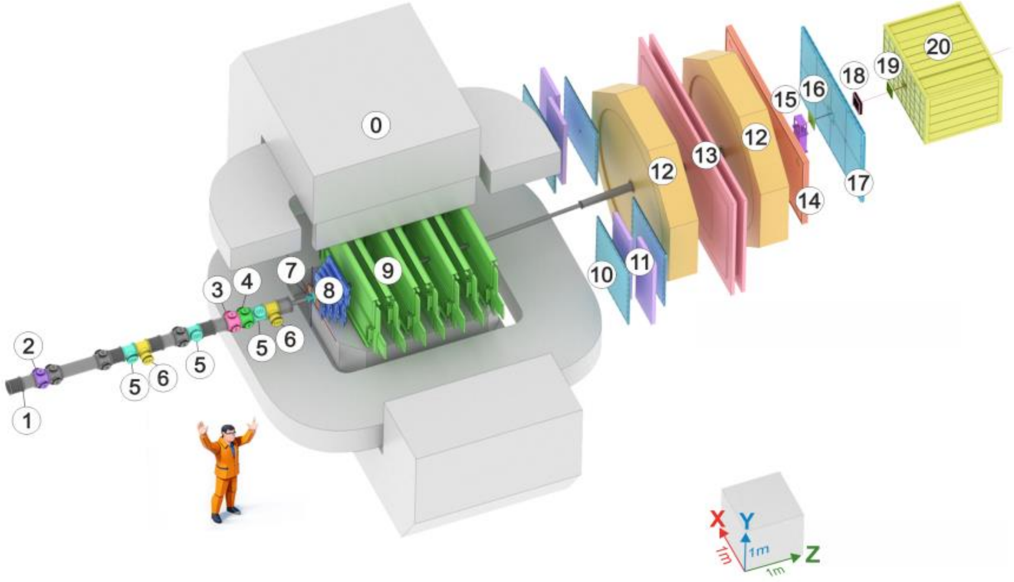
Outline

- BM@N experiment at NICA
- Silicon tracking station as a part of the BM@N tracking system
- Data acquisition system
- Results of the in-beam tests of the DSSD-modules and DAQ system
- Summary

BM@N experiment at NICA



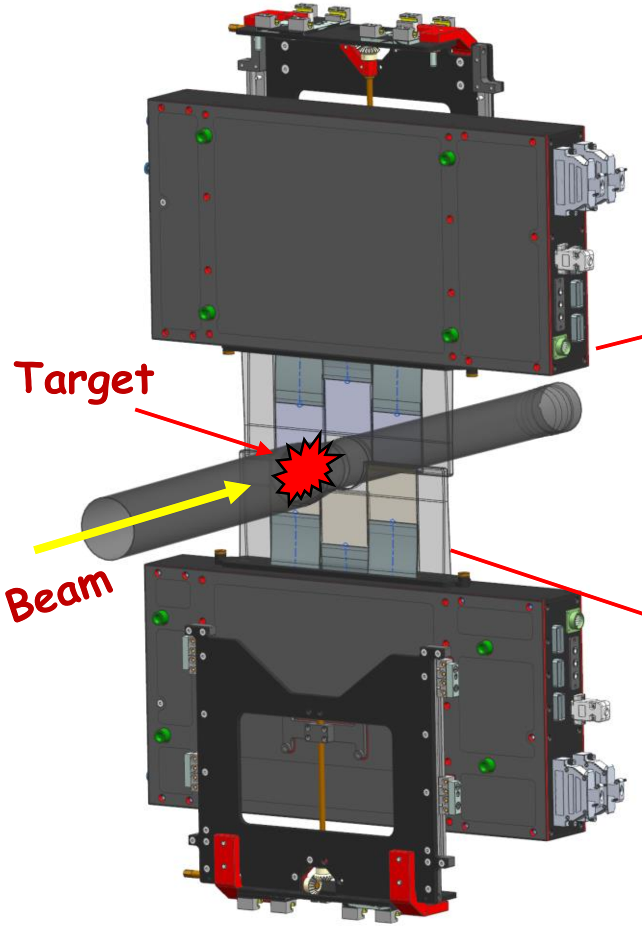


BM@N setup

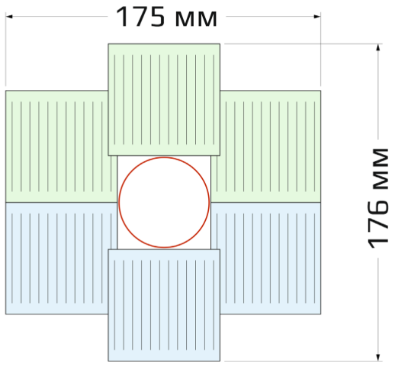
- Baryonic Matter at the Nuclotron (BM@N) will be focused on the study of the dense nuclear matter in the heavy ion collisions (up to Au) with energies up to 4.65 AGeV.
- One of the key observables: a subthreshold Ξ^- production.

Silicon tracking station of the BM@N

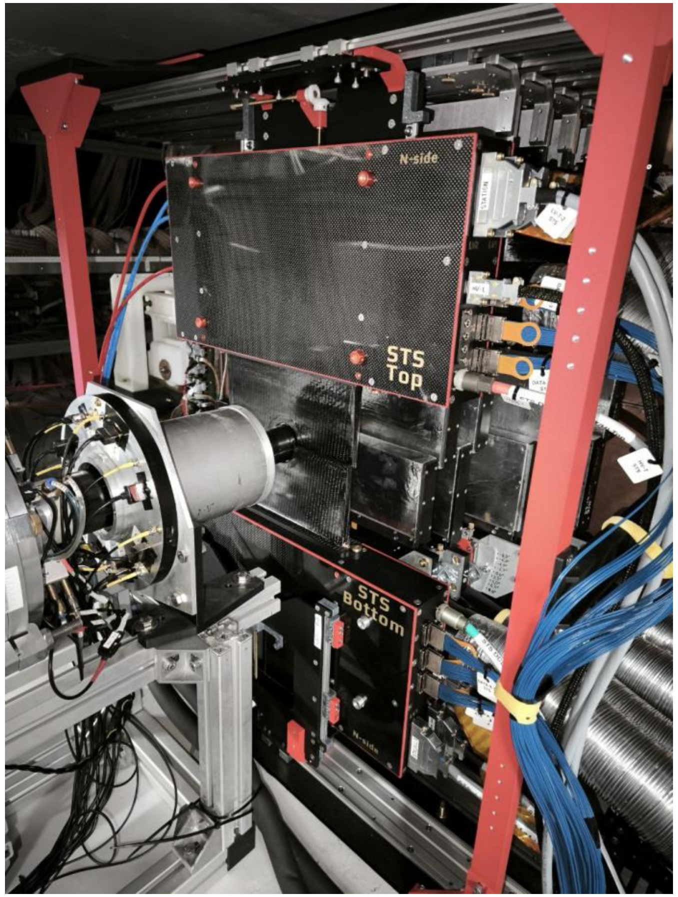
Two half-planes of STS



BM@N tracker configuration

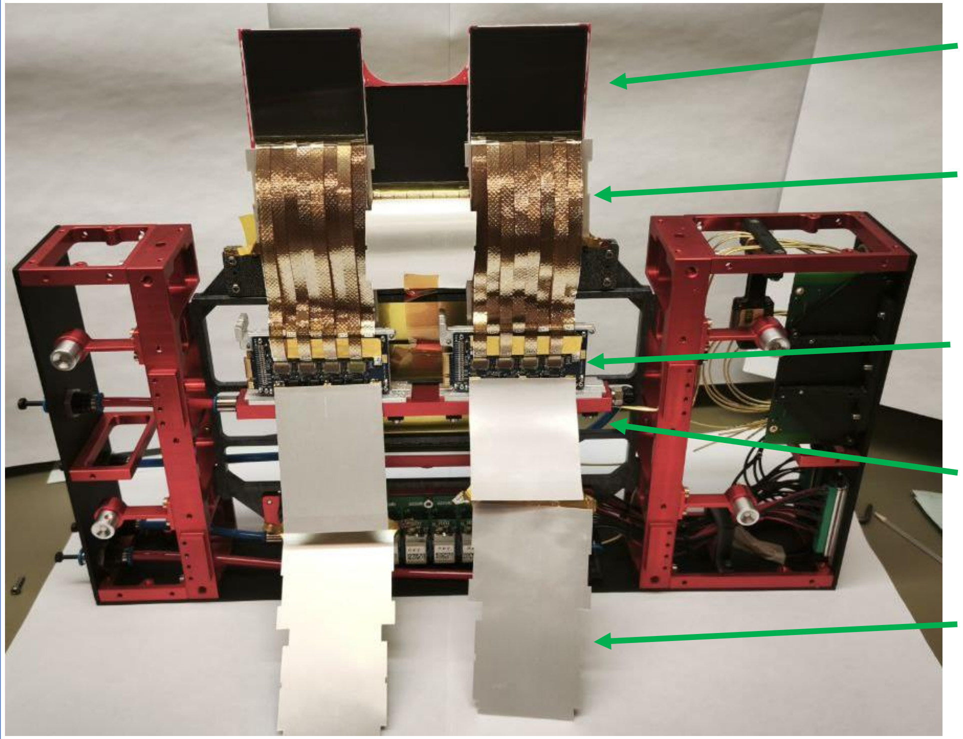


Two half-planes of STS



Total number of channels (6 modules): 12 288
Acceptance: 25° - 55°

STS half-stations



Sensors installed on the PCB frame

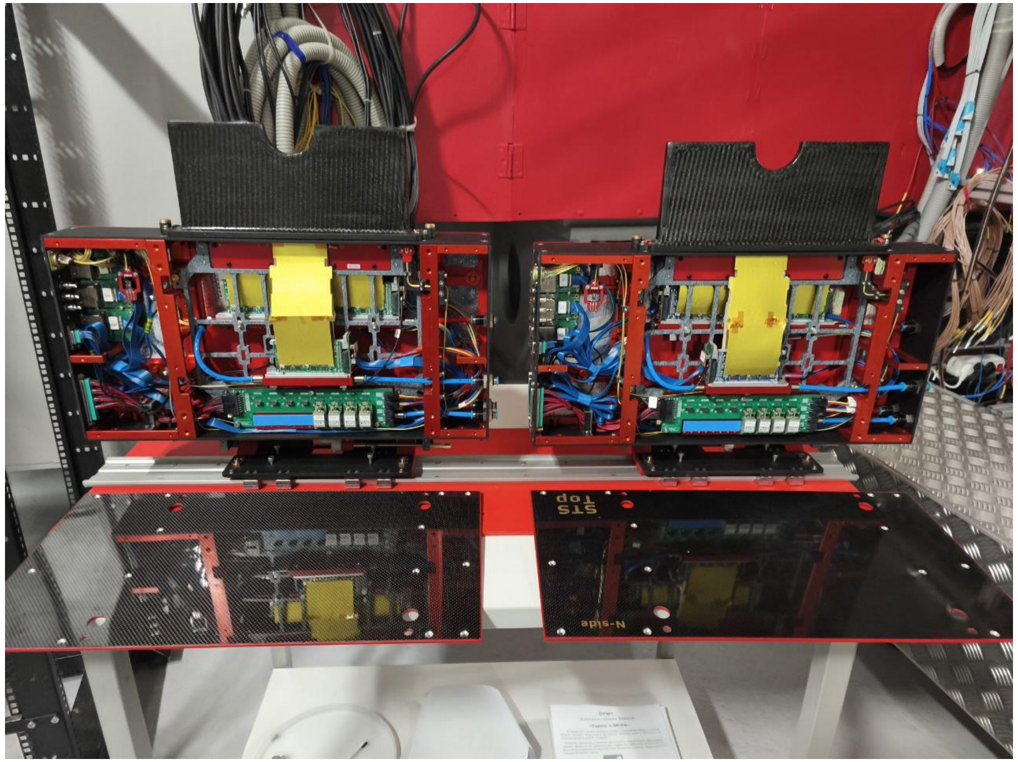
Microcables

Front-end electronics

Water cooling

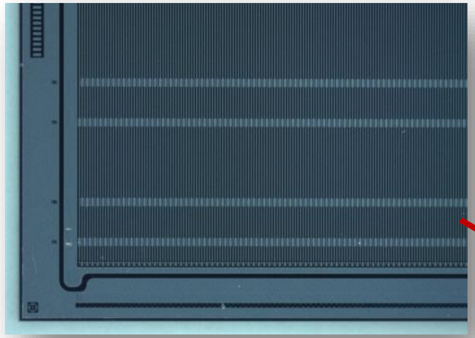
Shielding layers

Photo of the half-station after installation of the modules

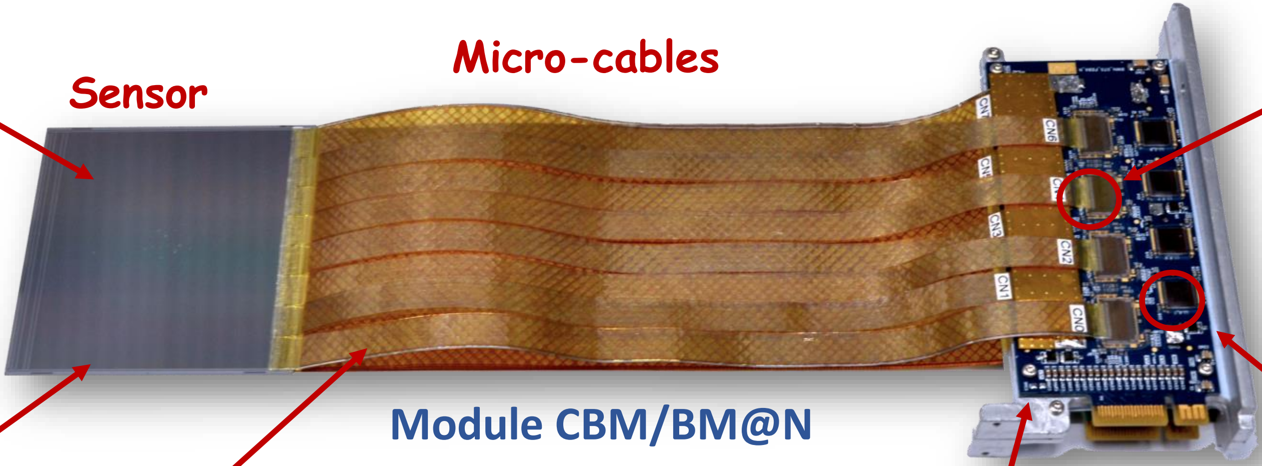


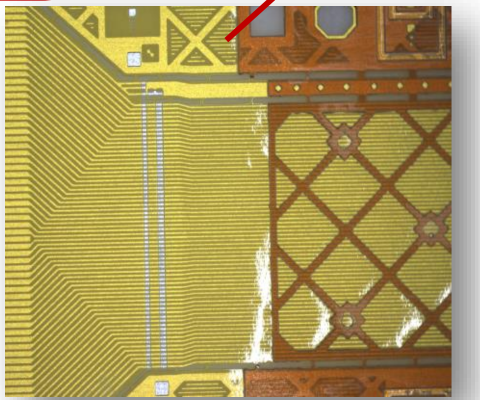
Two half-stations before installation inside the magnet

CBM/BM@N tracking module

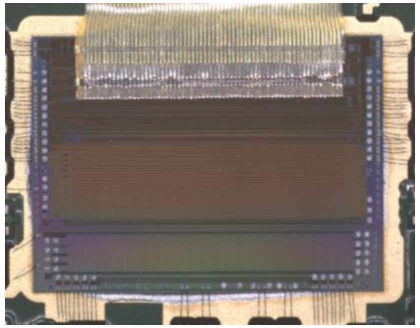


- Double-sided;
- Thickness: 300 μm;
- 1024 strips of 58 μm pitch;
- Stereo angle: 7.5°;
- Sensors size: 62×62 mm^2





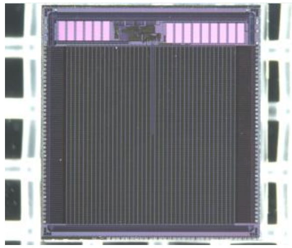
x8



STS-XYTER ASIC

- 8 STS-XYTER ASIC per FEB;
- Bonding of cables with sensors;
- Wire-bonding of ASIC on the PCB;
- Energy consumption: 12 W
- Hit spatial resolution ≈ 15 μm;
- 14-bit TDC with resolution ≈ 10 ns;
- AC-coupled LVDS links (80 Mb/s);

x4

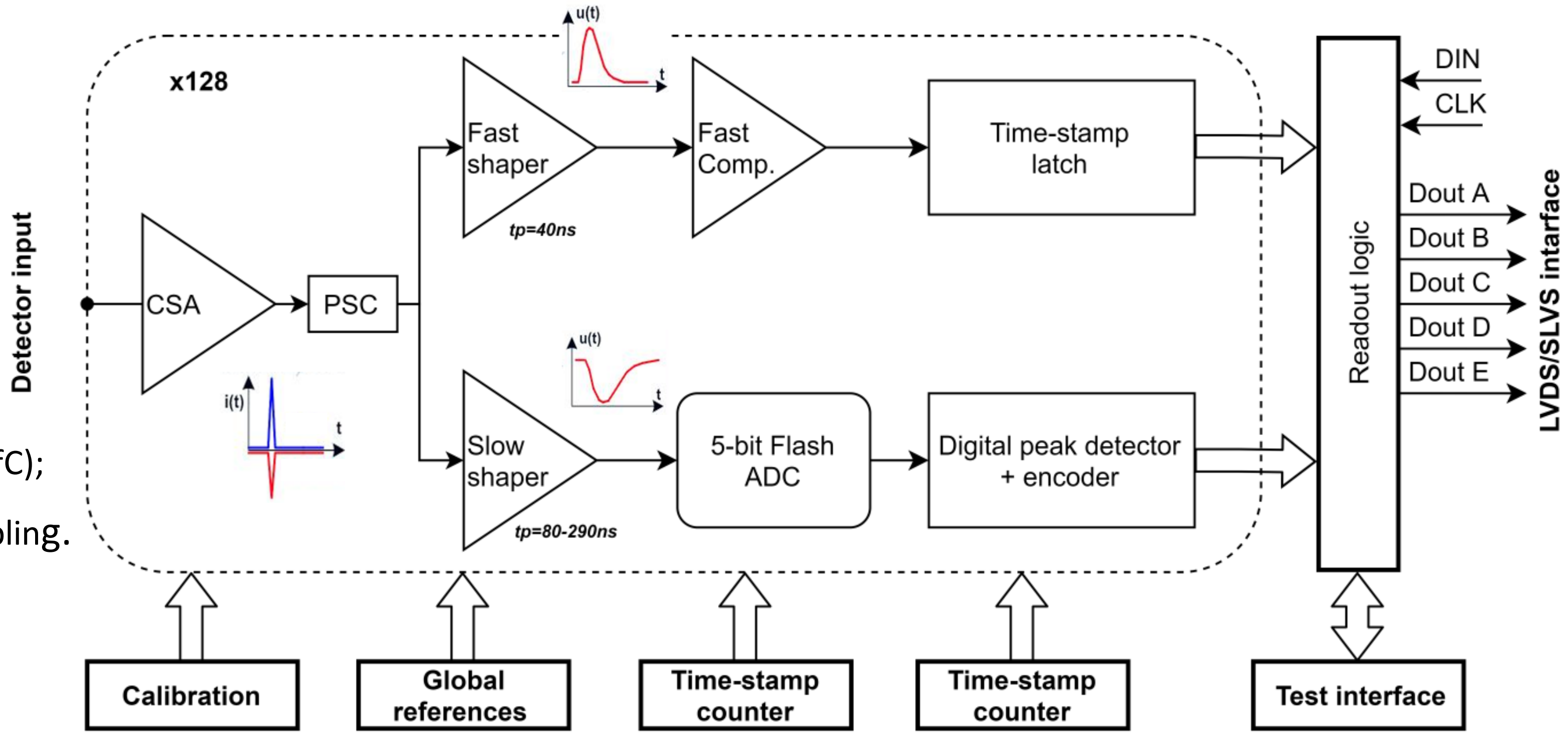


Low-dropout Regulator ASIC

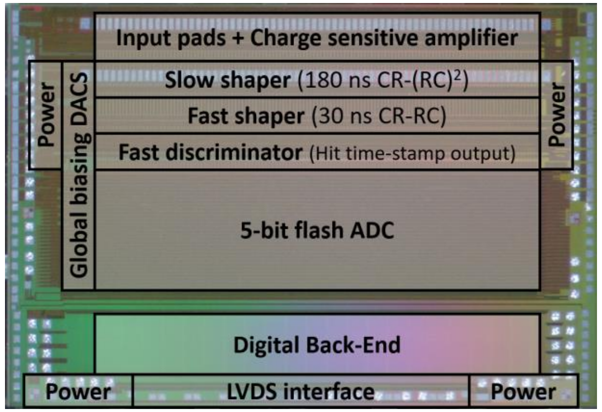
Front-end readout ASIC

Front-end electronics is based on STS-XYTER v.2.2 ASIC

- 128 channels;
- Self-triggered readout;
- UMC CMOS 180 nm process;
- Unpackaged die;
- Dynamic range up to 15 fC (typ. signal – 3.6 fC);
- 5 bit ADC, TDC < 10 ns;
- Shaping time 80-120 ns (Slow Shaper for Amp.);
- Noise performance: <1500 ENC with sensor (0,15 fC);
- Back-end interface : 5 e-link per ASIC with AC coupling.



Block diagram of the architecture of the STS-XYTER



**developed by K.Kasinski et. all, AGH (Krakov) for CBM collaboration*

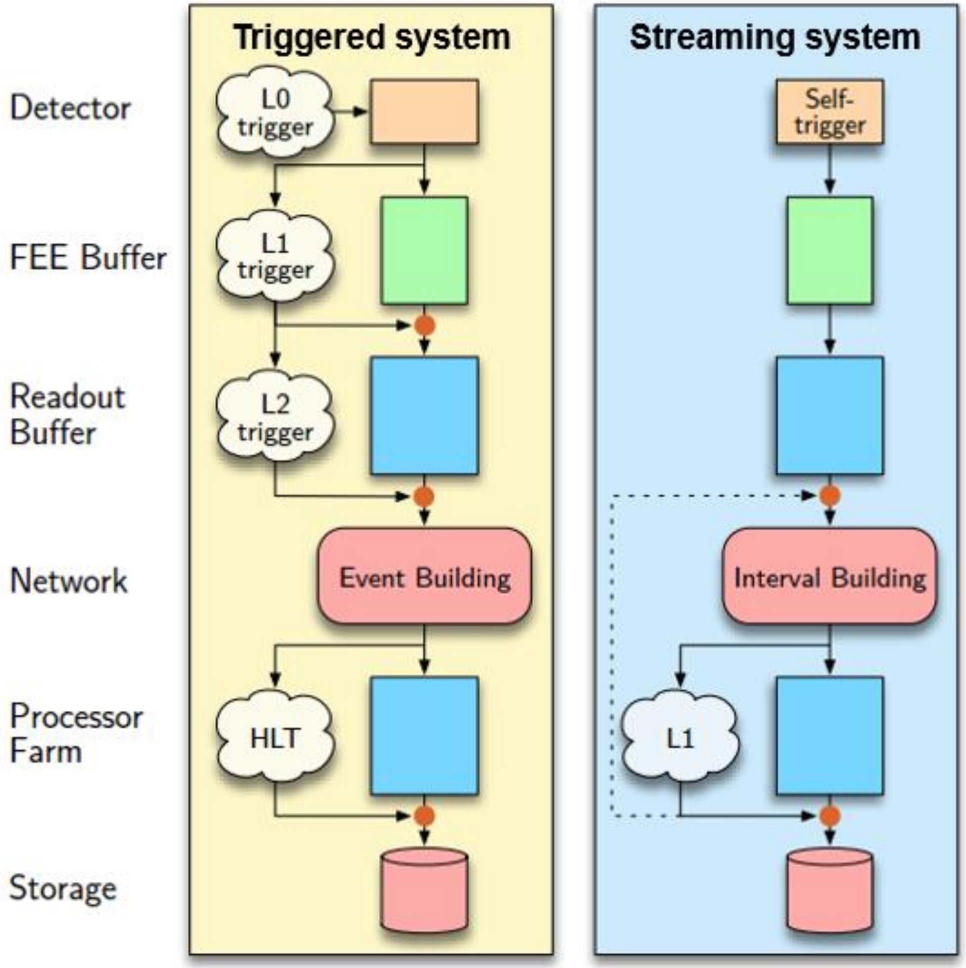
Free-streaming readout

Advantages of the streaming readout:

- High registration efficiency at high intensities;
- Dynamic adjustment of experiment parameters;
- No need for low level trigger;
- Dead time is minimized.
- 4D tracking

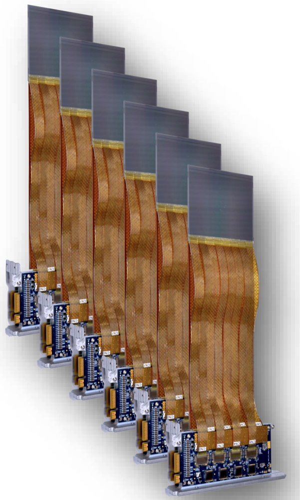
Difficulties in implementing a streaming readout :

- Requires a time synchronization system
- More sensitive to the noise;
- Higher power consumption;
- Requires online event reconstruction;
- Requires front-end buffers overflow throttling system.

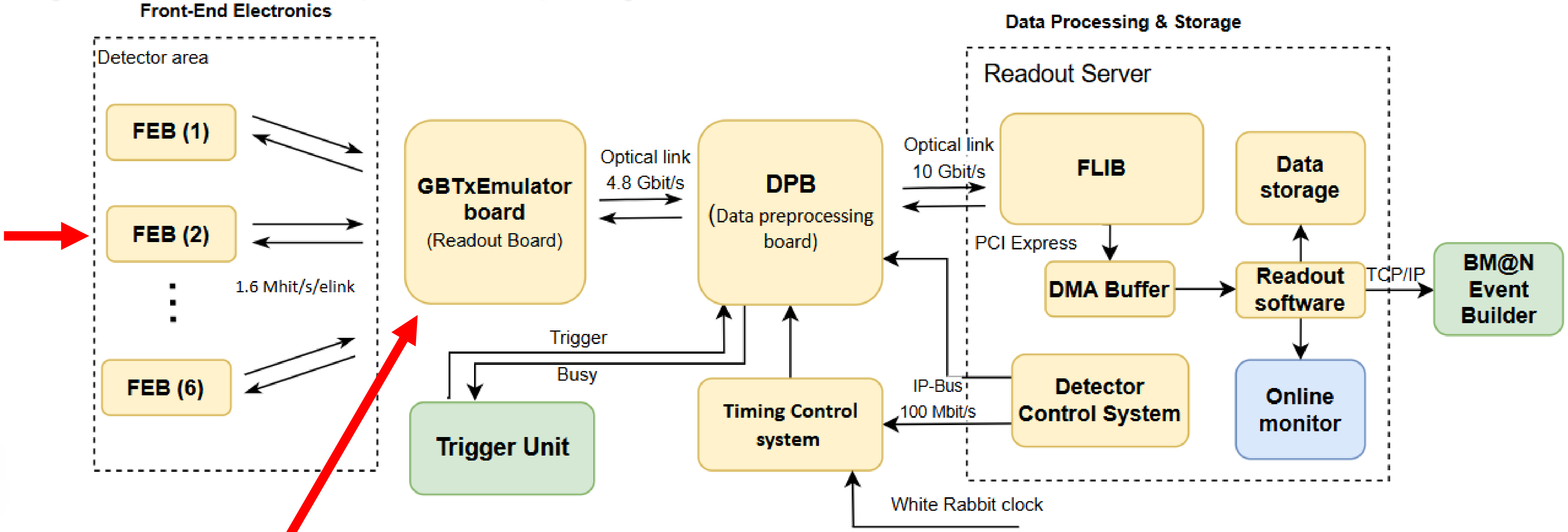


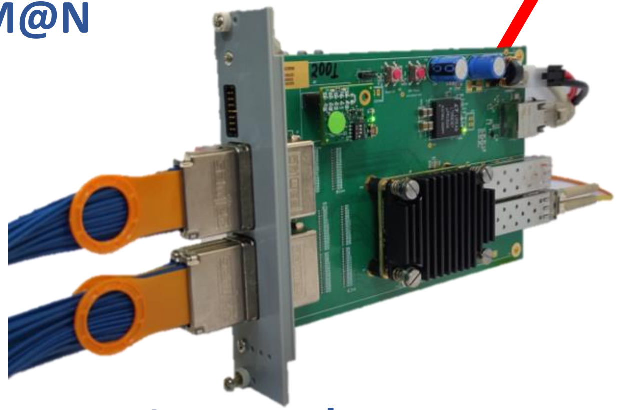
Comparison of triggered and free-streaming data acquisition systems

Data Acquisition (DAQ) system

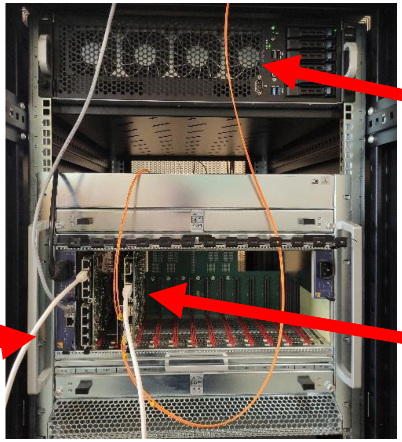


Modules CBM/BM@N

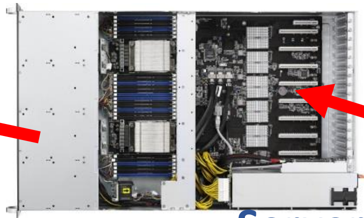




GBTxEmulator



uTCA crate



Server

FLIB

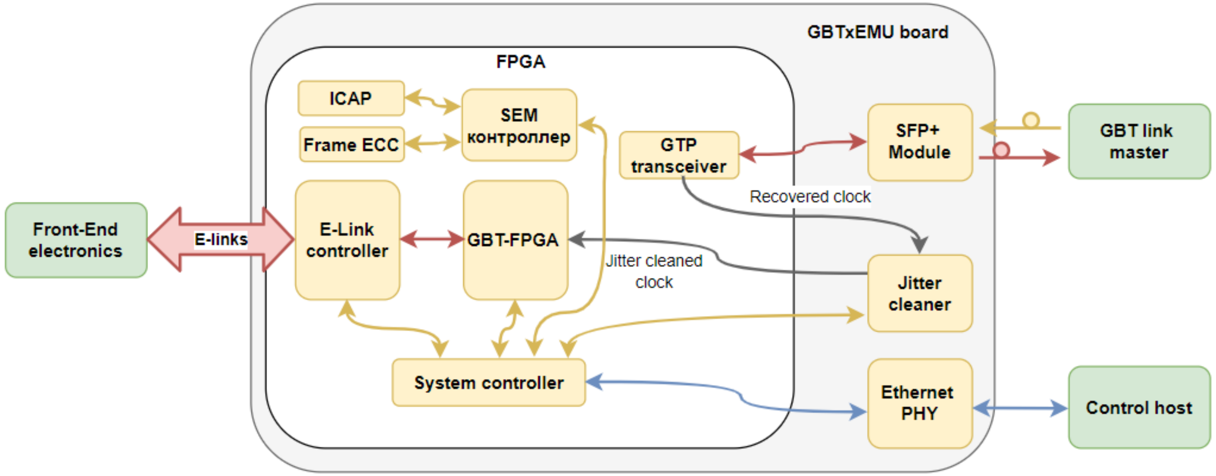
AFCK (Data Processing Board)

GBTxEmulator

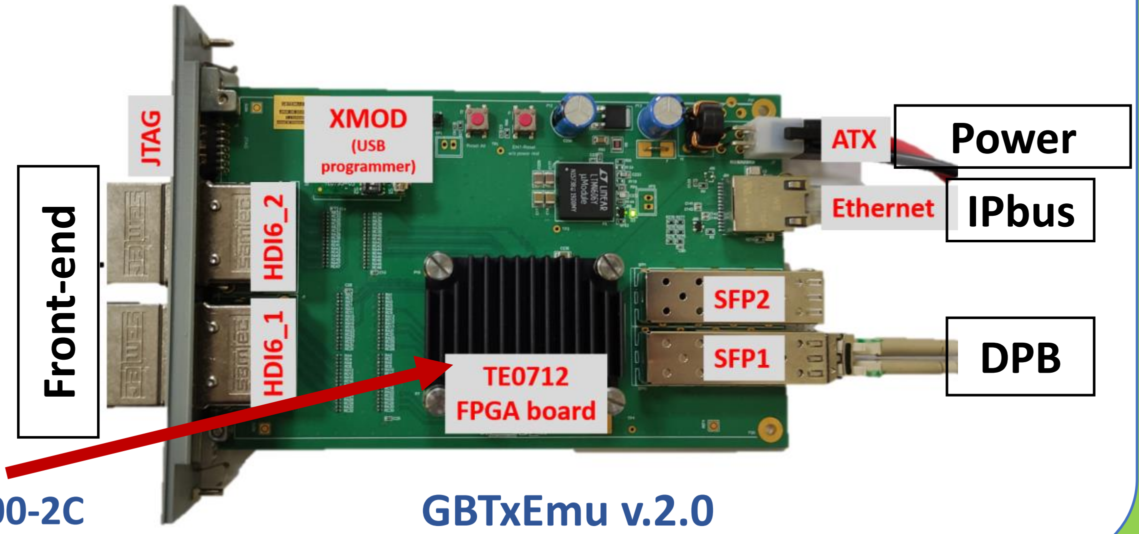
Provide interface between the Front-End Electronics and the Data Processing board

Features:

- Provides GBTx ASIC functionality;
  - Fast time deterministic transport of downlink message (control and monitoring);
  - high-speed transmission of hit data in the uplink direction;
- Platform: Trenz TE0712-02-100-2C based on Artix-7 FPGA;
- 4.8 Gb/s optical links connecting to the Data Processing board (DPB);
- E-Link interface:
  - 48 E-Links with 80 Mb/s data rate;
  - 6 E-Link clock – 40 MHz;
  - 6 downlink.
- Single Event Upset (SEU) control and mitigation



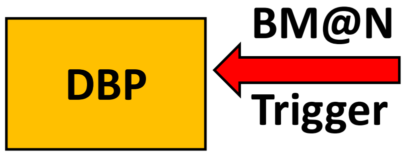
Block diagram of the Firmware GBTxEMU



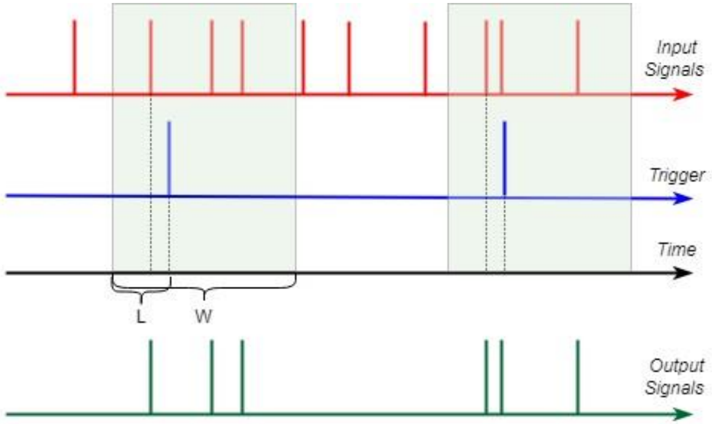
Trenz TE0712-02-100-2C

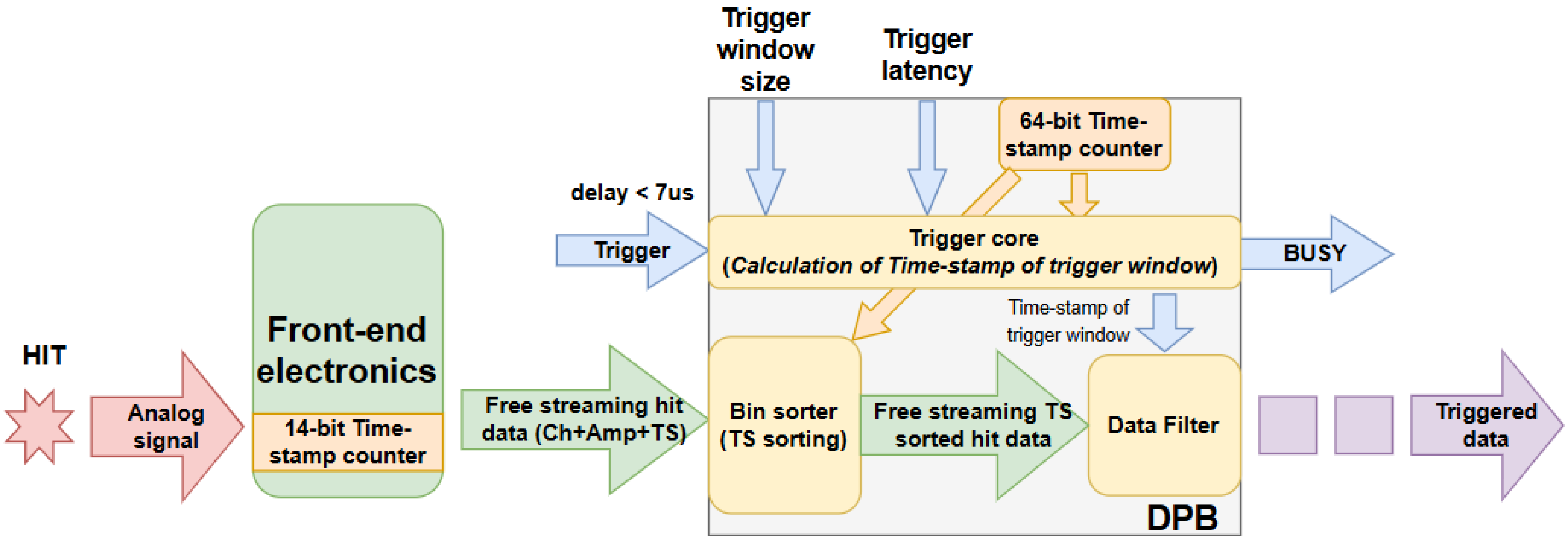
GBTxEmu v.2.0

Trigger implementation



- The front-end electronics of STS operates only in the self-triggered mode.
- The data filtering according the trigger decision is implemented in the DPB.
- Due to the free-streaming readout scheme, DPB 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.
- The concept of the triggered acquisition is elaborated and implemented.
- Trigger parameters:
  - Trigger latency <= 7 us;
  - Trigger rate <= 78 kHz;



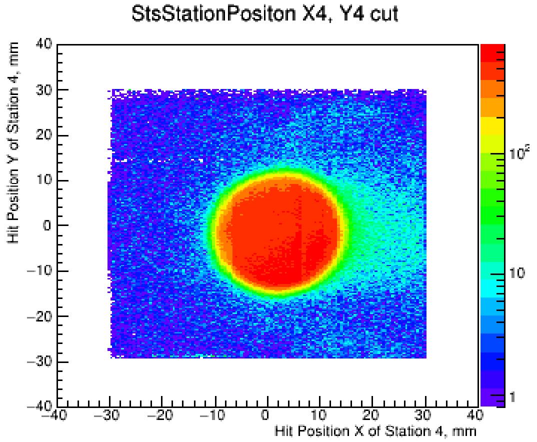


In-beam tests of the CBM/BM@N modules and readout system

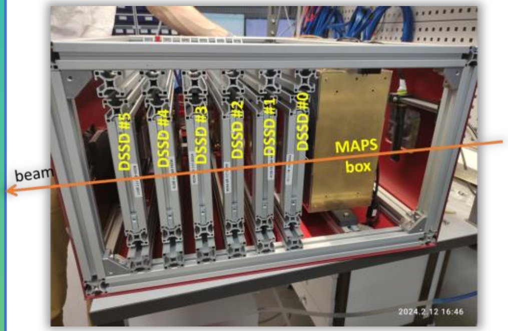
Beam telescope:

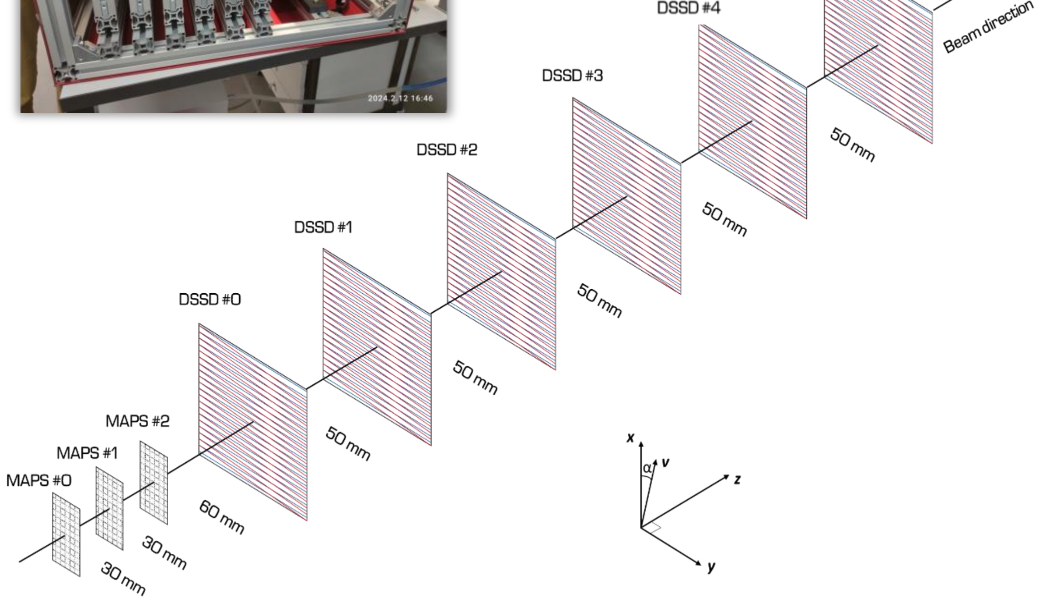
- 6 STS modules;
- 3 layers of MAPS;
- 2 scintillators (trigger)

- Was tested with 1 GeV proton at PNPI (Gatchina)
- 72 hours data taking
- Beam flux: $10^4 - 5 \cdot 10^5$ protons/(cm²·s)



Beam profile

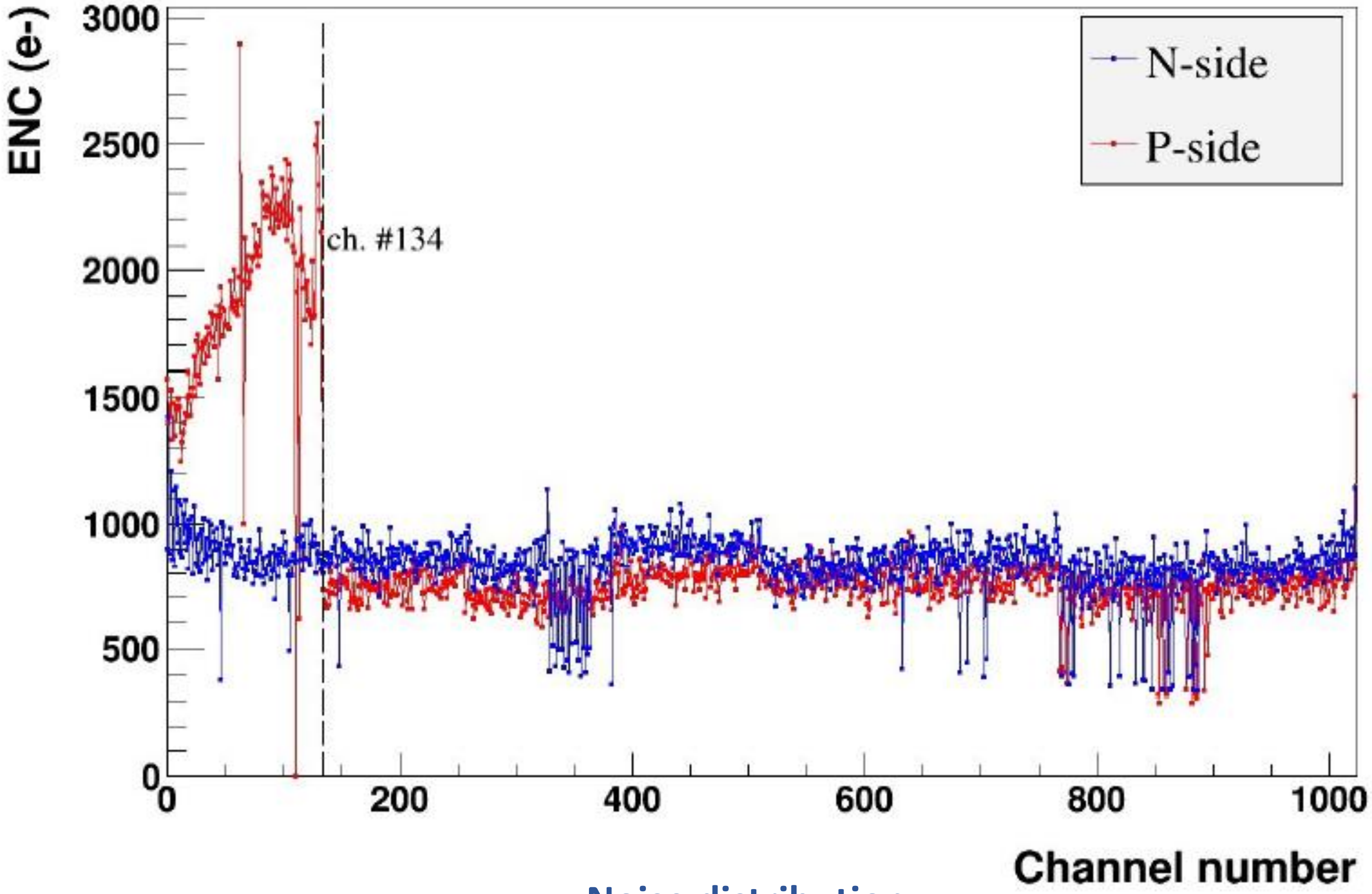




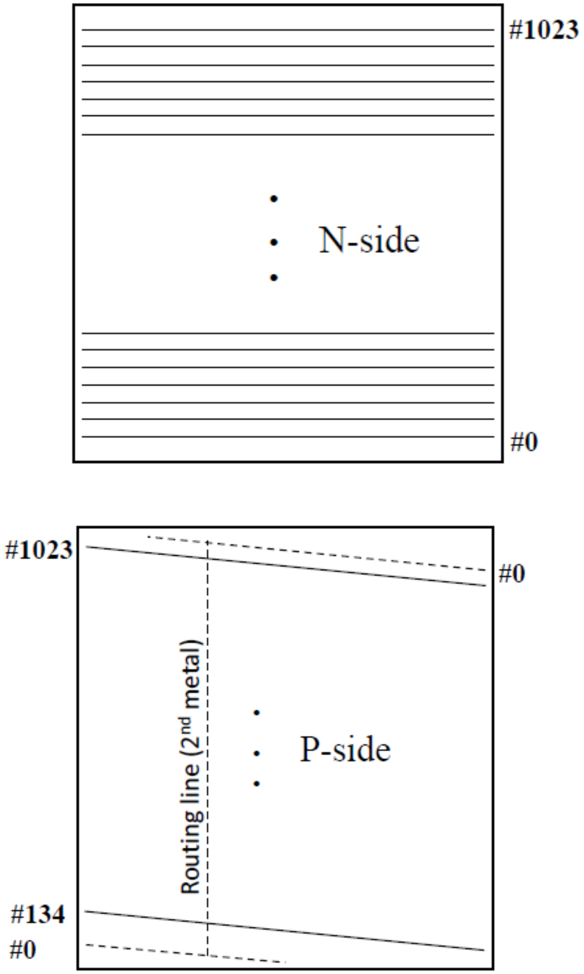
Results of the in-beam tests:

1. Data streams from two subsystems (MAPS & DSSD) were successfully merged into events based on the trigger signal.
2. Concept of the integration of the free-streaming STS readout into the trigger-based DAQ was proven.
3. The following parameters of DSSD modules were measured:
   - Signal- to- Noise ratio;
   - Av. spatial resolution;
   - Time resolution;
   - Efficiency;
4. Dependency of the module parameters on the detector bias voltage and ADC threshold was studied

Noise distribution

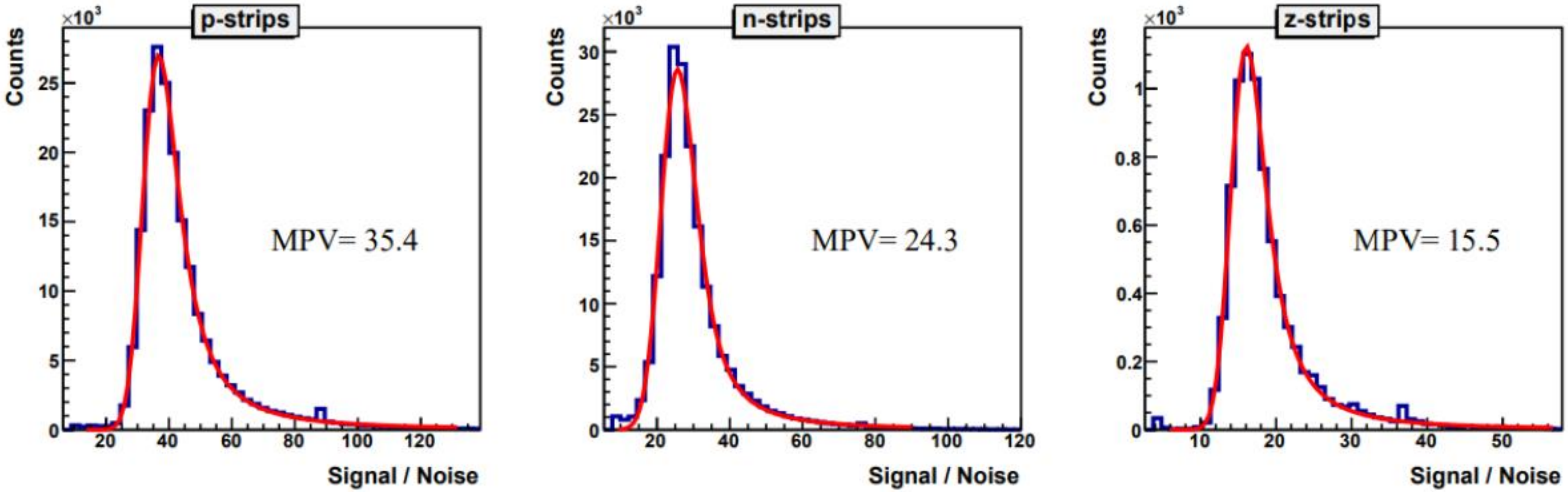


Noise distribution



Sensors channel map

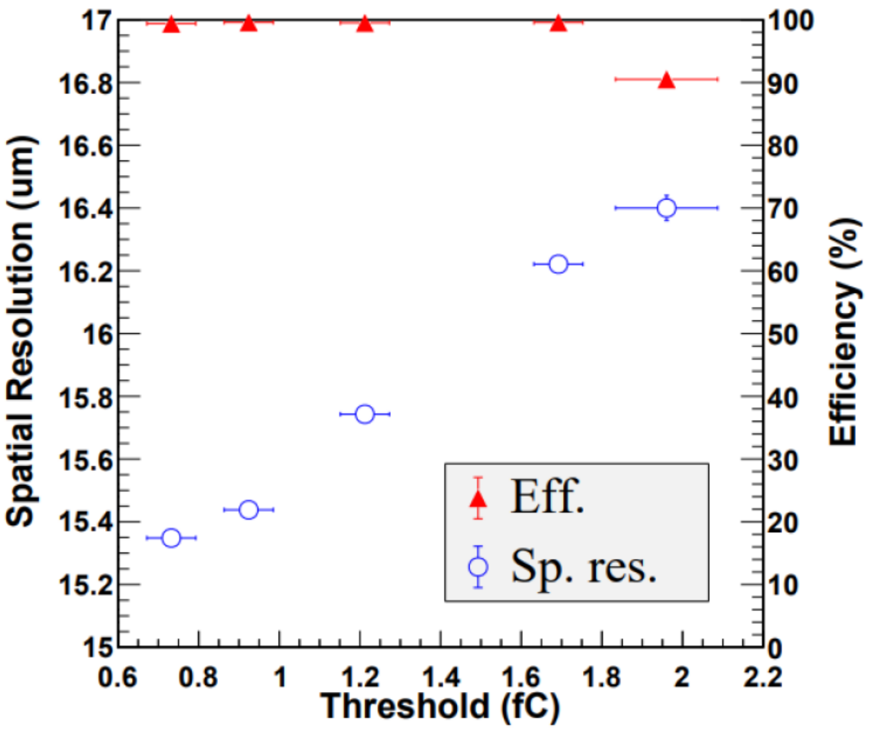
Signal/Noise distributions



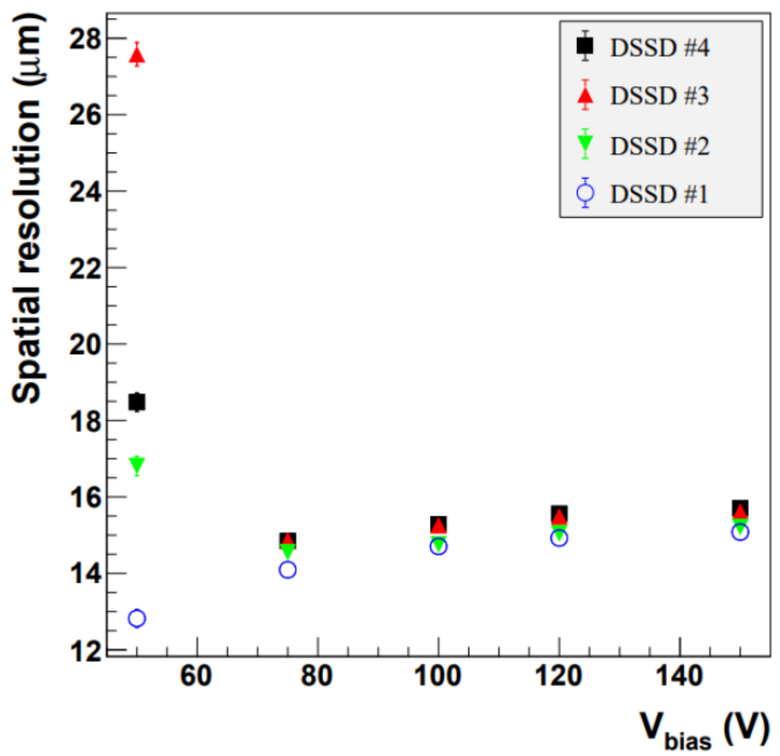
Signal-to-Noise distributions for the p-,n- and z-(with second metallization layer) strips for the 1 GeV protons

- ***P*-strips SNR_{MIP}: 28 - 30.5;**
- ***N*-strips SNR_{MIP}: 21 - 24.5;**
- ***z*-strips SNR_{MIP}: 8 – 13;**

Spatial resolution



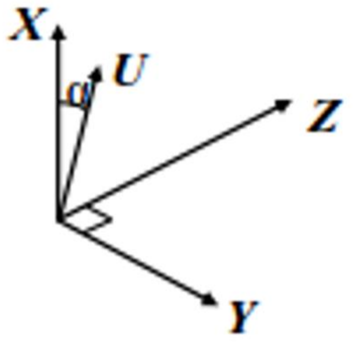
Spatial resolution and Efficiency vs ADC Threshold



Spatial resolution vs bias voltage

Selected operation values:

- Detector bias voltage: 80-100 V
- ADC Threshold: ~ 1 fC



$\sigma_{X,U}$ = 15.4 ± 0.4 μm for regular strips

σ_U = 16.4 ± 0.4 μm for the sensor areas with *z*–strips

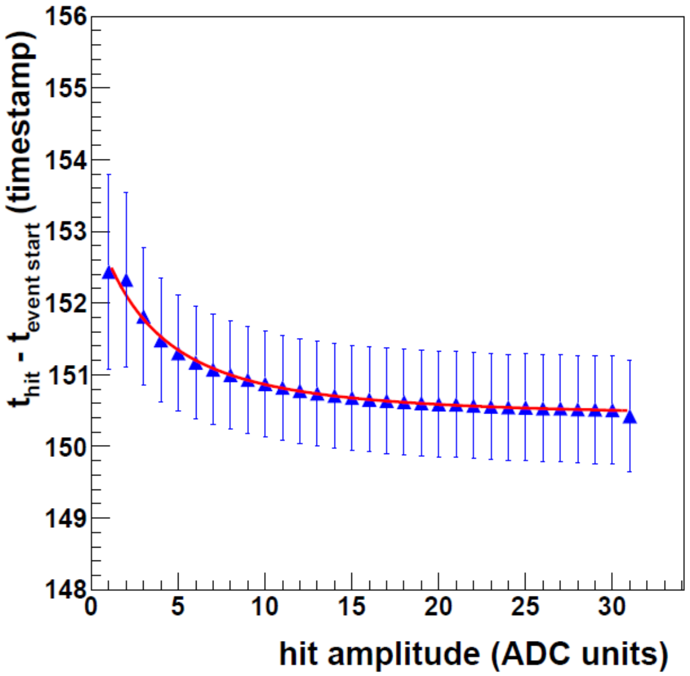
σ_Y = 170 ± 4μm

Efficiency: >99% (for regular strip)

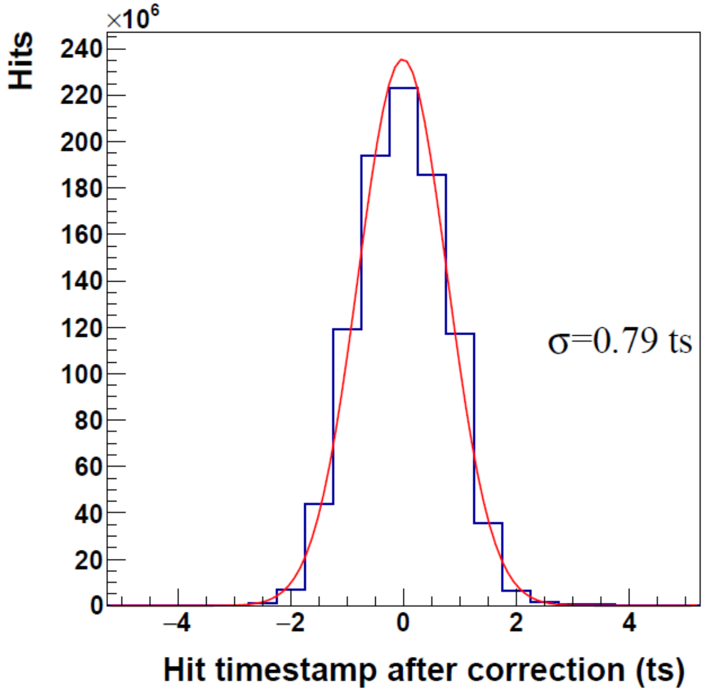
Efficiency of z- strips: ~90%

Time resolution

$$\sigma_{tot} = \sigma_{Jitter} \oplus \sigma_{TDC} \oplus \sigma_{Time\,Walk}$$

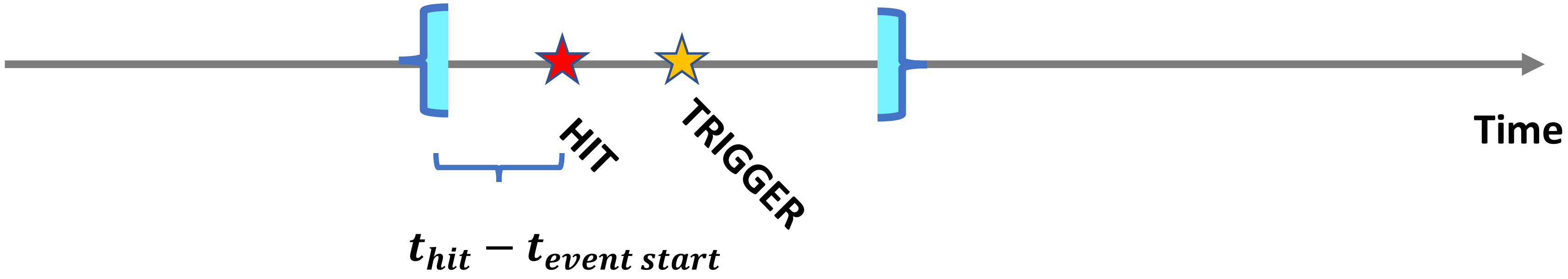


Time walk correction



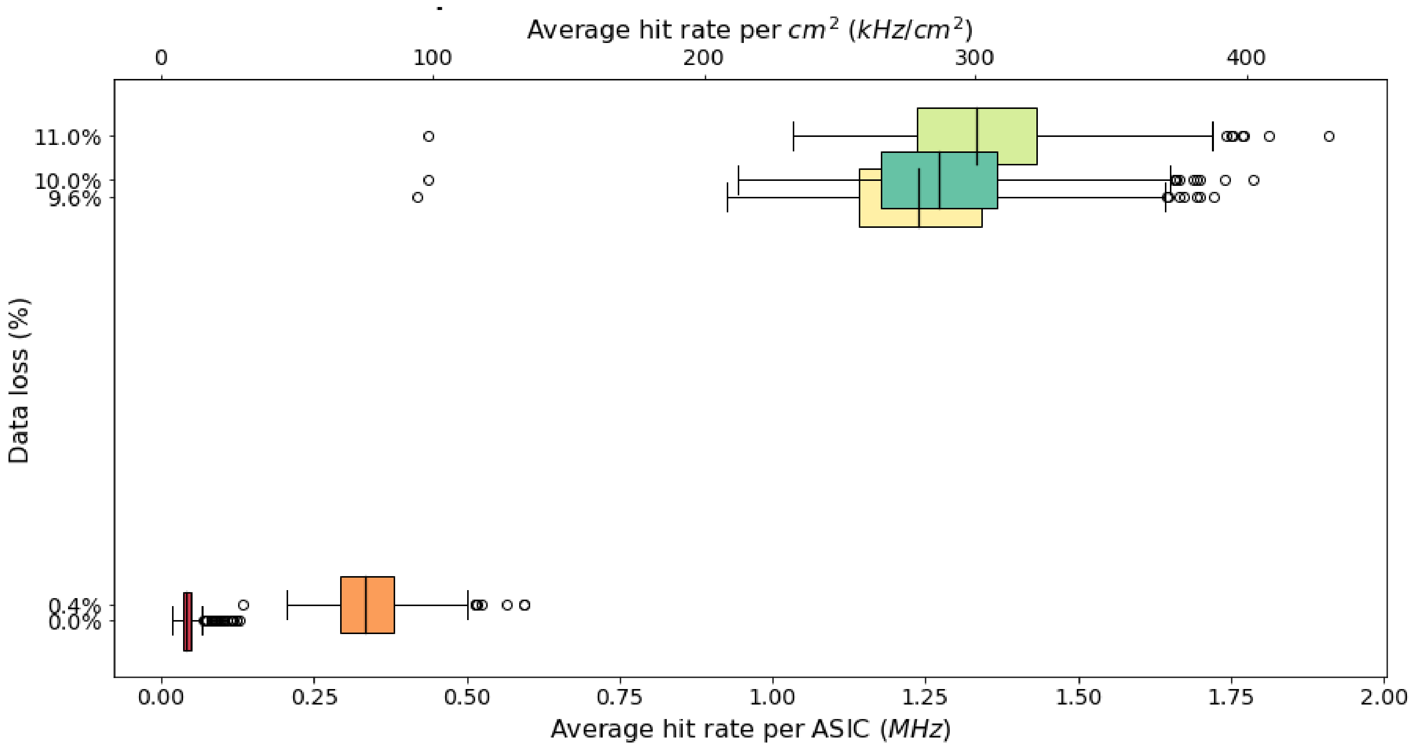
Time resolution

$\sigma_{tot} = 9.9$ ns



Throughput capacity

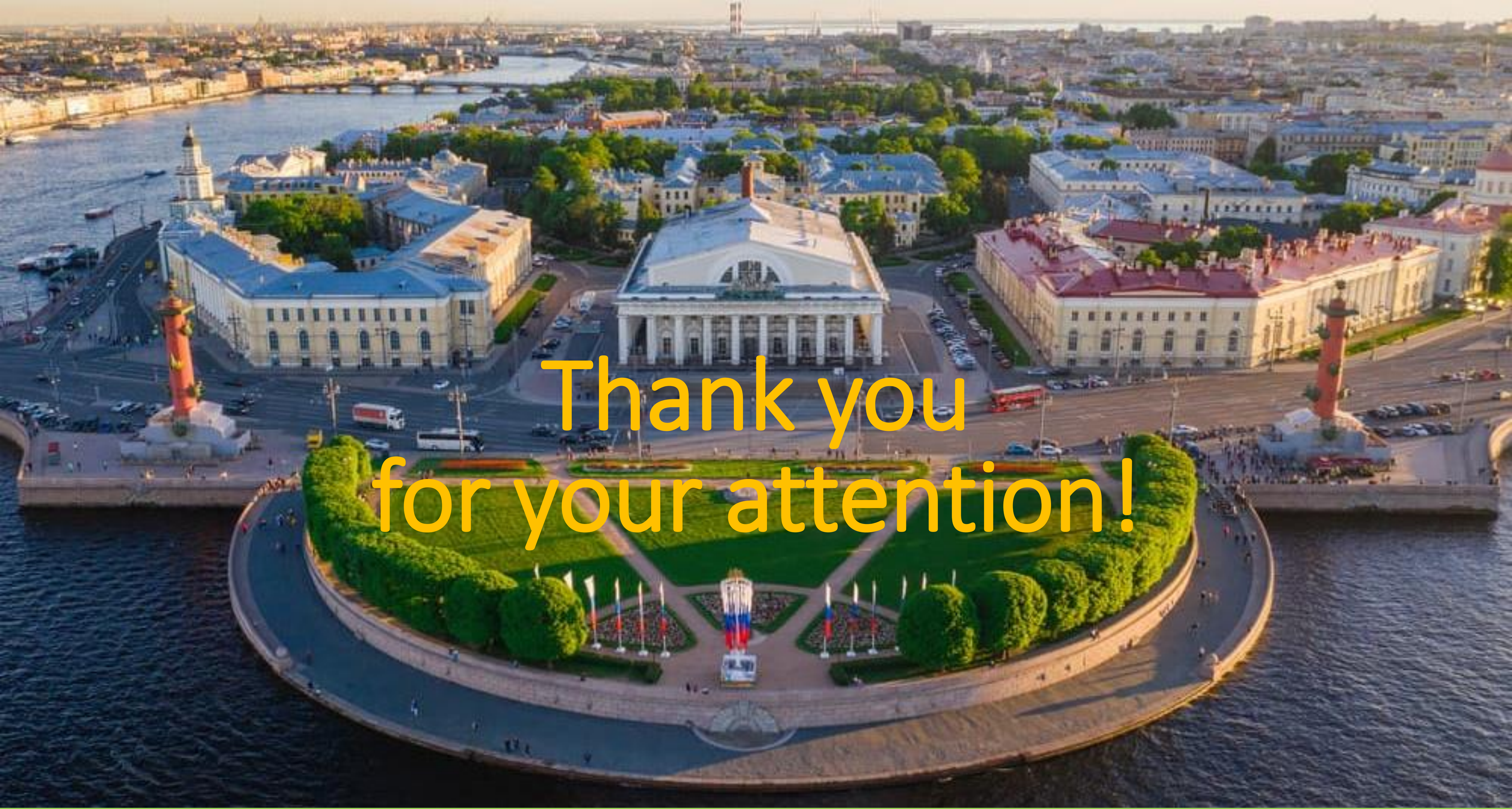
- F_{ASIC}= 1.6 MHits × s^{-1} / ASIC (12.5 kHits × s^{-1} / channel).
- $F_{Detector}$ = F_{ASIC}/4.4 = 360 kHits × s^{-1} / cm^2
- F_{GBT}= 3.84 Mb × s^{-1} (115.2 MHits × s^{-1} / link).
- Channel dead time ≈ 700 ns (Analog part)
- BM@N requirements: 19.2 kHits × s^{-1} / ASIC



Dependence of the Data Loss on the Hit Rate

Summary

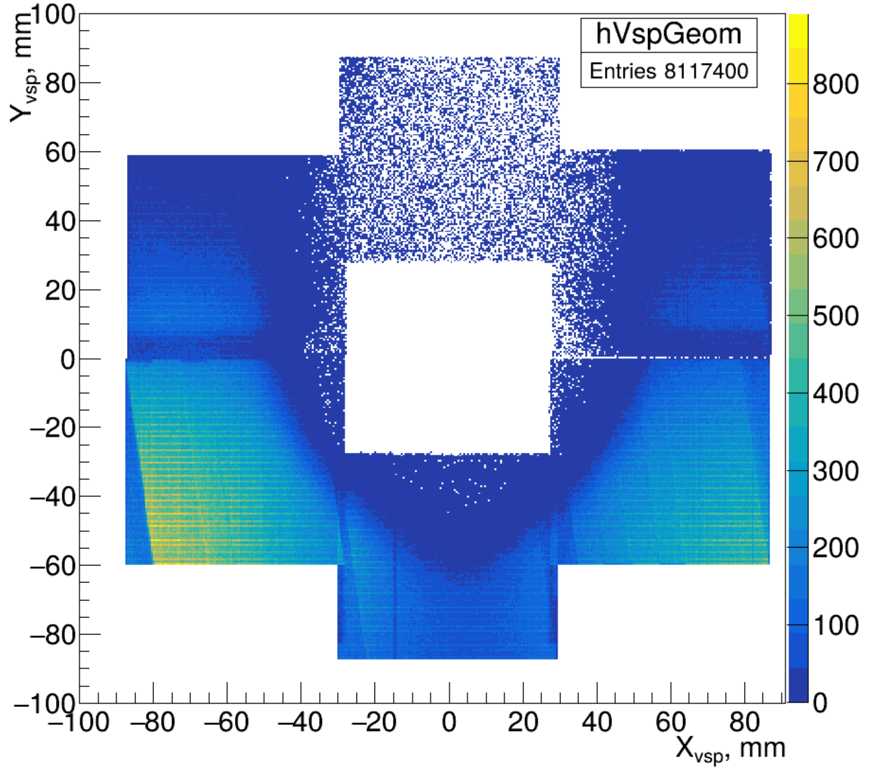
- The modules CBM/BM@N for the STS plane and DAQ system were tested with the proton beams in Gatchina;
  - Signal- to- Noise ratio: > 21;
  - Av. spatial resolution: 15.4 μm;
  - Time resolution: σ = 9.9 ns;
  - Efficiency: > 99% (for the areas without nonworking channels);
- The STS plane based on free-streaming DAQ system was already installed as a first step of modernization of the tracking system. BM@N STS fast streaming readout chain was elaborated and implemented;
- Integration of the free-streaming data acquisition system of BM@N STS with the global BM@N DAQ was done.



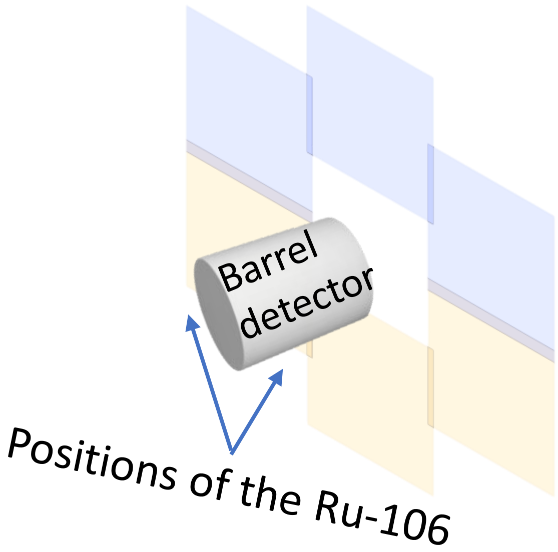
Thank you
for your attention!

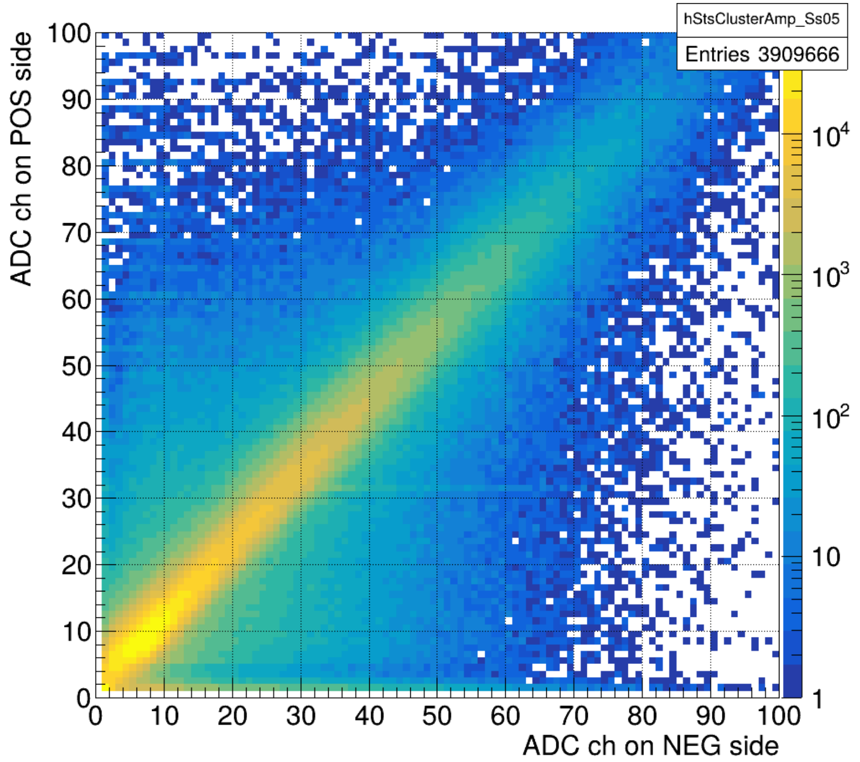
Backup

Tests of STS with Ru-106



Hit map

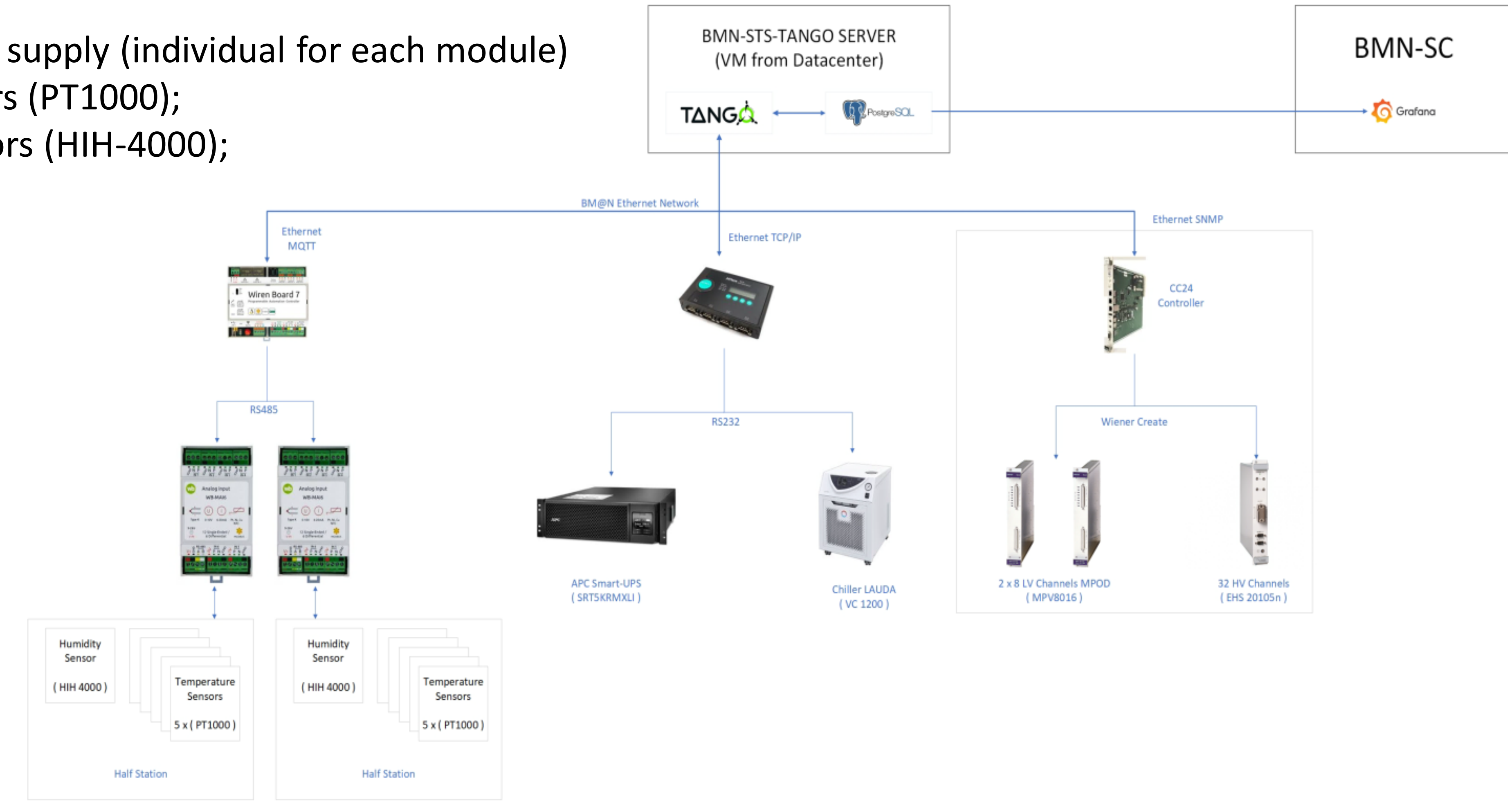




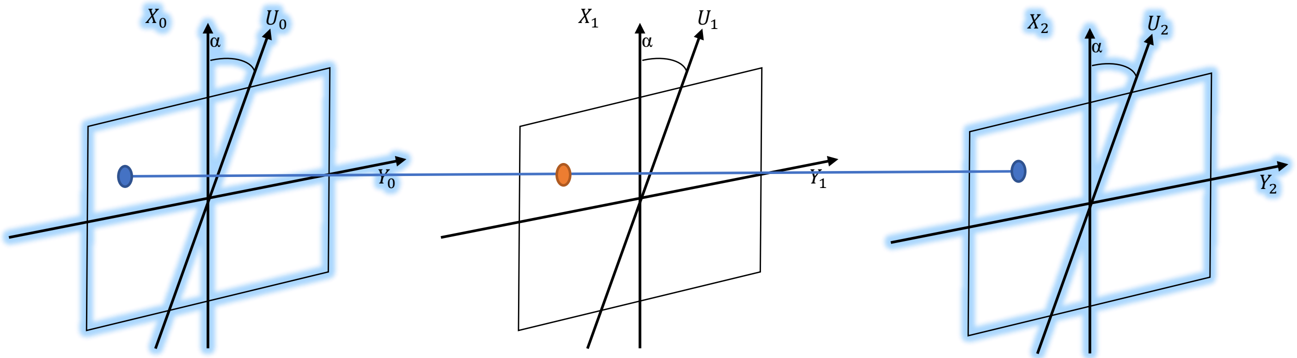
Correlations between hit amplitudes at p-and n- sides

Detector Control System of STS

Control parameters
- LV and HV power supply (individual for each module)
- 6 thermal sensors (PT1000);
- 2 humidity sensors (HIH-4000);
- UPS status
- Chiller status
- Water flow



Spatial resolution



$$\sigma_{res} = \sigma_{sp.res.} \oplus \sigma_{line} \oplus \sigma_{mcs}$$

$$\sigma_{line} = \frac{1}{\sqrt{2}} \sigma_{sp.res.}$$

$\sigma_{MCS} =$ 11.6 μm (GEANT)

σ_{res} - Measured residuals;
$\sigma_{sp.res.}$ - Spatial resolution of the detector;
σ_{line} - Inaccuracy of the straight-line track interpolation
σ_{mcs} - Uncertainties induced by Multiple Coulomb Scattering.