Beam tracker system for the BM@N/NICA experiment

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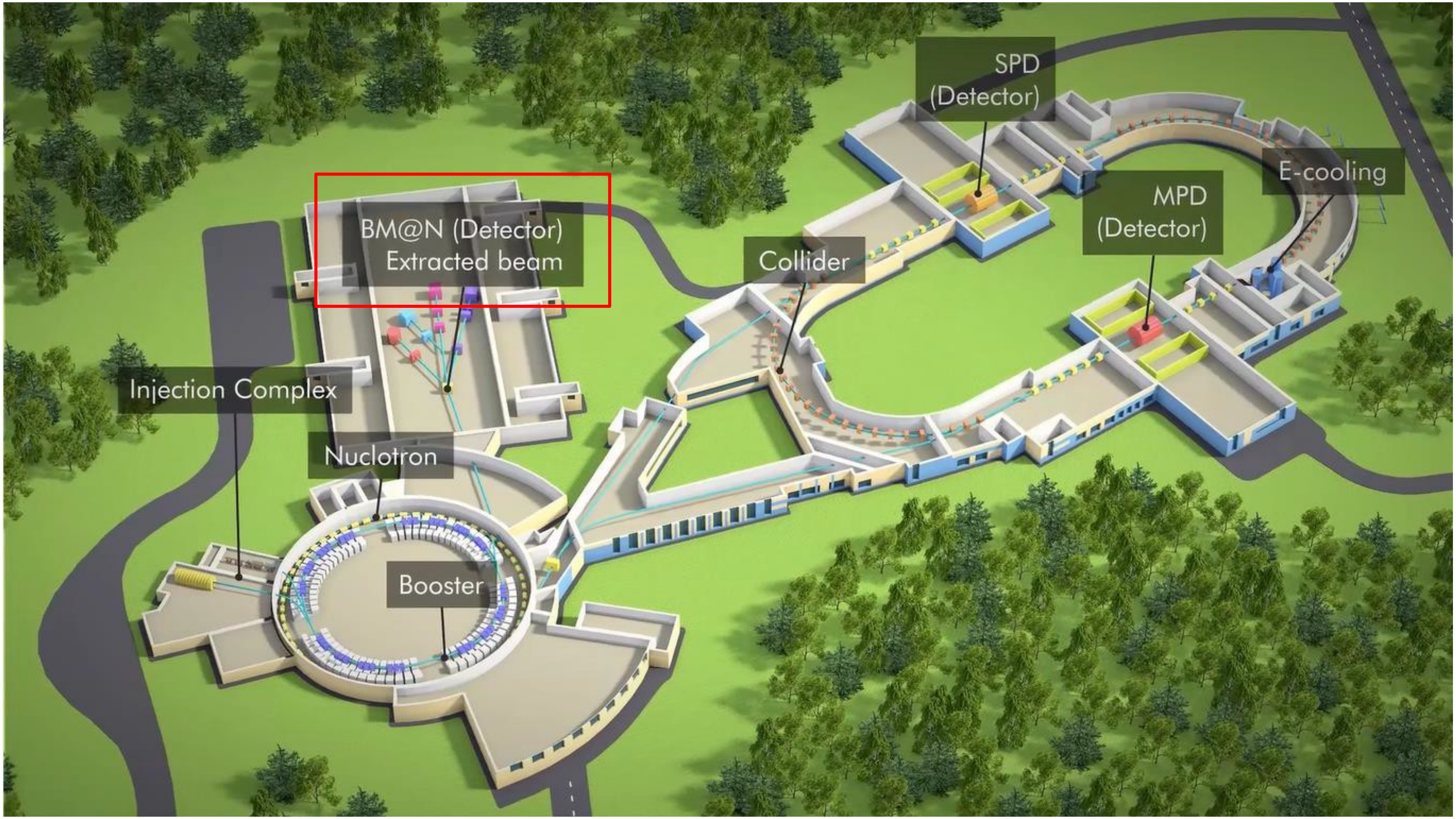
NICA accelerator complex and main experiments

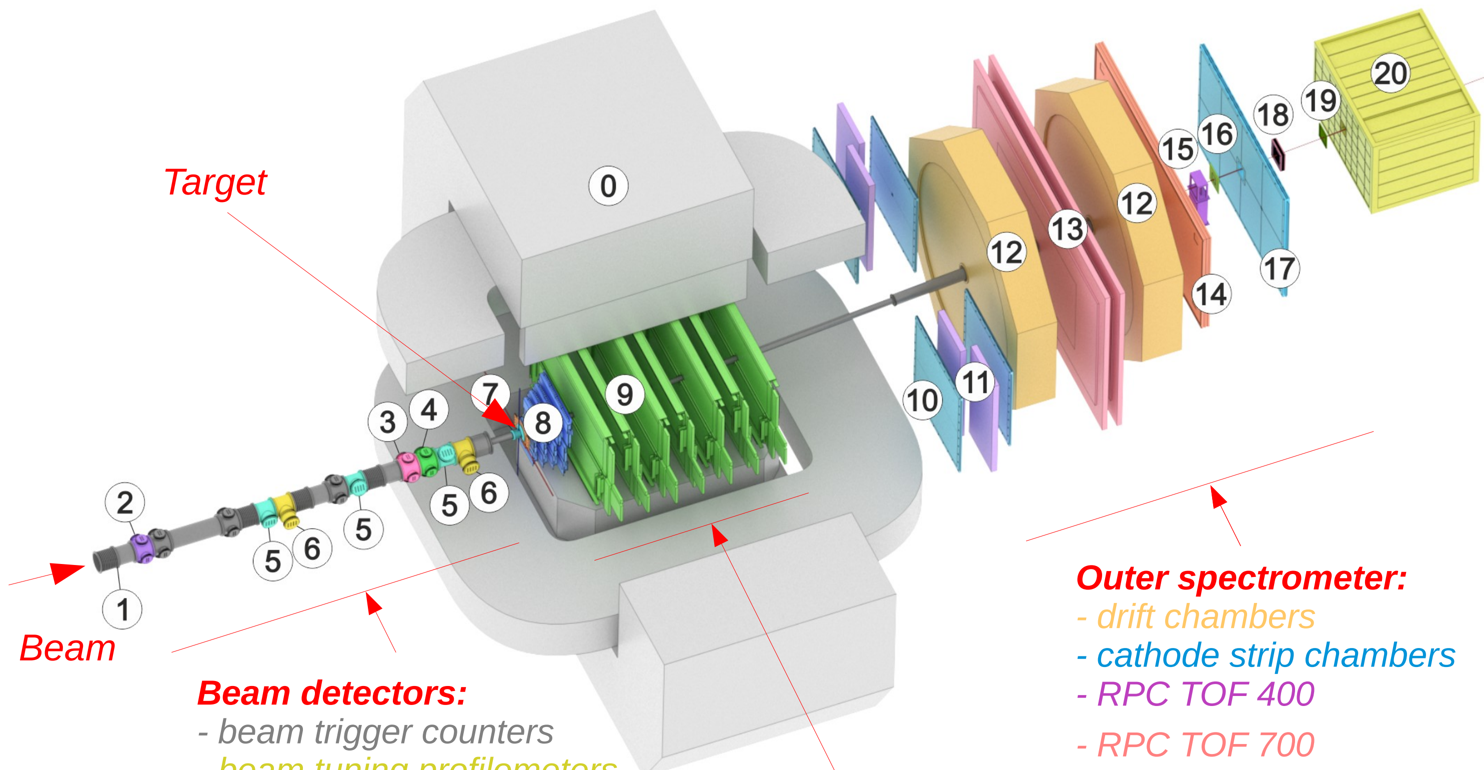


Collider beams: from p,d to ^{197}Au, ^{209}Bi
Energy: 1-3.8 GeV/u (heavy ions)
Luminosity: $\geq 10^{27}$ $cm^{-2}s^{-1}$

Extracted beams: ^{12}C, $^{36-40}Ar$, $^{78-86}Kr$, $^{124-136}Xe$, ^{209}Bi
Intensity: up to few times 10^6 1/s
Spill duration: up to 20 s

In 2023 Xe run: Nuclotron cycle 12 s; 3.8 A·GeV, spill ~2.2 s, intensity $3 \div 4 \cdot 10^5$ 1/s

Configuration of BM@N detector in ^{124}Xe run (Jan. 2023)



- Magnet SP-41 (0)
- Vacuum Beam Pipe (1)
- BC1, VC, BC2 (2-4)
- SiBT, SiProf (5, 6)
- Triggers: BD + SiMD (7)
- FSD, GEM (8, 9)
- CSC 1x1 m^2 (10)
- TOF 400 (11)
- DCH (12)
- TOF 700 (13)
- ScWall (14)
- FD (15)
- Small GEM (16)
- CSC 2x1.5 m^2 (17)
- Beam Profilometer (18)
- FQH (19)
- FHCal (20)

Beam detectors:
- beam trigger counters
- beam tuning profilometers
- beam tracker detectors

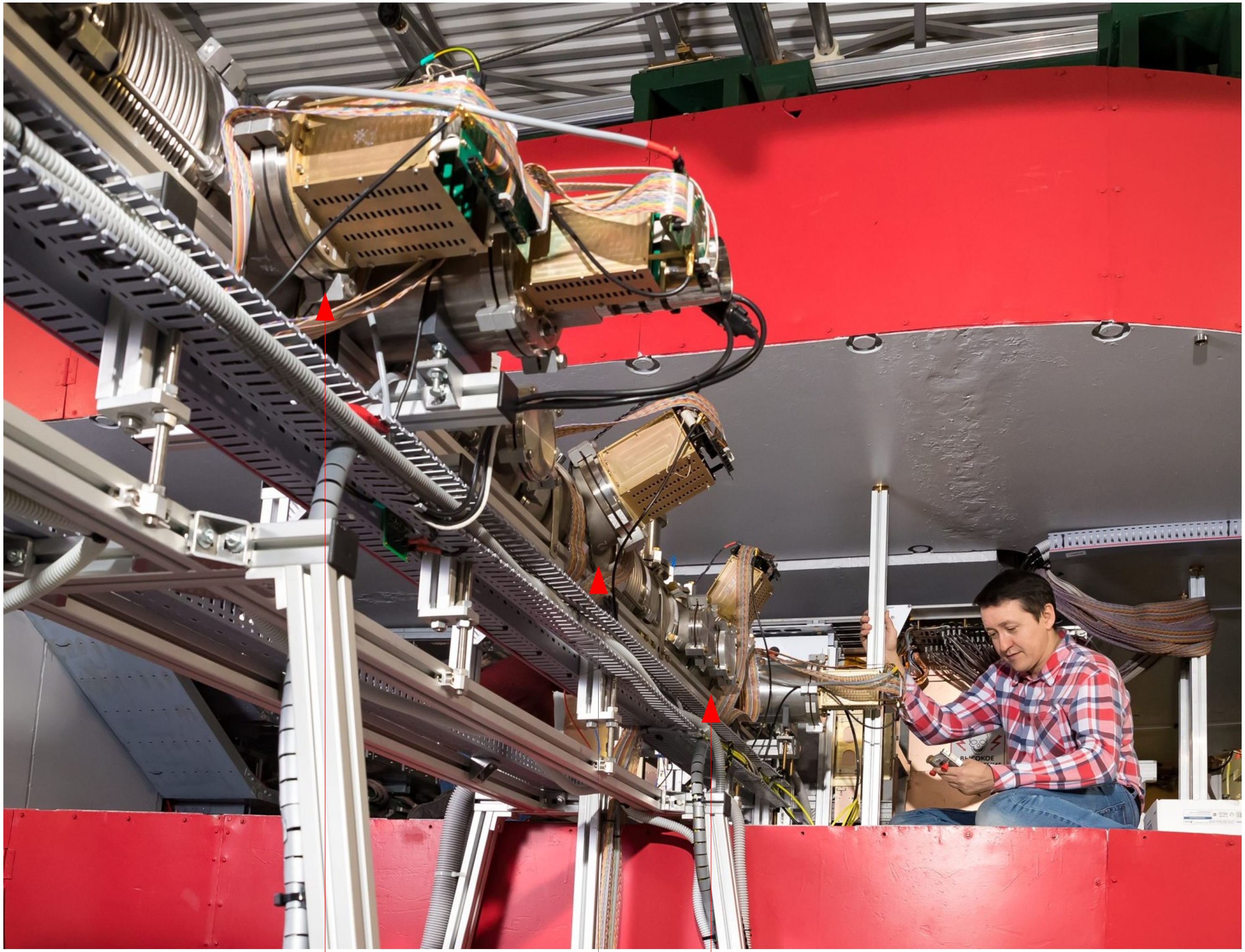
Silicon Beam Tracker

Central tracking system:
- silicon strip detectors
- GEM detectors

Outer spectrometer:
- drift chambers
- cathode strip chambers
- RPC TOF 400
- RPC TOF 700

Physics topics:
- π, K, Λ, p, d, light ions, neutrons (yield, spectra, flow, ratios);
- light hypernuclei production;
- Ξ, Ω sub-threshold production;
- particle correlations, etc.

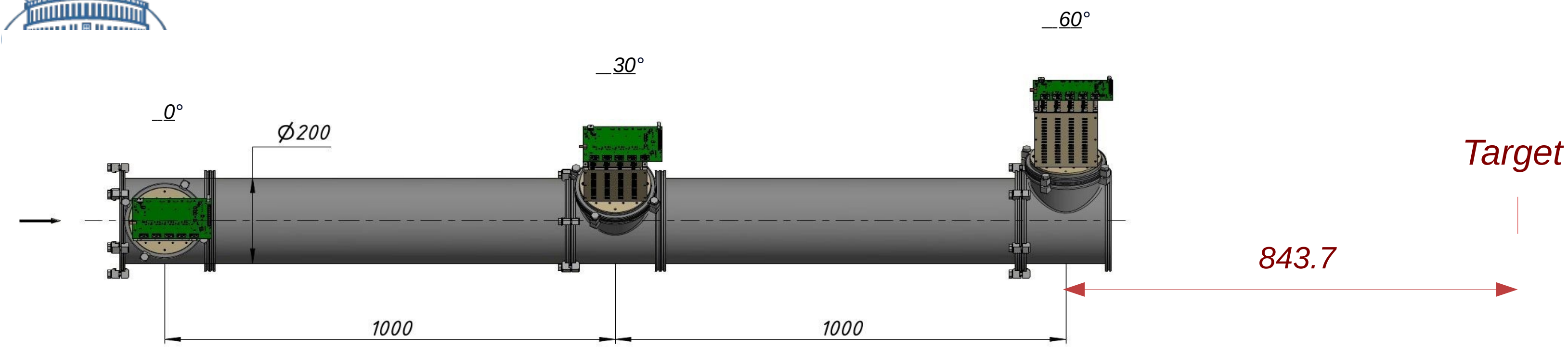
Beam tracker mounting in the vacuum line

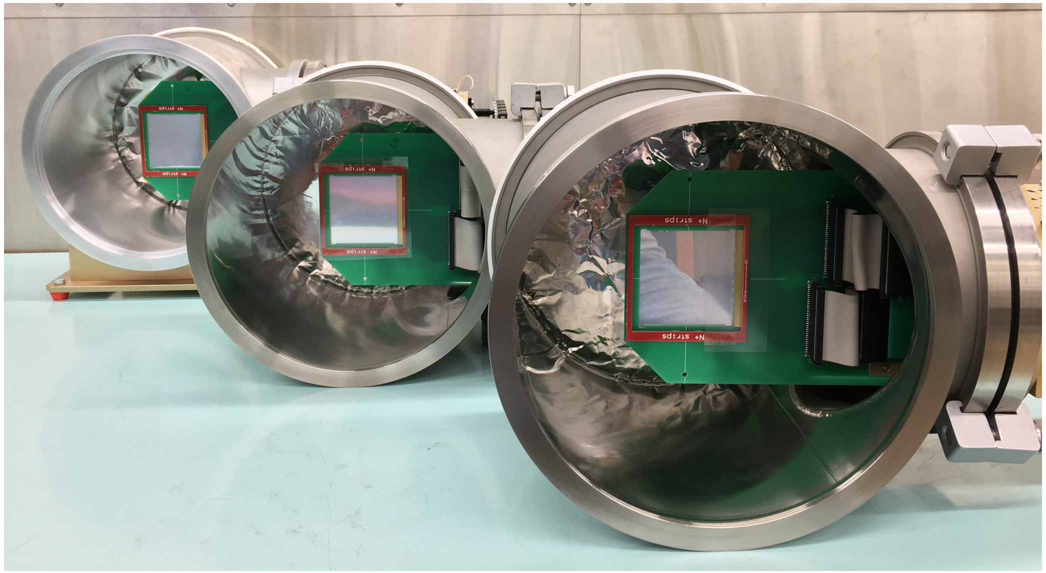


#1 #2 #3

Beam tracker stations in the beam line

Requirements and design parameters





Expected angular resolution estimated using Geant4 simulation ≈ *0.2 mrad*

Main physical tasks:

- measurement of beam ion trajectory, position and impact angles at the target;
- refinement of the primary vertex coordinates;
- reject upstream interactions by dE/dx in the last station;
- monitoring of the beam position.

Reasons to use tree stations:

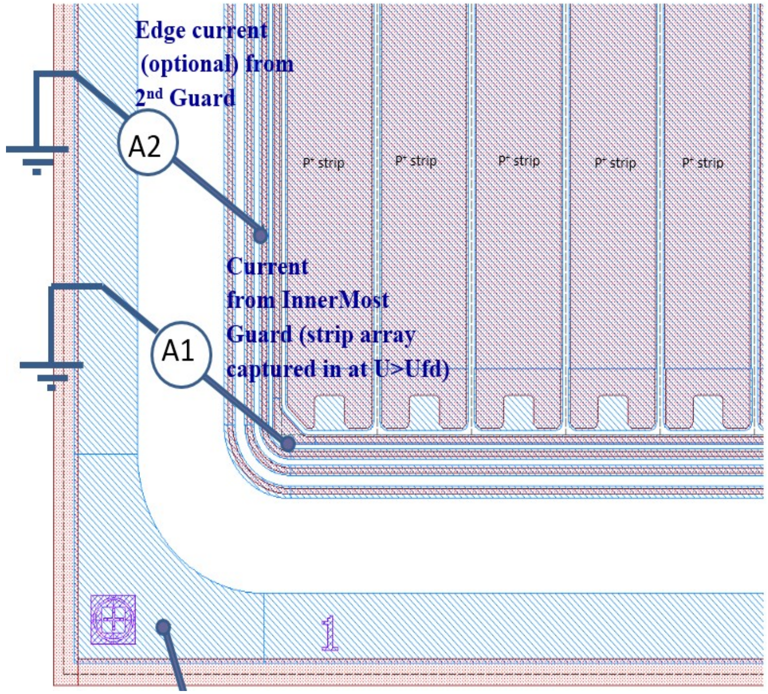
- tracks are partially in the magnetic field;
- capability to resolve hits from more than one ion (relative angles 0°, 30°, 60°).

Detector parameters:

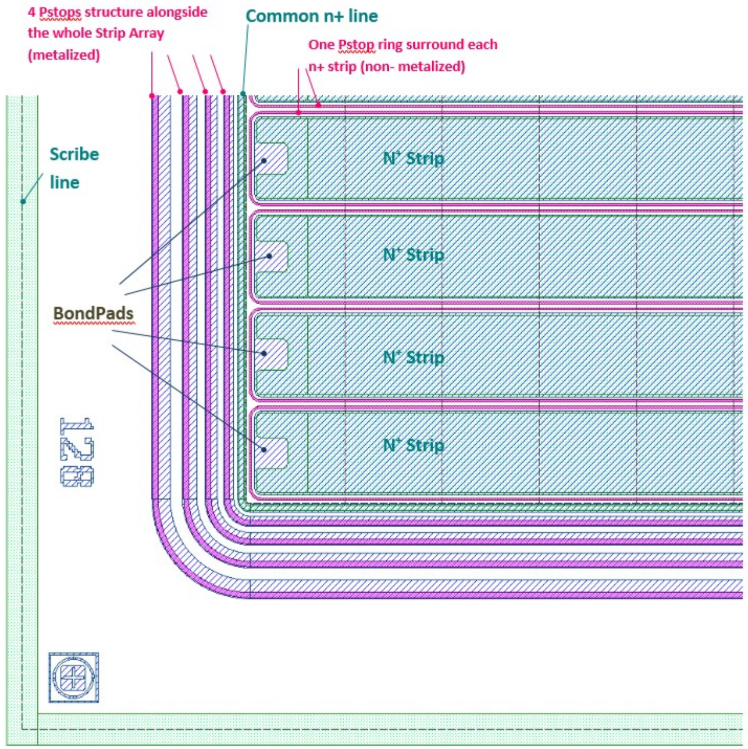
- active area should be in vacuum;
- sufficiently large size of active area 61×61 mm^2 (especially critical for the first station);
- DSSD with orthogonally oriented p+ / n+ strips;
- number of channels, 128×128 strips, 0.47 mm pitch on both sides;
- detector plane as thin as practically achievable (175 µm, manufactured in Zelenograd, Russia).

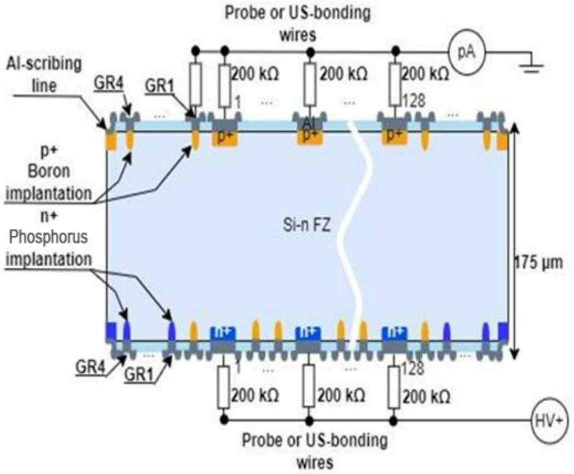
Details on DSSD planes

DSSD 128P┴N_SQ_63mm Pside Topology
(Measure Scheme/ N side isolated)



DSSD 128P┴N_SQ_63mm
Nside Topology detail





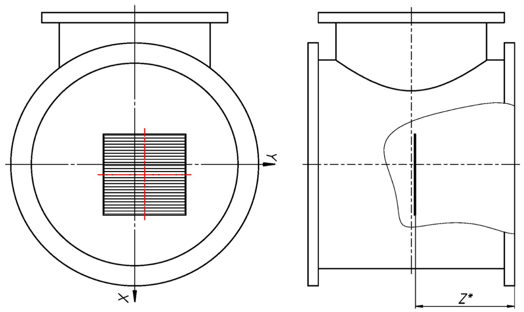
Planes are cut from 4” mono-crystalline Si wafers obtained by Float Zone method, ρ > 5 kΩ·cm;

p+ strips are made by *Boron* implantation;
n+ strips – by *Phosphorus* implantation;

Al-plated strips connected to *Au*-contact pads by ultrasonic bonding;

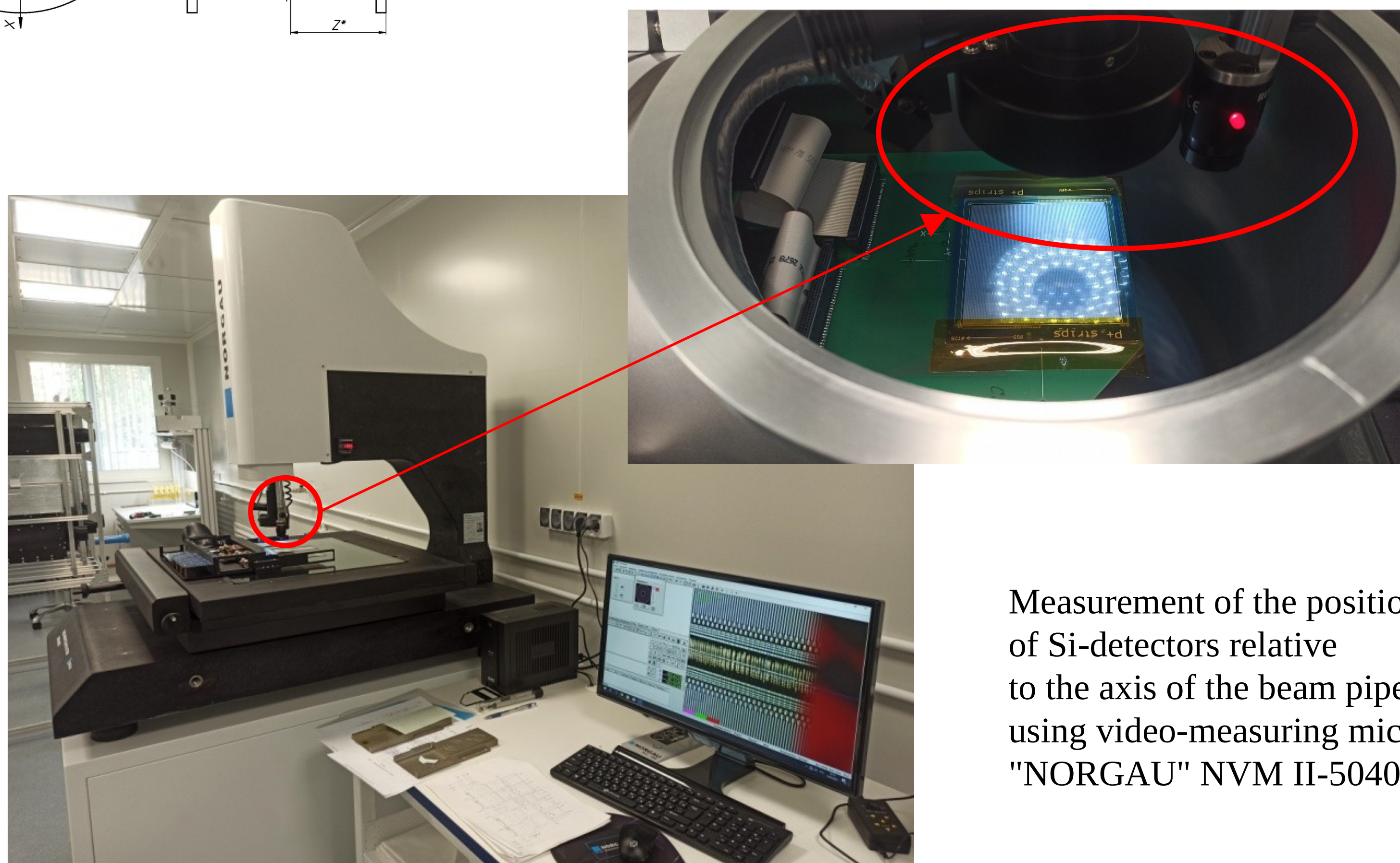
p+ side is grounded;
p guard rings around *n*+ strips.

Mechanical mount of the detectors



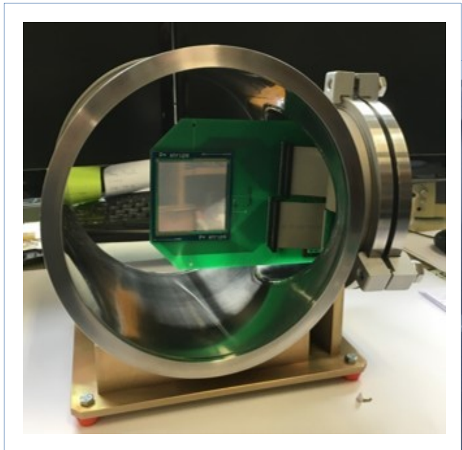
Positioning of detectors with respect to beam pipe elements is measured by *NORGAU NVM II-5040D183* video measuring microscope with accuracy ± *50 μm*

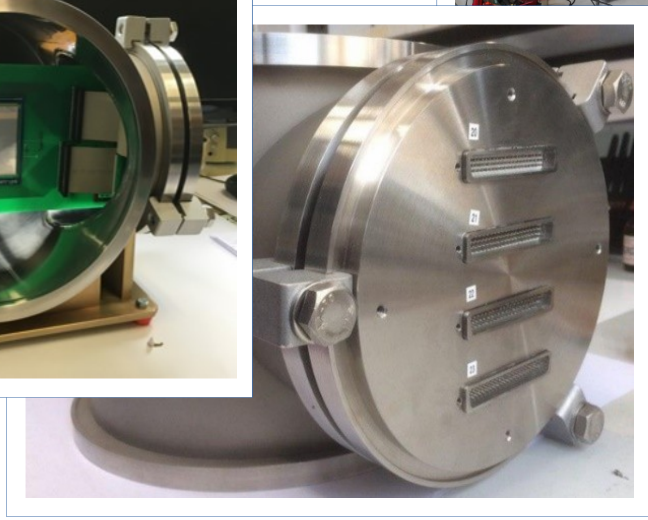
Relative shift of the last vacuum station, which accounts for the beam track curvature in the magnetic field (~2mm), was done based on the field measurements and expected beam momentum. Offline alignment corrections ≤ 2 mm.

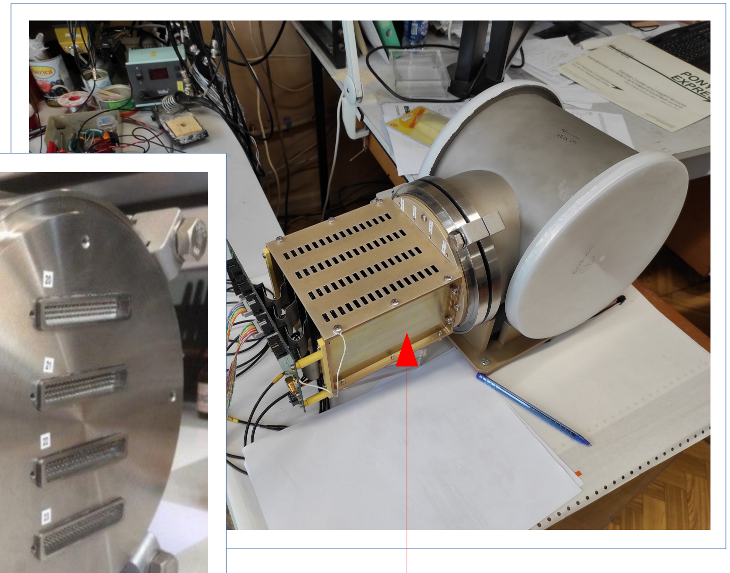


Measurement of the position of Si-detectors relative to the axis of the beam pipe using video-measuring microscope "NORGAU" NVM II-5040D.

Electronics and read-out





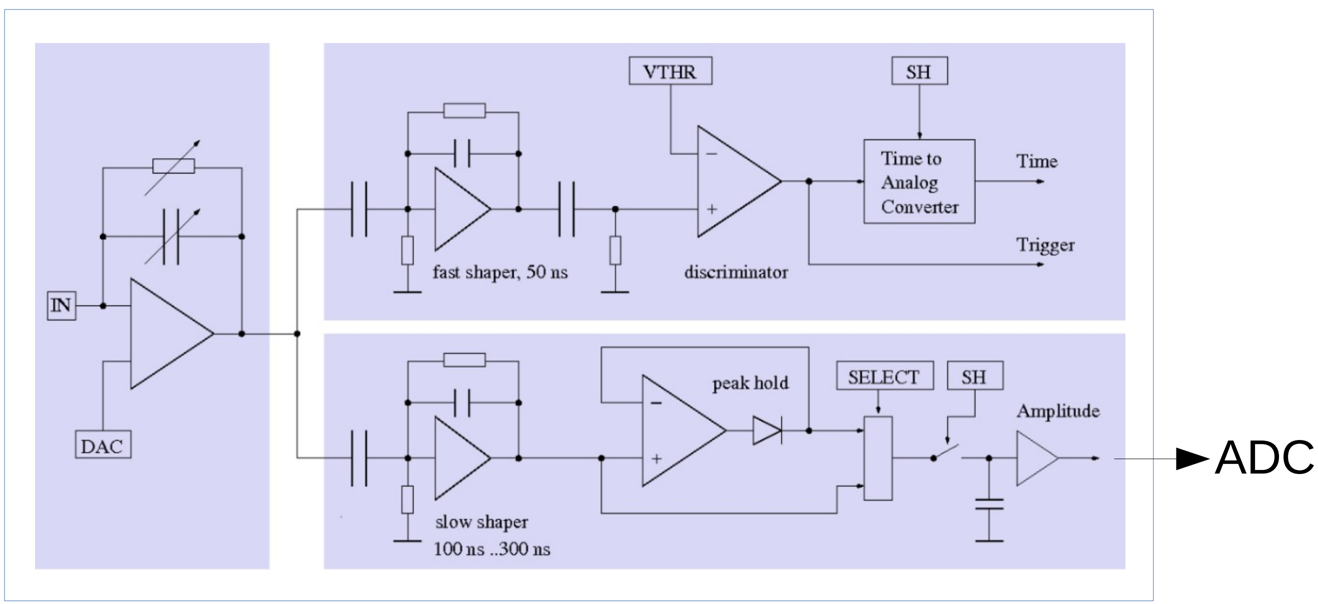


Box with FEE cards

FEE is placed outside of vacuum and far from the high radiation zone.

Based on IDEAS ASIC, programming of ASIC settings, distribution of control signals is done by a DAQ sequencer module.

External trigger mode is used in data taking during the run, and self-triggered mode is used for testing with radioactive source



Block diagram of the VATA64HDR16.2

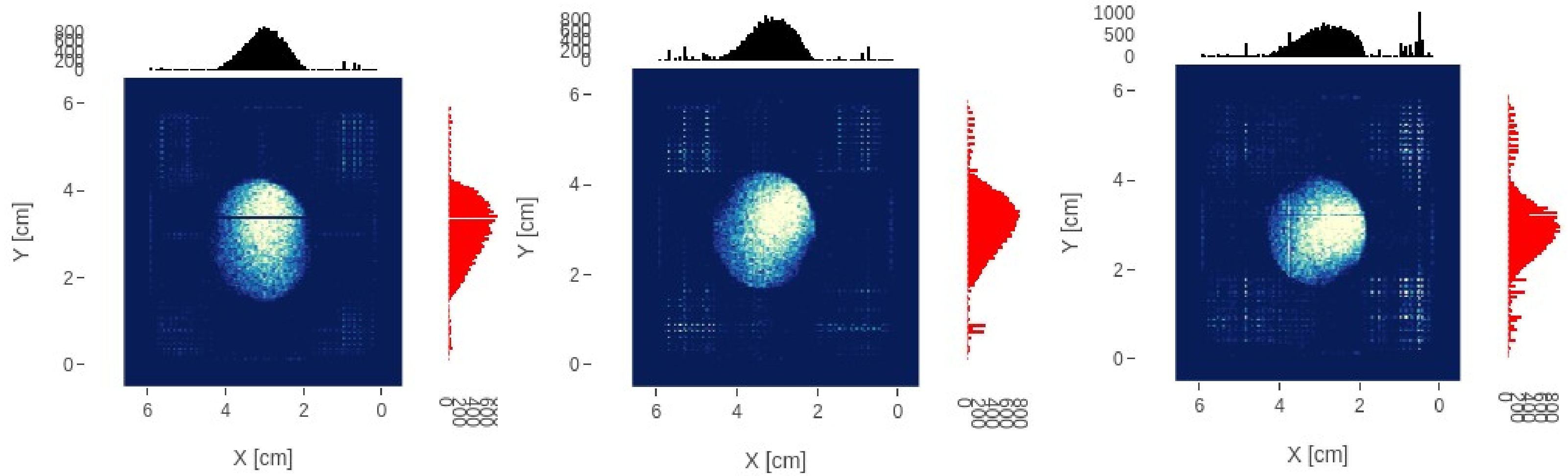
Parameters of the chip VATA64HDR16.2 (IDEAS, Norway)

No of channels	64
Input charge dynamic range	-20 pC ÷ +55 pC (Kr,Xe,Au: 4,11,18 pC)
Noise	1 fC
Trigger signal generation time	50ns
Shaping time	50,100,150,300 ns programmable
Gain	2 settings, high/low
Output	1 analog output for 64 multiplexed samples
ASIC power consumption	960 mW max.

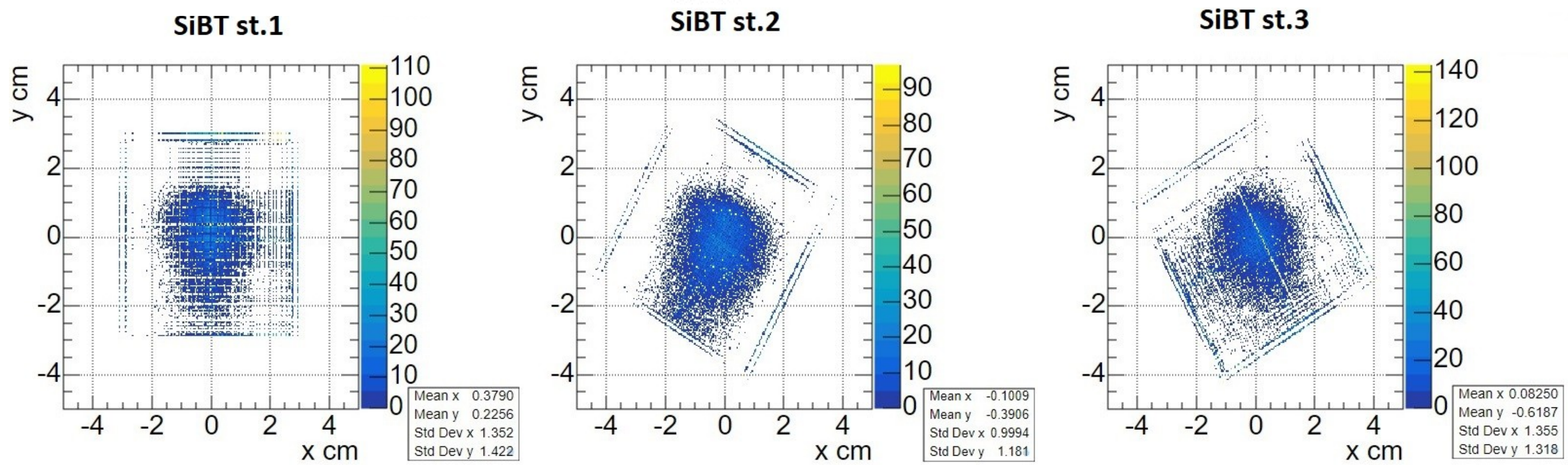
Performance in Xe+CsI run (Jan. 2023)
Beam tuning and monitoring

Station #1 Station #2 Station #3

Beam profiles in local coordinate system →



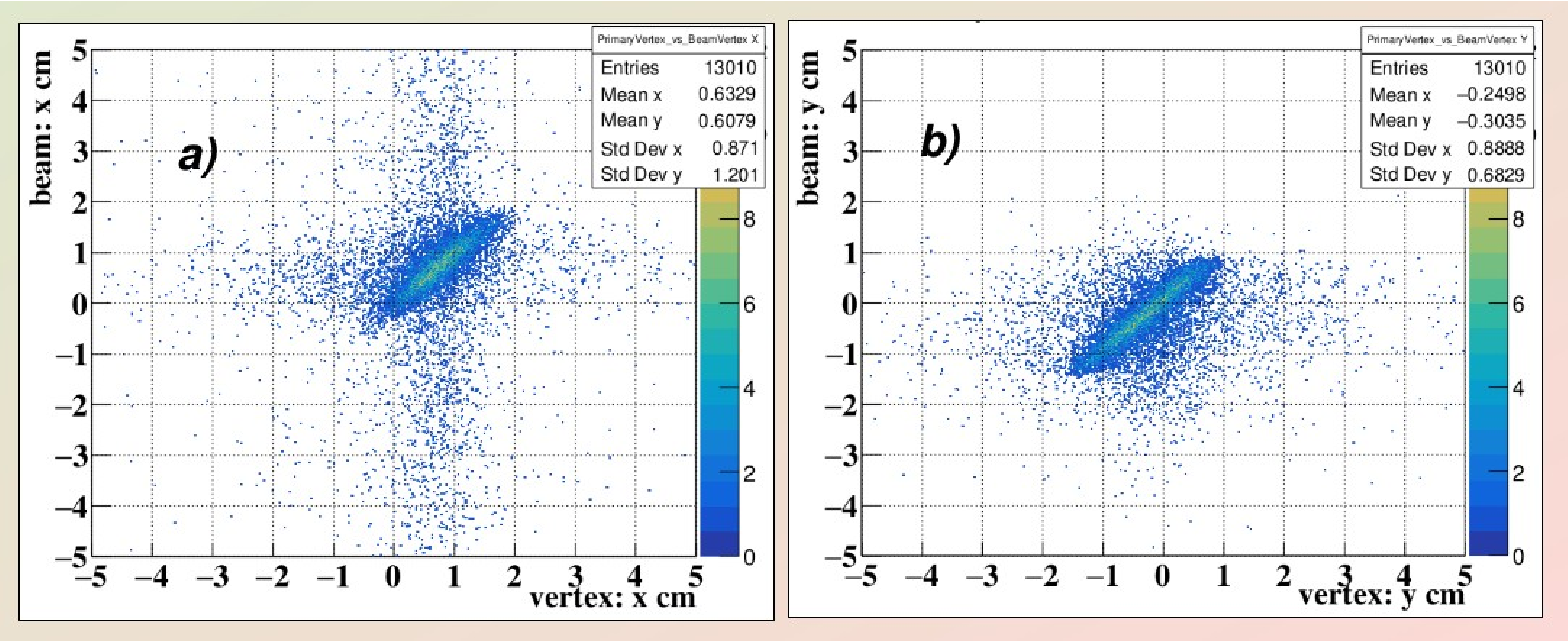
Hits distribution after offline rotation of coordinates →



Width of measured beam spot at target: σ_X = *5.3 mm*, $\sigma_Y \approx$ *6.7 mm*.

Target *ø30 mm*; Hole in the Veto Counter *ø25 mm* (accepts *~70%* of the beam)

Performance in Xe+CsI run (Jan. 2023)
Primary vertex confirmation



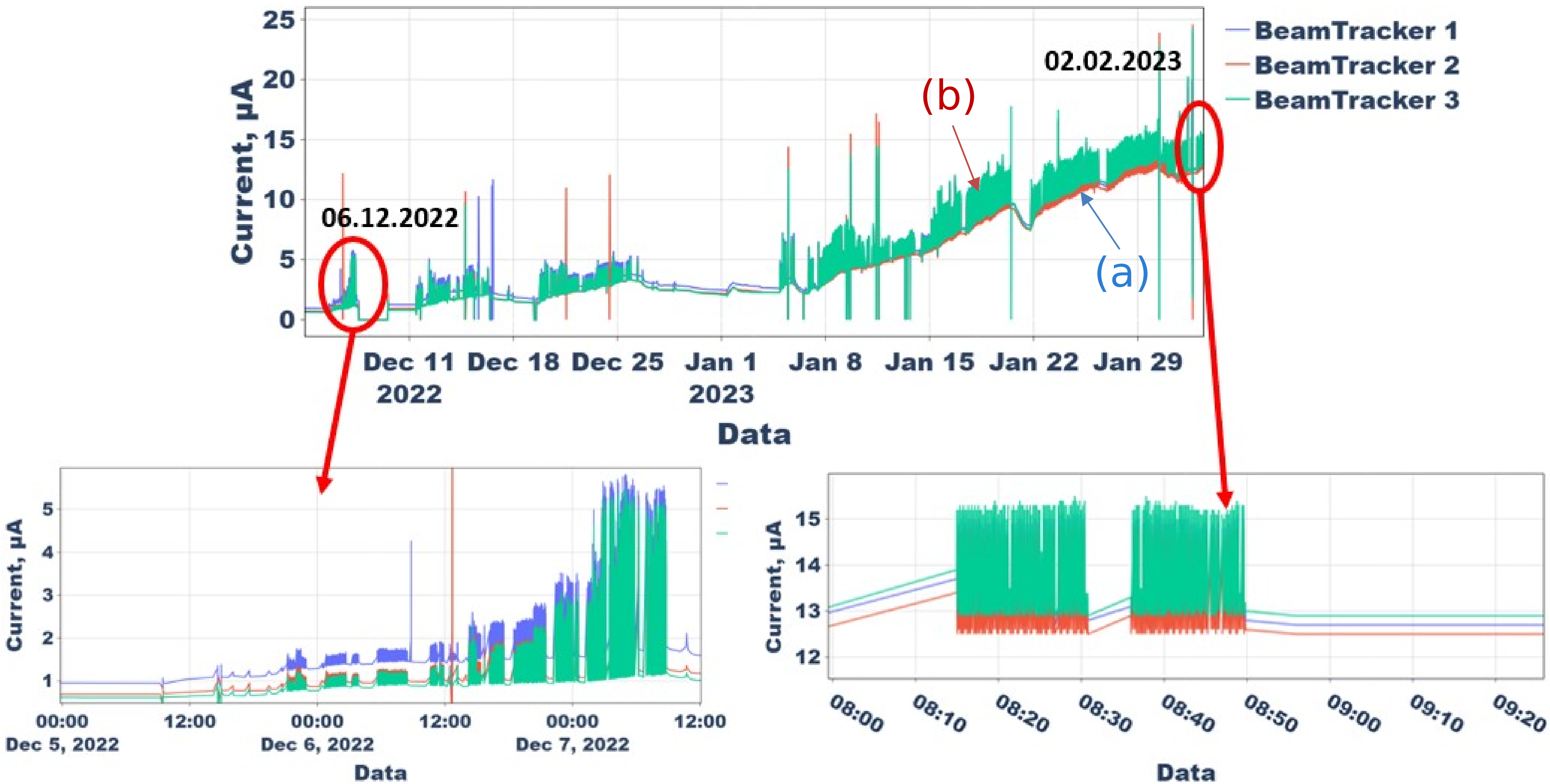
Correlation of primary vertex coordinates determined by beam tracker and central tracker
$\sigma(\Delta x) \approx 1.2$ mm; $\sigma(\Delta y) \approx 0.8$ mm;

Expected contribution from the Beam Tracker, based on Geant4 simulations is better than *0.1 mm*

Both, beam tracker and central tracker, are not yet fully optimized.

Typical amplitude resolution of Xe clusters in individual strips are 3-4%
(compared to 1% dE/dx fluctuations of 3-4 GeV/u Xe in 175 μm of Si).

Radiation damage in Xe+CsI run (Jan. 2023)
Monitoring the increase in the dark current



Run start, <I> = 0.761 µA; t = +22.5°C

Run stop, <I> = 12.7 µA; t = +26.8°C

(a) – slow (radiation damage) part I_d;

(b) – fast (ionization) part I_d;

Estimation of accumulated Xe fluence from the dark current measurements

	I_{d0}, µA/+20 V/+22.5°C 04.12.2022 (run start)	$I_{d(s)}$, µA/+20 V/+26.8°C 2.02.2023 (run stop)	$\Delta I = I_{d(s)} - I_{d0}$, µA **(at +20 °C)**
BT1	0.965	12.7	6.3
BT2	0.692	12.5	6.4
BT3	0.626	12.9	6.7
Mean	0.761	12.7	6.44

Fluence Φ_{Xe} was estimated by empirical formula:

$$\Delta I = \alpha \cdot \Phi_n \cdot V_{det}$$

$$, \alpha = 3 \cdot 10^{-17}\ A \cdot cm^{-1}, V_{det} = 61 \cdot 61 \cdot 0.175\ mm^3$$

$$\Phi_n = k \cdot \Phi_{Xe}$$

α – bulk radiation damage constant,

Φ_n – equivalent fluence of 1 MeV neutrons

$K = NIEL_n / NIEL_{Xe} = 276$ hardness coefficient

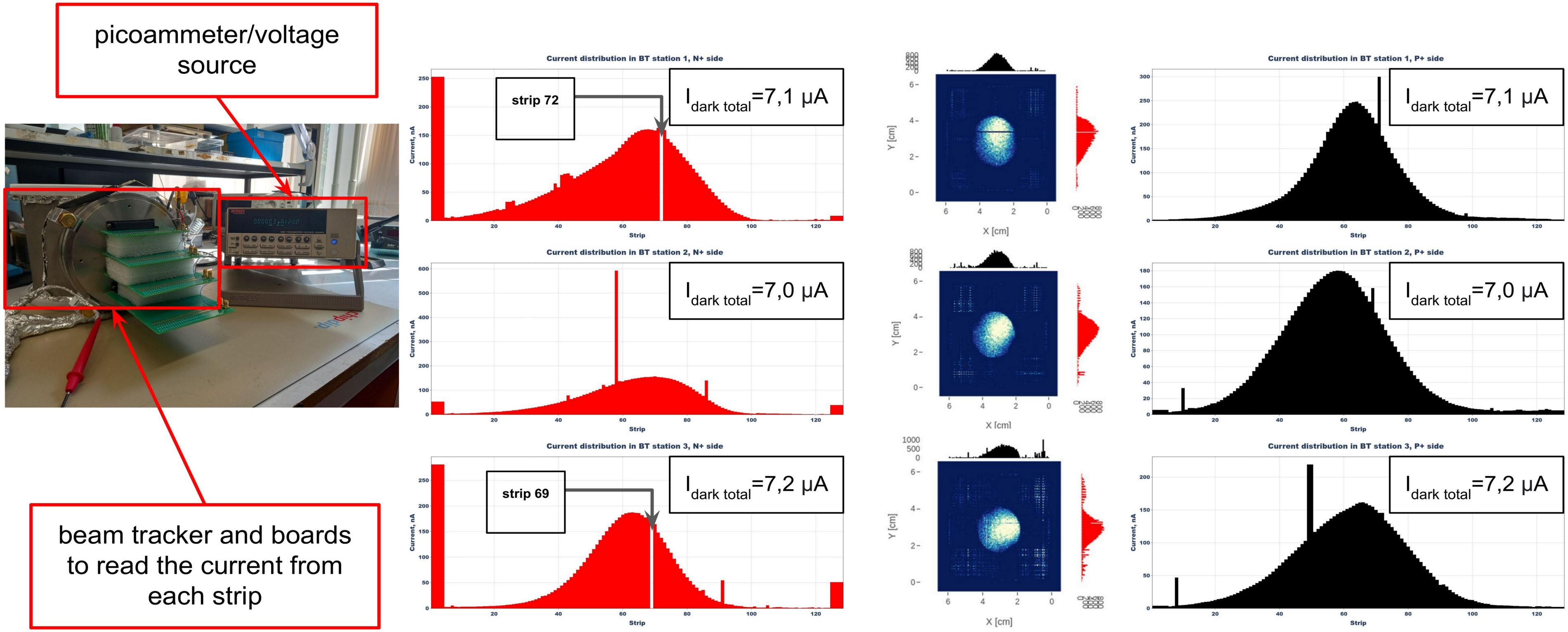
$NIEL_n = 0.0016\ MeV/g \cdot cm^2$ (ASTM Int. E722-19)

$NIEL_{Xe} = 0.46\ MeV/g \cdot cm^2$ (GEANT4+SR-NIEL)

$$N_{Xe} = \Phi_{Xe} \cdot S_{det}$$, $S_{det} = 6.1 \cdot 6.1\ cm^2$

	Fluence of 1 MeV neutrons, cm^{-2}	Fluence ^{128}Xe, cm^{-2}	Number of xenon nuclei
BT1	$3.21 \cdot 10^{11}$	$1.16 \cdot 10^{9}$	$4.33 \cdot 10^{10}$
BT2	$3.27 \cdot 10^{11}$	$1.18 \cdot 10^{9}$	$4.41 \cdot 10^{10}$
BT3	$3.41 \cdot 10^{11}$	$1.23 \cdot 10^{9}$	$4.60 \cdot 10^{10}$
Mean	$3.30 \cdot 10^{11}$	$1.19 \cdot 10^{9}$	$4.44 \cdot 10^{10}$

Dark current for each strip after Xe run

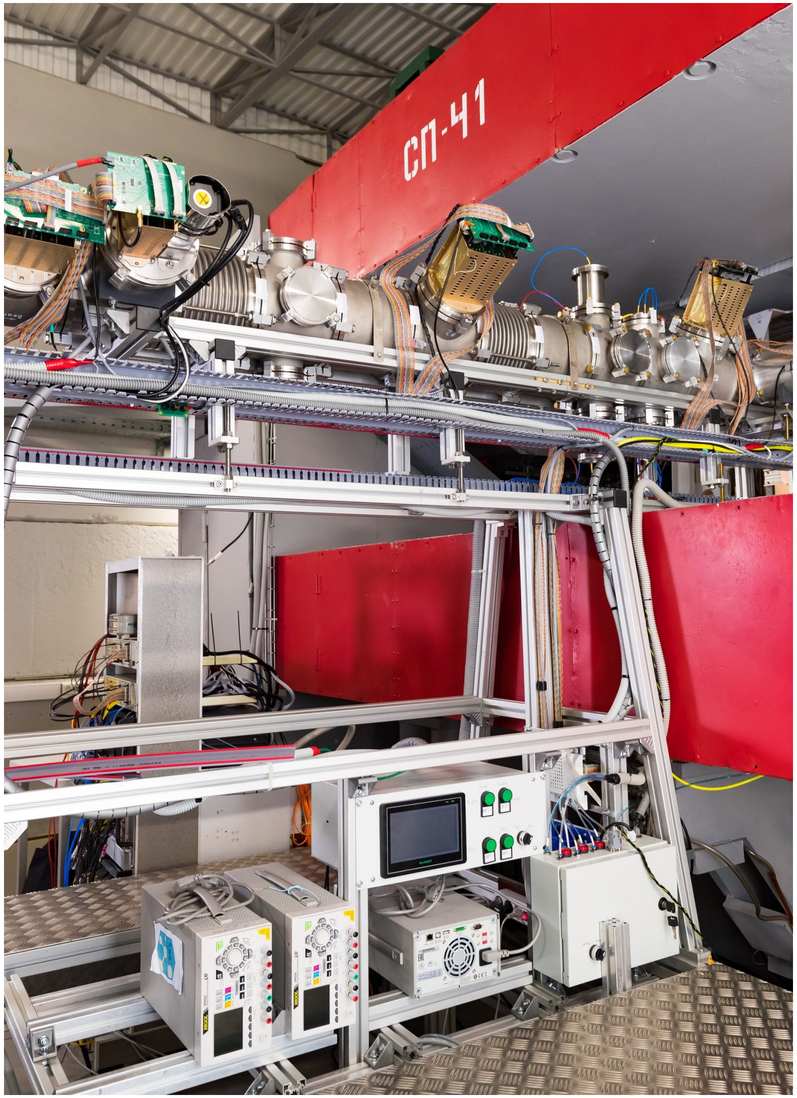


run 6705, 13.12.2022

After the run, the dark current in each strip was measured using a Picoammeter/Voltage Source Keithley 6487 at 20V (full depletion 5V).

Dark current profiles reflect Xe beam count per strip integrated over the entire run.

Additional tests with ^{241}Am *(E_α = 5.5 MeV)* placed on top of the strips with relatively high and low dark current didn't show any significant difference in signal amplitude or in the level of noise. Performance in the run (for example, dE/dx of 4 GeV/u Xe in 175 μm of Si is ~246 MeV) will be even less affected. Therefore, the replacement of the active area of the detectors is not yet needed (9 spare DSSD are available).



Summary

New silicon beam tracker system was developed for the BM@N experiment and successfully implemented and operated in the recent Xe run.

All the requirements and design parameters for the beam tracker were met.

Some radiation damage after the two-month long Xe run was observed and evaluated.

Performance of the detectors at the end of the run and the tests carried out after the run, showed that the detectors can be used in future heavy ion experiments.