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Beam tracker system for the BM@N/NICA experiment

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A new beam tracker system for BM@N experiment was developed and implemented in the recent experimental run with Xe beam. The tracker consists of three double sided silicon detectors, which determine beam ion trajectory in each event. Design parameters of the system are driven by the requirements of the experiment: ability to operate in beams of light and heavy ions, to cover relatively large transverse width of the beam profile, and to measure with sufficient accuracy the beam on position and impact angle at the target. Each detector has 61×61 mm^2 active area, 128 strips on each of the p+ and n+ sides (450 μm pitch), with orthogonal orientation of strips. The detectors are 175 μm thick, placed in vacuum, and positioned 1 m apart from each other along the beam direction. The front-end electronics of the detectors is developed based on ASIC VATA64HDR16.2 (IDEAS, Norway) with large dynamic range (-20 pC / $+50$ pC). The read-out electronics is placed outside of vacuum and is not subject to radiation damage. The detailed characteristics of the beam tracker detectors and front-end electronics are presented, as well as operational performance of the system in the experiment with Xe beam.

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1. Introduction

BM@N (Barionic Matter at Nuclotron) is the first experiment operational at Nuclotron/NICA accelerating complex. This experiment is dedicated to study interactions of relativistic ions with fixed targets [1]. The first physical run with 3.0 and 3.8 A GeV Xe beam ions and CsI target was carried out in January 2023. The schematic view of the BM@N setup in the run is shown in Figure 1. The facility consists of a dipole magnet and several detector systems to monitor the beam, identify the produced charged particles, measure their momentum, and determine the centrality of the nuclear collisions.

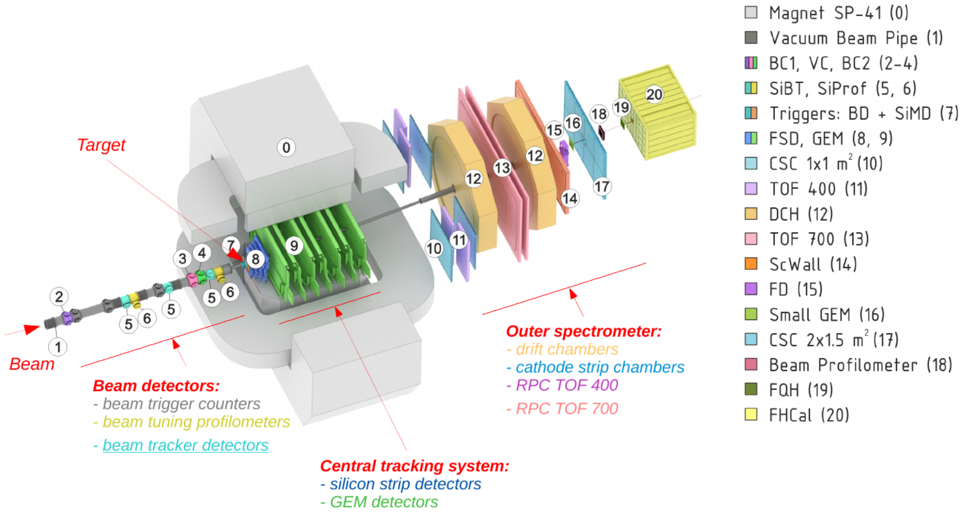

Figure 1: Schematic view of the BM@N setup in the 2023 Xe run. Main components: 0) SP-41 analyzing magnet, 1) vacuum beam pipe, 2-4) beam counters, 5) Silicon Beam Tracker (SiBT), 6) Silicon beam profilometers, 7) Barrel Detector and Target station, 8) Forward Silicon Detector, 9) Gaseous Electron Multiplier detectors, 10) Small cathode strip chambers, 11) time-of-flight system TOF400, 12) drift chambers, 13) time-of-flight system TOF700, 14) Scintillation Wall, 15) Fragment Detector, 16) Small GEM detector, 17) Large cathode strip chamber, 18) gas ionization chamber as beam profilometer, 19) Forward Quartz Hodoscope, 20) Forward Hadron Calorimeter.

Main physical tasks of the Silicon Beam Tracker (SiBT) include: measurement of beam ion trajectory, position and impact angles at the target; refinement of the primary vertex coordinates; rejection of the upstream interactions by measuring beam ion energy loss in the last station; monitoring of the beam position. SiBT consists of three identical planes based on double-sided silicon strip detectors (DSSDs) with orthogonal orientation of the strips on one side relative to the other. The sections with DSSDs are mounted as parts of the vacuum beam pipe upstream of the target. The choice of three detectors for the system is dictated by the presence of a magnetic field near the target, as well as the need to suppress false hit candidates. In the 2023 Xe run the most upstream beam tracker was placed at a distance of 284 *cm* from the target with strips oriented vertically and horizontally, each next tracker was set at a distance of 100 *cm* relative to the previous one. Also, the trackers were rotated around the beam axis by 0°, 30°, and 60°, respectively.

2. Silicon Beam Tracker design

Each SiBT station uses DSSD with dimensions of $63 \times 63 \times 0.175$ mm^3 made of high-resistivity ($\rho > 5$ $k\Omega \cdot cm$) 4-inch (100 mm) mono-crystalline silicon wafers obtained by the Float Zone method. Detectors thickness 175 μm was chosen as small as possible, taking into account the limitations of the planar technology applied to 4-inch plates. The minimum thickness of the detectors allows both to reduce the amount of material in the beam and to lower the volume of the spatial charge region, thus reducing the noise caused by radiation defects. Detectors are exposed to heavy ion beams with an intensity of up to ~ 1 MHz, therefore, decreasing the volume of the spatial charge region is very important.

Each detector has an active area of 61×61 mm^2 with strips on the p+ (boron implantation) and n+ (phosphorus implantation) sides. On each side of the detector there are 128 strips with a step of 470 μm. An insulating guard p+ ring has been created around each of the strips on the n+ side, the p+ side is grounded. Structurally, the detectors are assembled on printed circuit boards with gold pads, which are connected by ultrasonic bonding with Al-plated strips of the DSSD.

The signals from the detector strips, grouped in four bundles of 64 channels each, are sent via flat cables to 4 vacuum connectors fixed on the vacuum flange. The front-end electronic (FEE) plates for 128 p+ and 128 n+ strips are mounted on the flange outside the vacuum volume allowing to place the detector electronics outside of the high radiation zone [2]. Moreover, the FEE is available for testing and tuning, and, if necessary, can be replaced without breaking the vacuum in the beam pipe. The ASIC VATA64HDR16.2 (IDEAS, Norway) [3] was chosen for the FEE because of its large dynamic range (-20 pC – $+50$ pC) suitable for operation with highly ionizing heavy ion beams. Since a single VATA64HDR16.2 ASIC accepts up to 64 input channels, four chips are used in each of the SiBT stations. After passing through the pulse shapers, at the time defined by an external trigger, the values of signal amplitudes from 64 strips are stored in memory capacitors. After that, in sequential reading mode using an analog multiplexer, the 64 signals are transmitted for digitization into a single ADC channel. External trigger mode is used in data taking during the run, and self-triggered mode is used for testing with radioactive source.

Positioning of the detectors with respect to beam pipe elements is measured with accuracy of ± 5 μm by a NORGAU NVM II-5040D183 video microscope. Exact positioning of the stations in the experimental setup accounts for the beam track curvature in the magnetic field (horizontal shift is approximately ~ 2 mm for the station closest to the target).

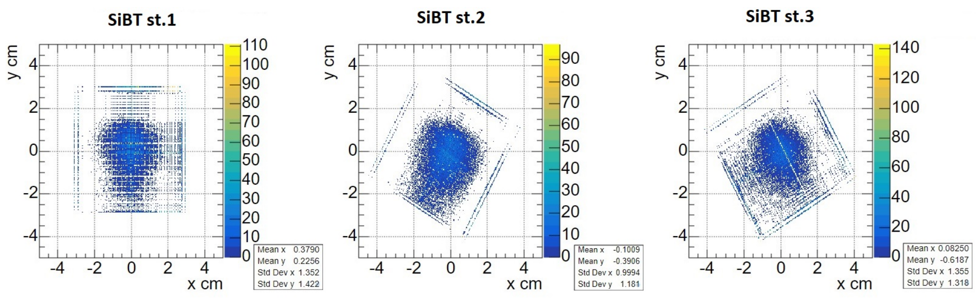

Figure 2: Two-dimensional beam profiles measured in the 2023 Xe run.

3. Silicon Beam Tracker performance in the 2023 Xe run

In the 2023 Xe run, the SiBT system was, first of all, used to tune the beam, to monitor its stability, and to measure its transverse size. Figure 2 shows the distributions of Xe ion hits in three SiBT stations. Measured horizontal (x) and vertical (y) mean width of the beam profile at the target was found to be approximately $\sigma_x = 5.2mm$ and $\sigma_y = 7.1mm$.

Using the information obtained from the SiBT system, it is also planned to refine the position of the primary interaction vertex measured in each event. Figures 3 and 4 show the correlation of the coordinates of the primary vertex obtained from the central tracker of the experiment and from the SiBT system. The two trackers display good agreement, typical deviations in measured vertex coordinates are at a level of $\sigma(\Delta x) \approx 1.2\ mm$ and $\sigma(\Delta y) \approx 0.8\ mm$.

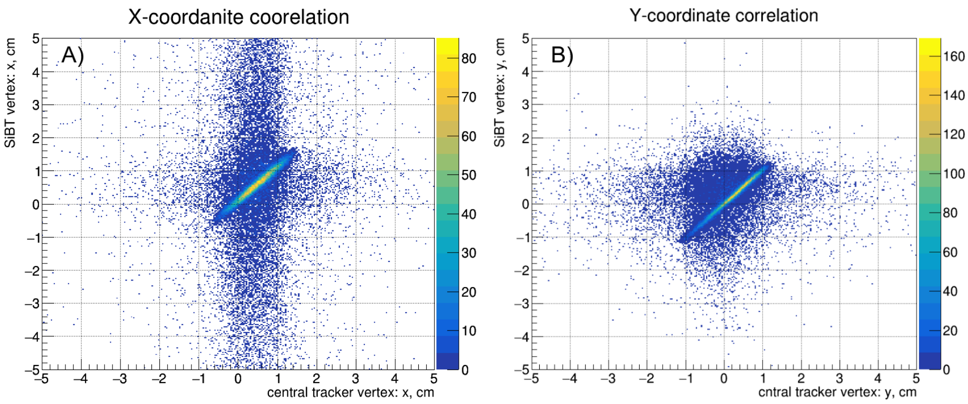

Figure 3: Comparison of vertex coordinates obtained from the central tracker and SiBT.
Correlation in: A) x coordinate; B) y coordinate.

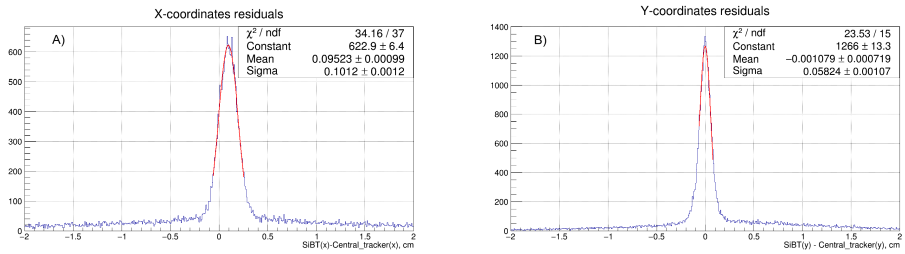

Figure 4: Comparison of vertex coordinates obtained from the central tracker and SiBT. Measured residuals: A) x coordinate; B) y coordinate.

4. Radiation damage in the 2023 Xe run and conclusion

Silicon strip detectors of the beam trackers were in the direct beam of Xe ions during the whole session of technical and physics run and, naturally, received noticeable radiation damage. Figure 5 shows the variation of detector currents in the three beam tracker stations over the run time. One can clearly see the gradual increase in the average dark current. Its value at the beginning of the

	run start, $I_{d0},\ \mu A, +22.5°C$	run end, $I_{ds},\ \mu A, +26.8°C$	$\Delta I,\ \mu A$ **(at +20°C)**
SiBT #1	0.965	12.7	6.3
SiBT #2	0.692	12.5	6.4
SiBT #3	0.626	12.9	6.7
Mean	0.761	12.7	6.44

Table 1: Average values of the dark current in SiBT detectors.

session was 0.761 μA, measured at +22.5°C; while the end of the session it was 12.7 μA, measured at +26.8°C. The values of the currents, adjusted for proper comparison to a temperature of +20 degrees Celsius, are summarized in Table1.

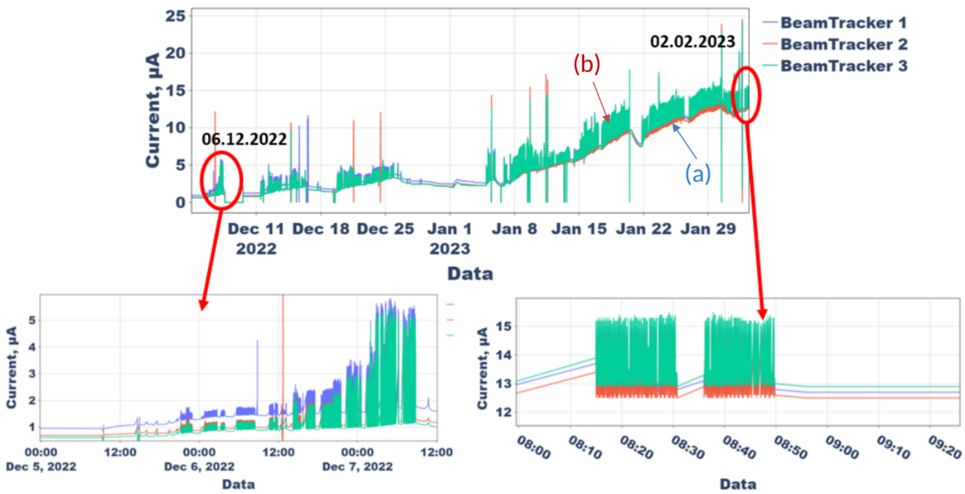

Figure 5: Variation of the reverse dark currents of silicon detectors in three SiBT stations during the run session. Current components: (a) slow, in the absence of the beam; (b) fast, during the beam spills.

On average, the dark current of the three silicon detectors increased during the run by 6.44 μA /detector/+20°C/20 V. This allows one to estimate the number of Xe ions passed through the detectors (assuming uniform irradiation of the detectors) based on the empirical formula [5]:

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

where α – bulk radiation damage constant, Φ_n – equivalent fluence of 1 MeV neutrons.
In addition, the following relation was taken into account:

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

where Φ_{Xe} – fluence of Xe ions, $k \approx 276$ – hardness coefficient (calculated using the SR-NIEL [4] GEANT4 library and using the ASTM Int. E722-19 standard as $NIEL_{Xe}/NIEL_n$).

The calculated values are presented in Table 2.

After the end of the 2023 Xe run we investigated the degree and uniformity of damage accumulated in each of the detectors in order to to evaluate whether the detectors can continue to be used in the following runs. For this purpose, the distribution of dark currents in individual strips of

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	Fluence of 1 MeV n	Fluence of 4 A GeV Xe	Number of Xe nuclei
SiBT #1	$3.21 \cdot 10^{11}$	$1.16 \cdot 10^{9}$	$4.33 \cdot 10^{10}$
SiBT #2	$3.27 \cdot 10^{11}$	$1.18 \cdot 10^{9}$	$4.41 \cdot 10^{10}$
SiBT #3	$3.41 \cdot 10^{11}$	$1.23 \cdot 10^{9}$	$4.60 \cdot 10^{10}$
Mean	$3.30 \cdot 10^{11}$	$1.19 \cdot 10^{9}$	$4.44 \cdot 10^{10}$

Table 2: Estimated equivalent fluence of 1MeV neutrons and Xe beam ions.

the detectors was measured using a specially created stand. The results are presented in Figure 6. One can clearly see the effect of the "radiation memory" of the detectors - the distribution of dark current values along the strips repeats the integral beam profile for the entire run. The maximum dark current in the beam passage region is of the order of 200 nA, which is a small value compared to a strong signal induced in the detectors by a heavy ion of the beam.

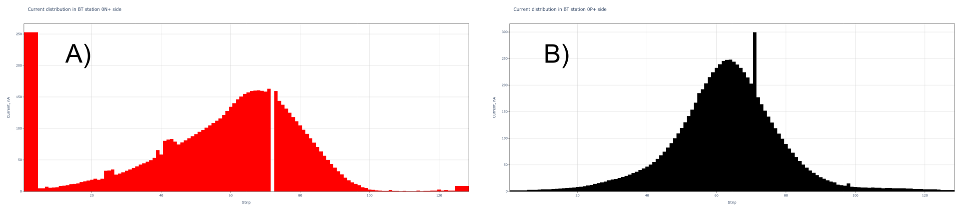

Figure 6: Dark current as a function of strip number. SiBT detector #1: A) n+ side; B) p+ side.

Summarizing, a new silicon beam tracker system was developed for the BM@N experiment and successfully operated in the 2023 Xe run. All the design requirements for the beam tracker were met. Some radiation damage accumulated in the DSSDs during the two-month long run was observed and evaluated. The tests carried out after the run showed that accumulated damage is tolerable and that the detectors do not have to be replaced and can be used in future runs.

References

[1] M. Kapishin, BM@N Coll., *Studies of baryonic matter at the BM@N experiment (JINR)*, Nucl. Phys. A 982 (2019) 967, https://doi.org/10.1016/j.nuclphysa.2018.07.014.

[2] Yu. A. Topko, S. Khabarov, N. Zamyatin et al., *The Development of Silicon Beam Tracker and Beam Profilometer at the BM@N Experiment*, Phys. Part. Nuclei 53 (2022) 398-402, https://doi.org/10.1134/S1063779622020812.

[3] IDEAS, *Integrated Circuits Products*, https://ideas.no/ideas-ic-products/.

[4] M. J. Boschini, P. G. Rancoita and M. Tacconi, *SR-NIEL–7 Calculator: Screened Relativistic (SR) Treatment for NIEL Dose. Nuclear and Electronic Stopping Power Calculator*, (ver. 2014) https://www.sr-niel.org/.

[5] A. I. Shafronovskaia, N. I. Zamyatin and A. E. Cheremukhin, *Method of measuring fast neutron fluence using the planar silicon detectors*, in proceedings of *24th Russian Particle Accelerator Conference, RuPAC 2014*, 272-274.

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