The Status of the Beam Loss Diagnostics System for the SKIF Synchrotron Light Source

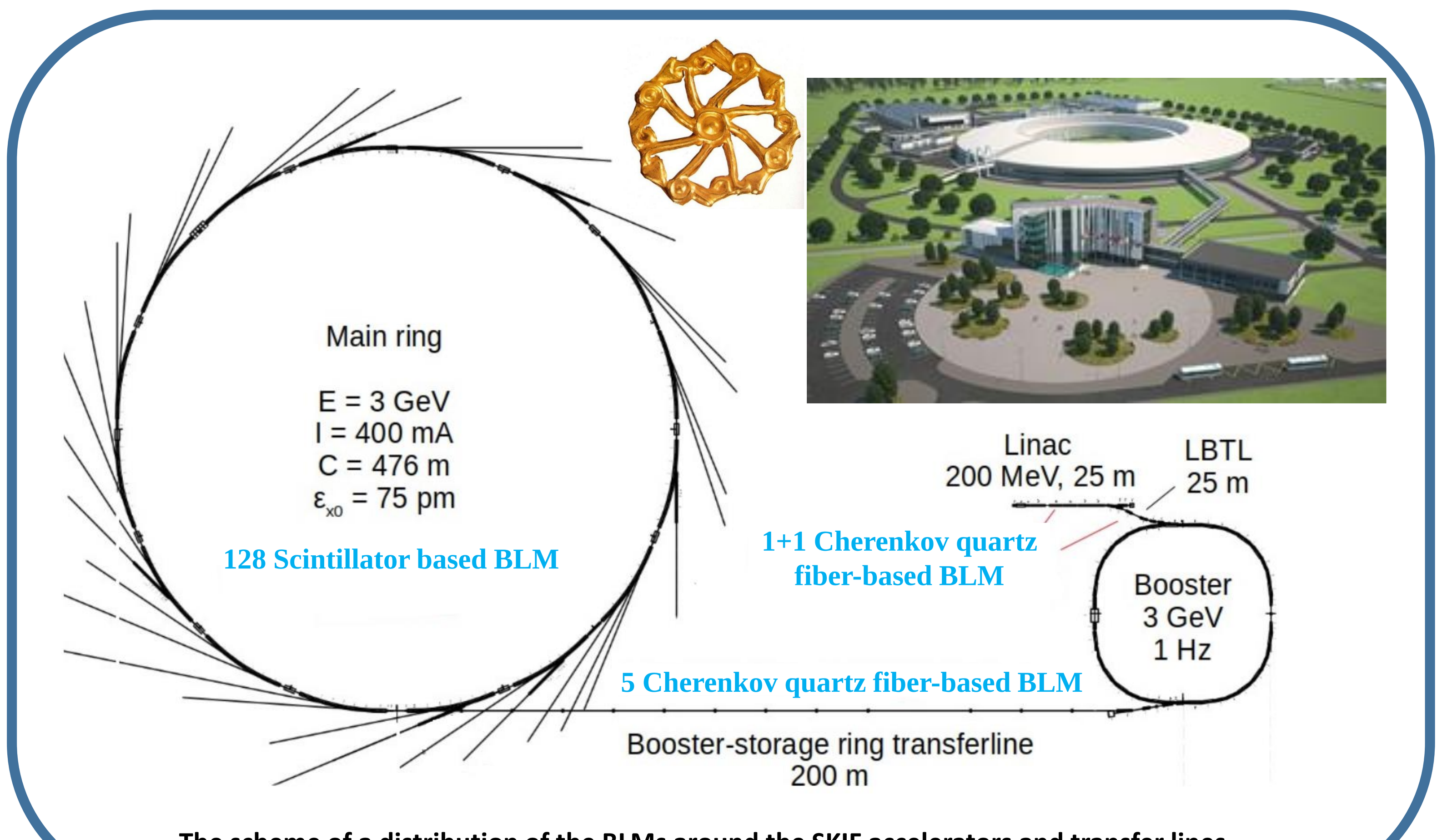
O.I. Meshkov, L. B. Fomin, A.D.Khilchenko, Yu. I. Maltseva, Ma Xiaochao[1], E.A.Puryga, P. V. Zubarev,

Budker Institute of Nuclear Physics, Novosibirsk, Russia

[1]National Synchrotron Radiation Laboratory, Hefei, China

Abstract

The Siberian Ring Photon Source (SKIF) is a fourth-generation synchrotron light source that operates at a beam energy of 3 GeV [1-3]. In order to ensure the reliable operation of the accelerator, a beam loss diagnostics sys-tem will be implemented [4]. For the linear accelerator, linear accelerator-to-booster and booster-to-storage ring transfer lines, fiber-based Cherenkov beam loss sensors will be used. Multi-mode quartz fibers and photo multiplier tubes (PMTs) will provide spatial resolution for this diagnostic system at a level of about 1 meter. The storage ring will be equipped with 128 scintillation-based detectors with acquisition electronics that are placed around the circumference of the ring. These detectors will be able to measure beam losses both during beam injection and during regular SKIF operations for SR users. Since SKIF will operate in different working modes, the BLMs system will require high sensitivity, a large dynamic range, and sophisticated electronics. The paper describes the design of both types of beam line magnets (BLMs) and the choice of their positioning around the storage ring. It also discusses the final design of the acquisition electronics, the tests of the BLMs and the current status of diagnostics.



The scheme of a distribution of the BLMs around the SKIF accelerators and transfer lines

CHERENKOV FIBER-BASED BLM (CBLM)

CBLMs are applied at the straightforward sections of the accelerator's complex, such as the linac and transfer lines. Electrons lost in the accelerator collide with the vacuum wall producing high-energy secondary electrons that travel at speed close to the light speed, which exceeds the speed of light in the quartz. When these secondary electrons pass through the quartz fiber, they generate Cherenkov radiation. The CR propagates upstream and downstream along the optical fiber and can be detected by a photodetector at both ends of the fiber [5]. The main features of the Cherenkov BLMs have been studied previously. Two PMT are used to convert optical signal into an electrical signal are installed at the ends of the fiber (Fig. 1). Upstream measurements provide better monitor spatial resolution while downstream measurements offer better sensitivity of the monitor (Fig. 2).

The 5 GHz ADC will be used for signal acquisition. By measuring the position and intensity distribution of Cherenkov radiation in the fiber can, we can map beam losses. We use PMT Hamamatsu, model R1924A with a spectral sensitivity between 300 and 600nm and a temporal resolution of 1.5 ns, which is sufficient for obtaining the required spatial resolution of about 1 m.

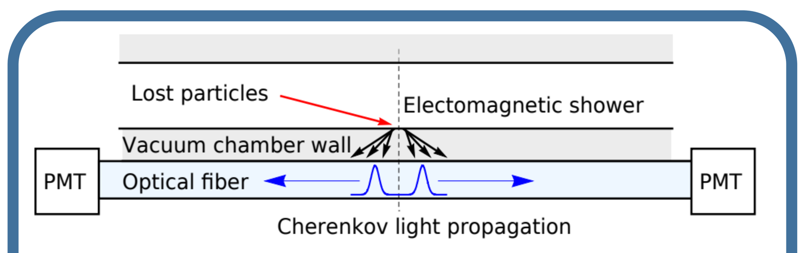


Figure 1: The layout of the CBLM.

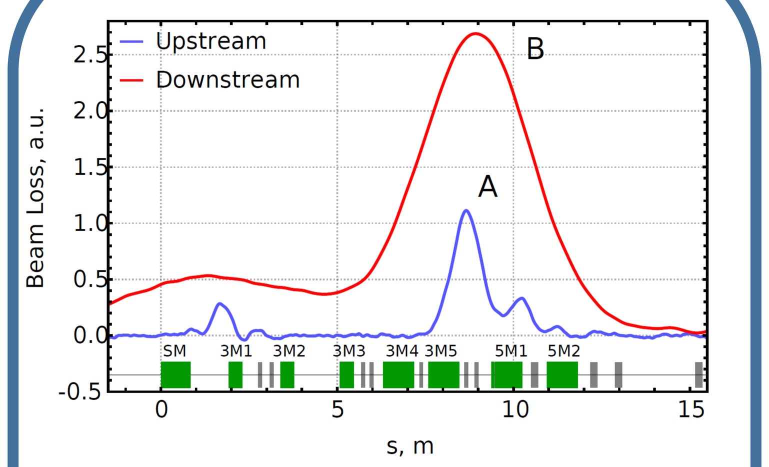


Figure 2: Upstream (blue) and downstream (red) losses distributions of the electron beam in the transfer line between the BINP facilities acquired by CBLM.

ADC for CBLM

The ADC105000 recorder (Fig. 3) is designed to build multichannel systems for capturing the shape of short pulse signals (lasting from a few nanoseconds to a few hundred nanoseconds) with a low repetition rate (kilohertz or lower). It has a sampling frequency of 5 GHz. Fig. 3 demonstrates the appearance of the modules. An example of its application is in the diagnostics of particles losses in accelerators using a fiber-optic sensor. It is also used to measure the local temperature and density values of the electrons in plasma using Thomson scattering. The main parameters of the ADC are listed in the Tab. 1.

Figure 3: The 5 GHz ADC for acquiring of signals from the PMT of the CBLMs.

Table 1: Technical specifications of the CBLM's ADC (Fig. 3)

Parameter	Value
Number of measuring paths	2/4
ADC bit rate	14
Sampling rate	5 GHz
Bandwidth of measuring signal.	0 – 150 MHz
Amplitude conversion scale	From 0.1V to 4V in 1 dB increments
Input resistance	50 Ohm
Trigger amplitude	2 – 5 V
Trigger input resistance	50 Ohm
Record duration	800 ns

SCINTILLATOR BASED BLM (SBLM)

SBLM consists of a plastic scintillator combined with a PMT. When shower particles (e−, e+, and γ), pass through the scintillator, they cause the scintillation to occur (Fig. 4). To maximize light output, the scintillator surfaces are covered with a Tyvek paper to reflect the light back. A polystyrene-based scintillator SC-205 (produced by IHEP, Protvino, Russia) has been selected. This material has a light output equivalent to 66 % of anthracene and a decay time of 2.5 ns, while also being cost effective (Fig.4).

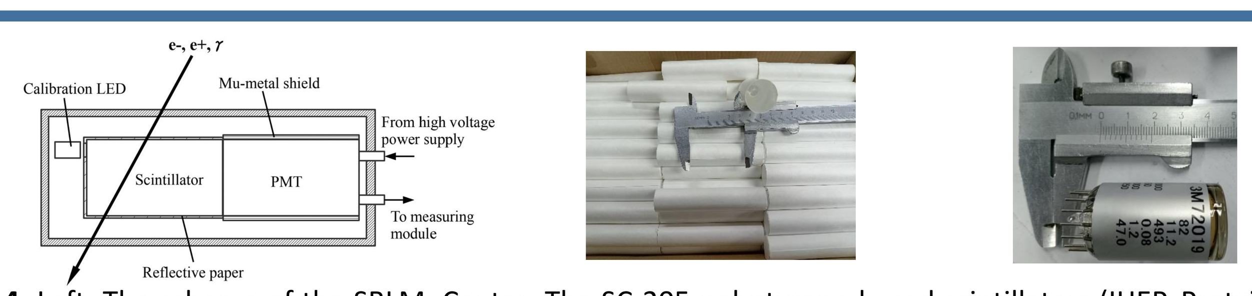


Figure 4: Left: The scheme of the SBLM. Center: The SC-205 polystyrene-based scintillators (IHEP, Protvino, Russia). Right: PMT R1924A Hamamatsu.

Mu-metal shielding, along with vertical orientation of the PMT will protect the device from the magnetic fields. The SBLM will be housed in a 3 mm-thick steel enclosure, which will protect it from the background radiation induced by the scattered SR. The maximum photon energy produced by the SR is approximately 100 keV, and Monte Carlo simulations have sown that a 3 mm thick steel housing is sufficient to prevent detection of scattered x-rays and to maintain the sensitivity of the monitor. Since the plastic scintillator has a moderate radiation hardness of up to about 10^5 Gy, the SBLM's signal level will decrease over time. A correct measurement of the signal level requires a periodic calibration of the SBLM signal with respect to radiation damage. This will involve attaching a blue LED to the free end of the scintillator (Fig. 4).

The FLUKA simulation of the beam loss scenarios has allowed us to determine the optimal number of SBLMs and their optimal placement in the SKIF storage ring. In order to estimate the BLM response, we have simulated the loss scenarios with a 3 GeV electron beam colliding the vacuum pipe at a small incident angle relative to the equilibrium orbit. The number of emitted photons ranges of 10^2–10^4 per primary particle (Fig. 5).

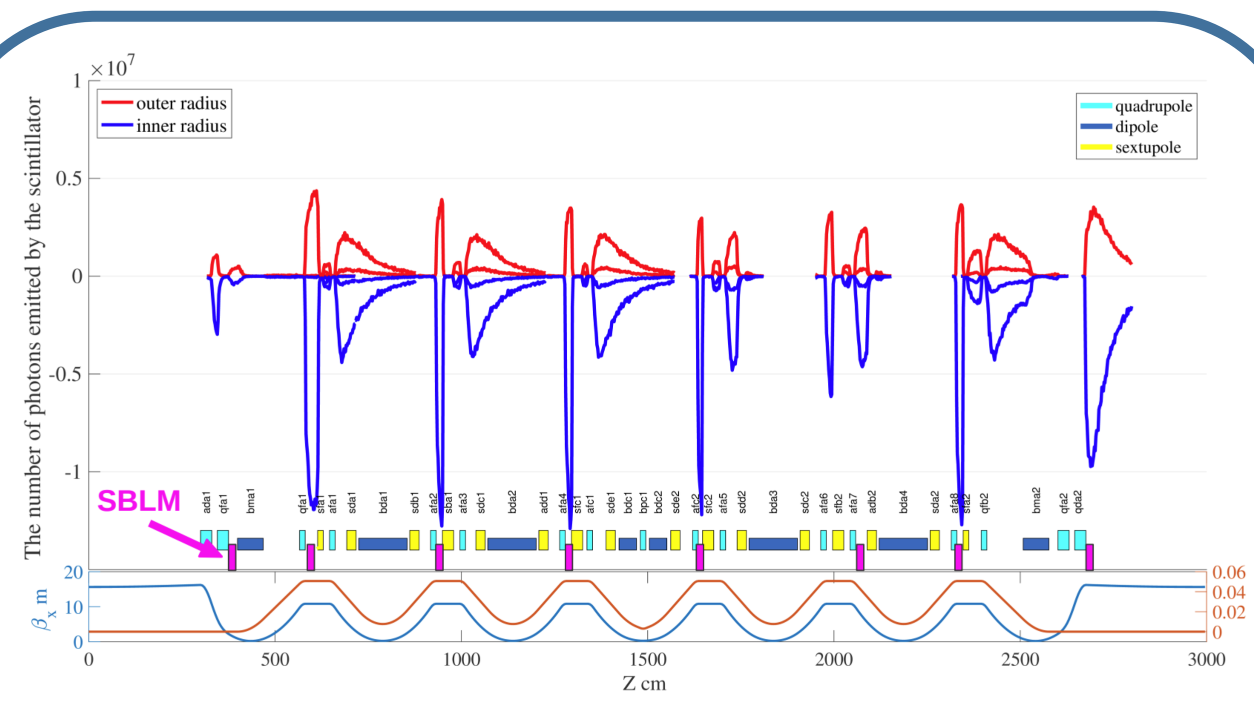


Figure 5: Simulation of the distribution of optical photons in the scintillators over the SKIF storage ring superperiod: at the outer (red) and inner one (blue, plot inverted) radii of the storage ring, with the SBLMs indicated in magenta.

To achieve the optimal diagnostic efficiency, we propose placing eight SBLMs per superperiod at the positions of the most significant shower peaks on the outer radius of the storage ring (Fig. 6). Due to the 16-fold symmetry of the ring [6], 128 SBLMs detectors will be installed in total in the SKIF storage ring. Unfortunately, we had to place the SBLMs at the outer radius of the main ring due to lack of space in the accelerator tunnel. Nevertheless, the sensitivity of the SBLMs is sufficient for reliable beam loss measurements .

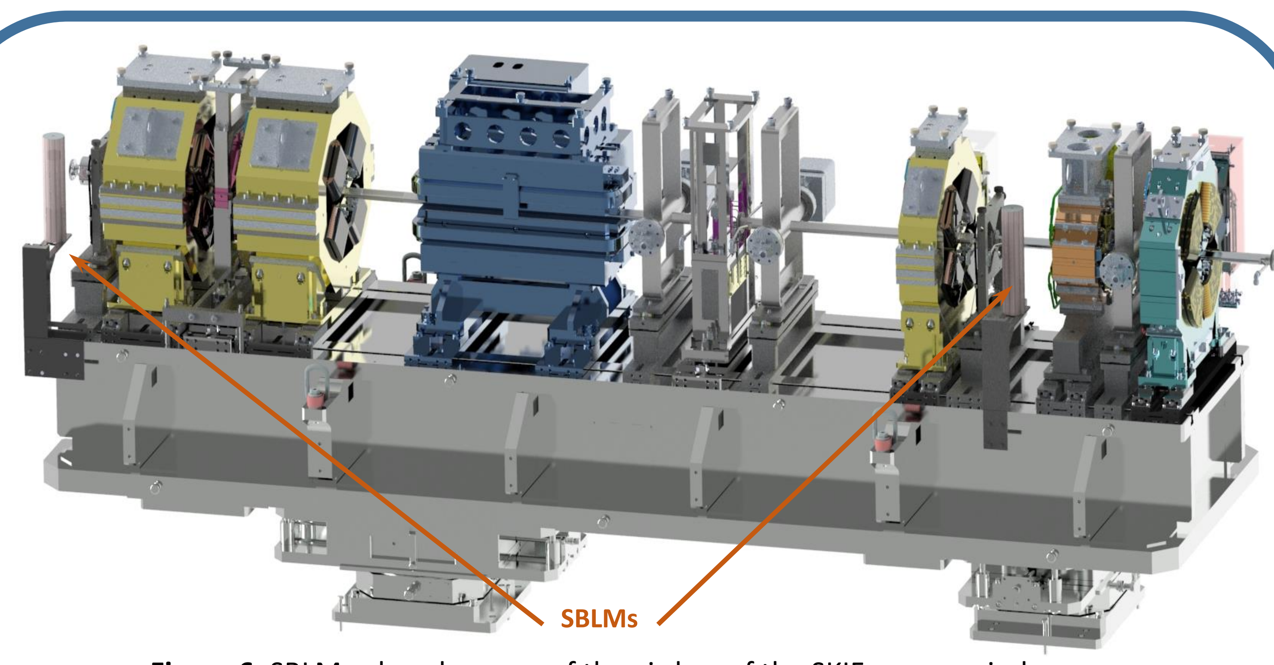


Figure 6: SBLMs placed on one of the girders of the SKIF superperiod

ADC for SBLM

From a functional point of view, the ADC14250/4 four-channel recording module is an example of the latest generation of devices designed for building data collection systems in research facilities at the INP SB RAS. These systems are used for research in plasma physics and high energy physics. The device is based on a 14-bit analog-to-digital converter (ADC) with a maximum sampling rate of 250 MHz (Fig. 7, Tabl. 2).

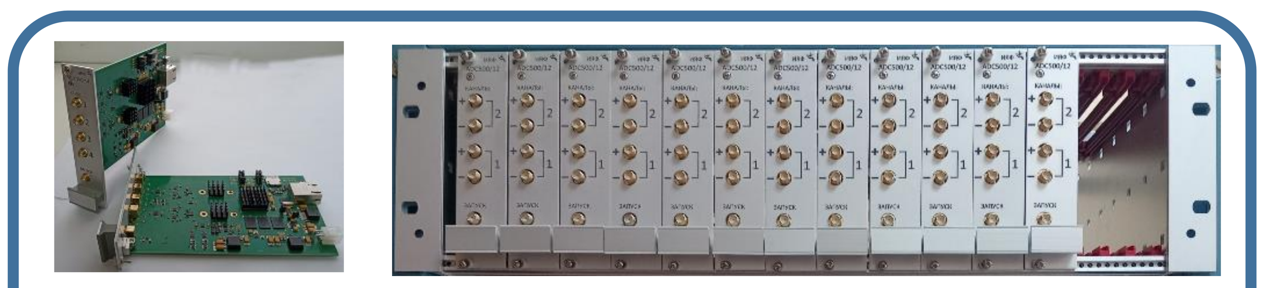


Figure 7: The view of the ADC14250/4

Table 2: Technical specifications of the SBLM's ADC (Fig. 7)

Parameter	Value
Number of measuring paths	4
ADC bit rate	14
Sampling rate	250 MHz
Bandwidth of measuring signal.	0 – 100 MHz
Amplitude conversion scale	From 0.2V to 8V in 1 dB increments
Input resistance	50 Ohm
Trigger amplitude	2 – 5 V
Trigger input resistance	50 Ohm
Memory	128 Mb

First prototype tests

The first SBLM prototype was assembled at the BINP storage ring to verify the signal calibration through numerical simulations and to conduct preliminary tests regarding monitor sensitivity and turn-by-turn beam loss measurements [7]. Figure 8 illustrates the turn-by-turn beam losses for the injected beam, the stored beam with a normal orbit, and the stored beam with an intentionally misaligned orbit due to a dipole corrector. In the latter case, the beam lifetime was only 25 seconds. During injection, the monitor's sensitivity was sufficient to record losses from other loss points on a damping ring with a 27.4-meter circumference, explaining the double pulses in Figure 8. For the stored beam, losses were lower compared to the injected beam, and not all turns had the same loss amount.

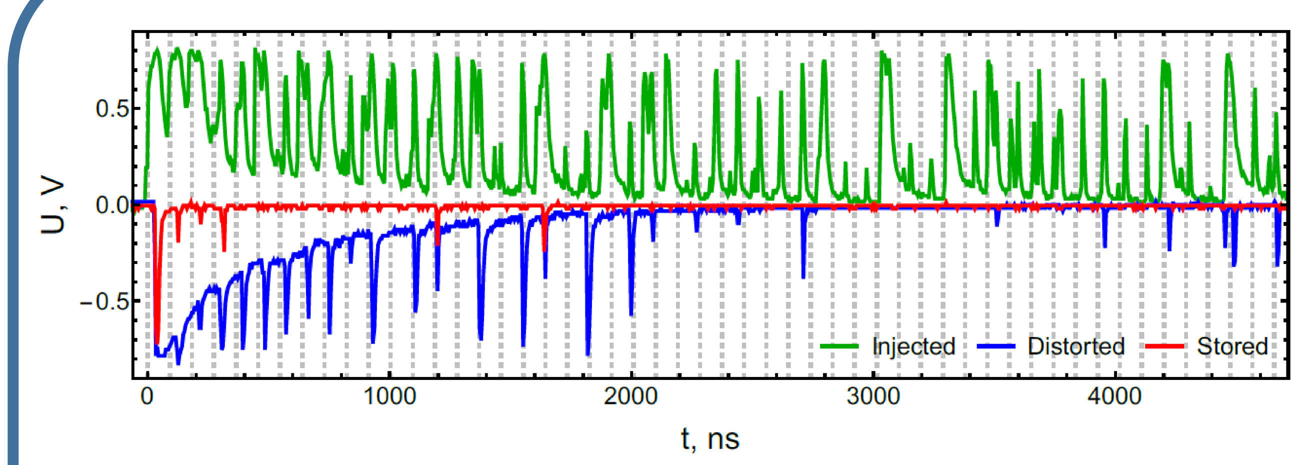


Figure 8: Turn-by-turn losses of the injected beam (green), the stored beam with a normal orbit (red), and the stored beam with an intentionally distorted orbit (blue) are shown. The green plot has been inverted for better visibility. Vertical lines indicate the revolution period.

CONCLUSION

The beam loss diagnostics system is crucial for the successful commissioning of the SKIF and its reliable operation and performance in different modes in the future. The design of the beam loss diagnostics system for SKIF has been completed, and the optimal BLMs parameters have been selected based on the test results of the prototypes at the BINP accelerators. Production of the BLMs is currently underway.

REFERENCES

[1] G. Baranov, A. Bogomyagkov, I. Morozov, S. Sinyatkin and E. Levichev, "Lattice optimization of a fourth-generation synchrotron radiation light source in Novosibirsk", *Phys. Rev. Accel. Beams*, vol. 24, 120704 (2021).
doi: 10.1103/PhysRevAccelBeams.24.120704

[2] X. Ma, M. V. Arsent'eva, A. M. Batrakov, A. E. Levichev, et al., "Measuring the parameters of a linear accelerator RF gun," *Sib. Fiz. Zh.*, vol. 18, no. 14, pp. 14-27, 2023.
doi: 10.25205/2541-9447-2023-18-1-14-27

[3] A. Andrianov, M. Arsentyeva, A. Barnyakov, D. Chekmenev, A. Levichev, O. Meshkov, et al., "Development of 200 MeV Linac for the SKIF light source injector", *J. Instrum.*, vol. 17, T02009, 2022
doi: 10.1088/1748-0221/17/02/T02009

[4] K. Wittenburg, "Beam loss monitoring and control", in *Proc. 8th European Particle Accelerator Conference*, EPAC02, Paris, France, June 2002, pp. 109-113.

[5] Yu. Maltseva, F. A. Emanov, A. V. Petrenko, and V. G. Prisekin, "Distributed Beam Loss Monitor Based on the Cherenkov Effect in Optical Fiber", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 1004-1006. doi:10.18429/JACoWIPAC2015-MOPTY034.

[6] G.N. Baranov, A.V. Bogomyagkov, E.B. Levichev and S.V. Sinyatkin, "Magnet lattice optimization for Novosibirsk fourth generation light source SKIF", *Siberian J. Phys.*, vol. 15, no. 1, pp. 5-23, 2020. doi: 10.25205/2541-9447-2020-15-1-5-23

[7] Y. I. Maltseva, S. V. Ivanenko, M. Xiaochao *et al.*, "Beam loss monitoring system for the SKIF synchrotron light source". *Journal of Instrumentation*, vol. 17, no. 5, 2022, T05004.
doi: 10.1088/1748-0221/17/05/T05004