TECHNICAL PHYSICS LETTERS

Founded by Ioffe Institute

Published since January 1975, 12 issues annyally

Editor-in-Chief: Grigorii S. Sokolovskii

ISSN: 1063-7850 (print), 1090-6533 (online)

TECHNICAL PHYSICS LETTERS is the English translation of ПИСЬМА В ЖУРНАЛ ТЕХНИЧЕСКОЙ ФИЗИКИ (PIS'MA V ZHURNAL TEKHNICHESKOI FIZIKI)

Published by Ioffe Institute

Saint Petersburg
Ioffe Institute

Technical Physics Letters, 2026, Vol. 52, No. 3

12

Modernization of the L-1 trigger of the CMD-3 detector

© *A.O. Gorkovenko*[1,2], *D.N. Grigorev*[1,3], *A.N. Kozyrev*[1–3], *V.G. Petrochenko*[1], *A.A. Ryban*[1,2], *A.A. Talyshev*[1,2], *D.V. Shelkovyi*[4], *L.B. Epshtein*[1–3], *Yu.V. Yudin*[1,2]

[1] Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
[2] Novosibirsk State University, Novosibirsk, Russia
[3] Novosibirsk State Technical University, Novosibirsk, Russia
[4] B.I. Stepanov Institute of Physics of the National Academy of Sciences of Belarus, Minsk, Belarus
E-mail: A.O.Gorkovenko@inp.nsk.su

Received September 1, 2025
Revised October 21, 2025
Accepted November 1, 2025

This paper describes the trigger system of the CMD-3 detector at the VEPP-2000 electron-positron collider and presents the results of its modernization. We review the operating principles and architecture of the original system. A key upgrade involved the development of a new Decision Making Block, which implements improved algorithms for selecting events of interest. This modernization enhanced the system's performance while maintaining high event registration efficiency. Tests under real experimental conditions confirmed the stable operation of the upgraded trigger system.

Keywords: trigger system, data processing algorithms.

DOI: 10.61011/TPL.2026.03.63051.20487

Experiments at the VEPP-2000 electron–positron collider, which has a record-high luminosity within the energy range from 320 to 2000 MeV in the center-of-mass system, have been conducted since 2010 at the Budker Institute of Nuclear Physics [1]. Two detectors are involved in these experiments: a spherical neutral detector and a cryogenic magnetic detector (CMD-3) [2]. Precise measurement of hadron production cross sections in electron–positron annihilation is one of the key objectives of CMD-3. CMD-3 is a unique setup that combines the characteristics of a magnetic spectrometer and a calorimeter with high energy and spatial resolutions. A data acquisition system (DAQ), which processes approximately 15 000 electronic measuring channels, ensures data collection and control of detector subsystem parameters. A trigger system ensures well-timed recording of data from all detector subsystems. It analyzes data from detector subsystems continuously and looks for signs of an event; if a useful event is detected, a trigger signal is generated.

A complex electronics system was designed for precision experiments at CMD-3. This design specifies a common architecture of electronic units and protocols of communication between them. Particular attention was paid to the temporal DAQ properties: synchronization of triggering of measurements, data collection, and transmission and control of the reliability and efficiency of the electronics system as a whole. A communication channel for transmitting synchronization signals and data (C-Link) was developed specifically for this purpose [3]. Logically, the DAQ may be divided tentatively into several functional levels (Fig. 1) that perform different tasks: recording electronics, primary (L-1) trigger, and service electronics. At the level of recording electronics, signals from the physical detector subsystems are amplified, subjected to analog processing, converted into digital form, and prepared for transmission to the event builder.

The key function of the L-1 trigger is to decide whether the current event in the detector should be recorded and to initiate (with a delay no greater than $2\,\mu$s) the process of measurement and data recording by all detector subsystems. To speed up the L-1 trigger operation, the volume of processed data is reduced by combining signals from several channels of the detector subsystems into trigger groups in the recording electronics. Trigger data are prepared for further analysis in the interface blocks of the L-1 trigger. The task of deciders is to search efficiently for useful events (based on the data on trigger groups that have been actuated) with the minimum possible processing time and make a decision about actuating the detector. The algorithms of deciders are implemented on FPGAs (field-programmable gate arrays), which ensures minimum processing time (due to parallel computing) and provides additional service capabilities.

Logically, the L-1 trigger may be divided into two parts: „charged“ and „neutral“ ones. The charged trigger processes data from the drift chamber [4], while the neutral trigger is focused on the detector calorimeters [5].

The input data for the charged trigger are actuations of 192 trigger groups, which are combined into eight layers (see Fig. 2, *a*). The decider of the charged trigger (Trackfinder, TF) searches for charged particle tracks in time slices corresponding to each beam revolution in VEPP-2000. The track search algorithm is based on sorting through pre-made track masks (trajectory templates). If the actuated trigger groups match at least one mask, a track is considered to

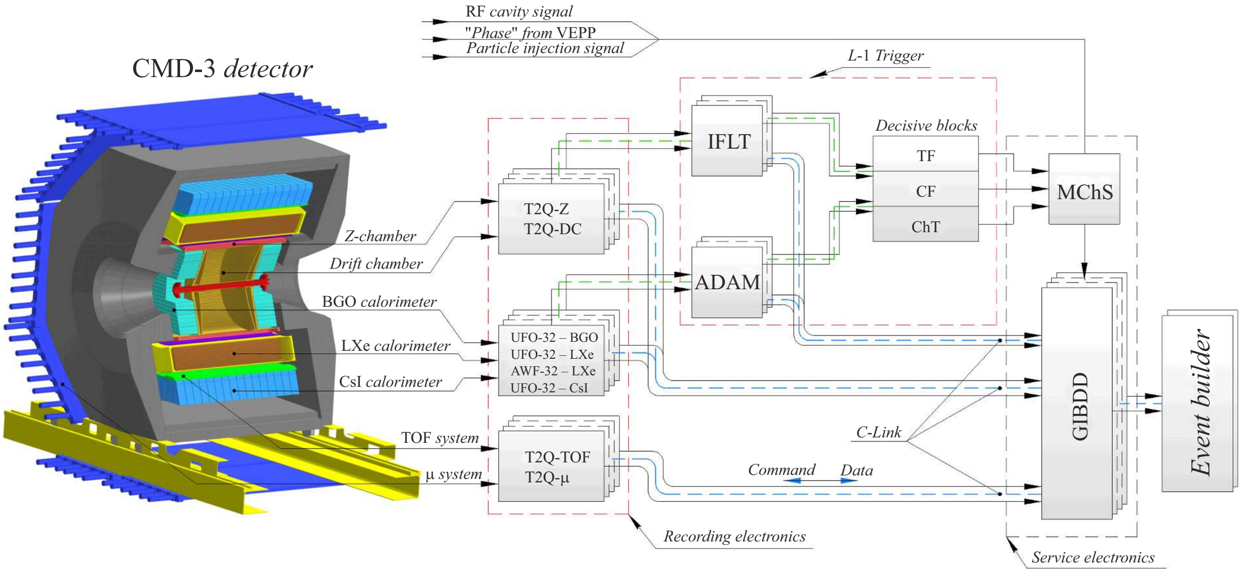

Figure 1. Data acquisition system of CMD-3.

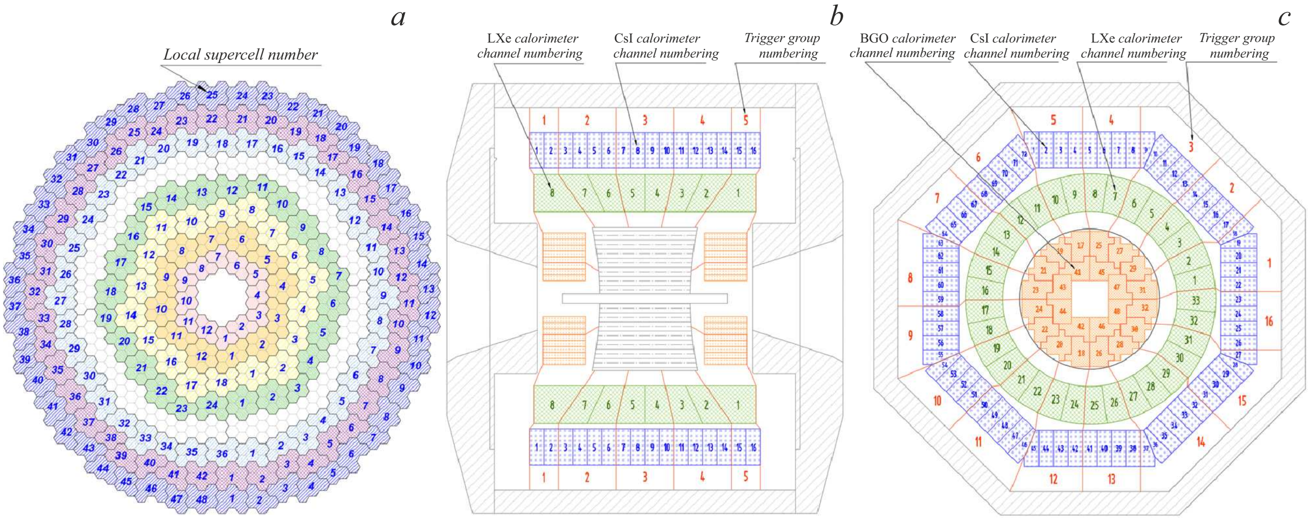

Figure 2. Diagram of division of the drift chamber (a) and calorimeters $(b,\ c)$ into trigger groups.

be detected and the corresponding event is considered useful.

The calorimeter detects neutral and charged particles by the energy release in a heavy material. The CMD-3 calorimeter has three parts: a cylindrical internal liquid LXe calorimeter, a cylindrical external crystalline CsI calorimeter, and an end (on both sides) crystalline BGO calorimeter. Each cylindrical calorimeter is divided into 80 trigger groups: 16 groups in azimuth angle and five groups in longitudinal direction. The end calorimeters on each side are divided into 24 groups: outer ring (16 groups) and inner ring (eight groups). Owing to high flux intensities, the inner ring is used only for on-the-fly luminosity measurements. The calorimeters are divided into trigger groups in accordance with the trigger group map shown in Figs. $2, b, c$. Trigger group signals are generated by analog summation of signals from the corresponding calorimeter channels. Analog signals are fed to ADAM modules, which digitize them, measure the energy, and transmit data on the trigger groups actuated in each beam revolution to the decider. The decider of the neutral trigger (Clusterfinder, CF) produces the features characterizing the current event. Since particles in calorimeters actuate several trigger groups, groups of actuated trigger cells (clusters) adjacent at the edges or corners are formed first. The cluster search algorithm determines their number, relative positions, and size. This algorithm applies Boolean operations to rows and columns of the map of actuated trigger groups.

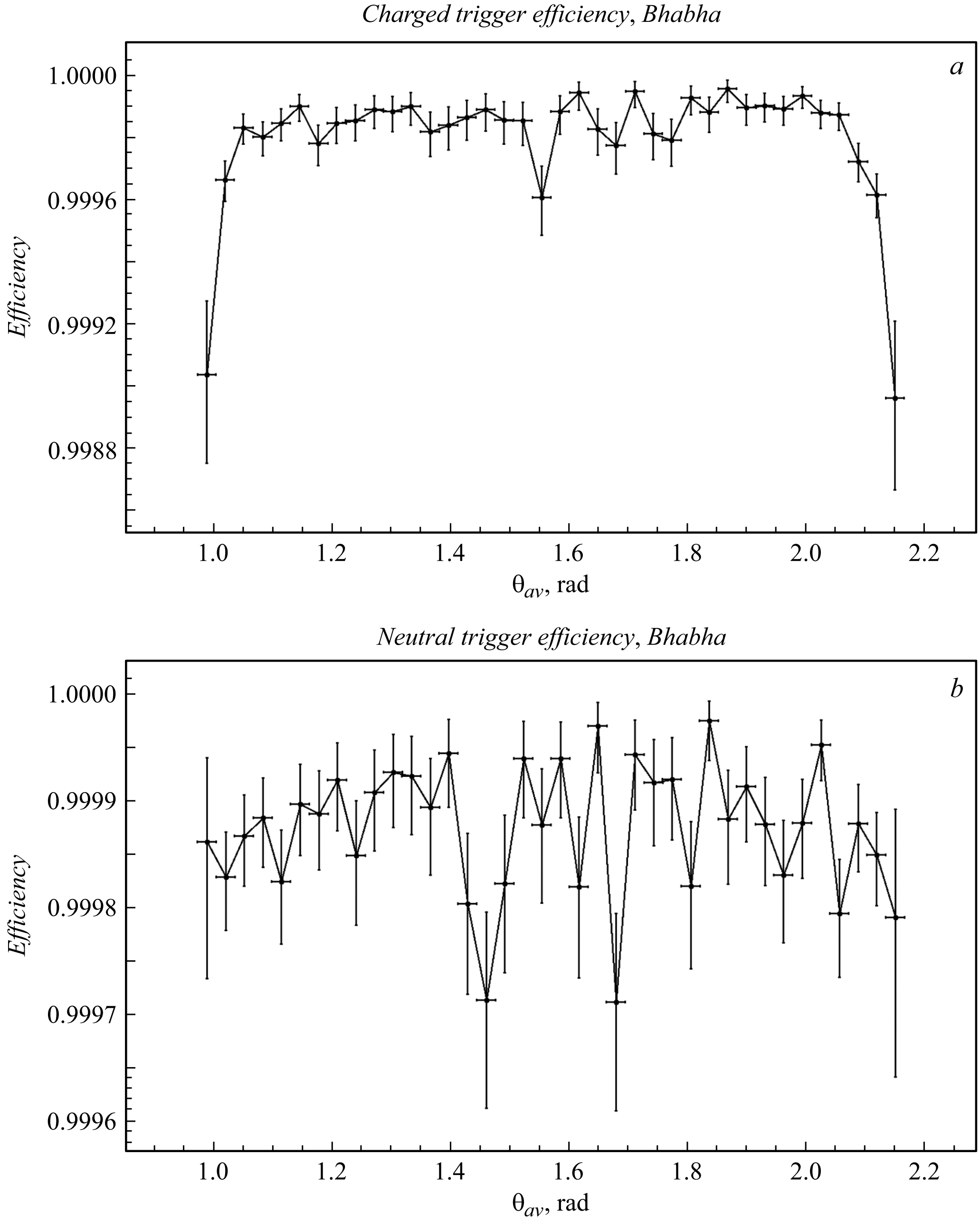

Figure 3. Efficiencies of charged (a) and neutral (b) triggers.

Based on the obtained cluster data, Clusterfinder generates 45 different event features for each beam revolution.

One of the key characteristics of the L-1 trigger is the efficiency of recording of useful events. Figure 3 shows histograms of the efficiency of charged and neutral triggers as a function of polar angle θ for elastic electron–positron scattering (Bhabha scattering) events. It can be seen that the charged and neutral triggers provide high efficiency of event detection within the entire sensitive area of the detector; however, the efficiency decreases gradually toward the edges. The developed event selection criteria provide an opportunity to detect efficiently both events with two or more particles and the production of nucleon–antinucleon pairs, which are the events that produce a signal only in one local region of the detector upon annihilation of antiparticles. The L-1 trigger was proven to be highly effective: it was used to accumulate a total luminosity exceeding one inverse femtobarn $(1\,\mathrm{fb}^{-1})$, which marks entry into the elite club of „particle factories.“ Its high efficiency enabled the measurement of dozens of physical processes (often with record-high accuracy).

The VEPP-2000 collider is continuously undergoing modernization, which leads to an increase in luminosity. Higher luminosities provide an opportunity to study rarer processes,

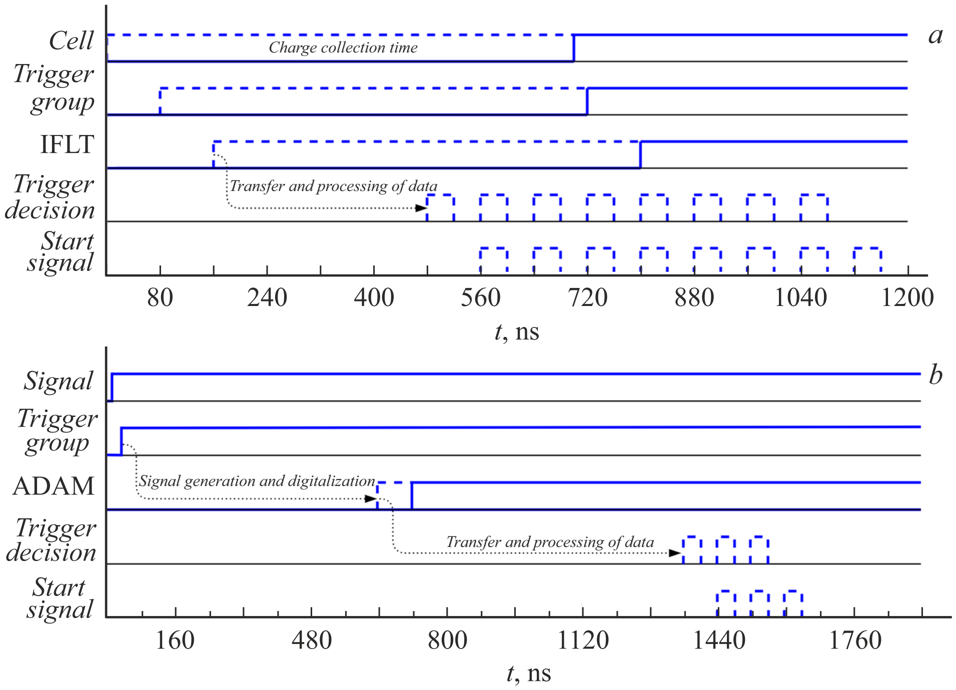

Figure 4. Temporal diagrams of operation of charged (a) and neutral (b) triggers.

but the number of background events also increases. Therefore, the quality of event selection also needs to increase. The main goals of L-1 trigger modernization are to optimize existing event selection methods, implement new ones, and increase performance and reliability. At the first step, the deciders were replaced with a new trigger module: Decision Board (DB). With the charged and neutral trigger functions combined in a single module, one gets a chance to form mixed masks for selection of more complex events. In addition, the use of modern hardware components expands significantly the opportunities for analysis of experimental events and monitoring the operation of the L-1 trigger as a whole and its components. An additional high-speed channel for data transmission in the DAQ was needed to implement these new capabilities. An Ethernet interface was added to the DB for this purpose.

Figure 4 shows the temporal diagrams of operation of the L-1 trigger with the DB. The decision-making time spread for the charged trigger is determined largely by the time of charge collection from the drift chamber wires (Fig. 4, a). In the case of the neutral trigger, the decision-making time spread is determined by the signal-to-noise ratio in the calorimeter trigger channels (Fig. 4, b).

The functionality of the DB as part of the DAQ was tested in experiments. A comparative analysis of operation of the deciders used previously and the DB was carried out. With this aim in view, input data on the actuated trigger groups was fed simultaneously to both versions of trigger blocks. This comparative analysis confirmed that the operating parameters of the trigger system were improved (specifically, operating speed was increased without sacrificing event detection efficiency, and trigger decision-making time spread was reduced). Track and cluster search times were reduced by 50 % and 30 %, respectively.

The next stage of trigger modernization will involve a 4-fold reduction in size of the calorimeter trigger cells and the transfer of energy deposit in each trigger channel to the DB. This is hardwired into the new electronics being developed [6] and, together with the use of more complex data processing algorithms, will provide an opportunity to improve radically the signal-to-background ratio [7]. At present, nearby particles merge into a single cluster when multiphoton events are analyzed. For example, when an eta meson decays into three neutral pions, six photons are produced, but only four or at most five clusters are identified; therefore, the threshold can only be set at four clusters. The main background here are quantum electrodynamics (QED) events, where the probability of production of each additional particle is proportional to fine structure constant $\alpha = 1/137$. Correct calculation of the number of clusters will allow one to raise the threshold to five or six clusters and suppress the background from QED events by several orders of magnitude. Two-photon production events, which are currently beyond the reach of CMD-3 due to the high background level, are even harder to detect. Cluster data are insufficient to identify them; one needs to calculate kinematic parameters (e. g., the invariant mass of two clusters) in real time. The expanded functionality of the DB made it possible to implement and test experimentally with real detector events the algorithm for selection of two-photon neutral pion production events proposed for the new electronics. Significant background suppression was achieved even at the current trigger cell size. Trigger modernization in the new electronics will improve significantly the accuracy of determination of kinematic parameters and open the way to studying a new class of events.

Experiments with CMD-3 at the VEPP-2000 electron–positron collider have been conducted for more than ten years. The work on modernization of the L-1 trigger and new electronics aimed at increasing the accuracy of identification of rare multiphoton processes and examining currently inaccessible two-photon production events is currently underway. The designed DB has been used successfully in experiments for a year and allowed us to accumulate a total luminosity exceeding $50\,\mathrm{pb}^{-1}$. The new block was found to be exceptionally efficient and reliable in data collection. The increased flexibility of the system made it significantly easier to use, configure, and maintain it. The expanded functionality of the DB allowed for experimental verification of a new algorithm for selection of two-photon neutral pion production events, which was developed for the new electronics design, and revealed a promising outlook for studies into this complex process.

Funding

This study was supported by grants No. 23-42-10025 from the Russian Science Foundation and No. F23RNF-118 from the Belarusian Republican Foundation for Fundamental Research (in regard to the development of new electronics) and was performed under state assignment FWGM-2025-0057 (within the scope of work on existing electronics).

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] D.E. Berkaev, D.B. Shwartz, P.Yu. Shatunov, Yu.A. Rogovskii, A.L. Romanov, I.A. Koop, Yu.M. Shatunov, I.M.Zemlyanskii, A.P. Lysenko, E.A. Perevedentsev, A.S. Stankevich, A.I. Senchenko, B.I. Khazin, A.V. Anisenkov, S.E. Gayazov, A.N. Kozyrev, A.E. Ryzhenenkov, D.N. Shemyakin, L.B. Epshtein, S.I. Serednyakov, P.M. Astigeevich, D.P. Kovrizhin, K.A. Martin, A.E. Obrazovskii, I.K. Surin, L.V. Kardapoltsev, O.V. Belikov, K.M. Gorchakov, A.N. Kirpotin, A.N. Skrinskii, JETP, **113** (2), 213 (2011). DOI: 10.1134/S1063776111060136.

[2] B.I. Khazin, Nucl. Phys. B — Proc. Suppl., **181-182**, 376 (2008). DOI: 10.1016/j.nuclphysbps.2008.09.068

[3] A.A. Ruban, V.M. Aulchenko, K.I. Kakhuta, A.N. Kozyrev, A.N. Selivanov, V.M. Titiov, Yu.V. Yudin, Nucl. Instrum. Meth. Phys. Res. A, **598**, 317 (2009). DOI: 10.1016/j.nima.2008.08.033

[4] F. Grancagnolo, G. Fiore, F.V. Ignatov, A.V. Karavdina, B.I. Khazin, A. Miccoli, V.S. Okhapkin, S.G. Pivovarov, A.S. Popov, A.A. Ruban, A.L. Sibidanov, I.G. Snopkov, Nucl. Instrum. Meth. Phys. Res. A, **623**, 114 (2010). DOI: 10.1016/j.nima.2010.02.166

[5] V.E. Shebalin, R.R. Akhmetshin, A.V. Anisenkov, V.M. Aulchenko, N.S. Bashtovoy, D.A. Epifanov, L.B. Epshteyn, A.L. Erofeev, A.A. Grebenuk, D.N. Grigoriev, F.V. Ignatov, V.F. Kazanin, O.A. Kovalenko, A.N. Kozyrev, A.E. Kuzmenko, A.S. Kuzmin, I.B. Logashenko, K.Yu. Mikhailov, V.S. Okhapkin, G.P. Razuvaev, A.A. Ruban, B.A. Shwartz, V.M. Titov, A.A. Talyshev, Yu.V. Yudin, Nucl. Instrum. Meth. Phys. Res. A, **824**, 710 (2016). DOI: 10.1016/j.nima.2015.11.128

[6] V.G. Petrochenko, A.O. Gorkovenko, D.N. Grigoriev, A.N. Kozyrev, A.A. Ruban, Dz.V. Shoukovy, L.B. Epshtein, Yu.V. Yudin, Phys. Part. Nuclei, **56** (3), 639 (2025). DOI: 10.1134/S1063779624702046

[7] D.V. Shelkovyi, S.N. Garkusha, A.O. Gorkovenko, D.N. Grigor'ev, Izv. Nats. Akad. Nauk Belarusi. Ser. Fiz.-Mat. Nauk **60** (4), 317 (2024) (in Russian). DOI: 10.29235/1561-2430-2024-60-4-317-326

Translated by D.Safin