



JOINT INSTITUTE FOR NUCLEAR RESEARCH

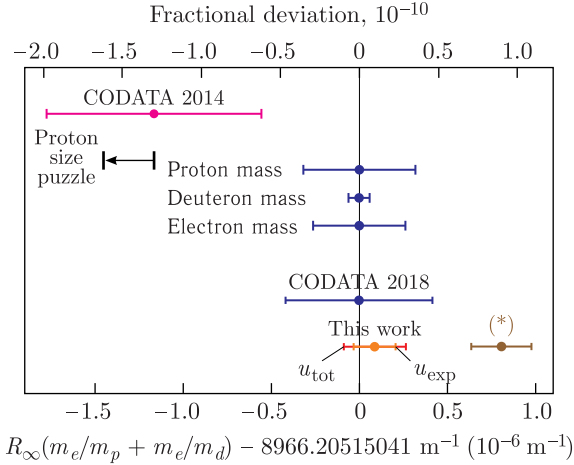
2021-3

**BRIEF REVIEW
OF TOPMOST SCIENTIFIC RESULTS
OBTAINED IN 2020
AT THE JOINT INSTITUTE
FOR NUCLEAR RESEARCH**

Dubna 2021

THEORETICAL PHYSICS

We improve our rotational spectroscopy technique for a sympathetically cooled cluster of molecular ions stored in a linear radiofrequency trap by nearly two orders in accuracy. We measured a set of hyperfine components of the fundamental rotational transition. An evaluation resulted in the most accurate test of a quantum-three-body prediction so far, at the level of $5 \cdot 10^{-11}$, limited by the current uncertainties of the fundamental constants. We determined the value of the fundamental constants combinations $R_\infty m_e (m_p^{-1} + m_d^{-1})$ and m_p/m_e with a fractional uncertainty of $2 \cdot 10^{-11}$, in agreement with, but more precise than, current Committee on Data for Science and Technology values. These results also provide strong evidence of the correctness of previous key high-precision measurements and a more than 20-fold stronger bound for a hypothetical fifth force between a proton and a deuteron.

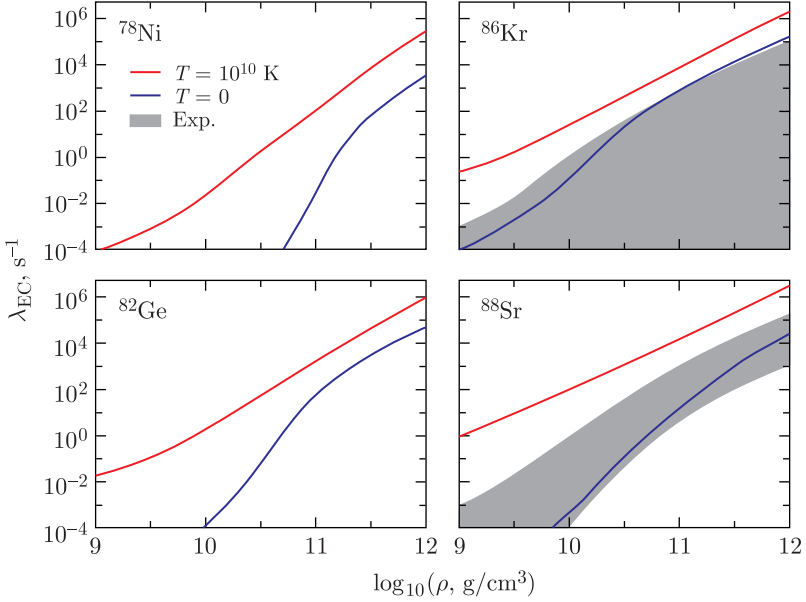


Comparison of results of this work with literature values

- *Alighanbari S., Giri G.S., Constantin F.L., Korobov V.I., Schiller S. // Nature. 2020. V.581. P.152.*

We study the effect of finite temperature on electron capture by nuclei near the $N = 50$ closed shell which dominate the composition

of core-collapse supernova. Applying thermodynamically consistent approach we show that thermal effects unblock Gamow–Teller (GT) transitions at astrophysically relevant temperatures $T \approx 10^{10}$ K. Comparison of electron capture rates on nuclei ground and thermal excited states for ^{78}Ni , ^{82}Ge , ^{86}Kr , and ^{88}Sr indicates that thermal effects are crucial for core-collapse supernova modeling. Obtained results contribute to solving the long-standing problem of explaining core-collapse supernova explosions.

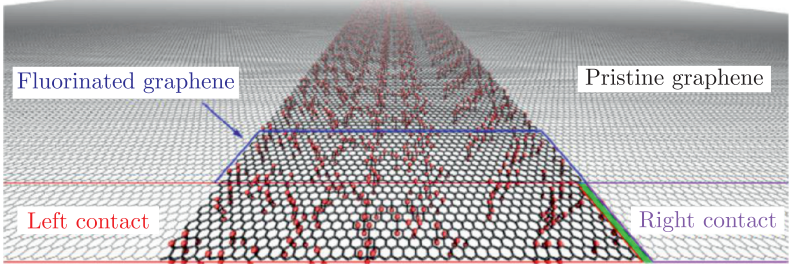


Electron capture rates as a function of density of collapsing core. The rates based on the experimental GT data are shown with experimental uncertainties

- *Dzhioev A. A., Langanke K., Martinez-Pinedo G., Vdovin A. I., Stoyanov Ch. // Phys. Rev. C. 2020. V. 101. P. 025805.*

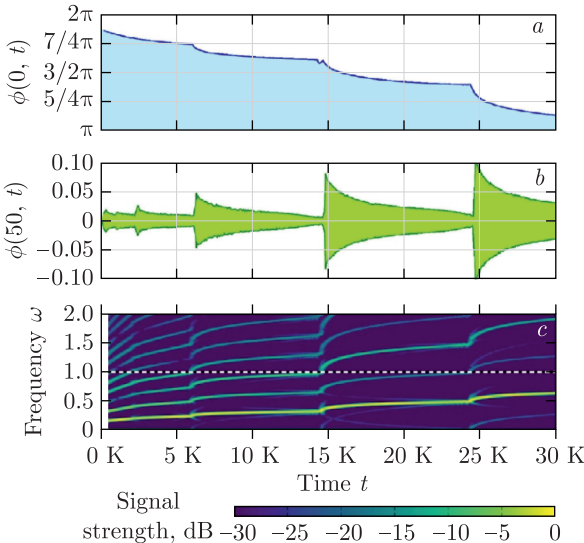
A statistical method for generating fluorinated graphene structures with desirable fluorine distribution is developed within the framework of stochastic reactive molecular dynamics simulations. Electronic transport properties of fluorinated graphene are investigated in a wide range of functionalization degrees and system ordering. A strong correlation is found between irregularities in fluorine distribution and electronic properties. In particular, proposed consideration allows for the reproduction

of both the experimentally observed electron–hole asymmetry in transport properties of fluorinated graphene and a recently revealed conductivity peak at 10% fluoride content.



- *Yamaletdinov R. D., Katkov V. L., Nikiforov Ya. A., Okotrub A. V., Osipov V. A. // Adv. Theory Simul. 2020. V. 3. P. 1900199.*

A new effect of staggered radiative decay of long-lived oscillating states is discovered. It is related to a series of transitions, during which higher harmonics are released as short, staccato bursts of radiation.



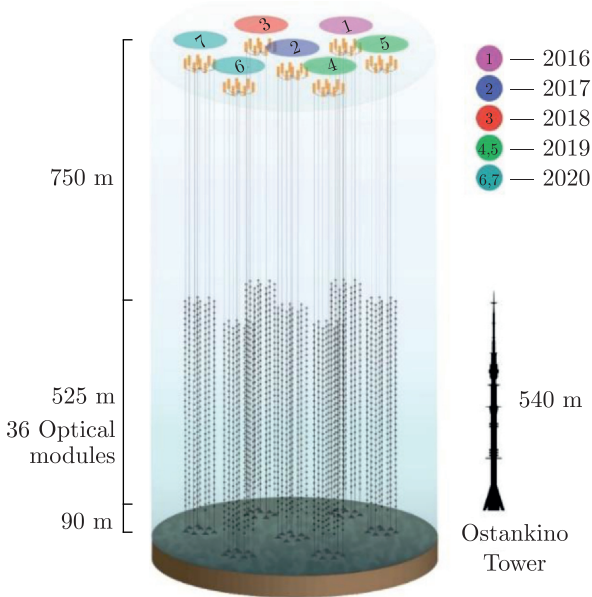
Power spectrum of the radiation flux of the quasi-breather in the deformed sine-Gordon theory

- *Dorey P., Romanczukiewicz T., Shnir Ya. // Phys. Lett. B. 2020. V. 806. P. 135497.*

EXPERIMENTAL PHYSICS

Particle Physics

The sixth and seventh clusters of Baikal-GVD (a cubic kilometer scale deep underwater neutrino telescope currently under construction in Lake Baikal) were deployed and commissioned in April 2020. With their introduction, the efficient telescope volume for the high-energy astrophysical neutrinos has reached 0.35 km^3 . The telescope has 2016 underwater PMT-based Cherenkov light detectors and operates in the regime of data acquisition and accumulation.



The obtained data for atmospheric muon and neutrino flux are in a good agreement with the expectation. The counting rate of the first detected high-energy neutrino events is in agreement with the data on the flux of astrophysical neutrinos obtained by the IceCube Antarctic neutrino telescope. The combined operation of these two largest telescopes of the Northern and Southern hemispheres allows for the whole-sky neutrino survey and searches for astrophysical sources. The Baikal-GVD detector participates in the international multi-messenger alert systems in order to search and study transient astrophysical sources with the techniques of multi-messenger astronomy.



Assembling the garland

- *Domogatsky G. V.* Deep Underwater Neutrino Telescope – Baikal-GVD // The 36th All-Russian Conf. on Cosmic Rays, 28 Sept. – 2 Oct. 2020, SINP MSU, online; <https://events.sinp.msu.ru/event/3/sessions/22/#20200930>
- *Safronov G. B.* Status of Baikal-GVD: Results of Track Reconstruction // The 40th Intern. Conf. on High Energy Physics, ICHEP2020, 28 July – 6 Aug. 2020, online; <https://indico.cern.ch/event/868940/contributions/3813595/>

In 2020, the $\text{NO}\nu\text{A}$ experiment (FNAL, USA) performed the data analysis with an increased integral exposure: $13.6 \cdot 10^{20}$ POT (protons on the target) in a neutrino beam and $12.5 \cdot 10^{20}$ POT in an antineutrino beam. The joint interpretation of various oscillation channel results allows one to refine parameters of the oscillation phenomenon: the best fit value is at the point with the normal hierarchy, upper octant of the angle θ_{23} with $\sin^2 \theta_{23} = 0.57^{+0.03}_{-0.04}$, $\Delta m_{32}^2 = (+2.41 \pm 0.07) \cdot 10^{-3} \text{ eV}^2$ and $\delta_{\text{CP}} = 0.82^{+0.24}_{-1.0} \pi$. Thus, the $\text{NO}\nu\text{A}$ data prefer combinations of oscillation parameters leading to the symmetry between neutrinos and antineutrinos, while opposite combinations “inverse hierarchy, $\delta_{\text{CP}} = \pi/2$ ” and “normal hierarchy, $\delta_{\text{CP}} = 3\pi/2$ ” are rejected at the level of $> 3\sigma$ and $> 2\sigma$, respectively.

- *Acero M. A. et al. (NOνA Collab.)*. Adjusting Neutrino Interaction Models and Evaluating Uncertainties Using $\text{NO}\nu\text{A}$ Near Detector Data // Phys. Rev. Lett. 2019. V. 123, No. 15. P. 151803.

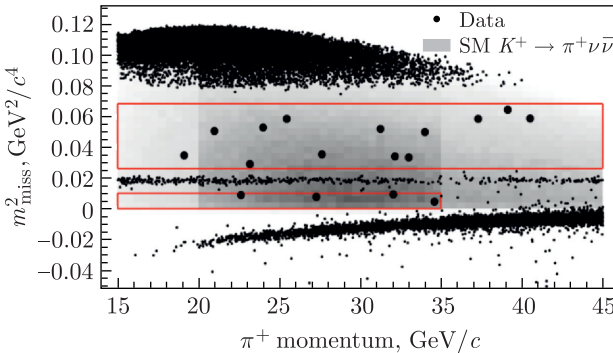
Within the ATLAS project at the LHC, a search for the decay of the SM Higgs boson into a bb pair when produced in association with a W or Z boson has been performed. The whole data collected in pp collisions of the LHC at $\sqrt{s} = 13$ TeV were used. The production of a Higgs boson in association with a W or Z boson is established with observed (expected) significances of 4.0(4.1) and 5.3(5.1) σ , respectively. The cross-section measurements are all consistent with the Standard Model expectations.

- *Aaboud M. et al. (ATLAS Collab.).* Measurements of the Production Cross-Section for a Z Boson in Association with b -Jets in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector // JHEP. 2020. V.07. P.44.

The A2 collaboration performed world's first precision measurements of the total cross sections and angular distributions for π^0 photoproduction off quasi-free nucleons bound in the deuteron. Significant difference was found between the cross sections for free and bound protons due to the effects from final state interactions. This difference was used to estimate the photoproduction cross section of neutral pions on free neutrons. These data are obtained using polarized proton (deuteron) target created by DLNP employees.

- *Dieterle M. et al. (A2 Collab.).* Helicity-Dependent Cross Sections for the Photoproduction of π^0 Pairs from Nucleons // Phys. Rev. Lett. 2020. V.125. P.062001.

A new result in the NA62 experiment at CERN SPS has been obtained in $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ rare decay study based on the data



Event-candidates for very rare decay (in the box) and background events in terms of the momentum of the charged pion and the square of the missing mass

collected in 2018. A total of 17 signal event candidates were observed with the expected background of 7 events. Together with three candidates registered earlier in NA62 in the data of 2016 and 2017, it resulted in the most precise $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ branching ratio measurement $\text{BR} = (11.0_{-3.5}^{+4.0} \pm 0.3_{\text{sys}}) \cdot 10^{-11}$ that is consistent with the Standard Model expectation of $(8.4 \pm 0.1) \cdot 10^{-11}$.

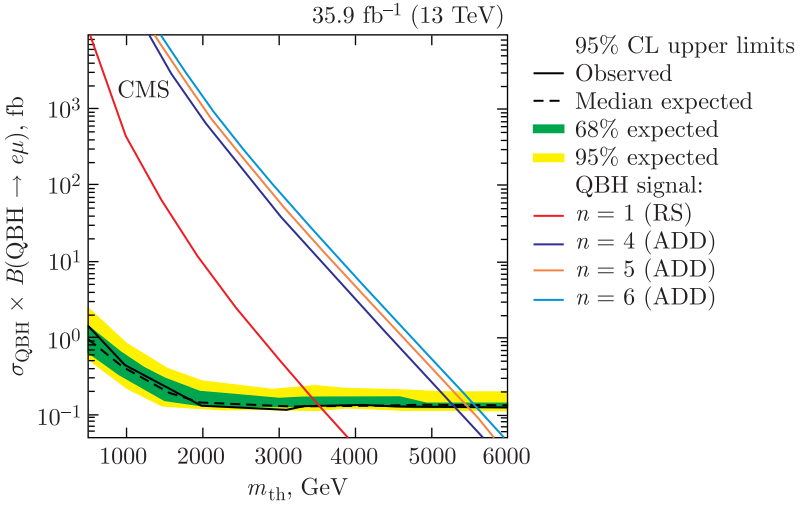
- *Marchevski R. (for the NA62 Collab.).* New Result on the Search for the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Decay at the NA62 Experiment at CERN // ICHEP-2020, 28 July – 7 Aug. 2020, Prague.

Several interesting results were obtained by the JINR group in the ALICE experiment at the LHC. A new analysis of femtoscopic correlations for pairs of identical charged pions and kaons in pp collisions at 13 TeV was performed separately for spherical ($S_T > 0.7$) and jet-like ($S_T < 0.3$) events, where S_T is the event transverse sphericity. A decrease in source radii with an increase in the transverse momentum of the pair was observed not only for jet-like events but also for spherical events that exhibit nontrivial collective-like particle behavior, which was expected only in heavy-ion collisions with the possible formation of quark–gluon plasma.

- *Malinina L. (for the ALICE Collab.).* Femtoscopic Correlations of Identical Charged Particles in pp Collisions at LHC Energies with Event-Shape Selection // The 5th Intern. Conf. on Part. Phys. and Astrophys. (ICPPA-2020), Oct. 7, 2020, MEPhI, Moscow.

A generalizing analysis of searches for signals of multidimensional low-energy gravity in the CMS experiment at LHC was performed. It is shown that LHC has reached the threshold of its capabilities to observe possible signals from semiclassical multidimensional RS- and ADD-type black holes. However, there is still a window of opportunity for the so-called “quantum” black holes (QBH) with a characteristic experimental signature with violation of flavor ($e\mu/e\tau/\mu\tau$). The figure shows that the obtained restrictions on the minimum acceptable values of the mass of quantum black holes are from 3.6 to 5.6 TeV/ c^2 depending on the model and the number of n extra dimensions.

- *Savina M. V., Seitova D.* The CMS Experiment Programme on Search for Multidimensional Low-Energy Gravity at the LHC // Yad. Fiz. 2021. V. 84, No. 1.

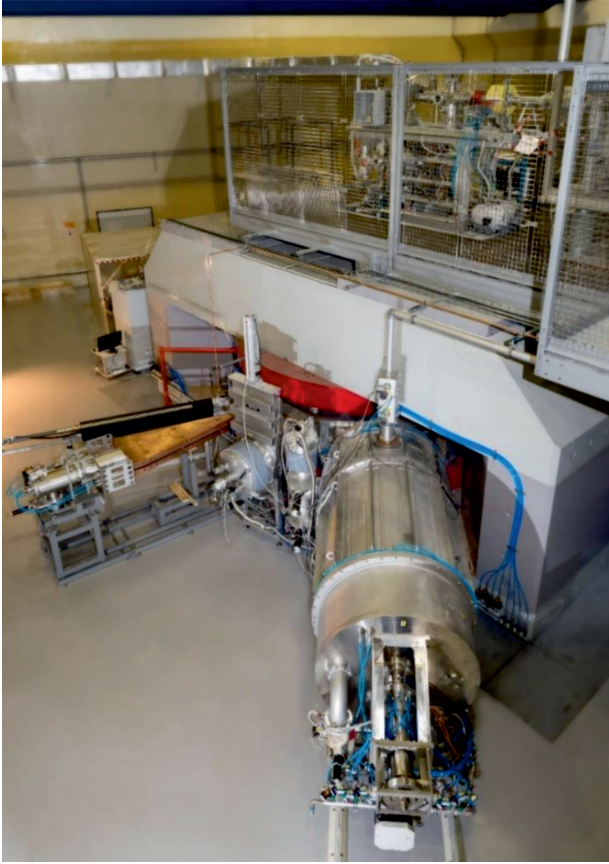


Upper limits at 95% CL for the mean value of the product of the signal cross section and the branching fraction for the QBH decay into $e\mu$ as a function of the threshold mass m_{th} . 68% and 95% CL intervals for the median are shown by the inner green and outer yellow shadings, respectively. Predictions are also shown for several models with large extra spatial dimensions, in particular, for one extra dimension (RS) and for 4, 5, and 6 extra dimensions (ADD)

Low Energy Heavy Ion Physics

The first experiment on the synthesis of isotopes of element 115 (moscovium) in the collision of ^{48}Ca ions and ^{243}Am was successfully launched at the Factory of Superheavy Elements accelerator complex. The experiment opens doors to a unique JINR programme on the study of nuclear and chemical properties of superheavy elements and shows that we are prepared for experiments on the synthesis of new elements with atomic numbers 119 and 120 — first members of the eighth row of Mendeleev’s Periodic Table.

- *Oganessian Yu. Ts., Dmitriev S. N., Utyonkov V. K.* Project of Priority Experiments at SHE Factory // Proc. of the Intern. Symp. on Exotic Nuclei “EXON-2018”, Petrozavodsk, Russia, 10–15 Sept. 2018. P. 431–436 / Eds.: Yu. E. Penionzhkevich, Yu. G. Sobolev. Singapore: World Sci. Publ., 2020.

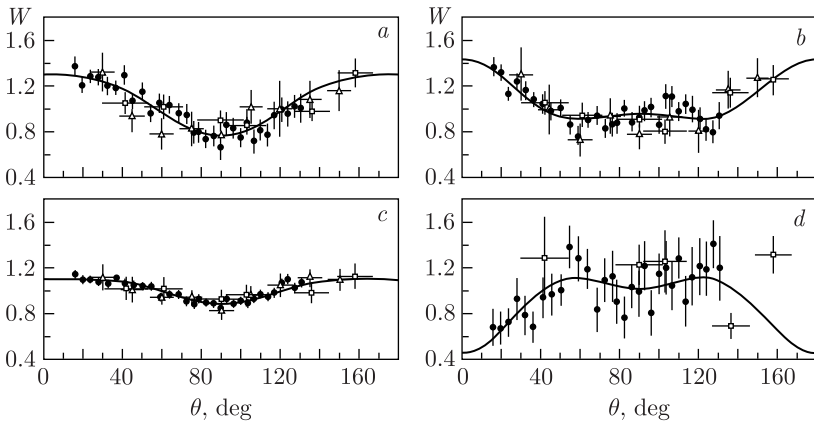


The DC-280 cyclotron — the basic facility of the SHE Factory

Neutron Nuclear Physics

The inelastic scattering of 14.1-MeV neutrons on chromium and magnesium nuclei is studied at the TANGRA facility using tagged neutrons and an ING-27 standard neutron generator. The energies and partial cross sections of visible γ transitions induced in different reactions between neutrons and nuclei are determined. The measured angular distributions of γ quanta are analyzed and compared to results from other experimental studies.

- *Fedorov N. A., Grozdanov D. N., Kopatch Yu. N. et al.* Measuring the Yields and Angular Distributions of γ Quanta from the



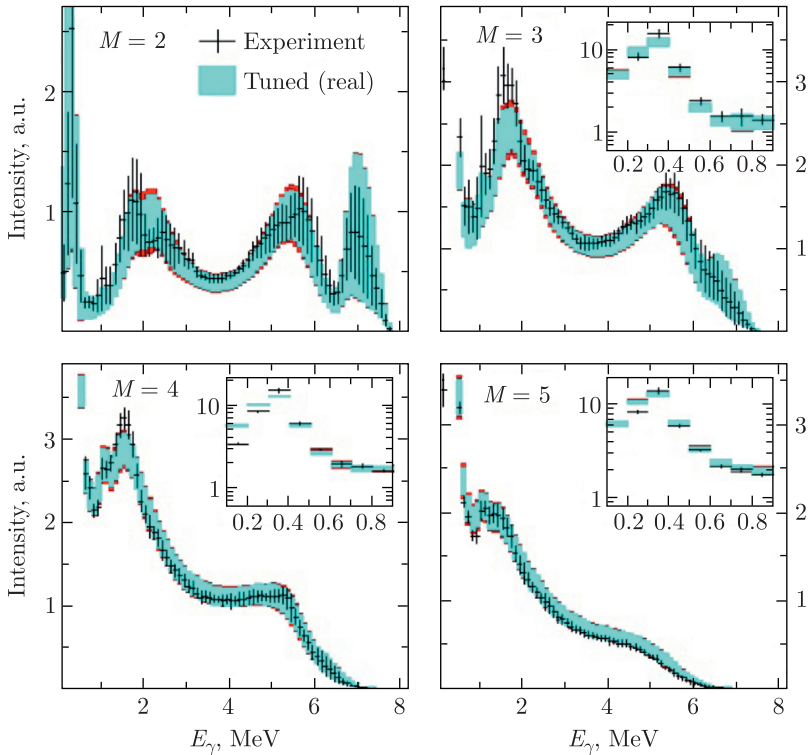
Angular distributions of γ quanta for $E_\gamma = 935.5$ keV (a), 1333.7 keV (b), 1434.1 keV (c), and 1530.7 keV (d) transitions in the reaction $^{52}\text{Cr}(n, n'\gamma)^{52}\text{Cr}$. Solid curve — approximation of data by Legendre polynomials

Interaction between 14.1 MeV Neutrons and Magnesium Nuclei // Bull. Russ. Acad. Sci. Phys. 2020. V. 84. P. 367–372.

- *Grozdanov D.N., Fedorov N.A., Kopatch Yu.N. et al.* Measurement of the Yield and Angular Distributions of Gamma Rays Originating from the Interaction of 14.1 MeV Neutrons with Chromium Nuclei // Phys. At. Nucl. 2020. V. 83, No. 3. P. 384–390.

The photon strength functions (PSFs) and nuclear level density (NLD) in ^{196}Pt have been examined from the γ -ray multistep cascade spectra measured at the multidetector DANCE facility. The received data are necessary quantities for calculating the interaction of photons with nuclei, in particular, the reaction cross sections. As such, PSFs and NLD are important especially in nuclear astrophysics and in the development of advanced nuclear technologies.

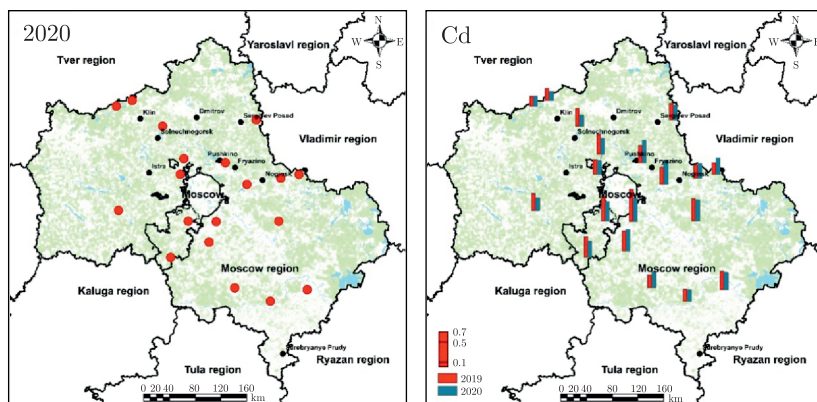
- *Simbirtseva N., Krtička M., Casten R., Couture A., Furman W., Knapová I., O'Donnell J.M., Rusev G., Ullmann J.L., Valenta S.* Examination of Photon Strength Functions and Nuclear Level Density in ^{196}Pt from the Gamma-Ray Spectra Measured at the DANCE Facility // Phys. Rev. C. 2020. V. 101. P. 024302; <https://doi.org/10.1103/PhysRevC.101.024302>.



Comparison of experiment data and simulations for resonances with spin 1^- . Black symbols indicate experimental data and resonance fluctuations, the blue band corresponds to simulations (the average and standard deviation)

The coronavirus disease, COVID-19, has had a great negative impact on human health and economies all over the world. To prevent the spread of infection in many countries, including the Russian Federation, public life was restricted. To assess the impact of the taken actions on air quality in the Moscow region, in June 2020, mosses *Pleurozium shreberi* were collected at 19 sites considered as polluted in the territory of the region based on the results of the previous moss surveys. The content of Cd, Cr, Cu, Fe, Ni, and Pb in the moss samples was determined using atomic absorption spectrometry. Compared to 2019 data, the Cd content in moss samples decreased by 2–46%, while the iron content increased by 3–127%. The content of Cu, Ni, and Pb in mosses decreased at most sampling sites, except for the eastern part of the Moscow region, where a considerable number of engineering

and metal processing plants operate. The stay-at-home order issued in the Moscow region resulted in a reduction of vehicle emissions affecting air quality, while the negative impact of the industrial sector remained at the level of 2019 or even increased.



Left: sampling map; right: cadmium content in moss samples in 2019 and 2020

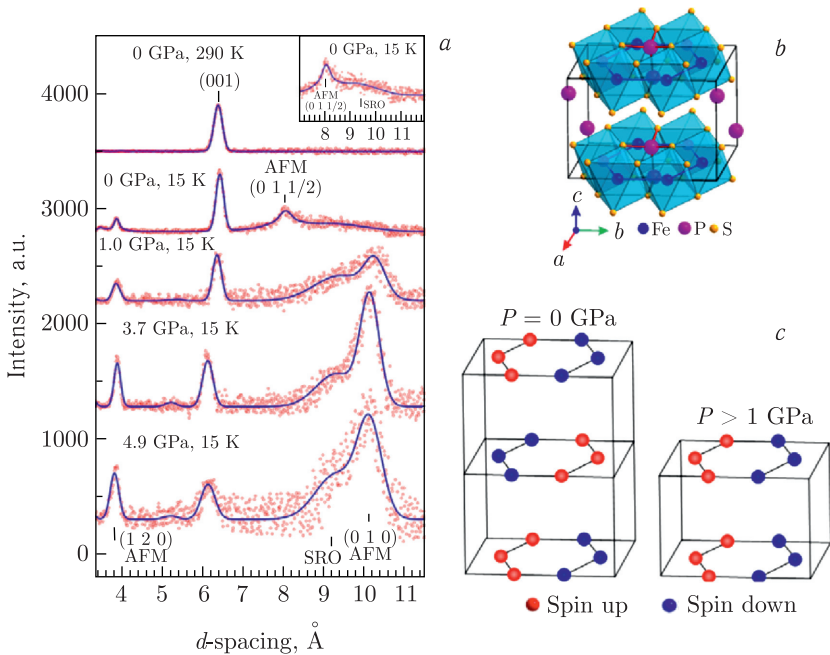
- *Yushin N., Chaligava O., Zinivouscaia I., Vergel K., Grozdov D.* Mosses as Bioindicators of Heavy Metal Air Pollution in the Lockdown Period Adopted to Cope with the COVID-19 Pandemic // *Atmosphere*. 2020. V. 11. P. 1194; <https://doi.org/10.3390/atmos11111194>.

The development of method of Neutron Resonance Capture Analysis (NRCA) in order to determine the element composition of samples continues. The method is non-destructive and based on registration of neutron resonances in radiative capture, measurement of the yield of reaction products in these resonances. To test the capabilities of this method, such investigations were carried out in collaboration with the Institute of Archaeology of RAS at the pulsed neutron source IREN of FLNP for the Bosphorus staters of the 3rd–4th centuries AD from Phanagoria’s treasure.

- *Sedyshev P. V., Simbirtseva N. V., Yergashov A. M., Mazhen S. T., Mareev Yu. D., Shvetsov V. N., Abramzon M. G., Saprykina I. A.* Determining the Elemental Composition of Antique Coins of Phanagorian Treasure by Neutron Spectroscopy at the Pulsed Neutron Source IREN in FLNP JINR // *Phys. Part. Nucl. Lett.* 2020. V. 17. P. 389–400.

Condensed Matter Physics

The van der Waals layered magnetic materials with the magnetic lattice symmetry similar to the graphene lattice demonstrate appearance of long-range magnetic order down to single atomic layer limit at sufficiently high temperatures. Such materials show a rich variety of novel physical phenomena under variation of thermodynamic parameters, including insulator–metal transition, spin crossover, superconductivity. At FLNP JINR, high-pressure effects on the atomic and magnetic structures of quasi-two-dimensional (2D) van der Waals antiferromagnetic material FePS₃ have been studied in a wide temperature range. The isostructural phase transition to a new monoclinic modification at $P = 1$ GPa, accompanied by significant changes of lattice parameters, was observed. The structural transition leads to a modification of the AFM order symmetry from 2D-like (propagation vector $k = (0\ 1\ 1/2)$) to 3D-like ($k = (0\ 1\ 0)$). At higher pressures $P > 14$ GPa in the region of the insulator–metal transition



a) Neutron diffraction patterns of FePS₃, measured at selected pressures and temperatures and processed with the Rietveld method. b) Monoclinic structure of FePS₃ with the C2/m symmetry. c) Magnetic structure of FePS₃ at ambient and high pressures

a suppression of the long-range AFM order and formation of the short-range magnetically ordered phase were found.

- *Coak M.J., Jarvis D.M., Hamidov H., Wildes A.R., Paddison J.A.M., Liu C., Haines C.R.S., Dang N.T., Kichanov S.E., Savenko B.N., Lee S., Kratochvilova M., Klotz S., Hansen T., Kozlenko D.P., Park J.-G., Saxena S.S.* Evolution of Magnetic Order in van der Waals Antiferromagnet FePS₃ through Insulator–Metal Transition // Phys. Rev. X. 2020 (in press).

The important mechanisms of the biological cells vital processes are connected with the interactions between the lipid membranes and cholesterol. For instance, one of the most serious chronic illnesses, seriously affecting the human living, is atherosclerosis, developing through the formation of cholesterol plaques on internal walls of blood vessels.

The collective dynamics of lipid molecules was studied by means of high-resolution inelastic X-ray scattering method (see the figure, p.44). The obtained dispersion curves of multicomponent membranes, in addition to well-known acoustic phonon modes, contain new optical phonon mode, which is associated with the existence of stable lipid pairs of two different types of lipid molecules. The observed phonon gap on the optical mode related to the finite size of the region, where optical phonons exist. Such regions are stable on a picosecond time scale, since their sizes do not depend on membrane composition. This means that any lipid raft consists of a set of stable lipid regions, and the number of such regions is determined by membranes thermodynamic parameters. This result is unique because it provides insight into the collective dynamics of lipid molecules on the picosecond–nanometer time–space window.

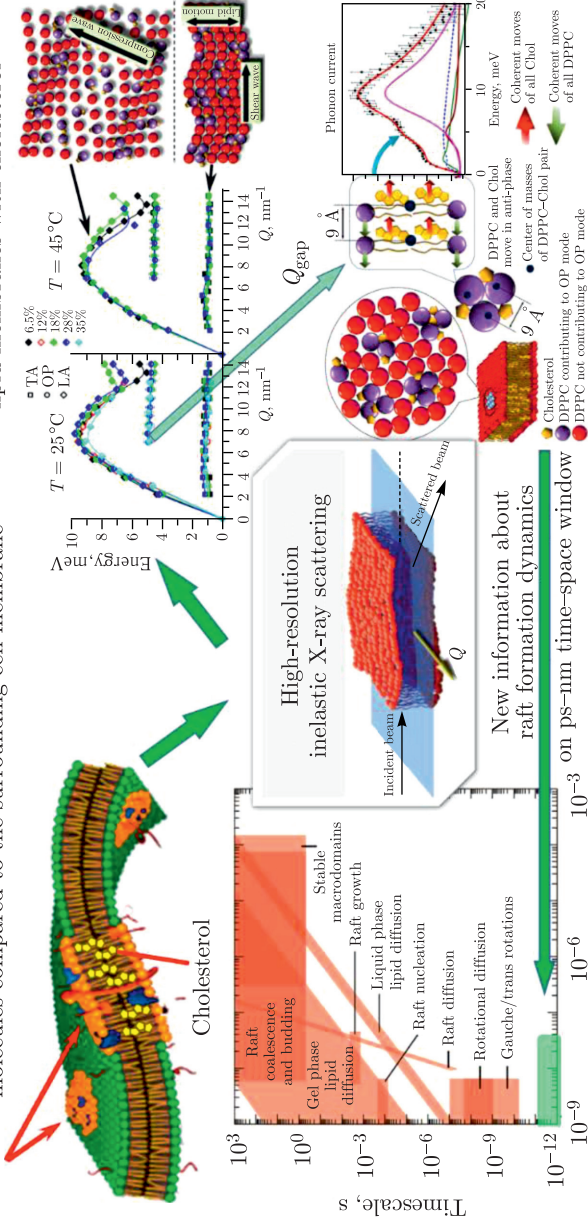
- *Soloviov D., Cai Y. Q., Bolmatov D., Sworov A., Zhernenkov K., Zav'yalov D., Bosak A., Uchiyama H., Zhernenkov M.* Functional Lipid Pairs as Building Blocks of Phase-Separated Membranes // Proc. Natl. Acad. Sci. USA. 2020. V. 117(9). P. 4749–4757.

Highly sensitive level of Raman spectrum registration and SERS-imaging of single 5-thio-2-nitrobenzoic acid (TNB) molecule released from the attomolar-concentrated solution of 5,5'-dithio-bis-[2-nitrobenzoic acid] (DTNB) has been achieved. Dendritic silver nanostructures, onto which analyte molecules of various concentrations were adsorbed, were used as SERS-active substrates.

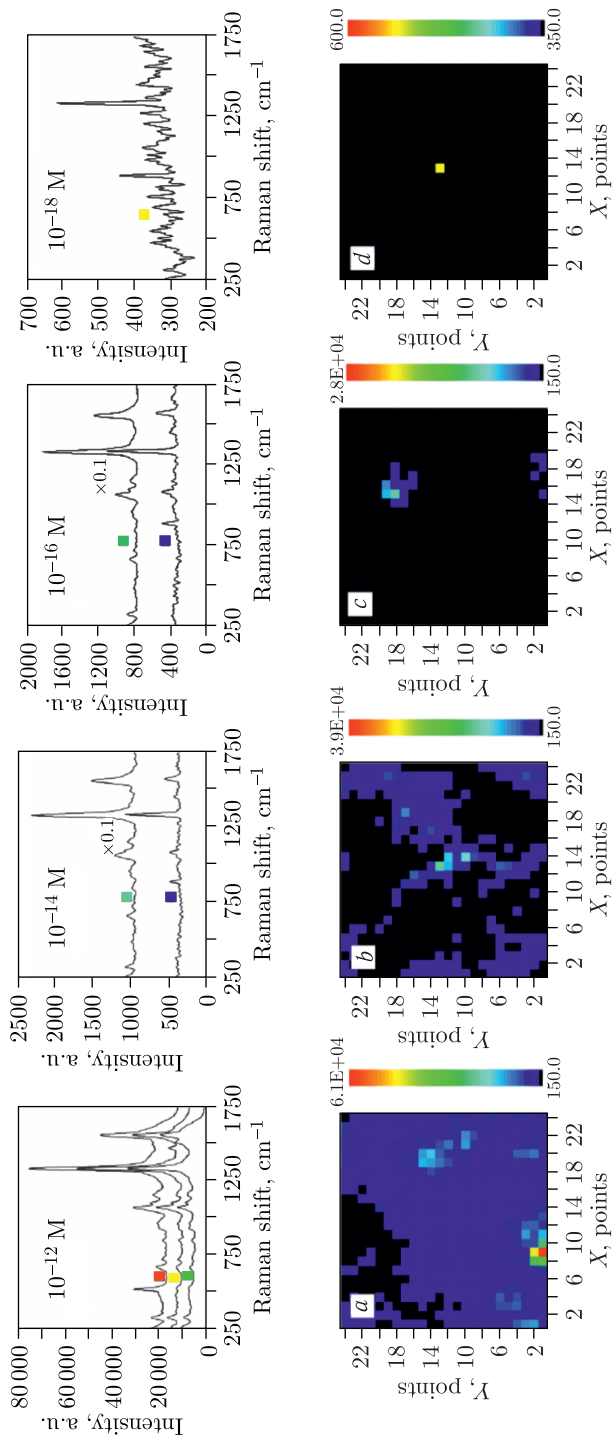
SERS spectra and corresponding maps were recorded and processed at analyte concentrations in the range from 10^{-12} M to

Lipid rafts — microdomains with highly ordered and tightly packed lipid molecules compared to the surrounding cell membrane

Dispersion curves of multicomponent lipid membranes with cholesterol



Schematic representation of the lipid rafts in membranes, experimentally measured dispersion curves of lipid membranes containing cholesterol, illustration of the shifts of structural units for different vibrational models, and representation of the length and time scales, corresponding to the studied collective dynamics effects

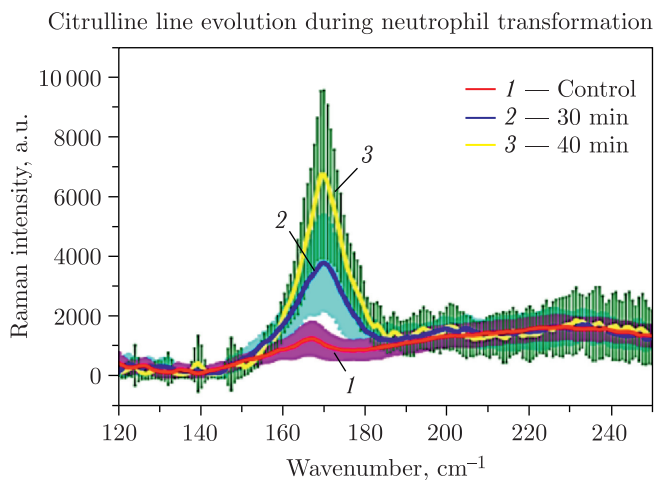


SERS spectra (top row) and corresponding SERS maps (bottom row) for DTNB concentrations: a) 10^{-12} M; b) 10^{-14} M; c) 10^{-16} M; d) 10^{-18} M

ultra-low attomolar concentration of 10^{-18} M (Fig. *d*, p.45), corresponding to a single molecule.

- *Bandarenka H., Khinevich N., Zavatski S., Mamatkulov K., Vorobyeva M., Arzumanyan G.* 3D Silver Dendrites for Single-Molecule Imaging by Surface-Enhanced Raman Spectroscopy // *ChemNanoMat.* 2020; doi: 10.1002/cnma.202000521.

The study is devoted to the application of Raman spectroscopy for distinction of neutrophils transformed during NETosis. It is known that as a result of NETosis, the so-called Neutrophil Extracellular Traps (NETs) arise. NETs are composite DNA complexes with neutrophil proteins transformed in the NETosis process. Our goal was to search for possible spectral markers in neutrophil Raman spectra, caused precisely by NETotic transformation of neutrophils.



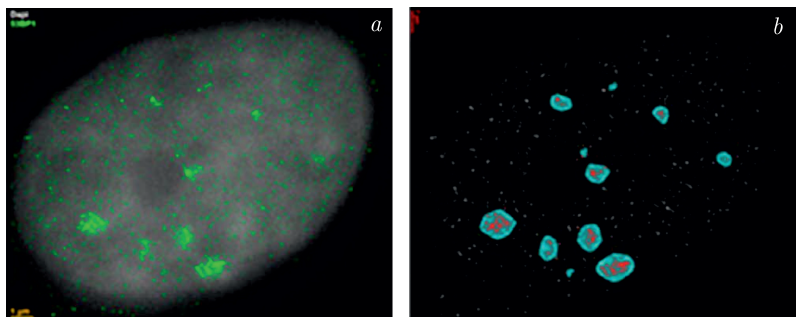
Low-frequency region of the Raman spectrum of neutrophils: evolution (increase) of the intensity of the citrulline line indicating pre-activation of NETosis

At the initial stage of NETs formation under the action of special enzymes, the antimicrobial elements are citrullinated in the granules of the neutrophil cell, indicating the start of the NETosis activation process. Highly sensitive Raman spectroscopy revealed in the low-frequency range the evolution (growth) of the citrulline peak within 30–40 min after the beginning of the inflammatory process, which can be classified as an early diagnosis of NETosis.

- *Arzumanyan G., Mamatkulov K., Volkov A., Vereschagin K. et al. // J. Raman Spectroscopy. 2020. V. 1. P. 10; <https://doi.org/10.1002/jrs.5844>.*

RADIATION AND RADIOBIOLOGICAL RESEARCH

In collaboration with Czech and German colleagues, a new method for the ultra-high resolution analysis of the fine structure of clustered DNA damage has been developed based on single molecule localization microscopy. Using this method, the structure of clustered DNA double-strand breaks induced by accelerated multi-charged ^{15}N ions has been researched, and a comparative study of their repair kinetics in human normal (fibroblasts) and tumor (U87 glioblastoma) cells has been performed. The proposed approach allows getting new insight into the nature of the radioresistance of a number of tumors.

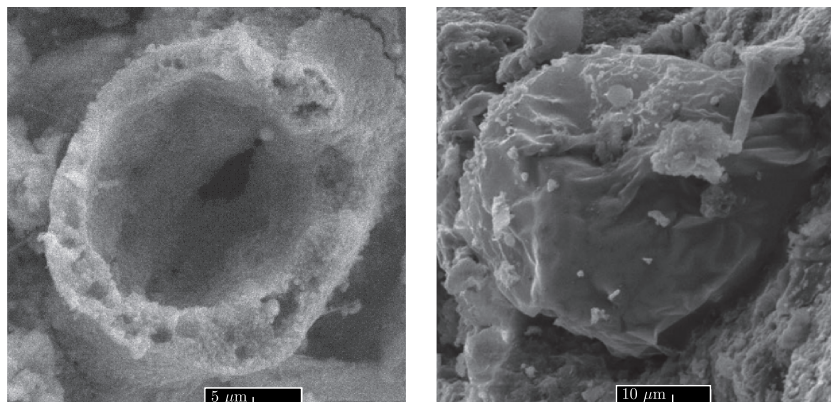


Visualization of the structure of 53BP1 repair protein clusters in nuclei of U87 human glioblastoma cells 24 h after irradiation with 13 MeV/nucleon ^{15}N ions at a dose of 1.3 Gy: a) microscope images; b) software-based post-processing

- *Hausmann M., Neitzel C., Bobkova E., Nagel D., Hofmann A., Chramko T., Smirnova E., Kopečná O., Pagáčová E., Boreyko A., Krasavin E., Falkova I., Heermann D. W., Pilarczyk G., Hildenbrand G., Bestvater F., Falk M. Single Molecule Localization Microscopy Analyses of DNA-Repair Foci and Clusters Detected along Particle Damage Tracks // Front. Phys. 2020. V. 8. P. 578662; doi: 10.3389/fphy.2020.578662.*

A large cycle of scanning electron microscopy and X-ray energy dispersive microanalysis studies of fossilized microorganisms (microfossils) in meteorites has been carried out. The first

illustrated atlas of microfossils in the Orgueil meteorite has been published. In cooperation with colleagues from Italy and the Czech Republic, the formation of complex prebiotic compounds under proton irradiation of simple organic compounds in the presence of meteorite matter as a catalyst has been studied. A new mechanism has been proposed that promotes the formation and processing of insoluble organic matter in meteorites and during prebiotic processes.



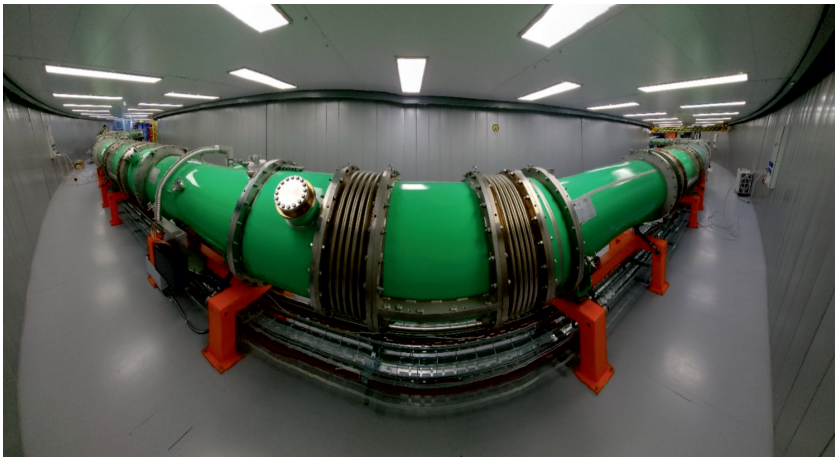
Images of fossilized microorganisms in the Orgueil meteorite

- *Rozanov A. Yu., Hoover R. B., Krasavin E. A., Samylina O. S., Ryumin A. K., Kapralov M. I., Saprykin E. A., Afanasyeva A. N.* An Atlas of Microfossils in the Orgueil Meteorite / Ed.-in-Chief A. Yu. Rozanov. M.: Paleontological Institute, Russian Academy of Sciences, 2020. 130 p. (in Russian and English).
- *Bizzarri B. M., Manini P., Lino V., Ischia M., Kapralov M. I., Krasavin E. A., Mrazikova K., Sponer J., Sponer E., Di Mauro E., Saladino S.* High-Energy Proton-Beam-Induced Polymerization/Oxygenation of Hydroxynaphthalenes on Meteorites and Nitrogen Transfer from Urea: Modeling Insoluble Organic Matter? // *Chem. Eur. J.* 2020. V. 26. P. 14919–14928; doi: 10.1002/chem.202002318.

ACCELERATOR TOPICS

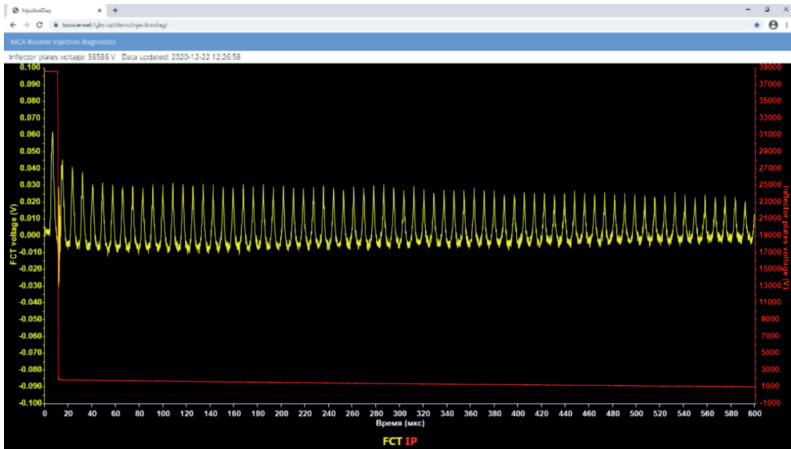
On November 20, 2020, the Prime Minister of the Russian Federation made a technological launch of one of the main units of the megascience project “NICA Complex” — a superconducting booster synchrotron, the Booster. This event was preceded by the

successfully completed long and intense work of the accelerator department of VBLHEP on the construction and commissioning of all objects of the injection complex of the project including sources of polarized, light and heavy ions and the heavy-ion linear accelerator — the basis for obtaining the required beams and their injection into the Booster. The Booster superconducting structural magnets were also produced, the built-in systems of the Booster ring were fabricated, assembled and tested: the accelerating RF system, the electron cooling system of the circulating electron beam, and the beam injection and extraction devices. The Booster cycle setting equipment, diagnostic and thermometry equipment, power supply systems, quenches detection and protection of the Booster magnetic cryostat system were produced.



The Booster for the NICA research complex

The technological run began with cooling down the magnetic cryostat system and a comprehensive inspection of the blocking and protection systems against the loss of superconductivity, tuning the magnetic field cycle and the accelerating system. In strict accordance with the schedule, on December 19, 2020, single-charged helium ions were injected into the Booster and a stable circulation of the beam was obtained. The photo taken from the monitor in the control room shows 3.2 MeV/a.m.u. beam of single-charged ions of He circulating in the Booster beam pipe with intensity of $\sim 10^9$ ions/turn. The high quality of production and assembly of all elements of the booster synchrotron magnetic



The first peak in the yellow diagram is the beam current that is injected into the ring while still in the injection system before the electric kicker is triggered (red line). The ratio of the first peak to the second one is indicative of small injection losses

system made it possible to work without using a correction system of the guiding magnetic field.

The striking result achieved is the completion of a long-term stage of well-coordinated work of a team of several generations of accelerator physicists and engineers in cooperation with partners from the Budker Institute of Nuclear Physics, the Institute for Nuclear Research, the Institute for Theoretical and Experimental Physics, the Institute for High Energy Physics and many Russian and foreign institutes.

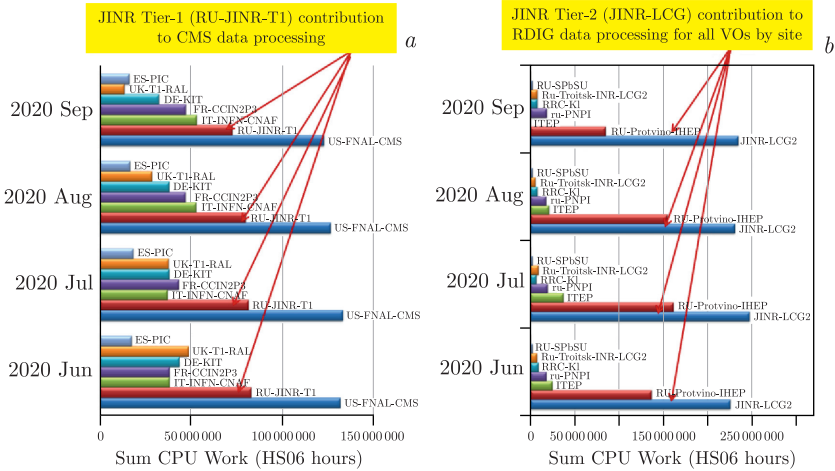
- *Emelianenko V.N. et al.* Analysis of the Results of Magnetic Measurements of the Structural Elements of the Nuclotron Booster // Phys. Part. Nucl. Lett. 2020. V. 17, No. 4. P. 453–455.
- *Bazanov M. et al.* Light-Ion Linear Accelerator for the NICA Project // Phys. Part. Nucl. Lett. 2020. V. 17, No. 4. P. 481–487.

INFORMATION TECHNOLOGY AND COMPUTER PHYSICS

The JINR grid infrastructure is represented by the Tier-1 center for the CMS experiment at the LHC and the Tier-2 center, which enables the processing of data from such experiments as BM@N, MPD, ALICE, ATLAS, CMS, LHCb, BES, BIOMED, COMPASS, NO ν A, STAR, ILC, etc.

In terms of performance, Tier-1 is ranked second among other Tier-1 centers for the CMS experiment to provide data exchange with all world sites operating for the CMS experiment. Since the beginning of the year, 13.23 PB of data have been transferred to Tier-1 from more than 180 grid sites, and over 19 PB of data have been downloaded. Moreover, simulation jobs for the MPD experiment at NICA are performed at JINR Tier-1.

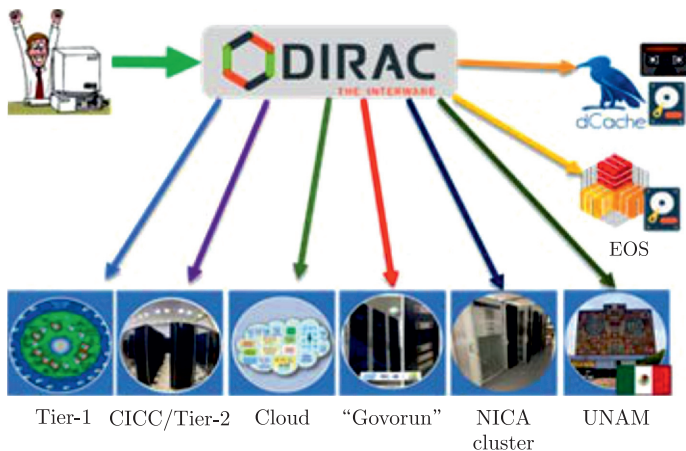
The JINR grid sites are the most productive in the Russian consortium RDIG (Russian Data Intensive Grid). More than 55% of the sum CPU time at RDIG was used for computing at our Tier-1 and Tier-2.



Distribution by the normalized CPU load time in HS06 hours within 2020 for Tier-1 sites for the CMS experiment (a) and Tier-2 sites being part of the RDIG consortium (b)

- *Korenkov V.V.* Trends and Prospects for the Development of Distributed Computing and Big Data Analytics to Support Megascience Projects // Nucl. Phys. 2020. V. 83, No. 6. P. 534–538.

Using the DIRAC (Distributed Infrastructure with Remote Agent Control) Interware, the computing resources of Tier-1/Tier-2, the “Govorun” supercomputer, the computing cloud of JINR and its Member States, the NICA cluster, the cluster of the National Autonomous University of Mexico (UNAM) and storage resources, namely, dCache, EOS and the Lustre ultrafast data storage system, were combined. Using this distributed infrastructure, the program of Monte Carlo data simulation for experiments of the NICA megascience project is performed.



Scheme of the integration of geographically distributed heterogeneous resources based on the DIRAC Interware

- *Pelevanyuk I. et al.* Integration of Distributed Heterogeneous Computing Resources for the MPD Experiment with DIRAC Interware // Phys. Part. Nucl. (in press).

Within JINR international cooperation, a kinematically complete experimental measurement of the characteristics of Compton scattering at free atoms, using the highly efficient method of COLD Target Recoil Ion Momentum Spectroscopy (COLTRIMS), was conducted, and a scientific paper by this international research group was published in *Nature Physics*. A theoretical description of the phenomenon is based on the calculations carried out at the “Govorun” supercomputer.

- *Kircher M. et al.* Kinematically Complete Experimental Study of Compton Scattering at Helium Atoms near the Threshold // Nature Phys. 2020. V. 16. P. 756–760.

On the basis of the HybriLIT platform, the active development of software and services for the joint project of the JINR Laboratory of Information Technologies and the JINR Laboratory of Radiation Biology on the creation of an information system (IS) for analyzing behavioral and pathomorphological changes in the central nervous system (CNS) in the study of the effects of ionizing radiation and other factors on biological objects is in progress. The IS under development is based on machine and deep learning methods and neural network approaches. To date, the client and server parts of the web service <https://bio.jinr.ru/> are implemented; a unified

storage of all data from experiments is elaborated; the first results of improved tracking of the experimental animal in the arena of the test setup are obtained; to test the training options for an artificial neural network, two ways of data marking are developed.

- *Kolesnikova I. et al.* Information System for Radiobiological Research // CEUR Workshop Proc. 2020. V. 2743. P. 1–10.
- *Bulatov A., Stadnik A., Streltsova O.* Computer Vision Algorithms for Studying the Influence of Various Factors on Biological Objects // CEUR Workshop Proc. 2020. V. 2743. P. 36–44.

A workable prototype of the Geometry Database for the BM@N experiment of the NICA project was developed. The main goal of the database is to provide a central storage of the BM@N geometries, convenient tools for managing its geometry modules, various software assembling versions of the BM@N setup from geometry modules and additional files. The developed information system includes a database, an intuitive and compact Graphical User Interface (GUI), and Application Programming Interface (API) tools as a set of ROOT macros. The experience of the Geometry Database design for the CBM experiment was applied to this development, and GUI improvements were made on the basis of BM@N users' requirements. The Geometry Database prototype was put into operation.

- *Akishina E. et al.* Development of the Geometry Database for the BM@N Experiment of the NICA Project // Eur. Phys. J. Web Conf. 2020. V. 226. P. 03003–03007.

EDUCATIONAL ACTIVITIES

In 2020, the studies and internships for the students at the JINR-based departments of MSU, MIPT, MEPHI, Dubna State University, and the universities of the JINR Member States were organized in the online format in order to prevent the spread of COVID-19.

Since September 2020, a new all-year-round student programme INTEREST (INTERNational REMote Student Training) has been run by the JINR UC. The Programme allows students and postgraduates from all over the world to get acquainted with the main fields of the Institute's research, find scientific supervisors for their theses, and raise their chances to be accepted to the full-time onsite internships at JINR. Each stage, or Wave, of the Programme

lasts for 4–6 weeks. During this period participants work online on scientific projects proposed by the Institute’s specialists, listen to introductory lectures, and get an opportunity to have a virtual tour of the JINR basic facilities. The first Wave was attended by 24 students from Cuba, the Czech Republic, Egypt, France, India, Poland, Romania, Russia, and Uzbekistan. Twenty-six students from Belarus, Brazil, China, Egypt, Great Britain, India, Mexico, Poland, Romania, Russia, Ukraine, and Uzbekistan took part in the second Wave of the Programme.

Sixty-three school students from Krasnodar, Nizhny Novgorod, Nizhny Tagil, Penza, Ufa, Volgograd, Yekaterinburg, and 20 more Russian cities took part in the online 5th Summer School “Physics. Mathematics. Informatics”. The 32nd International (interregional) Computer School was also run remotely for 23 school students from Dmitrov, Dolgoprudny, Dubna, and Moscow. For already 2 years, with the support of JINR, Yandex.Lyceum has been successfully working in Dubna.

The JINR UC participated in the organisation and running of the following events: All-Russian Science Festival NAUKA 0+ in Moscow and Saratov; forums “Start of a Career: Autumn” at NRNU MEPhI and “Career Day” at MIPT; educational new-format Olympiad for students of different specialties “I am a Professional”; second Russian–German Scientific and Educational Virtual Exhibition organized within the framework of the Russian–German Year of Scientific and Educational Partnerships 2018–2020 held under the patronage of the Ministry of Foreign Affairs of the Russian Federation and the Ministry of Foreign Affairs of the Federal Republic of Germany and with the support of the Ministry of Education and Science of Russia. The UC staff members organized an online meeting and a video tour for the participants of the summer Governor’s School for the Sciences & Engineering (GSSE) at the University of Tennessee (UT), USA.

**GENERAL DATA
ON THE NUMBER OF PUBLICATIONS BY JINR STAFF
MEMBERS
(from 20.12.2019 to 16.12.2020)**

- Books — 13

Mosses as Biomonitors of Air Pollution: 2015/2016 Survey on Heavy Metals, Nitrogen and POPs in Europe and Beyond: Report of the ICP Vegetation / M. Frontasyeva, H. Harmens, A. Uzhinskiy,

O. Chaligava, Yu. Aleksiyayenak, P. Jancik, P. Nekhoroshkov, D. Abdusamadzoda, M. Trinh, K. Vergel, N. Yushin, O. Culicov, I. Zinicovskaia, M. Shvetsova, S. Gundorina, T. Ostrovnaya, [et al.]. — Dubna: JINR, 2020. — 136 p.: ill. — (JINR; 2020-11). — Bibliogr.: end of papers.

Search for the Muon Charged Lepton Flavor Violation Processes at DLNP / Comp.: Yu. Budagov, V. Glagolev, Y. Davydov, P. Evtukhovich, N. Kuchinsky, N. Khomutov, I. Titkova, Z. Tsamalaizde. — Dubna: JINR, 2019. — 113 p.: ill. — (JINR; 2019-54). — Bibliogr.: p. 99–113.

The Silicon Tracking System as Part of the Hybrid Tracker of the BM@N Experiment: Technical Design Report / A. V. Baranov, D. Dementev, V. Elsha, P. I. Kharlamov, A. Kolzhvari, T. Lygdenova, M. M. Merkin, Yu. Murin, M. Protsenko, A. Sheremetev, A. Sheremeteva, N. Sukhov, M. Shitenkov, A. Voronin, A. Zinchenko, [et al.]; Eds.: D. Dementev, P. Senger. — Dubna: JINR, 2020. — 101 p.: ill. — (JINR; 2020-23). — Bibliogr.: end of papers.

Vadim Vasilievich Volkov: Warrior. Citizen. Scientist / Eds.: Yu. Ts. Oganessian, S. N. Dmitriev; Ed.-comp.: E. M. Molchanov. — Dubna: JINR, 2020. — 128 p.: ill.

“Dubna, My Dream...” / Comp.: L. N. Orelovich. — Dubna: JINR, 2020. — 79 p.: col. ill.

Chess Movement in Dubna / V. G. Berezin, S. Vokal, S. I. Kukarnikov, A. V. Slesarenko; Ed.: B. M. Starchenko. — Dubna: JINR, 2019. — 120 p.: col. ill. — (JINR; 2019-45).

Articles on Modern Particle Physics / Gen. ed.: V. A. Matveev, I. A. Golutvin; Ed.-comp.: G. A. Kozlov. — Dubna: JINR, 2020. — 335 p.: col. ill. — (JINR; 2018-50). — Bibliogr.: end of papers.

F. L. Shapiro: A Scientist and a Man: A Book of Memories / Comp.: L. B. Pikelner, A. V. Strelkov. — Ed. 2. — Dubna: JINR, 2019. — 220[35] p.: ill.

Aksenov V. L., Tropin T. V. Lectures on Condensed State Theory: Manual. — M.: MSU Physics Department, 2020. — 442 p.: ill. — Bibliogr.: p. 438–440.

Blokhintsev D. I. Quantum Mechanics Basics: Manual. — Ed. ster. — M.: URSS, 2019. — 664 p.: ill. — (Heritage in Physics and Mathematics: Physics (Quantum Mechanics)).

Perpelkin E. E., Sadovnikov B. I., Inozemtseva N. G. Calculations at Graphic Processors (GPU) in Tasks of Mathematical and

Theoretical Physics. — 3rd ed. — M.: URSS, 2019. — 235 p.: ill. — (MSU classical textbook). — Bibliogr.: p. 235.

Shvidkij S. Great in Small, Instant Like Eternity... — Dubna: JINR, 2020. — 91 p.

Shitov Yu. A., Brudanin V. B., Fomina M. V. Amazing Neutrino Transformations. — Dubna: JINR, 2020. — 30 p.: col. ill. — (JINR; 2020-21).

- Journal papers — 1106
- Publications in conference Proceedings — 285
- Preprints — 21
- Abstracts of theses — 10
- Total: 1435