2022

High-energy heavy-ion physics is connected to a large variety of physics disciplines. Researches probe fundamental concepts of classical and modern thermodynamics, hydrodynamics, and quantum theory. Therefore, they have several theoretical and practical topical research directions covering a wide spectrum, such as: thermodynamics, perturbative and non-perturbative QCD, high-energy nuclear effects, hadronization, hadron phenomenology, phenomenology of compact stars, and gravity/cosmology. These studies are strongly motivated by the needs of several recent and planned large-scale facilities, such as collaborations at the LHC (CERN, Switzerland) and RHIC (BNL, USA), and future experiments at FCC (CERN), FAIR (GSI, Germany) and NICA (Dubna, Russia). They have continued these theoretical investigations in the direction of high-energy physics phenomenology connected to existing and future state-of-the-art detectors. Concerning international theoretical collaborations, they have established joint work with the Goethe Institute (Germany), LBNL (USA), CCNU, MAP (China), UNAM (Mexico), Dubna (Russia) and ERI (Japan). The most important published results are highlighted below.

Investigating heavy-ion collisions — High-energy heavy-ion collisions are one of the best testbeds for the non-ideal, non-equilibrium, finite systems. In this areas the machine learning-based models are quite successful.

Together the Indian Institute of Technology (IIT) Indore they investigated whether a deep neural network (DNN) algorithm is able to map the momentum asymuthal anisotropy parameter (v_2 – the second Fourier component), measured in non-central heavy-ion collisions. They found that their machine learning based model predicted the centrality and transverse momentum dependence well, indeed the constituent quark number scaling (NCQ) was also encoded in the hyperparameters of the neural network [1,2].

In collaboration with the University of Berkeley (USA) and IoPP CCNU (Wuhan, China), they developed the HIJING++ heavy-ion Monte Carlo Generator with G. Papp (ELTE) and X.N. Wang (IoPP CCNU, LBNL). They built the future Monte Carlo generator for the heavy-ion collisions, HIJING++, which was tuned by applying a machine learning-based parameter-tune code. In parallel, together with University of Oxford, a machine learning-based hadronization model has been developed and tested successfully [21].

The effective field theory of the strong interaction — They investigated the large N_c limit in the framework of a 2+1 flavor (axial)vector meson extended constituent quark-meson model with Polyakov loops. At finite temperature, they implemented a general N_c-dependent Polyakov loop potential and a so-called uniform eigenvalue *ansatz* were applied to reduce the number of degrees of freedom. They found that the critical endpoint (CEP) becomes absent already for $N_c=4$, but a second CEP emerges on the temperature axis at around $N_c=53$ and moves to higher baryon chemical potential with the increase of N_c. For high baryon chemical potential, the chiral and deconfinement phase transitions, which are both crossover type in this region, become separated forming a chirally symmetric but confined region (Figure 1). This can be identified with the so-called quarkyonic phase. Their work, titled „Fate of the critical endpoint at large N_c”

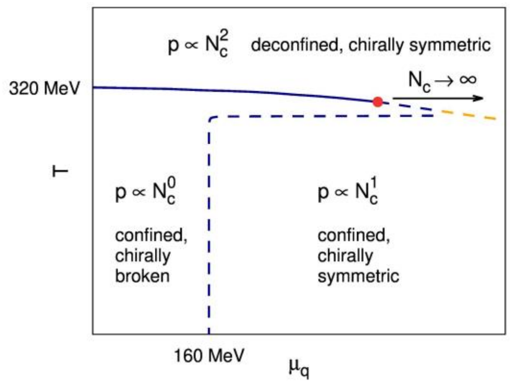


Figure 1: Figure 1. Phase diagram of the model (see details in the text).

has been marked as Editors' Suggestion in Phys. Rev. D [7] .

They developed the numerical code of functional renormalization group for the SU(2) case for the mirror-baryon sigma model using the Kurganov–Tadmor algorithm. They calculated J/Psi production in antiproton induced reactions with our transport model to study the ground state proton momentum distribution inside the nuclei by studying the J/Psi production threshold. In the charm excitation function it is almost indistinguishable whether the groundstate momentum distribution is the Fermi sphere or the realistic momentum distribution with the high momentum tail. They have shown, furthermore, that using an initial momentum distribution any realistic threshold shift is washed out in the excitation function of charmed vector mesons. We calculated charm production in antiproton, proton and pion induced reactions with our transport model using the in-medium modification of their masses. They have shown that even with a detector resolution of 50 MeV the in medium mass shift of Psi(3686) can be observed. We have built bottom cross section calculated in the statistical bootstrap model to the transport code and we are calculating the effect of their in-medium modification.

In collaboration with the HADES experimental group, they were able to compare their experimental results for di-electron production in pion-nucleon collisions at 1.5 GeV center-of-mass energy with the predictions of our effective Lagrangian model. The model provided good description of the differential cross section found in the experiment. Also, their predictions for the polarization density matrix elements of the virtual photon were found to be consistent with the experimental results. They also studied the di-electron production process in π+*N* collisions in a model independent way using the helicity formalism and worked out the relation of this approach to the effective Lagrangian model.

Chiral-symmetric baryon-meson model has been developed to describe the properties of nuclear matter during relativistic collisions of heavy nuclei. Special focus was directed on study of thermodynamical properties of matter in such conditions in frameworks of Functional Renormalization Groups, taking into account mesonic and baryonic fluctuations. Nuclear matter transition is studied via solution of flow equation with effective action [11].

Multi-wavelength astronomy and investigations of extreme matter in the Universe — Investigation of cold compact stars provides the opportunity to understand cold super-dense nuclear matter. These theoretical developments are strongly connected to recent measurements of compact stars by multi-wavelength observations and gravitational waves and the future Einstein Telescope, which are supported by theoretical networking EU COST action PHAROS (CA162014) until 2022. They also contributed to the AstroNet EU roadmap, the CREDO collaboration [9-10] and the CREMLIN+ H2020 project.

Based on the recent NISER data, they verified the variation of neutron star observables by dense symmetric nuclear matter parameters using the Maximal Mass neutron star assumption, where strong linear connection has been tested between macro- and microscopic parameters of neutron star and its matter these results [24]. They also utilized their model at zero temperature and finite baryon chemical potential as well, for which a concatenation to hadronic equations of state at lower densities was used in order to apply to the description of compact stars. They applied the acquired equations of state to hybrid stars and they used astrophysical observations in a Bayesian framework to investigate the parameter region with the highest posterior probability. They managed to constrain the values of the vector coupling and the sigma mass of our model by using the astrophysical observations mentioned above, and these results were published in [8].

As additional research in study of matter in extreme conditions, pycnonuclear reactions in compact stars at zero temperatures have been studied on quantum mechanical basis with high precision. Taking into account complete analysis of quantum fluxes in the internal nuclear region, rate and number of pycnonuclear reactions for ^{12}C + ^{12}C = ^{24}Mg are reduced on 1.8 times. They showed the appearance of new states (called as quasibound states) where the compound nuclear system is formed with maximal probability. Energy spectrum of zero-point vibrations is revised and estimated with high precision [11].

They studied the properties of Sedov-type self-similar solutions of non-relativistic self-gravitating fluids in completely spherically symmetric systems. By this self-scaling model, they were able to describe the evolution of the Universe with dark matter – in an analytical way [3].

They joined to the Einstein Telescope Collaboration and started working with the Site Preparation Board. They also participated in the group's infrasound measurement campaign at Sos Enattos mine in Sardinia. Another Atomki micropohone collects data at adVirgo detector.A windshield and protection against humidity for the Atomki infrasound monitoring system at the Jánossy Underground Research Laboratory (VLAB) has been developed. They also carried out test measurements, data processing and documentation writing in the project called SeismoCell – as an application of seismic and infrasound sensors.

Rare and anomalous radionuclei decay measurements were investigated during the year at the Jánossy Underground Research Laboratory (VLAB). To perform high-precision studies of nuclear decay anomalies they used a high-purity germanium (HPGe) detector setup. They started the long range measurements in the laboratory. A similar research project has been started on galactic archeology in collaboration with the Johns Hopkins University.

Applying novel thermodynamical and hydrodynamical approaches — They have presented the thermodynamic derivation and the extension of Newtonian gravitation theory and on simple exact solutions, together with Sumiyoshi Abe. The most important achievement of this study was the formulation and submission of results on the derivation of non-relativistic quantum theory using the same, thermodynamic methodology. It was shown, that the key element in the transition between field and particle-based theories is a property called *classical holography* and that this is a consequence of the Second Law of thermodynamics. They investigated novel thermodynamical models focusing on the non-Fourier heat conduction and the model test in biological systems [12-18]. These models were also tested on carbon-foam samples to obtain heat conductivity parameters for the CERN ALICE Collaboration's ITS3 R&D project – as an application.

Coordination of the Hungarian ALICE Group and participation in the Bergen pCT collaboration. — They coordinate the Hungarian contributions to CERN's largest heavy-ion experiment ALICE. This activity is many-folded: In addition to data analysis, our group has constructed a new specialized Analysis Facility for the CERN ALICE Collaboration in the WSCLAB at the Wigner RCP. This HPC unit is dedicated for Big Data challenges as a joint activity with the Vesztergombi High-energy Physics Laboratory (VLAB), which awarded the TOP50 Hungarian research infrastructure title in 2021.

They were involved to the summary of the last 30 years of the CERN ALICE experiment in the ALICE experiment – A journey through QCD [19]. This collects all discoveries of the Large Hadron Collider at CERN. In 2022 ALICE presented a "Letter of intent for ALICE 3: A next generation heavy-ion experiment at the LHC". They has been already engaged with this large-scale R&D project, and contributed to the proposal [20]. They also contributed to the Bergen pCT collaboration, where the detector prototype of the tracking calorimeter has been built, and analysis tracking softwares were developed based on machine learning techniques. They recent contribution is the development of the first application of Richardson–Lucy image reconstruction technique applied for proton-based imaging.

Coordination of the Wigner Scientific Computational Laboratory (WSCLAB) — WSCLAB, as the TOP50 research infrastructure of the Hungarian national grant agency, NRDIO, were involed in several national and international projects. These are primary dedicated to massively parallel classical and quantum computing at various field of sciences. They have improved the CERN ALICE Analysis Facility, the CERN WLCG Grid T2 site of the CERN's ALICE and CMS collaborations, and the Wigner GPU Laboratory. The Wigner GPU Laboratory's capacity has been doubled and intensively used by several projects such as the Nanoplasmonic Laser Fusion National Laboratory, the Astronomy Department of the Eötvös University, the LIGO gravitational wave signal search, Heavy-ion Research Group of the Wigner RCP together with the University of Oxford. They had also an academy-industry project together with the Lombiq LTD[6,21-23,25-41]. These research projects involved more than 12 PhD and 6 MSc students.

The WSCLAB has organized the "Massive Parallel Computing for Science and Industrial Applications – GPUDay 2022" conference, the "ALICE T1/T2" Workshop, the "Lectures on Modern Scientific Computing 2022". They participated in the "CERN-Wigner Artificial Intelligence Academia-Industry Matching Event (AIME22)" and the "MILAB 2022" workshop. As a Hungarian representative of the CERN's Quantum Technology Initiative, they organized the "Quantum Technology for High Energy Physics (QT4HEP) 2022" at CERN.

Education, PR and prizes. — Connected to the research group, they had 2 MSc students. Young colleagues participated in the young researcher's projects and 2 TDK theses were submitted for the competition, and one won price at the ELTE Physics TDK.

They had 8 young PhD fellow in the research group. Senior colleagues are members of the ELTE, BME, PTE doctoral programmes. Gábor Balassa and Mátyás Szűcs have obtained their PhD degree at the BME Physics Doctoral School. G. Balassa had also received the Györgyi Géza Price of the Wigner RCP.

Group members played key role in the following workshop, conference and seminar organizations: "GPU Day 2022" at the at Wigner RCP; "Zimányi Winter School 2022," Budapest, Hungary, "PP2022, Margaret Island Symposium on Particles and Plasmas 2022", Lectures on Modern Scientific Computing 2022, ALICE T1/T2 Workshop in Budapest and the "Quantum Technology for High Energy Physics (QT4HEP) 2022" at CERN. Group members participated in PR activities at their alma mater and high-school invitations, indeed the "Atomoktól a Csillagokig" public outreach series. They were also active in outreach in television and radio broadcasts, and outreach publications [22,23].

References in referred journals

1. **Mallick, N. ; Prasad, S. ; Mishra, A.N. ; Sahoo, R. ; Barnaföldi, G.G. Estimating elliptic flow coefficient in heavy ion collisions using deep learning, PHYSICAL REVIEW D 105 : 11 Paper: 114022 , 10 p. (2022) IF=5.407**
2. Mallick, N. ; Prasad, S. ; Mishra, A.N. ; Sahoo, R. ; Barnaföldi, G.G. Dynamics of hot QCD matter-Current status and developments, INTERNATIONAL JOURNAL OF MODERN PHYSICS E-NUCLEAR PHYSICS Paper: 2250097 , 148 p. (2022) IF=0.924.
3. Barna, Imre Ferenc; Pocsai, Mihaly Andras ; Barnafoldi, Gergely Gabor, Self-Similar Solutions of a Gravitating Dark Fluid, MATHEMATICS 10 : 18 Paper: 3220 , 11 p. (2022) IF=3.763
4. G. Balassa, 'Estimating scattering potentials in inverse problems with Volterra series and neural networks', Eur. Phys. J. A 58, (2022) 186. IF= **3.043**
5. G. Balassa. 'Estimating Scattering Potentials in Inverse Problems with a Non-Causal Volterra Model', Mathematics 10, (2022) 1257. IF=3.763
6. Gábor Bíró, Mihály Pocsai, Imre F. Barna, Gergely G.Barnaföldi, Joshua T. Moody, Gábor Demeter: Machine learning methods for schlieren imaging of a plasma channel in tenuous atomic vapor. OPTICS & LASER TECHNOLOGY, 159, 2023, 108948 (2022), IF=4.939
7. **P. Kovacs, Gy. Kovacs and F. Giacosa, The fate of the critical endpoint at large Nc, Phys. Rev. D106 11, 116016 (2022) IF=5.407**
8. Péter Kovács, János Takátsy, Jürgen Schaffner-Bielich, György Wolf. Neutron star properties with careful parameterization in the (axial)vector meson extended linear sigma model, Phys. Rev. D 105, 103014 (2022) IF = 5.407
9. O. Sushchov, P. Homola, M. Piekarczyk, O. Ruimi, K. Almeida Cheminant, O. Bar, L. Bibrzycki, B. Hnatyk, P. Kovács and B. Lozowski, et al. A New Method of Simulation of Cosmic-ray Ensembles Initiated by Synchrotron Radiation. Symmetry 14 (2022) no.10, 1961 IF=3.114
10. B. Poncyljusz, T. Bulik, N. Dhital, O. Sushchov, S. Stuglik, P. Homola, D. Alvarez-Castillo, P. Kovács, M. Piekarczyk, T. Wibig and J. Stasielak, et al. Simulation of the Isotropic Ultra-

High Energy Photon Flux in the Solar Magnetic Field. Universe 8 (2022) no.10, 498 IF=2.813

11. S. P. Maydanyuk, K. A. Shaulskyi, Quantum design in study of pycnonuclear reactions in compact stars: Nuclear fusion, new quasibound states and spectroscopy, Europ Phys. Journ. A, 58, 220 (2022), 14 p. IF= 3.043

12. T. Fülöp, M. Szücs: Analytical solutions for rheological processes around bores and tunnels. JOURNAL OF ENGINEERING MATHEMATICS 136 : 1 Paper: 1 , 28 p. (2022). IF= 1.509
13. M. Szücs, R. Kovács: Gradient-dependent transprt coefficients in the Navier-Stokes-Fourier system. THEORETICAL AND APPLIED MECHANICS: 00 pp. 9-9., 1 p. (2022). IF=0.767

14. Abe, S ; Van, P, Crossover in Extended Newtonian Gravity Emerging from Thermodynamics, SYMMETRY 14 : 5 Paper: 1048 , 7 p. (2022), IF: 2.940)

15. Ván, P. ; Kovács, R. ; Vázquez, F. Spectral Properties of Dissipation, JOURNAL OF NON-EQUILIBRIUM THERMODYNAMICS 47 : 1 pp. 95-102. , 8 p. (2022), IF: 4.29)

16. Shomali, Z. ; Kovács, R. ; Ván, P. ; Kudinov, I.V. ; Ghazanfarian, J., Lagging heat models in thermodynamics and bioheat transfer: a critical review, CONTINUUM MECHANICS AND THERMODYNAMICS 34 : 3 pp. 637-679. , 43 p. (2022) IF: 3.285)

17. Szücs, M. ; Pavelka, M. ; Kovács, R. ; Fülöp, T. ; Ván, P. ; Grmela, M., A case study of non-Fourier heat conduction using internal variables and GENERIC JOURNAL OF NON-EQUILIBRIUM THERMODYNAMICS 47 : 1 pp. 31-60. , 30 p. (2022), IF: 4.29)

18. **Ván, P. ; Abe, S. Emergence of extended Newtonian gravity from thermodynamics, PHYSICA A - STATISTICAL MECHANICS AND ITS APPLICATIONS 588 Paper: 126505 , 7 p. (2022), IF: 3.778)**

Further Highlighted publications (6)

19. Acharya S, ..., Barnaföldi G.G. Bencédi Gy, Biró G, Boldizsár L, Frajna E, Gyulai L, Hamar G, Lévai P, Nath Mischra A, Vértesi R, Varga D, Z Varga, Varga-Kőfaragó M, …, et al, ALICE Experiment – A journey through QCD https://arxiv.org/abs/2211.04384
20. Acharya S, ..., Barnaföldi G.G. Bencédi Gy, Biró G, Boldizsár L, Frajna E, Gyulai L, Hamar G, Lévai P, Nath Mischra A, Vértesi R, Varga D, Z Varga, Varga-Kőfaragó M, …, et al, Letter of intent for ALICE 3: A next generation heavy-ion experiment at the LHC https://cds.cern.ch/record/2803563
21. G. Bíró, B. Tankó-Bartalis, G.G. Barnaföldi, Testing of KNO-scaling of charged hadron multiplicities within a Machine Learning based approach, PoS ICHEP2022 (2022) 1188,
22. Hirdi, Henriett Éva ; Barnaföldi, Gergely Gábor, A hadronterápia ápolási vonatkozásai, NŐVÉR 35 : 4 pp. 18-29. , 12 p. (2022)
23. Horváth, Anna ; Bámer, Balázs ; Barnaföldi, Gergely Gábor , Kövessük a fényeket – délibábok numerikus szimulációja, FIZIKAI SZEMLE 72 : 9 pp. 296-301. , 6 p. (2022)
24. Szigeti , BE.; Barnaföldi, GG; Pósfay, P; Jakovác, A;. Estimating Microscopic Nuclear Data by Compact Star Observation. EPJ Web CON. 259, 13011 (2022)

WSCLAB-related publications

25. Rakyta P, Morse G, Nádori J, Majnay-Takács Z, Mencer O, Zimborás Z, Highly optimized quantum circuits synthesized via data-flow engines (arXiv: 2211.07685)

26. Zsurka E, Plaszkó N, Rakyta P, Kormányos A, Non-local Andreev reflection through Andreev molecular states in graphene Josephson junctions (arXiv: 2208.11536)

27. Rakyta P and Zimborás Z, Efficient quantum gate decomposition via adaptive circuit compression (arXiv: 2203.04426)

28. Rakyta P and Zoltán Zimborás Z Approaching the theoretical limit in quantum gate decomposition, Quantum 6, 710 (2022). https://quantum-journal.org/papers/q-2022-05-11-710/

29. Horváth A. et al. Délibábok numerikus szimulációja, Fizikai Szemle 2022/09 p297 (2022)

30. Barnaföldi GG. et al. Numerical simulation of mirages above water bodies (Submitted to AJP)

31. Gábor Bíró, Mihály Pocsai, Imre Ferenc Barna, Joshua T. Moody, Gábor Demeter, Machine learning methods for Schlieren imaging of a plasma channel in tenuous atomic vapor, Optics & Laser Technology Volume 159, April 2023, 108948, (2205.12731)

32. Legrady D., Tolnai G., Hajas T., Pazman E., Parko T., Pos I. Full Core Pin-Level VVER-440 Simulation of a Rod Drop Experiment with the GPU-Based Monte Carlo Code GUARDYAN, ENERGIES 15 : 8 Paper: 2712 , 17 p. (2022)

33. H.; Suhajda, E.; Sillitoe, I.; Nair, S.; Varadi, M.; Hegedus, T. Comprehensive, Collection and Prediction of ABC Transmembrane Protein Structures in the AI Era of Structural, Biology. Int. J. Mol. Sci. 2022, 23, 8877. https://doi.org/10.3390/ijms23168877

34. Code: Exploring SARS-CoV-2 variants code examples: https://github.com/csabaiBio/RBD-AlphaFold2-structures-and-phenotypic-information.

35. J. Jumper et al., “Highly accurate protein structure prediction with AlphaFold,” Nat. 2021 5967873, vol. 596, no. 7873, pp. 583–589, Jul. 2021, doi: 10.1038/s41586-021-03819-2.

36. T. N. Starr et al., “Deep Mutational Scanning of SARS-CoV-2 Receptor Binding Domain Reveals Constraints on Folding and ACE2 Binding,” Cell, vol. 182, no. 5, pp. 1295-1310.e20, Sep. 2020, doi: 10.1016/J.CELL.2020.08.012.

37. T. N. Starr et al., “Shifting mutational constraints in the SARS-CoV-2 receptor-binding domain during viral evolution,” bioRxiv, p. 2022.02.24.481899, Feb. 2022, doi: 10.1101/2022.02.24.481899.

38. Lin, Zeming, et al. "Language models of protein sequences at the scale of evolution enable accurate structure prediction." bioRxiv (2022).

39. Kilim, Oz et al. “SARS-CoV-2 RBD deep mutational AlphaFold2 structures carry phenotypic information”, submitted to Scientific Data (2022);

40. Sudár Á and Barnaföldi GG, Proton Computed Tomography Based on Richardson-Lucy Algorithm arXiv:2212.00126 (Submitted to Physics in Medicine & Biology)

41. Gergácz M. and Keresztúri Á.: Melting possibility of remnant seasonal water ice patches on Mars, arXiv:2212.02166 (Submitted to Earth and Planetary Science Letters)

2021

High-energy heavy-ion physics is connected to a large variety of physics disciplines. Researches probe fundamental concepts of classical and modern thermodynamics, hydrodynamics, and quantum theory. Therefore, they have several theoretical and practical topical research directions covering a wide spectrum, such as: thermodynamics, perturbative and non-perturbative QCD, high-energy nuclear effects, hadronization, hadron phenomenology, phenomenology of compact stars, and gravity/cosmology. These studies are strongly motivated by the needs of several recent and planned large-scale facilities, such as collaborations at the LHC (CERN, Switzerland) and RHIC (BNL, USA), and future experiments at FCC (CERN), FAIR (GSI, Germany) and NICA (Dubna, Russia). They have continued these theoretical investigations in the direction of high-energy physics phenomenology connected to existing and future state-of-the-art detectors. Concerning international theoretical collaborations, they have established joint work with the Goethe Institute (Germany), LBNL (USA), CCNU, MAP (China), UNAM (Mexico), Dubna (Russia) and ERI (Japan). The most important published results are highlighted below.

The effective field theory of the strong interaction — As a member of the CBM & HADES collaborations, they continued the planning of the details of the detector. They participated in the detector simulations. They studied the dilepton production process in pion-nucleon collisions in the energy range of the second resonance region, studied experimentally by the HADES collaboration. They extended our previous works by including both non-resonant (Born) contributions as well as contributions of baryon resonances. They gave predictions for the dilepton invariant mass spectrum and the polarization density matrix elements of the intermediate virtual photon and argued that the latter may be accessible in the HADES experiment by studying the angular distribution of dileptons. That way one would actually reconstruct the polarization state of the virtual photon, which would help disentangle various dilepton sources contributing to the process [1].

They calculated the one-loop fermion contribution to the vector and axialvector meson curvature masses in the framework of a (axial)vector meson extended Polyakov-constituent quark-meson model (ELSM). They showed that for certain fields the contribution splits up into transverse and longitudinal parts, which give different contributions to the tree-level masses at finite temperature. They also investigated the behavior of our constituent quark model at zero temperature when vector meson condensates are also included. They found that the inclusion of an additional parameter constraint is necessary to ensure that chiral symmetry is restored at high densities [2,3].

Multi-wavelength astronomy and investigations of super-dense matter in compact stars — Investigation of cold compact stars provides the opportunity to understand cold super-dense nuclear matter. These theoretical developments are strongly connected to recent measurements of compact stars by multi-wavelength observations and gravitational waves and the future Einstein Telescope, which are supported by theoretical networking EU COST action PHAROS (CA162014). They also contributed to the AstroNet EU roadmap, the CREDO collaboration and the CREMLINplus H2020 grant.

Based on the recent NISER data, they verified the variation of neutron star observables by dense symmetric nuclear matter parameters using the Maximal Mass neutron star assumption, where strong linear connection has been tested between macro- and microscopic parameters of neutron star and its matter these results were presented at the Strangeness in Quark Matter SQM2021 conference [4].

They applied nonzero vector condensate at finite baryon chemical potential and at zero temperature in the ELSM to model hybrid stars (compact stars with quark matter at their core). They studied the properties of compact stars when these modifications were included. They calculated mass-radius curves and managed to constrain certain parameters (like the vector coupling or sigma meson mass) of the model with the help of astrophysical observables. We also found a simple relation among the model parameters when we required vanishing of the scalar condensates at asymptotically large baryon chemical potentials[2,3].

Measuring anomalies in natural laws — They published the recent results of the re-measurements of the gravitaional constant by the Eötvös pendulum and they continued the infrasound background noise collection at the Matra Gravitational and Geophysical Laboratory (MGGL – a previous potential site for Einstein Telescope and another subterranean site)[5]. The background noise measured at the MGGL (Hungary), at the Sos Enattos mine in Sardinia (Italy) and at LIGO and adVirgo were compared to each other. They confirmed that it is advantageous to install a third generation interferometric gravitational-wave detector deep under the ground. They also presented, that below 2Hz, the infrasound background noise at adVirgo’s Central Building is dominated by wind. Above 2Hz, the HVAC system is the main contributor. They calculated the Newtonian noise of seismic and infrasound origin of MGGL. They also investigated the seasonal variation of Newtonian noise. An applied-physics project, SeismoCell, has been started to develop portable sensor applications based on the above technologies.

Rare and anomalous radionuclei decay measurements were investigated during the year at the Jánossy Underground Research Laboratory (VLAB). To perform high-precision studies of nuclear decay anomalies they used a high-purity germanium (HPGe) detector setup. A modern HPGe detector system was installed, and hardware and software infrastructure was developed that enables automated data-taking and environmental monitoring, remotely [6].

Investigating heavy-ion collisions — High-energy heavy-ion collisions are one of the best testbeds for the non-ideal, non-equilibrium, finite systems. The non-extensive statistical approach, developed by their group, can describe such a matter by enwidening the framework of classical thermodynamics and statistical physics towards non-equilibrium and complex system phenomena.

They studied the production rate of the X(3872) possible tetraquark state at a few GeV energies in proton-proton, pion-proton, and proton-antiproton reactions, near threshold, with a statistical based model. The model gave good match with the measured values for the inclusive production cross sections at TeV energy scale, where measured data were available. The low energy cross-sections were calculated with the model, using the the assumption that the X(3872) particle is a diquark-antidiquark bound state in the triplet-antitriplet representation [7].

They investigated new nuclear effects in high-energy heavy-ion collisions. Since classifications based on multiplicity and event-shape variables are available, new nuclear effect can mbe investigated from small to large systems. They obtained that the Tsallis-thermometer is an excellent tool to quantify the geometrical properties of the events[8-9].

In collaboration with the University of Berkeley (USA) and IoPP CCNU (Wuhan, China), they developed the HIJING++ heavy-ion Monte Carlo Generator with G. Papp (ELTE) and X.N. Wang (IoPP CCNU, LBNL). The transplantation of the original, 20 years old code from FORTRAN to C++ programming languages was successful. They built the future Monte Carlo generator for the heavy-ion collisions, HIJING++ were tuned during the passed year also for nucleus-nucleus (AA) collisions. In the framework of a Chinese-Hungarian TÉT project they investigated how a machine-learning hadronization model can be included to Monte Carlo Based particle event generators. A further machine-learning based project has been started after signing the MoU with the Indian Institute of Technology Indore. In the framework of this collaboration, a PhD has spent 3 months collaborating with them [10].

Applying novel thermodynamical approaches — They investigated novel thermodynamical models focusing on the non-Fourier heat conduction and the model test in biological systems [11-15]. They also gave numerical and analytical results to different ballistic-diffusive heat conduction equations [16].

Coordination of the Hungarian ALICE Group and participation in the Bergen pCT collaboration. — They coordinate the Hungarian contribution to CERN's largest heavy-ion experiment ALICE. This activity is many-folded: In addition to data analysis, our group has constructed and tested of the world largest, 90 m3-volume, GEM-based TPC for the ALICE and also the DAQ O2 CRU upgrade projects. This is a joint activity with the newly formed Vesztergombi High-energy Physics Laboratory (VLAB), which awarded the TOP50 Hungarian research infrastructure title. During 2021 the commissioning of the TPC, ITS and DAQ has been done and data taking has been successfully done during the first test beam time. They were involved in the first data challenge programme with the ALICE Analysis Facility of the WSCLAB, which resulted in a Public ALICE Note [17]. They also contributed to the Bergen pCT collaboration, where the detector prottype of the tracking calorimeter has been built, and analysis tracking softwares were developed based on machine learning techniques [18,19].

Coordination of the Wigner Scientific Computational Laboratory (WSCLAB) — They have formed a new open research infrastructure, which relies on the joint Wigner projects: CERN ALICE Analysis Facility, the CERN WLCG Grid T2 site of the CERN's ALICE and CMS collaborations, and the Wigner GPU Laboratory. The formed new laboratory has been selected as the TOP50 research infrastructure of the Hungarian national grant agency, NRDIO. The WSCLAB was awarded in December 2021 at the University of Pécs.

They operated and developed ALICE GRID Tier-2 Center with about 10% more computational power and storage. They built up 8 racks of the Wigner-ALICE Analysis Facility at the Wigner Datacenter and they have done multi-core run challenges for the ALICE experiment with 100% success rate.

The Wigner GPU Laboratory's capacity has been doubled by new hardwares, which was intensively used by several project such as the Nanoplasmonic Laser Fusion National Laboratory[20], the Astronomy Depaertment of the Eötvös University [21] the LIGO gravitational wave signal search [22], Heavy-ion Research Group of the Wigner RCP togerther with the Oxford University [10]. They had also an academy-industry project together with the Lombiq LTD [23]. These research projects involved 9 PhD and 3 MSc students.

The WSCLAB has organized the The Future of Computing, Graphics and Data Analysis – GPUday 2021 event jointly with the CERN-Wigner Artificial Intelligence Academia-Industry Matching Event (AI2ME21). Here they have about 80 in person participants from more than 20 countries all around the world in parallel to the online visitors.

Education, PR and prizes. — Connected to our group we had 2 BSc and 9 MSc students. Our young colleagues participated in young researcher's projects and a 1 TDK theses were submitted for the competition, which won the 1st Price at the BME, indeed the Pro Progressio TDK fellowship for 1 year.

So far they had 7 young PhD fellow in the research group. Senior colleagues are members of the ELTE, BME, PTE doctoral programmes. Two PhD theses by Dániel Berényi and Gábor Bíró has been successfully defended at the ELTE TTK Physics Doctoral School. Edit Fenyvesi has also obtained the PhD degree at the University of Debrecen.

Group members played key role in the following workshop, conference and seminar organizations: “GPU Day 2021” at the at Wigner RCP; Zimányi Winter School 2021 (Budapest, Hungary). Group members participated in PR activities at ther alma mater and high-school invitations.

References

1. Zétényi M, Nitt D, Buballa M, Galatyuk T, Role of baryon resonances in the pi(-)p -> ne(+)e(-) reaction within an effective-Lagrangian model, PHYSICAL REVIEW C 104, 015201 , 10 p. (2021) IF: 3.296 https://doi.org/10.1103/PhysRevC.104.015201

2. Gy. Kovacs, P. Kovacs and Z. Szep, One-loop constituent quark contributions to the vector and axial-vector meson curvature mass, Phys. Rev. D 104, no.5, 056013 (2021) IF=5.296 https://doi.org/10.1103/PhysRevD.104.056013

3. Takátsy, J.; Kovács, G.; Wolf, G., „Hybrid star properties from an extended linear sigma model”, ASTRONOMISCHE NACHRICHTEN, 342, 271 (2021), IF = 0.676 https://doi.org/10.1002/asna.202113918

4. B.E. Szigeti, G.G. Barnaföldi, P. Pósfay, A. Jakovác, Estimating Microscopic Nuclear Data by Compact Star Observations, https://arxiv.org/abs/2107.13476 (Accepten in SQM2021)

5. Völgyesi L; Tóth Gy; Szondy Gy; Kiss B; Fenyvesi E; Barnaföldi GG; Égető Cs; Lévai P; Ván P: Jelenlegi Eötvös-inga felújítások, fejlesztések és mérések GEOMATIKAI KÖZLEMÉNYEK / PUBLICATIONS IN GEOMATICS 24 : 1 pp. 129-139. ,11 p. (2021)

6. T.N. Szegedi, G.G. Kiss, P. Mohr, A. Psaltis, M. Jacobi, G.G. Barnaföldi, T. Szücs, G. Gyürky and A. Arcones, Activation thick target yield measurement of Mo100(alpha,n)Ru103 for studying the weak r-process nucleosynthesis, Phys. Rev. C104 (2021) no.3, 035804 https://doi.org/10.1103/PhysRevC.104.035804 IF=5.42

7. G. Balassa, Gy. Wolf, "Production cross sections of tetraquark states in elementary hadronic collisions", Eur. Phys. J. A, 57: 246 (2021) IF:3.043 https://doi.org/10.1140/epja/s10050-021-00553-1

8. A.N. Mishra, G.G. Barnaföldi, G.Paić , Quantifying the Underlying Event: Investigating Angular Dependence of Multiplicity Classes and Transverse-momentum Spectra in High-energy pp Collisions at LHC Energies https://arxiv.org/abs/2108.13938 (in review PRC)

9. R. Vértesi, A. Gémes and G.G. Barnaföldi “Koba-Nielsen-Olesen-like scaling within a jet in proton-proton collisions at LHC energies,", Phys. Rev. D103 (2021) no.5, L051503 https://doi.org/10.1103/PhysRevD.103.L051503 IF=5.296

10. G. Bíró, B. Tankó-Bartalis, G.G. Barnaföldi, Studying Hadronization by Machine Learning Techniques, https://arxiv.org/abs/2111.15655

11. M. Szücs, M. Pavelka, R. Kovács, T. Fülöp, P. Ván, and M. Grmela: A case study of non-Fourier heat conduction using internal variables and GENERIC, Journal of Non-Equilibrium Thermodynamics, vol. 46, 2021. IF=3.328

12. A. Fehér and R. Kovács: On the evaluation of non-Fourier effects in heat pulse experiments, International Journal of Engineering Science, vol. 169, pp. 103577, 2021. IF=8.843

13. R. Kovács, P. Rogolino, and D. Jou: When theories and experiments meet: Rarefied gases as a benchmark of non-equilibrium thermodynamic models, International Journal of Engineering Science, vol. 169, pp. 103574, 2021. IF=3.328

14. A. Fehér, N. Lukács, L. Somlai, T. Fodor, M. Szücs, T. Fülöp, P. Ván, and R. Kovács: Size effects and beyond-Fourier heat conduction in room-temperature experiments, Journal of Non-Equilibrium Thermodynamics, vol. 46, no. 4, pp. 403–411, 2021. IF=3.328

15. A. Sudár, G. Futaki, and R. Kovács: Continuum modeling perspectives of non-Fourier heat conduction in biological systems, Journal of Non-Equilibrium Thermodynamics, vol. 46, no. 4, pp. 371–381, 2021. IF=3.328

16. G. Balassa, P. Rogolino, A. Rieth, R. Kovacs, "New perspectives for modelling ballistic-diffusive heat conduction", Continuum Mechanics and Thermodynamics 33, pp. 2007-2026 (2021) IF:3.822

17. ALICE Collaboration (G. Bíró, G. G. Barnaföldi, P. Lévai, L. Betev, J.F. Grosse-Oetringhaus) The Wigner ALICE Analysis Facility, ALICE Public Note: https://cds.cern.ch/record/2791181

18. H.Pettersen,… M. Varga Kőfaragó, G.G Barnaföldi, Helium radiography with a digital tracking calorimeter—a Monte Carlo study for secondary track rejection, Phys. Med. Biol. 66 035004, (2021) IF= 3.609

19. H.Pettersen,… M. Varga Kőfaragó, G.G Barnaföldi, Investigating particle track topology for range telescopes in particle radiography using convolutional neural networks, Acta Oncologica,. 2021 Nov;60(11):1413-1418. doi: 10.1080/0284186X.2021.1949037. IF= 3.298

Other references connected to the WSCLAB:

20. I. Papp, L. Bravina, M. Csete, I.N. Mishustin, D. Molnár, A. Motornenko, L. M. Satarov, H. Stöcker, D.D. Strottman, A. Szenes, D. Vass, T.S. Biró, L.P. Csernai, N. Kroó (NAPLIFE Collaboration), Laser wake field collider, Phys.Lett.A 396 (2021) 127245 IF=2.654 DOI: 10.1016/j.physleta.2021.127245

21. Forgács-Dajka Emese, Dobos László, Ballai István: Time-dependent properties of sunspot groups – I. Lifetime and asymmetric evolution (arXiv: arXiv:2106.04917, DOI: 10.1051/0004–6361/202140731)

22. Kacskovics Balázs, Vasúth Mátyás Examination of orbital evolution and gravitational waves of OJ 287 in the 4PN order (arXiv: 2105.12496beadás alatt: CQG)

23. E. Dávid, D. El-Saig, Z. Lehóczky, G.G. Barnaföldi, Implementing Hastlayer support for Xilinx SoC Zynq FPGA family

---

2020

High-energy heavy-ion physics is connected to a large variety of physics disciplines. Researches probe fundamental concepts of classical and modern thermodynamics, hydrodynamics, and quantum theory. Therefore, they have several theoretical and practical topical research directions covering a wide spectrum, such as: thermodynamics, perturbative and non-perturbative QCD, high-energy nuclear effects, hadronization, hadron phenomenology, phenomenology of compact stars, and gravity/cosmology. These studies are strongly motivated by the needs of several recent and planned large-scale facilities, such as collaborations at the LHC (CERN, Switzerland) and RHIC (BNL, USA), and future experiments at FCC (CERN), FAIR (GSI, Germany) and NICA (Dubna, Russia). They have continued these theoretical investigations in the direction of high-energy physics phenomenology connected to existing and future state-of-the-art detectors. Concerning international theoretical collaborations, they have established joint work with the Goethe Institute (Germany), LBNL (USA), CCNU, MAP (China), UNAM (Mexico), Dubna (Russia) and ERI (Japan). The most important published results are highlighted below.

The effective field theory of the strong interaction — As a member of the CBM collaboration, they continued the planning of the details of the detector. They participated in the detector simulations. They proposed a statistical-based model to describe exclusive and inclusive hadronic cross sections from a few GeV center of mass energy up to a few tens of GeV in proton-proton, pion-proton and proton-antiproton reactions. With the proposed model it was possible to estimate the low energy inclusive charmonium and bottomonium production cross sections, which are necessary ingredients to transport simulations of heavy ion collisions [1] [2].

Multi-wavelength astronomy and investigations of super-dense matter in compact stars — Investigation of cold compact stars provides the opportunity to understand cold super-dense nuclear matter. These theoretical developments are strongly connected to recent measurements of compact stars by multi-wavelength observations and gravitational waves and the future Einstein Telescope, which are supported by theoretical networking EU COST action PHAROS (CA162014).

They improved the calculation of the tidal Love numbers in case of first-order phase transition at non-zero pressure, moreover they obtained a maximum value for the maximum relative error, ~5% [3] They also estimated the variation of neutron star observables by dense symmetric nuclear matter parameters using the Bayesian method. The equation of state (EoS) at finite chemical potential and zero temperature were calculated from the extended sigma-omega model and they found strong linear connection between macro- and microscopic parameters of neutron star and its matter [4] [5] [6].

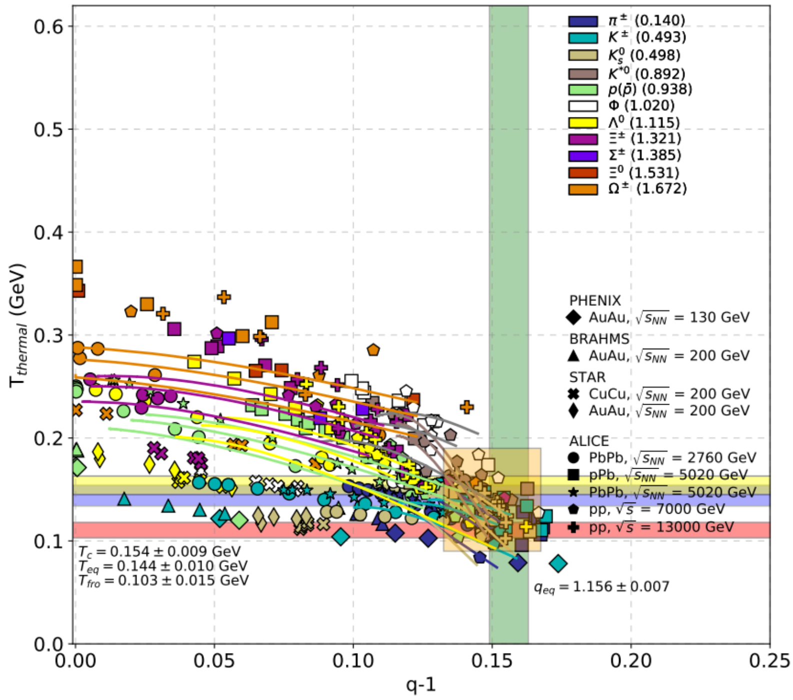
As members of the ALICE Collaboration they contributed to unveiling the strong interaction among hadrons at the energies of the Large Hadron Collider. This new analysis provided stronger constrains for compact star EoS [7].

They published the results of the long-time infrasound measurements at Matra Gravitational and Geophysical Laboratory (MGGL) [8]. These were the first results characterizing the infrasound noise at a subtrerranean candidate site for the Einstein Telescope. This work was carried out as part of the long-term site characterization campaign at MGGL. The results of this campaign contributed to the comprehensive investigations of an international collaboration. These investigations leaded to the designation of the site-selection criteria for the Einstein Telescope [9].

Investigating heavy-ion collisions — High-energy heavy-ion collisions are one of the best testbeds for the non-ideal, non-equilibrium, finite systems. The non-extensive statistical approach, developed by their group, can describe such a matter by enwidening the framework of classical thermodynamics and statistical physics towards non-equilibrium and complex system phenomena.

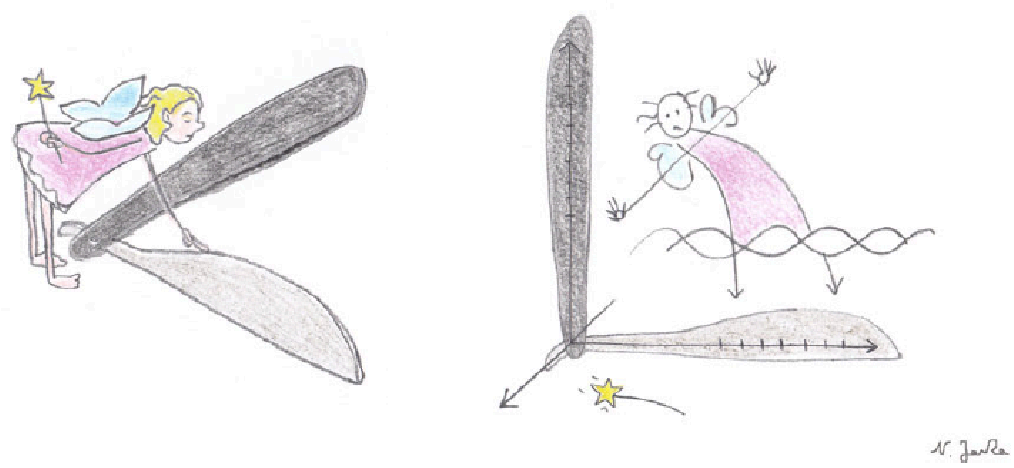
They introduced a new phrase, gintropy. This is a mule word from gini index and entropy, signalling the mathematical similarities to entropy while calculating the gini index. The latter is a familiar description of income and wealth inequalities [10].

Hadronization in proton-nucleus and nucleus-nucleus collisions were investigated based on the distribution parameters of the hadron spectra. They found, that depend on the size of the final hadronic state, it is possible to draw conclusions on the dense and strongly interacting matter which exists before hadronization. A linear relation between the mean transverse momentum of the final state hadrons and the T temperature parameter has been also obtained. In the analysis of the thermodynamical quantities and their comparison with other theoretical models they defined and used the Tsallis-thermometer (see Figure) to determine relation between collision energy and multiplicity configurations [11].



Relativistic hydrodynamic studies of heavy-ion collisions must face the problem of how to convert the fluid to particles. For shear viscous fluids, many different models have been proposed for this conversion, based on a variety of ad hoc assumptions. They demonstrated that these models are inconsistent with the microscopic dynamics of the fluid, and have utilized kinetic theory to design much improved fluid-to-particle models. Moreover, they showed how to cure the problem of negative phase-space densities that arise in additive shear viscous correction models [12].

Applying novel thermodynamical approaches — The numerical method developed for generalized nonlocal constitutive equations is tested and improved for a certain type of nonlinear problems: when the transport properties depend on the state variables, too. They found that in these particular cases, the nonlinear stability analysis can be exchanged with the linear one including an important a priori assumption, the maximum value of the primary field variable during its time evolution [Józsa, V; Kovács, R.: Solving Problems in Thermal Engineering: A Toolbox for Engineers. Cham, Svájc : Springer-Verlag (2020)]. They also investigated the connection of entropy principle and its consequences with the variational principles. They elaborated multiple examples in which we found that nonequilibrium thermodynamics suggests useful extensions. Moreover, the resulting set of equations also consist the models derived using variational methods as a special case [14].



Variational principles play a fundamental role in deriving the evolution equations of physics. They work well in the case of non-dissipative evolution, but for dissipative systems, the variational principles are not unique and not constructive. With the methods of modern nonequilibrium thermodynamics, one can derive evolution equations for dissipative phenomena and, surprisingly, in several cases, one can also reproduce the Euler–Lagrange form and symplectic structure of the evolution equations for non-dissipative processes. They examined some demonstrative examples and compare thermodynamic and variational techniques. They argued that, instead of searching for variational principles for dissipative systems, there is another viable programme: the second law alone can be an effective tool to construct evolution equations for both dissipative and non-dissipative processes (See Figure from [15]).

A volume dependent extension of Kerr-Newman black hole thermodynamics has been also develope in [16].

Formation of the National Laboratory on Nanoplasmonic Laser Fusion — They have studied a recently proposed novel idea for achieving laser-driven nuclear fusion using the enhanced absorption of laser energy in a medium infused with nanoscale gold particles (so-called nano-plasmonic laser inertial fusion). To further develop that idea theoretically, we have formed a National Laboratory to perform numerical simulations of Laser Wake Field Acceleration (LWFA) in a sample that is illuminated by two colliding laser beams. Our results can be applied to laser driven fusion, but also to other rapid phase transition, combustion, or ignition studies in other materials [17].

Development for heavy-ion computer simulations — In collaboration with the University of Berkeley (USA) and IoPP CCNU (Wuhan, China), they developed the HIJING++ heavy-ion Monte Carlo Generator with G. Papp (ELTE) and X.N. Wang (IoPP CCNU, LBNL). The transplantation of the original, 20 years old code from FORTRAN to C++ programming languages was successful. They built the future Monte Carlo generator for the heavy-ion collisions, HIJING++ were tuned also for nucleus-nucleus (AA) collisions, which will be public soon. In parallel a Chinese-Hungarian TÉT project has been started applying deep learning in HIJING++.

Coordinations of the ALICE upgrades and local facilities. — They coordinate the Hungarian contribution to CERN's largest heavy-ion experiment ALICE. This activity is many-folded: In addition to data analysis, our group has successfully finished the construction of the world largest, 90 m3-volume, GEM-based TPC for the ALICE and also the DAQ O2 CRU upgrade projects. These has been in the news, in radio reports, and prodcasts [18]. They operated and developed ALICE GRID Tier-2 Center and the pilot Wigner-ALICE Analysis Facility.

Education, PR and future. — Connected to our group we had 2 BSc and 6 MSc students. Our young colleagues participated in young researcher's projects and a 2 TDK theses were submitted for the competition.

So far they had 9 young PhD fellow in the research group. Senior colleagues are members of the ELTE, BME, PTE doctoral programmes. Péter Pósfay and Gyula Bencédi defended their PhD thesis at the Eötvös Loránd Univeristy, while PhD thesis by Dániel Berényi and also by Gábor Bíró were submitted to the ELTE TTK Doctoral School. dr. Péter Ván has successfully got the DSc degree by the Hungarian Academy of Sciences.

Group members played key role in the following workshop, conference and seminar organizations: “The Future of Many-Core Computing in Science: GPU Day 2020” at the at Wigner RCP; Zimányi Winter School 2020 (Budapest, Hungary). T.S. Bíró acts as the main organizer of the Wigner Colloquium series for our Institute. Group members participated in PR activities such as ELKH’s “The Capital of Sciences” series.

2019

High-energy heavy-ion physics is connected to a large variety of physics disciplines. Our researches probe fundamental concepts of classical and modern thermodynamics, hydrodynamics, and quantum theory. Therefore, we have several theoretical and practical topical research directions covering a wide spectrum, such as: thermodynamics, perturbative and non-perturbative QCD, high-energy nuclear effects, hadronization, hadron phenomenology, phenomenology of compact stars, and gravity/cosmology. Our studies are strongly motivated by the needs of several recent and planned large-scale facilities, such as collaborations at the LHC (CERN, Switzerland) and RHIC (BNL, USA), and future experiments at FCC (CERN), FAIR (GSI, Germany) and NICA (Dubna, Russia). We have continued our theoretical investigations in the direction of high-energy physics phenomenology connected to existing and future state-of-the-art detectors. Concerning international theoretical collaborations, we have established joint work with the Goethe Institute (Germany), LBNL (USA), CCNU, MAP (China), UNAM (Mexico), and ERI (Japan). We highlight below some of our major published results in details.

New developments in the effective field theory of the strong interaction. — As a member of the CBM collaboration, we continued the planning of the details of the detector. We participated in the detector simulations concentrated on the phi meson and on the double strange hypernuclei. We studied the physics cases as well.

We investigated the Fourier coefficients of the net-baryon number density in strongly interacting matter at non-zero temperature and density. In a QCD-like effective chiral model, we showed that the chiral and deconfinement properties are reflected by these coefficients, which approach can provide interesting insights into the criticality of QCD matter [1,2]. We modelled the flavor-dependent EMC effect from a nucleon swelling model applying nIMParton nuclear modifications. In addition, we presented the expected effect for the spectator-tagged deep inelastic scattering process, which will be performed by the CLAS12 collaboration with the ALERT detector [3].

We studied the masses of the low-lying charmonium states, and calculated if ψ(4040) state can generate the peak associated with Y(4008) [4].

Multi-wavelength astronomy and investigations of super-dense matter in compact stars. — Investigation of cold compact stars provides the opportunity to understand cold super-dense matter. These theoretical developments are strongly connected to recent measurements of compact stars by multi-wavelength observations and gravitational waves and the future Einstein Telescope, which are supported by theoretical networking EU COST action PHAROS (CA162014).
In collaboration with A. Jakovác (ELTE) we estimated the variation of neutron star observables by dense symmetric nuclear matter properties. We calculated the equation of state (EoS) at finite chemical potential and zero temperature using an extended sigma-omega model and we found strong linear connection between macro- and microscopic parameters of neutron star and its matter [5]. We also investigated the compact star properties with Zs. Szép (ELTE), using the equation of state given by the (axial-)vector meson extended linear sigma model, and we determined the mass-radius relation and study whether these restrictions are satisfied under the assumption that most of the star is filled with quark matter [6].

We summarized the long-term measurements from the Mátra Gravitational and Geophysical Laboratory. This project is related to one of the proposed next generation ground-based gravitational detector's location in Hungary. Results of seismic and infrasound noise, electromagnetic attenuation and cosmic muon radiation measurements were reported in the underground Matra Gravitational and Geophysical Laboratory near Gyöngyösoroszi. The collected seismic data of more than two years is evaluated from the viewpoint of the proposed third generation underground gravitational wave observatory, the Einstein Telescope. These results and the developed methods for the site selection will significantly improve the signal to nose ratio of the forthcoming multi-messenger astrophysics era, especially at the low frequency regime [7].

Results from the non-extensive statistical approach. — High-energy heavy-ion collisions are one of the best testbeds for the non-ideal, non-equilibrium, finite systems. The non-extensive statistical approach, developed by our group, can describe such a matter by enwidening the framework of classical thermodynamics and statistical physics towards non-equilibrium and complex system phenomena. This pioneering, novel approach to Tsallis, Rényi and further non-Boltzmannian entropy formulae have been applied by us in various physical phenomena from heavy-ion collisions, cosmology to networking. We reviewed in a detailed study of the applied forms of Tsallis–Pareto formulae and compared them on statistical basis. We have found, that apart from the thermodynamical consistency, we observed no relevant differences between various formulae [8,9]. We found relations between the temperature parameter, T and the Tsallis parameter, $q-1$, of many hadron states (mass-hierarchy), in parallel with multiplicity and logarithmic dependence on the c.m. energy [10].

Phenomenology, transport, and hydrodynamics for heavy-ion collisions. — Nearly back-to-back di-jets with medium or large transverse momenta become acoplanar even in the vacuum due to multi-gluon radiation. This effect could become stronger in hot matter, generated in energetic heavy ion collisions, where the acoplanarity is dominated by the vacuum (Sudakov) pQCD (perturbative Quantum ChromoDynamics) radiation. We suggested a higher precision measurement method of the tails of the acoplanarity distributions, which can help to resolve separately the medium opacity and the color screening scale from the path averaged BDMS saturation scale. The result was presented also at the Quark Matter 2019 in Wuhan, China [11]. We also participated in the CERN's Future Circular Collider project and contributed to the proposal of the future high-energy heavy-ion experiments [12-15]. The modification of the jet-structure in high-multiplicity proton-proton collisions was investigated. We calculated the effect of color reconnection and multiple-parton interactions and observed a multiplicity-independent characteristic jet size measure [16]. This jet structure study was also investigated in small collisional systems with the same results [17]. We made a further step in the theoretical model of the generalized Galilean transformations of tensors and cotensors with application to general fluid motion [18].

Development for heavy-ion computer simulations. — In collaboration with the University of Berkeley (USA) and IoPP CCNU (Wuhan, China), we finished to develop the HIJING++ heavy-ion Monte Carlo Generator with G. Papp (ELTE), G.Y. Ma (IoPP CCNU), and X.N. Wang (IoPP CCNU, LBNL). The transplantation of the original, 20 years old code from FORTRAN to C++ programming languages was successful. We built the future Monte Carlo generator for the heavy-ion collisions, HIJING++ where we finished the tuning of the nuclear effect for proton-proton (pp) and proton-nucleus (pA) collisions, and could present preliminary physics results in relation with the multiplicity and hadron mass dependence of the Tsallis parameters [10].

Coordination of the ALICE upgrades. — We coordinate the Hungarian contribution to CERN's largest heavy-ion experiment ALICE. This activity is many-folded: In addition to data analysis, our group plays key role in the construction of the world largest, 90 m^3-volume, GEM-based TPC for the ALICE and the DAQ O2 upgrade projects.

Operation and Management of the ALICE GRID Tier-2 Center. — We increased the capacity of the worker nodes by 20%, which becomes effective by January 2020.

Coordination of the MGGL. — Together with the Gravitational physics research group of the Theory Department, we coordinated and organized the establishment of the Mátra Gravitational and Geophysical Laboratory of Wigner RCP. It is situated in the Gyöngyösoroszi mine and performs various preparational underground measurements for future third generation gravitational wave detectors. In 2019, we published the long term data analysis for 2016-2018 in a joint paper, which was submitted to EPJ ST [VanP]. These data were presented for the LIGO/VIRGO collaborations. In connection with this, we renovated the Jánossy-pit at the KFKI campus and started an improved version of the Eötvös experiment.

Education, PR and future. — Connected to our group we had 6 BSc and 3 MSc students. Our young colleagues participated in young researcher's projects and 5 theses were submitted for the TDK competition.

Peter Pósfay and Dániel Berényi defended their theses at Wigner RCP and Pósfay submitted his PhD thesis to the Eötvös Univeristy. So far we have 7 young PhD fellow in the research group. Senior colleagues are members of the ELTE, BME, PTE doctoral schools.

Group members played key role in the following workshop, conference and seminar organizations: “The Future of Many-Core Computing in Science: GPU Day 2019” and “Lectures of Modern Scientific Programming 2019” at the at Wigner RCP; Balaton Workshop 2019 (Tihany, Hungary); Zimányi Winter School 2018 (Budapest, Hungary), Verhás80 Workshop, ELFT Vándorgyűlés (Sopron, Hungary); Electrodynamics in Space&Time, (Somogysimonyi, Hungary); AISIS 2019, UNAM, Mexico. T.S. Bíró acts as the main organizer of the Wigner Colloquium series at our Research Centre.

Group members participated in PR activities such as the MAFIHE Schools and Wigner Open Days. We receive regularly invitation by High Schools from Hungary and abroad for PR talks. Besides these activities, we established good media connection: we participated in several appearances of news, in radio and television programs, outreach films.

References:

1. Almási GA, Friman B, Morita K, Lo PM, Redlich K: Fourier coefficients of the net baryon number density and chiral criticality. PHYS REV D 100:1 016016/1-16 (2019)

2. Almási GA, Friman B, Morita K, Redlich K: Fourier coefficients of the net baryon number density and their scaling properties near a phase transition. PHYS LETT B 793: 19-25 (2019)

3. Bíró G, Barnaföldi GG, Papp G, Biró TS: Multiplicity dependence in the non-extensive hadronization model calculated by the HIJING++ framework. UNIVERSE 5:6 134/1-9 (2019)

4. Biró TS, Néda Z, Telcs A: Entropic divergence and entropy related to nonlinear master equations. ENTROPY 21:10 993/1-13 (2019)

5. Gyulassy M, Lévai P, Liao J, Shi S, Yuan F, Wang XN: Precision dijet acoplanarity tomography of the chromo structure of perfect QCD fluids. NUCLEAR PHYSICS A 982 pp. 627-630. , 4 p. (2019)

6. Kovács R: On the rarefied gas experiments. ENTROPY 21:7 718/1-13 (2019)

7. Ludwig F, Wagner L, Al-Abdullah T, Barnaföldi GG, Bemmerer D, Degering D, Schmidt K, Surányi G, Szücs T, Zuber K: The muon intensity in the Felsenkeller shallow underground laboratory. ASTROPART PHYS 112: 24-34 (2019)

8. Pettersen HES et al. incl. Barnaföldi GG, Varga-Kőfaragó M [33 authors]: Design optimization of a pixel-based range telescope for proton computed tomography. PHYS MEDICA 63: 87-97 (2019)

9. Piotrowska M, Giacosa F, Kovács P: Can the ψ(4040) explain the peak associated with Y(4008)? EUR PHYS J C 79:2 98/1-12 (2019)

10. Pósfay P, Barnaföldi GG, Jakovác A: Estimating the variation of neutron star observables by dense symmetric nuclear matter properties. UNIVERSE 5:6 153/1-10 (2019)

11. Shen K, Barnaföldi GG, Biró TS: Hadronization within the non-extensive approach and the evolution of the parameters. EUR PHYS J A 55:8 126/1-18 (2019)

12. Shen KM, Barnafoldi GG, Biró TS: Hadron spectra parameters within the non-extensive approach. UNIVERSE 5:5 122/1-9 (2019)

13. Somlai LÁ, Gráczer Z, Lévai P, Vasúth M, Wéber Z, Ván P: Seismic noise measures for underground gravitational wave detectors. ACTA GEOD GEOPHYS 54: 301-313 (2019)

14. Takátsy J, Kovács P, Szép Z, Wolf G: Compact star properties from an extended linear sigma model. UNIVERSE 5:7 174/1-11 (2019)

15. Tambave G et al. incl. Barnaföldi GG, Sudár A, Varga-Kőfaragó M [37 authors]: Characterization of monolithic CMOS pixel sensor chip with ion beams for application in particle computed tomography. NUCL INSTRUM METH A 958: 162626/1-4 (2019)

16. Ván P et al. incl. Barnaföldi GG, Dávid E, Debreceni E, Hamar G, Huba G, Kacskovics B, Kovács R, Lévai P, Oláh L, Varga D, Vasúth M, Zimborás Z, Somlai L [40 authors]: Long term measurements from the Mátra Gravitational and Geophysical Laboratory. EUR PHYS J-SPEC TOP 228:8 1693-1743 (2019)

Conference proceedings:

17. Jou D, Restuccia L, Ván P: Introducing Thermocon 2016. ATTI ACCAD PELORIT PERICOL Cl SCI FIS MAT NAT 97:S1 E1/1-17 (2019)

18. Völgyesi L, Szondy G, Tóth G, Péter G, Kiss B, Barnafoldi GG, Deák L, Égető C, Fenyvesi E, Gróf G, Somlai L, Harangozó P, Lévai P, Ván P: Preparations for the remeasurement of the Eötvös-experiment. In: Proc. Int. Conf. on Precision Physics and Fundamental Physical Constants - FFK2019 (Tihany, Hungary, 9-14 June, 2019). POS FFK2019 041/1-13 (2019)

19. Tóth Gy, Völgyesi L, Szondy Gy, Péter G, Kiss B, Barnaföldi G, Deák L, Égető C, Fenyvesi E, Gróf G, Somlai L, Harangozó P, Lévai P, Ván P: Remeasurement of the Eötvös-experiment, status and first results. In: Proc. Int. Conf. on Precision Physics and Fundamental Physical Constants - FFK2019 (Tihany, Hungary, 9-14 June, 2019). POS FFK2019 042/1-10 (2019)

20. Ván P, Ciancio V, Restuccia L: Generalized Galilean transformations of tensors and cotensors with application to general fluid motion. ATTI ACCAD PELORIT PERICOL Cl SCI FIS MAT NAT 97:S1 A25/1-16 (2019)

21. Ván P, Ciancio, A, Szücs M: Thermodynamics of Lotka-Volterra dynamics. In: Proc. 13th International Conference on Heat Engines and Environmental Protection (Budapest, Hungary, 25-26 May 2017). Ed.: Gróf G, BME EGR (2019) pp. 111-123

22. Völgyesi L, Szondy Gy, Tóth Gy, Barnaföldi G, Deák L, Égető Cs, Fenyvesi E, Harangozó P, Gróf Gy, Kiss B, Lévai P, Péter G, Somlai L, Ván P: Az Eötvös-kísérlet újramérése (Remeasurement of the Eötvös-experiment, in Hungarian). In: Proc. Földtani és Geofizikai Vándorgyűlés az évfordulók fényében: A Magyar Királyi Földtani Intézet jubileuma és az Eötvös Loránd Emlékév tiszteletére (Balatonfüred, Hungary, 3-5 Oct. 2019). Eds.: Budai T; Palotás K; Piros O, Magyarhoni Földtani Társulat, Magyar Geofizikusok Egyesülete, (2019) pp. 60-63.

23. Wolf Gy, Balassa G, Kovács P, Zétényi M, Lee SH: Observation of charmonium mass modification in proton induced reactions. In: Proc. 8th Int. Conf. on Quarks and Nuclear Physics QNP2018 (November 13-17, 2018, Tsukuba, Japan) JPS CONF PROC 26 024003/1-4 (2019)

Book:

25. Biró TS, Jakovác A: Emergence of temperature in examples and related nuisances in field theory. SpringerBriefs in Physics, Springer, Cham, 2019, pp. 1-84

Other:

26. Ván P: Alvajárunk? (Are we sleepwalking? in Hungarian). FIZIKAI SZEMLE 69:1 21-23 (2019)

2018

High-energy heavy-ion physics is connected to a large variety of physics disciplines. Our researches probe fundamental concepts of classical and modern thermodynamics, hydrodynamics, and quantum theory. Therefore, we have several theoretical and practical topical research directions covering a wide spectrum, such as: thermodynamics, perturbative and non-perturbative QCD, high-energy nuclear effects, hadronization, hadron phenomenology, phenomenology of compact stars, and gravity/cosmology. Our studies are strongly motivated by the needs of several recent and planned largescale facilities, such as collaborations at the LHC (CERN, Switzerland) and RHIC (BNL, USA), and future experiments at FAIR (GSI, Germany) and NICA (Dubna, Russia). We have continued our theoretical investigations in the direction of high-energy physics phenomenology connected to existing and future state-of-the-art detectors. Concerning international theoretical collaborations, we have established joint work with the Goethe Institute (Germany), LBNL (USA), CCNU, MAP (China), UNAM (Mexico), and ERI (Japan). We highlight below some of our major published results in details.

New developments in the effective field theory of the strong interaction — As a member of the CBM collaboration, we continued the planning of the details of the detector. We participated in the detector simulations concentrated on the phi meson and on the double strange hypernuclei. They studied the physics cases as well.

They proposed a model based on the Statistical Bootstrap approach to estimate the cross sections of different hadronic reactions up to a few GeV in center of mass energy. The method is based on the idea, when two particles collide a so called fireball is formed, which after a short time period decays statistically into a specific final state. They used in a transport model for unknown cross sections.

They studied the masses of the low-lying charmonium states, namely, the J/Ψ, Ψ(3686), and Ψ(3770) in antiproton induced reactions. The masses of these states are shifted downwards due to the second order Stark effect. They showed using their transport model that the in-medium mass shift can be observed in the di-lepton spectrum. Therefore, by observing the di-leptonic decay channel of these low-lying charmonium states, especially for Ψ(3686), thus one can gain information about the magnitude of the gluon condensate in nuclear matter. This measurement could be performed at the upcoming PANDA experiment at FAIR as they published.

They analyzed the Xi^- baryon production in subthreshold proton-nucleus (p+A) collisions in the framework of our BUU type transport model. They proposed a new mechanism for Xi production in the collision of a secondary Lambda or Sigma hyperon and a nucleon from the target nucleus. They find that the Xi^- multiplicity in p+A collisions is sensitive to the angular distribution of hyperon production the primary N+N collision. Using reasonable assumptions on the unknown elementary cross sections we are able to reproduce the Xi^- multiplicity and the i^-/(Lambda+Sigma^0) ratio obtained in the HADES experiment.

In connection to cosmology, they studied the time evolution of the Einstein-conformally coupled Higgs cosmological models in the presence of Friedman–Robertson–Walker symmetries. We have found all the analytical singularities. We have shown that beyond the Big Bang singularity (singular curvature and diverging Higgs field there is another new kind of physical spacetime singularity (`Small Bang') where the curvature singular but the Higgs field is finite. Furthermore, we also have shown that there are nonanalytical singularities as well.

Multi-wavelenth astronomy investigations of superdense matter in compact stars— Investigation of cold compact stars provides the opportunity to understand cold superdense matter and even, speculate on new states of matter. These theoretical developments are strongly connected to recent measurements of compact stars by multi-wavelength observations and gravitational waves. These projects are supported by theoretical networking EU COST action PHAROS (CA162014).

In collaboration with A. Jakovác (ELTE) they constructed a framework using the Functional Renormalization Group (FRG) technique for a one-fermion and one-boson theory with Yukawa-like coupling, where they calculated the equation of state (EoS) at finite chemical potential and zero temperature exactly – including quantum corrections. They investigated the effect of the quantum fluctuations on the nuclear equation of state and compact star observables. They demonstrated, that correction to the mean field model can result 30% difference in the EoS, which modifies the neutron star mass and radius by 5% (see Fig 1). These interesting results were published in Phys Rev C and an extended study on the compactness in connection with multiwavelength stronomy measurements of GW170817 were published in PASA.

They started to investigate a realistic Waleckatype mean field model within this new framework. However an alternative gravitational theory, a KaluzaKlein type compact object were also analyzed in a multifermion framework. This result has been presented on the IAU International Conference. In parallel, the foundations of continuum theories were further researched in non-relativistic, Galilean relativistic and special relativistic spacetimes.

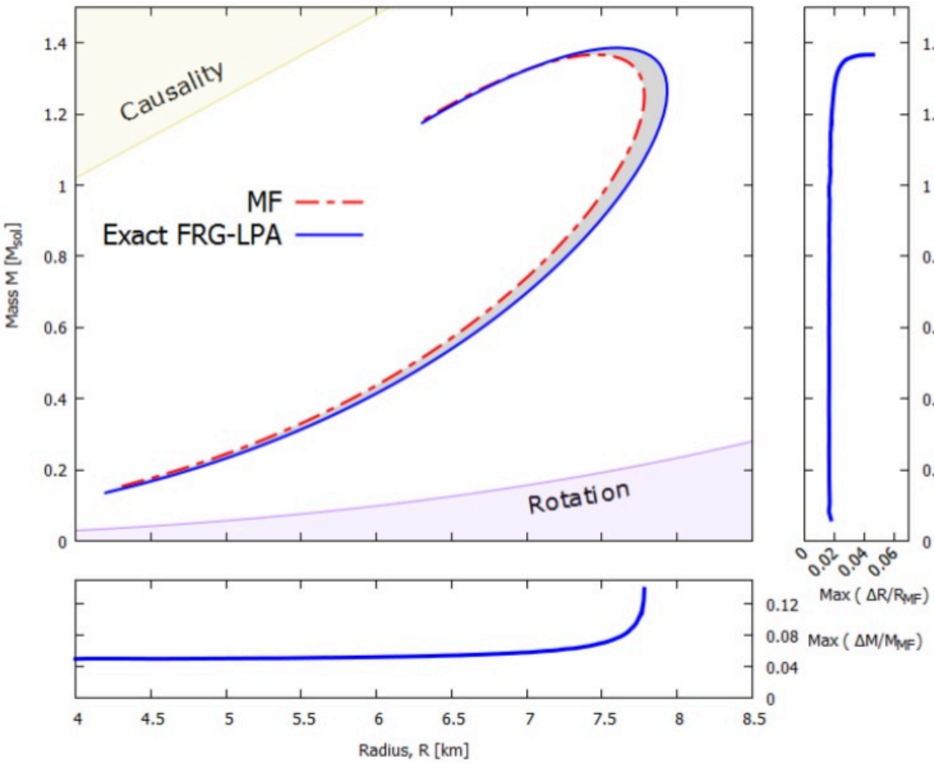


Figure 1. *Mass-radius diagram of the one-fermion and one-boson theory with Yukawa-like coupling, calculated in the mean field in and FRG framework. Relative difference of the two model is on the side graphs.*

Results from the non-extensive statistical approach — High-energy heavy-ion collisions are good testbeds for the non-ideal, non-equilibrium, finite systems. The non-extensive statistical approach, developed by their group, can describe such a matter by enwidening the framework of classical thermodynamics and statistical physics towards non-equilibrium and complex system phenomena. This pioneering, novel approach to Tsallis, Rényi and further non-Boltzmannian entropy formulae have been applied by us in various physical phenomena from heavy-ion collisions, cosmology to networking.

They started a detailed study of the applied Tsallis–Pareto formulae. We found linear relations between the temperature parameter, T and the Tsallis parameter, $q-1$, and the logarithmic dependence on the c.m. energy. They also fitted the quark-hadron channels of the Tsallis–Pareto-like fragmentation functions in electron-positron collisions. This result was quite promising, and presented similar values obtained from the fits of the hadron spectra in proton-proton collision. They also tested this fragmentation function parametrization in a direct pQCD calculation. Results were presented at The Hot Quarks Conference

The entropy production during hadronization of the quark-gluon plasma were also investigated, based on the idea, that at high-energies the pair production and the number of resonances is increasing. They extended the original model with an energy dependent (non-linear) potential (non-constant string force) scenario. This predicts well the beam energy dependence of the total cross section.

The derivation of Cahn-Hilliard equation with Liu procedure clarifies the thermodynamic background of phase field theories and they opened a new approach of deriving them without any variational principles. They analysed the connection between mechanical and thermal continuum phenomena apply the thermodynamic methodology of internal variables and its consequences to develop new numerical methods, to model experimental results and for a comparison with other theories.

Phenomenology, transport, and hydrodynamics for heavy-ion collisions. — They investigated the emergence of the Chiral Magnetic Effect (CME) and the related anomalous current using the real time Dirac-

Heisenberg-Wigner formalism. This method is widely used for describing strong field physics and QED vacuum tunneling phenomena as well as pair production in heavy-ion collisions. They investigated the strength of the Chiral Magnetic Effect (CME) in heavy ion collisions in the energy range of the SPS– RHIC–LHC accelerators, applying the Dirac–Heisenberg–Wigner formalism. The effect is strong and hopefully measurable at the Sqrt(s)=10-60 GeV energy range, starts to become weaker at 130-200 GeV and disappears at LHC energies. Recent experimental data confirms these theoretical results. Final conclusion can be obtained after the analysis of the Beam Energy Scan data at the RHIC accelerator. This result has been published in Phys Lett B.

They investigated the dijet acoplanarity in heavy ion collisions. Nearly back-to-back di-jets with medium or large transverse momenta become acoplanar even in the vacuum due to multi-gluon radiation. This effect could become stronger in hot matter,generated in energetic heavy ion collisions. Thus the acoplanarity could carry inforamtion on the opacity of the hot matter. They described theoretically this dependence and made suggestions for experimental indications of modified acoplanarity. The analysis of recent LHC data may bring new insigth into the understanding of this effect and new data could help to determine the opacity in the real collisions. They result were presented at the Quark Matter 2018.

They made a further step in the theoretical model of the generalized Fourier-Navier-Stokes system in the framework of non-equilibrium thermodynamics. Solution methods for generalized heat conduction models, and analyzing their related experiments. The detailed analysis of the possible connections with kinetic theory.

In Boltzmann transport model were also investigated together with D. Molnár (Purdue University, USA) and M.F. Nagy-Egri (RMI). They constructed parametrizations of nonlinear 2→2 transport model results in 0+1D Bjorken geometry, in order to better understand dissipative phase space corrections in kinetic theory and test simplified models/guesses for those commonly used in the literature. It was deemed most immediately suitable for GPGPU calculations because it mainly involves integration in two dimensions only. They studied, how strongly the initial conditions effect the final Tsallis-like distribution and the flow values. These results were presented at the Zimányi Winter School

An other interesting result of their thermodynamic investigation is related to Schwarzschild black holes. Here we have proved that introducing the volume as a new thermodynamic variable together with a new interpretation of the Bekenstein-Hawking entropy eliminates the negative heat capacity of the original theory. In a countinously accelerating system, similarities with the Unruh temperature were found.

Development for heavy-ion computer simulations — In collaboration with the University of Berkeley (USA) and IoPP CCNU (Wuhan, China), they finished to develop the HIJING++ heavy-ion Monte Carlo Generator with G. Papp (ELTE), G.Y. Ma (IoPP CCNU), and X.N. Wang (IoPP CCNU, LBNL). The transplantation of the original, 20 years old code from FORTRAN to C++ programming languages was successful. They built a parallel code, providing faster simulations.

The development of the future Monte Carlo generator for the heavy-ion collisions, HIJING++ were reached the stage. They finished the tuning of the nuclear effect for proton-proton (pp) and proton-nucleus (pA) collisions, and could present first preliminary physics results on pp and pPb collisions in a large and comprehensive study. The predictions were done for the identified hadron production for pPb collisions at 8.16 TeV cm energy in greement with the experimental data.

Coordination of the ALICE TPC upgrades. — They coordinate the Hungarian contribution to CERN's largest heavy-ion experiment ALICE. This activity is many-folded: In addition to data analysis, our group plays key role in the construction of the world largest, 90 m3 -volume, GEM-based TPC for the ALICE and the DAQ O2 upgrade projects.

Operation and Management of the ALICE GRID Tier-2 Center. — We extended our storage capacity: currently 3 storage servers are working. We updated the capacity up to 750TB, all configured and switched online by mid 2018.

Coordination of the MGGL. — Together with the Gravitational Wigner Research group of the Theory department, they coordinated and organized the establishment of the Mátra Gravitational and Geophysical Laboratory of Wigner RCP. This is situated in the Gyöngyösoroszi mine and performs various preparational underground measurements for future, third generation gravitational wave detectors. In 2018, they published the long term data analysis for 2016-2018 in a joint paper, which was submitted to Classical and Quantum Gravity. These data were presented for the LIGO/VIRGO collaborations, to the Hungarian Academy of Sciences and on various conferences and workshops. In connection to this, they renovated the Jánossy pit at the KFKI campus and they started an improved version of the Eötvös experiment.

Education, PR and future. — Connected to our group we had 5 BSc and 7 MSc students. Our young colleagues participated in young researcher's projects and a 4 TDK theses were submitted for the competition: András Leitereg (3rd price OTDK, D. Berényi) and Ádám Takács (G.G. Barnaföldi) awarded the Excellent student Prize of the ELTE TTK 2018), the Kovács Róbert got the “Györgyi Géza Prize” of the MTA Wigner FK.

Peter Pósfay and Dániel Berényi passed the Doctoral exams at the Eötvös Univeristy and they preparing their PhD theses for defense. So far we have 6 young PhD fellow in the research group. Senior colleagues are members of the ELTE, BME, PTE doctoral preogrammes. The following group members participated as guest editors: T. S. Biró as editor-in-chief in EPJ A Hadrons and Nuclei, and guest editor of the Wigner Yearbook 2018.

Group members played key role in the following workshop, conference and seminar organizations: “The Future of Many-Core Computing in Science: GPU Day 2018” and “Lectures of Modern Scientific Programming 2018” at the at Wigner RCP of the H.A.S.; “Mechanika a téridőn” space-time summer School;, Zimányi Winter School 2018 (Budapest, Hungary). T.S. Bíró act as the main organizer of the Wigner Colloquium series for our Institute.

Group members participated in PR activities such as the MAFIHE Schools, the “CERN 25 (H.A.S.), the CREDO tutorial workshop and CERN & Wigner Open Days. We receive regularly invitation by High Schools from Hungary and abroad for PR talks. Besides these activities, we established a good media connection: we participated in several appearances of news, in radio programs, outreach films and on television.

2017

High-energy heavy-ion physics is connected to a large variety of physics disciplines. Our research probe fundamental concepts of classical and modern thermodynamics, hydrodynamics, and quantum theory. Therefore, we have several theoretical and practical topical research directions covering a wide spectrum, such as: thermodynamics, perturbative and non-perturbative Quantum Chromodynamics (QCD), high-energy nuclear effects, hadronization, hadron phenomenology, phenomenology of compact stars, and gravity/cosmology. Our studies are strongly motivated by the needs of several recent and planned large-scale facilities, such as collaborations at the LHC (CERN, Switzerland) and RHIC (BNL, USA), and future experiments at FAIR (GSI, Germany) and NICA (Dubna, Russia). We have continued our theoretical investigations in the direction of high-energy physics phenomenology connected to existing and future state-of-the-art detectors. Concerning international theoretical collaborations, we have established joint work with the Goethe Institute (Germany), LBNL (USA), CCNU, MAP (China), UNAM (Mexico), and ERI (Japan). We highlight below some of our major published results in details.

New developments in the effective field theory of the strong interaction. — As a member of the CBM collaboration, we continued the planning of the details of the detector. We participated in the detector simulations concentrated on the phi meson and on the double strange hypernuclei. We studied the physics case as well.

We developed a linear sigma model extended with vector mesons, Polyakov loops and with quarks. We calculated the phase diagram. We found that there is a critical point at rather low temperature. By slightly changing the parameter set the critical point moves in the direction of the T=0 axes, and will disappear. In our model we also calculated the isentropic curves and compared them with lattice simulations. The agreement is remarkable.

The transport model developed here was extended to charmonium production in antiproton induced reactions. In the investigations the following picture arised: The antriprotons annihilate close to the surface of the heavy nuclei. The charmonium travels through the nuclei contribution to the dilepton spectra. Crossing again the thin surface the rest decay in vacuum. The higher lying charmonium states Ψ(3686) and Ψ(3770), expected to have a mass shift in dense matter in the range of about 100 MeV (see Fig. 1). We found that in the dilepton spectra the higher-lying charmonium states show up with two peaks. One of the peak is the contribution of the vacuum decay and the other one is developed from charmonium states decaying around ρ_0 density. The peaks are clearly separated and can be observed at the PANDA detector at FAIR/GSI.

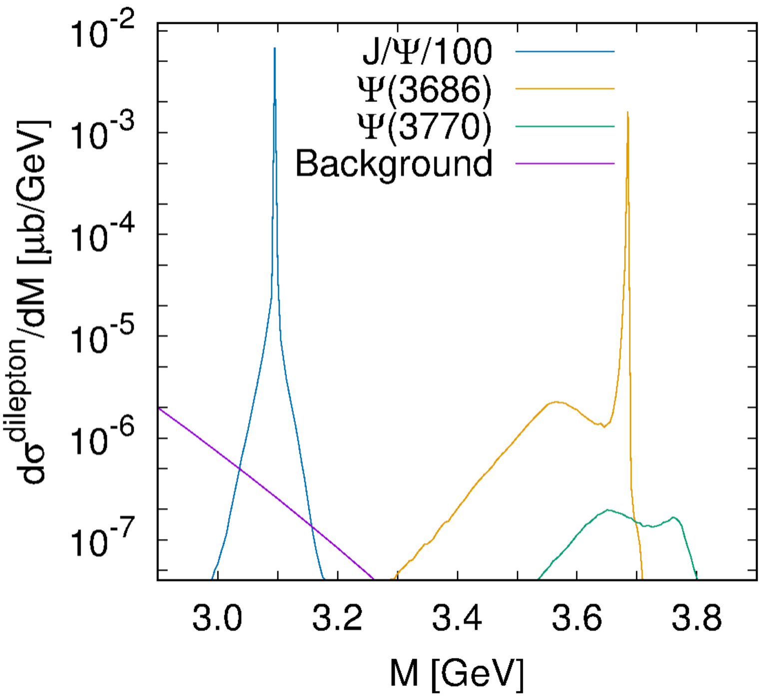


Figure 1. *Charmonium contribution to the dilepton spectra in a p̄Au collision at 6 GeV bombarding energies, where the in-medium modifications are accounted for.*

Investigations of superdense matter and extra dimensions in compact stars. — Investigation of cold compact stars provides the opportunity to understand cold superdense matter and speculate on new states of matter. These theoretical developments are strongly connected to recent measurements of compact stars by multi-wavelength observations and gravitational waves. Our projects are supported by theoretical networking EU COST actions: NewCompStar (MP1304) and PHAROS (CA162014).

In collaboration with A. Jakovác (ELTE) we constructed a framework using the functional renormalization group (FRG) technique for a one-fermion and one-boson theory with Yukawa-like coupling, where we calculated the equation of state (EoS) at finite chemical potential and zero temperature exactly – including quantum corrections. We investigated the effect of the quantum fluctuations on the nuclear equation of state and compact star observables. We demonstrated, that correction to the mean field model can result in 30% difference in the EoS, which modifies the neutron star mass and radius by 5%. The mathematical technique and the physical consequences of these results were presented on the Quark Matter 2017 conference and on several other conferences as invited talks.

In a joint work with E. Forgács-Dajka (ELTE) the existence of stable compact stars in a simple extra dimensional, Kaluza–Klein space-time were modeled. The mass-radius, M(R)-relation of a degenerated, non-interacting fermion star in extra dimensional space-time were presented in the cases of large- and small-sized extra dimension with several degrees of freedom (many-flavor model). As a result, we found both the observable maximal mass and the radius of a compact object may vary in a wide range as changing the size or the number of the extra dimensions.

Results from the non-extensive statistical approach. — High-energy heavy-ion collisions are good testbeds for the non-ideal, non-equilibrium, finite systems. The non-extensive statistical approach, developed by our group, can describe such a matter by enwidening the framework of classical thermodynamics and statistical physics towards non-equilibrium and complex system phenomena. This pioneering, novel approach to Rényi, Tsallis and further non-Boltzmannian entropy formulae have been applied by us in various physical phenomena like heavy-ion collisions, cosmology or network science.

We investigated the hadronization in high-energy pp and pPb collisions using the non-extensive statistical approach. We identified the mass and c.m. energy scaling of the Tsallis–Pareto parameters and compared our theoretical approach to the experimental data and other models. These results were published in a comprehensive study in the Entropy journal and presented on the JETC 2017 and QCD@LHC international conferences. We also compared different non-extensive models for transverse momentum spectra measured in heavy-ion collisions. In collaboration with K. Shen (CCNU Wuhan, China) we assumed to fix the relative variance of the temperature fluctuating event-by-event or alternatively a fixed mean multiplicity in a negative binomial distribution (NBD). We found linear relations between the temperature parameter, T and the Tsallis parameter, q−1. We revisited the “Soft+Hard” model by a T-independent average pT2 assumption.

Our description of the hadronization relies on the non-extensive approach may originated from the microscopical entropy driven (balanced) processes. Together with Z. Neda (Babes-Bolyai University), various models were tested: (i) the connection between transverse momenta and multiplicity distributions in a statistical framework. We connect the Tsallis parameters, T and q, to physical properties like average energy per particle and the second scaled factorial moment, measured in multiplicity distributions. (ii) applying a master equation, we developing a QCD-like branching model. (iii) A further unidirectional random growth branching with resetting were also presented, which can be applied to various networks, scientific citations and Facebook popularity, hadronic yields in high energy particle reactions, income and wealth distributions, biodiversity and settlement size distribution.

Phenomenology, transport, and hydrodynamics for heavy-ion collisions. — We investigated the emergence of the Chiral Magnetic Effect (CME) and the related anomalous current using the real time Dirac-Heisenberg-Wigner formalism. This method is widely used for describing strong field physics and QED vacuum tunneling phenomena as well as pair production in heavy-ion collisions. We extend earlier investigations of the CME in constant flux tube configuration by considering time dependent fields. In this model we can follow the formation of axial charge separation, formation of axial current and then the emergence of the anomalous electric current. Qualitative results have been calculated for special field configurations that help to interpret the predictions of CME related effects in heavy-ion collisions at different collision energies.

The Boltzmann transport model was also investigated together with D. Molnár (Purdue University, USA) and M.F. Nagy-Egri (Project R-C). We constructed parametrizations of nonlinear 2→2 transport model results in 0+1D Bjorken geometry, in order to better understand dissipative phase space corrections in kinetic theory and test simplified models/guesses for those commonly used in the literature. It was deemed most immediately suitable for GPGPU calculations because it mainly involves integration in two dimensions only.

In this year we have made three big steps in our ongoing fundamental research for constructing constitutive and evolution equations of internal variables with the second law of thermodynamics. First a new development of the methodology resulted in the Cahn-Hilliard equation for extensive internal variables. In our efforts for the validation of the developed theories we have analysed the low temperature NaF experiments, where the second sound and ballistic effects were detected together. Here we have shown that non-equilibrium thermodynamics with internal variables is capable to reproduce the available experimental observations better than other theories. An other important step of the validation was the discovery of non-Fourier heat conduction in several artificial and natural materials in macroscopic heterogeneous samples at room temperature. The experiments are analysed and the deviation from the Fourier theory is inevitable also considering the cooling of the samples.

An other interesting result of our thermodynamic research is related to Schwarzschild black holes. Here we have proved that introducing the volume as a new thermodynamic variable together with a new interpretation of the Bekenstein-Hawking entropy eliminates the negative heat capacity of the original theory.

Development for heavy-ion computer simulations. — In collaboration with the University of Berkeley (USA) and IoPP CCNU (Wuhan, China), we developed the HIJING++ heavy-ion Monte Carlo Generator with G. Papp (ELTE), G.Y. Ma (IoPP CCNU), and X.N. Wang (IoPP CCNU, LBNL). We transplanted the original, 20 years old code from FORTRAN to C++ programming languages, including new, parallel-computing features, resulting faster simulations as presented on Fig 2.

The development of the future Monte Carlo generator for the heavy-ion collisions, HIJING++ were reached the stage where we could present first preliminary physics results on pp and pPb collisions, however the new Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) -evolved, QCD-scale dependent nuclear shadowing is still under development. The first results were presented on Quark Matter 2017, FCC 2017, and QCD@LHC conferences and our predictions for pPb collisions at 8.16 TeV cm energy were accepted for publication.

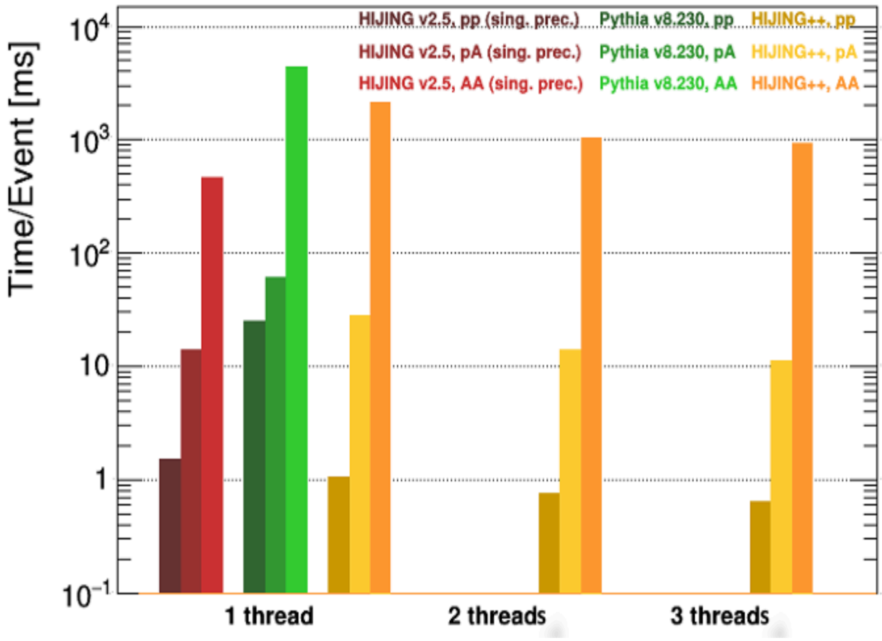


Figure 2. *Speedup of the new version of the HIJING++ in comparison to other Monte Carlo simaltors.*

Identified hadron spectra with ALICE. — We participated in the actual data taking and analysis. We took ALICE shifts and provided on call experts for the ALICE HMPID (High Momentum Particle Identification Detector) and ALICE IF (Interface) detectors.

The measurement of light flavor charged hadrons have been performed in pp collisions at 13 TeV around midrapidity with the ALICE detector. The pT-differential production yields and ratio of yields with respect to produced pions have been measured. Results are preliminary ALICE Collaboration data. Recent results on small collision systems (pp) were also presented in the EPSHEP 2017 Conference in Venice on behalf of the ALICE Collaboration, which will be published in Proceedings of Science (PoS). Two-particle angular correlation measurements at ALICE on the PbPb and pp data collected in 2010 and 2011 were analyzed. We have found that the jet-peak broadens towards central events at low transverse momentum in PbPb collisions and that it becomes asymmetric. We have also found that an unexpected depletion develops around the center of the peak. By analyzing data from AMPT (A Multi-Phase Transport) Monte Carlo simulations, we concluded that both phenomena are accompanied by large radial flow, suggesting that the broadening and the depletion is caused by an interplay of jets and the flowing medium. Results were presented at the Rencontres de Moriond QCD and High Energy Interactions in 2017, which was followed by a proceedings, and on the 12. WPCF, and at the Zimányi School 2016.

Heavy-flavour (beauty and charm) quarks are produced almost exclusively in initial hard processes, and their yields remain largely unchanged throughout a heavy-ion reaction. Nevertheless, they interact with the nuclear matter in all the stages of its evolution. Thus, heavy quarks serve as ideal self-generated penetrating probes of the strongly interacting Quark-Gluon Plasma (QGP). We started to determine the yield and nuclear modification of beauty jets in pPb collisions at 2.76 TeV recorded by ALICE during Run1 and Run2. We focused on developing b-jet identification techniques as well as the unfolding of the b-jet spectrum to correct for detector and background effects. We were appointed on DIS 2017, Zimanyi School 2016, Balaton Workshop 2017 QCD@LHC 2017 and Debrecen University Symposium 2017.

The Hungarian ALICE Group signed 56 SCI-referred collaboration papers, and several conference proceedings, and we presented several posters and talks on all these analysis results.

Coordination of the ALICE time projection chamber (TPC) upgrades. — We coordinate the Hungarian contribution to CERN's largest heavy-ion experiment ALICE. This activity is two-folded: In addition to data analysis, our group plays key role in the construction of the world largest, 90 m3-volume, gas electron multiplier (GEM) -based TPC for the ALICE. The ALICE TPC upgrade is a joint project with the Wigner's Innovative Particle Detector Development “Momentum” Group (D. Varga), the University of Helsinki (Finland), the GSI Darmstadt and TU Munich (Germany), the Oak Ridge National Laboratory (USA), and CERN. The Budapest Quality Assurance (QA) Center was built up to making the classification of GEM foils will be used in the ALICE TPC Upgrade project. The installation of necessary equipments in the Wigner's clean room were finished at late Autumn. The QA procedure is three-folded: high-definition optical scanning; long-term (5-20 hours) high-voltage leakage current tests, in N gas, with 500 V potential, monitoring the sparks and the leakage currents of the sectors of the GEMs; gain scanning (only in Budapest!) which is an operational test of the GEMs, measuring the gain features of the GEMs in realistic conditions with Fe-55, with similar spatial resolution as the optical scanning.

For these methods we use several equipments as the 3D High-Definition Scanner Robot with the ISEG controller, HD camera and optics, and led lighting with light controller (developed in Wigner RC); HV box for the long-term HV tests with picoAmper meter; and the gain scanner detector developed in Wigner RC. The main goal of gain scanning to study the correlation between the optical features (e.g. inhomogenities in ring diameter distribution) and the operational gain features of GEMs, and thus taking predictions for the operation phase. For the data taking and analysis we have developed a QA GUI application, which can process and classify the foils, displaying and evaluating both the leakage current and HD optical data. The code is open-source, and available on github.

There is also a middle step in the QA process to extract data from the images by a dedicated GPU based program running a neural-network-based image recognition routine. When the full QA procedure chain was installed and tested we organized a dedicated QA meeting in Budapest. We participated on the ALICE TPC UG TEST BEAM at CERN PS T10 experimental area, where the IROC GEM based test chamber were tested with 1-5 GeV PS beam.

The Budapest QA-center normal operation (for IROC and OROC2 GEMs) started in 2017 February. Between February and August 8 batch of GEMs (GEM Transport System, GTS) was classified in Budapest QA-Center: 1 GTS with 6 preproduction OROC2 GEMs + 7 GTS with 42 production IROC GEMs + 42 production OROC2 GEMs, which were totally: 90 GEMs. In details 90 GEMs went trough the optical scanning, 86 GEMs went trough the long-term HV test, 21 GEMs went trough the gain scanning. After QA procedures we sent 7 shipments (GTS) with 68 GEMs to framing centers Bonn (OROC2 - 4 shipments), WSU-Detroit (IROC - 2 shipments), and 10 failed GEMs back to CERN (1 shipment).

Coordination of the ALICE CRU upgrades. — The R&D of the ALICE Data Acquisition system, ALICE O2 project, Common Readout Unit (CRU) FPGA Firmware Development continues to be an ongoing effort. We introduced a schedule of quarterly firmware releases, and indeed created the 1st, 2nd, and 3rd CRU firmware releases, each implementing more and more of the functionality required by the Run3 UG.

Currently implemented features include: receiving LHC Clock and trigger via PON from the Central Trigger Processor / Local Trigger Unit (CTP / LTU) units, or running without them in standalone mode using a local trigger emulator; playing back detector specific control sequences to signal reset / calibration / physics trigger / etc events to the front end electronics modules; support for multiple GBT links (up to 24); acquiring data in raw datalink recorder mode, GBT packet based communication mode, and user logic mode; flow control features of Run3 (Heartbeat Frames, Time Frames, HB Accept/Reject scheme); packet aware multichannel DMA engine, delivering the recorded data to buffers in memory, or to raw binary files on disk.

Detector groups started using the firmware, some to read out front end card under development (ITS), some to add their own detector specific extensions (TPC, TRD), and others for system integration tests (O2). Results of the FW development was presented on the TWEPP 2017 conference. Other experiments (sPHENIX, MPD NICA DUBNA, CBM/PANDA GSI/FAIR) expressed their interest in reusing the CRU hardware and firmware in their ongoing upgrade projects, the CRU project will be presented to them. Since 2015, several MSc students has been participated continously from ELTE and BME our university-level laboratory course.

Operation and management of the ALICE GRID Tier-2 Center. — We extended our storage capacity: currently 3 storage servers are working. The newest, with 180TB capacity was configured and switched online in June 2017 with the full capacity of 500TB.

Coordination of the MGGL. — Our group, together with the Gravitational Wigner Research group of the Theory department, coordinated and organized the establishment of the Mátra Gravitational and Geophysical Laboratory of Wigner RCP. This is situated in the Gyöngyösoroszi mine and performs various preparational underground measurements for future, third generation gravitational wave detectors. In 2017, we published the first data in a joint paper in Classical and Quantum Gravity and in the Geofizika journals. These data were presented for the LIGO/VIRGO collaborations and for various conferences and workshops.

Education, PR and future. — Connected to our group we had 3 BSc and 3 MSc students. Our young colleagues participated in young researcher's projects and a TDK thesis for competition: András Leitereg (special price OTDK, D. Berényi) and Ádám Takács (G.G. Barnaföldi) were awarded the “New National Excellence Program of the Ministry of Human Capacities (2017-18), the “30 Under 30 2017” by Forbes Hungary 2017, and the 2nd place at “Sci-ndicator National Scientific Communication Competition 2017”.

In this year G.G. Barnaföldi received the “Physics Price of the H.A.S.”, PhDs student Róbert Kovács (P. Ván) László Oláh (GG Barnaföldi & D. Varga) defended their PhD at BME and ELTE doctoral schools, respectively. So far we have 7 young PhD fellow in the research group. Senior colleagues are members of the ELTE, BME, PTE doctoral programmes.

Group members participated in PR activities such as the Colorful Physics Bus of the Wigner Institute, Simonyi Day (Wigner RCP), Science Day (H.A.S.), the “50 Years of Pulsars” (H.A.S.), and CERN & Wigner Open Days. We receive regularly invitation by High Schools from Hungary and abroad for PR talks. Besides these activities, we established a good media connection: we participated in several appearances of news, in radio programs, outreach films and on television.