In memory of Mikhail Igorevich Polikarpov

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Abstract. This obituary is devoted to M. I. Polikarpov (28.12.1952 - 18.07.2013). We recollect some facts of his biography and stages of his scientific career, and make a brief review of some of his most known scientific works.

The first published paper [1] by Mikhail Polikarpov is dated 1975. It was devoted to the general properties of amplitudes in hadronic physics. Within the period between 1975 and 1982 more than 20 papers were published on the similar subjects in collaboration with Yu. A. Simonov and A. M. Badalyan. The review of the results obtained during this period appeared in Physics Reports [2] in 1982.

Mikhail started to study lattice gauge theories in collaboration with Yu. M. Makeenko and A. I. Veselov [3, 4]. In particular, in [4] the results of the first numerical investigation of instantons in gluodynamics were presented. The properties of gauge field configurations obtained by cooling the quantum fluctuations of the gauge fields on the lattice were investigated. It was found that the cooling process can be subdivided into three distinct stages: the emergence of semi-classical instanton-anti-instanton vacuum, annihilation of instantons and anti-instantons, and finally, relaxation to stable classical solutions. The distributions of instanton radii and inter-instanton distances were obtained. It was demonstrated that the contribution of the multi-instanton configurations to the value of the string tension was about 5%.

Remarkably, the analytical multi-instanton solution was also obtained by M. I. Polikarpov for the first time. This result remained unpublished and we became aware of it only after his death. A. A. Belavin (who was one of the authors of the first paper on instantons [5]) told us this story. The authors of [6] derived the equations that define the multi-instanton solutions in the Yang-Mills theory. M. I. Polikarpov was the first who obtained the analytical solutions of these equations. This was mentioned in [6], where these solutions were presented. It is worth mentioning, that independently and simultaneously the same problem was solved by E. Witten [7].
Prof. M. Polikarpov started to create his own scientific group in 1990. The first paper published by this group [8] was written in collaboration with his students T. L. Ivanenko and A. V. Pochinsky. In this paper it was numerically demonstrated in $SU(2)$ lattice gauge theory in maximal Abelian gauge that the density of Abelian monopoles which occupy several lattice cells (extended monopoles) is strongly correlated with the string tension. This result indicates that the string between quark and antiquark is the dual analog of the Abrikosov vortex in superconductors. In this study for the first time the Hausdorf dimension of the monopole current line was used as an order parameter.

After M. I. Polikarpov received his Habilitation degree in 1991, one of us (M. A. Z.) became his student. In 1993 the paper [9] was written, in which the partition function of the 4D lattice Abelian Higgs theory is represented as the sum over world sheets of Nielsen-Olesen strings. The creation and annihilation operators of these strings were constructed. The topological long-range interaction of the strings and charged particles was shown to exist; it is proportional to the linking number of the string world sheet and particle world trajectory.

In the later years Emil Akhmedov, Maxim Chernodub, and Fedor Gubarev joined the group of Prof. Polikarpov. As well as M. A. Z. they became the students of M. I. Polikarpov. Some of the most known works done in collaboration with Fedor and Maxim are [11, 12], where the authors have performed numerical calculation of the probability distribution of the value of the monopole creation operator in $SU(2)$ lattice gauge theory. It was found that in the low-temperature confining phase the maximum of this distribution is shifted from zero, which means that the effective constraint potential is of the Higgs type. Above the phase transition the minimum of the potential (the maximum of the monopole field distribution) is at the zero value of the monopole field. This fact confirms the existence of the Abelian monopole condensate in the confinement phase of lattice gluodynamics, and agrees with the dual superconductor model of the confining vacuum.

Emil Akhmedov after getting his PhD almost immediately became an independent researcher. Nevertheless, his own line of research began from the work [13] written under the supervision of M. I. Polikarpov. In this paper the continuum theory of quantum Abrikosov-Nielsen-Olesen strings...
was constructed starting from the Abelian Higgs field theory. It was shown that in four space-time dimensions in the limit of infinitely thin strings, the conformal anomaly is absent, and the quantum theory of such strings exists.

The new impulse was given to the ITEP lattice group when it was joined by the world famous physicist V. I. Zakharov. His experience and scientific intuition became the important ingredient of the further research work carried out by the group. With his participation, for example, the paper on anatomy of Abelian monopoles appeared [14]. In this paper the Abelian and non-Abelian action densities near the monopole in the maximal Abelian gauge of SU(2) lattice gauge theory were studied. It was found that the non-Abelian action density near the monopoles belonging to the percolating cluster decreases when the monopole center is approached. The estimate of the monopole radius was given (≈ 0.04 fm). Approximately at that time one of us (V. G. B.) joined ITEP lattice group as well.

The new generation of the members of the next generation of the ITEP lattice group are A. V. Kovalenko, S. N. Syritsyn, S. M. Morozov and P. Yu. Boyko, who were the students at ITEP. Later S. N. Syritsyn moved to US, while A. V. Kovalenko, S. M. Morozov and P. Yu. Boyko became PhD students and then researchers at ITEP. About at that time V.A. Belavin became the PhD student of M.I. Polikarpov. After getting PhD he moved to the investigation of conformal field theories. In the series of papers written by M. I. Polikarpov in collaboration with V. G. Bornyakov, M. N. Chernodub, F. V. Gubarev, V. I. Zakharov, A. V. Kovalenko, S. N. Syritsyn, S. M. Morozov and P. Yu. Boyko the lattice studies of the structure of QCD vacuum were continued. Some of the well-known publications of this period are [15, 16]. In [15] measurements of the action associated with center vortices in SU(2) pure lattice gauge theory were performed. In lattice units the excess of the action on the plaquettes belonging to the vortex turned out to be approximately constant and independent on the lattice spacing . Therefore, the action of the center vortex is of order , where is its area. Since the area is known to scale in the physical units, the measurements imply that the suppression due to the surface action is balanced, or fine tuned to the entropy factor which is to be an exponential of .

In [16] propagators of the diagonal and the off-diagonal gluons were studied numerically in the maximal Abelian gauge of SU(2) lattice gauge theory. It was found that in the infrared region the propagator of the diagonal gluon was strongly enhanced in comparison with the off-diagonal one. The enhancement factor is about 50 at the smallest momentum 325 MeV.

Around 2007 one of us (P. V. B.) and Elena Luschevskaya joined the ITEP lattice group. Both were the PhD students of M. I. Polikarpov, and then researchers at ITEP. At this time the research direction of the group shifted to the lattice studies of the effect of strong magnetic fields on QCD vacuum. In particular, in [17] the microscopic picture of the Chiral Magnetic Effect was studied on the lattice. There is a recent evidence that this effect is observed by the STAR Collaboration in heavy ion collisions at RHIC. In [17] it was found that indeed magnetic field strongly enhances the fluctuations of electric current in the direction of the magnetic field. In [18] this enhancement was related to the emergence of electric conductivity in the direction of magnetic field. It was predicted that this phenomenon should manifest itself in specific anisotropy of the distribution of soft leptons produced in heavy-ion collisions.

The last scientific topic investigated by Misha Polikarpov was the physics of graphene. In [19] a first-principle numerical study of spontaneous breaking of chiral (sublattice) symmetry in suspended monolayer graphene due to electrostatic interaction was performed. For the first time the screening of Coulomb potential by electrons on -orbitals was taken into account. In contrast to the results of previous numerical simulations with unscreened potential, it was found that suspended graphene is in the conducting phase with unbroken chiral symmetry. This finding is in agreement with the most recent experimental results obtained by the group of K. Novoselov and A. Geim.

M. I. Polikarpov collaborated fruitfully with the foreign colleagues from many countries.
very long collaborations were with T. Suzuki, M. Müller-Preussker, G. Schierholz, M. Ilgenfritz, G. Greensite, B. Bakker.

To conclude, let us simply list the former and current members of the ITEP lattice group, which was created by Misha Polikarpov, and which remains the only lattice group in Russia up to now: Emil Akhmedov, Vladimir Belavin, Vitaly Bornyakov, Pavel Boyko, Victor Braguta, Pavel Buividovich, Maxim Chernodub, Fedor Gubarev, Taras Ivanenko, Oleg Kochetkov, Anton Kononenko, Andrey Kotov, Alexey Kovalenko, Olga Larina, Elena Luschevskaia, Yurij Makeenko, Boris Martemyanov, Valentin Mitrjushkin, Alexander Molochkov, Sergey Morozov, Oleg Pavlovsky, Andrey Pochinsky, Mikhail Prokudin, Roman Rogalev, Vladimir Shevchenko, Sergey Syritsyn, Maxim Ulybyshev, Semen Valgushev, Alexander Veselov, Valentin Zakharov, Mikhail Zubkov.

The people listed above are the former students of Misha Polikarpov, his colleagues and friends. Not all members of the lattice ITEP group continue now to work in science. But, no doubts, all of them experienced the unique atmosphere of the scientific group created with love and passion by Misha Polikarpov and all of them will keep him in their hearts and memories forever.

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