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On the main results of advanced studies in the framework of SPAS "Physics of interactions" (2001-2005) and cooperation "Belarus-JINR-CERN"

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The short realization summary of the Belarus State Program for Advanced Studies "Physics of Interactions" (2001-2005) in the research area "Physics of fundamental interactions, elementary particles and atomic nuclei" is given. Main results obtained by Belarusian physicists on basis of the Fedorov's covariant approach and in cooperation with scientists from Joint Institute for Nuclear Research (JINR, Dubna, Russia) are listed. Particularly, a contribution of the Belarusian executors into preparation of the ATLAS and CMS experiments on Large Hadron Collider (LHC) in European Organization for Nuclear Research (CERN, Geneva, Switzerland) is outlined. The report is devoted to the 95 anniversary of birthday of Academician F.I.Fedorov and to the 50 anniversary of foundation of JINR in Dubna.

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1. Introduction

The wide and successful development of the scientific researches in particle physics in Belarus has been began on base and in the framework of the general covariant approach in the modern theoretical physics (see monograph [1]) worked out (1958-1968) by Academician Fedor Ivanovich Fedorov (1911-1994). Alongside with the general theoretical investigations, there have been elaborated and effectively applied the original covariant methods for description, calculation and analysis of the particular interaction processes as main source of information about elementary particles. They allow to obtain new results by putting and solving a series of actual physical problems. As one of the consequences, the Belarusian physicists have passed, first of all, thanks to the cooperation with Joint Institute for Nuclear Research (JINR, Dubna, Russia), from the purely theoretical investigations to the direct participation in the realization of the experimental programs (see, for example, [2]).

Starting from 1977, all research in physics of elementary particles, atomic nuclei and fundamental interactions in Belarus have been unified under leadership of the Academician F.I.Fedorov in the framework of the state complex program. In such a way, as a result, a formal authorization of the Belarus scientific school, now known as Fedorov's school, has been realized.

In the presented report the last such program, called as Belarus State Program of Advanced Studies **"Electroweak, strong and gravitational interactions in wide energy region. Theory and experiment"** (SPAS "Physics of Interactions", 2001-2005) will be briefly considered.

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2. Basic features of the program "Physics of interactions"

The SPAS "Physics of Interactions" has been worked out as a natural continuation and logical development of the previous Belarus state program "Quark" (1996-2000) and inherits its main aims and major features (see, for example, [3]).

The Program has explicitly complete, logically close character. On the one hand, this Program, due to its subject-matter, has covered the research themes relating to all basic types of the fundamental interactions, and to all known elementary particles (fermions and bosons, leptons and hadrons, quarks and gauge bosons), as well as atomic nuclei. On the other hand, all stages in the scientific theoretical and experimental research processes in the Program are projected.

Correspondingly, the all 24 tasks (themes) of the Program have been divided in the following six parts:

Part I. *Theory of elementary particles and fundamental interactions. Quantum systems. Gravity.*

Part II. *Theoretical and experimental study of elementary particle interaction processes and effects.*

Part III. *Elaboration (and realization) of propositions for inclusion in the experimental programs in high energy physics.*

Part IV. *Studies in the accelerator (detector, calorimeter) physics.*

Part V. *Nuclear optics. Theory and experiment.*

Part VI. *Physics of atomic nuclei and nuclear reactions. Theory and experiment.*

In the realization of the research related to the Program "Physics of Interactions" 185 scientists and engineers were participated, including 29 doctors and 81 candidates of sciences from the following 12 basic Belarusian scientific and high education organizations: 1. B.I.Stepanov Institute of Physics of National Academy of Sciences of Belarus (IP NASB), 2. Joint Institute of Power and Nuclear Research in Sosny of NASB (JIPNR-Sosny NASB), 3. Belarus State University (BSU), 4. National Center of Particle and High Energy Physics BSU (NC PHEP BSU), 5. Scientific Research Institute for Nuclear Problems BSU (SRI NP BSU), 6. Belarus State Pedagogical University (BSPU), 7. Gomel State University (GSU), 8. Gomel State Technical University (GSTU), 9. Belarus State Agrotechnical University (BSATU), 10. Brest State University (BrSU), 11. Belarus National Technical University (BNTU), 12. Belarus State University for Informatics and Radioelectronics (BSUIR).

3. On the international scientific cooperation

The elaboration and improvement, under guidance of F.I.Fedorov, of original effective methods and means of theoretical and experimental researches allow Belarusian physicists to put problems that would be difficult or impossible to solve by traditional ways or in other place. In virtue of this fact, the Fedorov's scientific school, whose representatives constitute the main part of participants of the Program, already for a long time the worthy place in world scientific community has managed. That was testified by extending of the international scientific and technical cooperation.

As a result, most of the tasks in Program have been confirmed in cooperation with scientists from foreign countries, including a participation of Belarusian physicists in the largest international scientific collaborations.

So, for example, in 2005 the fruitful scientific cooperation has been established in the framework of 42 projects and designs with 53 international centers, scientific institutes and universities in more than 20 countries.

On state level the long-time agreements for scientific cooperation with European Organization for Nuclear Research (CERN, Geneva, Switzerland) and Joint Institute for Nuclear Research (JINR, Dubna, Russia) have been concluded.

Particularly, the most of research works, 18 tasks from whole 24, entering the Program "Physics of Interactions" were covered by 23 joint themes included in the Annual Draft topical plans of research and international cooperation of JINR for 2001-2005. In addition, starting

from 2004, a series (14) of common projects in the framework of cooperation "Belarus–JINR" have been selected and financially supported.

The executors of 12 tasks of the Program have been participated in realization of five large international scientific projects and designs of CERN.

The fruitful cooperation has been also established with other well known international centers: DESY, ICTP, SLAC, FNAL, IAEA and so on.

Some research works in the Program have been financially supported by international organizations (ICTP, INTAS, ISCA, IAEA and so on): more than 10 grants have been received.

4. The main results obtained in the framework of the program "Physic of interactions"

As a result of performance of tasks of the Program for 2001-2005, a plenty of new scientific results, including those of high priority and fundamental character, have been obtained. Some from them have been included in Particle Data Group (PDG) database and IAEA database, what is the official acknowledgement of their high scientific level.

The main achievements which have been obtained during 2001-2005 as a result of performance of the SPAS "Physics of Interactions" can be divided by the following kinds:

- The new directions and areas of research are developed or proposed.
- The new approaches, methods of researches and calculations; the new physical and mathematical models; the new computer algorithms and programs; the new techniques of experiments, measurements and processing of the received data have been elaborated, developed and applied.
- The new types of technologies, designs, completing units and products for experimental installations have been created and tested.
- As a result, the new phenomena and effects have been predicted, discovered and experimentally observed, the new laws and features have been established.

As an illustration, it is possible to indicate only on several main results which are related to the all six parts of the Program and, most notably to the above mentioned JINR themes and common projects. (See also review works [4]).

Part I.

- As a significant new step in development of the Fedorov's covariant approach, the generalized relativistic vector algebra has been constructed on the basis of introduction of new mathematical operations, defined in the representation spaces of the geometrical and dynamical symmetry groups, what has allowed to give the most compact formulation of the gauge field theory. ([5], IP NASB).
- For the first time, the problem of scattering of particles on potentials of various type in Lobachevsky space has been put and solved, within the framework of the developed general approach to the analytical solution of quantum mechanical problems in the spaces of constant curvature. These results offer a new area of research in the framework of the quantum scattering theory. ([6], IP NASB; Belarus-JINR project "Particles and geometry").)

The new quantum-mechanical model for description of quasiparticle states in the nanodimensional structures has been proposed, based on non-Euclidean geometry. ([7] IP NASB).

- It has been worked out a dynamical model with oscillator-like Hamiltonian for description of movements in the interior of galaxies, which conserves the Talli-Fisher relation. The proposed model offers a new approach to solving problems of modern scientific cosmology. ([8], IP NASB).
- The new approach to the description of dynamics of the solitons, which allows to choose an optimal mode of their propagation in modern high-speed information systems, has been developed and applied. That opens new perspectives for creation of new devices on the basis of fiber-optical technologies. The solitons of new type, the composite multigap vector solitons, are predicted, which may be used in future as logical elements of optical computers and as memory cells in photonic crystalls. ([9], IP NASB; ISTC and London Scientific Society grants).
- An explicit expression for Berry phase has been obtained. That allows to realize the complete set of quantum gates in holonomic quantum computer. ([10], NC PHEP BSU).

Part II.

- In the framework of generalized diagrammatic approach the adequate models for gamma-quanta interactions with deuterons have been constructed, together which physicists from Lebedev Physical Institute. For the first time, on this bases a new major physical characteristic of nucleon structure - gyration (backward spin polarizability) - has been experimentally determined. It has been introduced and theoretically proved by the Belarusian scientists for 15 years earlier (1978) than abroad (1993). Simultaneously the most precise values of the usual electrical and magnetic polarizabilities of neutron have been obtained (MAMI-B, Mainz, Germany). The results are included in PDG database. ([11], IP NASB).

- As a result of the analysis of the existing experimental data, new numerical limitations on the parameters of the anapole interaction, leading to an extension of the Standard Model have been obtained. ([12], IP NASB).

- An effective covariant Lagrangian approach for diagrammatic description of electromagnetic interaction processes of hadrons, considered as composite systems with some electromagnetic intrinsic structure, has been developed and widely used. ([13], GSU).

The proposed early (1962, Bogush, Fedorov) covariant approach to direct calculation of the scattering amplitudes for polarized particles has been developed and used. The computer program for the analytical calculation of interaction matrix elements of leptonic and hadronic reactions at high energy has been created within the framework of the symbolic algebra system Mathematica. ([14], GSU).

- Cross-sections of deep inelastic scattering processes of neutrino and antineutrino off transversally polarized nucleons have been calculated. In this connection, the known problem of "spin crisis" has been considered: the contributions of spin of quarks into the spin of proton have been calculated. ([15], GSTU).

- The original nonperturbative methods in quantum chromodynamics have been elaborated and applied for description of tau-lepton decays in various vector channels and for calculation of strong interactions contributions into anomalous magnetic momentum of muon, in good agreement with experimental data. ([16], GSTU; project "Nonperturbative approach").

Part III.

- The universal covariant Bardin-Shumeiko approach to research and calculation of the radiation effects at high energies is essentially developed. In framework of this approach a wide series of computer programs have been created. They have been applied to interpretation of the high-energy experimental data in all leading accelerator centers of the world, such as CERN, DESY, SLAC, J-LAB. ([17], NC PHEP BSU; project"Lepton pairs"; CMS and other collaborations).

- The FORTRAN program MERA and Monte Carlo generator have been worked out and used for research of exclusive pion generation in deep-inelastic scattering in the framework of HERMES experiment at HERA in DESY. As a result, the spin-one-particle asymmetry has been firstly measured and reciprocal quark distributions have been observed. ([18], NC PHEP BSU; projects "Dimuons" and "Compass"; HERMES Collaboration).

- The effects of formation of the quantum squeezed and entangled collinear gluon states of the non-perturbative stage of quantum chromodynamics jet evolution have been predicted and studied.

([19], JIPNR-Sosny NASB; project "Multiple processes").

- For the first time, the pentaquarks have been found in central fragmentation area of electron-proton interaction at HERA in DESY. ([20], JIPNR-Sosny NASB; ZEUS collaboration).

- Original method of calculation of model-dependent and model-independent restrictions on parameters of 4-fermion contact electroweak interactions in processes of fermion pair production has been developed and used in the analysis of experimental data. The obtained results are included in the PDG database. ([21], GSTU; project "Graviton"; ICTP grant).

Part IV.

The major achievement of world importance, gained general recognition, is a significant contribution of scientists of our country (see, for example, [22,23]), in the framework of the SPAS "Physics of Interactions" and in cooperation at the state level with JINR and CERN, to the development and creation of calorimetric systems in detectors ATLAS and CMS for Large Hadron Collider (LHC), the world's largest accelerator of the protons (up to recording energies of 14 TeV).

For example (see also below, **5**):

- For processing of the test beam experimental data for ATLAS calorimeters, the new effective methods have been elaborated and fruitfully used. The foundation for development of the algorithms necessary for reconstruction of hadronic jets and single hadrons in a calorimeter of the detector ATLAS at Large Hadronic Collider (LHC) has been elaborated. ([22,23], IP NASB, JINR; "Discrete symmetries", ATLAS collaboration).

- The first samples of monocrystals of calcium molibdate with increased twice light output have been obtained, that opens new possibilities for increasing sensitivity of scintillators. The mass-production of such artifacts for needs of high energy physics has been realized in Russia. ([24], SRI NP BSU; ISTC and INTAS grants; ATLAS, CMS and other collaboration).

- New experimental prototypes of the stripper chambers for the CMS detector at LHC have been produced and tested. Testing and installation of special electronics design, including a wide dynamic range multiplifier ASIC family, have been performed. ([25], SRI NP BSU, NC PHEP BSU; project"Calorimeter"; INTAS grant; CMS collaboration).

Part V.

The new direction of scientific research (initiated in Belarus by V.G.Baryshevsky) called as "Nuclear Optics" has been successfully developed.

- The new physical phenomenon of spin dichroism with deuterons in a carbon target, that was theoretically predicted earlier by the Belarusian physicists, has been experimentally observed. The new data in experiment (Cologne, Germany) on studying of interaction of polarized deuteron beam with the non-polarized carbon target have been obtained. ([26], SRI NP BSU; project "Spin").

- For the first time in the world, generation of radiation on the laser of new type developed and created in Belarus - the Volume Free Electron Laser (VFEL) has been carried out. That may be considered as the scientific foundation for new high-technology directions. Belarus patent and the Euroasian patent have been received.([27], SRI NP BSU; project "VFEL").

- Powerful burst of neutrino radiation, accompanying a final stage of absorption of the white dwarf by a black hole has been predicted. The related mathematical model has been investigated. ([28], SRI NP BSU).

Part VI.

- A new method of the general estimation of nuclide amount in an active zone of a reactor, and a method of drawing up of a detailed map of Belarus territory pollution by neptunium, plutonium, americium and curium isotopes, due to Chernobyl power plant accident, have been elaborated. The model of multichannel spectrometer "Albegas" for simultaneous measurement of beta- and gamma-radiations has been developed and tested. ([29], IP NASB).

- The wide experimental and theoretical studies of transmutation phenomena for nucleus division products in neutron fields have been performed in cooperation with Dubna physicists. It has been shown that the transmutation velocity, normalized on one compacting particle, is, in fact, energy independent, what is of great meaning for choice of the slowing-down devices in future ADS (Accelerator Driven Systems). The original buster under-critical electro-nuclear system "Yalina-B" with mixed spectrum of neutrons and managed by external particle source has been built and brought into use for transmutation phenomena research. ([30], JIPNR-Sosny NASB, IP NASB; project "Energy and transmutation"; IAEA and ISTC grants).

- Computer programs have been developed, which have been allowed to find optical potentials of isotopes of tin, iron, zirconium, tritium, necessary for updating full files of the nuclear data for these isotopes. ([31], JIPNR-Sosny NASB; IAEA grant).

- Physical algorithms and computer programs for calculation of effective cross-sections, spectra and multiplicities of instantaneous neutrons in nucleus division processes have been worked out, in cooperation with foreign scientists. On this basis the observable characteristics of the cross-sections for series of actinides have been calculated. The obtained results have been as a series of directories published and in the world nuclear database in IAEA included. ([32], JIPNR-Sosny NASB; project "Actinid"; IAEA grant).

Certainly, this briefly formulated list of particular results requires additional comments revealing essence, the scientific and practical importance of each of the specified achievements. This list gives only a concise representation about problems which are put and solved in the framework of the SPAS "Physics of Interactions".

On materials of the executed researches for 2001-2005:

a) 1140 works have been published, including
52 book editions (21 - in authoritative international and foreign scientific editions), from them: 18 (9) monographes, and also
1088 scientific articles and preprints (586 abroad);
b) 785 (497 abroad) reports and lectures at the international conferences, seminars, workshops and schools have been given;
c) 3 doctors (4-th in 2006) of science and 25 candidates of science theses have been defended.
Scientific achievements of leading participants of the Program, V.G.Baryshevsky and V.V.Tichomirov (SRI NP BGU), I.D.Feranchuk (PTC BSU), A.V.Berestov and E.A.Rudak (IP NASB), have been marked by the State Prize of Belarus in the field of a science for 2002.
Winners for Academician F.I.Fedorov Prize in 2004 are V.I.Kuvshinov (JIENP-Sosny NASB), Y.A.Kurochkin and E.A.Tolkachev (IP NASB).
Thus, one can conclude that the purposes of the Program are carried out successfully.

5. On contribution of Republic of Belarus in creation of ATLAS and CMS experiments on the Large Hadron Collider (LHC) in CERN.

a. Starting from 1994, last twelfth years Belarusian physicists from National Academy of Sciences (IP NASB, under guidance of A.A.Bogush and Yu.A.Kulchitsky), thanks to the essential support of scientists from JINR, have been included and actively participated in the ATLAS Collaboration. (Spokespersons: Prof. Peter Jenni, CERN and Prof. N.A.Rusakovich, JINR (the former employee of IP NASB)).
The physicists and engineers from the NC PHEP were also strongly involved in ATLAS activity starting from 1996 (under guidance of V.S.Rumyantsev, the former employee of IP NASB) with the firm support of Prof. N.M.Shumeiko and JINR community.
The activity of them has been concerned not only theoretical grounding and process description but also construction, technical design and production of the main detector subsystems: Tile Calorimeter, Muon subsystem and Warm Structure.
The main results obtained in the framework of "Belarus-JINR-CERN" cooperation are related to: production of the absorber TileCal plates; production of support plates for Muon chambers; production of Connection Boxes and Voussuares for Warm Structure of Super Conducting Thoroidal Magnetic Subsystem; participation in the Test Beam performance study on the CERN SPS collider (in particular, investigation of hadronic energy resolution and linearity in the energy range from 10 to 400 GeV); investigation of the non-compensation of the Tile (hadronic) and LAr (electromagnetic) Calorimeters in frame of Combined Calorimeters performance; investigation of hadronic shower development in the Tile Calorimeter and ATLAS Combined Calorimeters.
As a result, it has been established that the experimentally measured and theoretically described characteristics of the hadronic Tile Calorimeter (the pion and electron responses, energy resolutions, muon energy loss spectra, non-compensations (e/h ratios), linearity, and so on) as well as the simulation of the physical processes (for example, hadronic shower development) in calorimeter well satisfy all rigorous demands which are necessary for realizing ATLAS experiments.
In connection with the future experimental researches of the particle generation processes with very high multiplicity in proton-proton collisions at LHC, in the last time the energy correlators K2(n) and K3(n) for high multiplicity events and their ratio R3(n) as a function of the hadron multiplicity have been studied in detail. It has been shown that the R3(n) is not dependent on multiplicity and can be studied at ATLAS.
Much work has been also focused on the test beam program which aimed at setting the electromagnetic scale, studying its uniformity and acquiring data to tune the detector simulation.
The algorithms for reconstructing the hadronic energy of single particle and the generalization of these algorithms for reconstructing the jet energy have been elaborated, as starting point for study at ATLAS the many problems where jets play a crucial role.
(Yu.A.Kulchitsky et al., IP NASB).

In the same time, our other physicists which participate in the ATLAS Collaboration (Yu.A.Kurochkin, I.S.Satsunkevich et al., IP NASB; V.V.Gilevsky, NC PHEP) have been also concentrated on the theoretical investigations related to the possible experimental search for new interaction effects (anapole interactions, existence of the Higgs bosons and magnetic monopoles, etc.) at the LHC.

b. Since 1990 Belarusian physicists and engineers of NC PHEP (under guidance of Prof. N.M.Shumeiko) actively participate in CMS Collaboration (Spokespersons: Prof. Michel Della Negra, CERN and Prof. I.A.Golutvin, JINR).

With active participation of NC PHEP physicists the collaboration CMS - RDMS (Russia Dubna Member States) has been created. Main tasks of Belarusian participants of CMS - RDMS collaboration has been successfully performed, as follows: design, production, delivery and assembling in CERN of two absorbers of the Endcap Hadron Calorimeter (EHC) and the Interface System for its integration into CMS detector; development and production of readout electronics for the prototype of the Cathode Strip Chamber of the Endcap Muon Detector (EMD); participation in the development and production of the final version of readout electronics for EMD; participation in the assembling, setting up and adjustment of the muon detector electronics in CERN; investigations of several physical processes such as dimuon production and 3- and 4-gauge boson's production within the frame of CMS physical program. As a result, for example: EHC has been designed by Belarusian scientists and produced at Minsk plant MZOR. Production of modules of anode readout (AFEB CMP) on the base of IC CMP16G, designed by CMS Collaboration, have been organized; 2000 modules has been already produced, tested and adjusted. 38 Cathode Strip Chambers (CSC) ME1/1 of the front endcap part CMS muon detector and 10 CSC of the rear endcap part have been prepared for installation.

In the last time the main search activity in NC PHEP is directed on the elaboration of the propositions which may be realized experimentally at LHC in the frames of detector CMS.

Particularly, the process of dimuon production at pp-collision has been investigated from two point of view. Directly, as a source of the information about the hadron's structure at TeV scale energies and as an important source of background for another interesting processes such as Z^0 production, Z' and Higgs bosons searches. Calculation of the electroweak radiative correction to Drell-Yan processes has been finished and the comparison of one- and two-boson exchange channels are in progress.

In addition, it is worthy to outline, that an essential contribution in the preparation and installation of the calorimeter systems for LHC has been also done by physicists and engineers from SRI NP BSU (under guidance of Prof. V.G.Baryshevsky; see, for example, [24, 25]).

c. During performance of related advanced researches, a wide set of the problems of important practical significance have been also put and solved.

In particular, within the framework of the cooperation "Belarus-JINR-CERN" have been elaborated, as a by-product, the three types of the original technologies.

By use of these technologies, under orders JINR and CERN, at participation, assistance or intermediary of executors of the Program, on the Belarusian factories have been made and put to Dubna and Geneva 6 types of the designs, completing units and elements for LHC experiments, for example:

- 2 complete sets of absorbers (about 600 tons) for face hadron calorimeters of installation CMS and 300 large-sized plates from aluminium for Warm Structure of the detector ATLAS. A total cost - 3450000 USD.

d. As a result, Belarusian physics have been obtained a unique opportunity for direct participation in realization of experimental programs on a first line of a modern physical science.

In this connection, let us cite the letter, which has been received (17 March 2005) from dr. Robert Aymar, Director-General CERN, where, in particular, has been outlined:

"The Belarusian physicists have made a significant contribution to the construction of the LHC experiments, and CERN hopes that they will be able to participate in the physics programme together with other scientists from all countries of the world".

6. CONCLUSION

Thus, the realization of the SPAS "Physics of interactions" defines one significant and fruitful stage in the development in Belarus of advanced studies in the framework of elementary particles, fundamental interactions and nuclear physics.

The performed investigations and obtained results form the basic foundation for the following continuation and extensions of scientific research in this area of modern physics, namely, in the framework of the new Belarusian State Program of Advanced Studies "Field and Particles" (2006-2010).

As has been clearly demonstrated above, there turns out to be really very effective and fruitful the cooperation of Belarusian physicists, working in the high energy physics, with the Joint Institute for Nuclear Research in Dubna.(See, for example, [33,34]).

In this connection, it is worthy to outline that by the JINR Director (up to 2006) Academician Vladimir Kadyshevsky in his letter from 20 April 2005 the very significant support of the new Belarusian program has been expressed:

"Taking into account importance of the further effective participation of Belarus in activity of the Joint Institute of Nuclear Researches, first of all, - in realization of actual joint scientific and technical projects, I would like to express the full understanding and support of the proposition on performance in Belarus a new SPAS... . This program, as well as finished in the current year SPAS "Physics of Interactions", will form a detailed basis of successful cooperation of many Belarusian institutes and universities with JINR".

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