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ПЕРСПЕКТИВЫ ЯДЕРНО-ФИЗИЧЕСКИХ ИССЛЕДОВАНИЙ В БЕЛАРУСИ

М. В. КОРЖИК[1)]

[1)]*Институт ядерных проблем БГУ, ул. Бобруйская, 11, 220006, г. Минск, Беларусь*

Обсуждаются ближайшие перспективы научных исследований в области ядерной физики для белорусских ученых. Рассматриваются следующие направления деятельности: участие в исследовательских проектах класса «мегасайенс», созданных в России и Евросоюзе, работа с новым поколением источников ионизирующего излучения, использование мировой ядерно-физической научной сети для краткосрочных исследований и мониторинг атомных электростанций. Предлагается сочетать дальнейшие изучение материи и определение ее состояния и эволюции во времени с рутинной деятельностью, связанной с выяснением деталей мира, для которых уже созданы достаточно хорошо проработанные модели. Далее уточняются гносеологические цели исследований в области ядерной физики. Они включают предотвращение потери знаний в области ядерной физики, сохранение приемлемой квалификации и ее воспроизводства, поддержание соответствующего уровня инженерного корпуса для восприятия новейших знаний. Статья основана на личном опыте участия автора в проектах высокой научной значимости. Маршрут рассмотрения областей приложения усилий ученых-ядерщиков построен по принципу максимальной отдачи от высококвалифицированных кадров – докторов и кандидатов наук. Подчеркивается важность подготовки магистрантов и аспирантов к научной карьере. Наконец, указывается на необходимость поддержания высокого уровня знаний в отрасли для проведения экспертизы по запросу правительства в рамках обеспечения безопасности и развития страны.

Ключевые слова: ядерно-физические исследования; научно-исследовательская платформа; ионизирующее излучение; ускоритель; коллайдер; ядерный реактор.

OUTLOOK FOR NUCLEAR PHYSICS RESEARCH IN BELARUS

M. V. KORZHIK[a]

[a]*Institute for Nuclear Problems, Belarusian State University, 11 Babrujskaja Street, Minsk 220006, Belarus*

The future nuclear physics research capabilities for scientists from Belarus are discussed. The following branches for the activity: megascience class research platforms created in Russia and the European Union, a new generation of ionising radiation sources, use of the world nuclear science network for short-term research and, monitoring of nuclear power plants are debated. The purposes of nuclear physics research are suggested to be a balanced combining of the further penetration deep into the matter, to clarify its status and time evolution and, the routine activity associated with clarifying the details of the world, for which sufficiently well-developed models have already been created. Further, the goals of nuclear physics research are specified. They include preventing the loss of knowledge in the field of nuclear physics; conservation of the acceptable qualification and its reproducibility, maintaining the appropriate level of the engineering

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Автор:
Михаил Васильевич Коржик – доктор физико-математических наук; заведующий лабораторией экспериментальной физики высоких энергий.

Author:
Mikhail V. Korzhik, doctor of science (physics and mathematics); head of the laboratory of experimental high energy physics.
korzhik@inp.bsu.by

corps for the perception of the latest knowledge. This article is based on the author's personal experience in participating in projects of high scientific significance. The route of considering the areas of application of nuclear physics scientists' efforts is formed according to the principle of maximum return from the highly qualified personnel (PhDs and doctors of science). Ain importance of training undergraduates and graduate students for a scientific career is underlined. Finally, a need to maintain a high level of knowledge in the branch for the expertise upon the request of the government to secure and develop the country is pointed out.

Keywords: nuclear physics research; research platform; ionising radiation; accelerator; collider; reactor.

Introduction

The role of nuclear physics research in science can be defined based on the driving force of the development of human civilisation. The core of this development is the improvement of the living standards, and the promptness of progress is determined by several factors, among which the development of new sources of energy and its storage is perhaps the most important. For thousands of years, progress has been ensured by utilising chemical sources to extract energy from combustion and explosion, and in the last 150 years by electrical sources. Both types of sources provide relatively low storage density and energy extraction efficiency. This is because the electromagnetic interaction is responsible for the functioning of such sources, the minimum volume from which energy is extracted is a volume of the order of the size of an atom. Nuclear physics has discovered the possibility of storing and extracting energy from nuclei, objects that are much smaller in volume than atoms. As a result, humanity has received both nuclear power plants and nuclear weapons, including its most fearsome component, thermonuclear weapons. The prototypes of thermonuclear reactors for generating electrical energy are in progress on the Earth [1]. Further energy capabilities utilisation is associated with deeper penetration into the matter, the use of its varieties, and the search for opportunities to release energy from volumes comparable to the volume of the constituent particles of the nuclei of familiar matter or, on the contrary, from the other types of the matter. Thus, the main purpose of nuclear physics research is further penetration deep into the matter, to clarify its status and time evolution. This does not exclude the routine activity associated with clarifying the details of the world, for which sufficiently well-developed models have already been created. Firstly, we note the Standard Model, the triumphant confirmation of which required three generations of accelerators at the European Organisation for Nuclear Research (CERN (Geneva, Switzerland)): Proton Synchrotron, Super Proton Synchrotron, and Large Hadron Collider (LHC). The methodical work on the preparation of the Higgs boson measurement at the LHC took more than 20 years, culminating in the discovery of the particle [2]. The team of authors of ~4000 scientific workers from all over the Earth with a population of 7 bln people also included 19 scientists from Belarus with a population of ~9.5 mln people, which undoubtedly demonstrates the high level of qualifications of the scientists and education in our country. The question arises about the application of further efforts of nuclear scientists, the goals should be carefully clarified. I would suggest three essential goals. They are the preventing the loss of knowledge in the field of nuclear physics; conservation of the acceptable qualification and its reproducibility, maintaining the appropriate level of the engineering corps for the perception of the latest knowledge. This article focuses on the consideration of nuclear physics research in the country in the nearest future based on the author's personal experience in participating in projects of high scientific significance. Although the investigations under discussion, in view of the diversity of the issues under study, have long been divided into several directions, including the rapidly developing areas of particle and high-energy physics, in this article we will keep the subject of discussion under the generalised name «nuclear physics research». The genesis of considering the areas of application of scientists' efforts is formed according to the principle of maximum return from the highly qualified personnel (PhDs and doctors of science). Next, training undergraduates and graduate students for a scientific career. Last but not least, the maintaining a high level of knowledge in the branch for expertise upon the request of the government in order to develop the country. We are talking about a relatively small group of people who are highly qualified and strive to achieve high qualifications. But, despite the seemingly small number, they will have the mission of making a significant contribution to the preservation and progress of our nation, which has more than a thousand-year-old confirmed history, through the perception of the foundations of future technologies and their implementation in our life.

Megascience class research platforms

Nowadays, the major direction in the development of research in the field of nuclear physics is the creation of multidisciplinary research platforms with the general name «megascience» to designate unique world-class scientific installations. The closest to us are the 4+ generation synchrotron radiation source being created in Russia (Novosibirsk region), the prototype of a pulsed neutron source based on the spallation type reactions

(Protvino, Moscow region), the International Center for Neutron Research based on the high-flux PIK reactor (Gatchina, Leningrad region), the Zelenograd synchrotron radiation source, the upgraded KISI-Kurchatov specialised synchrotron radiation source (Moscow), and the NICA collider (Joint Institute for Nuclear Research, Dubna). Russia, as the major direction for coming years, has chosen synchrotron-neutron research. Many the above facilities are being created for interdisciplinary research, much of nuclear physics, but also in the interests of materials science, biology and, mainly, the development of nature-like technologies. The NICA collider, conversely, has a highly specialised mission to penetrate deep into the matter and has a scientific program that would be complementary to the work at GSI (FAIR) accelerator-storage ring (Darmstadt, Germany).

Other centers of European importance are in Lund (Sweden) European Spallation Source (ESS) and CERN, perhaps the main platform for research in this area on the Earth. Belarusian physicists began to take an active part in CERN programs starting with the LHC program. Despite the fast discovery of the Higgs predicted particle during the first period of the data acquisition, all experiments on the LHC ring have a high potential for making measurements to refine the nuances of the Standard Model. Particular attention is paid to the modernisation of the ALICE and LHCb experiments, which are focused on the study of quark-gluon plasma and search for light-by-light scattering and search for physics beyond the Standard Model (axion-like particles). The work is planned for the next fifteen years.

At the same time, the creation and operation of general-purpose experimental facilities of the CMS and ATLAS collaborations [3; 4] also highlighted several problems of detectors created on the basis of twenty-year-old technologies. The prime motivation of these experiments at LHC was to elucidate the nature of electroweak symmetry breaking for which the Higgs mechanism is presumed to be responsible. The Standard Model predicts that the Higgs boson lasts for only a very short time before it breaks up, or decays, into other well-known particles. The boson decay channels $\gamma\gamma$, ZZ and WW are equally sensitive in the search for a Higgs boson around 125 GeV. The $\gamma\gamma$ channel is especially important as it allows the mass of the new particle to be measured with precision [5]. In the $\gamma\gamma$ channel, the mass is determined from the energies and directions of two high-energy photons measured by the electromagnetic calorimeter. Although the branching ratio for the decay of a 125 GeV Higgs into two γ-rays is as low as 0.3 %, this decay mode is one of the most important at this energy because both photons can be measured very accurately, and the backgrounds can be precisely estimated.

Apparently, the need to accurately measure the parameters of an open particle has led to the need to increase the luminosity of the LHC accelerator from 2025. This, in turn, will cause an increase in the radiation background, especially its hadronic component. Therefore, the radiation load on the detectors will increase, and the performance of the detectors will not drastically improve. Therefore, it was decided to create a new family of the Future Circular Collider (FCC) at CERN, Circular Electron – Positron Collider in China, and Future Electron-Ion Collider at Brookhaven (USA), which continue the LHC scientific program within the Standard Model and beyond. To reduce background at the experimental points all the colliders will use electron beams to create so-called Higgs factories. Both empirical and theoretical motivations of the new generation of the colliders include global matters: precision electroweak physics, dark matter, matter-antimatter asymmetry, electroweak hierarchy.

The Research Institute for Nuclear Problems of the Belarusian State University is actively involved in the work on the preparation of the scientific program and the development of the essential detecting techniques at FCC. The creation of new technologies for the next generation of circular colliders will require the attraction of fresh brains, which in turn creates unique opportunities for training highly qualified personnel in the following areas: nuclear physics, big data analysis, new materials, photonics, nano-electronics, computer science, accelerating technologies, global simulations. Worth noting, the preparation and the implementation of chains from term papers to dissertations on various topics of the collider creation program. Participation in these works will allow us to get access to the most modern means of measurement and analysis, including electronic equipment, supercomputers, and software. The positive experience has already been gained through the participation of the country's scientists in the framework of the LHC program. Participation in the programs of new nuclear physics platforms requires relevant intergovernmental and interagency agreements. The National Academy of Sciences of Belarus and National Research Centre «Kurchatov Institute» are negotiating on participation in research at megascience class facilities in Russia. Belarus is a JINR member state, and the next step is to update relationships with CERN.

Towards an accelerator' sources of ionising radiation

One of the major trends in nuclear physics measurements is the transfer to accelerator sources of ionising radiation operating on the principle of widespread artificial sources of electromagnetic radiation of type «plug and work» (PW). Recently, accelerator sources of charged particles coupled with targets for obtaining the X-ray spectrum have become widely spread in industry and measurement technology [6]. It should be noted the inspection technique for safety reasons, non-destructive testing, elemental analysis, medical diagnostics, and visualisation. The use of electron beams with an energy of more than 6 MeV also makes it possible to obtain a neutron flux due to photo-nuclear reactions with targets made of heavy metals. The main advantage of PW sources is that they cannot be used for other doubtful purposes. Unlike isotope-based sources, which generally have a small physical volume, intense PW sources contain massive shielding elements and high-voltage power supplies and can only be moved using vehicles. The use of PW sources eliminates the need to create an expensive infrastructure for the control, storage, and disposal of radioactive sources. The development of such sources, the creation of a new generation of sources for industry and research is an urgent need. To train specialists in this field, it is necessary to consider the possibility of creating a specialised center in the republic, for example, as part of the Institute for Nuclear Problems of the Belarusian State University, to install accelerators for protons and electrons with energies up to 20 MeV. Such accelerators are mass-produced in Russia and other countries with a developed nuclear instrumentation industry. This would make it possible to provide training for specialists in accelerator technologies and the operation of accelerator installations, as well as the acquisition of skills in methodical work for carrying out measurements with accelerator sources of ionising radiation.

Mastering international facilities for short-term measurements

For a Central European country like ours, there is no need to create separate research platforms in the field of nuclear physics that provide measurement services. This is due to the geographical proximity of countries such as Russia and the European Union. For example, the Russian program for the development of synchrotron-neutron research aims to create multi-user systems, the radiation will be distributed over measuring stations. Experts of various profiles, from biologists to physicists and chemists, can carry out measurements at the stations at the same time. In contrast, carrying out measurements with beams requires certain qualifications in understanding the architecture of the measuring equipment, the data collection system, and their processing. Thus, each of the groups carrying out the measurements should preferably have a nuclear engineer responsible for the safety and carrying out measurements, as well as the docking of the modelling of ionising radiation in objects and the measured properties. Nuclear physics modelling should become an integral part of the relevant profile of university education. A short-term visit to the measurement site should be preceded by a simulation of the measurement conditions and expected values and the time of the data acquisition. This is due to the significant cost of operating a measuring station at a synchrotron or neutron source however, the expenses for the short-time visits cannot be compared with the cost of the construction and operating the research platforms themselves. Measurement services will be provided by ESS and the Nuclear Research Center in Grenoble (France). The classic reactor research facilities on fuel rods, which were built near scientific clusters, as a rule, in the capital cities, are becoming a thing of the past. This is due not so much to the exhaustion of their research potential as to security issues.

Measurements near nuclear power plants

A widespread point of view is that nuclear power plants are commercial facilities for which the creator bears a warranty, that is, work by other specialists, except those authorised by the creator of the plant, is limited. In the State Atomic Energy Corporation (Russia nuclear energy plants producer), such authorisation can take years. The disasters at Chernobyl and Fukushima raised the level of corporate responsibility in many ways more stringent than in the space industry. At the same time, a compact localisation of nuclear power plants allows for external monitoring. Moreover, the development of techniques for ionising radiation measurements allows us to hope for rapid progress in the development of methods for remote monitoring of fuel cycles of stations. One of the promising methods is the registration of reactor antineutrinos. Antineutrino is a weakly interacting particle. Therefore, its detection is a special art in the technique of nuclear physics measurements. In contrast, the development of compact solid-state antineutrino detectors can make this procedure close to routine. Therefore, there will be a demand for specialists in the field of antineutrino registration. Yet, we do not completely understand the physics of neutrino and antineutrino at the same level as electromagnetic radiation. Rapid progress in this area could provide a bridge to measuring even less visible dark matter particles.

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