# PERSPECTIVE DIRECTIONS OF EXPERIMENTAL RESEARCH ON FUNDAMENTAL PHYSICS AT INTERMEDIATE ENERGIES ON THE PROPOSED NSC KIPT 730 MEV LINEAR ELECTRON ACCELERATOR

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Perspertive directions in fundamental nuclear and hadron physics with electromagnetic probes at intermediate energies up to 1 GeV are discussed. It is emphasized that for electron accelerator with the energy 500…730 MeV, duty factor ~1 and current up to 100 mkA, which is proposed at NSC KFTI there are following possible perspective topical trends which could be studied which will be; i) test of theoretical predictions of the chiral perturbation theory; ii) many-body processes and influence of nuclear medium on hadron properties; iii) test of the electroweak theory in scattering of polarized electrons on nucleons and nuclei, and the parity violation effects.

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## 1. MODERN TRENDS IN NUCLEAR AND HADRON PHYSICS WITH ELECTROMAGNETIC PROBES AT INTERMEDIATE ENERGIES

Study of the structure of hadrons (nucleons, mesons, resonances), which are the complex systems of the quarks and gluons, is one of the main purposes of research in fundamental nuclear and hadron physics. The features of the hadron structure reveal themselves in excitation spectra of hadrons and in processes of hadron interactions. These features can be studied by observing the products of reactions and decays of hadrons. The electron and photon beams (electromagnetic probes) are rather suitable instruments in such studies as they have certain advantages over the hadron beams.

The goal of this research is not only to understand the hadron structure, but also to describe it and the processes of hadron interactions at all energy regions from low (~MeV) to high (~TeV) energies, within the framework of the unified theory - the Standard Model (SM) of the strong and electroweak interactions. During recent years there has been a progress in development of the unified description of the low- and high-energy processes. Effective models and approaches, based on Quantum Chromodynamics (QCD), such as for instance chiral perturbation theory (ChPT) [1,2] have been developed. These models can be used in description of hadrons and nuclei and their interaction at intermediate energies up to 1 GeV. In particular, ChPT is considered as the low-energy limit of Standard Model; it fulfills all fundamental principles and symmetries of QCD and electroweak theory. In contrast to many phenomenological models, which had been used so far, ChPT allows one to perform calculations of different observables with high accuracy, take into account higher-order corrections and estimate the accuracy of the theoretical predictions. At present time, the theoretical predictions on the basis of this theory have been obtained for many observables in different processes. And these predictions can be tested in experiments with photons and electrons of relatively low energies, e.g. hadron polarizabilities in Compton scattering, or S- and P-wave amplitudes in the near-threshold pion photoproduction on nucleon. As it was emphasized in reports [3] the problem of the unified theoretical description of the processes at high and low energies within one theoretical framework, and re-interpretation of the already accumulated experimental material from the QCD point of view, will determine the direction of further researches in the intermediate energy nuclear physics in the near future.

Different aspects of ChPT test are included in research programs of many physics laboratories, which study nuclear physics at energies up to 1 GeV: MAX-lab, HIGS, MAMI. In realization of this task it is mandatory in the first place to have high-precision data for the simplest and fundamental reactions, such as for example photoproduction of the single pion and Compton scattering on nucleons. Only after the amplitudes of these processes are known with the high accuracy and adequately described theoretically, the chiral theory will become firmly established and universally recognized in hadron and nuclear physics at low and intermediate energies. This may open broad possibilities for applying ChPT in those fields of research and in those objects, where it is difficult or even impossible to obtain exact information, for example, in astrophysics.



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Thereby, one of the directions of research on the proposed electron accelerator facility can be related to the high precision measurements of the photo- and electroproduction of the pions and Compton scattering on nucleons. In spite of these processes have been studied for already many years, the accuracy for many observables, particularly for the neutron, is not adequate for modern requirements of all-round testing the theory. The accuracy of some experiments is considerably lower than the necessary up to date level of accuracy (~1...2%). The information, obtained with such accuracy, for instance, about $E_{0+}$ amplitudes for the pion photoproduction on the nucleon, will allow to test ChPT and determine the scale of isospin symmetry breaking and the ratio of *u* and *d* quark masses.

Investigation of the many-body systems and their interactions is another important direction of the research with electromagnetic (EM) probes. At present the interest in this area of physics is connected with the study of following problems:

-influence of nuclear matter on the properties of the hadrons (nucleons, mesons and resonances), and their interactions in nuclei;

-three-body (3N) forces, many-body correlation and clusters, meson exchange currents in nuclei;

-exotic nuclear systems (e.g., η- meson nuclei and the neutron surplus ones).

For progress in studies of the above topics it is imperative to perform the precise experiments on photo- and electroproduction of mesons on nuclei, the nuclear photo- and electrodisintegration with registration of all reaction products and state of the final nuclei. Because., as a rule, these processes involve many particles it is necessary for their study to use the tagged photon beams and 4π-detectors (for the photo processes) and the intensive electron beams and spectrometers with high energy resolution (for electro- processes). The progress in this direction also depends on our understanding and successful theoretical interpretation of the simplest fundamental reactions discussed above.

The other perspective direction aims at tests of the some aspects of the electroweak theory. In particular, it includes investigation of phenomena related to the interference of the amplitudes of electromagnetic and weak interactions. One of manifestations of this interference is the parity violation in elastic scattering of the longitudinally polarized electrons on nucleons and nuclei, and in reactions with circular polarized photons under relatively low energy, ~0.2...0.5 GeV. One also hopes to extract information about the strange quarks distribution in nucleon and details of the neutron distributions in nuclei. Such experiments are of great interest, however, they are very complicated from the view of the small effects under investigation, therefore they require high intensity polarized beams, polarized targets and high accuracy of the measurements.

The directions of the fundamental research in nuclear and hadron physics mentioned above are fully or partly included in the perspective research programs at all scientific centers and facilities which operate at intermediate energies up to 1 GeV: MAX-lab, HIGS, MAMI, BATES, ELSA, TJNAF (CEBAF). Therefore it is clear that the above proposed direction of research is in the focus of attention of the world physics community and new high-quality results in this direction will be in demand in the near future.

## 2. EXPERIMENTAL FACILITIES FOR RESEARCHES WITH EM PROBES AT INTERMEDIATE ENERGIES

At present the fundamental researches at intermediate energies have reached qualitatively new level, which is characterized by high requirements to accuracy of experiments and insistent need of polarization observables measurements. This in turn requires big efforts and heavy expenses for permanent modernization of the existing experimental technique, detectors and facilities and creation new ones if this is needed. As a result, on the one hand, process of concentration of the fundamental researches in limited number of scientific centers takes place, where optimal or even best conditions for long-term and complex studies are developed by efforts of international collaborations. In those places many perspective directions in the intermediate energy physics can be covered, an example is the facility in Mainz. On the other hand, in those scientific centers where in addition to fundamental the applied physics is developed as well, a more modest but at the same tome modern installations with good parameters are built for studying a limited number of fundamental topics, for instance, at MAX-lab or HIGS facilities. At present in the region of energies up to ~1 GeV there are five facilities in Europe and four in USA where experiments with EM probes are performed. Basic parameters of these facilities are listed in Table 1 (see also [4,5]).

1). In Darmshdat (Germany) on super conducting electron accelerator S-DALINAC with the maximal energy 130 MeV and beam current up to 50 mkA. Low energy of electron beam practically excludes researches in the fields which were discussed above (sect. 1.1). The nuclear physics program includes study of the nuclear fluorescence and experiments on electron scattering by nuclei. The accelerator is not equipped by the source of polarized electrons, and has no tagged photon beam.

2). In the MAX-laboratory (Lund, Sweden). During past time the upgrade is performed in this laboratory, directed on increasing of the beam maximal energy and improvement of the tagged system parameters. After the upgrade completion in 2004, MAX-lab will have the extracted electron beam with intensity ~40...50 nA, duty cycle 50...80% and maximal energy 250 MeV. Studies on nuclear physics program are planned to be carried out using the tagged photon beam with very high energy resolution (~0.3 MeV) and intensity about $0.5\ldots1\times10^6$ γ /sec/channel. It is planned to produce the linearly polarized photon beam on the base of coherent bremsstrahlung (CB) of electrons in diamond crystals. The research program includes study of the threshold pion photoproduction on nucleons and nuclei, Compton scattering and nuclear photodisintegration.

3). In MAMI laboratory of the nuclear physics institute at Mainz University (Germany). Accelerator complex MAMI was created step by step from the middle of 60-th and from 1990, and up to now it provided a wide program of researches in the energy range up to 850 MeV. After upgrade of the facility (in 2004 according to the plan), the laboratory will have accelerator complex from 4 race-track microtrons that will allow to get an continuos electron beam with the current ~100 mkA and energy 1.45 GeV. The accelerator has the source of polarized electrons that allows to obtain the polarized electron beam of high energy and circular polarized tagged photons with energy resolution ~2 MeV. There is also tagged beam of the linearly polarized photons on the base of CB of the electrons in the diamond crystals.

Main directions of the physical program at MAMI are the study of hadron structure by EM probes, test of ChPT and electroweak theory. The topics of research cover all directions referred above (sect. 1.1). Due to increase of the energy up to 1.45 GeV the focus of the physical program will be shifted to the higher energies and will include study of the photo and electroproduction of $\eta$ and $\omega$ mesons, production of high resonance, pion pairs, study effects of the parity violation in scattering of the polarized electrons on nucleons and nuclei, distribution of s quarks in nucleon. Owing to the splendid parameters of the beam, MAMI is a unique facility and one of the best accelerator complex for intermediate energy nuclear physics in Europe.

4). On the stretcher ELSA of Bonn University (Germany). The extracted electron beam with the maximal energy 3.5 GeV, low intensity (~20…100 nA) and duty factor ~65%, allows one to carry out experiments only on the tagged beam of bremsstrahlung and CB polarized photons. The main topic of the researches is the structure of hadron resonances in the energy range up to ~1.5 GeV.

5). In Grenoble (France) on GRAAL facility there is linearly polarized photon beam with the maximal energy ~1.47 GeV, produced in the backward Compton scattering of the laser photons on relativistic electrons of 6 GeV storage ring ESRF. For increasing the energy resolution photon beam is collimated and tagged. The research program is concentrated on the single and pair pion and $\eta$ meson production in the resonance range using linearly polarized photons.

There are four facilities in USA.

1). HIGS facility created by FEL laboratory of DUKE University. The photon beam is produced under the backward Compton scattering of the gamma's from FEL laser on the 500 MeV electrons circulating in storage ring.

At present the maximal energy of the beam does not exceed 10 MeV and the intensity ~$10^5$ $\gamma$/sec. In the future it is planned to raise the energy of the photon beam up to ~220 MeV. Monochromaticity of the beam ~1% is reached due to collimation, herewith expected intensity will not exceed ~$10^6$…$10^7$ $\gamma$/sec. The beam can be linearly polarized ~100%. Program of the investigation includes studying of the pion photproduction on nucleons and nuclei near threshold, Compton scattering and nuclear disintegration

2). Bates Linear Accelerator Center. It has electron linac with the maximal energy ~950 MeV, duty factor ~1% and storage ring. Extracted from storage ring electron beam has an intensity up to 7 mkA and duty factor ~50%. There is a source of the polarized electrons. This facility provides experiments on polarized and unpolarized electron scattering on nucleons and nuclei, study of the parity violation in scattering of polarized electrons.

3). LEGS collaboration (Brookhaven). There is a beam of linearly polarized photons with maximal energy ~330 MeV, which is produced by backscattering polarized laser light from the stored ~2.5 GeV electron beam in the synchrotron ring NSLS. The system of photon tagged is used for improving energy resolution (up to ~2%)

Research program is aimed on investigation of the light nuclei photodisintegration (d, $^3$He, $^4$He) using polarized photon beam.

4). TJNAF (CEBAF) facility. At present there operate intensive and continuous electron and photon beams in the energy range 0.4…6 GeV, and it is planned to increase the energy up to 12 GeV in near future. The excellent beam parameters allow to carry out a broad range of experiments, however, on the whole the program is basically oriented on researches in the energy range above 1 GeV.

Thereby, out of existing in the world nine facilities, where fundamental studies at intermediate energy (up to ~1 GeV) are performed, the majority of the facilities has limited possibilities due to design features and methods of the beam producing, namely:

a) low energy of the beam, <~ 300 MeV (below the first pion-nuclean resonance) (S-DALINAC, MAX-lab, HIGS, LEGS). This restricts or completely excludes studies of the perspective directions, which were discussed above in sect. 1.1 (S-DALINAC) or considerably limits area of investigations (MAX-lab, HIGS, LEGS).

b) beams only one type:

- photon beam of low intensity at MAX-lab, ELSA, HIGS, LEGS, GRAAL. The absence of the extracted electron beam (HIGS, LEGS, GRAAL) or its low intensity (MAX-lab, ELSA) excludes wide direction of studies of the electroprocesses on nucleon and nuclei;

- an electron beam (BATES). The absence of the photon beam excludes a wide direction of studies of the photoprocesses on nucleon and nuclei.

Only MAMI facility (in Europe) provides a possibility to perform the broad complex studies, both with the photon and electron beams in all perspective directions including the interesting area of the first and the second nucleon resonances. (as it was already discussed above, TJNAF is oriented to higher energies).

***Table 1**. Parameters of the existing facilities in intermediate energy range*

| Facility | $E_{max}$ GeV | Duty factor, % | Extract electron and photon beam of high energy | | | | |
|---|---|---|---|---|---|---|---|
| | | | Electron beams | | Photon beams | | |
| | | | Circular mkA | Polarization | Type of the beam | Intensity, γ/sec/channel | Polarization type |
| S-Dalinac | 0.13 | 100 | 80 | No | No | No | No |
| MAX-lab | 0.25 | 80 | 0.05 | No | Tagged | $10^6$ | Linear |
| MAMI | 1.45 | 100 | 100 | Yes | Tagged | $10^6$ | Linear<br>Circular |
| ELSA | 3.5 | 65 | 0.1 | No | Tagged | $10^6$ | Linear |
| GRAAL | 1.47 | 100 | No | No | Compton | $10^6$ | Linear |
| HIGS | 0.22 | 100 | No | No | Compton | $10^6…10^7$γ/sec | Linear |
| BATES | 0.95 | 50 | 7 | Yes | No | No | No |
| LEGS | 0.33 | 100 | No | No | Compton | $10^6$ | Linear |
| TJNAF | 12 | 100 | 100 | Yes | Tagged | $10^6$ | Linear<br>Circular |
| SALO | 0.73 | 100 | 100 | Yes | Tagged | $10^6$ | Linear<br>Circular |

***Table 2**. The main parameters of the proposed NSC KIPT linac*

| *Parameters of the NSC KIPT linac* | |
|---|---|
| Maximal energy, MeV | 730 |
| Electron current (max) mkA | 100 |
| Duty factor, % | 100 |
| Energy dispersion, % | 0.0008…0.00176 |
| Emittance of the beam, π*mm*mrad | 0.0007…0.004 |
| Number of beam lines | 3 |
| *Beam for experimental research* | |
| Range of electron beam energies, MeV | 240…730 |
| -polarization, % | Up to 80 |
| Tagged photon beam | |
| -Intensity, γ/sec/channel | $10^6$ |
| -Energy resolution of the tagger, MeV | ~1…2 |
| -Linear polarization on the base of CB in the range 20…360 MeV | 20…50% |
| -Circular polarization, % | Up to 80 |
| Bremsstrahlung, equivalent quanta/sec | Up to$10^{12}$ |
| Neutron source with multiplication target, neutrons/sec | Up to $2.9\times10^{17}$ |

It is expected that the new NNC KIPT facility (referred to in Table 2) will have a maximal energy of the extracted electron beam 730 MeV, current ~100 mkA, duty factor ~100%. It will be equipped with the source of polarized electrons, tagged photon system with energy resolution ~1...2 MeV and equipment for producing the CB linearly polarized photons. One can see that the parameters and possibilities of the proposed facility exceed the majority of the facilities discussed above. It can reach the MAMI level and will be able to provide the wide-scale polarized investigations, both with the photon and the electron beams. As was mentioned, due to increase of the energy, the focus of the MAMI research program is displaced on higher energies, above 800 MeV, and therefore the corresponding niche is becoming free. The new NNC KIPT facility is able to occupy it and take part of the-world scientific program in the energy range up to 0.8 GeV. It should be emphasized that studies with EM probes in this area have been performed at NNC KIPT for more than 30-years (from middle of 60s) and are traditional for nuclear physicists in Kharkov. The accumulated experience will be useful for development of the accelerator and experimental technique. The additional and essential advantage of the Kharkov future facility is a possibility to produce on the accelerator an intensive source of neutrons that will give a momentum to development of the fundamental studies in the neutron physics and open possibilities for applied researches.

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## ПЕРСПЕКТИВНЫЕ НАПРАВЛЕНИЯ ЭКСПЕРИМЕНТАЛЬНЫХ ИССЛЕДОВАНИЙ ПО ФИЗИКЕ ПРОМЕЖУТОЧНЫХ ЭНЕРГИЙ НА ПРЕДЛАГАЕМОМ 730 МэВ-ЛИНЕЙНОМ УСКОРИТЕЛЕ ННЦ ХФТИ


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Рассмотрены перспективные направления фундаментальных исследований по ядерной физике и физике адронов с электромагнитными зондами в области промежуточных энергий до 1 ГэВ. Подчеркивается, что на электронном ускорителе с энергией 500...750 МэВ, коэффициентом заполнения ~1 и током 100 мкА, который предлагается построить в ННЦ ХФТИ, возможны следующие направления фундаментальных исследований, которые будут актуальны в ближайшем будущем: i) проверка предсказаний киральной теории возмущений; ii) многочастичные процессы и влияние ядерной среды на свойства адронов; iii) проверка электрослабой теории в экспериментах по рассеянию поляризованных электронов на нуклонах и ядрах и нарушения четности.


## ПЕРСПЕКТИВНІ НАПРЯМКИ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ПО ФІЗИЦІ ПРОМІЖНИХ ЕНЕРГІЙ НА ПРОПОНОВАНОМУ 730 МеВ-ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ННЦ ХФТІ


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Розглянуто перспективні напрямки фундаментальних досліджень у галузі ядерної фізики та фізики адронів з електромагнітними зондами в області проміжних енергій до 1 ГеВ. Підкреслено, що на електронному прискорювачі прискорювачі з енергію 500…750 МеВ, коефіцієнтом заповнення ~1 і струмом до 100 мкА, що пропонується побудувати в ННЦ ХФТІ, можливі такі напрямки фундаментальних досліджень, що будуть актуальними у найближчому майбутньому: i) перевірка теоретичних передбачень кіральної теорії збурень; ii) багаточасткові процеси та вплив ядерного середовища на характеристики адронів; iii) перевірка електрослабкої теорії в експериментах з розсіяння поляризованих електронів на нуклонах та ядрах і ефекти порушення парності у цих процесах.