Training Plan

Doctoral School of Physical Sciences

University of Debrecen

1. General Characteristics of the Training Programme

The training programme of the Doctoral School of Physical Sciences is coordinated and compiled by the Head and the Secretary of the Doctoral School. During the preparation of the programme, the leaders of the doctoral programmes collect the list of courses and the course descriptions prepared by the responsible instructors. The assembled document is then circulated for review among the relevant parties, and—taking into account the comments received—the finalised version is approved by the Council of the Doctoral School. The approved training programme is made publicly available on the website of the Doctoral School.

The training programme is reviewed every three years. A key aspect of the review is the relevance and timeliness of the announced courses: courses must both support preparation for the Complex exam and provide the theoretical and methodological knowledge indispensable for the research conducted within the Doctoral School. As a result of the review, the course offering may be modified as necessary: certain topics may be discontinued, while new courses aligned with the development of the discipline and international research trends may be incorporated.

2. General Characteristics of the Doctoral School

2.1 Mission and Vision of the Doctoral School

The strategy of the Doctoral School is supported by three quality objectives, which are aligned with the quality goals of the Faculty Doctoral Council (TTDT):

- **Maintaining and, where possible, increasing the number of degree recipients**,
- **Keeping dropout rates at a low level**,
- **Strengthening internationalisation** (English-language training, involvement of foreign students, participation in international research networks).

Together, these strategic goals ensure that the Doctoral School of Physical Sciences remains, in the long term, a key actor in scientific excellence and in the societal and economic impact of research.

3. Personnel Background of the Training Conducted in the Doctoral School

The core members, supervisors, and instructors of the Doctoral School are primarily affiliated with the Faculty of Science and Technology of the University of Debrecen (UD) and the HUN-REN Institute for Nuclear Research (ATOMKI). However, colleagues from other faculties of UD and from external institutions also participate in the supervisory and teaching activities of the Doctoral School.

Head of the Doctoral School:

Dr. Ferenc Kun, Full Member of the Hungarian Academy of Sciences, Professor (UD)

Core members of the Doctoral School:

1. **Dr. Csaba Cserháti**, DSc, Professor (UD)
2. **Dr. Zoltán Erdélyi**, DSc, Professor (UD)
3. **Dr. Zsolt Fülöp**, DSc, Scientific Advisor (ATOMKI)
4. **Dr. Gábor József Halász**, DSc, Professor (UD)
5. **Dr. Attila Krasznahorkay**, DSc, Scientific Advisor (ATOMKI)
6. **Dr. Sándor Nagy**, DSc, Associate professor (UD)
7. **Dr. Ágnes Vibók**, DSc, Professor (UD)

A total of **98 persons** (instructors and supervisors) participate in the work of the Doctoral School.

Secretary of the Doctoral School:

Dr. László Oláh, PhD, Assistant Professor (UD).

4. Learning Outcomes Expected at the End of the Training Programme (Hungarian Qualifications Framework – Level 8)

The fundamental objective of the Doctoral School of Physical Sciences is that, by the end of the training period, doctoral students shall have achieved the following learning outcomes.

Knowledge

- They have a system-level and interconnected understanding of the general laws, fundamental theories, and conceptual framework of the physical sciences.
- At the level of a researcher, they are familiar with the subject, specific characteristics, main directions, and boundaries of their chosen scientific field, including both established and debated relationships.
- They possess a solid understanding of the fundamental interrelations in the neighbouring areas of physics, as well as the mathematical, computational, and methodological background required for these fields.
- They are able to comprehend and critically analyse the leading international scientific literature of their research area, and they possess the research methodology skills necessary for independent scientific work.

Skills

- They are able to identify, study (experimentally and theoretically), analyse, and interpret the physical laws manifested in natural phenomena.
- They are capable of designing and carrying out new research projects independently, and of developing new techniques and methods.
- They are capable of creative analysis, the synthetic and novel interpretation of complex phenomena, model construction, and critical evaluation.

- They are able to apply and further develop the specific methods of knowledge acquisition and problem-solving characteristic of their research field.
- They can provide professionally grounded, realistic, and critical assessments of their own and others' research results, and can communicate these findings effectively to both professional and non-professional audiences, in Hungarian and in English.
- They are capable of integrating into national and international research networks and collaborating within interdisciplinary research groups.

Attitudes

- They demonstrate a commitment to scientific inquiry, the advancement of knowledge, and the ethical norms of research.
- They are open to new scientific results, theoretical approaches, and methodological innovations, and are able to integrate these into their work.
- They cultivate a collaborative attitude, contributing constructively to professional dialogues within both national and international scientific communities.
- They value precision, objectivity, and critical thinking, and apply these consistently during their research and professional activities.
- They are committed to knowledge-sharing, supporting the scientific development of students and colleagues.

Autonomy and Responsibility

- They are capable of conducting independent research at a high professional standard, from conceptualisation through implementation to publication.
- They assume full professional and ethical responsibility for their research activities and their consequences.
- They are capable of managing research projects, coordinating smaller research groups, and contributing to the strategic planning of scientific work.
- They take responsibility for continuous professional development, the expansion of their own competencies, and staying up to date with international scientific trends.
- They participate actively in the professional evaluation of the research field, including peer review, conference organisation, and scientific committee work.

5. Characteristics of the Training Provided by the Doctoral School of Physical Sciences

The duration of the doctoral training is eight semesters (48 months), divided into two phases: (1) the training and research phase (24 months), and (2) the research and dissertation phase (24 months).

During this period, students must obtain a total of 240 credits, with an average of 30 credits per semester. A semester can be validated if the student earns at least 27 credits, while no more than 33 credits may be acquired in any single semester.

Doctoral students may also participate in teaching activities (e.g., conducting university practical classes). However, no credits are awarded for teaching, and to prevent overload, the weekly teaching activity must not exceed 4 hours.

5.1 Full-Time and Part-Time Training

During the first four semesters, students must obtain at least 16 and at most 20 study credits by completing courses. The recommended number of courses per semester is two, corresponding to 4 credits.

Out of the 16 required study credits:

- at least 12 credits must come from courses announced by the Doctoral School:
  - minimum 8 credits from the programme selected at admission,
  - 4 credits from the general course offerings of the DS.
- The remaining 4 credits may be obtained by:
  - completing doctoral courses offered at other Hungarian universities,
  - participating in teaching activities at the Institute of Physics (UD),
  - participating in international schools (maximum 2 × 2 credits),
  - giving a talk or presenting a poster at an international conference (maximum 1 × 2 credits), all with the prior approval of the Head of the Doctoral School.

To support this process, a separate course entry titled "Courses Completed at Other Institutions" has been created in the Neptun electronic study system.

5.2 Training Conducted in the Framework of Individual Preparation

Students participating in individual preparation are required to complete only the research and dissertation phase, which lasts 24 months.

The purpose of individual preparation is to make it possible for professionals who:

- have earned a master's degree (or equivalent qualification) at a Hungarian or foreign university,
- possess substantial teaching and/or research experience,
- and have documented scientific achievements with adequate number and quality of publications,

to obtain the doctoral (PhD) degree.

Individual preparation is considered an exceptional procedure, used only in particularly justified cases. Nevertheless, it offers an important opportunity for experienced professionals to advance their scientific careers.

Upon acceptance, the student enters a self-funded doctoral status. After admission, the Scientific Field Doctoral Council appoints the Complex exam committee and determines the exam subjects. The student must take the Complex exam during the first examination period following admission.

5.3 The Complex Exam

In full-time and part-time doctoral training, the Complex exam is held at the end of the fourth semester. It marks the completion of the training and research phase, and is a prerequisite for beginning the research and dissertation phase. The purpose of the exam is to provide a comprehensive evaluation of the student's academic and research progress.

Students must apply for the Complex exam in writing, in accordance with Annex 4 of the Doctoral Regulations of the University of Debrecen. Upon successful completion of the exam, the student automatically enters the degree-awarding procedure, meaning that the application for the Complex exam also constitutes an application for the degree procedure.

The Complex exam consists of two main parts:

1. Theoretical part:

   The student must demonstrate preparedness in at least two subjects (a major and a minor subject). The list of exam subjects is included in the training programme of the Doctoral School.

2. Dissertation part:

   The student presents, in the form of a talk:

   - the literature background of the research area,
   - the research results achieved so far, and
   - the research plan for the second phase of the doctoral training, including the schedule for completing the dissertation and the planned publications.

Students may enrol for the fifth semester only after successfully passing the Complex exam.

After completing the Complex exam, the student must submit the final (revised after the pre-defense) version of the dissertation within three years. In duly justified cases (e.g., childbirth, accident, illness, or other unavoidable circumstances), the deadline may be extended by up to one year by the decision of the Scientific Field Doctoral Council.

5.4 Recognition of Courses Completed at Other Institutions

The Doctoral School of Physical Sciences allows doctoral students to complete courses related to their research area at other Hungarian doctoral schools.

Of the required 16 study credits, up to 4 credits may be earned in this way.

The recognition of externally completed courses is decided by the Head of the Doctoral School, based on the recommendation of the supervisor.

To support administration, a separate course entry titled "Courses Completed at Other Institutions" has been created in the Neptun electronic study system.

6. Programmes of the Doctoral School of Physical Sciences

6.1 Atomic and Molecular Physics Programme

Programme Director:

Dr. Ágnes Vibók, Doctor of the Hungarian Academy of Sciences, Professor (University of Debrecen)

General Aim of the Programme

The aim of the Atomic and Molecular Physics Programme is to offer foundational courses for students intending to conduct scientific research in this field. These courses provide solid, practically illustrated knowledge. Building on this foundation — which can be partially acquired already in the MSc in Physics — the specialised courses systematically introduce students to their chosen research topics.

The programme ensures that doctoral students become familiar with, and are able to apply, the **theoretical and experimental techniques** relevant to the research area.

At later stages of the training, students may deepen their knowledge in specific subfields of atomic and molecular physics, as well as in other programmes of the Doctoral School, according to their individual interests.

Main Thematic Directions of the Courses

- calculation of atomic and molecular quantities
- theoretical description of atomic collision processes
- X-ray and electron spectroscopic investigation of atomic collisions

Educational and Research Significance of the Programme

The educational and research significance of atomic and molecular physics is outstanding. Atomic physics remains one of the most reliable experimental arenas for testing theoretical models and approximation methods.

A precise understanding of elementary atomic processes is essential for interpreting processes in both solid matter and living systems. The investigation of atomic collisions plays a key role in studying the behaviour of matter under extreme conditions — for example, in astrophysical and laboratory plasmas.

Personnel and Infrastructure

The instructors and researchers of the programme have successful and internationally recognised scientific backgrounds.

Theoretical investigations are supported by the modern computing centres and computing facilities of the University of Debrecen and ATOMKI.

Experimental research is supported by the accelerator facilities of ATOMKI (cyclotron, Tandetron, electron-cyclotron-resonance ion source), as well as by its modern X-ray (crystal and semiconductor) and electron spectrometers.

Through the extensive international collaborations of the participating researchers, talented and ambitious students gain access to some of the world's leading atomic physics laboratories.

6.2 Nuclear Physics Programme

Programme Director:

Dr. Zsolt Fülöp, Doctor of the Hungarian Academy of Sciences, Scientific Advisor (ATOMKI)

General Aim of the Programme

The aim of the Nuclear Physics Programme is to introduce students to nuclear physics research at a level that enables them to achieve meaningful scientific results. The objective of the training is to prepare doctoral students for independent research work in nuclear physics, as well as for the performance of high-level applied tasks based on solid scientific foundations. The programme offers wide-ranging research opportunities in all main branches of nuclear physics research (basic research, as well as methodological and applied areas).

Significance of the Programme

The international significance of nuclear physics research is determined by three main factors:

- the exploration of the structure of atomic nuclei, the properties of nuclear matter, and the interactions between nucleons;
- the investigation, in high-energy heavy-ion collisions, of the quark–gluon plasma, theoretically predicted to arise from a system of quarks and gluons;
- the wide applicability of nuclear-physics methodology, which yields direct benefits in related scientific disciplines, industry, energy production, environmental protection, and medicine.

Content and Methods of the Training

The training, built on a broad foundation, introduces students systematically to the nuclear-physics way of thinking. A large number of lectures, laboratory practices, and computing courses ensure thorough theoretical and practical preparation.

The range of course topics is rich and varied, enabling doctoral students to choose subjects that match their own research fields while also taking their individual interests into account. The structure of the courses is such that they build on prior university studies and do not impose specific prerequisites, therefore they can be selected flexibly and completed in any order.

Personnel and Infrastructure

The experimental background of the programme is provided primarily by the charged-particle accelerators of ATOMKI and their auxiliary equipment (detector systems, spectrographs, data acquisition systems, computers). In addition, through international collaborations, doctoral students may gain access to the facilities of major international accelerator centres as well.

Theoretical calculations are supported by the central computers of the University of Debrecen and ATOMKI, as well as by the workstations of the departments and research groups. The traditions and intellectual heritage of the Debrecen nuclear-physics school offer further guarantees for the successful research work of the doctoral students participating in the programme.

6.3 Solid State Physics and Materials Science Programme

Programme Director:

Dr. Zoltán Erdélyi, Doctor of the Hungarian Academy of Sciences, Professor (University of Debrecen)

General Aim of the Programme

The aim of the Solid State Physics and Materials Science Programme is to train specialists who, through a modern physical approach and strong methodological competence, contribute to the understanding and application of the properties of new materials. The objective of the programme is to prepare doctoral students for conducting both fundamental and applied research in materials science and solid state physics, as well as for participating in the solution of industrial and technological problems.

Significance of the Programme

Over recent decades, research in materials science has increasingly integrated **physical, chemical, and engineering knowledge**. Solid state physics methods play a key role in exploring the **atomic-scale structure**, the **micro- and macrostructure** of new materials, and their **physical, chemical, mechanical, electrical, magnetic, and optical properties**.

This programme serves to provide a deeper understanding of these relationships and establishes a direct connection between scientific research and practical applications.

Content and Methods of the Training

After acquiring the fundamental theoretical and experimental methods of solid state physics, students can take specialised courses related to their own research field, which are directly connected to the research carried out in the institutes and research groups. The programme places emphasis on an **interdisciplinary approach**: doctoral students gain insight into the full research spectrum, extending from the atomic-scale description of solids to their macroscopic material properties.

Personnel and Infrastructure

The programme is supported by the research traditions and modern laboratories of the **Institute of Physics of the University of Debrecen** and **ATOMKI**. The main research directions include:

- **Department of Solid State Physics (DE):** metals and alloys, metal–ceramic bonding, atomic transport processes, thin-film physics, electron microscopy;
- **Department of Experimental Physics (DE):** photosensitive functional materials, interactions of electron and ion beams with matter, photonic elements and structures;
- **Department of Theoretical Physics (DE):** ion irradiation of solids, spin glasses, fracture and fragmentation of solids;
- **ATOMKI:** superconductivity, magnetic properties, surface physics.

The wide research spectrum, the close connection of theoretical, experimental, and applied approaches, and the world-class infrastructure ensure that students graduating from this programme acquire **competitive knowledge and internationally relevant research competences**.

6.4 Physical Methods in Interdisciplinary Research Programme

Programme Director:

Dr. Ferenc Kun, Full Member of the Hungarian Academy of Sciences, Professor (University of Debrecen)

General Aim of the Programme

The aim of the programme is to train specialists who apply the modern methods of physics creatively in interdisciplinary research, including in areas that go beyond narrowly defined physical problems. The programme prepares doctoral students to pursue, within a unified methodological framework and at a high professional level, research addressing the challenges of statistical physics, environmental physics, engineering and space physics, solar physics, and the physics of complex systems.

Significance of the Programme

The particular strength of physical methods lies in their generalisability and wide range of applications. Within the framework of the programme, students learn how the modelling, measurement and analytical tools of physics can be applied to the investigation of complex systems, environmental processes, engineering problems, as well as astronomical and space-physics phenomena.

Physics of complex systems: students gain insight into how the concepts and models of statistical physics can be used to describe multi-component systems such as the economy, society, the functioning of living cells, the brain, or even the World Wide Web.

Solar and space physics: the training also extends to the study of the static and dynamic phenomena of solar activity, the operation of the Sun, and its interaction with the planets, with special emphasis on space-weather phenomena that have a direct impact on the Earth and on technological systems.

Environmental physics: the programme deals with atmospheric and hydrospheric processes altered by human activity, in particular the greenhouse effect, as well as the transport of pollutants — for example radioisotopes, freons or other anthropogenic substances — between the different spheres of the Earth.

A highlighted role is played by **computer simulation and modelling**, which are among the most important tools of modern research. Doctoral students also become involved in the use of domestic and international supercomputing infrastructures (e.g. Hungarian HPC systems), which make it possible to study problems with high computational demand.

Content and Methods of the Training

The programme introduces students, through a variety of lectures and practical classes, to the physical methods applied in interdisciplinary research. The curriculum covers:

- the theory and applications of statistical physics and complex systems,
- the foundations and current problems of solar and space-physics research,
- the methods of environmental physics and engineering physics,
- the environmental and industrial applications of nuclear and analytical techniques,
- computer simulation and modelling.

During the training, doctoral students learn how different physical methods can be combined in order to understand and solve complex problems.

Personnel and Infrastructure

The background of the programme is provided by the research base of the University of Debrecen and ATOMKI. Doctoral students have access to modern laboratories, analytical and radiation-measurement equipment, as well as modern computing infrastructure — including domestic supercomputing capacities — which together ensure the broad interdisciplinary research opportunities of the programme.

6.5 Particle Physics Programme

Programme Director:

Dr. Sándor Nagy, Doctor of the Hungarian Academy of Sciences, Associate professor (University of Debrecen)

General Aim of the Programme

The aim of the Particle Physics Programme is to introduce doctoral students to the world of elementary particles and the research of their interactions. The objective of the training is to enable students to become capable of independent research work in both basic research and applied areas, and to integrate into Hungarian and international particle-physics research.

Significance of the Programme

Particle physics is one of the most dynamically developing scientific fields today, investigating the fundamental building blocks of matter and their interactions. The experimental testing and further development of the **Standard Model**, the search for **new physical phenomena beyond the Standard Model**, and the study of **cosmological and astrophysical connections** all represent the forefront of worldwide research.

A key strength of the programme is that its students can directly participate in large international collaborations — for example in experiments at **CERN** — as well as in domestic particle-physics projects.

Content and Methods of the Training

The training provides wide-ranging theoretical and experimental knowledge. Students acquire both the **fundamental** and **advanced** concepts of particle physics, and become familiar with:

- analytical and numerical methods,
- state-of-the-art detector technology,
- the modern toolkit of data processing and analysis.

The programme includes lectures, specialised courses, and laboratory sessions that are directly linked to ongoing domestic and international research projects.

Training also enables doctoral students to participate in large-scale international collaborations and to take part in data-processing and analysis tasks.

Personnel and Infrastructure

The research background of the programme is provided by the particle physics research groups of the University of Debrecen and ATOMKI. Doctoral students may participate in experiments at **CERN** and other international research centres, and they have access to **state-of-the-art detector systems**, **data-acquisition and data-processing systems**. Theoretical work is supported by the **computing infrastructure** of the University of Debrecen and ATOMKI, as well as by access to **international supercomputing networks**.

Subjects of the Complex Examinations

Main subjects:

(topics enclosed)

1. Atomic- and molecular physics
2 Complex systems
3 Environmental physics
4 Nuclear physics
5 Solar physics
6 Particle physics
7 Solid state physics and material science

1. Atomic- and molecular physics

I. One-electron atoms

The Schrödinger equation of the hydrogen atom, energy levels, bound and continuum states, expectation values, hydrogenlike ions. Dirac equation, relativistic corrections.

II. Many-electron atoms

Schrödinger equation of the many-electron atoms, Pauli principle, Slater determinants, the independent particle model, approximation of spherical symmetry, Thomas-Fermi model, Hartree-Fock and self-consistent field method, L-S and j-j coupling, electron correlation, configuration interaction, density functional methods. Ground and excited states of the two-electron atoms, double excited states, Auger effect. Experimental checking of the calculation of the atomic structure, basic methods of the experimental photon and electron spectrometry.

II. Interaction of the atoms with the electromagnetic fields

The electromagnetic field and its interaction with atoms with one electron, transition probabilities, dipole approximation, Einstein coefficients, selection rules, line widths and lifetimes, Fine structure, Zeeman effect, Stark effect, Lamb shift, interaction of many-electron atoms with electromagnetic field.

III. Atomic collisions

Basic concepts, potential scattering, partial waves, Born approximation. Inelastic scattering, electron scattering on atoms, excitation, ionisation, resonances. Ion-atom and atom-atom collisions, ionisation, electron capture. Experimental identification of collision processes.

IV. Molecular physics

Separation of the motion of the electrons and nuclei, rotational, vibrational and electron states of diatomic molecules, symmetry properties of the electron states. The hydrogen molecule. Basic methods for calculation of the molecular structure, molecular orbit method, valence bound method. Polyatomic molecules, rotational, vibrational and electronic states, symmetry properties of the electronic states. Fundamental experimental methods for the investigation of the molecular structure.

Literature:

- B.H. Brandsden and C. J. Joachain: Physics of Atoms and Molecules, Longman Scientific & Technical, England 1988
- H. A. Bethe and E. E. Salpeter: Quantum Mechanics of One- and Two-Electron Atoms, Plenum Rosetta, New York, 1977.
- H. Friedrich: Theoretical Atomic Physics, Springer-Verlag, 1990.
- H. Haken and H. C. Wolf: Atomic and Quantum Physics, Springer-Verlag, 1991.
- M. Weissbluth: Atoms and Molecules, Academic Press, 1978.
- Kapuy E és Török F.: Az atomok és molekulák kvantumelmélete, Akadémiai Kiadó Budapest, 1975.
- M. R. C. McDowell and J. P. Coleman: Introduction to the Theory of Ion-Atom Collisions, Am. Elsevier, New York, 1970.
- B. H. Brandsden and M. R. C. McDowell: Charge Exchange and the Theory of Ion-Atom Collisions, Oxford Univ. Press (Int. Series of Monographs on Physics No. 82). Clarendon Press, 1992.
- Selected captures in C. Marton (Ed.): Methods of Experimental Physics, Academic Press, New York volumes

2. Complex systems

1. Density operator. The principle of unbiased statistical inference.

2. Density operator in thermodynamic equilibrium, partition function. The equivalence of equilibrium distributions in thermodynamical limit, thermodynamical potentials.

3. Statistical foundation of the I. and II. law of thermodynamics. Entropy compatible with the description level.

4. The Kubo theory of the linear response. Fluctuation-dissipation theorem.

5. Boltzmann equation, collision integral. Equilibrium, local equilibrium, law of detailed equilibrium.

6. Relevant and irrelevant parts of the density operator. Robertson-equation.

7. T ^{1} 0 Green-functions; perturbative and non-perturbative deduction. Matsubara frequencies.

8. The relation between thermodynamical potentials and the T ^{1} 0 Green-functions.

9. Kadanoff-construction. Renormalisation groups. Wilson-recurence relations, universality classes.

10. Fix points, relevant and irrelevant parameters, critical exponents. The relation between renormalisation groups and critical phenomena. Gauss and Wilson fix points.

11. Phase transition in localised spin systems.

12. Neuron networks. Learning rules, thermal noise, replica procedure.

13. Chaos. Attractors. Ljapunov exponents.

Literature:

- E. Fick, G. Sauermann: The Quantum Statistics of Dynamic Processes, Springer, Berlin, 1990.
- Shang-Keng Ma: Modern Theory of Critical Phenomena, W.A. Benjamin, London, 1976.
- A. A. Abrikosov, L.P. Gorkov, I. Ye. Dzyaloshinskii: Quantum Field Theoretical Methods in Statistical Physics, Pergamon Press, Oxford, 1965.

3. Environmental physics

1. Environment, risk, civilisation

2. Energy and civilization; Hazards and their sources; Risks in natural and anthropogenic processes; Perspectives, some remarks on environmental protection.

3. Atmosphere and climate

4. Constituents influencing the climate, air pollution; Climate models, climate theories – IPCC models.

5. Atmospheric aerosol: origin (emission sources, natural and anthropogenic components), transport, physical and chemical properties, its role; The detection and analysis of atmospheric aerosols; Long term observation of aerosol concentrations.

6. Greenhouse gases: Changes in the concentrations, their measuring techniques; The changing in the quantity of the atmospheric fossil CO_2, its measuring techniques (^{14}C method, CO method, etc.); The sources of CH_4 in the environment (natural, antropogenic); Detection of the changes of carbon-cycle with the help of global monitoring network. Ozone: stratospheric ozone layer, tropospheric ozone.

7. Radioactivity in the atmosphere and its environmental effects: Basic concepts of the dosimetry; Natural atmospheric radioactivity; Radon; Cosmogenic isotopes; Antropogenic atmospheric activity; Atmospheric tests of nuclear weapons; Emission from nuclear power stations under normal operational conditions; Reactor accidents; Radioactive emission of coal-fueled electric power stations.

8. Lithosphere and hydrosphere. Testing the conditions of geological environment

9. The radon as natural radioactive tracer. Underground motion of air and water. Microclimate of caves indicating the state of the environment, therapeutic uses. Underground waters; Water age determination (C-14, H-3, Freon, SF6, Kr-85 and Ar-39 method).The influence of the mean residence time on the decay of pollutants. Methods for measuring the mean residence time of water.

10. Isotope hydrological measurements for selecting proper sites for radioactive waste deposits. The classification of radioactive wastes. The principle of multiple protection. Radiometric geochronological methods in geological protection; Global survey of radioactive waste deposition plants.

11. Physical problems and perspectives of alternative energy sources
12. World energy problem, sources and their influences.
13. Renewable energy sources, flows of solar energy. Biomass: environmental impact and perspectives. Hydroenergy sources: environmental impact and perspectives. Wind energy: environmental impact and perspectives. Solar energy: perspectives. The comparison of efficiencies and environmental impacts of different renewable energy sources.
14. Nuclear fission systems with decreased environmental impact.

Literature:

- Boeker, E. and van Grondelle, R.: Environmental Physics, John Wiley & Sons, Chicester, 1995.
- Protecting the Earth's Atmosphere, An International Challenge, Interim Report of the Study Commission of the 11th German Bundestag "Preventive Measures to Protect the Earth's Atmosphere" Publ. by the German Bundestag, Publ. Sect., 1989.
- Reid, S.J.: Ozone and Climate Change, A beginner's Guide, Gordon & Breach Science Publishers, Australia, 2000.
- Clark, I.D. and Fritz, P.: Environmental Isotopes in Hydrogeology, Boca Raton, CRC press, 1997.
- Ramsey, Charles B., Modarres, Mohammad: Commercial Nuclear Power: Assuring Safety for the Future, BookSurge Publishing 2006.

4. Nuclear physics

1. **Fundamental properties of atomic nuclei**: size, mass, binding energy, parity, spin, electric and magnetic moments, isospin. (Basic experimental facts and their explanation)
2. **Nuclear forces, the nucleon-nucleon interaction**: general features of nuclear forces, two-nucleon systems, nucleon-nucleon scattering, phenomenological potentials, meson field theory. Theory of the strong interaction. Fundamental interactions.
3. **Interaction of radiation with matter, detection of nuclear radiation**: charged particles, interaction of gamma-rays and neutrons with matter, gas-filled ionization chambers, scintillation and Cherenkov detectors, semiconductor detectors, nuclear track detectors.
4. **Measurement of nuclear properties, spectrometers, foundations of dosimetry**: Measurement of nuclear masses, nuclear radii, nuclear moments, measuring of decay constants, alpha- and beta-spectrometers, gamma-spectrometry, Penning trap and the Mössbauer effect and their applications, basics of dosimetry.
5. **Accelerators**: ion sources, electrostatic accelerators, linear accelerators, cyclotrons, betatron, high-energy accelerators, storage rings, beam parameters. Preparation of radioactive beams.
6. **Single-particle states in nuclei**: magic numbers, independent particle model, nuclear shell model and its extensions: Nilsson model, large scale shell model, no core shell models, ab-initio methods. Effective interactions.
7. **Collective states in nuclei**: Binding energy, liquid drop model, rotational and vibrational states. Dipole collectivity and clusterization. Giant resonances. Symmetries in nuclei, link between basic nuclear models, microscopic interpretation of collectivity.
8. **Radioactivity, alpha-, and beta-decay of nuclei**: law of radioactive decay, theoretical grounds of alpha- and beta-decay, parity non-conservation in beta-decay. Gamma-decay and electron conversion.
9. **Nuclear reactions and their models**: classification of nuclear reactions, their main features (conservation laws, cross sections, excitation functions), direct reactions, compound nuclear reactions, heavy-ion reactions, relativistic heavy ion reactions. Nuclear reactions in inverse kinematics.
10. **Nuclear fission, basic principles of fission and fusion reactors**: main features of nuclear fission, thermal, fast, and breeder reactors, fusion reactor concepts.
11. **Applications of nuclear physics:** X-ray analysis, activation analysis, Rutherford back scattering spectrometry, scanning proton microprobe, geologic dating. Medical applications.
12. **Nuclear Astrophysics:** Star formation and evolution of the stars. Nuclear burning cycles. Nucleosynthesis in stars and in the early universe. Evolution of the Universe and puzzles associated with it: dark matter and dark energy.

Literature:

- J. Lilley: Nuclear Physics, Principles and Applications (John Wiley & Sons, NY, 2001).
- S.S.M. Wong: Introductory Nuclear Physics, (Wiley & Sons, NY, 1998).
- W.S.C. Williams: Nuclear and Particle Physics (Oxford Science Publications, Oxford, 1991).
- K. Heyde: Basic Ideas and Concepts in Nuclear Physics (IoP, London, 1999).
- S.G. Nilsson and B. Ragnarsson: Shapes and shells in nuclear structure, (Cambridge University Press, 1995).
- W.R. Leo: Techniques for Nuclear and Particle Physics Experiments (Springer, Berlin, 1994).
- Ch. Iliadis: Nuclear Physics of Stars (Wiley & Co., NY, 2007).

5. Solar physics

1. **The solar interior, helioseismology** (Standard solar model, nuclear reactions, the solar neutrino problem. Energy production, solar neutrino experiments. The three main layers of the solar interior, energy transport. Eigenmodes, k-omega diagram. Measurement of the sound speed and the differential rotation and their results.)

2. **Theory of convection and differential rotation** (Convective instability, mixing-length theory, statistical theories, overshooting. The observed characteristics of solar granulation. The origin of differential rotation and its observed features. Tachocline.)

3. **Magnetohydrodynamics, MHD waves** (The basic equations and their derivation from the Maxwell- and Vlasov-equations. Connection between the equations and the conservation theorems. Frozen-in fields, magnetic forces. Alfvén waves, magnetoacoustic and magneto-gravity waves. Tube waves. MHD discontinuities.)

4. **The solar dynamo** (Definition of the solar dynamo, anti-dynamo theorems. Mean-field theory, alpha-effect, alpha-omega dynamo. The global magnetic field of the Sun and its cyclic variation. Models of the solar dynamo. Dynamo in planets.)

5. **Force-free magnetic field** (Characteristics of potential fields, linear and non-linear force-free magnetic fields. The role of magnetic helicity. Magnetic free energy. The role of eruptive phenomena in the energy- and helicity-balance of the solar corona.)

6. **Solar activity phenomena in the photosphere and their origin** (Observed features, distributions, statistics and models of sunspots and solar faculae. 'Magnetic tree' structure, models of flux emergence and expansion.)

7. **Solar activity in the chromosphere and the corona** (Types and models of prominences. Magnetic reconnection, flares, Coronal Mass Ejections (CMEs). Their connection to other phenomena on the solar surface. Radio emission of the Sun. The problem of chromospheric and the coronal heating.)

8. **Observational methods of solar physics** (Types and properties of solar telescopes. Detailed description of the largest solar telescopes. Solar observation spacecrafts. Polarisation of light and its applications in solar physics.)

9. **The effects of solar activity on terrestrial life (**Terrestrial effects of solar eruptions. Magnetic storms: mechanism, predictability. Effects on the upper atmosphere and the climate of the Earth. Forbush-effect, reconstruction of the solar activity. Terrestrial effects of CMEs. Space Weather. Ground and Space-based observation of Space Weather)

6. Particle physics

1. **Symmetries and conserved quatities**, Noether's theorem. Continuous symmetries and fundamental interactions. Discrete symmetries: CPT-symmetry, parity violation, CP-violation.
2. **Abelian and non-abelian gauge theories**, spontaneous symmetry breaking and Abelian Higgs-mechanism.
3. **Standard model of particle interactions**: lepton and quark families and their quantum numbers, interactions.
4. **Brout-Englert-Higgs mechanism** in the standard model, masses of gauge bosons. Properties of the Higgs particle.
5. Flavour changing neutral current, **GIM mechanism**. Masses of fermions, their mixing, the Cabibbo-Kobayashi-Maskawa matrix.
6. Sources of **neutrinos** and means of their detection. Masses and mixing of neutrinos and discovery of neutrino oscillations. Neutrinos in the standard model.
7. P**arton model**; quark constituents of hadrons, the quark-quark interaction.
8. **Quantum Chromo-Dynamics**, and its experimental foundations. Asymptotic freedom. Predictions of cross sections and their uncertainties.
9. **Particle accelerators**: Linear accelerator, cyclotron, synchrocyclotron, synchrotron; Guiding, shaping and cooling of particle beams; storage rings and colliders.
10. **Particle deceleration in matter**: Mechanisms of energy-loss of photons and electrons. Deceleration processes of heavy charged particles. The non-relativistic and relativistic Bethe-Bloch formulae; mean ionazation potential and effective charge.
11. **Particle detection**: Ionization, proportional, streamer, drift and bubble chambers; plastic, cristal, glass, liquid and gas scintillation detectors, scintillation wires; semiconductor and microstrip detectors; particle identification with Cherenkov-detectors; sandwich and shower detectors, hodoscopes, hadron and müon calorimeters.
12. **Data acquisition, storage, analysis:** Event collection, trigger-logic, methods of on-line and off-line analyses. Data bases, event selection, kinematical conditions (discrimination). Monte-Carlo simulations, determination of efficiency and spectrum shape. Curve fitting, □^{2}, statistical and systematic errors, covariance and correlation.
13. **Description of a historical particle physics experiment** (E.g.: CP-violation, discovery of W^{+-}, measurement of the decay width of the Z-boson at LEP and its utilization for the determination of number of lepton families.)

Literature:

- D. Horváth, Z. Trócsányi: Introduction to Particle Physics, e-learning textbook http://falcon.phys.unideb.hu/kisfiz/okts.html

- F. Halzen, A. D. Martin: Quarks and Leptons, Wiley, New York, 1984.

- D. H. Perkins: Introduction to High Energy Physics, Addison-Wesley, Reading, MA, 1982
- M.E. Peskin, D.V. Schroeder: An Introduction to Quantum Field Theory, Perseus Books, 1995.
- D. Griffiths, Introduction to Elementary Particles, Viley-VCH, 2009.

7. Solid state physics and material science

1. **Bonding types** (Madelung constant). Crystallographical concepts, reciprocal lattice.
2. **Similarity of the potential shape** and its consequences (law of corresponding states).
3. **Bloch theorem**, cyclic boundary conditions.
4. **Diffraction**, Debye-Waller factor.
5. **Lattice vibrations**: phonons, inelastic neutron scattering.
6. **Electron states**: quasi free electron model, Kronig-Penney model, Bloch functions. Wannier functions, Drude model, Sommerfeld model, Semiclassical-model.
7. **Electrical conductivity**; Temperature dependence for conductors and isolators, effects of impurities.
8. **Superconductivity. Thermoelectricity. Optical properties of solids**.
9. **Magnetic properties** (dia-, para- and ferromagnetism).
10. **Dislocations** and plasticity.
11. **Point deffects**: vacancies, interstitial atoms. Atomic transport phenomena: diffusion, (cross effects).
12. **Surface energy**, structure. Structure of grain and phase boundaries (DSL, DSC lattices, relaxations) and their properties.
13. **Regular solid solutions**: ordering, precipitations, solubility.
14. **Surface and grain boundary segregation**.

Literature:

- C. Kittel: Introduction to Solid State Physics, Eighth Edition, John and Whiley, 2005
- J. M. Ziman: Principles of the Theory of Solids, Cambridge, University Press. Third Edition, 1972
- R. W. Cahn, P. Haasen: Physical Metallurgy, North-Holland, Amsterdam, 1983
- P. Haasen: Physical Metallurgy, Third Edition, Cambridge, University Press, 2003
- N.W. Ashcroft and N.D. Mermin: Solid State Physics, Brooks/Cole, 1976

Secondary subjects:

(topics should be defined at time of the application for the examination)

1. Fundamental interactions
2. Applied nuclear physics
3. Analytical methods in environmental research
4. Many body problem in atomic physics
5. Description and identification of the atomic collision processes
6. Atomic and nuclear microanalysis
7. Experimental methods in particle physics
8. Dosimetry and therapy
9. Emission and absorption of electromagnetic radiation, optical spectroscopy
10. Statistical physics of the phase transitions and critical phenomena
11. Physics of the surfaces and thin films
12. Accelerator physics
13. Waves
14. Isotope analysis
15. Instruments of the experimental nuclear physics
16. Effects of the environmental radiation, dosimetry
17. Quantum chemistry
18. Nuclear astrophysics
19. Nuclear models
20. Nuclear reactions
21. Nuclear spectroscopy and nuclear structure
22. Non equilibrium statistical physics
23. Neutron physics
24. Physics of alloys
25. Plasma physics
26. Detection of the radioactive radiation, signal processing
27. Radiometric methods for the determination of the age
28. Lattice defects
29. Lattice dynamics
30. Roentgen- and Auger-electron-spectroscopy

31. Electric and magnetic properties of the solid states
32. Many body problem in solid state physics
33. Experimental methods of the solid state research
34. Symmetries in quantum theory
35. Solar Magnetohydrodynamics

Registered courses 2025

(*A tantárgyak alábbi listája és részletes leírása megtalálható a doktori iskola honlapján is:* http://physphd.unideb.hu)

I. **Atom- and Molecular physics** program

Teacher/tutor	*Course*	*Code*	*Type L,D,S,Lab*	*Hours/ week*	*Credits*	*Remarks*
Dr. Cseh József	Symmetries in Two-Body and Many-Body Systems	PF1/319-97	L	2	2	
Dr. Csehi András	Atoms and molecules in electromagnetic fields	PF1/328-20	L	2	2	
Dr. Csehi András	Introduction to molecular quantum dynamics	PF1/329-20	L	2	2	
Dr. Erdélyi Róbert	Introduction to Plasmaphysics	PF1/326-18	L	2	2	
Dr. Gulácsi Zsolt	Many-Body Calculation Techniques and Applications I.-II.	PF1/37-93	L	2	2x2	2 semesters
Dr. Mezei János Zsolt	Low energy collisions in molecular astrophysics	PF1/330-20	L	2	2	
Dr. Nagy Ágnes	Quantum Mechanics of Classical Chaotic Systems (Quantum Chaos)	PF1/321-00	L	2	2	
Dr. Nagy Ágnes	Non-linear Phenomena, Chaos	PF1/315-93	L	2	2	
Dr. Nagy Ágnes	Density Functional Theory I.-II.	PF1/39-93	L	2	2x2	2 semesters
Dr. Pálinkás József, Dr. Sarkadi László	Experimental Atomic Collision Physics	PF1/35-93	L	2	2	
Dr. Sarkadi László	Theory of Atomic Collisions	PF1/34-93	L	2	2	

Dr. Tőkési Károly	Computational Simulation of Phenomena in Physics	PF1/322-08	L	2	2	
Dr. Tőkési Károly	Basic examples in Programming	PF1/323-08	L	2	2	
Dr. Tőkési Károly (Dr. Joachim Burgdörfer)	Introduction to the theory of attophysics	PF1/325-14	L	2	2	
Dr. Tőkési Károly	Modelling of collision processes by Monte Carlo technique	PF1/327-20	L	2	2	
Dr. Vibók Ágnes	Atomic and Molecular Physics	PF1/32-93	L	2	2	
Dr. Vibók Ágnes	Atomic Physics I.-II.	PF1/31-93	L	2	2x2	2 semesters

II. **Nuclear Physics** program

Teacher/tutor	*Course*	*Code*	*Type L,D,S,Lab*	*Hours/ week*	*Credits*	*Remarks*
Dr. Angeli István, Dr. Nyakó Barna	Charge and Mass Distributions of Atomic Nuclei I.-II.	PF2/31-93	L	2	2x2	2 semesters
Dr. Angeli István, Dr. Rajta István	High Energy Accelerators I.-II.	PF2/340-13	L	2	2x2	2 semesters
Dr. Cseh József	Symmetries in Two-Body and Many-Body Systems	PF2/32-93	L	2	2	
Dr. Cseh József	Seminars on Nuclear Physics	PF2/330-97	L	2	2	
Dr. Elekes Zoltán	Exotic nuclear physics	PF2/342-14	L	2	2	
Dr. Erdélyi Róbert	Introduction to Plasmaphysics	PF2/344-18	L	2	2	
Dr. Furka Andrea Ilona	Evaulation of novel techniques in radiotherapy	PF2/348-22	L	2	2	
Dr. Fülöp Zsolt, (Dr. Thomas Rauscher)	Introduction to Nuclear Astrophysics	PF2/338-12	L	2	2	
Dr. Fülöp Zsolt, (Dr. Kai Zuber)	Neutrino Physics	PF2/345-18	L	2	2	
Dr. Fülöp Zsolt, (Dr. Jordi Jose)	Nucleosynthesis in Stellar Explosions	PF2/346-20	L	2	2	
Dr. Fülöp Zsolt (Dr. Nigel J. Mason)	Astrophysics, Astrochemistry and the Origins of Life	PF2/347-21	L	2	2	
Dr. Fülöp Zsolt,	Laboratory Astrophysics: Taking Laboratory to Space	PF2/351-24	L	2	2	
Dr. Horváth Dezső	The Standard Model and its experimental tests I-II.	PF2/339-12	L	2	2x2	2 semesters
Dr. Kiss Gábor Gyula	The origin of the chemical elements	PF2/350-23	L	2	2	
Dr. Krasznahorkay Attila	Measurements with Magnetic Spectrograph	PF2/323-94	Lab	2	2	
Dr. Krasznahorkay Attila	Experiments with magnetic mass separator	PF2/335-06	Lab	2	2	
Dr. Krasznahorkay Attila	Collective excitations in atomic nuclei	PF2/336-10	L	2	2	
Dr. Krasznahorkay Attila,	Modern nuclear instruments and methods	PF2/341-14	L	2	2	

Dr. Csige Lóránt						
Dr. Mezei János Zsolt	Calculations of molecular photoabsorbtion and electron collisions cross sections for astrophysics and other purposes	PF2/349-22	L	2	2	
Dr. Molnár Mihály (Dr. Ulrich Ott)	Meteorites, the Early Solar System and Nuclear Astrophysics	PF2/343-14	L	2	2	
Dr. Raics Péter	Methods for the Analysis of Nuclear Reactions	PF2/312-93	L	2	2	
Dr. Sailer Kornél	Introduction to Quantum Field Theory	PF2/315-93	L	2	2	
Dr. Sailer Kornél	String Theory I.-II.	PF2/322-94	L	2	2	2 semesters
Dr. Sailer Kornél	Symmetries and Symmetry Breaking in Quantum Field Theory I.-II.	PF2/317-93	L	2	2x2	2 semesters
Dr. Sailer Kornél	Renormalization Group Methods in Physics	PF2/328-96	L	2	2	
Dr. Sailer Kornél	TRIANGLE-Course	PF2/314-93	L	2	2	
Dr. Sailer Kornél	Finite Temperature Quantum Field Theory	PF2/327-95	L	2	2	
Dr. Sailer Kornél	Non-Equilibrium Statistical Physics	PF2/313-93	L	2	2	
Dr. Sailer Kornél, Dr. Schram Zsolt	Models and Methods in Theoretical Physics	PF2/334-02	L	2	2	
Dr. Somorjai Endre Dr. Kiss Gábor	Nuclear Astrophysics	PF2/36-93	L	2	2	
Dr. Timár János	The rotating nucleus: an experimental view	PF2/337-11	L	2	2	
Dr. Trócsányi Zoltán	Standard model	PF2/321-94	L	2	2	
Dr. Vertse Tamás	Numerical Methods in Practice	PF2/329-97	Lab	2	2	
Dr. Vertse Tamás	Nuclear Models I.-II.	PF2/35-93	L	2	2x2	2 semesters

III. **Solid State Physics and Material Science** program

Teacher/tutor	*Course*	*Code*	*Type L,D,S,Lab*	*Hours/ week*	*Credits*	*Remarks*
Dr. Beke Dezső	Solid State Physics I.-II.	PF3/31-93	L	2	2x2	2 semesters
Dr. Csarnovics István	Solid State- and Optoelectronics	PF3/332-97	L	2	2	
Dr. Cserháti Csaba	Electron Microscopy	PF3/316-93	L	2	2	
Dr. Csík Attila	X-ray related technics for solid state studies	PF3/346-14	L+Lab	2+1	2	
Dr. Daróczi Lajos	Martensitic transformations	PF3/342-13	L	2	2	
Dr. Erdélyi Zoltán	Diffusion and segregation in nanostructures	PF3/339-02	L	2	2	
Dr. Gulácsi Zsolt	Theoretical Solid State Physics	PF3/32-93	L	2	2	
Dr. Gulácsi Zsolt, Dr. Beke Dezső	Phase Transitions	PF3/35-93	L	2	2x2	2 semesters
Dr. Gulácsi Zsolt	Theory of Magnetism	PF3/320-93	L	2	2	
Dr. Gulácsi Zsolt	Many-Body Calculation Techniques and Applications I.-II.	PF3/323-94	L	2	2x2	2 semesters
Dr. Gulácsi Zsolt	Quantum Phase Transitions	PF3/334-97	L	2	2	
Dr. Gulácsi Zsolt (de Chatel Péter)	Description of Superconductivity	PF3/338-00	L	2	2	
Dr. Gulácsi Zsolt	Many-body systems in periodic potential	PF3/340-08	L	2	2	
Dr. Gulácsi Zsolt,	Theory of Strongly Correlated Systems	PF3/343-14	L	2	2	
Dr. Gulácsi Zsolt	Quantum information and quantum computation	PF3/344-14	L	2	2	
Dr. Kun Ferenc	Computer simulation I.-II.	PF3/327-95	L	2	2x2	2 semesters
Dr. Langer Gábor	Thin Film Deposition Techniques	PF3/317-93	L	2	2	
Dr. Langer Gábor	Thin Films	PF3/324-94	L	2	2	
Dr. Szabó István	Atomic Resolution Microscopy	PF3/329-96	L	2	2	
Dr. Tóth László Zoltán	Micro- and Nanomagnetism I.-II.	PF3/331-97	L	2	2x2	2 semesters

IV. **Physical Methods in Interdisciplinary Researches** program

Teacher/tutor	*Course*	*Code*	*Type L,D,S,Lab*	*Hours/ week*	*Credits*	*Remarks*
Dr. Battistig Gábor	Microtechnology	PF4/333-25	L	2	2	
Dr. Csepura György	Radiation Protection	PF4/36-04	L	2	2	
Dr. Csige István	Subsurface Flow	PF4/315-12	L	2	2	
Dr. Erdélyi Róbert	Waves	PF4/320-15	L	2	2	
Dr. Erdélyi Róbert	Solar Magnetohydrodynamics	PF4/321-15	L	2	2	
Dr. Erdélyi Róbert	Advanced Solar Magnetohydrodynamics	PF4/322-16	L	2	2	
Dr. Erdélyi Róbert	Sunpy	PF4/323-16	L	2	2	
Dr. Erdélyi Róbert	Introduction to Plasmaphysics	PF4/324-18	L	2	2	
Dr. Kiss Árpád et al.	Atomic and Nuclear Microanalysis	PF4/31a-93	L	2	2	
Dr. Kiss Árpád et al.	Atomic and Nuclear Microanalysis lab	PF4/31b-93	Lab	4	4	together with L
Dr. Kertész Zsófia, Dr. Molnár Mihály	Atmosphere and climate	PF4/39-09	L	2	2	
Dr. Kertész Zsófia	Atmospheric Aerosol Sampling Procedures and Analysis Techniques Using Ion Beam	PF4/311-12	L	2	2	
Dr. Kun Ferenc	Computer simulation I.-II.	PF4/310-10	L	2	2x2	2 semesters
Dr. Kun Ferenc	Physics of Complex Systems	PF4/313-12	L	2	2	
Dr. Kun Ferenc, (Dr. Farkas Illés)	Perl Programming and Networks in Computational Biology	PF4/317-14	L	2	2	
Dr. Kun Ferenc, (Dr. Frank Raichel)	Criticality and Complex Systems	PF4/318-14	L	2	2	
Dr. Kun Ferenc	Complex networks	PF4/325-18	L	2	2	
Dr. Kun Ferenc, (Dr. Ódor Géza)	Universality classes in non-equilibrium systems	PF4/326-18	L	2	2	
Dr. László Elemér	Fundamentals of atmospheric modelling	PF4/331-24	L	2	2	
Dr. Mason, Nigel John	Planetary Sciences	PF4/330-22	L	2	2	
Dr. Mészáros Sándor	Superconductivity	PF4/328-19	L	2	2	
Dr. Molnár Mihály,	Radioactive dating	PF4/38-09	L	2	2	

Dr. Palcsu László					
Dr. Molnár Mihály, (Dr. Timothy Jull)	Geochronology and Paleoclimate	PF4/316-13	L	2	2
Dr. Molnár Mihály (Dr. Ulrich Ott)	Meteorites, the Early Solar System and Nuclear Astrophysics	PF4/319-14	L	2	2
Dr. Nagy Ágnes	Non-linear Phenomena, Chaos	PF4/312-12	L	2	2
Dr. Palcsu László, Dr. Csige István, Dr. Molnár Mihály	Nuclear Environmental Protection	PF4/37-09	L	2	2
Dr. Szabó István	Atomic Resolution Microscopy	PF4/327-18	L	2	2
Dr. Tóth L. Viktor	Space Astronomy	PF4/332-24	L	2	2
Dr. Tőkési Károly	Modelling of collision processes by Monte Carlo technique	PF4/329-20	L	2	2

V. **Particle Physics** program

Teacher/tutor	*Course*	*Code*	*Type L,D,S,Lab*	*Hours/ week*	*Credits*	*Remarks*
Dr. Angeli István, Dr. Rajta István	High Energy Accelerators I.-II.	PF5/31-95	L	2	2x2	2 semesters
Dr. Cseh József	Symmetries in Two-Body and Many-Body Systems	PF5/321-97	L	2	2	
Dr. Dávid Gábor , Dr. Nagy Sándor	Modeling, Simulation, Analysis in Experimental Particle Physics I.-III.	PF5/33-95	L	2	3x2	3 semesters
Dr. Dávid Gábor	Data Acquisition, Triggering and Online Monitoring	PF5/331-10	L	2	2	
Dr. Fülöp Zsolt, (Dr. Kai Zuber)	Neutrino Physics	PF5/340-18	L	2	2	
Dr. Horváth Dezső	The Standard Model and its experimental tests I-II.	PF5/326-00	L+Lab	2+2	2x(2+1)	2 semesters
Dr. Horváth Dezső	Experimental techniques of particle physics I-II.	PF5/327-01	L	2	2	
Dr. Kardos Ádám	Introduction to Effective Field Theories	PF5/339-18	L	2	2	
Dr. Kardos Ádám	Introduction to FORM programming	PF5/343-22	L	2	2	
Dr. Kovács Tamás György	Statistical field theory	PF5/334-14	L	2	2	
Dr. Kovács Tamás György	Solitons and Instantons	PF5/341-19	L	2	2	
Dr. Kovács Tamás György	Lattice Field Theory 2	PF5/342-19	L	2	2	
Dr. Nagy Sándor	Quantum renormalization group	PF5/338-17	L	2	2	
Dr. Nagy Sándor	Quantum theories of open systems	PF5/344-22	L	2	2	
Dr. Nagy Sándor	Closed time path formalism in physics	PF5/345-22	L	2	2	
Dr. Nándori István	Basics of functional renormalization group method	PF5/337-16	L	2	2	
Dr. Raics Péter	Particle Detectors	PF5/311-95	L	2	2	
Dr. Sailer Kornél	Introduction to Quantum Field Theory	PF5/312-95	L	2	2	
Dr. Sailer Kornél	Symmetries and Symmetry Breaking in Quantum Field Theory I.-II.	PF5/314-95	L	2	2	

Dr. Sailer Kornél	General Relativity	PF5/323-98	L	2	2	
Dr. Sailer Kornél, Dr. Nagy Sándor	Functional renormalization group method	PF5/333-13	L	2	2	
Dr. Sailer Kornél	T 0 Quantum-field theory	PF5/334-13	L	2	2	
Dr. Sailer Kornél	Cosmology	PF5/335-14	L	2	2	
Dr. Schram Zsolt	Lattice Field Theory	PF5/322-97	L	2	2	
Dr. Schram Zsolt	Variational principles of theoretical physics	PF5/332-11	L	2	2	
Dr. Somogyi Gábor	Methods of computing Feynman integrals	PF5/336-15	L	2	2	
Dr. Trócsányi Zoltán	Standard model	PF5/317-95	L	2	2	
Dr. Trócsányi Zoltán	Grand Unified Theories	PF5/318-95	L	2	2	
Dr. Trócsányi Zoltán	Perturbative Quantum Chromodinamics I.-II.	PF5/320-97	L	2	2x2	2 semesters
Dr. Zilizi Gyula	Electronics in the Experimental Particle Physics	PF5/316-95	L	2	2	

Abreviations:

L = Lectures
D = Discussion
S = Seminarium
Lab. = Laboratory exercise