COURSE SYLLABUS – DOCTORAL SCHOOL
EDUCATION CYCLE FROM 2024/2025 TO 2027/2028

GENERAL INFORMATION ABOUT THE COURSE	
Course title	***DOCTORAL LABORATORY***
Name of the unit delivering the course	Doctoral School at the University of Rzeszów
Course type (mandatory, elective)	*mandatory course*
Year/semester	**Year I–IV, semester: I–VIII**
Discipline	**physical sciences**
Language of instruction	English
Full name of the course coordinator	**dr hab. Marta Łuszczak, Prof. UR**
Full name of the course instructor(s)	**dr hab. Marta Łuszczak, Prof. UR**
Prerequisites	Scope of knowledge, skills and competences resulting from the Master's degree programme in Physics, in particular: classical and relativistic mechanics, quantum mechanics, elements of field theory and fundamentals of particle physics. Basic computational skills (numerical analysis, programming) and knowledge of English at B2 level enabling the use of foreign-language scientific information sources, preparation of publications and presentation of scientific achievements at specialist conferences.

COURSE SUMMARY
(synthetic description of the content and objectives of the course; 100–200 words)

The Doctoral Laboratory supports successive stages of the doctoral student's research work in the discipline of physical sciences, leading to the preparation of the doctoral dissertation. The classes include analysis and development of theoretical and numerical tools to describe exclusive photon-induced processes in lepton–proton, lepton–nucleus and hadron–hadron collisions. To describe these processes, generalized parton distributions (GPD - Generalized Parton Distributions) are used, including exclusive diffractive jet production and exclusive production of mesons and hadron pairs, as well as photon–photon and photon–Odderon processes. The doctoral student learns research planning, implementation of calculations (including in Monte Carlo generators), critical analysis of the literature, interpretation of results, uncertainty estimation, and preparation of publications and conference presentations. The outcomes are semester reports, presentations, and preparation of articles and dissertation chapters.

LEARNING OUTCOMES FOR THE COURSE AND METHODS OF VERIFICATION

Learning outcome symbol	Intended learning outcomes	Reference to learning outcomes for qualifications at level 8 of the PRK (Polish Qualifications Framework) (symbol)	Form of classes (lect., exc., etc.)	Methods of verification (e.g., test, oral exam, written exam, project, etc.)
Knowledge: **No.**	knows and understands, possesses knowledge			
P8S_WG1	knows and understands advanced issues of high-energy physics and hadron structure, including photon-induced processes (γγ – photon–photon fusion, γp – photon–proton, γ*p – virtual photon–proton) and the GPD formalism (generalized parton distributions, Generalized Parton	P8S_WG	seminar	Report (publication)

	Distributions) and GTMD (generalized transverse-momentum dependent distributions, Generalized Transverse-Momentum Dependent Distributions).			
P8S_WG2	knows the main development trends and current research problems in the description of strong interactions in QCD (quantum chromodynamics, Quantum Chromodynamics) and in studies of proton/hadron structure, in particular in the context of exclusive and diffractive processes in DIS (deep inelastic scattering, Deep Inelastic Scattering), including diffractive jet production.	P8S_WG	seminar	Report (publication)
P8S_WG3	knows and can use the terminology and formal tools used in the analysis of exclusive, diffractive processes (kinematics, amplitudes, cross sections, observables, parameterizations/modelling), and communicates research issues in English at a level appropriate for the discipline.	P8S_WG	seminar	Report (publication)
P8S_WG4	knows the principles of research methodology in theoretical physics and phenomenology: planning and documenting calculations, code verification, uncertainty analysis, and research integrity and ethics (including publication ethics and good practices for data and code management).	P8S_WG	seminar	Report (publication)
Skills: No.	***is able to***			
P8S_UW1	is able to formulate and solve complex research problems, select analytical and numerical methods, implement calculations and draw conclusions based on the obtained results in the context of GPD and GTMD models (generalized parton distributions) and exclusive and diffractive processes.	P8S_UW	seminar	Report (publication)
P8S_UW2	is able to carry out a critical literature review, plan a set of calculations and analyses, prepare reports and scientific publications, as well as present results (seminars, conferences) and develop documented software and repositories of computations.	P8S_UW	seminar	Report (publication)
P8S_UW3	is able to independently acquire and update knowledge, develop research competences, cooperate in a team (including an international	P8S_UW	seminar	Report (publication)

	one) and perform various roles in the research process (author, co-author, internal reviewer, presenter).			
Social competences: No.	***is ready to***			
P8S_KK1	is ready for critical evaluation of one's own and others' results in the chosen scientific discipline, to comply with the principles of research integrity and ethics, and to communicate results responsibly and cooperate in a research team.	P8S_KK	seminar	Report (publication)

FORMS OF TEACHING ACTIVITIES, NUMBER OF HOURS AND CREDITS

Semester (no.)	Lect.	Exc./Sem.	Lab.	Pract.	Other	**No. of ECTS credits**
I - VIII	**-**	**8 x 30 hrs – 240 hrs**	**-**	**-**	**-**	**24**

TEACHING METHODS

- problem-oriented seminars (discussion, analysis of papers);
- computational projects and work with code (Monte Carlo simulations, numerical calculations);
- semester presentations and critical analysis of results;
- interpretation of source texts (specialist literature in English);
- conducting research (modelling, validation, uncertainty analysis);
- individual consultations.

COURSE CONTENT

laboratory/seminar

semester I

Topic: Collection and critical analysis of literature on photon-induced processes (photon–photon ($\gamma\gamma$), photon–proton (γp), virtual photon–proton ($\gamma^* p$)) and exclusive and diffractive processes.

Topic: Mastering the GPD formalism (generalized parton distributions, Generalized Parton Distributions), GTMD (generalized transverse-momentum dependent distributions, Generalized Transverse-Momentum Dependent distributions) and the kinematics of exclusive diffractive jet production in DIS (deep inelastic scattering, Deep Inelastic Scattering); preparation of a calculation plan.

Topic: Preparation of the computational setup (environment, tests, initial reproduction of results from the working version of the paper).

semester II

Topic: Derivation of amplitudes and numerical implementation of integrals for the process γ^* p $\to$ (q\bar q) p.

Topic: Study of GPD models (DD (double distributions), GK (Goloskokov–Kroll model), Vinnikov) and the dependence on ξ and t; verification and comparison of models.

Topic: Preliminary calculations of observables and cross sections (gluon/quark contributions) and preparation of the semester report.

semester III

Topic: Calculations for different photon polarizations (L – longitudinal, T – transverse, TT – transverse–transverse, LT – longitudinal–transverse) and analysis of the impact of kinematic parameters (x_{Bj}, Q^2, z, $q_\perp$, $\Delta_\perp$).

Topic: Analysis of the sensitivity of results to the choice of the GPD model (generalized parton distributions, Generalized Parton Distributions) and uncertainty estimation; preparation of a set of plots.

Topic: Preparation of a publication draft (introduction, formalism, results) based on the developed manuscript.

semester IV Topic: Improvement of the theoretical description: Glauber absorption corrections. Topic: Physical interpretation of results in the context of EIC (Electron–Ion Collider), JLab (Jefferson Laboratory), LHC (Large Hadron Collider); identification of observables sensitive to GPD. Topic: Finalization of the article on exclusive diffractive jet production and preparation for publication in a journal. **semester V** Topic: Extension of research on γγ and γ–Odderon processes in electron–proton (ep), electron–nucleus (eA) reactions; exclusive production of ηc, χc or pion pairs. Topic: Implementation of selected processes in a Monte Carlo generator. Topic: First results and a presentation at a seminar/research group. **semester VI** Topic: Exclusive production of light mesons at JLab (Jefferson Laboratory) and EIC (Electron–Ion Collider) energies in the GPD formalism (generalized parton distributions, Generalized Parton Distributions); calculations of amplitudes and cross sections. Topic: Extension of the generator with absorption corrections for real-photon fusion; plan to include $q\bar{q}$ corrections in the next stage. Topic: Preparation of a publication/chapter and conference materials. **semester VII** Topic: Integration of results from several processes (dijets, γγ, γ–Odderon, mesons): comparison of sensitivity to GPD and a coherent analysis. Topic: Writing the doctoral dissertation – chapters: theory, computational methods, results; completion of the literature review. Topic: Consolidation and documentation of the code and the computation repository. **semester VIII** Topic: Finalization of the doctoral dissertation, editing, formatting and preparation for the defence. Topic: Final publications/revisions after reviews; preparation of the defence presentation. Topic: Summary of achievements and archiving of results (data, codes, documentation).
CONDITIONS FOR PASSING THE COURSE (GRADING CRITERIA)
Assessment covers the doctoral student's continuous work in each semester and academic year in the scope of: conducting research, expanding knowledge, studying the literature, engagement, and progress in preparing the doctoral dissertation (semester report, presentation, contribution to manuscripts/publications, development of computational tools). Possible semester grades are: 2.0, 3.0, 3.5, 4.0, 4.5, 5.0. Percentage requirements for the grading scale: - up to 50% – unsatisfactory; - 51%–60% – satisfactory; - 61%–70% – satisfactory plus; - 71%–80% – good; - 81%–90% – good plus; - 91%–100% – very good.

TOTAL DOCTORAL STUDENT WORKLOAD REQUIRED TO ACHIEVE THE INTENDED LEARNING OUTCOMES IN HOURS AND ECTS CREDITS	
Form of activity	Average number of hours to complete the activity

Hours completed in direct contact resulting from the study programme	8 x 30 hrs – 240 hrs
Other with the teacher's participation (participation in consultations, exam)	10
Godziny realizowane samodzielnie przez doktoranta (preparation for classes, exam, writing a presentation/paper, etc.)	470
TOTAL HOURS	720
TOTAL NUMBER OF ECTS CREDITS*	**24**

LITERATURE	
Core reading:	1) M. Diehl, Generalized parton distributions, Phys. Rept. 388 (2003) 41. 2) A.V. Belitsky, A.V. Radyushkin, Unraveling hadron structure with generalized parton distributions, Phys. Rept. 418 (2005) 1. 3) J.C. Collins, Foundations of Perturbative QCD, Cambridge University Press (2011). 4) S.V. Goloskokov, P. Kroll – review papers on GPD modelling in meson electroproduction (series of publications). 5) Key group papers on photon-induced processes (γγ, γp) and exclusive diffractive jet production (working manuscript). 6) M.E. Peskin, D.V. Schroeder, An Introduction to Quantum Field Theory, Addison-Wesley (1995). 7) F. Halzen, A.D. Martin, Quarks and Leptons: An Introductory Course in Modern Particle Physics, Wiley (1984). 8) R.K. Ellis, W.J. Stirling, B.R. Webber, QCD and Collider Physics, Cambridge University Press (1996). 9) R. Devenish, A. Cooper-Sarkar, Deep Inelastic Scattering, Oxford University Press (2004). 10) A. Donnachie, H.G. Dosch, P.V. Landshoff, O. Nachtmann, Pomeron Physics and QCD, Cambridge University Press (2002).
Supplementary reading:	1) M. Guidal, M.V. Polyakov, A.V. Radyushkin, M. Vanderhaeghen – selected papers on GPD and DVCS. 2) Budnev et al., The two-photon particle production mechanism, Phys. Rept. 15 (1975) 181 (two-photon mechanism/EPA). 3) Selected papers on the Odderon and γ–Odderon processes. 4) Documentation and descriptions of Monte Carlo generators for photon-induced processes (e.g., STARlight/SuperChic – user materials). 5) Current review articles on EIC/JLab and hadron tomography. 6) R.K. Bock, W. Krischer, J. Gaiser, R. Frühwirth, M. Regler, H. Grote, D. Notz, Data Analysis Techniques for High-Energy Physics, Cambridge University Press (2000). 7) G. Dissertori, I. Knowles, M. Schmelling, Quantum Chromodynamics: High Energy Experiments and Theory, Oxford University Press (2003).

**(1 ECTS CREDIT CORRESPONDS TO 25–30 HOURS OF THE DOCTORAL STUDENT'S TOTAL WORKLOAD REQUIRED TO ACHIEVE THE INTENDED LEARNING OUTCOMES)*

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Date and signature of the course instructor

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Approval by the Head of the Unit or an authorized person