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A COURSE SYLLABUS – DOCTORAL SCHOOL

REGARDING THE QUALIFICATION CYCLE FROM 2024/2025 TO 2027/2028

GENERAL INFORMATION ABOUT COURSE	
Course title	WORKSHOPS WITH AN EXPERT Scientific focus: Diffractive charm production: from quantum fields to dipole scattering and saturation
Name of the unit running the course	Doctoral School at University of Rzeszów
Type of course (<i>obligatory, optional</i>)	obligatory.
Year and semester of studies	Year III / semester V
Discipline	PHYSICS
Language of Course	English
Name of Course coordinator	Prof Roman Pasechnik
Name of Course lecturer	Prof Roman Pasechnik
Prerequisites	Undergraduate quantum mechanics and special relativity; Fourier transforms, elementary matrix algebra and perturbation theory. Familiarity with parton distributions is helpful. No previous course in quantum field theory is assumed; the field, state and scattering conventions needed for the calculation are introduced explicitly.
BRIEF DESCRIPTION OF COURSE (100-200 words)	
When does the first, two-gluon term cease to describe coherent diffractive charm production accurately? The workshop answers this question by constructing a longitudinal open-charm electroproduction spectrum in a specified finite-target dipole model. Starting from pair kinematics and elementary quantum-field definitions, the student follows the photon splitting amplitude, eikonal Wilson lines, the colour-singlet dipole and its dilute gluon-density matching. The full multiple-scattering result is compared with its dilute expansion using finite momentum bins. A soft-gluon emission step motivates small-x evolution and the Balitsky–Kovchegov equation. Charmonium projections and charge-conjugation properties connect the calculation to J/ψ, h_c and Pomeron/Odderon physics. The workshop distinguishes model-dependent saturation estimates from statements about factorisation theorems. Its outcome is a reproducible benchmark, controlled approximations and preparation for a possible subsequent research project, rather than a claim to complete original phenomenology during the meetings.	

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COURSE LEARNING OUTCOMES AND METHODS OF EVALUATING LEARNING OUTCOMES				
Learning outcome	The description of the learning outcome defined for the course	Relation to the degree programme outcomes (symbol)	Learning Format (Lectures, classes,...)	Method of assessment of learning outcomes (e.g. test, oral exam, written exam, project,...)
Knowledge (no.)	(Knows and understands)			
P8S_WG2	Possesses knowledge of research directions and current achievements, including international work, in high-energy QCD, diffractive charm production, dipole scattering and small-x evolution, and understands their connection to the doctoral student's research interests.	P8S_WG	Individual workshop and discussion	Written report and scientific discussion
P8S_WK1	Knows and understands how technological development influences scientific and societal progress in proton-structure and diffractive-scattering research. Can discuss the resulting consequences for the wider world, including the capabilities and limitations of the methods considered.	P8S_WK	Individual workshop and discussion	Discussion of technological context and wider implications
Skills (no.)	(Able to)			
P8S_UW1	Based on interdisciplinary knowledge, the doctoral student is able to identify and solve research problems related to the topic of scientific research conducted in the discipline of physical sciences, define research goals, formulate hypotheses and the subject of scientific research, develop research methods, techniques and tools, and draw constructive conclusions based on research results.	P8S_UW	Individual workshop and discussion	Report derivations and interpretation

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P8S_UK6	Using a foreign language at least at the B2 level of the Common European Framework of Reference for Languages, a doctoral student is able to present research results, take part in discussions and actively participate in scientific and professional debates both at the national and international level.	P8S_UK	Individual workshop and discussion	Scientific discussion and report in English
P8S_UU1	A doctoral student is able to independently acquire and update knowledge, develop analytical skills based on current interdisciplinary scientific achievements, and inspire others to conduct research and development activities.	P8S_UU	Individual workshop and discussion	Report sources and independent reconstruction
P8S_UU2	A doctoral student is able to share his or her knowledge, thanks to his or her extensive interdisciplinary knowledge, he or she is able to plan and implement interesting classes, and is also able to inspire others by supporting the learning process and by using modern and innovative teaching methods and tools.	P8S_UU	Individual workshop and discussion	Structured explanation of a derivation in the report and discussion
P8S_UU3	Thanks to the continuous learning process, the doctoral student updates his/her interdisciplinary knowledge, improves his/her scientific competences and plans his/her own development and the development of others.	P8S_UU	Individual workshop and discussion	Discussion of limitations and further study

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Social competence (no.)	(Ready to)			
P8S_KK1	The doctoral student is ready to critically evaluate scientific achievements in the chosen scientific discipline of physical sciences, taking into account current research trends and quality standards of scientific research in the field of physics	P8S_KK	Individual workshop and discussion	Critical evaluation of sources in the report
P8S_KK2	Is ready to critically evaluate his/her own research contribution to scientific achievements in the chosen scientific discipline of physics, in the area of his/her interests and research.	P8S_KK	Individual workshop and discussion	Attribution of reproduced results and appraisal of the student's own reasoning
P8S_KK3	Is ready to solve theoretical and practical problems using his/her knowledge of exact and natural sciences within the discipline of physical sciences and related disciplines, in particular those relating to the doctoral student's scientific interests.	P8S_KK	Individual workshop and discussion	Report reasoning and scientific discussion

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LEARNING FORMAT – NUMBER OF HOURS						
Semester (no.)	Lectures	Seminars	Lab classes	Internships	others	ECTS
V	-	-	-	-	10 academic hours (2 × 5)	2 ECTS (2 × 1 ECTS)

METHODS OF INSTRUCTION

Individual, expert-led workshop combining blackboard derivations with guided scientific discussion. Definitions and intermediate steps are developed from quantum mechanics; the student checks limiting cases, assumptions and physical interpretations. Selected literature and the supplied notes support independent study and preparation of a written report. The student explains selected reasoning during discussion; the report presents the calculation in a form understandable to another doctoral student.

COURSE CONTENT

Programme allocation in academic hours; discussion is integrated into each block.

Session 1, academic hour 1: Define coherent diffractive electroproduction $\gamma^* p \rightarrow c \bar{c} p$, its measured variables and heavy-quark pair kinematics. Introduce the Dirac field, particle states and the photon-quark interaction needed for the calculation.

Session 1, academic hour 2: Construct the longitudinal photon splitting amplitude with light-front momentum fractions and its energy denominator; identify spin, colour and normalization factors.

Session 1, academic hour 3: Fourier-transform the photon wavefunction to transverse dipole separation; establish the heavy-quark transverse scale, longitudinal photoproduction limit and normalization checks.

Session 1, academic hour 4: Derive eikonal colour transport and Wilson lines, the colour-singlet dipole operator and colour transparency. Explain independent-layer exponentiation and the assumptions behind dilute gluon-density matching.

Session 1, academic hour 5: Assemble the coherent open-charm amplitude and cross section; apply the finite-target model, state the averaging prescription and derive a completeness/Parseval normalization check.

Session 2, academic hour 1: Calculate the dilute spectrum and its Fourier-interference zero; obtain the all-opacity expression and the first nonlinear correction using a Schwinger-parameter integral.

Session 2, academic hour 2: Compare full and dilute predictions at identical target input and kinematics; interpret finite-bin errors, node shifts and numerical convergence. Distinguish the tested target-interaction expansion from a proof or violation of collinear factorisation.

Session 2, academic hour 3: Derive the leading soft-gluon real-virtual evolution step and explain the correlator hierarchy, the closure leading to the Balitsky-Kovchegov equation and its dilute limit.

Session 2, academic hour 4: Project the produced pair onto charmonium: S-wave J/ψ and spin-singlet P-wave h_c . Derive the relevant momentum moments, identify wavefunction and spin assumptions, and distinguish established matching input from an unfinished h_c electroproduction calculation.

Session 2, academic hour 5: Decompose the dipole into charge-even and charge-odd exchange sectors; discuss Pomeron/Odderon selection, interference and phenomenological limitations. Consolidate the calculated benchmark and formulate a bounded question for a possible subsequent research project. Discuss the role of experimental and computational advances and the wider implications of the methods.

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COURSE ASSESSMENT CRITERIA

Assessment: pass/fail, based on a written report related to the workshop, supported by the scientific discussion.

A written report reproducing two substantial derivations and one numerical check selected from the final notes: pair/photon normalization; the dilute, next-order and full open-charm amplitudes; the soft-gluon evolution step; or the charmonium P-wave projection. The numerical check may concern one finite-bin ratio or the stated one-step evolution benchmark. State conventions, assumptions, dimensions and applicable limits; include reproducibility information and one unresolved question. These are reproduction and interpretation tasks, not a requirement to deliver a new research result.

A pass requires a coherent account of the central problem; substantially correct, traceable calculations; explicit conventions, approximations and applicable limits; critical physical interpretation; and appropriate citation of sources. Numerical results, where requested in the notes, must include a convergence or consistency check. The report should distinguish reproduced literature results from the student's own analysis and explain at least one derivation clearly for a doctoral peer.

A fail applies if no report is submitted or the work does not demonstrate these essential outcomes. The submission date is communicated by the lecturer.

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TOTAL PhD STUDENT WORKLOAD REQUIRED TO ACHIEVE THE INTENDED LEARNING OUTCOMES – NUMBER OF HOURS AND ECTS CREDITS	
Activity	Number of hours
Scheduled course contact hours	10 hours
Other contact hours involving the teacher (consultation hours, examinations)	2 hours
Non-contact hours – student's own work (preparation for classes or examinations, project, etc.)	48 hours
Total number of hours	60 hours
Total number of ECTS credits	2 ECTS
INSTRUCTIONAL MATERIALS	
Compulsory literature:	1. G. Beuf, Dipole factorization for DIS at NLO: I. Loop correction to the photon to quark-antiquark light-front wave-functions, Physical Review D 94 (2016) 054016, arXiv:1606.00777. Selected tree-level definitions and photon wavefunction construction; the full NLO calculation is not required. 2. F. Salazar and B. Schenke, Diffractive dijet production in impact parameter dependent saturation models, Physical Review D 100 (2019) 034007, arXiv:1905.03763. Selected amplitude, normalization and analytic-limit sections. 3. R. Pasechnik and M. Taševský, Multi-dimensional hadron structure through the lens of gluon Wigner distribution, Physics Reports 1084 (2024) 3–57, arXiv:2310.10793. Selected sections on dipole distributions and diffractive observables.
Complementary literature:	1. Y. V. Kovchegov, Small-x F_2 structure function of a nucleus including multiple pomeron exchanges, Physical Review D 60 (1999) 034008, arXiv:hep-ph/9901281. 2. Y. Hatta, E. Iancu, K. Itakura and L. McLerran, Odderon in the Color Glass Condensate, Nuclear Physics A 760 (2005) 172–207, arXiv:hep-ph/0501171. 3. M. Krelina, J. Nemchik, R. Pasechnik and J. Cepila, Spin rotation effects in diffractive electroproduction of heavy quarkonia, European Physical Journal C 79 (2019) 154, arXiv:1812.03001.

ONE ECTS CREDIT CORRESPONDS TO 25–30 HOURS OF TOTAL DOCTORAL-STUDENT WORKLOAD.

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Date and signature of the Course lecturer

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Approved by the Head of the Department or an authorised person