SYLLABUS

1. Information about the study programme

1.1 Institution of higher education	West University of Timişoara
1.2 Faculty	Physics
1.3 Department of	Physics
1.4 Field of study	Physics
1.5 Study cycle	Master
1.6 Study programme / Qualification	Advanced Research Methods in Physics / conform COR: fizician (211101); profesor în învăţământul gimnazial (232201 - în condiţiile legii); asistent de cercetare (248102); referent de specialitate în învăţământ (235204); analist (213101; analist financiar (241493).

2. Information about the subject/discipline

2.1 Name	Relativistic fluid dynamics 1210						
2.2 Course coordinator	Pracheta SINGHA						
2.3 Seminar coordinator	Pracheta SINGHA						
2.4 Year of study	I	**2.5 Semester**	II	**2.6 Type of assessment**	E	**2.7 Type of discipline**	DS/DFAC

3. Total estimated time (hours of teaching per semester)

3.1 Number of hours per week	**4**	**3.2 course**	**2**	**3.3 seminars/labs**	**2**
3.4 Total hours in the curriculum	**56**	**3.5 course**	**28**	**3.6 seminars/labs**	**28**
Distribution of time:					**hours**
Study based on Instructions, course materials, bibliography and notes					**43**
Additional documentation library, specialized electronic platforms / field					**15**
Training seminars / laboratories, homework, essays, portfolios and essays					**22**
Tutoring					**10**
Examinations					**4**
Other activities					
3.7 Total hours of individual study	**94**				
3.8 Total hours per semester	**150**				
3.9 Number of credits	**6**				

4. Prerequisites (where applicable)

4.1 of curriculum	• Fluid Dynamics • Complements of Theoretical Physics • Statistical Physics and Thermodynamics
4.2 of skills	• General skills: ability to assimilate fundamental knowledge; correct usage of physics-specific terminology; ability to work individually and as part of a team; • Professional skills: the correct identification and usage of the main laws and principles of physics; ability to solve physics-specific problems.

5. Conditions (where applicable)

5.1 for the course	-
5.2 for the seminar	-

6. Discipline objectives – learning outcomes

Knowledge	• Accurately applying the fundamental laws and principles of physics that pertain to this course within a specific context • Formulations of relativistic hydrodynamics. • Connecting the fundamental interactions to the experimental observation in heavy ion collision experiments.
Skills	• Solving physics problems through both analytical and numerical methods
Responsibility and autonomy	• Acquaintance with modern techniques in relativistic hydrodynamics.

7. Contents

7.1. Course	Teaching methods	Observations
Chap. 1. Introduction and motivation (4 hours) - Special relativity - Anatomy of heavy-ion collisions - Fluid dynamics description of the quark-gluon plasma	Interactive lecturing at the blackboard or using the beamer.	[4] Sec. 1.3, 1.4; [2] Sec 1.1-1.4; [5] Chap. 1, 2, 4;
Chap. 2. Ideal Hydrodynamics (4 hours) - Energy-momentum tensor - Relativistic Euler equations - Hydrodynamic waves		[1] Sec 1.2, 3.2; [3] Sec 2.1, [4] Sec. 3.2 – 3.5 , Sec. 4.1 – 4.3 ; [5] Sec.13.1 - 13.3,
Chap. 3. Dissipative Hydrodynamics (8 hours) - Hydrodynamic frames - Second law of thermodynamics: entropy current - First-order (Navier-Stokes) theory - Second-order (transient) theory - Causal first-order theories - Hydrodynamic attractors in heavy-ion collisions		[1] Sec. 1.3-1.6, Chap 2, 3; [3] Sec. 2.2-2.6; [4] Sec. 6.1 – 6.6.2;
Chap. 4. Relativistic kinetic theory (8 hours) - The relativistic Boltzmann equation - Energy-momentum conservation and collision invariants - H-theorem and second law of thermodynamics - Method of moments - Hydrodynamic limit and transport coefficients - Far-from-equilibrium phenomena		[2] Chap. 2, Sec. 3.2,, Chap 4, Sec. 5.1 – 5.4.1, Sec. 6.1 – 6.4, 8.3; [4] Sec. 2.2 , 2.3; [3] Sec. 3.1; [1] chap 5-8;
Chap. 5. Heavy-ion collisions applications (4 hours) - Initial-state models - Cooper-Frye theory of hadronization - Flow response from geometry		[5] Chap 15, Sec. 24.1 – 24.4, 25.1, 25.2; [3] Chap. 4, 5 ;

Bibliography

1. G. S. Denicol, D. H. Rischke, Microscopic foundations of relativistic fluid dynamics (Springer, 2021).
2. C. Cercignani, G. M. Kremer, The relativistic Boltzmann equation: theory and applications (Springer Basel, 2002).

3. P. Romatschke, U. Romatschke, Relativistic fluid dynamics: in and out of equilibrium (Cambridge University Press, 2019).
4. L. Rezzolla, O. Zanotti, Relativistic hydrodynamics (Oxford University Press, 2013).
5. W. Florkowski, Phenomenology of ultra-relativistic heavy-ion collisions (World Scientific, 2010).

7.2. Seminar/laboratory	Teaching methods	Observations
Chap. 1. Introduction and motivation (4 hours) - Special relativity - Anatomy of heavy-ion collisions - Fluid dynamics description of the quark-gluon plasma	Problem solving using computer simulations. Interactive lecturing at the blackboard or using the beamer.	The bibliographic references follow those of the course
Chap. 2. Ideal Hydrodynamics (4 hours) - Energy-momentum tensor - Relativistic Euler equations - Hydrodynamic waves		
Chap. 3. Dissipative Hydrodynamics (8 hours) - Landau and Eckart frames - Onsager relations; thermodynamic consistency for transport coefficients - Linear causality and stability - BDNK theory - Bjorken flow - Gubser flow		
Chap. 4. Relativistic kinetic theory (8 hours) - Thermodynamic integrals - Quantum statistics - Killing theorem and global equilibrium - Marle and Anderson-Witting models - Chapman-Enskog expansion - Far-from-equilibrium phenomena - Bjorken flow solution		
Chap. 5. Heavy-ion collisions applications (4 hours) - Isochronous freezout - Glauber model and initial conditions - Single-hit approximation		
Bibliography See 7.1. Course.		

8. Corroboration of the course contents with the epistemic expectations of the community representative, professional associations and representative employers of the programme itself

Understanding and applying specific formulations of the relativistic hydrodynamics, analytical and computational techniques covered in this course, which are essential for developing practical skills in relativistic fluid dynamics. Additionally, fostering teamwork, planning and executing small-scale projects, and cultivating a scientific environment grounded in values and professional ethics are emphasized. Graduates will gain knowledge in modern research areas and ongoing endeavors in the field of high energy physics. They will learn to connect the basic fundamental theory to the outcome of detector experiments and will obtain a clear understanding of the theoretical as well as the experimental aspects of this rapidly

growing field of research in Modern Physics.

9. **Evaluation**

Type of activity	**9.1 Evaluation criteria**	**9.2 Evaluation methods**	**9.3 Percentage of the final mark**
9.4 Course	Activity during lectures; Knowledge of topics presented during lectures	Individual project (based on topics discussed during lectures + tutorials)	**100%**
9.5 Seminar	Activity during problem classes; Homeworks		
9.6 Minimum performance standards			
• Familiarity with basic topics within the course contents. • Ability to apply these topics in solving specific problems.			

- Minimum attendance: according to UVT regulations (50% lectures; 70% seminar)
- Final mark: 100% individual project

Date: 31.01.2025

Course leader:

Dr. Pracheta SINGHA

Date: 31.01.2025

Head of the department

Conf. Univ. Dr. Nicoleta ȘTEFU