DI.104.HEP Data analysis in high energy physics: a practical guide to statistical methods I

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	High Energy Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Data analysis in high energy physics: a practical guide to statistical methods I								
2.2. Teacher				Dr. Julien Maurer, Conf.Dr. Radu Slobodeanu					
2.3. Tutorials/Practicals instructor(s)				Dr. Julien Maurer, Conf.Dr. Radu Slobodeanu					
2.4. Year of study	I	2.5. Semester	1	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DS**	
							Type[2]	**DI**	

[1] fundamental (DF), specialized (DS); complementary (DC)
[2] compulsory (DI), elective (DO), noncompulsory disciplines (DFC)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**
Distribution of estimated time for study					**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography					**20**
3.2.2. Research in library, study of electronic resources, field research					**20**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks					**52**
3.2.4. Preparation for exam					**4**
3.2.5. Other activities					**0**

3.3. Total hours of individual study	**96**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Algebra, Programming languages
4.2. competences	Knowledge about: algebra, quantum mechanics, electrodynamics

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector

5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of the standard model • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum field theory, concepts, notions and problems in the area of theoretical particle physics and their interactions • Ability to use this knowledge in interpretation of experimental result and understand experiments at CERN; acquire the appropriate understanding of studied fundamental mechanisms
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1 General objectives	To expose the fundamental principles behind the analysis of observed data in particle physics experiments, and how to constrain theory models with observations via frequentist inference.
7.2 Specific objectives	The fundamental notions in the theories of probability and statistics are presented and exercised. They provide the formal ground to motivate common techniques used to measure quantities of interest and assign uncertainties, to model binned or unbinned data with parametric fits in one or several dimensions, or to quantify the compatibility between empirical distributions or parametric models. The construction of likelihood functions and their widespread usage to interpret results of particle physics experiments is detailed and practised. The concrete steps involved in a typical LHC analysis are presented, including the construction of signal and control regions and of meaningful observables, various background estimation techniques, and the different types of uncertainty sources.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Elementary probability theory: formal basis; central theorems; common probability distributions;	Systematic exposition - lecture. Examples.	4 hours
Elementary theory of statistics: formal basis; estimation theory; hypothesis testing;		4 hours
Regression; least squares; parametric fits		2 hours
Likelihood inference		2 hours
Confidence intervals; coverage probability		2 hours
Analysis concepts: basic workflows for searches, measurements, calibrations; construction of observables for relativistic bodies; background estimation; practical sources of uncertainty; visualization techniques		10 hours
Multivariate classification overview		2 hours
Bayesian statistics		2 hours

Bibliography:
1. O. Behnke et al, *Data analysis in high energy physics: A practical guide to statistical methods*, Wiley-VCH, 2013.
2. K. Hanagaki et al, *Experimental Techniques in Modern High-Energy Physics*, Springer Tokyo, 2021.
3. G. Cowan, *Probability* and *Statistics*. In *The Review of Particle Physics*, edited by S. Navas et al., Phys. Rev. D 110, 030001 (2024).

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Problems in probability theory		4 hours
Problems in theory of statistics		4 hours
Relativistic calculations with several bodies; interpretation of Dalitz plots		6 hours
Measuring efficiencies; binomial errors and beyond		2 hours
Reinterpretation of published LHC BSM search results; exclusion limits setting	Problem solving	4 hours
Construction of likelihood-based estimators for various scenarios		2 hours
Construction of observables highlighting spin correlations and quantum entanglement effects in pp collisions		2 hours
Review of important HEP measurements		4 hours

Bibliography:
1. J. D. Jackson et al, *Kinematics*. In *The Review of Particle Physics*, edited by S. Navas et al, Phys. Rev. D 110, 030001 (2024).
2. D. H. Perkins, *Introduction to High Energy Physics*, 4th ed, Cambridge University Press, 2000.
3. E. Maguire et al, *HEPData: a repository for high energy physics data*, J. Phys. Conf. Ser. 898 (2017) 10, 102006.
4. ATLAS and CMS Collaborations: Eur. Phys. J. C 80 (2020) 8, 754; Phys. Rev. D 110 (2024) 11, 112016; Nature 633 (2024) 8030, 542-547

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- coherence and clarity of exposition - correct use of equations/mathematical methods/physical models and theories - ability to indicate/analyse specific examples	Oral examination	40%
10.5.1.	- ability to use specific problem	Homeworks/Lab reports	60%

Tutorials/Practicals	solving methods - ability to analyse the results		
10.6. Minimal requirements for passing the exam			
Attendance of at least 50% for the lectures and at least 70% for the tutorials. **Correct solutions to the indicated subjects for obtaining the grade 5 (10 points scale) from all activities, part of the continuous evaluation.** **Correct solutions to the indicated subjects for obtaining the grade 5 (10 points scale) within the final exam.**			

Date
3.10.2024

Teacher's name and signature

Dr. Julien Maurer,
Conf.Dr. Radu Slobodeanu

Practicals/Tutorials instructor(s) name(s) and signature(s)

Dr. Julien Maurer,
Conf.Dr. Radu Slobodeanu

Date of approval

Head of Department
Lect.dr. Roxana Zus