CYA | Syllabus

**PHYS 350 | Particle Physics**
**Spring 2025, N.C.S.R. "Demokritos"**

**Course Instructor: Evangelia Drakopoulou**
**Email: drakopoulou@inp.demokritos.gr**

## Course Description

Have you ever wondered what matter is made of? What is antimatter? How can humans accelerate particles? How can Big Data lead to meaningful conclusions? How is Artificial Intelligence (AI) employed to solve challenging problems and foster scientific discoveries?
This course will address these and many other questions. We will explore our Universe and examine how scientific discoveries shape peoples life without getting lost in equations!
Initially, we describe the elementary particles of Nature and the fundamental principles that govern their interactions in our Universe. We will explain the state-of-the-art data analysis techniques, which are common to any field dealing with data from social to natural sciences. Then, we will employ these techniques to understand how artificial intelligence can be so efficient in solving complex problems in high energy physics, while examining the advantages and threats by the integration of AI technologies across various fields. During this course you will learn how to efficiently present your work via talks and posters communicating complex ideas to diverse audiences.

By the end of this course you will know how modern AI tools are employed in research, critiquing the technological advancements and understand how scientific discoveries alter cultural perspectives on reality, causality, and human significance thus evaluating their social and philosophical impact.
This course will not cover the mathematical site of these aspects and no prior knowledge of statistics or coding is assumed.

## Course Approach

The course topics will be explored by reading particle physics (also referred to as high energy physics) and AI bibliography (book chapters or scientific papers depending on the session) and by studying the material provided in the course slides. Occasionally, classes will be followed by short assignments to help understand each topic. Students will have first-hand experience in experimental particle physics instrumentation during the lab visits. They will develop their presentation skills via presentations and posters, further develop critical thinking on stage-of-the-art technological advancements and gain valuable insights in artificial intelligence developments.

## Learning Objectives

By the of the course you will be able to:

- understand the fundamental principles of our Universe (using non-technical language and analogies)
- recognize the main instrumentation of modern particle physics experiments
- discuss the societal impact of discoveries in high energy and particle physics
- evaluate the impact of AI in modern science and society
- experience in communicating complex ideas
- critiquing the Ethical Issues arising from new technologies
- efficiently present your work in talks and posters in diverse audiences

## Course Requirements

At the end of classes reading (either slides or bibliography) will be required along with short exercises for practice with delivery date the following week (see Assignment 1).
In some sessions these will be replaced by computing assignments (see Assignment 2).
During Week XI students will give a talk on a scientific discovery and present a poster (see Assignment 3).
Classroom attendance is required for this course. Each absence (with no valid reason) will reduce the final grade by 5%.
The final exam (written) will consist of questions covering the material of this course.

## Class Field Work

During Week X researchers of the N.C.S.R. "Demokritos" will provide seminars on AI and natural sciences topics. Lab visits to the research labs of the Institute of Nuclear and Particle Physics will follow. During these lab visits students will become familiar with the instrumentation and methodology required for particle physics experiments and expand their knowledge on the scientific procedures followed in high energy physics experiments.

## CYA Field Study
Not Applicable

## Evaluation and Grading
Your grade for this course will be based on the following distribution:

## Percentages
Assignment 1 - Exercises: Homework assignments. All assignments will contribute 10% to the final grade. Assignment 2 - Computing exercises. These exercises will contribute 25% to the final grade.
Assignment 3 - Talk and poster contributing 25% and 20% respectively to the final grade. Final exam - 20% of the final grade.

## Evaluation Criteria - Course Assignments
**Assignment 1:** Exercises
Description: Exercises will be solved during some classes. Similar exercises will be given for homework with delivery date the following week. These short weekly assignments will consist 10% (in total) of the final grade.
**Criteria 1: Correct solution and correct methodology**
**Assignment 2:** Computing exercises
Description: After the data analyses and artificial intelligence sessions a series of computing exercises (based on the examples studied in class) will be given for homework with delivery date the following week. These assignments will consist 25% of the final grade.
**Criteria 1: Correct solution and correct methodology**
**Assignment 3:** Talk and poster describing a Particle Physics experiment
Description: A 15-minutes talk and a poster will be prepared to describe a particle physics experiment. This assignment will consist 45% of the final grade.
- Criteria 1: Understanding the theory and the methodology of the experiment.
- Criteria 2: Slides and poster clarity and appearance
- Criteria 3: Presentation skills

## CYA Regulations and Accommodations
### Attendance Policy
CYA regards attendance in class and on-site (in Athens or during field study trips) as essential. Absences are recorded and have consequences.

## ePolicy on Original Work
Unless otherwise specified, all submitted work must be your own original work. Any ideas taken from the work of others must be clearly identified as quotations, paraphrases, summaries, figures etc., and accurate internal citations and/or captions (for visuals) as well as an accompanying bibliography must be provided.

## Use of Laptops
In-class or onsite use of laptops and other devices is permitted if this facilitates course-related activities such as note-taking, looking up references, etc. Laptop or other device privileges will be suspended if devices are not used for class-related work.

## Class Schedule

| Class Day | Topic / Readings / Assignments Due |
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| Week Ia | **From Ancient Greek philosophy to modern Particle Physics**<br>*Description*<br>A quick travel through the history of physics. How everything started with Demokritos, and why it is important to understand our existence..<br>*Required reading*<br>Class slides |
| Week Ib | **What is Fundamental? - From the Atom to Standard Model**<br>*Description*<br>An introduction to particle physics basic theory and concepts will be provided. The Standard Model of Physics with particles and antiparticles will be explained.<br>*Required reading*<br>Class slides |
| Week IIa | **Matter and Antimatter**<br>*Description*<br>Matter and antimatter: naming conventions, conservation laws and particle decays. |

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| | *Required reading*<br>Class slides |
| Week IIb | **The Interactions of Nature**<br>*Description*<br>The forces of Nature will be discussed.<br>Required reading<br>Class slides<br>*Required assignment*<br>Exercises (Assignment 1) |
| Week IIIa | **Accelerators and Particle Detectors (I)**<br>*Description*<br>The experimental methods will be discussed emphasizing on the physical principles behind the methods. In the first session the accelerators and beams will be presented and the particle interactions with matter will be discussed.<br>*Required reading*<br>Class slides |
| Week IIIb | **Accelerators and Particle Detectors (II)**<br>*Description*<br>The experimental methods will be discussed emphasizing on particle detectors and major physics experiments.<br>Required reading<br>Class slides<br>*Required assignment*<br>Exercises (Assignment 1) |
| Week IVa | **How can scientists interpret data?**<br>*Description*<br>The scientific procedure from experimental data collection in the detectors to sci- entific discoveries will be described.<br>*Required reading*<br>Class slides |
| Week IVb | **Overview of experiments in High Energy Physics: Discuss the multidisciplinary importance of particle physics**<br>*Description*<br>An overview of recent experiments in high energy (particle and astroparticle) physics will be presented. At the end of this session students will choose an experiment from a list of experiments in high energy physics. Each student will present the experi- ment (in view of its scientific impact, the instrumentation used, the social/technolo- gical/philosophical impact) in the class during week XI.<br>*Required reading*<br>Class slides<br>Optional bibliography<br>Scientific publications from each experiment. |
| Week Va | **Particle Physics Connections to Philosophy**<br>*Description*<br>Similar to the planets moving around the Sun, we have electrons moving around the atom, we have people forming groups and societies...Philosophical issues that arise in contemporary particle physics will be discussed.<br>*Required reading*<br>Class slides<br>Optional bibliography<br>Scientific publications |
| Week Vb | **From fundamental particles to the mysterious phenomena of our Universe**<br>*Description*<br>The most energetic and catastrophic phenomena taking place in our Universe will be discussed. From supernovae explosions to the cosmic accelerators, we will describe the observations in high energy astroparticle physics and the implications of new discoveries.<br>*Required reading*<br>Class slides<br>Optional bibliography<br>Scientific publications provided in slides. |
| Week VIa | **Discoveries in High Energy Physics and the impact in Society**<br>*Description*<br>The impact of scientific advancements in society will be discussed (think for ex- ample, the development of Internet at CERN!). How have major discoveries changed the world and the way people think? Students will analyze the impact of particle physics discoveries on technology, policy, and societal development, discussing both positive and negative implications.<br>*Required reading*<br>Class slides |

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| Week VIb | **How is high energy physics evolving in the era of Artificial Intelligence(AI)?**<br>*Description*<br>The high energy physics has achieved major breakthroughs with the use of AI in physics analyses. Is AI a useful or dangerous tool for science? Advantages and pos- sible caveats will be discussed.<br>*Required reading*<br>Class slides<br>Optional bibliography<br>Scientific publications provided in slides. |
| Week VIIa | **Data Analysis Techniques**<br>*Description*<br>How can data be converted to meaningful conclusions? During this session the major data analysis tools for data analysis will be discussed. These techniques are common to any field dealing with data from social to natural sciences. No prior knowledge of statistics or coding is needed.<br>*Required reading*<br>Class slides with theory and hands on exercises. During this session laptop is required.<br>Required assignment<br>Computing Exercises (Assignment 2) |
| Week VIIb | **Data Exploration and Data Visualisation**<br>*Description*<br>During this session the modern tools and procedures to explore and visualise data will be described.<br>*Required reading*<br>Class slides with theory and hands on exercises. During this session laptop is required.<br>*Required assignment*<br>Computing Exercises (Assignment 2) |
| Week VIIIa | **Introduction to Artificial Intelligence concepts**<br>*Description*<br>During this session the basic concepts and principles of Artificial Intelligence will be discussed.<br>*Required reading*<br>Class slides with theory and hands on exercises. During this session laptop is required.<br>*Optional bibliography*<br>Introduction to Statistical Machine Learning, M. Sugiyama, 2016, p. 3-6 |
| Week VIIIb | **Artificial Intelligence: Machine Learning - Classification**<br>During this class the machine learning techniques for classification problems will be explored. Possible caveats and threats from their use will be discussed.<br>*Required reading*<br>Class slides with theory and hands on exercises. During this session laptop is required.<br>*Optional bibliography*<br>Introduction to Statistical Machine Learning, M. Sugiyama, 2016, p. 343 - 354<br>*Required assignment*<br>Computing Exercises (Assignment 2) |
| Week IXa | **Artificial Intelligence: Machine Learning - Regression**<br>*Description*<br>During this class the machine learning techniques for regression problems will be explored. Possible caveats and threats from their use will be discussed.<br>*Required reading*<br>Class slides with theory and hands on exercises. During this session laptop is required.<br>*Optional bibliography*<br>Introduction to Statistical Machine Learning, M. Sugiyama, 2016, p. 355 - 362<br>*Required assignment*<br>Computing Exercises (Assignment 2) |
| Week IXb | **Artificial Intelligence: Deep Learning**<br>*Description*<br>During this class the deep learning techniques for classification and regression problems will be explored. Possible caveats and threats from their use will be discussed.<br>*Required reading*<br>Class slides with theory and hands on exercises. During this session laptop is required.<br>*Required assignment*<br>Computing Exercises (Assignment 2) |
| Week Xa | **Philosophical Aspects of AI in Natural Sciences**<br>*Description*<br>The philosophical aspects of AI technology and its use will be discussed analyzing the implications of different philosophies for the use of AI in science and society, including some of the likely problems that can arise.<br>*Required reading*<br>Class slides. |
| Week Xb | **Seminars on AI and Natural Sciences** |

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| | *Description*<br>During this class, seminars will be provided by researchers of the N.C.S.R. "Demokritos" on the AI and natural sciences topics. Building on previous classes these seminars will expand students knowledge of these topics. Lab visits to the research labs of the Institute of Nuclear and Particle Physics will follow.<br>Optional bibliography<br>Researchers will suggest scientific publications for each field. |
| Week XI (a,b) | **Talk and poster describing the impact of a Particle Physics Discovery**<br>*Description*<br>Students will present their chosen particle physics experiment. Questions and discus- sion in class will follow.<br>*Required reading*<br>Scientific Papers<br>Required assignment<br>Slides and poster (Assignment 3)<br>Optional bibliography<br>PhD/MSc thesis for the chosen experiment |
| Week XII (a,b) | **Build a AI project step-by-step using real data: Evaluate and criticise the results of the AI predictions**<br>*Description*<br>During these sessions we will use real/open data from high energy physics (and/or real life datasets), employ the data analysis techniques we have learnt so far to ex- plore the datasets and develop efficient AI solutions. Then, we will criticise the AI predictions, investigate possible threats from their (blind) use and understand their impact in humans life.<br>*Required reading*<br>Class slides with theory and hands on exercises. During this session laptop is required. |
| Week XIII | **Final exams**<br>Description<br>Written exams.<br>The final exams will consist 20% of the final grade. |

N.B.: The course schedule, in terms of subjects and readings, may be subject to change to benefit student learning and to keep up to date with current research.

## COURSE BIBLIOGRAPHY

The Quantum Universe: (And Why Anything That Can Happen, Does), B. Cox and J. Forshaw, 2011
Particle Physics, A very short Introduction, F. Close, Oxford University Press, 2023
Philosophy of Particle Physics, P. Williams, Cambridge University Press, 2023

Optional Reading:

Particle Physics, B.R.Martin & G. Shaw, 3rd edition, 2008 Introduction to Statistical Machine Learning, M. Sugiyama, 2016