General Information

Course unit name: *Instrumentation, Data Analysis and Machine Learning*

Course unit code:

Academic year: 2023—2024

Coordinator: Carla Marin Benito

Department: Department of Quantum Physics and Astrophysics

Credits: 6

Single program: S

Estimated learning time

Total number of hours: 150

Face-to-face or online activities: 60

- Lectures: 15
- PC exercises: 20
- Lab work: 5
- Field work: 20

Supervised project: 50

Independent learning: 40

Recommendations

It is expected that students have followed the Mathematical and Statistical Techniques course, since we will apply the techniques presented there to real data from ongoing experiments. Students need to have basic programming skills to follow this course. Python will be the main language used in the course, but students can choose to use other programming languages for their work and to complete the assignments.

Competences

General

- Teamwork skills
- Problem solving skills
- Self-learning capacity for continued autonomous learning
- Capacity to acquire and apply state-of-the-art techniques in a research context
- Application of acquired knowledge to new multidisciplinary environments
- Capacity to solve complex situations even from limited information
- Capacity to communicate conclusions and the arguments sustaining them to both general and specialized audiences
- Capacity to communicate, present and write up scientific results

Specific

- Knowledge and practical application of astronomical observation methods from Earth and space
- Capacity to identify relevant observables in an specific physical system
- Capacity to check model predictions against experimental data and observations

- Capacity to develop and apply new technologies
- Capacity to plan and execute experiments and computations using specialized equipment
- Capacity to critically analyse results from computations, experiments and observations, considering potential uncertainty sources.

Learning objectives

- Understand the requirements for the design of a modern particle physics or astrophysics experiment, the role of each of its subdetectors, and the data acquisition and processing techniques
- Learn the working principles of modern particle detectors and astrophysical instrumentation (ground-based detectors, space-borne facilities)
- Understand the mechanisms, techniques and characteristic parameters of particle accelerators and detectors, and real data reconstruction techniques
- Learn real astrophysical data analysis and reconstruction techniques: optical, X-rays, Gamma-rays, VHE Cherenkov data
- Application of machine learning techniques to both particle physics and astrophysics data

Teaching blocks

1. **Requirements of particle physics experiments**
    1. Particle production and detection
    2. Measurements and observables
2. **Requirements of astrophysical observations**
    1. Radiative processes in astrophysics
    2. Astroparticles: cosmic rays, neutrinos, solar/stellar winds
3. **Particle accelerators**
    1. Types of accelerators
    2. Acceleration techniques
    3. Accelerating leptons vs accelerating hadrons
4. **Detection techniques**
    1. Scintillators
    2. Tracking with gas and solid detectors
    3. Silicon detectors
    4. Calorimetry
    5. Cherenkov radiation detectors
5. **Design of high energy physics experiments**
    1. Physics program and main characteristics
    2. Trajectory and momentum measurement
    3. Energy measurement
    4. Particle identification
6. **Astrophysical instrumentation**
    1. Optical and radio telescopes
    2. Interferometry techniques
    4. High energy telescopes: X-rays and gamma-rays
7. **Astrophysical observation techniques**
    1. The effect of the atmosphere in astronomical observations
    2. Site testing

3. Optical telescopes; adaptive and active optics.
4. Detectors: concepts and characterisation

8. Data acquisition and processing

1. Trigger and data acquisition systems
2. Calibration techniques
3. Reconstruction methods
4. Offline data storage and processing

9. Practical exercises

1. Data analysis: machine learning and fitting techniques; hands-on sessions
2. Measurement of the ALBA synchrotron beam emittance
3. Measurement of the muon lifetime
4. Astrophysical observation at Observatori Astronòmic del Montsec
5. Astrophysical proposal and observation at Calar Alto Astronomical Observatory
6. Data analysis: cloud computing hands-on sessions
7. Data analysis: X-rays using *Chandra* and XMM-*Newton* data; hands-on sessions
8. Data analysis: High-Energy gamma-rays using *Fermi*-LAT data; hands-on sessions
9. Data analysis: Very High Energy gamma-rays using CTA/Monte Carlo simulations data; hands-on sessions

Assessment of learning outcomes

Avaluació continuada

The final grade is the average between computer assignments (50%) and a research work (50%).

Repeat assessment

Repeat assessment of continuous assessment follows the same procedure as repeat assessment of single assessment.

Avaluació única

The final grade is the average between computer assignments (50%) and a research work (50%).

Repeat assessment

The final grade is the average between computer assignments completed throughout the course (50%) and a research work (50%).

Reading and study resources

- Fernow, Richard, Introduction to experimental particle physics, Cambridge University Press cop. 1986
- Cahn, Robert N, The experimental foundations of particle physics, Cambridge ; New York : Cambridge University Press 2009
- Ferbel, Thomas, et al., Experimental techniques in high-energy nuclear and particle physics, Singapore [etc.] : World Scientific, cop. 1991