NPAC Noyaux Particules Astroparticules Cosmologie

Master 2 Recherche

Course Title : **Neutrino and Dark Matter Physics**

Number of hours/semester : 30 h, 2nd Semester

Number of ECTS : 3

Lecture outline, contents :

The lectures will tackle both experimental and theoretical aspects of modern neutrino physics, giving an overview of the most salient developments of the last decade. The proximity of the experimental techniques adopted in underground neutrino physics and direct dark matter detection offers the additional opportunity to discuss the latest developments in the field of dark matter.

The theoretical part covers the history of neutrino physics, which is strongly linked to the one of the Standard Model. The theory part spreads from Fermi Theory to Beyond Standard ones (BSM). The oscillation phenomena will be addressed with a discussion of the matter effect. The topics discussed in these lectures include general properties of neutrinos, their nature (Dirac or Majorana), their absolute mass scale, the violation of lepton number, and the potential of the lepton CP violating phases with their main signatures. An important part will be devoted to the origin of neutrino masses and their mixings, in link with BSM physics. In particular the different seesaw mechanisms will be addressed with their phenomenological consequences. A strong emphasis on the sterile neutrino hypothesis and all relevant implications and constraints (cosmological and phenomenological), depending on their mass regimes will close the theory part.

The experimental part will start with a historical discussion of the different processes and experiments that led to the discovery of neutrinos, and then to the study of their fundamental properties and interactions. An important part of the lectures is devoted to review neutrino oscillation results, with an emphasis on the variety of experimental approaches that have been used (solar and atmospheric neutrino detectors, reactor neutrinos and neutrino beams). The measurement of the neutrino masses is also addressed. Current challenges in neutrino physics will be discussed in the context of the next generation of neutrino experiments. Finally, the role of neutrinos in multi-messenger astronomy will be presented along with a presentation of the main astrophysical neutrino sources.

The dark matter part will first overview the evidences of the existence of dark matter through cosmological and astrophysical indirect observations. We briefly review the dark matter particle candidates, then focus on the Weakly Interacting Massive Particle (WIMP) and on the estimation of its flux. An important section will be dedicated to the experimental techniques, emphasizing the connections with background challenges already discussed in the experimental neutrino part. The next generation of experiments will be sufficiently sensitive to detect solar and atmospheric neutrino interactions via coherent scattering off nucleus, an irreducible background for WIPMs, but also a new window for observing neutrinos. We conclude with an outlook on the future of dark matter searches, on the envisaged techniques for discriminating neutrinos, and on the possibility to build giant observatories for both neutrinos and dark matter.

Pedagogical methods: Lectures and Tutorials

Prerequisites: S1 NPAC Particle-Physics course (or an equivalent course in another University for Erasmus students)

Modalities of knowledge assessment: 3 hours written examination at the end of the semester for the first session and Oral examination for second session (for the second session, the maximum grade is limited to 10)

Bibliography:

BOOKS
- R. N. Mohapatra and P. B. Pal, “Massive neutrinos in Physics and Astrophysics”, World Scientific (3d edition, 2004)
- C. Giunti and C. W. Kim, "Fundamentals of Neutrino Physics and Astrophysics", Oxford University Press (2007)
- K. Zuber, "Neutrino Physics", CRC Press (2d edition, 2012)
- A. Kouchner and S. Lavignac, « A la recherche des neutrinos », éd. Dunod, Coll. Quai des Sciences (in French)

REVIEWS
- A. Abada, *et al.*, "Low energy effects of neutrino masses", JHEP 0712 (2007) 061, https://arxiv.org/pdf/0707.4058.pdf
- C. Giganti, S. Lavignac and M. Zito, "Neutrino oscillations: the rise of the PMNS paradigm", Prog. Part. Nucl. Phys. 98 (2018) 1, https://arxiv.org/pdf/1710.00715.pdf
- Particle Data Group Reviews: http://pdg.lbl.gov/2018/reviews/contents_sports.html
→ K. Nakamura & S. T. Petcov, "Review on Neutrino mass, mixing and oscillations”
→ various authors, “Particle detectors for non-accelerator physics”
→ Particle properties – Neutrinos (several reviews)
- M. C. Gonzalez-Garcia and M. Maltoni, "Phenomenology with massive neutrinos", http://arxiv.org/pdf/0704.1800.pdf
- T. Marrodan Undagoitia and L. Rauch, “Dark matter direct-detection experiments”, J. Phys. G43 (2016) no.1, 013001, https://arxiv.org/abs/1509.08767

WEBSITES
- *Neutrino Unbound*, http://www.nu.to.infn.it/
- *History of the Neutrino*, https://neutrino-history.in2p3.fr/