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# TITLE:

## *Neutrino Physics*

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## Program of the course:

**1) Introduction**

Neutrinos are neutral particles of the Standard Model of elementary particles that interact only via the weak force. The discovery of neutrinos oscillation, i.e the observation that neutrinos change flavour dring their flight, imply that they have a non zero mass. This discovery is a breakthrough since neutrino oscillations are not predicted by the Standard Model. These lectures aims to provide a historical overview on neutrino physics and an introduction to the phenomenology of neutrino oscillations.

**2) Solar neutrinos**

The deficit of solar neutrino flux with respect to the prediction of the Solar Standard Model (SSM) had been an unsolved puzzle for more than 30 years questioning the correctness of the SSM and the presence of unknown nuclear effects. This evidence was confirmed by several other experiments and eventually it was proved that the deficit of solar neutrino flux was due to neutrino oscillations. Since then, the investigation on solar neutrinos had a tremendous impact not only on the understanding of the functioning of the Sun and other stars, but only in of the neutrino properties thanks to the more and more accurate measurements of neutrino oscillation parameters. These lectures is an overview on the solar experiments and main results.

**3) Neutrinos from the SuperNova SN1987A**

During the explosion of the SuperNova SN1987A in the Magellanum cloud a handful of neutrinos was detected in several experiments. In spite of the very small number of the detected neutrino (17), this observation allows to obtain information of outmost importance on SuperNova explosions. The experimental observations and their interpretation is described in this lecture.

**4) Neutrino oscillation experiments**

Neutrino oscillations allow to investigate the neutrino properties and to probe the CP violation in lepton sector. This task is pursued by means of a large variety of experiments that exploit the availability of natural neutrinos sources, such as the Sun and atmospheric neutrinos, and artificial sources such as accelerators and reactors. The determination of Neutrino Mass Hierarchy and the measure of neutrino CP violation are the last elements of PSWM oscillation matrix to be measured. Moreover, anomalies in the oscillation pattern have been observed in some experiments providing a hint for the existence of sterile neutrinos. These lectures address the main experimental results and future perspectives.

**5) Majorana vs Dirac mass term. Neutrino mass**

The only way to probe the Majorana nature of neutrinos is the double beta zero neutrino decay. The signature is a monochromatic line in the energy spectrum, but several sources can mimic the signal thus requiring strong expertise in low background techniques. Future efforts aims at increase of detector mass and exposure, improvement of energy resolution and background rejection.

The direct measurement of the neutrino mass is extremely challenging. The latest spectrometer measurements are expected to reach a sensitivity of about 0.2 eV. Further improvements could be obtained for example with a bolometric approach which are in an R&D stage.

In these lectures the main results and perspectives are presented.

**7) Cosmic neutrinos**

The discovery of a flux of cosmic neutrinos marked the opening of a new window on the Universe. The observation of a very energetic neutrino in space-time coincidence with a blazar triggered an estensive multi messenger campaign where photons from radio to very high energy gamma were detected. This observation puts in evidence the importance of the role of neutrinos in multi-messenger astronomy. In the near future the enlargement of the sky coverage and the improvement of the angular resolution will increase the discovery potential. In these lectures experimental challenges, results and perspectives are presented.

In these lectures the experimental