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Some notes on Neutrino Physics and Particle Cosmology

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Abstract

In the first part of these notes I will discuss the main properties of neutrinos and the related rich phenomenology that we observe (neutrino oscillations, neutrino-less double beta decay, kinematic decays..) except their cosmological role that is postponed to the second part. I will also briefly discuss the seesaw mechanism, the simplest extension of the standard model (SM) that has been proposed in order to describe neutrino masses and mixing able today to explain why neutrinos are so light compared to all other massive particles. As an example of class of models able to embed the see-saw mechanism, in his minimal version (type-I seesaw), I will discuss the interesting case of $SO(10)$-inspired models.

In the second part, after a short introduction to cosmology, I will discuss the interplay between cosmology and particle physics. I will start discussing the kinetic theory in the early universe and then apply this to CMB, dark matter and baryogenesis. I will give particular emphasis to the role of neutrinos in the history of the early Universe and how these can help, or even be crucial, to explain many cosmological observations. On the other hand, it is also true the converse: cosmological observations disclose a precious information on neutrino properties and on the underlying models of new physics. I will then discuss dark matter, models and searches and the problem of the matter-antimatter asymmetry of the Universe, the need of a model of baryogenesis for its solution and two of the most attractive proposals: leptogenesis and electroweak baryogenesis. I will conclude discussing inflation, how this is necessary to solve some of the problems of old cosmology and how this is supported by the current data (though the recent data from the Planck satellite seem to imply some quite strong constraints selecting inflationary models with various drawbacks). I will consider some popular model of inflationary potentials and see how some of them are currently ruled our severely constrained by cosmological observations.

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Part I

Neutrino Physics

Introduction

There are many reasons why neutrinos can be considered quite special among all other elementary particles. This is why the study of neutrino physics presents many attractive specific features. However, even though your research interests can appear quite orthogonal to neutrino physics, there are different motivations to get entangled with neutrino physics in some respect.

First of all neutrinos are a powerful and unique investigative tool in many phenomenological contexts from nuclear physics to the early Universe, from supernovae explosions to colliders. Furthermore there are many reasons to believe that neutrinos are actually telling us much more then it looks like at first sight, encoding some precious information on theories beyond the SM otherwise hardly testable with colliders. It could be that one day we will look at neutrino physics as the Rosetta's stele (or at least an important part of it) to decrypt fundamental puzzles of Nature such as grand-unification, the flavour problem and the matter-antimatter asymmetry of the Universe.