Beta Decay

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Historically, the insight from nuclear beta decay experiments have played a pivotal role in the development of the Standard Model (SM) of fundamental interactions. In these lectures I will present an overview of beta decays from a broader and more modern perspective. The goal is to connect the phenomenology of beta decays to the ladder of effective field theories (EFTs) representing fundamental interactions at different energy scales. I will show how EFTs above and below the electroweak scale, which describe the SM physics as well as hypothetical interactions beyond the Standard Model, can be matched to an EFT of nucleons and nuclei. I will discuss in great detail how the beta decay rates and correlations depend on the parameters of these EFTs at the leading and subleading orders. Some time will be devoted to the possibility of measuring CP violation in beta decays, as well as to the special case of double beta decay.

The important advantage of this EFT framework is the opportunity to compare the sensitivity of different experiments operating in different energy regimes. In particular, one can compare the sensitivity of beta decays (MeV scale), pion and kaon decays (GeV scale), and lepton pair production at the high-energy tail in the LHC (TeV scale). This exercise will also allow me to formulate some general conclusions about the chances of finding new physics in beta decay experiments.

These lectures consist of four parts. The first part is a historical review of beta decays, introducing the most important concepts and observables. The second part discusses the connection between the EFT of beta decays and the quark-level EFTs below and above the electroweak scale. This matching allows one to establish the sensitivity of beta decays to new particles beyond the SM. In the third part this sensitivity is compared to the one achievable in other experiments, which highlights the most promising directions in beta decay research. The final part is focused on CP violation in beta decay and on double beta decay, with the emphasis on understanding which kind of new physics these observables may uncover.