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Neutrino oscillation (student talk)

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Neutrino Oscillations In Quantum Mechanics

Summary

Neutrino oscillation is one of the most exciting subjects in elementary particle physics today. It was rst conrmed in 1998 by the Super-Kamiokande group from their studies of atmospheric neutrinos. Experimental studies of neutrino oscillation have been rapidly progressing since then, and a number of oscillation results have been observed in atmospheric, solar, accelerator, and reactor neutrinos. The implication of the existence of neutrino oscillation is that neutrinos have nite masses and mixings, which are not accounted for in the framework of the standard model of elementary particles. Therefore, the standard model now must be extended to include the new information. Because the neutrino masses are extremely small, it is considered to be unnatural to be included in the standard model similar to the way quark and charged lepton masses are. Therefore, the neutrino oscillation is believed to provide an important new concept that will be a big step toward the unied understanding of elementary particle physics. In this document, we present studies for neutrino oscillation.

1. Neutrino oscillation Neutrino oscillation is a simple quantum mechanical phenomenon in which neutrino changes avour as it propagates. In 1957, Pontecorvo gave the concept of neutrino oscillation based on a two-level quantum system. This hypothesis was nally conrmed by the Super-Kamiokande experiment which presented signicant new data on the decit of muon neutrinos produced in the Earth's atmosphere . Neutrino oscillation can only happen if the neutrinos are massive particle.
2. When the neutrino mass is measured We consider the neutrino oscillation in pion decay into a neutrino and muon. Assume that by measuring energies and momenta of the pion and muon involved in this decay with high precision in each event and we can determine the energy E and momentum p of the emitted neutrino. If the momentum and energy of pion and lepton are observable, the neutrino mass is measurable. But now we have a problem, measuring the muon momentum with extreme precision would destroy the coherence and oscillation of the components of the entangled state corresponding to dierent neutrino mass eigenstates. This result is in accordance with Heisenberg's Uncertainty Principle.
3. Coherence in neutrino oscillation

Since it is not possible to know which mass eigenstate was produced, neutrino avour eigenstates , and are coherent super positions of mass eigenstates . The coherence length is such a distance between the neutrino source and detector at which mass eigenstates i and j are separated by an interval comparable to the size of the wave packet when they arrive at the detector is so large that they cannot be observed coherently. Plane wave treatment cannot describe the coherence of massive neutrinos at a given time and point, in the simple plane wave approach there is no indication of a

coherence length for neutrino oscillations.Coherence between mass eigenstate waves will occur if the momentum dierence
between the dierent mass eigenstates with the same energy, is much smaller than momentum uncertainty. Since neutrino oscilla
tion are a result of interference of amplitude corresponding to dierent mass
eigenstates, absence of their coherence means that no oscillation will will occur.

This means that for existence oscillation the momentum should not be
determined too precisely. The presence of the momentum or energy spread in
the neutrino beam is one of the oscillation existence condition.
The wave packet is a coherent
superposition of dierent waves whose momenta are distributed around the
most probable value, with a certain width or dispersion. Therefore, a wave
packet is localized in space-time as well as in energy-momentum space. A
wave packet treatment of neutrino oscillations is necessary in order to derive
the oscillation probability in a consistent quantum framework, which must
take into account the localization of the production and detection processes
and the associated momentum uncertainties.

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