Precision Measurements of Neutrino Mixing Parameters

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Future very long baseline experiments with intense neutrino beams from neutrino factories will allow high precision measurements of the leading oscillation parameters and a search for the presently undetermined mass and mixing parameters.

The solar neutrino deficit and the results of atmospheric neutrino experiments indicate strongly that, in contradiction to the standard model, neutrinos are massive particles. An extension of the standard model is necessary to describe neutrino masses. New concepts like the discrimination between Dirac and Majorana masses play a role and there has to be found an answer to the question why neutrinos are so light compared to the charged fermions. Supposition for the solution of these problems is a precise knowledge about neutrino masses, mixing parameters and CP-phases. Together with the corresponding quantities in the quark sector this will help to progress the development of a GUT theory.

Neutrino oscillation experiments allow measurements of mass differences and mixing parameters. Introduced to explain the solar neutrino deficit, the oscillation hypothesis is today strengthened by the results of atmospheric neutrino experiments. Based on new technology, experiments are developed today to precisely measure neutrino mass differences and mixing parameters.

Oscillations in the hierarchical three neutrino mass model are parameterized by two mass differences ($\Delta m^2_{\rm atm}$ and $\Delta m^2_{\rm sol}$ with $\Delta m^2_{\rm atm} \gg \Delta m^2_{\rm sol}$), three mixing angles ($\theta_{12}$, θ_{13}, θ_{23}) and the CP-Phase (δ). Thereby ($\Delta m^2_{\rm sol}$ θ_{12}) determine the solar neutrino oscillation whereas ($\Delta m^2_{\rm atm}$, θ_{23}) determine the oscillation of atmospheric neutrinos. For the mixing angle θ_{13} which controls the amplitude of the oscillation $\nu_e \to \nu_\mu$ presently the CHOOZ experiment gives the upper bound of $\sin^2 2\theta_{13} \leq 0.1$.

So called "long baseline experiments" like e.g. K2K (KEK $\to$ Super-Kamiokande, 250 km), CNGS (CERN $\to$ Gran Sasso, 732 km) und MINOS (Fermilab $\to$ Soudan-Mine, 732 km) allow the exploration of the parameter space down to small values of Δm^2 and a more precise measurement of the mixing angles. The determination of the small mixing angle θ_{13} however is out of reach of these experiments. This and high precision measurements will become possible with neutrino factory experiments [1]. Neutrino factories are low energy (≈ 50 GeV) initial stages of muon colliders. They make use of the principle of muon storage rings. In long straight sections of the storage rings, decaying muons produce sharply focused high intensity neutrino beams which allow a number of interesting investigations:

- Precision measurements of the leading oscillation parameters $\Delta m^2_{\rm atm}$ and θ_{23} [2].
- Measurement of the subleading mixing angle θ_{13} and of the sign of the mass squared difference which discriminates between two possible mass hierarchies. These measurements profit strongly from matter effects which appear when neutrinos travel through Earth matter. Hence also a first direct test of the MSW-effect could be performed. [3].
- Measurement of effects from $\Delta m^2_{\rm sol}$, mainly CP-violating effects [4]. A determination of

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the CP violating phase δ in the neutrino sector could be possible.

Detailed studies of the performance of neutrino factory experiments can be found in the listed references and the references therein.

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