STATUS OF NEUTRINO OSCILLATION SEARCHES

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The current status of neutrino oscillation searches with reactors and accelerators is reviewed. An outlook, especially on future long baseline neutrino oscillation projects, is given.

1 Introduction

The existence of massive neutrinos opens up a variety of new phenomena which could be investigated by experiments. One of these is neutrino oscillations. In the simplified picture of two flavour oscillations they can be parametrized by two parameters, $\sin^22\theta$ and $\Delta m^2$. While $\sin^22\theta$ describes the amplitude of the oscillation, $\Delta m^2 = m_2^2 - m_1^2$ determines the oscillation length given in practical units as

$$L = \frac{4\pi E\hbar}{\Delta m^2 c^3} = 2.48\left(\frac{E}{MeV}\right)\left(\frac{eV^2}{\Delta m^2}\right) m$$

(1)

As can be seen, oscillations do not allow an absolute mass measurement and neutrinos must not be exactly degenerated. For a discussion of direct bounds on neutrino masses see [1]. From first principles, there is no preferred region in the $\Delta m^2 - \sin^22\theta$ parameter space and therefore the whole has to be investigated experimentally.

On earth, two artificial neutrino sources exist in form of nuclear power reactors and accelerators. For a more detailed overview see [2].

2 Reactor experiments

Reactor experiments are looking for $\bar{\nu}_e \rightarrow \bar{\nu}_X$ disappearance. Reactors are a source of MeV $\bar{\nu}_e$, due to the fission of nuclear fuel. Experiments typically try to measure the positron spectrum which can be deduced from the $\bar{\nu}_e$ - spectrum and either compare it directly to the theoretical predictions or measure it at several distances from the reactor and search for spectral distortions. Both types of experiments were done in the past. The detection relies on the reaction

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

(2)

[1] to appear in Proc. COSMO’97, Ambleside (UK), September 1997
with an energy threshold of 1.804 MeV. Different strategies are used for the detection of the positron and the neutron. Normally, coincidence techniques are used between the annihilation photons and the neutrons which diffuse and thermalise within 10-100 µs and materials like Gd are then used for neutron-capture. The most recent experiment is CHOOZ in France. Compared to previous experiments, this detector has some advantages. First of all, the detector is located underground with a shielding of 300 mwe, reducing the background due to cosmics by a factor of 300. Moreover, the detector is about 1030 m away from the reactor (more than a factor 4 in comparison to previous experiments) enlarging the sensitivity to smaller $\Delta m^2$. In addition, the main target has about 4.8 t of a specially developed Gd-loaded scintillator and is therefore much larger than those used before. First results can be seen in Fig.1. An upcoming experiment is the Palo Verde (former San Onofre) experiment near Phoenix, AZ (USA). It will consist of a 12 t liquid scintillator also loaded with Gd. The experiment will be located under a shielding of 46 mwe in a distance of about 750 (820) m to the reactors. The experiment will be online by late 1997.

A first long-baseline reactor experiment (KamLAND) using a 1000 t liquid scintillator detector at the Kamioka site in a distance of 150 km to a reactor.
is approved by the Japanese Government. It could start data taking in 2000.

3 Accelerators

Accelerators typically produce neutrino beams by shooting a proton beam on a fixed target. The produced secondary pions and kaons decay and create a neutrino beam dominantly consisting of $\nu_\mu$. The detection relies on charged current reactions $\nu_i N \rightarrow i + X \ (i = e, \mu, \tau)$, where $N$ is a nucleon and $X$ the hadronic final state. Depending on the intended goal, the search for oscillations therefore requires a detector which is capable of detecting electrons, muons and $\tau$ - leptons in the final state. Accelerator experiments are mostly of appearance type working in the channels $\nu_\mu - \nu_X$ and $\nu_e - \nu_X$.

3.1 Accelerators at medium energy

At present there are two experiments running with neutrinos at medium energies ($E_\nu \approx 30 - 50$ MeV) namely KARMEN and LSND. The limits reached so far and the LSND evidence are shown in Fig.2. Recently LSND published their $\nu_e - \nu_\mu$ analysis for pion decays in flight which is in agreement with the former evidence from pion decay at rest. To improve the sensitivity by reducing the neutron background KARMEN constructed a veto shield against atmospheric muons which has been in operation since Feb.1997 and is surrounding the whole detector. The region which can be excluded in 2-3 years of running in the upgraded version is also shown in Fig.2. Also LSND continues with data acquisition.

To test the LSND region of evidence several new projects are planned. The Fermilab 8 GeV proton booster offers the chance for a neutrino experiment (BooNE) which could start data taking in 2001. An increase in sensitivity in the $\nu_e - \nu_\mu$ oscillation channel could also be reached by a proposed experiment at the CERN PS or if there is a possibility for neutrino physics at the planned European Spallation Source (ESS) or the National Spallation Neutron Source (NSNS) at Oak Ridge which might have a 1 GeV proton beam in 2004.

3.2 Accelerators at high energy

High energy accelerators provide neutrino beams with an average energy in the GeV region. Here, at present especially CHORUS and NOMAD at CERN are providing new limits. Both experiments are 823 m (CHORUS) and 835 m (NOMAD) away from a beam dump and designed to improve the existing limits on $\nu_\mu - \nu_\tau$ oscillations by an order of magnitude. The present limits
The final goal is to reach a sensitivity down to \( \sin^2 2\theta \approx 2 \times 10^{-4} \) for large \( \Delta m^2 \). Having a good electron identification NOMAD also offers the possibility to search in the \( \nu_e - \nu_\mu \) channel. The exclusion plot is shown in Fig.2 with a limit of \( \sin^2 2\theta < 2 \times 10^{-3} \) (90\% CL) for large \( \Delta m^2 \). While the CHORUS data taking is complete, NOMAD will continue 1998.

4 Future accelerator experiments

Possible future ideas split into two groups depending on the physical goal. One part is focussing on improving the existing bounds in the eV-region by another order of magnitude with respect to CHORUS and NOMAD and to investigate the LSND evidence. Other groups plan to increase the source - detector distance to probe smaller \( \Delta m^2 \) and to be directly comparable to atmospheric scales.
4.1 Short and medium baseline experiments

Several ideas exist for a next generation of short baseline experiments. At CERN the follow up could be TOSCA, combining features of NOMAD and CHORUS. The idea is to use 2.4 tons of emulsions together with large silicon microstrip detectors within the NOMAD magnet. For TOSCA the option to extract a neutrino beam at lower proton energies (350 GeV) at the CERN SPS exist. At Fermilab the COSMOS (E803) experiment at the new Main Injector is proposed. It will produce a proton beam of 120 GeV resulting in an average neutrino energy of $\langle E_\nu \rangle \approx 12$ GeV. The main target consists of emulsions with a total mass of 865 kg. The distance to the beam dump will be 960 m. Both experiments are designed to improve the sensitivity in the $\nu_\mu - \nu_\tau$ channel by one order of magnitude (Fig.3) with respect to CHORUS and NOMAD and could start data taking at the beginning of the next century. Also proposals for a medium baseline search exist. The present CERN neutrino beam is coming up to the surface again in a distance of about 17 km away from the beam dump offering the chance for an experiment there.

Figure 3: $\nu_\mu - \nu_\tau$ exclusion plot showing the present limits of CHORUS and NOMAD as well as the proposed limits of TOSCA and COSMOS. The shaded region corresponds to the region of an $\nu_\tau$ in the eV-region motivated by dark matter considerations and the quadratic see-saw-mechanism (SSM).
4.2 Long baseline experiments

Several accelerators and underground laboratories around the world offer the possibility to perform long baseline experiments.

KEK - Superkamiokande: The first of these experiments will be the KEK-E362 (K2K) experiment in Japan sending a neutrino beam from KEK to Superkamiokande. The distance is 235 km. A 1 kt front detector, about 1 km away from the beam dump will serve as a reference and measure the neutrino spectrum. The neutrino beam with an average energy of 1 GeV is produced by a 12 GeV proton beam dump. The detection method within Superkamiokande will be identical to that of their atmospheric neutrino detection. The beamline should be finished by the end of 1998 so the experiment could start data taking in 1999. The experiment is of disappearance type. However an upgrade of KEK to a 50 GeV proton beam is planned, which could start producing data around 2004 and allow $\nu_\tau$-appearance searches.

Fermilab - Soudan: A big neutrino program is also associated with the new Main Injector at Fermilab. The long baseline project will send a neutrino beam to the Soudan mine about 735 km away from Fermilab. Here the MINOS experiment will be installed. It consists of a front detector located at Fermilab close to COSMOS and a far detector at Soudan. The far detector will be made of 10 kt magnetized Fe toroids in 600 layers with 4 cm thickness interrupted by about 32000 m$^2$ active detector planes in form of streamer tubes with x and y readout to get the necessary tracking informations. The project could start at the beginning of next century.

CERN - Gran Sasso: A further program considered in Europe are long baseline experiments using a neutrino beam from CERN to Gran Sasso Laboratory. The distance is about 732 km. Several experiments have been proposed for the oscillation search. The first proposal is the ICARUS experiment which will be installed in Gran Sasso anyway for the search of proton decay and solar neutrinos by using a liquid Ar TPC. A prototype of 600 t is approved for installation in 1999. A second proposal, the NOE experiment plans to build a giant lead-scintillating fibre detector with a total mass of 4 kt. It will consist of 4 modules followed by a module for muon identification. A third proposal is a 27 kt water-RICH detector (AQUA-RICH), which could be installed either inside or outside the Gran Sasso tunnel. Finally there exists a proposal for a 1 kt iron-emulsion sandwich detector (OPERA). It could consist of 2240 modules arranged in 140 planes each containing 4 × 4 modules. It is also under consideration for the Fermilab-Soudan beam.
5 Summary and Conclusion

Massive neutrinos allow a wide range of new phenomena in neutrino physics, especially that of neutrino oscillations. Evidence for such oscillations comes from solar neutrinos, atmospheric neutrinos and the LSND experiment. Terrestrial neutrino experiments in form of nuclear reactors and high energy accelerators already exclude large parts of the parameter space because of non-observation of oscillation effects. Because the region of the MSW-solution for solar neutrinos are out of range for terrestrial experiments, current and to a large extend future oscillation experiments are motivated by the atmospheric neutrino deficit, an eV-neutrino as dark matter candidate and a proof of the LSND results.

6 References

1. D. Caldwell, these proceedings
2. K. Zuber, Proc. 4 Int. Solar Neutrino Conference, Heidelberg, 9.-11. April 1997, hep-ph/9706364
3. H. de Kerret et al.,The CHOOZ Experiment, Proposal, LAPP Report (1993), M. Apollonio et al., hep-ex/9711002
4. G. Gratta, Proc. Neutrino'96, p.248, World Scientific 1997
5. M. Nakahata, Talk presented at Conf. EPS'97, Jerusalem, Aug. 1997
6. J. Kleinfeller, these proceedings
7. R. Imlay, these proceedings
8. Updated information: [http://www.neutrino.lanl.gov/BooNE/](http://www.neutrino.lanl.gov/BooNE/)
9. N. Armenise, et al., CERN-SPSC-97-21
10. J. Herin, these proceedings
11. A.S. Ayan et al., CERN-SPSC-97-5
12. K. Kodama et al., COSMOS coll., Fermilab-Proposal P803 (1993)
13. J.P. Revol et al., Proposal ICARUS-TM-97/01, D. Autiero, et al., CERN-SPSC-97-23
14. Y. Suzuki, Proc. Neutrino’96 (Helsinki) p.73, World Scientific 1997, KEK-E362 at [http://pnahp.kek.jp/](http://pnahp.kek.jp/)
15. E. Ables et al., MINOS coll., Fermilab-Proposal P875 (1995)
16. C. Rubbia, Nucl. Phys. B (Proc. Suppl.) 48, 172 (1996)
17. M. Ambrosio et al., Nucl. Instrum. Methods A 363, 604 (1995)
18. T. Ypsilantis et al., Preprint LPC/96-01, CERN-LAA/96-13
19. H. Shibuya, et al., CERN-SPSC-97-24