GDR-NEUTRINO

FRENCH NEUTRINO ROADMAP (2006)

The proposed roadmap in this document is part of the activity report of the CNRS/CEA "Groupement De Recherche" neutrino (GDR-neutrino, http://gdrneutrino.in2p3.fr/) and is based on physics results and extrapolations in the future, subjects largely discussed within the working groups of the GDR. More particularly, the future projects on neutrino oscillations concentrate on the observation of the oscillation $\nu_\mu \rightarrow \nu_e$, the measurement of the " missing" angle θ_{13} and on the observation of double beta decay without neutrino emission. This roadmap also fits in a certain continuity with the participation of the French groups in the passed projects like Gallex, Chooz, NOMAD and the "double beta" projects. It will be brought up to date according to new experimental and theoretical results in the field of neutrino physics and following new ideas of experiments in this same field.

A. PRESENT PROJECTS

The projects in progress studying the neutrino properties in which French teams play an important role are:

- NEMO3: Observation of double beta decay without neutrino emission. This experiment in progress tries to determine the neutrino nature, Dirac or Majorana, and consequently give information on the neutrino mass absolute scale (sensitivity $\langle m_\nu \rangle < 0.7$ eV). NEMO3 proposes to take data until 2010. We consider this physics program essential for the comprehension of the neutrino properties and a constant support must be brought to this project in which France plays a leading role.

- OPERA: Observation ν_τ appearance in a ν_μ beam. This project will start gradually by this year and will take data during 5 years to observe in total about fifteen $\nu_\mu \rightarrow \nu_\tau$ events. The observation of this oscillation in a direct way is necessary to stop any other speculation in this subject. It is also necessary to note the perfect complementarity of this experiment with the MINOS experiment which will precisely measure the parameters of the same oscillation.

NEMO, and soon OPERA, will be the only projects in data taking phase, moreover European, where French teams have an important contribution. These teams, attracting PhD students and young researchers, must be supported. A policy of recruitment of young researchers for the next years must be established to reinforce this projects and to ensure the future of the French neutrino community.

In addition, in the landscape of the experiments with a French participation which will start taking data in the near future, it is also necessary to include Borexino.

- Borexino: Direct detection of low energy solar neutrinos and neutrinos from supernovae explosions. This experiment underwent a delay of more than two years due to security reasons at the LNGS underground laboratory. The water filling has already started and it is expected to start filling with scintillator by January 2007, in this way the detector could start taking data during 2007. Such an experiment could also attract PhD students working on subjects complementary to the ones of the two above experiments especially on low energy neutrino astronomy.

B. SHORT-TERME PROJECTS

These projects are approved or on the way to be by IN2P3 and CEA.

- Double-Chooz: This experiment on a nuclear plant proposes to observe the oscillation $\overline{\nu}_e \rightarrow \overline{\nu}_\mu$ and, in absence of signal, to put a more strict limit (sensitivity $\sin^2 2\theta_{13} > 0.03$) that the existing one ($\sin^2 2\theta_{13} < 0.15$) on the oscillation angle θ_{13}. The great interest of this experiment lies in the fact that it can be done quickly (first results at the end of 2008) and thus, guide future projects proposed to measure θ_{13}. The project, taking place in France, with a recognized French leadership, must have a strong support by IN2P3 and CEA.

- T2K phase I (sensitivity $\sin^2 2\theta_{13} > 0.01$): This project, located in Japan, using an intense proton beam would enter in operation after Double-Chooz to observe for once again the oscillation $\nu_\mu \rightarrow \nu_e$. The beginning of data taking is planned for the end of 2009 and will last for at least 5 years, before passing to a second phase with an even more intense proton beam. This experiment will also help to better define the characteristics of future neutrino beams coming after 2015 (super-beam, beta-beam, neutrino factory). The French groups concentrate their effort on the design and the construction of the "near" detectors.

C. MEDIUM-TERM PROJECTS

For projects beyond 2011, not relating to the future neutrino beams, the GDR considered the following subjects:

- Second generation experiments on nuclear plants (sensitivity $\sin^2 2\theta_{13} > 0.01\text{-}0.02$): This step will depend on the results of the preceding projects (Double-Chooz, T2K, Nova). These projects could be Triple-Chooz or Daya Bay (in China).

- Super-NEMO (sensitivity $< m_N > > 50$ meV): Currently, R&D is carried out primarily within IN2P3 to improve the performances of the "traco-calo" technique already used by NEMO3. This R&D concentrates on the enrichment of the isotopes used, on low radioactivity materials and on the improvement of the energy resolution of plastic scintillator. These studies will continue until the end of 2008, at the end of this period, following the results obtained, a decision must be taken concerning the feasibility of the Super-NEMO experiment.

D. LONG-TERM PROJECTS

For projects by 2015, concerning the future neutrino beams, the GDR considered and supports the following subjects:

- CERN To Fréjus (C2F): super-beam project based at CERN coupled to a remote detector located at the underground laboratory of Modane in the Fréjus tunnel. This large volume facility is proposed to use, for an intense neutrino beam production, a very intense proton beam of 4 MW. This "proton driver" could be part of the CERN infrastructure and could also be used for other projects. This project requires the presence of a large megaton detector (MEMPHYS) which could be placed in an enlargement of the underground laboratory of Fréjus. Two axes of R&D are already launched, concerning the neutrino beam (feasibility of the proton driver, of the hadron collection system and the target) and the detector (excavations, photodetectors, fluids to be used).

- Beta-beams ("low γ"<250): project based at CERN coupled to a remote detector in Fréjus tunnel. It consists of producing intense neutrino beams with a better defined energy and an increased purity compared to the technique of super-beams, using beams of β emitter radioactive ions like, e.g., ^{6}He for anti-neutrinos and ^{18}Ne for neutrinos. This facility could be part of EURISOL project concerning the production of radioactive elements. It could use thereafter the existing CERN infrastructures and direct its neutrino beam towards the same detector as that of C2F project.

Many studies showed the complementarity between the projects C2F and beta-beams and the power of the combination of the results of the two projects in the field of the measurement of θ_{13} (sensitivity $\sin^2 2\theta_{13} > 0.002$) and of the CP violation in the lepton sector.

For these two projects, the availability of a megaton detector offers synergy possibilities with "non accelerator" physics: proton decay and supernovae neutrinos in particular.

E. PROJETS IN THE VERY LONG TERM

Concerning the projects to come after 2020-2025 ($\sin^2 2\theta_{13} < 0.01$), the GDR considered the following subjects:

- Neutrino Factory: This project proposes to use an intense neutrino beam produced by a beam of muons suitably accelerated. This technique never used up to now, requires an intense R&D to prove its feasibility. The project could largely profit from the experience gained on proton drivers previously developed for the super-beam projects. It also will be able to benefit from the physics results of the two preceding projects (super-beam and beta-beams) for better adjustment of its parameters and thus optimizing its physics performance. On the other hand, the "modest" size detector (50 kt) offers limited possibilities in the field of "non accelerator" physics.

- Beta-beams ("high γ">250): This project requires a certain R&D concerning the production of a high γ beam. It will be the continuation of "low γ" project and it will be able to largely benefit from the gained experience of the latter. The two projects "neutrino factory" and "high γ" beta-beams, will primarily allow to measure precisely the CP violation with even a very low θ_{13} value.

Considering currently existing technological uncertainties, the construction costs and the extent of the tasks, the GDR prefers to recommend a time "staging" of the various projects on intense neutrino beams. The next "proton driver", necessary to these three projects and to other independent projects, can be built relatively early and hence, this will immediately open in Europe the way to super-beams and to the MEMPHYS project, in good synergy with other programs of "non accelerator" physics. The beta-beam project coupled to the EURISOL project could come a little later according to the decision calendar of EURISOL. The most ambitious and expensive project, still requiring a significant R&D, is that of the Neutrino-Factory.

Go directly towards a construction of a Neutrino-Factory ("Fast Track" option) which construction is placed beyond 2020 does not appear a good solution on the scientific and strategic point of view. An absence of European projects for a so long time would pose major problems for the renewal of the neutrino community in Europe and more particularly in France. Also, the participation in projects located in Japan or the USA during a so long European R&D period for a possible neutrino factory, would not be very easy.

The approach of the problem by steps has the advantage of better adjusting the parameters of the following steps according to the previously obtained results. The MEMPHYS project, necessary to the first stages, also opens the way to other studies related to neutrino oscillations (solar and atmospheric neutrinos) or not (proton decay, neutrinos coming from supernovae explosions) supporting the interaction with other communities.

Concerning the R&D, necessary to the future intense neutrino beam projects (super-beams, beta-beams, neutrino factory), it would be judicious to be separated in technological lines carried out in parallel by well identifying their common parts which could be developed in good synergy by various groups. The financing requests could go in this same direction without opposing the three projects the ones against the others.

The GDR is also favorable to the continuation of the “very high energy neutrino” projects using the neutrino as a probe of the universe but which could also give significant information on the neutrino properties. These projects are mainly considered by the GDR PCHE.