Available online at www.sciencedirect.com

SCIENCE DIRECT®

Nuclear Physics B (Proc. Suppl.) 145 (2005) 87–92

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

www.elsevierphysics.com

Neutrino long base line experiments in Europe

F. Ronga[a]

[a]INFN Laboratori Nazionali di Frascati
P.O. box 13, Frascati(Rome) Italy

A short summary of the past, present and future neutrino experiments in Europe is given. The main emphasis is on long base line accelerator experiments.

1. MOTIVATIONS FOR LBL EXPERIMENTS

Neutrino oscillations[1] were suggested by B. Pontecorvo in 1957 after the discovery of the $K^0 \leftrightarrow \overline{K^0}$ transitions and later by Maki, Nakagava and Sakata[2]. In 1968, the first experimental results from the Homestake detector showed a deficit in the solar neutrino flux: the value was at the level of 1/3 of the expected one[3]. This was the first hint of neutrino oscillation. After more than 30 years neutrino oscillations are now firmly established, thanks mainly to the atmospheric neutrino and to solar neutrino experiments.

The most common parameterization of the PMNS 3×3 unitary mixing matrix U for three neutrino flavors in vacuum is written separating U in 4 matrices[4]:

$$U = R_{23}\, W_{13}\, R_{12}\, D(\lambda_{21}, \lambda_{31}) \qquad (1)$$

$$R_{23} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}$$

$$W_{13} = \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\varphi_{13}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\varphi_{13}} & 0 & c_{13} \end{pmatrix}$$

$$R_{12} = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

with $c_{ij} \equiv \cos\vartheta_{ij}$, $s_{ij} \equiv \sin\vartheta_{ij}$, where ϑ_{12}, ϑ_{23}, ϑ_{13} are the three mixing angles, φ_{13} is the Dirac phase and $D(\lambda_{21}, \lambda_{31}$ is the diagonal matrix with Majorana phases λ_{21},λ_{31}. It can be shown that these phases cancel out in all oscillation formulas.

The first matrix R_{23} is related to the oscillations $\nu_\mu \to \nu_\tau$ and has been detemined mainly with the atmospheric neutrino experiment on a terrestrial path-length (100-10000 km). The third matrix R_{12} is related mainly to the oscillations $\nu_\mu \to \nu_e$ and has been studied with solar neutrino experiments and reactor experiments. The angle and the CP violating Dirac phase of the third matrix W_{13} should be determined with future experiments looking to subdominant $\nu_\mu \to \nu_e$ effects on terrestrial base line. So far the limits have been obtained mainly with the CHOOZ experiment.

Long base line future neutrino experiments should be dedicated to the study of the matrix W_{13}, to increasing the accuracy of the measurement of the matrices R_{23} and R_{12} and to checking of the oscillation mechanism looking to the ν_τ appareance in a ν_μ beam.

Other important informations should come from non accelerator experiments. The Katrin experiment[5] has a sensitivity of the order of 0.2 eV to the direct measurement of the neutrino mass: an interesting value because it is lower than the value suggested in a neutrinoless double beta experiment [6]. Future experiments searching for neutrinoless double beta decays, allowed if neutrinos are Majorana particles, are sensitive to mass lower than 0.2 eV. This is the standard scenario at the moment. Of course, if the LSND effect is confirmed, this will imply major changes in this scenario.

0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2005.03.041

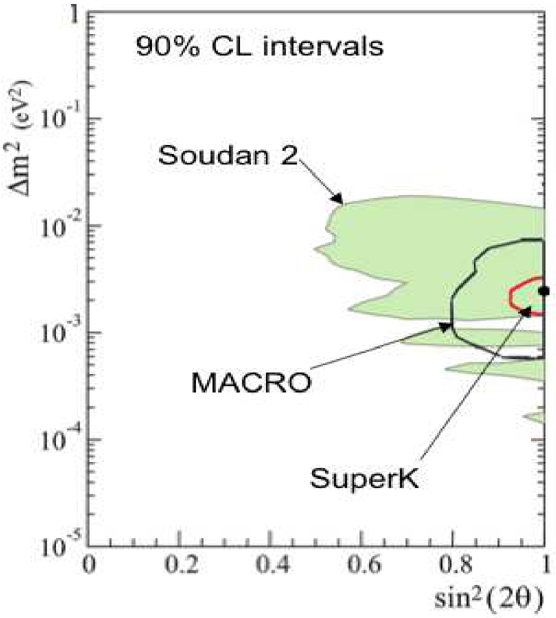

Figure 1. The 90% $\nu_\mu \rightarrow \nu_\tau$ MACRO C.L. allowed regions computed combining all data, compared to Soudan2 and Superkamiokande[9]. The black point indicates the MACRO highest probability peak in the physical region corresponding to $\Delta m^2 = 0.0023 eV^2$ with 1σ interval [0.001,0.0065] eV^2.

2. PAST EXPERIMENTS IN EUROPE

Neutrino oscillations have been studied in many past experiments in Europe: NOMAD and CHORUS searching for neutrino oscillation over a short distance at CERN, GALLEX , GNO (at the Gran Sasso) and SAGE (Baksan Laboratory in Russia) searching for solar neutrino oscillations, CHOOZ (France) using reactor electron neutrinos and MACRO (Gran Sasso) searching for neutrino oscillation using the atmospheric neutrinos.

The GALLEX 30-ton Gallium neutrino experiment was dedicated to the search for germanium atoms produced by solar neutrino interaction in a GaCl3 liquid solution in water and HCl. The reaction is $71Ga(n_e, e^-)71Ge$ with a threshold of 233 keV. About 53% of interactions are due to pp neutrinos. GNO started in 1998 with a subset of the GALLEX collaboration after the end of GALLEX. GNO concluded in December 2003. The 50-ton metallic gallium SAGE started to take data in 1990 and is still running.

The combination of all the 1990-2003 GALLEX/GNO/SAGE data gives 68.1 $\pm$ $3.65_{stat} \pm 5.5_{sys}$ SNU to be compared with the predicted $127^{+12}_{-10} SNU$ for no oscillation giving very strong support to the neutrino oscillation[7].

The MACRO (Monopole and Cosmic Ray Observatory) experiment has been collecting data starting from 1989 with a small fraction of the detector and starting in 1995 with the full detector. Data taking ended in December 2000. The final analysis for atmospheric neutrino oscillation, containing analysis of the different event topologies has recently been published[8], and Figure(1) shows the 90% MACRO C.L. regions for $\nu_\mu \rightarrow \nu_\tau$ oscillations computed combining all the different event topologies.

3. THE GRAN SASSO LABORATORY AND THE CERN NEUTRINO BEAM

The Gran Sasso laboratory is the largest general purpose underground laboratory in the world for experiments in particle physics and nuclear astrophysics. It is used as a worldwide facility by scientists, at present: 750 in number, from 22 different countries, working on about 15 experiments in their various phases. The main research topics of the present programme are: neutrino physics with neutrinos naturally produced in the Sun (BOREXINO) and in Supernova explosions (LVD), neutrino oscillations with a beam from CERN (CNGS program, ICARUS and OPERA), search for neutrino mass in neutrinoless double beta decay (CUORE,CUORICINO,GENIUS,HDMS) dark matter search (DAMA,COBRA) and nuclear reactions of astrophysical interest (LUNA, LUNA2). The current allocation of the space in the experimental halls is shown in Figure 2.

The BOREXINO solar neutrino detector has 1300 tons of scintillator and 2400 tons of water.

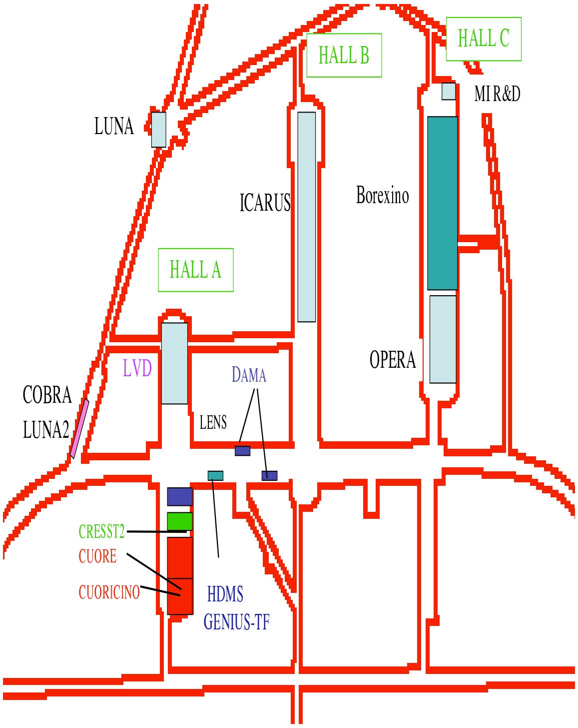

Figure 2. Gran Sasso Laboratory experimental halls and space allocation

The experiment is designed to detect the almost monocromatic solar neutrinos coming from the ^7Be line.

In summer of 2002 an accident occurred to the Borexino group: about 50 litres of pseudocumene leaked into the external environment from the Hall C of the LNGS where the experiment is being installed. The accident occurred in the midst of heated local debate about the safety tunnel project and in October 2002 the Borexino detector was sequestrated by the prosecuting magistrate of Teramo. In May 2003 some tests originated strong doubts upon the water-tightness of the draining system of the Highway and the Gran Sasso laboratory. INFN decided as a precaution to suspend the activities involving manipulation of any kind of liquid and asked for immediate intervention of the government authorities. In the same day the entire Hall C was placed under judicial attachment by the magistrate. In June 2003 the Council of Ministers declared the State of Emergency for the Gran Sasso facility (road tunnels, experimental halls, water system). This allowed radical and urgent technical intervention by a government authority (Commissioner), without bureaucratic delays. The summer of 2004 saw the end of the judicial attack and the laboratory is again in almost normal conditions.

The CERN CNGS neutrino beam was designed to provide unambiguous evidence for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the region of atmospheric neutrinos by looking for ν_τ appearance in a pure ν_μ beam. The energy $< E_\nu >= 17 GeV$ was chosen to optimize the number of ν_τ over a pathlength of 732 km. The main features of the beam are in Table 1. An upgrade of this beam is planned. The increase of the CNGS intensity is possible performing a double batch injection from the CERN PS (protosincroton) booster to the PS. It is also necessary to reduce beam losses during the PS extraction to avoid radiation problems. In this way the proton intensity could increase by a factor 1.5.

Beam construction is proceeding according to the original time schedule. The civil engineering, hadron stop, decay tunnel at CERN are completed. The first beam will be in May 2006.

$< E\nu_\mu >$	17 GeV
ν_τ prompt	negligible
$(\nu_e + \overline{\nu_e})/\nu_\mu$	0.87%
$\overline{\nu_\mu}/\nu_\mu$	2.1%
$< L/E >$	43 km/GeV
ν_μ CC/kton/year	2450

Table 1
The CERN Gran Sasso beam (CNGS), rates assuming the approved 4.5×10^{19} protons on target /year (maximum 7.6×10^{19}) without intensity increase.

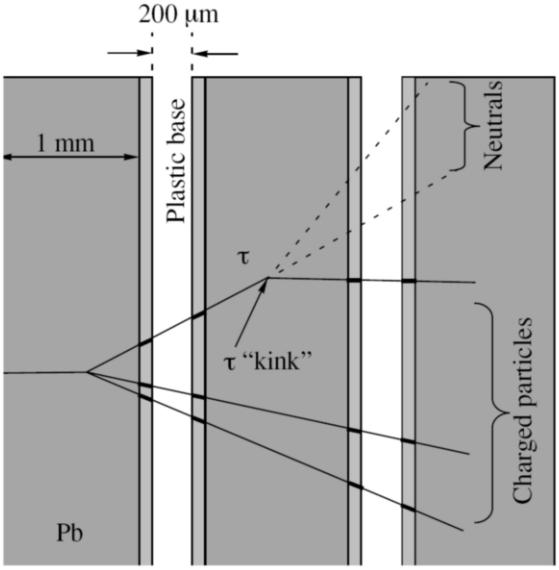

Figure 3. OPERA: the τ detection principle

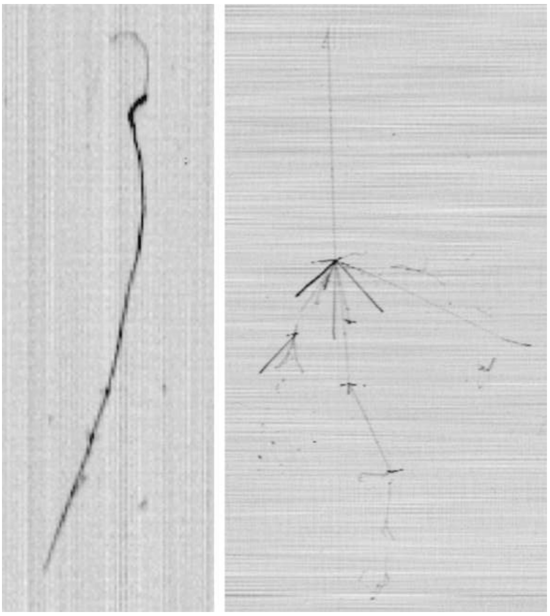

Figure 4. Cosmic rays in ICARUS T600: a decaying muon(left) and a hadronic interaction

4. OPERA AND ICARUS

OPERA and ICARUS will use the CNGS beam to detect the ν_τ produced by neutrino oscillations. Although neutrino oscillations are now considered to have been established I believe that is very important to clarify all the points concerning this process: for example at the moment there is no clear evidence for a sinusoidal pattern in the oscillations and no evidence for the apparition of ν_τ. This measurement is possible only with CNGS because MINOS and T2K will have low energy beams unable to produce $\nu_\tau' s$. Both detectors also have good electron identification. This allows for a good sensitivity to the ν_e appareance even if this search is not the one optimized for the beam energy.

The OPERA [10] experiment will use the CNGS beam and a hybrid detector to perform direct observation of $\nu_\tau' s$ with a very low background. In order to detect $\nu_\tau' s$ OPERA will detect τ leptons produced during these interactions. An unambiguous signal of the presence of $\tau' s$ in the detector will be the precise detection of the τ decay topology. To this end, OPERA will use lead foils as target and nuclear emulsions for charged track detection. This technique is able to give track reconstruction accuracy (better than one micron) needed to detect the τ decay point (kink), while allowing for coverage of large surfaces and a high target mass. The detection principle is depicted in Figure 3. The neutrinos interact with the 1 mm thick lead target plates and the charged tracks are detected by the $50\mu m$ emulsion films, with a spatial resolution of about $0.5\mu m$. In addition to the emulsion detectors OPERA will have electronic detectors and a magnetic spectrometer. The main role of the electronic detectors will be to select the emulsion to be scanned in order to identify the τ.

OPERA construction will end on time for the first neutrino beam planned in 2006. Assuming $\Delta m^2 = 0.0024 eV^2$ the number of detected τ will be 10.5 against a background of 0.7 in 5 years of data taking at the nominal planned intensity of 4.5×10^{19} protons on target per year without considering the increase in proton intensity. The limit of $sin^2(2\theta_{13})$ at 90% C.L. will be 0.06.

The ICARUS Collaboration has developed,

over a long duration R&D programme, the Liquid Argon Time Projection Chamber (LAr TPC) technology having as goal a 3000 Ton detector[11]. Current state of the art is represented by a 600ton detector (T600), which was built using fully industrial methods in about 5 years from 1997 to 2001. During 2001 the detector was activated and fully tested in a 3-month run, taking cosmic rays data in the assembly hall located in Pavia (Italy). The quality of the recorded data (see Figure 3), subsequently analyzed during 2002-2003, demonstrates that the detector performances are consistent with those of laboratory sized prototypes. ICARUS is like an electronic bubble chamber with bubble size of the order of $3 \times 3 \times 0.4 mm^3$.

Installation of the T600 detector in the Gran Sasso laboratory will start in December 2004. The T600 commissioning will be carried out during 2005. INFN has already approved and financed a second module having 1200 Tons of liquid argon.

The main physics issues of the ICARUS experiment are the search for neutrino oscillations with direct observation of atmospheric and beam neutrinos and search for nucleon decay. In addition ICARUS is also sensitive to solar and supernova neutrinos. Assuming $\Delta m^2 = 0.0025 eV^2$, a total fiducial mass of 2.35kton and 4.5×10^{19} proton on target per year in 5 years the number of detected τ will be 11.9 against a background of 0.7. The limit of $sin^2(2\theta_{13})$ at 90% C.L. combined with the one of OPERA will be 0.03 [12].

There is a strong R&D program with the ICARUS techniques to realize neutrino near detectors of of mass of the order of 100 Tons or giant detectors of mass of the order of 100000 Tons for future generation proton decay or neutrino oscillation experiment[13].

5. FUTURE EXPERIMENTS AND BEAMS

The goal of the future experiments with beams is to measure θ_{13} and in the case of non zero values to study CP violation effects in the lepton sector. To compare different experiments it must be considered that in equation (1) the value of $\sin\vartheta_{13}$ is correlated with the value of the phase φ_{13}. This means that the sensitivity in θ_{13} depends on the value of φ_{13}. Matter effects in the path between production and detection could also be important for the purpose of comparison.

A possible way to measure θ_{13} is using neutrinos produced in reactors, looking for $\overline{\nu}_e$ disappareance. In this case there is no correlation between θ_{13} and φ_{13} and matter effects are small. The systematic errors in reactor experiments to measure θ_{13} could be reduced using two identical detectors at different distances. This is the basic idea of the DOUBLE CHOOZ proposal [14]. The far detector will be at the site of the original CHOOZ, in France, experiment at a distance of 1050 m, the near detector will be at a distance of 100-200 m from the nuclear core. Assuming $\Delta m^2 = 0.0024 eV^2$ the sensitivity will be $sin^2(2\theta_{13}) < 0.02$ at 90% C.L for any value of φ_{13}.

A possible evolution of the CNGS beam is described in reference[15]. The idea is to build an a underwater detector with a few thousand photomultipliers in the Gulf of Taranto to measure θ_{13}. However the technology of this kind of detector is a great leap forward from the one used in the existing detectors.

Several new neutrino beams have been proposed: conventional neutrino beams of very high intensity (superbeams), neutrino produced by beta decay (beta beams) and neutrino produced by muon decay in muon storage rings (neutrino factories). Several talks in this conference are dedicated to the argument[18].

Recently a letter of intent has been presented for a super beam and a beta beam from CERN pointing at a Megaton Cherenkov water class detector in the Frejus area[16]. The technology is the one used in SuperKamiokande to detect the Cherenkov light. There are two possible ways to overcome the problem due to the attenuation of light in water : a giant UNO like detector with only one detector but with several sensitive layers or three independent detectors. This detector will have a good non accelerator physics potential (proton decay, relic neutrinos, supernova neutrinos ecc).

Liquid Argon could be an excellent alternative to water, having a lower energy threshold and a much better event topology, provided that the ICARUS technology could be scaled to the 100 kton[13].

In terms of sensitivity to θ_{13} (at $\varphi_{13} = 0$), such experiment could improve by a factor 5 the T2K sensitivity measuring ν_e appearance in the ν_μ SPL-SuperBeam neutrinos , by a factor 8 when using the Beta-Beam (ν_μ appearance in a ν_e beam) and by a factor 9 combining the two beams. These sensitivities are computed for 5 years data taking. CP violation could be established for θ_{13} of the order of few degrees. However, the cost of this complex is quite high (of the order of 10^9 Euros), the energy resolution is smeared by Fermi motion (due to the low beam energy) and there is no way to measure the sign of Δm^2.

Currently there is some debate in Europe on the best strategy for the future of neutrino physics. Various study groups are working inside the European program CARE for new particle accelerators. One of the programs inside CARE is the study of new neutrino beams. The main message that is coming is that future facilities will be very expensive and that a strong worldwide strategy will be necessary. Moreover since there are no firm theoretical prediction on the value of θ_{13}[19] it is particular import to avoid duplication and to try to set a multipurpose program to have a "bread and butter" physics output.

It is also important to remember in this discussion the relevance of non accelerator experiments, particularly the neutrino-less double beta experiment and the direct mass experiment. In addition to the experiments in the Gran Sasso laboratory there are neutrinoless double beta experiments in the Frejus laboratory (NEMO3) and in the Canfranc laboratory (IGEX). The size of this kind of experiments will increase in the future and some competition for the financial resources could occur. Competition could also occur with the planned km^3 underwater neutrino detector in the Mediterranean sea for neutrino astronomy.

Workshop like this are important to understand all the problems involved in designing such a strategy and help to establish a strong community, with a common view of the problem.

REFERENCES

1. B. Pontecorvo J.Exptl. Theoret. Phys. 33, 549 (1957), Z. Maki, M. Nakagava and S. Sakata, Prog. Theor. Phys. 28, 870 (1962).
2. S. M. Bilenky, arXiv:hep-ph/0410090.
3. Davis R. et al.: Phys. Rev. Lett. 20,(1968) 1205.
4. C. Giunti, arXiv:hep-ph/0409230.
5. A. Osipowiczetal. (KATRINCollab.), FZKAreport6691, hep-ex/0109033
6. H. Klapdor-Kleingrothaus : these procedings
7. C. Cattadori. Neutrino 2004 conference (Paris)
8. M. Ambrosio *et al.* [MACRO Collaboration], Eur. Phys. J. C 36, 323 (2004) and G Giacomelli in this conference.
9. H Gallagher Neutrino 2004 conference
10. OPERA Collab., Experiment Proposal, CERN-SPSC-2000-028 and LNGS P25/2000 (2000) and G Rosa in this conference
11. C.Rubbia, CERN-EP/77-08(1977) and Icarus collaboration , a second generation proton decay experiment and neutrino observatory at the Gran Sasso Laboratory, LNGS-P28/2001
12. M. Komatsu, P. Migliozzi and F. Terranova, J. Phys. G 29, 443 (2003) [arXiv:hep-ph/0210043].
13. A. Rubbia Now2003 Workshop on Neutrinos in Venice , 2003 hep-ph/0402110
14. G. Mention: The Double Chooz experiment in this conference [15]
15. R. Voss, CERN-OPEN-2004-005 Prepared for 2nd International Workshop on Neutrino Oscillations in Venice (NO-VE 2003), Venice, Italy, 3-5 Dec 2003
16. L. Mosca, A European Megaton Project at Frejus talk at TAUP2003.
17. M. Mezzetto, arXiv:hep-ex/0410083.
18. J.J Gomez-Cadenas, M Mezzetto, P. Migliozzi: these proceedings
19. F Feruglio: these procedings