The experimental programme with the CNGS neutrino beam

A. Ereditato[a]

[a]INFN Naples, Italy

1. The CNGS neutrino beam

The experimental results on the atmospheric neutrino anomaly [1] motivated the design of a series of facilities able to provide neutrino beams for LBL experiments [2–4]. Here, we briefly describe the design and the experimental programme of the CNGS beam [4] from the CERN SPS towards the Gran Sasso Laboratory located underground in central Italy 732 km from CERN. The project has been approved by CERN and INFN in 1999, the civil engineering work started in October 2000, and the commissioning is expected in the year 2005.

The neutrino beam is produced by the decay of π and K mesons originating from the high energy, high intensity SPS proton beam hitting a production target. The total length of the proton beam from the SPS to the CNGS target is 830 m and its momentum 400 GeV/c. The target design profits from the experience of the former CERN-WANF beam. 13 rods of graphite 10 cm long and 4 mm diameter each form a 2 m long target array. The change from beryllium (WANF) to graphite has been motivated by the change from fast-slow (6 ms) to fast (10 μs) proton beam extraction and by the better thermo-mechanical properties of graphite. The WANF experience is also at the origin of the choice for the focusing elements, the horn and the reflector, two coaxial lenses similar in shape but different in size. The distance of horn and reflector from the target as well as the shape of the magnetic field are chosen to optimise a wide-band high-energy ν_μ beam. The typical π decay lengths (2.2 km at 40 GeV) make a long decay tunnel desirable. Given the angular distribution of the parent mesons which can produce neutrinos, the longer the decay tunnel the larger has to be its diameter. A tunnel of 2.45 m diameter and 1000 m length has been chosen for the CNGS. A massive iron beam dump is situated at the exit of the decay tunnel. Signals induced by muons from meson decays in arrays of silicon detectors placed in the hadron stopper allow on-line monitoring and tuning of the beam.

The experimental programme at the CNGS is focused towards $\nu_\mu \leftrightarrow \nu_\tau$ appearance. Since the appearance of the ν_τ is detected through its charged current (CC) interaction with the experimental target, its energy must be sufficient to produce the τ partner. This sets a lower limit on the energy of the neutrino beam. The threshold to produce a τ is $\sim$3.5 GeV and the ratio of cross-sections (σ_τ/σ_μ) increases slowly with the energy. High energy beams are therefore more suitable for a $\nu_\mu \leftrightarrow \nu_\tau$ appearance search. On the other hand, the oscillation probability is higher for low energies of the ν_μ. The optimisation for $\nu_\mu \leftrightarrow \nu_\tau$ oscillation searches has led to the design of the CNGS reference beam design developed by a CERN/INFN Technical Committee [5]. The expected yield of interacting ν_τ computed for Δm^2=3.5$\times$10^{-3} eV^2, for full mixing and with standard sets of neutrino cross-sections is 6.7/[10^{19} protons on target (pot)$\times$kton]. Details on the CNGS beam expected performance can be found in [5]. A running scheme called *shared* [5] foresees an average of 4.5$\times$10^{19} pot/year. The number of pot/year goes up to 7.6$\times$10^{19} with the so-called *dedicated* mode which assumes no SPS users other than the CNGS. Concerning the scientific programme at the Gran Sasso Laboratory, the choice of a beam optimised for a $\nu_\mu \leftrightarrow \nu_\tau$ appearance search is reflected in the experiments which are being envisaged, namely ICARUS [6] and OPERA [7]. Both experiments focus on the

τ detection. ICARUS exploits a kinematical selection of the signal. OPERA aims at the direct detection of the τ topology.

2. Status of the ICARUS project

The aim of the ICARUS Collaboration [6] is the construction of a liquid argon time projection chamber (TPC) detector with a space resolution comparable to that of bubble chambers. The ICARUS physics programme includes decay-mode independent proton decay search, model-independent solar neutrino flux measurements as well as search for oscillations with atmospheric and accelerator neutrino beams [8].

The working principle of the ICARUS detector is simple. A large liquid argon volume is contained in a cryostat equipped with two wire readout planes (one at each end of the volume) and a high voltage plane at the center giving a long drift length. Ionisation electrons produced by charged particles crossing the liquid argon are collected at the readout planes. The arrival time of the different electrons allows the reconstruction of the particle track trajectory by the time projection technique. Each readout plane has three coordinates at 60° from each other and wire pitch of 3 mm. This corresponds to a *bubble* diameter of about 3 mm. This was the bubble size of the Gargamelle detector at CERN. The detector is a homogeneous tracking device capable of dE/dx measurement. Its high dE/dx resolution allows good momentum measurement and particle identification of soft particles. Electromagnetic and hadronic showers are, in fact, fully sampled. ICARUS features excellent electron identification and e/π^0 separation.

An extensive R&D programme has been undertaken by the ICARUS Collaboration to thoroughly study the detection technique. A small prototype (50 liters) of the ICARUS detector has been successfully exposed to the CERN WANF neutrino beam. Recently, a 15 ton prototype (10 m^3) has been made operational at the Gran Sasso Laboratory. With this detector, the cryostat operation, the wire chambers, the liquid Argon purification, the trigger and the readout electronics will be studied. A larger module of 600 ton is under construction and expected to be operational at the Gran Sasso Laboratory in the year 2001. Its layout is schematically shown in Fig. 1.

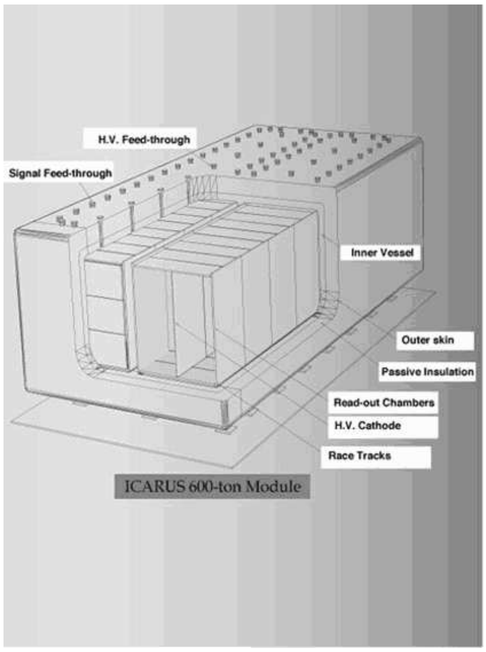

Figure 1. Schematic view of the ICARUS 600 ton module.

3. The OPERA experiment

The OPERA experiment has been proposed [7] for an appearance search of $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in the CNGS beam, in the parameter region indicated by Super-Kamiokande as the explanation of the zenith dependence of the atmospheric neutrino deficit. The detector is based on a massive lead/nuclear emulsion target. Emulsions films are used as high resolution tracking devices, for the direct observation of the decay of the τ leptons from ν_τ CC interactions. Electronic detectors (scintillator strips readout by WLS fibres) locate the events in the emulsions. Iron spectrometers (made of dipolar magnets, drift tube planes and RPC planes) measure charge and momentum of muons for background rejection.

The detector is designed starting from the ECC concept, which combines the high precision tracking capabilities of nuclear emulsions and the large target mass given by the lead plates (see [7] and references therein). By piling-up a series of thin emulsion films and lead plates (*cells*) in a sandwich-like structure one obtains a *brick*, which constitutes the detector element appropriate for the assembly of more massive planar structures (*walls*). A wall and its related electronic tracker planes constitute a *module*. A *supermodule* is made of a *target* section, which is a sequence of *modules*, and of a downstream *muon spectrometer*. A sequence of three supermodules constitute the detector. A key feature of the target structure is its design which allows the prompt removal of the bricks selected on the basis of the electronic detector information and the analysis of the emulsion films during the run.

A cell is composed of a 1 mm thick lead plate followed by a thin film made up of a pair of emulsion layers 50 μm thick on either side of a 200 μm plastic base. A charged particle produces a track segment in each of the two layers. The number of grain hits in 50 μm is $\sim$15-20. They are detected for reconstruction of track segments by means of automatic scanning devices. Fast and efficient scanning methods of the emulsion films will be used, based on automatic microscopes operated by the the so-called Track Selector system [7]. Each brick has transverse dimensions of 10.2×12.7 cm^2. It consists of 56 cells with a total thickness of about 7.5 cm (10 X_0) and a weight of 8.3 kg. A target supermodule is made of 24 modules, each consisting of a wall of 3264 bricks followed by two planes of electronic trackers. The module dimensions are $\sim$12 cm in thickness and $\sim$6.75 m side to side. The total length of the supermodule target is about 290 cm. A supermodule comprises 78336 bricks for a mass of 623 ton of lead. A total mass of about 2000 ton is needed to meet the physics goal of the experiment. This can be obtained with three supermodules. A schematic view of the OPERA detector is shown in Fig. 2.

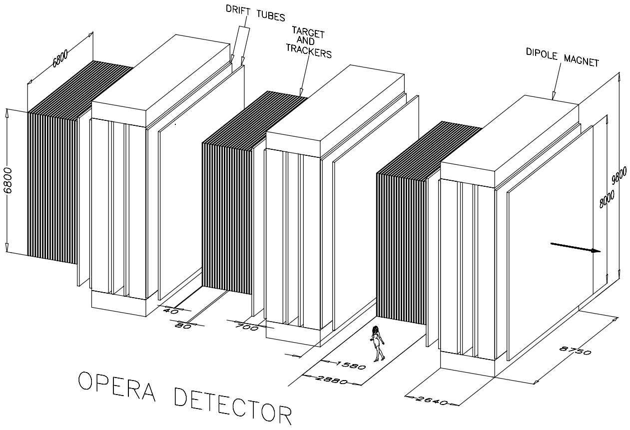

Figure 2. Schematic view of the OPERA detector.

The most relevant feature of OPERA is its very low background. Nuclear emulsions allow to identify the τ lepton in the final state through the direct observation of the topology of its decay into an electron, a muon and a single charged hadron. If a τ is produced in a lead plate it will decay either in the same plate (*short decays*) or further downstream (*long decays*). For long decays, the τ is detected by measuring the angle between the charged decay daughter and the parent direction (kink topology) and short decays by exploiting an impact parameter method. All single-prong τ decay modes are used to search for long τ decays. Short decays are considered for the $\tau \rightarrow e$ channel.

Muonic τ decays are characterised by an identified muon originating from the τ track kink. For these events the main background is constituted by large angle muon scattering in the lead plates. Similarly, the $\tau \rightarrow e$ decay mode is identified by a detected electron from the τ decay, through its characteristic energy loss in the lead/emulsion brick structure. The main background to this channel is given by charm production in ν_μ CC interactions with an electron decay and with the primary muon escaping detection. Hadronic decay candidates are defined as those events in which the kink daughter particle is not identified either as an electron or a muon. In this case, charm production with subsequent hadronic decay and hadronic reinteractions in the lead give a similar contribution to the background.

An additional tool for background rejection is the determination of the transverse momentum of the daughter particle with respect to the direction of the τ track candidate. For electronic τ decays the ECC technique is well suited to identify electrons and to determine their energy by measuring the density of track segments associated to their showering in the brick. For charged hadrons and muons, the momentum is deduced from the measurement of the multiple scattering in the lead plates. The muon momentum is also measured by the electronic detectors and by the muon spectrometer in a large fraction of the cases. Kinematical cuts can then be applied in order to enhance the signal to background ratio.

Weighing each τ decay channel by its branching ratio, the total detection efficiency amounts to 8.7%. In five years of running in the CNGS beam (shared mode), OPERA will collect about 18 events (with about 0.6 background events) if oscillations occur at $\Delta m^2 = 3.2\times10^{-3}$ eV^2 and full mixing, as indicated by Super-Kamiokande [1]. The OPERA sensitivity at the 90% CL is shown in Fig. 3 together the most recent result of a global fit to the Super-Kamiokande data [1].

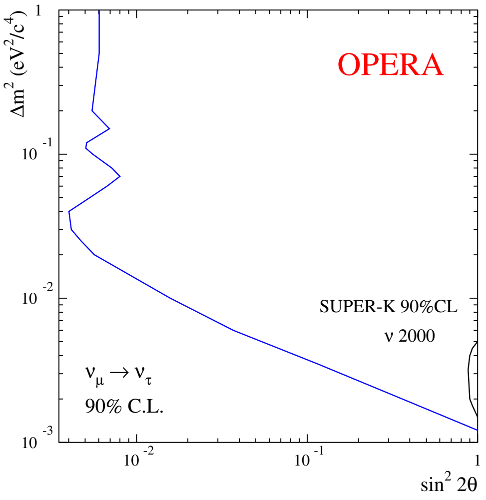

Figure 3. OPERA sensitivity to $\nu_\mu \leftrightarrow \nu_\tau$ oscillations for 5 years CNGS running.

4. Conclusions

The CNGS beam will provide by the year 2005 an intense neutrino beam suitable for long baseline experiments with detectors placed at the Gran Sasso Laboratory. The experimental programme is focused on the appearance search for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in the parameter region indicated by the atmospheric neutrino anomaly. This is achieved by the optimisation of the beam features and by experiments with τ detection capabilities. ICARUS and OPERA will accomplish this task by complementary methods and are expected to effectively contribute to the clarification of the experimental scenario.

REFERENCES

1. H. Sobel, Proc. of the XIX Int. Conf. on Neutrino Phys. and Astroph., Sudbury, 2000.
2. H. Noumi et al., Nucl. Instr. and Meth. A 398 (1997) 399.
3. Fermilab Report NuMI-346, 1998.
4. G. Acquistapace et al., CERN 98-02, INFN/AE-98/05, 1998.
5. http://www.cern.ch/CNGS; R. Bailey et al., CERN-SL/99-034(DI), INFN/AE-99/05, 1999.
6. ICARUS Proposal, LCNGS-94/99-I (1994); C. Rubbia, Nucl. Phys. B 48 (1996) 172; J.P. Revol et al., ICARUS-TM-97/01; ICARUS Coll. CERN/SPSC-98-33.
7. M. Guler et al., CERN/SPSC 2000-028, SPSC/P318, LNGS P25/2000.
8. G. Battistoni, these Proceedings.