Liquid Argon Neutrino Detectors

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The Liquid Argon imaging technique, as proposed for the ICARUS detector, offers the possibility to perform complementary and simultaneous measurements of neutrinos, as those of CERN to Gran Sasso beam (CNGS) and those from cosmic ray events. For the currently allowed values of the Super–Kamiokande results, the combination of both CNGS and atmospheric data will provide a precise determination of the oscillation parameters. Since one can observe and unambiguously identify ν_e, ν_μ and ν_τ components, this technology allows to explore the full (3 x 3) mixing matrix. The same class of detector can be proposed for high precision measurements at a neutrino factory.

1. Introduction

The reference mass for underground detectors is now set by the operating Super–Kamiokande[1] detector, which is of the order of 30 ktons. However the rather coarse nature of the Cherenkov ring detection is capable to reconstruct only part of the features of the events.

New generation underground experiments are now facing new challenges, for which novel and more powerful technologies are required, with respect to the existing detectors. The *long baseline accelerator neutrino oscillation* experiments require, with respect to existing short baseline detectors a large increase of the detector fiducial mass (up to several kilotons), in order to cope with the flux attenuation due to the distance. Moreover, the detector must be able to tag efficiently the interaction of ν_e's and ν_τ's out of the bulk of ν_μ events. This requires a detailed event reconstruction that can be achieved only by means of a high granularity detector.

Likewise, the comprehensive investigation of *atmospheric neutrinos* events, in order to reach the level of at least one thousand events/year, also requires a fiducial mass of several ktons. The capability to observe all separate processes, electron, muon and tau neutrino charged currents (CC) and all neutral currents (NC) without detector biases and down to kinematical threshold is highly desirable.

Event imaging should be provided by a modern bubble chamber-like technology since (1) it has to be able to provide high resolution, unbiased, three dimensional images of ionizing events; (2) it has to provide an accurate measurement of the basic kinematical properties of the particles of the event, including particle identification. (3) it has to accomplish simultaneously the two basic functions of target and detector.

In the ICARUS design a fully sensitive, bubble chamber-like detector will permit discovery limits at the few events level and a much more powerful background rejection. A detector of this kind, already at the level of a few ktons of mass will be able to extend much further the investigations now performed by Super–Kamiokande.

The quality of event vertex inspection and reconstruction of the liquid Argon must however be complemented by the addition of the external module capable of magnetic analysis of the muons escaping the LAr chamber. Bubble chambers have in fact often been very similarly complemented in the past by external identifiers. An example of such is under design by the ICARUS Collaboration for the experimental activities with the CNGS beam at Gran Sasso: *ICANOE*, *i.e.* ICARUS Neutrino Oscillation Experiment[2]. The general ideas for such a detector are outlined in the next section.

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2. Design of a detector for a Long Baseline Neutrino Experiment

A detector suitable for Long Baseline neutrino experimental activity can be similar to that of a "classical" neutrino detector, segmented into almost independent supermodules. Each supermodule results from the combination of a liquid target module and an external muon spectrometer module. The liquid argon module is dedicated to extremely high resolutiont tracking, dE/dx measurements, full e.m. calorimetry and hadronic calorimetry, where electrons and photons are identified and measured with extremely good precision and π/μ, K and p separation is possible at low momenta; The muon spectrometer has aim of providing the measurement of the sign and momentum of muons escaping the liquid argon module. A supermodule behaves as a complete building block, capable of identifying and measuring electrons, photons, muons and hadrons produced in the events.

The ICARUS Collaboration is now on the way to prepare a new proposal, following the orginal *ICANOE* design, on the basis of a liquid Argon module having 1.4 kton (1.9 kton) of active (total) mass, and a magnetized calorimeter module, for the baseline option. We stress that this detector design is capable to achieve the full reconstruction of neutrino (and antineutrino) events of *any* flavor, and with an energy ranging from the tens of MeV to the tens of GeV, for the relevant physics analyses. No other combinations can provide such a rich spectrum of physical observations, including the systematic, on-line monitoring of the CNGS ν-beam at the LNGS site. The unique lepton capabilities of this kind of detector are really fundamental in tagging the neutrino flavor. In general, the oscillation pattern of the neutrinos may be complicated and involve a combination of $\nu_\mu \to \nu_\tau$, $\nu_\mu \to \nu_e$ and $\nu_\mu \to \nu_{sterile}$ transitions. In order to fully sort out the mixing matrix, unambiguous neutrino flavor identification is mandatory to distinguish τ's from ν_τ's and electrons from ν_e's interactions. In other words, we stress the importance of constraining the oscillation scenarios by coupling appearance in several different channels and disappearance signatures.

Δm^2 (eV^2)	No. of ν_τ CC events
1×10^{-3}	52
2×10^{-3}	208
3.5×10^{-3}	620
5×10^{-3}	1250
7.5×10^{-3}	2850
1×10^{-2}	4330

Table 1
Expected event rates of $\nu_\mu \to \nu_\tau$ appearance for an exposure of 20 kton$\times$ year for the liquid target (assuming $\sin^2 2\theta = 1$).

3. Physics with the CNGS beam

In order to separate separate ν_τ events from the background, two basic criteria can be used:

- an unbalanced total transverse momentum due to neutrinos produced in the τ decay,
- a kinematical isolation of hadronic prongs and missing momentum in the transverse plane.

In addition, given the baseline L between CERN and GranSasso, for the lower Δm^2 values of the allowed region indicated by the atmospheric neutrino results, we expect most of the oscillation to occur at low energy. In this case, a criteria on the visible energy is also very important to suppress backgrounds. Table 1 shows for different values of Δm^2, the ν_τ CC rates expected in case oscillations take place.

The unambiguous detection and identification of ν_e CC events endows such a detector with the ability of performing also a $\nu_\mu \to \nu_e$ oscillation search. In this case, the oscillation reveals itself as an excess on the number of expected events having a leading identified electron. Given the expected rates for a 20 kton $\times$ year exposure, the statistical error is about 4%. Therefore the sensitivity to $\nu_\mu \to \nu_e$ oscillations is dominated by the systematic error on the beam knowledge. The full (3 x 3) mixing matrix can then be explored. These feature make this detector design a well suited choice in view of future activity at a neutrino factory, where high precision detectos are necessary to fully exploit the achievable accuracy in the determination of the parameters involving oscillation, CP violation and matter effects[3].

4. Atmospheric neutrinos

The physics goals of new atmospheric neutrino measurements are to firmly establish the evidence of neutrino oscillations with a different experimental technique, possibly free of systematic biases, measure the oscillation parameters and clarify the nature of the oscillation mechanism. A detector based in the ICARUS will provide, in addition to comfortable statistics, an observation of atmospheric neutrinos of a very high quality. Unlike measurements obtained up to now in Water Cherenkov detectors, which are in practice limited to the analysis of "single-ring" events, complicated final states with multi-pion products, occurring mostly at energies higher than a few GeV, will be completely analyzed and reconstructed in ICARUS . This will be a significant improvement with respect to previous observations. Given the clean event reconstruction of ICARUS , the ratio R of "muon-like" to "electron-like" events can be determined free of experimental systematic errors. In fact, the expected purity of the samples is above 99%. In particular, the contamination from π^0 in the "electron-like" sample is expected to be completely negligible. The measurement accuracy will be dominated by the statistical uncertainty and by the theoretical systematic error on the double ratio.

5. Current Developments

At present the ICARUS Collaboration is reaching the fundamental milestone of completing the first large 600 ton module, to be operated in the laboratory of Pavia (Italy) starting from the beginning of 2001. The aim is to demostrate the operation capability with 2 m electron drift in a large module (see Fig.1).

Soon after, the 600 ton module is committed to be installed in the undeground laboratory of LNGS for a first run which must be intended as a technical run both from the point of view of detector setup and physics performance. The aim is to demonstrate the of identifying rare events with the expected detection, triggering and reconstruction efficiency, together with the necessary background rejection capability.

Figure 1. Final operations on the wiring of the 600 ton module of ICARUS .

REFERENCES

1. Y. Fukuda et al. (Super–Kamiokande Collab.), Phys. Rev. Lett. **81** (1998) 1562; for a recent update see H. Sobel, Proc. of Neutrino 2000 Conference, Sudbury (Canada), June 16, 2000; T. Kajita, these proceedings
2. F. Arneodo et al. (ICARUS and NOE Collab.), "ICANOE: Imaging and calorimetric neutrino oscillation experiment," LNGS-P21/99, INFN/AE-99-17, CERN/SPSC 99-25, SPSC/P314; see also A. Rubbia (ICARUS collaboration), hep-ex/0001052.
3. A. Bueno et al., hep-ph/0005007, Nucl.Phys. **B589** (2000) 577.