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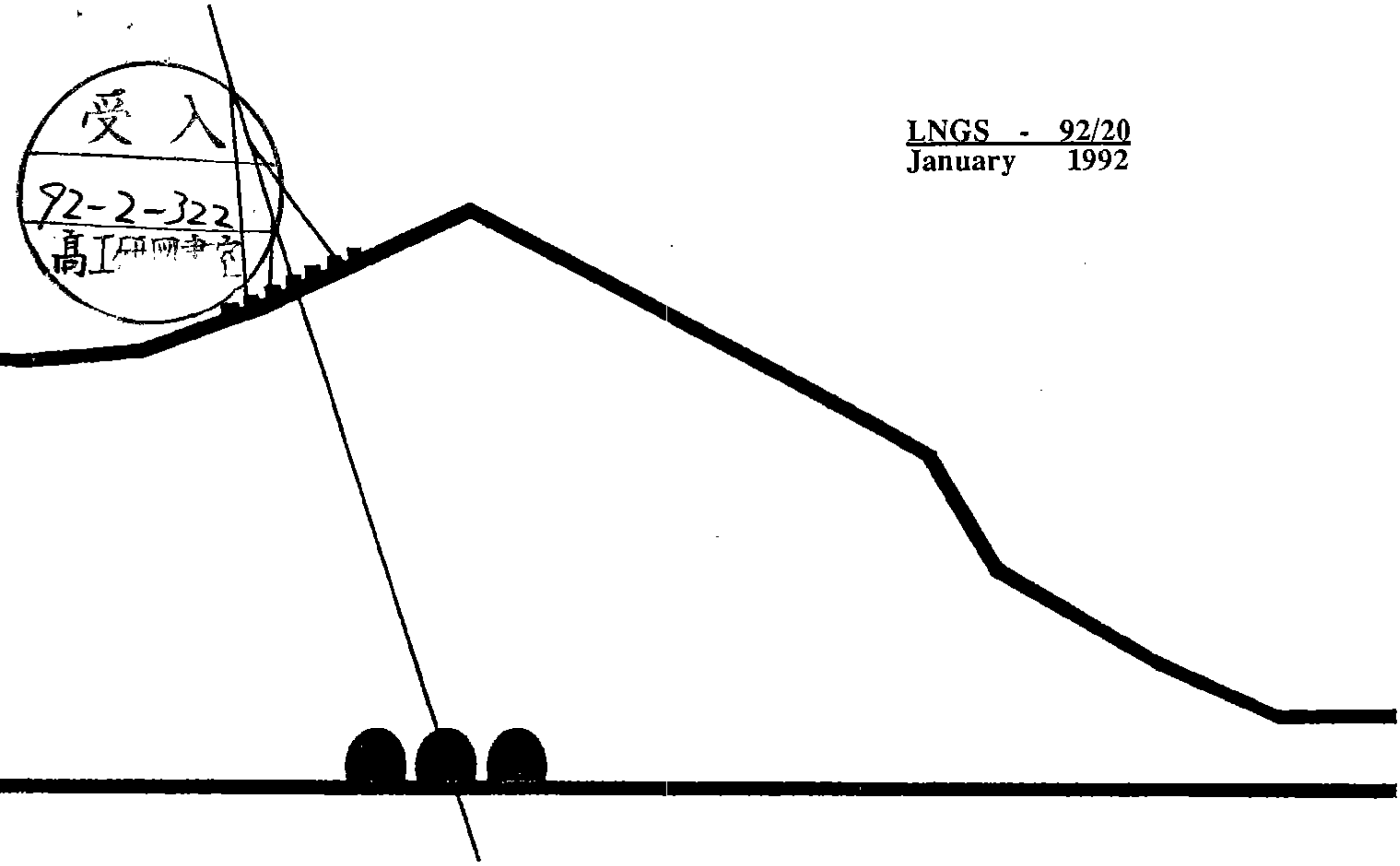

THE ICARUS LIQUID ARGON TPC: A NEW DETECTOR FOR ν_τ SEARCH

The ICARUS coll.

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THE ICARUS LIQUID ARGON TPC: A NEW DETECTOR FOR ν_τ SEARCH*

P.BENETTI, E.CALLIGARICH, R.DOLFINI, A.GIGLI BERZOLARI, F.MAURI, C.MONTANARI, A.PIAZZOLI, A.RAPPOLDI, G.L.RASELLI, D.SCANNICCHIO
Dipartimento di Fisica e INFN, Università di Pavia, via Bassi 6, Pavia, Italy

A.BETTINI, F.CASAGRANDE, P.CASOLI, S.CENTRO, B.DAINESE, C.DE VECCHI, G.MURATORI, A.PEPATO, F.PIETROPAOLO, P.ROSSI, S.SUZUKI, S.VENTURA
Dipartimento di Fisica e INFN, Università di Padova, via Marzolo 8, Padova, Italy

F. CAVANNA, G.PIANO MORTARI
Dipartimento di Fisica e INFN, Università dell'Aquila, via Vetoio, Coppito (AQ), Italy

P.CENNINI, S.CITTOLIN, C.RUBBIA
CERN, CH-1211, Geneva 23, Switzerland

M.CHENG, D.CLINE, M.ZHOU
Department of Physics, UCLA, Los Angeles, CA 90024, USA

F.GASPARINI
Dipartimento di Fisica e INFN, Università di Udine, via Larga 36, Udine, Italy

L.FORTSON, P.PICCHI, H.WANG
Laboratori Nazionali di Frascati dell'INFN, via E.Fermi 40, Frascati (Roma), Italy

L.PERIALE
Istituto di Cosmo Geofisica del CNR di Torino, cso. Fiume 4, Torino, Italy

ABSTRACT

We describe the characteristics of a novel detector technology which we are successfully testing at CERN: the LAr three-dimensional time projection chamber. We report on the detector performance using data from cosmic rays and a 6 MeV gamma ray source. We give a few examples within the wide range of experimental issues where such a technology can be applied with an emphasis on ν_τ detection.

1. Introduction

A liquid argon time projection chamber (LAr-TPC) working as an electronic bubble-chamber with the ability to provide 3-D imaging of any ionizing event together with a good calorimetric response while continually sensitive and self-triggering was first proposed by C. Rubbia in 1977 [1]. In the following years, experiments were undertaken to verify the feasibility of such a detector and to solve the main technological problems; namely: the purification of liquid argon to the level of 0.1 ppb to allow for long drift

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distances by the ionization electrons; the realization of a nondestructive read-out (3-D imaging) made of several wire planes with a few mm pitch; the development of very low noise preamplifiers since no multiplication occurs in LAr. All these problems had been successfully resolved on small scale tests [2,3,4] by 1989 when the ICARUS collaboration presented a proposal [5] for the construction of a large scale prototype. At present, a complete, 3 ton detector has been working at CERN under stable conditions for several months and its characteristics are described in a previous paper [6].

2. Detector response

The experience with the 3 ton prototype, equipped with complex mechanical and electrical apparata immersed in the liquid and with hundreds of feed-throughs, has shown that the ultrapure liquid argon technique is fully reliable even for large volumes since, after several months of continual operation, no degradation of the very high electron lifetime has been observed.

This detector provides electronic bubble-chamber quality images with millimeter sized "bubbles". But, unlike a bubble-chamber, it can be built with a large, continually sensitive volume and due to an electronic readout, it is self-triggering. The spatial resolution is in the range of 100 μm while an energy resolution of ≈3 % at a few MeV has been indirectly estimated. Ionization and range measurements are used to provide particle identification and the high granularity enables a measurement of particle direction. All these properties make the LAr-TPC a superb homogeneous detector for contained events and for vertex identification. In fact, the detector is essentially bias free and it can detect a very broad class of events: i.e. proton decay and solar neutrinos at Gran Sasso, CP violating interference at the ϕ-factory, ν_τ oscillations in a ν_μ beam or direct detection of the ν_τ at LHC and, like in a bubble-chamber, all kinds of unexpected phenomena.

Cosmic ray muons and 6 MeV monochromatic gamma source events comprise the data collected and are used to study the detector response. An event that illustrates very well the specific characteristics of the detector is presented in fig. 1: a 210 MeV cosmic muon stopping with the subsequent decay to an electron. It shows that the LAr-TPC works as an electromagnetic calorimeter with high granularity (2·2·2 mm^3 cell) and low electronic noise (equivalent to 25 KeV). For example, this detector allows to measure the dE/dx along the muon track (fig. 2) with the increase of ionization near the decay as well as the exact point of the decay and the track of the electron. Also due to the high granularity, the muon lifetime can be determined by measuring the gap along the drift direction between the muon stopping point and the electron starting point.

3. Applications

We believe that the LAr-TPC detector technology is now available for physics both in underground laboratories and at accelerators/colliders. Among the experimental issues mentioned above, we would like to stress the possibility of using such a detector for a ν_τ search in an oscillation experiment at a neutrino beam or for direct search at LHC.

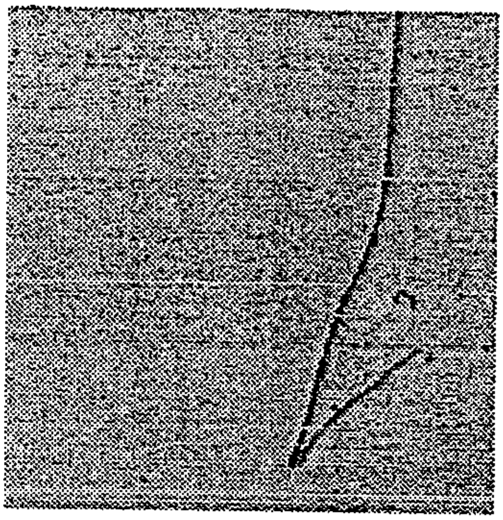

Fig. 1 Muon stopping and successive electron decay as seen by the collection wire plane in a window of 40•40 cm^2. Increasing gray intensity is proportional to the energy deposited on each wire. The total energy deposited along the muon track is 210 MeV, the electron energy is 21 MeV.

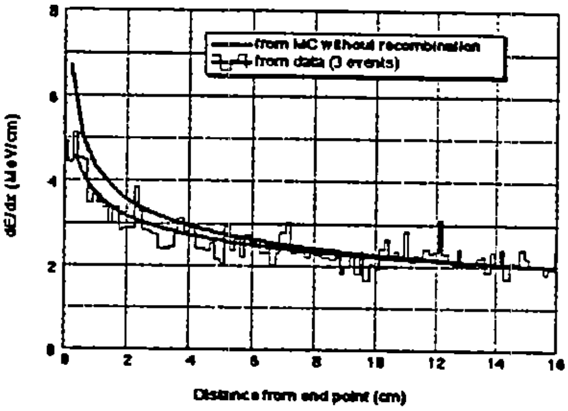

Fig. 2 The dE/dx vs track path of the muon together with the expected behaviour from MC; a saturation effect is visible.

Up to now, the conceptual design for tau neutrino detection aims at detecting the tau decay modes with single charged particles (mainly muons). The identification of a tau decay vertex requires a visible transverse impact parameter (kink) of one particle track with respect to the event vertex and/or a careful analysis of the event kinematics. The transverse decay length is almost invariant with respect to the tau neutrino energy (≈ 100 μm), hence the vertex detector should have a space resolution of about 20 μm. With the various techniques proposed up to now to obtain the required resolution it is possible to assemble only small volumes.

With this type of detector, it should be possible to detect ν_τ charged current interactions by identifying the tau lepton through its decay into different channels. Considering the CERN wide band neutrino beam energy spectrum, the mean tau decay length is about 1 mm leading to events with an average multiplicity of five charged particles. When the decay path is required to be longer than 1 cm, the fraction of tau events selected would be reduced to 2-3 %. However, this reduction in rate is offset by the gain in ease of selection as the events are very clean (low residual multiplicity) because the tau lepton receives most of the neutrino energy.

The tau decay mode into 3 charged pions (BR ≈ 13%) is the easiest to identify using a liquid argon TPC with the following characteristics: large volume (≈ 100 tons); 2 mm pitch of the read-out electrodes (wires or strips); three-dimensional read-out; high resolution in the drift direction (≈ 60 μm, useful for the track separation); energy resolution for the charge deposited over 2 mm by a MIP about 3 % (mainly due to electronic noise and delta-ray production). The basic idea consists of exploiting the last characteristic for the recognition of the tau track inside the event by means of the sudden increase in the total number of charged particles at a finite distance from the main vertex.

In fig. 3 we show a typical event generated by MonteCarlo as it is seen by the LAr TPC. In fig. 4 we show the jump in the ionization along the event development where we have excluded the large angle low energy tracks. This jump corresponds to the ionization due to two minimum ionizing particles.

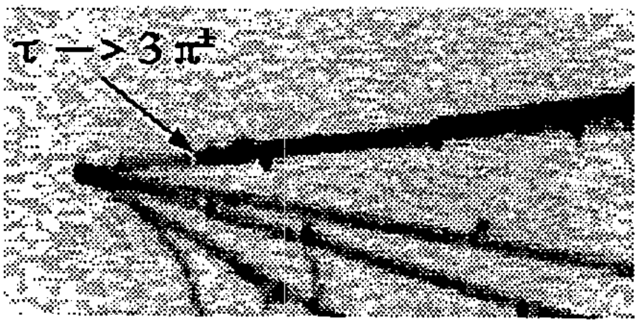

Fig.3 Simulation of a ν_τ CC interaction followed by τ decaying in $3\pi^{\pm}$.

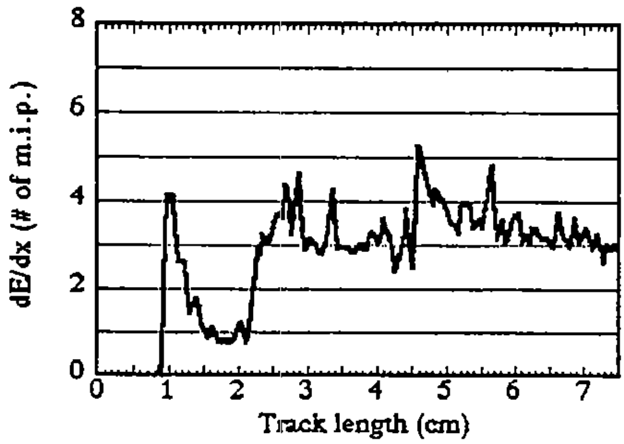

Fig.4 Detection technique consists in identifying the secondary vertex by the sudden increase in the dE/dx (+2 minimum ionizing particles) exiting the main vertex.

With the aim to measure values of $\sin^2(2\theta_{\mu\tau})$ as low as $4 \cdot 10^{-4}$, the tau recognition efficiency mentioned above implies that the experiment should collect about 10^7 ν_μ events corresponding to one year of data taking. This number can be reduced by at least a factor of 10 without reduction in the tau efficiency by exploiting the fact that muons are easily identified (the detection inefficiency is $< 10^{-3}$ as the muons can be tracked up to the point where they escape the detector) as well as using a trigger based on the energy deposition inside the detector. The former requirement eliminates most of the CC interactions while the latter cuts out the low energy NC events.

The most dangerous background for this specific channel is a secondary K^0_s decaying into two charged pions at a distance of 1 to 3 cm from the main vertex superimposed on a charged track. By means of kinematic cuts and exploiting the accurate spatial resolution along the drift coordinate to separate tracks which are close together, we are confident that a rejection factor better than 10^{-6} is easily reachable. Charmed particles are a less dangerous background because the total contribution from charm events which can simulate the signal process is between 10^{-6}-10^{-7}. This is the result of combining the following factors: c-$\bar{c}$ production in NC events is $1.5 \cdot 10^{-3}$, the branching ratio of the charm particle into MIPs which can simulate the jump in ionization level is $\approx 10^{-1}$, and finally the probability of decaying after 1 cm from the interaction vertex is $<10^{-2}$. Backgound from single charm production is negligible due to the very high probability of detecting the decay muon.

The direct search for ν_τ with the LAr-TPC at LHC is a more well defined experiment than the one just described for neutrino oscillation because the average tau decay length integrated over the neutrino energy spectrum is about 1 cm and because the tau neutrino abundance directly produced at the LHC interaction point is about 3% of the total neutrino flux It follows that the tau detection efficiency in the 3 charged pions channel can be as high as 7 % and the background rejection is easier to handle.

4. References

1. C. Rubbia, *CERN-EP Internal Report* 77-8 (1977).
2. E. Buckley et al., *Nucl. Instr. and Meth.* **A275** (1989) 364.
3. E. Bonetti et al., *Nucl. Instr. and Meth.* **A286** (1990) 135.
4. A. Bettini et al., *Nucl. Instr. and Meth.* **A305** (1991) 177.
5. ICARUS collaboration, *ICARUS I: An Optimized Real Time Detector of Solar Neutrinos* LNF-89/005(R) (1989).
6. A. Bettini et al., *The ICARUS Liquid Argon TPC: a complete imaging device for particle physics* LNGS-91/16 (1991).