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THE ICARUS 50 l LAr TPC IN THE CERN ν BEAM

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The 50 liter liquid Argon TPC is a detector built and successfully operated at CERN for R&D purposes within the ICARUS programme. In the year 1997 it has been exposed at the CERN neutrino beam for the entire SPS neutrino run period as proposed and approved at the SPSLC of January 1997 [1]. The detector, complemented with scintillators acting as veto, trigger counters and pre-shower counters, was installed in front of the NOMAD detector. The year 1997 was scheduled to be the last for the operation of the West Area Neutrino Facility. It was important to take this last opportunity for a parasitic exposure, which did not interfere with running experiments, of an already existing and operating liquid Argon TPC. As we had expected, the collected data brought important information for a better understanding of the performance of liquid Argon TPC's which should be useful for the entire ICARUS program.

1 Physics motivations

An important part of the ICARUS physics program aims at the measure of neutrino oscillations through the detection of LBL neutrino interactions[2]. Both the $\nu_\mu \rightarrow \nu_e$ and the $\nu_\mu \rightarrow \nu_\tau$ channels have been condidered.

The possibility to isolate ν_τ charged current interactions by means of kinematic cuts on the reconstructed events has been studied in details. It turned out that the main limitation of this method comes from the bad knowledge of the effect of Fermi motion and nuclear rescattering on the final state kinematics[3]. It was therefore very important to acquire experimental data in order to tune the Monte Carlo models.

The exposure of a small Lar TPC prototype at the CERN neutrino beam with the collection of a substantial sample of quasi-elastic $\nu_\mu + n \rightarrow p + \mu^-$ events matched the above requirements. The main physics items which we planned to study in this test were the following:

- appearance of nuclear fragments at the vertex of the interaction in events having the $\mu - p$ topology;
- measurement of the $\nu - \mu - p$ acoplanarity and missing transverse momentum in events with the $\mu - p$ topology interactions, in order to assess Fermi motion and proton re-scattering inside the nucleus;
- a preliminary of evaluation of e/γ and e/π^0 separation capability by means of the measurement of the specific ionisation on the wires, however, limited by the size of the chamber.

A further goal of this test was to gain experience with real neutrino events. This experience has provided general information useful for the study of atmospheric neutrinos, proton decay and high energy neutrinos from CERN. For example the test has led to the optimization of the readout chain in view of best extracting the features of these events.

2 Setup of the test

2.1 The ICARUS 50 liter liquid Argon TPC

The detector structure consists in a stainless steel cylindrical main vessel, 70 cm diameter, 90 cm height, whose upper face is an UHV flange housing the feed-through's for vacuum, liquid Ar filling, high voltages and read-out electronics. Inside the main vessel an ICARUS type liquid argon TPC is mounted. The TPC has the shape of a parallelepiped whose opposite horizontal faces (32×32 cm^2) act as cathode and anode, while the side faces, 47 cm long, support the field-shaping electrodes. The mass of the liquid argon contained in the active volume is 65 kg.

The read-out electrodes, forming the anode, are two parallel wire planes spaced by 4 mm. Each plane is made of stainless steel wires, 100 μm diameter and 2.54 mm pitch. The first plane (facing the drift volume) works in induction mode while the second collects the drifting electrons. The wire direction on the induction plane runs orthogonally to that on the collection plane (cfr. with the ICARUS 600 ton set-up where the three planes are foreseen at 60^o to each other). The wire geometry is the simplest version of the ICARUS readout technique [4] since both the screening grid and field wires in between sense wires have been eliminated. The wires are soldered on a vetronite frame which supports also the high voltage distribution and the de-coupling capacitors.

The front-end electronics for the 256 read-out channels is mounted directly on the frame in order to minimise the input capacitance of the pre-amplifiers which are foreseen to work immersed in liquid Argon [5].

The cathode and the field shaping electrodes have been obtained with a printed board technique on a vetronite support. The printed boards are glued on a honeycomb structure which ensures their rigidity. The field-shaping electrodes are horizontal strips, 1.27 cm wide, spaced by 2.54 cm. A high-voltage divider, made by a series of resistors (100 MΩ each) interconnecting the strips, supplies the correct potential to each strip. The drift high voltage ($\leq$ 15 kV) is brought to the cathode through a commercial ceramic feed-through.

The whole main vessel is immersed in a thermal bath of commercial liquid Ar, contained in an open air stainless steel dewar. The argon evaporation from the open-air dewar is about 50 liters/day. The detector is equipped with a standard ICARUS recirculation-purification system [7]. The full set-up was already tested and successfully operated in CERN for R&D purposes.

2.2 Installation in the CERN neutrino beam

The layout of the experimental set-up is sketched in fig. 1. Since muon identification and momentum measurement were essential for the studies we wished to perform, the chamber had to be complemented with a muon identifier and a spectrometer. Together with the NOMAD collaboration we came to the conclusion that the NOMAD detector could perform these tasks.

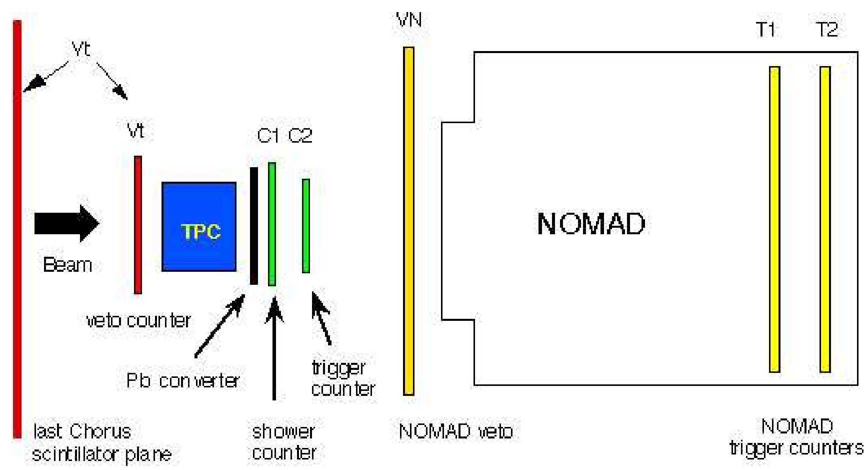

Figure 1: Experimental set-up of the 50 liter Liquid Argon TPC in the CERN ν beam.

Given the size of the TPC and the radiation length of liquid Ar ($X_0 =$ 14 cm), π^0's produced in neutrino interactions may escape detection, thus $\mu - p - \pi^0$ events, with undetected π^0, could fake quasi-elastic interactions with large missing P_T. The installation of a pre-shower counter downstream of the TPC was implemented in order to attempt to identify gammas leaving the chamber.

The detector has been installed in CERN hall 191 between CHORUS and NOMAD detectors. Dewar, argon purification system, vacuum pumps, veto and trigger scintillators, trigger and read-out electronics and data acquisition system, have been placed on a platform at 3.90 m from ground level. An argon tank of 5000 liters has been installed outside of the hall. Liquid argon, for periodic re-filling, has been brought from the outer tank to the dewar containing the TPC by isolated pipes running in protected position on the floor of the hall and reaching the platform along its scaffolding.

Immediately upstream of the chamber a double plane of scintillators, acting as a veto counter, have been installed; downstream of the chamber there is a 6 mm thick lead sheet followed by a plane of scintillators, acting as trigger and pre-shower counter.

2.3 Set-up of read-out and data aquisition

A standard ICARUS read-out of the 256 channels was implemented allowing to acquire up to 4 triggers per neutrino burst. Being the electron drift velocity about 1 mm/μs and the signals sampled by FADC at 400 ns, to span the total drift space one needs about 2 kb per channel or about 600 kb/event.

The events are written in raw-data format without any zero suppression; they are stored locally on disk and automatically transfered to the main CERN tape facility using the network. The trigger of the TPC read-out was based on coincidences between the down-stream scintillators and the NOMAD muon trigger planes. The upstream scintillators, ORed with signals from the CHORUS muon spectrometer scintillator planes were used to veto passing through particles (mostly muons produced by neutrino interactions upstream). At he beginning of each spill NOMAD sent, as pulse trains on standard BNC cables, run number and burst number, which have been recorded by scalers read-out by the TPC acquisition system. This allowed off-line matching of events in the TPC with muons reconstructed by NOMAD. For some specific period of times (calibration, gamma rays source, etc...) we also self-triggered the chamber exploiting the analog-sum of the collection wires.

The dead time of the TPC data acquisition was measured to be lower than 5%, while the NOMAD dead time is around 15%.

3 Results obtained so far with the test

3.1 Experience with the chamber operation

The detector was filled with ultra pure liquid argon flown through the ICARUS purification system in liquid phase (at a rate of 60 liter/hour) [6].

- The initial lifetime was about 100 μs. The recirculation/purification system, circulating about 5 liters of LAr/hour allowed to increase this value to more than 8 ms in three weeks (see fig. 2). This performance was excellent since the maximum drift time was 400 μs and therefore the attentuation of the ionization over the drift distance was negligible.

- This purity level was kept stable for all the running period of 9 months.

- The same recirculation system allowed to dissolve in pure LAr a small concentration of TMG (few ppm) necessary to recover the linearity response in deposited energy [8].

- The total LAr consumption necessary to circulate the pure LAr and to compensate the heat losses of the set-up was about 200 liter/day.

- The planned operating value for the drift high voltage was 25 kV to reach the nominal drift field of 500 V/cm. Unfortunately we have experienced some instabilities of uncertain origin which forced us to operate at a safe value of 10 kV. We believe that most likely this limitation was due to residual humidity in the HV feed-through at the level of the LAr interface. In the newly designed feed-through this problem should not arise. Given the achieved argon purity and the relatively short drift length, the reduced drift field did not affect significantly the performance of the chamber.

- The new wire chamber configuration appeared to be sound. The visibility of the induction signal was optimized by varying the ratio of the fields in the drift and gap regions.

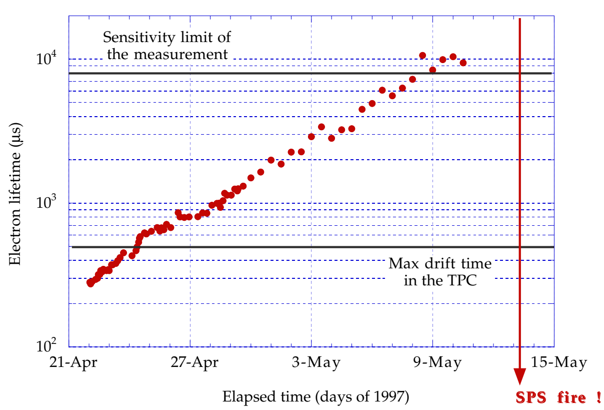

Figure 2: Lifetime of the drifting electrons in the 50 liter Liquid Argon TPC at the CERN ν beam. The filling of the chamber with LAr was performed on the fourth of April 1997.

Figure 3: An example of recorded neutrino interaction in the 50 liter Liquid Argon chamber prototype located at the CERN ν beam. The neutrino comes from the top of the picture. The horizontal axis is the time axis (drift direction) and vertically is the wire number. The visible area corresponds to $47 \times 32\ cm^2$

3.2 Experience gained with the front-end electronics

In fig. 3 we show, as an example, a neutrino event recorded with the 50 liter LAr TPC exposed at the CERN neutrino beam. From the inspection of many similar events and from the analysis of simulations of neutrino interactions in Liquid Argon, we decided to adopt a front-end configuration based on a current amplifier with a feed-back resistance of $R_f = 5\text{M}\Omega$.

With this configuration we obtained a signal-to-noise ratio $S/N = 11$ with mip signal equivalent to 10 ADC counts. This choice was satisfactory because the risk of pile-up in events containing electromagnetic showers was highly suppressed. This is essentially due to the fact that the duration of the signal was comparable with the distance between tracks in electromagnetic showers.

A further consequence of the front-end choice was that the digital dynamic range of 8 bits was sufficient even for the case of electromagnetic showers. A detailed analyis of the performance of the adopted front-end scheme can be found in reference [9].

3.3 Preliminary analysis of quasi-elastic neutrino events

During the 1997 CERN-SPS neutrino run we collected more than 10^5 triggers. The sample of all triggers accumulated during the run has been visually scanned to select neutrino interaction candidates. The whole scanning has been performed three times in order to ensure a high efficiency. About 9000 charged current ν_μ events have been identified in agreement with the expectation for the 1.2 10^{19} pot integrated in the 1997 run. The quasi-elastic candidates amount to 350. A typical example of quasi-elastic candidate is shown in fig. 4.

Analysis is presently being performed on a subsample of quasi-elastic candidates which satisfy the following criteria:

- a vertex is identified with at most two tracks leaving it;
- one of the track has to be a mip exiting the chamber; its has to be recognized as a muon by the NOMAD spectrometer;
- the second track, if any, has to be recognized as a proton dE/dx;
- no other hadron or gamma has to be present.

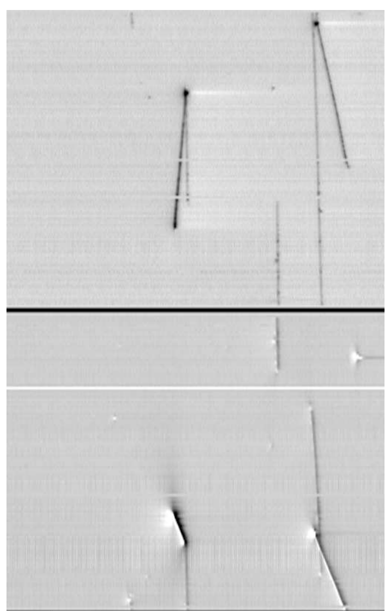

Figure 4: An example of neutrino quasi-elastic interaction in the 50 liter Liquid Argon TPC. The two orthogonal views are shown. The neutrino comes from the top of the picture. The horizontal axis is the time axis (drift direction) and vertically is the wire number. The visible areas corresponds to $47 \times 32\ cm^2$

The sample selected in this way amounts to about 150 clean quasi-elastic $\nu_\mu n \to \mu^- p$ events and is expected to contain about 1/2 of the total quasi-elastic events and some contamination deu to unseen π^0. This is probably a biased sample of quasi-elastics, however it has the advantage of consisting of simple events in which particles are well identified and measured.

The preliminary results from the analysis of these events are summarized in fig. 5; it shows the reconstructed momentum unbalance of the interaction in the transverse plane. Only a fraction of the events with small proton kinetic energy present a large missing p_t and acolinearity.

At proton kinetic energy larger then 150 MeV all the analized events present a good behaviour, namely acolinearity and missing p_t compatible with the Fermi motion without hard rescattering. A small part of the large missing p_t sample could be due to background.

A detailed simulation of these events, based on the FLUKA 97.5 pakage, is underway to determine the reliability of our Monte Carlo models. Preliminary comparisons are satisfactory.

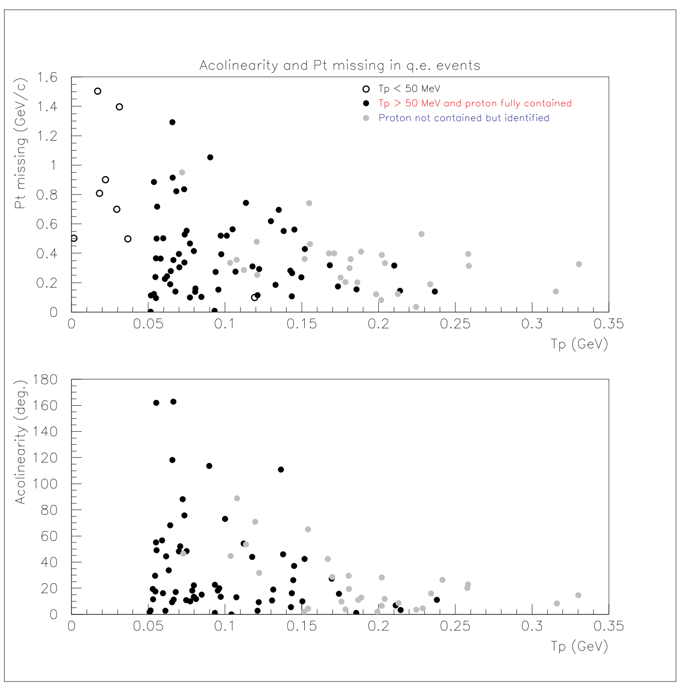

Figure 5: Missing p_t and acolinearity distributions as a function of the reconstructed kinetic energy of the leading proton.

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References

1. S. Ragazzi *et al.*, *'Request for a test of liquid argon TPC on the neutrino beam'*, SPSLC/M 594, 1997.
2. ICARUS Collab., *'A Search Programme for Explicit Neutrino Oscillations at Long and Medium Baseline With ICARUS Detectors'*, ICARUS-TM-97/01, 1997.
3. D. Cavalli *et al.*, *'Simulation of Nuclear Effects in Neutrino Interactions'*, ICARUS-TM-97/18, 1997.
4. ICARUS Collab., *'ICARUS-II. A Second-Generation Proton Decay Experiment and Neutrino Observatory at the Gran Sasso Laboratory'*, Proposal Vol. I & II, LNGS-94/99, 1994.
5. ICARUS Collab., *'A First 600 ton ICARUS Detector Installed at the Gran Sasso Laboratory'*, Addendum to proposal, LNGS-95/10, 1995.
6. P. Cennini *et al.*, *Nucl. Instrum. Methods* A **333**, 567 (1993).
7. P. Cennini *et al.*, *Nucl. Instrum. Methods* A **345**, 230 (1994).
8. P. Cennini *et al.*, *Nucl. Instrum. Methods* A **355**, 660 (1995).
9. P. Cennini *et al.*, ICARUS-TM-97/24, 1997.