LNGS - 91/16
October 1991

The ICARUS Liquid Argon TPC:
a complete imaging device for particle physics

INFN - Laboratori Nazionali del Gran Sasso

The ICARUS Liquid Argon TPC:

a complete imaging device for particle physics

A. Bettini 4), A. Bragiotti 4)*, F.Casagrande 4), P.Casoli 4), F.Cavanna 3),
P.Cennini 1), S.Centro 4), M.Cheng 6), A.Ciocio 2)**, S.Cittolin 1),
D.Cline 6), B.Dainese 4), F.Gasparini 5), L.Mazzone 1), G.Muratori 4),
A.Pepato 4), G.Piano Mortari 3), P.Picchi 2), F.Pietropaolo 4), P.Rossi 4),
C.Rubbia 1), S.Suzuki 4), S.Ventura 4), H.Wang 2), Z.H.Wang 7),
M.Zhou 6).

1) CERN, CH-1211, Geneva 23, Switzerland.

2) Laboratori Nazionali di Frascati dell'INFN, via E. Fermi 40, Frascati, Roma, Italy.

3) Dipartimento di Fisica e INFN, Università de L'Aquila, via Vetoio, Coppito (AQ), Italy.

4) Dipartimento di Fisica e INFN, Università di Padova, via F. Marzolo 8, Padova, Italy.

5) Dipartimento di Fisica e INFN, Università di Udine, via Larga 36, Udine, Italy.

6) Departement of Physics, UCLA, Los Angeles, CA 90024, USA.

7) IHEP, 19 - Yuquan street - Beijing, 100039, China.

* Present address: CNR, corso Stati Uniti, Padova, Italy.

** Present address: Physics Division, LBL, 1 Cyclotron Rd, Berkeley, CA 94720, USA.

INFN - Laboratori Nazionali del Gran Sasso

The ICARUS Liquid Argon TPC: a complete imaging device for particle physics

A. Bettini ⁴⁾, A. Bragiotti ^{4)*}, F.Casagrande ⁴⁾, P.Casoli ⁴⁾, F.Cavanna ³⁾,
P.Cennini ¹⁾, S.Centro ⁴⁾, M.Cheng ⁶⁾, A.Ciocio ^{2)**}, S.Cittolin ¹⁾,
D.Cline ⁶⁾, B.Dainese ⁴⁾, F.Gasparini ⁵⁾, L.Mazzone ¹⁾, G.Muratori ⁴⁾,
A.Pepato ⁴⁾, G.Piano Mortari ³⁾, P.Picchi ²⁾, F.Pietropaolo ⁴⁾, P.Rossi ⁴⁾,
C.Rubbia ¹⁾, S.Suzuki ⁴⁾, S.Ventura ⁴⁾, H.Wang ²⁾, Z.H.Wang ⁷⁾,
M.Zhou ⁶⁾.

1) CERN, CH-1211, Geneva 23, Switzerland.

2) Laboratori Nazionali di Frascati dell'INFN, via E. Fermi 40, Frascati, Roma, Italy.

3) Dipartimento di Fisica e INFN, Università de L'Aquila, via Vetoio, Coppito (AQ), Italy.

4) Dipartimento di Fisica e INFN, Università di Padova, via F. Marzolo 8, Padova, Italy.

5) Dipartimento di Fisica e INFN, Università di Udine, via Larga 36, Udine, Italy.

6) Departement of Physics, UCLA, Los Angeles, CA 90024, USA.

7) IHEP, 19 - Yuquan street - Beijing, 100039, China.

* Present address: CNR, corso Stati Uniti, Padova, Italy.

** Present address: Physics Division, LBL, 1 Cyclotron Rd, Berkeley, CA 94720, USA.

Introduction

A Liquid Argon time projection chamber (LAr-TPC) working as an electronic bubble-chamber, continuously sensitive, self-triggering, able to provide 3-D imaging of any ionizing event together with a good calorimetric response was first proposed by C. Rubbia in 1977 [1]. In the following years experimentations were undertaken to verify the feasibility of such a detector. It was soon realized that the main technological problems to be solved were:

- 1) the Liquid Argon purity that has to be kept at the level of 0.1 ppb of electronegative molecules so that the ionization electrons could drift for large distances;
- 2) the extreme cleanliness of the material employed in the construction of the detector and the complete reliability of the feed-throughs between pure argon and outside world to avoid contamination due to degassing or leaks;
- 3) the realization of wire chambers, able to perform a nondestructive read-out (in order to get a 3-D image of the event), made of several wire planes with few mm pitch; this requires high precision, very reliable mechanics and very good knowledge of the electric field inside the detector;
- 4) the development of very low noise preamplifiers to get a good signal to noise ratio.

All this was successfully achieved on small scale tests [2, 3, 4] beginning in 1989, when the ICARUS collaboration presented a proposal [5] for the construction of a large scale prototype. At that time it was clear to us which difficulties we were going to face as well as the way to overcome them, namely to simplify as much as possible the chosen technical solutions.

At present a 3 tons complete detector is working at CERN under stable conditions since several months. This step, from small to large volumes, has been made possible by:

- a) the purification of the Argon, performed with industrial methods, with special care for the cleaning of the materials that will be in contact with the purified Argon;
- b) the use of a recirculation system that purifies continuously the gas due to the heat leakage of the dewar and liquefies it back into the detector. This system prevents the diffusion of electronegative impurities, produced by the degassing of the materials in the high temperature region of the detector, into the liquid phase;
- c) the use of signal feed-throughs made on a vetronite support with the technique of the printed circuit board and welding each pin on it.

General features

The 3 ton detector configuration is well described in our proposal [5]. Here we want to

remind the following aspects.

- a) The active volume is split into two independent semi-cylindrical sections, each one a mirror image of the other (fig. 1).
- b) Each section is faced by a wire chamber that covers a surface of $2.4 \cdot 0.9 \text{ m}^2$ and consists of three parallel grids. Drifting electrons pass successively through the following wire planes:
  - 1. a plane with the function of screen transparent to the electrons;
  - 2. a sense wire plane where the electrons give an induction signal (again completely transparent);
  - 3. a plane with the wires perpendicular to the previous ones where the charge is collected.

The pitch of each sense wire is 2 mm. The separation between planes is also 2 mm. The maximum drift path is 42 cm. The chambers are made of 3600 vertical wires (stainless steel, 100 μm diameter) 2.4 m long and 4800 horizontal wires 0.9 m long. The signal cables are made of kapton flat cables, 3.5 m long inside the detector, with a low capacitance (40 pF/m). The 2100 signal feed-throughs are grouped in 8 flanges located on top of the dewar. Low noise pre-amplifiers are placed inside cooled boxes mounted directly on top of the signal feed-throughs flanges.

- c) The electron lifetime in LAr inside the detector is monitored continually by measuring the attenuation of an electron cloud photo-produced by a UV laser pulse impinging on a metallic cathode and moving in a small drift gap [4]. Fig. 2 shows that the lifetime steadily increases during the filling of the dewar and reaches a stable value, higher than 5 ms (corresponding to an attenuation length of more than 10 m). This result is mainly due to the recirculation system (fig. 3) mentioned above.
- d) The detector also exhibits the important feature of being self-triggering. This has been obtained exploiting the prompt current signal, proportional to the total charge of the track moving in the drift space, induced on the electrodes facing the drift volume.

An event that illustrates very well the peculiar characteristics of the detector is shown in fig. 4: a 210 MeV cosmic muon stopping with electron decay. It proves that the LAr-TPC works as an electromagnetic calorimeter with high granularity ($2 \cdot 2 \cdot 2 \text{ mm}^3$ cell) and low electronic noise (equivalent to 25 KeV); in fact this detector allows to measure the dE/dx along the track with the increase of ionization near the decay, the exact point of the decay and the track of the electron, whose total energy is about 21 MeV.

Detector response

A large amount of data have been collected, both with a small LAr-TPC (8 liters, 24 cm drift) in a beam and with the 3 ton prototype using cosmic rays and 6 MeV monochromatic gamma rays, to study the response of the detector in a wide range of energy from few MeV to several GeV. As an example in fig. 5 we show a muon crossing the drift volume and producing a delta ray of ≈ 3 MeV. The event is seen from two orthogonal views: the induction plane (non-destructive read-out) and the collection plane (destructive read-out) with the sense wire direction at 90° in one plane with respect to the other and with the drift time (third orthogonal coordinate) in common to both of them; the last feature together with the charge deposited along the tracks allows a 3-D reconstruction. The signal to noise ratio is ≈ 6 for the induction wires and ≈ 10 for the collection ones. The electric field in the drift volume is 330 V/cm corresponding to an electron drift velocity of 1.25 mm/ μ s. The sampling time is 200 ns. In fig. 6 we present a two dimensional view of a cosmic ray shower in a window of 40×40 cm².

From the analysis of 5 GeV pions and muons crossing the 24 cm TPC [3] it has been possible to extract a high energy Landau distribution (fig. 7). From the residual to a linear fit for the coordinate along the drift direction an r.m.s. spatial resolution of 58 μ m has been found for $S/N=10$ (fig. 8) [6]. By isolating the delta rays from the high energy tracks it has been possible to extract informations such as dE/dx , recombination, diffusion, etc. for low energy electrons. This information has been integrated into a MC program, based on GEANT, used to generate single electrons and photons; from these data an energy resolution of $\approx 3\%$ for electrons and photons in the few MeV energy range has been estimated. Identification of charged particles stopping inside the detector is obtained comparing the range with the dE/dx along the track: the expected π/μ contamination for kinetic energies around 100 MeV is $\approx 1\%$.

All the data taken with the 3 ton prototype exploit the self-triggering capability of the detector. In fig. 5 the signal induced on the screening grid is visible: the fast component is used to trigger the data acquisition, the slow one gives indication on the absolute position inside the detector where the ionizing event has occurred. At present we are able to trigger on isolated events with energy down to ≈ 1 MeV; in fig. 9 we show, as an example, an isolated pair produced inside the detector by a 6 MeV gamma. In a large volume detector the self-triggering capability, together with a segmentation of the electrodes, provides a useful way to data reduction because it selects a window, both in time and in space, where to look for an event above a given threshold.

Conclusions

We believe that a novel detector is now available for physics both in underground laboratories and at accelerator/colliders: the Liquid Argon Image Chamber.

The experience with the 3 ton prototype, equipped with complex mechanical and electrical apparatus immersed in the liquid and with hundreds of feed-throughs, has shown that the ultra-pure Liquid Argon technique is fully reliable since, after several months of continuous operation, no degradation of the very high electron lifetime has been observed.

This detector provides electronic bubble-chamber quality images with millimeter size “bubbles”. It is continuously sensitive, it can be built with high sensitivity mass and it is self-triggering. Spatial resolution is in the range of 100 μm . Energy resolution of $\approx 3\%$ at few MeV has been indirectly estimated. Ionization and range measurements provide particle identification. The high granularity enables 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. We give here briefly a number of possible applications keeping in mind that, like in a bubble-chamber, all kind of unexpected phenomena could be observable as well:

- Solar neutrinos @ GRAN SASSO
- Proton decay “ “ “
- CP violating interference @ DAΦNE
- Direct ν_τ detection at LHC (fig. 10)
- .....

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).
- [6] P. Astier et al., “Detecting ν_τ with electronic techniques”, Univ. Paris VI, LPNHEP/8907 (1990) and LPNHEP/9006 (1990).

Figure captions

- Fig. 1 LAr-TPC body: the active volume is split into independent semi-cylindrical sections. The drift volume is defined by the cathode at one end, the wire chamber at the other; a series of field shaping rings is used to avoid electric field distortions in the drift region due to the walls of the dewar.
- Fig. 2 Electron lifetime in LAr inside the 3 ton prototype as a function of time. Liquefaction of ultrapure LAr into the dewar starts at $t = 0$ and lasts for 380 hours; during that time interval lifetime keeps increasing and stabilizes at the

end of liquefaction (≥ 5 ms). At $t = 730$ hours the recirculation has been stopped during 10 hours; the sudden decrease of the lifetime and the successive restoring to a very high value demonstrate the necessity of a continuous purification.

- Fig. 3 Recirculation system (not in scale with respect to the dewar) including purifier units.
- Fig. 4 (a) Muon stopping and successive electron decay as seen by the collection plane in a window of 40×40 cm² (the maximum allowed by the number of read-out channels available at present). Increasing grey intensity is proportional to the energy deposited on each wire. The total energy deposited along the muon track is ≈ 210 MeV and (b) it is shown as dE/dx vs. track path; the electron energy is ≈ 21 MeV.
- Fig. 5 Two orthogonal view of a cosmic muon crossing the drift volume and producing a delta ray of 3 MeV.
- Fig. 6 Cosmic ray shower. The detector configuration is as in fig. 4.
- Fig. 7 Landau distribution obtained with a 5 GeV pion beam crossing the 24 cm TPC.
- Fig. 8 Distribution of the residual to a linear fit of the measured coordinates along beam tracks in the 24 cm TPC.
- Fig. 9 Two orthogonal view of an isolated pair produced inside the detector by a 6 MeV gamma.
- Fig. 10 (a) Simulation of a ν_τ CC interaction followed by τ decaying in $3\pi^\pm$.
(b) Detection technique consists in identifying the secondary vertex by the sudden increase in the dE/dx (+2 minimum ionizing particles) exiting the main vertex. The charmed particles background could be suppressed by requiring no single muon/electron from the main vertex. The background due to pair production along the track can be reduced exploiting the different hadron/electron energy loss development in the first 15 cm of the event (before shower takes place).

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10