A. Bettini, A. Braggiotti, F. Casagrande, P.Casoli, P.Cennini, S.Centro, M.Cheng,
A.Ciocio, S.Cittolin, D.Cline, B.Dainese, F.Gasparini, L.Mazzone, G.Muratori,
G.Pancheri, A.Pepato, G.Piano Mortari, P.Picchi, F.Pietropaolo, P.Rossi, C.Rubbia,
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a full imaging device for low energy e+e- colliders?

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Presented by F. Pietropaolo

A. Bettini [4], A. Braggiotti [4]+, F. Casagrande [4], P. Casoli [4], 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], G. Pancheri [2],
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], 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 Marzolo 8, Padova, Italy.*
5) *Dipartimento di Fisica e INFN, Università di Udine, via Larga 36, Udine, Italy.*
6) *Department of Physics, UCLA, Los Angeles, CA 90024, USA.*

+ *Present address: CNR, corso Stati Uniti, Padova, Italy*
* *Present address: Physics Division, LBL, 1 Cyclotron Rd, Berkeley, CA 94720, USA*

Introduction

The ICARUS experiment is a very large time projection chamber (TPC) with ultra-pure liquid argon (LAr) [1] aiming at the study of rare underground events: a 2 ton prototype is now working and is presently taking data at CERN. Its configuration and technological solutions are well described in our proposal [2]. Here we want to remind the following:

a) The active volume of the detector 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•0.9 m² and consists of three wire planes configurated in such a way (non-distructive read-out) to permit a 3-D imaging of any ionizing event together with a dE/dx measurement along the track. The pitch of each sense wire is 2 mm. The separation between planes is also 2 mm. The maximum drift path is 42 cm.

c) The electron lifetime in LAr inside the detector is monitored continually by measuring the attenuation of an electron cloud photo-produced by a laser UV pulse impinging on a metallic cathode and moving in a small drift gap [3]. Fig. 2 shows that the lifetime steadily increases during filling and reaches a stable value higher than 5 ms (corresponding to an attenuation length of more than 10 m) thanks to the recirculation system that purifies continually the gas phase on top of the dewar and liquefies it back at the bottom of the detector.

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 (fig. 10).

An event that illustrates very well the peculiar characteristics of the detector is shown in fig. 3: a real 210 MeV cosmic muon stopping with electron decay. It proves that our LAr TPC works as an electromagnetic calorimeter with high granularity (2•2•2 mm³ cell) and low electronic noise (the equivalent of 25 KeV); infact 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 long track of the electron whose total energy is about 21 MeV.

The aim of this paper is to demonstrate that such a device is particularly suited for the detection of electrons and photons, for the identification of low energy charged tracks and for a precise measurement of their kinetic energy.

Detector response

A large amount of data has been collected both with a 24 cm 2-D drift chamber [4] and with the 2 ton prototype to study response of the detector both to low energy electromagnetic showers and to pions and muons. As an example in fig. 4 we show a muon crossing the drift volume and producing a delta ray of ≈3 MeV. The event is seen in 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 sampling time is 200 ns. In fig. 5 we present a two dimensional view of a cosmic ray shower in a window of 40•40 cm² , the maximum allowed by the available digital channels at the present time.

By isolating from high energy tracks the delta rays it has been possible to extract informations such as dE/dx, recombination, diffusion, etc. for low energy electrons. These informations have been integrated into a MC program, based on GEANT, used to generate single electrons and photons; from these data the energy resolution for electrons and photons in the few MeV energy range has been obtained (fig. 6).

From the analysis of 5 GeV pions and muons crossing the 24 cm chamber it has been possible to extract a high energy Landau distribution (fig. 7) which has also been introduced into the MC in order to widen its energy range of validity.

As a result of our MC we show:

a) the energy resolution and the linearity for photons in the range between 20 and 280 MeV: ≈ 3% (fig. 8);

b) the resolution for the kinetic energy of pions and muons: 5 to 3 % in the range from 70 to 160 MeV (fig. 9a);

c) the π/μ separation obtained comparing the energy deposited versus the range of the particle stopping inside the detector: the contamination between pions and muons is ≈ 2 % at E_{kin} = 70 MeV (fig. 9b).

All the data taken with the 2 ton prototype exploit the self-triggering capability of the detector. In fig. 4 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 a large volume detector this feature 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 LAr TPC with the characteristics described above can be the basis for a poweful 4π detector around a high luminosity e^+e^- collider, operating at the energy of the ϕ resonance, to study CP/CPT violation in the K^0_L-K^0_S quantum system. Indeed a detector optimized for the ϕ-factory requires hermeticity, complete sensitivity, tracking capability and excellent calorimetric properties for low energy events; these features are essential for an efficient measurement of the kinetic energy and the position both for photons and for charged tracks. These requirements are fulfilled by a single LAr TPC surrounding the crossing point. The beam pipe acts as the inner wall of the detector:

a) the dead solid angle is reduced to the minimum;
b) the vacuum around the beams allows a very thin material (negligible in radiation length) which is as well the inner wall of the LAr cryostat;
c) the vacuum region around the interaction point can be enlarged to such an extent as to have a sufficient decay length to observe the full time evolution of the K^0_L-K^0_S mixture before reaching the Argon. In this way, the serious problem of K^0_L regeneration in LAr can be avoided.

In view of the very good kinetic energy measurement both for charged tracks and for photons and of the precise localization of the impact point (the conversion point for photons, the entrance into the detector for the charged tracks) it appears possible to get a precise total reconstruction of the events, even in the presence of the large multiple scattering in LAr. In principle the magnetic field does not appear as necessary, although it could be quite useful, for instance for identifying the sign of charges. Detailed Montecarlo calculations give support to the above statements and they will be published elsewhere [5].

References

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[3] A. Bettini et al., DFPD 90/EP/29, to be published on Nucl. Instr. and Meth.
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[5] A. Bettini et al., in preparation.

H.V. feed-troughs

6 cooled boxes for low-noise preamplifiers

42cm drift
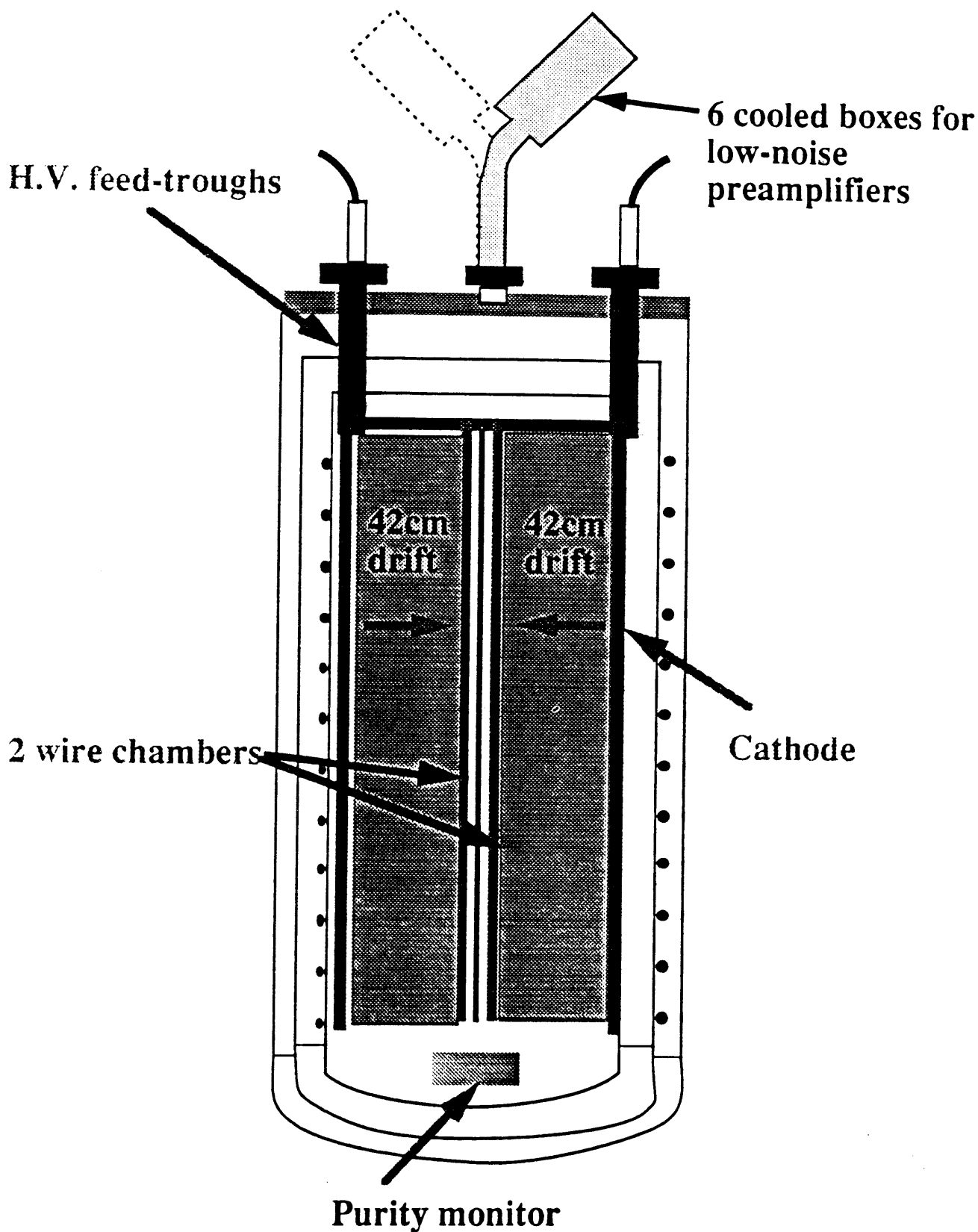
42cm drift

2 wire chambers

Cathode

Purity monitor

Fig. 1 - LAr TPC body: the active volume is split into two 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.
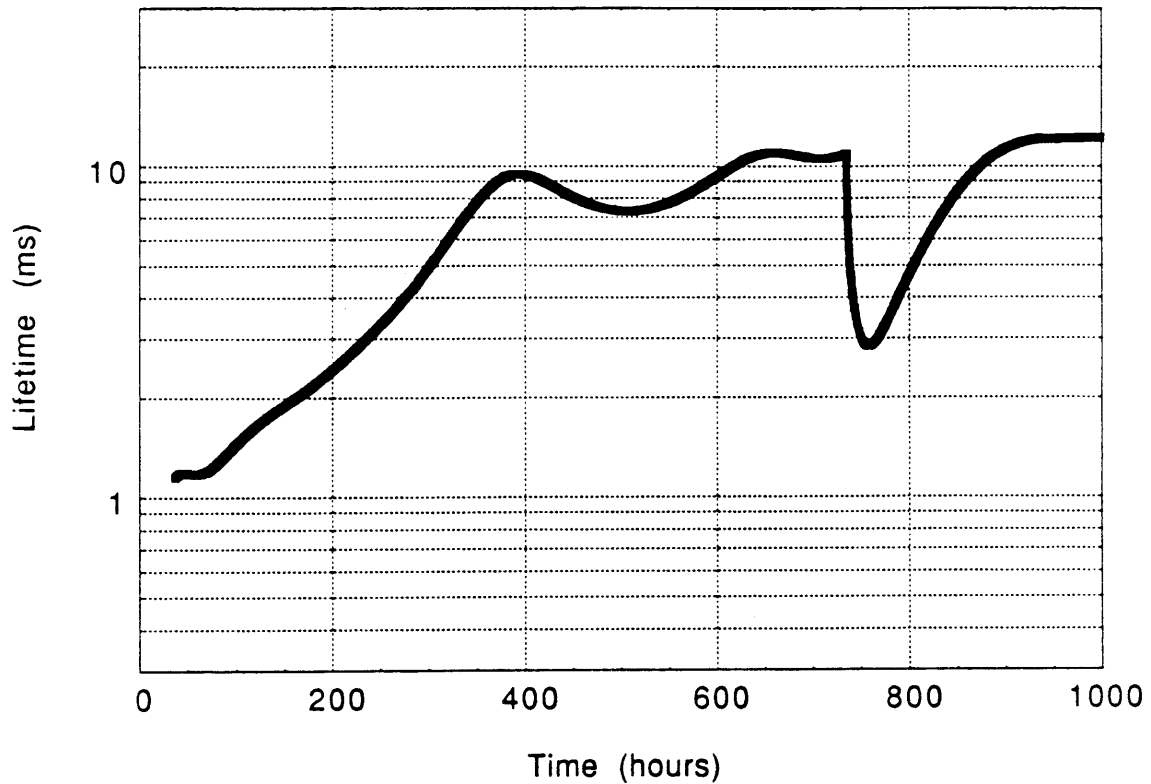
Fig. 2 - Electron lifetime in LAr inside the 2 ton prototype as a function of time. Liquefaction of ultra-pure LAr into the dewar starts at t = 0 and lasts for 380 hours; during that time interval lifetime keeps increasing and stabilizes at the end of liquefaction (> 5 ms). AT t = 730 hours the recirculation system 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 continous purification.
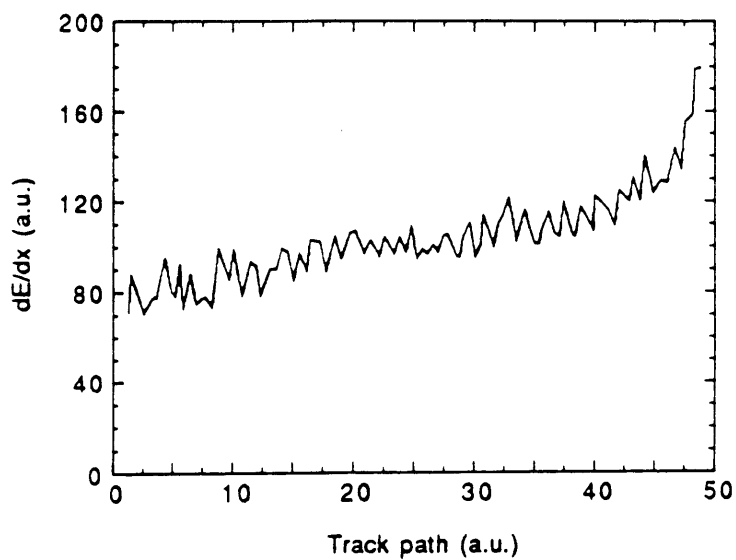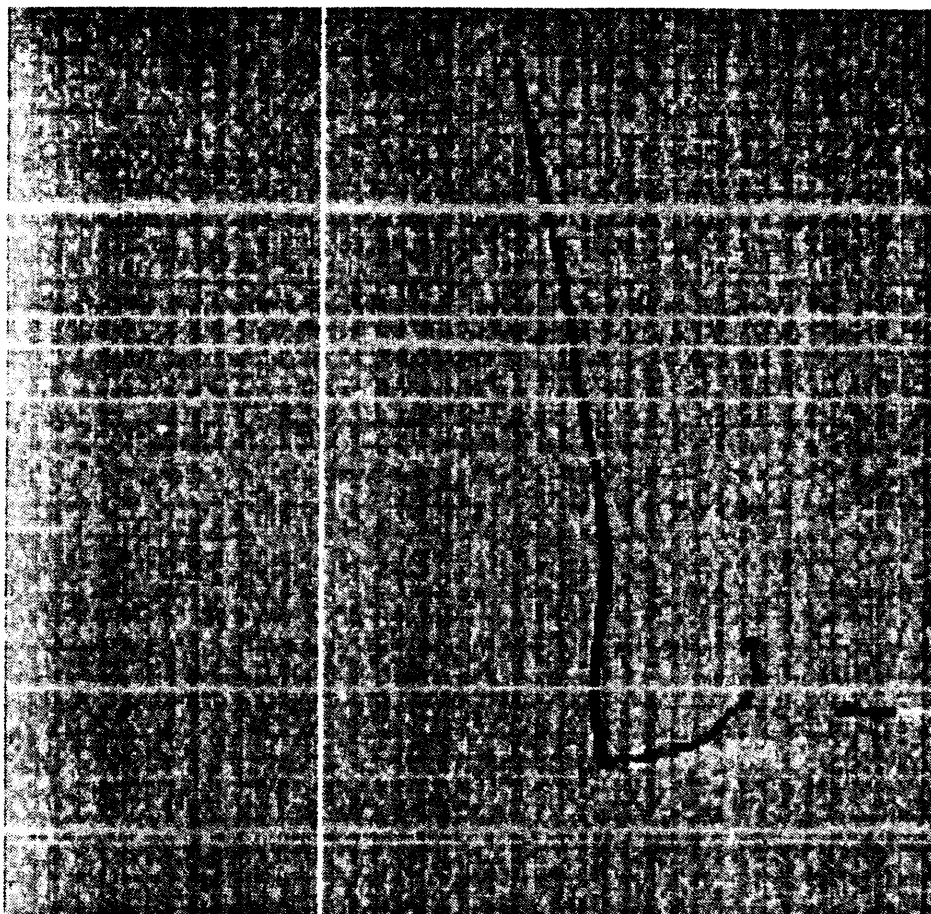
Fig. 3 - Muon stopping and successive electron decay as seen by the collection plane in a window of 40•40 cm². The energy deposited along the muon track is ≈ 210 MeV and is shown as dE/dx vs. track path; the electron energy is ≈ 21 MeV.
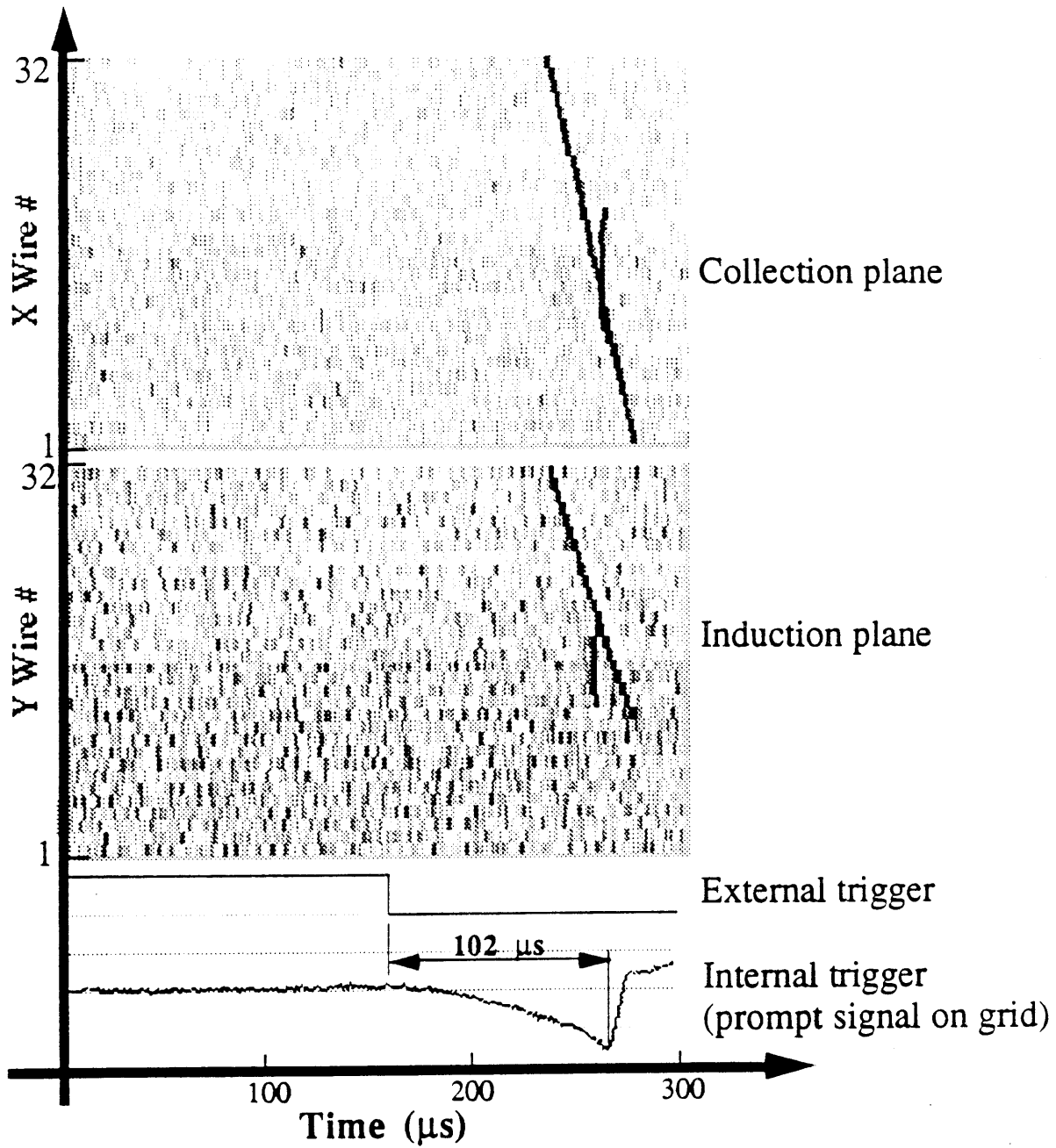
Fig. 4 - Cosmic muon crossing the drift volume and producing a delta ray of ≈ 3 MeV.
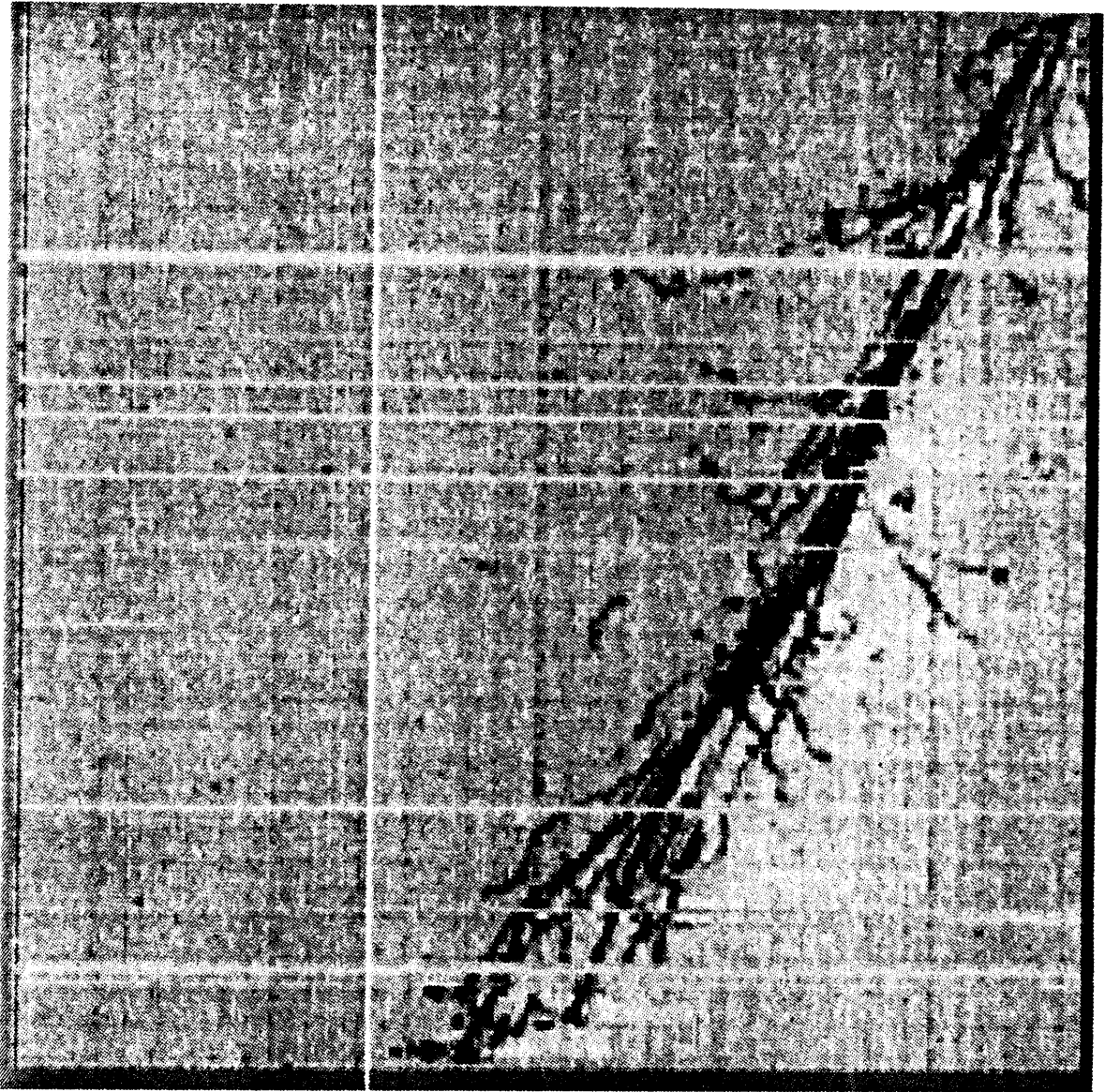
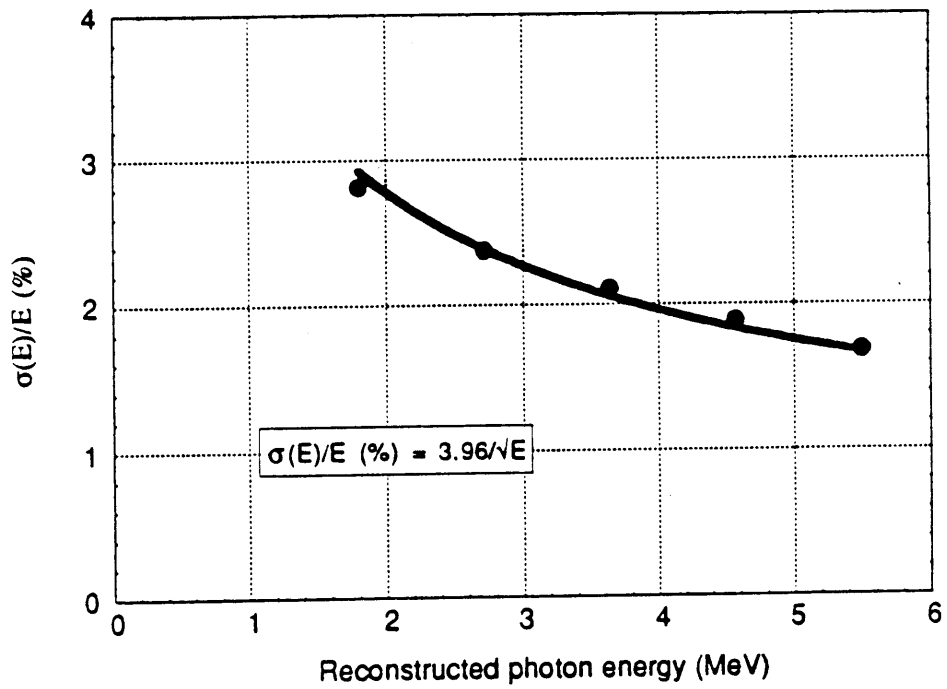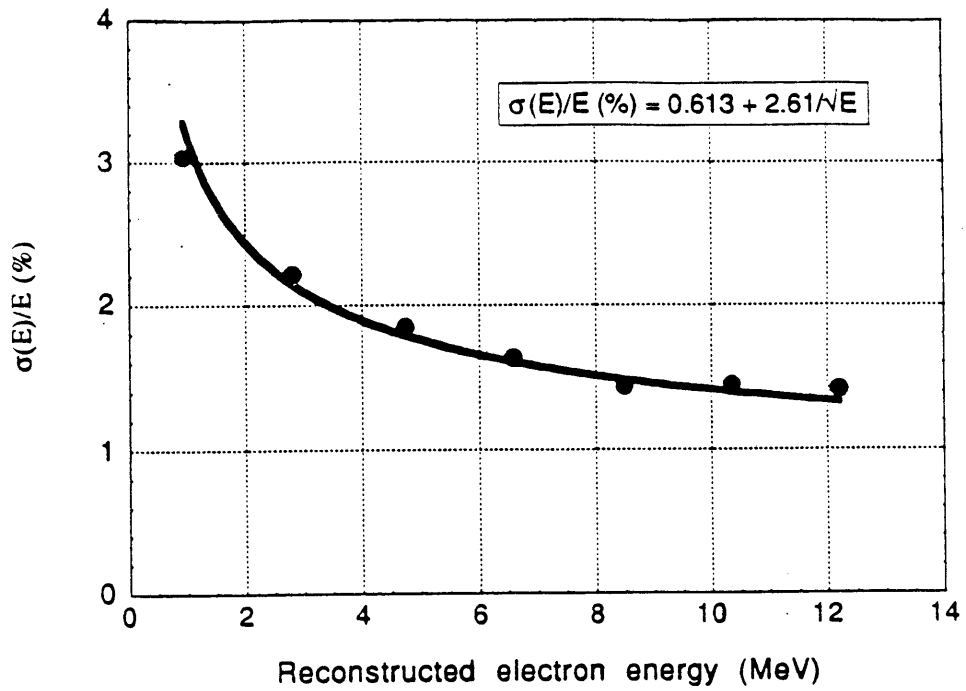**Fig. 5** - Cosmic ray shower. The detector configuration is as in fig. 3.

$$\sigma(E)/E\ (\%) = 0.613 + 2.61/\sqrt{E}$$

σ(E)/E (%)

Reconstructed electron energy (MeV)

$$\sigma(E)/E\ (\%) = 3.96/\sqrt{E}$$

σ(E)/E (%)

Reconstructed photon energy (MeV)

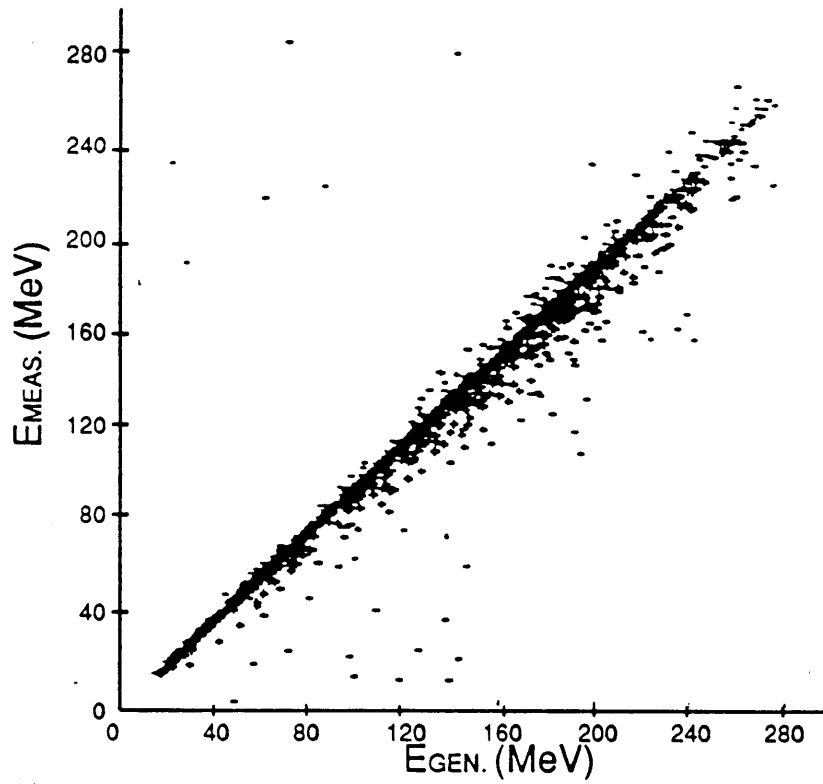**Fig. 6** - Expected energy resolution for low energy electrons and photons.
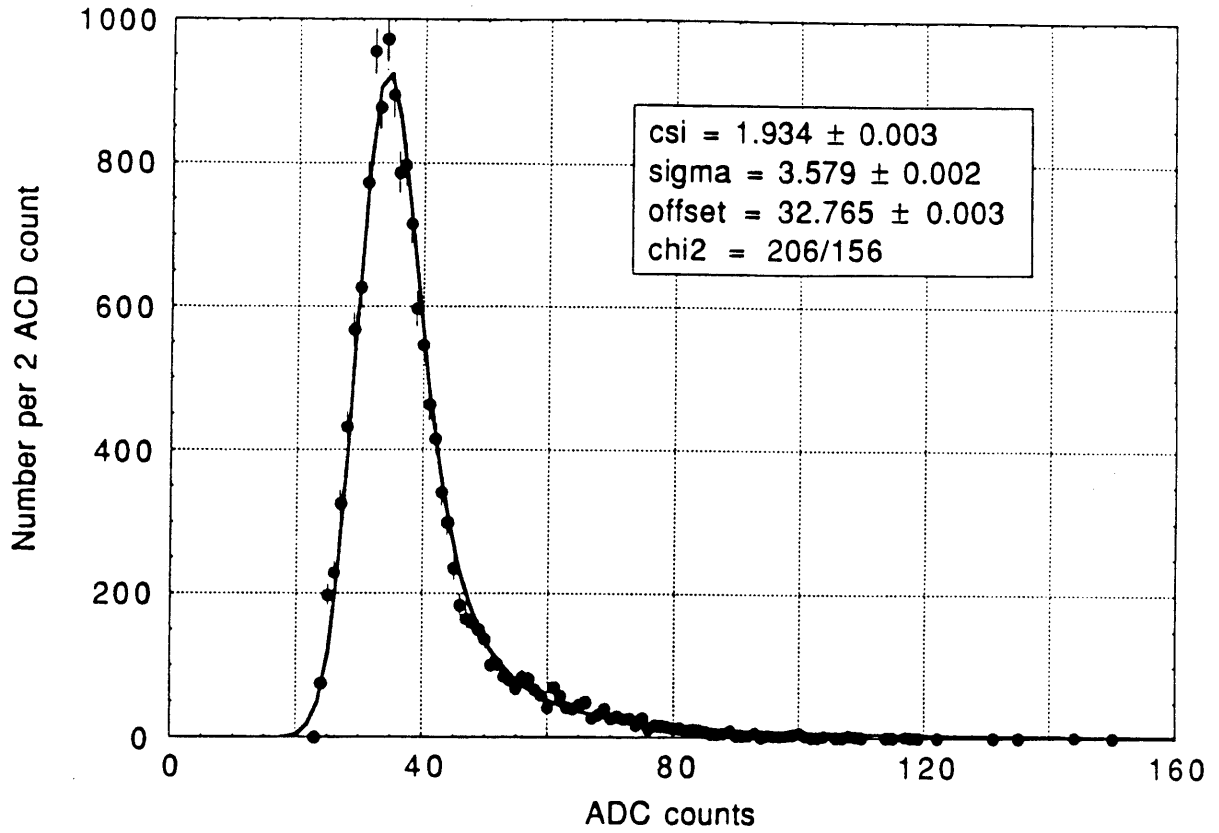
Fig. 7 - Landau distribution obtained with a 5 GeV pion beam crossing the 24 cm drift chamber [3], whose parameters have been introduced in the MC simulation the LAr TPC.
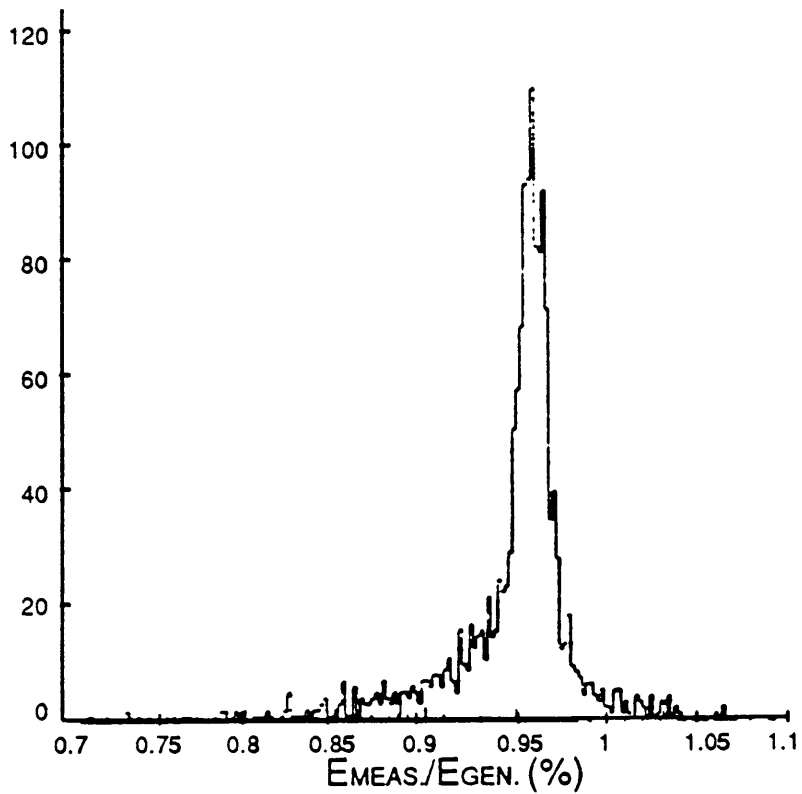
LINEARITY

RESOLUTION

Fig. 8 - Linearity and energy resolution for photons in the energy range from 20 to 280 MeV as obtained from MC simulations.
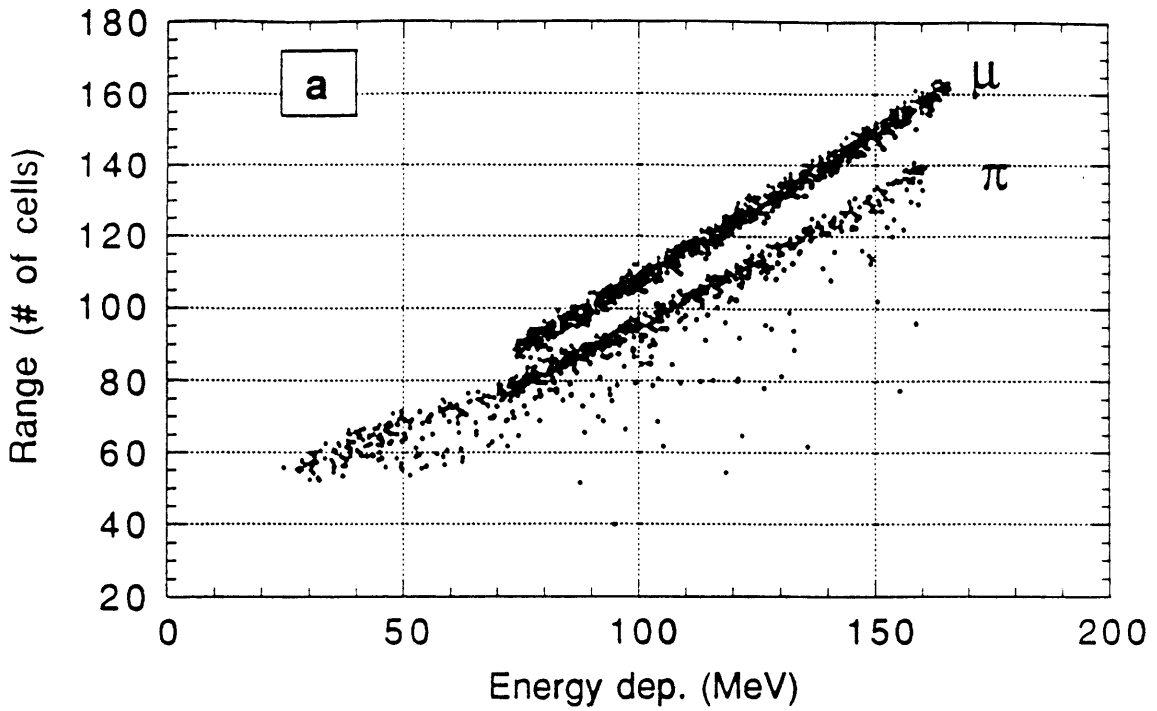
Fig. 9a - π/μ separation using energy deposited vs. range of the particle stopping inside the detector in the kinetic energy range between 70 and 169 MeV. π events with deposited energy less than 70 MeV are due to nuclear interactions or decay on flight.
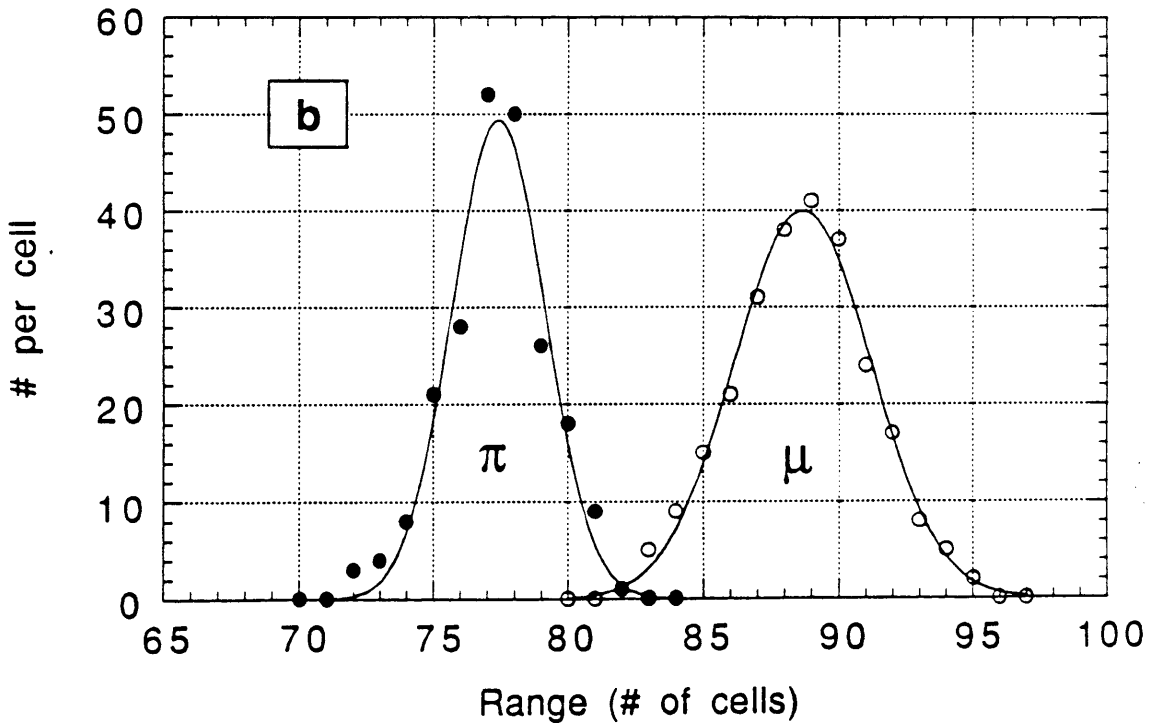

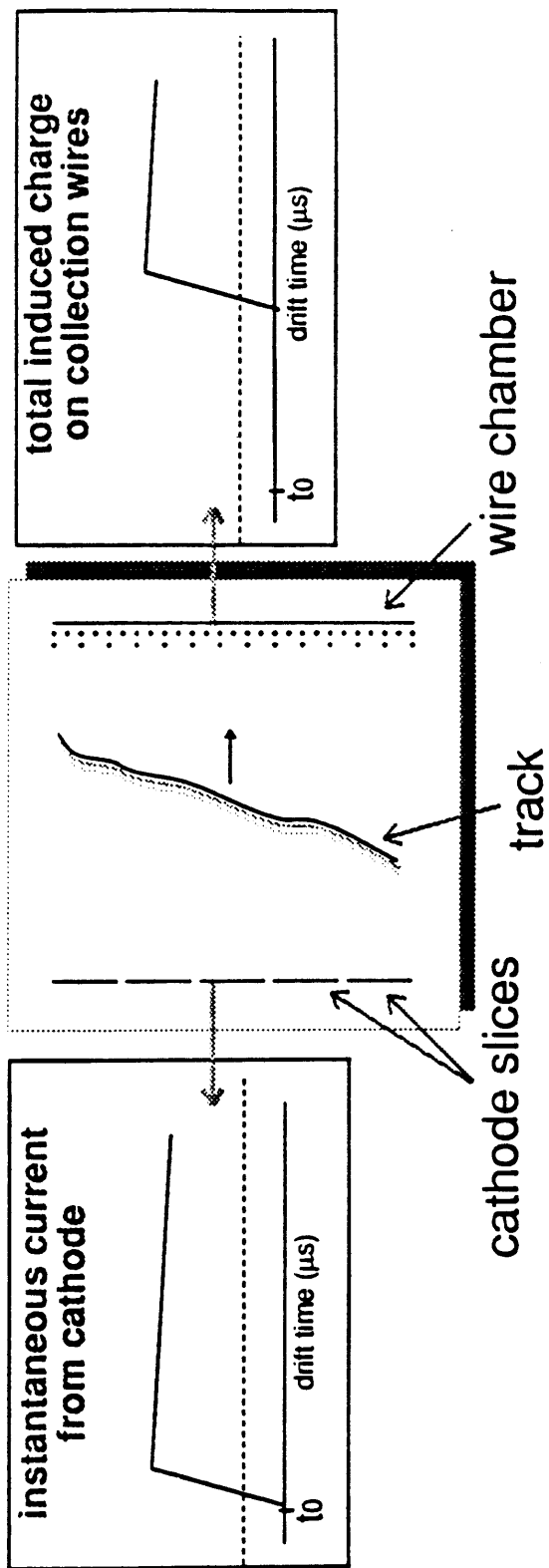**Fig. 9b** - Contamination between pions and muons at E_{kin} = 70 MeV.

Fig. 10 - A possible fast self-trigger in the LAr TPC. It makes use of the prompt current signal induced on the electrodes facing the drift volume by an ionizing event. The signal is proportional to the total charge deposited along the tracks.