LXe TPC

T.Tauchi, 6 September 2006

General Property of Liquid Xenon

http://www.pd.infn.it/~conti/LXe.html

Rich detection media : Scintillation and Ionization

Scintillation	Ionization
energy	position
photomultipliers	ionization chamber with low noise amp. 300e
GEM/photocathod	GEM in 2 phase Xe
Avalanche Photodiodes	

22,000 VUV photons/511KeV with 3ns, 27ns and 45ns

30,000 electron-ion pairs/511KeV
electron drift at 2.3mm/us with 2kV/cm

At 511 keV, 22% photoelectric, 78% Compton with xenon
half a mm for 511 keV photoelectron

Primary ionization signal is weak: of the order of 1, 10, 100 and 500 keV for coherent neutrino, dark matter, solar neutrino and PET respectively.

$$\sigma^2 = 2Dt = 2DL/v$$

$$C_D^2 = D/v$$

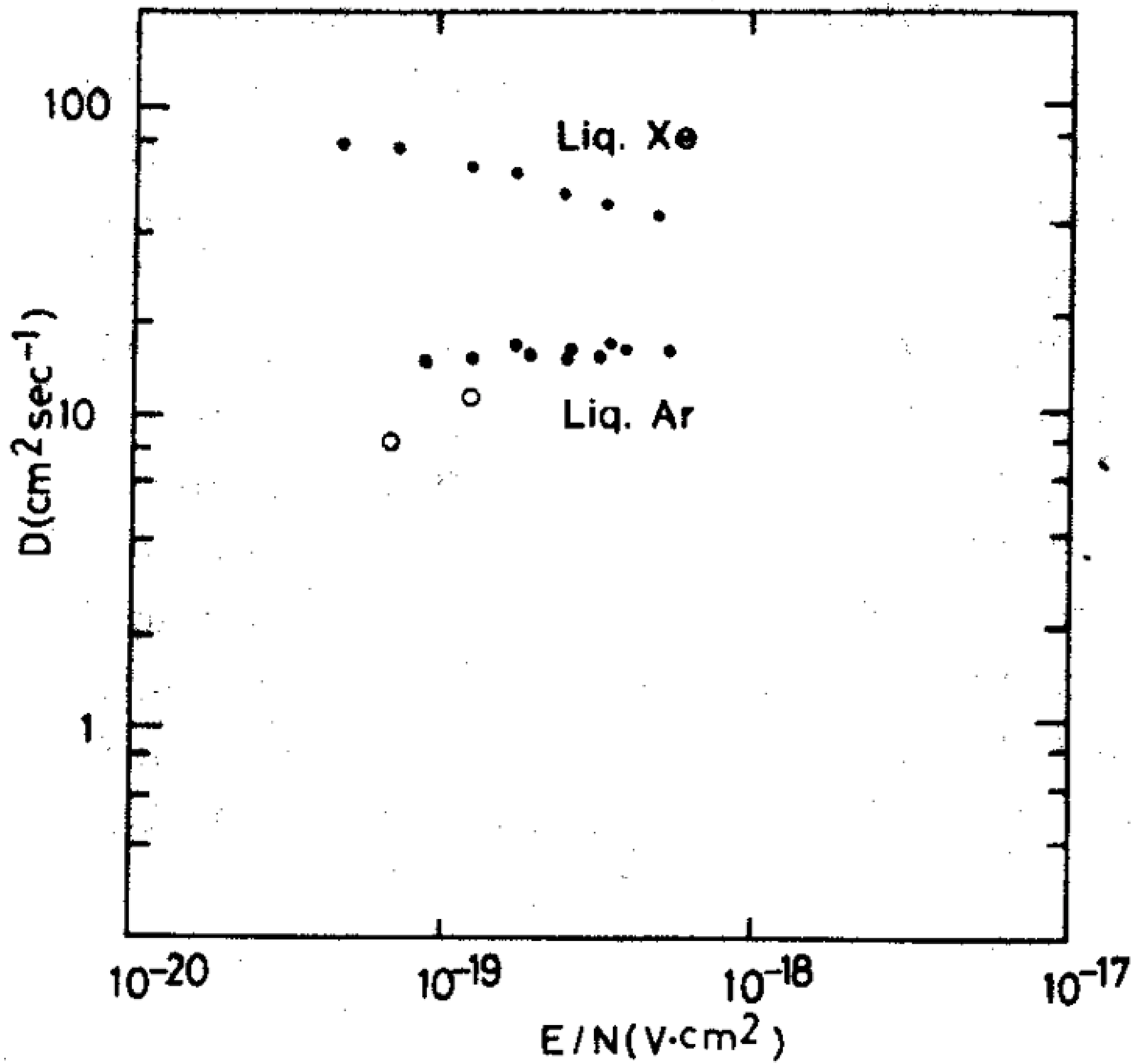

Fig. 1. Diffusion coefficients of electrons in liquid xenon and argon versus the density-normalized electric field. The full circles represent the authors' results and the open circles the results obtained by Derenzo [LBL, Group A Physics Note No. 786 (1974) unpublished]. T.Doke, NIM 196 (1982), 87

Example:
t=104usec
D=50cm^2/sec
σ=1mm

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NUCLEAR
INSTRUMENTS
& METHODS
IN PHYSICS
RESEARCH
Section A

Measurement of attenuation length of drifting electrons in liquid xenon

Masayuki Ichige [a], Elena Aprile [b], Tadayoshi Doke [a], Katsuhito Hasuike [a], Ken Itoh [a], Jun Kikuchi [a] and Kimiaki Masuda [c]

[a] *Science and Engineering Research Laboratory, Waseda University, 17 Kikui-cho, Shinjuku-ku, Tokyo 162, Japan*
[b] *Physics Department, Columbia University, New York, NY 10027, USA*
[c] *Saitama College of Health, 519 Kamiokubo, Urawa-shi, Saitama 338, Japan*

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To realize a long attenuation length of drifting electrons in liquid xenon, a purification system which consists of Oxisorb, molecular sieves and a Zr–V–Fe alloy getter has been constructed A dual type gridded ionization chamber is used for the measurement of the attenuation length. An attenuation length longer than 2 m is achieved in the purified liquid xenon.

LXe-PET : no segmentation with PMT, TPC

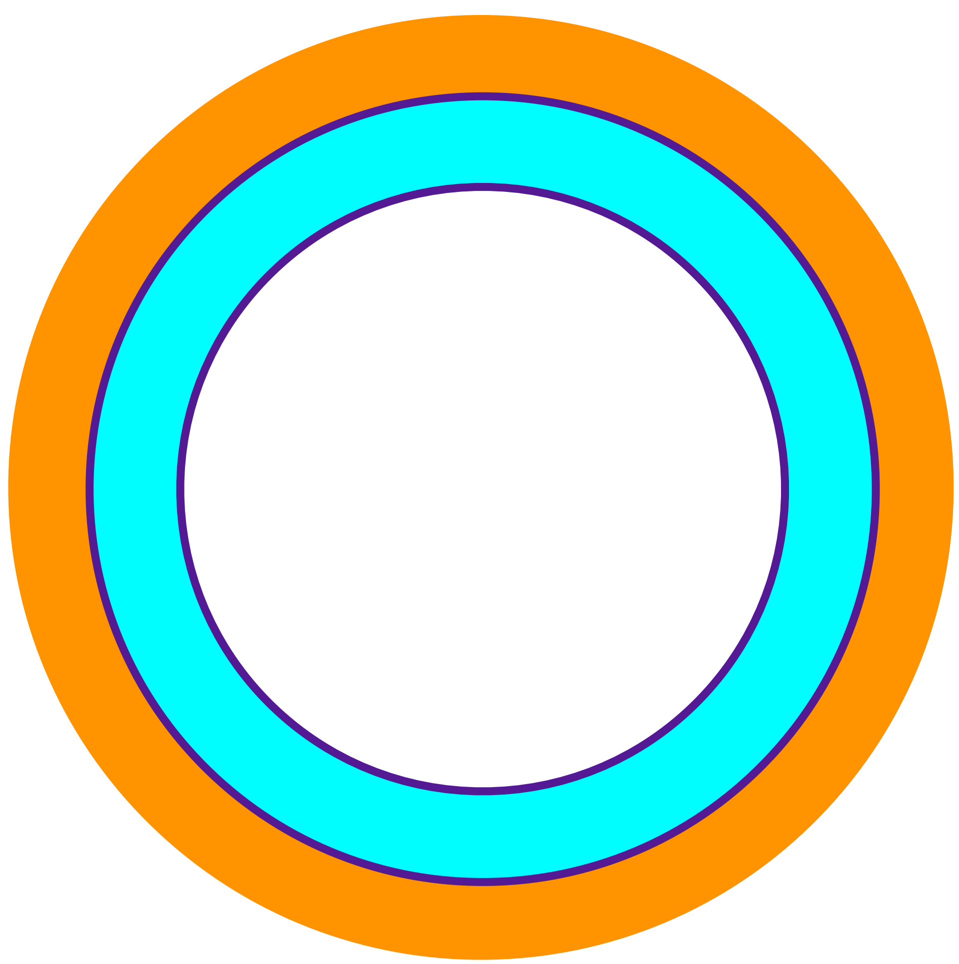
39 l, 80cmΦ , 6cm depth, 24cm axial length

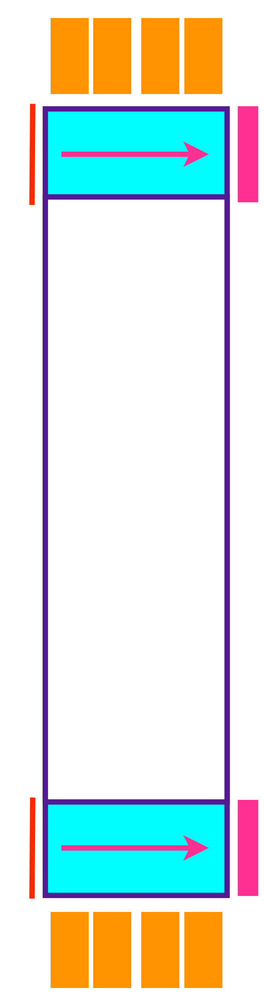
(1)

2"PMT : 4x54=216

Spatial resolution = 2 mm
Time resolution = 1 nsec
timing for the TPC

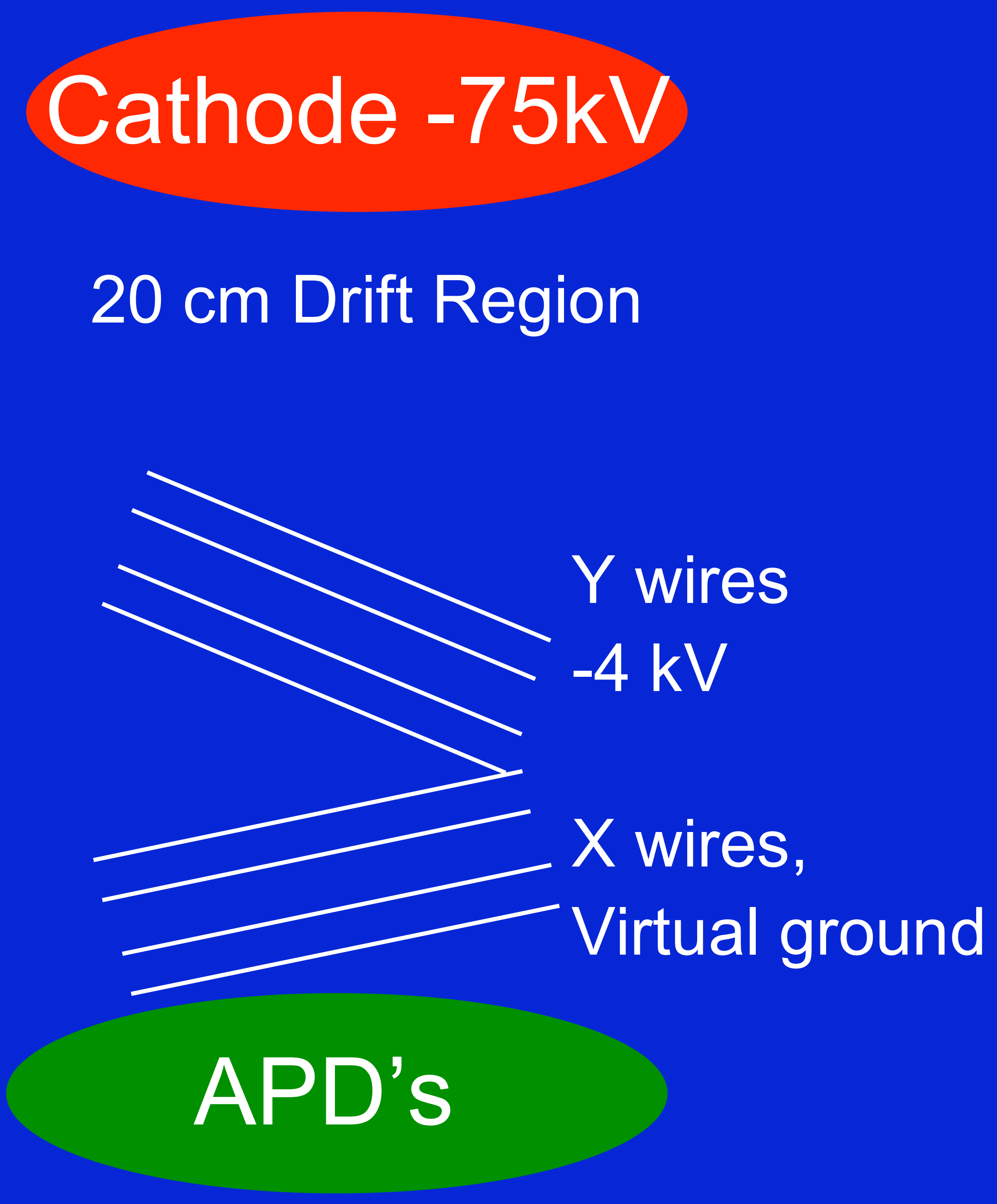
TPC : 48kV
104 μsec/24cm
(2.3mm/μsec)
continuous readout
with time stamp by PMT



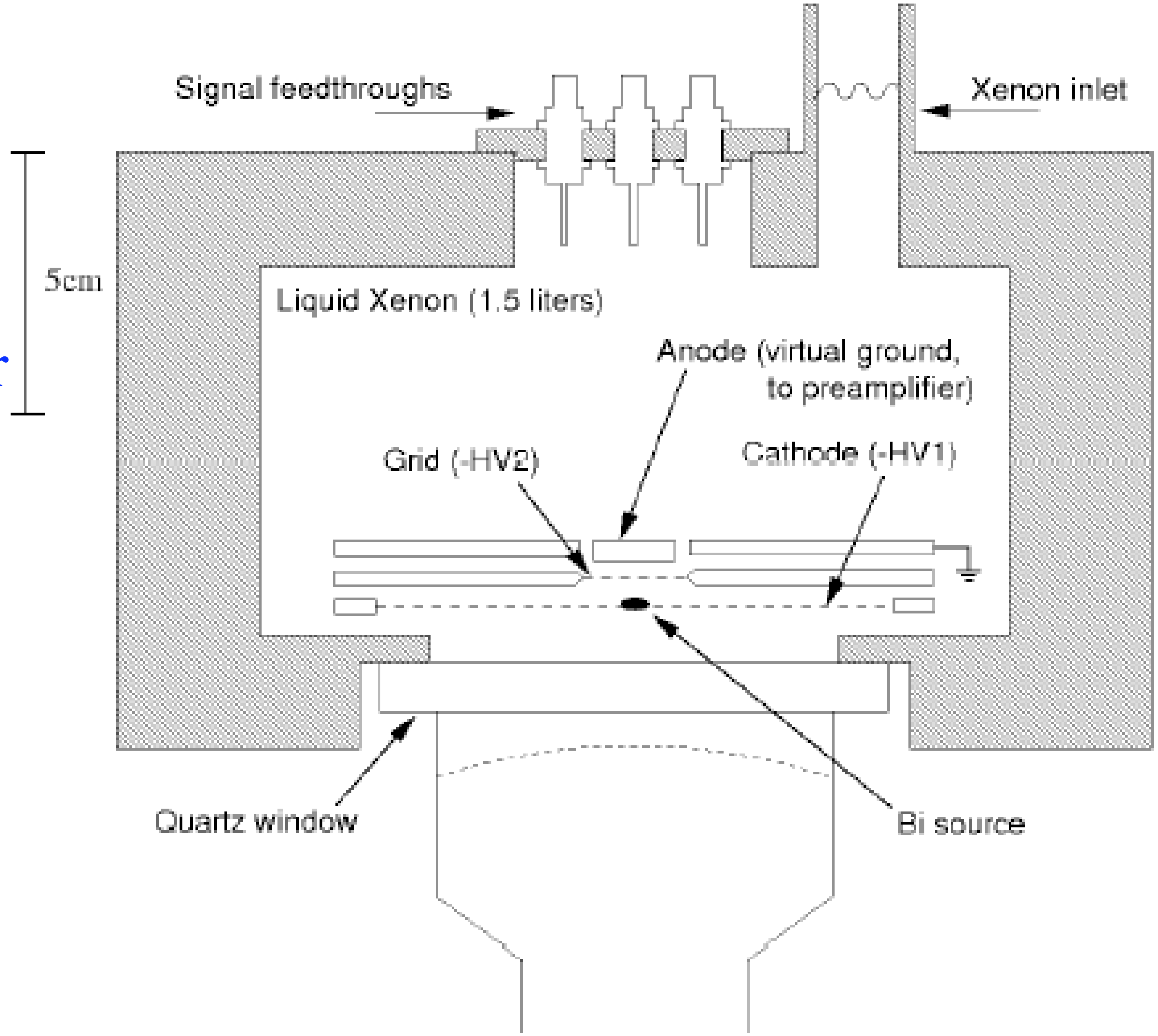


Charge Detection

- Double-ended TPC chamber with ~20 cm drift regions
- Mid-plane cathode biased at -75 kV
- 38 Inductive “Y” wires per side at -4 kV, 100% charge transparent.
- 38 “X” wires at virtual ground to collect the charge.
- LXE electron mobility ~2000 $cm^2/(Vs)$
- Saturation velocity ~ 0.28*cm/μs
- Electron lifetime goal of 3ms
  => 2.4% loss at 20 cm.



EXO LXe energy resolution experiment



Good acceptance for both ionization and scintillation

"There are indications that correlations between the two variables help improve resolution" *[J.Seguinot et al. NIM A 354 (1995) 280]*

Xenon Purity

Impurities (O_2, CO_2, H_2O, ect.) capture electrons as they drift through the liquid. We remove impurities with a SAES high temperature Zirconium getter.

To monitor remaining impurities, we measure the electron lifetime (τ):

$$Q(t) = Q_0 e^{-t/\tau} \quad \text{or} \quad Q(x) = Q_0 e^{-x/\lambda} \quad \text{where} \quad \lambda = v\tau$$

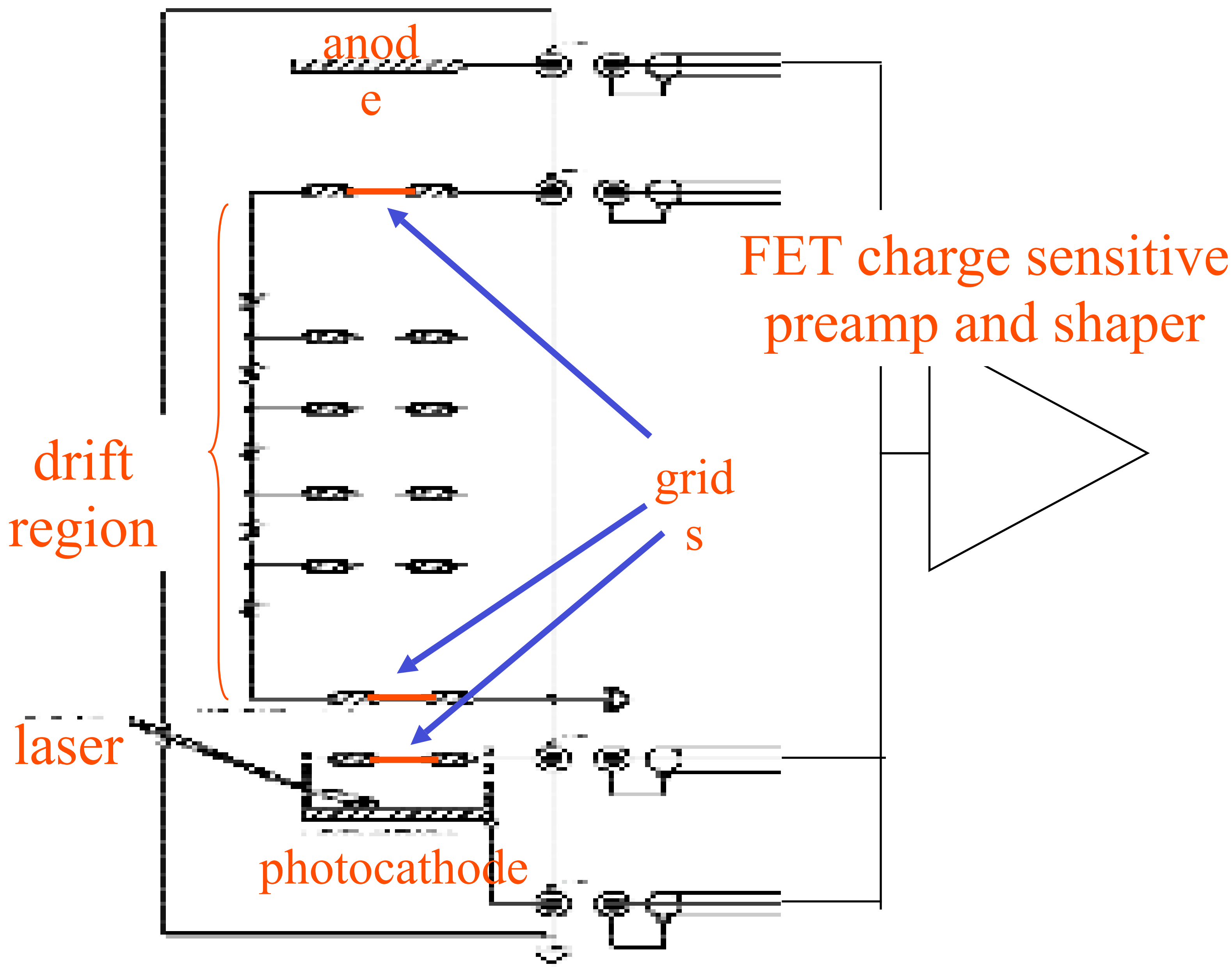
For a maximum drift distance of 15 cm, we aim for:

$\lambda > 300$ cm

$\tau \sim 3$ ms

0.1 ppb O_2 equivalent

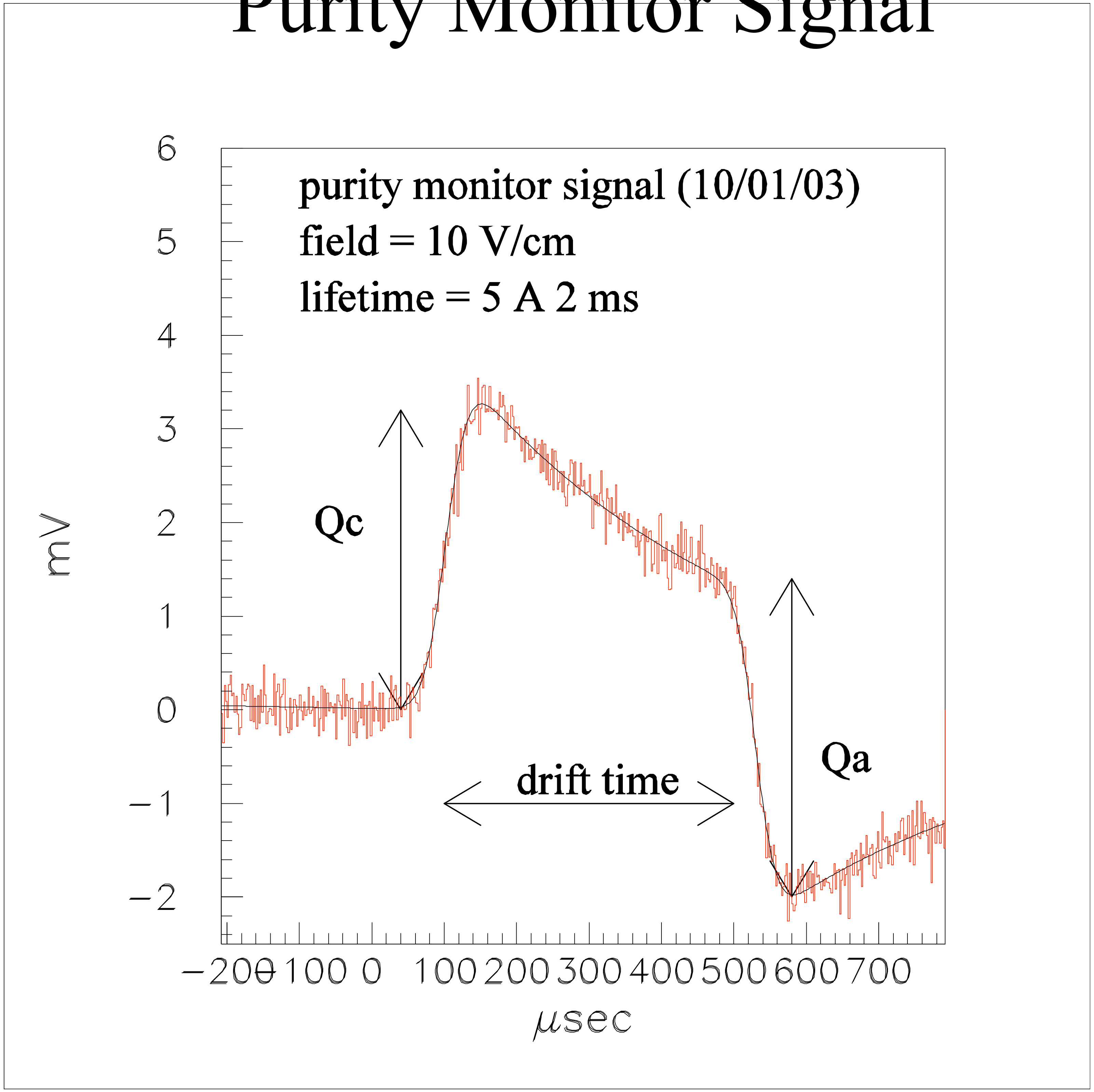
Xenon Purity Monitor



To measure the electron lifetime:

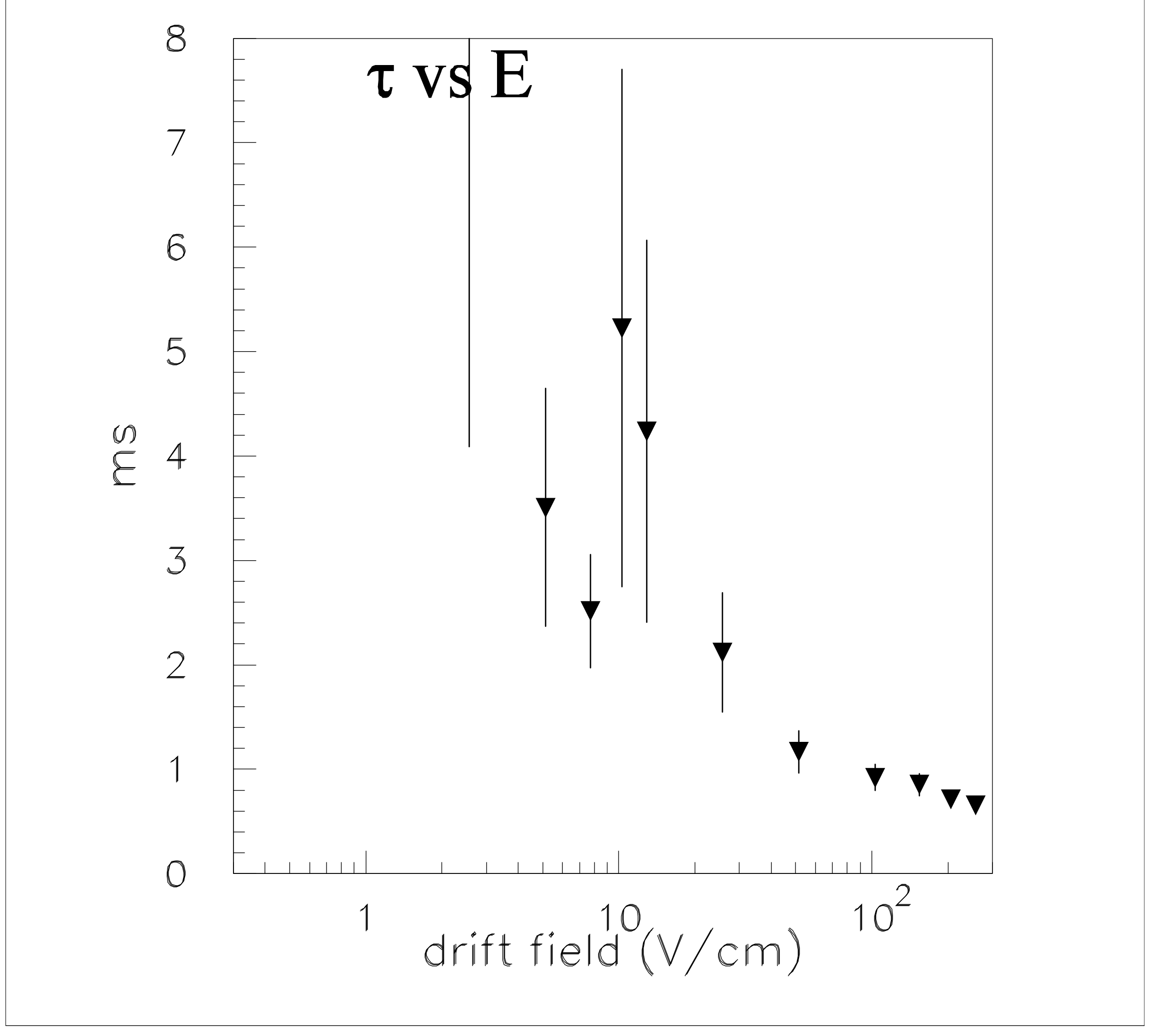
- ~10^6 photoelectric electrons produced by laser
- initial charge measured by induction grid
- electrons drift through 11 cm of LXe
- final charge measured by anode

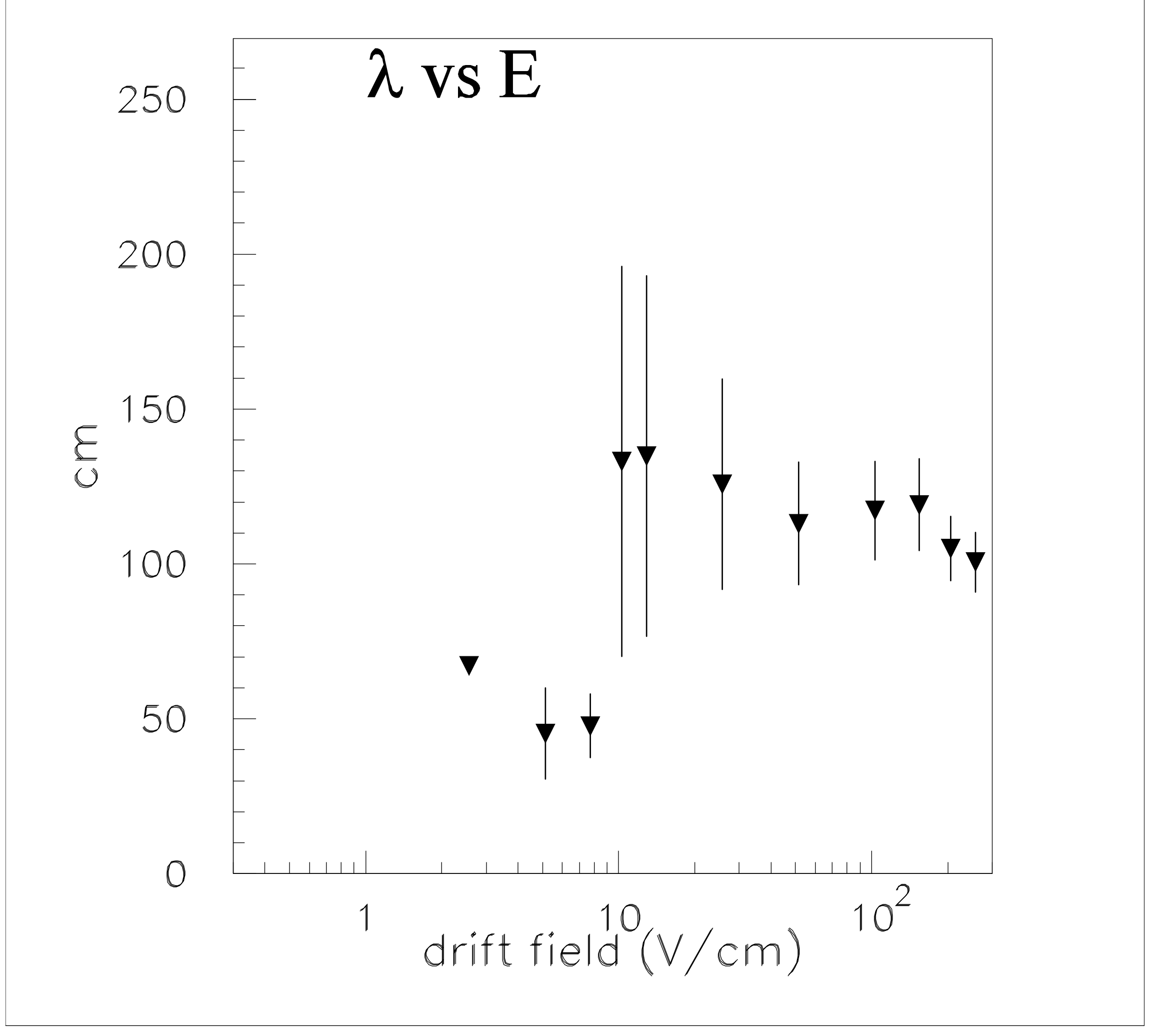
Purity Monitor Signal



Lifetime vs field

We typically find that the lifetime decreases at high field:





Our goal is to improve by a factor of two at high field.

LXe-GRIT ; 1 phase

2004

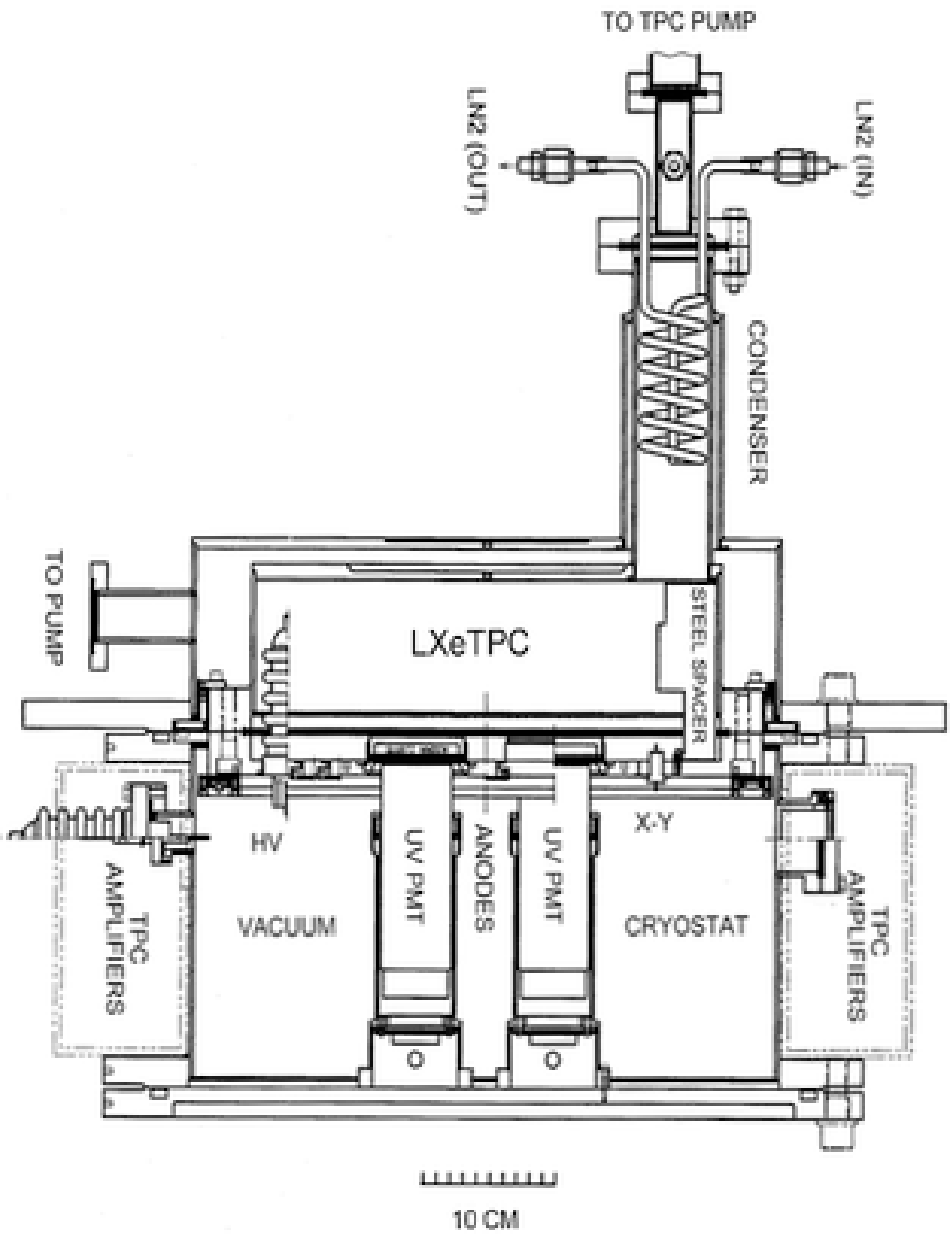
Columbia university - XENON collaboration

baloon flights(1997-2000) of the Liquid Xenon Gamma-Ray Imaging Telescope

γ energy range = 0.511 - 70MeV (e^+ - π^0)

LXeTPC (prototype of Compton telescope) with 7cm long drift

-direction of incident γ can be estimated by sequence of Compton scattering



LXeTPC : 18.6x18.6x7cm^3 (2.4 l)

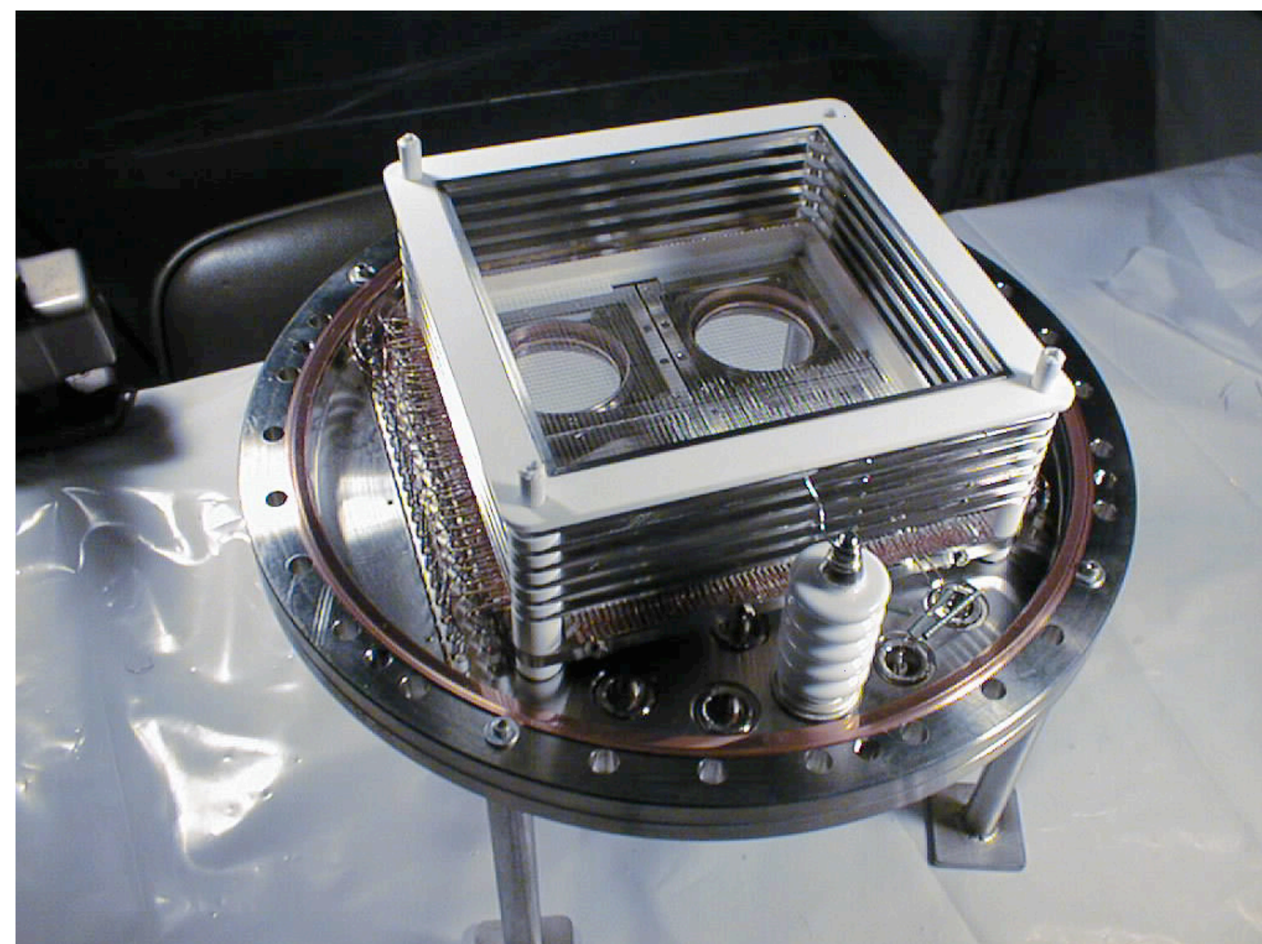


Figure 2.3: Top view of the LXeTPC with the field-shaping rings. The ceramic HV feedthrough is visible in the lower part of the picture.

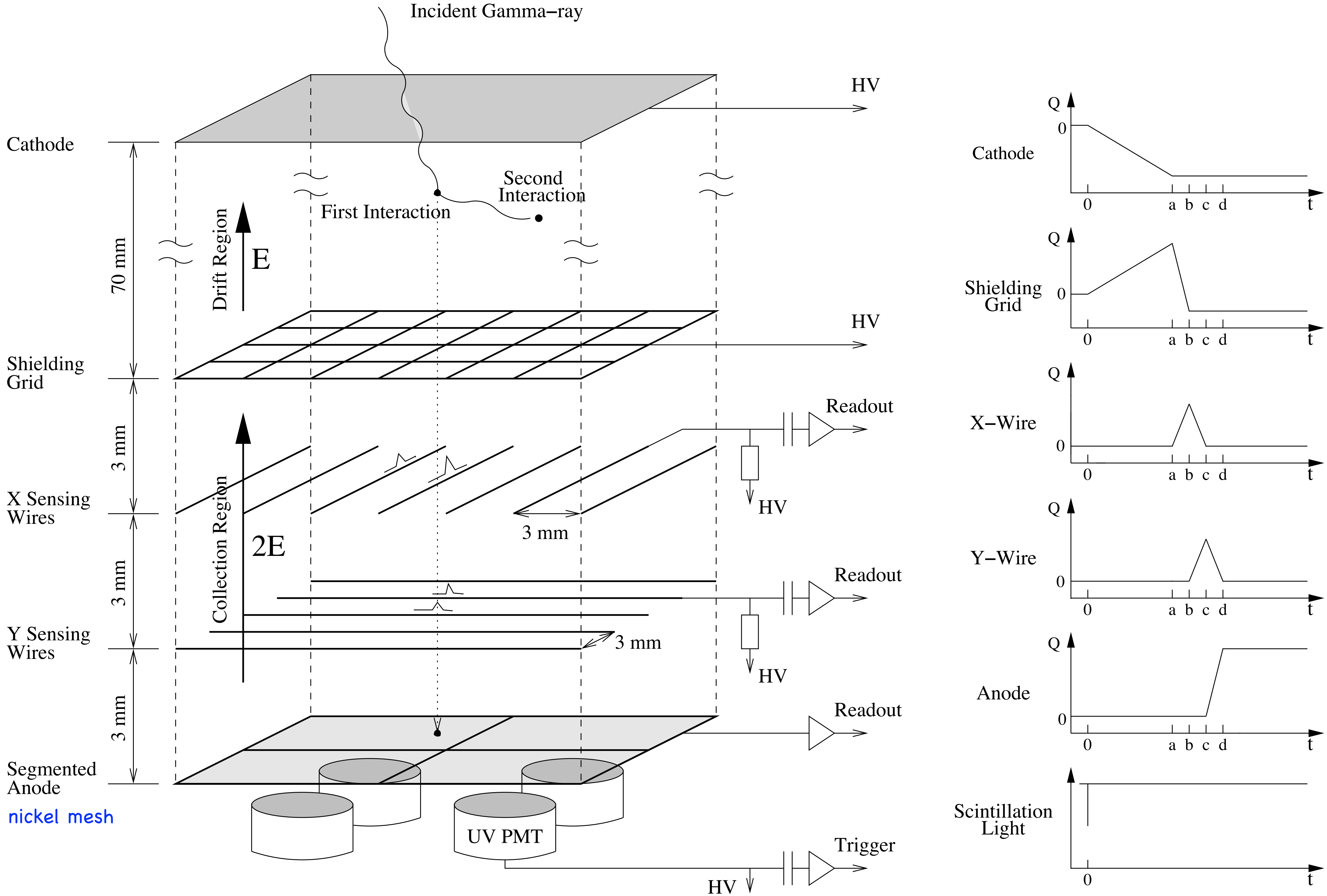


Figure 2.6: Schematic of the LXeTPC read-out structure with corresponding light trigger and charge signals (from (98) and (74)).

the wires are stainless steel 100um diameter,

signals   charge sensible amp.
  noise < about 450 and 1000 e- RMS for the wires and anodes
            + custom-built digital electronics at 5MHz, 8 and 10 bits
               for the wires and anodes

TPC can detect gamma with energy deposits as low as about 100keV (about 940e- on wires)

PMT signals are trigger to readout the TPC with requirement of no PMT signal within 50usec.

performances in TPC Active volume 20 x 20 x 7 cm^3 :

- position resolution 1mm (3 dimensions), 350um in z
- angular resolution 3 degree at 1.8MeV by Compton telescope with multiple interaction
- energy resolution (FHM) 8.8%/SQRT(E(MeV)) by anode signal

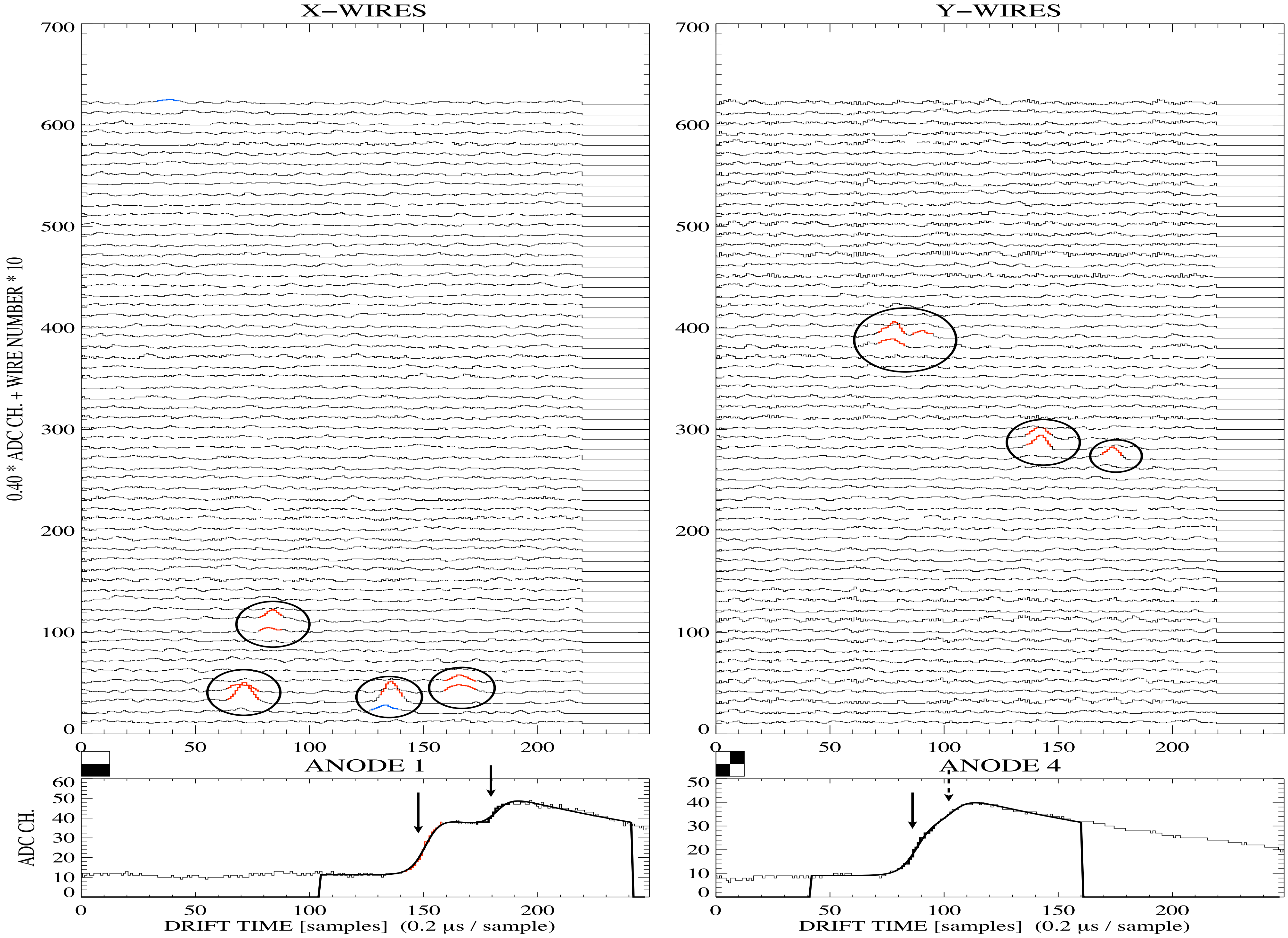


Figure 2.9: Digitized waveforms on wires and active anodes as a function of drift time in FADC samples, for an ^{88}Y 1836 keV γ-ray event with 4 interactions. The upper panels show all wire waveforms, in scaled units of ADC channels, each separated by an offset. Matched wire signals are indicated by circles, and only their corresponding anodes are shown. The wire-anode correspondence is indicated by the dark fields at the top left corner of each anode display. The solid arrows mark three steps found by the anode signal algorithm, and the dashed arrow marks an additional step, included in the fit (smooth solid line) after signal recognition on the wires (from Ref. (74)).

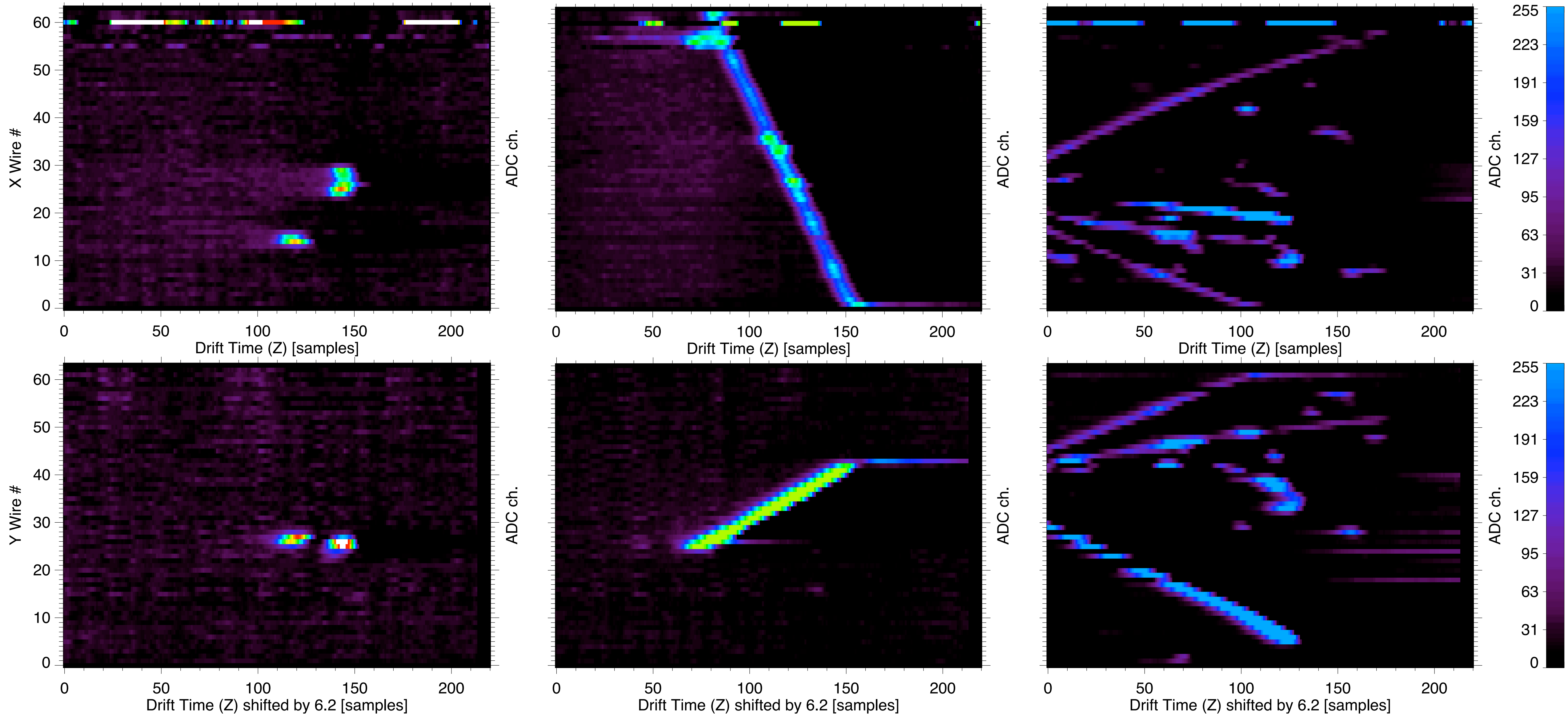


Figure 5.7: "Snapshots" of three different events in the LXeTPC recorded during the balloon flight in year 2000; for each of them the X-Z view and the Y-Z view are shown. *Left:* a 2-site γ-ray interaction. *Center:* a relativistic particle passing through the fiducial volume. Several δ-rays are visible in the X-Z view. *Right:* a more complex interaction with several particles detected in the fiducial volume. The vertex happens below the fiducial volume, i.e. at $Z < 0$.

High purity (<1ppb O_2 equivalent) Xe gas is liquified into the vessel by a controlled flow of liquid nitrogen(LN2) through the copper coil of the condenser on the top. The liquid temperature is $-95^\circ C$, at a pressure of 1.5atm.

i.e. $O_2 < 0.1$ppb, $H_2O < 0.5$ppb

7cm drift in 1kV/cm, 35usec
drifting electron lifetime is about 360usec, which corresponds to an attenuation length of about 80cm

R&D

- multi-anode pads (サイズ 3mm x 3mm 以下）readout
- GEM or MHSP like readout (multiplication ?)
  simulationで有効性を確認後試みる
- purity of Xe， O^2 contents (<0.1ppb) v.s. attenuation length
- continuous readout with time stamping by PMT coincident signals (10nsec)
- 『多数の検出器出力信号をリアルタイム処理するための
  ASICの技術が不可欠である』
- position and energy resolution by PMTs

note : LXeGRITとの違い

two dimensional readout (multi-anode pads, GEM, MHSP etc.)
energy by PMT 10% -> 5%

先ず、R&Dとして、液体１相で、２次元の位置読み出しと、液体キセノンの純度したがってdrift方向のattenuation lengthの関係を測定すること、そして、PMTによるtime stampされたTPCの連続的readout。

PMTについては、10nsec以下でのゲート幅でのcoincidenceの確認と位置（cm程度）とエネルギー分解能（5%程度）の測定。