Basis for Liquid Xe TPC

LIQ course

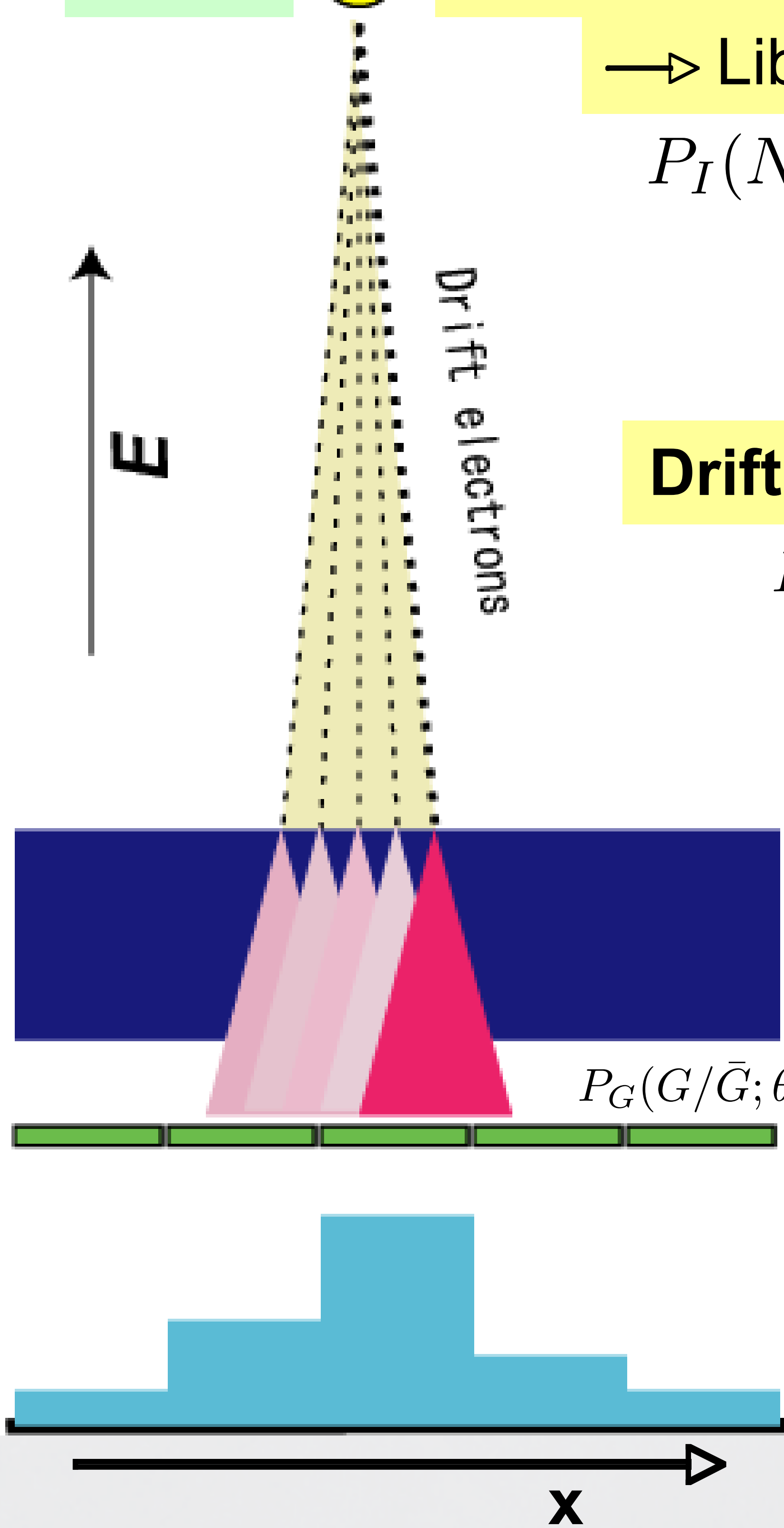
Fundamental Processes

Beam **Ionizations**

→ Liberation of Electrons

$P_I(N;\bar{N})$ Normal incidence (no angle effect)

No δ-ray



Drift Volume

Drift and Diffusion

$$P_D(x_i;\sigma_d) = \frac{1}{\sqrt{2\pi}\sigma_d} \exp\left(-\frac{x_i^2}{2\sigma_d^2}\right)$$

$$\sigma_d = C_d\sqrt{z}$$

Amplification Gap

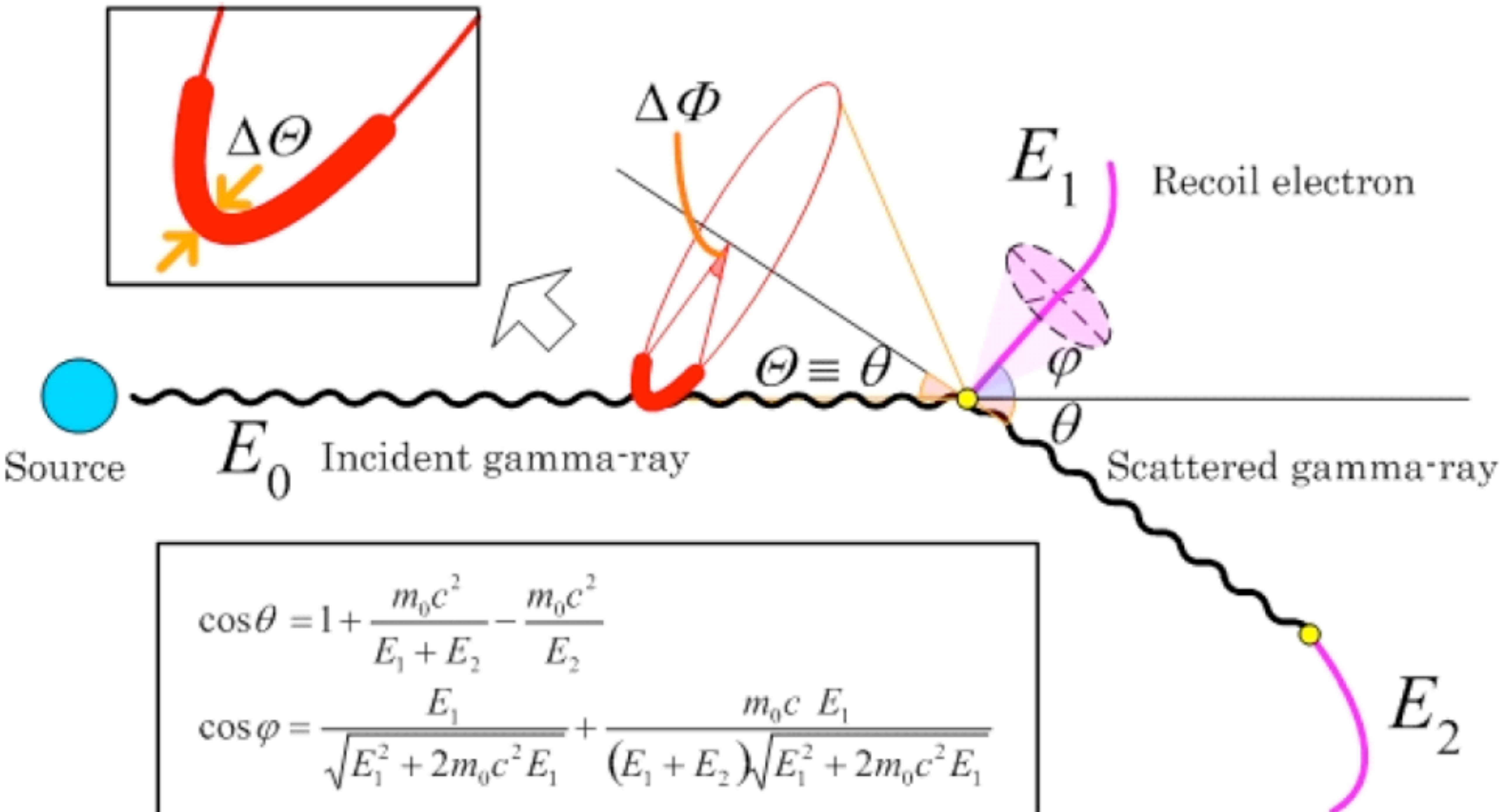
Amplification and further Diffusion

$$P_G(G/\bar{G};\theta) = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)}\left(\frac{G}{\bar{G}}\right)^{\theta} \exp\left(-(\theta+1)\left(\frac{G}{\bar{G}}\right)\right)$$

Readout Pads

Pad Response

→ **Coordinate**



Reconstruction of incident angle in Compton scattering

Table 1.5: Physical properties of noble liquids (adapted from Ref. (98)).

	LAr	LKr	LXe
Atomic Number Z	18	36	54
Atomic Weight A	39.95	83.8	131.3
Density (g/cc)	1.39	2.45	3.06
Melting Point T_m (K)	83.8	115.8	161.4
Boiling Point T_b (K)	87.3	119.8	165.1
Critical Temperature T_c (K)	150.7	209.5	289.7
Critical Pressure P_c (atm)	48.3	54.3	57.64
Critical Density (g/cc)	0.54	0.91	1.10
Volume Ratio (ρ_l/ρ_g)	784	641	519
Fano Factor	0.107	0.057	0.041
Drift Velocity (mm/μsec) @ 1(5) kV/cm	1.8(3.0)	2.4(4.0)	2.2(2.7)
Mobility (cm $V^{-1}s^{-1}$)	525	1800	2000
Radiation Length (cm)	14.3	4.76	2.77
(dE/dx) (MeV/cm)	2.11	3.45	3.89
Liquid Heat Capacity (cal/g-mole/K)	10.05	10.7	10.65
W-value (eV) (ionization)	23.3	18.6	15.6
W-value (eV) (scintillation)	19.5	15.5	14.7
Wavelength of Scintillation Light (nm)	130	150	175
Decay const.			
fast (ns)	6.5	2	2
slow (ns)	1100	85	30
Refractive index @ 170 nm	–	1.41	1.60
Dielectric constant	1.51	1.66	1.95

diffusion :

widening pulse shape

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

$C_D^2 = D/v$

Example:
t=104μsec
$D = 50cm^2/sec$
C_D=145μm/SQRT(cm)
σ=1mm
note : 170μm/SQRT(cm)

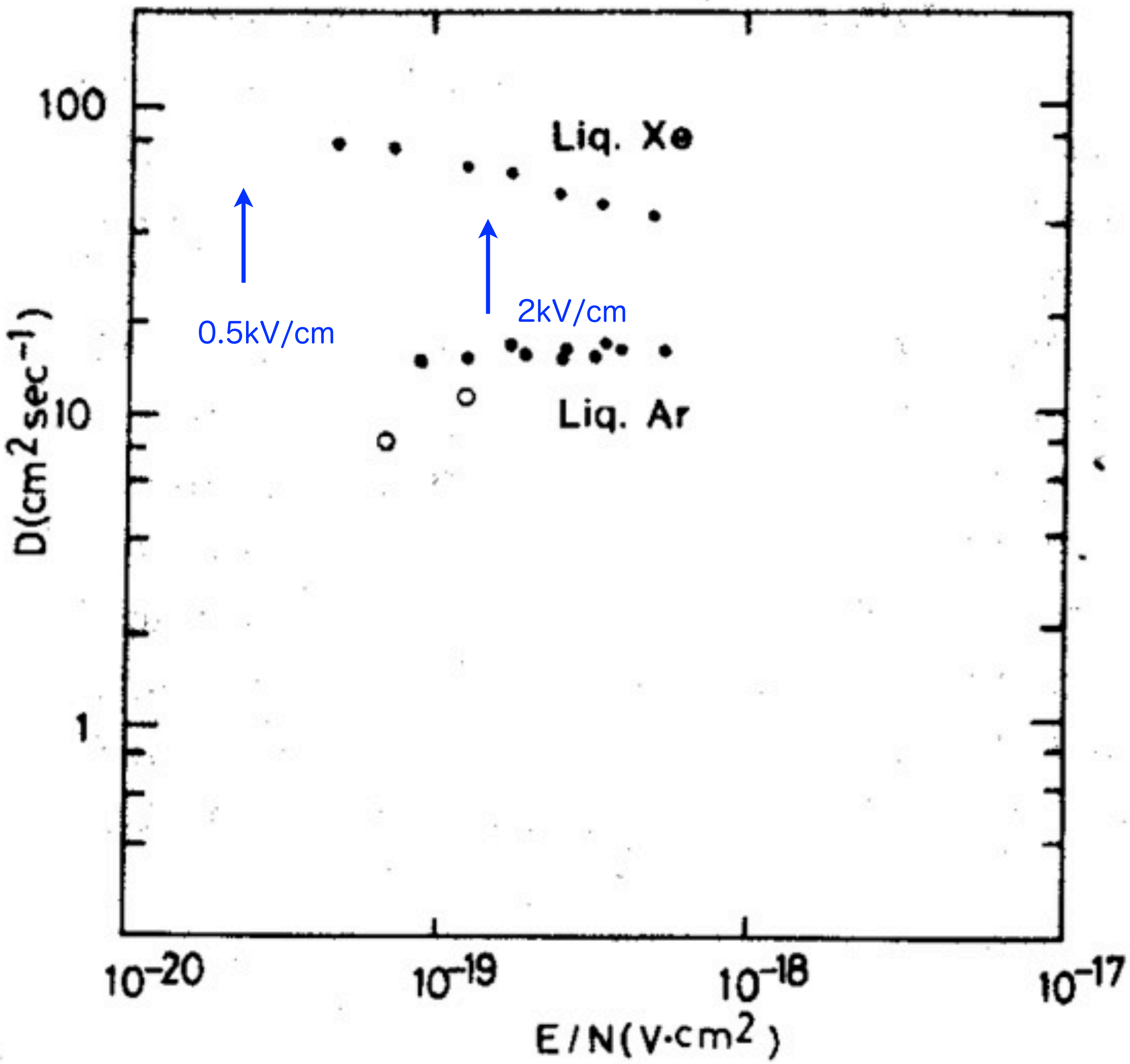
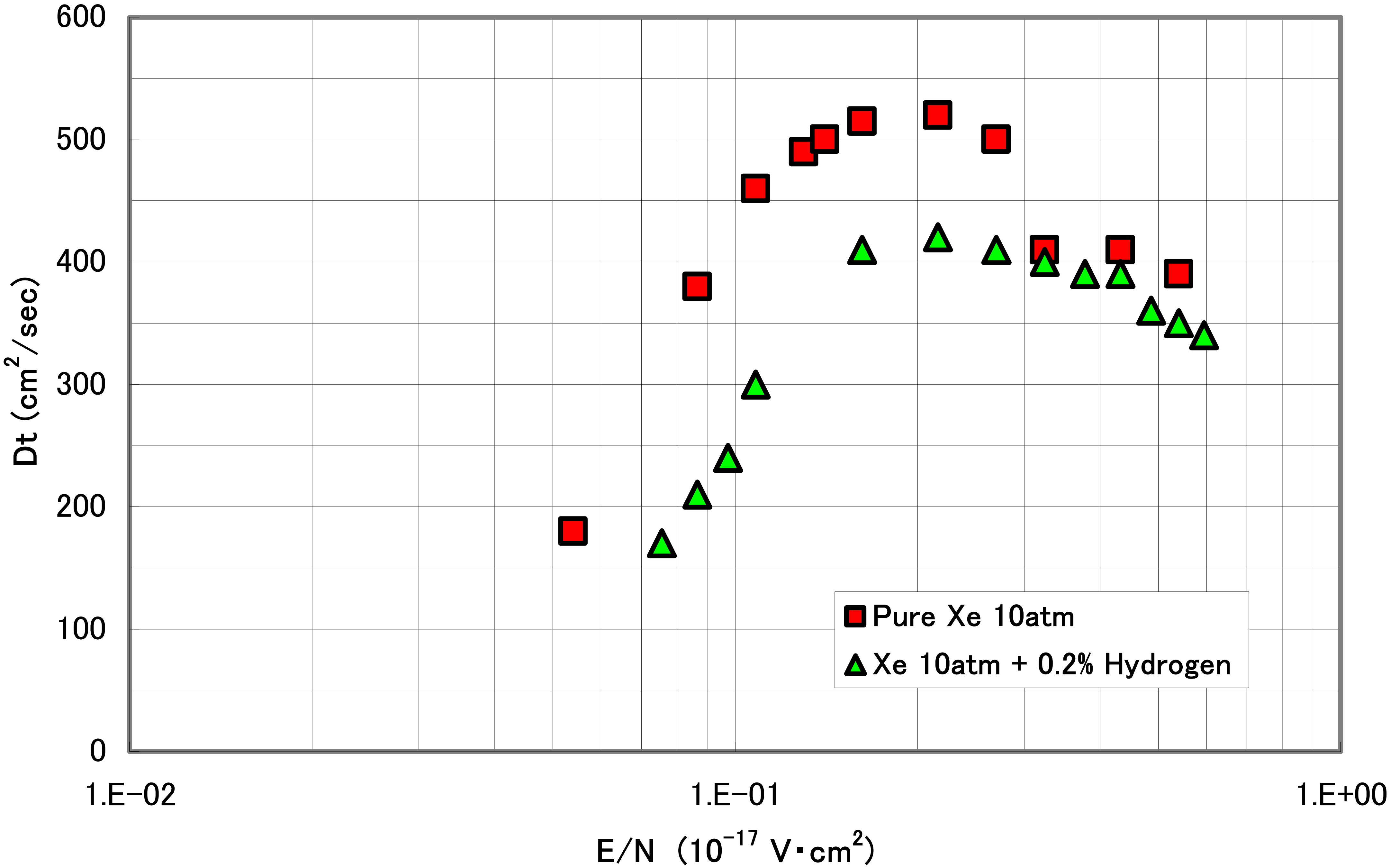


Fig. 1. Diffusion coefficients of electrons in liquid xenon and argon versus the density-normalized electric field. The full circles represent the authors' results and the open circles the results obtained by Derenzo [LBL, Group A Physics Note No. 786 (1974) unpublished]. T.Doke, NIM 196 (1982), 87

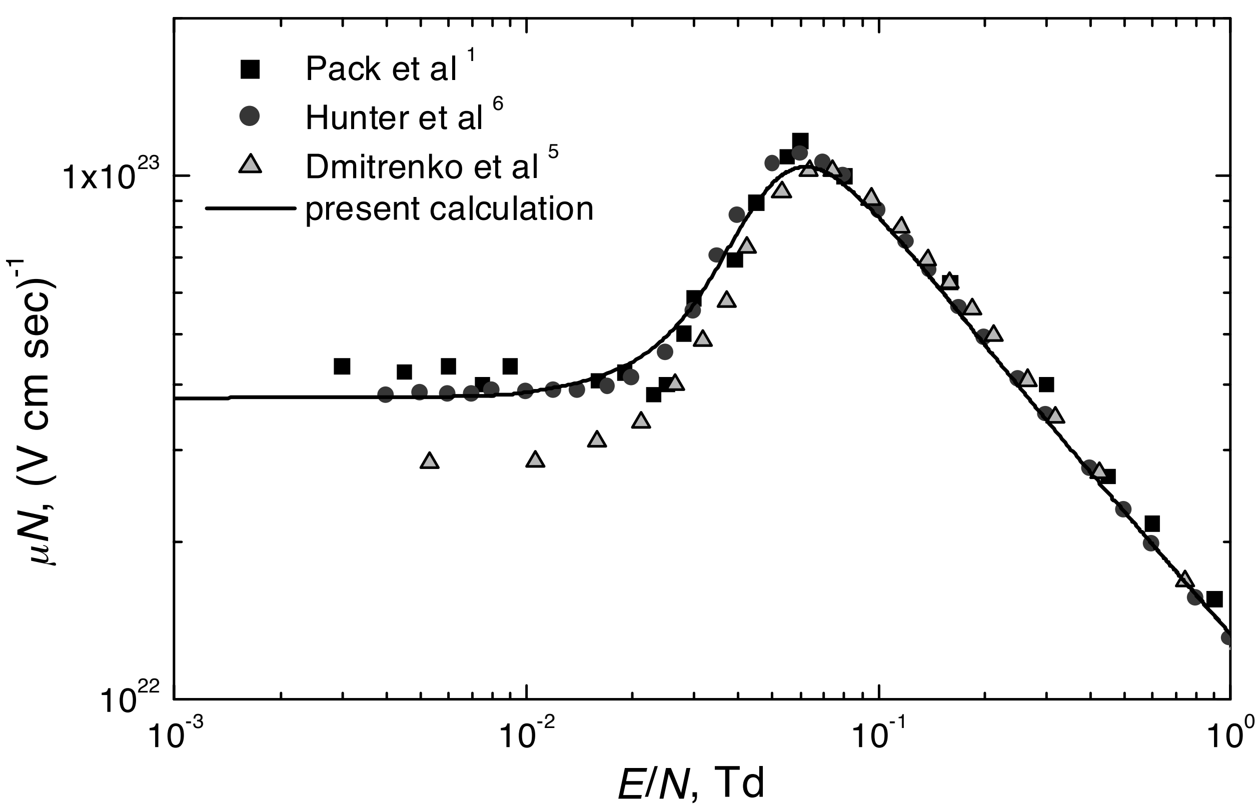
spatial resolution

$\sigma_x = \sqrt{\sigma_x(0)^2 + C_D^2/N_{eff}z}$

N_{eff}=no. of electrons
if N_{eff}=1000 and z=24cm,
$C_D^2/N_{eff}z = (20\mu m)^2$
with pad-analog readout



Transverse diffusion coefficient to electric field



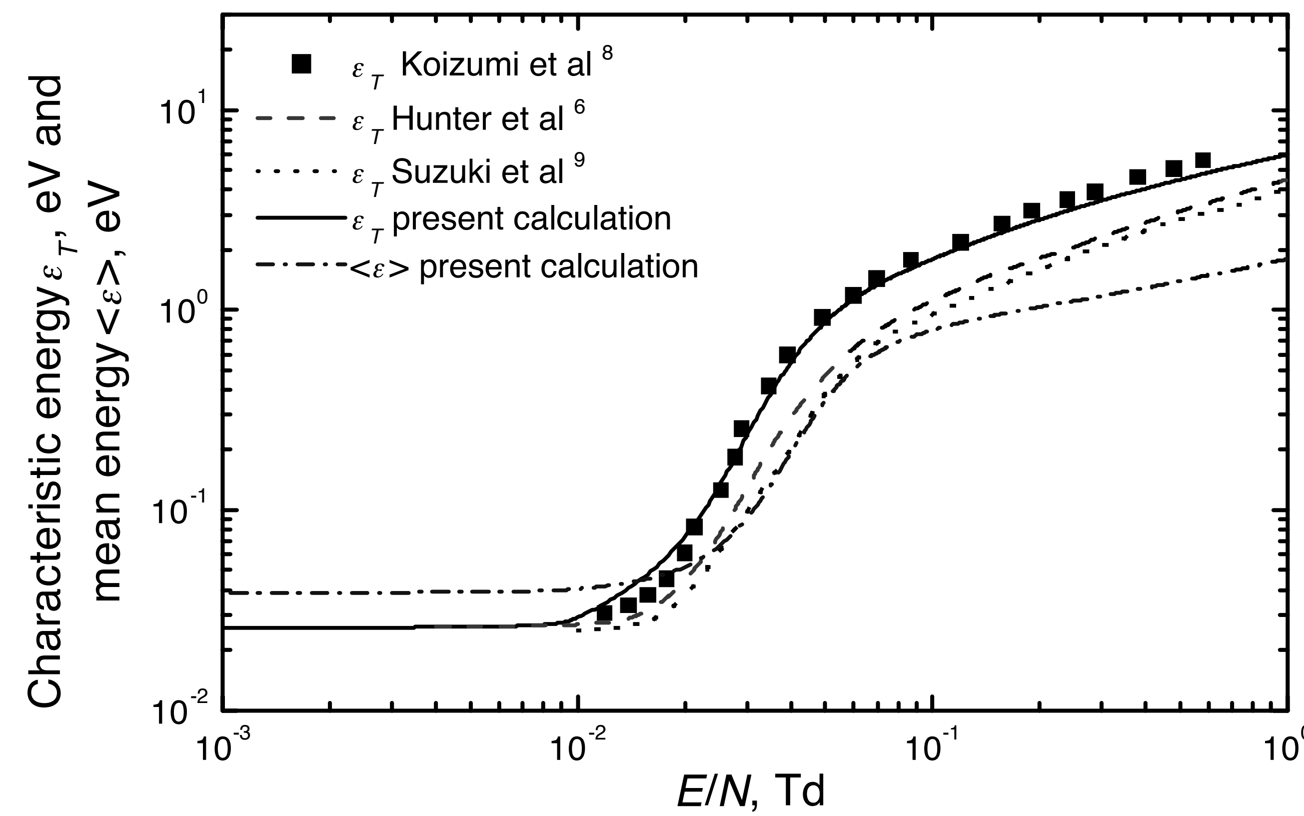


Fig. 1. Density-normalized electron mobility $N\mu(E/N)$ as a function of E/N. Present calculation in comparison with measurements by refs. 1,5 and 6.

Fig. 2. Electron transverse characteristic energy $\varepsilon_T(E/N)$ and mean electron energy $\langle\varepsilon\rangle(E/N)$ as a function of E/N. Present calculation in comparison with measurements by ref. 8 and calculations.[6,9)]

$\mu N = 1.5 \times 10^{22}$ (V cm sec)$^{-1}$ at Td=1

N=2.5 x 10^{19} cm^{-3} for Xe gas, 1atm

$\mu = 602$ V^{-1} cm^2 sec^{-1} at Td=1

$<\varepsilon> = 7$eV at Td=1

$\varepsilon = eD/\mu$ in eV

D = $\mu/e <\varepsilon>$ = 602 x 7 = 4,215 cm^{2}sec^{-1} at Td=1

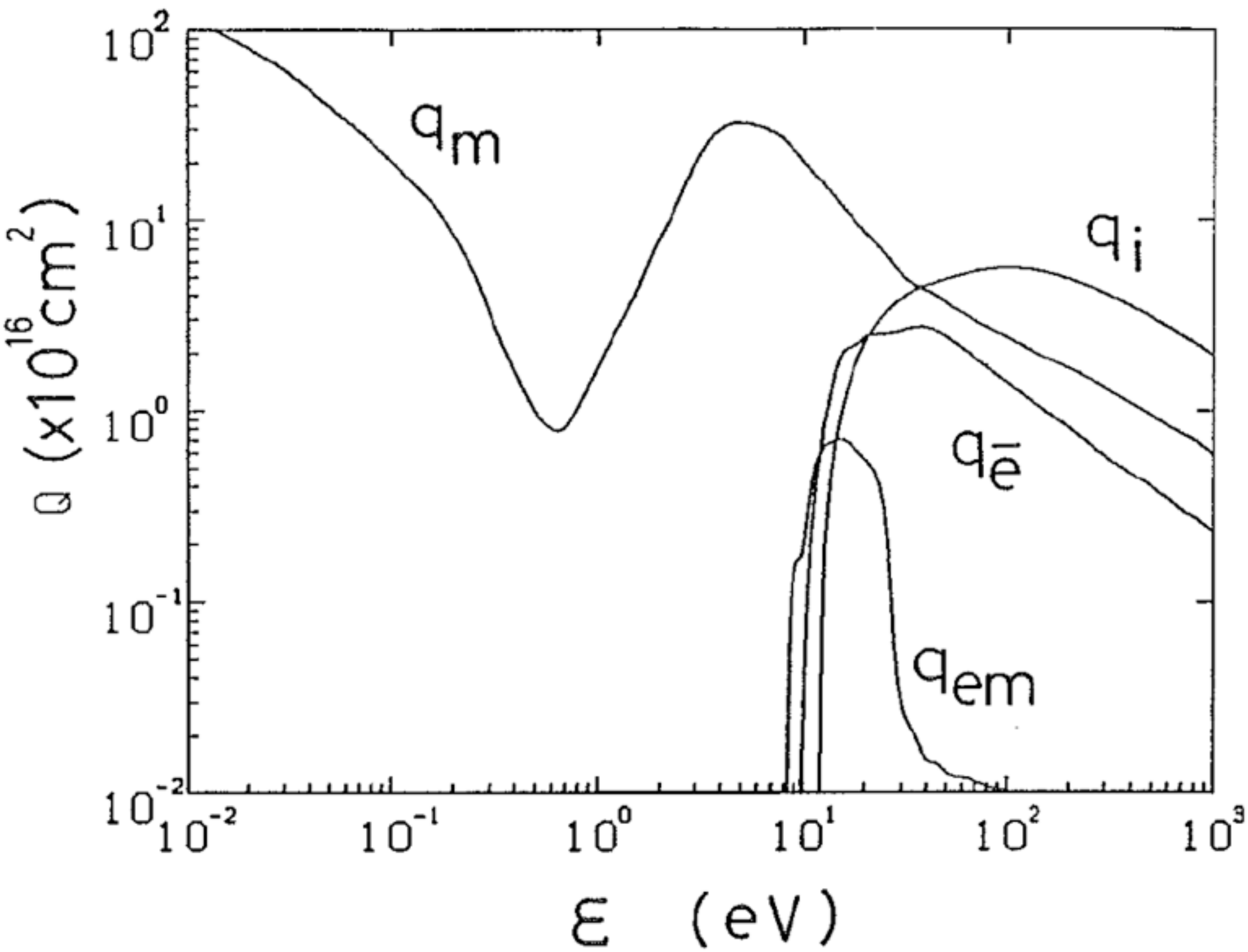


Figure : Electron cross section in Xe : q_m=momentum transfer, q_i=ionization, q_{em}=excitation to meta stable levels, q_e=other excitations than q_{em}

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North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Measurement of attenuation length of drifting electrons in liquid xenon

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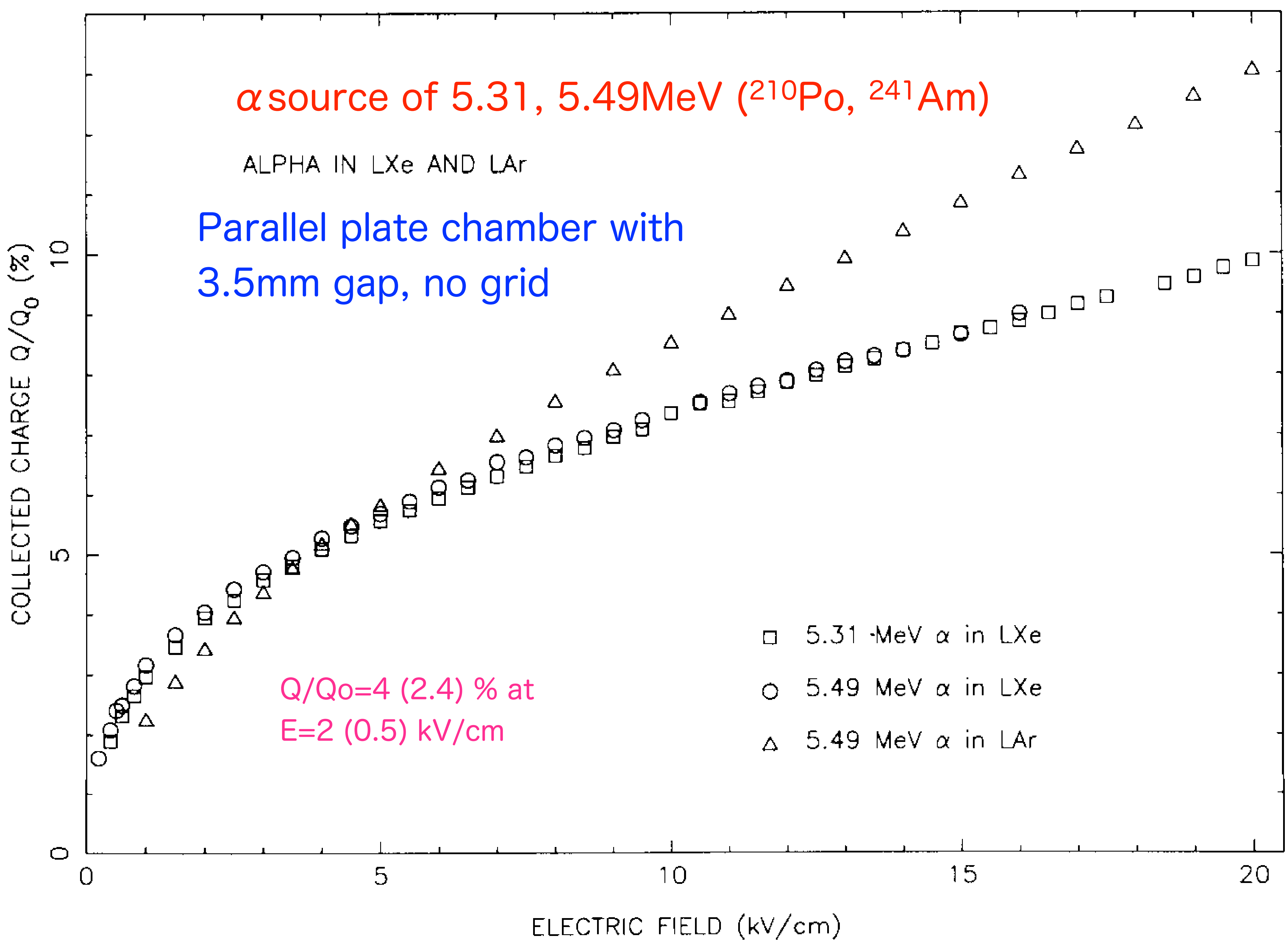
To realize a long attenuation length of drifting electrons in liquid xenon, a purification system which consists of Oxisorb, molecular sieves and a Zr–V–Fe alloy getter has been constructed. A dual type gridded ionization chamber is used for the measurement of the attenuation length. An attenuation length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

attenuation length > 2m !, -11% at 24cm drift



Collected charge (Q/Q_0%) vs. electric field for ^{210}Po in liquid xenon (□) and ^{241}Am in liquid xenon (○) and liquid argon (△

E. Aprile et al., NIM A307 (1991)119-125

E. Aprile et al., NIM A307 (1991)119-125

α source of 5.31, 5.49MeV (^{210}Po, ^{241}Am)

Parallel plate chamber with 3.5mm gap, no grid

Q/Qo=4 (2.4) % at E=2 (0.5) kV/cm

Energy resolution in FWHM =5.1% at E=2kV/cm

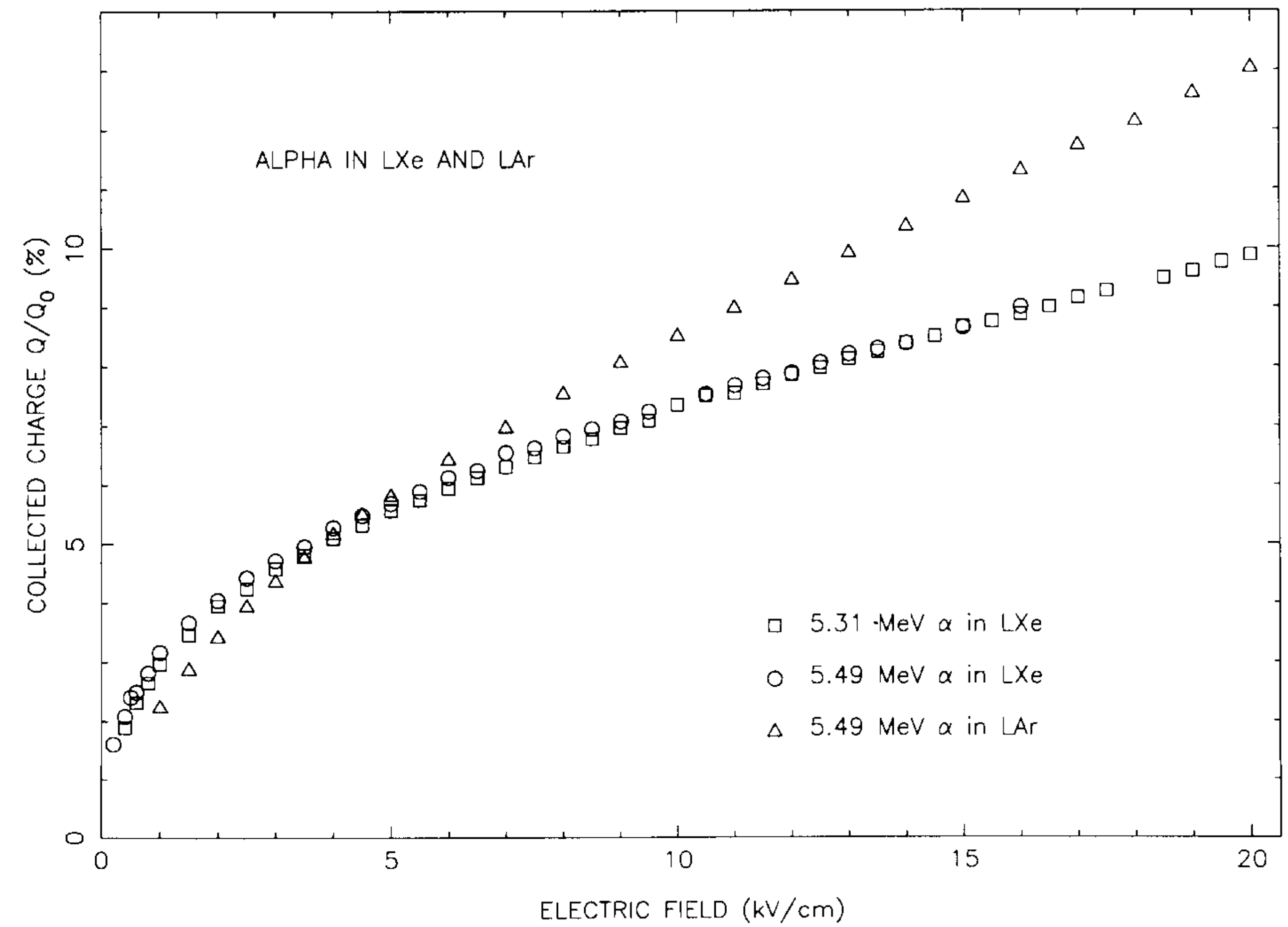


Fig. 5. Collected charge (Q/Q_0%) vs. electric field for ^{210}Po in liquid xenon (□) and ^{241}Am in liquid xenon (○) and liquid argon (△).

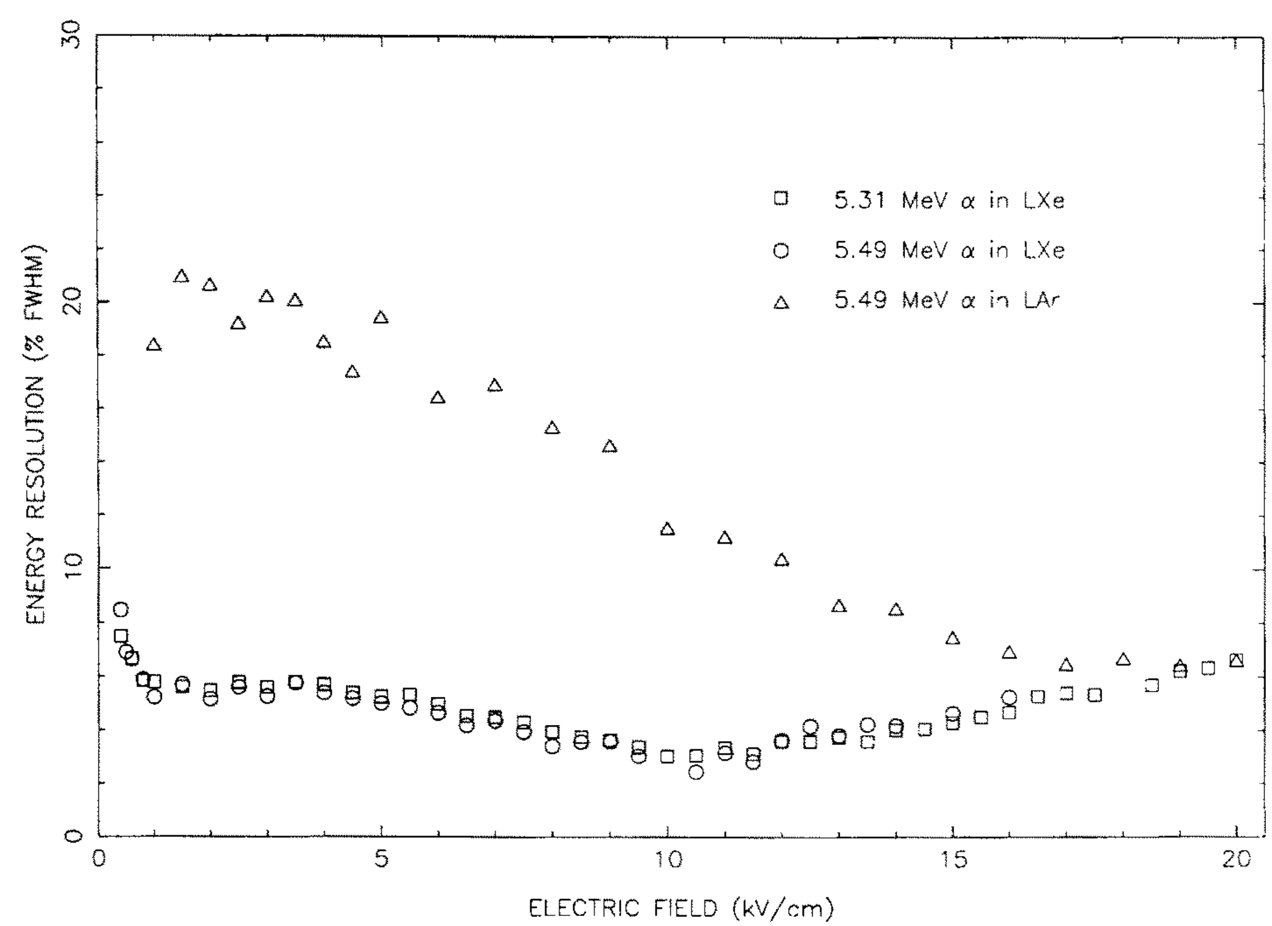


Fig. 6. Noise subtracted energy resolution vs. electric field for ^{210}Po in liquid xenon (□) and ^{241}Am in liquid xenon (○) and liquid argon (△).

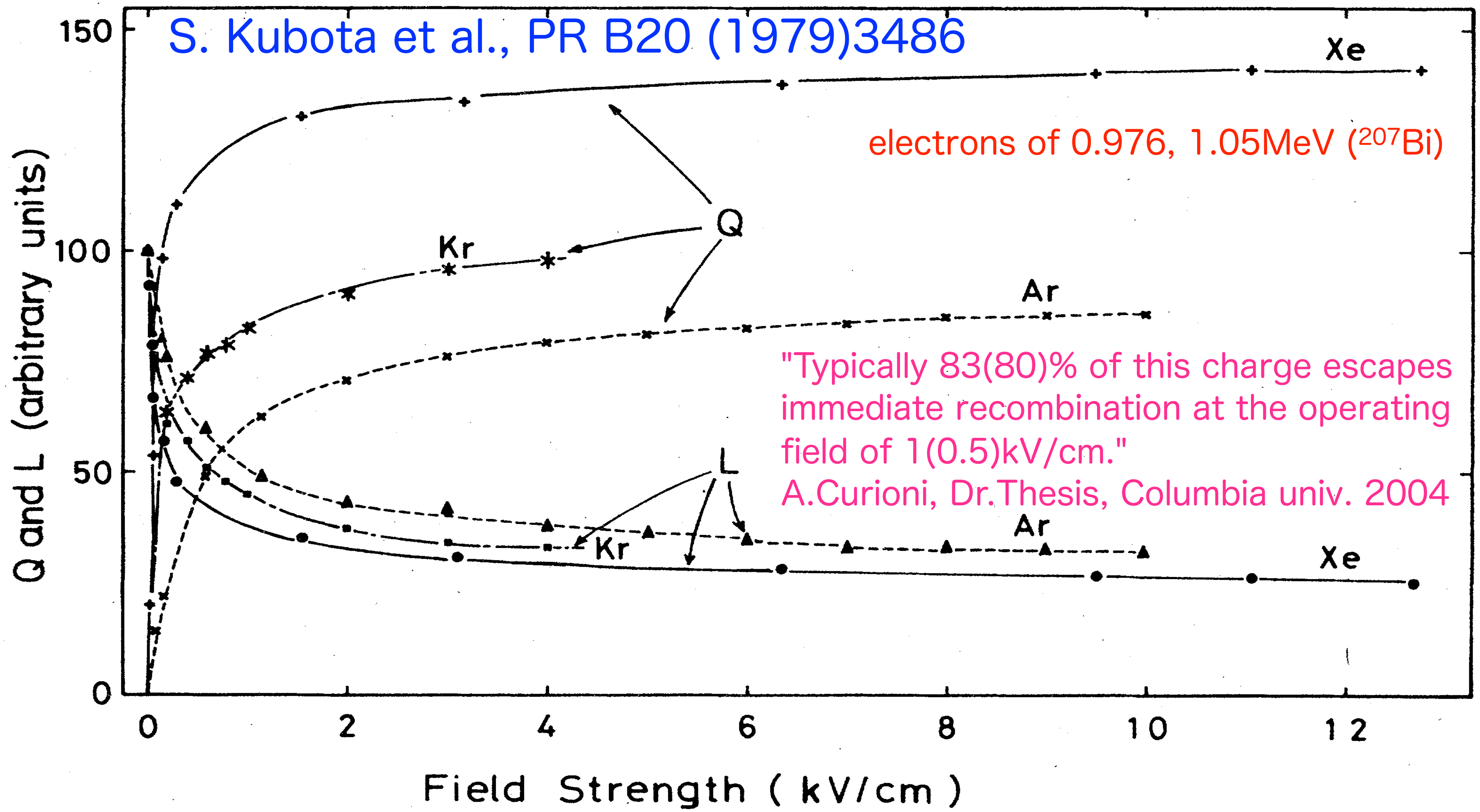
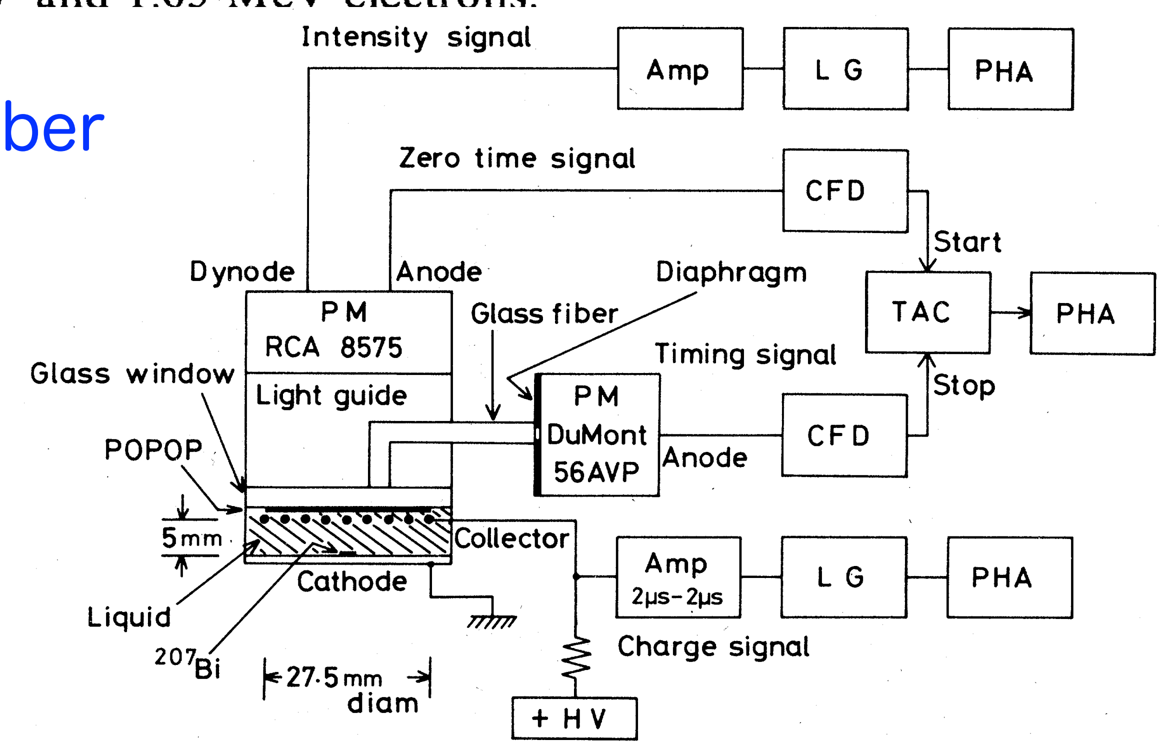
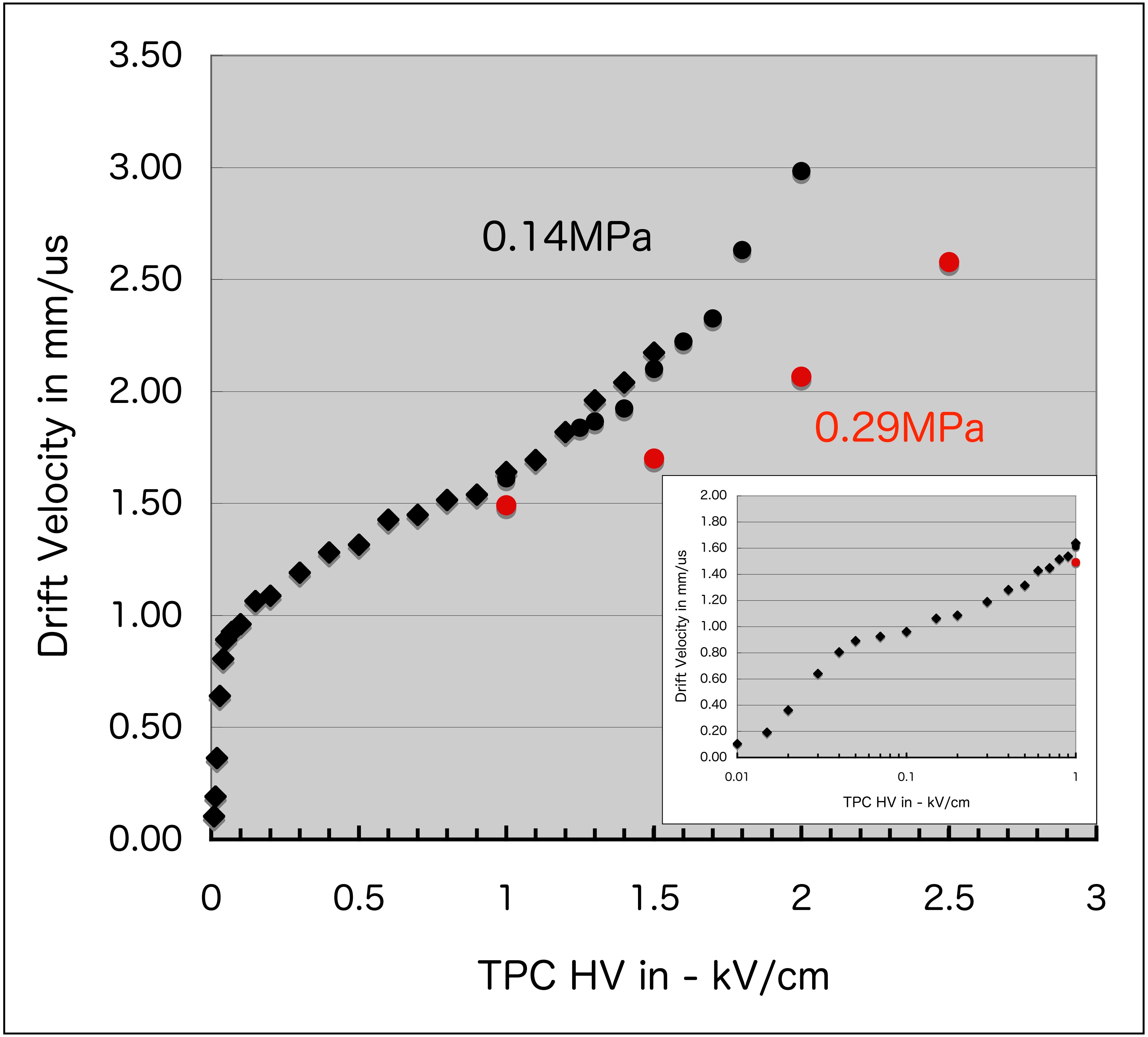


FIG. 2. Variation of relative luminescence intensity L and collected charge Q in liquid argon, krypton, and xenon vs applied-electric-field strength for 0.976- and 1.05-MeV electrons.

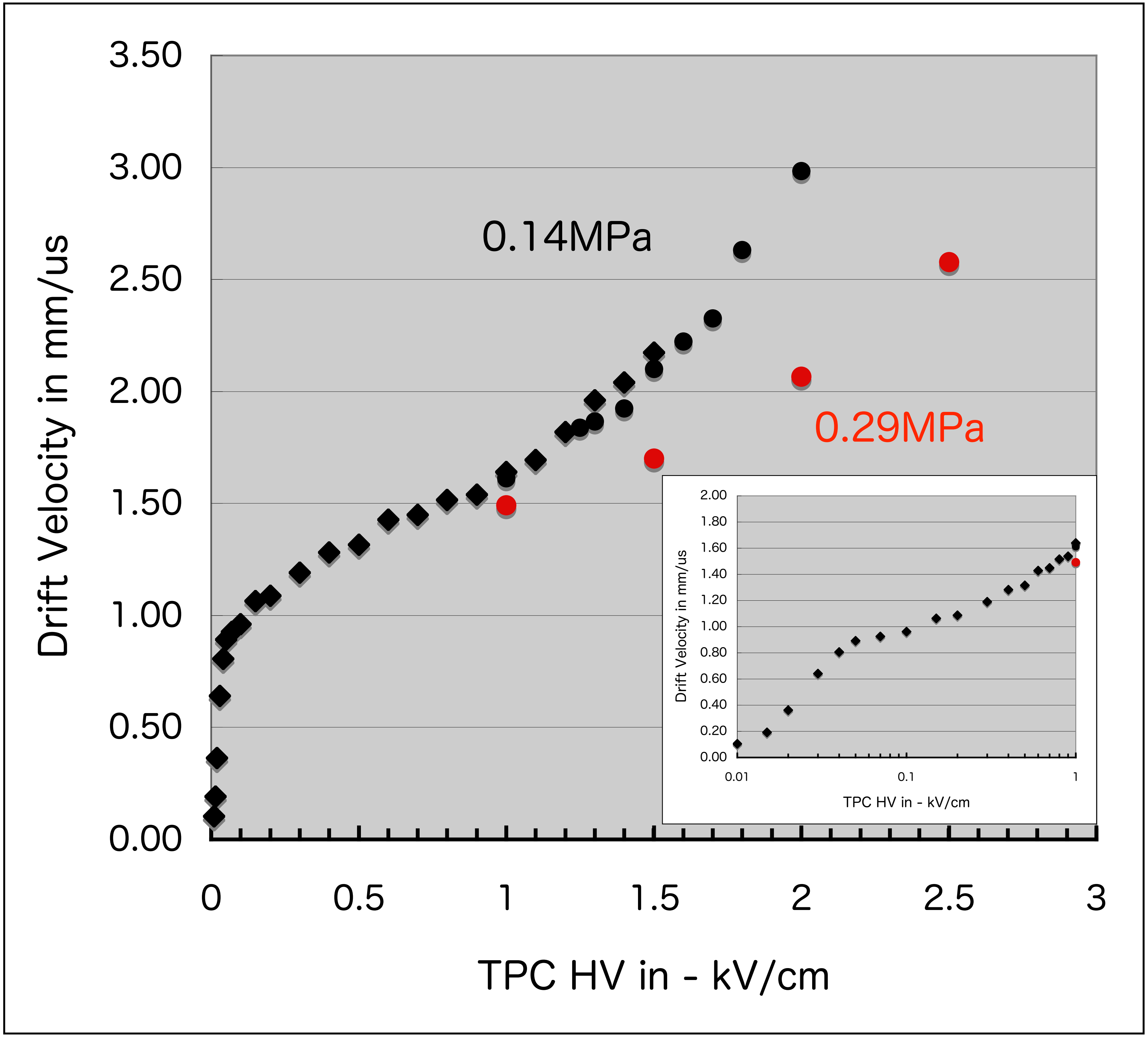
Parallel plate chamber with 5mm gap



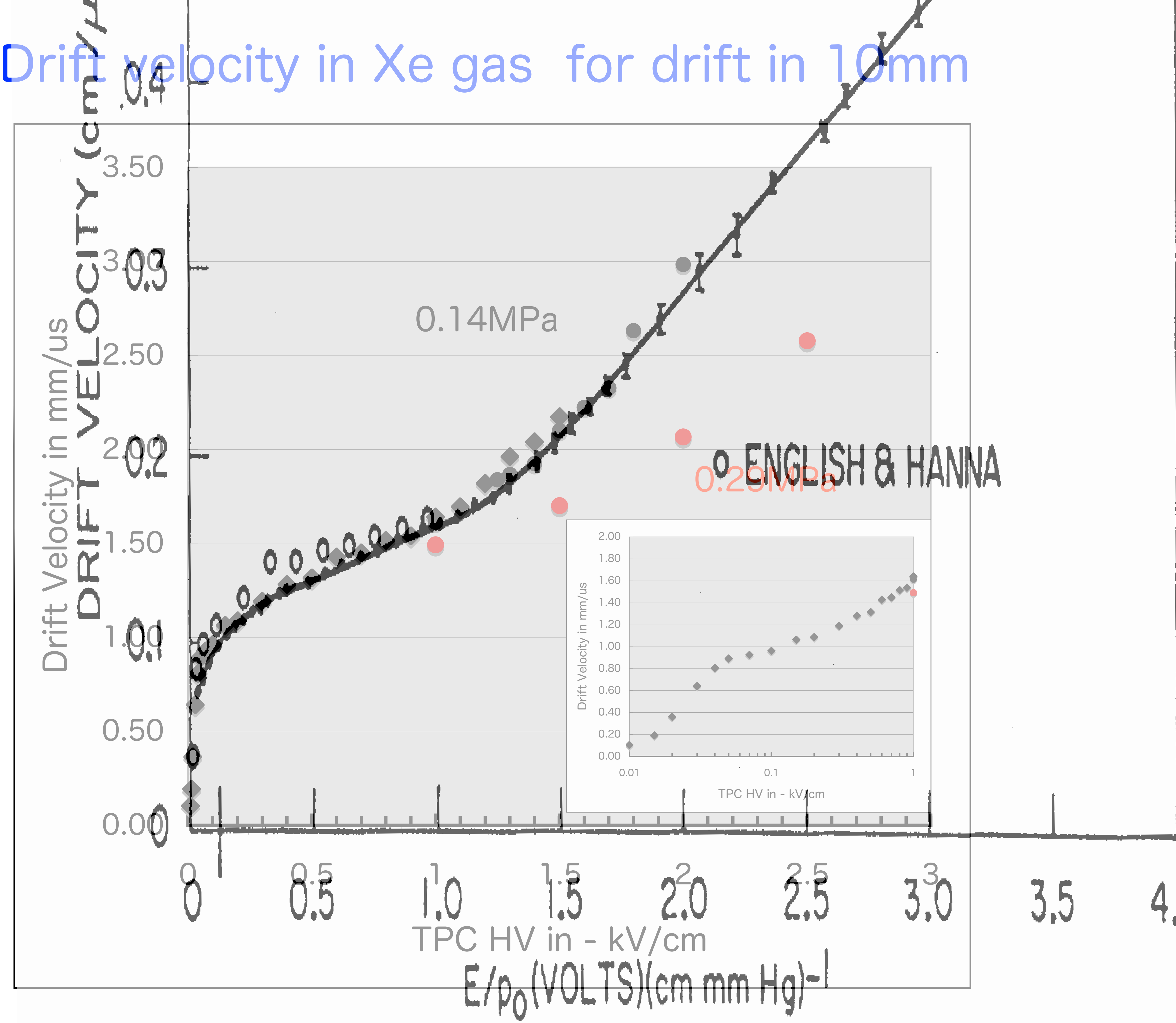
Drift velocity in Xe gas for drift in 10mm



Drift velocity in Xe gas for drift in 10mm



Drift velocity in Xe gas for drift in 10mm



2013年 3月 20日 水曜日

Drift velocity in liquid Xe

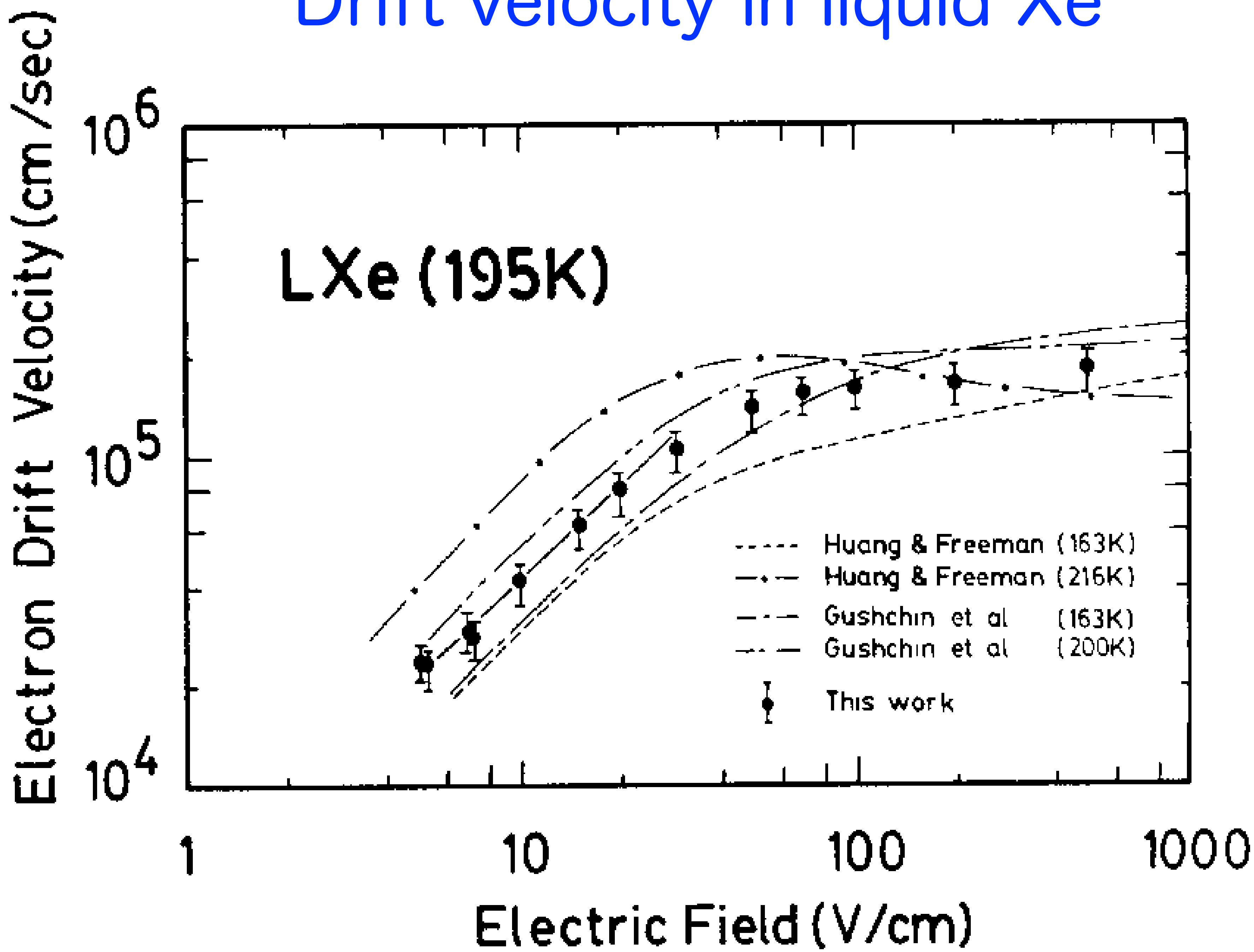
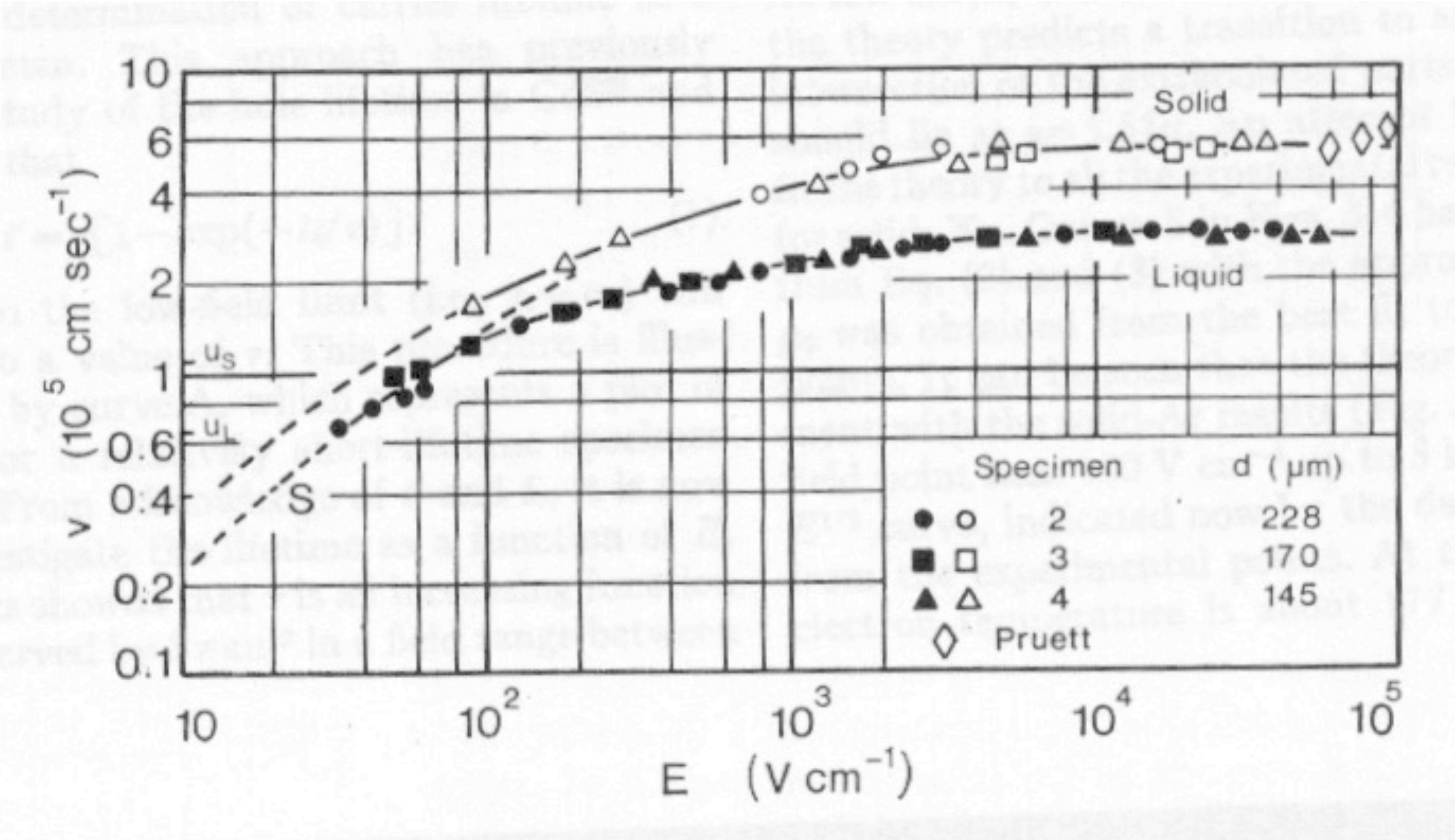


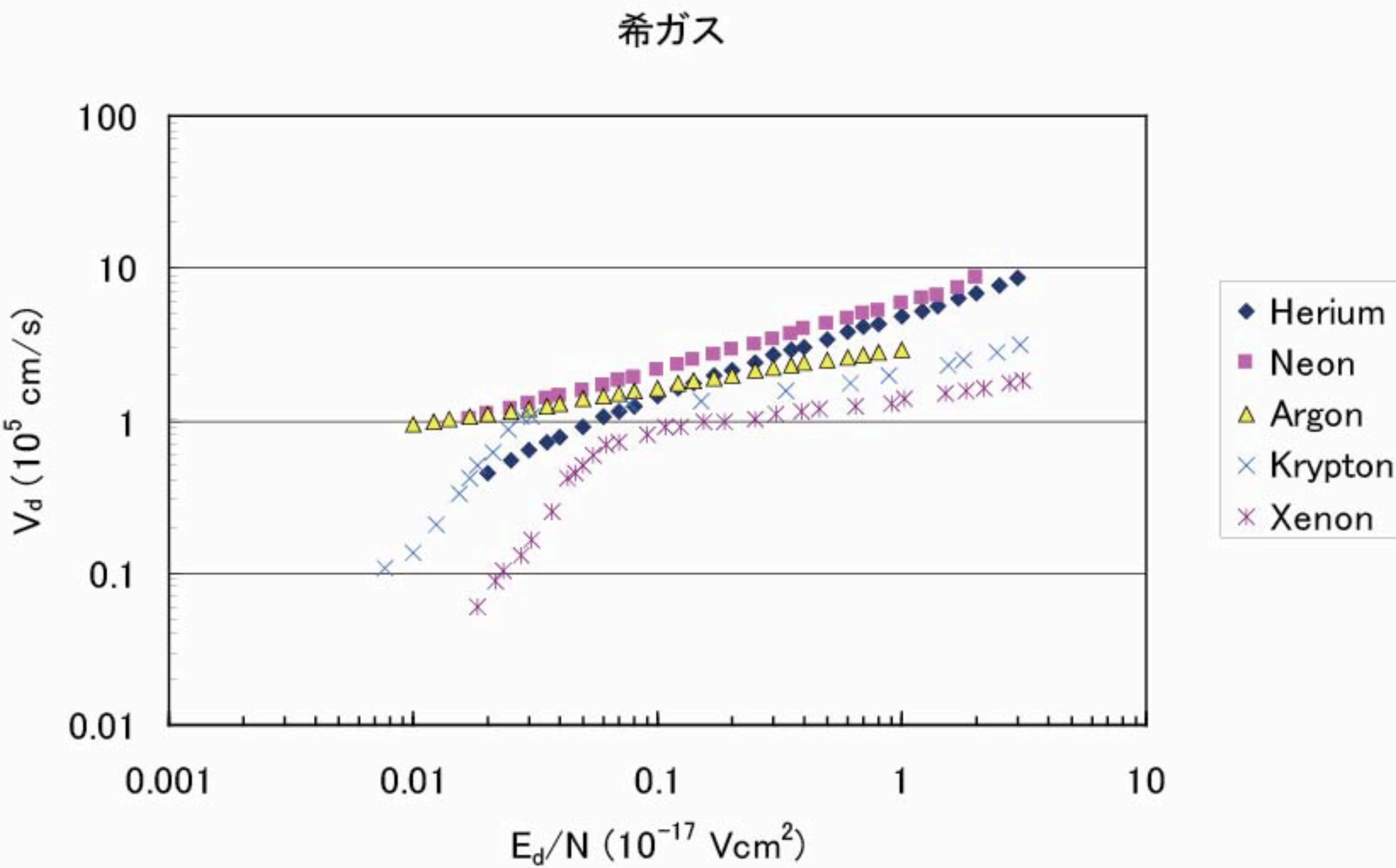
Fig. 5. Electric field dependence of the electron drift velocity in liquid xenon at $T = 195$ K. The solid line is the fit of $v_d = \mu_0 E$, giving $\mu_0 = (4230 \pm 400)\ cm^2 V^{-1} s^{-1}$. Other lines are from refs. [23,24].

Ref) E.Aprile et al., NIM A300 (1991) 343-350

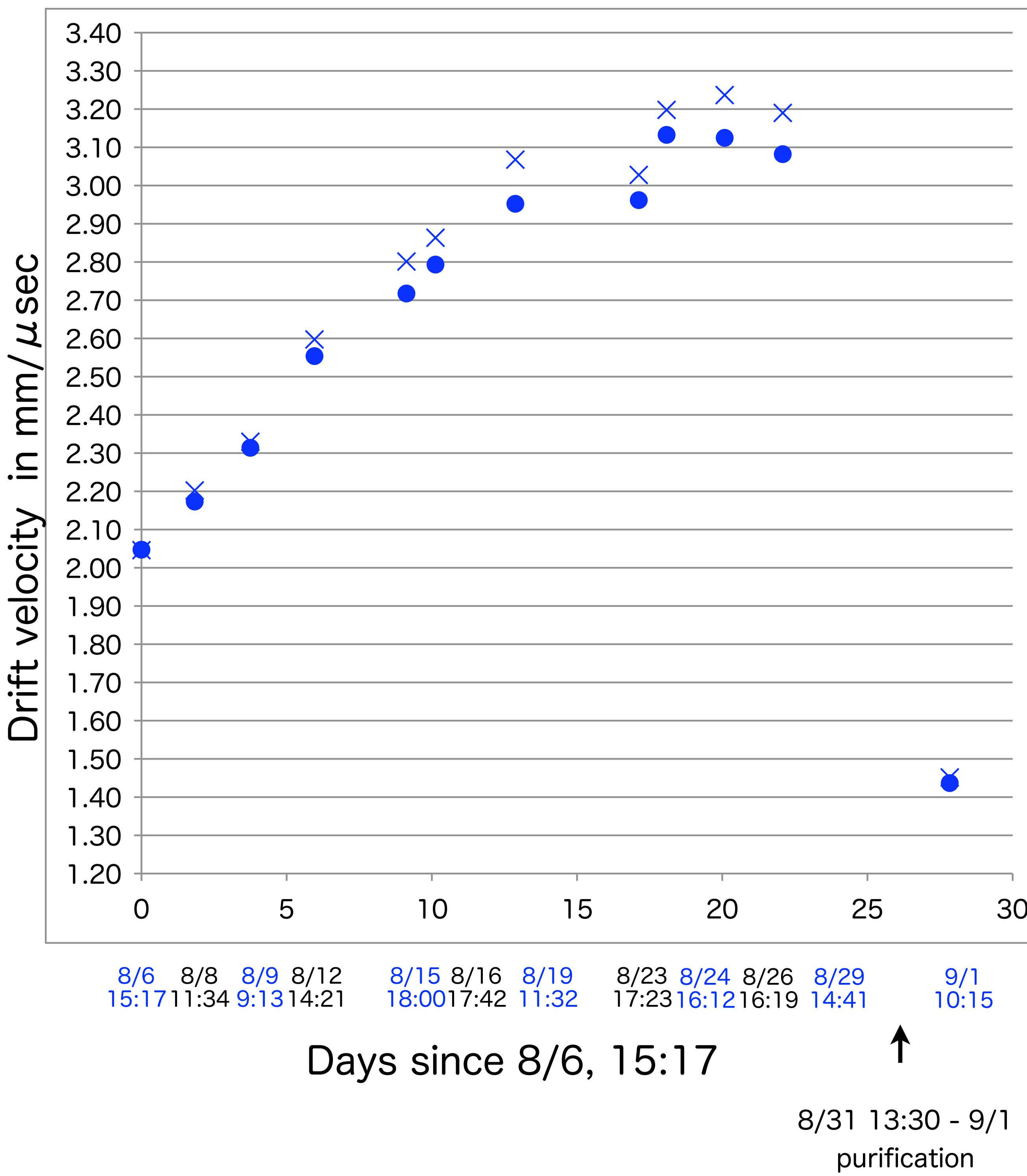
Drift velocity in liquid and solid Xe

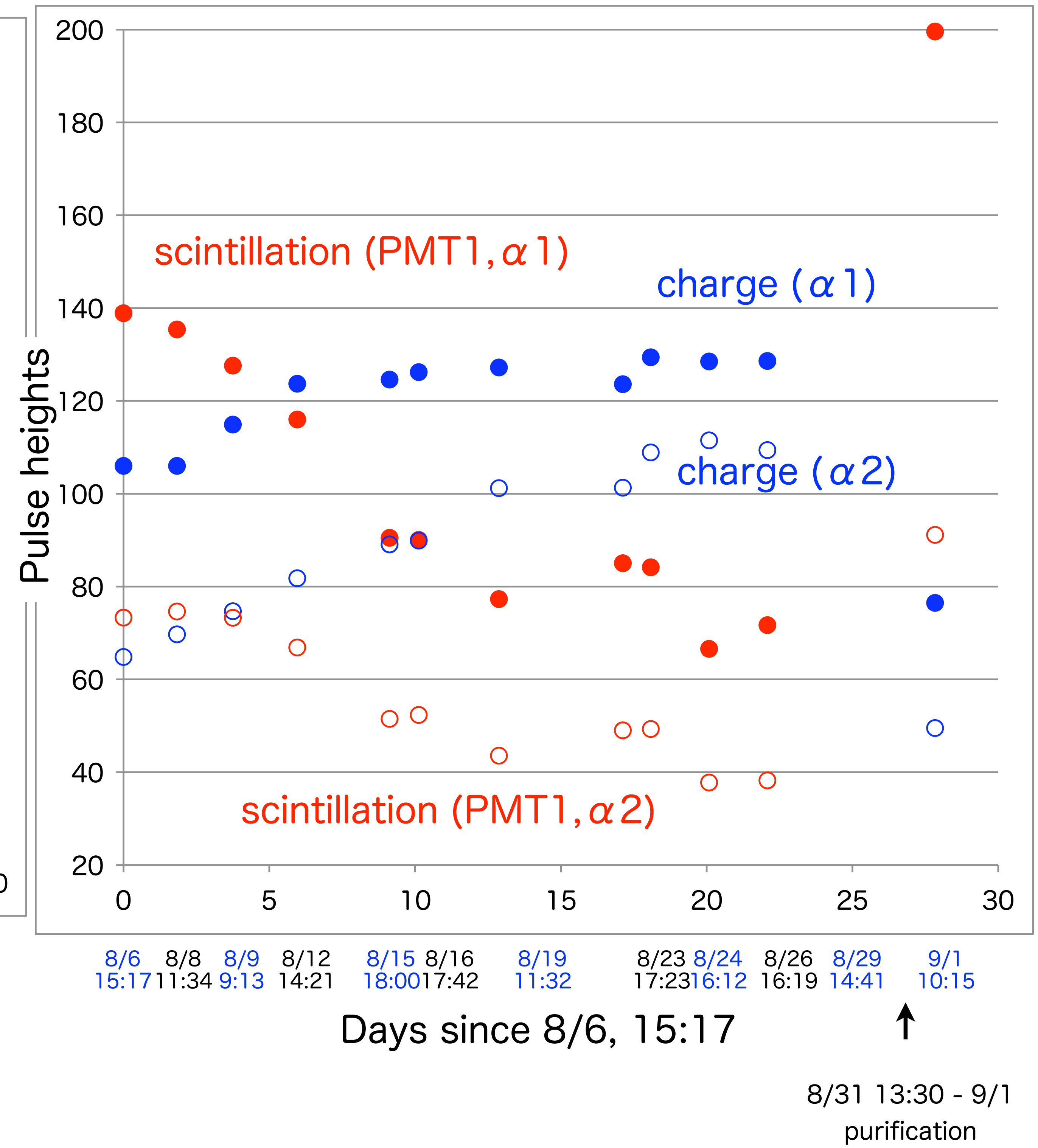


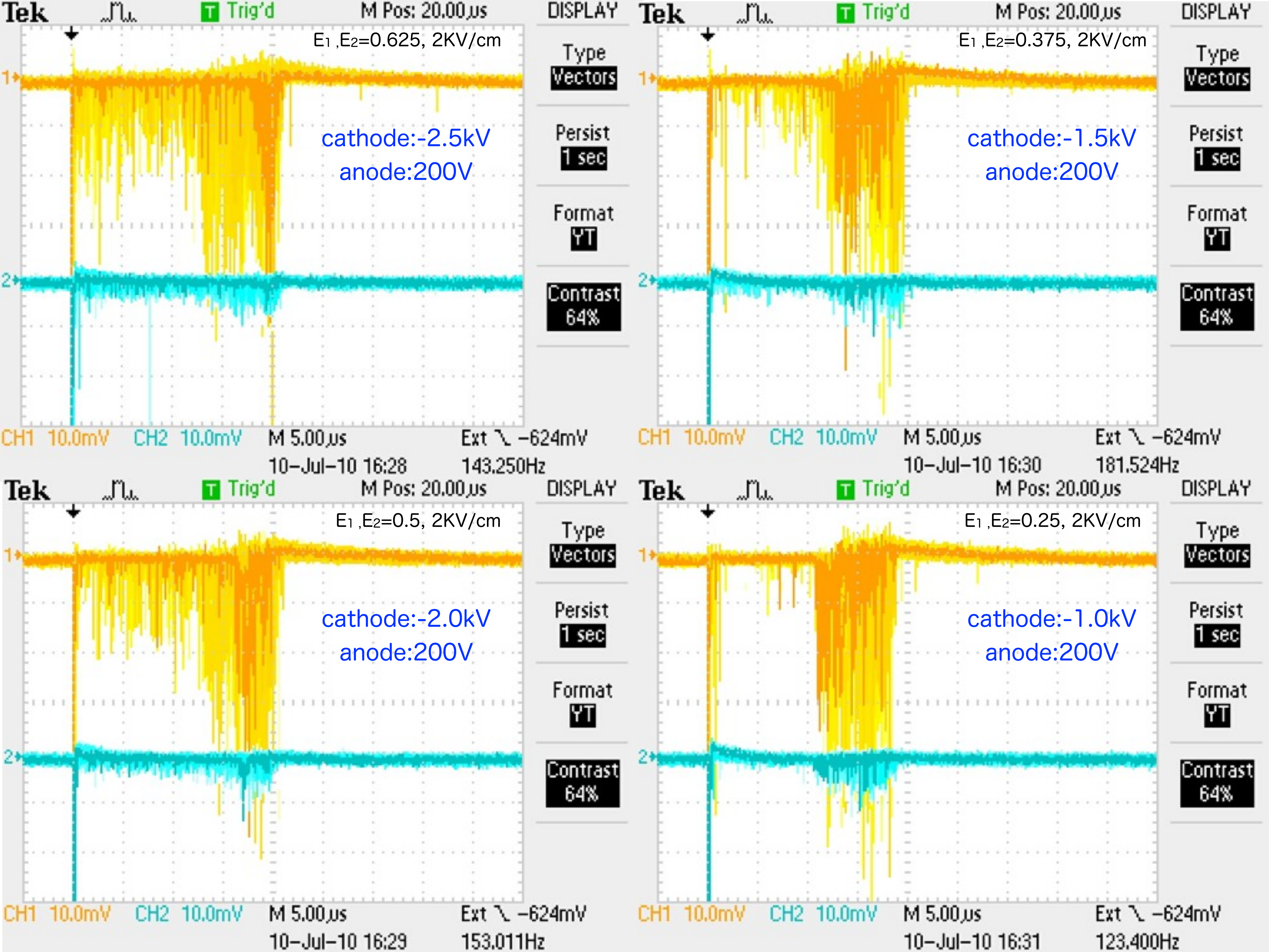
from L.S.Miller, S.Howe, W.E.Spear, Phys. Rev. 166 (1968), 871


希ガス
100
10
1
0.1
0.01
0.001
0.01
0.1
1
10
Vd (10^5 cm/s)
Ed/N (10^-17 Vcm^2)
Herium
Neon
Argon
Krypton
Xenon

Signals in Xe Gas at 1.4atm, Aug.-Sept, 2011



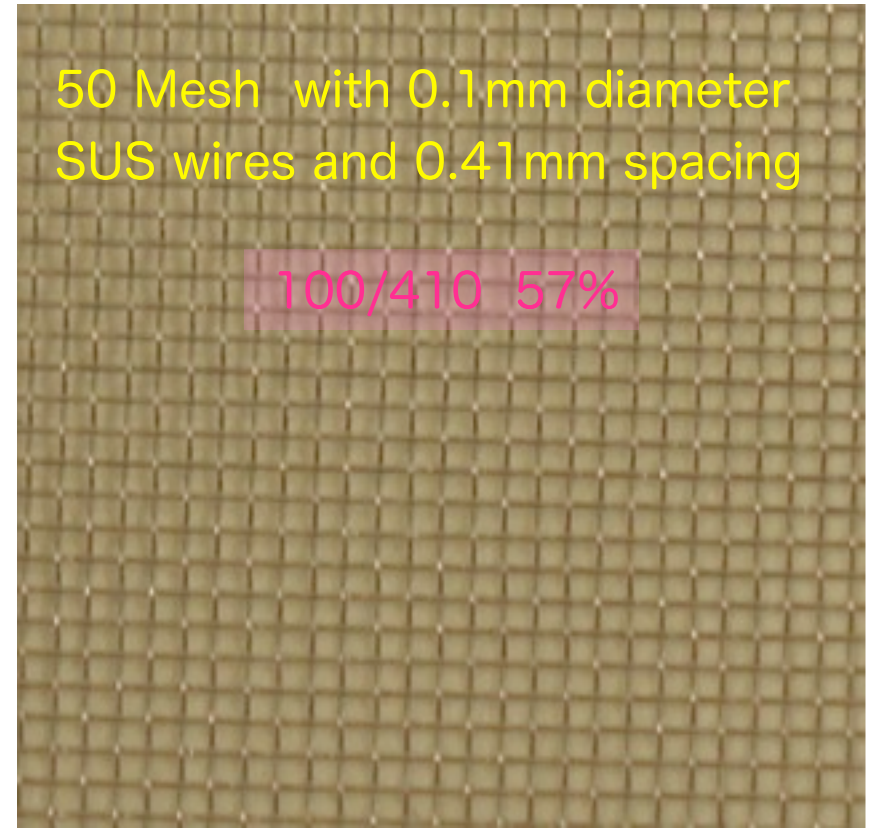


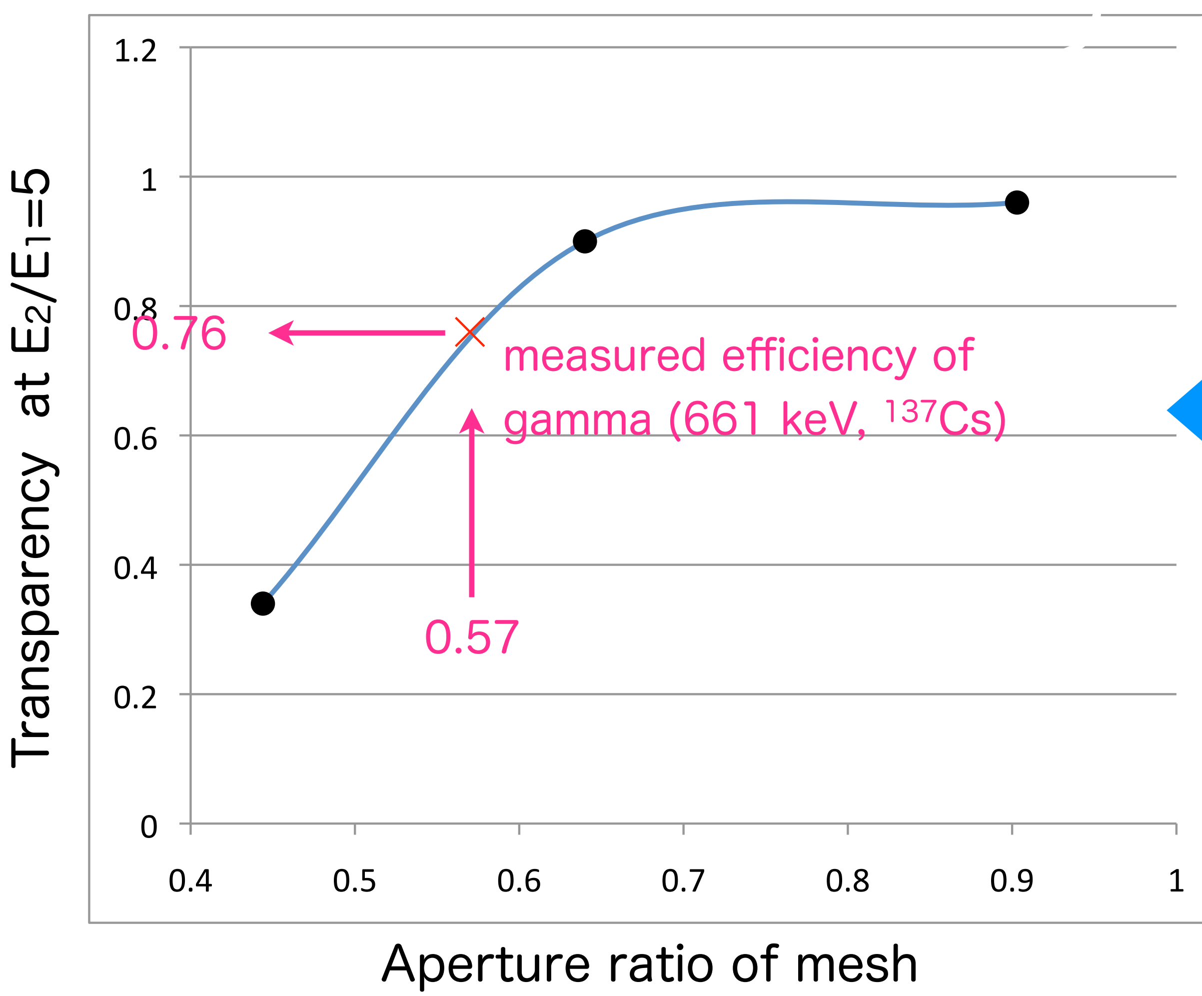

E1 ,E2=0.625, 2KV/cm
cathode:-2.5kV
anode:200V
E1 ,E2=0.375, 2KV/cm
cathode:-1.5kV
anode:200V
E1 ,E2=0.5, 2KV/cm
cathode:-2.0kV
anode:200V
E1 ,E2=0.25, 2KV/cm
cathode:-1.0kV
anode:200V
Tek Trig'd M Pos: 20.00µs DISPLAY
Type Vectors
Persist 1 sec
Format YT
Contrast 64%
CH1 10.0mV CH2 10.0mV M 5.00µs Ext -624mV
10-Jul-10 16:28 143.250Hz
10-Jul-10 16:30 181.524Hz
10-Jul-10 16:29 153.011Hz
10-Jul-10 16:31 123.400Hz

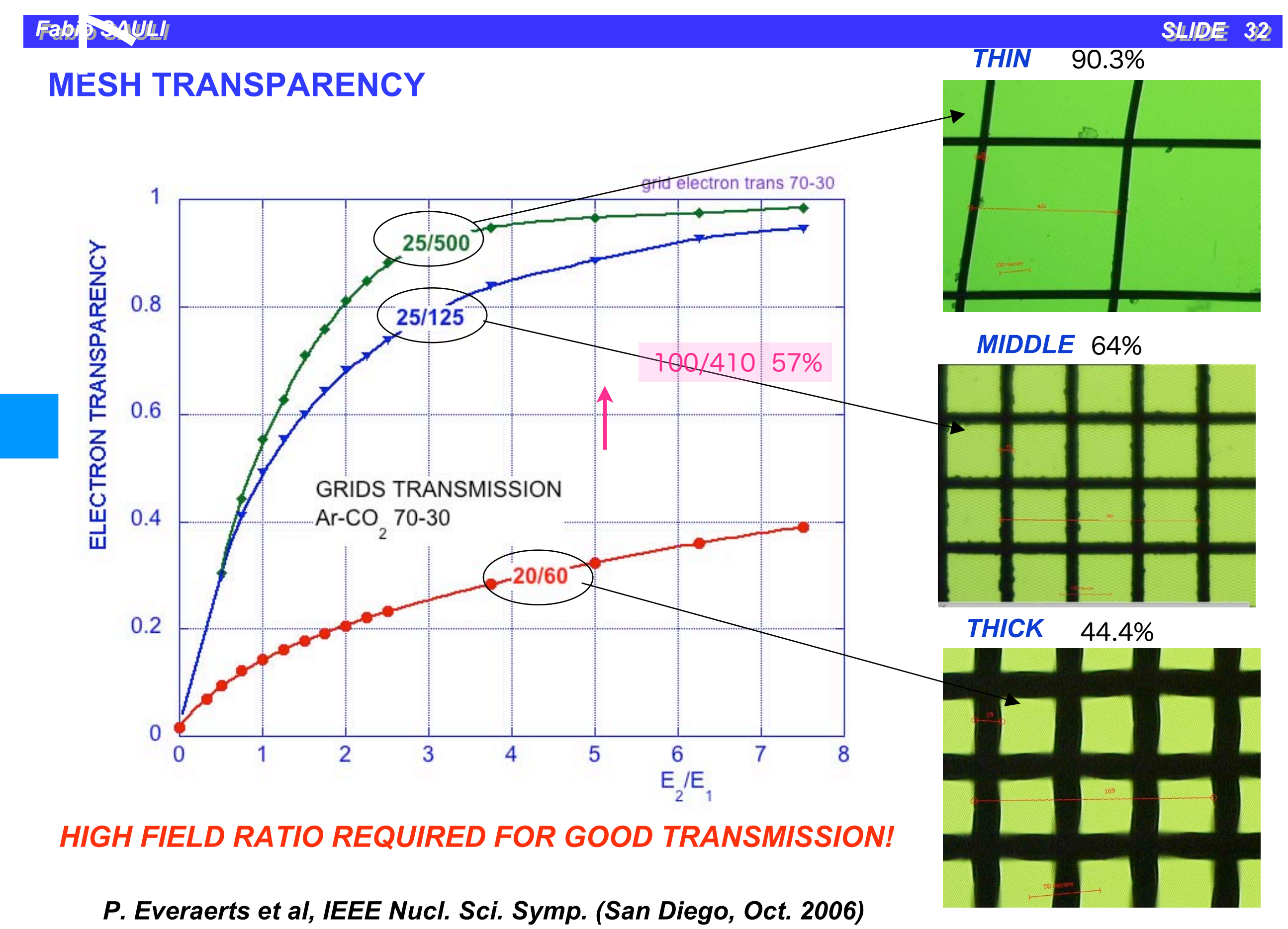
Estimation of the grid transparency

assumption of no dependence of medium ？

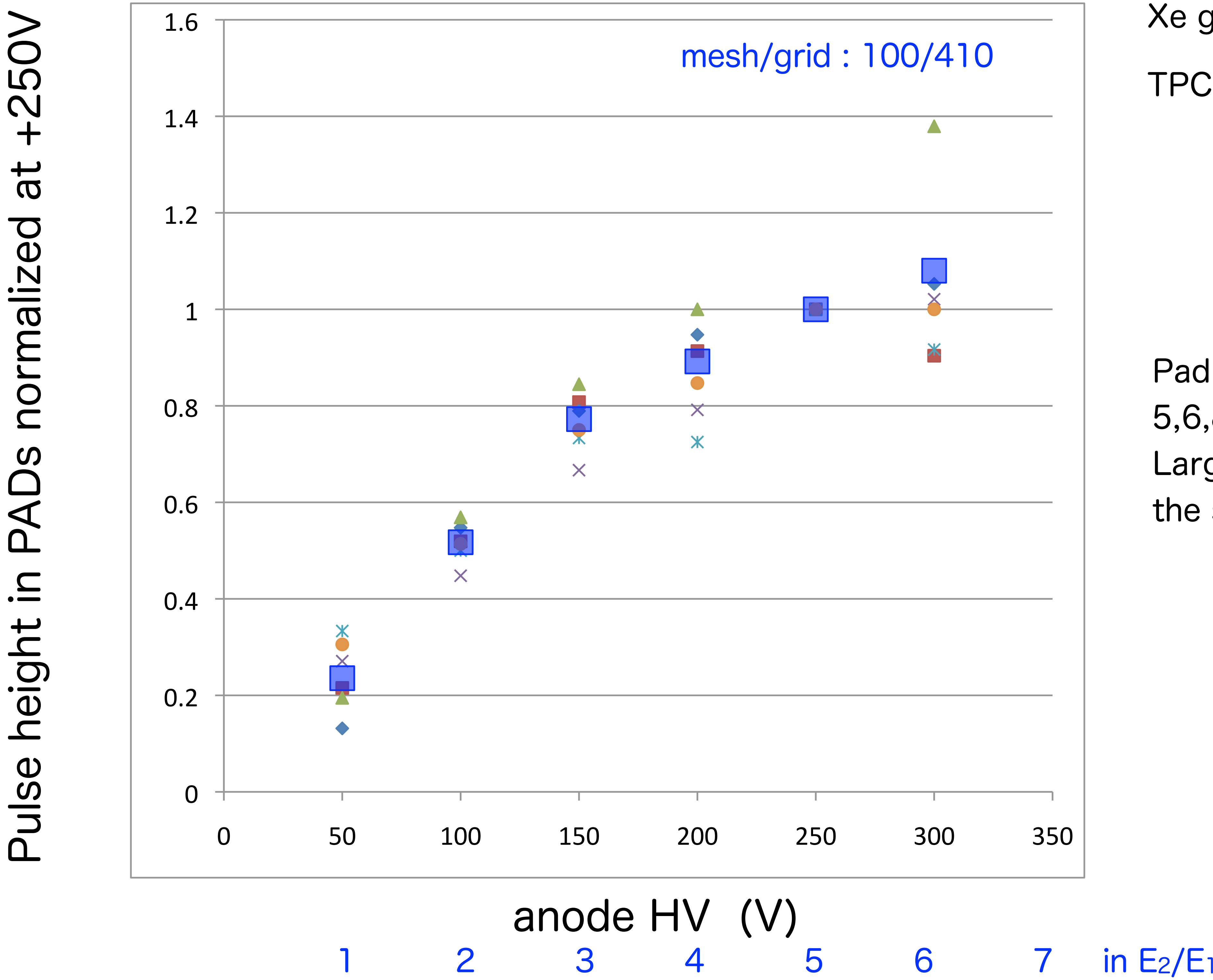
Our mesh for the grid







Performance of grid transparency

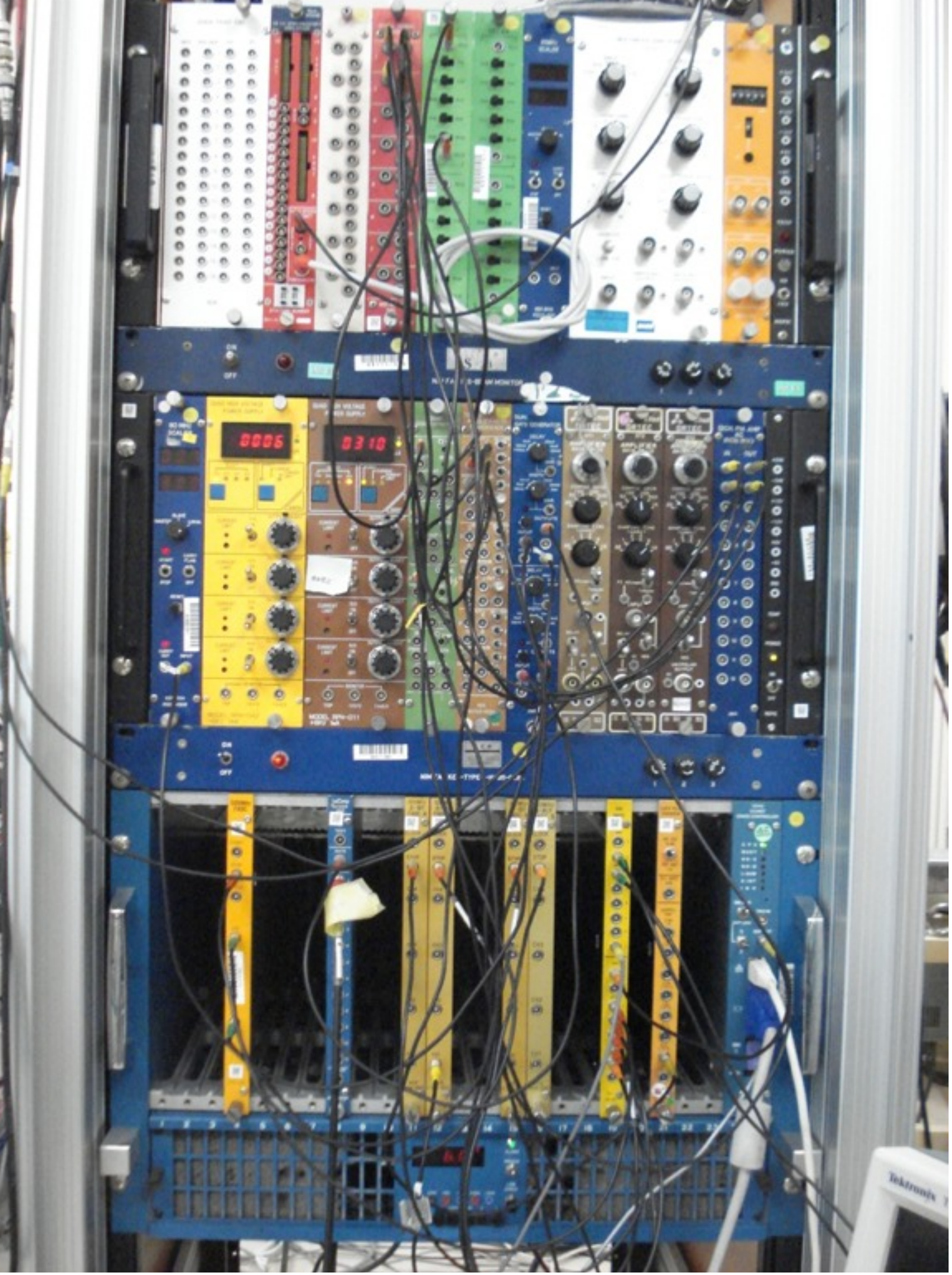


Xe gas at 1.4 atm

TPC : 5cm drift
-2.5KV

Pad channels:
5,6,8,9,10,12
Large squares for
the sum

note : grid of 50 mesh with 100um diameter SUS wires and 410um spacing, so aperture of 57%



Pre-amp (A250) NIM 16ch
post amp CAEN/N568B 16ch
(shaping amplifier)

Trigger: pmt1xpmt2, test pulse, cosmic
HV power supplies
- positive (brown) : PMTs
- negative cathode, PMT3(cosmic)

DAQ : CAMAC
FADC 500MHz 2ch/module
8bits/3.3V, 8k words/ch
FADC 20MHz 16ch/4modules
8bits/2V, 1k words/ch
ADC 2249W 12ch, 11bit integrated ADC
0.25pC/count, 800nsec gate