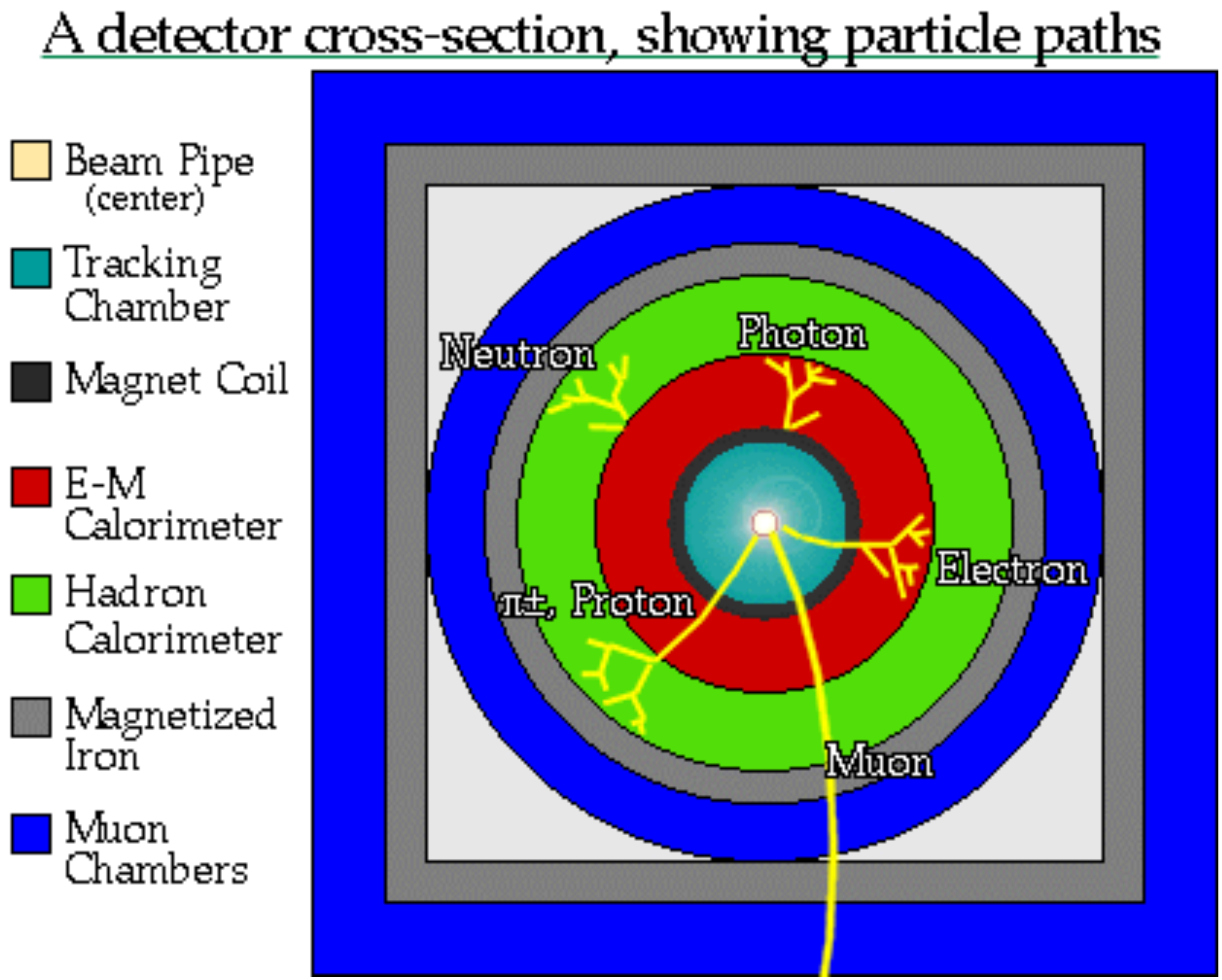
Generic Detector



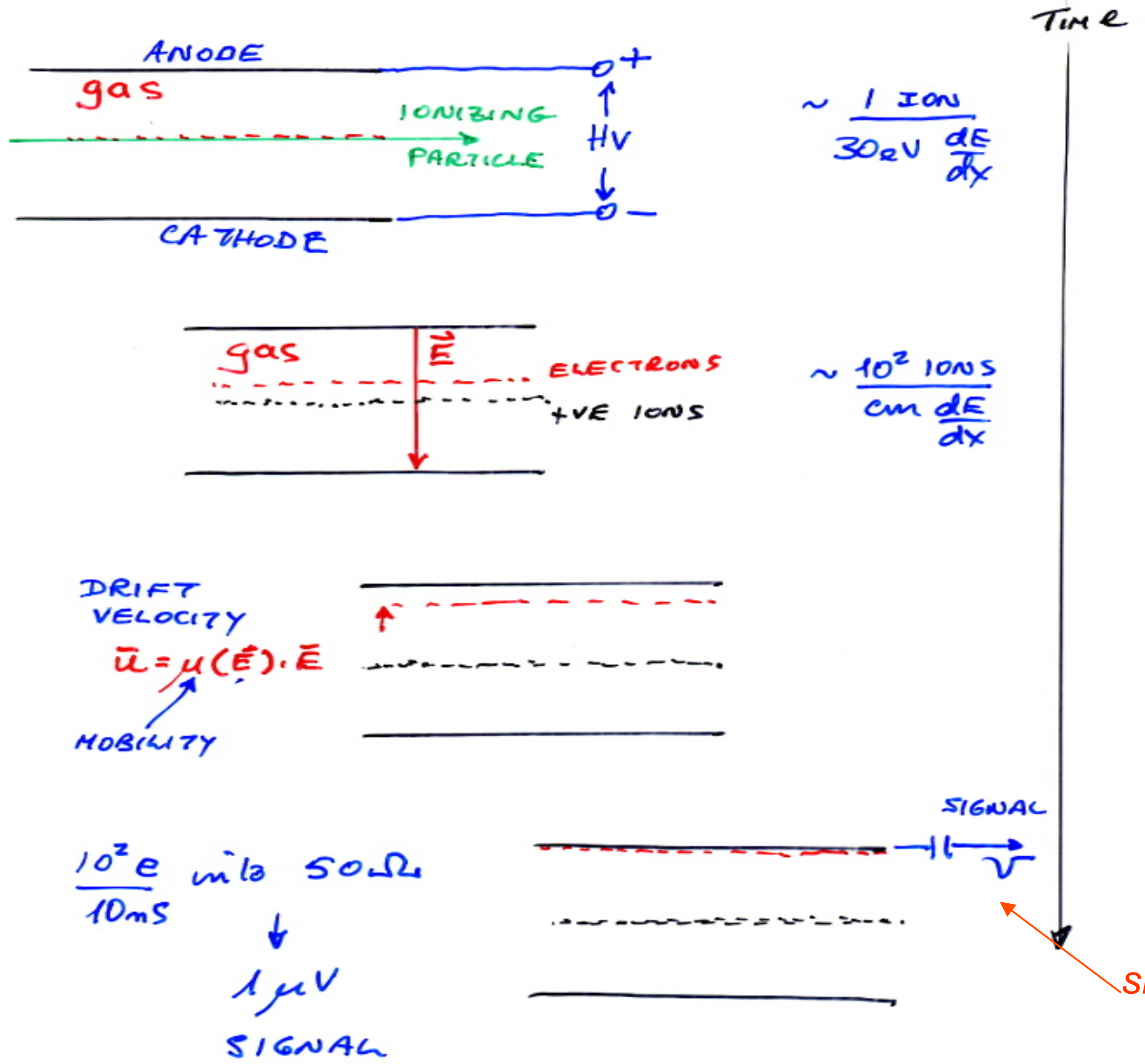
- Layers of Detector Systems around Collision Point

Tracking Detectors

- Observe particle trajectories in space with as little disturbance as possible
    - use a thin ($gm.cm^{-2}$) detector
  - Scintillators $(\sigma : cm)$
  - Scintillating fibres $(\sigma : 150\mu)$
  - Gas trackers $(\sigma : 150\mu)$
  - Solid state trackers $(\sigma : 10\mu)$

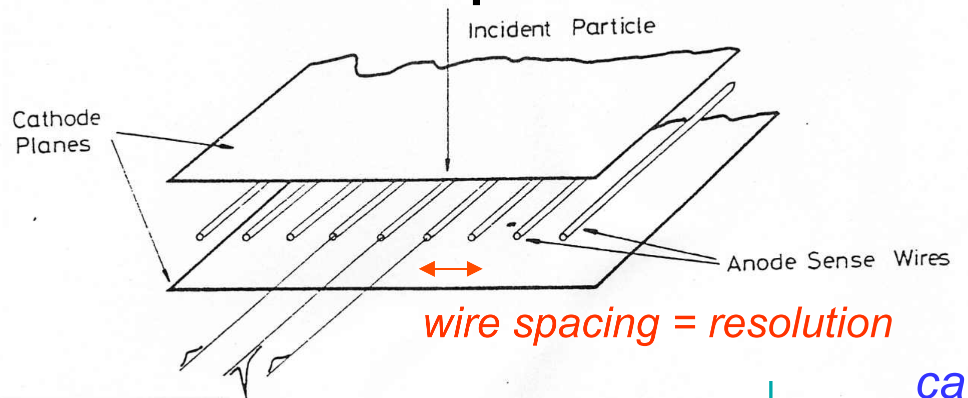
- Gas Based Detectors
  - Multiwire proportional chamber
  - Drift Chamber
  - Time projection chamber
  - Gas microstrip
  - GEM (gas electron multiplier)

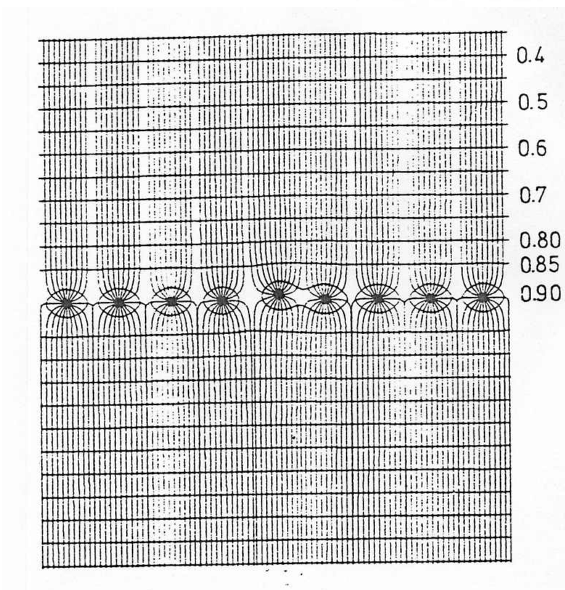
IONIZATION DETECTORS

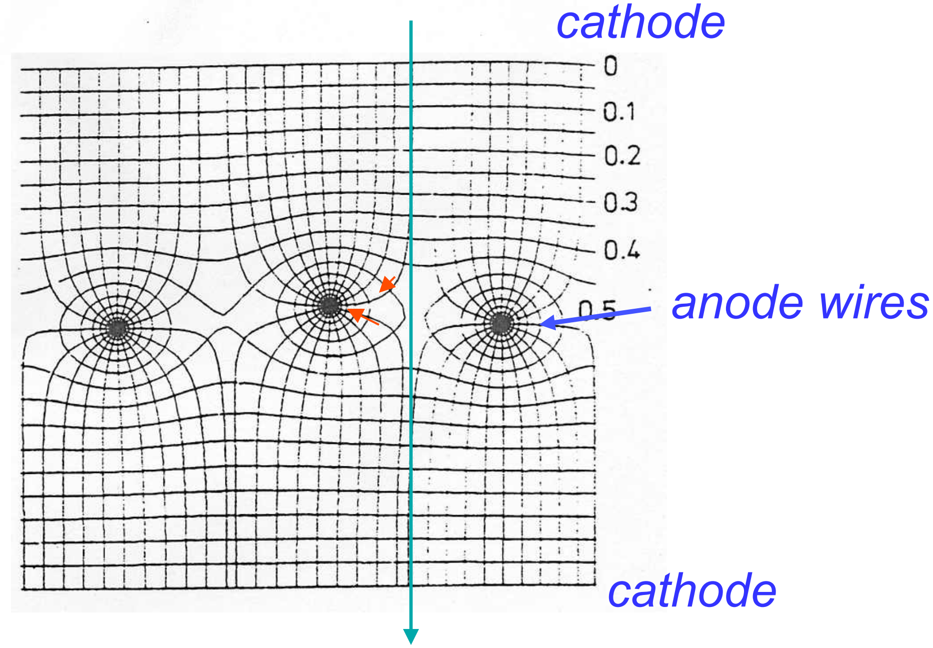


small – amplification?

Multiwire Proportional Chamber

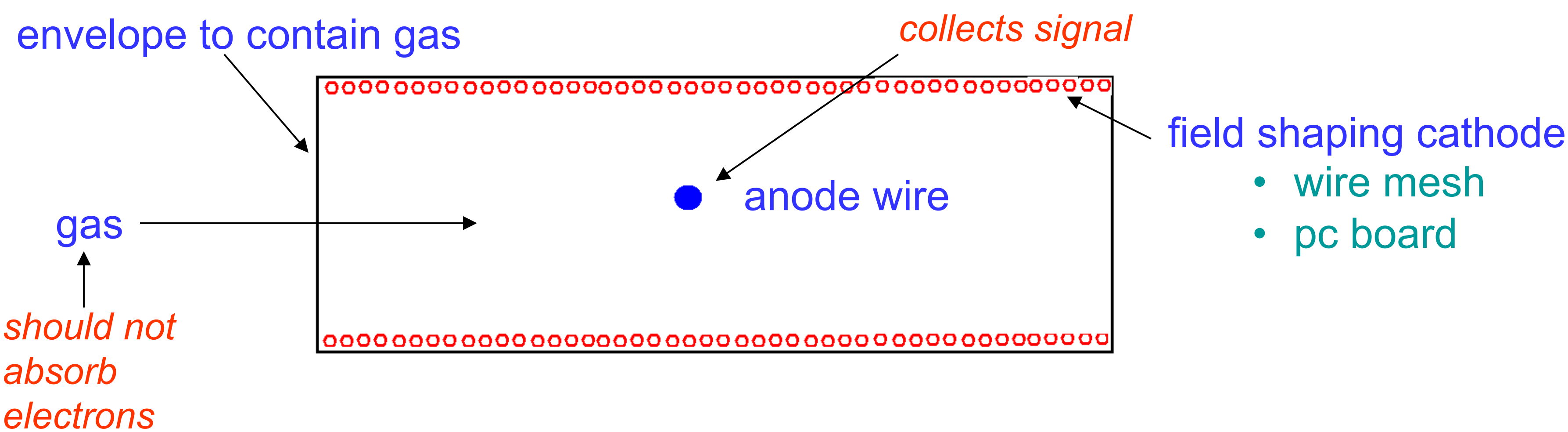






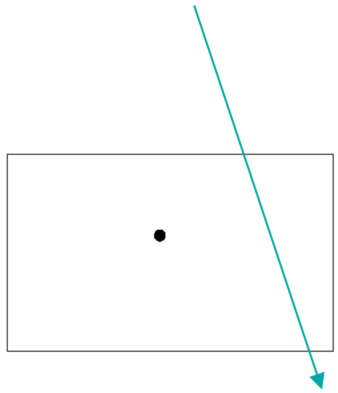
Drift Chamber – measure arrival time of charge = spatial resolution

Schematic of Wire Chamber Cell

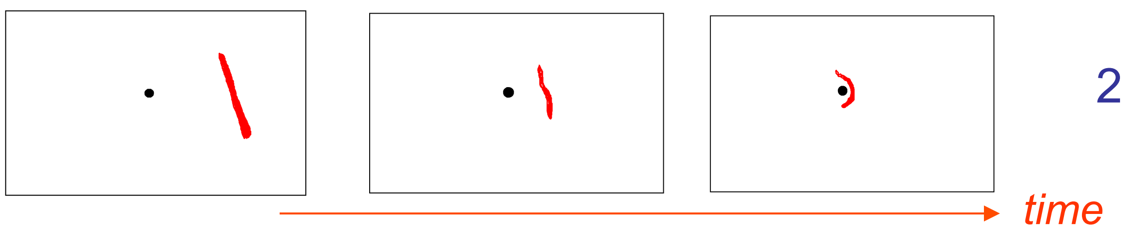


Repeat “n” times

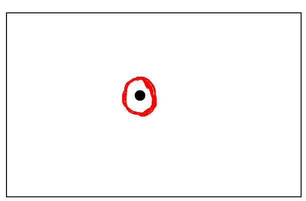
3 stages in signal generation



1) Ionization by track passing through cell



2) Ionization drifts in E field

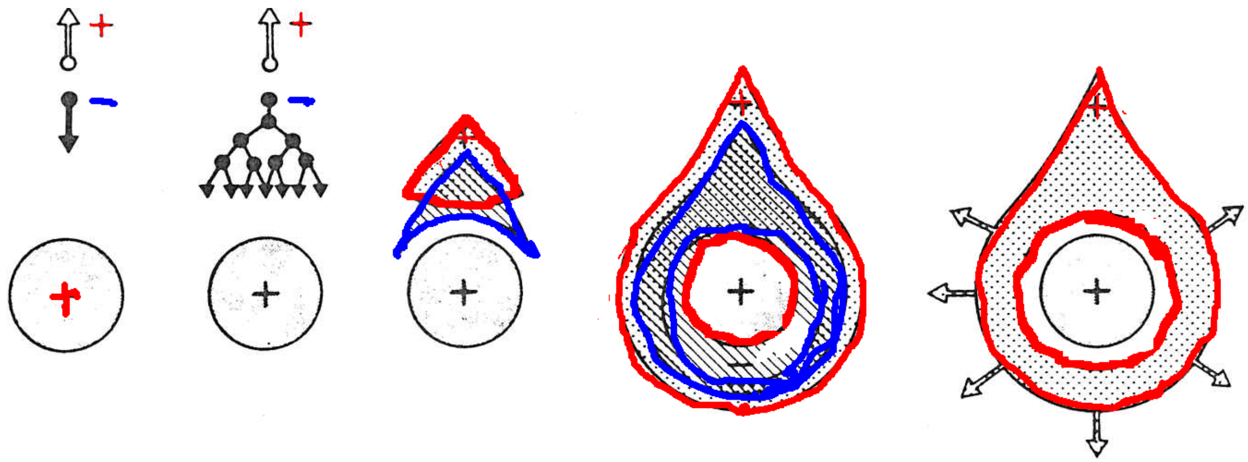


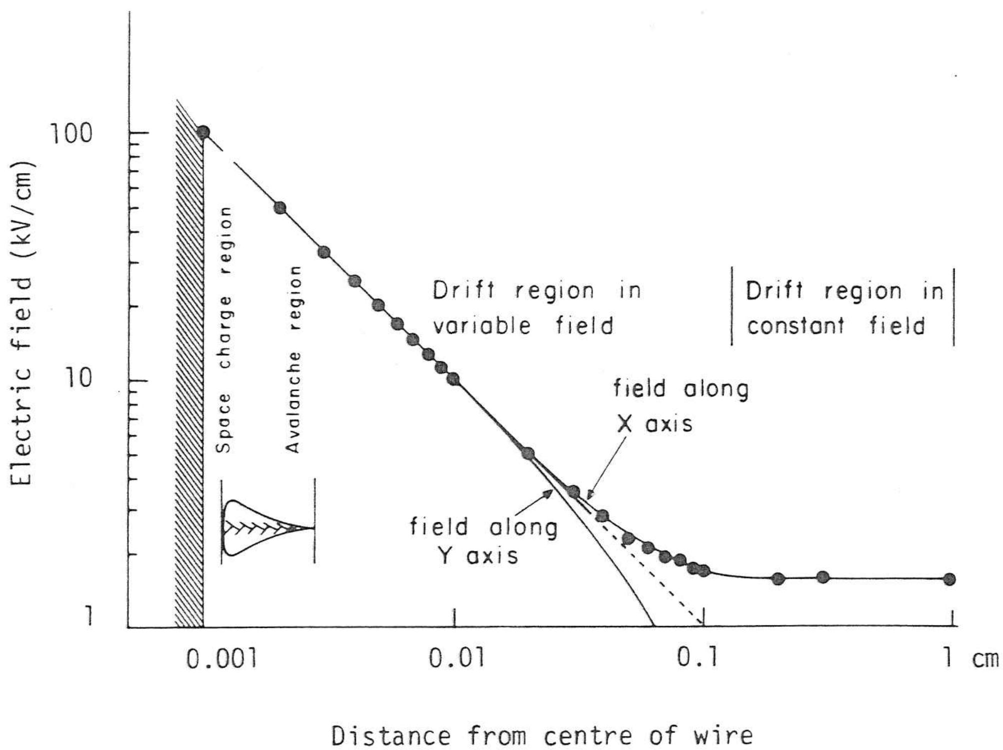
3) In high E field region near wire, primary ionization electrons gain enough energy to start ionizing the gas

- Avalanche
- More charges
- Charge amplification $\sim 10^7$
- Noise free amplifier

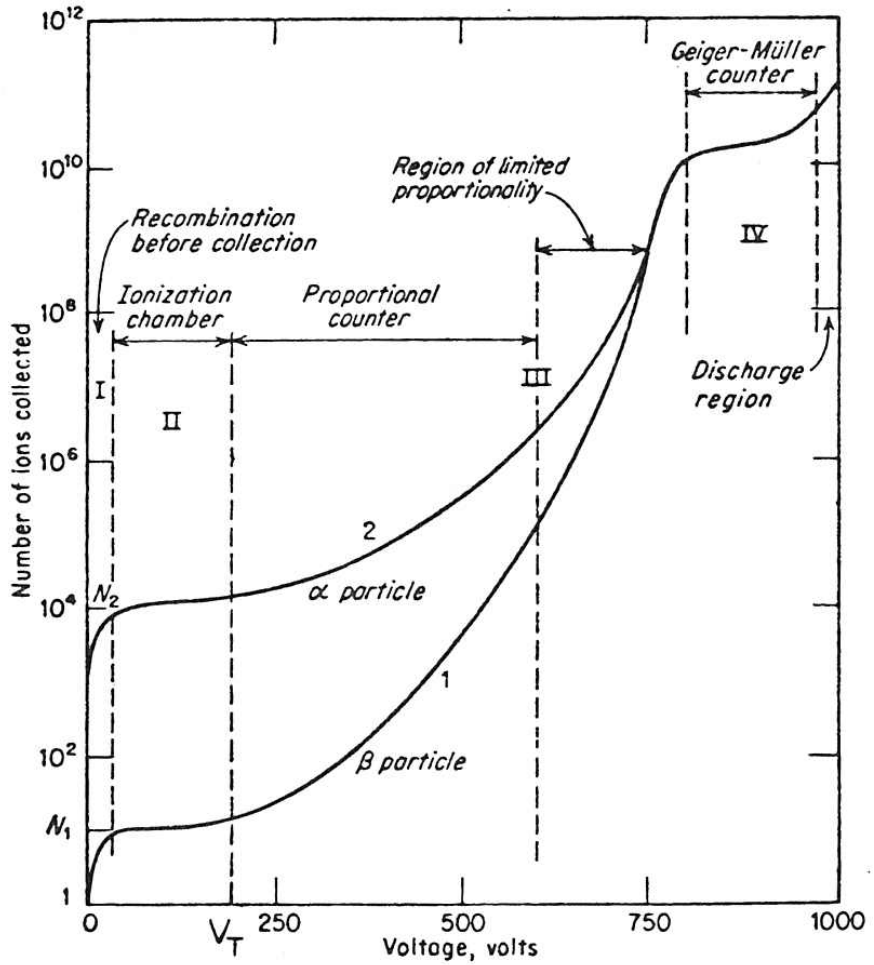
microvolt signal if no amplification

Gas Amplification





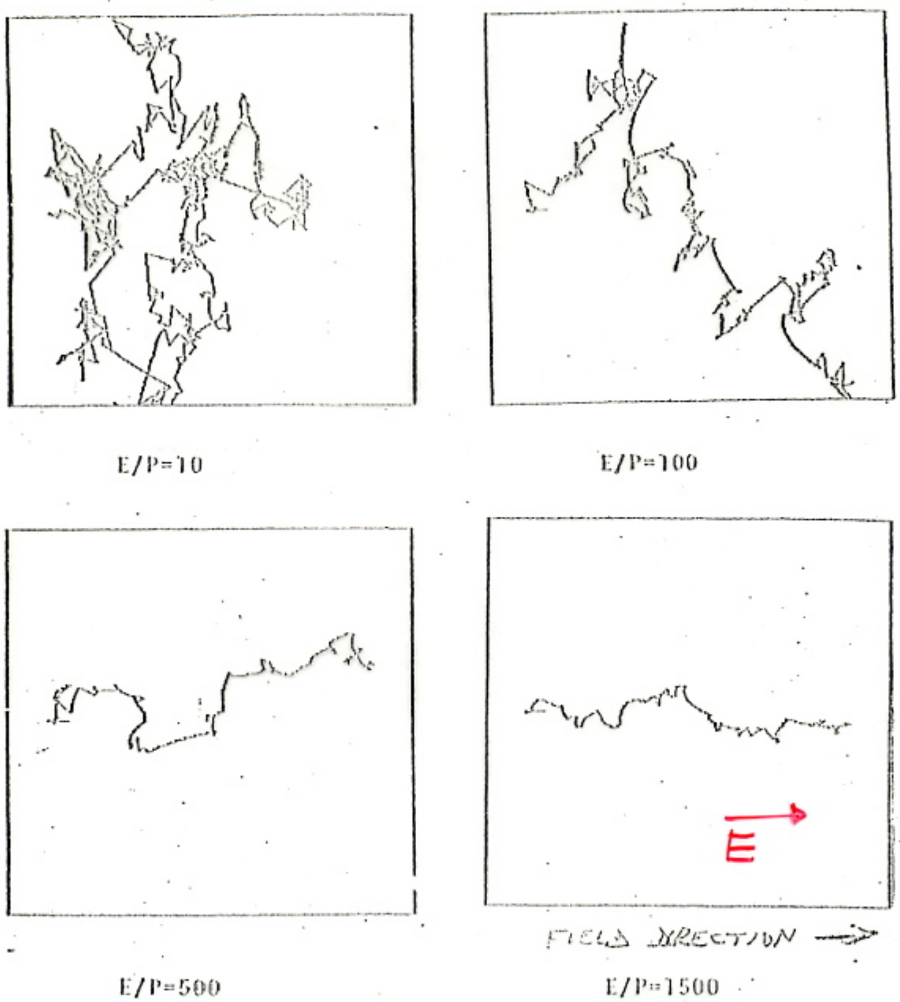
Behaviour as Voltage Increased



Volts

- Collection – Recombination dominated
- All charge collected
- Amplification by gas multiplication
  - Still proportional – particle ident
- Saturation
- Breakdown – Geiger/Mueller

Diffusion



$$\frac{E}{P} = \frac{V/cm}{mm\,Hg}$$

- Ions & electrons diffuse in space
- E field determines average direction

- Collisions limit velocity
- Maximum average velocity
=Drift velocity

Diffusion

- Ions and electrons diffuse under influence of electric field
  - Maxwell velocity distribution

$$v = \sqrt{\frac{8kT}{\pi m}}$$

$$v_e : 10^6 cm.s^{-1} \quad v_{I^+} : 10^4 cm.s^{-1}$$

- From Kinetic theory , after *t*, linear distribution due to diffusion

number of particles

$$\frac{dN}{dx} = \frac{N_0}{\sqrt{4\pi Dt}} \exp\left\{\frac{-x^2}{4Dt}\right\}$$

Diffusion coefficient

RMS Spread

$$\sigma(x) = \sqrt{2Dt} \quad \text{2-d}$$

$$\sigma(r) = \sqrt{6Dt} \quad \text{3-d}$$

about 1mm after 1 sec in air

Mobility

- For a classical gas

$$\mu = \frac{2}{3\sqrt{\pi}} \frac{q}{p\sigma_0} \sqrt{\frac{kT}{m}} = \frac{u}{E}$$

drift velocity (u)

electric field (E)

q, m	ion charge and mass
p	gas pressure
σ_0	ion scattering cross section

$\sigma_0 \equiv \sigma_0(E)$

ELECTRIC FIELD

- In argon

$$\mu_e = 40 \frac{\mu m/ns}{kV/cm}$$

$$\mu_{I^+} = 0.1 \frac{\mu m/ns}{kV/cm}$$

- Electrons collected quickly compared to +ve ions

Diffusion and Drift Chamber Accuracy

$$D = \frac{1}{3} v \lambda$$ Diffusion coefficient from kinetic theory

$$\lambda = \frac{1}{\sqrt{2}} \frac{kT}{\sigma_0 p}$$ Mean free path

$$D = \frac{2}{3\sqrt{\pi}} \frac{1}{\sigma_0 p} \sqrt{\frac{(kT)^3}{m}}$$

In argon $D_e : 10\mu^2 / ns$

Diffusion gives limit on spatial accuracy drift chamber

- To reduce D
  - Lower temperature
  - Raise pressure (reduce mobility)

Working Gas

- Noble gases give multiplication at lowest electric field
  - Polyatomic gases have non-ionization energy loss mechanisms

- Choose cheap noble gas with low ionization potential
  - Krypton X
  - Xenon X
    rare, expensive
  - Argon OK *cheap – welding etc*

Argon

- Cheap, safe, non-reactive
  - remove electro-negative contaminants O_2, CO_2, H_2O

- Pure argon limited to gain $\leq 10^3$
- Many excited ions produced during avalanche

$$Ar^{*+} \rightarrow Ar^{+} + \gamma(11.6\, eV)$$

absorbed on cathode

$$\gamma + cathode \rightarrow e^{-} \left(photo - emission\right)$$

returns to anode - breakdown

- Absorb - quenchers

Quenchers

$$Ar^{*+} \rightarrow Ar^{+} + \gamma(11.6\,eV)$$

Absorb

$$\gamma + X \rightarrow X^{*}$$ *non-radiative*

Poly-atomic gas
e.g. Methane

Rotational vibrational modes

Typical gases

$$80\%\ Ar + 20\%\ CH_4 \qquad G \sim 10^6$$
$$90\%\ Ar + 10\%\ C_3H_8$$

or add electronegative gas *(a bit of poison)*

$$X + (photo - electron) \rightarrow X^{-}$$

Typical $90\%\ Ar + 10\%\ CO_2$ $\quad G \sim 10^7$

Polymerization

- Organic quenchers polymerize
- Deposits on cathodes
  - high resistance
  - ion buildup – discharge
  - sparks, broken wires
- Add non-polymerizing agent – water
  methylal

Magic Gas

$75\%\ Ar$

$24.5\%\ (CH_3)_2\ CH\ CH_3$

$0.5\%\ Freon$

$trace\ methylal$

$1\%\ H_2O$

SMALL ADMIXTURES CAN MAKE A LARGE DIFFERENCE IN DRIFT VELOCITY →

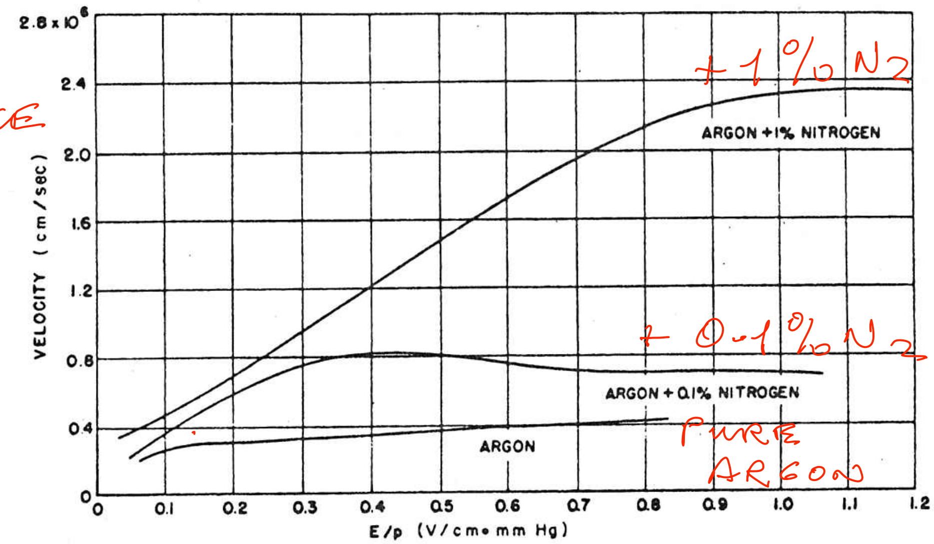
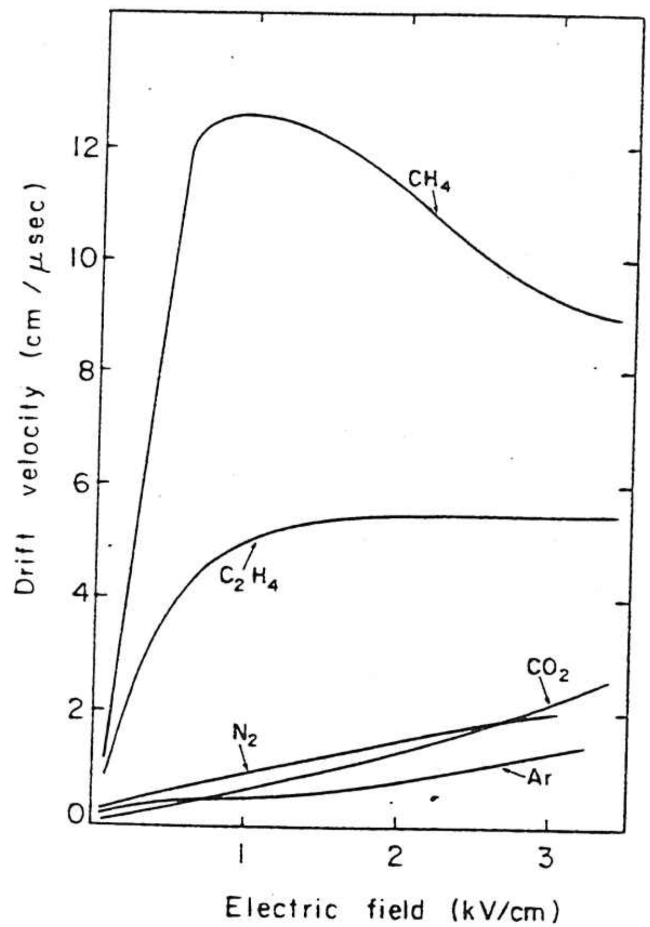
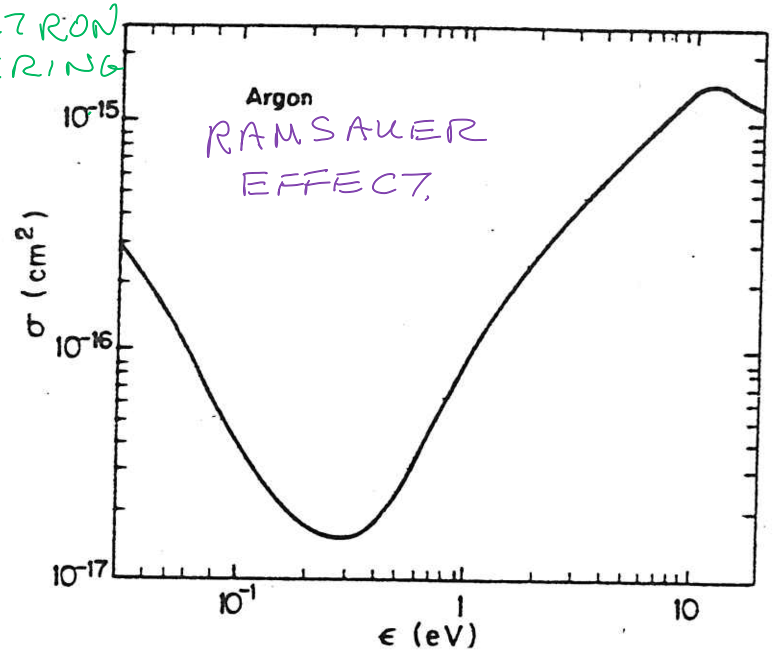


Fig. 25 Drift velocity of electrons in pure argon, and in argon with small added quantities of nitrogen. The very large effect on the velocity for small additions is apparent[22].

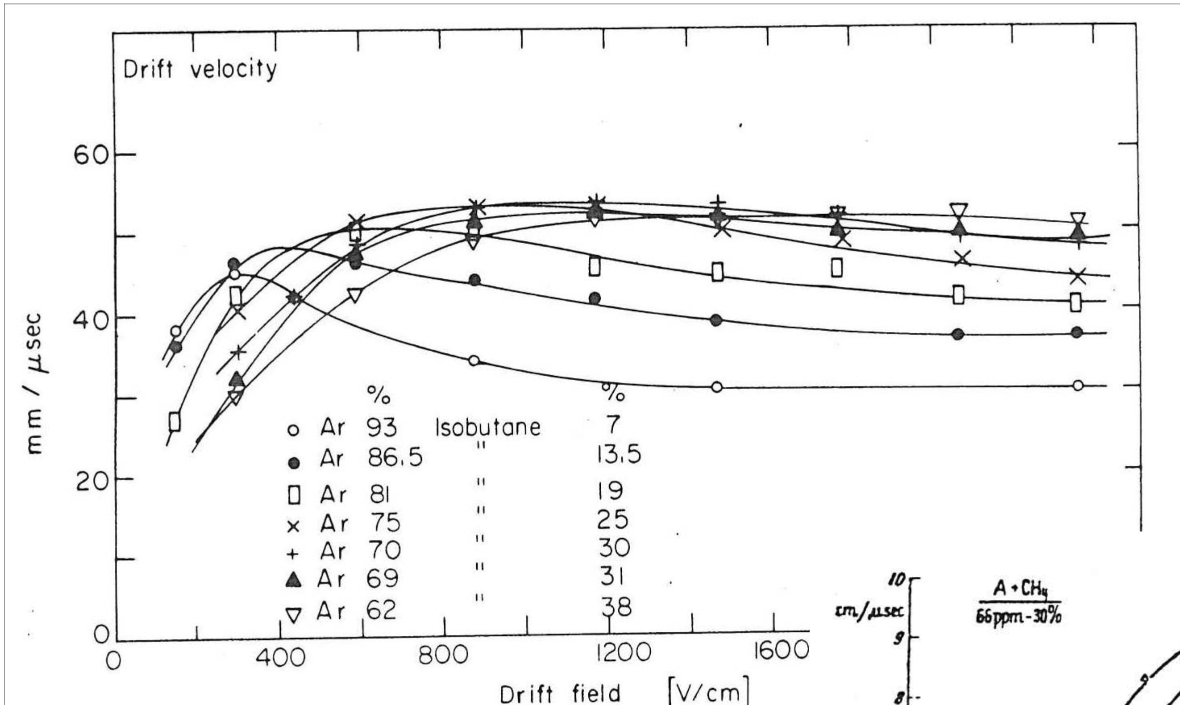
DIFFERENT GASES

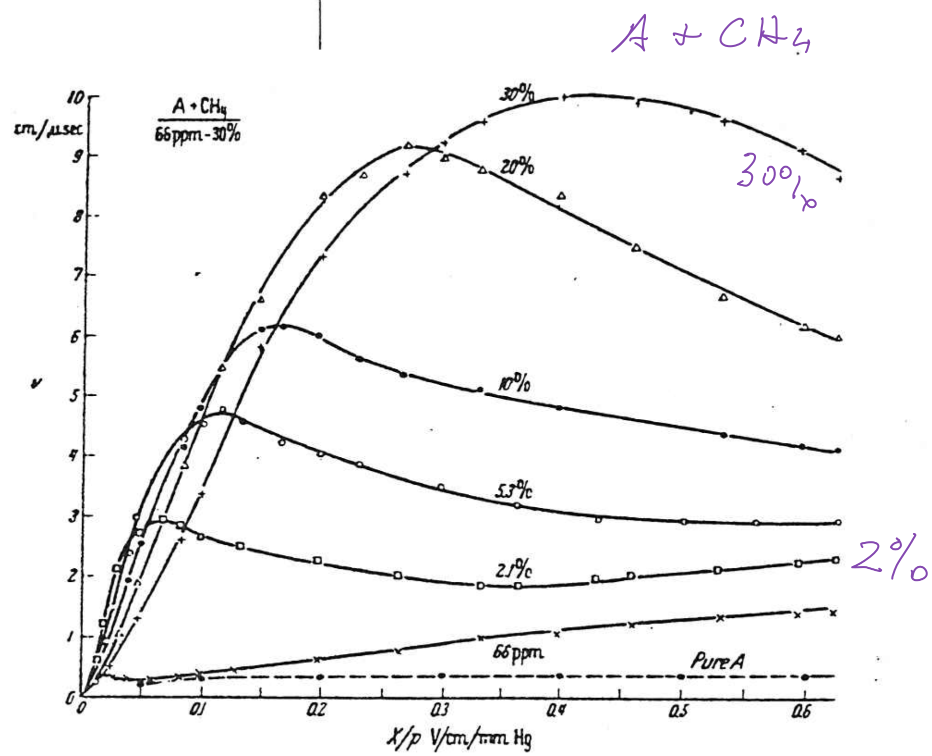


ELECTRON SCATTERING CROSS SECTION →

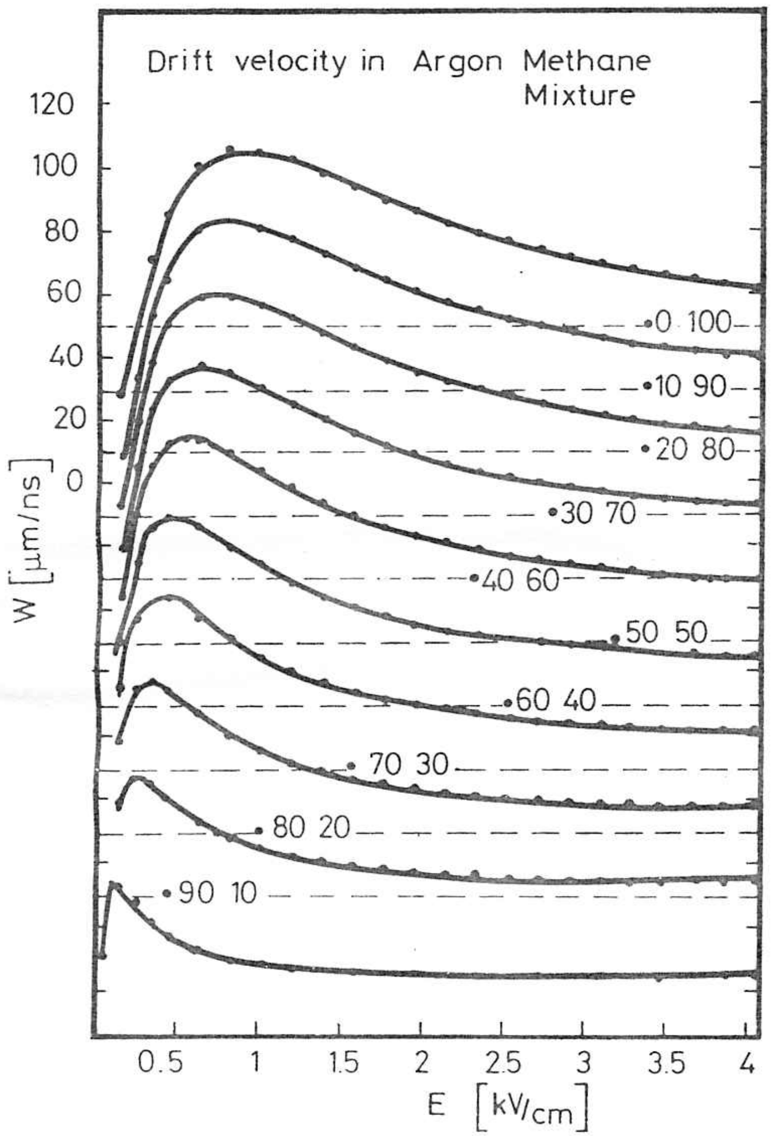


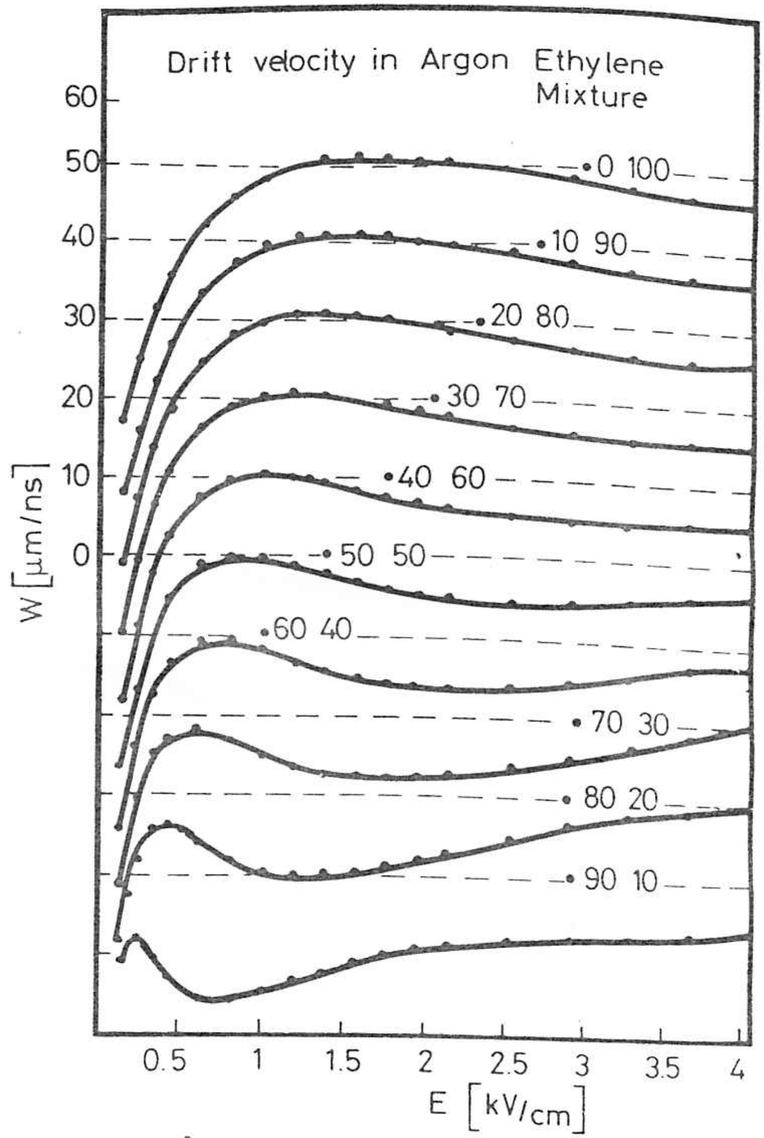
Gas Admixtures



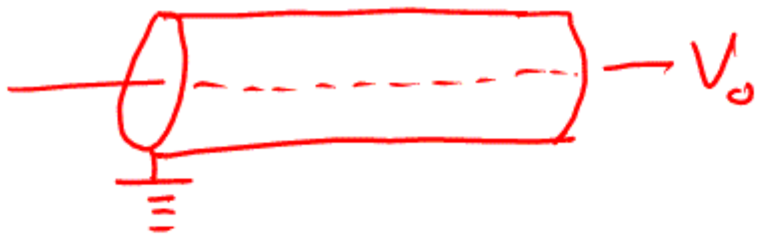


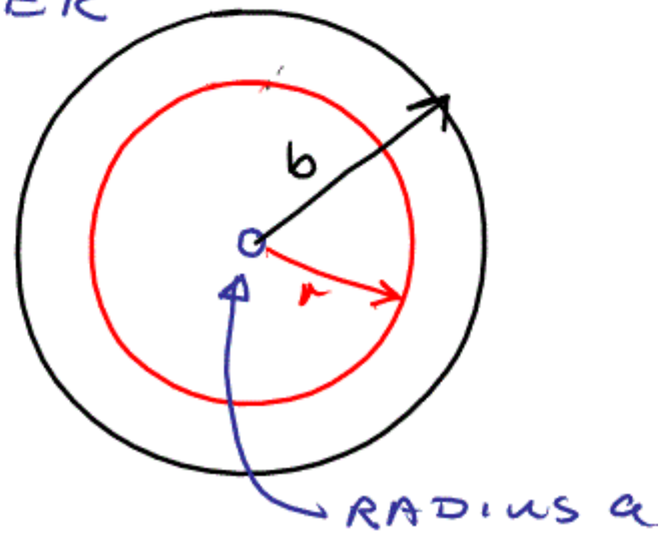
WANT DRIFT VELOCITY TO BE INDEPENDENT OF THE ELECTRIC FIELD


Drift velocity in Argon Methane Mixture
120
100
80
60
40
20
0
W [μm/ns]
0 100
10 90
20 80
30 70
40 60
50 50
60 40
70 30
80 20
90 10
0.5
1
1.5
2
2.5
3
3.5
4
E [kV/cm]


Drift velocity in Argon Ethylene Mixture
60
50
40
30
20
10
0
W [μm/ns]
0 100
10 90
20 80
30 70
40 60
50 50
60 40
70 30
80 20
90 10
0.5
1
1.5
2
2.5
3
3.5
4
E [kV/cm]

WIRE IN COAXIAL CYLINDER





$$E(r) = \frac{C V_0}{2\pi \varepsilon_0} \frac{1}{r}$$

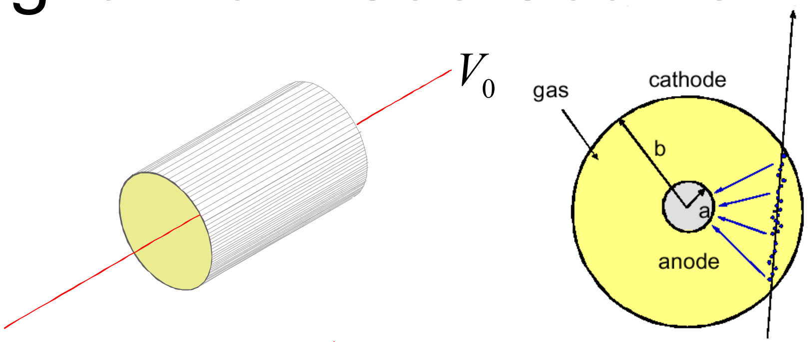
POTENTIAL $\quad \phi(r) = \dfrac{C V_0}{2\pi \varepsilon_0} \ln\left(\dfrac{r}{a}\right)$

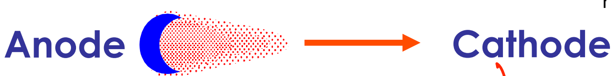
WIRE RADIUS

$$C = \frac{2\pi \varepsilon_0}{\ln(b/a)}$$

PER UNIT LENGTH

Signal from Gas Counter





MULTIPLICATION STARTS λ FROM WIRE

charge *q* moved by *dr*

$$dV = \frac{Q}{lCV_0}\frac{d\phi(r)}{dr}dr$$

potential

length of counter

capacitance/unit length

- Electrons produced in avalanche close to anode wire
- Small dr – small signal

- +ve ions drift across whole radius
- Large dr – large signal

electrostatic energy of field

$$W = \frac{1}{2}lCV_0^2$$

$$dW = lCV_0 dV$$

potential energy of q

$$W = Q\phi(r)$$

$$dW = Q\frac{d\phi(r)}{dr}dr$$

$$lCV_0 dV = Q\frac{d\phi(r)}{dr}dr$$

$$dV = \frac{Q}{lCV_0}\frac{d\phi(r)}{dr}dr \qquad \phi(r) = -\frac{CV_0}{2\pi\varepsilon_0}\ln\frac{r}{a}$$

$$V_{electron} = -\frac{Q}{lCV_0}\int_{a+\lambda}^{a}\frac{d\phi(r)}{dr}dr = -\frac{Q}{2\pi\varepsilon_0 l}\ln\frac{a+\lambda}{a}$$

$$V_{ion} = +\frac{Q}{lCV_0}\int_{a+\lambda}^{b}\frac{d\phi(r)}{dr}dr = -\frac{Q}{2\pi\varepsilon_0 l}\ln\frac{b}{a+\lambda}$$

$$V_{electron}\Big/V_{ion} = \ln\frac{a+\lambda}{a}\Big/\ln\frac{b}{a+\lambda}$$

Typically 1%

Time Development of Signal

- Assume
  - All signal comes from ions
  - Start from *a*

$$V(t) = -\frac{Q}{4\pi\varepsilon_0}\ln\left(1+\frac{\mu^+ C V_0}{\pi\varepsilon_0 a^2}t\right) = -\frac{Q}{4\pi\varepsilon_0}\ln\left(1+\frac{t}{t_0}\right)$$

$$t_0 = \frac{a^2\pi\varepsilon_0}{\mu^+ C V_0}$$

$$V(t) = \int_0^t dV = \int_a^{r(t)} \frac{dV}{dr}dr = \frac{Q}{lCV_0}\int_a^{r(t)}\frac{d\phi(r)}{dr}dr$$

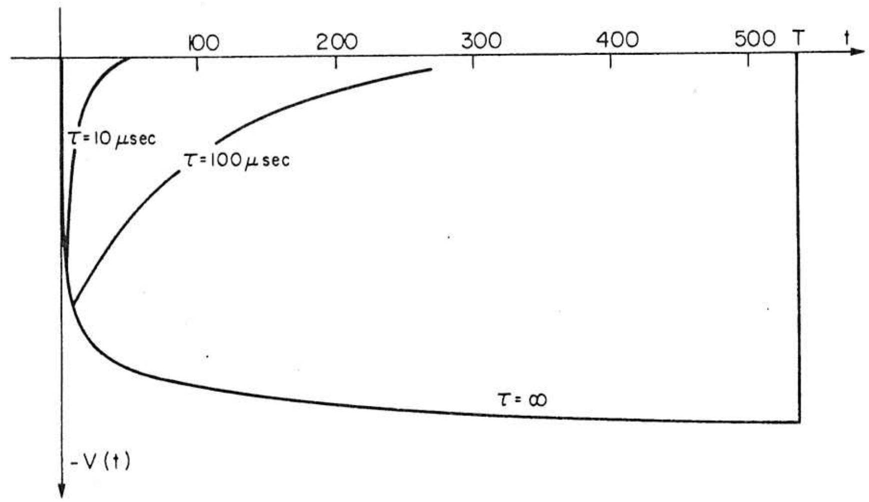
$$= \frac{Q}{lCV_0}\left[-\frac{CV_0}{2\pi\varepsilon_0}\ln\frac{r}{a}\right]_a^r = -\frac{Q}{2\pi\varepsilon_0 l}\ln\frac{r(t)}{a}$$

$$\frac{dr}{dt} = \mu^+ E = \frac{\mu^+ C V_0}{2\pi\varepsilon_0}\frac{1}{r}$$

$$\int_a^r r\,dr = \frac{\mu^+ C V_0}{2\pi\varepsilon_0}\int_0^t dt$$

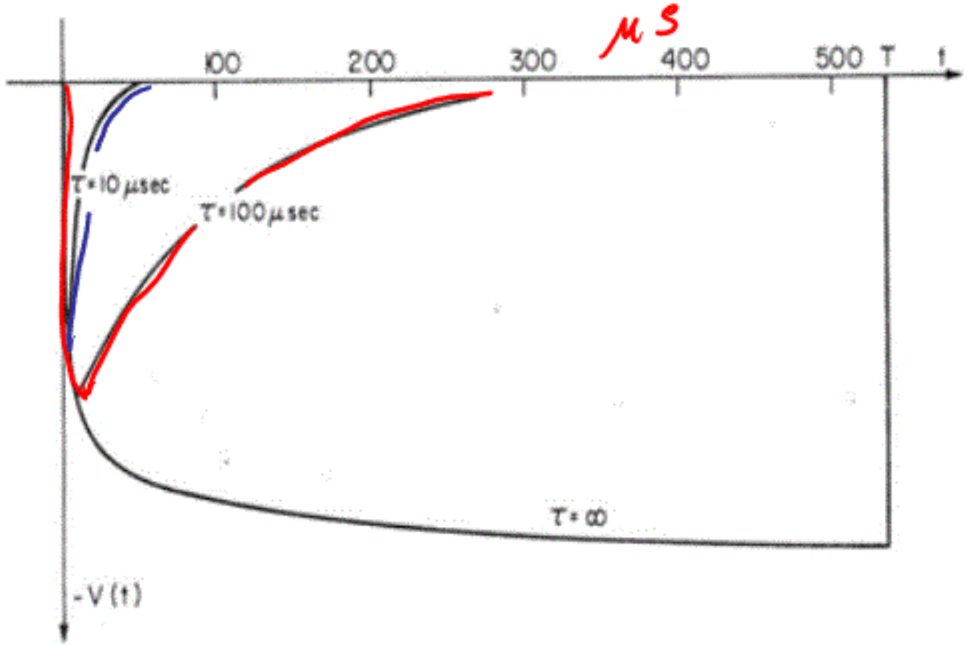
$$r(t) = \sqrt{a^2 + \frac{\mu^+ C V_0}{\pi\varepsilon_0}t}$$

$$r(0) = a$$



Typically get 50% of signal in 10^{-3} T ~700ns

RC differentiation for fast signal



TYPICAL

$a = 10\mu \;,\; b = 8mm$

$C = 8pF/m$

$\mu^+ = 1.7\, cm^2 s^{-1} V^{-1} atm^{-1}$

$V_0 = 3kV$

SIGNAL GROWS QUICKLY 50% IN $10^{-3}\,T \sim 700\,nS$

TERMINATE COUNTER WITH R

$\tau = RC$

TOTAL DRIFT TIME $T = \frac{t_0}{a^2}\left(b^2 - a^2\right)$