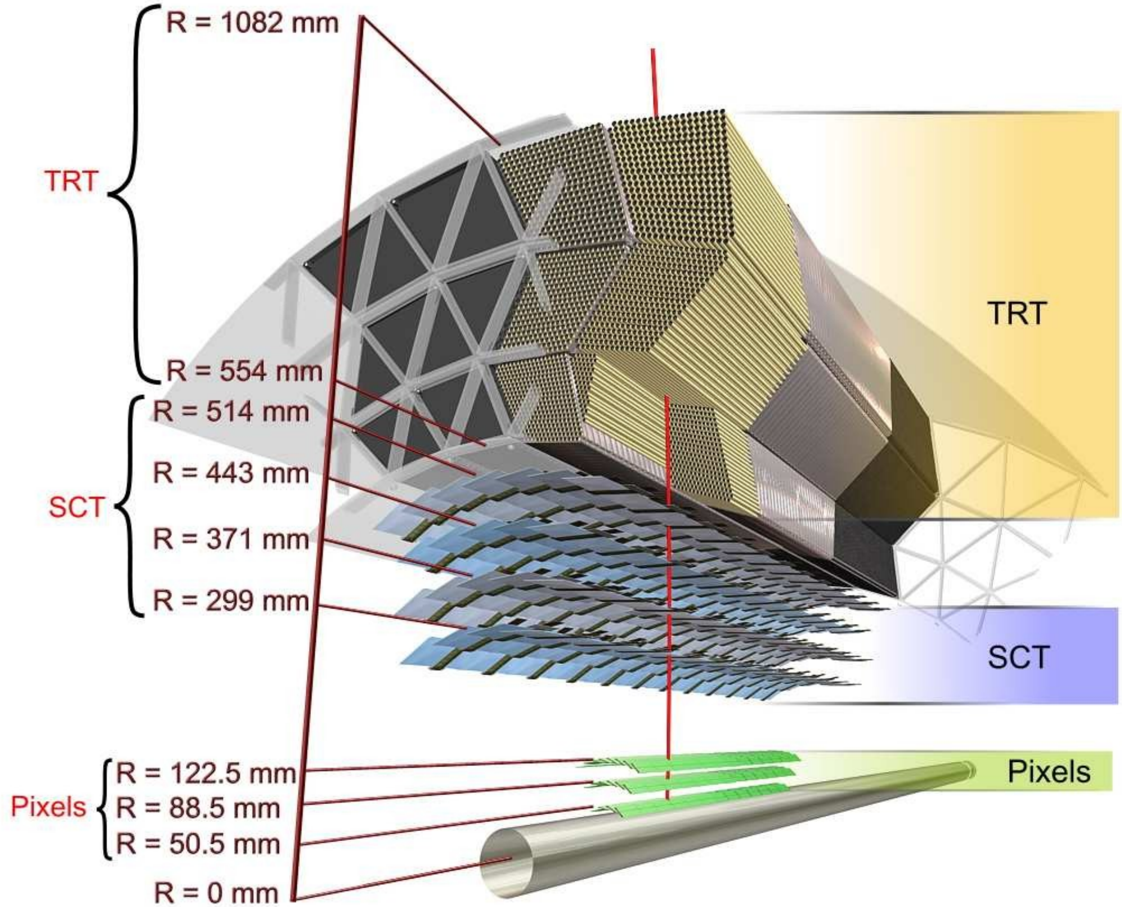
TRACKING DETECTORS



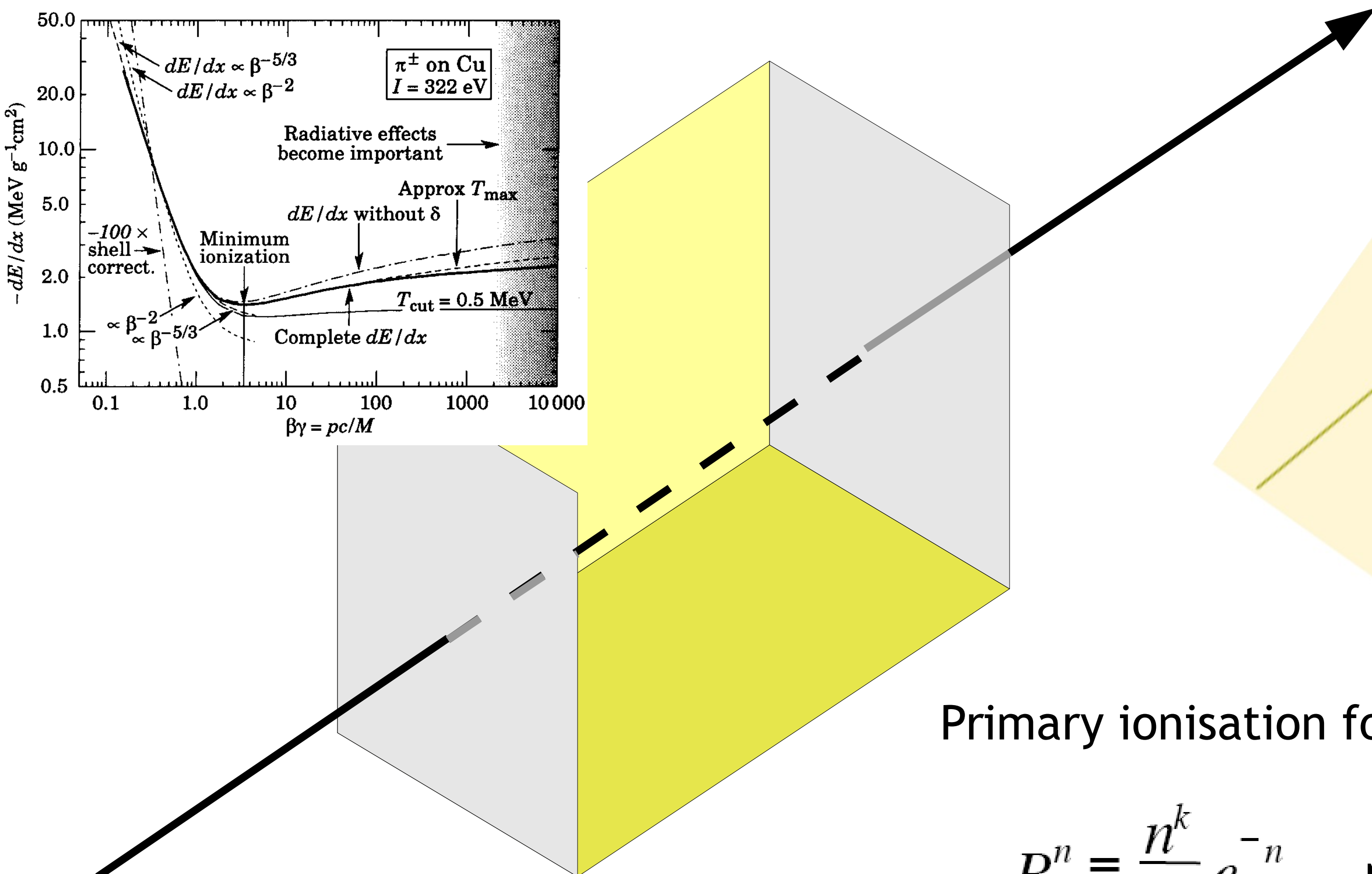
Lecture 1

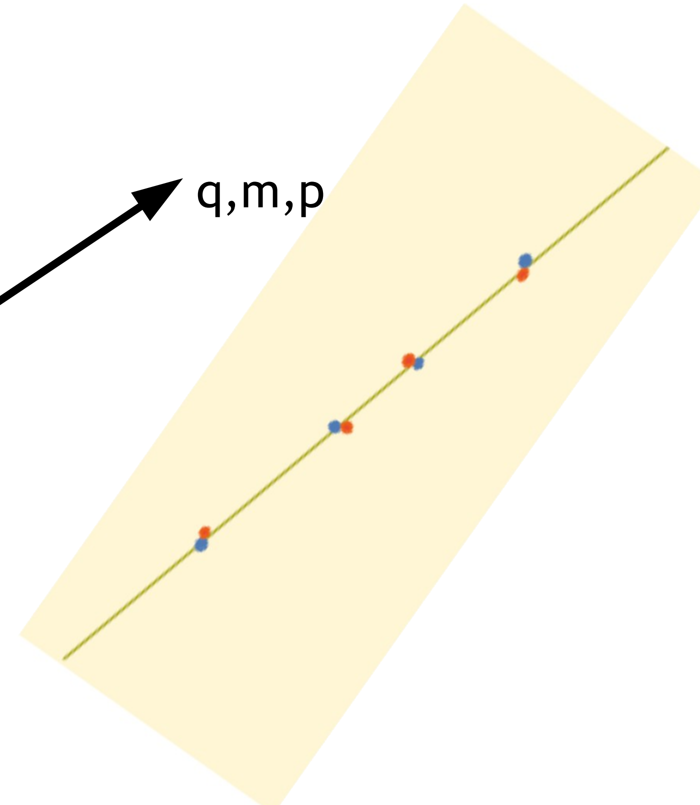
Basic considerations and gaseous detectors

Parts of this lecture taken from lectures given by Fabio Sauli at

RADIATION DETECTION AND MEASUREMENT
Prof. Glenn Knoll, organizer
Short Courses November 10-11
2002 IEEE NSS/MIC
Norfolk, November 10-16, 2002

Tracking volume filled with gas/semiconductor





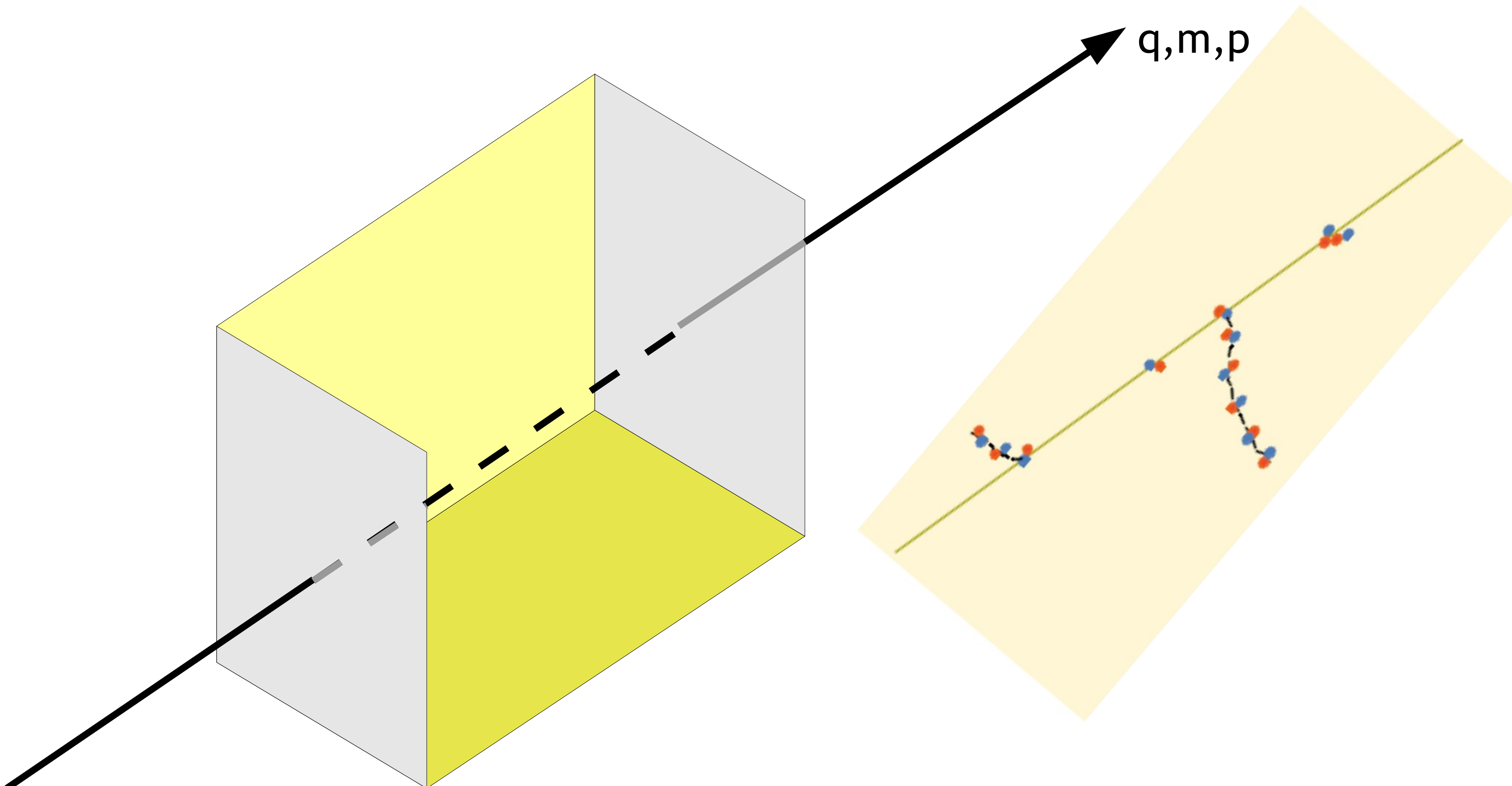
Primary ionisation follow Poisson statistics

$$P_k^n = \frac{n^k}{k!} e^{-n}$$

n= average number
k=actual number

GAS (STP)	Helium	Argon	Xenon	CH_4	DME	SI	Ge
dE/ dx (keV/ cm)	0.32	2.4	6.7	1.5	3.9	3870000	8830000
n (ion pairs/ cm)	6	25	44	16	55	~1E6	~3E6

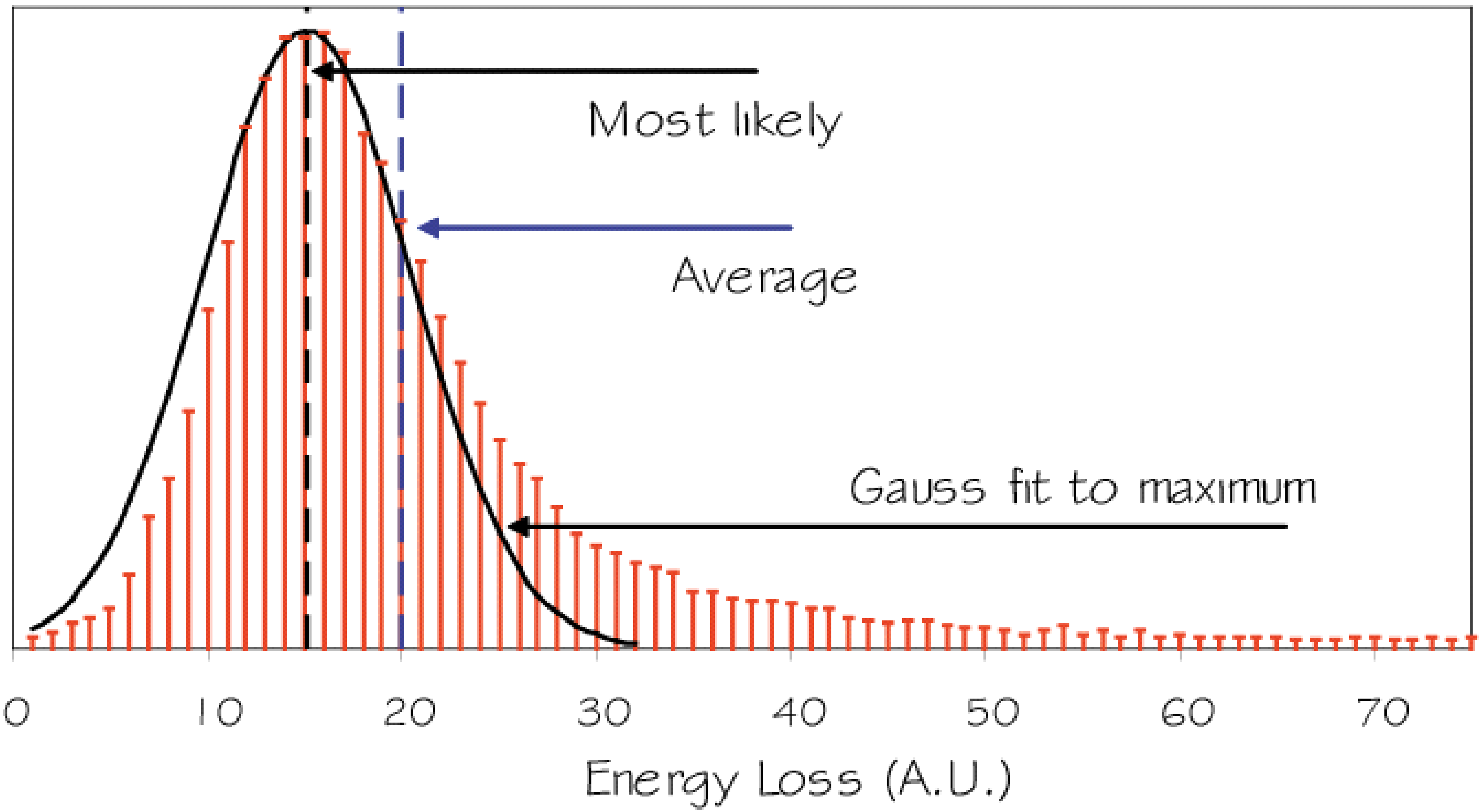
NOTE: Signal in gas detector is too small to be directly read out with amplifier. The thermal noise (kT) in the amplifier is higher!



The electrons ejected in the ionisation process have kinetic energy. These δ-electrons can have enough energy to ionise some distance from the primary ionisation. The total number of ionisations is approx. **3X** the number of primary ionisations.

A large number of measurements lead to a distribution with a long tail towards high energy loss- the **Landau fluctuation**

$$f(\lambda) = \sqrt{\frac{e^{-(\lambda + e^{-\lambda})}}{2\pi}}$$



Some more considerations on detecting charge

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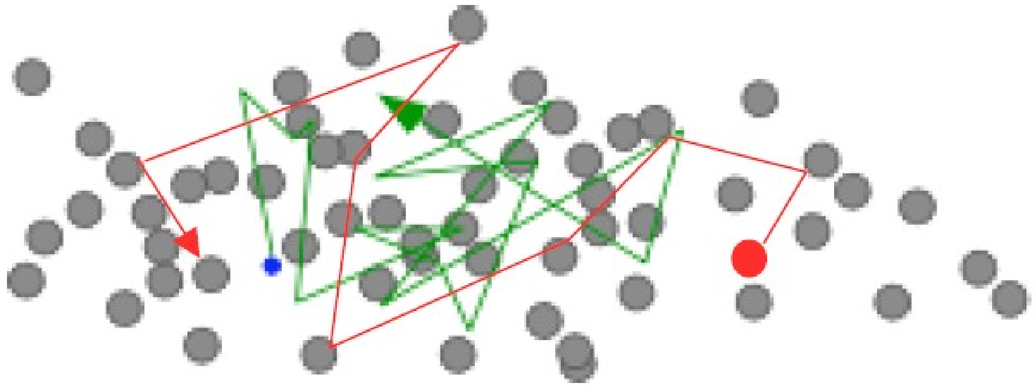
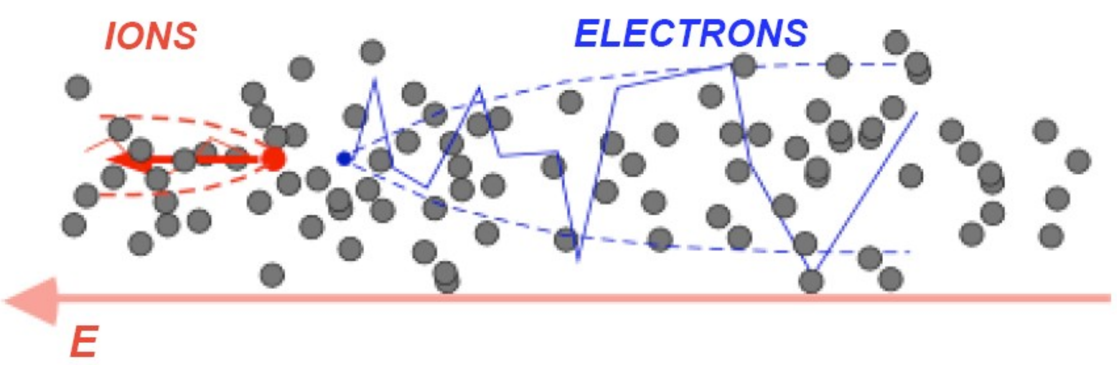
Without electric field in the tracking volume the charge created by the ionisation will diffuse



With electric field the charge (ions and electrons) will drift

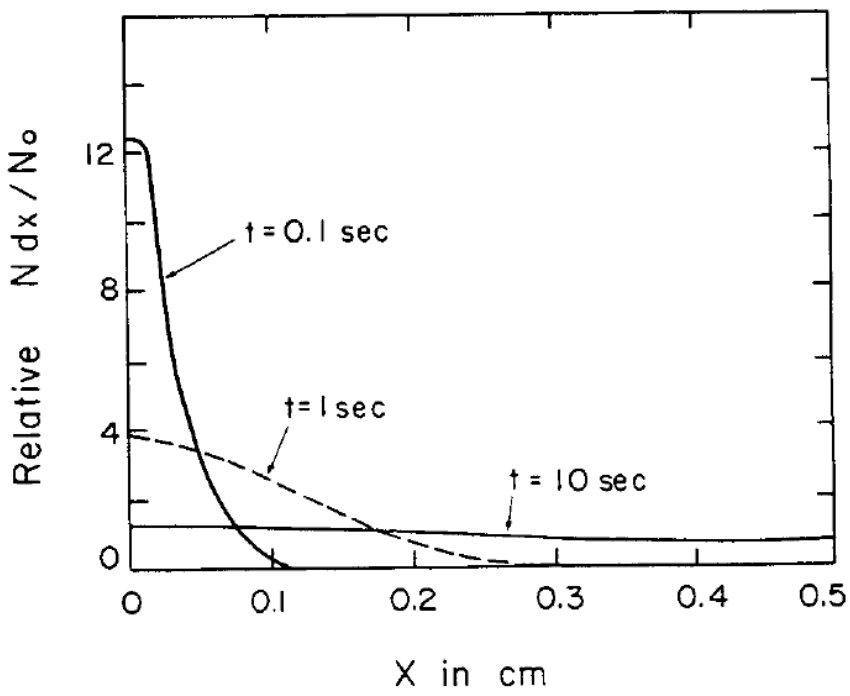


Diffusion equation gives the fraction of ions at a distance x at a given time t

$$\frac{dN}{N} = \frac{1}{\sqrt{4Dt}} e^{-\frac{x^2}{4Dt}} dx$$

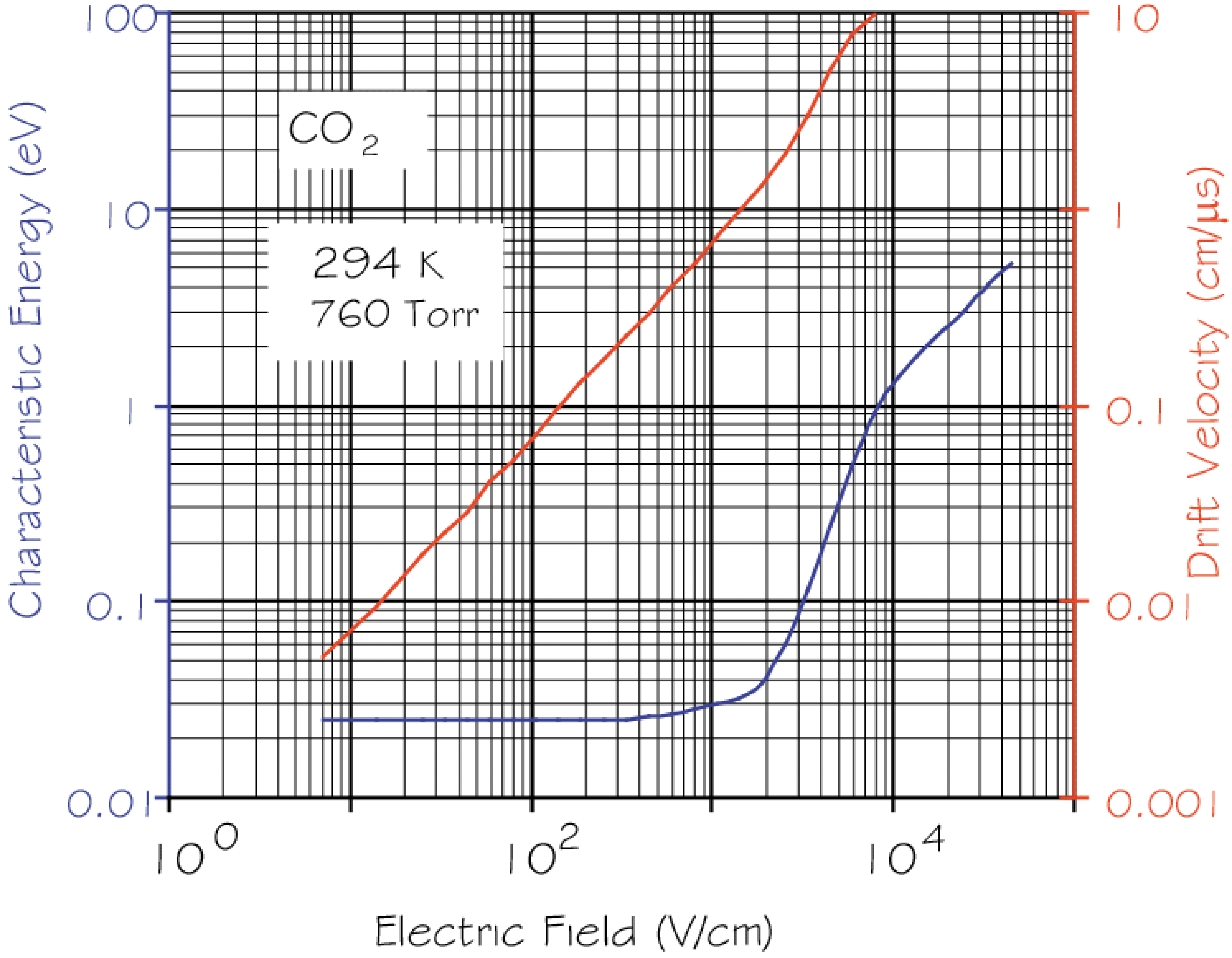
,where D is the diffusion coefficient

The RMS for linear diffusion is $\sigma_x = \sqrt{2Dt}$



Diffusion is not very efficient for charge transport ....but an enemy for charge collection

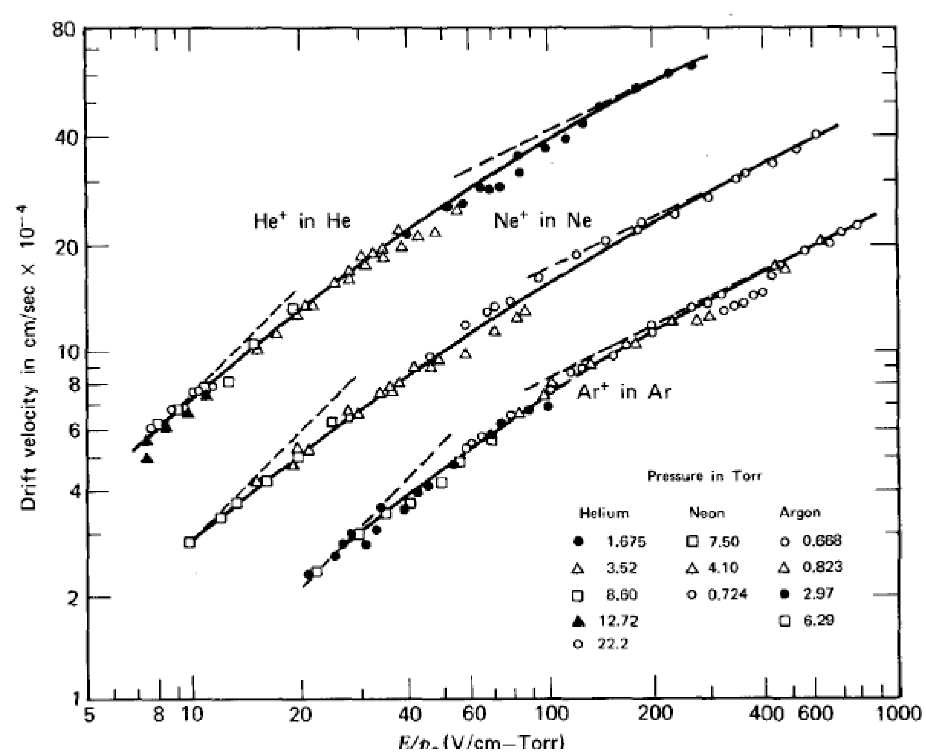
Drift of electrons in an electric field



Drift of positive ions is much slower than electrons. In CO_2 the difference is about 1000
The drift speed is almost linear with the electric field.

$$v_{ion} = \mu_{ion} \times E$$

GAS	ION	μ^+ ($cm^2 V^{-1} s^{-1}$) @STP
Ar	Ar^+	1.51
CH_4	CH_4^+	2.26
Ar-CH_4 80-20	CH_4^+	1.61

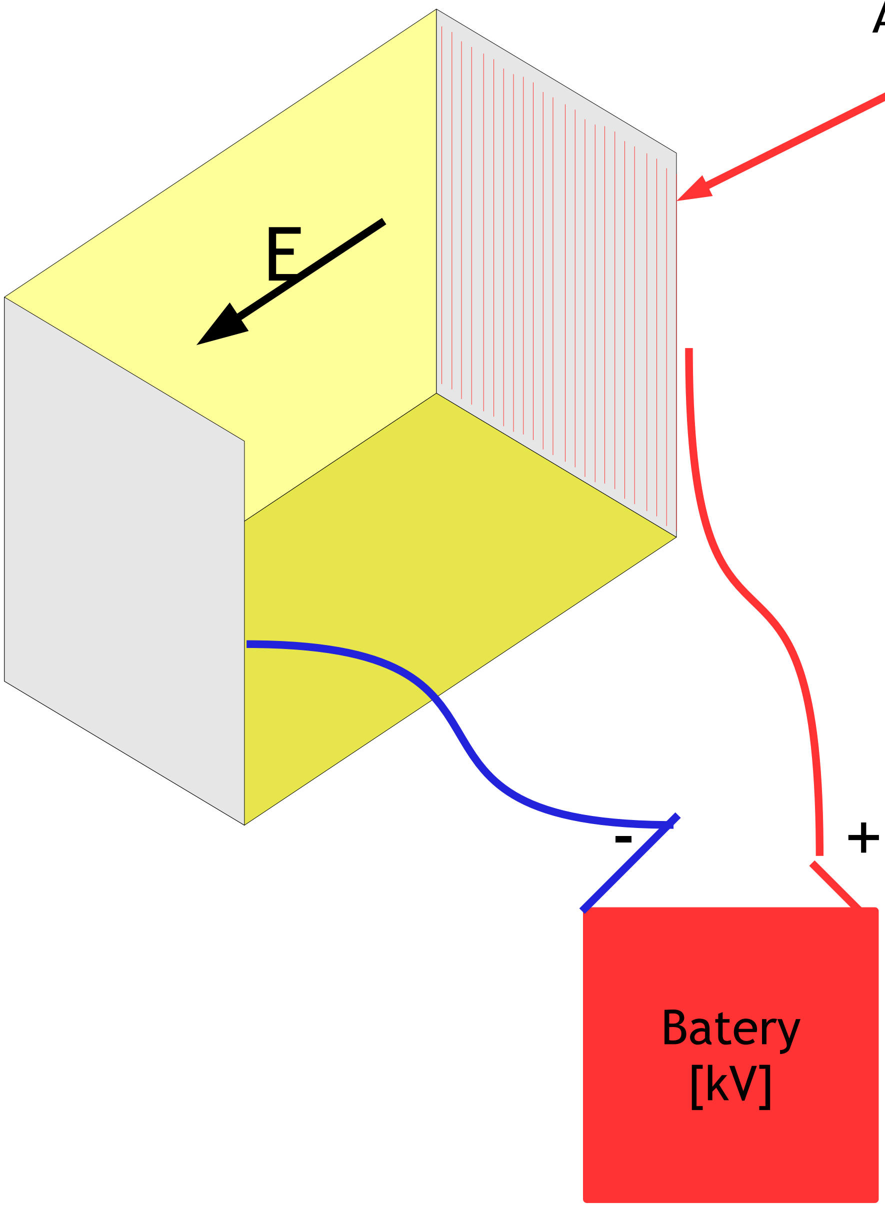


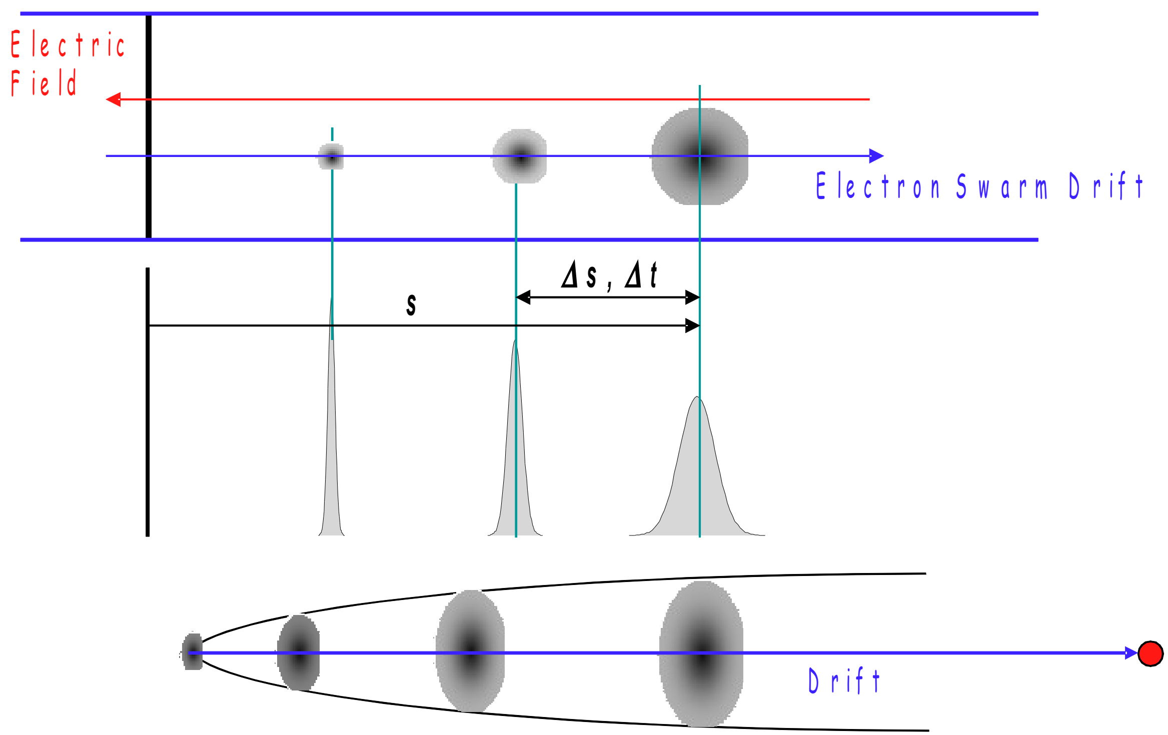
Now lets build a gas filled detector

....

Build a wire chamber

Anode wires, radius 10-100 μm
material gold plated tungsten





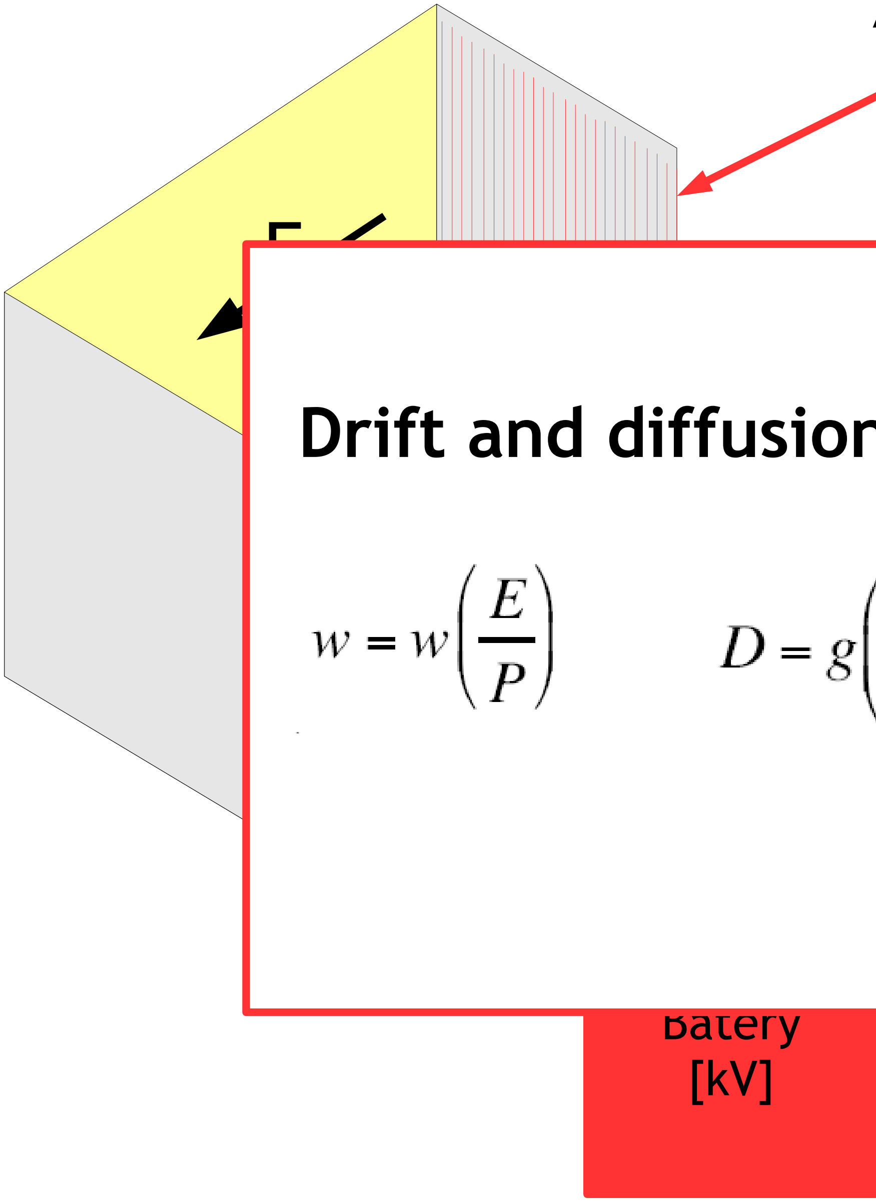
Drift velocity $$w = \frac{\Delta s}{\Delta t}$$

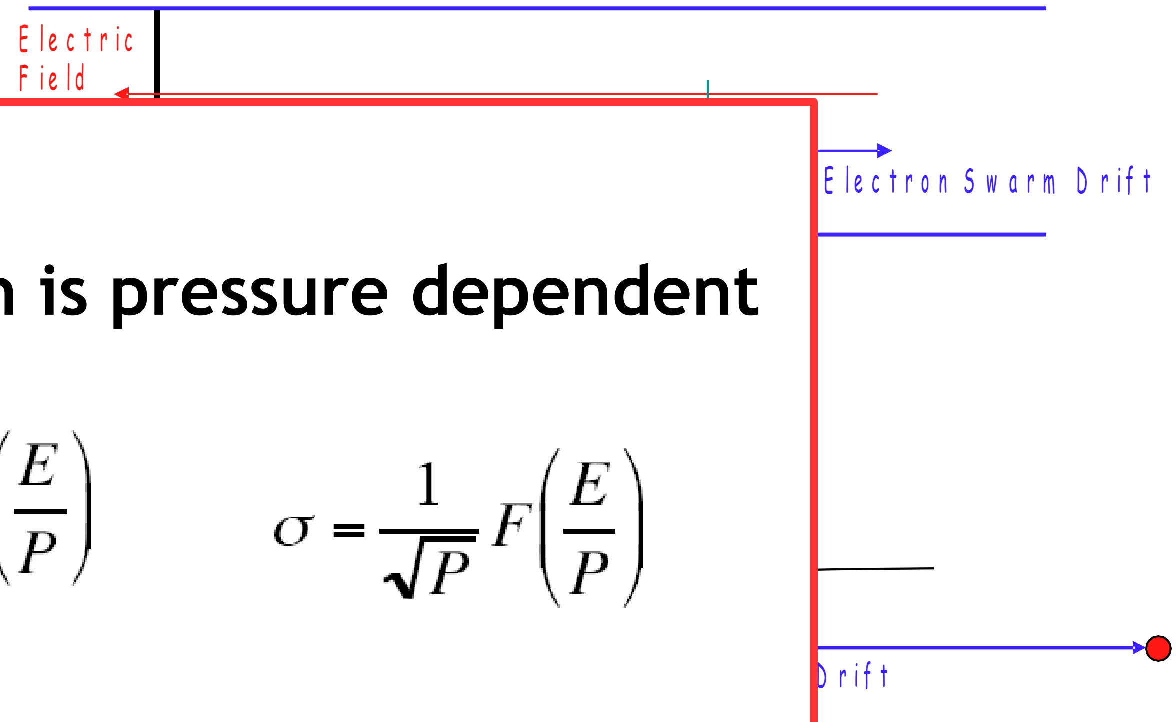
Space diffusion $$\sigma = \sqrt{2Dt} = \sqrt{2D\frac{s}{w}}$$

$$\sigma_x = \sigma_1 \sqrt{x}$$

Build a wire chamber

Anode wires, radius approx. 10μm
material gold plated tungsten





Drift and diffusion is pressure dependent

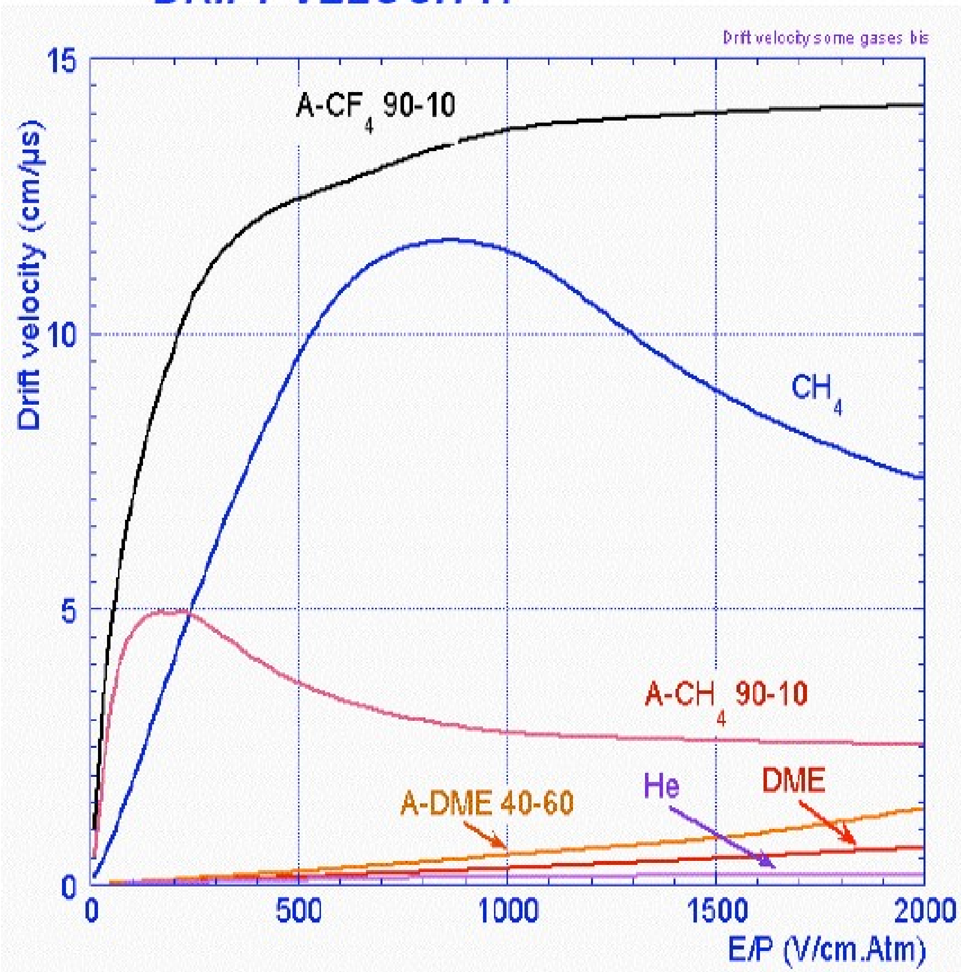
$$w = w\left(\frac{E}{P}\right) \qquad D = g\left(\frac{E}{P}\right) \qquad \sigma = \frac{1}{\sqrt{P}}F\left(\frac{E}{P}\right)$$

Space diffusion

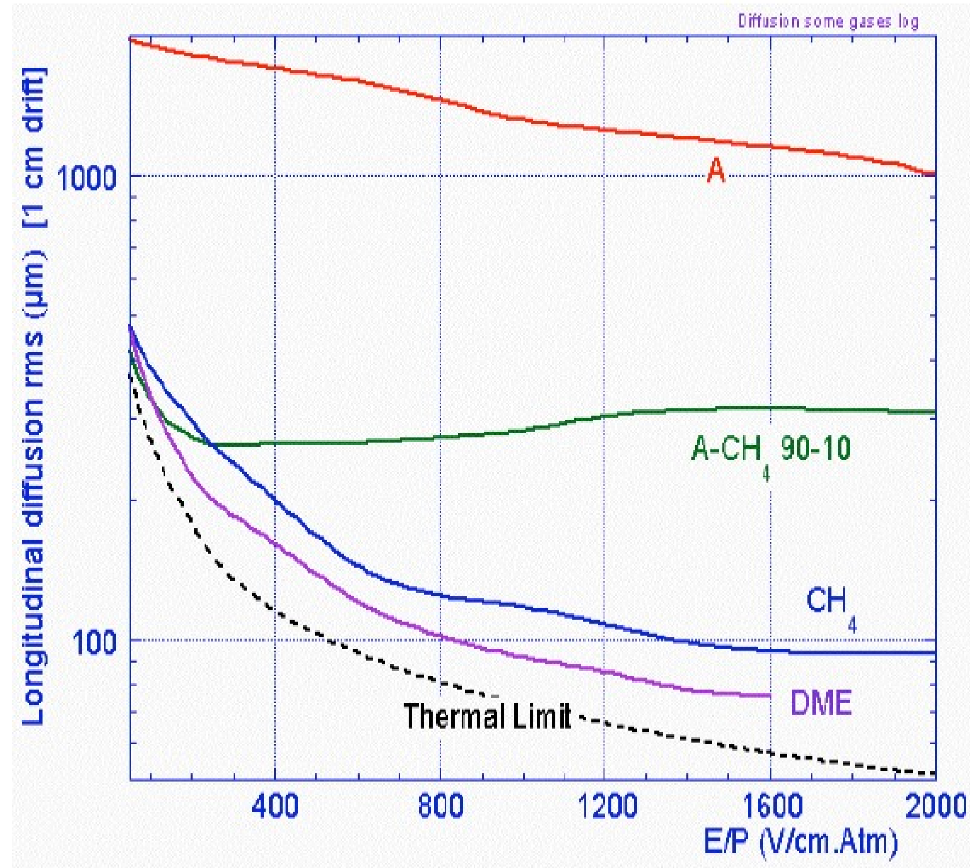
$$\sigma = \sqrt{2Dt} = \sqrt{2D\frac{s}{w}}$$

$$\sigma_x = \sigma_1\sqrt{x}$$

DRIFT VELOCITY:



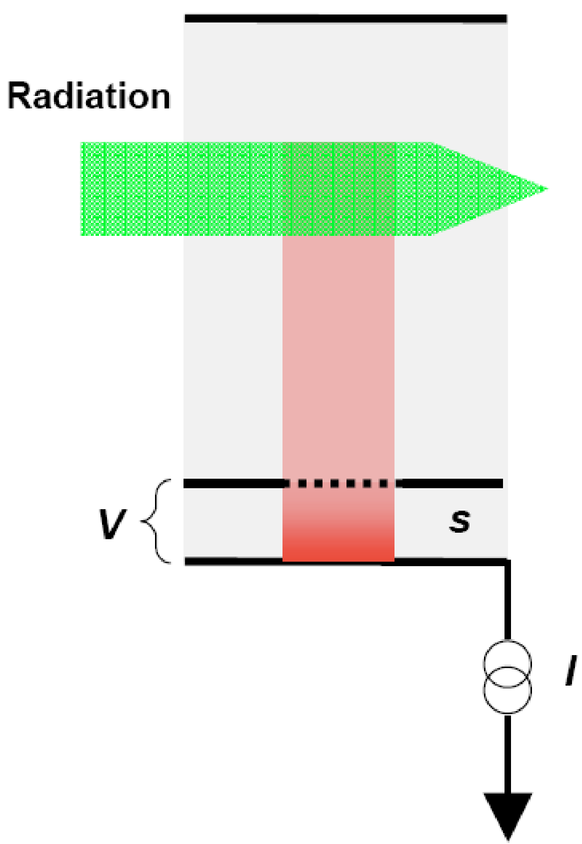
DIFFUSION:

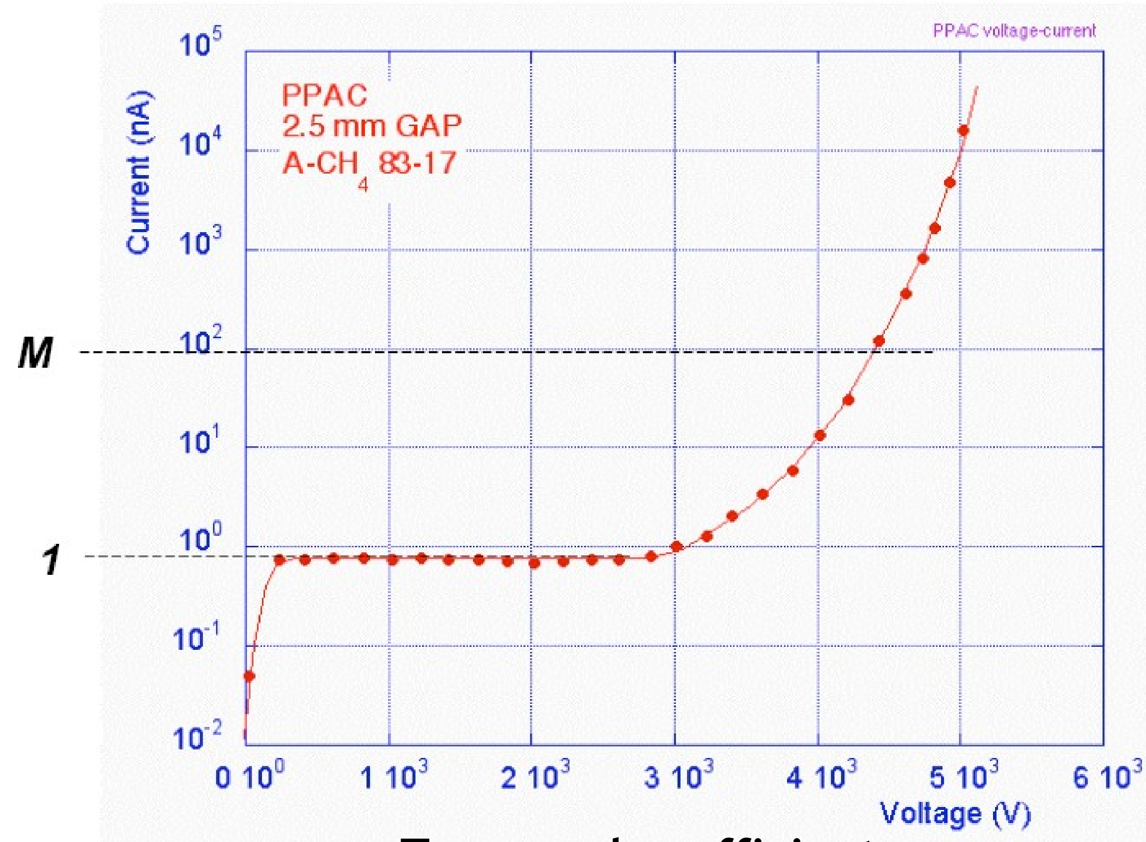


Gas amplification and saturation effects in gaseous detectors

- When the electrical field is increased in the detector the kinetic energy of the drifting electrons increase
- The electrons with kinetic energy will collide creating new free electrons and ions

Simple study:





Townsend coefficient, α

$$\alpha = \frac{\ln M}{s}$$

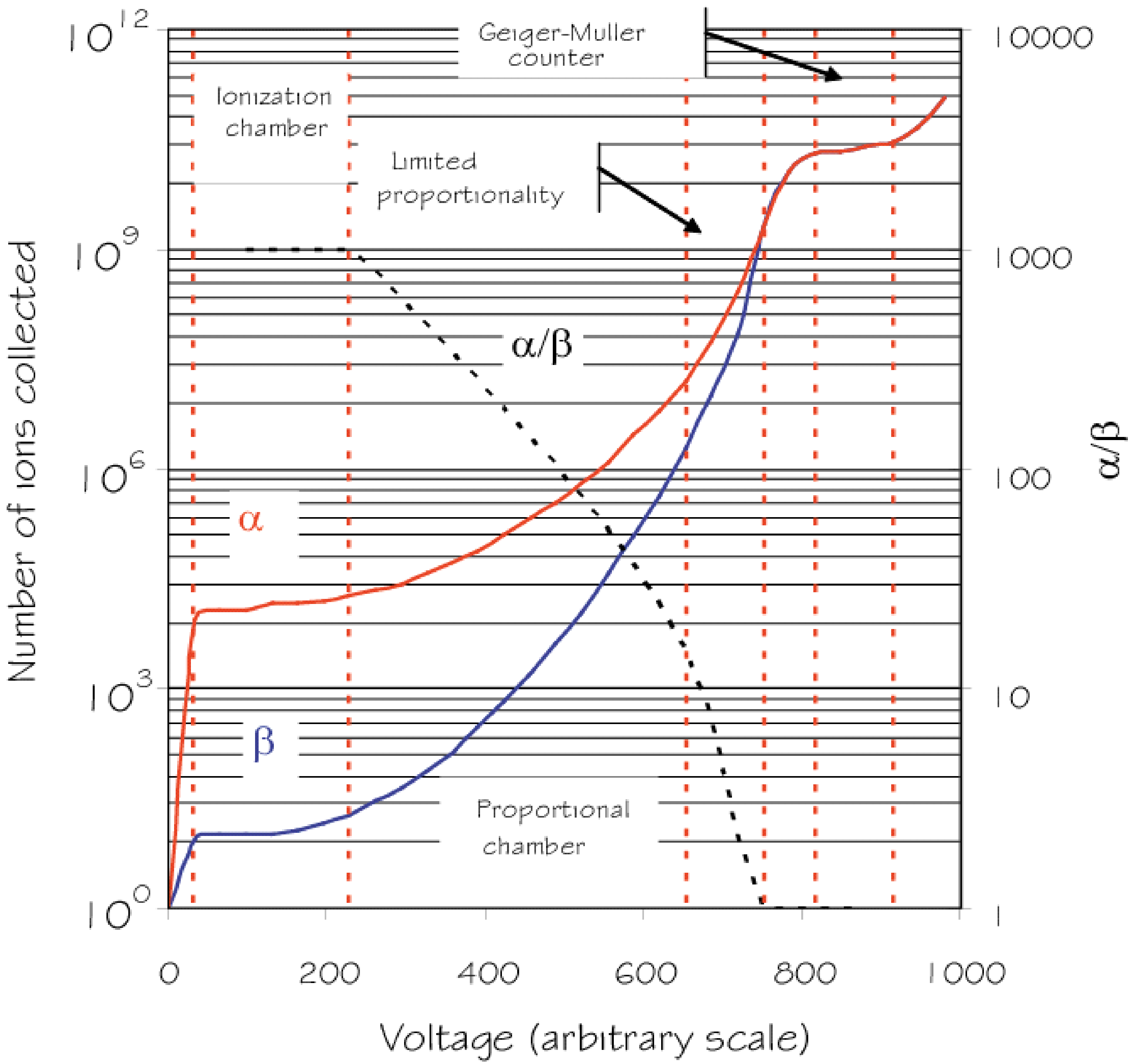
M = multiplication factor

$$\alpha = \frac{1}{\lambda}$$

ionising collisions/cm

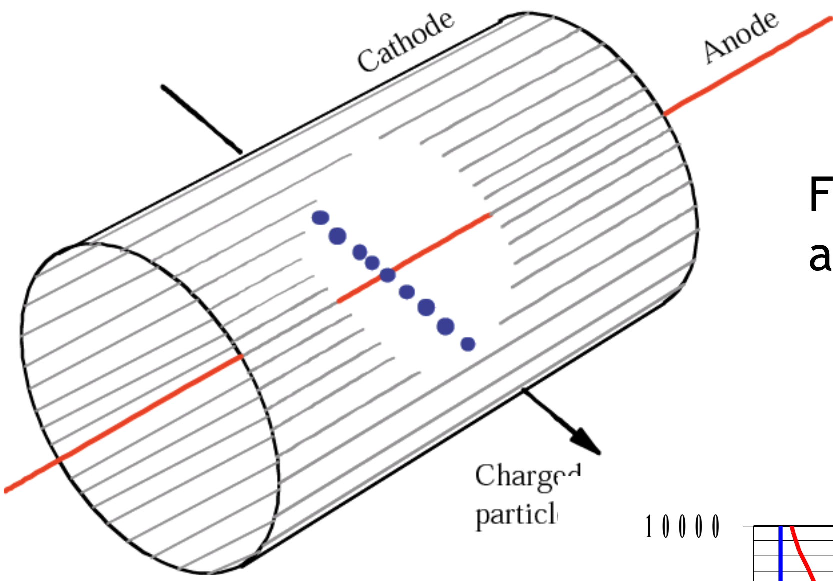
$$\lambda = \frac{1}{N\sigma}$$

N= molecules/cm^3



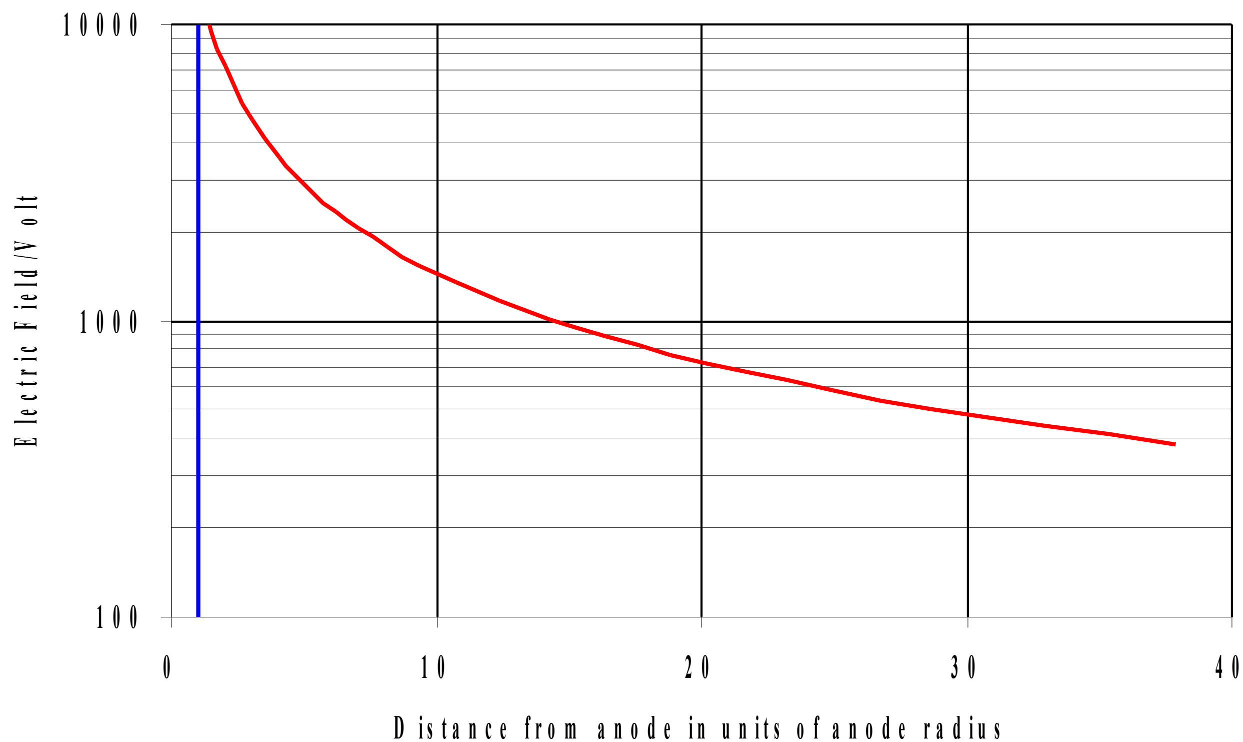
Geiger-Muller counter
Ionization chamber
Limited proportionality
α/β
α
β
Proportional chamber
10^{12}
10^9
10^6
10^3
10^0
10000
1000
100
10
1
0
200
400
600
800
1000
Number of ions collected
Voltage (arbitrary scale)
α/β

High field is also developed near the anode wire-for a simple geometry e.g. a straw tube

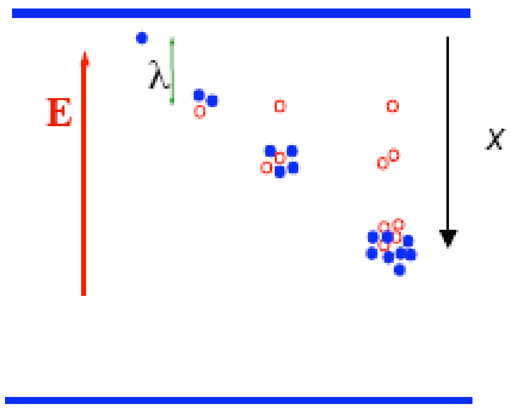


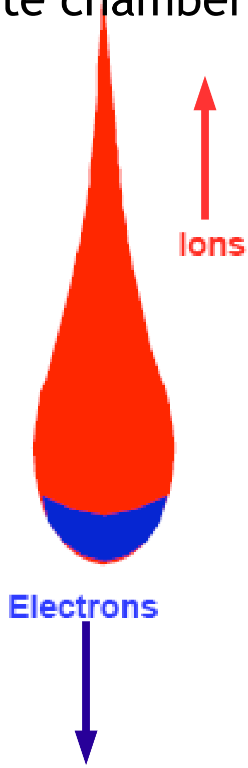
For a cylinder with radius R and anode wire radius r_0(~10μm):

$$\frac{E}{V_0} = \frac{1}{r}\frac{1}{\ln\left(\frac{R}{r_0}\right)}$$



Avalanche development in a plate chamber with uniform filed





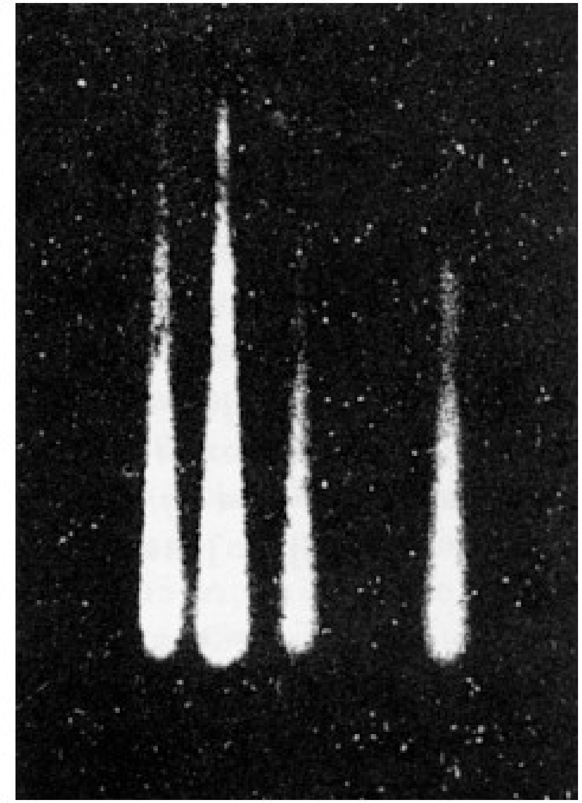
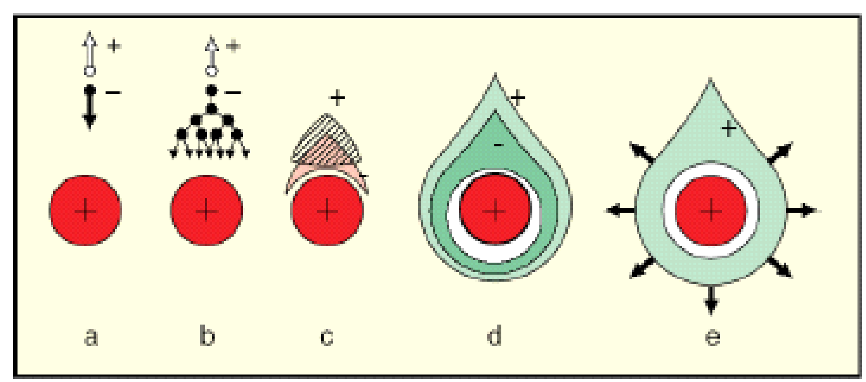


image from cloud-avalanche chamber

$$dn = n\,\alpha\,dx$$

$$n(x) = n_0 e^{\alpha x}$$

Development of avalanche close to the anode wire



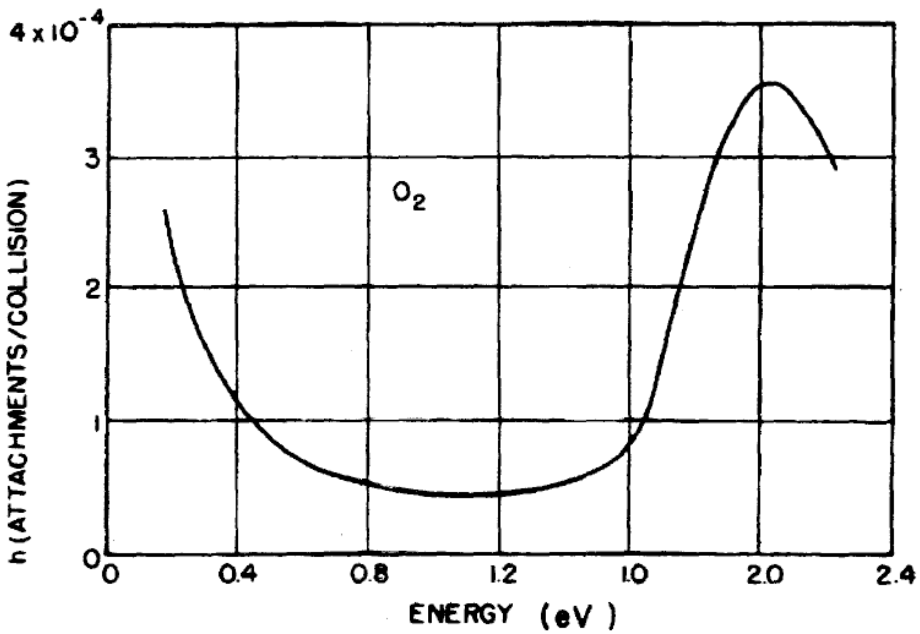
Multiplication factor (gain)

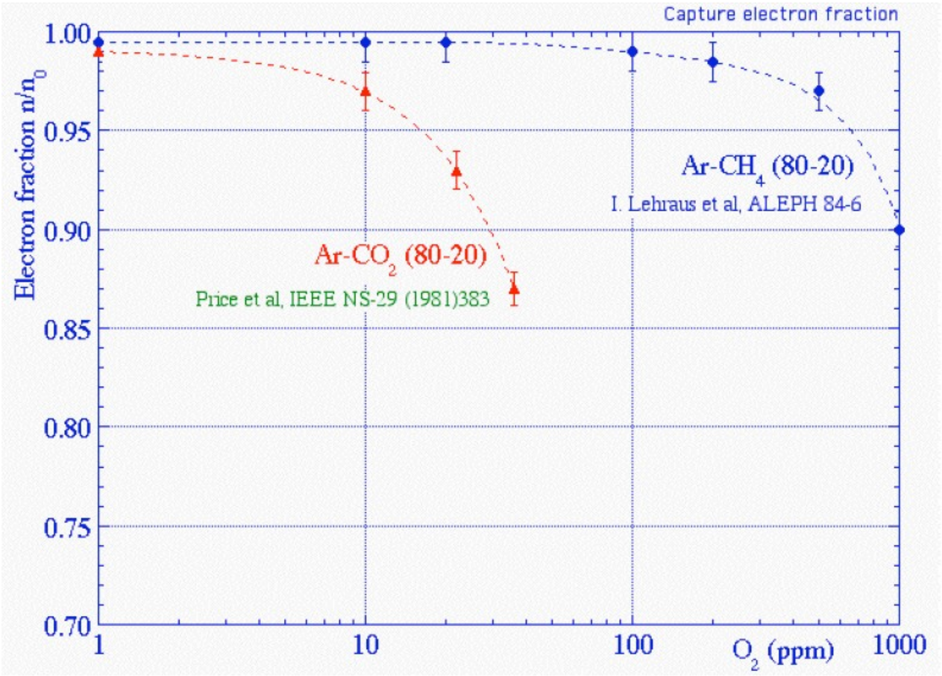
$$M(x) = \frac{n}{n_0} = e^{\alpha x}$$

Quenching

1: To get a stable behavior over a large range of particle rates and ionisation levels a quenching gas is added. The gas should have a large electron capture cross- section for energetic electrons to not let the avalanches to grow enormous and a low cross-section for thermal electrons.

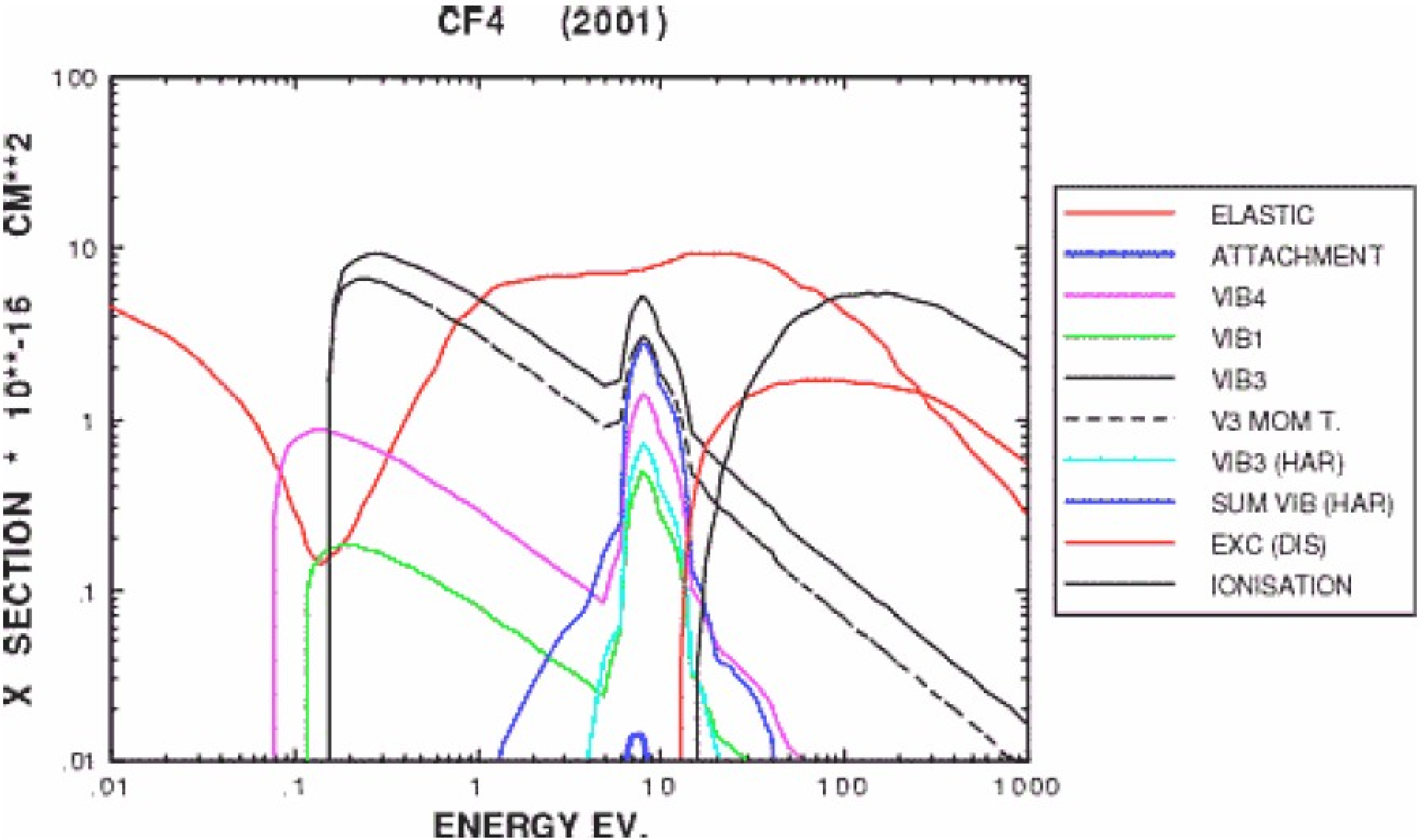
2: An other problem is that noble gases emit photons above the ionisation threshold of other molecules. Poly-atomic gases works as quenchers absorbing the photons.





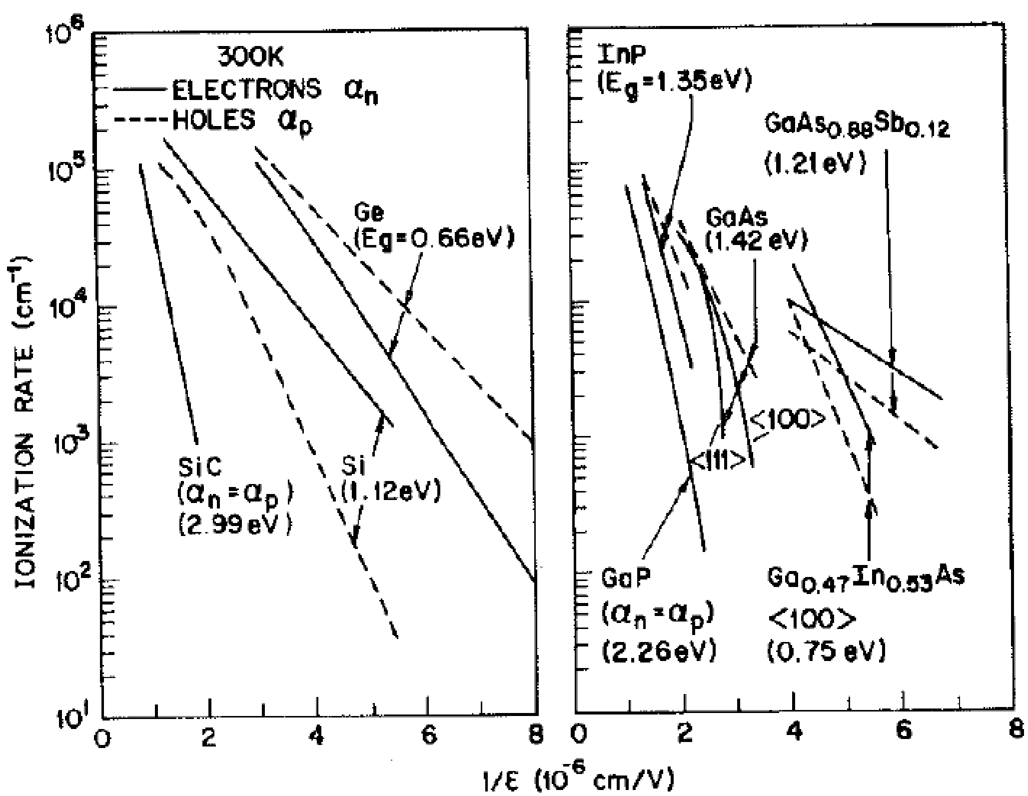
Oxygen has a good electron capture cross-section ⇒ why not use $C0_2$

CF4 is a good quenching gas



Charge multiplication in solid state sensors (Si, Ge, GaAs etc)

• Avalanche breakdown may occur in semiconductor sensors when the kinetic energy of electrons/holes between collisions acquired by the electric field is sufficient to trigger multiplication process.
• As for the gaseous detectors the probability to initiate an avalanche depends not only on electric field strength but also on the extent of the high field region
• Avalanche breakdown is an unwanted effect in most semiconductor sensors (avalanche photo diodes and silicon multipliers are based on this effect)

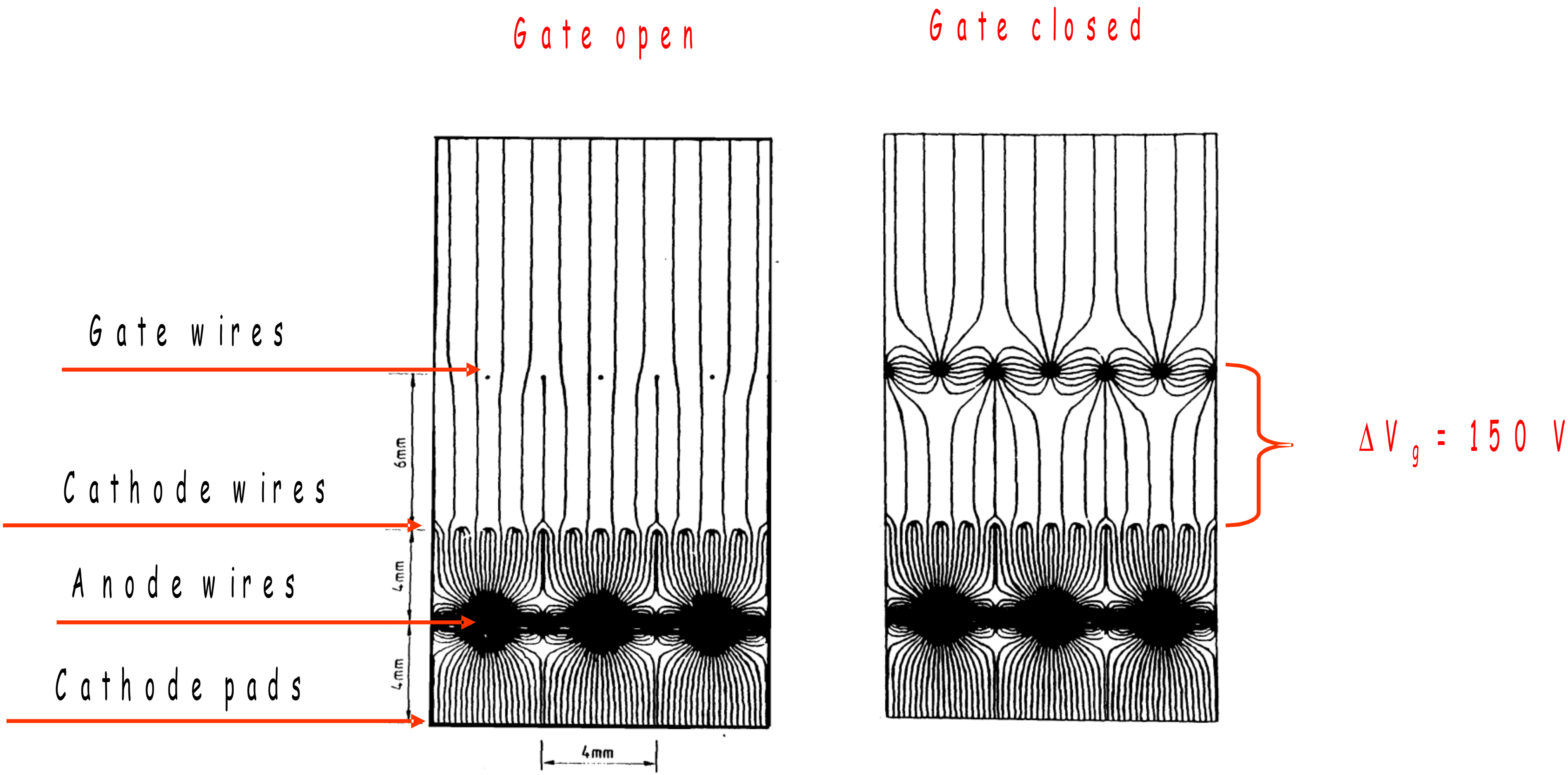


After Sze, S.M. "Physics of semiconductor devices". Wiley

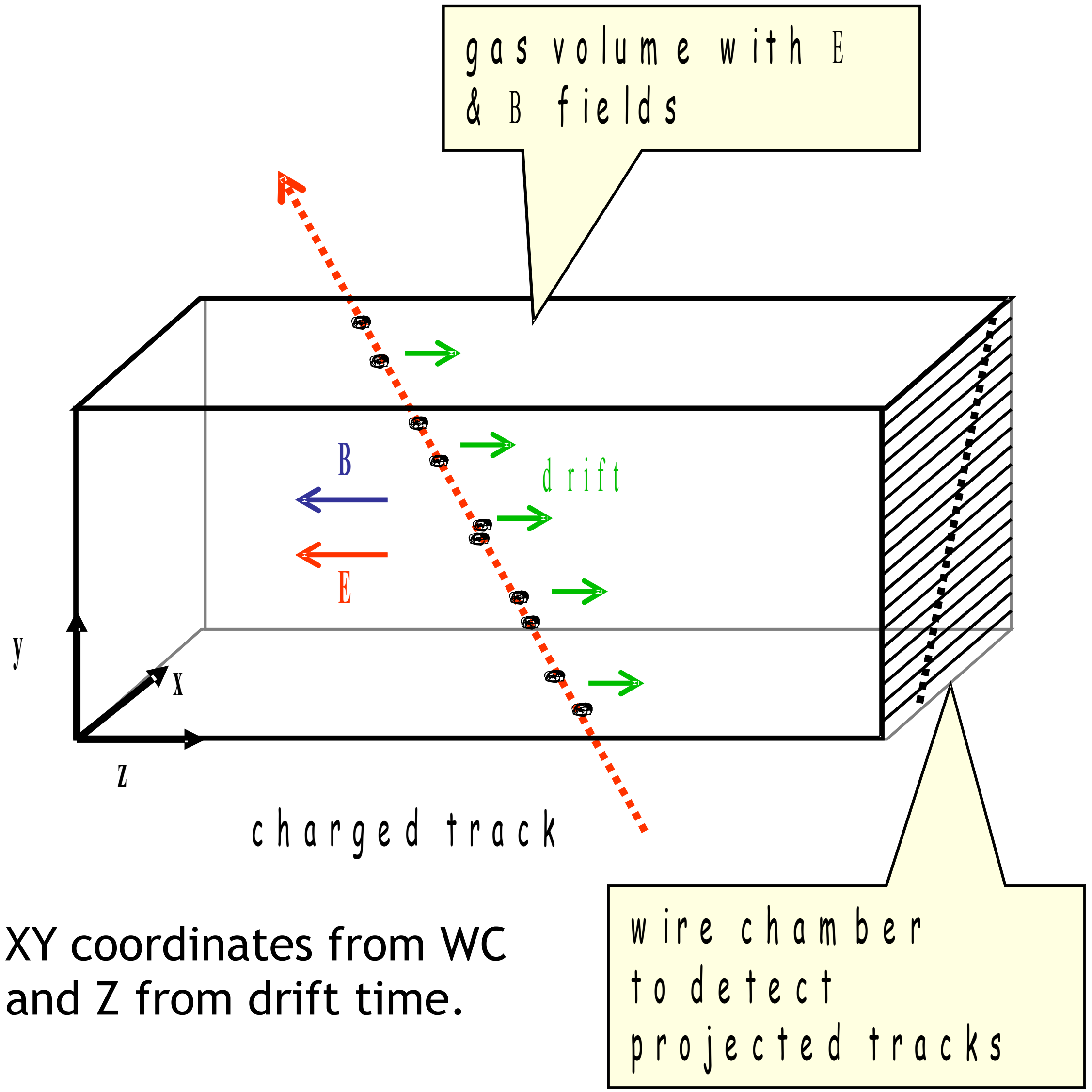
And now some more realistic gaseous detector designs ....

1: Split the drift chamber in a low field drift volume and a high field amplification volume

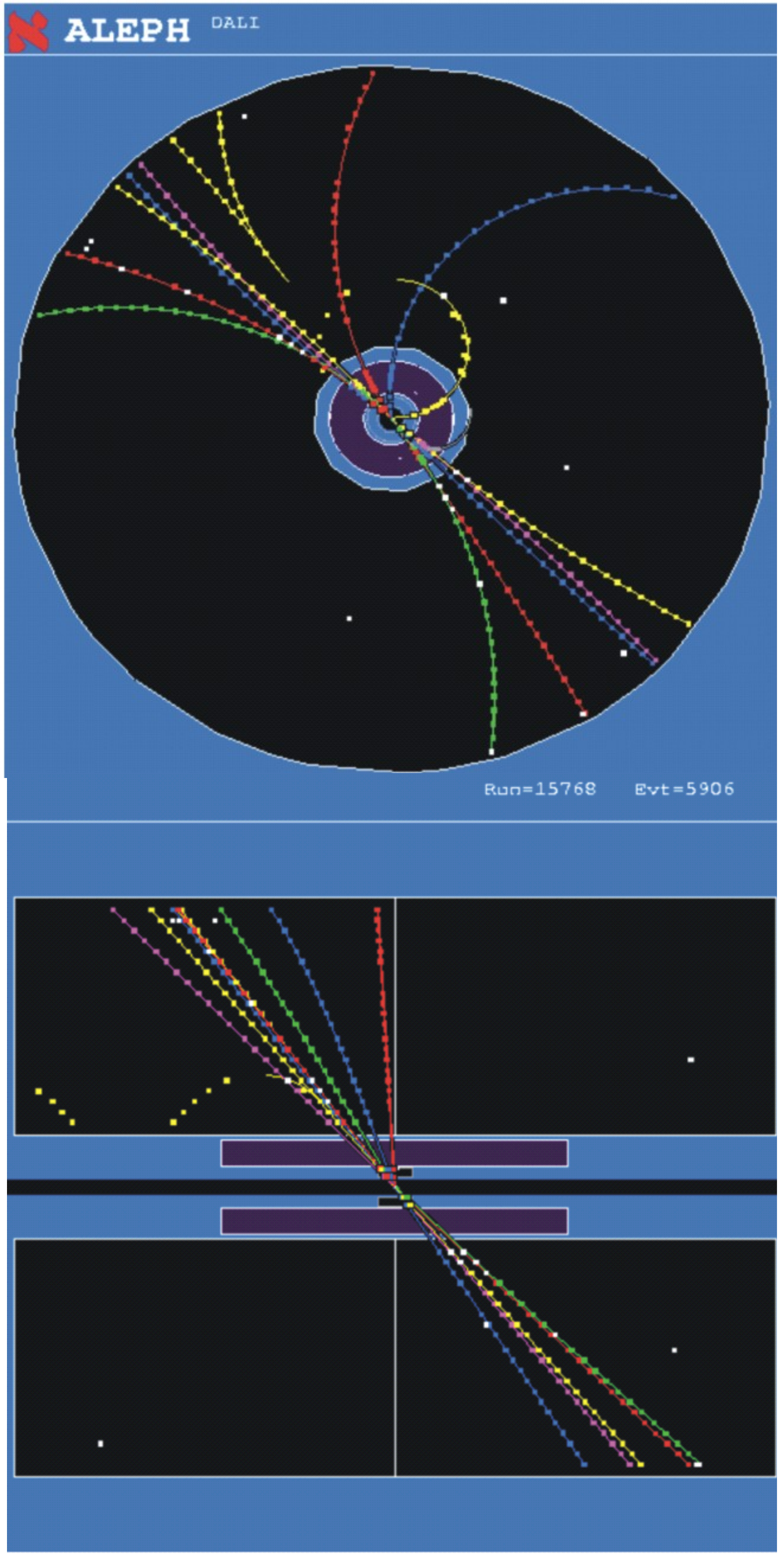
2: To control and reduce the drift time and accumulated space charge of of slow positive ions one may use gating techniques.



The **Time Projection Chamber (TPC)** is the **ultimate** tracking detector giving 3D space points (and dE/dx) for track reconstruction and adding little mass in tracking volume keeping multiple scattering small.

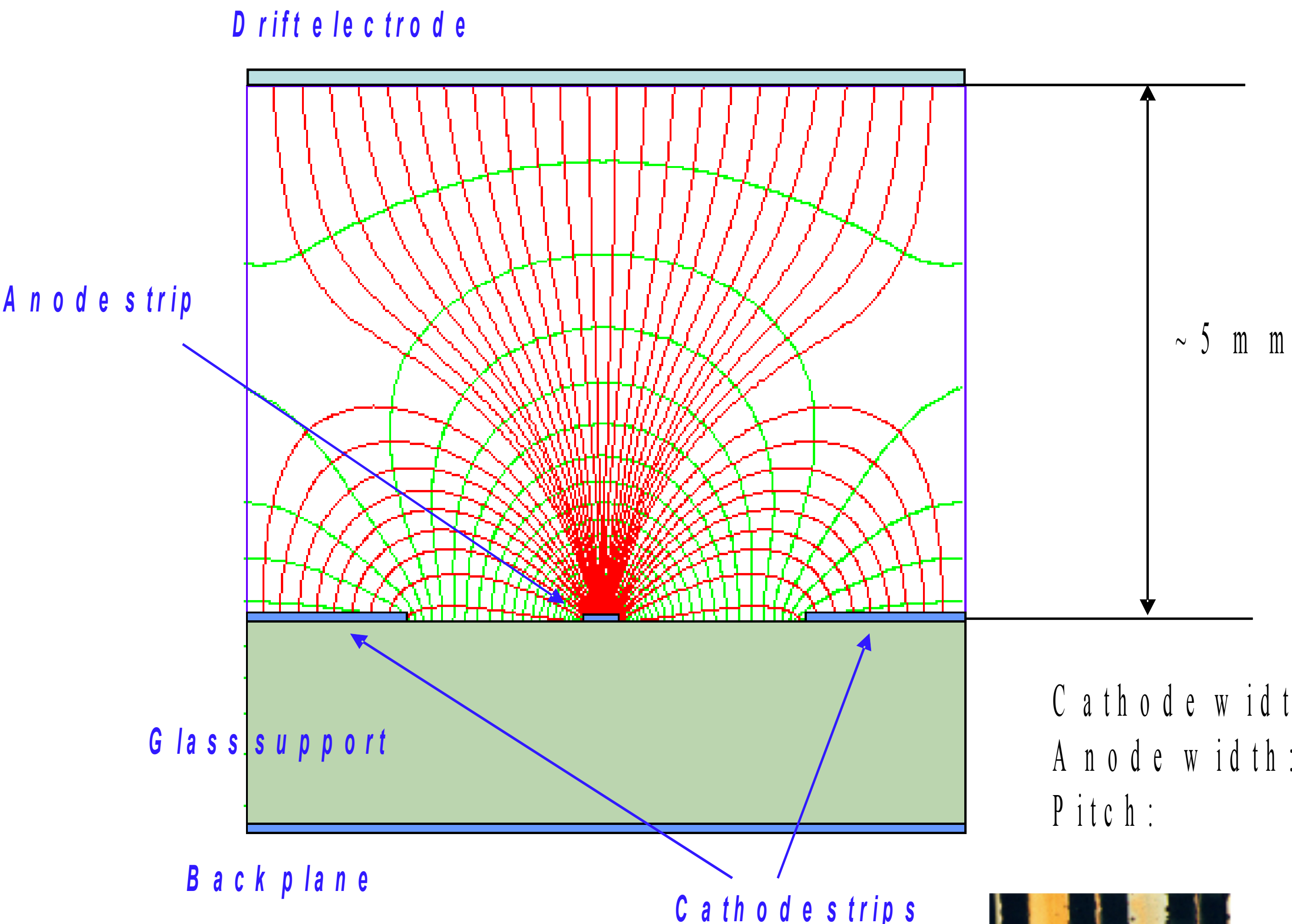


XY coordinates from WC and Z from drift time.



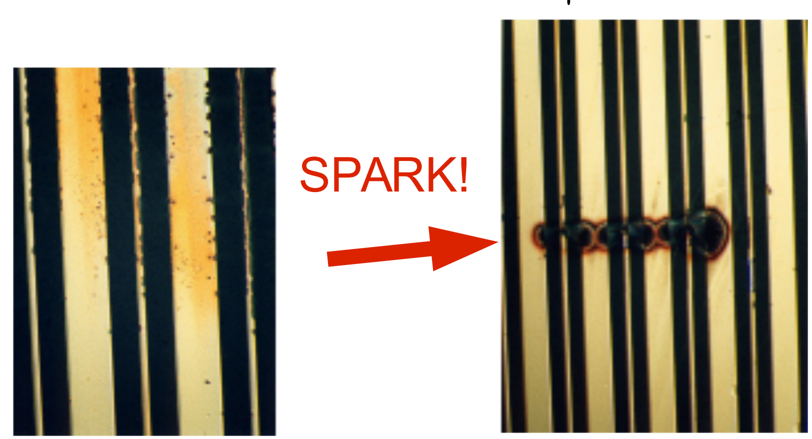
High resolution gaseous detectors for tracking are:

• Micro-Strip Gas Chambers (MSGC), baseline technology for outer tracker in CMS TDR

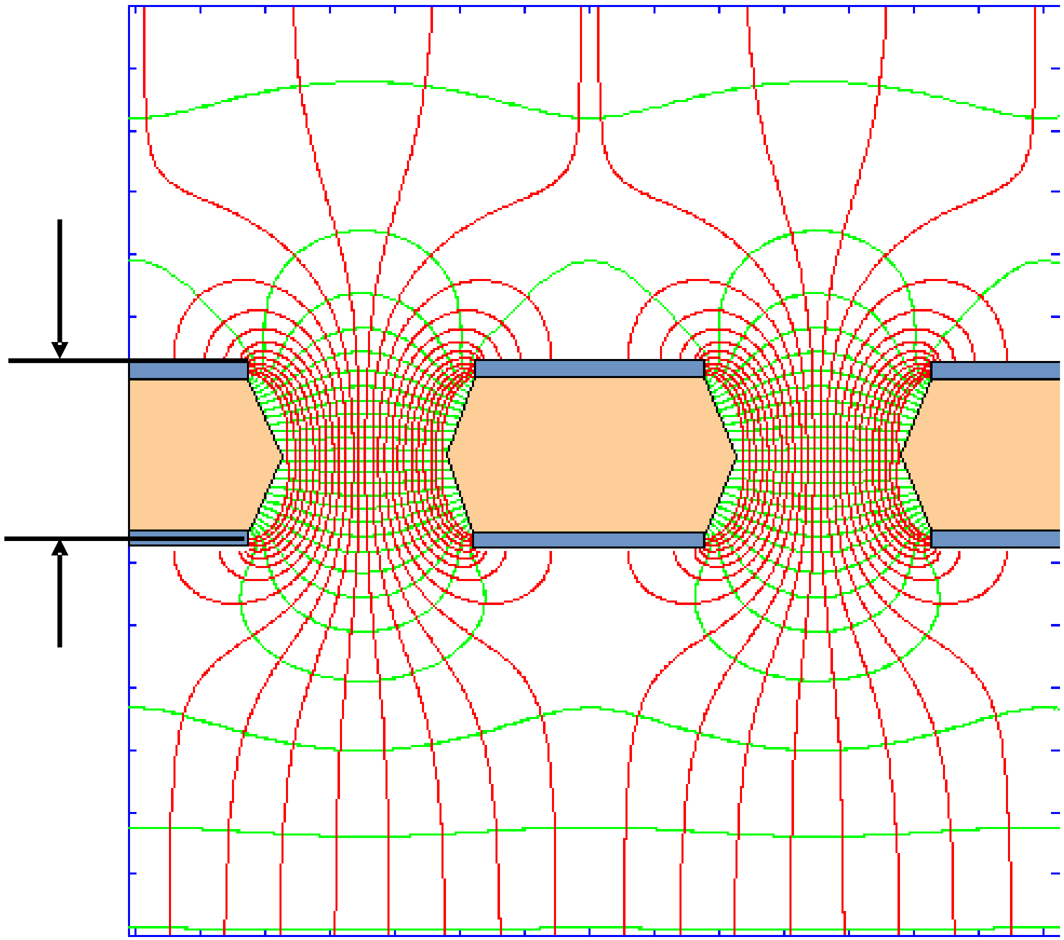


Anodes and cathodes strips on a insulating substrate

Cathode width: 90 μm
Anode width: 10 μm
Pitch: 200 μm



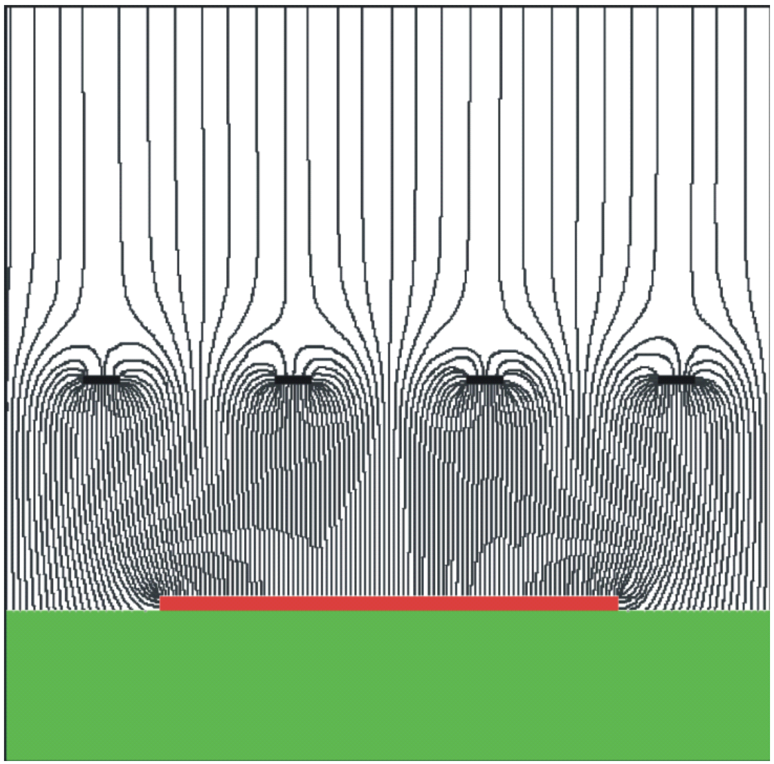
•Gas Electron Multiplier (GEM) [used in TOTEM]

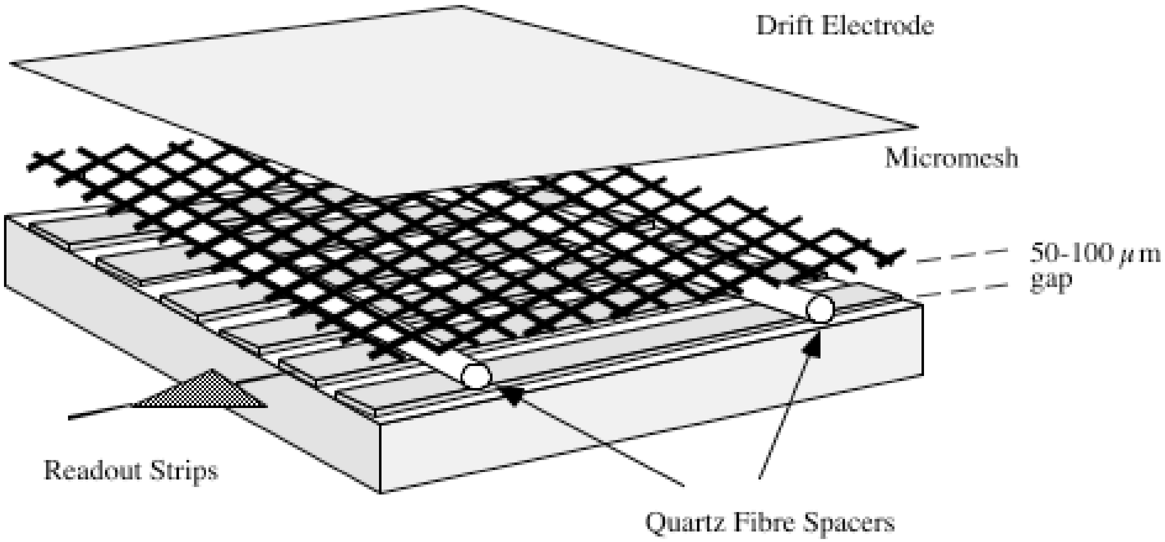


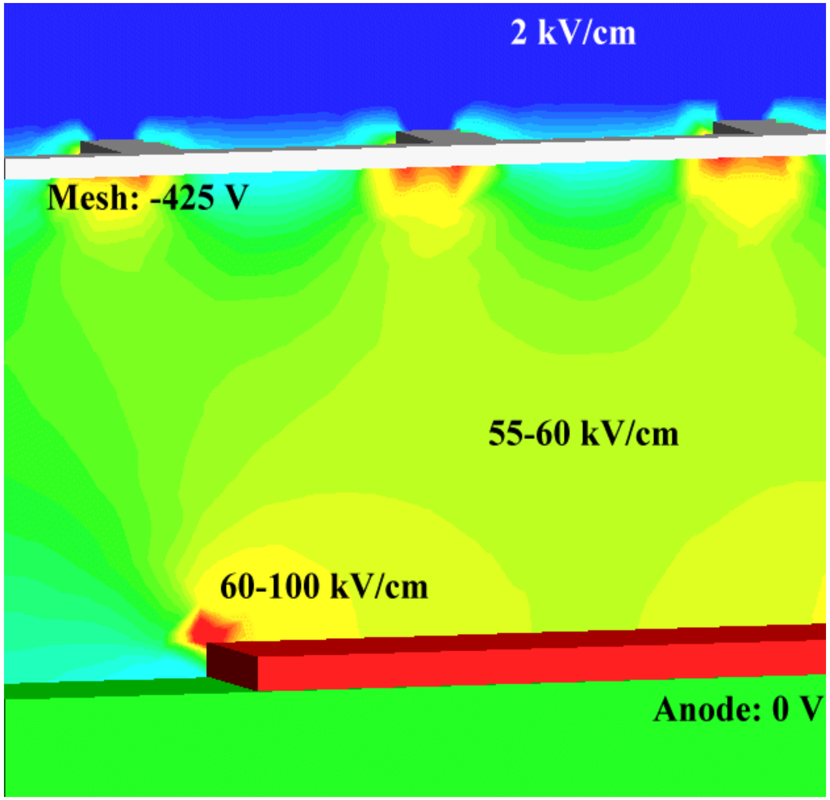
Thin kapton foil pierced with holes. The foil is metallised on both sides and a potential difference between the two sides gives an amplification of electrons up 1000 when traversing the hole in most common gases.

Thickness:	~ 50 μm
ΔV:	400 – 600 V
Hole Diameter:	~ 70 μm
Pitch:	~140 μm

• MICROMEGAS-thin gap parallel plate chamber [candidate technology for ATLAS small forward muon wheels in phase I upgrade]







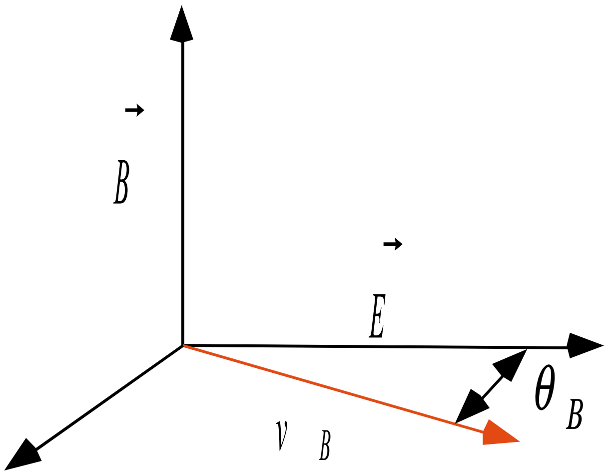
END LECTURE

Detector in magnetic field:

$\vec{E} \perp \vec{B}$

$$\tan\theta_B = \omega\tau$$

$$v_B = v_0 \frac{1+\omega\tau}{1+\omega^2\tau^2}$$



τ : mean collision time

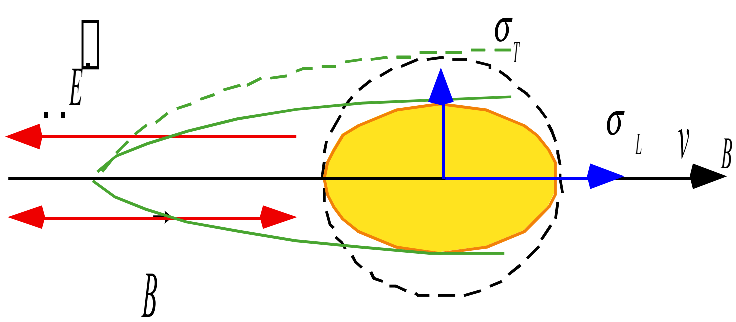
$\omega = eB/m$ Larmor frequency

$\vec{E} \parallel \vec{B}$

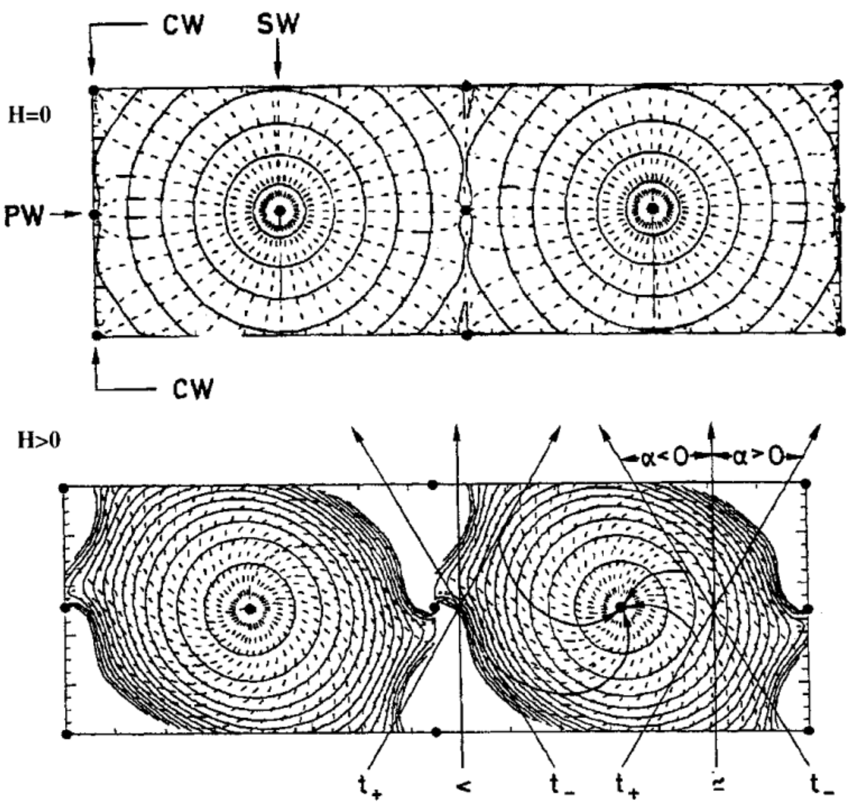
$$v_B = v_0$$

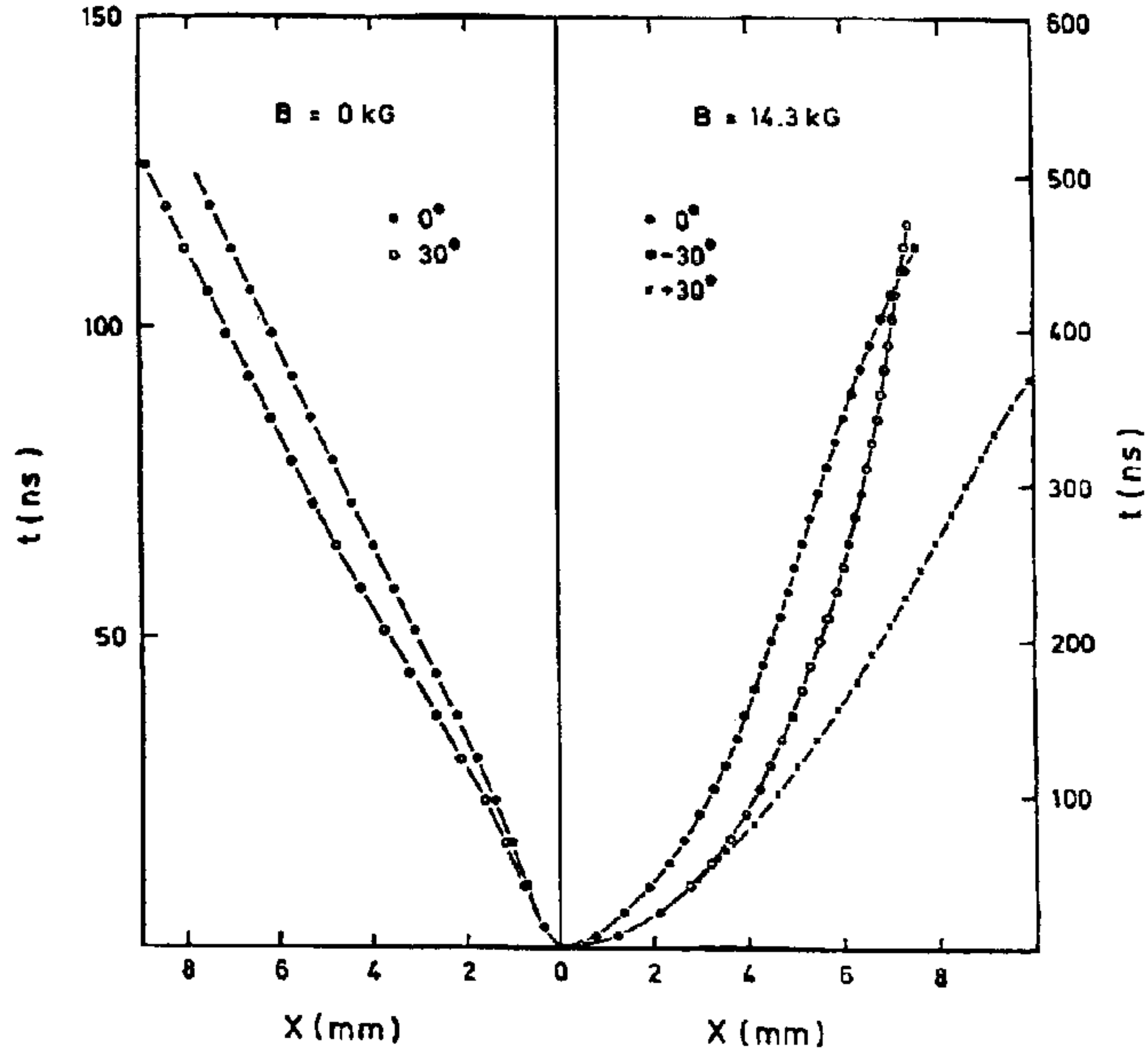
$$\sigma_L = \sigma_0$$

$$\sigma_T = \frac{\sigma_0}{\sqrt{1+\omega^2\tau^2}}$$



Magnetic field distortion of electric field in drift chambers





⇒The magnetic field will distort the position of the collected charge (cluster)