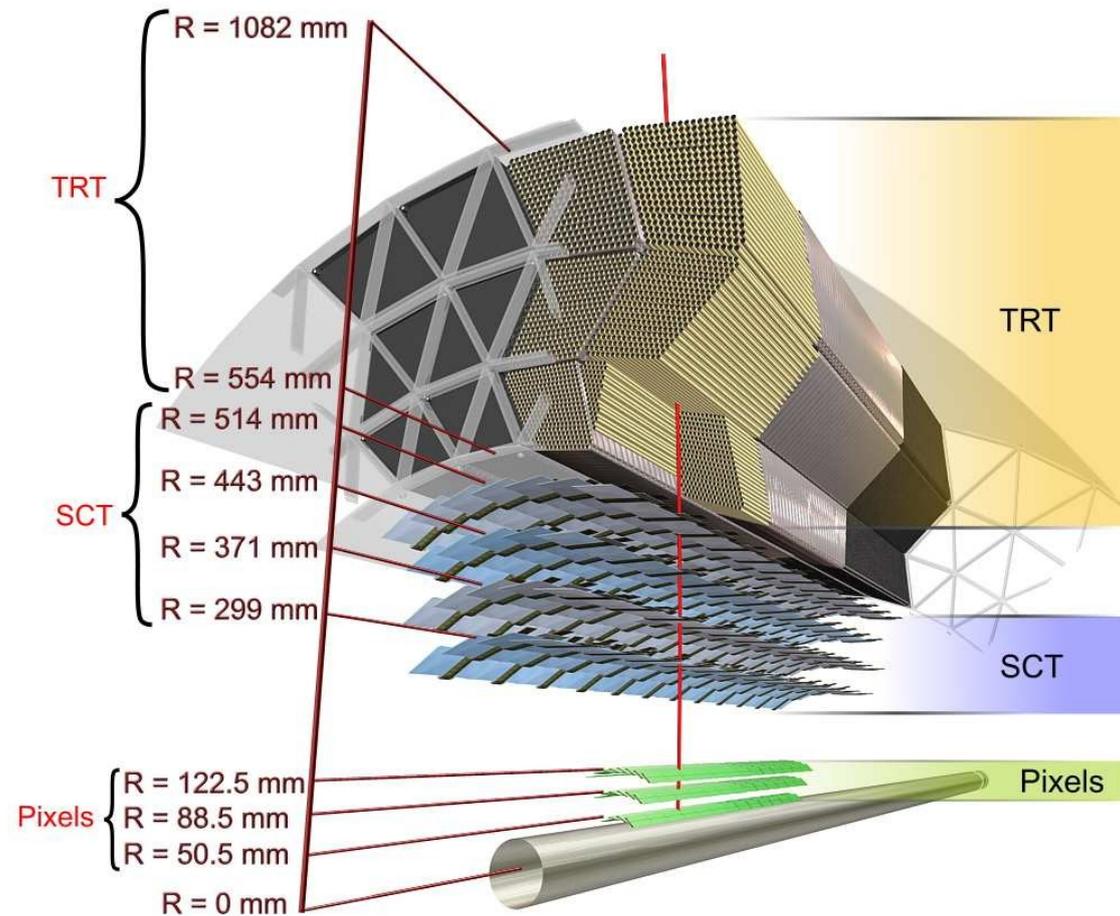


# TRACKING DETECTORS



# Lecture 1

## Basic considerations and gaseous detectors

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

**RADIATION DETECTION AND MEASUREMENT**

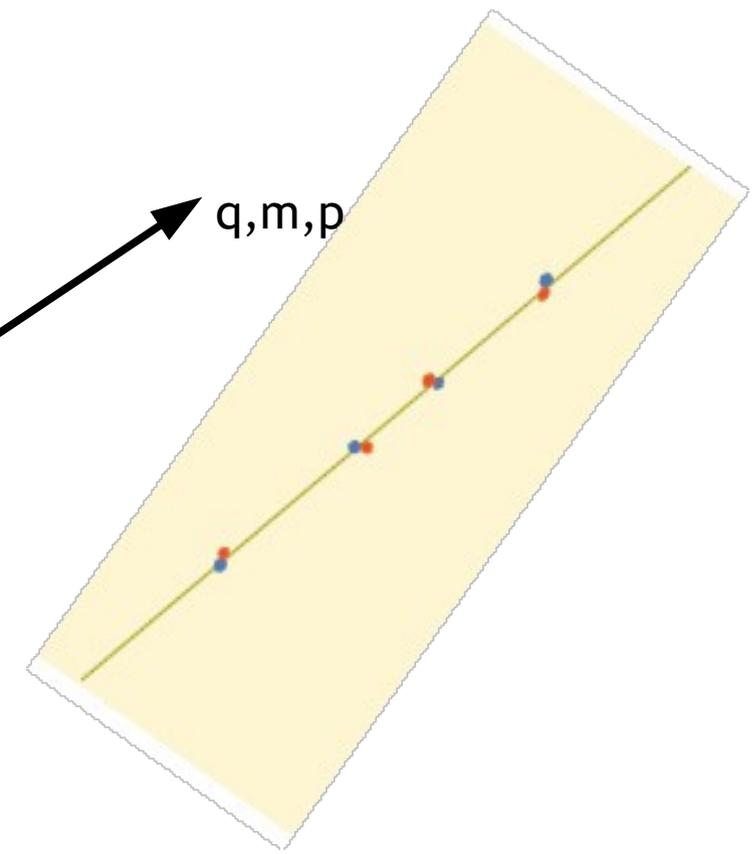
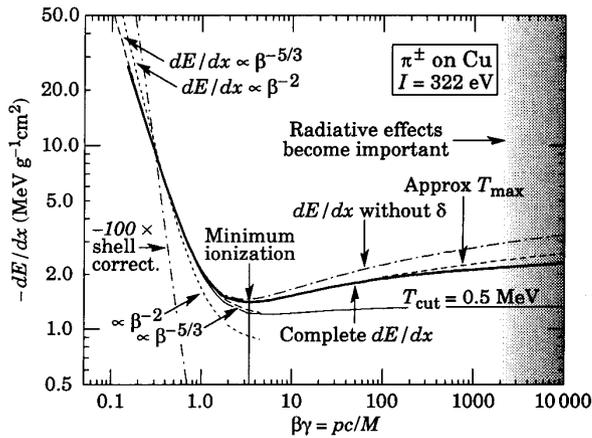
**Prof. Glenn Knoll, organizer**

**Short Courses November 10-11**

**2002 IEEE NSS/ MIC**

**Norfolk, November 10-16, 2002**

# Tracking volume filled with gas/semiconductor



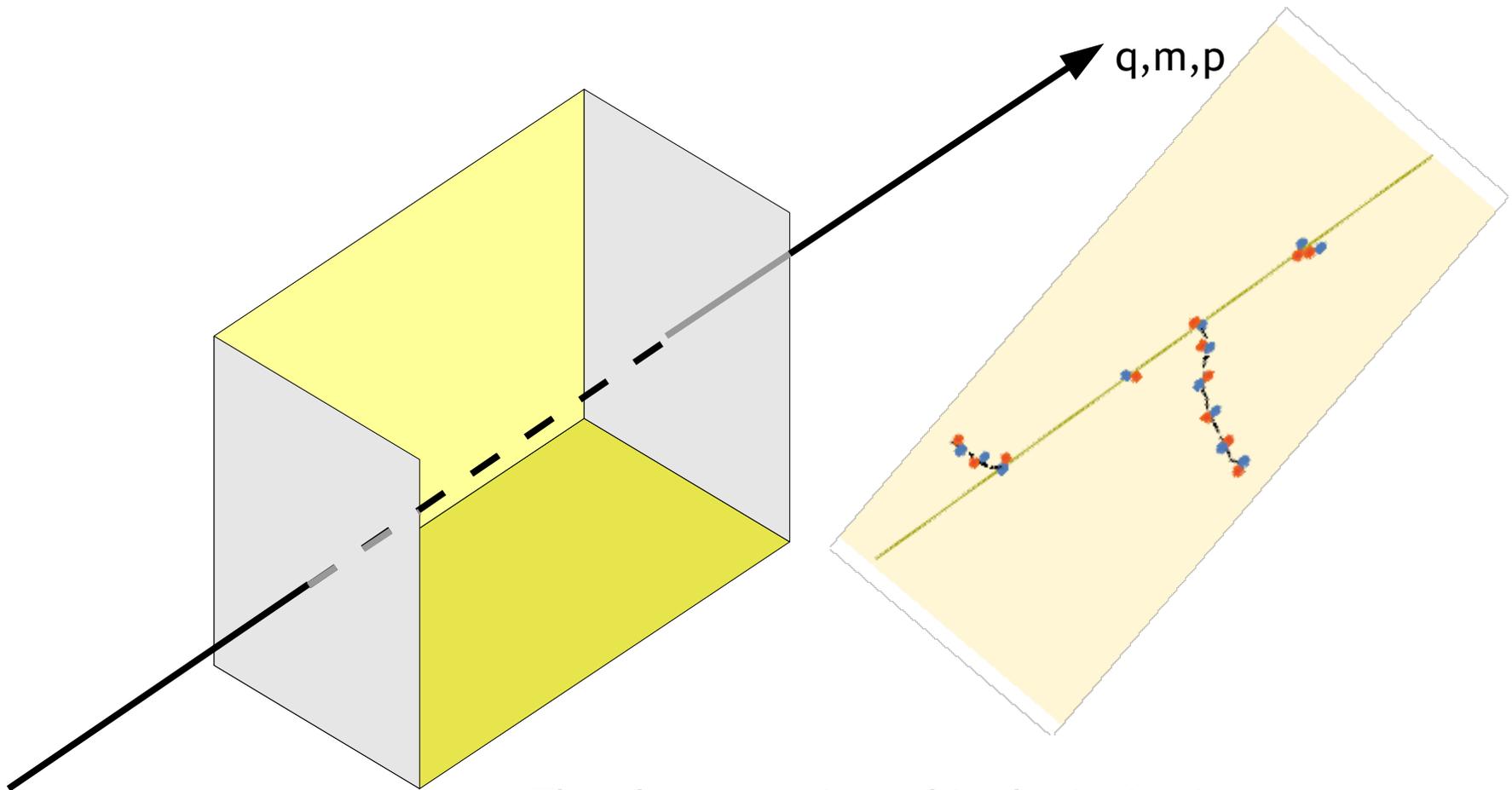
Primary ionisation follow Poisson statistics

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

n= average number  
k=actual number

GAS (STP)	Helium	Argon	Xenon	CH <sub>4</sub>	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

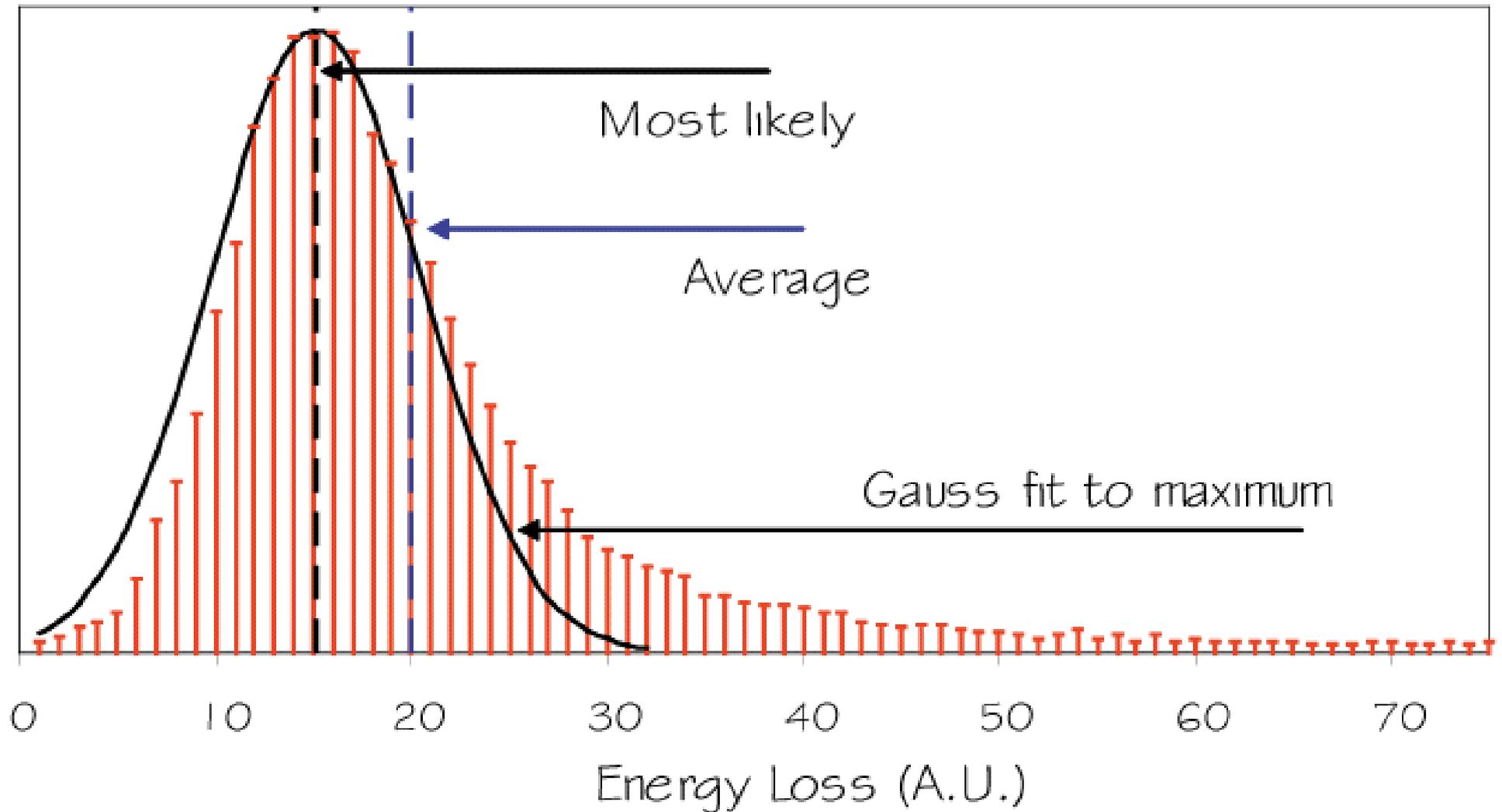
NOTE: Signal in gas detector is too small to be directly read out with amplifier. The thermal noise (kT) in the amplifier is higher!



The electrons ejected in the ionisation process have kinetic energy. These  $\delta$ -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

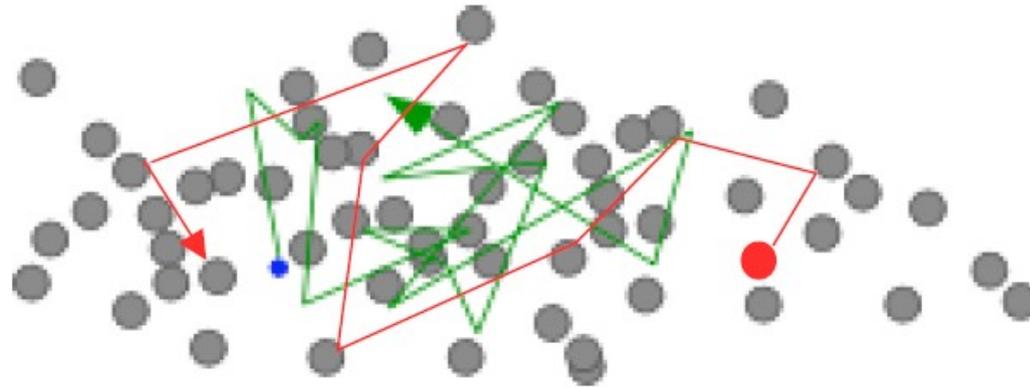
$$f(\lambda) = \sqrt{\frac{e^{-(\lambda + e^{-\lambda})}}{2\pi}}$$



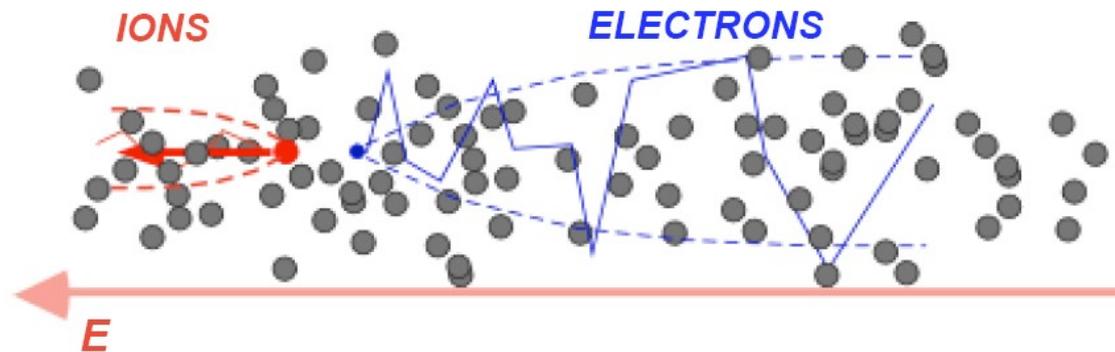
Some more considerations on detecting charge

.....

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

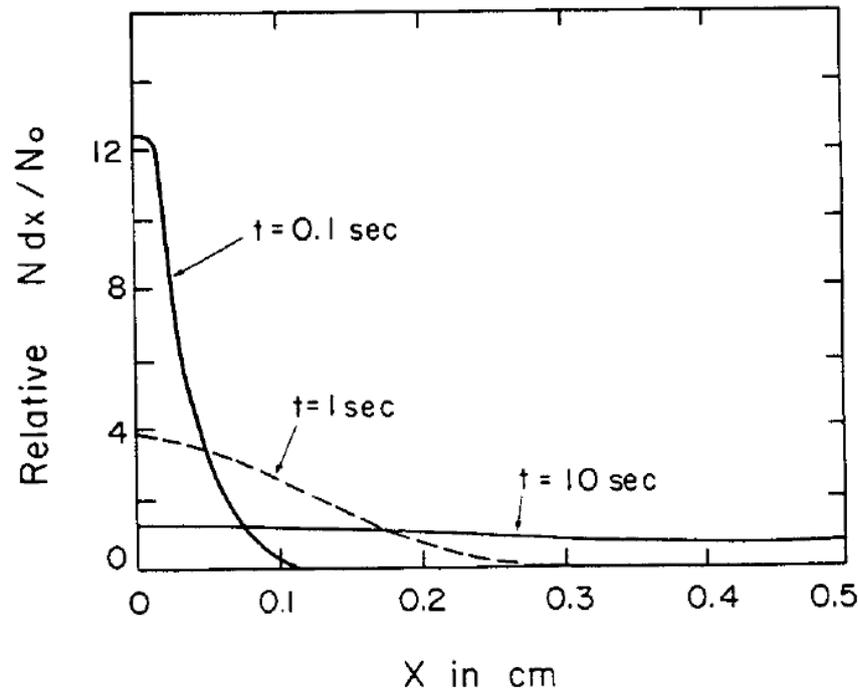


Diffusion equation gives the fraction of ions at a distance x at a given time t

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

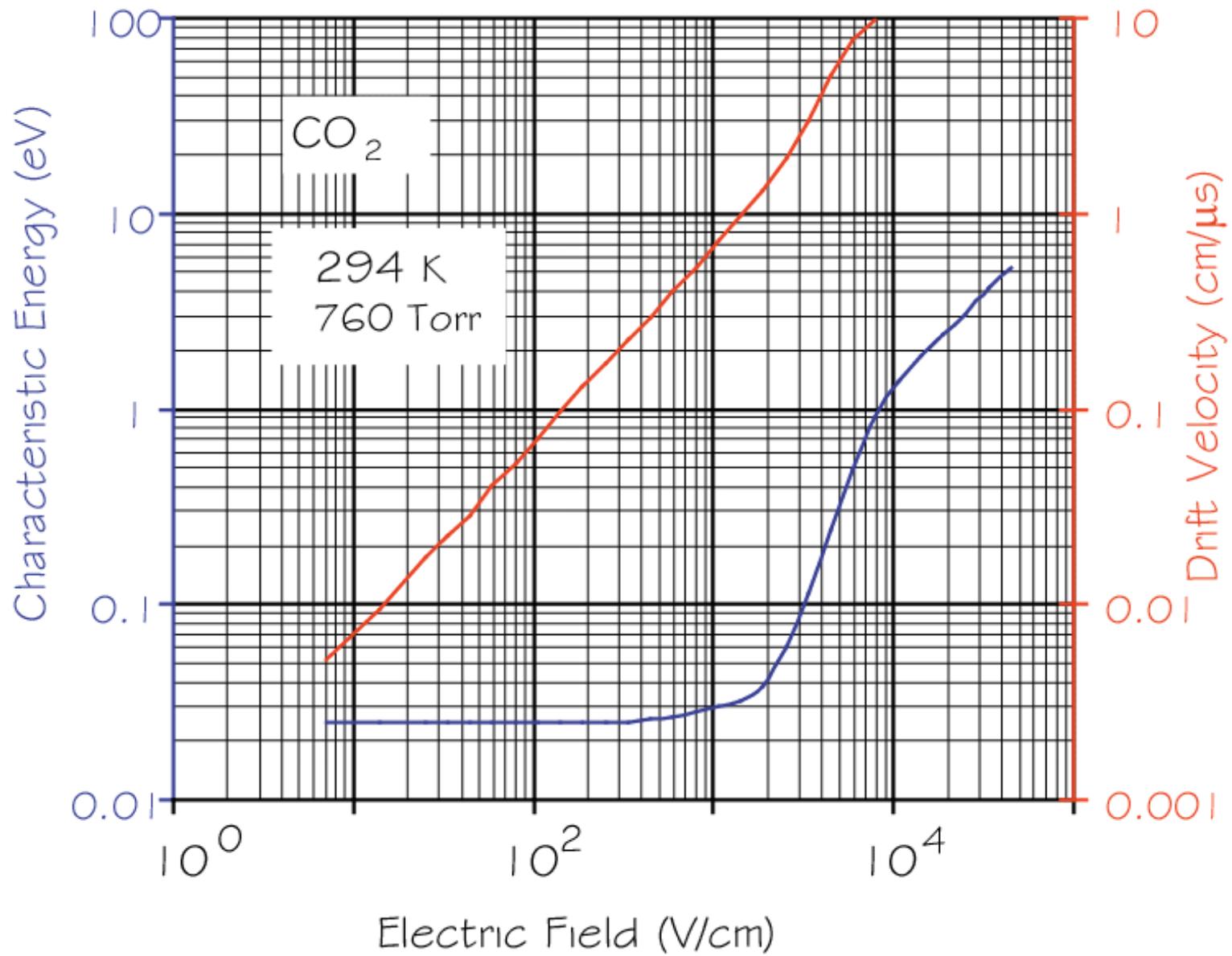
, where D is the diffusion coefficient

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



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

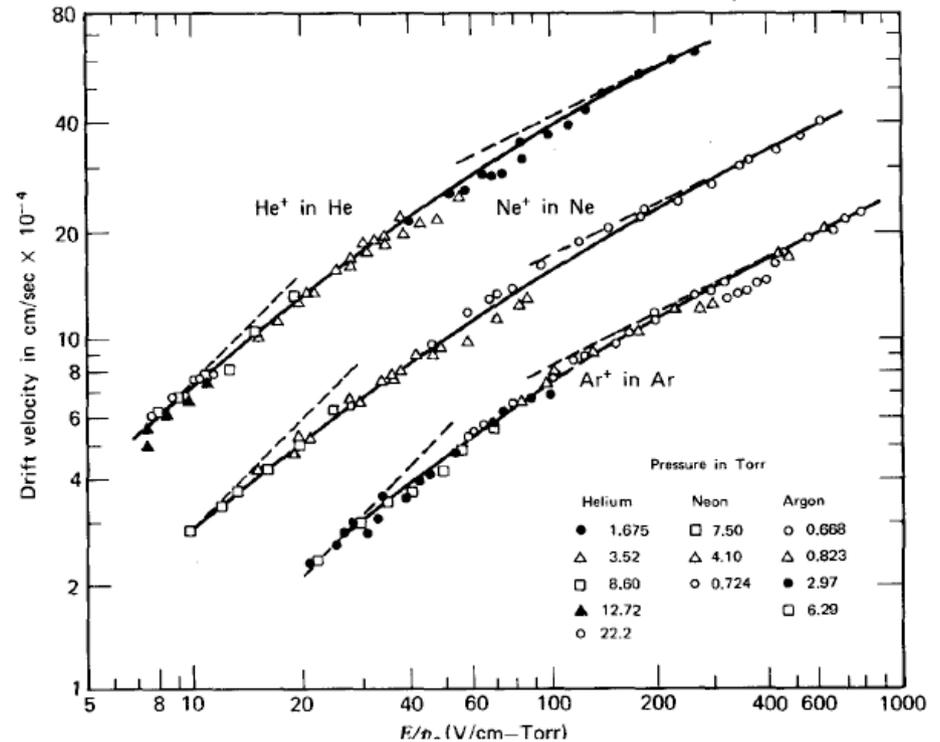
# Drift of electrons in an electric field



Drift of positive ions is much slower than electrons. In  $\text{CO}_2$  the difference is about 1000  
 The drift speed is almost linear with the electric field.

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

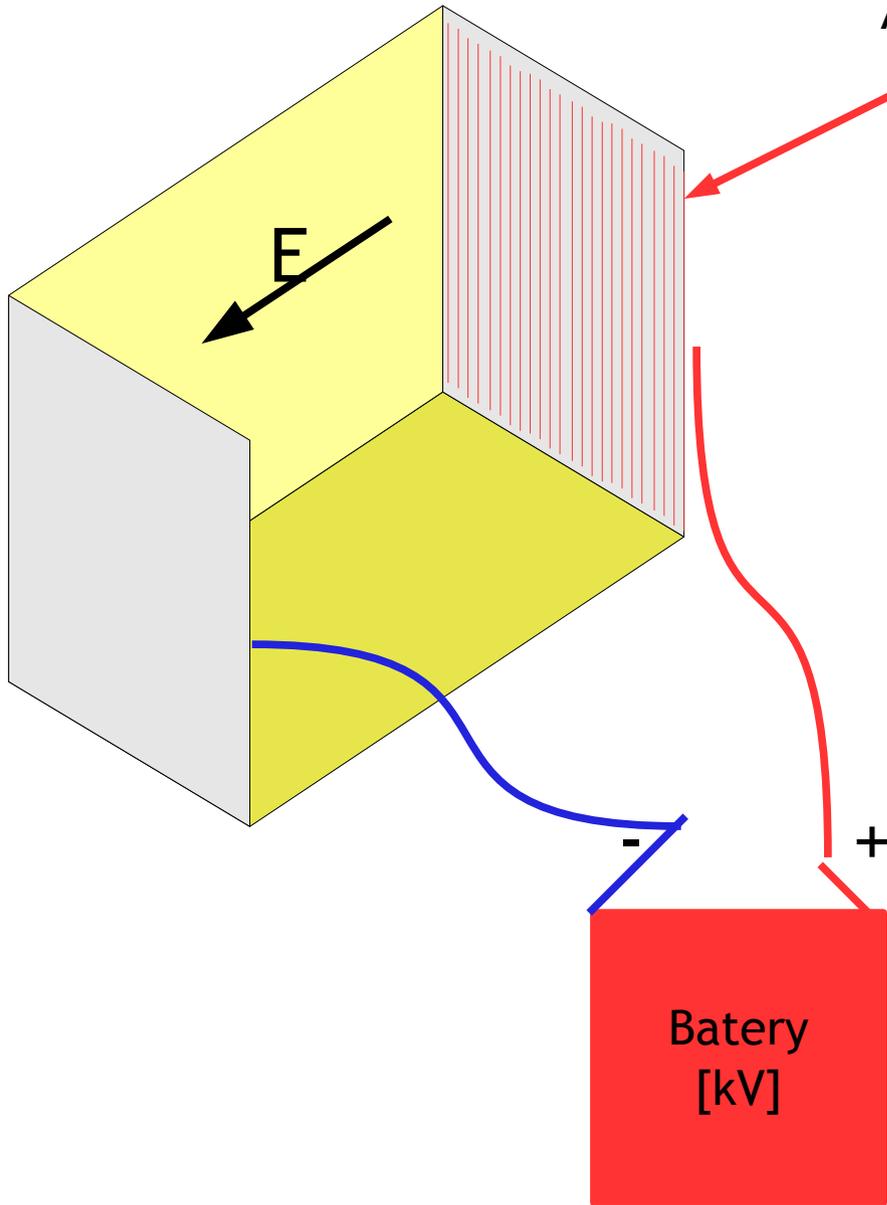
GAS	ION	$\mu^+$ ( $\text{cm}^2 \text{V}^{-1} \text{s}^{-1}$ ) @STP
Ar	$\text{Ar}^+$	1.51
$\text{CH}_4$	$\text{CH}_4^+$	2.26
Ar- $\text{CH}_4$ 80-20	$\text{CH}_4^+$	1.61



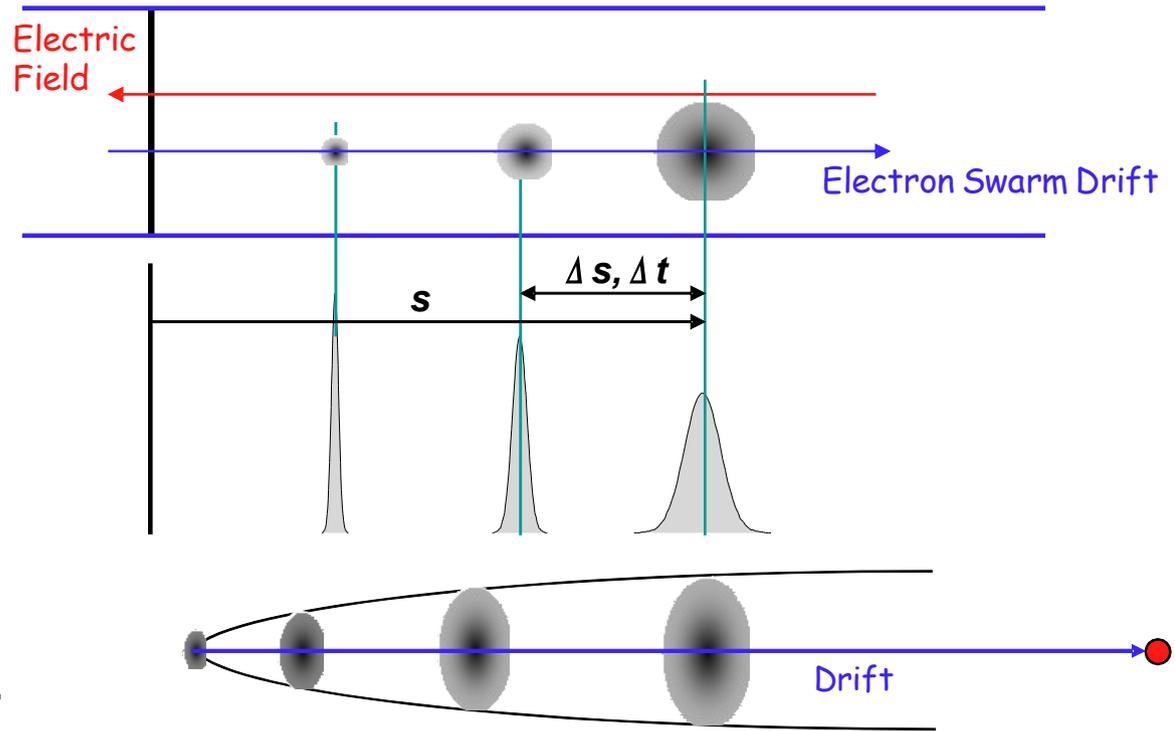
Now lets build a gas filled detector

.....

# Build a wire chamber



Anode wires, radius 10-100  $\mu\text{m}$   
material gold plated tungsten



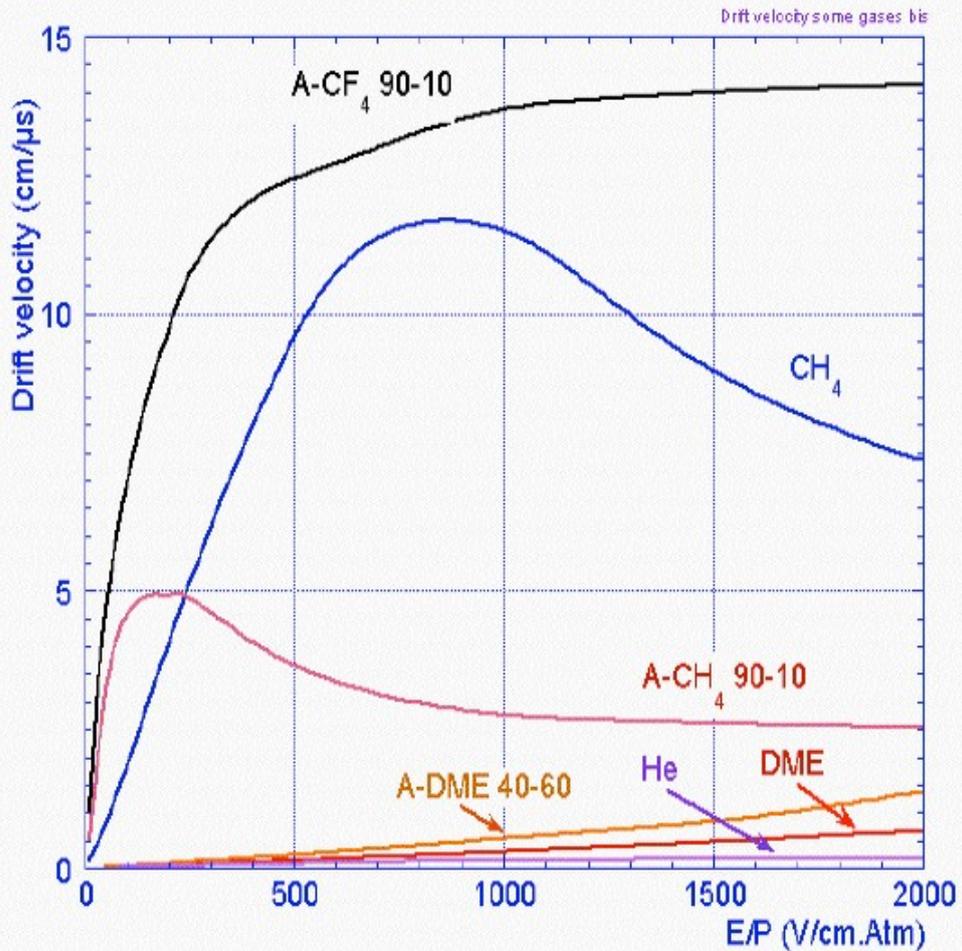
Drift velocity  $w = \frac{\Delta S}{\Delta t}$

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

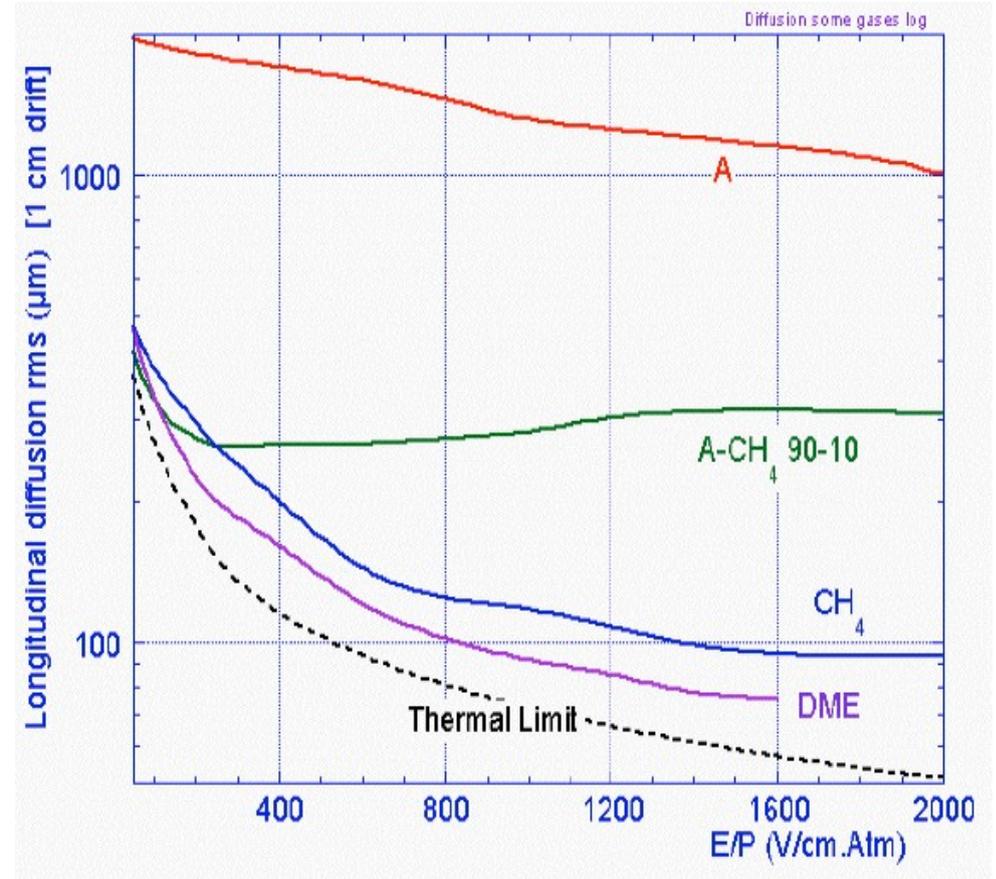
$\sigma_x = \sigma_1 \sqrt{x}$



## DRIFT VELOCITY:



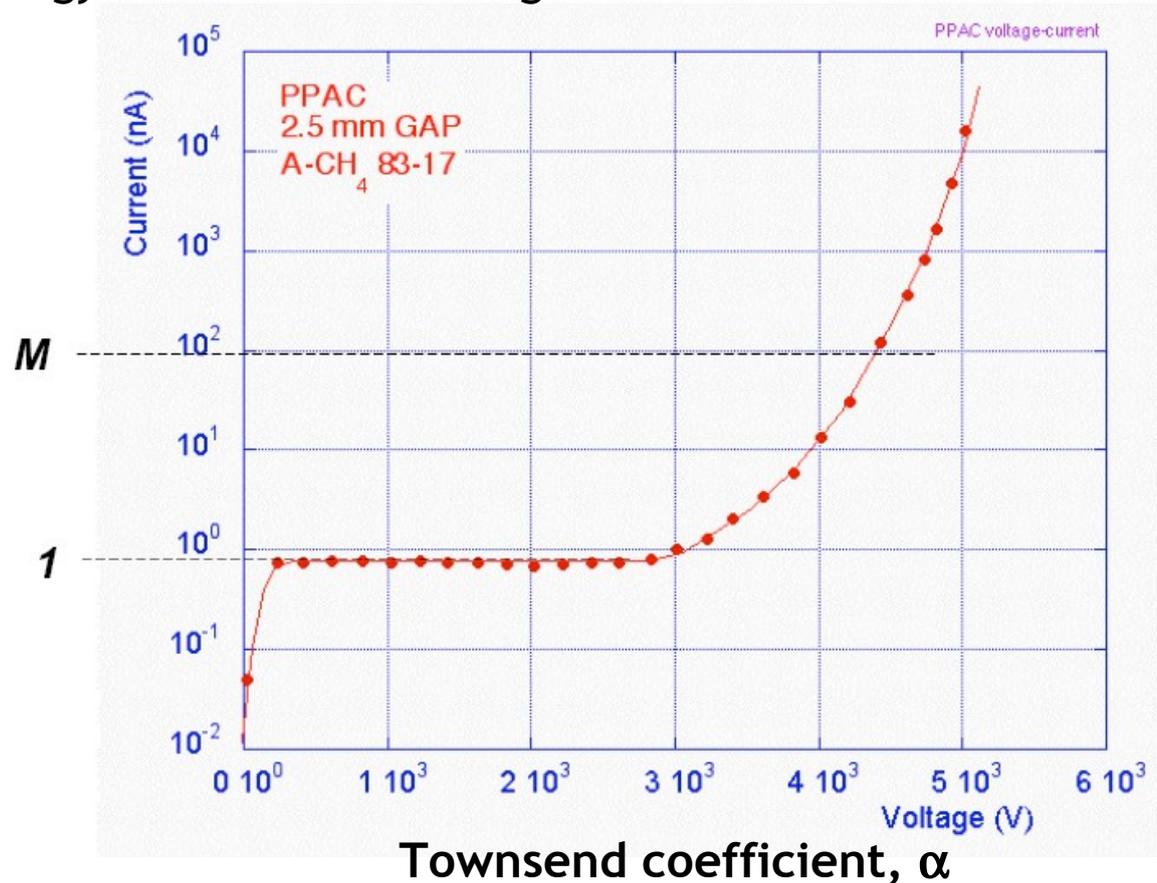
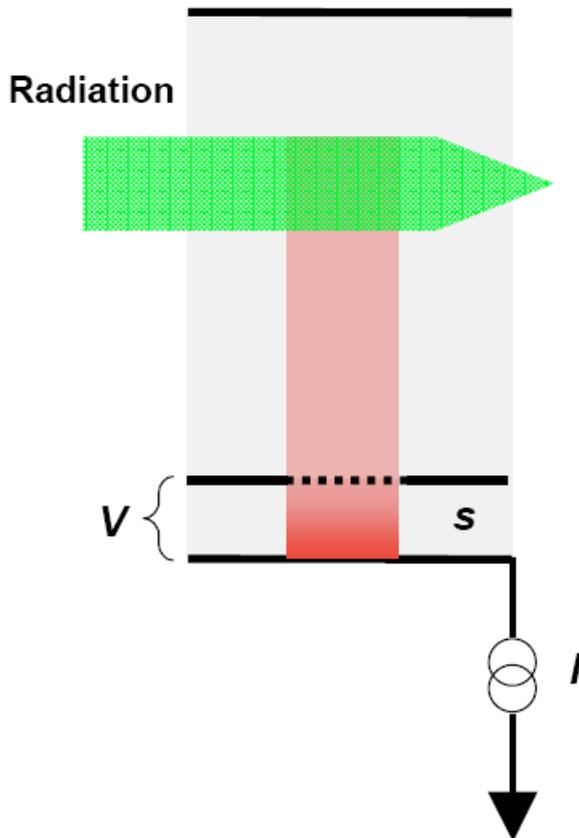
## DIFFUSION:



# 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:

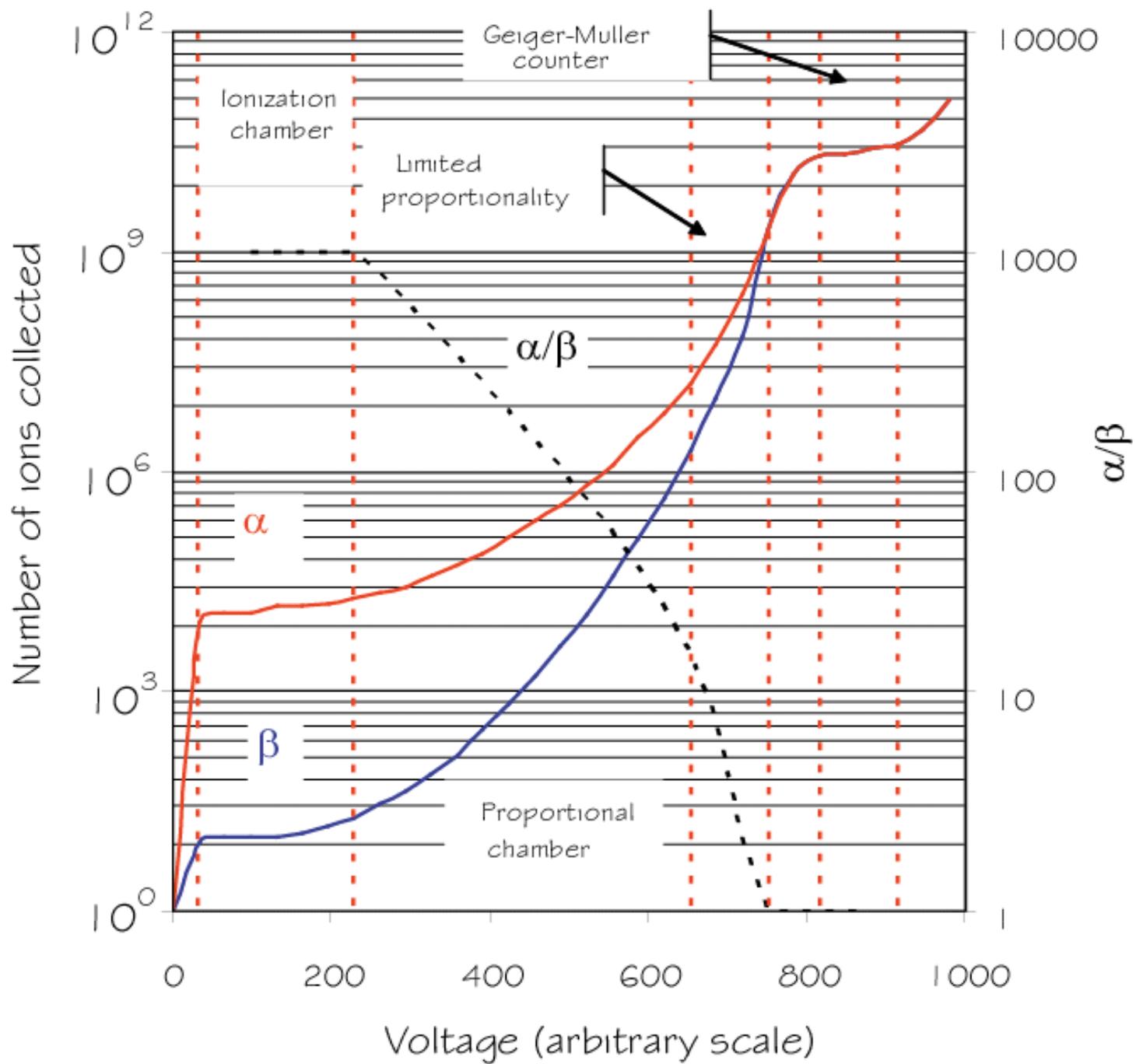


$$\alpha = \frac{\ln M}{s}$$

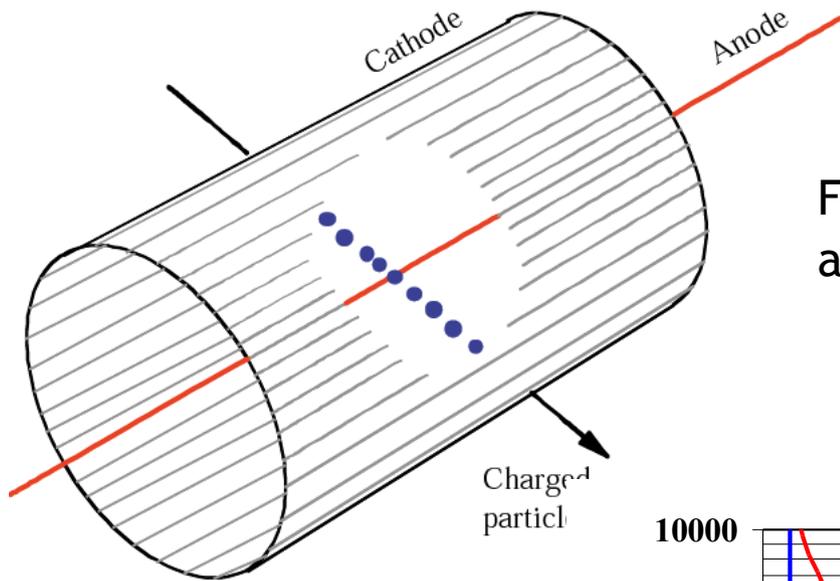
M = multiplication factor

$$\alpha = \frac{1}{\lambda} \quad \text{ionising collisions/cm}$$

$$\lambda = \frac{1}{N\sigma} \quad N = \text{molecules/cm}^3$$

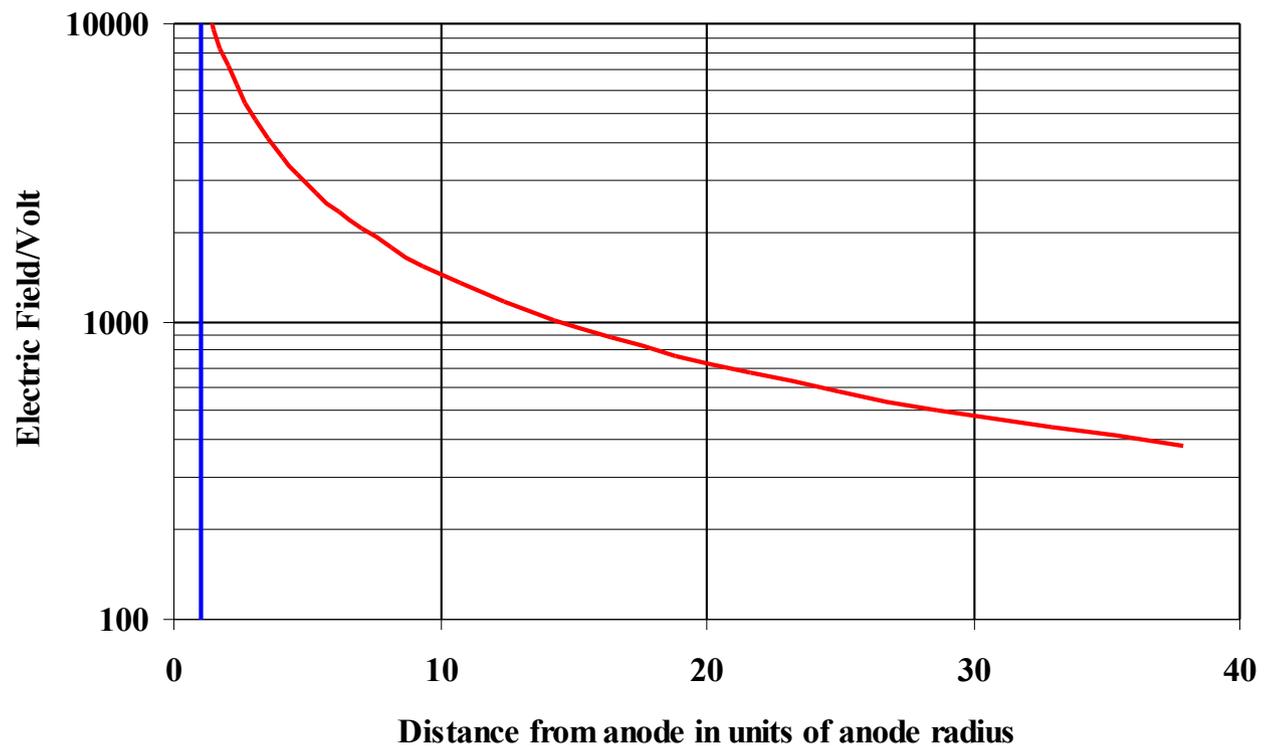


High field is also developed near the anode wire-for a simple geometry e.g. a straw tube



For a cylinder with radius  $R$  and anode wire radius  $r_0$  ( $\sim 10\mu\text{m}$ ):

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



# Avalanche development in a plate chamber with uniform field

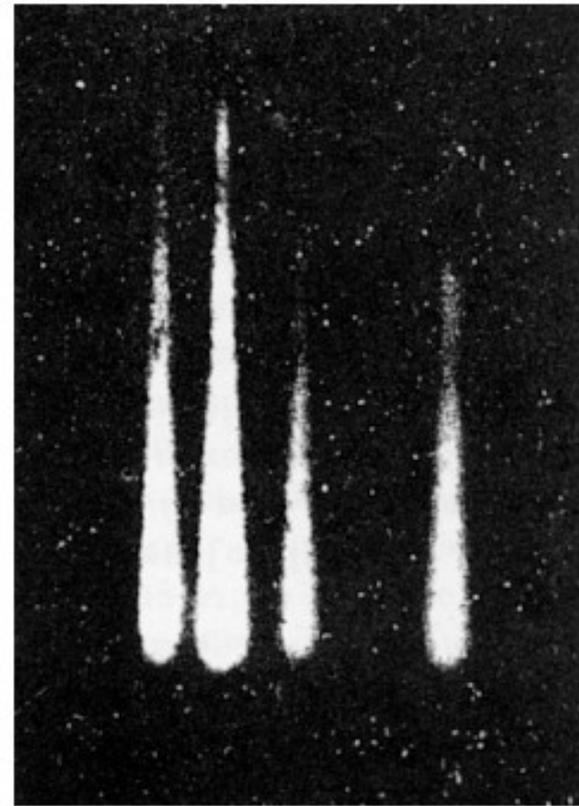
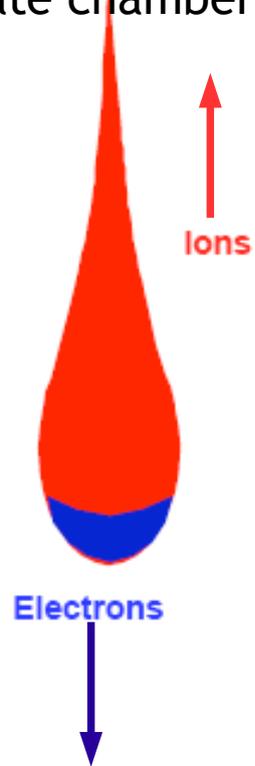
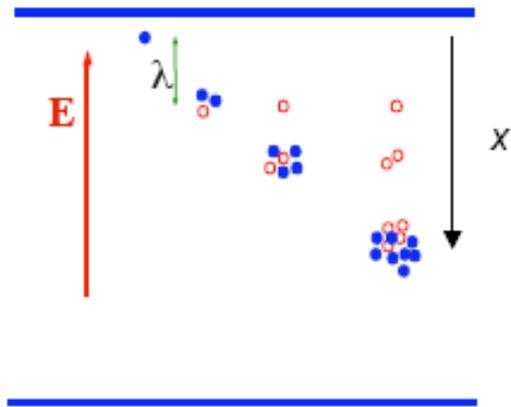


image from cloud-avalanche chamber

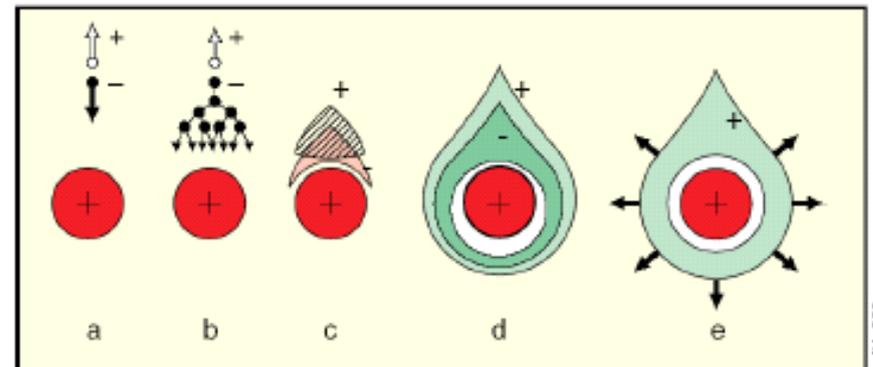
$$dn = n \alpha dx$$

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

Multiplication factor (gain)

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

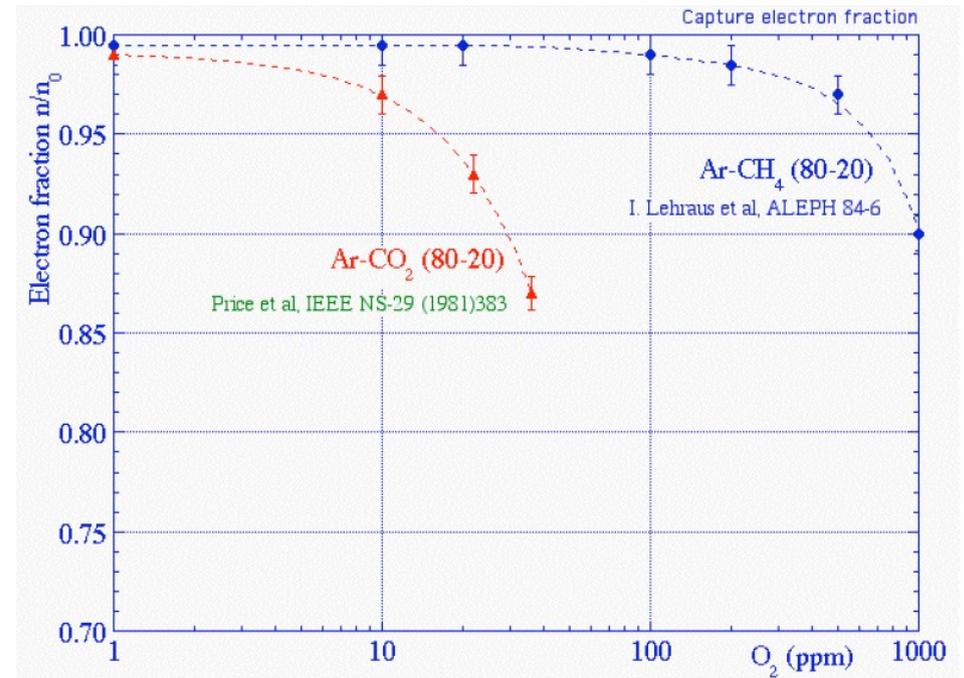
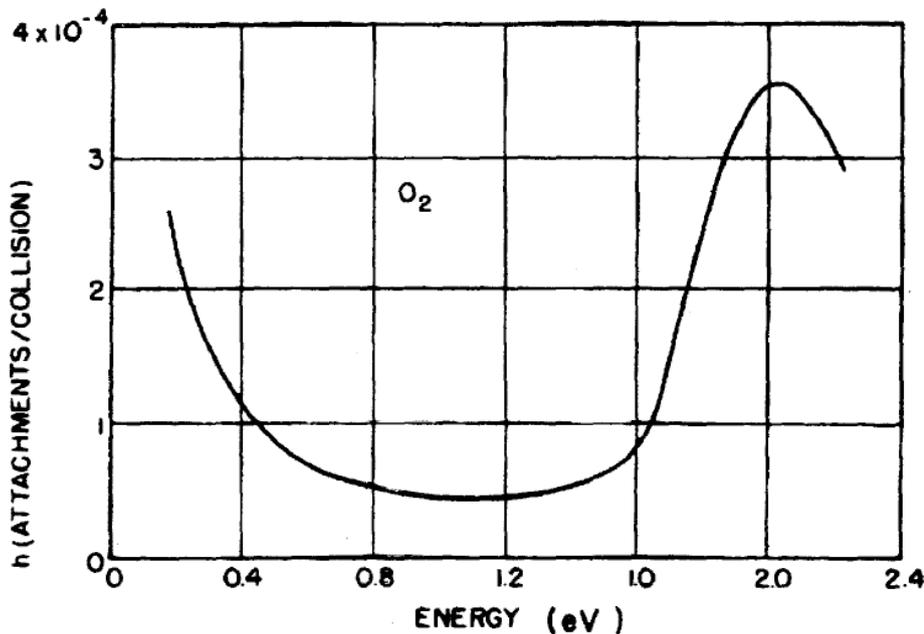
## Development of avalanche close to the anode wire



# 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.

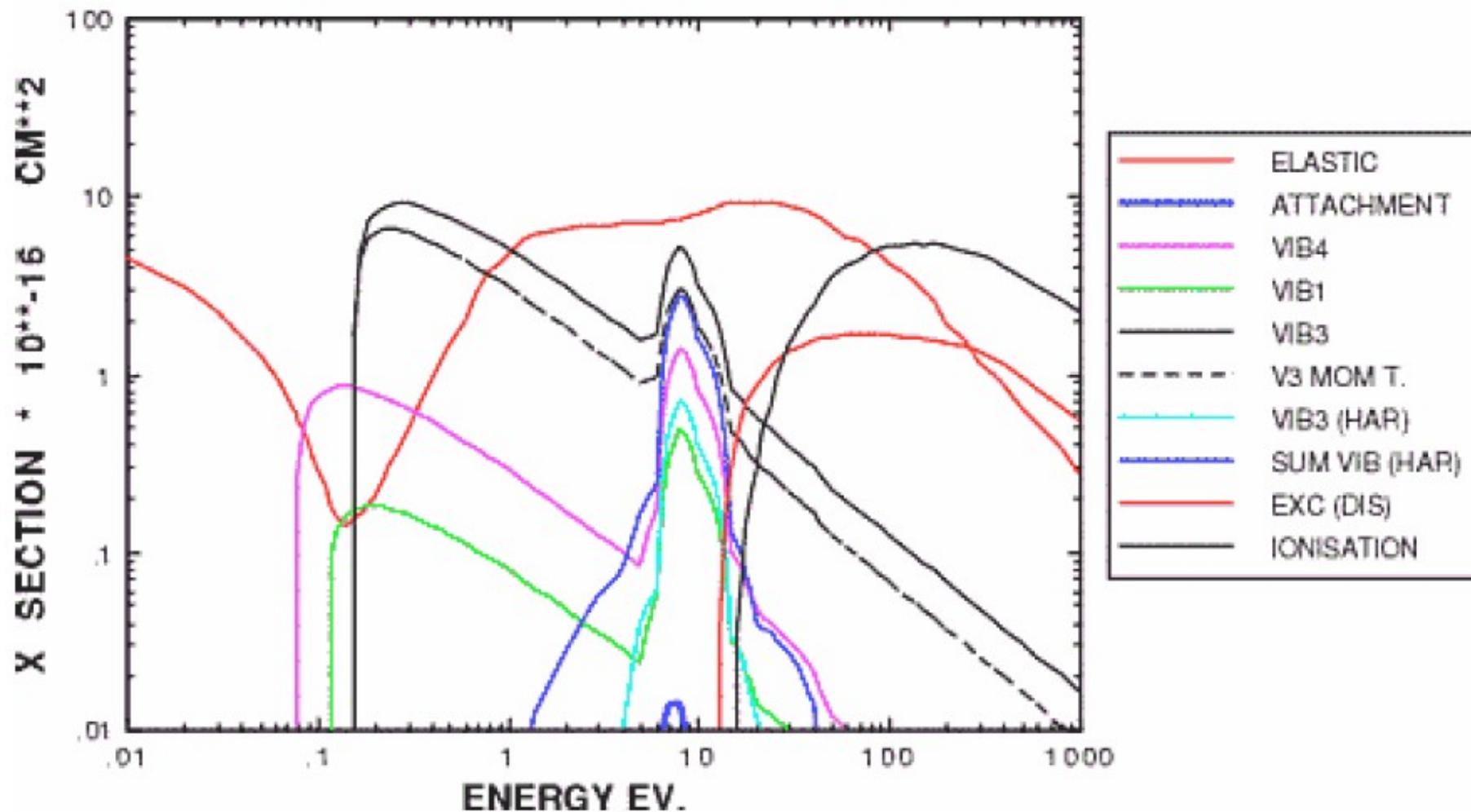
2: An other problem is that noble gases emit photons above the ionisation threshold of other molecules. Poly-atomic gases works as quenchers absorbing the photons.



Oxygen has a good electron capture cross-section  $\Rightarrow$  why not use  $CO_2$

CF4 is a good quenching gas

CF4 (2001)

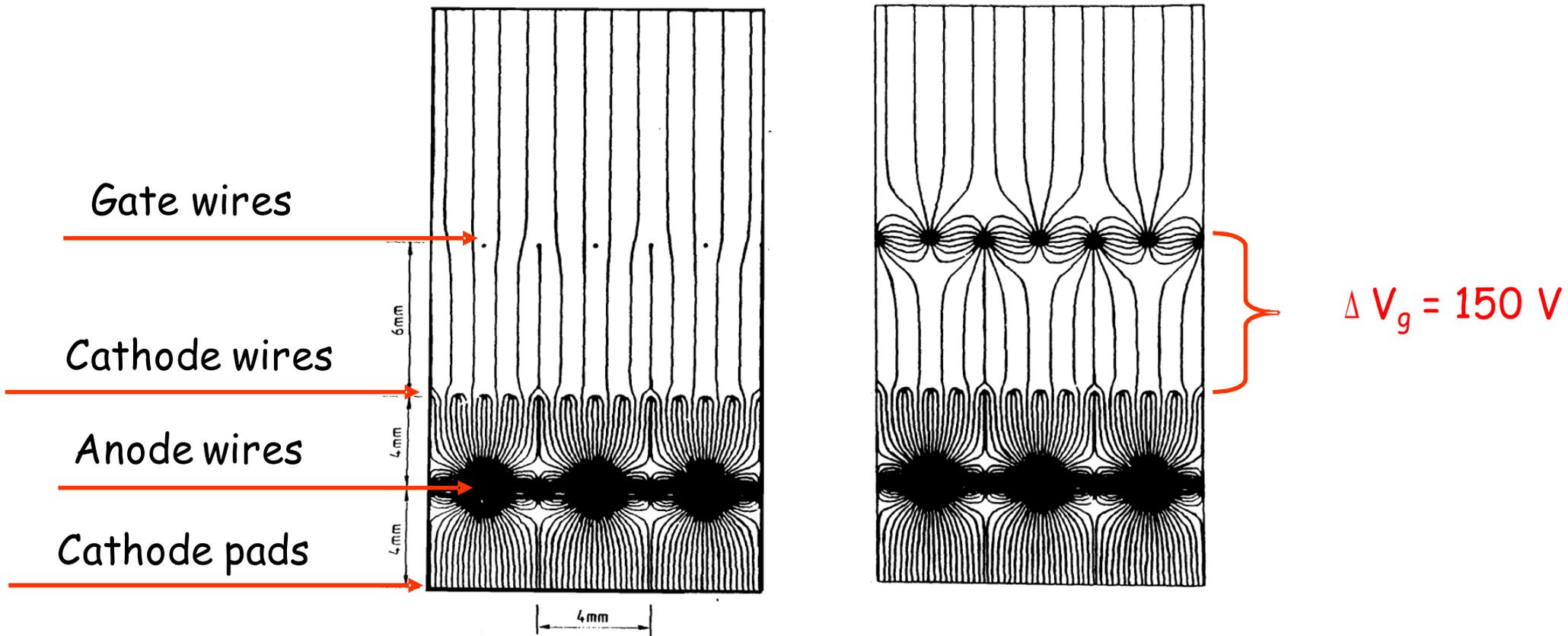


And now some more realistic detector  
designs .....

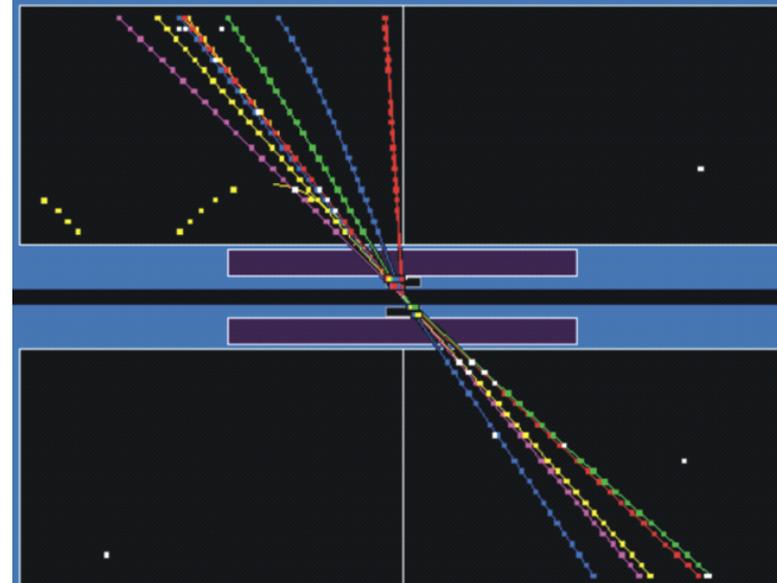
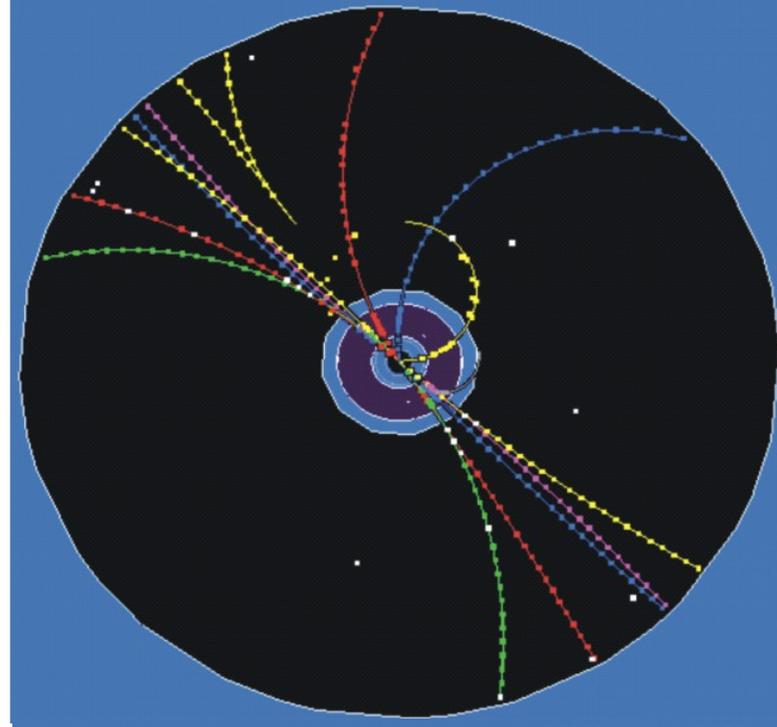
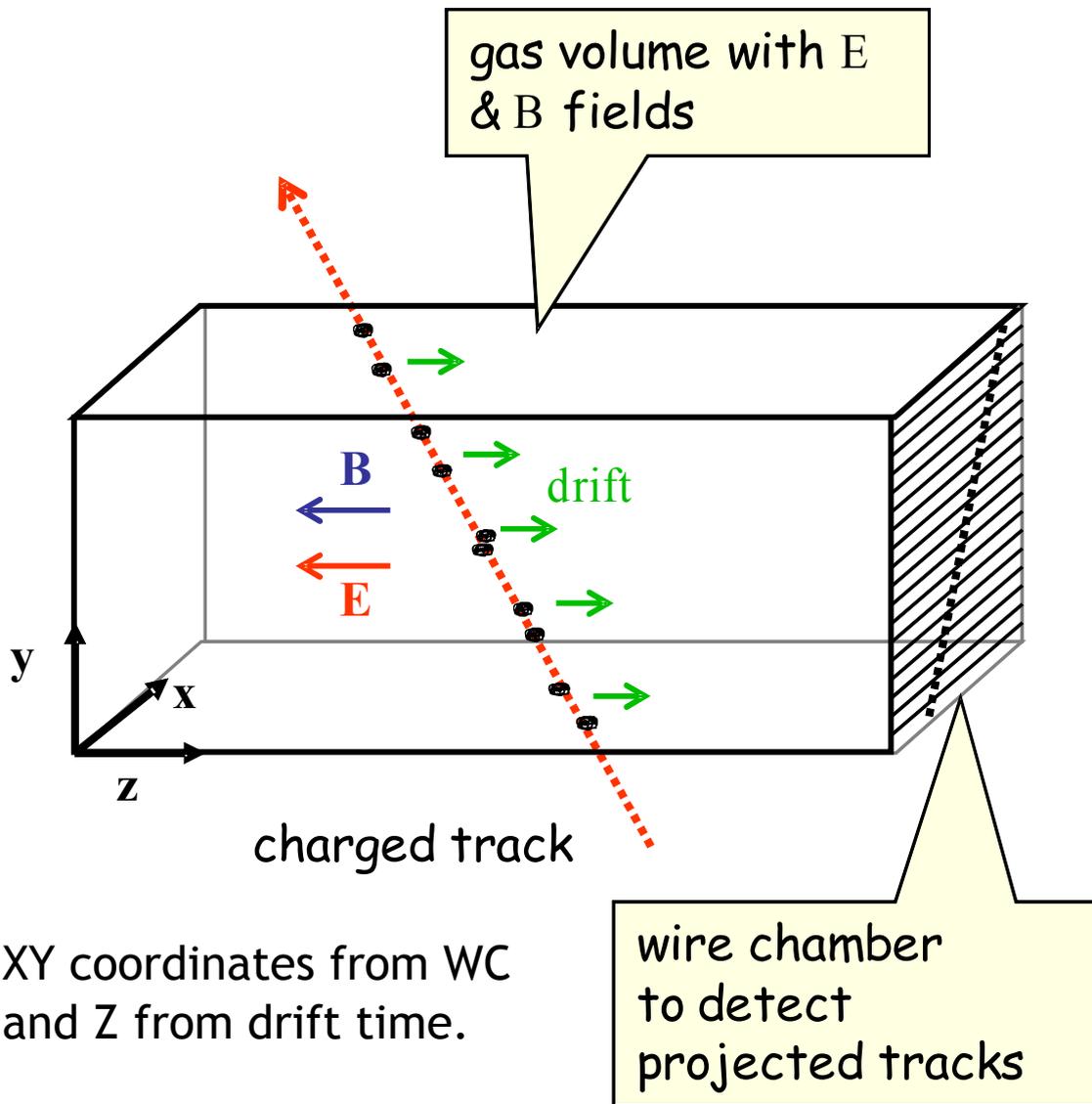
- 1: Split the drift chamber in a low field drift volume and a high field amplification volume
- 2: To control and reduce the drift time and accumulated space charge of slow positive ions one may use gating techniques.

Gate open

Gate closed

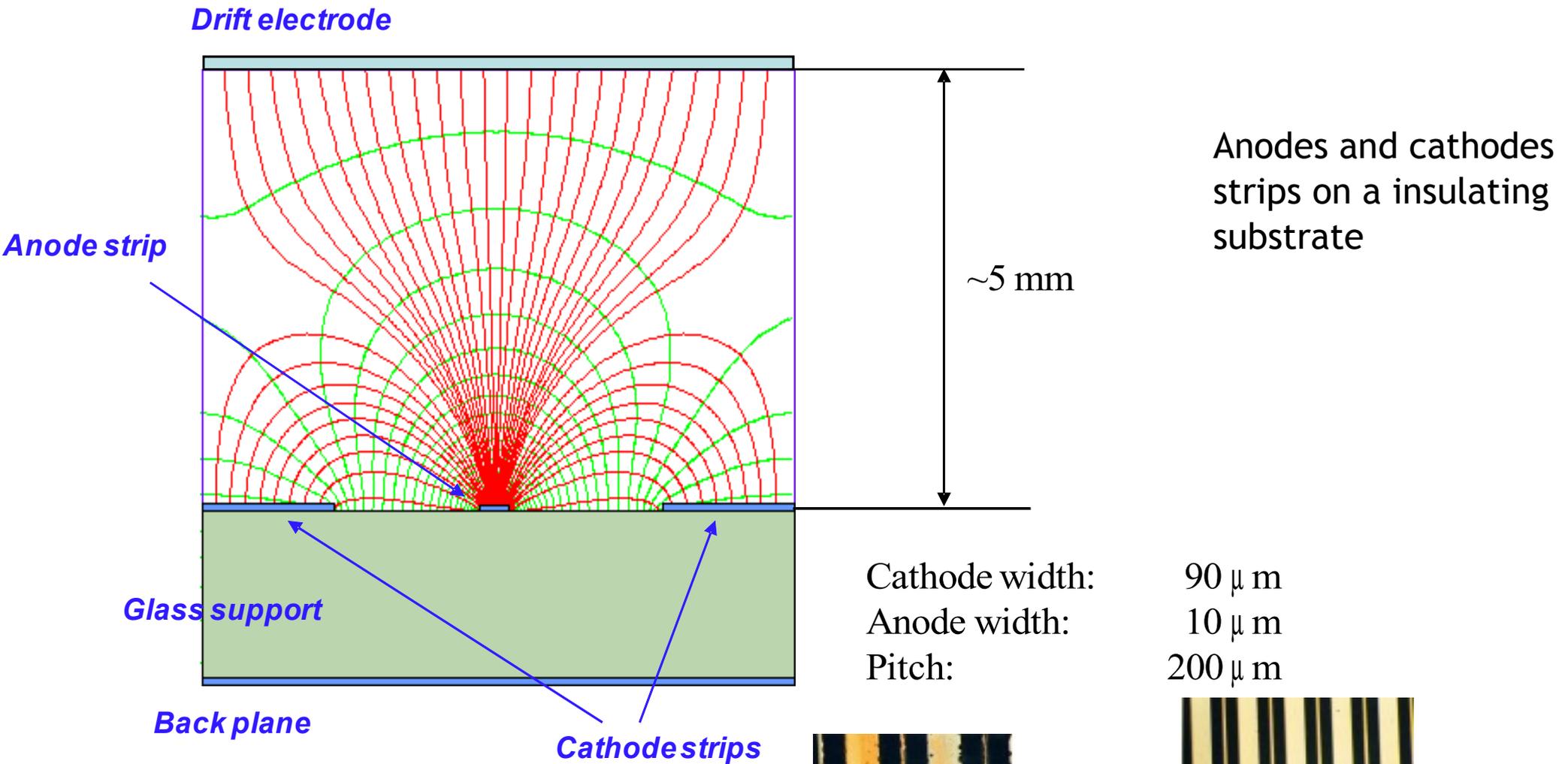


The Time Projection Chamber (TPC) is the ultimate tracking detector giving 3D space points (and  $dE/dx$ ) for track reconstruction and adding little mass in tracking volume keeping multiple scattering small.

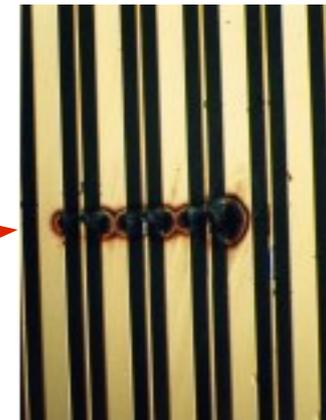


# High resolution gaseous detectors for tracking are:

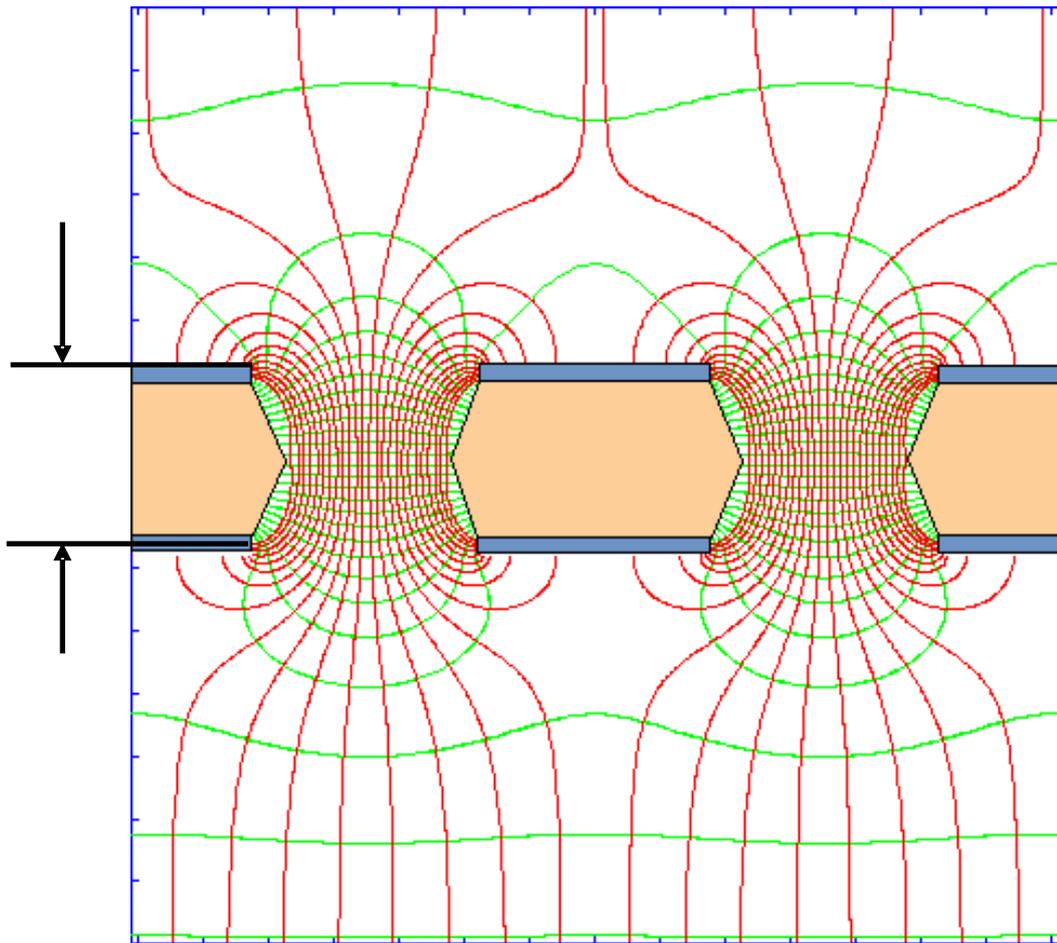
- Micro-Strip Gas Chambers (MSGC), baseline technology for outer tracker in CMS TDR



SPARK!



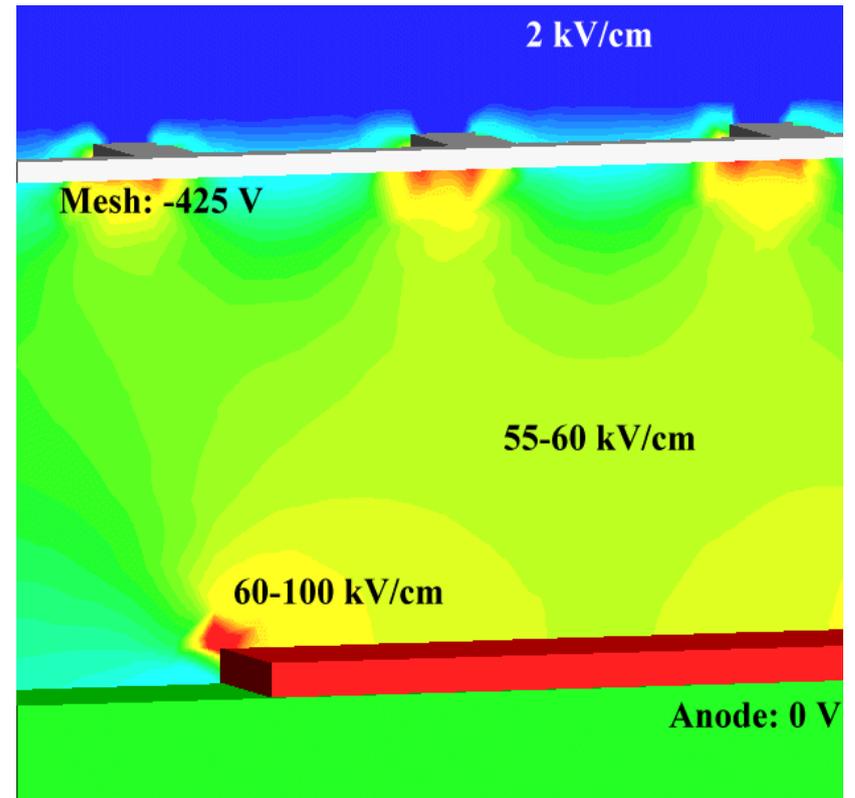
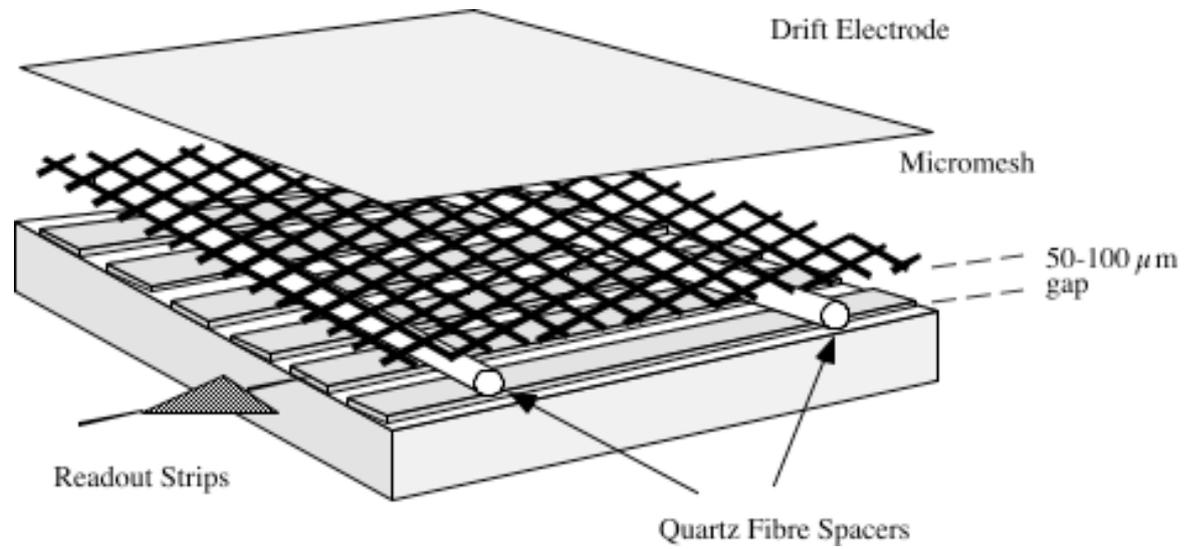
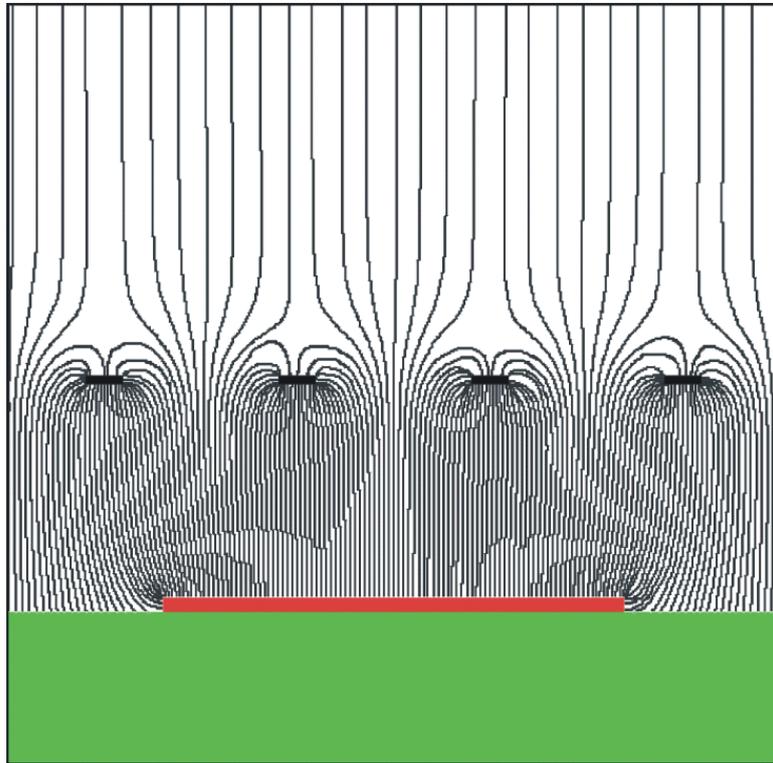
•Gas Electron Multiplier (GEM)



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:	$\sim 50 \mu\text{m}$
$\Delta V$ :	400 - 600 V
Hole Diameter:	$\sim 70 \mu\text{m}$
Pitch:	$\sim 140 \mu\text{m}$

- MICROMEAS-thin gap parallel plate chamber



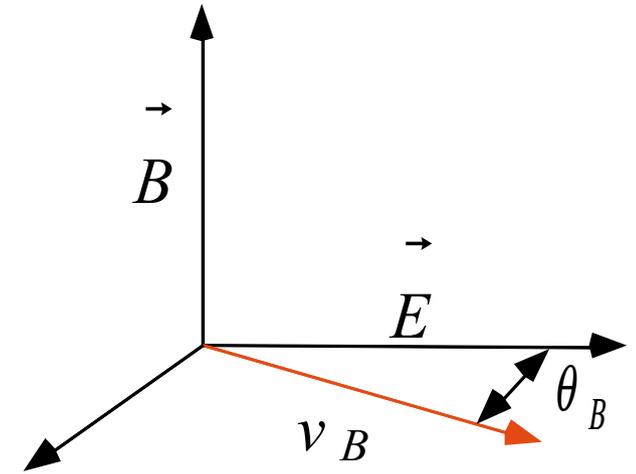
**END LECTURE**

# Detector in magnetic field:

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

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

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



$\tau$  : mean collision time

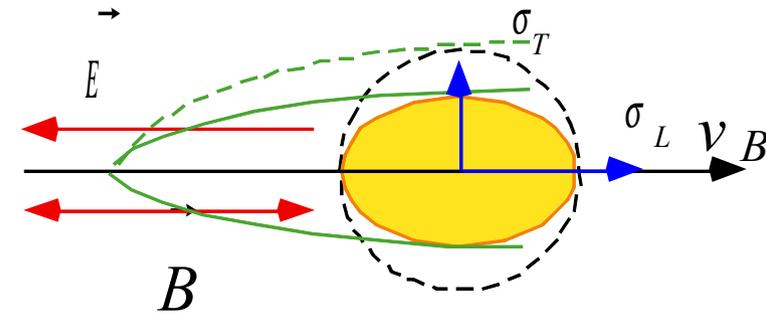
$\omega = e B / m$  Larmor frequency

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

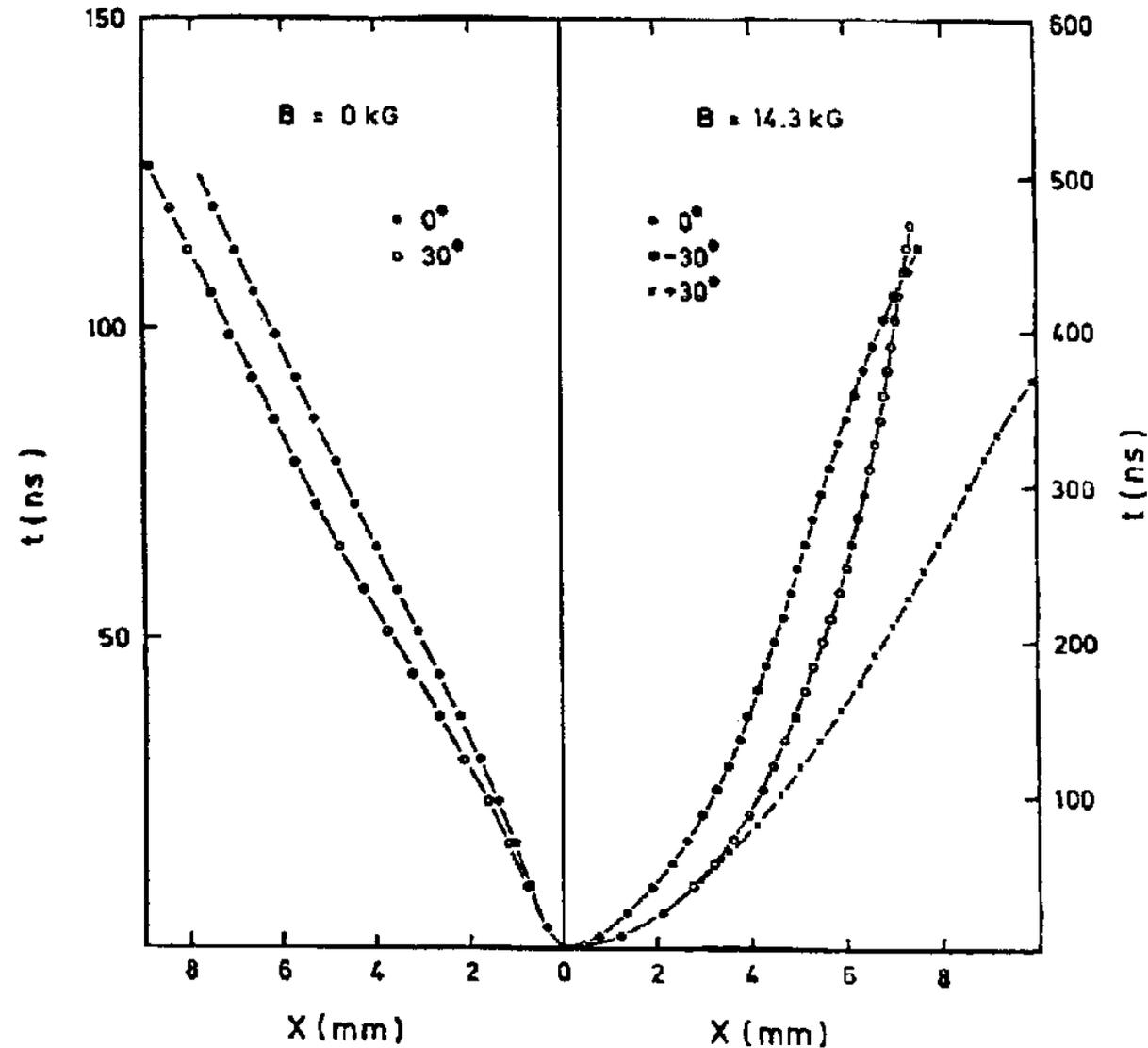
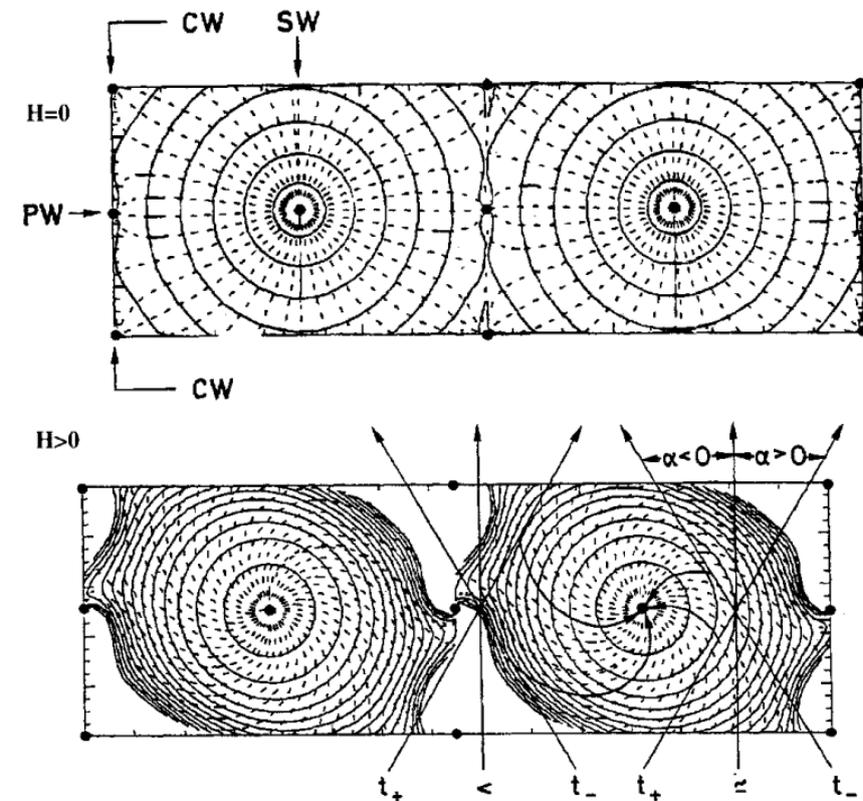
$$v_B = v_0$$

$$\sigma_L = \sigma_0$$

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



# Magnetic field distortion of electric field in drift chambers



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