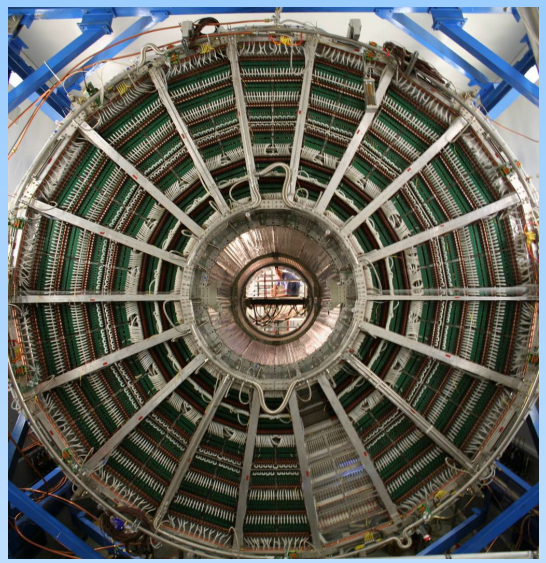
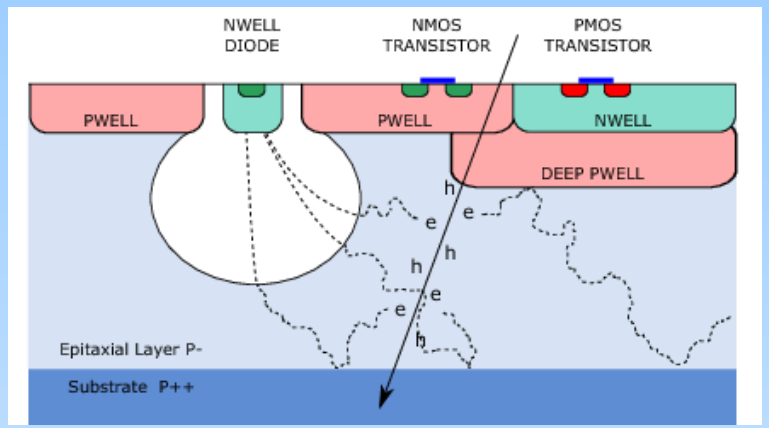




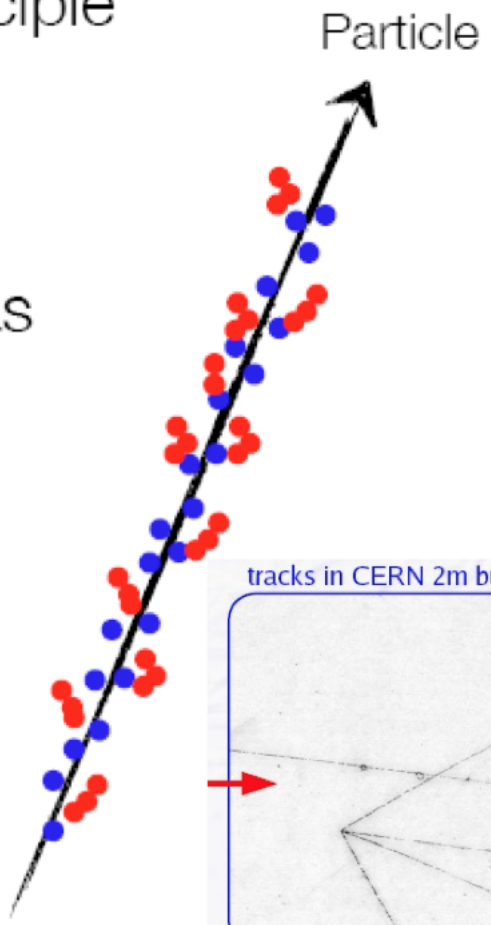
Gaseous detectors - 1

Silvia Masciocchi,
GSI and University of Heidelberg

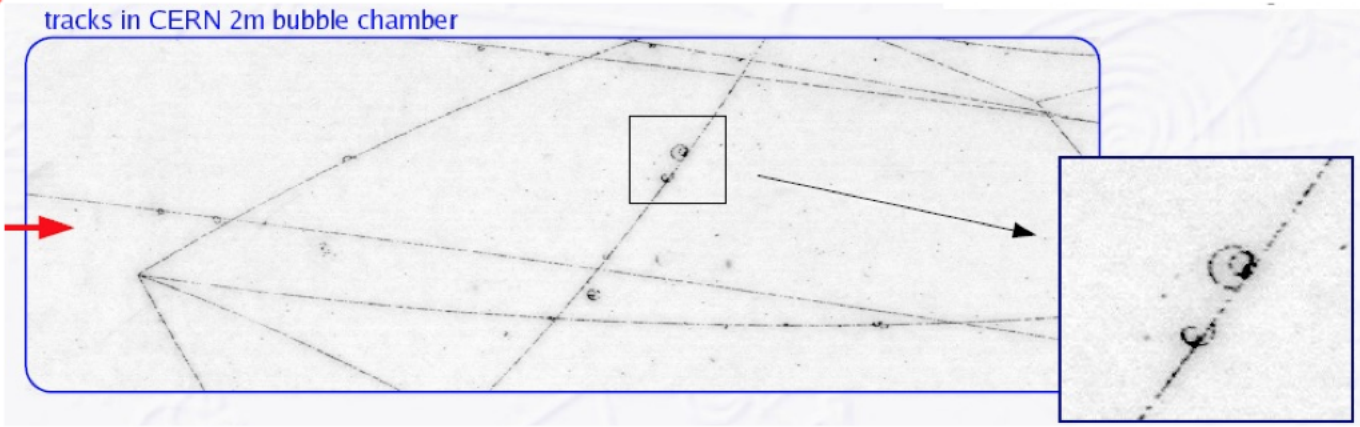
SS2017, Heidelberg
May 10, 2017

Gaseous detectors

Schematic Principle
of gas detectors

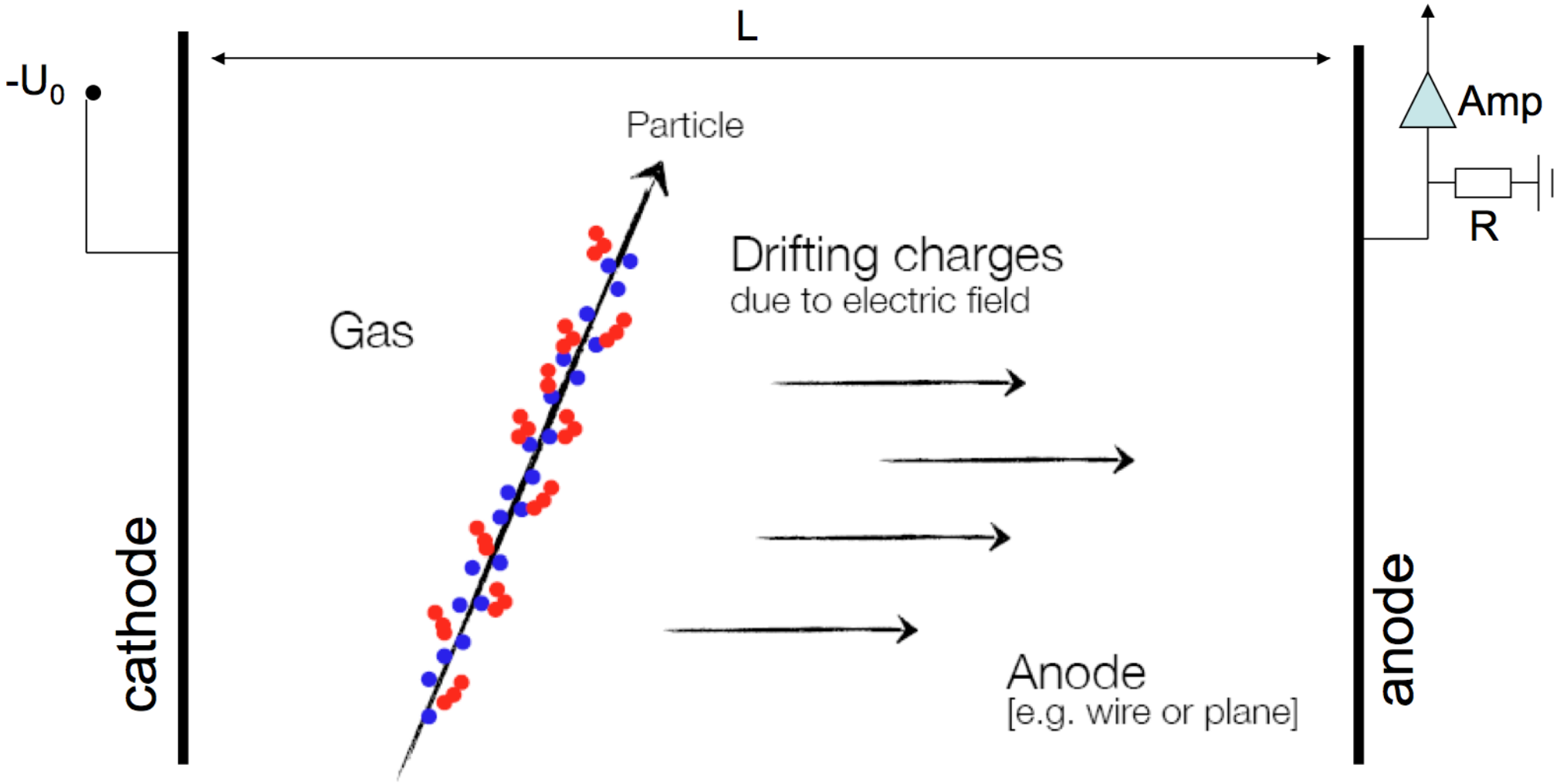


δ-electron



- Primary Ionization
- Secondary Ionization (due to δ-electrons)

Gaseous detectors



- Primary Ionization
- Secondary Ionization (due to δ-electrons)

Gas detectors

Modes of operation, depending on the strength of the electric field

W. Price, “Nuclear Radiation Detection”, 1958

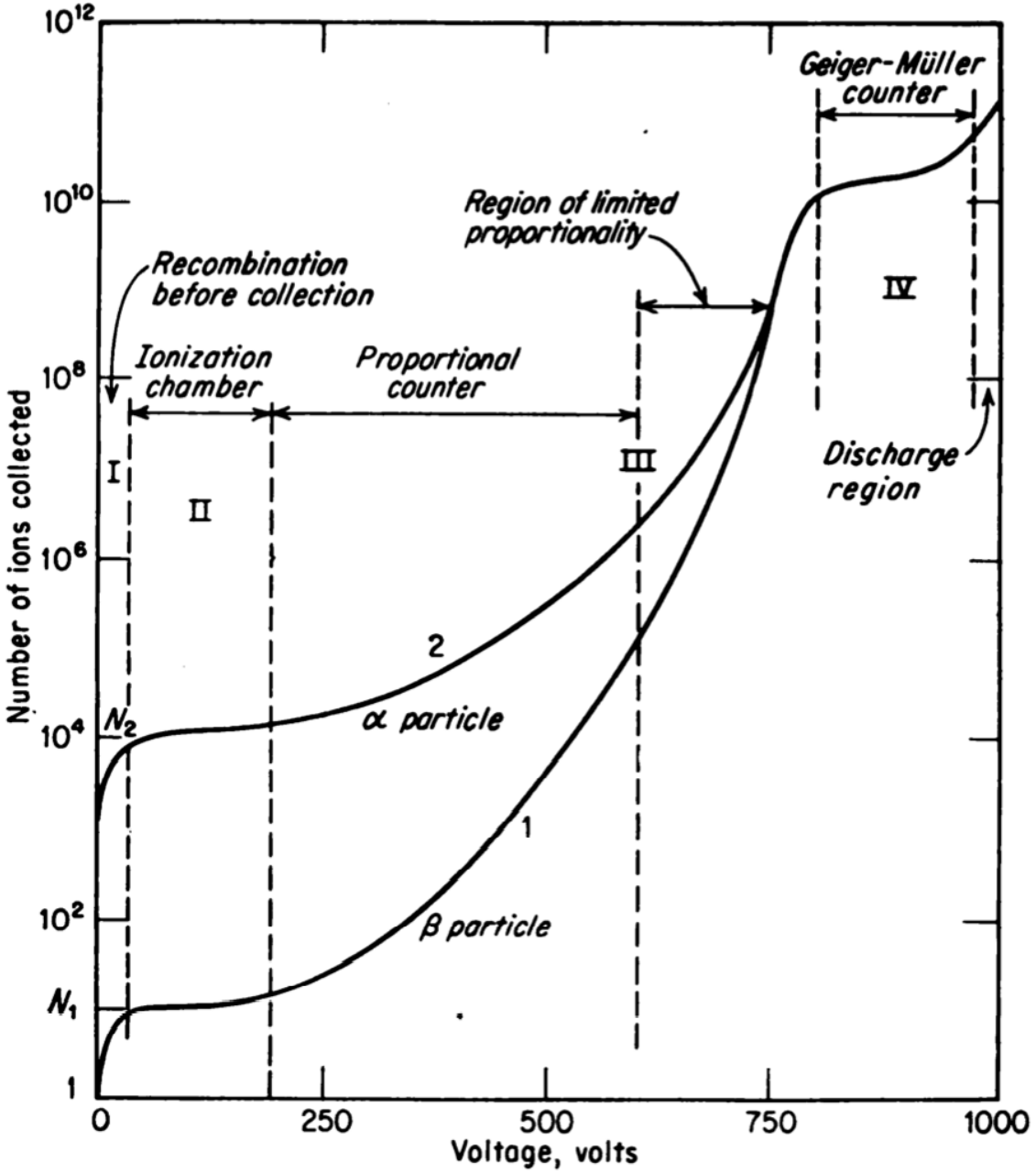


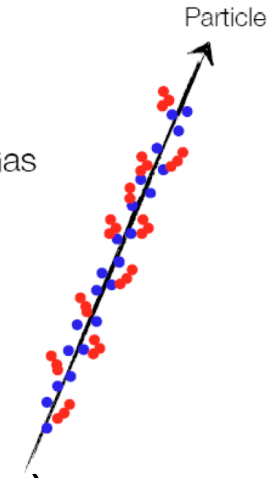
FIG. 2–2. Pulse-height versus applied-voltage curves to illustrate ionization, proportional, and Geiger-Müller regions of operation.

Gas detectors: outline

- Ionization in gas
- Charge transport in gas: electron and ion mobility
- Diffusion
- Drift velocity
- Charge multiplication / gas amplification

- Ionization chamber
- Proportional counter
  - Multiwire proportional chambers
- Drift chambers
  - Cylindrical wire chambers
  - Jet drift chambers
- Time projection chambers

Ionization



p: charged particle traversing the gas

X: gas atom or molecule

Primary ionization:

$$p + X \rightarrow p + X^+ + e^-$$

Secondary ionization: if E_e is high enough ($E_e > E_i$, δ electrons)

$$e^- + X \rightarrow X^+ + e^- + e^-$$

length scale ~ 10-20 μm

Relevant parameters for gas detectors:

- Ionization energy: E_i
- Average energy per e-ion pair: W_i
- Average # of primary e-ion pairs [per cm]: n_p
- Average # of e-ion pairs [per cm]: n_T

$$\langle n_T \rangle = \frac{L \cdot \left\langle \frac{dE}{dx} \right\rangle_i}{W_i}$$

L = layer thickness

n_T ~ 2-6 times n_p

Typical values: E_i ~ 30 eV

n_T ~ 100 pairs / 3 keV incident particle

Ionization in most common gases

($E_i = I_o$)

Gas	ρ (g/cm^3) (STP)	I_0 (eV)	W_i (eV)	dE/dx (MeVg^{-1}cm^2)	n_p (cm^{-1})	n_t (cm^{-1})
H_2	$8.38 \cdot 10^{-5}$	15.4	37	4.03	5.2	9.2
He	$1.66 \cdot 10^{-4}$	24.6	41	1.94	5.9	7.8
N_2	$1.17 \cdot 10^{-3}$	15.5	35	1.68	(10)	56
Ne	$8.39 \cdot 10^{-4}$	21.6	36	1.68	12	39
Ar	$1.66 \cdot 10^{-3}$	15.8	26	1.47	29.4	94
Kr	$3.49 \cdot 10^{-3}$	14.0	24	1.32	(22)	192
Xe	$5.49 \cdot 10^{-3}$	12.1	22	1.23	44	307
CO_2	$1.86 \cdot 10^{-3}$	13.7	33	1.62	(34)	91
CH_4	$6.70 \cdot 10^{-4}$	13.1	28	2.21	16	53
C_4H_{10}	$2.42 \cdot 10^{-3}$	10.8	23	1.86	(46)	195

From: K. Kleinknecht, “Detektoren für Teilchenstrahlung”, B.G. Teubner, 1992

Ionization statistics

The production of e-ion pairs follows a Poisson distribution: with

$\lambda = \frac{1}{\rho \sigma_I}$ mean distance between ionization events with cross section σ_I and electron density ρ in material

<n> = L/λ mean number of ionization events

$$P(n, \langle n \rangle) = \frac{\langle n \rangle^n \exp(-\langle n \rangle)}{n!}$$

We consider the probability of having NO ionization: $P(0, \langle n \rangle) = e^{-\langle n \rangle} = e^{-L/\lambda}$

Measuring the efficiency of gas detectors, we can determine the value of λ, and therefore σ_I

Typical values:

	λ (cm)
He	0.25
air	0.053
Xe	0.023

$\rightarrow \sigma_I = 10^{-22}$ cm^2 or 100 b

Effects relevant to particle detection

- Recombination and electron attachment
  admixture of electronegative gases (O_2, F, Cl) influences detection efficiency
- Delta electrons
  can influence the spatial information resolution
- Diffusion
  influences the localization of the charge and the spatial resolution
- Mobility of charges
  influences the timing behavior of gas detectors
- Avalanche process via impact ionization
  important for the gain factor

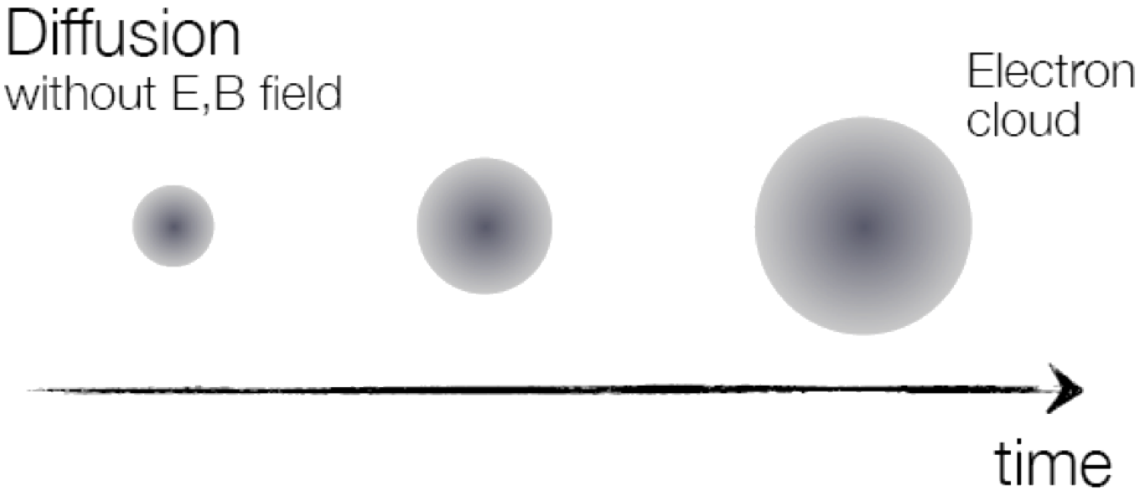
Charge transport

- Thermal motion
- Motion under the influence of external fields
- Collisions with gas atoms/molecules

Charge transport: diffusion

Thermal motion

E = B = 0



Classical kinetic theory of gases:

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

After a time t, the cloud of electrons/ions has diffused to a Gaussian distribution with width:

$$\sigma(r) = \sqrt{6Dt}$$

D: diffusion coefficient:

$$D = \frac{1}{3} v \lambda$$

Longitudinal	1/3 D
Transversal	2/3 D

Charge transport: diffusion

D: diffusion coefficient: $D = \frac{1}{3} v \lambda$

Mean free path of electrons/ions in gas: $\lambda = \frac{1}{\sqrt{2}} \frac{kT}{\sigma_0 P}$

Mean velocity according to the Maxwell distribution: $v = \sqrt{\frac{8kT}{\pi m}}$

m=mass of particle (note difference e / ion!)

Therefore:

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

Diffusion depends on the **gas pressure P and temperature T** !!!

Charge transport: ion mobility

- **Action of external electric field**

  Ions move along the lines of the electric field E and gain a velocity $\vec{v}_D$, in addition to their random thermal motion (isotropic)

- **Collisions with non-ionized gas atoms**

  Ions keep colliding with other (non-ionized) atoms of the gas. In such collisions (comparable mass) they transfer typically half of their kinetic energy → ion kinetic energy is approximately equal to thermal energy

$$\langle T_{ion}(E \neq 0) \rangle = \langle T_{ion}(\text{Therm}) \rangle = \frac{3}{2} k T$$

- **Drift velocity develops between collisions** $\tau = \lambda(T_{kin})/v_{therm} = \text{const.}$

  Assume: $v_D(t=0) = 0$; after τ = typical collision time the velocity is

$$\vec{v} = \vec{a} \cdot \tau = \frac{e\vec{E}}{M} \cdot \tau$$

$$\vec{v}_D = \langle \vec{v} \rangle = \frac{1}{2}\vec{v} = \frac{e|\vec{E}|}{2M} \cdot \tau = \mu_+ |\vec{E}| \qquad v_D^{ions} \propto E !$$

  μ_+ = **ion mobility**

  E.g. μ_+ = 0.61 cm²/Vs for C_4H_{10}. E = 1 kV/cm. Typical drift distances = few cm → typical ion drift time = few ms

Electron mobility: old and hot gases

Situation different for electrons ($m_e \ll M$) $\rightarrow$ $\mu_+ \ll \mu_-$

Two cases for the electron mobility, depending on the gas used:

- **Cold gases**: gas atoms have many low-lying levels $\rightarrow$ electrons in a collision can loose substantial part of the kinetic energy which they gain between collisions (similar to ions!!):

  $T_e \approx kT$; $\mu \approx$ const. $\rightarrow$ $v_D^e \propto E$!

  Examples: Ar/Co_2, Ne/CO_2

  In Ne/CO_2, $\mu \approx 7.0 \times 10^{-3}$ cm^2/μsV at 10% CO_2, or v_D = 2 cm/μs at 300 V/m

  $\mu \approx 3.5 \times 10^{-3}$ cm^2/μsV at 20% CO_2, or v_D = 1 cm/μs at 300 V/m

- **Hot gases**: gas atoms have few low-lying levels $\rightarrow$ electrons loose little energy in collisions with the gas $\rightarrow$ $T_e \gg kT$

  Acceleration in E field and friction lead to a constant v_D at given E

  But $\mu \propto \tau \propto 1/\sigma(|\vec{E}|)$ not constant!!

  Example: Ar/CH_4 (90:10), v_D = 3-5 cm/μs (saturating with E)

Electron mobility: E≠0, B≠0

Equation of motion of electron in superimposed E and B-fields (Langevin):

$$m\frac{d\vec{v}}{dt} = e\vec{E} + e(\vec{v}\times\vec{B}) + \vec{Q}(t)$$

Instantaneous velocity v; stochastic, time dependent term Q due to collisions with the gas atoms.

Assume: collision time τ

E and B constant between collisions

take $\Delta t \gg \tau$ (average) → Q(t) is a friction term $= -\frac{m}{\tau}\vec{v}_D$ (Stokes type)

Steady state is reached when the net force is zero → defines $\vec{v}_D$

$$\left\langle m\frac{d\vec{v}}{dt}\right\rangle = e(\vec{E} + \vec{v}\times\vec{B}) - \frac{m}{\tau}\vec{v}_D = 0$$

With constant drift velocity, the measurement of the drift times provides information on the point of ionization:

$$\Delta t = \frac{L}{v_D}$$

Charge transport: electron mobility

Electron mobility:

$B=0 \rightarrow \vec{v}_D = \mu_- \vec{E}$ with $\mu_- = \frac{e\tau}{m}$

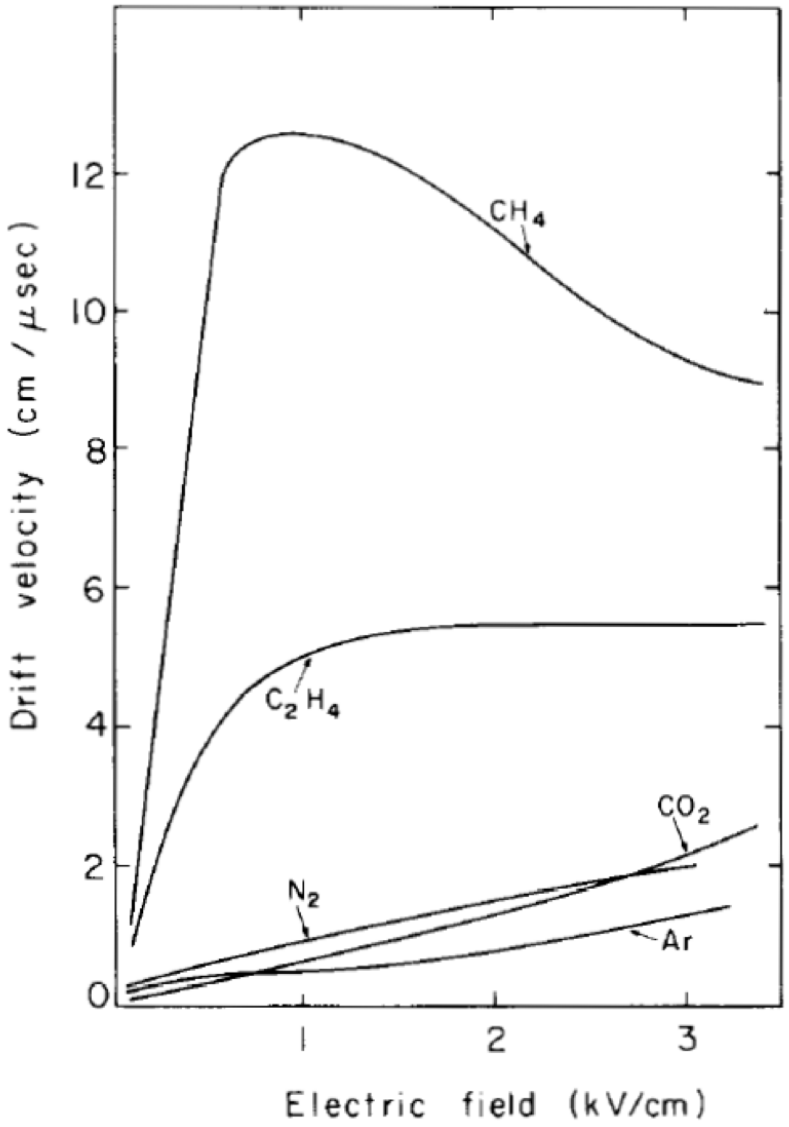
$B\neq 0 \rightarrow \vec{v}_D = \mu_- \vec{E} + \omega\tau(\vec{v}\times\vec{B})$ with Larmor frequency $\omega = \frac{eB}{m}$

Drift velocity in combined E and B-fields:

$$\vec{v}_D = \frac{\mu|\vec{E}|}{1+\omega^2\tau^2}[\hat{E} + \underbrace{\omega\tau\hat{E}\times\hat{B}}_{\substack{\text{component}\\ \text{in direction}\\ \vec{E}\times\vec{B}\\ \propto \omega\tau}} + \underbrace{\omega^2\tau^2(\hat{E}\cdot\hat{B})\hat{B}}_{\substack{\text{component}\\ \text{in direction}\\ \vec{B}\\ \propto (\omega\tau)^2}}]$$

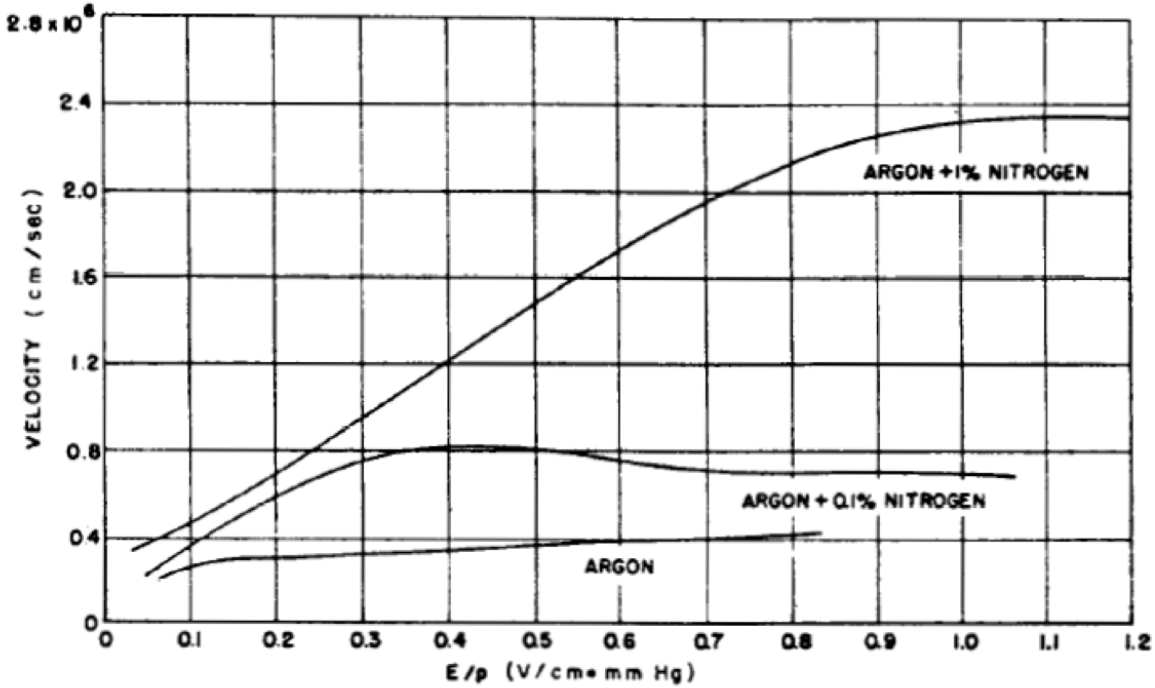
$\hat{E}$, $\hat{B}$: unit vectors in direction of E- and B-field

Drift velocity of electrons



Drift velocity of electrons
in several gases at normal conditions

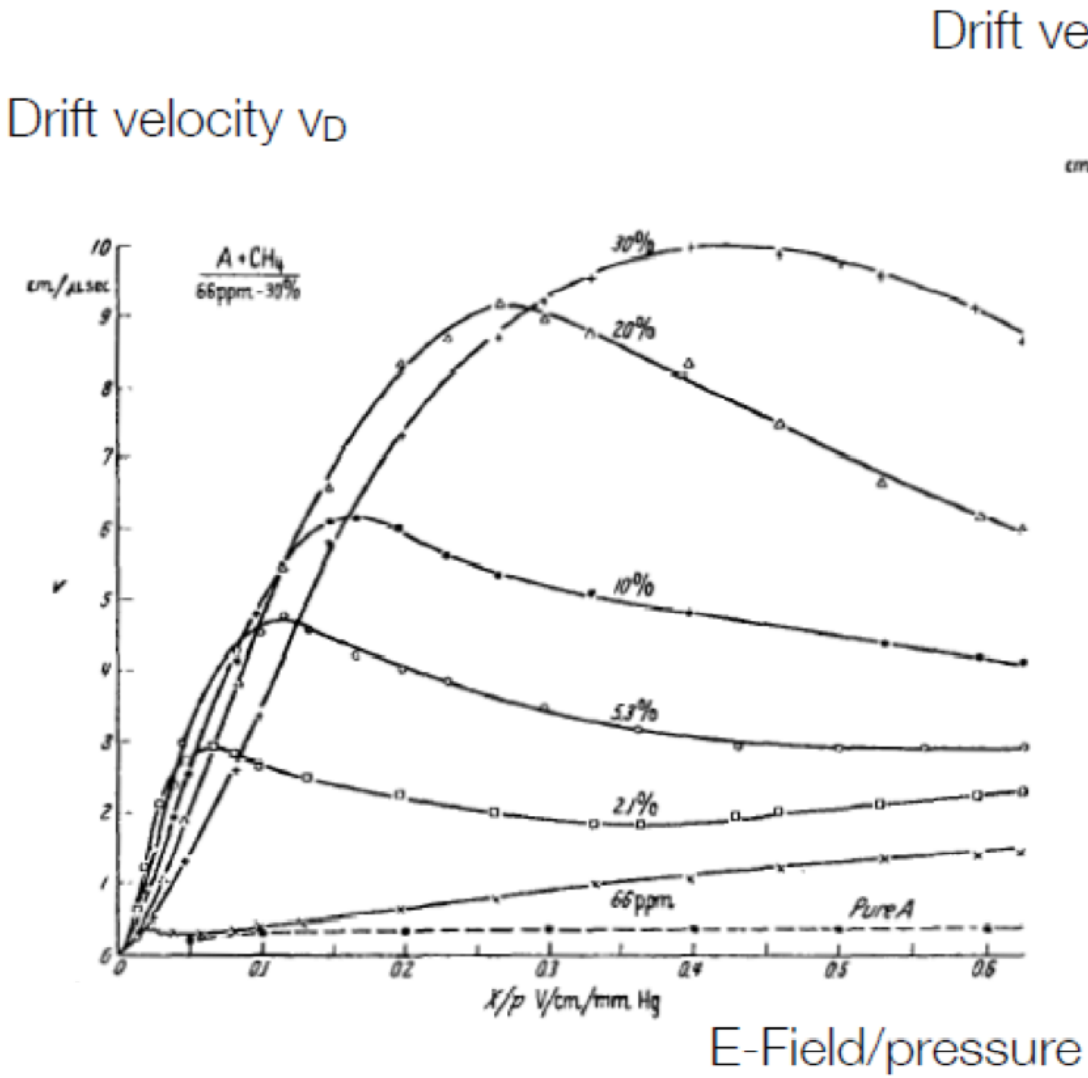
Use gas mixture to obtain constant v_D
Important for applications using drift time to get spatial information

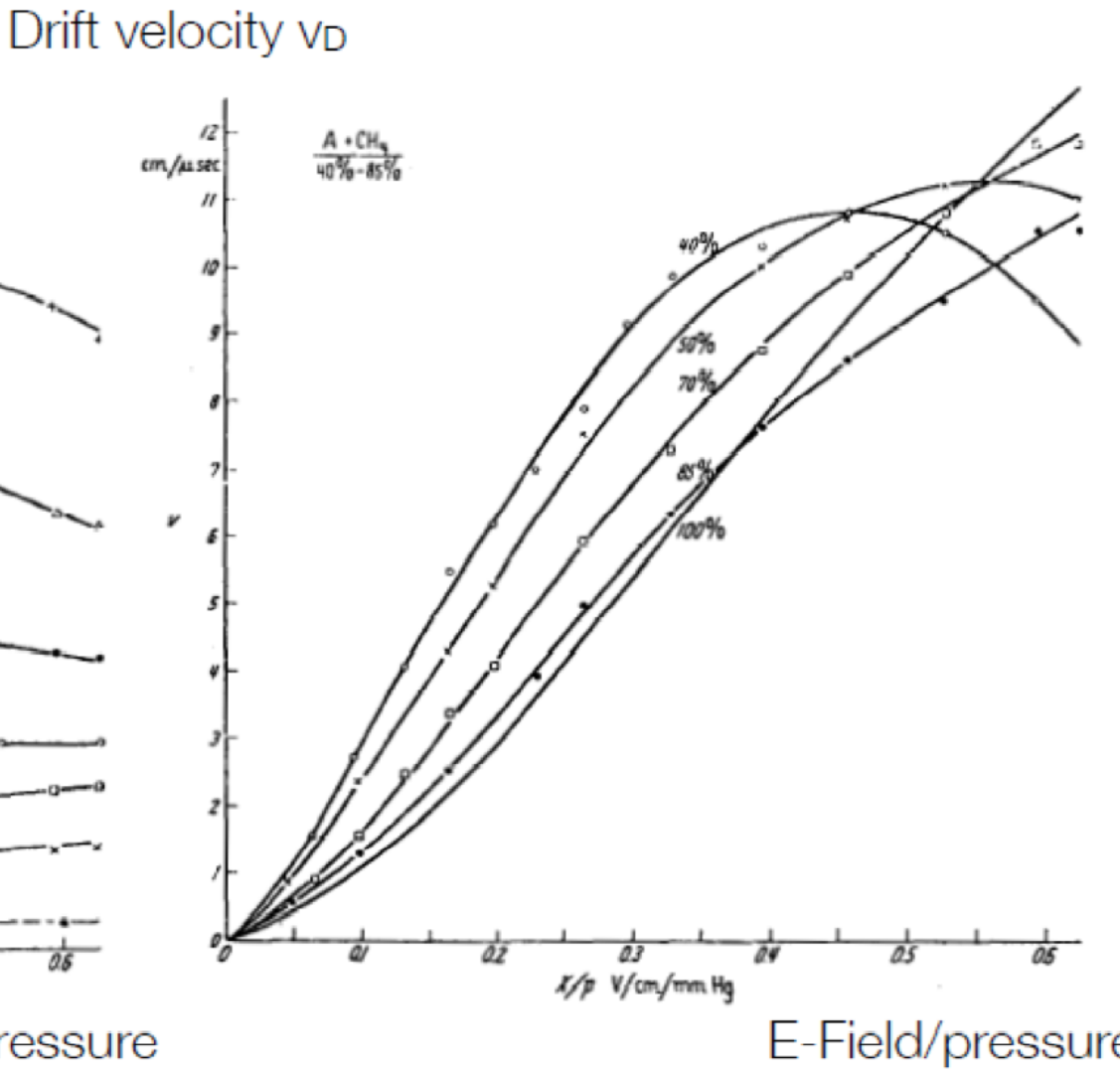


E-Field/pressure

Drift velocity of electrons

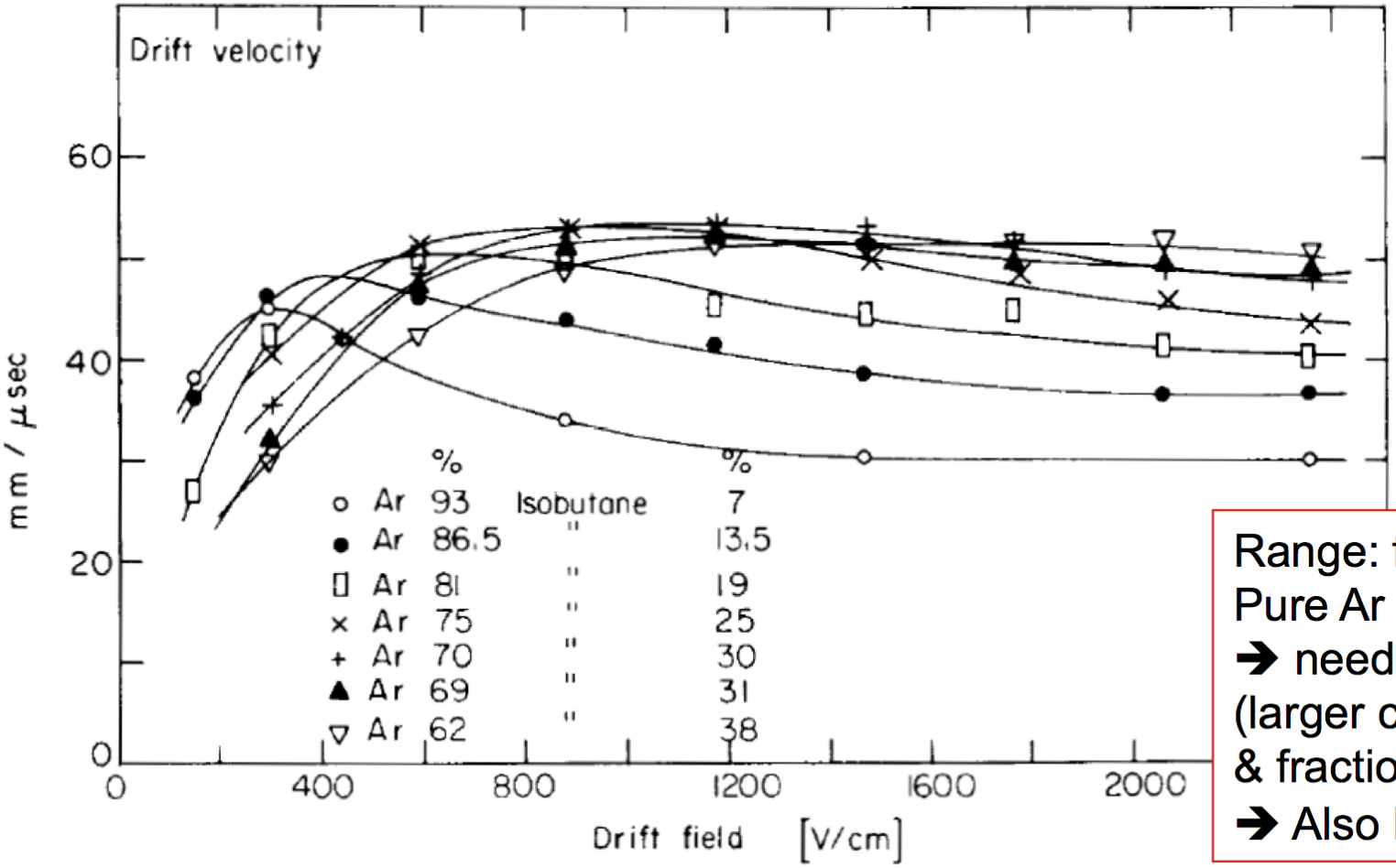
Argon-methane mixtures:





Drift velocity of electrons

Argon-isobutane mixtures:

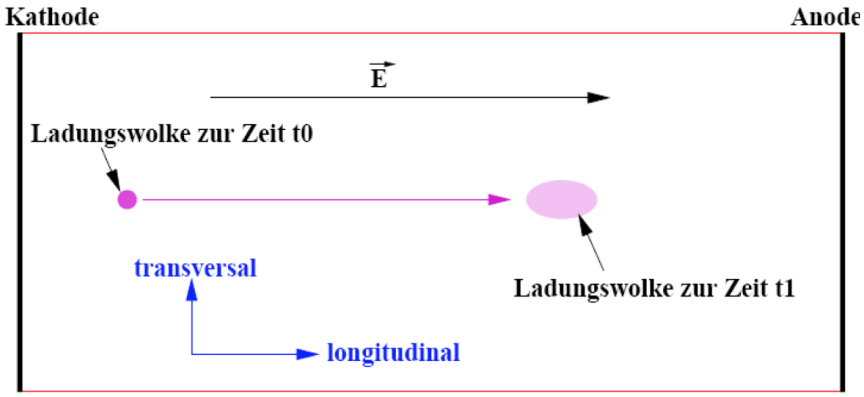


Range: few 10 mm/μs
Pure Ar : ~10 mm/μs
➔ need quenching gas
(larger cross-sections
& fractional energy loss)
➔ Also less diffusion

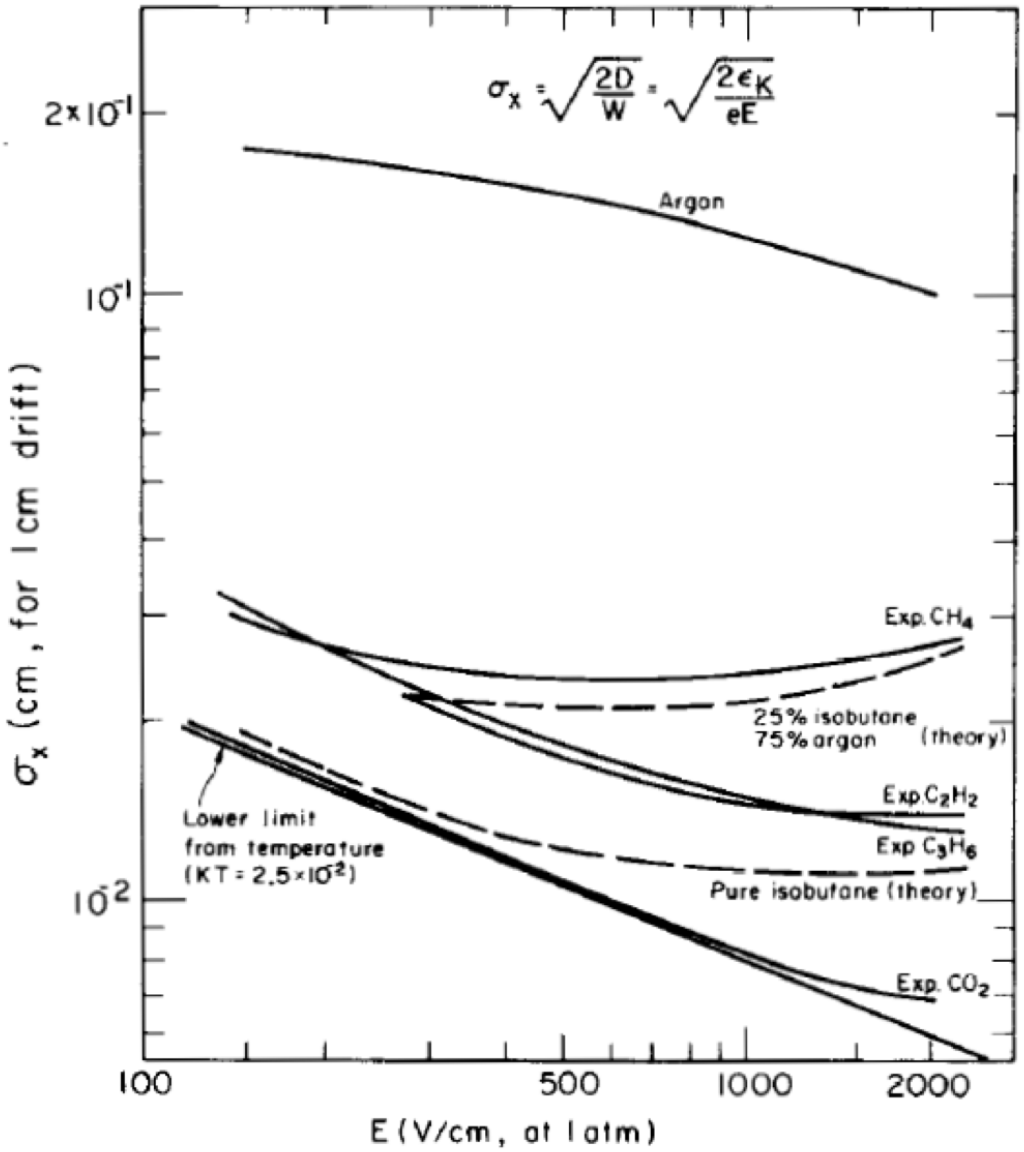
Diffusion in electric fields

Drift in direction of E-field is superimposed to statistical diffusion

Extra velocity influences the longitudinal diffusion. The transversal diffusion is not affected



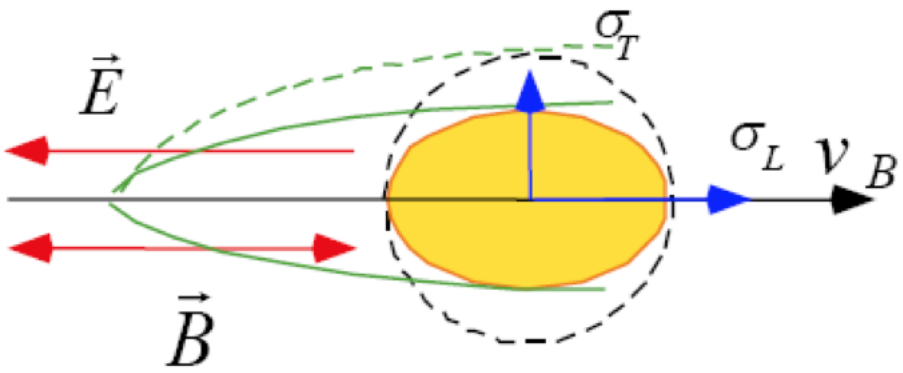
The E-field reduces the longitudinal diffusion



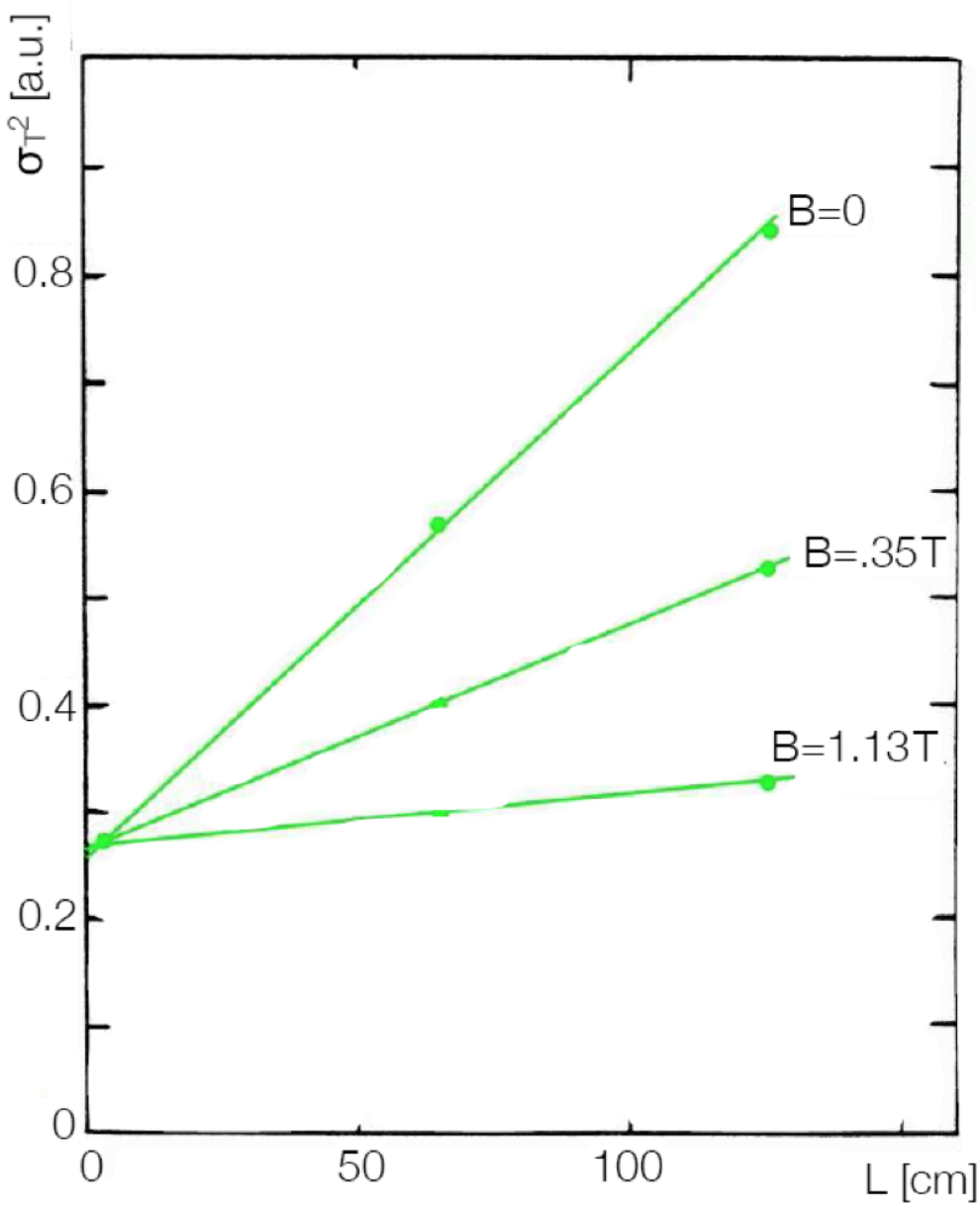
Diffusion in magnetic field

Different effects on longitudinal and transverse diffusion.

No Lorentz force ALONG the direction of the B-field



The B-field can substantially reduce the diffusion transversal to its direction



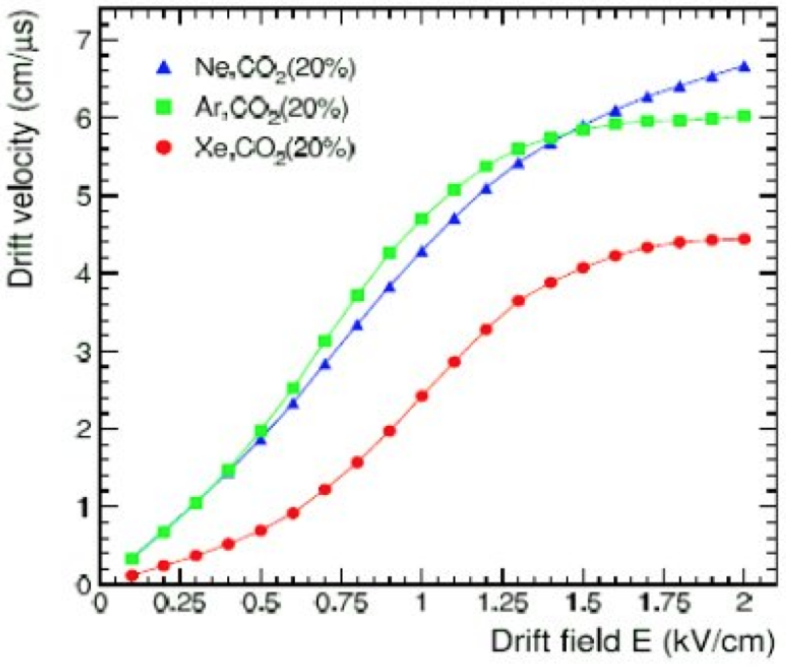
Charge transport: exact solution

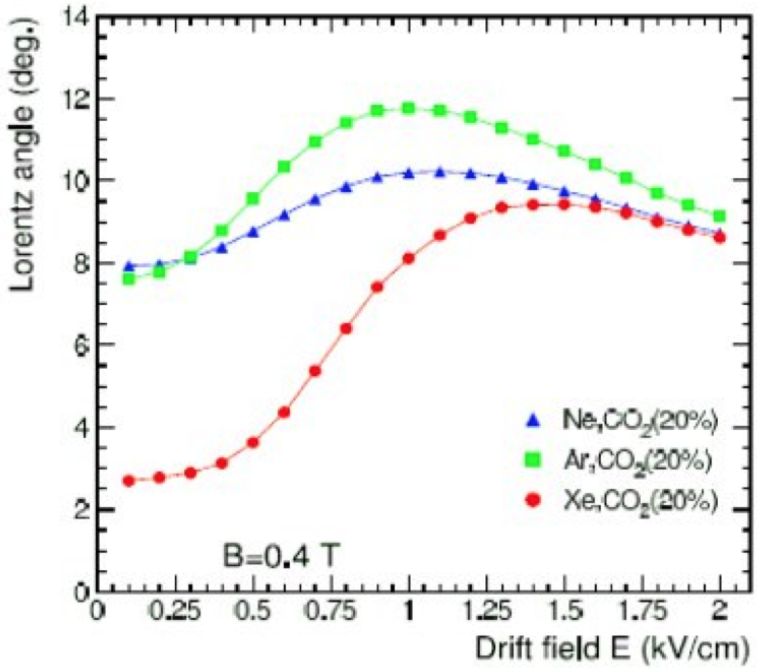
For a full and exact solution, need to solve the transport equation for electron density distribution $f(t, \vec{r}, \vec{v})$

$$\frac{\partial f}{\partial t} + \vec{v}\frac{\partial}{\partial \vec{r}} f + \frac{\partial}{\partial \vec{v}}\left(\frac{e\vec{E}}{m} + \vec{\omega}\times\vec{v}\right) f = Q(t)$$

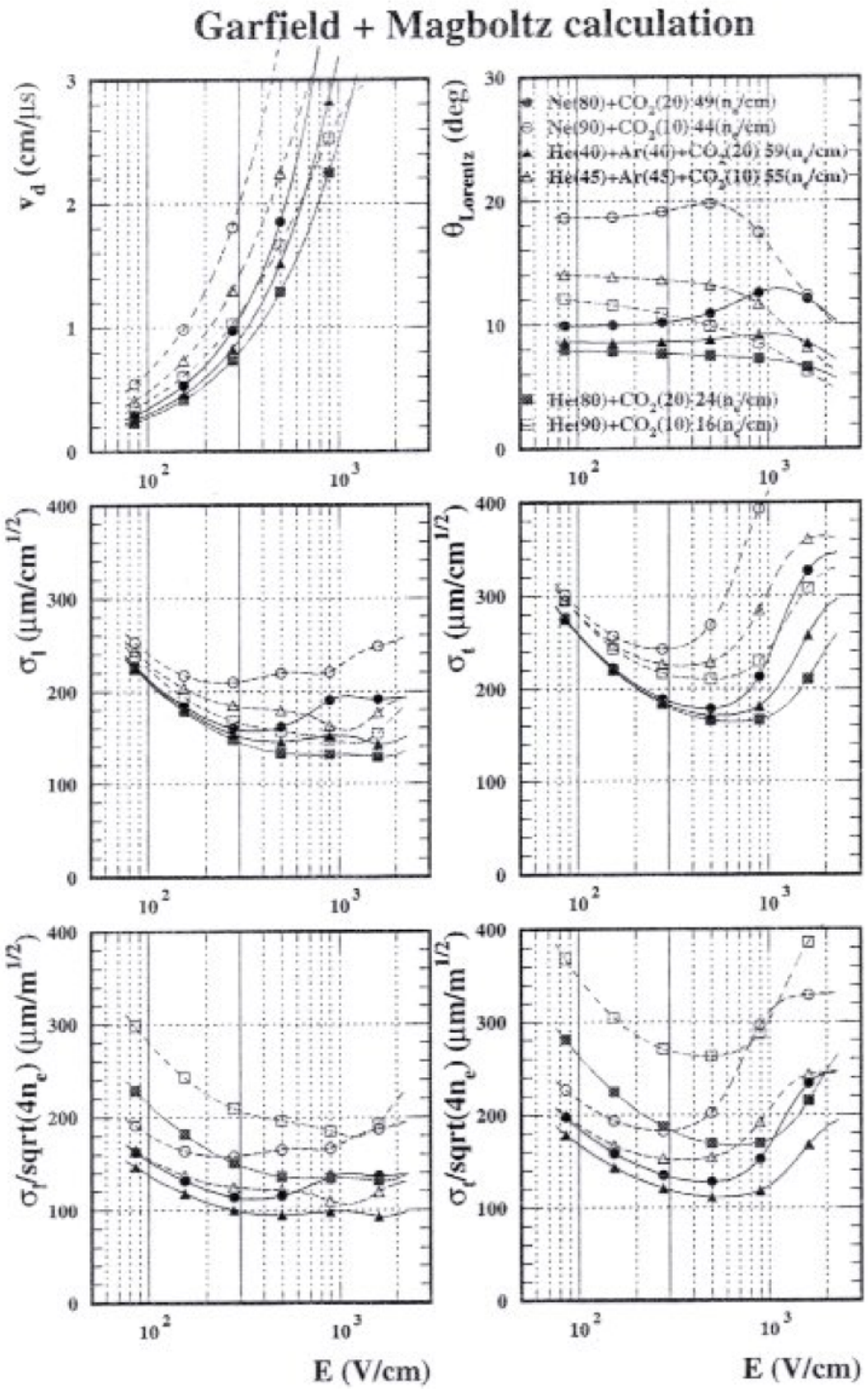
diffusion external forces stochastic collision term

Typically solved numerically, with codes like Magboltz & Garfield:





Lorentz angle: angle between E-field and drift velocity of electrons if B not perpendicular to E



Drift velocity (top left), Lorentz angle (top right), longitudinal and transverse diffusion constants (middle) and longitudinal and transverse diffusion constants normalized to the square root of the number of charge carriers (bottom) for different mixtures of noble gas and CO_2.

Lorentz angle: angle between E-field and drift velocity of electrons in presence of B not $\perp$ to E

Loss of electrons

Electrons might be lost during the drift via:

- **Recombination** of ions and electrons

  Depends on number of charge carriers and recombination coefficient. Generally not too significant

- **Electron attachment**:
  - electro-negative gas molecules (O_2, Freon, …) bind electrons:

    $e^- + M \rightarrow M^-$ for $T_e \approx 1$ eV or $e^- + XY \rightarrow X + Y^-$
  - electron attachment coefficient h is strongly energy dependent (Ramsauer effect)
  - Example O_2: h = 10^{-4} at 1 eV. Collisions for electrons/second: 10^{11}

    typical drift time of electrons: 10^{-6} s

    Fraction lost: $X_{loss} = 10^{-4}\ 10^{11}\ s^{-1}\ 10^{-6}\ s\ p = 10\ p$

    $X_{loss} < 1\% \rightarrow p = 10^{-3} \rightarrow$ less than 1‰ in gas mixture!
  - Certain quencher gases such as $C0_2$ enhance the effect of O_2 such that 10 ppm of O_2 can lead to 10% loss within 10 µs

Ionization chamber

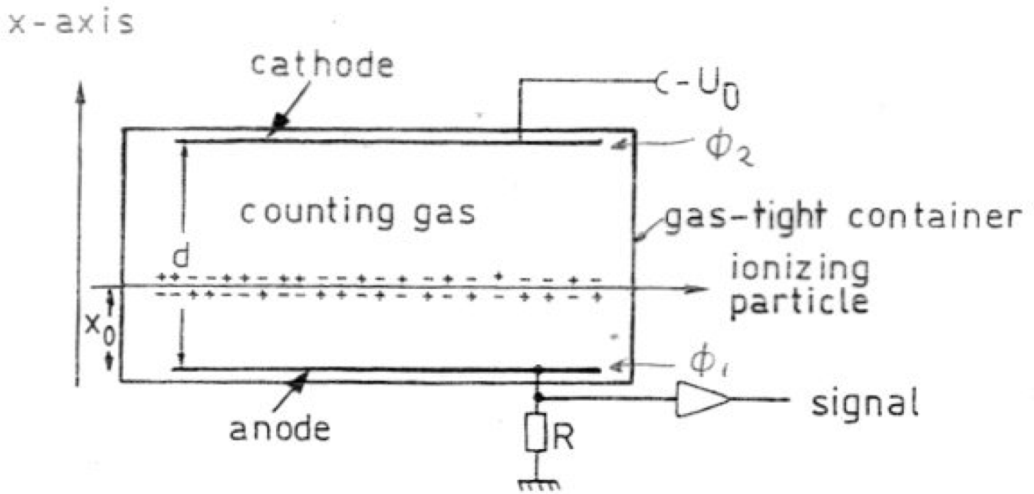
No gas gain: ionization charges move in electric field and induce a signal on the electrodes

Here: planar geometry

2 electrodes → parallel plate capacitor

Free charge q moves: electric field does work → capacitor is charged

$$q\vec{\nabla}\Phi\cdot d\vec{x} = dq_i\cdot U_0$$



leads to induced current:

$$I_{ind} = \frac{q}{U_0}\vec{\nabla}\Phi\cdot\vec{v}_D$$

Where:

$$\vec{E} = -\vec{\nabla}\Phi \qquad U_0 = \phi_1 - \phi_2$$

Ionization chamber

- Current is constant while the charge is drifting
- Total induced signal (charge) is independent on x
- Signal induced by electrons:

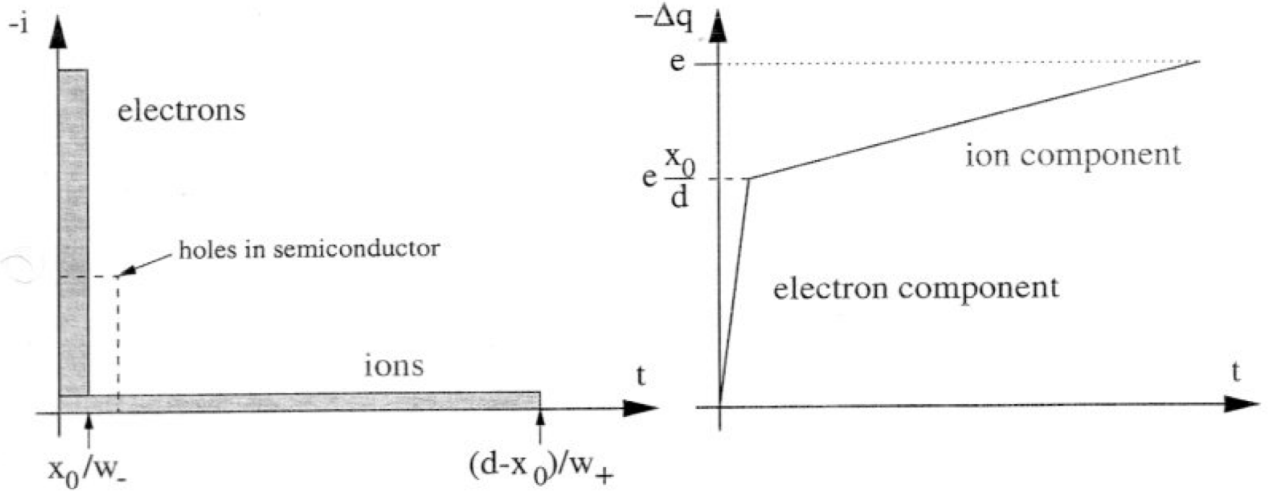
$$\Delta q_{-} = \frac{N_e}{U_0}(\phi(x_0) - \phi_1)$$

- Signal induced by ions:

$$\Delta q_{-} = -\frac{N_e}{U_0}(\phi(x_0) - \phi_2)$$

- $|N_{ion}| = |N_e|$ → total $\Delta q = \Delta q_{-} + \Delta q_{+} = N_e$
- Remember: $\mu_{+} = 10^{-3} \ldots 10^{-2}\ \mu_{-}$ (velocity $w_{+} = 10^{-3} \ldots 10^{-2}\ w_{-}$)

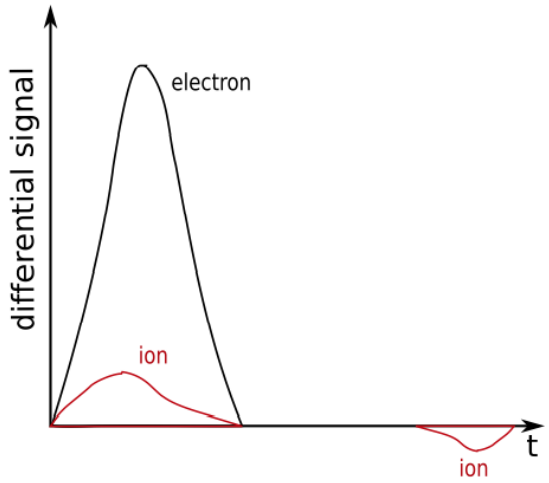
  → induced current and charge for parallel plate case. Ratio between mobilities reduced for purpose of illustration



Ionization chamber: pulse shape

Signal generated during drift of charges:

- Induced current ends when the charges reach the electrode
- Induced charge becomes constant (tot el. N_e)
- Signal shape by differentiation (speed of readout) → suppresses slow ion component

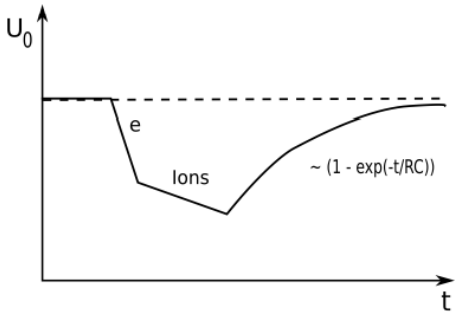


Change in potential dU = dQ/C

Typical **time constant** of power supply (+cables ..)

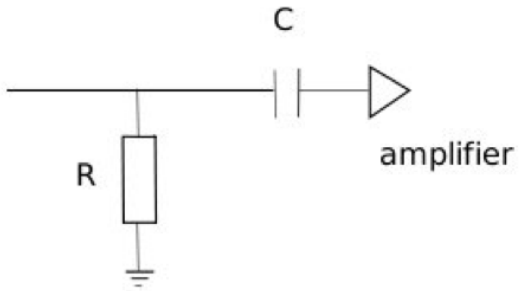
$RC \gg \Delta t^-, \Delta t^+$ (long!)

Usually some electronic signal shaping is needed



Signal shaping by RC-filter:

Choose it such that $\Delta t^- \ll RC \ll \Delta t^+$ → damps ion component



$$\Delta U = \Delta U^- + \Delta U^+ = \frac{\Delta Q^-}{C} + \frac{\Delta Q^+}{C}$$

ΔQ= charge induced in the anode by electrons and ions for total n. of ionizations N_e

Ionization chamber: pulse shape

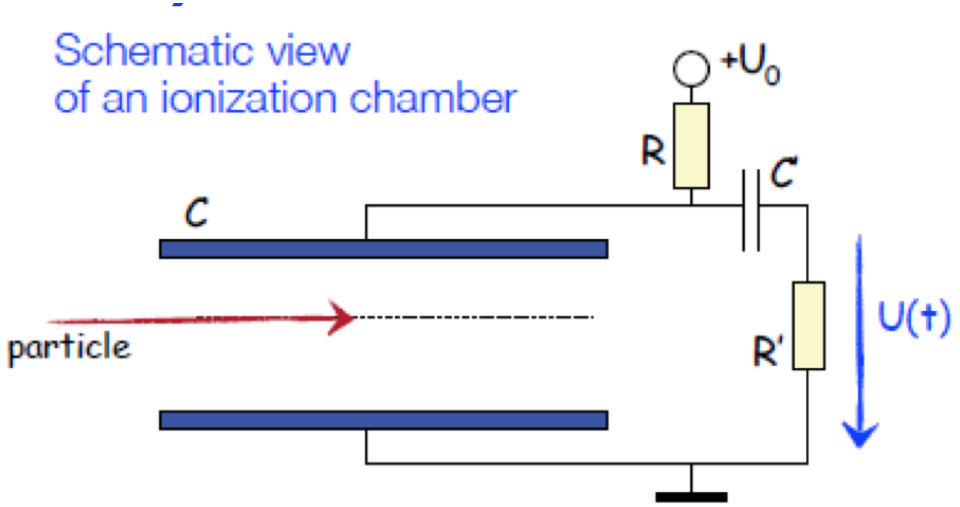
$$\Delta Q^- = N_e \frac{\Phi(x_0) - \Phi_1}{U_0} = N_e \frac{x_0}{d}$$

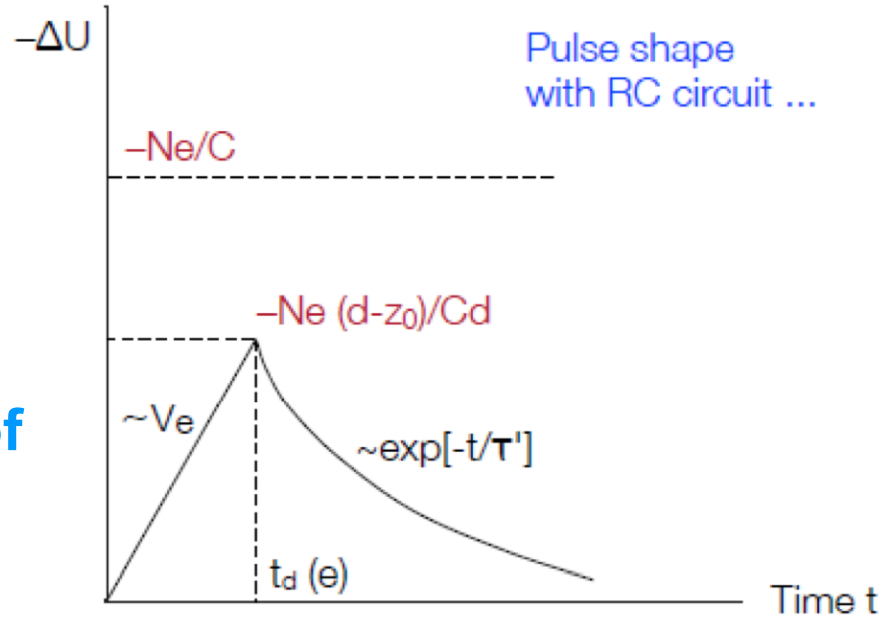
$$\Delta Q^+ = -N_e \frac{\Phi(x_0) - \Phi_2}{U_0} = N_e \frac{d - x_0}{d}$$

without filter $\Delta Q = N_e, \quad \Delta U = \frac{N_e}{C}$

with filter $d - x_0 = v^+ \Delta t^+$

$$\rightarrow \underbrace{v^+ RC \left(1 - \exp(-\frac{\Delta t^+}{RC})\right)}_{\text{damping of ion component}}$$





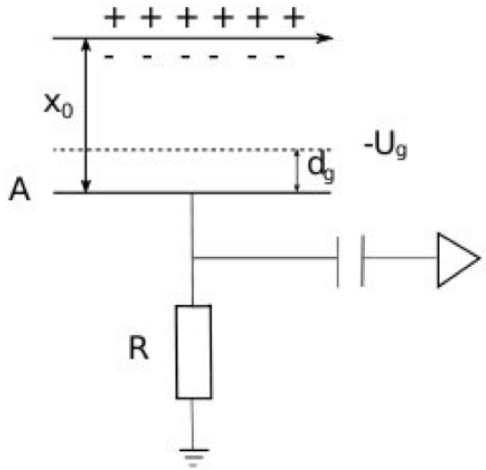
This achieves a fast rise and decrease of the signal BUT now the pulse height depends on position x_0 !!!

Ionization chamber: Frisch grid

Trick to avoid the position dependence: introduce a grid (Frisch grid, 1944) above the anode

While the electrons drift, they induce a signal on the grid but not on the anode!

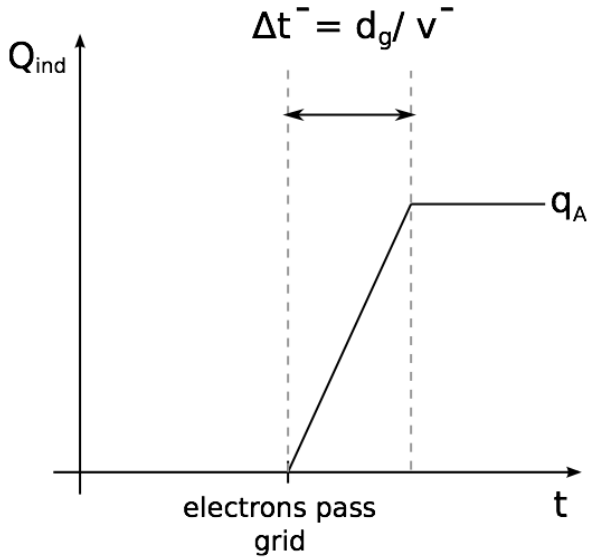
Only after passing the Frisch grid, they start inducing a signal on the anode itself



Choose U_g such that the E-filed is unchanged

$$\Delta Q = \Delta Q^{-} = N_e$$

$$\Delta t^{-} = \frac{d_g}{v^{-}}$$



Ionization chamber: general difficulty

Signals in ionization chambers are generally VERY SMALL

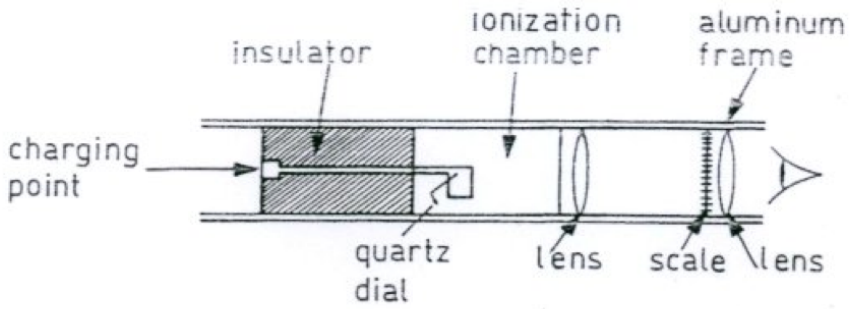
Example: 1 MeV particle stops in gas

$$
\begin{aligned}
N_e &\simeq \frac{10^6 \text{ eV}}{35 \text{ eV}} \simeq 3 \cdot 10^4 \\
C &\simeq 100 \text{ pF} \\
\Rightarrow \Delta U_{max} &= \frac{3 \cdot 10^4 \cdot 1.6 \cdot 10^{-19} \text{ C}}{10^{-10} \text{ F}} \\
&= 4.6 \cdot 10^{-5} \text{ V}
\end{aligned}
$$

They need very sensitive, low-noise pre-amplifiers

Ionization chamber: examples

- Dosimeter for ionization



Construction of an ionization pocket dosimeter

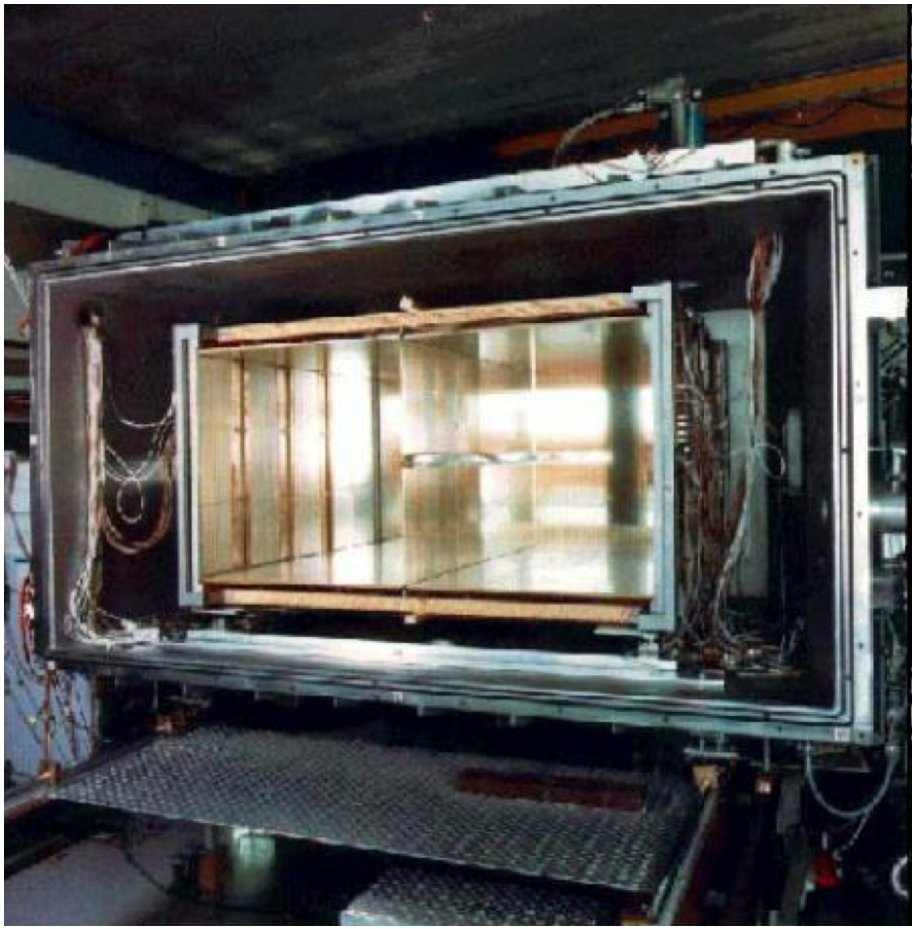
- cylindrical capacitor filled with air
- initially charged to potential U_0
- ionization continuously discharges capacitor
- reduction of potential ΔU is measure for integrated absorbed dose (view e.g. via electrometer)

- Nuclear physics experiments, with energies of 10-100 MeV

  Measure the energy deposit of charge particle, it should be highly ionizing or even stop

  Combination of E and ΔE measurement → particle identification (nuclei)

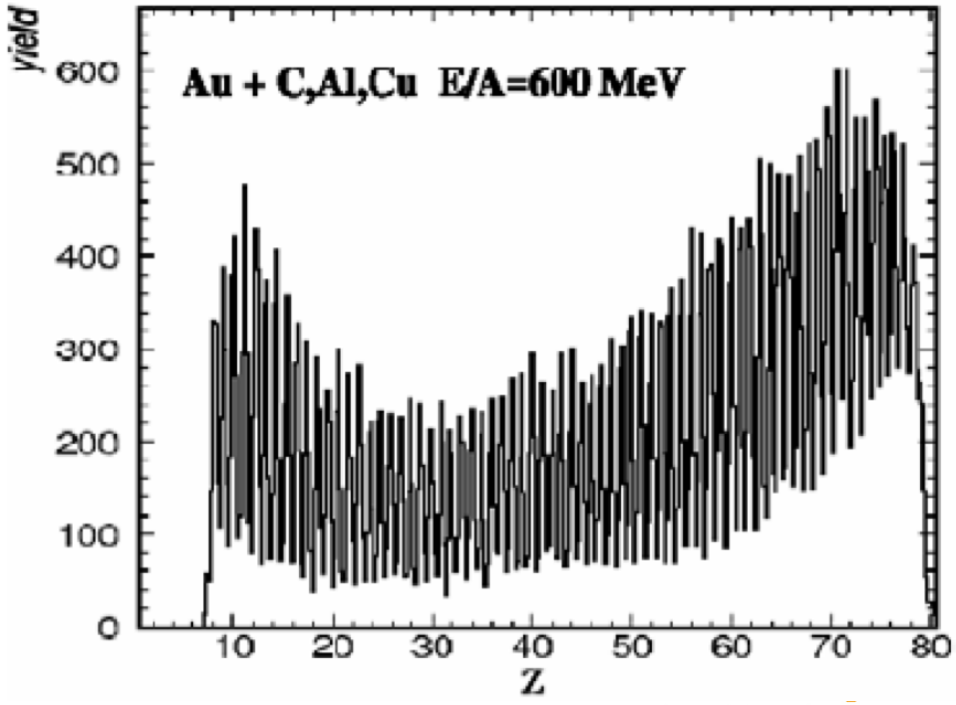
Ionization chamber: MUSIC II - GSI



gas	P10 (Ar/Methan 90/10)
pressure	1 atm
active area	102 x 60 cm^2
depth	51 cm
electric field	150 V/cm
potential	9 kV
ionization	70 Z^2 pairs/cm
drift velocity	5 cm/µsec

Multi-sampling ionization chamber to identify the highly charged fragments in nucleus-nucleus collisions at GSI

multiple dE/dx measurements + velocity → charge of the ion



Gas detectors

Modes of operation, depending on the strength of the electric field

W. Price, “Nuclear Radiation Detection”, 1958

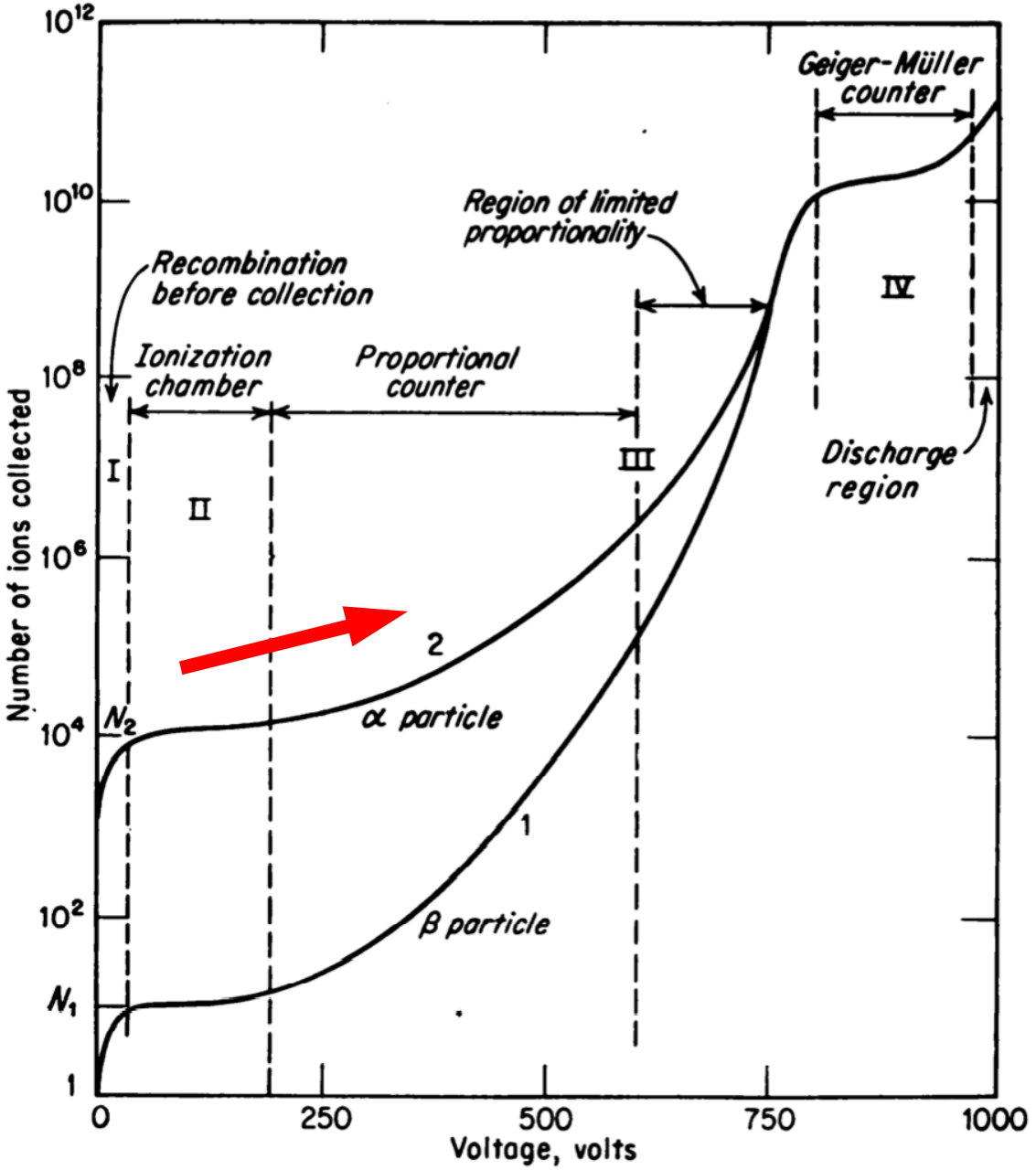


FIG. 2–2. Pulse-height versus applied-voltage curves to illustrate ionization, proportional, and Geiger-Müller regions of operation.

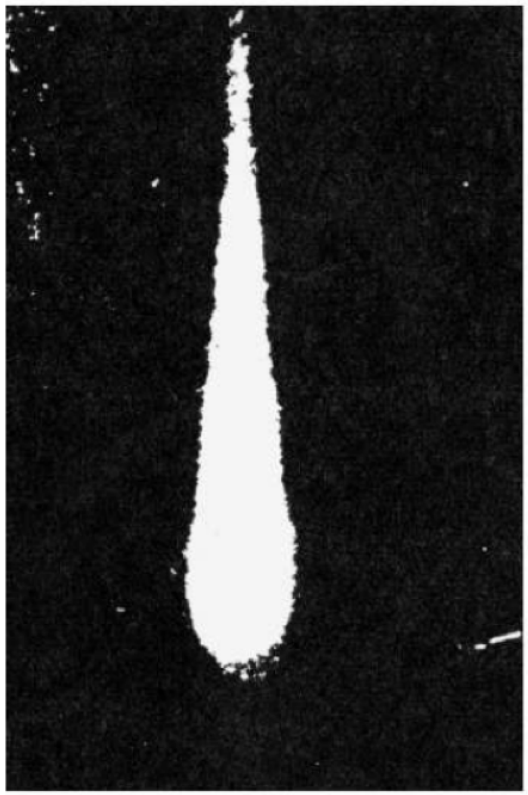
Avalanche multiplication

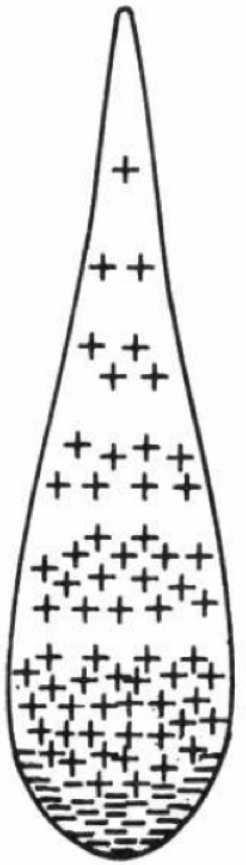
In presence of a very large electric field, the electrons will gain a very large kinetic energy → further ionization

→ Up to avalanche formation

The high mobility of electrons results in liquid-drop-like avalanche, with electrons at the head

Townsend avalanche





Drop-like shape of an avalanche
Left: cloud chamber picture
Right: hematic view

Mean free path (to secondary ionization): λ_{ion}

Probability of an ionization per unit path length: $\alpha = 1/\lambda_{ion}$ **1st Townsend coefficient**

n(x) = electrons at location x

$dn = n\,\alpha \cdot dx \quad \rightarrow \quad n = n_0\, e^{\alpha x}$

First Townsend coefficient α

GAIN

Number of electrons: $n(x) = n_0 e^{\alpha x}$

Mean free path:

$$\lambda_{ion} = \frac{1}{\alpha} = \frac{1}{n\sigma(T_e)}$$

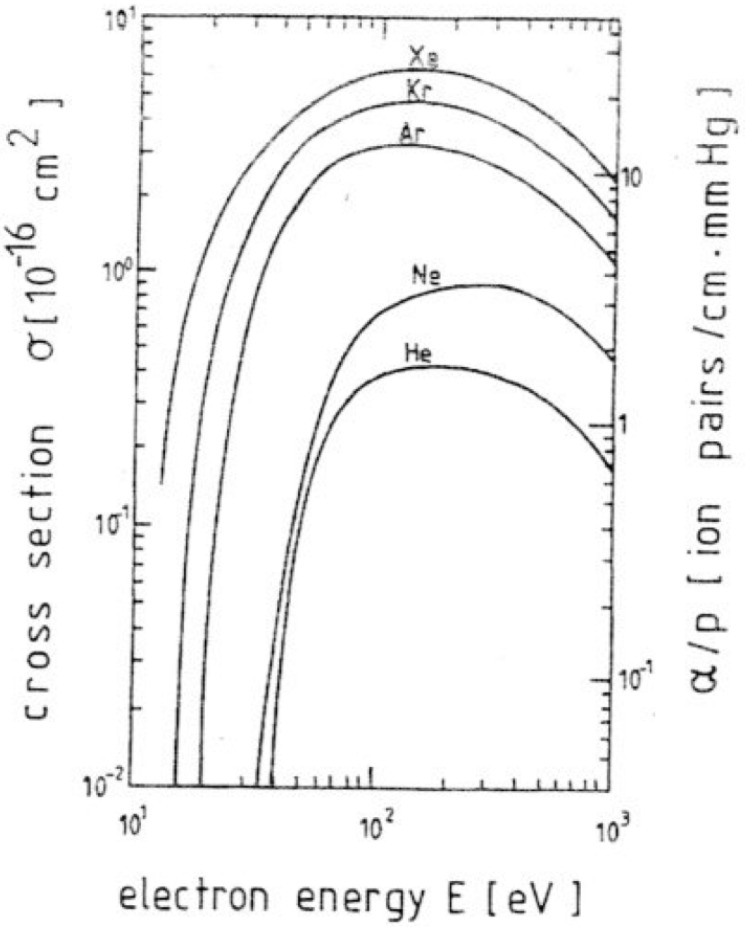
More precisely: α = α(x) →

$$G = \frac{n}{n_0} = \exp\left[\int_{x_1}^{x_2} \alpha(x)\,dx\right]$$

Typically 10^4 -10^5, up to 10^6 possible in proportional mode.

Raether limit: $G \approx 10^8 \leftrightarrow \alpha x \approx 20$

Afterwards sparking sets in



Energy dependence of the cross section for ionization by collision.

Second Townsend coefficient γ

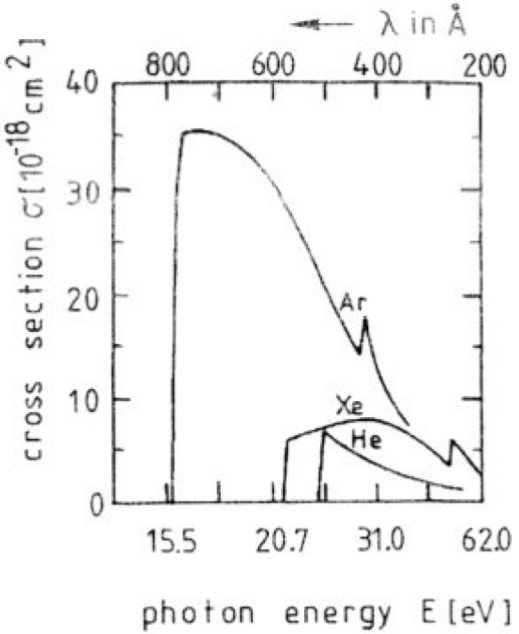
Gas atoms which are excited generate UV photons: they will induce photoelectric effect in the gas and in walls → contribute to the avalanche

$$\gamma = \frac{\text{n. photo effect events}}{\text{n. avalanche electrons}}$$

Gas gain needs to include the photo effect:

$$G_\gamma = G + G(G\gamma) + G(G\gamma)^2 + \ldots = \frac{G}{1-\gamma G}$$

no photo effect events — one — two — ....



Energy dependence of the cross section for photoionization

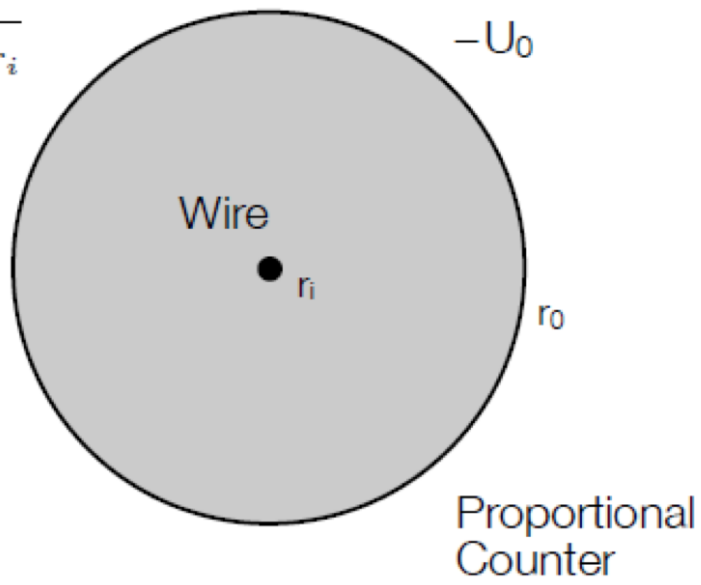
Limit: γG → 1 **continuous discharge**, independent from primary ionization

To prevent it: add a quench-gas which absorbs UV photons, leading to excitation and radiationless transitions (e.g. CH_4, C_4H_{10}, CO_2, ...)

Gas amplification: cylindrical geometry

Take cylindrical geometry with anode represented by a very thin wire: E close to wire is very large ($E \propto 1/r$) → electrons gain very large kinetic energy

$$E = \frac{U_0}{r \ln r_0/r_i}$$

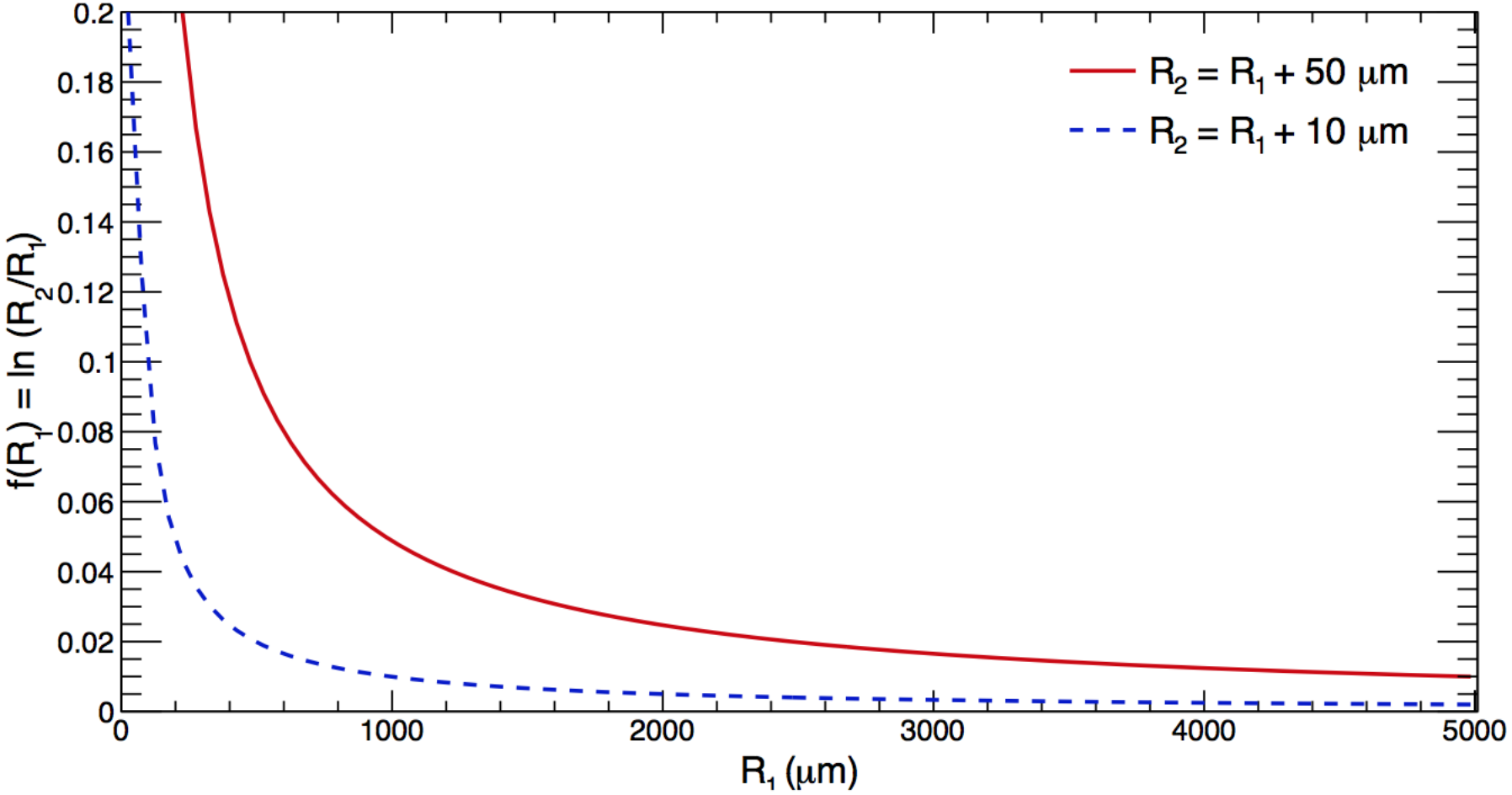


$$\Delta T_e = e\Delta U = e\int_{r_1}^{r_2} E(r)\,dr$$

$$= \frac{eU_0}{\ln \frac{r_o}{r_i}} \int_{r_1}^{r_2} \frac{1}{r}\,dr = eU_0 \frac{\ln \frac{r_2}{r_i}}{\ln \frac{r_o}{r_i}}$$

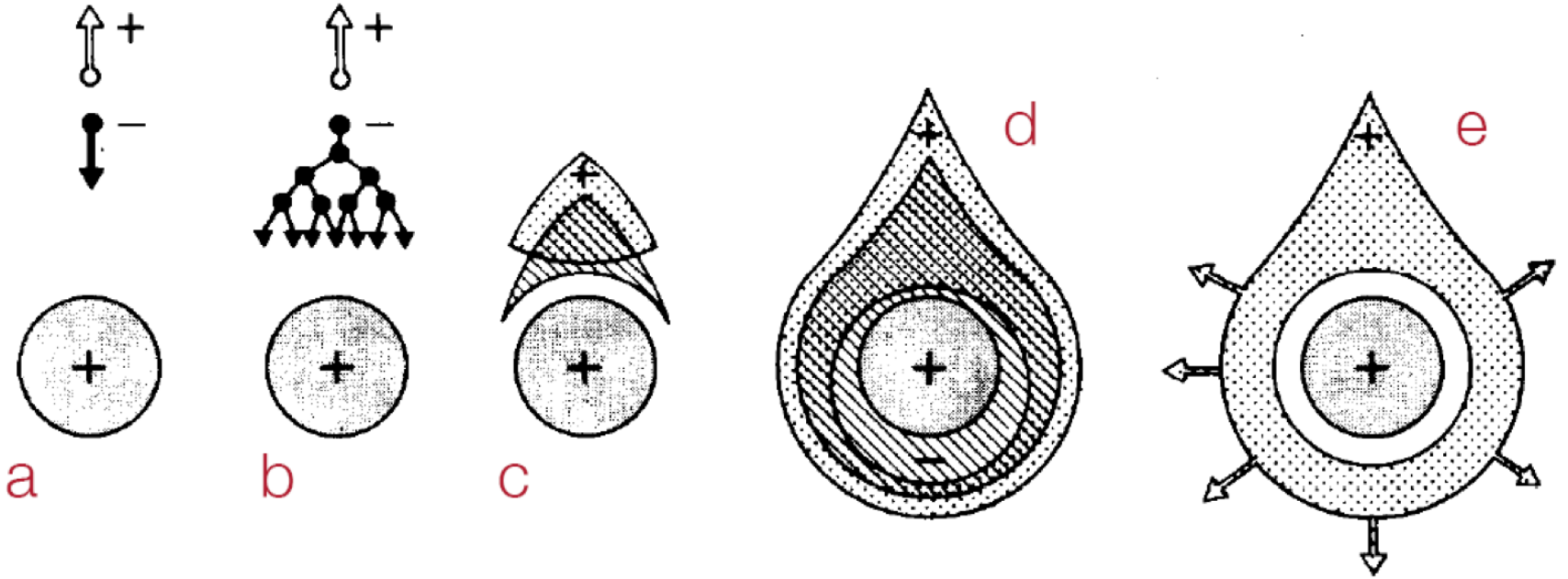
Gas amplification: cylindrical geometry

- To obtain large E and hence large ΔT_e, use very thin wires ($r_i \approx 10 – 50$ µm)
- Within few wire radii, ΔT_e is large enough or secondary ionization
- Strong increase of E → avalanche formation for r → r_i



Avalanche formation close to a wire

Time development of an avalanche near the wire of a proportional counter



a) a single primary electron proceeds towards the wire anode,
b) in the region of increasingly high field the electron experiences ionizing collisions (avalanche multiplication),
c) electrons and ions are subject to lateral diffusion,
d) a drop-like avalanche develops which surrounds the anode wire,
e) the electrons are quickly collected (~1ns) while the ions begin drifting towards the cathode generating the signal at the electrodes.

Avalanche formation close to a wire

Details of effects of lateral diffusion

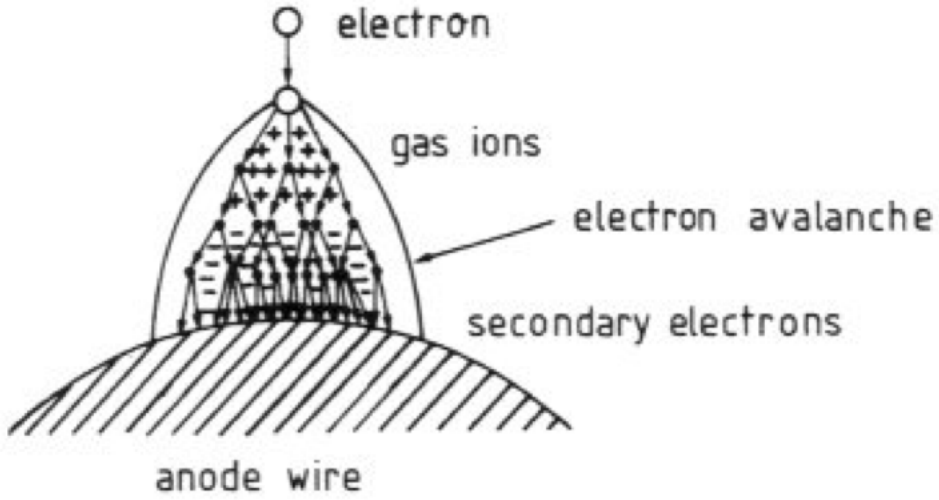


Illustration of the avalanche formation on an anode wire in a proportional counter. By lateral diffusion a drop-shaped avalanche develops.

Proportional counter: cylindrical geometry

Gas amplification:

$$N = A \cdot N_e$$

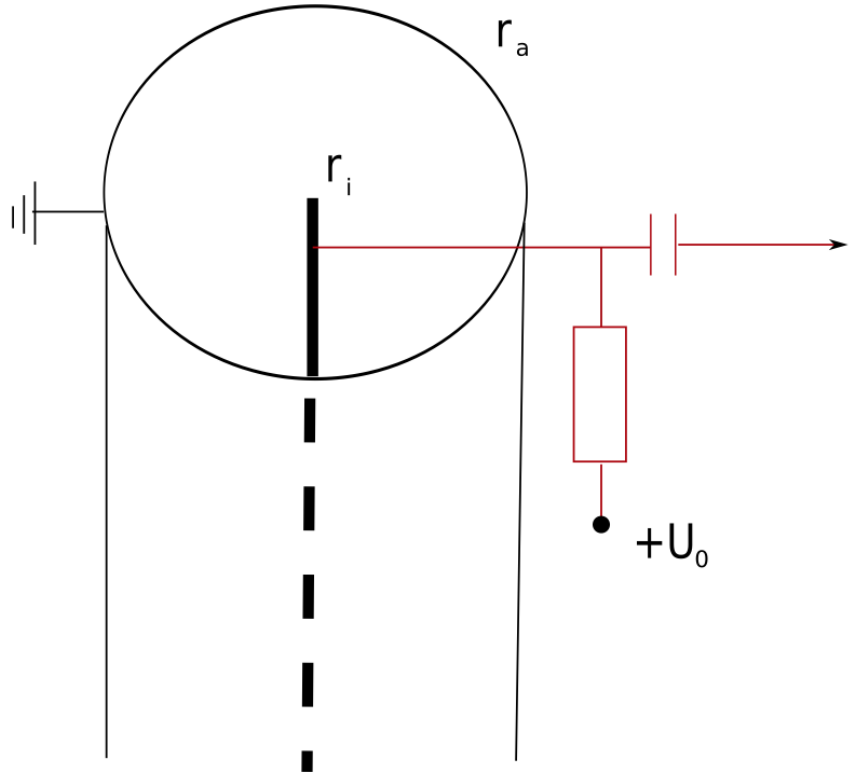
In the vicinity of the wire:

$$A = \exp \int_{r_0}^{r_i} \alpha(x)\,dx$$

The charge avalanche typically builds up within 20 μm from the wire. Effectively it starts at $r_0 = r_i + k\lambda$, where:

λ = mean free path of electrons (~ μm)

k = number of mean free paths needed for avalanche formation



$$\Delta U^- = -\frac{N_e A}{C} \frac{\ln r_0/r_i}{\ln r_a/r_i}$$

$$\Delta U^+ = -\frac{N_e A}{C} \frac{\ln r_a/r_0}{\ln r_a/r_i}$$

Proportional counter: cylindrical geometry

$$\frac{\Delta U^+}{\Delta U^-} = \frac{\ln r_a/r_0}{\ln r_0/r_i} = R$$

Typically: r_a = 1 cm, r_i = 30 μm, kλ = 20 μm for Argon at atmospheric pressure

→ R ≈ 10 !

In a proportional counter, the signal at the anode wire is mostly due to the ion drift !!

Signal timing:

- Rise time of electron signal: $\Delta t^- = \frac{\ln(r_a/r_i)}{2\mu_{-U_0}}(r_0^2 - r_i^2)$ → order of ns
- Ion signal slow, Δt^+ order of 10 ms

→ differentiate with $R_{diff} \cdot C$

E.g. if $R_{diff} \cdot C \approx$ 1ns, the time structure of individual ionization clusters can be resolved (see next slide)

Proportional counter

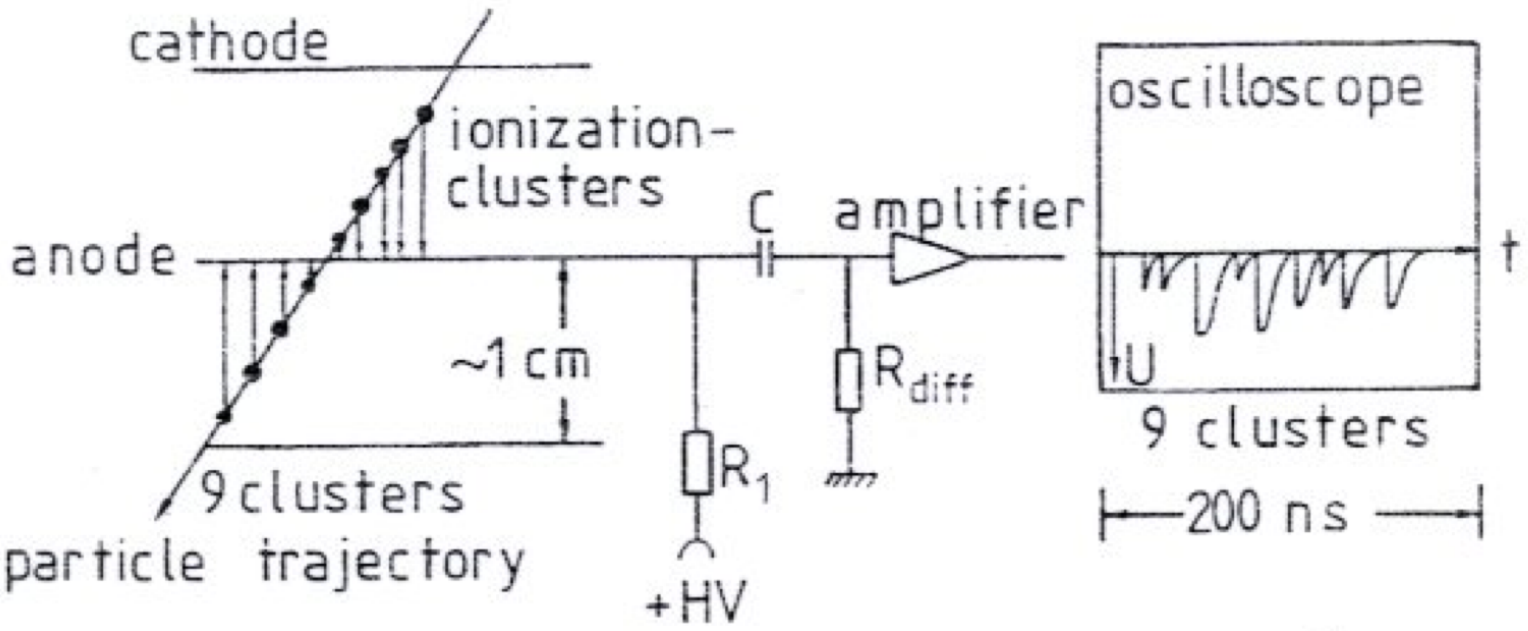
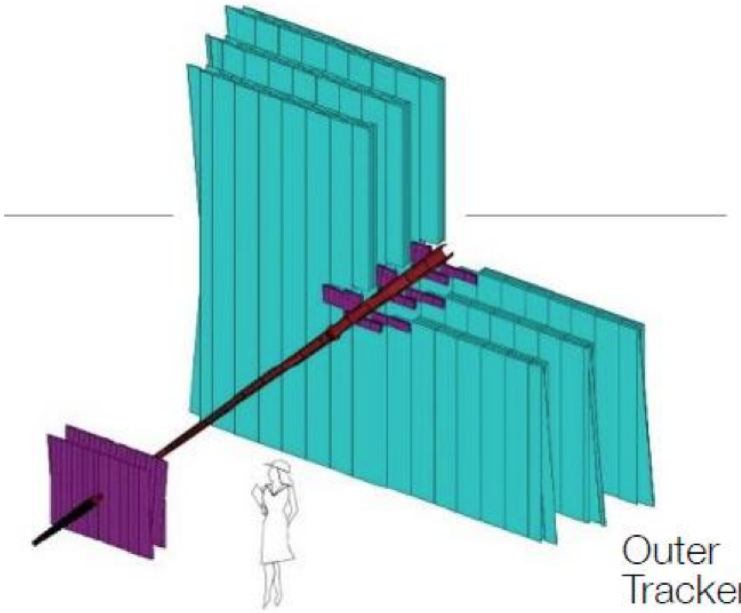


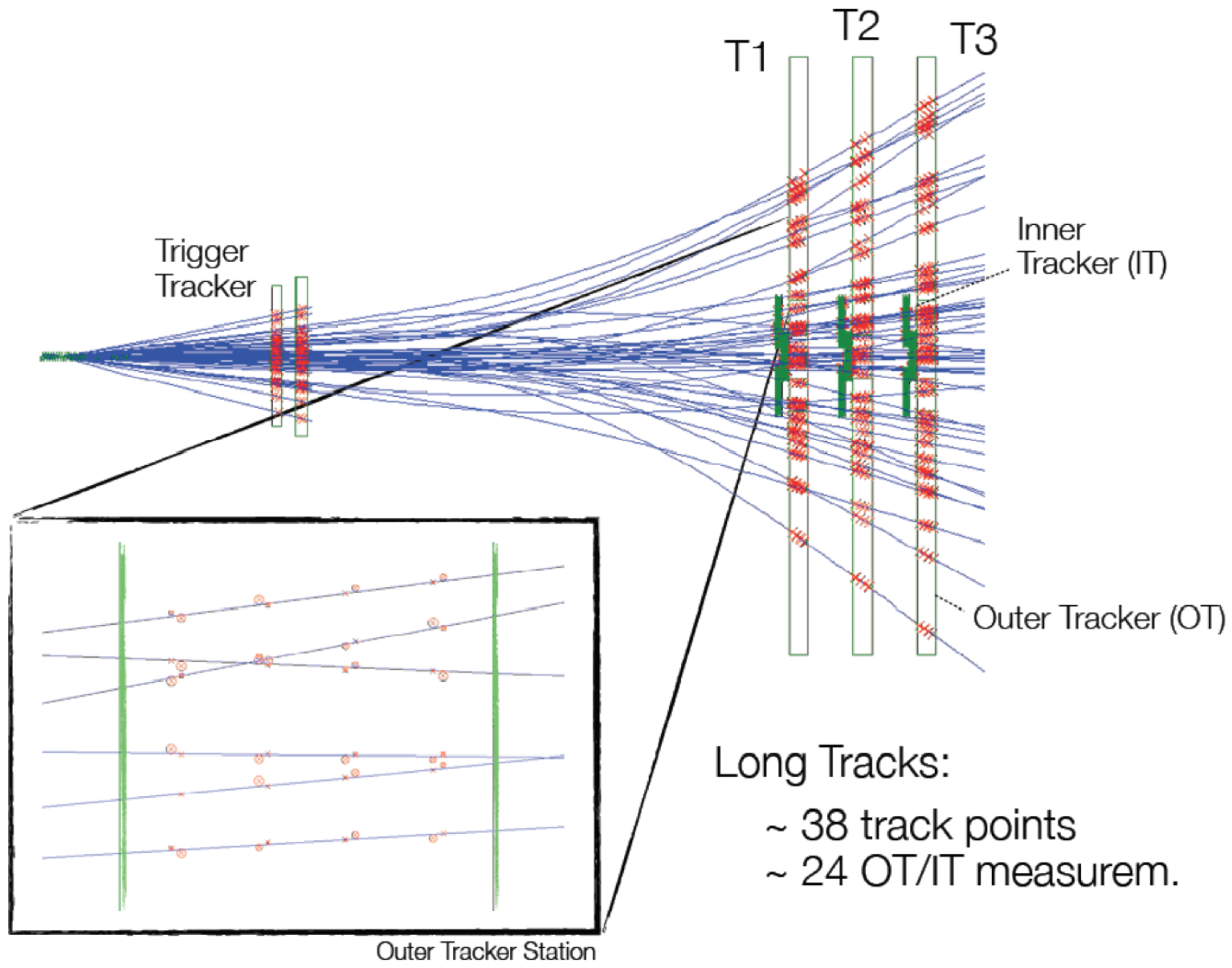
Illustration of the time structure of a signal in the proportional counter

LHCb outer tracker: straw tubes



- **double layer of straw tubes**
- **3 chambers with 4 layers (18 modules each)**

LHCb outer tracker: straw tubes

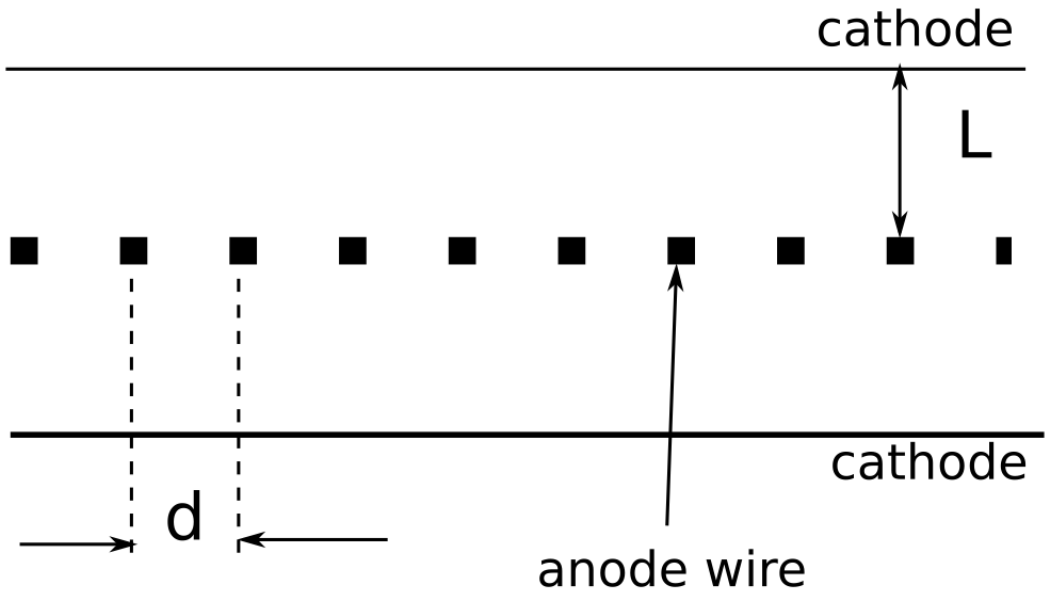


Multi-wire proportional chamber - MWPC

Planar arrangement of proportional counters, without separating walls

G. Charpak at al., NIM 62 (1968) 202

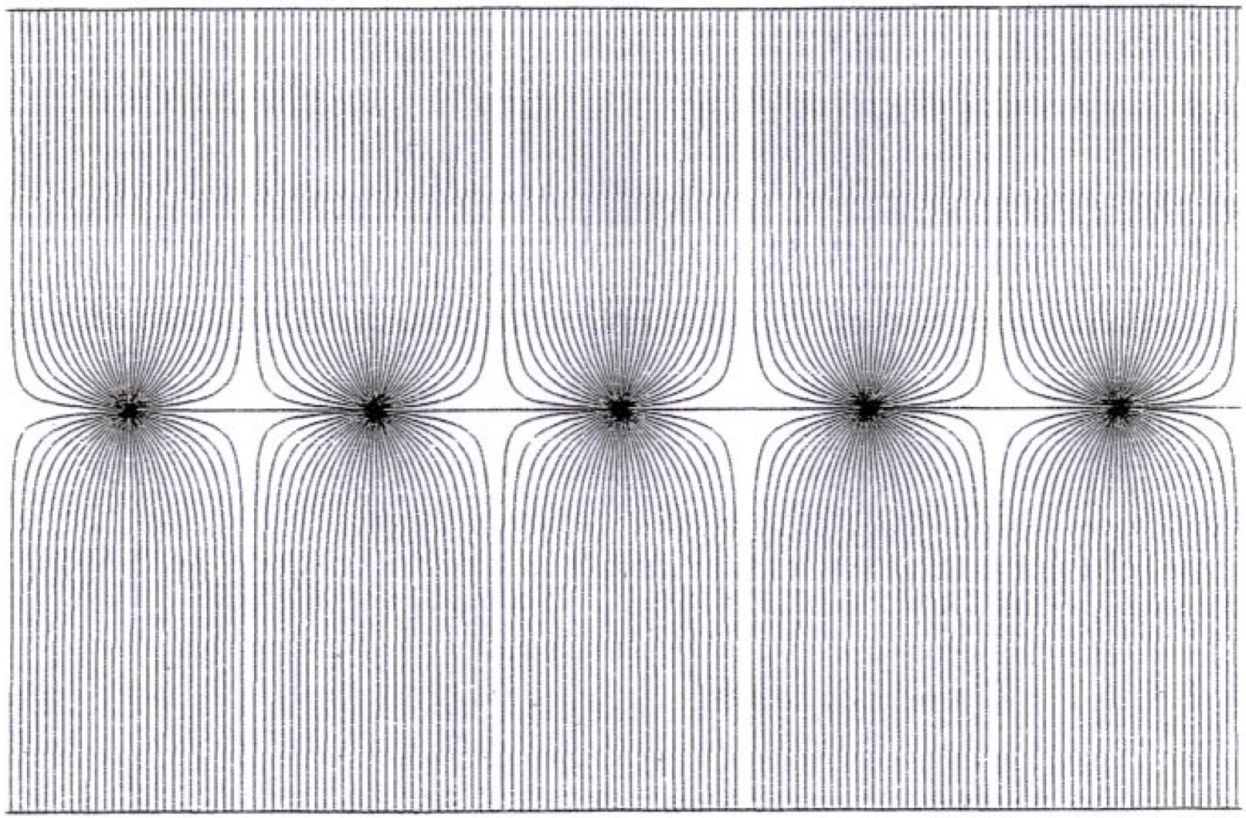
Nobel prize 1992



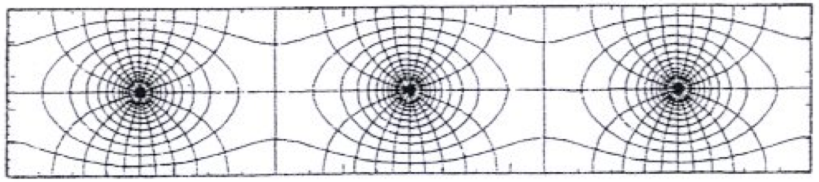
Tracking of charged particles, large area coverage, high rate capability, moderate pid capabilities via dE/dx

MWPC: electric field

Typical geometry of electric field lines in MWPC:



Typical parameters:
d = 2-4 mm
r_i = 15-25 µm
L = 3-6 mm
U_0 = several kV
Total area: many m^2



In the vicinity of the anode wires: radial field

Close to the cathodes: homogeneous, as parallel-plate capacitor

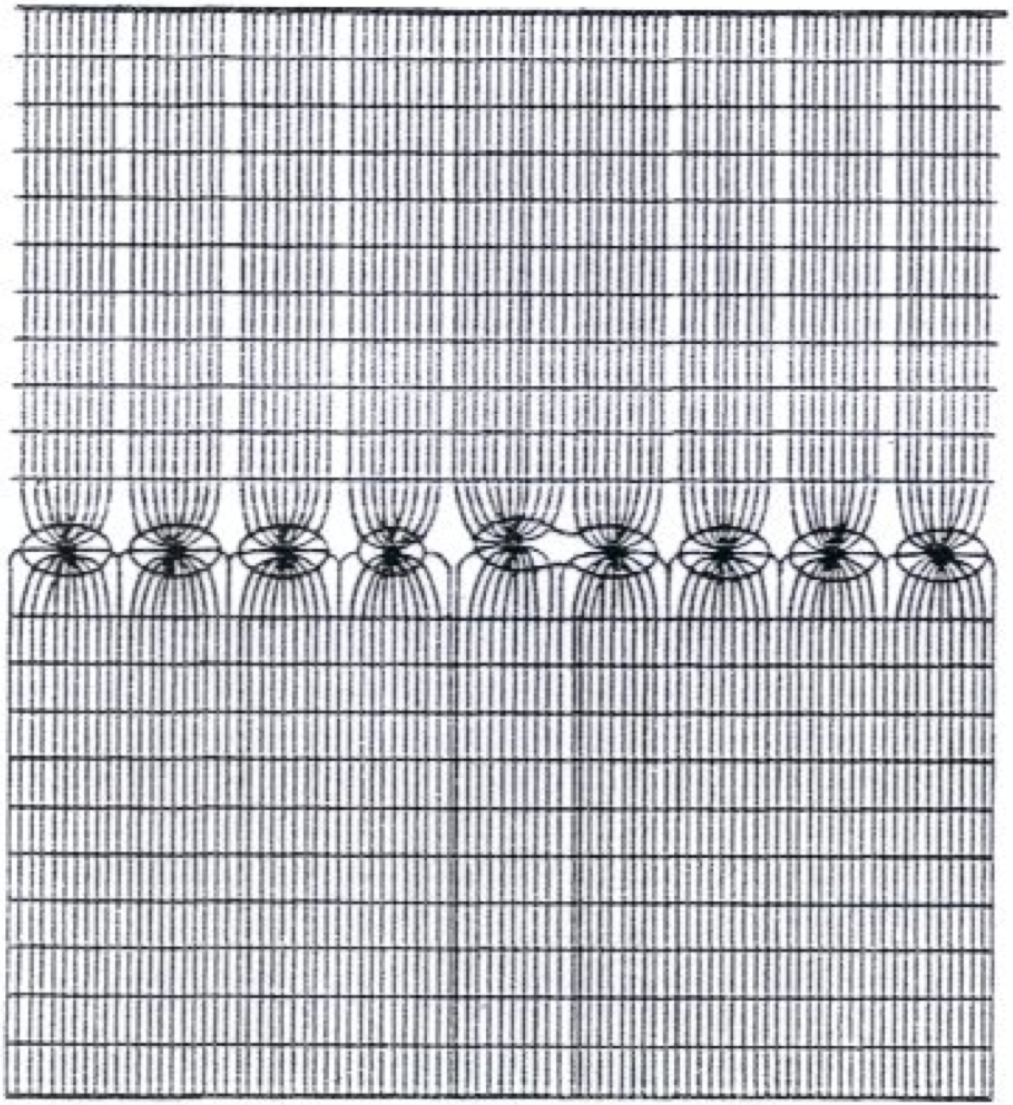
MWPC: mechanical precision

Field lines, and equipotential lines

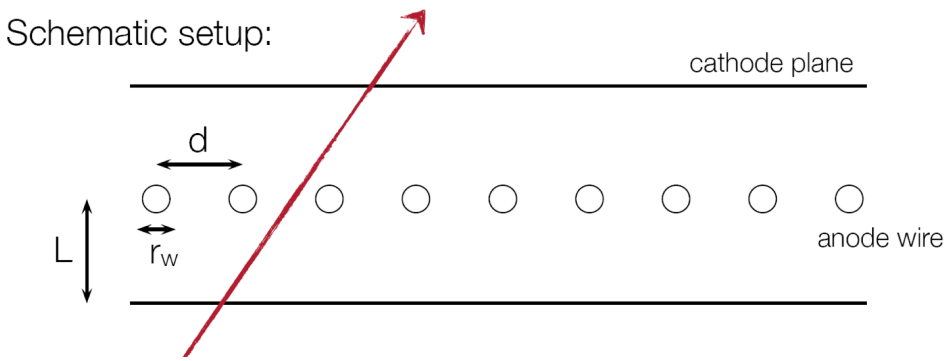
Difficulty evident:

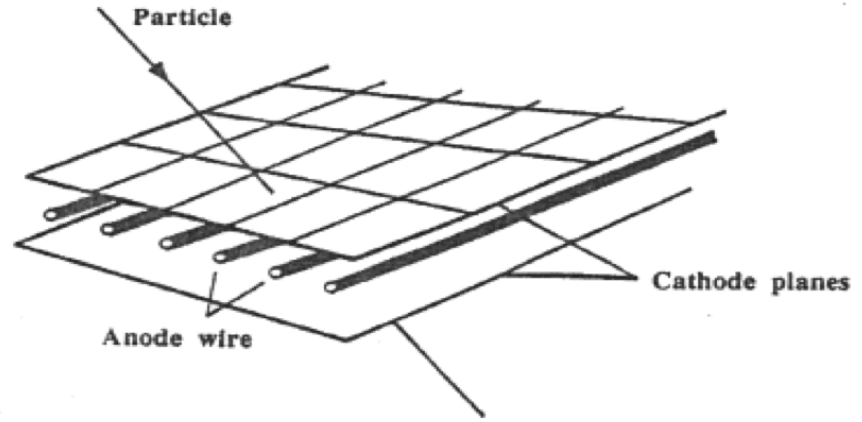
Even small geometric displacements of an individual wire lead to effects on the field quality

Need of high mechanical precision, both for geometry and wire tension (electrostatic effects and gravitational wire sag, see later)



MWPC: signal

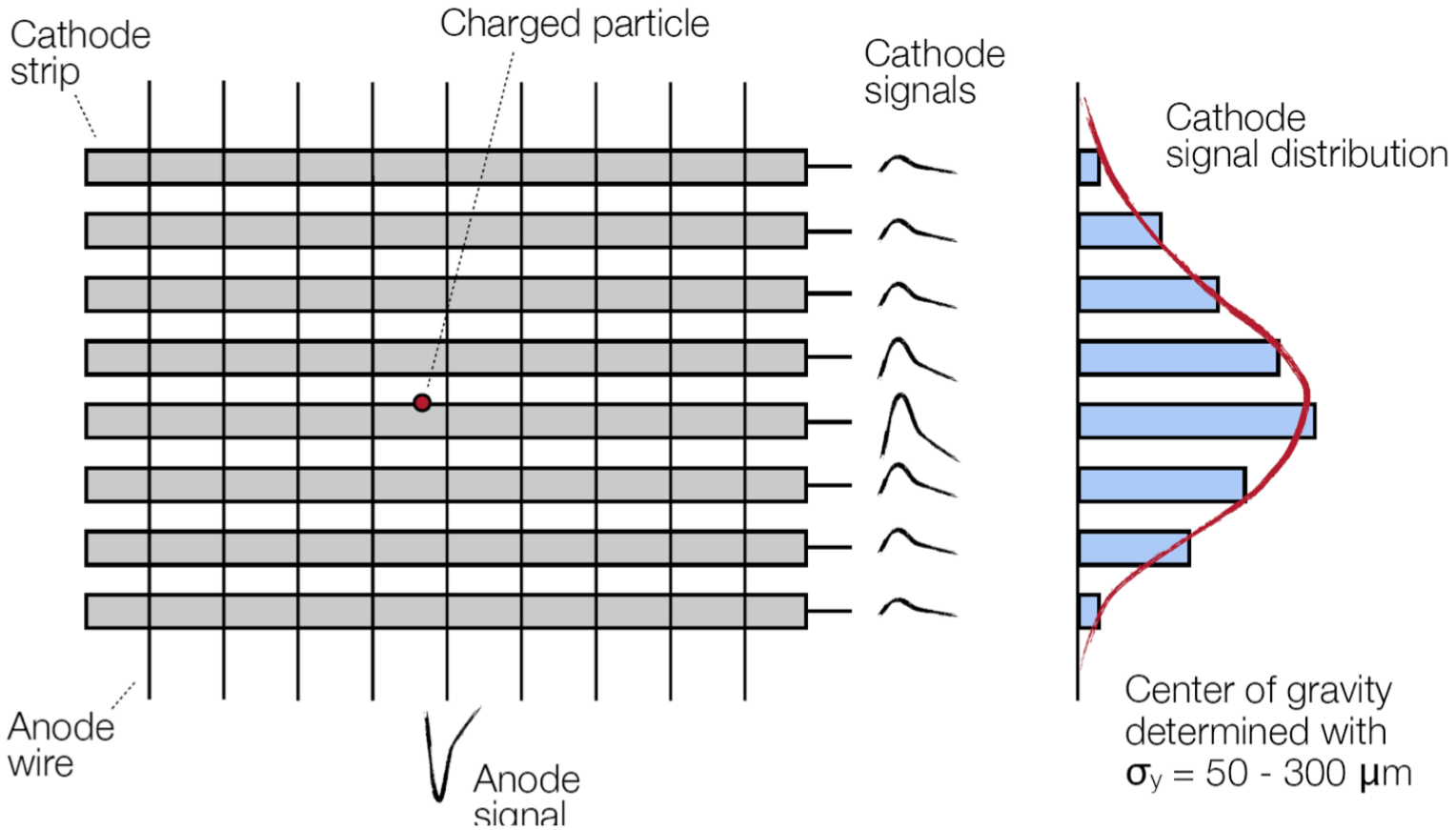




- Electrons from primary and secondary ionization drift to the closest anode wire (signal on 1 wire!)
- In the vicinity of the wire: gas amplification → formation of avalanche
  Ends when the electrons reach the wire, or when the space charge of positive ions screens the electric field below a critical value
- The signal is generated to electron- and (MOSTLY!) slow ion-drift

MWPC: spatial point resolution

- Perpendicular to wire: since information comes only from closest wire → δx = **d/√12** = e.g. 577 μm for d = 2 mm not quite so precise!
- Then: segment the cathode in strips: the induced signal is spread over more strips. Using the **center of gravity** of the signal (charge sharing), high precision of 50 – 300 μm can be reached



MWPC – resolution of ambiguities

When 2 particles cross the MWPC, with only one orientation of the cathode strips we are left with the ambiguity of the combinations of signals •• ∘∘

→ 4 possibilities: 2 real, 2 ghosts

Possible solution: use different orientation of strips on the second cathode plane

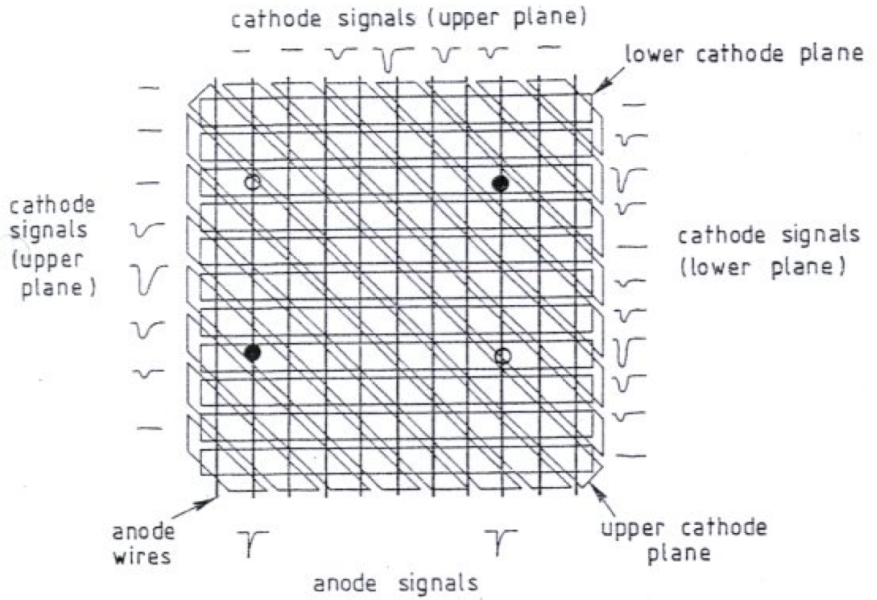
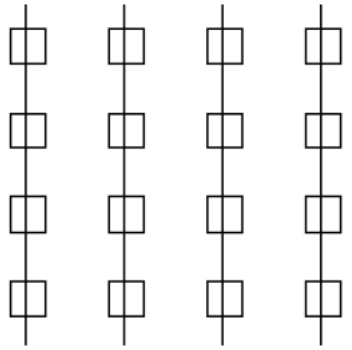


Illustration of the resolution of ambiguities for two particles registered in a multi-wire proportional chamber

For high multiplicities and high hit density: segment the **cathode in pads** for a 2-dimensional measurement

Disadvantage: number of readout channels grows quadratically (expensive!)



Overview

Ionization mode:

Full charge collection

No multiplication – gain = 1

Proportional mode:

Multiplication of ionization

Signal proportional to ionization

Measurement of dE/dx

Secondary avalanches need quenching

Gain ~ 10^4 – 10^5

Limited proportional mode (saturated, streamer):

Strong photoemission

Strong quenches or pulsed HV

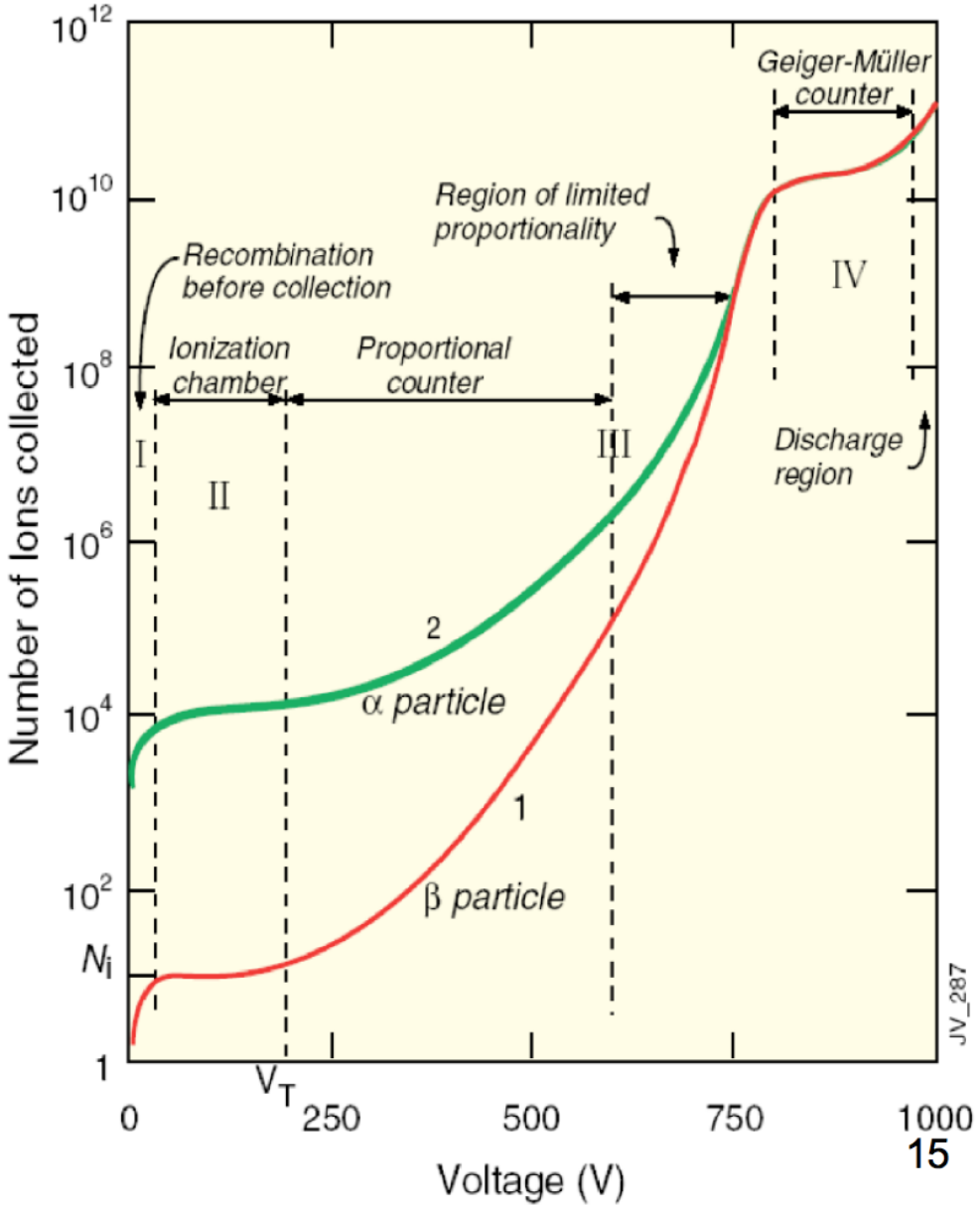
Gain ~ 10^{10}

Geiger mode:

Massive photoemission

Full length of anode wire affected

Discharge stopped by HV cut



Next time: May 17, 2017

- MWPC spatial resolution: wire stability and limitation in spatial resolution
- → micro-pattern gas detectors (microstrip gas detector, gas electron multiplier)

- DRIFT CHAMBERS
  - Cylindrical drift chamber
  - Jet drift chamber

- TIME PROJECTION CHAMBERS