Gaseous Ionization Detectors

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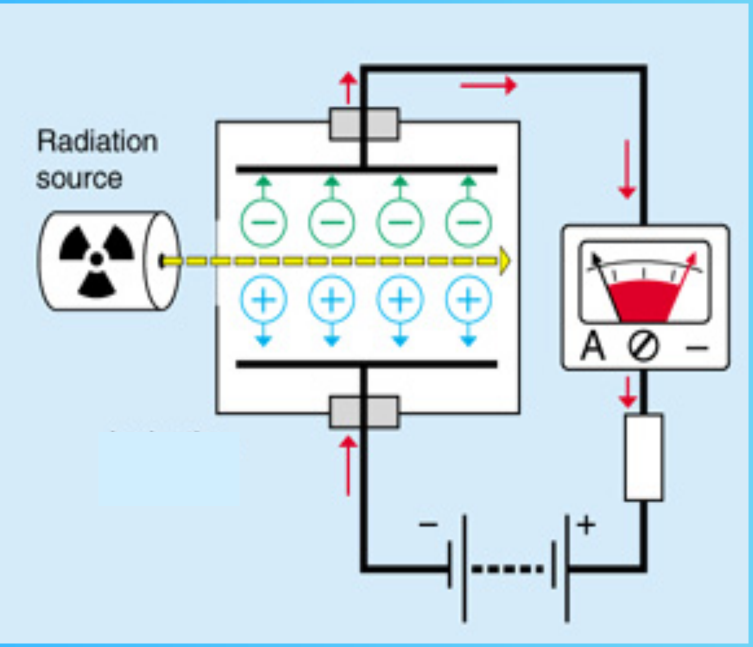
Gaseous detectors sense the movement of charge (electrons + ions), produced by ionizing radiation, induced by an electric field



Interaction of charged particles in a gas:

Primary processes:

- excitation: X → X*
- ionization: X → X^++e^-
- dissociation: X → Y*+Z*
- elastic collision: X → X

Secondary processes:

- non-radiative transitions: X*+Y → X+Y*
- radiative transitions: X* → X+*hν*
- Penning effect: X*+Y → X+Y^++e^-
- charge exchange: X^++Y → X+Y^+
- electron capture: X+e^- → X^-+*hν*
- recombination: X^++e^-→X+*hν*
- secondary ionization: e^-+X→X^++2e^-

Tertiary processes:

- photoelectric effect: *hν*+X→X^++e^-
- …

Primary processes

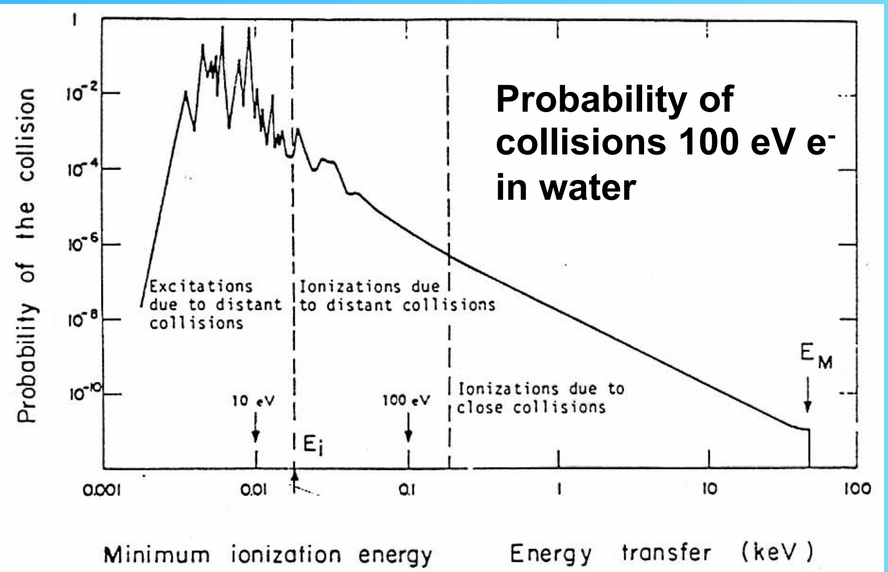
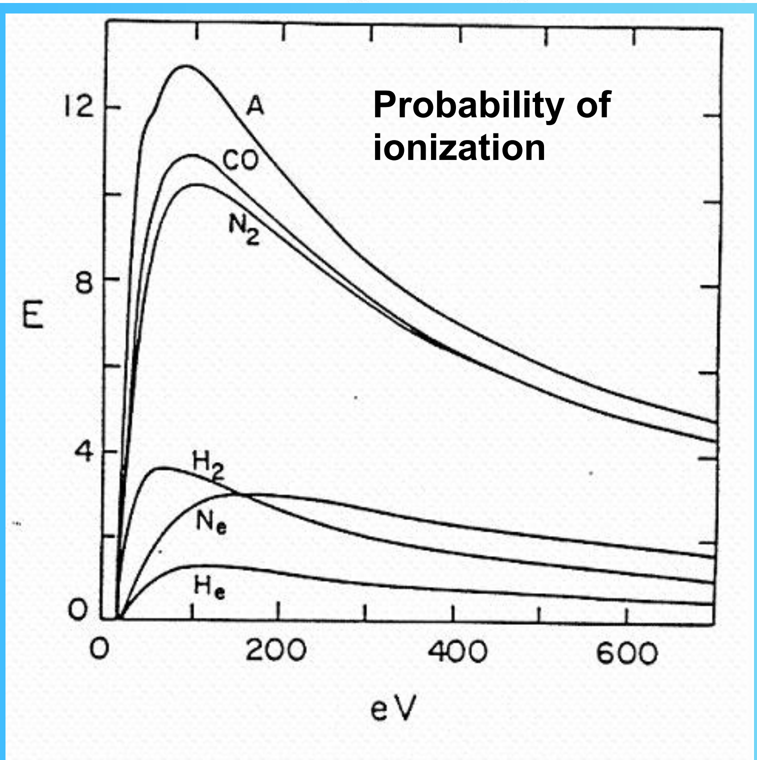


TABLE 5-1 Values of the Energy Dissipation per Ion Pair (the *W*-Value) for Different Gases[a]

Gas	*W*-Value (eV/ion pair) Fast Electrons	Alpha Particles
Ar	26.4	26.3
He	41.3	42.7
H_2	36.5	36.4
N_2	34.8	36.4
Air	33.8	35.1
O_2	30.8	32.2
CH_4	27.3	29.1

Number of pairs N_P: $$N_P = \frac{\Delta E}{W}$$



Fano factor *F*: $$\sigma_{N_P} = \sqrt{F \cdot N_P}$$

Table 6.2. Measured Fano factors for various gas mixtures

Gas	*F*	Ref.
Ar 100%	$0.2^{+0.01}_{-0.02}$	[6.4]
	$<0.40 \pm 0.03$	[6.5]
Ar + 80% Xe	$<0.21 \pm 0.03$	[6.5]
Ar + 24% Xe	$<0.23 \pm 0.02$	[6.5]
Ar + 20% Xe	$<0.16 \pm 0.02$	[6.5]
Ar + 5% Xe	$<0.14 \pm 0.03$	[6.5]
Ar + 5% Kr	$<0.37 \pm 0.06$	[6.5]
Ar + 20% Kr	$<0.12 \pm 0.02$	[6.5]
Ar + 79% Kr	$<0.13 \pm 0.02$	[6.5]
Xe 100%	$<0.15 \pm 0.01$	[6.6]

Movement of electrons and ions

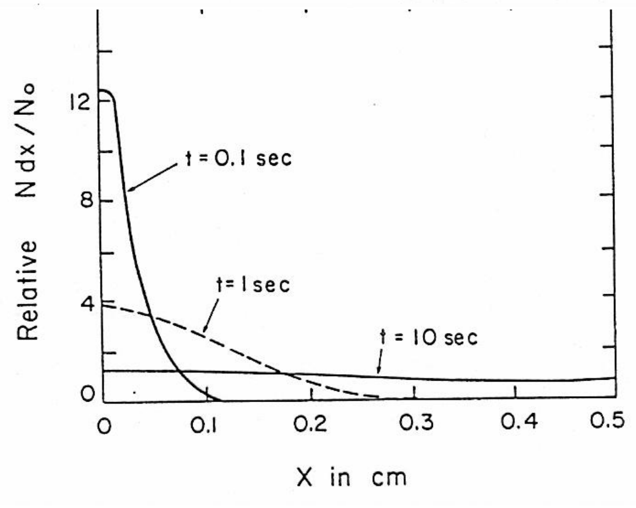
• **Thermal diffusion by interaction with gas molecules at T and p**

$$\frac{1}{n_0}\frac{dn}{dx} = N(x_0, \sigma_D) \quad , \quad \sigma_D = \sqrt{2Dt}$$

$$D \propto \frac{T^{3/2}}{m^{1/2} p}$$: diffussion coefficient

Classical mean free path, velocity, diffusion coefficients, and mobility for molecules, under normal conditions[18-21]

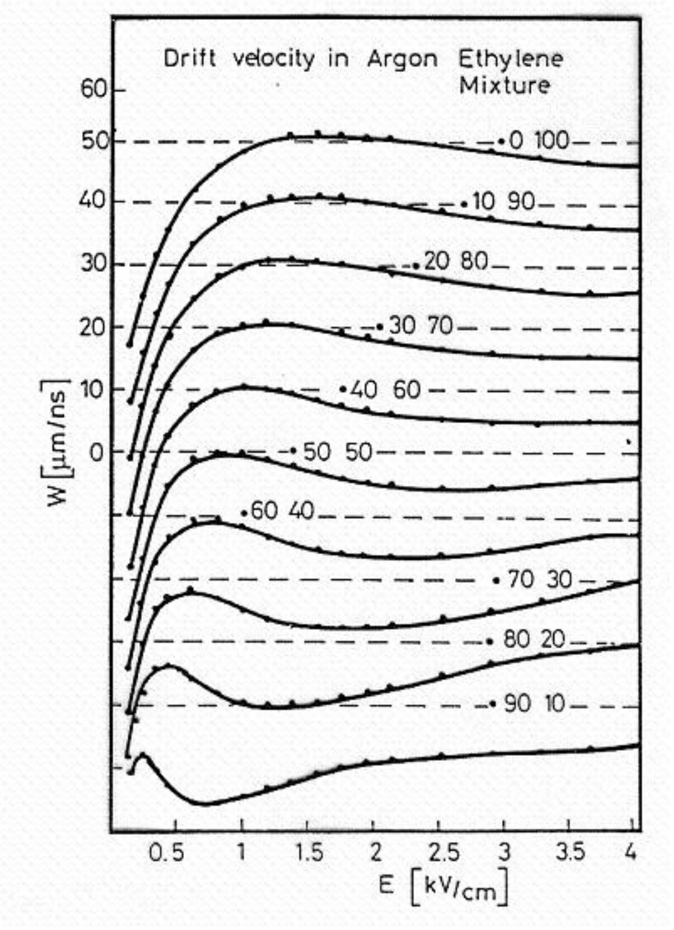
Gas	λ (cm)	u (cm/sec)	D^+ (cm²/sec)	μ^+ (cm² sec⁻¹ V⁻¹)
H_2	1.8×10^{-5}	2×10^{5}	0.34	13.0
He	2.8×10^{-5}	1.4×10^{5}	0.26	10.2
Ar	1.0×10^{-5}	4.4×10^{4}	0.04	1.7
O_2	1.0×10^{-5}	5.0×10^{4}	0.06	2.2
H_2O	1.0×10^{-5}	7.1×10^{4}	0.02	0.7



• **Drift velocity under electric field E**

ions: $$v = \mu \frac{E}{p} \quad , \quad \mu = \frac{eD}{kT}$$

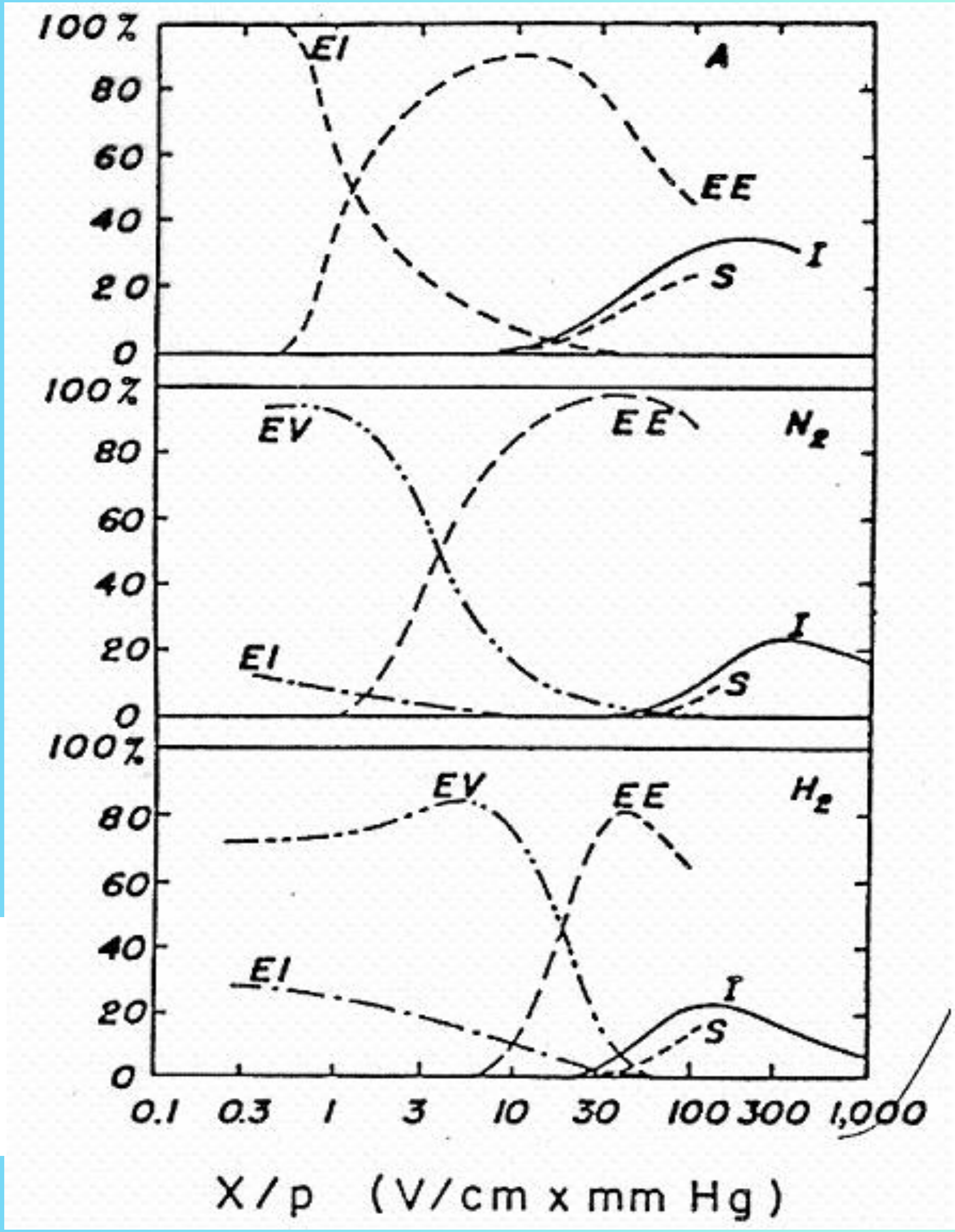
electrons:



Secondary ionizations

If electric field is high enough, moving electrons can ionize new molecules

Energy fraction into different processes



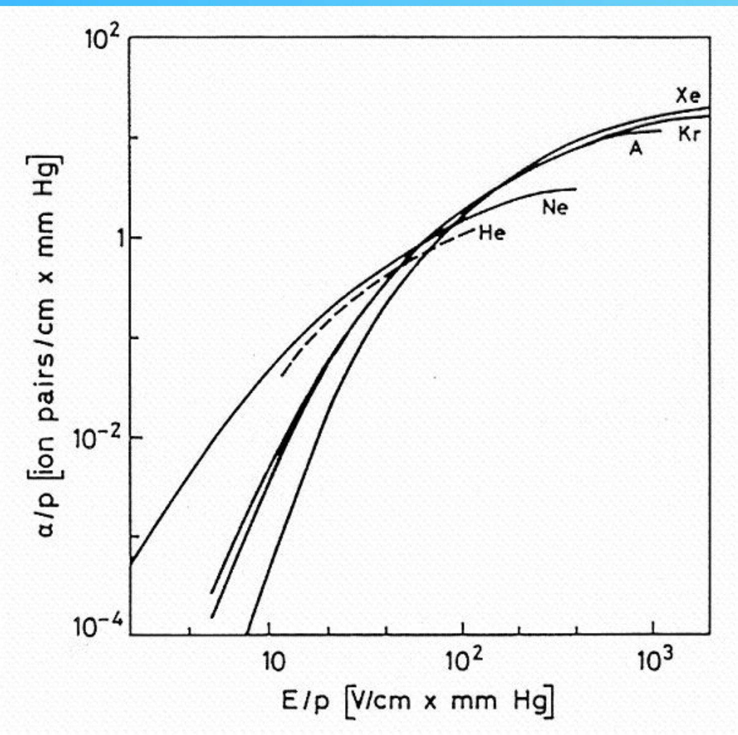
EI: elastic collisions
EV: vibrational excitations
EE: radiative excitations
I: ionizations

Gas multiplication effect

If electric field is high enough the secondary secondary ionization can take place several times

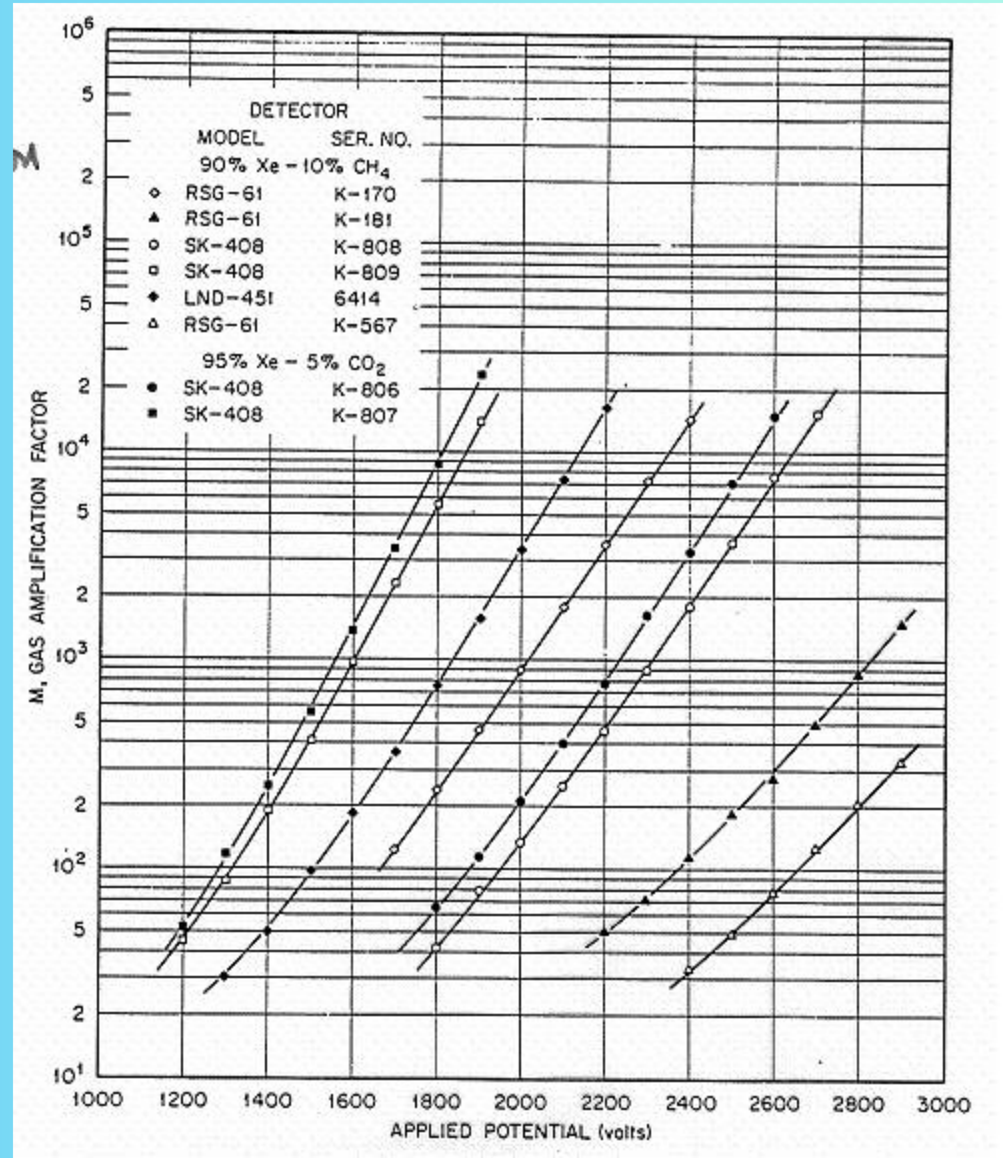
Townsend coefficient α $\alpha = \frac{1}{\lambda_I}$

λ_I : mean free path for ionization



Multiplication factor M

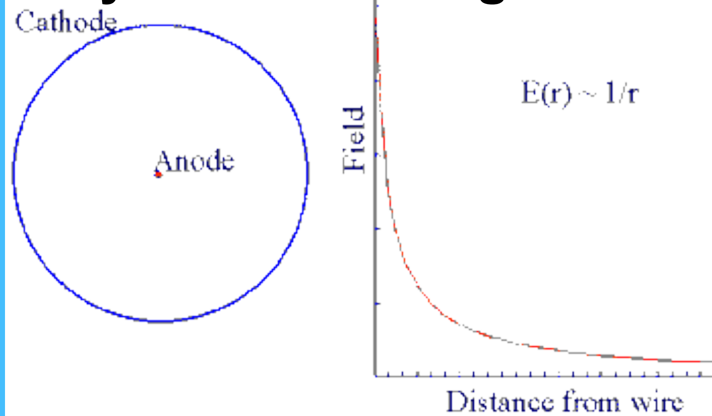
$$M = e^{\int \alpha(x)\,dx}$$

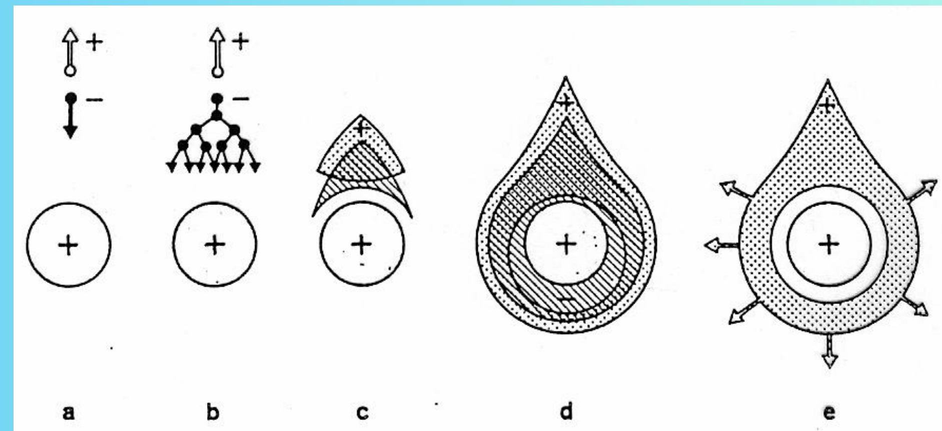


Avalanche formation

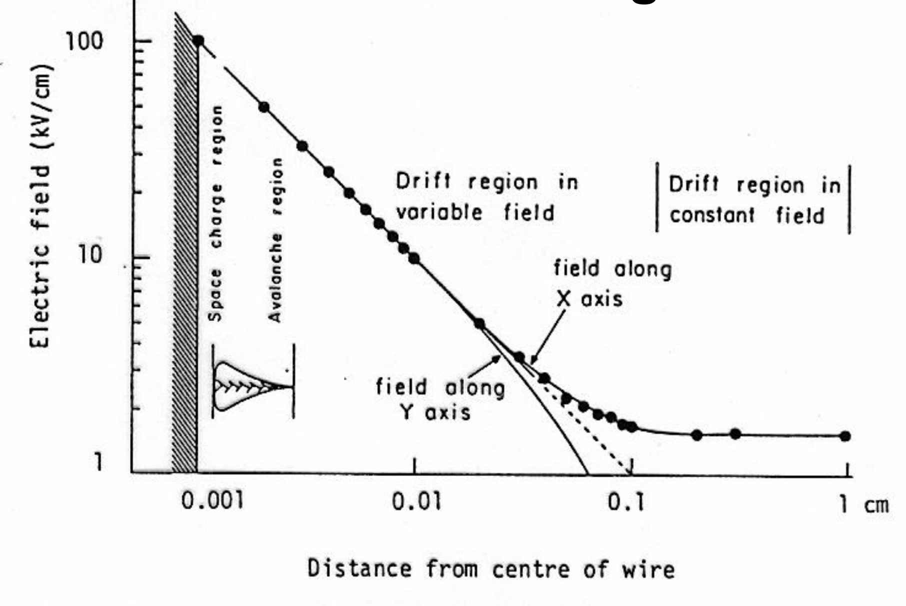
In cylindrical-like configuration the avalanche is formed very close to the anode wire

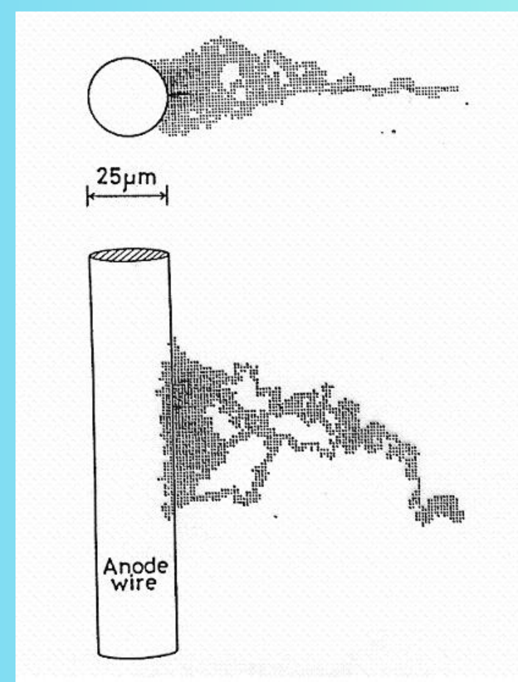
cylindrical configuration



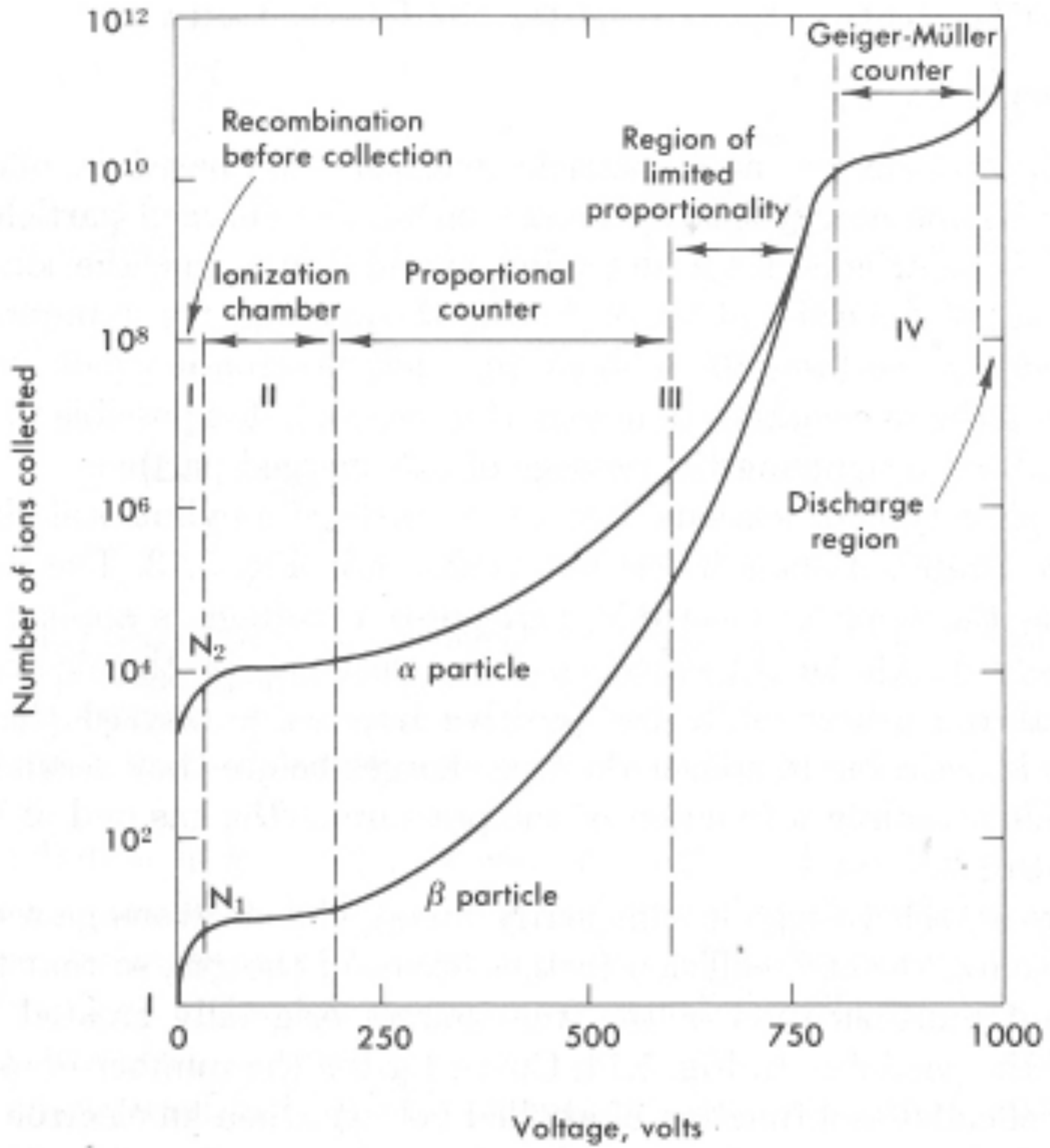


multi-wire configuration





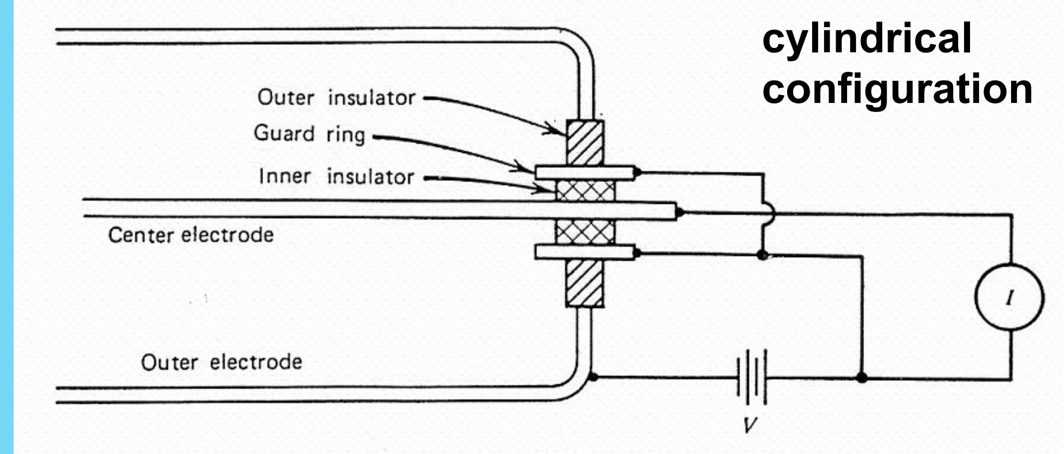
Depending on the magnitude of the electric field there is a variety of configurations and working points



Ionization chamber

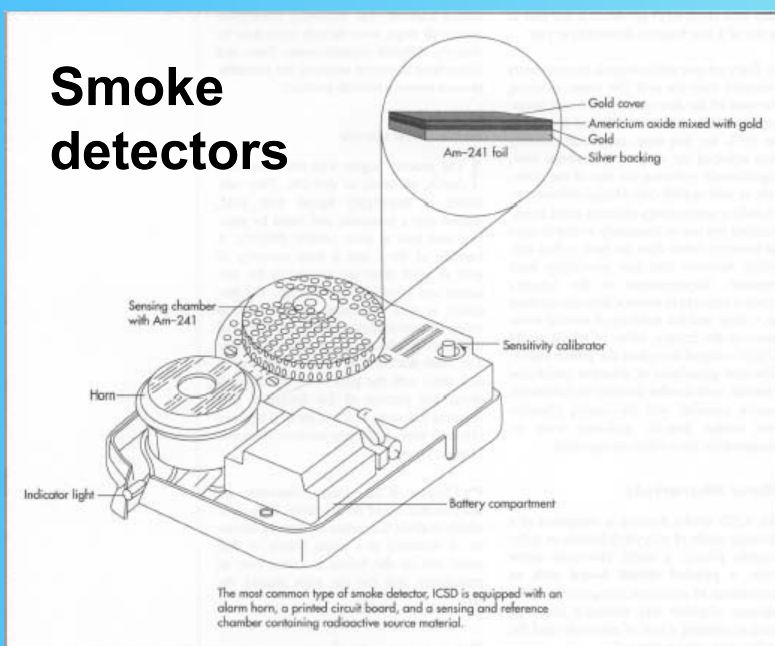
Commonly used in current mode

cylindrical configuration



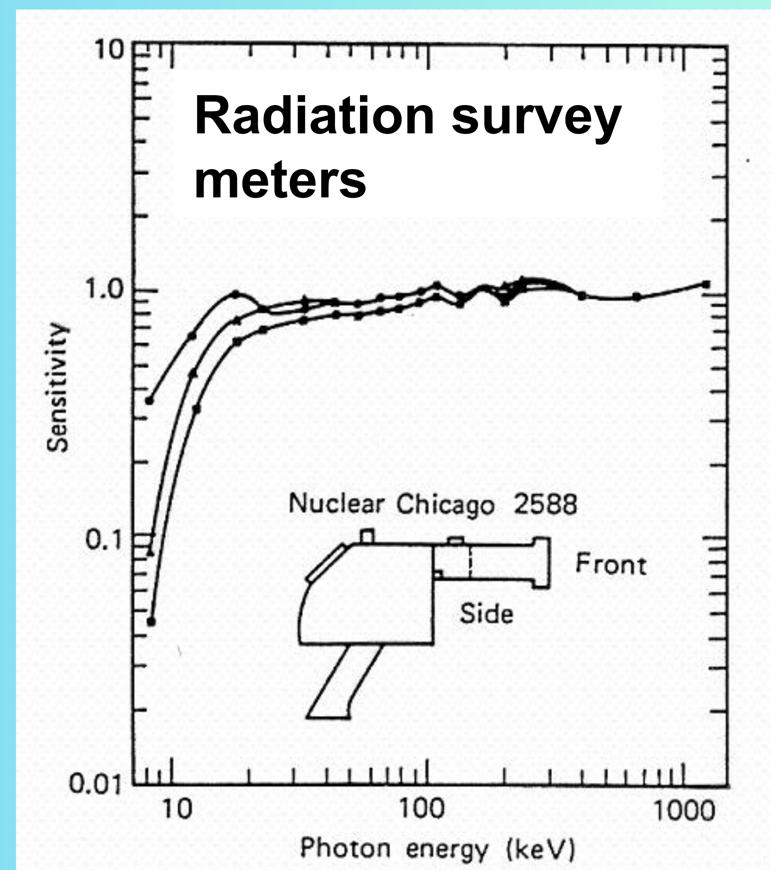
Therapy dosimeter

Smoke detectors



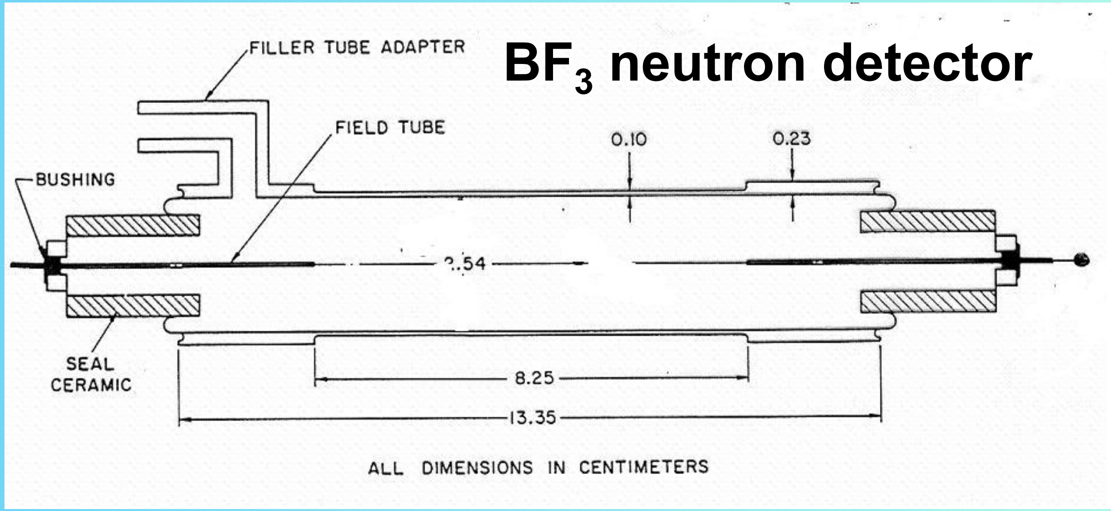
The most common type of smoke detector, ICSD is equipped with an alarm horn, a printed circuit board, and a sensing and reference chamber containing radioactive source material.

Radiation survey meters

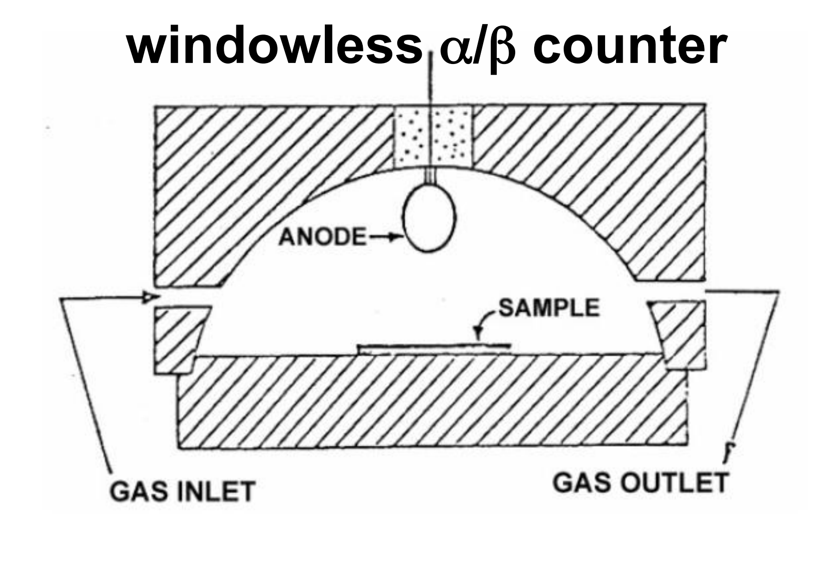


Proportional counters

Cylindrical configuration



2π configuration



Gas-filled chamber as neutron detector

Gases:

- H_2 (recoil)
- ^3He (reaction)
- ^4He (recoil)
- BF_3 (reaction)

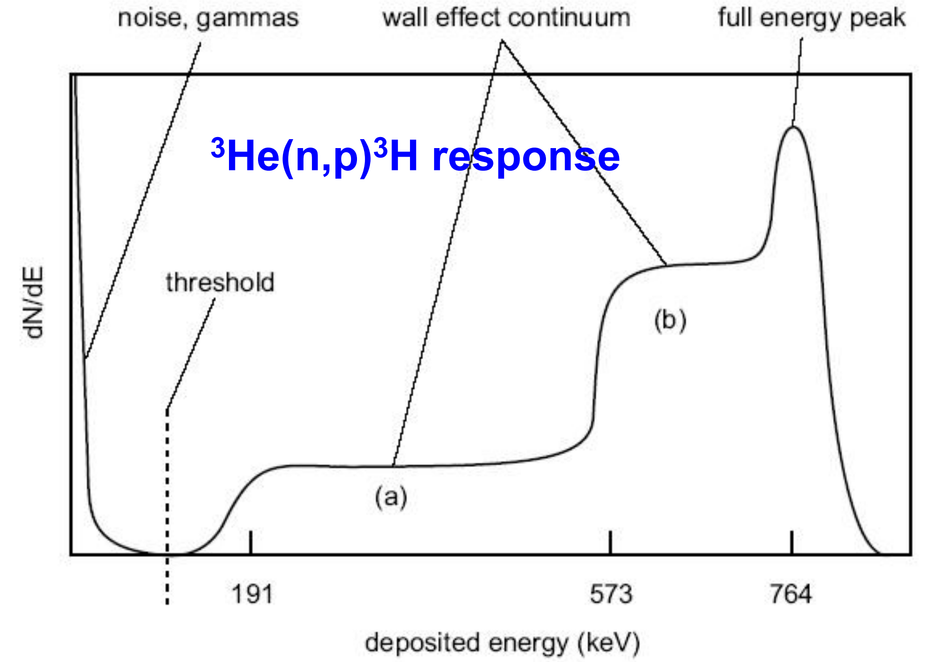


Figure 1: Expected pulse height spectrum from a ^{3}He tube. The two steps in the spectrum are caused by one of the reaction products hitting the detector wall. In area (a), the triton energy is fully deposited, but the proton only deposited a fraction of its energy, and vise versa in area (b).

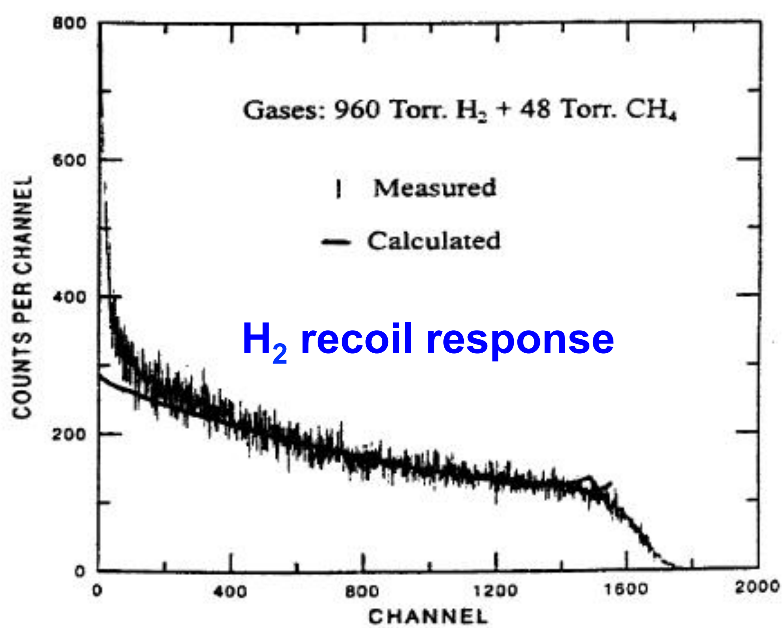
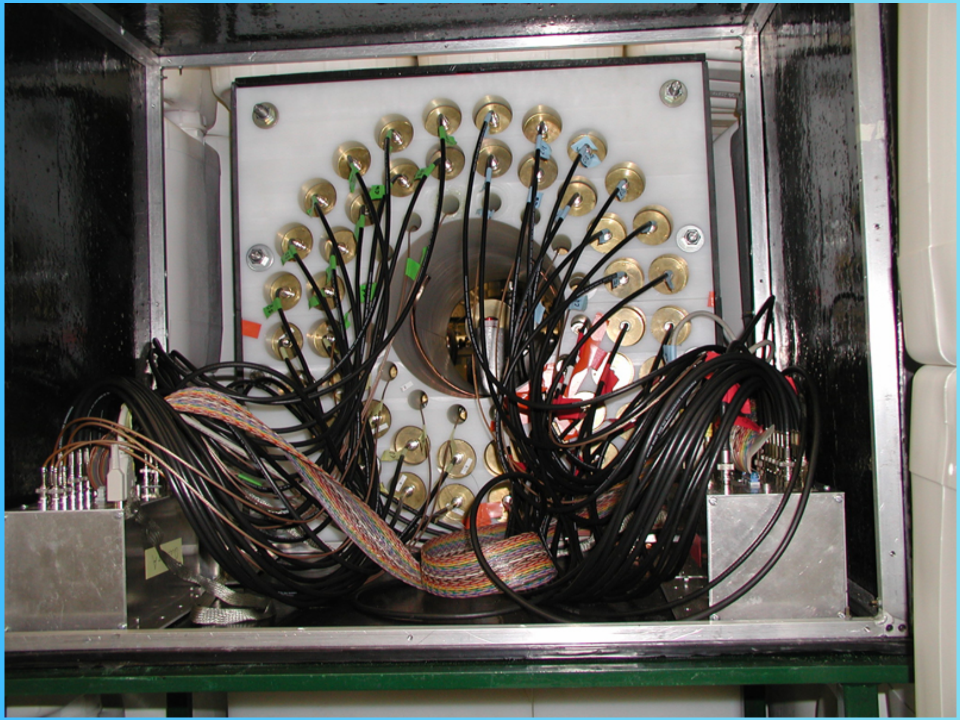


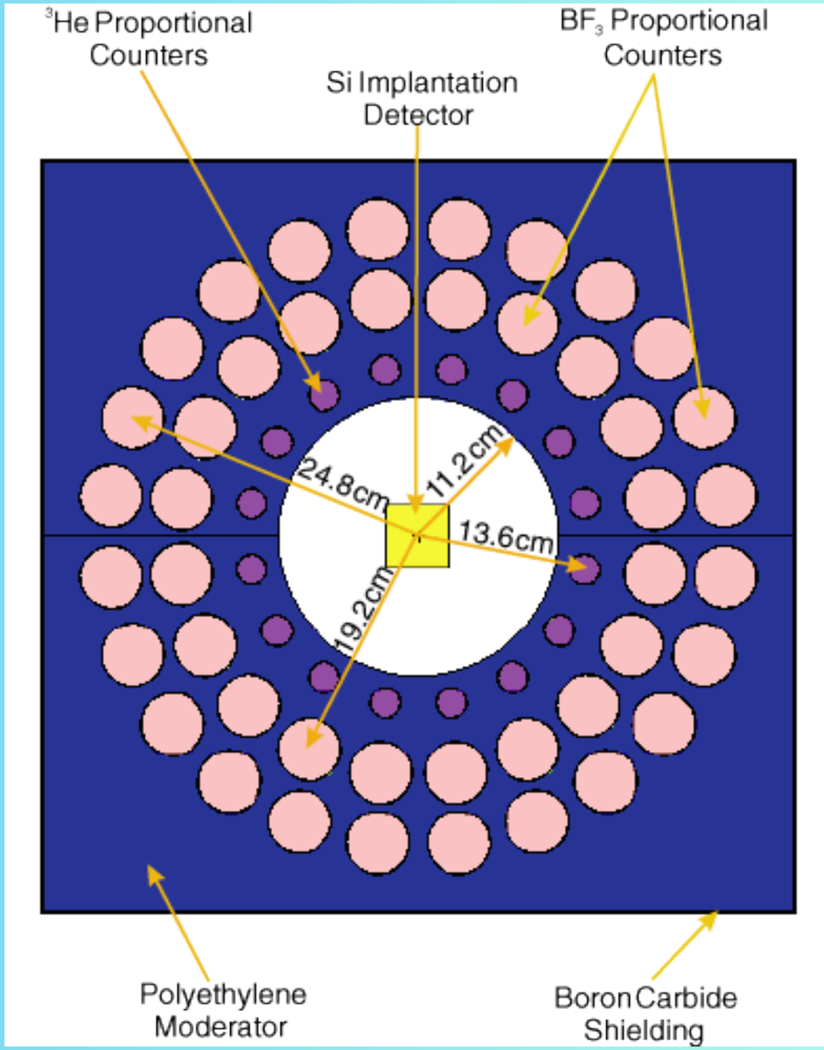
Fig. 1. Measured and calculated pulse height distributions for 0.565 MeV neutrons incident on a cylindrical proportional counter (active volume 38 mm diameter × 178 mm). From Ref.

Moderated cylindrical array: NERO (NSCL-Michigan)

Polyethylene block ($60x60x80 cm^3$)
16 ^3He and 44 BF_3 proportional counters

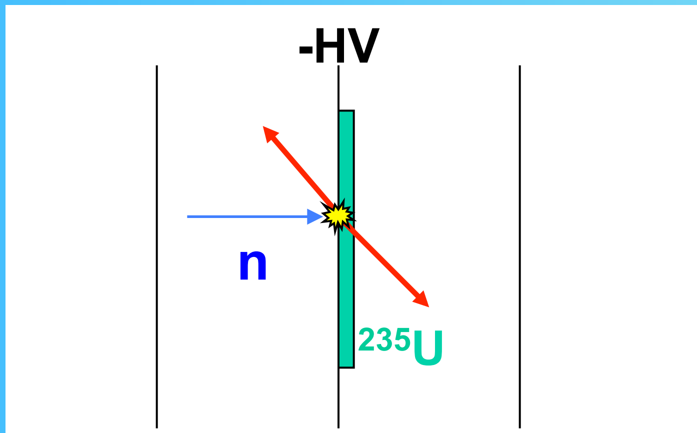
$$\varepsilon = 40\ \%$$





Fission chamber:

Parallel plate with 2 anodes



Very thin deposits

NIMA336 (1993) 226

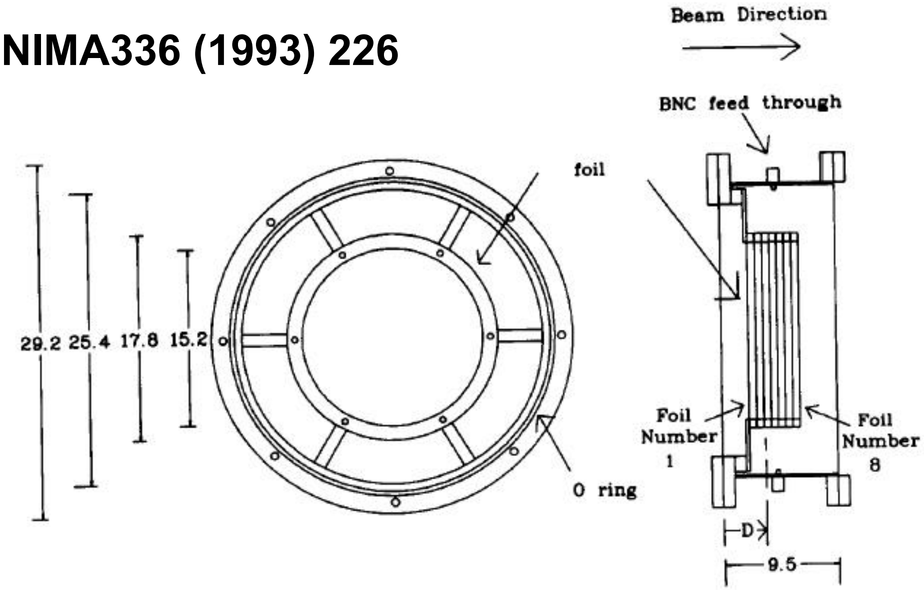
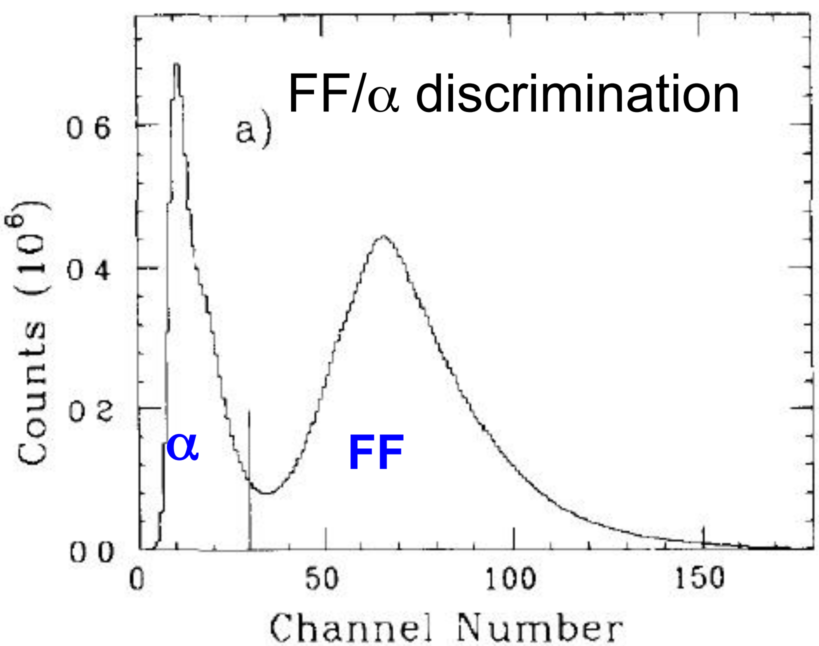


Fig. 1. Schematic diagram of the ionization chamber housing. Dimensions are in centimeters.



Multiple layers

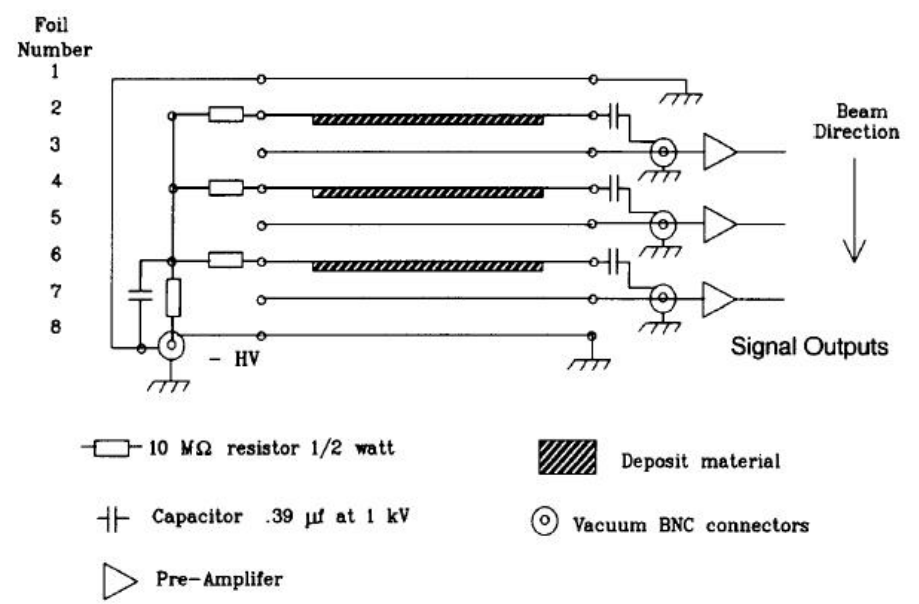
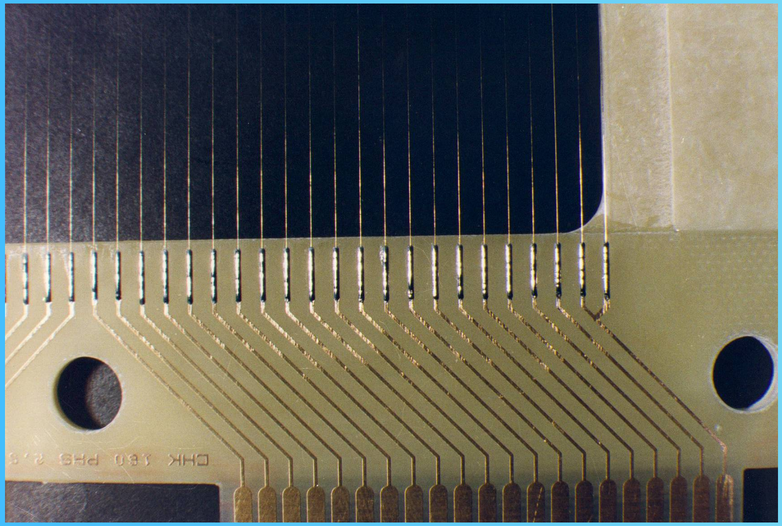
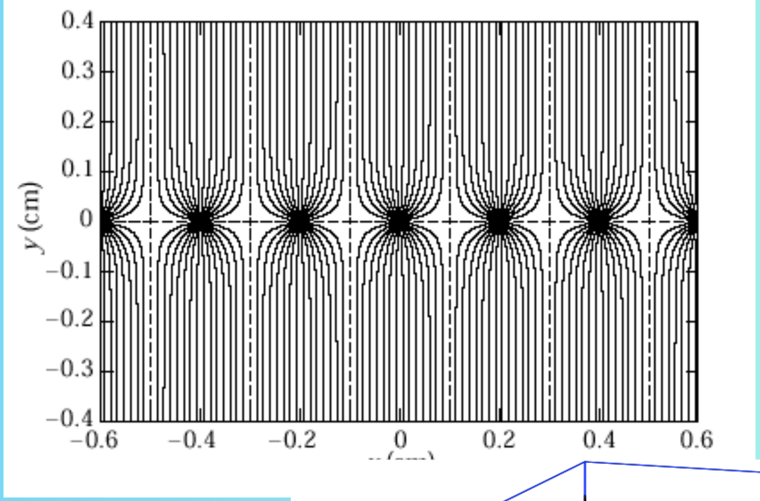
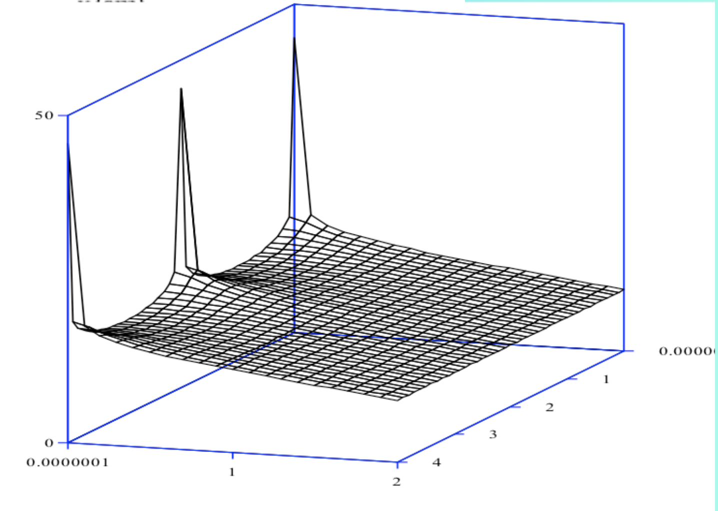


Fig. 2. Electrical wiring diagram of the ionization chamber.

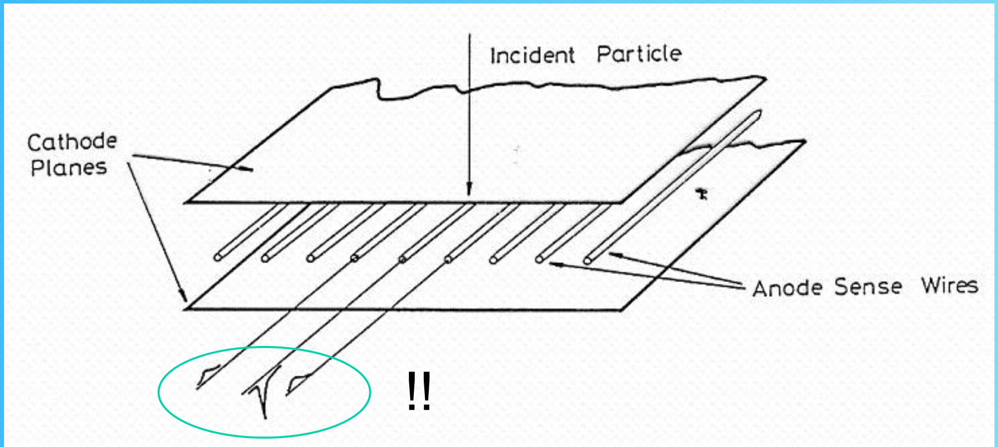
Multi-Wire Proportional Chamber (MWPC)

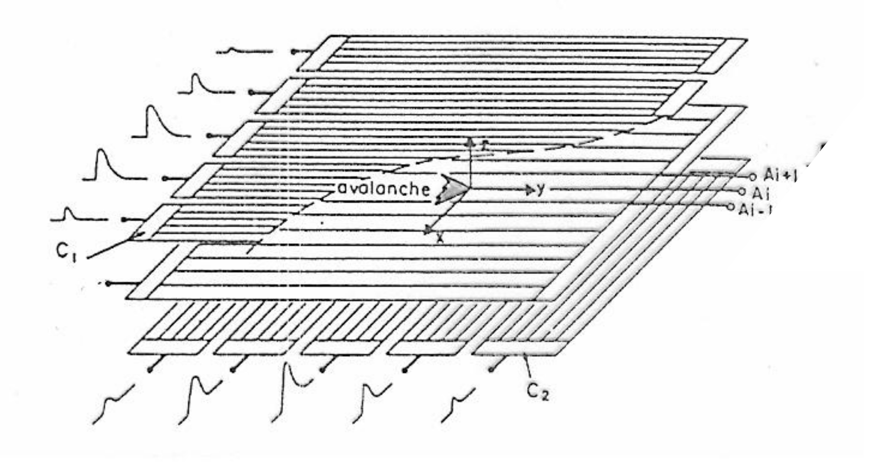






The current induced on electrodes by the avalanche allows 2D localization





Pulse formation:

Shockley-Ramo's Theorem:

- Created charges move according the electric field
- Current is induced in the electrodes by the moving charges in the *weighting* field

$$i(t) = q \cdot \vec{v}\left(\vec{r}(t)\right) \cdot \vec{E}_W\left(\vec{r}(t)\right)$$

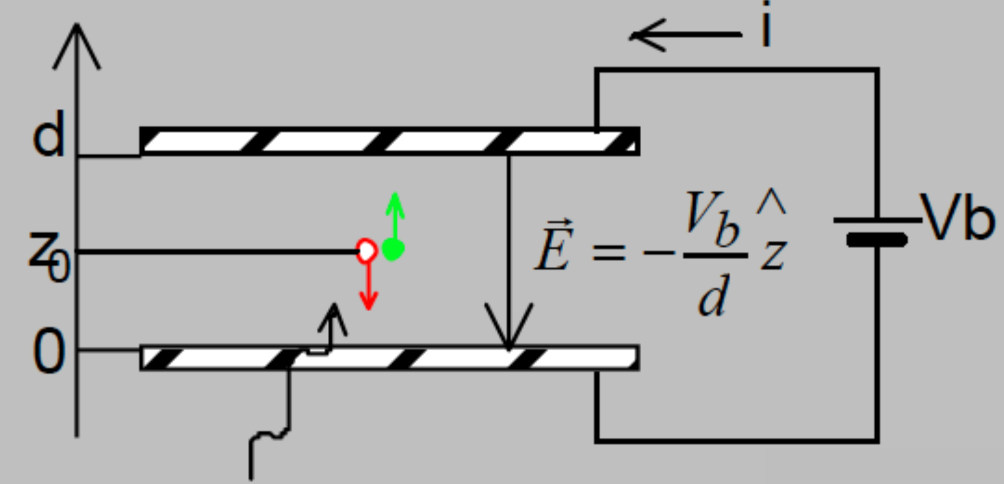
induced-current=charge×velocity×weighting-field

$$Q_{0\to 1} = q \cdot \left(V_W\left(\vec{r}_0\right) - V_W\left(\vec{r}_1\right)\right)$$

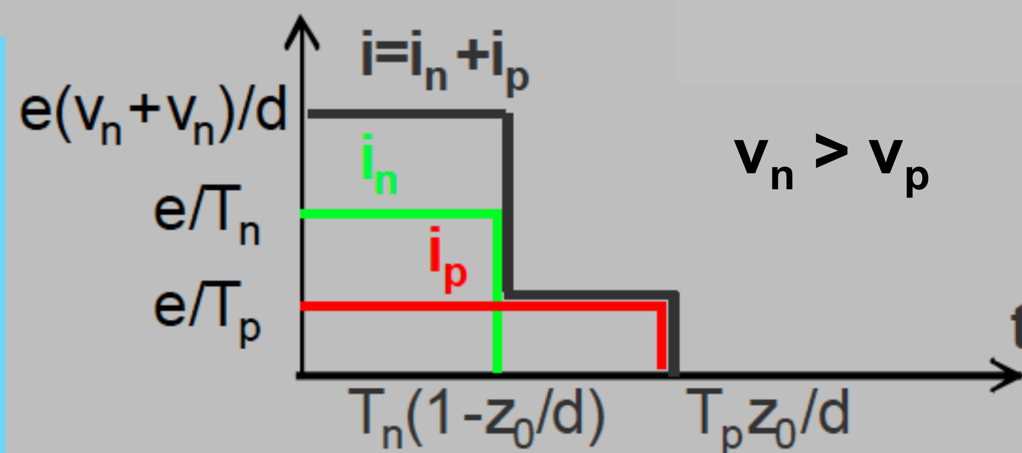
induced-charge=charge×weighting-potential-difference

Weighting-potential: created by the electrode at 1V when all other electrodes at 0V and no charge present

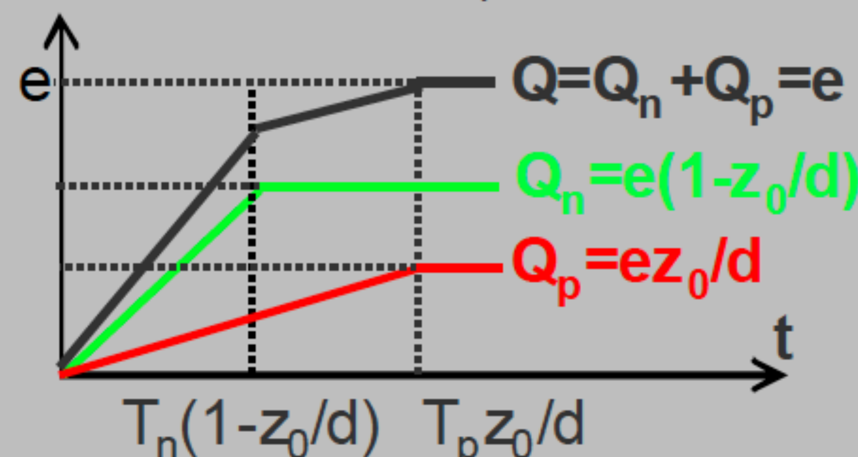
Planar 2-electrode configuration



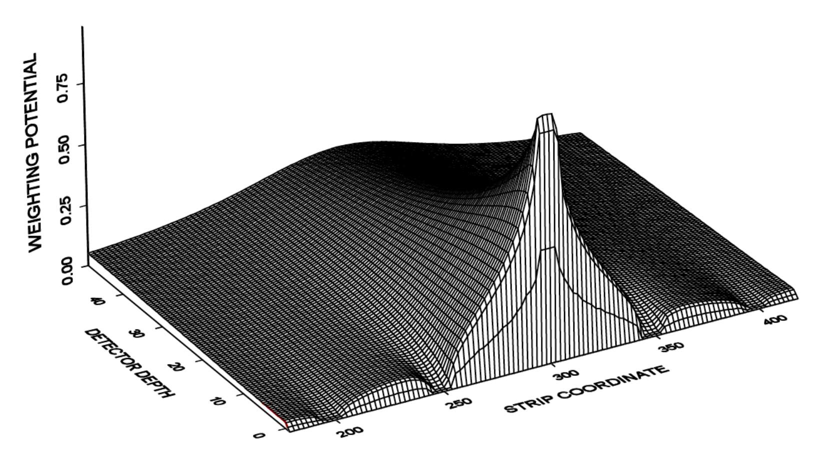
Induced-current



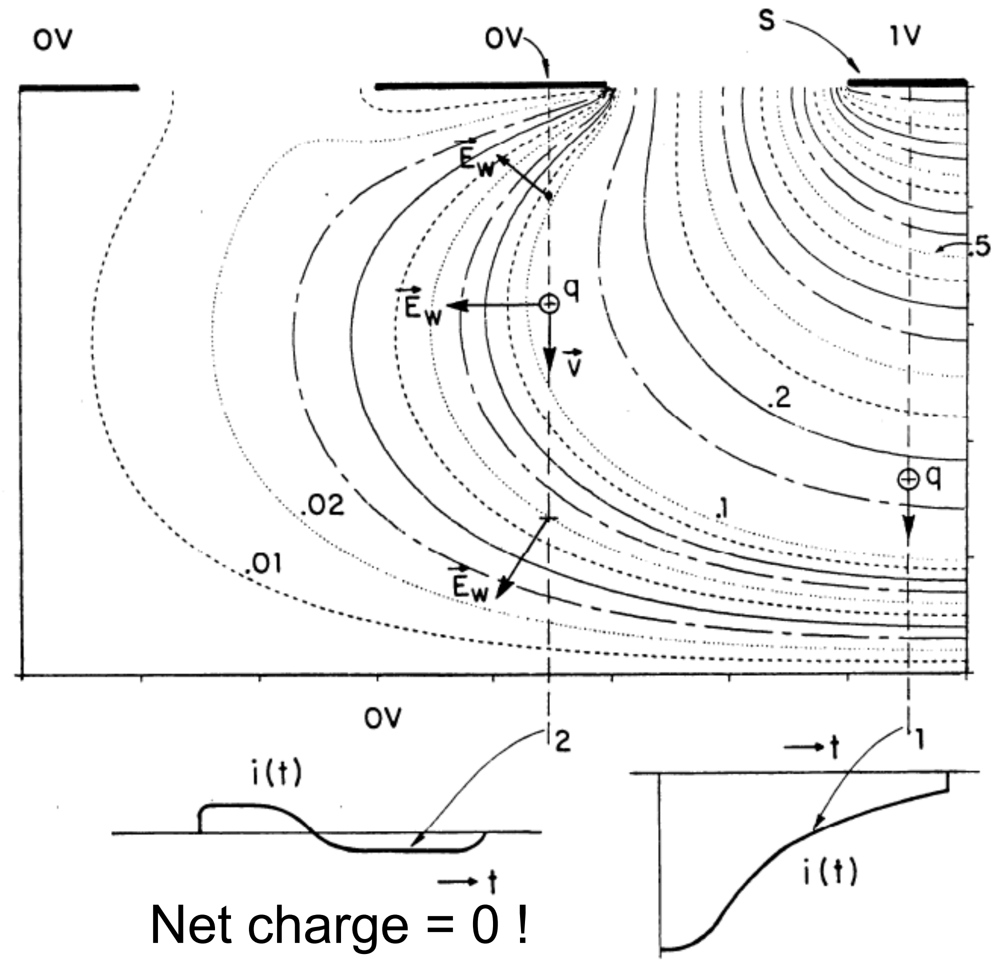
Induced-charge



Multi-electrode configuration



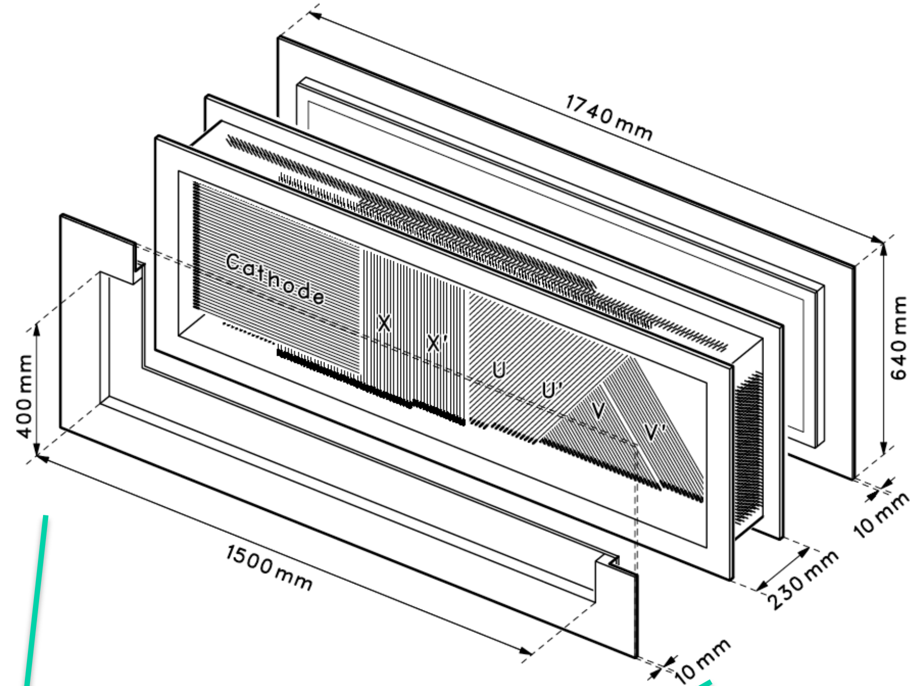
Weighting potential and induced currents



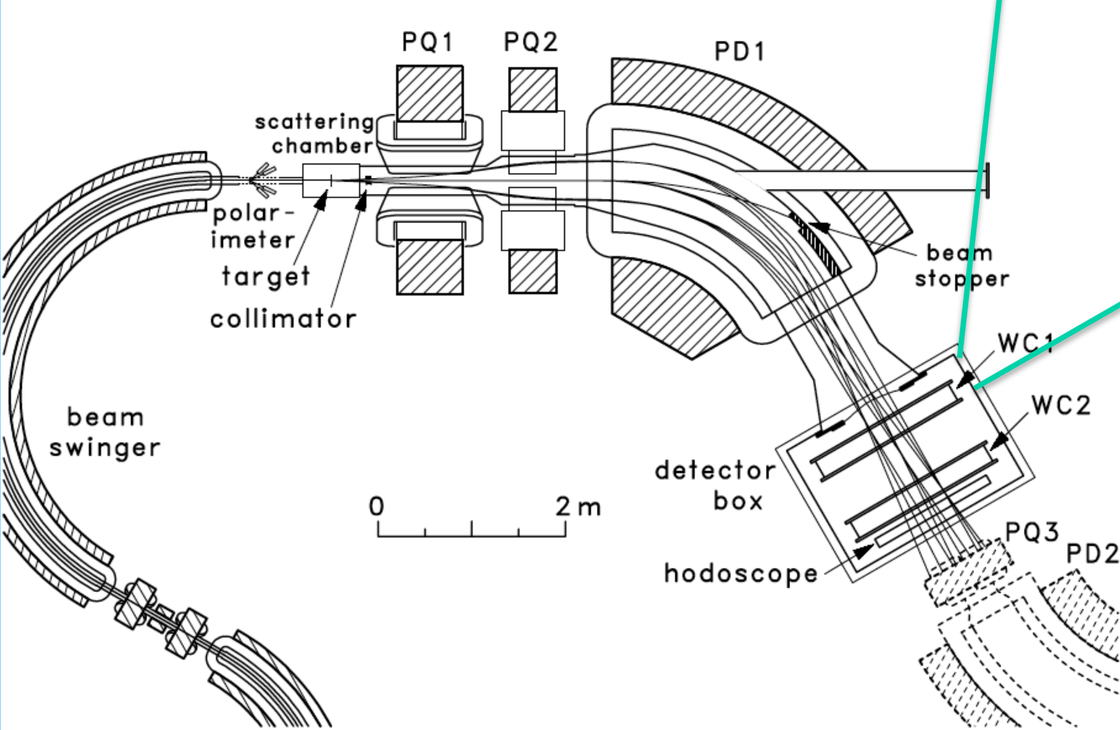
The shape of the pulse depends on the position of charge generation!

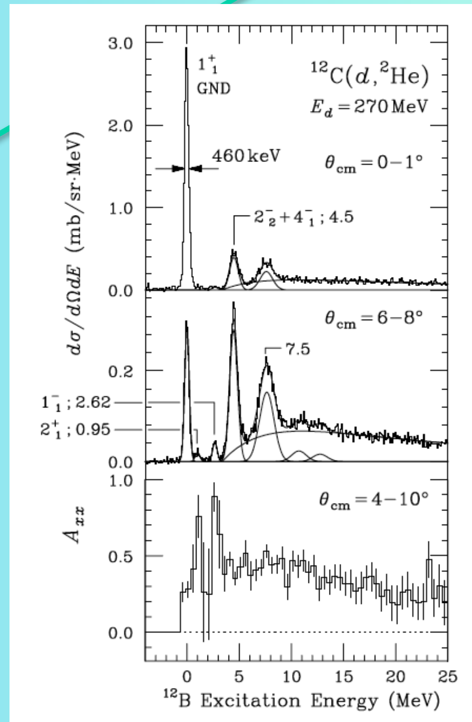
MWPC as position sensitive detector for magnetic spectrometers

- Several wire planes allow 2D position reconstruction



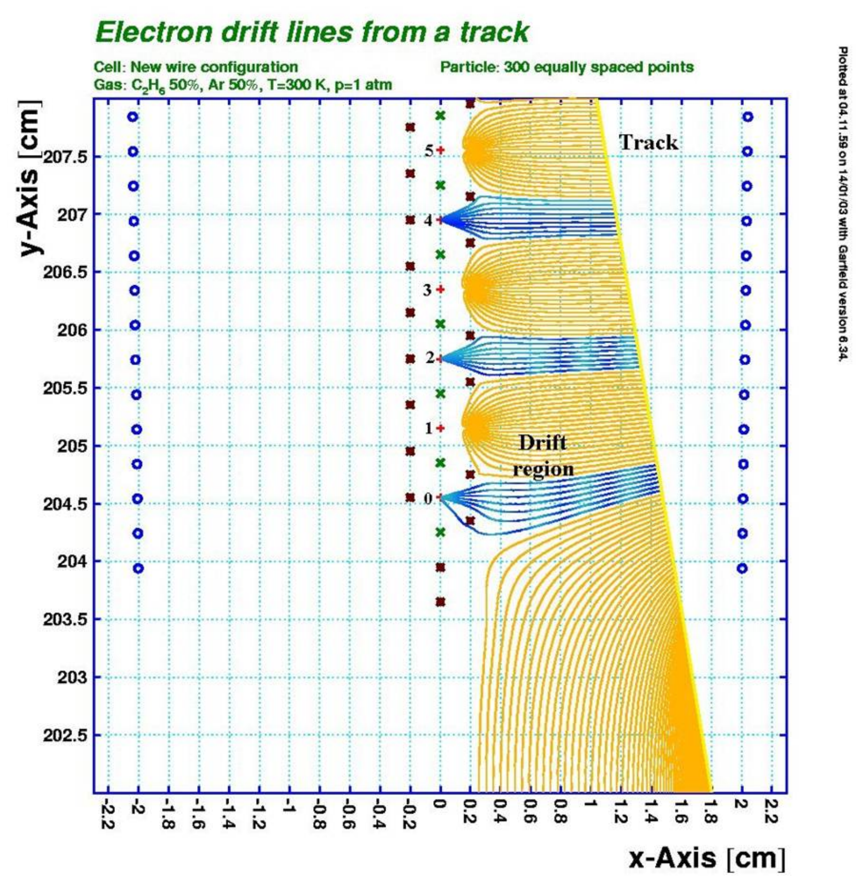
SMART spectrometer at RIKEN

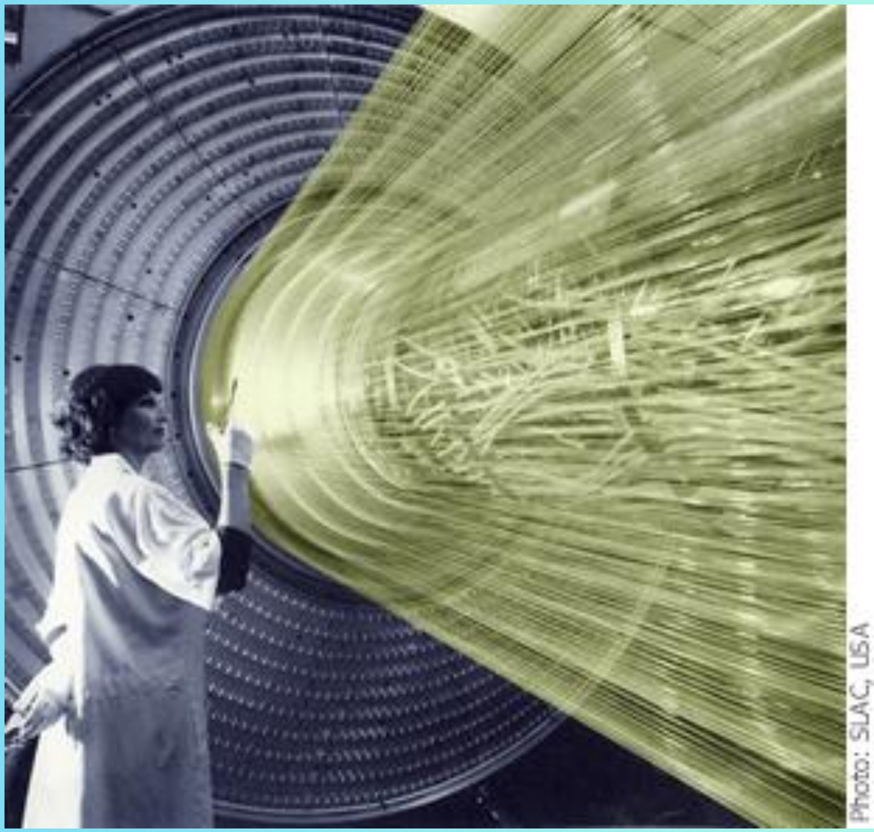




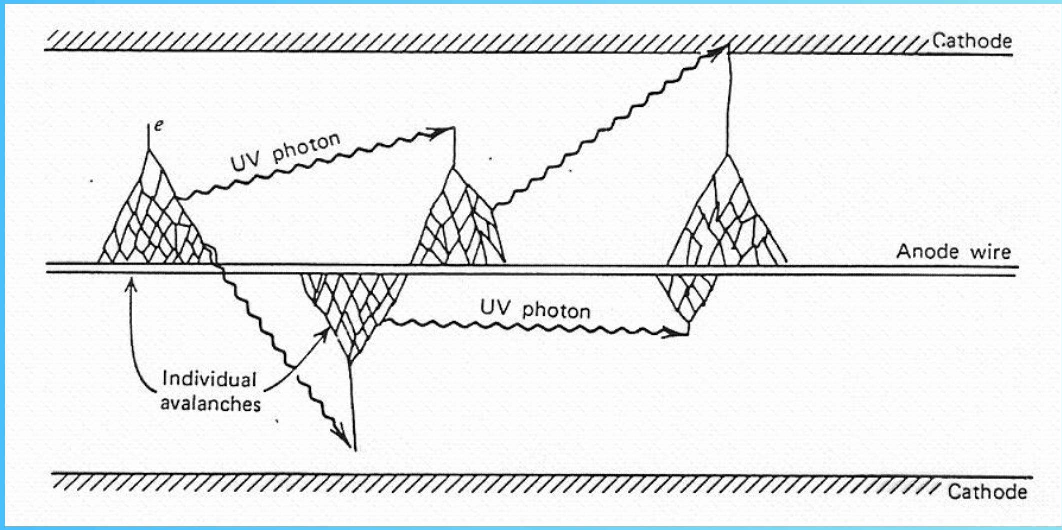
Drift Chambers

The drift time of the electrons is used for position localization





Geiger-Muller discharge



Avalanches develop along the anode wire

Loss of information on initial ionization

Geiger-Muller ratemeter (dosimeter)

Gas Electron Multiplier (GEM)