# Week 5: Proportional & G.M. Counters

Ion Chambers

**Proportional Counters, Ch. 6**

-- multiplication process
-- resolution
-- position measurement
--- wires
--- holes
--- plates

**Geiger-Mueller Counters, Ch. 7**

Principles of Scintillation Counters

Consider the drift motion of an ion in a simple ion chamber. The ions will have a thermal velocity plus a component along the field lines. Then after traveling for a mean-free-path they will undergo a collision that will randomize their velocity and they start over. What if the energy gain in one step is greater than the FIP of the buffer gas?

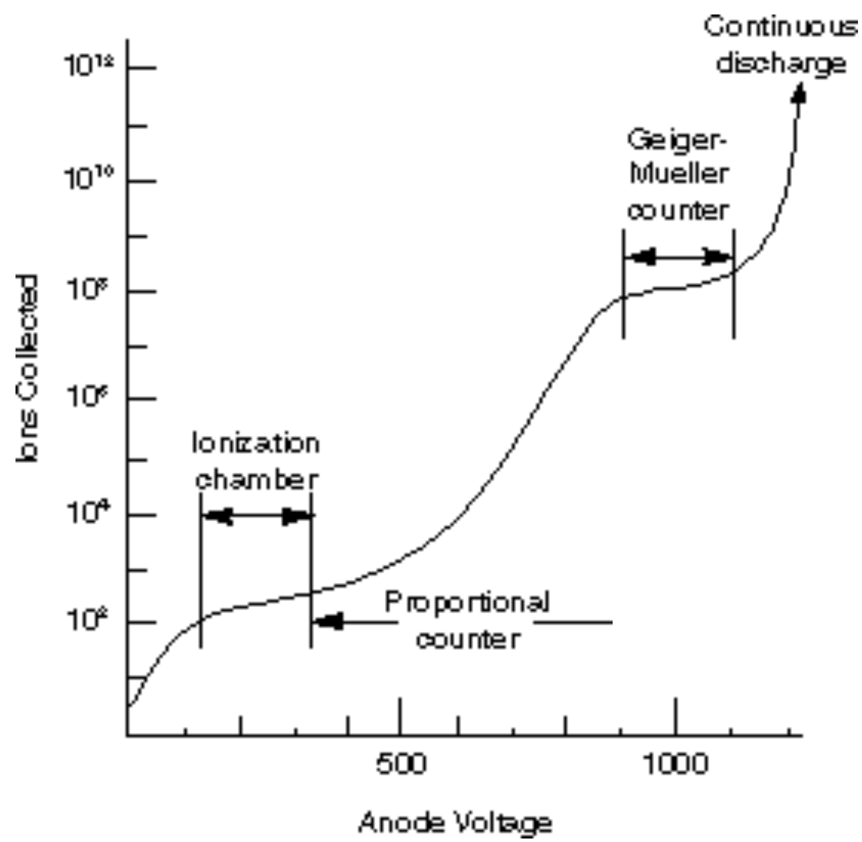
$$\Delta E \sim q_e\, \varepsilon\, \Delta x \quad where \quad \Delta x \sim \lambda_{MFP} \qquad \rightarrow \quad q_e\, \varepsilon \sim \frac{\Delta E}{\lambda_{MFP}}$$

$$\lambda_{MFP} = \frac{1}{\sqrt{2}\, \pi d^2 \rho_n}$$ (for molecules)

$$\lambda_{MFP}(air) = 6.6\, mm / Pa \quad or \quad 6x10^{-8}\, m \text{ at } 1 atm$$

$$q_e\, \varepsilon \sim \frac{FIP}{6x10^{-8}\, m} \sim 200\, MV/m$$

This value is too large for a nominal detector and so no multiplication of/by molecular ions. However, MV/m = keV/mm is achievable over short distances. Recall that the electrons will have much longer mean-free paths – electrons can be multiplied or "avalanched".



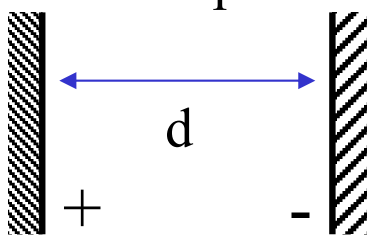

Similar to qualitative Fig. 6.2 Knoll, 3rd ,4th Eds.

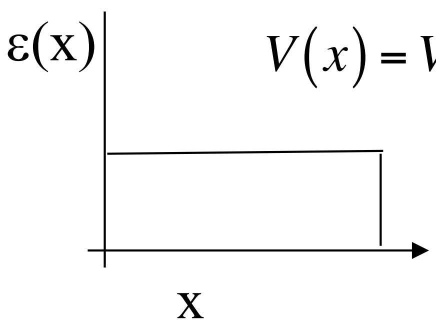
# Proportional Counters – Multiplication on Wires

Proportional counters are gas filled and generally use wire anodes (recent devices use thin lines or holes on printed circuit boards).

a)

Parallel plates




$$V(x) = V_0\left(1 - \frac{x}{d}\right)$$

b)

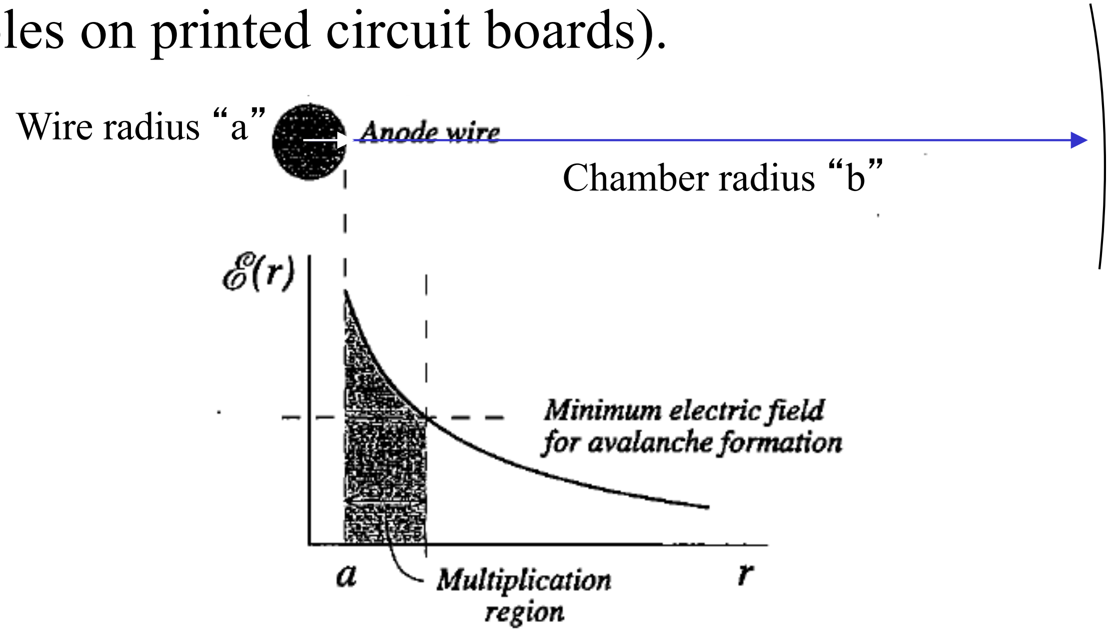



Fig. 6.4

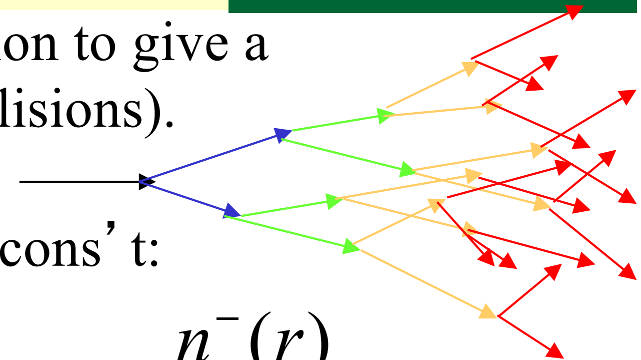
Knoll, 3rd,4th Eds.

$$\varepsilon(r) = \frac{V_0}{r\ln(b/a)}$$

Typical Case: wire radius, a = 80 μm @ 2 kV & chamber radius 2cm

# Proportional Counters – Townsend Avalanche

Start with one electron, each generation follows in proportion to give a distribution governed by the mean-free-path (w/ binary collisions).



Uniform field produces exponential growth, $\alpha(E) = \alpha(r) = \text{cons't}$:

$$\frac{dn^-}{dr} = +\alpha(r)\,n^- \quad \rightarrow \quad n^-(r) = n_0^-\, e^{\alpha r} \quad \leftrightarrow \quad M = \frac{n^-(r)}{n_0^-}$$

Non-uniform field requires a transformation $\alpha(E)$ to $\alpha(r)$ using dr/dE:

$$\int \frac{dn^-}{n^-} = \int \alpha(E) \frac{dr}{dE}\, dE$$

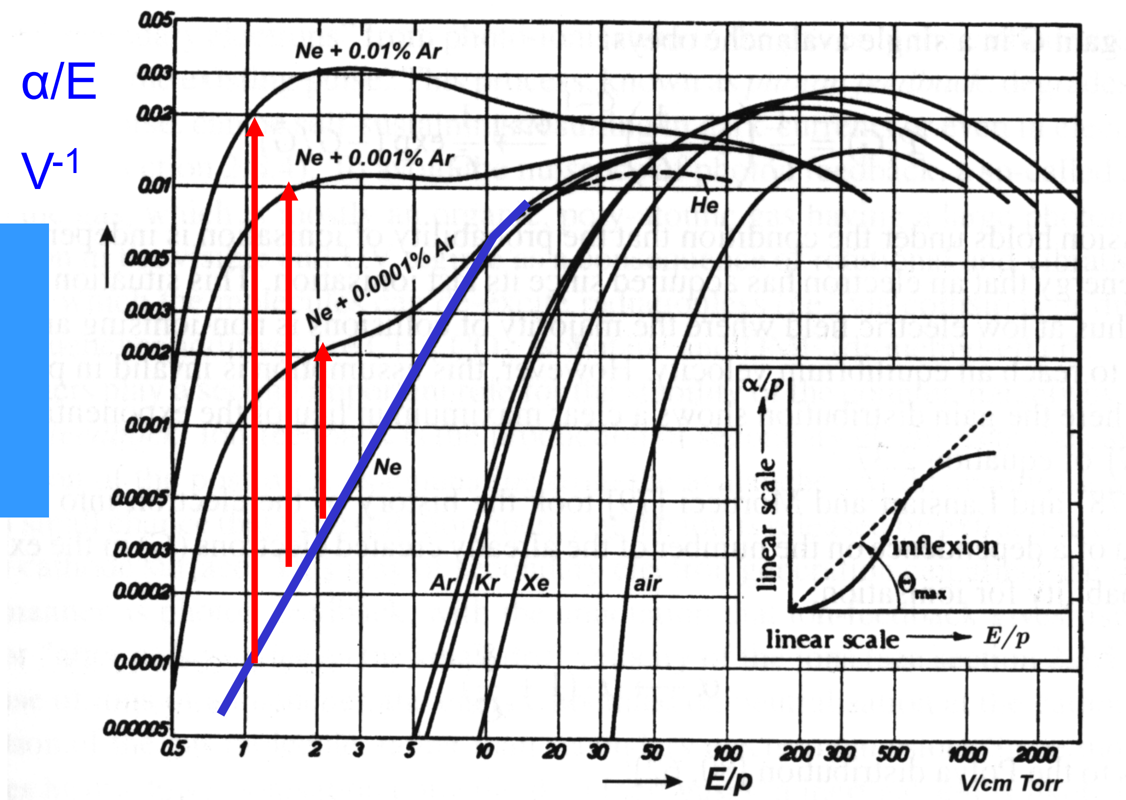
Townsend coefficients, $\alpha$, depend on cross sections (mean free paths) and on "w" – thus depend on gas and are strong functions of E.

Additional mechanism of Penning ionization:

$Ne^* + Ar \rightarrow Ne + Ar^+ + e^-$

FIP (Ar) = 15.7 < $E_1$ (Ne) = 16.6

FIP (Ne) = 21.5 eV



# Proportional Counters – "M"

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The general form for the multiplication factor, M, can be derived from simple arguments:

$$\int \frac{dn^-}{n^-} = \int \alpha(E) \frac{dr}{dE}\, dE$$

For a cylindrical detector:

$$E(r) \propto 1/r \quad \rightarrow \quad r \propto 1/E(r)$$

$$\ln M \propto \int_{r-anode}^{r-crit} \alpha(E) \left(\frac{1}{E^2}\right) dE$$

$$if\ \alpha(E) \propto E \quad [e.g.\ Ne + 0.01Ar] \quad then \quad \ln M \propto \ln E$$

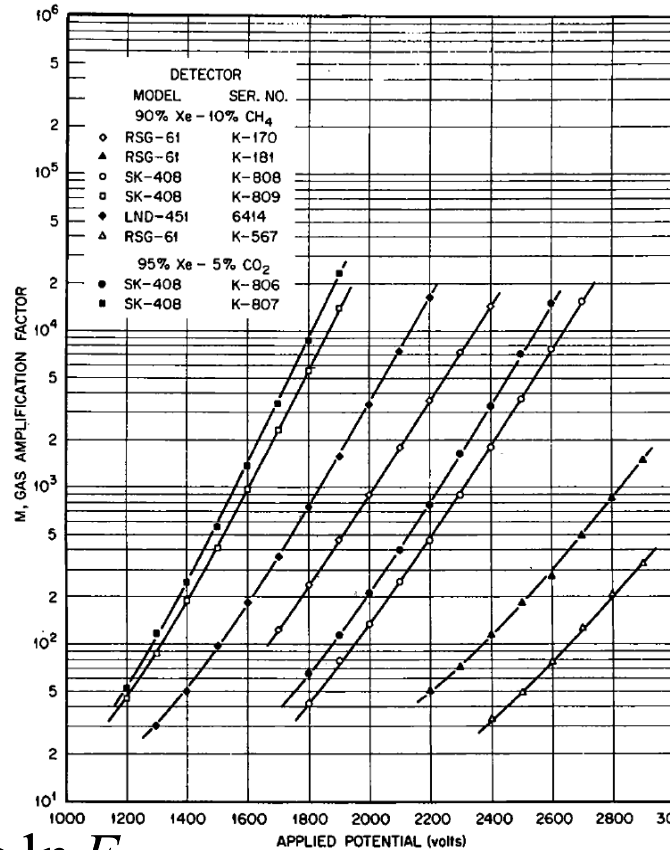



Fig. 6.10 Knoll, 3rd Ed.

Fig. 6.11 Knoll, 4th Ed.

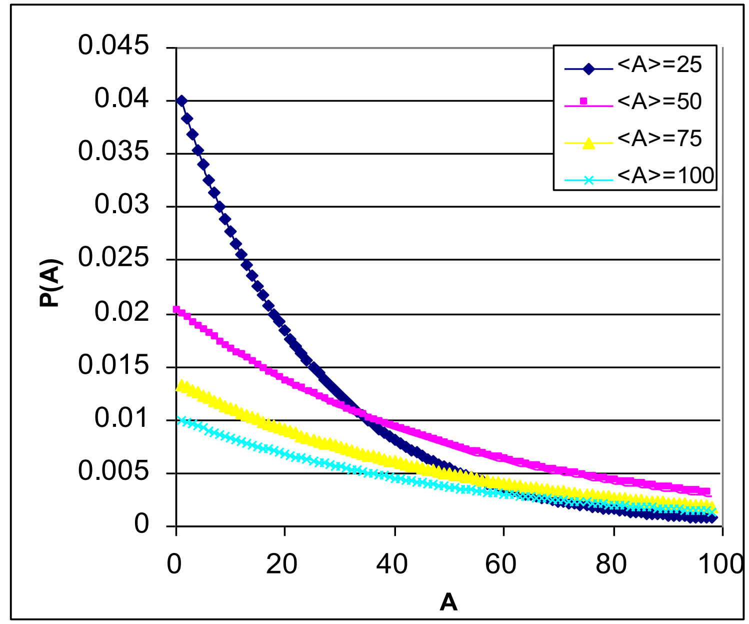
$$\ln M = \frac{V}{\ln(b/a)} \frac{\ln 2}{\Delta V_\lambda} \left[ \ln\left( \frac{V}{pa \ln(b/a)} \right) - \ln K \right] \quad Eq.\, 6.8\ in\ text$$

Diethorn's equation with two parameters that depend on the gas.

ΔV is the voltage drop in one MFP, K is the critical E/p for multiplication

# Proportional Counters – Resolution

If the electrons don't have a history (reset at each mean-free path) then each ionization event is independent. The probability of such independent events follows the Furry Distribution of "A-sized" avalanches with average $\overline{A} = M$ (essentially a power-law):




$$P_{Flury}(A) = \frac{\left(1 - \frac{1}{\overline{A}}\right)^{A-1}}{\overline{A}} \quad \rightarrow \quad P_{Flury}(A) \approx e^{-\frac{A}{\overline{A}}} \Big/ \overline{A} \qquad \sigma_A^{\;2} = \overline{A}^2$$

The resolution of the total charge, Q, will have two contributions: variation of the primary charge production and the multiplication

$$Q = N_{IP} q_e M$$

$$\left(\frac{\sigma_Q}{Q}\right)^2 = \left(\frac{\sigma_N}{N_{IP}}\right)^2 + \cancelto{0}{\left(\frac{\sigma_{qe}}{q_e}\right)^2} + \left(\frac{\sigma_M}{M}\right)^2 \quad but \quad \sigma_N^2 = F\, N_{IP}$$

$$\left(\frac{\sigma_Q}{Q}\right)^2 = \left(\frac{F}{N_{IP}}\right) + \left(\frac{\sigma_M}{M}\right)^2$$

$$M = \overline{A} \equiv \frac{1}{N_{IP}} \sum_{i=1}^{N_{IP}} A_i = \frac{A_1}{N_{IP}} + \frac{A_2}{N_{IP}} + \ldots \rightarrow \sigma_M^2 = \left[\left(\frac{\partial (A_1 / N_{IP})}{\partial A}\right)^2 \sigma_{A_1}^2 + \ldots\right]$$

$$\sigma_M^2 = \left(\frac{1}{N_{IP}}\right)^2 \sum_i \sigma_{A_i}^2 = \frac{1}{N_{IP}} \overline{\sigma}_A^2 \quad but \quad \sigma_{A_1}^2 = \sigma_{A_2}^2 \cdots = \overline{\sigma}_A^2$$

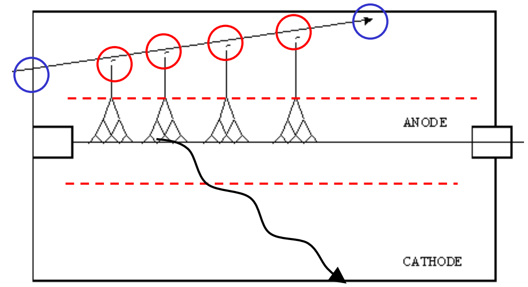
$$\frac{\sigma_M^2}{M^2} = \frac{1}{N_{IP}} \frac{\sigma_A^2}{M^2} \quad but \quad M^2 = \overline{A}^2 = \sigma_A^2$$

$$\left(\frac{\sigma_Q}{Q}\right)^2 = \left(\frac{F}{N_{IP}}\right) + \left(\frac{1}{N_{IP}}\right)$$

The text argues that $(\sigma_A / A)^2$ is < 1 … perhaps ½ .

# Proportional Counters – some difficulties

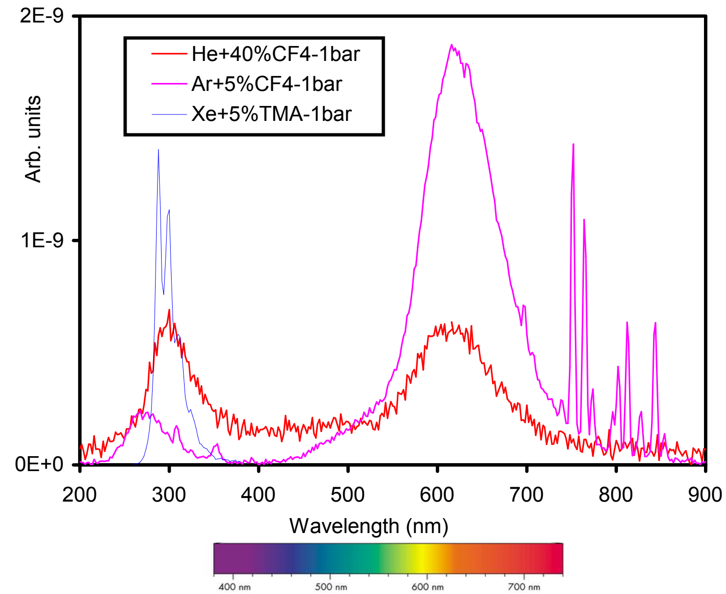
Approximately ½ of the charge is created ~ $\lambda_{MFP}$ from the anode. The motion of the cations *away* from the anode induces the signal.




***Beware of Cartoon !***

Fast rising signal; HV is shielded, slow cations have a long way to move to be neutralized on cathode. [ use grids ]

Multiplication process produces much more radiation damage to filling gas than primary ionization – no problem for noble gases (see below) but can damage anode itself.




*T.L. van Vuure, Ph.D, TU-Delft, 2004*

<u>Gas mixtures</u>? The number of atoms in excited states will grow in proportion to the multiplication. The excited states tend to decay by photon emission rather than by Penning ionization in pure gases – the photons are often UV and strike the cathode (wall). Being a metal, the cathode will tend to emit a photoelectron … similarly the collision of an atomic *ion* with the cathode during the neutralization can release an electron.

"Quench gas": Mix in a small amount of a small molecule – molecules have vibrational modes that can absorb energy and they tend not to radiate UV photons (IR more likely). Also these molecules will tend to collect the charge due to charge-exchange reactions and are less likely to emit electrons from the cathode on neutralization. However, these molecules tend to get damaged – need to flow the gas. Most used mixture: "P-10" 90% Ar 10% methane

# Proportional Counters – Multiwires & Position

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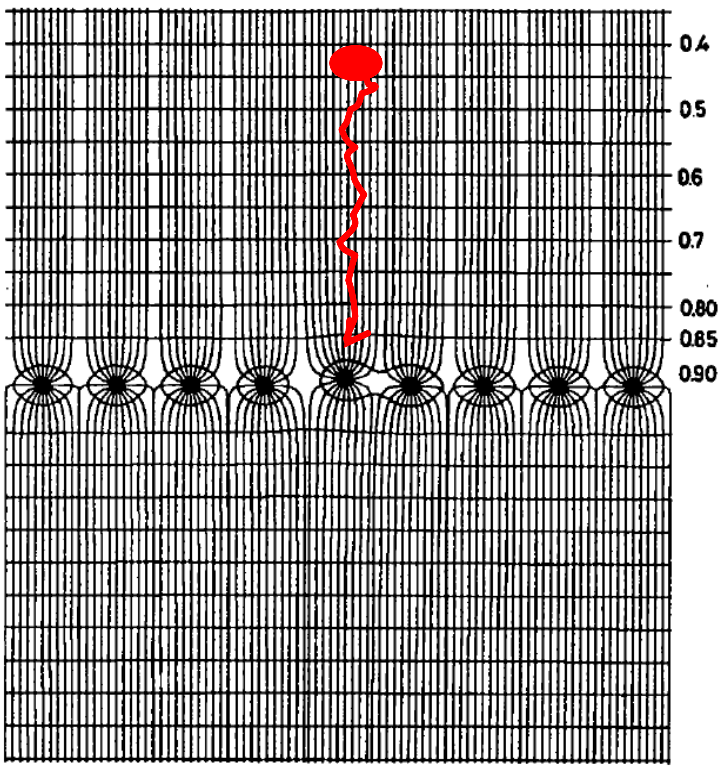
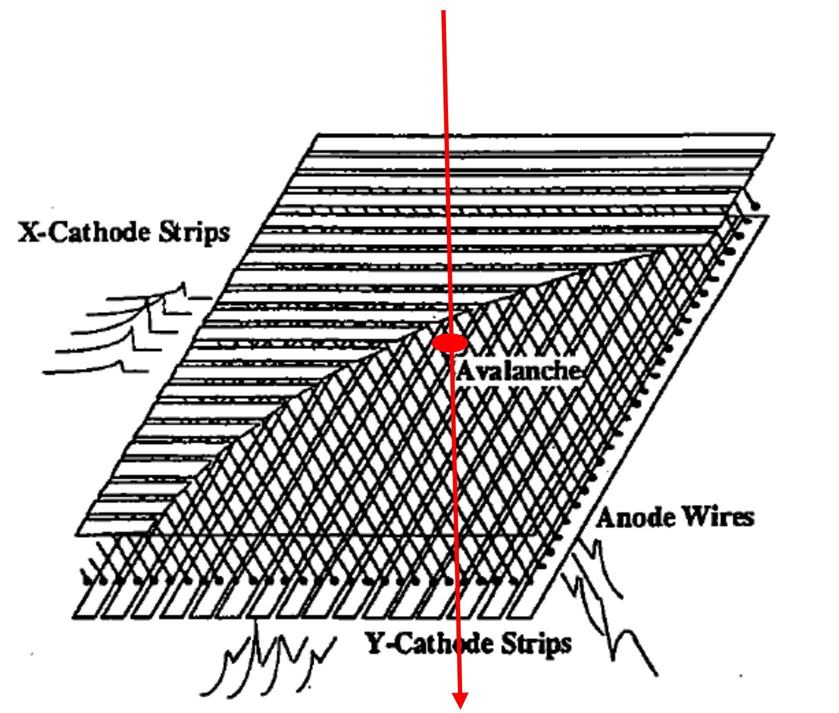
Field lines are approximately perpendicular to wire plane at large distances – electrons drift towards plane and retain position information. Many “wire chambers” have been developed to measure the positions of various particles.




Figs. 6.19 & 20 Knoll, 3rd Ed.

Figs. 6.21 & 22 Knoll, 4th Ed.

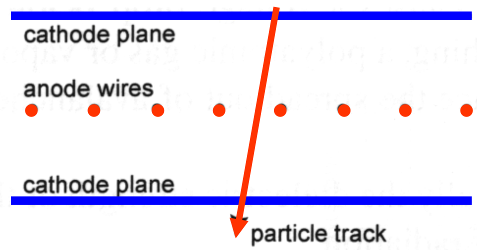
Read primary signal on wires, induced signals on cathode strips top and bottom – calculate 2D position.

# Proportional Counters – Wires → Stripes

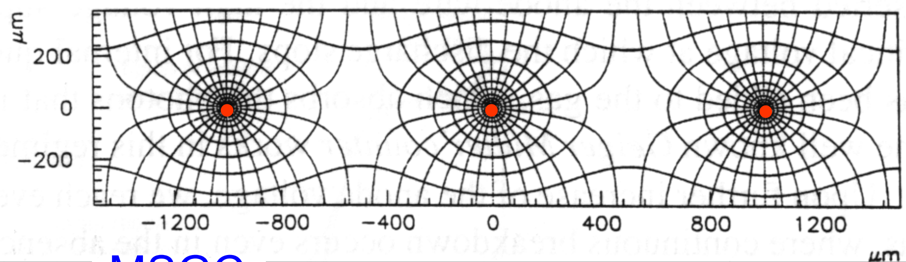
More sensitive detectors require more amplification – smaller "wires." Tiny anodes can be made by photoetching techniques but they must be supported on substrates (thick materials). Importantly the distance to the cathode traveled by the slow cations can be reduced enormously.

Multi-wire proportional chamber

Charpak

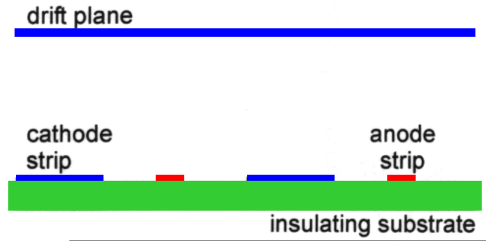



MWPC

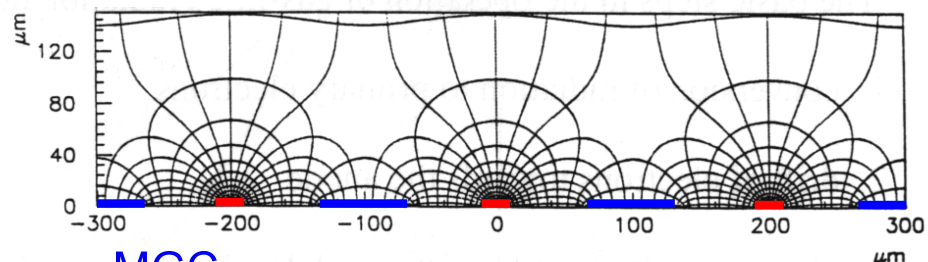



Micro-strip gas chamber

Oed

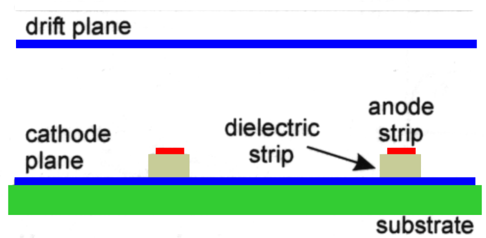



MSGC

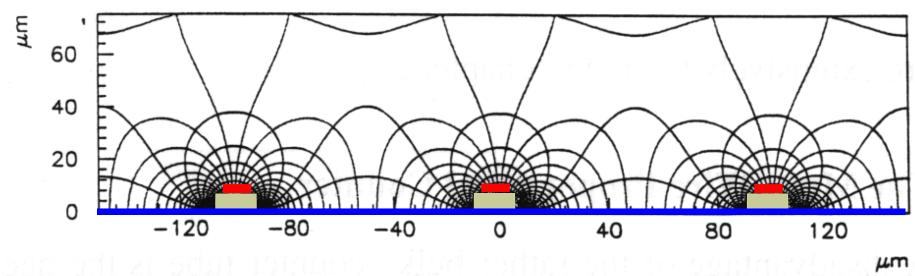



Micro-gap chamber

Bellazini




MGC



# Proportional Counters – Wires → Stripes, Nope!

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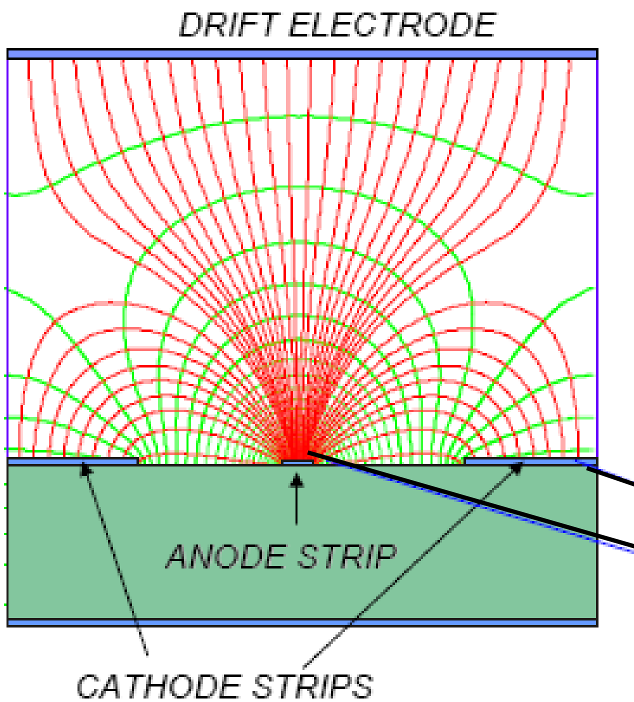
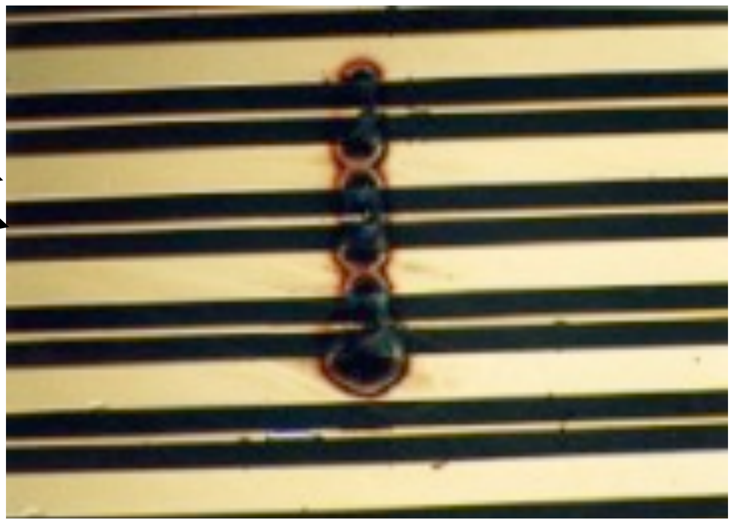
Thin metal strips on insulating support, generally resistive glass, have a very high rate capability due to high fields and short distance of travel for the cations.



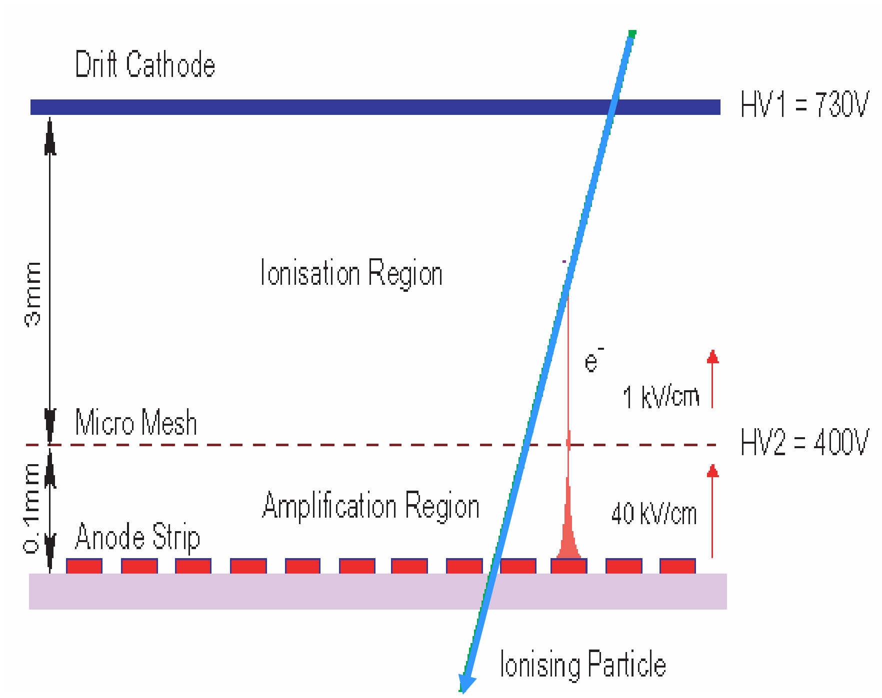

A.Oed, Nucl. Instr. and Meth. A263(1988)351

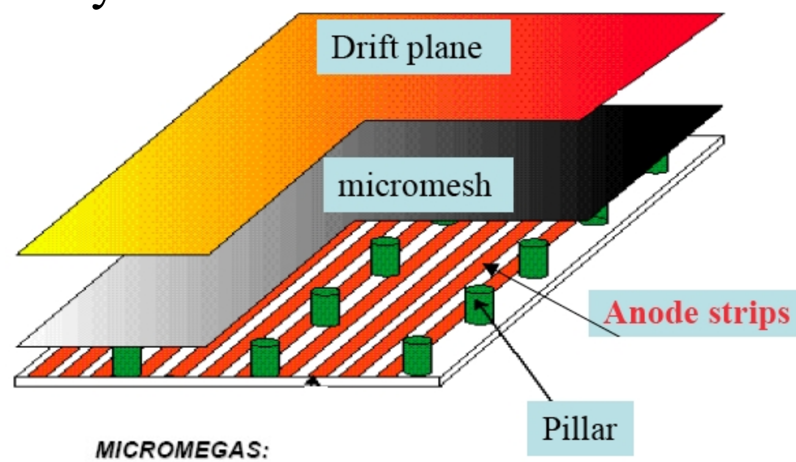
However, strips are permanently damaged by sparks or other discharges which kills the detector.

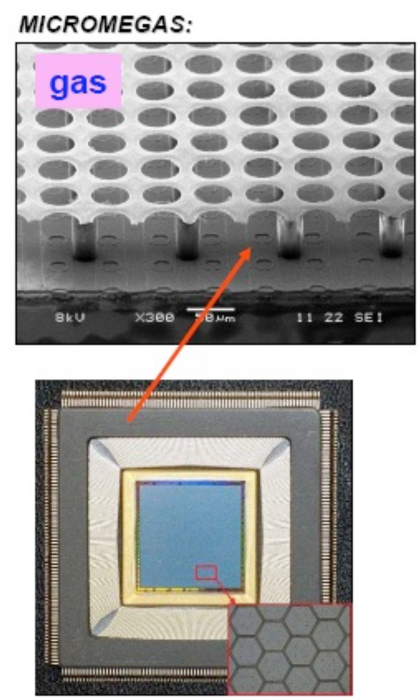


# Proportional Counters – Micro Frisch Grid

MicroMeGas detectors are made on a tiny scale with micro fabrication techniques. These devices have high spatial resolution but may be gain limited because they are only one-stage by definition. Also they can be integrated with electronics, but they are generally small.



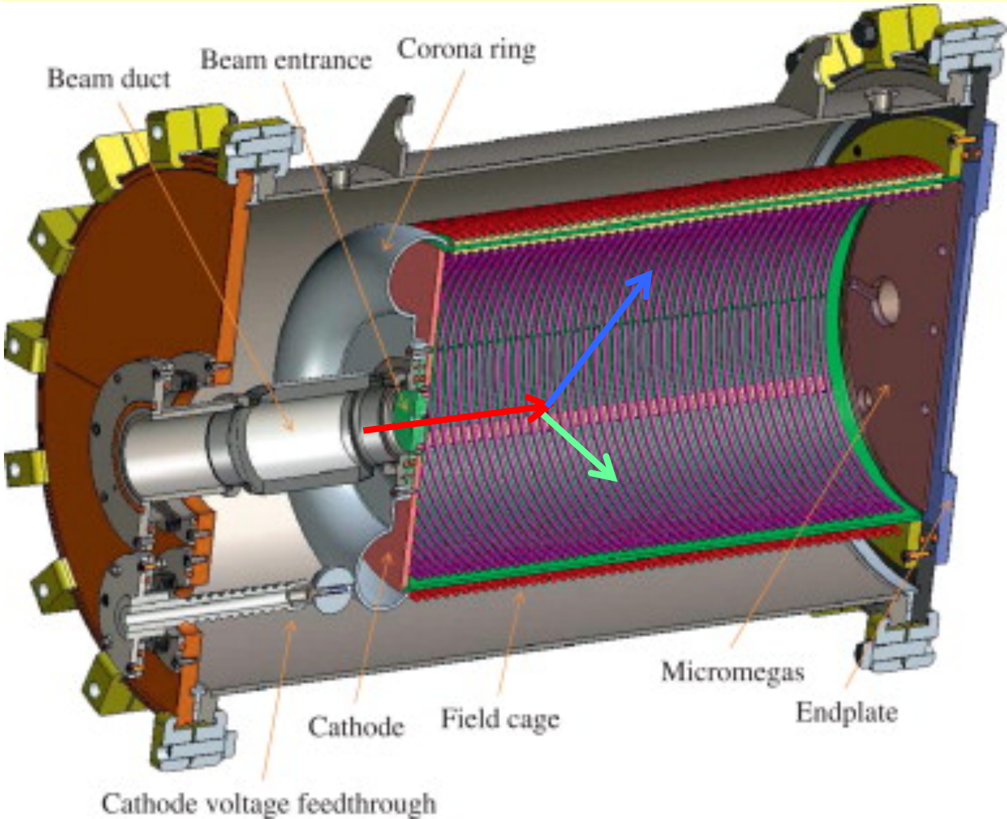




Y. Giomataris, et al. NIM A376 (1996) 29

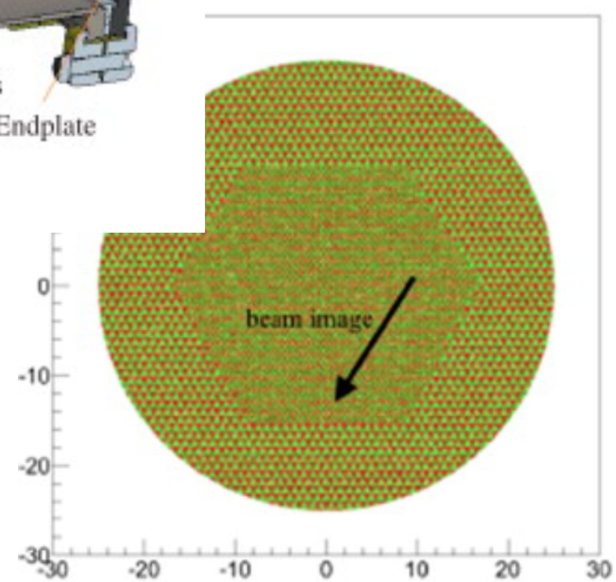
$14x14\ mm^2$ , $256x256$ pixels, $55x55\ \mu m^2$

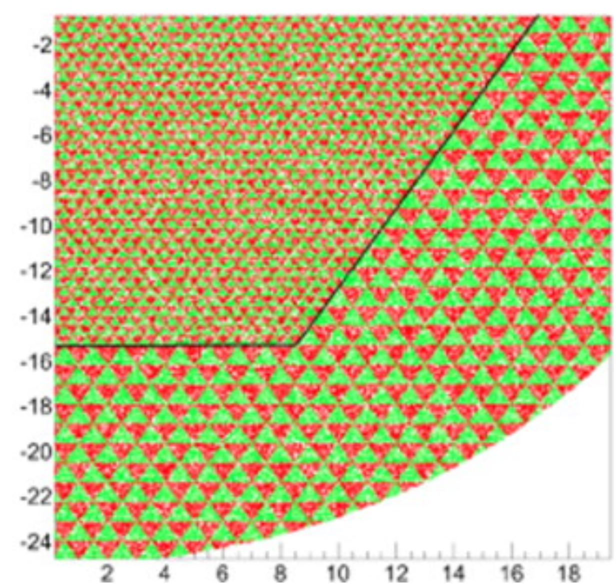
H. Van der Graaf, IEEE-NSS workshop, 2007

# Proportional Counters – MicroMeGas – AT-TPC




•1m length, 50cm diameter gas volume
•Electrons amplified using a Micromegas with 10,240 triangular pads
•Embeded in a 2T magnetic field for B-rho analysis (tracks curve …)



D. Suzuki et al., Nucl. Instrum. Meth. A 660 (2011) 64.
D. Suzuki et al., Nucl. Instrum. Meth. A 691 (2012) 39–54
D.Suzuki et al., Phys. Rev. C 87 (2013) 054301

# Proportional Counters – Wires → Holes

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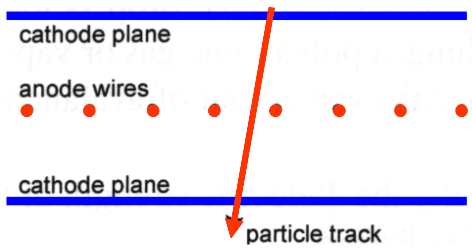
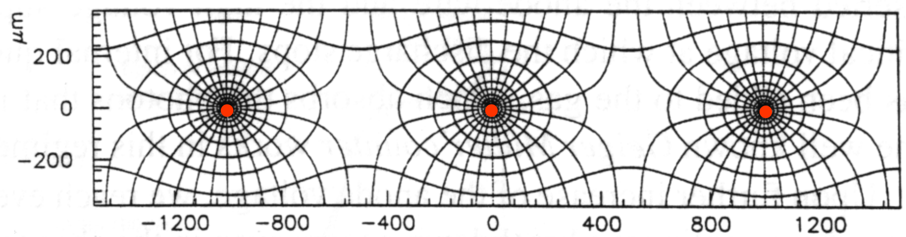
Get rid of the wires and use holes in an insulator… Gas Electron Multiplier (GEM). Typically a plastic foil, Kapton 50 μm, metal plated on both sides with small holes ~50 μm diameter. This creates a very high electric field 'in' the holes, perhaps 20kV/cm depending on the details. They can be stacked to get high gain.

Multi-wire proportional chamber

Charpak

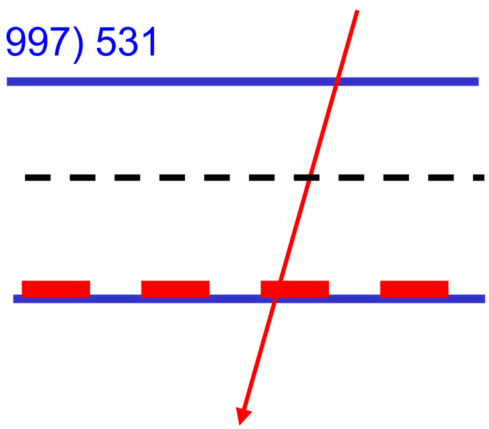



MWPC

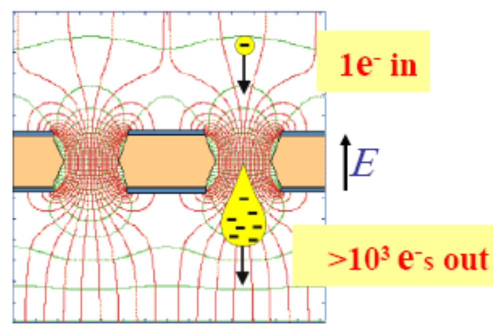



Gas Electron Multiplier

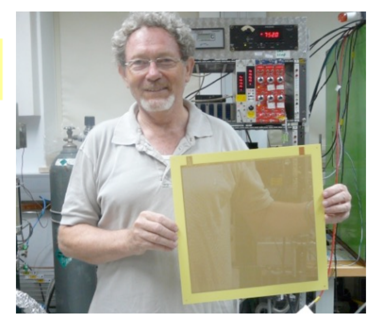
Sauli, NIM A433 (1997) 531



GEM




*Electric field in the holes >20kV/cm*



Amos Breskin,
Thick GEM, 2008

# Proportional Counters – PPAC

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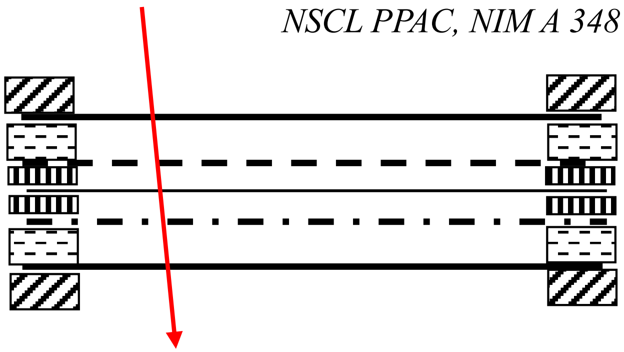
Transmission detectors in the path of the beam should be highly uniform.
Opinion: The MWPC devices are not suitable for radioactive ion beams …
parallel-plate avalanche counters

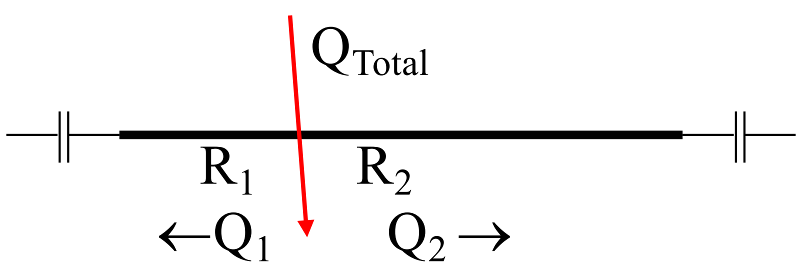
*NSCL PPAC, NIM A 348 (1994)314*

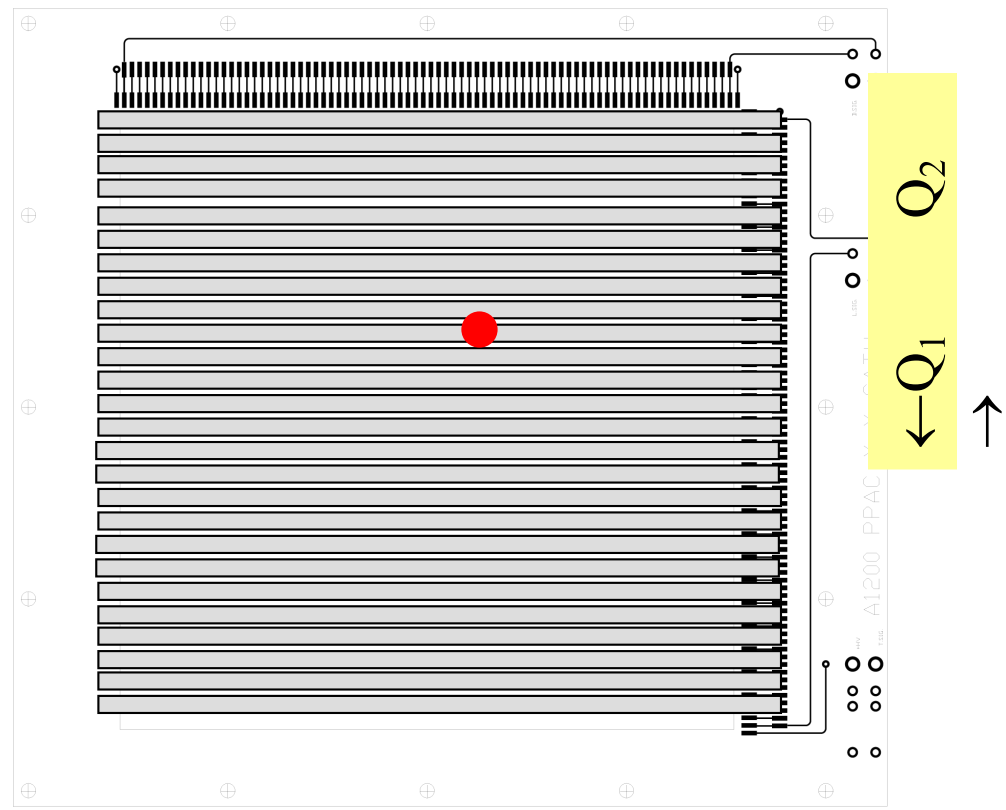



$V_0 \sim 500$ V, p = 5 torr,
~ 3mm gap anode-cathode

$$\frac{\varepsilon}{p} = \frac{500\,V}{0.003\,m}\,\frac{760\,torr/atm}{5\,torr} = 20\,\frac{MV}{m\,atm}$$

Resistive charge division



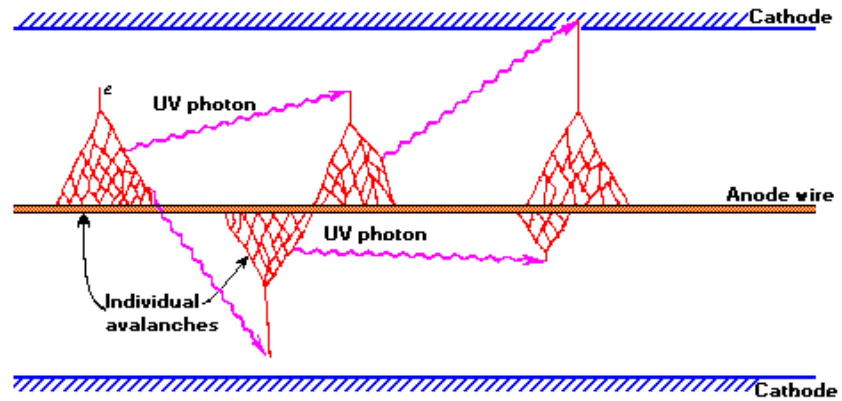




Cathode foil with stripes
Resistor chain on pcb
Induced charge is divided in two.

# Chap. 7 Geiger-Mueller Counters

Increase field in Proportional counter so that the avalanche spreads along the entire length of the wire … this will produce the largest signal but a sheath of cations will terminate the applied field.

Rutherford & Geiger, 1908




*Beware of cartoon !*

Recombination at the wall leads to "after pulse"

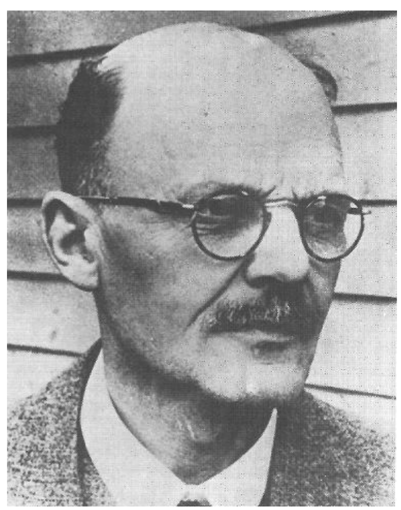
$He^{+} + e^{-}$ (wall) $\rightarrow$ $He^{*} \rightarrow He + h\nu$ (UV)

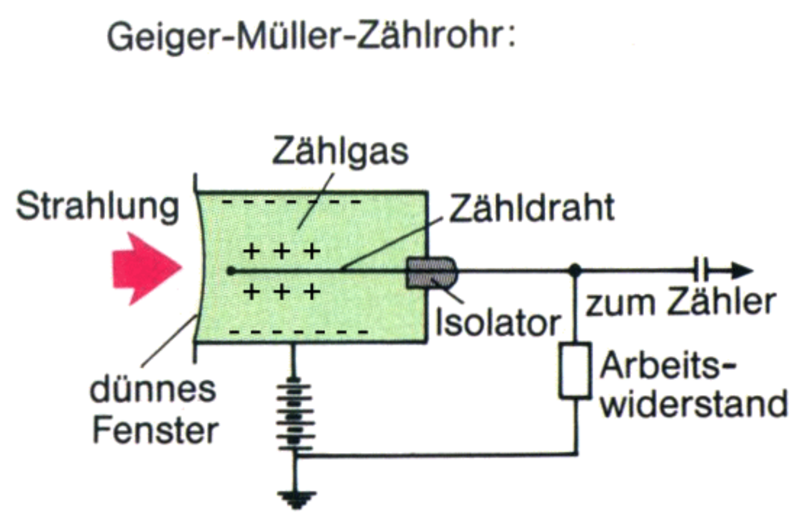
$He^{+} + M \rightarrow He + M^{+}$

$M^{+} + e^{-}$ (wall) $\rightarrow$ $M^{*} \rightarrow M + h\nu$ (IR)

GM tubes are sealed … "M" gets burned up.

*Hans Geiger (1882-1945) was a German physicist who introduced the first reliable detector for alpha particles and other ionizing radiation.His basic design is still used, although more advanced detectors also exist.*
*His first particle counter was used in experiments that identified alpha particles as being the same as the nucleus of a Helium atom.He accepted his first teaching position in 1925 at the University of Kiel, where he worked with Walther Müller to improve the sensitivity and performance of his particle counter.*





# Geiger-Mueller Counter Example

Typical device: 1 atm P-10 gas (90%Ar, 10%$CH_4$)
Anode: $r_a \sim 30\ \mu m$; Cathode $r_b \sim 1$ cm; 10 cm long

M~$10^6$ gives $V_R \sim 1$ V – Estimate $V_0$ , $\tau$, C & R