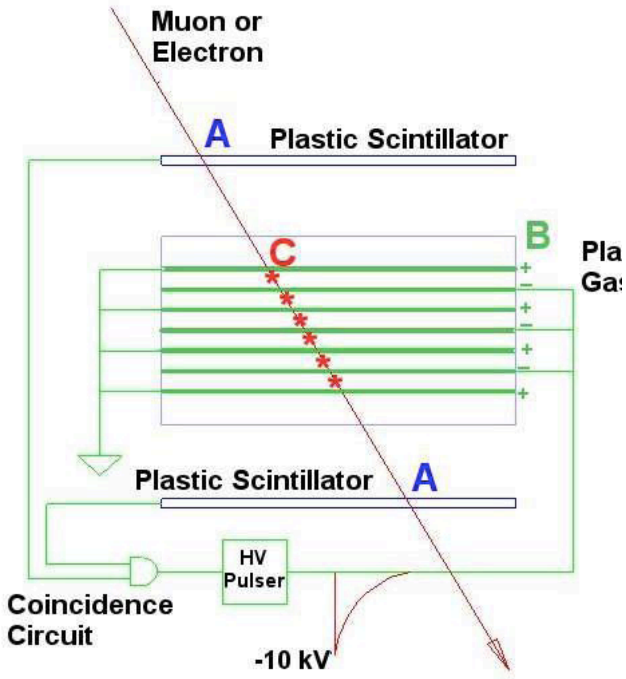
Lecture 22

HISTORICAL TRACKING TECHNIQUES
Wire readout technologies

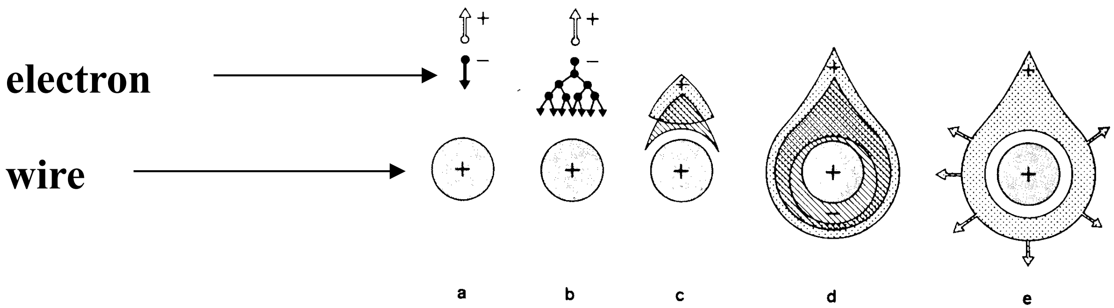
Spark chambers – stack of metal plates
enclosed in a gas filled box.

- Charged particle traverses the detector and leaves an ionization trail. Normally this ionization is invisible.
- The scintillators trigger an HV pulse between the metal plates and sparks form in the place where the ionization took place.
- Resulting information: position of the plate with a signal. Typical spatial resolution < 1 mm.



Signal Formation on a wire

(F. Sauli, CERN 77-09)

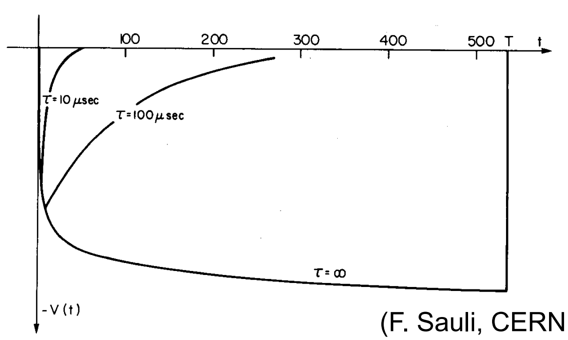


Avalanche formation within a few wire radii and within t < 1 ns!

Signal is induced by the moving charges both on anode and on cathode (electrons and ions).

$$dv = \frac{Q}{lCV_0}\frac{dV}{dr}dr$$

Electrons collected by anode wire, i.e., *dr* is small (few μm)



(F. Sauli, CERN 77-09)

Ions have to drift back to cathode, *dr* is big. Signal duration limited by total ion drift time !

Need electronic signal differentiation to limit dead time.

Cross section for ionization by collisions of electrons with atoms of noble gasses

$$n = n_0 e^{\alpha(E)x} \quad \text{or} \quad n = n_0 e^{\alpha(r)x}$$

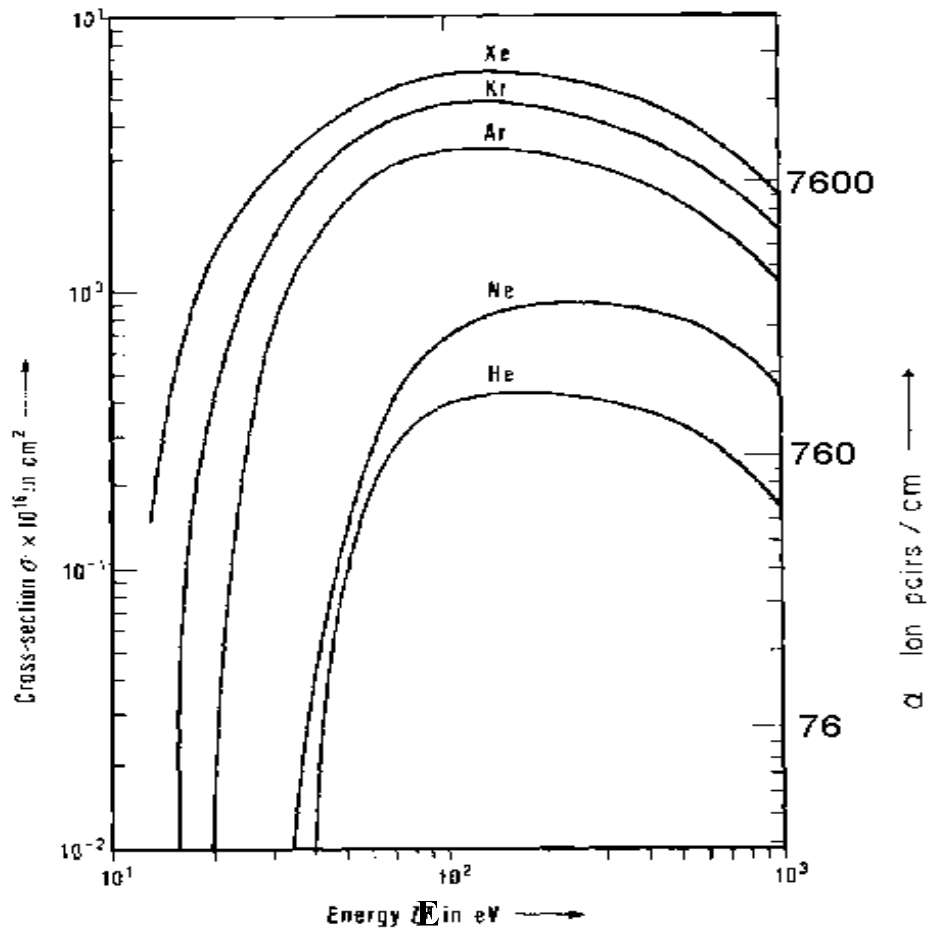
α: First Townsend coefficient (e⁻-ion pairs/cm)

λ: mean free path

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

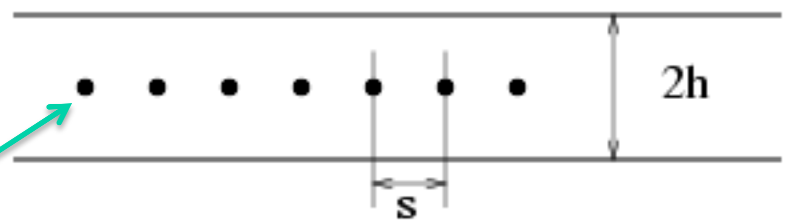
$$M = \frac{n}{n_0} = \exp\left[\int_a^{r_C} \alpha(r)\,dr\right]$$

Gain $$M \approx k e^{CV_0}$$



Total signal (number of collected electrons) is proportional to the total ionization generated by the passage of charged particle.
-> proportional chambers

Charpak 1968: Multiwire proportional chambers



Negative potential

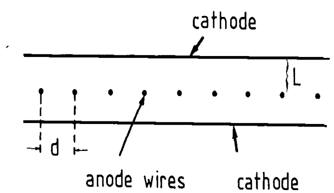
Wires are kept at positive HV.

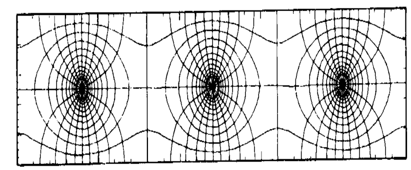
A charged particle traversing the detector leaves a trail of electrons and ions.

- Electrons drift to the wires in the E field and form an avalanche close to the wire.
- This induces a signal on the wire which can be read out by an amplifier.

Multi wire proportional chambers

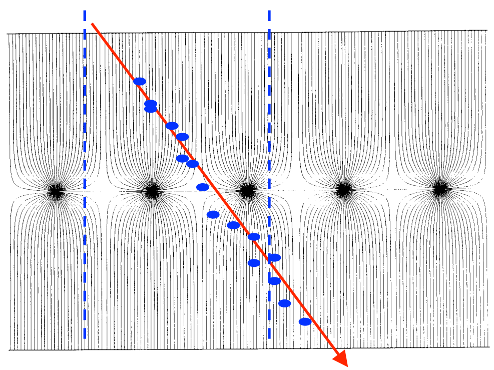
G. Charpak et al. 1968, Nobel prize 1992





field lines and equipotentials around anode wires

Negative signals on all wires.



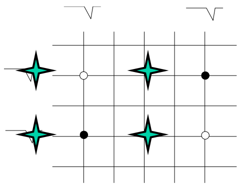
Typical parameters:
L=5mm, d=1mm,
a_{wire}=20mm.

Digital readout:
spatial resolution limited to

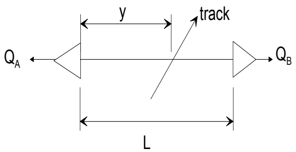
$$\sigma_x \approx \frac{d}{\sqrt{12}}$$

(d=1mm, s_x=300 mm)

Second coordinate

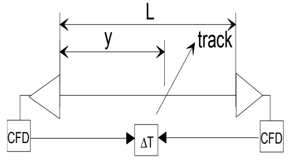


- Crossed wire planes. Ghost hits. Restricted to low multiplicities. Also stereo planes (crossing under small angle).



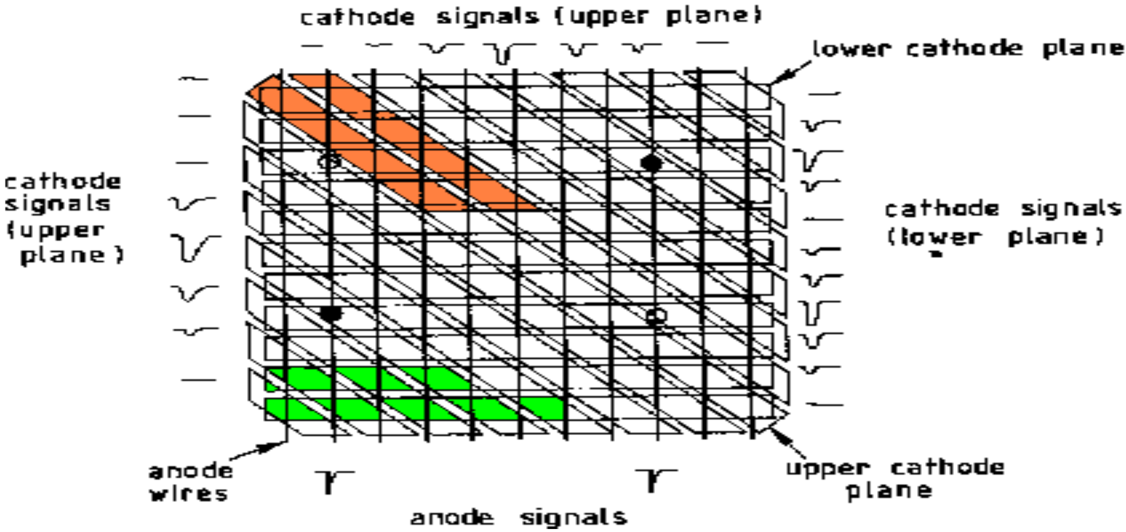
$$\frac{y}{L} = \frac{Q_B}{Q_A + Q_B} \qquad \sigma\left(\frac{y}{L}\right) \text{ up to } 0.4\%$$

- **Charge division. Resistive wires (Carbon, 2kΩ/m).**



$$\sigma(\Delta T) = 100\,ps$$
$$\rightarrow \sigma(y) \approx 4cm \qquad \text{(OPAL)}$$

- **Timing difference**

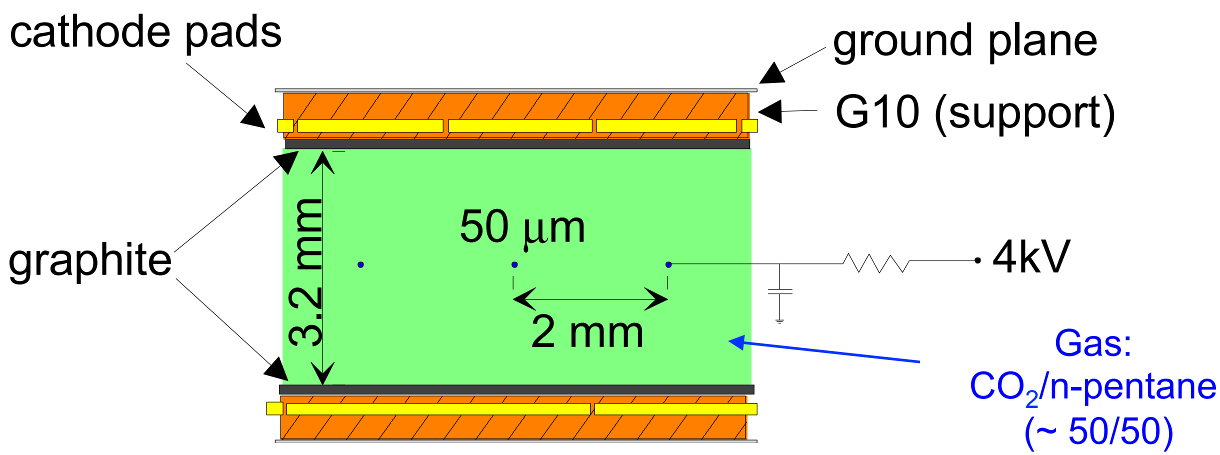


Analog readout of cathode planes.
→ σ ≈ 100 mm

- **1 wire plane**
  + 2 segmented cathodes

Derivatives of proportional chambers

Thin gap chambers



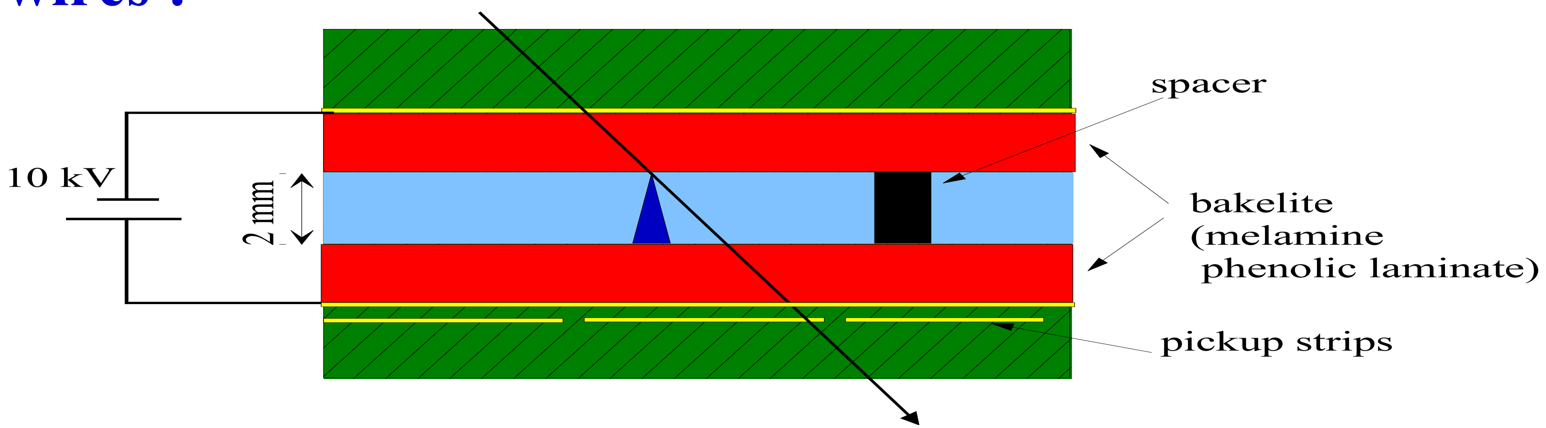
Operation in saturated mode. Signal amplitude limited by by the resistivity of the graphite layer (< 40kW/cm).

Fast (2 ns rise time), large signals (gain 10^6), robust

Application: ATLAS muon endcap trigger, Y.Arai et al. NIM A 367 (1995) 398

Resistive plate chambers (RPCs)

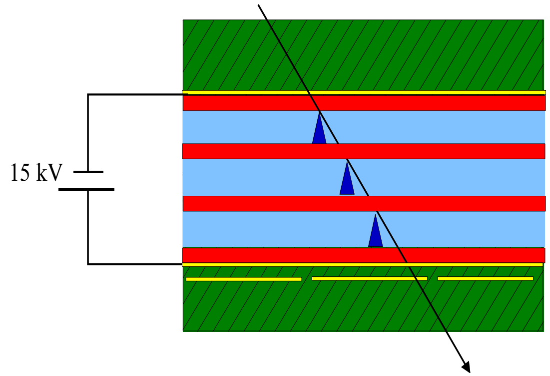
No wires !



Gas: $C_2F_4H_2$, (C_2F_5H) + few % isobutane

(ATLAS, A. Di Ciaccio, NIM A 384 (1996) 222)

Time dispersion ~ 1..2 ns → good as trigger chamber
Rate capability ~ 1 kHz / cm^2

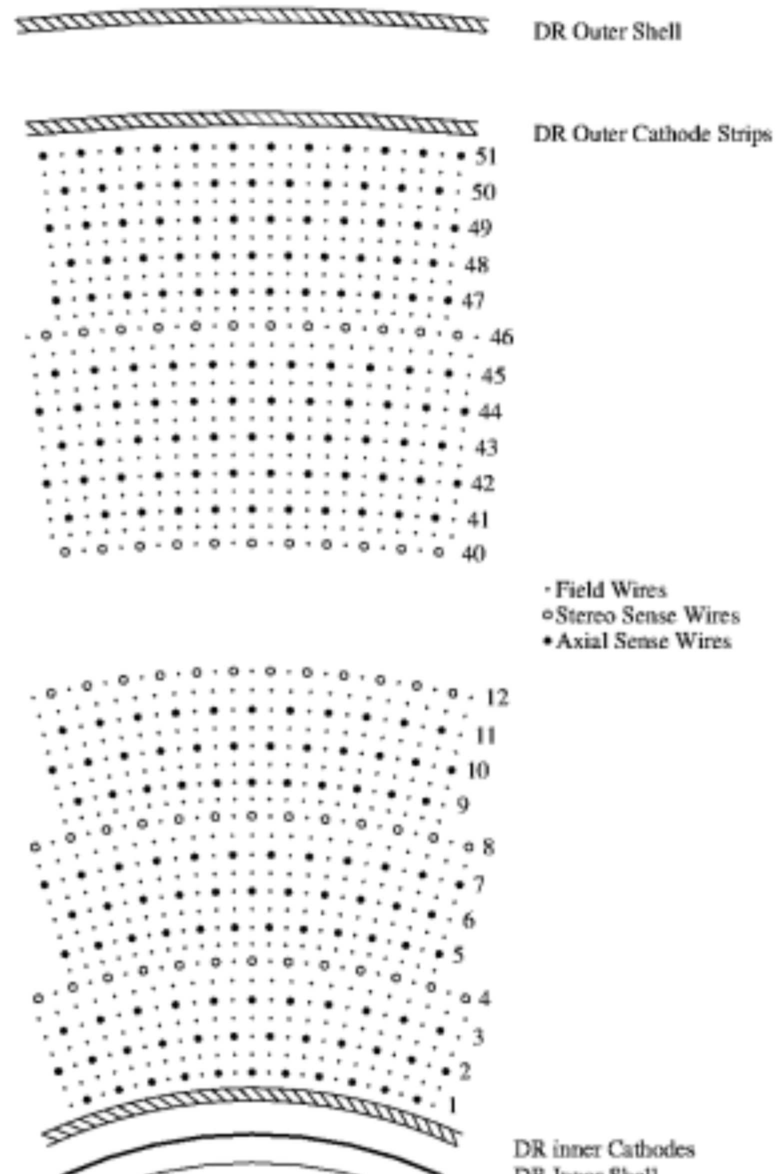


Double and multigap geometries → improve timing and efficiency

Problem: Operation close to streamer mode.

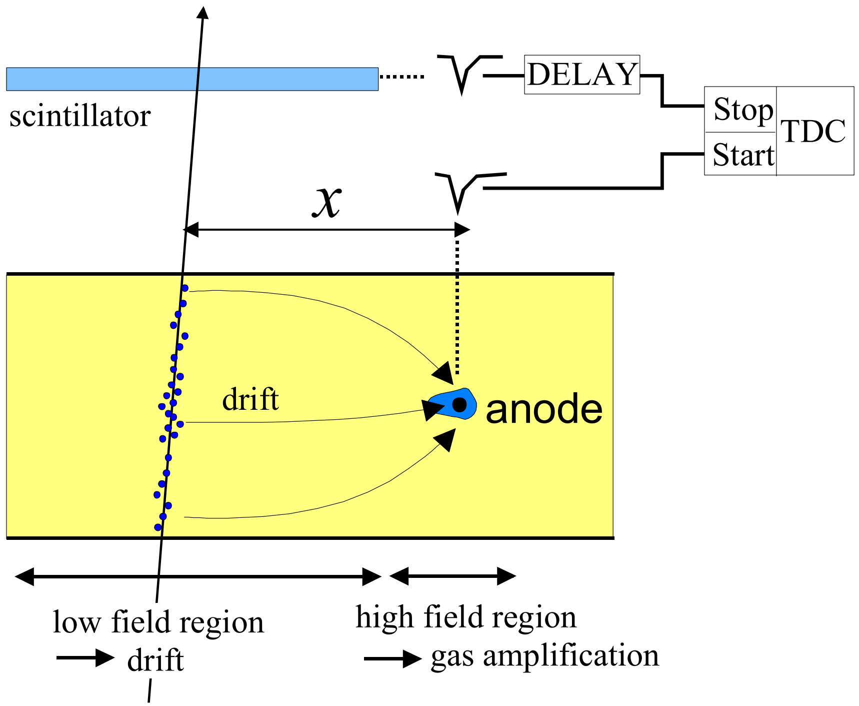
Time used to determine position

Drift chambers:
Maintain uniform electric field using a set of the “field wires” surrounding “sense wires”. Constant drift velocity of ionization electrons together with a measurement of time allows to reconstruct the position of original ionization with a position resolution of ~ 60 μm. “Stereo” wires are not parallel. Small crossing angle provides additional information of location along the length of the wire.



Drift Chambers

(**First studies: T. Bressani, G. Charpak, D. Rahm, C. Zupancic, 1969**
First operation drift chamber: A.H. Walenta, J. Heintze, B. Schürlein, NIM 92 (1971) 373)



Measure arrival time of electrons at sense wire relative to a time t_0.

$$x = \int v_D(t)dt$$

What happens during the drift towards the anode wire ?

- Diffusion
- Changes of drift velocity

Drift and diffusion in gases

With no external fields electrons and ions lose their energy due to collisions with the gas atoms → thermalization

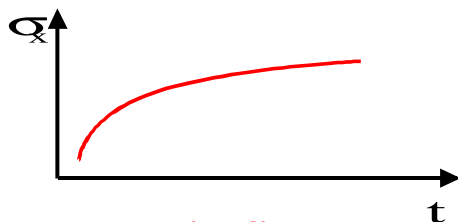
$$\varepsilon = \frac{3}{2}kT \approx 40\ \text{meV}$$

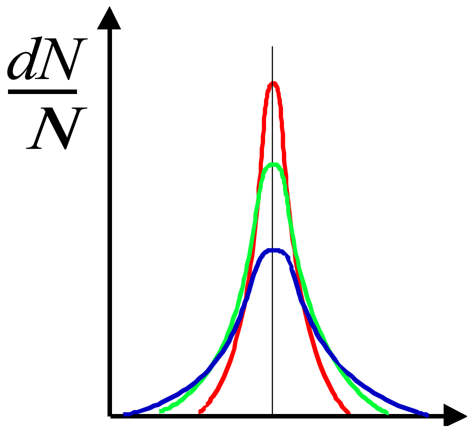
Localized charges will diffuse due to multiple collisions

$$\frac{dN}{N} = \frac{1}{\sqrt{4\pi Dt}} e^{-(x^2/4Dt)}\, dx$$

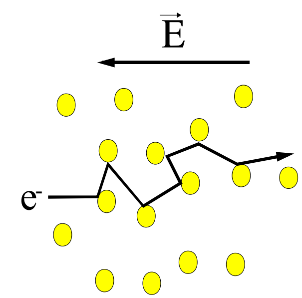
D **- diffusion coefficient**

$$\sigma_x(t) = \sqrt{2Dt} \qquad or \quad D = \frac{\sigma_x^2(t)}{2t}$$





With external electric field electrons will scatter on atoms of gas → drift (stop and go)



$$\vec{v}_D = \mu \vec{E} \qquad \mu = \frac{e\tau}{m}\ \text{(mobility)}$$

Equilibrium

$$\frac{x}{v_D \tau} \lambda_\varepsilon \varepsilon = eEx$$

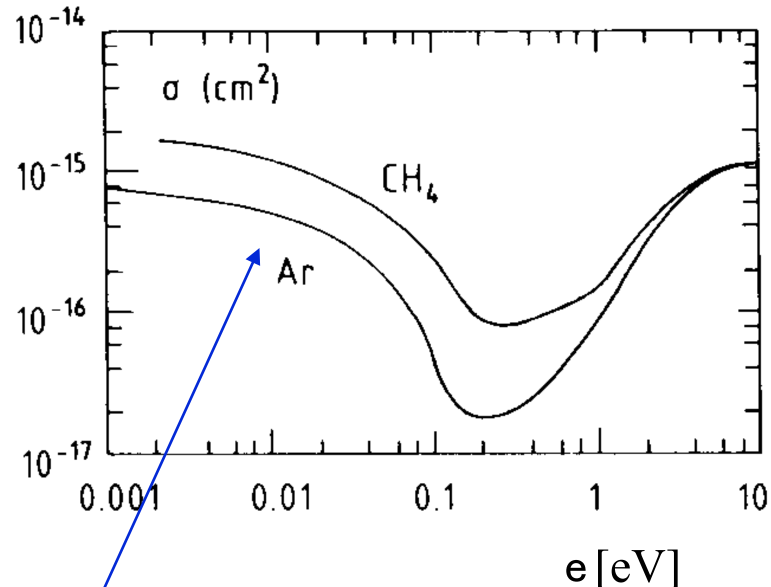
λ_e **- fractional energy loss / collision**

$$\tau = \frac{1}{N\sigma v}$$

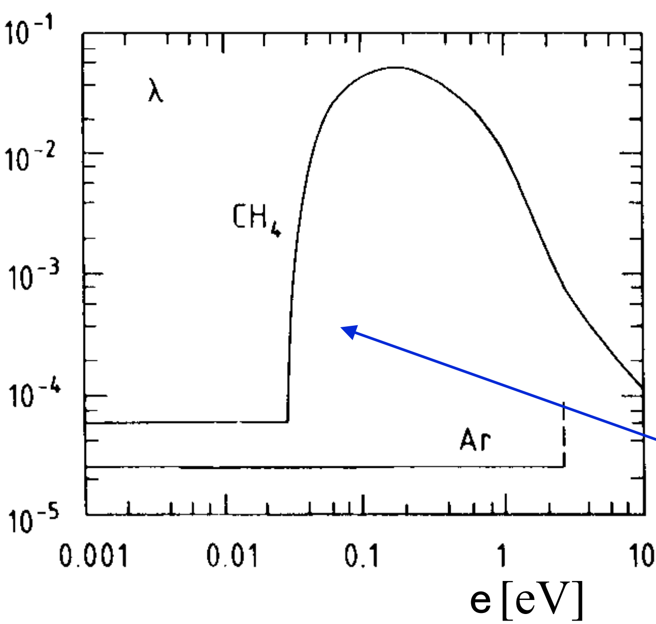
v **- instantaneous velocity**

v^2_D **– drift velocity (electron ~ 5cm/μs, ion ~10^3 slower)**

$$v_D^2 = \frac{eE}{mN\sigma}\sqrt{\frac{\lambda}{2}}$$



s=s(e)



λ=λ(e)

Drift and diffusion in gases

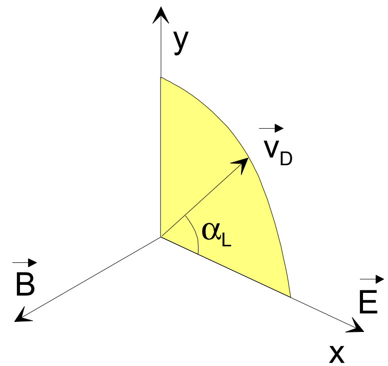
In the presence of electric and magnetic fields drift and diffusion are driven by E ✕ B effects

Special case: $\vec{E} \perp \vec{B}$

$$\tan\alpha_L = \omega\tau$$

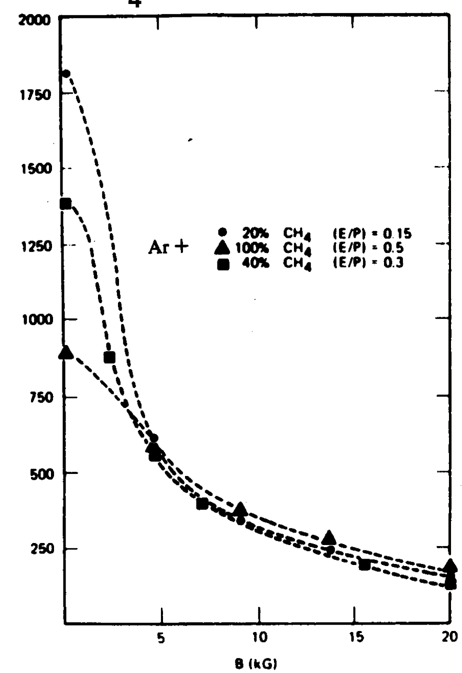
α_L: **Lorentz angle**

$$\omega = \frac{e\vec{B}}{m}$$ **cyclotron frequency**



$\vec{v}_D \nparallel \vec{E}$

Transverse diffusion s (mm) for a drift of 15 cm in different Ar/CH_4 mixtures



Special case: $\vec{E} \parallel \vec{B}$

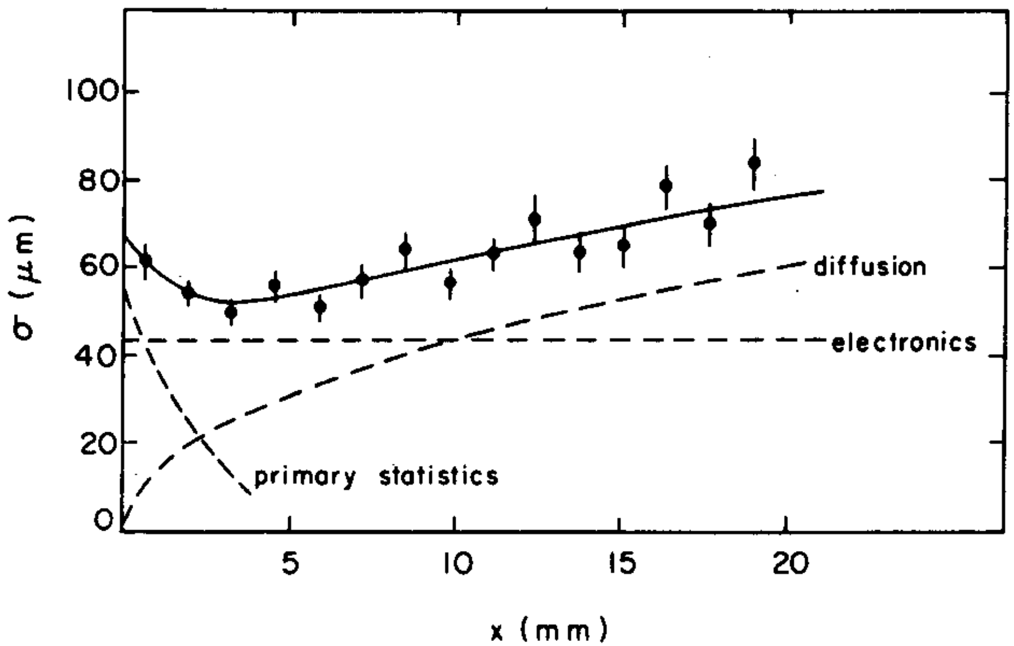
The longitudinal diffusion (along B-field) is unchanged. In the transverse direction the electrons are forced onto circle segments with the radius v_T/ω. The transverse diffusion coefficient is reduced

$$D_T(B) = \frac{D_0}{1+\omega^2\tau^2}$$

Drift chamber resolution

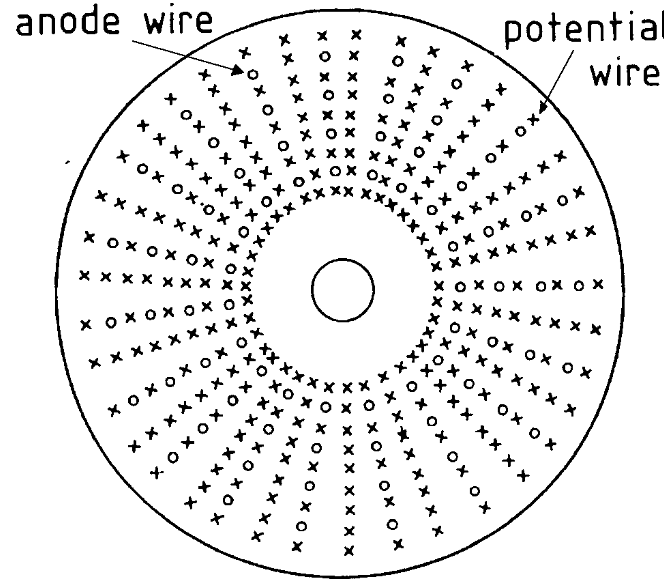
Resolution is determined by
- diffusion,
- path fluctuations,
- electronics
- primary ionization statistics

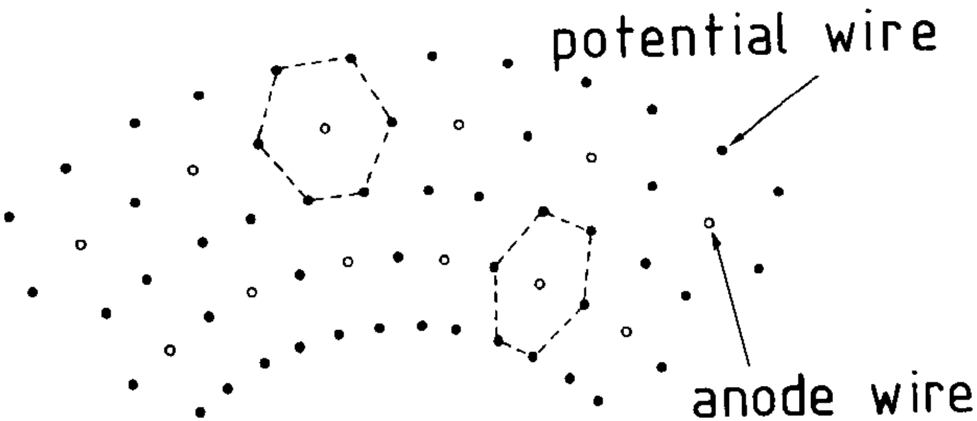
(N. Filatova et al., NIM 143 (1977) 17)

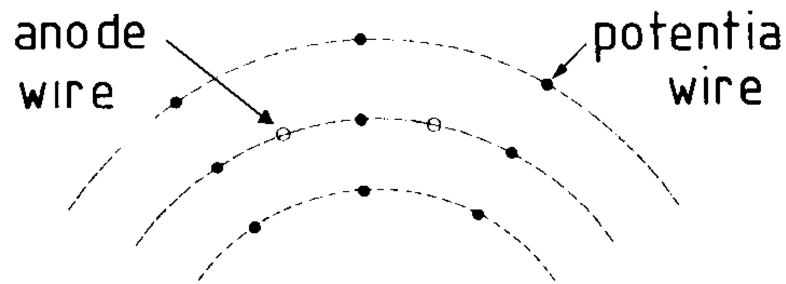


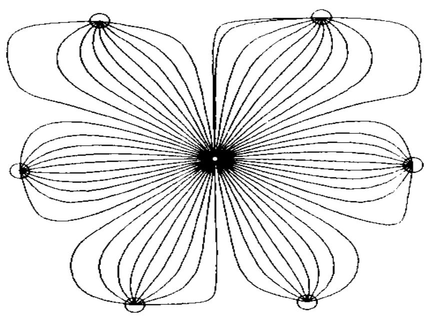
Geometry of drift chambers

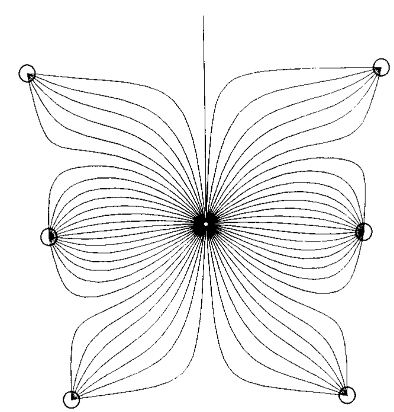
Various geometries of
cylindrical drift chambers

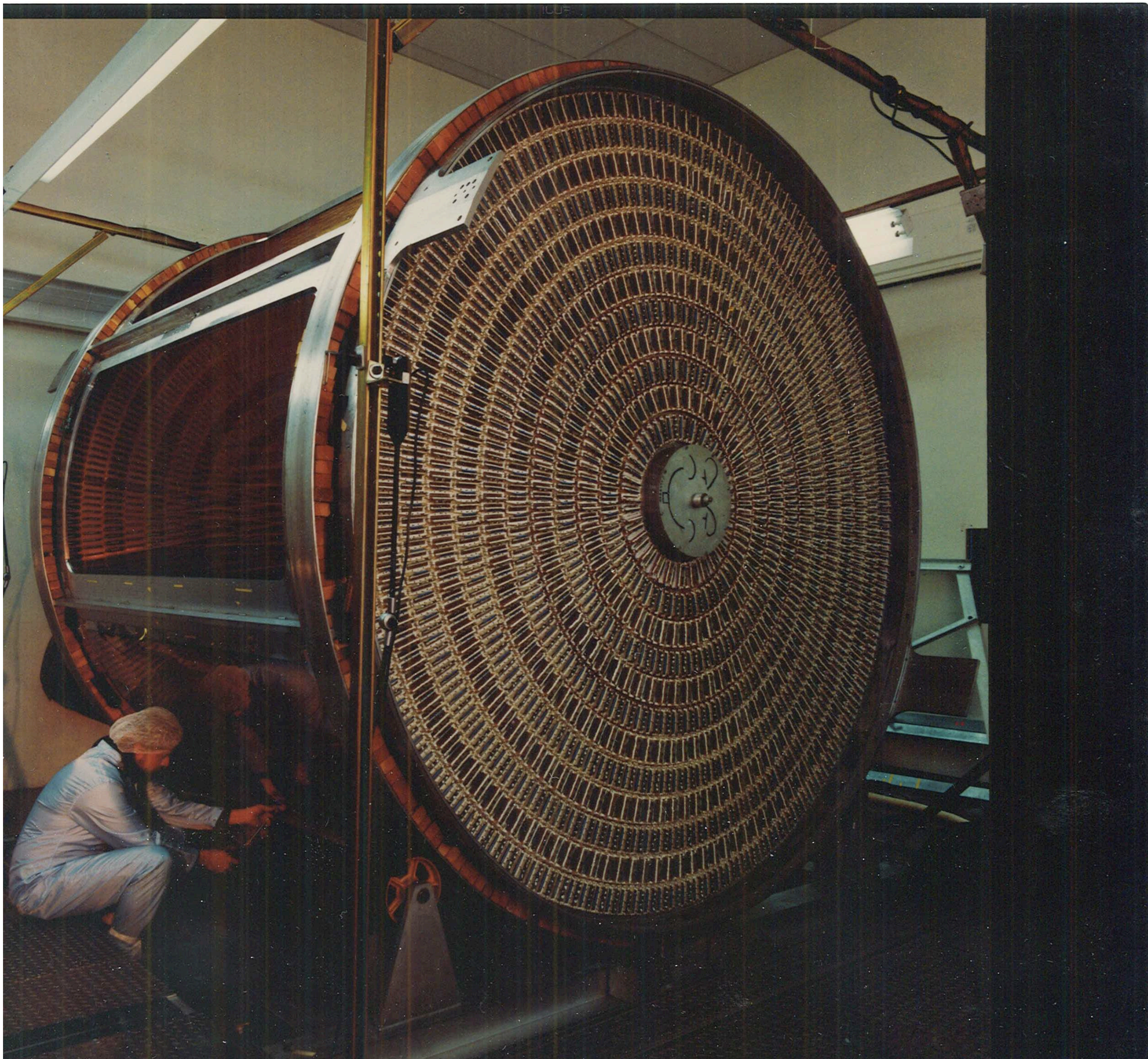


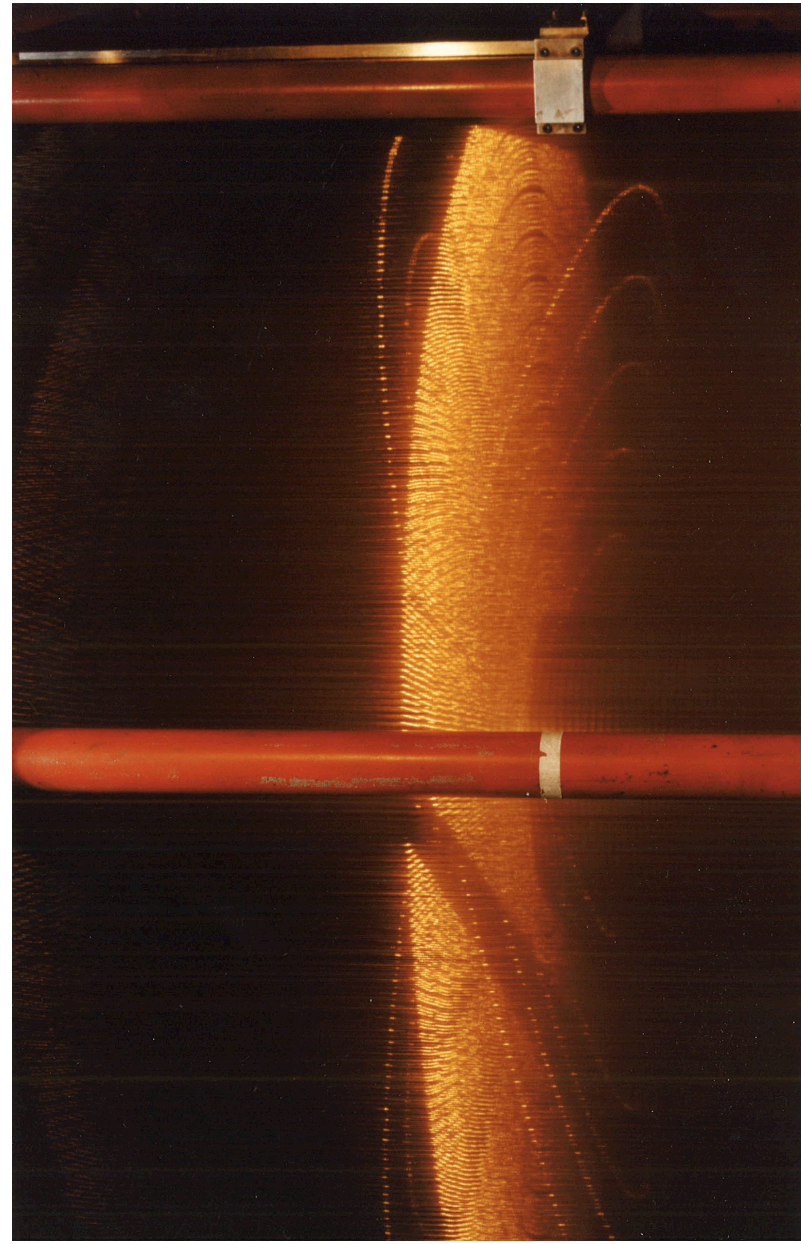












MicroMegas

Metalic micromesh placed ~50 microns from segmented electrode
400V between micromesh and signal readout -> gain ~10^4
Timing resolution ~100 ns, spatial resolution ~100 µm