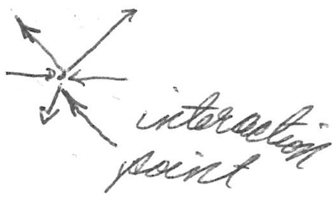
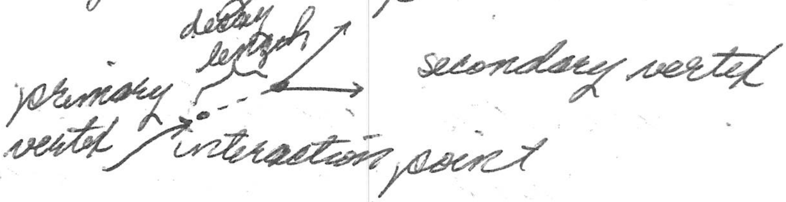
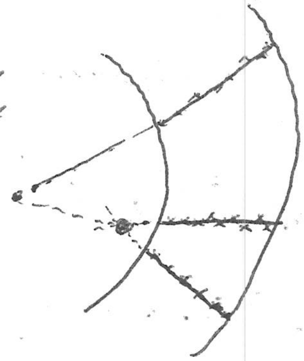
# Tracking Detectors

- critical to measure the trajectory of a particle
  - establish directionality
  - decay of unstable particles
    - find originating vertex



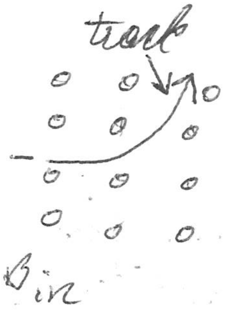


Need a non-destructive position measurement
→ ionization
→ low # of $X_0$



Example:
Drift chamber
→ extrapolate tracks toward interaction point

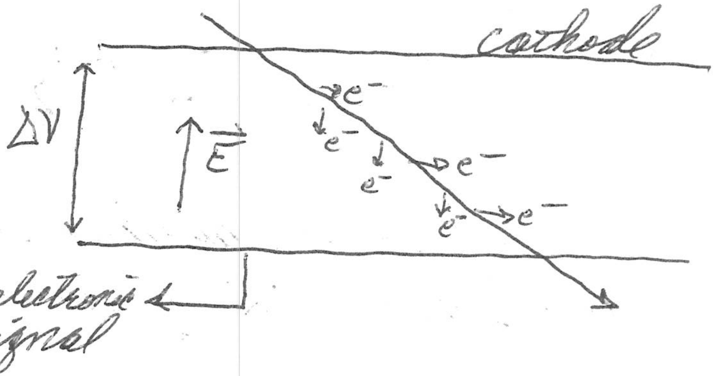
- of a magnetic field
  - charged particle trajectory curvature yields momentum ($\vec{F} = q\vec{v} \times \vec{B}$)



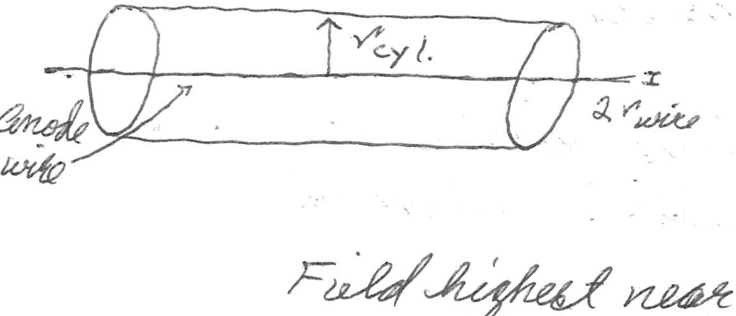
3 categories of common trackers
- gaseous ionization detectors
- semiconductors
- scintillating fiber tracker

# Proportional ~~Counters~~ Detectors

- proportional chamber



- when $\vec{E}$ large enough
  - primary $e^-$ ionization gets enough KE to cause more ionization
  - → if $\vec{E}$ lower than avalanche threshold
    $N_e \propto$ # of primary ion pairs (i.e. $\frac{dE}{dx}$)
- cylindrical arrangement



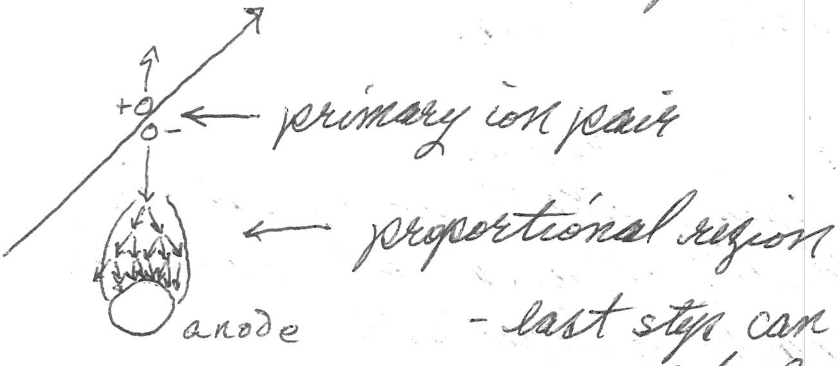
$$|E| = \frac{V_0}{r \ln(r_c/r_w)}$$

$$\propto \underline{\underline{\frac{1}{r}}}$$

Field highest near anode
- most secondary ionization here

# Ionization Parameters in Gases

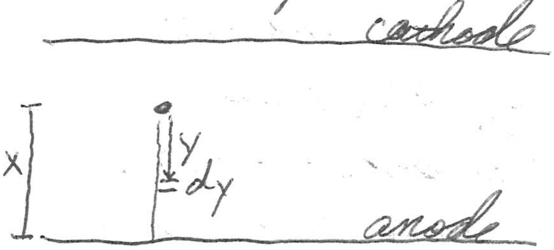
- secondary ionization
  - cross section maximum when $E \sim 100\,\mathrm{eV}$ (Noble gases)
- primary ionization
  - some $\delta$ rays may produce further ionization
  - photons produced from atomic deexcitation can also yield ionization
  - total number ions per unit length varies with substance
  - average energy lost per ion pair $\sim 30\,\mathrm{eV}$ irrespective of gas



- last step can avalanche (much more e⁻)
  - maybe last 10 um – 20 um

# Simple Example

Ionization at location between electrodes



More $e^-$ as approach anode:

$$dN = \boxed{\alpha} N_0 \, dy$$

coefficient a function of
- E-field
- gas pressure

N = total # free $e^-$s to anode

→ the change in # of $e^-$s yields relation:

$$N(x) = N_0 \, e^{\alpha x}$$ ($N_0$ = number of primary $e^-$s)

- speak of "total electron multiplication" or "gas amplification factor"

$$M(x) = e^{\alpha x} = \exp\left[\int_{\boxed{r_k}}^{r_w} \alpha(y) \, dy\right]$$

$r_k$ – radius where E high enough to cause more ionization

- in proportional counters

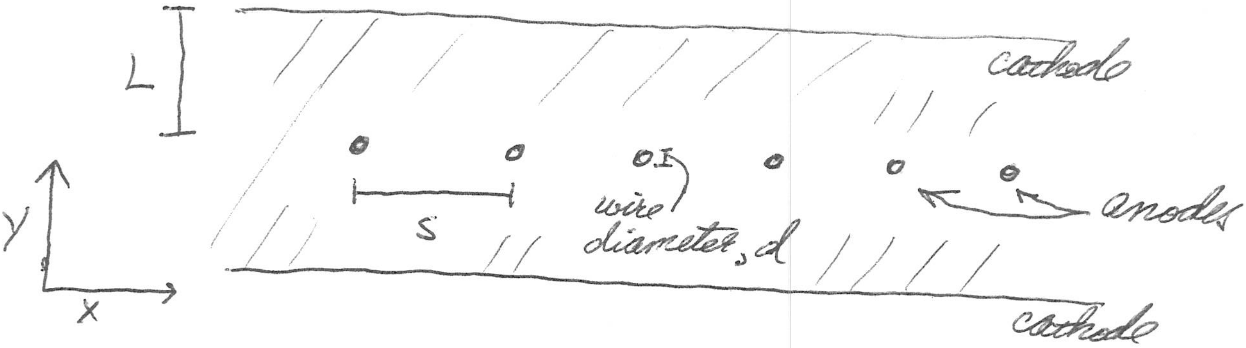
$$\boxed{M \to \text{constant} * e^{V_0/V_{ref}}}$$

= constant for given experimental configuration

# Multiwire Proportional Chamber

Configuration in which anodes become thin wires

- a plane of these can be sandwiched between cathode planes



L = anode - cathode spacing
~ 3-5 times anode wire spacing
s = anode wire spacing (~2mm often)
d = wire diameter (10-30 $\mu$m)

- Ability to collect charge on multiple wires allows an improved spatial resolution

$$\sigma(x) \sim \frac{s}{\sqrt{12}} = 580\,\mu m \quad (\text{if } s = 2mm)$$

- Gases: Noble gas + hydrocarbon admixture

## Electrostatics

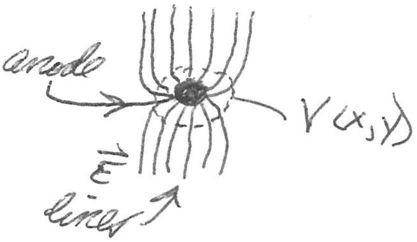
As wire diameter, $d$, $\to 0$

$$\boxed{V(x,y) = \frac{CV_0}{4\pi\epsilon_0}\left\{\frac{2\pi L}{s} - \ln\left(4\sin^2\frac{\pi x}{s} + 4\sinh^2\frac{\pi y}{s}\right)\right\}}$$

$= V_0$ at anode wires

$= 0$ at cathodes

In region of avalanche (near anode) $\sim$ nearly circular equipotential



$\therefore$ behave like proportional counter

There is a capacitance associated with this configuration

$$\boxed{C = \frac{2\pi\epsilon_0}{\frac{\pi L}{s} - \ln\left(\frac{\pi d}{s}\right)}}$$

If $s = 2\,mm$, $L = 8\,mm$, $d = 30\,\mu m$, then

$C = 3.6\,pF/m$

## Wire Geometry + Tension

Nonuniformities in wire spacing or diameter

- cause $\vec{E}$-field variations
- significant variations in charge to wires
- can shift positions of wires
- all of these impact the amplification, or 'gain' in avalanche region (eg. by 30%)
- if appreciable, these effects must be modeled properly (+ therefore measured)

Wire must be able to accept electrostatic forces

- $\Delta V$ between anode - cathode must be less than restoring force from tension can tolerate

$$\boxed{\Delta V = V_0 \leq \frac{s\sqrt{4\pi\epsilon_0 T}}{LC}}$$

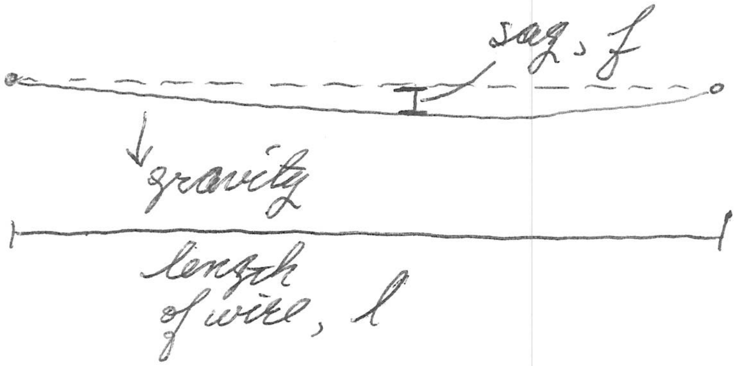
T = tension ($\propto d^2$)

  - limits how small wire spacing can be
- have minimum tension to hold wires stably

$$\boxed{T \geq \left(\frac{V_0 LC}{s}\right)^2 \frac{1}{4\pi\epsilon_0}}$$

# Sagging of Wires

Consider a gold-plated tungsten wire supported at its ends



Sag is

$$f = \frac{\overset{\text{area of wire}}{\boxed{A_{wire}}}}{8}\underset{\text{wire density}}{\boxed{\rho}}\underset{\text{gravitational acceleration}}{\boxed{g}}\frac{l^2}{\boxed{T}\text{ — tension (N)}}$$

Assuming uniform density, the mass of the wire, $m = A_{wire}\rho l$

$$\therefore \boxed{f = \frac{mgl}{8T}}$$

## Example:

Take a tungsten wire with diameter 30 μm, length 1m under 0.5 N of tension.

$$r_w = \frac{d}{2} = 15\,\mu m \qquad l = 1m$$

$$T = 0.5N \qquad \rho_w = 19.3\,g/cm^3$$

The mass of the wire is

$$m = \rho \pi r_w^2 l = 19.3\,g/cm^3 \left(\pi (1.5\times10^{-3}\,cm)^2 \times 100\,cm\right)$$

$$= \underline{1.36\times10^{-2}\,g}$$

This gives a sag of

$$\underline{\underline{f}} = \frac{1.36\times10^{-5}\,kg}{8}\, 9.8\,m/s^2\, \frac{1m}{0.5\,kg\,m/s^2}$$

$$= \underline{\underline{33\,\mu m}}$$

# Segmentation + Spatial Resolution

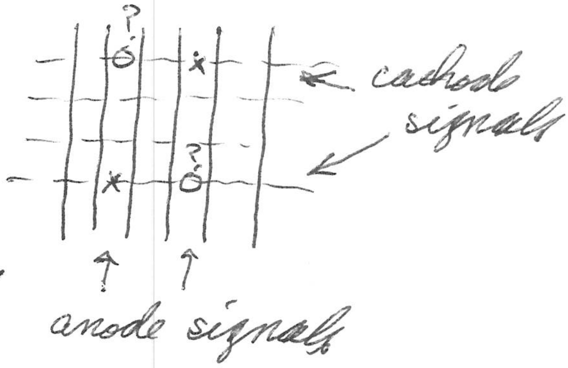
Position resolution from anode signals confined to direction in anode plane + ⊥ to wires

How obtain second coordinate || to wires?

→ timing of anode signal

→ an induced charge shows up on the cathodes

- could have cathodes into strips ⊥ to anodes
  - in high occupancy environment may need 2 cathode orientations



A 2nd cathode plane @ 45° would resolve ambiguity