Experimental Particle Physics
PHYS6011
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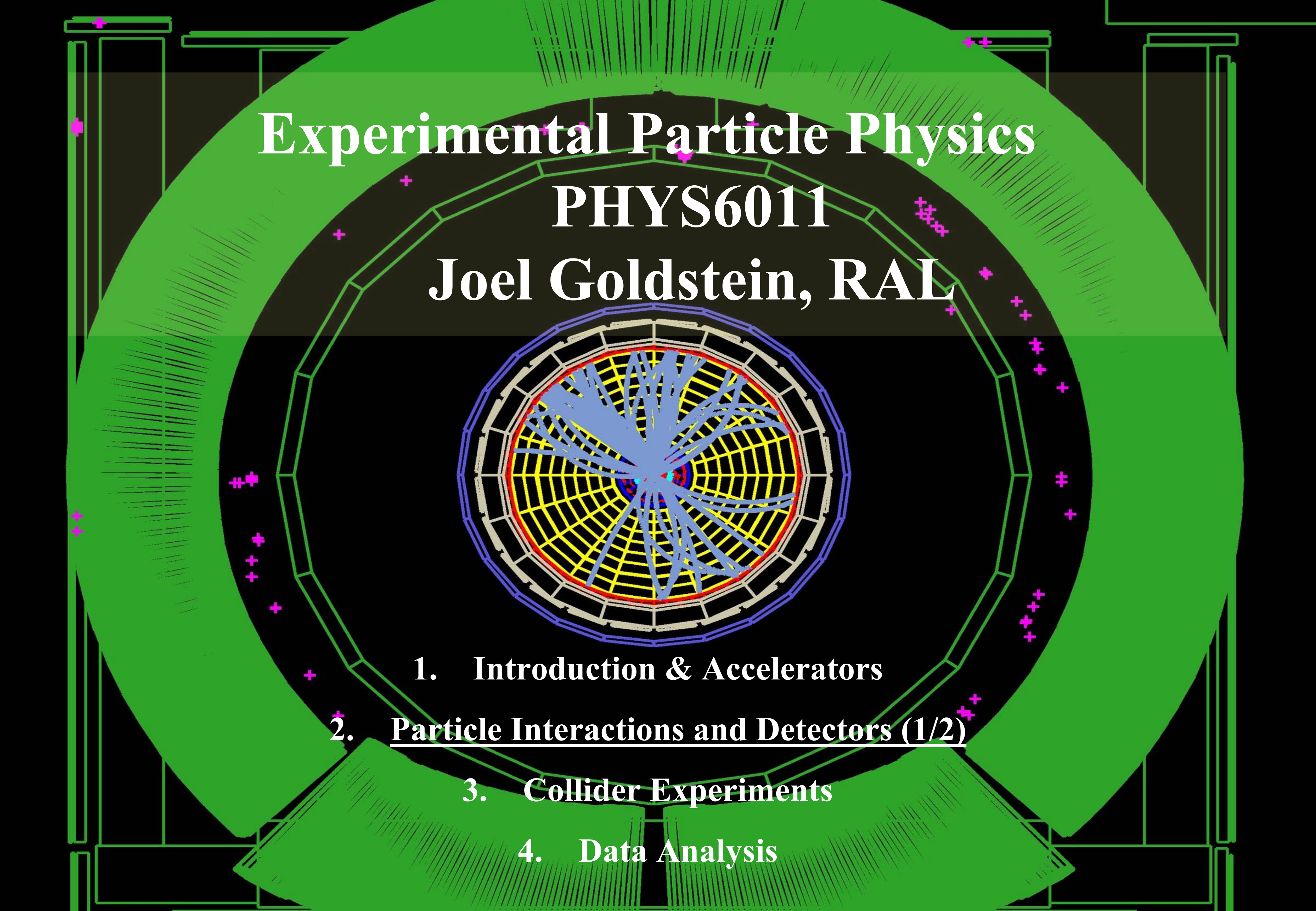


1. Introduction & Accelerators
2. <u>Particle Interactions and Detectors (1/2)</u>
3. Collider Experiments
4. Data Analysis

Charged Particle Detectors

1. Ionisation losses
2. Ionisation detectors
   a) Non-electronic
   b) Scintillation
   c) Wire chambers
   d) Drift detectors
   e) Solid state
3. Cerenkov and transition radiation detectors

Ionisation and Excitation

- **Charged particles interact with electrons in material as they pass**
- **Can be calculated: *The Bethe-Bloch Equation***

Maximum energy loss in single collision

$$T_{\max} \approx 2m_e c^2 \beta^2 \gamma^2$$

Constant

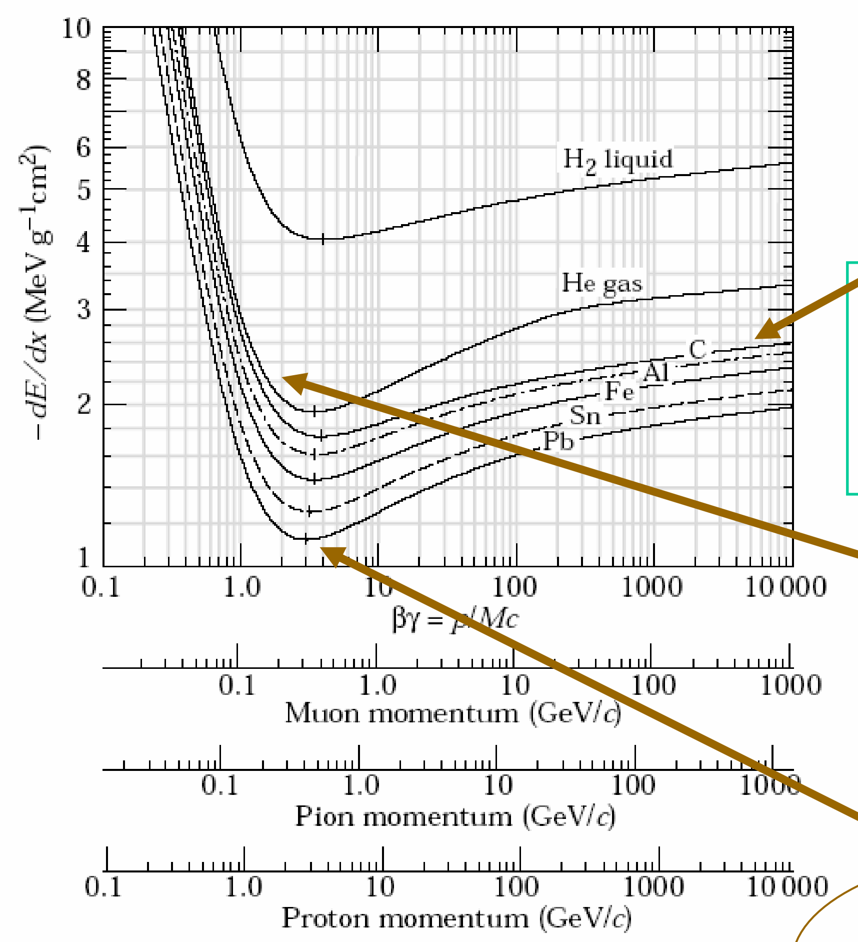
$$-\frac{dE}{dx} = Kq^2 \frac{Z}{A\beta^2}\left[\frac{1}{2}\ln\frac{2m_e c^2\beta^2\gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

≈1/2

Constant for material

Small correction

Mean Energy Loss



High energy ~ ln γ

$$-\frac{dE}{dx} \approx Kq^2 \frac{Z}{A\beta^2}\left[\ln\frac{2m_e c^2 \beta^2 \gamma^2}{I^2} - \beta^2\right]$$

Low energy ~ 1/β²

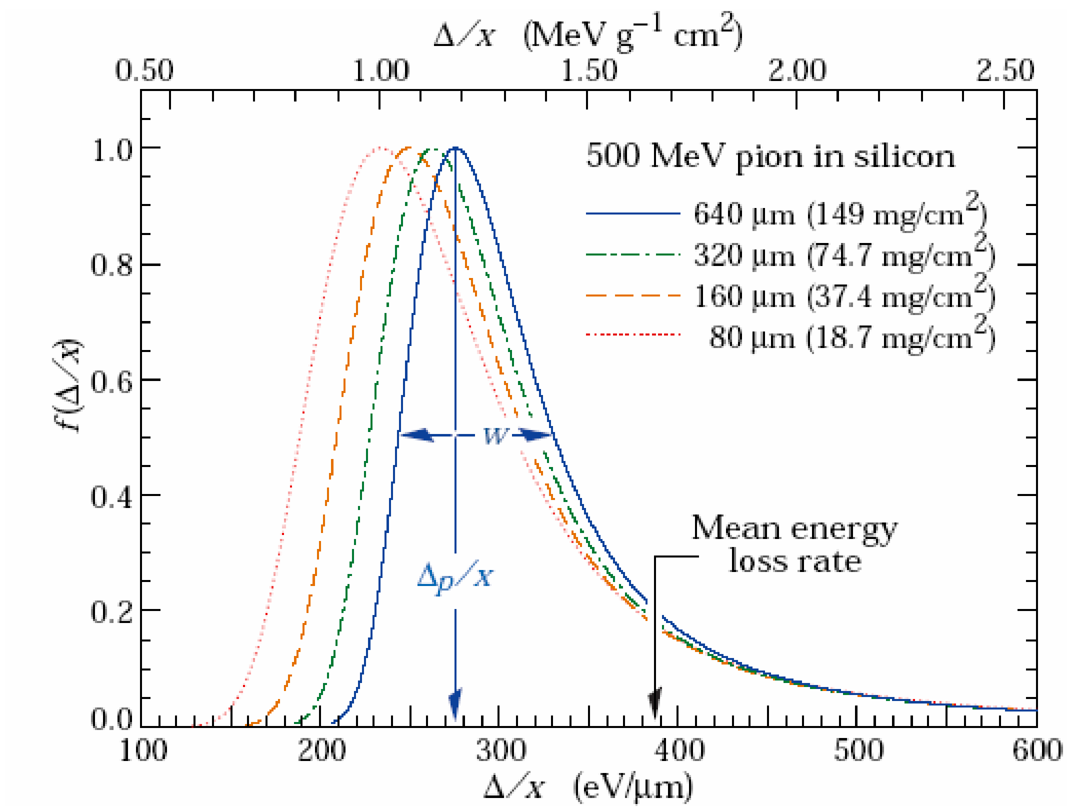
Minimum at γ≈3

Distance units:

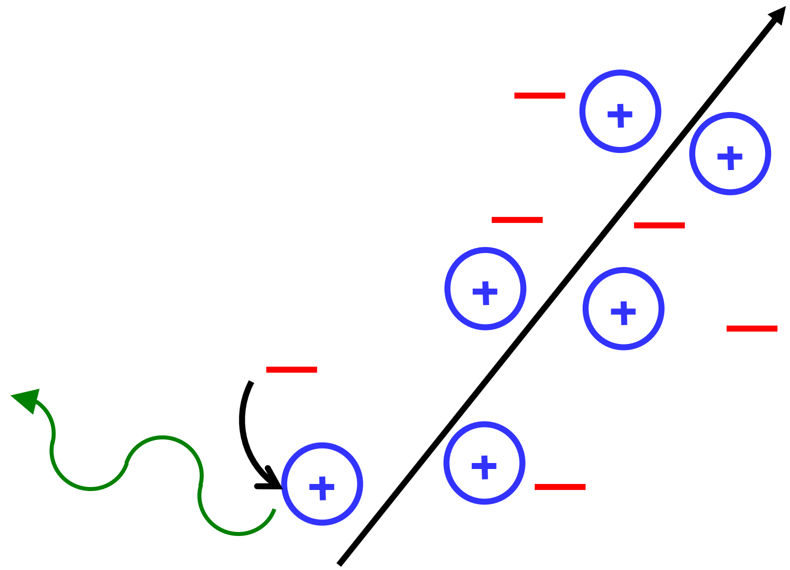
- **g cm^{-2}**

Fluctuations

- **Bethe-Block only give mean, *not* most probable**
- **Large high energy tail – δ rays**
- **Landau distribution:**



Ionisation Detectors

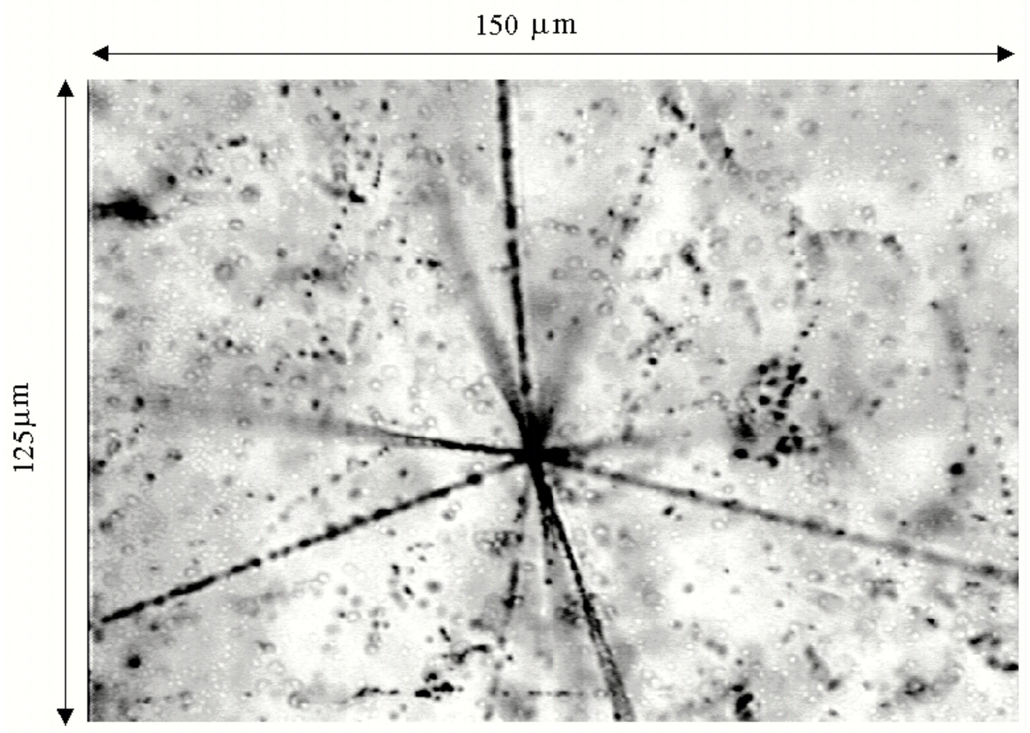


Ionisation used to detect particles in different ways:

1. **Observe physical or chemical change due to ions**
2. **Detect energy from recombination - scintillation**
3. **Collect and measure free charges - electronic**

Emulsions

- Expose film to particles and develop

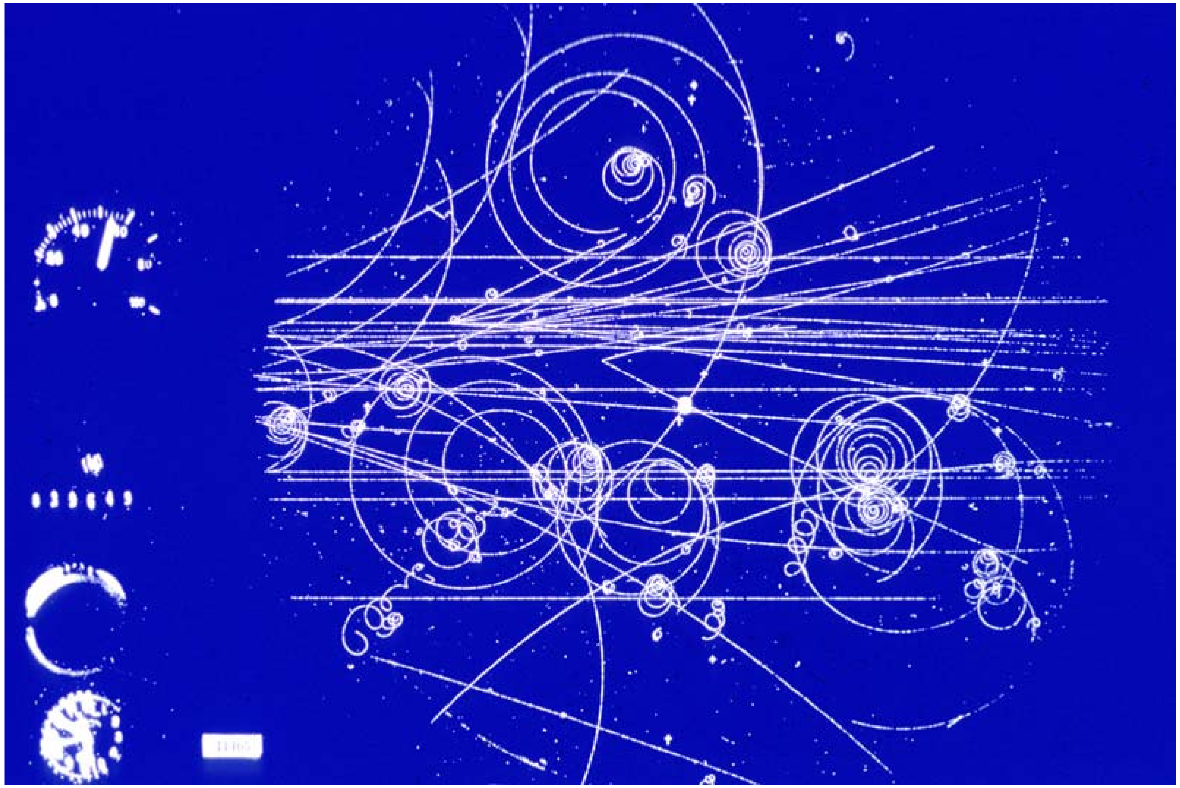


- Natural radioactivity was discovered this way
- Still occasionally used for very high precision, low rate experiments
- Similar technique in etched plastics

Bubble Chambers

- Ionisation trail nucleates bubbles in superheated liquid

1. Liquid H_2 (or similar) close to boiling point
2. Suddenly reduce pressure
3. Fire beam into chamber
4. Take photo

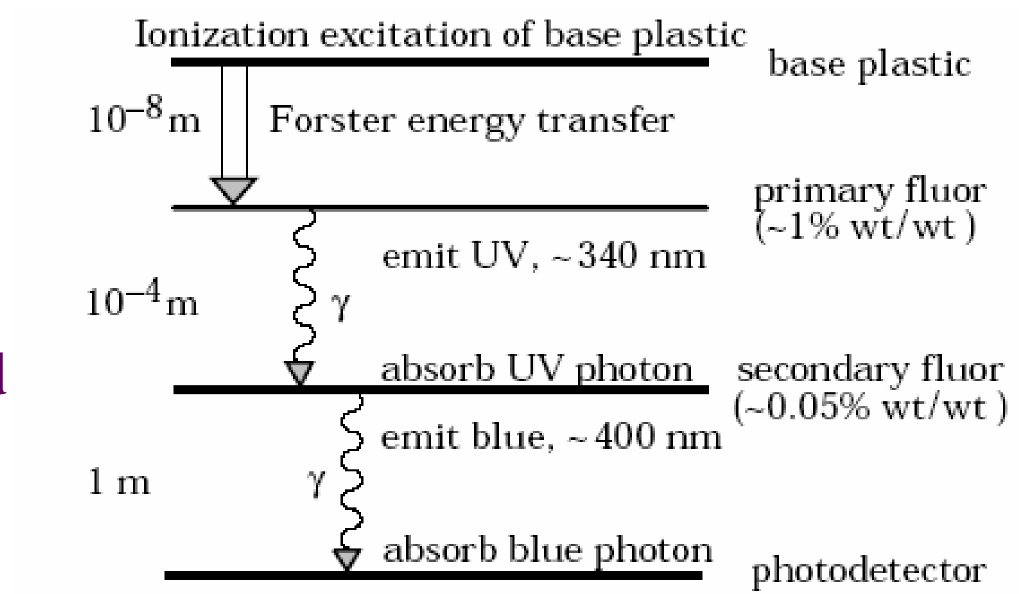


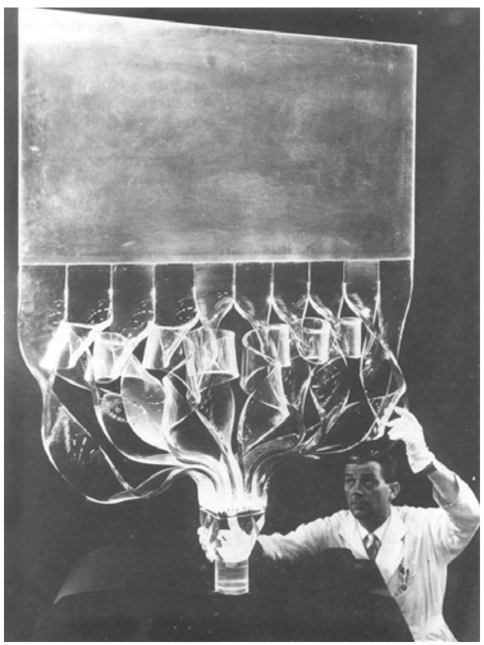
- Cloud chamber similar: ions nucleate condensation in saturated vapour

Scintillation Detectors

Detect photons from electronic recombination of ions

- **Organic (plastic)**
- **Inorganic (crystal or glass)**
  - **doping normally required**

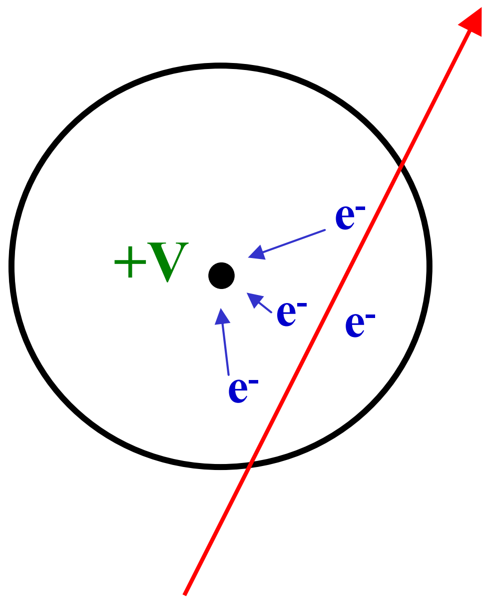


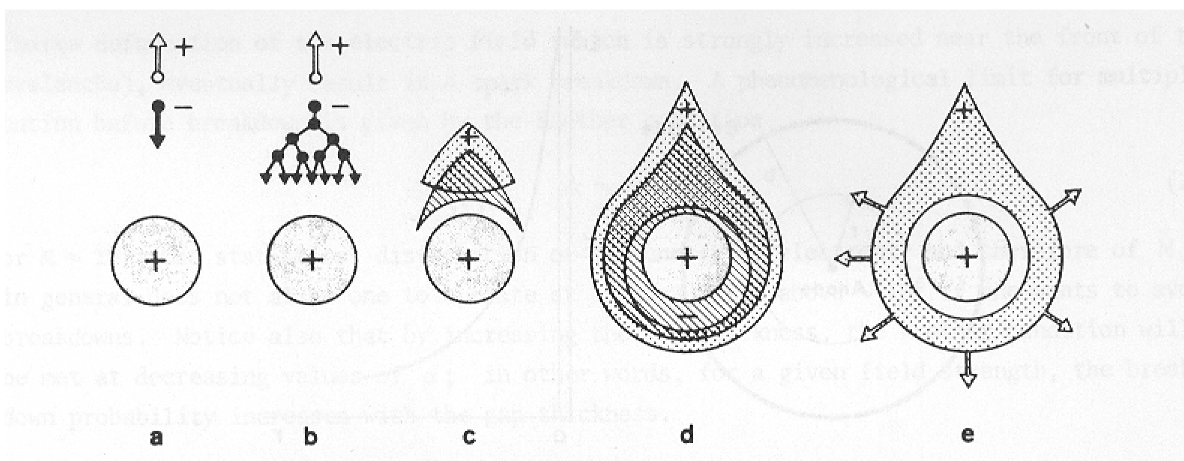


- **Not very efficient**
  ~1 photon/100eV
- **Light carried to sensitive photodetectors**
- **Fast, cheap and flexible**

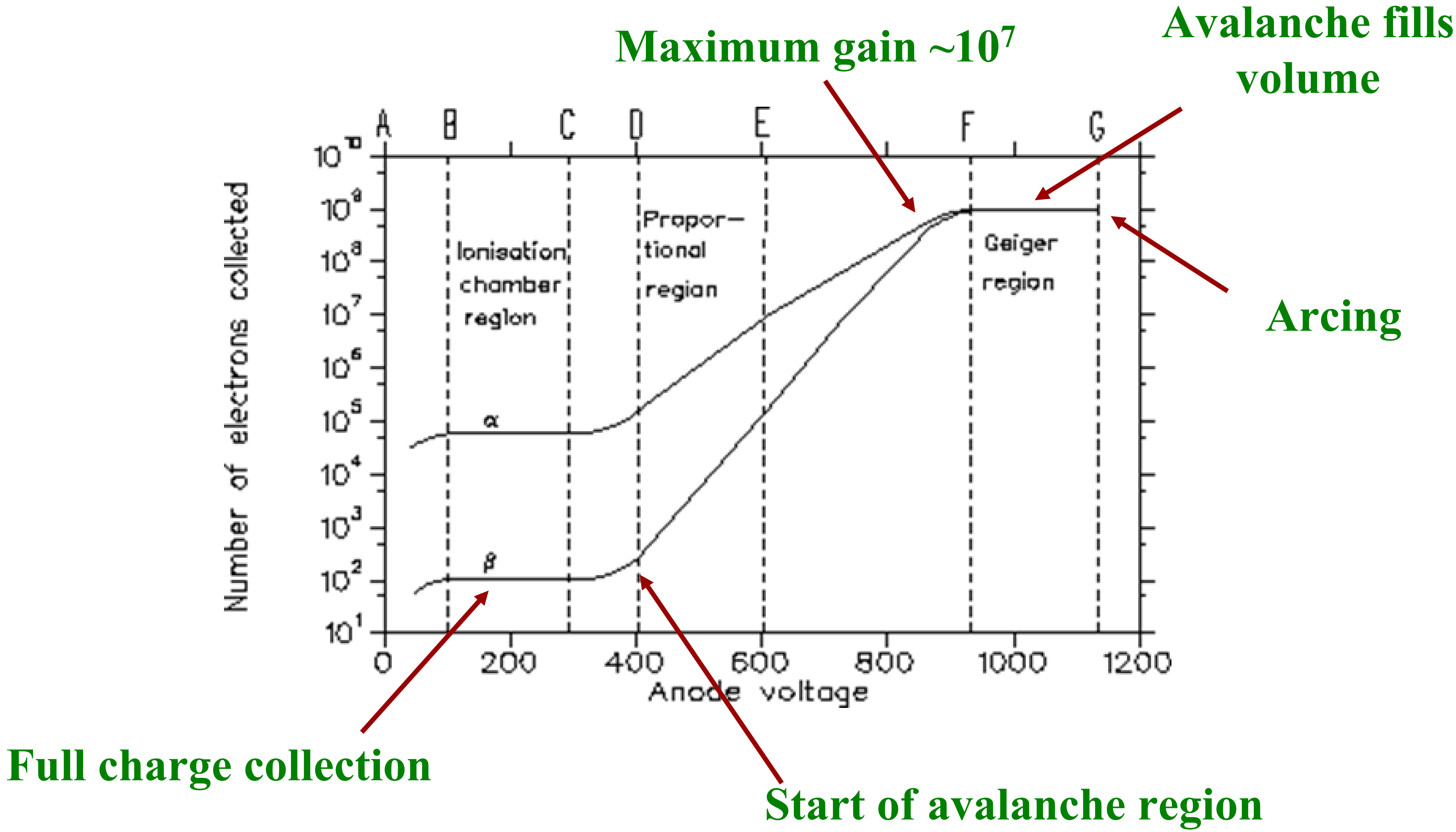
Wire Chambers

- Free electrons will be attracted to anode
- Electric field near thin wire increases
- Secondary ionisation may start to occur
  - *avalanche!*



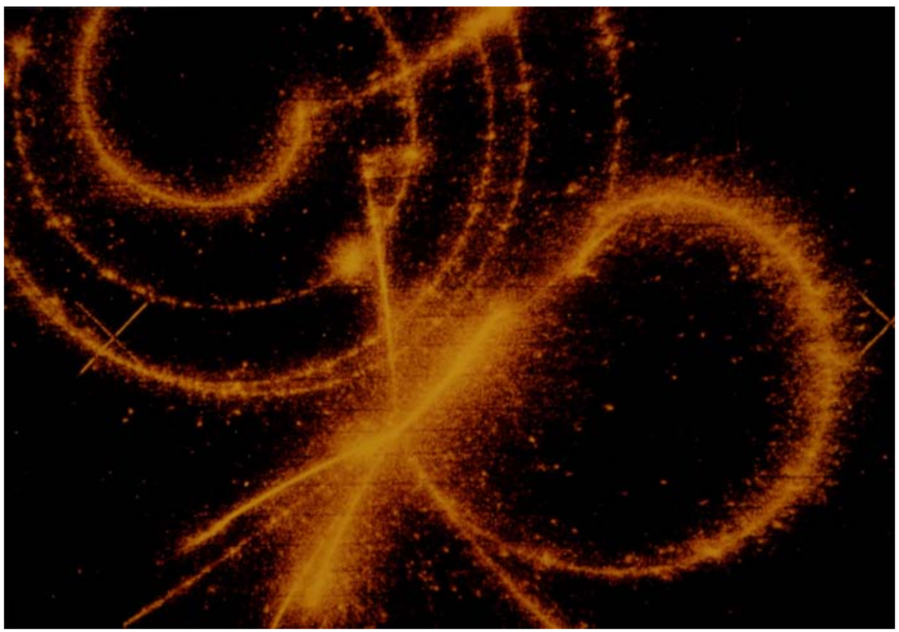


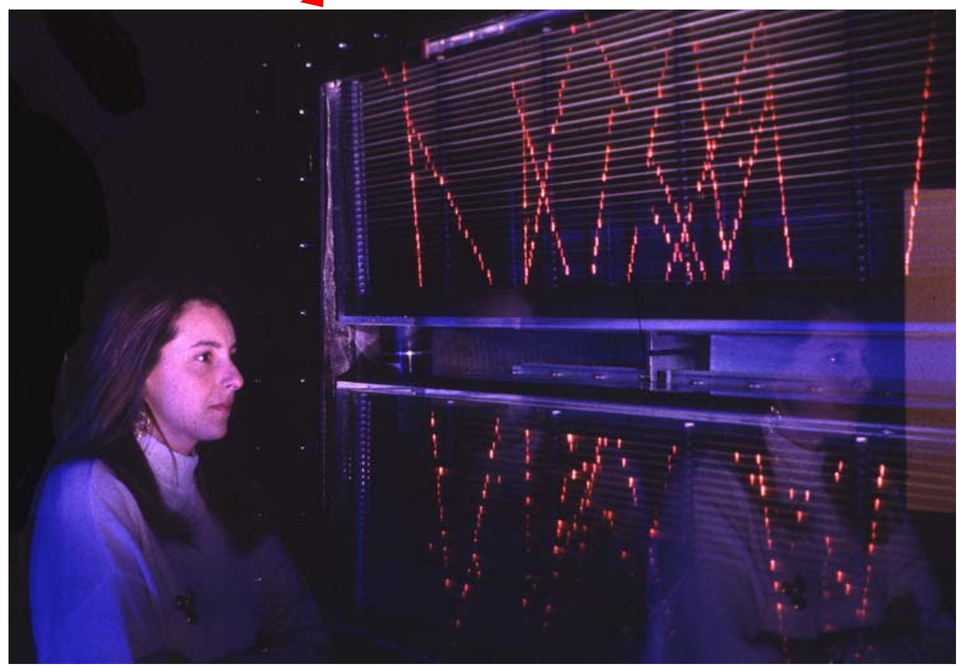
Gas Amplification



Geiger Region

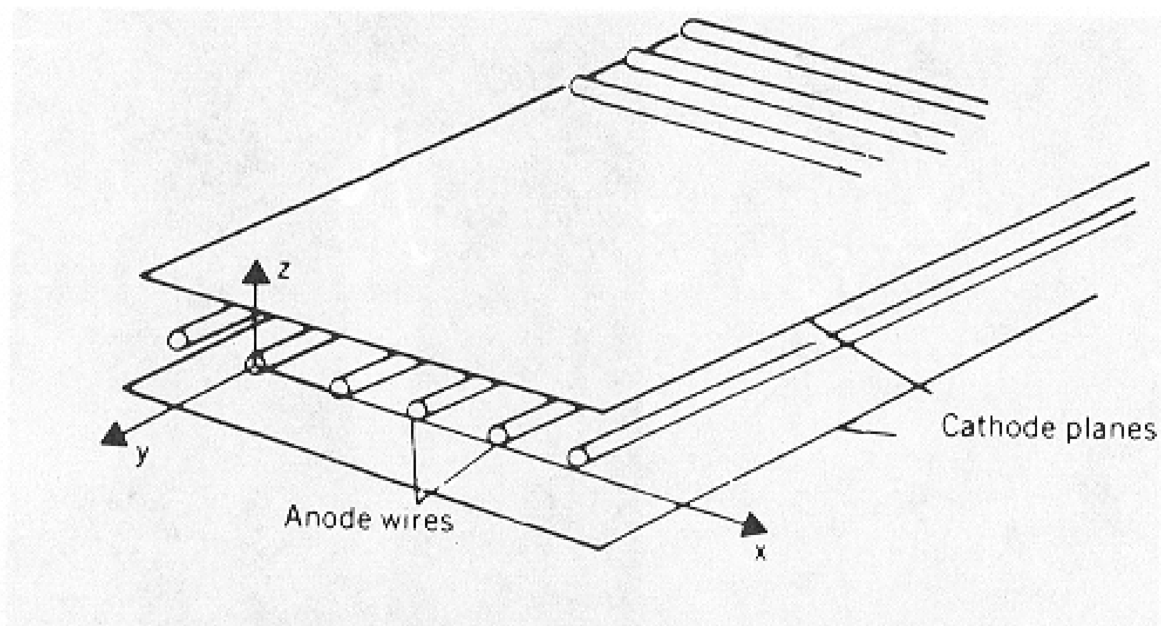
- Geiger Counter
- Spark Chamber
  - short bias pulse->localise breakdown
- Streamer Chamber
  - Large volume, transparent electrodes



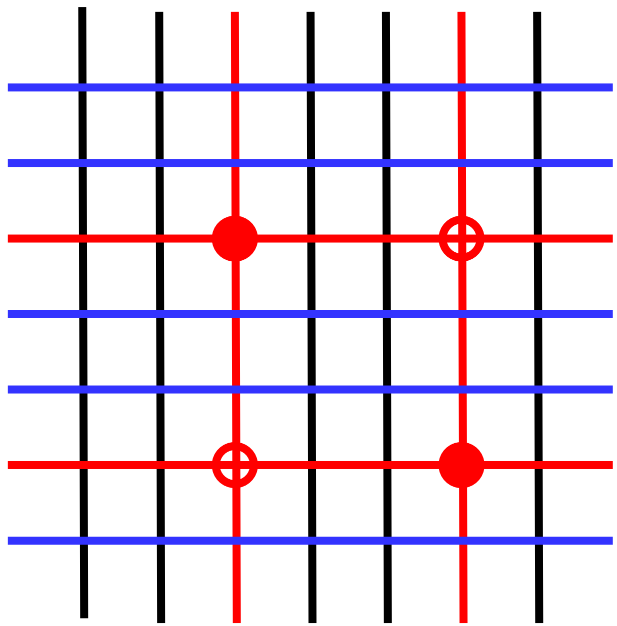


MWPC

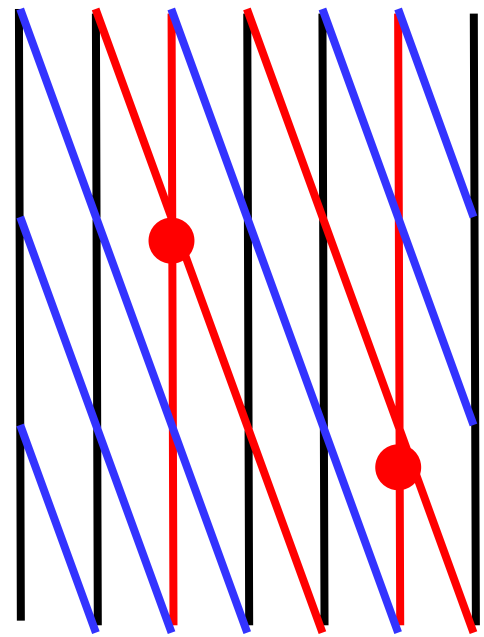
- Need better idea for large volume coverage at high rates
  - Multiwire Proportional Chamber
  - Fast
  - Resolution ~pitch/√12
  - *x* from anode
  - *y* from ions at segmented cathode plane



Stereo Readout



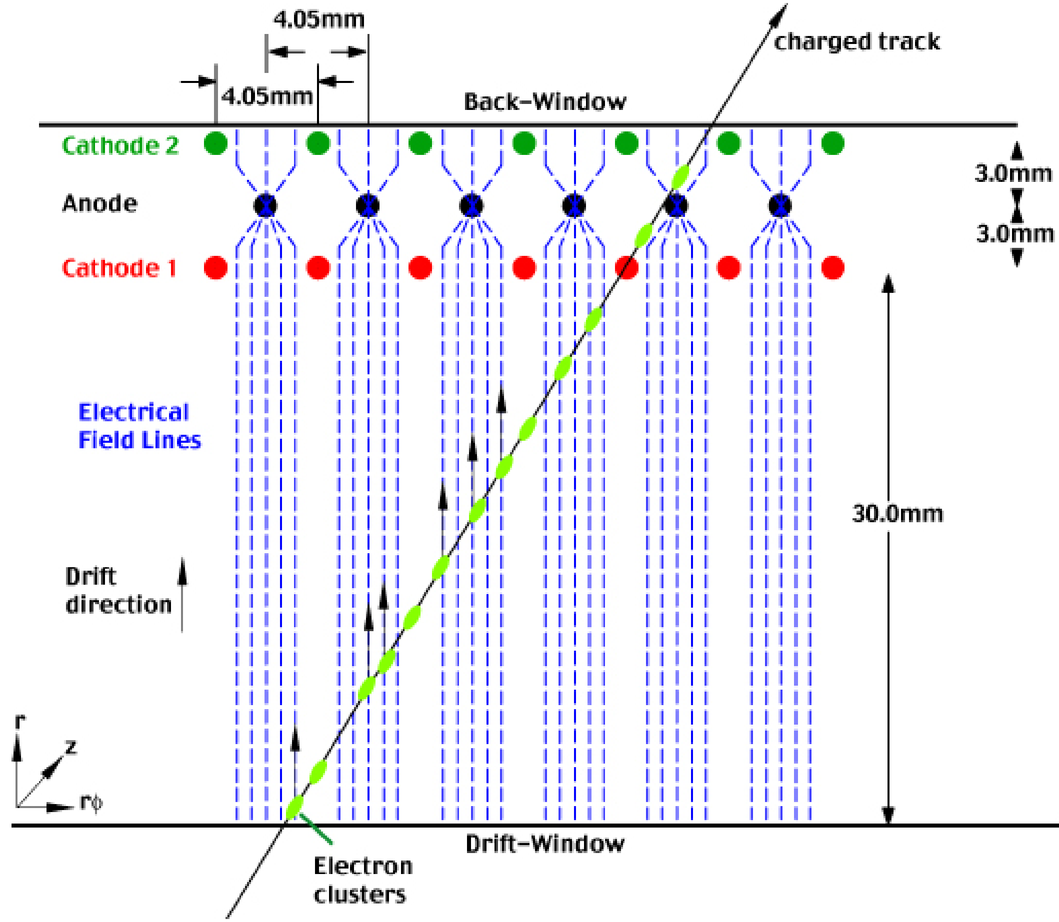
- Good *z* resolution
- Need readout along length
- Ghost hits



- Good pattern recognition
- Readout from ends
- Poor *z* resolution

Drift Chambers

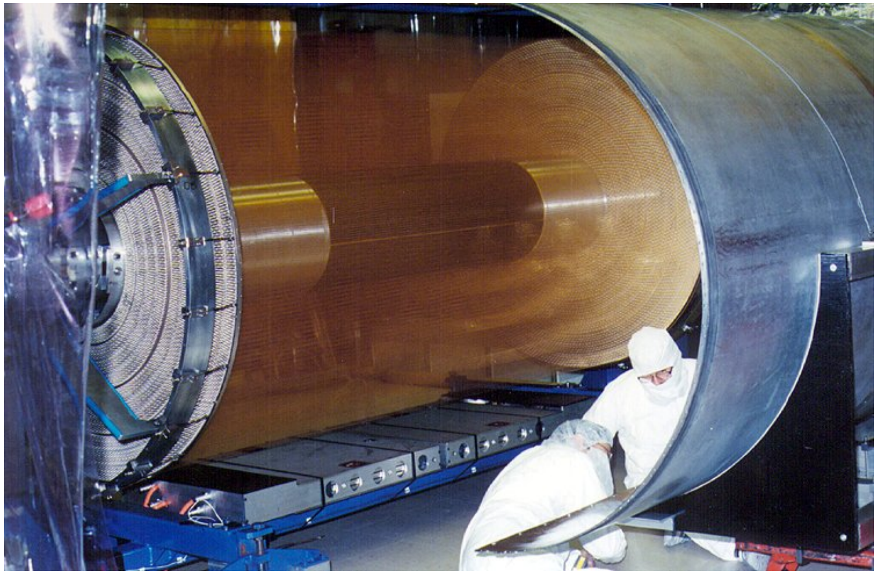
- Electron drift speed depends on electric field and gas
- Time delay of hit gives distance from sense anode
- Extra wires can be used to separate drift and avalanche regions
- Typical values:
  - drift distance ~cm
  - drift time ~μs
  - precision ~100 μm

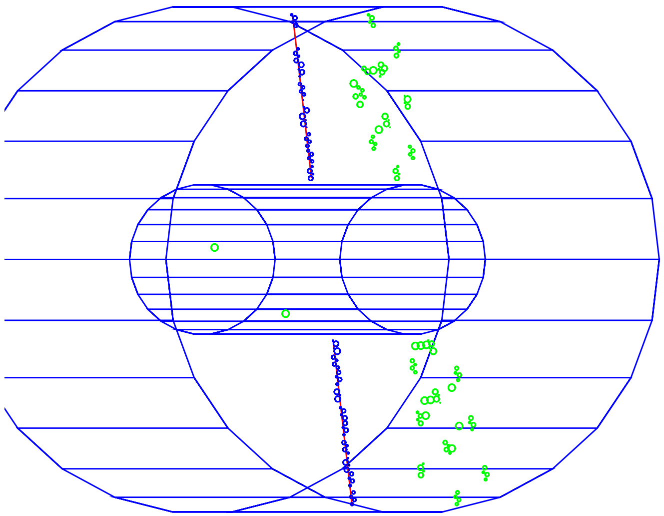


BaBar Drift Chamber

Open Cell Drift Chamber

- 2.8 m long
- Gas volume ~ 5.6 m^3
- 7100 anode wires
- Axial and stereo
- ~50,000 wires in total

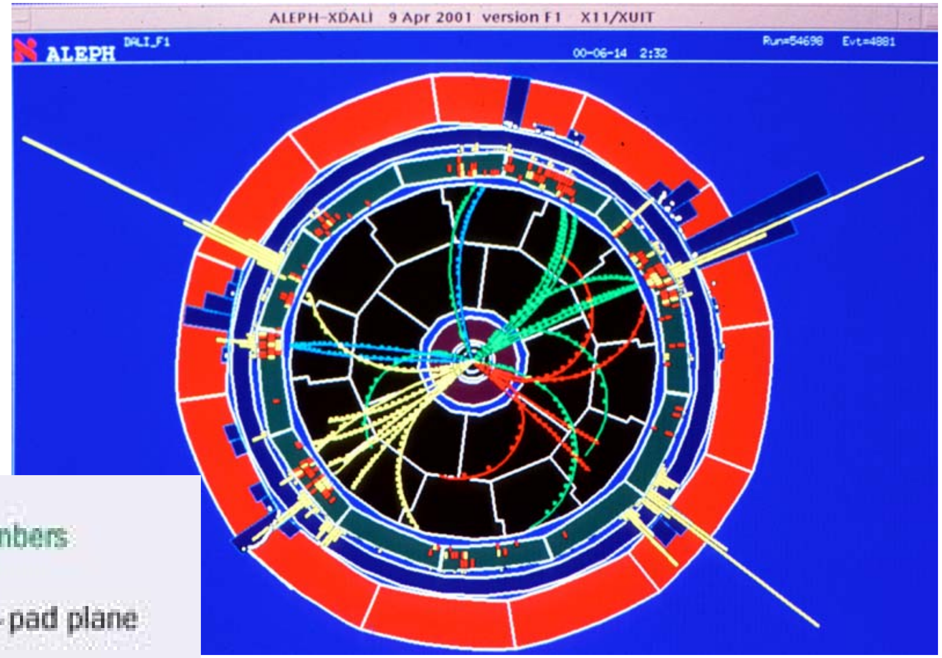


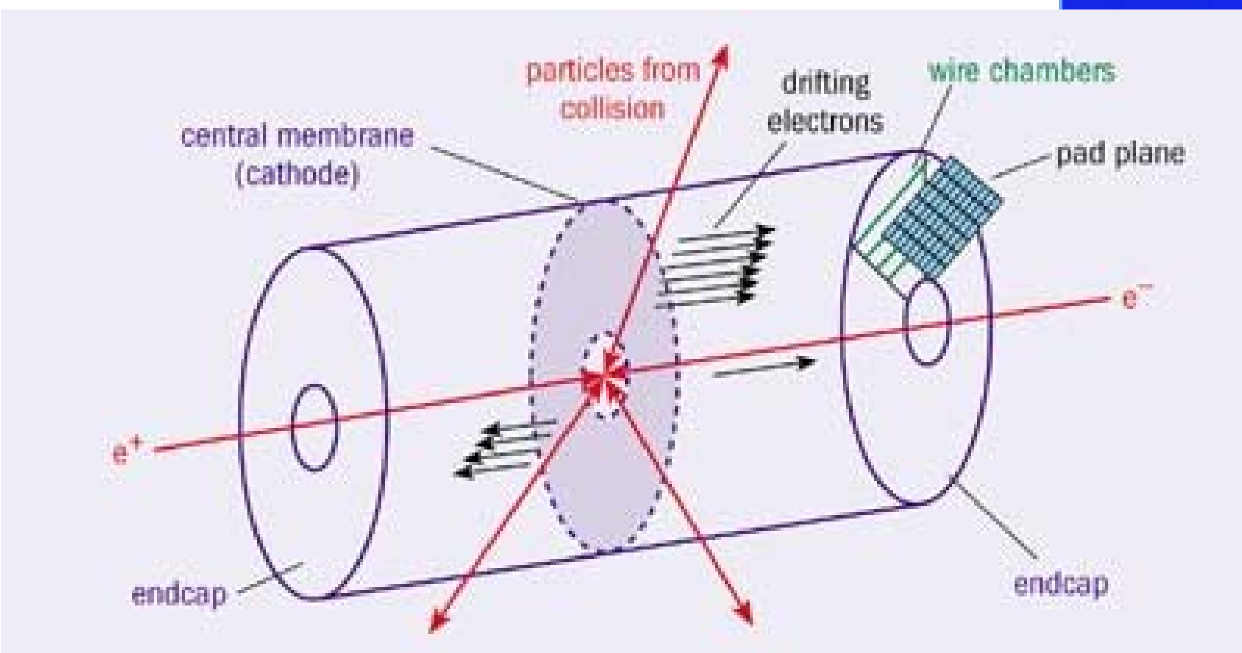


Time Projection Chamber

Large gas volume with uniform z field

- **Electrons drift to end caps**
- **2D readout (e.g. MWPC) at end for *xy***
- **Timing gives *z* measurement**

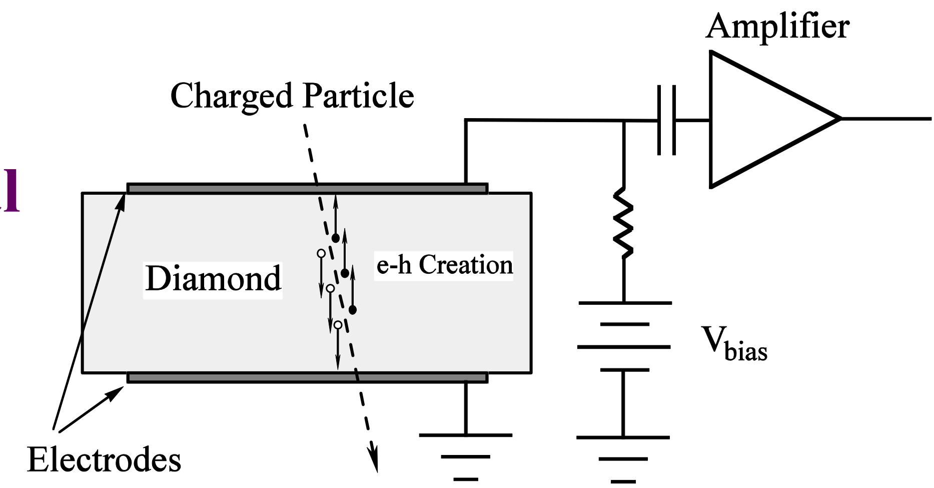




Operating Wire Chambers

- Gas, voltage and geometry must be chosen carefully
  - precision, amplification, avalanche characteristics...
- External magnetic field influences behaviour
- MWPC:
  - fast, reliable
  - often used for triggering
- Drift/TPC:
  - large volume, reasonably precise
  - high incident fluxes can cause “short circuit”
  - long readout time
- Need other solution for high rates and/or extreme precision

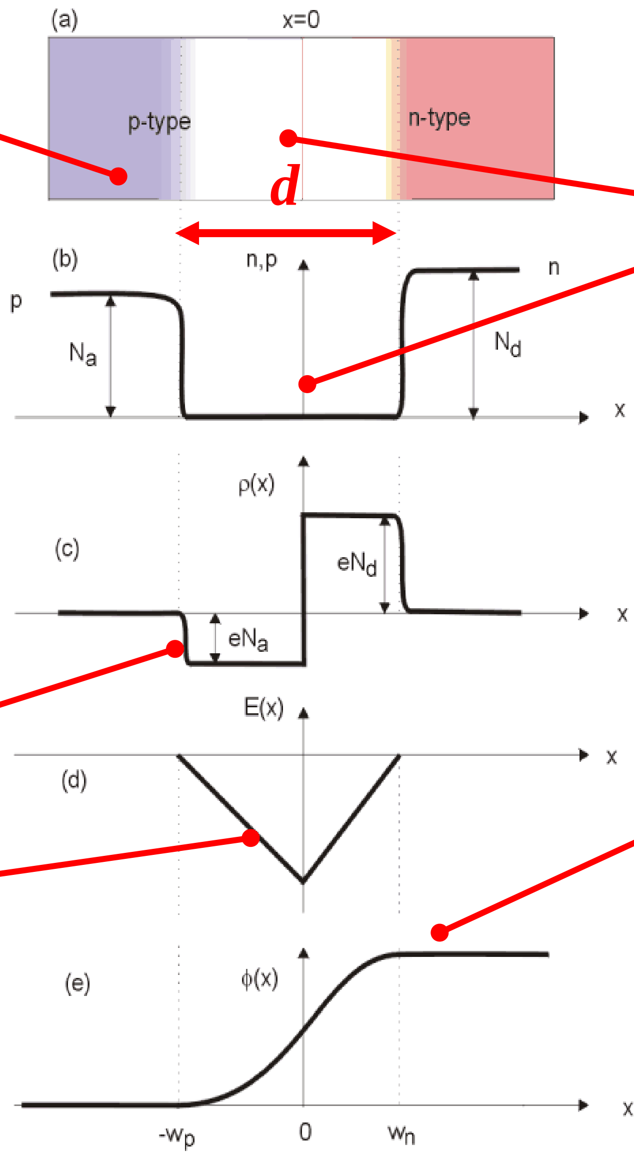
Solid State Detectors



- **Detect ionisation charges in solids**
  - **high density → large *dE/dx* signal**
  - **mechanically simple**
  - **can be very precise**
- **Semiconductors**
  - **small energy to create electron-hole pairs**
  - **silicon extremely widely used**
    - **band gap 1.1 eV**
    - **massive expertise and capability in electronics industry**
- **Resistors**
  - **plastic – cheap**
  - **diamond – robust**

Reminder: p-n Junctions

Silicon doped to change electrical properties



Charge carriers diffuse out of depletion region

Net space charge ⇒ electric field

Intrinsic depletion can be increased by reverse bias

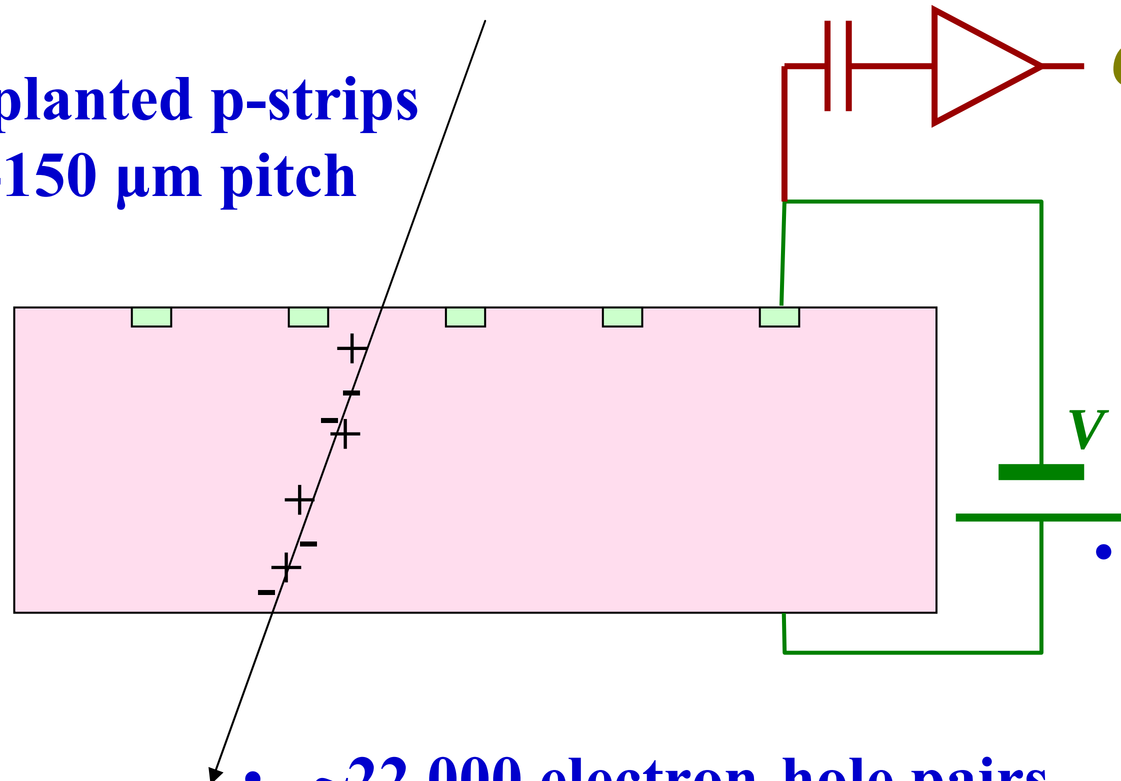
$$d \approx 0.5\sqrt{\rho(V+0.5)}\,\mu\text{m}$$

Silicon Strip Detector

- Resolution ~ pitch/√12

- implanted p-strips
  50-150 µm pitch

- 300 µm thick
  n-type silicon

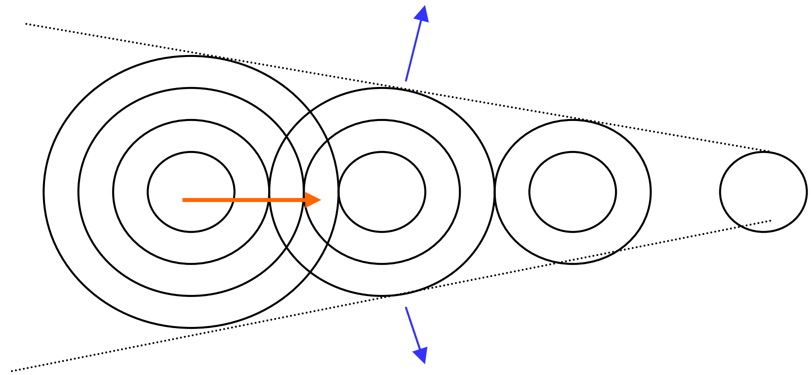


- Fully depleted

- ~22,000 electron-hole pairs per MIP *(most probable)*

Cerenkov & Transition Radiation

- Cerenkov Radiation
  - speed of light in medium = c/n
  - charged particles produce light “shock waves” if v>c/n
  - light cone $\cos\theta = c/vn$
  - “eerie blue glow”



- Transition Radiation
  - emitted as particle moves from one medium to another
  - function of γ

- Energy loss small, but can be detected
  - Very useful for particle ID

Next Time...

More interactions and detectors