8.701

Introduction to Nuclear and Particle Physics

Markus Klute - MIT

10. Instrumentation

2. Tracking Detectors

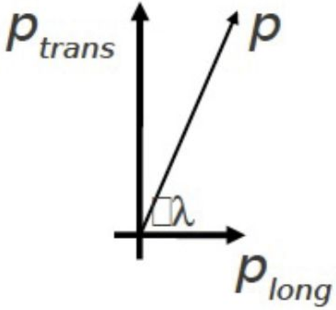
Momentum Measurement

Charged particles are deflected by magnetic fields

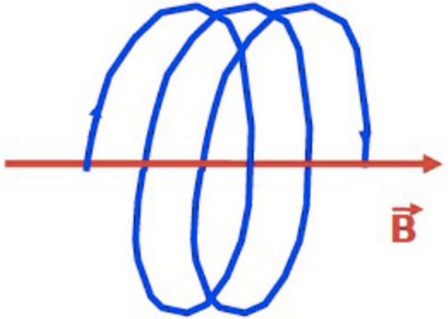
- Homogeneous B-field particle follows a circle with radius r

$$p_t\,[GeV/c] = 0.3 \cdot B\,[T] \cdot r\,[m]$$

- Particle with longitudinal momentum component follow a helix

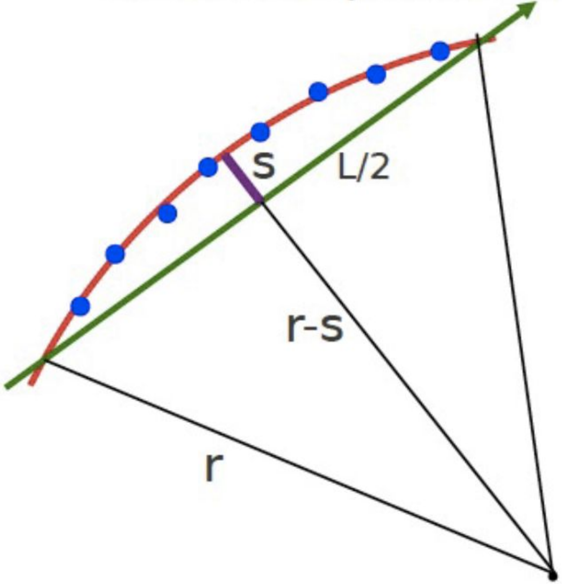


$$p = \frac{p_t}{\sin\lambda}$$



Momentum Measurement

- Tracking detectors measure the position of the charged particle on various points along the helix (circle)



$$r = \frac{L^2}{8s} + \frac{s}{2}$$ if L >> s $$r \approx \frac{L^2}{8s}$$

$$\boxed{\sigma_s = \sqrt{\frac{A'_N}{N+4}}\,\frac{\sigma_{r\phi}}{8}}$$

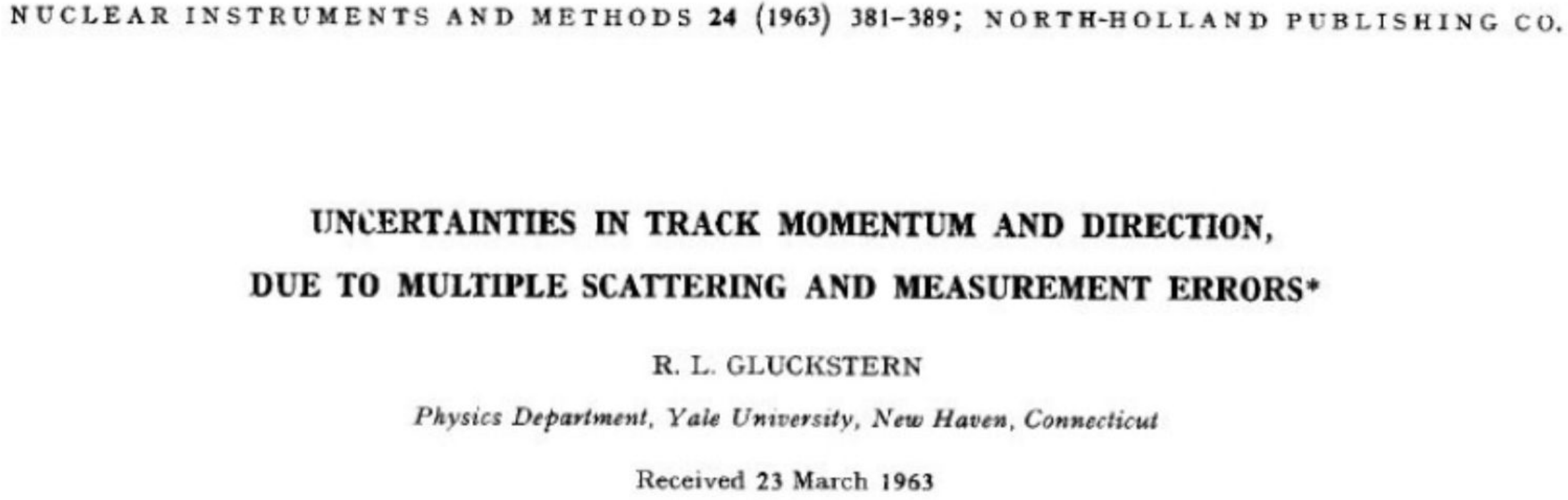
Gluckstern formula
Nucl. Inst. Meth.
24(1963) 381

$$A'_N = 720$$

$$\frac{\sigma_{p_t}}{p_t} = \frac{8p_t}{0.3BL^2}\cdot\sigma_s$$

$$\boxed{\frac{\sigma_{p_t}}{p_t} \propto p_t}$$

Momentum Measurement



NUCLEAR INSTRUMENTS AND METHODS **24** (1963) 381–389; NORTH-HOLLAND PUBLISHING CO.

UNCERTAINTIES IN TRACK MOMENTUM AND DIRECTION, DUE TO MULTIPLE SCATTERING AND MEASUREMENT ERRORS*

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Physics Department, Yale University, New Haven, Connecticut

Received 23 March 1963

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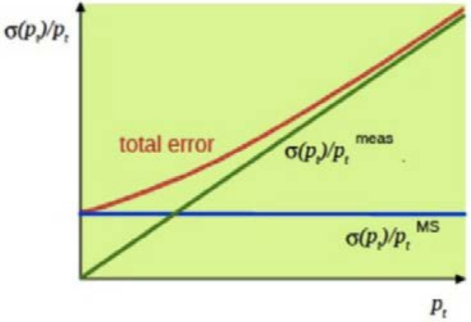
Momentum Resolution

Dominated by two components

- Contribution from measurement error $\frac{\sigma_{p_t}}{p_t} \propto p_t$
- Contribution from multiple scattering $\Theta_0 \propto \frac{1}{p_t}\sqrt{\frac{L}{X_0}}$

$$\frac{\sigma_{p_t}}{p_t} \propto p_t \cdot \sigma_{r\phi}$$

- Multiple scattering contribution to transverse momentum error is constant!



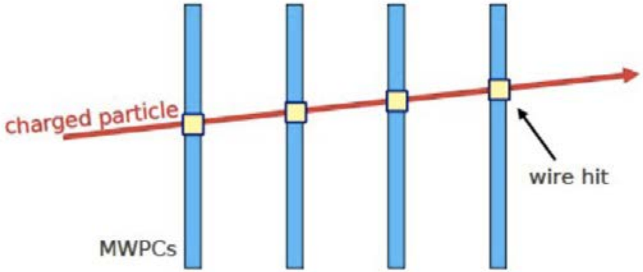
Wire Chambers

Multi Wire Proportional Chamber

- Was first electronic device allowing hugh statistics experiments
- With reasonable resolution

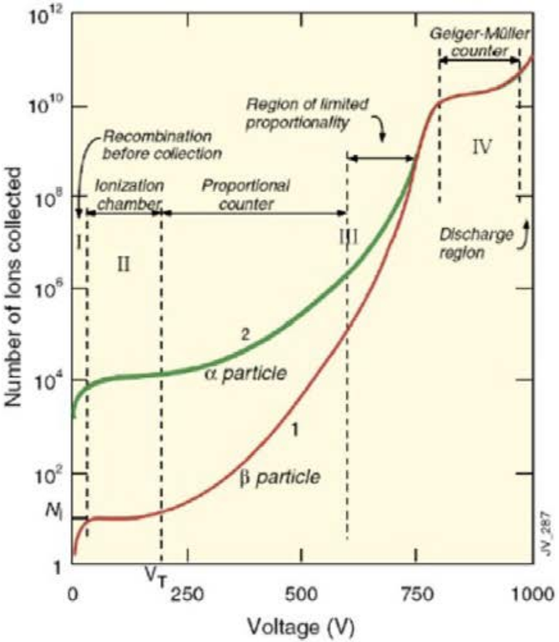
Typically several 100-1000 wires, 1mm spacing

- Hit on wire give 2d track measurement
- Signal on wire for 3d measurement (or using stereo wires)
- Resolution: $\sigma_x \approx \frac{d}{\sqrt{12}}$ e.g. for d=1 mm; ~300 μm resolution



Wire Chambers

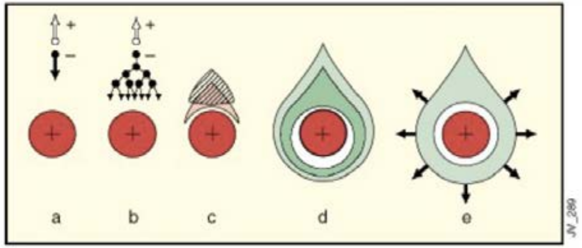
- No collection (I)
  - Ions recombine before collected
- Ionization mode (II)
  - Ionization charge is fully collected, no charge multiplication yet
  - Gain ~ 1
- Proportional mode (IIIa)
  - Gas multiplication, signal on wire proporational to original ionization
  - Gain ~10^4
- Limited Proportional Mode (IIIb)
  - Secondary avalances created by photoemission from primary avalances, signal no longer proportional
  - Gain ~10^{10}
- Gaiger mode (IV)
  - Massive photoemission + discharge, stopped by HV breakdown



Wire Chambers

Signal formation is different to what you may think

- Electrons from avalance are collected within a few ns
- Contribution of electrons to wire signal only a few %

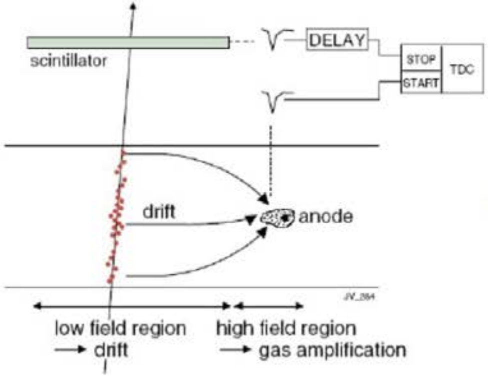


Main part of signal comes from ions

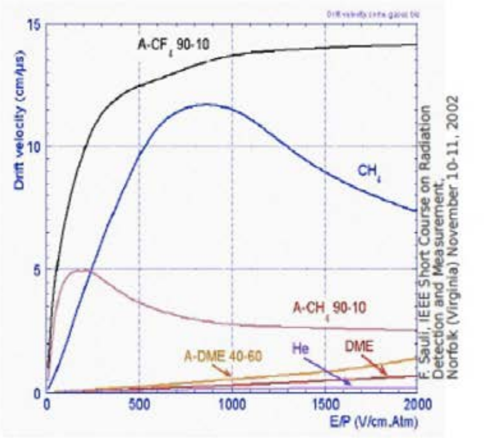
- Ions drift back to cathode over long distance (mm-cm) and time (μm-ms)
- Moving ions charge creates signal via influence (mirror charge in conductor)

Wire Chambers

- Resolution limited by wire spacing
  - Better resolution, shorter wire spacing, more wires, larger wire forces and strong electrostatic forces when wires are close to each other
- Solution
  - Obtain position information from drift time
  - Drift time = time between primary ionization and arrival on wire



$$s = \int_{t_{start}}^{t_{stop}} v_D dt$$

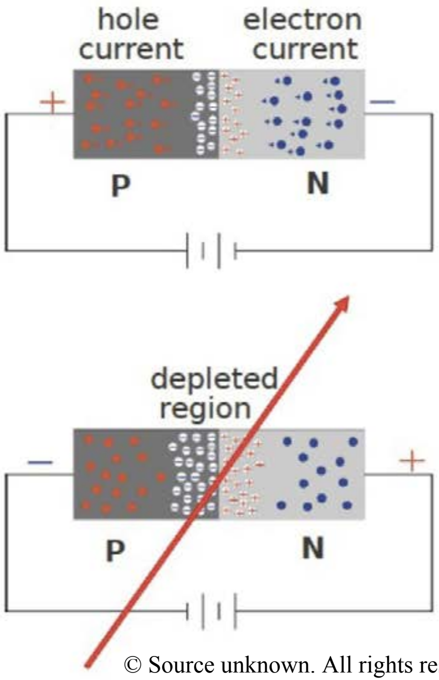


F. Sauli, IEEE Short Course on Radiation Detection and Measurement, Norfolk (Virginia) November 10-11, 2002

Solid state tracking detectors

Basic element of a solid state (silicon) detector is ... a diode

- p-type (more holes) and n-type (more electrons) doped silicon material is put together.
- for use as particle detector diode needs to be connected in opposite way.
- Around junction of p- and n-type material depletion region is created.
- Charged particle can create new electron/hole pairs in depletion area sufficient to create a signal.



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