Tracking detectors

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What are tracking detectors?

- This is a kind of detectors used when it's necessary to determine the position of a particle at several points along its path with very high precision (typically 10–100 μm)
  - the measured points ("hits") are used to reconstruct the path of the particle ("track")
- Measurements obtained in tracking detectors are used in two ways:
  - they are used to recover the momentum vector of the particle. Tracking detectors are usually embedded in a uniform magnetic field, so by measuring the radius of the spiral one can calculate the absolute value of the particle momentum;
  - by fitting together tracks from several particles which are believed to originate from the same interaction, one can determine the position of the interaction point ("vertex").
- Tracking detectors usually measure many particles at the same time, so the hits have to be sorted out, separated from noise and assigned to relevant tracks ("pattern recognition")

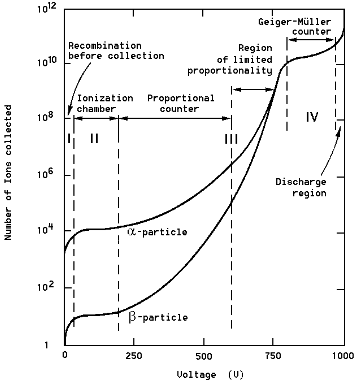
Technologies

- Tracking detectors are based on ionization
  - measure position of ionization, total charge, and time when the signal occured
- Two main types:
  - gaseous detectors
  - solid state detectors
- Like in electronics, solid state detectors win in most aspects
  - speed
  - can be operated at lower voltage
  - no need to deal with tricky gas systems (cleaning, temperature and humidity control)
  - simple construction (no tensioned wires)
- Gaseous detectors are cheaper when one needs to cover large ares

Gaseous detectors: summary of operating modes

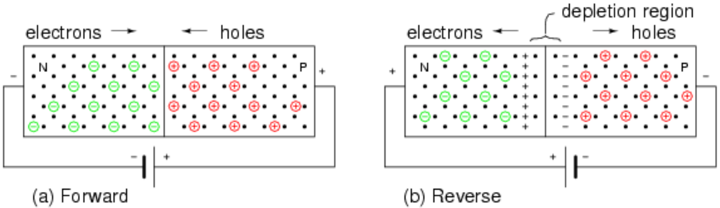
- gas has low density – primary ionization is not enough to produce large signal due to a single particle
  - need amplification (avalanche)
- Gaseous detectors can be operated in single ionization, proportional, or saturated mode

- ionization chamber (found in smoke detectors) – no avalanche, low signal (not good for single particles)
- Geiger counter, spark chamber – saturated mode, ionization produces a maximum avalanche independent of particle energy
- proportional chamber – ionizations occur in a low voltage area (ion drift region) and do not produce an avalanche until drifting electrons approach the collecting wire (avalanche region)



Solid state detectors

- They are basically diodes with reverse bias
  - no particles – no signal (except for very low “dark current”)
  - a charged particle produces a track of carriers (electron-hole pairs) along its way → a charge pulse



- Energy to create an e/h pair in silicon: 3.6 eV (an order of magnitude lower than in gas)

Why silicon detectors?

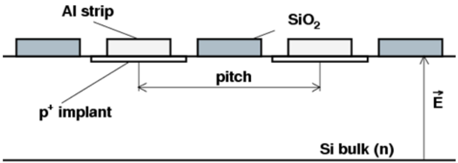
- High density and atomic number
  - reduced range of secondary particles
  - can build thin detectors
  - better spatial resolution
- High carrier mobility
  - typical charge collection times <30 ns
  - no slow component (ions)
- Excellent mechanical rigidity
- Industrial fabrication techniques
- Detector and electronics can be integrated

Problems

- Cost
  - proportional to area covered
  - most of the cost is moving to read out channels
- Material budget
  - for complex detectors can be as large as 1-2 radiation lengths
  - affects tracking accuracy (multiple scattering)
- Cooling
  - need it to reduce leakage current (thermal energy 0.025 eV at 300 K)
- Radiation hardness
  - particles damage the crystal structure
  - leakage currents increase, gain drops
- What to do?
  - replace detectors every so often
  - switch to radiation hard technology (e.g. diamonds)

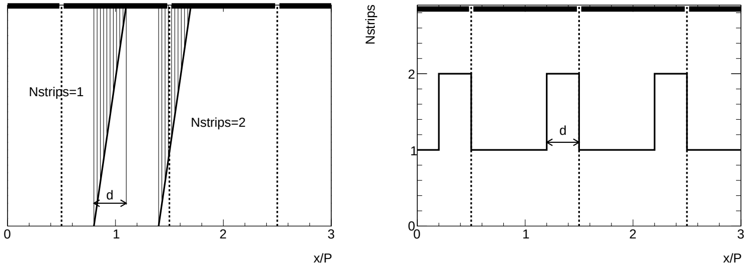
Strip detectors

- How to detect the particle position?
  - idea: divide the large-area diode into many small strip-like regions and read them out separately
- Distance between the strips is called "pitch"
  - typical pitch size P is from 20 to few hundred μm
- Spatial resolution σ depends on whether the read-out is "digital" (binary, signal/no signal) or analog (measure actual charge pulse)
  - digital read-out: $\sigma = P\sqrt{3}/6$
  - analog read-out: $\sigma = P/(\mathrm{signal}/\mathrm{noise})$



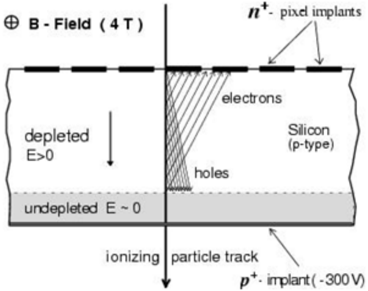
Strip sharing

- If a particle passes at an angle with respect to the detector plane, the collected charge may get spread between two or more strips
  - cluster sharing increases (bad)
  - spatial resolution improves (good)
- For digital readout, the resolution is $\sigma = P\sqrt{3}/6$ at $d = 0$, goes down to $P\sqrt{3}/12$ at $d = P/2$



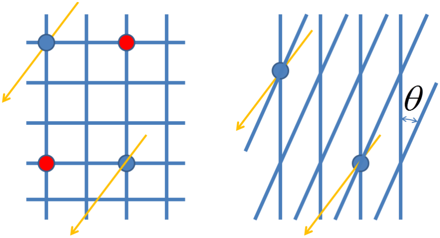
Lorentz shift

- If a detector is placed in magnetic field (parallel to its strips), charge careers are deflected as they drift towards the strips
  - introduce systematic shift of the measured position
- The result is effective inclination of the track
  - for low momentum particles, resolution is different for negative and positive charges



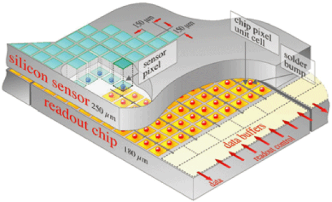
Stereo strip detectors

- A single layer strip detector only measures two coordinates (can't determine the position of the particle along the strips)
  - to get a 2-d measurement, need to install strips on both *p*- and *n*-side or combine detectors with different strip directions
- possible problem: "ghosts" (ambiguities if more than one particle hits a detector)
- solution: set strips at small angle θ
  - minimum resolution degrades $\sim 1/\tan(\theta)$

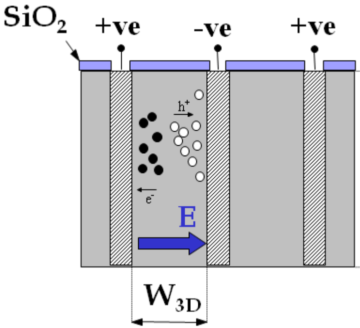


Pixel detectors

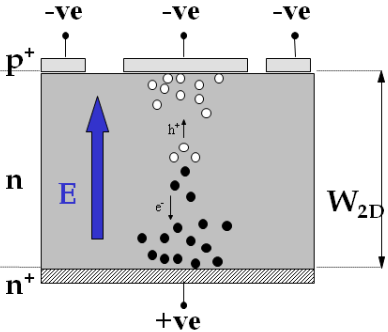
- Instead of strips, the diode can be divided in small cells (usually squares or rectangles) called pixels
  - perfect 3-d resolution
  - low "occupancy" (probability that more than one particle hits the same detecting element)
- Problems: complicated read-out, a lot of electronic channels



Pixel operation



pixel operation



strip operation