Position-Sensitive Detectors using Silicon Detectors

Design goals and constrains

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Overview

- Peculiarities of positron PS detection for µSR
- Possible silicon detector choices
- Global detector layout – a mixed type?
- Future work

Silicon Properties

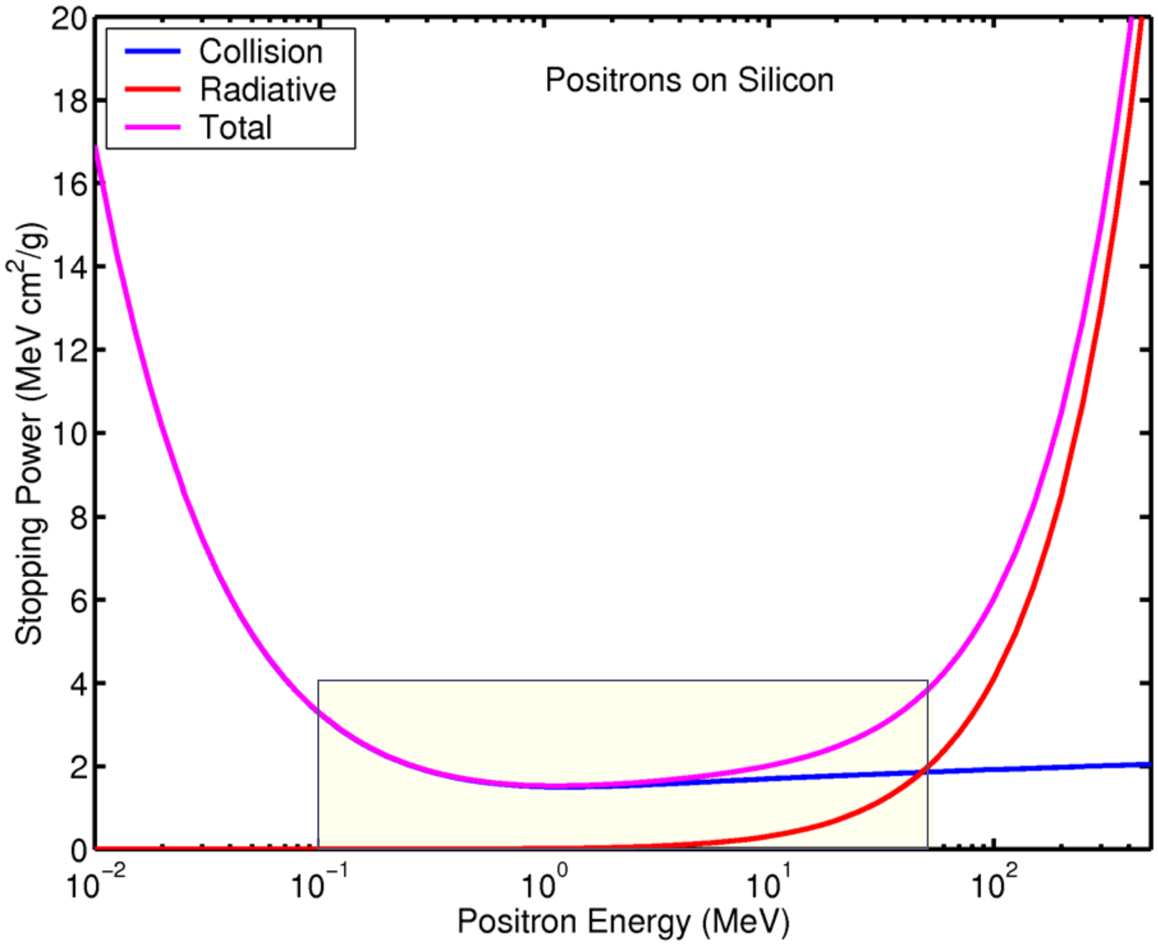
- Small band gap (1.12 eV) => low e-h pair generation energy (3.6 eV) (ionisation energy in gases ≈ 20 eV)
- High density (2.33 g/cm^2) => large energy loss/length for ionising particles => thin detectors; small range δ-electrons; precise posit. measurement
- Almost free movement of electrons and holes
- Mechanical rigidity => self supporting structure
- Doping creates fixed space charges; building of sophisticated field structures
- Integr. of detector and electronics in a single device

Needs for positron detection

Positrons from μ decay have $0 < T < 53$ MeV ($T_m = 37$ MeV), are different from particles in colliders ($T \sim 1$ GeV) and hence experience worse multiple scattering effects:

- **Low Energy** – Higher deviation from original path.
- **Low Mass** – During interaction with nuclei positrons undergo considerable deflection ($a = F/m$).

Energy loss of positrons in Si



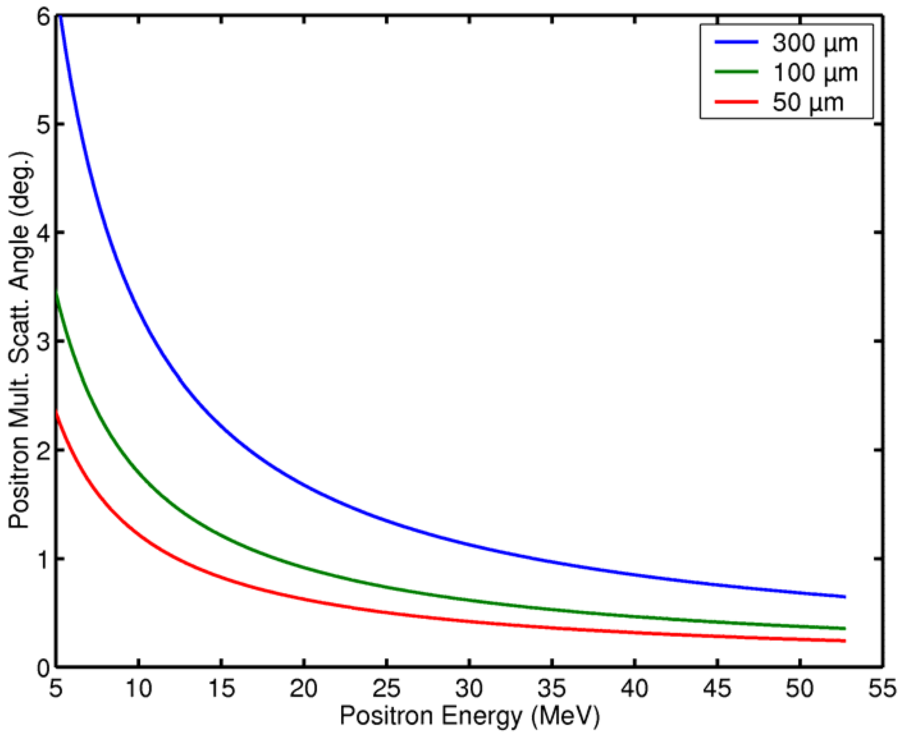
Positrons from μ decay behave as MIPs (minimum ionizing particles)

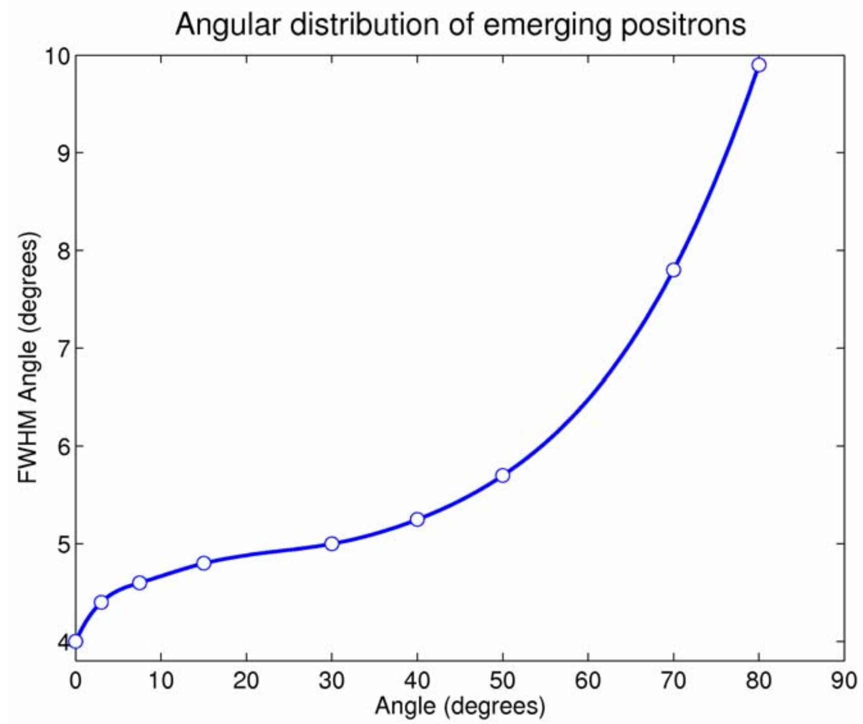
Efficient positron detection

To reduce the effects of multiple scattering one should follow the vertex detector paradigm:

- **ASIC** at the end of ladders (separate from detectors)
- **Minimize mass** inside the tracking volume
- **Minimize the distance** to the innermost detector

Energy loss of positrons in Si





Multiple scattering vs. detector thickness

Angular spread of 20 MeV positrons due to MS

Possible detector approaches

Two different strategies in dealing with detectors:

- **Conservative** (use existing silicon detectors, e.g. microstrips):
  - ✓ Well established, low-cost, low-tech, immediate availability, reliable
  - ✗ No margin for future improvements, separate front-end, high radiation length (thick), slow electronics FE
- **Innovative** (plan to use novel technology detectors, e.g. DEPFET):
  - ✓ Highly pixelated, thinner, faster, low-power, on-chip amplification, low noise and low capacity
  - ✗ Still immature, risky, uncertain, high-cost, not ready available

Microstrip detectors

Main features of **strip and microstrip** detectors:

- Simple idea: divide the sensing diode into thin strips to achieve PSD (typical pitch p = 50 µm)
- Digital readout: resolution p/sqrt(12) ~ 15 µm
- Analogue readout: better resolution p/SNR ~ 5 µm
- Double-sided strips – complex structure to isolate n-side
- Intrinsically fast (only 7 ns for electrons, 3 times more for holes)
- Need for separate electronics front-end: typically 100 ns or more.
- Matching electrical contacts and signal transmission lines.

Pixel detectors

- **Drift detectors** (measure position from travel time):
  - ✓ Good resolution, precise, highly-taylored field profile
  - ✗ One dimensional, need external reference time
- **CCD** (shift the signal charge along rows and columns):
  - ✓ Highly developed, high resolution, small thickness
  - ✗ Rather slow, poor radiation tolerance, errors during charge transfer
- **Hybrid Detectors** (Pixel detector + Electronics front-end):
  - ✓ Flip-chip bonded (two layers), high integration
  - ✗ Large thickness for positron detection

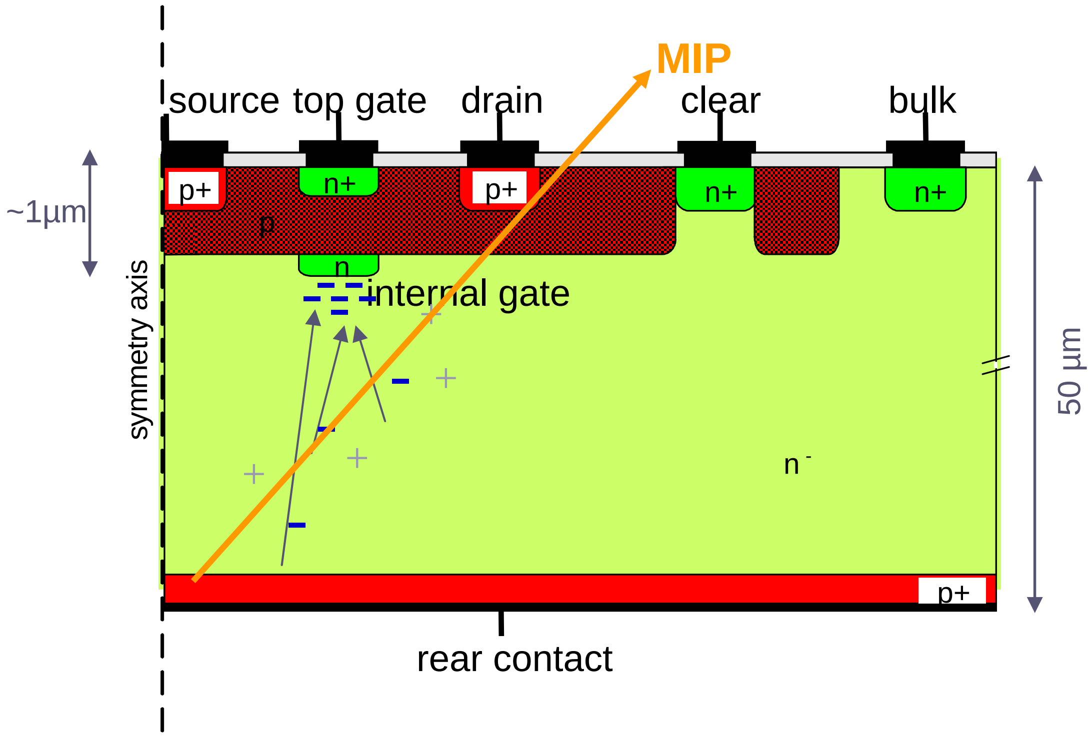
State-of-the-art

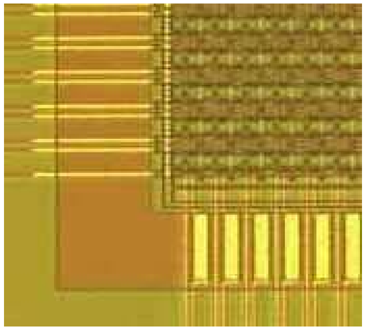
Pixel detectors - MAPS

MAPS (monolithic active pixel sensor – detector into chip)

- **CMOS-based** (CMOS technology):
  - ✓ Industry standard, cost-effective, high integration (MIMOSA)
  - ✗ Charge collected by diffusion in 150 ns, poor S/N due to thin charge collection Si-layer, low fill factor, radiation tolerance issues
- **DEPFET** (Depletion FET):
  - ✓ Low noise operation, in situ charge-to-current conversion and amplif., allow the design of very thin detectors (~30 μm).
  - ✗ Still immature, custom-made, high cost

Pixel detectors - DEPFET





- FET on top of fully depleted bulk
- Charge generated in bulk assembles under-neath the transistor channel and modulates the transistor current
- Combined function of sensor and amplifier
- Low capacitance and low noise
- Signal charge remains undisturbed by readout

Silicon Detectors: who makes them?

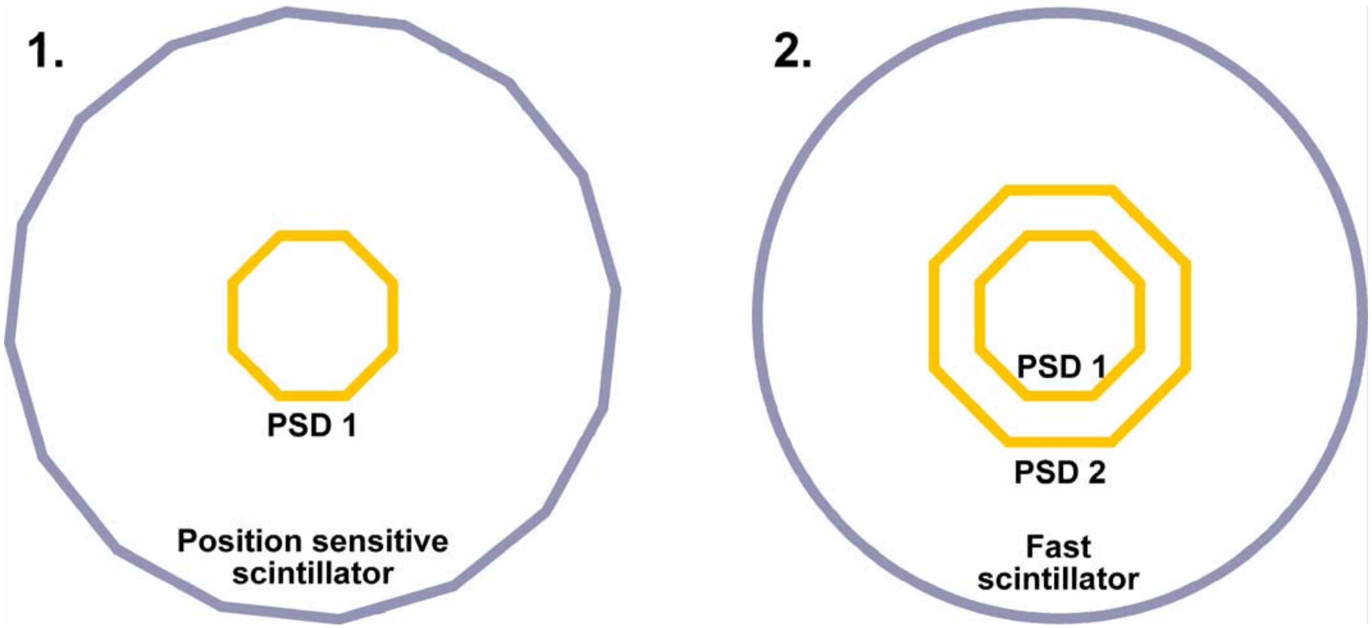
- **SINTEF** (Norway) – Pixel, pad and microstrip detectors, etc.
- **Canberra Eurisys** (Belgium) – Double-sided strip detectors, position-sensitive pad detectors, etc.
- **Micron Semiconductor** (UK) – Microstrip double-sided detectors, Pixel detectors, etc.
- **CSEM** (Switzerland) – Various custom-made detectors
- **VTT** (Finland) – Various custom-made detectors
- **CiS Institut für Mikrosensorik** (Germany) – Flip-chip assembly and hybrid circuitry.

Alternative solutions

- **MCP** – microchannel plates: Good position resolution and magnetic field indipendence, fast timing (100 ps), but poor efficiency for *E* > 10 keV.
- **SciFi** (Scintillating fibers) – High speed, high efficiency detectors. Highly complex, still in development
- **Combined detector** – inner Si detector + outer light scintillator. The main limitation is the VLPC (Visible Light Photon Counter) cost and low temperature operation (6 K).

Possible position-sensitive detectors

High resolution High field



Combined silicon strip/pixel and scintillating fibre detector

Future work

- **Choice and testing of prototypes** – Request prototypes from various manufacturers and assess their position sensitive capabilities and timing in realistic conditions.
- **Detector simulation** – Simulate the best parameters, e.g. thickness and geometry, behaviour in magnetic field, etc.

Magnetic field effects on positrons