JRA8

Position-sensitive detection for spatial resolution and high detector segmentation

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Motivation for the work

Question:

Can we improve the performance of current μSR spectrometry detectors?

Answer:

Yes, if we use state-of-the-art technology and detector optimisation

Overview

- Limitations of the current μSR detectors
- New development ideas
- Finding the best alternatives
  - Possible position-sensitive detector (PSD) choices
  - Detector simulations
- Conclusions and future work

Limitations of current μSR detectors

- Current μSR experiments rely on detectors comprising: scintillators – light guides – photomultipliers

Advantages

- ✓ Fast response
- ✓ High detection efficiency
- ✓ High flexibility
- ✓ Inexpensive
- ✓ Etc…

Weaknesses with

- ✗ High magnetic fields
- ✗ Low-energy muons
- ✗ Tiny samples
- ✗ Etc…

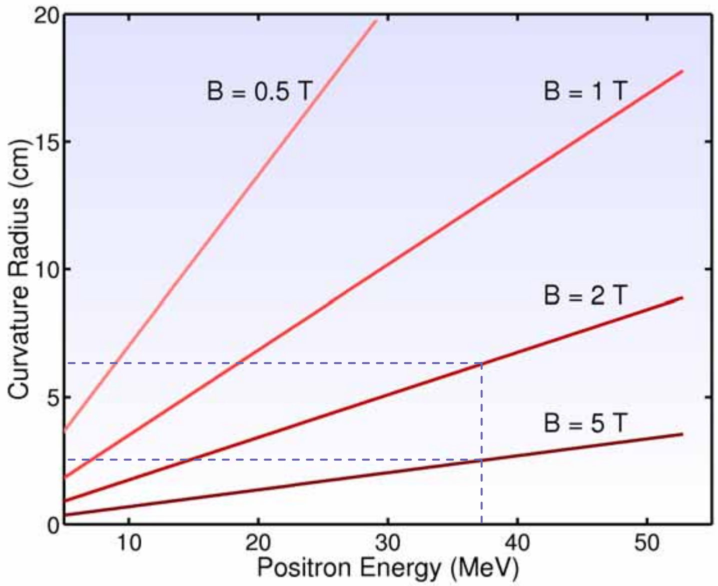
Limitations of current μSR detectors

- High magnetic fields ➔ Highly curved positron tracks
  ➔ Poor solid angle coverage
- Tiny samples ➔ High background
- Complex samples ➔ Origin of positrons
- Low energy muons ➔ Large beam/High background

Examples:

$H = 2$ T => $r = 6$ cm

$H = 5$ T => $r = 2$ cm



JRA 8 – Work Package 1

Objectives

- Development of **position-sensitive detectors** (PSD) and electronics readout based on new solid state and integrated technologies

- Fast timing detector system for **high magnetic field** and RF spectrometers

- Exploration of **analogue detection** techniques

PSD – New development ideas

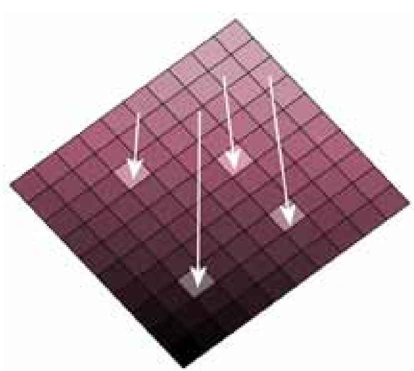
Problem

- Poor solid angle coverage
- Pile-up effects
- Origin of positrons/backgr.
- High magnetic fields

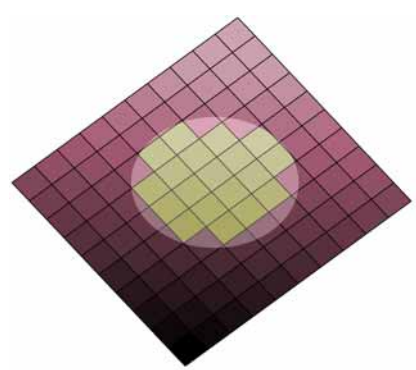
Proposed solution

- ➔ Cover almost 4π
- ➔ High detector segment.
- ➔ Path reconstruction
- ➔ Positron tracking

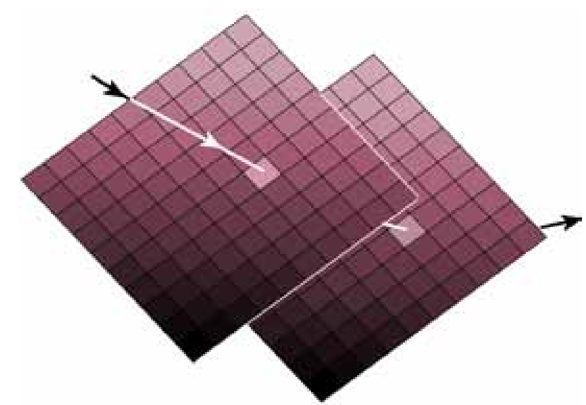
Position-Sensitive Detectors



Simple position sensitive detector



Software defined pixel geometry



Full positron tracking ?

Desirable PSD features for μSR

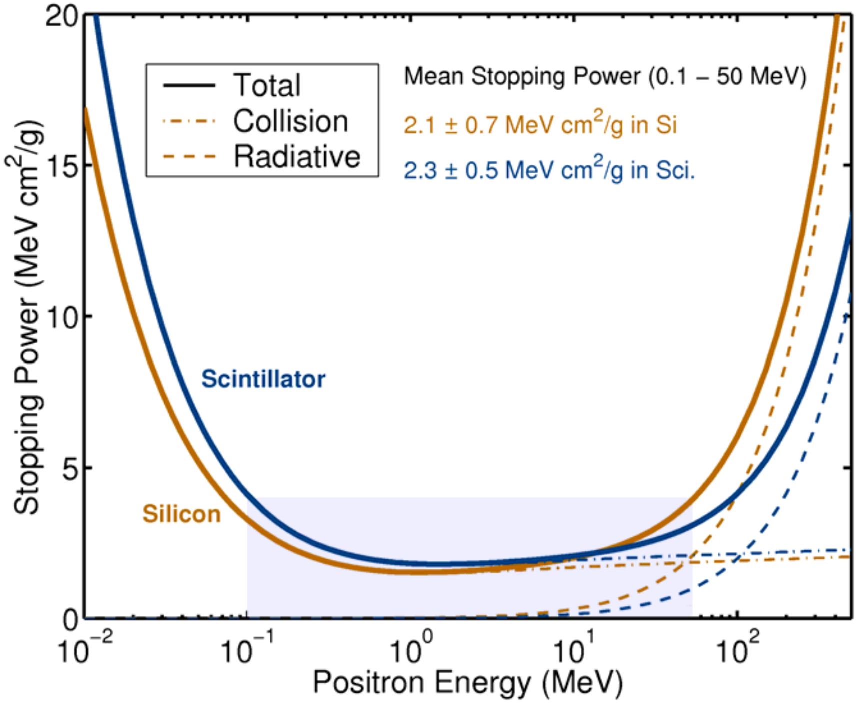
- High spatial resolution (at least 1 mm or better)
- High positron detection efficiency (> 95%)
- Good time resolution (1 ns or better)
- Good channel granularity (1024 channels or more)
- Possible reconstruction of positron flight path

S. Manolopoulos, et al., Tech. Rep.,
RAL-TR-2004-013

PSD comparison at a glance

Detector technology	Major application	Pros	Cons
Gaseous detectors (Wire, MSGC)	Large volume and high-rate tracking	Rugged, cheap, radiation hard, tailored to exp. needs	Sensitive to magnetic field, limited precision
Solid-state detectors	Vertex detection, high-rate tracking	High precision and good energy resolution	Radiation sensitive (Si), expensive
Scintillating fibre detectors	Vertex detection, high-rate tracking and triggering	Fast, insensitive to magnetic field	Low light yield, critical readout
Visual tracking detectors	Vertex measurem. (outdated)	High track precision	Very slow, dangerous

Peculiarities of decay positrons



Stopping power vs. positron energy in silicon and scintillating fibres

Positrons in μ^+ decay:

- T = 37 ± 11 MeV, much different from particles in colliders (T ~ 1 GeV)
  ➔ **large multi. scattering**
- Behave as minimum ionising particles (MIPs)
  ➔ **low-level signals**
- Radiation level is low
  ➔ **very limited damage**

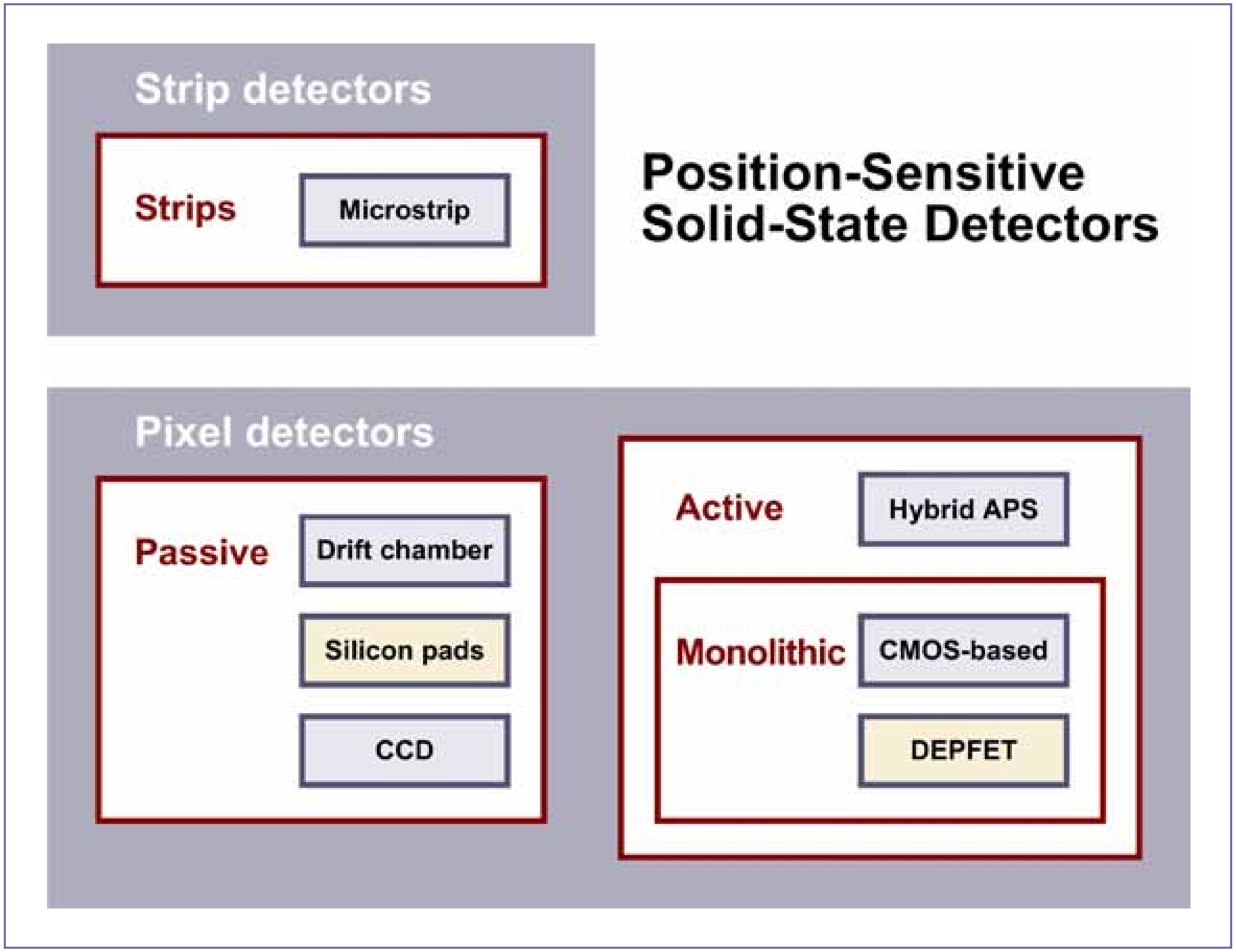
http://physics.nist.gov/PhysRefData/

Main features of silicon detectors

- 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 position measurement
- High mobility of electrons and holes ➔ relatively fast
- Mechanical rigidity ➔ self supporting structure
- Possibility for building-in electronics in a single device

G. Lutz, A.S. Schwarz, *Annu. Rev. Nucl. Part. Sci.*, **45** (1995) 295

Map of silicon PSDs

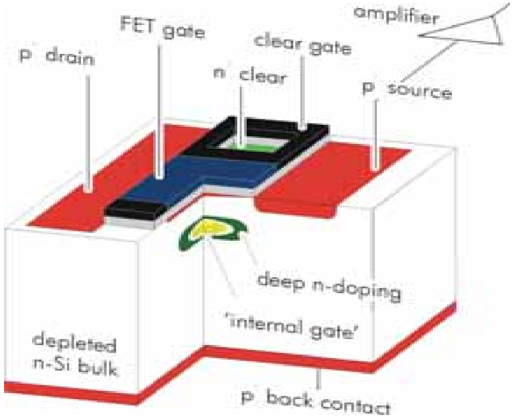


Possible detector approaches

- **Conservative** (use existing silicon detectors: µ-strips):
  - ✓ Well established, low-cost, low-tech, immediate availability, reliable
  - ✗ High radiation length (thick), slow electronics front-end, no margin for future improvements, separate front-end

- **Innovative** (use novel technology detectors: DEPFET, MIMOSA):
  - ✓ Highly pixelated, thinner, faster, low-power, on-chip amplification, low noise and capacity
  - ✗ Still immature, risky, uncertain, high-cost, not ready available

DEPFET



G. Lutz, *Semiconductor radiation detectors* (Springer, Berlin, 1999)

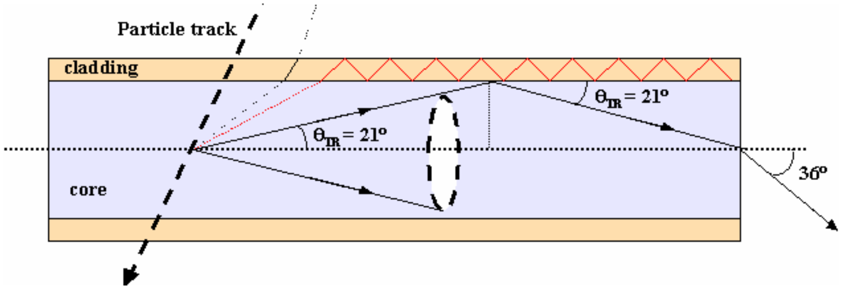
Beyond silicon – scintillating fibres

- Scintillating fibres are appealing for fast tracking:
  - ✓ High speed, insensitive to magnetic fields, lower costs and higher flexibility
  - ✗ Fair spatial resolution, still limited efficiency, highly complex (for many channels), still in development

1 mm resolution (~ fibre diameter)

3 ns timing (e.g. in plastic NE 102)

Multi-channel readout



Scintillating fibre – SciFi

R.C. Ruchti, *Annu. Rev. Nucl. Part. Sci.*, **46** (1996) 281

H. Leutz, *Nucl. Instr. and Meth. A* **364** (1995) 422

Detector simulation aspects

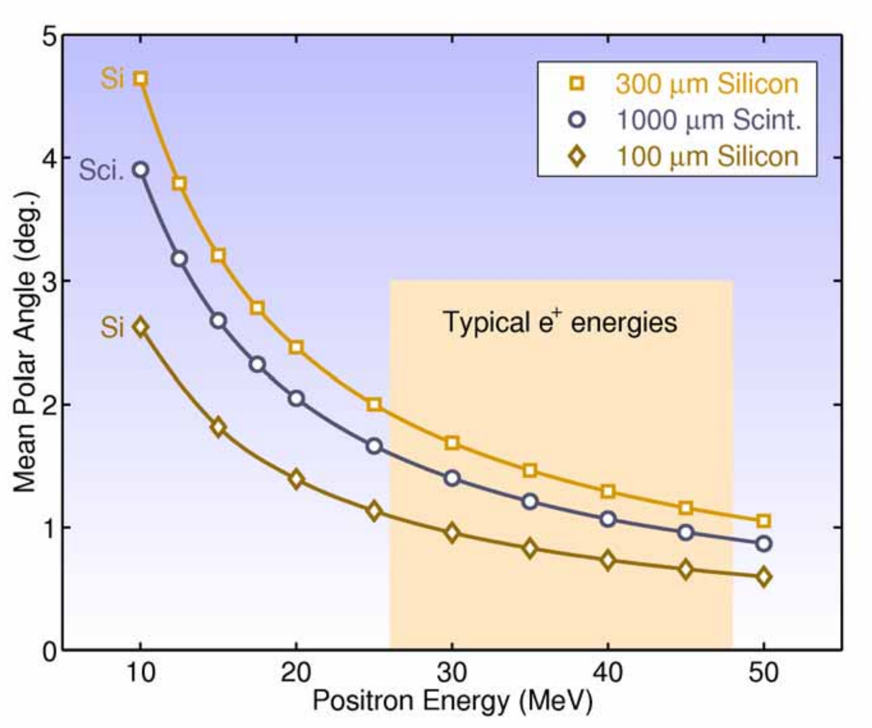
- Simulations are crucial for:
  - Selecting detector type and determine its limits
  - Optimising detector geometry and parameters
- They could account for:
  - Deterministic effects – e.g. influence of magnetic fields
  - Random effects – e.g. multiple scattering events
- Most suitable simulation codes:
  - SRIM 2000 (muons)
  - PENELOPE, **GEANT4** (positrons)

J.F. Ziegler – www.SRIM.org

J. Sempau, et al., *Nucl. Instr. and Meth. B* **132** (1997) 377

S. Agostinelli et al., (Geant4 Collaboration), *Nucl. Instr. and Meth. A* **506** (2003) 250

Some simulation results



Angular deviation vs. incident particle energy for e^+ going through Si (100 and 300 µm) and scintillator (1 mm)

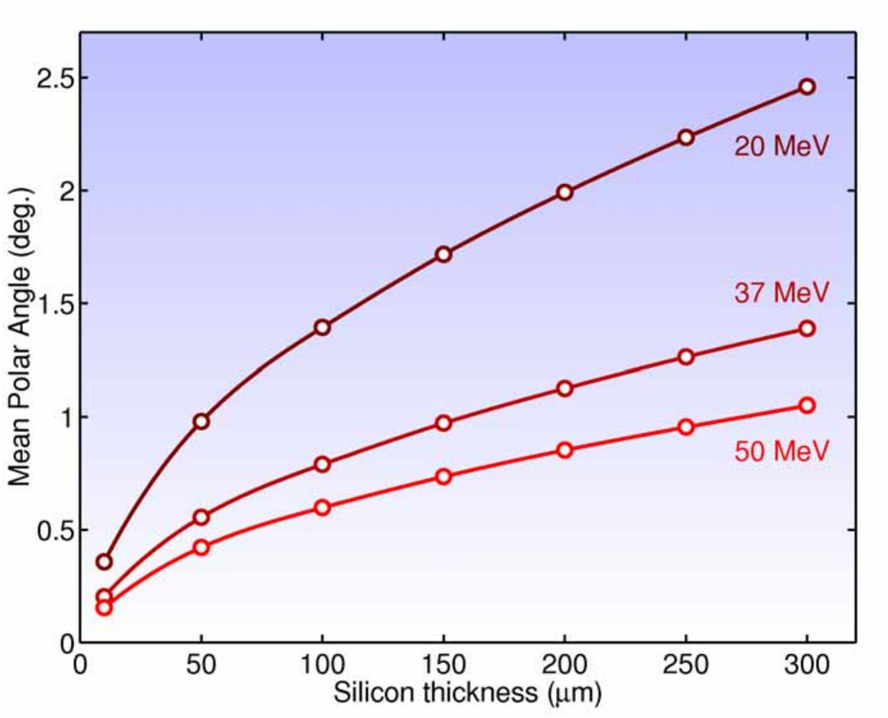
Multiple scattering effects:

- Mean angular deviation is ~ 1.5° and even with ultra-thin Si detectors cannot be reduced below 0.8° !

Is tracking possible ?

- For telescopes 3 cm apart the error is Δx = 1 mm
- Useless having very small pixels in second layer
- Very high precision is **intrinsically** impossible

Some simulation results



Multiple scattering effects vs. silicon detector thickness for different incident positron energies.

Multiple scattering effects:

- By **halving** the standard detector thickness (300 μm) the mean polar angle is reduced by ~ 40%
- **Filtering** of high-energy positrons yields only a small improvement (~ 20%)

Efficient detection of positrons

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

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

H.F.-W. Sadrozinski. *IEEE Trans. Nucl. Sci*, **48 (**2001) 933

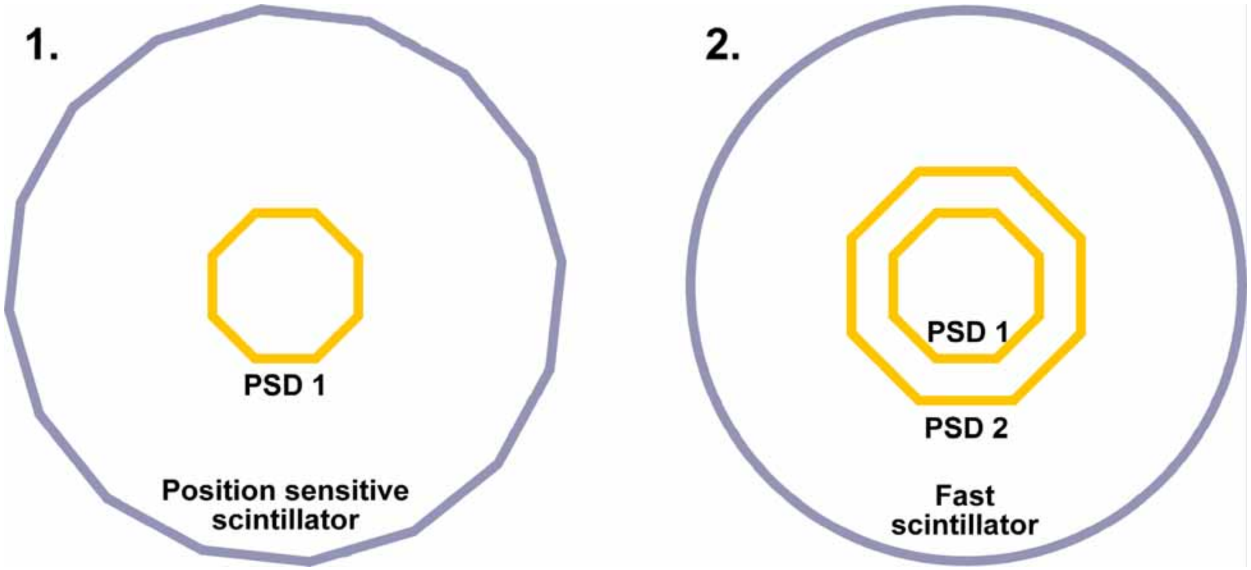
Possible detector layouts

Mixed type detectors successfully used in: NA58, FAROS, etc.

Detector = Silicon devices (position) + Scintillating fibres (timing)

⬇

Improved overall performance due to **complementary advantages**



Layout for better position precision

Layout for high magnetic fields

B. Seitz, *Nucl. Instr. and Meth. A* **535** (2004) 538

W. Baldini, et al., *IEEE Trans. Nucl. Sci.*, **48** (2001) 1122

Conclusions and future work

- Simple position sensitive detection is **possible**, but full positron tracking is rather **challenging**
- A **mixed type** detector (silicon + scintillator) would benefit from its parts' complementary advantages
- Detector **simulation** is crucial in optimising detector parameters and guiding the building of prototypes

Future work

- Choice and **testing of prototypes**: assess their position sensitive capabilities and timing in realistic conditions
- **New ideas** and suggestions are always welcome