Silicon Detector for Neutron β-decay Measurements with PERC

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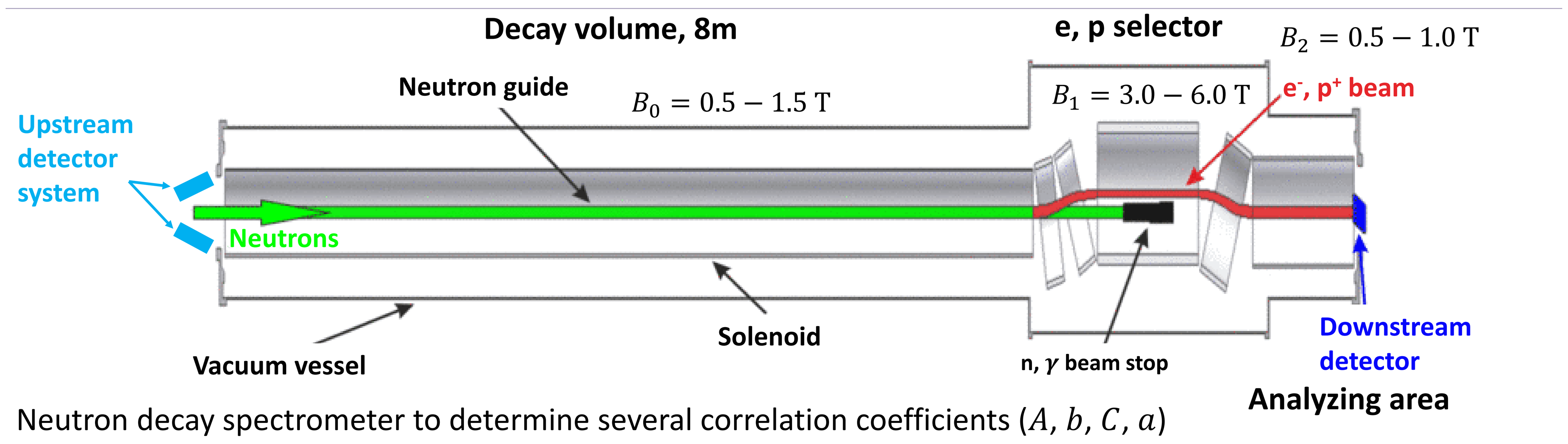
Introduction & Motivation

Abstract

The PERC facility is currently under construction at the FRM II in Garching, Germany. It will serve as an intense and clean source of electrons and protons from free neutron beta decay for precision studies. It aims to improve the measurements of the properties of weak interaction by one order of magnitude and to search for new physics via new effective couplings.
The downstream detector and the two upstream backscattering detectors will initially be scintillation detectors with (silicon) photomultiplier readout. In a later upgrade, the downstream detector will be replaced by a pixelated silicon PIN detector.
We present the current design status of this silicon detector prototype.

PERC Schematic



- Neutron decay spectrometer to determine several correlation coefficients (A, b, C, a)
- Electrons are guided by magnetic field towards one of the detectors
- Magnetic filter allows phase space selection and supresses backscattering
- Downstream detector is the main detector for spectroscopy
- Upstream detector system as active particle dump to veto backscatter events

For details on upstream detector: see poster of K. Bernert (MO-023)
For details on beam stop: see poster of J. Klenke (TU-110)

Concept of new Detector

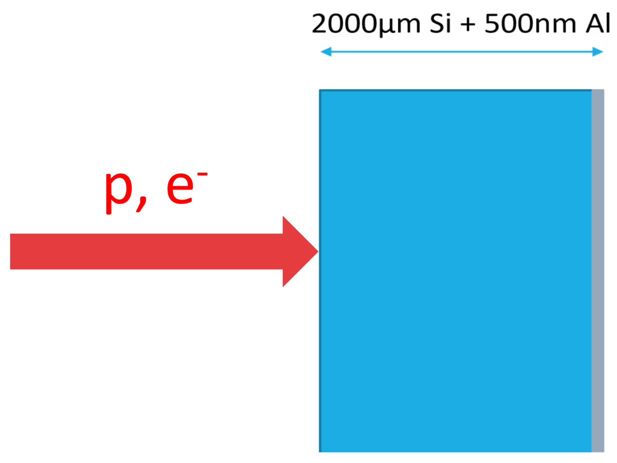
Downstream Detector Characteristics

- This is the main detector for energy spectroscopy
- In an initial step a plastic scintillator with photomultiplier readout will be used as detector
- Requirements to achieve the precision goal of PERC :
  - Handle particle rates of up to $\approx 10^5 s^{-1}$
  - Area of about 12×12 cm^2 with $\mathcal{O}\left(1 \frac{\text{cm}^2}{\text{pixel}}\right)$
  - Resolve the calibration peak of ^{207}Bi at ≈ 975 keV
  - Trigger time resolution < 10 ns for coincidence measurements
  - Thin dead layer $\mathcal{O}(100 \text{ nm})$
  - Low non-linearities
  - Energy resolution of $\mathcal{O}(1\%)$

Possible Detector Designs

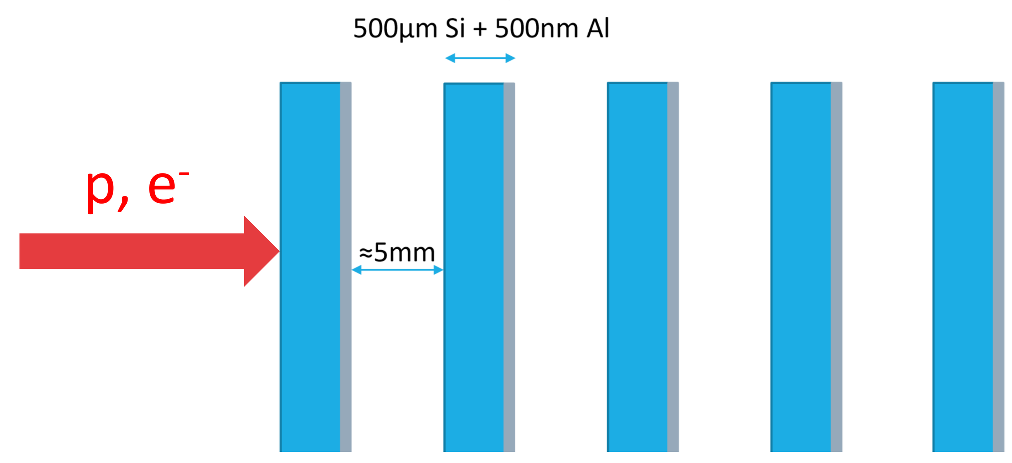
Single 2000 µm thick Si detector

- \+ One detector with readout electronics
  ➔ Easier analysis
- \+ No additional dead layers
  ➔ Better energy resolution
- – Difficult to manufacture
- – High voltages needed
- – Triggering is most likely too slow



Stack of five 500 µm Si detectors

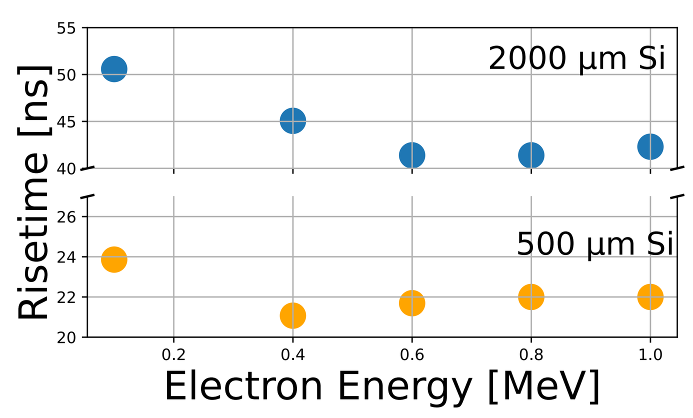
- \+ Faster signal formation
- \+ Easier to manufacture
- \+ Background suppression
- – Five times the readout electronics
- – More dead layers
  ➔ Additional non-linearity
  ➔ Worse energy resolution
- – Complicated calibration

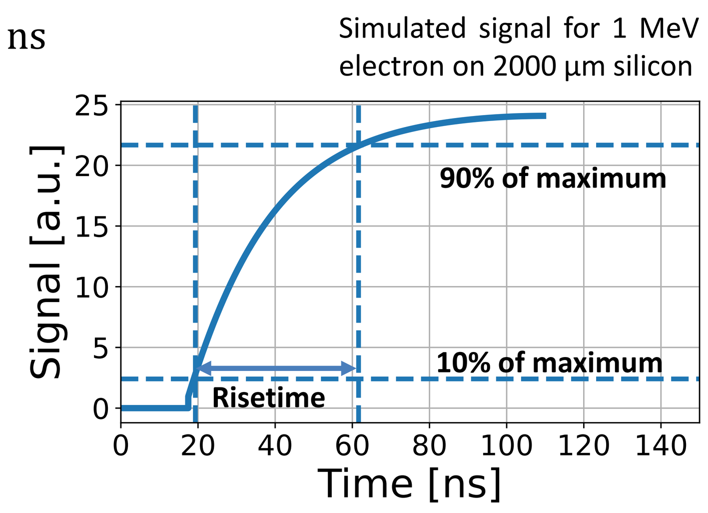


Simulations & Results

Risetime Simulations

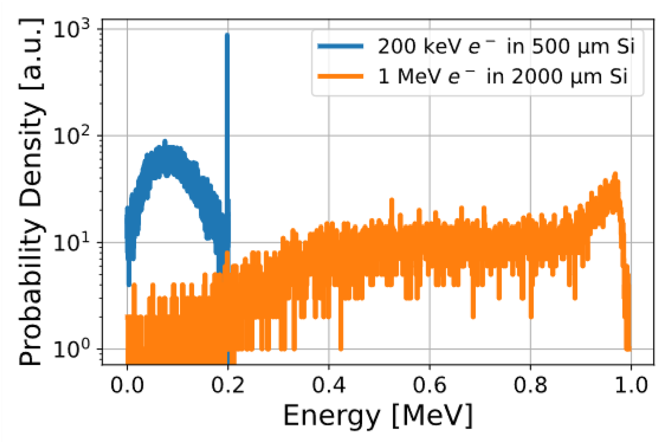
- Short risetime of the detector signal needed for ToF coincidence measurements with upstream detector to identify backscatter events
- Energy deposition of electrons in silicon simulated with PENELOPE [1]
- Signal formation calculated following [2, 3]
- **Risetime results:** 2000 µm detector: $\lesssim 50$ ns
  500 µm detector: < 25 ns





Calibration Concept

- Using Compton edge of photons for calibration
- The single 2000 µm or one 500 µm detector can use monoenergetic conversion electrons
- Stack can be calibrated seperately and checked with Compton edge after assembly

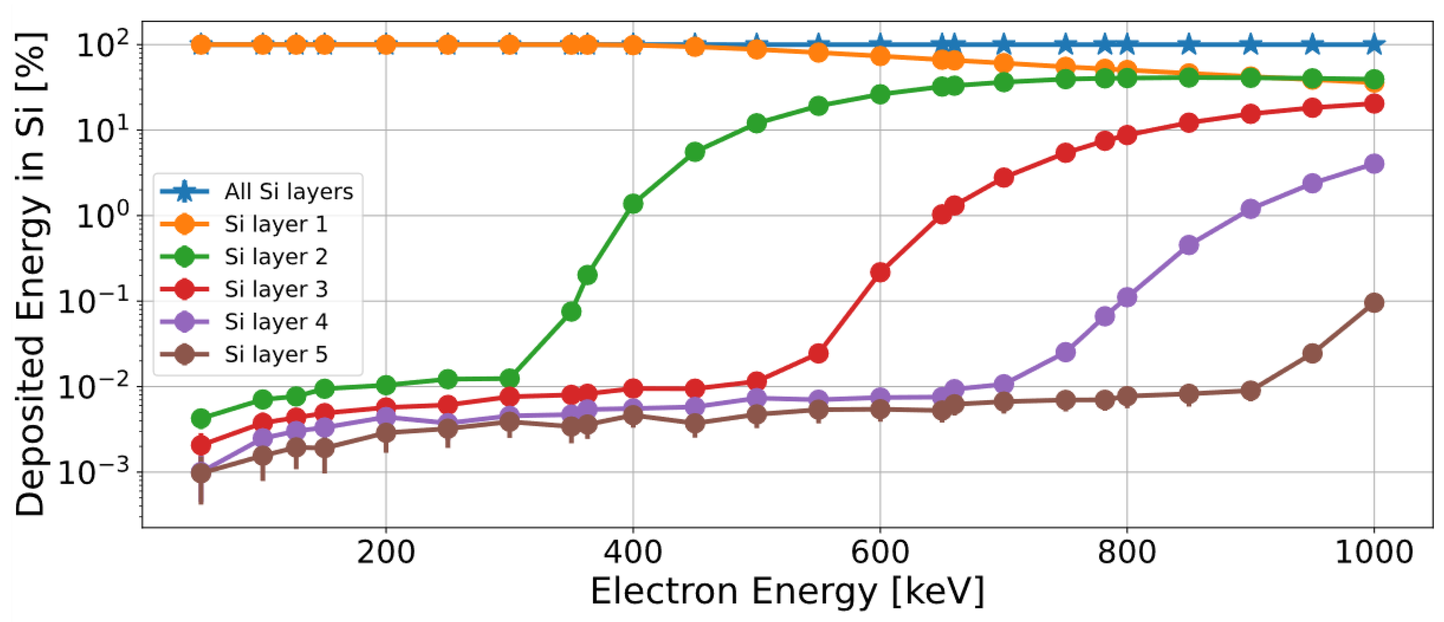


Energy Deposition Simulations

- Energy deposition simulated with PENELOPE [1] without magnetic field (still including backscattering of electrons which will be suppressed by the magnetic filter or detected by the upstream detector)
- **Results:**
  - In the single 2000 µm detector only a negligible amount of energy is lost in the aluminium layer and also only at energies around 1 MeV
  - In the stack detector ≈ 0.1% of the deposited energy at 1 MeV is lost in the aluminium layers

  ➔ Thin dead layers have only a small effect at these energies.

  ➔ Calibration peak of ^{207}Bi can be measured with both detectors.



Deposited energy in each silicon layer stack detector normalized to the total deposited energy.

[1] NEA, PENELOPE 2018: A code system for Monte Carlo simulation of electron and photon transport, 2019.
[2] Spieler, H.: Semiconductor Detector Systems, 2005.
[3] Li, Z.; Kraner, H. W.: Modeling and simulation of charge collection properties for neutron irradiated silicon detectors, 1993.

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