Silicon detector for neutron β-decay measurements with PERC

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Abstract

The PERC (Proton and Electron Radiation Channel) facility is currently under construction at the MEPHISTO beamline of the FRM II. It will serve as an intense and clean source of electrons and protons from 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.

PERC's central component is a 12 m long superconducting magnet system that has recently been delivered. It hosts an 8 m long decay region in a uniform field. An additional high-field region selects the phase space of electrons and protons, which can reach the downstream detector and systematic uncertainties.

The downstream main 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 detector. We present the current design status of the silicon detector prototype.

Correlations of Neutron Beta Decay

$$d\Gamma_n \propto G_F^2 |V_{ud}|^2 F(E) \left(1 + b\frac{m_e}{E} + a\frac{\vec{p_e}+\vec{p_\nu}}{E E_\nu} + < \vec{s_n} > \left[A\frac{\vec{p_e}}{E} + B\frac{\vec{p_\nu}}{E_\nu}\right]\right)$$

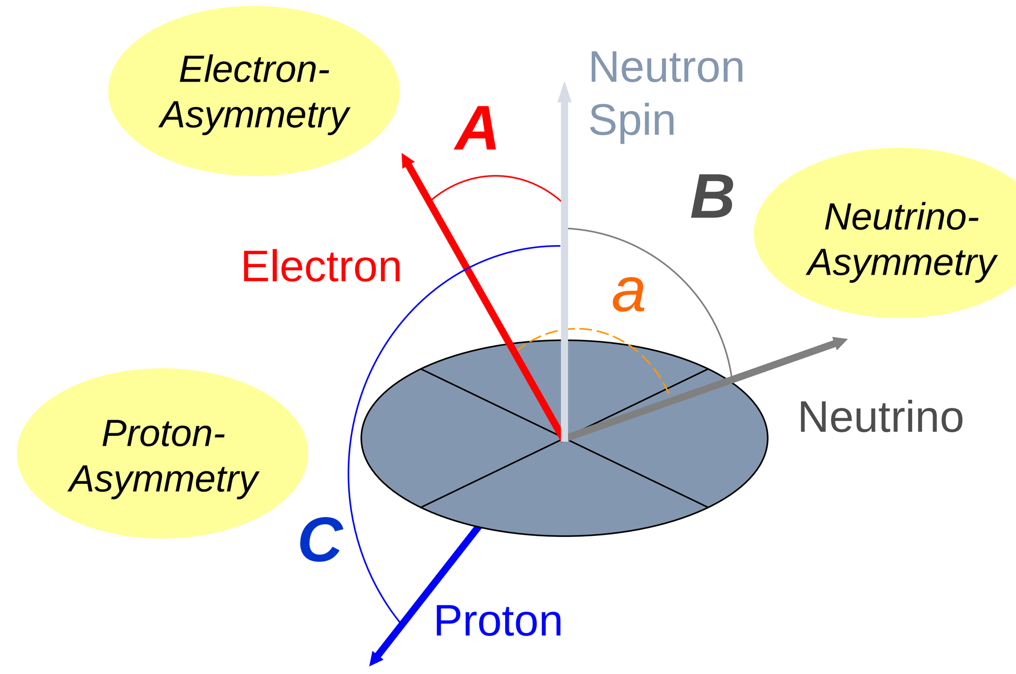
$$A_{exp} = \frac{N_e^{\uparrow}(E) - N_e^{\downarrow}(E)}{N_e^{\uparrow}(E) + N_e^{\downarrow}(E)} \propto AP_n \frac{v}{c}$$

$$A = -2\frac{\lambda^2 + \lambda}{1 + 3\lambda^2} \quad with \ \lambda = \frac{g_A}{g_V}$$

Beta Asymmetry [1] $A = -0.11985(21)$

Proton Asymmetry [2] $C = -0.2377(26)$

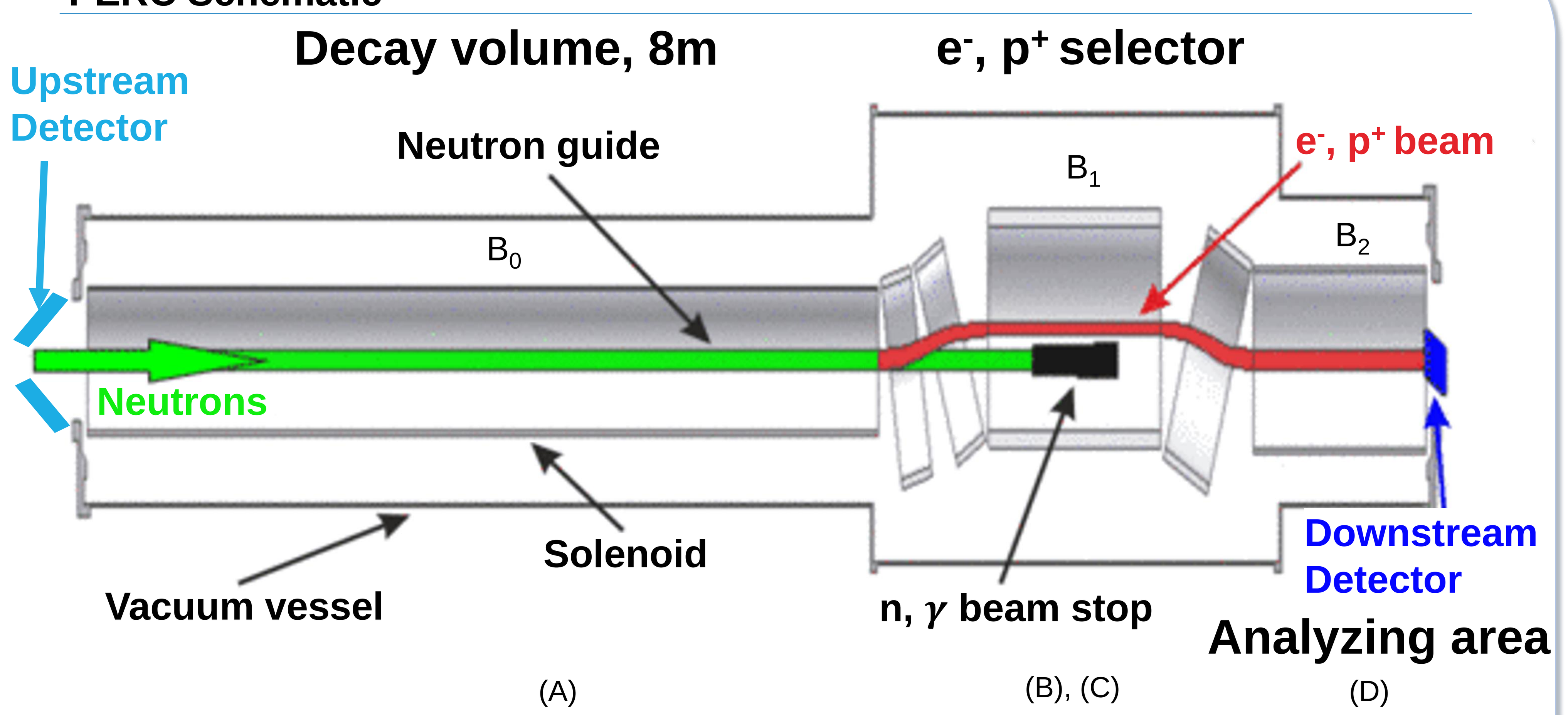
Fierz Interference Term [3] $b = 0.017(21)$



MEPHISTO Beamsite and Beamline

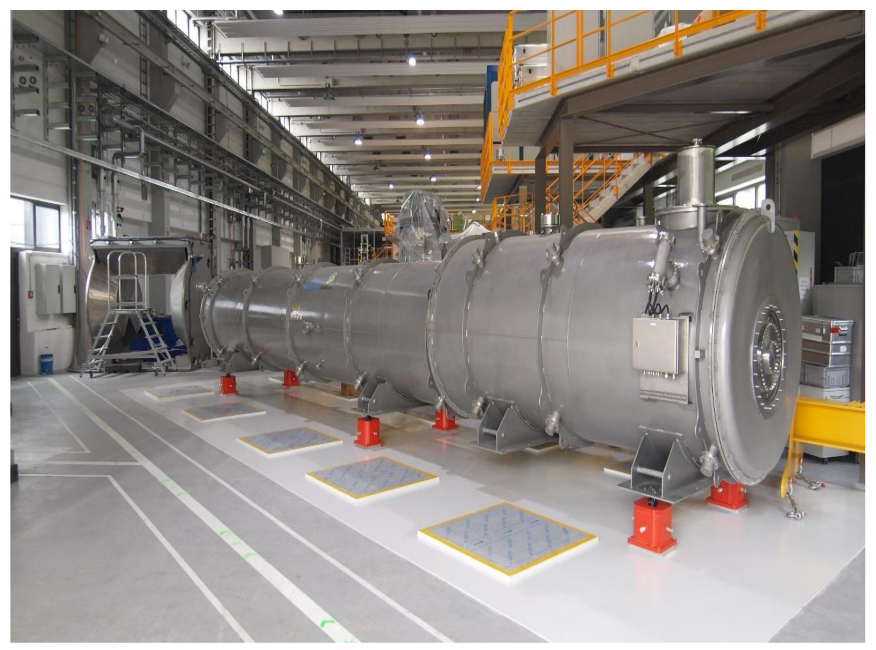
- The MEPHISTO beamsite is in the new hall east of the FRM II
- Cold neutrons
- Distance to reactor core: 42 m
- Neutron guide with m = 2.5 Curvature radius: 3000 m
- Expected neutron flux density: $2 \times 10^{10}\mathrm{s}^{-1}\mathrm{cm}^{-2}$
- Expect very low ambient background from neighbouring instruments

PERC Schematic



Four magnet sub-systems:

A) decay volume B_0 coil	0.5 - 1.5 T
B) separator (bending coils and 3T solenoid)	3.0 T
C) magnetic selector B_1	0 - 3.0 T
D) detector section B_2	0.5 - 1.0 T



Improvements compared to previous experiments:

- Cold neutron guide inside the decay volume
- Long decay volume ➔ Many events!
- Tunable and strong magnetic field to select energy of decay products
  ➔ Also suppresses backscattering off the main detector

Expected Timeline

Q1 - Q2 2022:
First sample tests of Si-detector
Delivery of mounting support, liquid helium system for PERC

Q2 2022:
Start of magnet tests of PERC

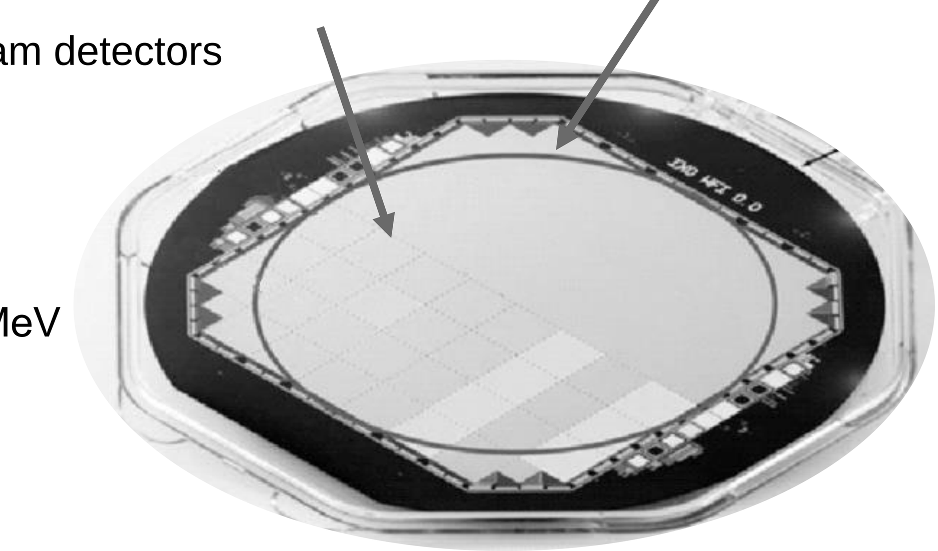
Q2 - Q4 2022:
Setup of shielding and neutron guide

Q4 2022:
Neutrons at the MEPHISTO beamsite

Downstream Detector Requirements

- Main detector for the energy measurements
- Initial detector type: plastic scintillator, like the upstream detectors
- Requirements to achieve the final precision goal:
  - Handle particle rates of up to $\approx 10^5\mathrm{s}^{-1}$
  - Area of about 12×12 cm² with $\mathcal{O}\left(1\,\frac{\mathrm{cm}^2}{\mathrm{pixel}}\right)$
  - Resolve the calibration peak of ^{207}Bi at ≈ 1.1 MeV
  - Fast signals for coincidence measurements (< 10 ns trigger time resolution)
  - Thin dead layer $\mathcal{O}(100\ \mathrm{nm})$
  - Low non-linearities
  - Energy resolution of $\mathcal{O}(1\%)$

Possible wafer segmentation Ø 10,7 cm



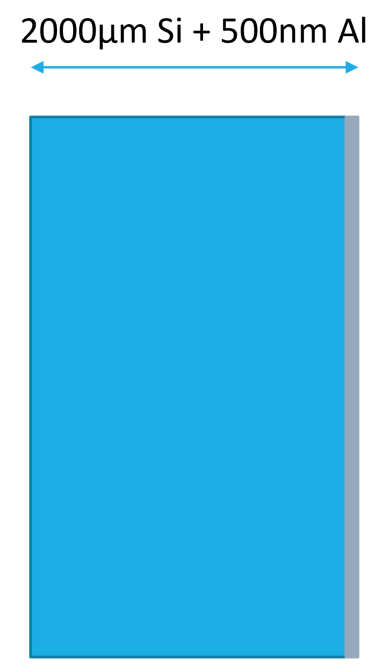
Possible detector layout
Picture taken from [4]

Silicon Detector Design Proposals

Single 2000µm thick Si detector:

\+ Only one detector with electronics
➔ Easier analysis
\+ No additional dead layers
➔ Better energy resolution

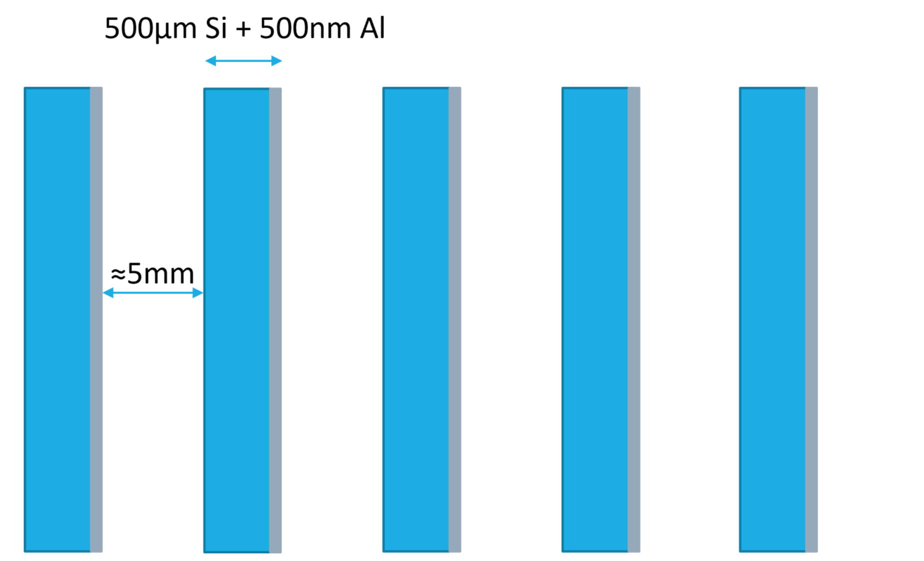
– Difficult to manufacture
– High voltages needed
– Likely is too slow to trigger



Stack of five 500µm thick Si detectors:

\+ Faster readout
\+ Easier to manufacture
➔ "off the shelf"
\+ Background reduction possible

– Five times the electronics
– More dead layers
➔ Additional non-linearity
➔ Worse energy resolution
– Complicated calibration



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