Characterization of the detector dead layer for a sterile neutrino search with KATRIN
Outline

- The dead layer – what we know so far
- Which…
  - Model?
  - Particles?
  - Method?
- Next steps
  - Experiment
  - Simulation
The dead layer – what we know so far

SiO$_2$ „dead“ layer sensitive volume
10 nm ~ 30 nm ~ 450 µm
The dead layer – what we know so far

Marc Korzeczek,
Internal Group Meeting,
July 22th 2016
The dead layer – what we know so far

Marc Korzeczek, Internal Group Meeting, July 22th 2016
The dead layer – what we know so far

Marc Korzeczek, Internal Group Meeting, July 22th 2016

Low-energy tail

DL: 100nm, CCE: stepfct (0, 0)

counts (l)

E_{dep} (eV)
The dead layer – what we know so far

Electrons can pass dead layer several times due to magnetic reflection

Marc Korzeczek, Internatl Group Meeting, July 22th 2016

Low-energy tail

DL : 100nm, CCE : stepfct (0.0)
Which model?

Charge collection efficiency vs. Detector depth.

D
Which model?

![Diagram](image)

- Charge collection efficiency vs Detector depth
- Models: D, S, τ, c, l

- Model D: Constant efficiency
- Model S: Step-like efficiency
- Model τ: Exponential efficiency
- Model c: Sigmoidal efficiency
- Model l: Linear efficiency
Which model?

The one that describes best the measurement

Charge collection efficiency

Detector depth
Idea

- Shoot particles onto detector with certain incident energy
Idea

- Shoot particles onto detector with certain incident energy
- Measure energy and energy loss
- Compare with simulations
Idea

- Shoot particles onto detector with certain incident energy
- Measure energy and energy loss
- Compare with simulations
- Repeat with different incident energies

Greenwald 2007, "Characterization of the Proton Source in the Frictional Cooling Demonstration Experiment", Master thesis
Characterization of the detector dead layer for a sterile neutrino search with KATRIN
### Which particles?

<table>
<thead>
<tr>
<th>Photons</th>
<th>Electrons</th>
<th>Protons</th>
<th>Alphas</th>
</tr>
</thead>
<tbody>
<tr>
<td>No anti-reflective coating</td>
<td></td>
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Which particles?

- Photons
- Electrons
- Protons
- Alphas

No anti-reflective coating
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Photons, Electrons, Protons, and Alphas are listed in the table. KESS and SRIM are mentioned as methods for handling certain particles.
### Which particles?

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**Diagram:**
- [Image of detector setup]
- [Image of neutron scattering]

**Text:**
- Which particles? (Photons, Electrons, Protons, Alphas)

**Table:**
- Photons: No anti-reflective coating
- Electrons: KESS
- Protons: SRIM
- Alphas: Radioactive sources too high energetic
Electrons – simulation

- **KESS** (KATRIN Electron Scattering in Silicon)

- $E_{\text{electron}} = 0 - 50$ keV

- Step by step simulation in two layers (dead and sensitive) of silicon

- Elastic scattering, inelastic scattering, ionization, atomic relaxation
Electrons – simulation

- 10000 electrons
- $E_{in} = 20$ keV
- No dead layer
- No read-out simulation yet
Electrons – simulation

$E_{\text{dep}}$ (eV)

DL: 100nm, CCE: stepfct (0.0)

DL: 40nm, CCE: linfct
Electrons – experiment

- Scanning electron microscope @ HLL (Halbleiterlabor der MPG)
- \( E_{\text{electrons}} = 0.3 \text{ - } 30 \text{ keV} \)
- 5-axis sample stage
- Optical table / feedthrough
Protons – simulation

- **SRIM** (Stopping and Range of Ions in Matter)
  - Based on tables of stopping powers, range and straggling distributions
  - Step by step simulation of “any ion at any energy in any elemental target”
  - No secondaries
Protons – simulation

Incident energy $E_{\text{in}}$

Dead layer thickness $d$

Incident angle $\theta$

\[ \cos \theta = \frac{d}{d'} \]
Protons – simulation

Incident energy $E_{\text{in}}$

Dead layer thickness $d$

Incident angle $\theta$

$$\cos \theta = \frac{d}{d'}$$
Protons – simulation

Incident energy $E_{\text{in}}$

Dead layer thickness $d$

Incident angle $\theta$

$$\cos \theta = \frac{d}{d'}$$

Analyzing peak shapes
Protons – experiment

New construction @ MPP

Greenwald 2007, “Characterization of the Proton Source in the Frictional Cooling Demonstration Experiment”, Master thesis
Protons – experiment

- New construction @ MPP
- Performance simulations

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Protons – experiment

- New construction @ MPP
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Which method?

- Energy-shifting method
  - Measure energy loss for different incident energies
  - Prone to intensity and energy fluctuations
Which method?

- **Energy-shifting method**
  - Measure energy loss for different incident energies
  - Prone to intensity and energy fluctuations

- **Tilted-beam method**
  - Measure energy loss for different incident angles
  - Increasing backscattering probability → small angles only
Tilted-beam method

\[ \cos \theta = \frac{d}{d'} \]
Tilted-beam method

Backscattering increases with $\theta$

$\cos \theta = \frac{d}{d'}$

Graph showing backscattered protons vs. incident angle.
Conclusion - which…

- Model?
- One has to adjust to data
Conclusion - which…

- Model?
  - One has to adjust to data

- Particles?
  - Electrons: KESS
  - Protons: SRIM
Conclusion - which...

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- Particles?
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- Particles?
  - Electrons
  - Protons

KESS
SRIM
Conclusion - which…

- Model?
  - One has to adjust to data

- Particles?
  - Electrons KESS
  - Protons SRIM

- Method?
  - Tilting-beam method
Thank you


Tim Brunst, KATRIN CM32, Mar 8th 2017
Backup slides
Electrons – experiment

- Evaporated Rb/Kr source of monoenergetic electrons
  - Available in weeks / few months

![Theoretical spectrum with 400 μm Si](image)

Plot by Martin Slezák
Electrons vs. protons

Renschler 2011,
“A new Monte Carlo simulation code for low-energy electron interactions in silicon detectors”.
Ph. D. thesis
Protons – simulation

- $d = 10 \text{ nm}$
- $E_{\text{in}} = 20 \text{ keV}$
- $\theta = 0^\circ$
- $d \pm 1 \text{ nm} \quad (10\%)$
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- $d \pm 1 \text{ nm} (10 \%)$
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- $\theta \pm 25^\circ$
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- $\theta \pm 25^\circ$

Further discrimination analyzing peak shapes
Thicker dead layer or wider incident angle have stronger impact on peak width than incident energy.

This is only the energy loss in the sensitive area – not the measured signal.
Tilted-beam method

- 20 keV protons
  - Red: thicker dead layer, incident angle = 0°
  - Blue: 10nm dead layer, large incident angle