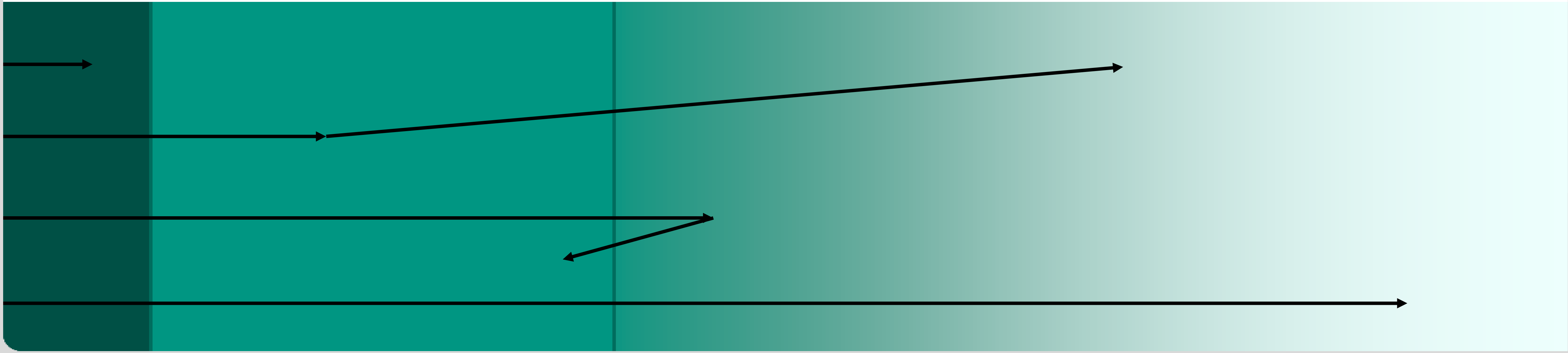
Characterization of the detector dead layer for a sterile neutrino search with KATRIN

Tim Brunst, DPG81 Münster, Mar 29th 2017

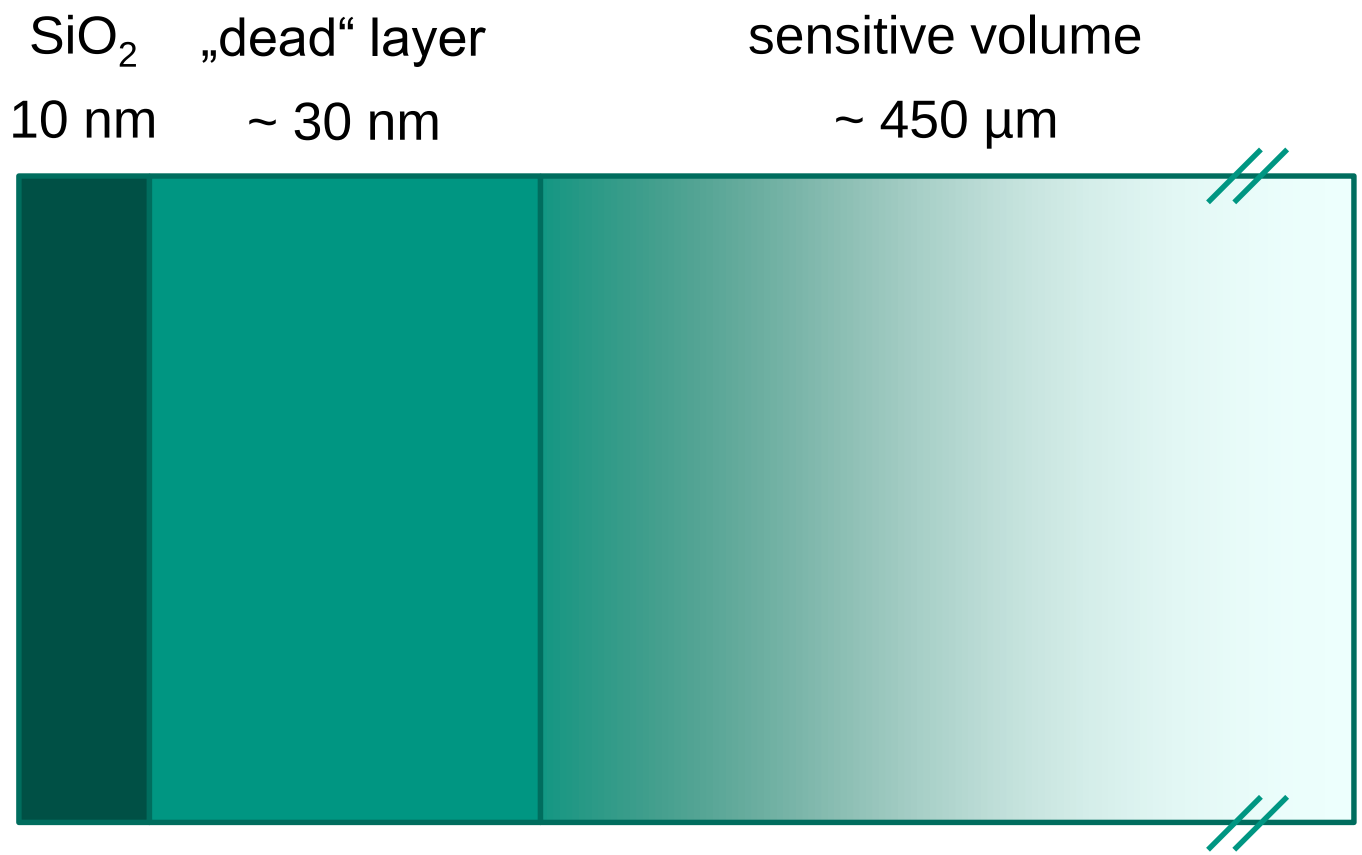


Max Planck Institute for Physics, Munich
KATRIN Collaboration – TRISTAN Group

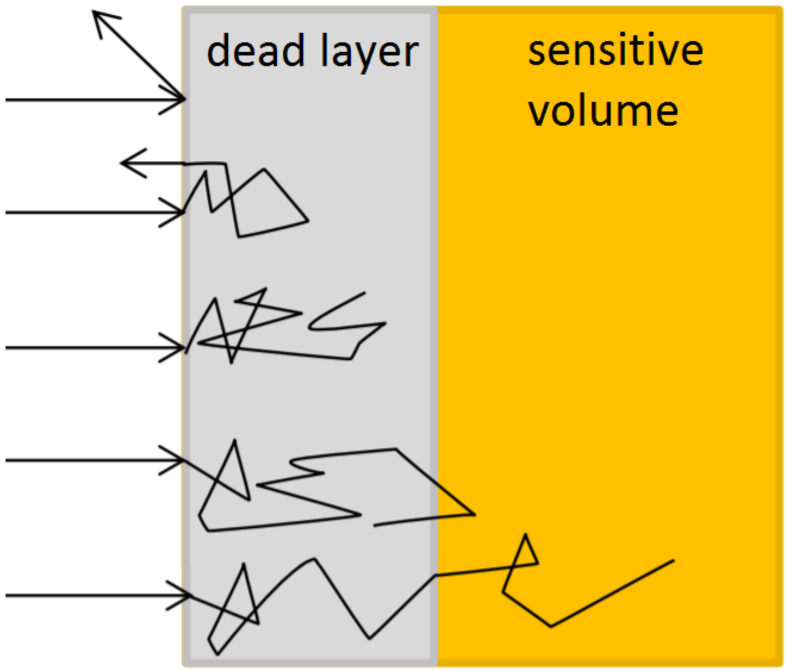
Outline

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

The dead layer – what we know so far

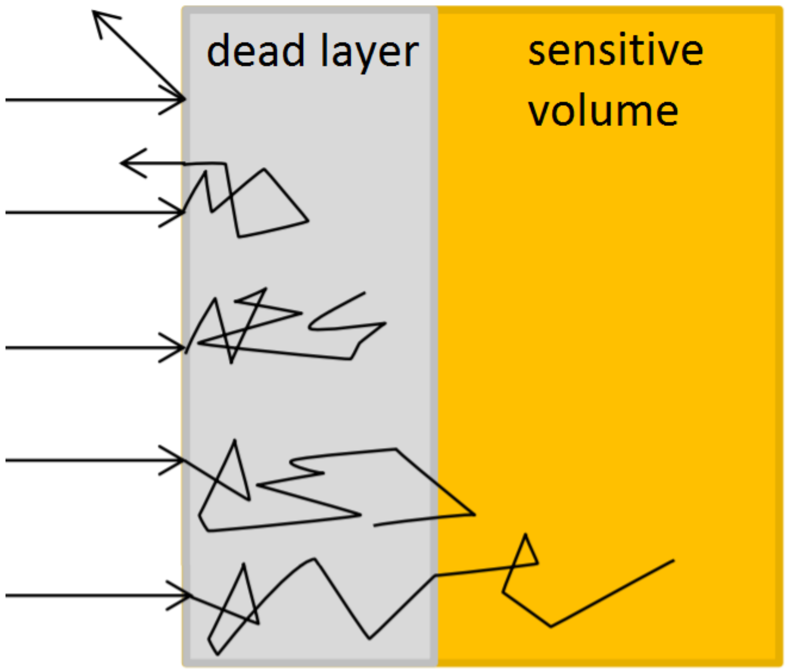


The dead layer – what we know so far



Marc Korzeczek,
Internal Group Meeting,
July 22th 2016

The dead layer – what we know so far



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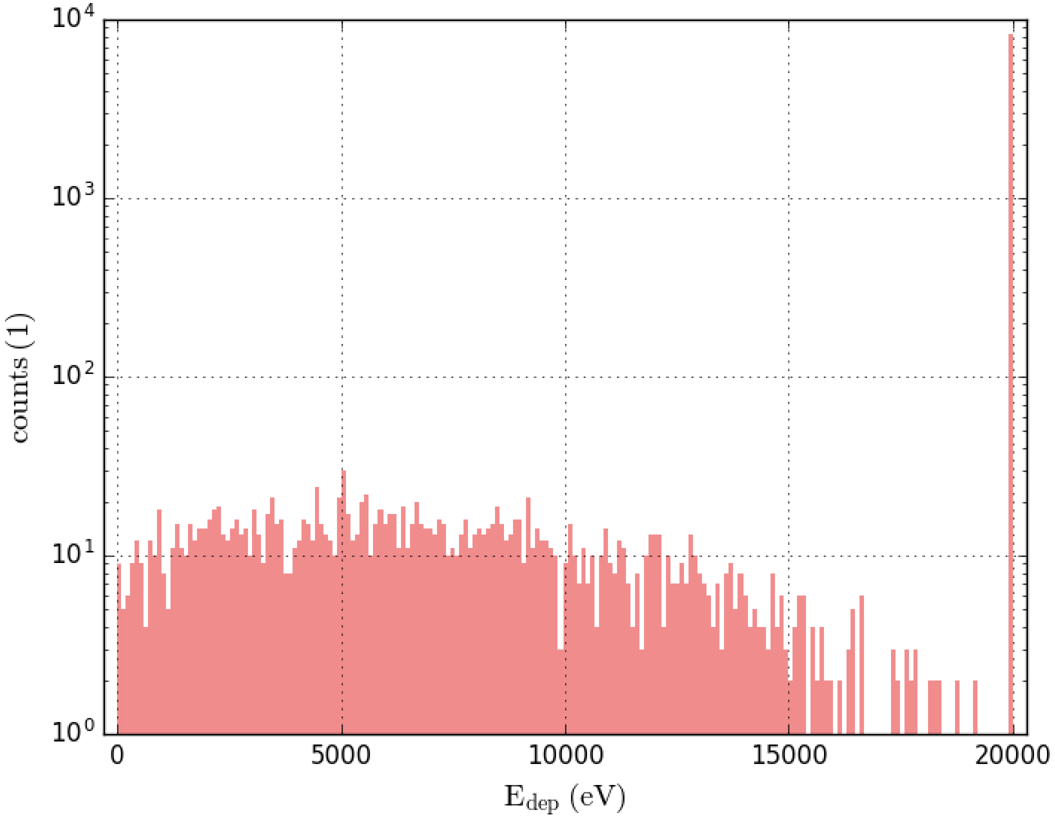
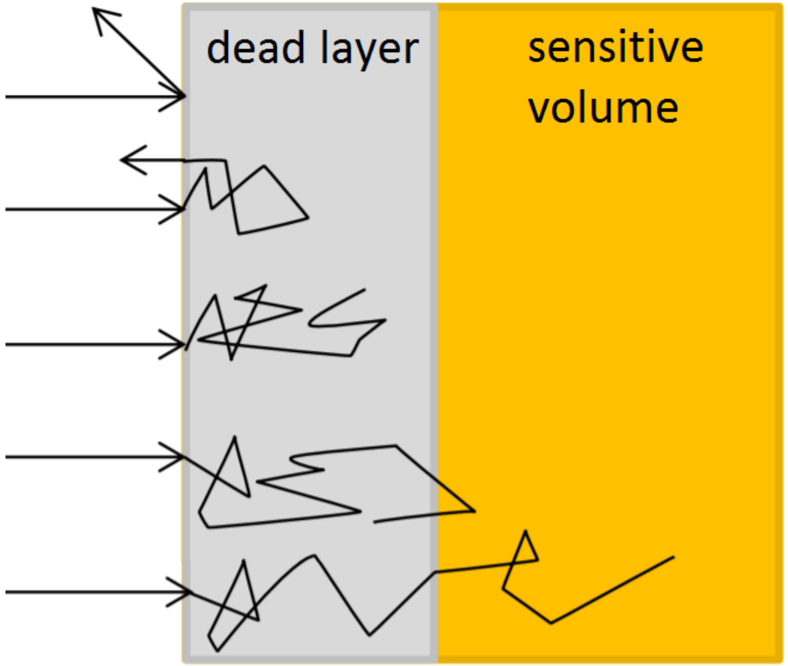


The dead layer – what we know so far



Marc Korzeczek,
Internal Group Meeting,
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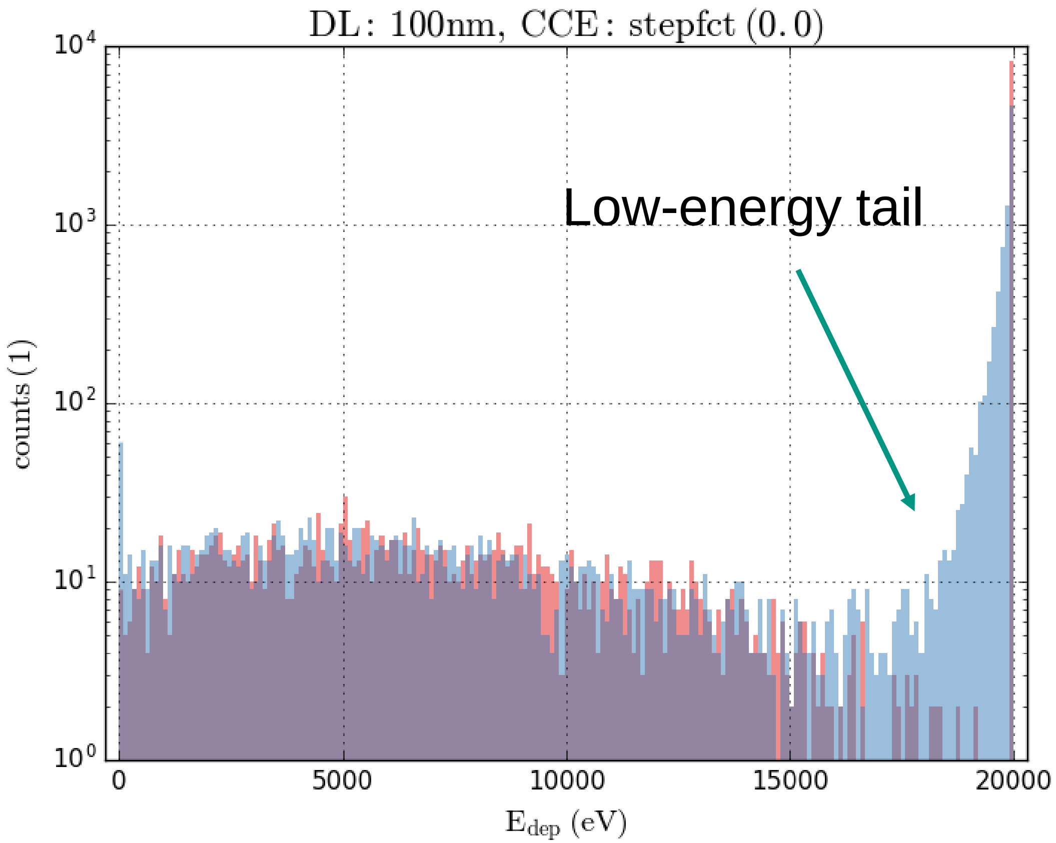
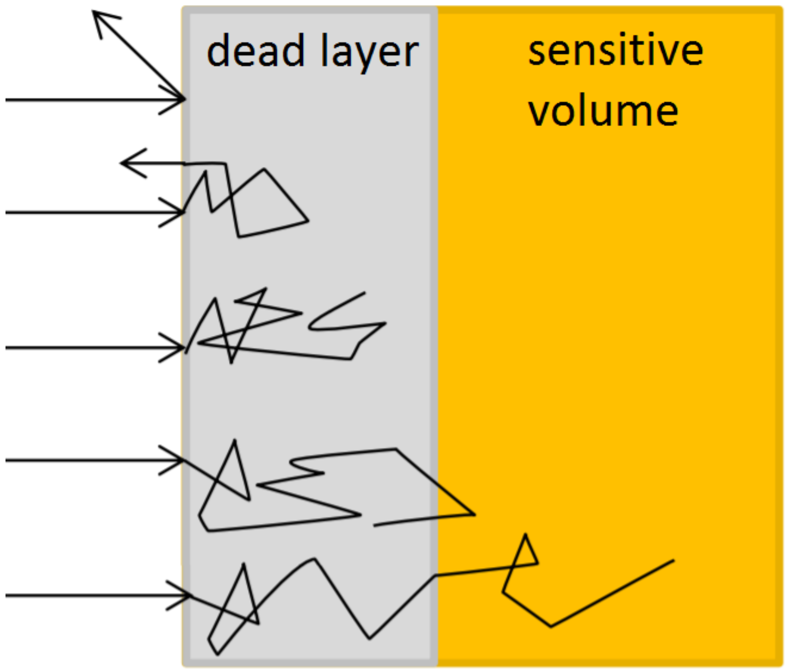


The dead layer – what we know so far



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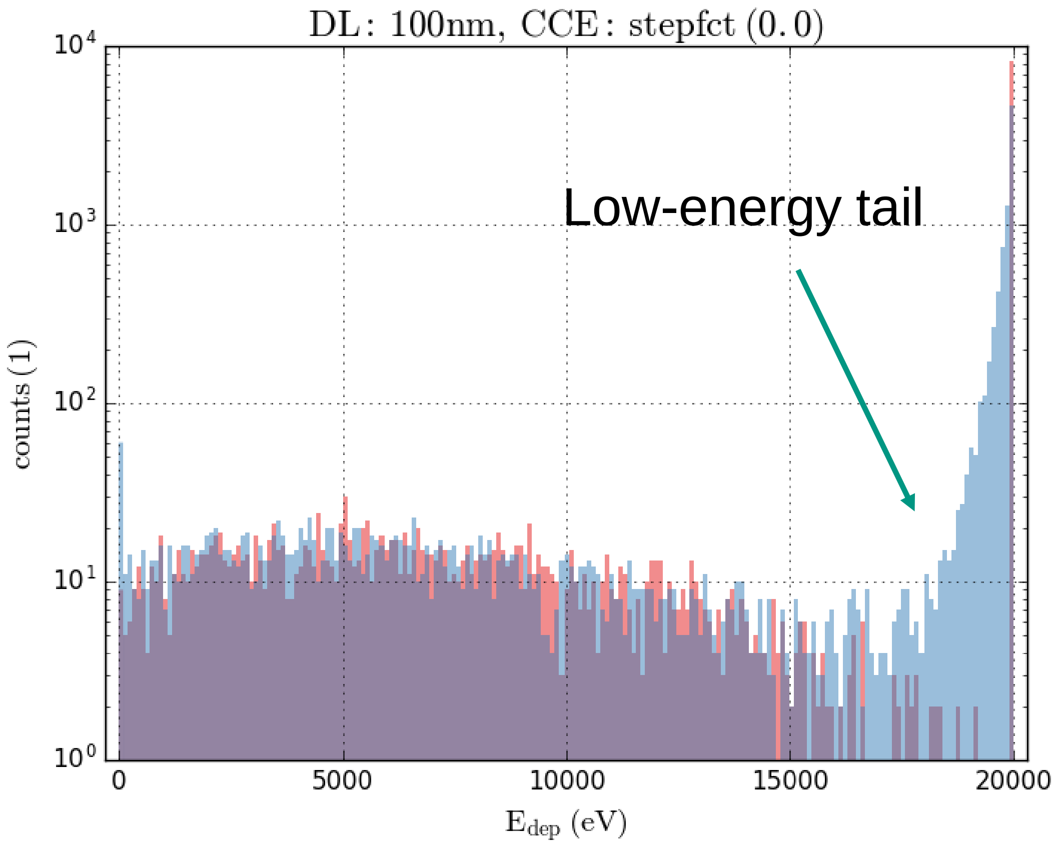
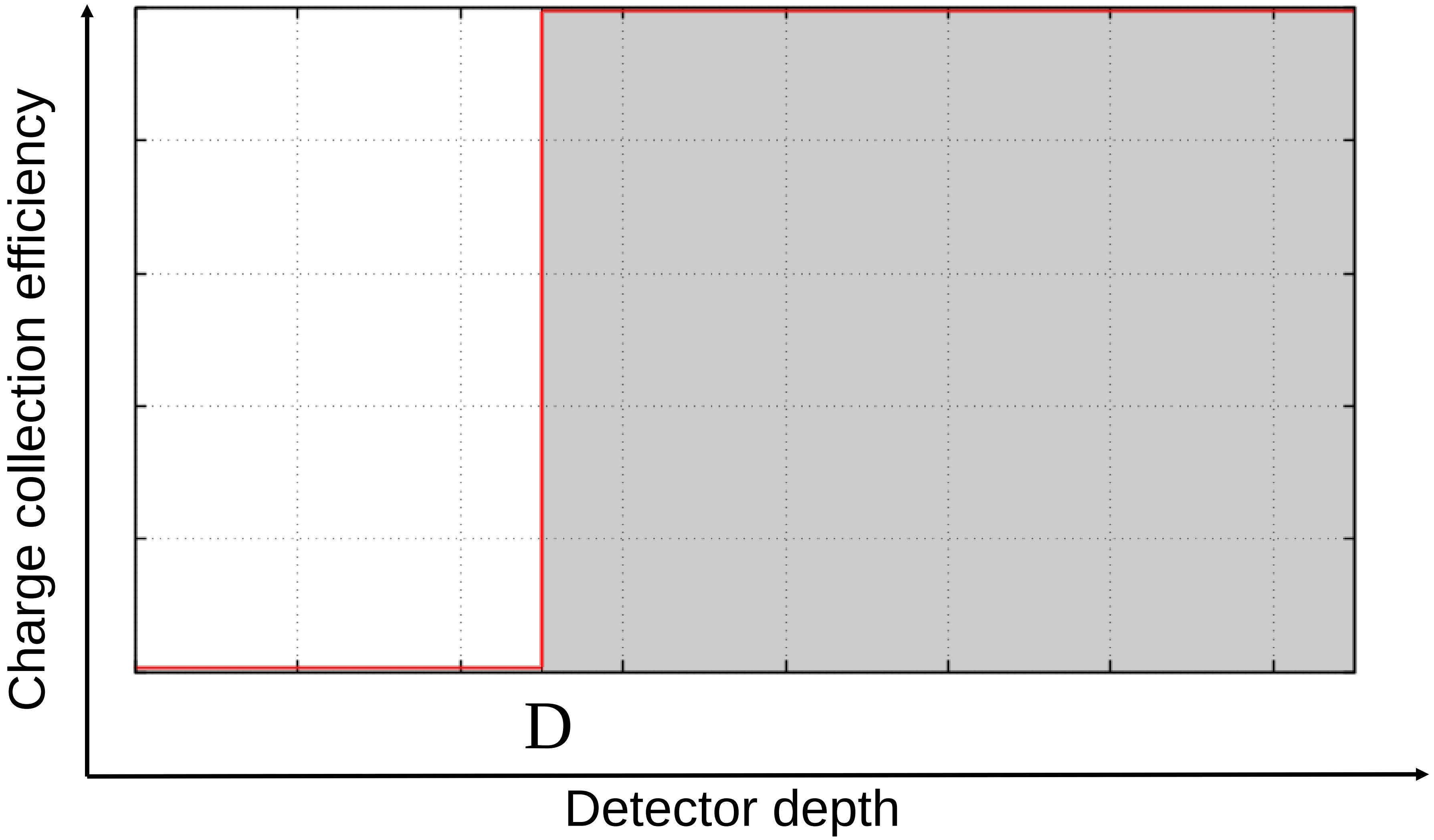
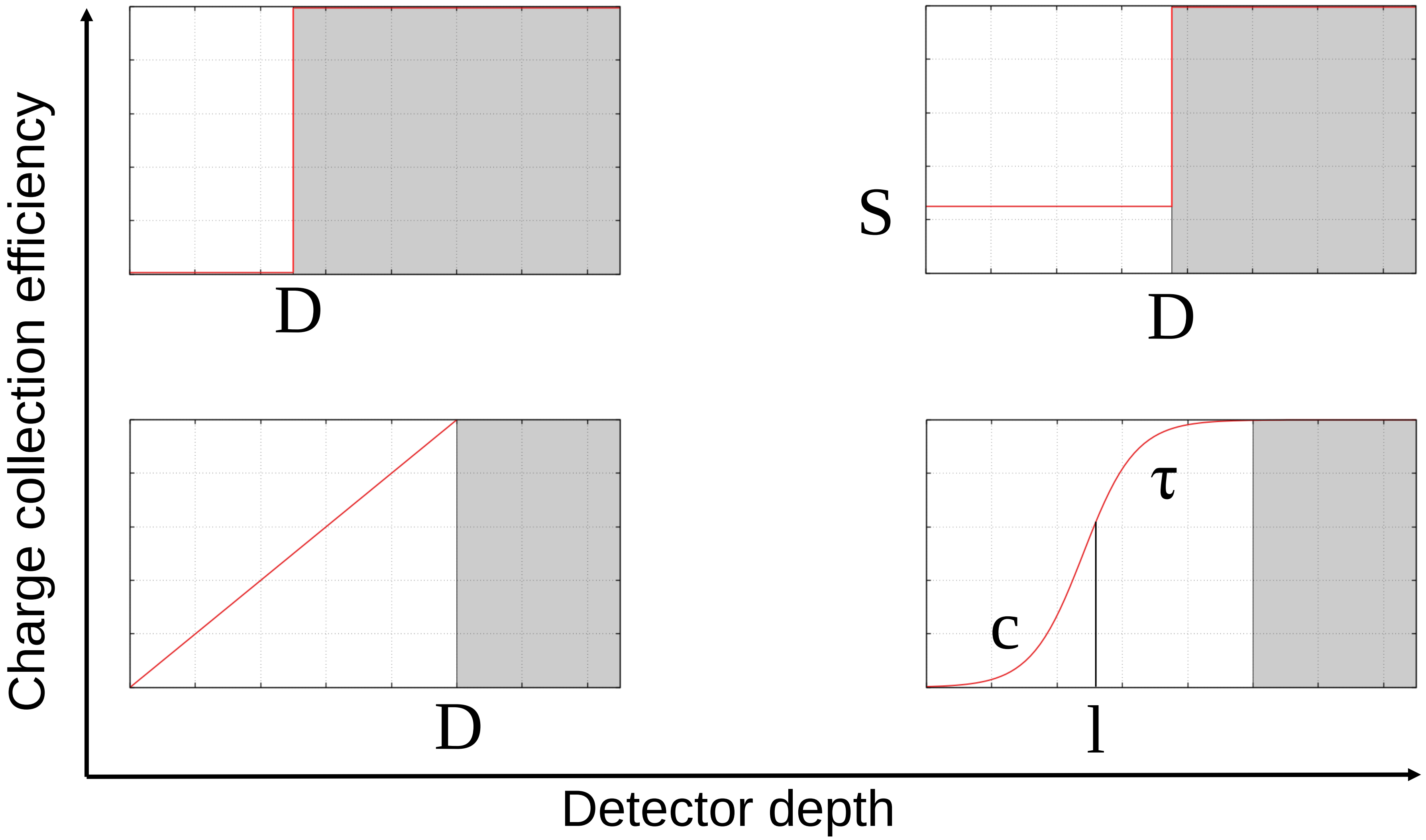


Electrons can pass dead layer several times due to magnetic reflection

Which model?



Which model?



Which model?

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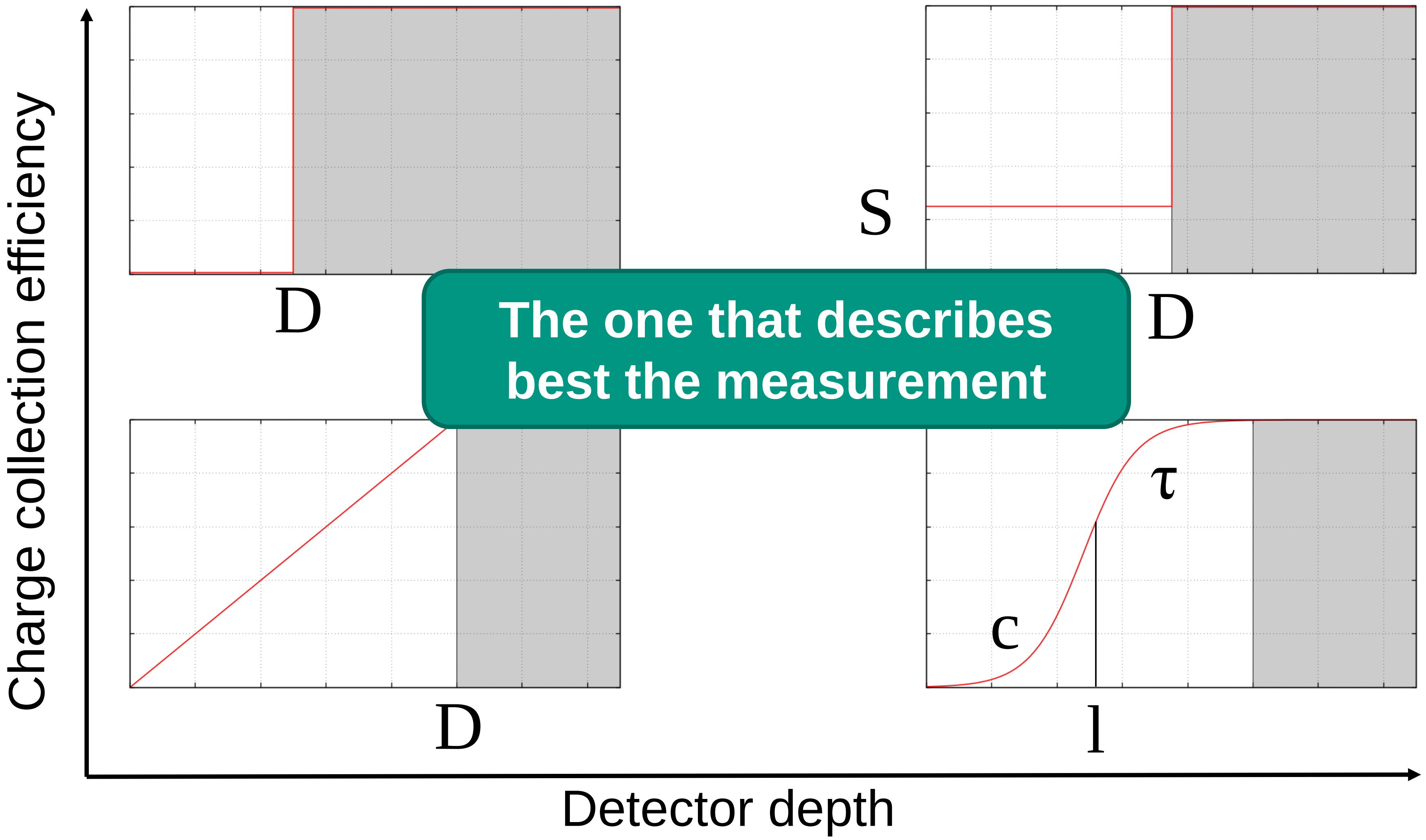
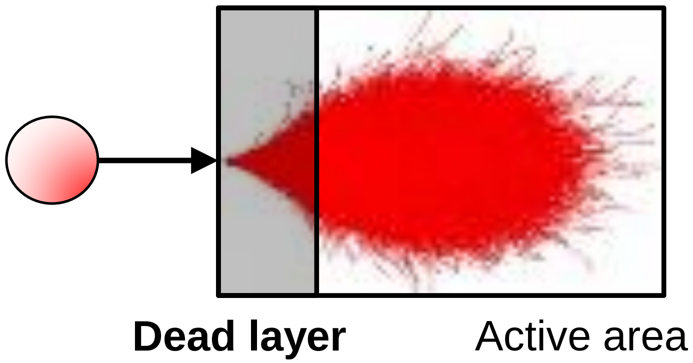
(Werner-Heisenberg-Institut)



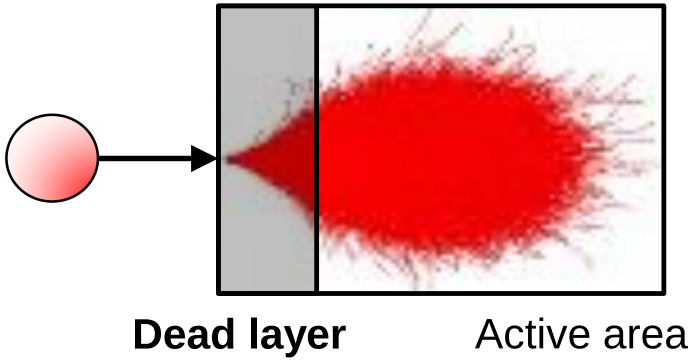
The one that describes best the measurement

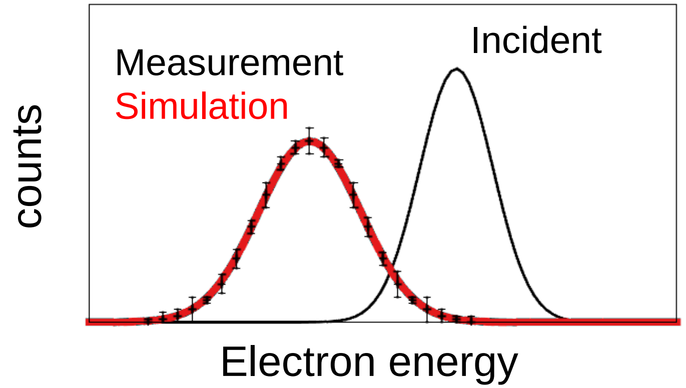
Idea



- Shoot particles onto detector with certain incident energy

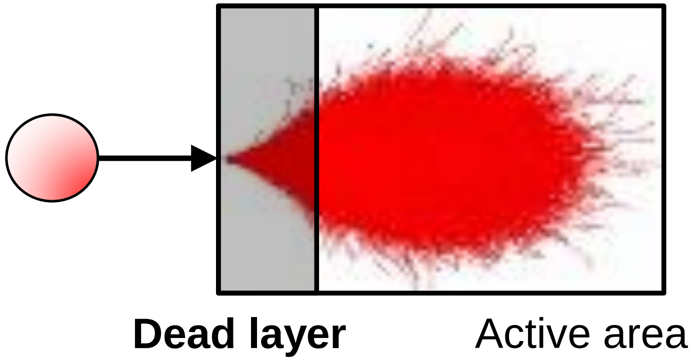
Idea

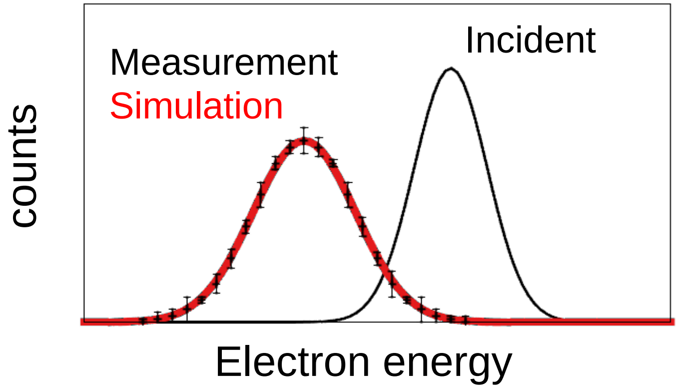


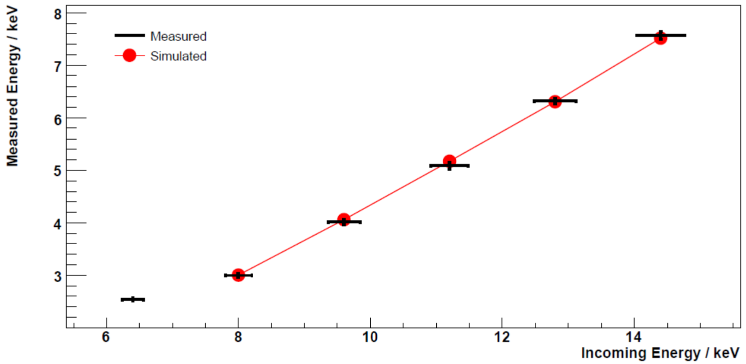


- Shoot particles onto detector with certain incident energy
- Measure energy and energy loss
- Compare with simulations

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

Which particles?

Photons	Electrons	Protons	Alphas

Which particles?

Photons	Electrons	Protons	Alphas
No anti-reflective coating			

Which particles?

Photons	Electrons	Protons	Alphas
No anti-reflective coating	KESS		

Which particles?

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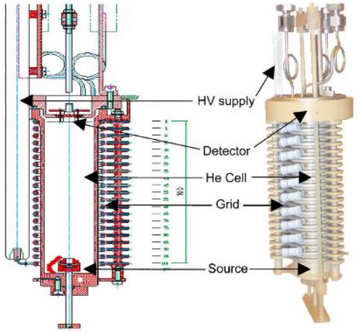
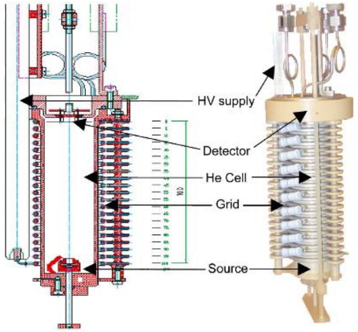
(Werner-Heisenberg-Institut)

Photons	Electrons	Protons	Alphas
No anti-reflective coating	KESS	SRIM	



Which particles?

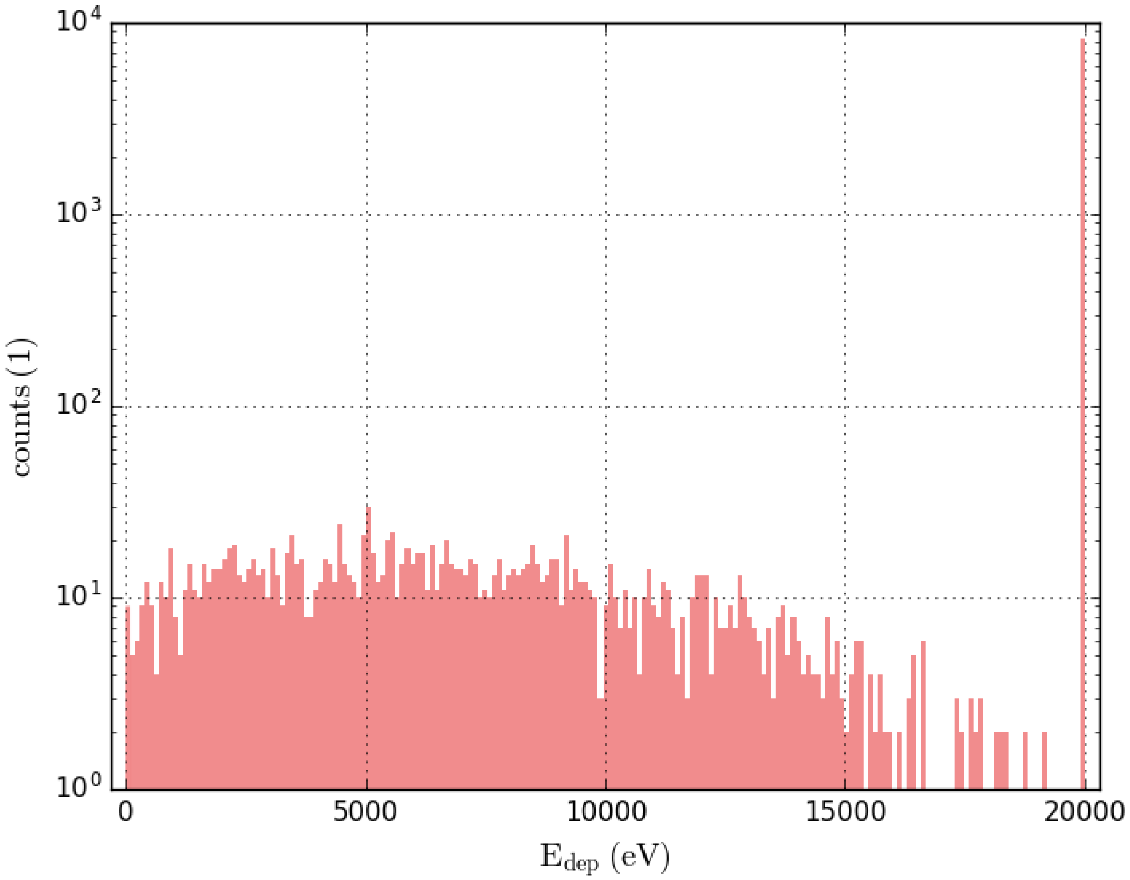
Photons	Electrons	Protons	Alphas
No anti-reflective coating	KESS	SRIM	Radioactive sources too high energetic



Electrons – simulation

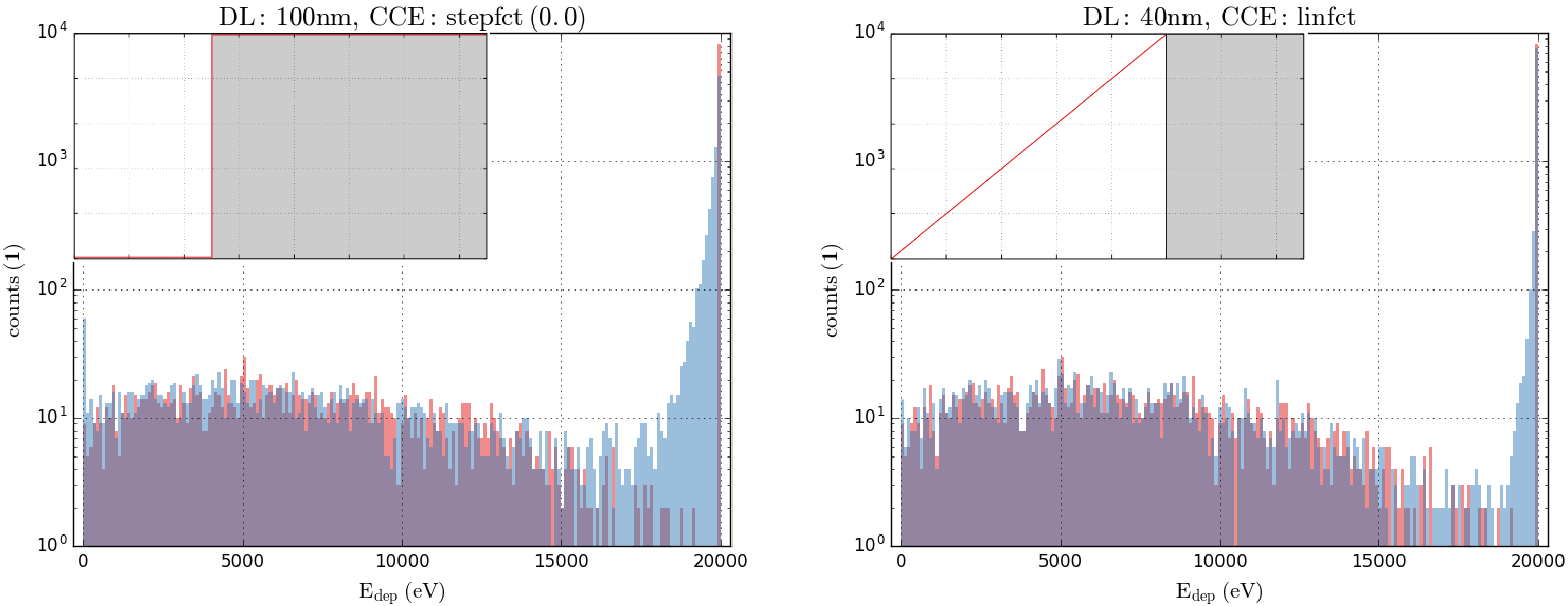
- **KESS** (KATRIN Electron Scattering in Silicon)
  - $E_{electron}$ = 0 – 50 keV
  - Step by step simulation in two layers (dead and sensitive) of silicon
  - Elastic scattering, inelastic scattering, ionization, atomic relaxation

Electrons – simulation



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

Electrons – simulation



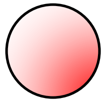
Electrons – experiment

- Scanning electron microscope @ HLL
  (Halbleiterlabor der MPG)
- $E_{electrons}$ = 0.3 - 30 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

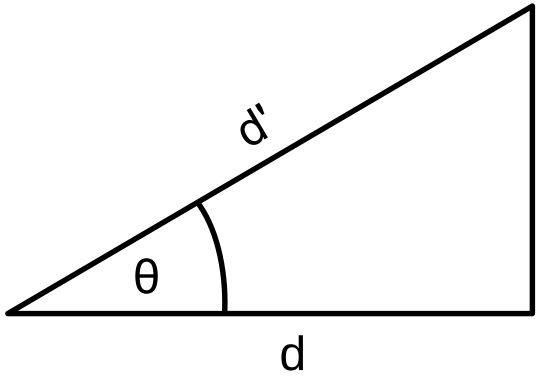
Protons – simulation



Incident energy E_{in}

Dead layer thickness d

Incident angle θ



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

Protons – simulation

Incident energy E_{in}

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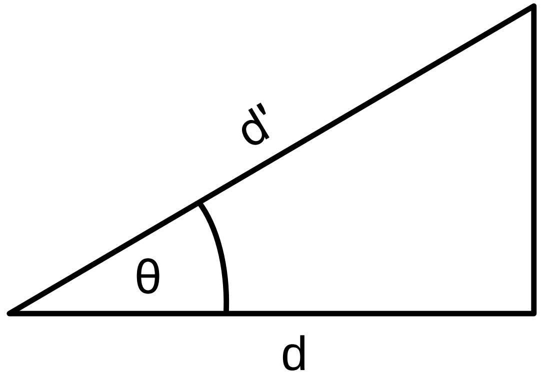

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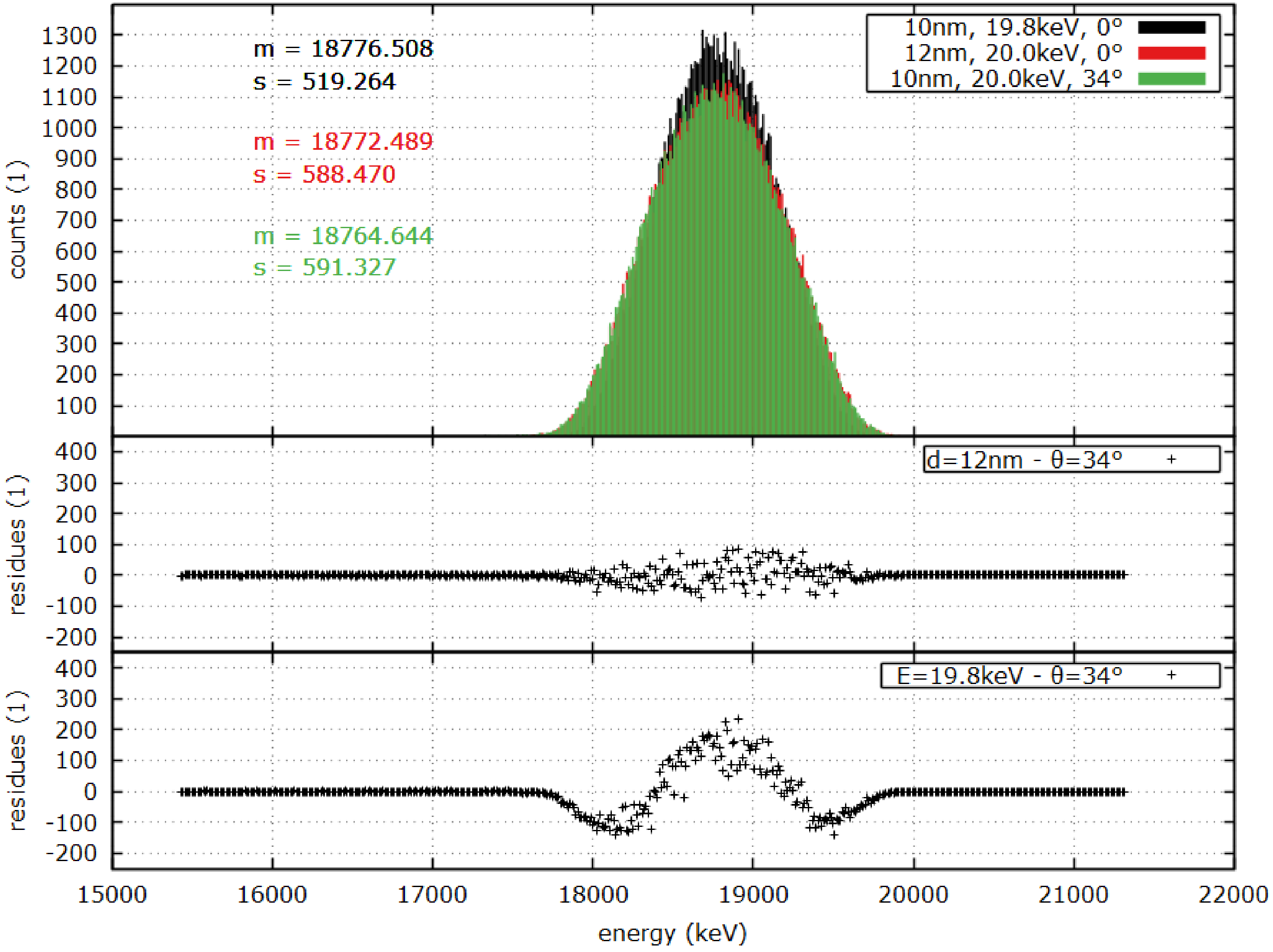
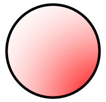


Protons – simulation



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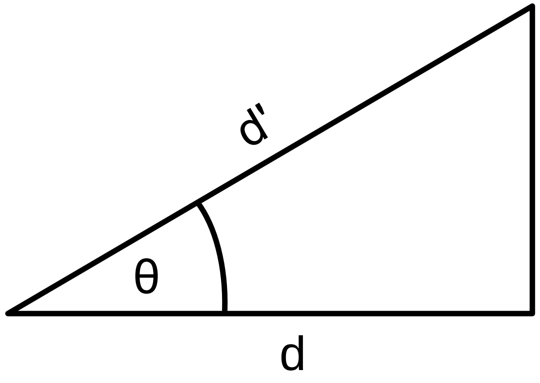
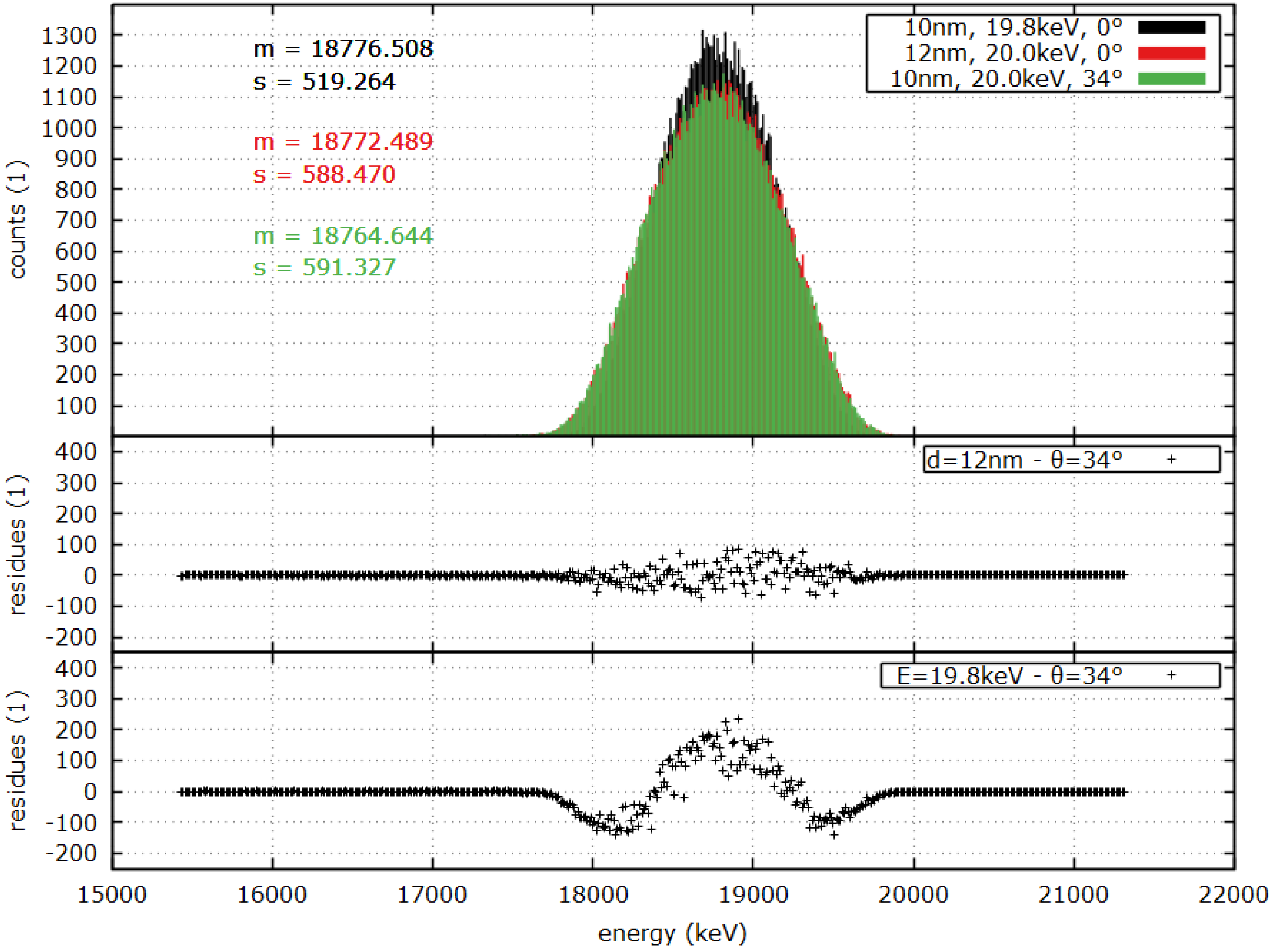
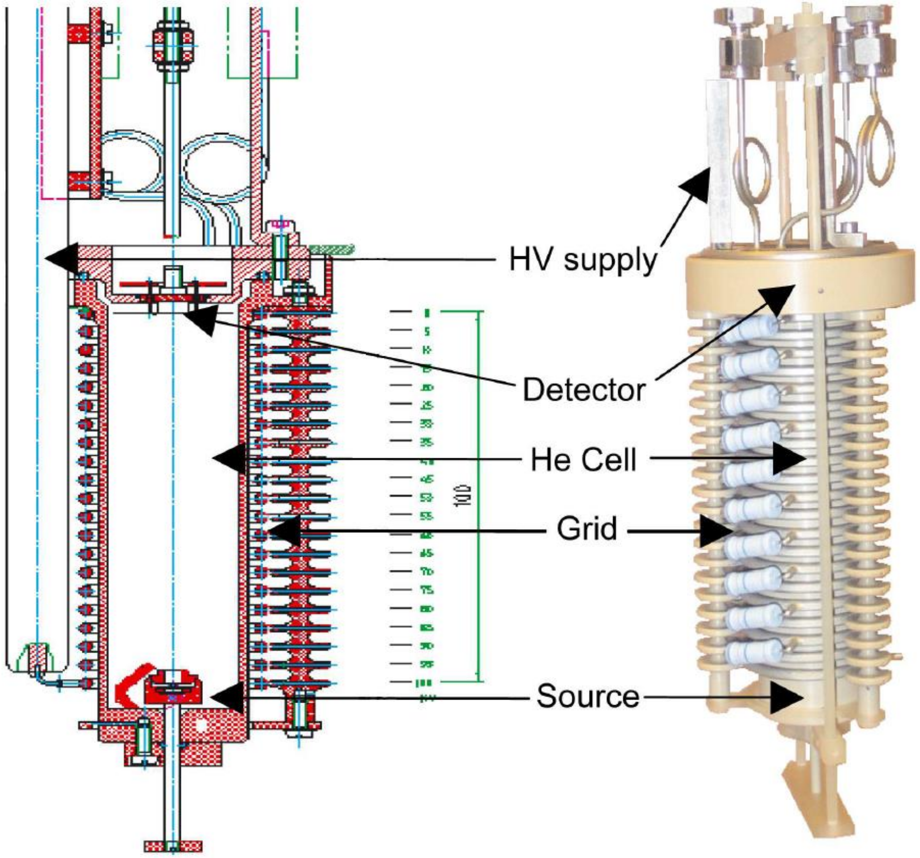


$$\cos\theta = \frac{d}{d'}$$

Analyzing peak shapes



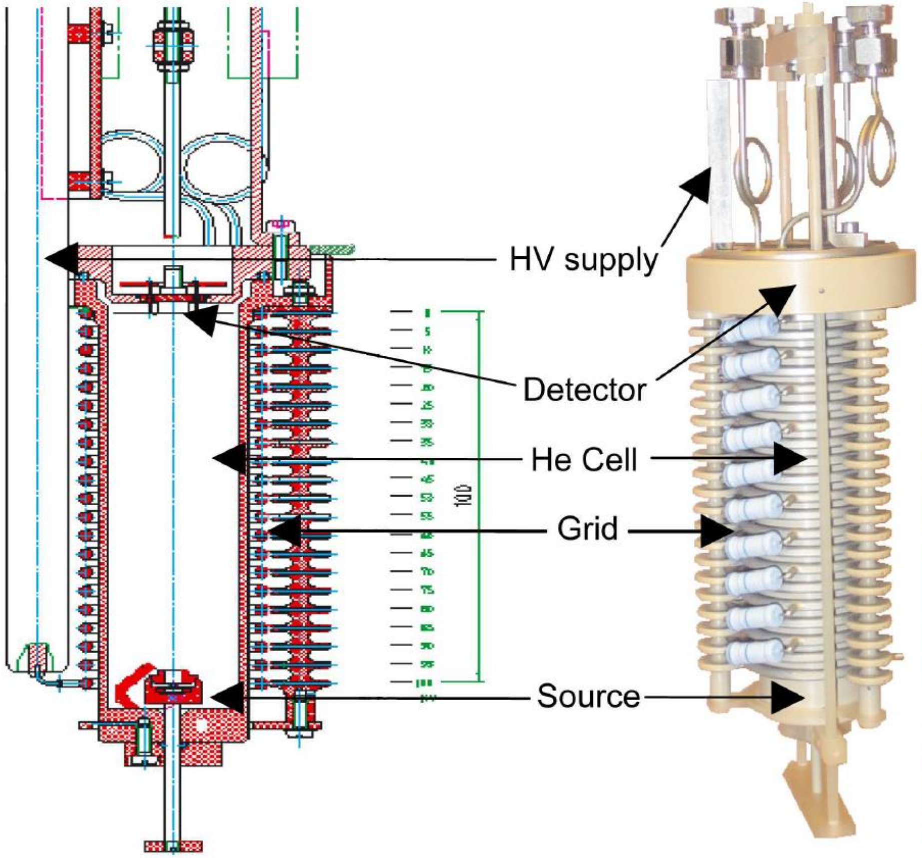
Protons – experiment



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

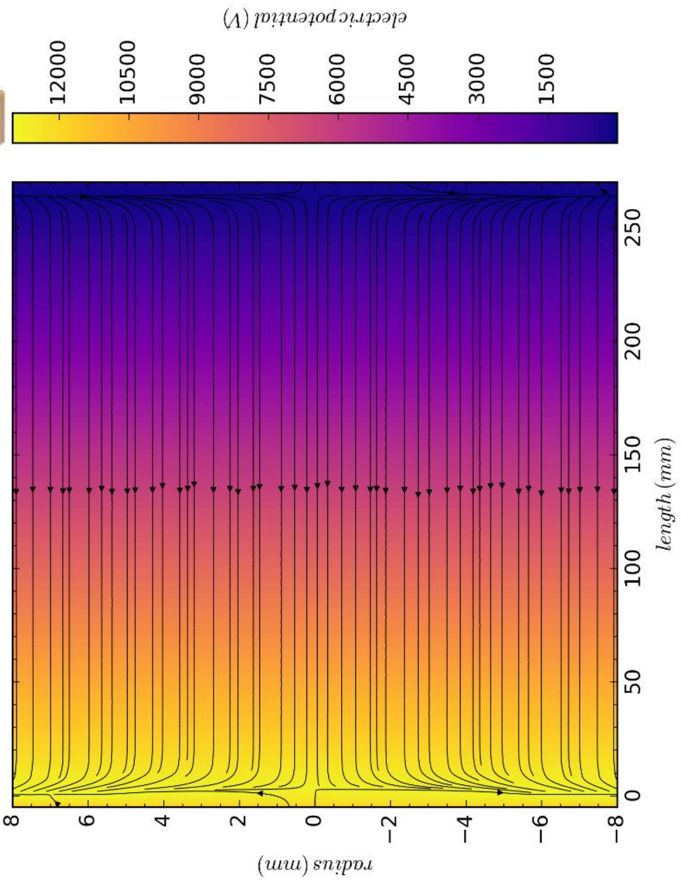
- New construction @ MPP

Protons – experiment

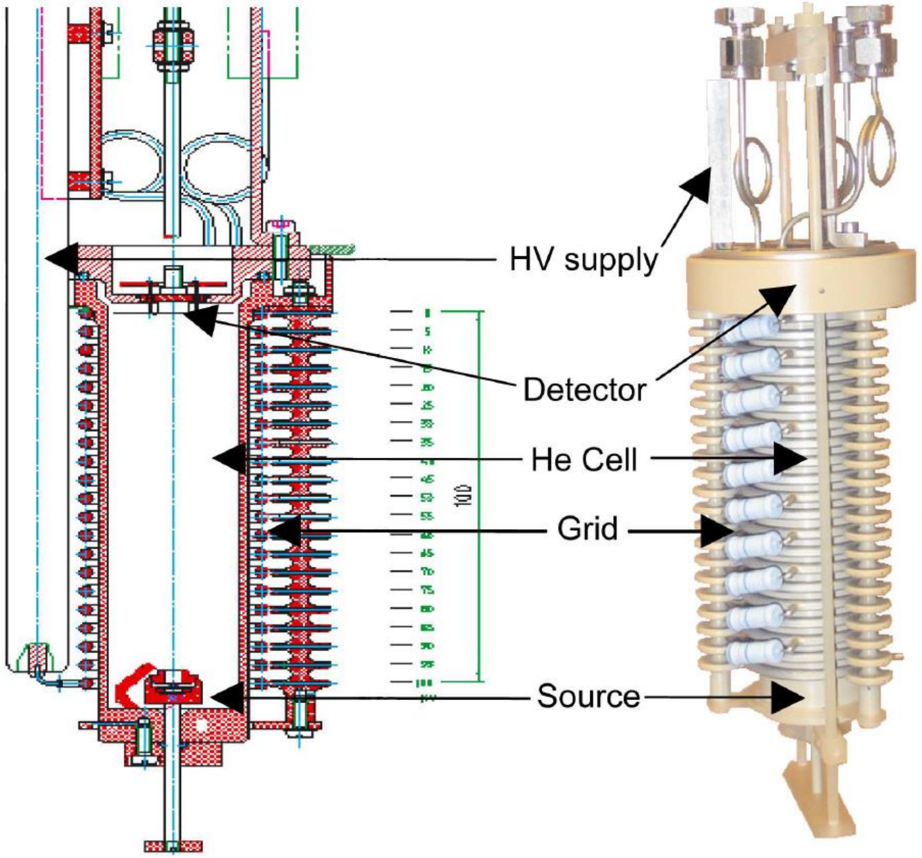


Greenwald 2007,
“Characterization of the Proton Source in the Frictional Cooling Demonstration Experiment”, Master thesis

- New construction @ MPP
  - ➡ Performance simulations



Protons – experiment



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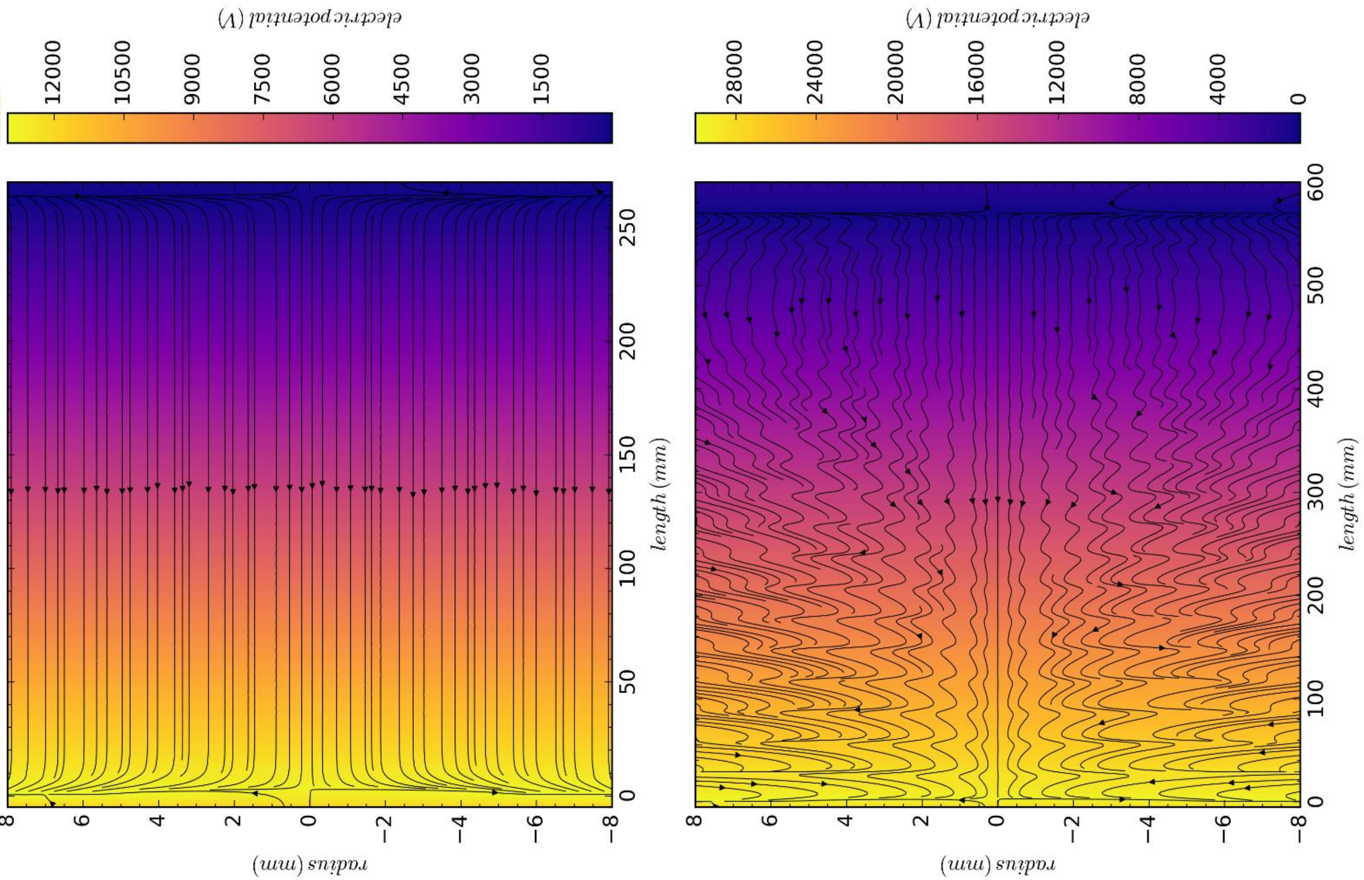
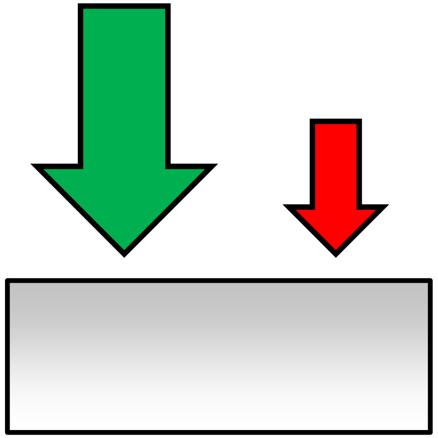


Which method?

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



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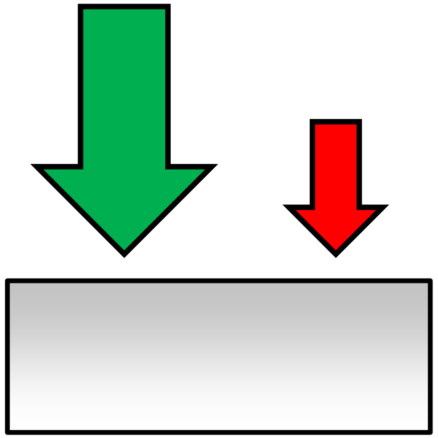
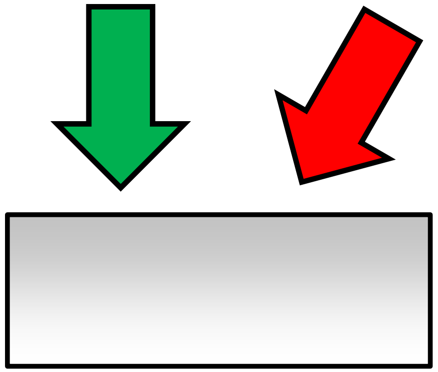
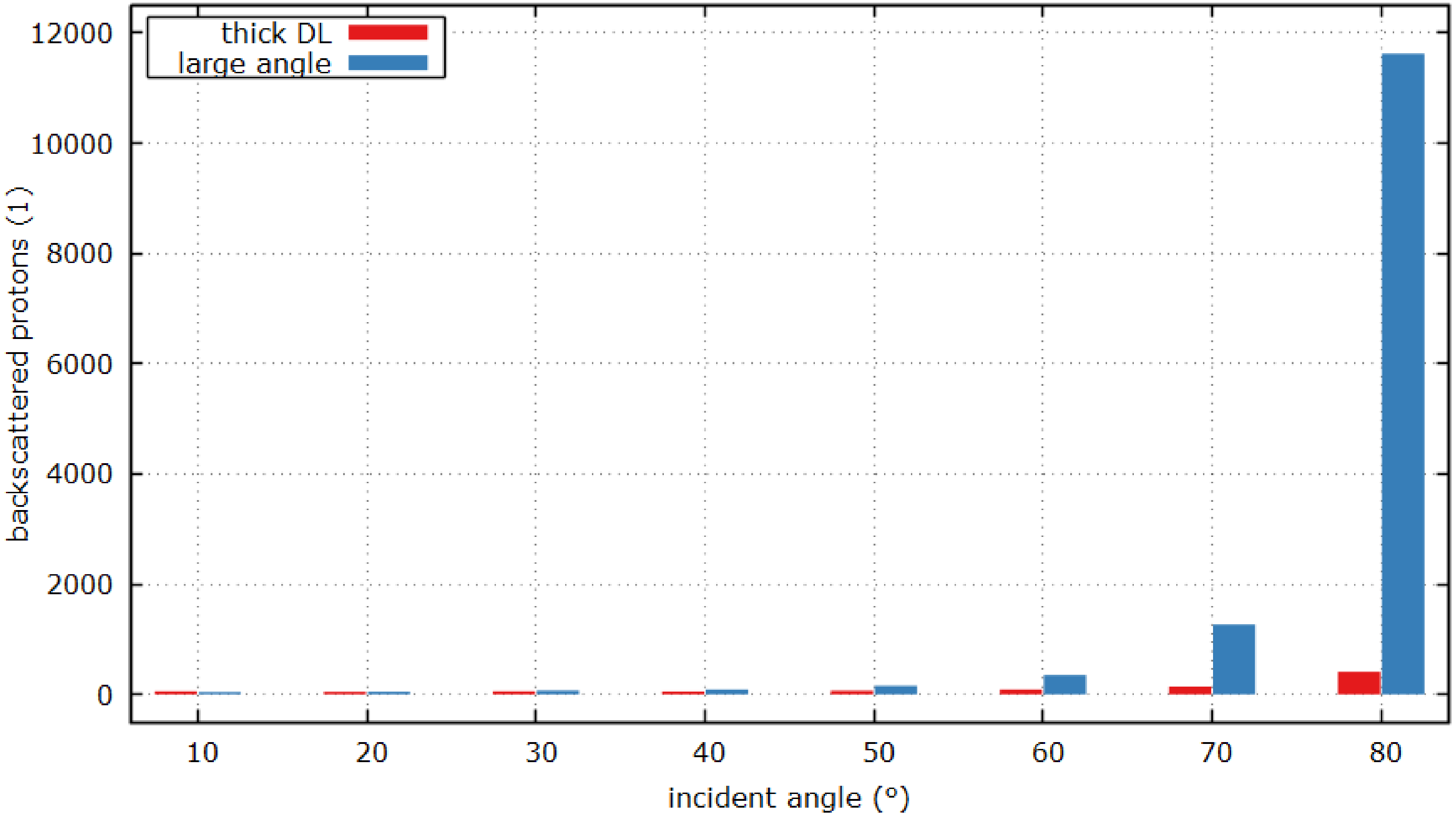
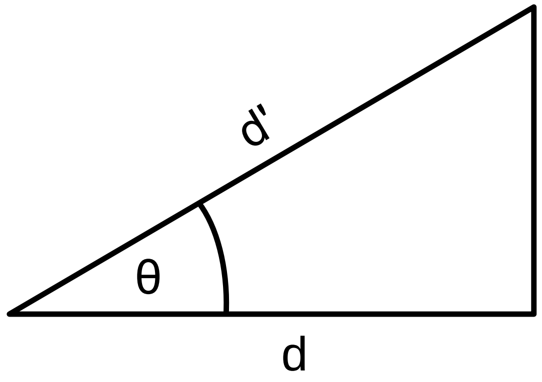


- Tilted-beam method
  - Measure energy loss for different incident angles
  - Increasing backscattering probability → small angles only



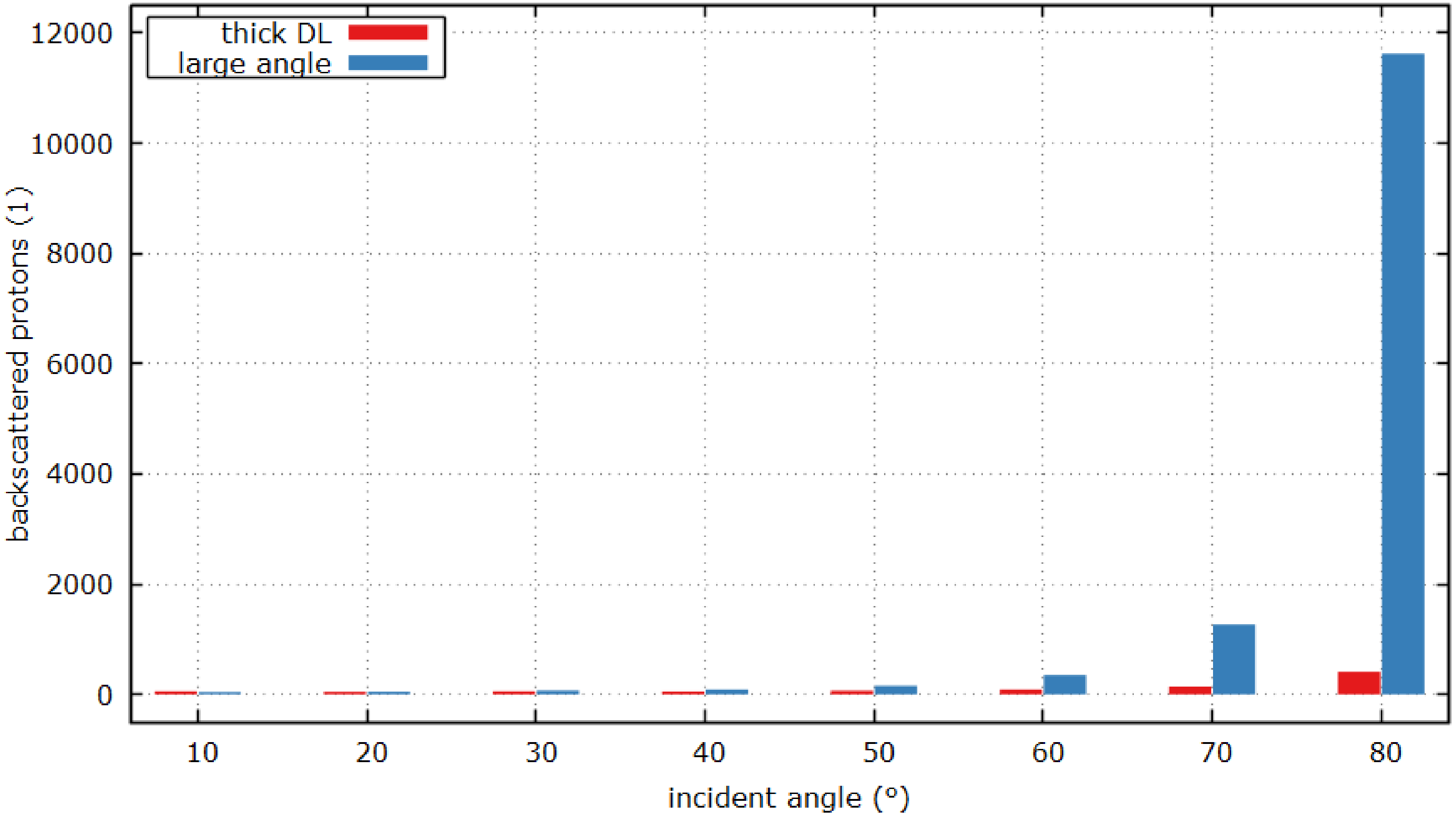
Tilted-beam method

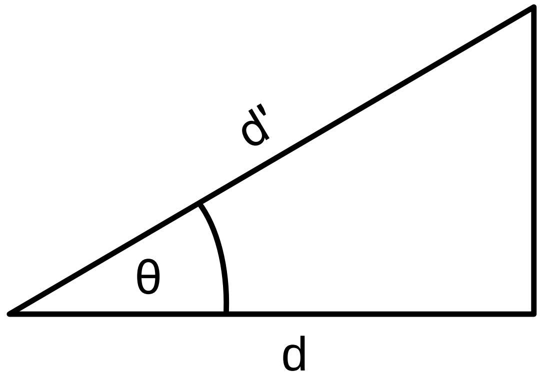




$$\cos\theta = \frac{d}{d'}$$

Tilted-beam method





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

Backscattering increases with θ

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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Conclusion - which…

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(Werner-Heisenberg-Institut)

- Model?
  - One has to adjust to data
- Particles?
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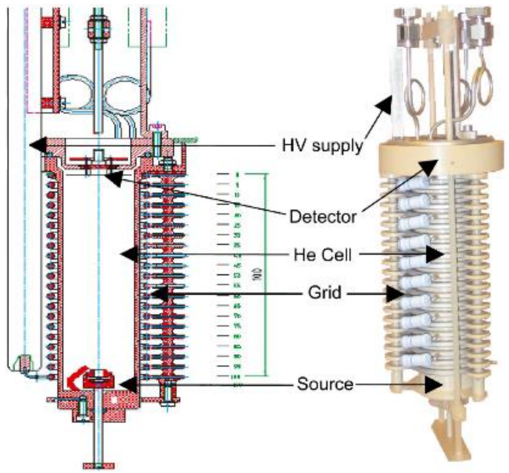
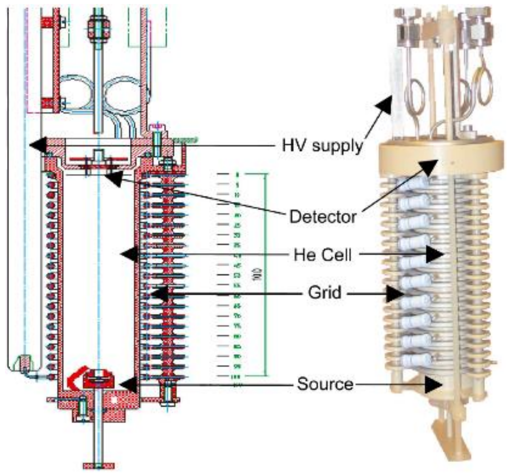


Conclusion - which…

- Model?
  - One has to adjust to data
- Particles?
  - Electrons KESS
  - Protons SRIM
- Method?
  - Tilting-beam method



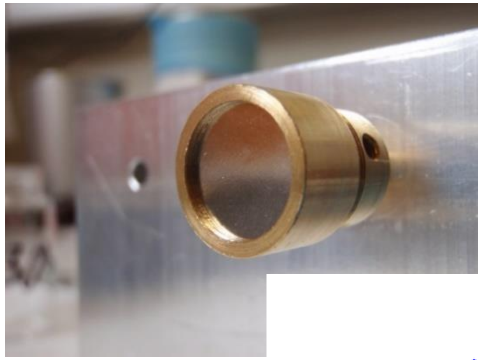
Thank you

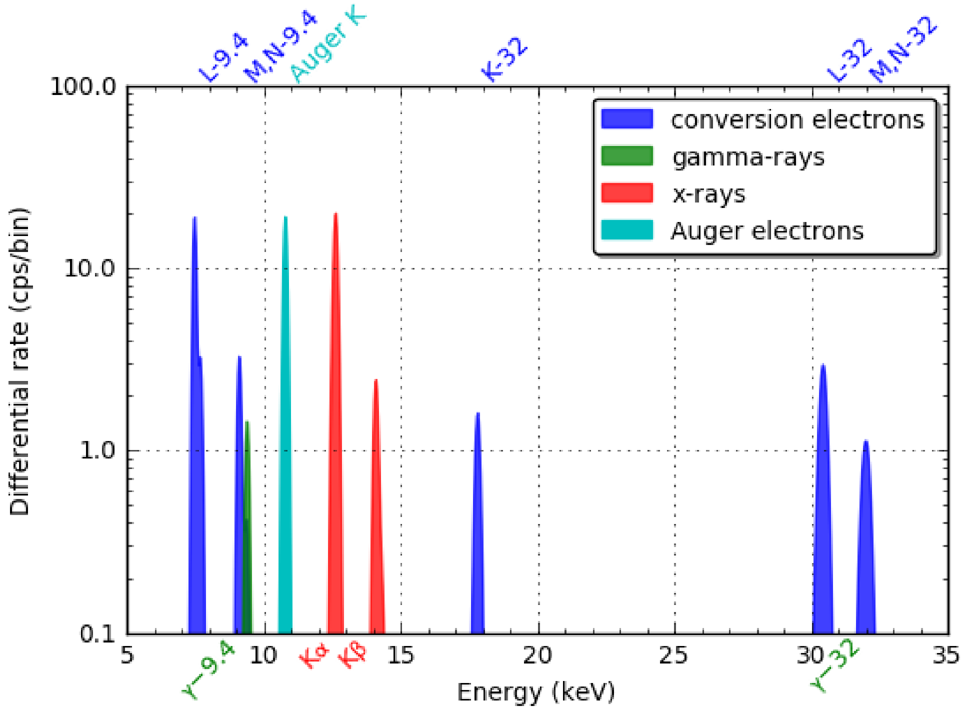
T. Bode, F. Glück, T. Haubold, A. Huber, M. Korzeczek, T. Lasserre, P. Lechner,
A. Lokhov, S. Mertens, D. Radford, F. Roccati, F. Schopper, M. Slezák, J. Wolf

Backup slides

Tim Brunst, KATRIN CM32, Mar 8th 2017

Electrons – experiment

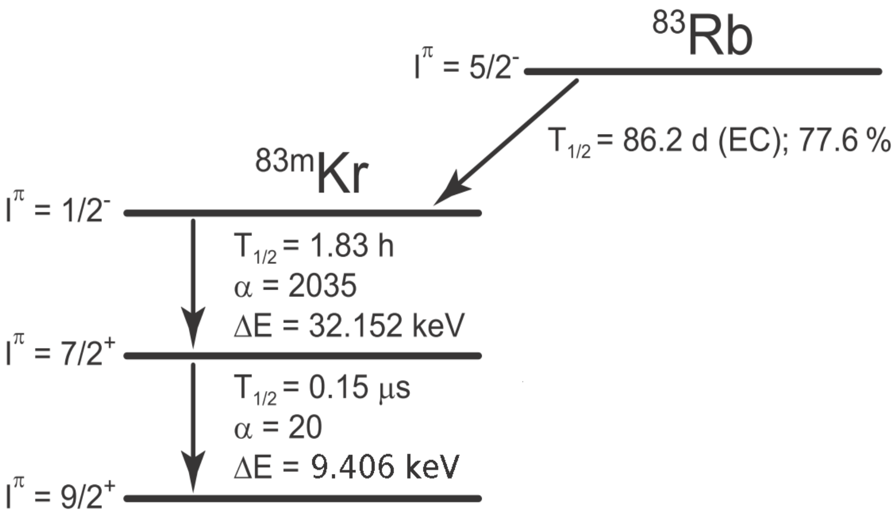




Theoretical spectrum with 400 µm Si

Plot by Martin Slezák

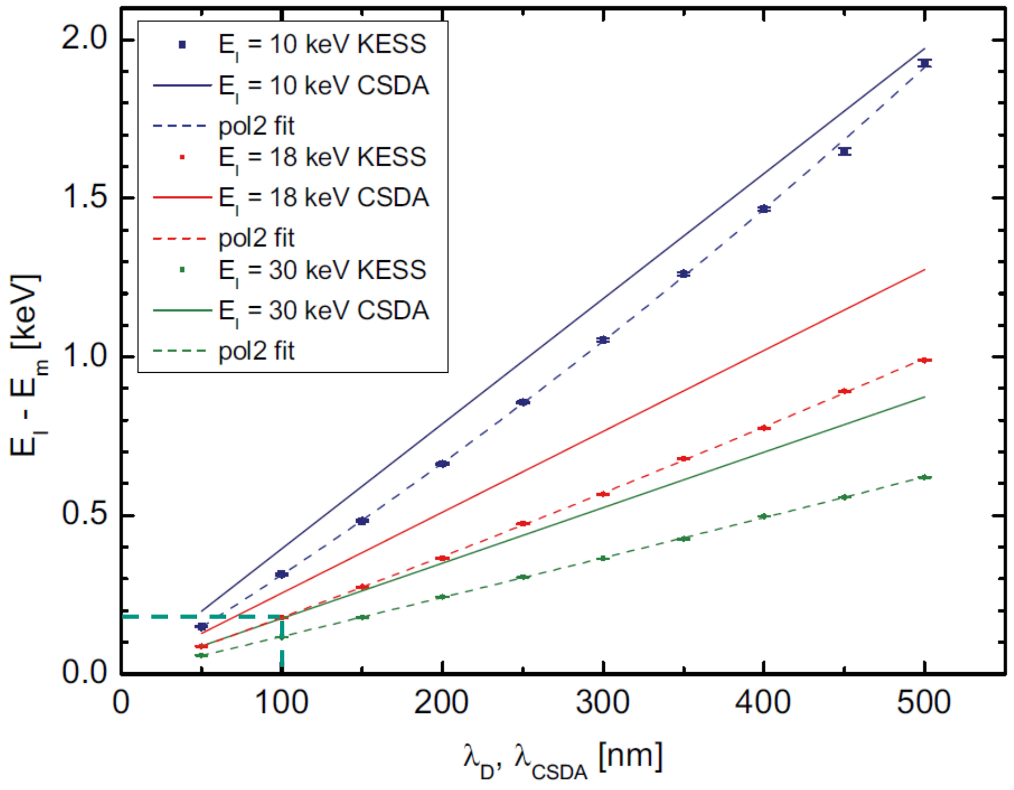
- Evaporated Rb/Kr source of monoenergetic electrons



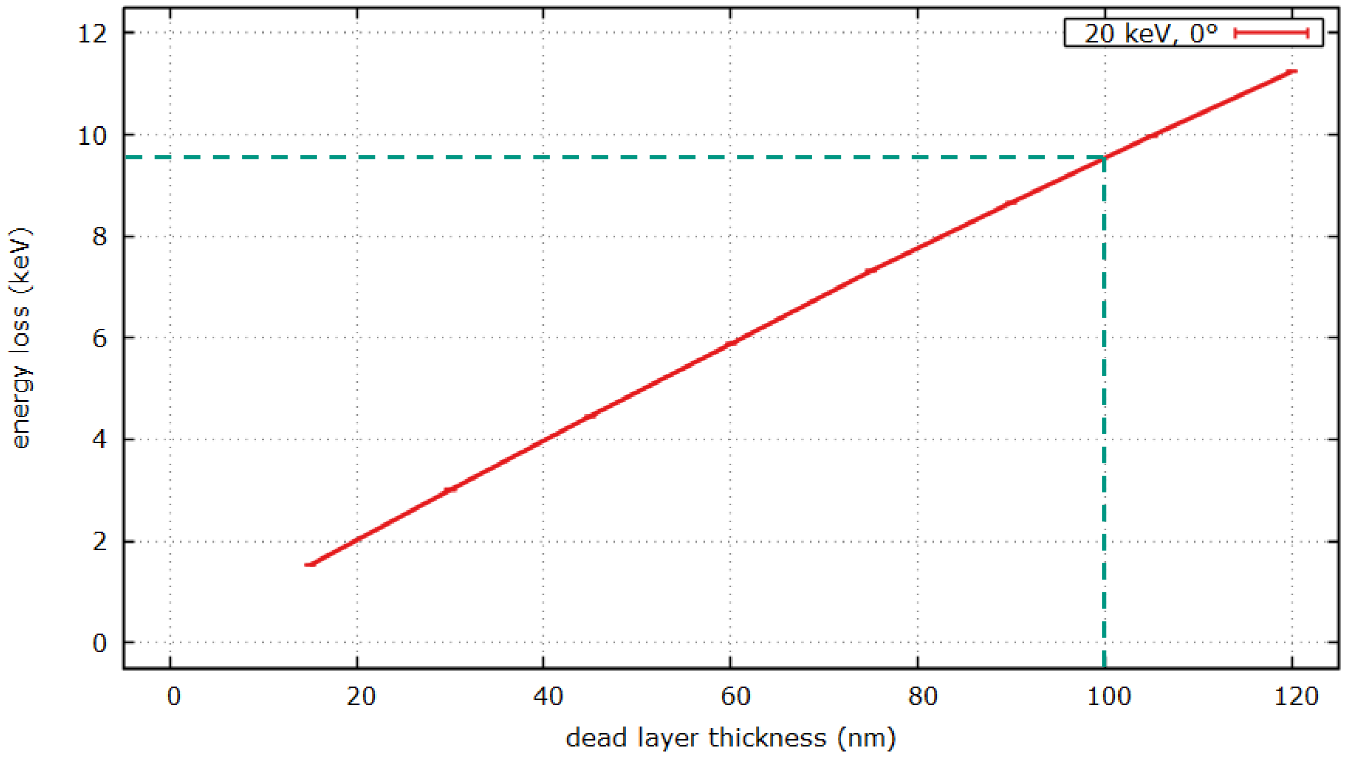
- Available in weeks / few months

Electrons vs. protons

KESS

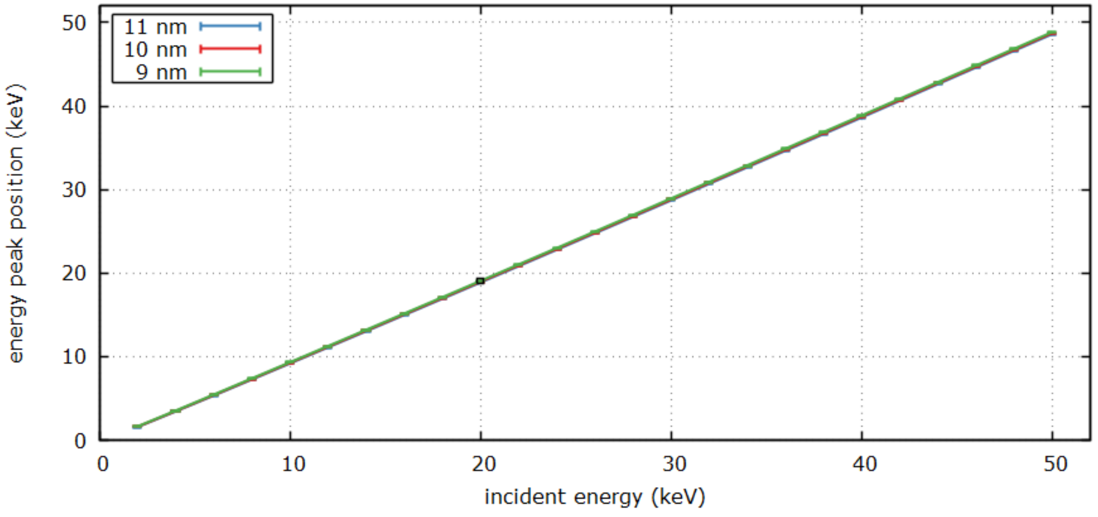


SRIM



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

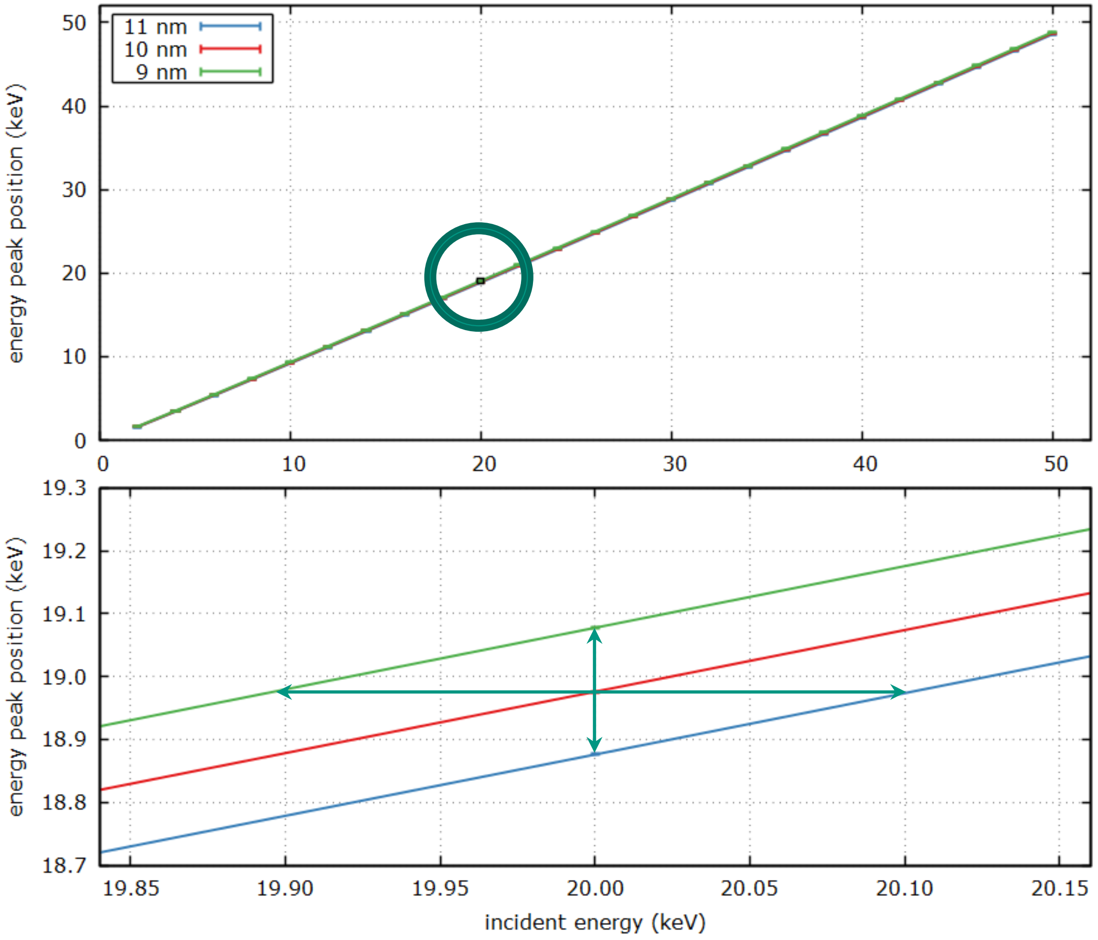
Protons – simulation



- d $= 10$ nm
  $E_{in} = 20$ keV
  $\theta = 0°$

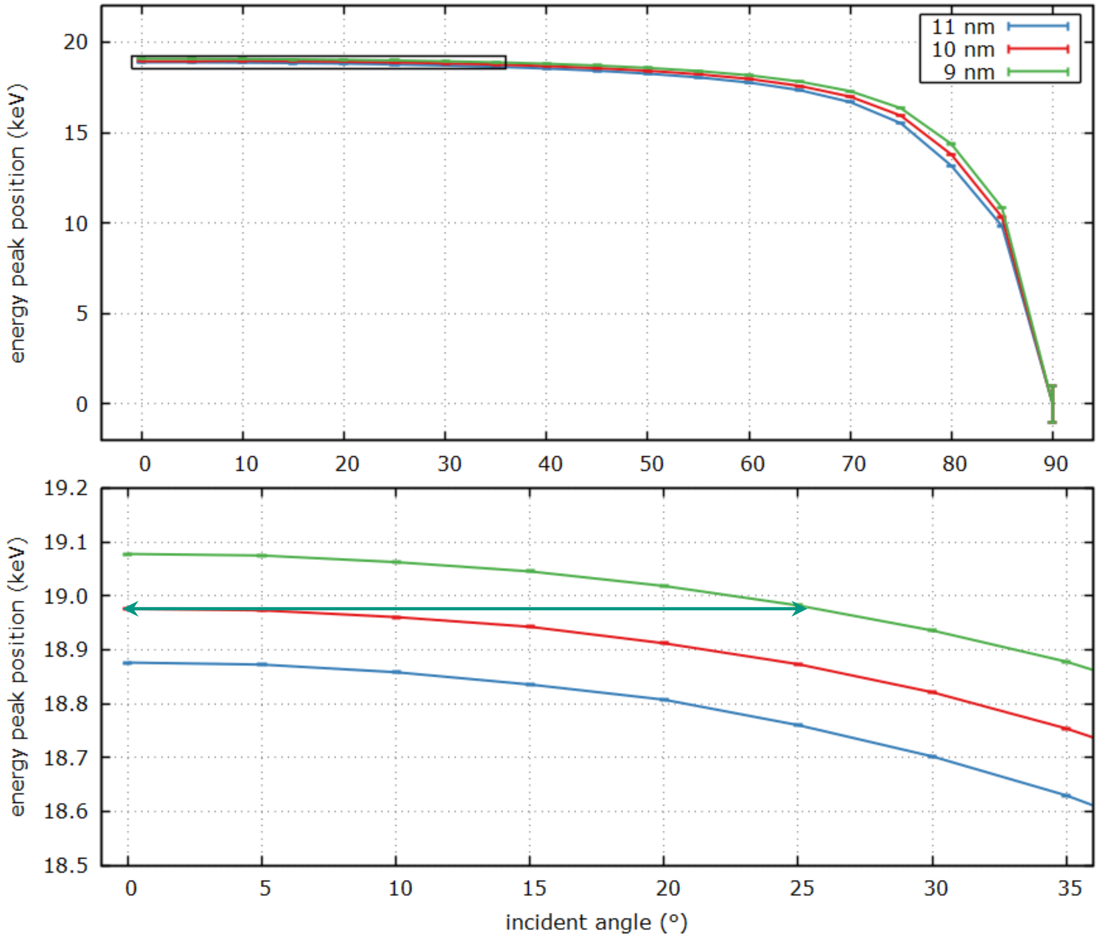
- d ± 1 nm (10 %)

Protons – simulation



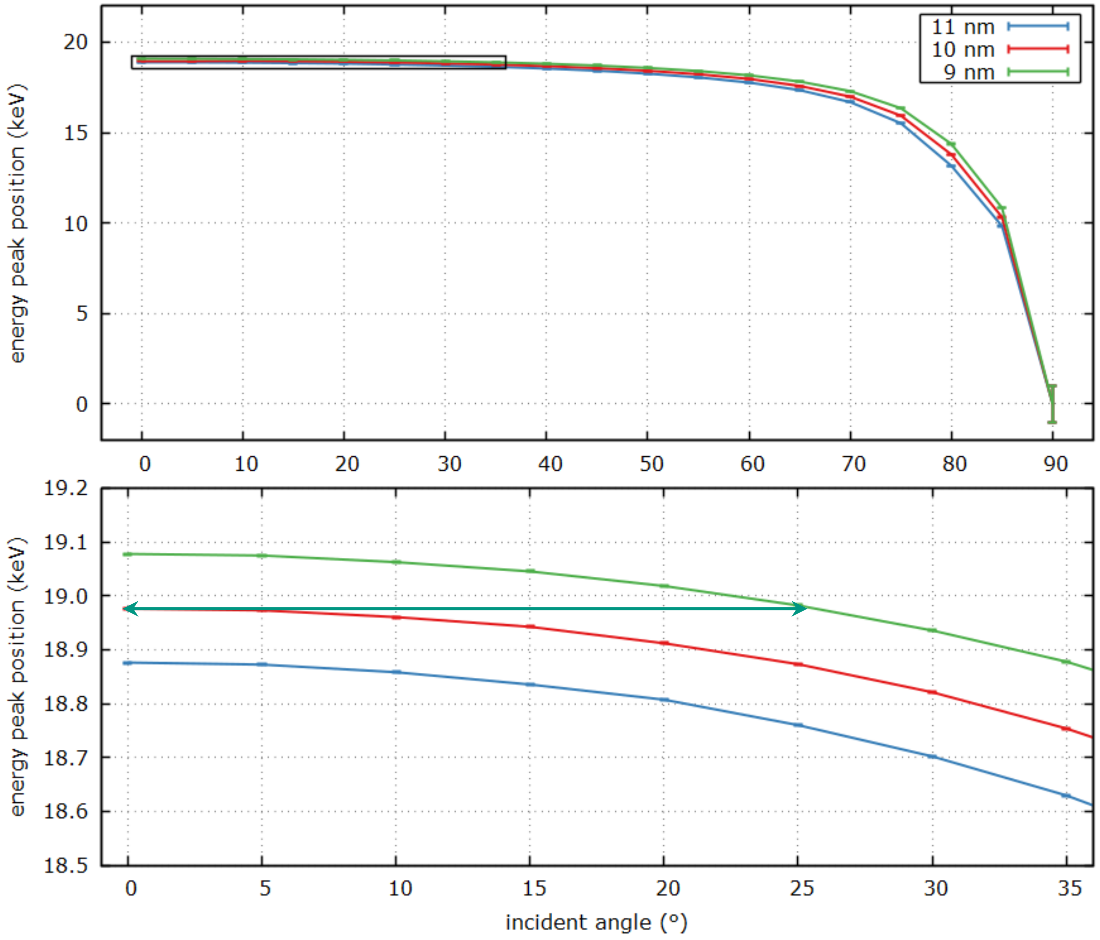
- d = 10 nm
  E_{in} = 20 keV
  θ = 0°
- d ± 1 nm (10 %)
- E_{in} ± 100 eV (0.5 %)
  E_{mess} ± 100 eV (0.5 %)

Protons – simulation



- d = 10 nm
  E_{in} = 20 keV
  θ = 0°
- d ± 1 nm (10 %)
- E_{in} ± 100 eV (0.5 %)
  E_{mess} ± 100 eV (0.5 %)
- θ ± 25°

Protons – simulation



- d = 10 nm
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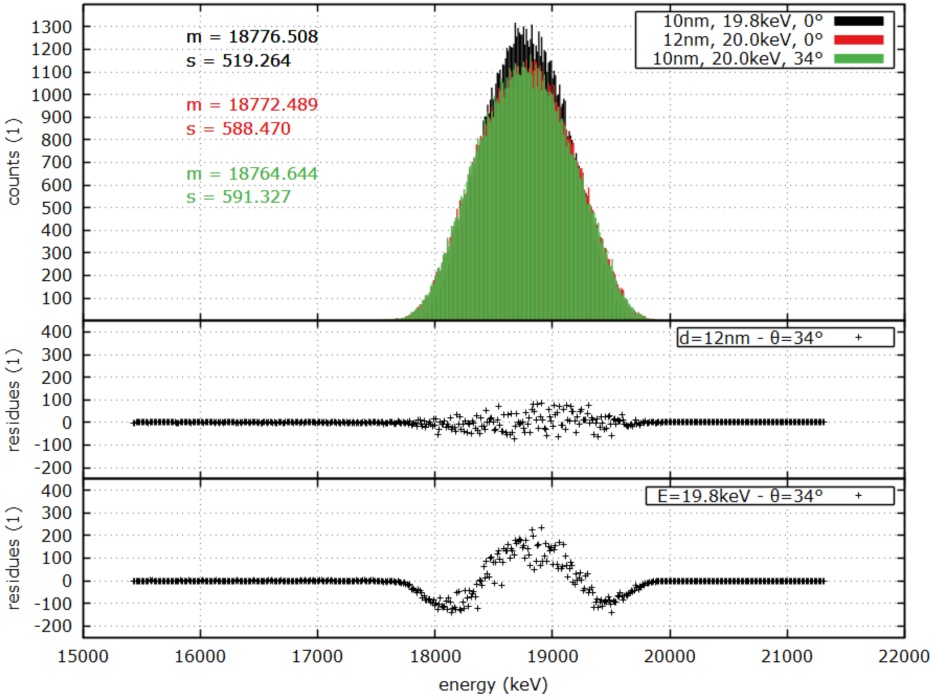
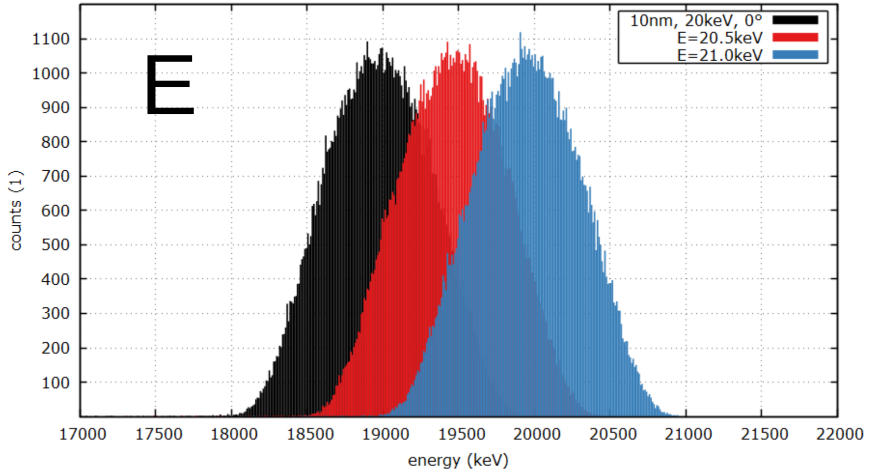
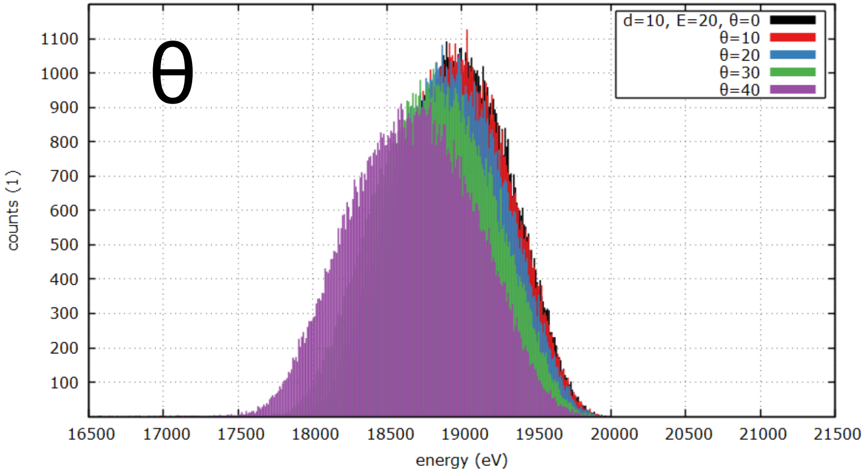
  θ = 0°
- d ± 1 nm (10 %)
- E_{in} ± 100 eV (0.5 %)
  E_{mess} ± 100 eV (0.5 %)
- θ ± 25°

Further discrimination analyzing peak shapes

Protons – uncertainty estimation

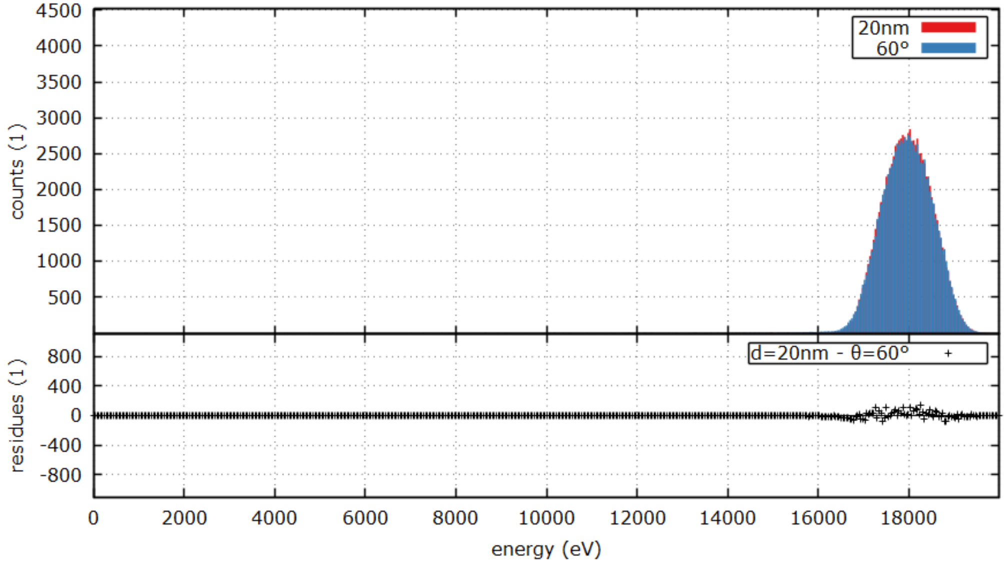


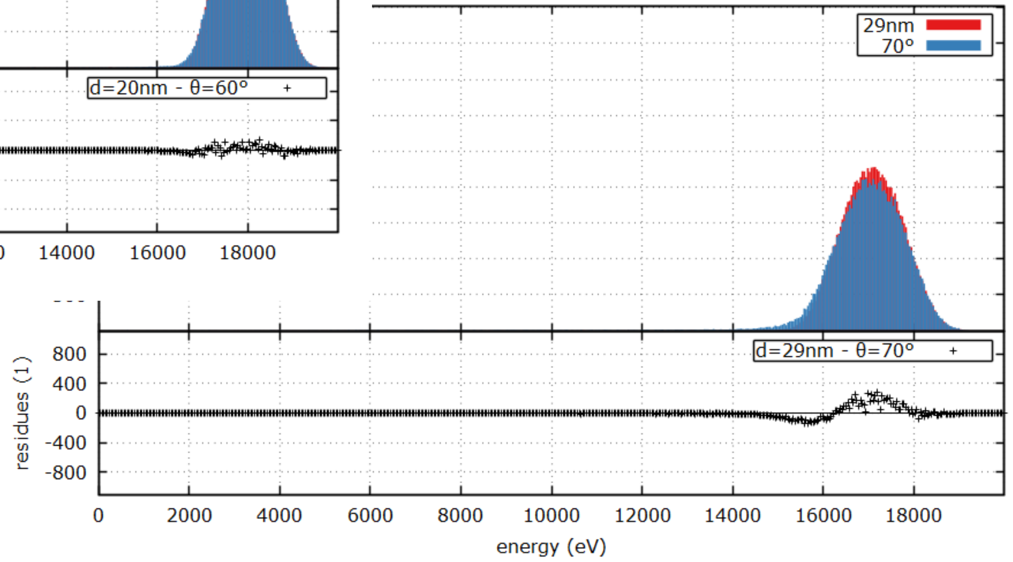


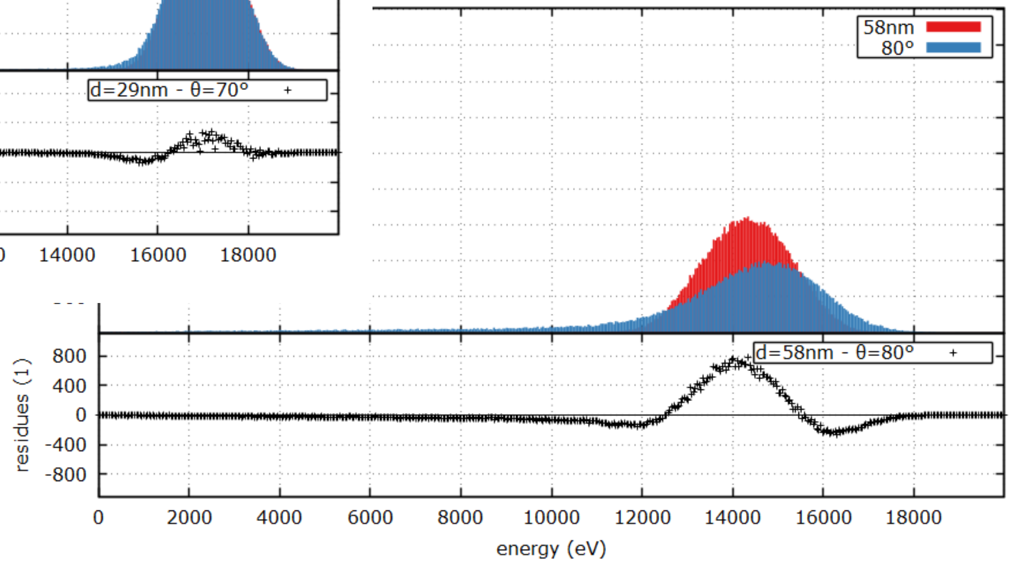


- Thicker dead layer or wider incident angle have stonger impact on peak width than incident energy
- This is only the energy loss in the sensitive area – not the measured signal

Tilted-beam method







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