Backscattering Characterization

BERTA - Backscattering-Electrons Relations Testing Apparatus

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für Physik

The Plan

Goal

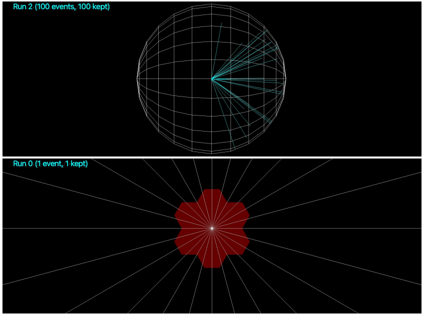
Investigation of electron backscattering and its impact on the sterile neutrino search with TRISTAN

- **Step 1:** Simulate backscattering with Geant4
- **Step 2:** Develop experimental setup
- **Step 3:** Take measurements + Analyse data
- **Step 4:** Compare measurements to simulations
- **Step 5:** Improve simulations
- **Step 6:** Extract backscattering coefficients for TRISTAN

Step 1: Geant4 Simulations

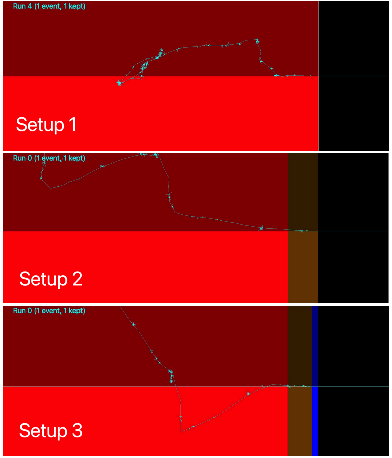
Geant4

- **Physics List:** G4EmStandardPhysicsSS (details see Geant4 - Guide For Physics Lists, Release 10.7, p.27)
- **Range Cut:** 10 nm
- **Energy Production Cut:** 10 eV
- **Basic Setup:**
  - World = Sphere ($R = 0.5$ m) filled with vacuum (G4-Galactic)
  - Point-like mono-energetic e^- source at (0,0,-10)cm



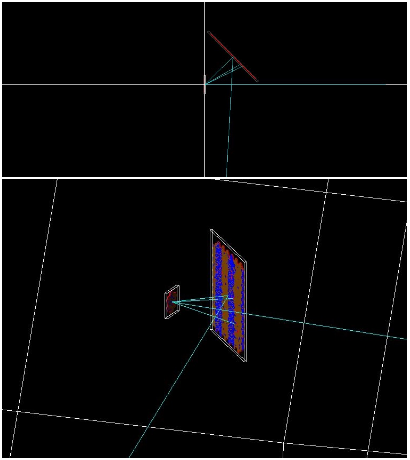
Setups

- **Setup 1 to 3:**
  - 1st detector = 7-Pixel SDD at (0,0,0) made of 7 polyhedras (d = 3 mm)
  - 2nd detector = World sphere as backscattering detector (save energy and position of leaving e^-)
- **Setup 1:** 450 µm silicon (G4-Si), fully sensitive
- **Setup 2:** Setup 1 including a 50 nm dead layer at entrance side
- **Setup 3:** Setup 2 including a 10 nm silicon dioxide (G4-Silicon-Dioxide) layer at entrance side

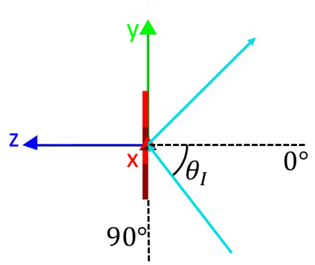


Setup 4 to x:

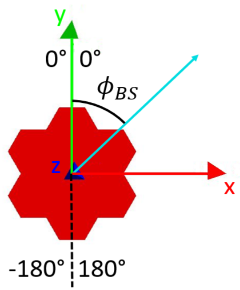
- 1st detector = 7-Pixel SDD made of 7 polyhedras (d = 3 mm)
- 2nd detector = 166-Pixel SDD made of 166 polyhedras (d = 3 mm) as backscattering detector
- 3rd detector = World sphere
- 1st and 2nd detector: 450 μm thickness , 50 nm dead layer and 10 nm silicon dioxide layer
- Still work in progress



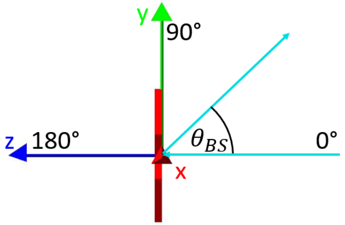
Incident angle Θ_{I}



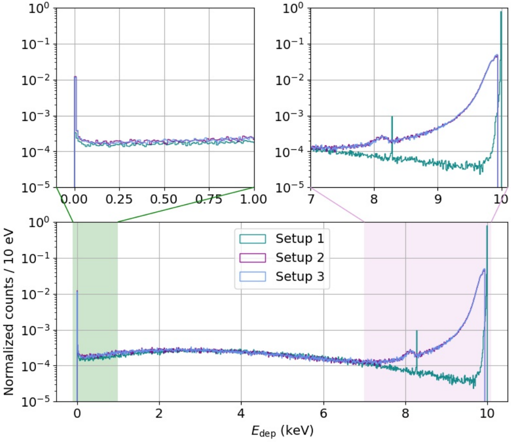
Azimuthal backscattering angle Φ_{BS}



Polar backscattering angle Θ_{BS}

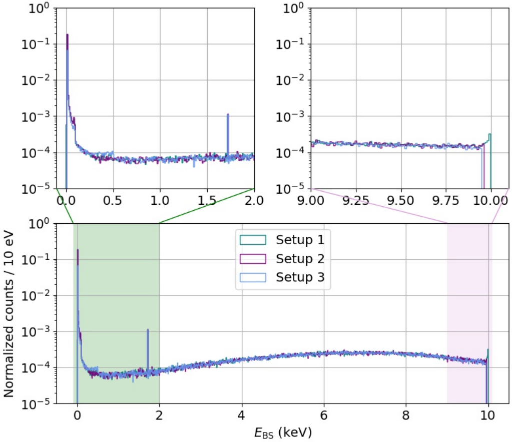


7-Pixel SDD Energy Spectrum



- Peak at $E_I = 10\,\mathrm{keV}$ (complete energy deposition of incoming e^- in SDD)
- Silicon escape peak at $E_I - 1.74\,\mathrm{keV}$
- Dead Layer $\rightarrow$ Smearing of peaks
  Reason: Incomplete charge collection
- Backscattering $\rightarrow$ Rising counts towards lower E_{dep}
  Reason: Incomplete energy deposition
- Silicon Dioxide Layer $\rightarrow$ No effect on spectrum shape

Backscattering Energy Spectrum



- Small peak at $E_I \hat{=}$ Elastic scat. peak
- Dead Layer shifts maximal E_{BS} to lower energies
  Reason: Probably related to Geant4 Production Cut (tbi)
- Plateau $\hat{=}$ Inelastic scat. continuum
- 'True' secondary e^- peak at $E_{BS} \leq 50\,\mathrm{eV}$
- At low energies: SiO2 Layer lowers amount of backscattered e^-
  Reason: Lower atomic number of O

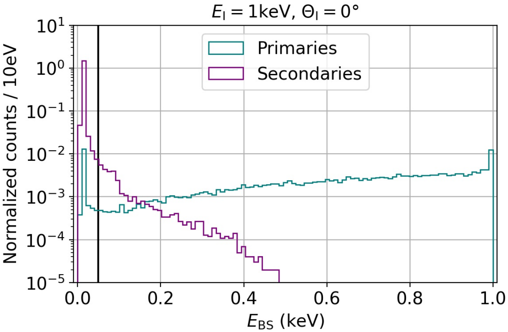
Backscattering Coefficient Definition

Primary backscattering coefficient:

$$\eta = \frac{N_{\mathrm{BS}}(E_{\mathrm{BS}} > 50\,\mathrm{eV})}{N_{\mathrm{I}}} \tag{1}$$

Secondary backscattering yield:

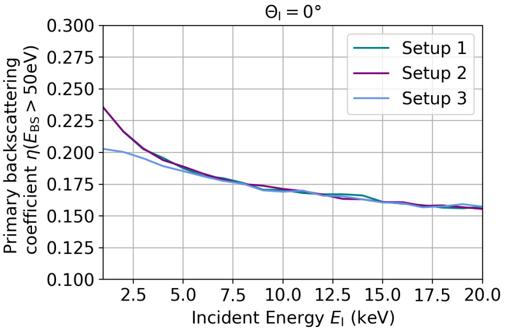
$$\delta = \frac{N_{\mathrm{BS}}(E_{\mathrm{BS}} < 50\,\mathrm{eV})}{N_{\mathrm{I}}} \tag{2}$$

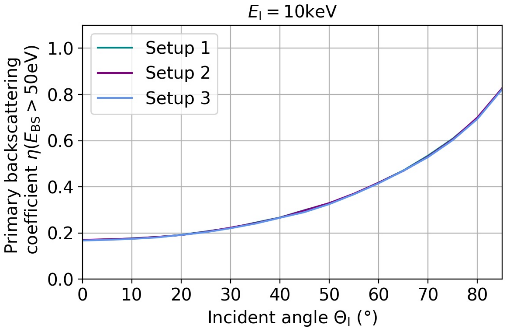


Experimental Motivation for threshold $E_{\mathrm{BS}} = 50\,\mathrm{eV}$:

Primary e^- of lower energy $\approx$ True secondary e^- of higher energy

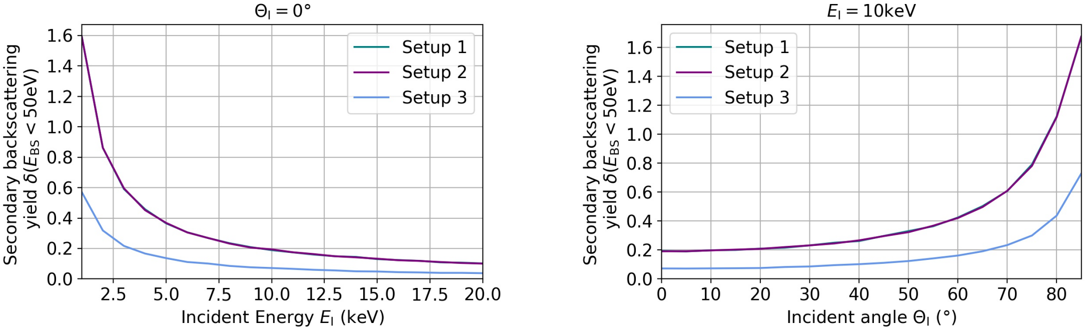
Primary backscattering coefficient





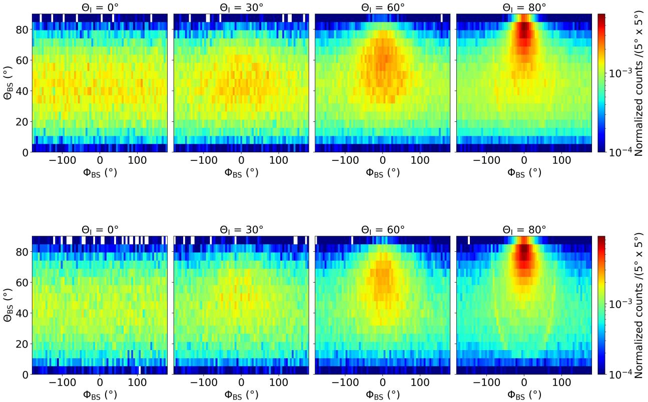
- η decreases for increasing E_I and increases for increasing Θ_I
- Only for low E_I the SiO2 layer leads to less backscattering of primaries

Secondary backscattering coefficient



- Same trends for δ like for η
- The Dead Layer does not affect backscattering (as expected)
- The SiO2 layer leads to less backscattering of secondaries (lower atomic number)

Spacial backscattering distribution



Setup 1

Setup 3

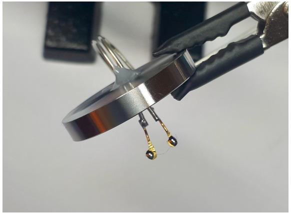
Ring-like → Cone-like

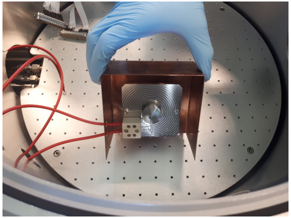
Simulation Improvement Options

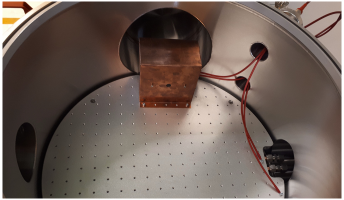
- **Detectors:** Implement energy resolution/noise, charge charing, etc. (alters the measured spectrum shape and count rate)
- **E-Gun:** Implement angular and energy spread of electron beam; Introduce acceleration field (influences E_{I} and Θ_{I})
- **Total Setup:** Include vacuum chamber and other hardware (produces further scattering processes); Implement Earth magnetic field (influences electron beam line)
- **DAQ:** Introduce dead time, pile up, etc. (alters the count rate)

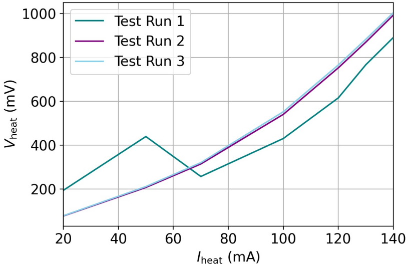
Step 2: Experimental Setup

BERTA - E-Gun

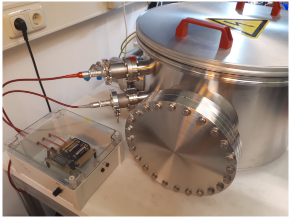




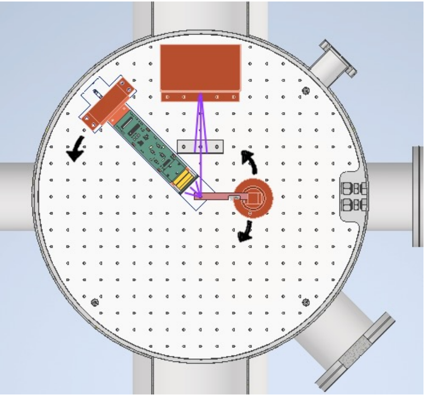


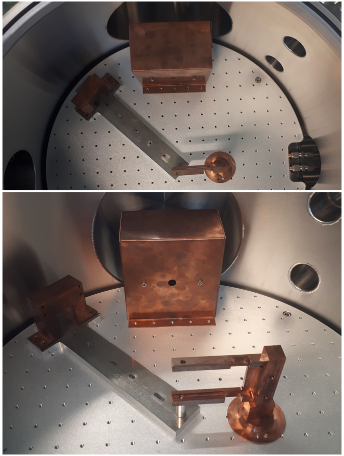


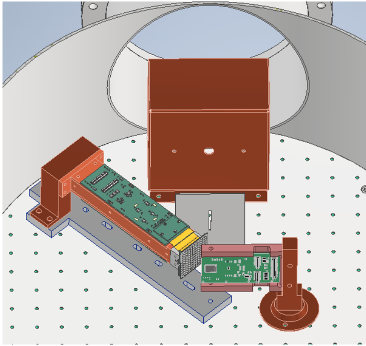
Test Run 1
Test Run 2
Test Run 3
V_{heat} (mV)
I_{heat} (mA)
1000
800
600
400
200
20
40
60
80
100
120
140



BERTA - In-Vacuum Setup (so far)

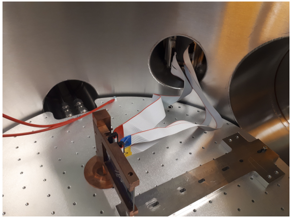


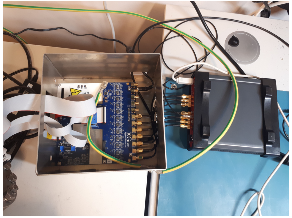




Next Steps

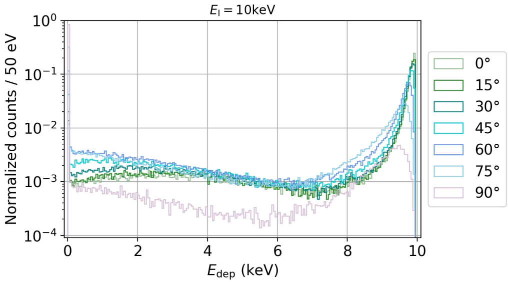
- Finish setting up the detectors and DAQ
- Find optimal DAQ setting and calibrate system with Fe-55
- Develop a measurement and analysis plan
- Start with Step 3: Take first measurement with $E_\mathrm{I} = 10\,\mathrm{keV}$ and $\Theta_\mathrm{I} = 0^\circ$ in vacuum

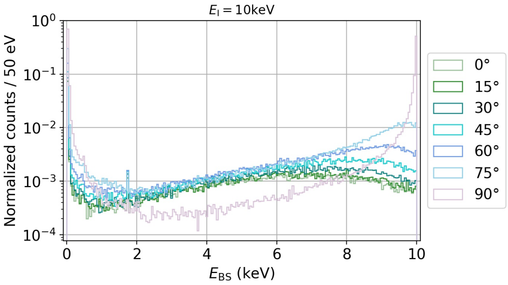




Backup Slides

Spectral Distortion - Setup 3

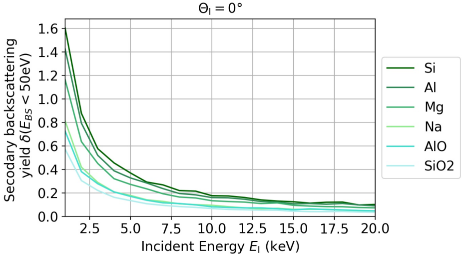




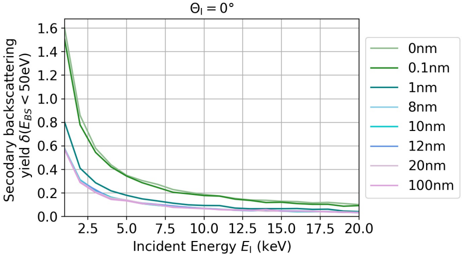
- 7-Pixel SDD energy deposition: For higher Θ_I less counts at high E_{dep} and more at low E_{dep}
- Backscattering energy distribution: For higher Θ_I more counts at high E_{BS} and low E_{BS}

Entrance Window Effects (Preliminary Results)

Vary Material



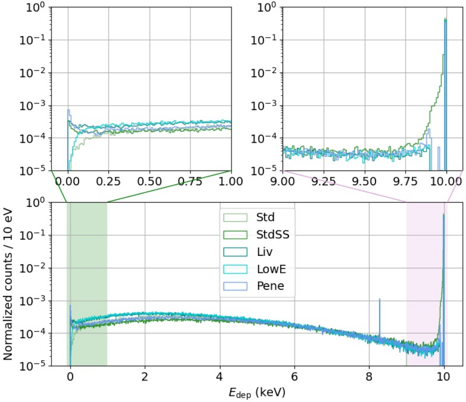
Vary Thickness



- The lower the average atomic number the lower δ; No effect on η observed
- The thicker the layer the lower δ; No more change of δ for thickness $> \mathcal{O}(10\,\text{nm})$; No effect on η observed
- Same behaviour for varying incident angles Θ_I

Compare Geant4 Physics Lists

7-Pixel SDD Energy Spectrum



Backscattering Energy Spectrum