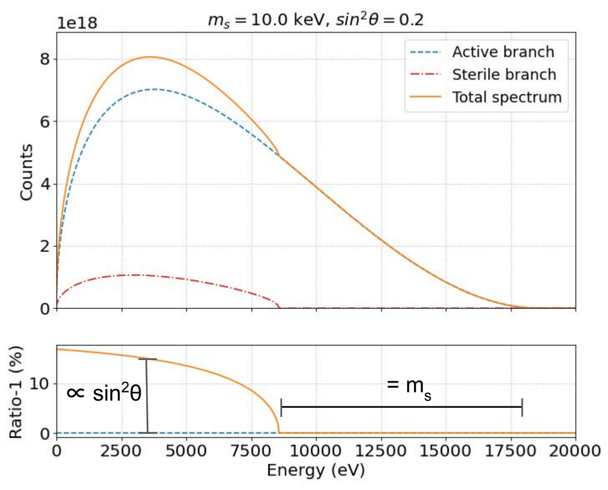
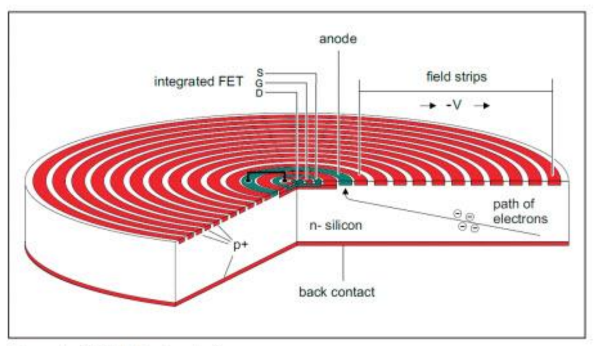
SDDs for high-rate and high-resolution electron spectroscopy

A. Nava, M. Biassoni, S. Pozzi, M. Carminati - 15th Pisa Meeting on Advanced Detectors

Sterile neutrino search with KATRIN

- KATRIN can search for keV sterile neutrinos by measuring the whole Tritium spectrum -> the signature is a kink [1]
- A high-statistics differential measurement is needed -> KATRIN detector has to be changed with a faster one that can provide a better energy resolution

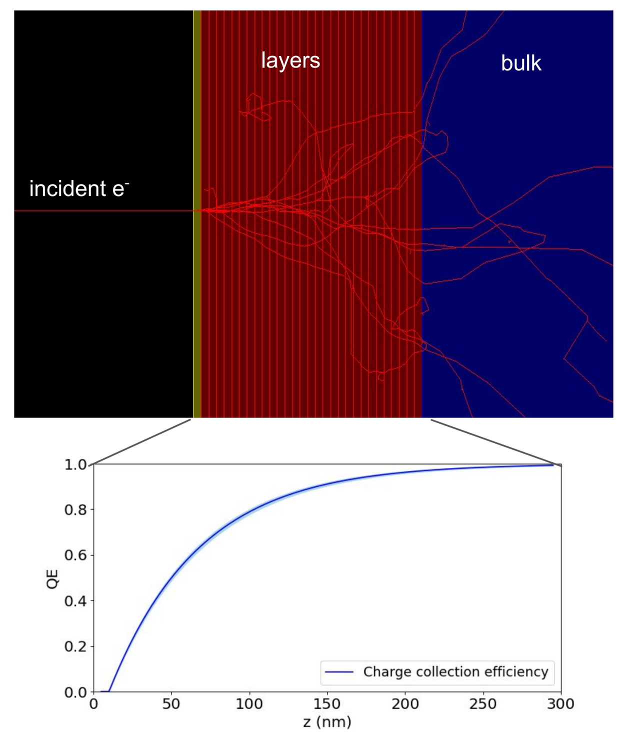




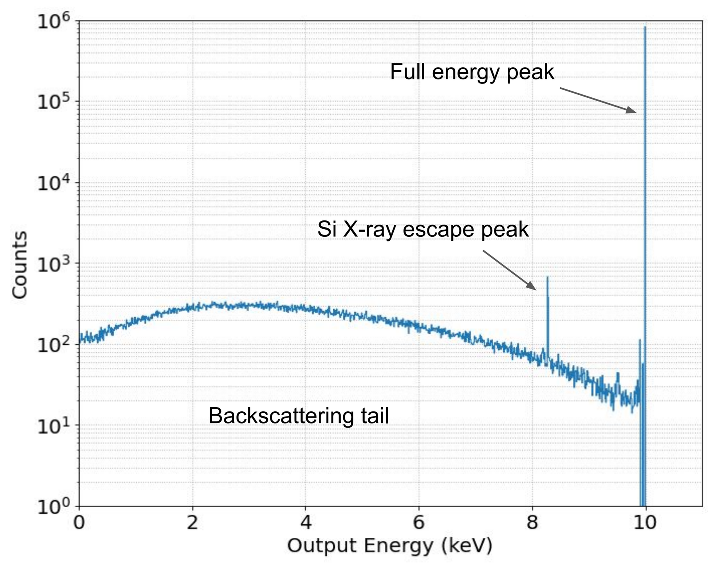
- Silicon Drift Detectors (SDDs) are an excellent choice, being characterized by a small anode capacitance, they present:
  - rise-times of the order of tens of ns -> high-rate measurements possible
  - energy resolution close to the Fano limit in Silicon [2]

Entrance window model

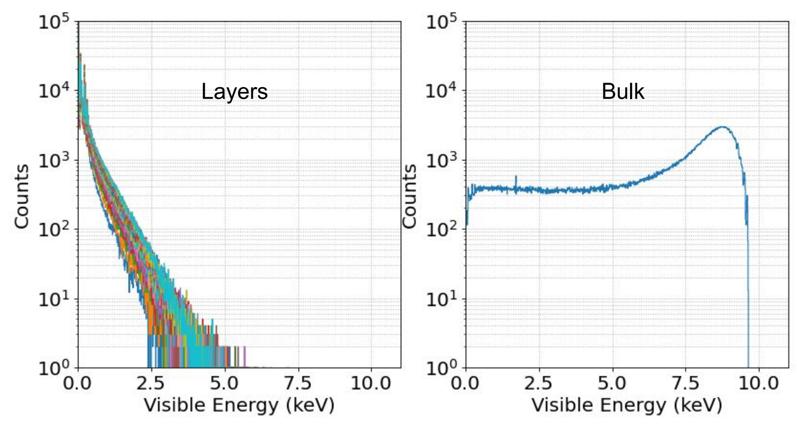
- Electron spectroscopy is challenging because electrons not always deposit all their energy in the detector:
  - they can be backscattered -> depends on the interaction with Silicon, simulated in Geant4
  - they lose energy in the dead layer
- The last point is treated empirically [3][4]:
  - 30 layers on top of the detector simulated in Geant4 (10 nm each)
  - the energy deposited in each layer is saved
  - the total energy is the weighted sum of the ones deposited in layers and bulk
  - weights are assigned assuming an exponential QE with respect to the depth



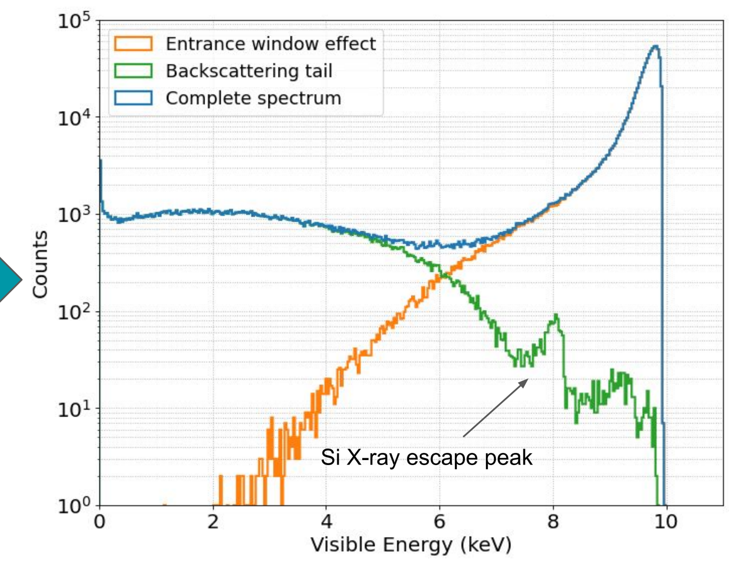
How to build the prediction



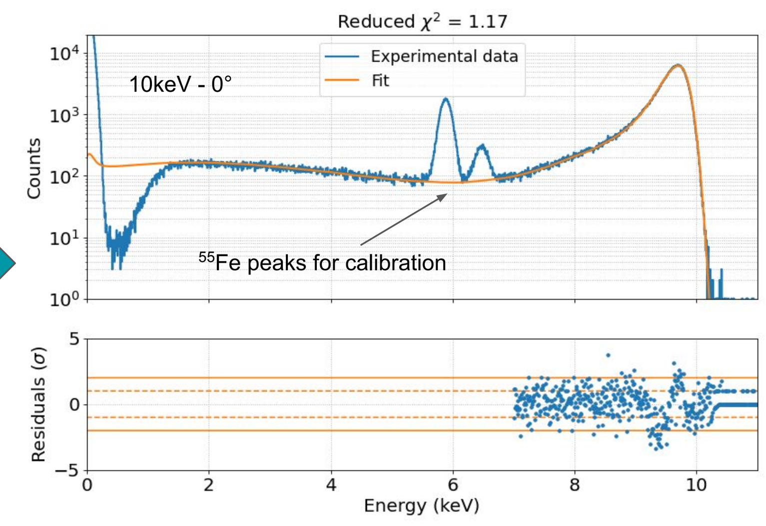
Raw spectrum: it includes backscattering electrons and escape X-rays



Separate the energy deposited in the 30 layers and in the bulk



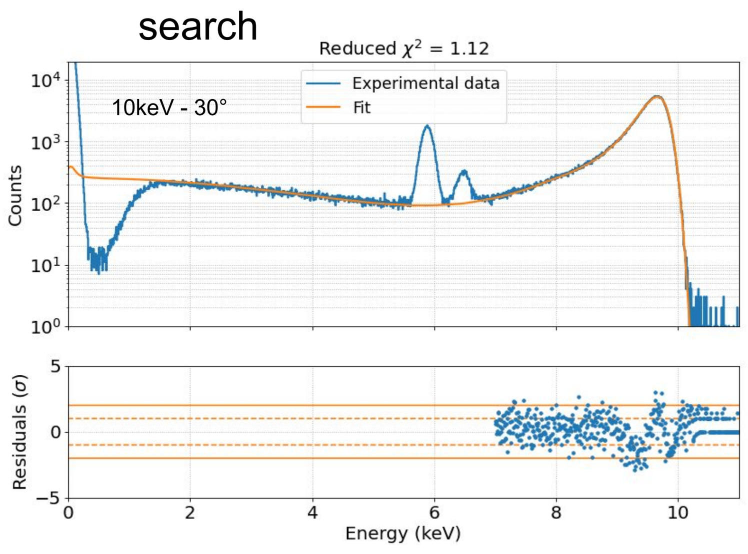
Apply weights to the energy deposited in the layers and sum up to obtain the total visible energy

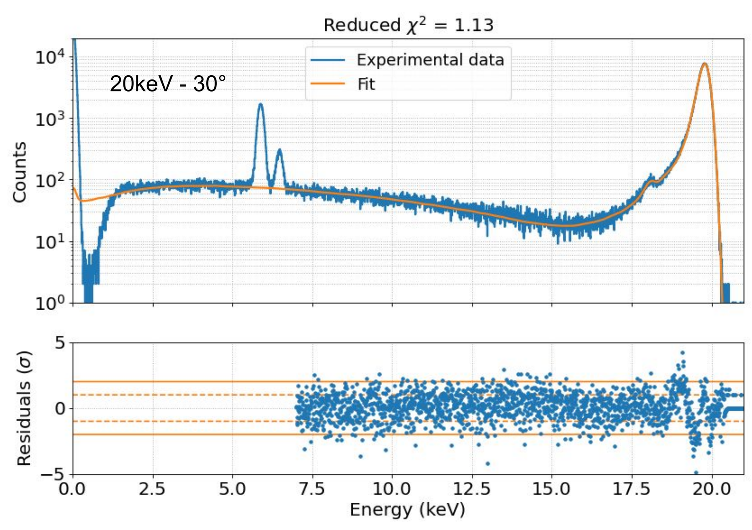


Apply energy resolution and compare with data

Comparison with SEM data

- Monochromatic and collimated electrons from a Scanning Electron Microscope (SEM) -> different energies and angles
- Good agreement between data and simulation found for all the combinations
- A reliable model for the electron response is mandatory for the sterile neutrino search

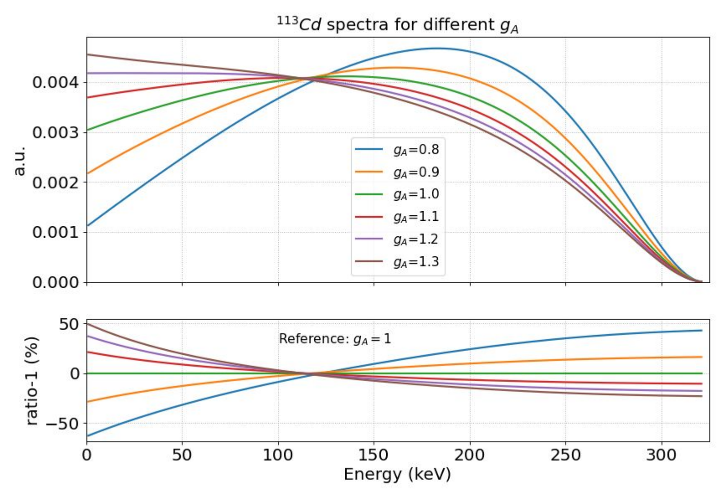


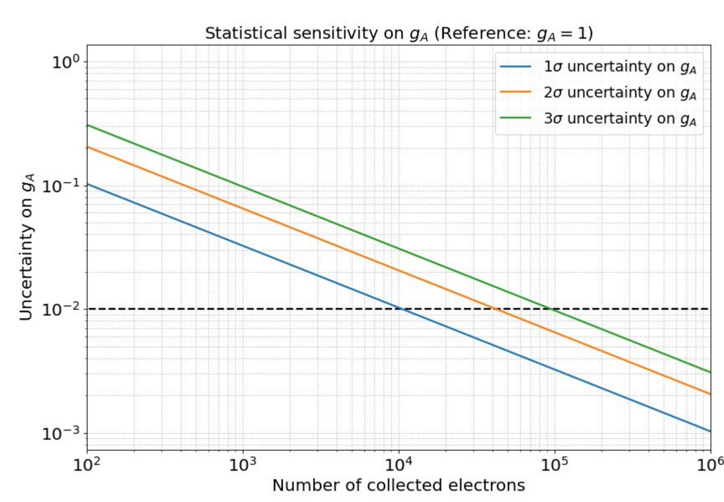


see poster "*The TRISTAN Detection Module: a 166-Pixel Monolithic SDD Array for Beta Spectroscopy*" by C. Fiorini for details about the current status of the TRISTAN detector

Forbidden β spectra and g_A

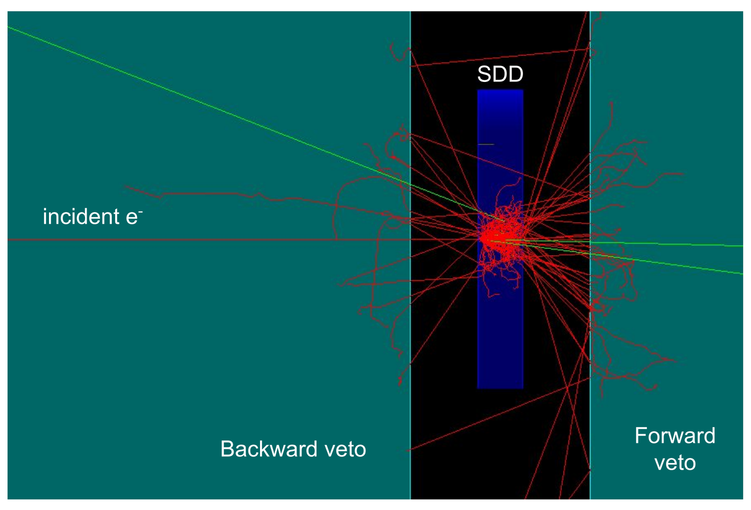
- Forbidden β spectra description depends strongly on the nuclear model and on g_A
- Recent measurements found out a g_A quenching for some isotopes [5]
- Up to 50% differences in β shape assuming different g_A (for ^{113}Cd)



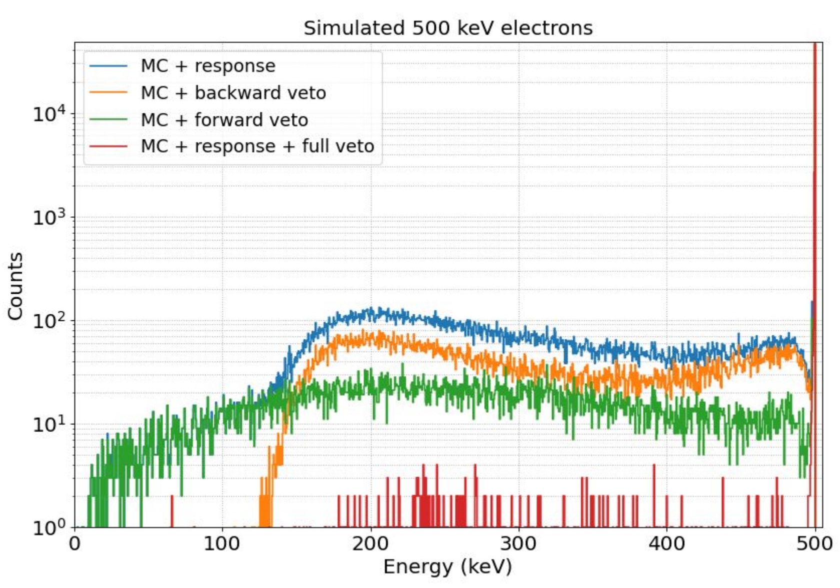


- With 10^4 collected electrons a statistical uncertainty on g_A compatible with calorimetric measurements [5] can be achieved
- A quasi-monochromatic response function is needed to reach this level

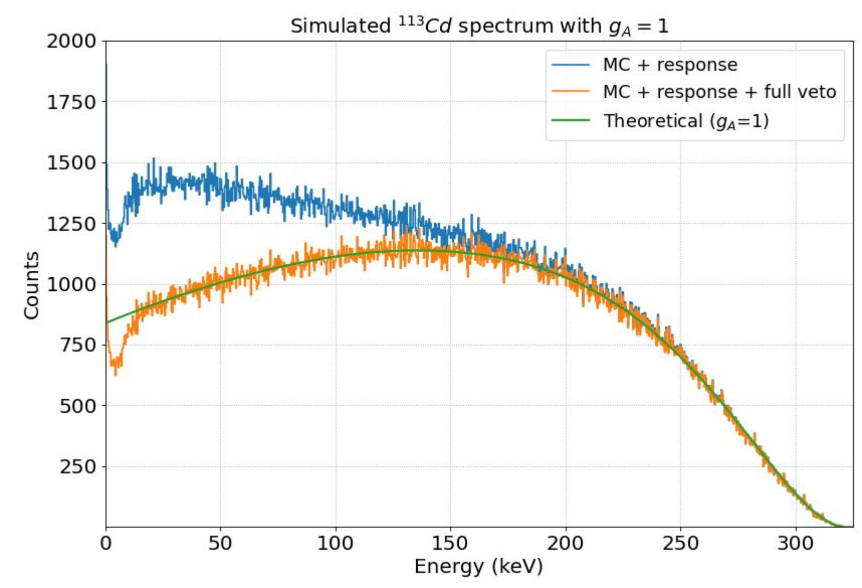
SDD based spectrometer to measure β spectra



- Geant4 simulation of an SDD and a veto system made by fast scintillators [6]
- Higher energies than previous study, electrons can be backscattered or pass through the SDD, but are vetoed



- 500 keV electrons simulated, a 10 keV threshold is assumed for scintillators
- With a full veto the energy response is quasi-monochromatic -> reduced systematics



- ^{113}Cd simulated, enabling full veto the spectrum shape is compatible with the theoretical one
- Using this standard and flexible setup g_A can be determined precisely with a few-days measurement

[1] Susanne Mertens et al. "*A novel detector system for KATRIN to search for keV-scale sterile neutrinos*". In: Journal of Physics G: Nuclear and Particle Physics 46.6 (May 2019)
[2] Matteo Gugiatti et al. "*Characterisation of a silicon drift detector for high-resolution electron spectroscopy*". In: Nuclear Instruments and Methods in Physics Research
[3] Biassoni M. *et al* 2021 "*Electron spectrometry with Silicon drift detectors: a GEANT4 based method for detector response reconstruction*" *Eur. Phys. J. Plus* **136** 125
[4] A. Nava *et al* 2021 "*A Geant4-based model for the TRISTAN detector*". *J. Phys.: Conf. Ser.* **2156** 012177
[5] Lucas Bodenstein-Dresler et al. "*Quenching of gA deduced from the β-spectrum shape of 113 Cd measured with the COBRA experiment*". In: Physics Letters B 800 (2020)
[6] Biassoni M. et al. "*A novel application of solid state detectors for high precision, low systematics measurement of beta decay energy spectra of interest for neutrino and nuclear physics*". arXiv:1905.12087 [physics.ins-det]

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