SDDs for the measurement of forbidden β spectra of interest to astroparticle physics

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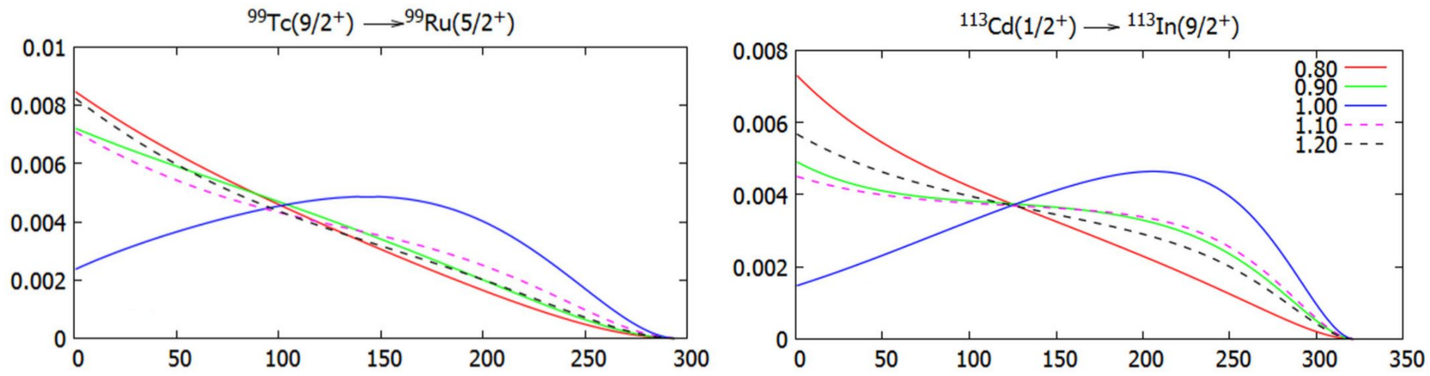
The importance of forbidden β spectra measurements

- **nuclear calculations are key inputs** in many fields in astroparticle physics:
  - $0\nu\beta\beta$ → Nuclear Matrix Elements and g_A
  - reactor oscillation → anti-neutrino spectrum
  - Dark Matter → shape of low-energy β spectra
- Different nuclear models give **different predictions**!
- the **shapes of forbidden non-unique β spectra** are sensitive to details in nuclear calculations (g_A quenching …) [1]
- measurements of several spectra are needed!



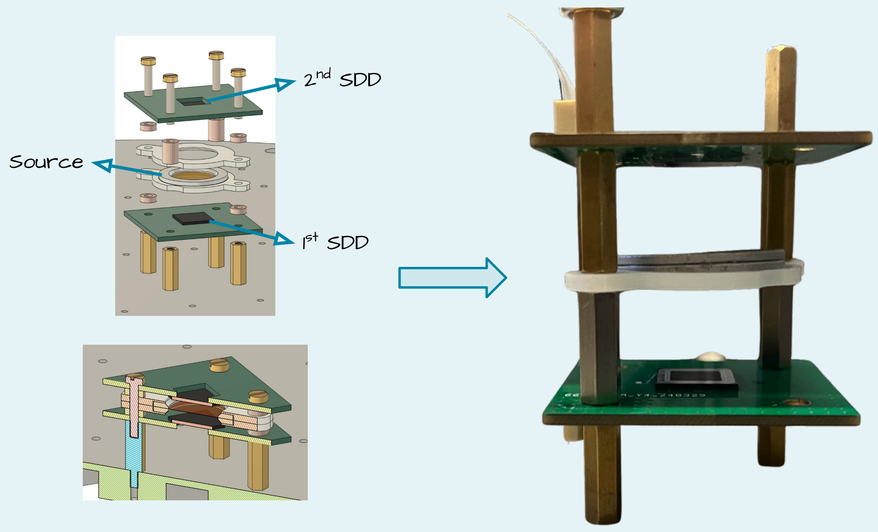
Predicted energy spectra of ^{99}Tc and ^{113}Cd forbidden β decays for different g_A values

The ASPECT-BET project

- the idea of **ASPECT-BET** [2] is to use Silicon Drift Detectors (**SDDs**) → low energy threshold, very good energy resolution, very good linearity
- usually used for X-ray measurements, but already applied to electron spectroscopy in the context of the KATRIN-TRISTAN experiment [3]
- main challenge: reconstruct partial energy depositions in the SDD → **MC simulations** [4]

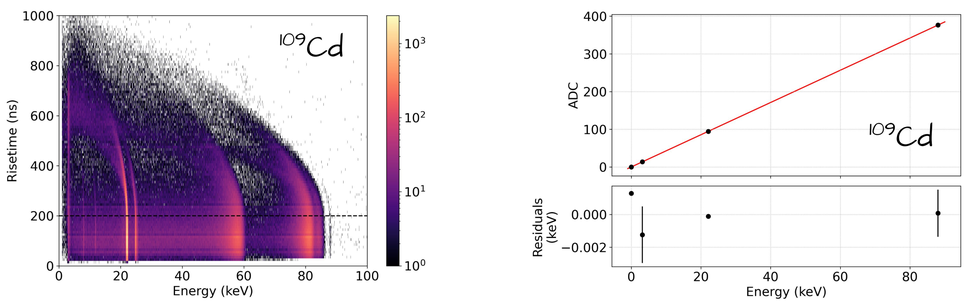
Detector concept

thin entrance window (O (10 nm)) → minimize energy loss
thick SDD (1 mm) + custom electronics → energy range up to 1 MeV
large active area (64 mm^2) → minimize border effects
sandwich configuration → reject backscattering (quasi-4π)
source deposited on an SDD → minimize self-absorption

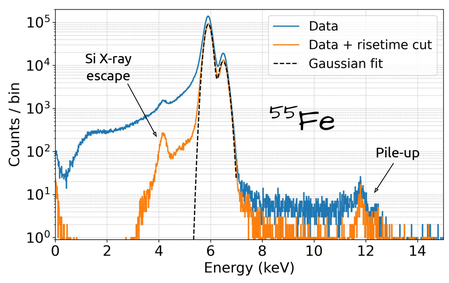


Detector fully assembled, but here only results from single SDD analysis are presented

Detector performance



- **Rise time cut** @ 200 ns to reject border events (partial energy reconstruction)
- calibration using ^{109}Cd X-rays and γ → **excellent linearity**



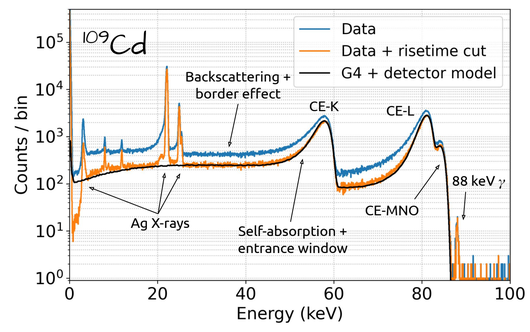
- **energy threshold < 2 keV**
- FWHM ~ 250 eV @ 5.9 keV (T ~ -10 °C)
- clean spectrum with gaussian peaks after rise time cut

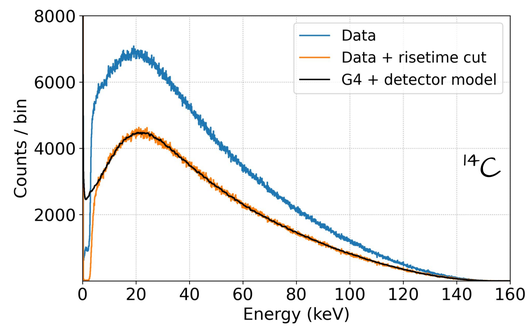
Validation with commercial electron sources

Analysis chain

- data processing including rise time cut
- Geant4 MC electron simulations with Penelope for low-energy EM physics
- Detector response added following procedure described in [5]
- χ^2 minimization with free calibration parameters

- **all the structures are well reproduced** both for monochromatic and β electrons!





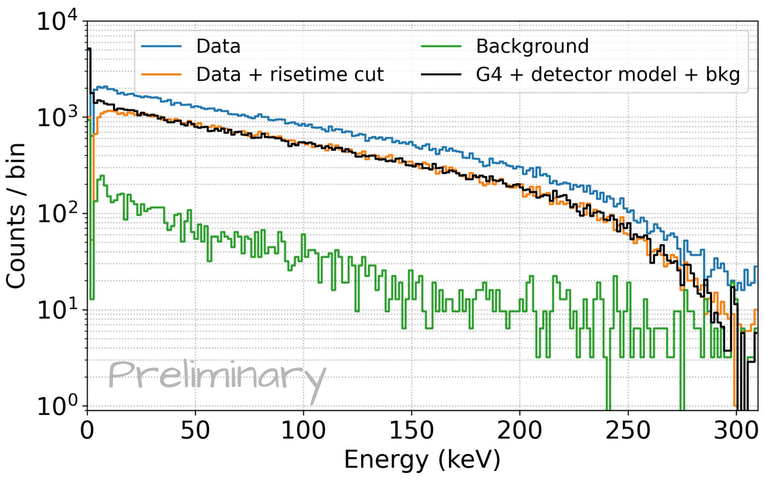
Measurement of the ^{99}Tc forbidden β spectrum

Deposition of NH_4TcO_4 solution on Silicon substrate → custom source with 150 Bq

- 100% B.R. for **2nd non-unique forbidden β decay** → Q-value = 297.5 keV
- simulation using as input for Geant4 the spectrum predicted by the **Realistic Shell Model** [6] → good agreement

Outlook

- systematics study of entrance window and border effects
- preparation of a new thinner ^{99}Tc source → freeze-drying technique
- high-statistics measurement + comparison with nuclear predictions and other data [7]



First ever β spectrum up to 300 keV measured using SDDs!

[1] Kostensalo, Joel, Mikko Haaranen, and Jouni Suhonen. *"Electron spectra in forbidden β decays and the quenching of the weak axial-vector coupling constant gA."* in: Physical Review C 95.4 (2017): 044313.
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[3] S. 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)
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[5] A. Nava *et al.* *"Silicon Drift Detectors for the Measurement and Reconstruction of Beta Spectra"*. In: Sensors 2024
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