Radioactivity-induced background electrons in the KATRIN spectrometers

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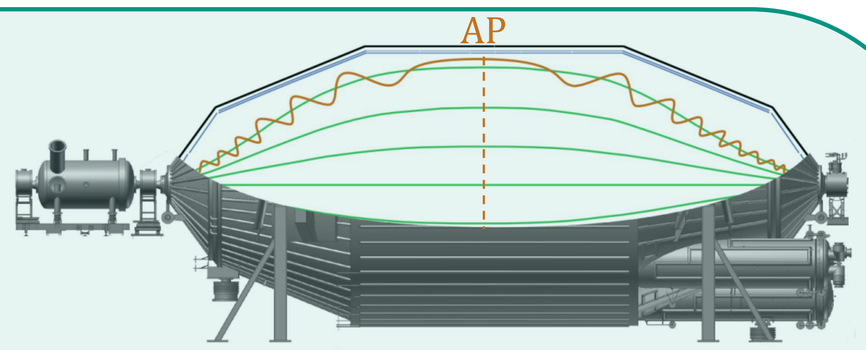
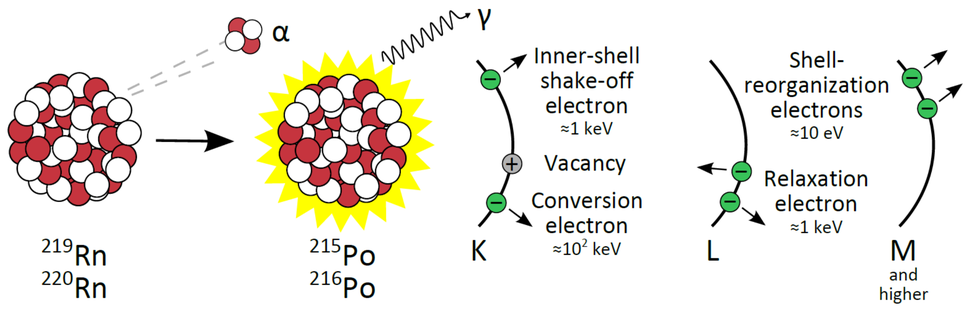
- Spectrometers work as high-pass filters and are operated with ultra-high vacuum condition
  - MAC-E (magnetic adiabatic collimation with electrostatic filter)
  - Equipped with NEG (non-evaporable getter) pumps for UHV
- Signal electrons are decelerated until they reach the analysing plane (AP) – nearly no energy
  - Background electrons generated in the volume mimic signal electrons
  - Electrons due to radioactive decays within volume or at vessel surface



- The KATRIN sensitivity is limited by an unexpectedly high background which exceeds the design value by a factor of 50
- The main contributions are due to Radon (Rn) decays in residual gas and contamination of radioactive Lead (Pb)

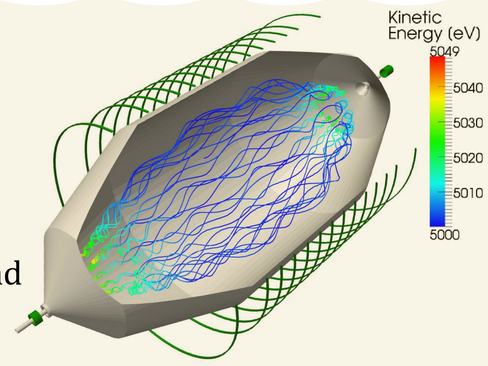
Radon-induced background

- ^{219}Rn in residual gas from the NEG pumps and the walls decays within flux-tube volume
- Electrons from several eV to $O(100\ \text{keV})$



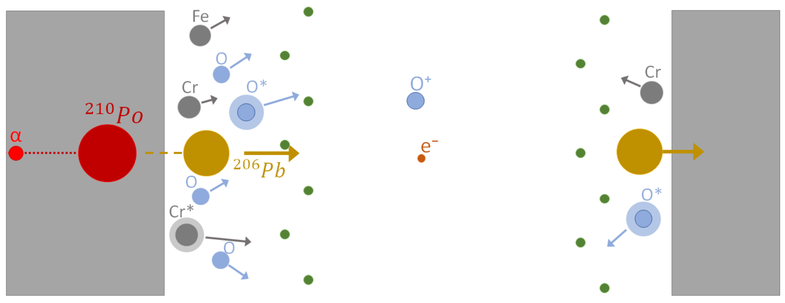
- keV electrons get magnetically stored over several hours
- Secondary e^- due to residual gas ionisation by trapped e^-

- Strong pressure dependence
- Increasing rate to smaller radii
- Trapping simulation with Kassiopeia
- Background e^- up to $O(\text{eV})$
- $O(\text{keV})$ conversion electrons lead to hundred of secondaries



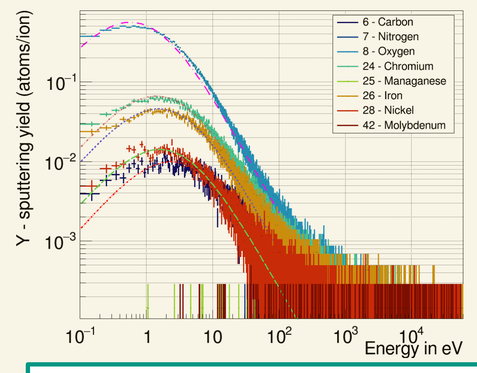
Rydberg-induced background

- Decay of ^{210}Pb ($t_{1/2} \sim 22$ y) leads to sputtered atoms from the vessel wall, some of which are in excited states

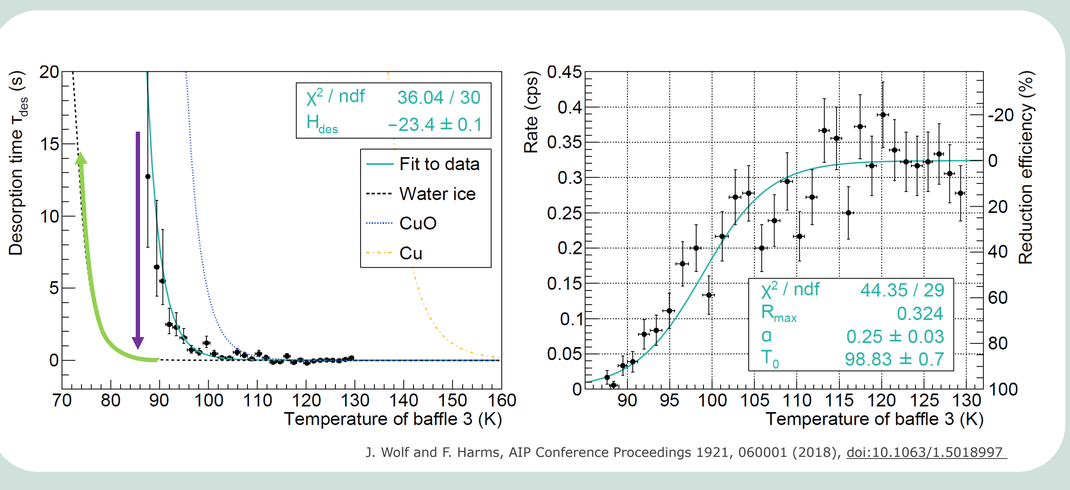


- Ionisation through blackbody radiation or autoionisation
- Homogeneous background distribution requires long enough lifetimes of the excited states
- Survival probability $\propto \exp(-r/\chi)$, $\chi = v \cdot \tau$, $\tau \sim 10^{-3} s$

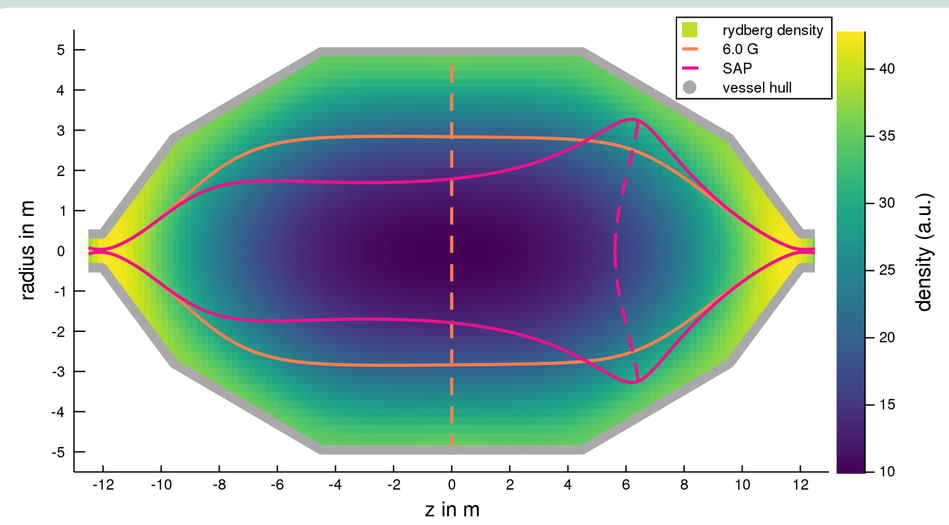
- Strong volume dependence
- Temperature dependence
- Increasing rate to higher radii
- e^- of sub-eV energy
- SRIM simulations for characteristics of sputtered atoms, like E and v



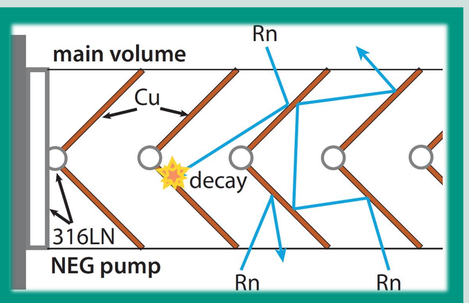
COUNTERMEASURES



J. Wolf and F. Harms, AIP Conference Proceedings 1921, 060001 (2018), doi:10.1063/1.5018997



❖ Cold baffles before NEG pumps as radon retention system
  ❖ It strongly depends on the baffle temperature
  ❖ But adsorbed water-ice or oxidation of copper surface decreases efficiency (purple arrow)
❖ Sub-cooling compressor under construction
  ❖ Increases desorption time (green arrow)
  → Baffle temperature below 77 K
❖ EM pulsing to prevent trapping of electrons



❖ Rydberg density simulation to investigate the origin of the contribution by excited atoms
❖ Bake-Out of spectrometer to 200°C
  ❖ Reduces surface-adsorbed atoms → Less sputtered atoms
  ❖ Background reduction by a factor of 1.7
❖ Reduce the flux-tube volume
  ❖ Higher magnetic field in AP
  ❖ Shifted analysing plane (SAP) → see poster by A. Lokhov
    ❖ Functionality successfully tested
    ❖ Background significantly improved by a factor of 2.3
    ❖ But less energy resolution which can be optimised