Background processes in the KATRIN experiment

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Introduction

The **KA**rlsruhe **TRI**tium **N**eutrino (**KATRIN**) experiment has the objective to determine the neutrino mass with an unprecedented sensitivity of better than 0.3 eV (90% CL) using β-decay spectroscopy of molecular tritium. KATRIN completed its neutrino mass measurement campaigns at the end of 2025 and has improved the upper bound on the effective electron-neutrino mass to **0.45 eV** (90% CL) based on data collected before July 2021.

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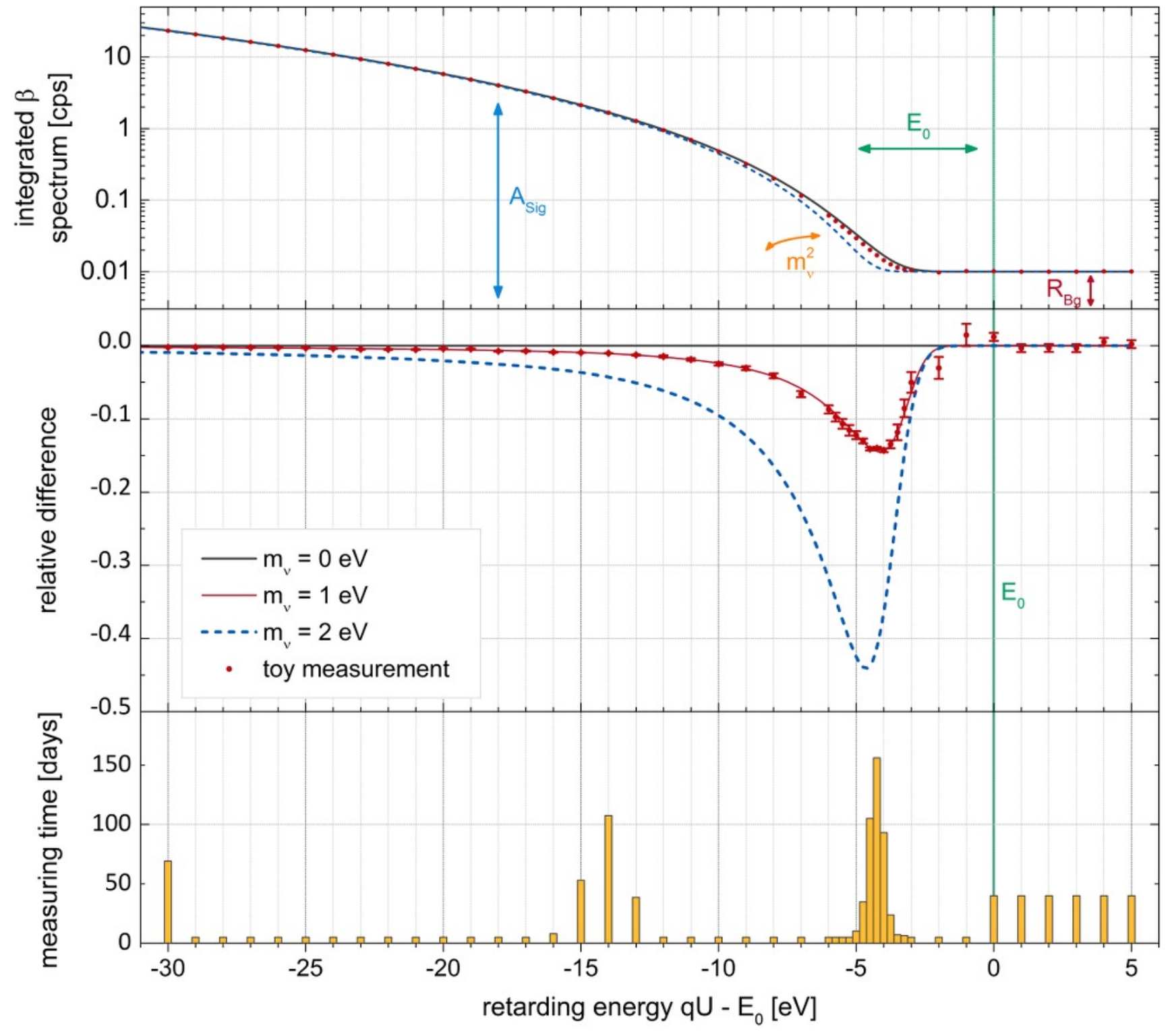
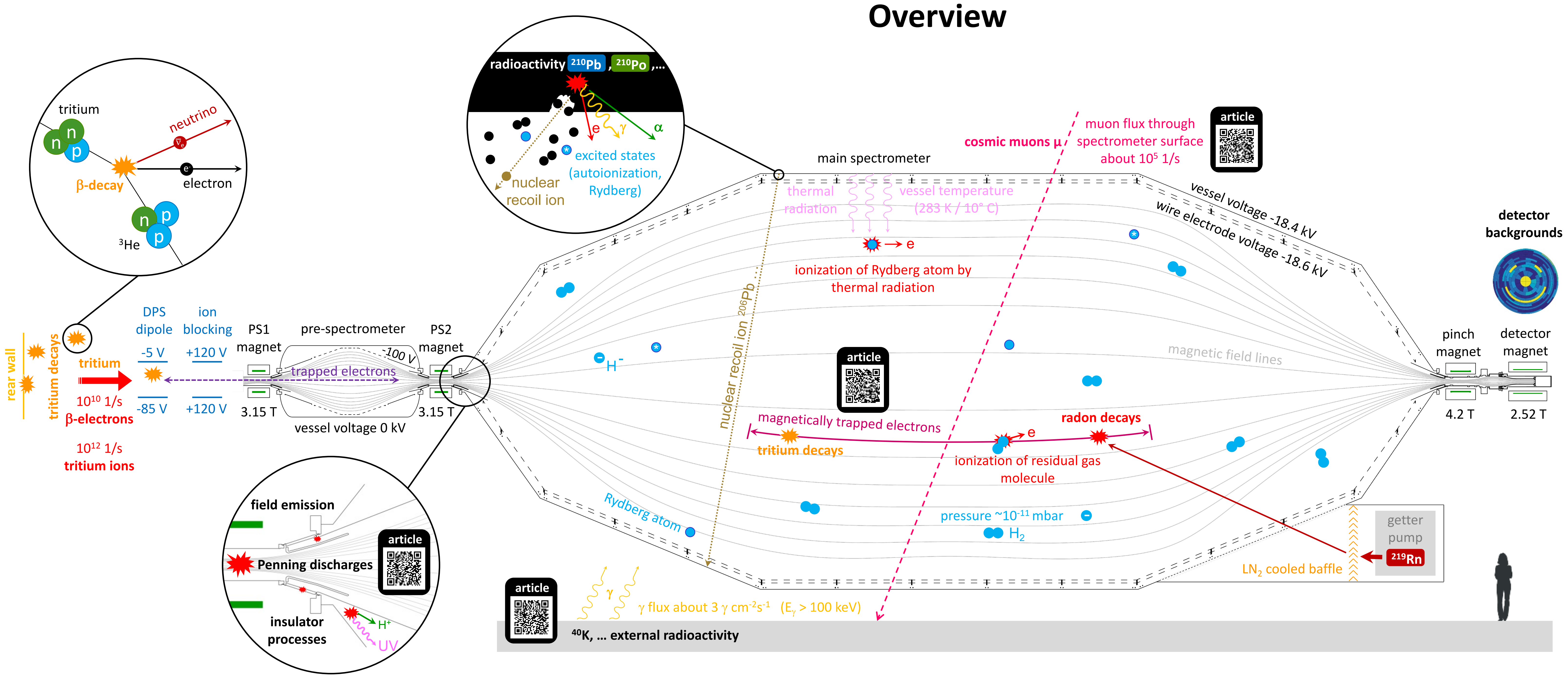
A major limiting factor for the KATRIN sensitivity is a background level which is an order of magnitude higher than the original specification of 0.01 counts per second (cps).

- KATRIN measures the integrated β-spectrum close to the tritium endpoint E_0.
- The influence of m_ν is most pronounced a few eV below E_0.
- The background obscures the region of the spectrum most sensitive to neutrino mass.
- Various different background processes contribute to the KATRIN background.
- Most of them are efficiently suppressed with passive or active methods.

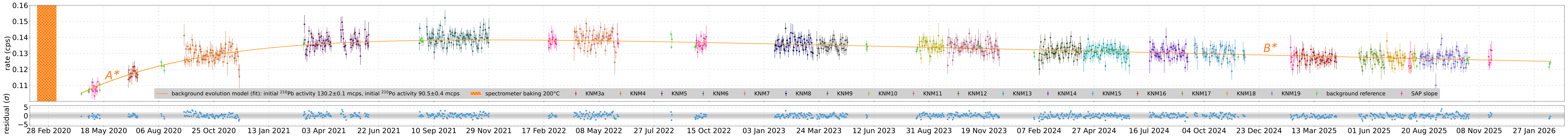
Neutrino mass measurement and background



Overview



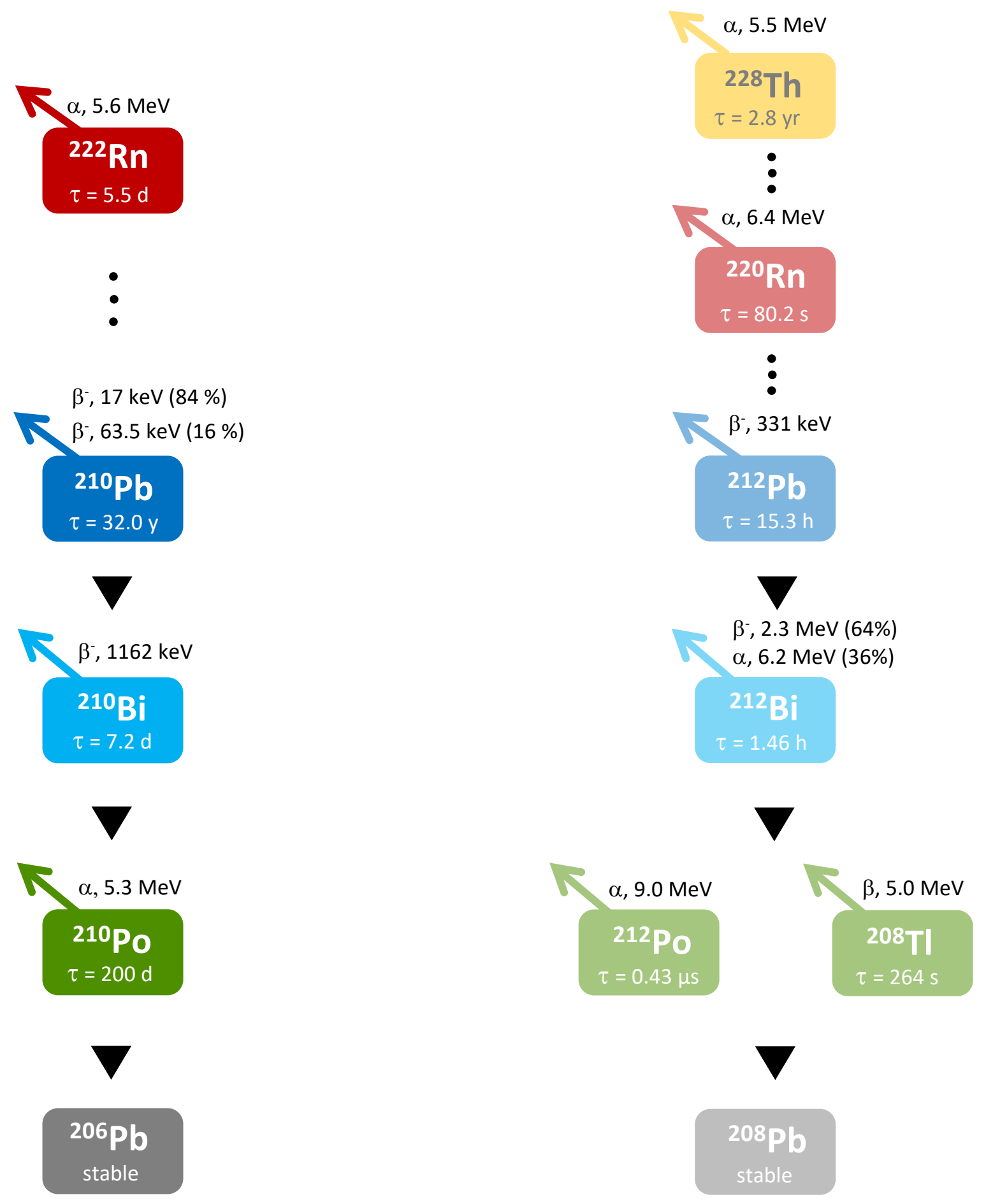
Long-term background evolution



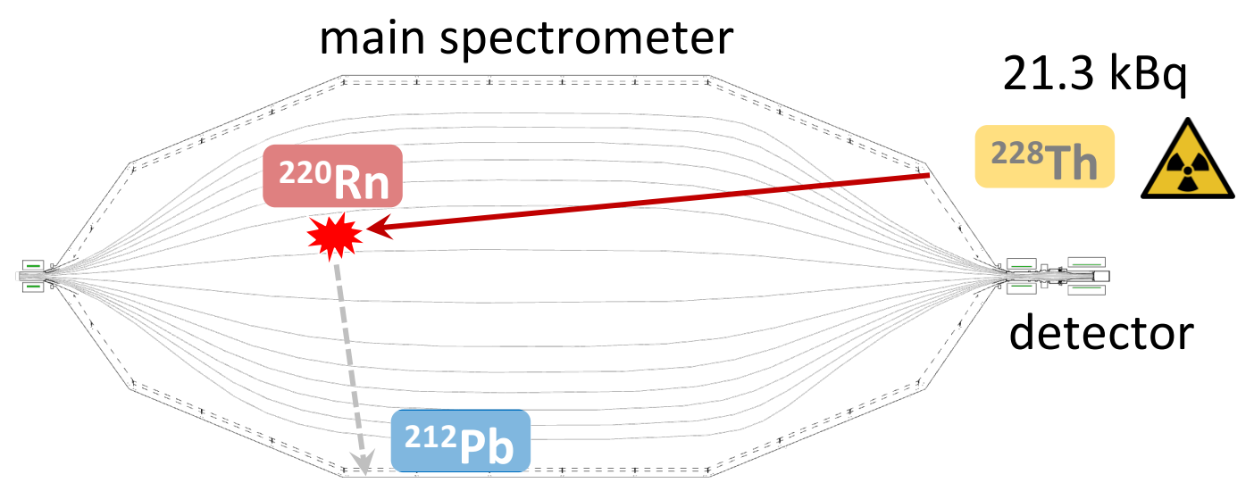
Background model

- The main spectrometer was exposed to ambient air (^{222}Rn) for an extended time, introducing a small ^{210}Pb reservoir (1 Bq/m²).

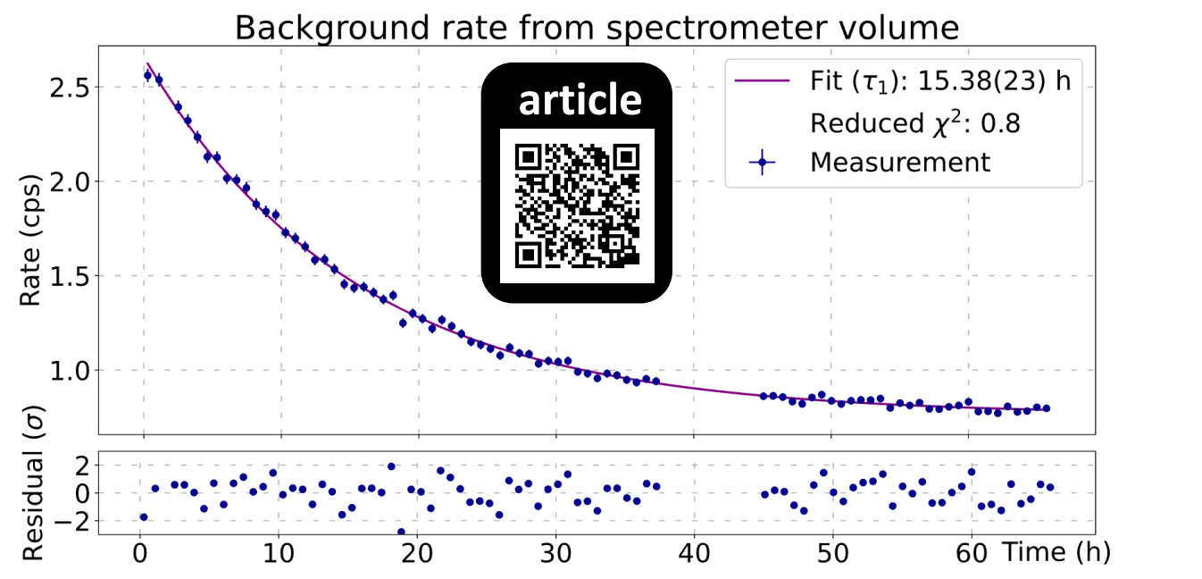
- The recoil nucleus of the ^{210}Po α-decay sputters away atoms on the inner surface and leaves some of them in excited states (Rydberg, autoionization, …).
- These excited states can release electrons in the volume of the spectrometer.



Background model test



- The main spectrometer was exposed to ^{220}Rn from a ^{228}Th source.
- The observed spectrometer background decreases with the lifetime of ^{212}Pb after disconnecting the ^{228}Th source.



Background evolution

- The long-term background evolution was monitored using data from tritium β-scans, systematic measurements, and dedicated reference measurements.
- All available background data within a calendar day was combined into an individual data point.
- Baking the spectrometer to 200°C removed about one third of the ^{210}Po, leaving the ^{210}Pb decay chain out of equilibrium.
- The rate evolution can be described with a Bateman equation for two isotopes.
- The initial increase *A** is due to replenishing the ^{210}Po reservoir, the decrease *B** is due to the decay of ^{210}Pb.
- The measurement data indicates that there is no unknown time-independent background r_0.
- KATRIN would have achieved its background goal of 0.01 cps without the ^{210}Pb contamination.

$$r(t) = \frac{N_{Po}}{\tau_{Po}} e^{-\frac{t}{\tau_{Po}}} - N_{Pb} \frac{\frac{1}{\tau_{Pb}\tau_{Po}}}{\frac{1}{\tau_{Po}} - \frac{1}{\tau_{Pb}}} \left(e^{-\frac{t}{\tau_{Po}}} - e^{-\frac{t}{\tau_{Pb}}}\right) + r_0$$

- *r(t)*: rate *r* as a function of time *t* at the detector
- N_{Pb}: effective number of ^{210}Pb atoms at *t*=0
- N_{Po}: effective number of ^{210}Po atoms at *t*=0
- τ_{Pb}: ^{210}Pb lifetime (32.03 ± 0.32 year)
- τ_{Po}: ^{210}Po lifetime (199.6348 ± 0.0036 day)
- r_0: time-independent background (14.6 mcps)

^{210}Pb (mcps)	^{210}Po (mcps)	τ_{Pb} (year)	τ_{Po} (day)
130.2 ± 0.1	90.6 ± 0.4	fixed	fixed
124 ± 3	85 ± 3	30.5 ± 0.9	189 ± 6

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