Background in the KATRIN experiment

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The KATRIN Experiment

- **goal:** sensitivity of $m(\nu_e) = 0.2$ eV (90 % C.L.) after 3 years of data taking
- high-luminosity, ultra-stable tritium source
- high-resolution spectrometers

**Diagram:**
- Focus on the KATRIN setup:
  - Windowless gaseous tritium source
  - Focal Plane Detector
  - Spectrometer section: pre- and main spectrometer
  - Pumping section
  - Rear section

**Graph:**
- Comparison of $m_\nu$ for $m_\nu = 0$ eV and $m_\nu = 1$ eV
  - Differential decay rate vs. energy
  - Energy below endpoint (eV)
High-resolution spectrometers: MAC-E filter

**Magnetic Adiabatic Collimation with Electrostatic filter**

- High pass filter: all electrons with $E_{||} > qU$ pass the analyzing plane
- Energy resolution:
  \[ E_{\text{res}} = E_{\text{ret}} \frac{B_{\text{min}}}{B_{\text{max}}} \]
  \[ \rightarrow E_{\text{res}} < 1 \text{ eV at } 18.6 \text{ keV} \]
- electrons generated in the flux volume that have
  - high energies are trapped
  - low energies are transmitted
First neutrino mass measurement 2019

- 33 days of data taking (Apr – May 2019) at 25% of nominal tritium activity
- 274 “golden” tritium scans, each spends ~25% in the background region
Background during the first neutrino mass measurement

- elevated, but stable background rate over whole measurement period
- events are not Poisson distributed
- distribution can be described by Poisson broadened with Gaussian

\[ p(\text{Poisson}) < 1\% \]

\[ p(\text{Normal}) \sim 45\% \]
Background – dependency on retarding potential

- 50 eV measurement point above endpoint to constrain the slope
- additional dedicated measurement to constrain retarding voltage dependence
- no indication for a significant slope, uncertainty of 5 mcps/keV

\[ R(qU) = \text{const} + a \cdot qU \]
\[ a = (5 \pm 5) \text{ mcps/keV} \]
Impact of background on first neutrino mass

What is the origin?

- elevated background in KATRIN
  - limits the neutrino mass sensitivity
  - is by far the dominant systematic
    - slope
    - non-Poisson
Background in KATRIN

**Radon induced background**

- origin: residual radon from NEG pumps
- non-Poisson distributed

F. Fränkle et al, Astrop. Physics, V 35, Oct. 2011, P. 128-134,
N. Wandkowsky et al, New Journal of Physics 15 (2013) 083040,
Görhardth et al., JINST 13 (2018), T10004

**Rydberg induced background**

- origin: $\alpha$ – decays in the walls
- IE voltage dependence (field ionization)
- Poisson distributed
Characterizing the Rydberg background

- **goal**: Confirm $\alpha$-decay in walls as origin
- **methodology**: generate artificial background and investigate IE dependence (idea: Ernst Otten)
- **realization**: introduce $^{223}$Ra source to spectrometer → only short-lived isotopes → 4 $\alpha$-decays → large Rydberg background expected
Technical implementation

- $^{223}$Ra source produced at ISOLDE at CERN (thanks to K. Blaum)
- source activity of ~7 kBq during measurement
- source mounted to steel arm which is magnetically steered to MS surface level (thanks to K. Schlösser, H. Frenzel, K. Blaum)
Artificial Rydberg background - results

- $^{223}\text{Ra}$-induced background shows the same IE dependence as the main spectrometer background
- confirms $\alpha$-decays in the walls as the origin of the main spectrometer background
- consistent with previous results:
  F. Harms, PhD thesis
  F. Harms, DPG Spring meeting, Münster 2017
  N. Trost, PhD thesis
Background in KATRIN - countermeasures

Radon induced background
- retention by cold baffles in front of NEG pumps
- efficiency depends on baffle temperature and surface conditions (e.g. adsorbed water ice)
- baking of baffles prior to next measurements

Rydberg induced background
- background proportional to volume
- decrease “visible” volume
Mitigating the Rydberg background

- Magnetic field
- Retarding potential
- Visible volume in standard settings

Rydberg atom

Ionization $e$
Mitigating the Rydberg background

visible volume with shifted analyzing plane (SAP)

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Mitigating the Rydberg background

Various SAP configurations reduction limited by residual Radon background eliminated after bake-out

- Background reduction by more than factor of 2

Standard settings
Shifted analyzing plane - challenges

- Large inhomogeneity of magnetic field and potential
- needs to be taken into account in the analysis
- fields need to be determined precisely

\[ \Delta U, \Delta B \]

\[ \text{averaged transmission function} \]
Field determination in KATRIN - $\Delta U$

- each pixel detects a rate corresponding to a different retarding potential
- Tritium: shift of endpoint
- $^{83m}$Kr: shift of line position
Field determination in KATRIN - $\Delta U$

- good agreement
- dominated by statistics
Conclusion

• Background during first neutrino mass measurement:
  – stable but not Poisson distributed
  – dominating systematic because of elevated background and low statistics

• origin of the KATRIN background: Radon & Rydberg induced background

  ➔ non-Poisson retention by improving baffle performance
  ➔ Poisson & proportional to volume mitigation by shifted analyzing plane

• shifted analyzing plane:
  – background reduction successfully demonstrated
  – first results towards a full field characterization were obtained

• Stay tuned for future results!