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# Background processes in the KATRIN main spectrometer

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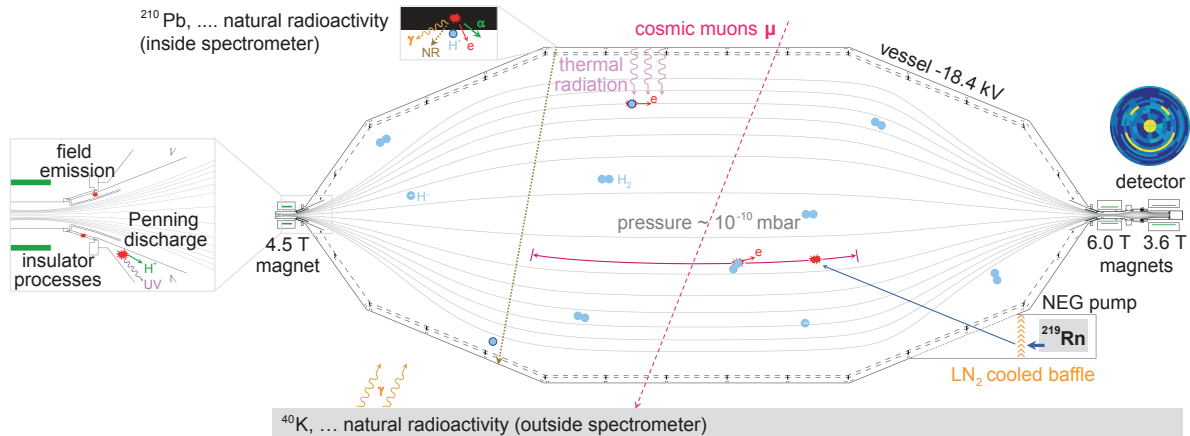
**Abstract.** The Karlsruhe TRitium Neutrino (KATRIN) experiment is a large-scale experiment which aims for the model-independent determination of the effective mass of electron anti-neutrinos with a sensitivity of  $200 \text{ meV}/c^2$ . It investigates the kinematics of electrons from tritium  $\beta$ -decay close to the endpoint of the energy spectrum. Low statistics at the endpoint requires an equally low background rate below 0.01 counts per second. The measurement setup consists of a high luminosity windowless gaseous molecular tritium source (WGTS), a differential and cryogenic pumped electron transport and tritium retention section, a tandem spectrometer section (pre-spectrometer and main spectrometer) for energy analysis, followed by a detector system for counting transmitted beta decay electrons. The background characteristics of the KATRIN main spectrometer were investigated in detail during two commissioning measurement phases. Of particular interest were backgrounds due to the decay of radon in the volume of the spectrometer, cosmic-muon-induced backgrounds, backgrounds due to natural radioactivity and Penning-discharge-related backgrounds. This proceeding will present results of the commissioning measurements and focuses on different background processes and their contribution to the overall background of the KATRIN experiment.

## 1. Introduction

The absolute neutrino mass scale is one of the big open questions in particle physics, astrophysics and cosmology. A model independent, direct approach to determine the neutrino mass is the precise investigation of weak decays such as  $\beta$ -decay. The Karlsruhe TRitium Neutrino (KATRIN) experiment [1] has the goal to determine the effective mass of electron anti-neutrinos with a sensitivity of  $200 \text{ meV}/c^2$  via high-precision spectroscopy of electrons from tritium  $\beta$ -decay close to the endpoint energy  $E_0 = 18.59 \text{ keV}$ . In order to achieve this sensitivity, KATRIN aims for a low background rate below 0.01 counts per second (cps).

The experimental setup consists of a windowless gaseous tritium source where molecular tritium decays with an activity of  $10^{11} \text{ Bq}$ , a transport section for tritium retention and magnetic guidance of the  $\beta$ -electrons, and a spectrometer and detector section for the energy analysis of the  $\beta$ -electrons. The KATRIN main spectrometer is operated as an electrostatic high-pass filter of MAC-E filter type [2], transmitted  $\beta$ -electrons are counted with a segmented silicon detector [3] at the downstream end of the spectrometer. The background characteristics of the KATRIN main spectrometer were investigated in detail during two commissioning measurement phases.





**Figure 1.** Overview of the KATRIN spectrometer and detector section. For more details on the depicted background processes, see section 2.

## 2. Background processes

The KATRIN main spectrometer vessel is operated at a potential close to the endpoint of the tritium  $\beta$ -spectrum. Low-energy electrons ( $< 100$  eV) produced in processes in the spectrometer hull or the spectrometer volume, will be accelerated by the spectrometer potential in case they are able to escape from the spectrometer. They have the same energy as transmitted  $\beta$ -electrons at the detector, thus creating an indistinguishable background.

### 2.1. Muon induced backgrounds

The KATRIN main spectrometer is located above ground and has no shielding against cosmic muons. A muon flux of about  $10^5$  per second is estimated to go through the inner spectrometer surface of  $1222$  m<sup>2</sup>. Secondary electrons produced by these muons are expected to be magnetically shielded by the guiding magnetic field for the  $\beta$ -electrons. In order to test the magnetic shielding, a muon detector was installed close to the main spectrometer and the local muon flux was monitored for more than two weeks. A correlation study between variations of the muon flux and the spectrometer's background rate showed no correlation; therefore, the observed background is not muon induced and the magnetic shielding is working. Measurements with a special magnetic field configuration where electrons from the inner spectrometer surfaces are guided to the detector showed that  $14.4 \pm 0.7$  % of secondary electrons are induced by muons.

### 2.2. Radon induced backgrounds

A major background source in the KATRIN spectrometers is due to  $^{220}\text{Rn}$  and  $^{219}\text{Rn}$  [4, 5]. Radon emanates from materials inside the vacuum region of the spectrometer, in particular, from the non-evaporable getter (NEG) pump and decays in the volume of the spectrometer. Electrons emitted in processes accompanying the Rn  $\alpha$ -decay, such as shake-off, internal conversion of excited levels in the Rn daughter atoms, Auger and Coster-Kronig electrons are magnetically trapped inside the spectrometer. Depending on their initial energy, which can be on the order of up to 10 keV, the trapped electrons can produce hundreds of secondary electrons via subsequent ionization of residual gas molecules. These secondary electrons are able to leave the spectrometer and reach the detector. A liquid nitrogen cooled baffle system installed in the pump ports of the main spectrometer, between the NEG pump and the main volume of the spectrometer, could reduce the radon induced background of about 0.5 cps with an efficiency of about 97 %.

### 2.3. Natural radioactivity

The  $\gamma$ -flux from natural radioactivity (e.g.  $^{40}\text{K}$ ) inside the spectrometer building was measured to be on the order of  $1 \gamma \text{ cm}^{-2} \text{ s}^{-1}$  ( $E_\gamma > 100 \text{ keV}$ ). In order to check for  $\gamma$ -induced background processes, the  $\gamma$ -flux was significantly increased for several hours by placing a  $^{60}\text{Co}$  source (activity 53 MBq) about 1 m away from the main spectrometer vessel. No increase in background rate was observed, therefore it was concluded that  $\gamma$ -induced background processes are efficiently suppressed by the main spectrometer.

The electron energy spectrum of a long-term background measurement shows characteristic peaks of  $^{210}\text{Pb}$ . The total  $^{210}\text{Pb}$  activity on the inner spectrometer surface was estimated to be on the order of 1 kBq. Simulations were used to determine the detection efficiency for electrons from the decay of  $^{210}\text{Pb}$ . Secondary electrons from  $^{210}\text{Pb}$  decays are magnetically shielded, however Rydberg atoms could be produced in processes accompanying the  $^{210}\text{Pb}$  decay. As neutral particles, Rydberg atoms are not affected by the magnetic shielding and can be ionized in the spectrometer volume by thermal radiation. This process is currently expected to be responsible for the majority of the observed main spectrometer background, which is about 50 times higher than the design value of 10 mcps for nominal spectrometer settings. Although the background is much larger, the effect on the neutrino mass sensitivity is small.

### 2.4. Penning discharges

Penning traps created by strong magnetic and electric fields at the entrance/exit regions of the spectrometer can cause very high background rates ( $> 1 \text{ kcps}$ ) due to Penning discharges [6]. The electrode system of the main spectrometer was carefully designed to avoid Penning traps. A dedicated measurement where the spectrometer voltage was changed from the nominal voltage of -18.4 kV to -32 kV showed no increase in background rate, therefore excluding voltage dependent background processes such as Penning discharges or field emission.

## 3. Conclusions

All previously known background processes in the KATRIN main spectrometer, such as background induced by muons, radon decays, natural radioactivity or Penning discharges, are efficiently suppressed. A new background process involving the ionization of Rydberg atoms in the volume of the spectrometer by thermal radiation appears to be responsible for a majority of the spectrometer background and is currently limiting the KATRIN sensitivity to about  $240 \text{ meV}/c^2$ . This background model, as well as possible counter measures, will be investigated during the final commissioning phase of the KATRIN main spectrometer which will start in October 2016.

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