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The Windowless Gaseous Tritium Source (WGTS) of the KATRIN experiment

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The Windowless Gaseous Tritium Source (WGTS) of the KATRIN experiment

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Abstract. The Karlsruhe Tritium Neutrino Experiment (KATRIN) will perform a direct, kinematics-based measurement of the neutrino mass with a sensitivity of 200 meV (90 % C. L.), which will be reached after 3 years of measurement time. The neutrino mass is obtained by investigating the shape of the energy spectrum of tritium β-decay electrons close to the endpoint at 18.6 keV with a spectrometer of MAC-E filter type. This contribution reviews the current status of the tritium source cryostat and magnet system which is currently in its first cool-down phase. Furthermore, the next steps of the comprehensive pre-tritium measurement programme to characterise the apparatus and investigate important systematics are outlined.
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1. Introduction

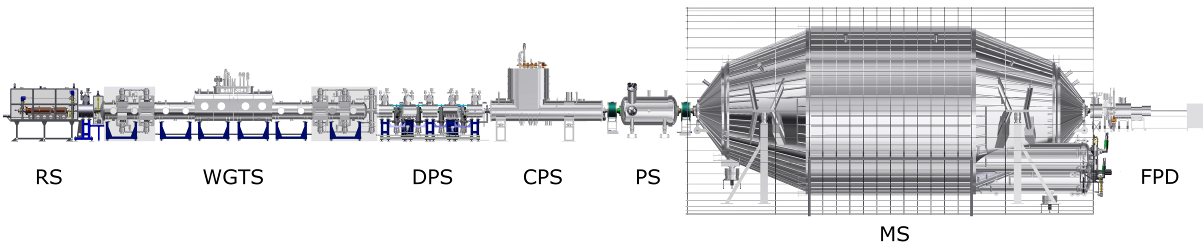

Figure 1. Schematic overview of the 70 m KATRIN beamline: (RS) rear section, (WGTS) windowless gaseous tritium source, (DPS) differential-pumping section, (CPS) cryogenic-pumping section, (PS) pre-spectrometer, (MS) main spectrometer, and (FPD) focal-plane detector.

KATRIN is currently in its commissioning phase. All major components are on site and will be operated together for “first light” measurements in October 2016. The full KATRIN beamline is 70 m long and depicted in Fig. 1. In a circular flow, molecular tritium gas is injected at the centre of the windowless source tube and pumped out at both ends, providing a constant gas column density of $5{\cdot}10^{17}\,\mathrm{cm}^{-2}$ which is stabilised on the per mille level. About 10^{10} β-decay electrons per second leave the windowless gaseous tritium source (WGTS) and are adiabatically guided in strong magnetic fields. While the electrons reach the spectrometers, the tritium flux is reduced by 14 orders of magnitude by the differential and cryogenic pumping sections (DPS and CPS). The spectrometer of MAC-E filter type analyses the energy of the electrons in fine steps at the endpoint region. Electrons passing the high-pass energy filter are counted by a 148-pixel detector. At the rear side of the WGTS, the rear section houses the rear wall and an electron gun for calibration and monitoring purposes. A detailed description of the KATRIN setup can be found in [1]. This paper focuses on the WGTS. Most of the KATRIN systematics are linked to this component and this is why a comprehensive commissioning measurement programme is planned. Following a description of the WGTS design goals the current status of the installation, instrumentation and commissioning is reported. Finally, an outlook towards the cold pre-tritium measurement phase is given, in which the first quantification of systematic uncertainties is expected.

2. Design requirements

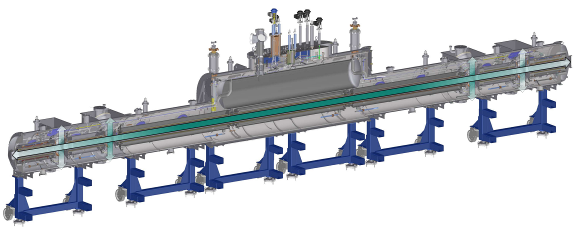

Figure 2. Cross-sectional view of the WGTS. The gas density profile inside the beam tube is shown in green.

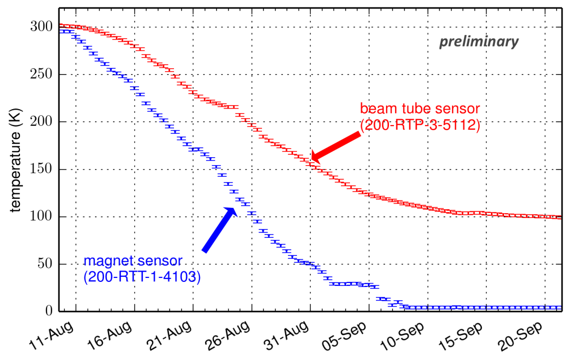

Figure 3. Temperature behaviour (preliminary, uncalibrated) of a PT500 beam tube sensor and a TVO sensor of one magnet.

The 16 m long source cryostat weighs 27 t, and houses 7 superconducting magnets with field strengths of 3.6 and 5.6 T. A complex cooling system, comprising several shields and cryogenic cycles, allows operating the inner beam tube (diameter 90 mm) at a stabilised temperature of about 30 K. As detailed in the KATRIN design report [1] the WGTS has to fulfill the following requirements:

- High activity: In order to collect sufficient statistics, KATRIN needs a highly luminous tritium source (for illustration: only a tiny fraction of $2 \cdot 10^{-13}$ of all tritium β-decays emits electrons with energies in a 1 eV interval below the endpoint [1]). The beam tube geometry with 3.35 μbar inlet pressure at the centre of the cryostat and four turbo molecular pumps at both ends lead to a column density of $5{\cdot}10^{17}\,\mathrm{cm}^{-2}$. The resulting effective column density taking into account losses in the count rate due to scattering is close to optimum [1]. A drawing of the source cryostat, illustrating also the gas density profile inside the source tube, is depicted in Fig. 2.
- High stability: The KATRIN systematics budget tolerates fluctuations of the column density on the per mille level only. This requires a per mille level stabilisation of the source cryostat temperature and of the inlet and outlet pressure. The stability of the source temperature is achieved by two-phase neon cooling at about 30 K [2]. Test measurements found the stability to be more than one order of magnitude better than projected [3]. The stability of the inlet pressure is achieved by a pressure controlled buffer vessel, which also exceeded the design goal by one order of magnitude [4].

- High monitoring precision: Key parameters of the source have to be monitored on the per mille level. Besides temperature and pressure, the tritium purity and the β-decay rate are of interest. The tritium purity is monitored by a laser Raman system positioned in the inner tritium loop [5]. The rate is continuously monitored by β-induced X-ray spectrometry via the rear section and by a forward beam monitor at the location of the CPS, and can furthermore be checked in regular intervals using the rear section electron gun [6].

3. Installation and commissioning

The WGTS apparatus was delivered to KIT in September 2015; installation and set-up of the mechanical and cryogenic infrastructure are now complete. About 800 sensors of the cryostat have been tested successfully. A first leak test at room temperature showed an integral leak rate of less than 10^{-8} mbar l/s. At the beginning of August 2016 the first cool-down of the magnets and the beam tube started (Fig. 3). The cool-down of the beam tube was done without coolant, relying solely on heat radiation absorbed by the inner shield cooling cycle. At a stabilised temperature of 100 K, integral leak tests were performed to confirm a leak rate of less than $2 \cdot 10^{-8}$ mbar l/s, which is within specifications. Tests of the superconducting magnet system are ongoing.

4. Upcoming measurement programme

Before starting with first tritium measurements in summer 2017, a comprehensive and dedicated measurement programme is foreseen for the WGTS in interplay with the other components:

- The two-phase neon cooling system of the beam tube will be commissioned to verify the temperature stability of former test measurements [3]. For October 2016 a "first light" measurement campaign for the whole KATRIN beamline is planned. Electrons and ions produced at the rear section will be guided by the magnetic fields of all components to the detector to verify precision alignment of the overall beamline [7].
- In the first half of 2017, a cold pre-tritium measurement campaign with the whole KATRIN beamline at nominal conditions but with deuterium gas circulating in the WGTS will be performed [7]. The aim is to demonstrate the functionality of all safety installations for tritium operation but also to determine and test some of the major systematic uncertainties of the KATRIN experiment, e. g., the test and quantification of the stability of the column density and the related parameters and monitoring units as described in Sec. 2, the test of the unfolding procedure of the energy loss function of electrons scattering inside the source volume [8], and the test of the WGTS $^{83\mathrm{m}}$Kr mode, in which the WGTS is operated at 110 K and $^{83\mathrm{m}}$Kr is added to the normal gas mixture to determine the plasma potential inside the source [9].

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