PROCEEDINGS OF SCIENCE

Status of the KATRIN experiment

Sebastian Fischer[*†]
Karlsruhe Institute of Technology, Germany
E-mail: sebastian.fischer@kit.edu

The aim of the Karlsruhe Tritium Neutrino experiment - KATRIN - is the direct measurement of the anti-neutrino mass with a sensitivity of 200 meV/c^2 (90% C.L.). It is based on the study of the endpoint region of tritium β decay where a non-vanishing anti-neutrino mass causes a distortion of the β spectrum. KATRIN will allow to probe a part of the cosmology-relevant neutrino mass parameter space and hence further constrain cosmological models and help to clarify the role of neutrinos as dark matter. KATRIN uses a windowless gaseous tritium source for production of β electrons in combination with an electrostatic filter for energy analysis.

An overview of the status of the KATRIN experiment will be given.

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[*] Speaker.
[†] for the KATRIN collaboration

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1. Introduction

Cosmological observations and the detection of neutrino flavour oscillations have shown that neutrinos are massive particles. Although the mass splittings between the neutrino mass eigenstates are known to be $|\Delta m_{31}{}^2| = (2.32^{+0.12}_{-0.08}) \times 10^{-3}$ eV^2/c^4 [1] and $\Delta m_{21}{}^2 = (7.41^{+0.21}_{0.19}) \times 10^{-5}$ eV^2/c^4 [2], the overall mass scale is still unknown. A complementary approach is the study of the endpoint region of tritium β decay $^3\mathrm{H} \rightarrow {}^3\mathrm{He} + \mathrm{e}^- + \bar{\nu}_\mathrm{e}$ where a non-zero anti-neutrino mass m_ν causes a distortion of the β spectrum

$$\frac{d^2N}{dEdt} \propto p(E + m_e c^2)(E_0 - E)\sqrt{(E_0 - E)^2 - \mathrm{m}_\nu^2 c^4} \qquad \text{with } \mathrm{m}_\nu = \sum_{i=1}^{3} |U_{ei}|^2 \, m_i{}^2. \tag{1.1}$$

This measurement allows a direct and model-independent determination of m_ν and based on the results of the Mainz [4] and Troitsk [5] experiments an upper limit of 2 eV/c^2 (95 % C.L.) can be deduced [6]. The aim of the KArlsruhe TRItium Neutrino (KATRIN) experiment is the measurement of m_ν with 200 meV/c^2 design sensitivity (90% C.L.) [3]. By improving the sensitivity by one order of magnitude in comparison to foregoing experiments, KATRIN will probe a cosmology-relevant part of the neutrino mass parameter space.

2. The KATRIN experiment: Principle and status of the main components

The KATRIN experiment consists of four main sections (figure 1): The windowless gaseous tritium source (1) in which the β electrons are produced. The transport section (2) which reduces the tritium flow rate by 14 orders of magnitude and adiabatically guides the electrons to the spectrometer and detector section (3) where the energy analysis is performed. The calibration and monitoring system (4) monitors the activity of the WGTS and performs systematic studies. An overview of the status of these main sections will be given in the following.

2.1 Status of the windowless gaseous tritium source

The main parameters of the windowless gaseous tritium source (WGTS), i.e. the source temperature, the gas inlet and outlet flow rate and the isotopic composition of the inlet gas, have to be stabilized to the 10^{-3} level and accordingly monitored in order to reach the design sensitivity of 200 meV/c^2. The test experiment Demonstrator has proven that cooling concept of the WGTS

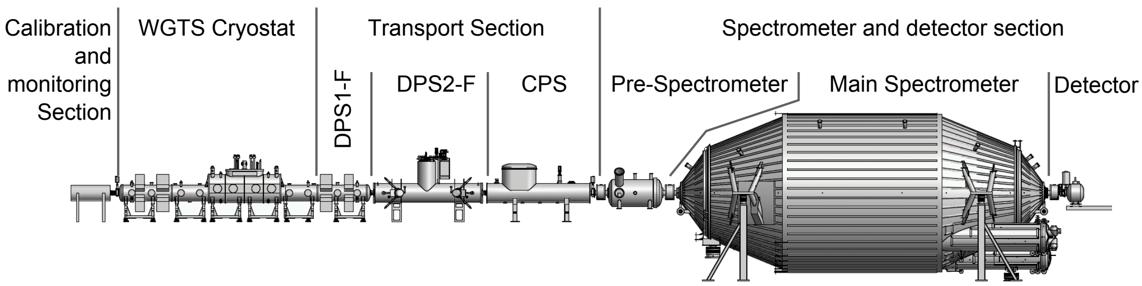

Figure 1: Overview of the KATRIN experiment. The tritium loop system of the WGTS are not shown. For further details see main text.

cryostat can achieve a temperature stabilization of the 30 K beam tube in the mK range (Requirement: 30 mK stability). After completing the tests, the Demonstrator will be upgraded to the final WGTS by installing the tritium related parts and the magnets for electron guiding.

The precise knowledge of the composition of the tritium inlet gas of the WGTS is necessary to account for systematic effects in the WGTS, e.g. Doppler broadening, elastic scattering, nuclear recoil and the final state distribution of the $(^3\text{HeT})^+$ daughter molecules. Laser Raman spectroscopy (LARA) is the method of choice for the monitoring of the gas composition in KATRIN since it allows the simultaneous monitoring of all hydrogen isotopologues (T_2, DT, HT, D_2, HD, H_2) [7]. Laser Raman spectroscopy is based on Raman scattering, i.e. the inelastic scattering of photons on molecules. In this process the wavelength of the scattered light changes due to the rotational-vibrational (de-)excitation of the molecule which produces characteristic spectra for each hydrogen isotopologue. As an optical method, Raman spectroscopy is non-invasive, i.e. no samples have to be taken and hence no radioactive waste is produced.

The test of the LARA system in the closed tritium loop LOOPINO during 3 weeks of non-stop operation showed that the required 0.1% precision is achieved under KATRIN-like conditions [8]. Further improvement of precision due to an optimisation of the laser beam path and the read-out mechanism of the optical detector are expected. Experimental tests of calculated Raman scattering cross-sections of all hydrogen isotopologues were made to improve the accuracy of the LARA measurements.

2.2 Status of the transport section

The transport section consists of the differential pumping sections (DPS1-F and DPS2-F) and the cryogenic pumping section (CPS). After commissioning of the DPS2-F, the gas reduction factor has been measured for D_2, He and other noble gases at room temperature. The measured reduction factors vary between $(1.86 \pm 0.37) \times 10^4$ (for D_2) and $(5.6 \pm 1.1) \times 10^4$ (for Kr) [9]. A further improvement of the gas reduction factor is expected when the complete beam tube instrumentation of the DPS2-F is installed. The manufacturing of the CPS is ongoing and the delivery to KIT is expected for 2012.

2.3 Status of the spectrometer and detector section

Two electrostatic filters, based on the MAC-E [10] principle, are used for energy analysis: The pre-spectrometer will reject most of the electrons which have energies less than about 300 eV below the endpoint, i.e. which do not contain information on the anti-neutrino mass. The retarding potential of the main spectrometer will be varied to measure the spectrum in the last $\sim$30 eV below the endpoint. The pre-spectrometer has been operated as a prototype for systematic investigations and hardware developments which are also relevant for the main spectrometer. A radon induced background signal, emerging from the material of vacuum getter strips, has been identified and suitable experimental measures for suppression were found [11]. The test operation of the pre-spectrometer is finished and it is ready for its final integration into the KATRIN setup.

The installation of the wire frame modules [12] in the main spectrometer, which are used for reduction of muon induced electron background, is completed. The detector system has arrived in Karlsruhe in summer 2011 and has been commissioned. The commissioning and first measurements of the main spectrometer are scheduled for 2012.

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2.4 Status of the calibration and monitoring system

The feasibility of source activity monitoring using β induced X-ray spectroscopy has been successfully demonstrated at Tritium Laboratory Karlsruhe. A technical design of the calibration and monitoring section has been developed.

3. Conclusions

Test measurements of several main components of KATRIN have been successfully performed and important milestones were achieved. The LARA system has reached 0.1% precision (1σ) under KATRIN-like conditions and further imrovements are expected. With the upcoming measurements at the main spectrometer in 2012 the commssioning of KATRIN main components will continue.

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