Measurements with the KATRIN Pre-Spectrometer

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Abstract. The KArlsruhe TRItium Neutrino (KATRIN) experiment aims at directly measuring the anti-electron neutrino mass by investigating the kinematics of the tritium-$\beta$ decay with a sensitivity of $0.2\,\text{eV}/c^2$. The measurement set-up will comprise a windowless gaseous molecular tritium source, a differential and cryogenic pumped electron transport section, a tandem spectrometer system for the energy analysis, followed by a detector-system for counting transmitted $\beta$-decay electrons [1][2].

The pre-spectrometer, being the first major component in operation, is used as a prototype for further investigation and validation of the vacuum concept as well as the novel electro-magnetic design of the MAC-E filter. The test measurements presented here verify both vacuum concept and the electro-magnetic design.

1. Measurements with the pre-spectrometer test set-up
The pre-spectrometer test set-up (figure 1) comprises the ultra high vacuum (UHV) recipient, two super-conducting solenoids (max 4.5T), an e-gun system, and a detector chamber either housing a multi-channel plate or a segmented PIN diode array. All-metal gate valves allow to shut off the satellite systems for maintenance if necessary.

The spectrometer tank (volume: $8.5\,\text{m}^3$, surface $25\,\text{m}^2$) is designed to maintain UHV-conditions. Therefore the vacuum vessel is made of stainless steel, specifically 316LN, favourable for its non-magnetic properties.

At the horizontal pump port (not visible in figure 1) a cascaded system of turbo-molecular pumps (TMP) in conjunction with a dry fore-pump are installed, pumping the system with regard to noble gases and non getter-able gases, and entering in that way the $p \leq 10^{-10}\,\text{mbar}$ pressure regime. The $45^\circ$-pump port houses a non evaporable getter (NEG) pump. This allows to pump the hydrogen gas load which is, due to outgassing effects, dominant in this regime, thus reaching a final pressure about $10^{-11}\,\text{mbar}$. In the pre-spectrometer vessel the outgassing rate was measured with the pressure rise method to approximately $10^{-13}\,\text{mbar}\,\text{l/s cm}^2$ [3].

The pre-spectrometer’s function as a high pass filter not only requires a magnetic field for the guiding of electrons but also an electro-static retarding potential for the analysis of the electron’s energy. Unlike in the predecessor experiments the vacuum recipient itself will be put on high-voltage. An additional inner wire-electrode allows for fine-tuning and stabilization of the retarding potential. This configuration minimizes the occurrence of Penning traps and optimizes the adiabatic transmission properties of the spectrometer. The layout of the electrode offers the possibility to apply different voltages to different parts of the wire-electrode, thus accelerating trapped charged particles into a set direction which effectively empties possible particle traps.
Figure 1. The pre-spectrometer test set-up: UHV recipient (1), inner wire-electrode (2), detector chamber (3), e-gun system (4), super-conducting solenoid (5), all-metal gate valve (6), 45°-pump port (7), ceramic insulators (8).

Instead of using a radioactive isotropically emitting electron source like tritium in the final set-up, the pre-spectrometer test experiment uses a point like source of quasi monoenergetic electrons, also referred to as e-gun. The electrons feature a small energy spread (< 1 eV @ 18.6 kV) with a rate that can be changed from about 400 Hz to several kHz.

The electrons, guided by the magnetic field lines and passing the analyzing plane, where the retarding potential reaches its maximum, leave the pre-spectrometer tank and hit the detector. For the first commissioning of the high-voltage system and the first measurements with the pre-spectrometer system a robust Hamamatsu F2223-21S multi-channel plate (MCP) was used to detect low energy electrons. After reaching the safe operation mode the segmented PIN diode (SPD) array (64 pixels, 16 cm$^2$) can be used. The SPD features energy and spatial resolution, necessary for precise investigation of the spectrometer’s transmission properties. This detector is an in-house design in collaboration with the University of Washington.

The electro-magnetic tests with the set-up were focused on transmission measurements to deduce the energy resolution of the pre-spectrometer $\Delta E = 10.5 \pm 0.5$ eV at 3 kV retarding potential, on the commissioning of the SPD, determining its most important properties (average energy resolution $\Delta E = 4.4$ keV, overall noise level in the energy interval of 15-22 keV of $(439.8 \pm 2.7) \times 10^{-3}$ events/s, after noise cut $(20.3 \pm 0.6) \times 10^{-3}$ events/s), and on the investigation of Penning traps in the spectrometer volume. The importance of the latter investigation showed after the observation a vacuum breakdown due to a Penning discharge. After analyzing the problem a shielding electrode was designed, manufactured, and built in. Initial measurements with the new set-up indicate that the Penning problem has been solved. Detailed measurements to further validate these first results are under way.

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