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Monitoring the KATRIN source properties within the beamline

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Abstract. The *Karlsruhe TRitium Neutrino* (KATRIN) experiment will measure the mass of the neutrino with a sensitivity of 0.2 eV (90 % CL). The *Forward Beam Monitor* (FBM) is a monitoring system which comprises of a complex mechanical setup capable of inserting a detector board into the KATRIN beamline at the end of the source and transport section. The detector board contains a Hall sensor, a temperature gauge, and two PIN diodes which can detect electrons from the source with a precision of 0.1 % in less than a minute within an electron flux density of $10^6 \text{ s}^{-1} \text{ mm}^{-2}$.

1. Introduction

The mass of the neutrino is obtained by KATRIN by observing the β -electron spectrum from the decay of tritium in the *Windowless Gaseous Tritium Source* (WGTS). The β -electrons are emitted isotropically and guided magnetically through the beamline to the spectrometers[1]. Monte Carlo simulations have been performed to understand scattering and other processes and to produce simulated spectra. Another crucial task of this beam transport is the efficient retention of tritium ions. During commissioning the detector board may be replaced by a Faraday cup to study the ion retention.

The tritium source properties are required to be stable and known to a high precision, and will therefore be monitored continuously by several systems, including the FBM[2]. The FBM will measure real-time count rates and differential β -electron spectra. Analysis of such spectra result in continuous monitoring of the tritium source with high energy resolution and precision.

2. Monitoring of the tritium source with 0.1 % precision

Two key parameters of the WGTS which are required to be continuously monitored are

- **Column density, \mathcal{N}**

The number of molecules within a flux tube volume of unit cross section.

- **Tritium purity, ϵ_T**

The ratio of tritium ions (T_2) to the total sum of atoms (DT, HT, D_2 , HD, He).

The FBM measures the count rate S from the source which can be used together with the tritium purity to monitor the column density via

$$S = C \cdot \epsilon_T \cdot \mathcal{N} \quad (1)$$



where C is a proportionality constant encompassing experimental properties.

3. The FBM detector board

The Forward Beam Monitor is the only device of KATRIN capable of taking measurements directly inside the β -electron flux tube. A 2 m long UHV manipulator (figure 1) moves the detector to any position within the flux tube with 0.1 mm precision.

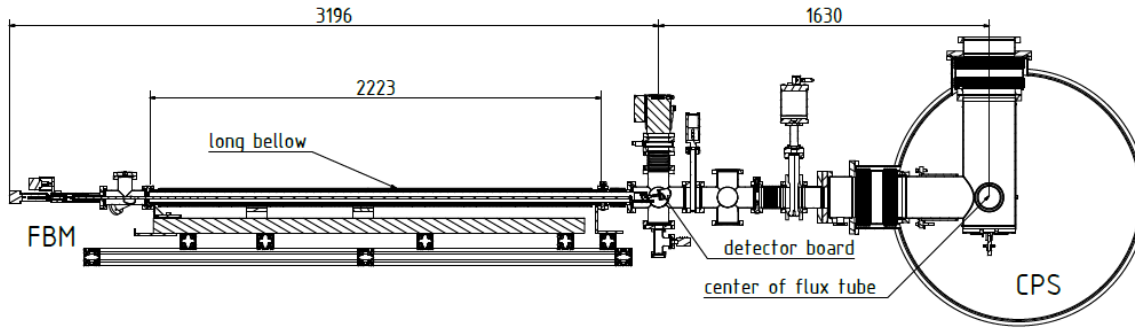


Figure 1. The FBM (left) attached to the CPS (right). The detector board can be inserted into the flux tube in the CPS.

3.1. PIN diodes for electron detection

The detector board is equipped with two Hamamatsu PIN diodes of different sizes to fulfil several purposes. As part of the monitoring system the FBM will determine the relative β -electron flux with a precision of 0.1 % in less than 60 s. A differential β -electron spectrum can be obtained with an energy resolution of $\text{FWHM} = 2.0 \text{ keV}$ at a threshold of 6.5 keV ¹.

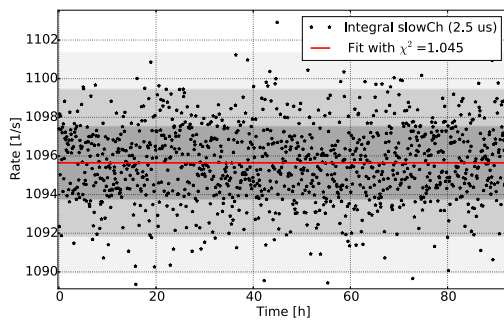


Figure 2. Three day stability test using a ⁸³Rb source.

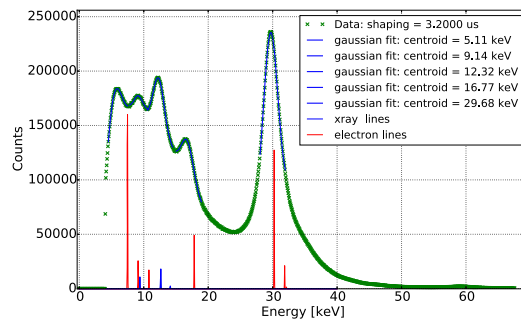


Figure 3. ⁸³Rb spectrum obtained with a Hamamatsu PIN diode.

3.2. Additional measurement capabilities

The FBM detector is equipped with further devices for supplementary measurements, including

- **Faraday Cup**

An alternative detector board, equipped with a Faraday cup[4], will be used during commissioning in order to check ion blocking, measure the radial ion distribution in the beamline, and check the simulated source gas models by measuring secondary electrons.

¹ For x-rays the energy resolution is $\text{FWHM} = 1.5 \text{ keV}$ and the threshold is 4.0 keV .

- **Temperature gauge**

To monitor temperature for detector drifts and offline corrections.

- **Hall sensor**

To measure the magnetic field inside the flux tube for relative position determination and validation of magnetic field models.

- **LED**

To find absolute position inside the beam tube.

4. MC simulations of differential e^- spectra from the KATRIN source

Small fluctuations of the source properties lead to changes in the shape of the differential e^- spectrum. To understand these effects Monte-Carlo simulations have been performed using the KATRIN software package Kassiopeia.

The acceptance angle for the FBM is expected to be 52.6° , however the electrons undergo scattering effects which change their inclination angle. Therefore, electrons were generated spherically and tracked through the WGTS. The amount of electrons leaving the WGTS towards the transport section are compared to those generated with particular inclination angle (figure 4). A plateau can be seen between 60° and 110° . The FBM will measure deep into the energy spectrum where electrons with a smaller kinetic energy are more likely to scatter in the source and change their respective inclination angle (figure 5).

Fluctuations in the column density are expected to be in the 10^{-3} regime, which requires high statistics MC simulation to be resolved. Each electron with an energy between 1 keV and 18.6 keV is tracked until it leaves the WGTS or is trapped inside the source, thereby undergoing elastic and inelastic scattering as well as ionisation of atoms.

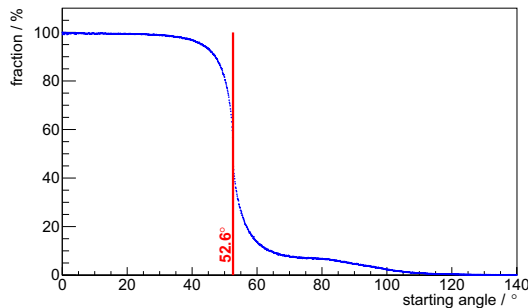


Figure 4. Electron angular distribution.

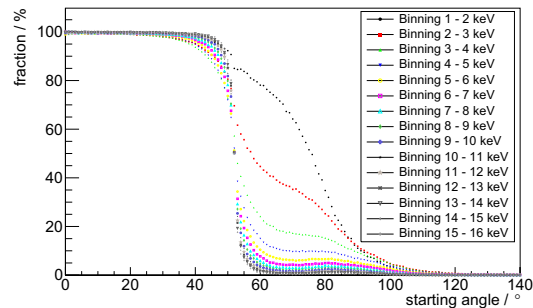


Figure 5. Energy binning of starting angle.

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