Characterisation of a monoenergetic electron source for the KATRIN main spectrometer calibration

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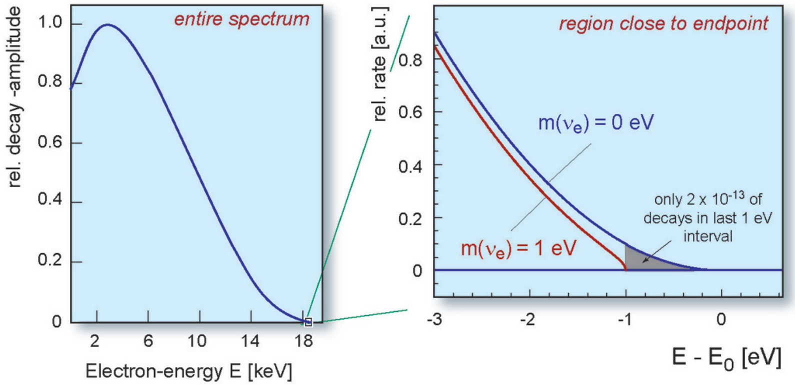
Karlsruhe Tritium Neutrino Experiment

Contents

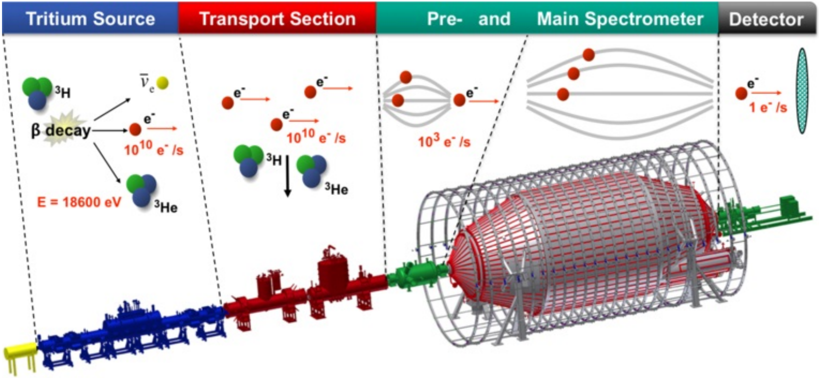
Introduction: Neutrinos and KATRIN

- Determination of the mass of $\bar{\nu}_e$ by measuring the ^3H β-decay energy spectrum
- The endpoint can give information about the neutrino mass



KATRIN: The experimental setup

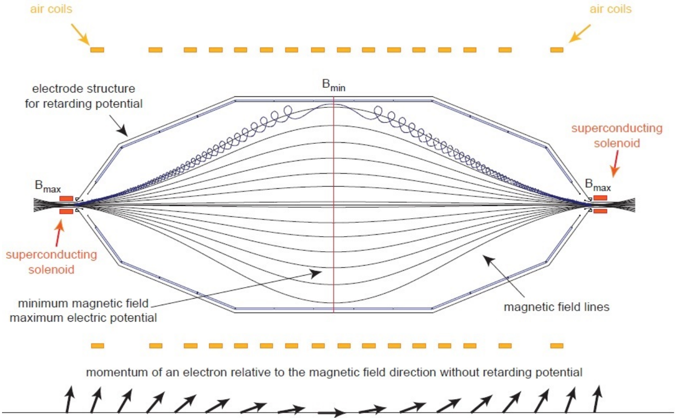
- Over 70 m long experimental setup
- The pre and main spectrometers work in MAC-E filter mode



KATRIN: The main spectrometer

KATRIN: MAC-E filter transmission function

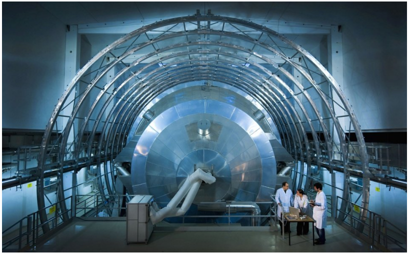
- **M**agnetic **A**diabatic **C**ollimation with **E**lectrostatic filtering
- Essential elements: Retarding potential and magnetic field
- Electrons are guided adiabatically along magnetic field lines in cyclotron motion: $\mu = \frac{E_\perp}{B} = \text{const.}$
- At the analysing plane: U_0 max, B min
- $E_\perp \rightarrow E_\|$



KATRIN: MAC-E filter transmission function

- Why such a freakin' big spectrometer?
- Energy resolution depends depends on ratio of B_{max} and B_{min}

$$\Delta E = E_{\text{start}}^{\text{max}} \cdot \frac{B_{\text{min}}}{B_{\text{max}}} = 0.93\,\mathrm{eV}$$



KATRIN: Main spectrometer calibration

- At the analysing plane: $E_\perp \rightarrow E_{||}$
- $E_{||}$ depends on starting angle of the electron
- Dependency of transmission probabiltiy on the starting angles
- Different transmission functions for each of the 148 detector segments
- Transmission functions have to be determined to locate and compensate variances in the electric potential

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  Calibration source requirements:

  $\Rightarrow$ Sharp energy distribution

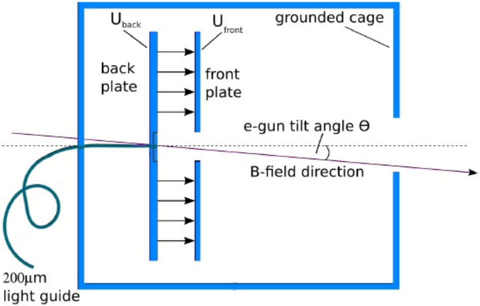
  $\Rightarrow$ Small spot size

  $\Rightarrow$ Angular selectivity

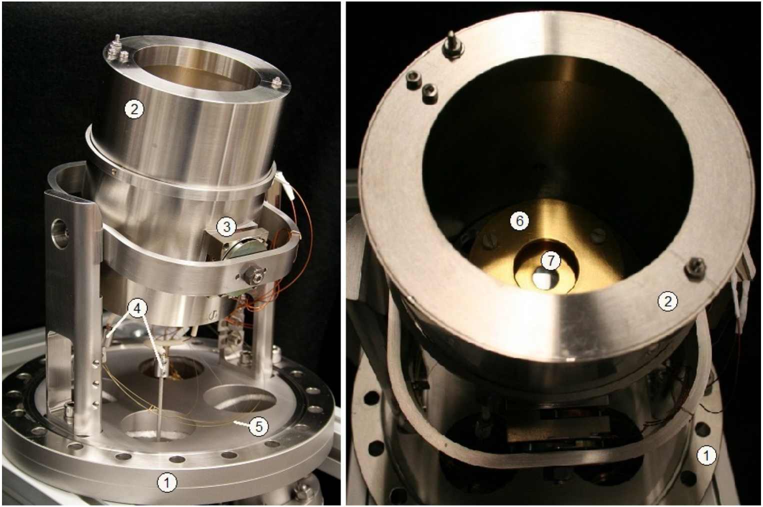
  $\Rightarrow$ Adjustable rate

The eGun

- The eGun provides monoenergetic electrons with any desired starting angle
- Photoelectric effect to eject zero-energy electrons from a thin gold layer with UV laser light



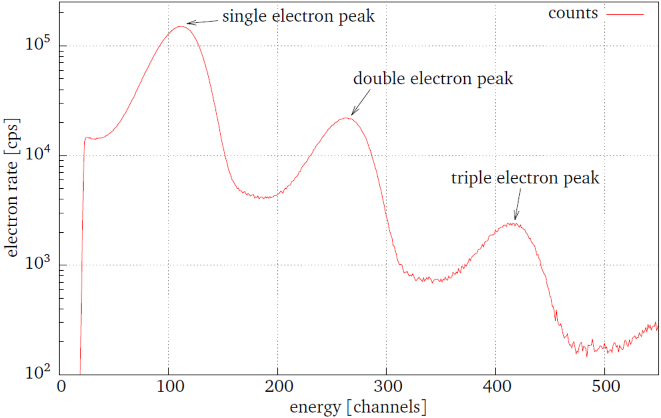
The eGun



(1) vacuum flange
(2) enclosure
(3) attocube motor for position readout
(4) HV feedthrough
(5) optical fibre
(6) front plate
(7) back plate with gold layer

The eGun: Energy spectrum

- Ideally: monoenergetic electrons → single delta peak spectrum
- Some uncertainties (e.g. detector noise) lead to Gaussion function

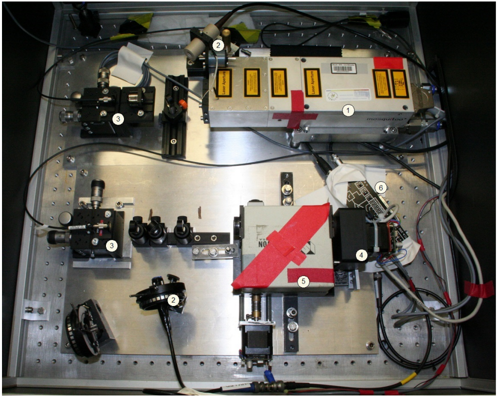


Characterisation of the eGun photocathode: Work function measurements

- Work function has to be determined to define ideal photon wavelength to eject zero-energy electrons from gold layer
- Theoretical work function of pure gold: $w_{\mathrm{Au,th.}} = 5.1\,\mathrm{eV}$
- Lower w expected for eGun gold layer
- Measurement of photoelectron yield as a function of the wavelengths

Characterisation of the eGun photocathode: Work function measurements

- LED-Revolver: Rotable plate with 8 UV LEDs, controlled by stepper motor
- Monochromator: Selection of any desired wavelength interval



(1) pulsed UV laser

(2) photodiode

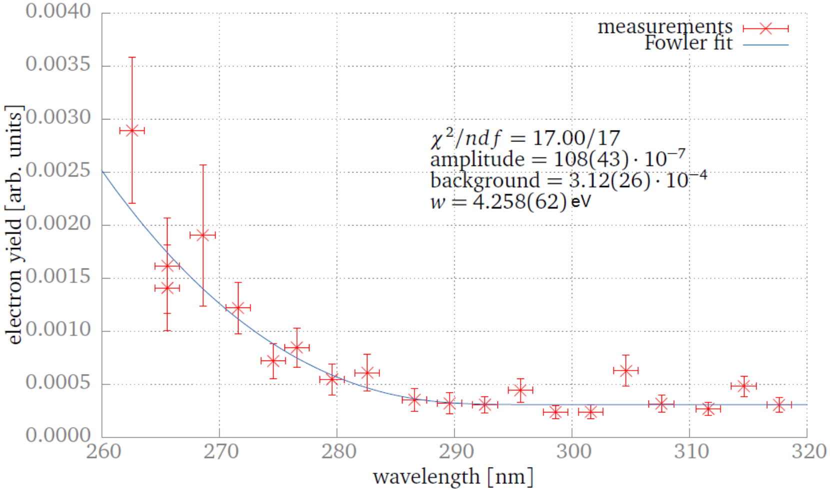
(3) coupling to the optical fibre

(4) UV-LED revolver

(5) monochromator

(6) photodiode amplifier

Characterisation of the eGun photocathode: Work function measurements



Summary and Outlook

- Mechanical, electrical and optical systems of the eGun: good test measurement results
- Angular selectivity between 0° and 90° achieved
- Good energy resolution
- Good long term stability
- Work function changes drastically over time
- Further measurements will show whether the gold photocathode is after all suitable for the main spectrometer calibration

$\Rightarrow$ Anyway: eGun will perform well as the KATRIN main spectrometer calibration source! :)

Backup slides: Fowler Function

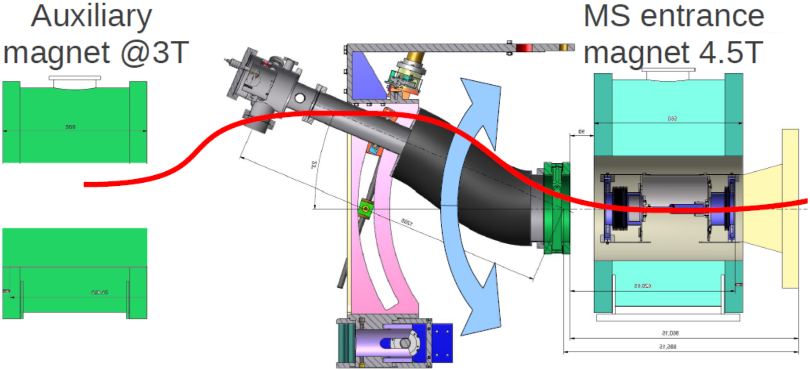
- R.H. Fowler developed a theory of the effect of temperature on the work function of metals
- The eGun's electron yield has to be measured as a function of the photon wavelengths and fittet with the Fowler function:

$$f(\mu) = \begin{cases} e^{\mu} - \frac{1}{4}e^{2\mu} + \frac{1}{9}e^{3\mu} + ... & ,\mu \leq 0 \\ \frac{\pi^2}{6} + \frac{\mu^2}{2} - \left(e^{-\mu} - \frac{1}{4}e^{-2\mu} + \frac{1}{9}e^{-3\mu} + ...\right) & ,\mu > 0 \end{cases}$$

- The parameter μ includes the work function:

$$\mu = \frac{1}{k_B T}\left(\frac{hc}{\lambda} - w\right)$$

Backup slides: Manipulator



Sources

- Jan Behrens: *Report on the e-gun test measurements at the monitor spectrometer*, 2014.
- Raffaela Busse: *Characterisation of a photocathode for a monoenergetic electron source for the KATRIN experiment*, Bachelor Thesis, Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, 2014.
- "Electron Work Function of the Elements" in Robert C. Weast, (Ed.): *CRC Handbook of Chemistry and Physics, 62th edition*, CRC Press, Boca Raton, FL, 1981.
- Daniel Winzen, Volker Hannen, Hans-Werner Ortjohann, Michael Zacher, Christian Weinheimer: *Design of a pulsed angular selective electron gun for the Katrin main spectrometer*, poster, 2011.
- Alexander Potthoff: *Aufbau einer durchstimmbaren UV-Lichtquelle für das KATRIN-Experiment*, Bachelor thesis, Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, 2013.
- Michael Zacher: *Electron gun tests and characteristics*, presentation, 2013, and personal communication.