Determination of the column density for the KATRIN neutrino mass measurement

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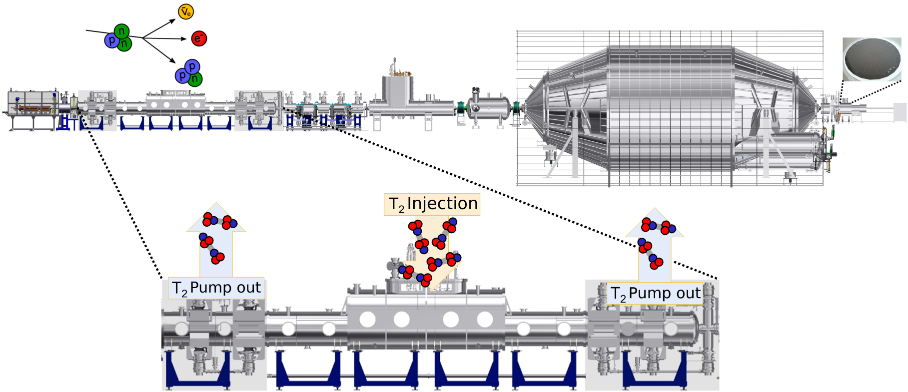
Outline

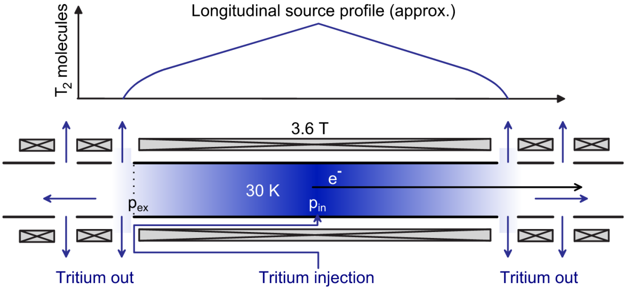
Windowless, Gaseous T_2 Source



- T_2 purity > 95 %
- Throughput: 40 g/day (nominal)
- High activity: 10^{11} B_q (nominal)

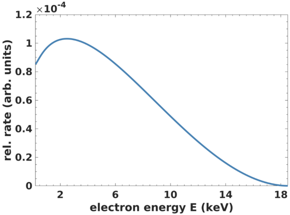
Column density

- T_2 retention before spectrometers $> 10^{14}$

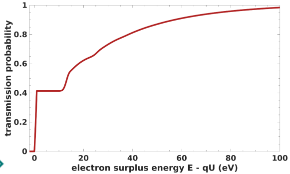


- Source scattering depending on:
  - Electron path
  - Column density
  - Cross section

Integral β-spectrum

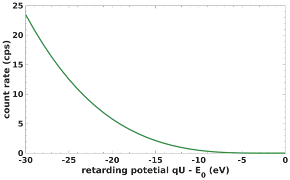


differential spectrum



response function

$$\boxed{S(qU)} = N \cdot \int_{qU}^{E_0} \boxed{\frac{\mathrm{d}\Gamma}{\mathrm{d}E}(E)} \cdot \boxed{R(E,qU)} \mathrm{d}E + B$$

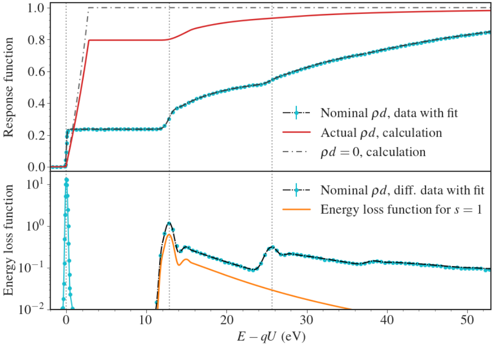


integral β-spectrum

Response function: column density

- Response function:
  - Probability of transmission of an electron with initial energy E
  - Depends on:
    - Transmission function
    - Energy loss function (ToF method used)
    - **Scattering probability in the source**

→ Precise determination of the column density needed

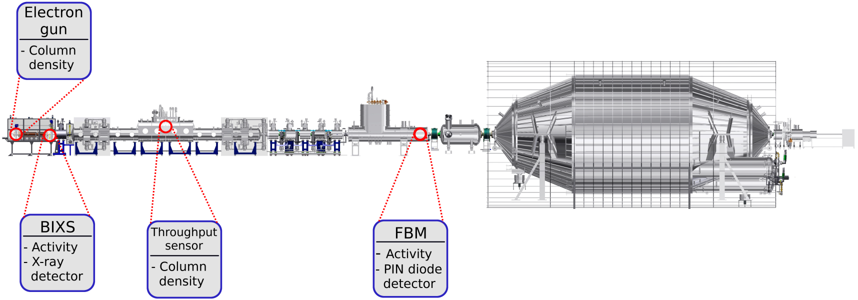


M. Aker et al., arXiv: 1909.06048

Outline

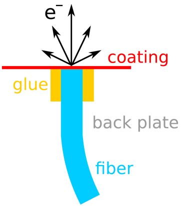
Tritium source monitoring: Overview

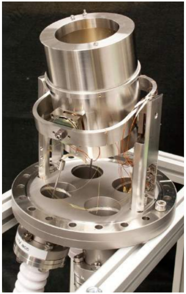
- Column density determination:
  - Photo-electrons traverse the whole beamline
  - Gas throughput sensor

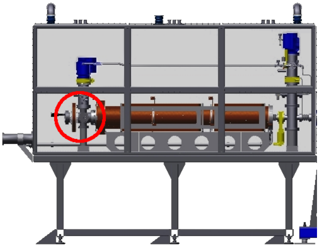


- Activity detectors:
  - Fluctuations of the WGTS activity
  - High precision on a timescale of minutes

Photo-electron source



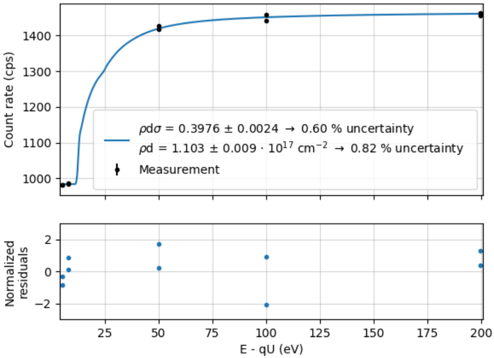




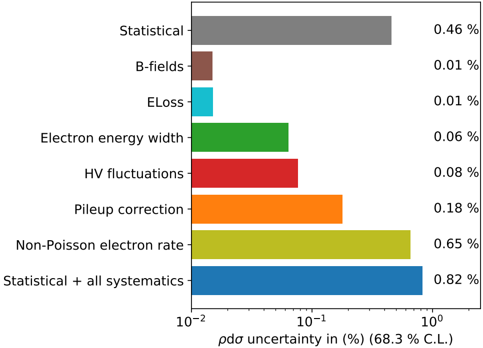
- Most precise measurement of absolute column density value
- Measures $\rho d \sigma$ (column density $\times$ cross section)
- High rate of 18.6 keV monoenergetic electrons
- Small angular spread

Column density scan

- Measure electron rate at different retarding potentials
- 30 min measurement
- Fit model response function to the data
- Two parameter fit:
  - Electron rate, $\rho d\sigma$
- Retrieve $\rho d\sigma$ with small uncertainty
- $\sigma = 3.64 \times 10^{-18} \mathrm{cm}^2$



Uncertainty of ρdσ scan



- Error propagation via Covariance Matrix, V
- $\chi^2 = (\vec{\mu} - \vec{N})^T \, V_{tot}^{-1} \, (\vec{\mu} - \vec{N})$
- $V_{tot} = V_1 + V_2 + ...$
- Dominant systematic contributions:
  - Detector pileup correction
  - Non-Poisson photo-electron rate

Outline

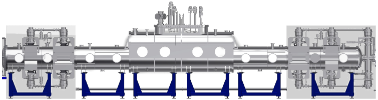
Measurement overview

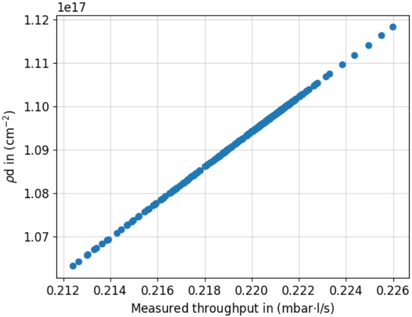
- Tritium β-decay:
  - April 10 - May, 13 2019
  - High source activity: $2.45 \cdot 10^{10}$ B_q
  - High Tritium purity: $\epsilon_T = 97.5\ \%$
- Column density:
  - Photo-electron source: 10 Measurements (each ≈ 30 min)
  - Continuous data taking with other monitoring devices

Gas throughput sensor

- Estimation of column density with gas model
- Model parameter uncertainty
- Simultaneous measurement during tritium scans
- Idea: Combination of ρdσ result from photo-electron source with throughput sensor value

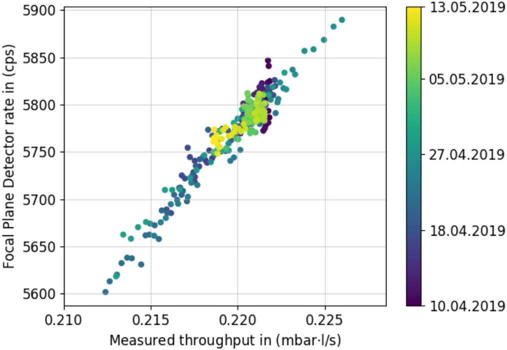
→ Precise continuous determination of the column density



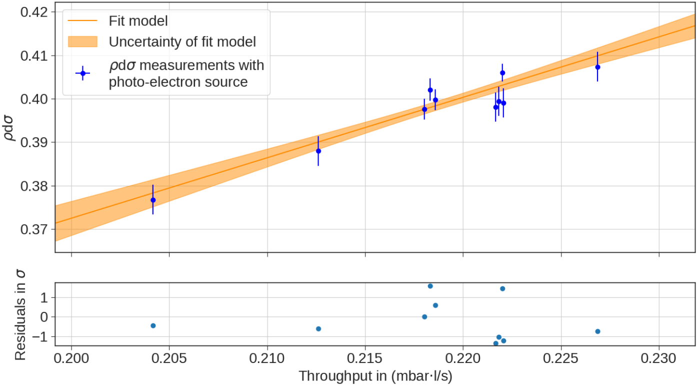


Throughput sensor stability

- Comparison of:
  - Electron rate from tritium β-decay
  - Gas throughput value
- Strong correlation
- No time dependence

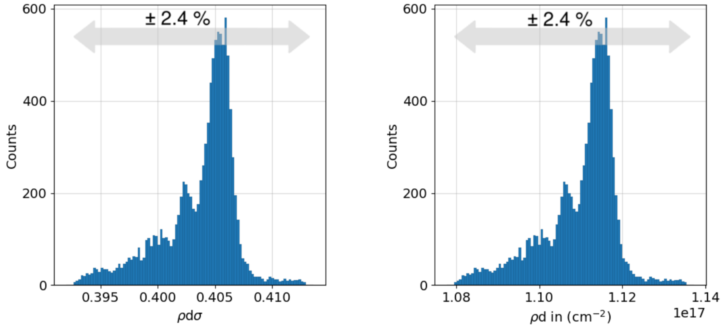


Calibration of throughput to ρdσ



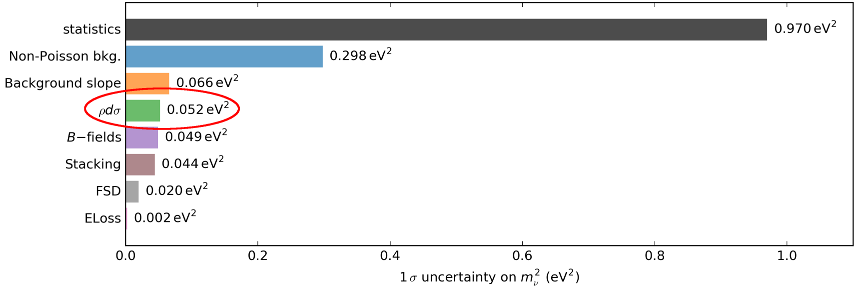
- Precise column density scans with photo-electron source
- Simultaneous values from throughput sensor
- Calibration of throughput to ρdσ with linear model

Column density distribution



- Uncertainty of $\rho d\sigma < 0.85$ %
- Uncertainty of $\rho d < 1.03$ %
- Goal for final KATRIN sensitivity: $\rho d\sigma < 0.2$ %

Effect on neutrino mass sensitivity



- Small impact of column density uncertainty

Summary and outlook

- Column density determination for the first neutrino mass measurement
  - Continuous monitoring
  - Relative uncertainty $\rho d \sigma < 0.85\ \%$
  - Relative uncertainty $\rho d < 1.03\ \%$
- Monitoring devices with enhanced precision in commissioning
- Upgrade of the existing photo-electron source