Column Density Determination for the KATRIN Neutrino Mass Measurement

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Christoph Köhler, Fabian Block, Alexander Marsteller

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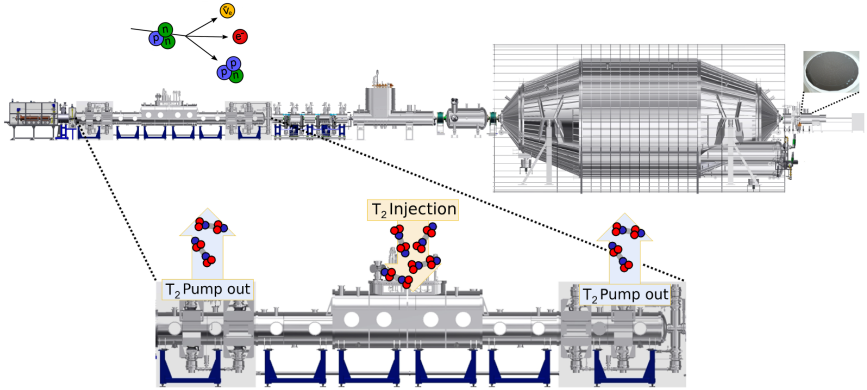
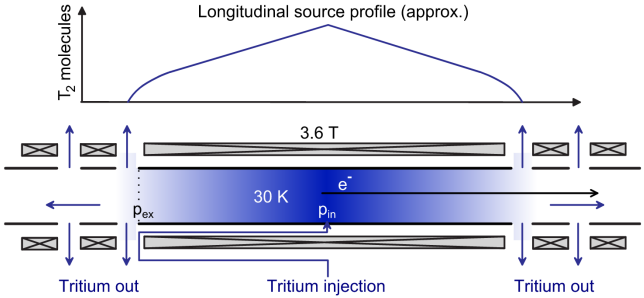
Outline

Windowless, Gaseous T_2 Source

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

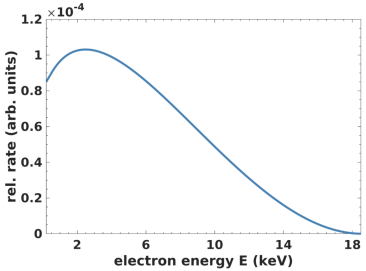


Column density



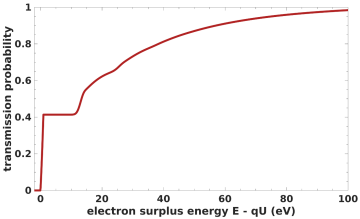
- T_2 retention before spectrometers $> 10^{14}$
- Source scattering depending on:
  - Electron path
  - Column density
  - Cross section

Integral β-spectrum

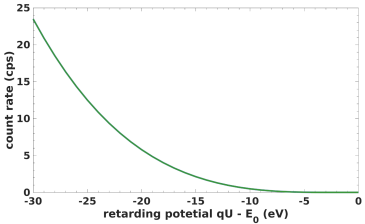


differential spectrum

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



response function

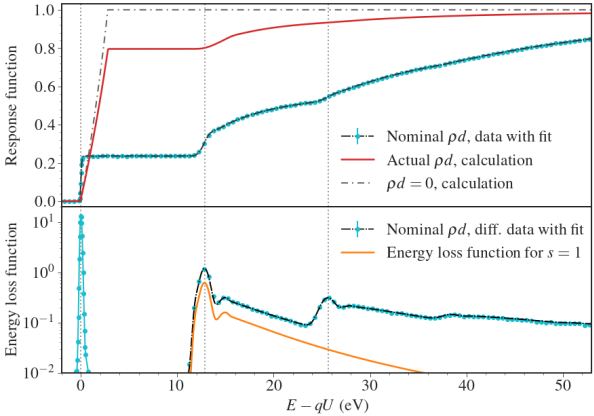


integral β-spectrum

Response function: Column density

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

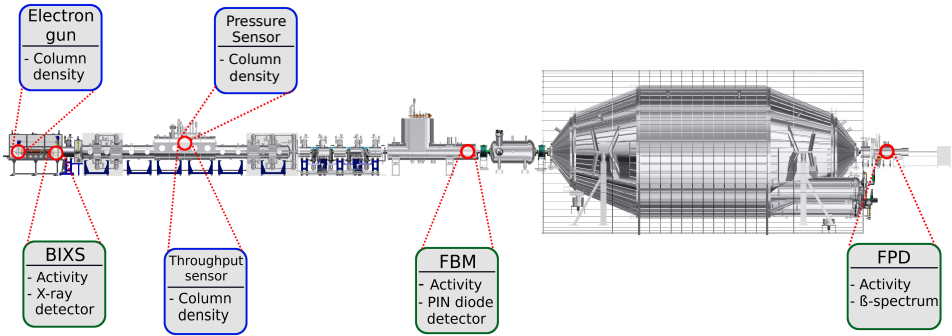
→ Precise determination of the column density needed



M. Aker et al., arXiv: 1909.06048

Outline

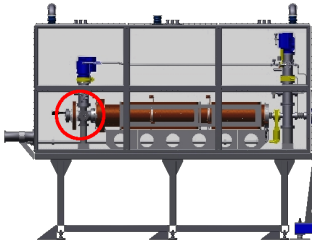
Tritium source monitoring: Overview

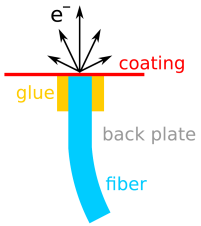


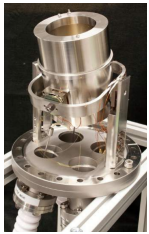
- Column density determination:
  - Photo-electrons traverse the whole beamline
  - Gas throughput sensor
  - Gas pressure sensor
- Activity detectors:
  - Fluctuations of the WGTS activity
  - High precision on a timescale of minutes

Photo-electron source

- Most precise and accurate 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 measurement
- Not simultaneous during β-decay

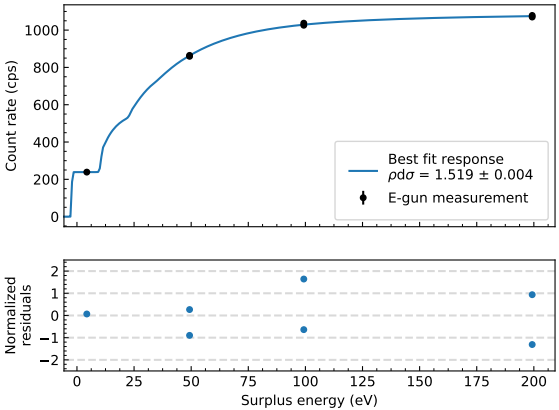






Column density scan

- 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
- $\sigma = 3.64 \times 10^{-18} \mathrm{cm}^2$



Outline

Measurement overview

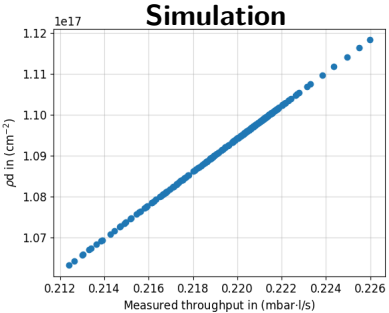
- Tritium β-decay:

Information	KNM1	KNM2
Duration	10.4.2019 - 13.5.2019	27.9.2019 - 14.11.2019
Tritium purity	97.5 %	98.6 %
# e^- in ROI	2 Mio	4.3 Mio

- Column density:

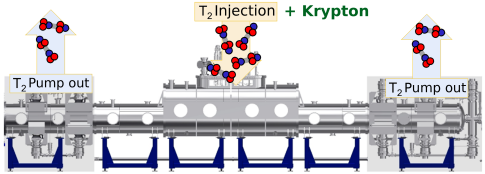
Information	KNM1	KNM2
Photo-electron source measurements	10	11
Continuous tritium source monitoring	✓	✓

Tritium + Krypton operation



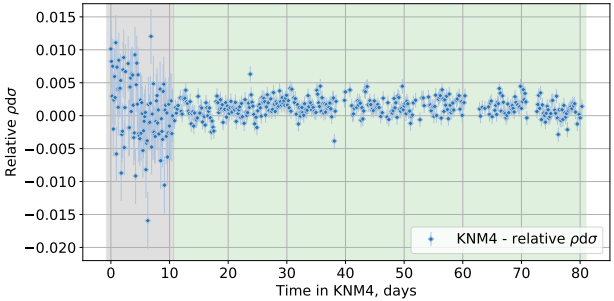
- Linear relation between throughput and column density
- Combination of ρdσ result from photo-electron source with throughput sensor value

- Since KNM4: Novel loop operation modus → Fast injection of ^{83m}Kr into gas circulation possible
- Throughput and pressure sensor no longer representative

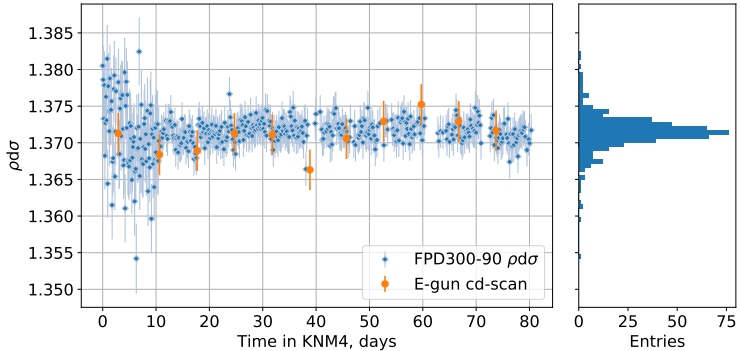


FPD monitoring rates

- 2 monitoring points with different (E_0 - qU):
  - FPD300: $300\,\mathrm{eV}$
  - FPD90: $90\,\mathrm{eV}$
- Disentanglement of ρdσ variations from other time varying effects
- Obtain deviation of FPD300 and FPD90 rates to reference point $\rightarrow$ Relative column density evolution



Column density determination



- Calibration of relative ρdσ to absolute ρdσ with e-gun cd-scan results
- Uncertainty on mean ρdσ $= 0.15\,\%$, TDR goal: $0.1\,\%$ to $0.2\,\%$

Summary and outlook

- Continuous monitoring of the column density
- Novel determination method with $0.15\,\%$ accuracy
- Upgrade of the existing photo-electron source $\rightarrow$ Commissioning measurements already started