

# COLUMN DENSITY DETERMINATION FOR THE KATRIN NEUTRINO MASS MEASUREMENT

DPG 2021

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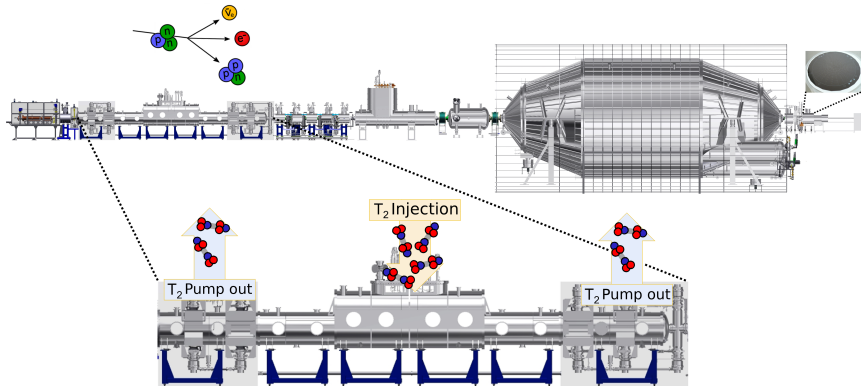
March 16, 2021

# Outline

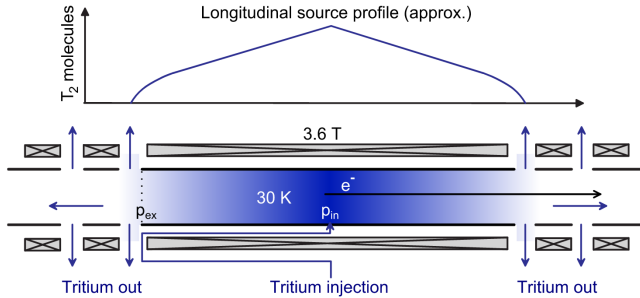
- 1 Column density as systematic parameter
- 2 Monitoring devices
- 3 First neutrino mass measurements
- 4 Outlook

# Windowless, Gaseous T<sub>2</sub> Source

- ▶ T<sub>2</sub> purity > 95 %
- ▶ Throughput:  
40 g/day (nominal)
- ▶ High activity:  
10<sup>11</sup> B<sub>q</sub> (nominal)



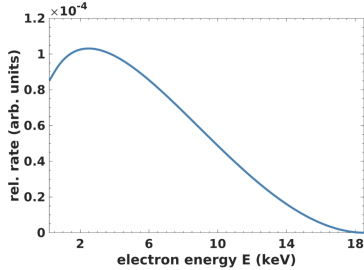
# Column density



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

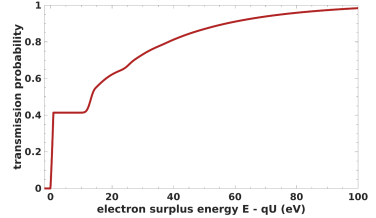
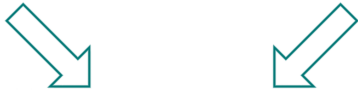


# Integral $\beta$ -spectrum

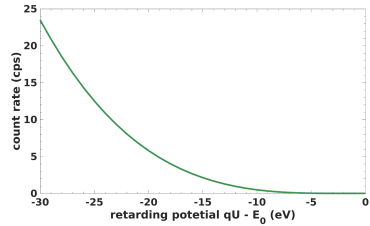


differential spectrum

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



response function

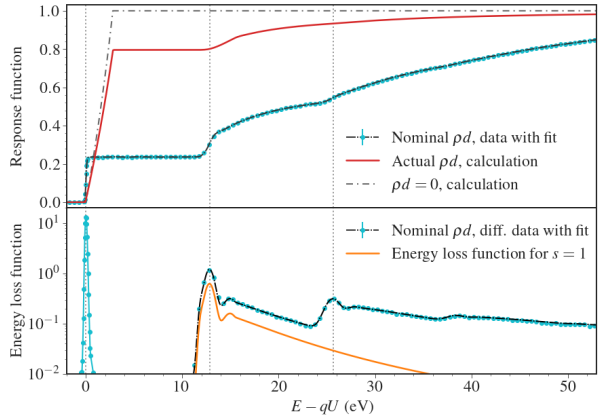


integral  $\beta$ -spectrum

# 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

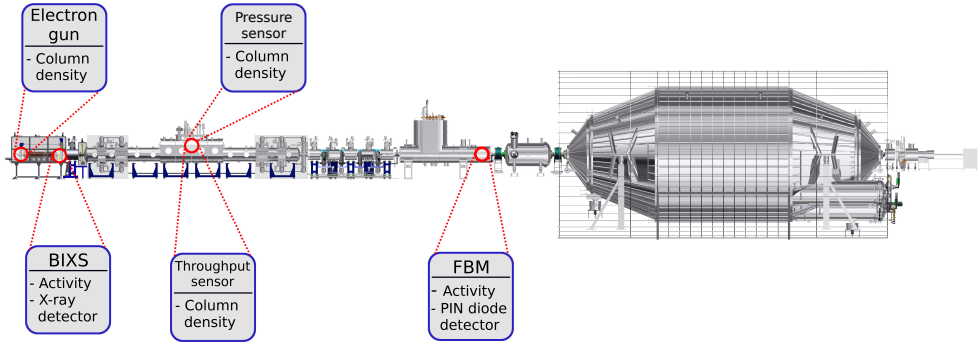


M. Aker et al., arXiv: 1909.06048

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# Tritium source monitoring: Overview



## ▶ Column density determination:

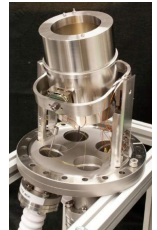
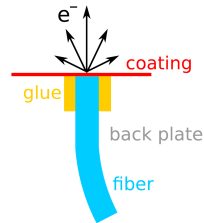
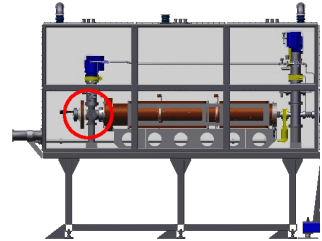
- ▶ Photo-electrons traverse the whole beamline
- ▶ Gas throughput sensor
- ▶ Gas pressure sensor

## ▶ Activity detectors:

- ▶ Fluctuations of the WGTS activity
- ▶ High precision on a timescale of minutes
- ▶ BIXS detector
- ▶ FBM detector

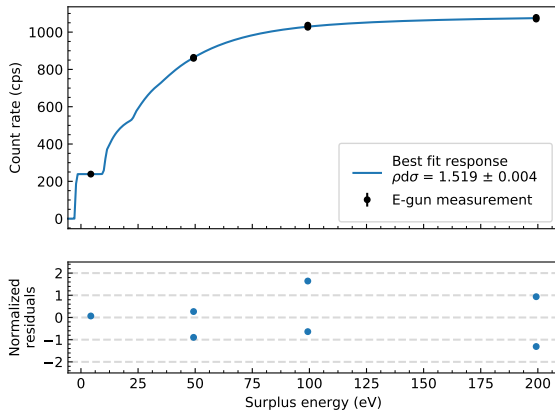
# Photo-electron source

- ▶ 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

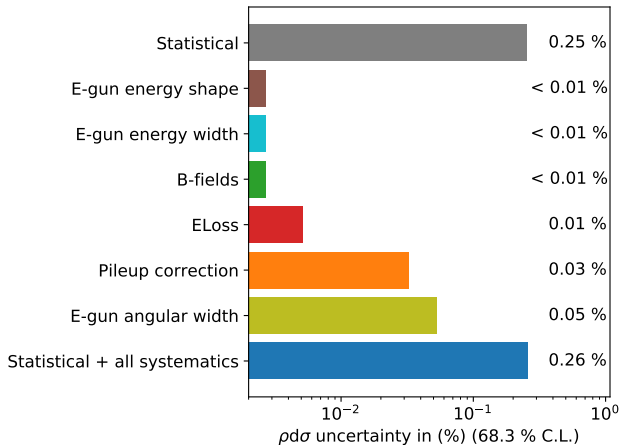


# Column density scan

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



# Uncertainty of $\rho d\sigma$ scan



- ▶ Error propagation via Covariance Matrix,  $V$
- ▶  $\chi^2 = (\vec{\mu} - \vec{N})^T V_{tot}^{-1} (\vec{\mu} - \vec{N})$
- ▶  $V_{tot} = V_1 + V_2 + \dots$
- ▶ Dominant systematic contributions:
  - ▶ Photo-electron angular width
  - ▶ Pileup correction

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# Measurement overview

► Tritium  $\beta$ -decay:

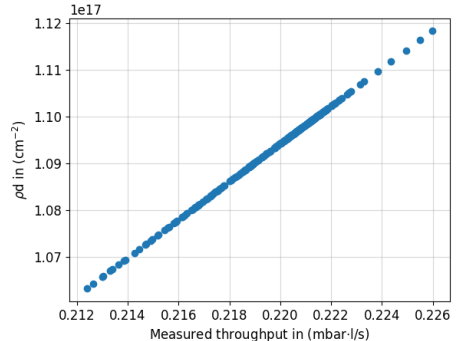
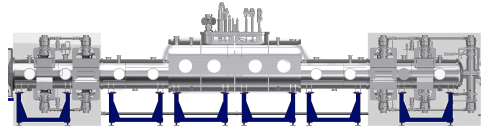
Information	KNM1	KNM2
Date	10.4.2019 - 13.5.2019	27.9.2019- 14.9.2019
Tritium purity	97.5 %	98.6 %
# e <sup>-</sup> in ROI	2 Mio	4.3 Mio

► Column density:

Information	KNM1	KNM2
Photo-electron source measurements	10	11
Continuous data taking with other monitoring devices	✓	✓

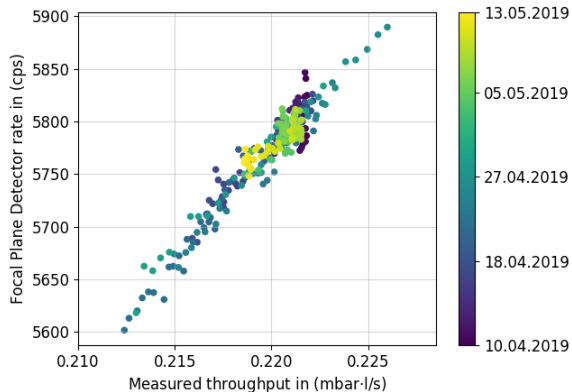
# Gas throughput sensor

- ▶ Estimation of column density with gas model
- ▶ Model parameter uncertainty
- ▶ Simultaneous measurement during tritium scans
- ▶ Idea: Combination of  $\rho d\sigma$  result from photo-electron source with throughput sensor value
- Precise continuous determination of the column density

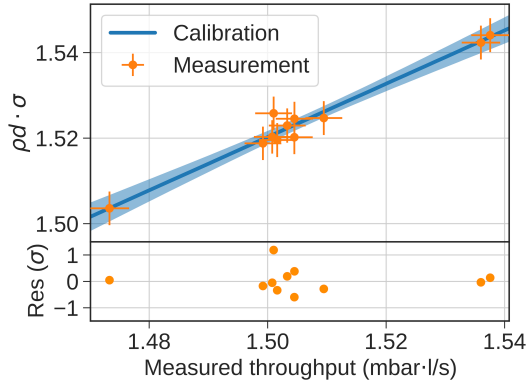


# Throughput sensor stability

- ▶ Comparison of:
  - ▶ Electron rate from tritium  $\beta$ -decay
  - ▶ Gas throughput value
- ▶ Strong correlation
- ▶ No time dependence

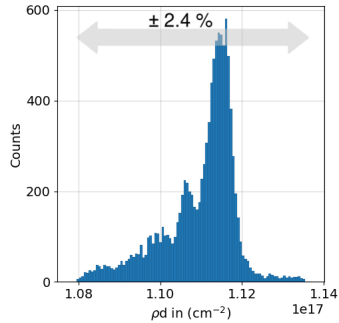
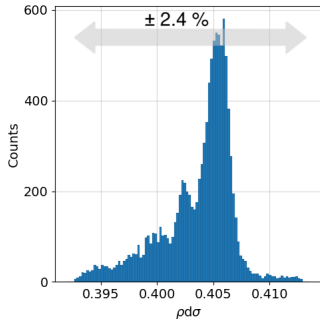


# Calibration of throughput to $\rho d \cdot \sigma$



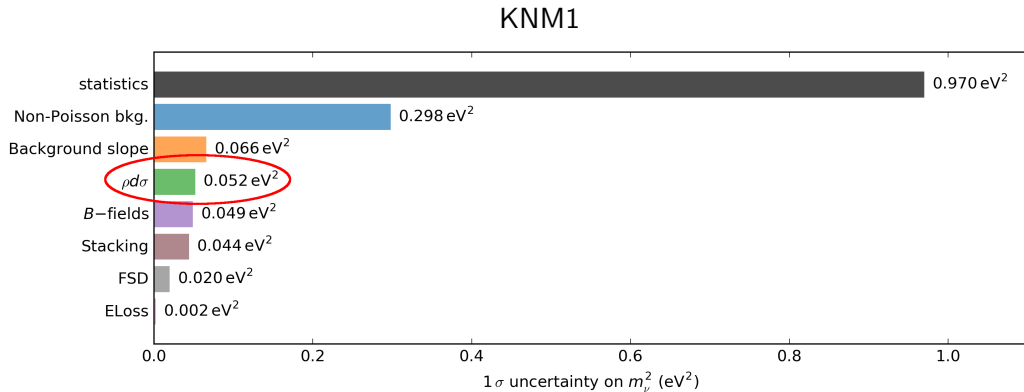
- ▶ Precise column density scans with photo-electron source
- ▶ Simultaneous values from throughput sensor
- ▶ Calibration of throughput to  $\rho d \sigma$  with linear model

# Column density in KNM1



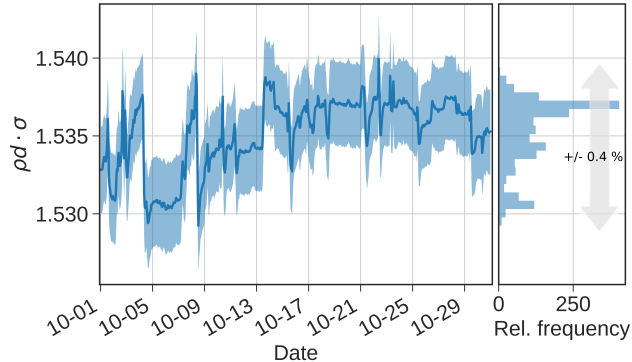
- ▶ 22 % of nominal value
- ▶ Uncertainty of  $\rho d\sigma < 0.85\%$
- ▶ Uncertainty of  $\rho d < 1.03\%$
- ▶ Goal for final KATRIN sensitivity:  $\rho d\sigma < 0.2\%$

# Effect on neutrino mass sensitivity



- Small impact of column density uncertainty

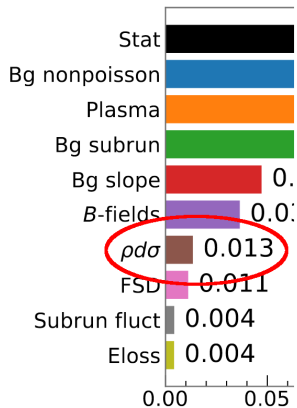
# Column density in KNM2



- ▶ 84 % of nominal value
- ▶ Uncertainty of  $pd\sigma < 0.25\%$
- ▶ Uncertainty of  $pd < 0.65\%$
- ▶ Goal for final KATRIN sensitivity:  $pd\sigma < 0.2\%$

# Effect on neutrino mass sensitivity

KNM2



To be approved

$1\sigma$  uncertainty on  $m_\nu^2$  (eV<sup>2</sup>)

- Small impact of column density uncertainty



# Summary and outlook

- ▶ Continuous monitoring of the column density
- ▶ First neutrino mass measurement campaign
  - ▶ Relative uncertainty  $\rho d\sigma < 0.85\%$
  - ▶ Relative uncertainty  $\rho d < 1.03\%$
- ▶ Second neutrino mass measurement campaign
  - ▶ Relative uncertainty  $\rho d\sigma < 0.25\%$
  - ▶ Relative uncertainty  $\rho d < 0.65\%$
- ▶ Upgrade of the existing photo-electron source

