First Neutrino Mass Measurement with the KATRIN Experiment

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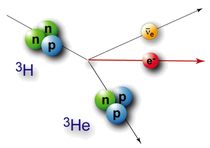
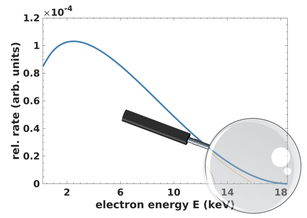
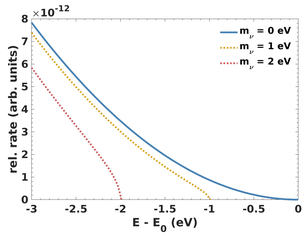
The Idea







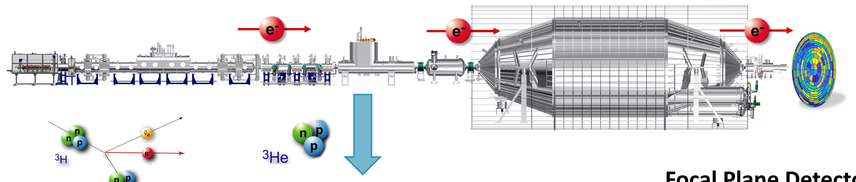
- Kinematics of tritium β-decay
- Spectral distortion from neutrino mass
- Effective electron anti-neutrino mass m_ν^2
- Design sensitivity 200 meV (90% C.L.)

$$m_\nu^2 = \sum_{i=1}^{3} |U_{ei}|^2 \, m_i^2$$

Measurement Principle

Tritium Source
- 95% gaseous T_2
- High activity $2 \cdot 10^{10}$ decays/s

Spectrometer
- MAC-E filter → High pass filter
- Energy resolution 2.7 eV



Transport and Pumping
- Transport of electrons
- Rejection of tritium ions

Focal Plane Detector
- Silicon detector
- 148 pixels
- Counts electrons

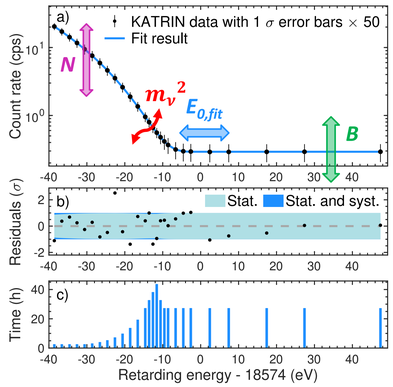
Analysis Strategy

Free Fit Parameter
1. m_ν^2 Neutrino mass
2. $E_{0,\mathrm{fit}}$ Endpoint
3. N Signal normalization
4. B Background rate (flat)
5. P_{FSD} Molecular final states (optional)

χ^2-Statistic

$$\chi^2 = \sum_{ij} (D_i - M_i)\, V_{ij}\, (D_j - M_j) + \chi^2_{\mathrm{pulls}}$$

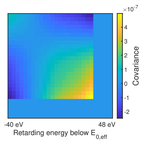
$M(m_\nu^2, E_{0,\mathrm{fit}}, N, B)$ = Model
D = Data
V = Covariance Matrix



Systematics Treatment

Covariance Matrix Approach

Propagation of systematic uncertainties:



1. Vary model within (correlated) uncertainties
   example: inel. scattering probability
2. Repeat $\mathcal{O}(10^4)$ times: Monte Carlo sample spectra
3. Estimate covariance matrix with Monte Carlo samples
4. Normalize covariance matrix to remove rate uncertainties
   → Shape-only analysis
5. Include covariance matrix in fit through χ^2 formula

$$V_{\mathrm{total}} = V_{\mathrm{scattering}} + V_{\mathrm{FSD}} + V \ldots$$

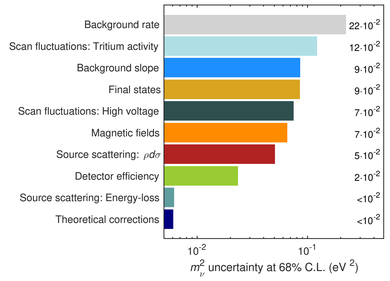
✓ HV set point correlations taken into account
✓ Applicable to data and simulation in the same way

Uncertainty breakdown

1st KATRIN Neutrino Mass Run
- Equivalent to 5 net days out of 1000 days nominal KATRIN
- Statistics dominated
- Most important systematics: Background

Relation to previous experiments
- Systematic uncertainty improved by factor 6
- Statistical uncertainty improved by factor 2

m_ν^2 uncertainty at 68.3% C.L.	
stat	0.94 eV^2
sys	0.30 eV^2
total	0.98 eV^2

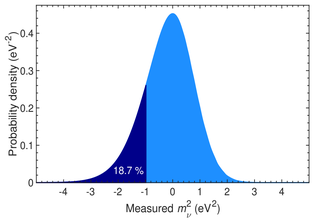


1st Neutrino Mass Measurement

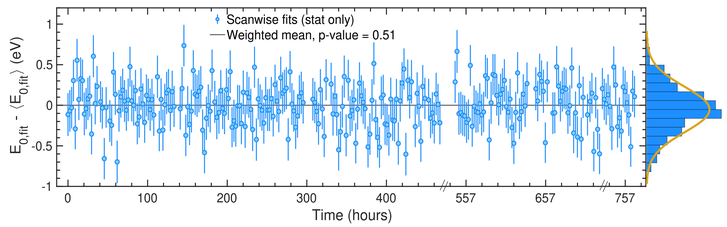
- April/March 2019: First physics run in KATRIN
- 23 days net measurement time
- 22% nominal tritium activity
- Twofold blinding scheme: data & model
- Full analysis chain developed on Monte Carlo data

Best fit

$$m_\nu^2 = -0.98^{+0.89}_{-1.06}\ \mathrm{eV}^2$$
$$\chi^2_{\mathrm{min}} = 21.4\ (23\ \mathrm{dof})$$

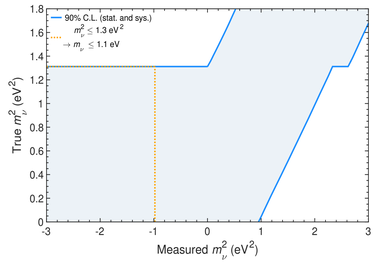


- 18.7% chance to measure $m_\nu^2 \leq -0.98\ \mathrm{eV}^2$ assuming $m_\nu^2 = 0\ \mathrm{eV}^2$
- Stable endpoint over 780 live hours

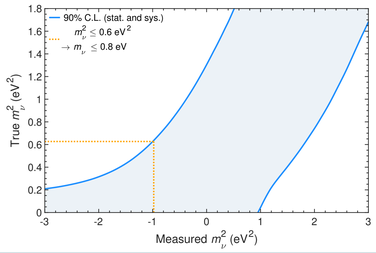


1st Neutrino Mass Limit

Lokhov-Tkachov Limit (Sensitivity Limit)
- $m_\nu \leq 1.1$ eV at 90% C.L.
- Constrain measured m_ν^2 to be positive in confidence belt construction
- Quote sensitivity for negative measured m_ν^2



Feldman-Cousins Limit
- $m_\nu \leq 0.8$ eV at 90% C.L.



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