New results on Neutrino Mass from the KATRIN Experiment

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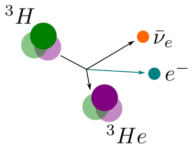
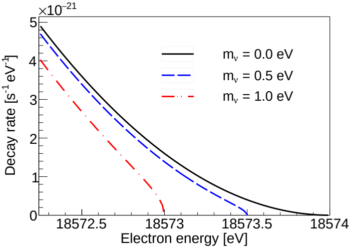
Neutrino mass from tritium beta decay

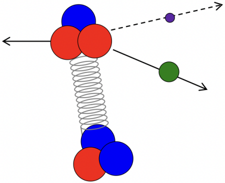
- Kinematics affected by neutrino mass
- Direct, model-independent measurement requiring high energy resolution $\Delta E \sim$ eV
- KATRIN sensitive to a degenerated neutrino mass scale

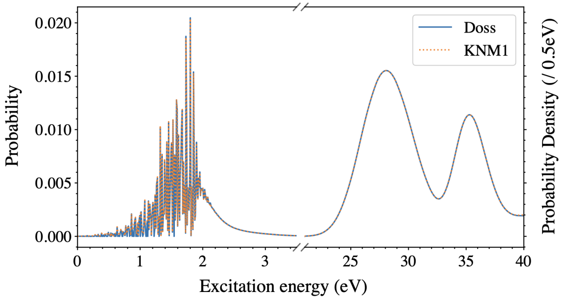


$$m_\nu = \sqrt{\sum_{i=1}^{3} |U_{ei}|^2 m_i^2}$$



Molecular tritium final state distribution

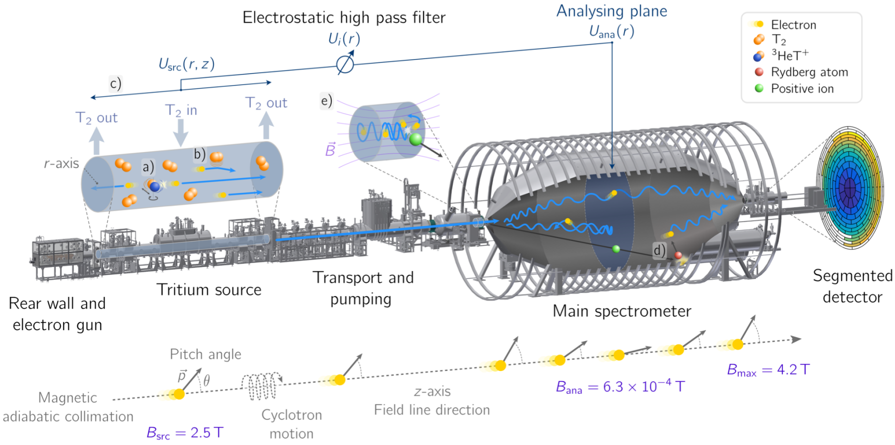




- Correction from rovibrational final states:

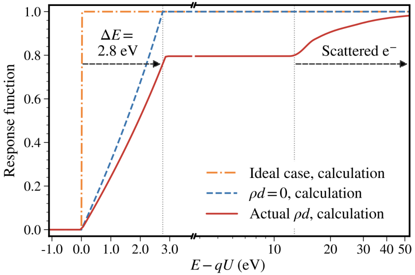
$$\frac{d\Gamma}{dE} \to \left(\frac{d\Gamma}{dE}\right)' = \sum_f P_f \left.\frac{d\Gamma}{dE'}\right|_{E'=E-V_f}$$

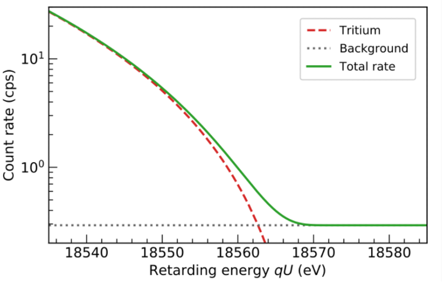
The KATRIN Experiment



Energy resolution characterized by $\frac{\Delta E}{E} = \frac{B_{ana}}{B_{max}} \sim 10^{-4}$.

Integrated spectrum to measure





- Pixel-wise response function

  - Filter width ΔE from transverse momentum at analyzing plane

  - Additional complexity from electron scattering

- Integrated spectrum

  - Flat background

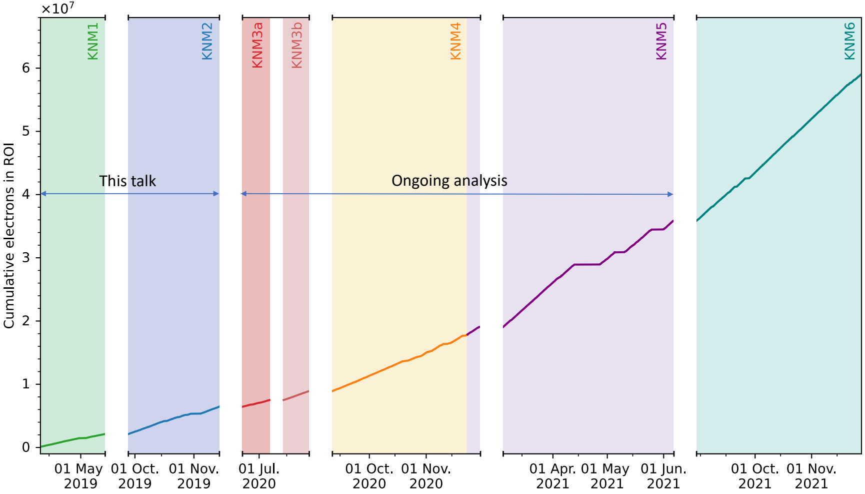
  - $N_j^{\text{sig}} \propto \int_{qU}^{\infty} \frac{d\Gamma}{dE} \cdot R_j(E, qU) dE$

  - Measurement time adjusted to maximize sensitivity

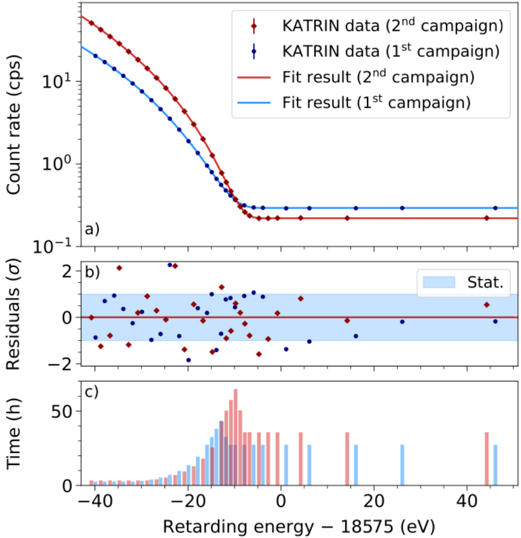
Background

- Steady-state background
  - Ionization of hydrogen Rydberg atoms from the recoiling ^{206}Pb in the ^{222}Rn decay chain, Poissonian
  - Primary and secondary electrons produced by scattering of trapped electrons from ^{219}Rn decays on residual gas, non-Poissonian
- Time-dependent background
  - Electrons produced from scattering of residual gas and trapped electrons between pre- and main spectrometer, removed after each scan by inserting an electron catcher
- Background rates are predicted to be nearly independent of high voltage settings

KATRIN timeline

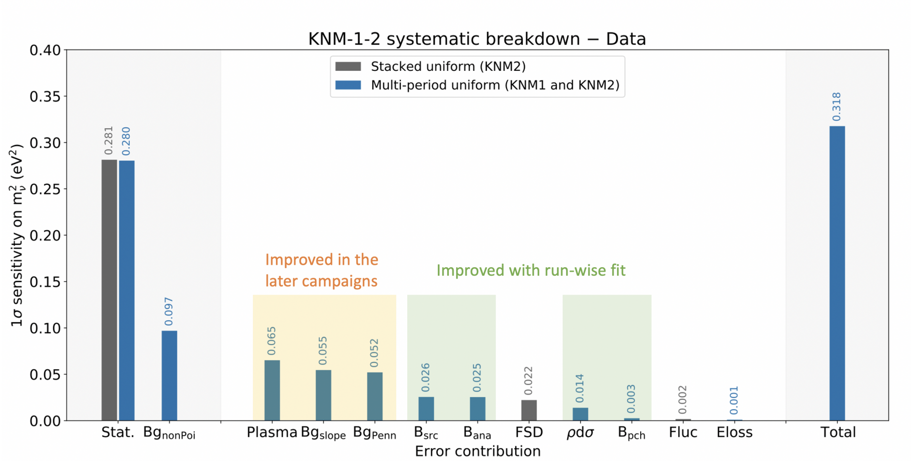


KNM1+KNM2 statistics



- Livetime for neutrino mass scan
  - KNM1: 22 days
  - KNM2: 31 days
- Source activity relative to nominal value
  - KNM1: 22%
  - KNM2: 84%
- Background rate
  - KNM1: 293 mcps
  - KNM2: 220 mcps

Breakdown of uncertainty



Analysis strategy and results

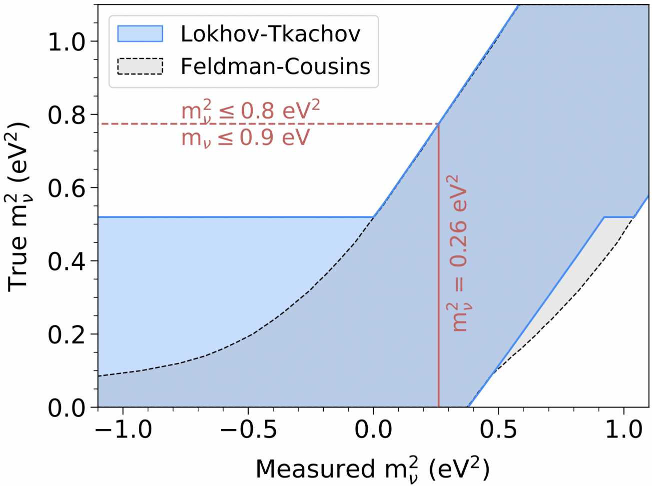
- Blind analysis
  - Generate artificial final state distributions for each campaign
  - Freeze all systematic inputs based on Monte Carlo data with blinded FSD
  - Unblind the FSD for real data

- Ring-wise fitting for golden run lists
  - 1 common m_ν^2, 12 $\times$ ring-wise endpoint, signal and background rates

- Three independent approaches: pull term, covariance matrix and Monte Carlo propagation

- Best fit value for m_ν^2, with extrapolated model in the negative region for Frequentist approach
  - KNM1: $m_\nu^2 = -1.0^{+0.9}_{-1.1}\mathrm{eV}^2$
  - KNM2: $m_\nu^2 = 0.26^{+0.34}_{-0.34}\mathrm{eV}^2$

First sub-eV upper limit on neutrino mass



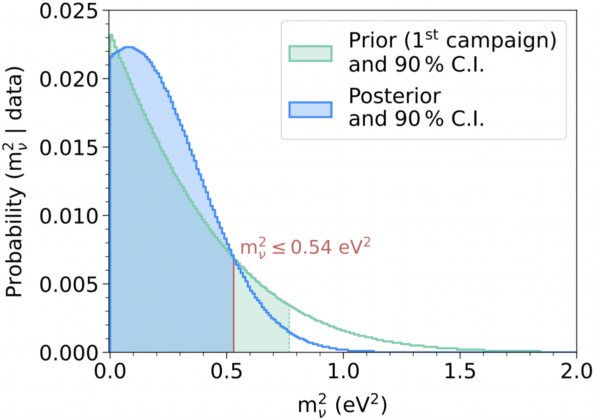
- KNM1 at 90% C.L.:
  $m_\nu < 1.1$eV
- KNM2 at 90% C.L.:
  $m_\nu < 0.9$eV
- Combined result at 90% C.L.:
  $m_\nu < 0.8$eV

Nature Physics 18.2 (2022): 160-166

Reference for the Lokhov-Tkachov construction:
Phys. Part. Nucl. 46, 347-365 (2015)

Bayesian combination of the two campaigns

$$\pi(\theta|y) \sim \pi(y|\theta) \cdot \pi(\theta)$$



- Currently based on generated covariance matrix

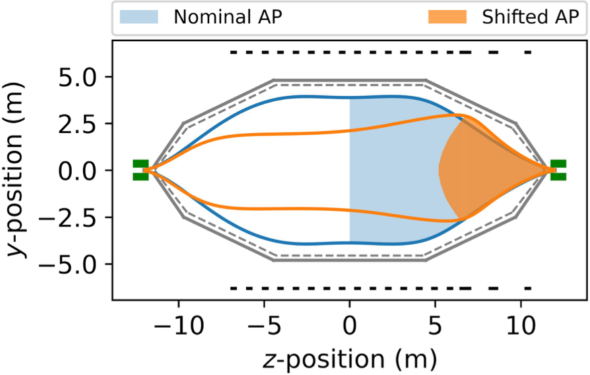
- Flat prior for KNM1

- KNM1 prior for KNM2

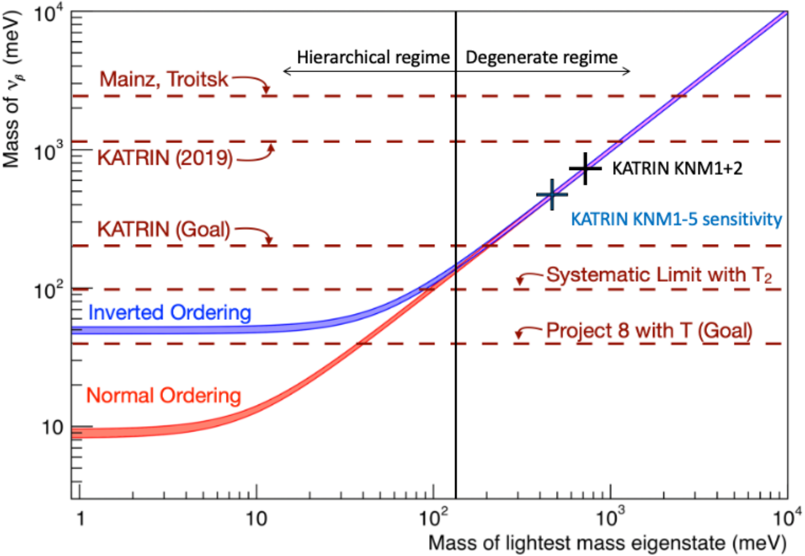
- Bayesian limit at 90% C.I.:
  $m_\nu < 0.7$eV

Improvements in the following campaigns

- Shifted analyzing plane – reduce 50% of background
- New Krypton source to reduce plasma systematics
- Eliminate background from penning trap
- Precise calculation of molecular final states

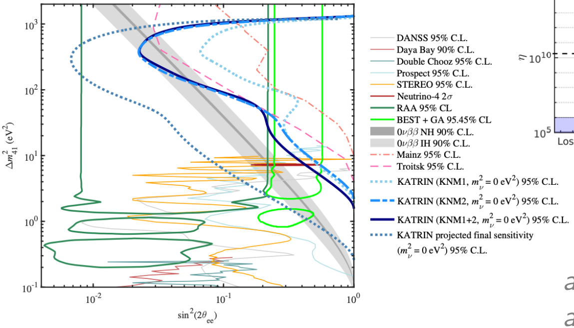


The future of neutrino mass measurements

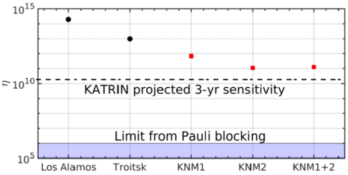


KATRIN: beyond neutrino mass

- Sterile neutrinos



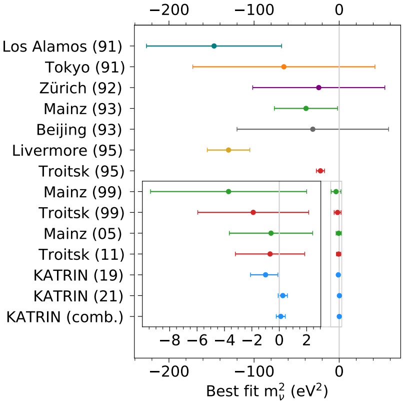
- Relic neutrinos



arXiv:2201.11593
arXiv:2202.04587

Summary

- KATRIN has improved the model-independent upper limit of $m_\nu < 0.8$eV at 90% C.L. with the first two measurement campaigns
- With various improvements, KATRIN has a better sensitivity reaching $m_\nu < 0.5$eV for the next three campaigns (data release planned by early 2023)



Thanks for your attention!

Backup: approaches to Neutrino mass

- Determine the neutrino masses with ...

	Cosmology	$\mathbf{0\nu\beta\beta}$	**Single β decay**
Observable	$\sum_i m_i$	$\lvert\sum_i U_{ei}^2 m_i\rvert^2$	$\sum_{i=1}^3 \lvert U_{ei}\rvert^2 m_i^2$
Upper limit	0.12eV	0.18eV	0.8eV
Dependency	ΛCDM	Majorana m_ν	Kinematics

Backup: Energy loss from multiple scattering