Karlsruhe Institute of Technology

SnowMass2021

Searches for BSM Physics with the KATRIN Experiment

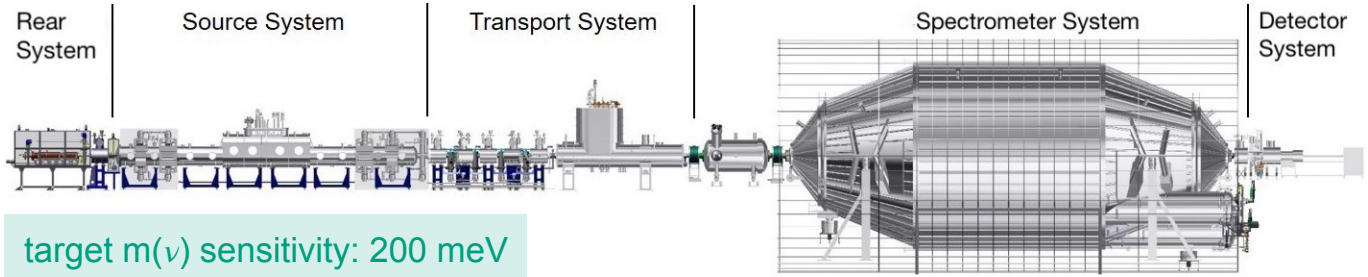
Snowmass 2021 | NF03 Workshop | September 17, 2020

K. Valerius for the KATRIN collaboration

- Active and sterile neutrinos (sub-eV … eV … keV scale)
- Right-handed currents and exotic weak interactions
- Cosmic relic neutrinos
- Lorentz invariance violation

KATRIN in a nutshell

- **Primary science mission:** measurement of effective electron neutrino mass through direct, kinematic method (precision β-decay spectroscopy of molecular tritium)
- **Requirements:** strong tritium source (~10^{11} β-decays/sec) at high purity & stability, high energy resolution (ΔE ~ 1 eV at E_0 ~ 18.6 keV), low background rate (~100 mcps or lower)



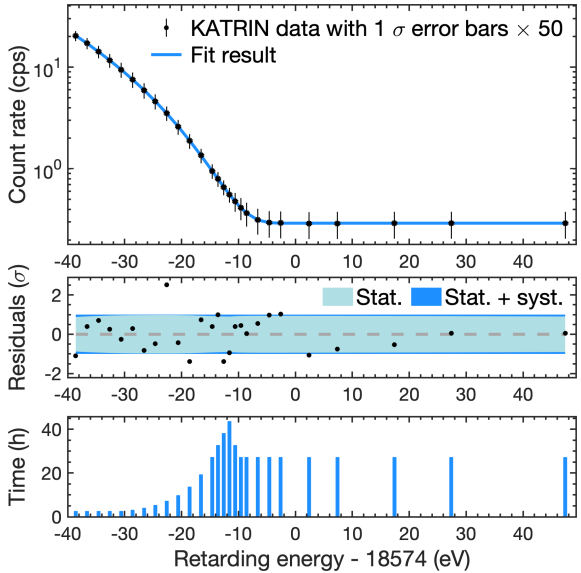
target m(ν) sensitivity: 200 meV

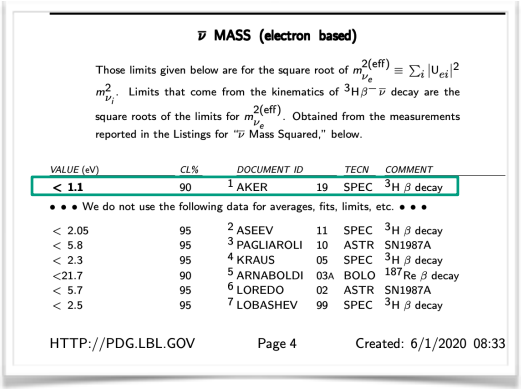
katrin.kit.edu

- **Deliverable:** precision β-decay spectrum measurement close to endpoint
  (typically E_0 - 40…100 eV; extendable to ~1600 eV at reduced source strength during commissioning or to full phase space with detector upgrade)

First neutrino-mass result

- Initial neutrino-mass data set (~ 4 weeks at reduced source strength) demonstrates excellent quality of measured spectra and model description
- Improved upper limit: m(ν) < 1.1 eV (90% CL) [PRL *123* (2019) 221802]





$\bar{\nu}$ MASS (electron based)

Those limits given below are for the square root of $m^{2(\text{eff})}_{\nu_e} \equiv \sum_i |U_{ei}|^2 m^2_{\nu_i}$. Limits that come from the kinematics of $^3\text{H}\beta^-\bar{\nu}$ decay are the square roots of the limits for $m^{2(\text{eff})}_{\nu_e}$. Obtained from the measurements reported in the Listings for "$\bar{\nu}$ Mass Squared," below.

VALUE (eV)	CL%	DOCUMENT ID		TECN	COMMENT
< 1.1	90	[1] AKER	19	SPEC	^{3}H β decay
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 2.05	95	[2] ASEEV	11	SPEC	^{3}H β decay
< 5.8	95	[3] PAGLIAROLI	10	ASTR	SN1987A
< 2.3	95	[4] KRAUS	05	SPEC	^{3}H β decay
<21.7	90	[5] ARNABOLDI	03A	BOLO	^{187}Re β decay
< 5.7	95	[6] LOREDO	02	ASTR	SN1987A
< 2.5	95	[7] LOBASHEV	99	SPEC	^{3}H β decay

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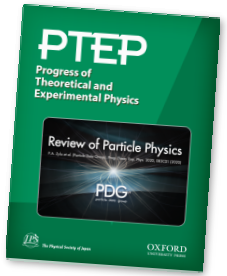
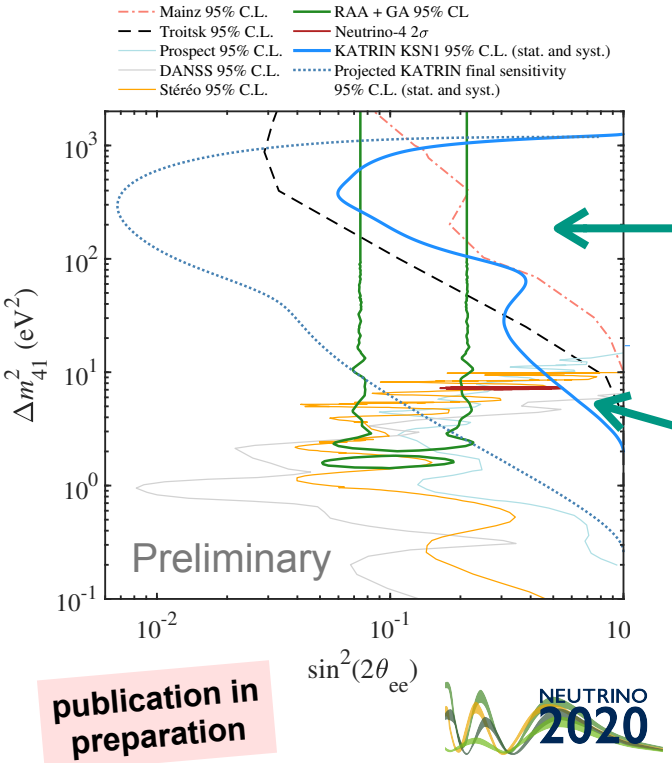


➜ Precision β-decay spectroscopy opens up sensitivity to look for a range of BSM phenomena through distortions of the spectral shape

Search for light sterile neutrinos



publication in preparation

Initial 4-week data set: Demonstrate potential of KATRIN to probe sterile neutrino hypothesis; complementarity with short-baseline oscillation experiments

Region of high Δm^2:

- Improve exclusion with respect to DANSS, PROSPECT, STÉRÉO
- Exclude large Δm^2 solution preferred by reactor & gallium anomalies

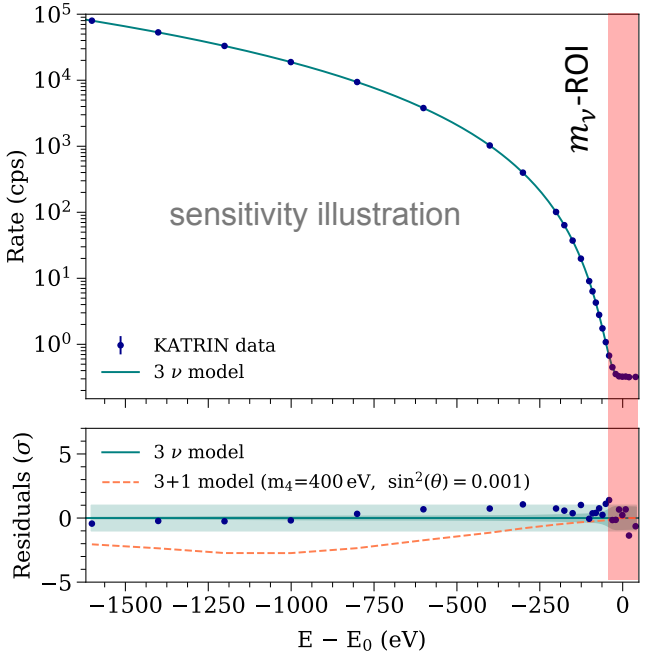
Region of low Δm^2:

- Improve limits by Mainz and Troitsk
- Neutrino-4 hint region is at the edge of our 95% exclusion

Outlook: Large fraction of reactor/gallium anomalies and Neutrino-4 hint will be probed with full KATRIN data set

see also Giunti++ 2020

Search for more massive sterile neutrinos

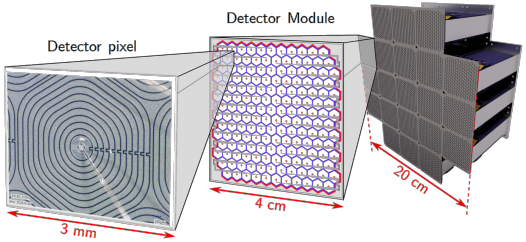


NEUTRINO 2020

- **Proof of principle:** Deep scan (1.6 keV) with low-activity commissioning data
- Excellent agreement of model and data
- Sensitivity to $\sin^2\theta = 10^{-3}$ at $m_4 = 0.4$ keV

publication in preparation

- **Future perspectives:** Novel multi-pixel Silicon Drift Detector array (TRISTAN)
  - High-statistics search, coverage of entire spectrum
  - Target sensitivity of $\sin^2\theta < 10^{-6}$



goal: operation in KATRIN by 2025

➜ see separate LOI (Mertens *et al.*) in NF02 “Sterile Neutrinos” for details!

Exotic weak interactions

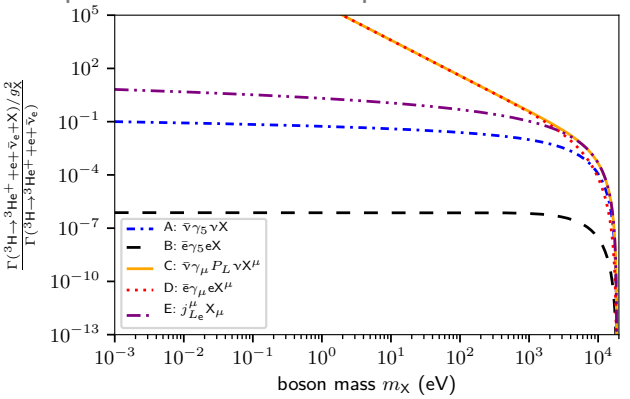
What if …

… weak interactions were hiding a left-right symmetric sector?

… additional, very light bosons might exist?

- Imprint of right-handed currents in tritium β-spectrum difficult to observe unless E_0 fixed externally
  ➜ e.g. Severijns++ 2006; Bonn++ 2011
- Picture could change in presence of sterile neutrinos and RH/LH interference
  ➜ see Barry, Heek & Rodejohann 1404.5955; Ludl & Rodejohann 1603.08690; Steinbrink++ 1703.07667

spectrum with vector or pseudoscalar boson *X*

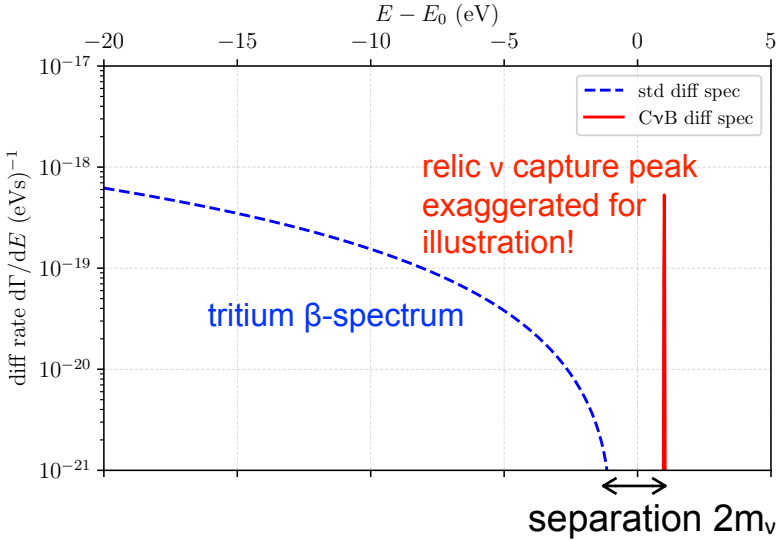


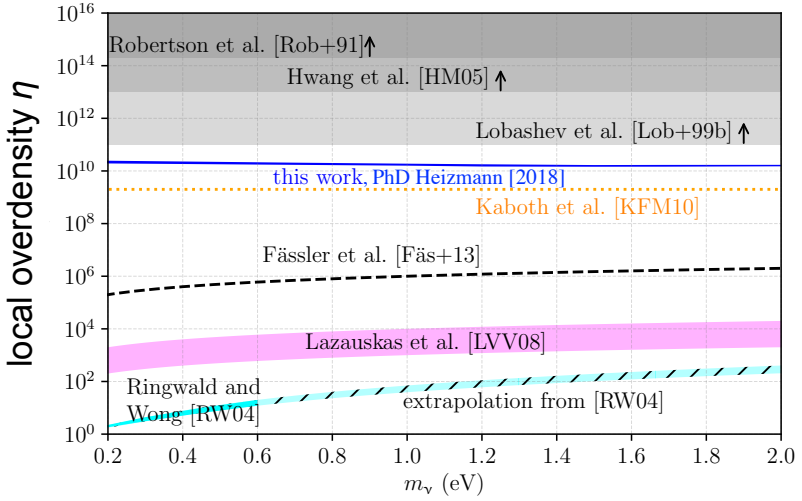
➜ see Arcadi++ 1811.03530

NB: Wider phase-space coverage of the β-spectrum beyond m(ν) search window will broaden the reach of BSM physics opportunities ➜ extra incentive for detector upgrade

Search for capture of relic neutrinos

Possibility of relic neutrino capture in KATRIN's gaseous T_2 source discussed in several works (e.g., Kaboth *et al.* 2010, Fässler *et al.* 2013, Heizmann 2018)





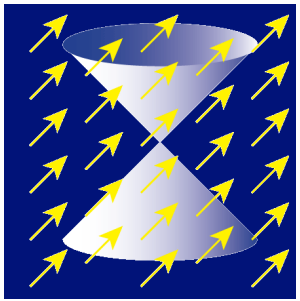
"Target" mass not likely to support detection, but could constrain local relic overdensities.

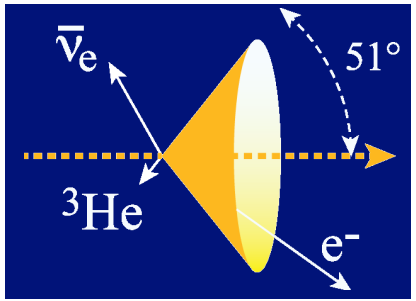
Probing Lorentz invariance with KATRIN

“Countershaded” LIV in neutrino sector: Oscillations and direct kinematics can probe complementary quantities (oscillation-free parameters accessible in endpoint experiments)

Standard Model Extension (SME), based on effective field theory + background fields:
Anisotropic effects could be observable at KATRIN (“intrinsic direction” via acceptance cone)

illustrations by R. Lehnert





Possible impact on tritium β-spectrum:

- Global shift of endpoint E_0
- Sidereal oscillation of E_0: can be looked for in repeated spectrum scans (typ. scan sequence ~2 hrs)

➜ See, e.g.: Colladay & Kostelecký 1998; Díaz, Kostelecký & Lehnert 1305.4636

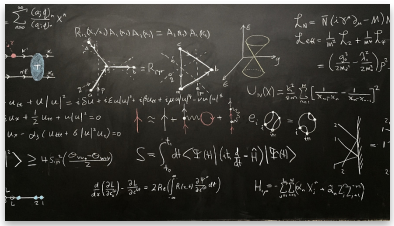
analysis in progress

➜ Presentation by J. Díaz in this workshop

Summary

- Direct kinematics of weak decays offer intriguing opportunities for BSM physics searches!

- KATRIN experiment (tritium β-decay):
  - First data release (2019) allowed for new neutrino-mass upper limit and demonstration of potential for sterile neutrino search.
  - Studies of more BSM cases ongoing
    (e.g. relic neutrinos, right-handed currents
    & light extra bosons, Lorentz invariance violation).
  - … further ideas & proposals welcome! :)



https://physics.anu.edu.au

- Data-taking in progress (goal: 1000 measurement days or ~5 calendar years in total), plans for subsequent detector upgrade will further boost BSM search at KATRIN.

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*) no attempt at completeness; rather a starting point for further reading

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