Search for new light bosons with the KATRIN experiment

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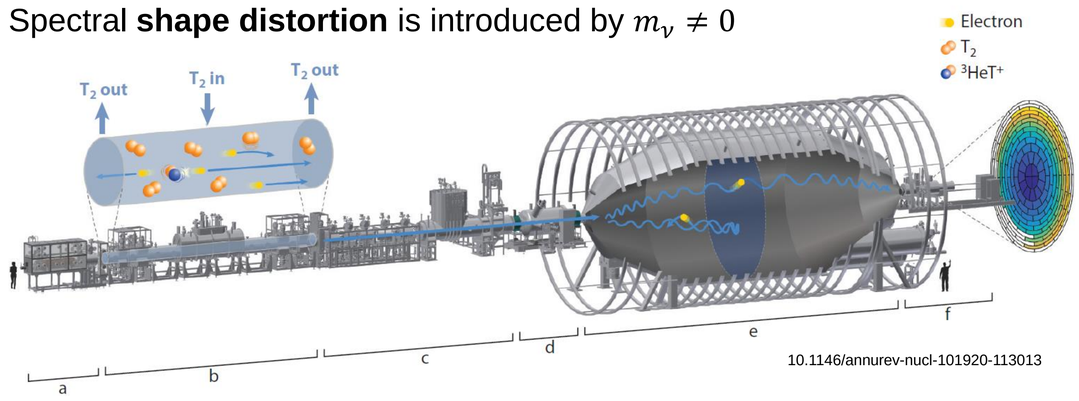
Neutrino mass measurement with the Karlsruhe Tritium Neutrino (KATRIN) experiment

- Tritium β-decay precision spectroscopy (endpoint $E_0 = 18.6\,\mathrm{keV}$)
- **Three-body decay kinematics**: electron energy spectrum $\mathrm{d}\Gamma/\mathrm{d}E|_\beta$ of

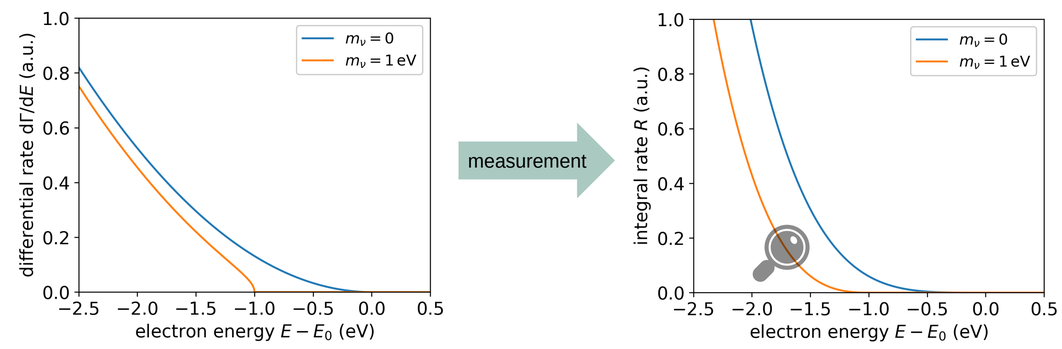
$$\mathrm{T}_2 \rightarrow {}^3\mathrm{HeT}^+ + e^- + \bar{\nu}_e$$

- Spectral **shape distortion** is introduced by $m_\nu \neq 0$



10.1146/annurev-nucl-101920-113013

- Electron spectroscopy close to E_0 via magnetic adiabatic collimation and electrostatic filtering (MAC-E principle, section e in figure)
- Integral measurement: $2.8\,\mathrm{eV}$ resolution at E_0 (1.5×10^{-4} relative precision)
- Observable: *effective* mass-square $m^2_{\bar{\nu}_e} = \sum_i |U_{ei}|^2\, m_i^2 \;\Rightarrow\; \boldsymbol{m_{\bar{\nu}_e}}$ (eff.)



- Current limit (from 259 days): $m_\nu < 0.45\,\mathrm{eV}\ (90\%\ \mathrm{CL})$ 10.48550/arXiv.2406.13516
- Sensitivity goal: $m_\nu < 0.3\,\mathrm{eV}\ (90\%\ \mathrm{CL})$

Beyond standard decay

- **Bosons X coupling** $\propto \boldsymbol{g_{(\ell)X}}$ to leptons $\ell = \nu, e$ in BSM theories, e.g.

- Pseudoscalars $X = J$ via $\mathrm{i}\boldsymbol{g_{\nu J}}\bar{\nu}\gamma_5\nu J$, $\mathrm{i}\boldsymbol{g_{eJ}}\bar{e}\gamma_5 eJ$
- Vector-bosons $X = Z'$ via $\boldsymbol{g_{\nu Z'}}\bar{\nu}\gamma^\mu P_\mathrm{L}\nu Z'_\mu$, $\boldsymbol{g_{eZ'}}\bar{e}\gamma^\mu eZ'_\mu$, $\boldsymbol{g_{LZ'}}j^\mu_{L_e}Z'_\mu$

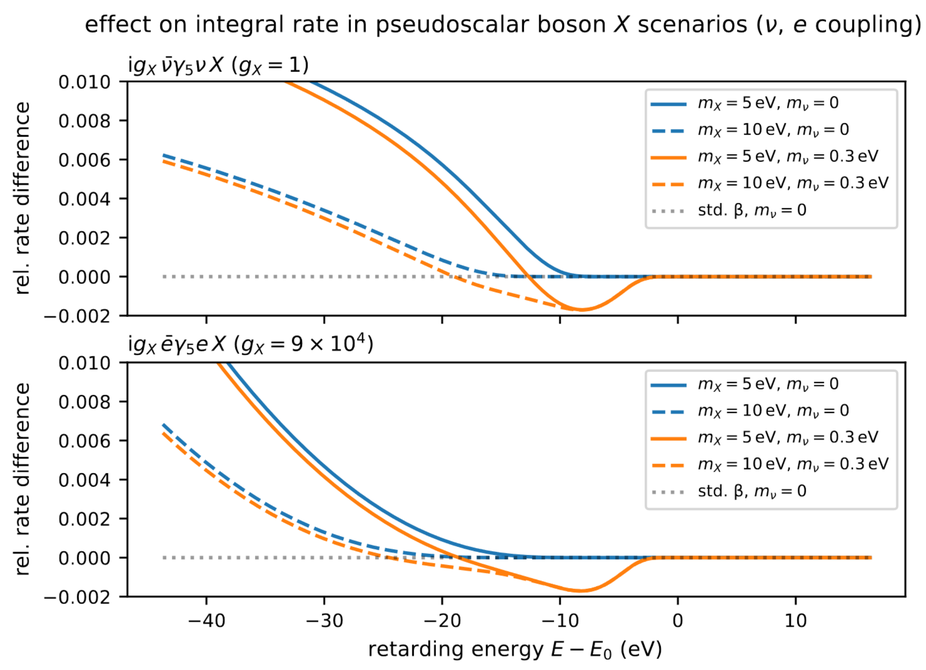
10.1007/JHEP01(2019)206

- Modified tritium β-decay: additional **four-body decay** channel

$$\mathrm{T}_2 \rightarrow {}^3\mathrm{HeT}^+ + e^- + \bar{\nu}_e + X$$

- Real boson emission → new spectral branch $\mathrm{d}\Gamma/\mathrm{d}E|_X \propto g_X^2$ (decay rate $\Gamma_\beta \rightarrow \Gamma_\beta + \Gamma_X$)
- Boson mass $\boldsymbol{m_X}$ limited by available decay energy → **light new physics** $< 20\,\mathrm{keV}$

- → new parameters: boson mass $\boldsymbol{m_X}$ and coupling $\boldsymbol{g_X}$
- Spetral shape depends on interaction structure and boson mass



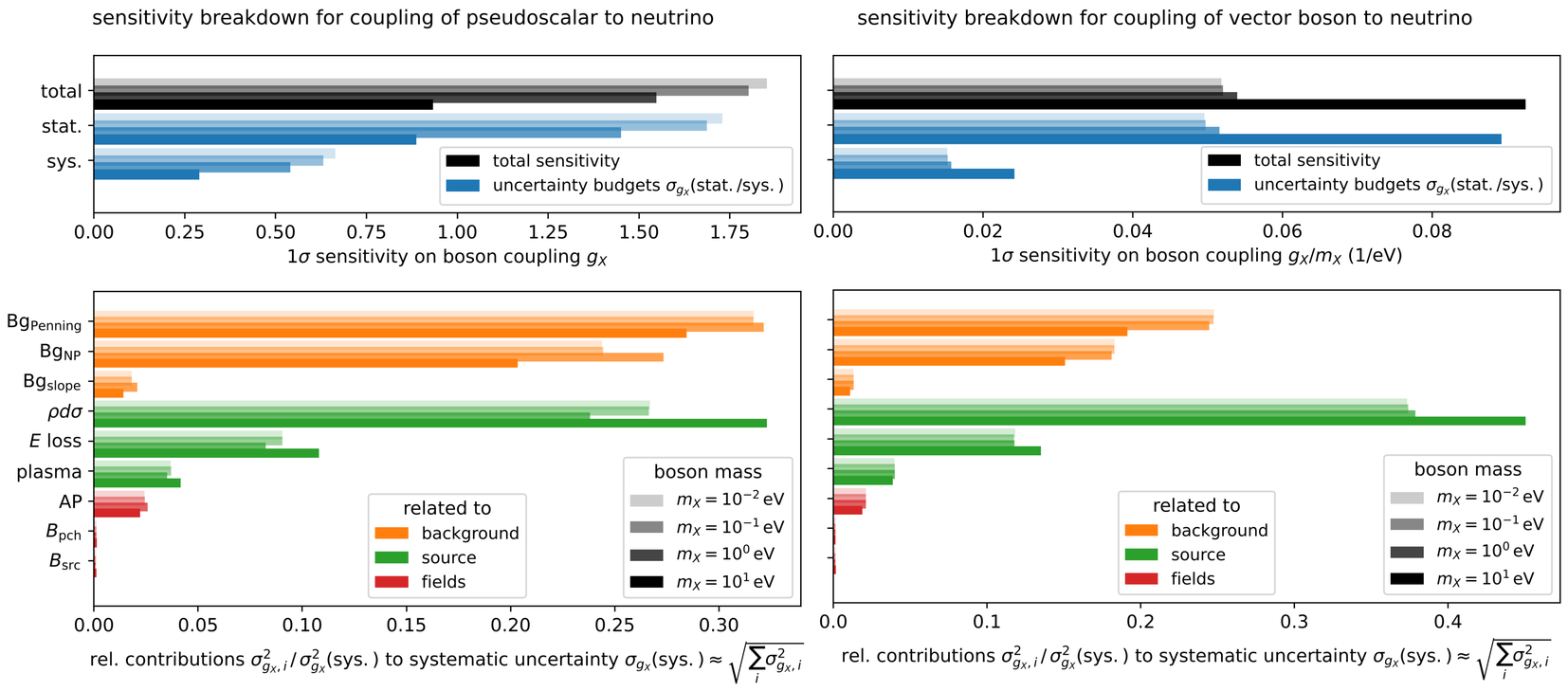
This analysis: dataset *KNM2* (2019)

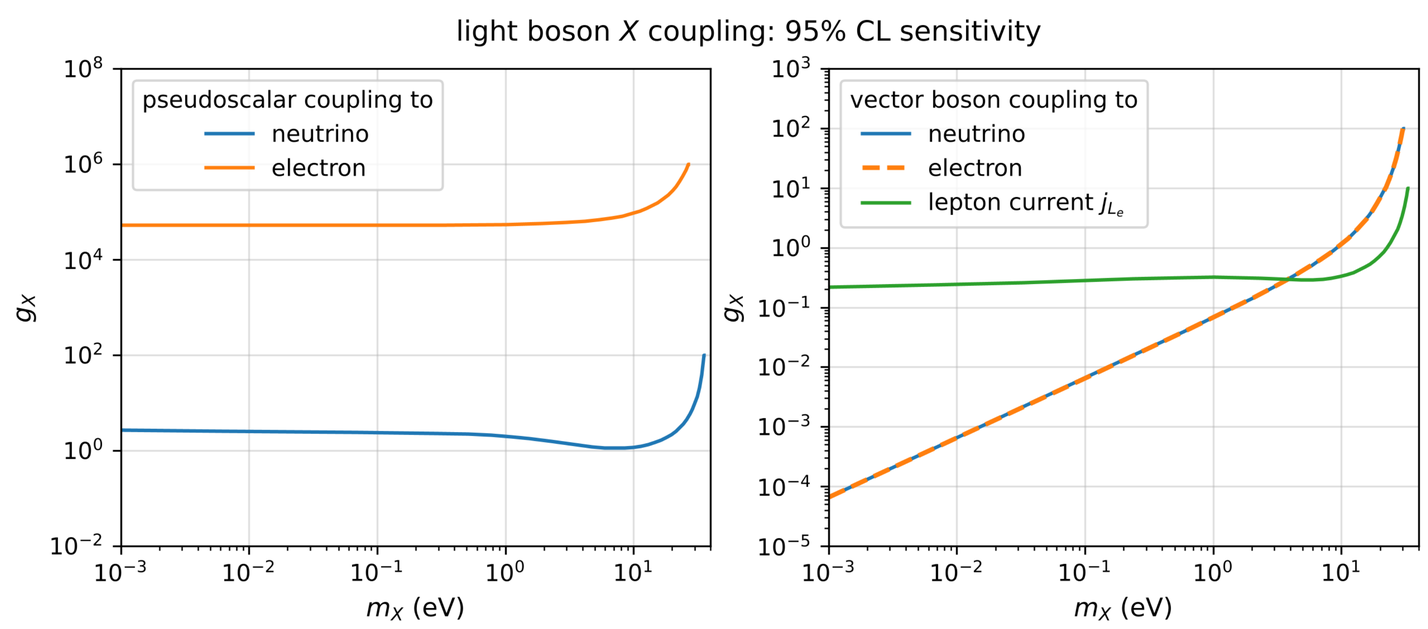
- $= 2^{\mathrm{nd}}$ KATRIN measurement campaign
- 45 days, 4×10^6 electrons in ROI
- ROI: $[-40, +130]\,\mathrm{eV}$ around E_0

Experimental sensitivity

- Sensitivity estimation based on synthetic Asimov MC data of KNM2
- Model computation based on **type** of interaction and $\boldsymbol{g_X}$, $\boldsymbol{m_X}$
- Experimental reponse function and corrections are applied to theo. spectrum
- Maximum likelihood fits across parameter space of interest
- **Systematic effects** included by means of pull terms → breakdown of impacts

- **Right:** comparison of the two scenarios with exclusive neutrino coupling





Light boson sensitivity of KATRIN

- Based on 45 days of measurement in 2019
- → dominated by statistics, systematic contributions differ between the considered BSM scenarios

- → KATRIN: an interesting **complementary and model-independent laboratory probe**, due to **direct** access to new light physics
- Couplings are investigated at **energy scale** of Q-value, i.e. below $20\,\mathrm{keV}$

- Analysis for eV-scale bosons can be repeated with data obtained in the first KATRIN science runs

We acknowledge the support of Helmholtz Association (HGF), Ministry for Education and Research BMBF (05A23PMA, 05A23PX2, 05A23VK2, and 05A23WO6), the doctoral school KSETA at KIT, Helmholtz Initiative and Networking Fund (grant agreement W2/W3-118), Max Planck Research Group (MaxPlanck@TUM), and Deutsche Forschungsgemeinschaft DFG (GRK 2149 and SFB-1258 and under Germany's Excellence Strategy EXC 2094 – 390783311) in Germany; Ministry of Education, Youth and Sport (CANAM-LM2015056, LTT19005) in the Czech Republic; Istituto Nazionale di Fisica Nucleare (INFN) in Italy; the National Science, Research and Innovation Fund via the Program Management Unit for Human Resources & Institutional Development, Research and Innovation (grant B37G660014) in Thailand; and the Department of Energy through Awards DE-FG02-97ER41020, DE-FG02-94ER40818, DE-SC0004036, DE-FG02-97ER41033, DE-FG02-97ER41041, DE-SC0011091 and DE-SC0019304 and the Federal Prime Agreement DE-AC02-05CH11231 in the United States. This project has received funding from the European Research Council (ERC) under the European Union Horizon 2020 research and innovation programme (grant agreement No. 852845). We thank the computing cluster support at the Institute for Astroparticle Physics at Karlsruhe Institute of Technology, Max Planck Computing and Data Facility (MPCDF), and the National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Laboratory.