Karlsruher Institut für Technologie

Probing the neutrino mass scale with the KATRIN experiment

TAUP2023 – Vienna – August 30, 2023

Alexey Lokhov on behalf of the KATRIN collaboration
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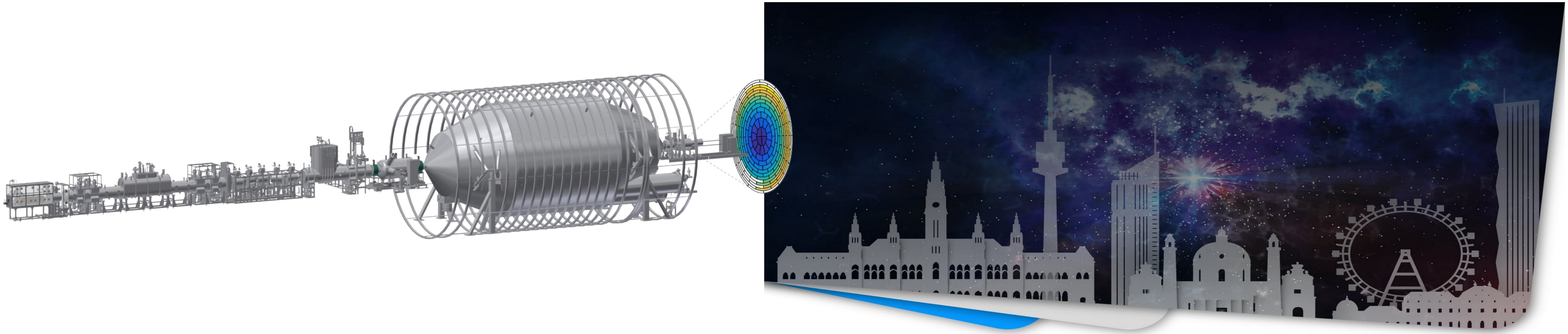
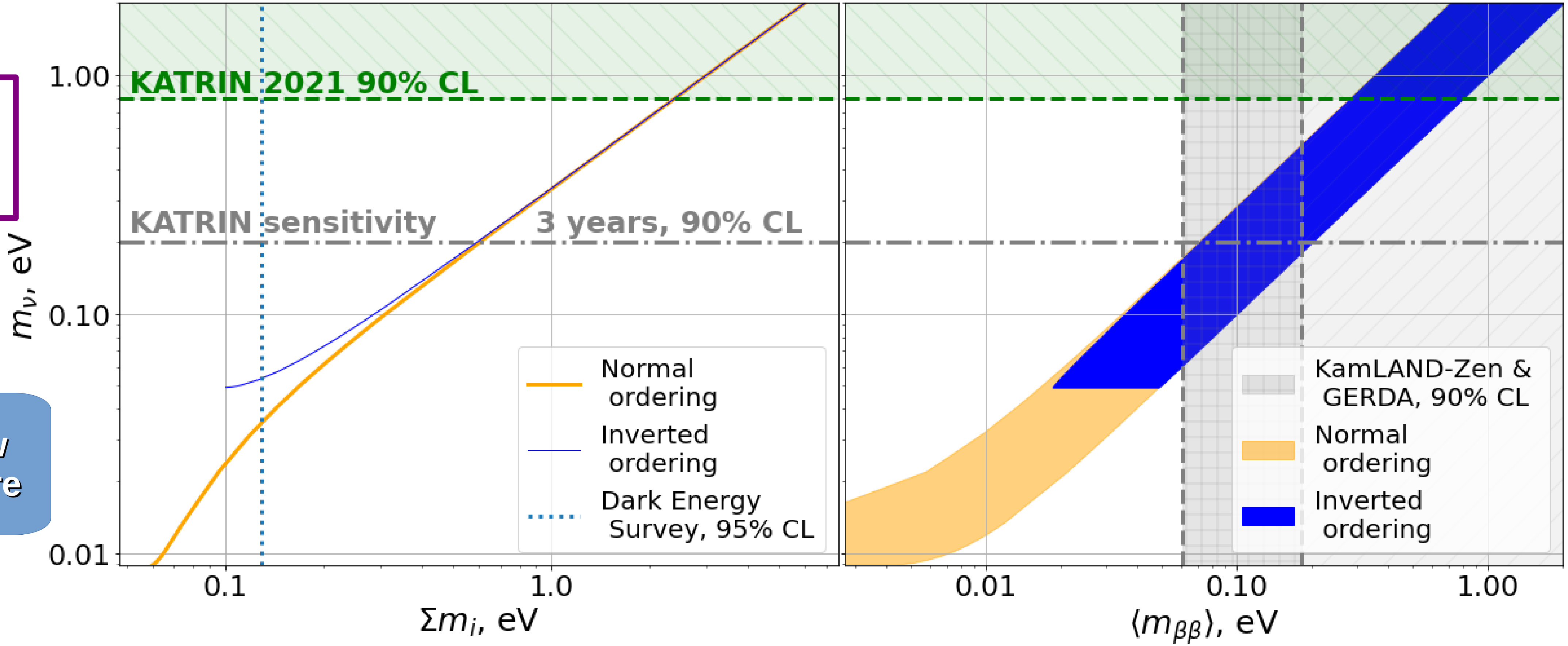


Three ways to assess the absolute neutrino mass scale

Direct neutrino mass determination

See overview by Th.Lasserre



Cosmological observables **Neutrinoless double β-decay**

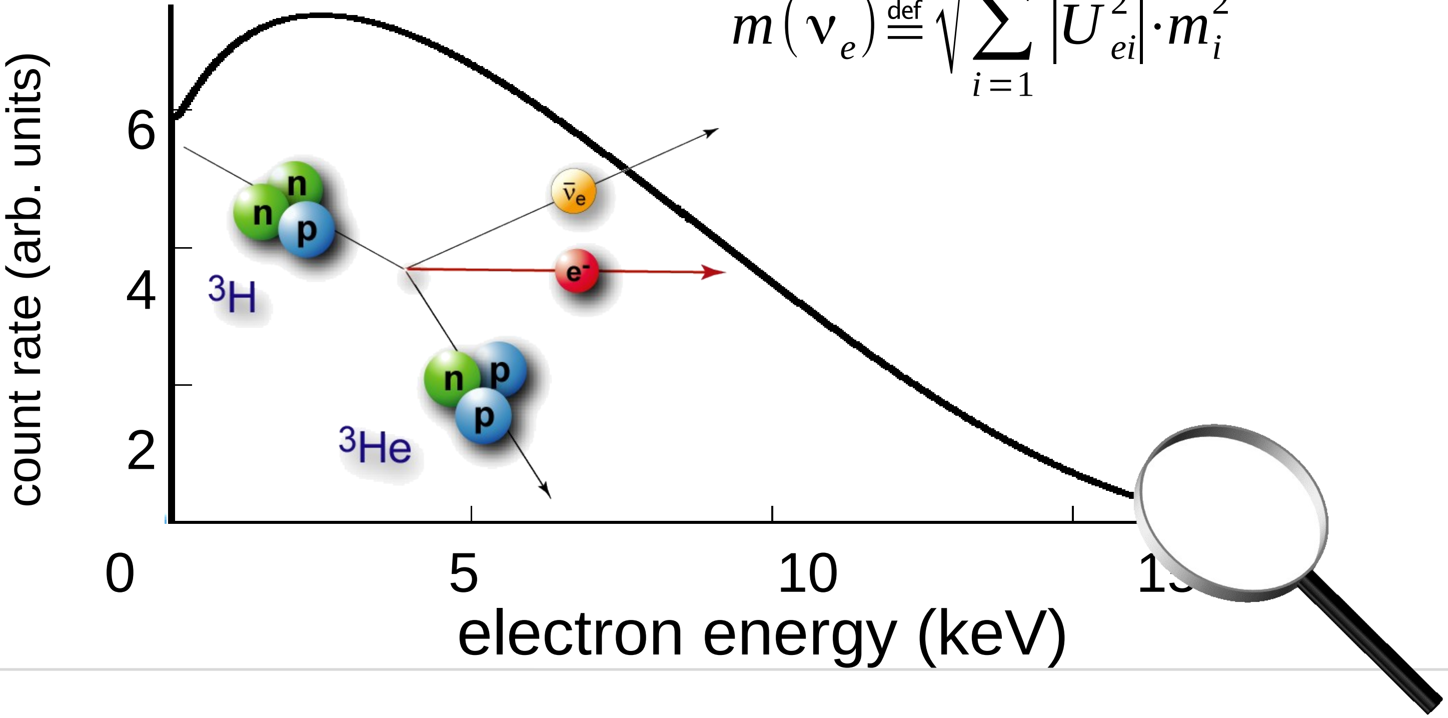
Ann.Rev.Nucl.Part.Sci. 72 (2022) 259-282

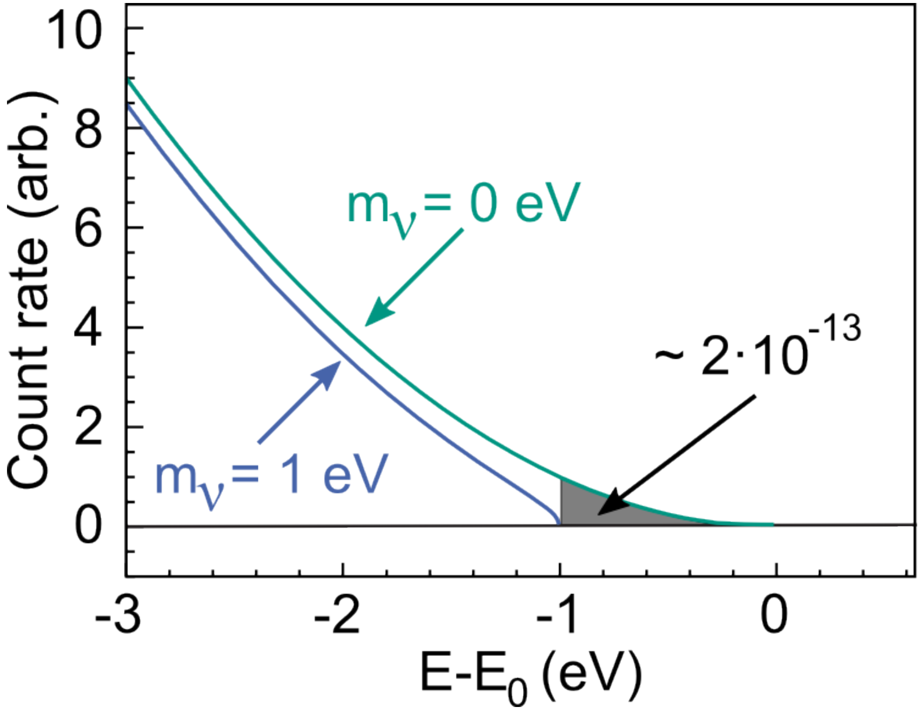
Tritium β-decay

Continuous β-spectrum described by Fermi´s Golden Rule, measurement of effective mass m(ν_e) based on **kinematic parameters & energy conservation**

$$\frac{d\Gamma}{dE}=C\cdot p\cdot(E+m_e)\cdot(E_0-E)\cdot\sum_{i=1}^{3}\left|U_{ei}^2\right|\cdot\sqrt{(E_0-E)^2-m_{\nu_i}^2}\cdot F(E,Z)\cdot\theta(E_0-E-m_{\nu_i})$$

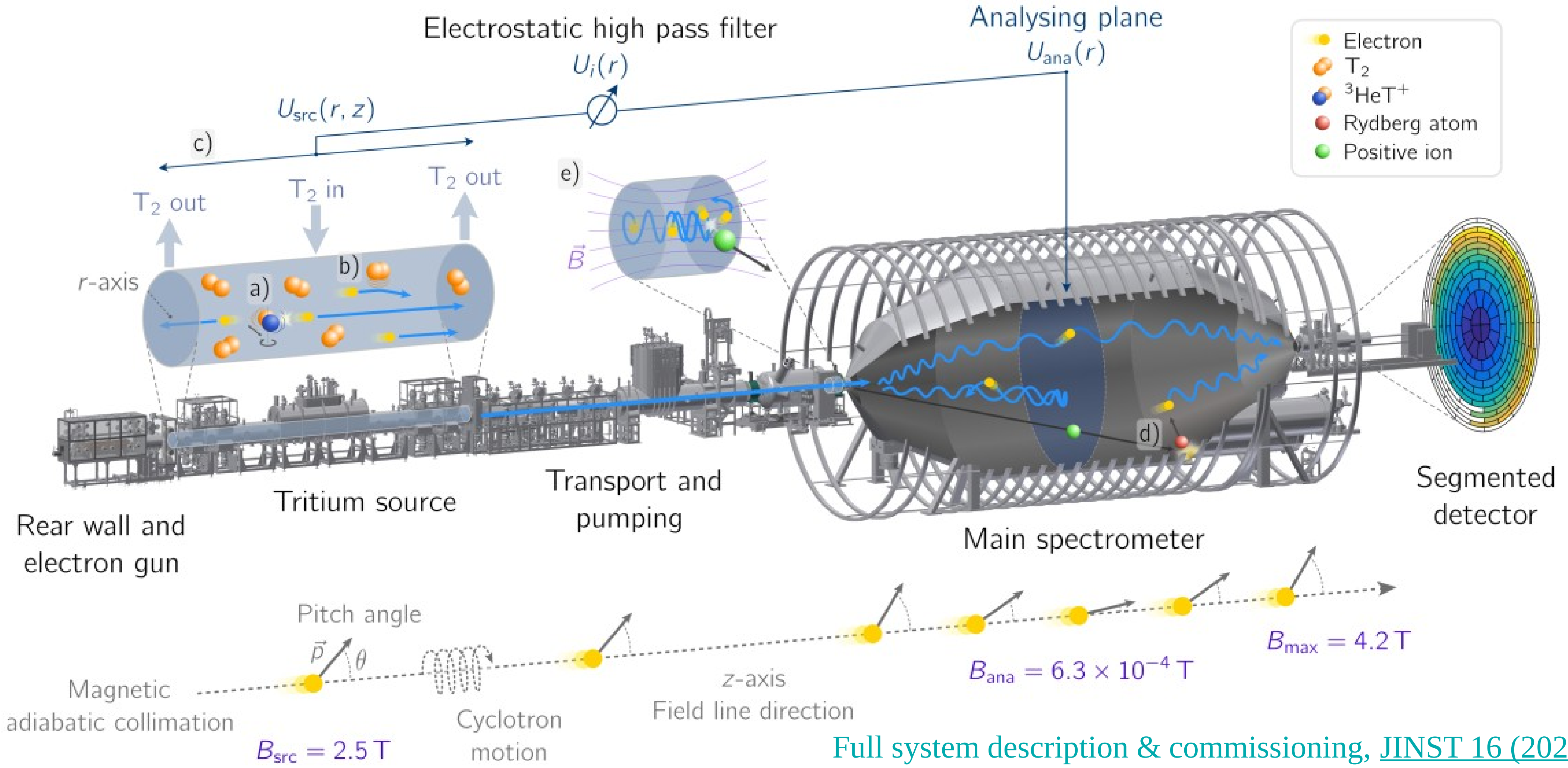
$$m(\nu_e)\stackrel{\text{def}}{=}\sqrt{\sum_{i=1}^{3}\left|U_{ei}^2\right|\cdot m_i^2}$$





KATRIN: Karlsruhe Tritium Neutrino Experiment

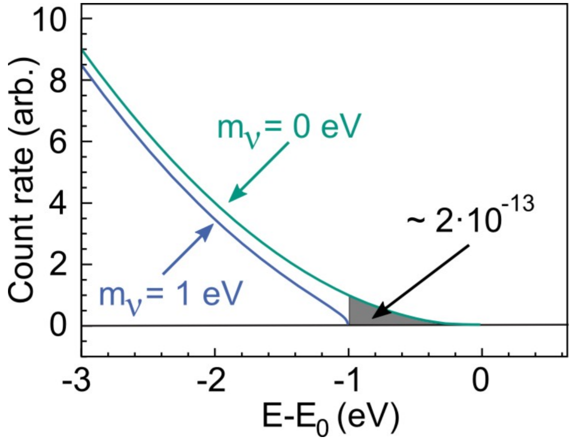
KATRIN experiment



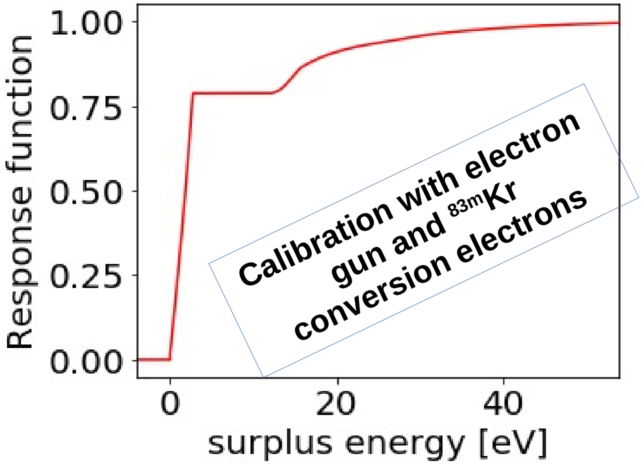
Full system description & commissioning, [JINST 16 (2021) T08015]

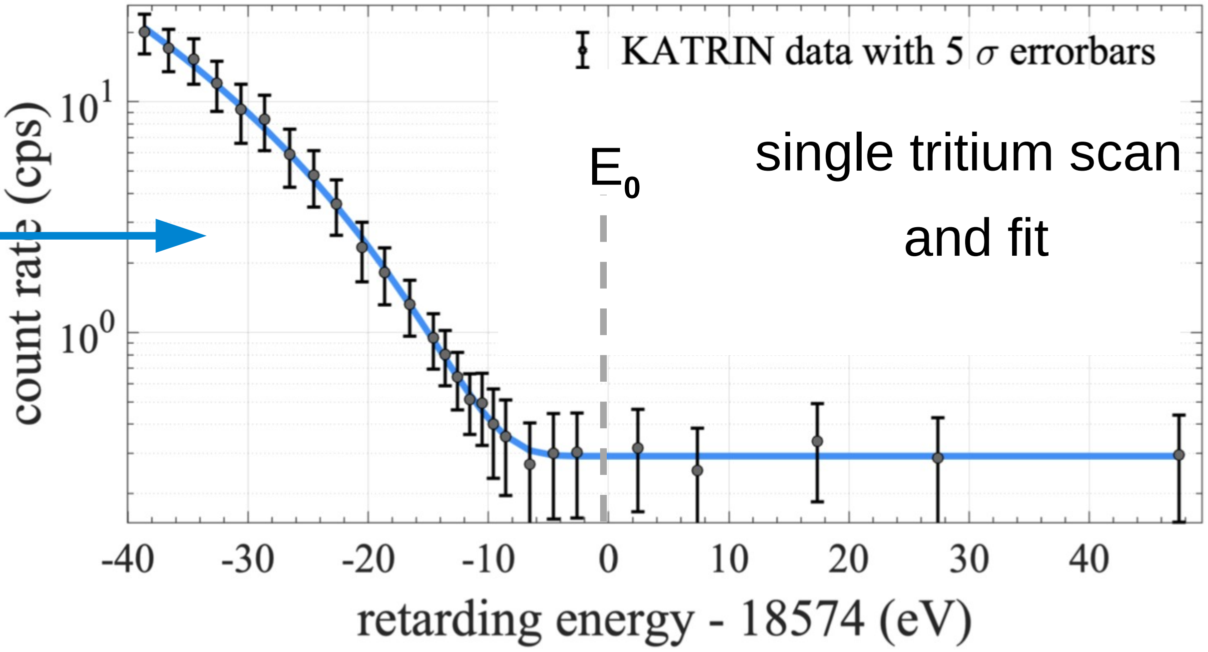
Beta-spectrum and neutrino mass

- **Beta spectrum: $R_\beta(E, m^2(\nu_e))$**



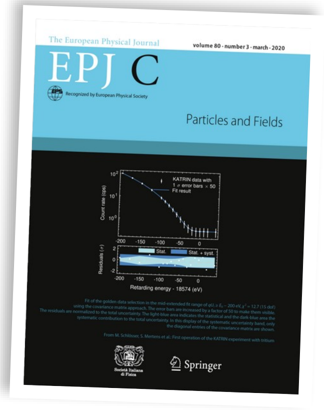
- **Experimental response: f(E-qU)**





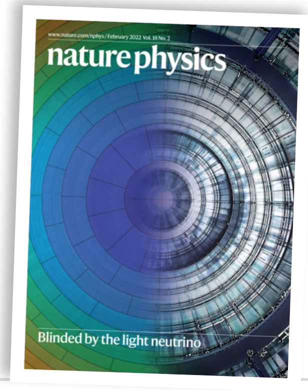
$$R(qU) = A_s \cdot N_T \int_{qU}^{E_0} R_{ß}(E, m^2(\nu_e)) \cdot f(E - qU)\, dE + R_{bg}$$

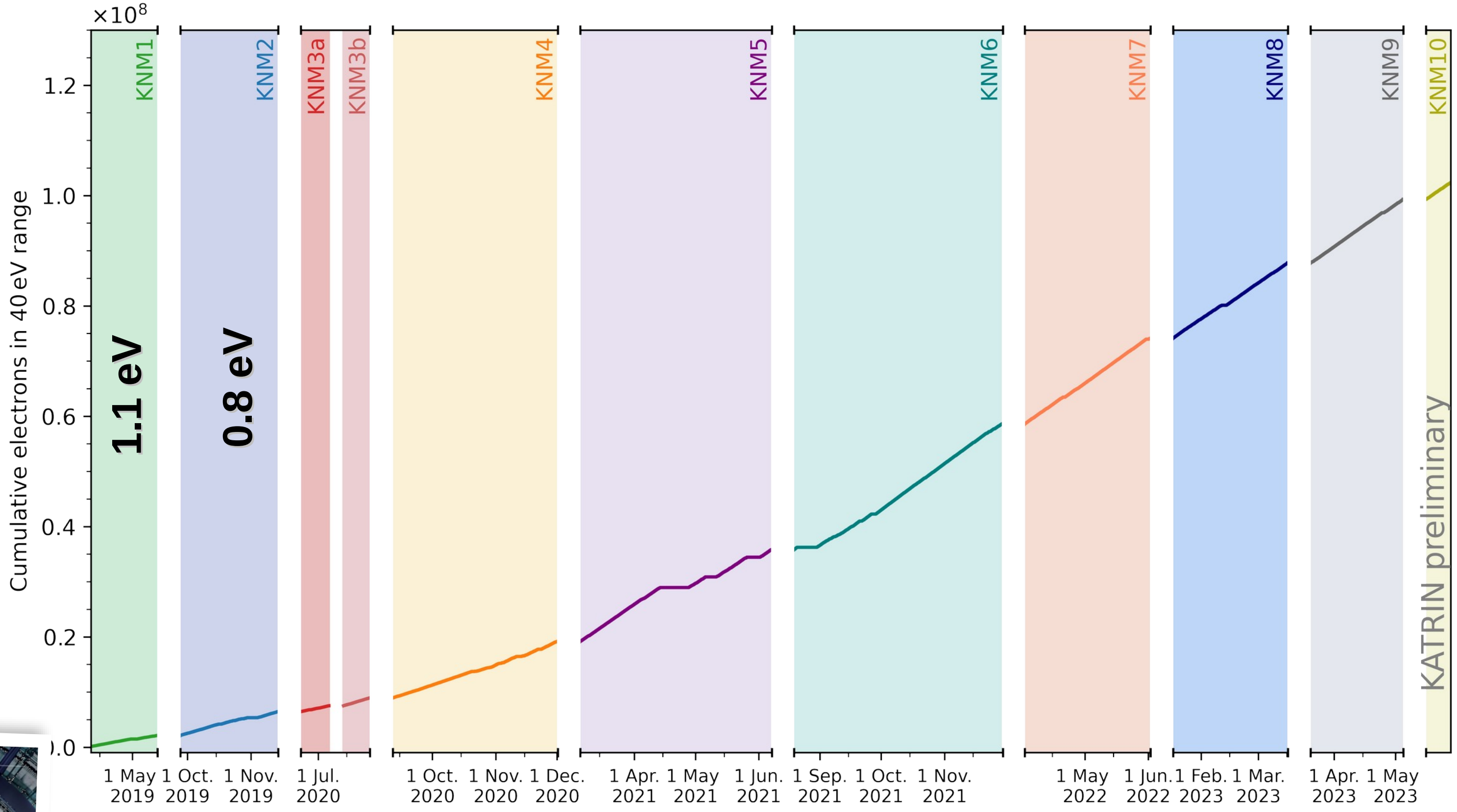
KATRIN Data taking



EPJ C 80, 264 (2020)

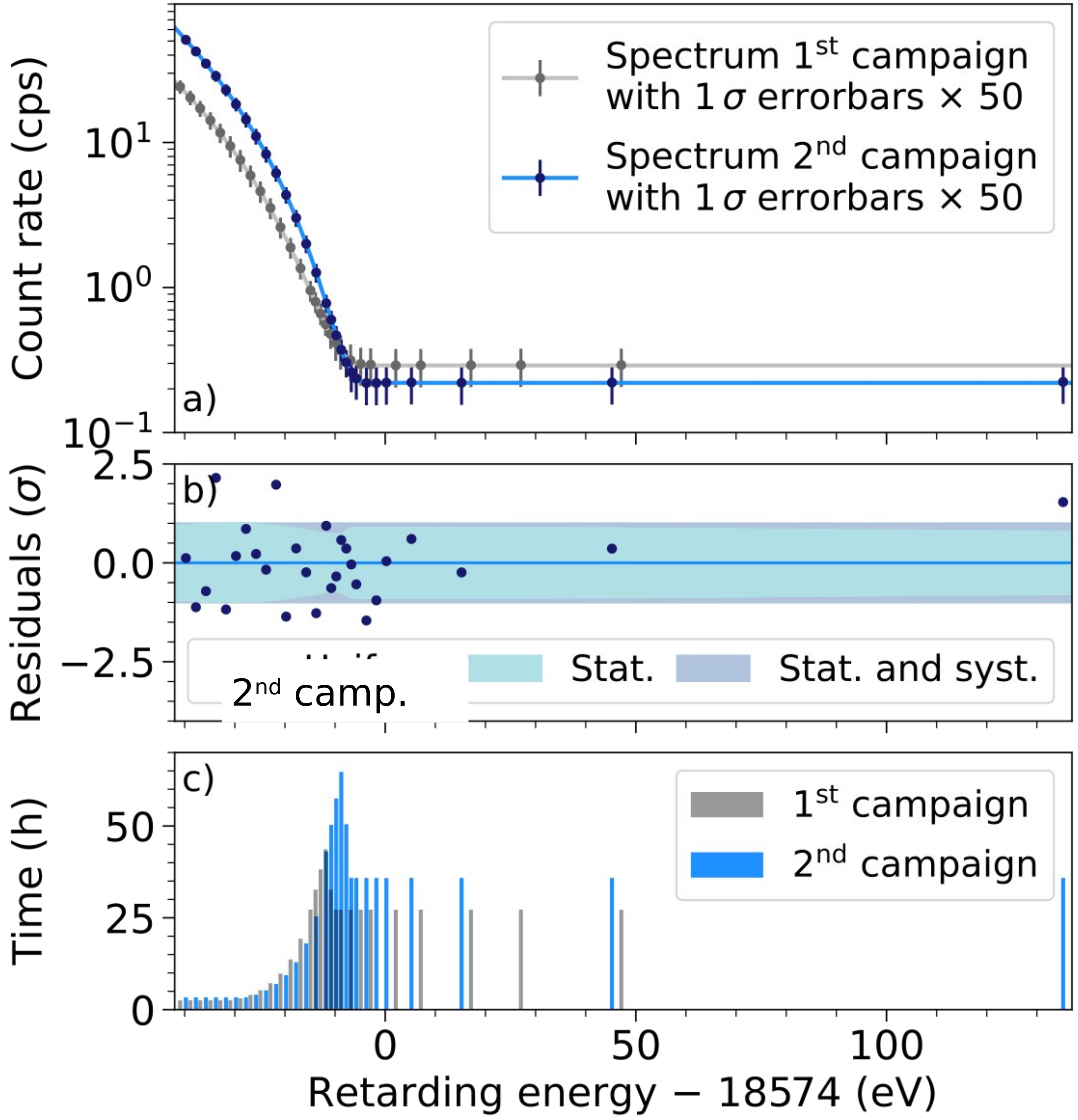
PRL 123 (2019) 221802
PRD 104 (2021) 012005





Nature Phys. 18 (2022) 160

ν-mass results



First campaign (spring 2019):

✓ total statistics: 2 million events

✓ best fit: $m_\nu^2 = (-1.0^{+0.9}_{-1.1})$ eV² (stat. dom.)

✓ limit: $m_\nu < 1.1$ eV (90% CL)

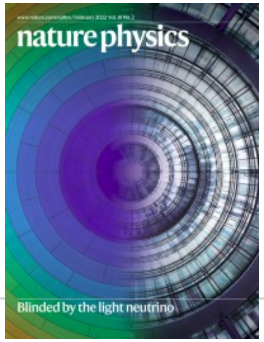
Second campaign (autumn 2019):

✓ total statistics: 4.3 million events

✓ best fit: $m_\nu^2 = (0.26^{+0.34}_{-0.34})$ eV² (stat. dom.)

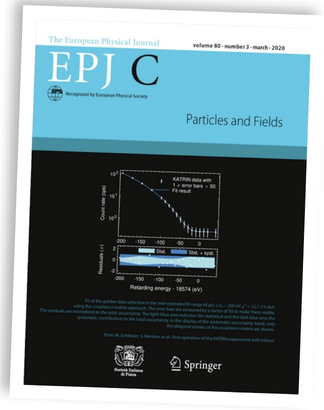
✓ limit: $m_\nu < 0.9$ eV (90% CL)

Combined result: $m_\nu < 0.8$ eV (90% CL)



KATRIN Collab, Phys. Rev. Lett. 123, 221802 (2019); Nature Phys. 18 (2022) 160

KATRIN Data taking



EPJ C 80, 264 (2020)

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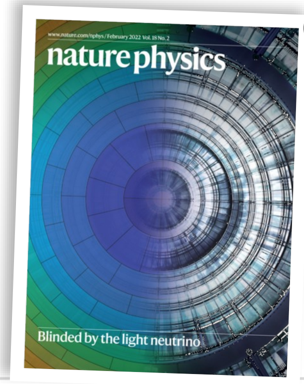
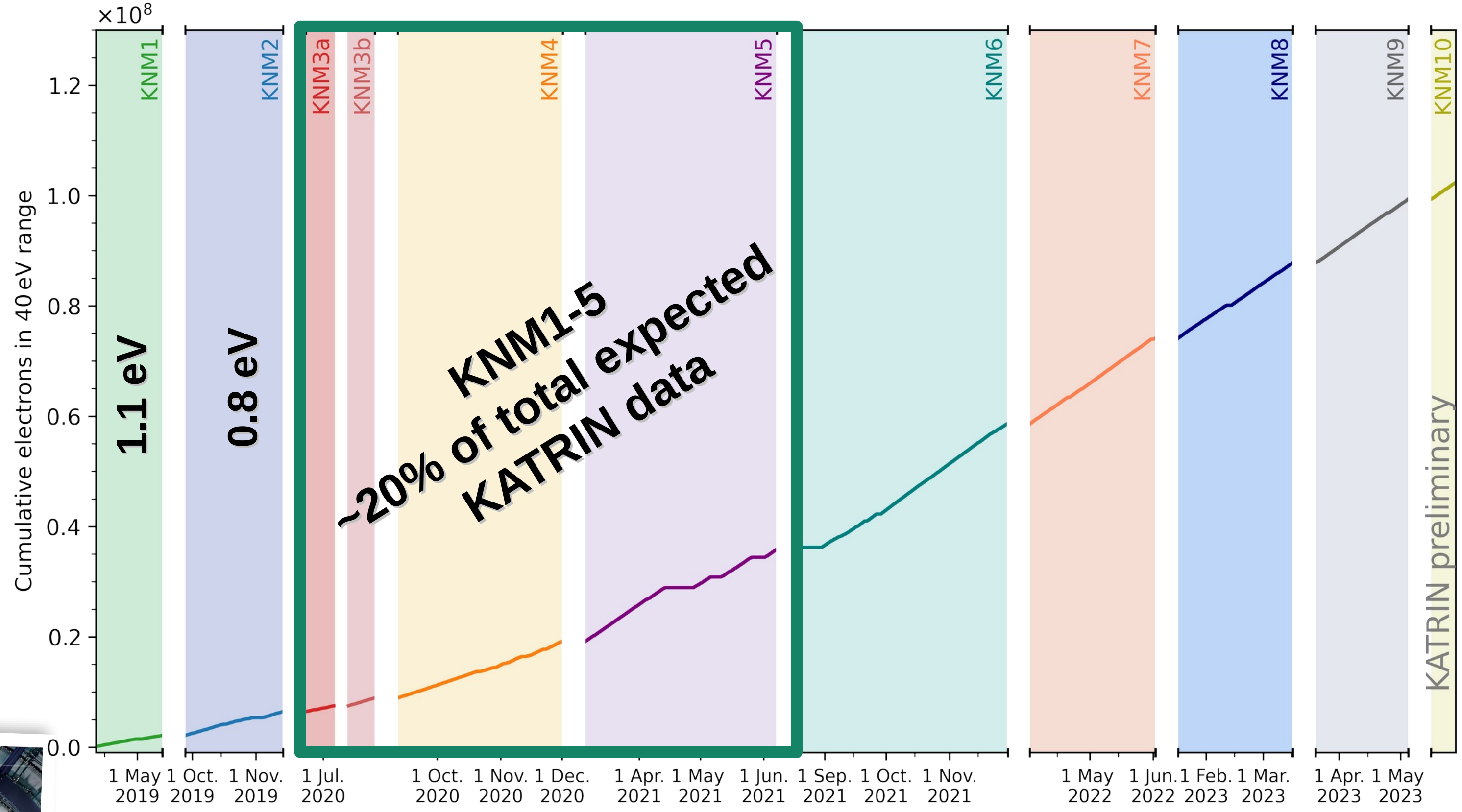
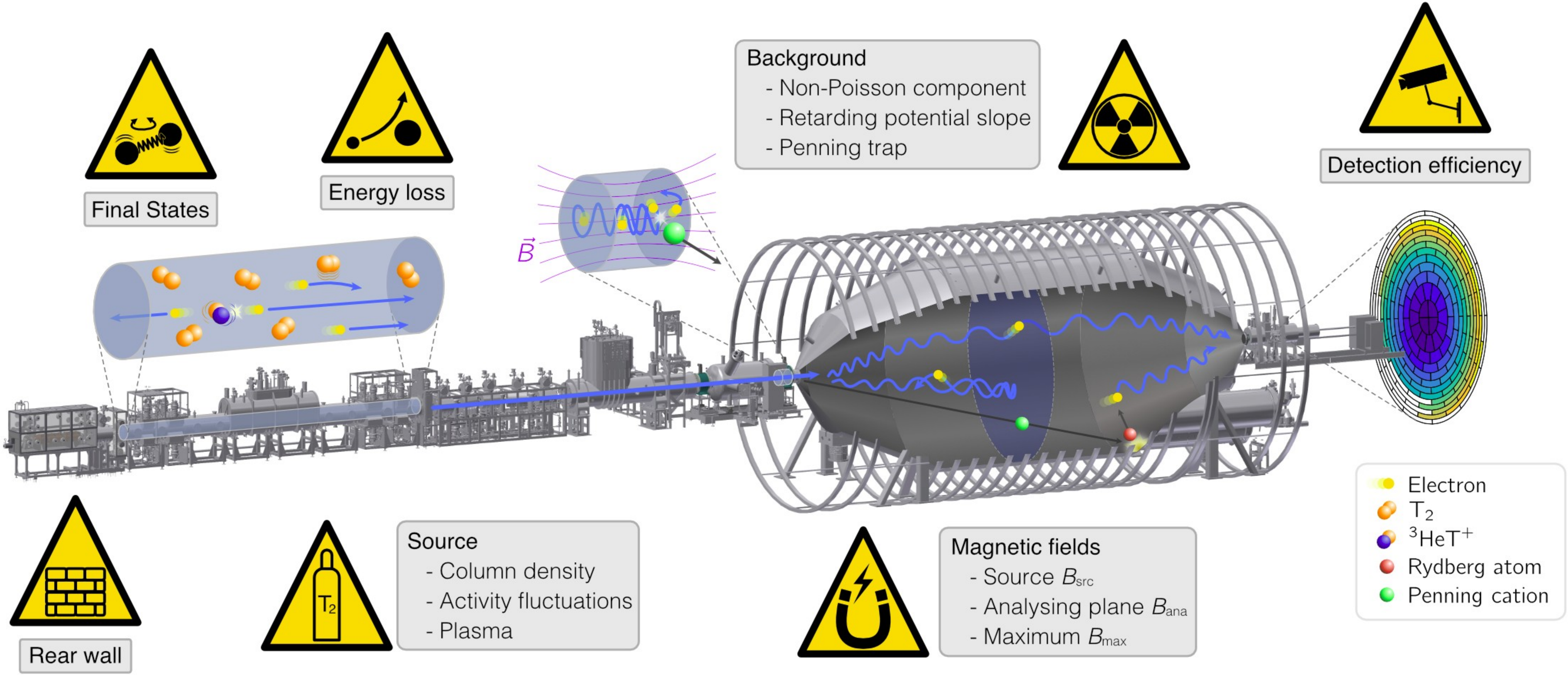




Nature Phys. 18 (2022) 160

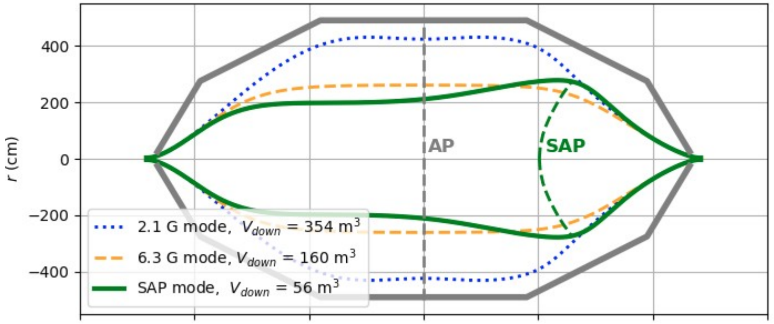
Systematic effects



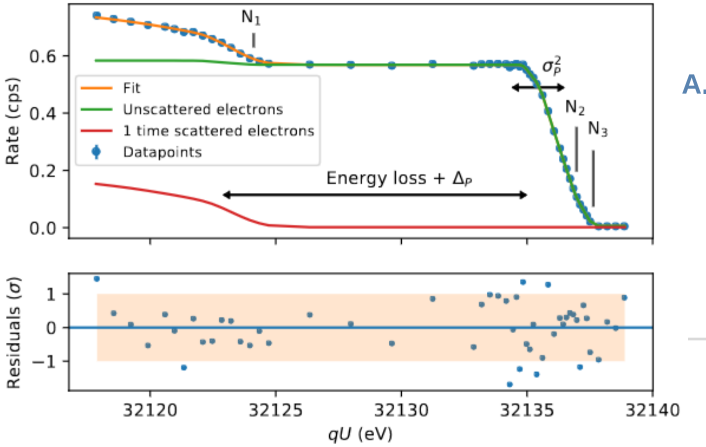
Experimental improvements

- Background reduction using *“shifted analyzing plane”* configuration

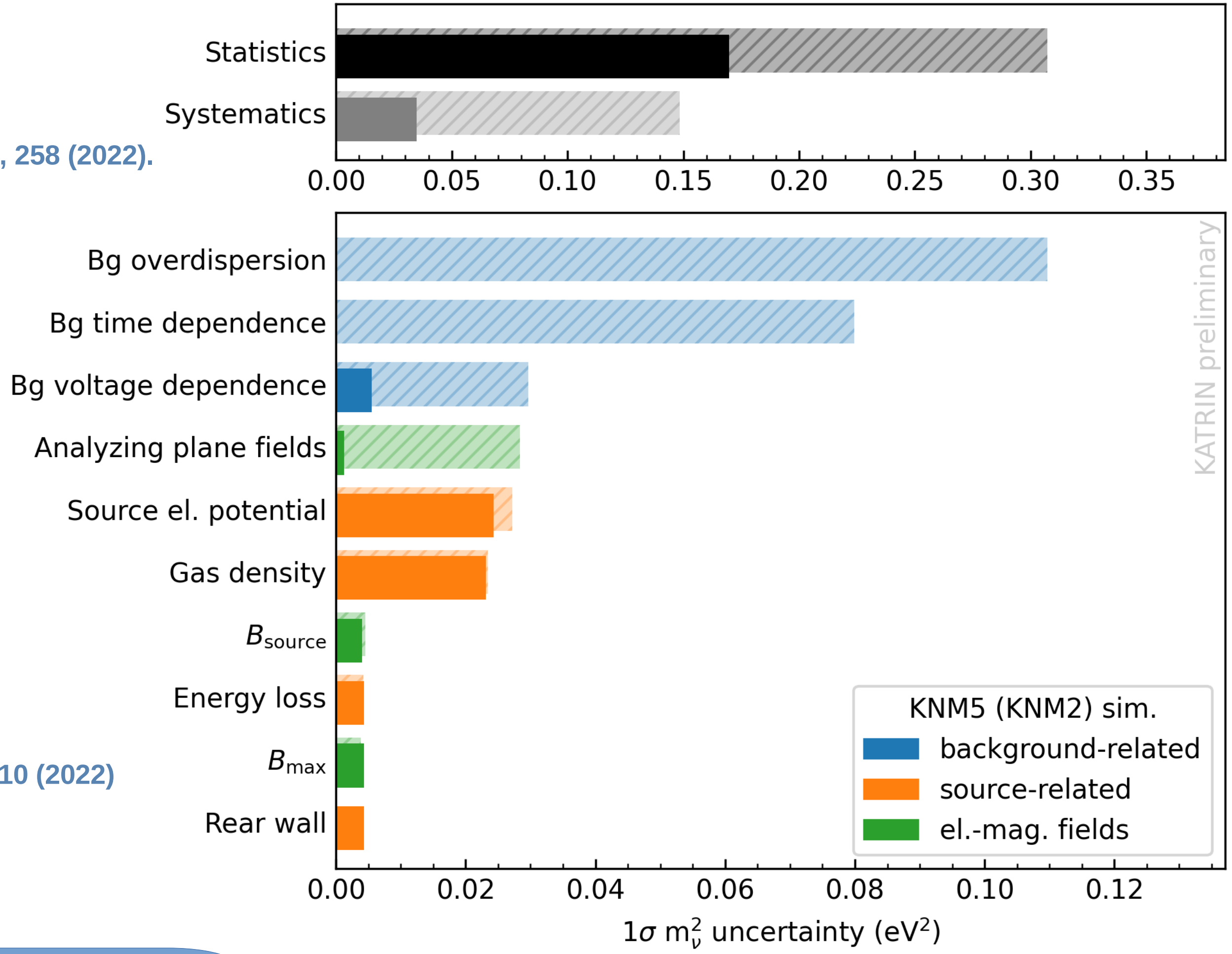
A. Lokhov, et al., Eur. Phys. J. C 82, 258 (2022).



- Precise calibration measurements with electron gun and ^{83m}**Kr** co-circulation



A. Marsteller, et al., JINST 17, P12010 (2022)



Further improvements: posters by A.Huber, M.Böttcher, B.Bieringer

Analysis challenges

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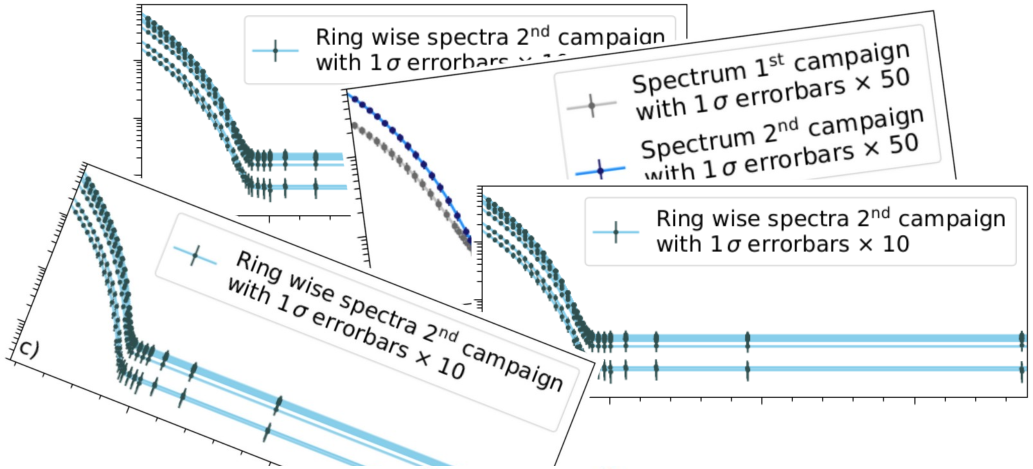
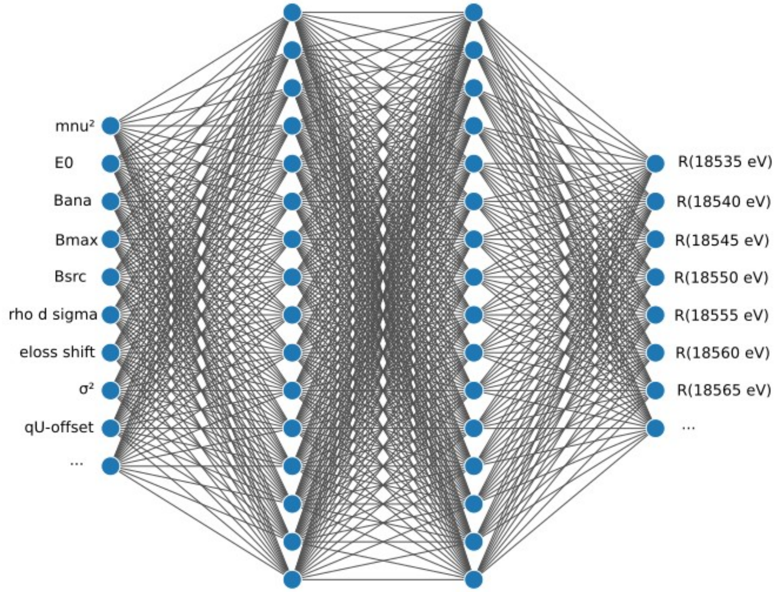
- Highly segmented data (>1000 data points)
- Computationally expensive model evaluations
- Large number of correlated systematic parameters
- Two independent analysis teams and tools
  - optimized model evaluation
  - fast model prediction with a neural network
- Two-step blinding scheme
  - fixing analysis procedure on MC data
  - using model blinding



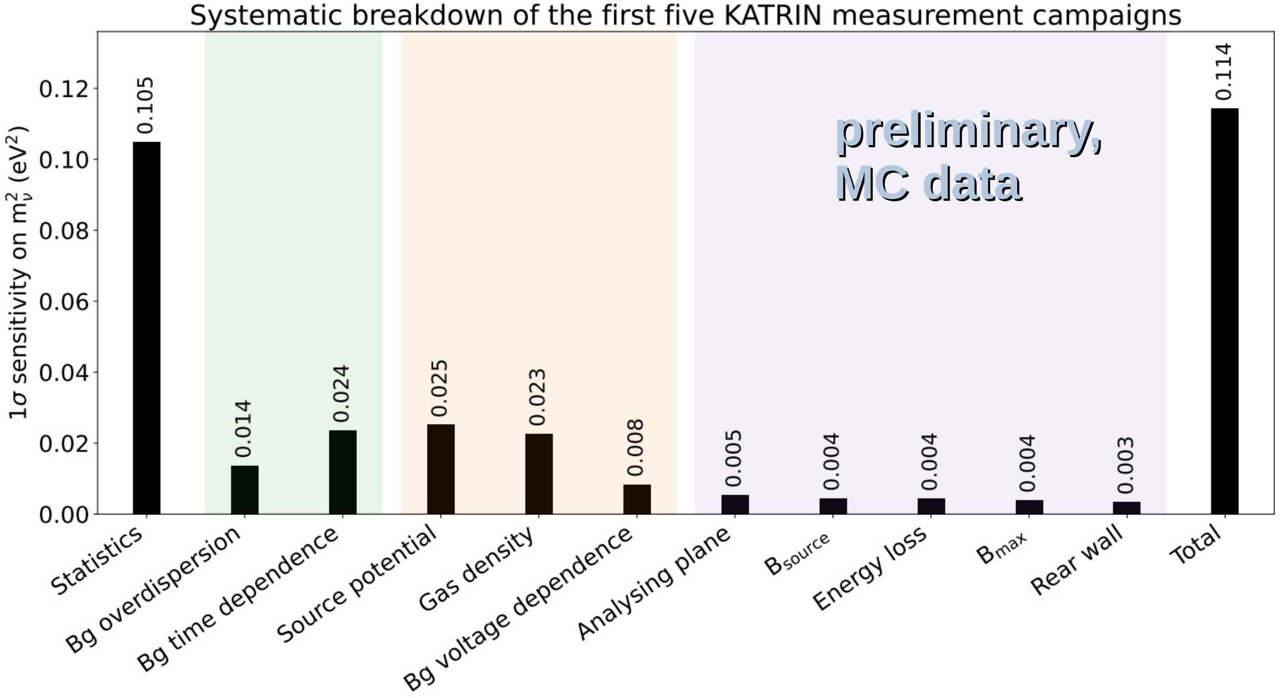


See poster by Ch.Wiesinger

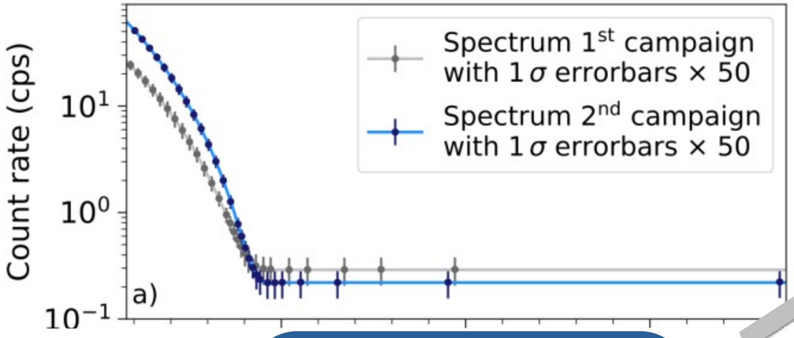
C. Karl, P. Eller, S. Mertens, Eur. Phys. J. C 82, 439 (2022)

Next neutrino mass release of KATRIN

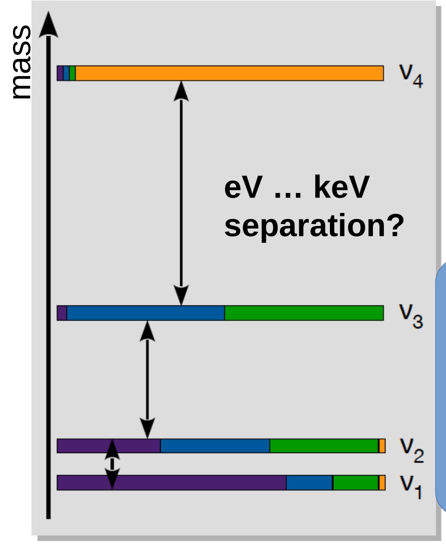
- First 5 campaigns analyzed simultaneously
- **x6** the statistics, significant improvement of systematics
- Sensitivity of **0.5 eV** (90 % CL)
- Publication is almost ready – stay tuned!



“Beyond neutrino mass” in KATRIN



Is there a fourth (sterile) neutrino?



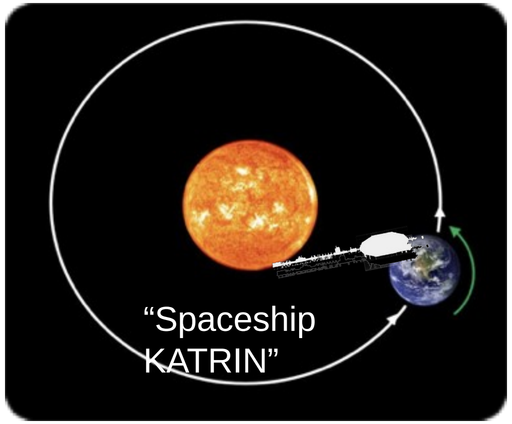
Neutrino mixing: “Kink” in regular β-spectrum tail (eV scale) or deep β-spectrum (keV scale)

Talk: A.Onillon, posters: L.Köllenberger, K.Urban

β-spectrum of high statistics and precision

Search for exotic interactions (spectrum shape)

Search for Lorentz invariance violation (sidereal modulation)



Constrain local density of cosmic relic neutrinos

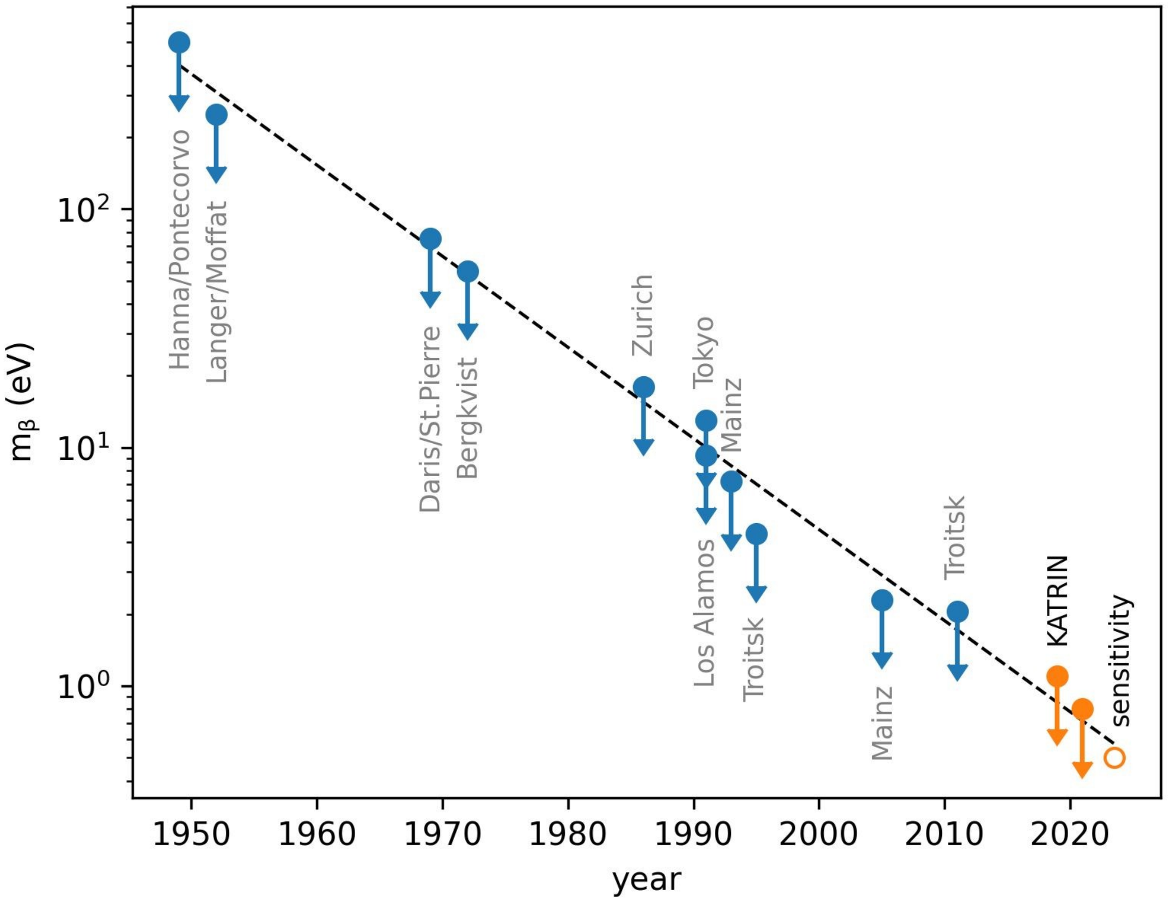
Phys.Rev.D 105 (2022) 7, 072004
arXiv:2207.06337, accepted to EPJC

Phys.Rev.Lett. 129 (2022) 1, 011806

Phys.Rev.D 107 (2023) 8, 082005

Summary & Outlook

- First direct neutrino-mass measurement with sub-eV sensitvity from KATRIN:
  - **m_ν < 0.8 eV** (90% CL)
- Combination of first 5 campaigns:
  - significant improvement of systematics and reduction of the background, x6 statistics
  - Sensitivity: **0.5 eV** (90% CL)
- Final goal: **m_ν < 0.3 eV** (90% CL) with the full KATRIN data set (end of 2025)
- Multiple physics searches beyond the neutrino mass



Thank you for your attention!

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