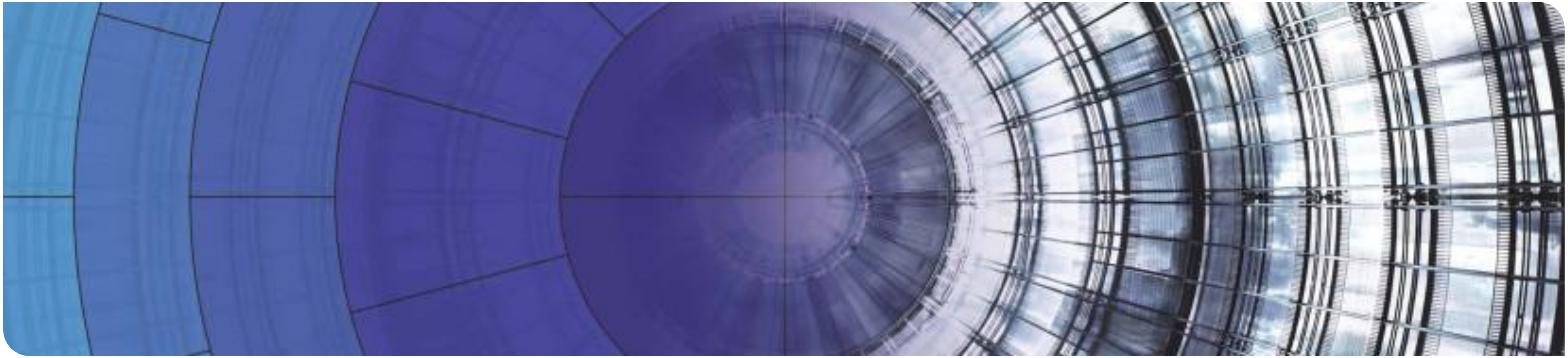
Karlsruhe Institute of Technology

Tritium Laboratory Karlsruhe

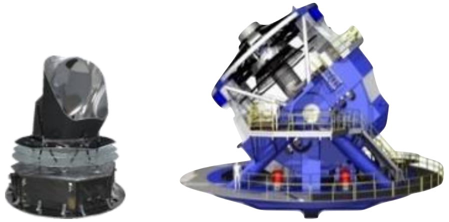
KATRIN

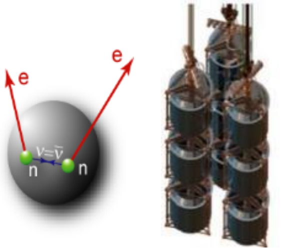
Alexander Marsteller for the KATRIN Collaboration

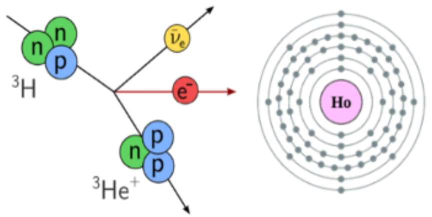
58th Rencontres de Moriond 2024



Access to the absolute neutrino mass scale







	Cosmology	Search for 0νββ	β-decay & electron capture
Observable	$M_\nu = \sum_i m_i$	$m_{\beta\beta}^2 = \left\|\sum_i U_{ei}^2 m_i\right\|^2$	$m_\beta^2 = \sum_i \|U_{ei}\|^2 m_i^2$
Present upper limit	0.12 eV*	0.18 eV*	0.8 eV
Model dependence	Multi-parameter cosmological model	- Majorana ν - nuclear matrix elements, g_A	**Direct,** only kinematics; no cancellations in incoherent sum

Stöcker et al., Phys.Rev.D 103 (2021) 12, 123508
Tanseri et al., JHEAp 36 (2022), 1-26

M. Agostini et al., Phys. Rev. Lett. 125, 252502
S. Abe et al., Phys. Rev. Lett. 130, 051801

M. Aker et al., Nat. Phys. 18, 160–166 (2022)

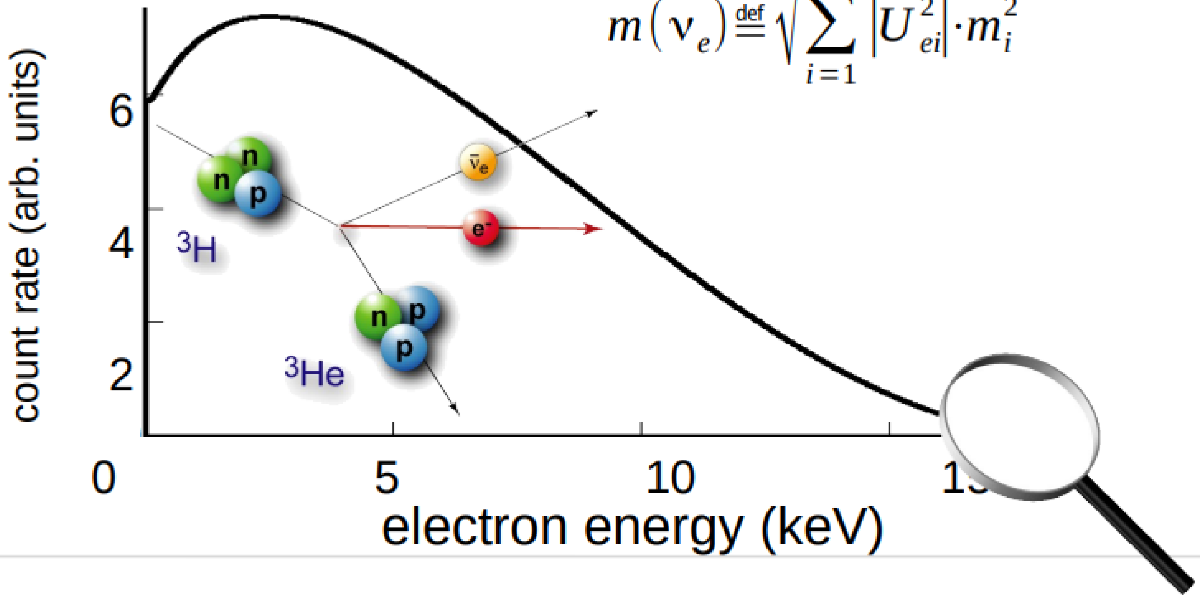
Tritium β-decay

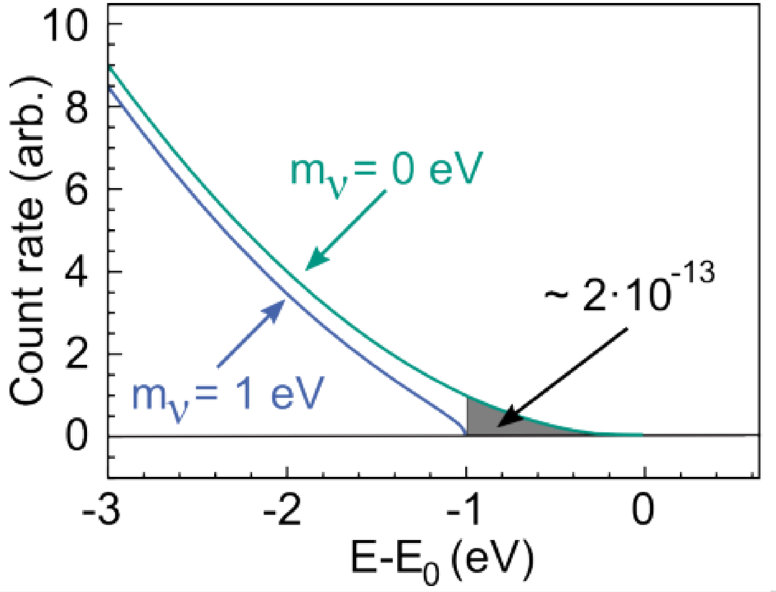
- Continuous β-decay spectrum described by Fermi‘s Golden Rule

- Simple structure allows accurate theoretical modelling

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

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





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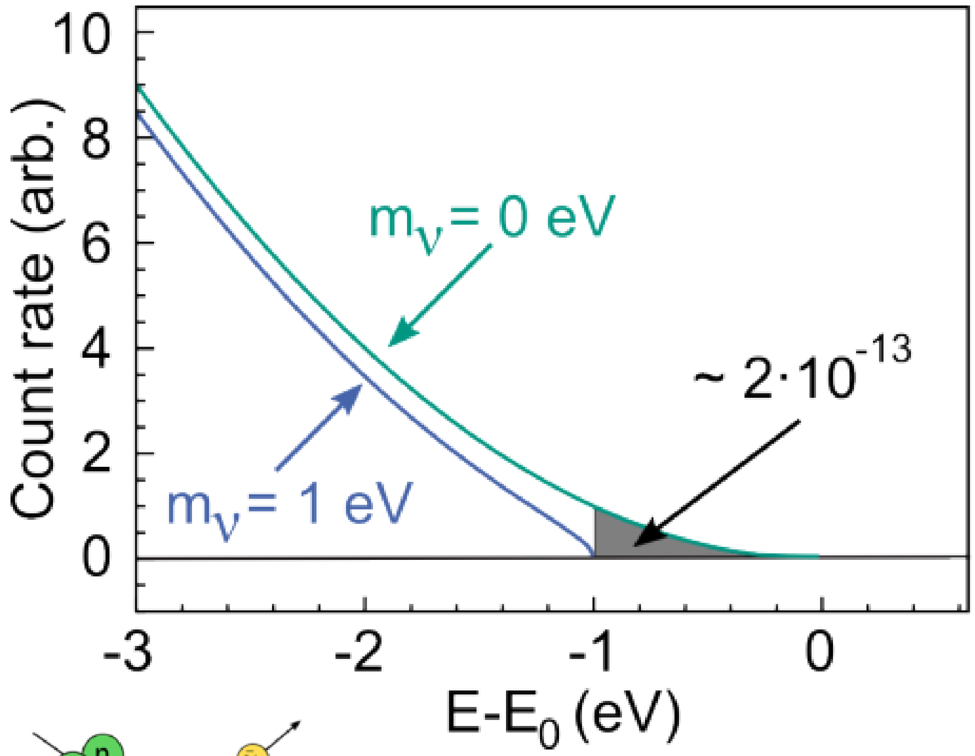
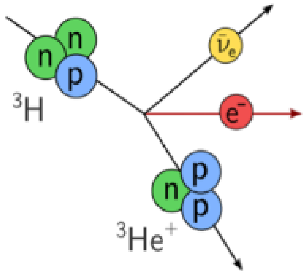
KATRIN requirements

- Low probability for decays to be in interesting energy region → small rate
  - Source with high luminosity
  - Low background
- Distortion is on the scale of the neutrino mass
  - Good energy resolution
- Source not single atom in complete vacuum
  - Exact understanding of spectrum shape and all contributing effects





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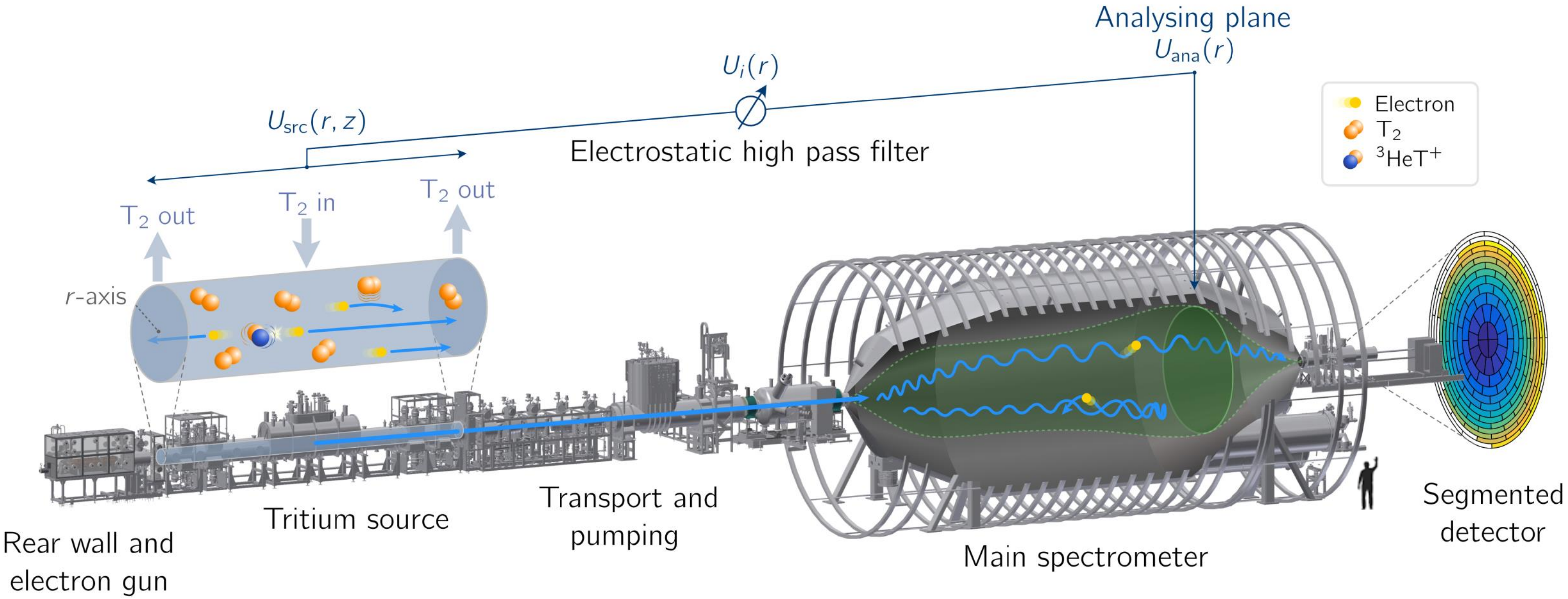
The KATRIN experiment



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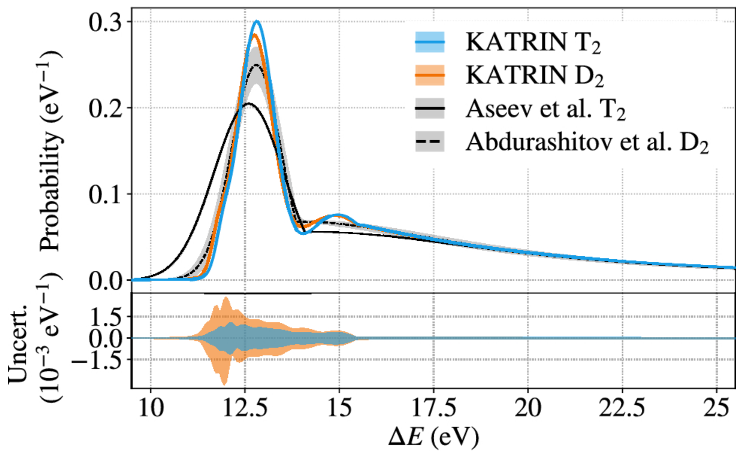
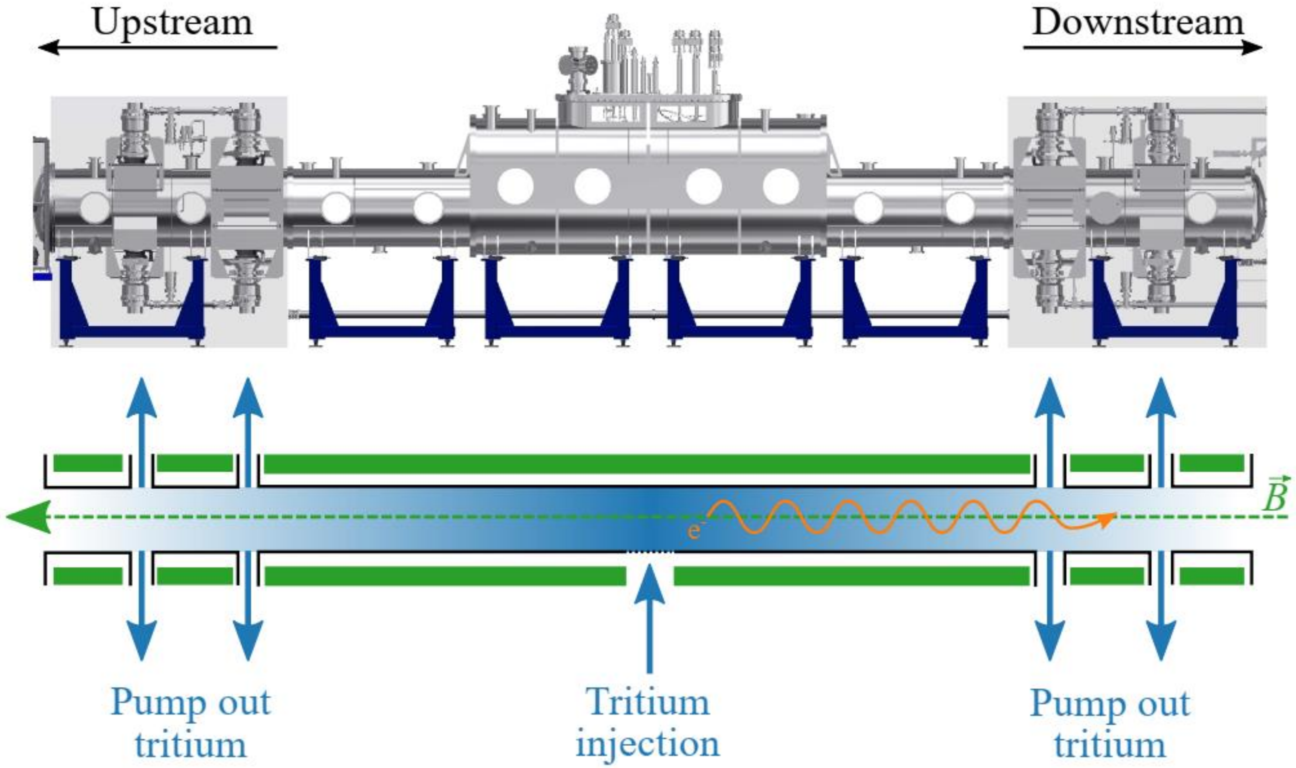
Tritium Source

- Stabilzed tritium gas column
  - Temperature (80 ± 0.01) K
  - Throughput $< 0.1\%$
- Magnetic guiding of decay electrons with nominal field strength of 2.5 T
- Activity of 10^{11} Bq
  - Optimum with regards to opacity

Aker, M. et al. Eur. Phys. J. C 81, 579 (2021).





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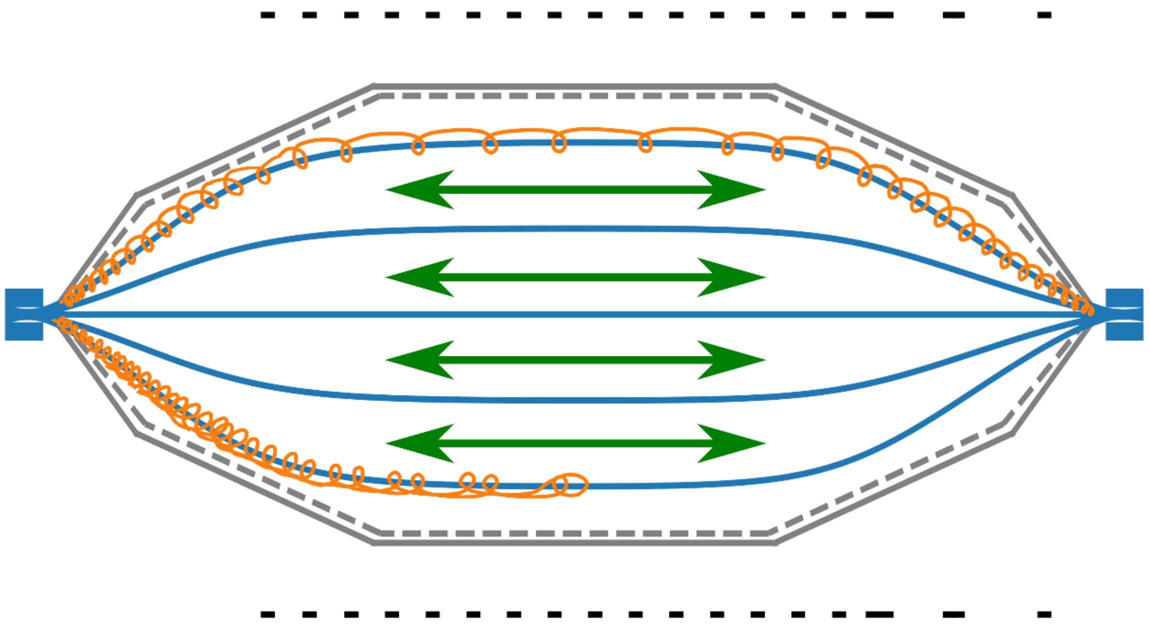
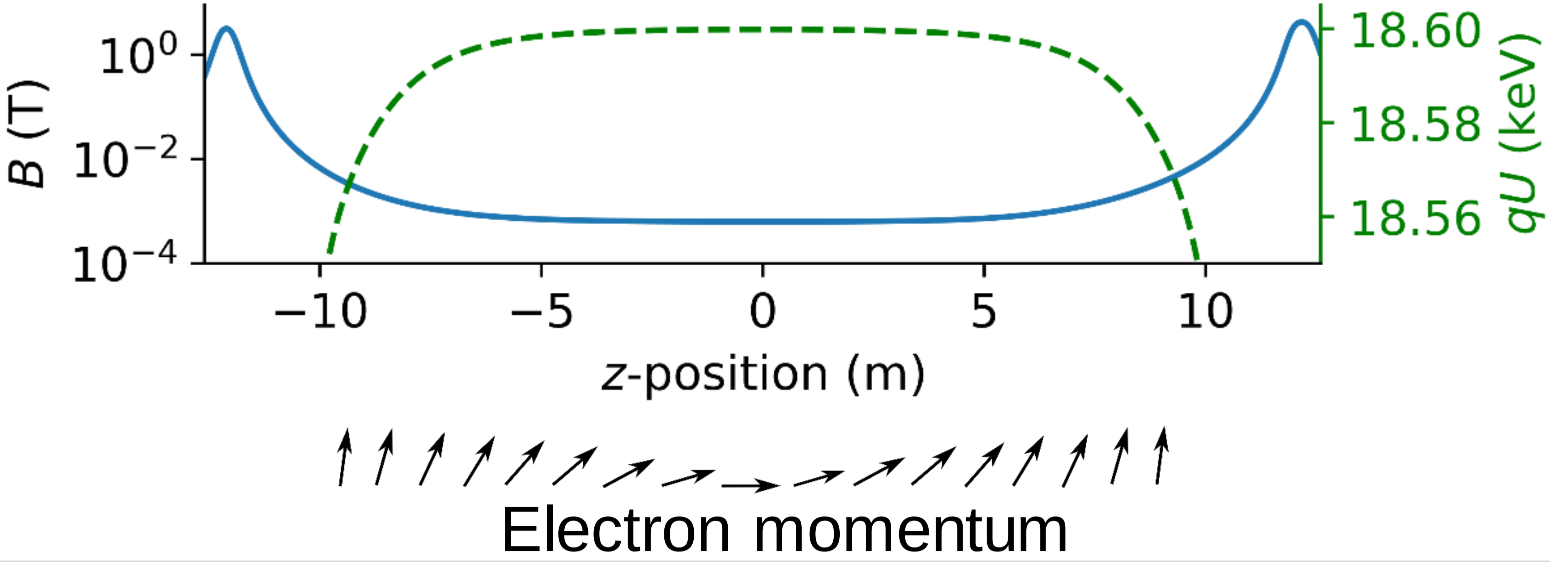
Main Spectrometer

- Magnetic Adiabatic Collimation with Electrostatic (MAC-E) filter



- Energy resolution proportional to magnetic field ratio

- Large acceptance angle



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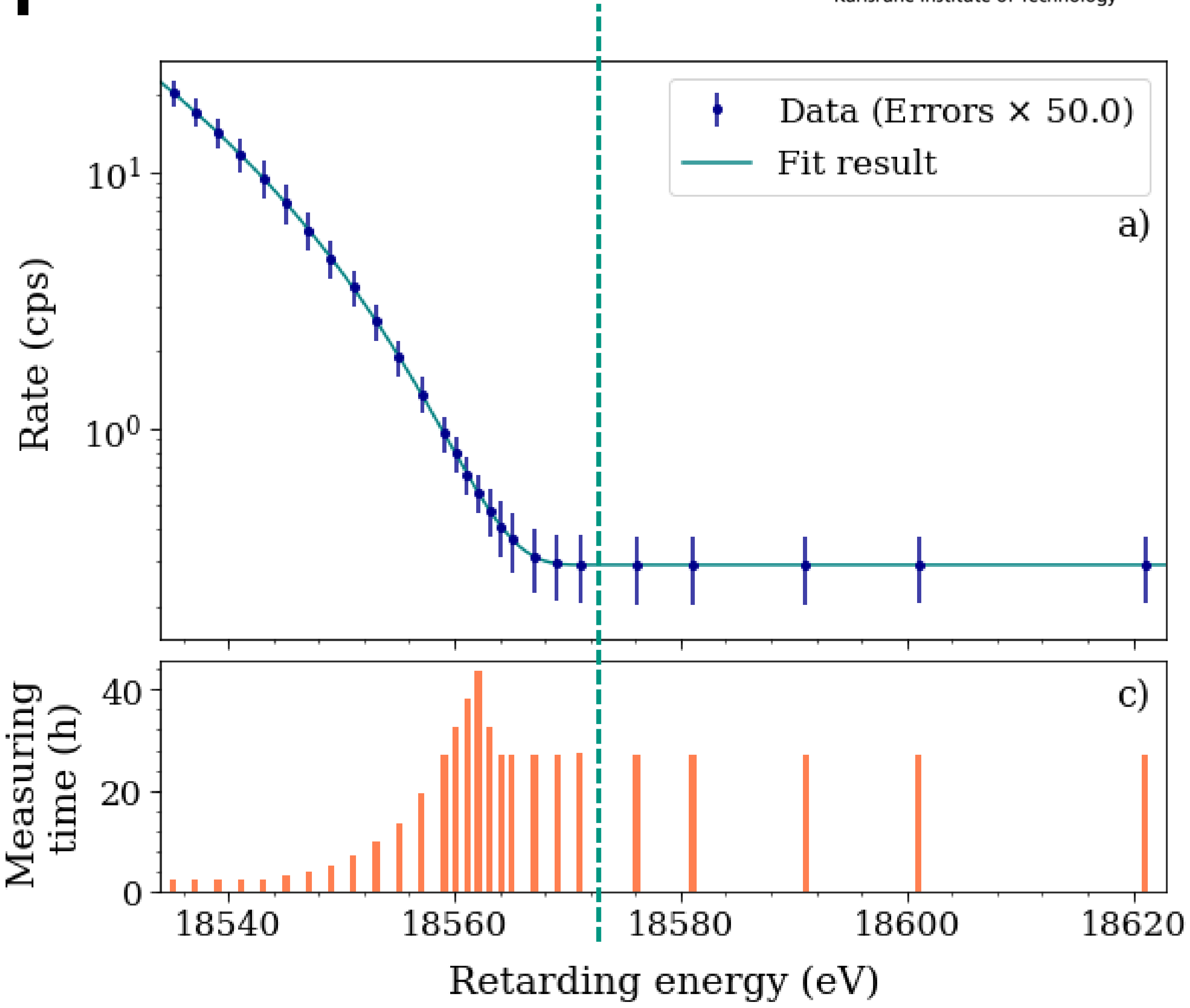
KATRIN measurement principle

- Scan through spectrum integrated by highpass MAC-E filter:
  - ~30 steps with varying duration
  - From $E_0 - 40\ \mathrm{eV}$ to $E_0 + 130\ \mathrm{eV}$
  - ~3 h measurement time per scan
  - O(500) scans per year



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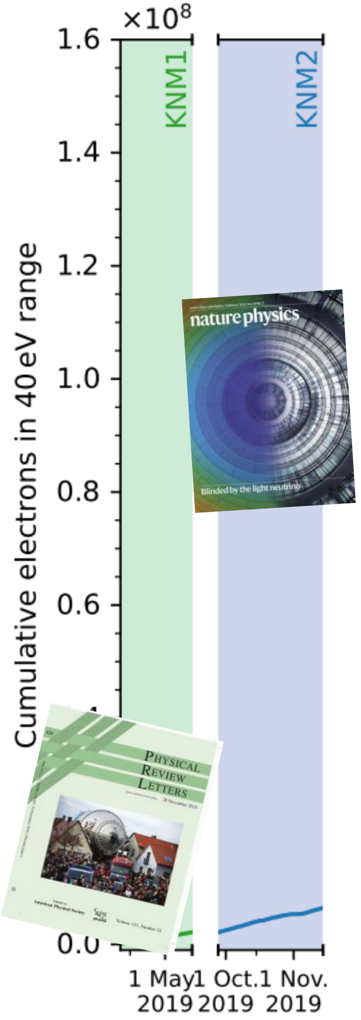
Overview of data taking



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Latest neutrino mass results

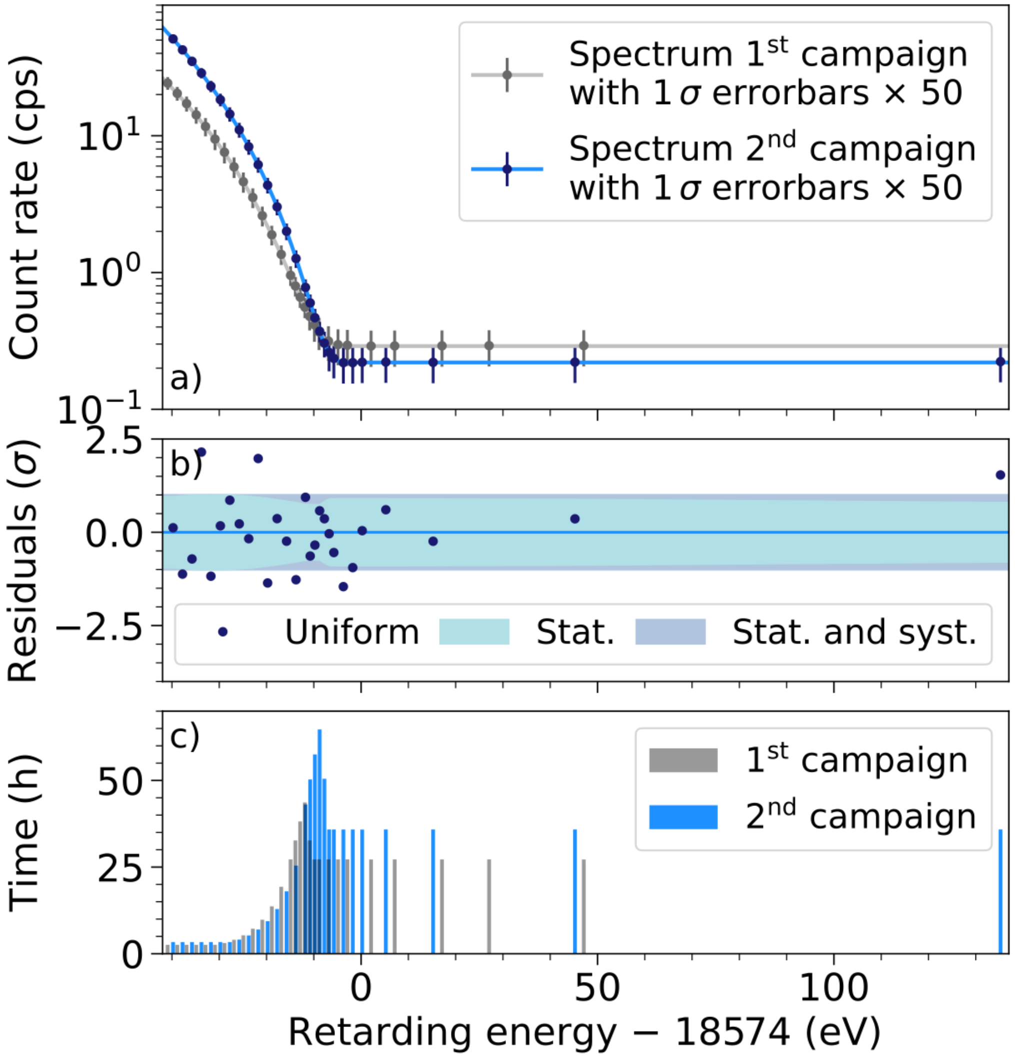
- First measurement campaign (KNM1)
  - Best fit: $m_\nu^2 = (-1.0^{+0.9}_{-1.1})\ \mathrm{eV}^2$
  - Upper limit: $m_\nu < 1.1\ eV\ (90\%\ C.L.)$

M. Aker et al., Phys. Rev. Lett. **123**, 221802

- Second measurement campaign (KNM2)
  - Best fit: $m_\nu^2 = (0.26^{+0.34}_{-0.34})\ eV\ (90\%\ C.L.)$
  - Upper limit: $m_\nu < 0.9\ eV\ (90\%\ C.L.)$

- Combined result: $m_\nu < 0.8\ eV\ (90\%\ C.L.)$

M. Aker et al., *Nat. Phys.* **18**, 160–166 (2022)



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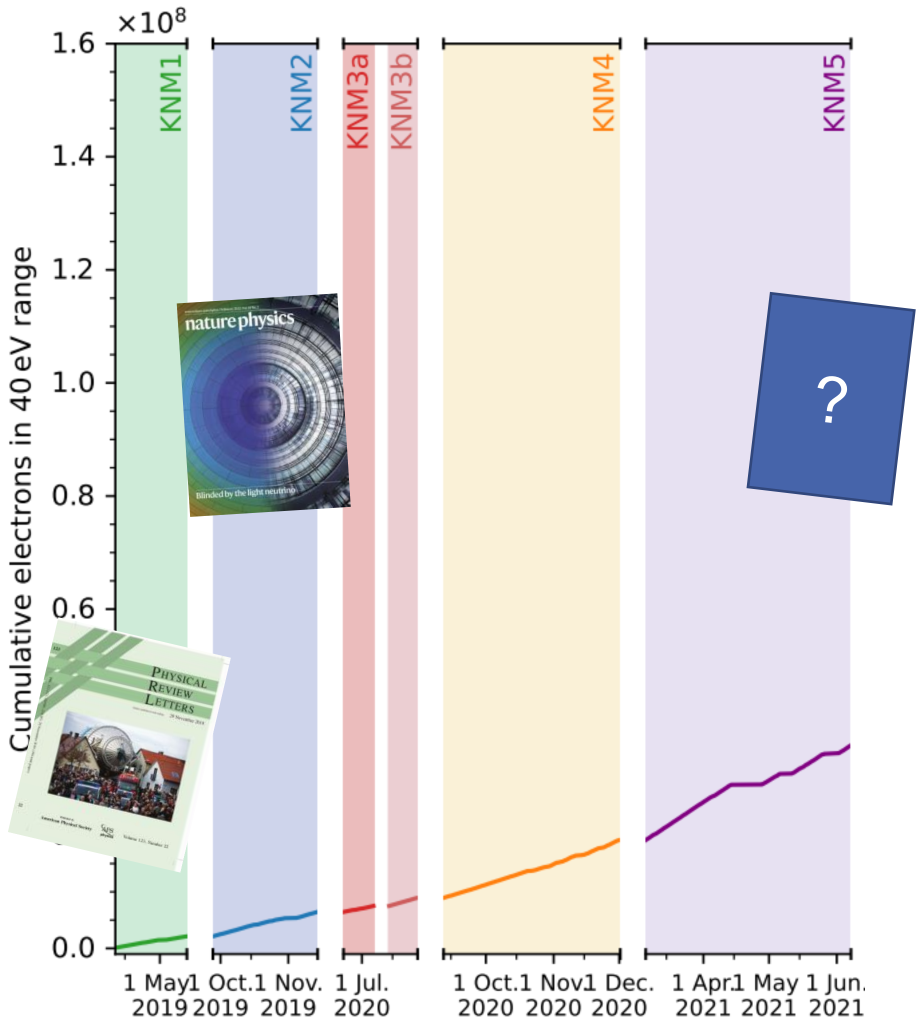
Next analysis release



- Combined analysis of first five campaigns (KNM1-5)
  - Currently in final preparation
  - Data release in summer
- Sensitivity projection:

$$m_\nu < 0.5\,eV\ (90\%\ C.L.)$$

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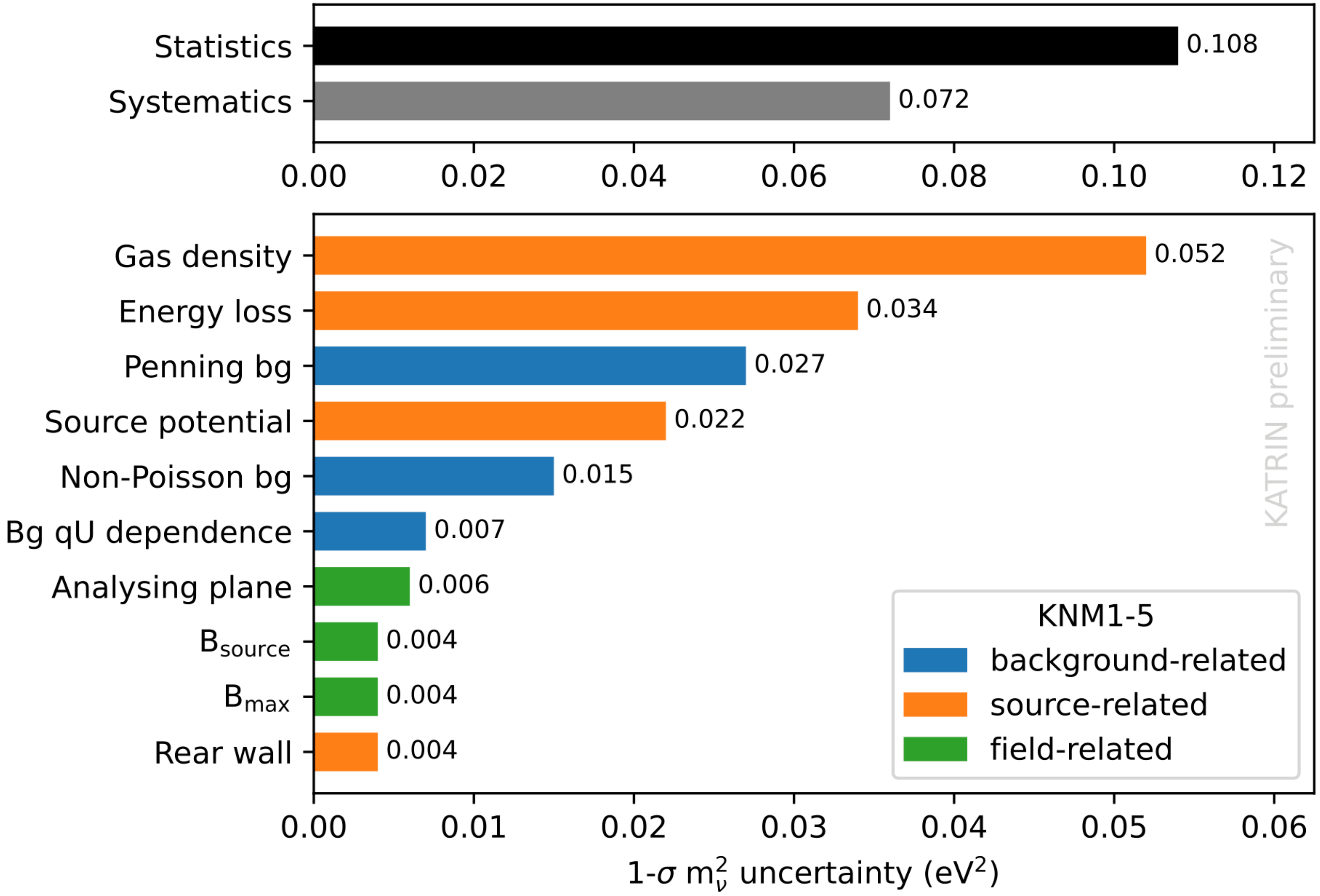
Uncertainty breakdown projection for next analysis release

- Uncertainty dominated by statistical uncertainty
- Thorough reevaluation of systematic uncertainties



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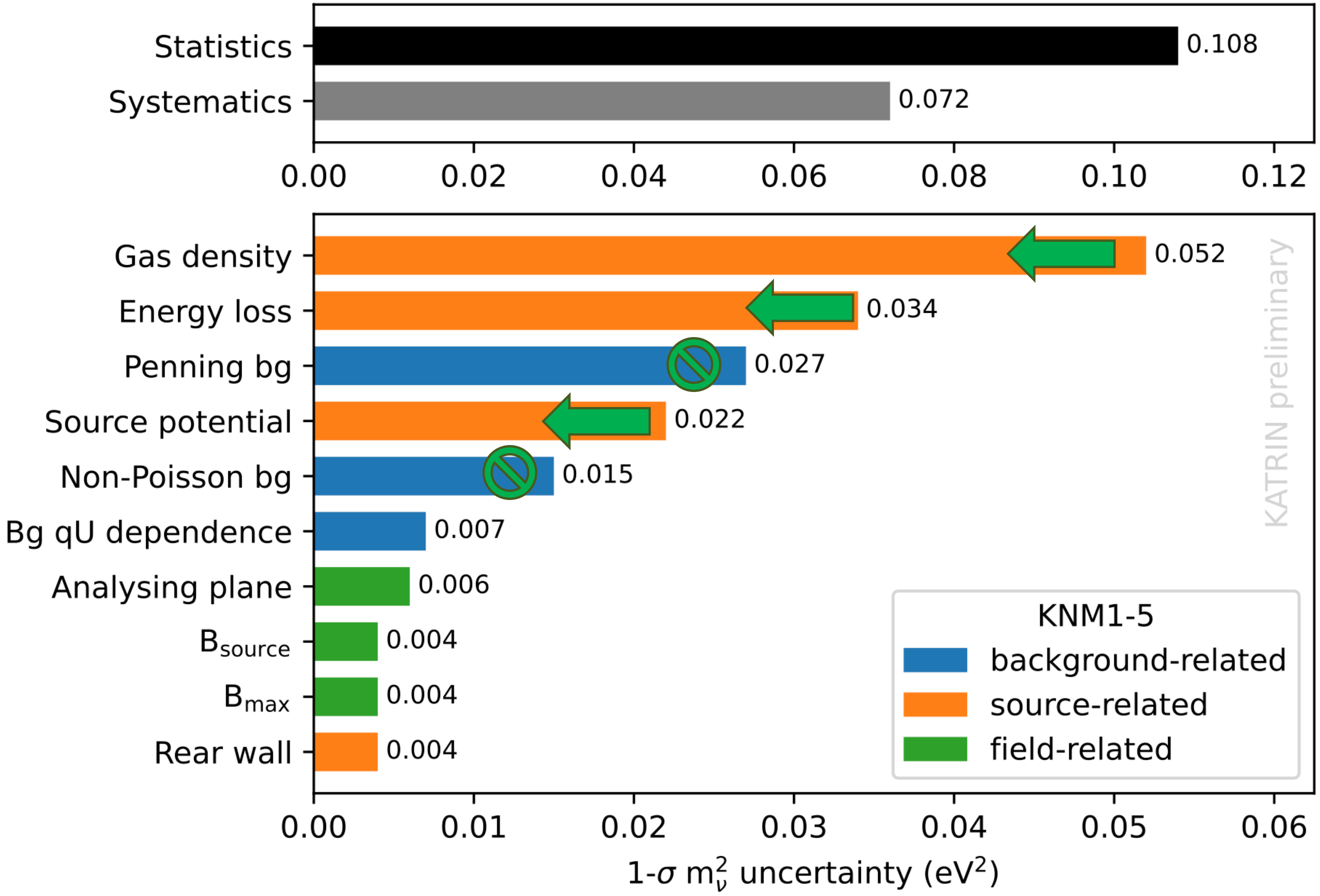
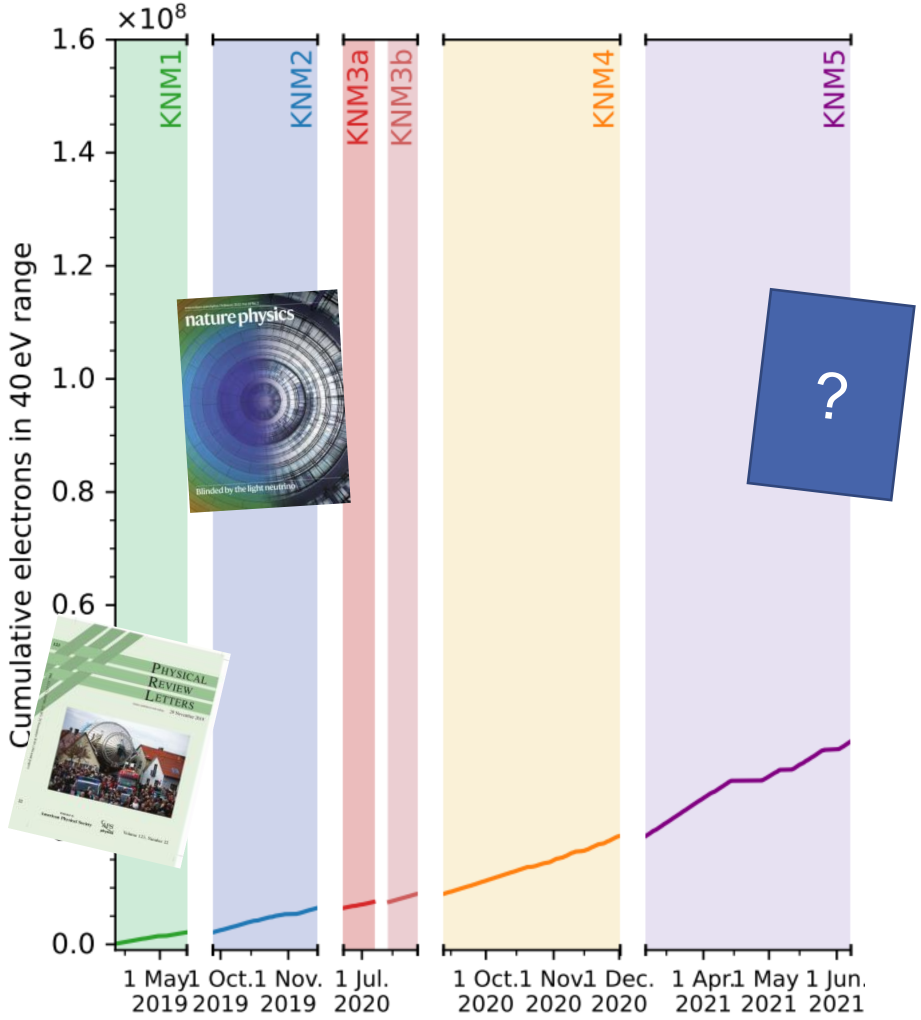
Uncertainty breakdown projection for next analysis release

- Uncertainty dominated by statistical uncertainty
- Thorough reevaluation of systematic uncertainties
- Efforts to minimize systematic uncertainties continue



Next analysis release



- Combined analysis of first five campaigns (KNM1-5)
  - Currently in final preparation
  - Data release in summer
- Sensitivity projection:

$$m_\nu < 0.5\, eV\ (90\%\ C.L.)$$

- Improvements
  - 6 times more events (still stat. dominated)
  - Reduced background
  - Better understanding of systematic effects

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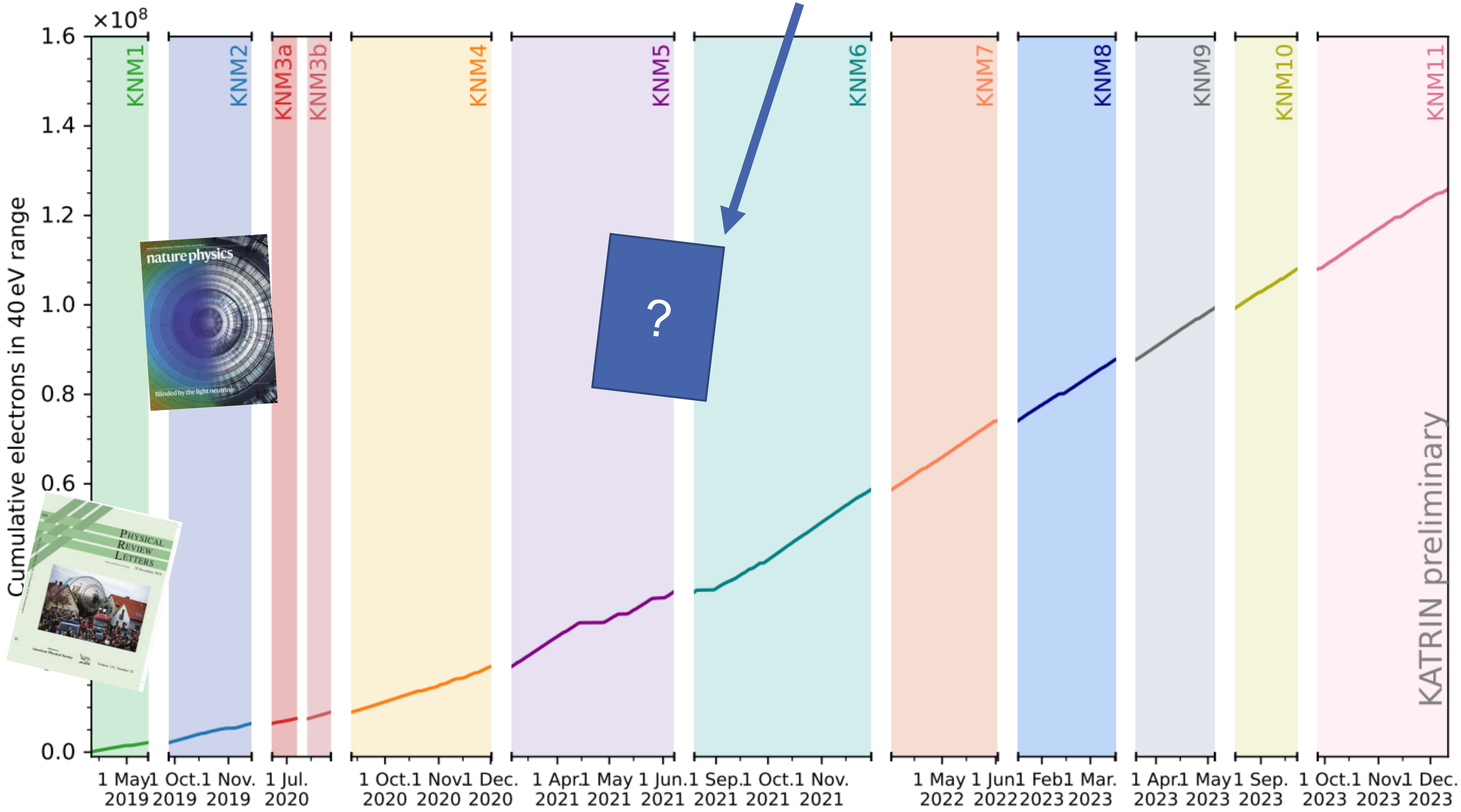
Overview of data taking

Release planned
for mid of 2024



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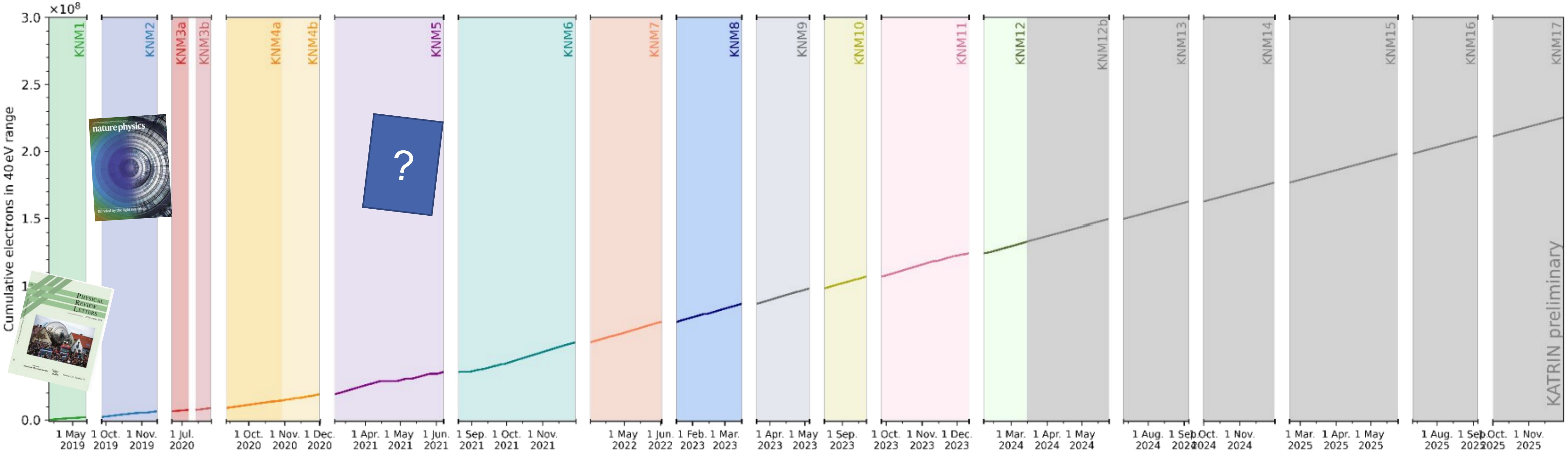
Future projection of data taking



- 60% of entire KATRIN statistics on tape
- KATRIN projected to conclude neutrino mass data taking **end of 2025**

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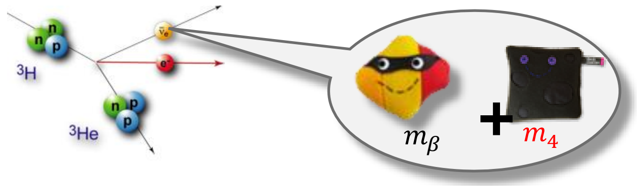
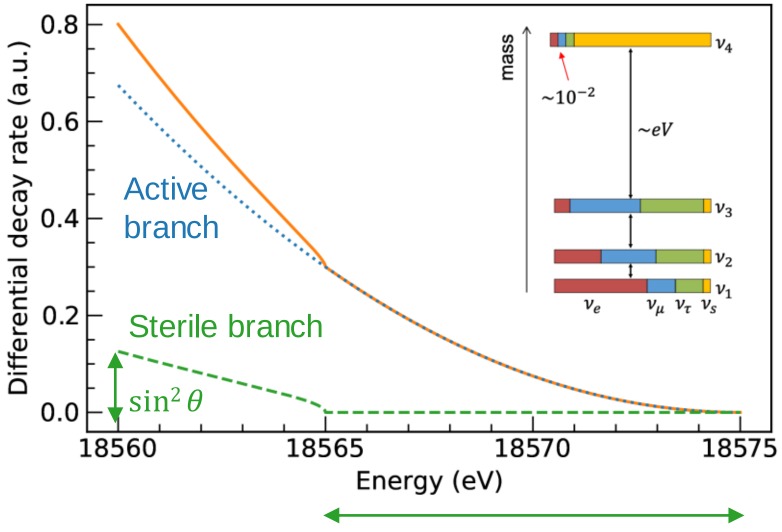
KATRIN beyond the neutrino mass

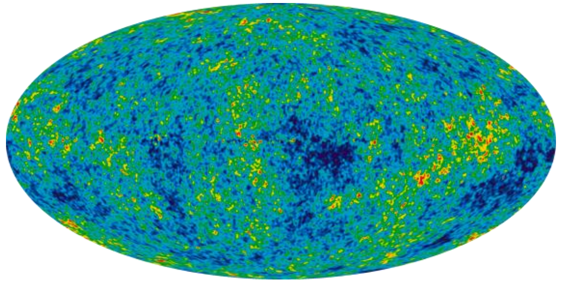
- High precision spectroscopy might show signature of new physics:



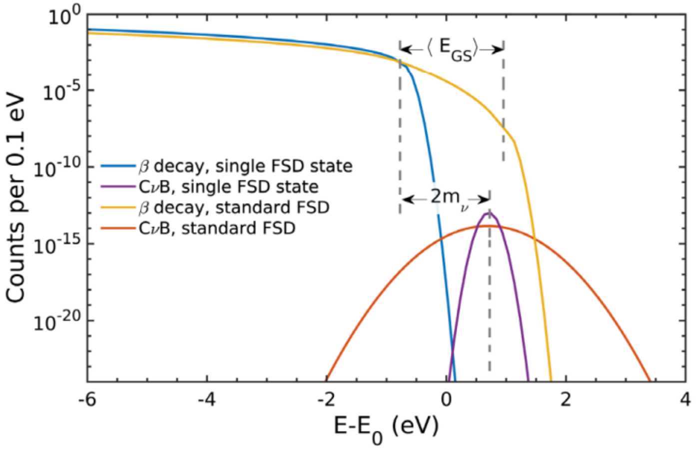
Sterile neutrinos



Aker et al., 2022 *Phys. Rev. D* **105** 072004
Aker et al., 2021 *Phys. Rev. Lett.* **126** 091803
Mertens et al., 2015 *J. Cosmol. Astropart. Phys.* **JCAP02**(2015)020



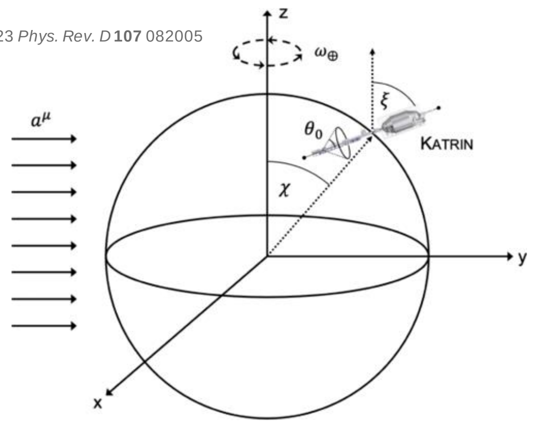
Cosmic relic neutrinos



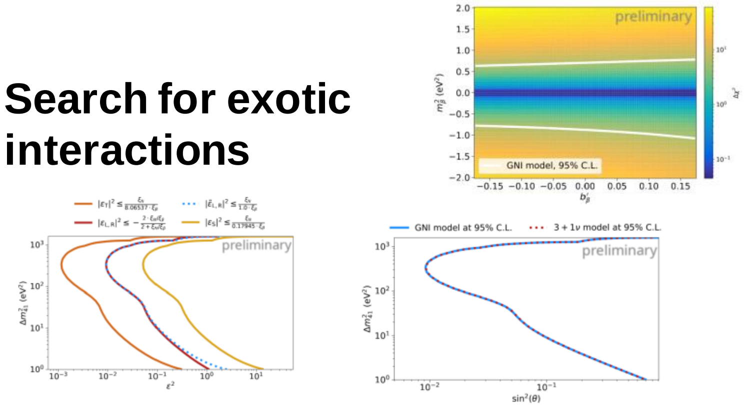
Aker et al., 2022 *Phys. Rev. Lett.* **129** 011806

Aker et al., 2023 *Phys. Rev. D* **107** 082005

Lorentz invariance violation



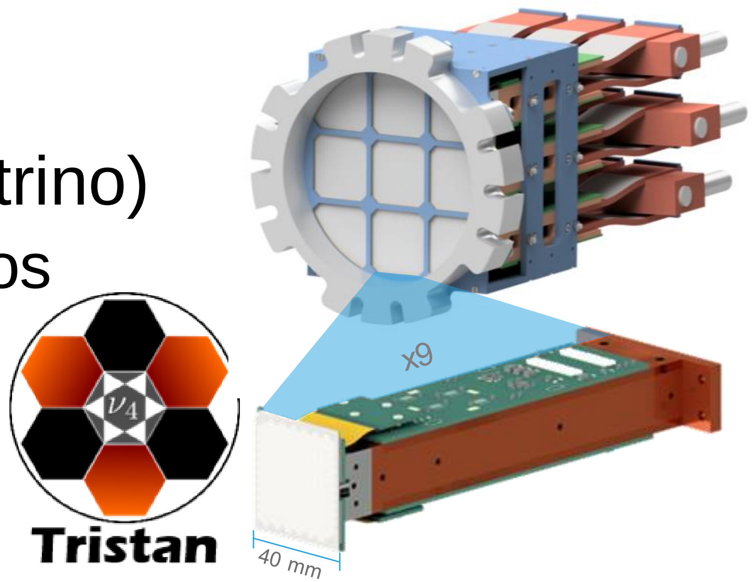
Search for exotic interactions

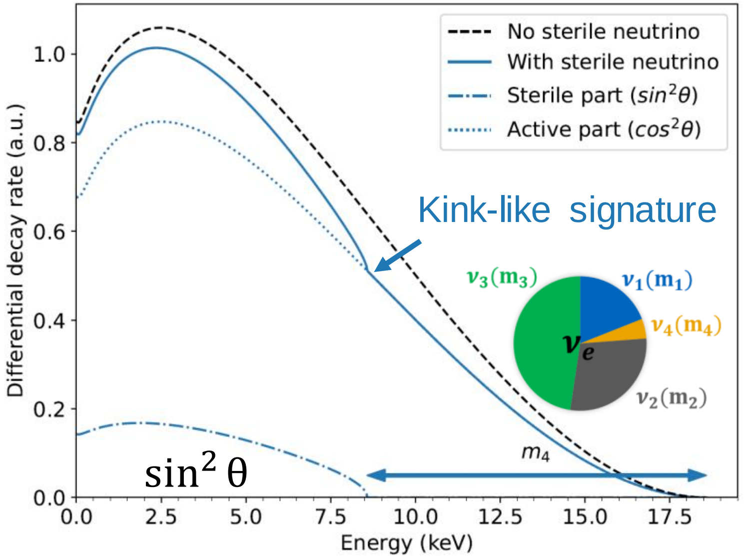


Arcadi et al., 2019 *J. High Energy Phys.* JHEP01(2019)206
Fengler et al., 2024 *PoS, DISCRETE2022* **011**

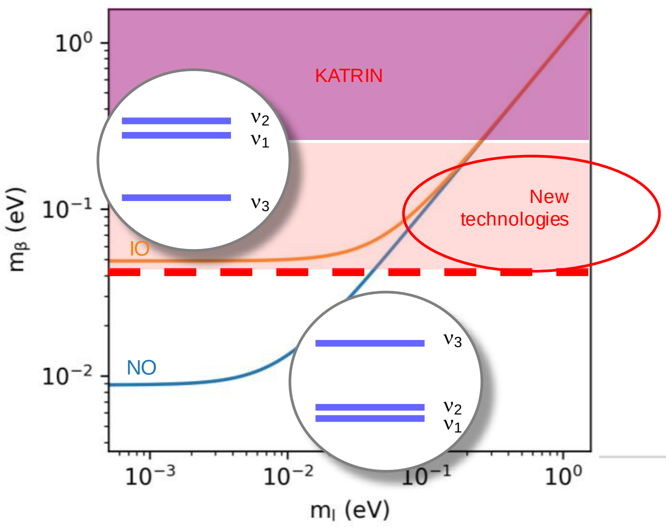
KATRIN beyond KATRIN

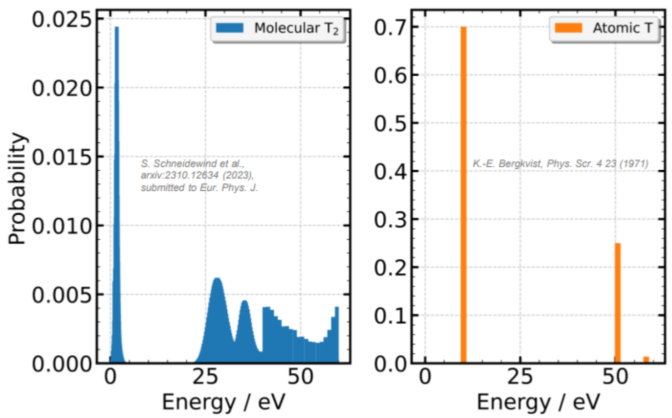
- TRISTAN
  (TRItium Sterile Anti-Neutrino)
  - keV-scale sterile Neutrinos
  - Coming 2026





- KATRIN++
  - Upgrade with new technologies
    - Atomic tritium source
    - Differential detectors
  - R&D Phase





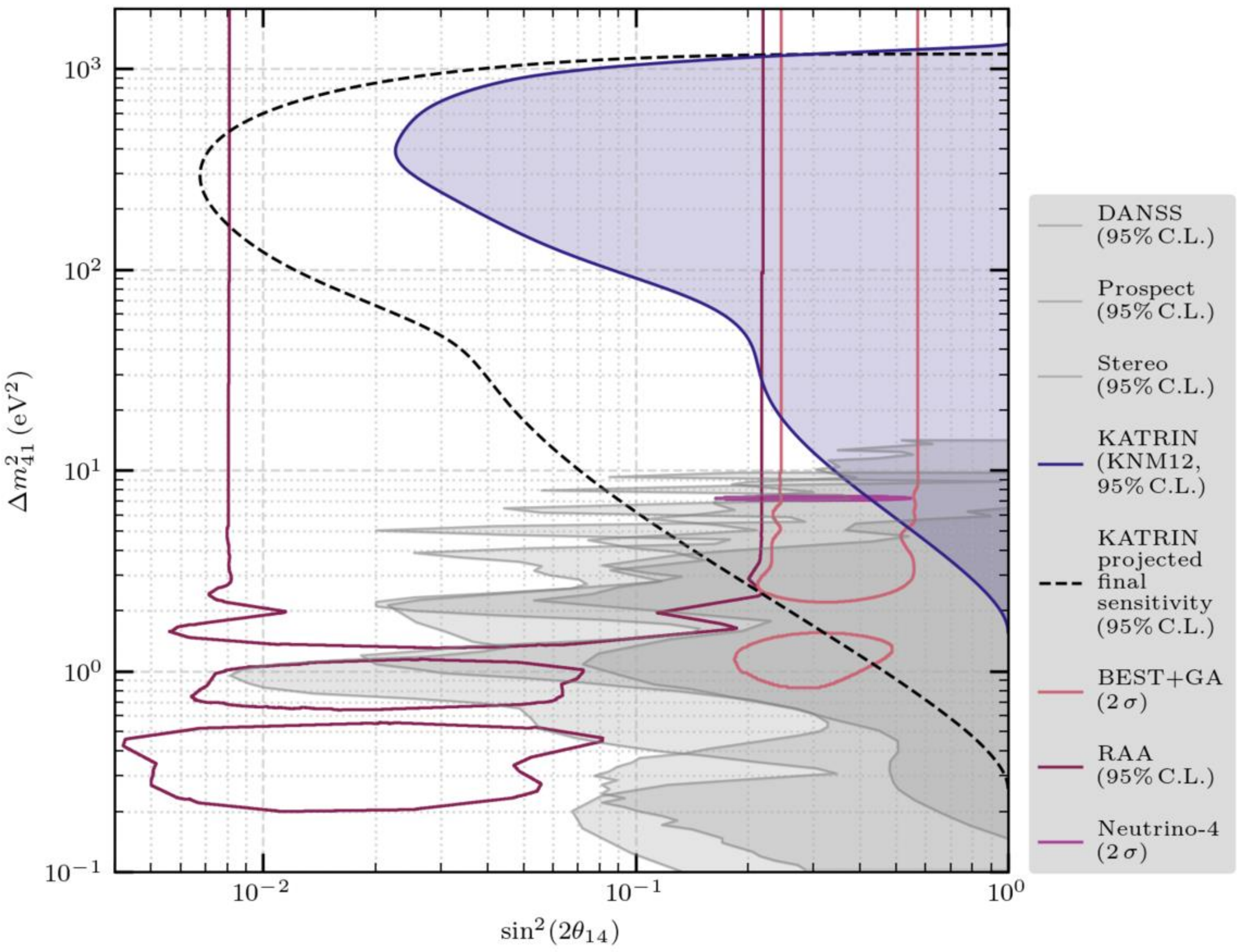
Summary

- KATRIN data taking ongoing until end of 2025
- Results on campaigns 1-5 planned to be released mid-2024
  - Neutrino mass measurement with 0.5 eV sensitivity
  - sterile neutrino search, general neutrino interactions, …
- Dedicated sterile search with TRISTAN upcoming in 2026
- R&D for KATRIN++ to reach the inverted ordering mass scale

Thank you for your attention

Backup – Light Sterile Neutrino

- Full KATRIN dataset estimated sensitivity will cover:
  - Neutrino-4 region
  - Large section of BEST+GA anomaly
  - Part of the reactor antineutrino anomaly



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