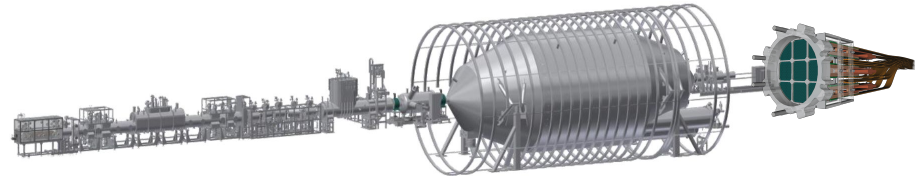


Search for keV Sterile Neutrinos with the KATRIN Experiment

Leo Laschinger¹
on behalf of the KATRIN collaboration

¹Max-Planck-Institut für Kernphysik, Technical University of Munich



- What are sterile neutrinos?
- How can we measure them in KATRIN?
- What sensitivity do we expect?

What are Sterile Neutrinos?

Sterile Neutrinos are...

- hypothetical particles
- a natural extension of the Standard Model
- motivated by several open questions in (neutrino) physics

reactor neutrino anomaly
(~eV scale)

neutrino mass generation/Seesaw
(~GeV scale)

dark matter candidate
(~keV scale)

Three generations of matter (fermions) spin 1/2

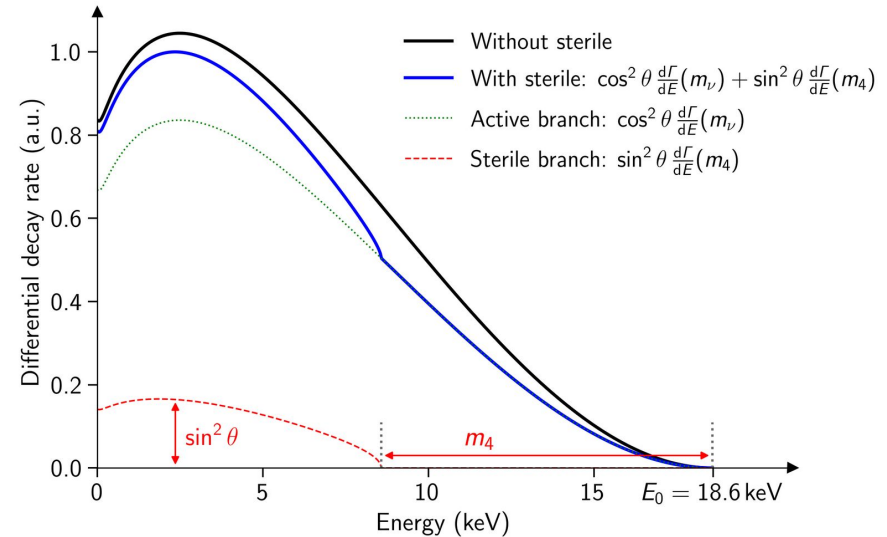
	I	II	III		
Mass→	2.4 MeV	1.27 GeV	171.2 GeV	0	0
Charge→	2/3	2/3	2/3	0	0
Name→	Left u Right Up	Left c Right Charm	Left t Right Top	0	0
Quarks	Left d Right Down	Left s Right Strange	Left b Right Bottom	0	0
	Left ν_e Right Electron neutrino	Left ν_μ Right Muon neutrino	Left ν_τ Right Tau neutrino	91.2 GeV	> 114 GeV
	Left N_1 Right Sterile neutrino	Left N_2 Right Sterile neutrino	Left N_3 Right Sterile neutrino	0	0
Leptons	Left e Right Electron	Left μ Right Muon	Left τ Right Tau	80.4 GeV	Spin 0
	Left ν_e Right Electron neutrino	Left ν_μ Right Muon neutrino	Left ν_τ Right Tau neutrino	± 1	
	Left N_1 Right Sterile neutrino	Left N_2 Right Sterile neutrino	Left N_3 Right Sterile neutrino	0	0
				Bosons (forces) spin 1	
				0	0
				0	0
				91.2 GeV	> 114 GeV
				0	0
				0	0
				80.4 GeV	Spin 0
				± 1	
				0	0
				0	0
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keV Sterile Neutrino Signal in Beta Decay Spectra

How can we measure sterile neutrinos in KATRIN?

- production of a fourth, heavy mass state via mixing with the active neutrinos
- spectral distortion : “kink-like” signal extending deep into the spectrum
- previous searches for eV and low keV scale steriles with existing KATRIN data

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_S \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} \\ U_{S1} & U_{S2} & U_{S3} & U_{S4} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{pmatrix}$$



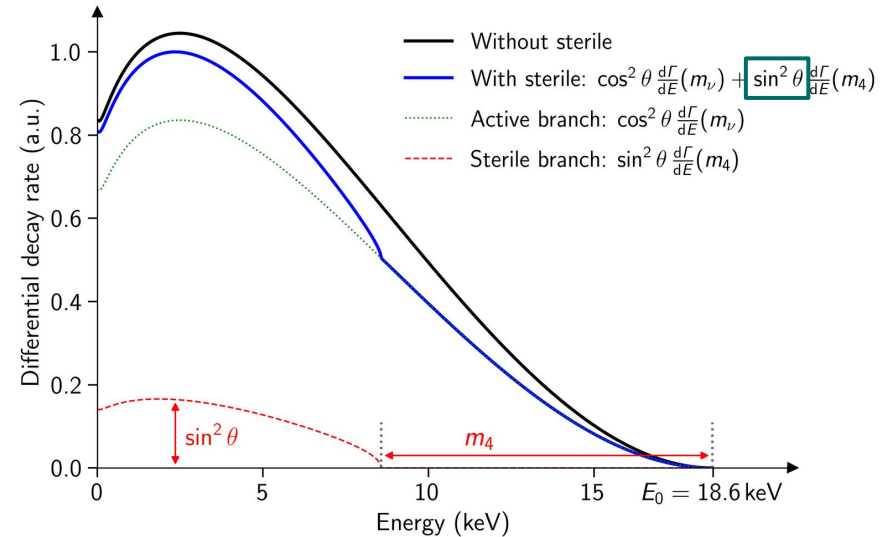
KATRIN Collaboration, Eur. Phys. J. C (2023) 83:763
KATRIN Collaboration, Nature vol. 648, p. 70–75 (2025)

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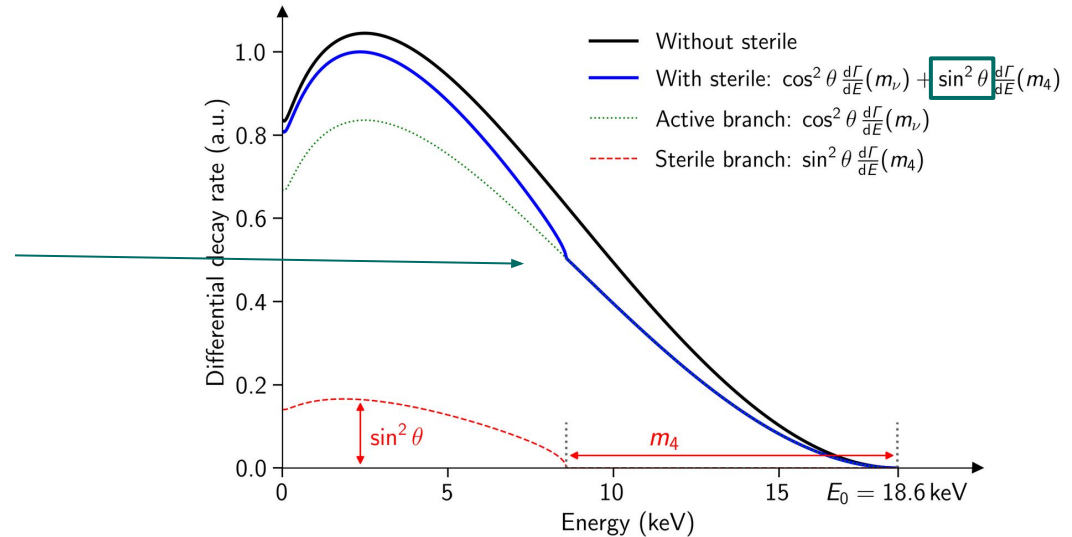
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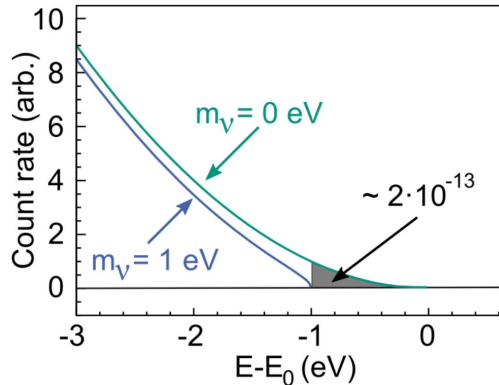
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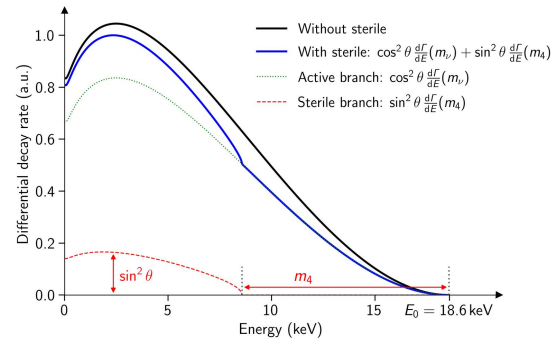
keV Sterile Neutrinos in KATRIN

Neutrino Mass Measurement



- signal near endpoint ($\sim 40 \text{ eV ROI}$)
- low count rates ($\sim 1 \text{ cps}$)
- integral measurement
- total statistics $\sim 2 \times 10^8 \text{ e.}$ in 1000 days

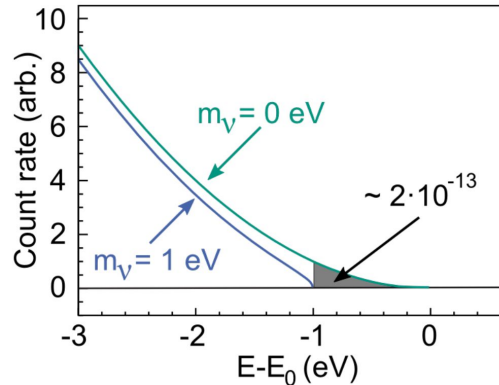
Sterile Neutrino Search



- signal anywhere in the spectrum ($\sim 15 \text{ keV ROI}$)
- very high count rates ($\sim 1 \text{ e}8 \text{ cps}$)
- differential measurement
- total expected statistics $\sim 4 \times 10^{14} \text{ e.}$ in ~ 4 months

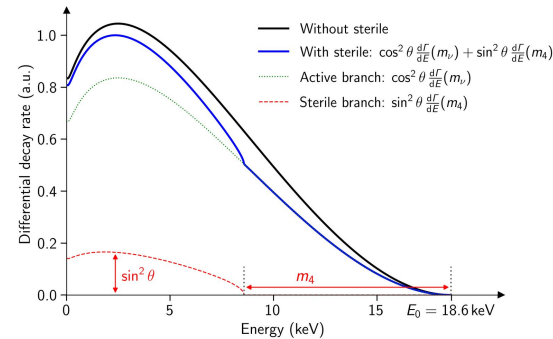
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→ development of new detector system

keV Sterile Neutrinos in KATRIN

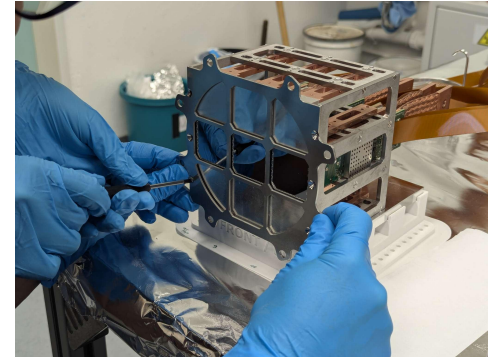
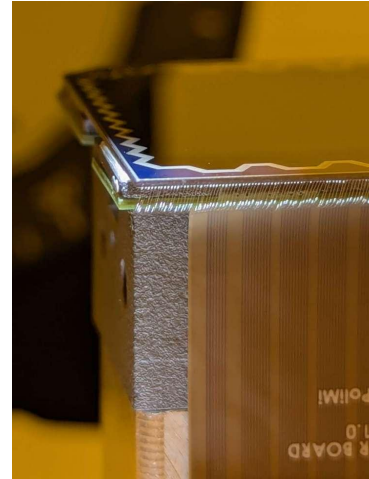
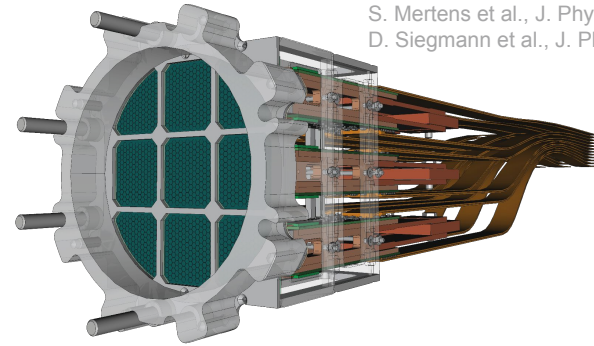
The TRISTAN Detector

- pixelated silicon drift detector (SDD)
- high rate capabilities: $\sim 10^5$ cps/pixel
- good energy resolution: ~ 300 eV at 20keV

Milestones

- **2017**: first 7 and 47 pixel prototypes
- **2022**: first 166-pixel module operated in KATRIN-like environment
- **2024**: successful operation of multi-module tower in replica of KATRIN detector section
- production of 9 modules of 166 pixels each for integration in the KATRIN beamline currently ongoing (8 already produced and characterized)

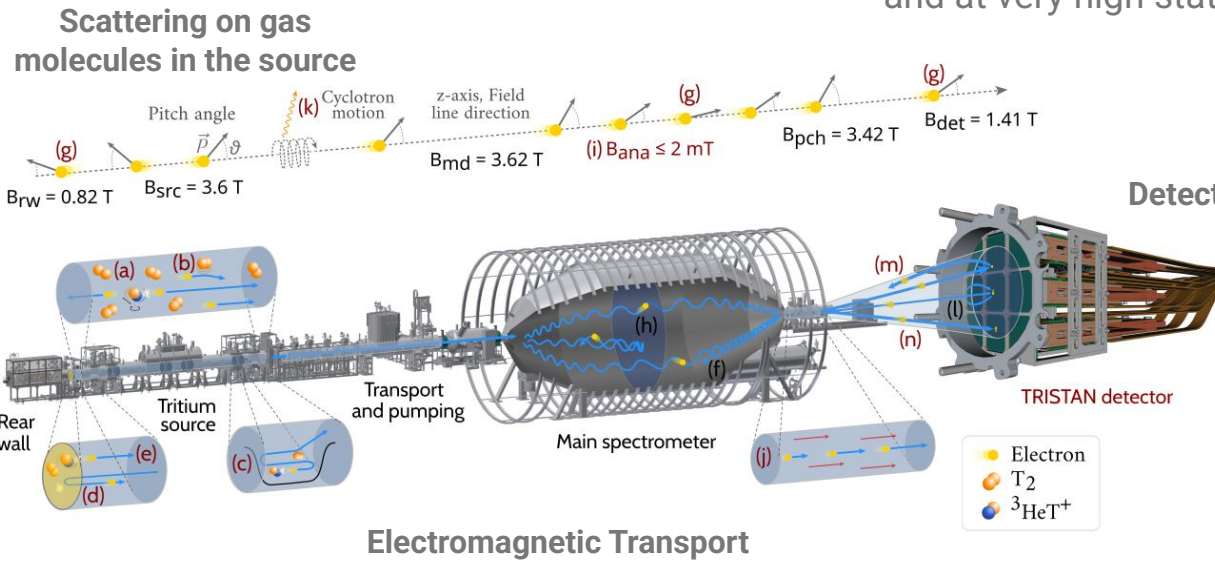
S. Mertens et al., JCAP02(2015)020
S. Mertens et al., J. Phys. G46 065203 (2019)
D. Siegmann et al., J. Phys. G51 085202 (2024)



keV Sterile Neutrinos in KATRIN

Systematic Effects

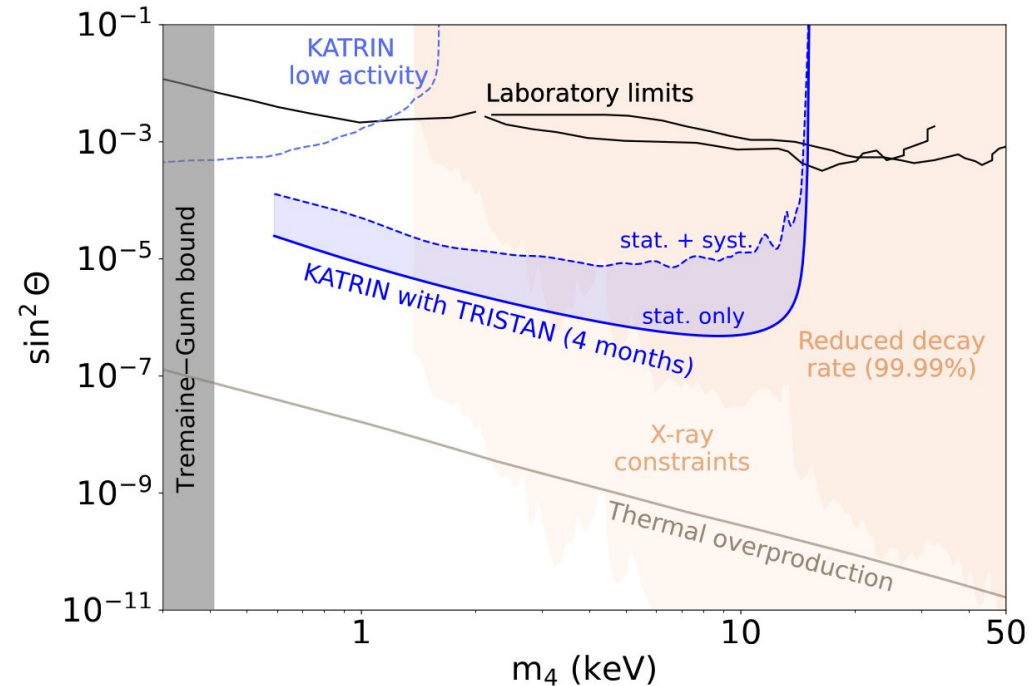
Challenge: Control and correctly model systematics over a wide energy range and at very high statistics



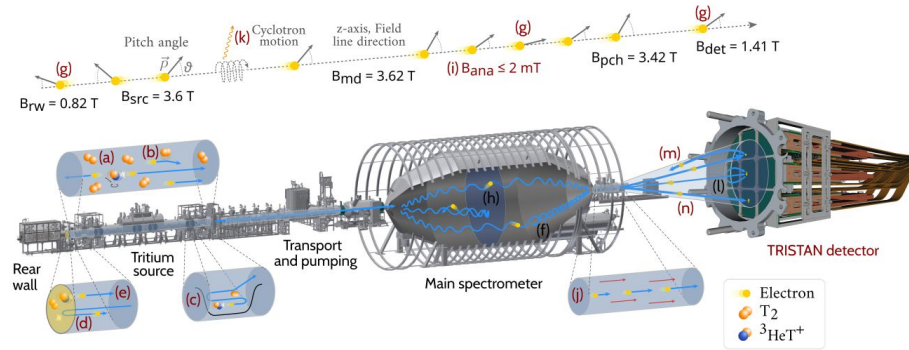
KATRIN Sensitivity to Sterile Neutrinos

- statistical power to reach a sensitivity of $\sin^2(\theta) < 10^{-6}$ with 4 months of measurement
- sensitivity degraded by factor 10-50 by systematic uncertainties
- potential to improve previous laboratory limits by two orders of magnitude
- measurement independent of cosmological production assumptions

KATRIN Collaboration, [arXiv:2603.23256](https://arxiv.org/abs/2603.23256)

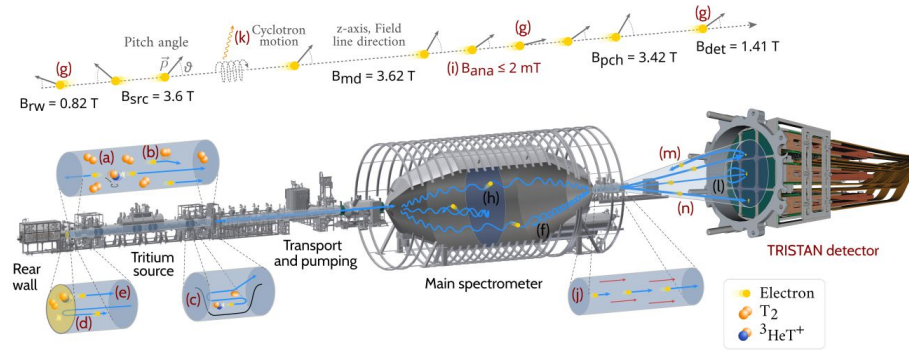


Outlook



- Preparations underway for installation of TRISTAN detector after the final neutrino-mass systematic measurements.
- TRISTAN will enable a high-statistics, model-independent laboratory search for keV sterile neutrinos with sensitivity beyond current laboratory limits
- beyond TRISTAN: R&D for next generation neutrino mass experiments (KATRIN++) →next talk

Outlook

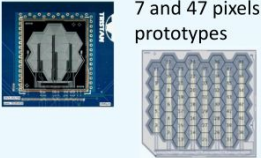
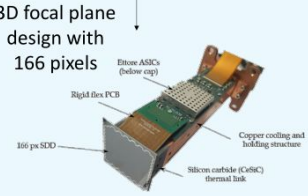
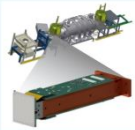
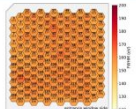
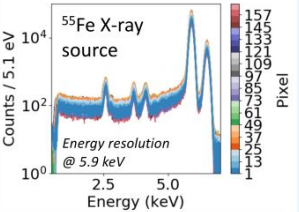

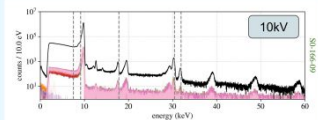
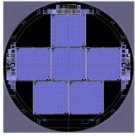
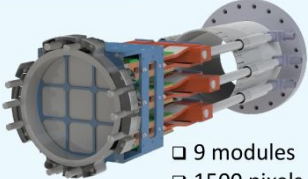


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Thank you for your attention!

Backup

Detector Milestones

2017	2022	2024-2025	2026-2027
<p>1st prototype</p> <p>7 and 47 pixels prototypes</p>  <p>3D focal plane design with 166 pixels</p>  <p>Labels: Filter ASICs (below chip), Rigid flex PCB, 166 pin SSD, Silicon carbide (SiC) thermal link, Copper cooling and holding structure</p> <p>⇒ Bench test, performance demonstrated to match requirement ✓</p>	<p>1st module in monitor spectrometer</p> <ul style="list-style-type: none"> Refurbished MAC-E filter from Mainz exp. reassembled in KIT.  <p>[j.nima.2021.166102]</p>   <p>Labels: ⁵⁵Fe X-ray source, Counts / 5.1 eV, Energy resolution @ 5.9 keV, Pixel</p> <p>⇒ Successful operation in KATRIN-like environment ✓</p>	<p>Multi-module tower in detector replica</p> <ul style="list-style-type: none"> KATRIN detector section replica Multi-modules calibration   <p>Labels: counts / 100kV, energy (keV), 10kV</p> <p>⇒ Successful deployment of 3 modules in 2024 ✓ 9 modules by end 2025</p>	<p>Detector tower in KATRIN beamline</p> <p>SSD in production</p>  <p>SSD wafer</p>  <p>□ 9 modules □ 1500 pixels</p> <p>⇒ First KATRIN keV sterile neutrino search with TRISTAN</p>

Changes from Neutrino Mass to keV Sterile Search

Low source activity

- Rate constraint -
- 100% → ~1%

Low retarding voltage

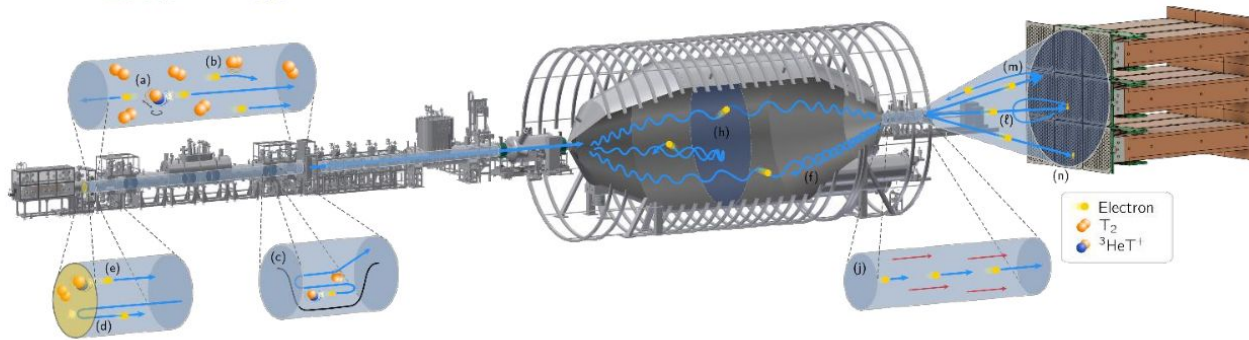
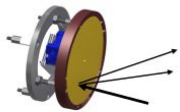
- Differential full-spectrum measurement -
- 40 eV → < -15 keV

New TRISTAN detector and DAQ

- High rates & high resolution -
- < 1 e⁻.s⁻¹ → ~10⁸ e⁻.s⁻¹

New rear wall

- Reduced backscattering -
- Au → Be



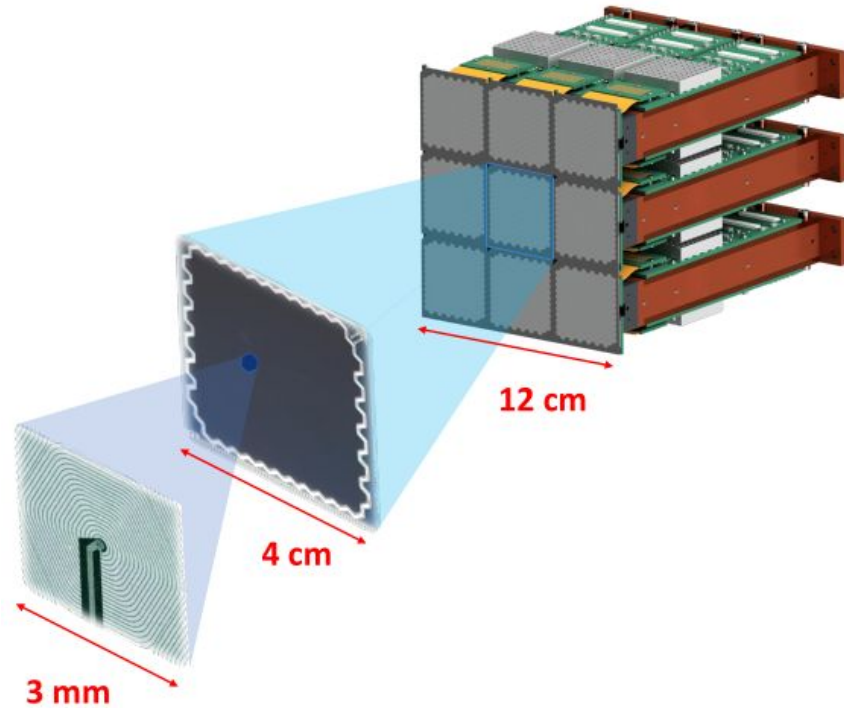
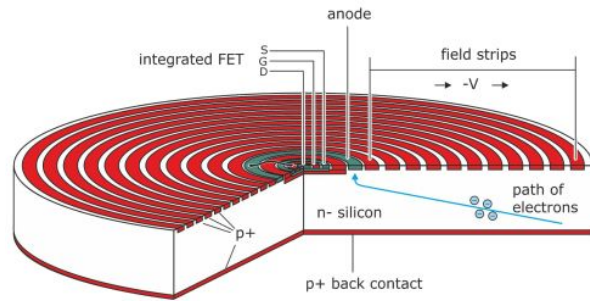
Optimised electromagnetic field settings

- Ensure adiabaticity / optimize systematic effects -

New post acceleration system

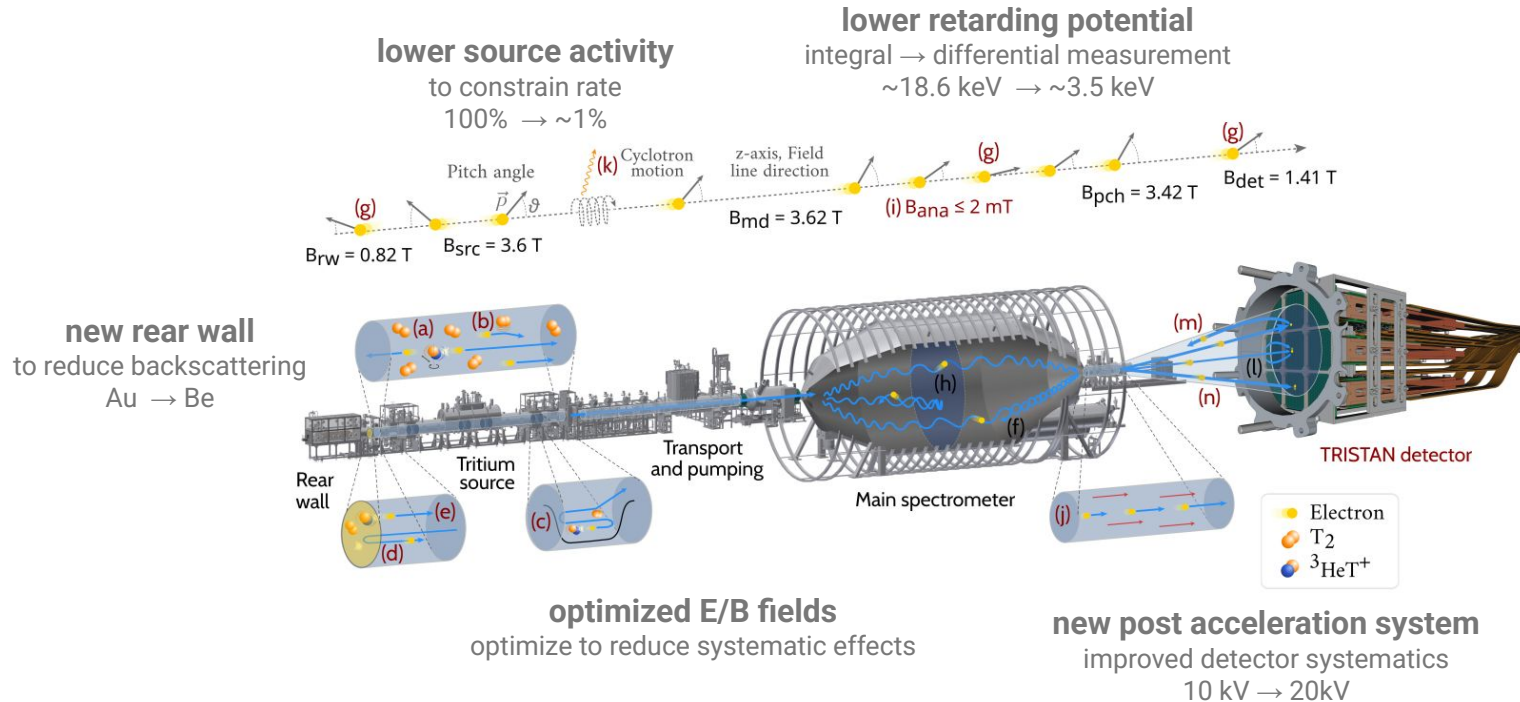
- Improved detector systematics -
- +10 kV → +20 kV

SDD Working Principle

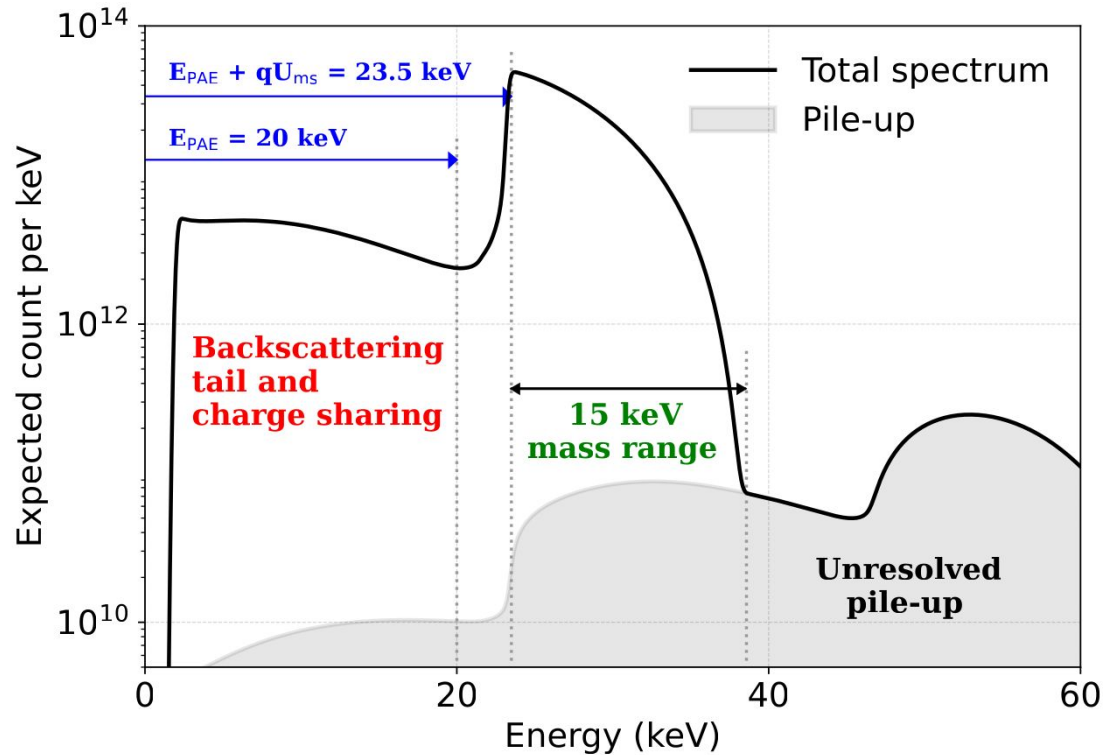


keV Sterile Neutrinos in KATRIN

Other Changes to the Beamline



Expected Full Measured Spectrum



KATRIN Sensitivity to Sterile Neutrinos

- statistical power to reach a sensitivity of $\sin^2(\theta) < 10^{-6}$ with 4 months of measurement
- sensitivity degraded by factor 10-50 by systematic uncertainties
- not dominated by single group of systematics
- potential to improve previous laboratory limits by two orders of magnitude

KATRIN Coll., [arXiv:2603.23256](https://arxiv.org/abs/2603.23256)

