The TRISTAN Detector Upgrade for the keV Sterile Neutrino Search with the KATRIN Experiment

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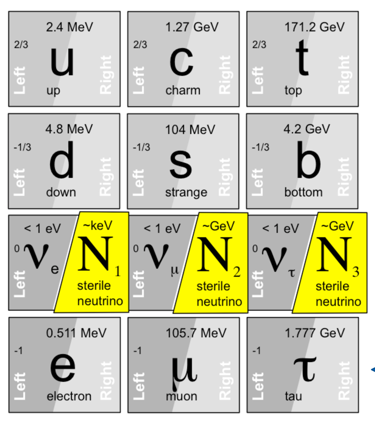
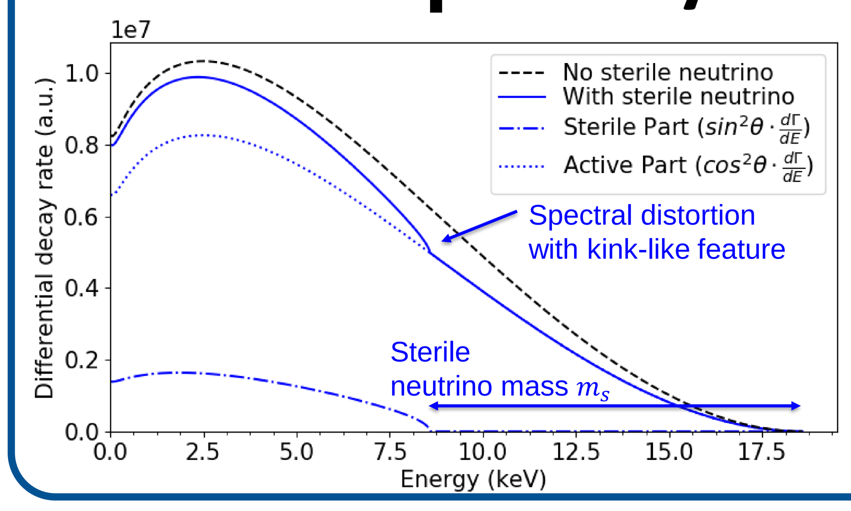
Sterile Neutrinos – Key to the Universe?

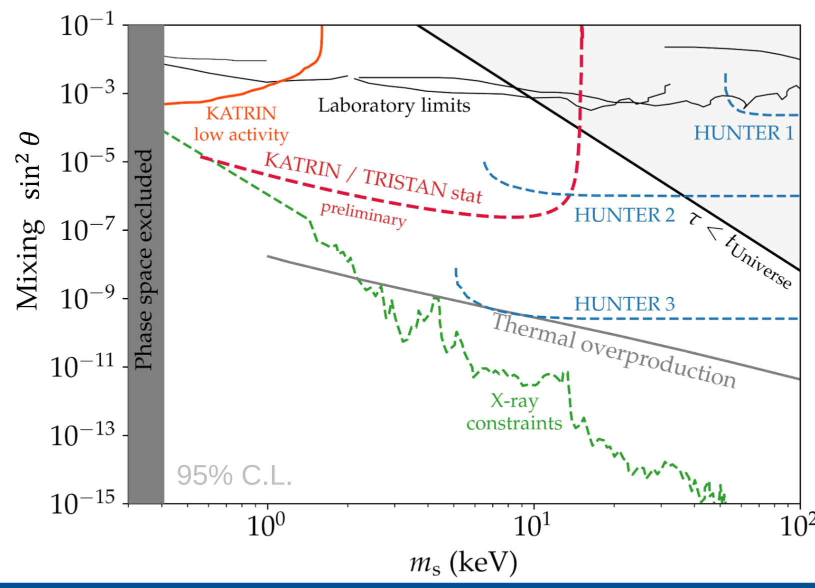


- **Sterile neutrinos** are a **minimal extension** of the Standard Model
- **keV-sterile neutrinos** are viable **dark matter** candidates

◄ *Standard Model of particle physics with 3 sterile neutrinos*

Sterile ν in β-Decay

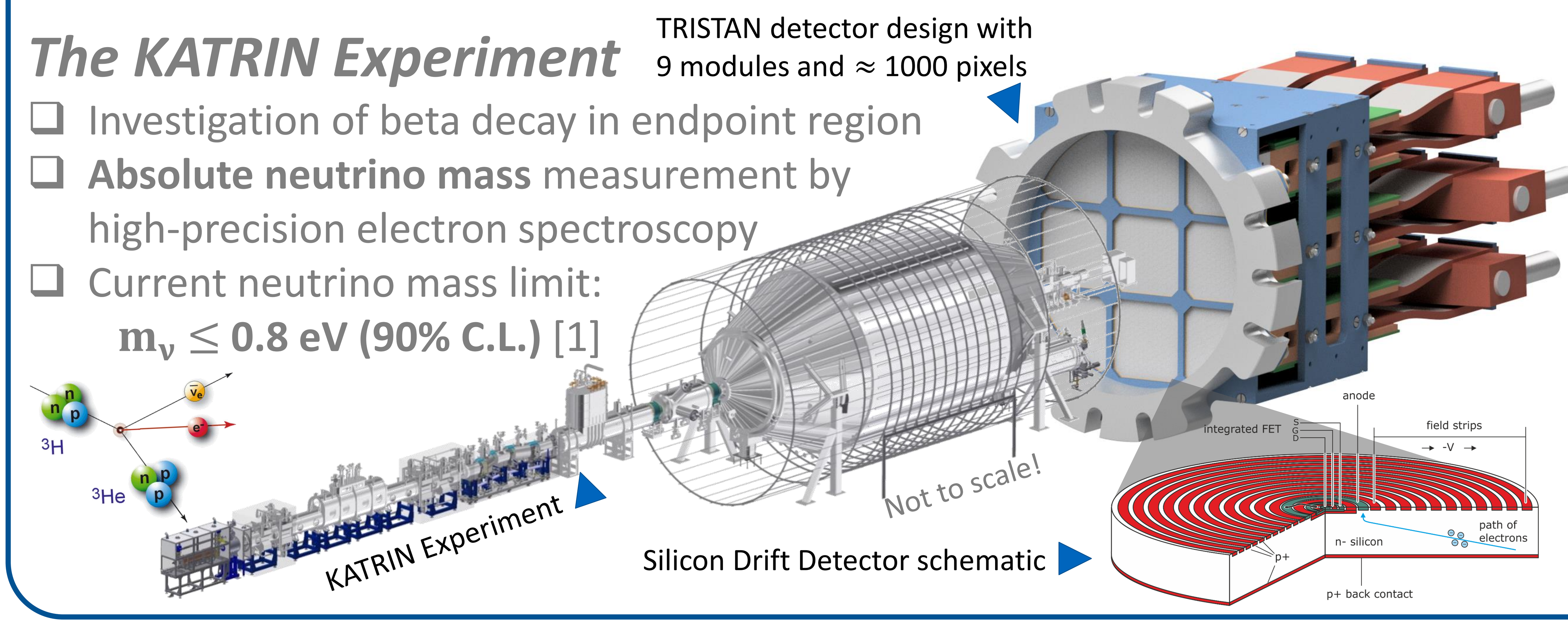




keV Sterile Neutrino Search with KATRIN – The TRISTAN Detector Upgrade

The KATRIN Experiment

- Investigation of beta decay in endpoint region
- **Absolute neutrino mass** measurement by high-precision electron spectroscopy
- Current neutrino mass limit: $\mathbf{m_\nu \leq 0.8}$ **eV (90% C.L.)** [1]



Physics Goals

- Target stat. sensitivity: $\sin^2(\theta_{14}) \approx 10^{-6}$ [2]
- Mass range: 0 keV $< m_s \leq$ 18.6 keV
- Installation planned beginning of 2026

Detector Requirements

- Silicon Drift Detector: ~1000 active pixels
- Energy resolution of 300 eV FWHM @ 20 keV
- Handling of high rates of $\mathcal{O}(10^8$ cps$)$
- Low energy threshold (≈ 2 keV)
- Large area of coverage (Ø 20 cm)

TRISTAN

166-Pixel 3D Module

- Hide electronics behind SDD to maximize detection area
- All parts selected for vacuum compatibility (goal: 10^{-9} mbar)

Silicon Drift Detector

- Chip size: 40 x 38 x 0.45 mm
- 166 pixels with each Ø 3 mm
- Integrated nJFET amplifiers
- Leakage current:
  ≈ 100 pA/cm² @ room temp.
  ≈ 2 pA/cm² @ -35°C

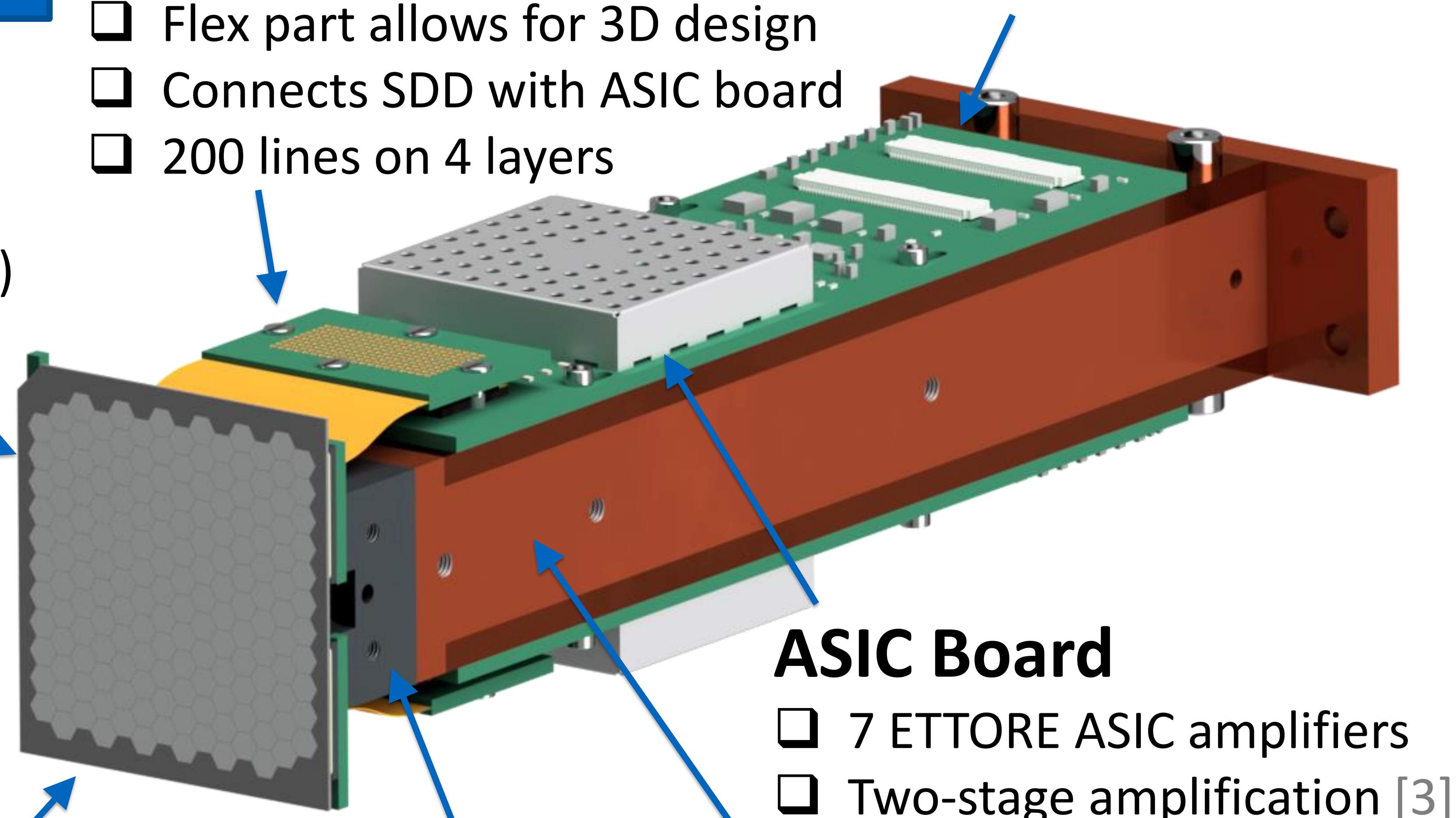
Wire bond connections

- Connect SDD to electronics

Rigid-Flex Cable

- Flex part allows for 3D design
- Connects SDD with ASIC board
- 200 lines on 4 layers

Flex Connector



Cesic Interposer

- Matches CTE of SDD
- Mechanical solid interface to SDD

ASIC Board

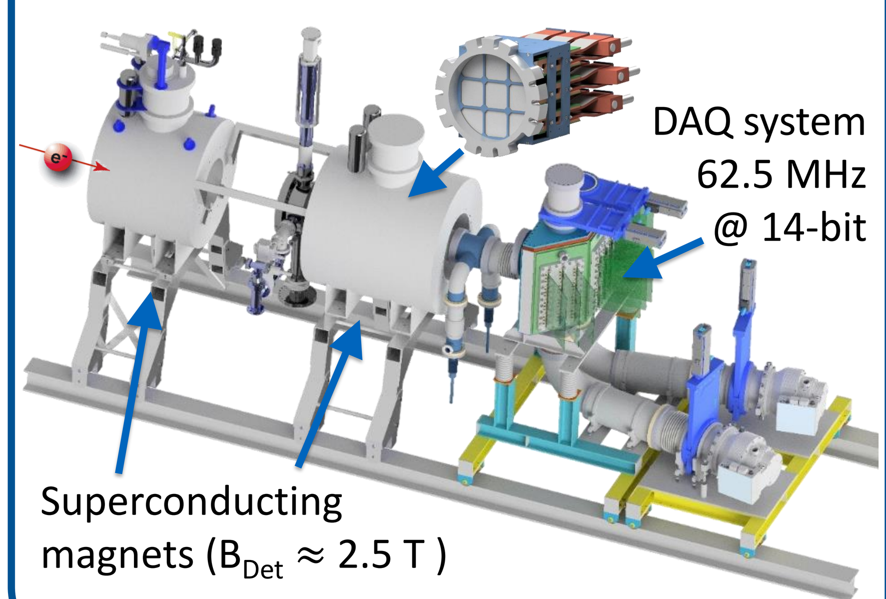
- 7 ETTORE ASIC amplifiers
- Two-stage amplification [3]

Copper Cooling Block

- Thermal interface to chiller
- Cooling to -35°C @ SDD

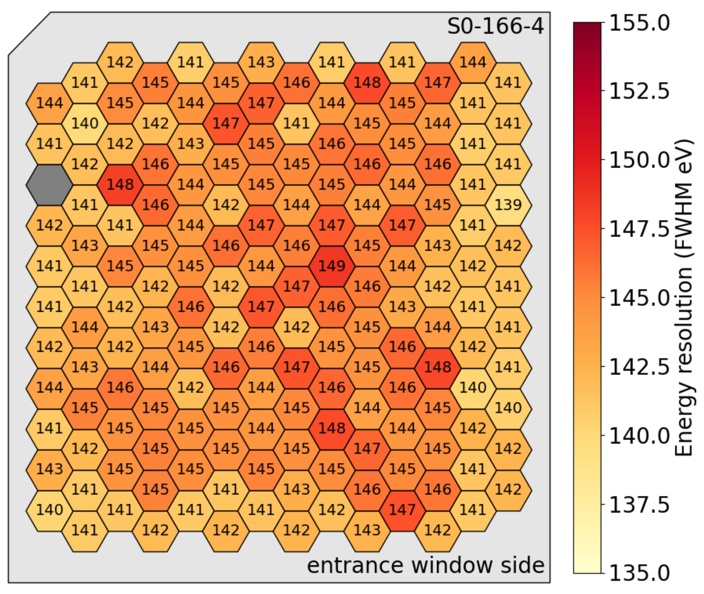
Detector Section

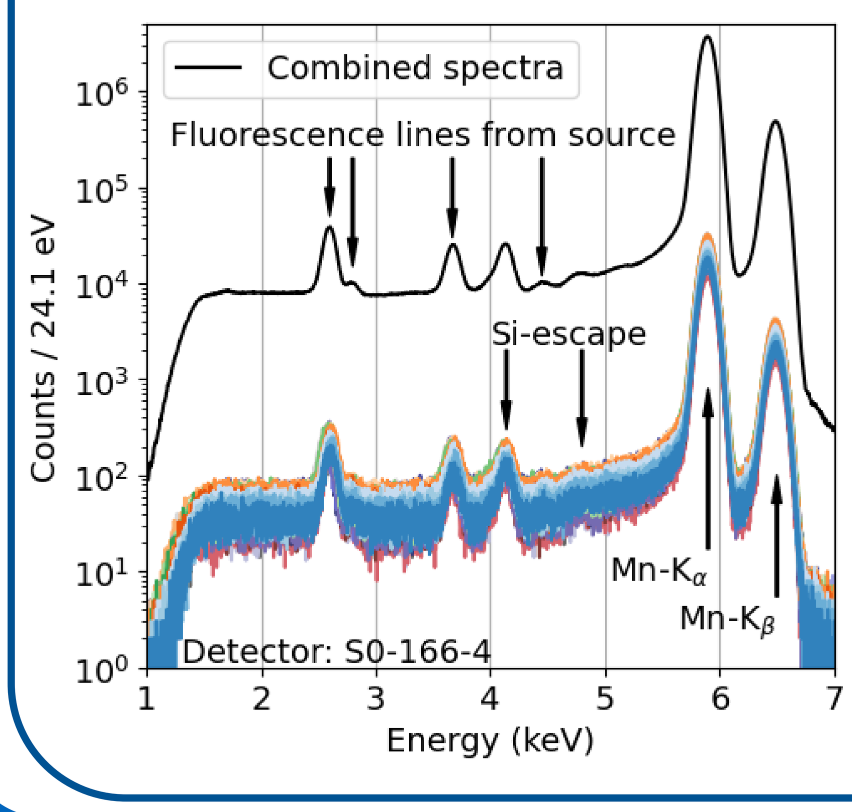
- Replica of the detector section currently in assembly
- First tests with 3 detector modules and remote ADC DAQ system end of this year
- Test of full TRISTAN detector system expected in 2025

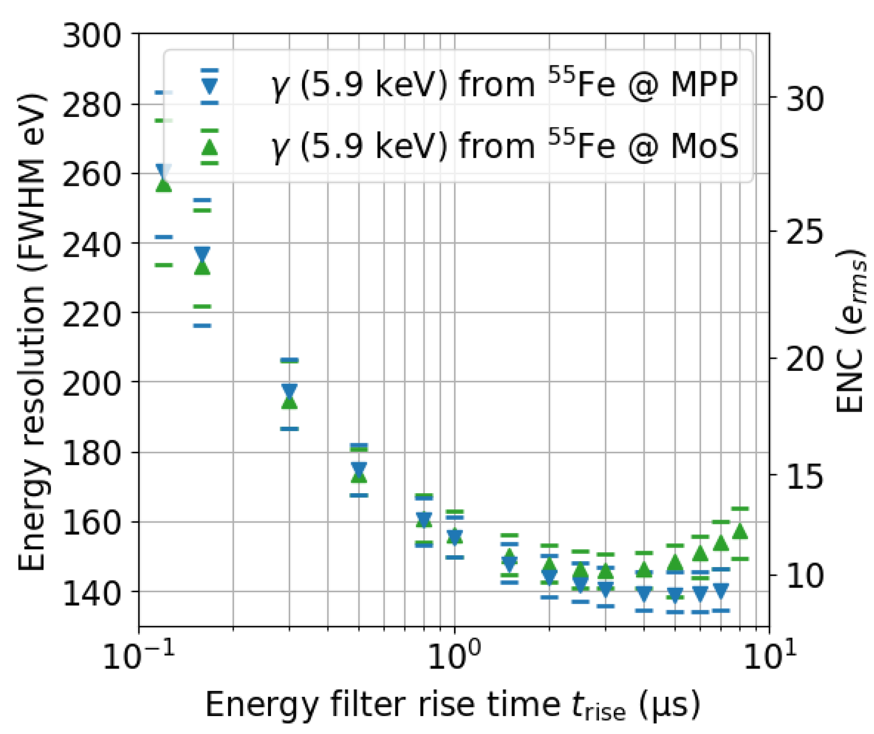


Characterization with X-rays

- Mean energy resolution: 143.7 eV (FWHM γ @ 5.9 keV)
- Energy threshold ≈ 1.5 keV
- Operation temperature: -35°C
- Similar noise performance in different environments [4]

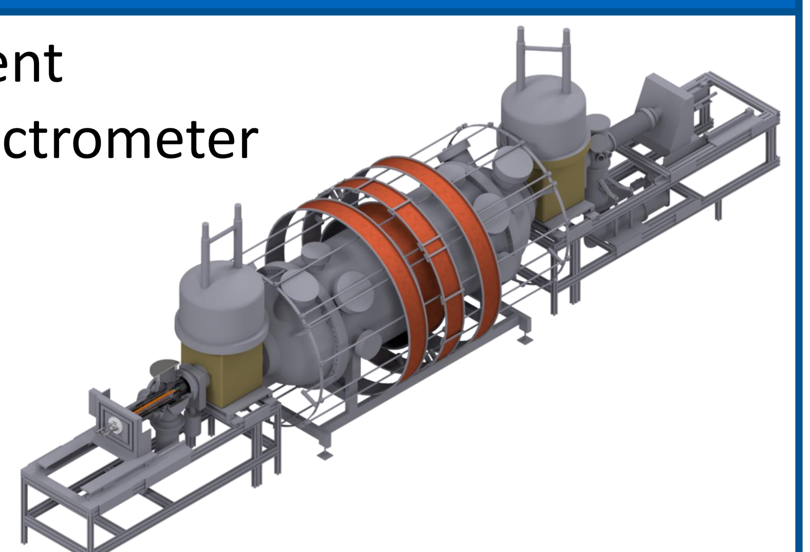


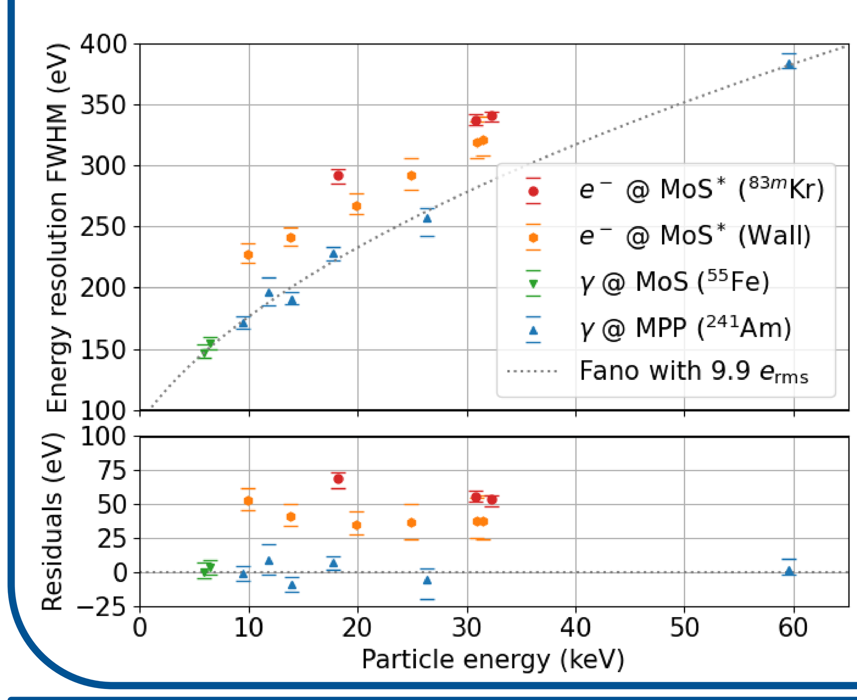


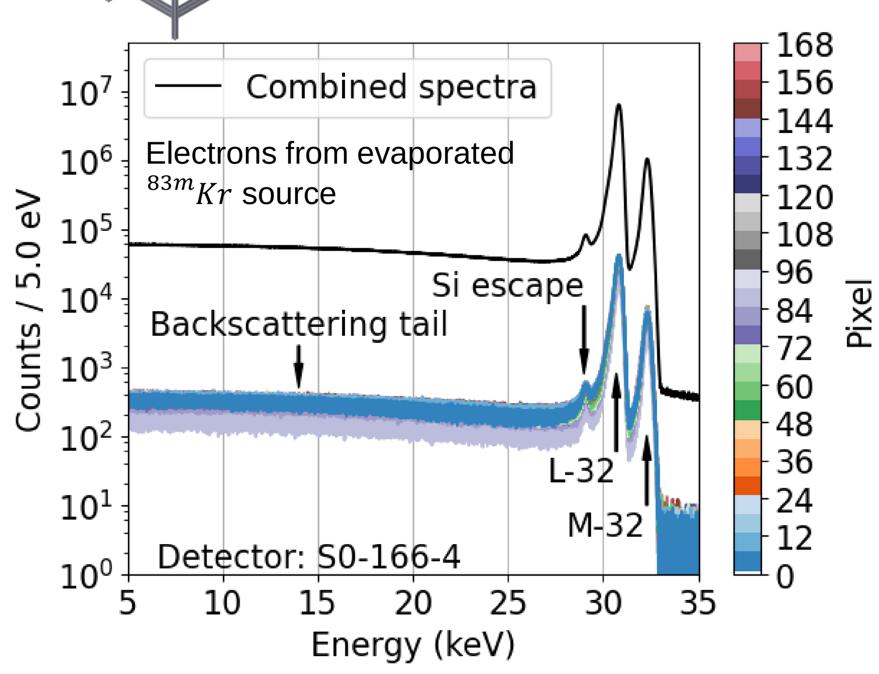


Test in KATRIN Monitor Spectrometer

- Predecessor of KATRIN experiment
  - Vacuum of 10^{-10} mbar in spectrometer and 10^{-8} mbar at detector
  - Magnetic field of 100 mT
- Successfully installed and tested detector module [4]
- Used different electron sources







[1] M. Aker et al. (KATRIN Collaboration), *First direct neutrino-mass measurement with sub-eV sensitivity, Nat. Phys. 18, 160–166 (2022)*
[2] S. Mertens et al., *A novel detector system for KATRIN to search for keV-scale sterile neutrinos* , Journal of Phys. G, 46-6, (2019)
[3] P. Trigilio et al., *ETTORE: a 12-Channel Front-End ASIC for SDDs with Integrated JFET*, IEEE NSS/MIC, pp. 1-4 (2018)
[4] D. Siegmann et al. Development of a Silicon Drift Detector Array to Search for keV-scale Sterile Neutrinos with the KATRIN Experiment arXiv:2401.14114 (2024)

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