Assembly and test of the first TRISTAN detector modules

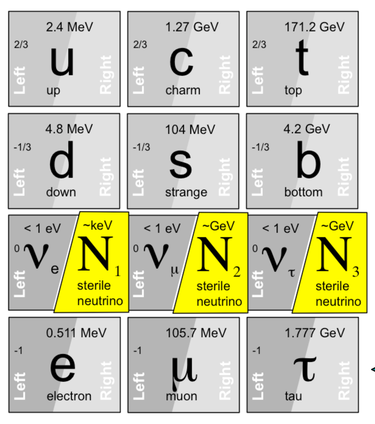
A keV-sterile Neutrino Search with KATRIN

Max-Planck research group KATRIN & TRISTAN

Daniel Siegmann[1,4], S. Mertens[1,4], M. Carminati[2], F. Edzards[1,4], C. Fiorini[2], M. Gugiatti[2], P. King[2], P. Lechner[3], K. Urban[1,4] on behalf of the KATRIN Collaboration

[1]Max-Planck-Institut für Physik, [2]Politecnico di Milano & INFN, [3]Halbleiterlabor der Max-Plack-Gesellschaft, [4]Technische Universität München

Sterile neutrinos – Key to the universe?



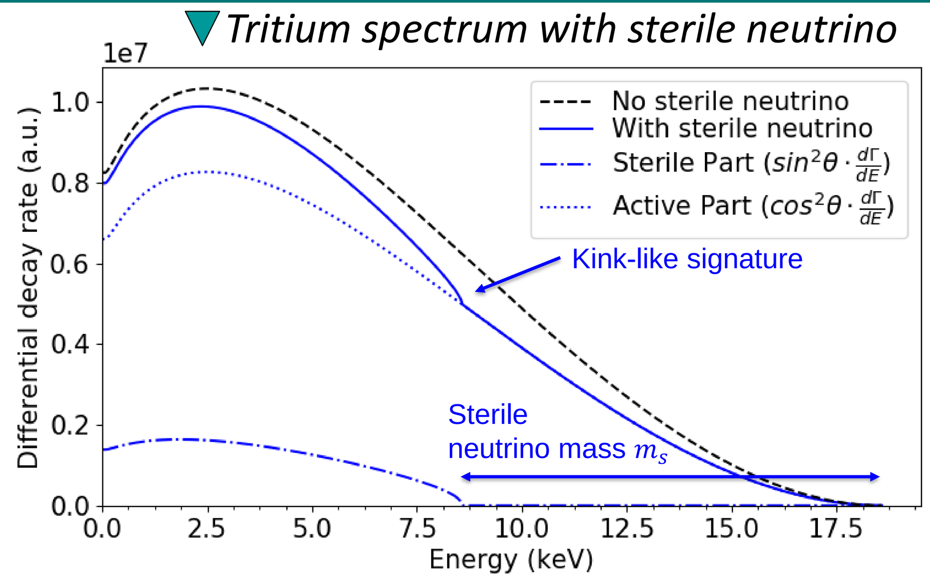
- ❑ **Sterile neutrinos** are a **minimal extension** to the Standard Model
- ❑ **keV-sterile neutrinos** are viable **dark matter** candidates

Standard particle model with 3 sterile neutrinos

Sterile ν in β-decay

- ❑ **Kink-like signature** in beta decay spectrum
- ❑ $\frac{d\Gamma}{dE} \propto \cos^2(\theta)\frac{d\Gamma}{dE}(m_a) + \sin^2(\theta)\frac{d\Gamma}{dE}(m_s)$

Tritium spectrum with sterile neutrino

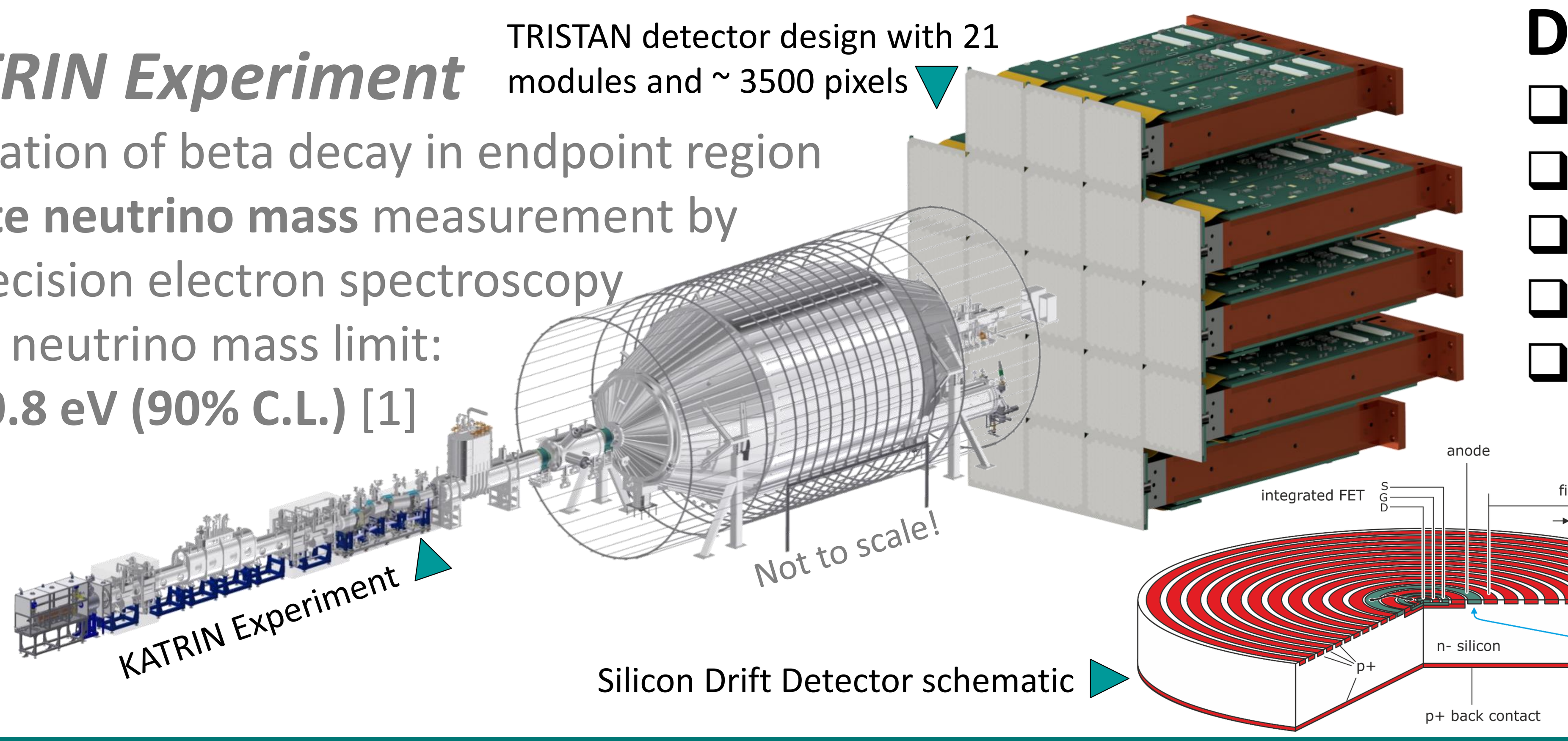


TRISTAN Project – High rate electron spectroscopy detector upgrade for KATRIN

The KATRIN Experiment

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

TRISTAN detector design with 21 modules and ~ 3500 pixels



Silicon Drift Detector schematic

Detector requirements

- ❑ **Energy resolution** of **300 eV FWHM** @ 20 keV
- ❑ Handling of **high rates** of $\mathcal{O}(10^8$ **cps**$)$
- ❑ Low energy **threshold (≈ 1 keV)**
- ❑ Large area of coverage (Ø 20 cm)
- ❑ Ultra-high vacuum compatibility

Physics goals

- ❑ **Silicon Drift Detector:** ~3500 pixels
- ❑ **Target sensitivity:** $\sin^2(\theta) \approx 10^{-6}$ [2]
- ❑ Mass range: 0 keV $< m_s \leq 18.6$ keV
- ❑ Installation expected 2025

166-Pixel 3D module

- ❑ Hide electronics below SDD to maximize detection area
- ❑ All parts selected for vacuum compatibility (Goal: 10^{-10} mbar)

Silicon Drift Detector (SDD)

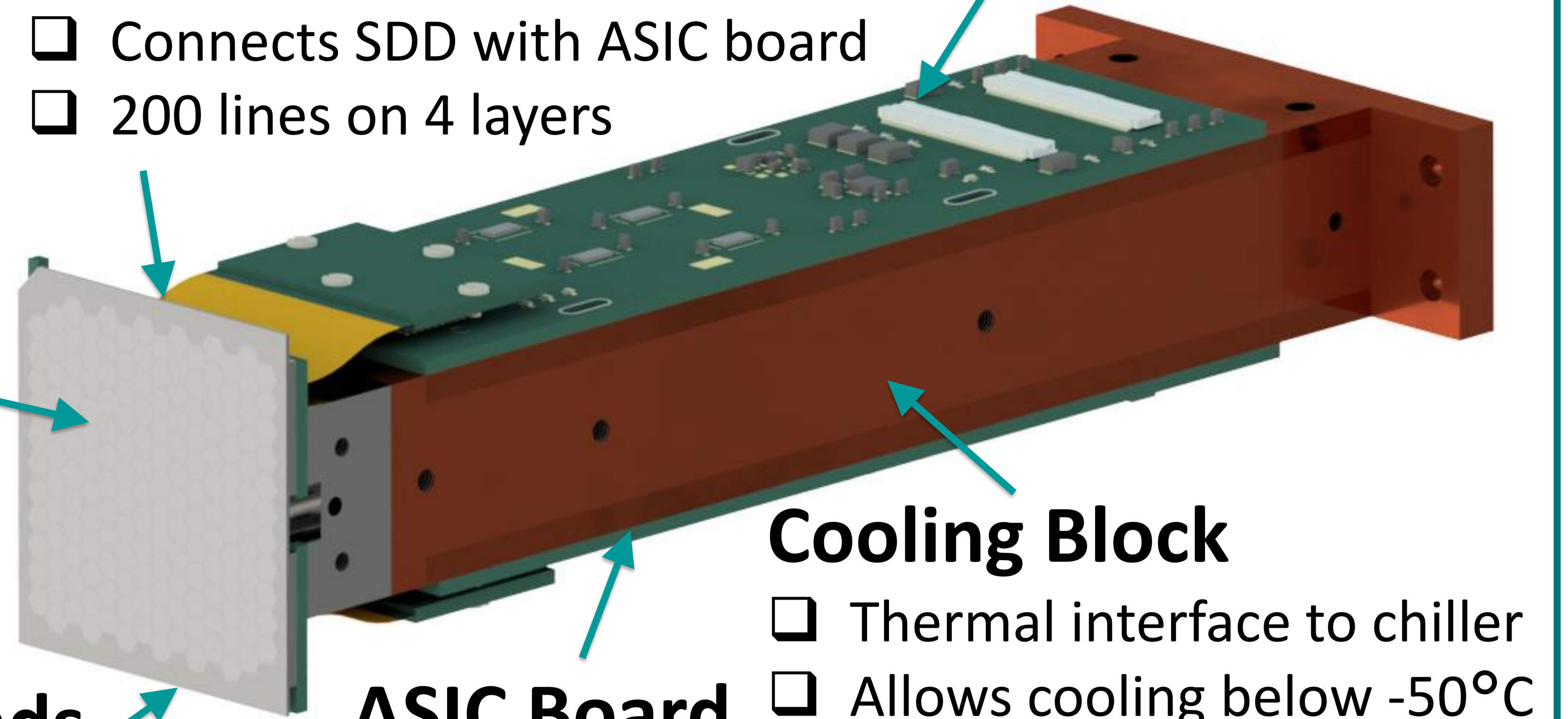
- ❑ Size: 40 x 38 x 0.45 mm
- ❑ 166 Pixel with each Ø 3 mm
- ❑ Integrated JFET amplification
- ❑ 359 electrical connections

Rigid-Flex Cable

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

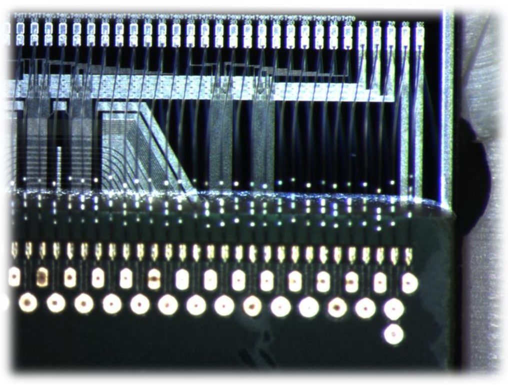
Flex Connector

- ❑ 100 lines each



Cooling Block

- ❑ Thermal interface to chiller
- ❑ Allows cooling below -50°C



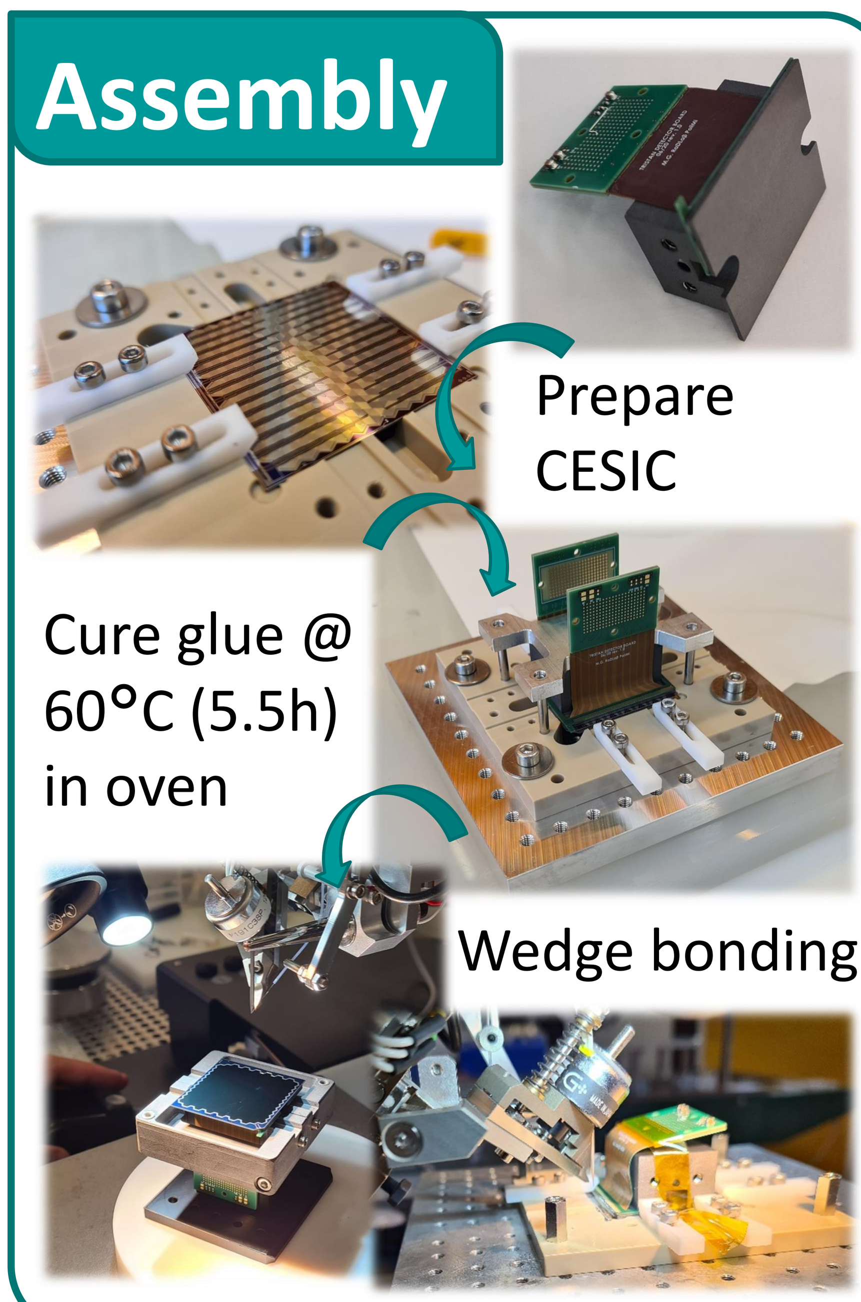
Wire Bonds

- ❑ Ø 14 μm (Hair Ø 60 μm)
- ❑ Welding with ultrasonic vibrations

ASIC Board

- ❑ 7 Ettore ASIC Amplifier [3]
  - ➢ Second amplification stage
  - ➢ Pulsed reset for integrated JFET
- ❑ Routing for signals and power supplies

Assembly

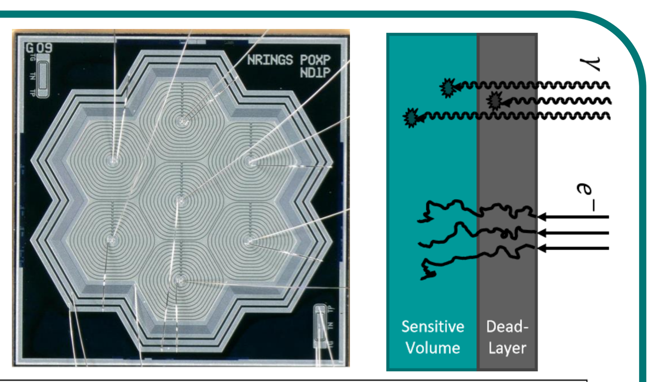


Prepare CESIC

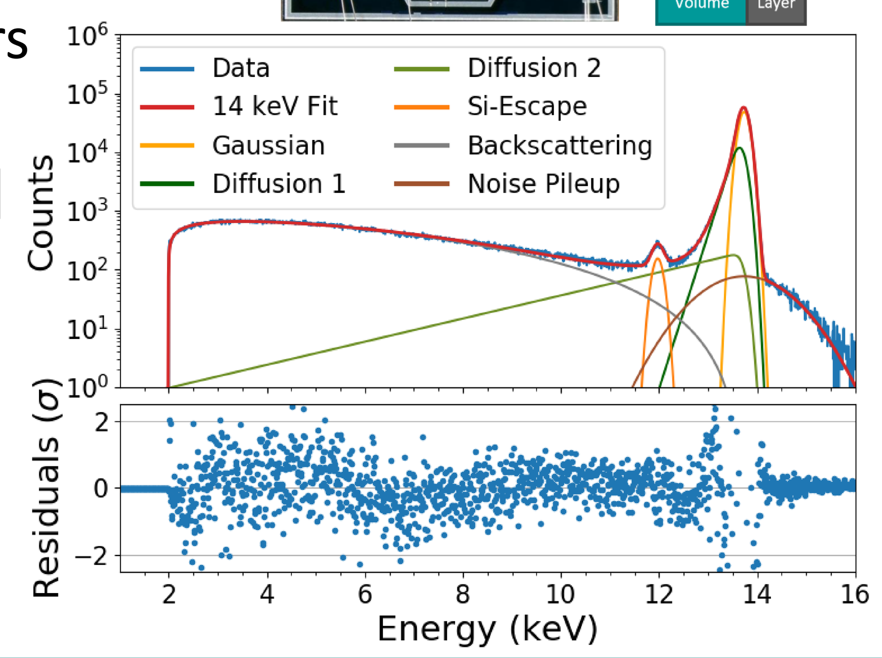
Cure glue @ 60°C (5.5h) in oven

Wedge bonding

7 Pixel prototype chips

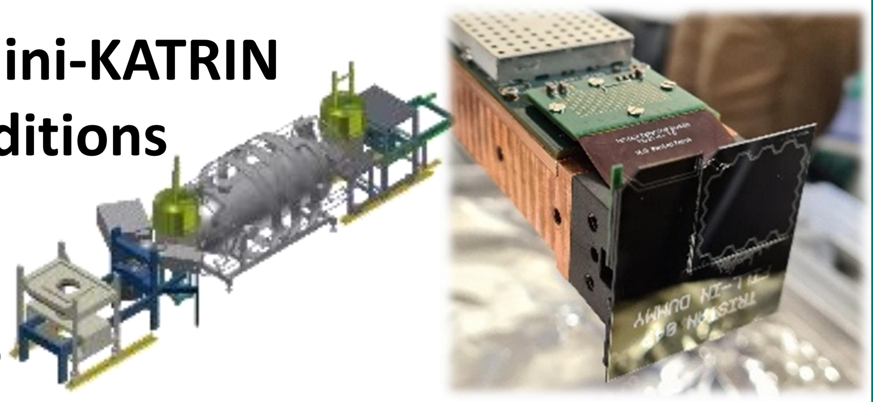


- ❑ Well established technology for γ-and X-rays
- ❑ **7 Pixel** prototype detectors
- ❑ **Resolution** γ @ 5.9 keV: 140 eV FWHM (-30 °C) [2]
- ❑ **Resolution** e⁻ @ 20 keV: < 300 eV FWHM (+20 °C) **Shaping time:** < 1 µs
- ❑ **Threshold**: 300 - 500 eV
- ❑ **Dead-Layer**: < 50 nm



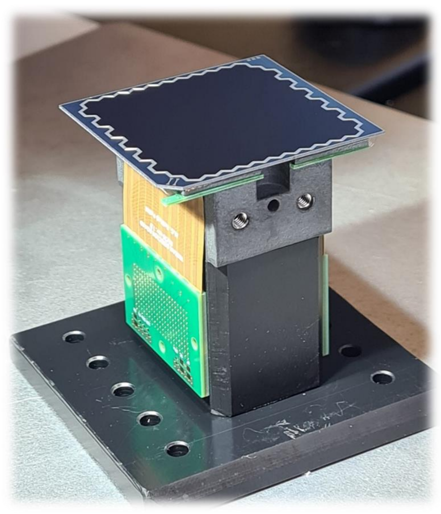
First Integration – "Mini-KATRIN"

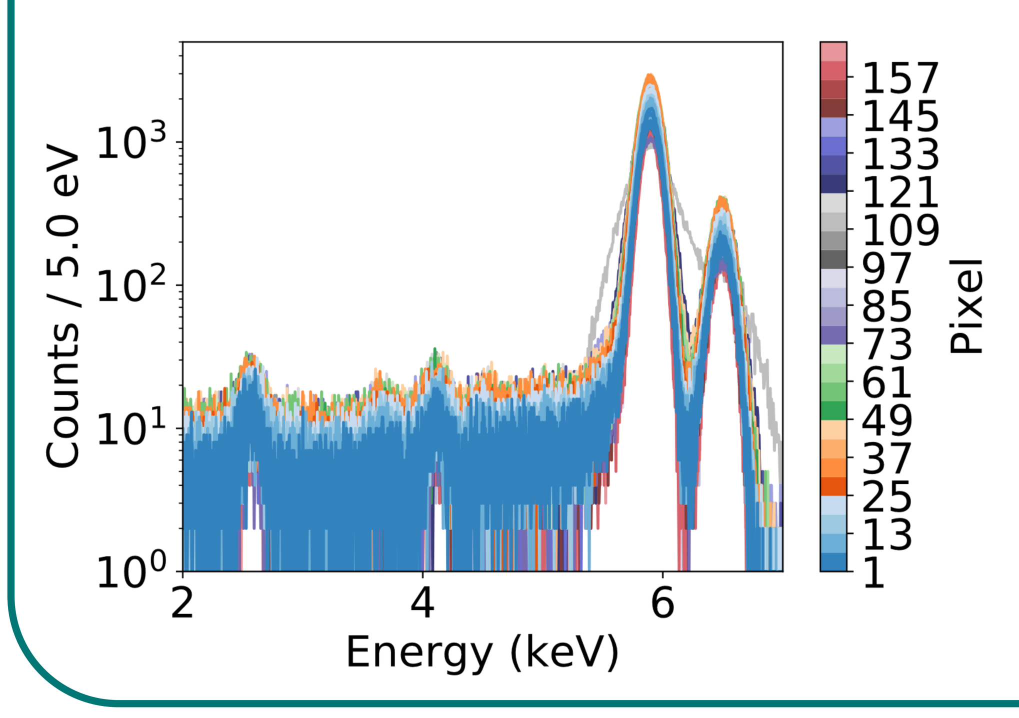
- ❑ Monitor spectrometer ≈ **Mini-KATRIN**
- ❑ **Realistic experimental conditions**
- ❑ **47 pixel** detector installed successfully in March **2021**
- ❑ **166 pixel** upgrade **this year**



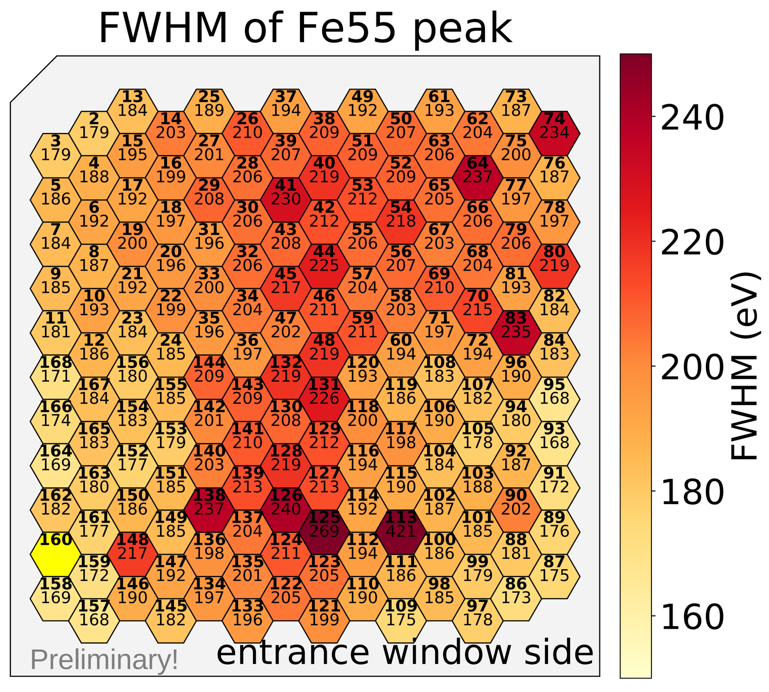
Commissioning of 166-Pixel 3D Module

- ❑ Critical gluing process between SDD and CESIC
- ❑ Successful assembly of two 166 pixel modules
- ❑ Characterization measurements started
  - ❑ 165 of 166 pixel functional for both modules
  - ❑ $\overline{FWHM}_{2\mu s,-50°C} \approx 194$ eV (γ @ 5.9 keV)
- ❑ Energy resolution and homogeneity expected to improve with next wafer production





FWHM of Fe55 peak



[1] M. Aker et al. (KATRIN Collaboration), *First direct neutrino-mass measurement with sub-eV sensitivity*, arXiv 2105.08533,(2021)
[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)