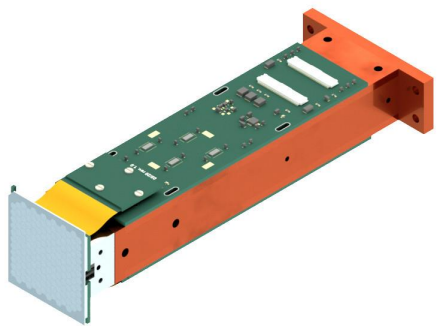
Technical University of Munich
Department for Physics

Max Planck Institute for Physics

Measurement of the drift time in a silicon drift detector for the KATRIN experiment by laser pulsing

Korbinian Urban
KATRIN collaboration



DPG Spring Meeting, Heidelberg

Content

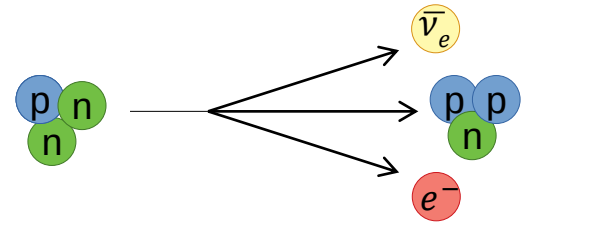
- Introduction to KATRIN and the TRISTAN detector
- Laser measurement idea
- First results

Idea of TRISAN

$$\begin{pmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \\ |\nu_S\rangle \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{S1} & U_{S2} & U_{S3} & U_{S4} \end{pmatrix} \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \\ |\nu_3\rangle \\ |\nu_4\rangle \end{pmatrix}$$

Idea: Search for a keV sterile neutrino with the KATRIN experiment

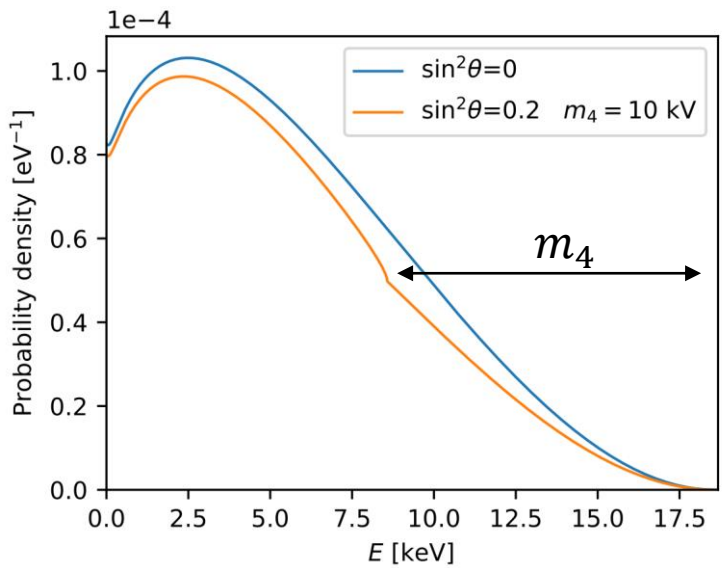
- **Sterile neutrino**:
  - Hypothetical heavy mass eigenstate mixed into the $\bar{\nu}_e$
  - Several theoretical motivations:
    - Warm dark matter candidate
    - ...



$$^3\mathrm{H} \longrightarrow {}^3\mathrm{He} + e^- + \bar{\nu}_e$$

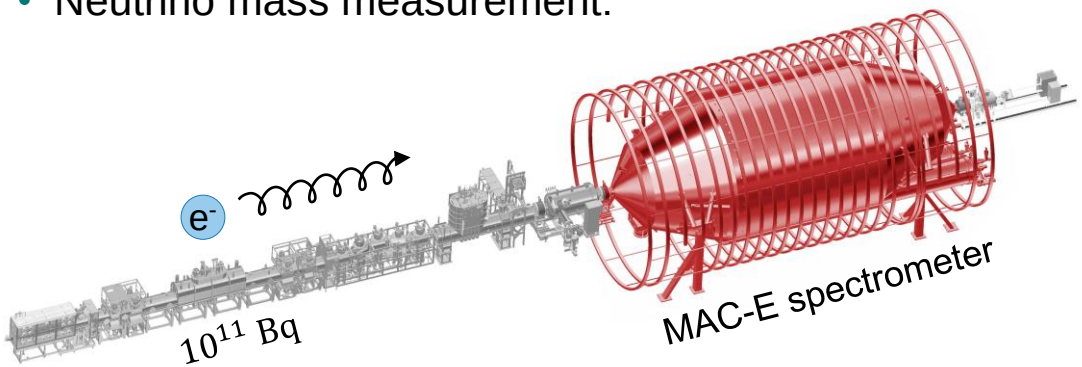
- Imprint of a sterile neutrino on tritium β-decay:
  - If mass is in the keV regime: Kink-like signature in electron spectrum of tritium β-decay

- What do we need to measure this kink with KATRIN?

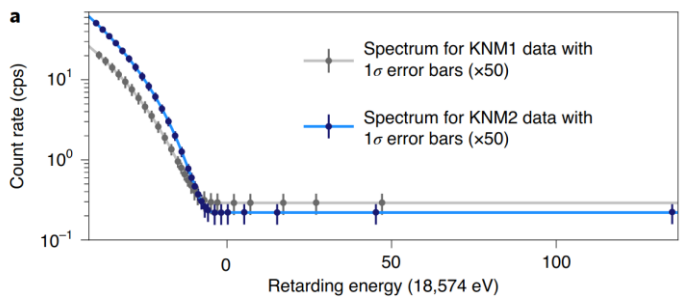


KATRIN experiment and TRISTAN

- Neutrino mass measurement:



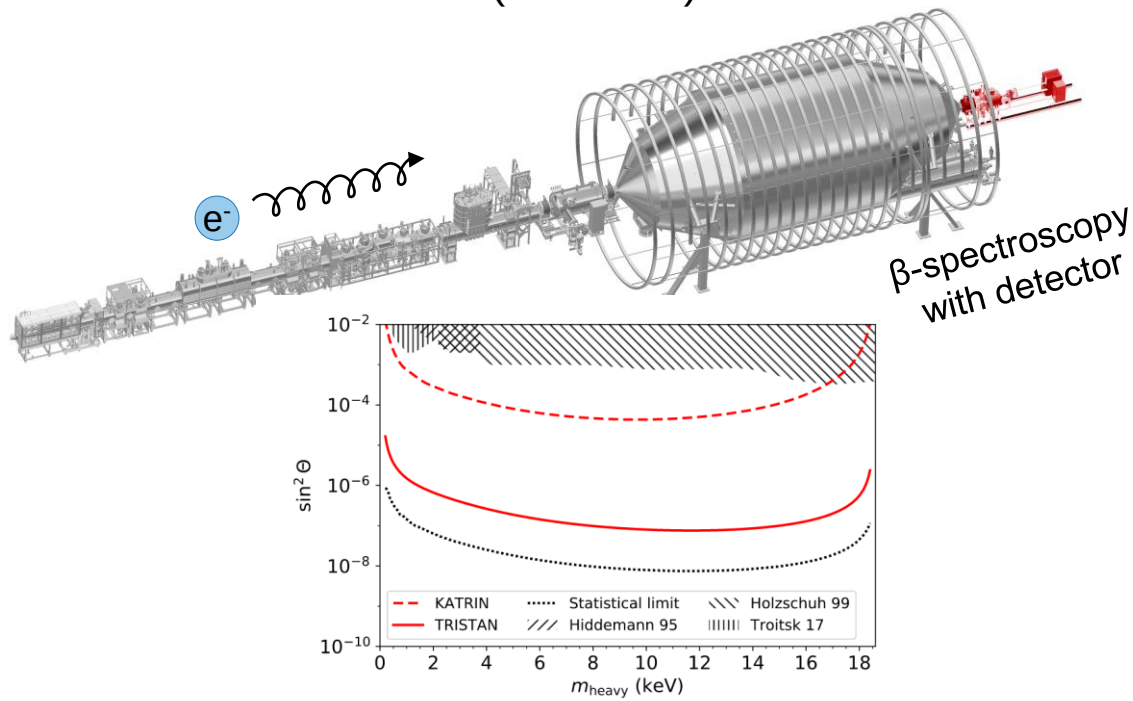
- **Integral** measurement, near endpoint



$$m_\nu < 0.8 \frac{\mathrm{eV}}{\mathrm{c}^2}$$
$$(90\%\ C.L.)$$

2022: The KATRIN Collaboration. Direct neutrino-mass measurement with sub-electronvolt sensitivity. Nat. Phys. 18, 160–166

- Sterile neutrino search (TRISTAN):



- **Differential** measurement, deep in the spectrum
  - High rate at detector (~10^8 cps)
  - Excellent detector resolution (~300 eV)

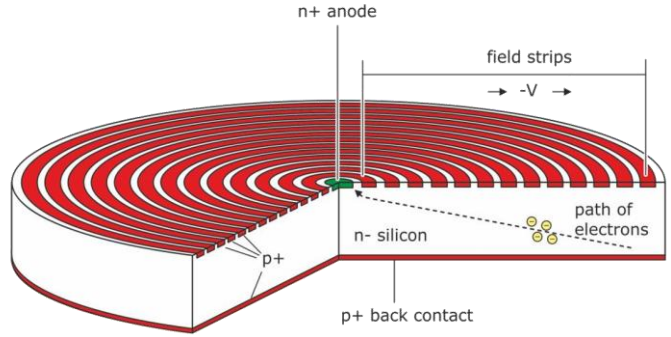
→ New detector being developed

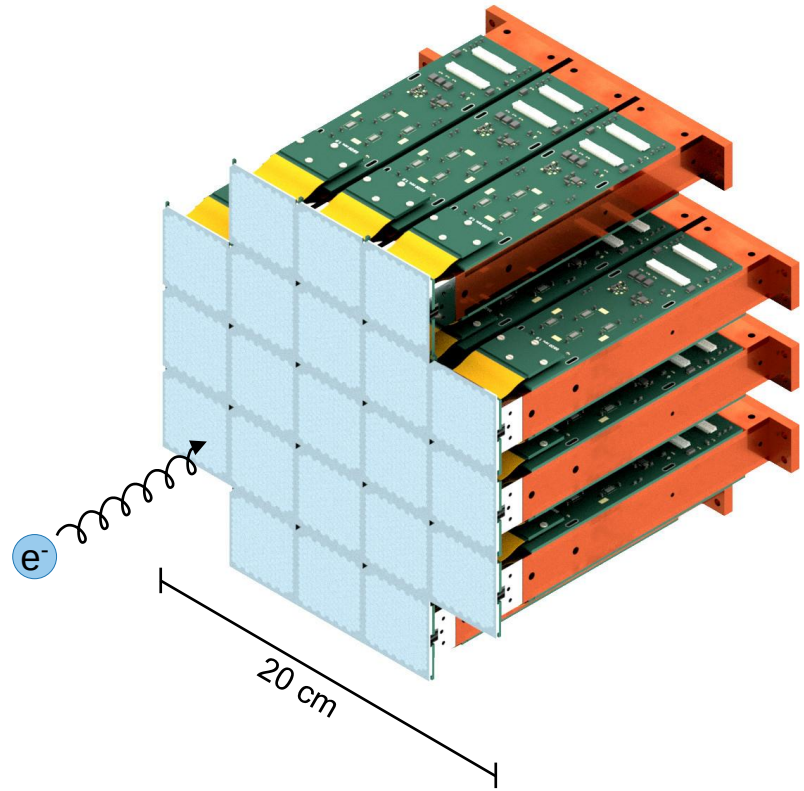
2019: Mertens et al: A novel detector system for KATRIN to search for keV-scale sterile neutrinos, DOI: 10.1088/1361-6471/ab12fe

About the TRISTAN detector

New detector for high rate, high resolution β-spectroscopy:

- Multi-pixel Silicon Drift Detector (SDD) focal plane array
- ~3000 pixels, grouped into 166-pixel modules
- 3 mm pixel diameter
- Aimed count rate: 10^5 cps per pixel
- More challenges:
  - Environmental constrains, mechanics, etc ...
  - **Understand detector response to a very precise level**
    - Dead layer
    - Backscattering
    - Readout
    - **Edge effects**
    - **Drift properties**

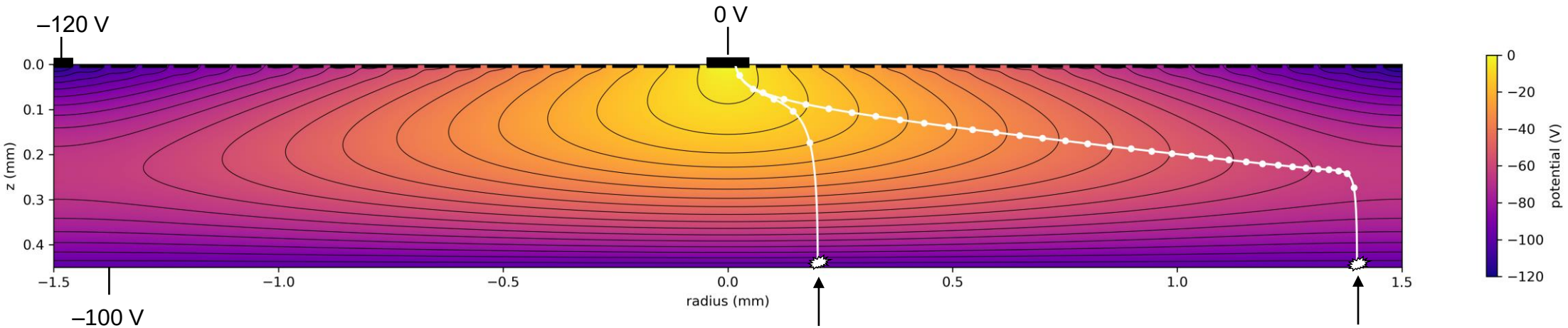




SDD drift

- How long takes the drift inside the SDD?

Important for edge effects, backscattering timing, time coincidence, TOF measurements etc...



- Calculated potential inside one SDD pixel
- Drift simulation
- Radial drift is much slower than vertical drift
  - Drift time varies between 20 ns to 170 ns with interaction radius

Assumed electron mobility:

$$\mu = 2180 \frac{cm^2}{Vs}$$

Measurement of drift time by laser pulsing

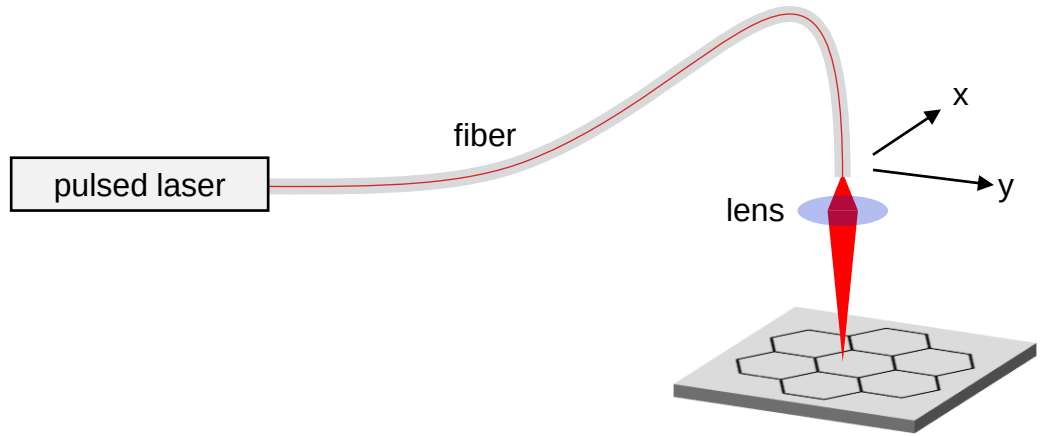
Idea: Use pulsed, focused laser to mimic events in the detector

Advantages:

✓Precise, known interaction point (xy-stage)

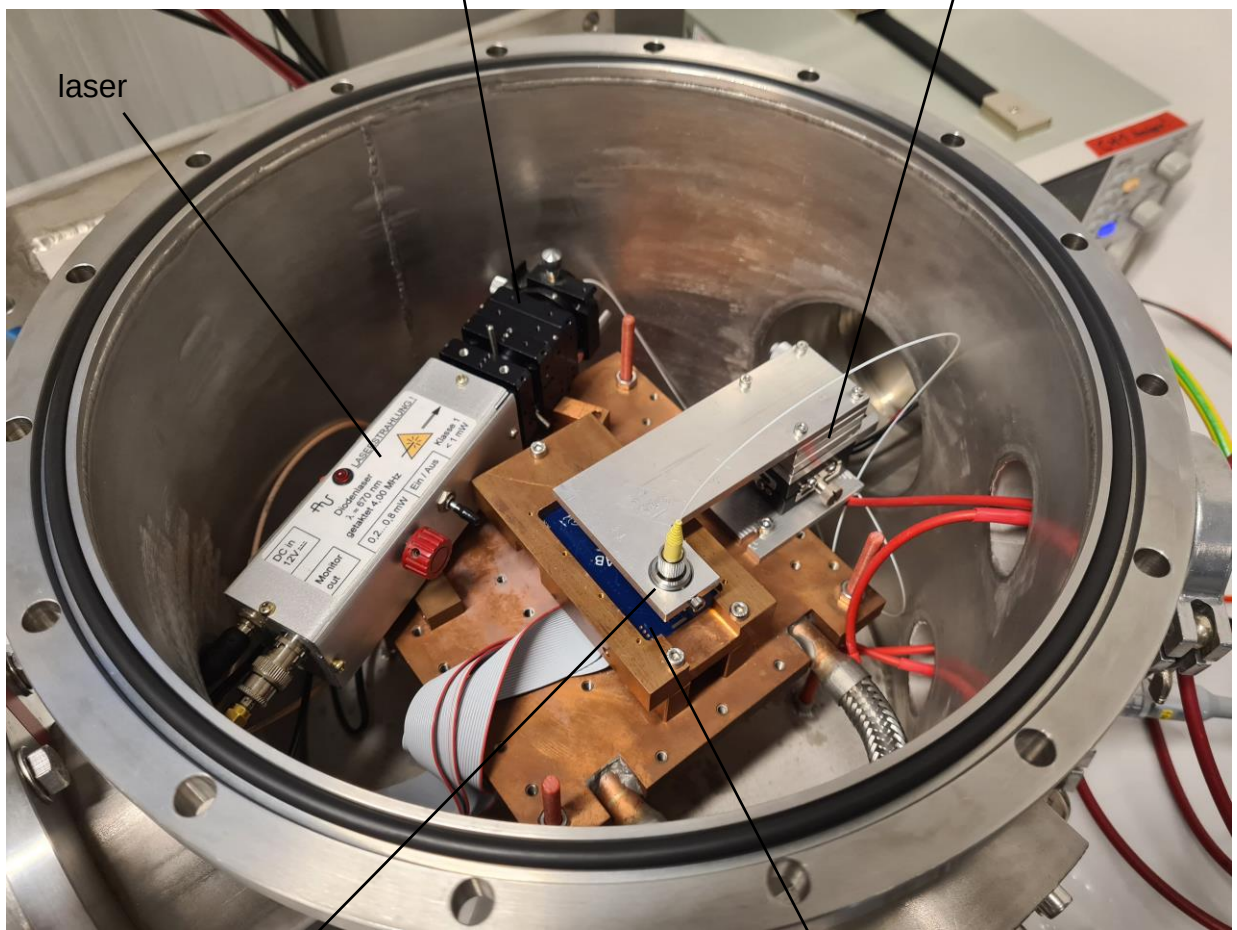
✓Known timing of pulse

✓Flexible intensity and rate of pulse



→ Very promising to study timing and edge effects of SDD

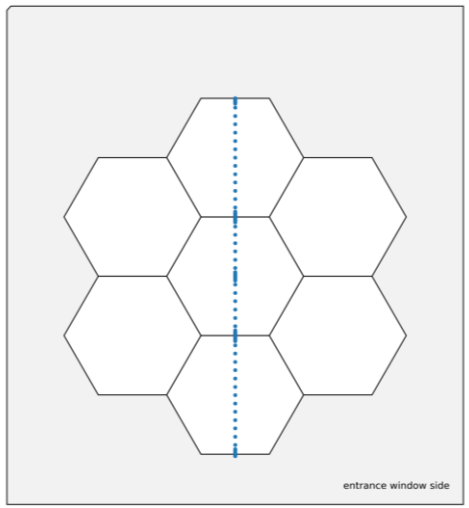
Laser setup

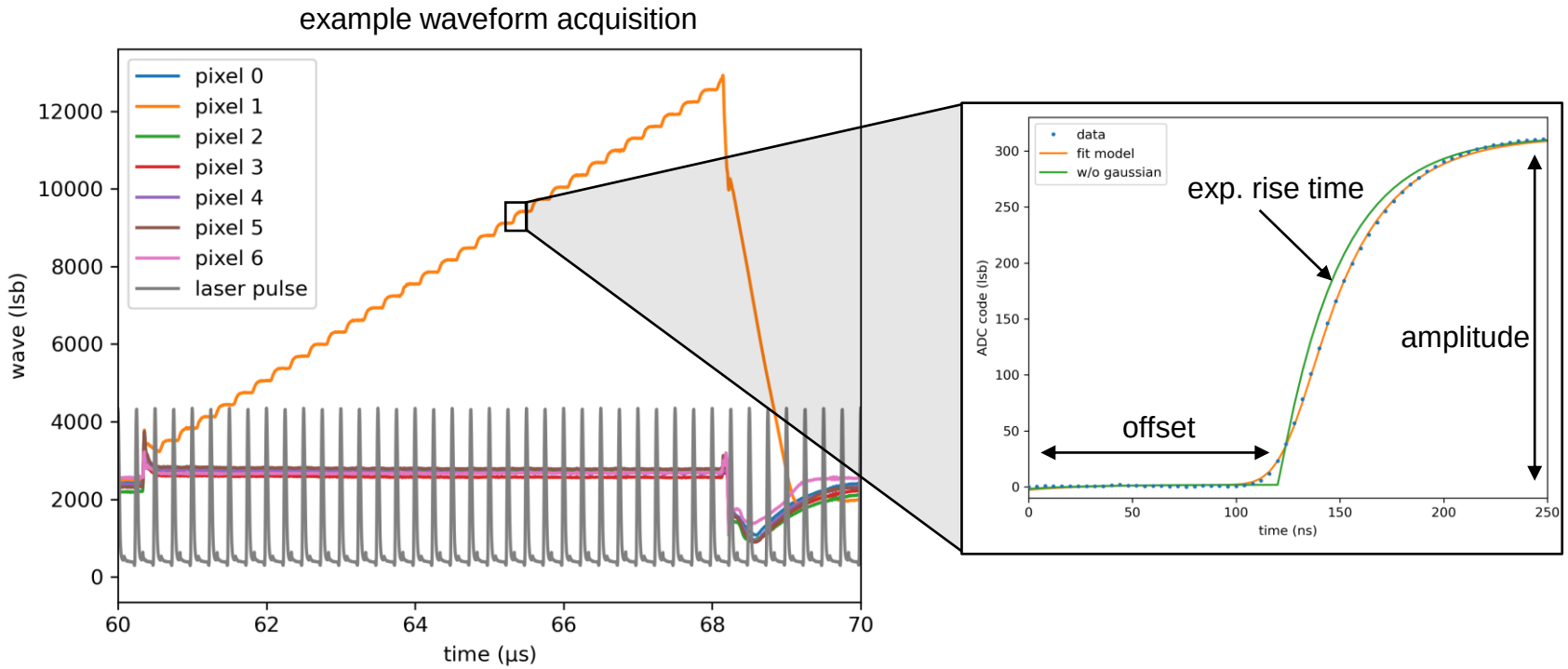


Laser:

- Pulse width: 20 ns
- Wavelength: 670 nm
  → penetration depth ~5 µm
- Spot size: <50 µm
- Intensity: ~10000 photons
  → mimic 30 keV electrons

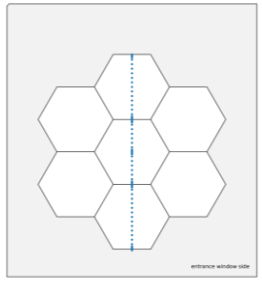
Measurement





- Scan 125 points
- Fit of detector output waveform with four parameters: **offset, amplitude, exp. rise time, gaussian width**

Results



Observations:

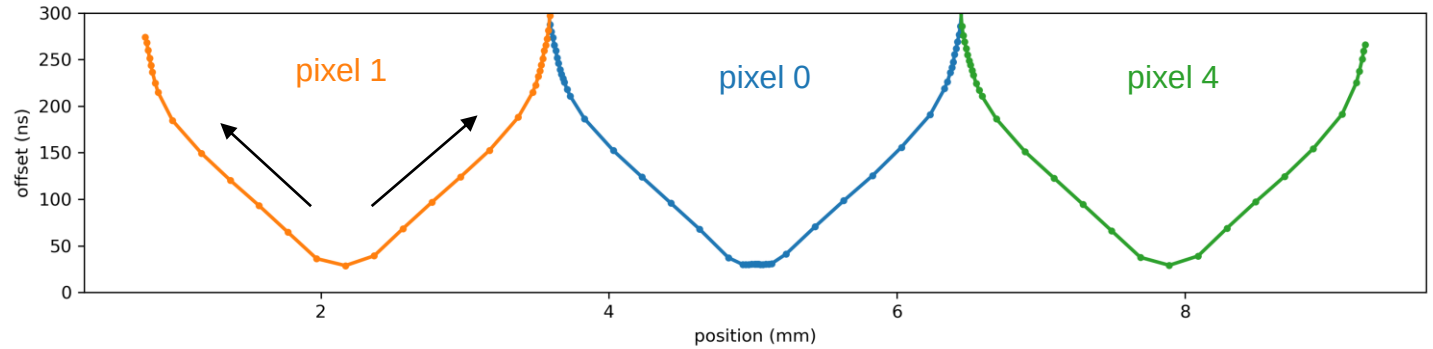
- Drift time increases with radius (distance to the anode)
  →roughly 200 ns absolute time resolution

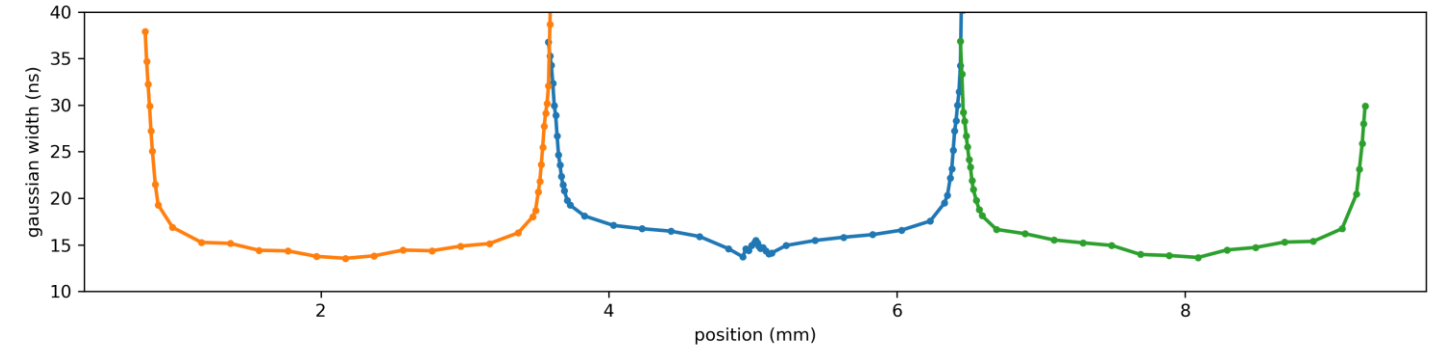
- Risetime (Gaussian width) increases significantly at pixel edge

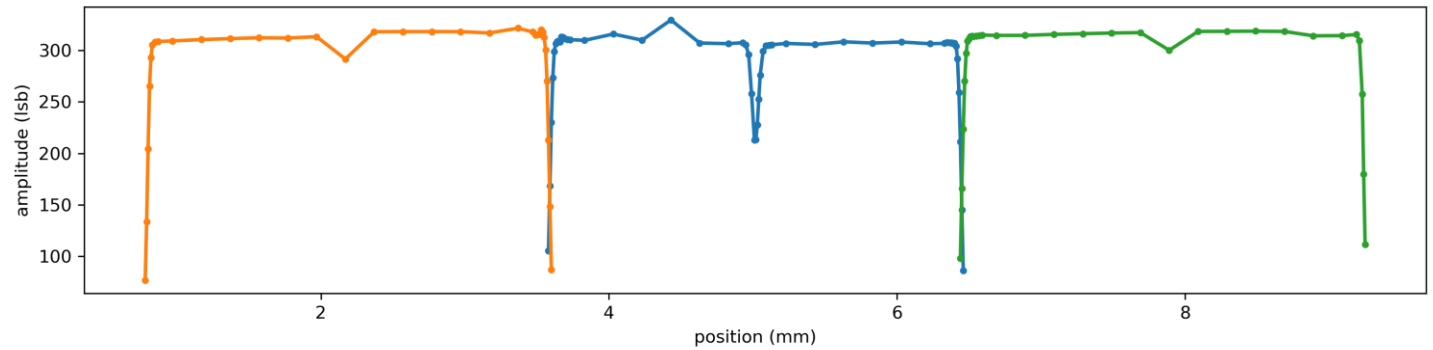
✓Promising measurement approach

- Outlook:
  - 2D scans
  - Study influence of detector bias parameter
  - ...

New setup currently under construction



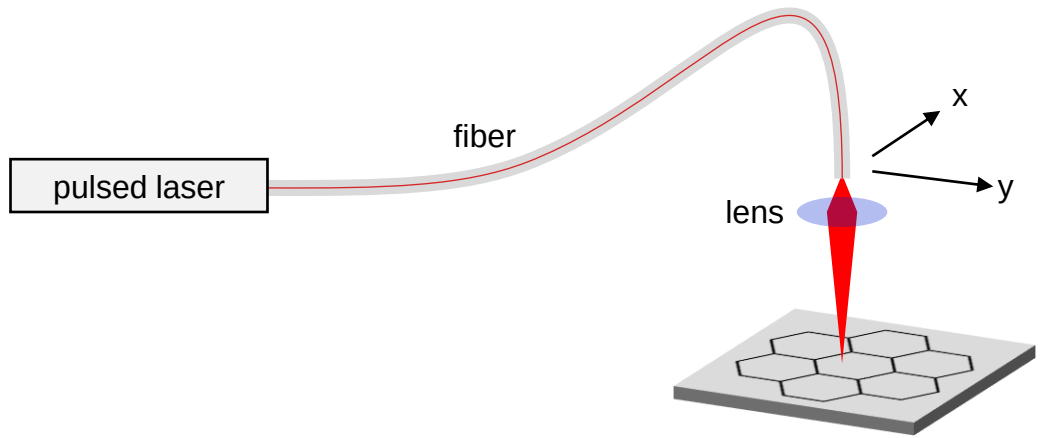




Summary

- The TRISTAN detector is a **silicon drift detector** for electron spectroscopy
- For **sterile neutrino** search at KATRIN: Precise understanding of detector response is important.

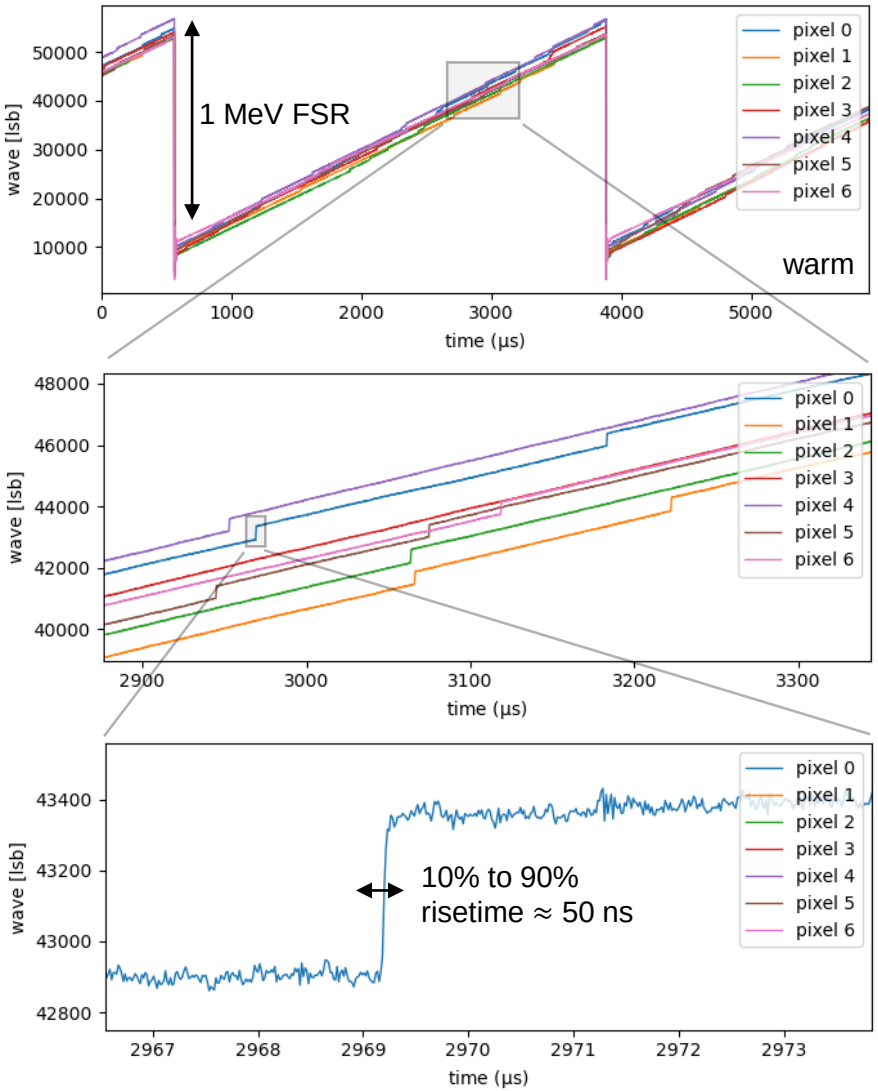
- To measure **drift properties**: Laser measurement
- Promising first results: Drift times up to ~200 ns

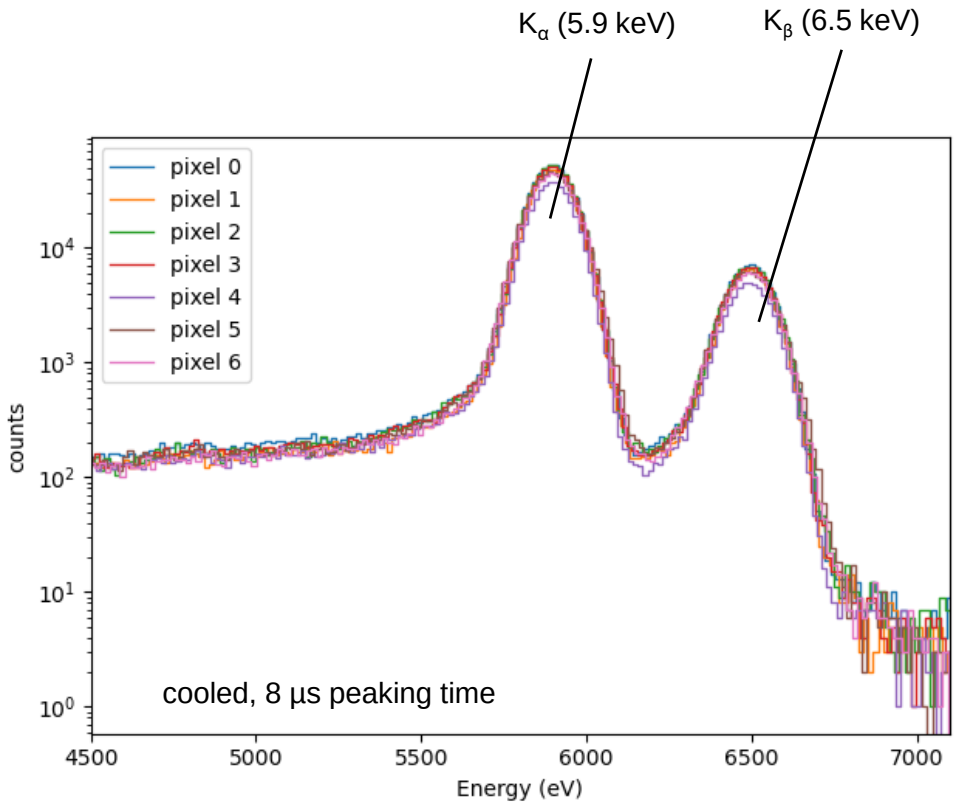


Thanks for your attention!

Backup

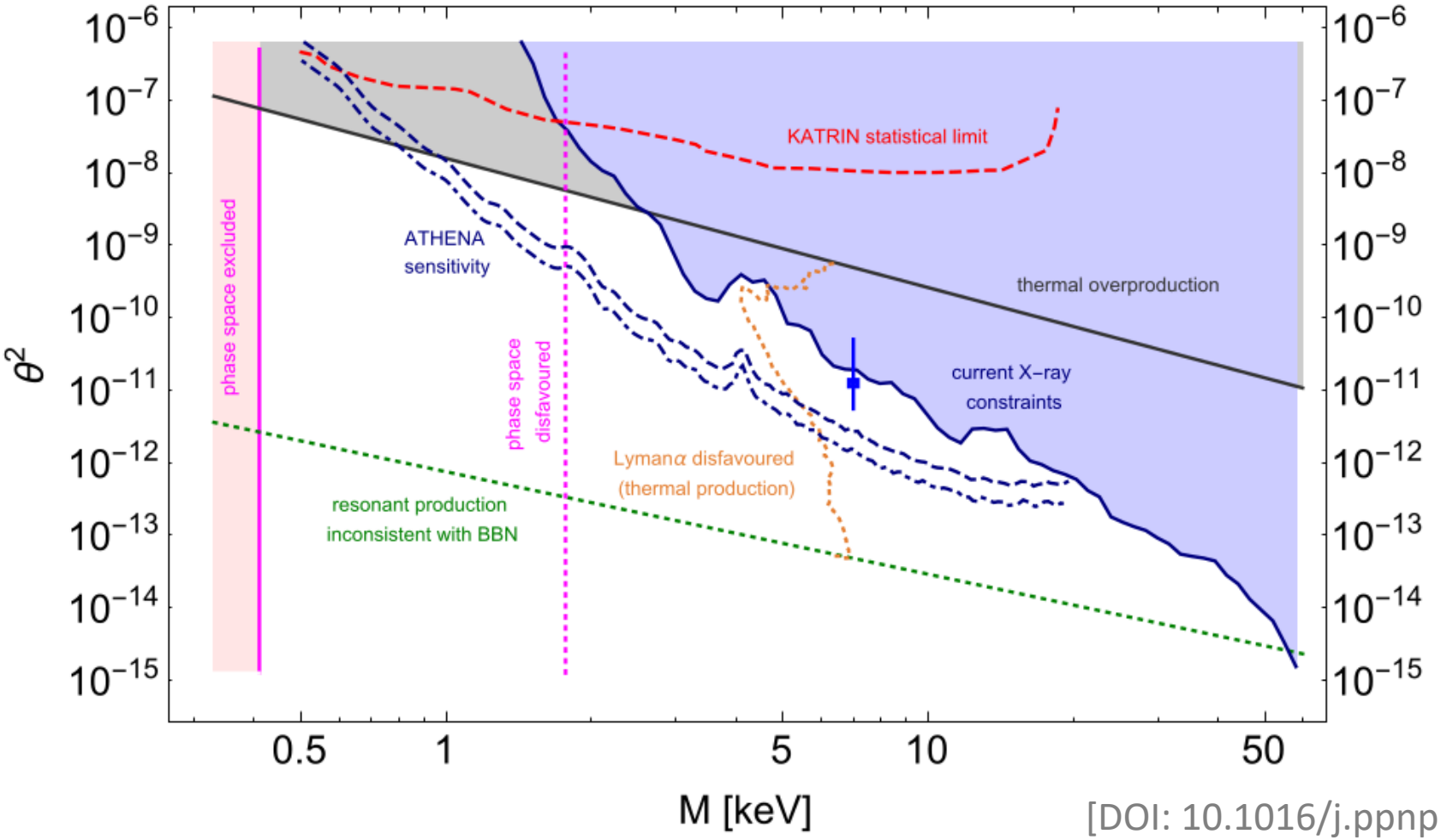
^{55}Fe X-ray performance





- Very good uniformity on the 7 pixels

Sterile neutrinos as dark matter



[DOI: 10.1016/j.ppnp.2018.07.004]

The 3D detector module