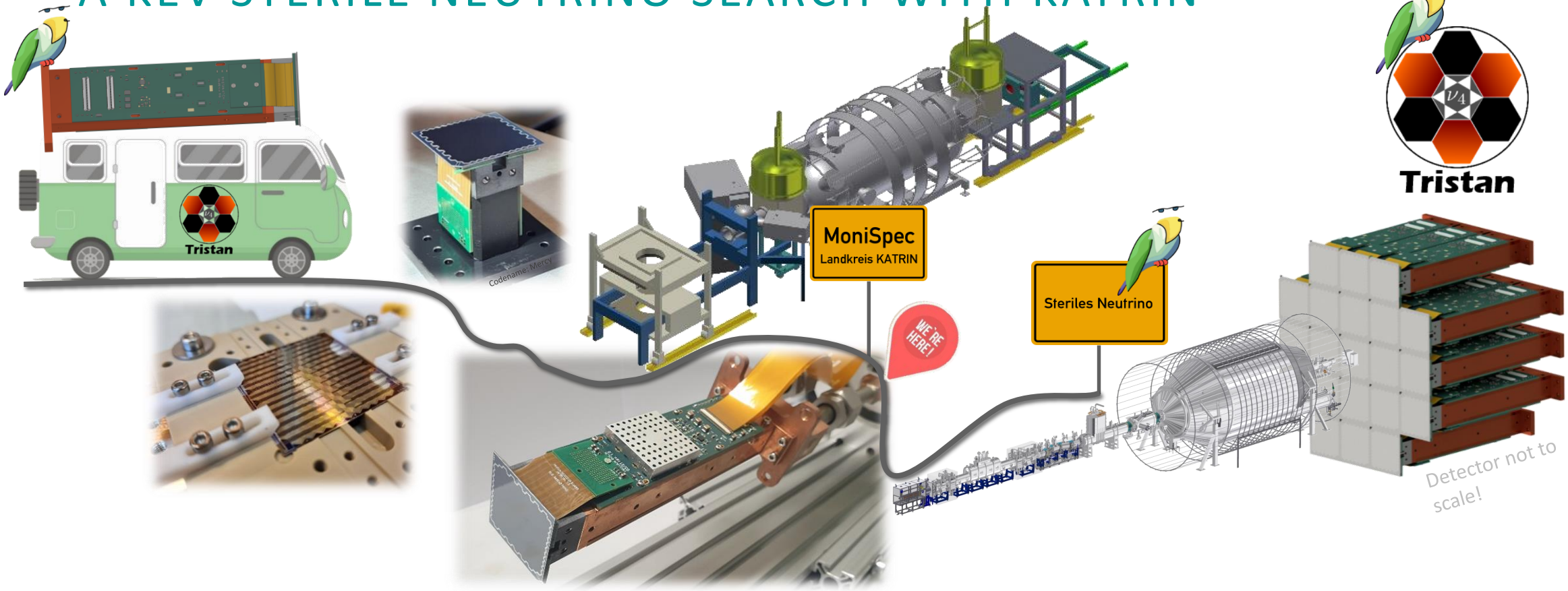
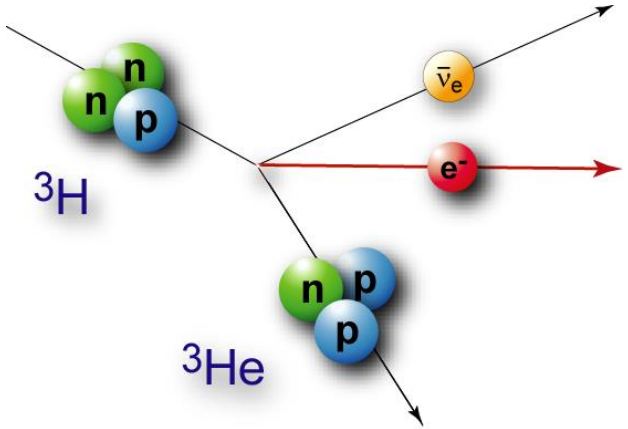
Tests of the first TRISTAN Detector Modules

A KEV STERILE NEUTRINO SEARCH WITH KATRIN

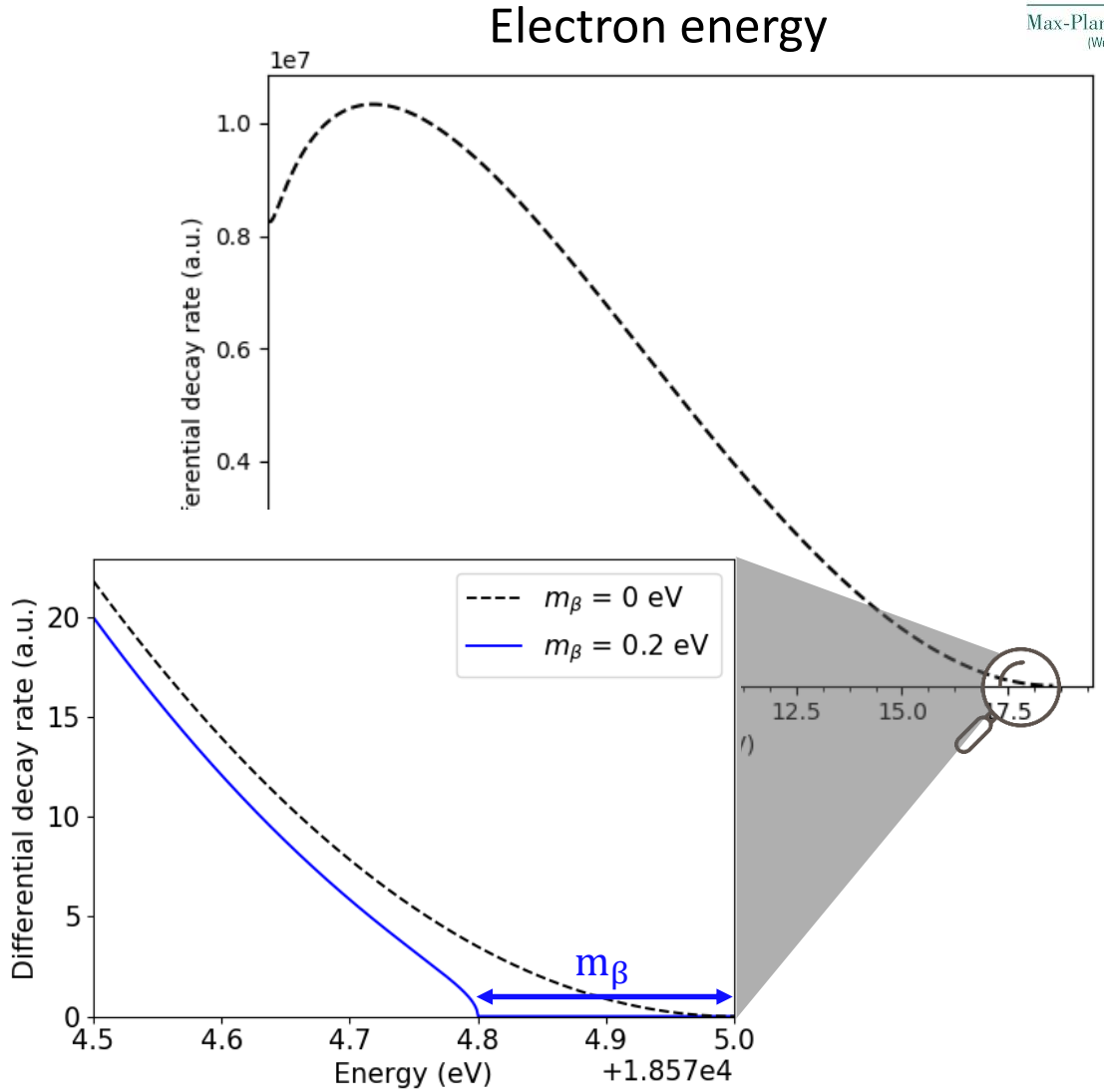


Tritium and Neutrinos

- β-decay of tritium



- e^- and ν share energy
- $E_{e^-} = E_{Total} - E_{\nu}$

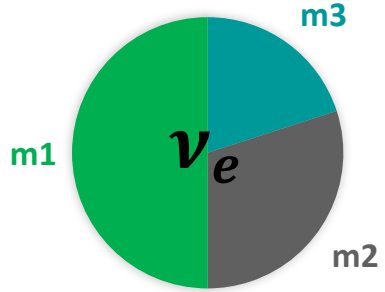


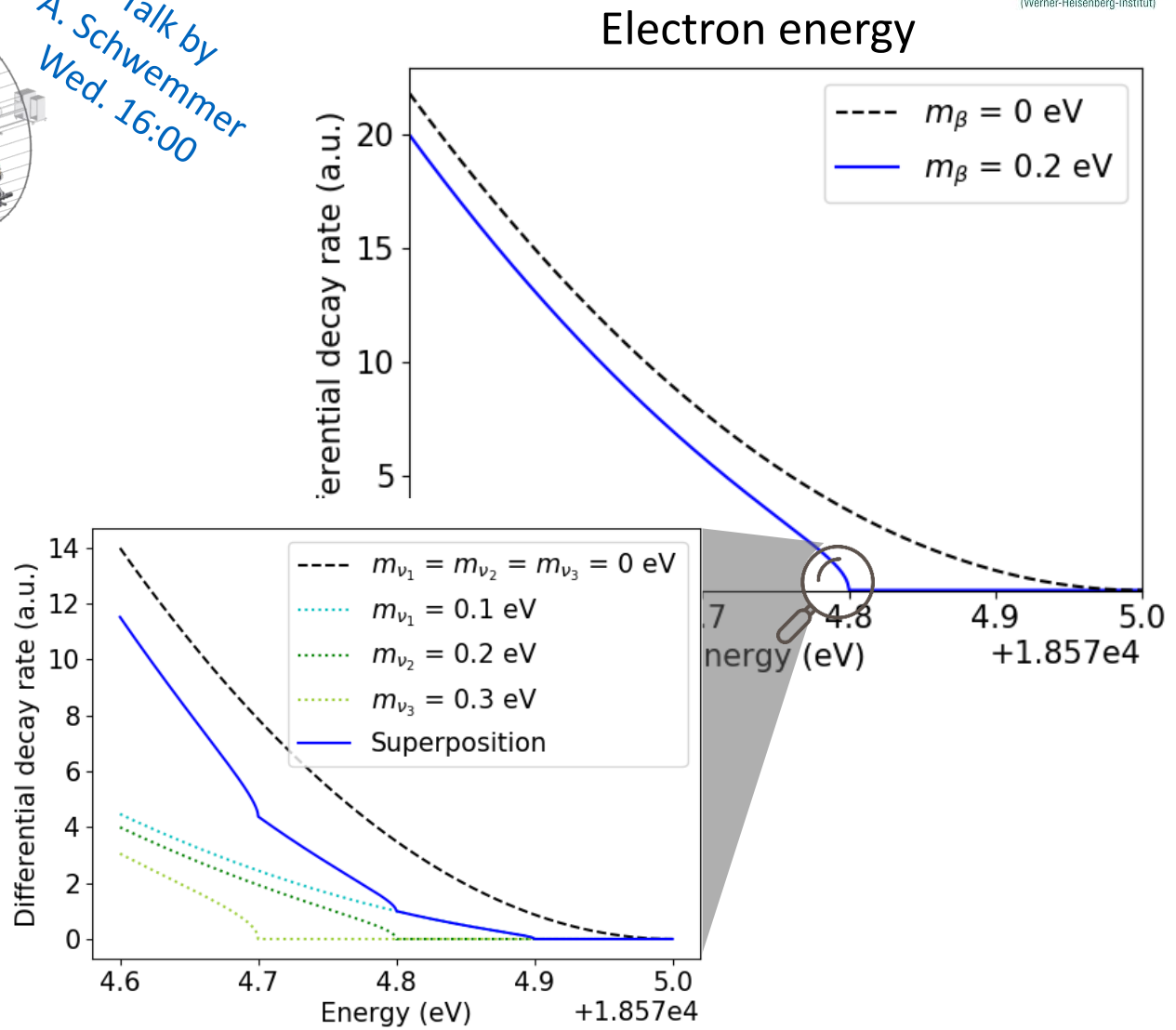
Neutrino Mass Measurement

Talk by A. Lokhov Wed. 12:30

Talk by A. Schwemmer Wed. 16:00

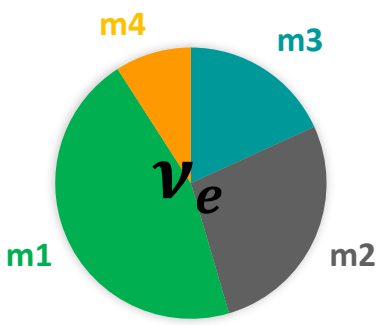
- Effective neutrino mass $m_\beta^2 = \sum_{i=1}^{3} |U_{ei}|^2 \, m_{\nu_i}^2$
- MAC-E filter principle
- Superposition of mass eigenstates

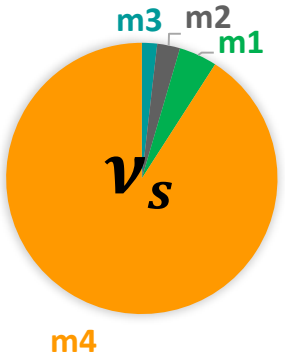


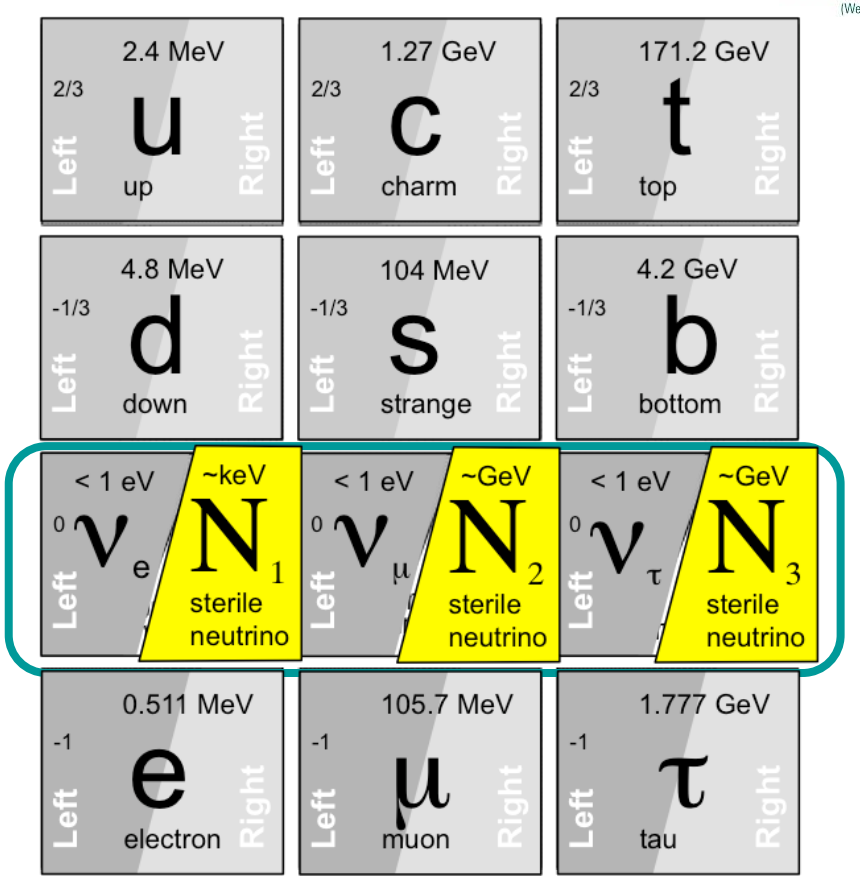


What are sterile Neutrinos?

- Neutrinos are **only left-handed**
- **Right-handed neutrinos** are a **minimal extension** to **SM**
- No weak interaction -> **sterile**
- Additional mass eigenstates
- **keV sterile -> dark matter candidate**



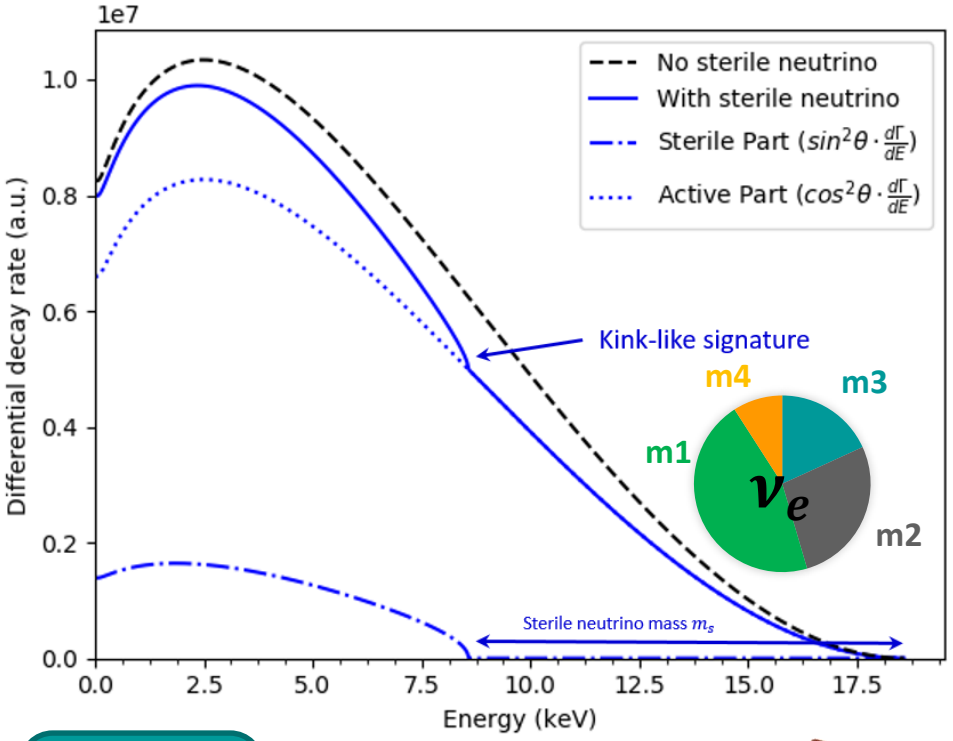




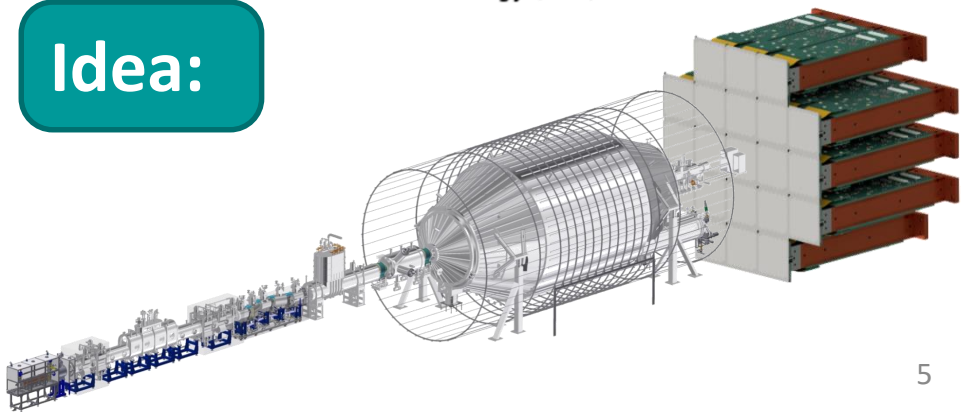
TRISTAN Project

- β-decay sensitive to all mass eigenstates < E_{Total}
- **keV sterile neutrino** search
- **Dark matter** candidate
- Tiny **kink**-like imprint in β-decay
- Target sensitivity $|U_{e4}|^2 = 10^{-6}$
  - High rates required $\mathcal{O}(10^8$ e/s)

➢ **TRISTAN** Project = **KATRIN Detector Upgrade** for sterile neutrino search



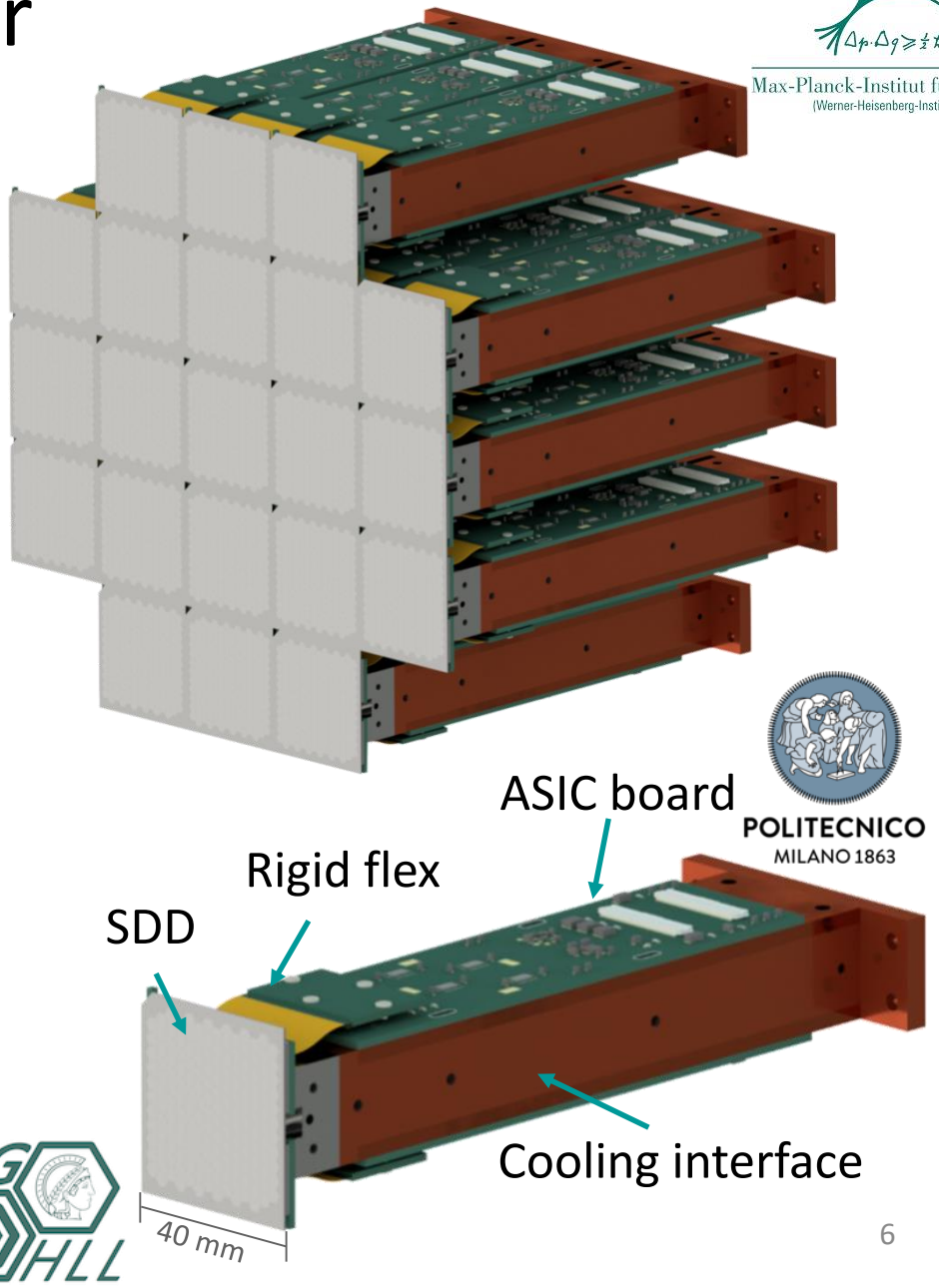
Idea:



Challenges for TRISTAN Detector

- High rates $\mathcal{O}(10^8$ e/s)
  - 3500 Pixel (100 kcps per pixel)
  - Flux-tube Ø 20 cm -> Ø 3mm pixels
- Energy resolution < 300 eV (@20 keV)
  - Small anode (Ø90 µm)
- Low energy threshold < 2 keV
  - Thin entrance window (< 100 nm)

➢ **Silicon Drift Detector (SDD)**
➢ **21 Modules with each 166 pixel**



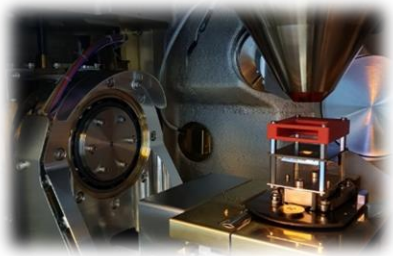
Staged Approach

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Proof of concept

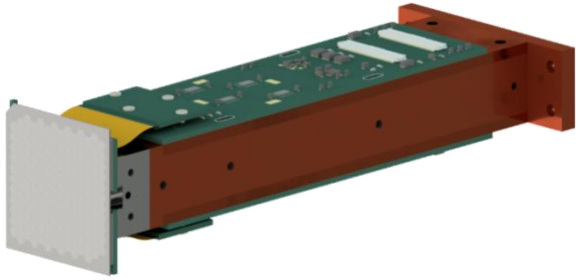
Prototype-0

Understanding the SDD technology



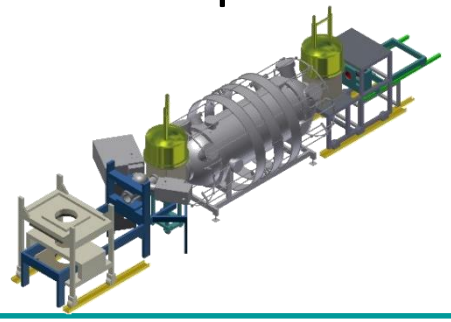
Technical Realization

First Module

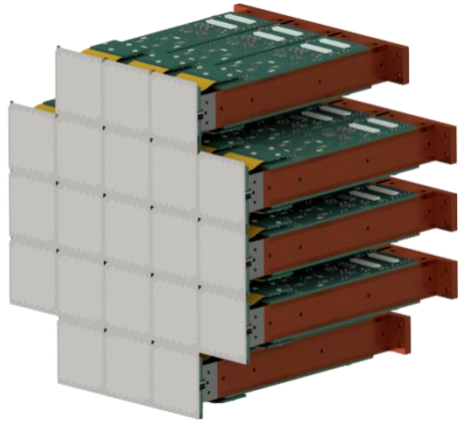


Apply and test detector in realistic environment

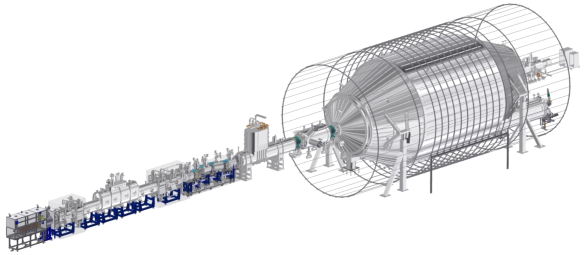
- Monitor spectrometer



Sterile Neutrino Measurement



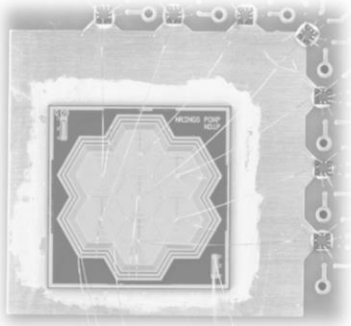
Sterile neutrino search with KATRIN experiment



Staged Approach

Proof of concept

Prototype-0



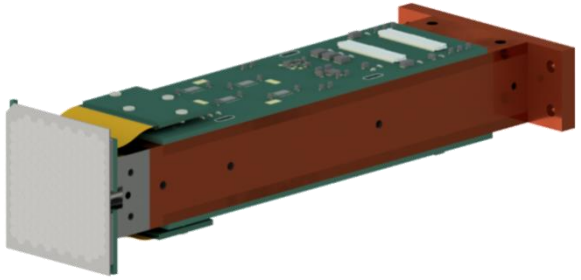
Understanding the SDD technology

(2019, Mertens et al.), Astropart. Phys. 108, 40

(S. Mertens et al 2021) J. Phys. G: Nucl. Part. Phys. 48 015008

Technical Realization

First Module



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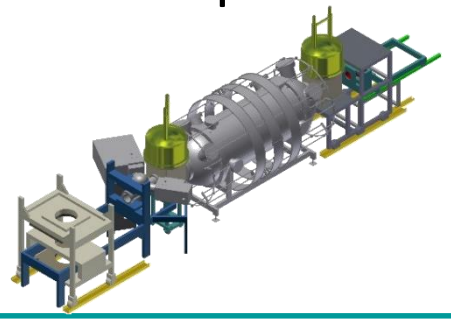

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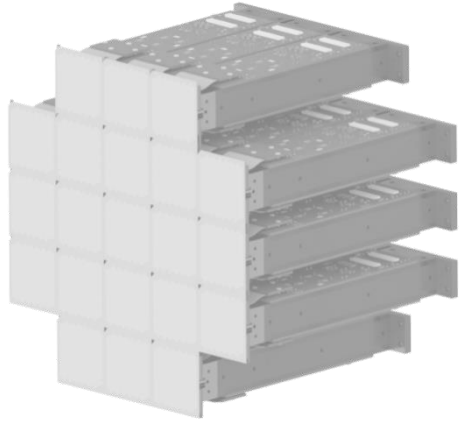

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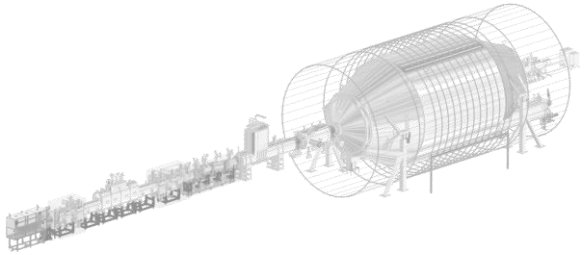
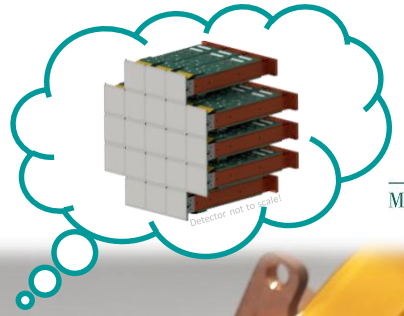
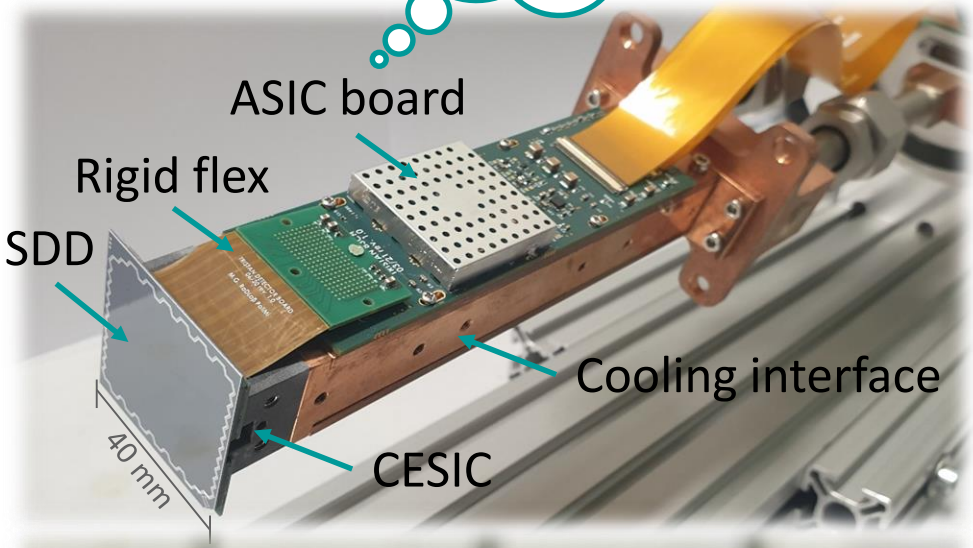
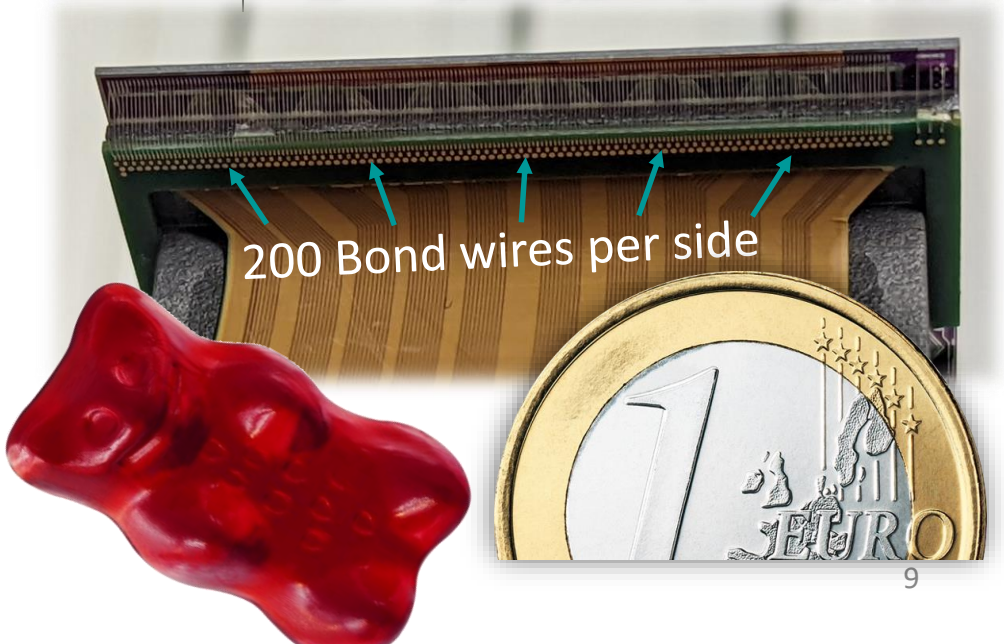


TRISTAN Detector Module with 166 Pixel



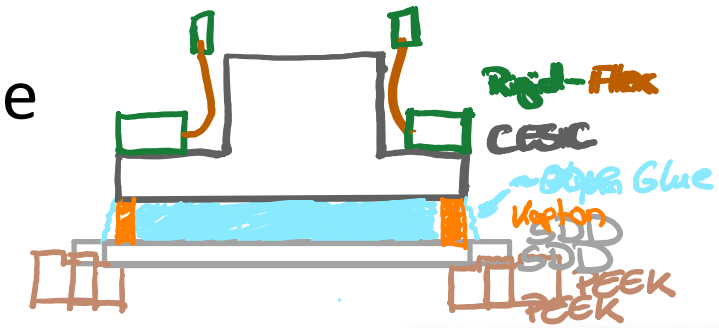
- High rates $\mathcal{O}(10^8$ e/s)
  - 166 independent pixel per module
  - Maximize detection area by ‘hiding’ electronics behind SDD
- Energy resolution < 300 eV (@20 keV)
  - Operate detectors at -30 °C
  - Short distance to amplifier
- Modular detector
  - Close to technological limit for chip size
  - Manufacturing & repair
  - Easier to upscale

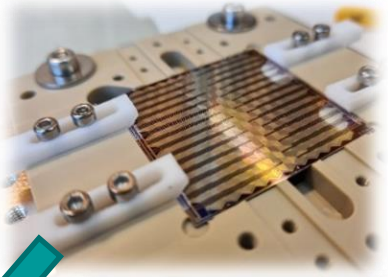


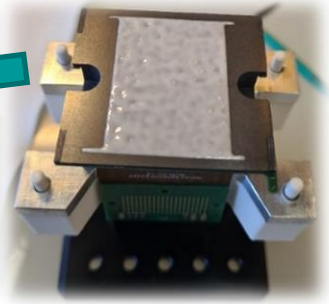


Critical Assembly Step – Gluing SDD to CESIC

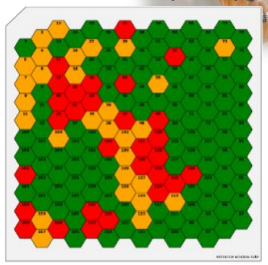
- SDD is glued to CESIC heat exchange
  - CESIC (silicon ceramic composite)
    - Same thermal expansion as silicon (SDD)
  - No material allowed to touch entrance window
- First attempts with less than 70% pixels working
  - Investigations for cause performed
  - Swapping to glue without spacer pills
- 99% yield for the following three detectors

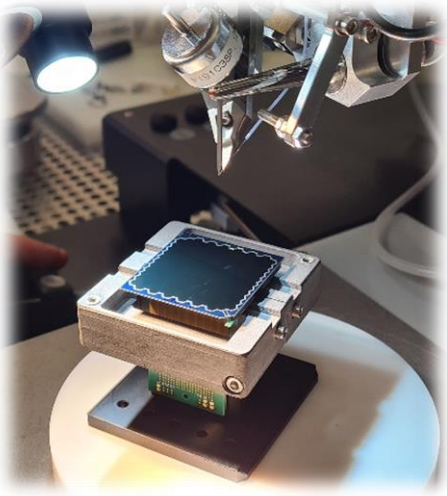




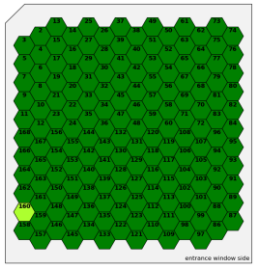


S0-166-1 (D.Va)

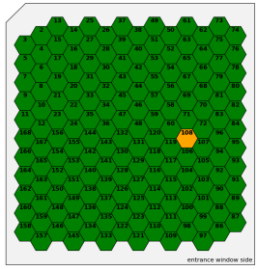




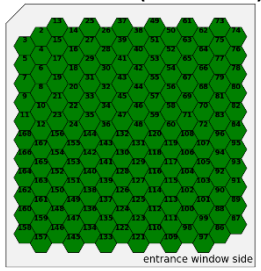
S0-166-2 (Mercy)



S0-166-3(Echo)



S0-166-4 (Winston)



➢ Gluing procedure works ☺

Characterization S0-166-4 (Winston)

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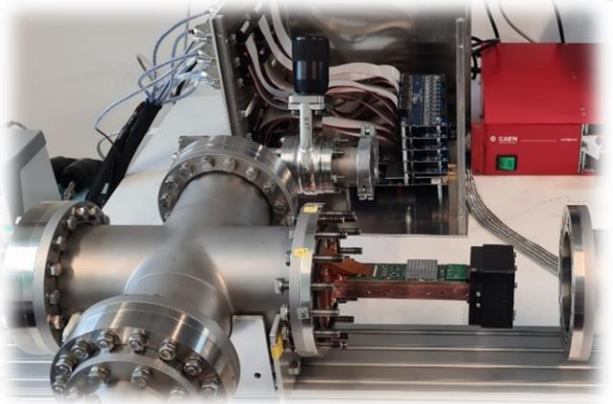
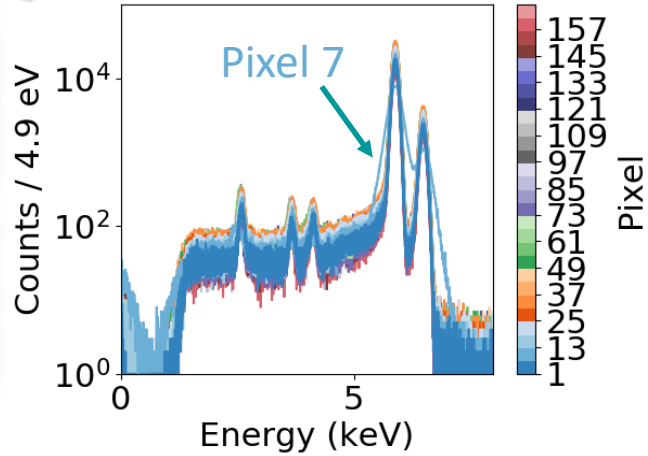
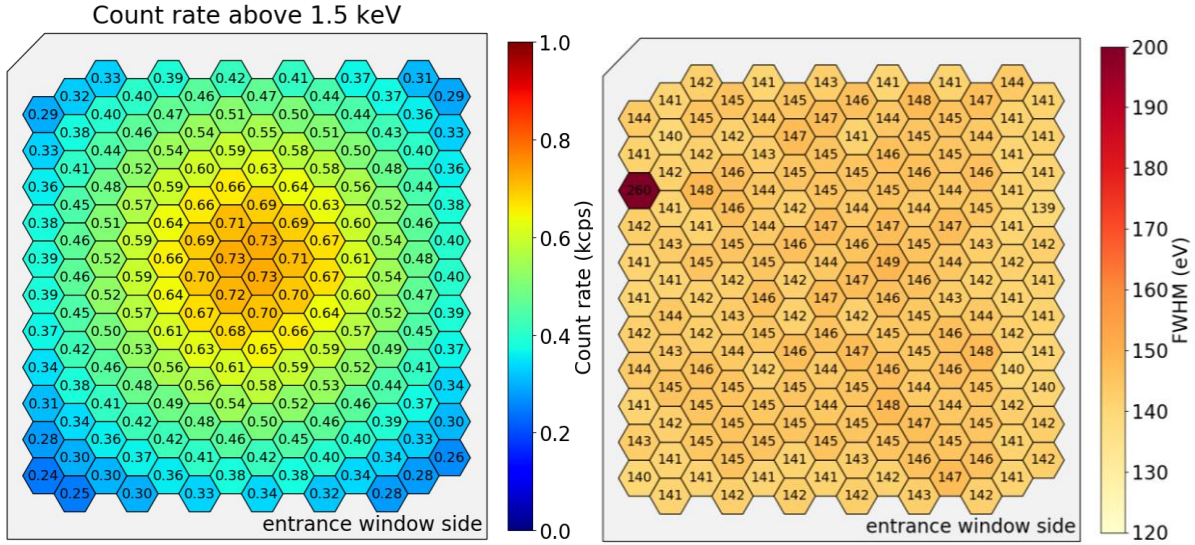
(Werner-Heisenberg-Institut)

- Detector installed in test bench
  - Source: ^{55}Fe (2x γ @ $\approx$ 6keV)
  - SDD temperature approx. -27°C
  - Connection problem @ pixel 7
    -> increased noise
- Count rate in expected range
- Overall good energy resolution
  - $\overline{\mathbf{FWHM}}_{\mathbf{2\mu s},\gamma\ @\ \mathbf{5.9\ keV}} = \mathbf{143.7\ eV}$
  - Expect $\mathrm{FWHM}_{e^-\ @\ 20\ \mathrm{keV}} = 253\ \mathrm{eV}$

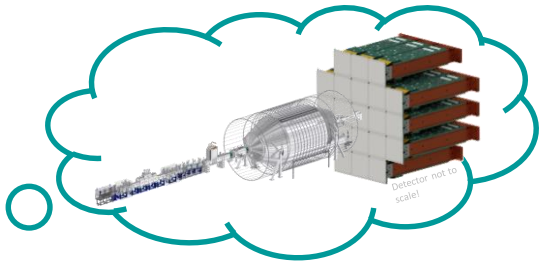
➢ Detector fully functional



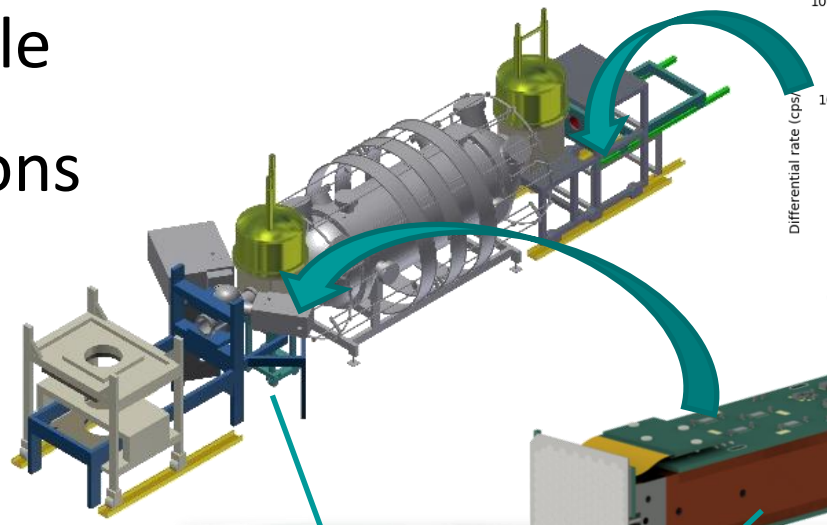


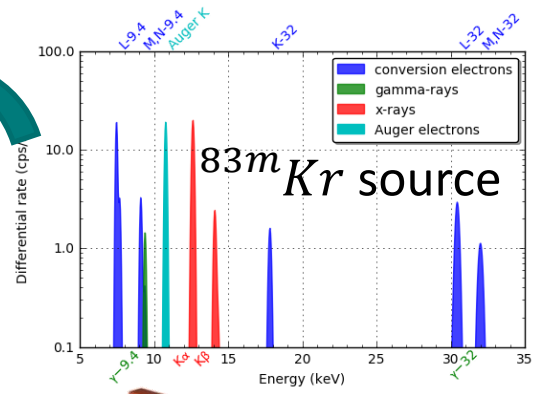


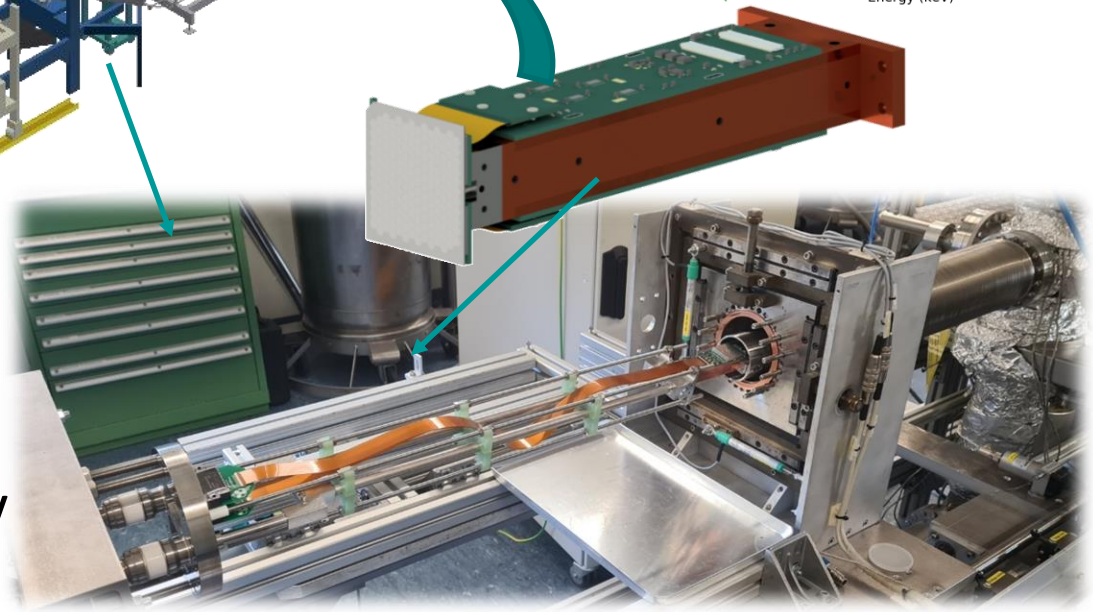
TRISTAN Module in Monitor-Spectrometer



- Exchange current detector in Monitor Spectrometer with 166 pixel TRISTAN-Module
- Testing in KATRIN-like conditions
  - Vacuum compatibility
  - Magnetic compatibility
  - Cabling and interconnections
  - Understanding electronic noise
  - Experience with KATRIN framework
- Evaporated ^{83m}Kr source
  - Electron lines between 7 keV to 32 keV







Installation of Detector in Monitor Spectrometer

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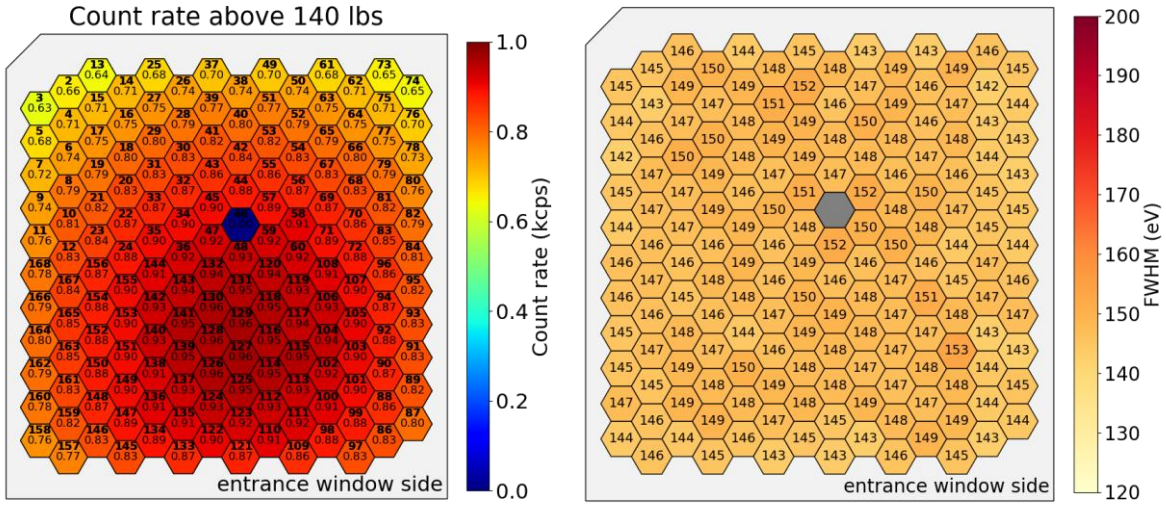
➢ Successful installation of new 166 pixel detector in MoS

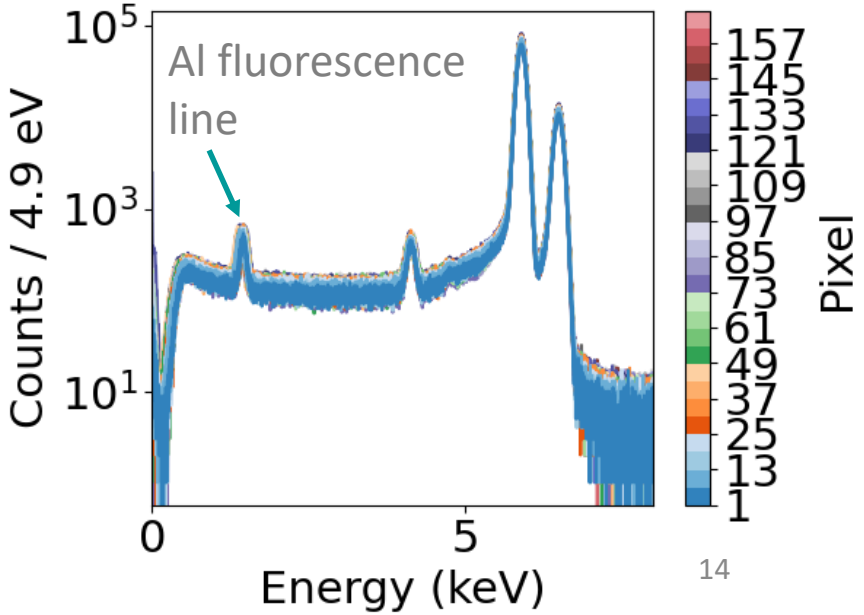
- Placed ^{55}Fe source in front of detector for first tests

Detector Characterization in Monitor Spectrometer

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

- First tests without magnets
  - 8.3e-8 mbar in detector chamber
  - ^{55}Fe (2x γ @ $\approx$ 6keV) with Al foil
- 165 out of 166 pixels functional
  - Problems finding working point for Pixel 46 (hope to fix it soon)
- $\boldsymbol{\overline{FWHM}_{2\mu s,-29°C,\,@MoS} = 146.8\ eV}$
  - $\overline{FWHM}_{2\mu s,-27°C\,@MPP} = 143.7\ eV$



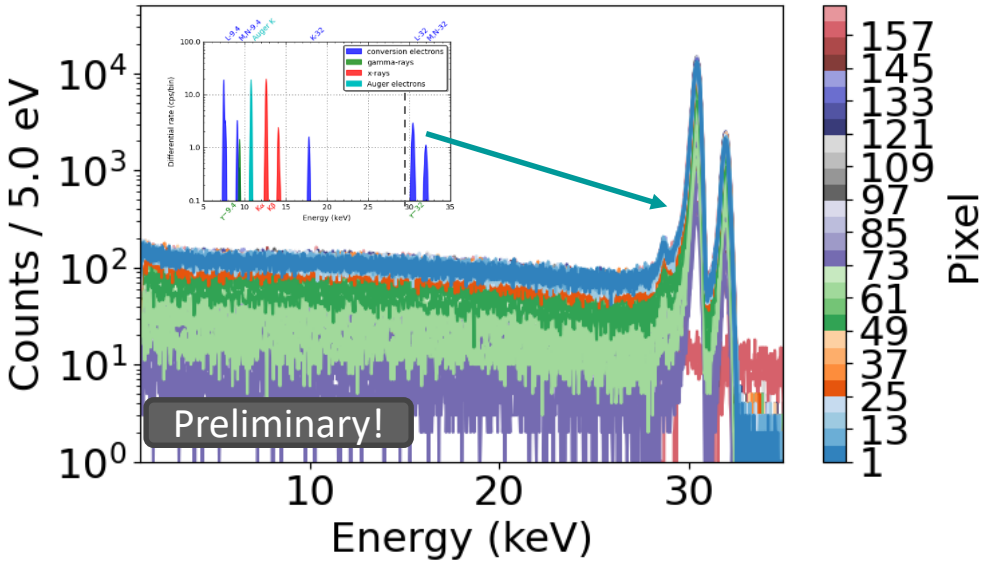


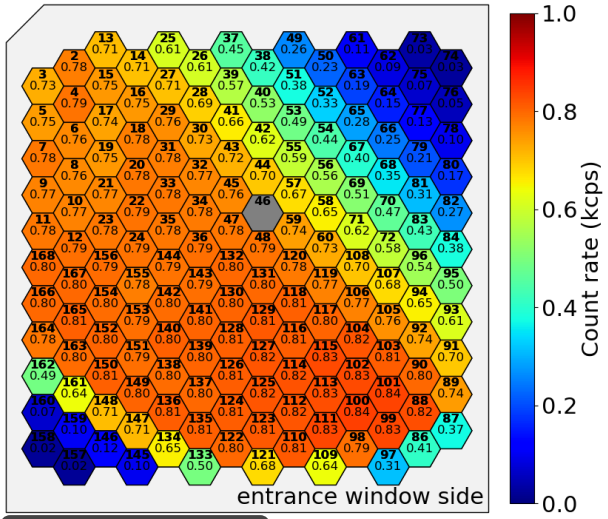
➢ Performance acceptable, slightly worse than in 'optimal lab conditions'

Electrons from Monitor Spectrometer

- Installed ^{83m}Kr source this week
  - Aligned detector and source using wall electrons + simulations
  - Optimized experimental setup
- Electrons visible on detector
  - Retarding potential set to 30 kV
  - Count rate plot shows source profile

➢ First measurements look very promising
➢ More detailed analysis will follow in the next days

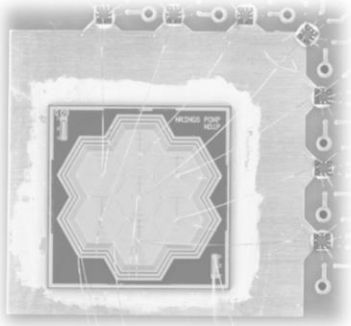




Staged Approach

Proof of concept

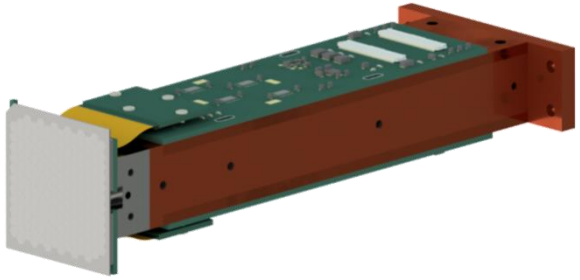
Prototype-0



Understanding the SDD technology

Technical Realization

First Module



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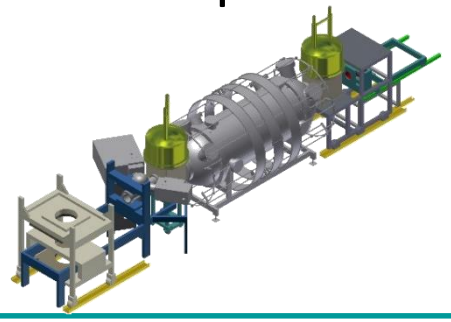

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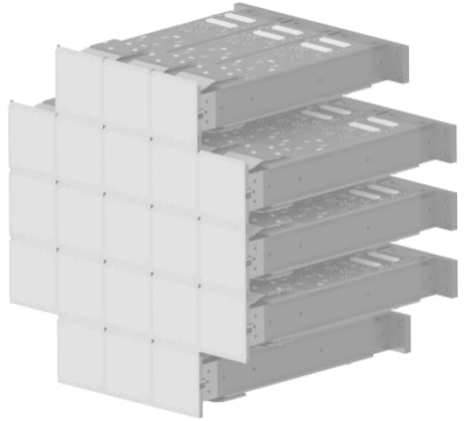

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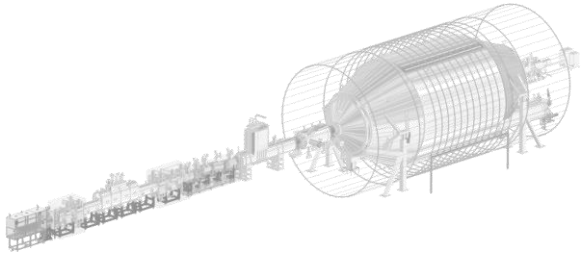

Towards the Final TRISTAN Detector

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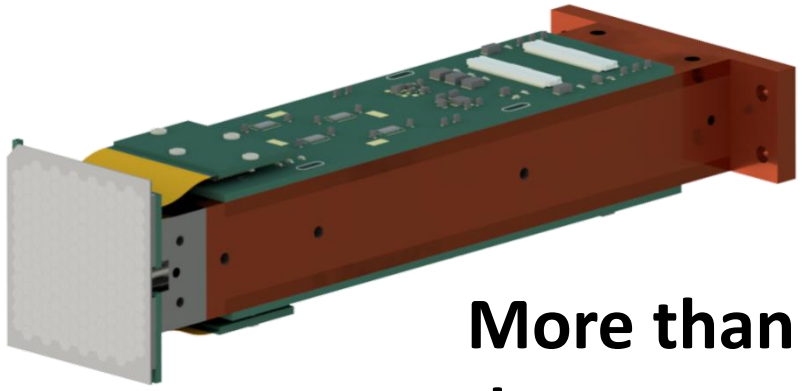
(Werner-Heisenberg-Institut)

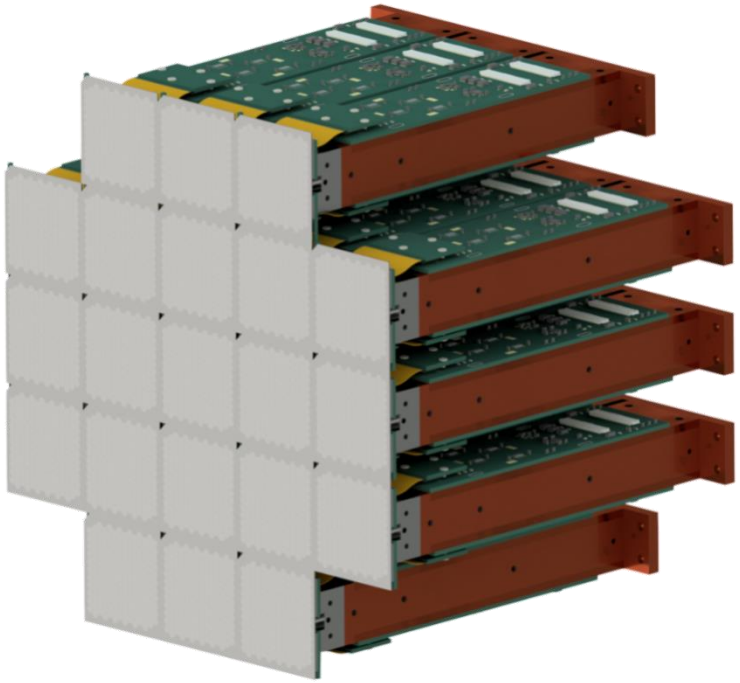
TRISTAN Module

- 166 Pixels Detector
- Commissioning 2022

Full TRISTAN Detector

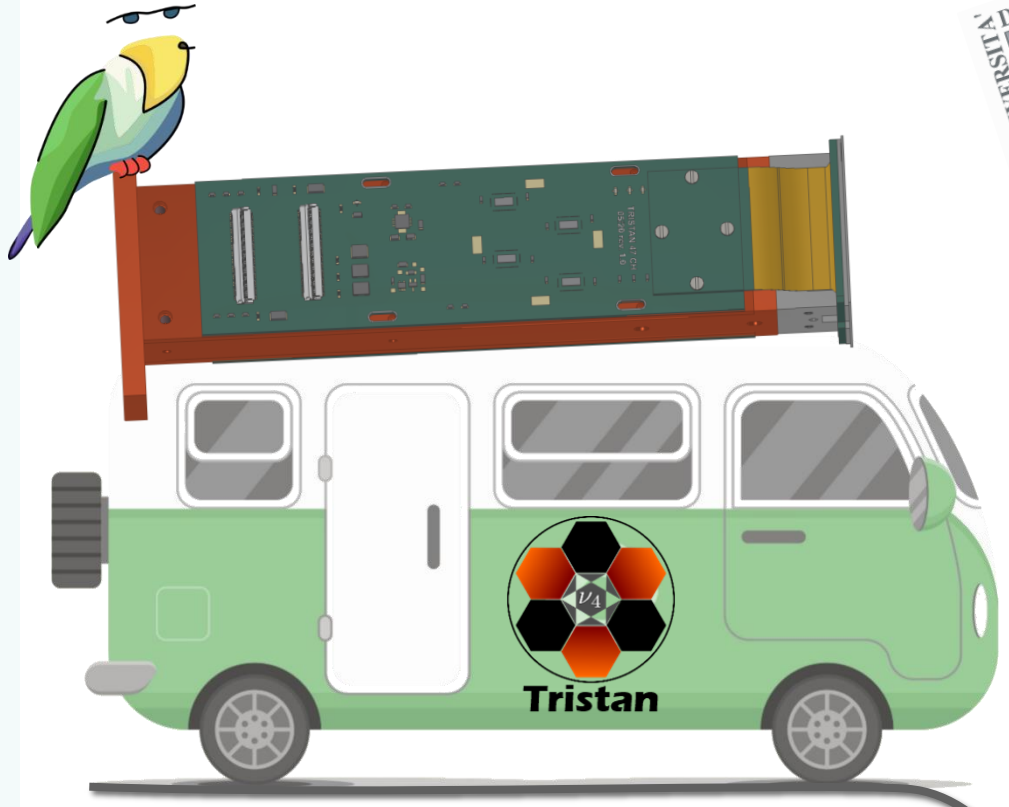
- 21 x 166 Pixels ≈ 3500 Pixels
- Integration after completion of ν-mass measurement





More than scaling up the detector

- Detector chamber
- Outgassing
- High density electronics
- …



... and many more!

Steriles Neutrino

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