KATRIN – First data and the Future…

Susanne Mertens
Max Planck Institute for Physics & Technical University Munich
Project Review 2018, MPP, December 2018, Munich

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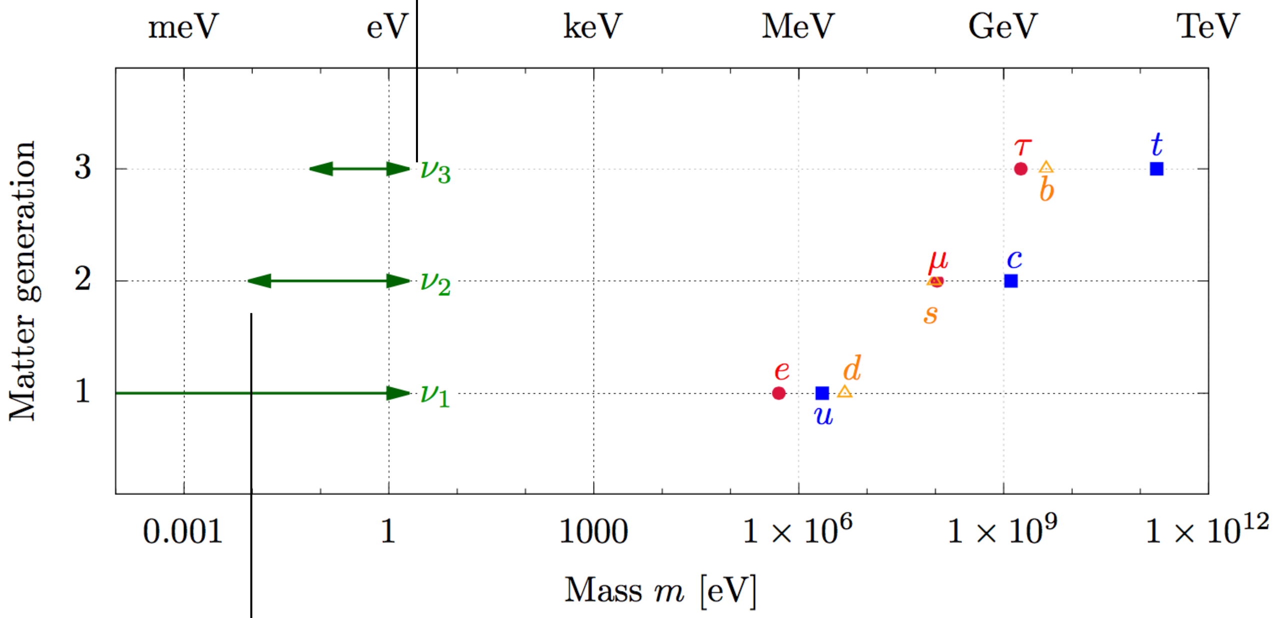
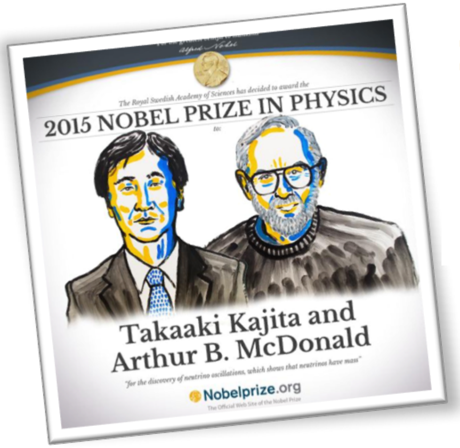
Neutrino mass

Upper bound
from laboratory measurements

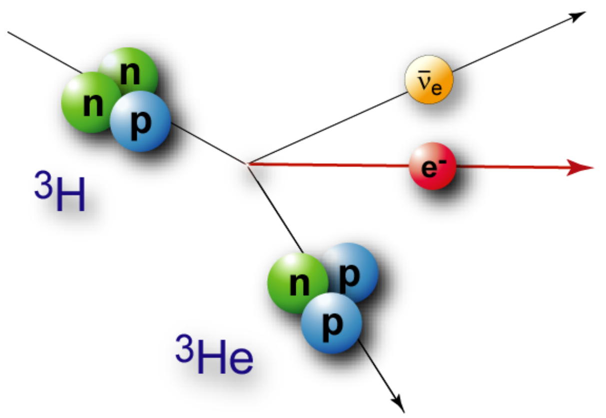


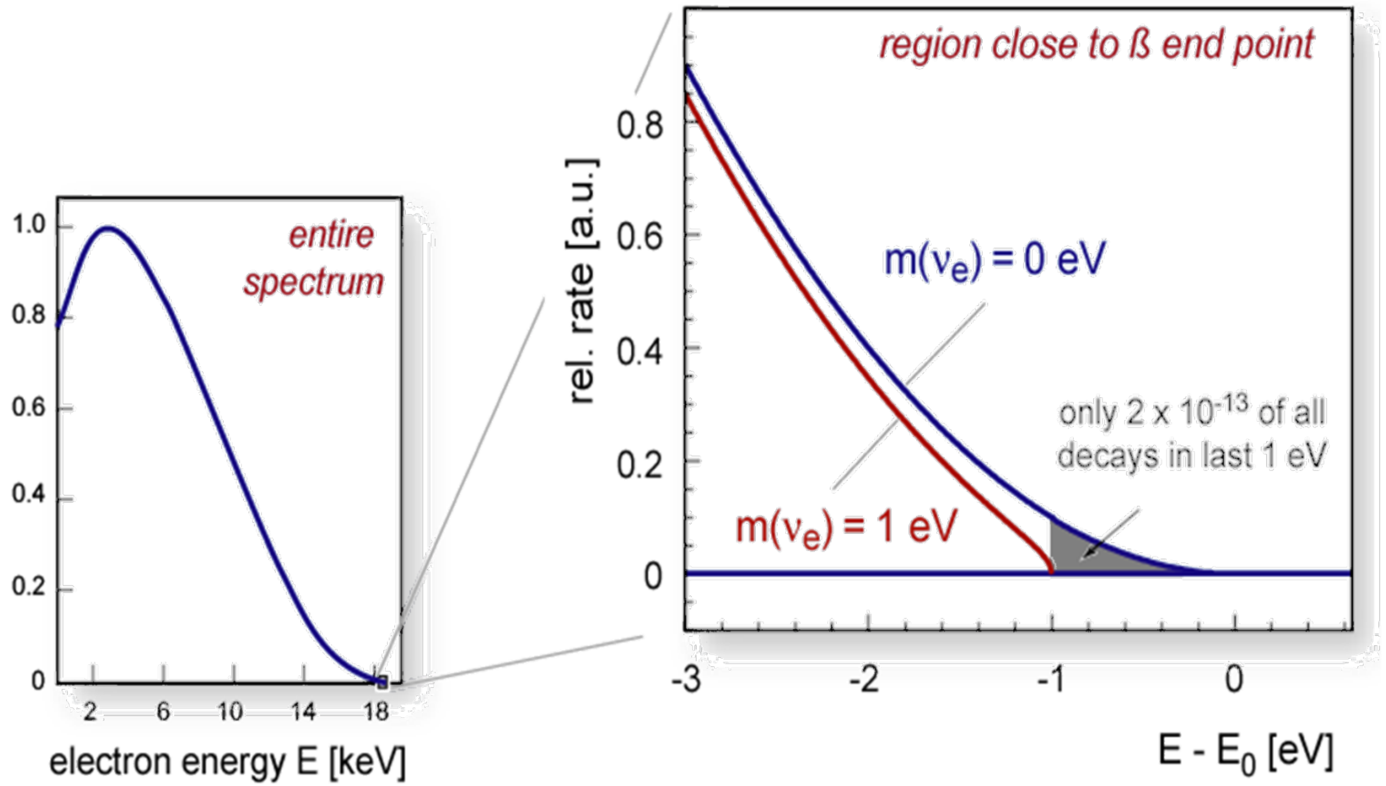


Lower bound
from oscillation experiments

General idea

- Kinematic determination of the neutrino mass
- Non-zero neutrino mass reduces the endpoint and distorts the spectrum

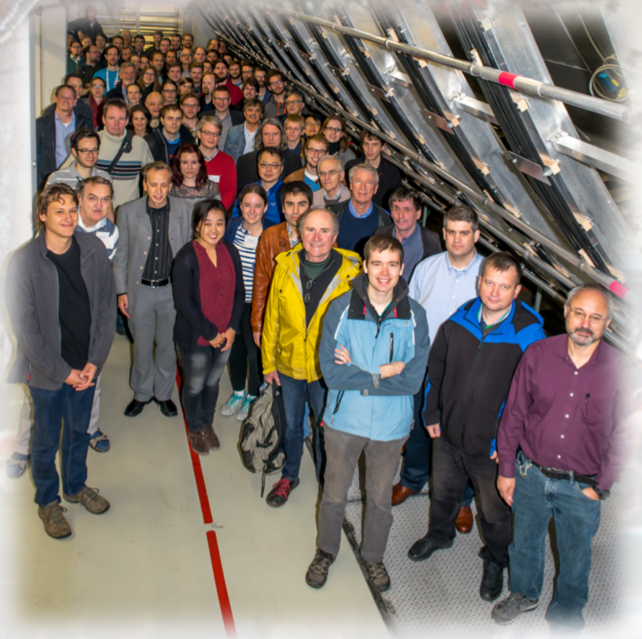




Karlsruhe
Tritium
Neutrino
Experiment

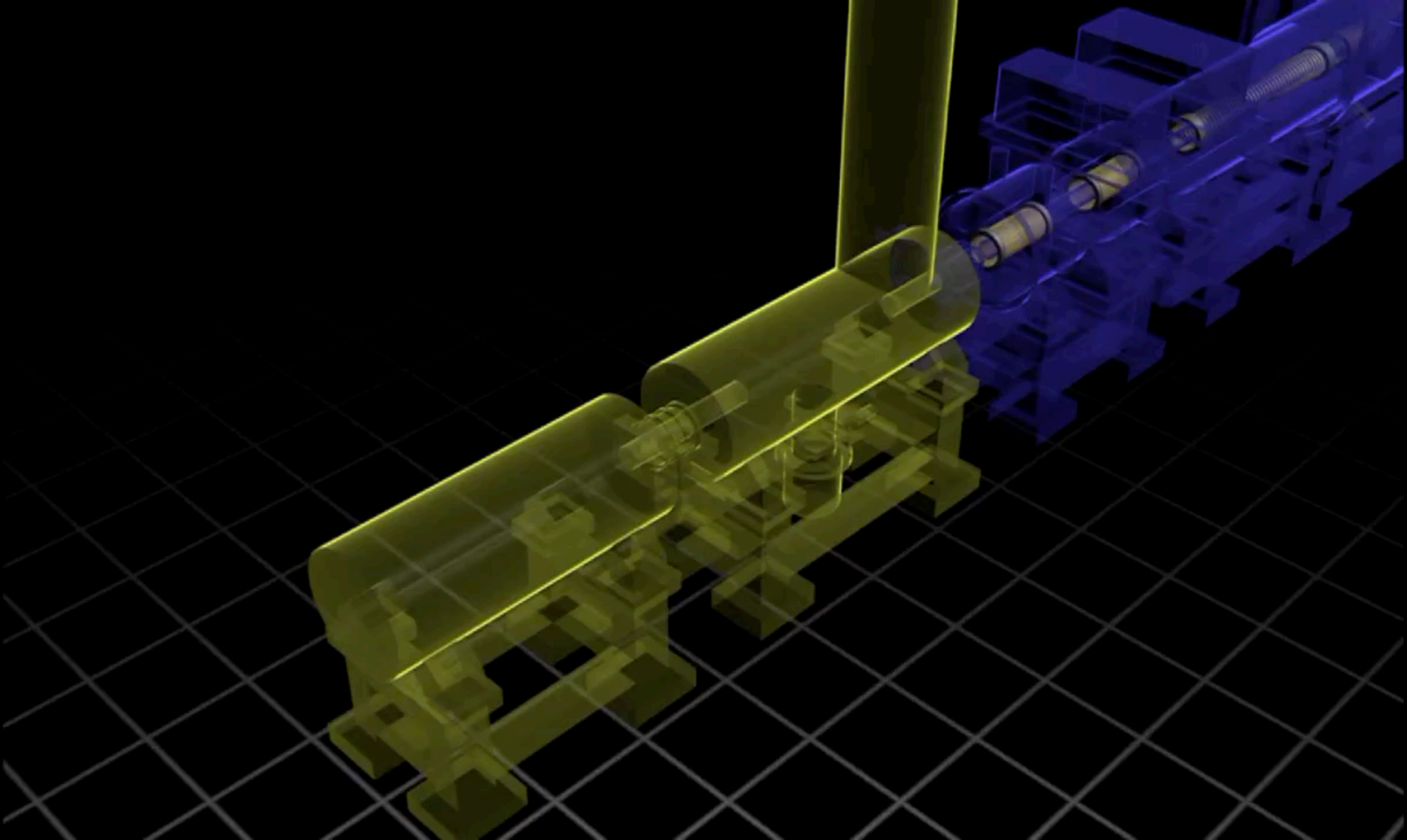
Karlsruhe
Tritium ($T_{1/2}$ = 12.3 years, E_0 = 18.6 keV)
Neutrino
Experiment

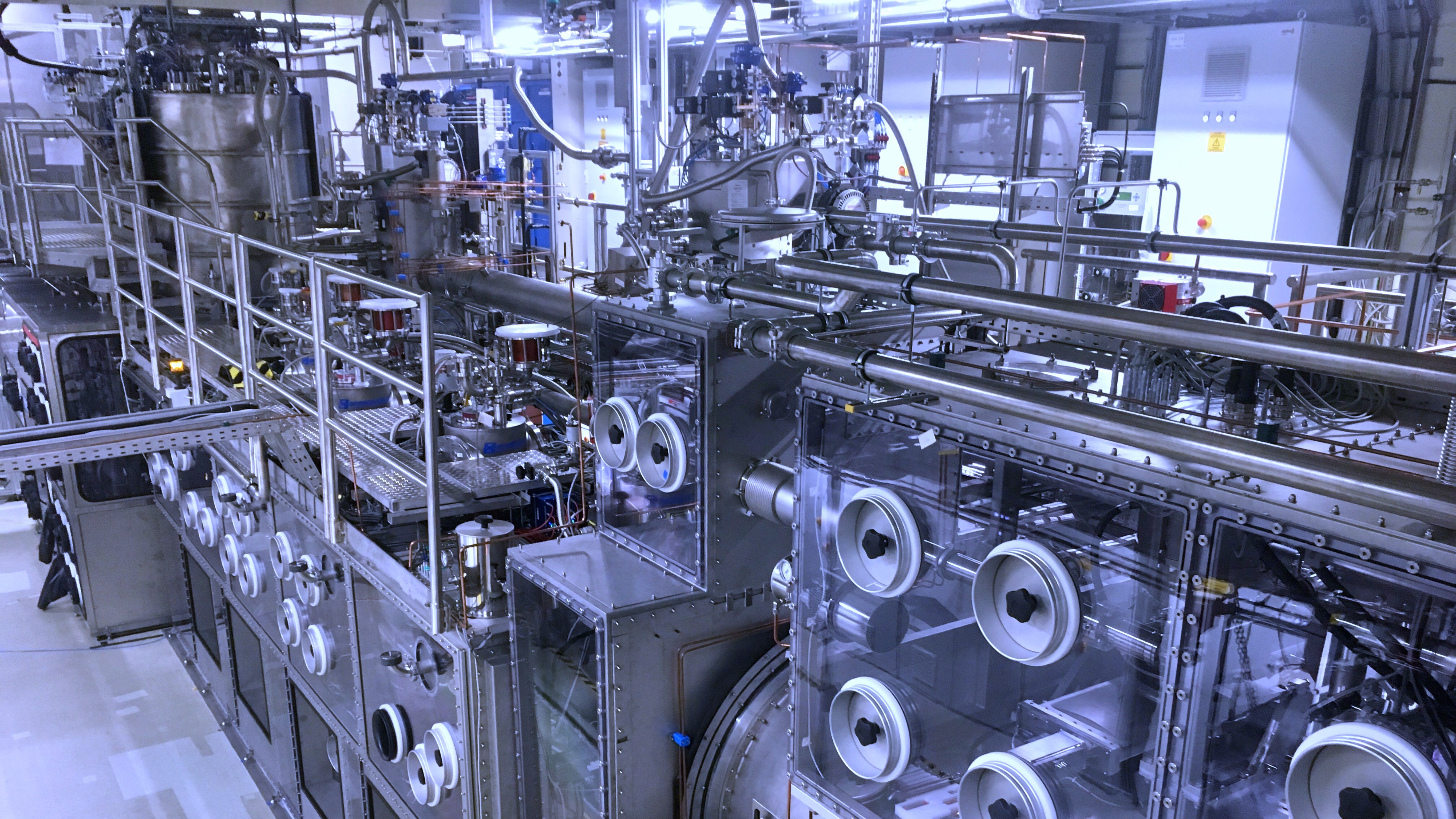
Karlsruhe
Tritium
Neutrino
Experiment

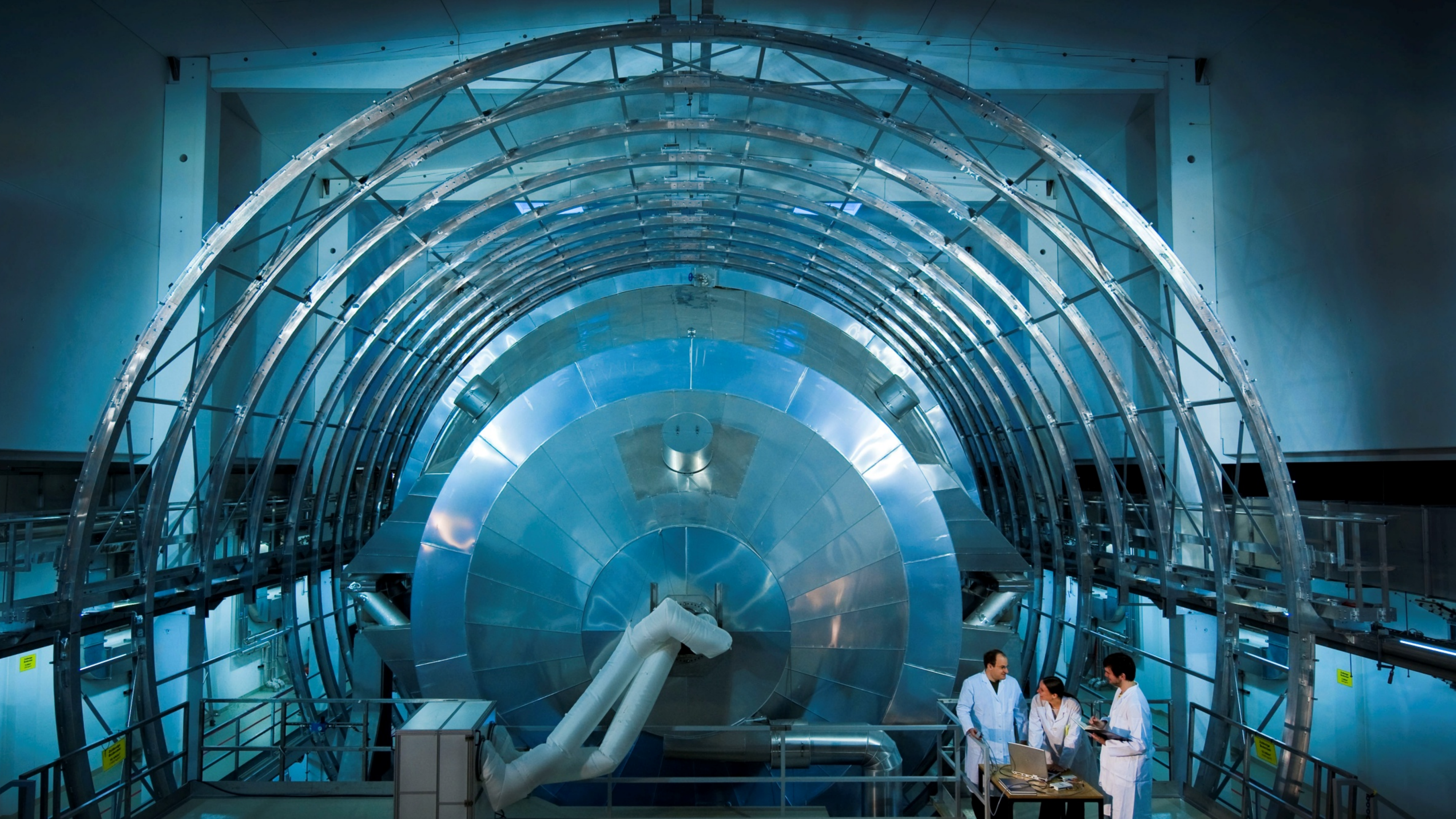


- Experimental site: Karlsruhe Institute of Technology (KIT)
- International Collaboration (150 members)
- Sensitivity m_{ν} = 200 meV (90% CL) after 3 net-years

KIT Karlsruher Institut für Technologie
Max-Planck-Institut für Kernphysik Heidelberg
University of Washington
Case Western Reserve University EST. 1826 think beyond the possible
Westfälische Wilhelms-Universität Münster
Massachusetts Institute of Technology
The University of North Carolina at Chapel Hill
The Czech Academy of Sciences
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)
cea
Carnegie Mellon University
Universidad Complutense Madrid
Russian Academy of Sciences
JG|U Johannes Gutenberg Universität Mainz
Technische Universität München
universitätbonn
Hochschule Fulda University of Applied Sciences
Bergische Universität Wuppertal
Berkeley Lab







First tritium campaign May / June 2018

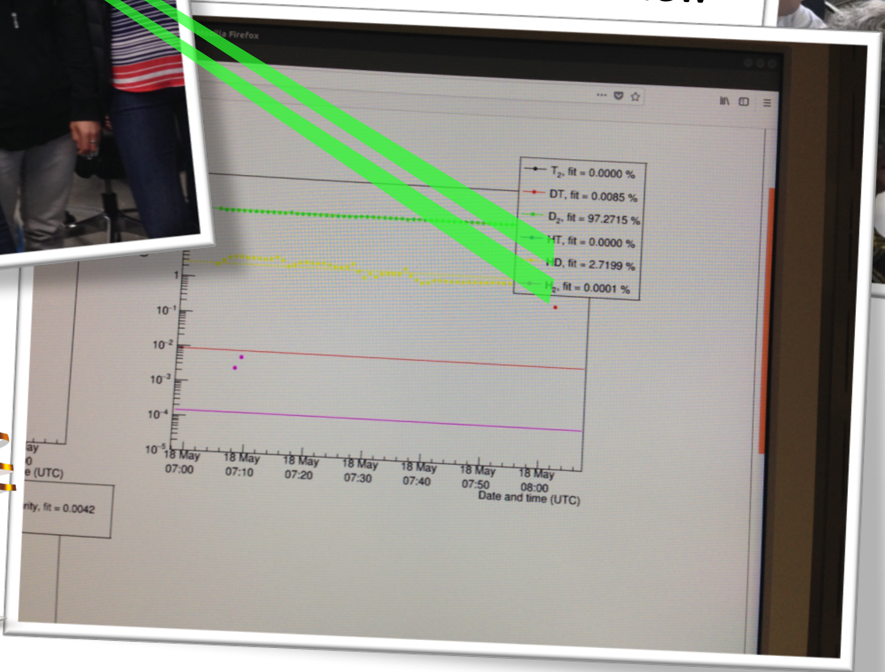
- Commissioning of system with tritium (1% of nominal activity = ~500 MBq!)
- 14 days of operation (without interruption)
- Two goals:

1. Demonstrate 0.1% global system stability
2. Study different analysis strategies

First tritium injection:
Friday 18 May
7:48 am UTC

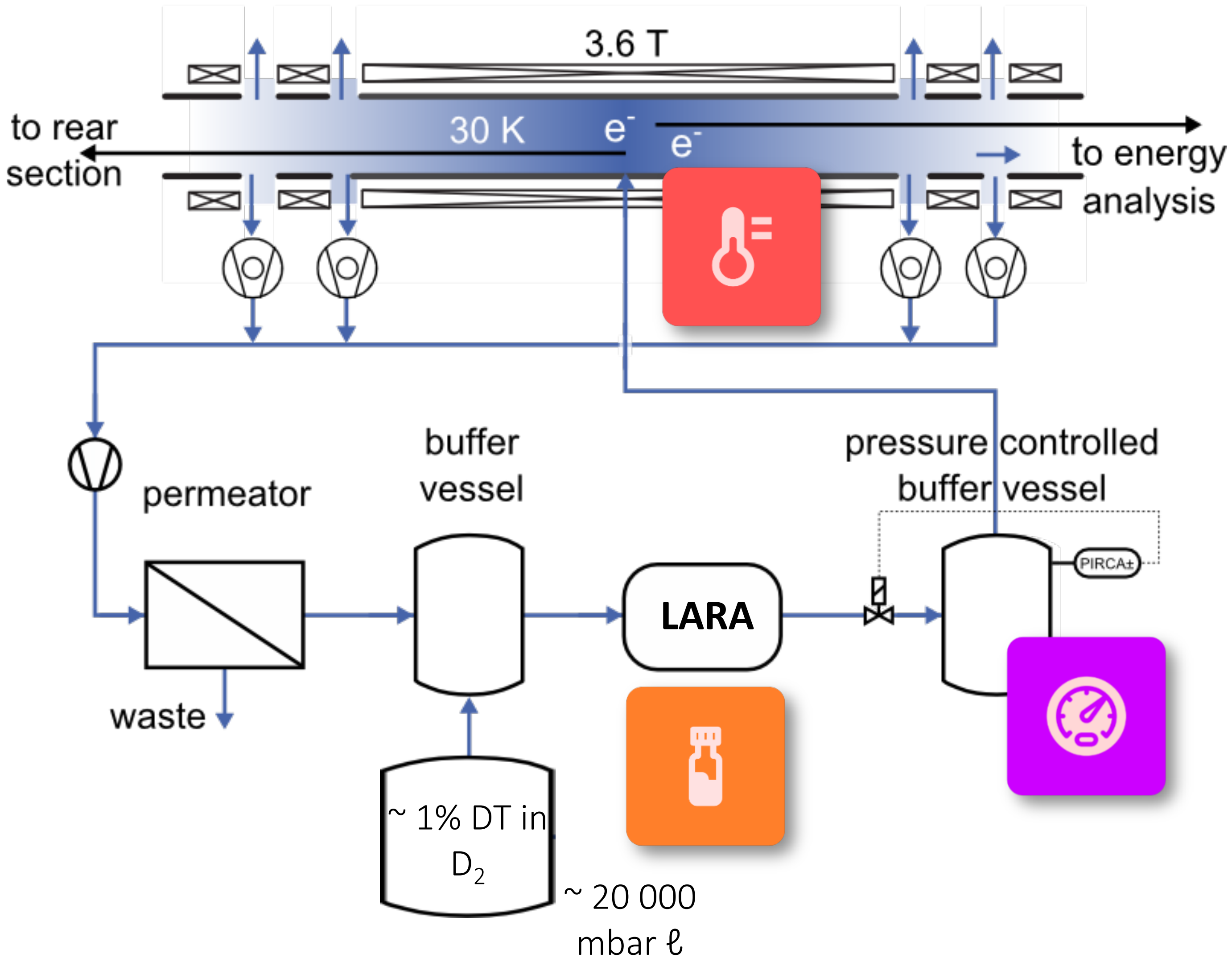
18th May 2018

Laser Raman online view

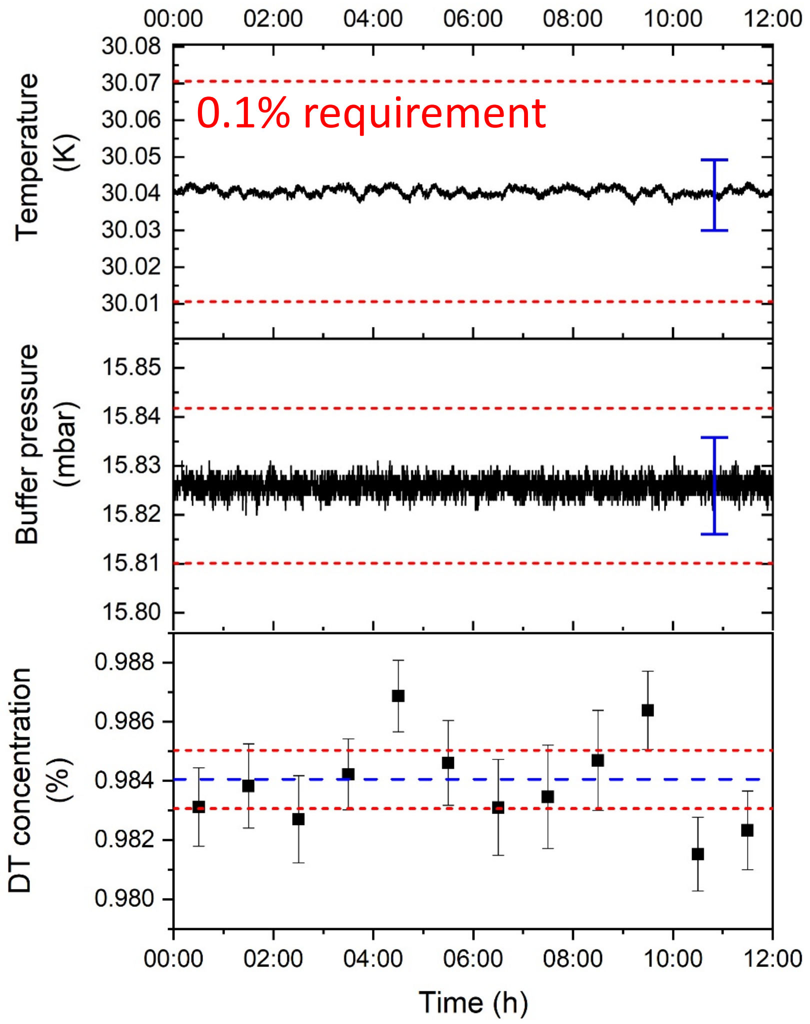


"Münchner Analysis Stubn"

Stability of source parameters



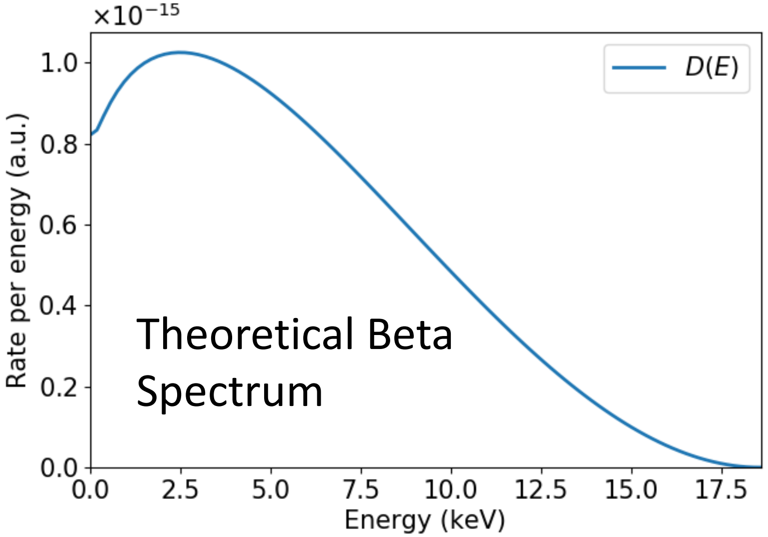
Stability of source parameters



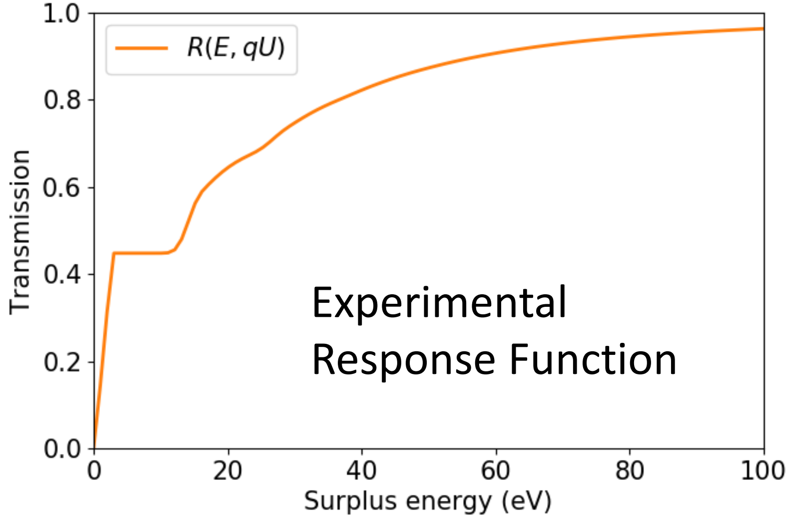
- Relevant parameters that determine stability of activity:
  - temperature
  - pressure
  - tritium concentration

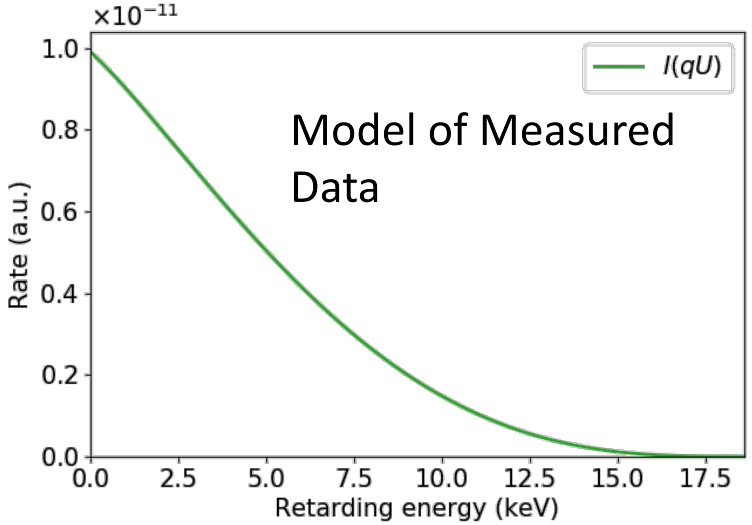
✓ Source parameters are stable and within the specifications

First Tritium Analysis

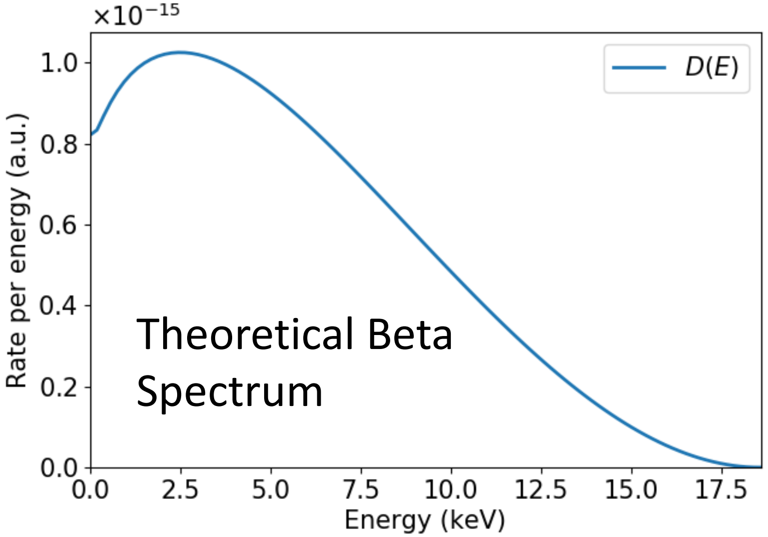


$$I(qU) = \int_{qU}^{E_0} D(E)R(E,qU)dE$$





First Tritium Analysis



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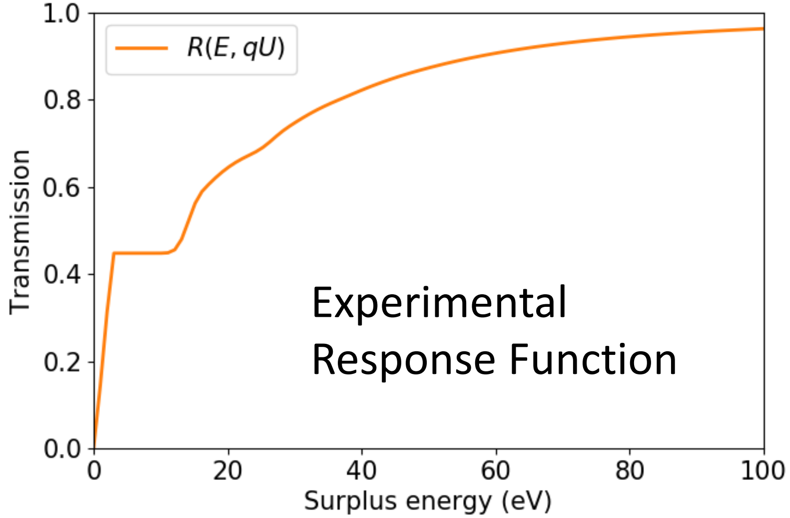
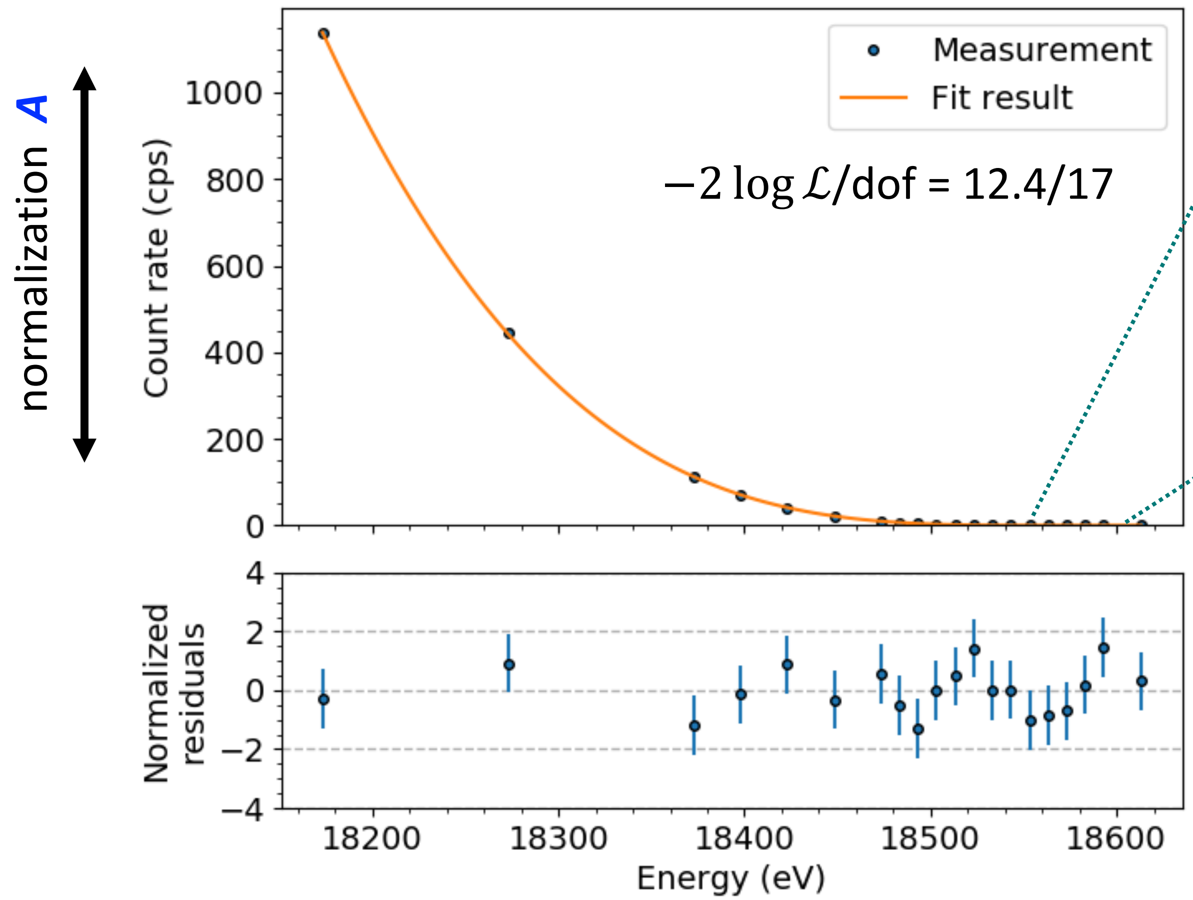
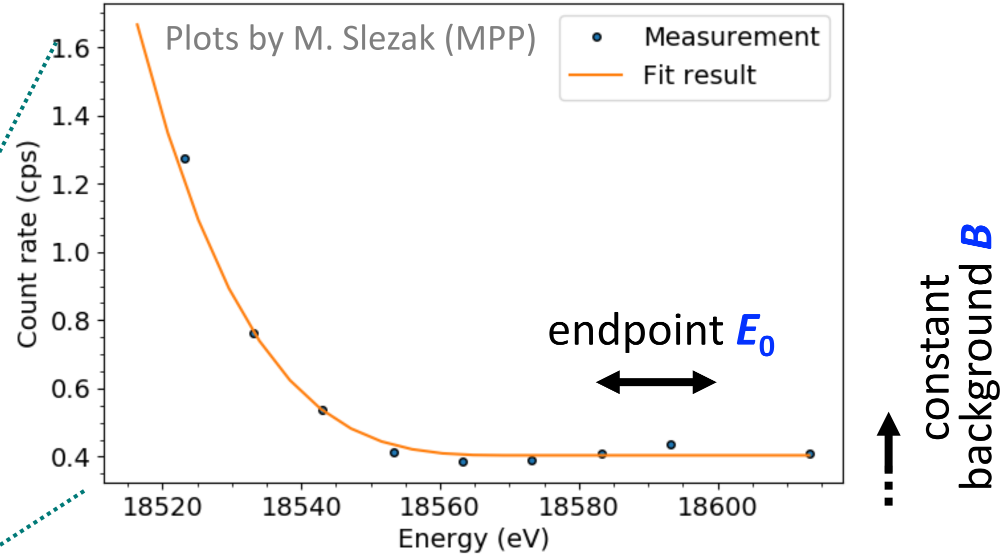


Thierry Lasserre, Mercator Fellow
Martin Slezak, Postdoc
Anna Pollithy, PhD
Christian Karl, PhD
Dominik Fuchs, MSc - done
Martin HaMinh, MSc - done
Pablo Morales, MSc - done
Lisa Schlüter, MSc
Fotis Megas, MSc
Madlen Steven, MSc
Christoph Köhler, MSc

First Tritium Results

$$\Gamma(qU) \propto \boldsymbol{A} \cdot \int_{qU}^{\boldsymbol{E_0}} \frac{d\Gamma}{dE}(E; \boldsymbol{m_\nu^2}, \boldsymbol{E_0}) \cdot R(qU, E)\, dE + \boldsymbol{B}$$



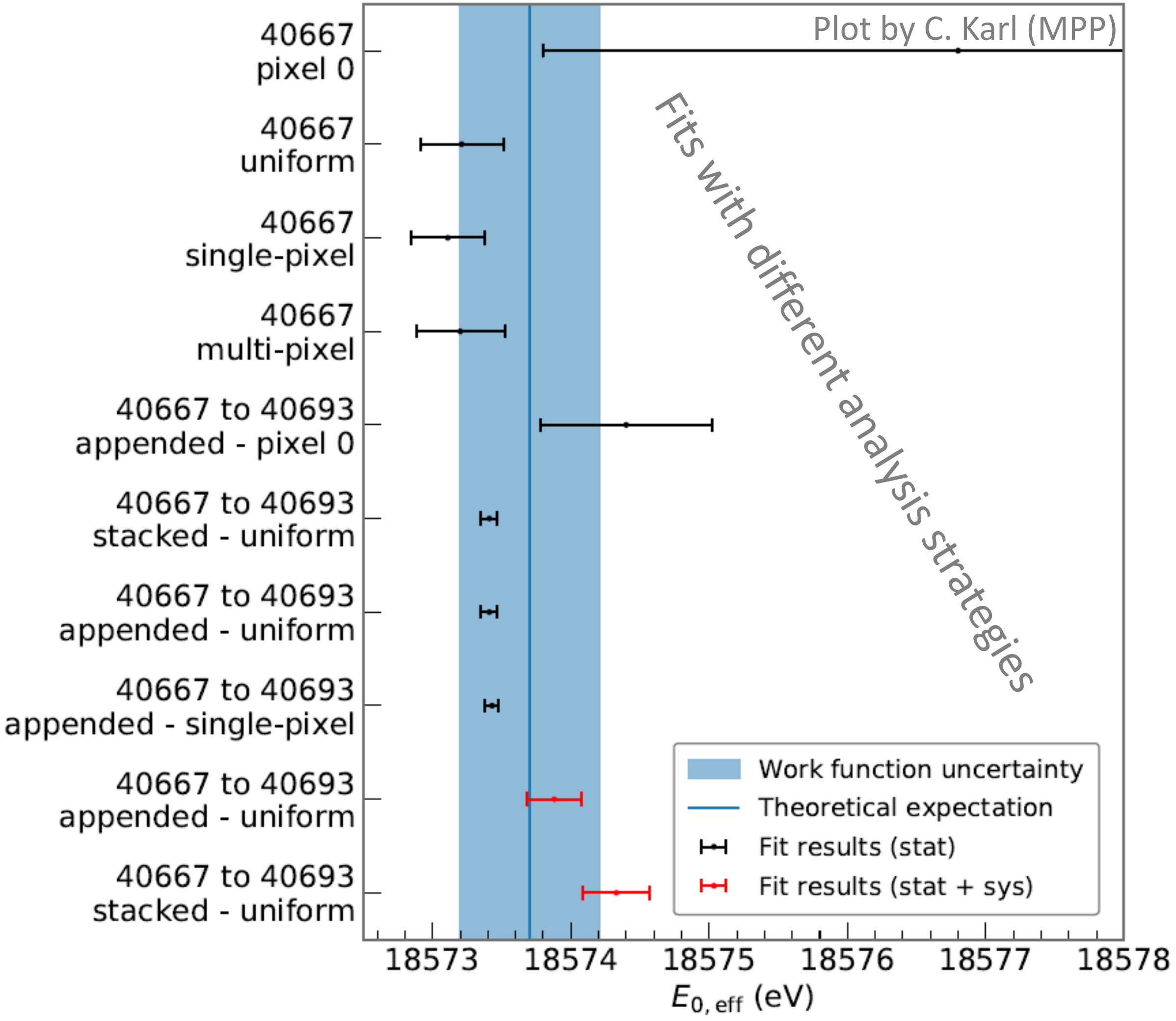


- Fit endpoint E_0, normalization **A**, background **B**
- No sensitivity to neutrino mass, yet

✓ Very good agreement of model and data

First Tritium Results

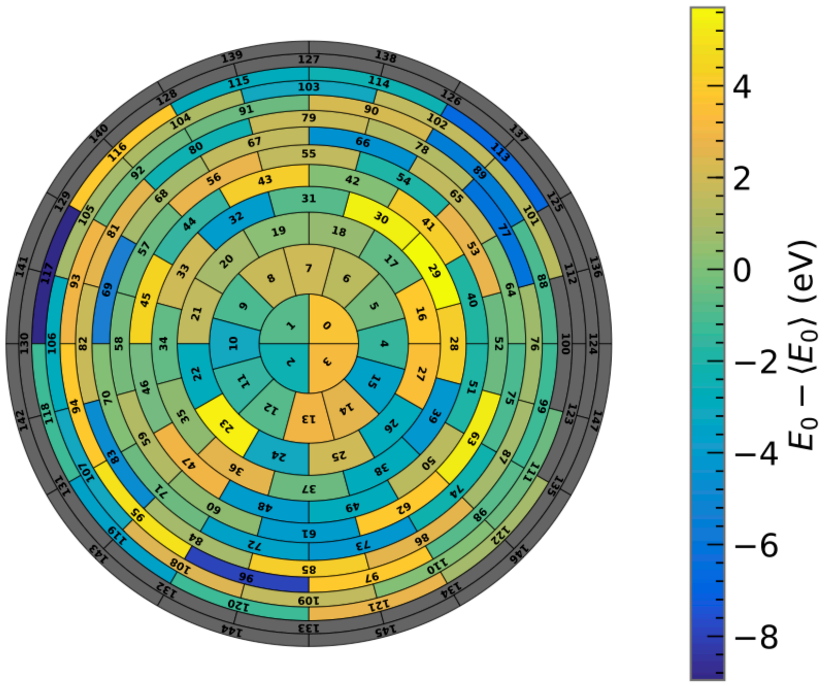
- ✓ Different fitting strategies agree within uncertainty
- ✓ < 500 meV uncertainty on effective endpoint
- ✓ Fitted effective endpoint agrees with expected value



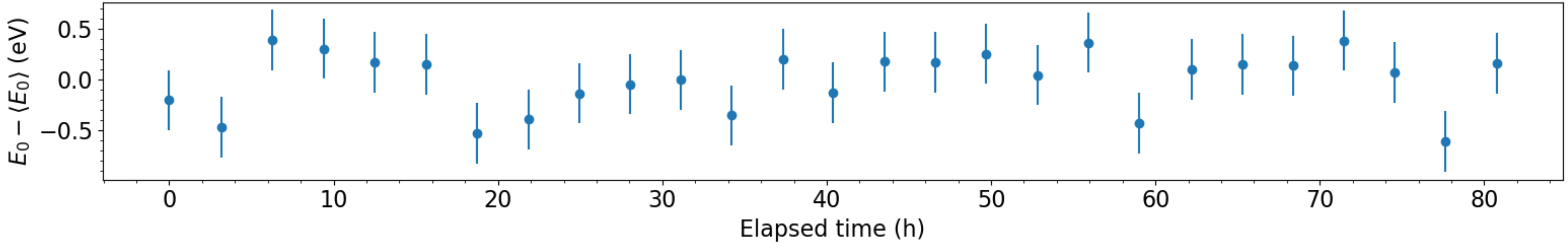
First Tritium Results

✓ Fitted effective endpoint is stable in space

✓ and stable as a function of time

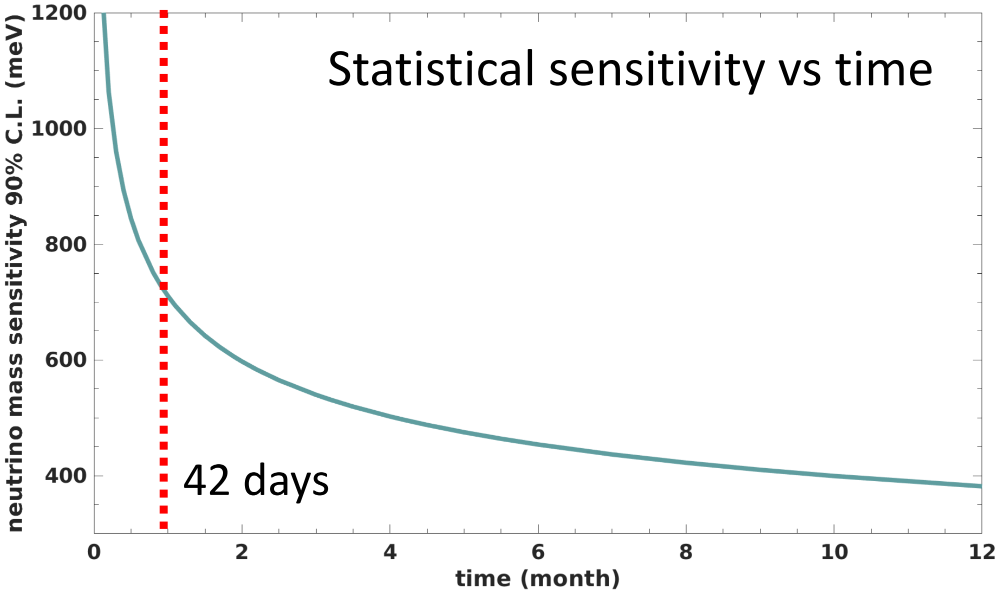


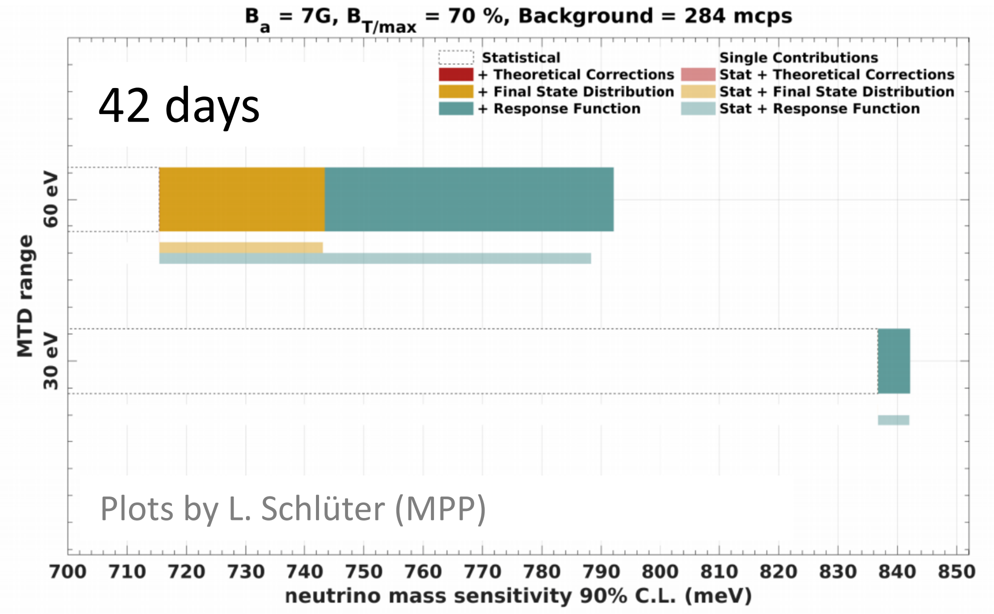
Plots by C. Karl (MPP)

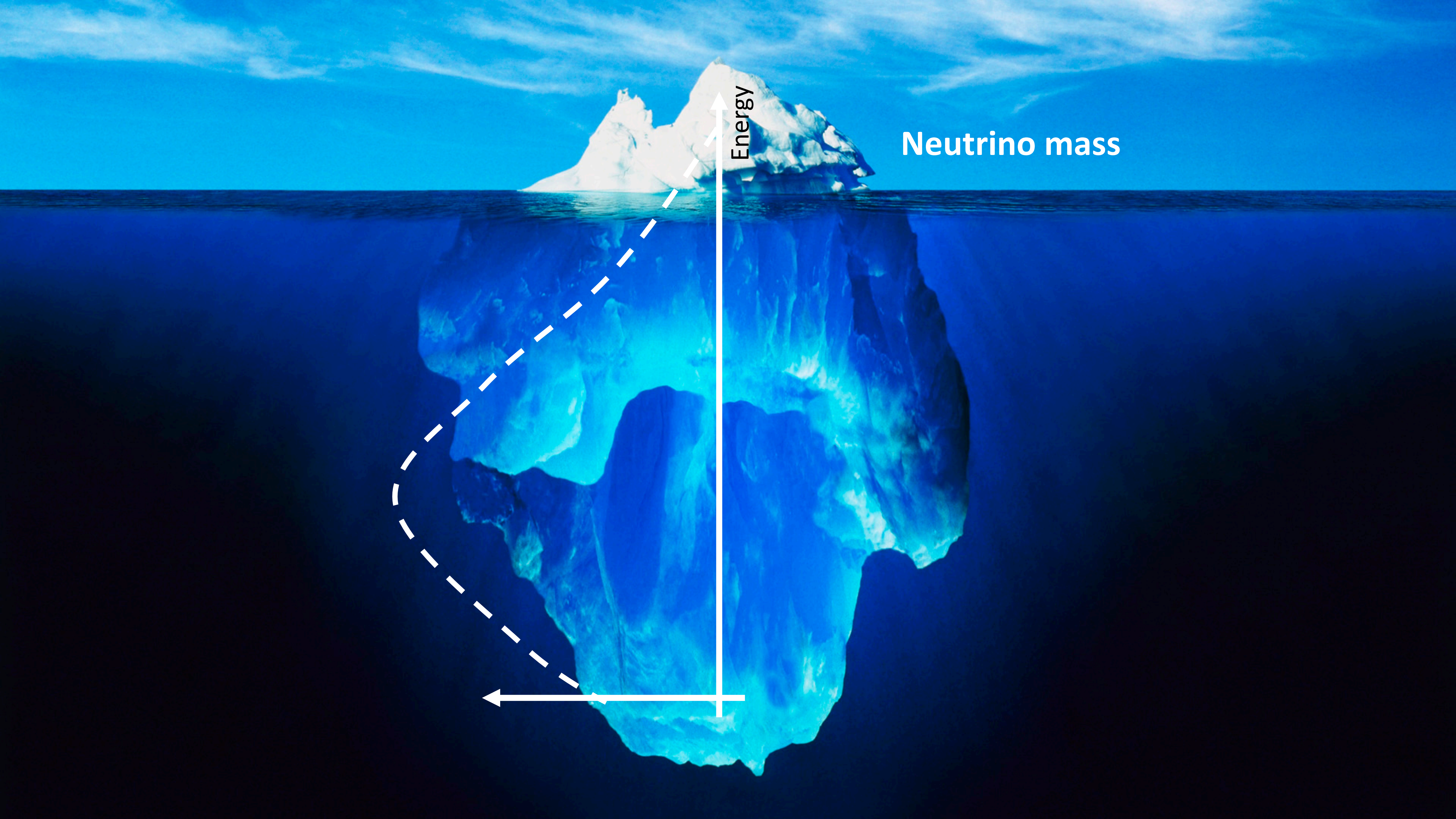


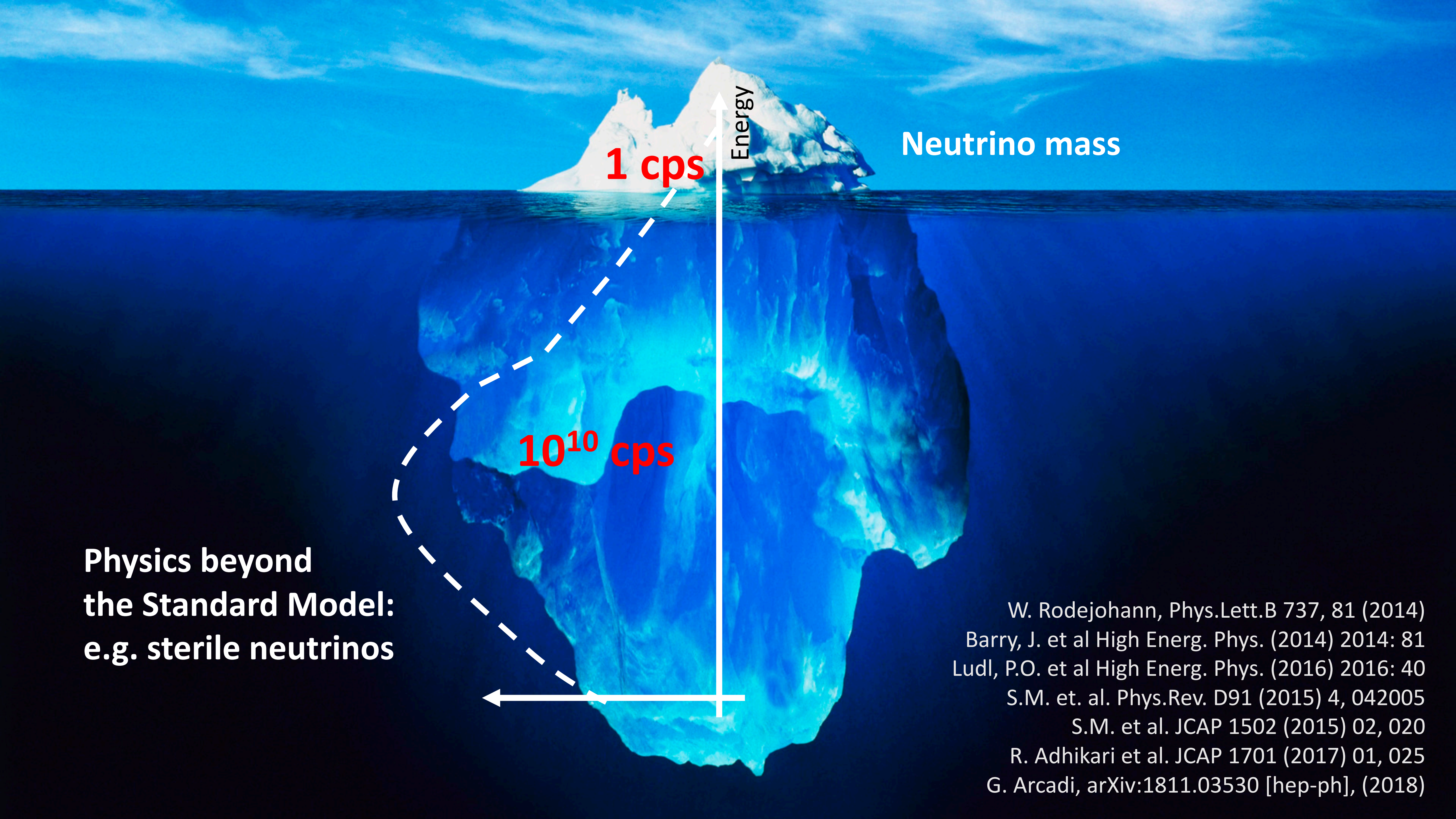
Next Tritium: March 1st 2019

- Start of nu-mass measurement in March 2019
- First sub-eV results in September 2019
- After 3 yrs of data (5 calendar yrs): balance of statistics and systematics






Energy
Neutrino mass

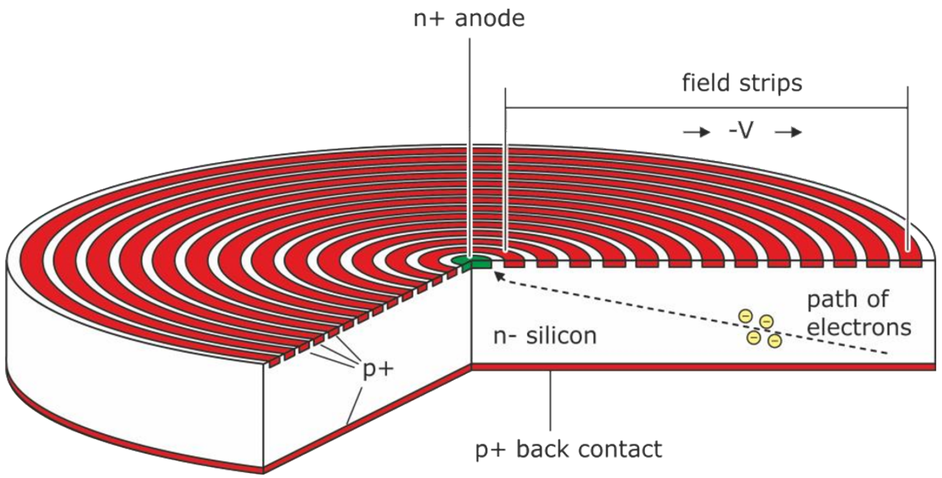


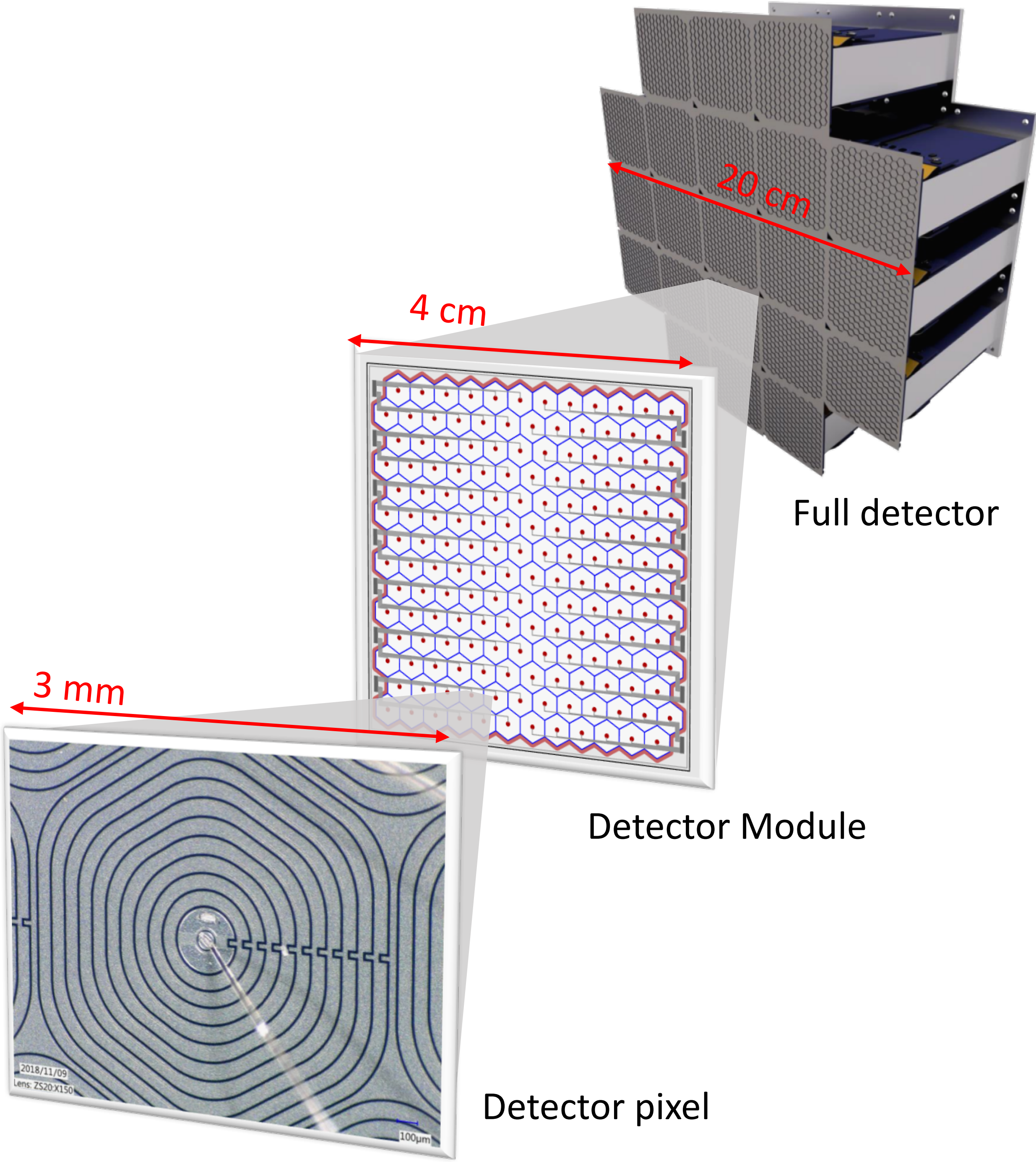
W. Rodejohann, Phys.Lett.B 737, 81 (2014)
Barry, J. et al High Energ. Phys. (2014) 2014: 81
Ludl, P.O. et al High Energ. Phys. (2016) 2016: 40
S.M. et. al. Phys.Rev. D91 (2015) 4, 042005
S.M. et al. JCAP 1502 (2015) 02, 020
R. Adhikari et al. JCAP 1701 (2017) 01, 025
G. Arcadi, arXiv:1811.03530 [hep-ph], (2018)

TRISTAN Detector R&D

Capability of handling high rates (> 3 x 10^8 cps)
+ Excellent energy resolution (300 eV @ 20 keV)

- Silicon Drift Detector Technology
- Novelty: large number of pixels: O(3000)
- Novelty: application to electrons: thin deadlayer





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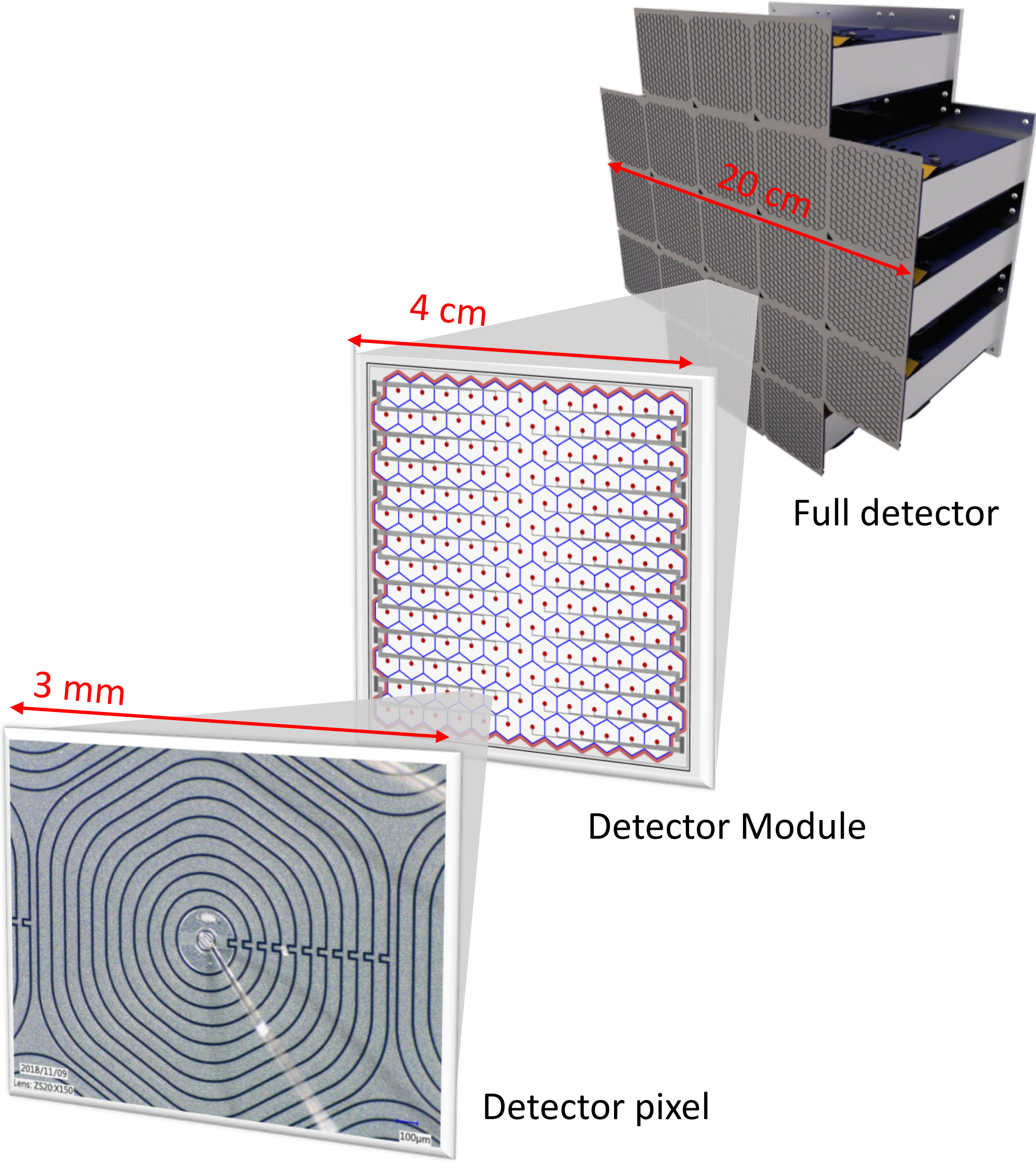
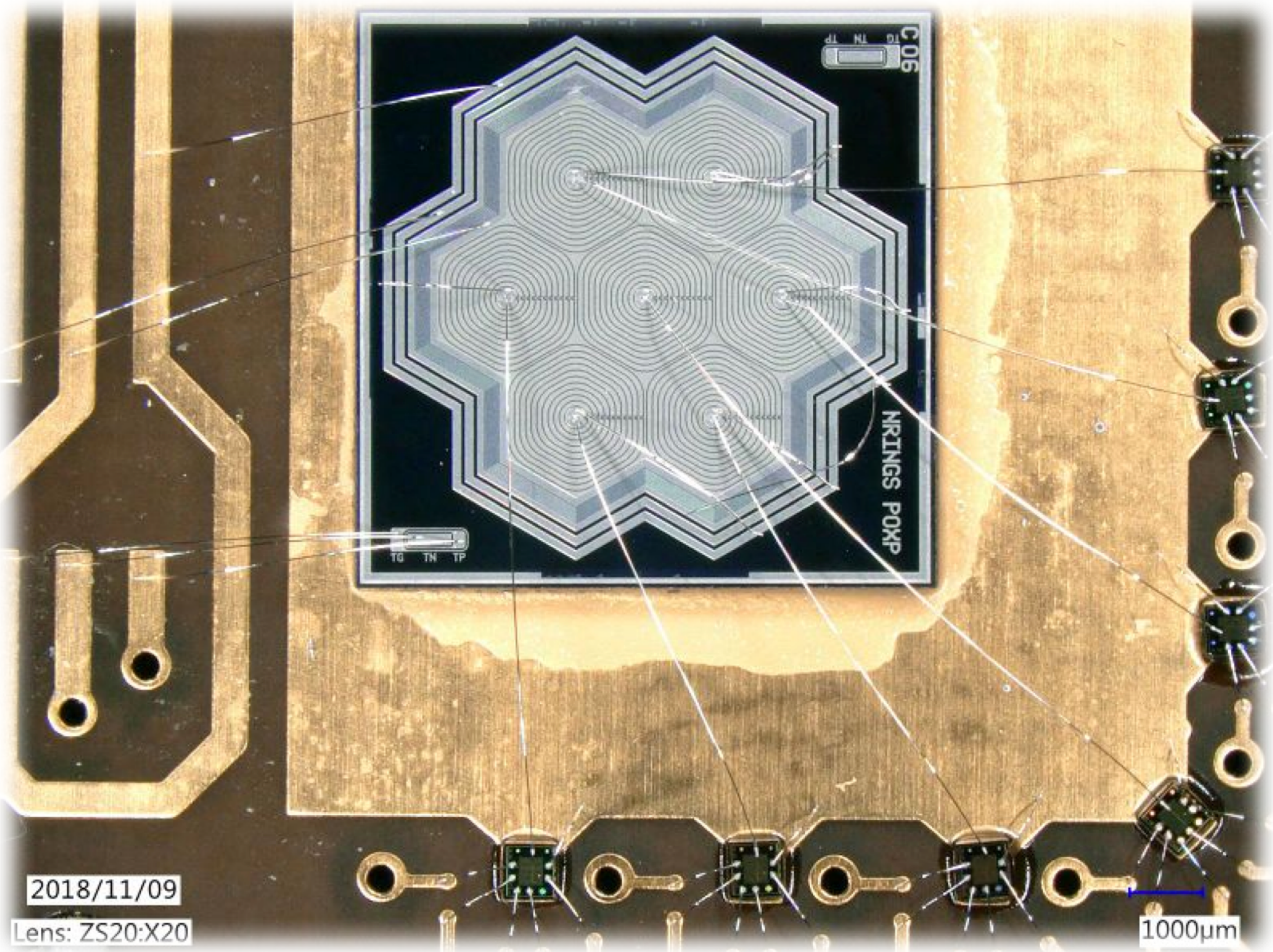
David Fink, Engineer
Thibaut Houdy, Postdoc
Tim Brunst, PhD
Manuel Lebert, MSc
Daniel Siegmann, MSc
Korbinian Urban, MSc
Matthias Meier, MSc
Cornelius Schätz, MSc
Xavier Pawlowski, BSc - done



TRISTAN Prototype

- 7-pixel prototype
- Produced at the semiconductor lab of the Max-Planck-Society (HLL)
- Low-noise readout by XGLab (Italy)
- Detector laboratory at MPP

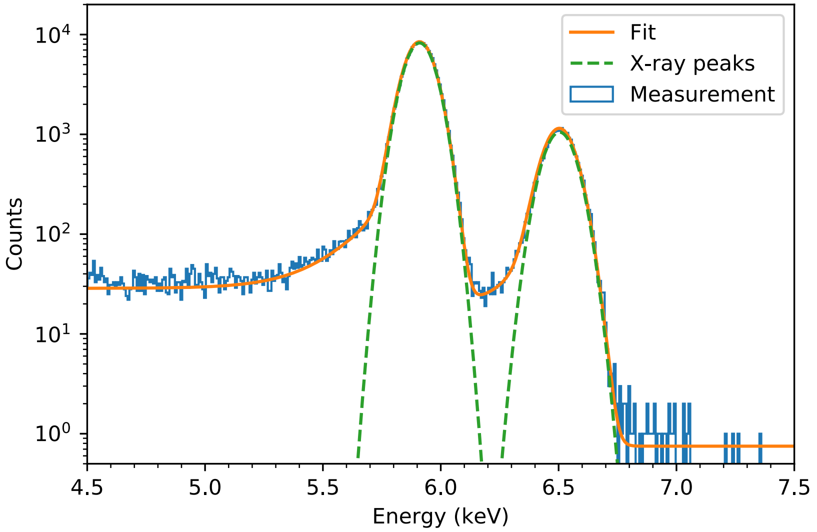


Characterization with X-rays

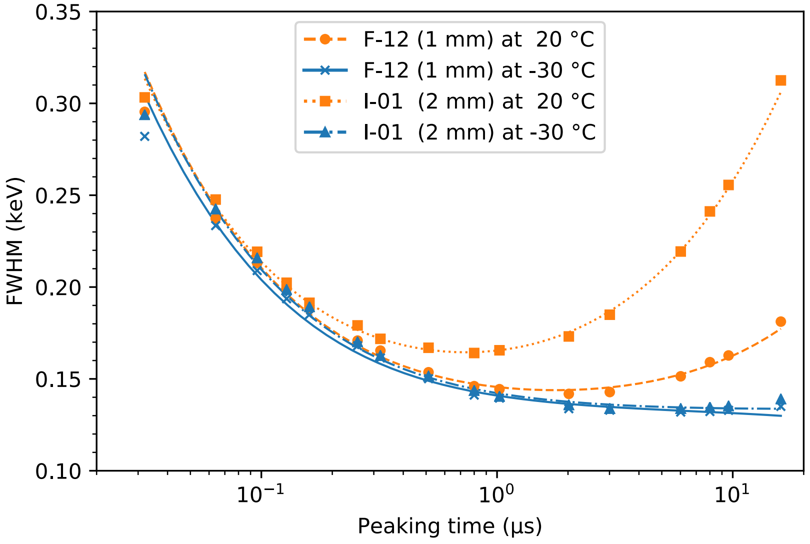
✓ Excellent performance demonstrated

S.M. et al, https://arxiv.org/abs/1810.06711, Oct 2018

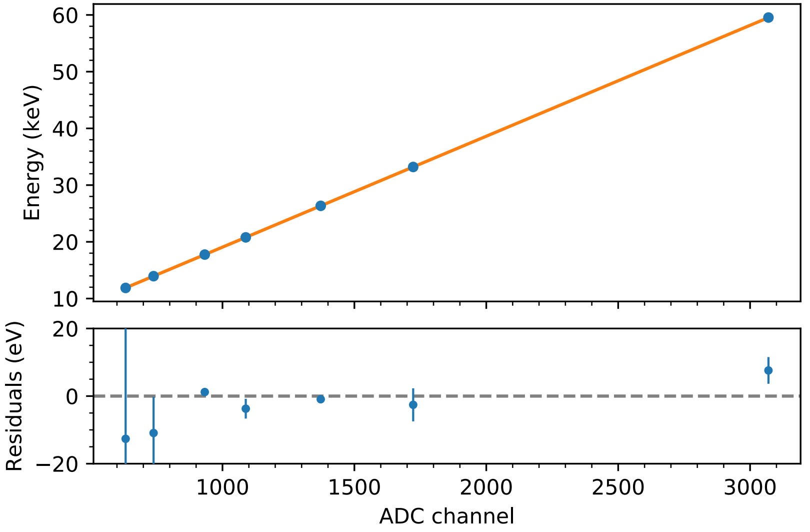
130 eV (FWHM) @ 6 keV



< 150 eV (FWHM), < 1µs shaping time



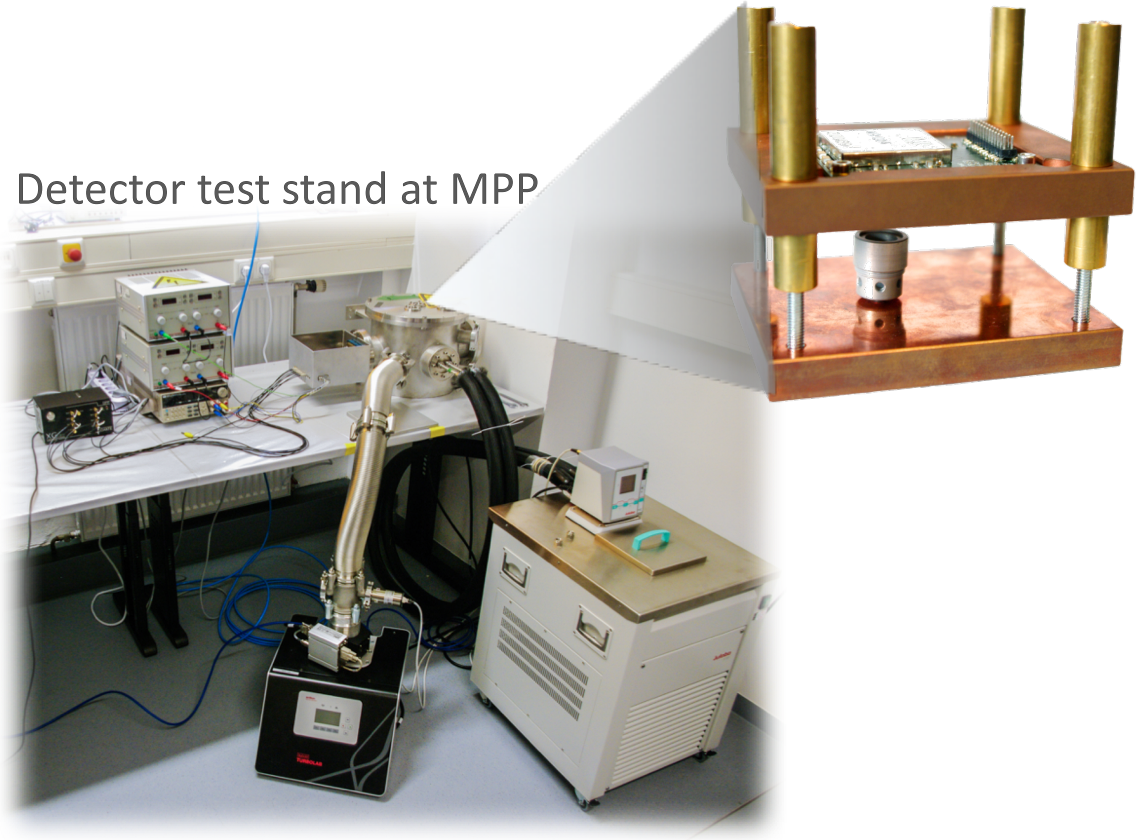
0.1% linearity over 60 keV range

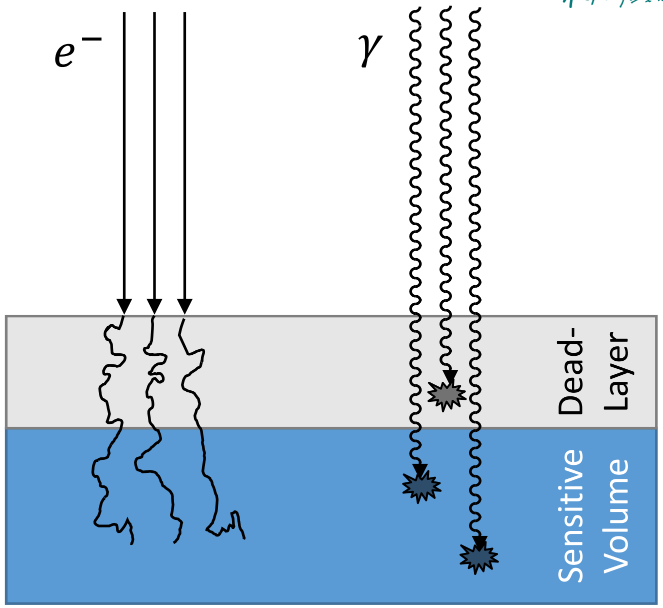


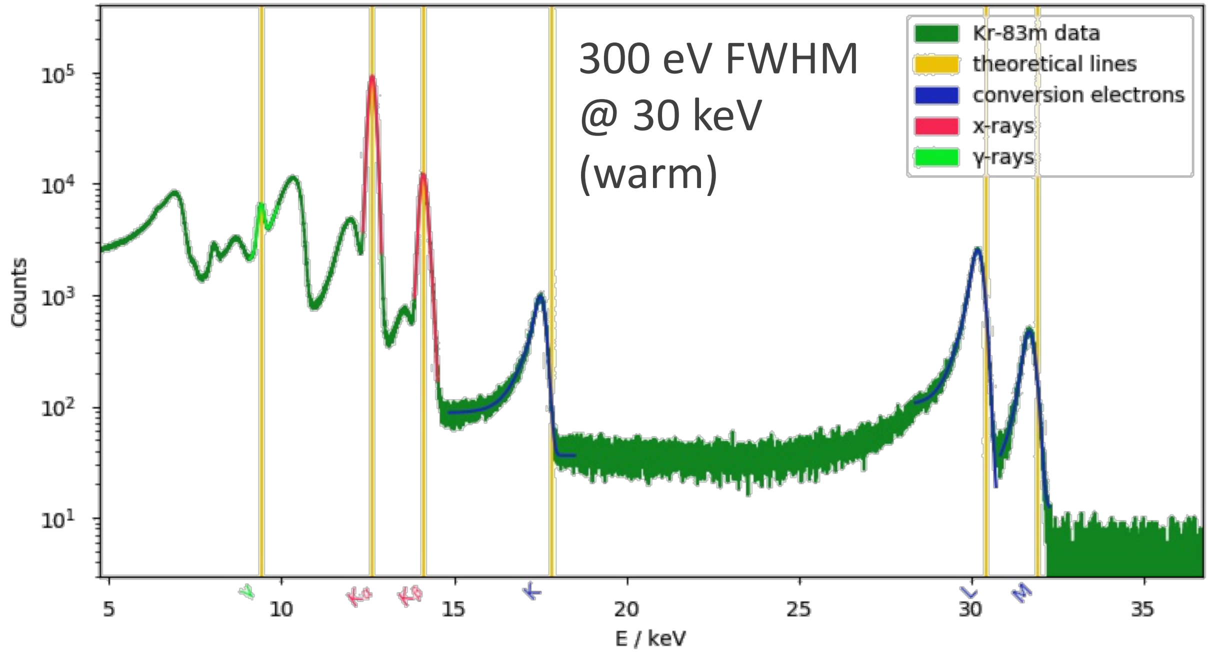
Characterization with electrons

1. Evaporated 83m-Kr source from Czech

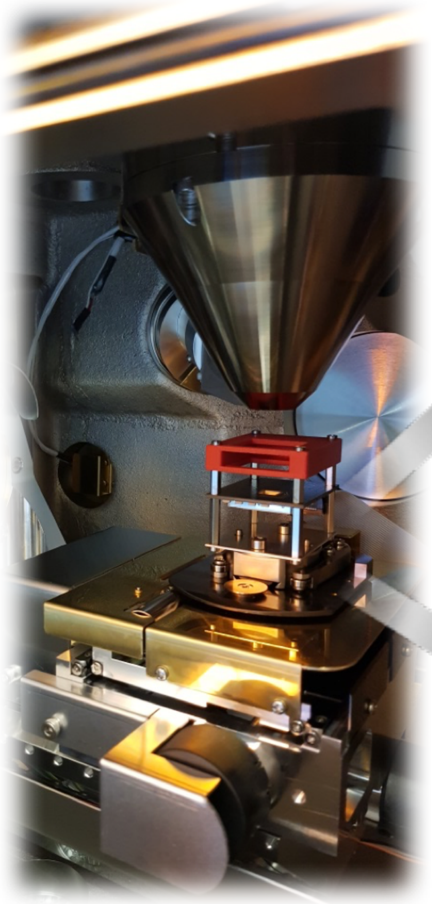
Detector test stand at MPP

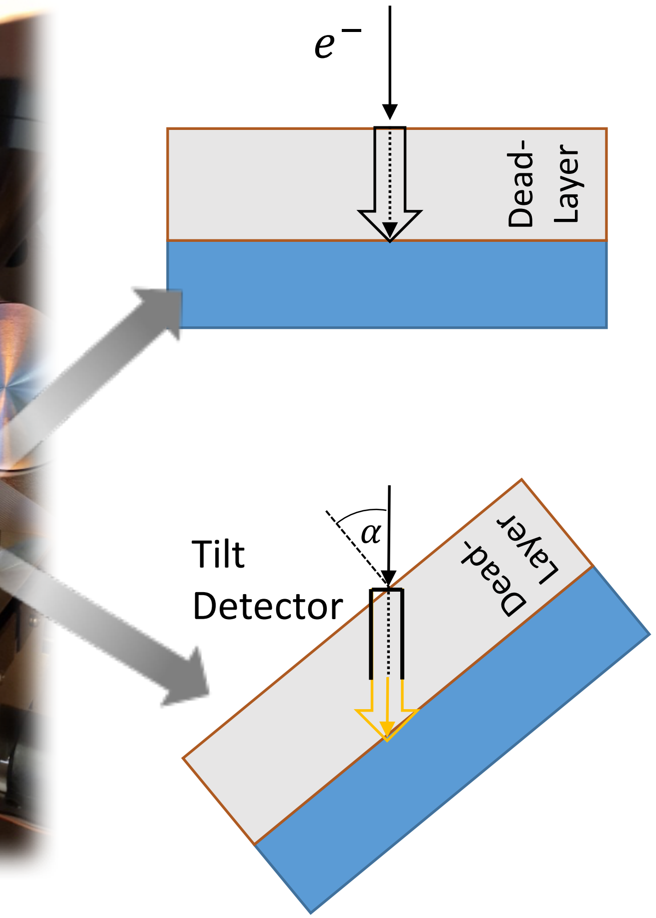




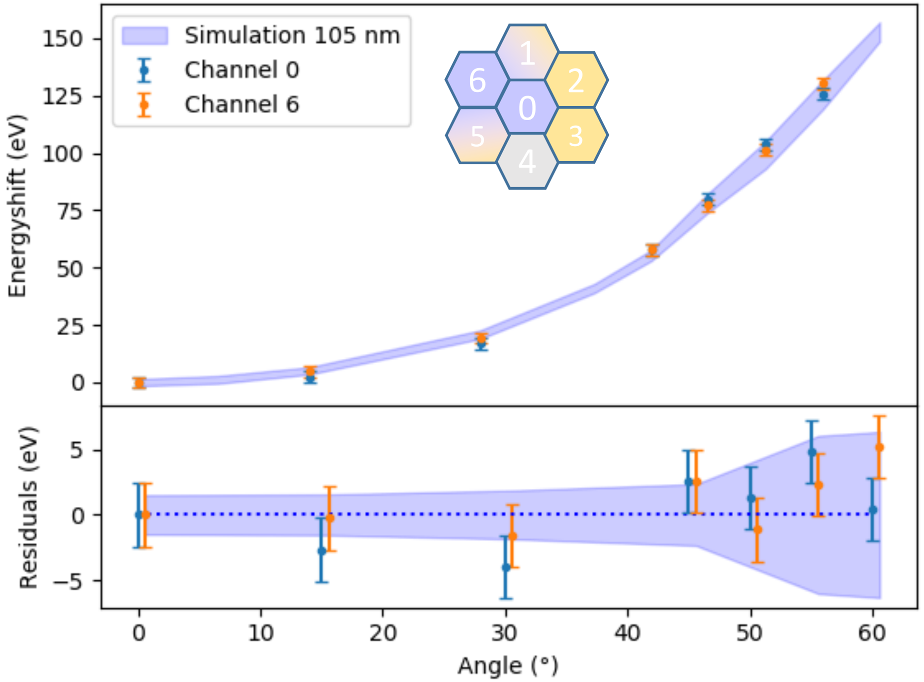


Characterization with electrons

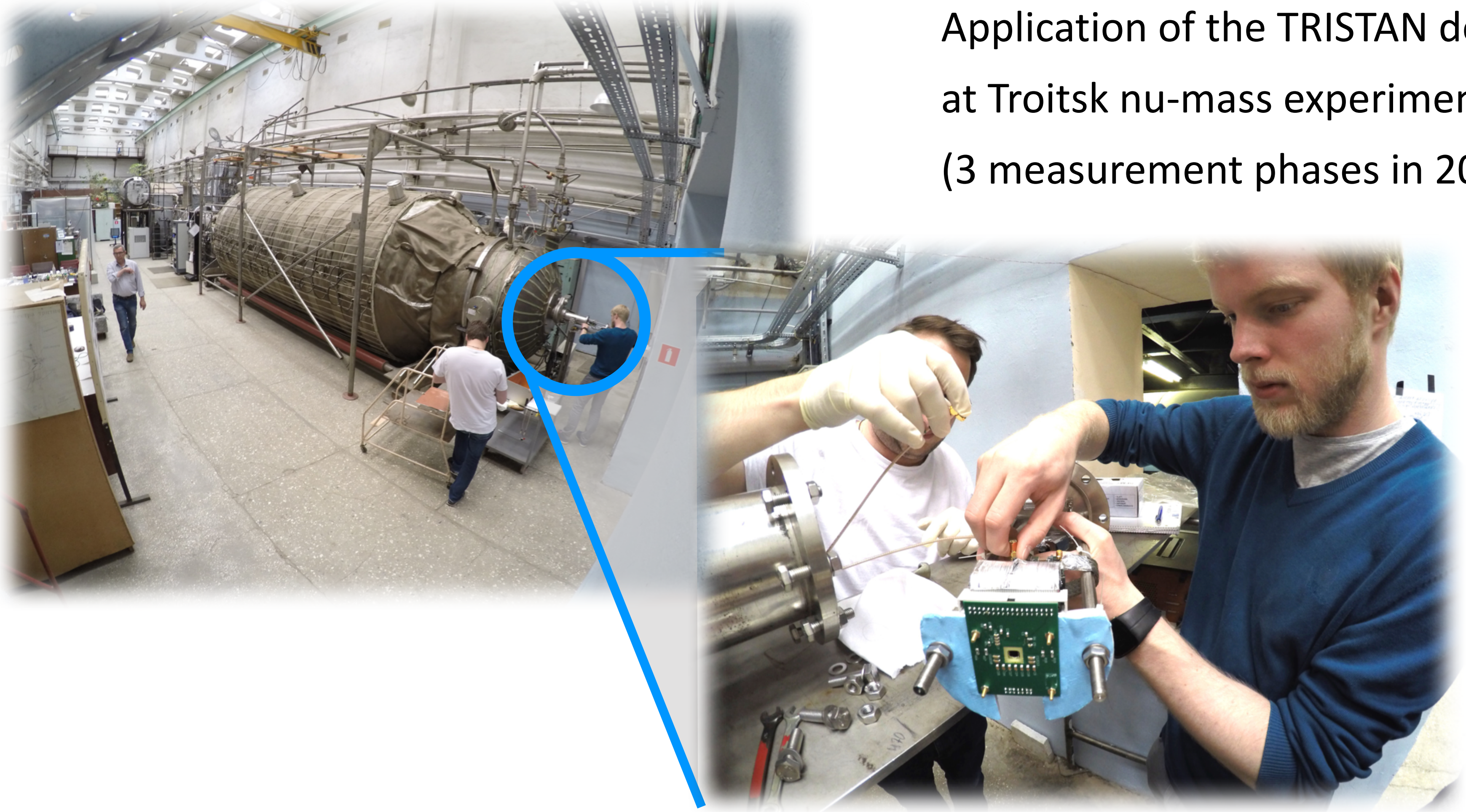




2. Electron microscope at Semiconductor Lab of Max Planck (HLL)



TRISTAN in TROITSK



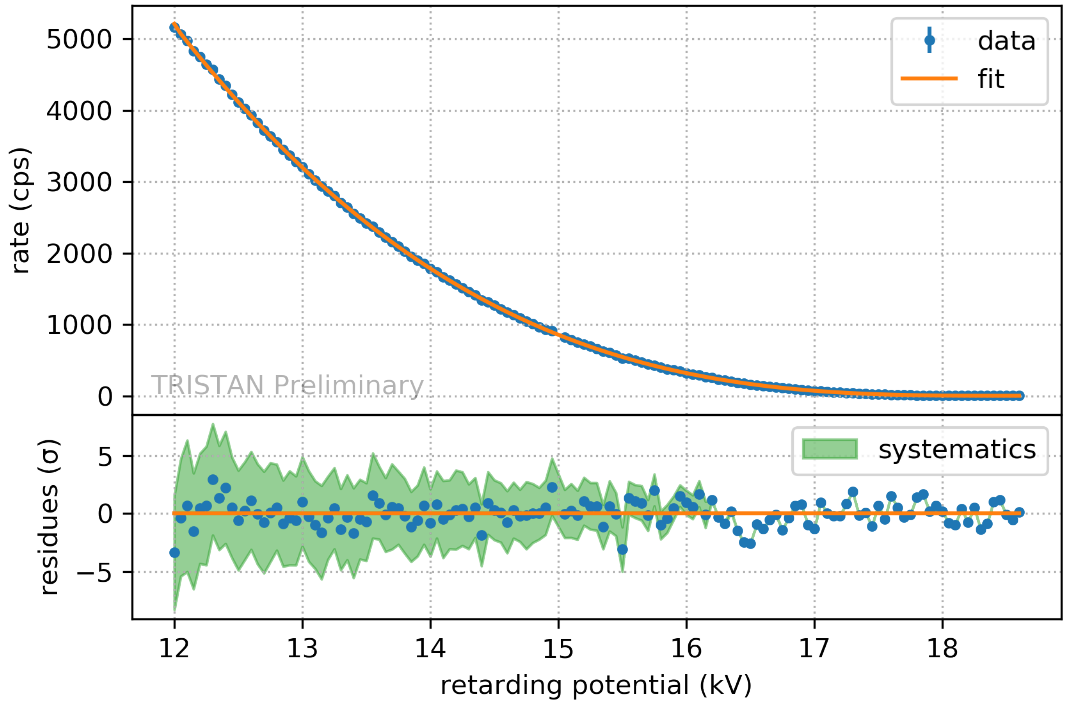
Application of the TRISTAN detector

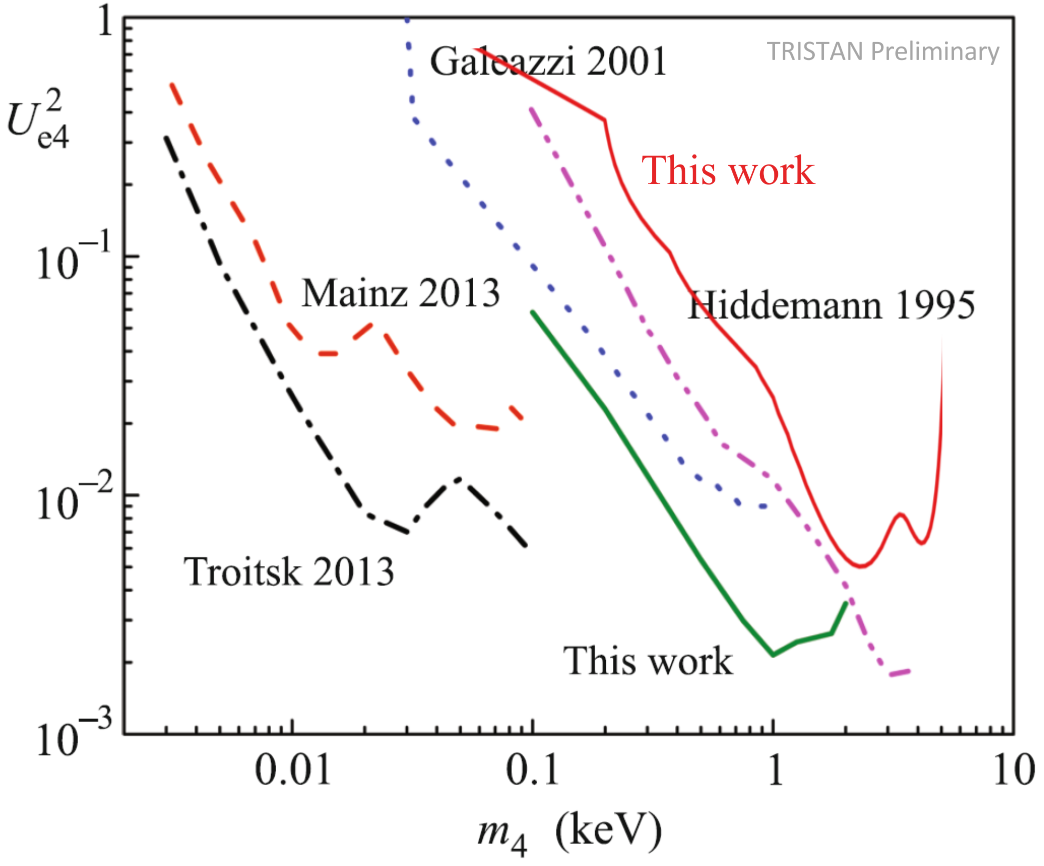
at Troitsk nu-mass experiment

(3 measurement phases in 2017 and 2018)

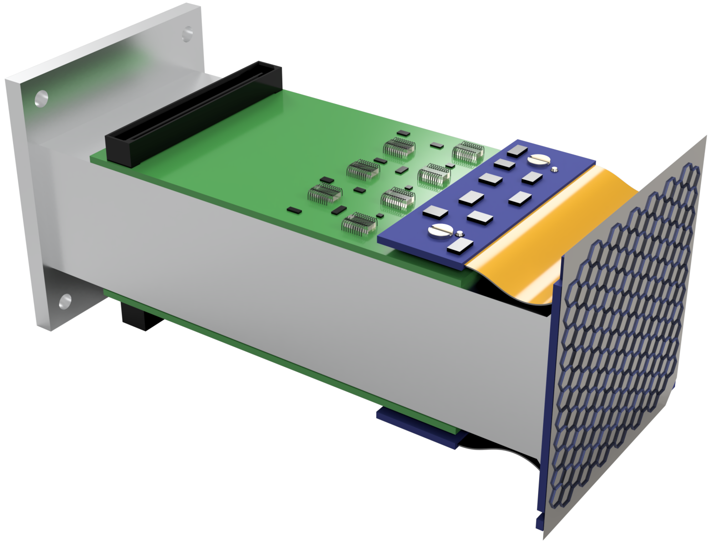
TRISTAN in TROITSK

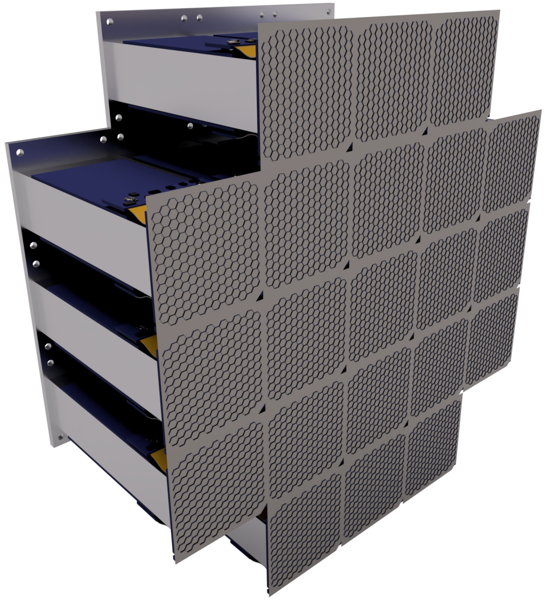
- ✓ Both **differential** and **integral** measurements
- ✓ First physics results





Towards the final system

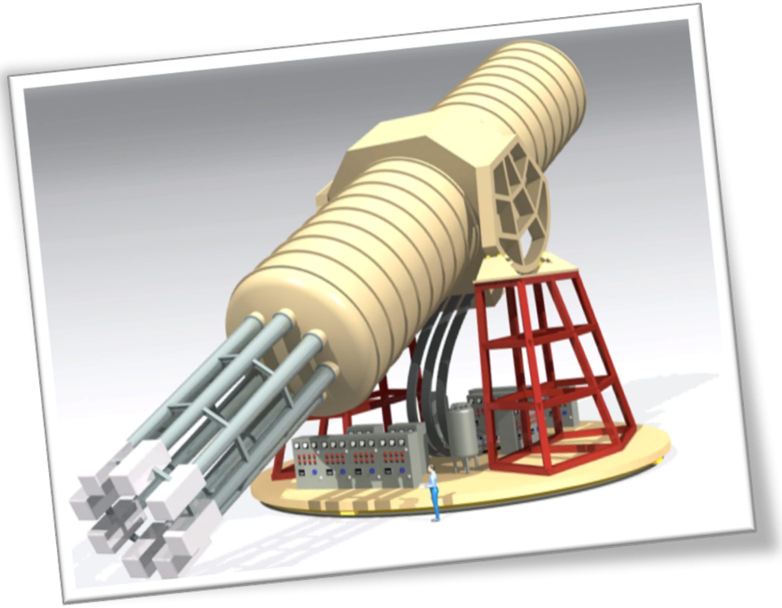


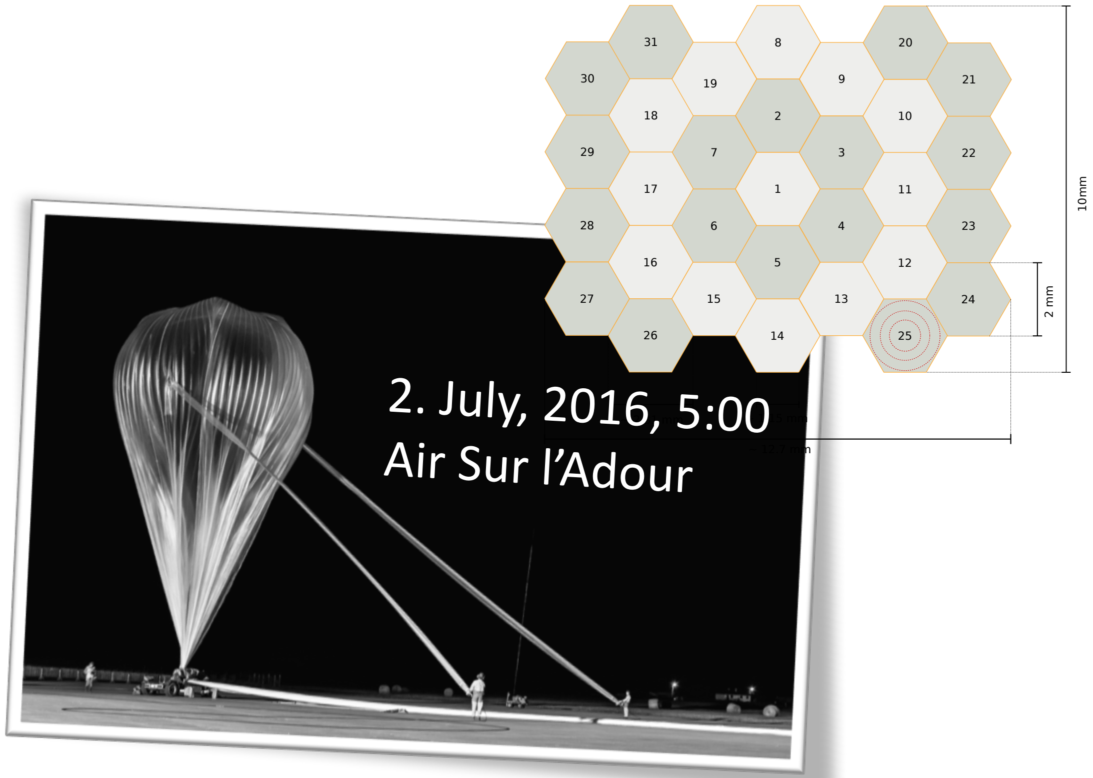


- TRISTAN module
  - 166-pixel detector with integrated JFET
  - **Commissioning mid-2019**
- Full TRISTAN detector
  - 21 x 166-pixel module = 3500 pixels
  - **Integration in 2023**

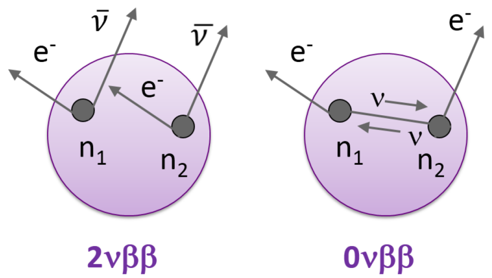
Other applications of TRISTAN

- TRISTAN as X-ray detector in the solar axion experiment IAXO
- TRISTAN in a CubeSat space mission as Compton telescope COMPOL





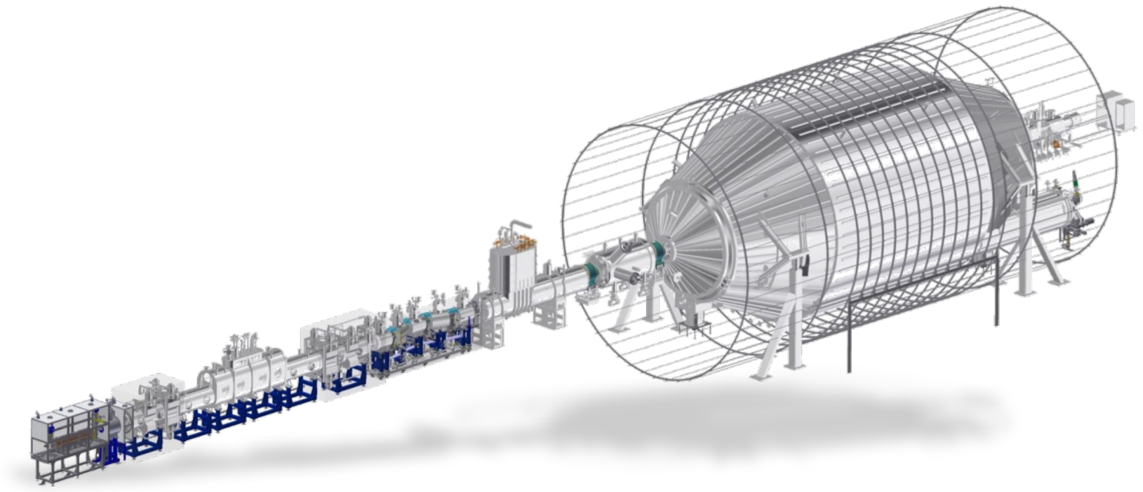
Neutrino mass



Kinematics of ß-decay

Laboratory-based
potential: m_β = 50 - 200 meV
e.g. KATRIN

$$m_\beta^2 = \sum_i |U_{ei}|^2 \cdot m_i^2$$



Search for 0νßß

Laboratory-based
potential: $m_{\beta\beta}$ = 15-50 meV
e.g. LEGEND

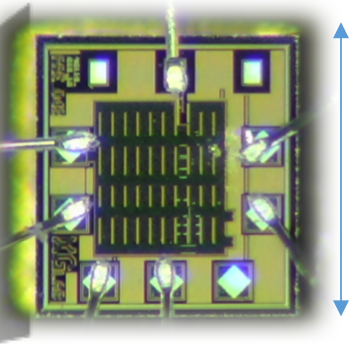
$$m_{\beta\beta} = \left|\sum_i U_{ei}^2 m_i\right|$$

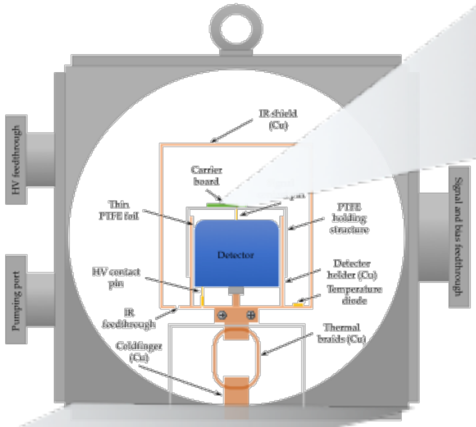
Frank Edzards, PhD

Novel read-out technology

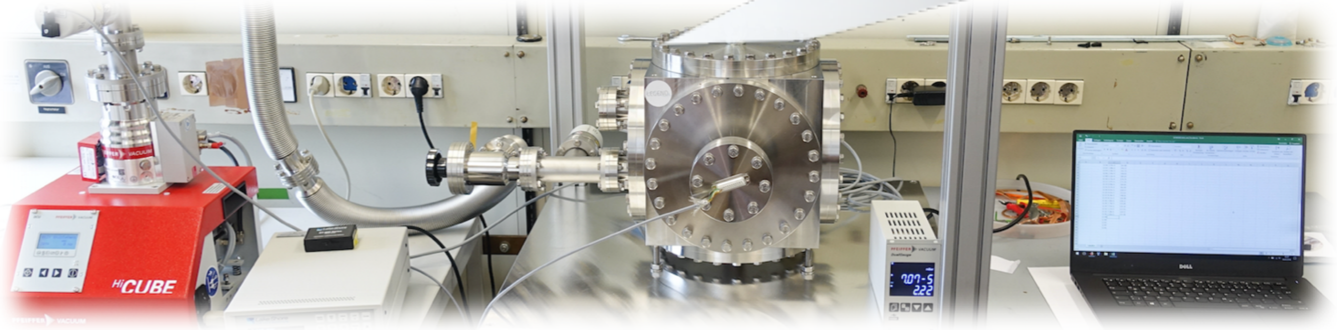
- Goal: Combine high resolution with low background
- Develop a low mass ASIC-based read-out

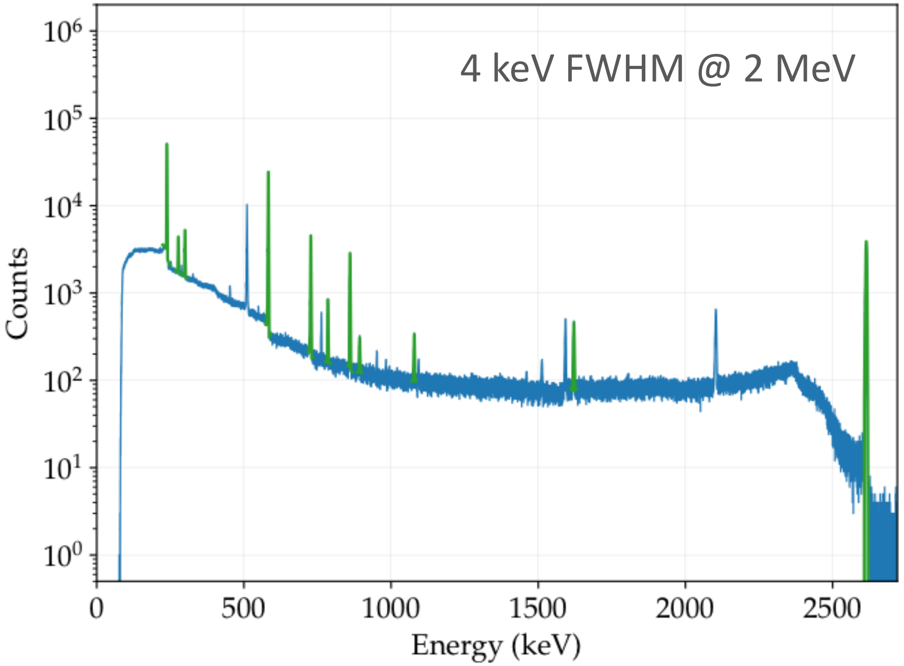
✓ First results show that required resolution can be reached

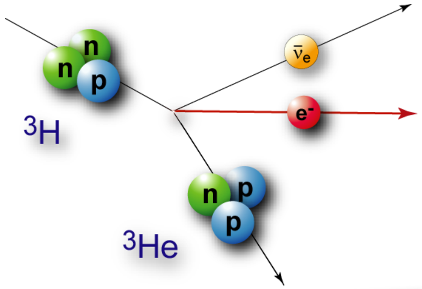




Ge-detector test stand





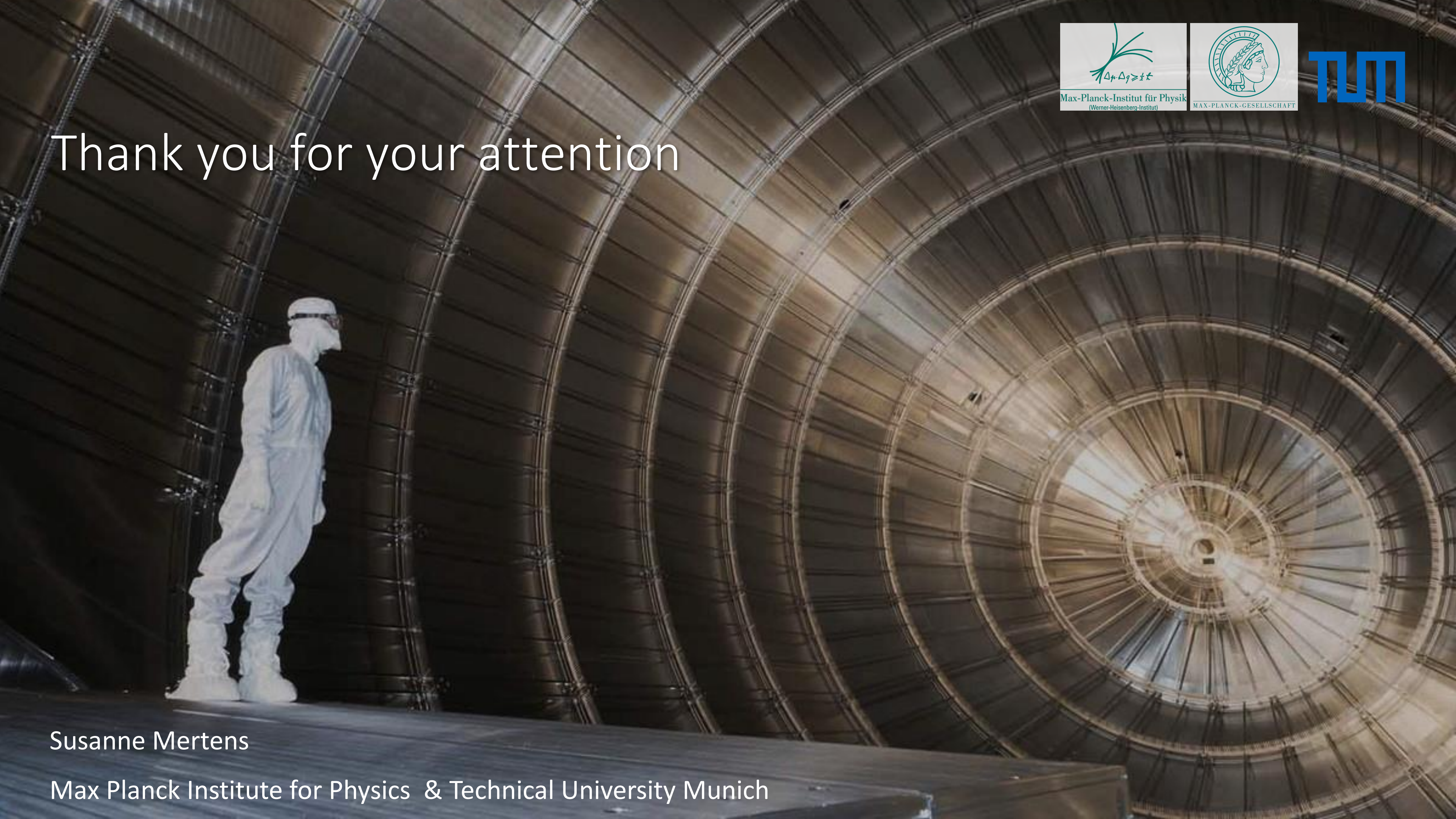


Summary

- Neutrinos provide us with exciting open questions…
- KATRIN will start nu-mass measurement in March 1st
- TRISTAN has the potential to extend KATRIN and search for sterile neutrinos
- LEGEND will perform the ultimate search for $0\nu\beta\beta$

Thanks to my group

Thank you for your attention



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