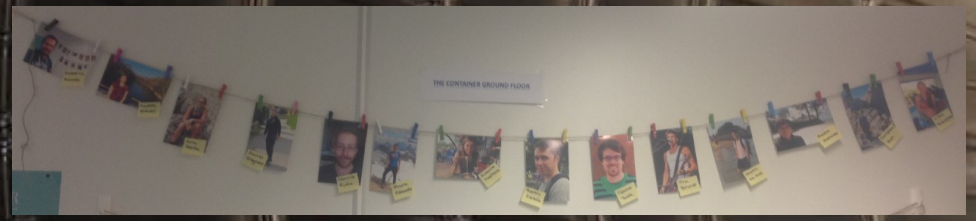
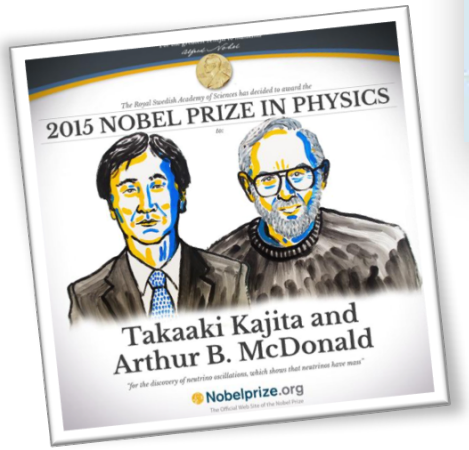
Probing ν–mass & searching for sterile ν's with KATRIN & TRISTAN

MPP, Project Review, 2017

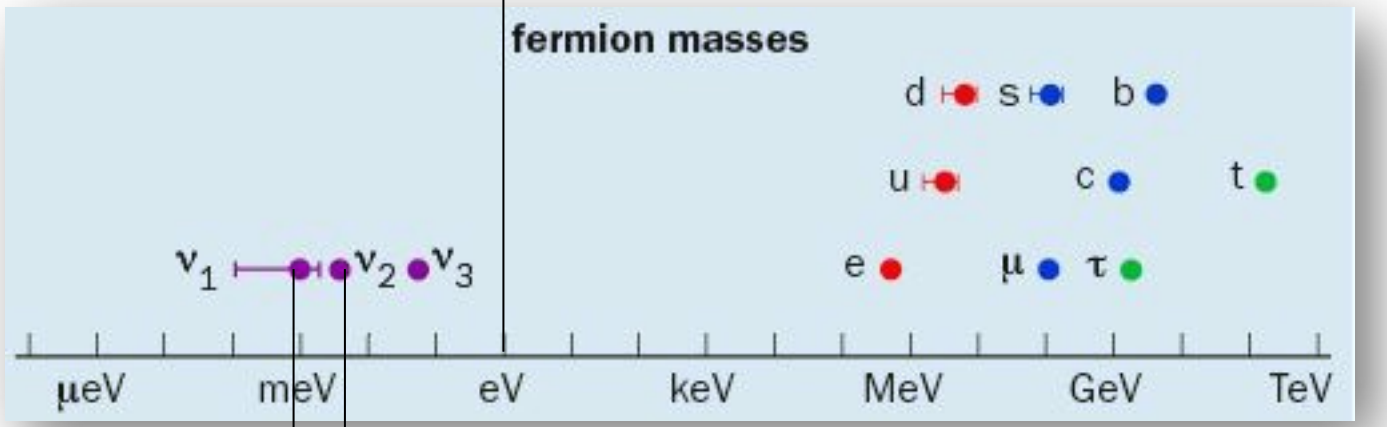


Susanne Mertens, Martin Slezak (Postdoc), Tobias Bode (Postdoc), Tim Brunst (PhD), Frank Edzards (PhD), Anna Pollithy (PhD), Dominik Fuchs (Master), Pablo Morales (Master), Madlen Stark (Master), Martin Ha Minh (Master), Christian Karl (Master), Lisa Schlüter (Master), Federico Roccatti (Master), Daniel Siegmann (HiWi), Thierry Lasserre (Mercator Fellow)

Neutrinos

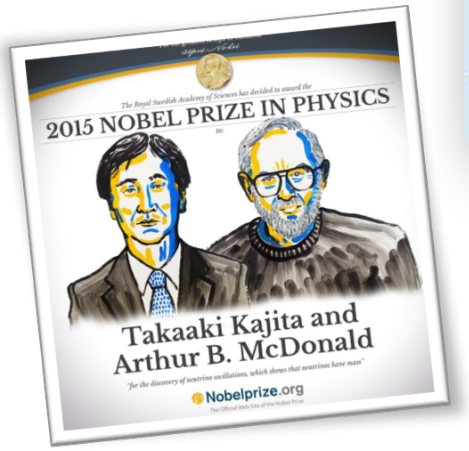


Upper bound
from direct measurements

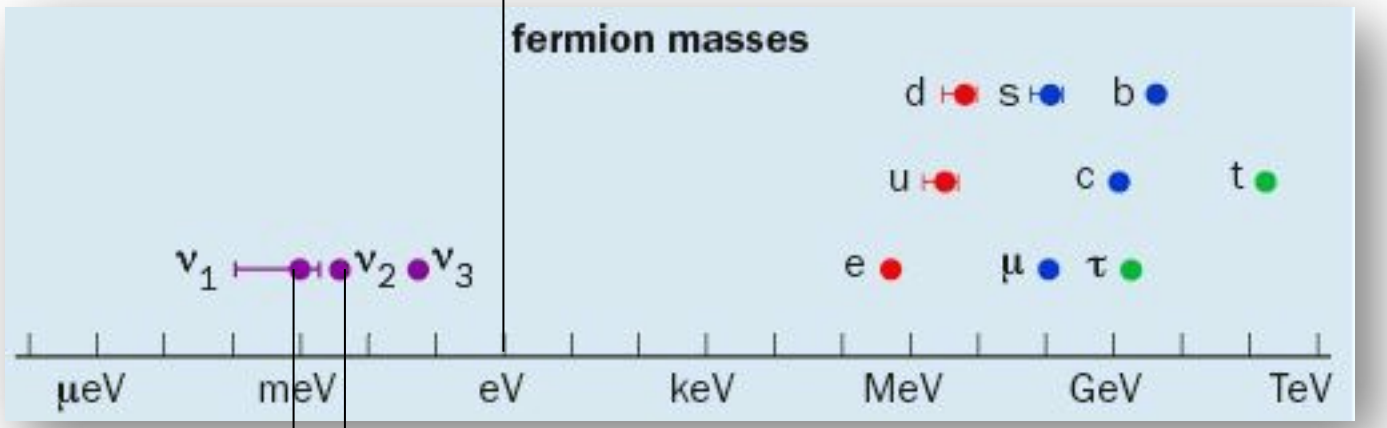


Lower bound
from oscillation experiments

Neutrinos



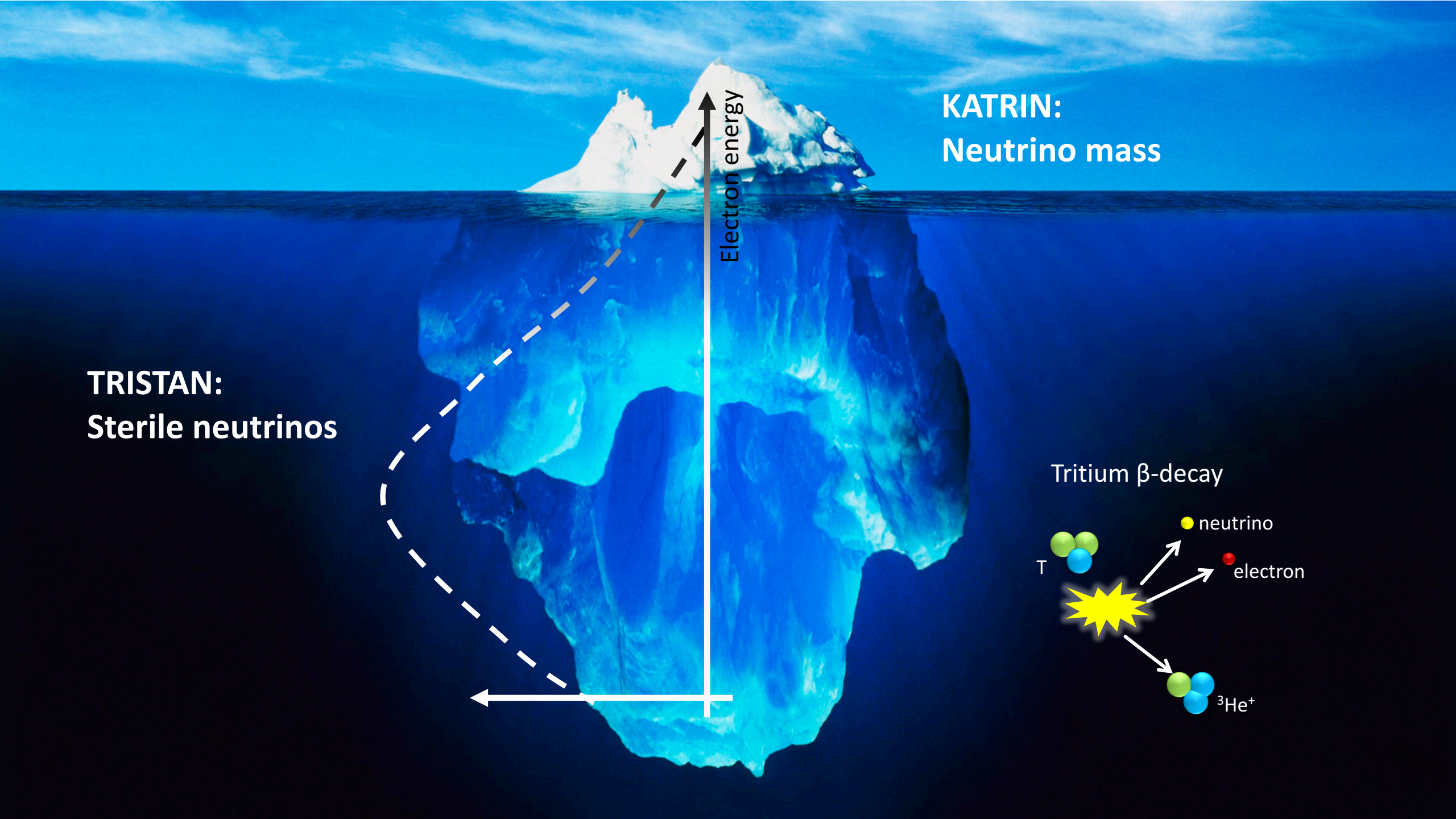
Upper bound
from direct measurements



Lower bound
from oscillation experiments

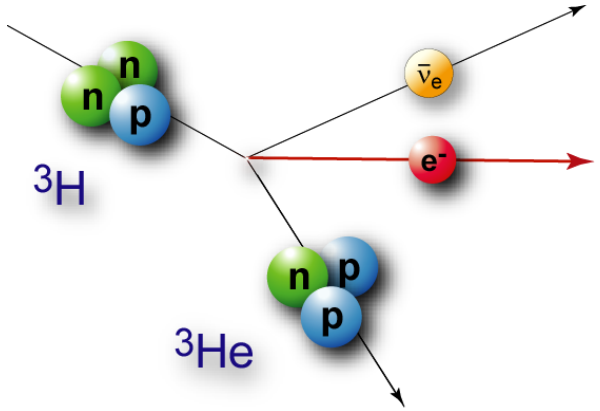
How light
am I?

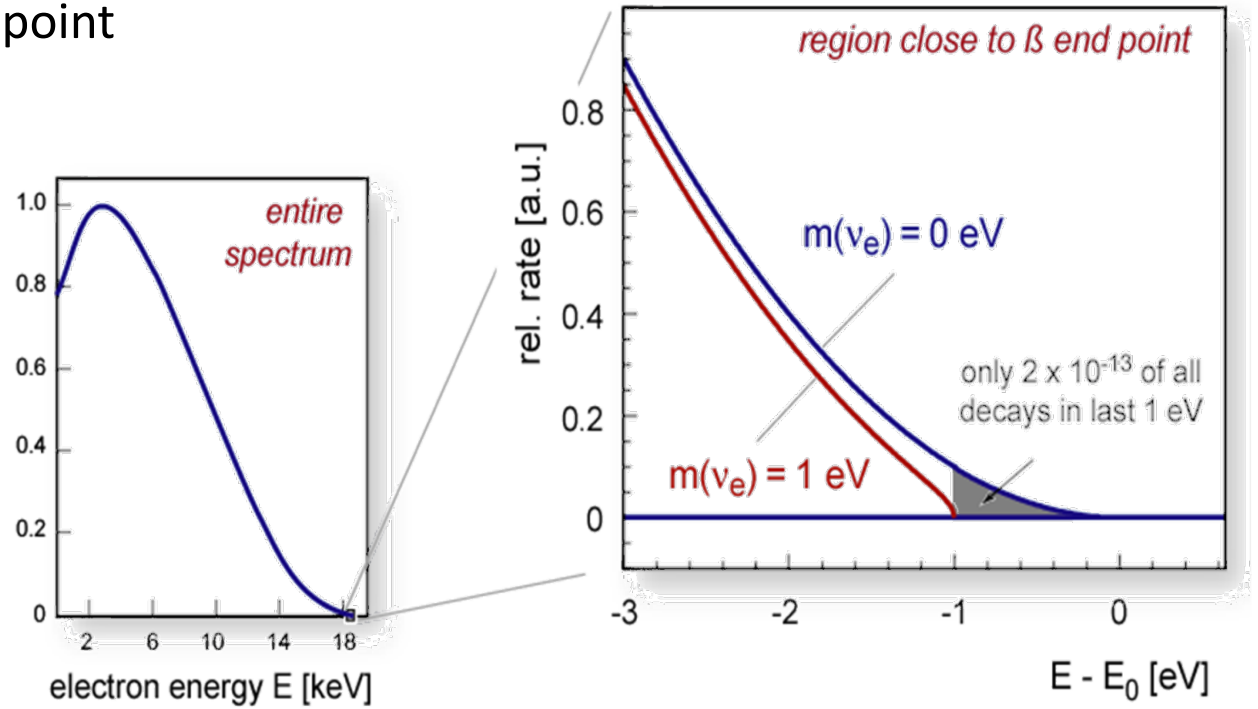
Do I have a
heavier
brother?


KATRIN:
Neutrino mass
TRISTAN:
Sterile neutrinos
Electron energy
Tritium β-decay
T
neutrino
electron
$^3He^+$

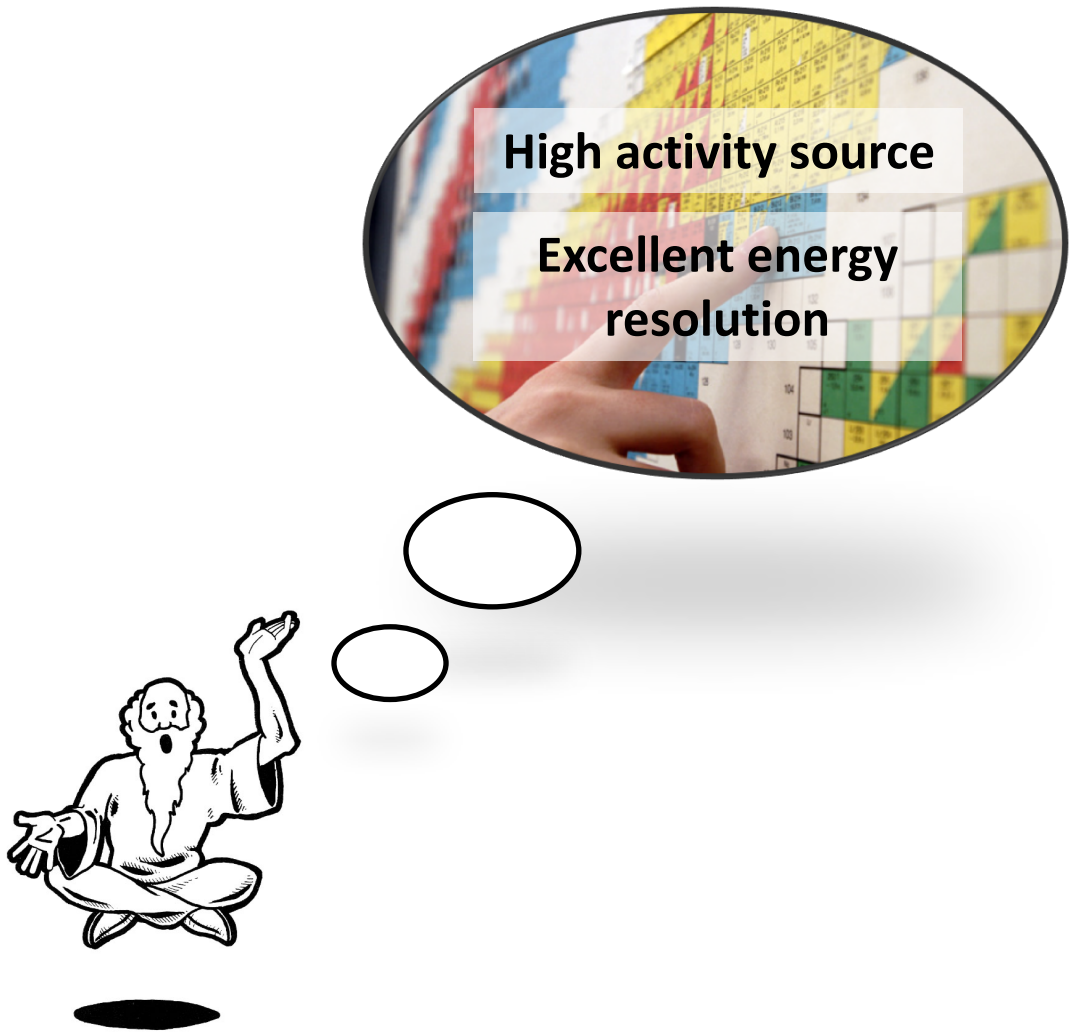
The Idea

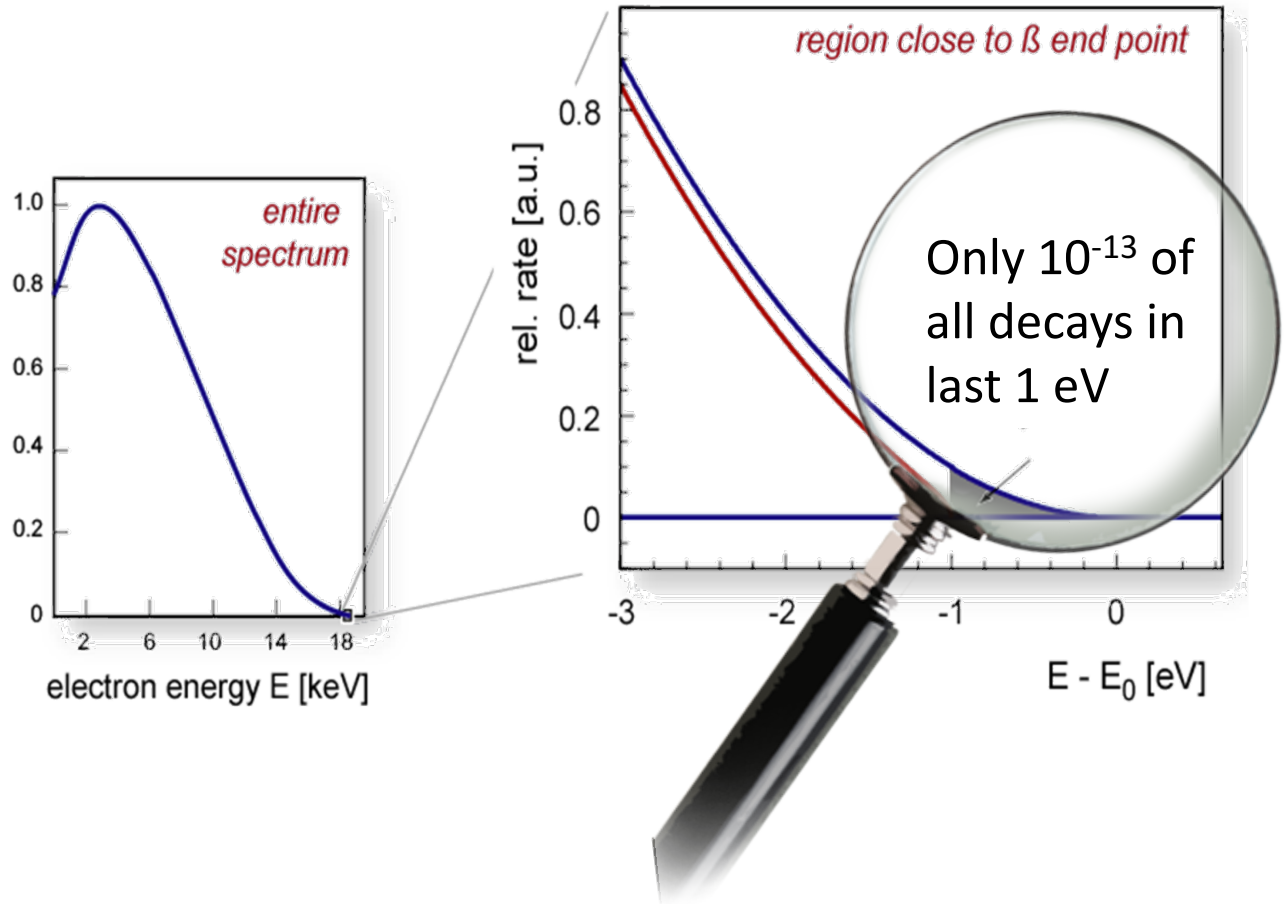
- Kinematics of β-decay
- Non-zero neutrino mass reduces the endpoint and distorts the spectrum





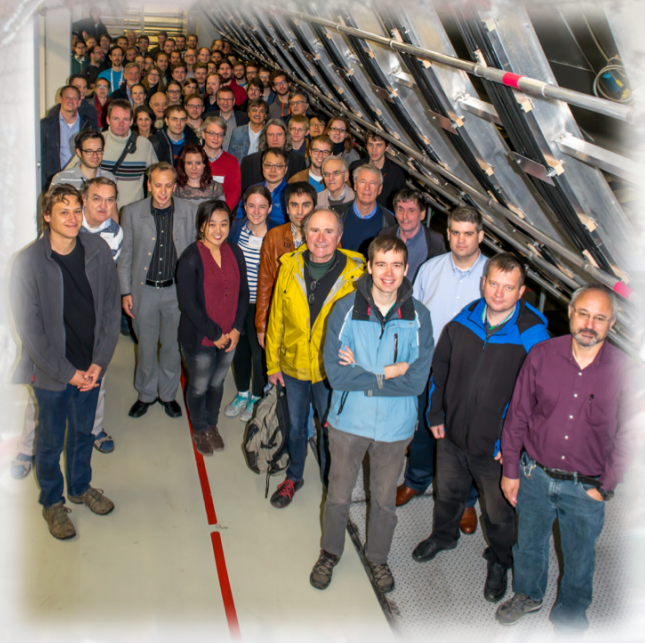
The Challenge






Karlsruhe Tritium Neutrino
KATRIN Experiment

Karlsruhe Tritium Neutrino
KATRIN Experiment

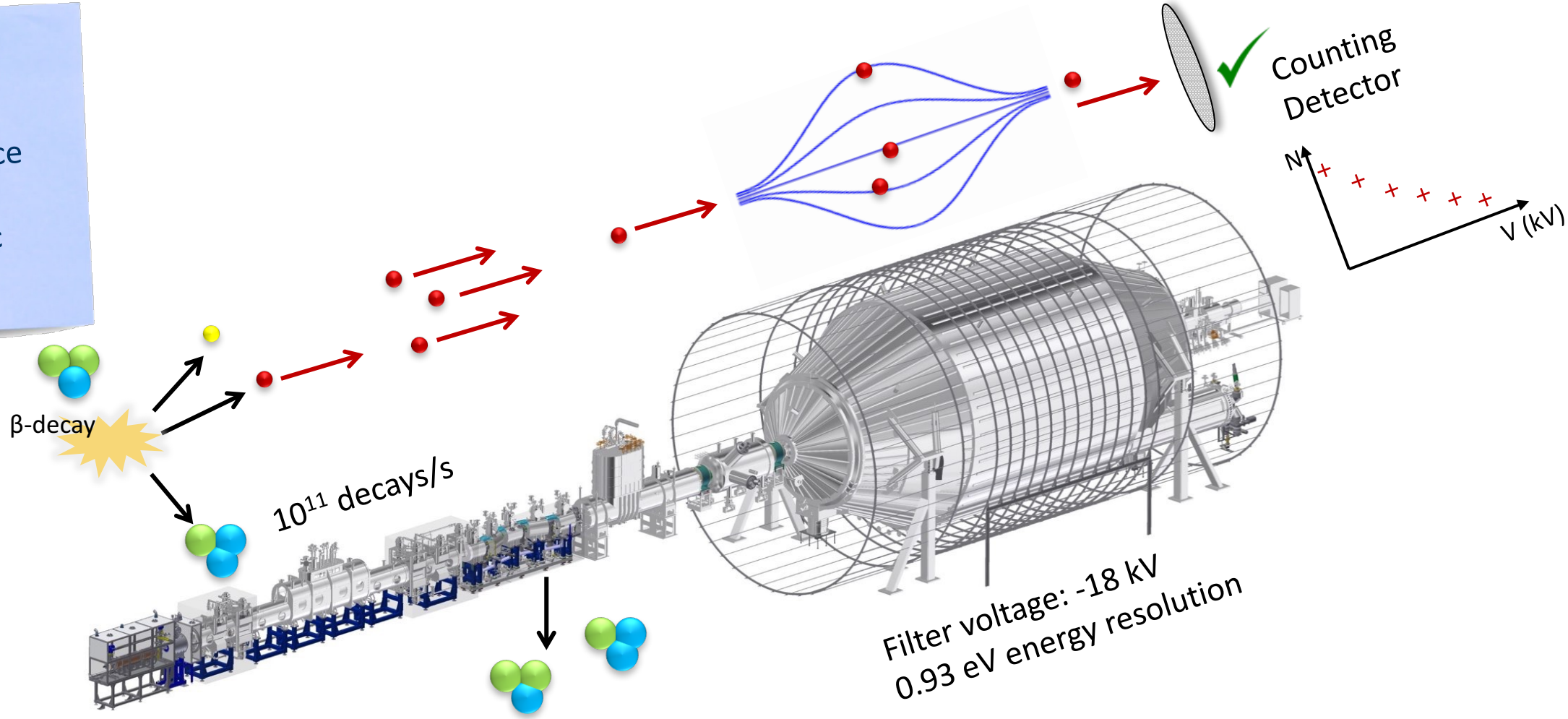


- Experimental site: Karlsruhe Institute of Technology (KIT)
- International Collaboration (150 members)
- Design sensitivity 200 meV (90% CL) after 3 net-years

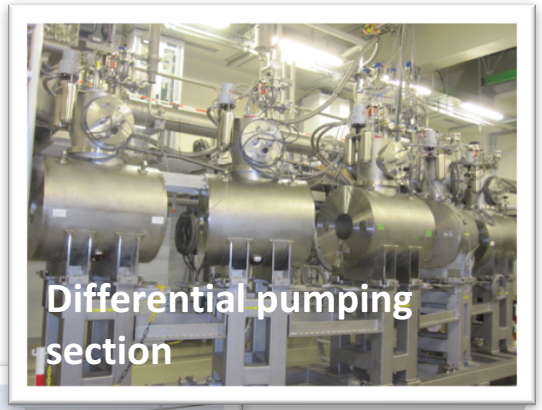
KIT Karlsruher Institut für Technologie
Max-Planck-Institut für Kernphysik Heidelberg
University of Washington
Case Western Reserve University EST. 1826 think beyond the possible
Westfälische Wilhelms-Universität Münster
Massachusetts Institute of Technology
The University of North Carolina at Chapel Hill
The Czech Academy of Sciences
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)
cea
Carnegie Mellon University Pittsburgh Pennsylvania 1900
Universidad Complutense Madrid
Russian Academy of Sciences
JGU Johannes Gutenberg Universität Mainz
universitätbonn
Technische Universität München
Hochschule Fulda University of Applied Sciences
Bergische Universität Wuppertal
Berkeley Lab

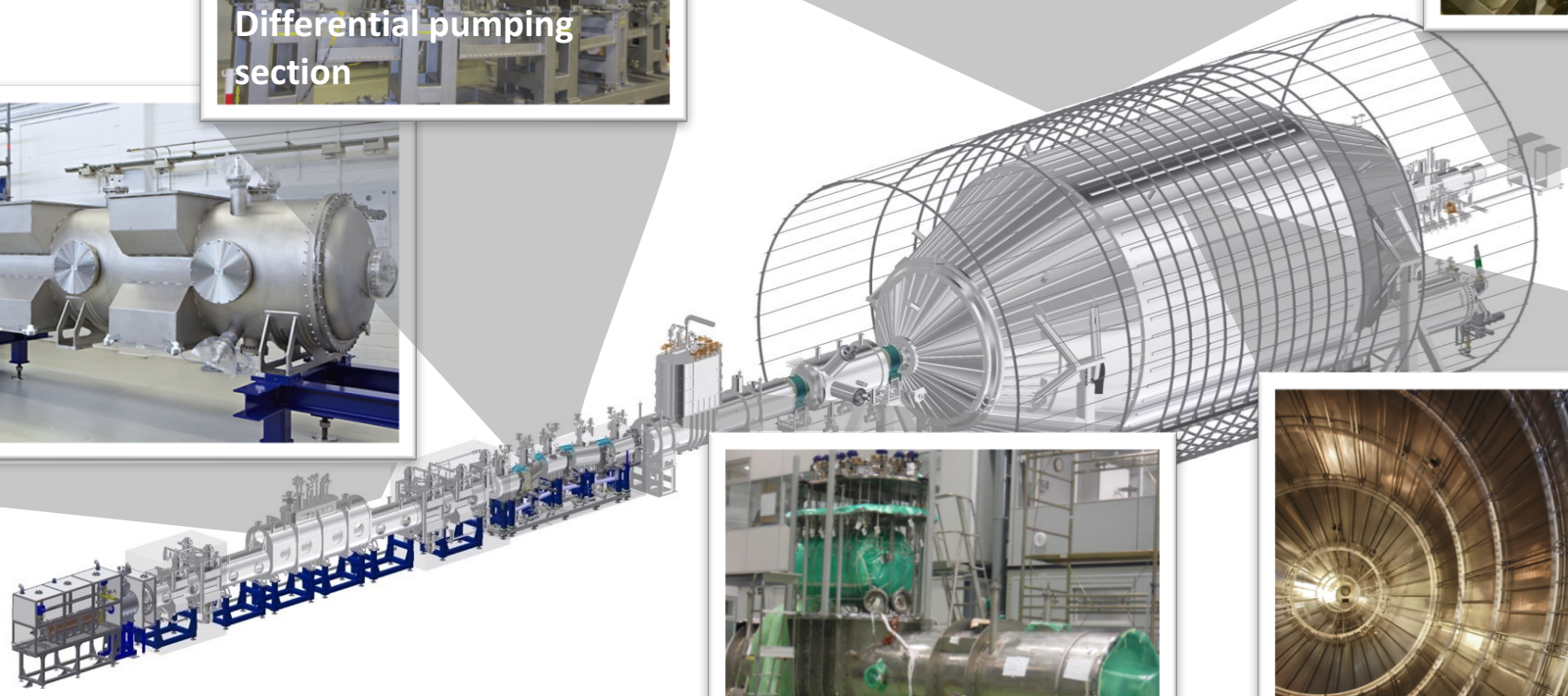
KATRIN Working Principle

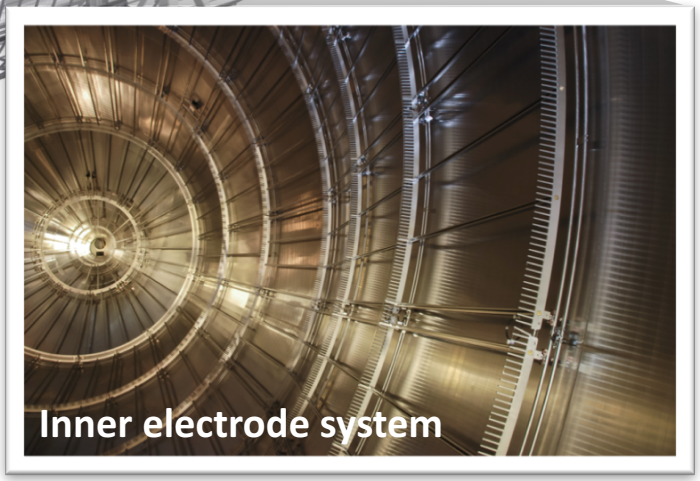
- Ultra-high luminosity tritium source
- Sharp electrostatic filter



KATRIN Status



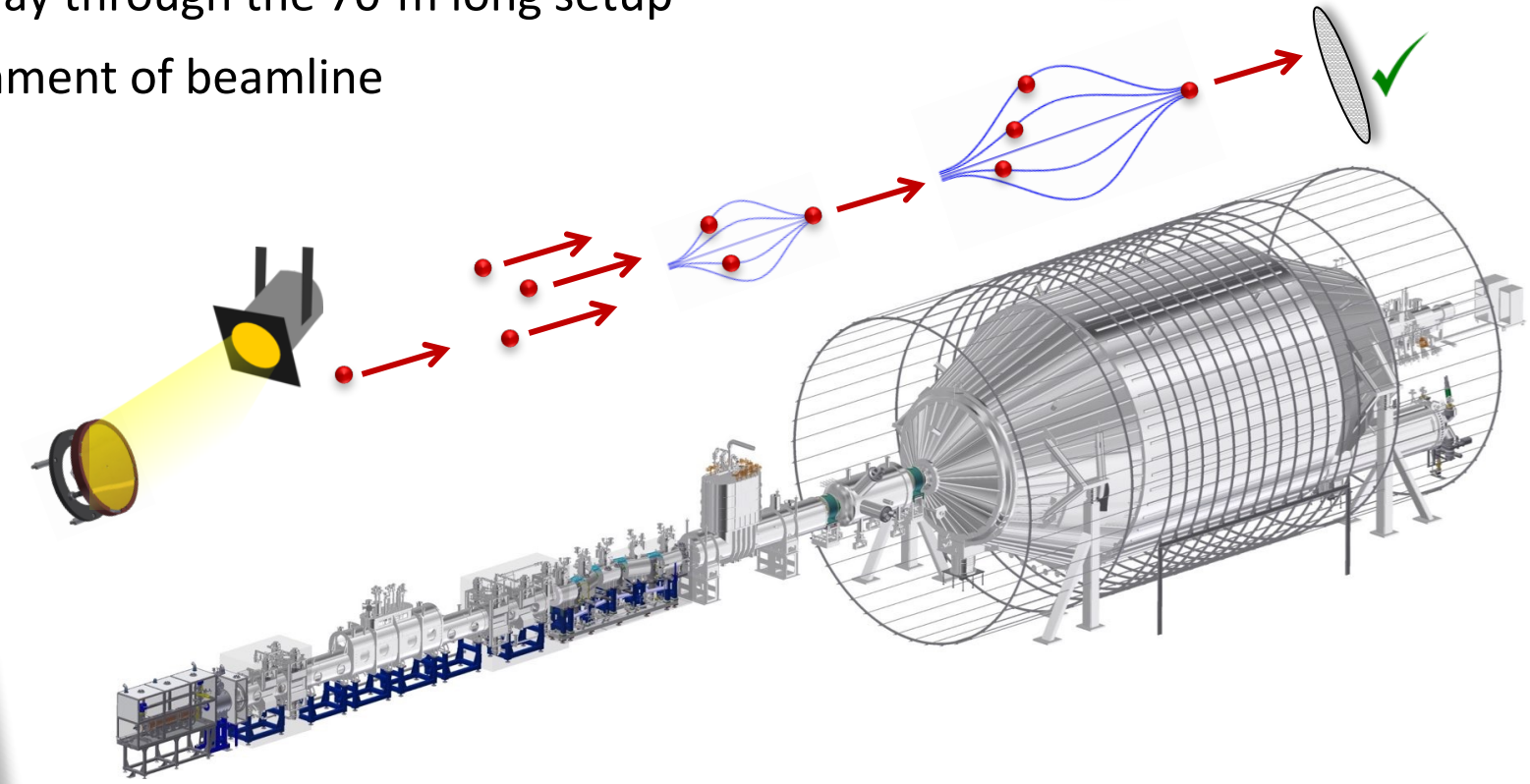




KATRIN all, *J. Instrum.*, 11, 2016

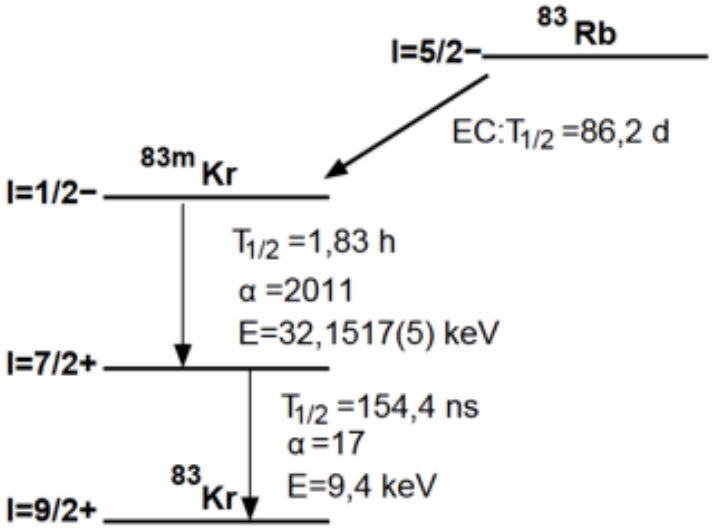
KATRIN's first light: October 2016

- The first electrons found their way through the 70-m long setup
- First promising results, e.g. alignment of beamline

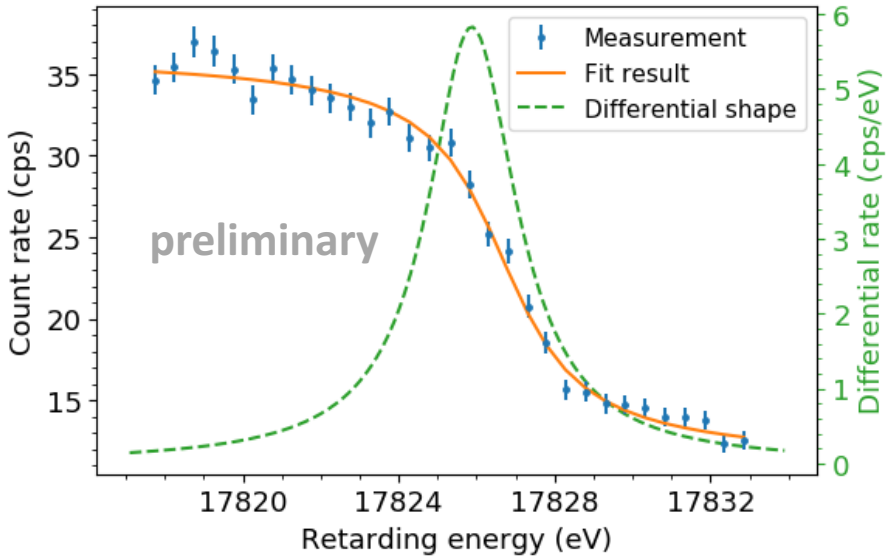


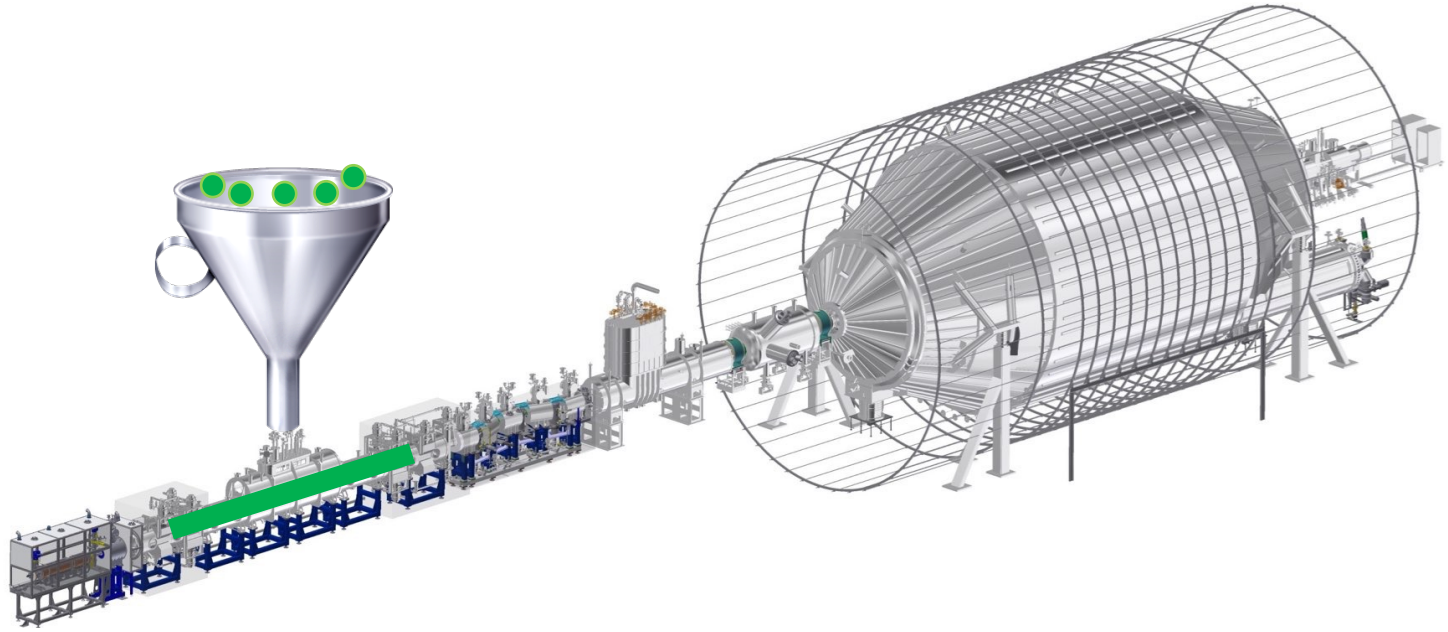
KATRIN's first run: July 2017

- Calibration with gaseous and condensed krypton sources
- Test of full beamline, excellent energy resolution



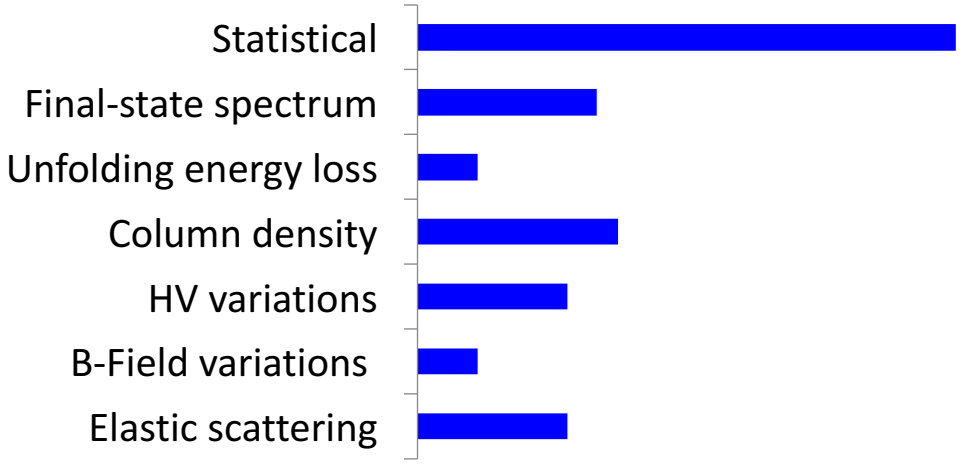
K-32 line (17.8 keV)

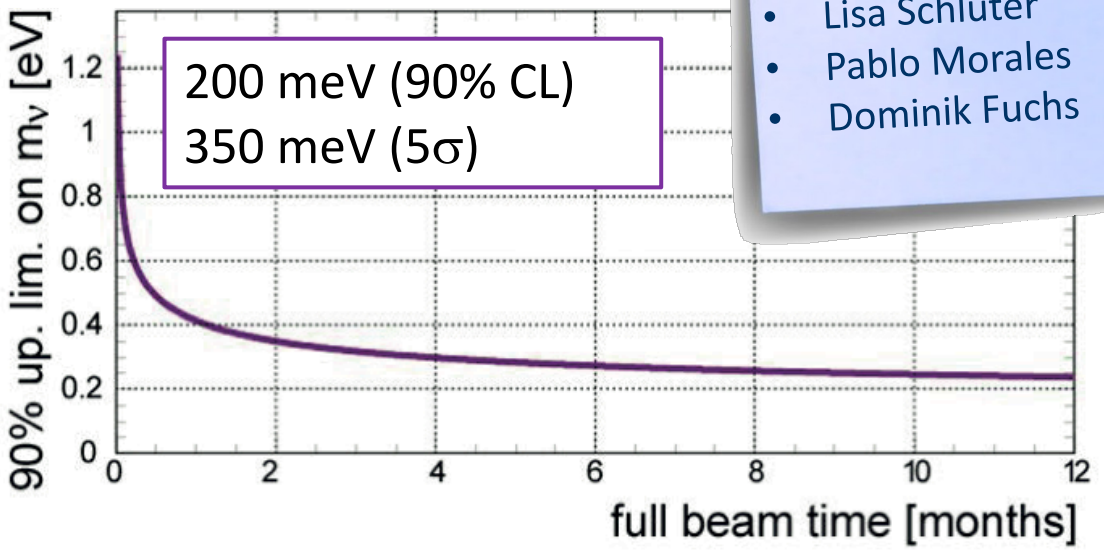




Paper in preparation (lead by M. Slezak, MPP)

KATRIN's first tritium: May 2018





- Martin Slezak (Postdoc)
- Frank Edzards (PhD)
- Anna Pollithy (PhD)
- Thierry Lasserre (Mercator)
- Christian Karl
- Lisa Schlüter
- Pablo Morales
- Dominik Fuchs

- MPP group: Getting analysis tools and strategy ready for the first data !
- After 3 yrs of data (5 calendar yrs): balance of statistics and systematics

m_ν extraction

MC Generator

BAT analysis tool

KATRIN's first tritium: May 2018

- Martin Slezak (Postdoc)
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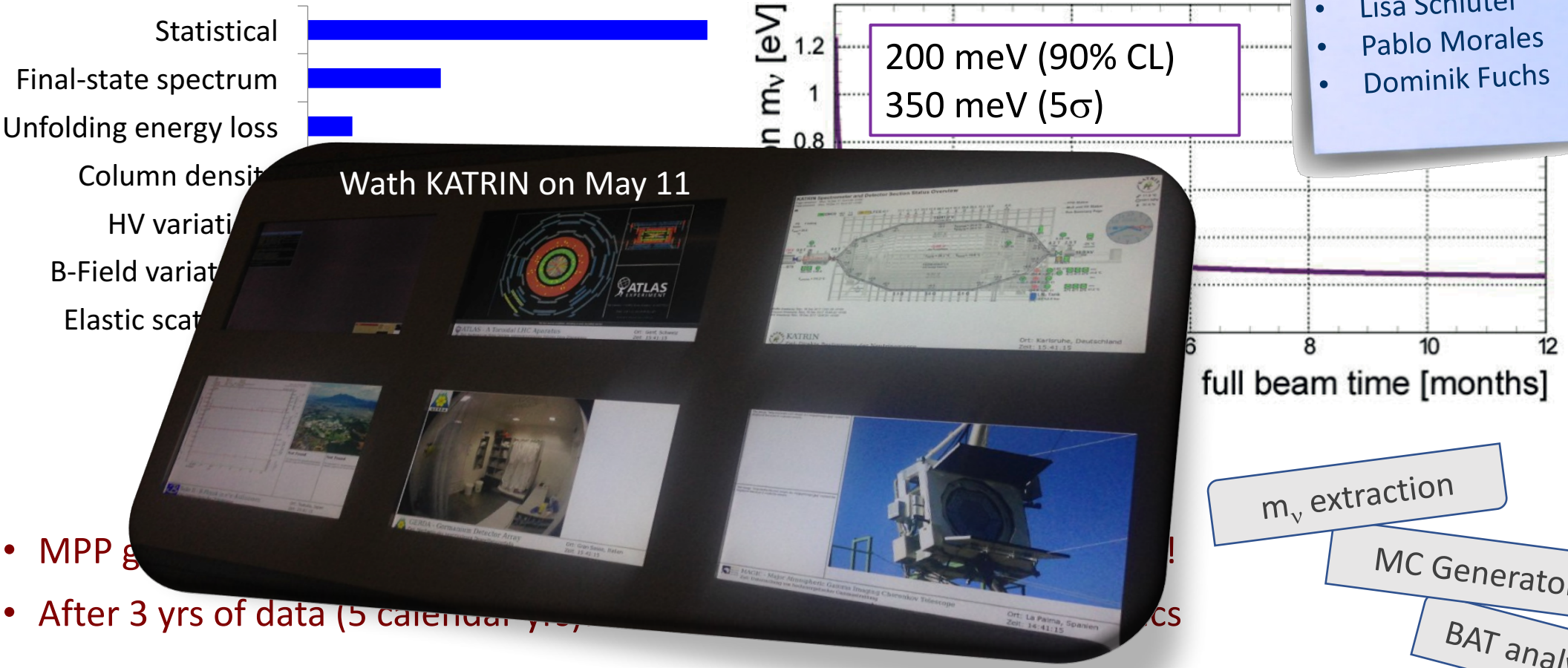


- MPP g !
- After 3 yrs of data (5 calendar yrs) cs

m_ν extraction

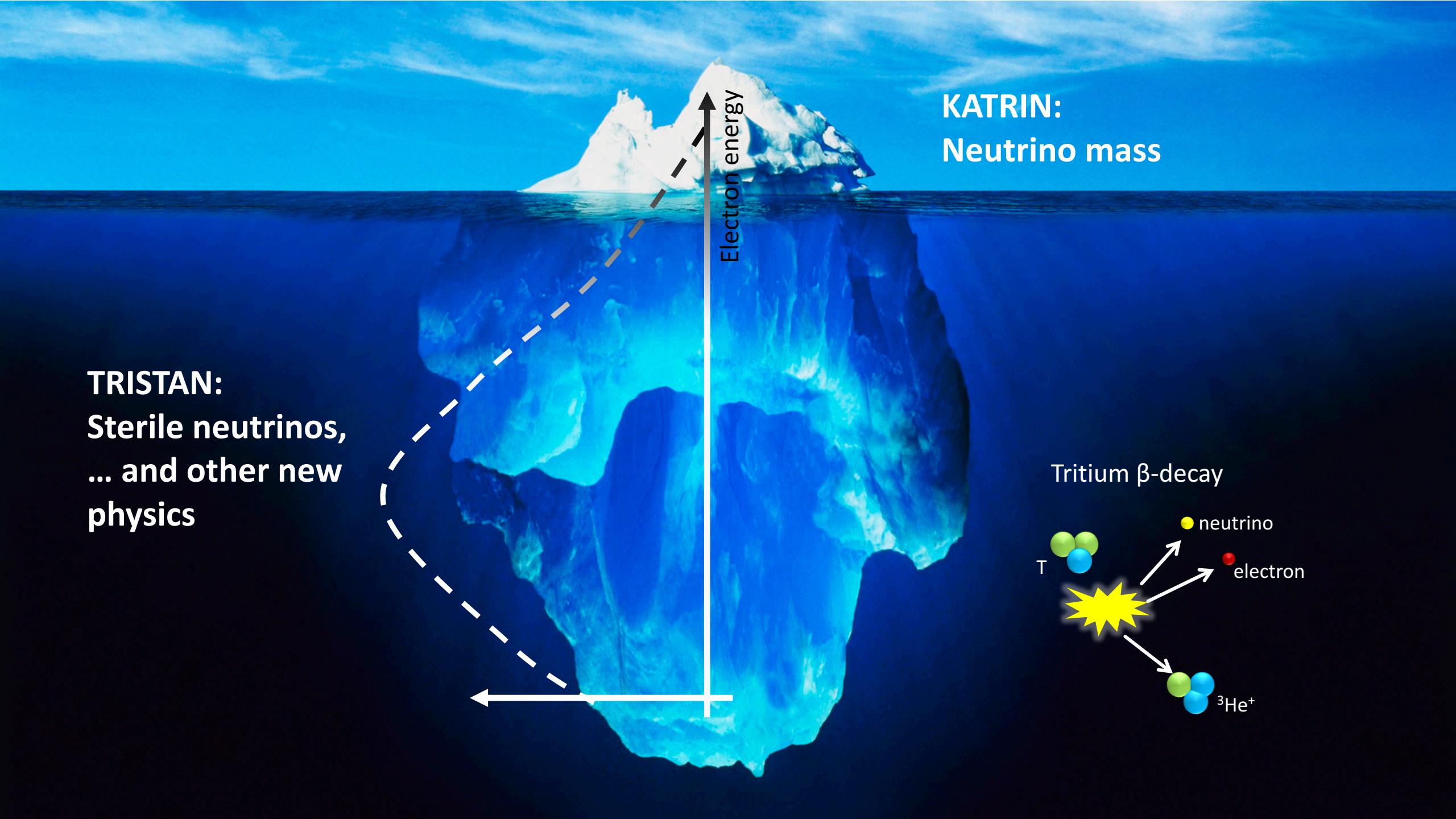
MC Generator

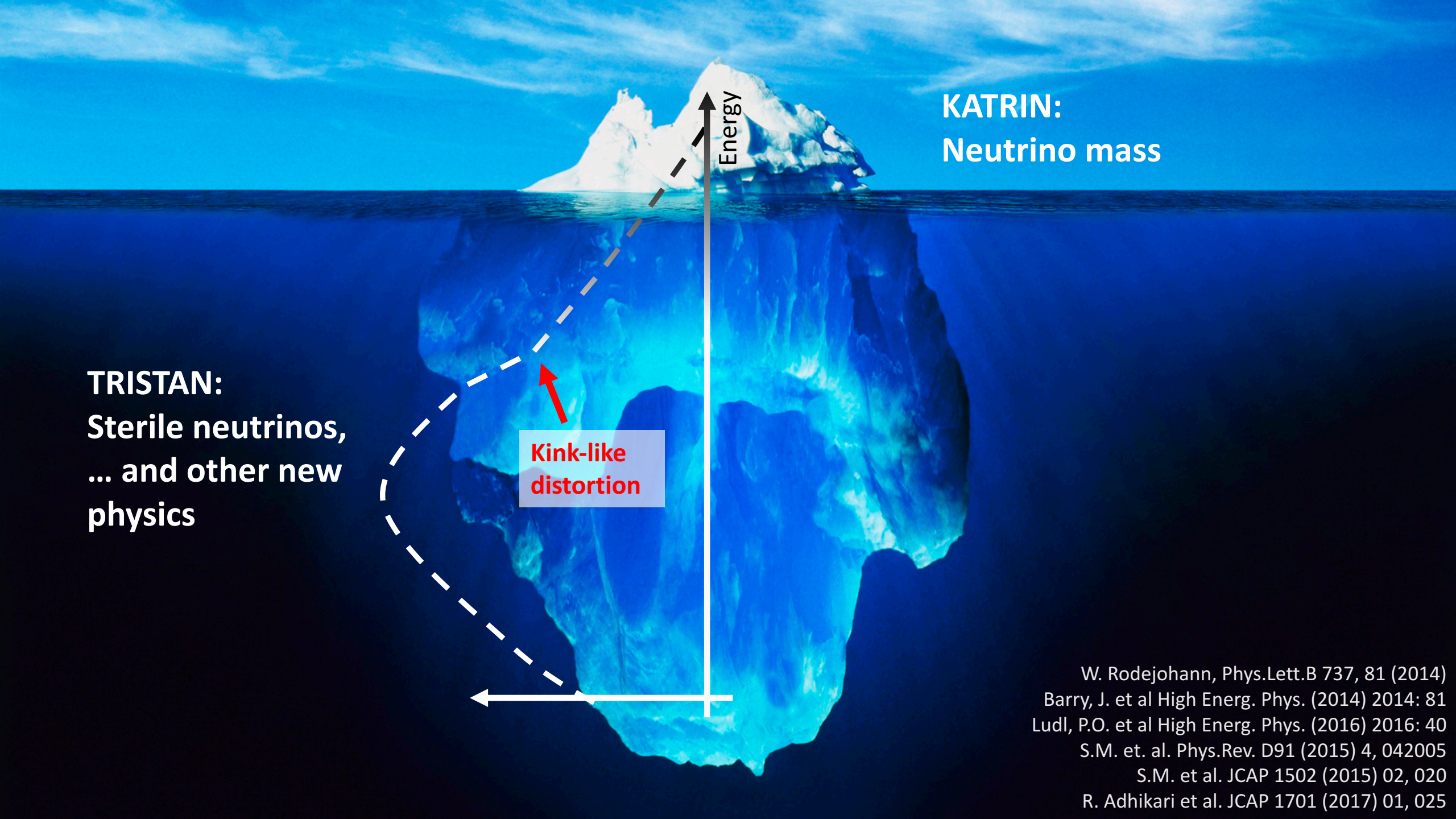
BAT analysis tool

New Project: TRISTAN

TRISTAN meeting November 2 – 3, 2017
~30 participants
KIT, Politecnico and Bicocca Milano, Oak Ridge, CEA

TRISTAN:
Tritium Beta Decay to Search for Sterile Neutrinos


KATRIN:
Neutrino mass
Electron energy
TRISTAN:
Sterile neutrinos,
… and other new
physics
Tritium β-decay
T
neutrino
electron
$^3He^+$



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

Active neutrinos

Sterile neutrinos

Sterile Neutrinos

Heavy sterile neutrinos (> GeV)

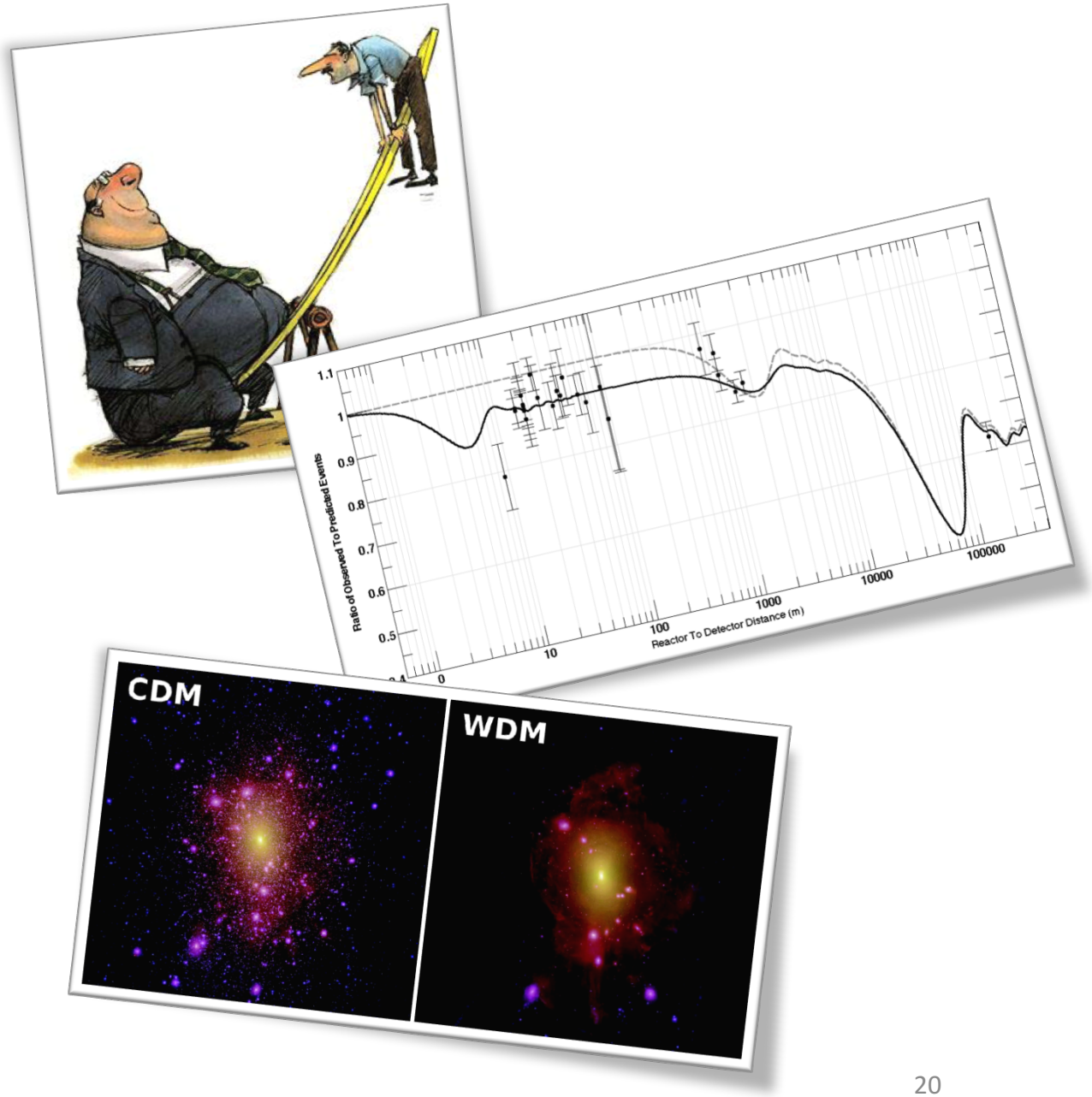
- Lightness of neutrinos
  + Matter/Anti-matter asymmetry

Light sterile neutrinos (~1 eV)

- Short-baseline neutrino oscillation anomalies

KeV-scale sterile neutrinos (~ 1 - 50 keV)

- Dark matter candidate



Sterile Neutrinos

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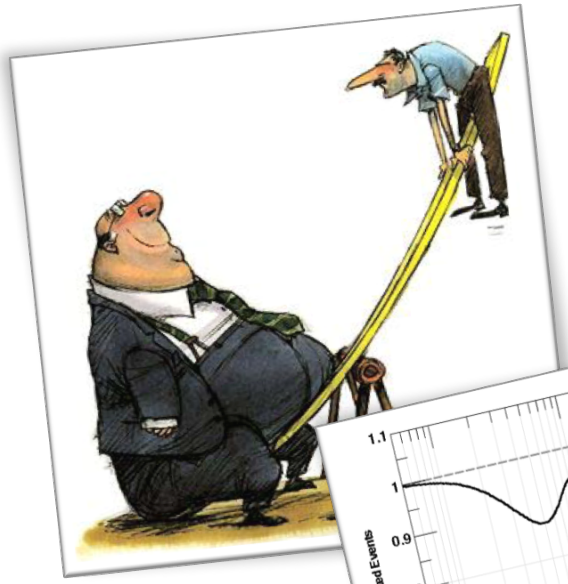
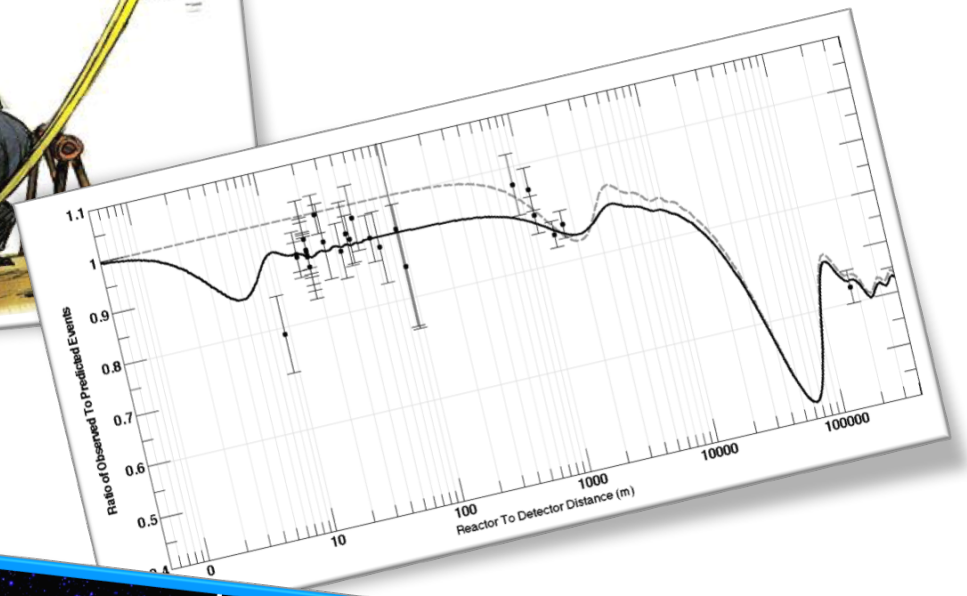
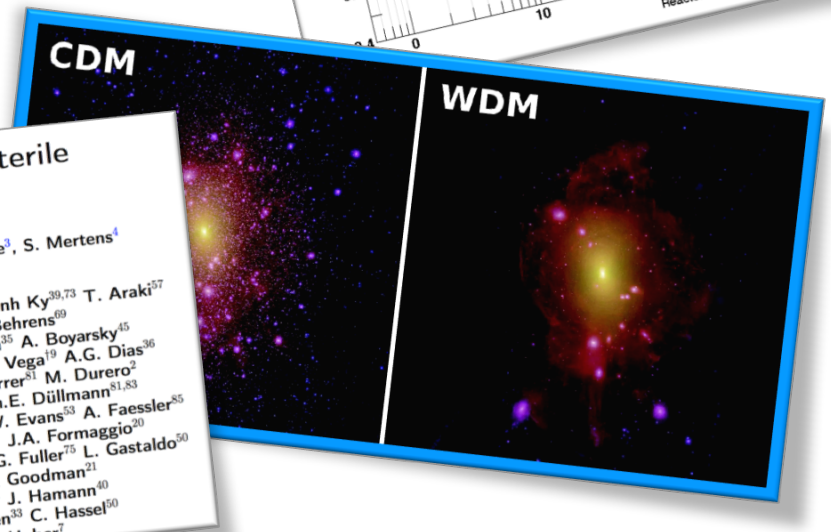
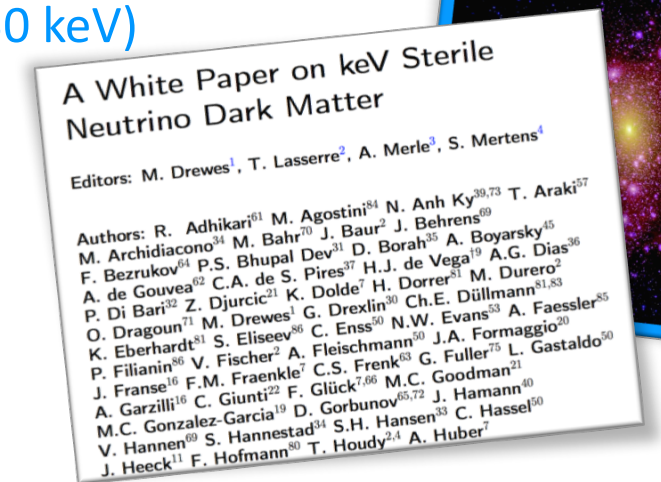
➢ Goal of TRISTAN









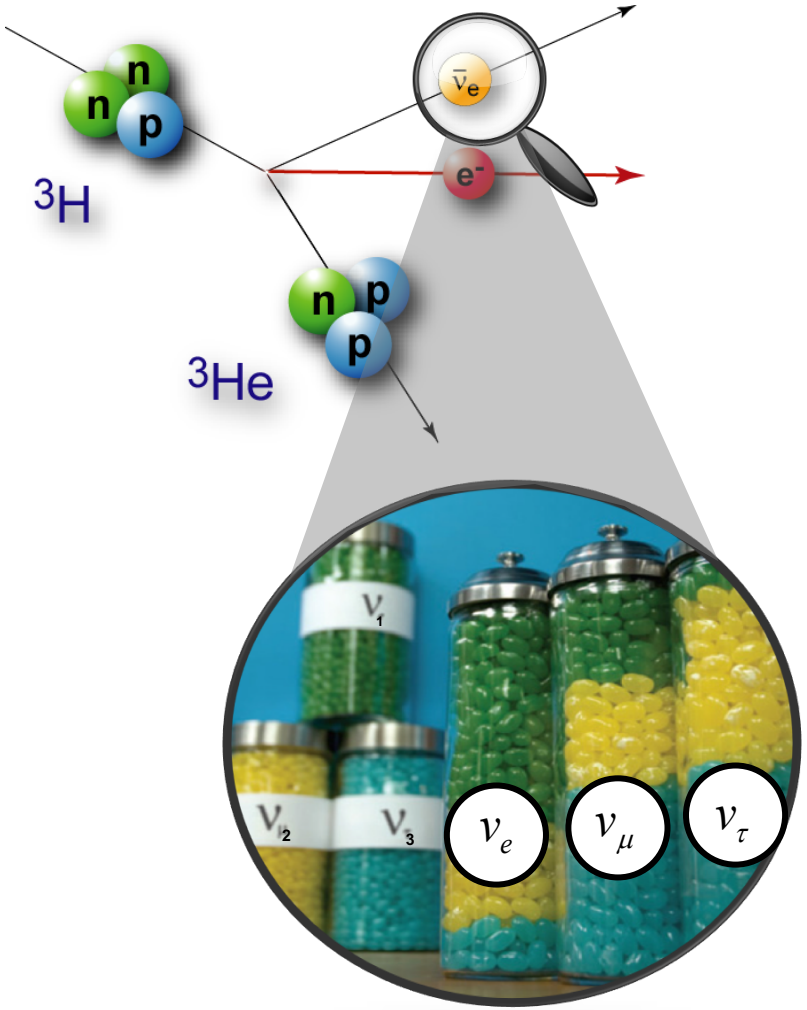
A White Paper on keV Sterile Neutrino Dark Matter

Editors: M. Drewes[1], T. Lasserre[2], A. Merle[3], S. Mertens[4]

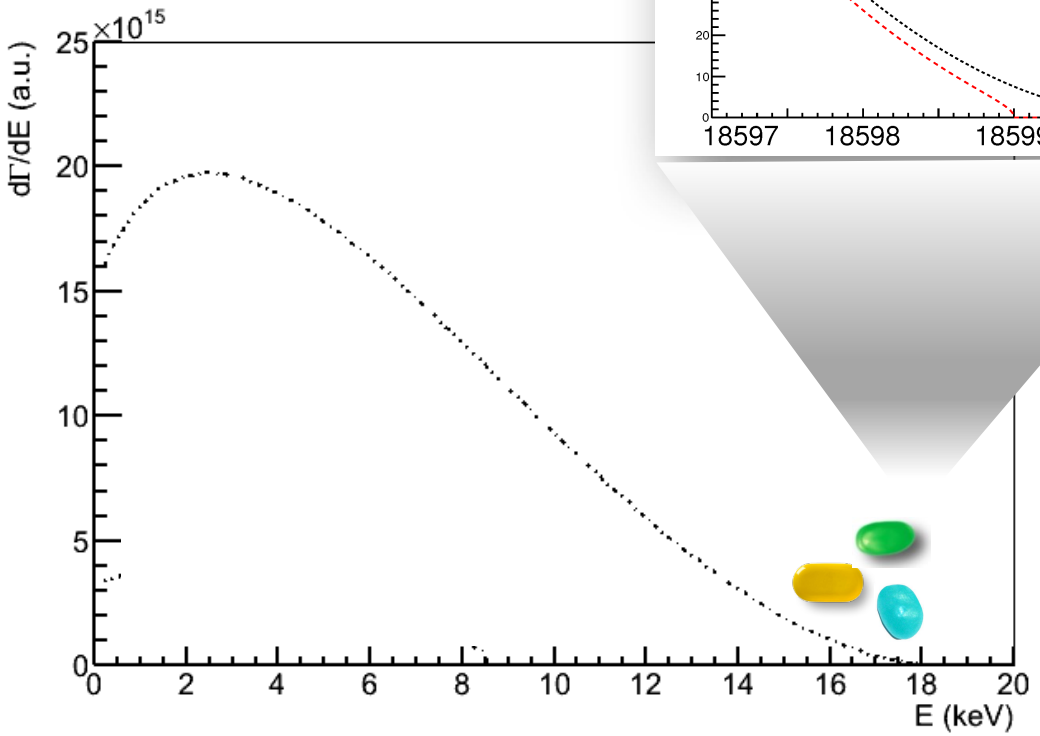
Authors: R. Adhikari[61] M. Agostini[84] N. Anh Ky[39,73] T. Araki[57] M. Archidiacono[34] M. Bahr[70] J. Baur[2] J. Behrens[69] F. Bezrukov[64] P.S. Bhupal Dev[31] D. Borah[35] A. Boyarsky[45] A. de Gouvea[62] C.A. de S. Pires[37] H.J. de Vega[19] A.G. Dias[36] P. Di Bari[32] Z. Djurcic[21] K. Dolde[7] H. Dorrer[81] M. Durero[2] O. Dragoun[71] M. Drewes[1] G. Drexlin[30] Ch.E. Düllmann[81,83] K. Eberhardt[81] S. Eliseev[86] C. Enss[50] N.W. Evans[53] A. Faessler[85] P. Filianin[86] V. Fischer[2] A. Fleischmann[50] J.A. Formaggio[20] J. Franse[16] F.M. Fraenkle[7] C.S. Frenk[63] G. Fuller[75] L. Gastaldo[50] A. Garzilli[16] C. Giunti[22] F. Glück[7,66] M.C. Goodman[21] M.C. Gonzalez-Garcia[19] D. Gorbunov[65,72] J. Hamann[40] V. Hannen[69] S. Hannestad[34] S.H. Hansen[33] C. Hassel[50] J. Heeck[11] F. Hofmann[80] T. Houdy[2,4] A. Huber[7]

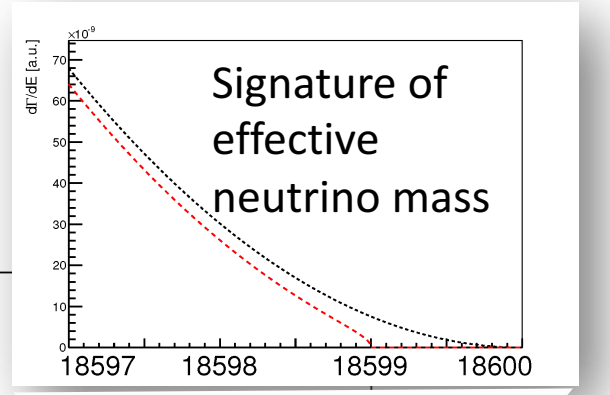
(JCAP 2017, 10.1088/1475-7516/2017/01/025)

Imprint of sterile ν‘s on ß-spectrum



$$m_\beta^2 = \sum_i |U_{ei}|^2 m_{\nu i}^2$$





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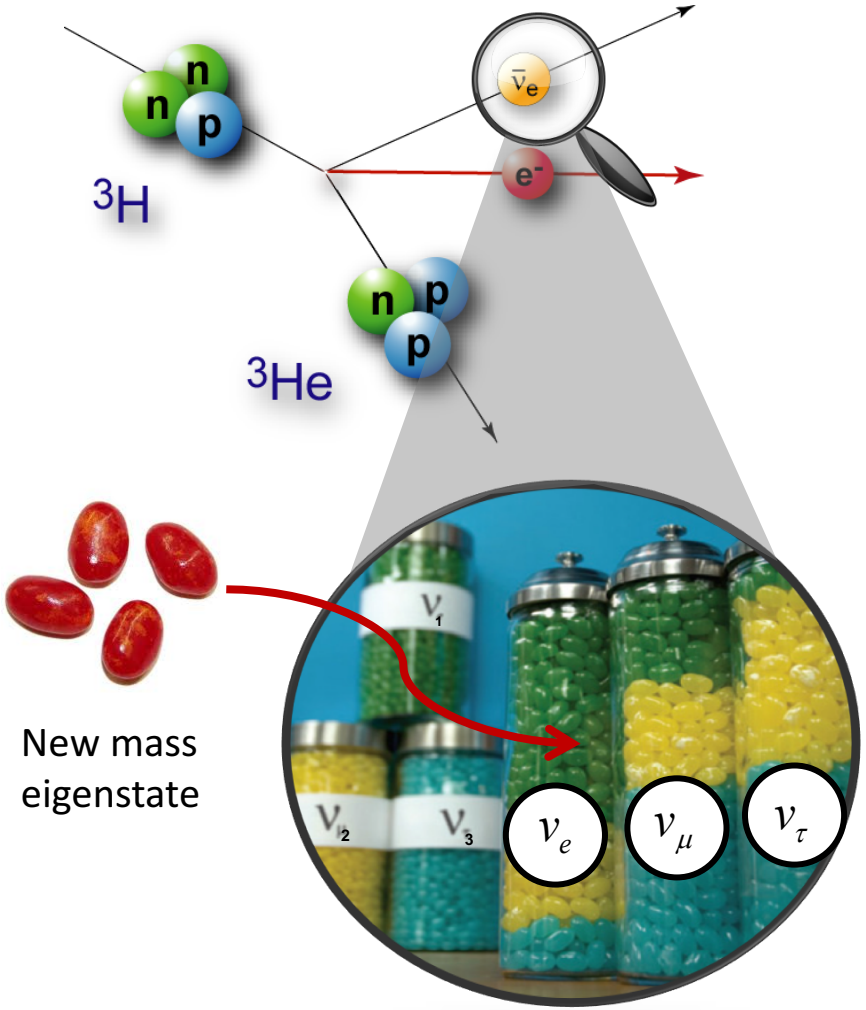
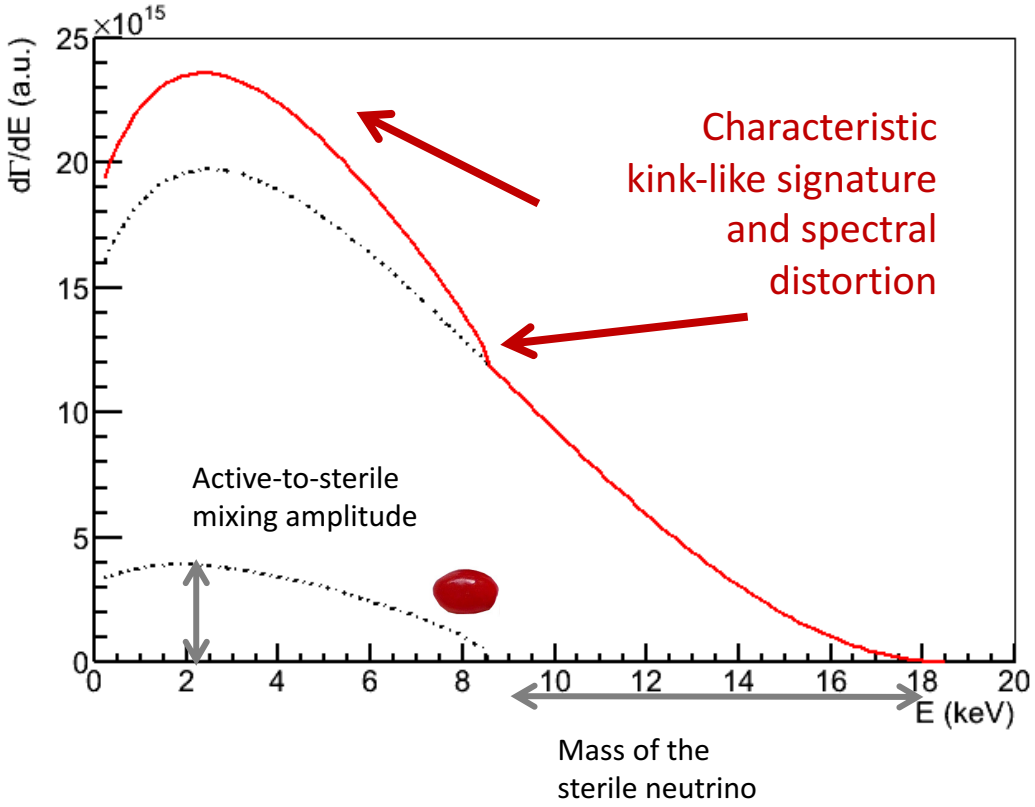
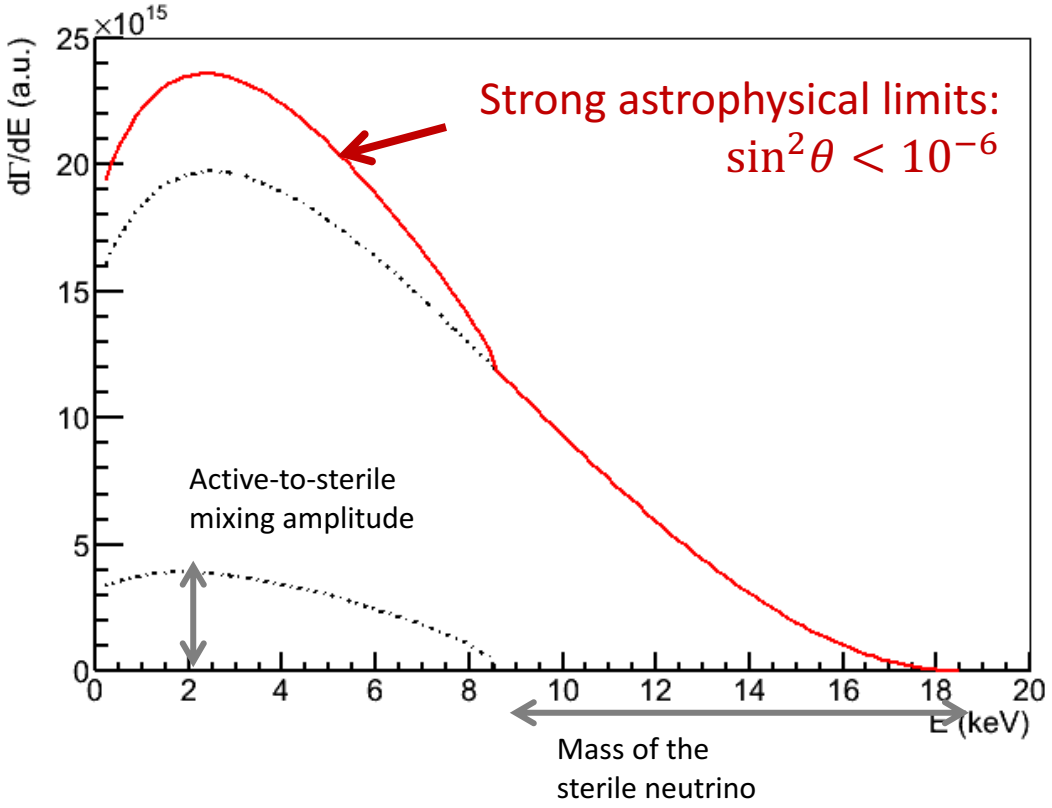


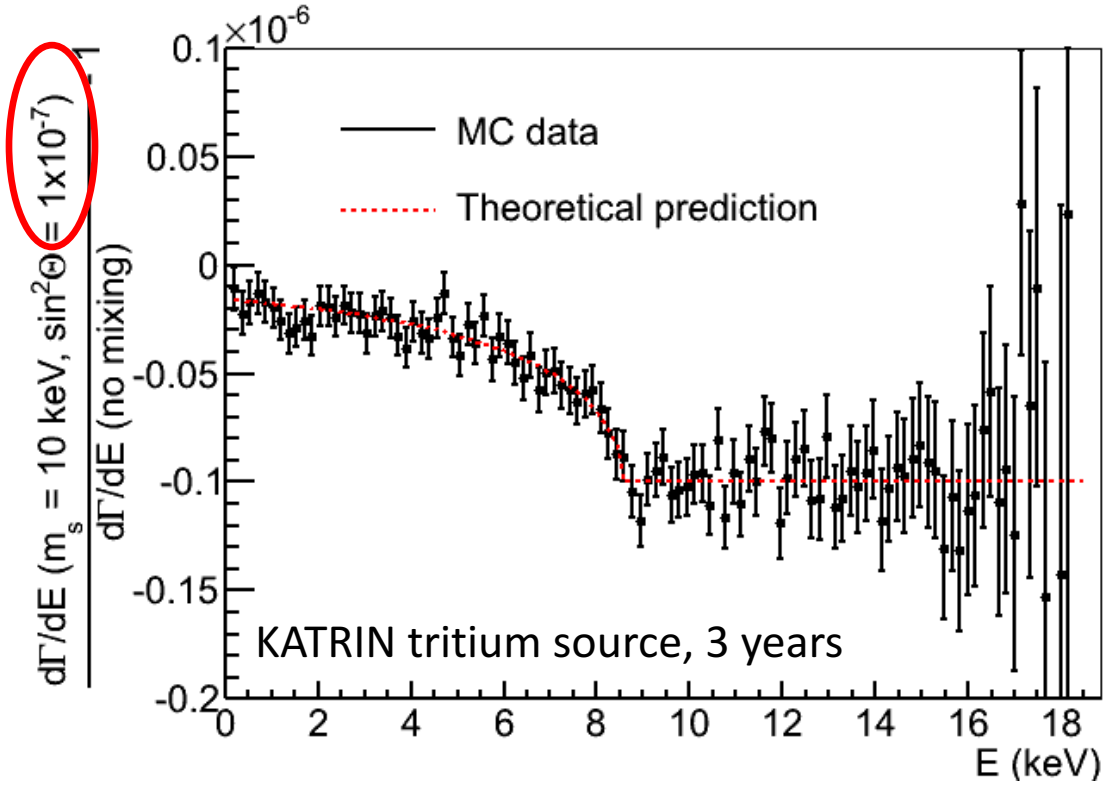
$$\frac{d\Gamma}{dE} = \cos^2\theta \frac{d\Gamma}{dE}(m_\beta) + \sin^2\theta \frac{d\Gamma}{dE}(m_s)$$



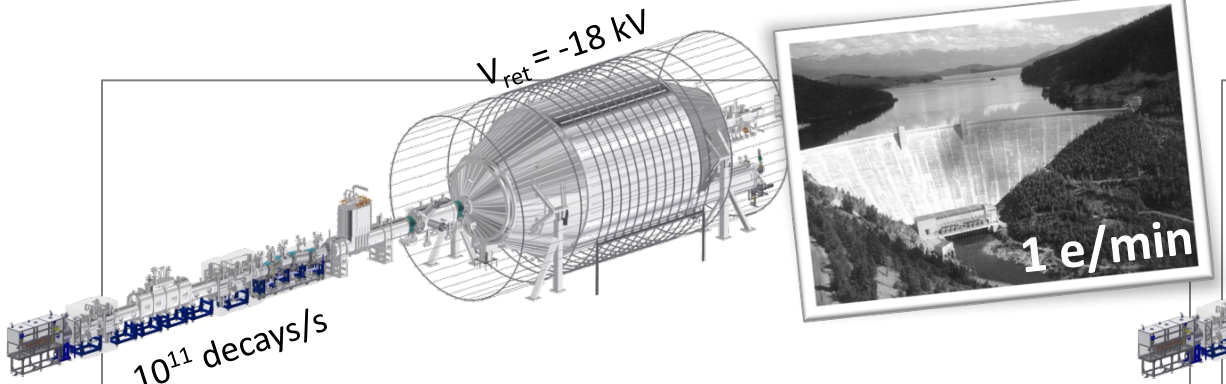
The Challenge (1)

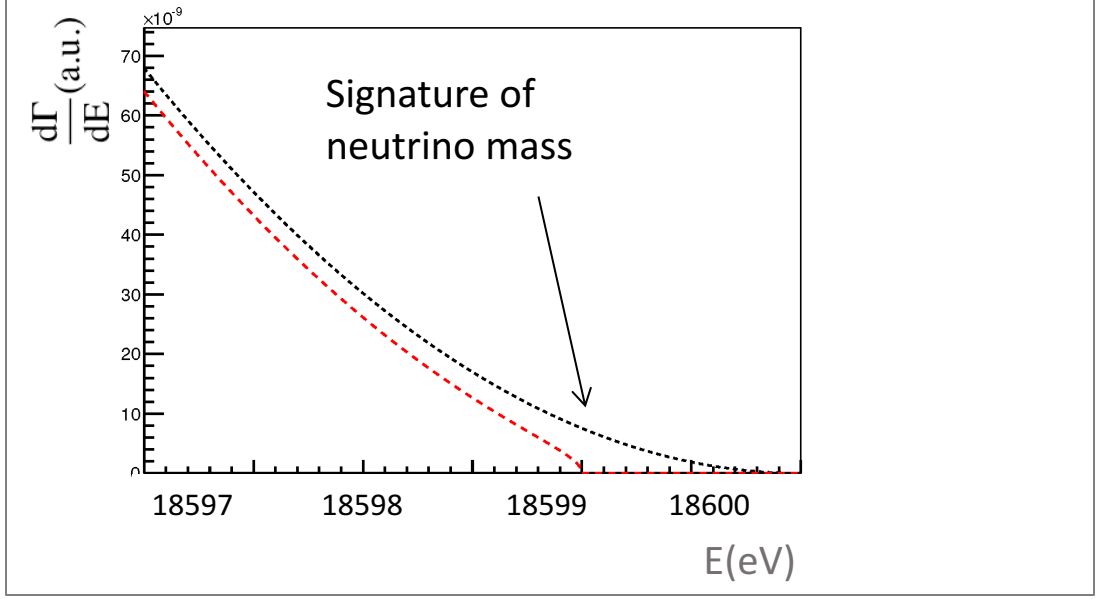
$$\frac{d\Gamma}{dE} = \cos^2\theta \frac{d\Gamma}{dE}(m_\beta) + \sin^2\theta \frac{d\Gamma}{dE}(m_s)$$

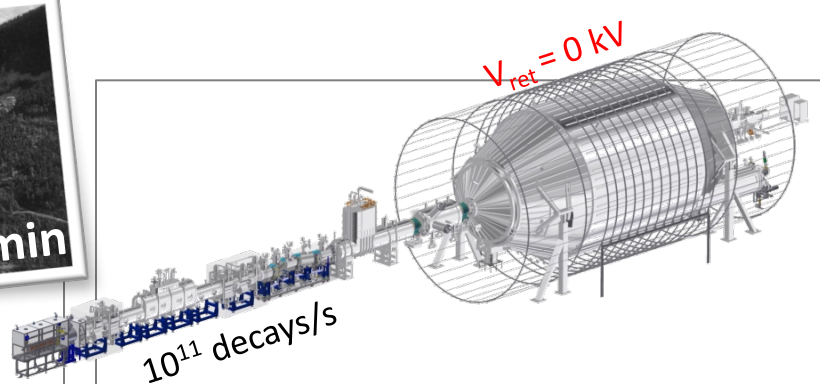




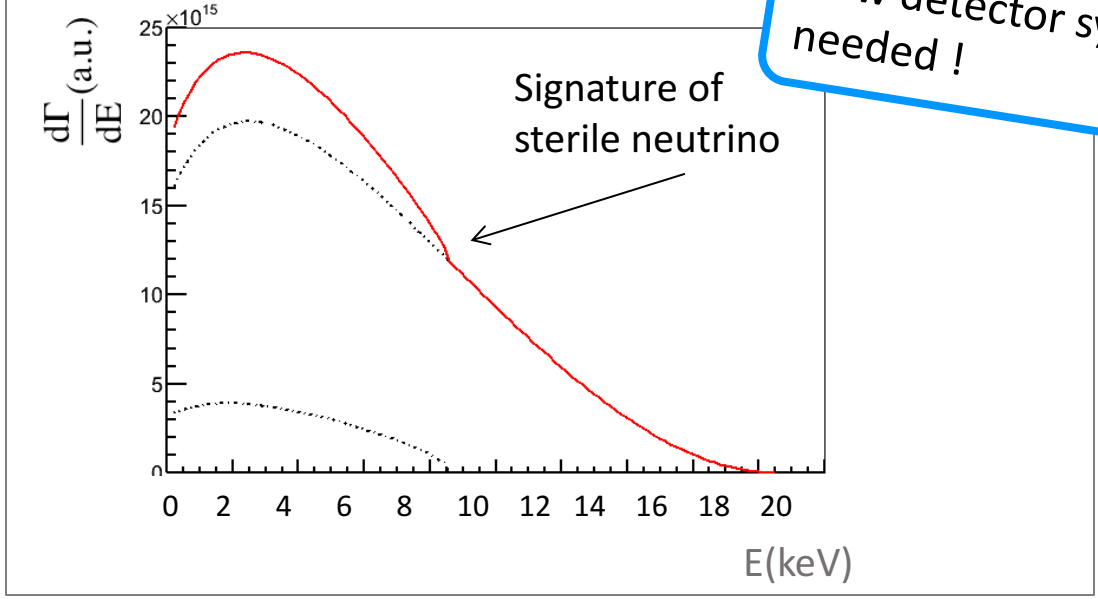
The Challenge (2)





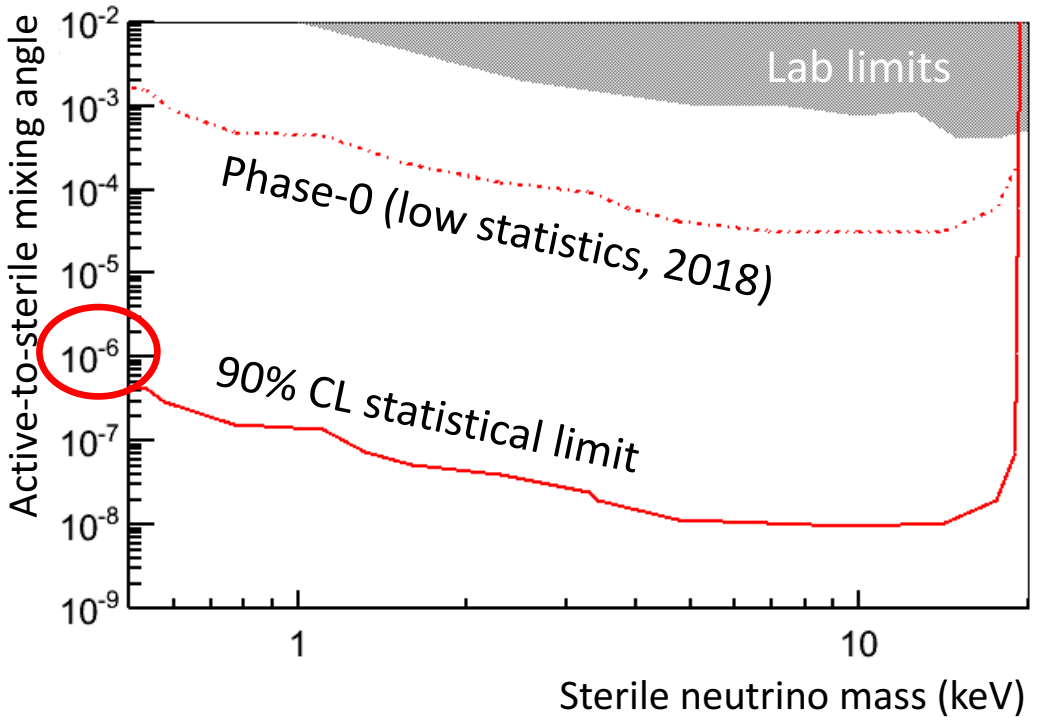


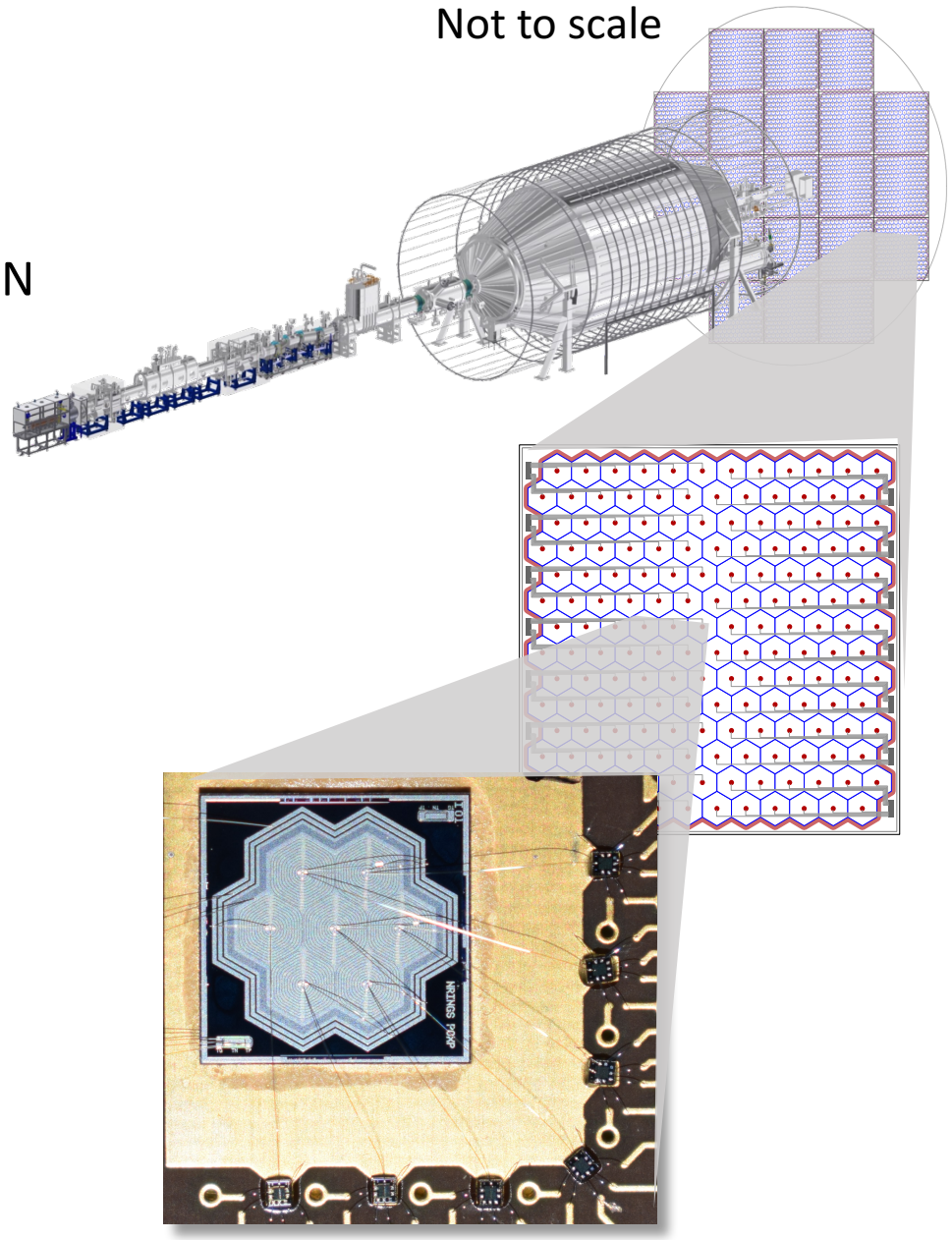
New detector system needed !



TRISTAN Project

- Multi-pixel Silicon Drift Detector (SDD) System for KATRIN
- FWHM ~ 200 eV @ keV energies @ high rates
  + thin entrance window



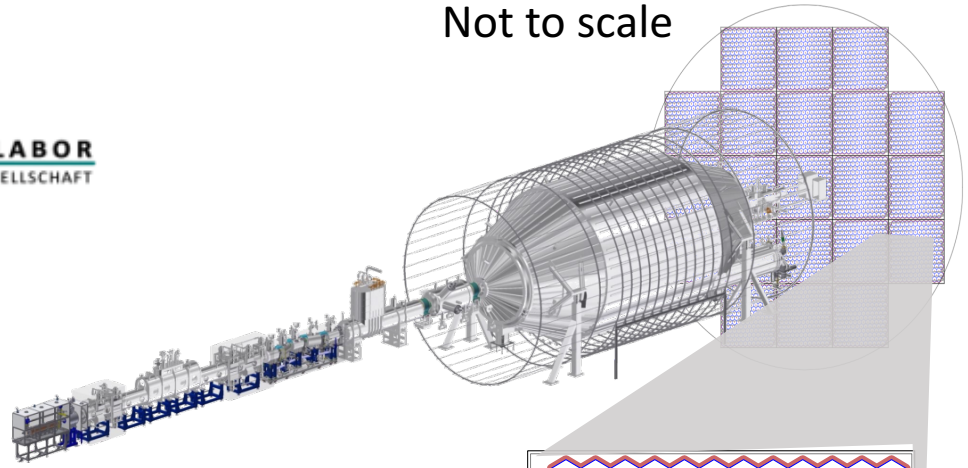


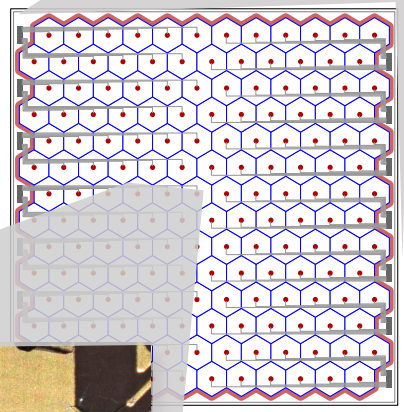
K. Dolde, S.M., D. Radford et. al. NIM-A 848 (2017)

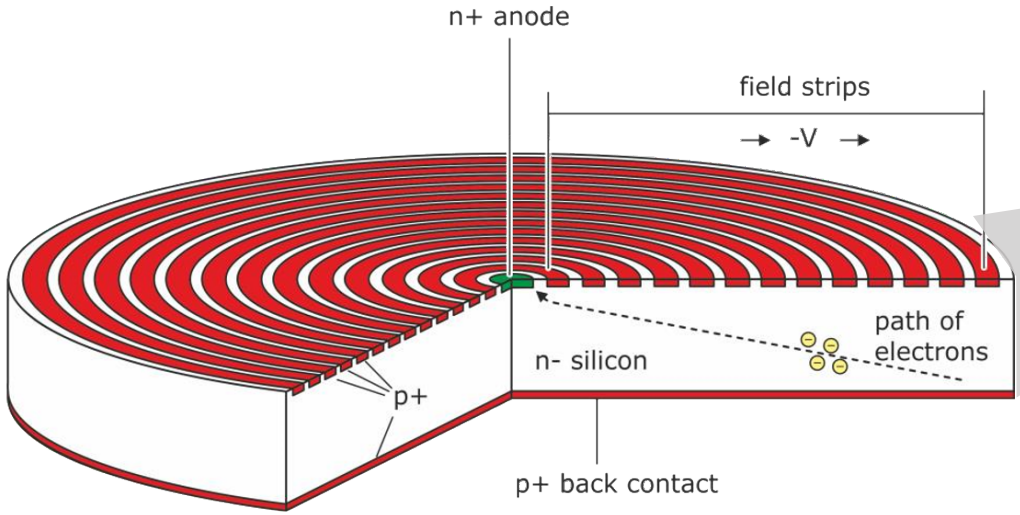
First Prototypes

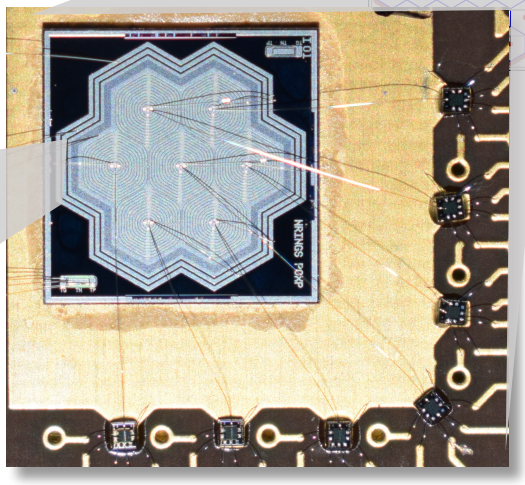
- 7-pixel prototype produced by Halbleiterlabor of the Max Planck Society (HLL)
  - Silicon Drift Detector Design (SDD)
  - Combined with thin deadlayer
  - Test different sizes, ring numbers

Not to scale







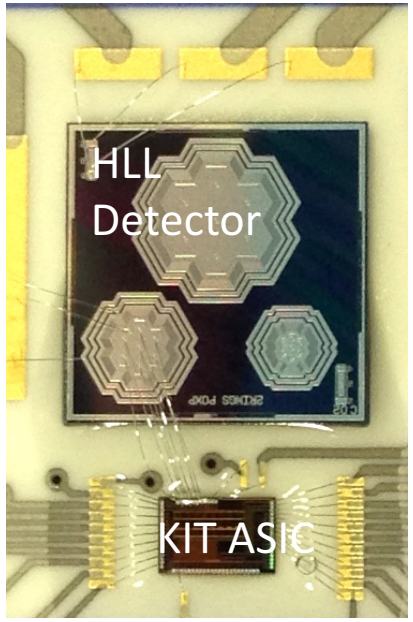


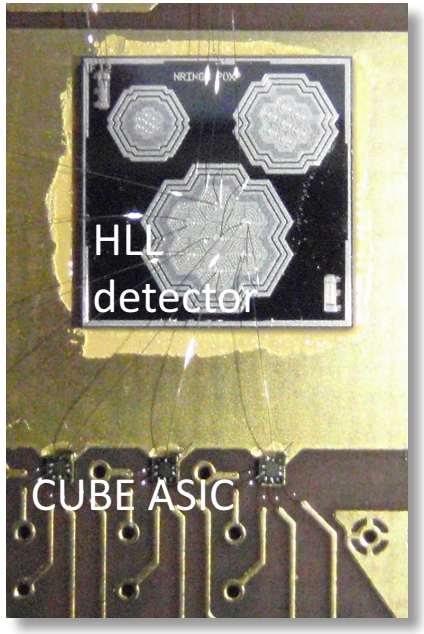
Prototype detector

First Prototypes

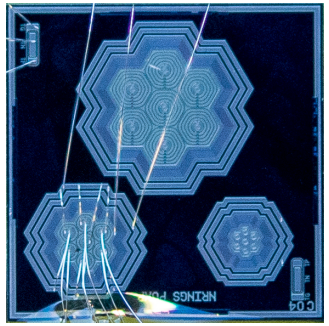
- 7-pixel prototype produced by Halbleiterlabor of the Max Planck Society (HLL)
  - Silicon Drift Detector Design (SDD)
  - Combined with thin deadlayer
  - Test different sizes, ring numbers

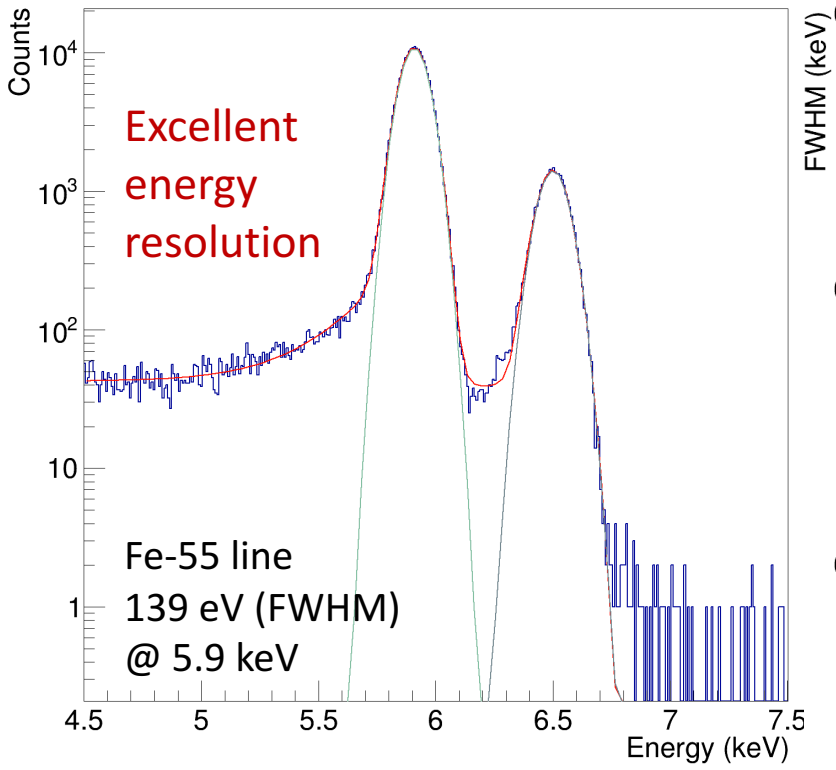
- Three running systems:
  - CEA, Saclay (IDEFIX ASIC)
  - XGLab, Milano (CUBE ASIC)
  - KIT, Karlsruhe (KIT ASIC)

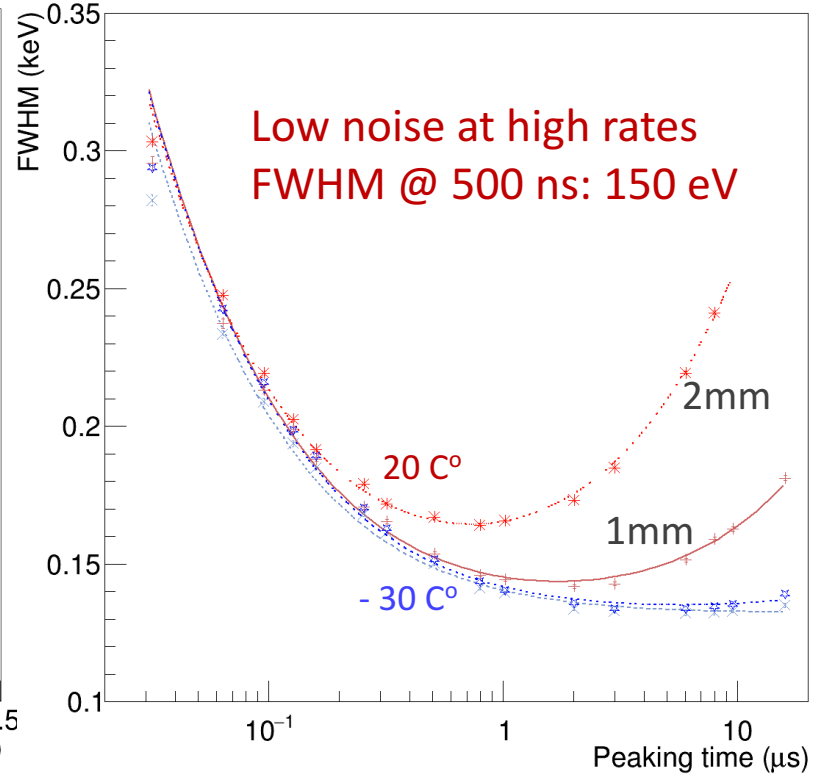


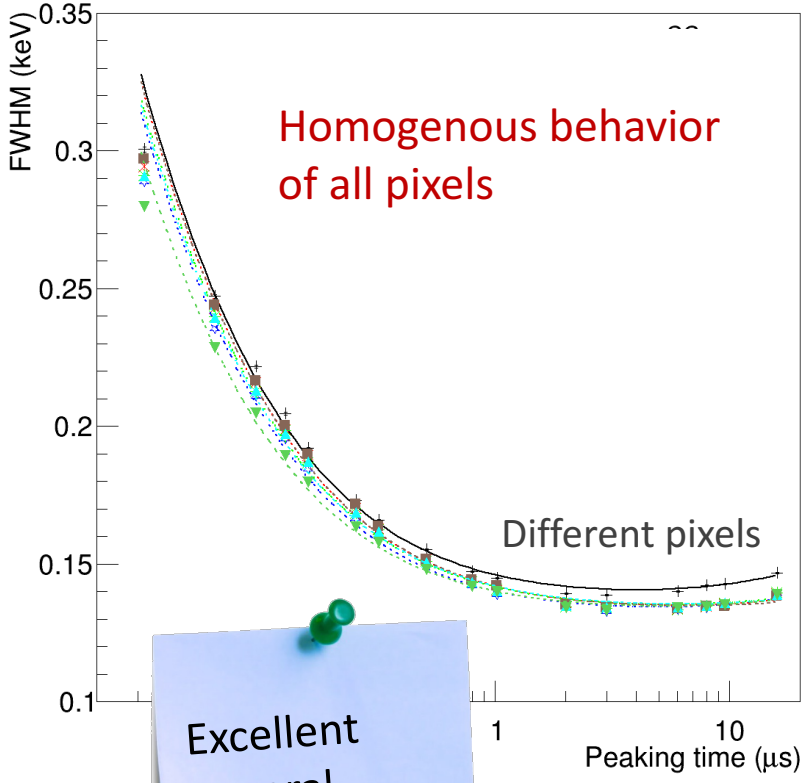


General performance (XGLab system, X-ray sources)







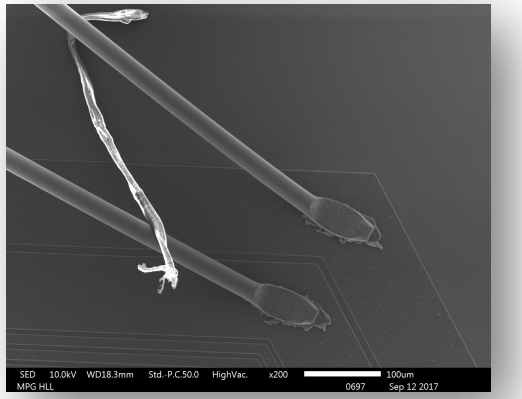


Excellent general performance

Paper in preparation (lead by Tobias Bode, MPP)

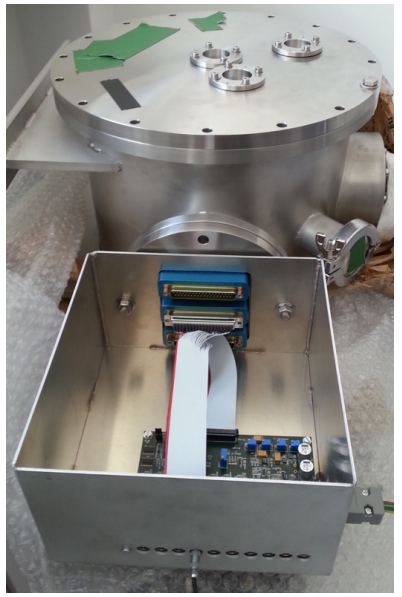
Characterization with electrons

- Electron microscope



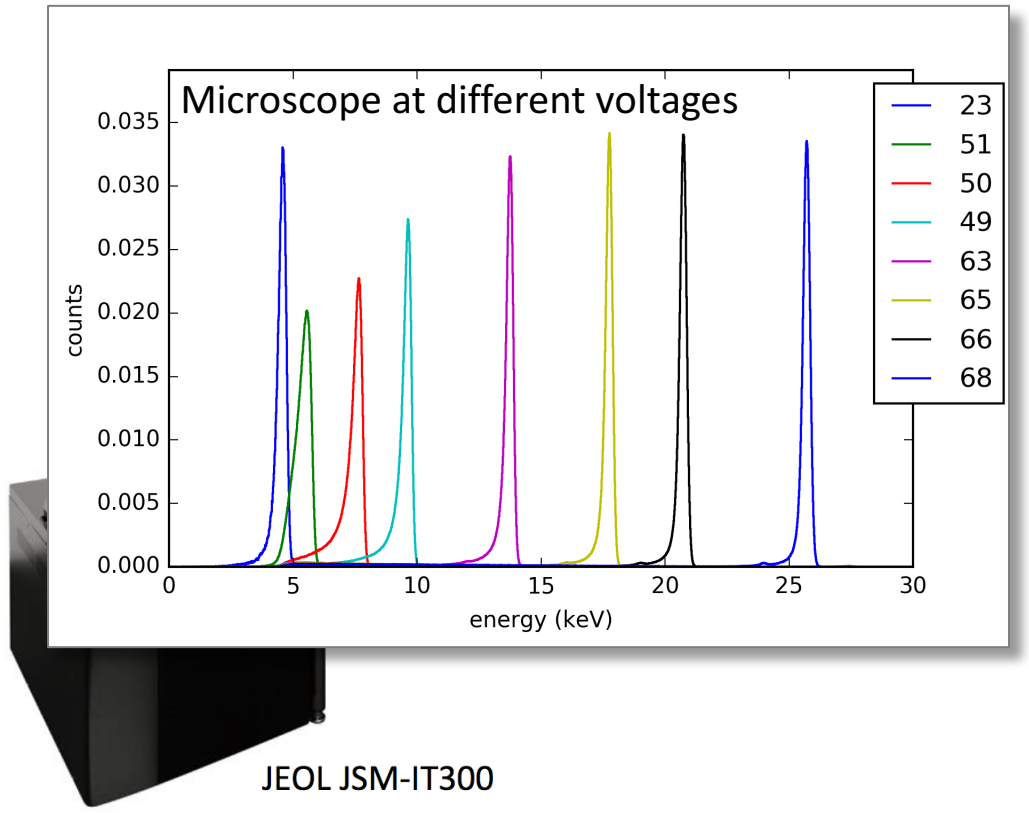
JEOL JSM-IT300

- Evaporated Kr source



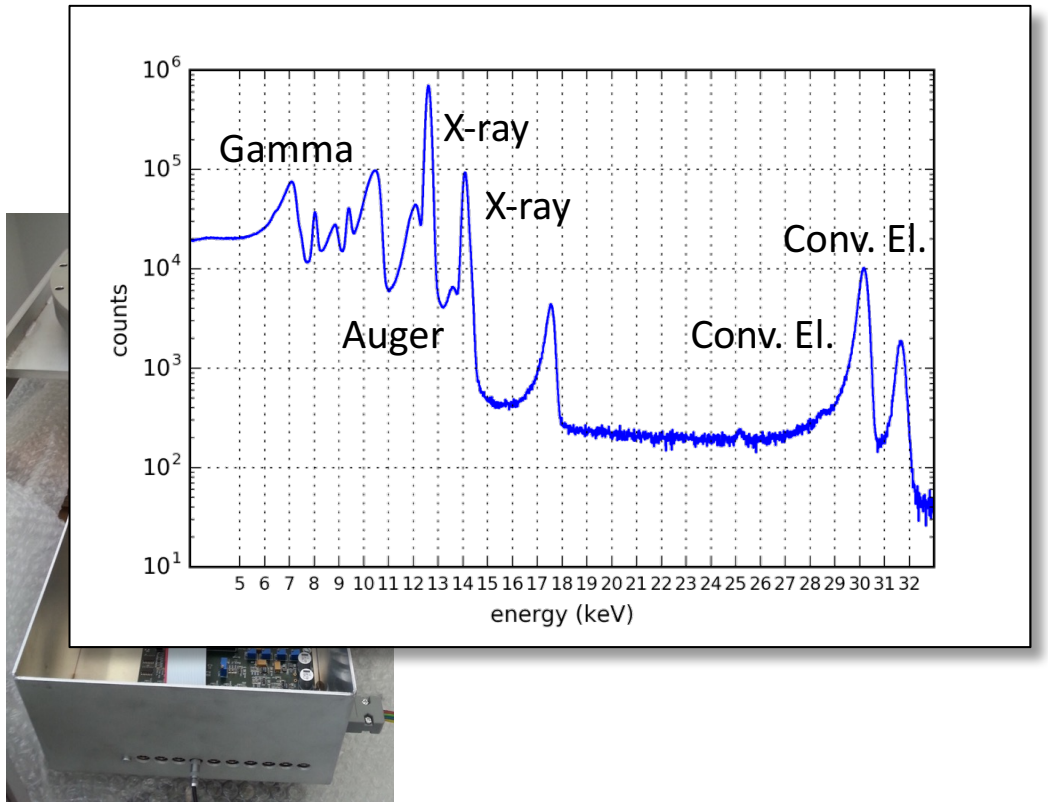
Characterization with electrons

- Electron microscope



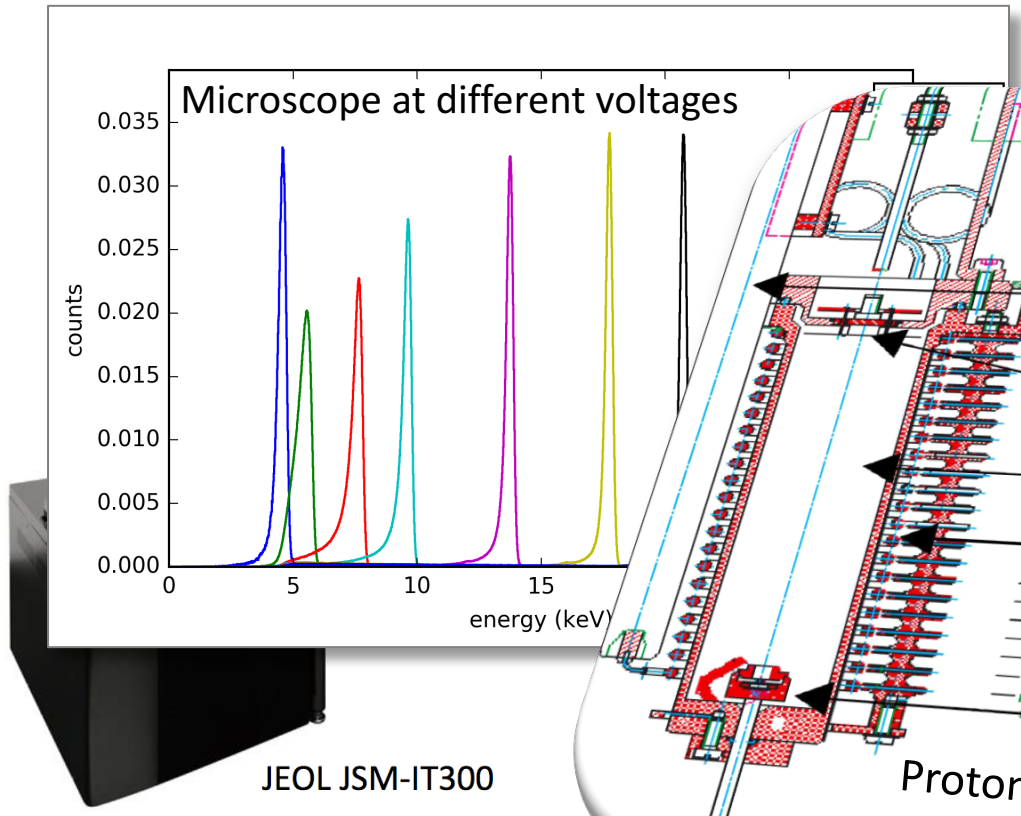
JEOL JSM-IT300

- Evaporated Kr source

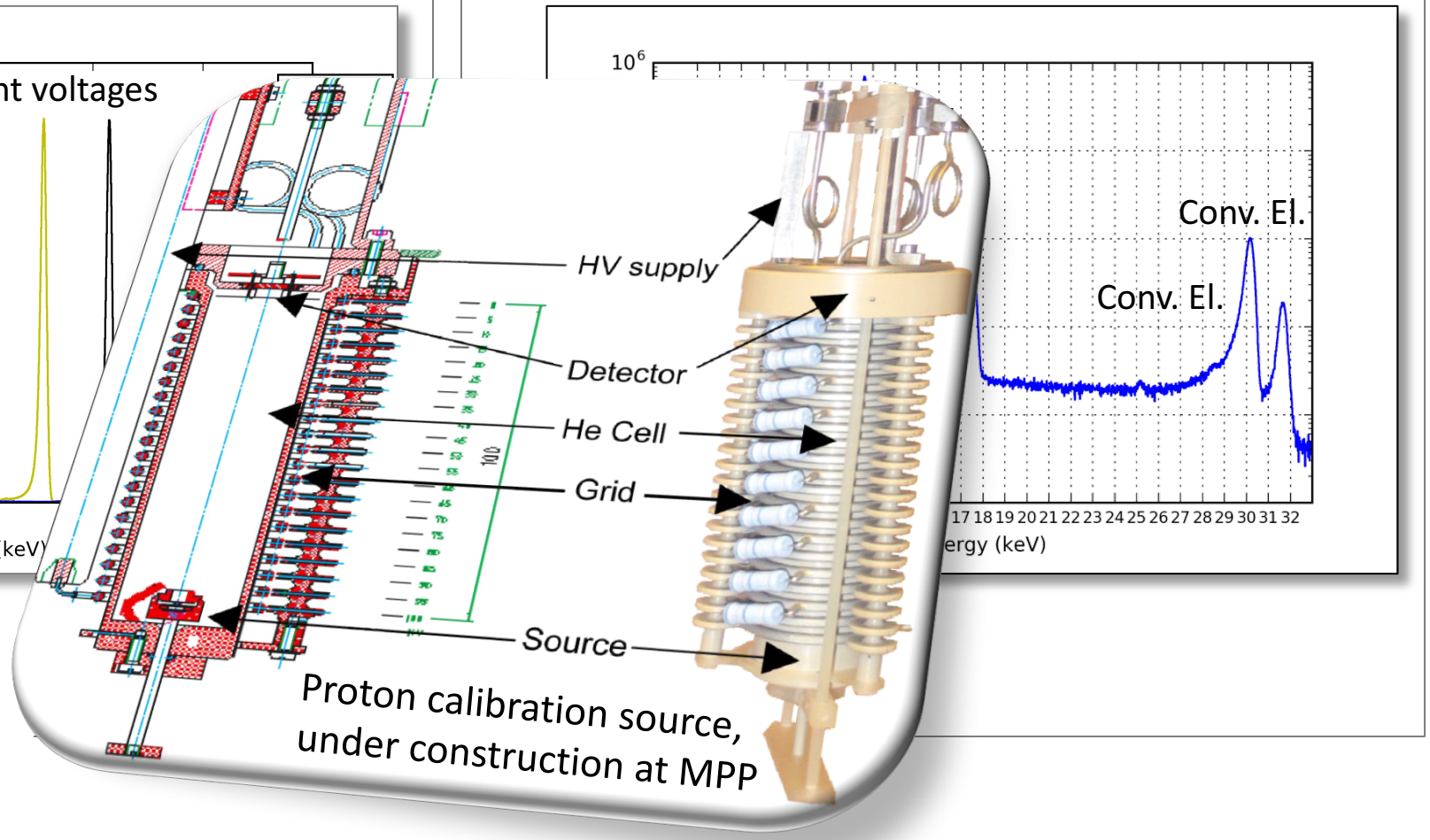


Characterization with electrons

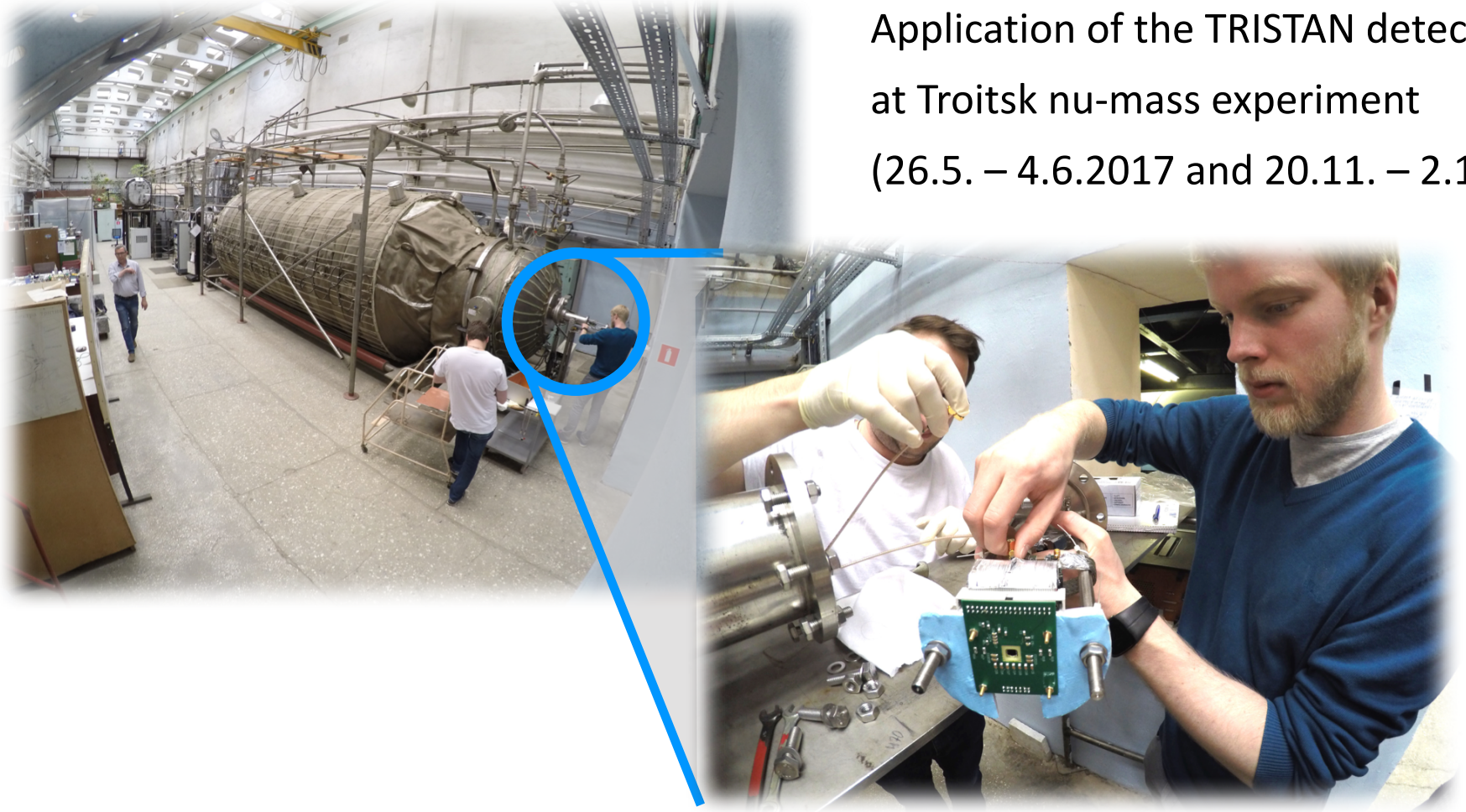
- Electron microscope



- Evaporated Kr source



TRISTAN in TROITSK



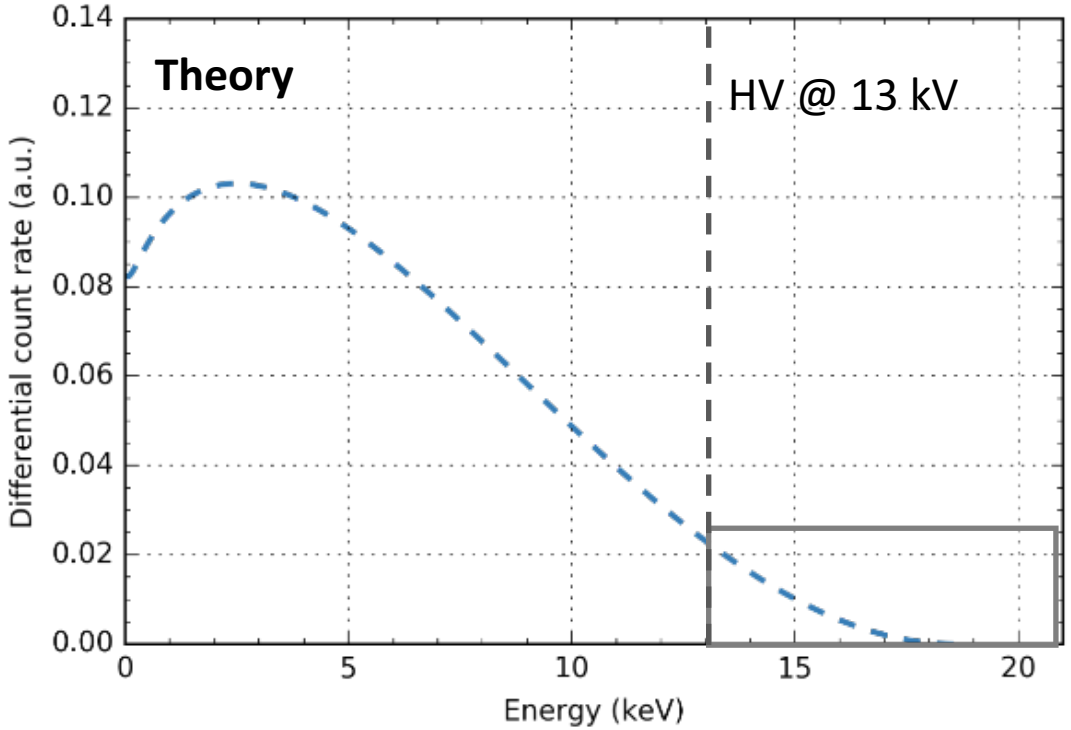
Application of the TRISTAN detector

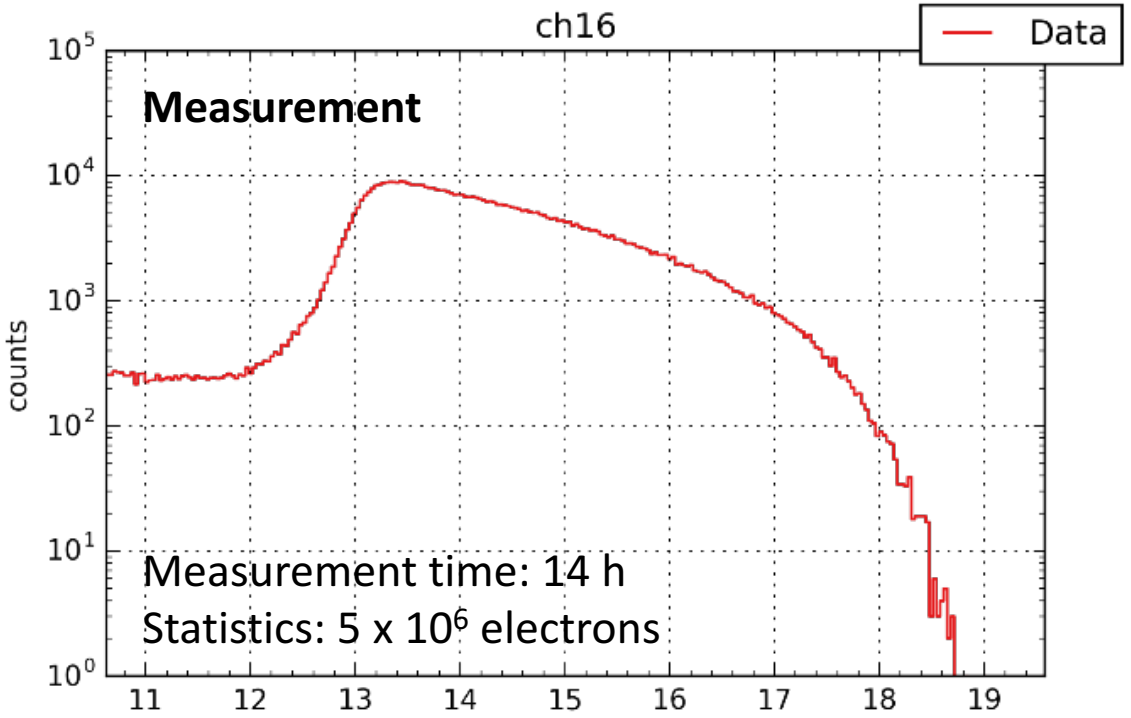
at Troitsk nu-mass experiment

(26.5. – 4.6.2017 and 20.11. – 2.12.2017)

- Good performance in “real conditions”
- Development of analysis tools

Our first tritium spectrum

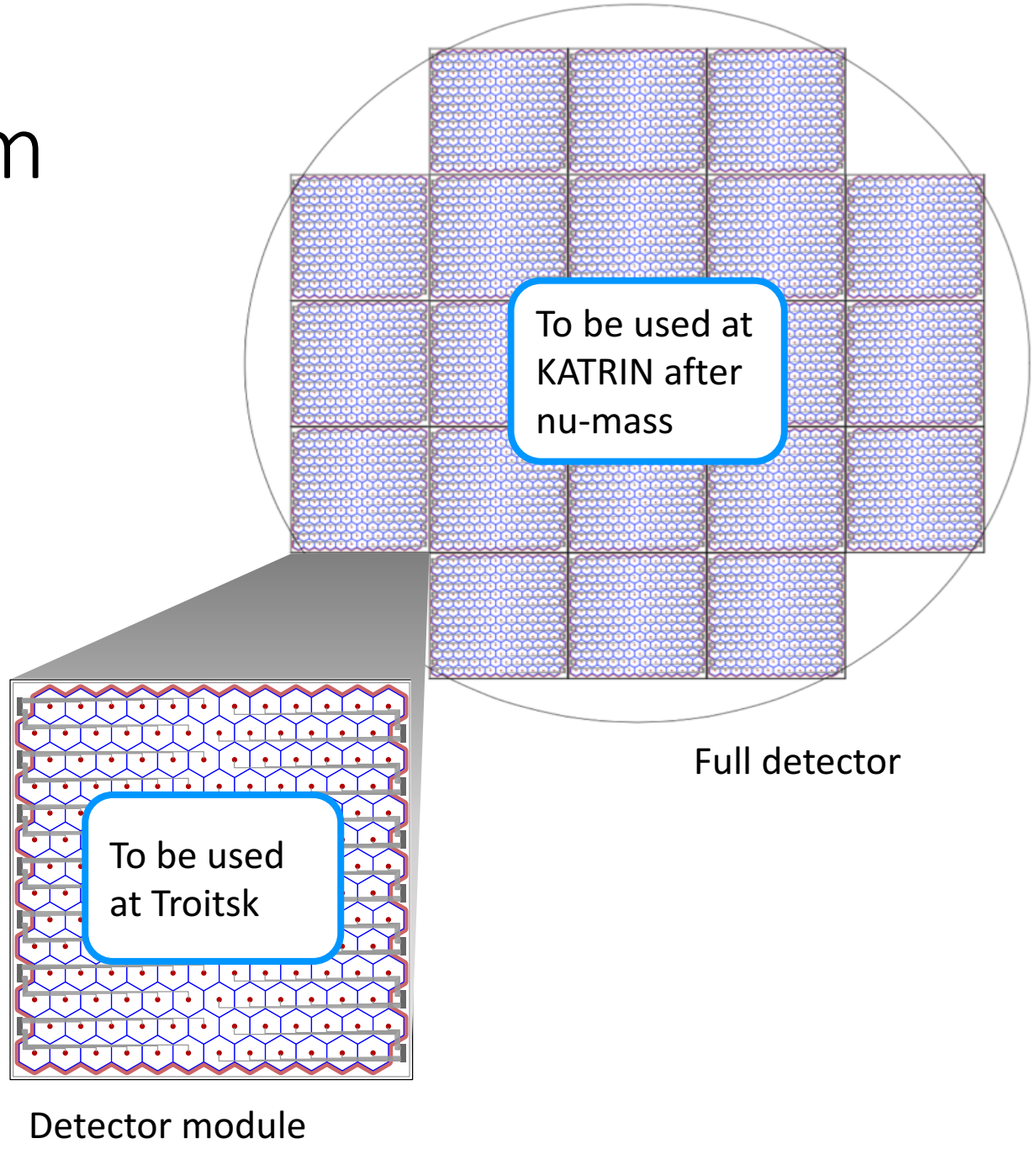




Analysis ongoing (Tim Brunst, PhD., MPP)

Towards the final system

- **Pixel design:**
  - SDD with integrated nJFET
  - Pixel size: ~3 mm diameter
- **Module design:**
  - 168 pixels
  - Module size: ~4 cm diameter
- **Final detector design:**
  - 21 modules → 3500 pixels
  - Detector size: ~20 cm diameter



TRISTAN takes off…

Other applications of TRISTAN:

- Satellite mission (CUBE-Sat project)
- Axion search with IAXO
- Electronics R&D for LEGEND
- Forward beam monitor for KATRIN

New idea:

- Project “Spargel”: detection the collective cyclotron radiation of electrons in KATRIN to search for sterile neutrinos

2. July, 2016, 5:00
Air Sur l’Adour
COCOTE
Compact Compton Telescope

Summary

- Neutrino are key to unraveling some of the most compelling mysteries of the universe

- MPP group heavily involved in KATRIN data taking and analysis
- MPP group leads the TRISTAN project
  - Very encouraging first results with prototype detector
  - First tritium data taken at Troitsk


Thanks for your attention