First data of the KATRIN experiment

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Max Planck Institute for Physics & Technical University Munich
NTIHP, September 2018, Montenegro

Neutrino mass

Previous talk

This talk

Cosmology

model-dependent
potential: m_ν = 15-50 meV
e.g. Planck

$$m_\nu = \sum_i m_i$$

Search for 0νßß

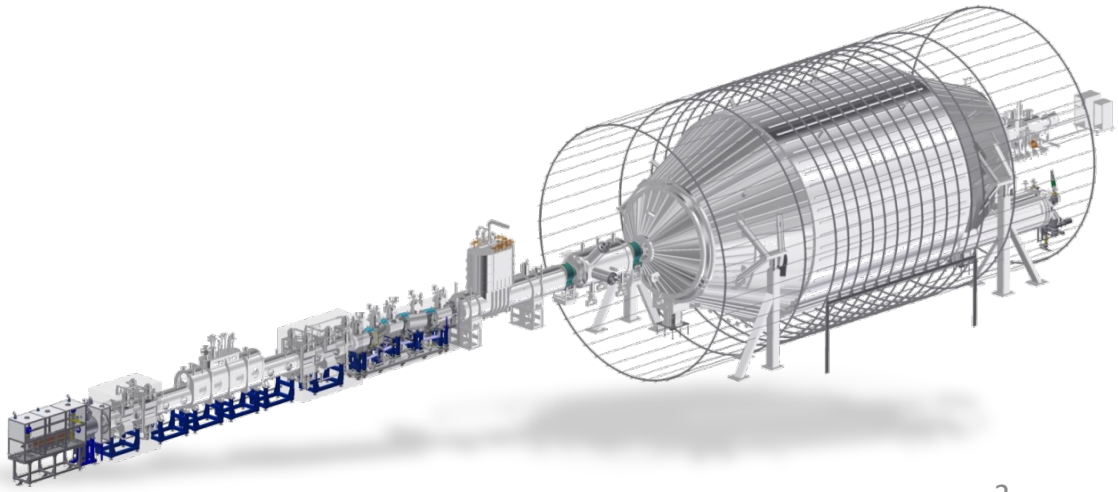
model-dependent
potential: $m_{ßß}$ = 15-50 meV
e.g. GERDA

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

Kinematics of ß-decay

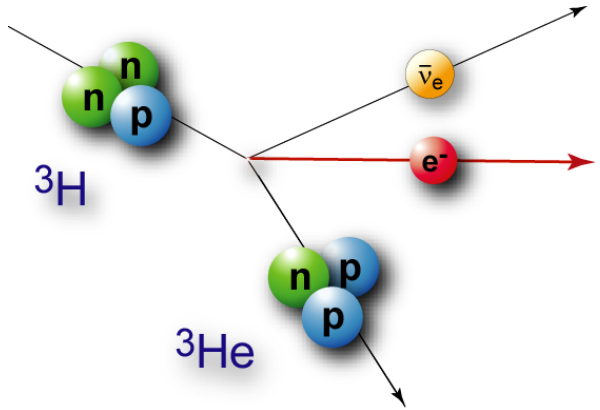
model-independent
potential: m_β = 50 - 200 meV
e.g. KATRIN

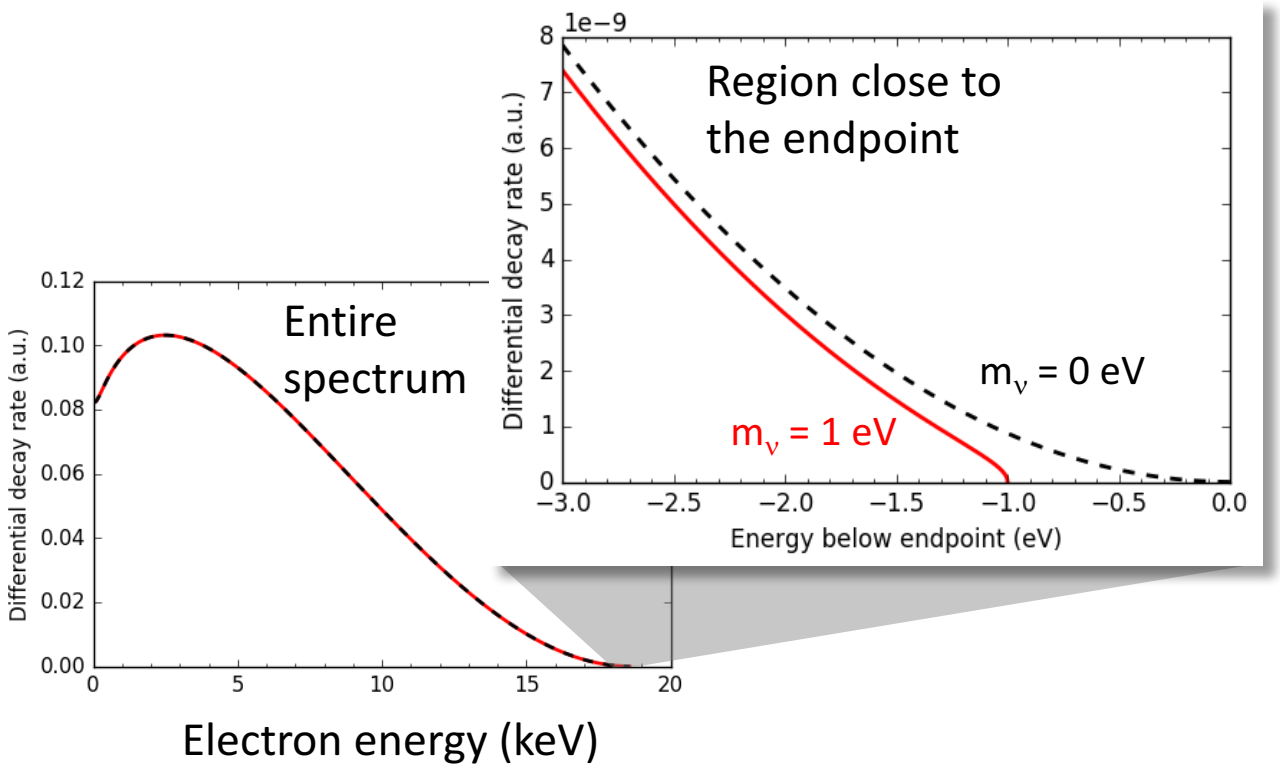
$$m_\beta^2 = \sum_i |U_{ei}|^2 \cdot m_i^2$$



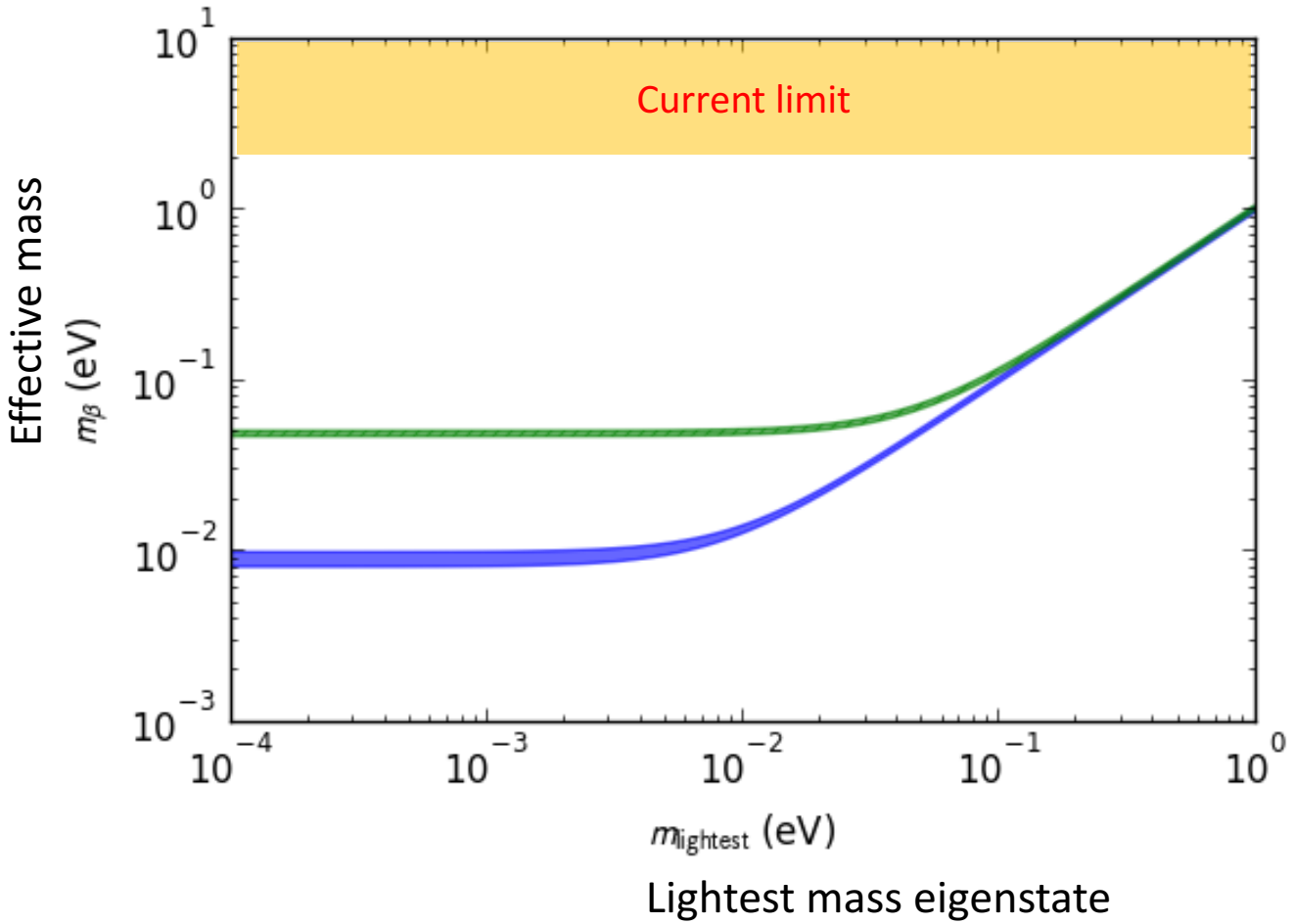
General idea

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





Where do we stand?



- Current limit:
  Mainz and Troitsk Experiment
  V. N. Aseev et al., Phys. Rev. D 84 (2011) 112003
  Kraus, C., Bornschein, B., Bornschein, L. et al. Eur. Phys. J. C (2005)

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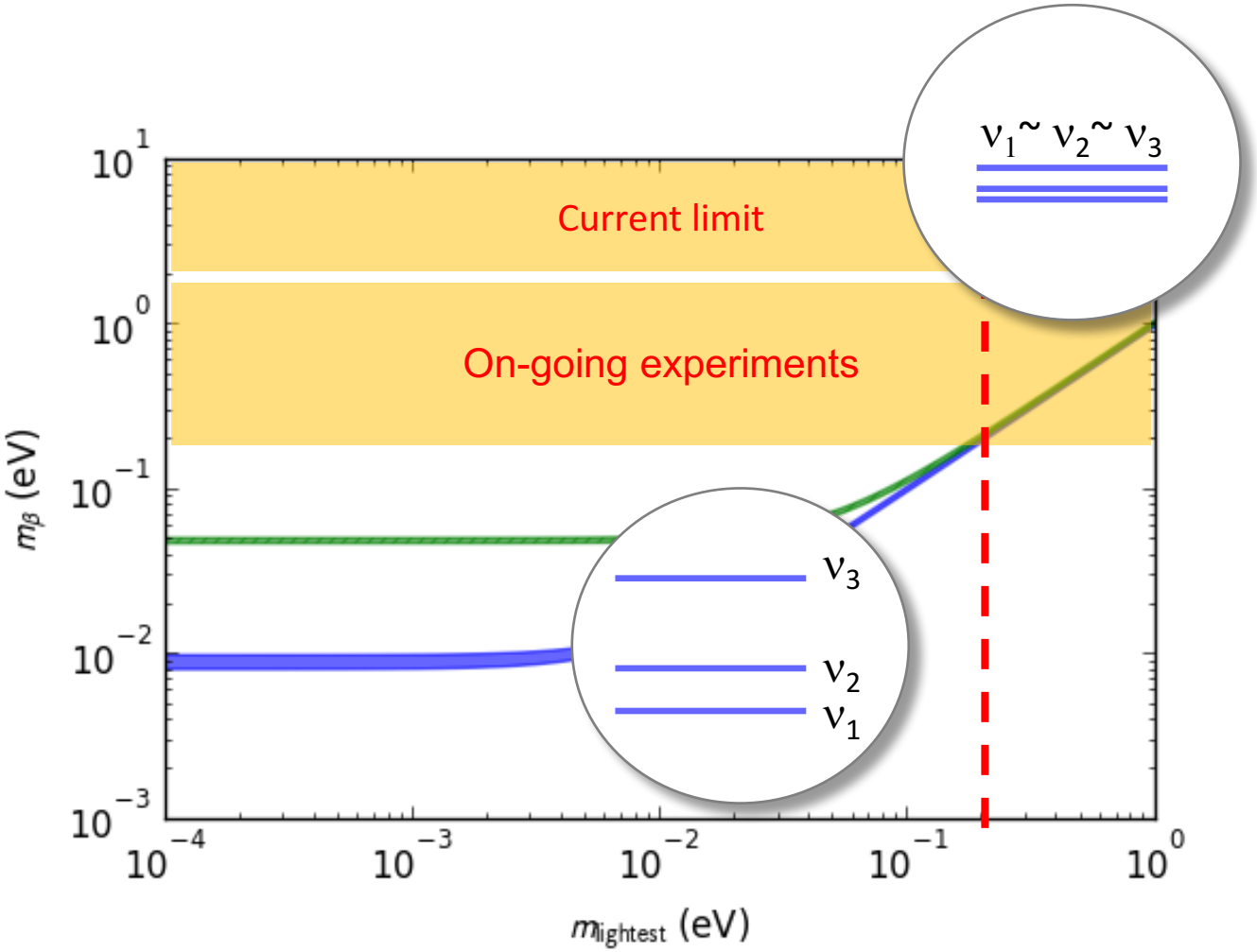

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- Ongoing experiments:
  Distinguish between **degenerate** and **hierarchical** scenario

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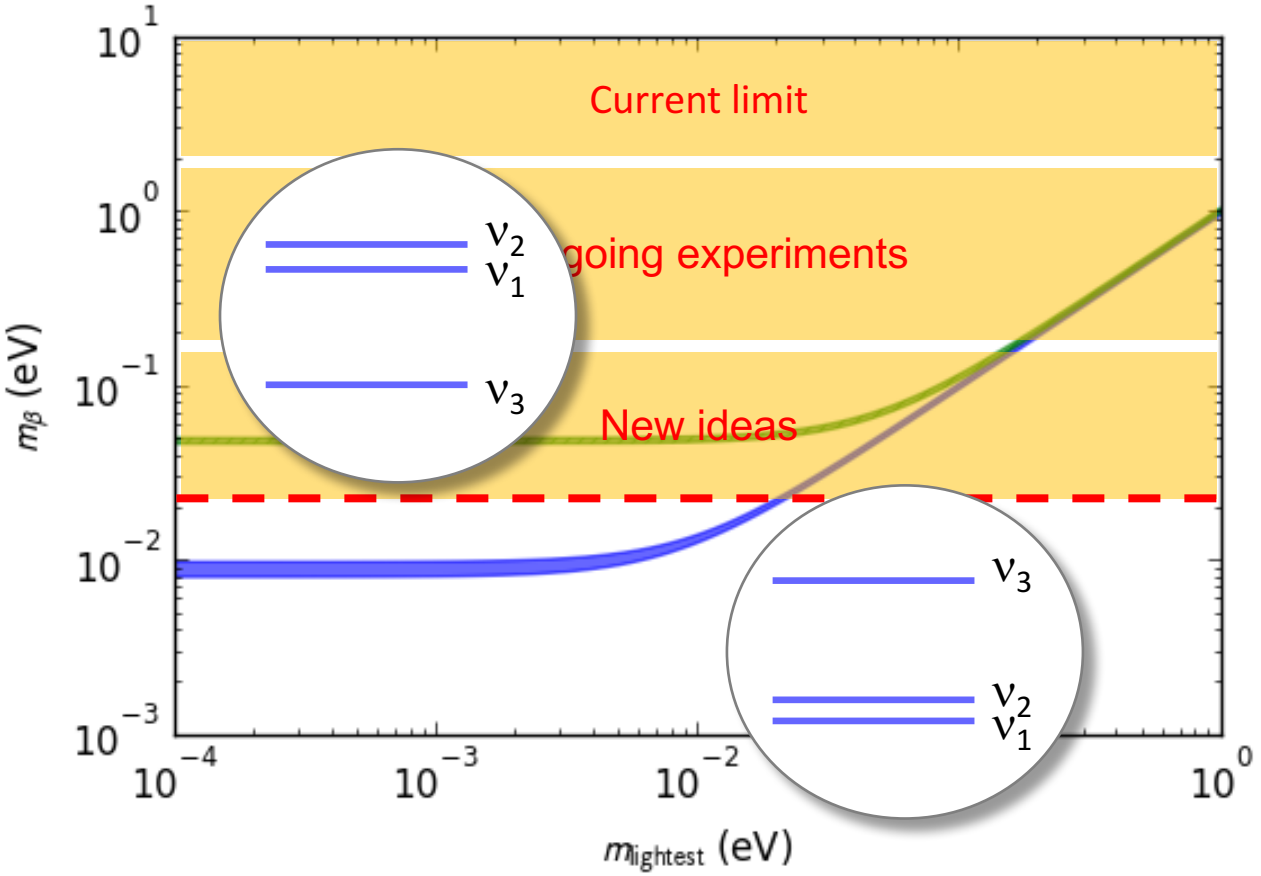

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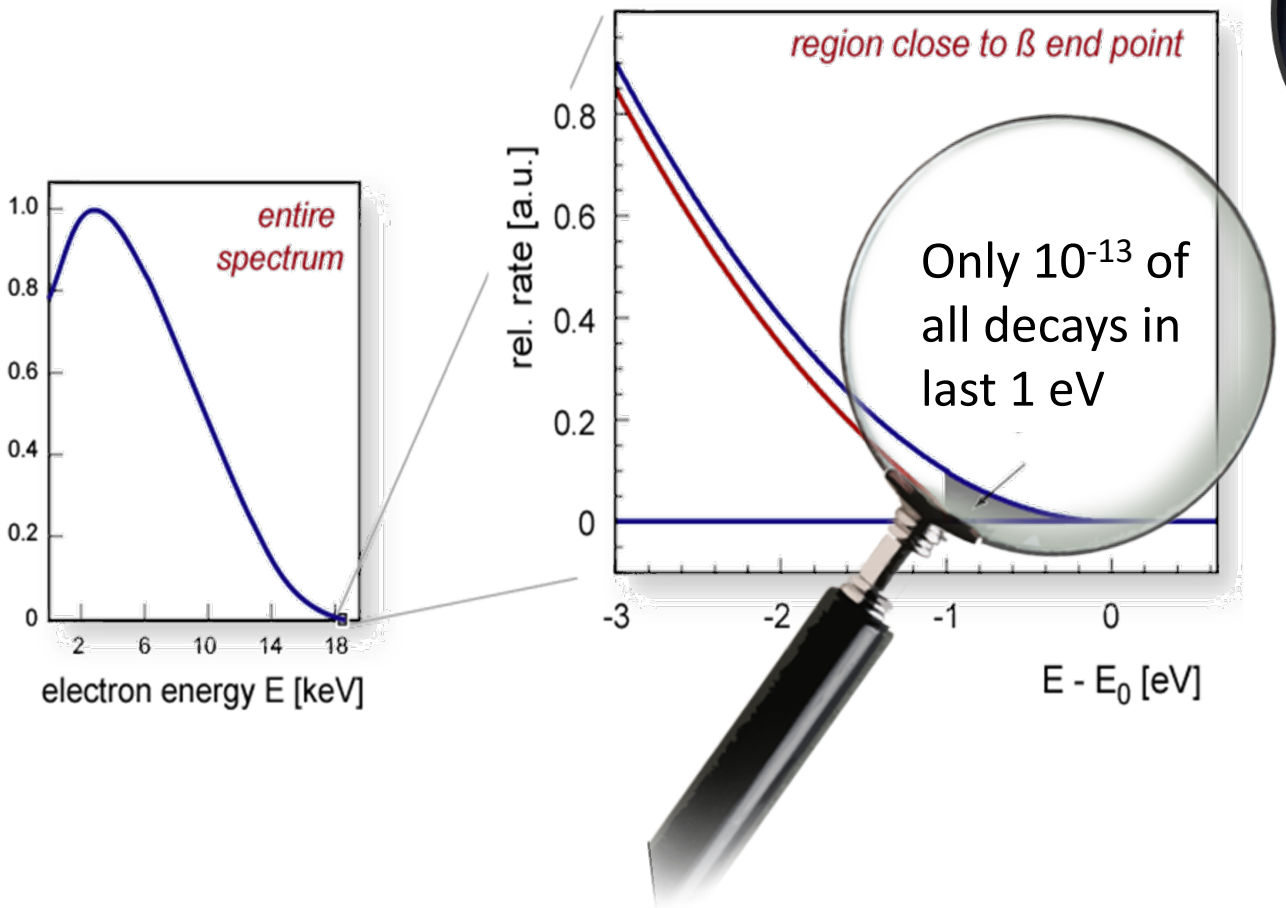
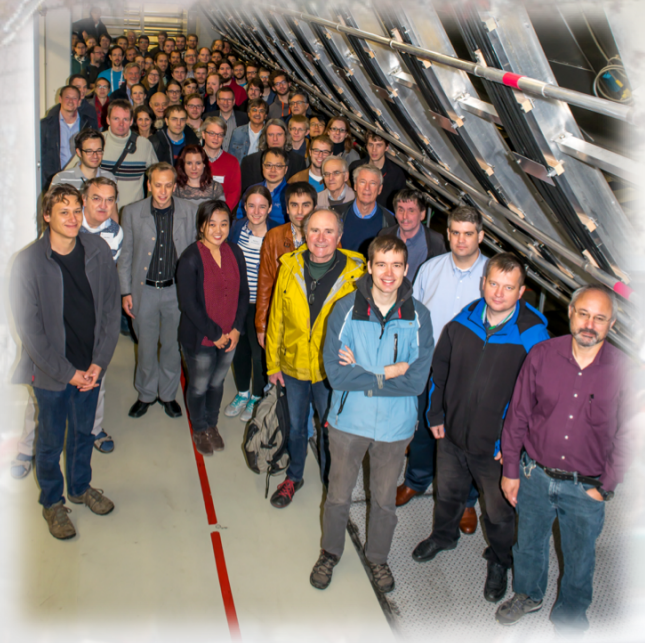
- Ongoing experiments:
  Distinguish between **degenerate** and **hierarchical** scenario
- New ideas:
  Resolve **normal** vs **inverted** neutrino mass hierarchy

The challenge




Karlsruhe
Tritium
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

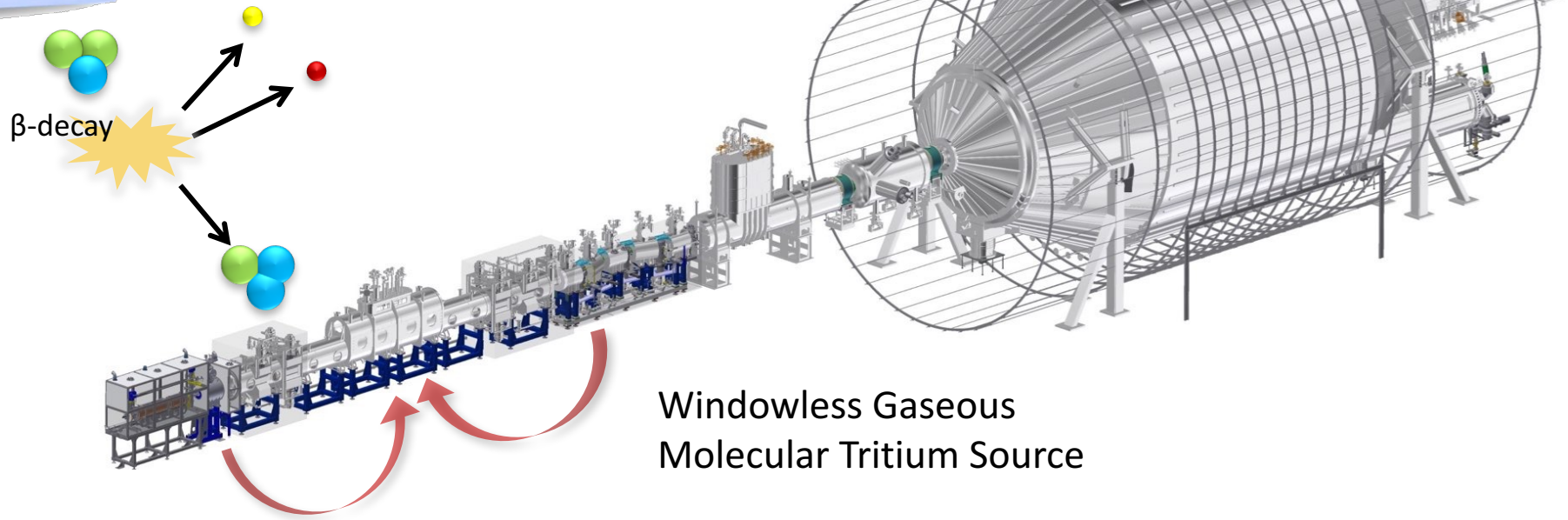
Karlsruher Institut für Technologie
Max-Planck-Institut für Kernphysik Heidelberg
University of Washington
Westfälische Wilhelms-Universität Münster
Case Western Reserve University
think beyond the possible
Massachusetts Institute of Technology
The University of North Carolina at Chapel Hill
The Czech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

KATRIN Working Principle

Gaseous molecular tritium source of high stability and luminosity

(10^{11} decays/sec)

	^{3}H
	super-allowed β-decay
$T_{1/2}$	12.3 years
E_0	18.6 keV

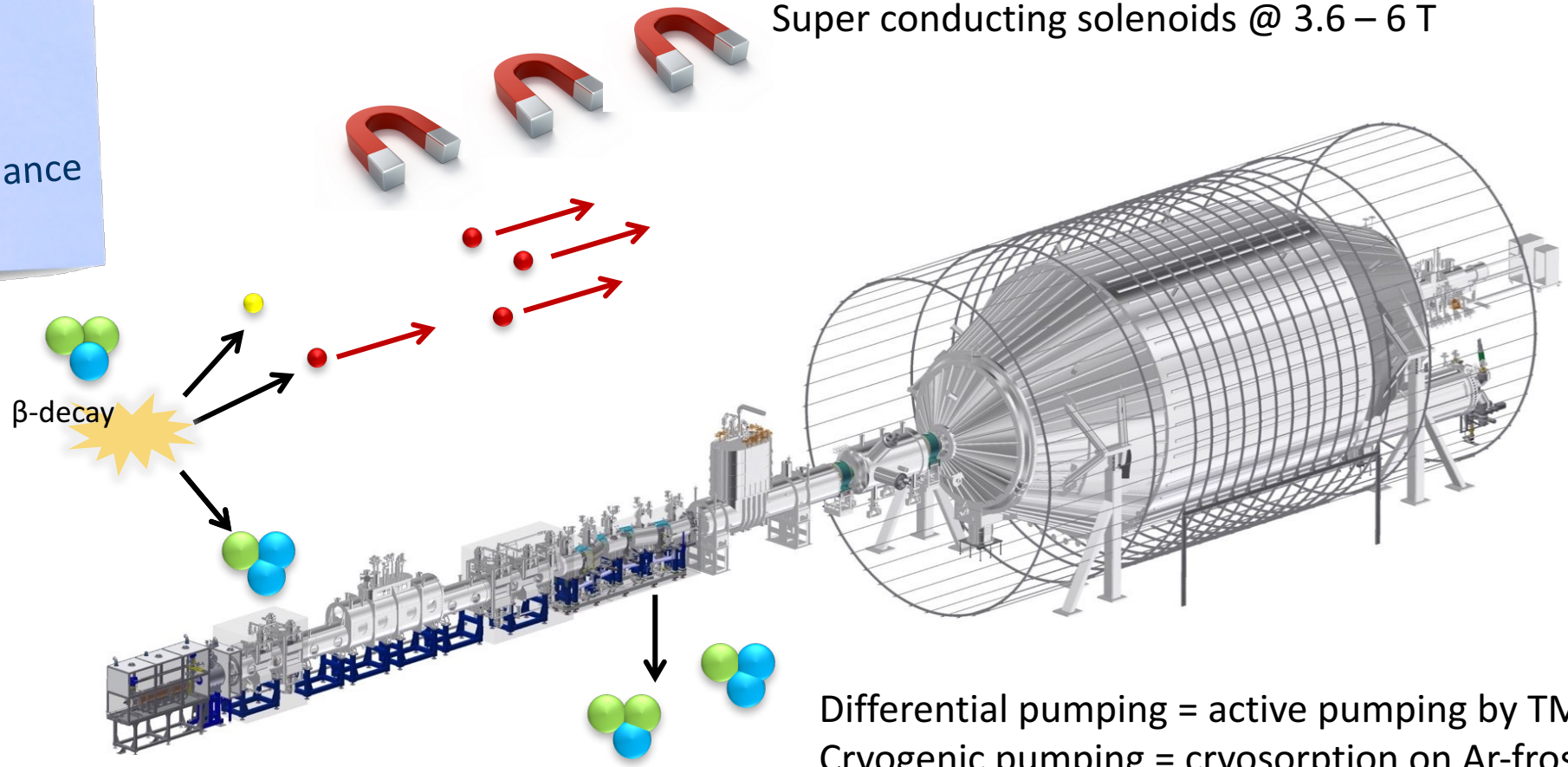


Windowless Gaseous Molecular Tritium Source

KATRIN Working Principle

Tritium flow reduction by 14 orders of magnitude, adiabatic guidance of electrons

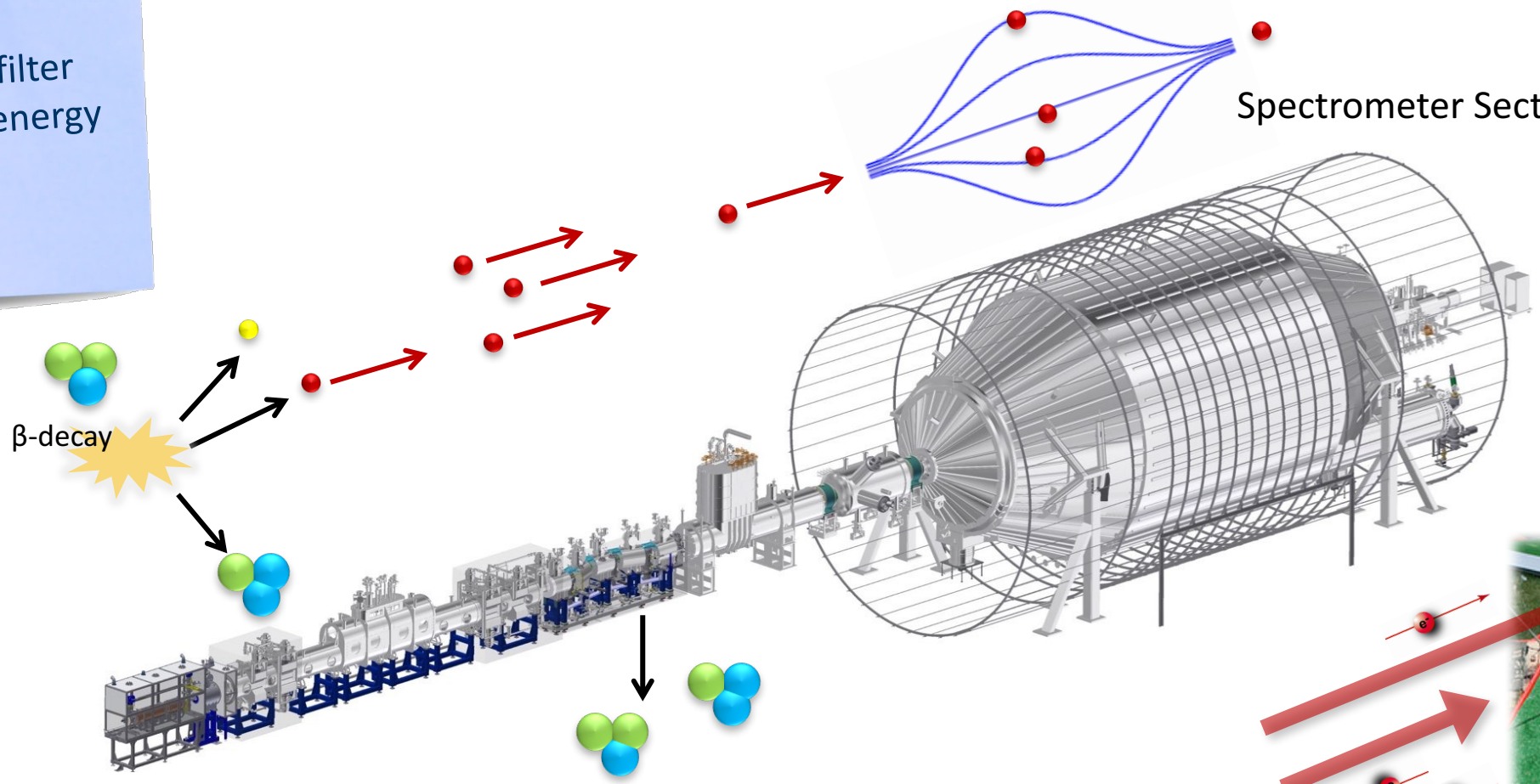
Super conducting solenoids @ 3.6 – 6 T

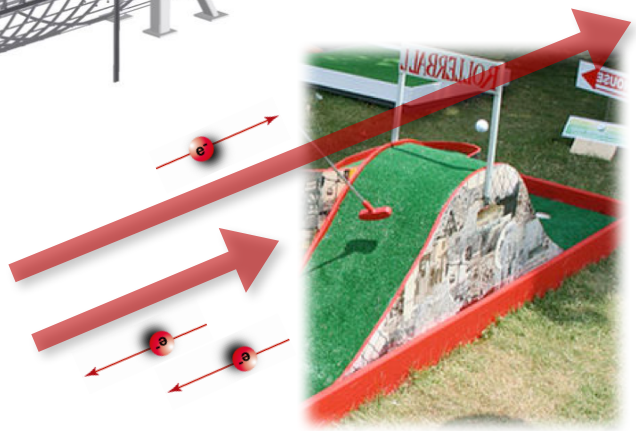


Differential pumping = active pumping by TMPs
Cryogenic pumping = cryosorption on Ar-frost

KATRIN Working Principle

Electrostatic filter selects high energy electrons

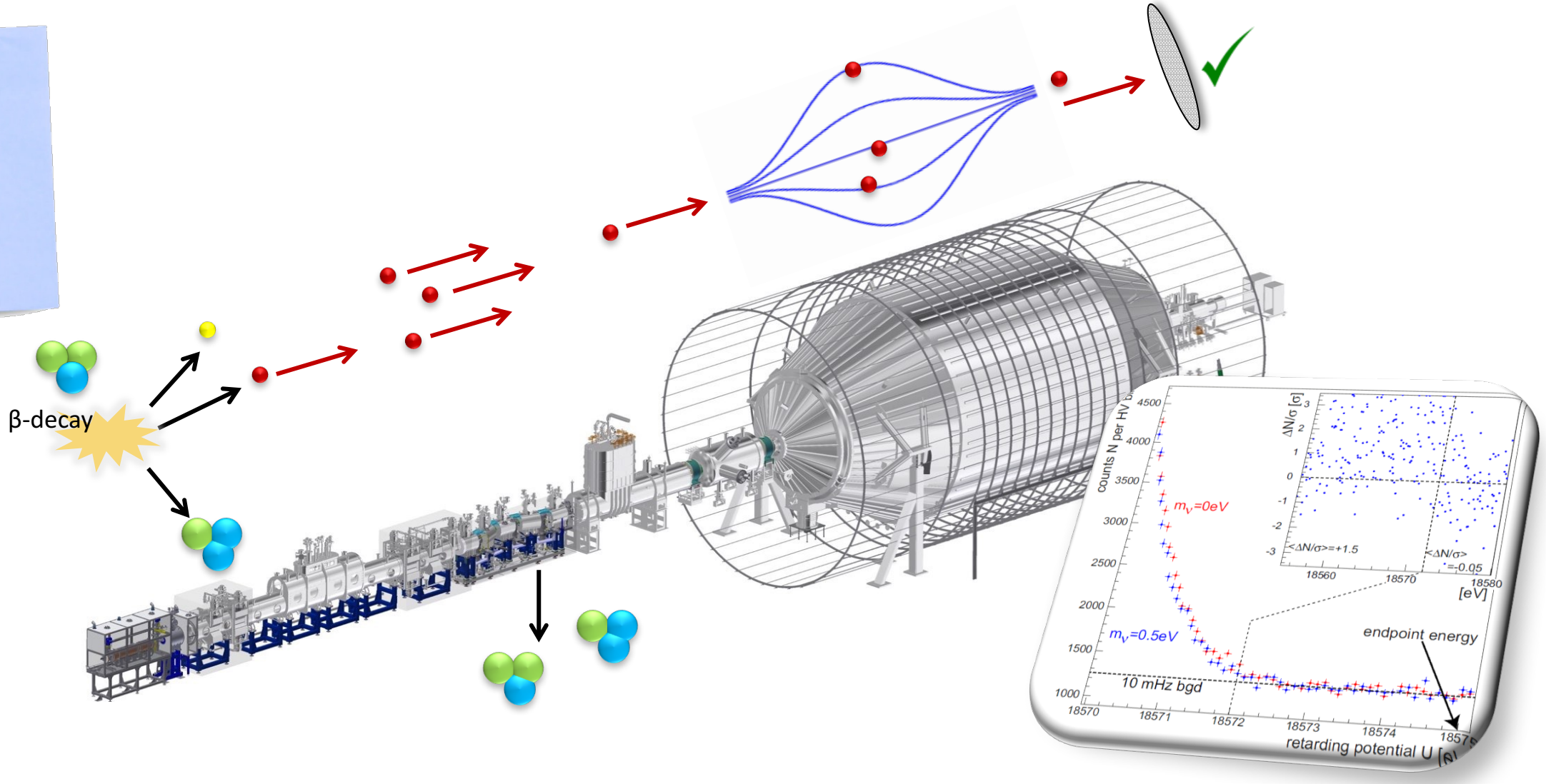




KATRIN Working Principle

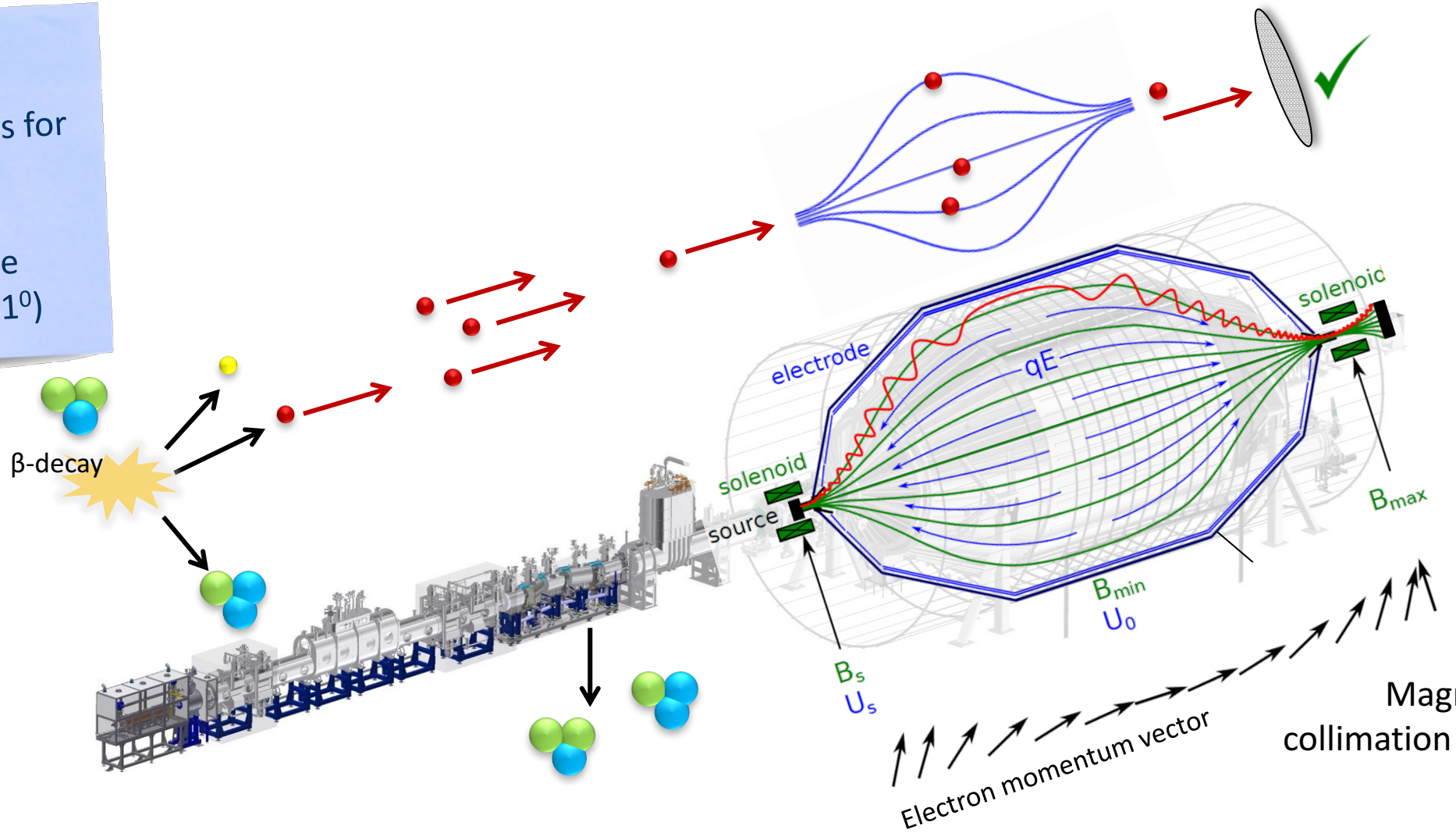
148 Pixel Si-pin diode detector system

Integral measurement down to 30 eV below the endpoint



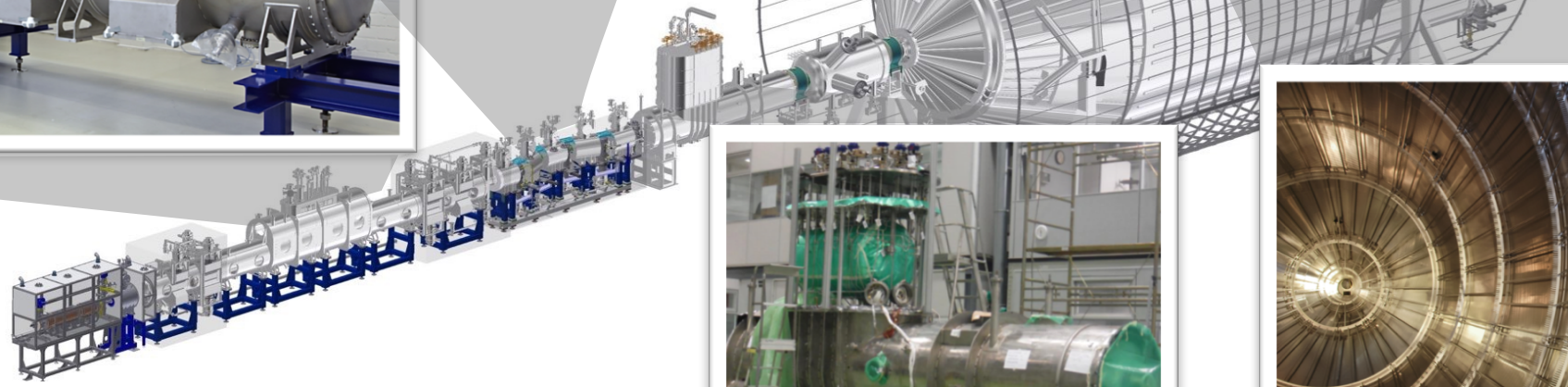
KATRIN Working Principle

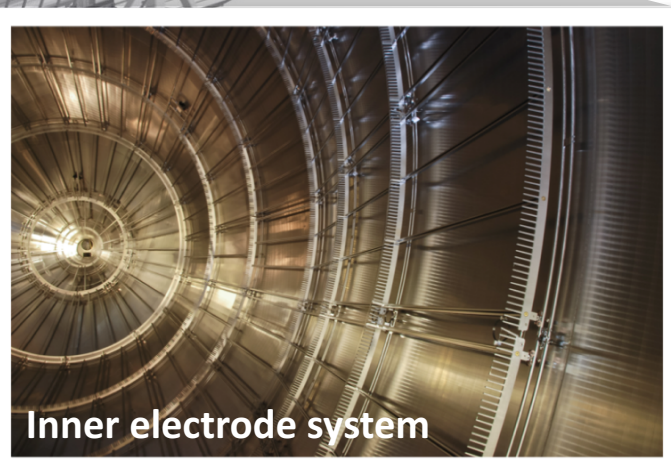
MAC-E Filter principle allows for < 1 eV energy resolution and large angle acceptance (51^0)



Magnetic adiabatic collimation + electrostatic filter (MAC-E)

KATRIN Status



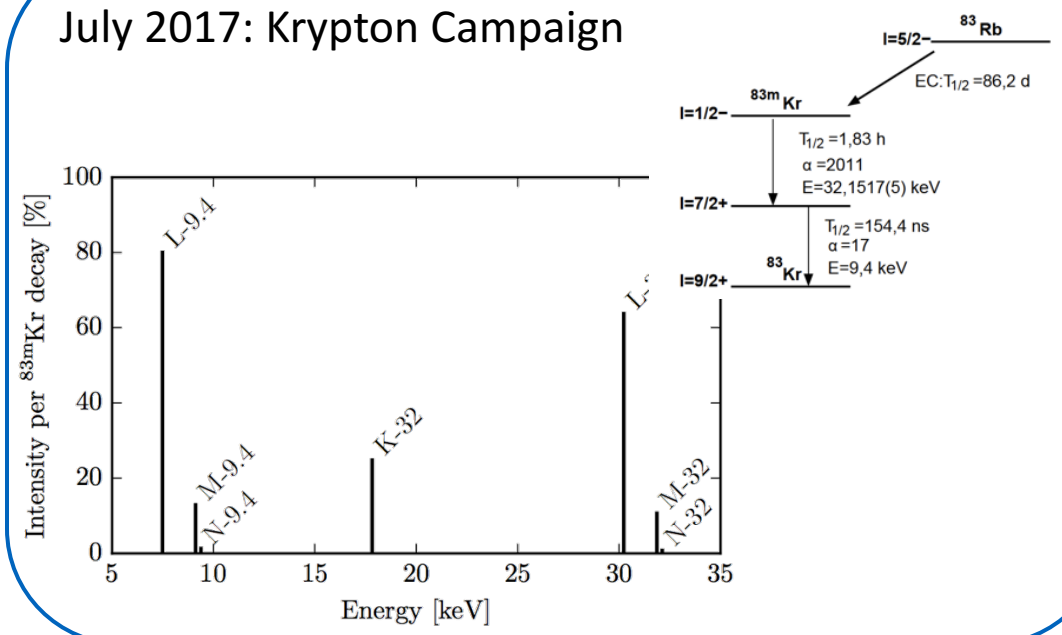


KATRIN all, *J. Instrum.*, 11, 2016

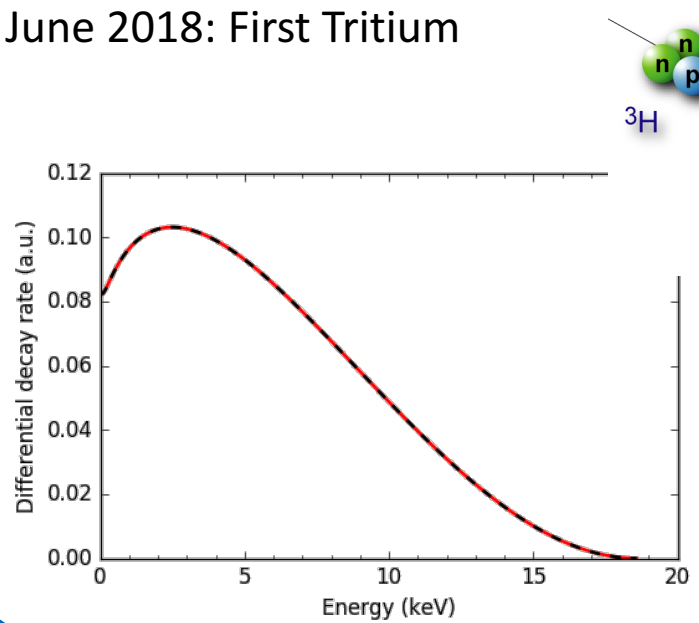
Test of Unique Properties of KATRIN

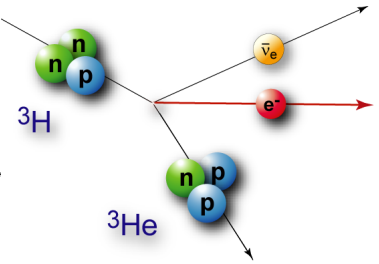
- ultra-stable high-luminosity windowless gaseous tritium source
- high-resolution MAC-E filter with < 1 eV energy resolution

July 2017: Krypton Campaign

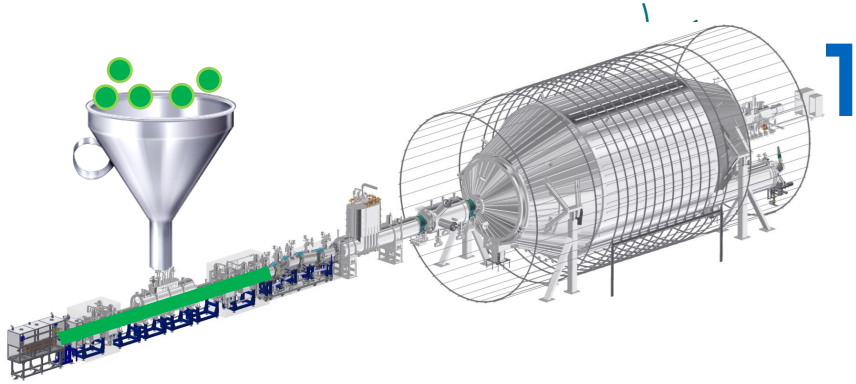


June 2018: First Tritium

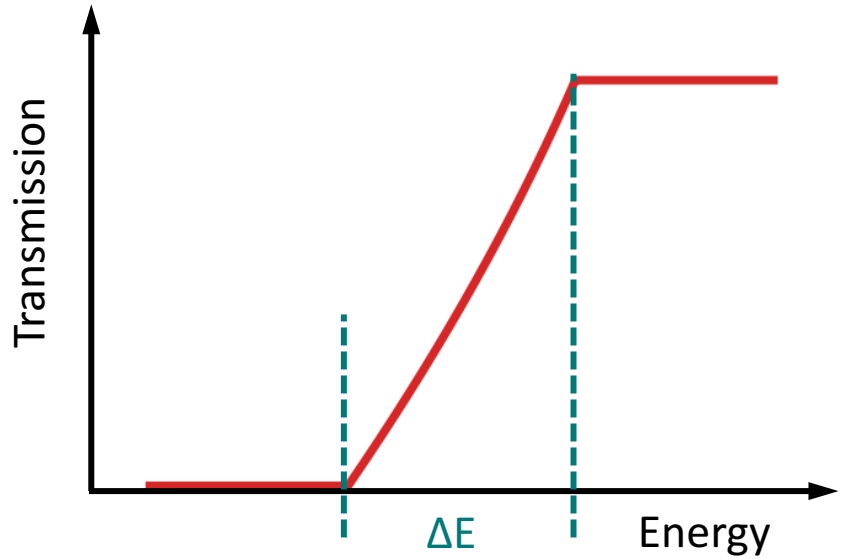


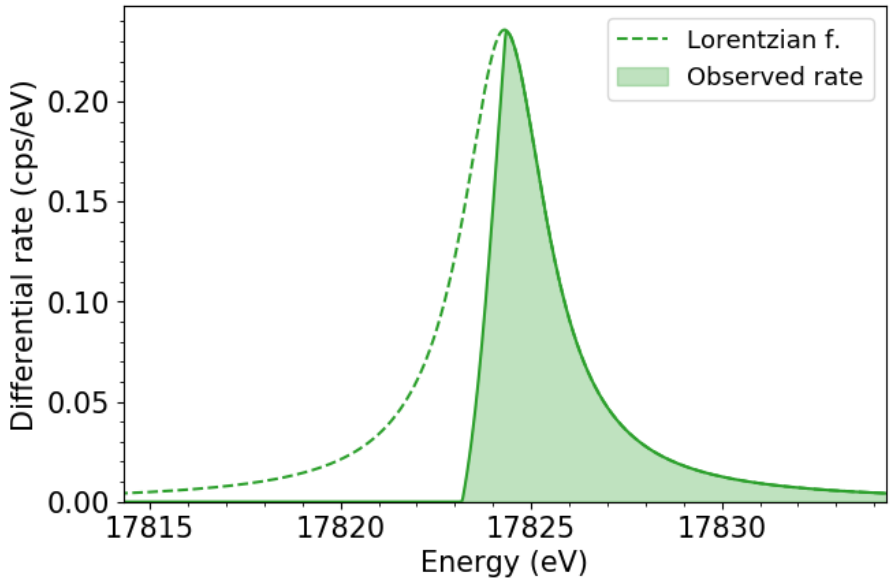


Krypton Calibration



- Quasi-mono-energetic, isotropic electrons from gaseous krypton decay





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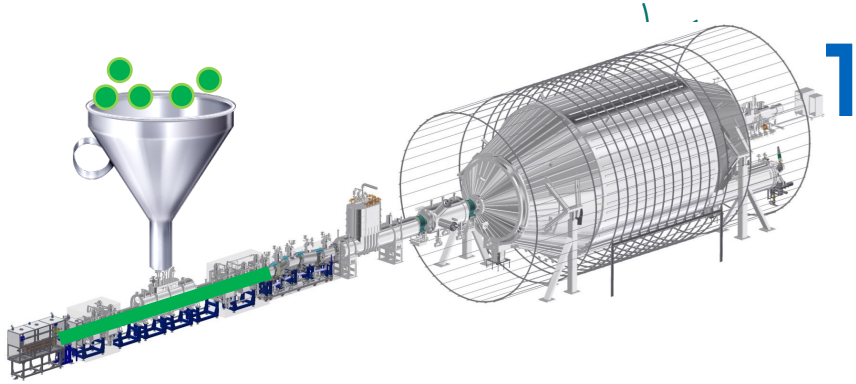

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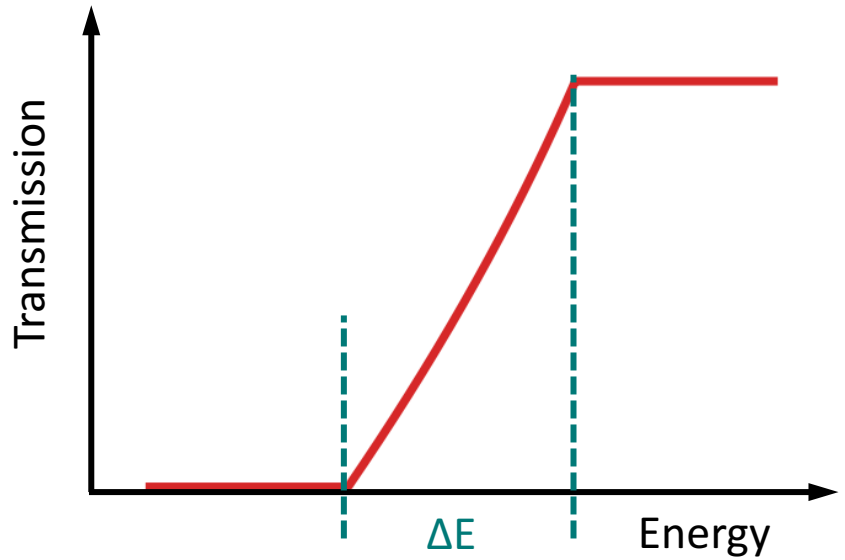

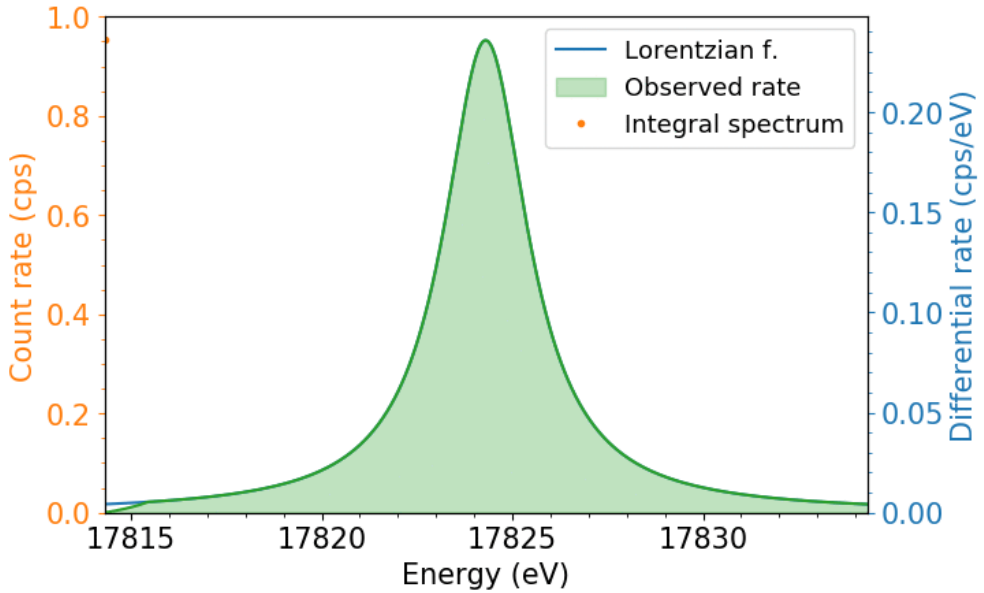

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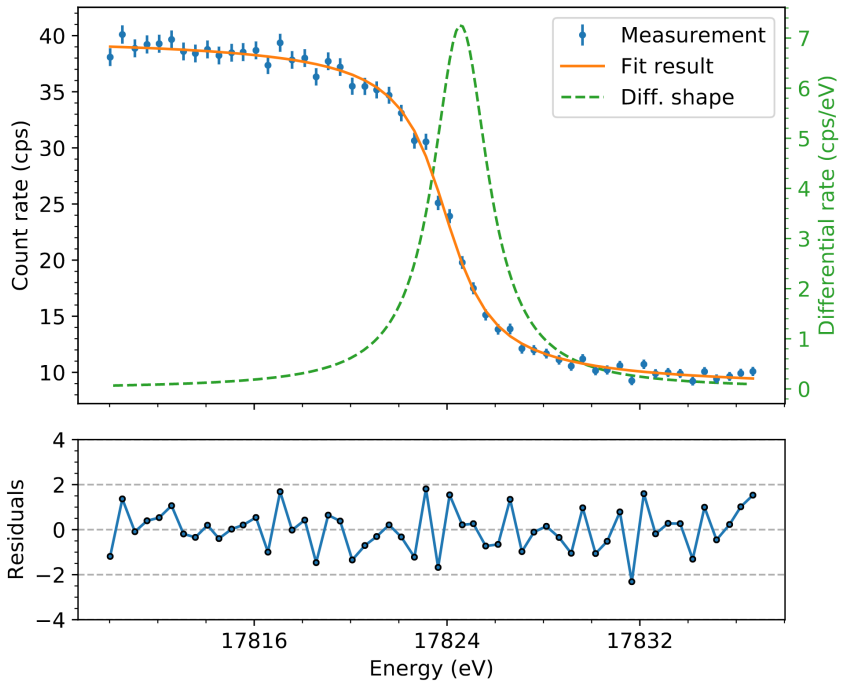
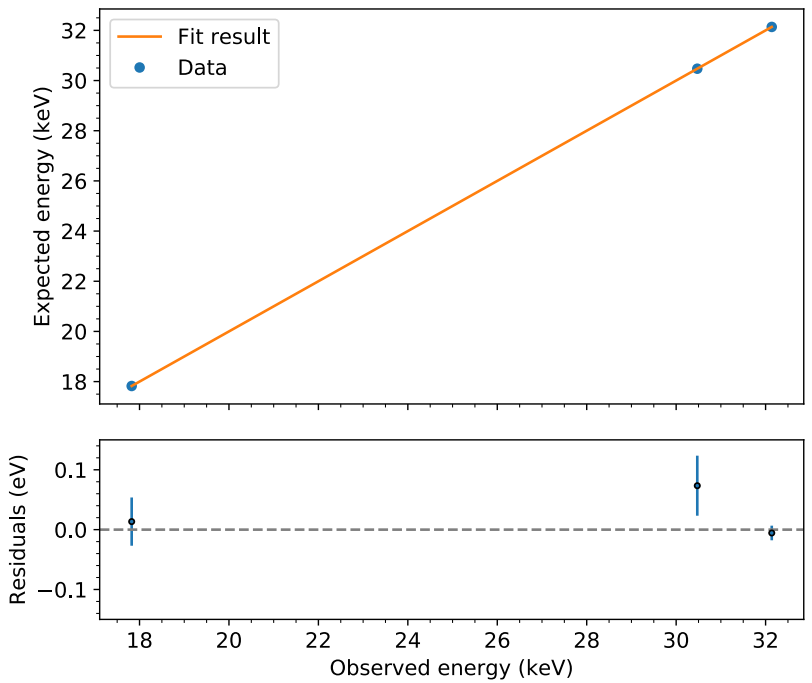




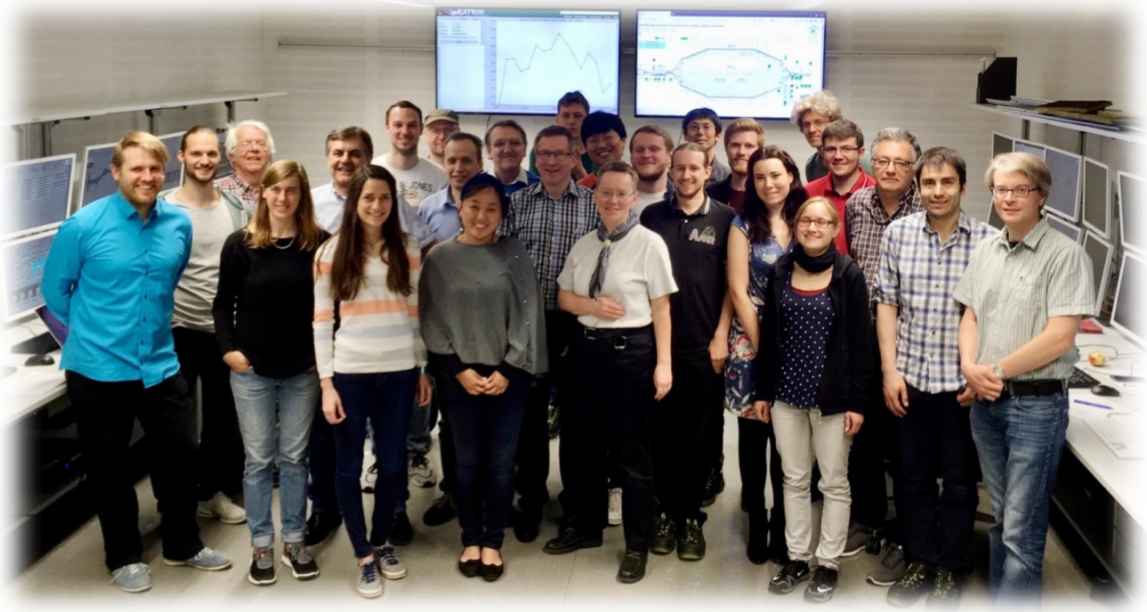
- ✓ HV calibration on the ppm level
- ✓ Spectrometer resolution of ~1 eV

*KATRIN collab., JINST **13** P04020 (2018)*
*KATRIN collab., EPJ C **78** 368 (2018)*

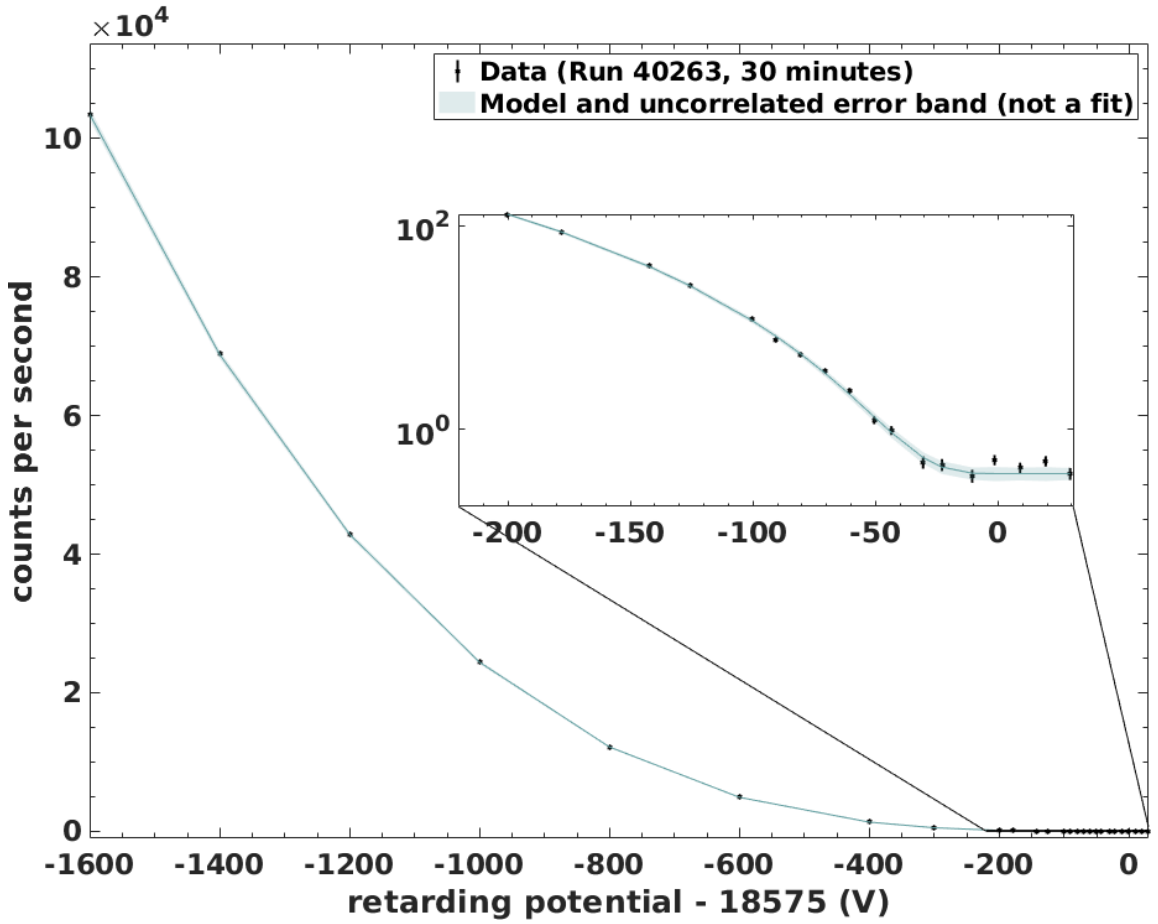
First tritium campaign May / June 2018

- Motivation:
  - Commissioning of system with tritium (1% of nominal activity = ~500 MBq!)
  - Demonstrate 0.1% global system stability
  - Study beta spectrum for systematic effects and test analysis strategies

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

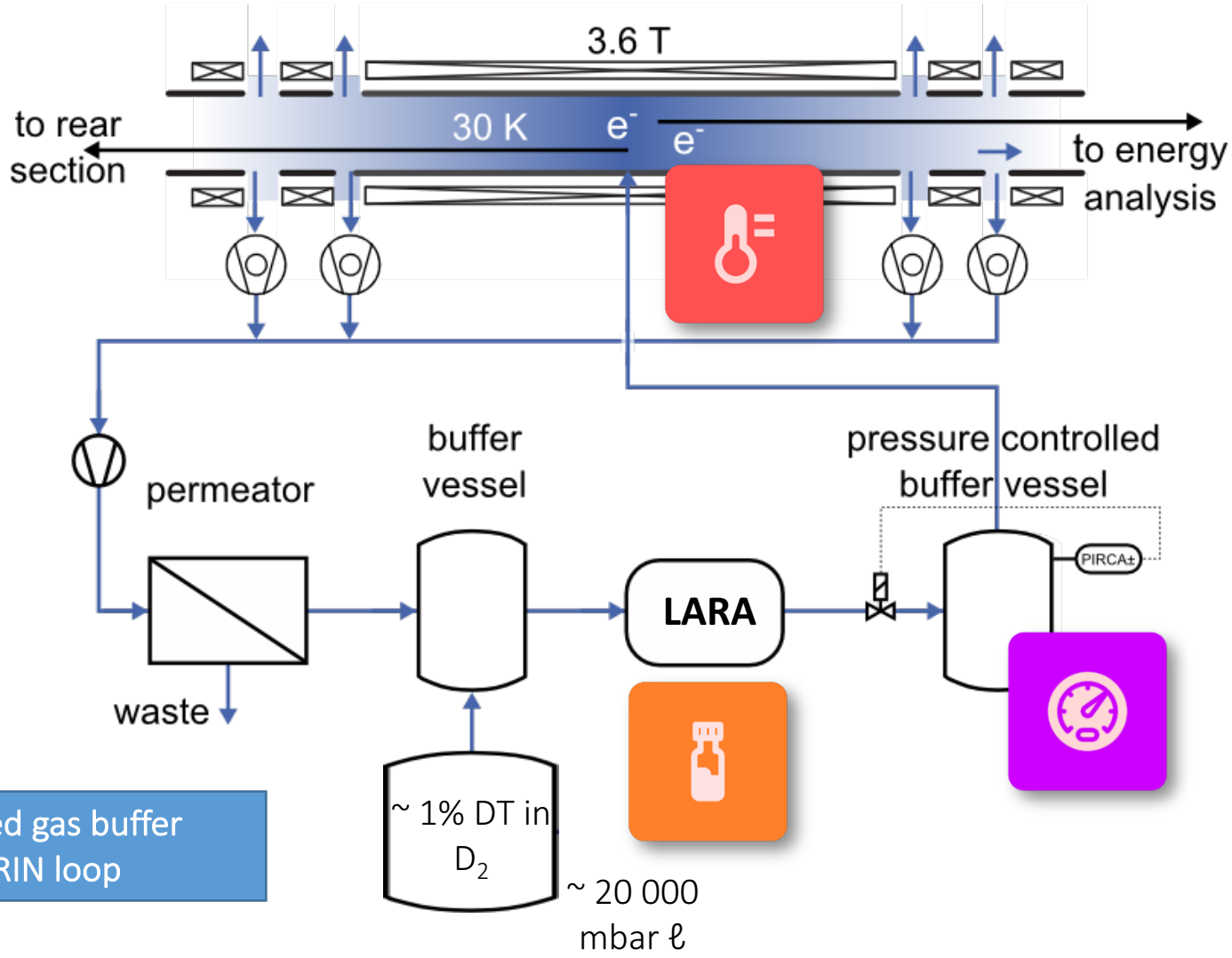


Very first glance at the data (May 19)



- ✓ Good agreement (1%) of model and data without fit
- ✓ Agreement over a wide energy range (1.6 keV below the endpoint)

Stability of source parameters

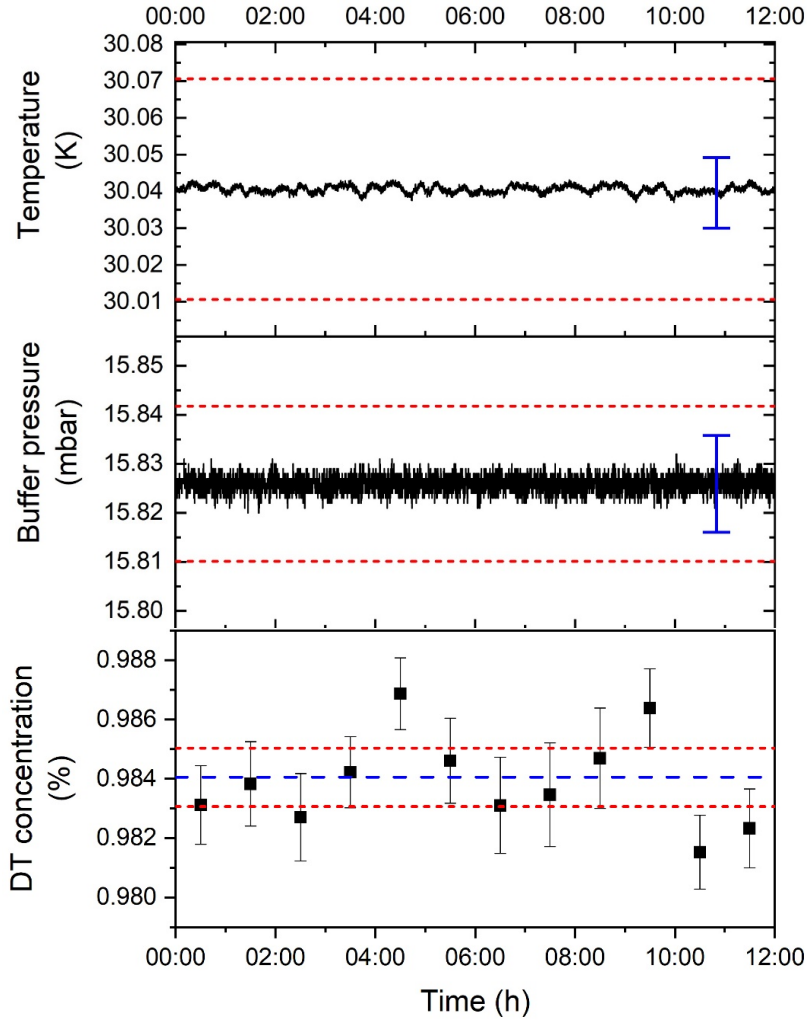


Prefilled gas buffer in KATRIN loop

Relevant parameters:

- Temperature
- Pressure
- Isotopic composition

Stability of source parameters



Blue arrow:
systematic uncertainty

Red dashed line:
± 0.1 % stability
required for neutrino
mass taking

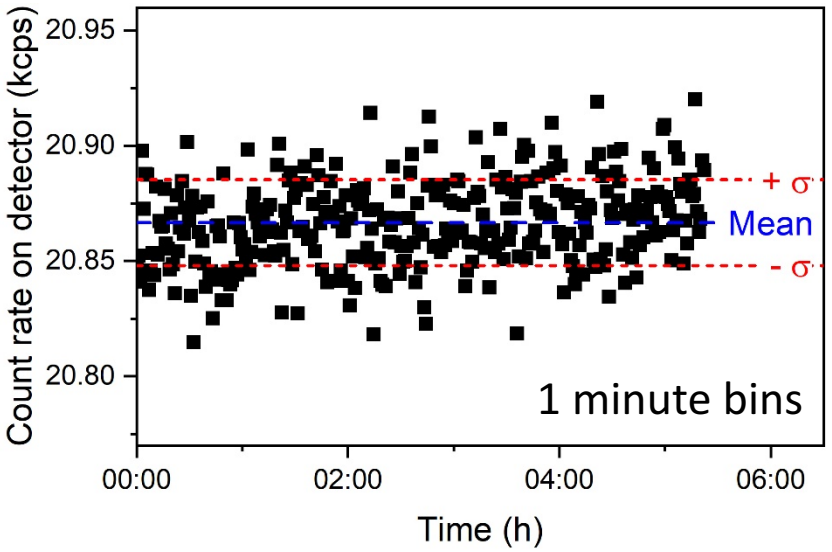
✓ Source parameters are stable and within the specifications

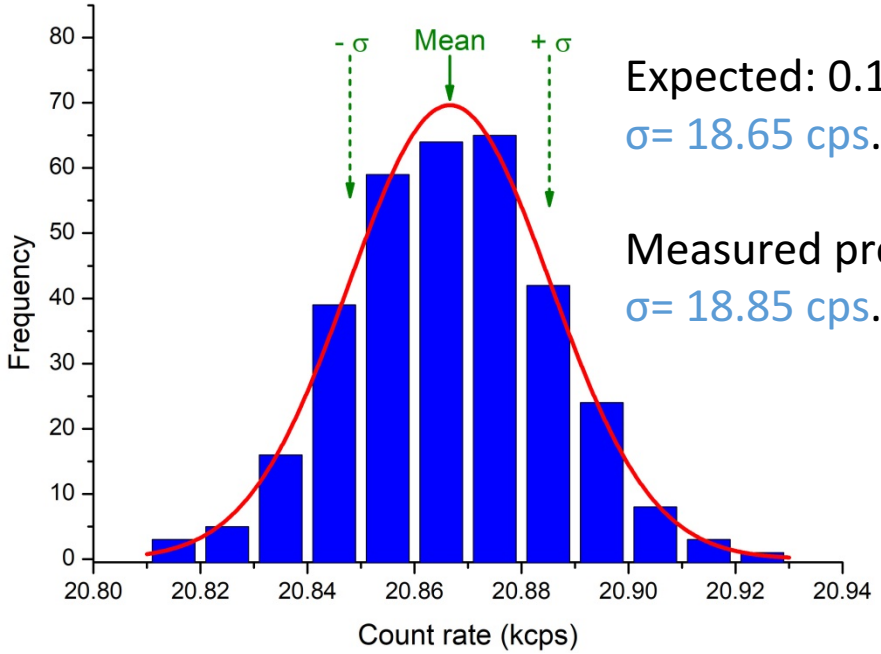
Stability of rate at the detector

- Set spectrometer high-voltage to 1000 V below kinematic endpoint

➢ Constant rate expected

✓ Precision requirement achieved on minute base over 5 h! Integral KATRIN stability on 0.1% level!

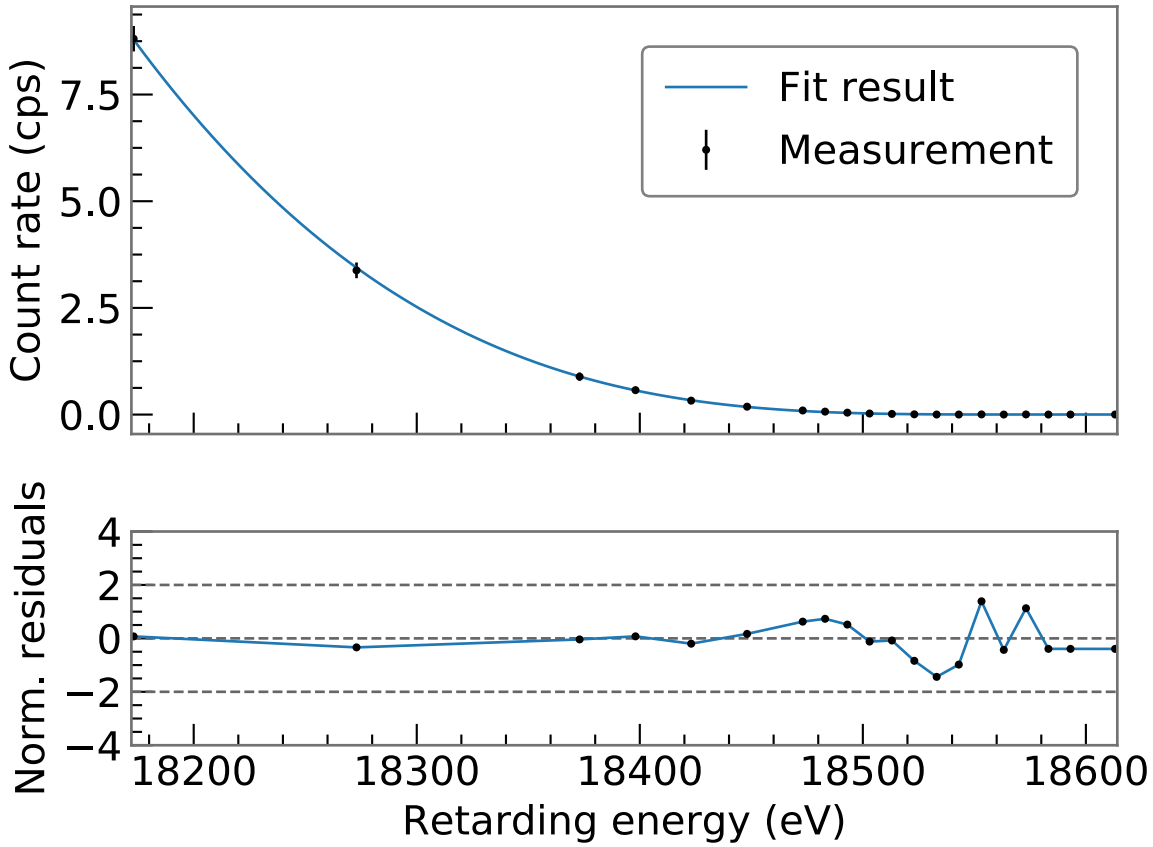


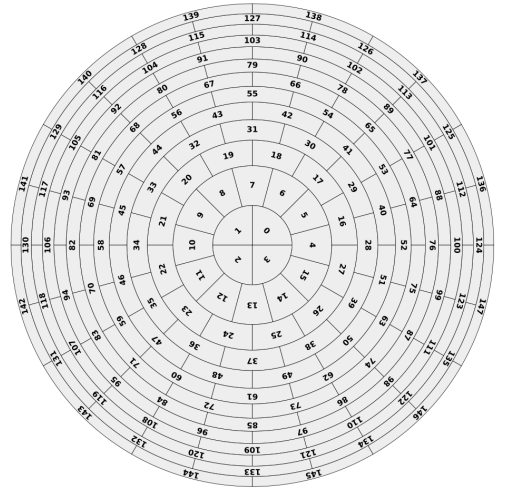


Expected: 0.1%
σ= 18.65 cps.

Measured precision
σ= 18.85 cps.

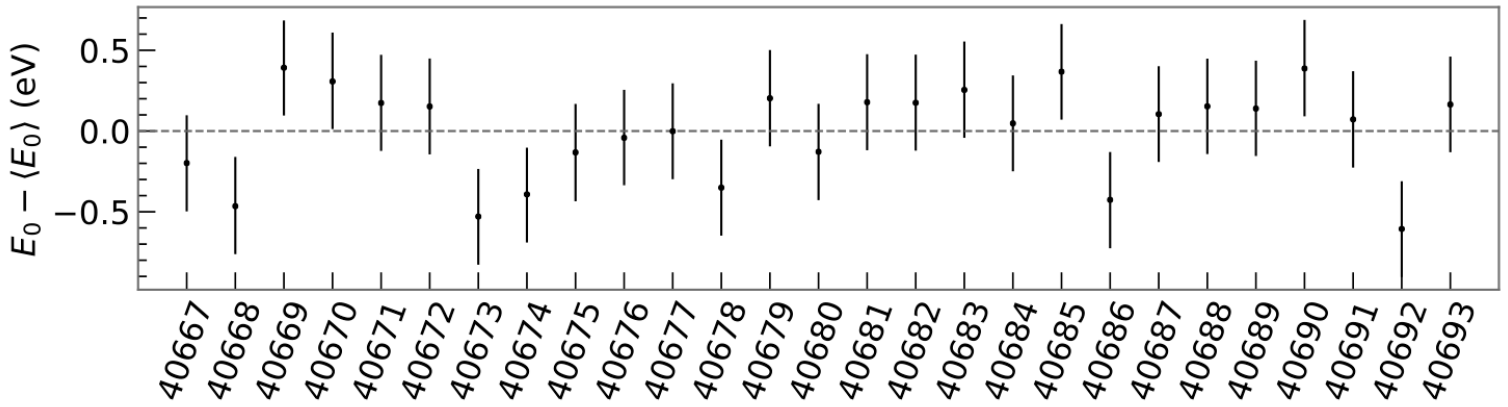
Spectral analysis





- Fit to single pixel (#0) and single run (3h)
- 3 free parameters:
  (effective endpoint, background rate, signal rate, m_ν fixed to zero)
- No residual structure
- Excellent agreement of data and model
  (9.002 @ 17 dof => p-value 94.02 %)
- Fit values are as expected

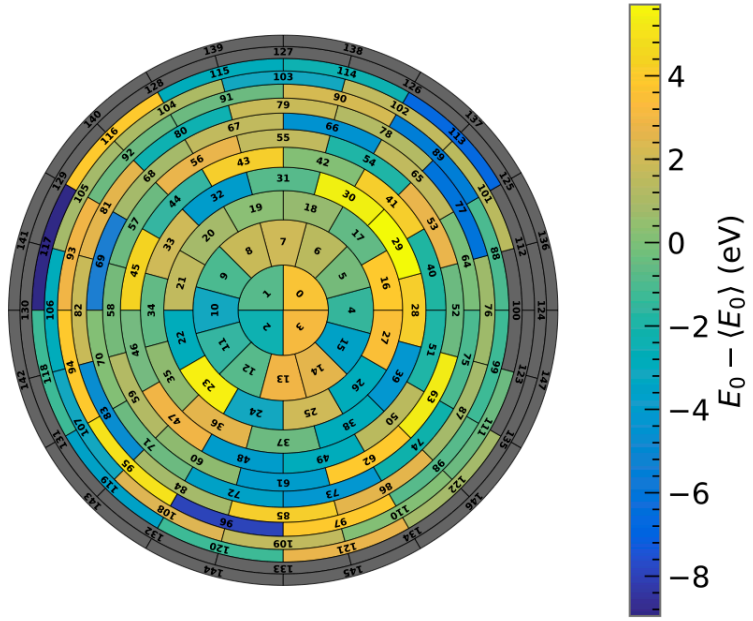
Effective endpoint stability and homogeneity



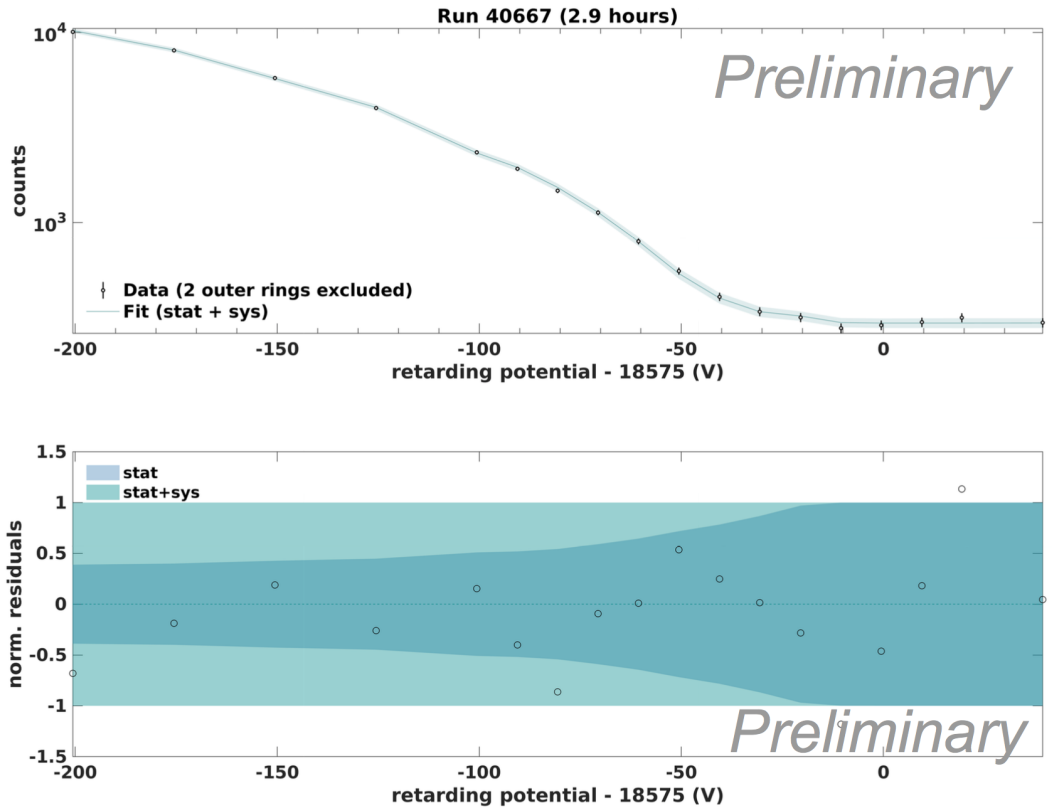
- Fit all pixels simultaneously
- Effective endpoint stable within < 1 eV

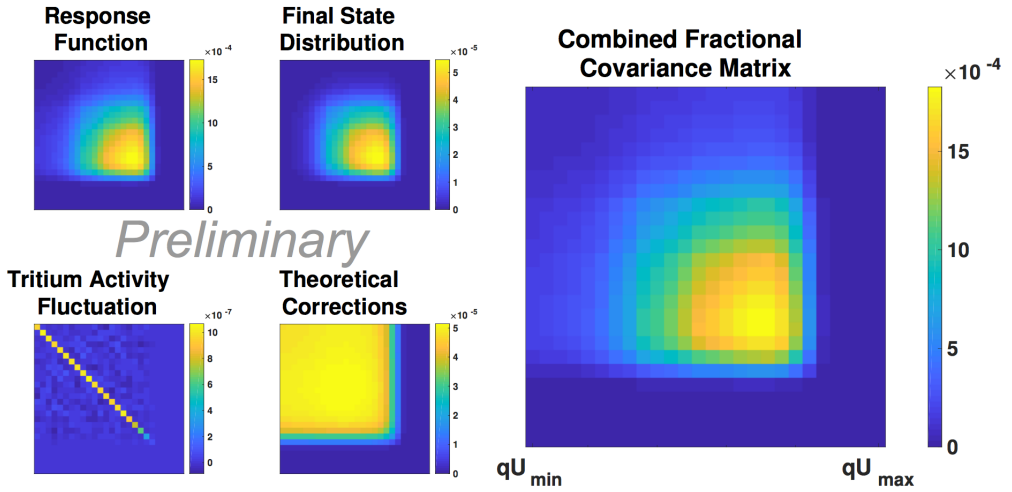
Fit results are stable and behave as expected

- Fit all runs simultaneously
- No feature visible in the pixel map (outer pixels excluded)



Systematic uncertainties

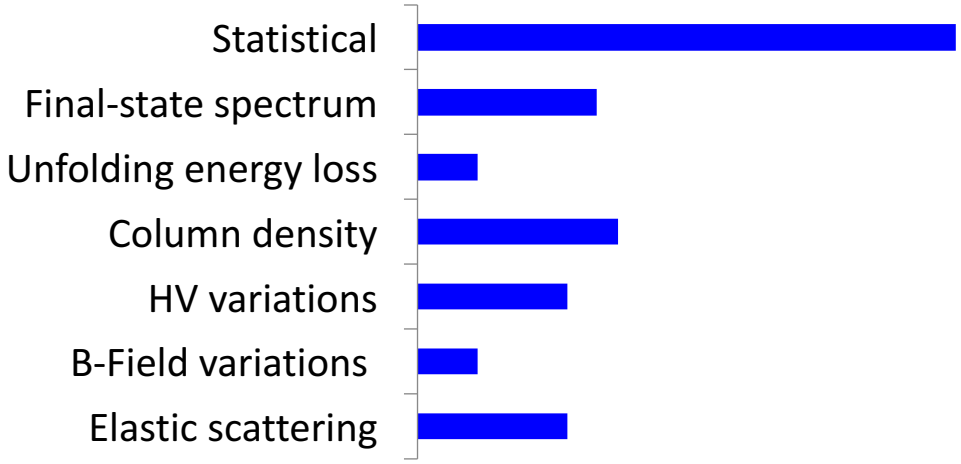


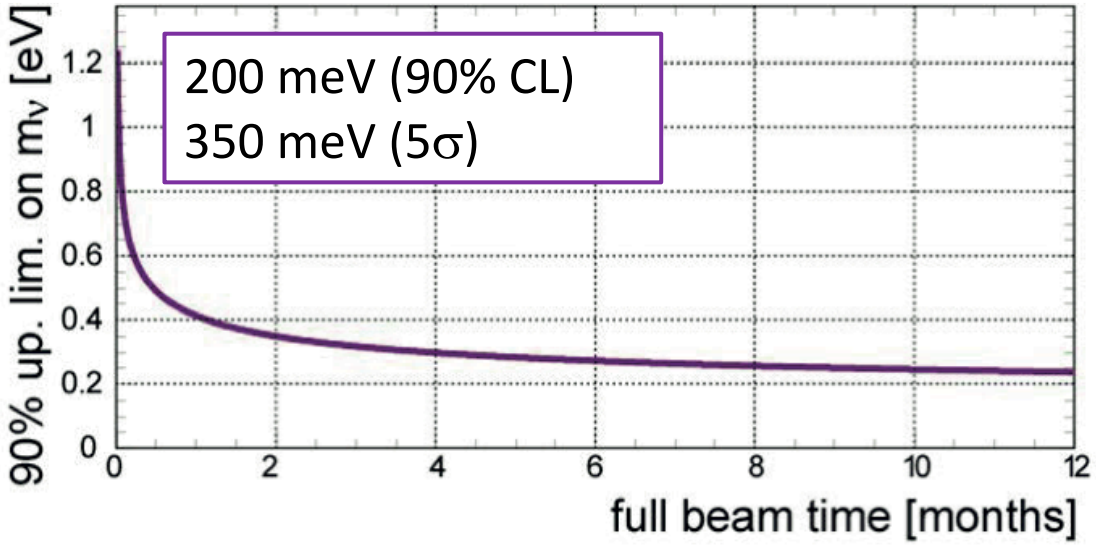


Successful investigation of different techniques:

- Multi-sim Covariance matrix approach
- Nuisance parameters
- Bayesian methods

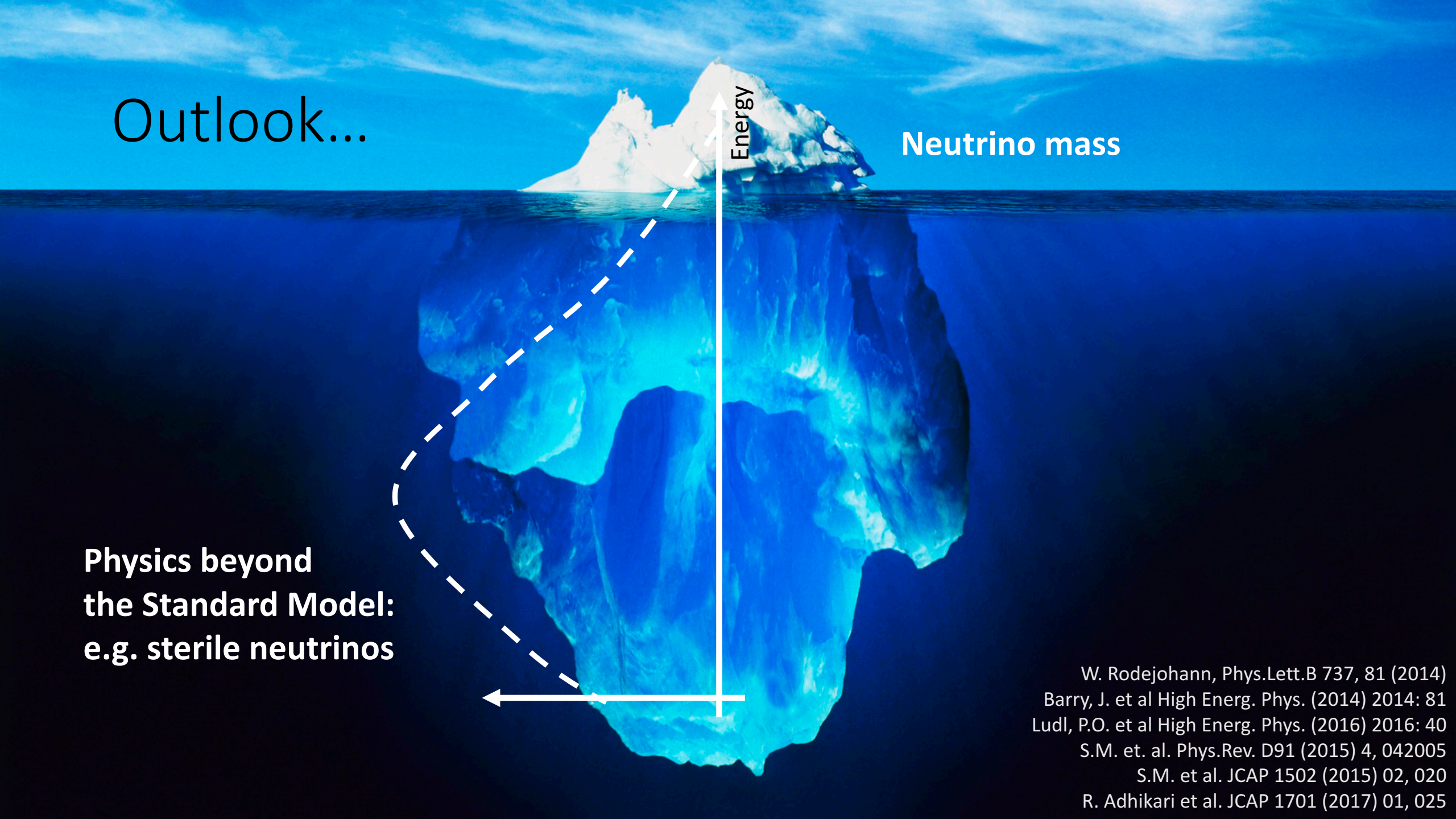
KATRIN's first tritium: May 2018





- Start of nu-mass measurement in March 2019
- Sub-eV sensitivity very quickly after the start of the measurement
- After 3 yrs of data (5 calendar yrs): balance of statistics and systematics

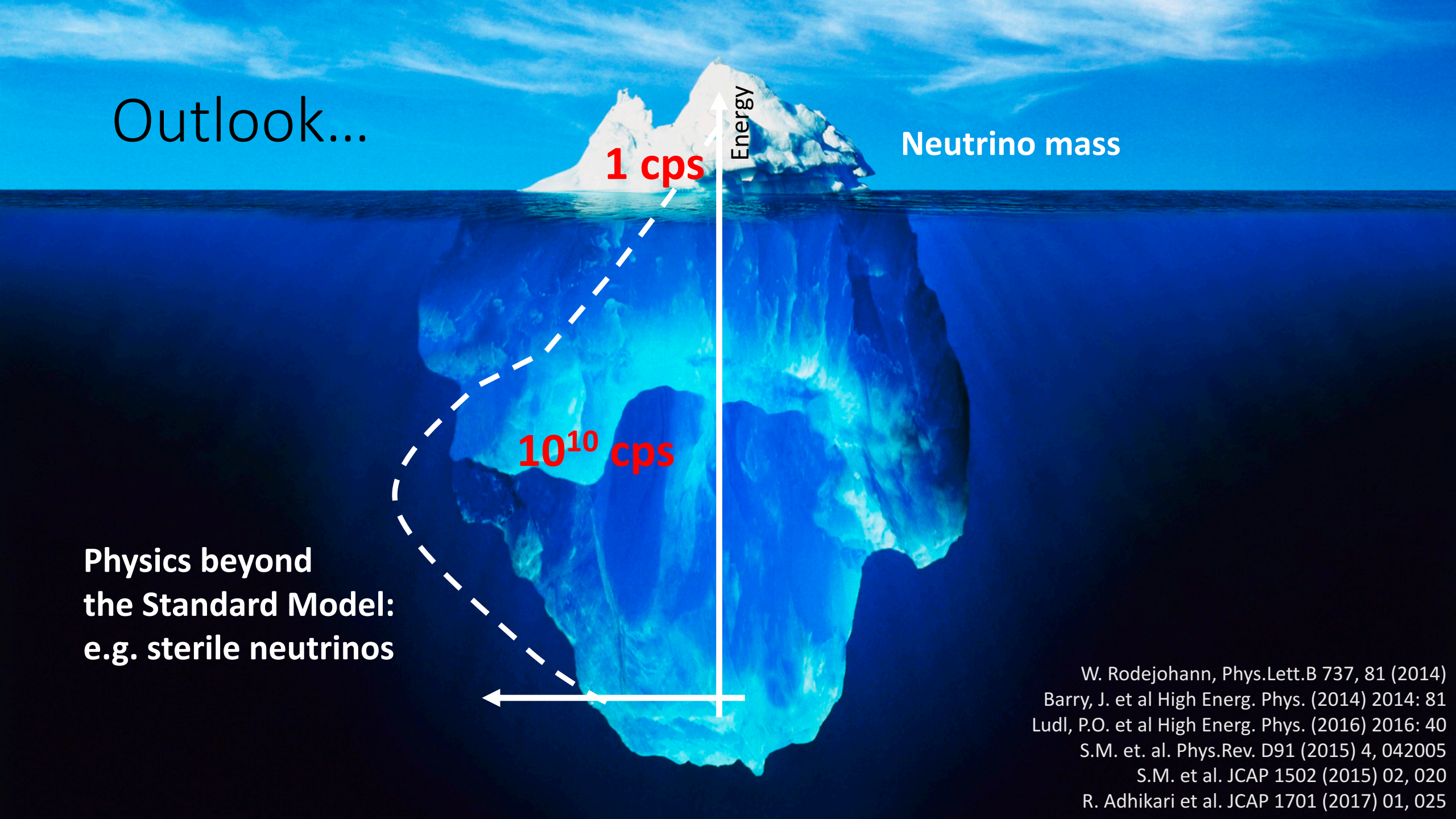
Outlook…



Physics beyond the Standard Model: e.g. sterile neutrinos

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

Outlook…



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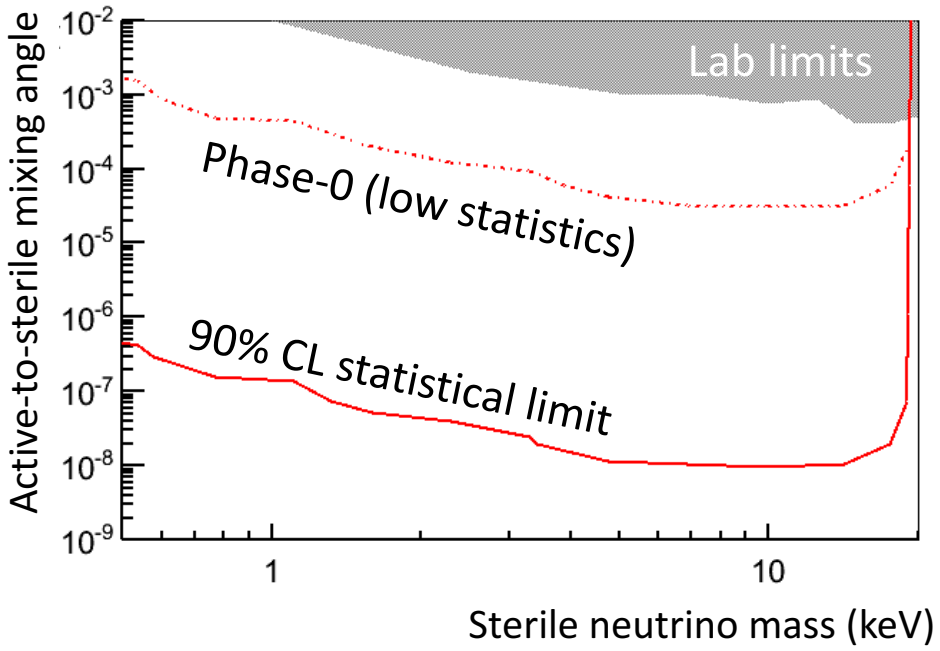
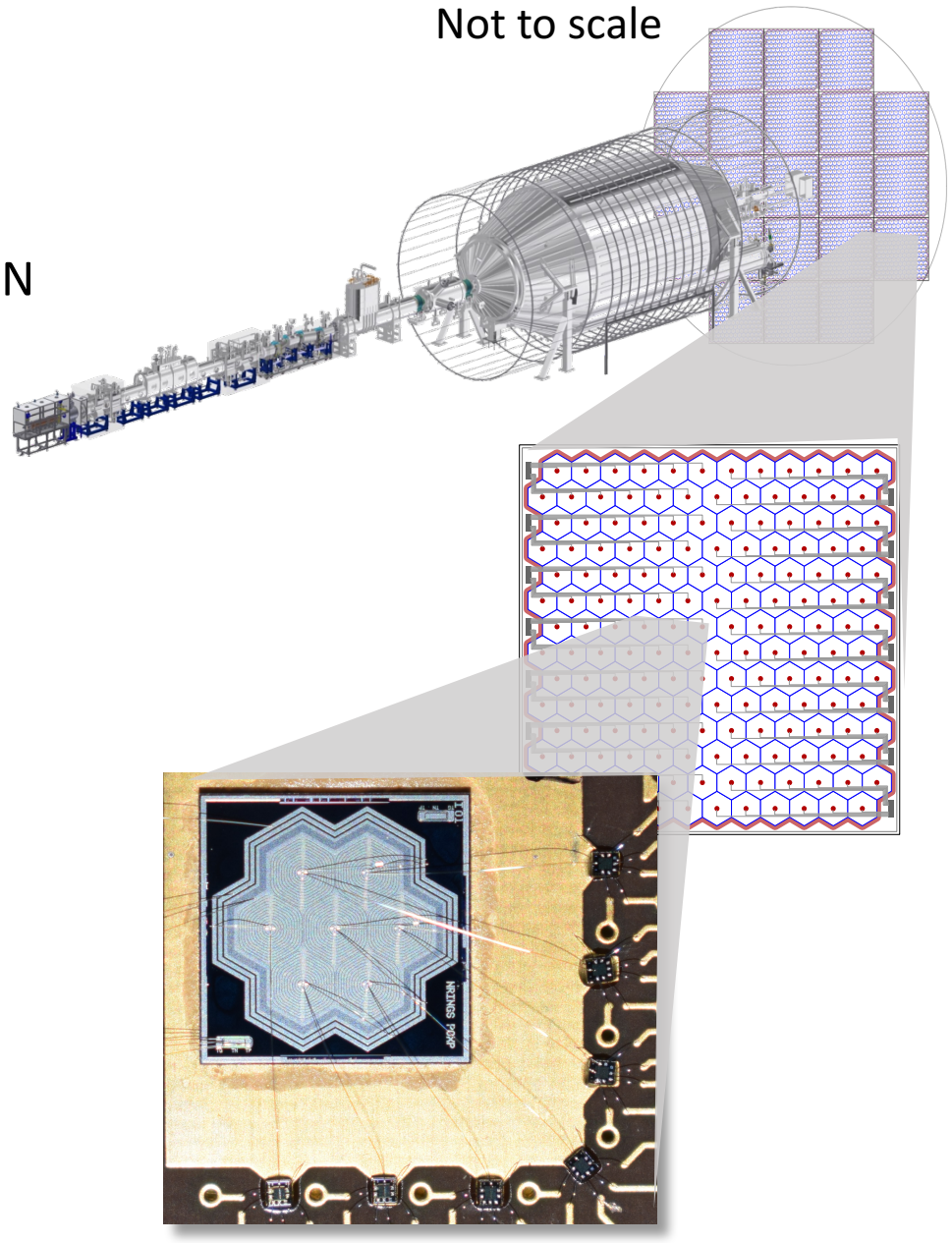
TRISTAN Project

- Multi-pixel Silicon Drift Detector (SDD) System for KATRIN
- Significant improvement of laboratory limits on keV-scale sterile neutrinos expected

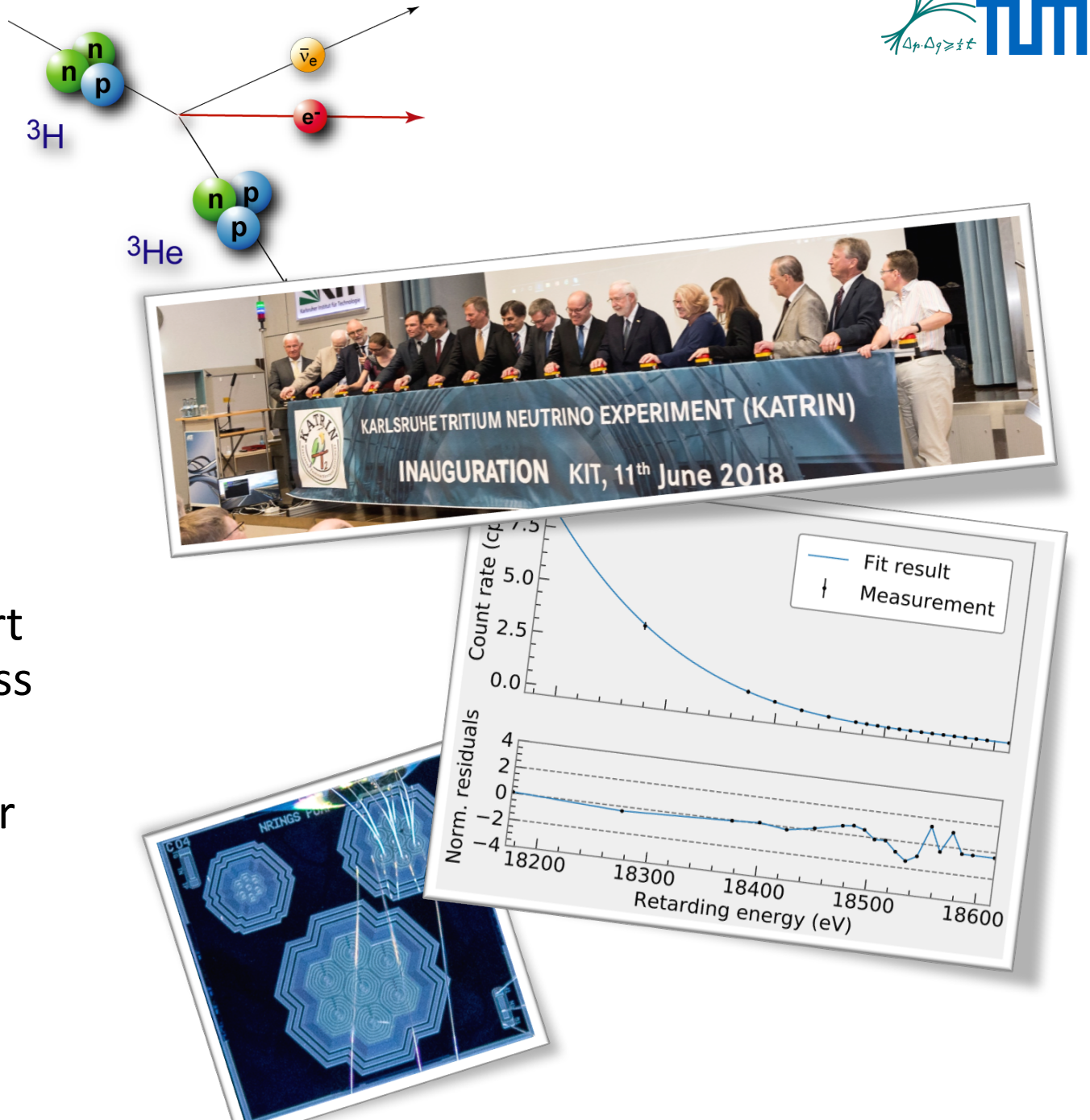




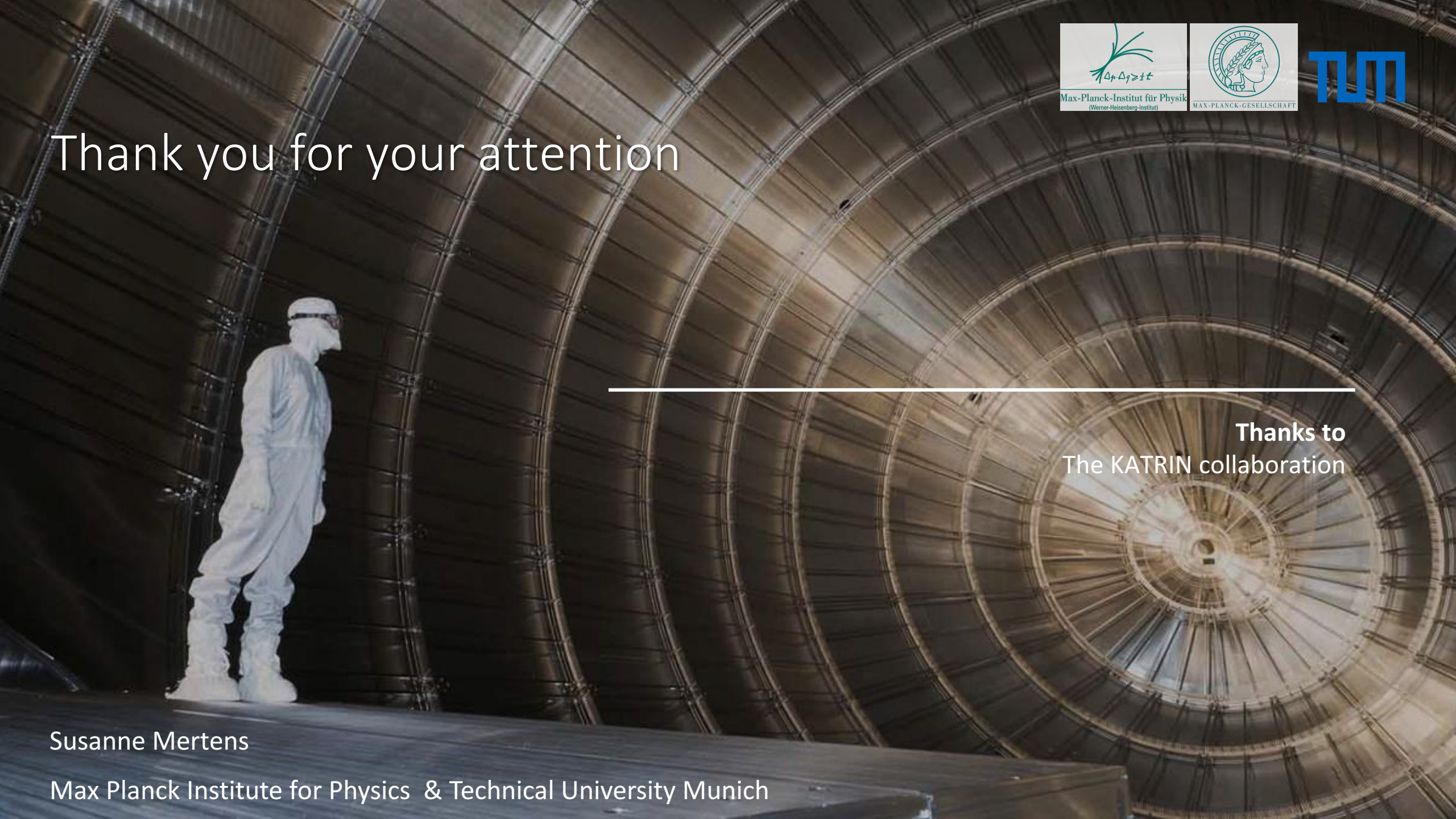
S.M. et al. JCAP 1502 (2015) 02, 020

Summary

- Direct neutrino mass measurement provide a model-independent measurement of the neutrino mass
- KATRIN demonstrated its “tritium-readiness”
- Neutrino mass measurement will start in the beginning of 2019. First nu-mass results expected soon
- KATRIN has the potential to search for sterile neutrinos



Thank you for your attention



Thanks to
The KATRIN collaboration

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