The KATRIN Neutrino Mass Experiment

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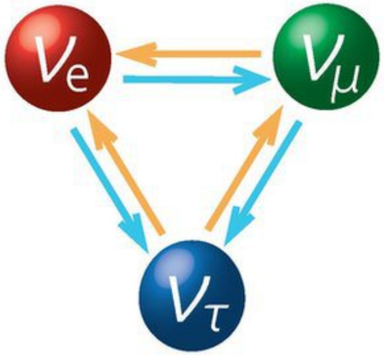
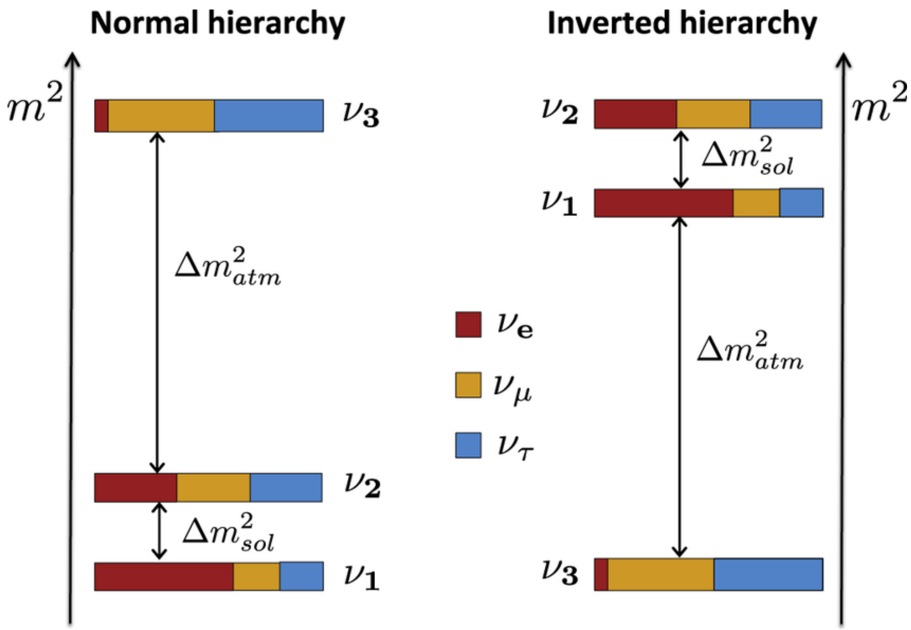
Composite 2019 Workshop, Nov 23, 2019, Guangzhou

Motivation

- Neutrino oscillation → $m_\nu > 0$
- Evidence for BSM physics
- m_ν of major interest for astrophysics and cosmology
- Neutrino Mass Hierarchy

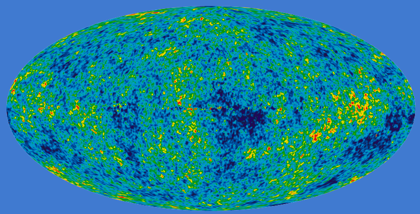




→ $\boldsymbol{m_\nu = ?}$

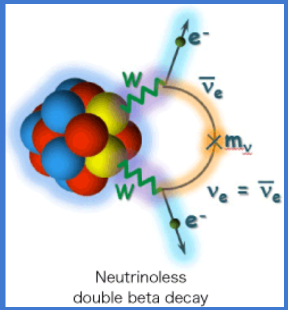
Neutrino Mass

Cosmology & astrophysics



CMB, LSS, etc.

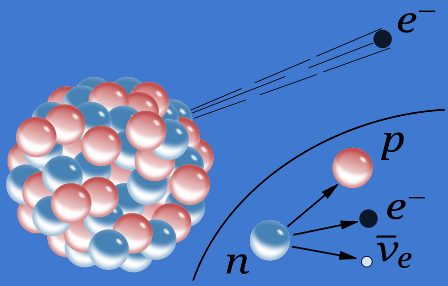
Double-beta Decay



Model-dependent

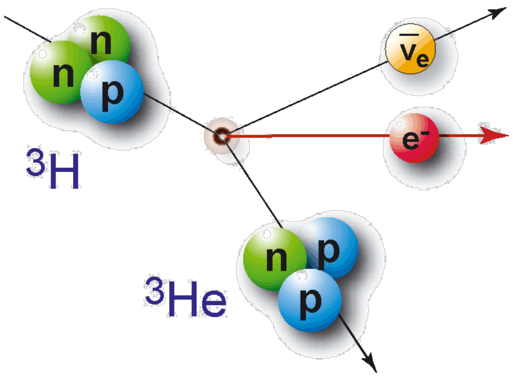
Neutrino mass measurement

Beta Decay



Direct, Model-independent

Tritium Beta Decay

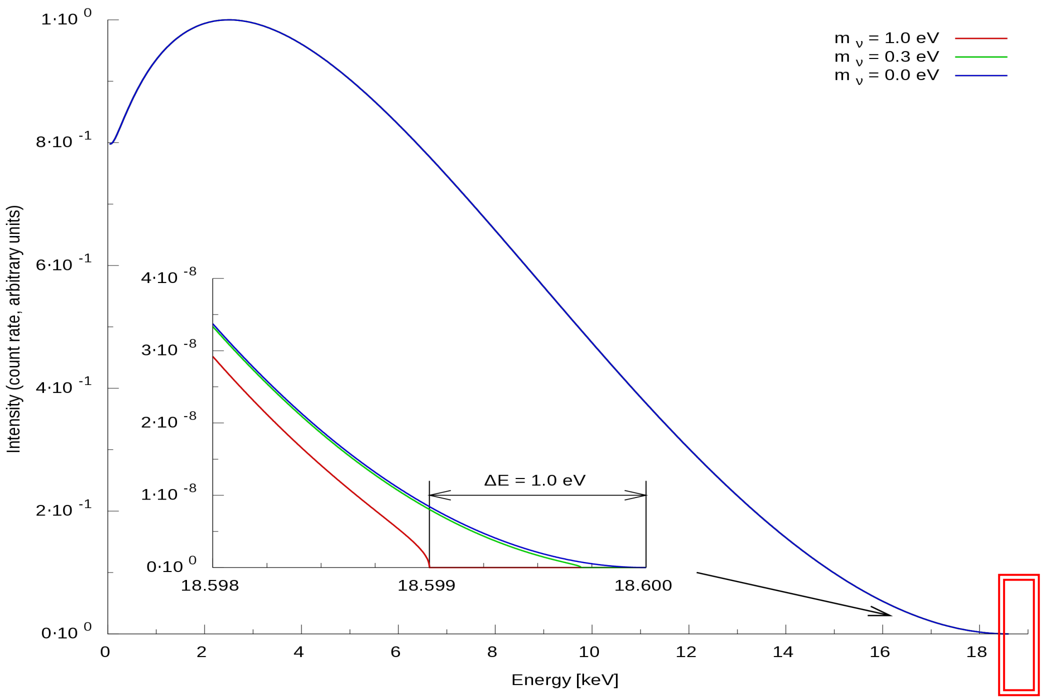


$$\frac{dN}{dE} \propto \sqrt{(E_0 - E)^2 - m_\nu{}^2}$$

Low endpoint energy — $E \backsimeq 18.6$ KeV

Short half-life — $T_{1/2} = 12.3$ yr

Model-independent determination of the neutrino mass by kinematics

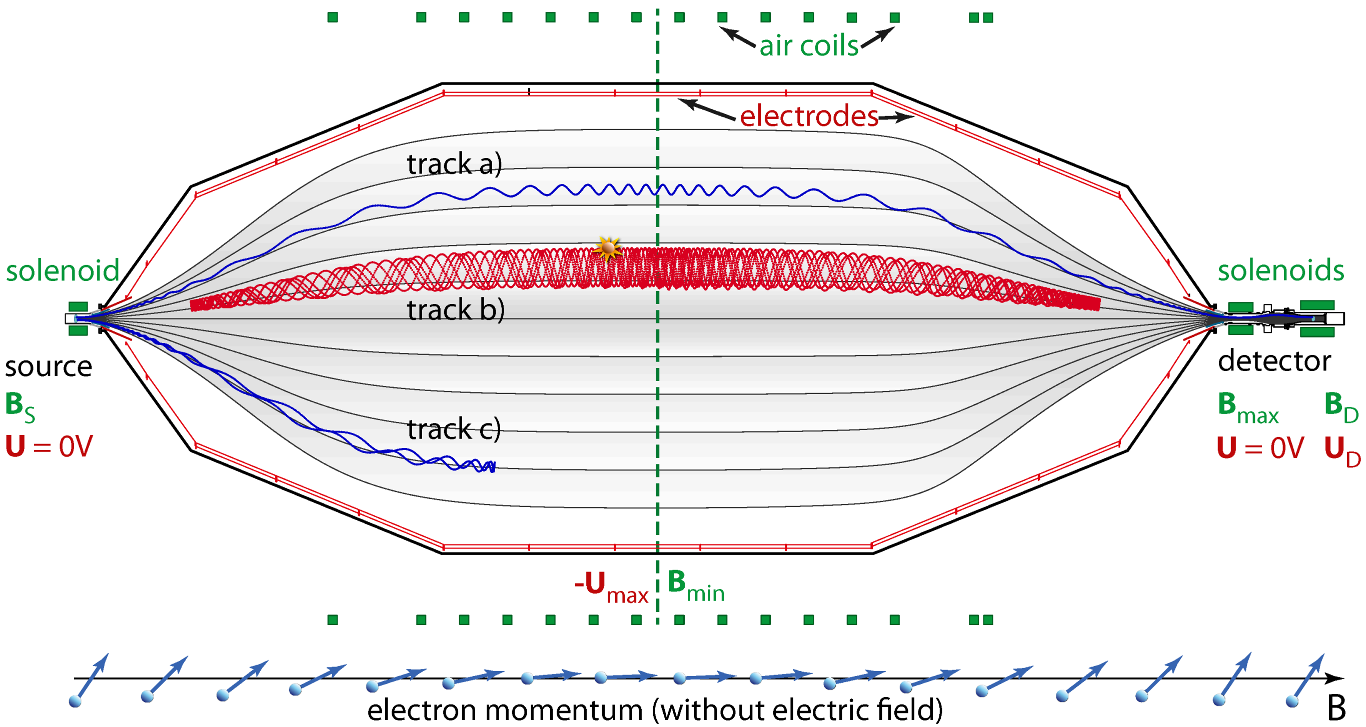


Need excellent energy resolution

High-resolution β spectrometer

Magnetic Adiabatic Collimation & Electrostatic Filter (MAC-E)

- An integrating high-energy pass filter
- Energy Resolution of KATRIN spectrometer:
  - $\Delta E \sim 0.93$ eV at 18.6 KeV



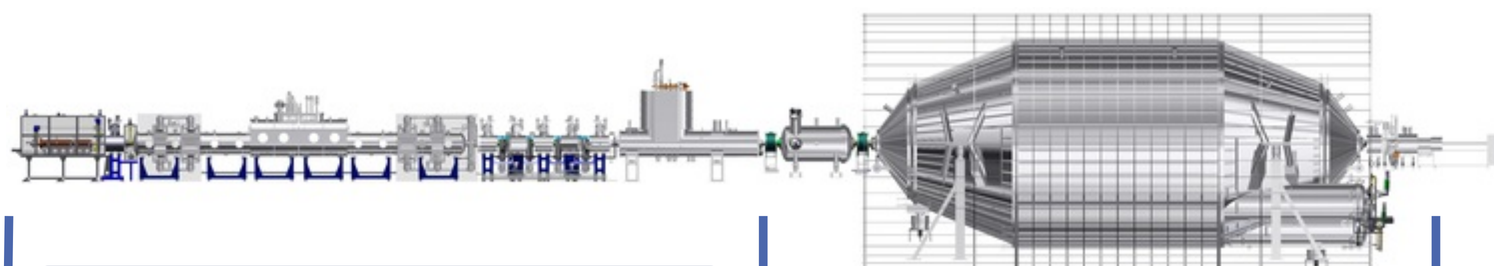
$$\mu = \frac{E_\perp}{B} = const$$

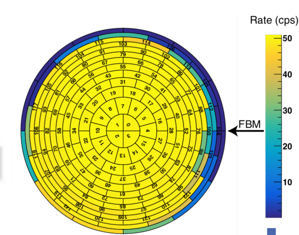
$$\frac{\Delta E}{E} = \frac{B_{min}}{B_{max}}$$

KATRIN

KATRIN - **Ka**rlsruhe **Tri**tium **N**eutrino Experiment

- Located in Karlsruhe Institute of Technology (KIT), Germany
- Ultra-luminous tritium source
- Goal: measure neutrino mass with a sensitivity of 200 meV/c^2

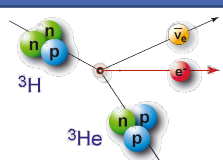


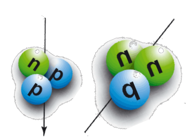


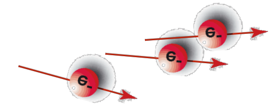
Source and Transport Sections

Spectrometer

detector



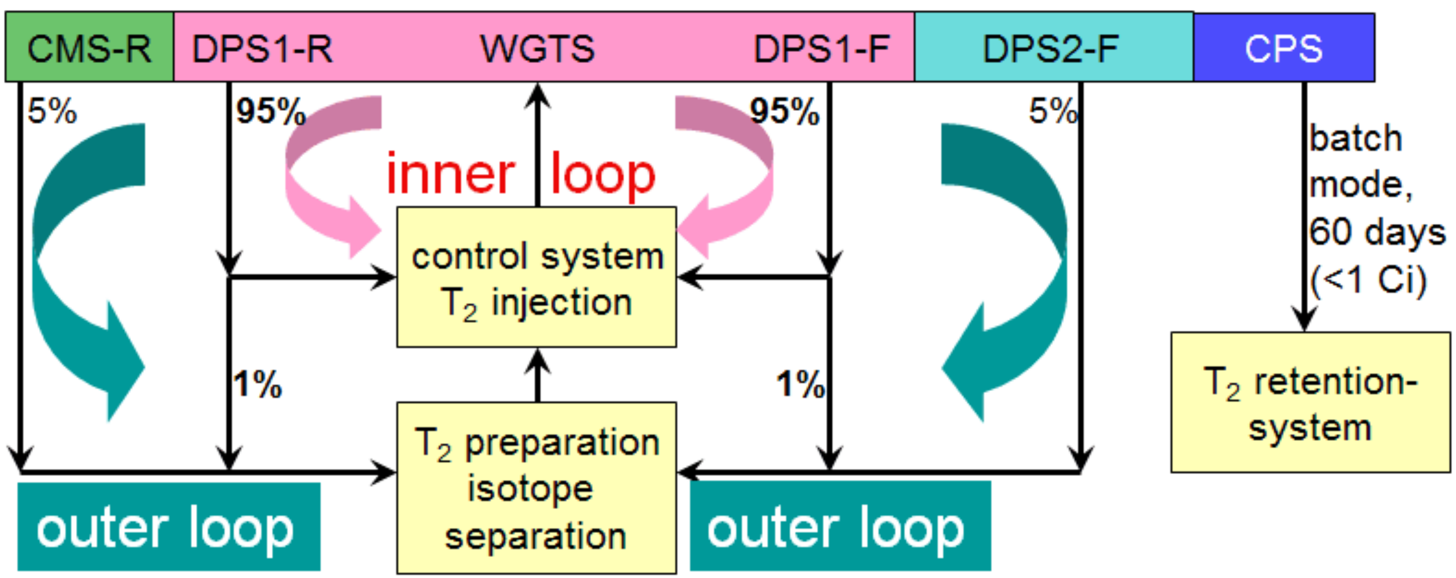




KATRIN Tritium Source

Windowless gaseous tritium source

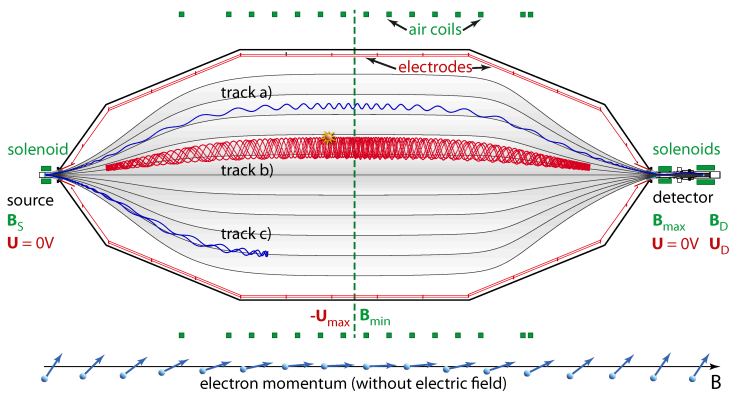
- High luminosity (10^{11} Bq)
- Ultra-stable tritium source (Stable to 0.1% level)
- High isotopic purity ($\varepsilon_T > 95\%$)

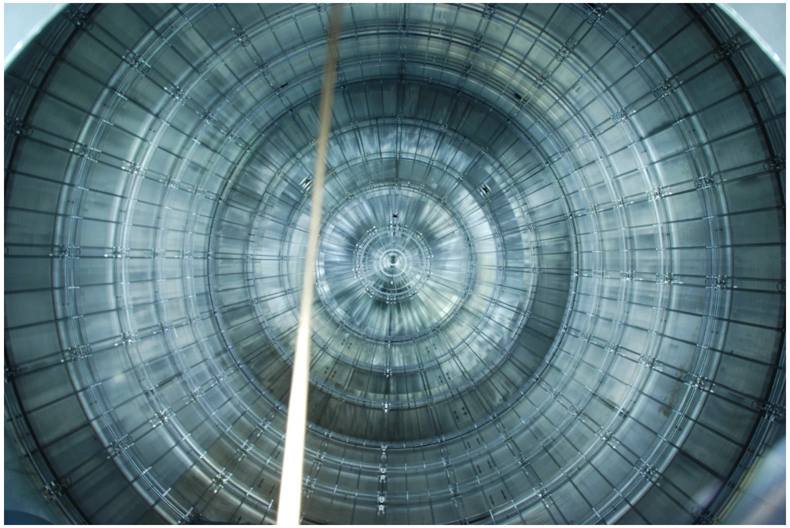


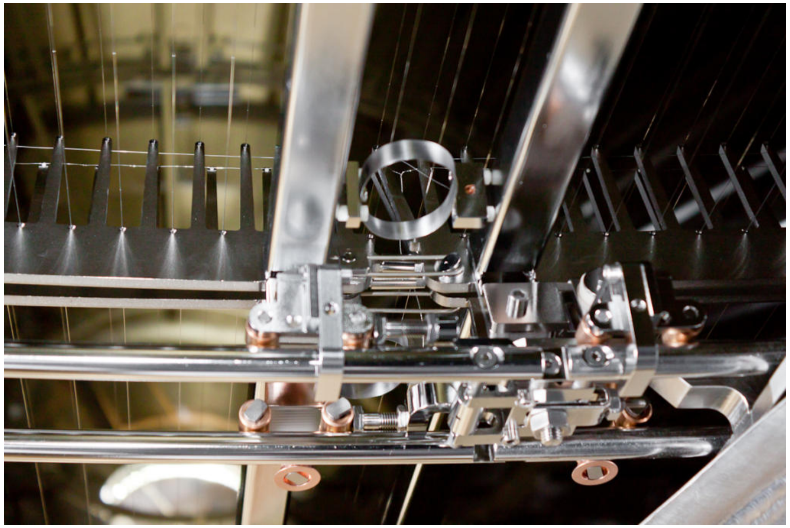
KATRIN Main Spectrometer

UNIVERSITY of WASHINGTON

KATRIN will measure the integrated beta decay spectrum



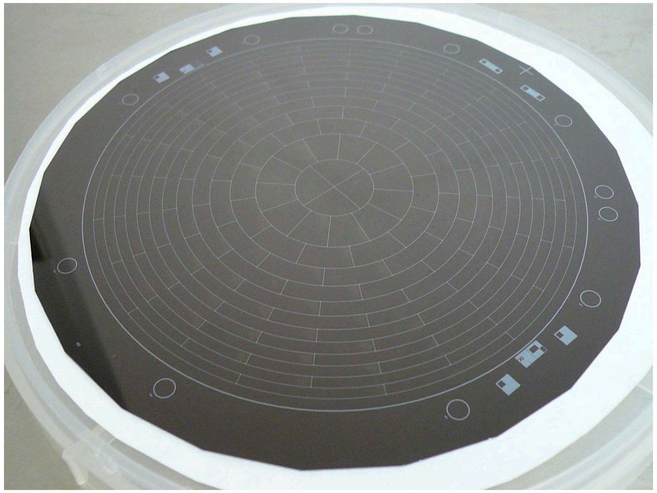


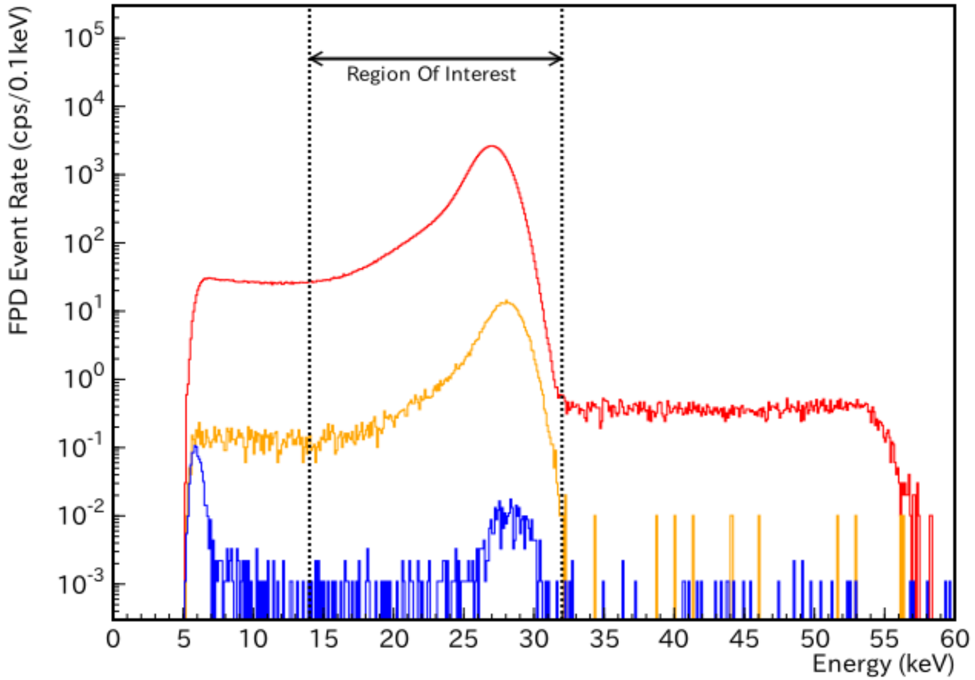


KATRIN Detector

Focal Plane Detector

- Si-PIN diode
- 148 pixels
- low intrinsic background
- Is able to provide 30 kV of "post-acceleration" to the electrons





Region of interest used in first neutrino mass measurement:
14 – 32 KeV

Data Taking

May 18th, the WGTS was operated with tritium for the first time.

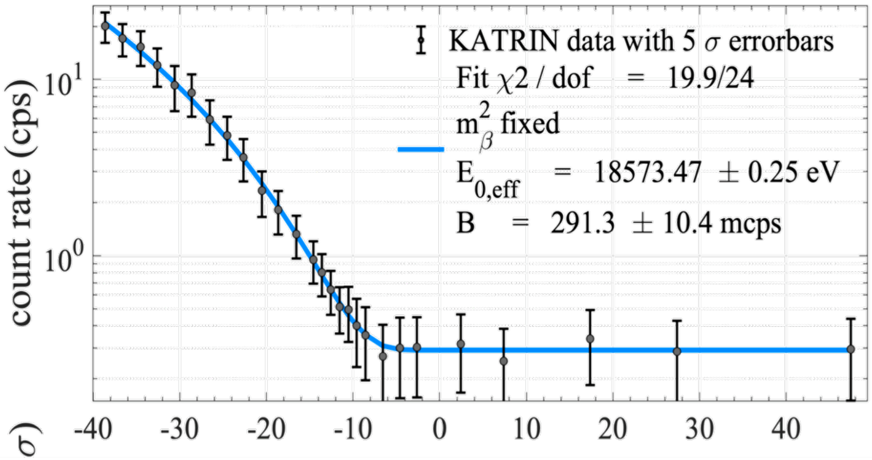
First Neutrino Mass Campaign

4-week long measuring campaign in spring 2019

- Goal: 1eV neutrino mass sensitivity
- High-purity tritium
- High source activity:
  - 2.45 x 10^{10} Bq
- Tritium gas density:
  - 22% nominal density

Tritium Scanning:

- 274 scans of tritium spectrum
  - [E_0 – 40 eV, E_0 + 50 eV]
  - 2 hours per run
  - Alternating up-/down- scans

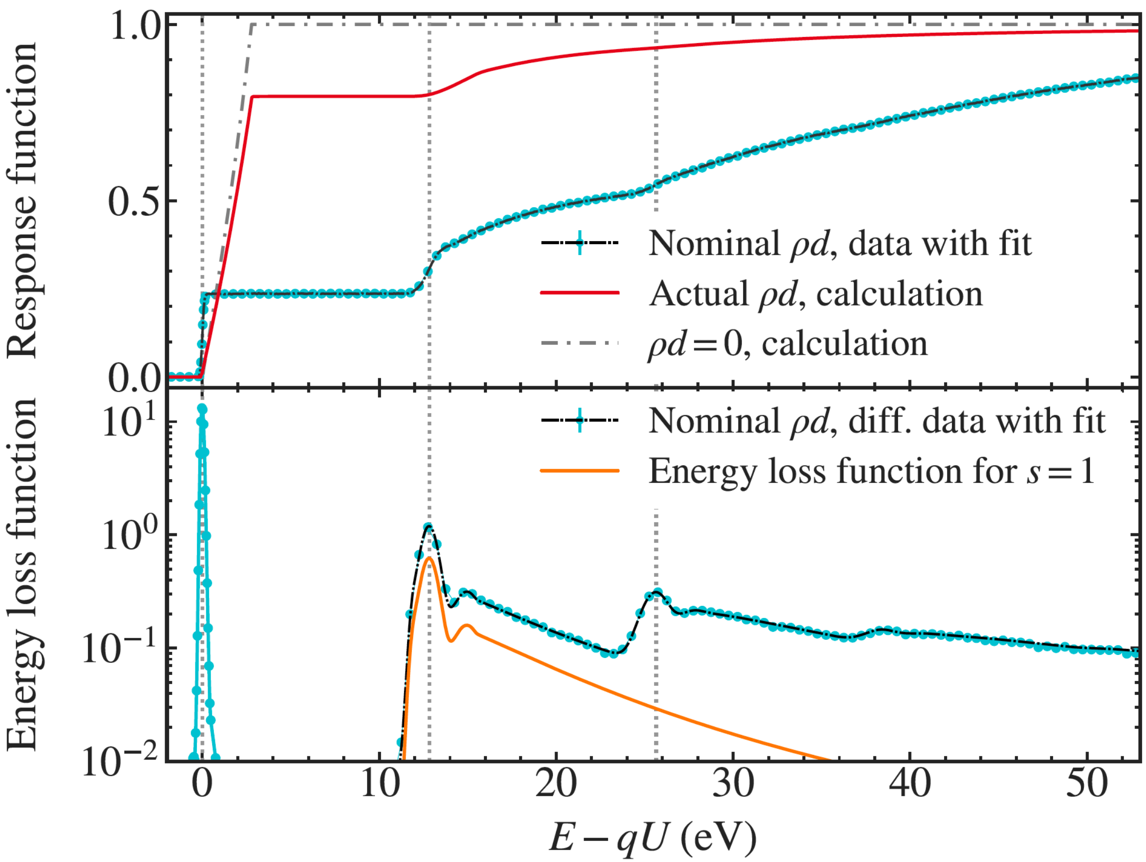


Analysis – modelling of data

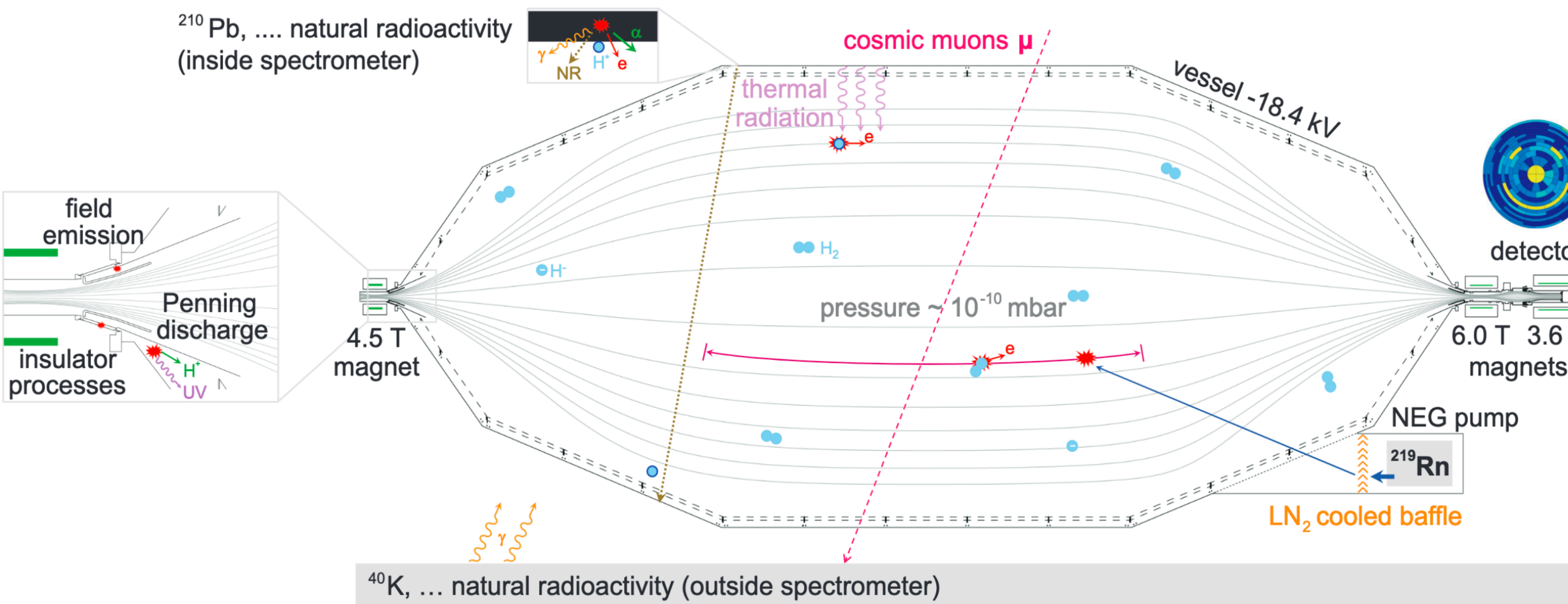
- Model of the spectrum =
  Beta-decay spectrum ⊗
  Response function

- The response function is measured with an e-gun located at the rare section

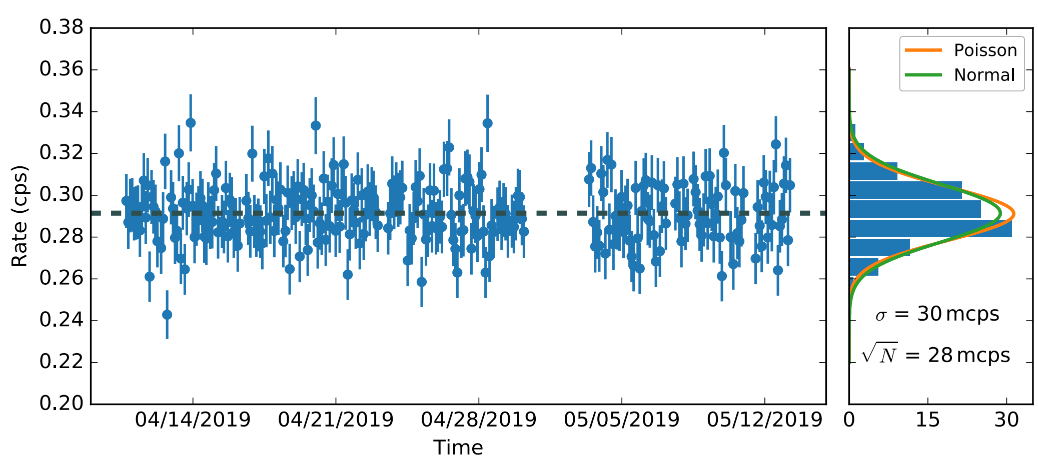
- The propagation of the electrons in the beamline and spectrometer is well modeled by simulation software.



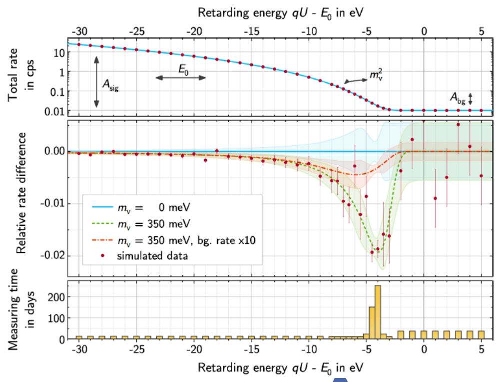
Analysis – Background



The background rate is measured by setting qU above the endpoint.



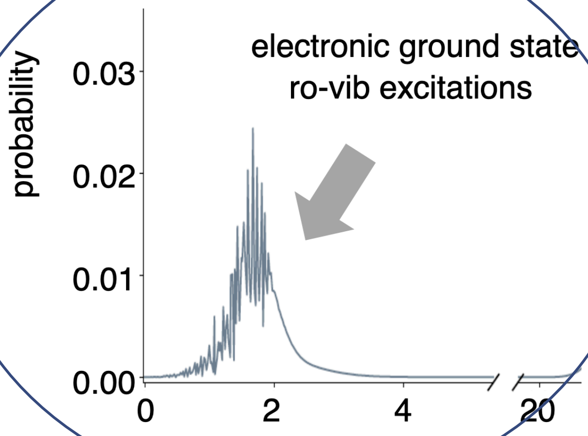
Analysis – bias-free analysis



Data blinding:
Test & freeze analysis methods using simulated data

Bias free analysis

Model blinding:
Smeared Final State Distribution



Three fitting team:

- KaFit
- Fitrium
- Samak

Cross check results

Analysis – Fitting result

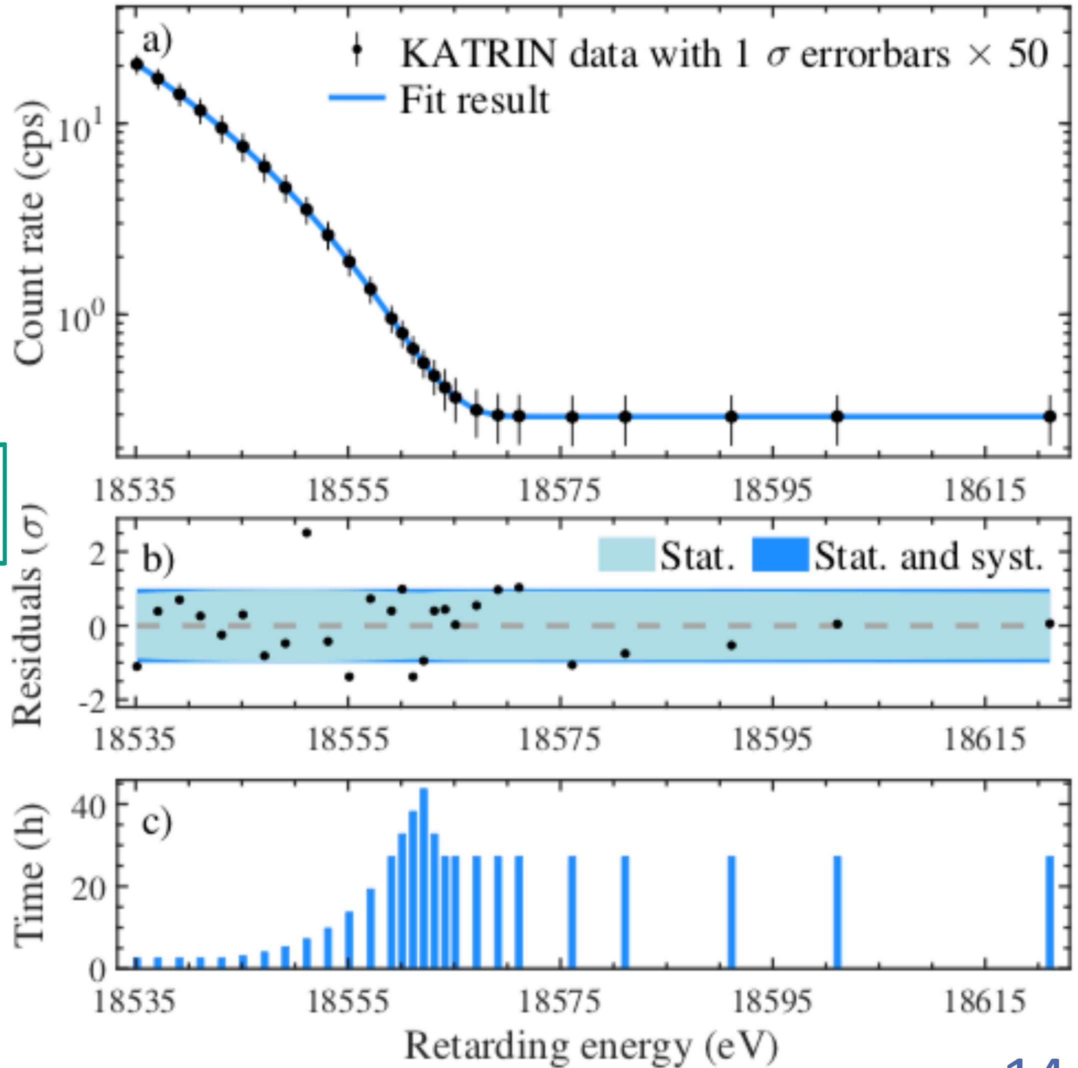
- Fit of experimental spectrum to model with 4 parameters:
  - M_v^2 : neutrino mass
  - E_0 : beta-decay endpoint
  - A_{sig}, A_{bkg} : signal and background amplitude

- Neutrino mass: best fit results

  E_0 = (18573.7 +- 0.1) eV

$$m^2(\nu_e) = \left(-1.0 \begin{array}{l} +\,0.9 \\ -\,1.1 \end{array}\right) \mathrm{eV}^2 \ (90\%\ \mathrm{CL})$$

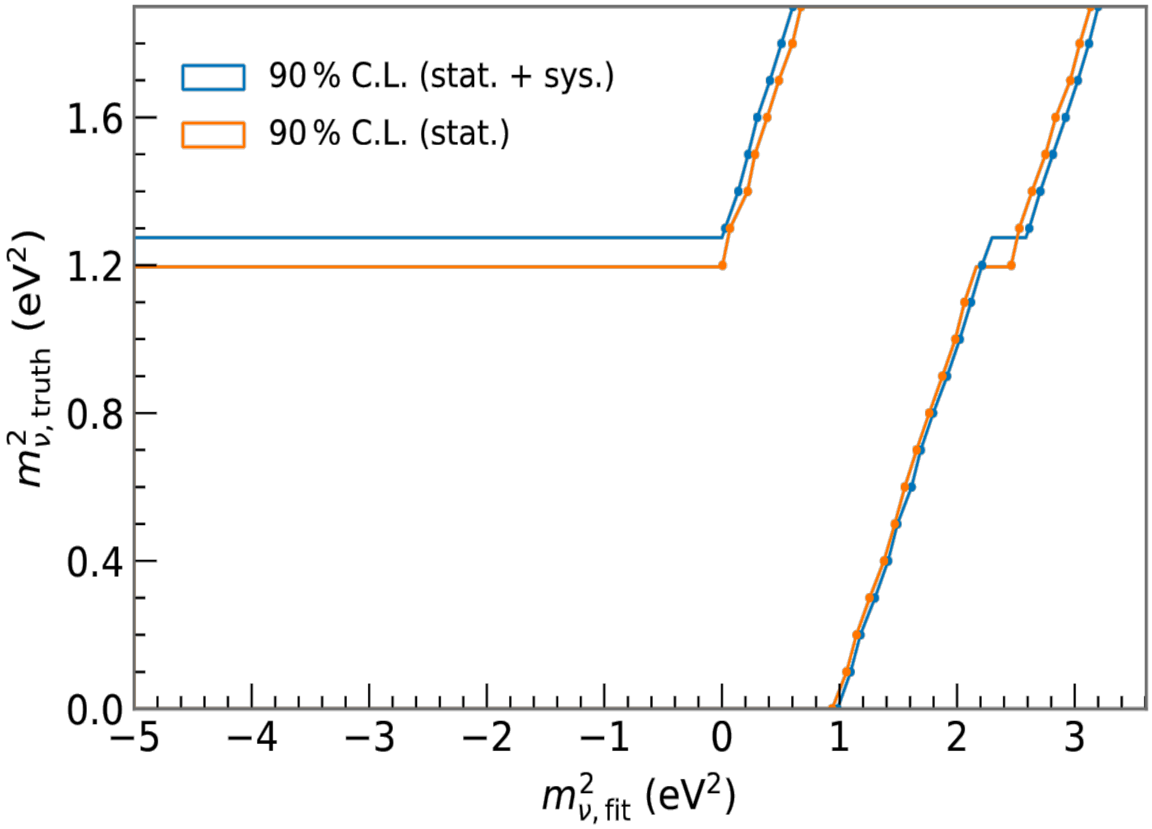
- Goodness-of-fit:
  Chi^2/dof = 21.4/23
- Two uncertainty propagation methods
  - Covariance matrix
  - MC propagation



Upper limit on neutrino mass

- KATRIN upper limit on neutrino mass:
  $m_\nu < 1.1\ eV$ (90%)

- Here we follow the Lokhov and Tkachov method



A.V. Lokhov, F.V. Tkachov, Phys. Part. Nucl. 46 (2015) 347

Upper limit on neutrino mass

- KATRIN: probe neutrino mass via tritium decay
  - High-luminosity tritium source
  - High-resolution MAC-E spectrometer
  - Goal: 200 meV/c^2 sensitivity

- First neutrino mass compaign:
  - T_2 gas with high purity was used
  - Best fit result on neutrino mass:
  - Upper limit: $m_\nu < 1.1$ eV (90% CL)

$$m^2(\nu_e) = \left(-1.0 \,{}^{+\,0.9}_{-\,1.1}\right) \mathrm{eV}^2 \ (90\%\ \mathrm{CL})$$

- Paper: "An improved upper limit on the neutrino mass from a direct kinematic method by KATRIN"

The KATRIN Collaboration

cea

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Westfälische Wilhelms-Universität Münster

BERKELEY LAB

The Czech Academy of Sciences

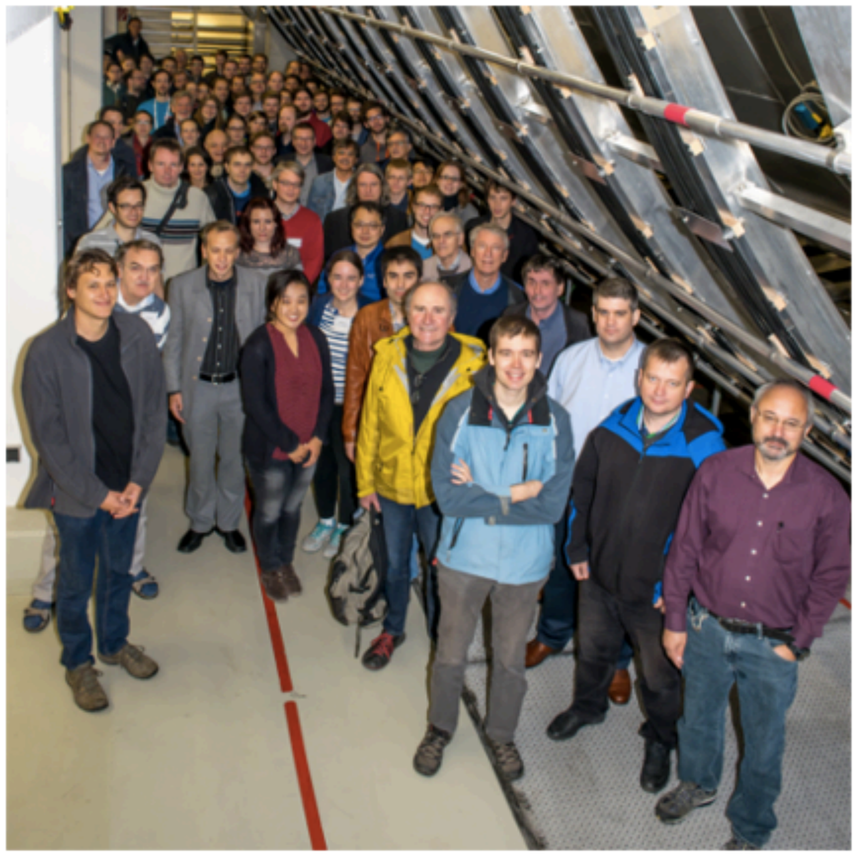
Massachusetts Institute of Technology

Hochschule Fulda University of Applied Sciences

Russian Academy of Sciences

Max-Planck-Institut für Physik

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL



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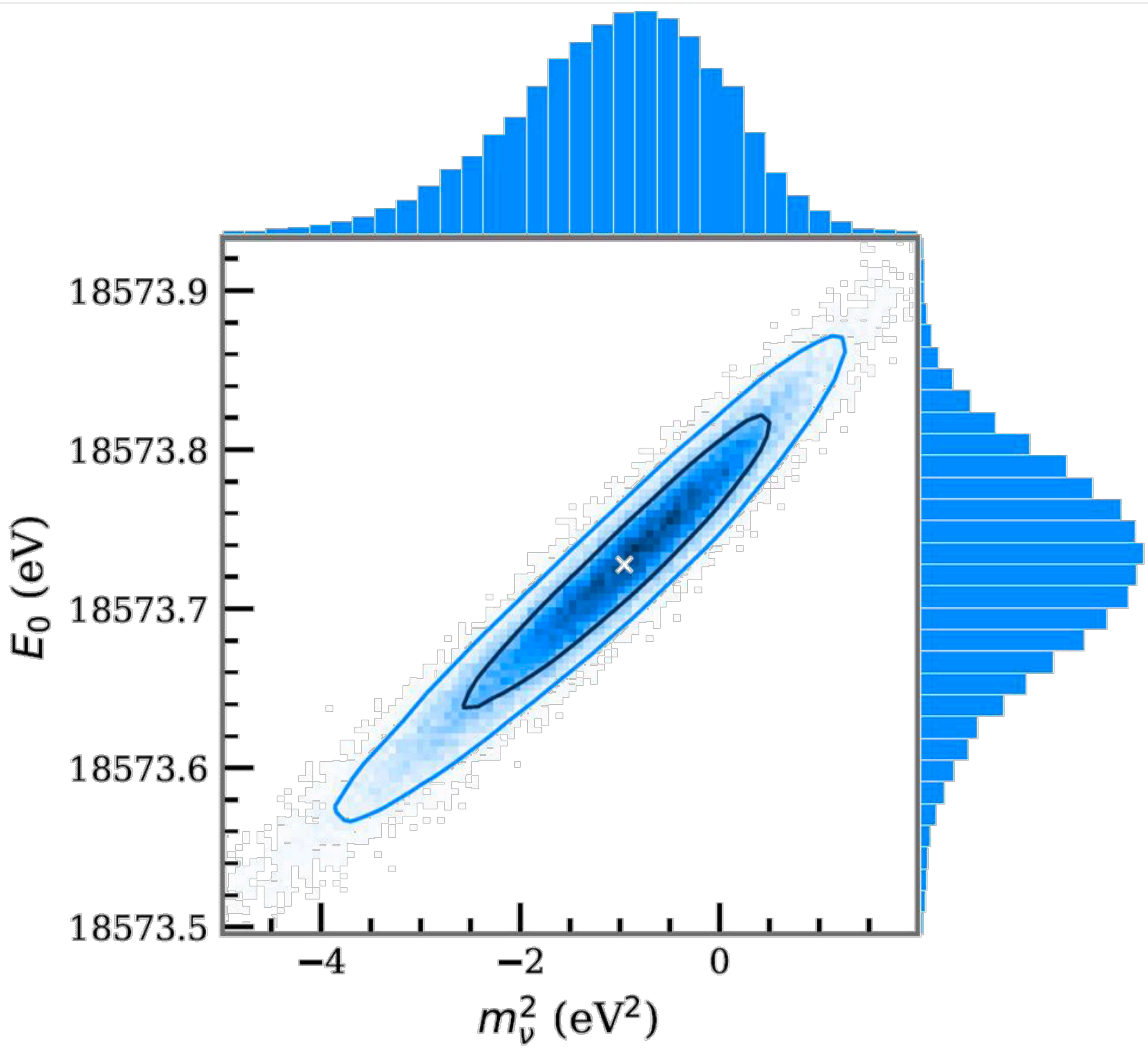
Bergische Universität Wuppertal

Back Up


18573.9
18573.8
18573.7
18573.6
18573.5
E_0 (eV)
−4
−2
0
m_ν^2 (eV^2)

best-fit result corresponds to a 1-σ statistical fluctuation to negative $m^2(\nu_e)$

- p-value is derived from 13 000 MC samples with $m^2(\nu_e) = 0$ and properly fluctuated σ_{stat} and σ_{syst}

p-value = 0.16