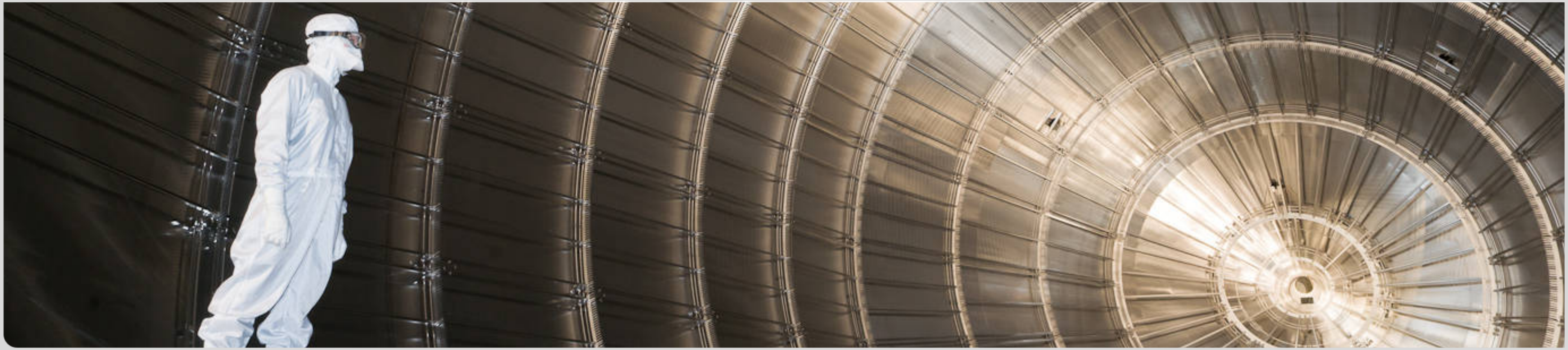
“The neutrino mass experiment KATRIN”

Florian Fränkle for the KATRIN collaboration

Institute for Nuclear Physics (IKP), Karlsruhe Institute of Technology (KIT)



Outline

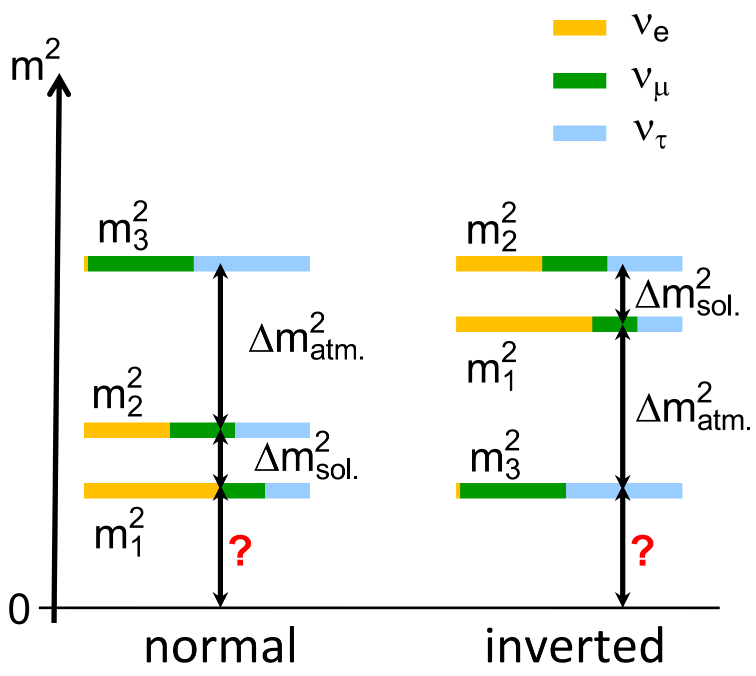
- Neutrino mass and β-decay
- KATRIN experiment
- First tritium measurements
- KATRIN backgrounds
- Summary & Outlook

Neutrino masses

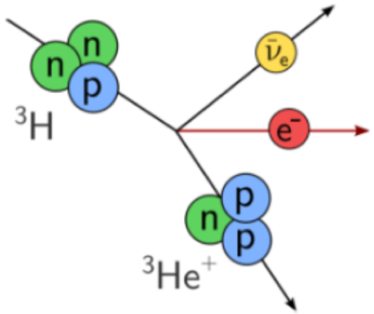
- Neutrino flavour eigenstates are related to neutrino mass eigenstates by the lepton mixing matrix (PMNS)
- Neutrino oscillations are sensitive to the differences between the squares of neutrino masses
- Two mass ordering scenarios possible
- The value of the lightest neutrino mass is unknown

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix}$$

mass ordering



Neutrino mass and single β-decay



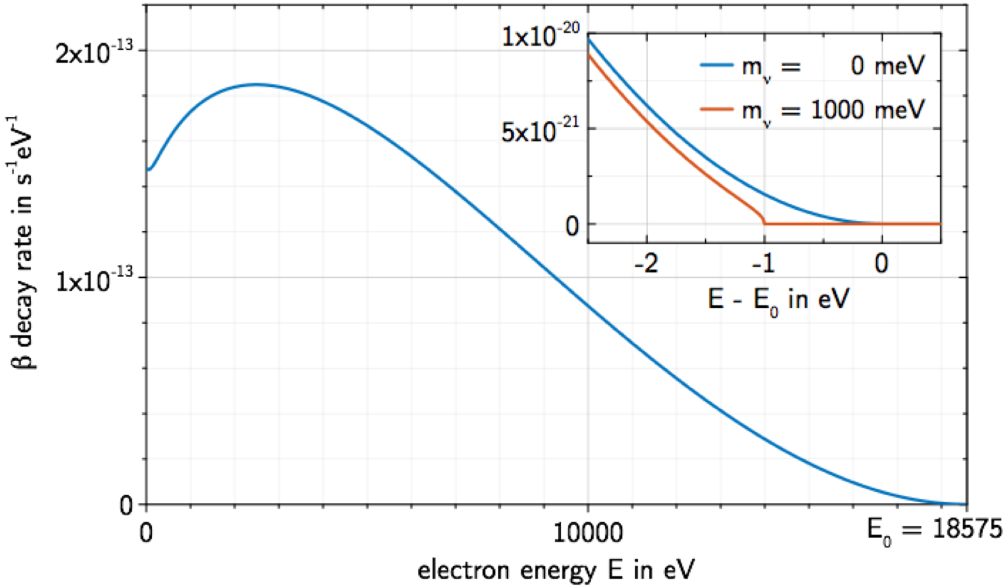
- β-decay: $n \rightarrow p + e^- + \overline{\nu}_e$
- Neutrino mass influences energy spectrum of β-decay electrons
- Neutrino mass determination via precise measurement of the spectral shape close to the endpoint
- Model independent method

Fermi theory of β-decay:

$$\frac{dN}{dE} = C \cdot F(E,Z) \cdot p(E+m_e) \cdot (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_\nu^2}$$

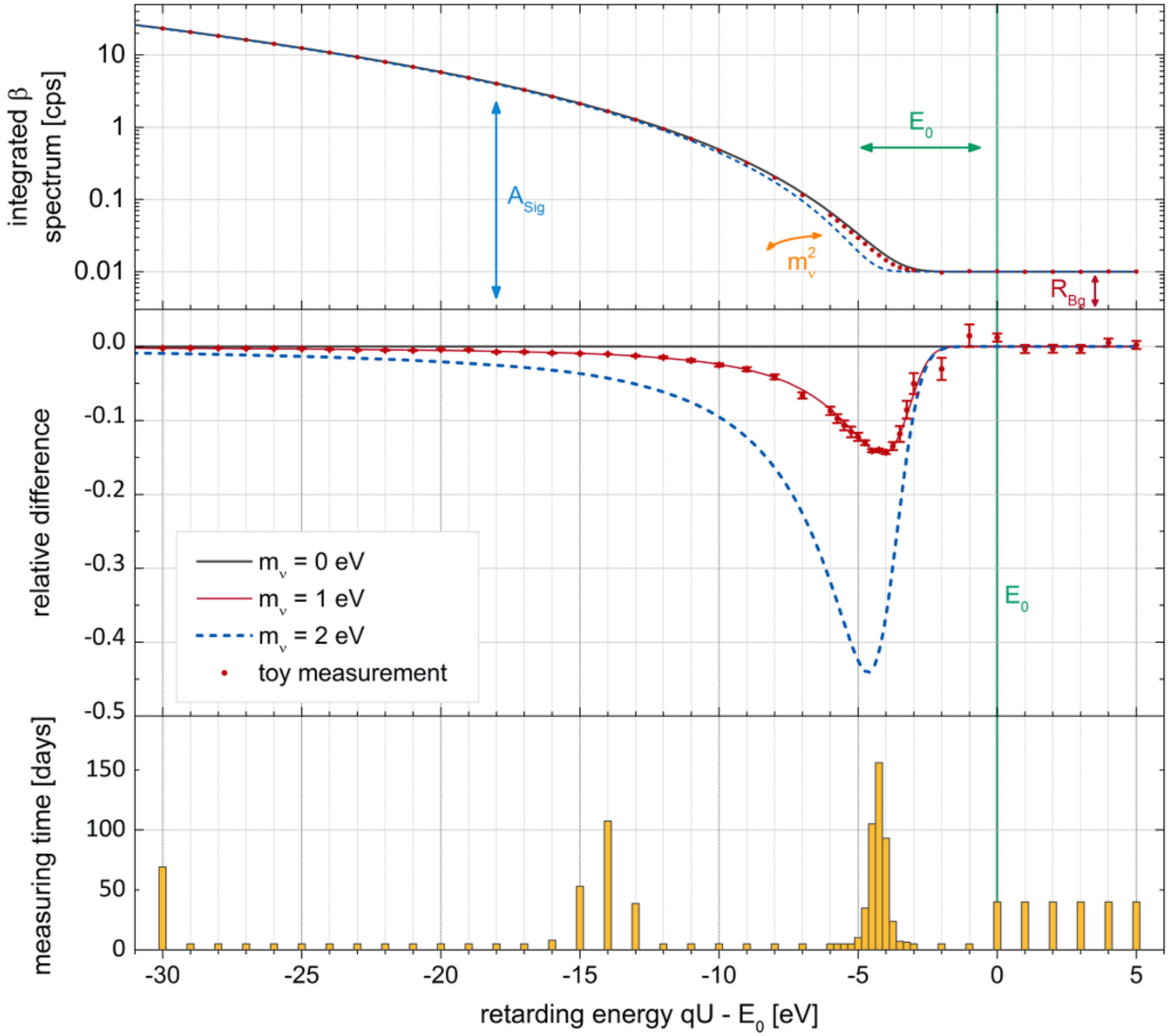
$$m_{\nu_e}^2 = \sum_{i=1}^{3} |U_{ei}|^2 m_i^2$$

β-spectrum for tritium (E_0 = 18.6 keV, $T_{1/2}$ = 12.3 y):




KATRIN
Karlsruhe Tritium Neutrino Experiment

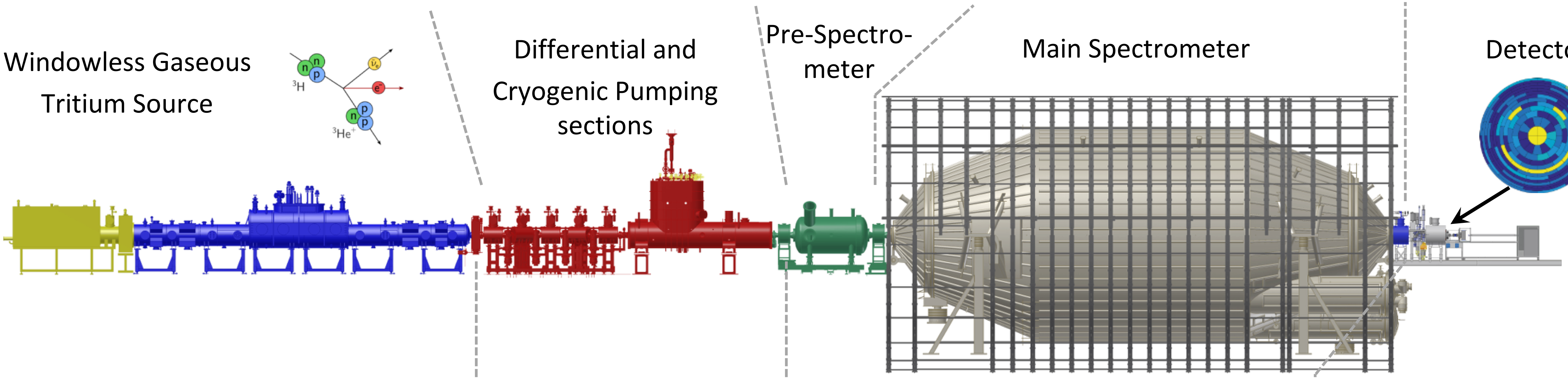
Neutrino mass measurement



- KATRIN will measure the integrated β-spectrum close to the T_2 endpoint E_0
- The influence of m_ν is most pronounced a few eV below E_0
- Optimized measurement time distribution to increase sensitivity
- Background obscures region of spectrum most sensitive to neutrino mass
- Design goal is a background rate of 0.01 cps for a sensitivity of 0.2 eV/c²

The KATRIN experiment

- **KA**rlsruhe **TRI**tium **N**eutrino experiment
- Goal: Measure neutrino mass with a sensitivity of **0.2 eV/c²** (90% C.L.)



- tritium β-decay
- decay rate: 10^{11} 1/s
- T_2 pressure: 10^{-3} to 10^{-6} mbar

- β-electron transport
- tritium retention (factor > 10^{14})

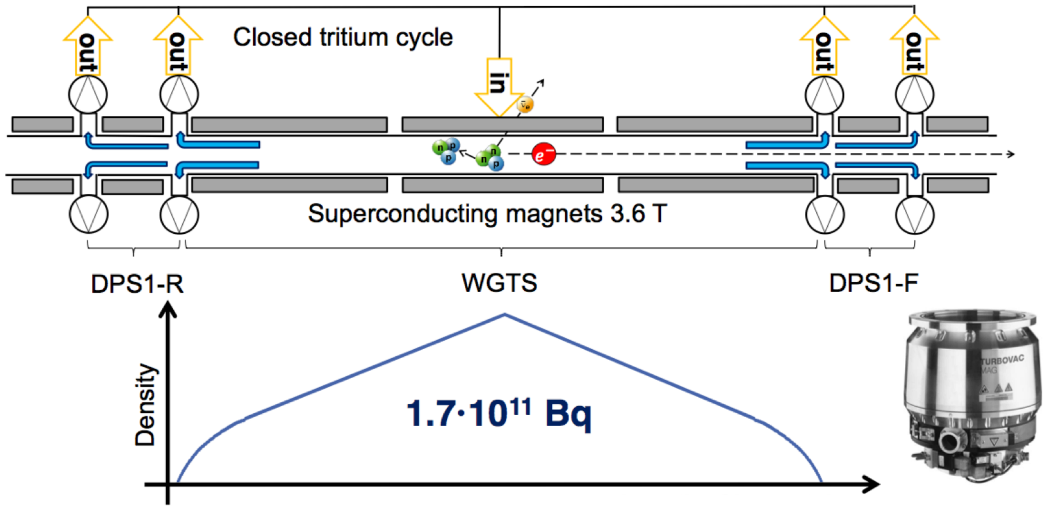
- energy analysis of β-electrons
- resolution 0.93 eV @ 18.6 keV
- pressure < 10^{-10} mbar

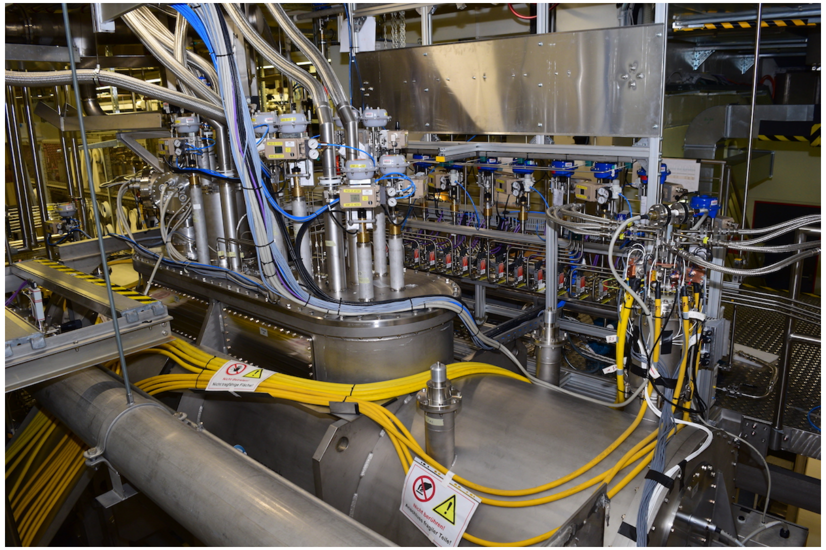
- counting of transmitted β-electrons

about 70 m

Windowless Gaseous Tritium Source

- **Purpose:** delivery of 10^{11} β-decay electrons per second

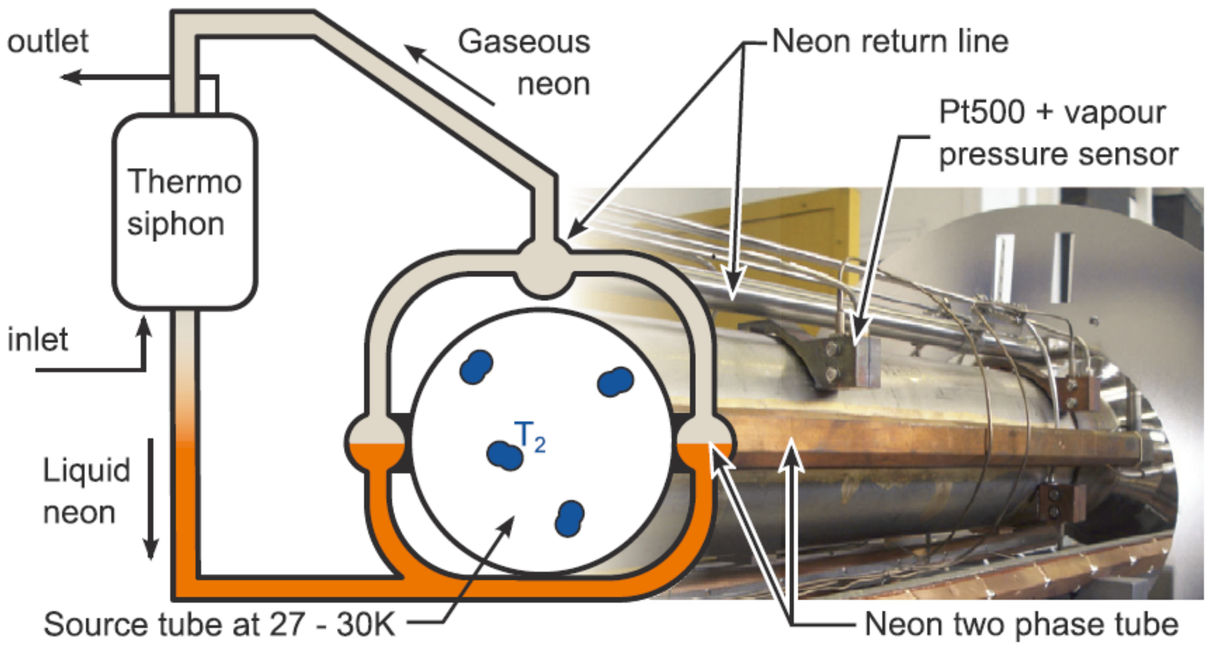


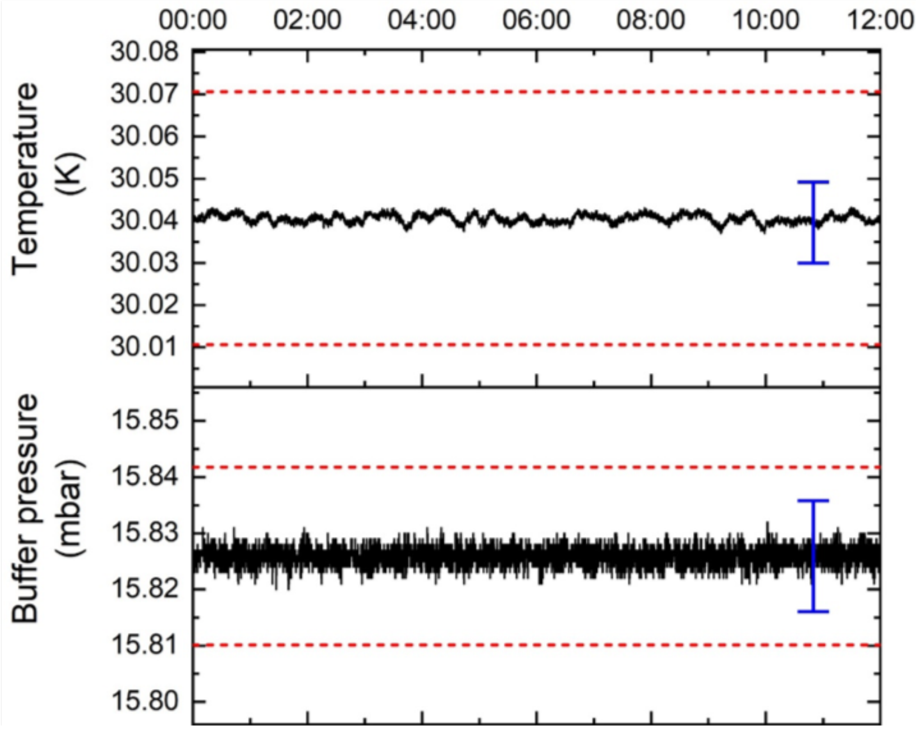


- Stability of T_2 density profile of **10^{-3}** (function of T_2 injection rate, purity, beamtube temperature stability and homogeneity, pump rate)
- Complex cryostat, 16 m length, 27 t weight, > 800 sensors and valves
- High isotopic purity (> 95%)
- Tritium loop processes 40 g T_2 / day (same scale as ITER)

Windowless Gaseous Tritium Source

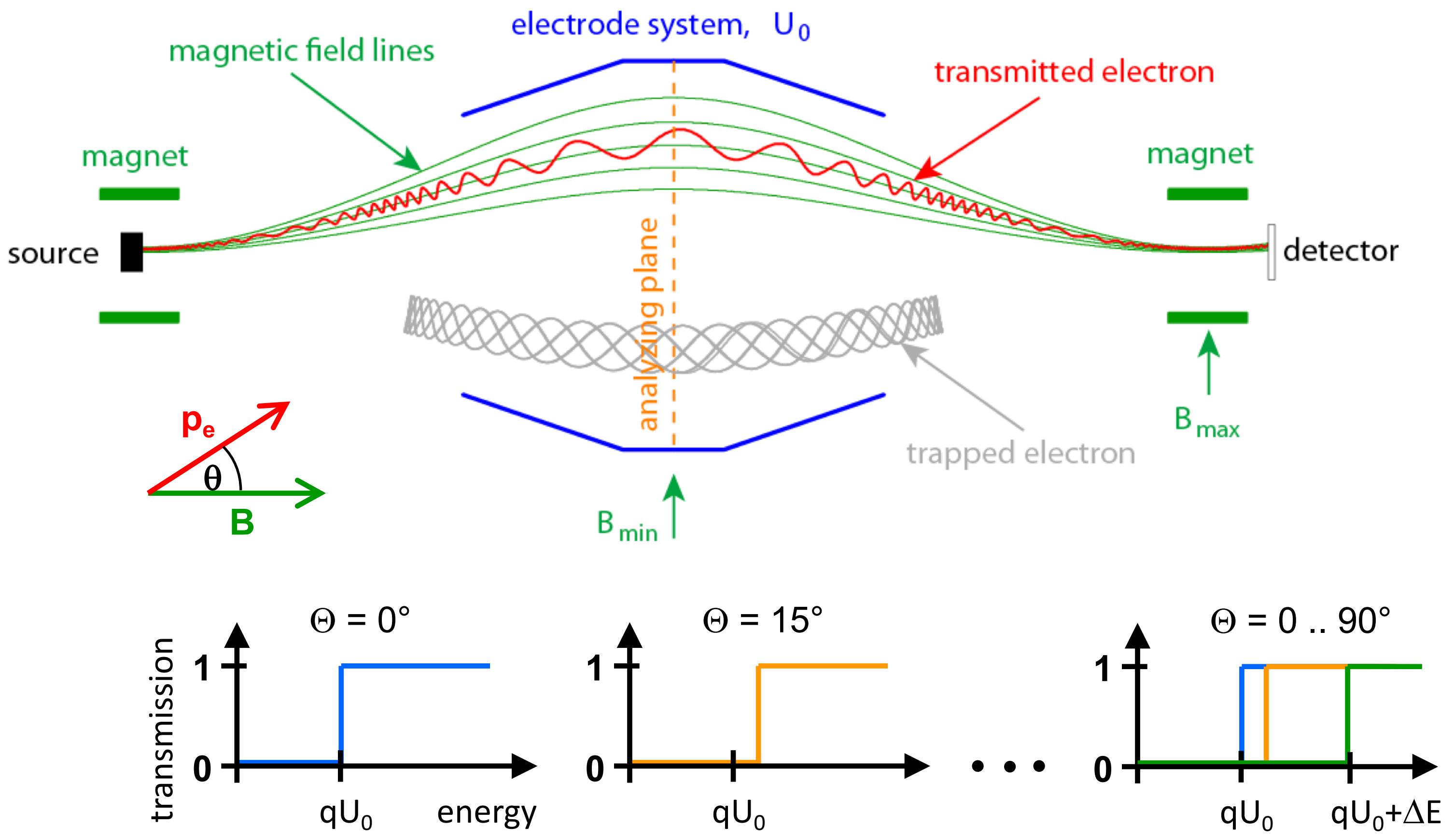
- Successful commissioning of magnet system at maximum field (3.6 T)
- Test of two phase beam tube cooling system: temperature stability exceeds requirements by one order of magnitude!





MAC-E filter

- **M**agnetic **A**diabatic **C**ollimation combined with an **E**lectrostatic Filter
- Technique used by Mainz and Troitsk neutrino mass experiments

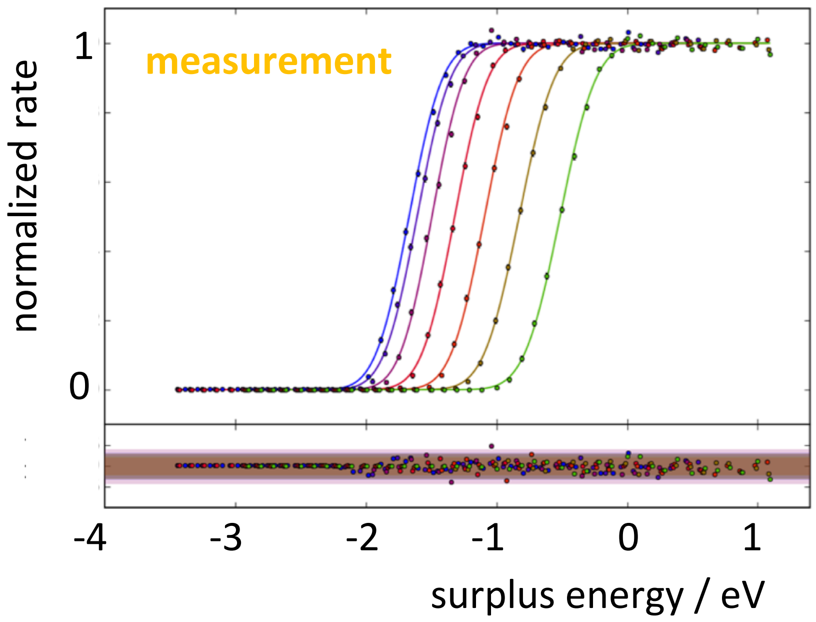


magnetic moment:

$$\mu = \frac{E_t}{B} = const$$

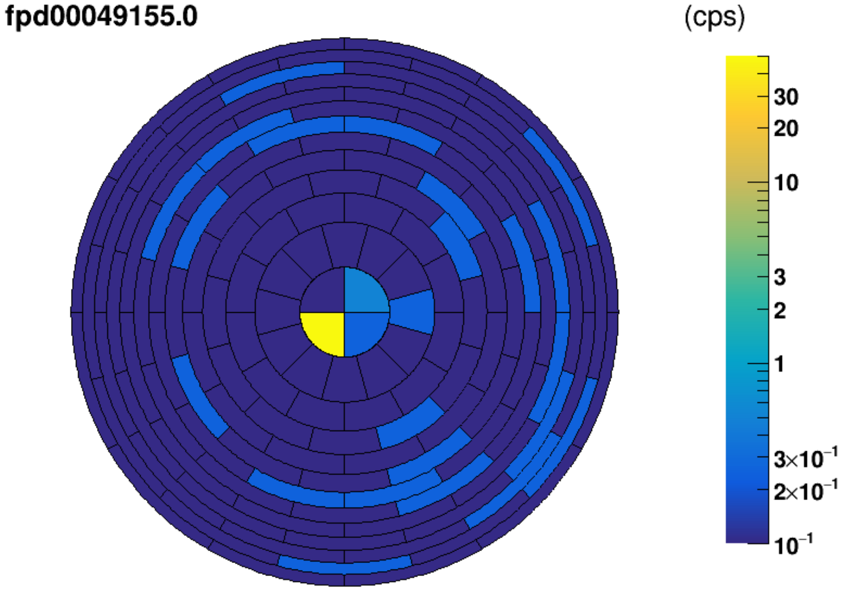
energy resolution:

$$\Delta E = \frac{B_A}{B_{max}} E_t$$

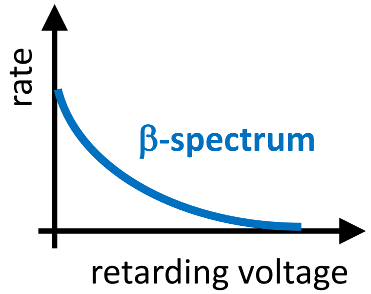


main spectrometer

- **Purpose:** energy analysis of β-decay electrons (ΔE = 0.93 eV @ 18.6 keV)



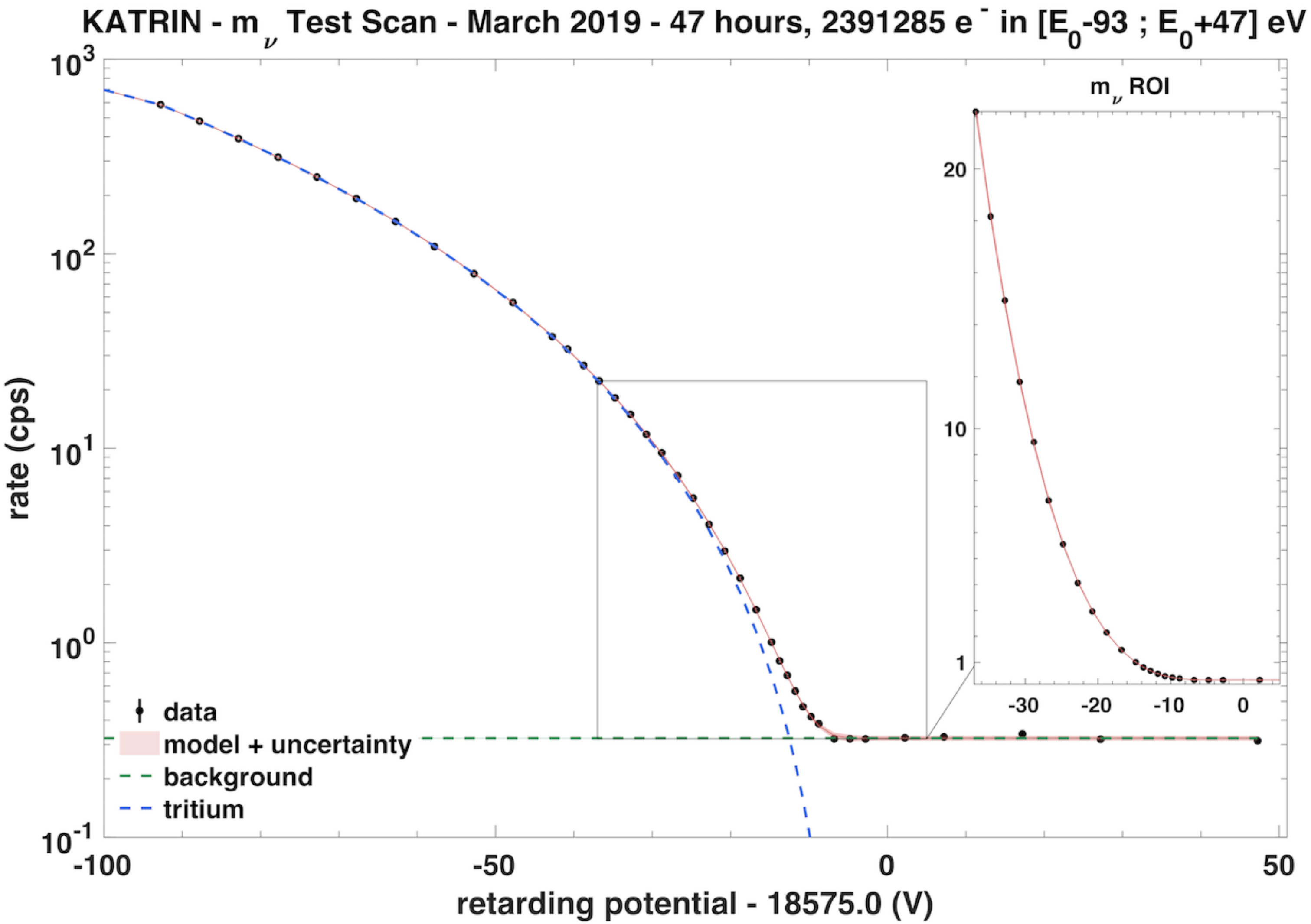
- Spectrometer mass 200 t, volume 1240 m^3, inner surface 689.6 m^2
- Pressure ~ 10^{-11} mbar
- Inner wire electrode system for fine-tuning of retarding potential
- Voltage monitoring precision 3 ppm @ -18.6 kV
- Variable voltage to scan E_0 region



KATRIN Inauguration / First Tritium

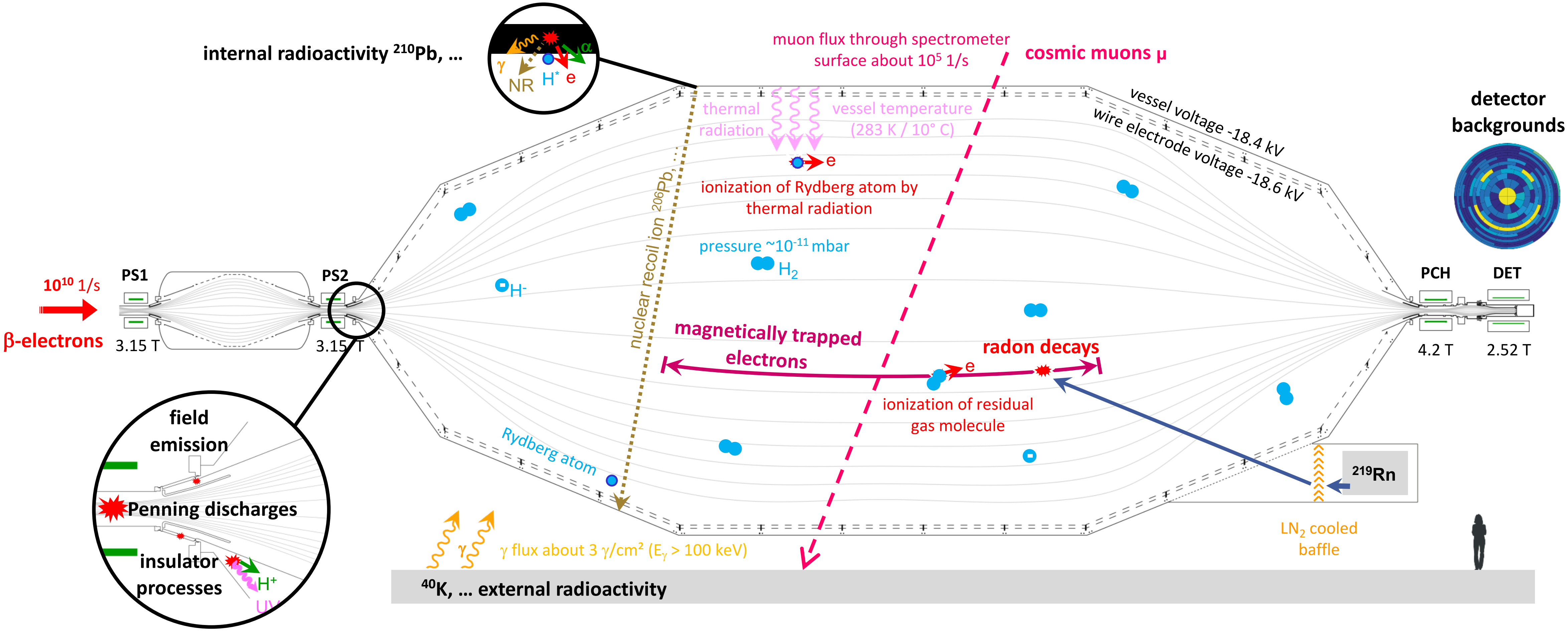
- First tritium measurement campaign and official inauguration in May/June 2018
- Successful commissioning of system with tritium (< 1% nominal activity)
- Investigation of β-spectrum for systematic effects and test analysis strategies

“KATRIN neutrino mass 1 (KNM1)“ measurements



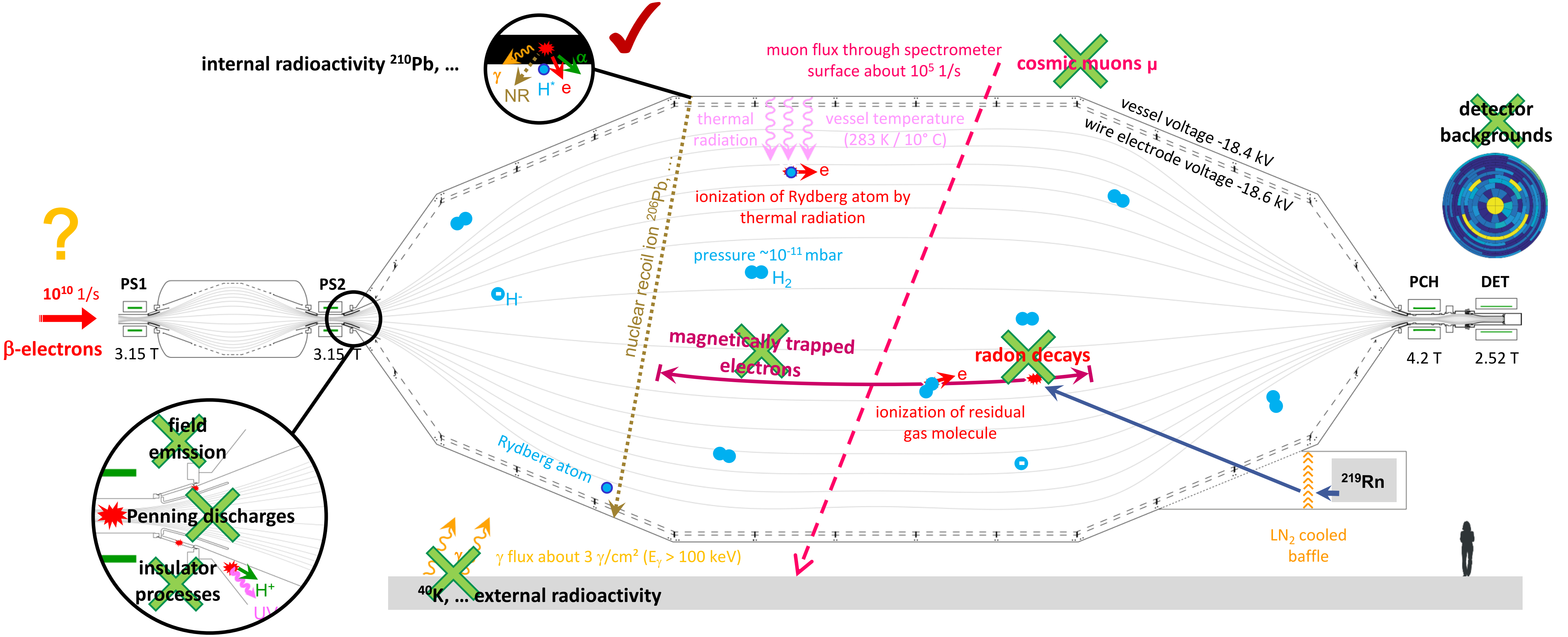
- Ongoing measurement campaign since beginning of March 2019
- Step wise increase of tritium source activity (0 -> 100 %)
- Investigation of systematic effects (electron energy loss, source plasma potential)
- β-spectrum scans

Background overview



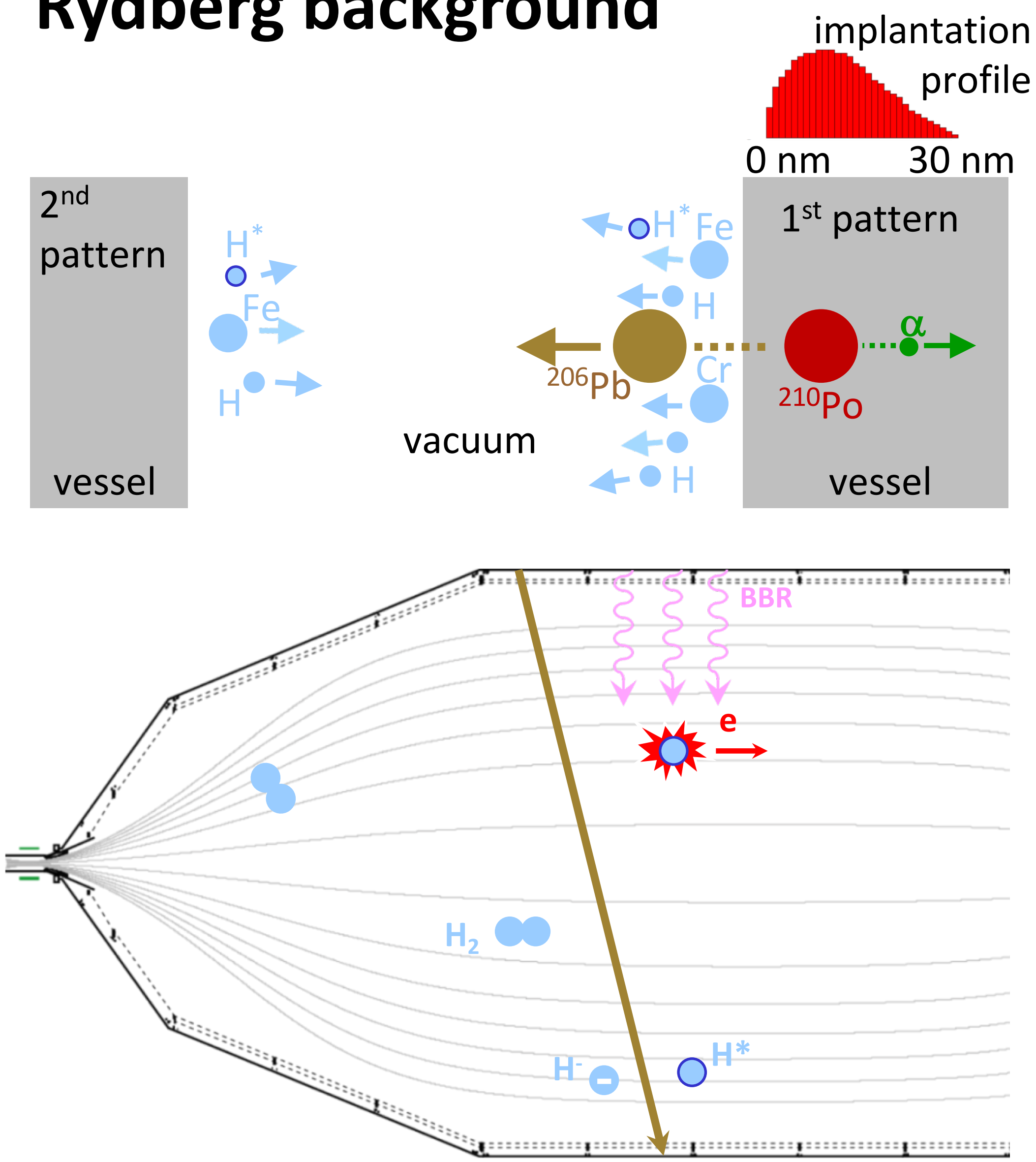
- Various processes contribute to the KATRIN background

Background overview



- Most background processes are efficiently suppressed, but remaining background is about 50 times larger than design value

Rydberg background



Rydberg model:

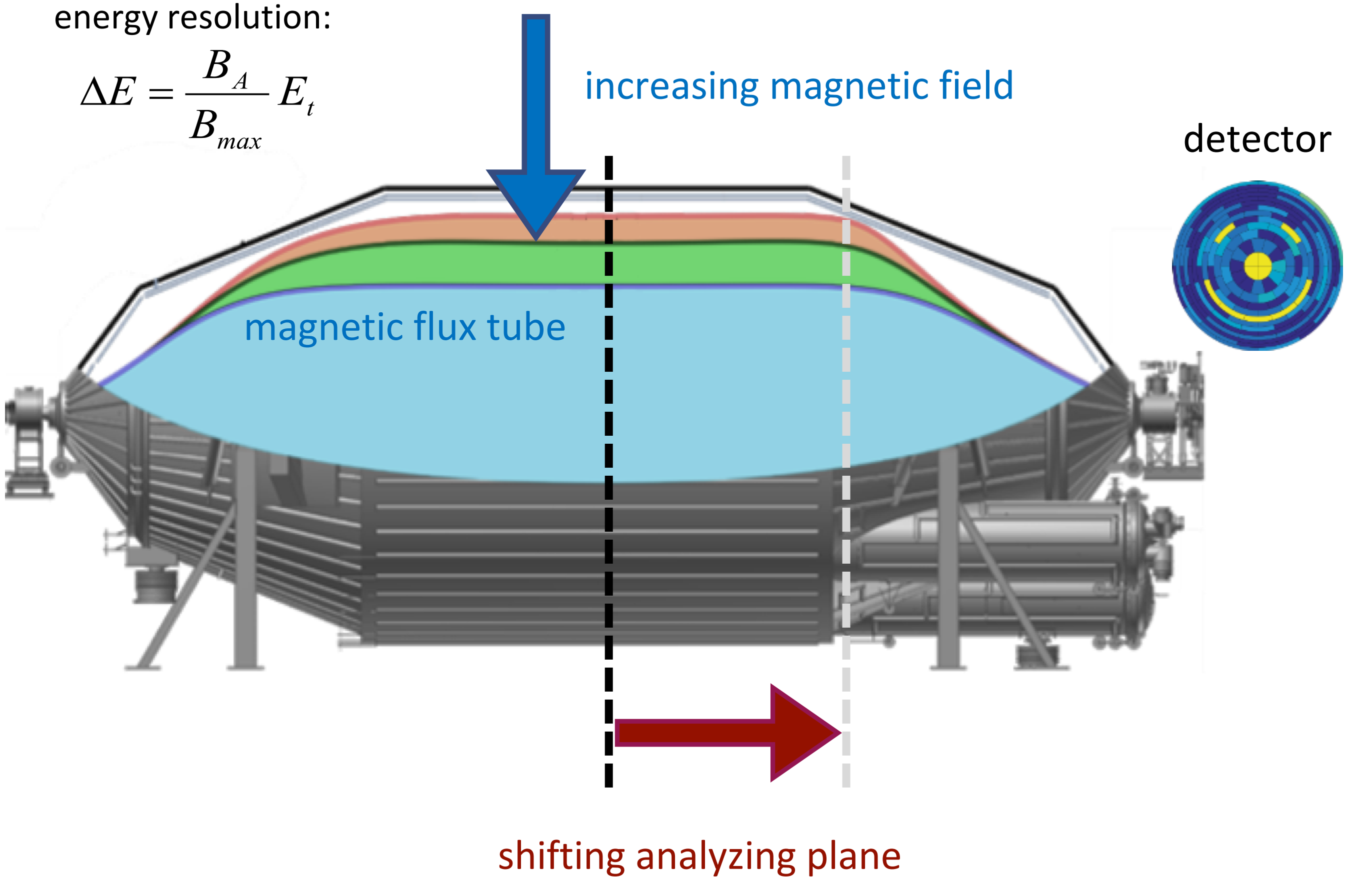
- Rydberg atoms created in the decay of ^{210}Po and accompanying processes, enter the spectrometer volume where they are ionized by thermal radiation, thus creating low-energy electrons
- This process creates about the same number of electrons for each volume element of the main spectrometer

Rydberg background reduction methods

- Reducing the volume of the magnetic flux tube mapped on the detector reduces the background
- Increasing the magnetic field in the analyzing plane broadens the energy resolution
- Shifting the analyzing plane downstream increases inhomogeneities of the retarding potential

energy resolution:

$$\Delta E = \frac{B_A}{B_{max}} E_t$$



Summary and outlook

Summary:

- KATRIN aims to measure the neutrino mass with 0.2 eV/c^2 sensitivity (90% C.L.)
- Official inauguration of KATRIN on June 11th, 2018
- First neutrino mass measurement campaign started in March 2019

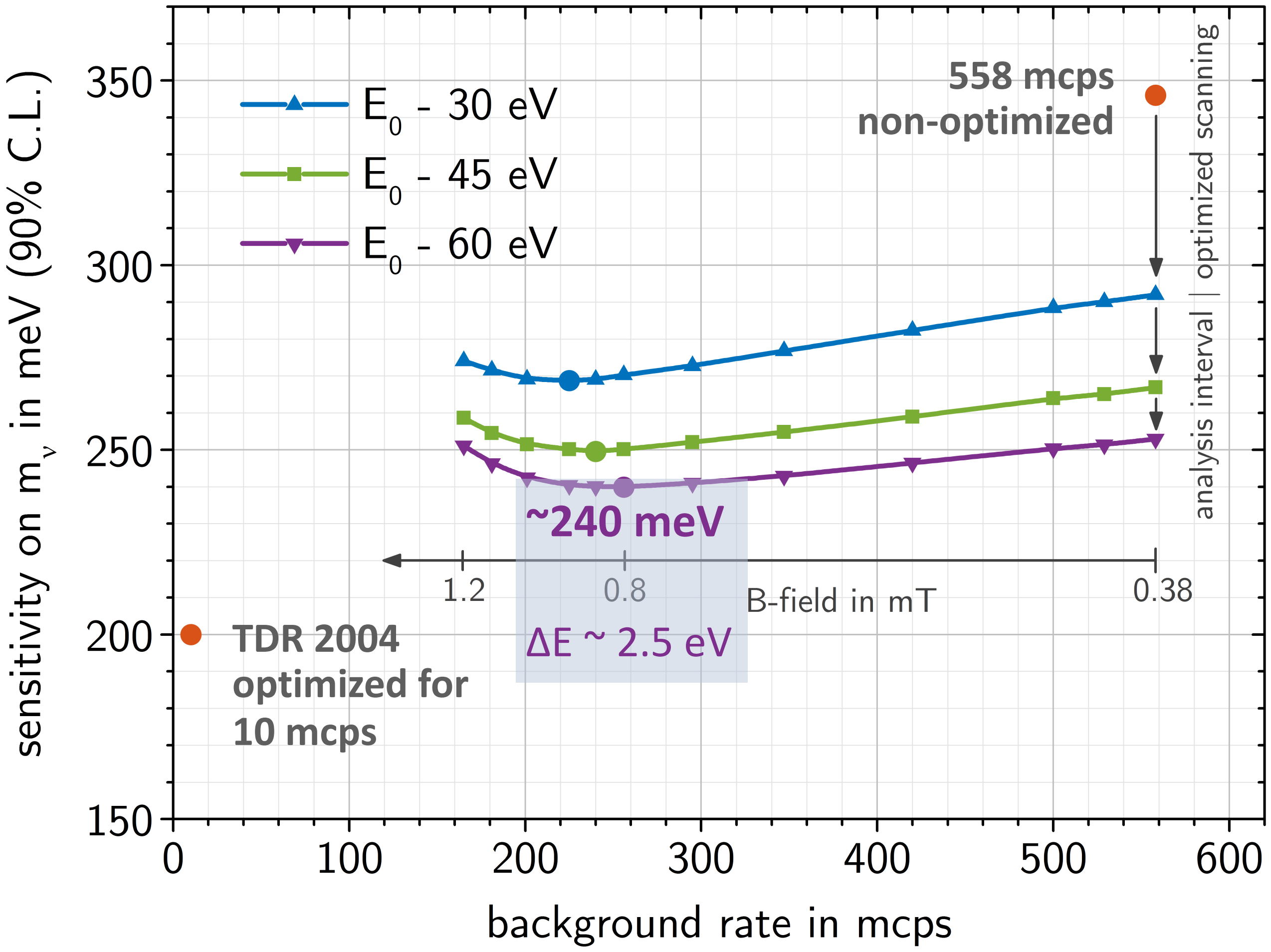
Outlook:

- Results of the first neutrino mass measurements are planned to be presented at the TAUP conference in September 2019
- Accumulate 3 years of measurement time to reach full KATRIN sensitivity
- Search for keV sterile neutrinos (TRISTAN)

KATRIN collaboration

Backup

KATRIN background & sensitivity



- KATRIN sensitivity limited by backgrounds