Sensitivity Studies towards a next-generation neutrino mass experiment using tritium β-decay

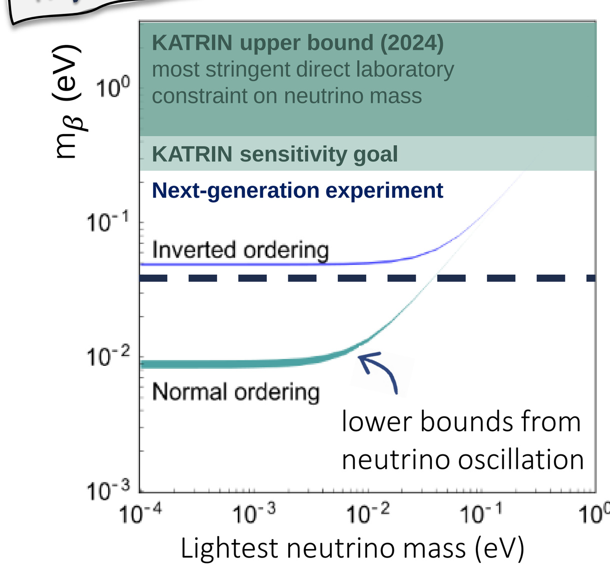
Svenja Heyns for the KATRIN++ R&D Group

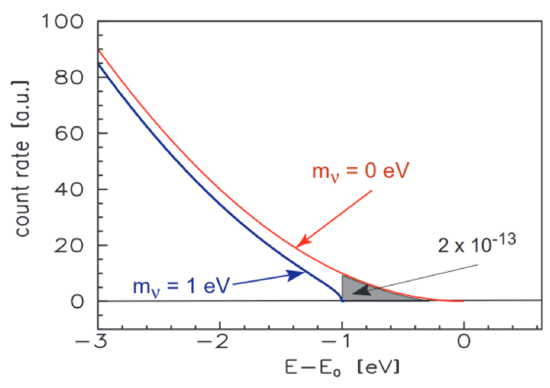
Institute for Astroparticle Physics (IAP), Karlsruhe Institute of Technology (KIT)

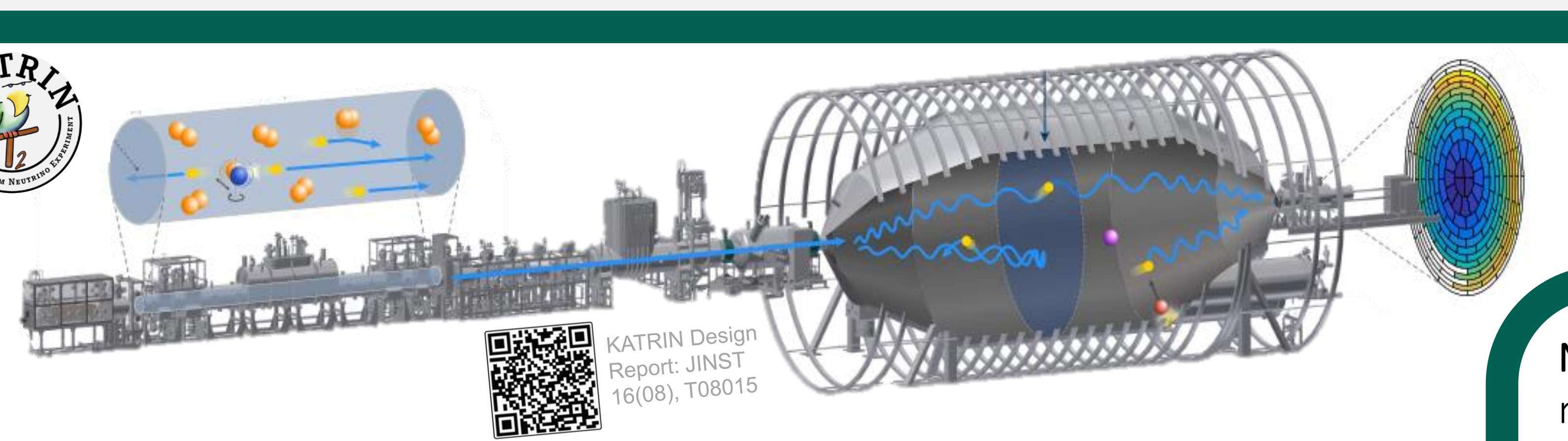
Motivation

$m_\nu < 0.45$ eV

New results after 259 days of data taking







To learn more about KATRIN's new release and projectivity, also have a look at

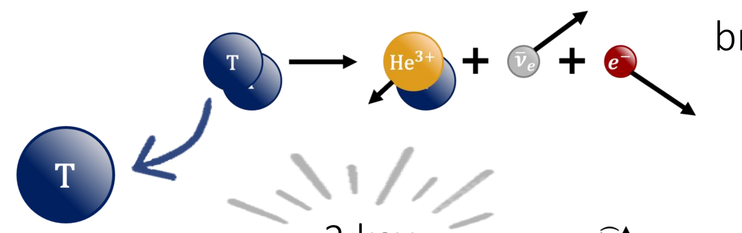
Talk by Christoph Wiesinger →

Poster by Jaroslav Štorek →

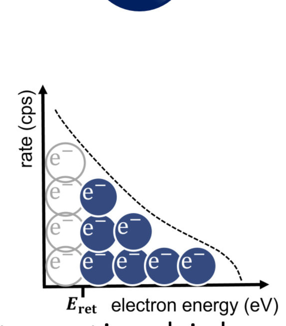
Opportunities for further improvement:

- ... differential measurement to improve energy resolution, statistics & intrinsic accumulation of background
- ...atomic tritium source to eliminate rovibrational broadening

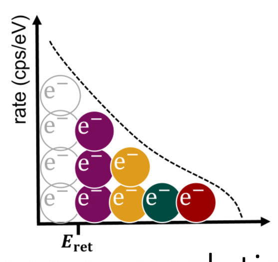
Atomic tritium source to eliminate molecular broadening



2 key strategies:



Integrating high-pass MAC-E filter



Ultra-high energy resolution detector (with quantum sensor technology, ...)

Outlook

Next-generation experiment to probe inverted mass ordering requires paradigm shift in technologies

→ Ongoing research efforts for differential measurement: quantum sensor detector arrays and ToF measurements; investigation if combination can enhance advantages of both

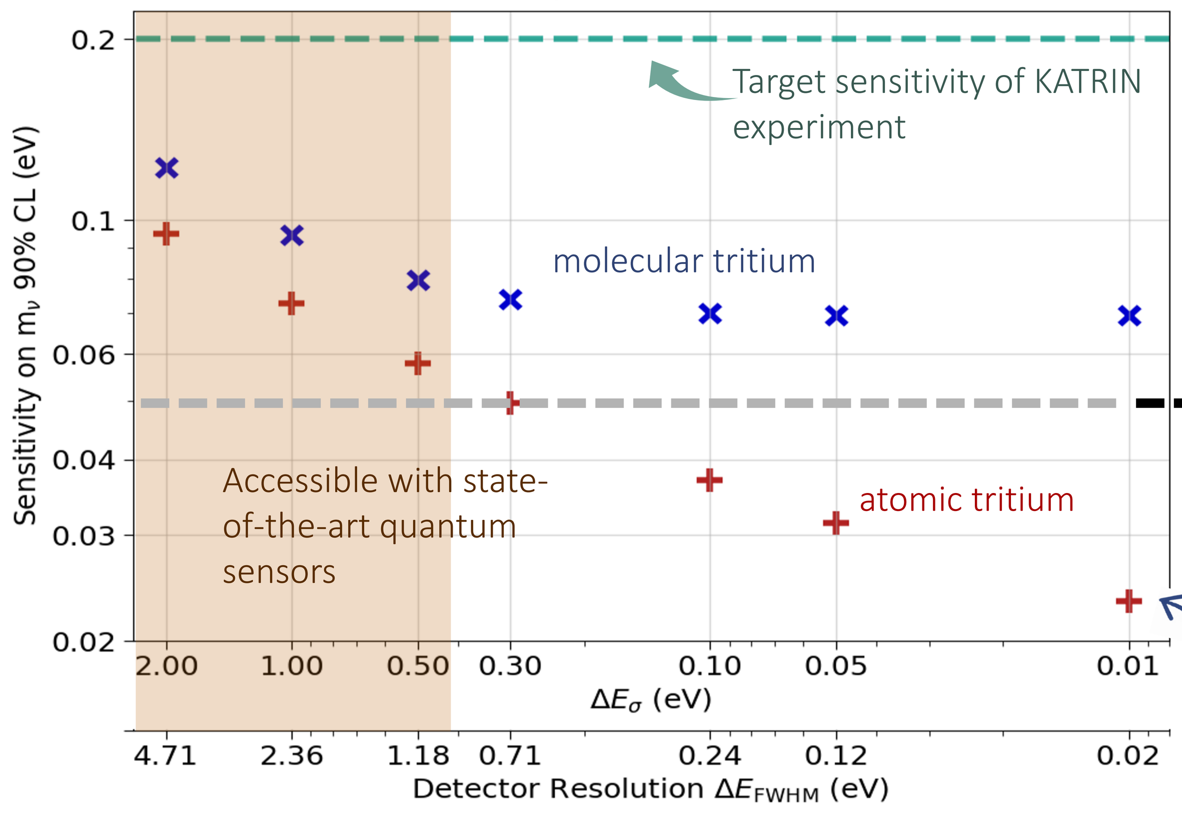
→ Building research community for atomic tritium source, to combine knowledge and develop stable high-luminosity source

→ New simulation and analysis software SUNSET to translate hardware progress into achievable sensitivity on neutrino mass and guide the conceptual design

The KATRIN beamline and Tritium Laboratory Karlsruhe offer a unique facility to test and develop novel technologies for a next-generation neutrino mass experiments with tritium

Implementation of key strategies in spectrum model

3 years of measurement
Analysis window 30 eV below spectrum endpoint
Data generation with m_ν = 0 eV



→ atomic tritium essential for energy resolutions $\Delta E_{FWHM} < 1$ eV

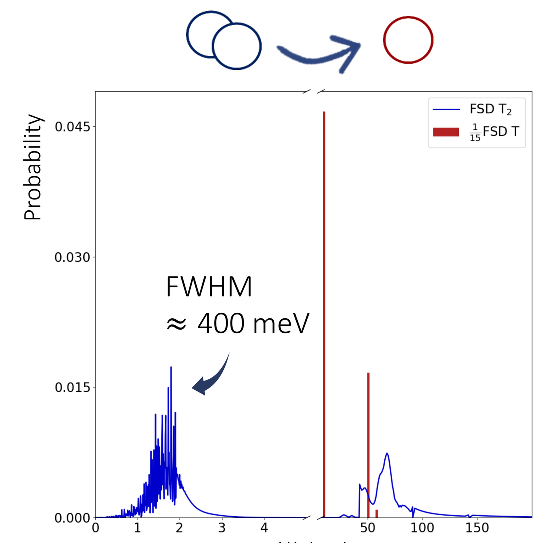
Inverted neutrino mass ordering

Purpose of simulation studies

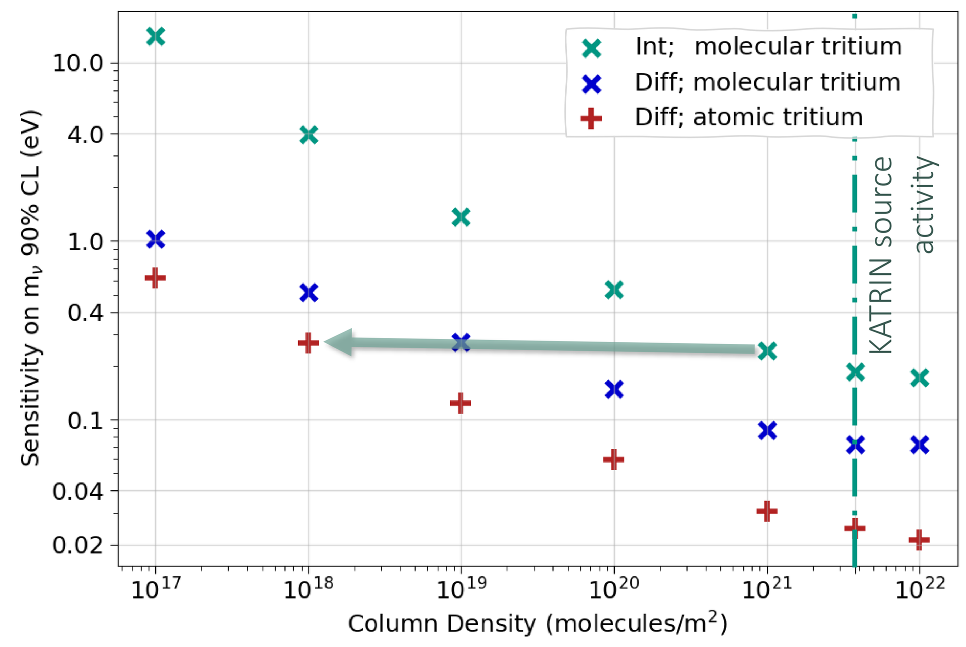
Specify particular hardware requirements to reach sensitivity on neutrino mass < 0.05 eV

Why Atomic Tritium Source?

- No rovibrational broadening of elementary final states
- No Doppler broadening at operating temperature below 1 K
- Reduced scattering cross section by factor of ~10



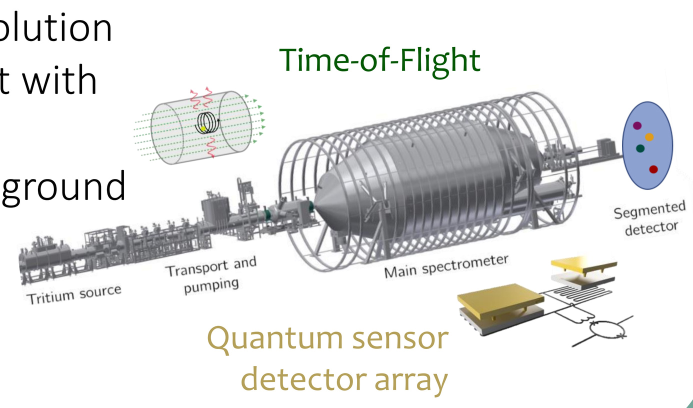
more efficient use of statistics combined with lower background & sub-eV energy resolution



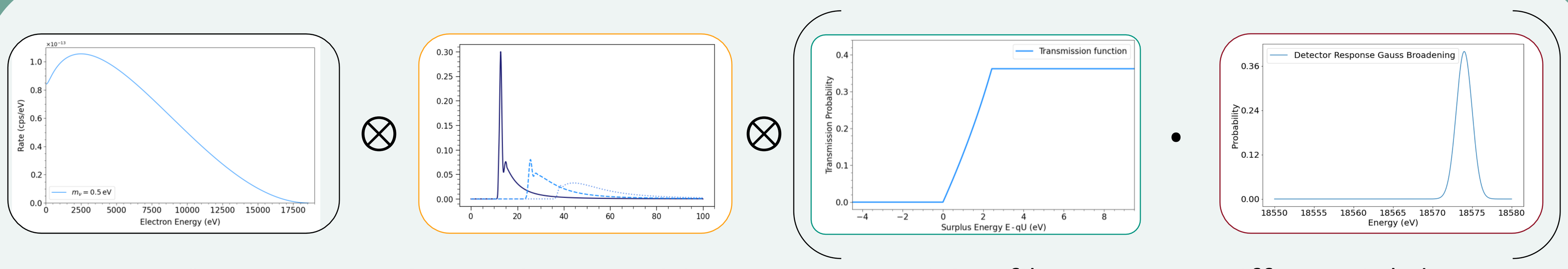
3 years of measurement, no background
ΔE_{FWHM} = 10 meV

Why Differential Detector?

- Resolve individual electron energies with sub-eV resolution
- Acquire high statistics fast with fixed retarding potential
- Mitigate low-energy background



Toolbelt for simulation of setup's impact on electron energy



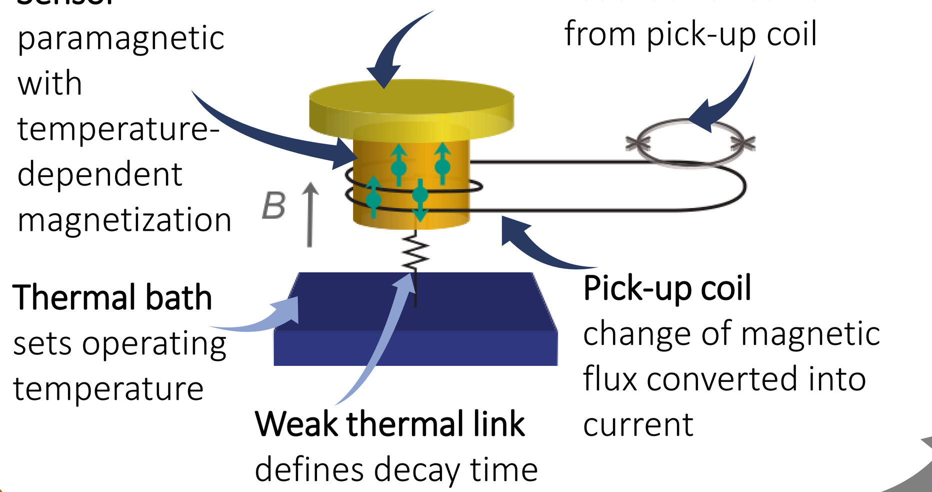
Tritium β-decay spectrum ⊗ Scattering on tritium gas molecules ⊗ MAC-E filter transmission function · Differential detector response

$$\frac{dN}{dt}(E_{ret}, E_{meas}) \propto \frac{d\Gamma}{dE}(E_0, m_\nu^2) * [f(\varepsilon) * (T(E, E_{ret}) \cdot D(E, E_{meas}))]$$

Differential Detection Technologies under investigation

- Quantum sensor detector arrays (metallic magnetic calorimeters, transition edge sensors, ...)
- Time-of-Flight Measurements

The example of MMC's
metallic magnetic calorimeters



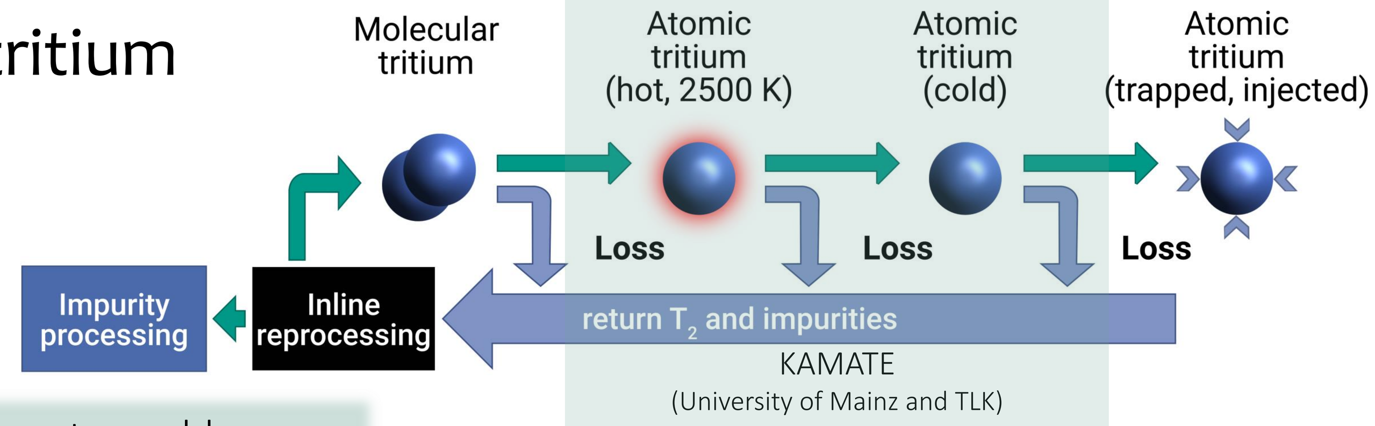
Research Challenges

(1) Single electron tagging for time-of-flight measurement (University of Münster and University of North Carolina)
(2) Enabling quantum sensors for detecting external electrons (KIT-IMS and KIT-IAP)
(3) Coupling cryo-platform at mK with RT spectrometer (University of Milano-Bicocca)
(4) Operation in magnetic field ~10 mT (KIT-IMS and KIT-IAP)
(5) Multi-plexing of ~10^6 channels (KIT-IPE)
(6) Confining hardware requirements to reach defined physics goals (all groups)
(7) Constructing calibration sources (KIT-IAP, TLK, University of Bonn, CAS-UJF Rez)

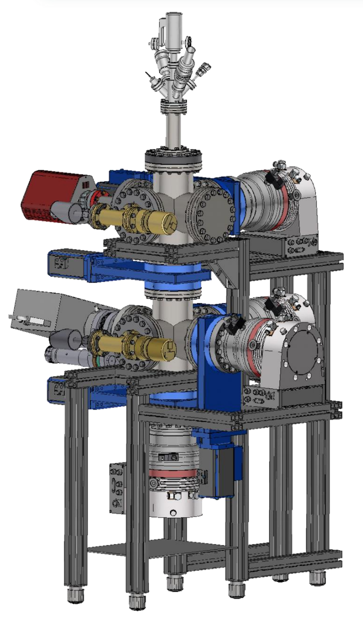
Potential to reach sub-eV resolution in coming years

First tests with external electrons ongoing

Atomic tritium source



→ Key technology to enable paradigm shift in future tritium-based neutrino-mass experiment

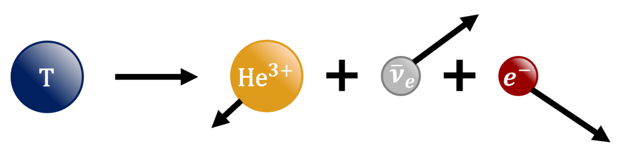


Atomic Tritium Demonstrator:

- Development at *Tritium Laboratory Karlsruhe* for future m_ν-experiments
- Simple setup to demonstrate tritium operation
- And investigate tritium compatibility, recovery and isotopic effects

Challenges to produce stable atomic tritium source

- Development of atom cooling mechanism to ≈10 mK
- Magnetic trapping of atoms for extended time and densities
- In process of forming joint working group with Project 8, QTNM, ... for atomic tritium demontrator



Setup installed at Tritium Laboratory Karlsruhe (TLK) - First proof of principle expected in 2024