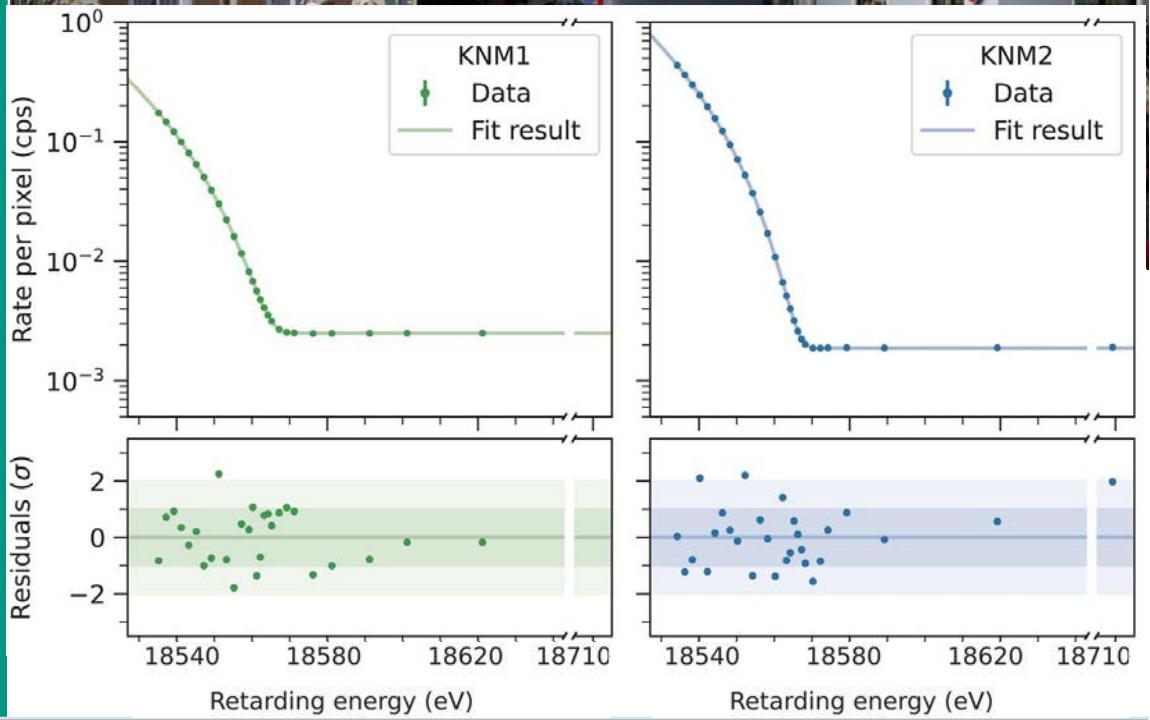
KATRIN experiment

Master & Bachelor



Contact: markus.steidl@kit.edu ; alexey.lokhov@kit.edu

11.08.2025

Investigation of electron emission from the inner spectrometer surface

One of the major factors limiting the sensitivity of the KATRIN experiment on the neutrino mass is an elevated background rate due to an accumulation of ^{210}Pb on the inner spectrometer surface. A series of dedicated measurements to study the emission of electrons from the spectrometer surface was performed throughout the operation of KATRIN. The scope of this master thesis is a detailed analysis of these data sets, including simulations of electric and magnetic fields. Depending on the timing of the thesis, participation in a final measurement campaign is possible.

Focus: Data analysis and simulation of electric and magnetic fields

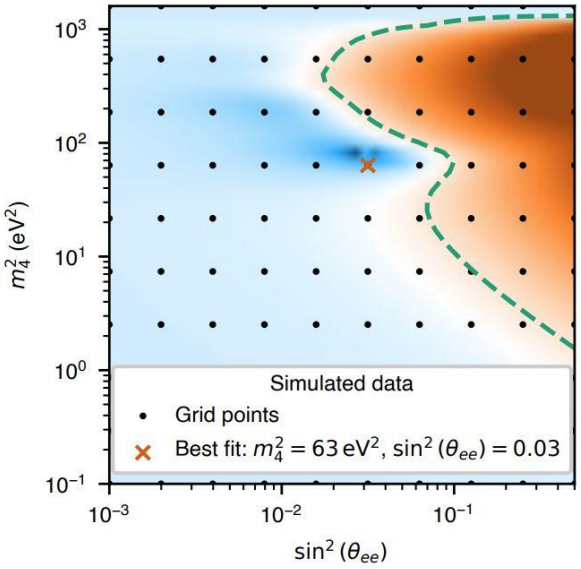
Where: Campus North, B402, KATRIN
Supervisors: Florian Fränkle
Start: ready to start

Sensitivity of the KATRIN Experiment to eV-Scale Sterile Neutrinos

KATRIN searches for light sterile neutrinos by looking for a spectral distortion (a kink) in the high-energy tail of the tritium β spectrum. Using 36 million β-decay electrons collected in 259 days (KNM1–5), KATRIN excluded substantial regions of parameter space relevant to the gallium anomaly and challenged other claimed signals. The KNM1–5 sterile analysis describes a grid-scan (shape only) analysis, Wilks-theorem usage with Monte-Carlo validation, campaign-wise combination and projected 1000-day sensitivity.

More info/References

KNM6 (and later campaigns) are available for analysis and future campaigns will increase statistics and re backgrounds, improving sterile sensitivity. This provides an opportunity to (1) extend the sterile search to KNM6+ data; and (2) investigate analysis improvements (systematics, pixel-wise strategies, Wilks validity optimized Region Of Interest) to reach the projected KATRIN sensitivity.



Focus: Data analysis and sensitivity projection

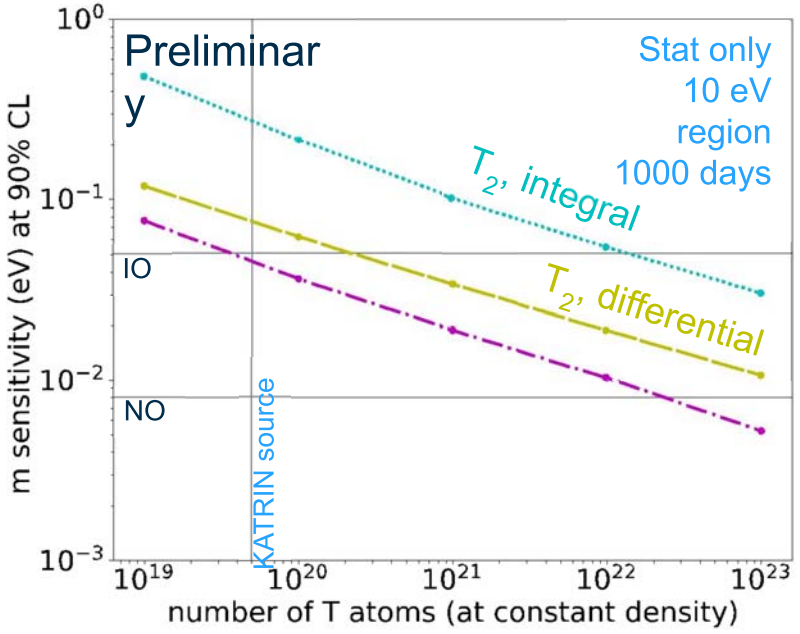
Where: Campus North, B402, KATRIN

Supervisors: Shailaja Mohanty, Alexey Lokhov
1st referent: Prof. Kathrin Valerius.
Start: Ready to start

KATRIN++ - sensitivity studies for a next-generation neutrino mass experiment

Work breakdown:

This thesis is part of the active research & development phase for a future neutrino mass experiment to close the gap to theory more.



Focus: software development and data analysis (no pre-knowledge necessary)

Where: Campus North, B402 in the KATRIN Analysis group

Supervisor: Svenja Heyns & Prof. Dr. Kathrin Valerius

Start: anytime

KATRIN with TRISTAN Detectors

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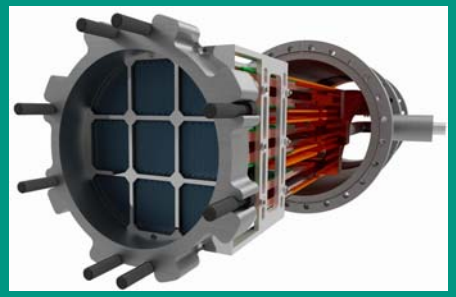
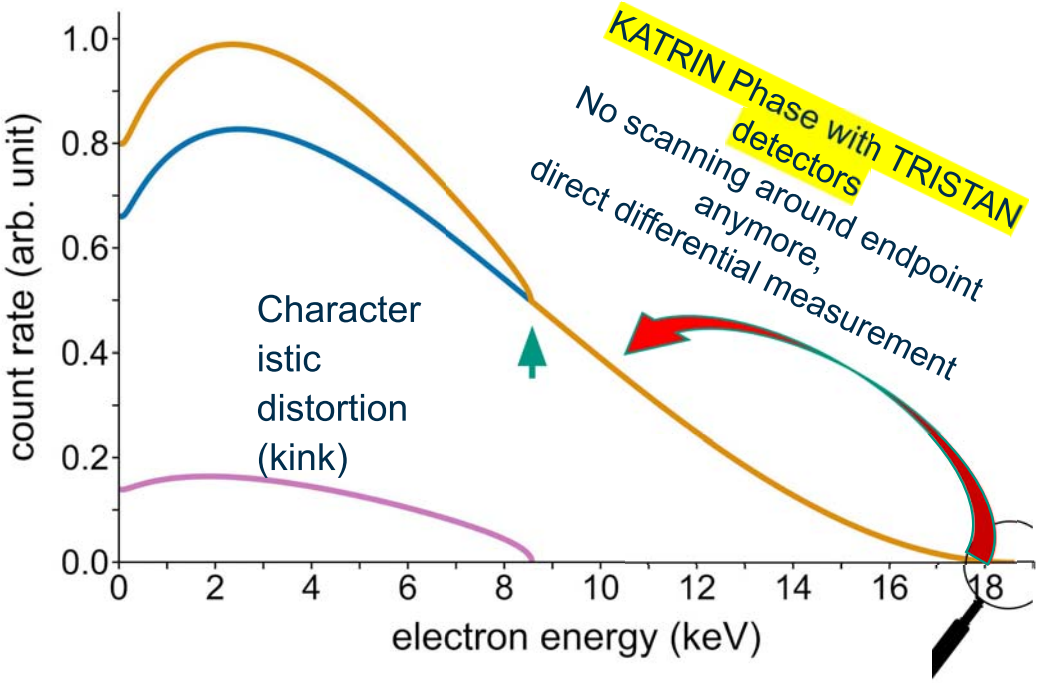


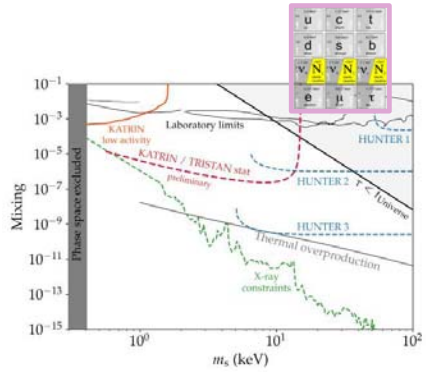
Contact: Markus Steidl, Dominic Hinz

markus.steidl@kit.edu & dominic.hinz@kit.edu

07.08.2025



- Perform most precise beta-spectrum ever (10^{14} counts)
- Improve world leading laboratory limits
  on sterile keV neutrinos (<18 keV)
  by a factor of >100
  w/o astrophysical assumptions



Status of preparations at KIT

Current status

- General concept of the new detector section works
- Specifications of new detector section for vacuum & cryo achieved
- 3 prototype detectors operated (12/24-04/25)
- First selection with new IPE-DAQ (Tile Main Board) was successful
- First promising results for post-acceleration (from 10 kV to over 20 kV)

Outlook

- **Endurance tests of post-acceleration with a detector module**
- **Detailed characterization of DAQ (Tile MainBoard and Backend)**
- **From December: operation with 9 modules**

Master thesis topics – KATRIN with TRISTAN detectors

The work is embedded in the group "KATRIN R&D" at IAP and fully within the KATRIN collaboration. Participation in the local group meeting (Mo. 14:00, in presence) and an international call (Wed. 14:00, virtual) is required. Office space is located at B402, typically 10 to 15 KATRIN team members join daily the office in an open, friendly and international environment. Presentations in English are mandatory.

We can adapt topics and find specific solutions. Contact markus.steidl@kit.edu or dominic.hinz@kit.edu .
1st referent is Prof. Kathrin Valerius or Prof. Guido Drexlin.

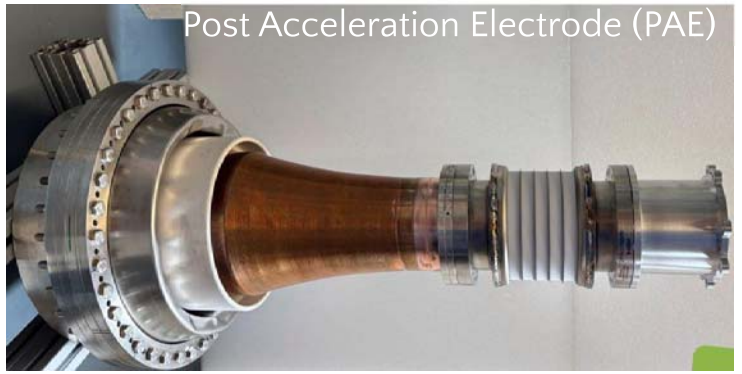
Measurement and analysis of detector response with the new post-acceleration-electrode
(Experimental work and analysis)

Development of an LED-based calibration method
(Experimental work, strongly focused on hardware)

Performance tests and investigations of the new FPGA based data-taking system
Experimental work, strongly focused on hardware, strongly connected to IT processes)

Measurement and analysis of detector response with the new KATIN post-acceleration-electrode

In order to achieve a better signal-to-background ratio, electrons at KATRIN are accelerated by +10 kV in front of the detector. Due to the high magnetic field used to guide the electrons, this is technologically challenging, as smallest Penning traps can dynamize into macroscopic and destructive discharges. After intensive work, the KATRIN team has developed a new post-acceleration line +20 kV potential.



The aim of the measurements to be carried out is to prove stable detector conditions of the new electrode and to prove the potential sensitivity gain for KATRIN with TRISTAN detectors through this configuration. In this thesis, you will learn how to operate a complex system that will expand the physical program of the KATRIN experiment in the coming years. Through the associated data analysis and extensive aspects of interpretation, you will be introduced to the challenges of an experiment like KATRIN.

Focus: Experimental work (25%) and Analysis (75%)

Supervisors: Roman Hiller as well as participating doctoral students

Where: Campus North, B402 and B601, KATRIN R&D Group

Start: ready to start

Development of a pulsed LED-based calibration method for TRISTAN detectors

For the search for ppm signals in the tritium spectrum, a precise calibration of the detector is important. This is achieved by using several calibration sources, in particular radioactive sources and artificial electron sources (e-guns). In this thesis, we want to expand the portfolio to include pulsed LED or pulsed laser-based methods. This potentially allows new methods to monitor changes of the detector surface (by using different wavelengths) and determine so-called pile-up effects (by generating a high rate of optical pulses with precisely known rate).

The aim of the thesis is to work and try out different options for implementing these methods into the standard calibration routine for the TRISTAN detectors.

Focus: Experimental work (70%) and Analysis (30%)

Where: Campus North, B402 and B601, KATRIN R&D Group

Supervisors: Rudolf Sack as well as participating doctoral students

Start: requires 2 months preparation time at our side (purchase of hardware)

Performance tests and investigations of the new FPGA based data-taking system for KATRIN

The differential measurement method of the entire tritium spectrum is challenging for the data processing. We expect more than 6 orders of magnitude of increased data. This means a redesigning of the entire data processing and using a new data acquisition system (DAQ). This has been developed over the last 5 years at the Institute for Data Processing and Electronics (IPE) and Max-Planck Institutes. The new system is ready for use.

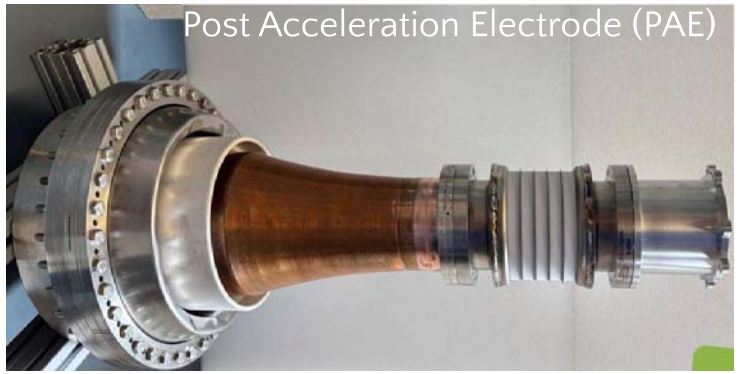
In this work, you intensively characterize and test the performance of the DAQ system. For example, you will examine long term stabilities. You will also support to combine the new processing chain of the data with existing analysis tools of the collaboration. In this work, enjoyment and ideally, previous knowledge, of IT processes are an advantage. This work is in close cooperation with the Max-Planck-Institute for Nuclear Physics, Heidelberg. Regular participation in a virtual meeting (Fri. 11:00) is required.

Focus: Experimental work (50%) and Analysis (50%) **Where:** Campus North, B402 and B601, KATRIN R&D Group

Supervisors: Markus Steidl, Sascha Wüstling (IPE), Andrew Gavin (MPIK Heidelberg) **Start:** Oct-Nov

Measurement and analysis of detector response with the new KATIN post-acceleration-electrode

In order to achieve a better signal-to-background ratio, electrons at KATRIN are accelerated by +10 kV in front of the detector. Due to the high magnetic field used to guide the electrons, this is technologically challenging, as smallest Penning traps can dynamize into macroscopic and destructive discharges. After intensive work, the KATRIN team has developed a new post-acceleration line +20 kV potential.



The aim of the measurements to be carried out is to prove stable detector conditions of the new electrode and to prove the potential sensitivity gain for KATRIN with TRISTAN detectors through this configuration. In this thesis, you will learn how to operate a complex system that will expand the physical program of the KATRIN experiment in the coming years. Through the associated data analysis and extensive aspects of interpretation, you will be introduced to the challenges of an experiment like KATRIN.

Focus: Experimental work (25%) and Analysis (75%)

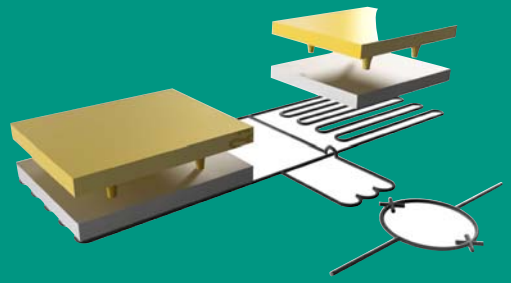
Supervisors: Roman Hiller as well as participating doctoral students

Where: Campus North, B402 and B601, KATRIN R&D Group

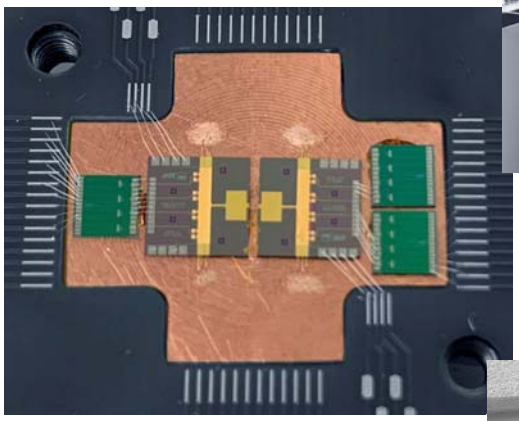
Start: ready to start

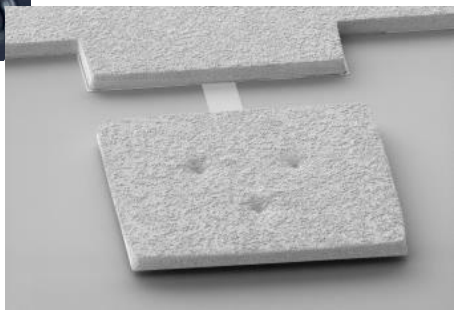
Quantum Sensors for KATRIN++

Master & Bachelor

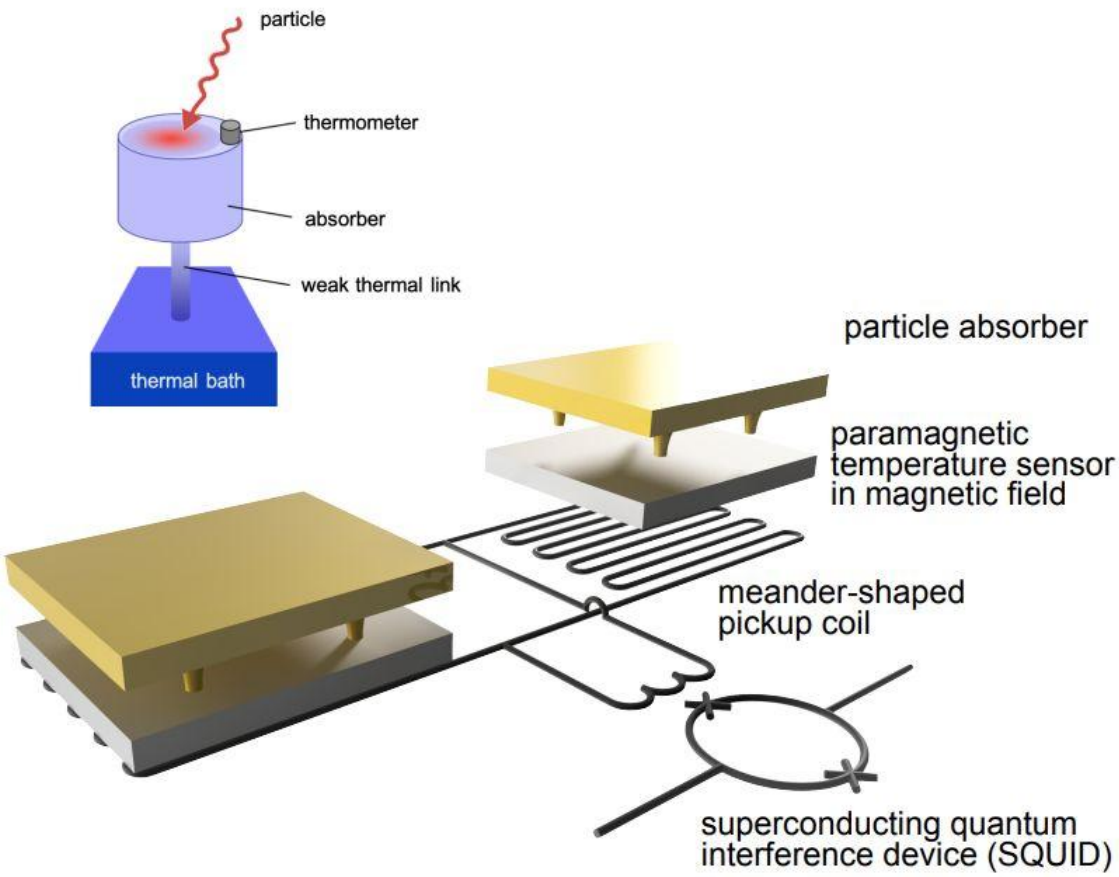


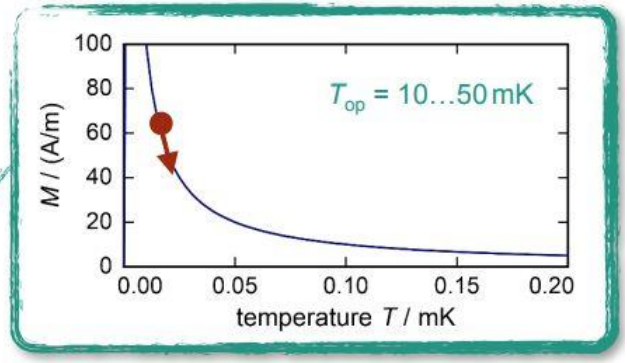
Contact: Markus Steidl (IAP) markus.steidl@kit.edu
Sebastian Kempf (IMS) sebastian.kempf@kit.edu

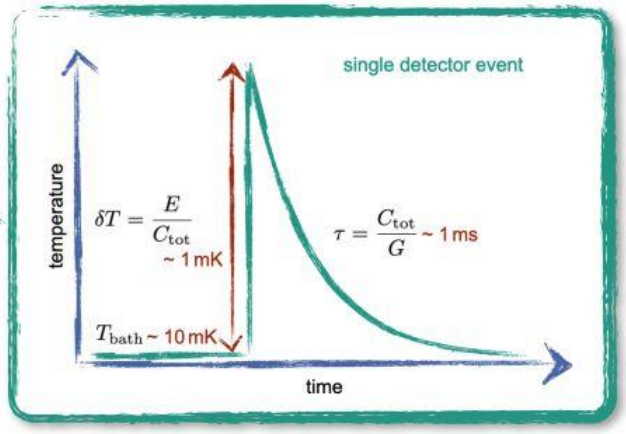




Magnetic microcalorimeters

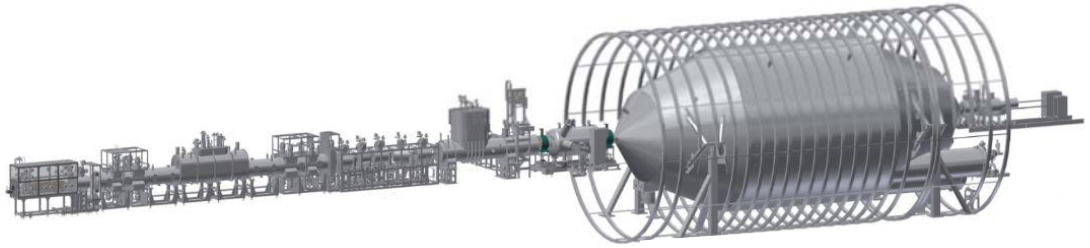




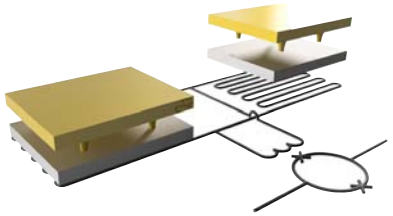


Precision probe tritium beta decay

2019-2025: Integral MAC-E filter technology



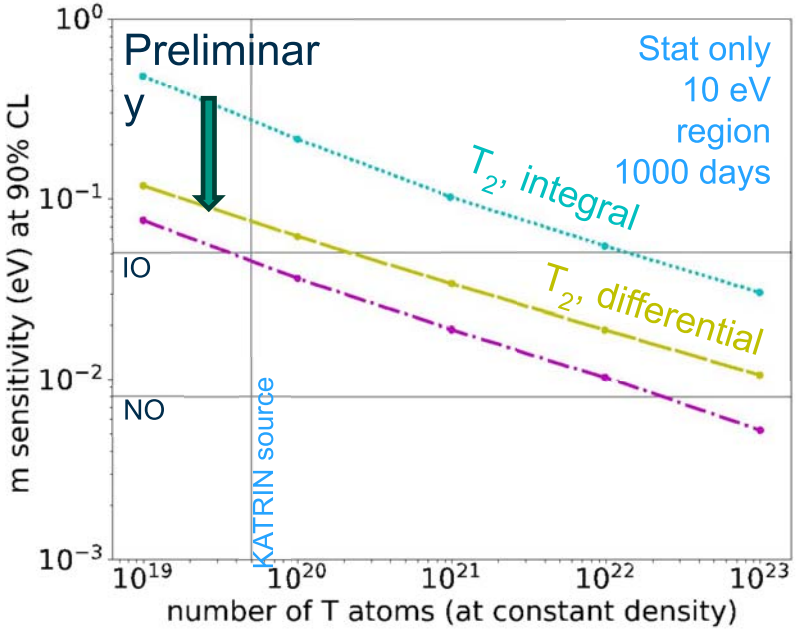
+ 10^6 x



Sensitivity improvement on observable m_ν^2 by a factor ~20

Challenges of coupling quantum sensor detector array to KATRIN infrastructure

- Type of quantum sensor
- Operation in magnetic field (~10 mT)
- Coupling of mK cryo-platform with RT spectrometer
- Large area detector and multiplexing of ~1e6 channels
- Limits to energy resolution

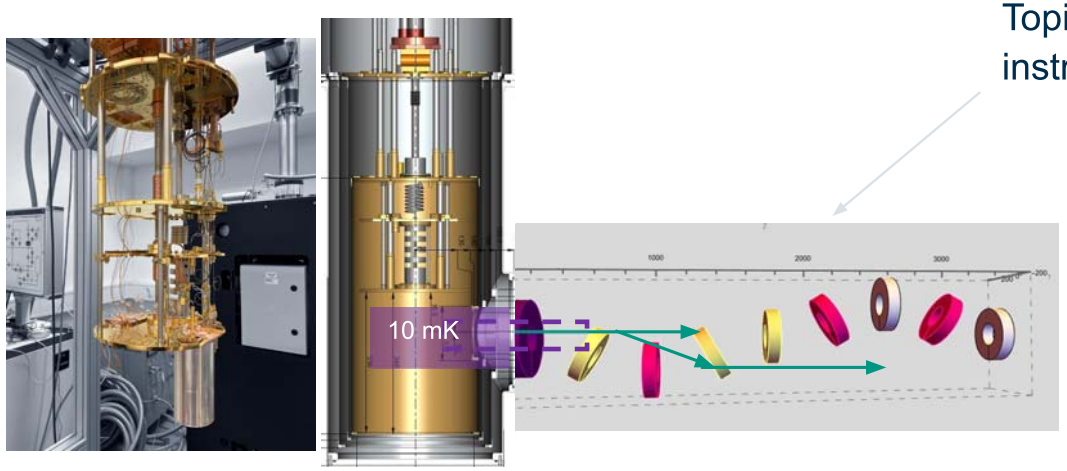


Master thesis topics – Quantum sensors for KATRIN++

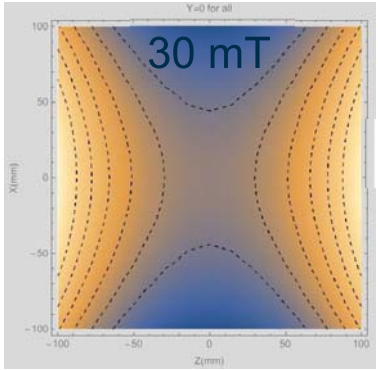
- *The work is embedded in the group "KATRIN R&D" at IAP and within the KATRIN collaboration. Participation in the local group meeting (Mo. 14:00, in presence) and a monthly international call (Mon. 14:00, virtual) is required.*
- *Office space is located at B402, typically 10 to 15 KATRIN team members join daily the office in an open, friendly and international environment. Presentations in English are mandatory.*
- *The work is in very close cooperation with the group of Prof. Sebastian Kempf at the IMS (currently Campus West). Integration into the group "KATRIN R&D" at IAP, as well at the group at IMS is required.*

- *1st referent is Prof. Kathrin Valerius.*

MMCs in strong magnetic fields (IAP, IMS)



Topic 1: Setup and test of a magnetic chicane to couple external instruments to a 10mK- dilution refrigerator



40 mT

Topic 2: Performing and analyzing measurements of MMC in an external magnetic field

(at IMS, AG Kempf, Campus West)

Topic 1: Setup and test of a magnetic chicane to couple external instruments to a 10mK- dilution refrigerator

Work breakdown:

1) Field calculations of possible designs with simulation tools

2) Specifications and purchase of a segment

3) In parallel to 2): setup and test source and detector system (direct line of sight)

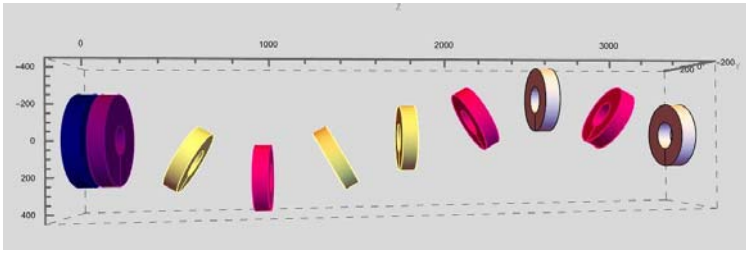
4) Specifications of vacuum system for room temperature tests

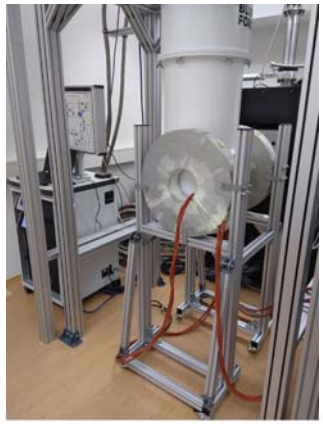
5) Setup of a segment in close coordination with our engineering group

6) Characterization of transport properties (rate & profile)

Detector side

Source side





example of an air coil

Focus: Experimental work (90%) and Analysis (10%)

Where: Campus North, B402 and B601, KATRIN R&D Group in close cooperation with engineering group

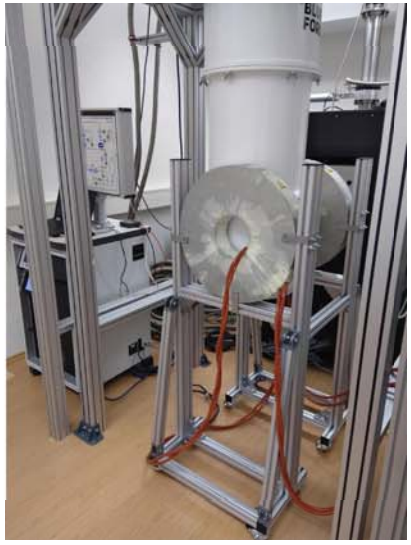
Supervisor: Markus Steidl and Luisa La Cascio (engineering)

Start: October–November

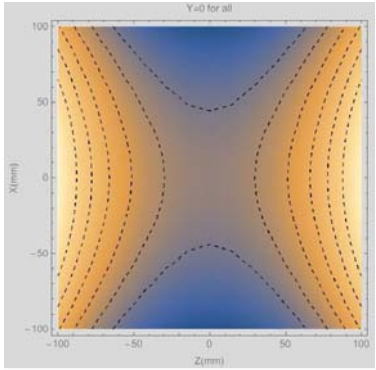
Topic 2: Performing and analyzing measurements of MMC in an external magnetic field.

Work breakdown:

1) Training in operation of MMCs and dilution refrigerators
2) Measurement campaign (typically 1–2 weeks)
3) Data analysis
4) Modelling of detector responses
5) Optimizing setup
6) In parallel: Sensitivity studies for neutrino mass measurements using MMCs



Test setup existing and commissioned, first measurements taken



Field calculations of air coil

Focus: Experimental work (50%) and Analysis (50%)

Where: Campus West, IMS, groups of Prof. Kempf, Campus North, B402, KATRIN R&D Group (IAP)

Supervisor: Markus Steidl (IAP) & Michael Müller (IMS)

Start: whenever you are ready