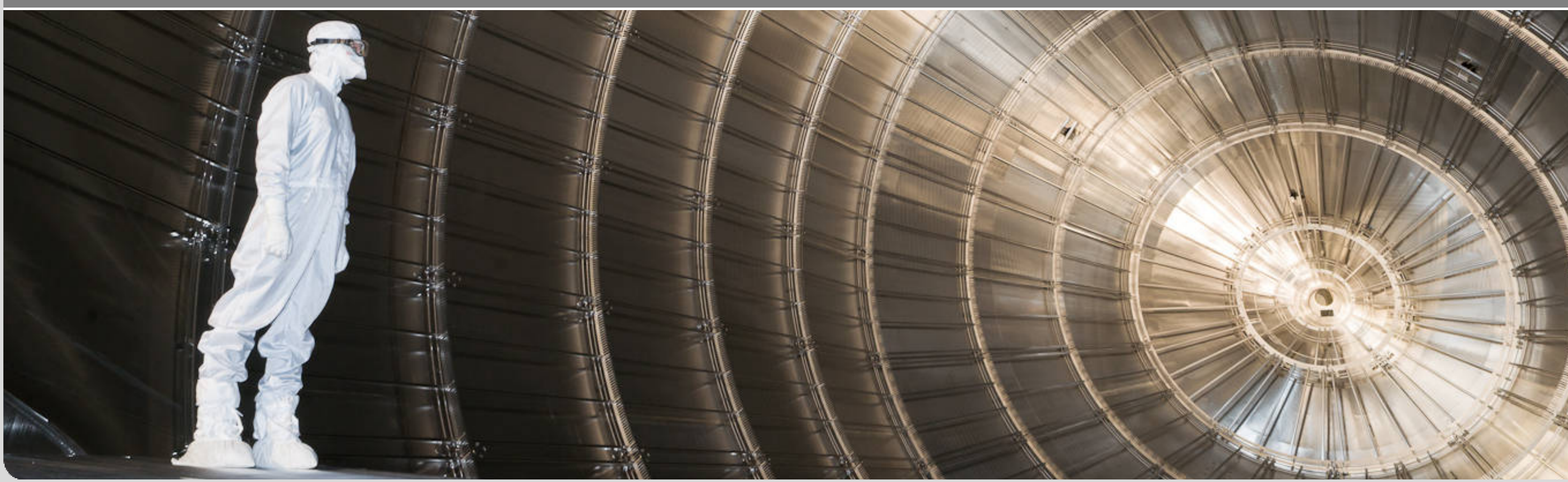
Karlsruhe Institute of Technology

“The neutrino mass experiment KATRIN”

- Florian Fränkle for the KATRIN collaboration -

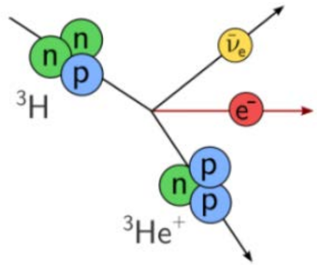
Institute for Nuclear Physics (IKP), Karlsruhe Institute of Technology (KIT)



Outline

- Neutrino mass & single β-decay
- The KATRIN experiment
- Commissioning measurements
- Summary & outlook

Neutrino mass and single β-decay



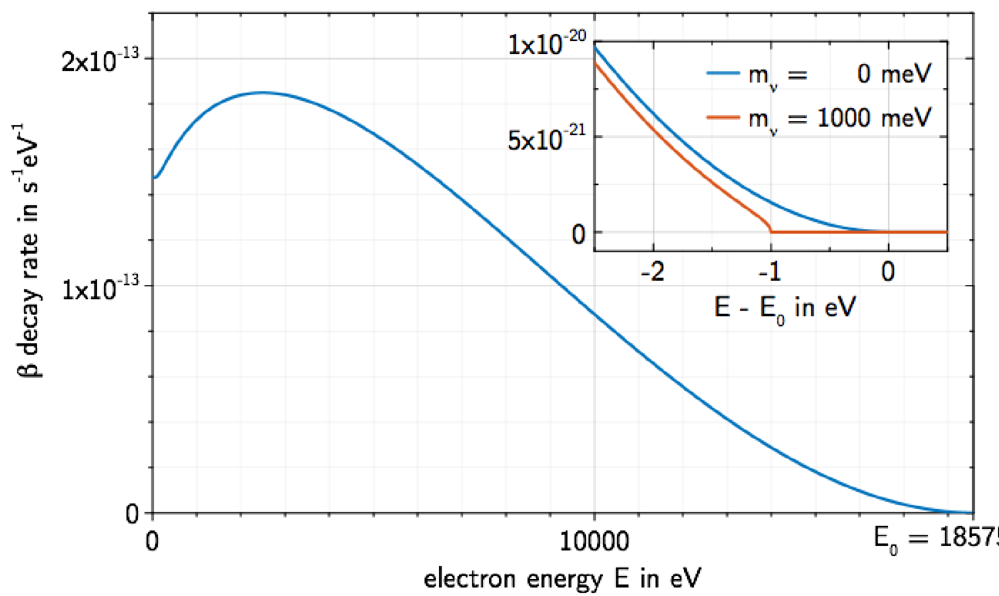
- β-decay: $n \rightarrow p + e^- + \overline{\nu}_e$
- Neutrino mass influences energy spectrum of β-decay electrons
- Neutrino mass determination via precise measurement of the spectral shape close to the endpoint
- Model independent method

Fermi theory of β-decay:

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

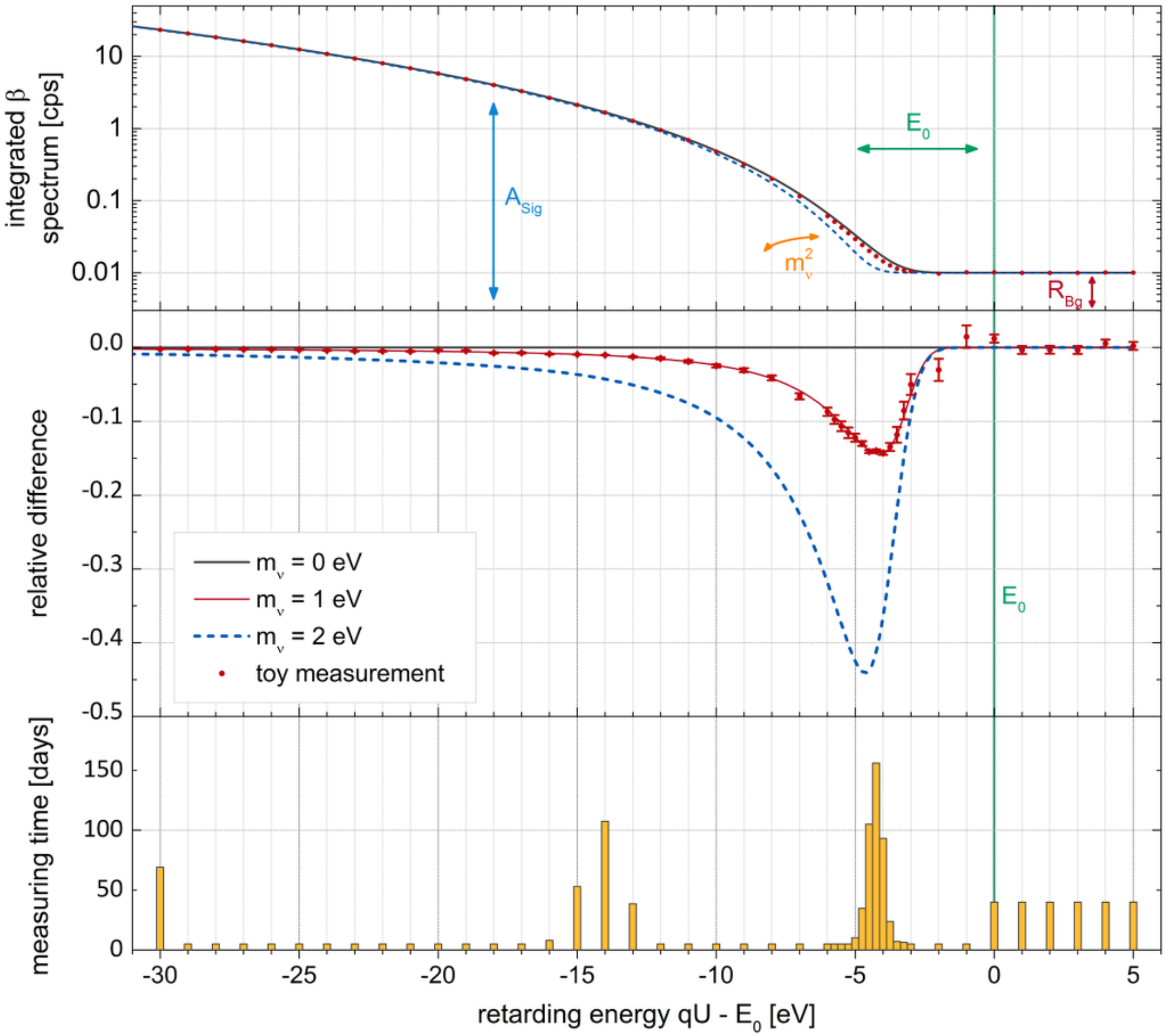
observable: $m_{\nu_e}^2 = \sum_{i=1}^{3} |U_{ei}|^2 m_i^2$

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



→ "Absolute neutrino mass", C. Weinheimer, plenary session 07/25

KATRIN measurement



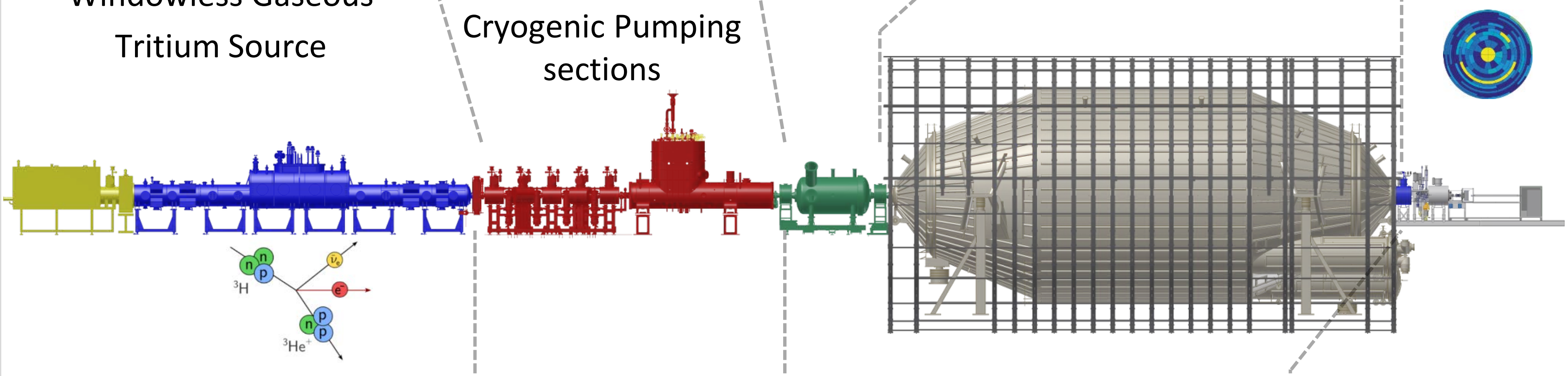
- KATRIN will measure the integrated β-spectrum close to the T_2 endpoint E_0
- The influence of m_ν is most pronounced a few eV below E_0
- Optimized measurement time distribution to increase sensitivity

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.)

~ 70 m

Windowless Gaseous Tritium Source	Differential and Cryogenic Pumping sections	Pre-Spectro-meter	Main Spectrometer	Detector



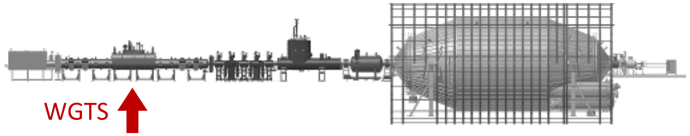
- tritium β-decay
- decay rate: 10^{11} 1/s
- T_2 pressure: 10^{-3} to 10^{-6} mbar

- β-electron transport
- tritium retention (factor < 10^{-12})

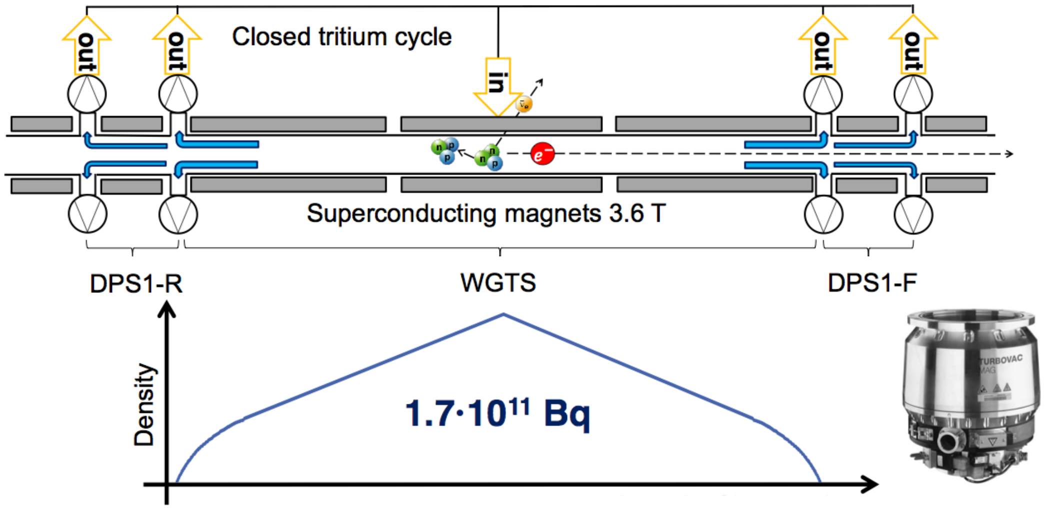
- energy analysis of β-electrons
- resolution 0.93 eV @ 18.6 keV
- pressure < 10^{-10} mbar

- counting of transmitted β-electrons

Windowless gaseous tritium source

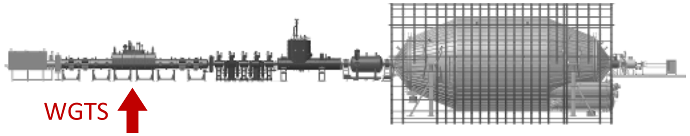


- **Purpose:** delivery of 10^{11} β-decay electrons per second

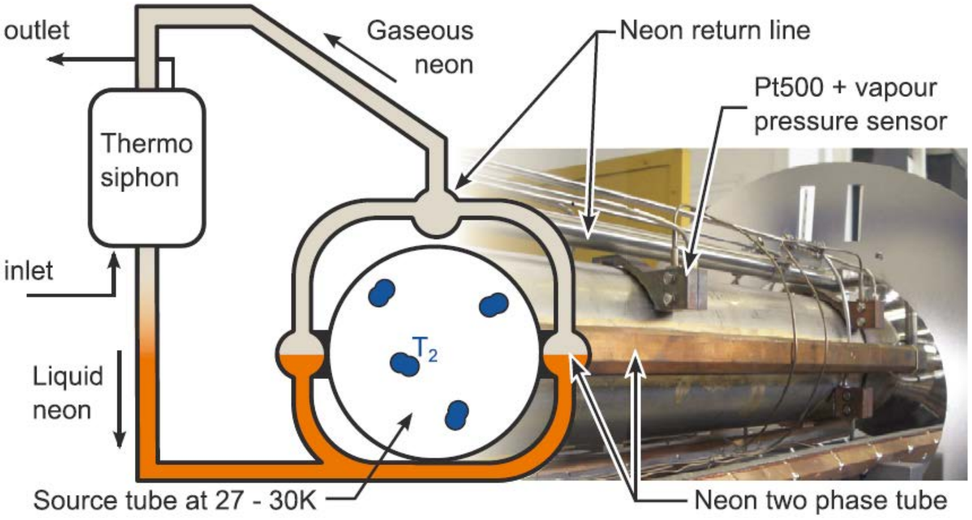


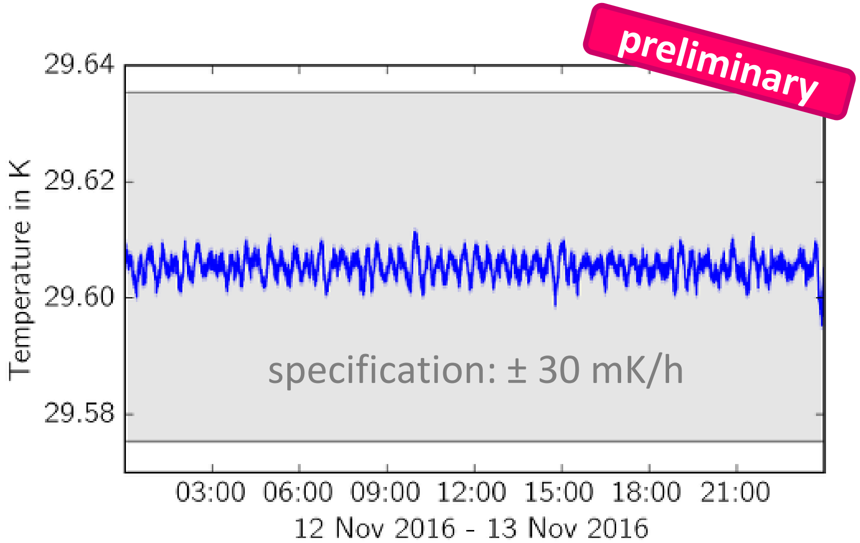
- Stability of T_2 density profile of **10^{-3}** (function of T_2 injection rate, purity, beamtube temperature stability and homogeneity, pump rate)
- Complex cryostat, 16 m length, 27 t weight, > 800 sensors and valves
- High isotopic purity (> 95%)
- Tritium loop processes 40 g T_2 / day (same scale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

Windowless gaseous tritium source

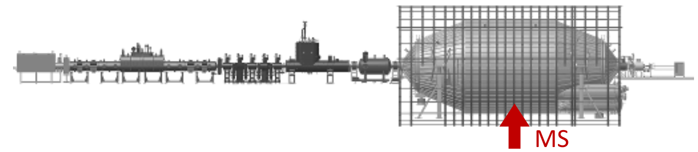


- Successful commissioning of magnet system at maximum field (3.6 T)
- Test of two phase beam tube cooling system: temperature stability exceeds requirements by one order of magnitude!

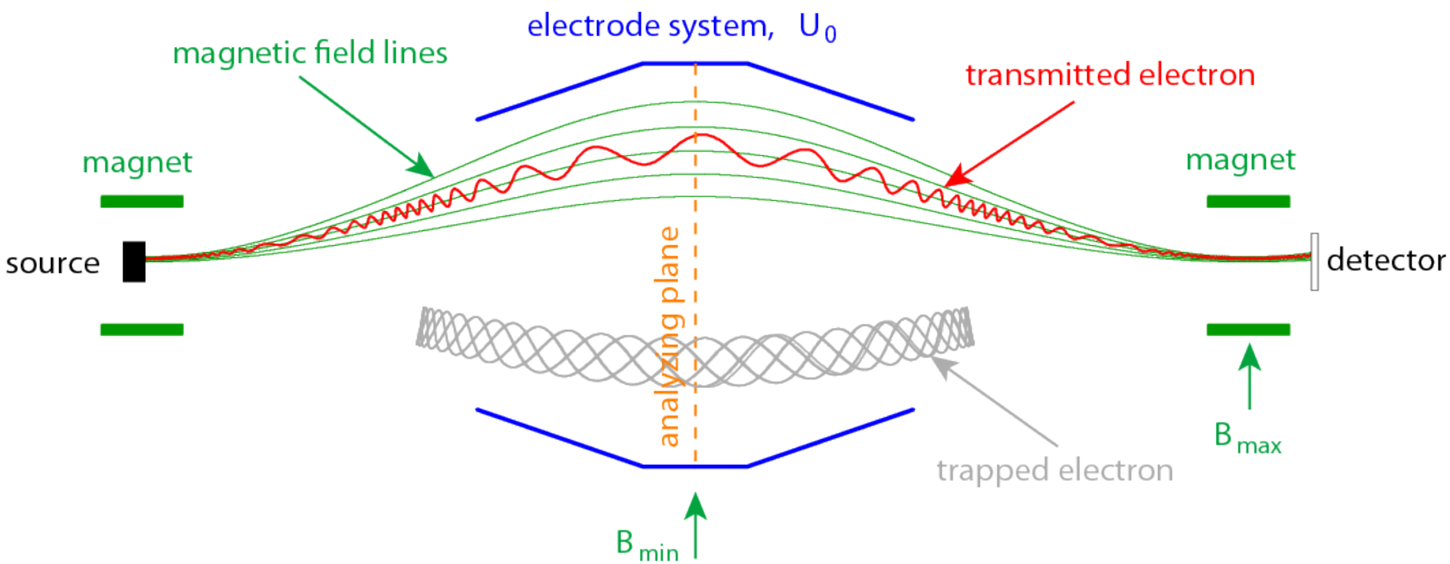




Main spectrometer – MAC-E filter



- **M**agnetic **A**diabatic **C**ollimation combined with an **E**lectrostatic Filter

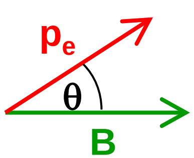


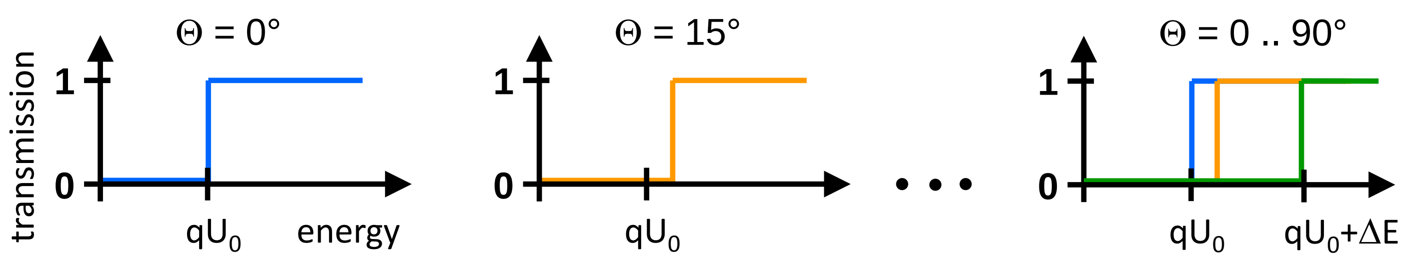
magnetic moment:

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

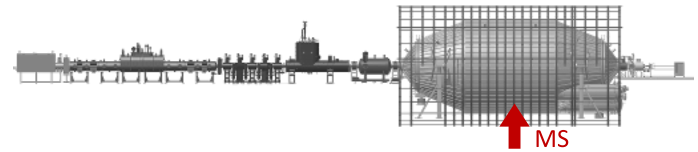
energy resolution:

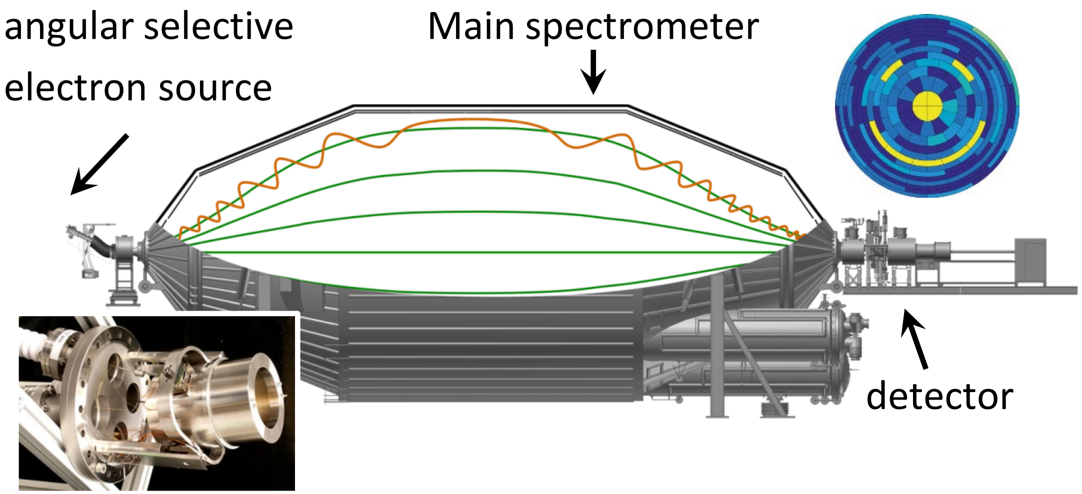
$$\Delta E = \frac{B_A}{B_{max}} E_t$$

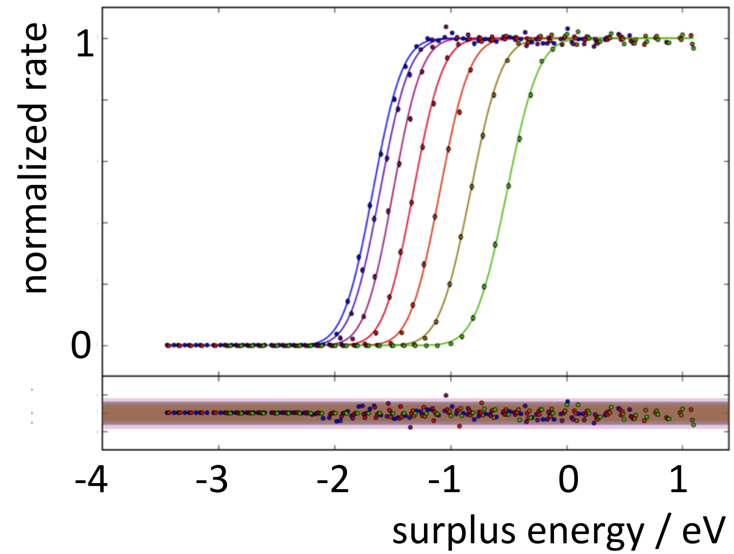




Main spectrometer – MAC-E filter







- Several commissioning measurement phases since autumn 2013
- Main spectrometer successfully operated from 0 to -33 kV
- Transmission characteristics of main spectrometer as expected

October 14th, 2016 – KATRIN first light

The New York Times: Experiment to Weigh 'Ghost Particles' Starts in Germany

CERN Courier: KATRIN celebrates first beam

Bild: Experimente zum Wiegen von Neutrinos starten in Karlsruhe

SWR Aktuell: Neutrinos kommen auf die Waage

The China Post: Experiment starts to find weight of 'ghost particles'

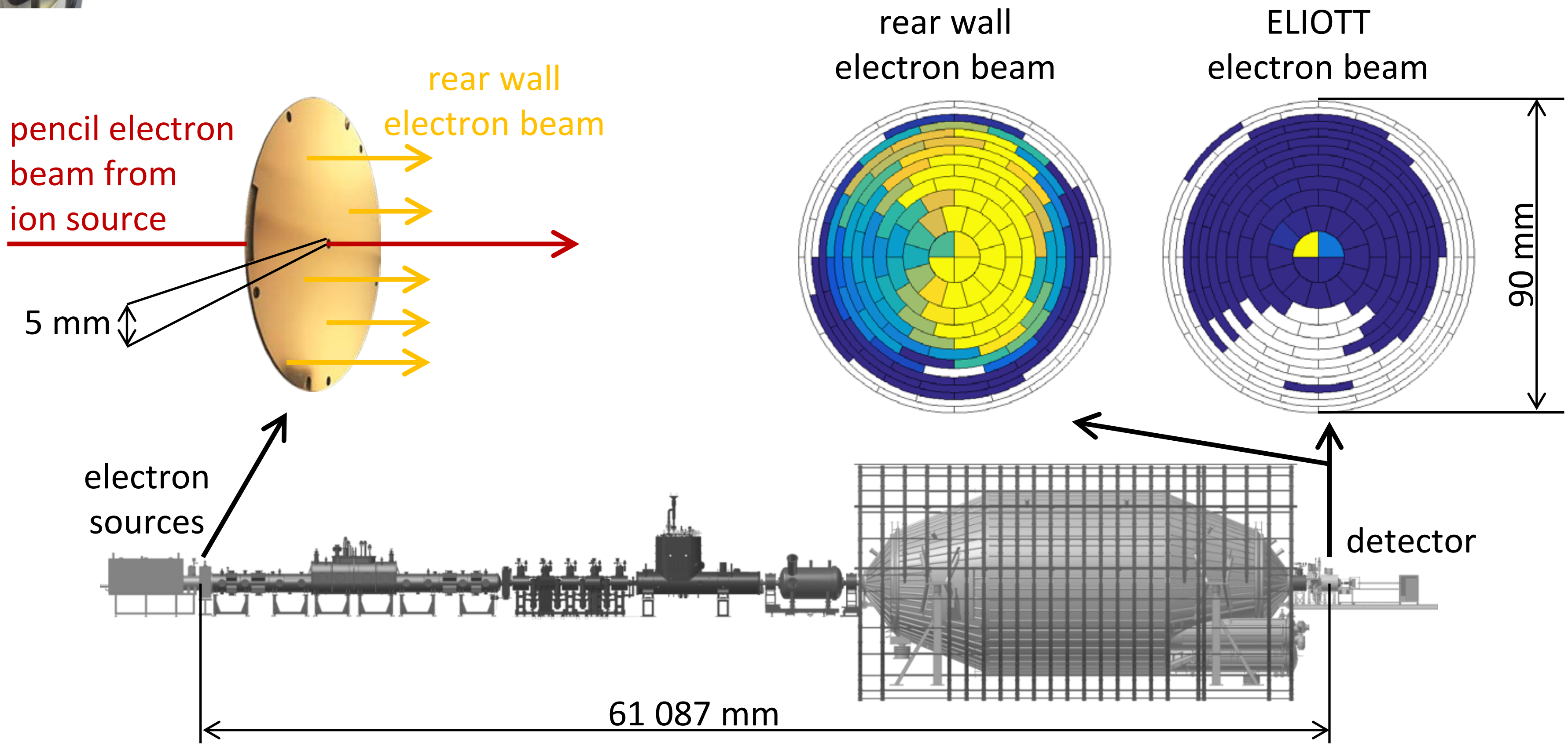
Zeit Online: Forscher geben Startschuss zum Wiegen von Geisterteilchen

DW: The KATRIN Tritium Neutrino experiment: A giant scale for the tiniest of particles

International Business Times: Neutrino Mass: Germany's KATRIN Experiment Aims To Weigh The Universe's Lightest Particle

Physik Journal: Neutrinos auf der Waage

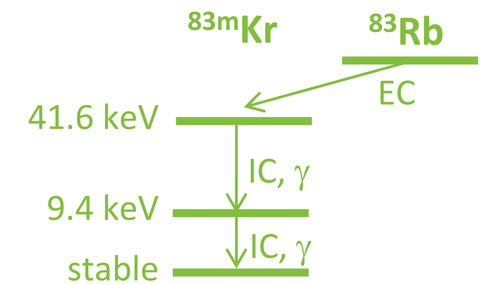
KATRIN first light – alignment

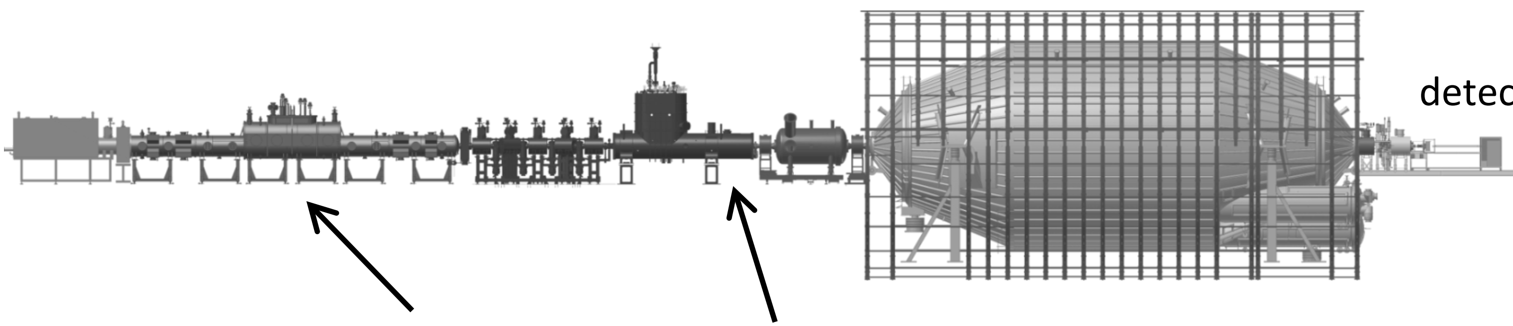


- KATRIN beamline is aligned and in good agreement with simulations
- Unobstructed transport of 191 Tcm² flux tube from source to detector

KATRIN krypton commissioning measurements

- Injection of ^{83m}Kr into the KATRIN source beamtube, no carrier gas, single ^{83m}Kr atoms
- ^{83m}Kr has well known lines from conversion electrons, for example K-32 (17.824 keV), L_3-32 (30.472 keV)
- Measurement phase: July 3rd, 2017 – July 19th, 2017



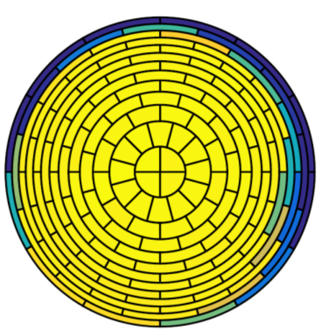


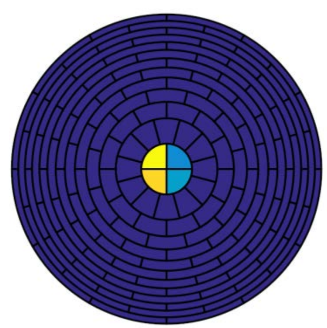
detector

gaseous Kr source

Kr decays inside WGTS beamtube

^{83}Rb emanator ~ 1 GBq



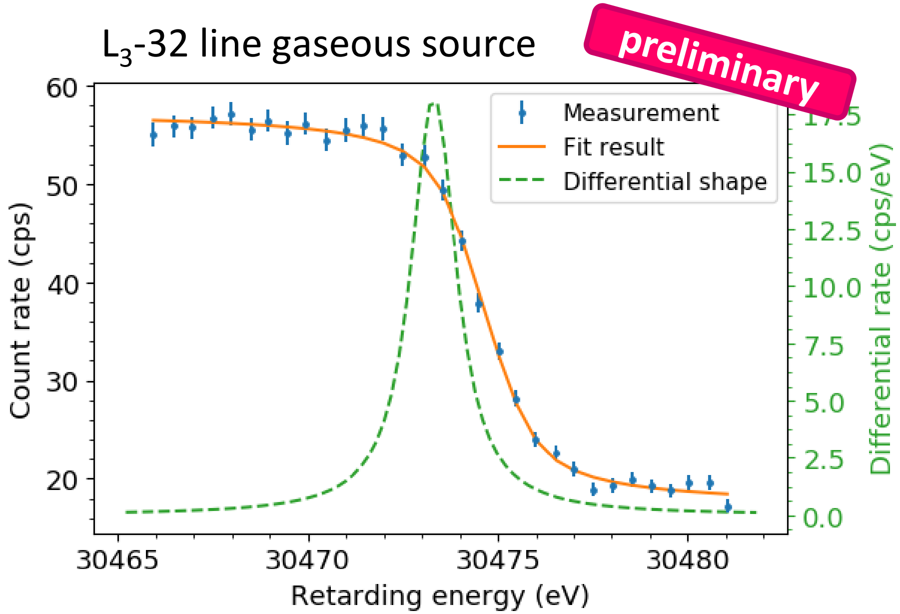


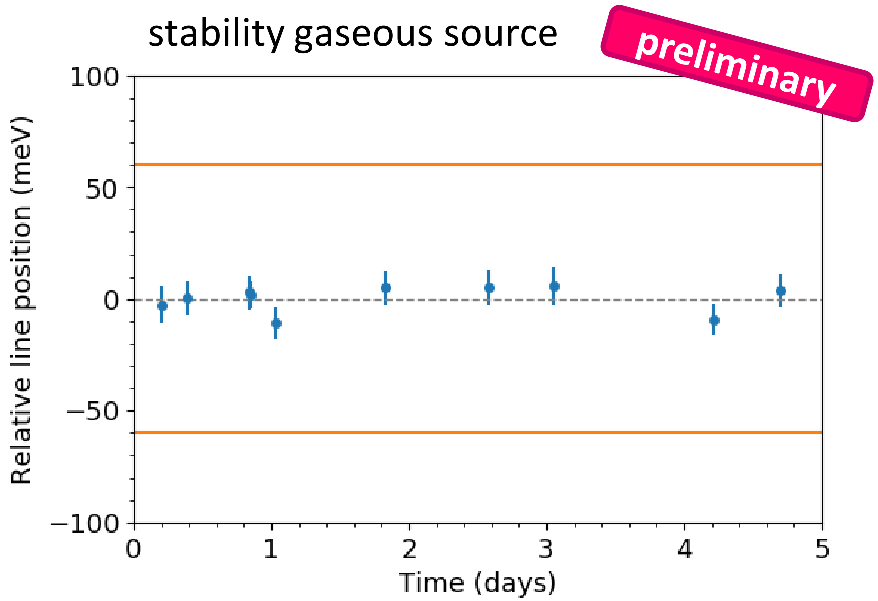
condensed Kr source

“spot-like” source, can be scanned across flux tube

^{83}Rb emanator ~ 1 MBq

KATRIN krypton commissioning measurements





- example run (one of many line scans)
- only events on detector ring 0 (30x more statistics available)
- repeated scans of L3-32 line
- line position stability well within KATRIN goal of ± 60 meV

→ "Calibration of the high voltage and the energy scale of the KATRIN experiment", O. Rest, poster session

Summary & outlook

Summary:

- KATRIN aims to measure the neutrino mass with 0.2 eV/c^2 sensitivity (90% C.L.)
- For the first time electrons were transmitted along the complete KATRIN beamline
- Successful commissioning measurements with ^{83m}Kr , data analysis ongoing

Outlook:

- Prepare KATRIN for tritium operation
- Start of neutrino mass measurements in 2018
- Official KATRIN inauguration on **June 11th, 2018**

KATRIN collaboration

Karlsruhe Institute of Technology

Westfälische Wilhelms-Universität Münster

Johannes Gutenberg Universität Mainz

Bergische Universität Wuppertal

University of Washington 1861

The University of North Carolina at Chapel Hill

Carnegie Mellon University Pittsburgh Pennsylvania 1900

MIT

Berkeley Lab

Max-Planck-Institut für Kernphysik

Hochschule Fulda University of Applied Sciences

cea

TUM

Max-Planck-Institut für Physik

Uni Bonn Rheinische Friedrich-Wilhelms-Universität

Universidad Complutense Madrid

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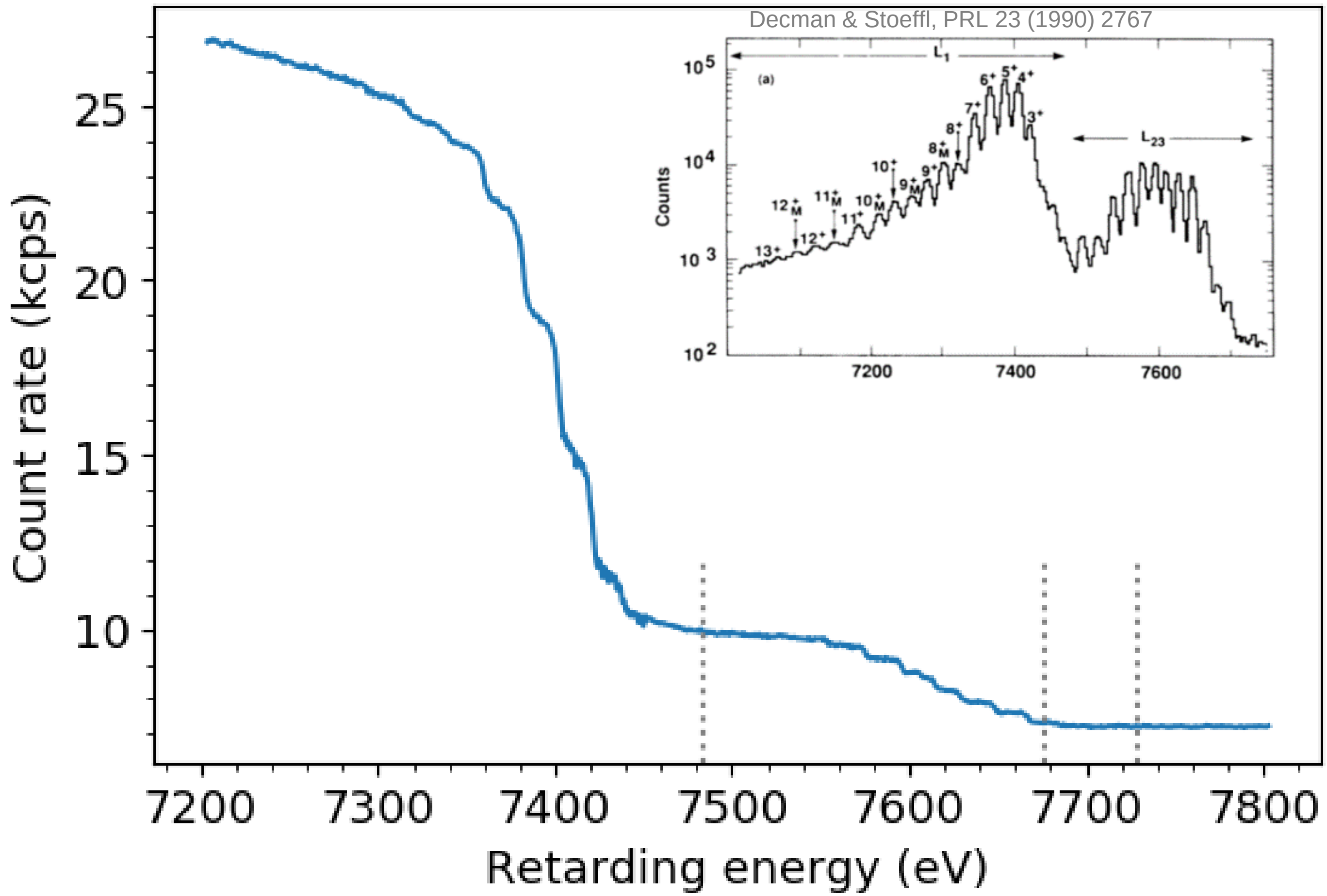
Backup

Auger and conversion electrons in ^{83m}Kr decay

Line	Energy a) $E(ce)$ (eV)	ICC–α b) [Kib08]	Intensity I_{ce} c) per decay (%) [McC15b]	Natural line width Γ (eV) [Pic92b]	[Cam01]	[Ost08]
L-Auger*	1000–1600 [Kov92]		168.4(4)			
γ 9405.7						
K	–	–	–	–	–	–
L1	7481.1(10)	11.57(17)	66.8(19)	5.30(4)	3.75	3.72(19)
L2	7673.74(60)	1.29(3)	7.45(25)	1.84(5)	1.25	1.29(14)
L3	7726.44(60)	0.99(4)	5.72(27)	1.40(2)	1.19	1.58(16)
M1	9112.90(67)	1.88(3)	10.8(4)	4.27(5)	3.5	3.123(4)
M2	9183.52(62)	0.206(4)	1.18(4)	1.99(32)	1.6	0.63(39)
M3	9191.10(61)	0.157(6)	0.901(43)	1.66(8)	1.1	1.1(4)
M4	9310.61(60)	0.00289(6)	0.017(1)	–	0.07	–
M5	9311.85(60)	0.00259(4)	0.015(1)	–	0.072	–
N1	9378.13(60)	0.191(3)	1.11(4)	0.19(4)	0.4	0.288(93)
N2	9390.98(60)	0.0152(2)	0.088(18)	–	–	0.0
N3	9391.64(60)	0.0114(2)	0.066(23)	–	–	0.0
K-Auger*	10300–14200 [Kov92]		8.62(16)			
γ32151.6						
K	17824.23(50)	483.0(70)	24.8(5)	2.83(12)	2.71	2.70(6)
L1	30226.80(94)	31.4(5)	1.61(4)	–	3.75	–
L2	30419.49(50)	472.0(70)	24.2(6)	1.84(5)	1.25	1.165(69)
L3	30472.19(50)	737.0(110)	37.8(10)	1.40(2)	1.19	1.108(13)
M1	31858.65(58)	4.97(7)	0.254(6)	–	3.5	–
M2	31929.27(53)	78.4(11)	4.01(10)	1.99(32)	1.6	1.230(61)
M3	31936.85(51)	122.2(18)	6.25(16)	1.66(8)	1.1	1.322(18)
M4	32056.35(50)	1.154(17)	0.059(1)	–	0.07	–
M5	32057.60(50)	1.627(23)	0.083(2)	–	0.072	–
N1	32123.88(50)	0.504(7)	0.0258(6)	0.19(4)	0.4	0.4
N2	32136.73(50)	5.82(9)	0.298(8)	0.59(4)	–	–
N3	32137.39(50)	8.93(13)	0.458(11)	0.59(4)	–	–

Krypton 9.4 keV "hedgehog"



KATRIN sensitivity