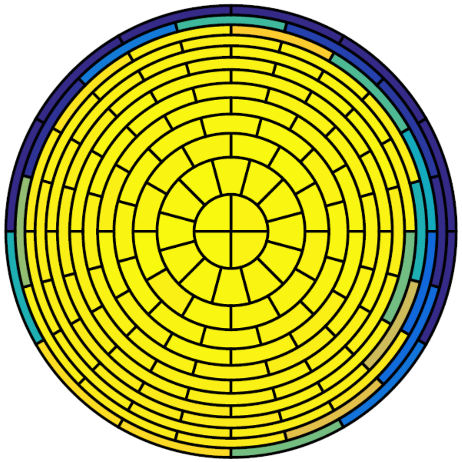
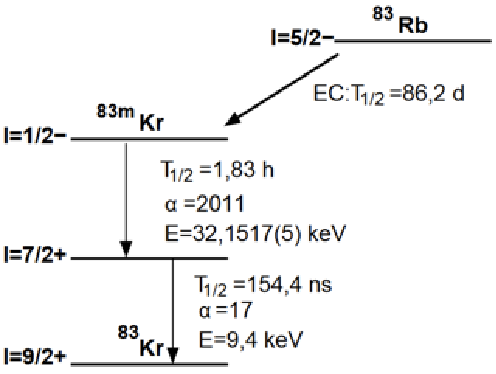
Commissioning the KATRIN Experiment with Krypton-83m

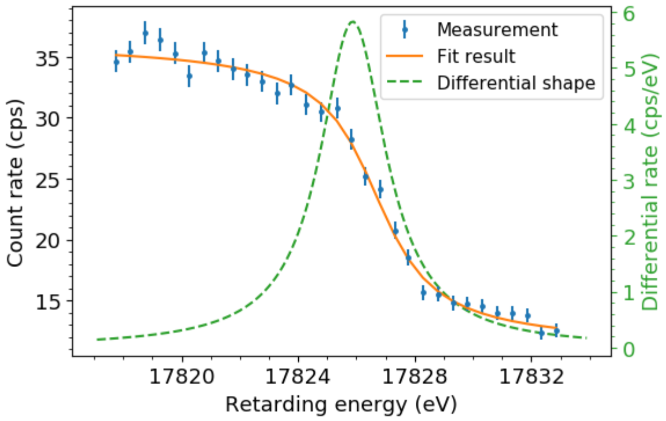
Hendrik Seitz-Moskaliuk, KIT-ETP

International School of Nuclear Physics, 39th course, Erice, 16.09.-24.09.2017

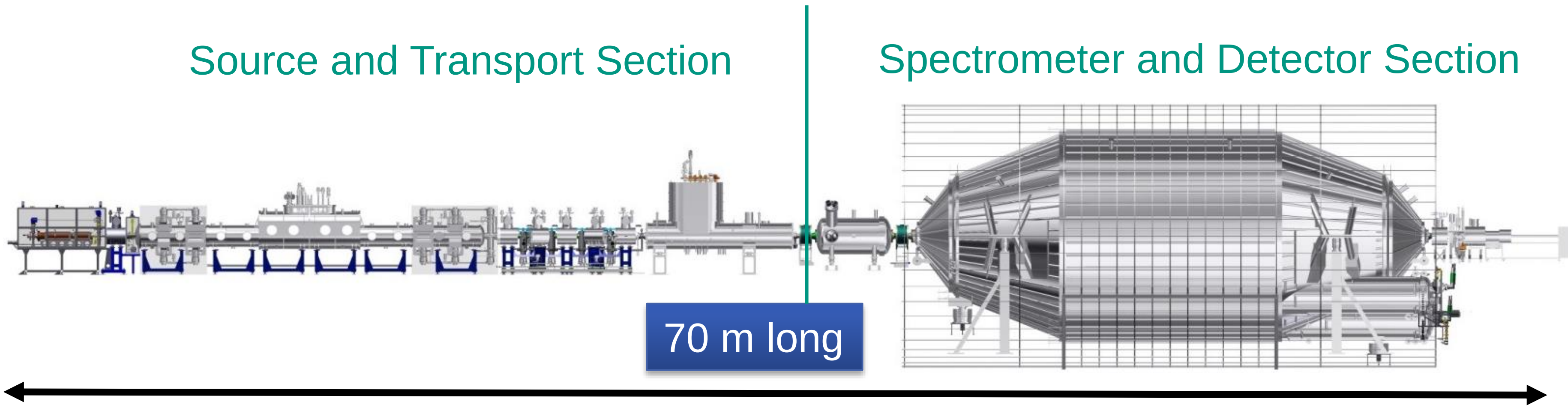
ETTORE MAJORANA FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE
TO PAY A PERMANENT TRIBUTE TO ARCHIMEDES AND GALILEO GALILEI, FOUNDERS OF MODERN SCIENCE AND TO ENRICO FERMI, THE "ITALIAN NAVIGATOR", FATHER OF THE WEAK FORCES







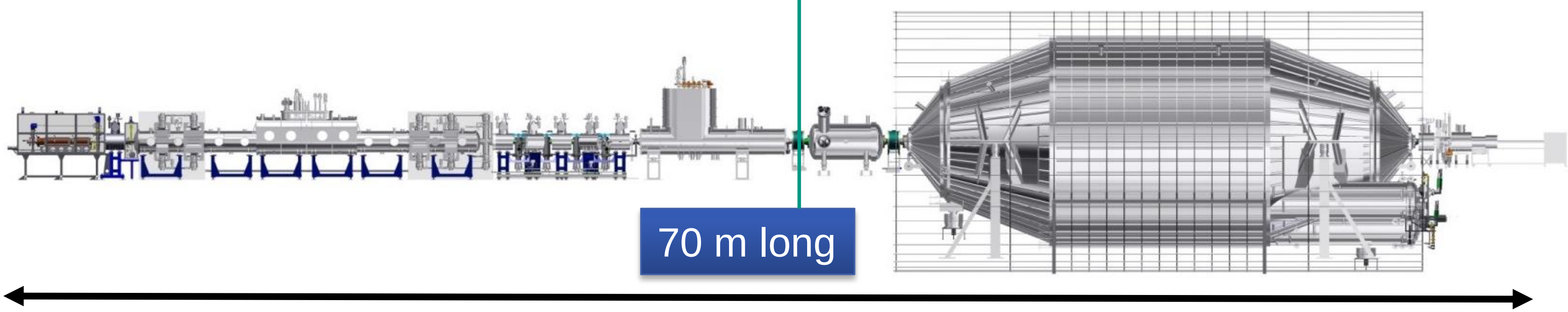
The KATRIN Experiment

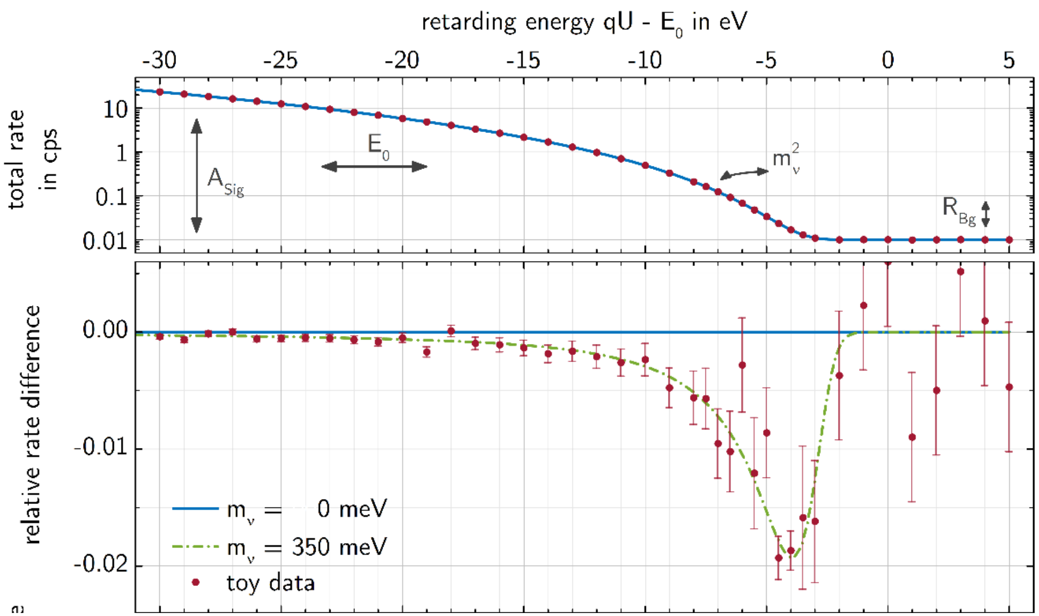


The KATRIN Experiment

Source and Transport Section

Spectrometer and Detector Section





M. Kleesiek, PhD thesis, KIT (2014)

KATRIN's sensitivity on electron anti neutrino mass: 0.2 eV/c² (90 % C. L.)

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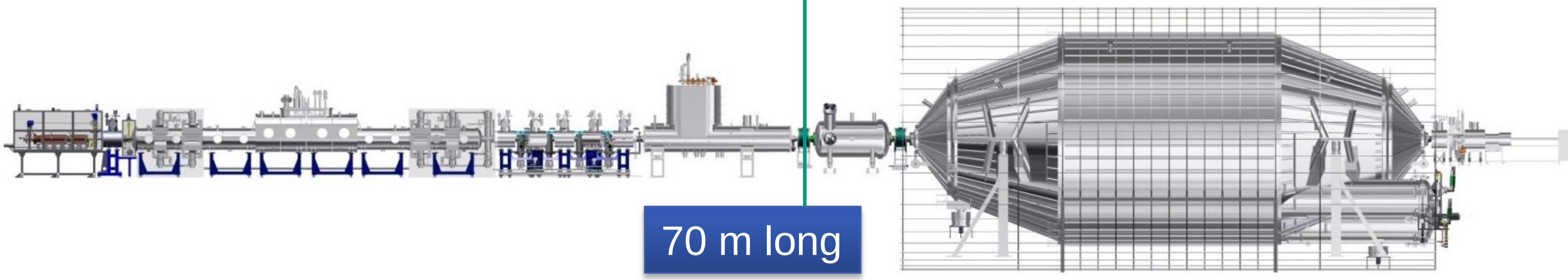

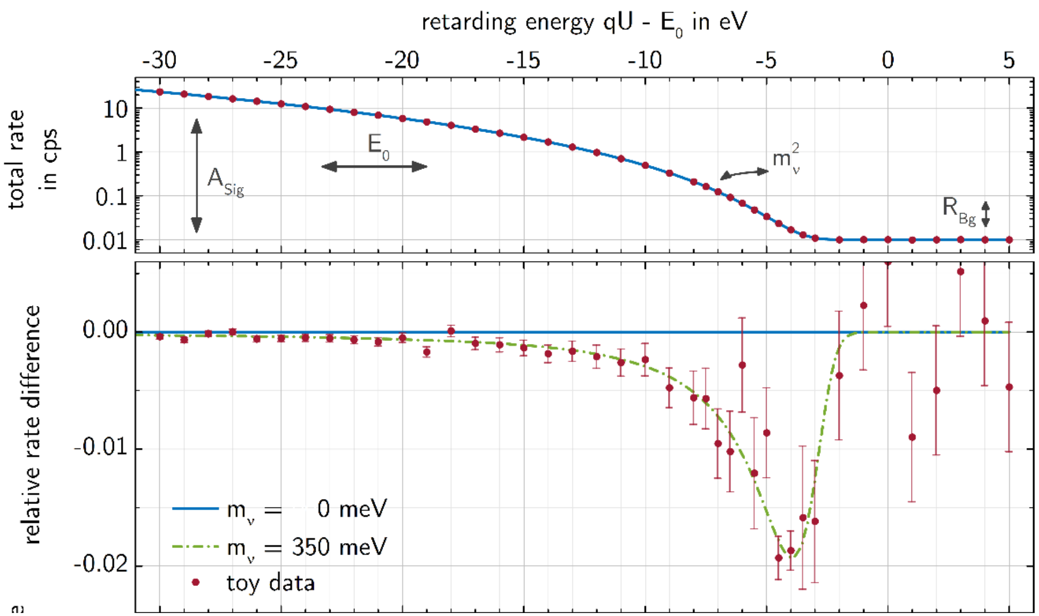

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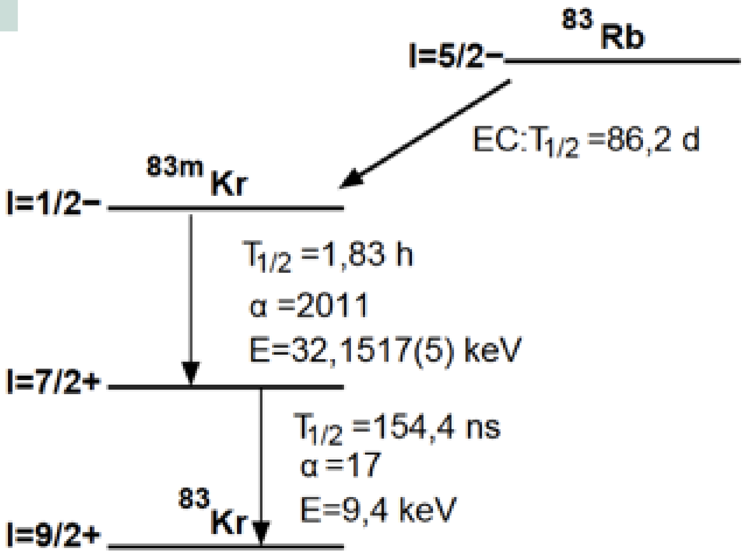
See also talks by Kathrin Valerius (today), Sebastian Mirz (today) and lecture by Guido Drexlin (Thursday)

Krypton-83m: a unique nuclear standard for KATRIN

	Tritium	Krypton-83m
Electron emitter	β decay	Internal conversion
Electron energy	Continuous up to E_0=18.6 keV	Several sharp lines between 7-32 keV K32 at 17.8 keV
Half-life	12.3 a	1.83 h

- ^{83}Rb produced at Rez cyclotron
- Sources easy to handle due to “long” half-life of ^{83}Rb
- High activity > 1 GBq possible



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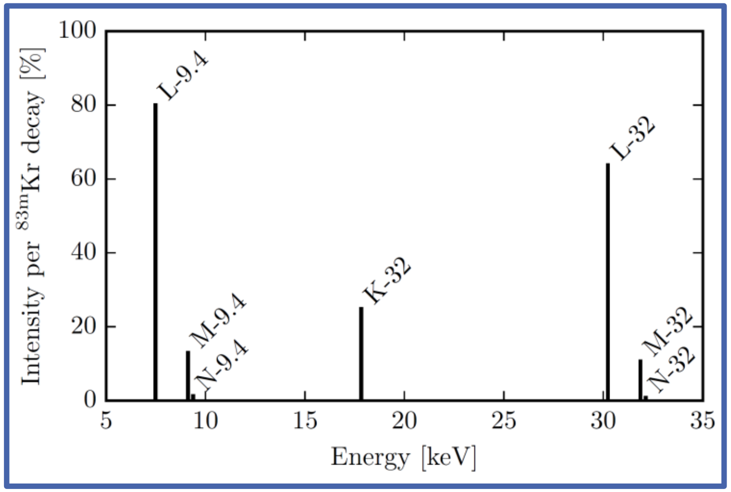
Martin Slezak, PhD thesis, Prague 2015



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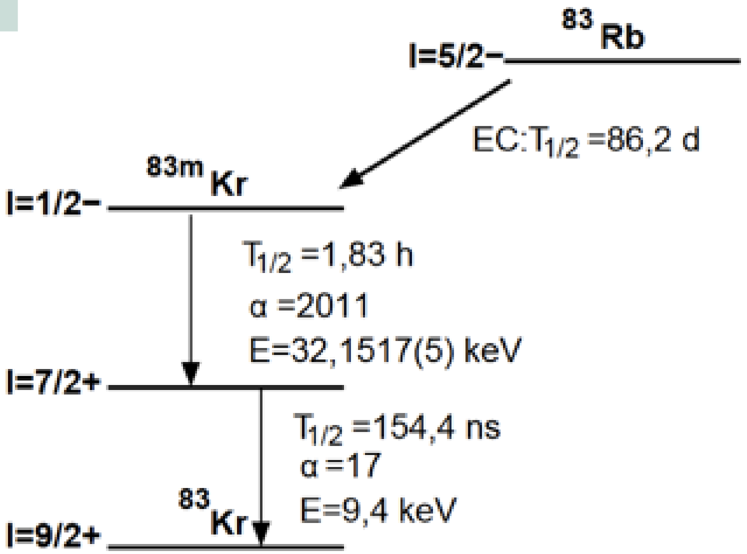

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No risk of contamination

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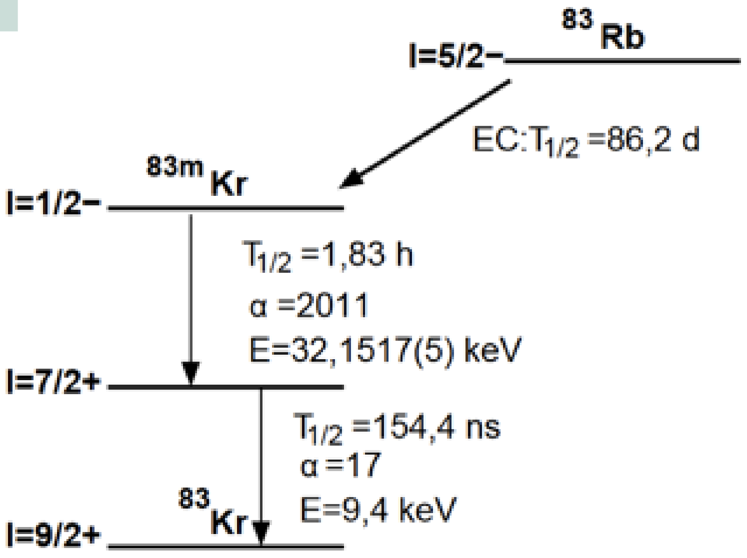
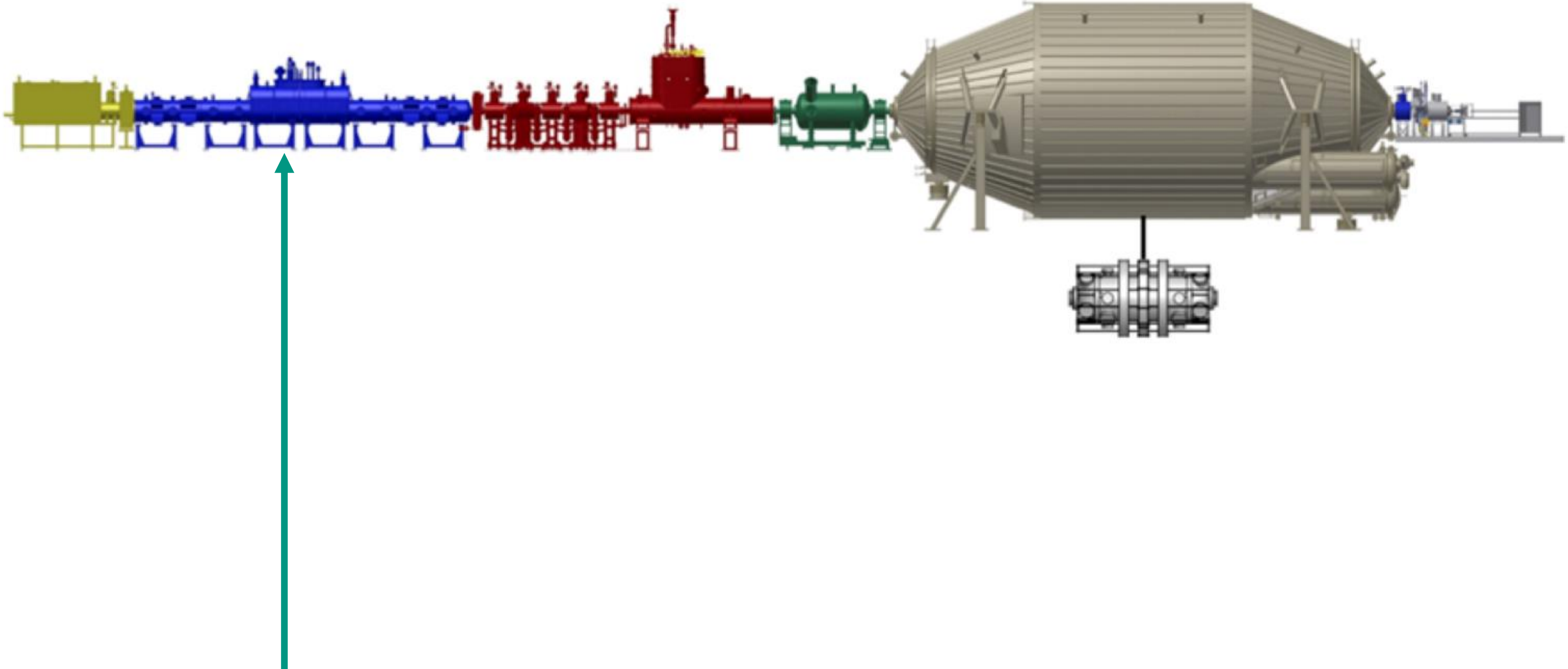


Krypton sources at KATRIN



Gaseous ^{83m}Kr source

- ^{83m}Kr decays inside beam tube
- Homogeneous spatial distribution
- Ca. 1 GBq of ^{83}Rb

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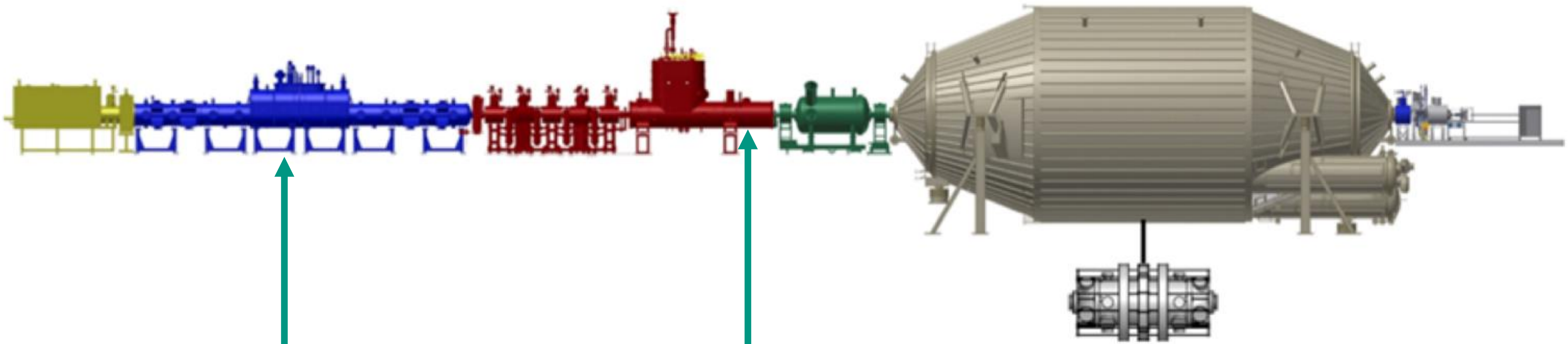

Condensed ^{83m}Kr source
- Thin film on cold substrate
- Spot-like, movable across flux tube
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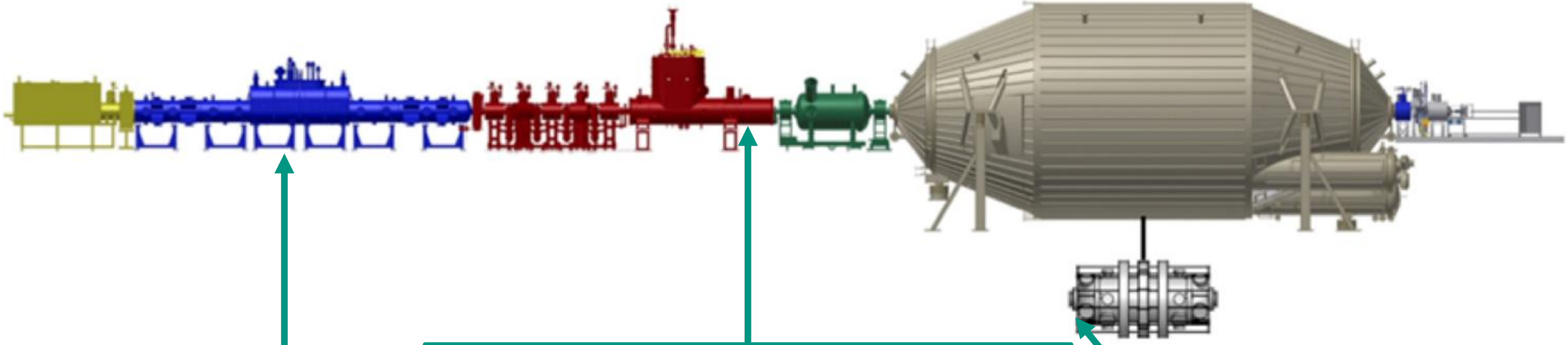

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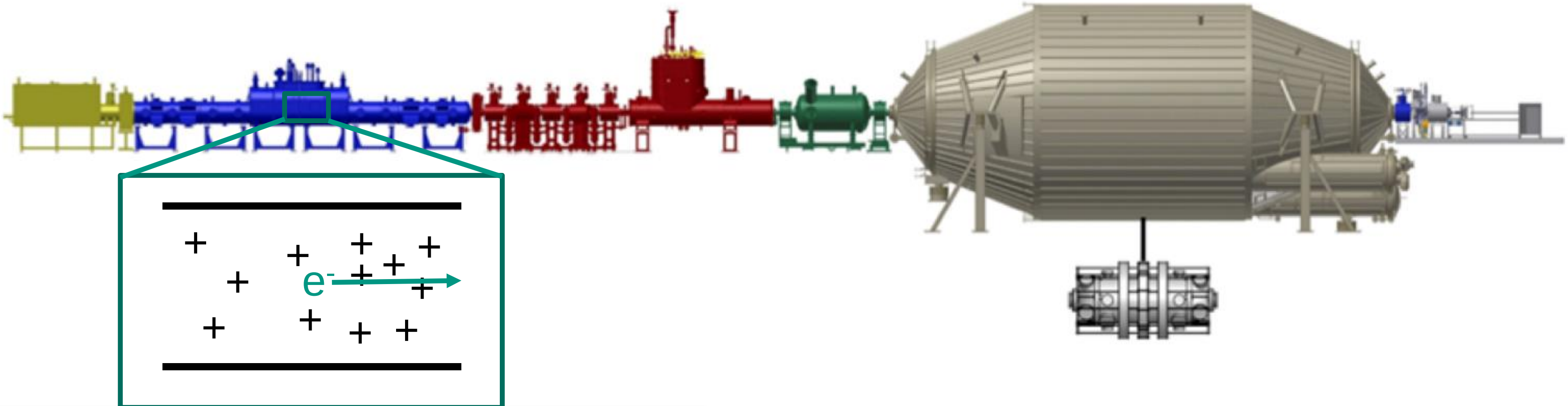
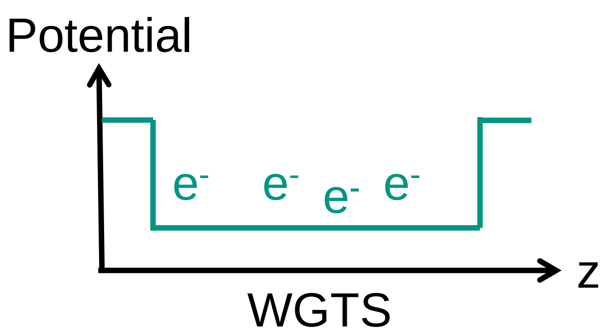
Implanted ^{83m}Kr source
- Parallel measurement at separate monitor spectrometer beamline
- Ca. 2.5 MBq of ^{83}Rb

Gaseous ^{83m}Kr source

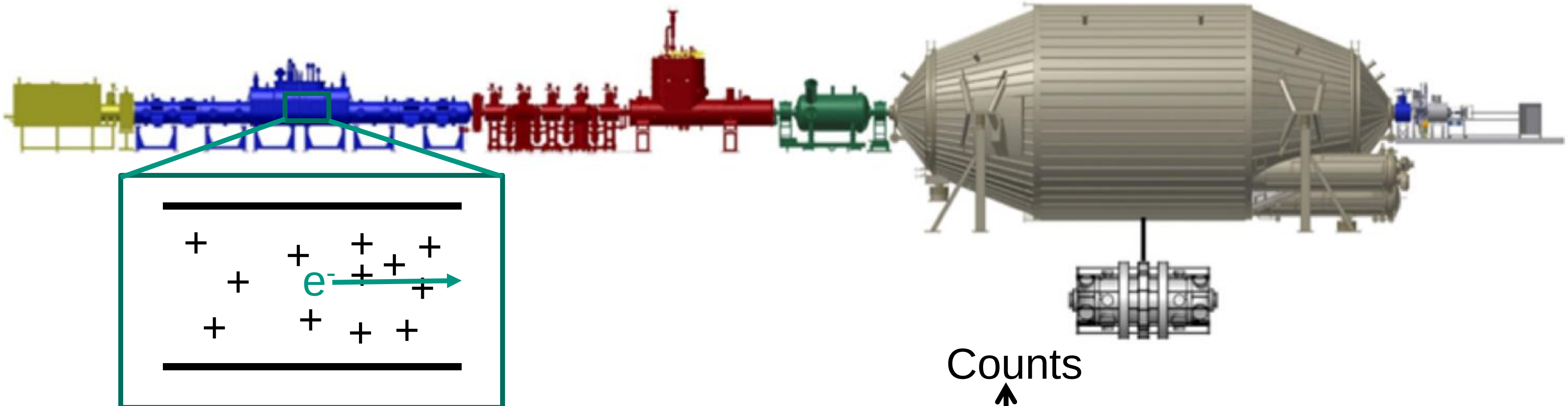


Space charge inside source since electrons leave towards spectrometer



Electron energy shifted on the order of 10 meV.

Gaseous ^{83m}Kr source



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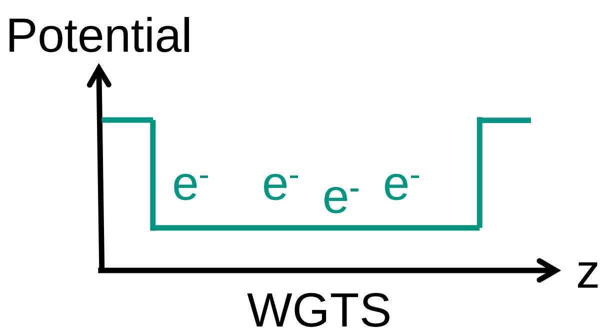

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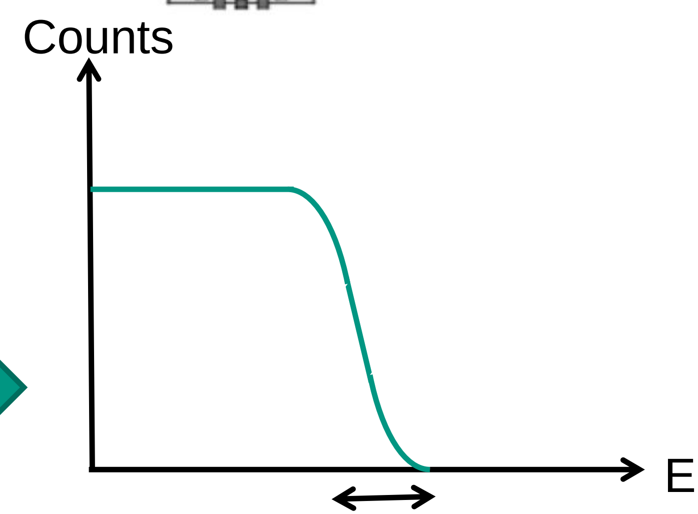
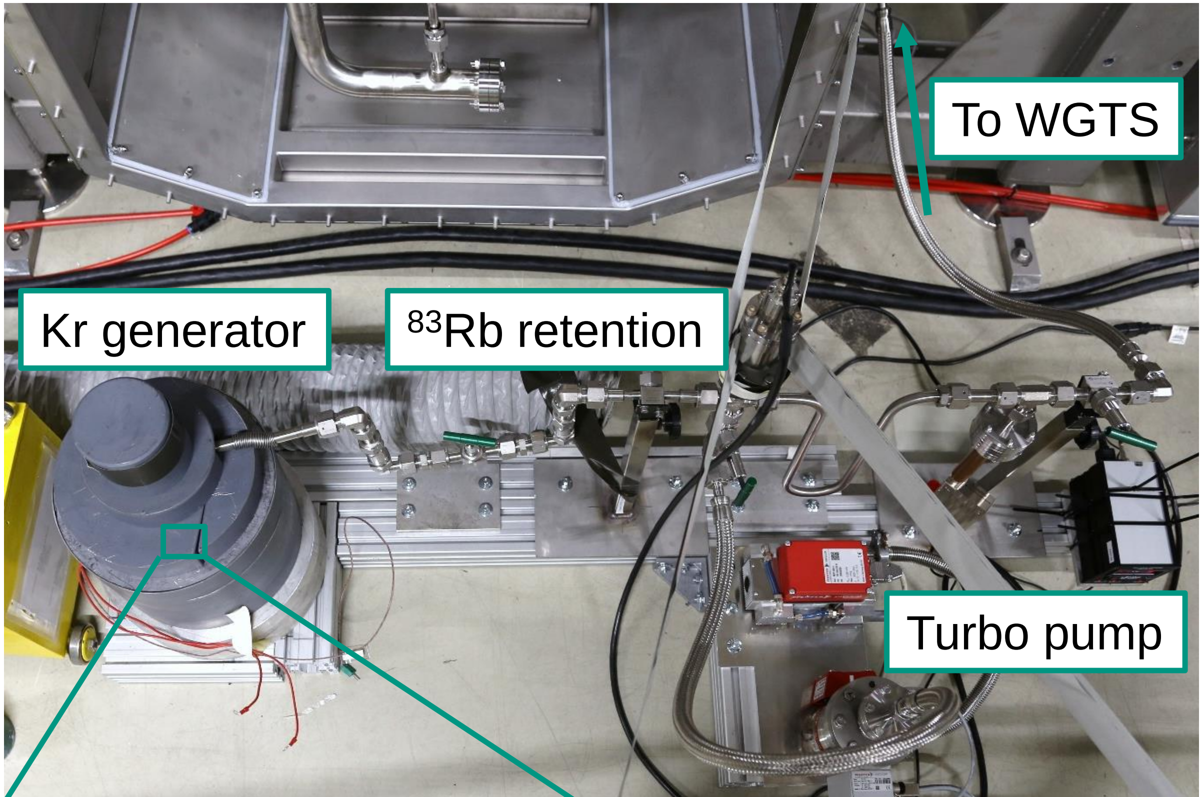
Quantification



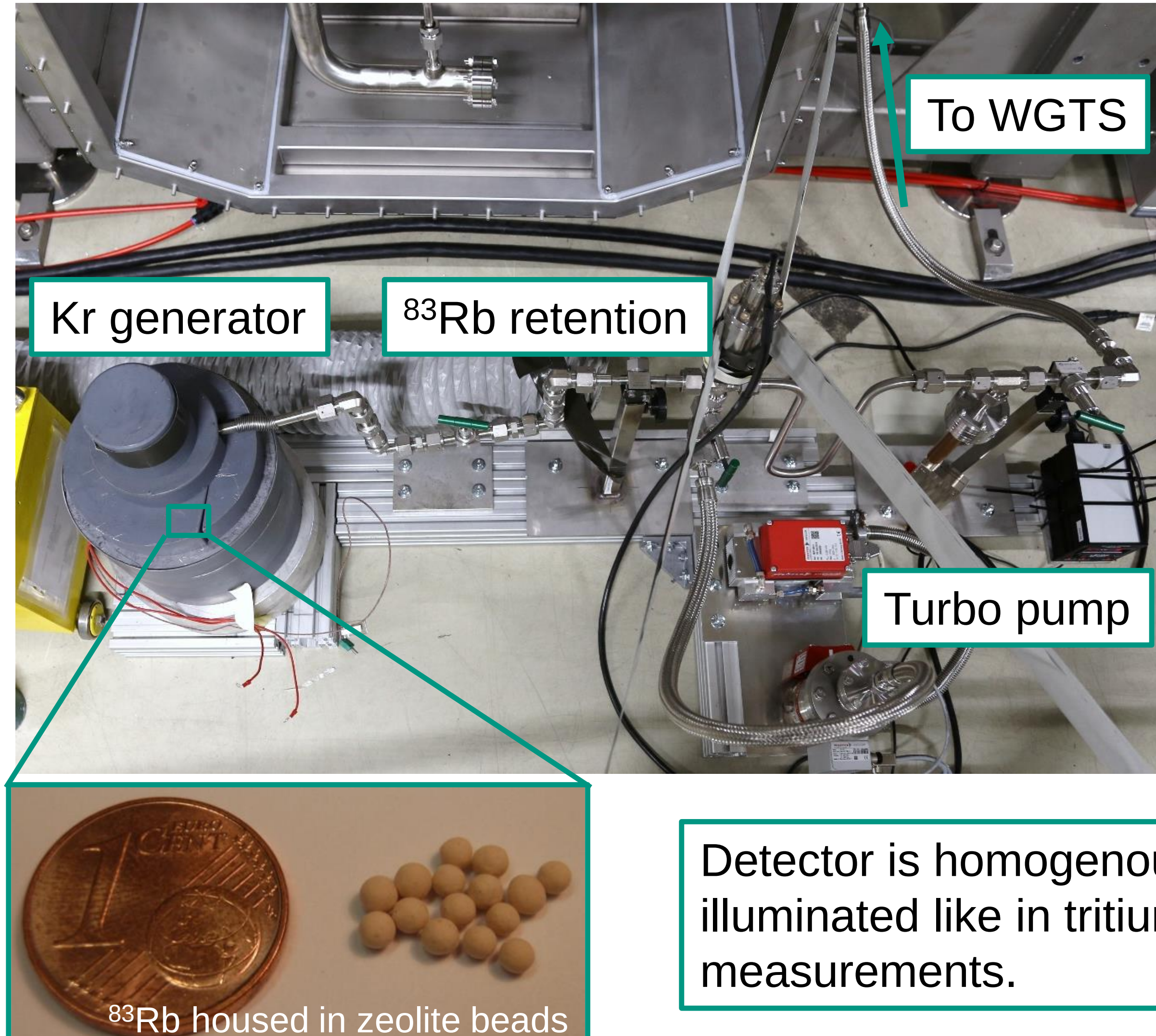
Determine step position in integrated spectrum of ^{83m}Kr line (admixed to tritium).

Gaseous ^{83m}Kr source



Change WGTS operation mode from 30 K (tritium operation) to 100 K (Kr operation)

Gaseous ^{83m}Kr source



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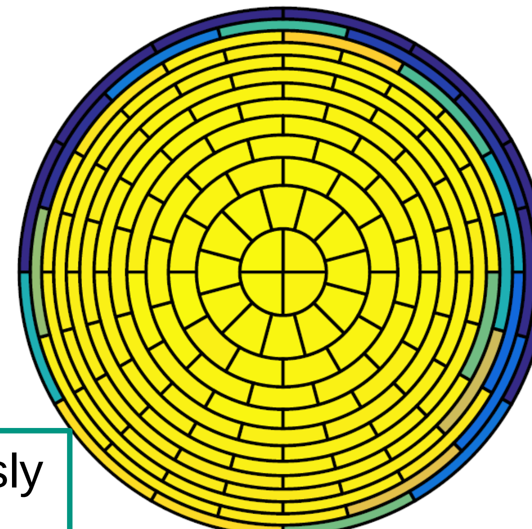
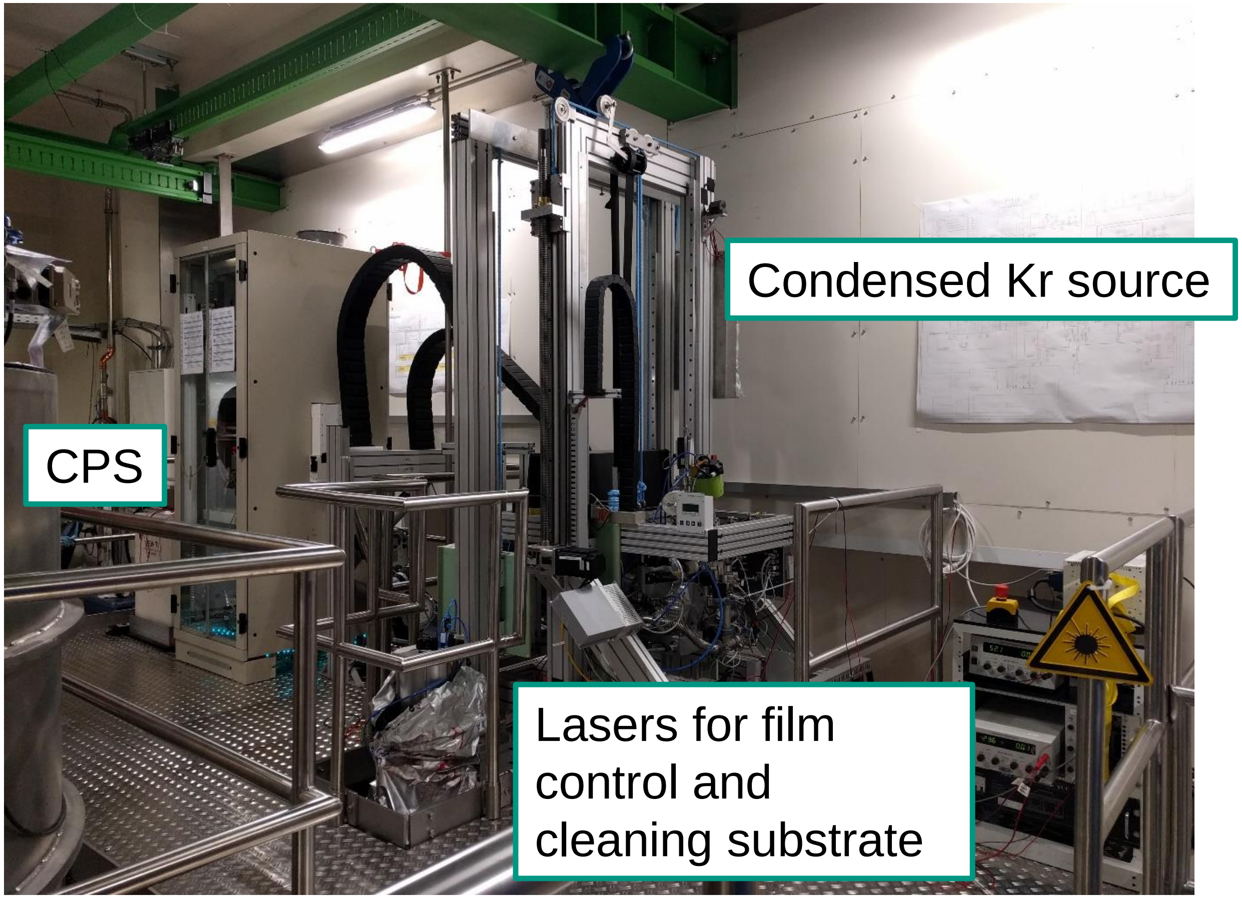
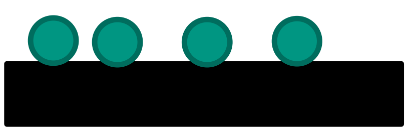


Detector is homogenously illuminated like in tritium measurements.

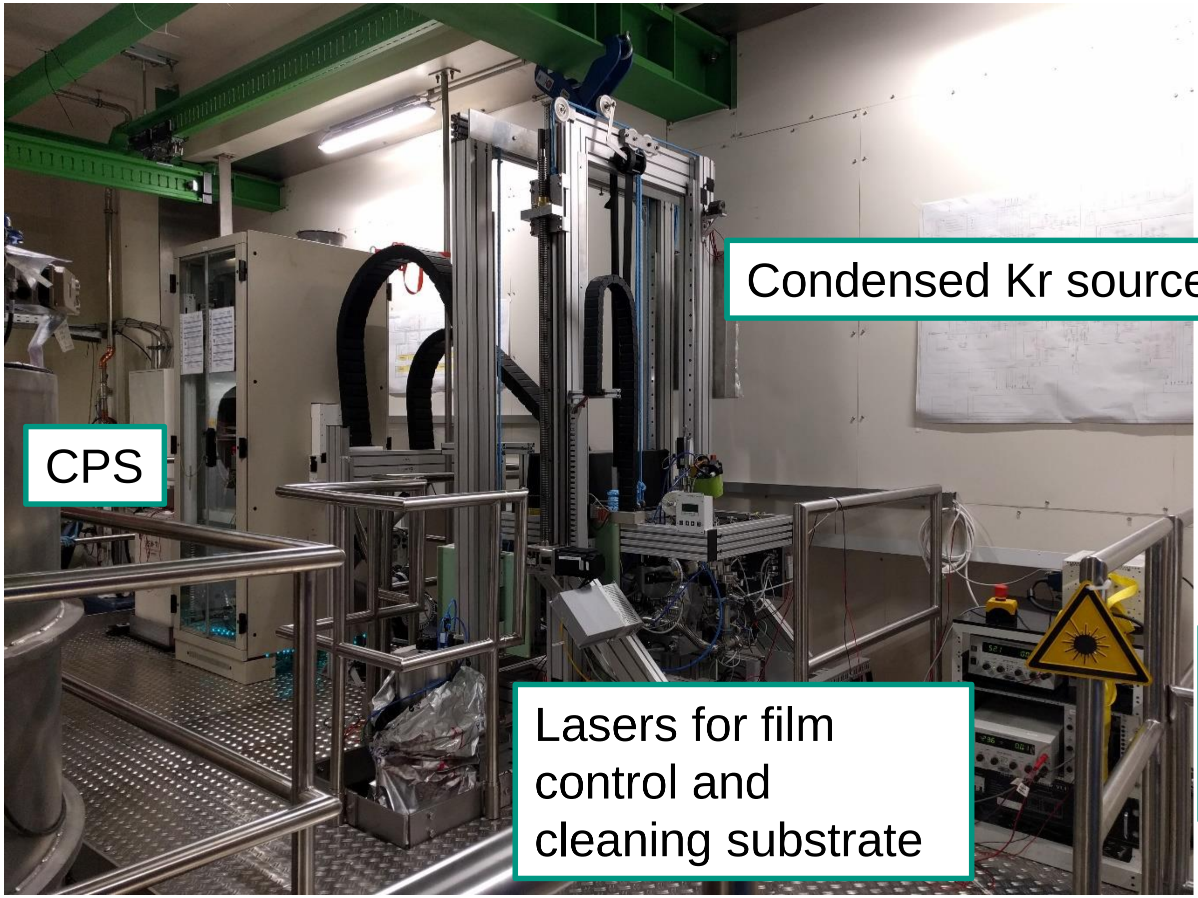
Condensed ^{83m}Kr source

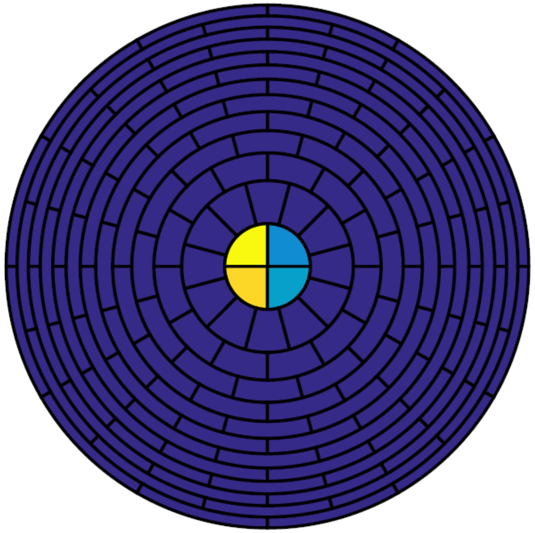




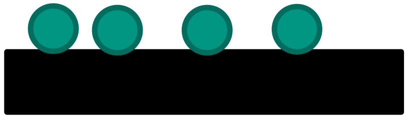
Sub mono layer of ^{83m}Kr is condensed continuously on HOPG substrate.

Condensed ^{83m}Kr source





Spot-like source enables pixel-selective investigations of transmission properties.



Sub mono layer of ^{83m}Kr is condensed continuously on HOPG substrate.

Implanted ^{83m}Kr source

The Czech Academy of Sciences

universität bonn

KIT Karlsruhe Institute of Technology

Advantage: Can be handled easily.

Disadvantage: Solid state effects.

^{83}Rb implemented in Pt or HOPG substrate at Bonn Isotope Separator (BONIS)

Implanted ^{83m}Kr source

Monitor spectrometer connected to high voltage of main spectrometer.
➔ Scan of ^{83m}Kr line position to monitor high voltage stability.

Uncertainty of line position 15 meV after 15 min, 3 MBq source
➔ sub-ppm level

M. Slezak, PhD thesis, Prague, 2015

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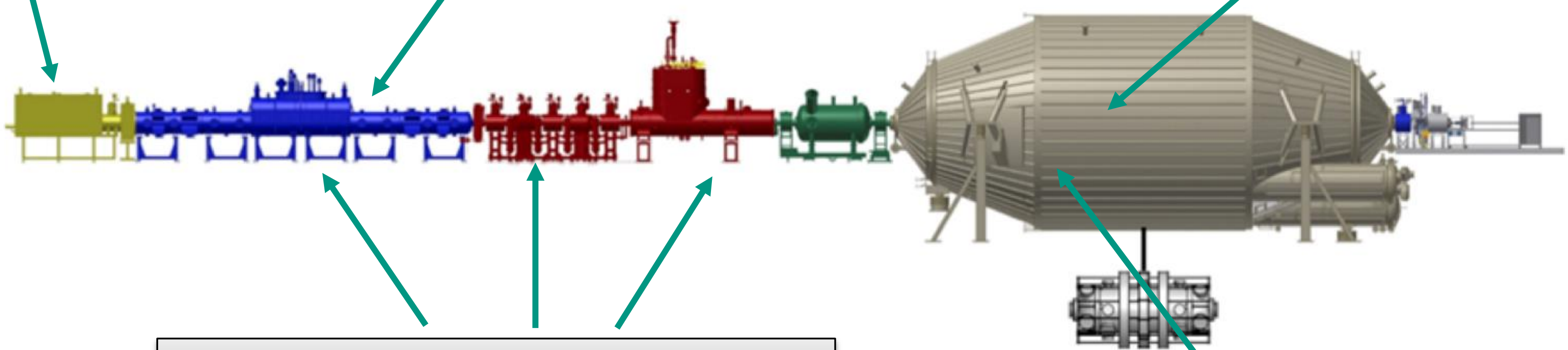
The Kr Measurement Campaign: Hardware

No rear section

No gas circulation
➔ Only Kr, no gas admixture of D_2, T_2

Baked-out spectrometers



No pumps, Kr freezes out in CPS

High voltage up to -35 kV

- All beamline magnets at their nominal field strength.
- **All three Krypton sources operable.**

The Kr Measurement Campaign

3 major goals:

1. Operation and characterization of KATRIN Kr sources and whole beamline

2. Test of overall KATRIN analysis chain

3. Kr spectroscopy

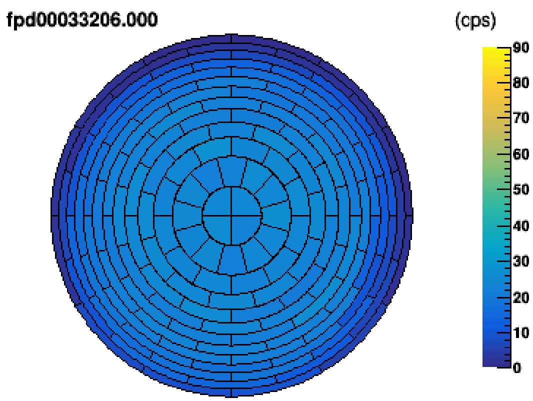
Schedule:

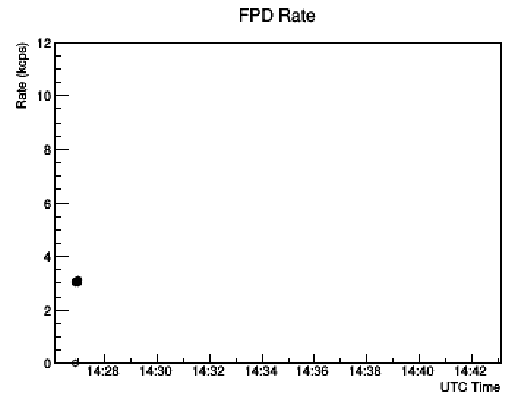
Monitor spectrometer in parallel

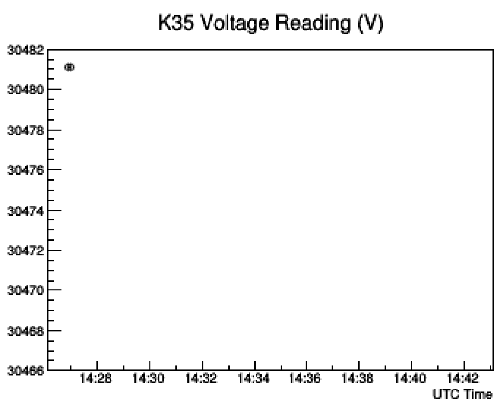
1 week WGKrS

1 week CKrS

How KATRIN measures conversion lines







ΔE= 2 eV @ 30400 V.

Lowering the voltage at the main spectrometer with a constant step size, here: 0.5 V

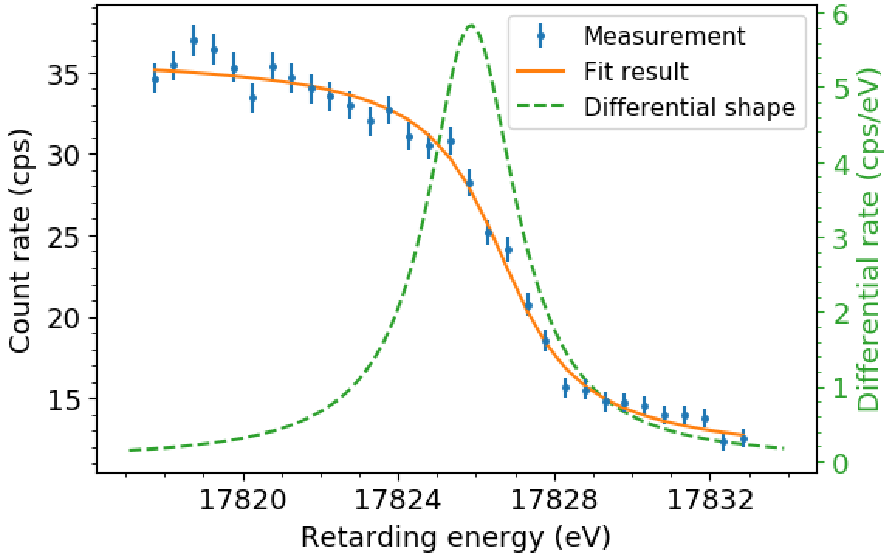
Measuring at each step with the same time, here: 10 s.

As soon as the energy of the electrons exceeds the retarding voltage, they are transmitted.

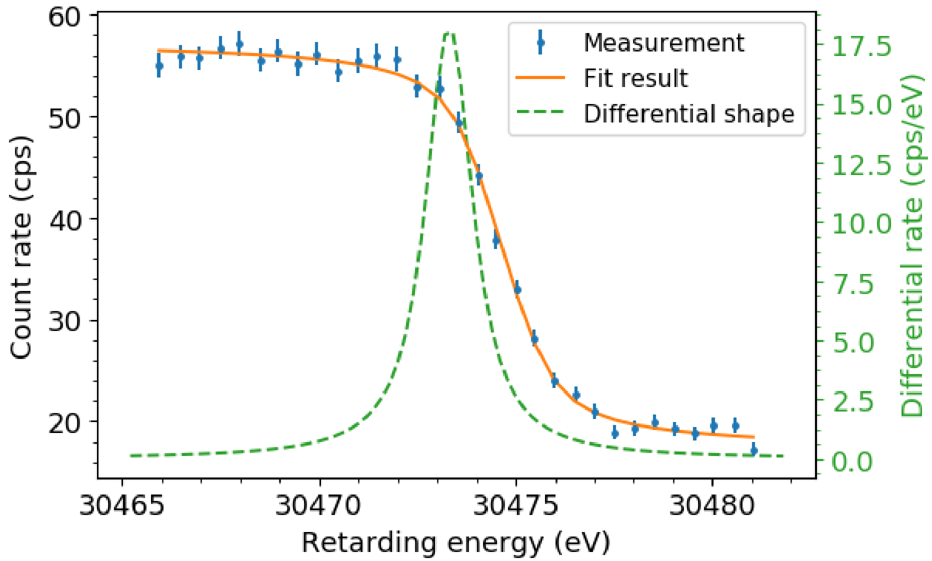
Preliminary results

K-32 and L_3-32 are two of the most intense lines of Kr-83m.

K-32 line (Lor. width 2.8 eV)



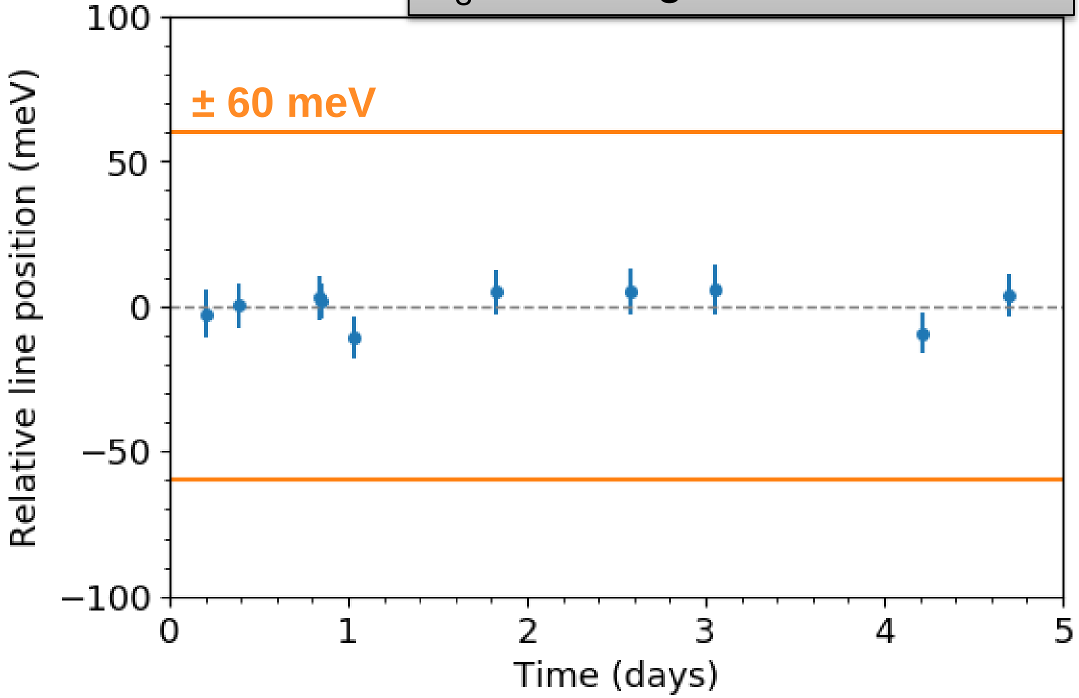
L_3-32 line (Lor. width 1.4 eV)



Fit together with transmission function lead to differential shape
➔ very good agreement with data

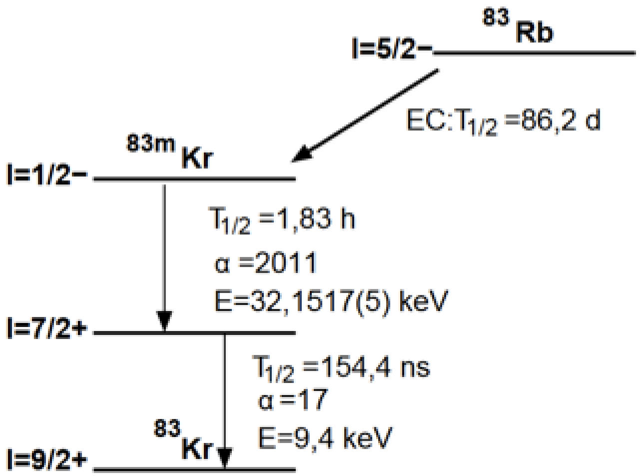
Preliminary results

Repeated reference scans of L_3-32 line, gaseous source.



KATRIN requirement: HV stability/energy scale stability < 3 ppm per 60 days of running KATRIN.

Preliminary results

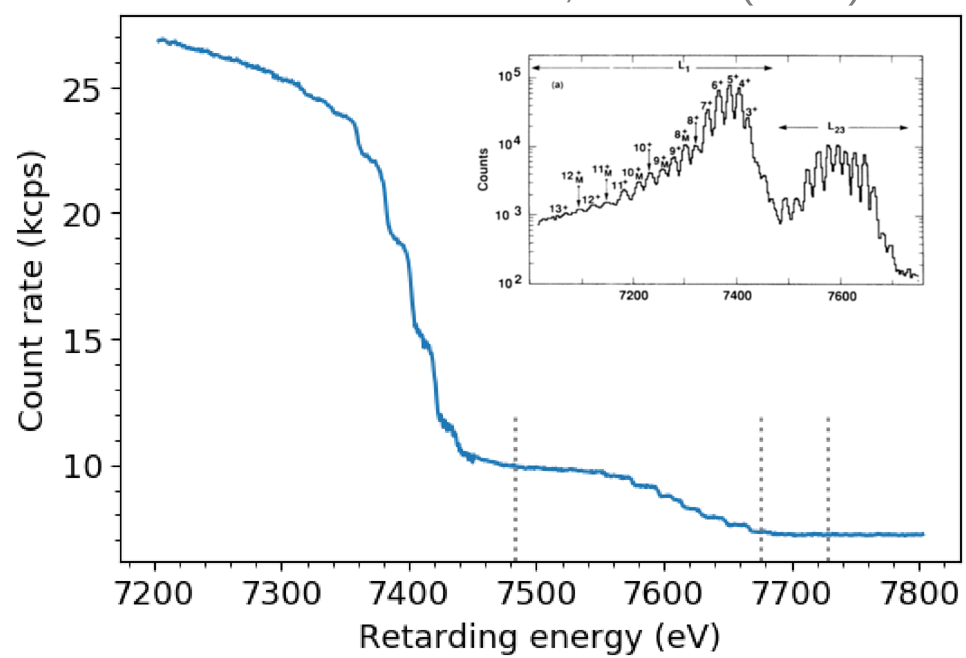


Kr atoms are in different ionization states after first transition and are not neutralized before the second one.
➔ Lines split in several sub lines.

KATRIN sees this effect in the gaseous source measurements.

Analysis still ongoing.

Decman & Stoeffl, PRL 64 (1990) 2767

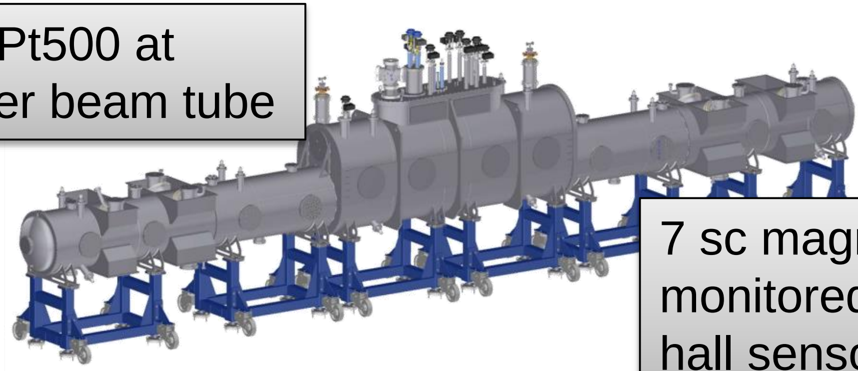


Other results

Requirement:
System stability for KATRIN < 0.2 %/h

Here: Temperature and magnetic field stability of WGTS, two sensors as example.

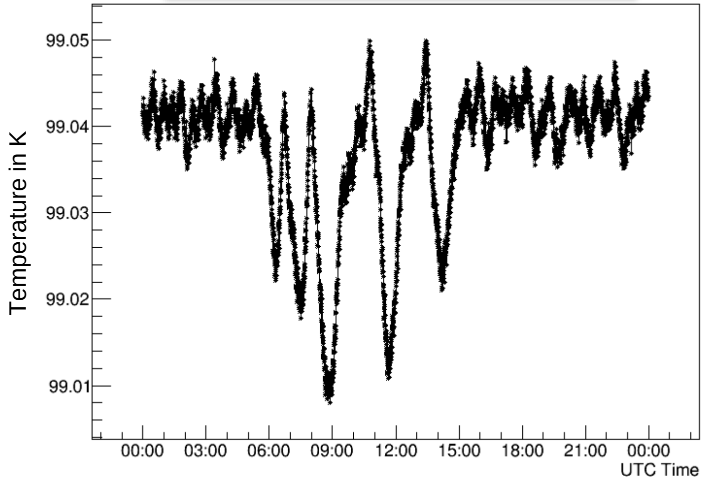
24 Pt500 at inner beam tube



7 sc magnets, monitored by hall sensors

Other results

Temperature WGTS



$\Delta T/T < 1\cdot 10^{-4}$ per day

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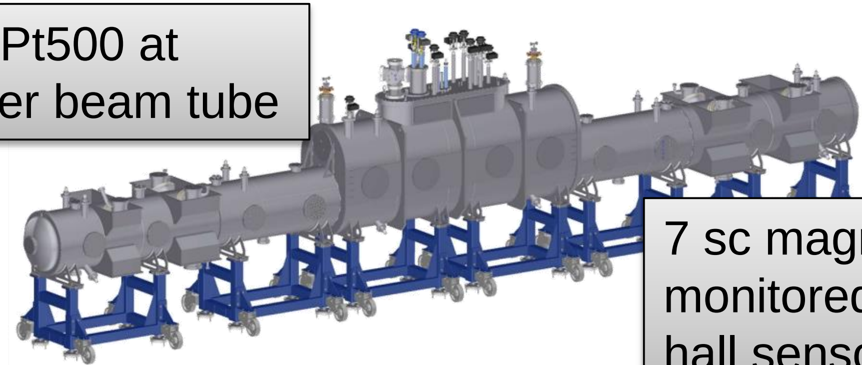

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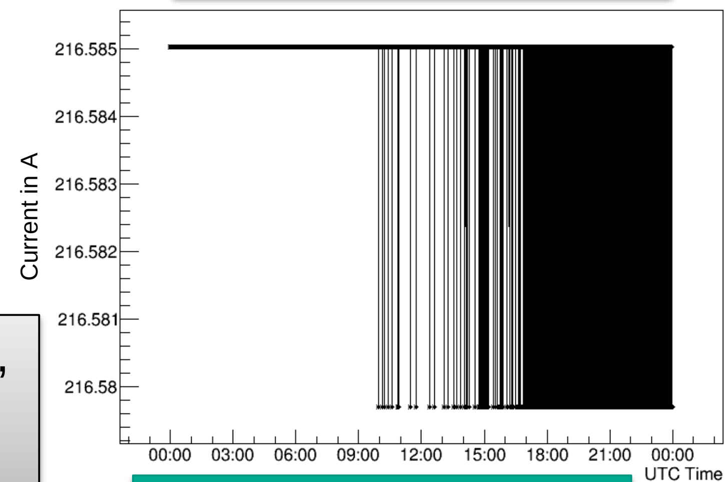
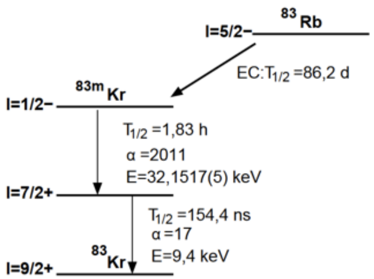
Magnetic field WGTS



$\Delta B/B < 1\cdot 10^{-5}$ per day

Conclusions

Kr-83m is an optimal nuclear standard for monitoring and calibration purposes for KATRIN.



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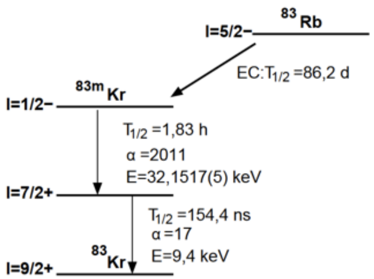
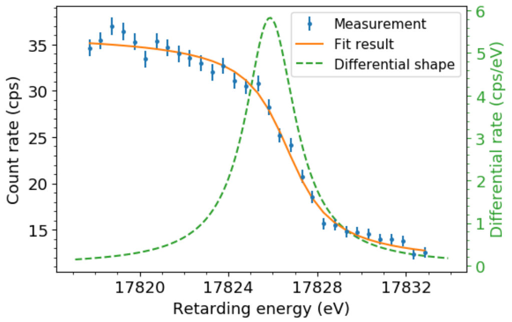
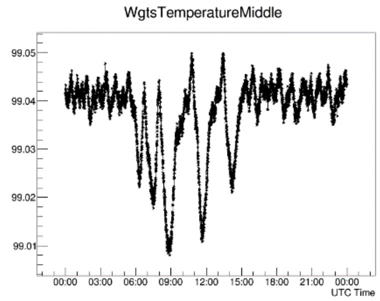
The three Kr-83m sources of KATRIN have been tested in a measurement campaign of two weeks:

- Electron transport along entire beam line
- Kr-83m spectroscopy
- Stability of the system

➔ Great success







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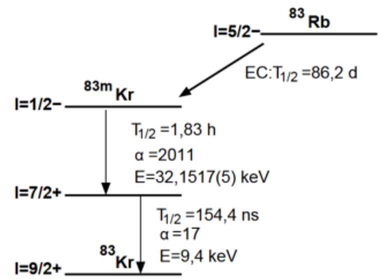

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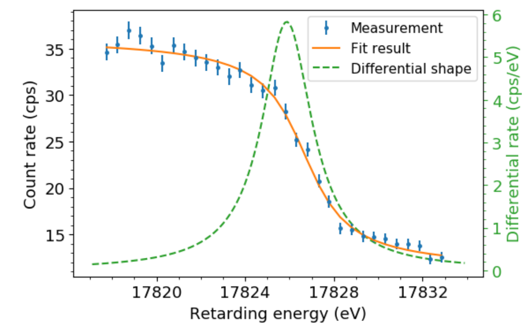

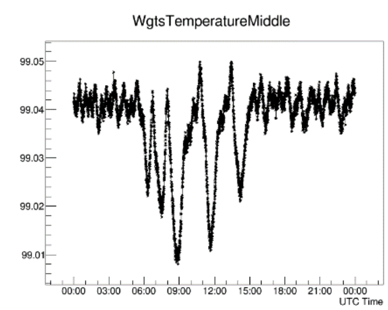

Still a lot of data to analyze.

Talk by Kathrin Valerius

Important milestone on the way to first tritium data 2018.

Thank you for your attention!

WWU MÜNSTER

KIT Karlsruhe Institute of Technology

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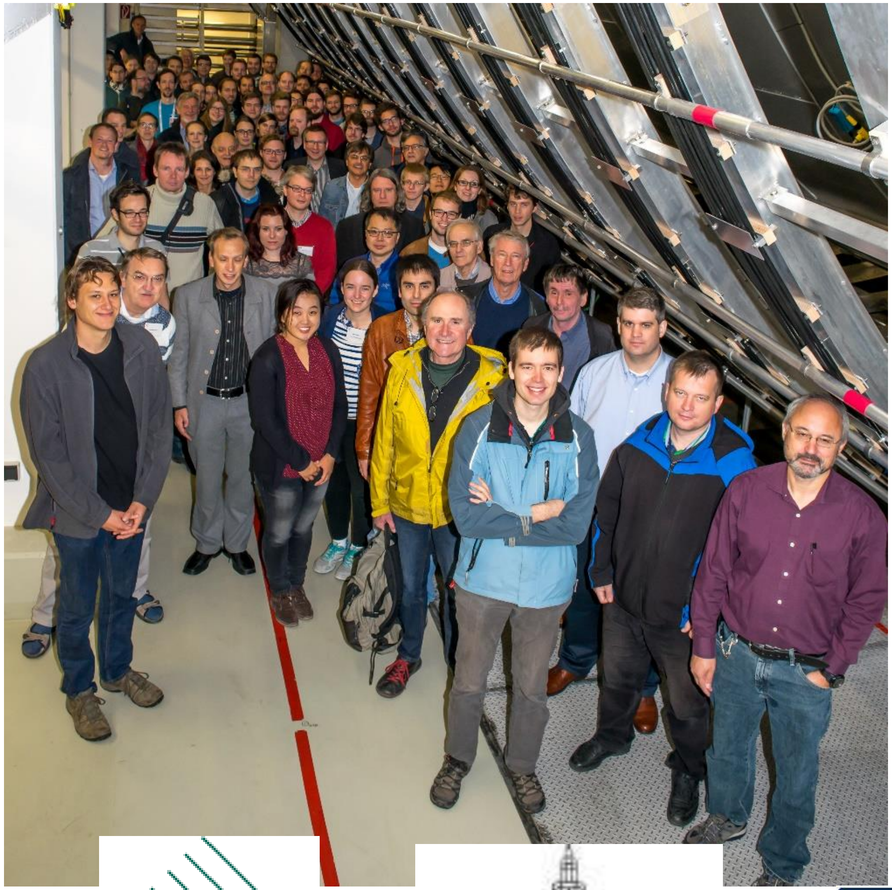
The Czech Academy of Sciences



Massachusetts Institute of Technology

University of Washington 1861

University of North Carolina Chapel Hill

Carnegie Mellon University

Universitas Complutensis Matritensis

Case Western Reserve University 1826

Max-Planck-Institut für Kernphysik

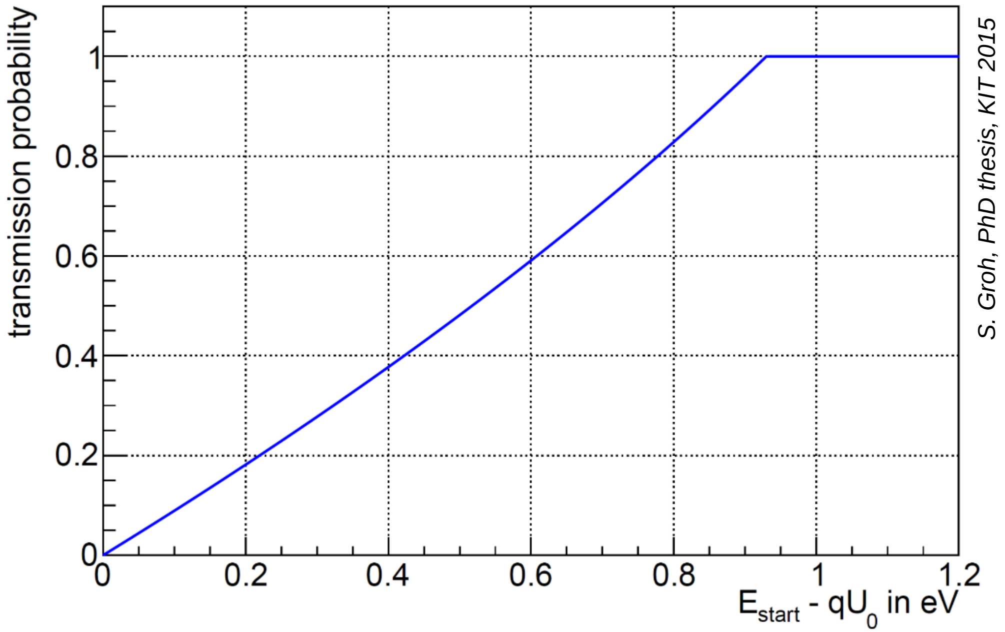
Russian Academy of Sciences

BERKELEY LAB

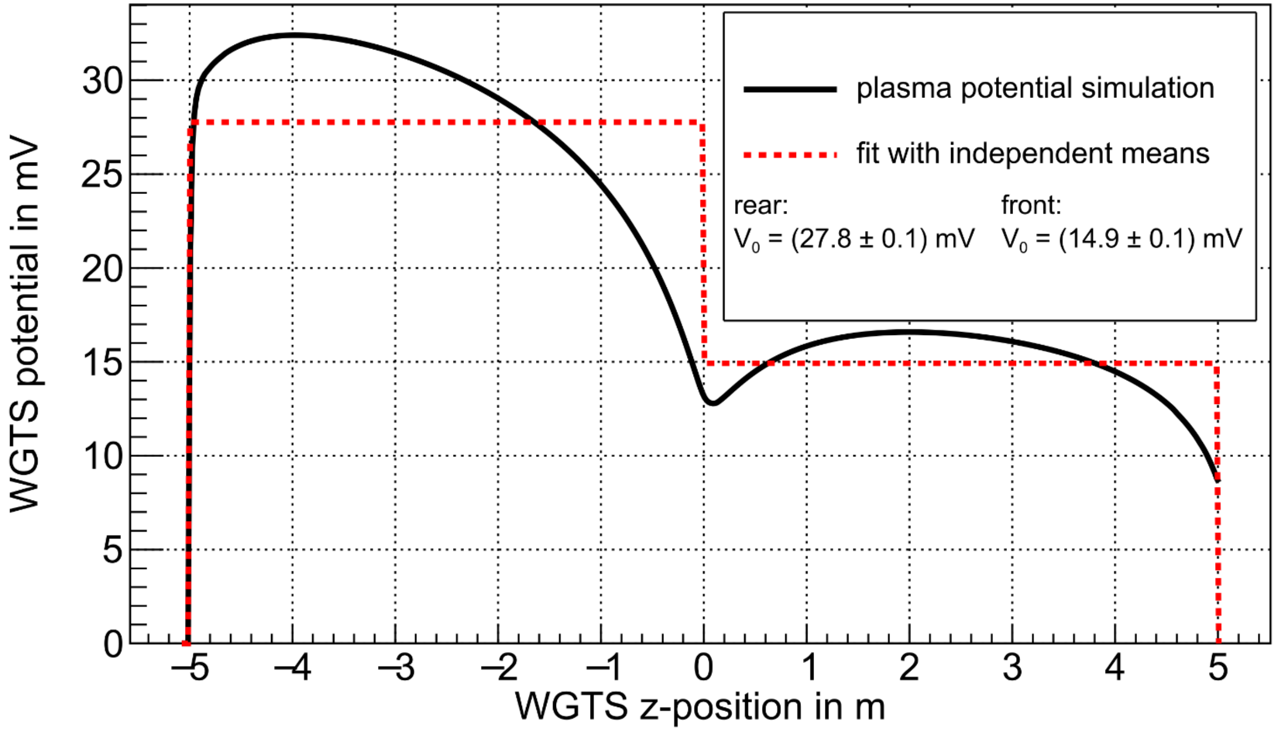
cea

KATRIN Transmission Function

$$T(E,qU) = \begin{cases} 0 & E - qU < 0 \\ \dfrac{1 - \sqrt{1 - \frac{E-qU}{E} \cdot \frac{B_S}{B_A}}}{1 - \sqrt{1 - \frac{\Delta E}{E} \cdot \frac{B_S}{B_{max}}}} & 0 \leq E - qU \leq \Delta E \\ 1 & E - qU > \Delta E \end{cases}$$



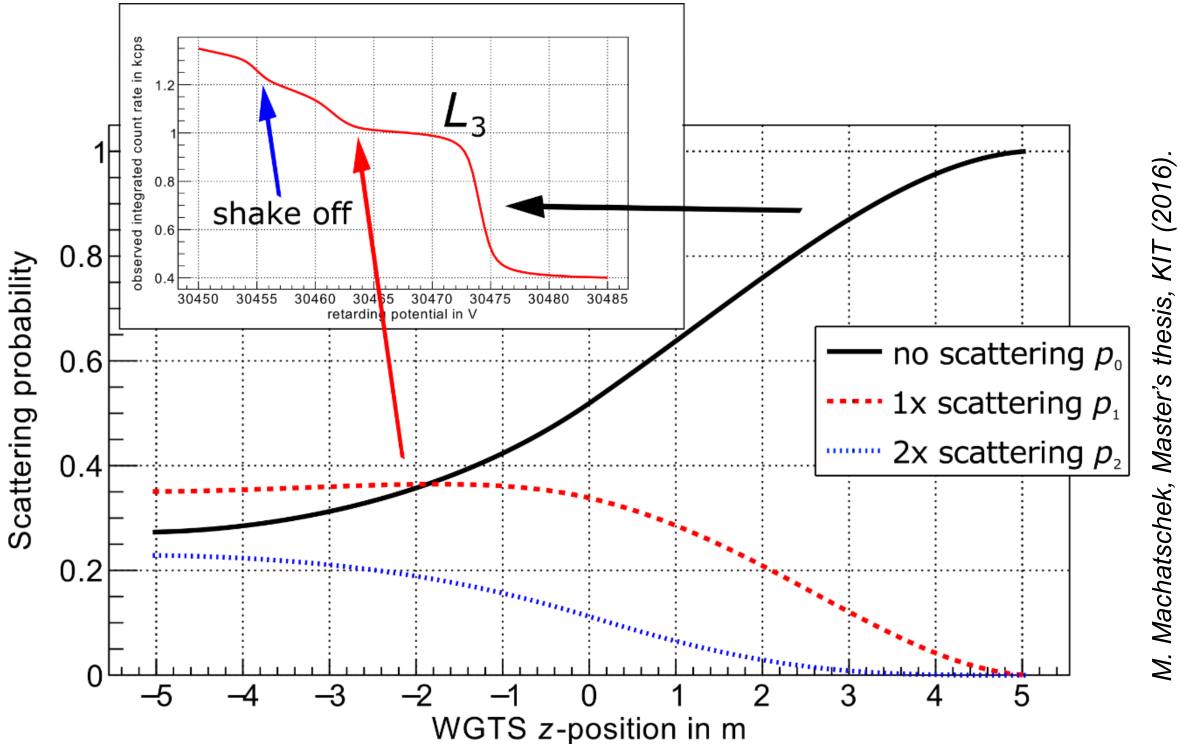
WGTS plasma potential



M. Machatschek, Master's thesis, KIT (2016).

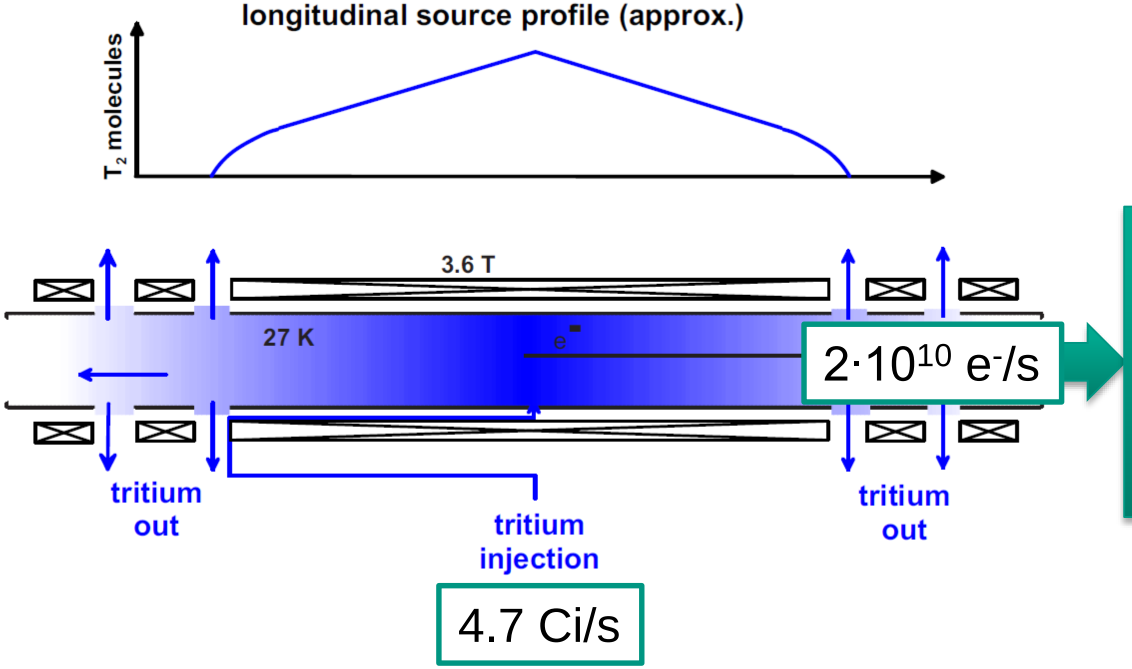
Electrons of the rear side are stronger effected by plasma than electrons from the front side.

Determining the plasma potential of WGTS



Information on potential of front half of WGTS are hidden in unscattered electrons shoulder, information on potential of rear half are hidden in corresponding singly scattered electrons shoulder.

WGTS for KATRIN

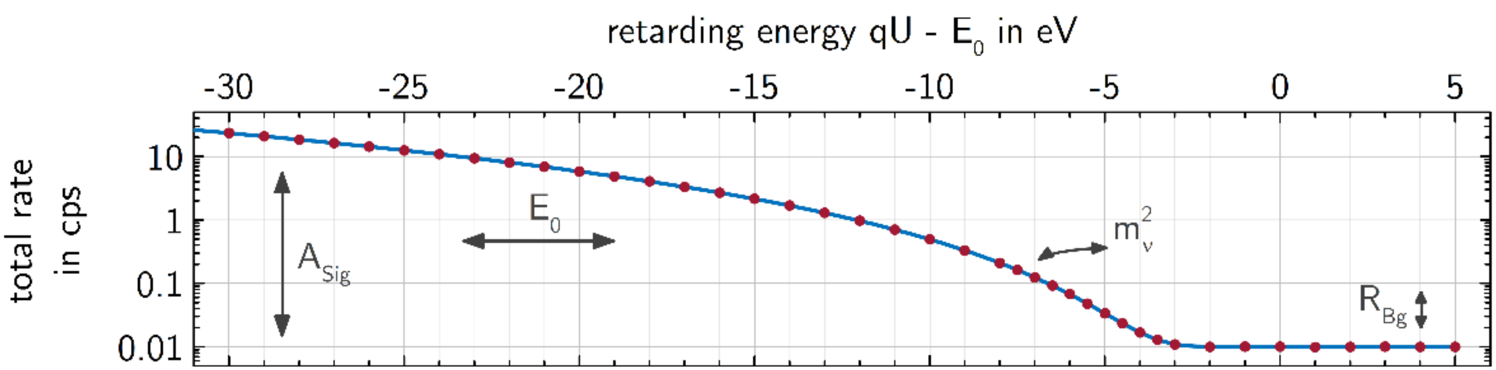


Required: $\Delta\rho d/\rho d < 0.001/h$

➔Temperature:

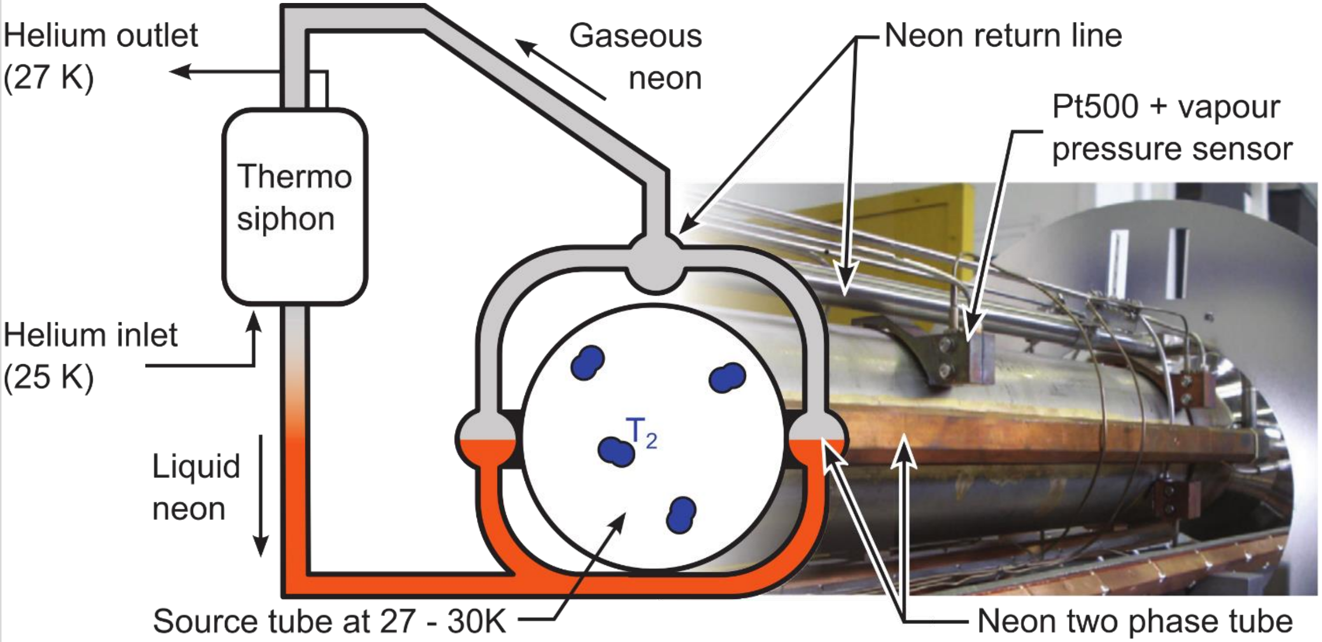
- Stability $\Delta T/T = \pm 30$ mK/h
- Homogeneity $\Delta T = \pm 30$ mK

WGTS specification 2004



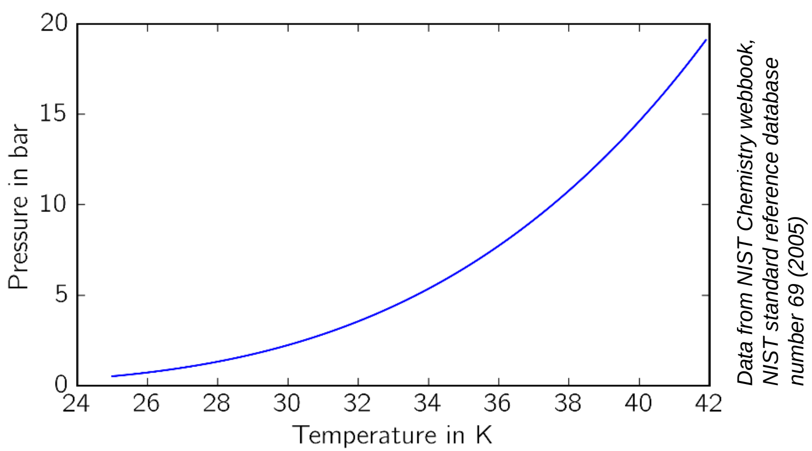
M. Kleesiek, PhD thesis, KIT (2014)

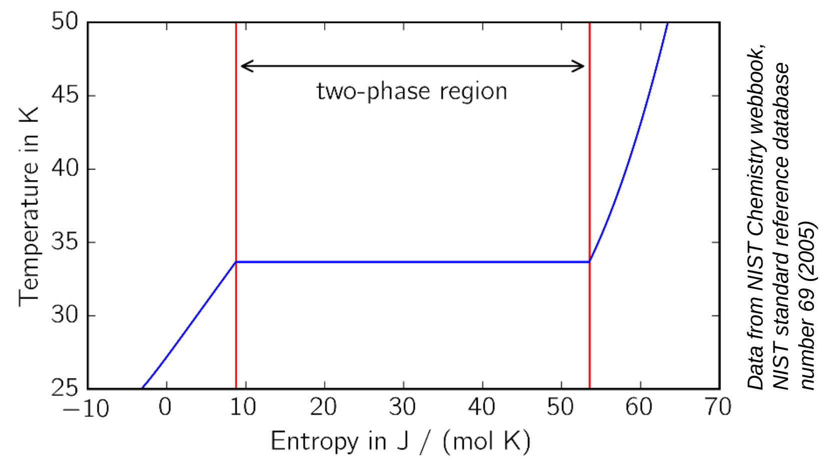
2-phase neon cooling



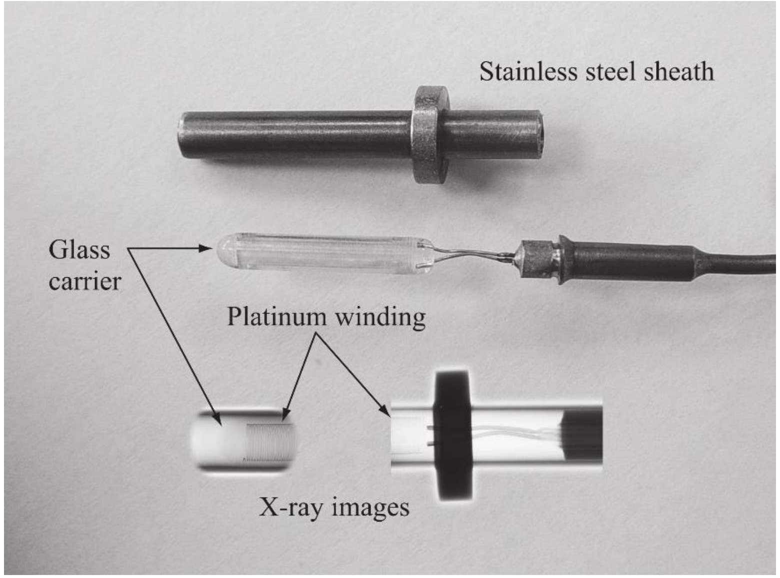
Grohmann, Cryogenics 49 (2009),
Grohmann et al., Cryogenics 51 (2011),
Babutzka et al., New J. Phys. 14 (2012)

- Reasonable pressure regime @ 30 K
- Latent heat → no temperature increase due to cooling
- No pumps necessary

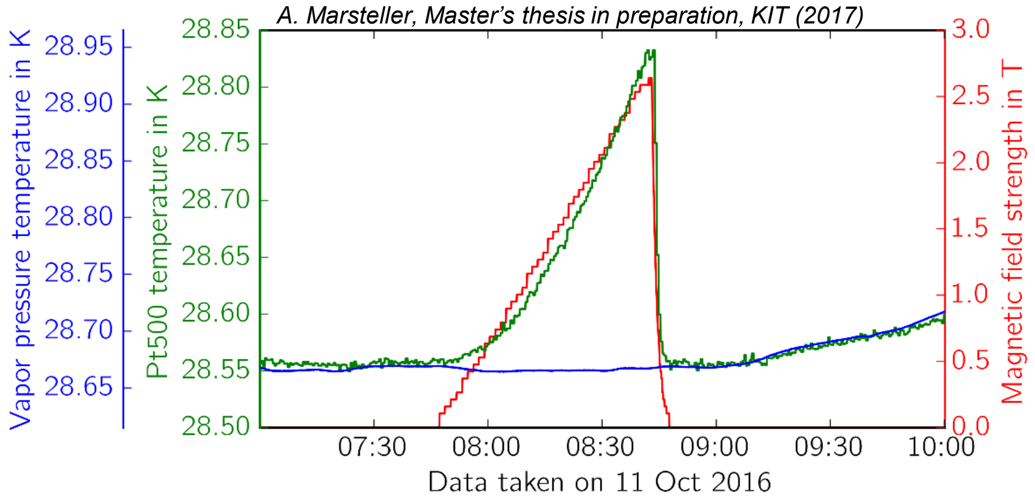




Performance of Pt500 sensors



T. Bode, Diploma Thesis, KIT (2011)



Measurement uncertainties:	
Sensor dispersion	0.087 K
+Magnetic field dependence	0.087 K
+Other (instruments, ageing processes)	0.023 K
Total:	0.125 K

Grohmann et al., Cryogenics 51 (2011)

Calibration necessary for homogeneity requirement ΔT = ±30 mK