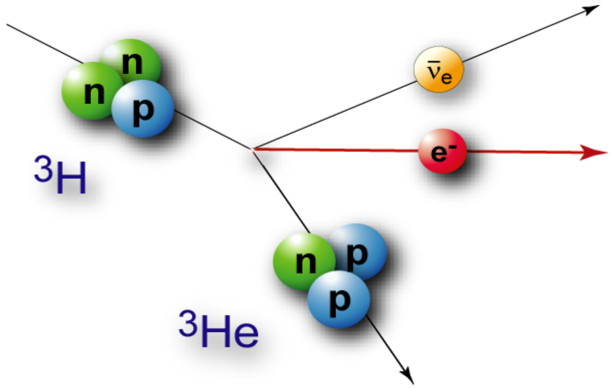
KATRIN: an experiment to determine the neutrino mass

Florian M. Fränkle
for the KATRIN Collaboration

outline

- introduction
- experimental setup & status
- spectrometer background processes
- summary & outlook

tritium β-decay



$$^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$$

Fermi theory of β-decay:

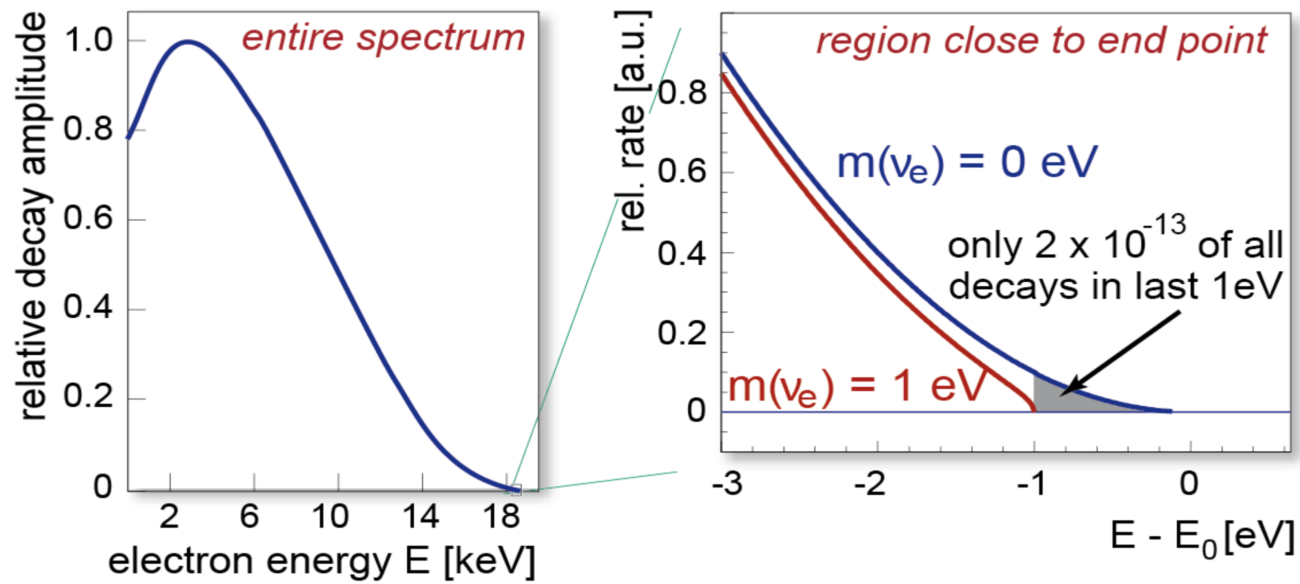
$$\frac{dN}{dE} = C \cdot F(E,Z) \cdot p(E+m_e) \cdot (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_\nu^2}$$

observable:

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

tritium as β emitter:

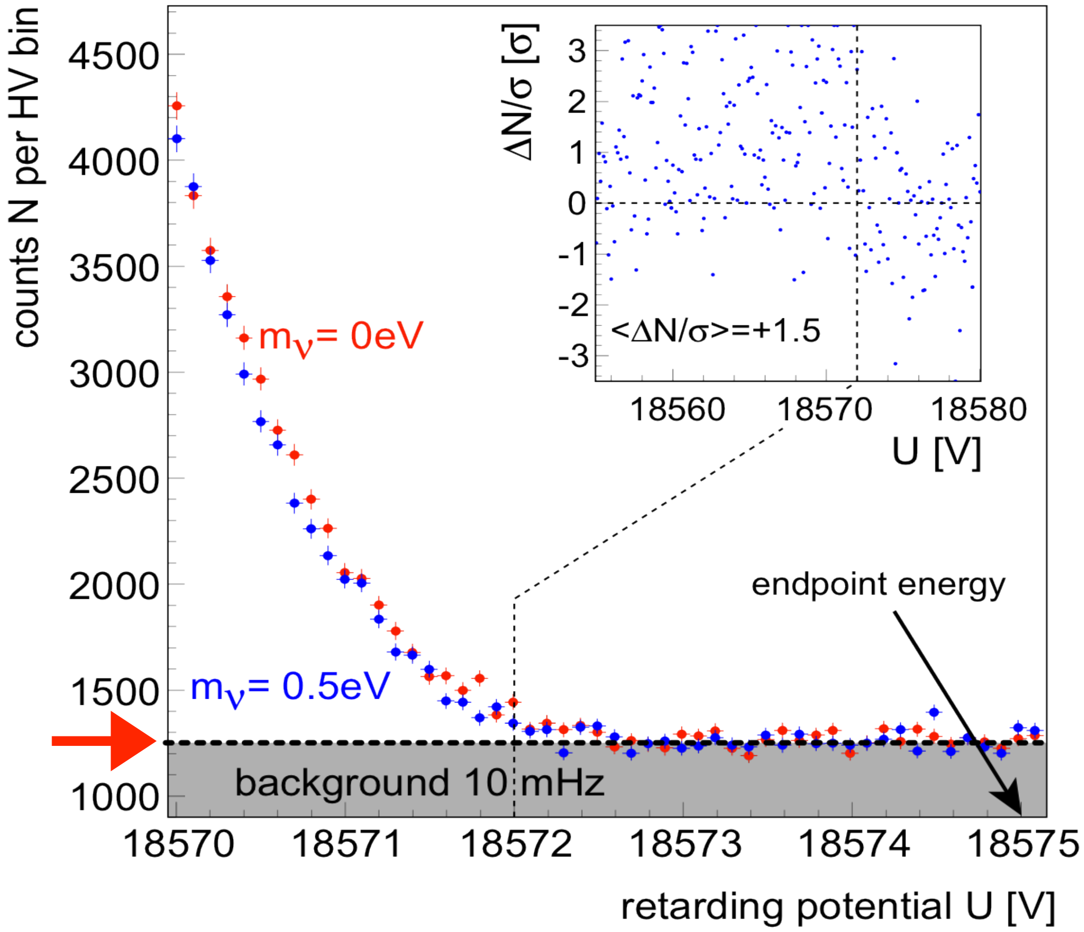
- high specific activity (half-life: 12.3 years)
- low endpoint energy E_0 (18.57 keV)
- super-allowed

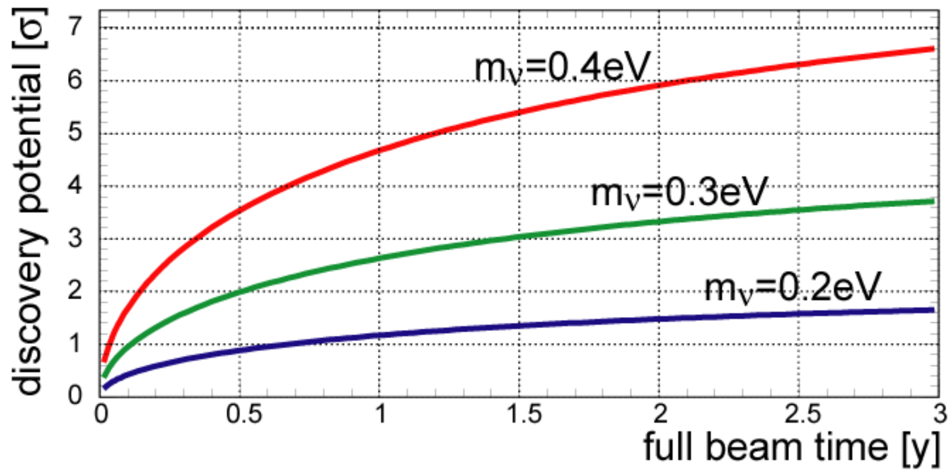


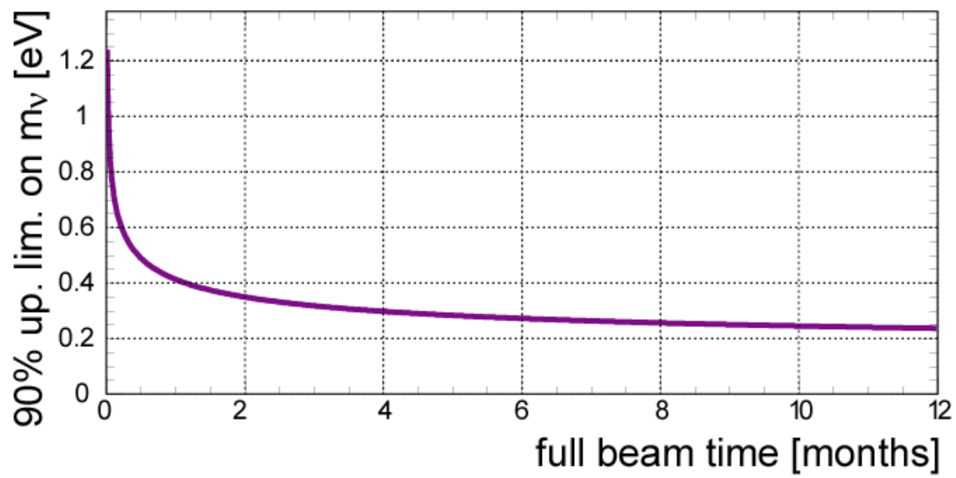
→ model independent measurement of neutrino mass

KATRIN sensitivity

MC energy spectrum (1 year)





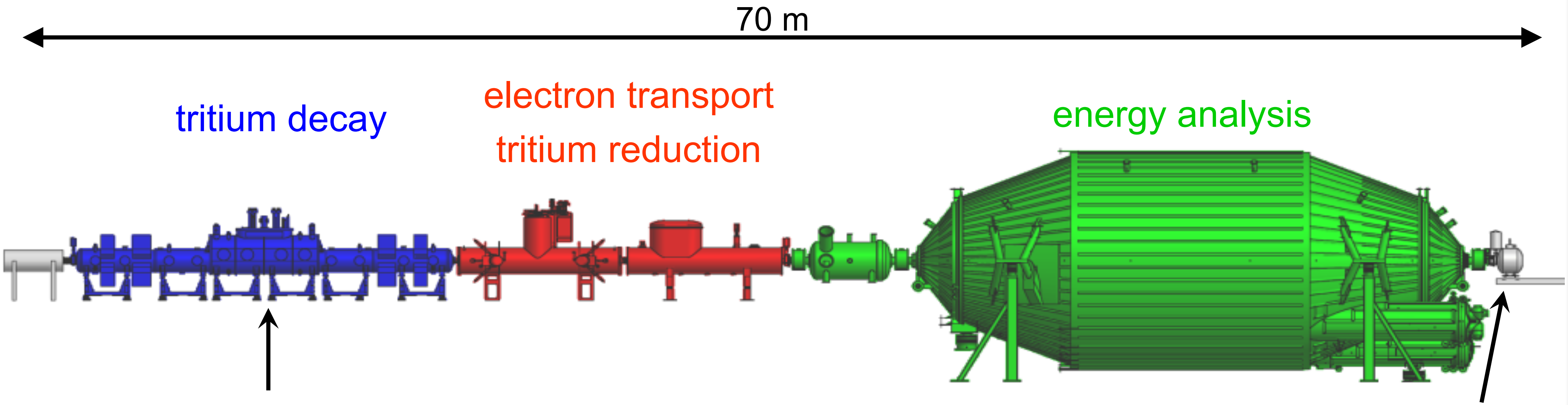


- KATRIN sensitivity 200 meV/c^2, discovery potential (5σ) after 3 years: 350 meV/c^2
- low background level (10 mHz) essential

KATRIN experiment

(**KA**rlsruhe **TRI**tium **N**eutrino experiment, location: Karlsruhe Institute of Technology)

sensitivity on electron anti-neutrino mass: **200 meV/c²**



β-decay rate: **10^{11}** Hz

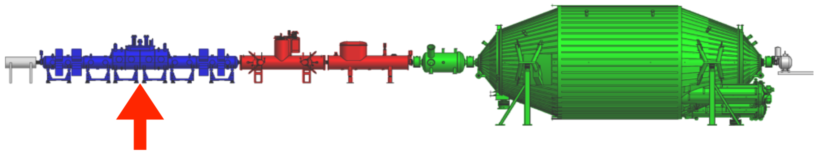
T_2 pressure: **10^{-6}** mbar

about **14** orders of magnitude →

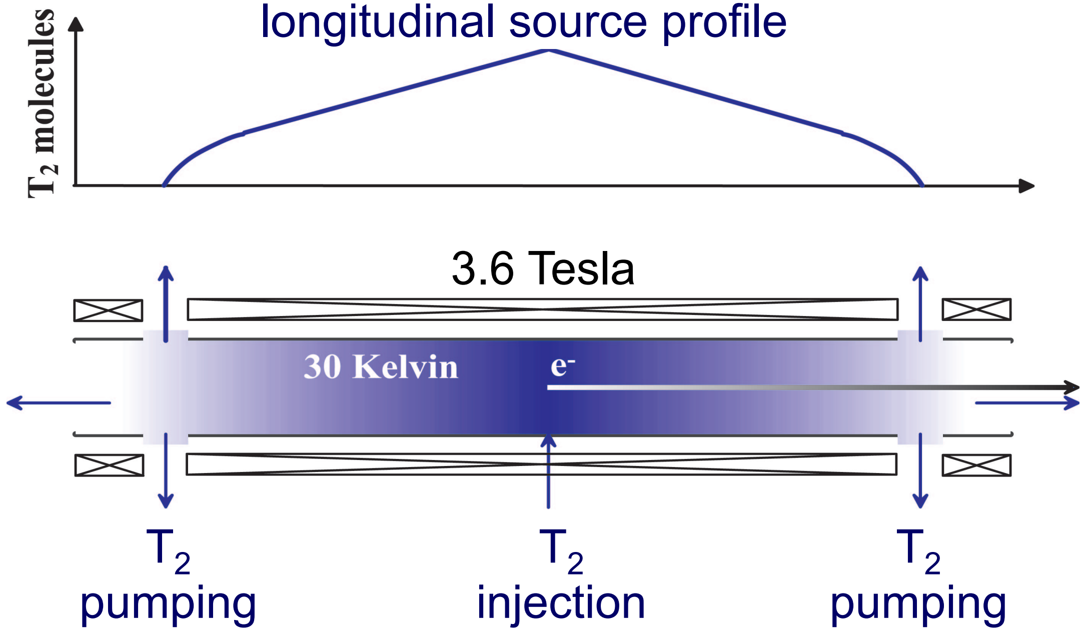
background rate: **10^{-2}** Hz

T_2 pressure: **10^{-20}** mbar

adiabatic guiding of electrons on meV level



tritium source



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

requirements:

- stability of T_2 density profile of **10^{-3}** (function of: injection rate, purity, beamtube temperature T_B, pump rate)
- T_B homogeneity ±30 mK
- T_B stability ±30 mK • h^{-1}

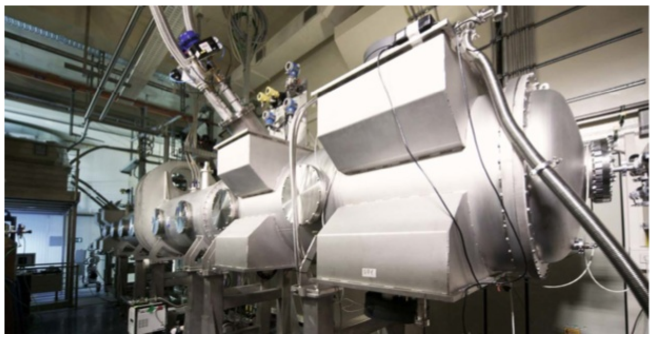
properties:

- beam tube: 10m length, 90mm diameter, absolute temperature 30 K
- windowless gaseous tritium source (WGTS)
- tritium loop: 40g T_2 / day

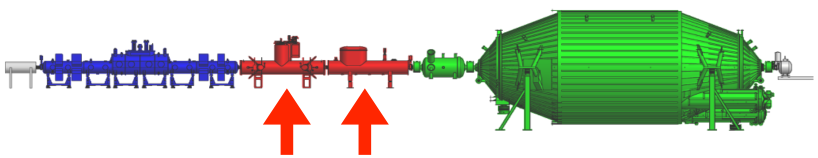
status:

- WGTS demonstrator measurements at TLK
- demonstrator temperature stability 10 times better than specified
- construction 2012
- commissioning 2013

TLK provides complex infrastructure to handle tritium



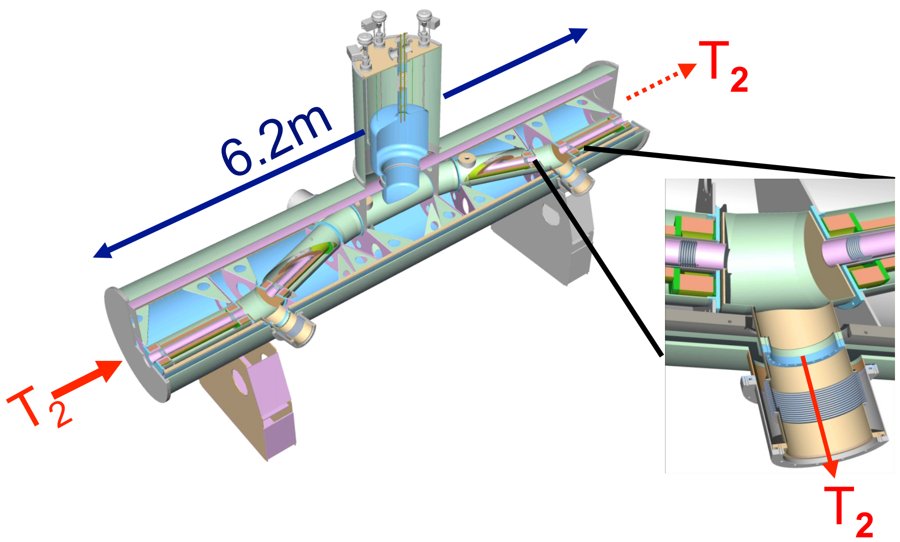
WGTS demonstrator



tritium reduction

Differential **P**umping **S**ection:

purpose: reduce T_2 partial pressure by 10^5



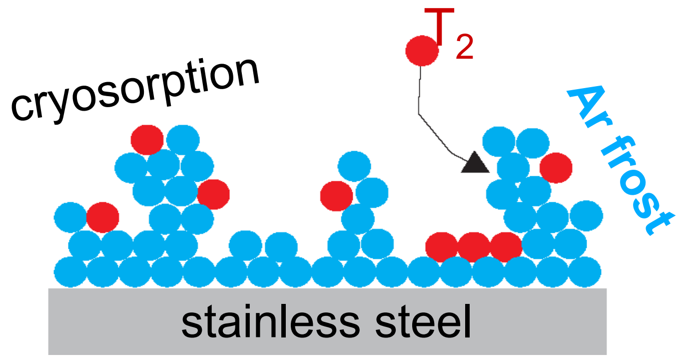
- differential pumping of T_2 (TMPs)
- magnetic guiding of β-electrons (5.6T)
- removal of positive ions (dipole)

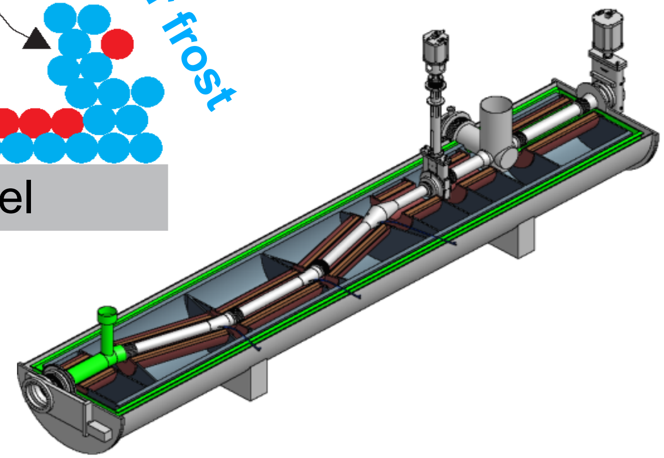
status:

- acceptance tests completed
- test of physical properties (reduction factor, ion suppression,…) ongoing

Cryogenic **P**umping **S**ection:

purpose: reduce T_2 partial pressure by 10^7

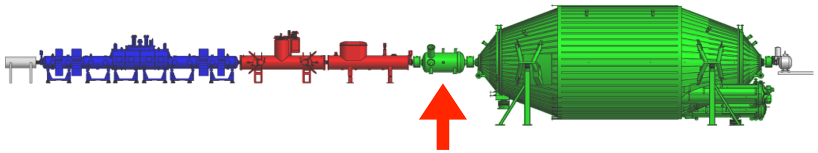




- cryosorption of T_2 on Argon frost
- concept successfully tested (TRAP)

status:

- presently being manufactured
- delivery in 2011
- commissioning 2012



pre-spectrometer

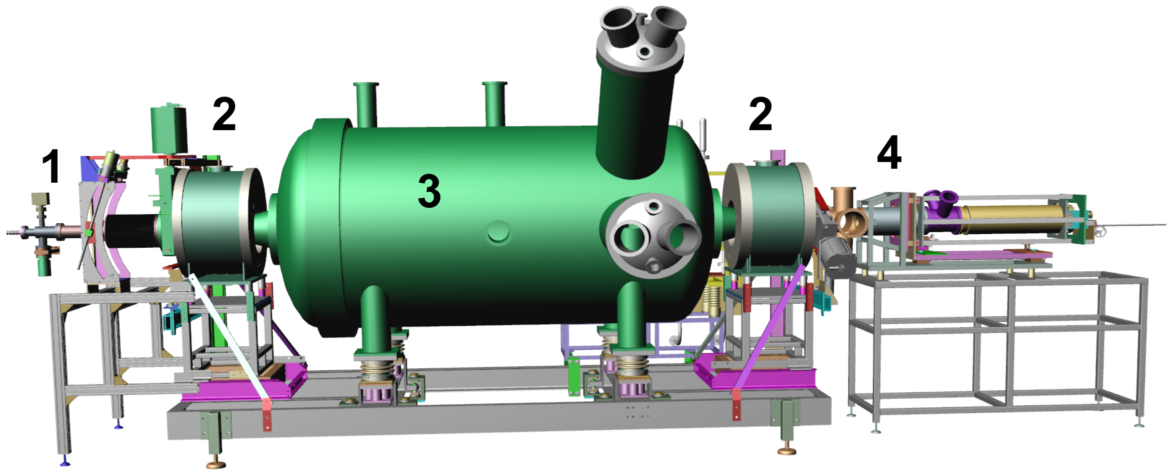
purpose:
- reduce β-decay electron flux by 10^6
- reduction of T_2 flow (getter pump)

- MAC-E filter
- energy resolution 70eV @ 18.4 keV
- pressure 10^{-11} mbar

prototype for main spectrometer:

- vacuum concept successfully tested ($p = 10^{-11}$ mbar, routinely)
- active HV stabilization tested
- test of new electromagnetic design
- background suppression
- optimization of electrode system

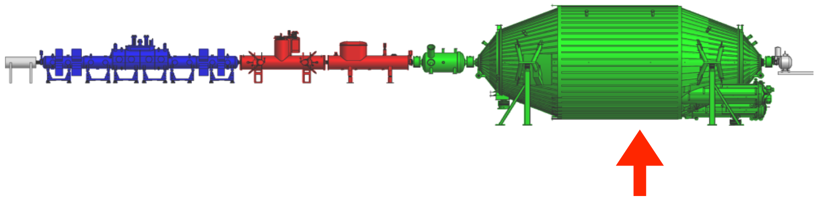
pre-spectrometer test setup



1 electron gun **2** magnets (4.5 T)
3 vessel **4** detector

status:
- test measurements ended 04/21/2011
- relocation of pre-spectrometer to main spectrometer hall ongoing

→ pre-spectrometer test setup yielded important input for the design of the main spectrometer.



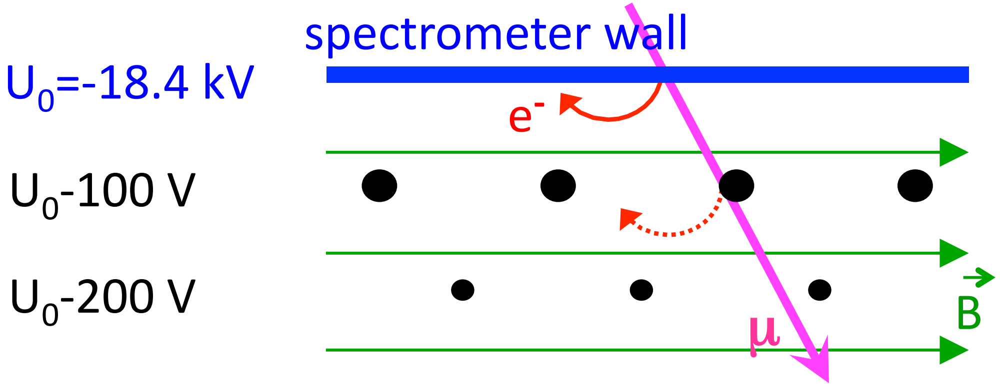
main spectrometer

purpose: energy analysis

requirements:

- energy resolution 0.93 eV @ 18.6 keV
- pressure < 10^{-11} mbar
- background event rate < 10 mHz
- stable HV system (1ppm @ -18.6 kV)

background rejection:



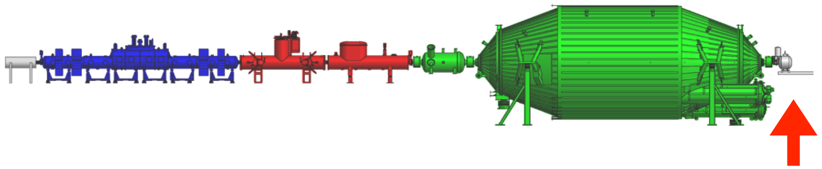
properties:

- MAC-E filter (integrating high pass filter)
- volume: 1240 m³, surface: 689,6 m²
- inner electrode system
- variable voltage to scan E_0 region

status:

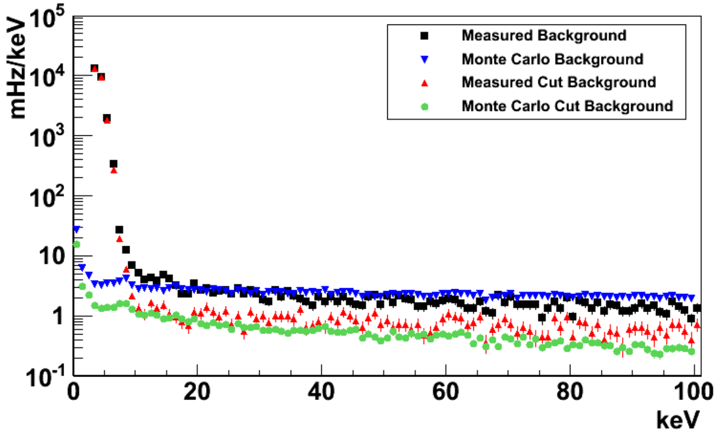
- first vacuum test without getter pump successful (10^{-10} mbar)!
- mounting of inner electrode system almost finished
- electro-magnetic test measurements 2012

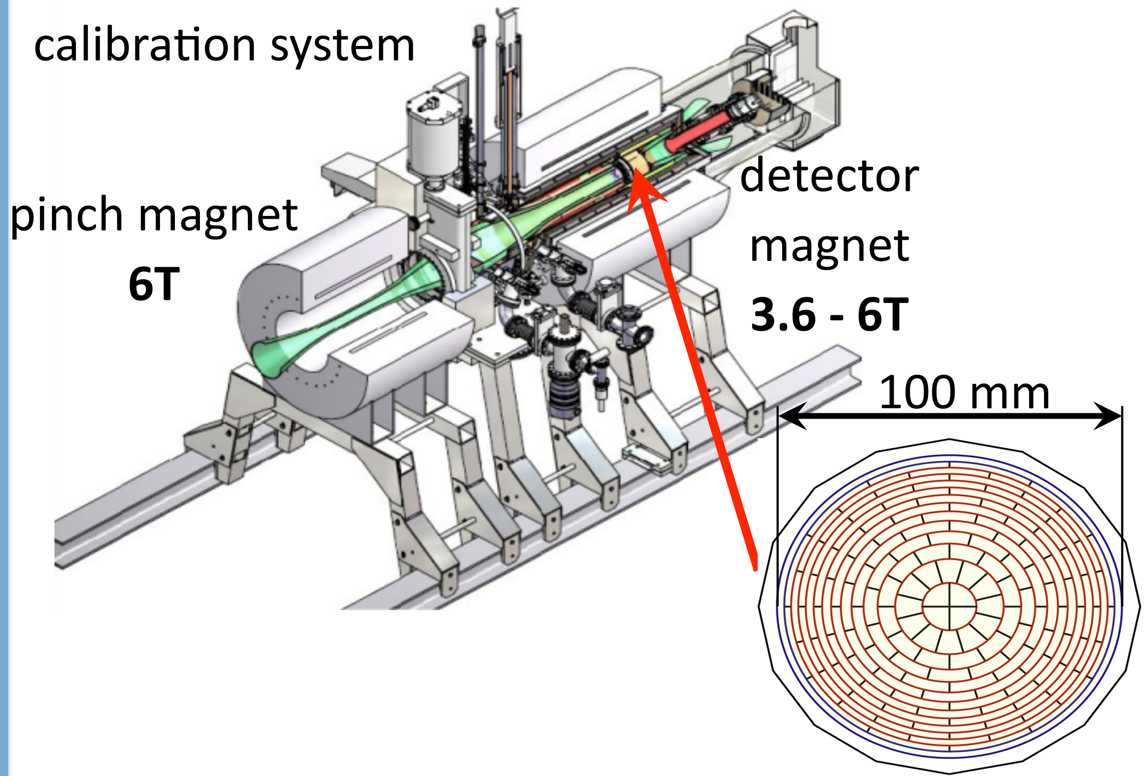
inside the main spectrometer (05/03/2011)



detector system

detector system @ UW





purpose: counting transmitted β-decay electrons

requirements:

- intrinsic background rate < 1 mHz in RoI
- electron energy range 5 to 100 keV
- energy resolution < 1 keV

properties:

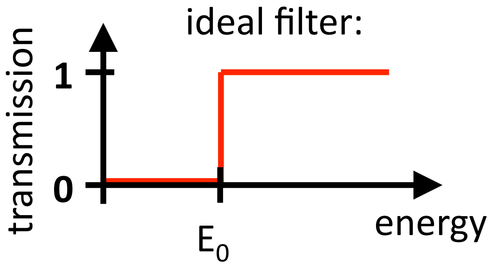
- segmented monolithic Silicon PIN Diode
- 148 pixels, area ~ 50 mm² each
- post acceleration (up to 30 kV)
- muon veto

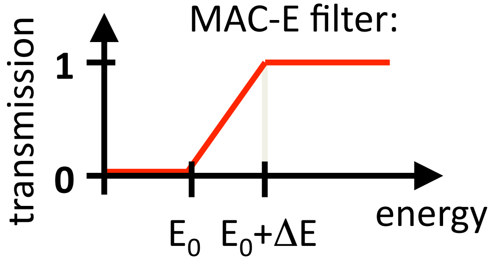
status:

- first commissioning phase at UW finished
- mounting of the system at KIT right now
- detector will be used for the commissioning phase of the main spectrometer in 2012

MAC-E filter

Magnetic **A**diabatic **C**ollimation combined with an **E**lectrostatic Filter



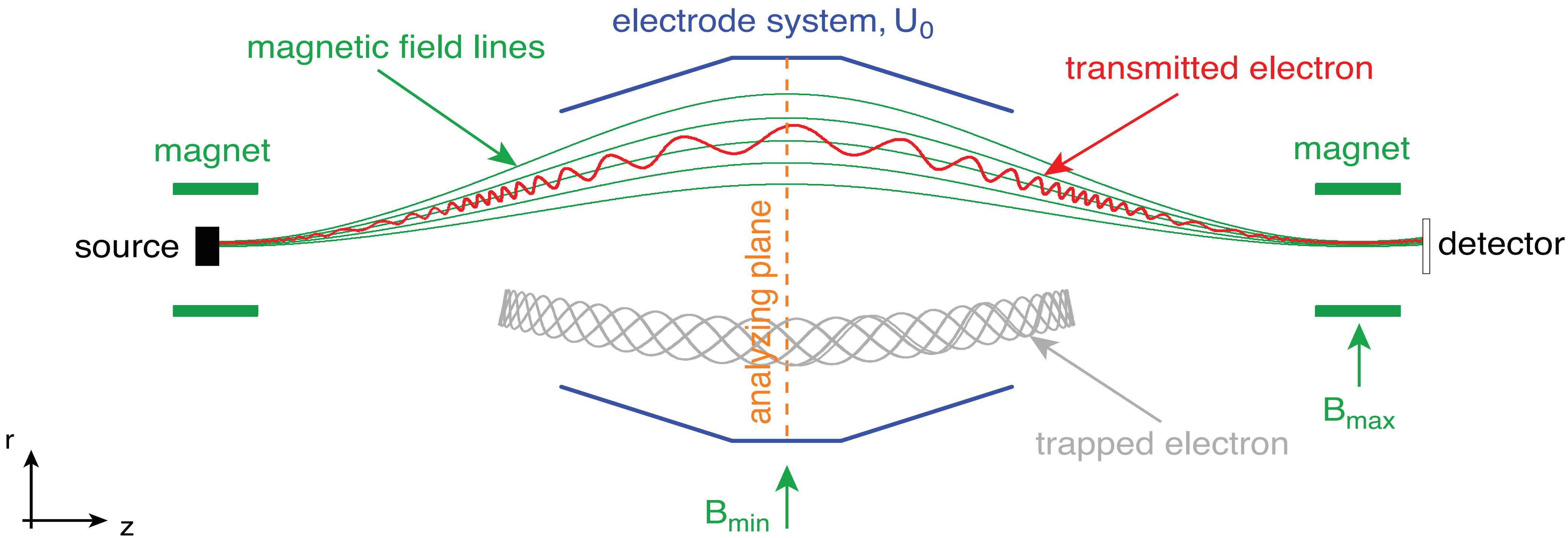


Magnetic moment:

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

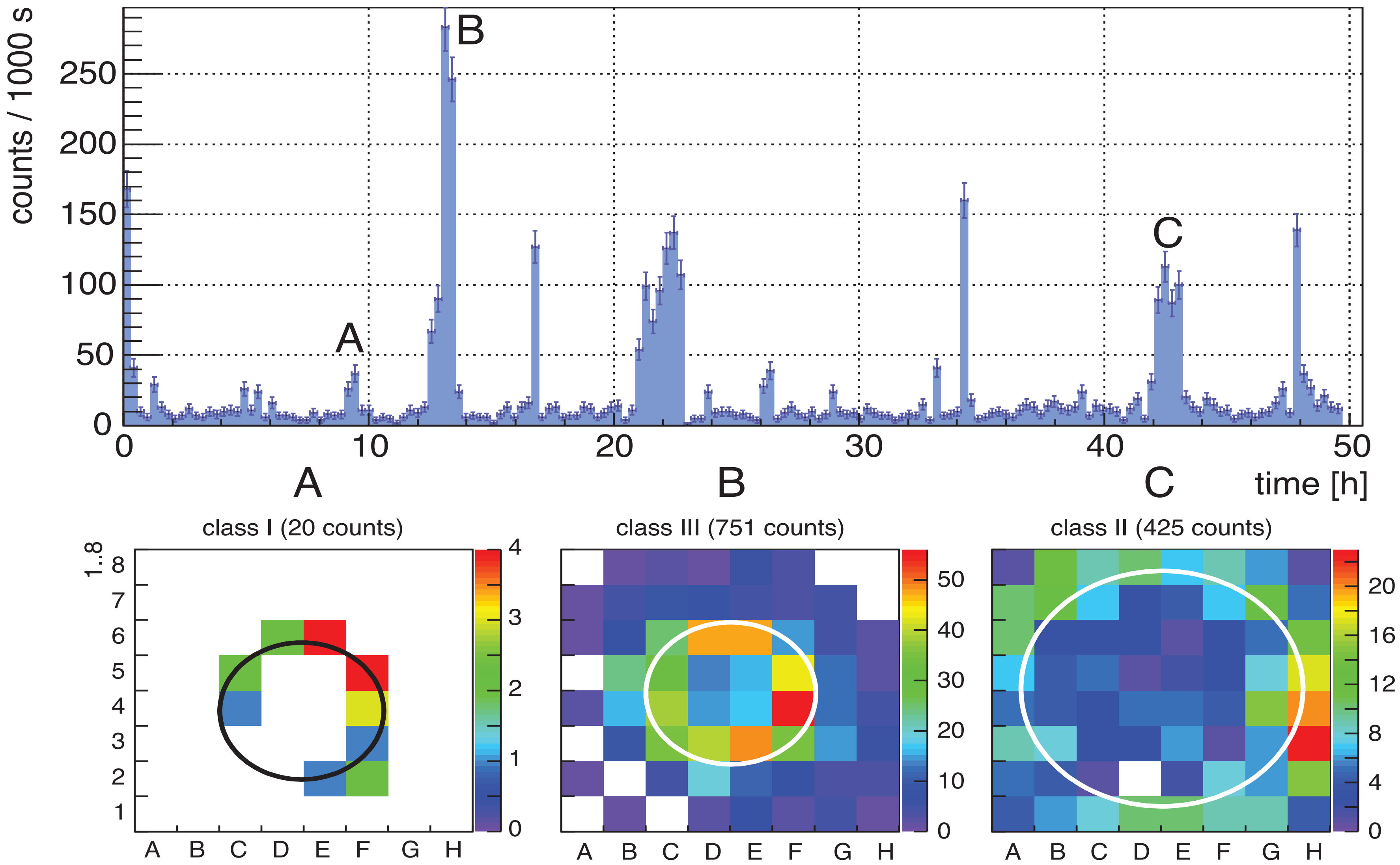
Energy resolution:

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



- combines high luminosity with high energy resolution
- intrinsic protection against background via magnetic shielding

pre-spectrometer background

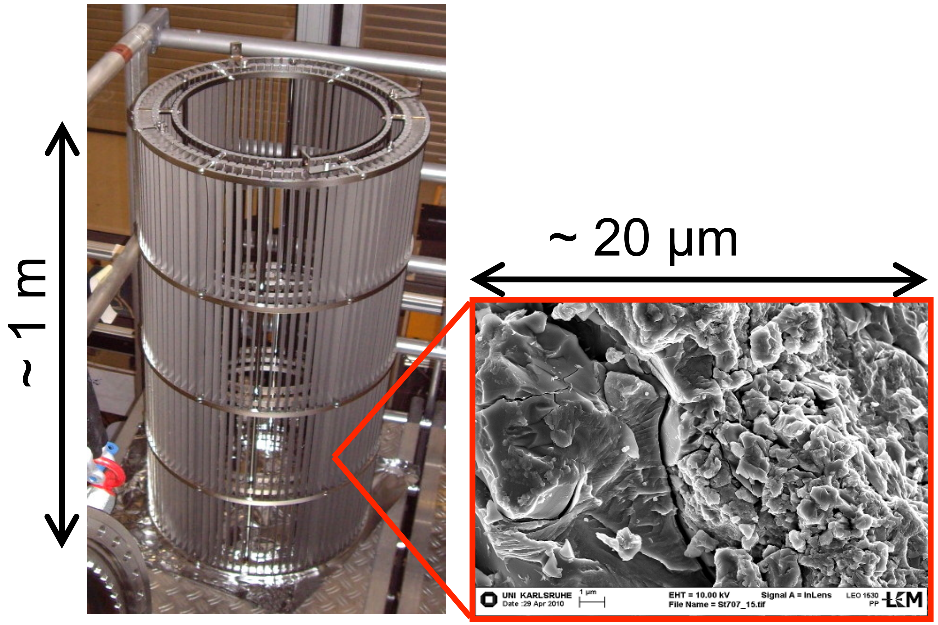


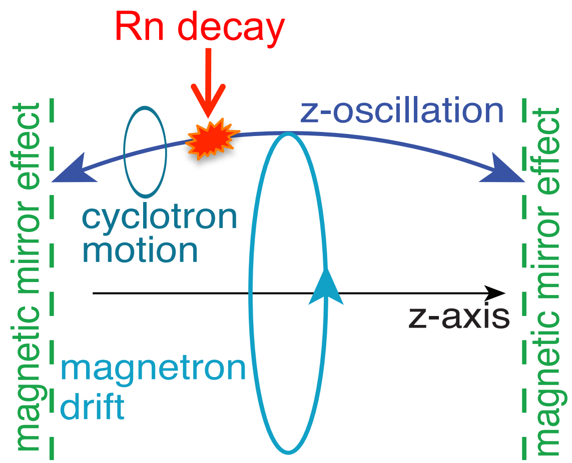
- time dependent background (average rate 23.3 ± 0.4 mHz, aim < 10 mHz)
- intervals of elevated rate show ring pattern on detector

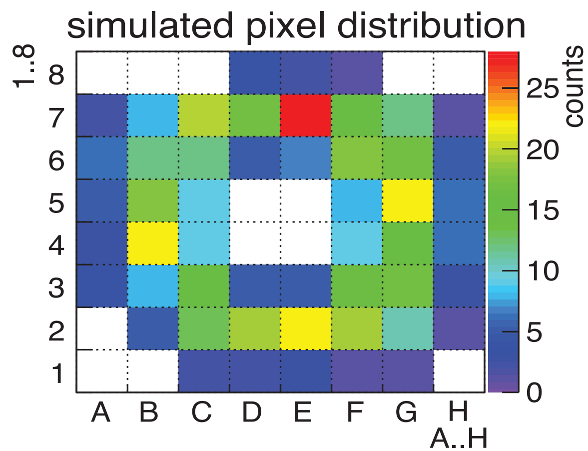
radon background model

- pre-spectrometer getter pump (SAES St707 NEG, 270 m^2) emanates ^{219}Rn
- Rn penetrates into the flux tube where it decays

[DOI: 10.1016/j.astropartphys.2011.06.009]







- electrons released in processes accompanying the Rn α-decay can be magnetically trapped inside the spectrometer
- depending on their initial energy, the trapped electrons can produce thousands of secondary electrons via ionization of residual gas molecules

→ Estimated Rn induced background rate at main spectrometer: 300 mHz

mitigation of Rn background

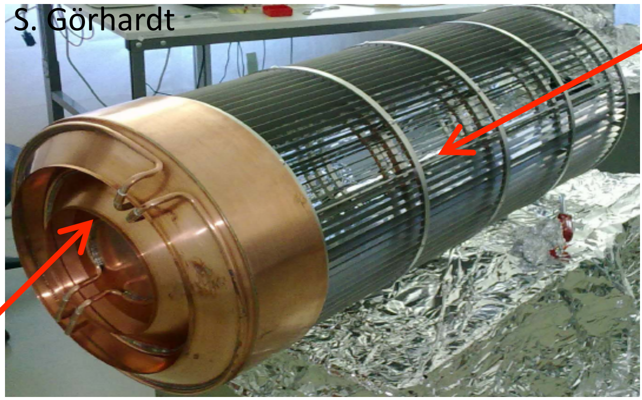
- main spectrometer without getter pump:

  increase of background due to T_2 decays and pressure dependent processes
- LN2 cooled baffle between getter pump and spectrometer:

  tests at pre-spectrometer successful (about 100 % reduction), baffles will be installed at main spectrometer
- electric dipole field:

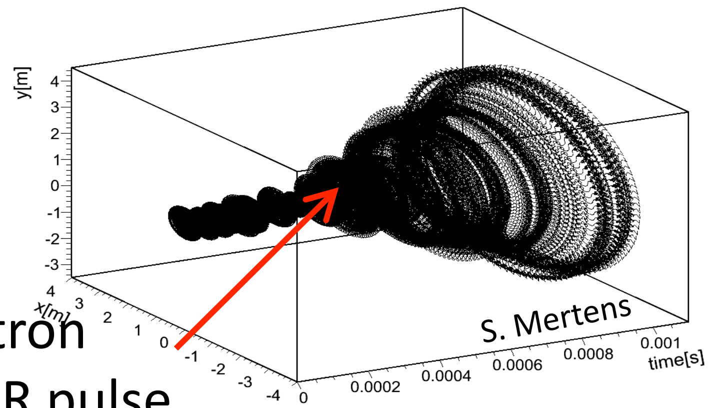
  not effective against high energy (order of 10 keV) trapped electrons
- electron cyclotron resonance (ECR) pulse:

  proof of principle at pre-spectrometer successful (reduction up to factor 6)
- magnetic pulse (to be tested)



getter pump

baffle



simulated electron track during ECR pulse

summary & outlook

summary:

- KATRIN will measure the mass of the electron anti-neutrino, sensitivity: 200 meV/c^2
- installation of main spectrometer electrode system almost finished
- Rn decay in the spectrometer volume is a major background source, different technologies to mitigate Rn induced background were tested
- detector system (major US contribution) has been shipped to KIT and is being installed

outlook:

- commissioning and test measurements at the main spectrometer start in 2012
- commissioning of the complete KATRIN beam line will start 2013/2014
- start of neutrino mass measurements 2014

KATRIN collaboration

Karlsruhe Institute of Technology

Westfälische Wilhelms-Universität Münster

UCL

University of Washington

Berkeley Lab

Hochschule Fulda
University of Applied Sciences

Swansea University
Prifysgol Abertawe

Johannes Gutenberg Universität Mainz

The University of North Carolina at Chapel Hill