Status of the KATRIN Experiment

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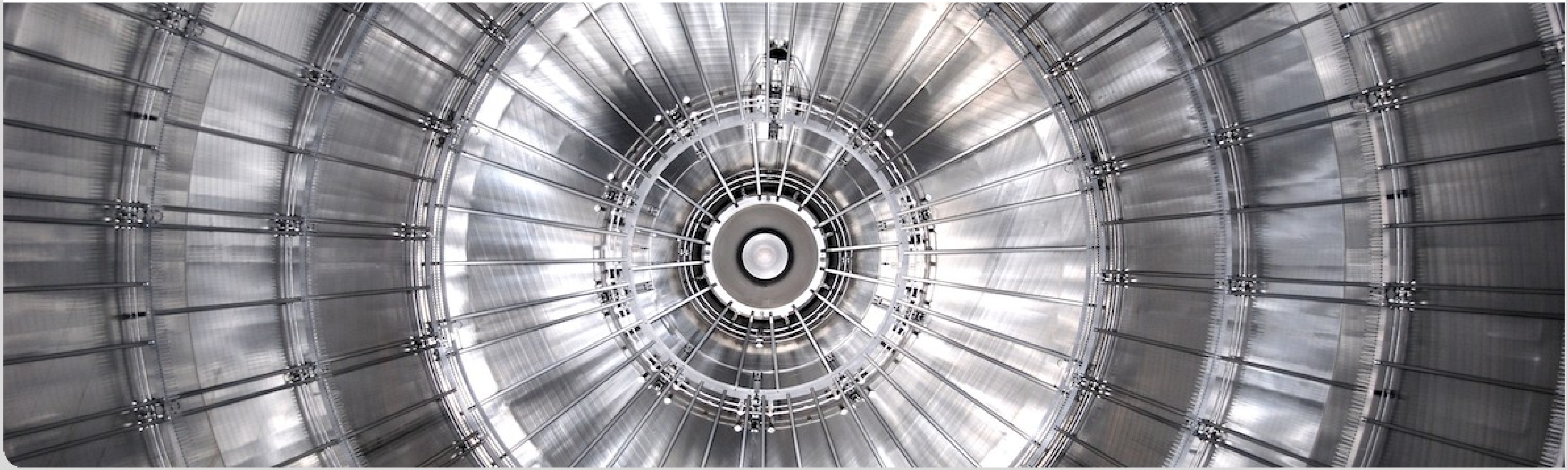
for the KATRIN collaboration

PANIC 2014, Hamburg

HELMHOLTZ ASSOCIATION

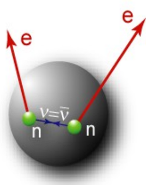
bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

KIT Center Elementary Particle and Astroparticle Physics (KCETA)



Neutrino mass: laboratory experiments

search for 0νββ decay



model-dependent (CP-phases)

- effective Majorana mass:

$$m_{ee} = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$

- probes Majorana nature of ν
- status: $m_{\beta\beta} < 0.2 - 0.4$ eV
- potential: $m_{\beta\beta} = 20 - 50$ meV

GERDA, EXO/nEXO, SNO+, MAJORANA, CUORE, CANDLES KamLAND-Zen, NEXT ...

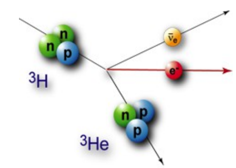
Track 3
Session I + II.5

kinematics of β-decay or EC

model-independent

- squared neutrino mass:

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



- **direct**, from kinematics
- status: $m_\nu < 2.3$ eV
- potential: $m_\nu = 200$ meV

KATRIN, MARE, **Project 8**, ECHO

This session
II.1 & II.2
Poster 167

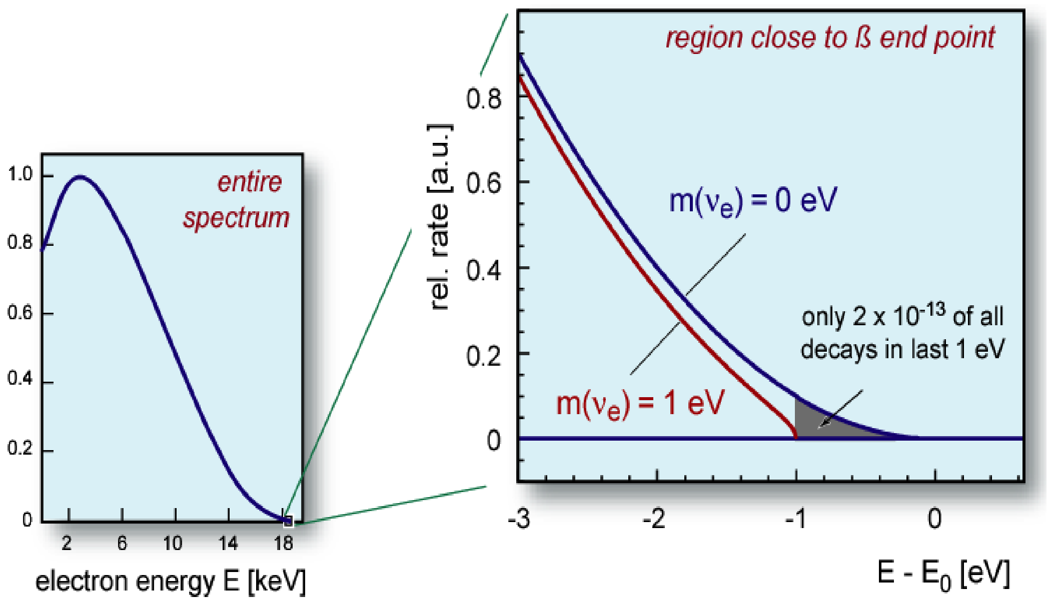
Direct neutrino mass measurements

Imprint of m_ν on endpoint region of β spectrum (similar for EC):

$$\frac{d\Gamma}{dE} = C\cdot p\cdot(E+m_e)\cdot(E_0-E)\cdot\sqrt{(E_0-E)^2-m^2(\nu_e)}\,F(Z,E)\cdot\Theta(E_0-E-m(\nu_e))$$

observable: effective mass square

$$m^2(\nu_e) = \sum |U_{ei}|^2 m_i^2$$



key requirements

- low-endpoint β source
- high count rate
- very good energy resolution
- very low background

β-decay: ^{3}**H** (^{187}Re)
EC: ^{163}Ho

ν-mass measurement in tritium β-decay

Karlsruhe Institute of Technology

^{3}H β-decay

- Short $T_{1/2}$ of 12.3 y
  → high-intensity source
- Low endpoint of 18.6 keV
  → good rel. signal strength
- Gas, closed loop
  → high isotopic purity
- Computation of final states, radiative & recoil corrections

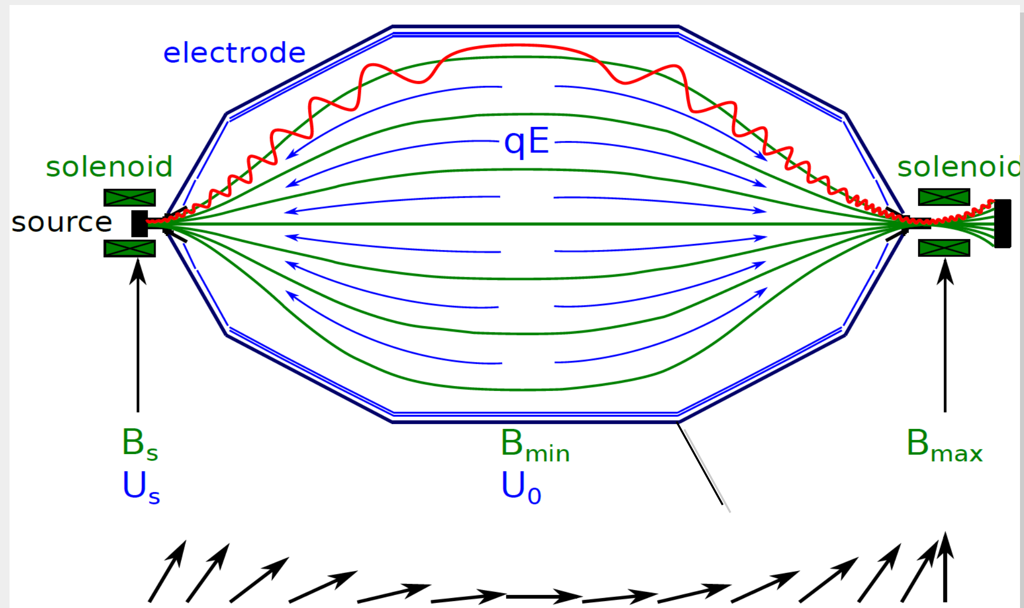
- Isotropic emission, strong B_s
- Energy filtering, weak B_{min}
- Resolution:

$$\frac{\Delta E}{E} = \frac{B_{min}}{B_{max}} = \frac{1}{20000}$$

(at KATRIN)

MAC-E filter technique

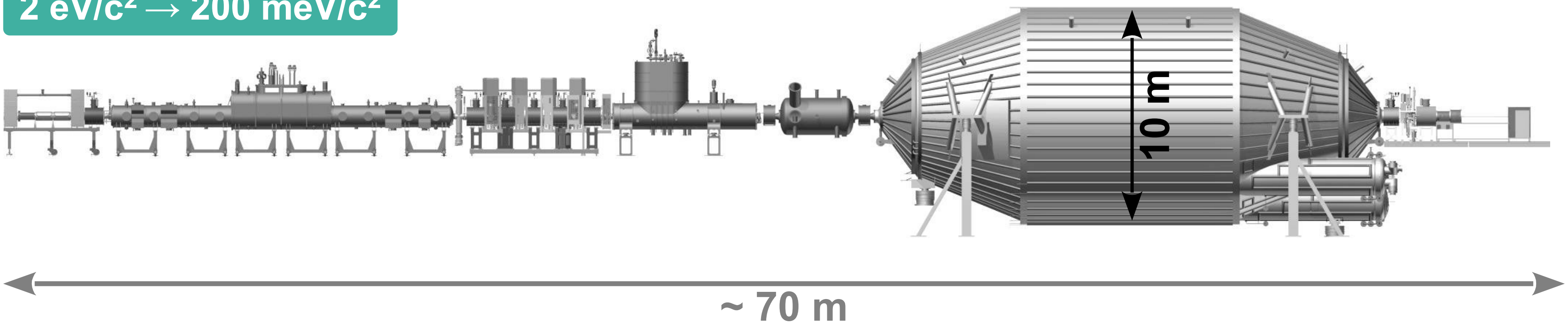
Magnetic Adiabatic Collimation with Electrostatic filter
Picard et al., NIM B63 (1992) 345



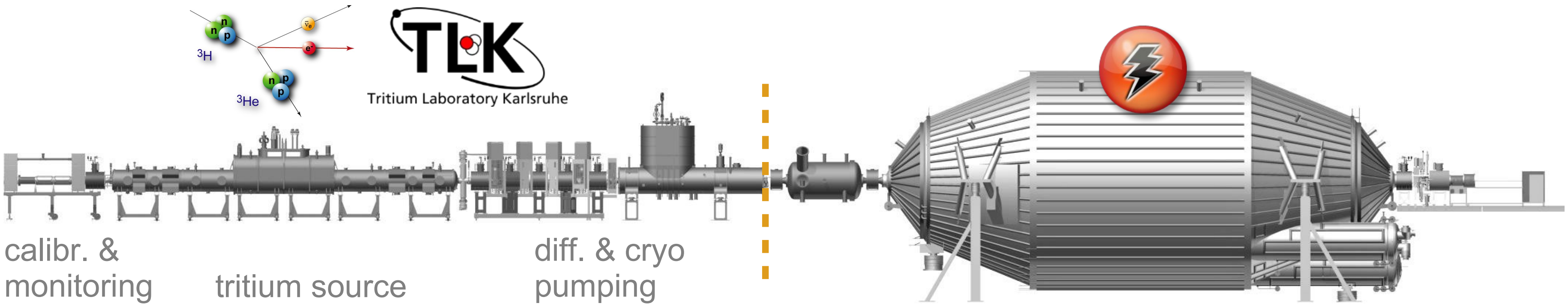
$$\mu = \frac{E_\perp}{B} = \text{const.}$$

KATRIN: overview

sensitivity on $m(\nu_e)$:
$2\ eV/c^2 \rightarrow 200\ meV/c^2$



KATRIN: main components



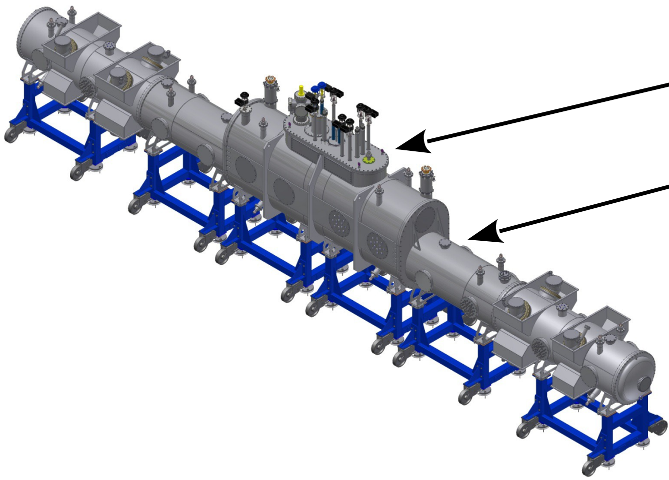
Source & transport section

- Windowless gaseous tritium source
  - Intensity (10^{11} s^{-1})
  - Stability (10^{-3} h^{-1})
  - Isotopic purity (> 95%)
- Tritium retention factor (> 10^{14})
- Adiabatic transport of electrons

Spectrometer & detector section

- Spectrometer UHV (p < 10^{-11} mbar)
- Energy resolution (<1 eV at 18.6 keV)
- High voltage stability (ppm/month)
- Low background rate (10^{-2} cps)
- High detection efficiency (mHz to kHz)

Windowless gaseous tritium source



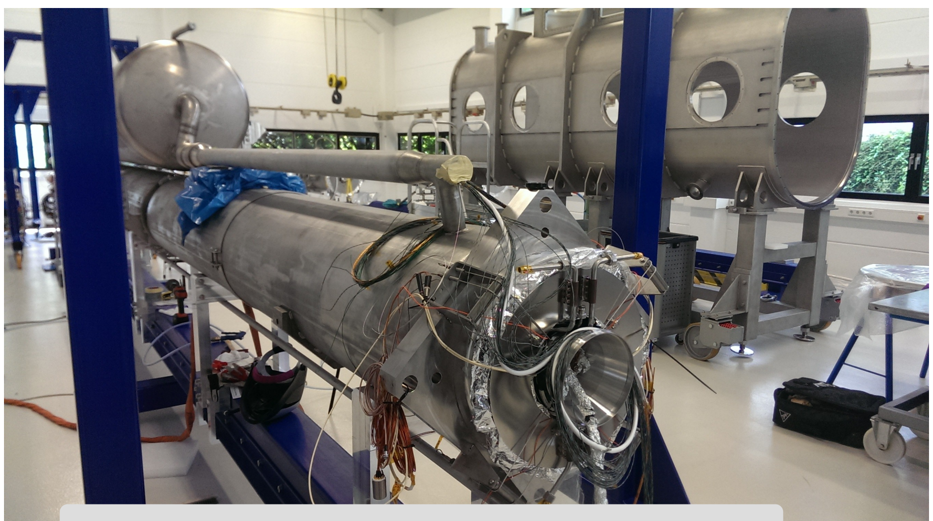
Pressure-stabilized tritium injection

Circulation & purification (throughput 20 g/day)

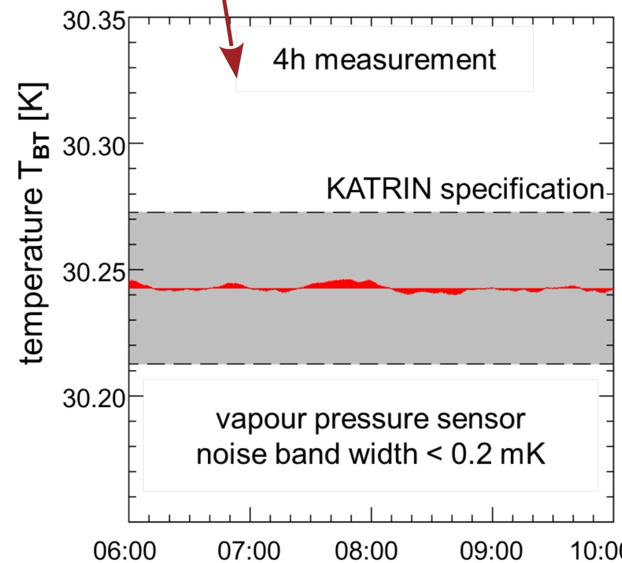
10 m beam tube

Novel 2-phase neon cooling:
T = (30 ± 0.03) K (1 h stability requirement)

**demonstrator experiment:
successful cold-test
on site (2010-12)**



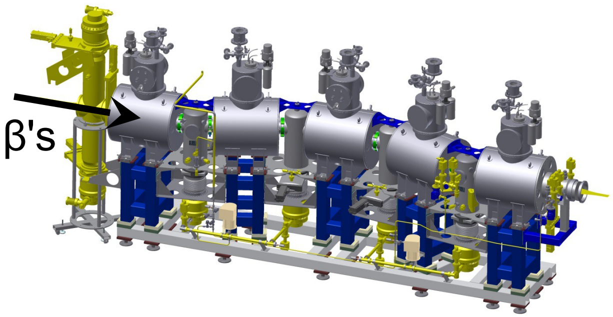
WGTS assembly, delivery mid-2015



Transport and pumping sections

Differential pumping section (DPS)

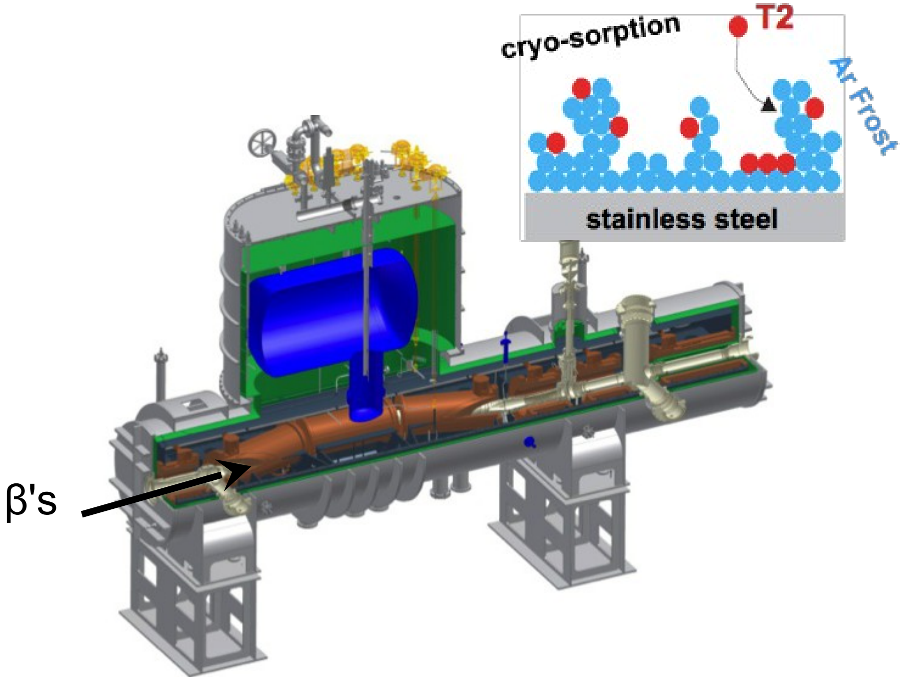
- 4 turbo-molecular pumps
- Tritium retention **~10⁵**
- Magnetic guiding of β's (5.6 T)



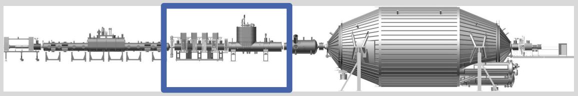
DPS being installed right now

Cryogenic pumping section (CPS)

- Cryo-sorption on 3-4 K argon frost
- Tritium retention **>10⁷**
- Magnetic guiding of β's (5.6 T)



CPS under construction,
delivery end of 2014



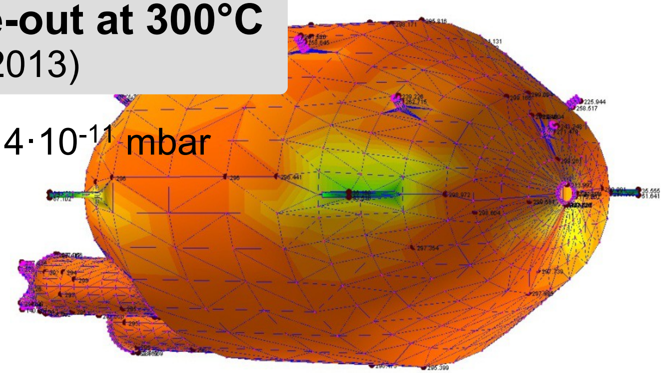
Spectrometer and detector section

Installation of wire electrodes (~2007-2012)

240 modules
23000 wires
2 layers
UHV compatible

Bake-out at 300°C (Jan 2013)

- ✔ $p = 4\cdot10^{-11}$ mbar



Detector tests (until spring 2013)

- 148 pixel Si-PIN diode
- FWHM < 1.5 keV at 18.6 keV
- Post-acceleration up to 10 kV

Commissioning of main spec. & detector: mid-2013 (phase I)

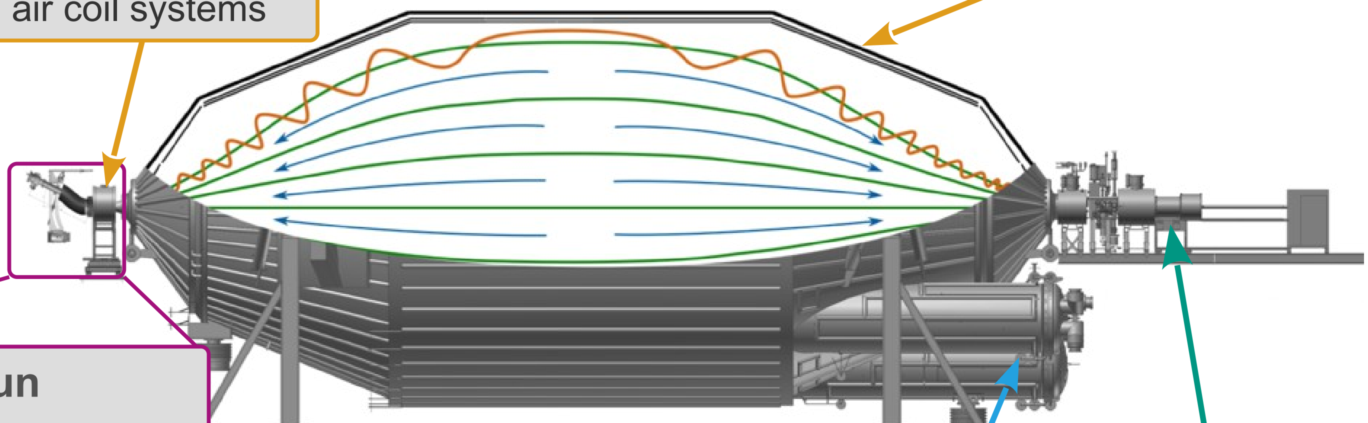
KATRIN: commissioning measurements

Set-up for spectrometer & detector commissioning, phase I (summer 2013)

Magnetic fields
- s.c. magnets
- field-shaping air coil systems

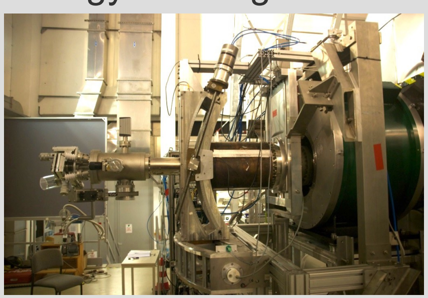
Precision high voltage

vessel + wire electrode at separate HV

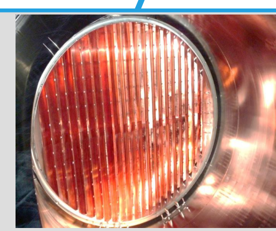


electron gun

well-defined, sharp energy and angle

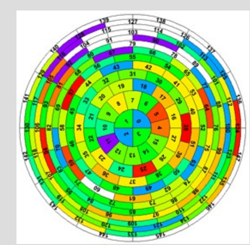


vacuum system
- TMPs
- 3 x 1 km NEG strips, 10^6 ℓ/s (+ LN-cooled baffles)



148-pix detector

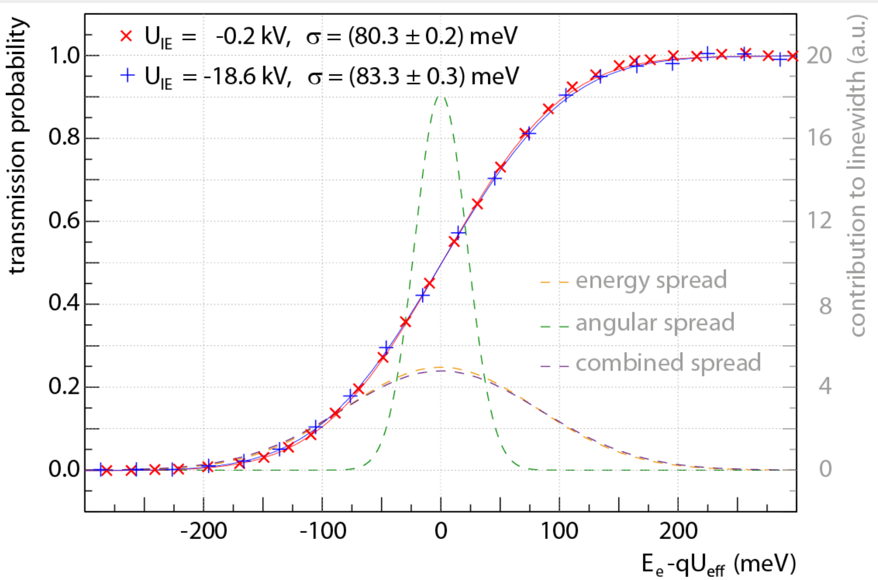
spatial & timing info



KATRIN: commissioning measurements

Characterisation of transmission

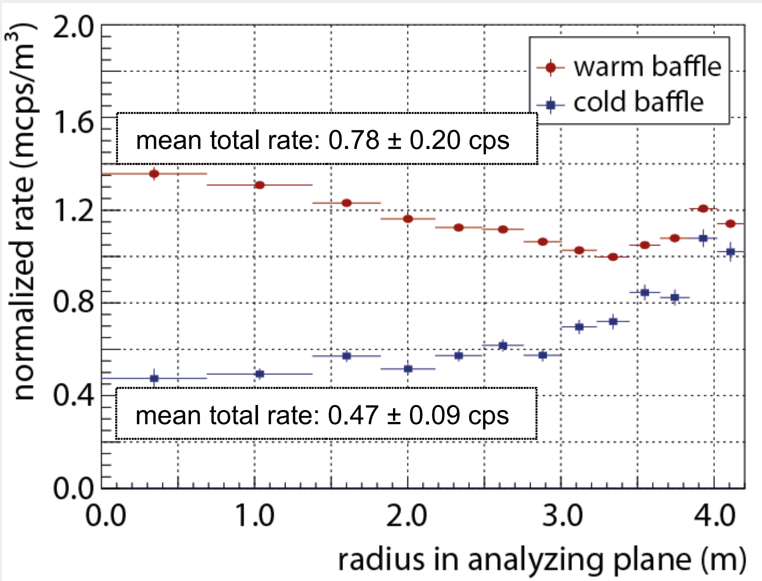
Quasi-monoenergetic, angular selective electron source



- At 18.6 kV, width < 100 meV
- Sharpest transmission function of a MAC-E filter

Extensive background studies

Radial dependence; various E, B, residual gas pressure settings



- Discriminate cosmic- and Rn-induced BG
- Need to cut down total rate to **~0.01 cps**

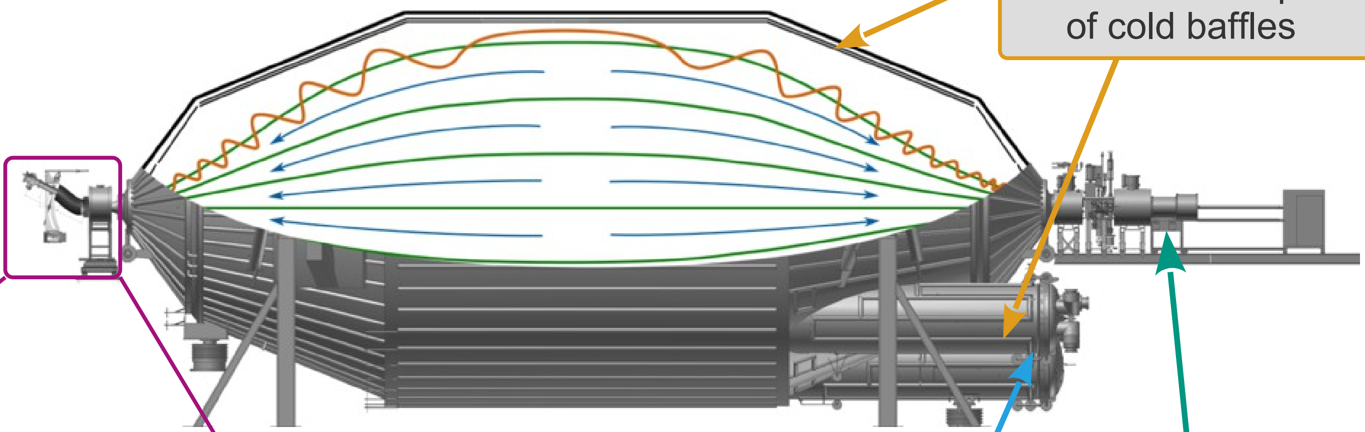
… will be improved during 2014 commissioning runs

Next steps for KATRIN

Spectrometer & detector commissioning:
phase II starting **09/2014**

improved background suppression

- double-layer wire electrode
- continuous operation of cold baffles

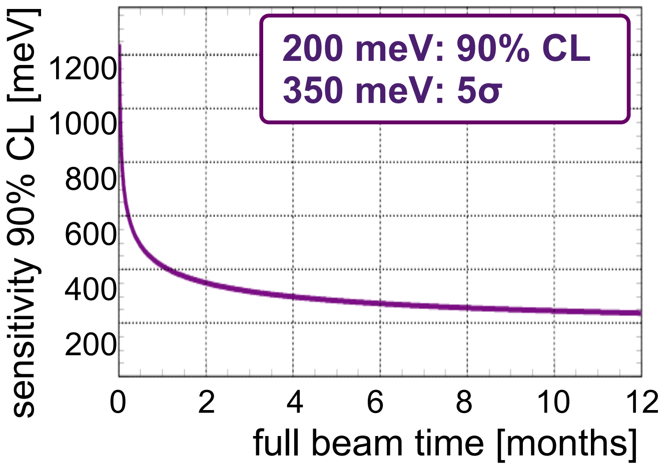


upgrade of electron gun
improved angular selectivity and energy res.

upgrade of vacuum system
electrical heating of NEG pumps

refined system alignment
imaging of flux tube onto detector

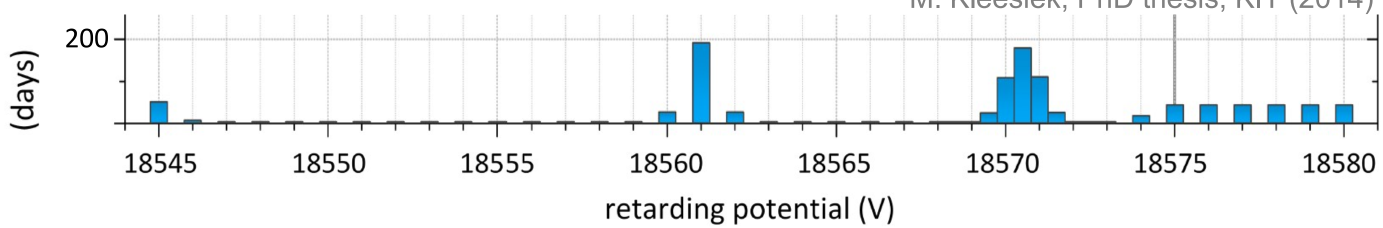
KATRIN: ν-mass sensitivity



Reference neutrino mass sensitivity

- Observable: $\mathbf{m^2(\nu_e)}$
- After **3 yrs** of data (5 calendar yrs): balance of statistics and systematics

$\sigma_{stat}(m^2_\nu) \leq 0.018\ eV^2$ (even **$0.016\ eV^2$** with optimized measuring time distribution)
M. Kleesiek, PhD thesis, KIT (2014)



$\sigma_{syst}(m^2_\nu) \leq 0.017\ eV^2$ – total systematic uncertainty budget

- Source-related (final states, energy loss, column density, plasma potential, ...)
- Other (HV fluctuations, transmission function, non-Poissonian backgrounds, ...)

KATRIN: ν-mass sensitivity … and more:

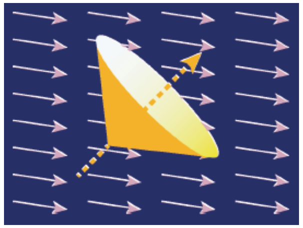
Explore physics potential

- **close to the spectral endpoint E_0:**

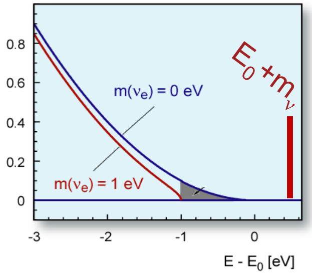
standard operation mode for KATRIN

RH currents
Bonn et al. (2011)

Violation of Lorentz symmetry
Diaz, Kostelecky & Lehnert (2013)

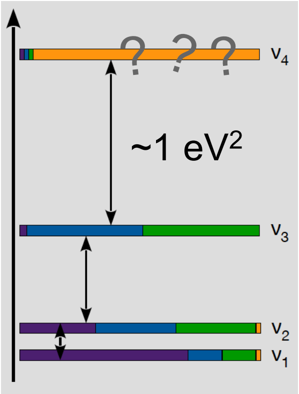


Constraining local CνB overdensities
e.g. Kaboth & Formaggio (2010)



capture of relic ν on β-instable nuclei

Search for eV-scale sterile ν



- **and further away from E_0:**

  search for keV-mass scale sterile ν as WDM candidates
  N. Steinbrink et al. (2013), S. Mertens et al. (in prep.)

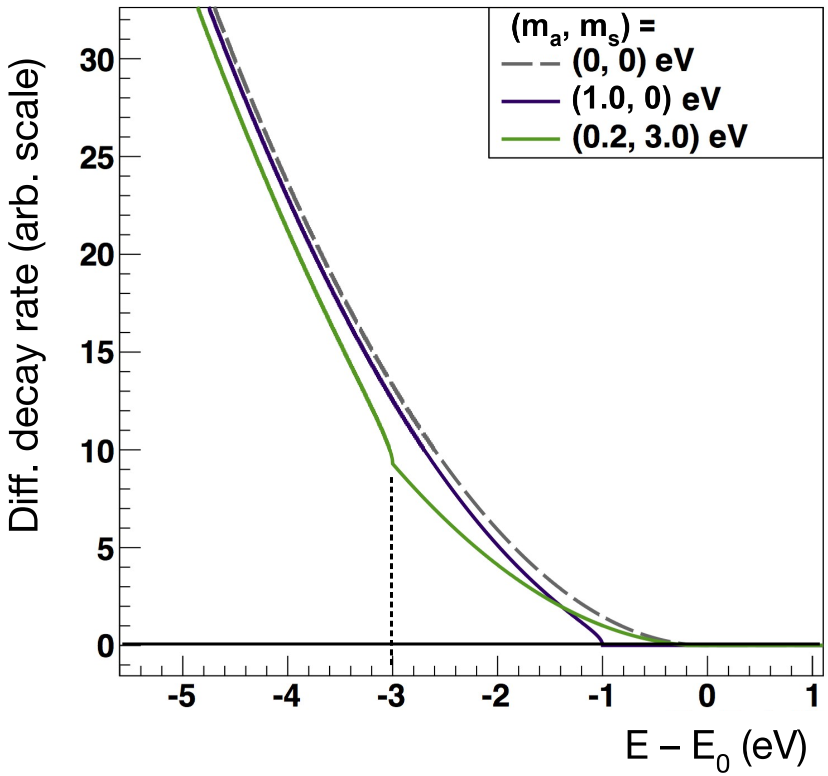
non-standard operation, requires novel concepts

Search for eV-scale sterile neutrinos

Shape modification below E_0 by active $(m_a)^2$ and sterile $(m_s)^2$ neutrinos:

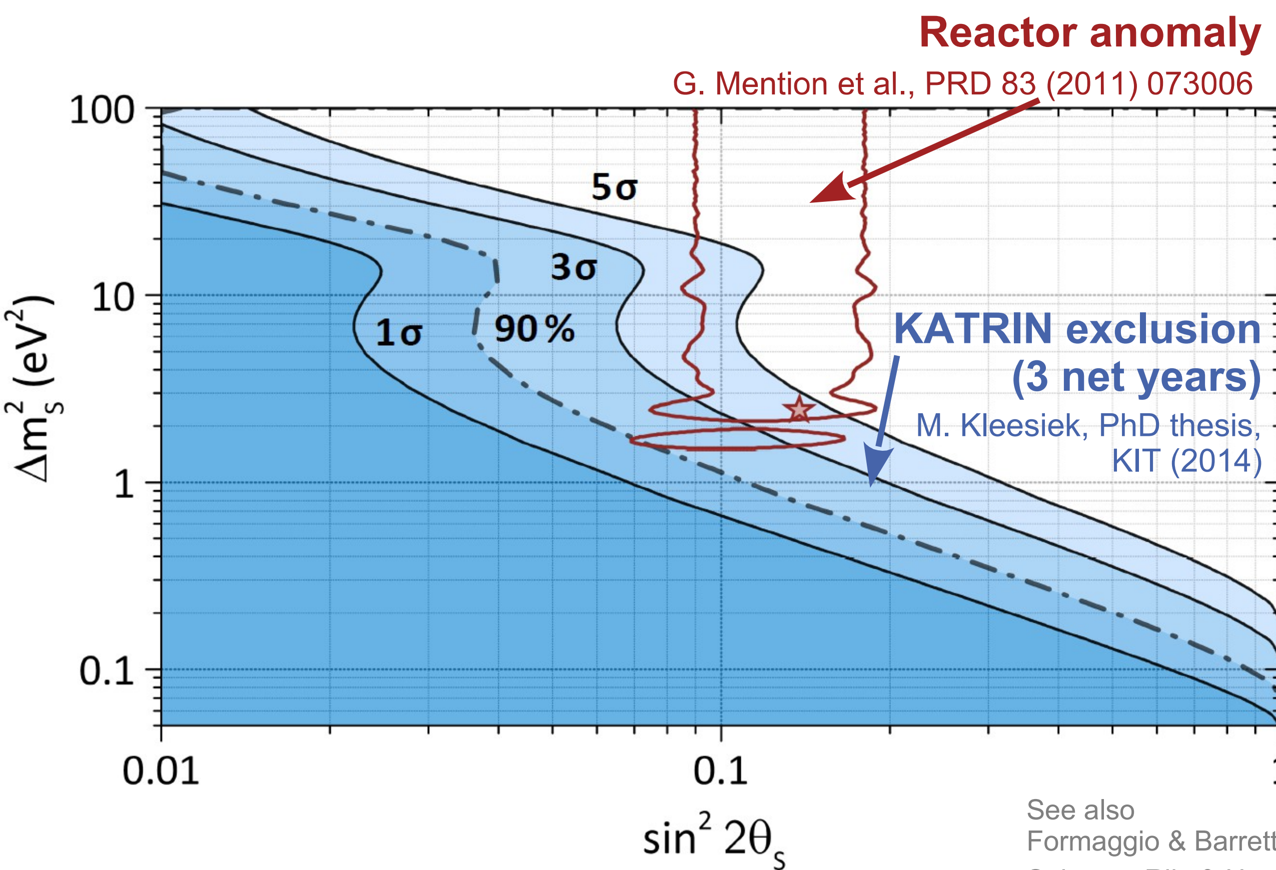
$$\frac{\mathrm{d}\dot{N}}{\mathrm{d}E} = \cos^2\theta_s \, \frac{\mathrm{d}\dot{N}}{\mathrm{d}E}(m_a^2) + \sin^2\theta_s \, \frac{\mathrm{d}\dot{N}}{\mathrm{d}E}(m_s^2)$$

additional kink in β spectrum at $E = E_0 - m_s$



Search for eV-scale sterile neutrinos

- "Reactor antineutrino anomaly": $\Delta m^2_s \sim 1\ eV^2$, $\sin^2(2\theta_s) \sim 0.1$
- Favoured parameter space can be probed by KATRIN:



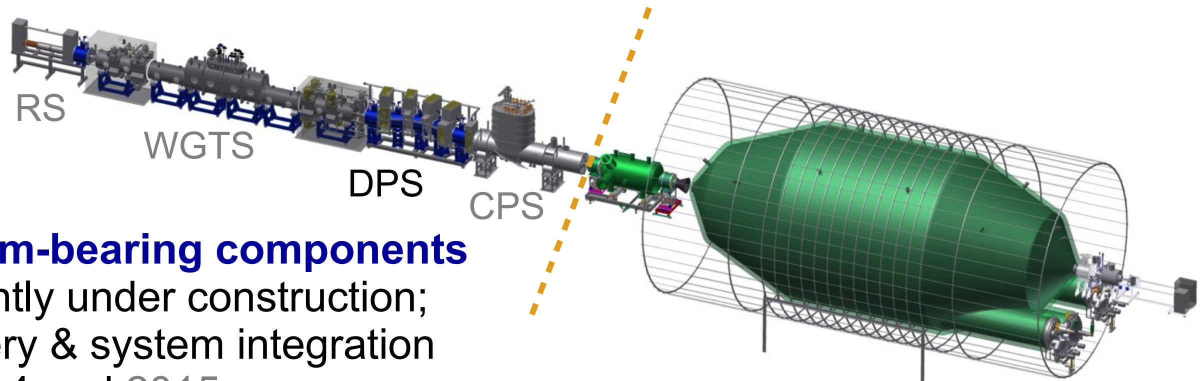
See also
Formaggio & Barrett, PLB 706 (2011) 68;
Sejersen Riis & Hannestad, JCAP02 (2011) 011;
Esmaili & Peres, arXiv:1203.2632

Status & outlook

- β decay offers model-independent, direct access to neutrino mass scale
- KATRIN sensitivity on $m(\nu_e)$: **200 meV/c²** (90% CL, 3y)
  → ultimate MAC-E type experiment using molecular tritium

"Cyclotron spectroscopy": exciting exploratory work with **Project 8** (→ talk M. Fertl)

Status of KATRIN hardware & system integration



Tritium-bearing components
currently under construction;
delivery & system integration
in 2014 and 2015

Spectrometer & detector section
successfully completed commissioning phase I
just now entering phase II

First runs with entire KATRIN beam line in 2016