



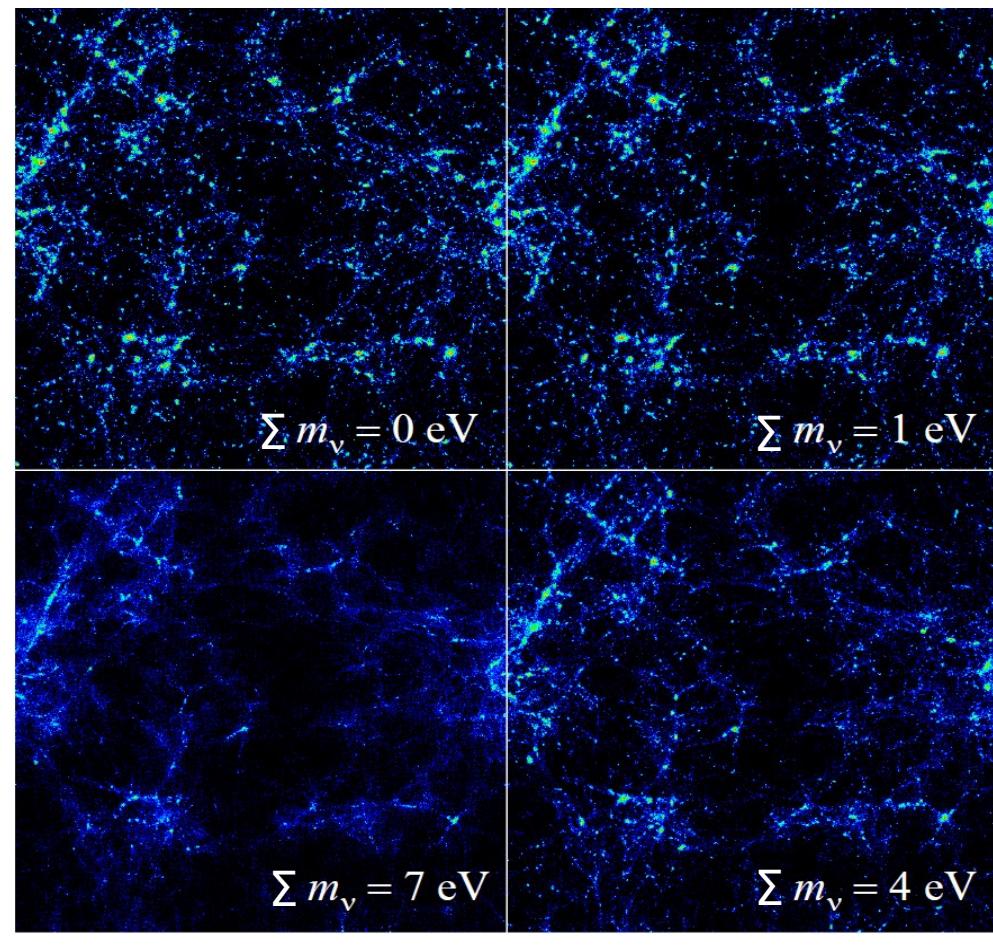
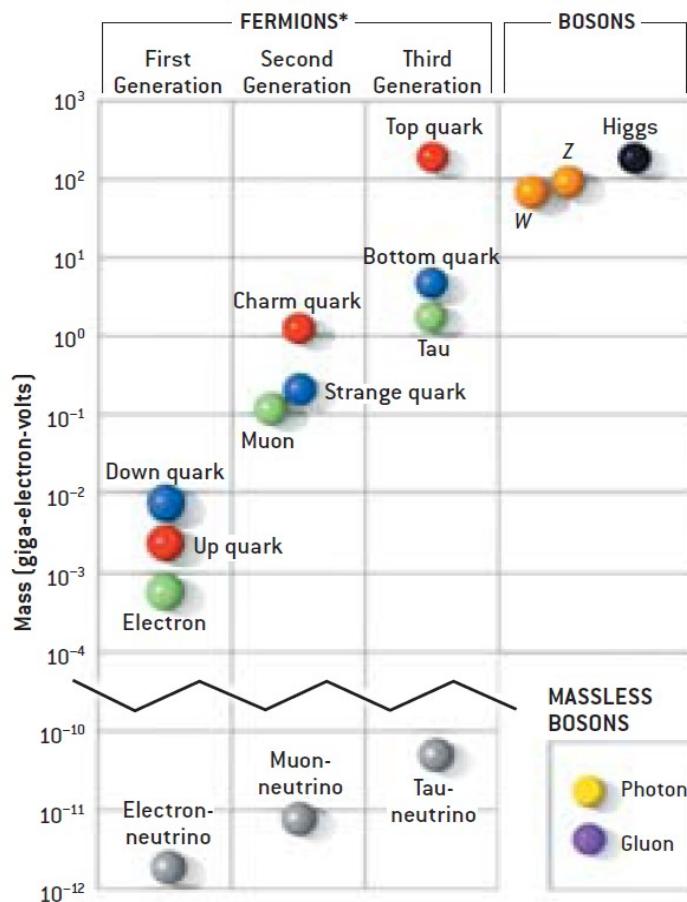
The KATRIN neutrino mass experiment

V.M. Hennen for the KATRIN collaboration

Institut für Kernphysik,
Westfälische Wilhelms-Universität Münster

Particle physics viewpoint:

- Mass gap between charged fermions and neutrinos ([sea-saw I / II models](#)) ?
- Dirac or Majorana nature of neutrinos ?
- Normal or inverted hierachy ?
- CP violating phases in mixing matrix ?
- [Absolute mass scale](#) ?



simulation Chung-Pei Ma 1996

Cosmology viewpoint:

- Influence on structure formation ?
- Warm dark matter in the form of keV mass sterile neutrinos ?

Search for neutrino mass

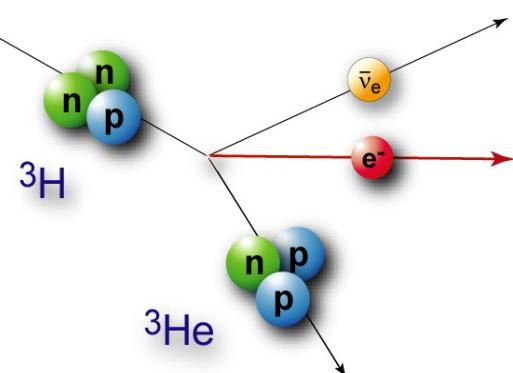
β -decay: absolute ν -mass

model independent, kinematics

status: $m_\nu < 2.3$ eV

potential: $m_\nu \approx 200$ meV

e.g.: KATRIN, MARE-II



neutrino mass measurements

m_ν

$m_{\beta\beta}$

Σm_i

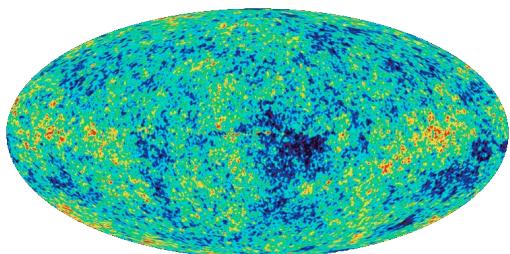
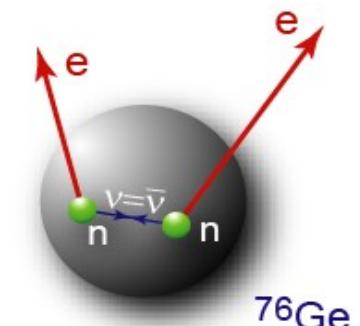
$0\nu\beta\beta$ -decay: eff. Majorana mass

model-dependent (CP-phases)

status: $m_{\beta\beta} \leq 140 - 380$ meV (EXO-200),

potential: $m_{\beta\beta} \approx 20-50$ meV arXiv:1205.5608v1

e.g.: GERDA, CUORE, EXO, SNO+, Majorana, Nemo 3, COBRA, KamLAND-Zen



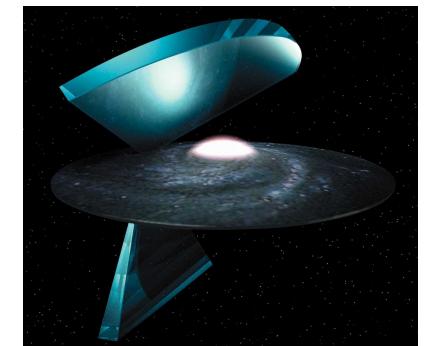
cosmology: ν hot dark matter Ω_ν

model dependent, analysis of LSS data

status: $\Sigma m_\nu < 440$ meV (Hannestad et al., JCAP08(2010)001)

potential: $\Sigma m_\nu \approx 20-50$ meV

e.g.: WMAP, SDSS, LSST, Planck

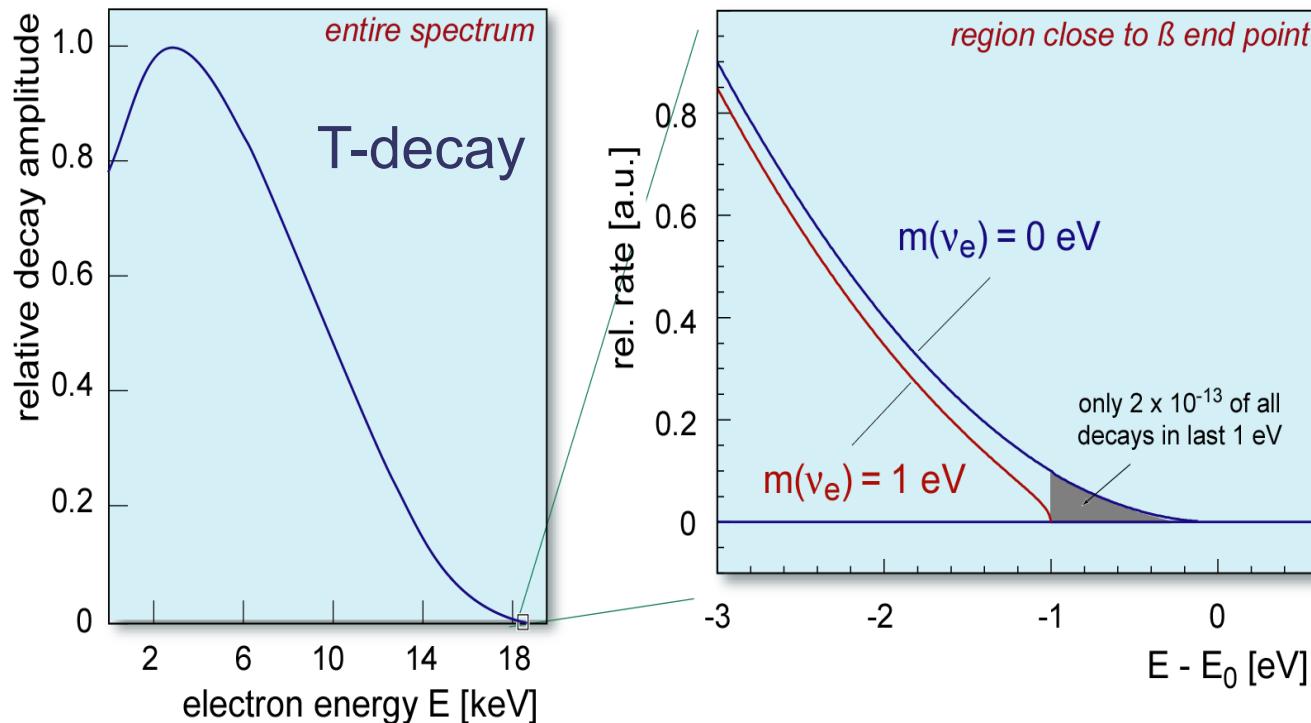


Kinematic determination of $m(\nu_e)$

$$\frac{d\Gamma}{dE} = C p(E+m_e)(E_0-E)\sqrt{(E_0-E)^2 - m_{\nu_e}^2} F(Z+1, E) \Theta(E_0-E-m_{\nu_e})$$

$$C = \frac{G_F^2}{2\pi^3} \cos^2 \theta_C |M|^2$$

(modified by final states, recoil corrections, radiative corrections)



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

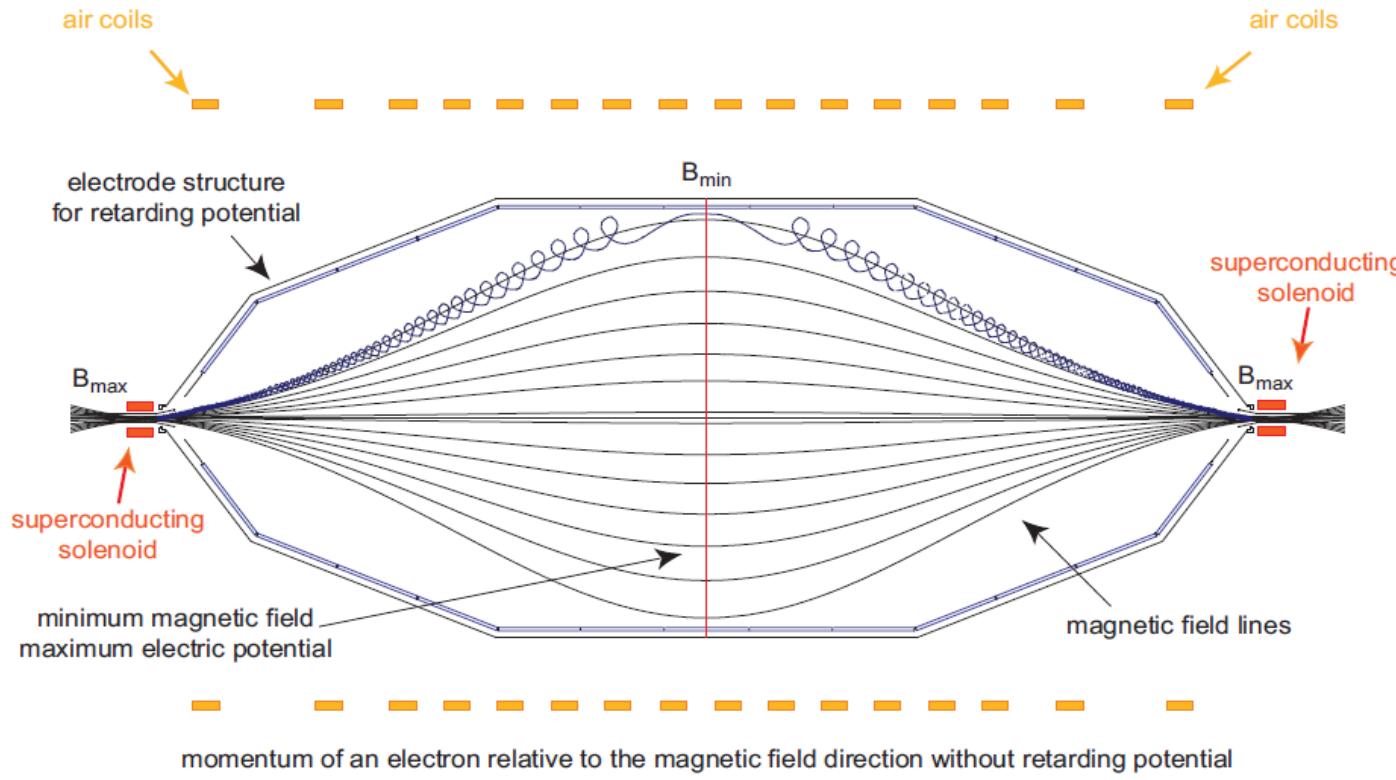
Requirements

- low endpoint energy
- high count rate
- high energy resolution
- very low background

Tritium

- $E_0 = 18.6$ keV
- $T_{1/2} = 12.3$ a
- superallowed transition
- simple electronic structure

MAC-E filter concept



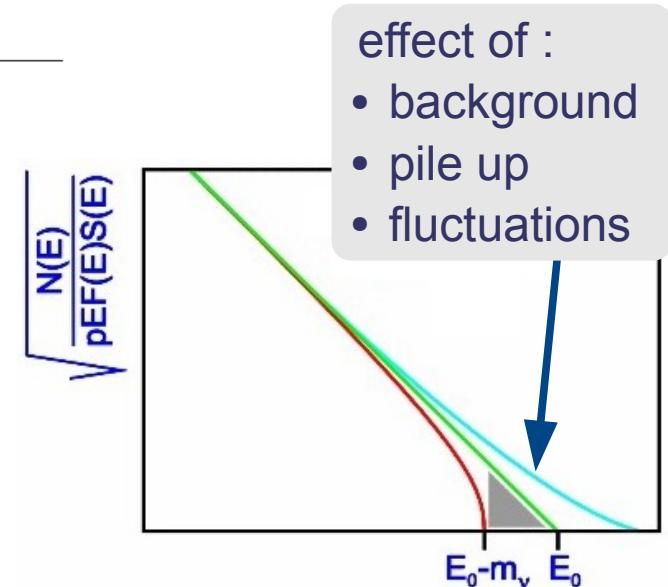
- adiabatic transport $\rightarrow \mu = E_{\perp} / B = \text{const.}$
- B drops by $2 \cdot 10^4$ from solenoid to analyzing plane
 $\rightarrow E_{\perp} \rightarrow E_{||}$
 $\rightarrow E_{\perp, \text{ana}} = E_{\perp, \text{start}} \cdot B_{\min} / B_{\max} < 1 \text{ eV}$
- only electrons with $E_{||} > eU_0$ can pass the MAC-E filter
- Energy resolution depends on ΔU_0 and E_{\perp}

Magnetic Adiabatic Collimation with Electrostatic Filter

Advantages:

- up to 2π opening angle
- high energy resolution

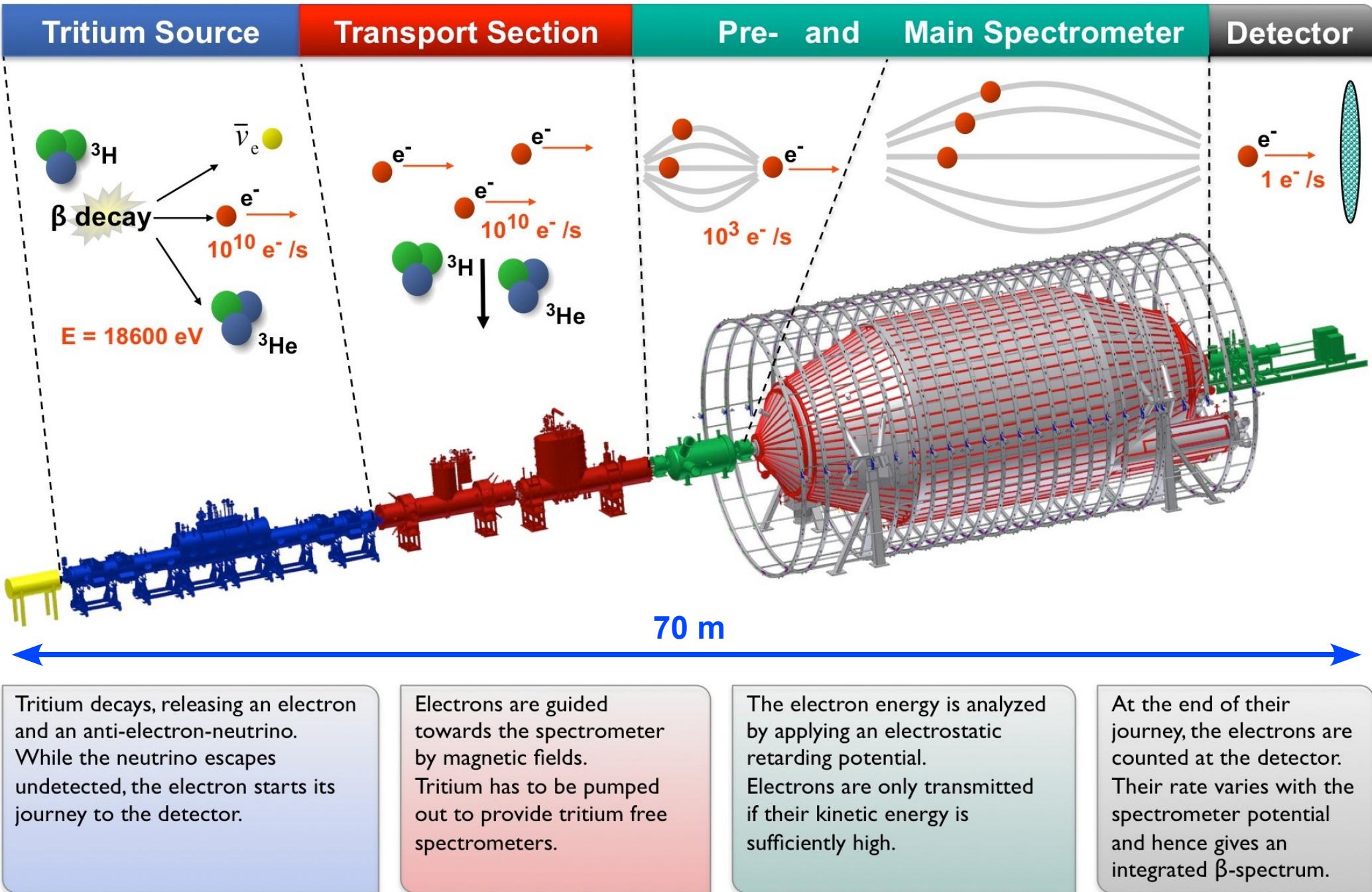
A. Picard et al., NIM B 63 (1992)



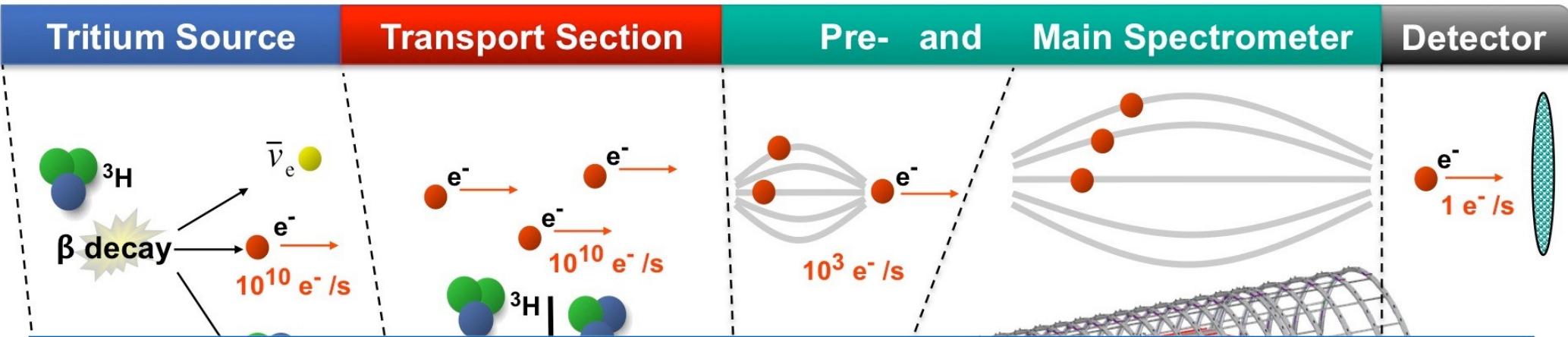
effect of :

- background
- pile up
- fluctuations

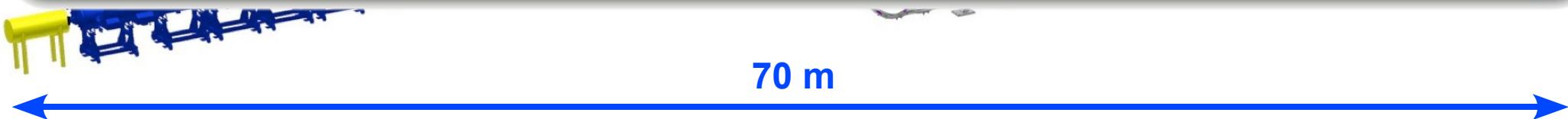
KATRIN overview



KATRIN overview



KATRIN is currently being set up at the Karlsruhe Institute of Technology (KIT) by an international collaboration (ca. 150 people from 14 institutions from 5 countries)



Tritium decays, releasing an electron and an anti-electron-neutrino. While the neutrino escapes undetected, the electron starts its journey to the detector.

Electrons are guided towards the spectrometer by magnetic fields. Tritium has to be pumped out to provide tritium free spectrometers.

The electron energy is analyzed by applying an electrostatic retarding potential. Electrons are only transmitted if their kinetic energy is sufficiently high.

At the end of their journey, the electrons are counted at the detector. Their rate varies with the spectrometer potential and hence gives an integrated β -spectrum.

Recent WGTS developments

T_2 inner loop

- successfully comissioned at the TLK
- Pressure fluctuations < 0.02%
→ 5 times better than specified



WGTS demonstrator tests

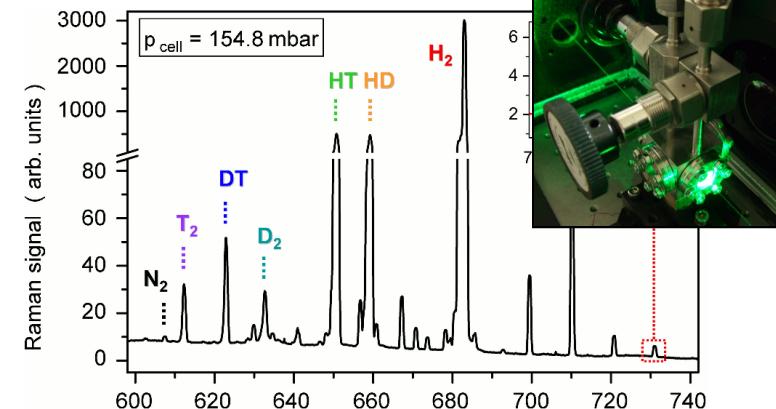
- cool-down to 30 K successful
- test of 2-phase liquid Neon cooling
→ temperature stability
4 mK (1σ) over 24 h
- Next steps: completion of demonstrator to full WGTS

S. Grohmann, *Cryogenics* 49 (2009) 413

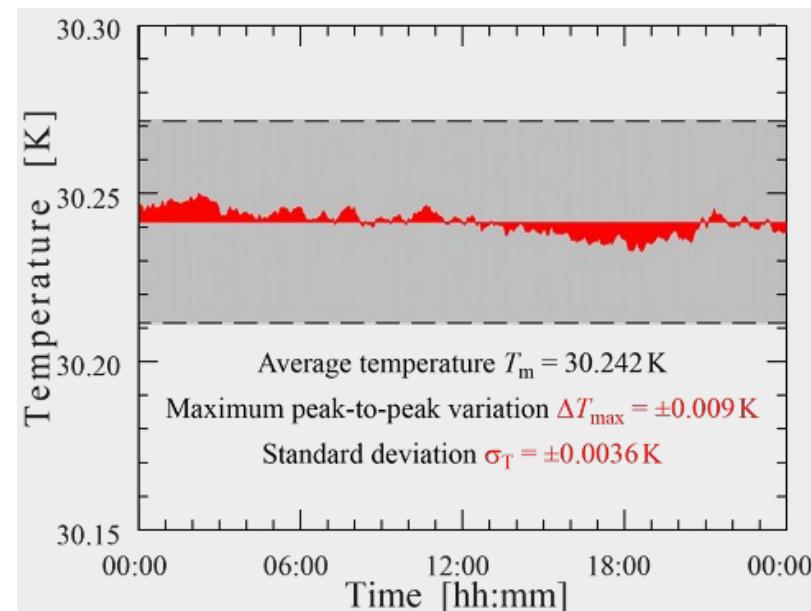


Laser Raman spectroscopy

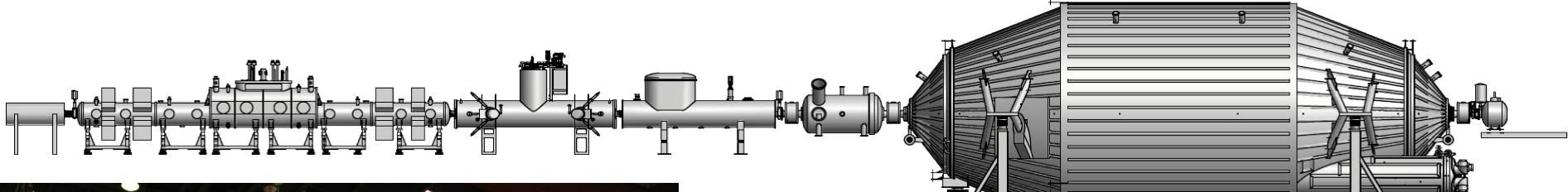
- monitoring of T_2 purity
- 0.1% precision (1σ)



R.J. Lewis et al., *Las. Phys. Lett.* 5 (2008) 522
M. Sturm et al., *Las. Phys.* 20 (2010) 493

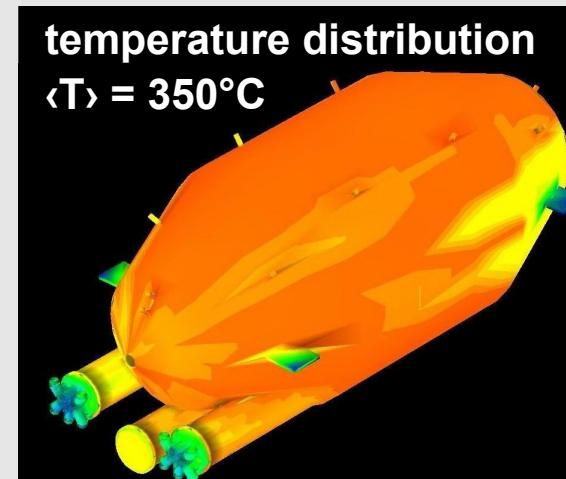


Main-Spectrometer



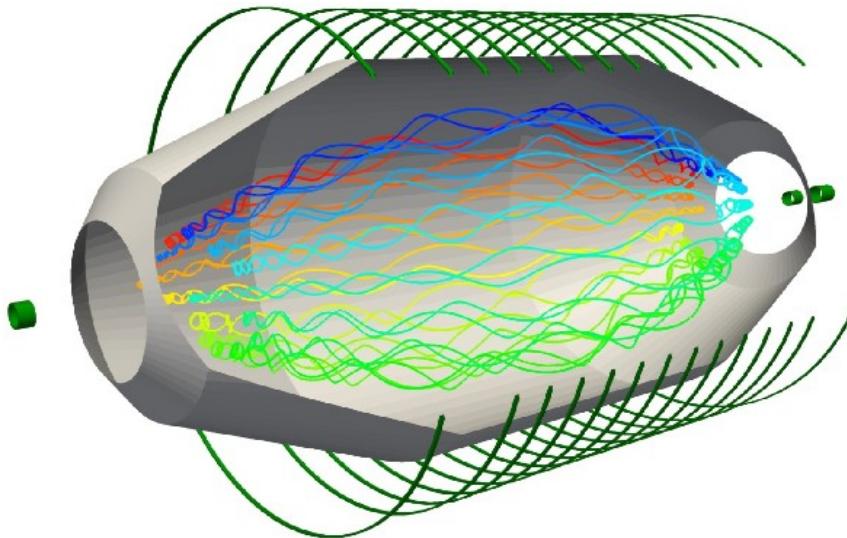
- 18.6 kV retardation voltage, $\sigma < 60 \text{ meV}$
- 0.93 eV resolution
- required background rate $< 10 \text{ mHz}$
- pressure $< 10^{-11} \text{ mbar}$
- Vacuum tests after initial bake-out (6 TMPs only)
→ outgassing rate @ 20°C:
 $1.18 \times 10^{-12} \text{ mbar l/cm}^2\text{s}$, $p = 10^{-10} \text{ mbar}$
- Air coil system for earth magnetic field compensation
- Inner wire electrode for background suppression and field shaping

J Wolf, Journal of the
Vacuum Society of Japan,
Vol. 52 (2009) , No. 5



Background suppression I

Stored electron by magnetic mirrors
F. Fränkle et al., Astropart. Phys. 35 (2011) 128

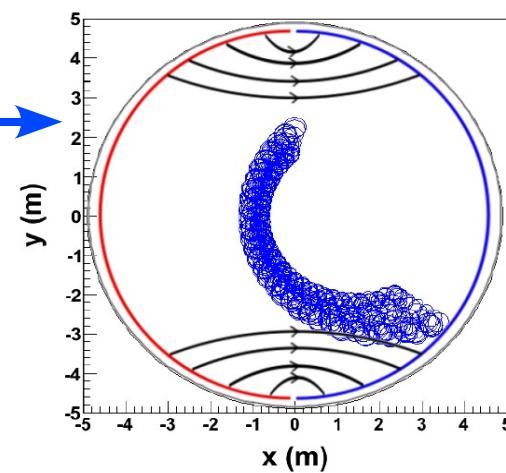


- Trapped particles create background by interactions with rest gas molecules
- Several methods investigated to remove trapped particles:

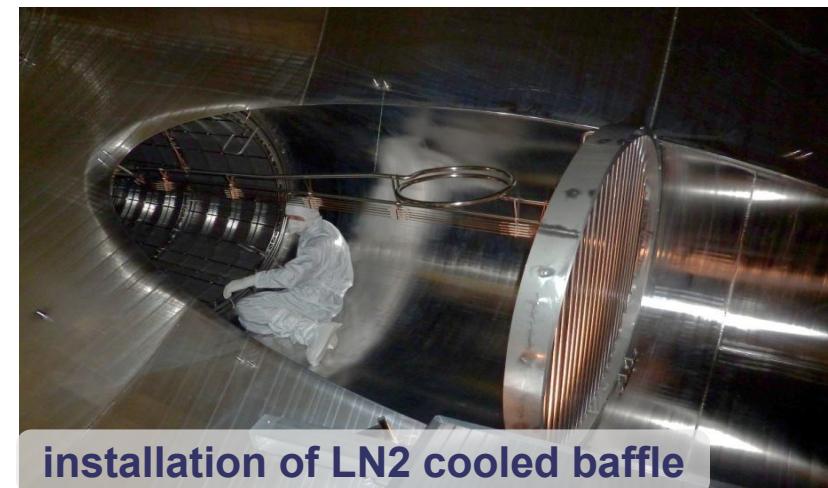
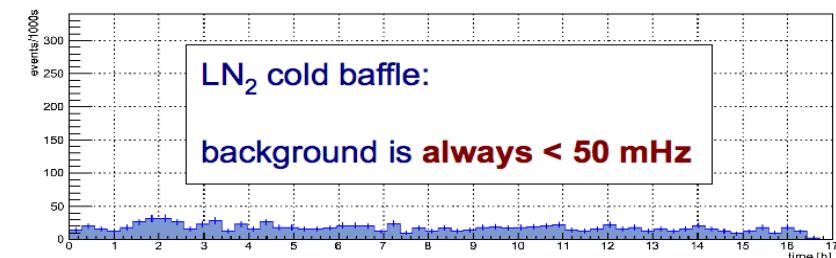
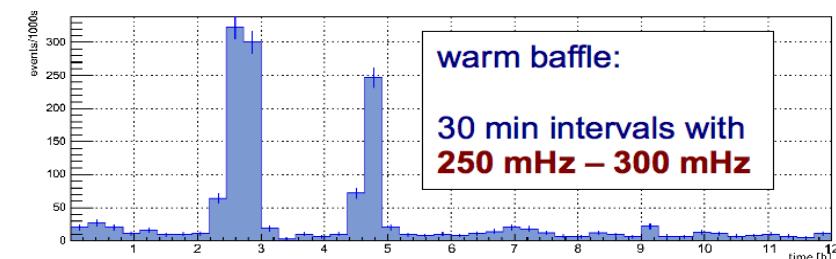
- Magnetic pulse
- Electric dipole
- Electron catcher

M. Beck et al,
Eur. Phys. J.
A44 (2010) 499

- Electron cyclotron resonance: ECR



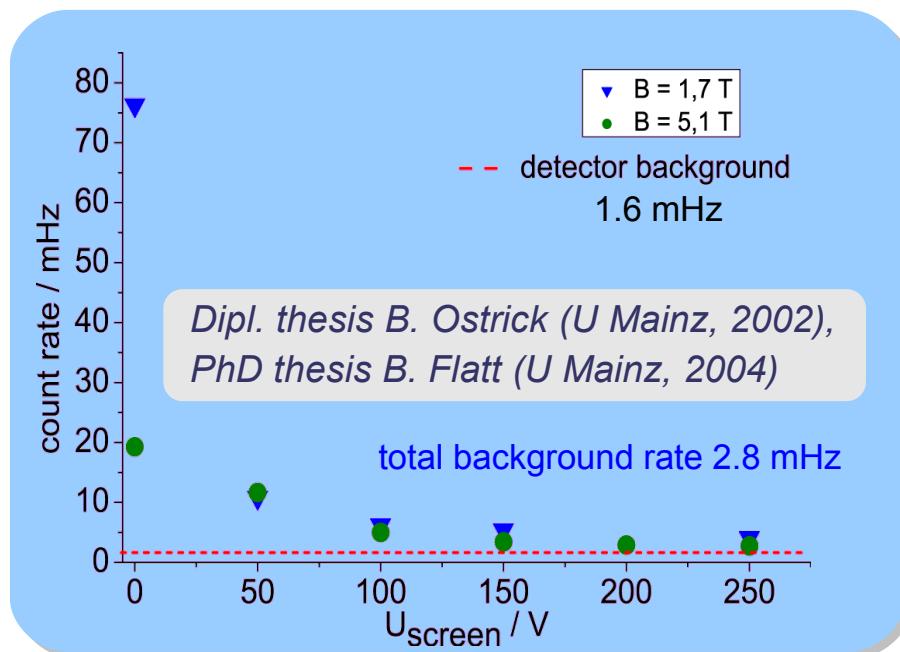
- Radon emission from getter material needs to be suppressed to avoid background from high energy electrons → introduction of LN₂ cooled baffles
- Proof of principle at pre-spectrometer:



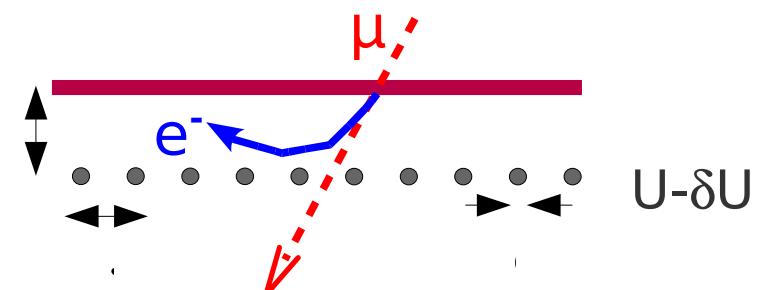
installation of LN2 cooled baffle

Background suppression II

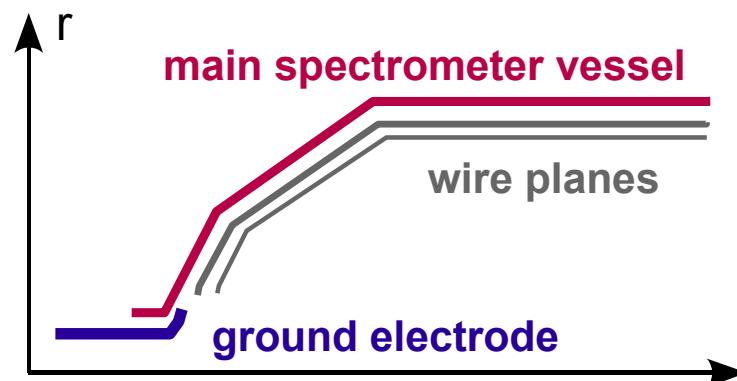
- e^- from cosmics and radioisotopes can mimic e^- in endpoint energy region
- 650 m^2 surface of main spectrometer → ca. $10^5 \mu / \text{s}$ + contamination
- Reduction due to B-field: factor $10^5\text{-}10^6$
- Real signal rate in the mHz region
- Additional reduction necessary !



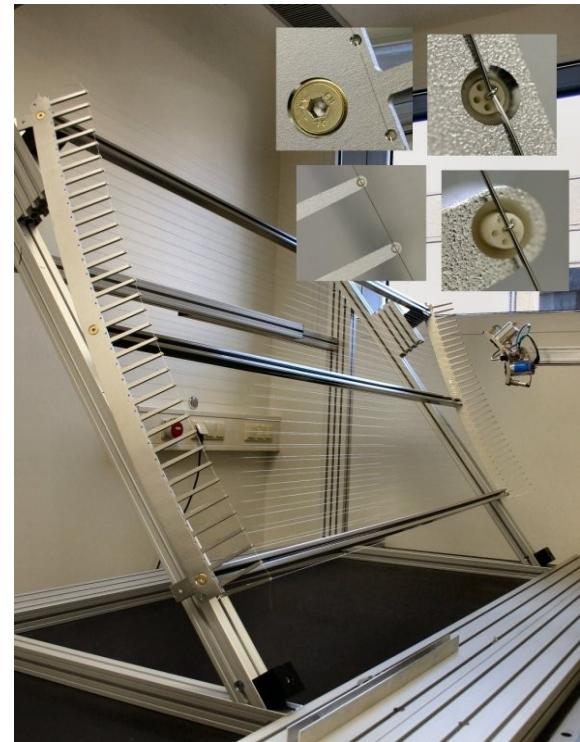
- Screening of background electrons with a wire grid on a negative potential
- The grid has to be 'massless' to avoid background from the grid itself



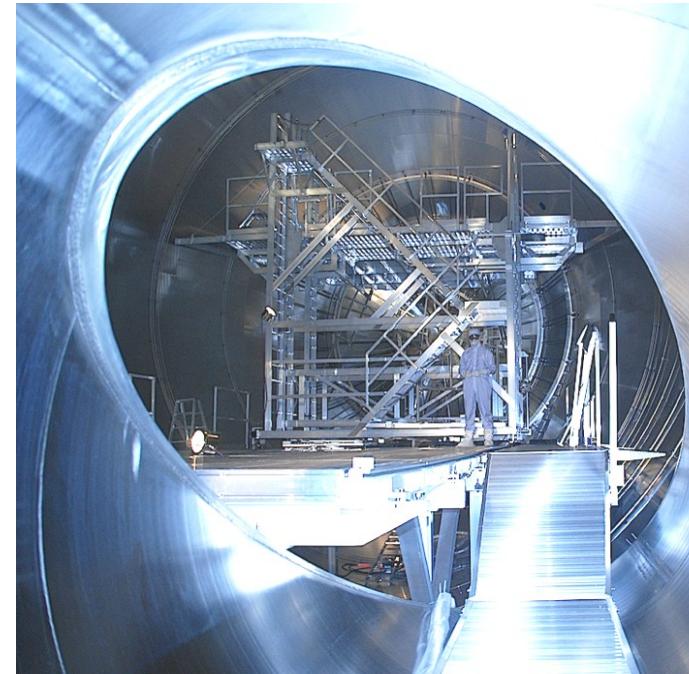
- Background suppression tested at the former Mainz neutrino mass experiment → at 200 V shielding potential background reduction by a factor 10
- KATRIN uses an improved 2 layer design → expect reduction by a factor 10-100



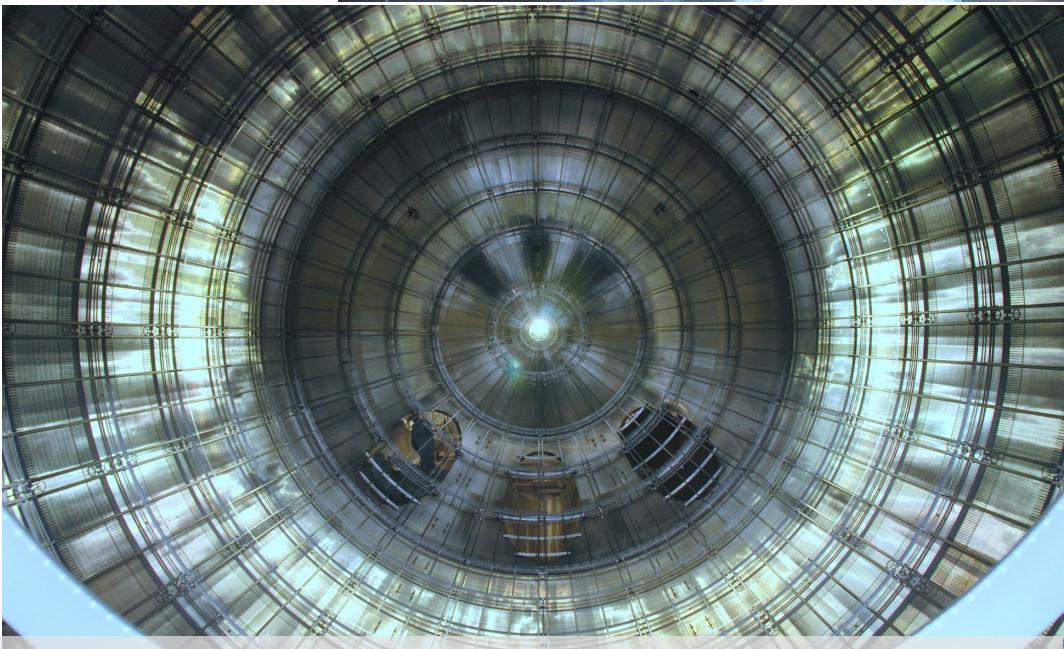
Inner wire electrode



- modular design of two layer wire electrode
- $\Sigma = 248$ modules, 23000 wires manufactured at IKP Münster cleanroom
- QA of electrode modules with specialized sensors on automated 3D coord. table
- modules are arranged in 15 rings in main spectrometer
- 46 different HV potentials available



- installation of modules on rail system inside the spectrometer using a movable intervention system
- module installation completed spring 2012
- currently:
 - installation of ground and anti-Penning electrodes in the entry and exit ports
 - leak checks and bake-out of the system
- Main spectrometer commissioning fall 2012



M. Prall et al., The Wire Electrode of the KATRIN Main-Spectrometer, in preparation

Systematic effects and error budget

1. Inelastic scattering of β 's in the source (WGTS)
 - calibration measurements with e-gun necessary
 - deconvolution of electron energy loss function
2. Fluctuations of WGTS column density (required < 0.1%)
 - rear wall detector, Laser - Raman spectroscopy, T=30K stabilization, e-gun measurements
3. Transmission function
 - spatially resolved e-gun measurements
4. WGTS charging due to decay ions (MC: $\phi < 20\text{mV}$)
 - Injection of low energy (meV) electrons from the rear end, diagnostic tools available
5. Final state distribution
 - reliable quantum chem. calculations
6. HV stability of retarding potential on 3ppm level required
 - precise HV-Divider (PTB), monitor spectrometer, calibration sources

fluctuations σ^2 lead to a downward shift in m_ν^2

$$\Delta m_\nu^2 = -2 \sigma^2$$

allow only few contributions with $\Delta m_\nu^2 \leq 0.007 \text{ eV}^2$
 $\Leftrightarrow \sigma < 60 \text{ meV}$

$$\frac{\Delta U}{U} = \frac{0.06}{18575} \approx 3 \cdot 10^{-6}$$

\Rightarrow 3 ppm long term stability

Systematic effects and error budget

1. Inelastic scattering of β 's in the source (WGTS)

- calibration measurements with e-gun necessary
- deconvolution of electron energy loss function

2. Fluctuations of WGTS column density (required < 0.1%)

- rear wall detector, Laser - Raman spectroscopy,

**KATRIN sensitivity:
5 year measurement
(eff. 3 y of data)**

*KATRIN Design Report
(Scientific Report FZKA 7090)*

statistical uncertainty
systematic uncertainty
→ $m(v_e) = 0.35 \text{ eV observable with } 5\sigma$
sensitivity for upper limit 0.2 eV/c^2 (90% C.L.)

fluctuations σ^2 lead to a downward shift in m_ν^2

$$\Delta m_\nu^2 = -2 \sigma^2$$

5. Final state distribution

- reliable quantum chem. calculations

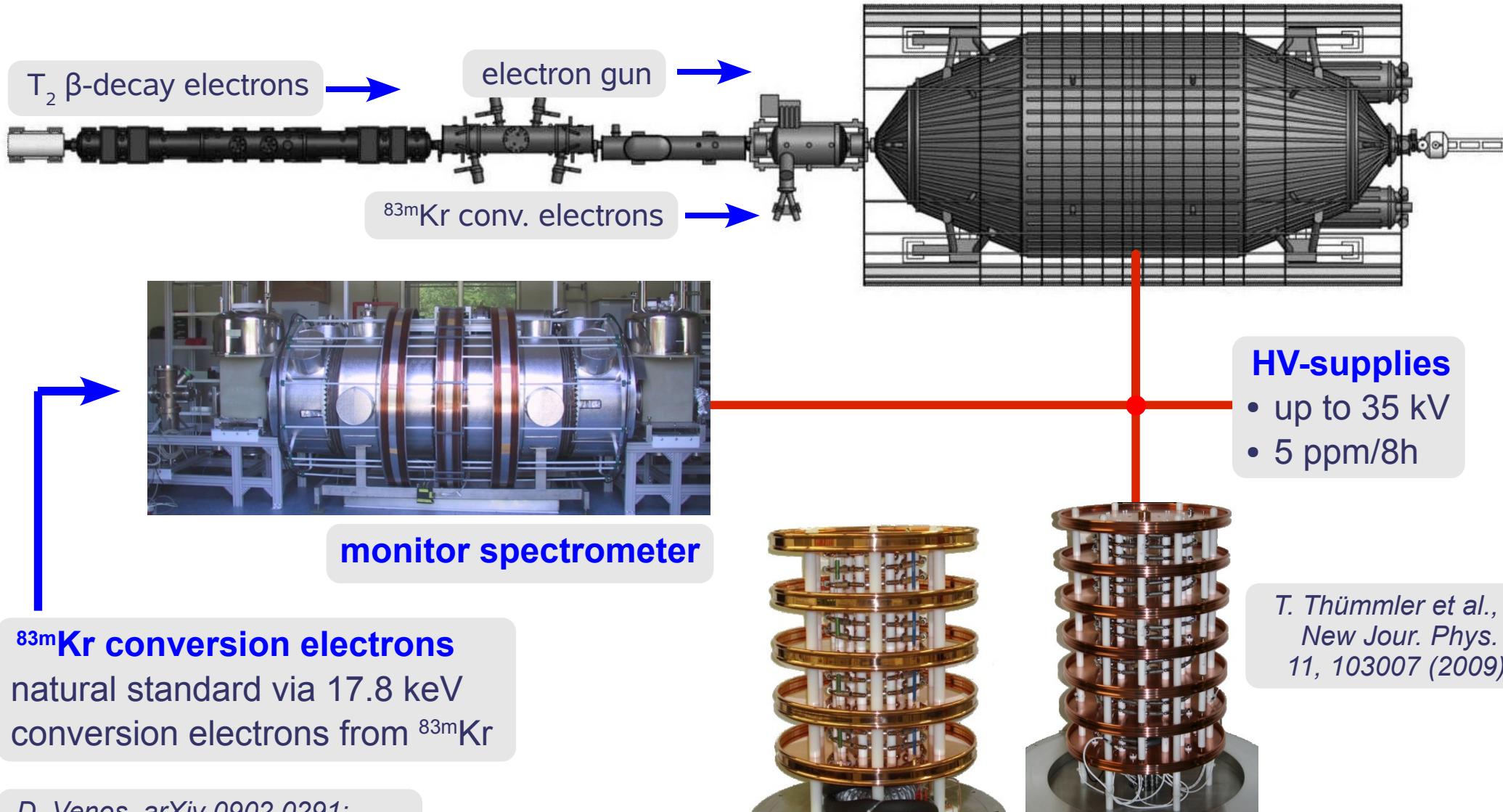
6. HV stability of retarding potential on 3ppm level required

- precise HV-Divider (PTB), monitor spectrometer, calibration sources

$$\frac{\Delta U}{U} = \frac{0.06}{18575} \approx 3 \cdot 10^{-6}$$

⇒ 3 ppm long term stability

Spectrometer calibration and monitoring



precision HV dividers (with PTB)
error budget: $\Delta m_U^2 < 0.0075 \text{ eV}^2/\text{c}^4 \rightarrow \sigma_U < 60 \text{ mV} @ 18.6 \text{ kV}$

Summary

- Studies of β -decay kinematics offer a model-independent way to determine the neutrino mass, complementary to cosmology and $0\nu\beta\beta$ searches.
- KATRIN will probe the cosmologically relevant mass range down to 200 meV
- KATRIN timeline:
 - Winter 11/12 - Summer 2012: pre-commissioning measurements at the monitor spectrometer
 - Fall 2012: start commissioning of main spectrometer and detector system
 - WGTS completion in 2012-2013, commissioning in 2014
 - Commissioning KATRIN transport section 2014-2015
 - Start of neutrino mass measurements 2015



Federal Ministry
of Education
and Research

supported by



universität bonn



Max-Planck-Institut
für Kernphysik



Thanks for your attention !!

