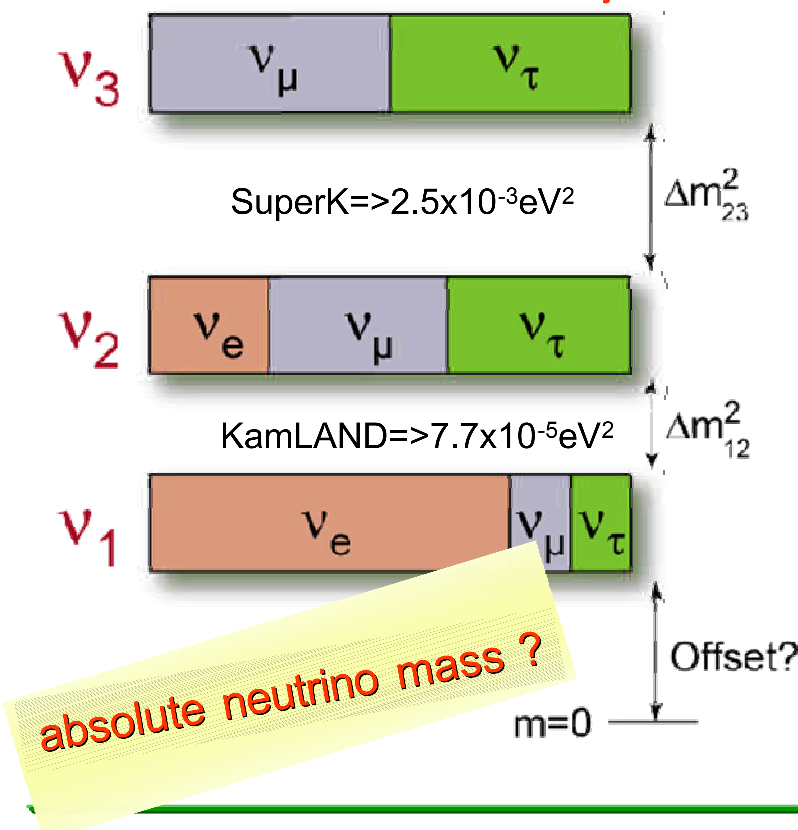
The Sensitivity of the KATRIN Neutrino Mass Experiment

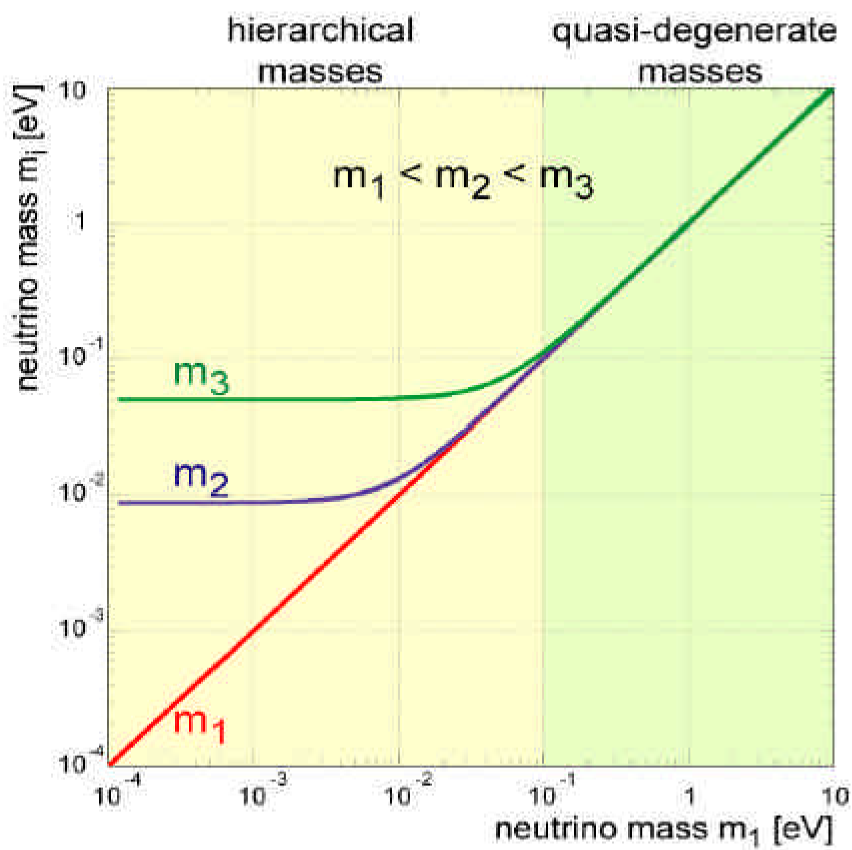
Joachim Wolf, University of Karlsruhe

- motivation for KATRIN
- principle of the measurement
- sensitivity of the spectrometer
- status, goals and schedule of KATRIN

Neutrino mass in particle physics

oscillation experiments measure D$m^2 = (m_i^2 - m_j^2)$





Neutrino mass in astrophysics

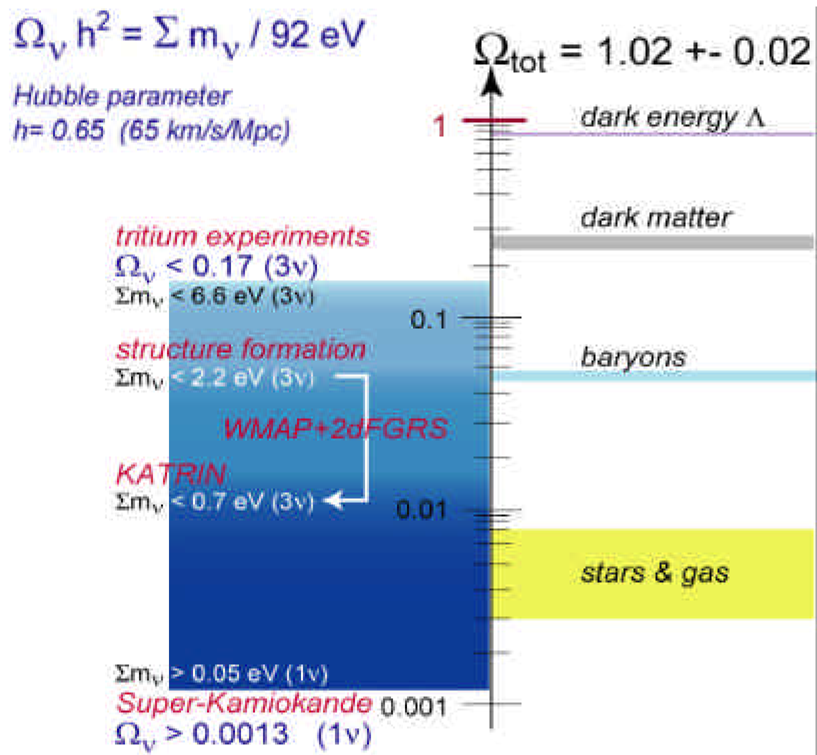
- CMB and large scale structures
  - WMAP + 2dFGRS + …

    $\Sigma m_\nu < 0.7$ eV (95% CL)

    (D.N. Spergel et al., astro-ph/0302209)
  - WMAP + 2dFGRS + …

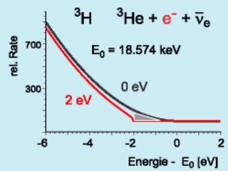
    $\Sigma m_\nu < 1.0$ eV (95% CL)

    (Hannestad, astro-ph/0303076)
  - …
- supernova neutrinos (tof)



Neutrino mass in nuclear physics: decay experiments

direct measurement:



tritium decay

$$m_\beta^2 = \sum |U_{ei}|^2 m_i^2$$

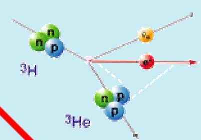
current sensitivity $m_\beta < 2.2$ eV (Mainz, Troistk)

future sensitivity $m_\beta < 0.2$ eV (KATRIN)

mass value independent of

Marojana or Dirac type

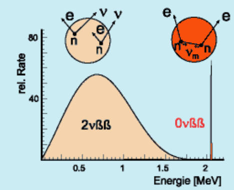
CP phases of U_{ei}



indirect measurement:

2β0ν decay

$$m_{ee} = \left| \sum U_{ei}^2 \; m_i \right|$$



$m_{ee} < 0.11$-0.56 eV **!** (Heidelberg-Moscow)

$m_{ee} < 0.05$ eV (CUORE,EXO,GENIUS,MOON)

requirements

marojana particle

no cancellations due to CP phases

COMPLEMENTARY MEASUREMENTS

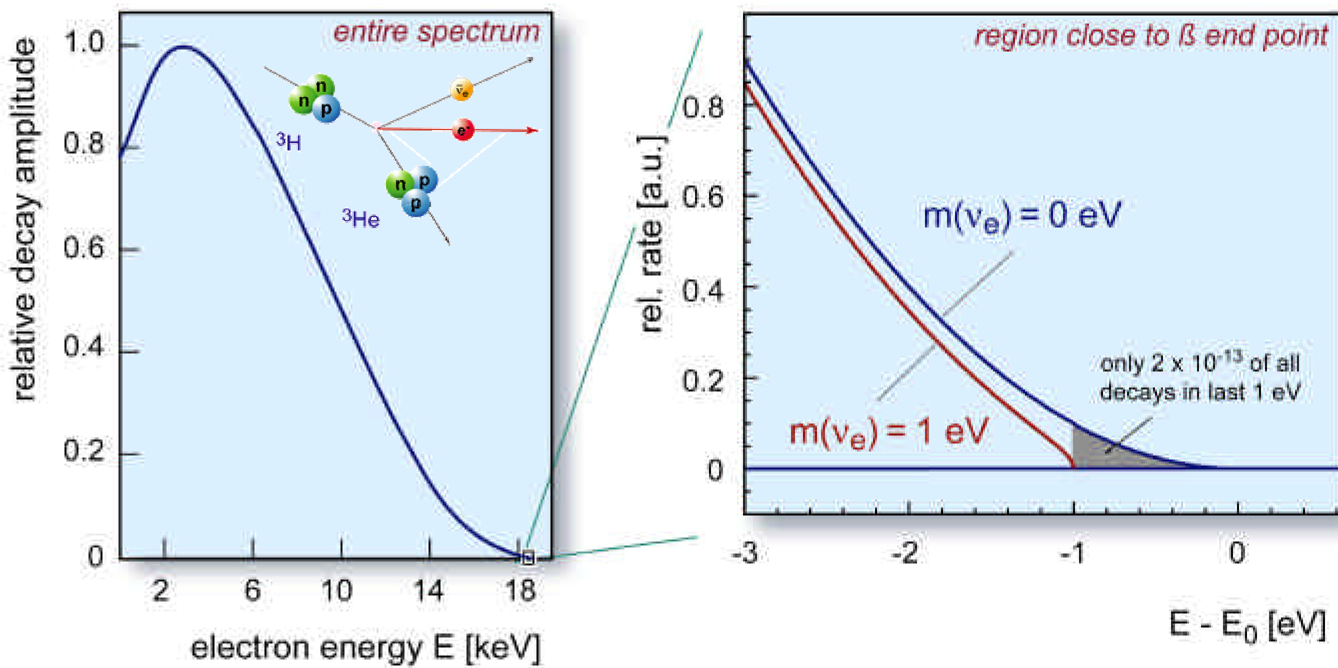
Tritium-b-decay and n-rest mass

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

superallowed

half life : $t_{1/2}$ = 12.32 a

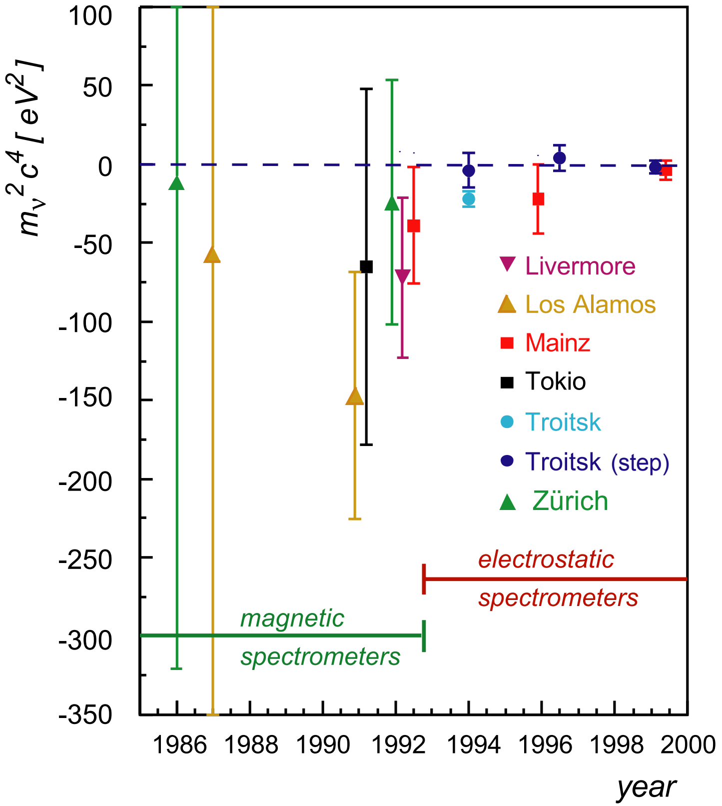
ß end point energy : E_0 = 18.57 keV



Tritium-b-decay experiments

	m_ν
ITEP *T_2 in complex molecule* *magn. spectrometer (Tret'yakov)*	17-40 eV
Los Alamos *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 9.3 eV
Tokio *T - source* *magn. spectrometer (Tret'yakov)*	< 13.1 eV
Livermore *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 7.0 eV
Zürich *T_2 - source impl. on carrier* *magn. spectrometer (Tret'yakov)*	< 11.7 eV
Troitsk (1994-2001) *gaseous T_2 - source* *electrostat. spectrometer*	< 2.2 eV
Mainz (1994-2001) *frozen T_2 - source* *electrostat. spectrometer*	< 2.2 eV

experimental results

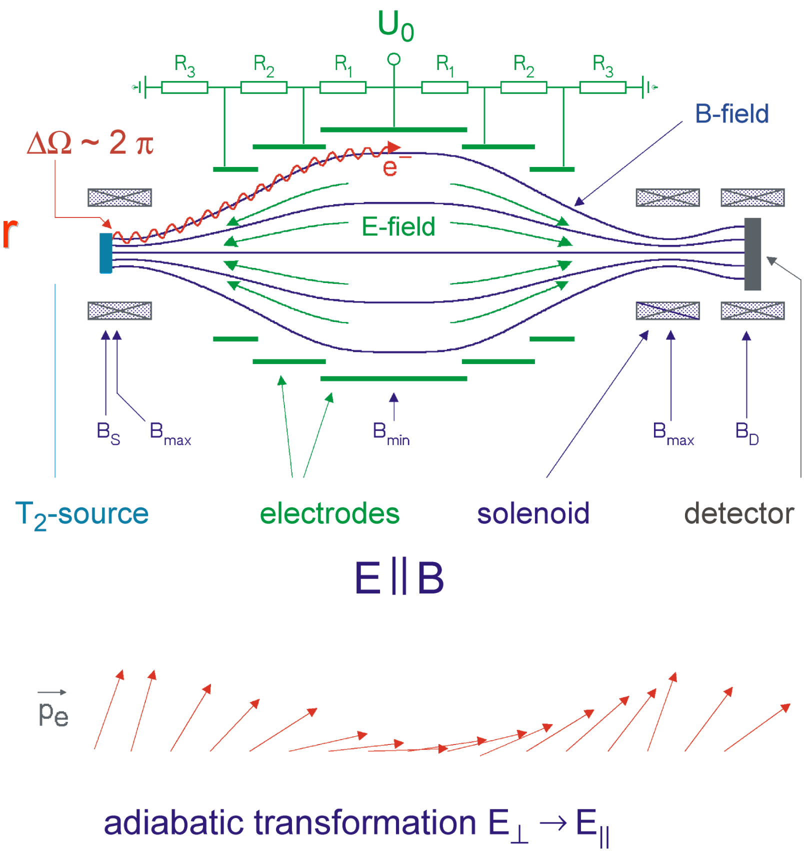


Principle of the electro-static spectrometer

- **adiabatically guided electrons** along magnetic fieldlines
- **electro-static filter:** transmission or reflection at the analysing plane
- ***integral energy spectrum***
- **energy resolution: 1eV**

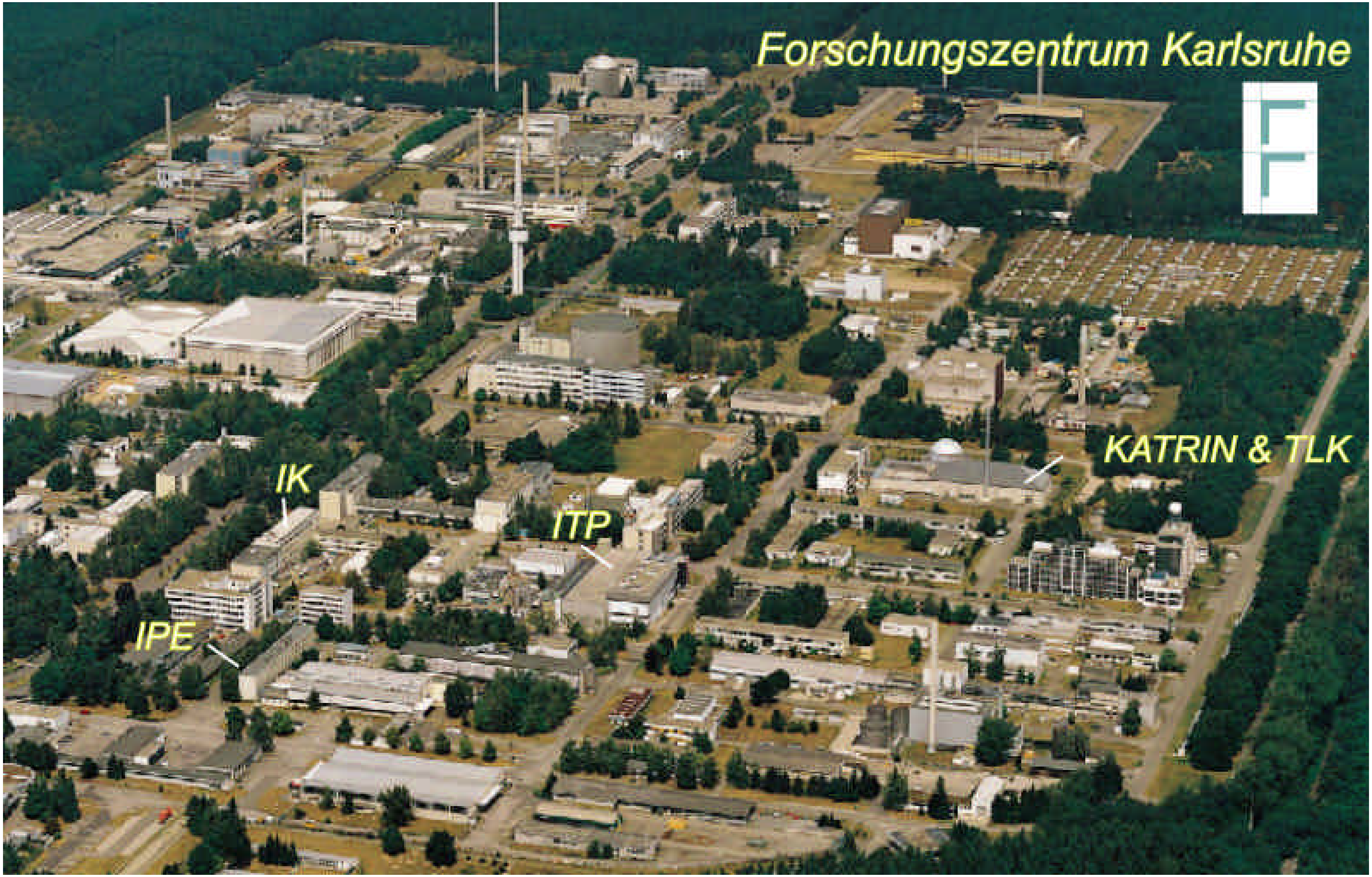
  $\Delta E/E = B_{min}/B_{max}$

  B_{max} = 3-6 T ; $B_{min} \leq 0.3$ mT
- **large solid angle**



KATRIN: KArlsruhe TRItium Neutrino experiment

- **Goal:** measurement of the ν mass with a sensitivity in the 0.2 eV range
- **International collaboration:** >65 members
- **measurement:** electro-static spectrometer with a gaseous tritium source

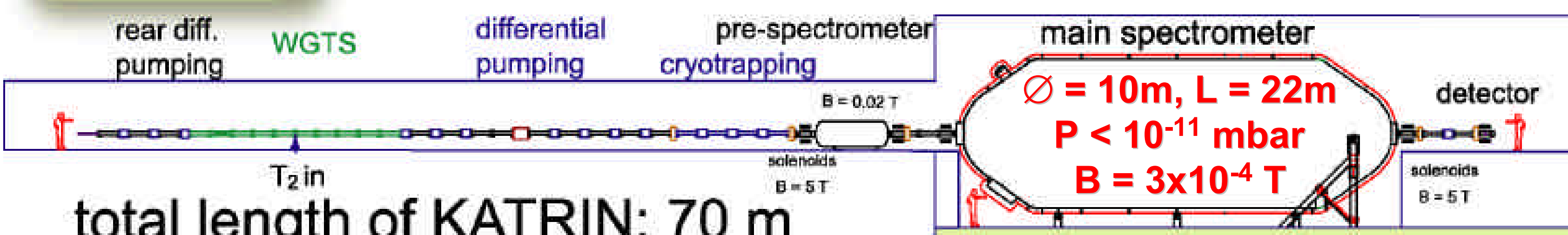

Forschungszentrum Karlsruhe
KATRIN & TLK
IK
ITP
IPE

Experimental Setup of KATRIN

- WGTS: Windowless Gaseous Tritium Source (95% purity)
- differential pumping section and cryo-section
- pre-spectrometer with electrodes
- main spectrometer with electrodes (ΔE = 1 eV)
- Si-detector

superconducting magnets guide β-electrons from the source to the detector

side view of KATRIN



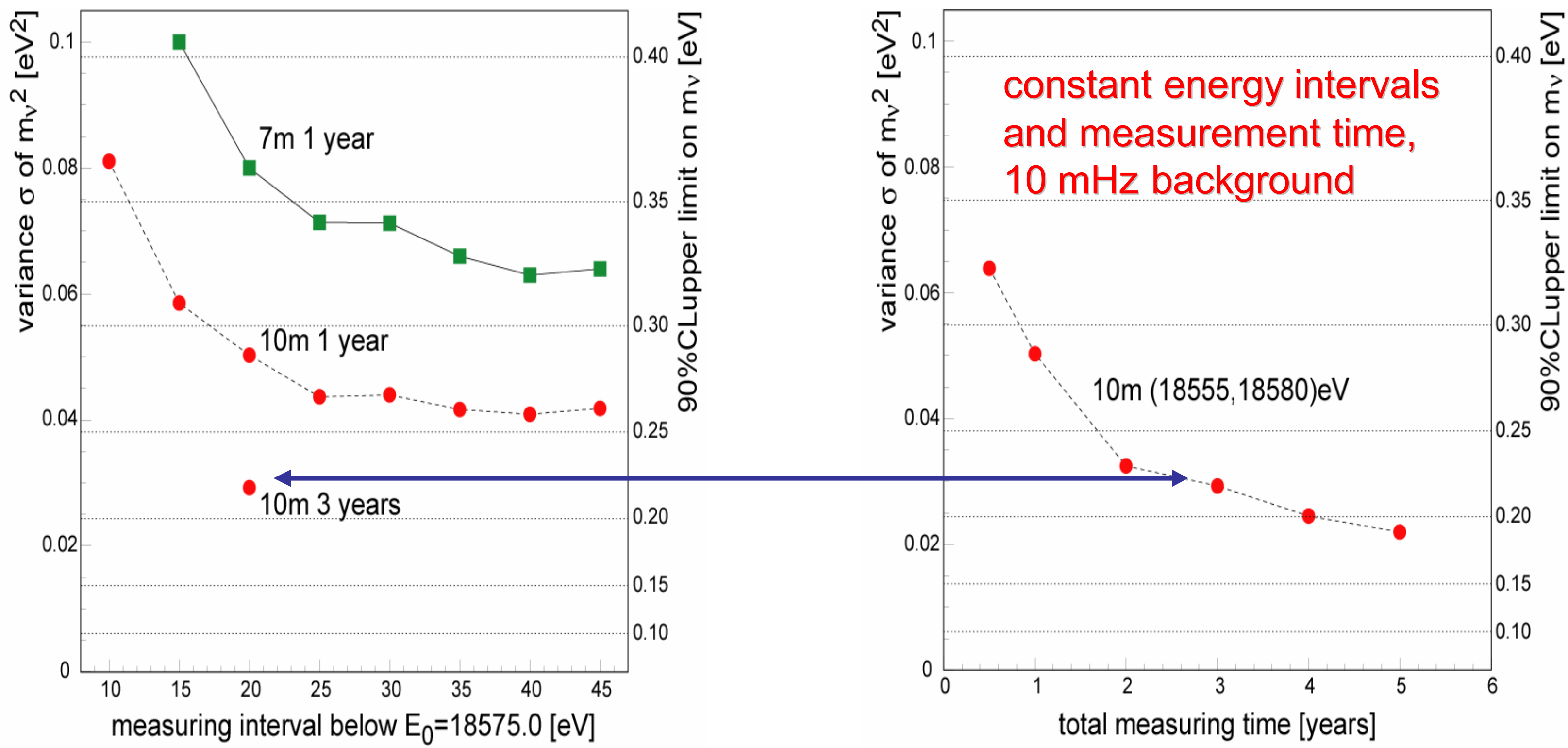
total length of KATRIN: 70 m

Improved Design Parameters

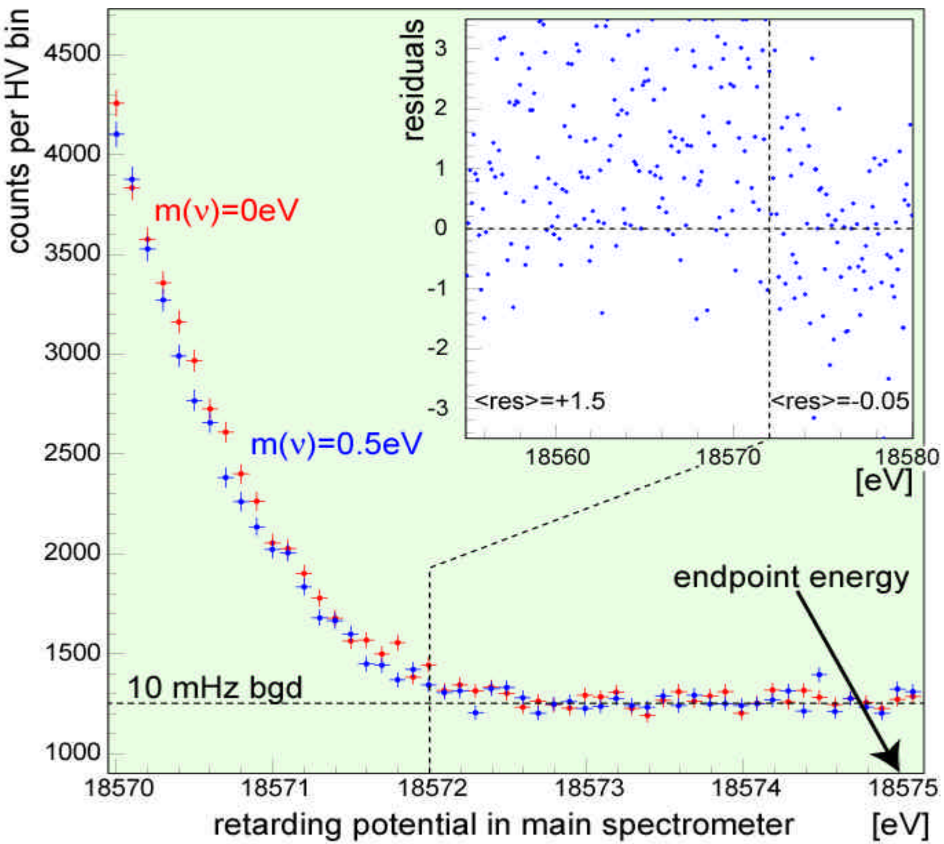
(compared to COSMO 2002)

- **Larger spectrometer tank (Æ 7 m ? Æ 10 m) and …**
- **… larger source diameter (70 mm ? 90 mm)**
  - higher tritium flux (x 1.7)
  - same energy resolution as in 7 m version ($\Delta E = 1$ eV)
  - smaller statistical error
  - same flux as in 7 m tank but $\Delta E = 0.5$ eV improves sensitivity only slightly
- **Optimized energy intervalls**
  - energy dependent energy and time intervalls
  - smaller statistical error
- **Monopole / dipole wire electrodes**
  - strong background reduction in first prototype measurements (Mainz)

Sensitivity on Neutrino Mass
(statistical error only)



Simulation of b spectra



KATRIN after:

1 year effect. meas.time,

10 mHz background,

[18555.0,18580] eV

in 0.1 eV – steps

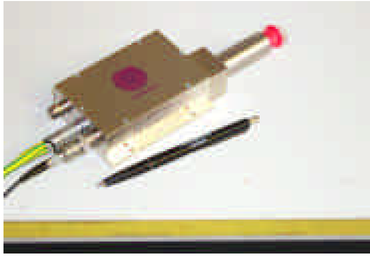
10m main spectrometer

Systematic Error

- **Influence of systematic uncertainties on sensitivity under detailed investigation**
- **Total systematic error after 3 years of data taking should be about the same size as the statistical error**
- **Possible sources of systematic errors:**
  - Energy loss due to excitation of the daughter molecule
  - Energy loss due to inelastic scattering on gas molecules in the source
  - Density profile in the source; space charge within the source
  - T_2-purity (T2, TH, H_2)
  - HV fluctuations
  - Stability of the background rate
  - …

Status of KATRIN Activities

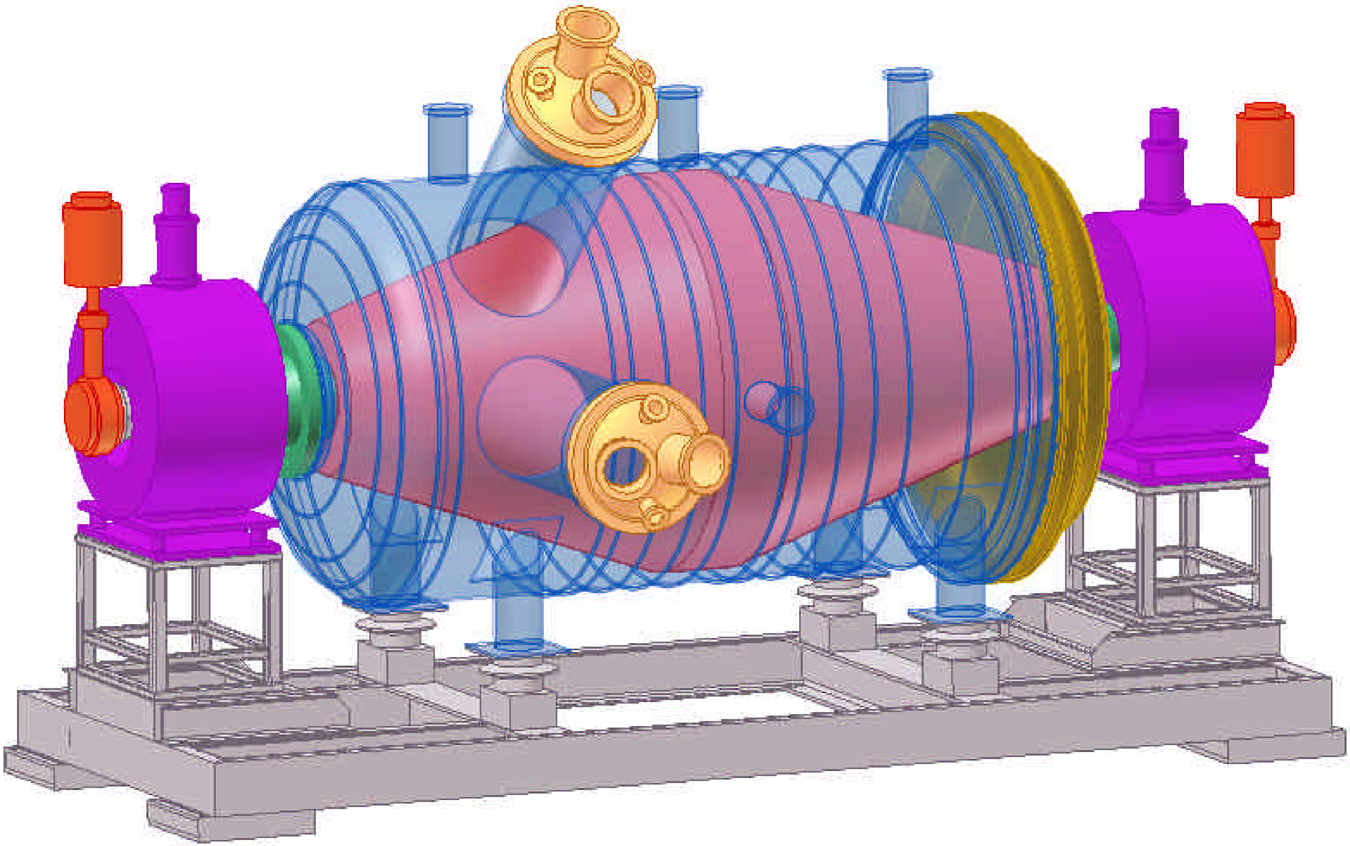
- **Si-detector** (tests with e-gun and X-ray sources)
- **DAQ** (pre-spectrometer tests)
- **Slow Control System** (pre-spectrometer tests)
- **Main spectrometer** (design studies)
- **Pre-spectrometer** (under construction, prototype for main spectrometer)
- **High voltage** (pre-spectrometer tests)
- **Electrodes** (monopole and dipole electrodes in Mainz spectrometer)
- **Superconducting magnets** (first magnets ordered for pre-spectrometer)
- **Differential pumping section** (design studies, simulations)
- **Tritium source** (Raman spectroscopy)
- **Calibration** (development of sources and e-guns)
- **Simulation** (influence of systematic effects, meas. strategy)



KATRIN Pre-Spectrometer

- **First vacuum tests with 300 l tank:**
  - 10^{-11} mbar (2002-2003)
- **Delivery to FZK: Sep. 2003**
  - ∅ = 1.7 m, L = 3.5 m
  - super-cond. magnets
- **Vacuum tests: 2003/4**
  - goal: < 10^{-11} mbar
  - pumps: Getter, TMPs
  - baking: 350°C
  - outgassing < 10^{-13} mbar l/s cm^2
- **Electro-mag. tests: 2004**
  - electrodes and magnets
  - e-gun and Si-detector
  - background suppression

Pre-Spectrometer Prototype Setup



Goals and Schedule of KATRIN

KATRIN sensitivity after 3 years of measuring:

- sensitivity: $m_\nu < 0.2$ eV (90%CL)
- discovery potential: $m_\nu = 0.35$ eV with 5σ ($m_\nu = 0.3$ eV with 3σ)
- statistical and systematic uncertainties contribute about equally

KATRIN schedule:

- since 2001: prototype studies to improve:
  - background suppression (Mainz, Troitsk)
  - vacuum (< 10^{-11} mbar)
  - e-m design and calibration (electrodes, magnets, e-gun)
  - Si-detector (SDD, APD, PIN)
- September 2003: delivery of the pre-spectrometer
- 2005/2006: construction of the main spectrometer
- 2007: start of measurements

KATRIN Collaboration

K. Essig, B. Müller, T. Thümmler, C. Weinheimer
Universität Bonn, Helmholtz Institut für Strahlen- und Kernphysik

A. Osipowicz
Fachhochschule Fulda, FB Elektrotechnik

H. Blümer, L. Bornschein, L. Huianu, T. Kepcija, J. Reichenbacher, J. Wolf
Universität Karlsruhe, Institut für Experimentelle Kernphysik

G. Drexlin, K. Eitel, R. Gumbsheimer, H. Hucker, G. Meisel, P. Plischke, F. Schwamm, M. Steidl
Forschungszentrum Karlsruhe, Institut für Kernphysik

A. Beglarian, H. Gemmeke, S. Wüstling
FZ Karlsruhe, Institut für Prozeßdatenverarbeitung u. Elektronik

C. Day, R. Gehring, V. Hauer, K.-P. Jüngst, P. Komarek, W. Lehmann, H. Neumann, M. Noe, J. Pitel
Forschungszentrum Karlsruhe, Institut für Technische Physik

B. Bornschein, L. Dörr, M. Glugla
Forschungszentrum Karlsruhe, Tritium Labor Karlsruhe

J. Bonn, F. Glück, B. Flatt, C. Kraus, E.W. Otten, J.-P. Schall
Universität Mainz, Institut für Physik (EXAKT)

V.N. Aseev, E.V. Geraskin, O. Kazachenko, V.M. Lobashev, B.E. Stern, N.A. Titov, S.A. Zadorozhny, Y. Zakharov
Russ. Akademie der Wissenschaften, INR Troitsk

O. Dragoun, J. Kaspar, A. Kovalik, M. Rysavy, A. Spalek, D. Venos
Tschech. Akademie der Wissenschaften, NPI, Rez / Prag

D.L. Wark
Rutherford-Appleton Laboratory, Chilton

P.J. Doe, J. Formaggio, R.G.H. Robertson, J.F. Wilkerson
University of Washington, Seattle

M. Charlton, A.J. Davies, H.H. Telle
University of Wales, Swansea

J. Herbert, O. Malyshev, K. Middleman, R. Reid
ASTeC, CCLRC Daresbury Laboratory