The KATRIN Neutrino Mass Experiment

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(KATRIN Collaboration)

- First evidence for massive neutrinos from oscillation searches:
  - atmospheric neutrinos (disappearance)
  - solar neutrinos (disappearance, full NC flux)
  - accelerator neutrinos (hints from K2K, LSND)
- Only Δm^2 known
- Absolute mass measurement needed
  - indirect: neutrinoless double beta decay
  - direct: beta decay

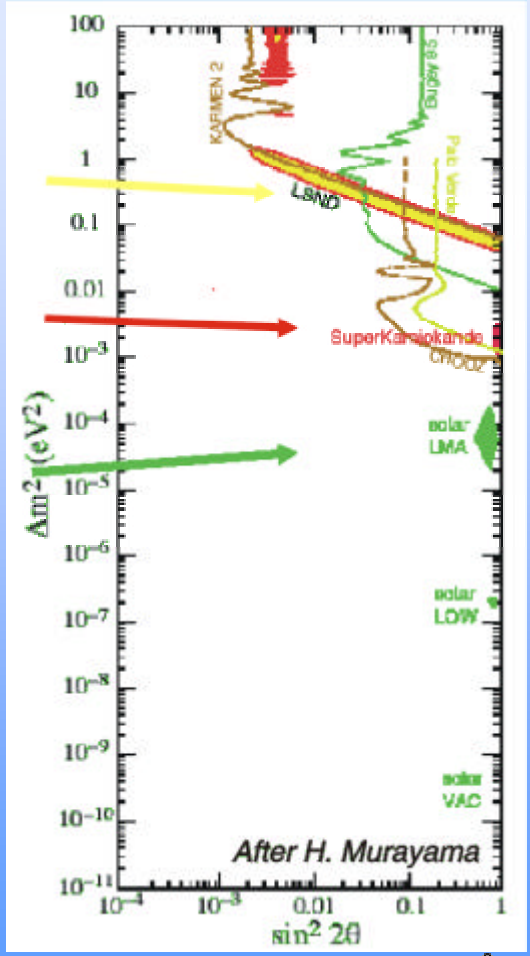
Neutrino-Oscillation Results

- atm. and solar n provide compelling evidence for flavour oscillation
- large mixing angles, unlike quark sector (CKM)
- oscillation measures only
  $Dm_{ij}^2 = m_i^2 - m_j^2$
- oscillation results yield LOWER BOUND on m_n:
  - m_{atm} > 50 meV
  - m_{sol} > 7 meV
  - m_{LSND} > 200 meV

$\bar{\nu}_\mu \Rightarrow \nu_s \Rightarrow \bar{\nu}_e$

$\nu_\mu \Rightarrow \nu_\tau$

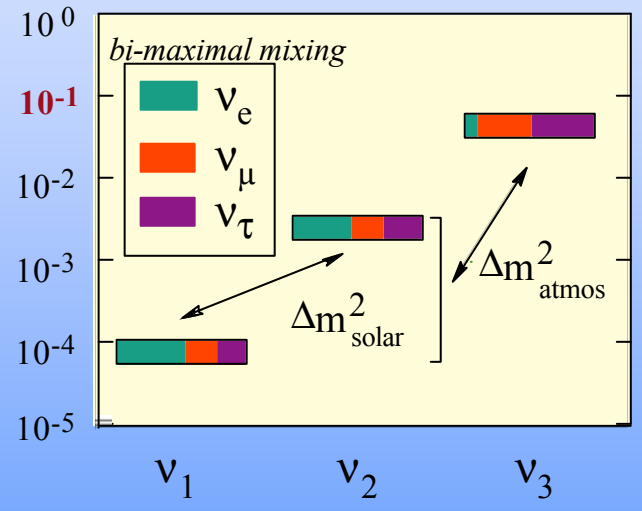
$\nu_e \Rightarrow \nu_{\mu\tau}$



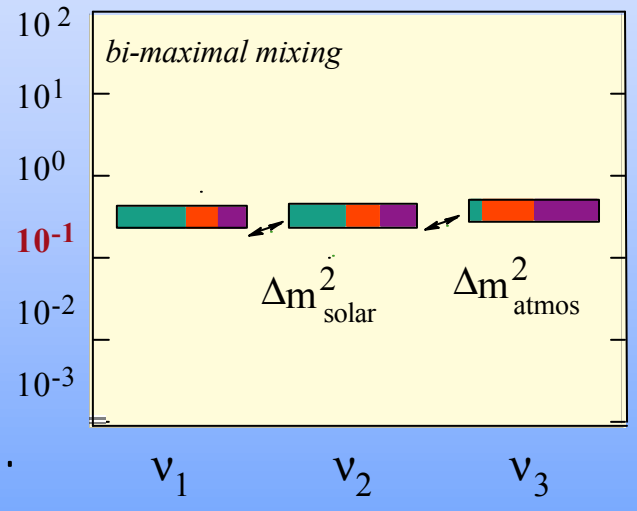
Neutrino Mass Schemes

are neutrino masses hierarchical or degenerate ?

hierarchical scenarios



degenerate scenarios



Δm_{ij}^2-values and mixings $\sin^2 2\theta_{ij}$ measured by ν-oscillation experiments

need absolute mass scale of neutrinos

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Neutrino Mass Meassurements

direct measurement

indirect measurement

Laboratory

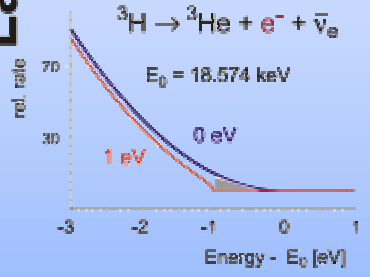
tritium-ß-decay : m_ν

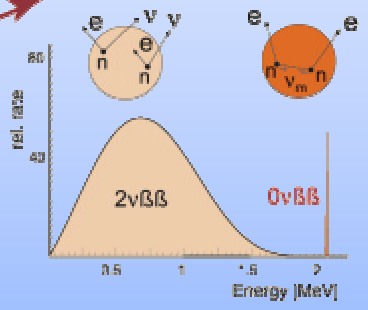
status 2001 : m_ν < 2.2 eV (95% CL.)
potential 2010 : m_ν < 300 meV (90% CL.)
exp. : KATRIN, µ-calorimeter(?)

0νßß-decay : ‹ m_ν ›

status 2002 : ‹m_ν› = 0.11- 0.56 eV (2.2 σ)
potential 2010 : ‹m_ν› < 20-50 meV (90% CL.)
exp. : ^{76}Ge (Genius Majorana), ^{136}Xe (EXO), ^{100}Mo (MOON)

m_ν ‹m_ν›





neutrino mass measurements - status and perspectives

m_ν Σm_i

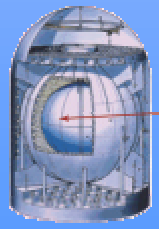
Universe

astrophysics : ν_e, ν_μ & ν_τ

status 2000 : m_ν < 23 eV
potential 2010 : m_ν < ~ 1 - 5 eV
exp. : Super-K, SNO, OMNIS

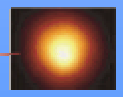
cosmology : Σm_i

status 2000 : Σm_i < 1.8-2.2 eV
potential 2010 : Σm_i < ~ 0.65 eV
exp. : MAP, Planck, SDSS,
} model-dependent

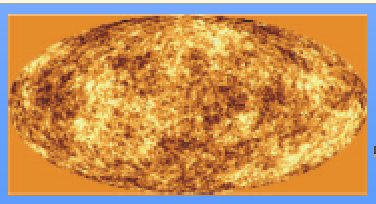


ν

SN200x(?)-ν-ToF



SN20xx



CMB (Planck)

Tritium

KATRIN

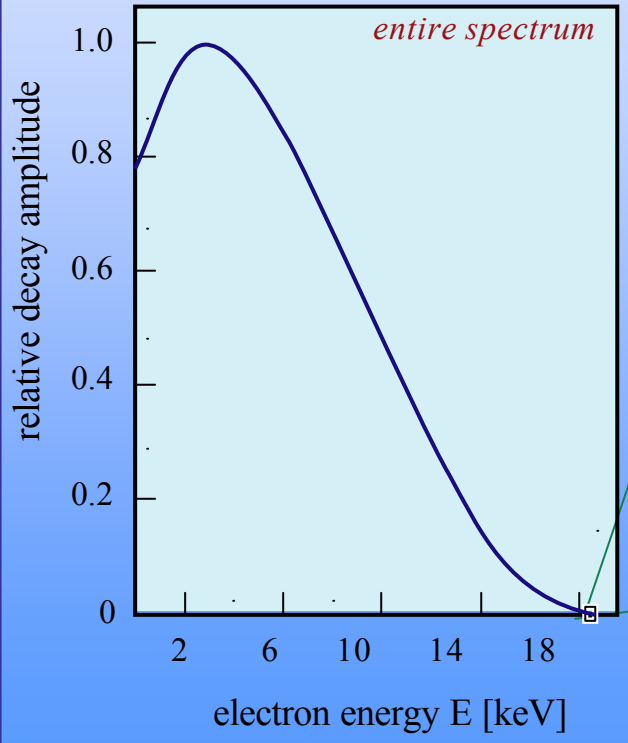
Tritium b-Decay and n rest mass

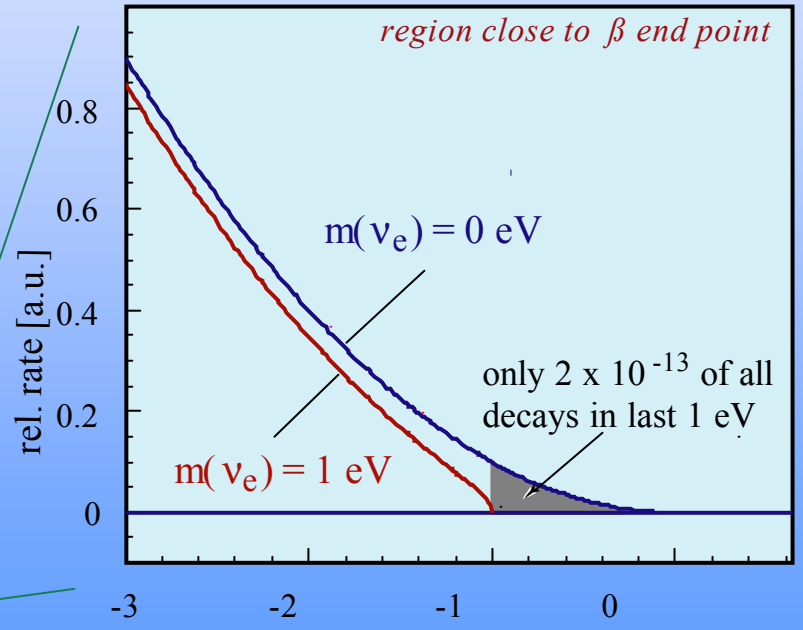
$$^{3}H \rightarrow {}^{3}He + e^{-} + \bar{\nu}_e$$

superallowed

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

ß end point energy : E_0 = 18.57 keV





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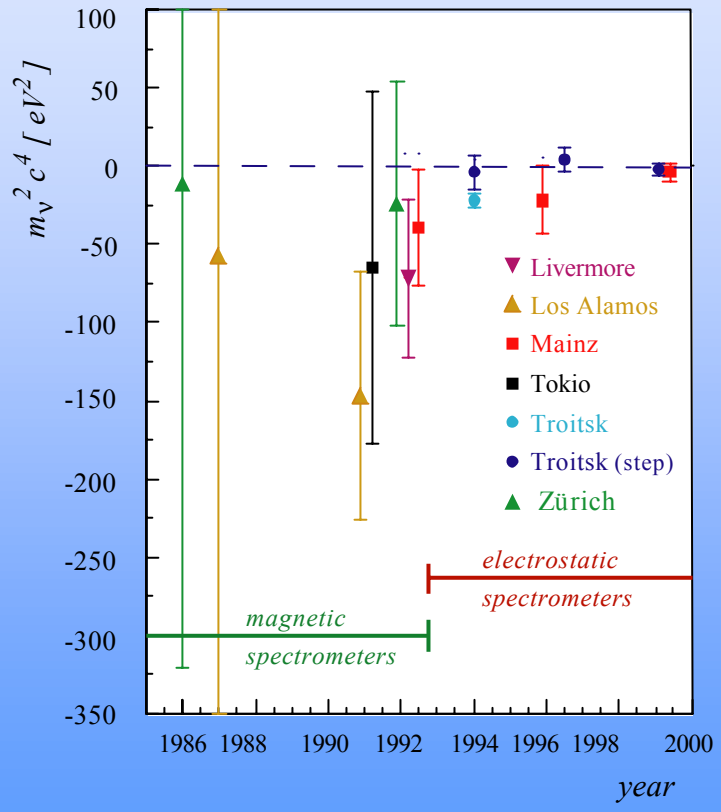
Tritium b-Decay Experiments

	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

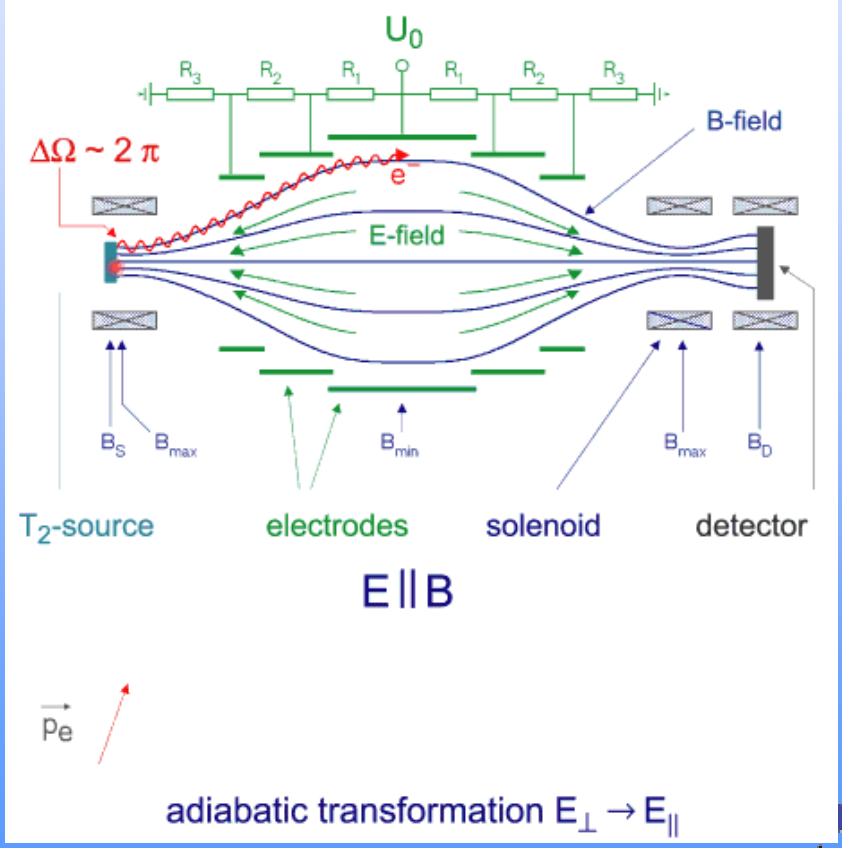
guiding by magnetic fields
(*magnetic adiabatic collimation*)
$\Delta\Omega \sim 2\pi$

electric (retarding-) field :
analysis of electron energies
(*electrostatic filter*)
integral transmission : $E > U_0$

$$\vec{F} = (\vec{\mu} \cdot \vec{\Delta})\,\vec{B} + q\,\vec{E}$$

$$\mu = E_{\perp} / B = \text{const}$$

adiabatic motion



Planning the next-generation direct n mass experiment

experimental observable in ß-decay is m_n^2

aim : improvement of m_n by one order of magnitude (3 eV ® 0.3 eV)

requires : improvement of m_n^2 by two orders of magnitude (9 eV^2 ® 0.09 eV^2)

improve statistics :

- stronger tritium source (factor 40) (& larger analysing plane)
- longer measuring period (~100 days ® ~1000 days)

improve energy resolution :

- large electrostatic spectrometer with D E=1 eV (factor 4 improvement)

but : count rate close to ß-end point drops very fast (~ d E^3)

last 10 eV : 2 x 10^{-10}

last 1 eV : 2 x 10^{-13}

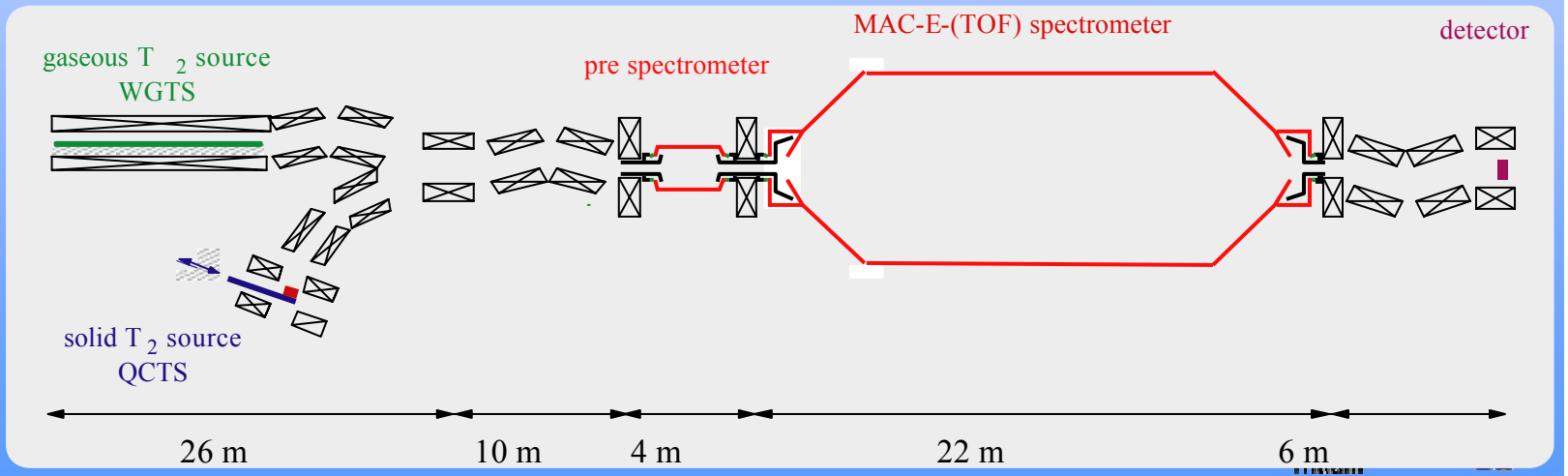
of total ß-intensity

Karlsruhe Tritum Neutrino Experiment KATRIN

next-generation experiment with sub-eV neutrino mass sensitivity

FH Fulda - FZ & U Karlsruhe - U Mainz - INP Prague - U Seattle - INR Troitsk - U Wales

high luminosity	*background suppression*	*high energy resolution*	*control of systematics*
molecular tritium source	pumping	pre-filter	energy analysis	ß-electron counting



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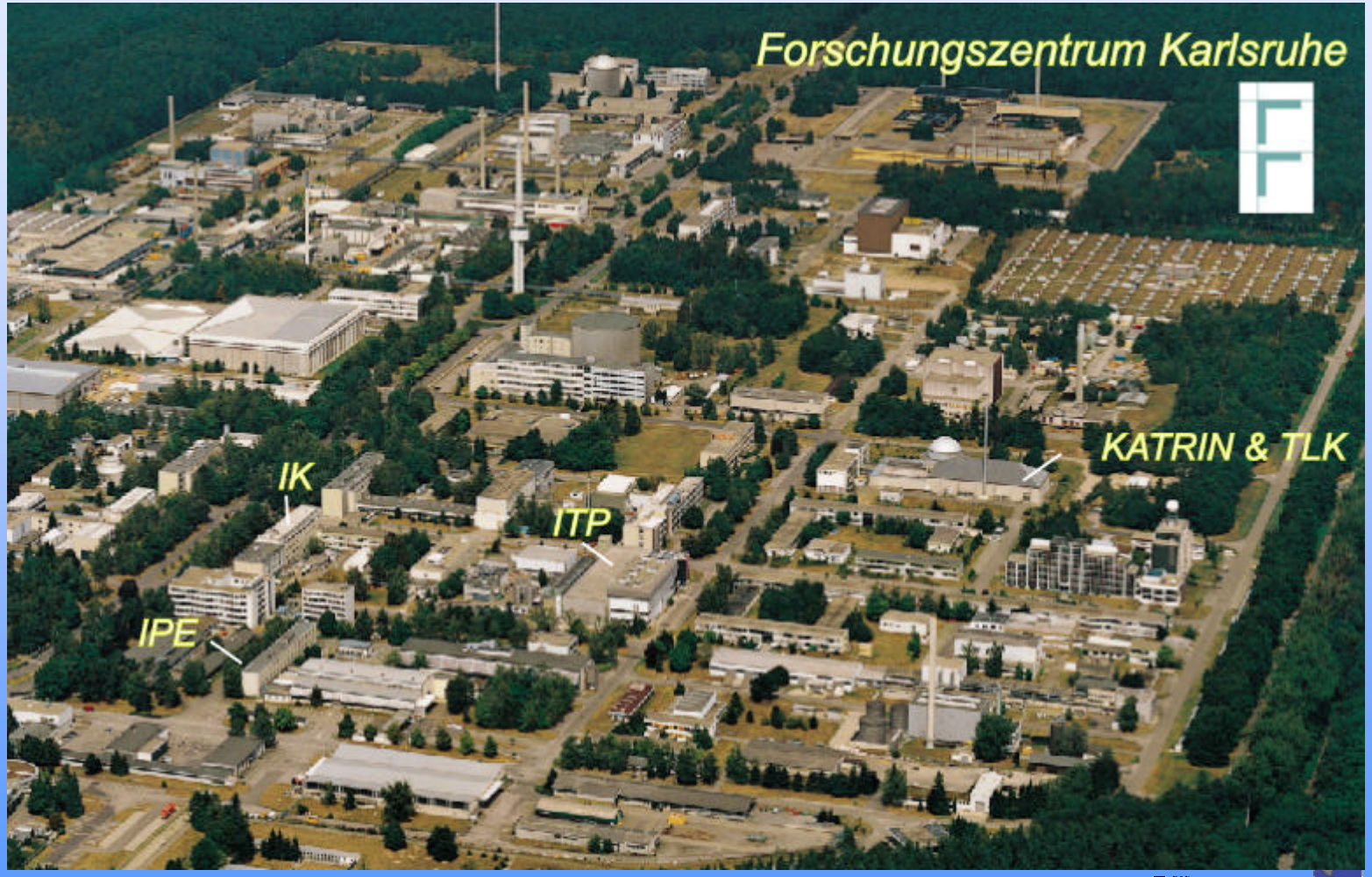
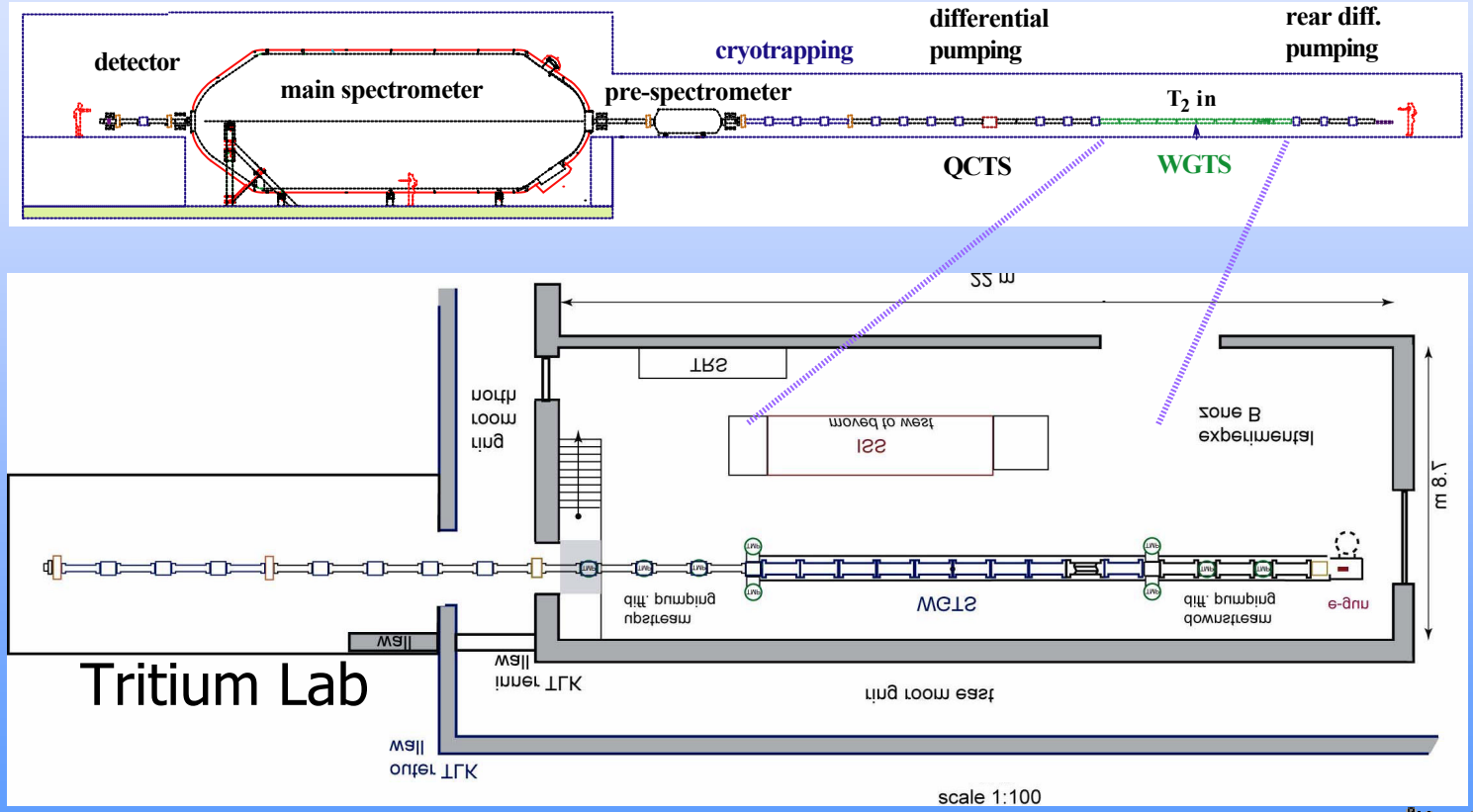
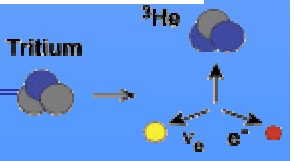

Forschungszentrum Karlsruhe
KATRIN & TLK
IK
ITP
IPE

Tritium

Setup of the KATRIN Experiment





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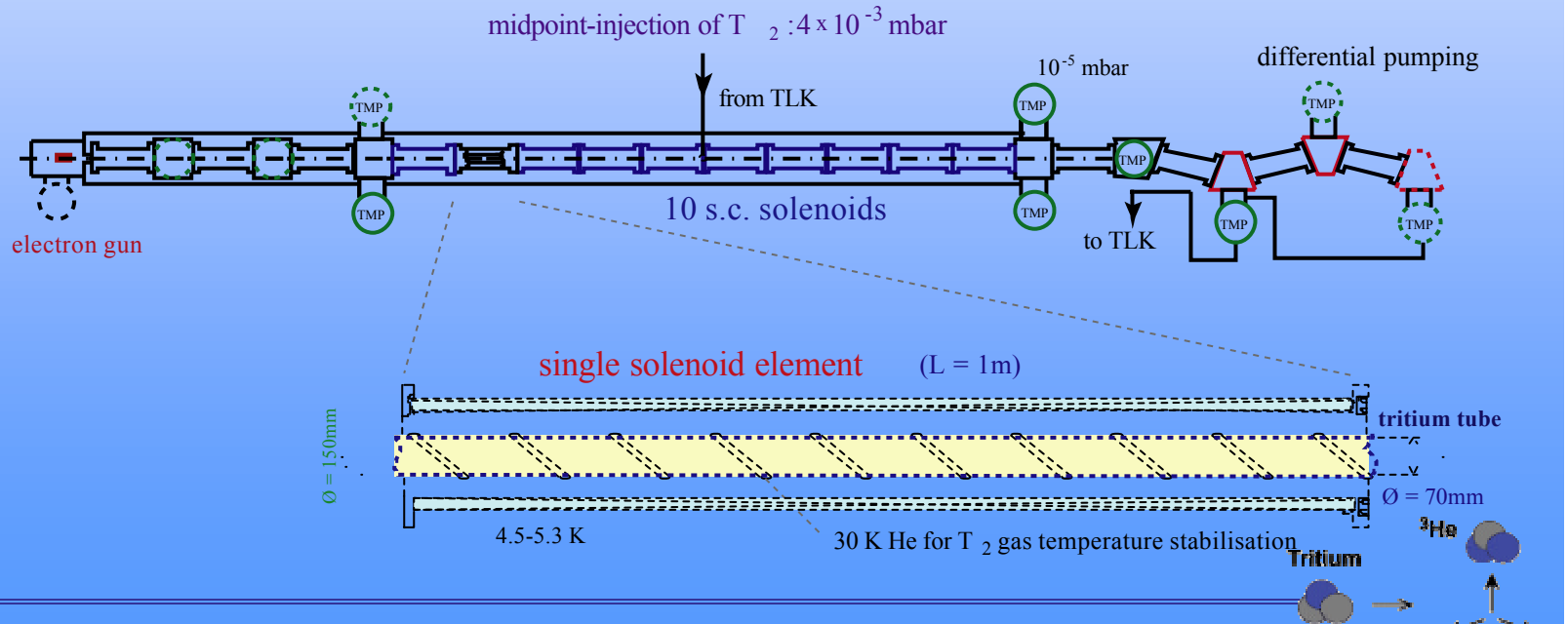
WGTS - Windowless Gasous Tritium Source

WGTS : maximum T_2 luminosity & smallest possible systematic errors
adiabatic electron transport in strong magnetic field & tritium diffusion

source parameters : L = 10 m, Ø = 70 mm, B_S = 6 T, gas purity > 99.5% T_2
T = 30 K (± 0.2°), column density ρd : 5 x 10^{17} T_2 / cm^2



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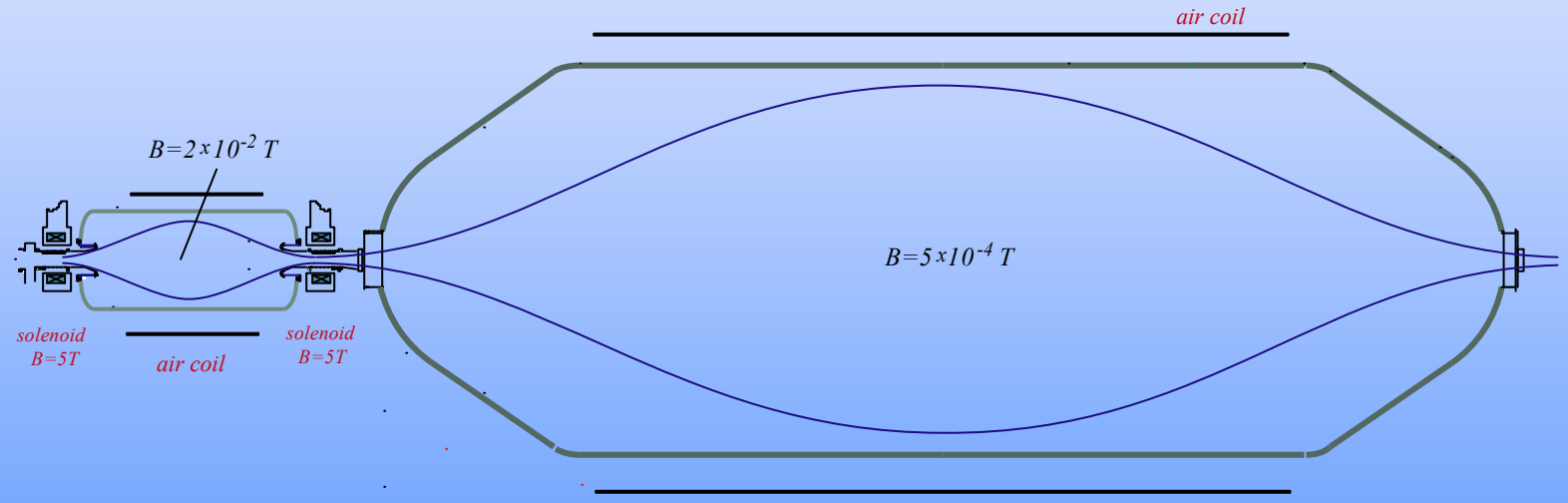
Electrostatic Spectrometers Properties and Geometry

electrostatic analysis of tritium ß-decay electrons (electrode system)

XUHV - conditions : $p < 10^{-11}$ mbar (degassing rate 10^{-13} mbar l / cm ² s)



pre-spectrometer

fixed retarding potential 18.4 kV

Ø = 1.7 m / L = 3.4 m

ΔE = 80 eV

main spectrometer

variable retarding potential 18.5-18.6 kV

Ø = 7-10 m / L = 20 m

ΔE = 1 eV

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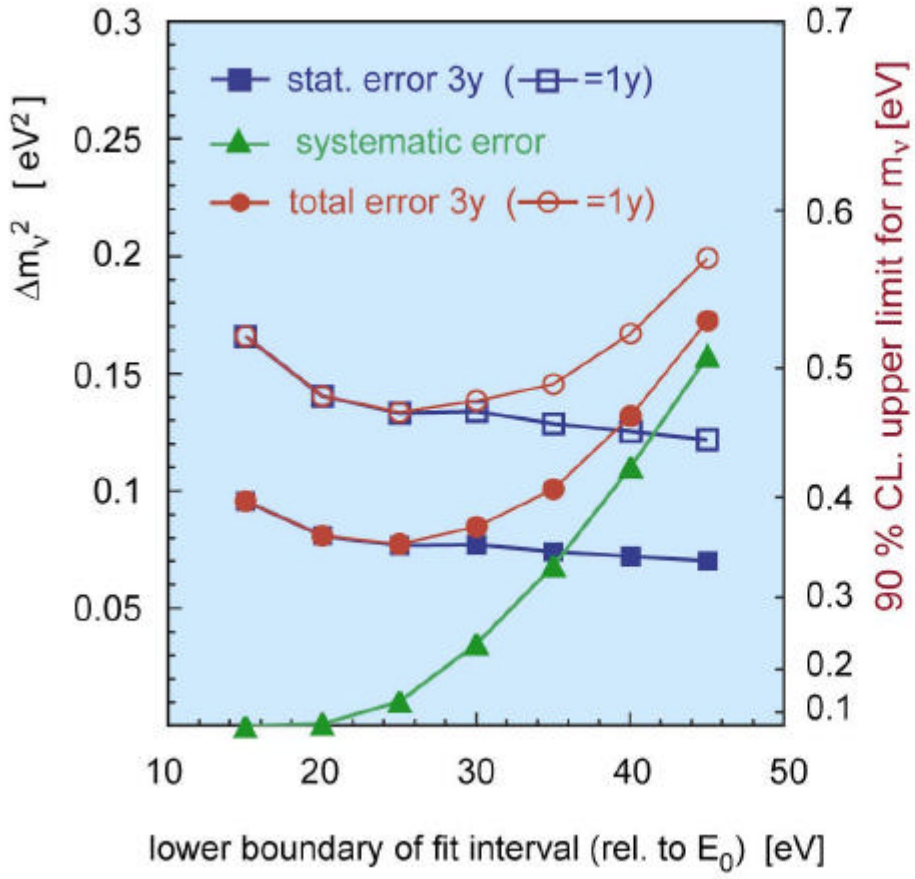
Estimates of KATRIN Sensitivity for m_n



assumptions for simulation:

ΔE = 1 eV (spectrometer)

background rate = 11 mHz

WGTS : $\rho d = 5 \times 10^{17} / cm^2$

area = 29 cm^2

max. accepted angle 51°

systematic error :

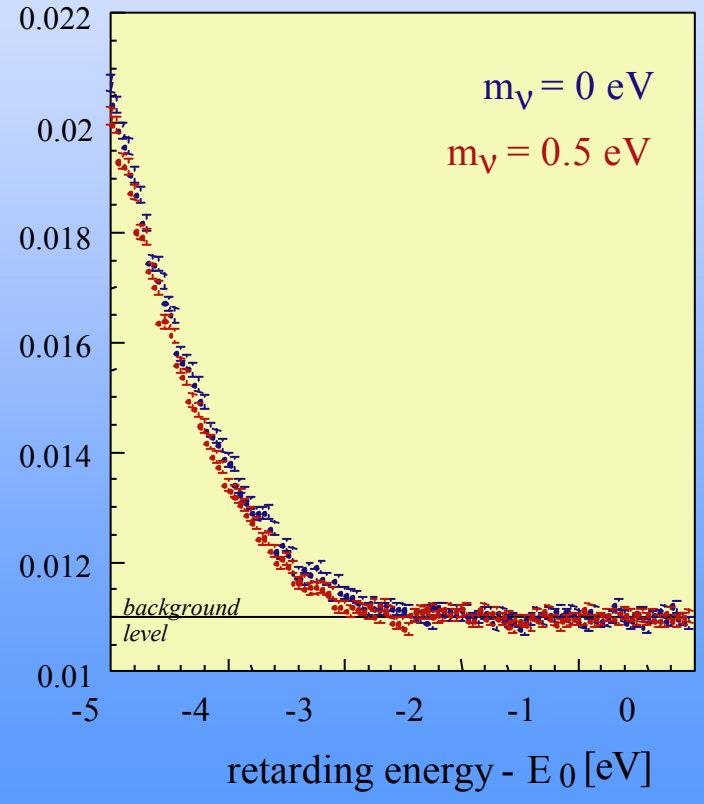
2% energy loss in WGTS

$m_\nu < 0.35$ eV (90% CL.)

Estimated KATRIN sensitivity

realistic MC simulation of sub-eV n -mass signal close to sensitivity limit

narrow interval close to b end point (last 5 eV) from WGTS



input paramters for simulation :

measuring time : 3 years

DE = 1 eV (spectrometer)

background rate = 11 mHz

WGTS :
column density 5 x 10^{17} / cm^2

max. accepted angle 51°

molecular excitations included

Conclusions and Outlook

- **KATRIN: a next generation tritium ß-decay experiment with sensitivity to a sub-eV electron neutrino mass**

- **motivations:**
  - cosmology (neutrino HDM)
  - particle physics (mass models)
- **many technological challenges**
- **strong international collaboration has formed**
- **2002 : first vacuum tests at Karlsruhe**
- **2006/7: first measurements with KATRIN**
- **running time ~ 5 years**