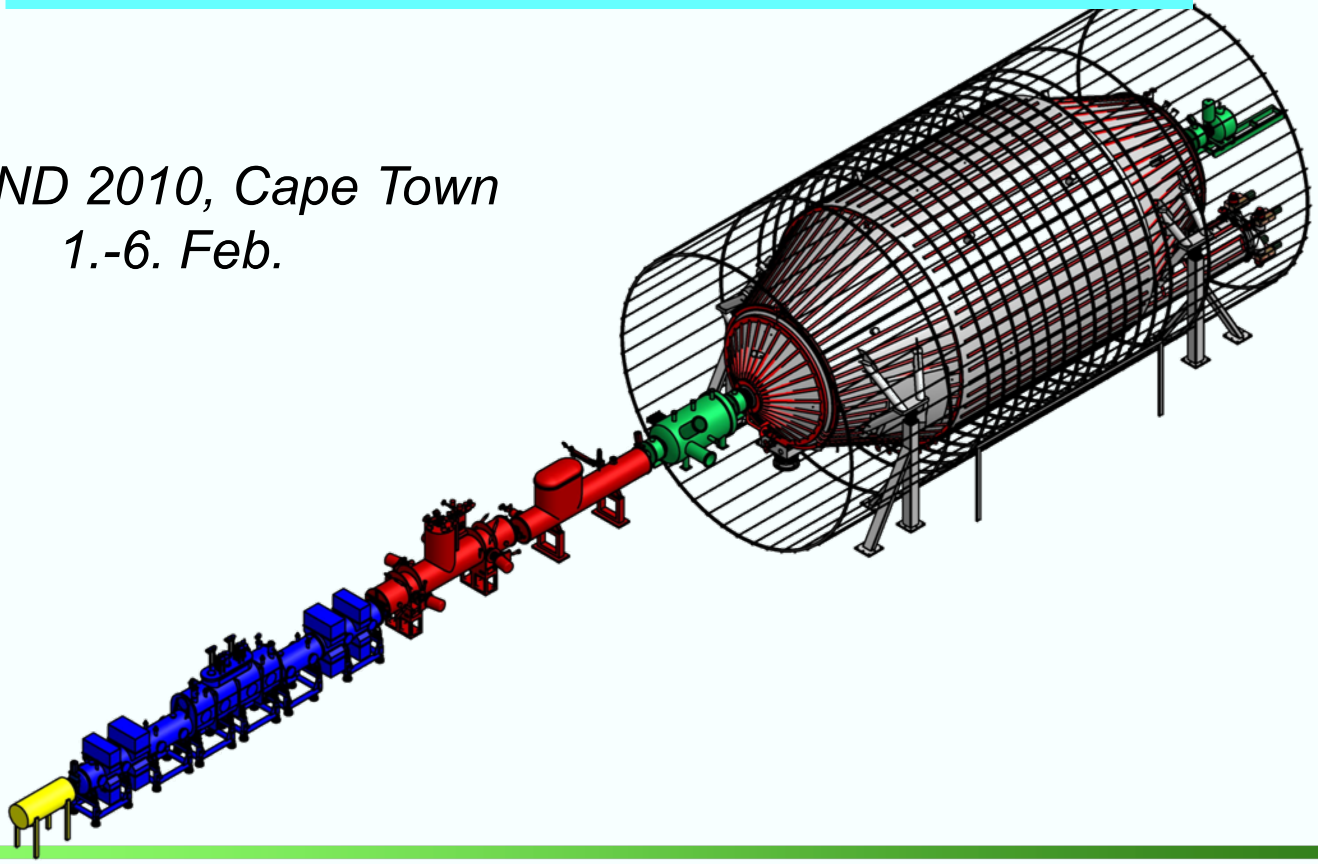
The KATRIN experiment

Karlsruhe Tritium Neutrino

Alexander Osipowicz (KATRIN Collaboration)

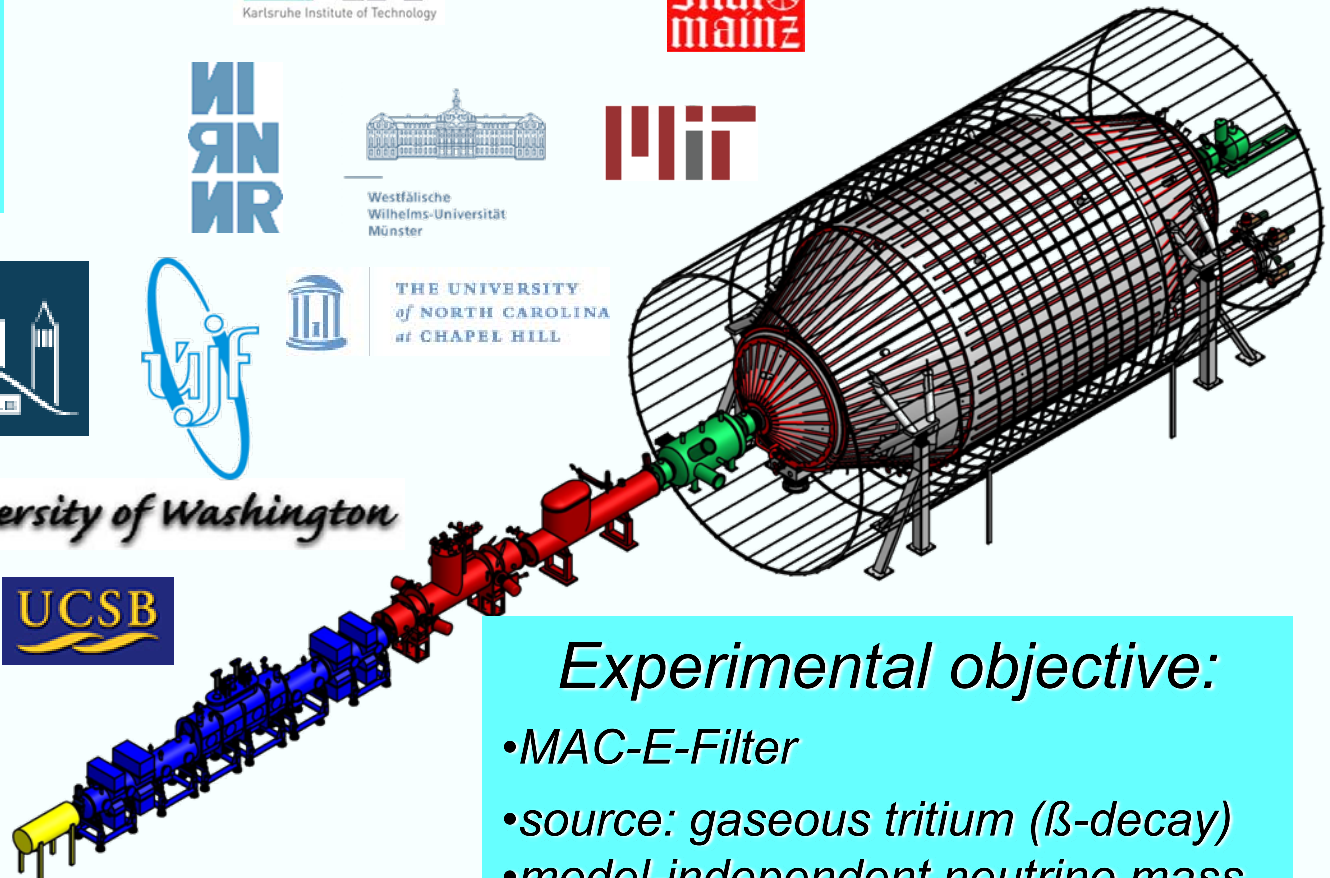
BEYOND 2010, Cape Town
1.-6. Feb.



The KATRIN experiment

Collaboration

- 120 scientists
- 5 countries
- 14 institutions

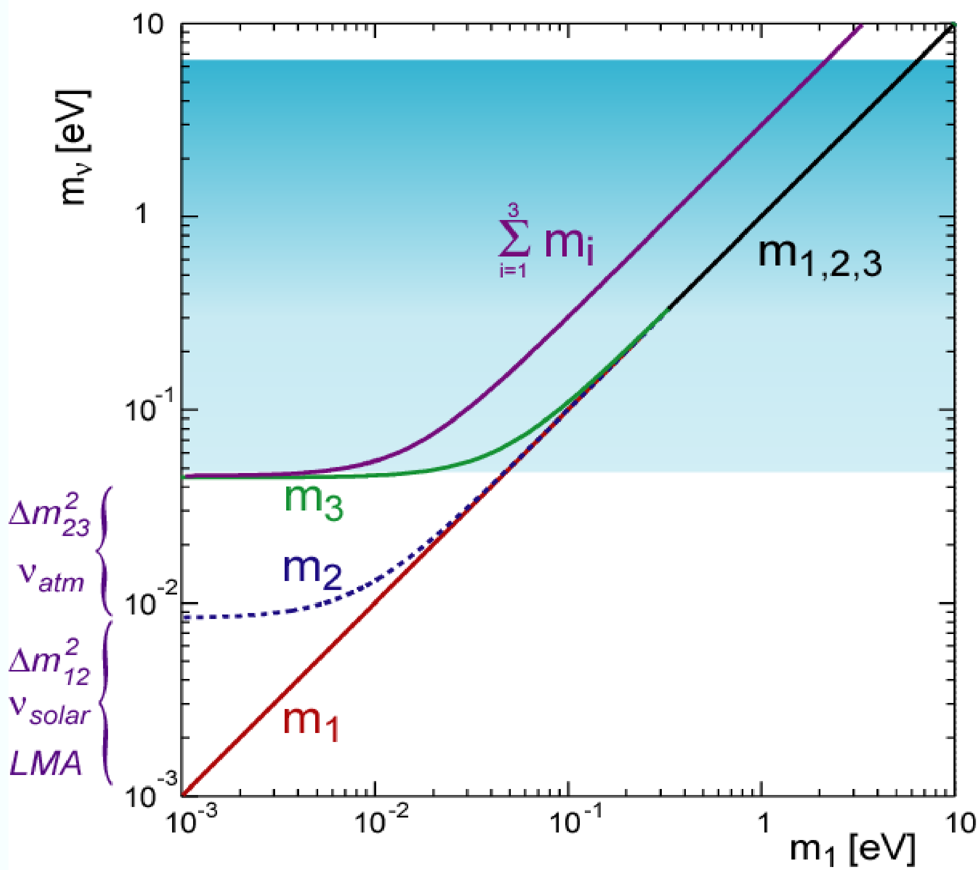


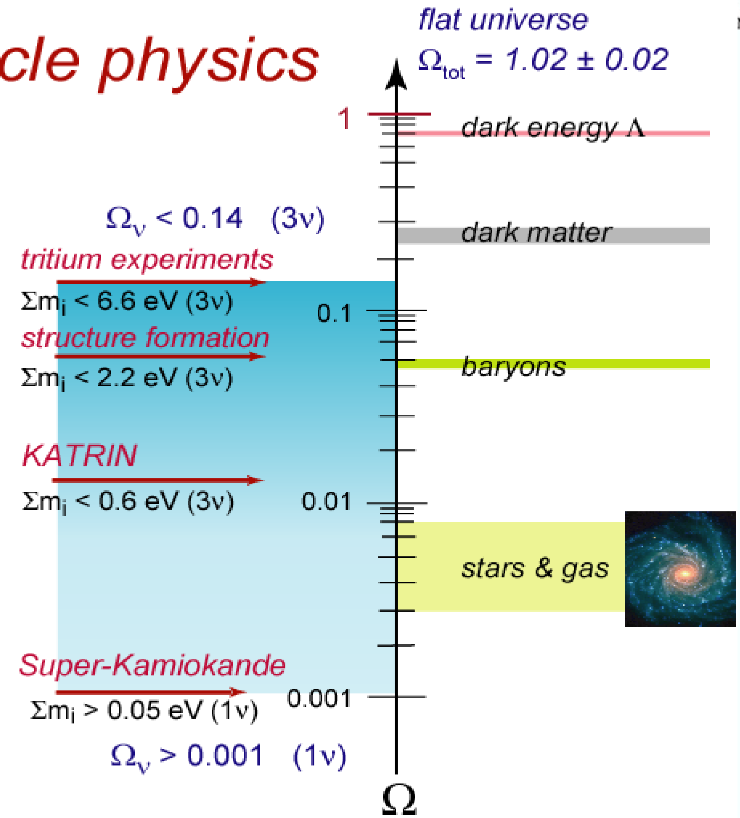
Experimental objective:

- MAC-E-Filter
- source: gaseous tritium (ß-decay)
- model-independent neutrino mass
- sensitivity: 0.2 eV/c²

ν-masses in cosmology & particle physics

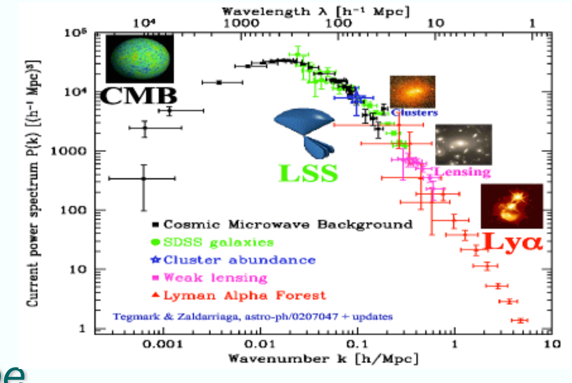
neutrino mass and hot dark matter





$$\Omega_\nu h^2 = \Sigma m_\nu / 93.5 \text{ eV}$$

How to determine the neutrino mass scale ?

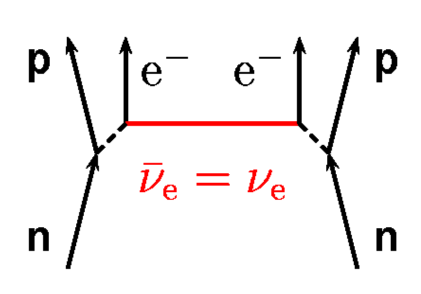


1) Cosmologycal observations

very sensitive, but model dependent
current sensitivity: $\Sigma m(\nu_i) \approx 0.4 - 2$ eV

2) Search for $0\nu\beta\beta$

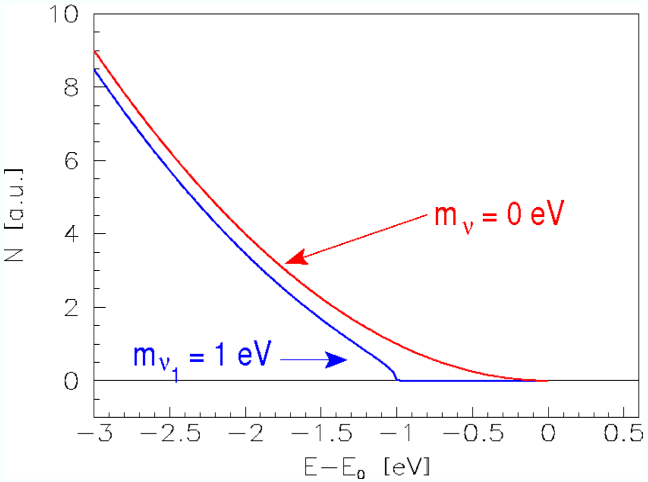
very sensitive, but needs ν to be of Majorana-type
sensitive to coherent sum: $m_{ee}(\nu) = |\,\Sigma\, |U_{ei}^2|\, e^{i\alpha(i)}\, m(\nu_i)|$
$\Rightarrow$ partial cancelation possible
Evidence for $m_{ee}(\nu) \approx 0.4$ eV (Klapdor-Kleingrothaus et al.)?



3) Direct neutrino mass determination:

No further assumptions needed ($E^2 = p^2c^2 + m^2c^4 \Rightarrow m^2(\nu)$)

- ***Time-of-flight measurements** (ν from supernova)*
  SN1987a $\Rightarrow m(\nu_e) < 5.7$ eV (PDG 2006)
- ***Kinematics of weak decays** (β-decay search for $m_{\nu e}$)*
  - *^{187}Re β-decay bolometers*
  - *tritium ß-decay spectrometers*



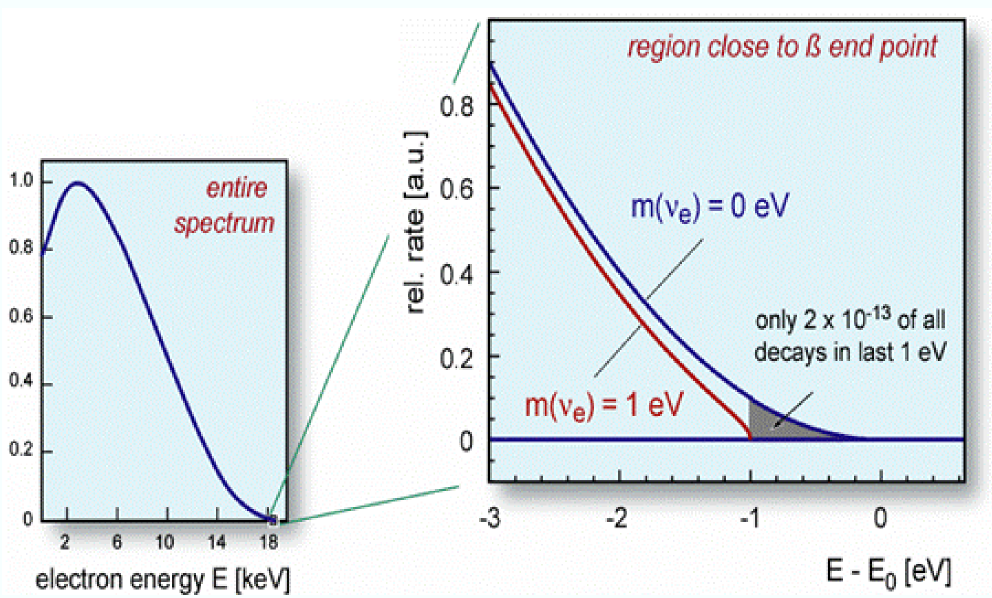
β-decay and neutrino mass

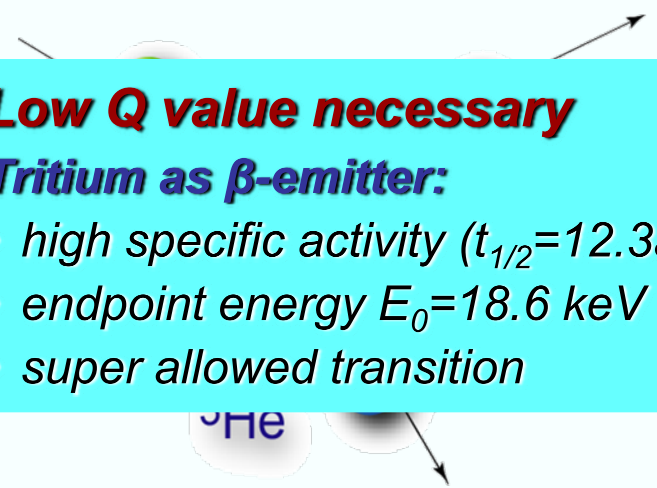
kinetic measurement of the effective neutrino mass

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

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

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



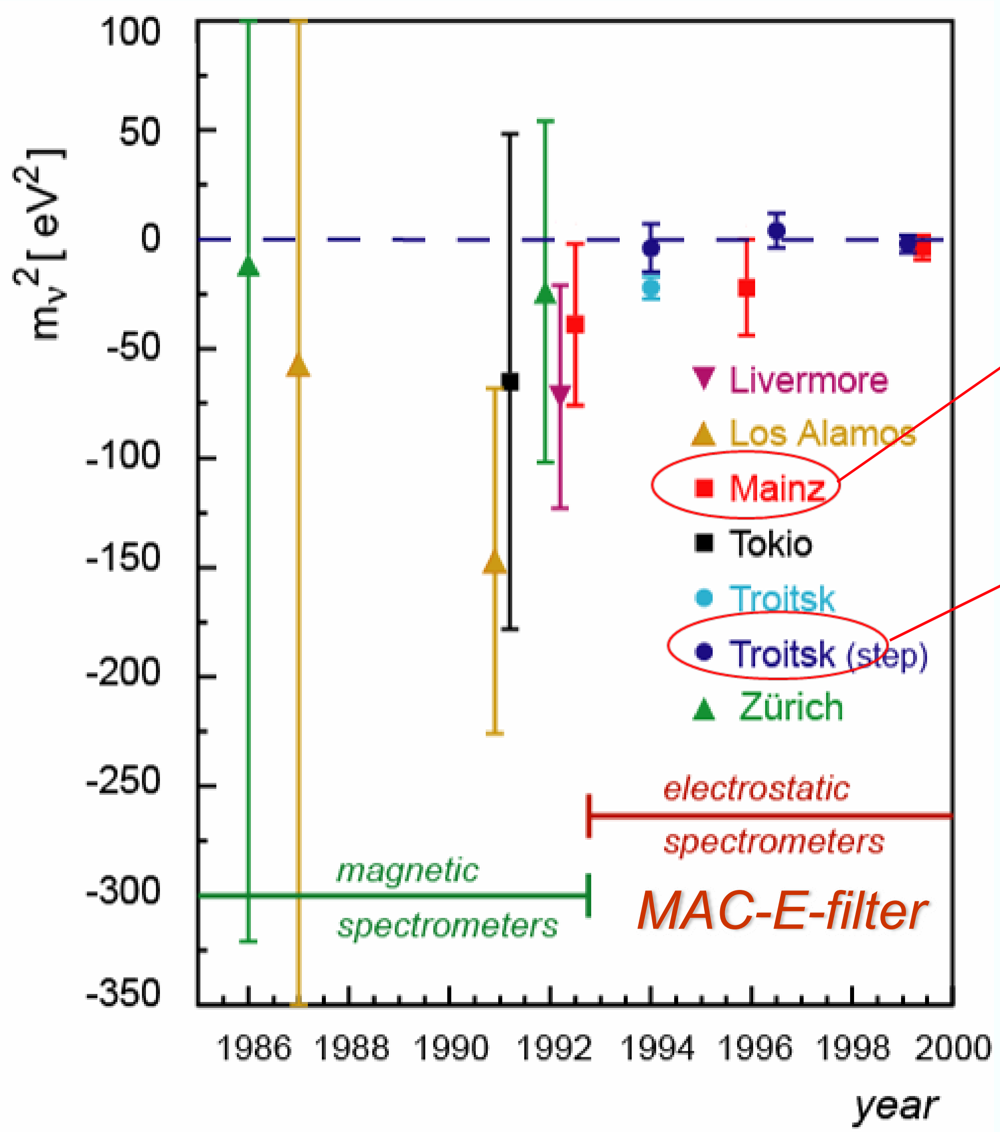


Low Q value necessary

Tritium as β-emitter:

- *high specific activity ($t_{1/2}$=12.3a)*
- *endpoint energy E_0=18.6 keV*
- *super allowed transition*

History of ^3H β-decay experiments



$$m_\nu^2 = -0.6 \pm 2.2_{stat} \pm 2.1_{syst}\ \mathrm{eV}^2$$
$$m_\nu \leq 2.3\ \mathrm{eV}\ (95\%\ CL)$$

$$m_\nu^2 = -1.2 \pm 2.2_{stat} \pm 2.1_{syst}\ \mathrm{eV}^2$$
$$m_\nu \leq 2.2\ \mathrm{eV}\ (95\%\ CL)$$

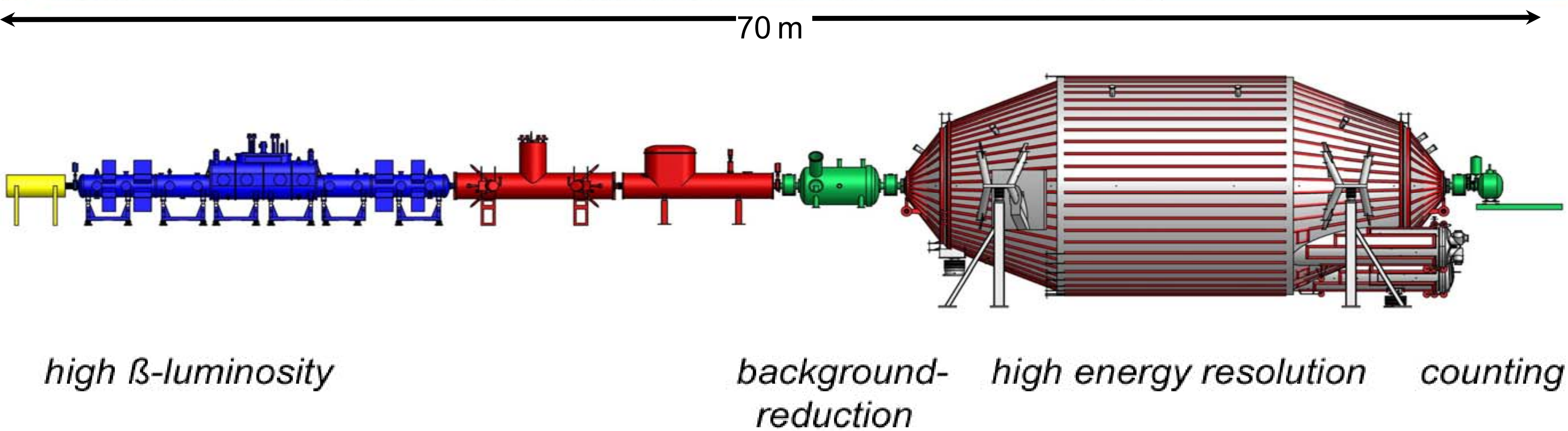
Mainz & Troitsk have reached the limit of their sensitivity

⇓

both experiments are used now to conduct systematic studies for one large experiment

KATRIN

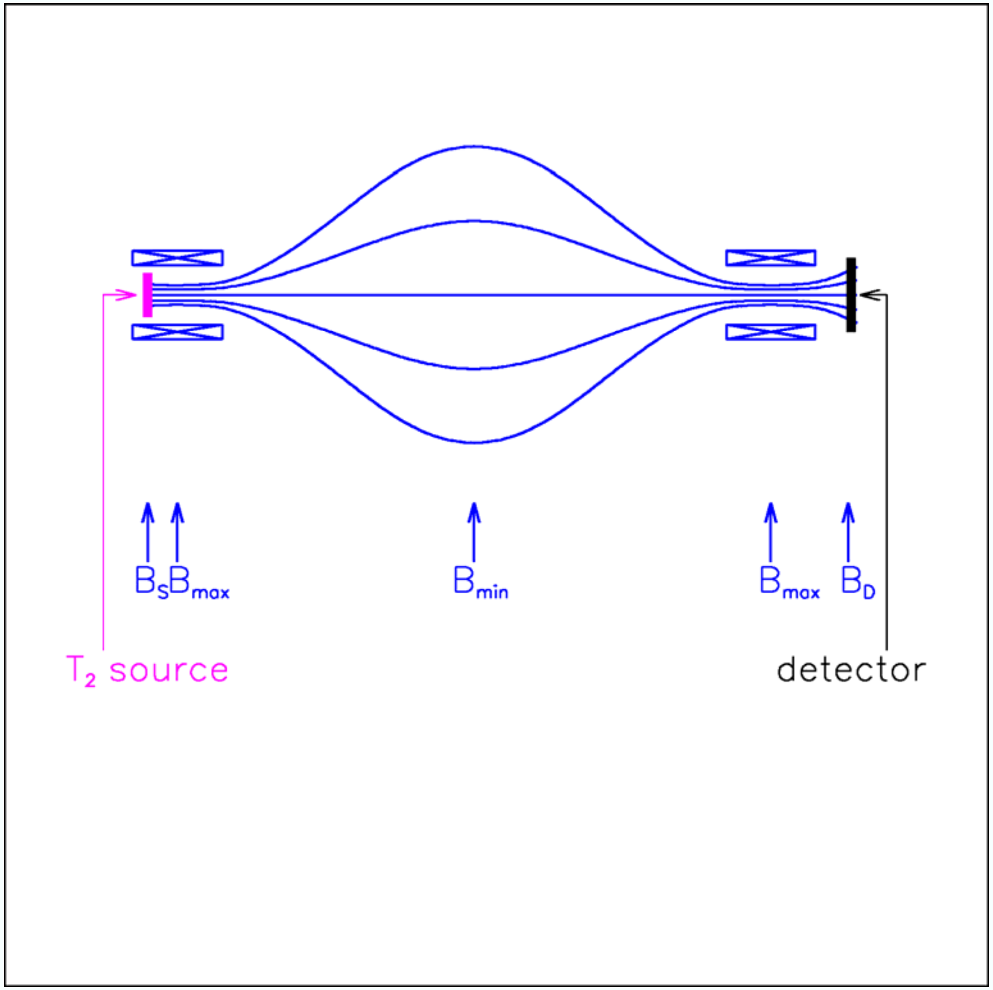
KATRIN at FZ Karlsruhe



Principle of the MAC-E-Filter

Magnetic Adiabatic Collimation + Electrostatic Filter
(A. Picard et al., Nucl. Instr. Meth. 63 (1992) 345)

- Two supercond. solenoids compose magnetic guiding field
- Electron source (T_2) in left solenoid



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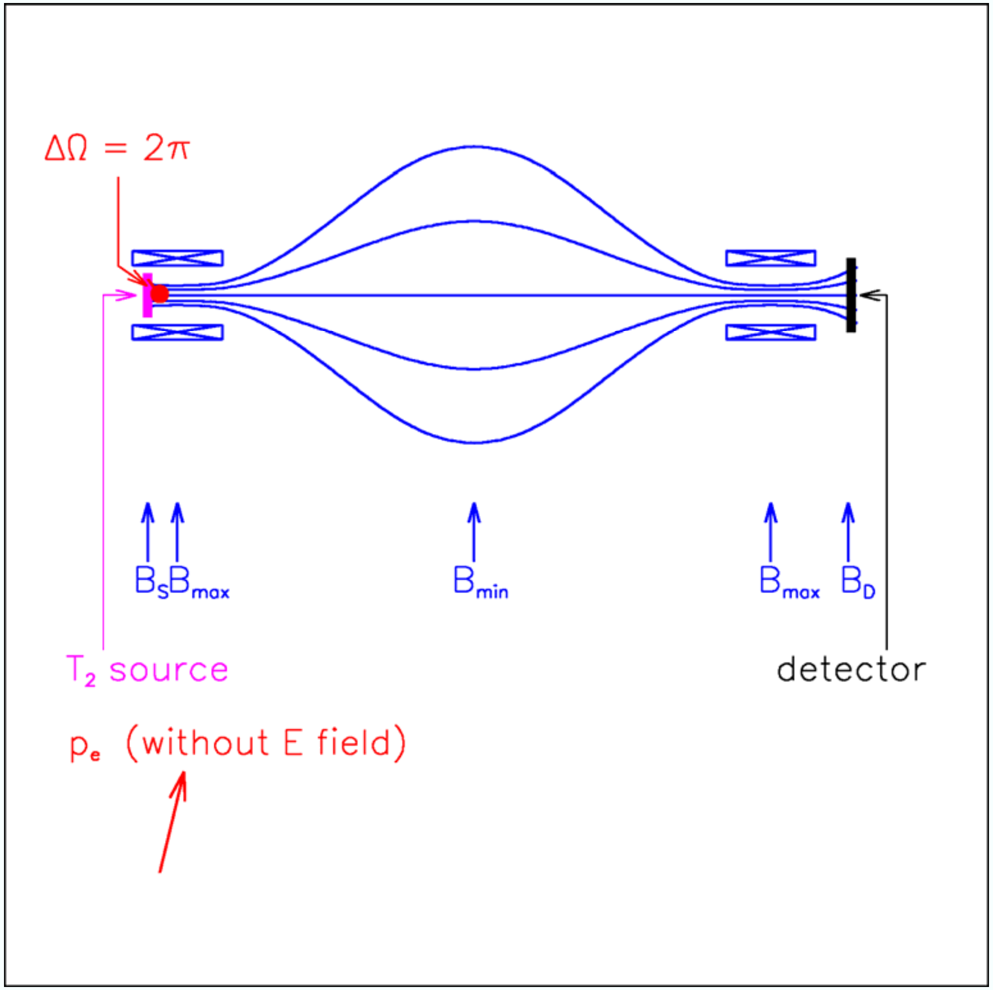
- Two supercond. solenoids compose magnetic guiding field
- Electron source (T_2) in left solenoid
- e^- in forward direction:
  magnetically guide ($F=\mu$ grad B)
- adiabatic transformation:
  $\mu = E_T/B = const.$
  $\Rightarrow$ parallel e^- beam



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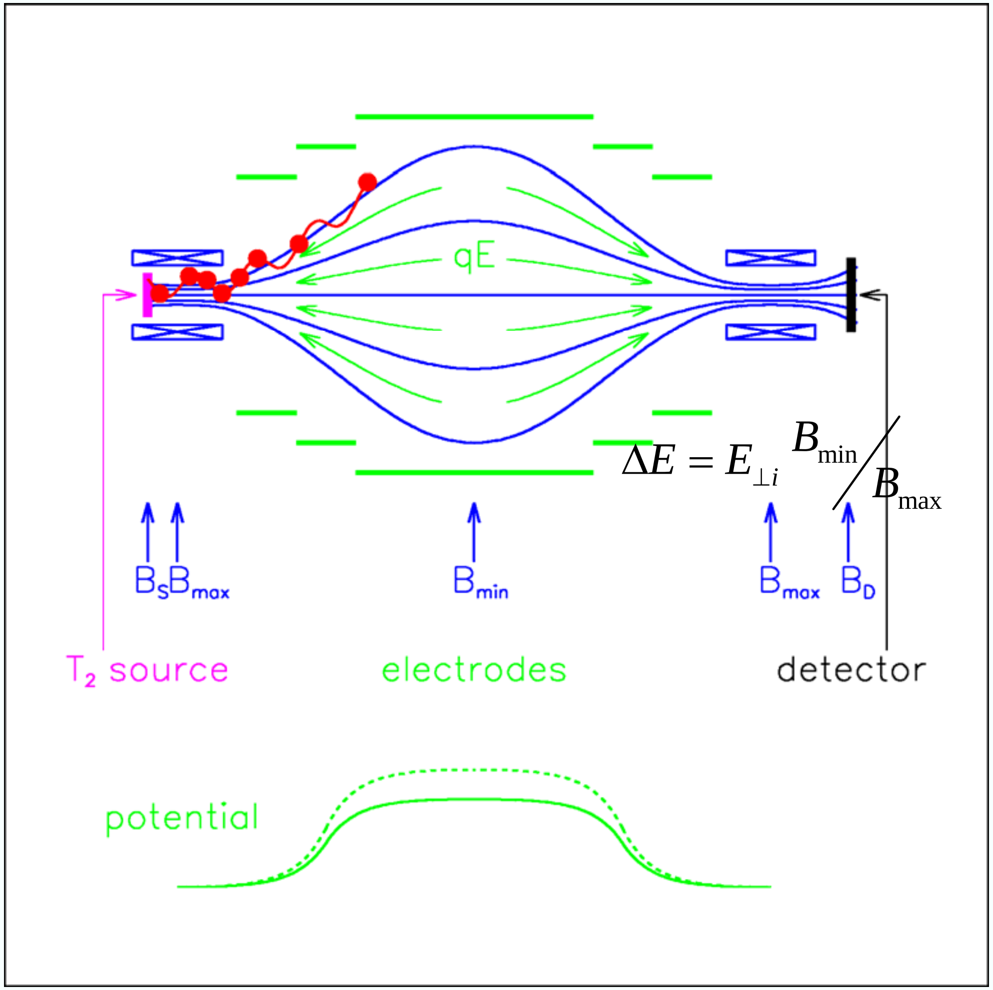
(A. Picard et al., Nucl. Instr. Meth. 63 (1992) 345)

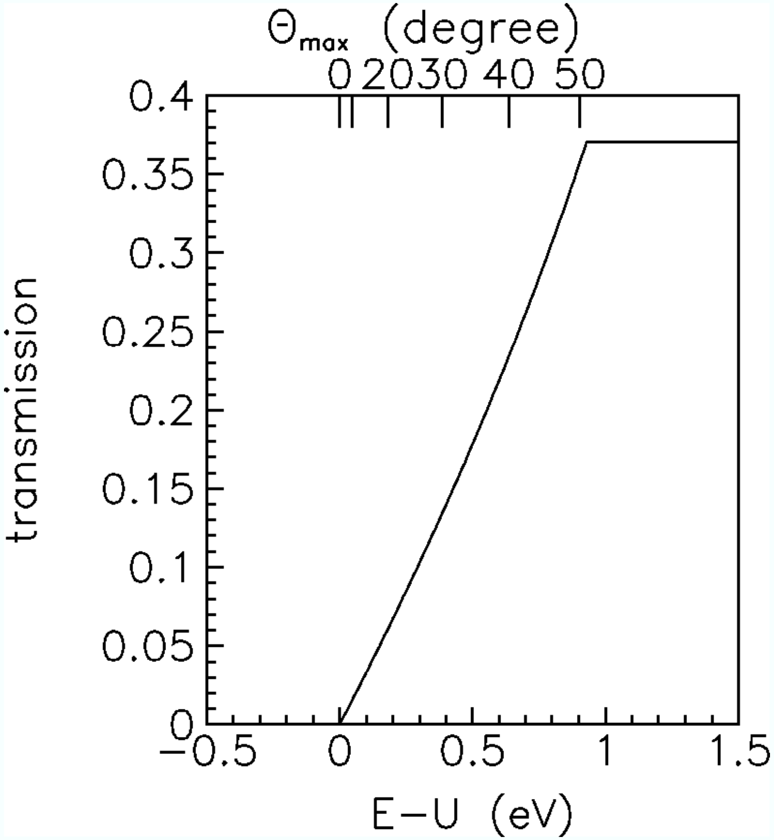
- Two supercond. solenoids compose magnetic guiding field
- Electron source (T_2) in left solenoid
- e^- in forward direction: magnetically guided
- adiabatic transformation: $\mu = E_T / B = \text{const.}$ $\Rightarrow$ parallel e^- beam
- Integral energy analysis by electrostat. retarding field
  - $E = E_{T,i} \, B_{min} / B_{max}$



Principle of the MAC-E-Filter

Magnetic Adiabatic Collimation + Electrostatic Filter
(A. Picard et al., Nucl. Instr. Meth. 63 (1992) 345)

⇒*sharp integrating transmission function without tails:*



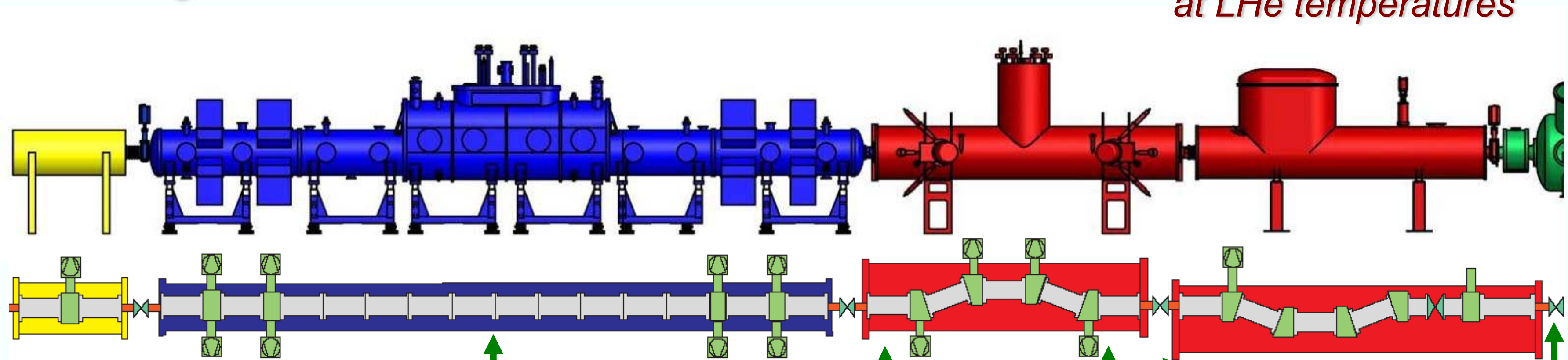
$\Delta E = E_{T,i}\, B_{min}/B_{max} = E_{T,i}\, A_{s,eff}/A_{analyse}$ Mainz ≈ 4.8 eV; KATRIN = 0.93 eV

Source and transport section (tritium system)

Molecular windowless gaseous tritium source

Differential pumping

Cryogenic pumping
with Argon snow
at LHe temperatures



T_2-injection 1.8 mbar l/s (STP)
= 1.7*10^{11} Bq/s = 40 g/d
Source activity = 10^{11} Bq

FT-ICR Penning traps to measure ions from WGTS

~ 10^{-7} mbar l/s

< 2.5 10^{-14} mbar l/s

⇒ adiabatic electron guidance & T_2 reduction factor of ~10^{14}

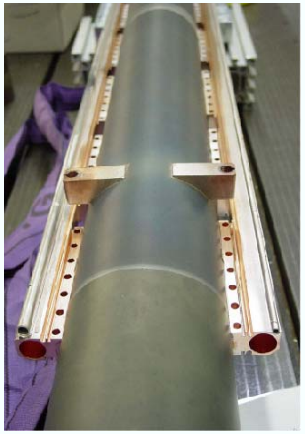
Windowless Gaseous Tritium Source

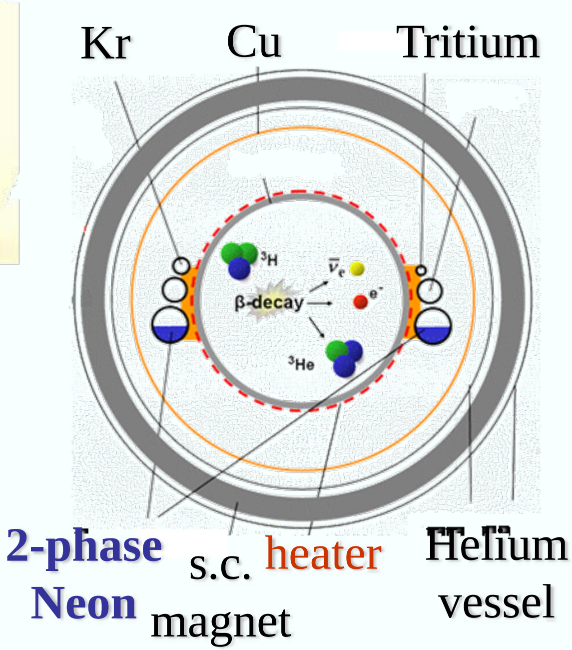
Status:

cryostat under construction
2010: 12 m demonstrator
2011: 16 m WGTS

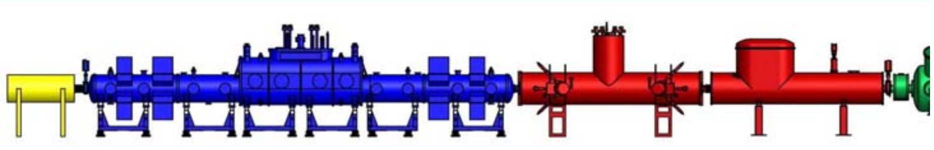
Complex 16m long cryostat:

- *12 cryogenic circuits*
- *500 sensors from 4 – 600 K*
- *super conducting magnets (4.5 K, 3.6T)*
- *2 phase Neon cooling of source tube*
- *tritium temperature: 27 ± 0.03 K*
- ***long term stability: ± 0.1%***



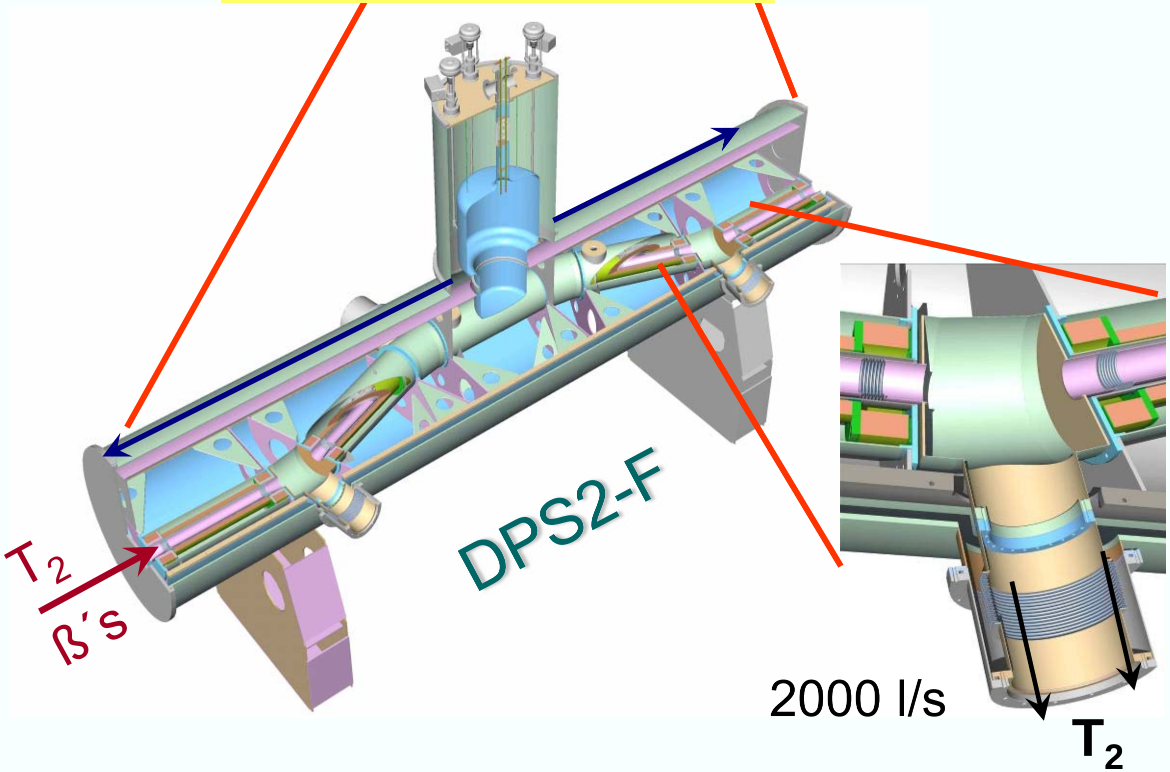


Differential Pumping Section (DPS)

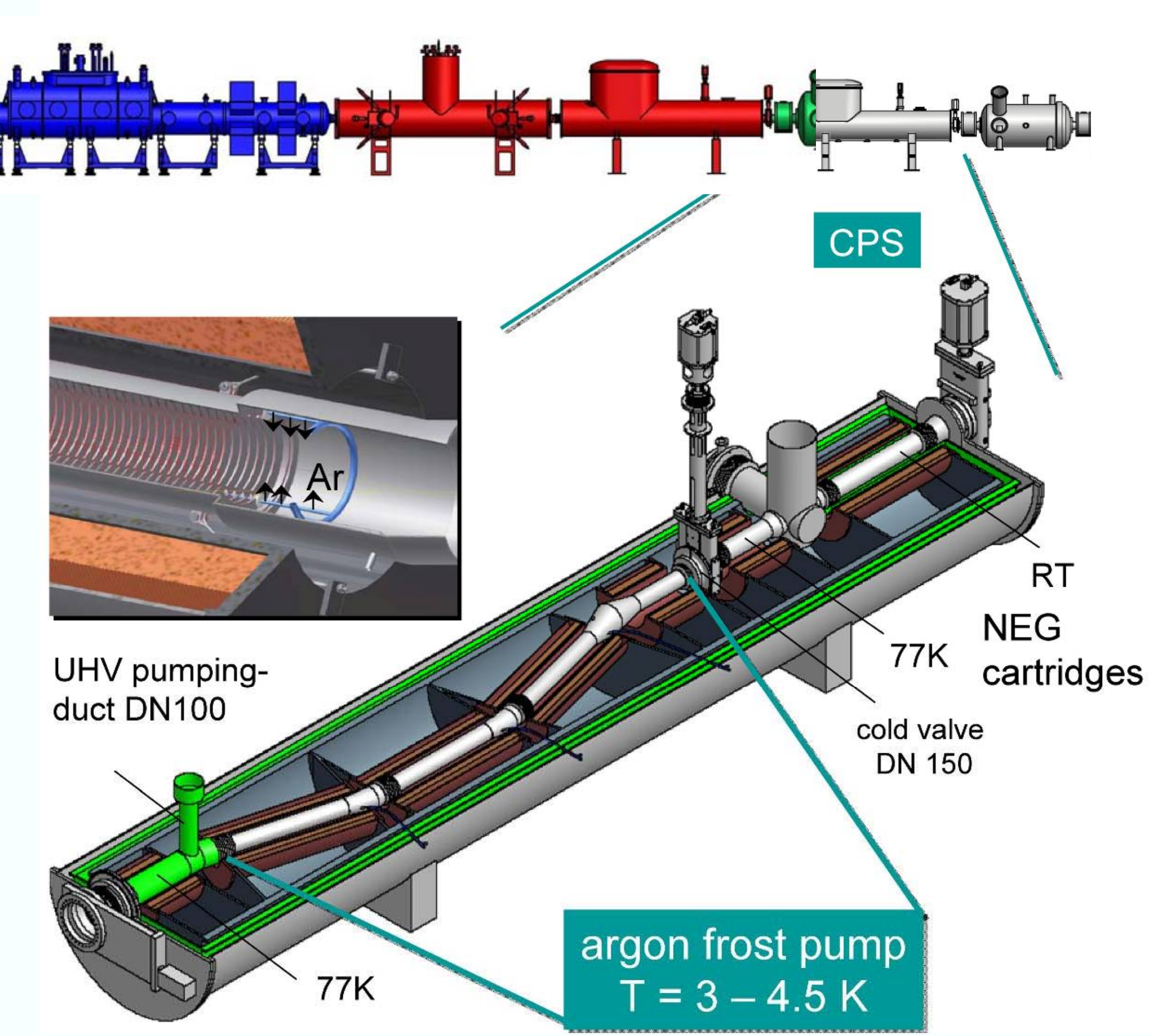


- *active pumping of T_2 with TMPs*
- *TMP tests in B-field (< 4mT)*
- *tritium reduction: 10^5*
- *delivery: July 15, 2009*

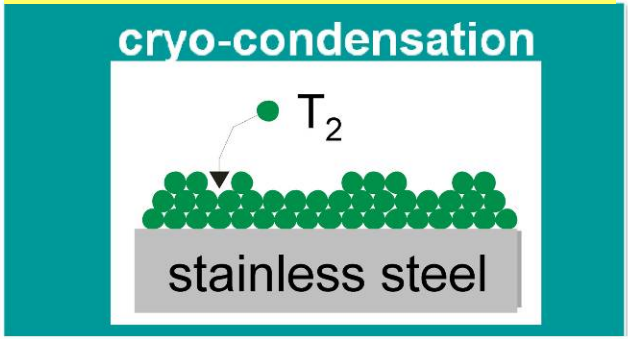
6.2 m long
s.c. magnets (5.6 T)

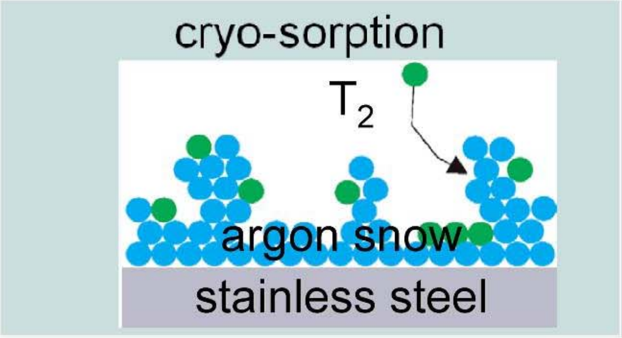


Cryo pumping section (CPS)



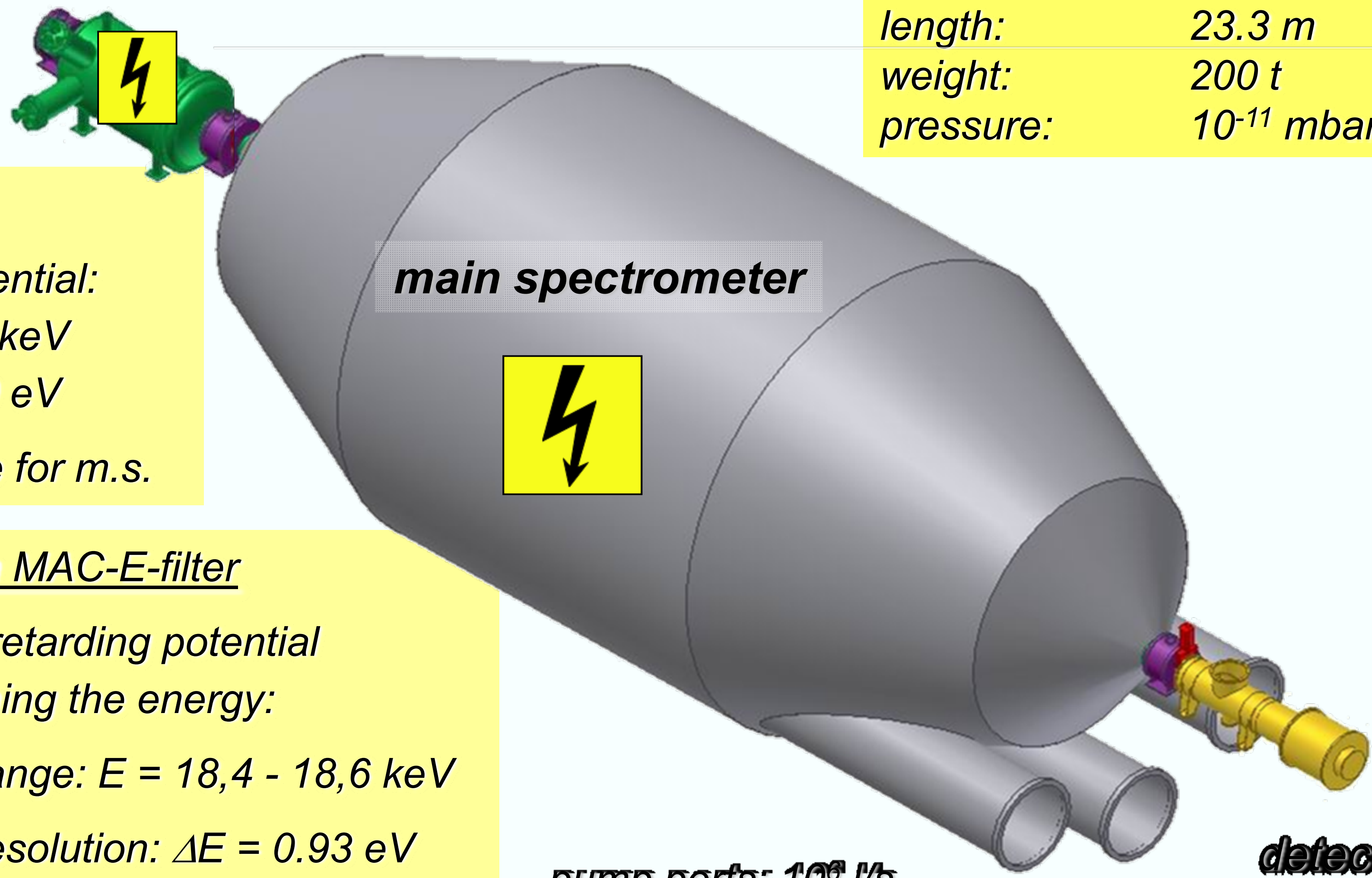
- *cryo-sorption of T_2*
- *tritium reduction: 10^7*
- *s.c. magnets*
- *delivery: 2010*





Electro-static tandem-spectrometer

diameter:	10 m
length:	23.3 m
weight:	200 t
pressure:	10^{-11} mbar



Pre-filter

fixed potential:
E = 18.3 keV
$\Delta E \approx 100$ eV

prototype for m.s.

Precision MAC-E-filter

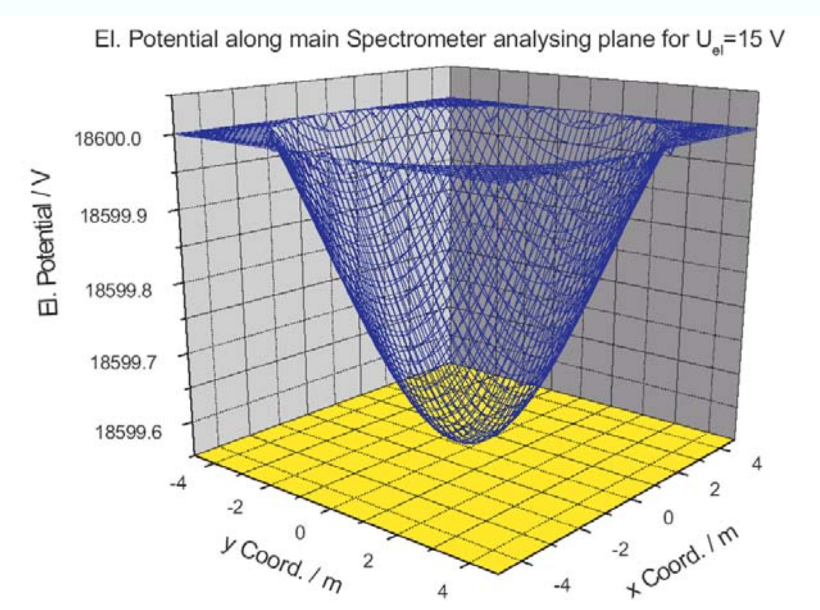
variable retarding potential
for scanning the energy:

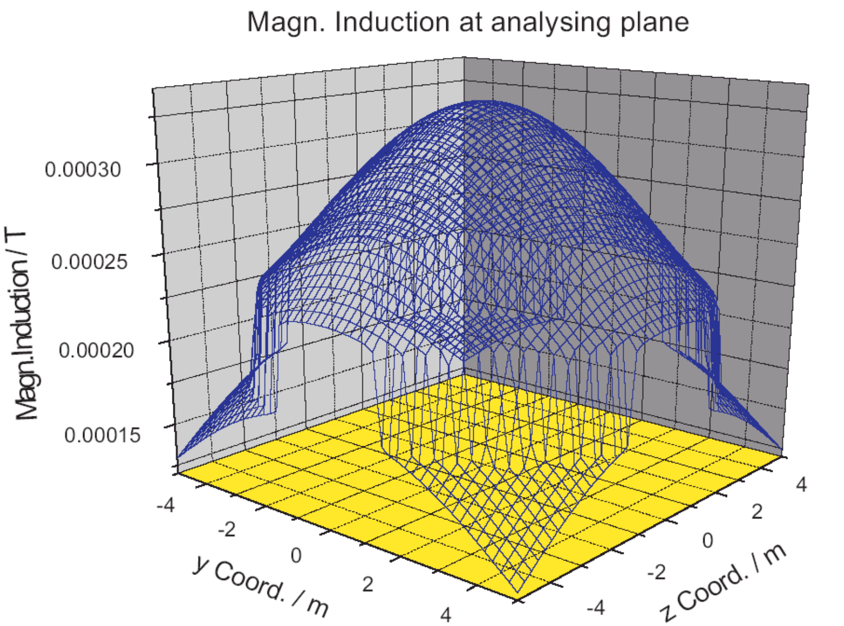
energy range: E = 18,4 - 18,6 keV

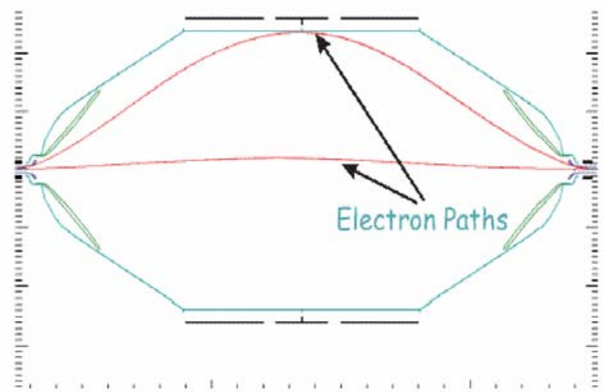
energy resolution: $\Delta E = 0.93$ eV

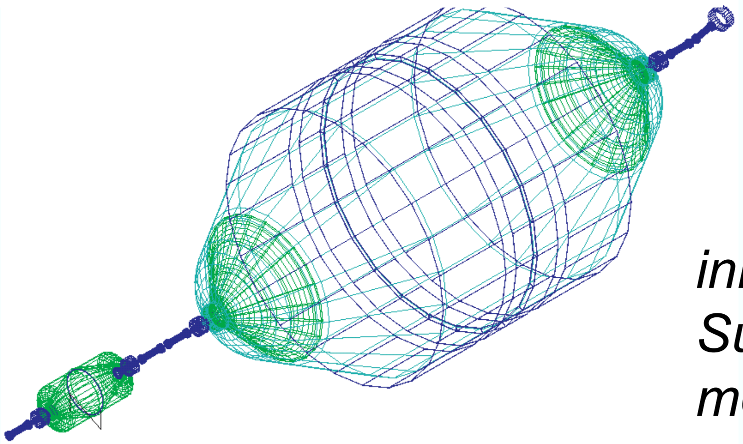
Design of the spectrometers

Codes: customized IGUN, Simion, native Codes ,PartOpt



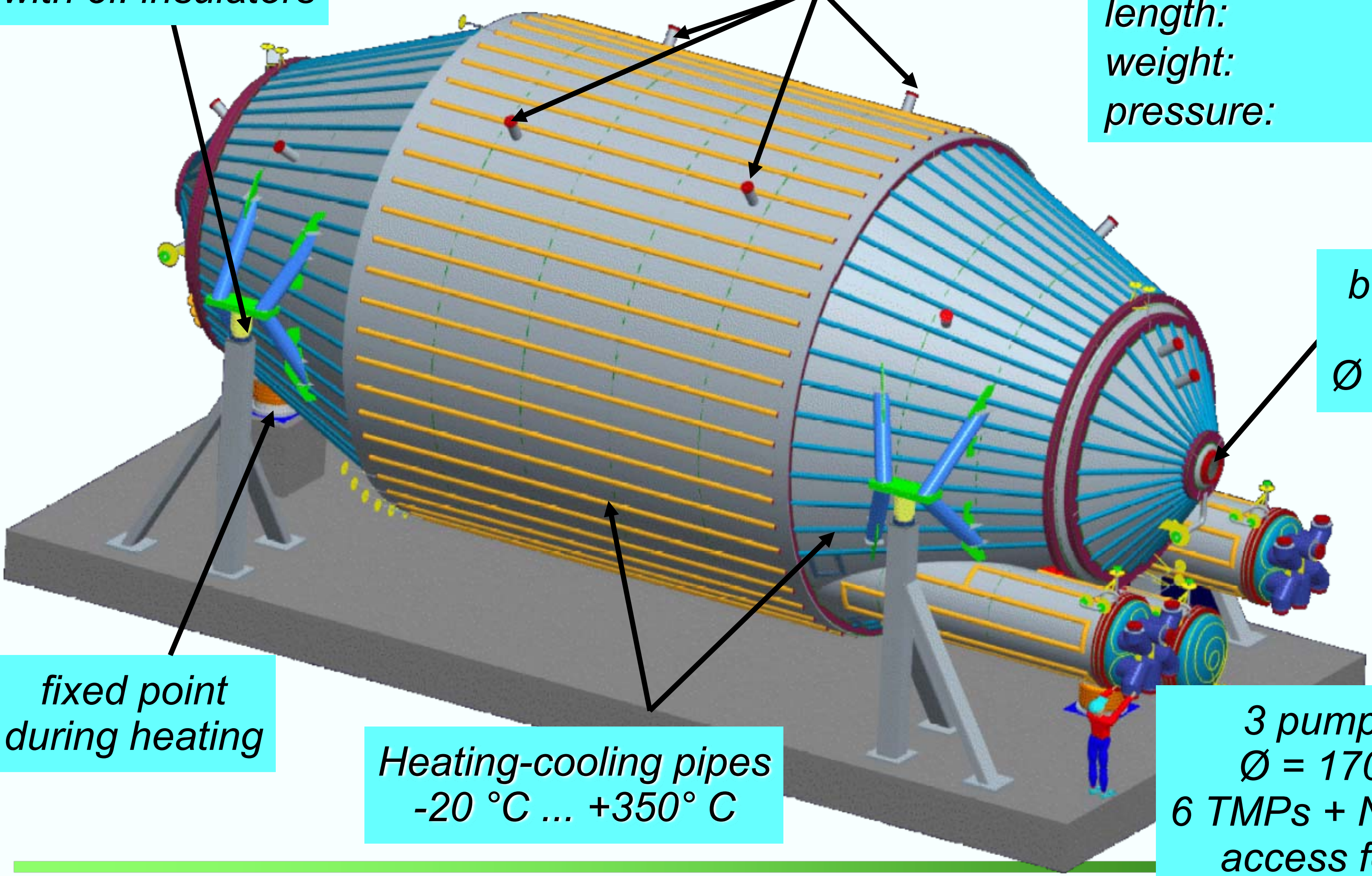






inner Surface model

Design of the main spectrometer



Support stands
with el. insulators

Ports for HV feed-throughs
for inner electrodes

diameter:	10 m
length:	23.3 m
weight:	200 t
pressure:	10^{-11} mbar

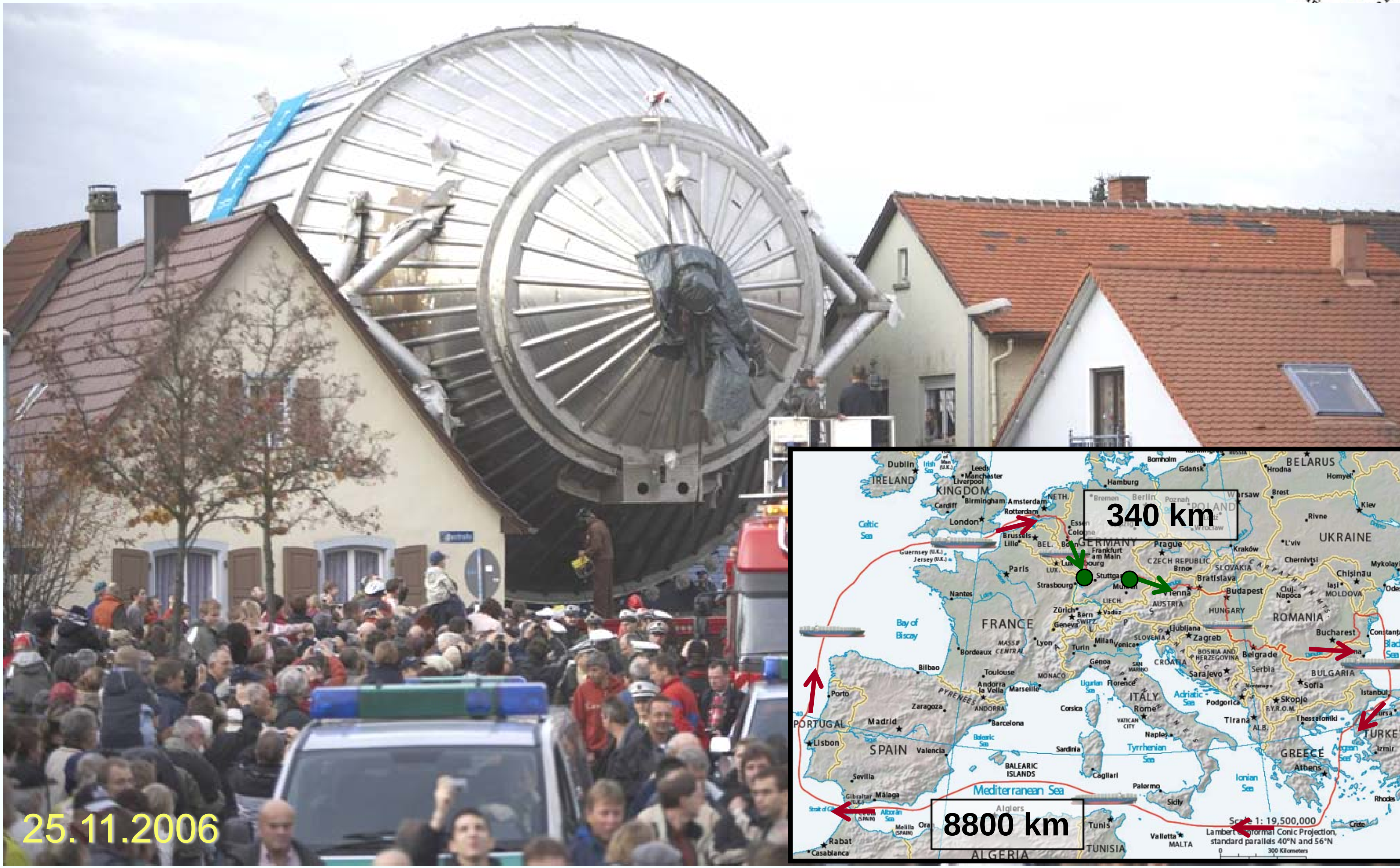
beam line-
flanges
Ø = 500 mm

fixed point
during heating

Heating-cooling pipes
-20 °C ... +350° C

3 pump ports
Ø = 1700 mm
6 TMPs + NEG strips
access for work

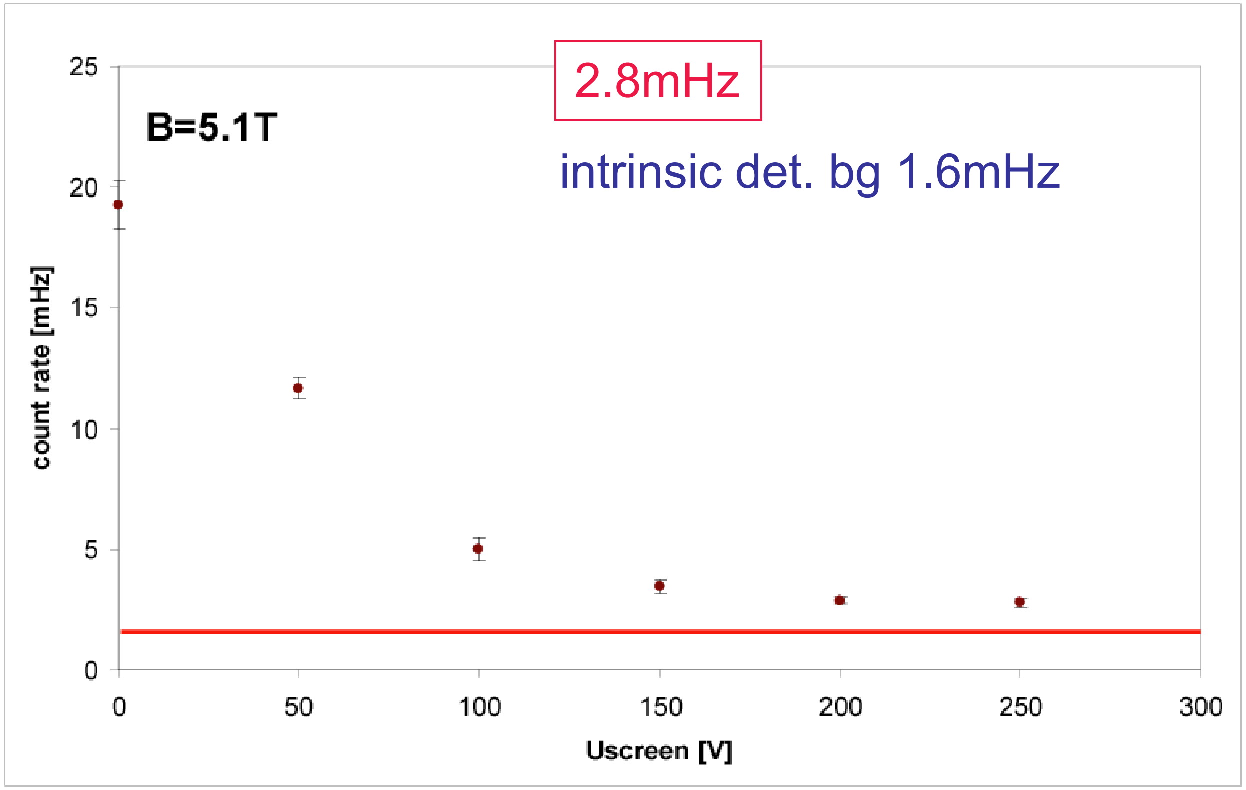
Arrival of the main spectrometer after a voyage of 8800 km around Europe

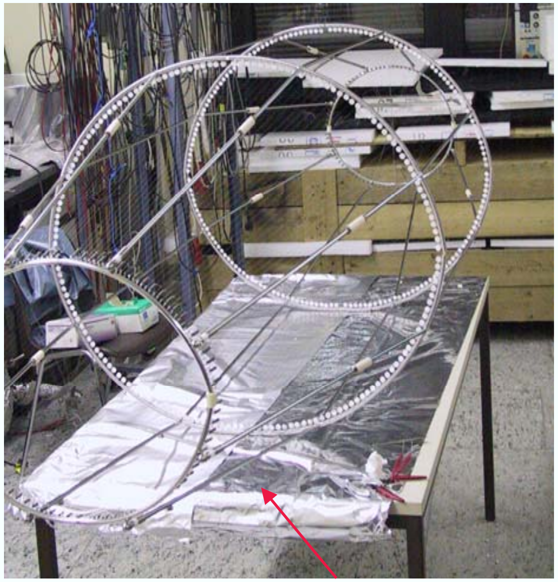


Minimisation of spectrometer background

- UHV: $p \leq 10^{-11}$ mbar
- „massless“ inner electrode system to protect against secondary electrons from the walls

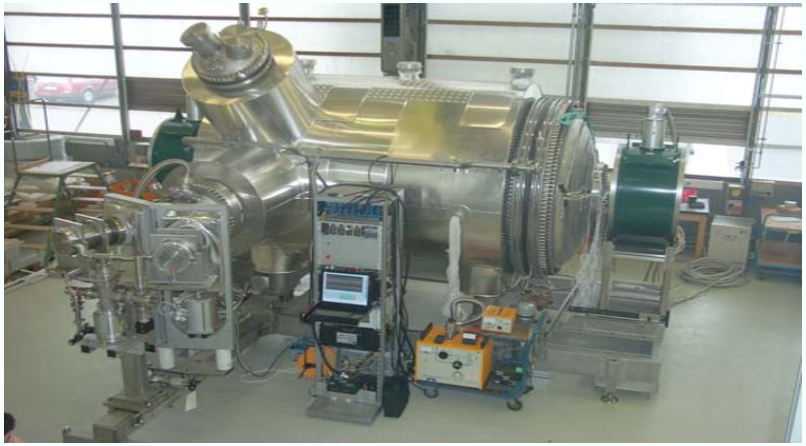
Results from the Mainz spectrometer:

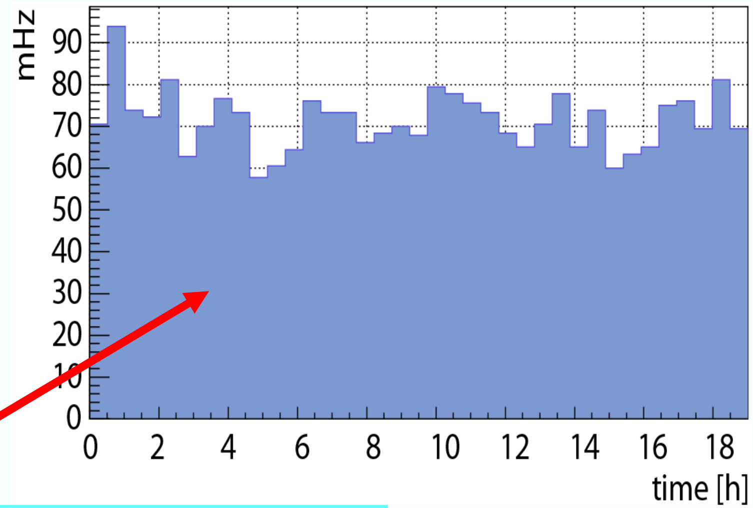




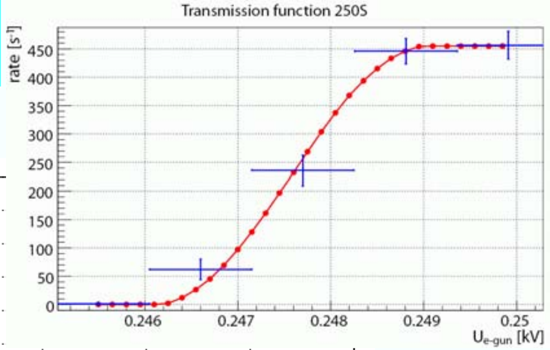
inner electrode installed in Mainz spectrometer for background tests

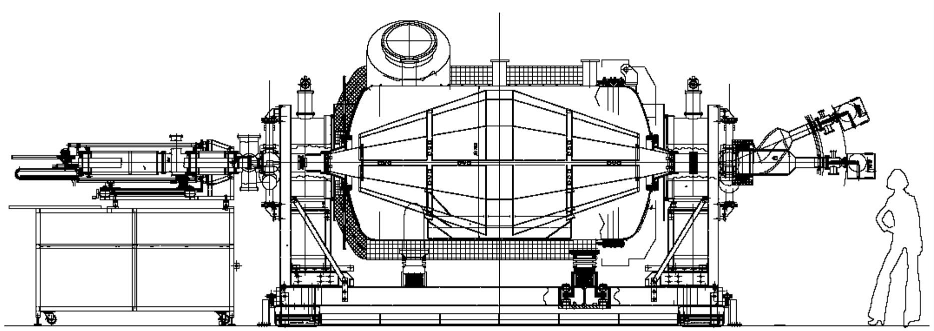
Pre-spectrometer

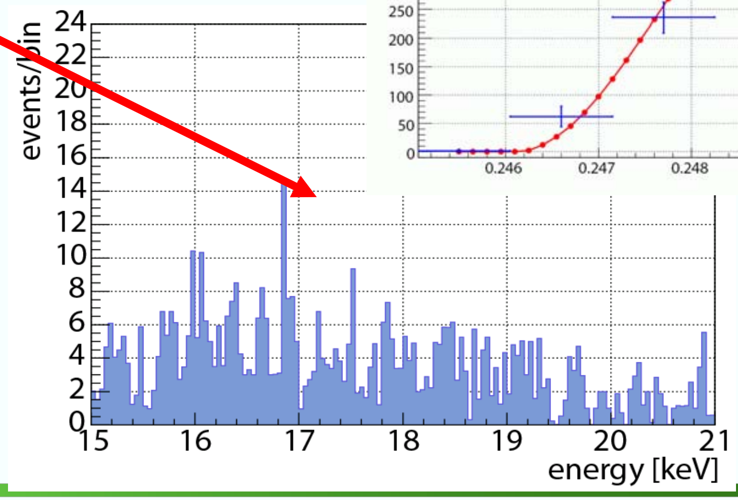




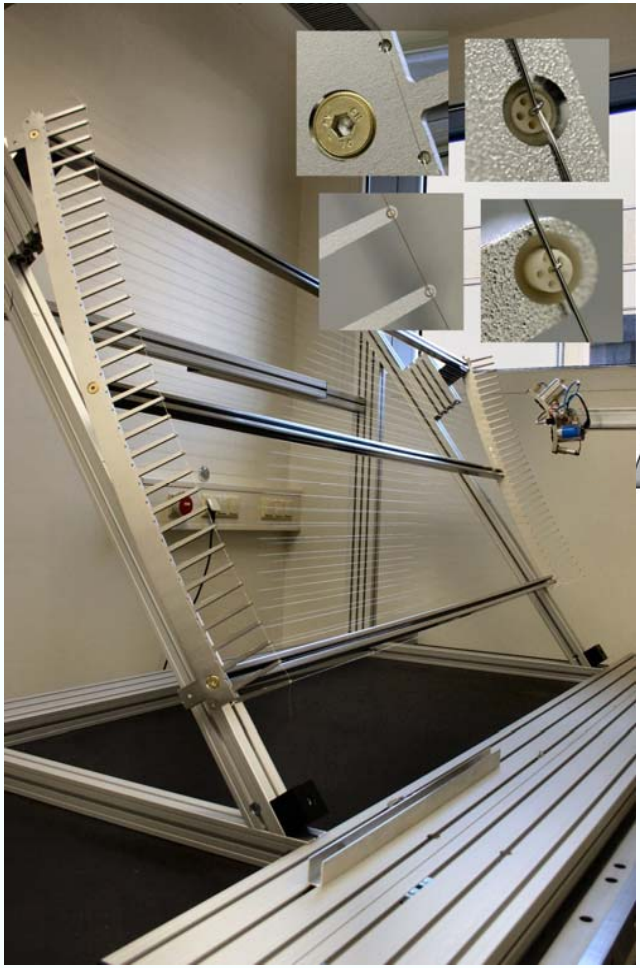
electronic background < 1 Hz

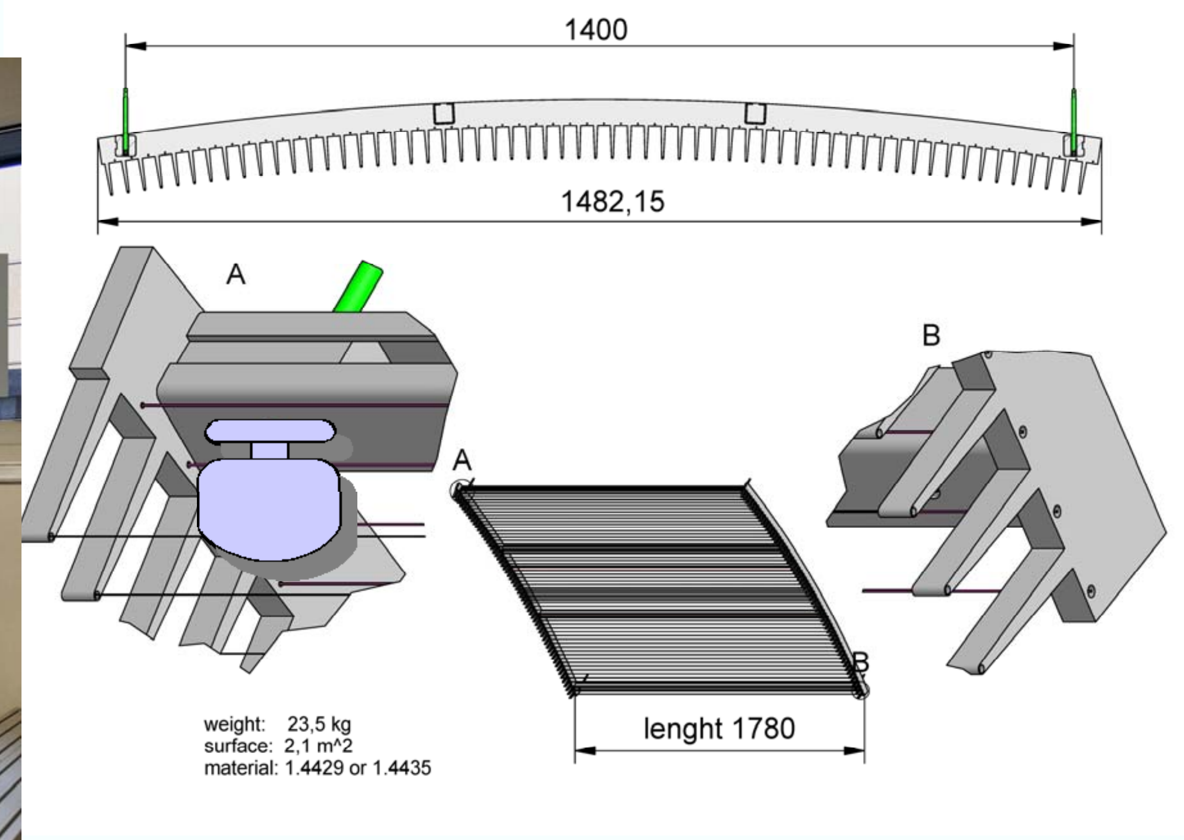






frame for the cylindrical part of main spectrometer



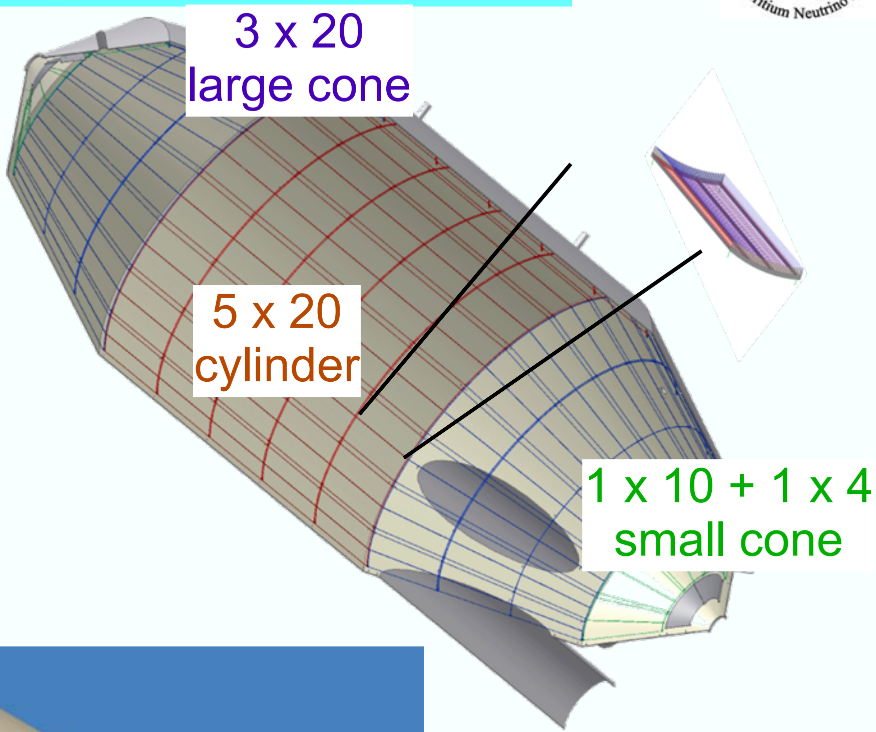


Two layers:
- to improve background shielding
- to increase electrical shielding
- to allow mechanical precision

Electrode concept for main spectrometer: 650 m² surface: 2-layer wire modules

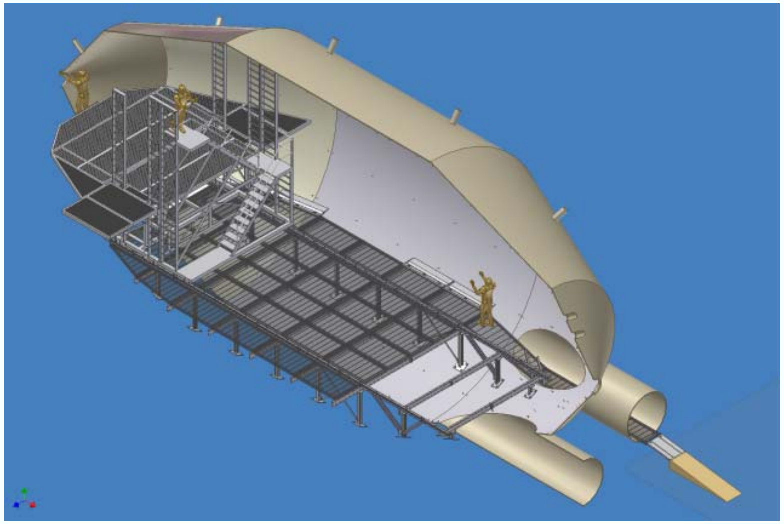
Wire electrode system of KATRIN main spec:

- 248 modules, 23440 wires, 46240 ceramics



Technical requirements:

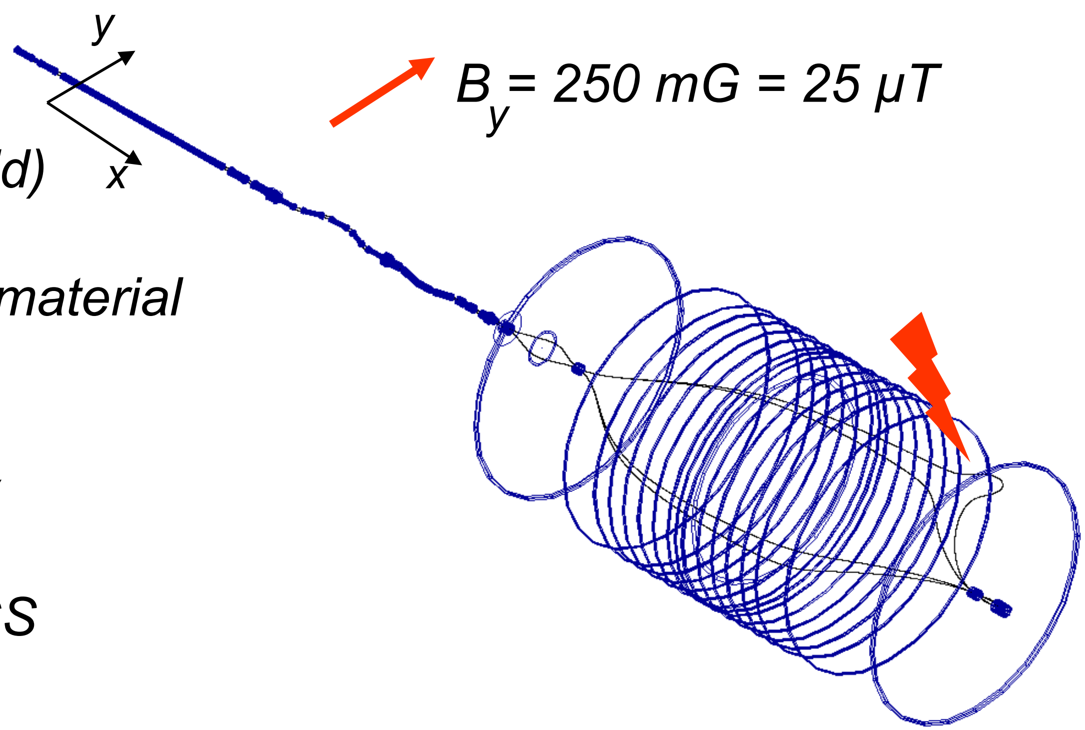
- bake-out at 350°C
- vacuum requirements (10^{-11} mbar)
- position ($\Delta x = \pm 200\ \mu m$)



Electrode module installation: a flexible scaffold inside „cleanroom“

Railway installation finished:
May 2009
Start of wire electrode installation:
June 2009

Determination ot the magnetic field inside the main spectrometer



$B_y = 250\ mG = 25\ \mu T$

•*global fields , dipols (e.g. earth magnetic field)*

• *permanet magnetised material (construct steel)*

•*magnetised material by KATRIN components*

➡ *LFCS, EMCS*

Accuracy of B in central analysing area

$$\Rightarrow \frac{\Delta(B_A)}{B_A} < 4\times10^{-2}$$

Measurement of magnetic field inside main spectrometer

In rotational free volumes

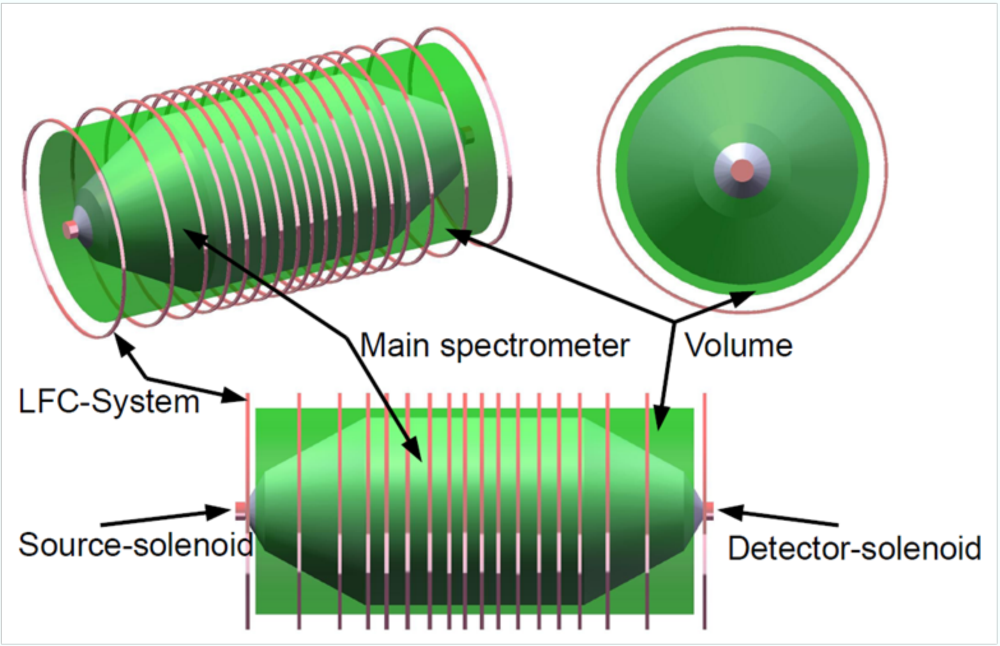
$$\vec{B} = \left(\vec{\nabla} \cdot V\right)$$

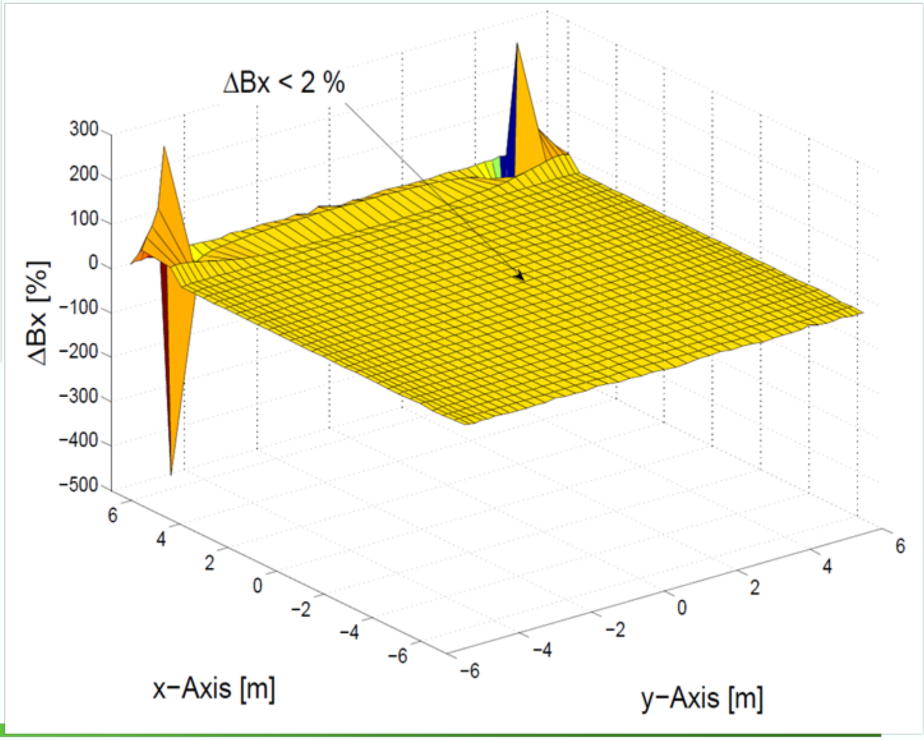
Ampere's Law

$$\vec{\nabla}^2 \cdot V(x, y, z) = 0$$

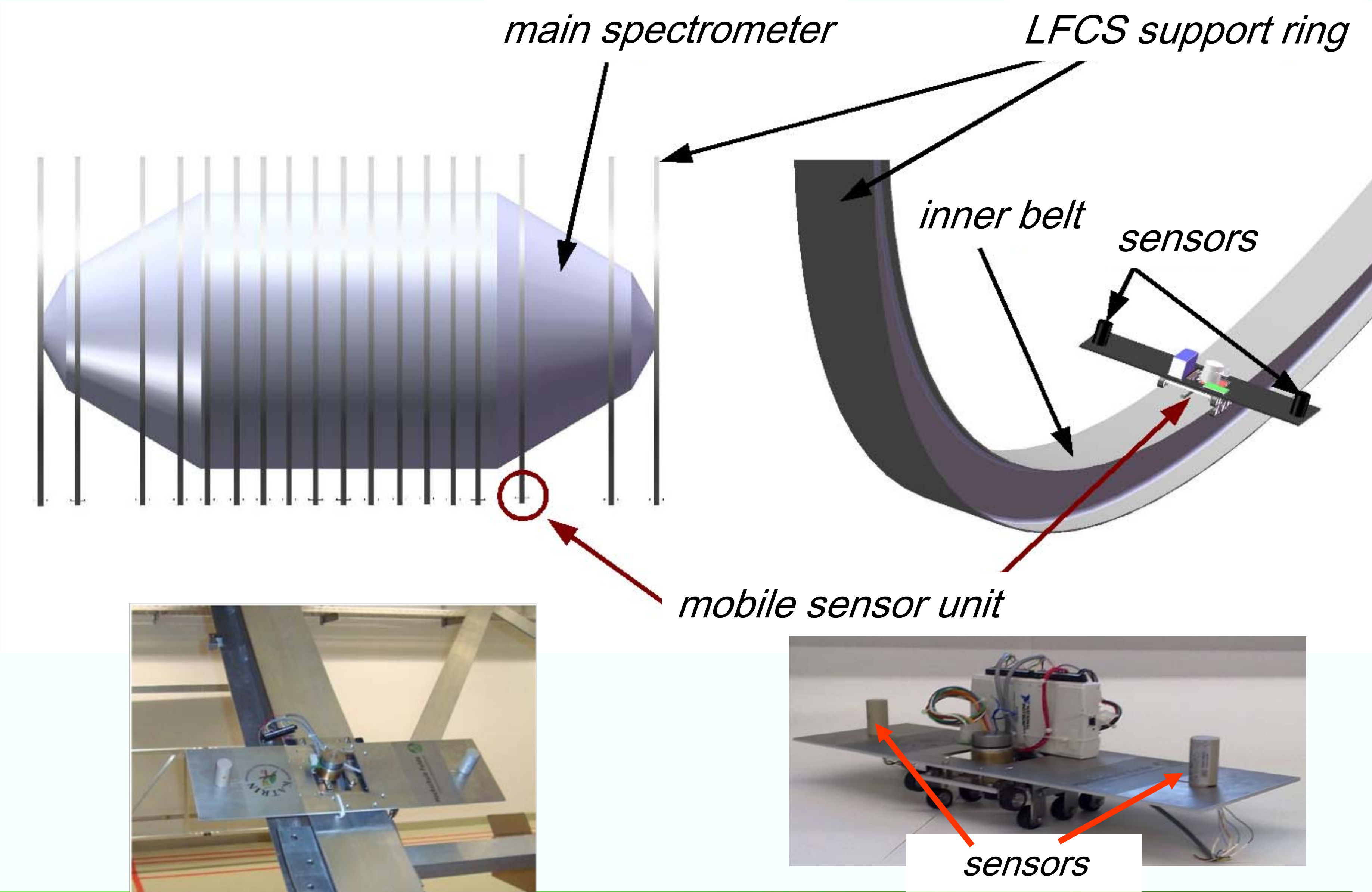
Laplace-eq.

Finite difference method (FDM) boundary values $B_{surface}$ allowes reconstruction of B in volume.



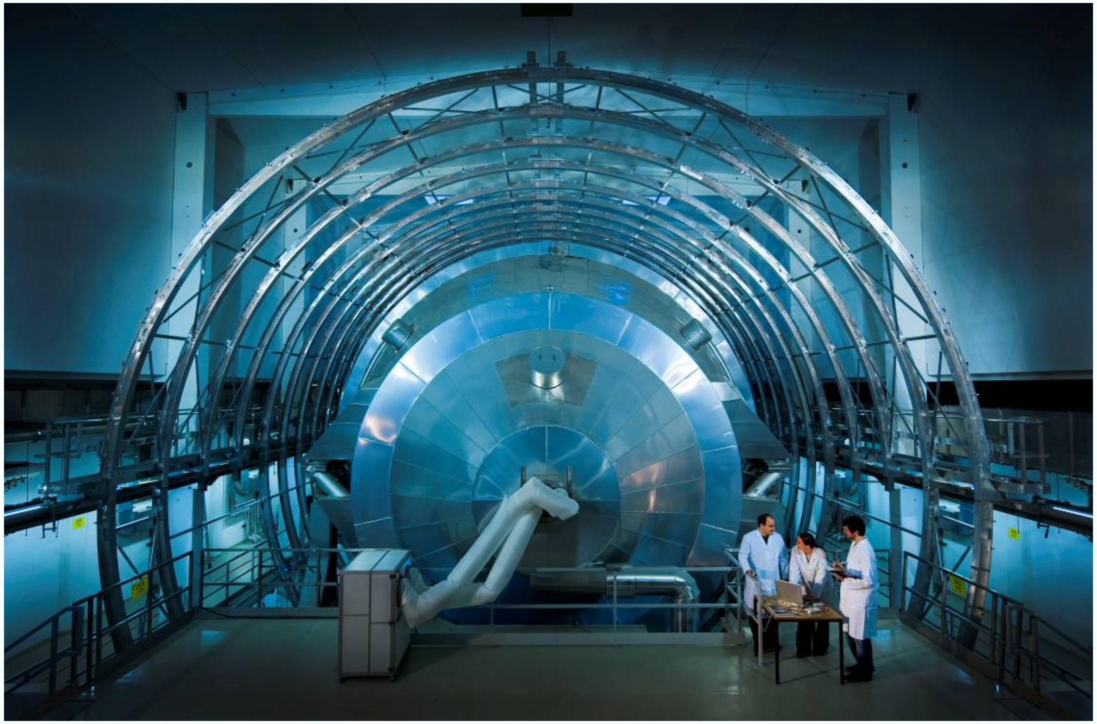


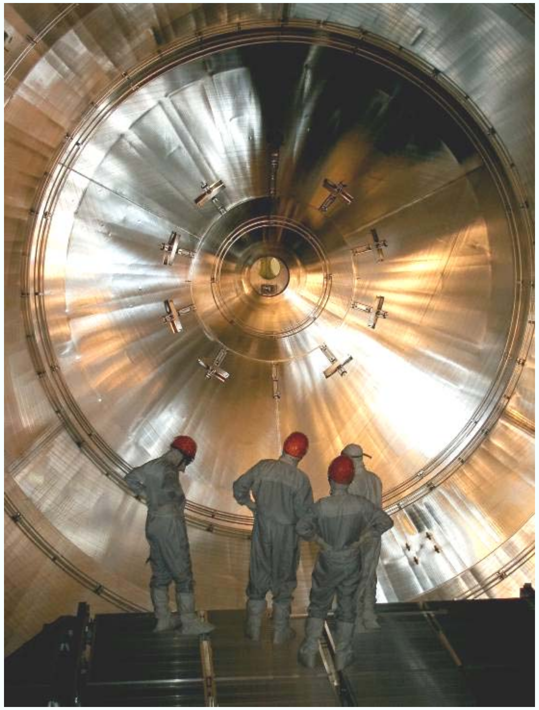
Scheme of mobile sensor unit (MOBS) mounting



Status of the main spectrometer

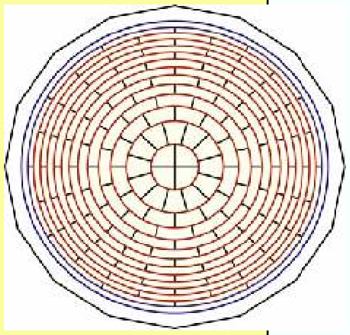
- *successfull bake-out (350°C) and vacuum tests*
- *inner electrode system being prepared for installation*
  - ***23440 individual wires in 248 frames (University Münster)***
  - ***clean room scaffolding inside vessel installed, mounting ongoing***
- *Helmholtz coils with 12.6 m diameter installed*
- *first electromagnetic tests planned in 2010*
- *Installation & test of mag. field monitoring system start 2010*

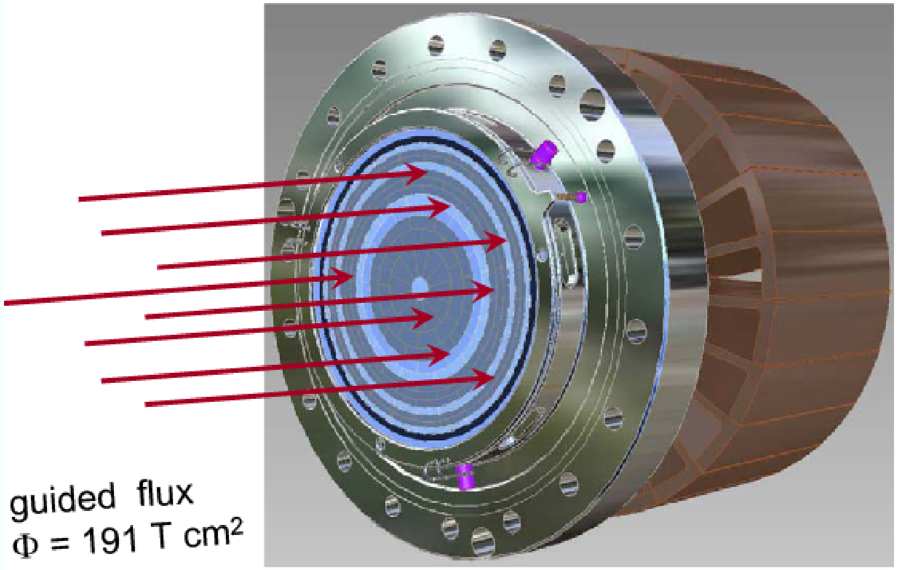


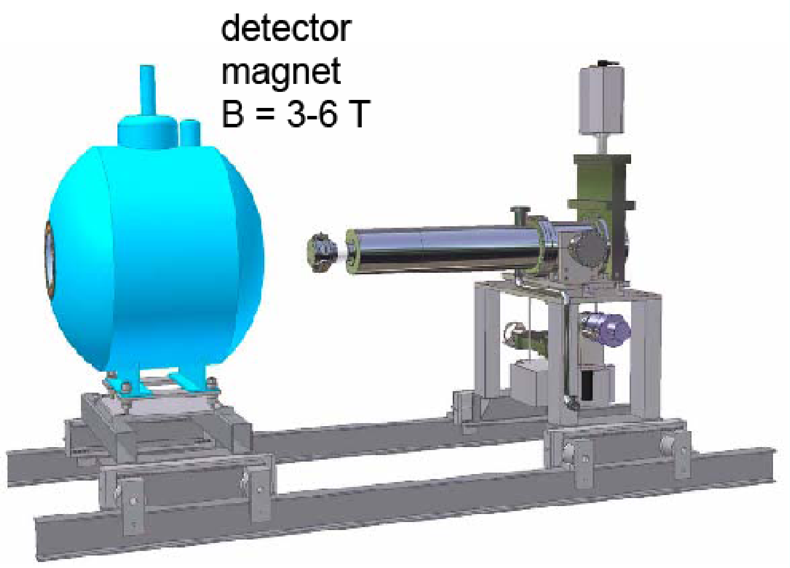


Focal plane detector and pinch magnet

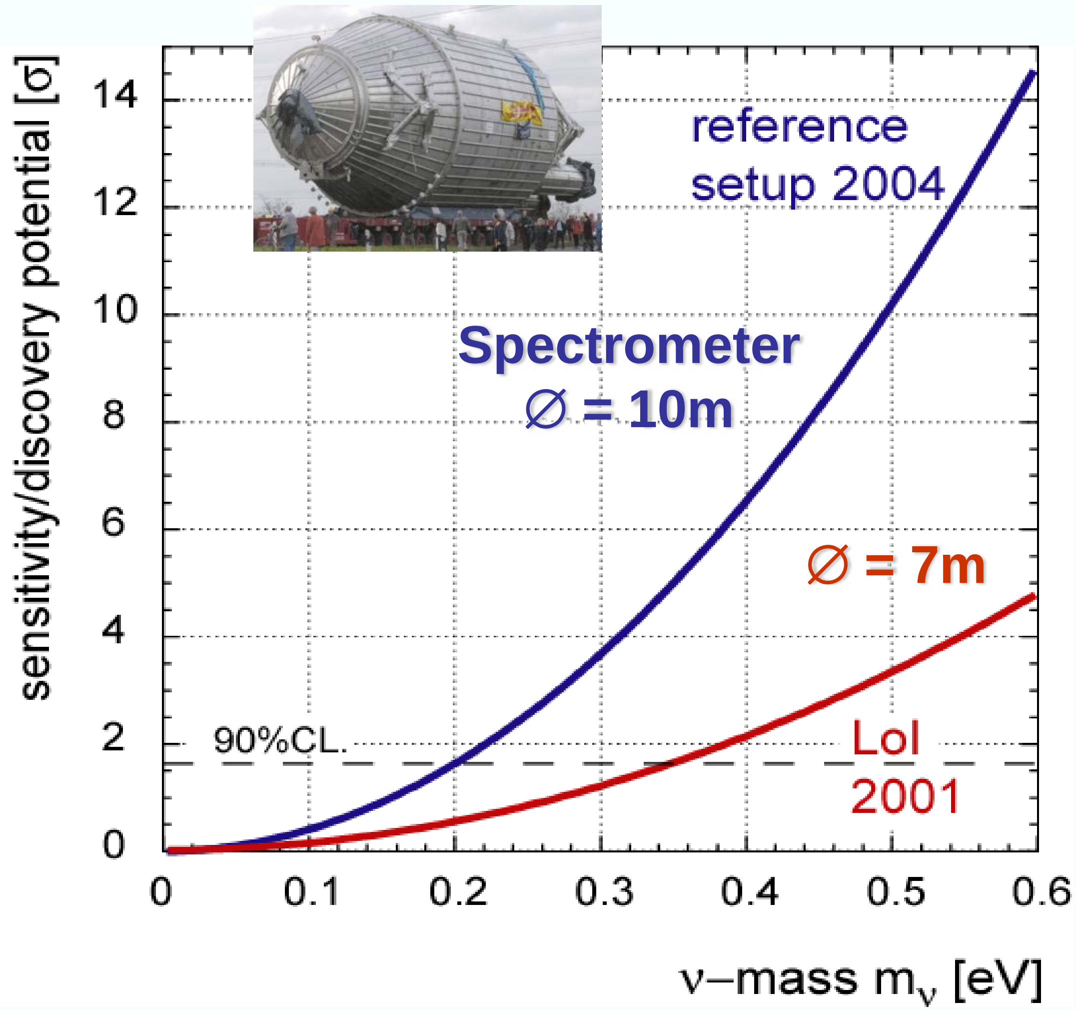
- *monolithic segmented SI-PIN-diode array*
  - *counts transmitted electrons after main spectrometer*
  - *very low background*
  - *determines radial position and azimuth angle*
- *s.c. detector and pinch magnets (3 – 6 T)*
- *developed and supplied by US collaborators (UW, MIT)*
- *will be shipped to Karlsruhe in 2010*







KATRIN sensitivity and discovery potential



sensitivity (90% CL)

m(ν) < 0.2 eV

discovery potential

m(ν) = 0.35 eV (5σ)

begin of measurements

2012

measurement: 5-6 years

(3 years of data)

KATRIN Design Report 2004

http://bibliothek.fzk.de/zb/berichte/FZKA7090.pdf


Thank you for your attention

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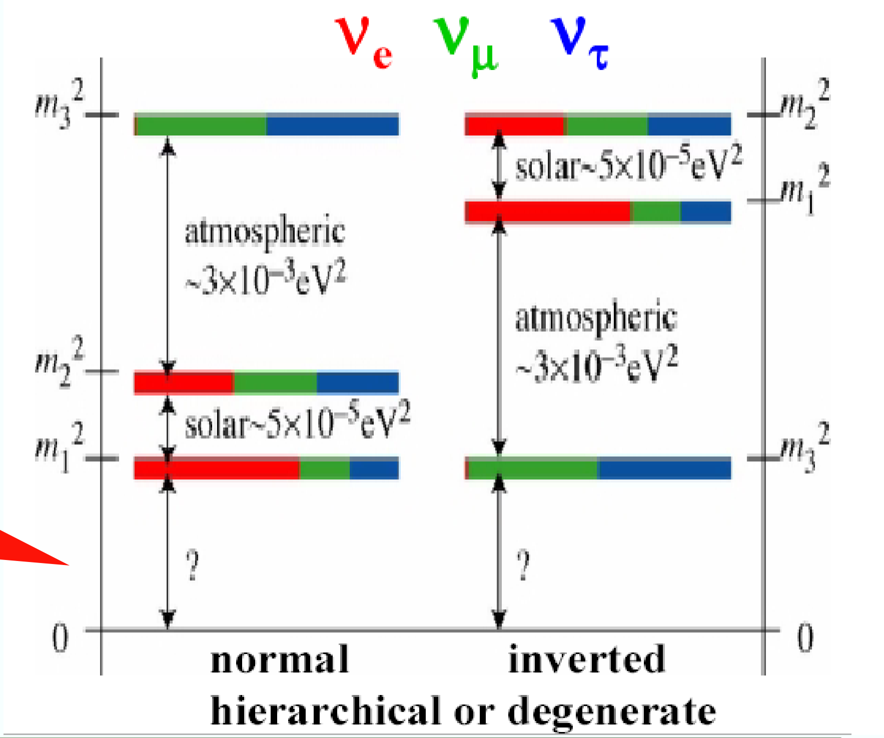
From neutrino oscillation experiments:
mass splittings $\Delta m^2_{ij}=(m_j^2 - m_i^2)$ & mixings angles $\sin^2 2\theta_{ij}$

flavour eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

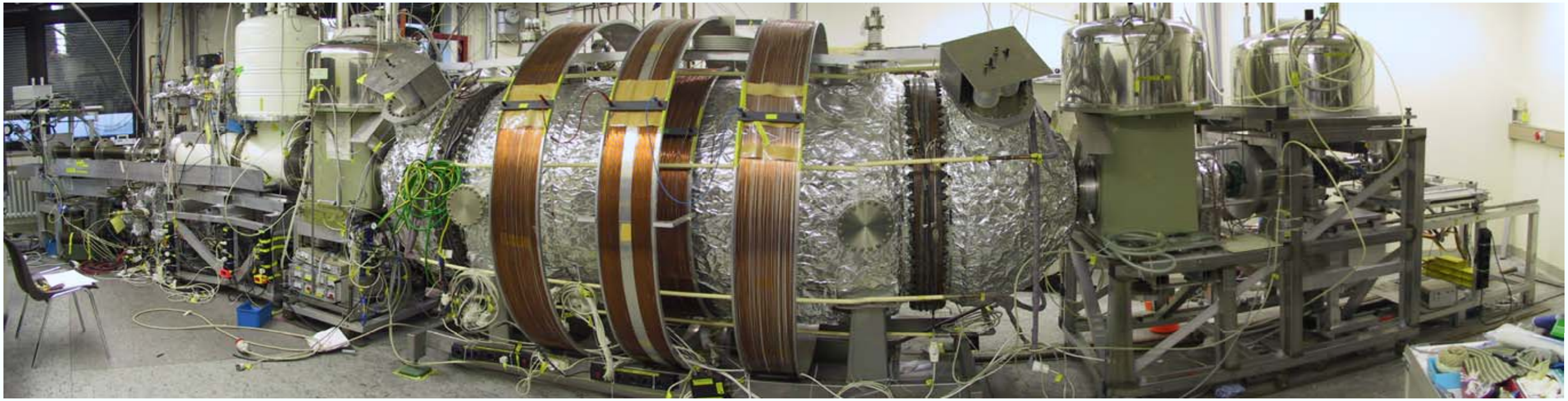
mass eigenstates

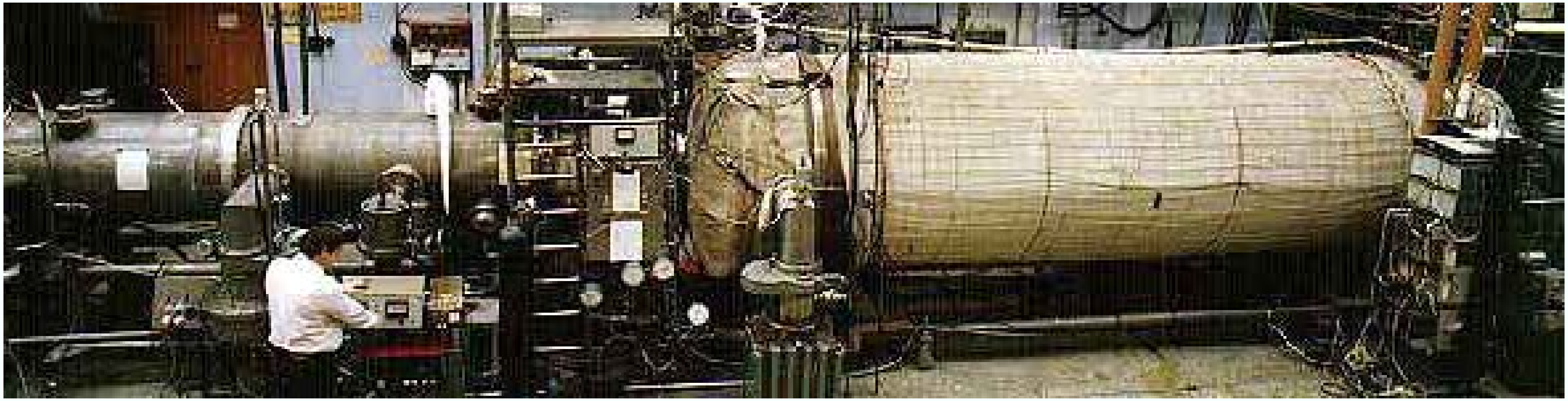
absolute neutrino mass scale??



The most stringent direct upper limits on m_ν

electrostatic filter with magnetic adiabatic collimation (MAC-E)



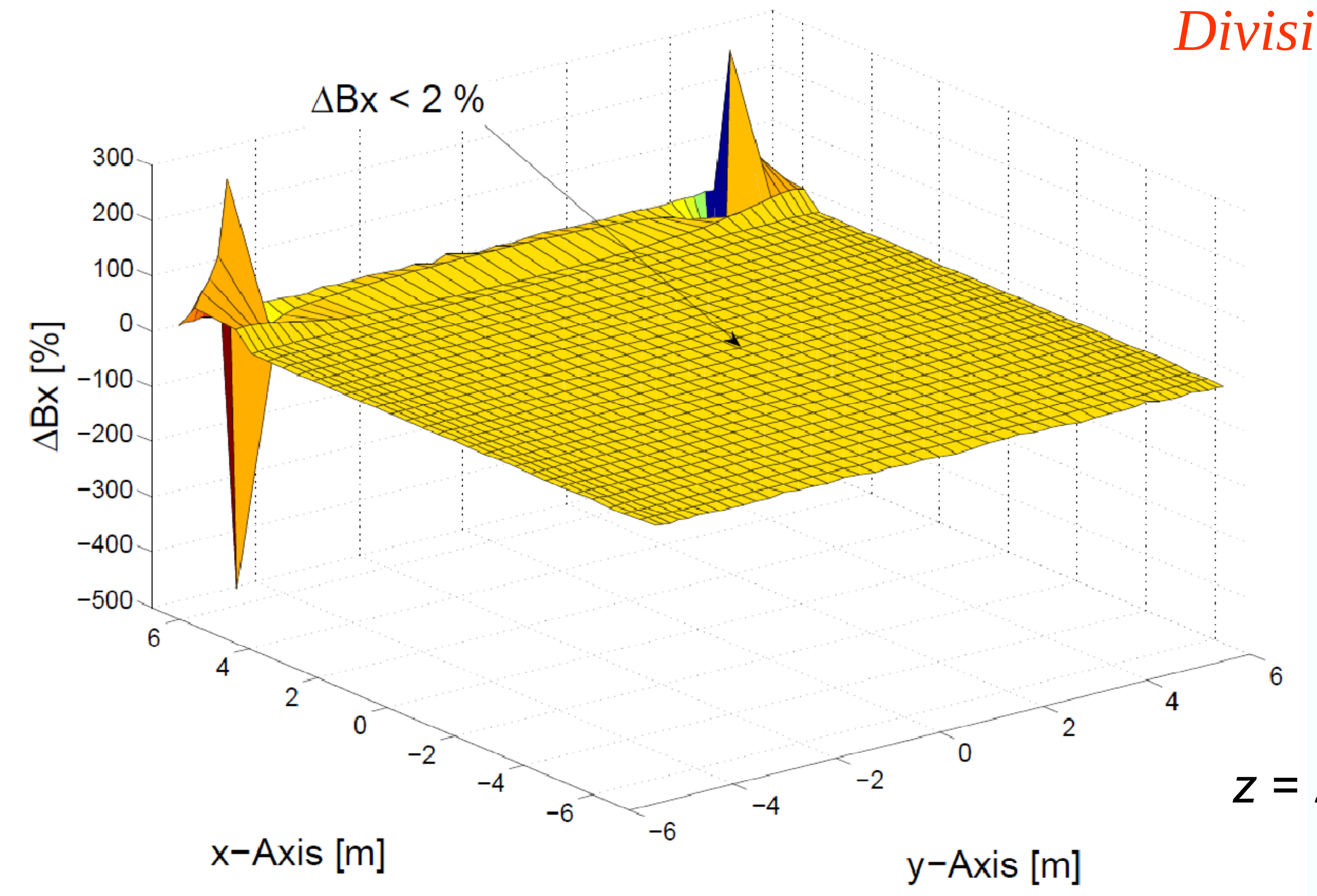


Simulation results

rel. difference

$$\Delta B_x = \frac{B_{xrec} - B_{xorg}}{B_{xorg}}$$

Spikes: Division by ~ 0

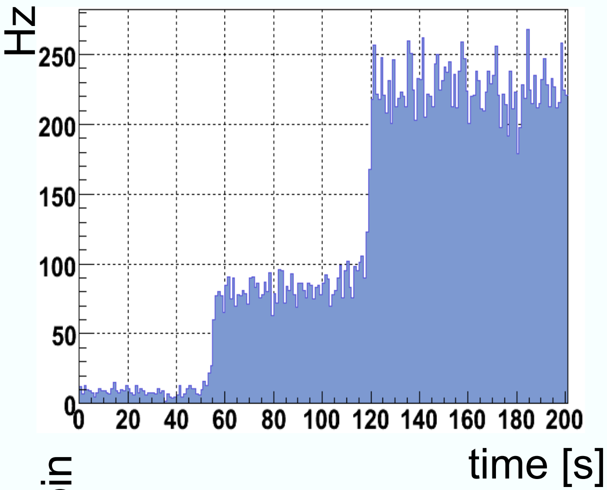


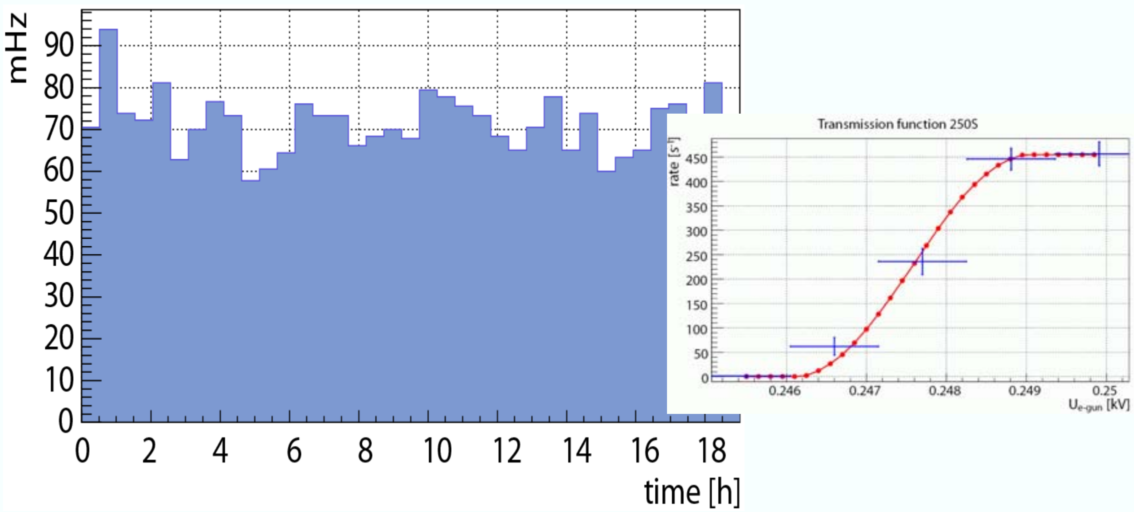
z = 2.4994 m

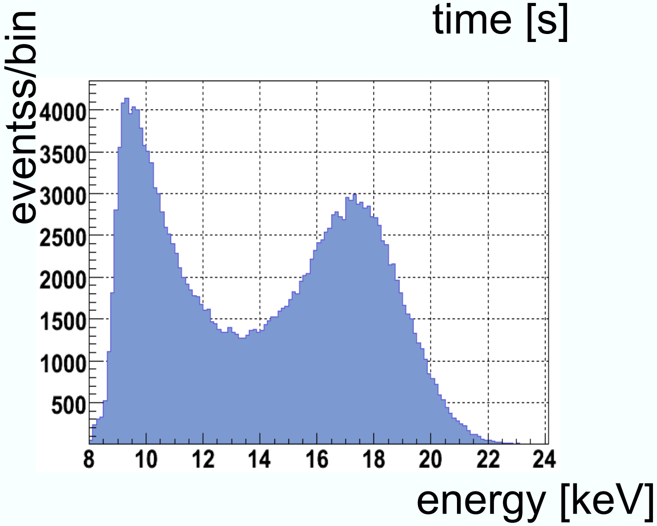
new electrode to avoid Penning trap

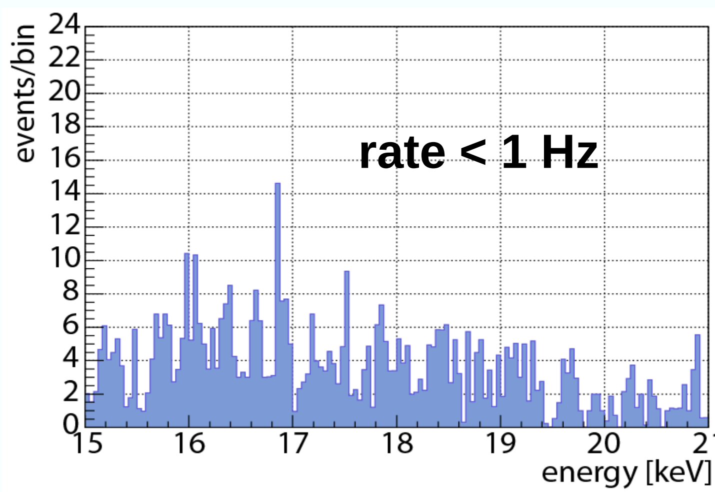
before

after









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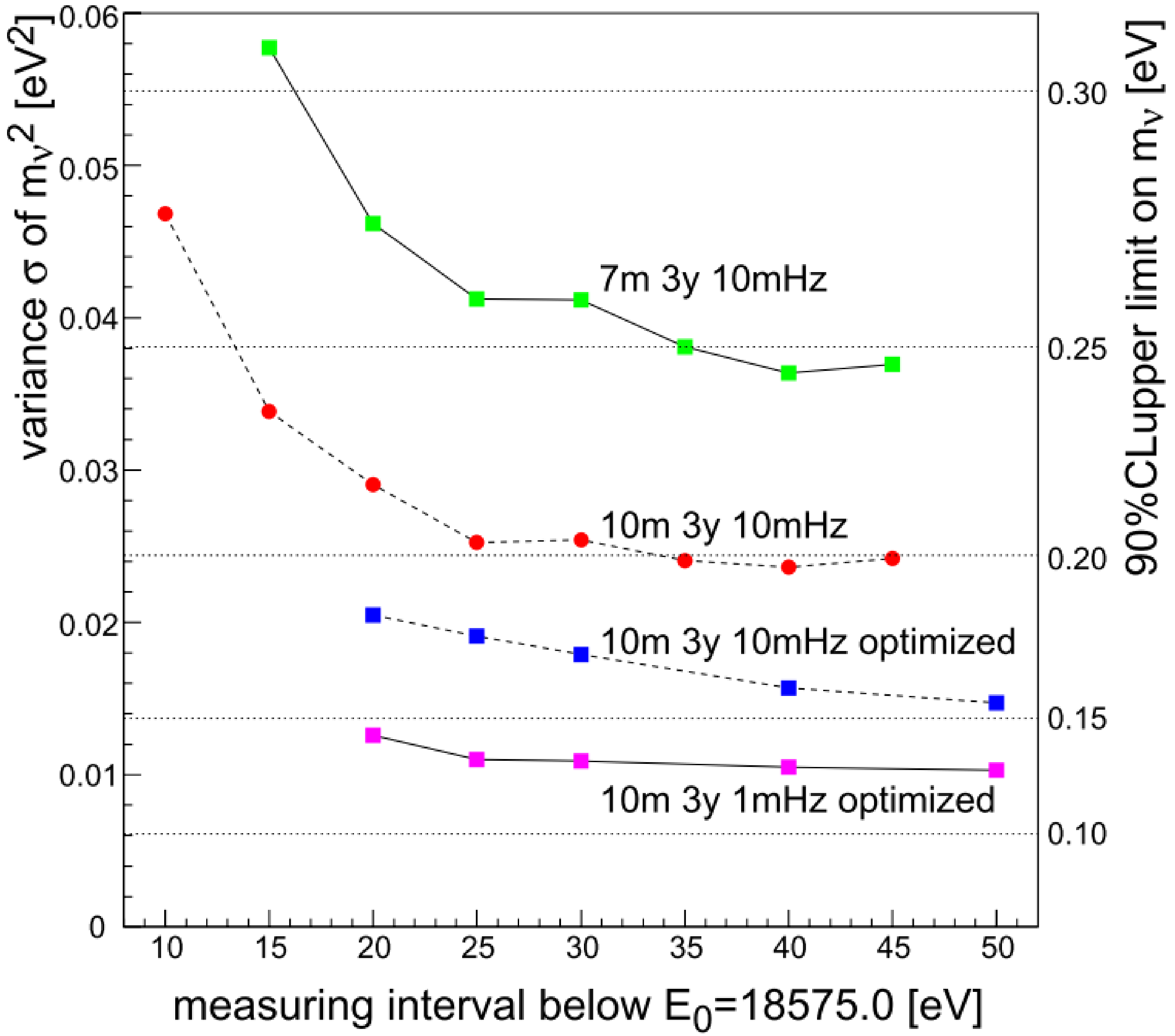
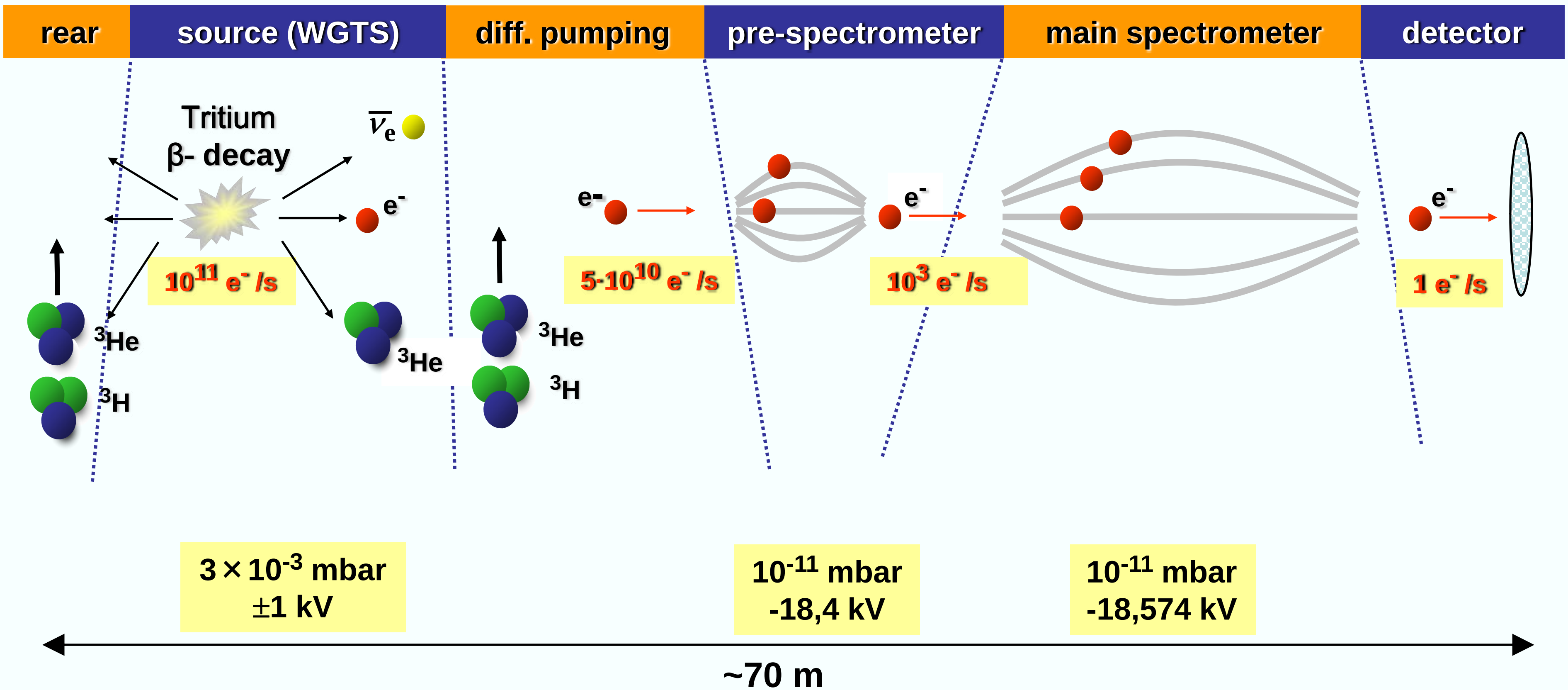
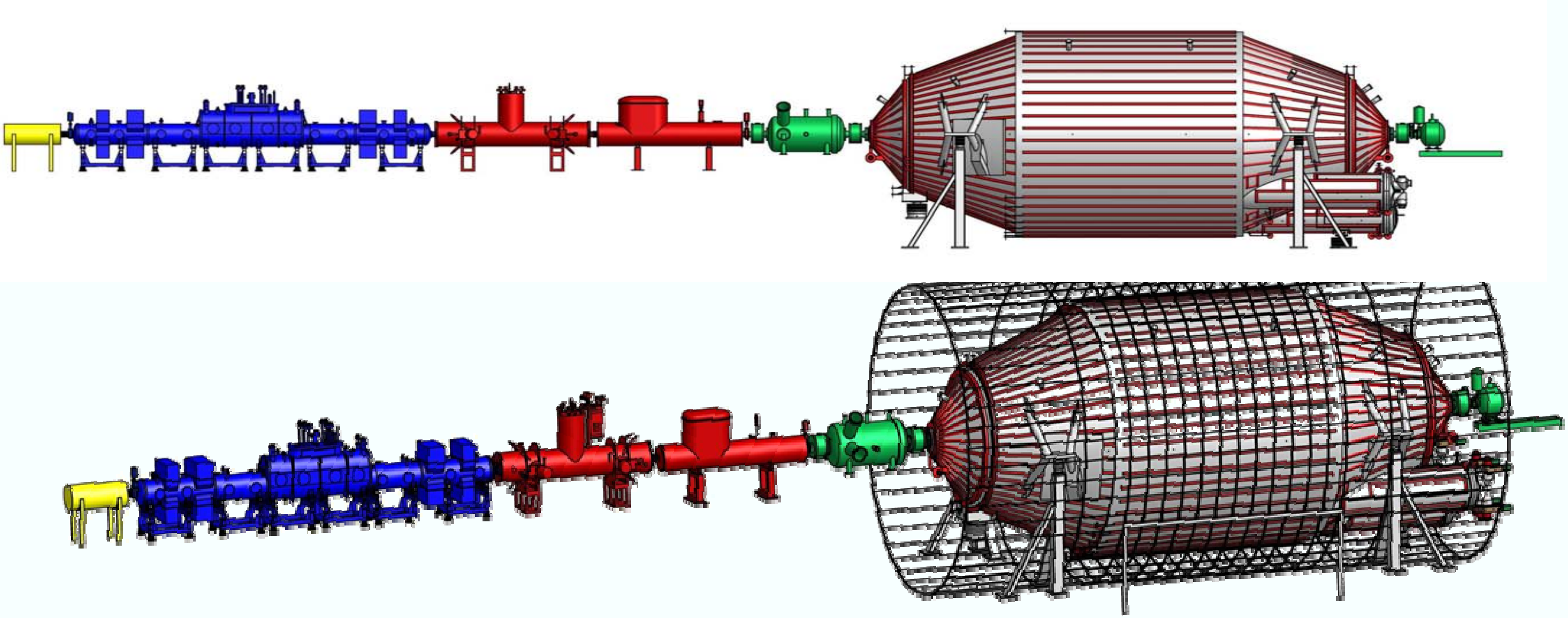


KATRIN main components

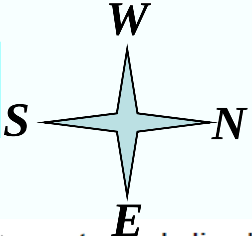
source & transport section | spectrometer & detector section

source parameter	stable tritium column density	electron transport tritium retention	reflection of low energy electrons	high precision energy analysis of electrons	position sensitive electron counter

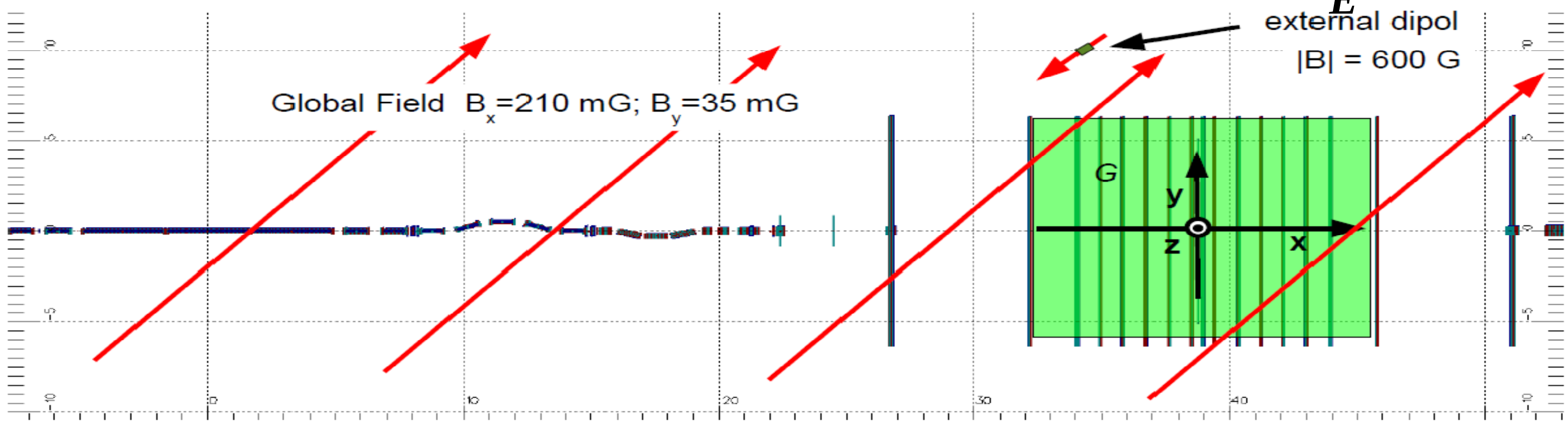




Simulation conditions



PartOpt View of simulation scenario



- *volume : -7.03 m < x < 6.83 m, R = 6 m*
- *global field*
- *external dipol*
- *LFCS energised*
- *bounday values randomised to sim 2% sensor error*
- *Calc. Time: MATLAB: 4-5 days, C: < 5 min*

$$\Delta B_x = \frac{B_{xrec} - B_{xorg}}{B_{xorg}}$$