Karlsruhe Institute of Technology

Status of the KATRIN experiment

Europhysics Conference on High-Energy Physics (EPSHEP)
2011/07/22, Grenoble

Sebastian Fischer for the KATRIN collaboration **Karlsruhe Institute of Technology**

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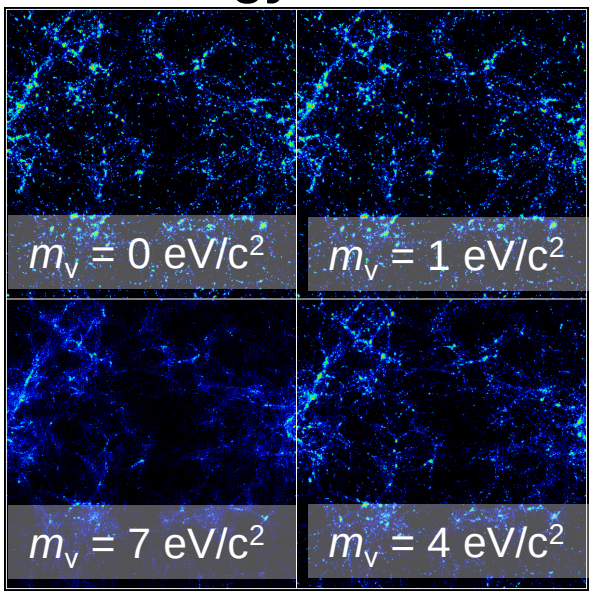
- Motivation of m_ν measurement
- KATRIN experiment
  - Measurement principle
  - Status

Motivation for neutrino mass measurement

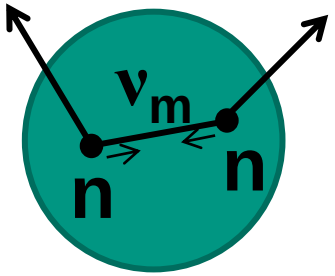
Cosmology



$\Sigma m_\nu < (0.6 – 2)$ eV/c²

(95 % C.L.) (Hannestad)

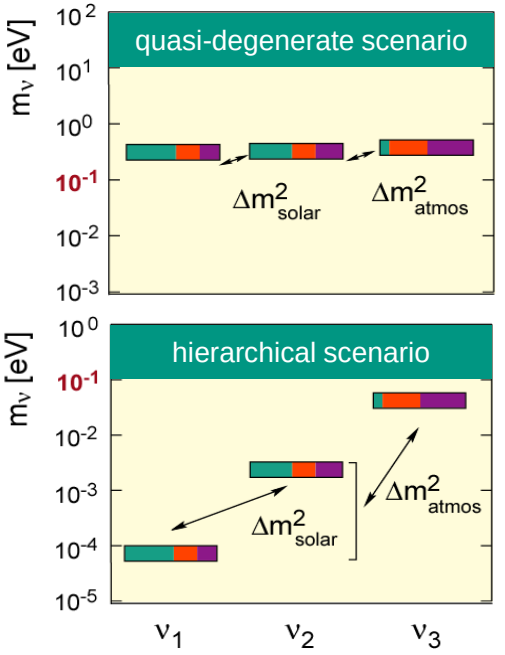
0νββ decay



$$\left\langle m_{\beta\beta} \right\rangle = \sum_{i=1}^{3} \left| U_{e,i} \right|^2 m_i \cdot e^{i\alpha_i} \leq 0,35 \text{ eV}$$

(Heidelberg-Moscow, IGEX)

Mass hierarchy



Neutrino oscillations:

Atmospheric neutrinos:

$(\Delta m_{32})^2 \cong 2.4 \times 10^{-3}$ eV²/c⁴

Solar neutrinos:

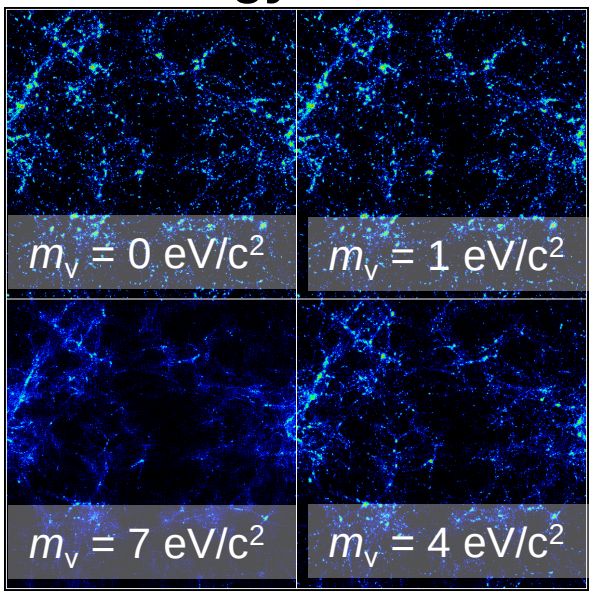
$(\Delta m_{21})^2 \cong 7.6 \times 10^{-5}$ eV²/c⁴

→ **$m_\nu \neq 0$**

(PDG08)

Motivation for neutrino mass measurement

Cosmology



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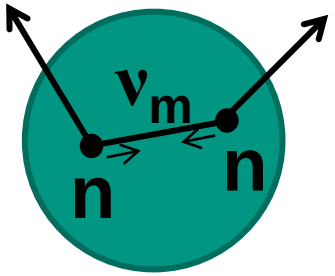

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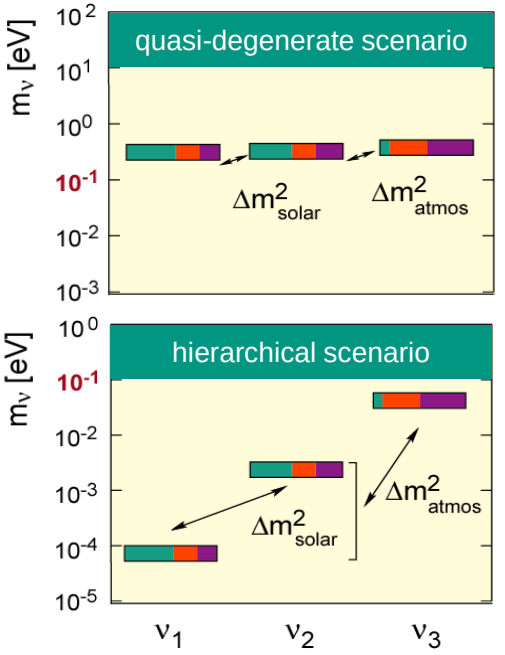

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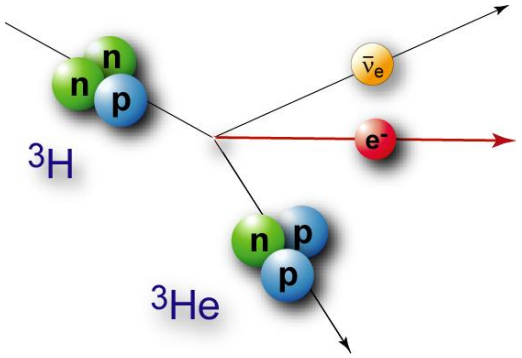
Direct beta decay measurements (Mainz, Troitsk):

$m_\nu < 2$ eV/c² (95 % C.L.) (PDG08)

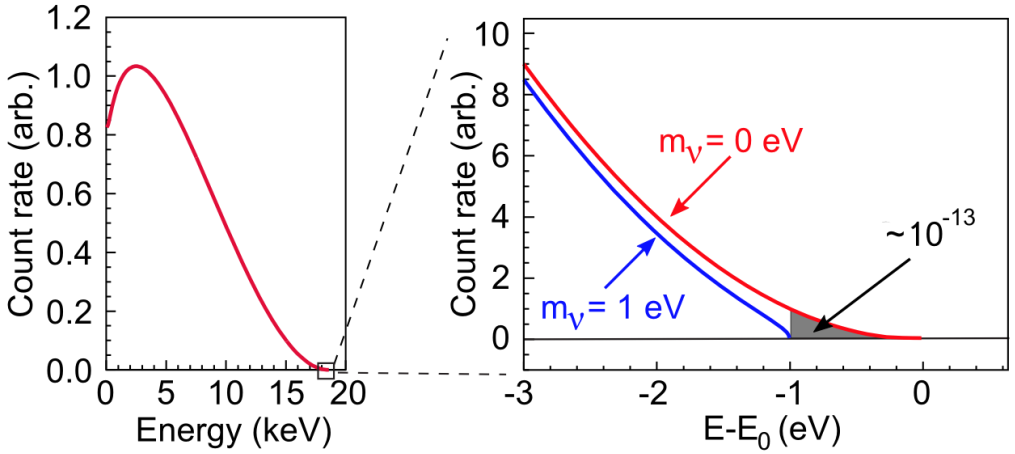
Improved direct measurement necessary

Tritium beta decay



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

E_0 = 18.6 keV
$T_{1/2}$ = 12.3 y

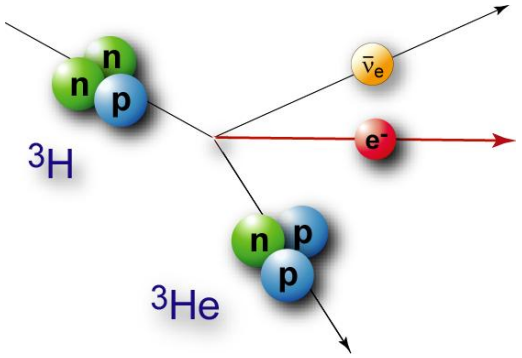


$$\frac{dN}{dE} = C \cdot F(E,Z) \cdot p(E + m_e) \cdot (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_\nu^2}$$

observable:

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

Tritium beta decay



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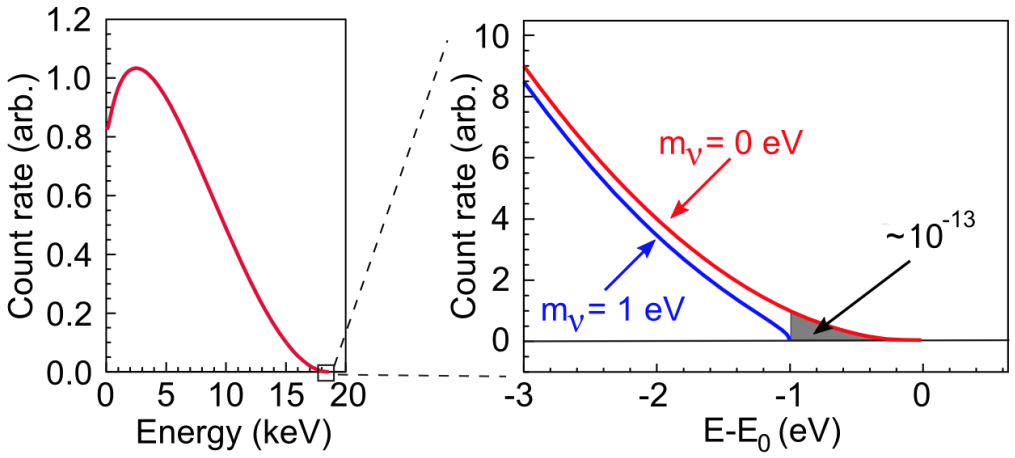

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- Requirements:
  - High tritium activity
    → Strong source (> 1 GBq)
  - High energy resolution (< 1 eV)
  - Low background + small systematic uncertainties

KATRIN experiment:
200 meV sensitivity (90 % C.L)

The KATRIN experiment

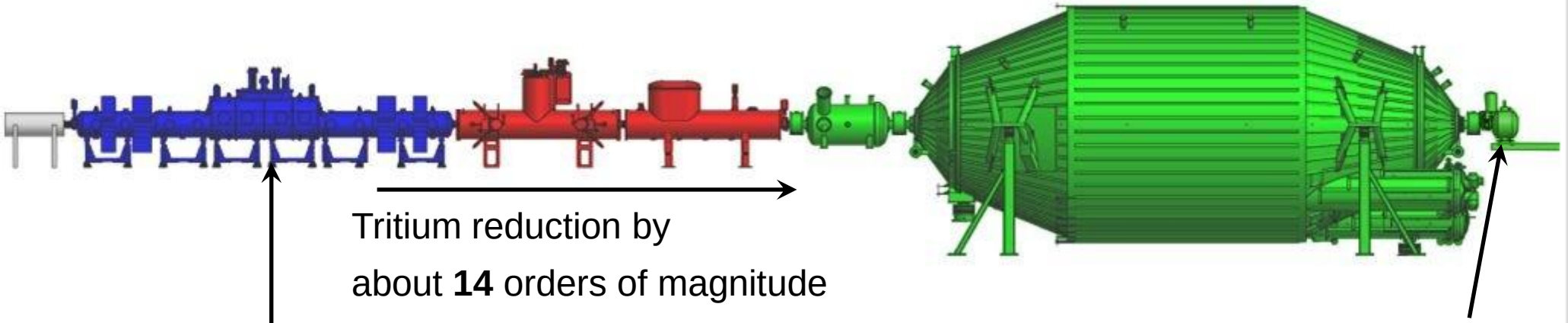
(**KA**rlsruhe **TRI**tium **N**eutrino experiment, location: Karlsruhe, Germany)

70 m

tritium decay

electron transport
tritium retention

energy analysis + detection



Tritium reduction by
about **14** orders of magnitude

β-decay rate: **10^{11}** Hz

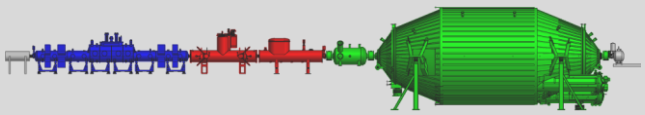
T_2 gas flow: 1 mbar l / s

background rate < **10** mHz

T_2 gas flow < **10^{-14}** mbar l /s

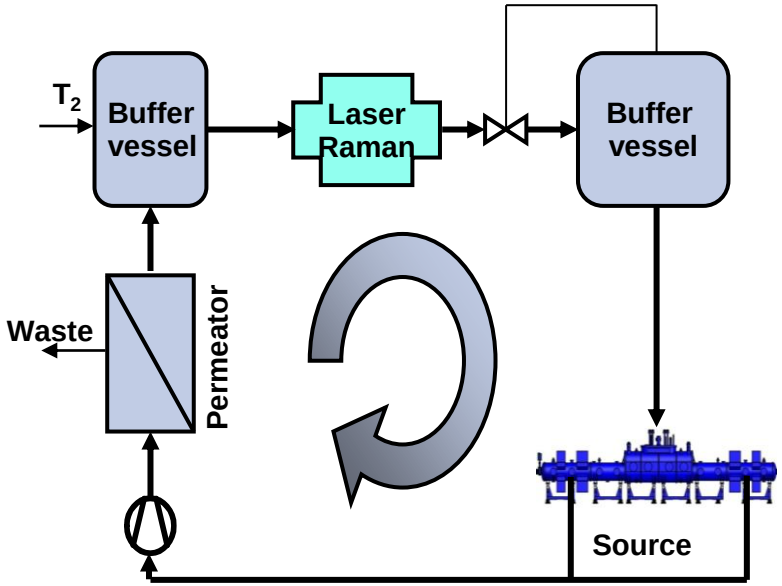
→ pressure < **10^{-20}** mbar

adiabatic guiding of electrons on meV level



Windowless gaseous tritium source (WGTS)

- Closed tritium loop “Inner loop”
  - 40g tritium / day = $1.5 \cdot 10^{16}$ Bq /day
  - > 95% tritium purity
  - Pressure stabilization $\Delta p/p < 0.1\%$



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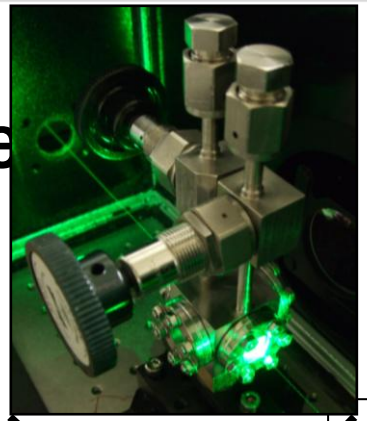
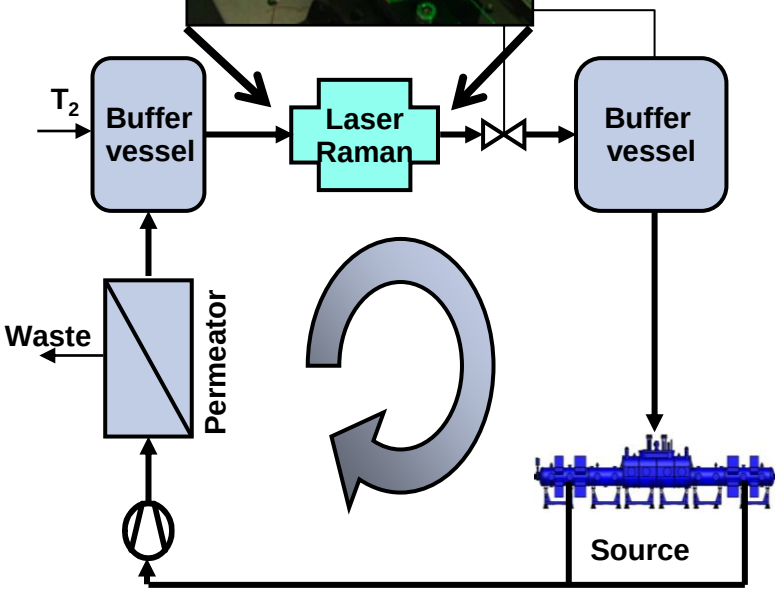
Laser Raman spectroscopy with 0.1% (1σ) precision





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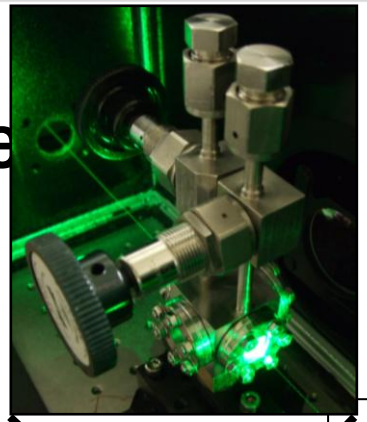
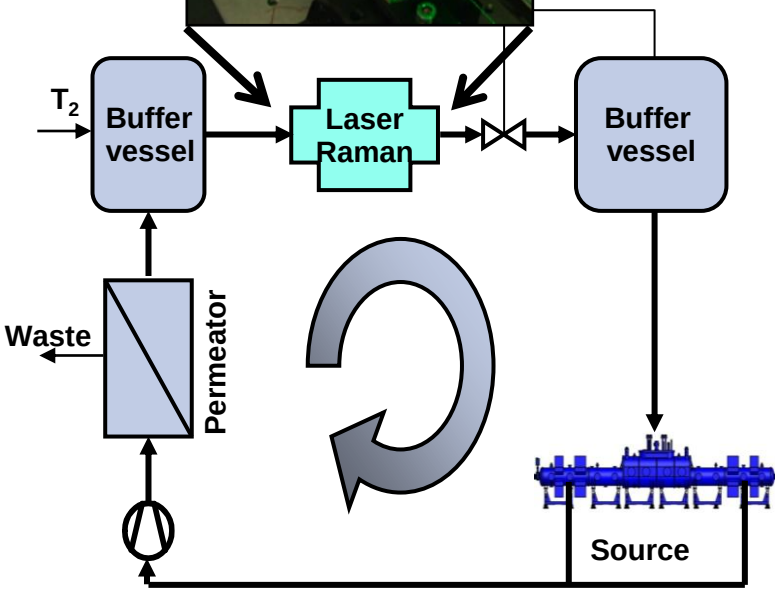
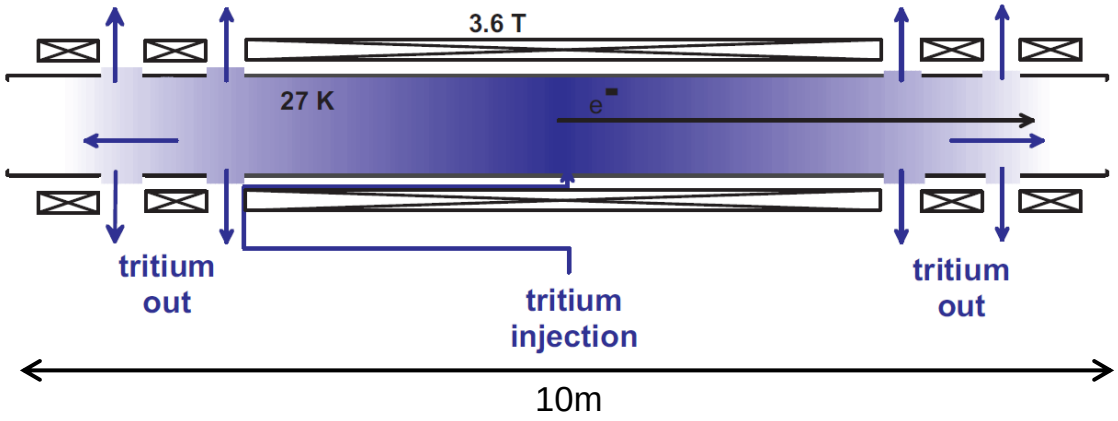




- WGTS cryostat
  - Superconducting solenoids (3.6T)
  - 10m long beam tube @ 30K with ΔT < 30 mK
    - 2 phase Ne cooling circuit



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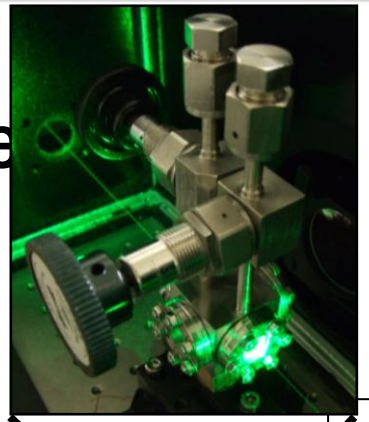
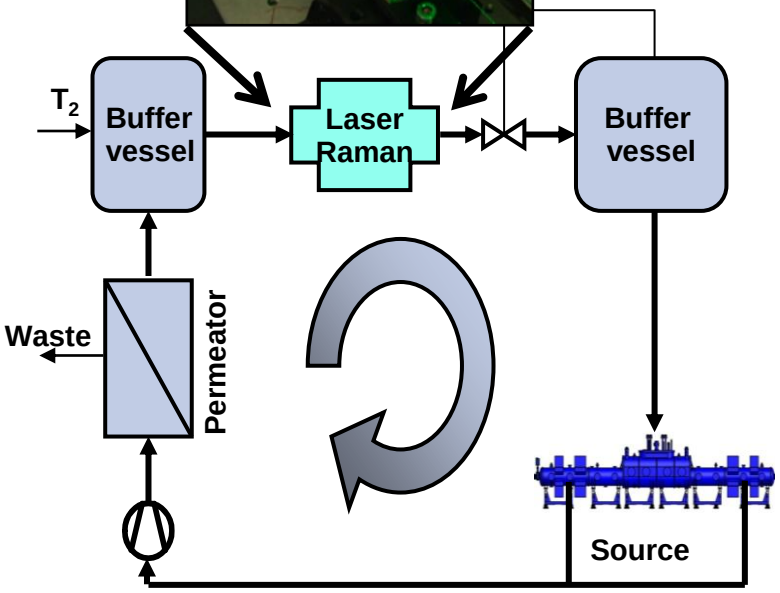
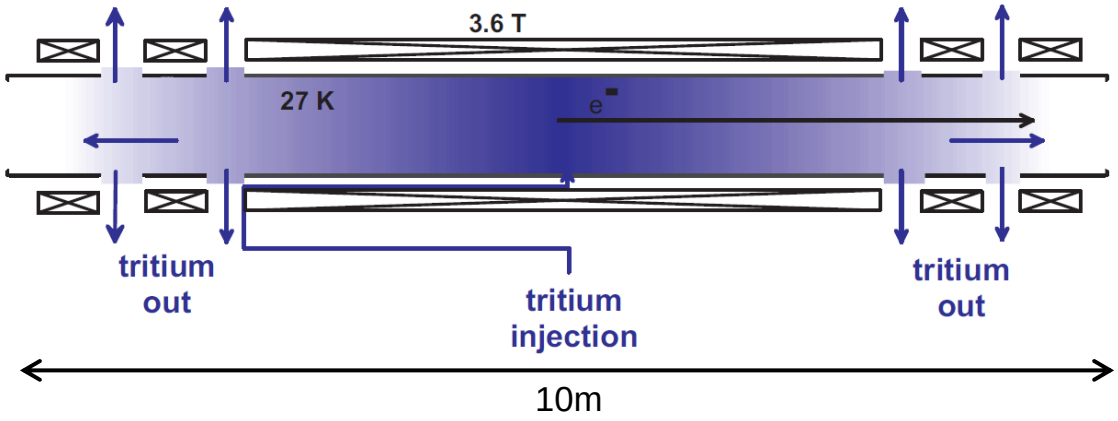
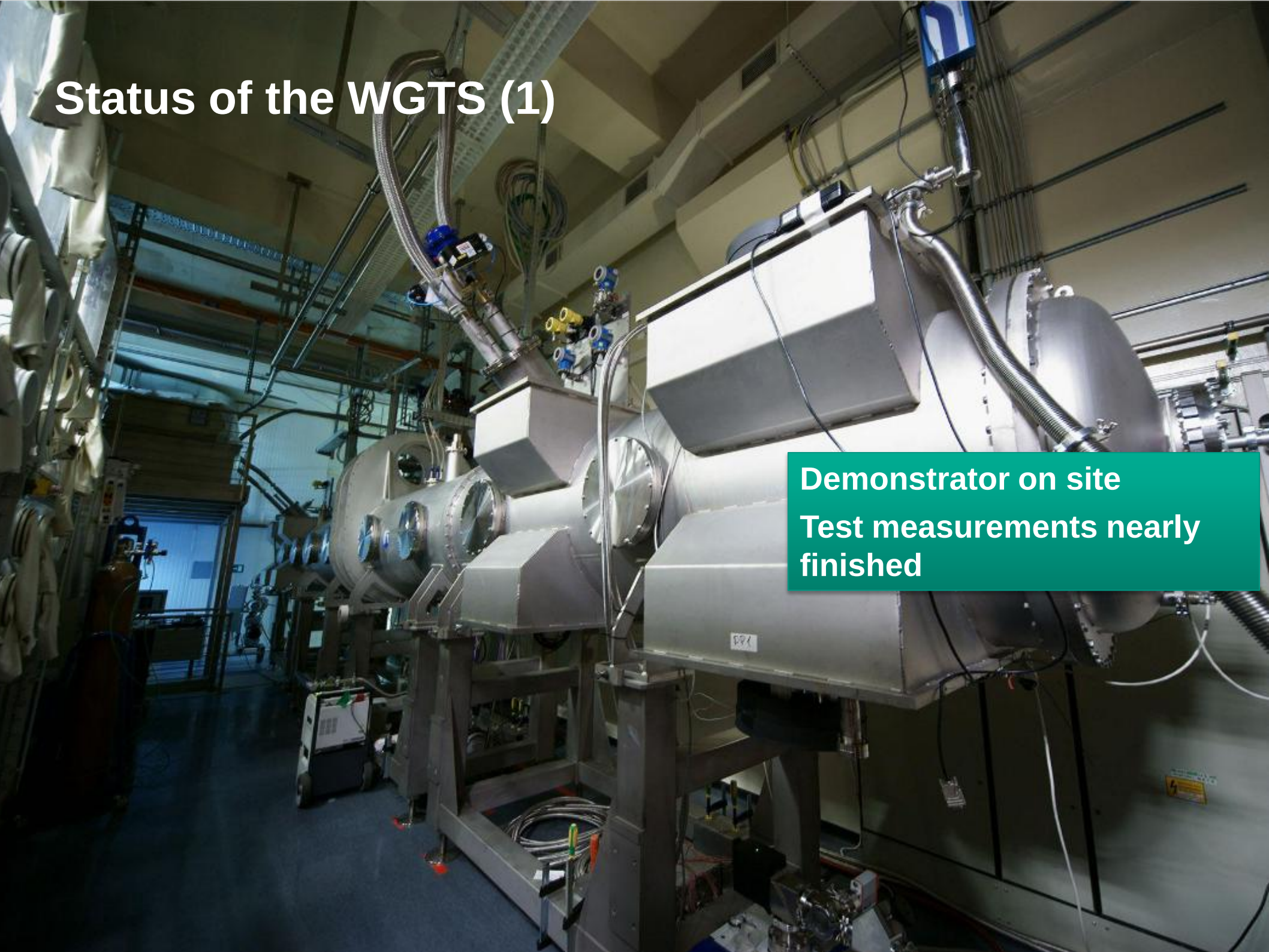
Experimental test necessary → „Demonstrator“







Status of the WGTS (1)



Demonstrator on site

Test measurements nearly finished

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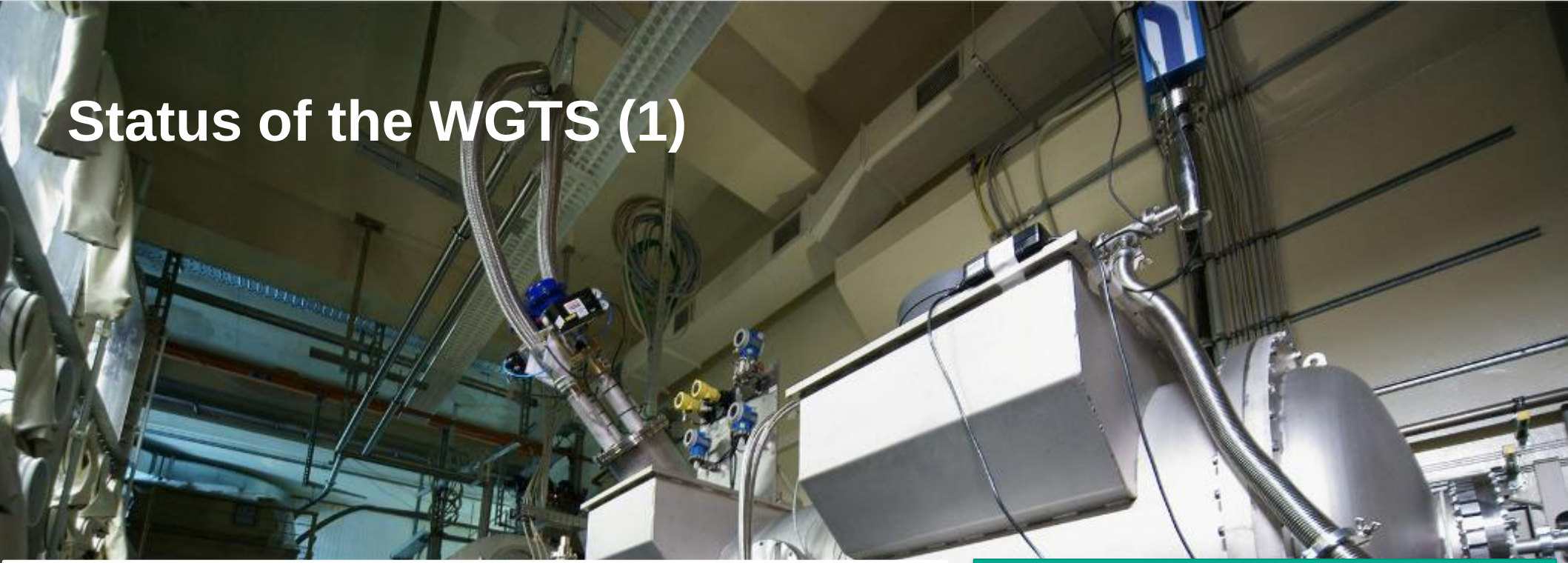

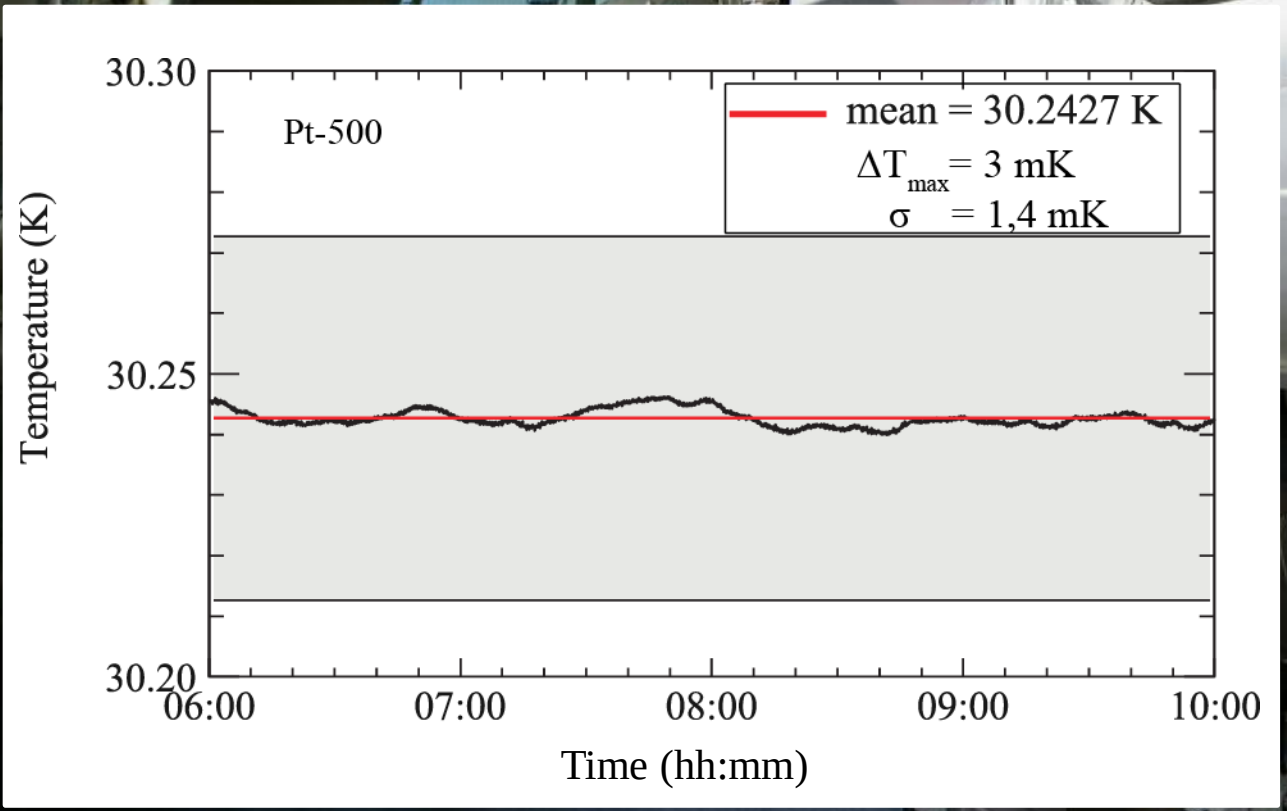

Demonstrator on site

Test measurements nearly finished

Temperature stability in mK range
→ Improvement by 10-20 w.r.t. specification

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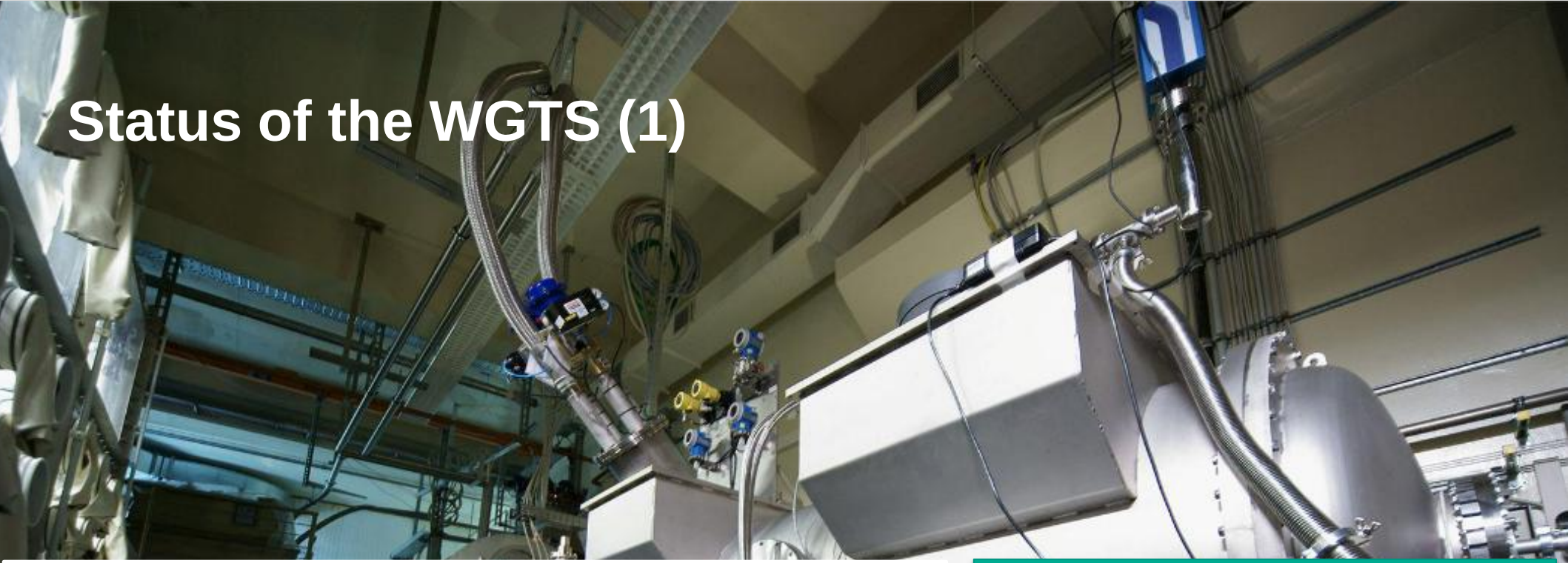

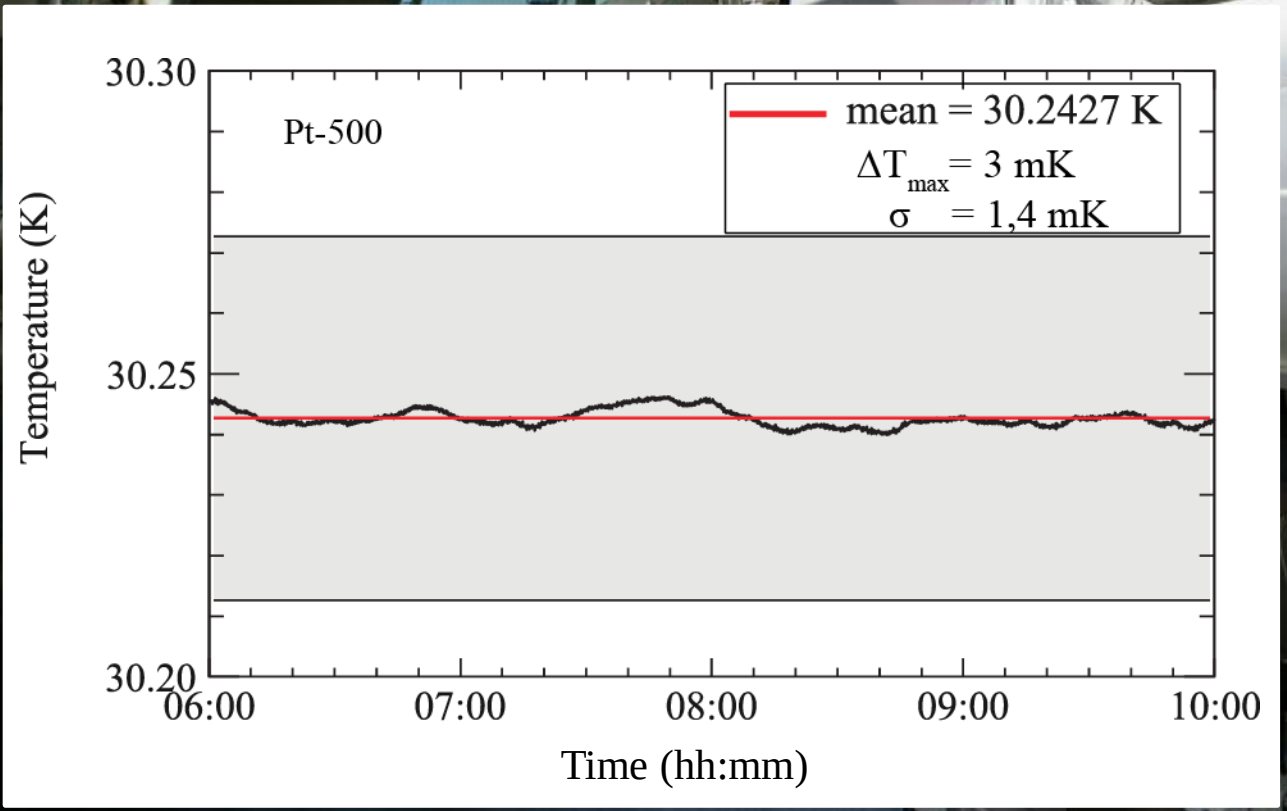

Demonstrator on site

Test measurements nearly finished

Temperature stability in mK range
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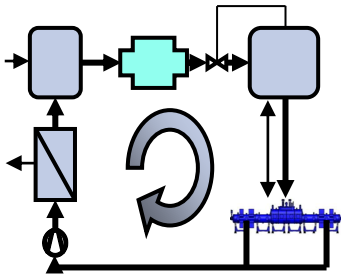
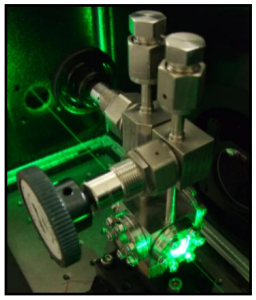
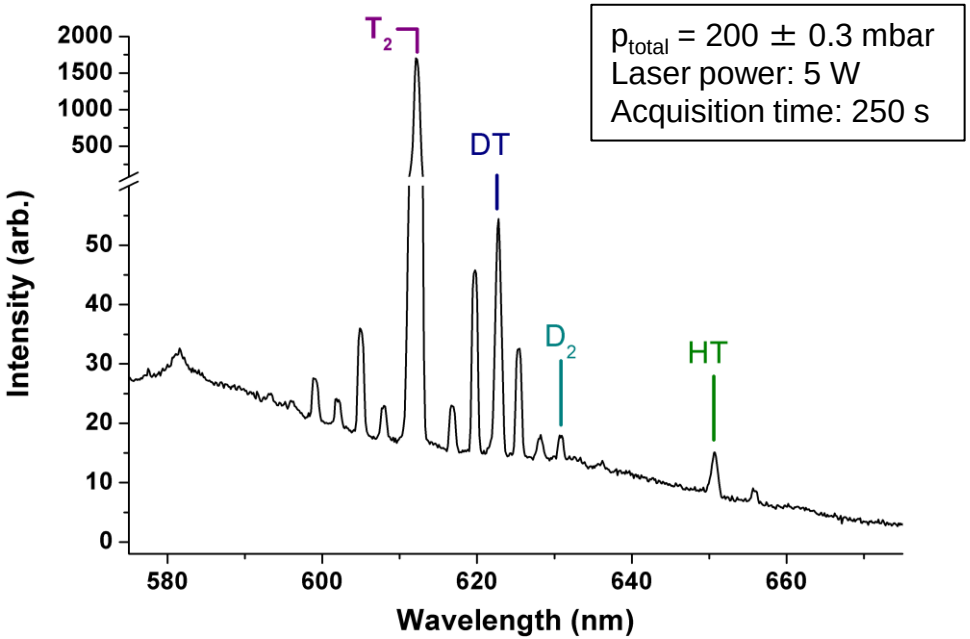
Next step: Upgrade Demonstrator → WGTS

Status of the WGTS (2)

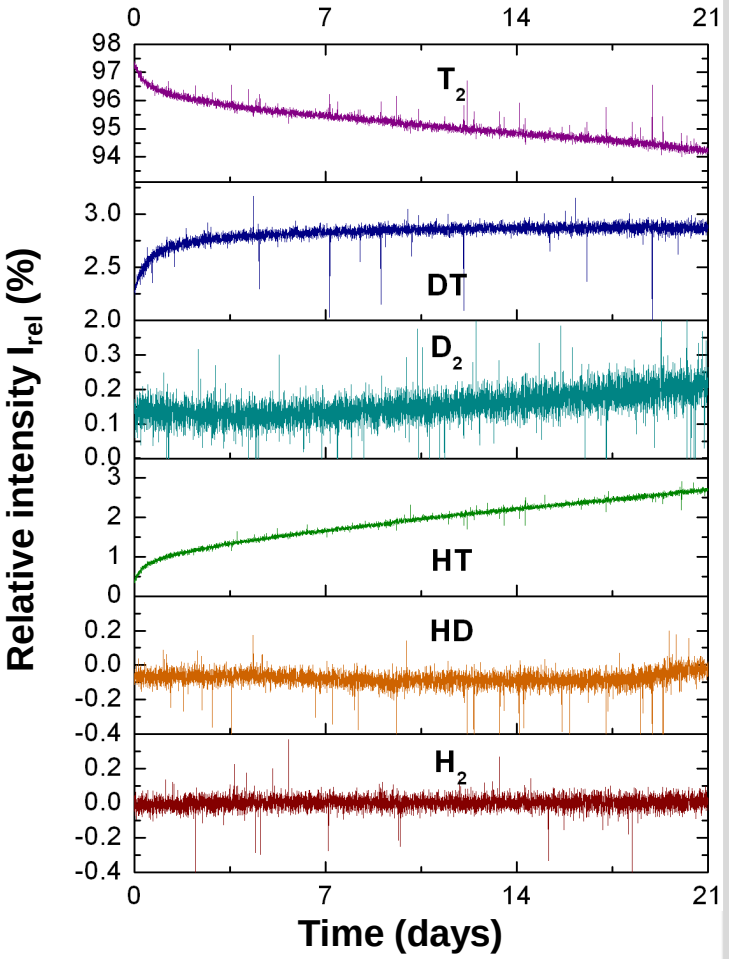
- Inner Loop system
  - Pressure fluctuations < 0.02%
    → 5 times better than specified
- Laser Raman (LARA) system
  - Study of systematic effects
  - Nonstop test of LARA
    over > 21 days







p_{total} = 200 ± 0.3 mbar
Laser power: 5 W
Acquisition time: 250 s



S. Fischer, et al., Fusion Sci. Technol., in press (2011)

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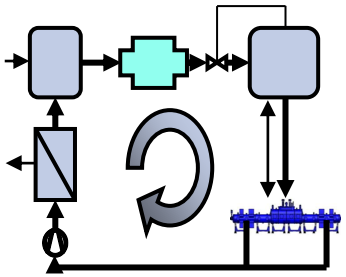

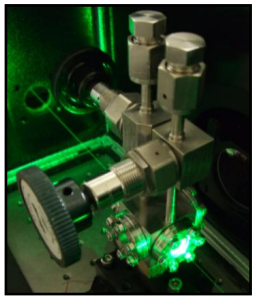

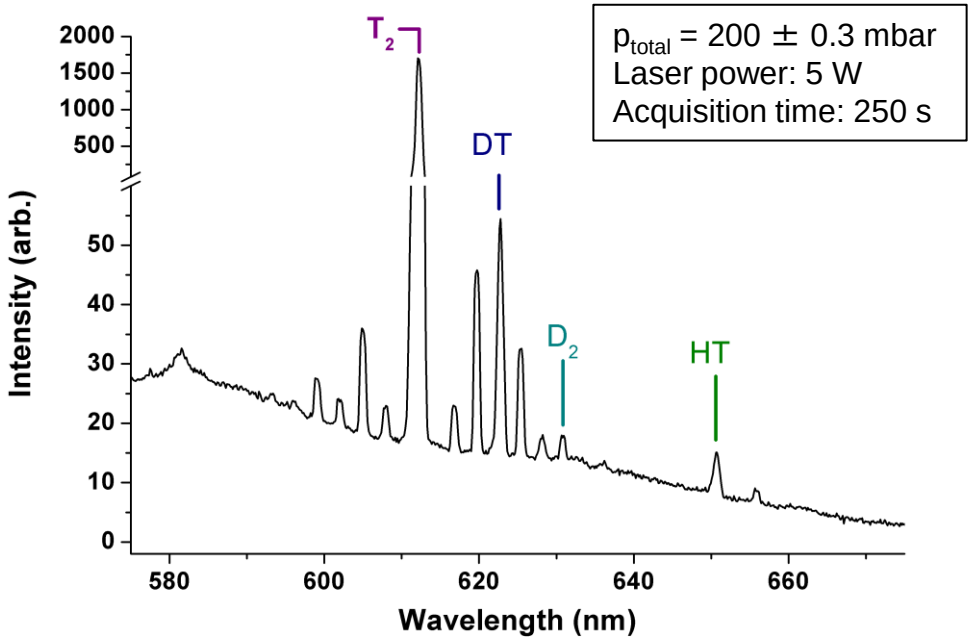

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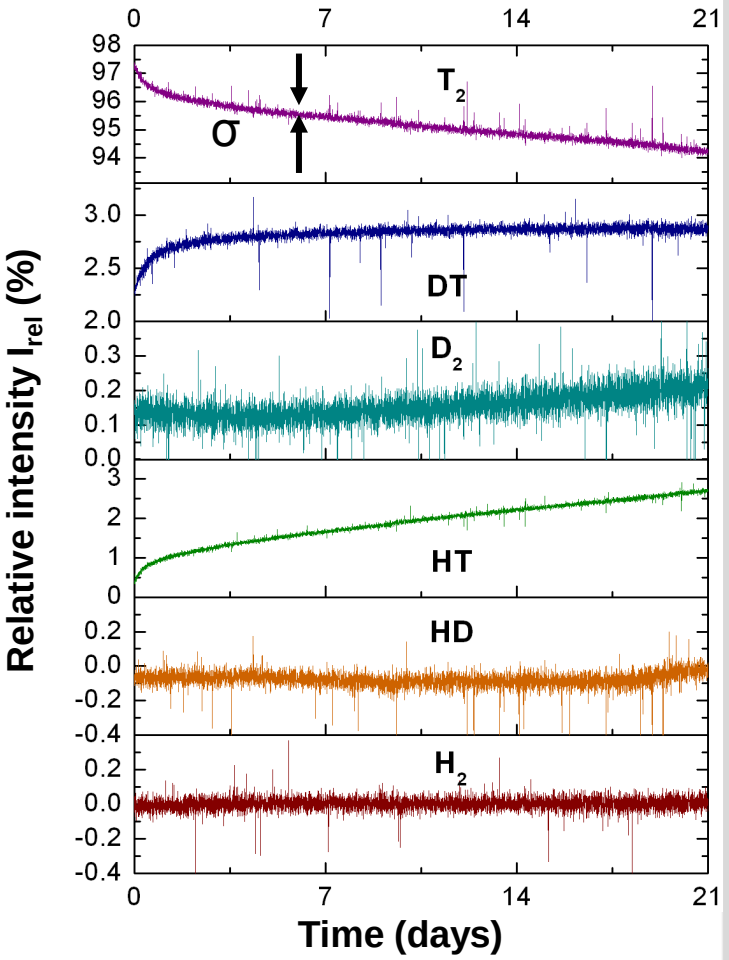
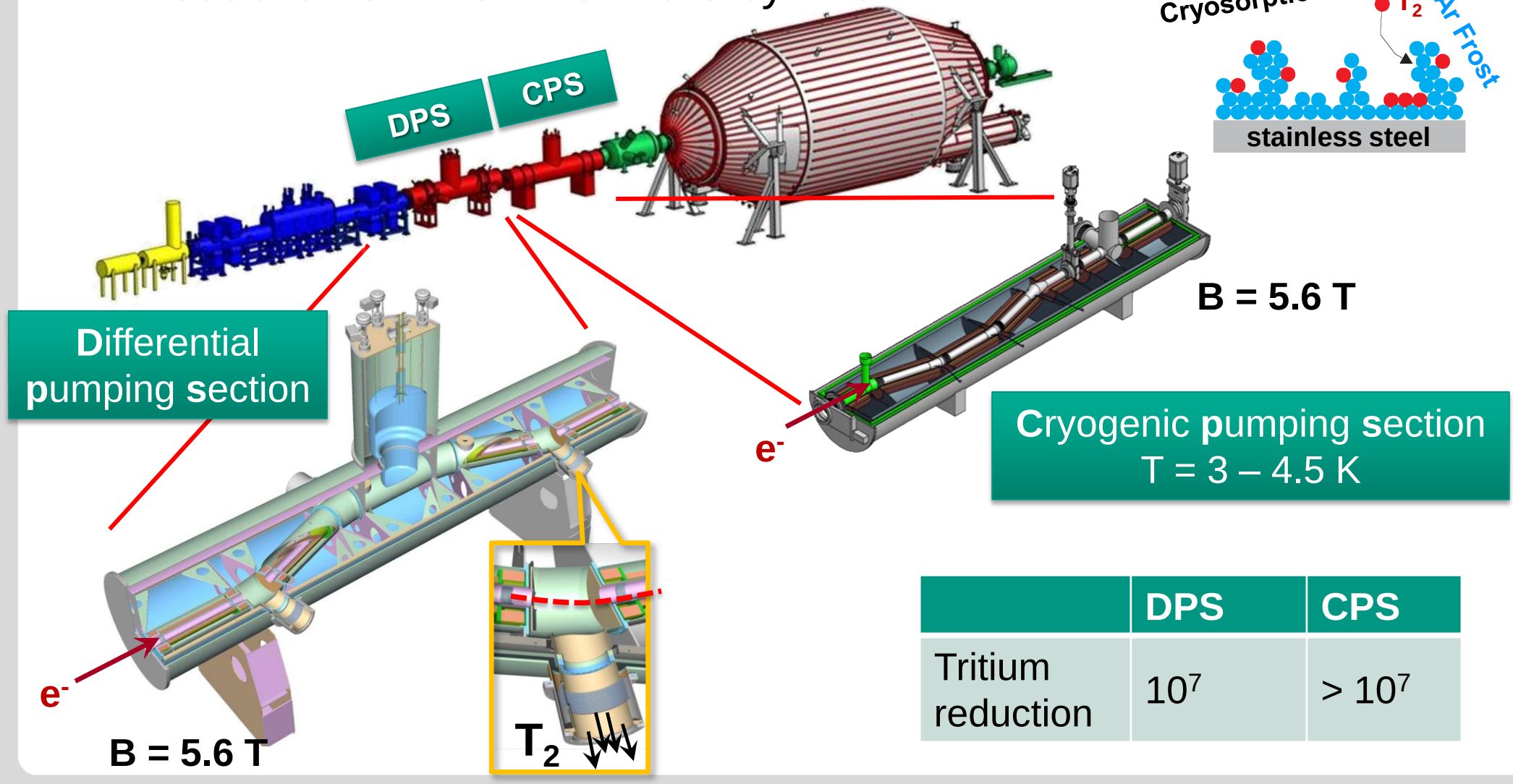


0.1% precision (1σ) reached
→ KATRIN requirements fulfilled

S. Fischer, et al., Fusion Sci. Technol., in press (2011)

Transport section

- Adiabatic guidance of electrons to spectrometers
- Reduction of tritium flow rate by >10^{14}



	DPS	CPS
Tritium reduction	10^7	$> 10^7$

Status of the transport section

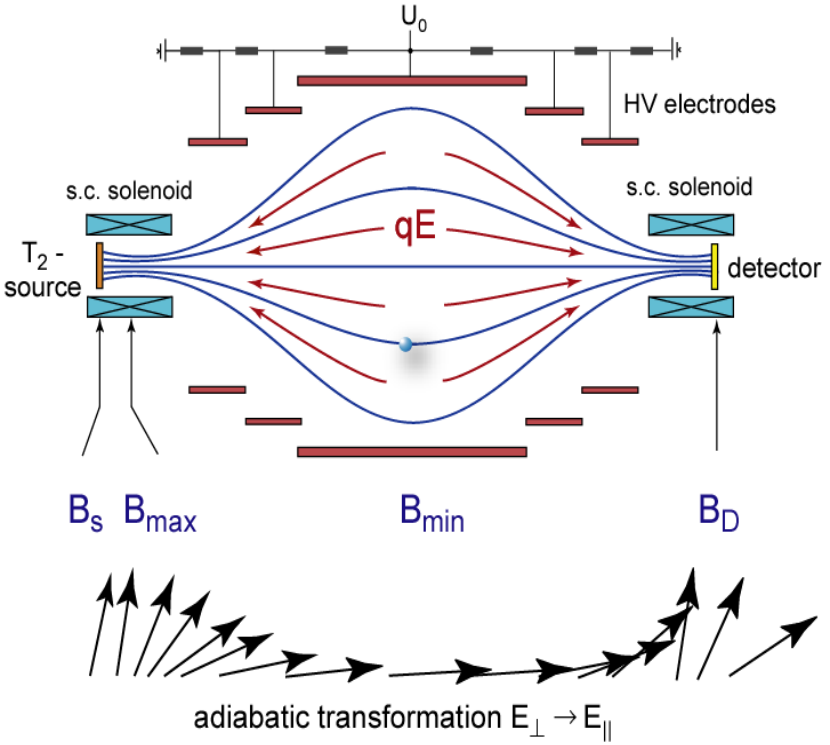
- DPS2-F test program
  - Measurement of reduction factor ongoing
  - Measurement of electron guiding properties
- Cryogenic pumping section
  - Delivery to KIT in Spring 2012

DPS2-F on site at KIT

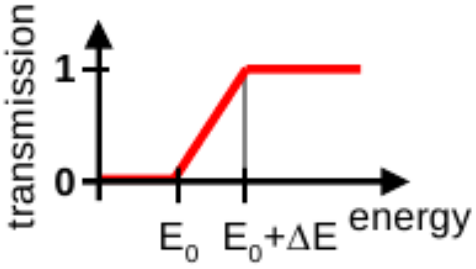
Gold plated beam tube of CPS

The MAC-E spectrometers

Magnetic Adiabatic Collimation with Electrostatic Filter



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



$B_{min} = 2 \cdot 10^{-4} B_{max}$

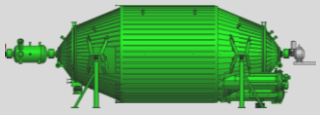
$\Delta E = E \cdot B_{min} / B_{max}$

$= 0.93$ eV $(E_0 = 18.6$ keV$)$

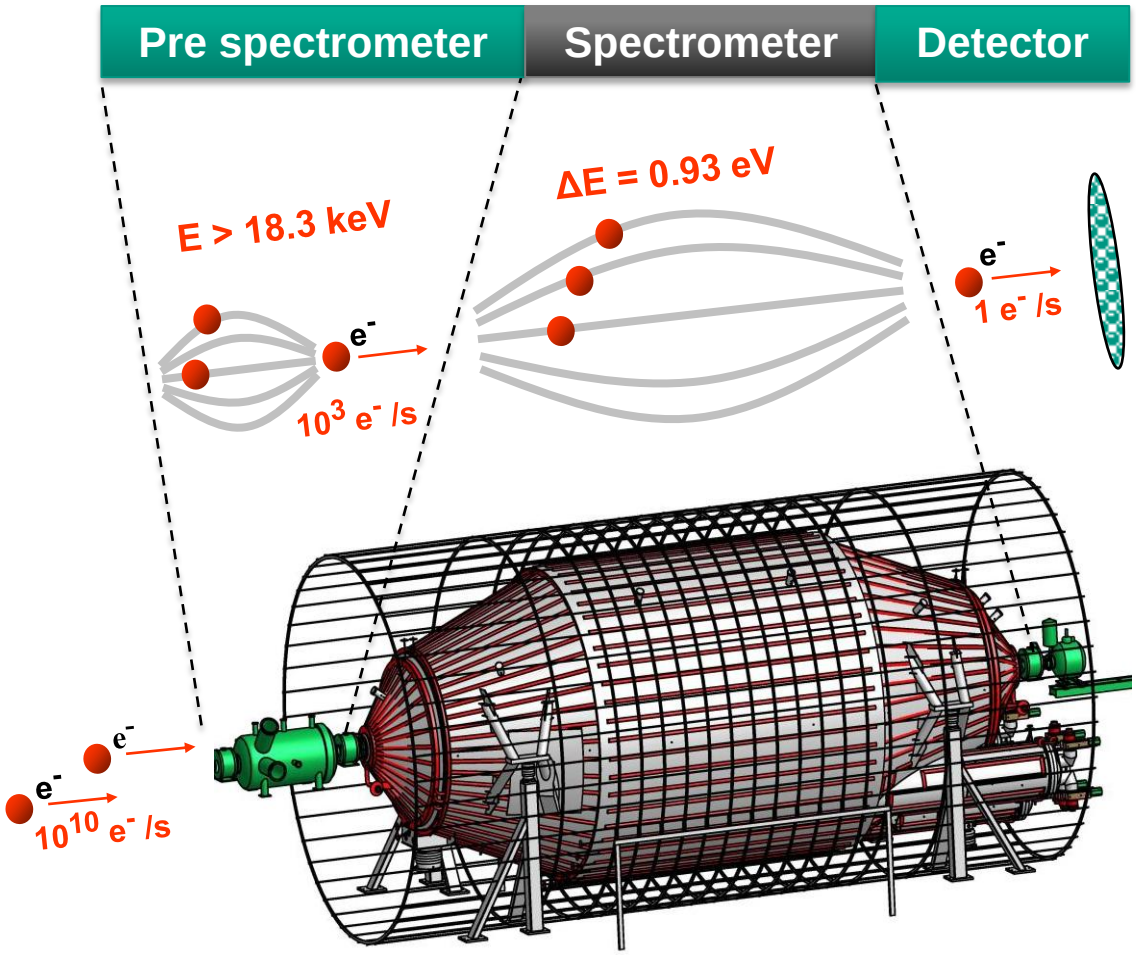
Magnetic moment $\mu = E_t / B = const.$

Magnetic adiabatic collimation

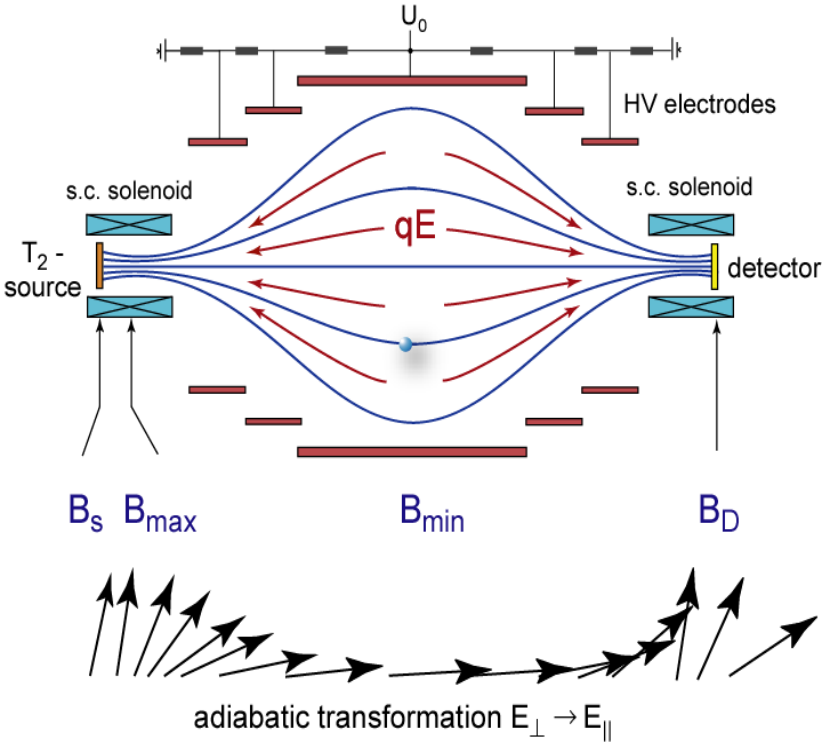
→ Large solid angle (2π)



The MAC-E spectrometers



Magnetic Adiabatic Collimation with Electrostatic Filter



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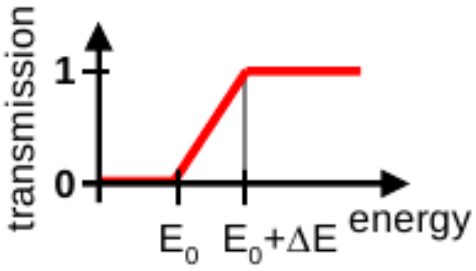

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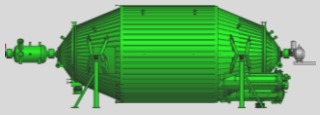
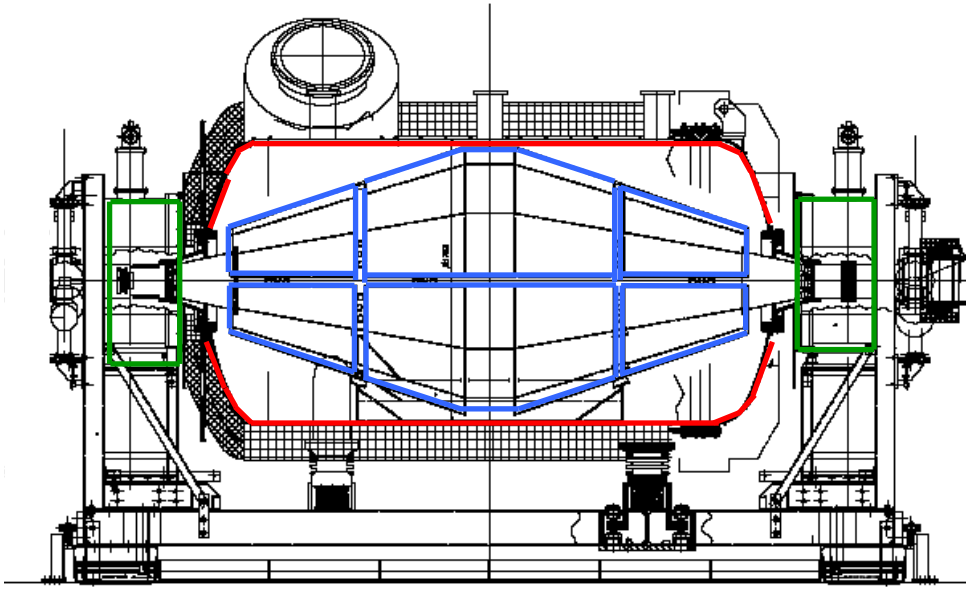
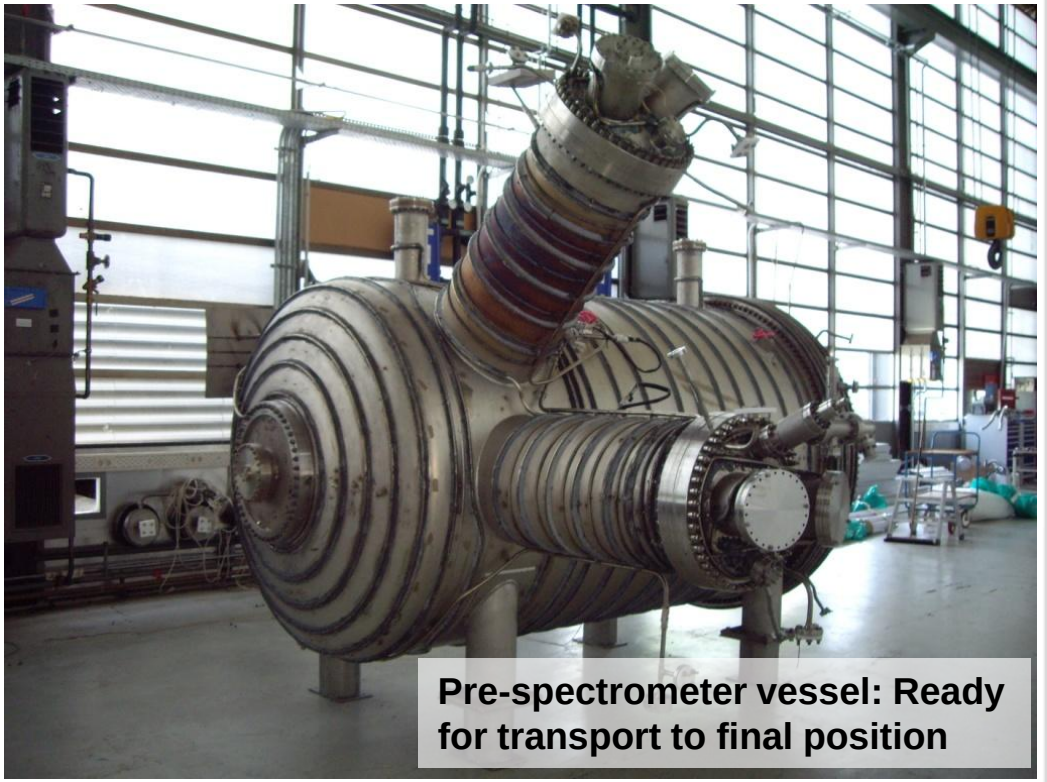


Status of the pre-spectrometer

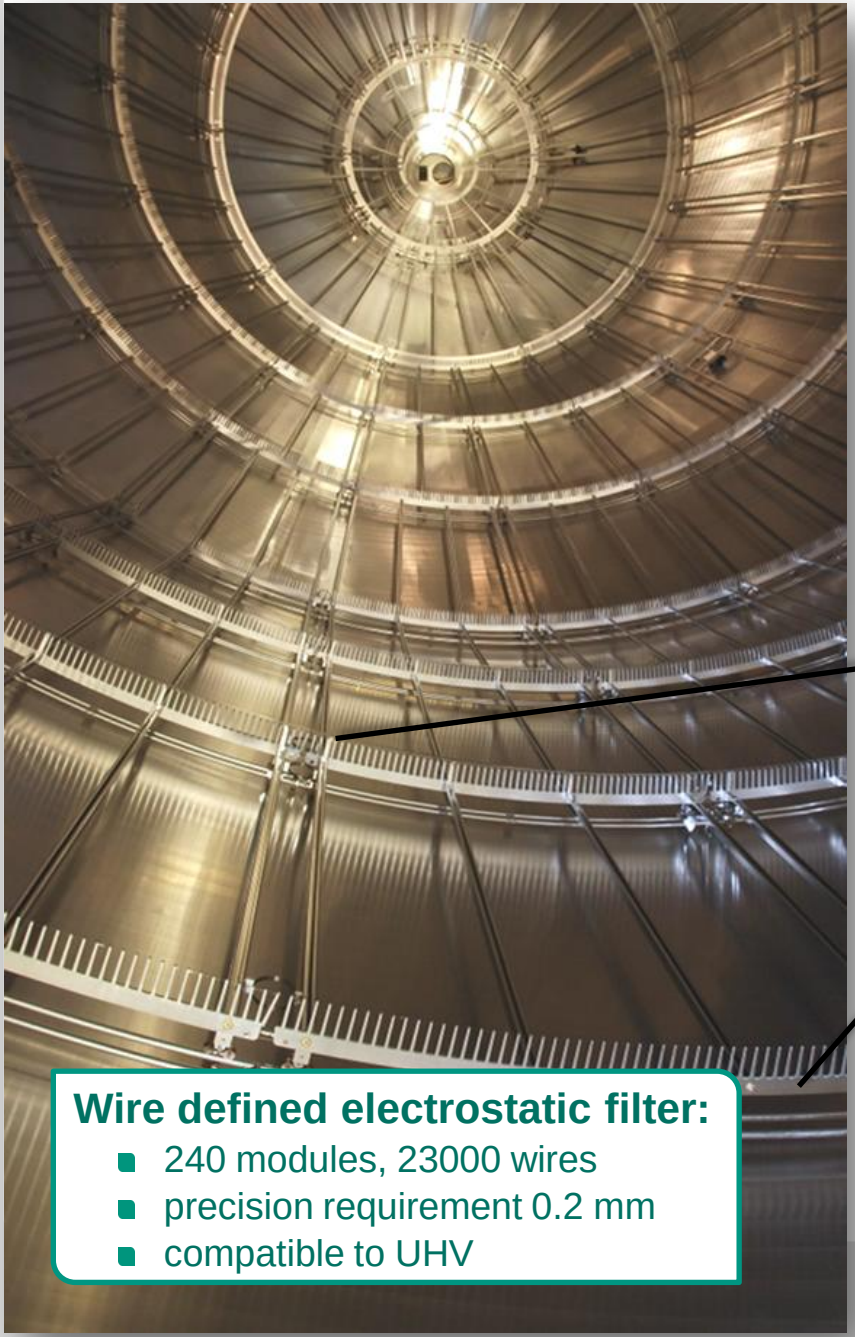
- Ground electrode design finished
- Radon-219 background identified and reduced
  → Background reduction
- Next step: Transfer to final position in spring 2012

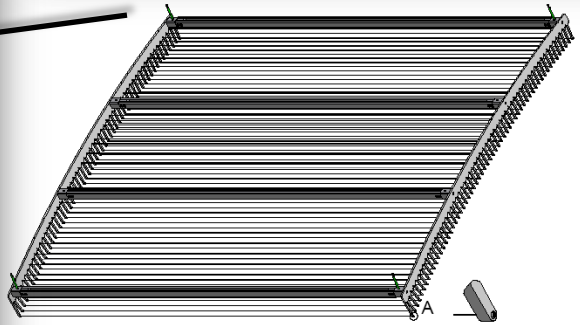




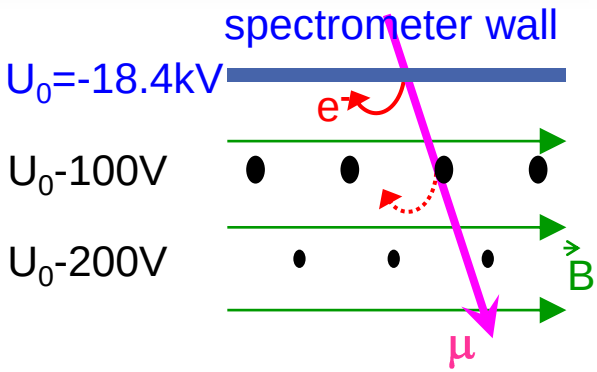
Pre-spectrometer vessel: Ready for transport to final position

Status of the main spectrometer





wire frame module

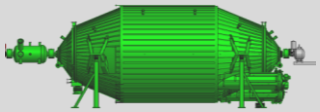


Wire defined electrostatic filter:

- 240 modules, 23000 wires
- precision requirement 0.2 mm
- compatible to UHV

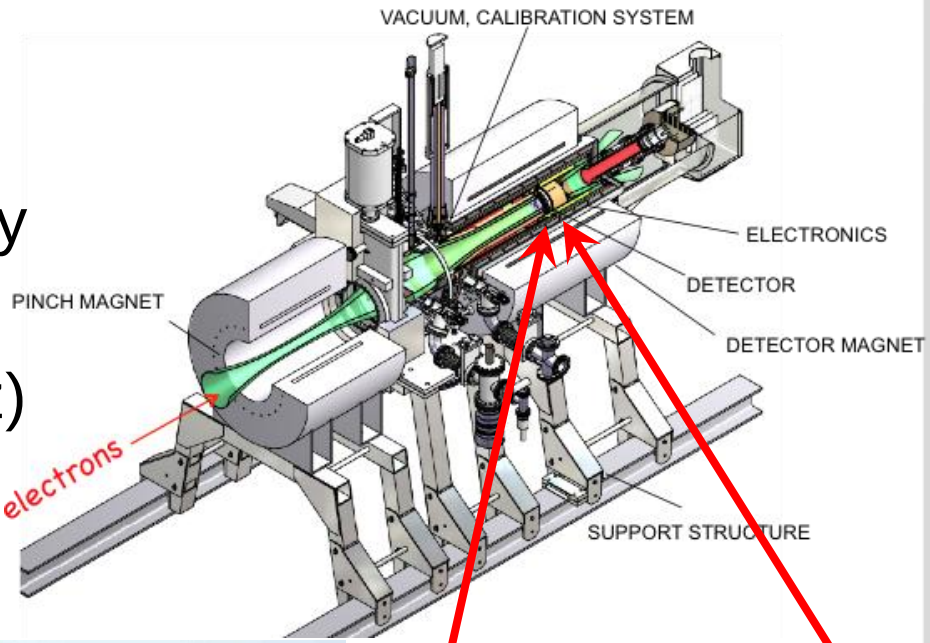
Wire modules installed

First measurements in spring 2012



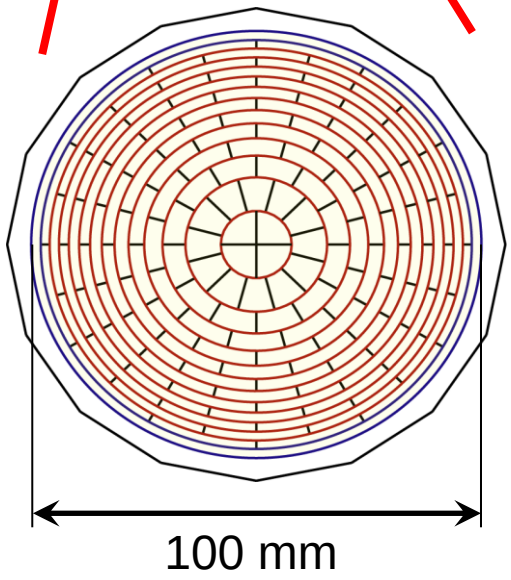
The detector system

- Segmented Si-PIN diode
- Detection of transmitted beta decay electrons (Hz to kHz)
- Low intrinsic background (< 1 mHz)
- Commissioning ongoing



Detector system at University of Washington before shipping

Delivery to KIT, July 2011

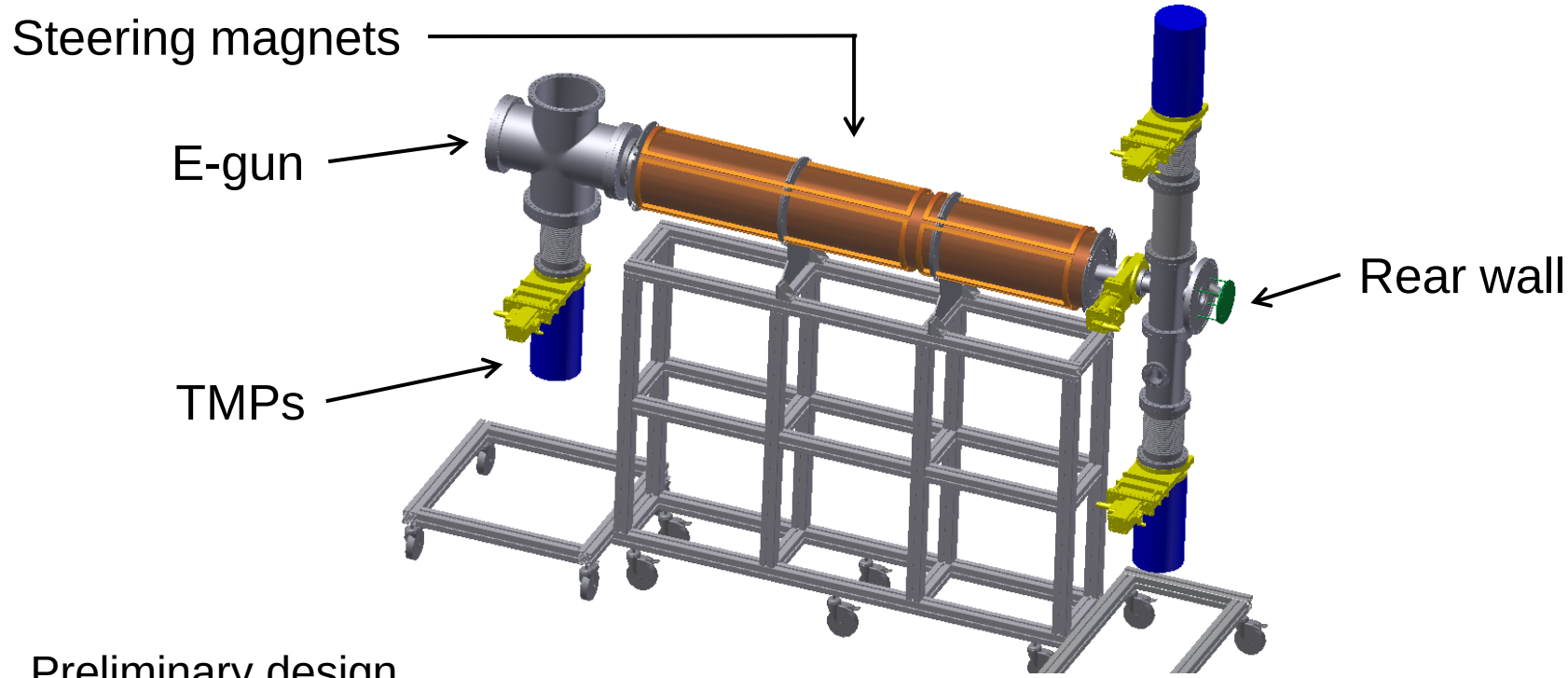


Summary

- Measurement of m_ν with 200 meV/c^2 design sensitivity (90 % C.L.)
- Electron spectroscopy of tritium beta decay
- Commissioning of components ongoing
- Many central parameters better than specified
- Many systematic effects understood
- Start of tritium measurements
  1 year after delivery of WGTS

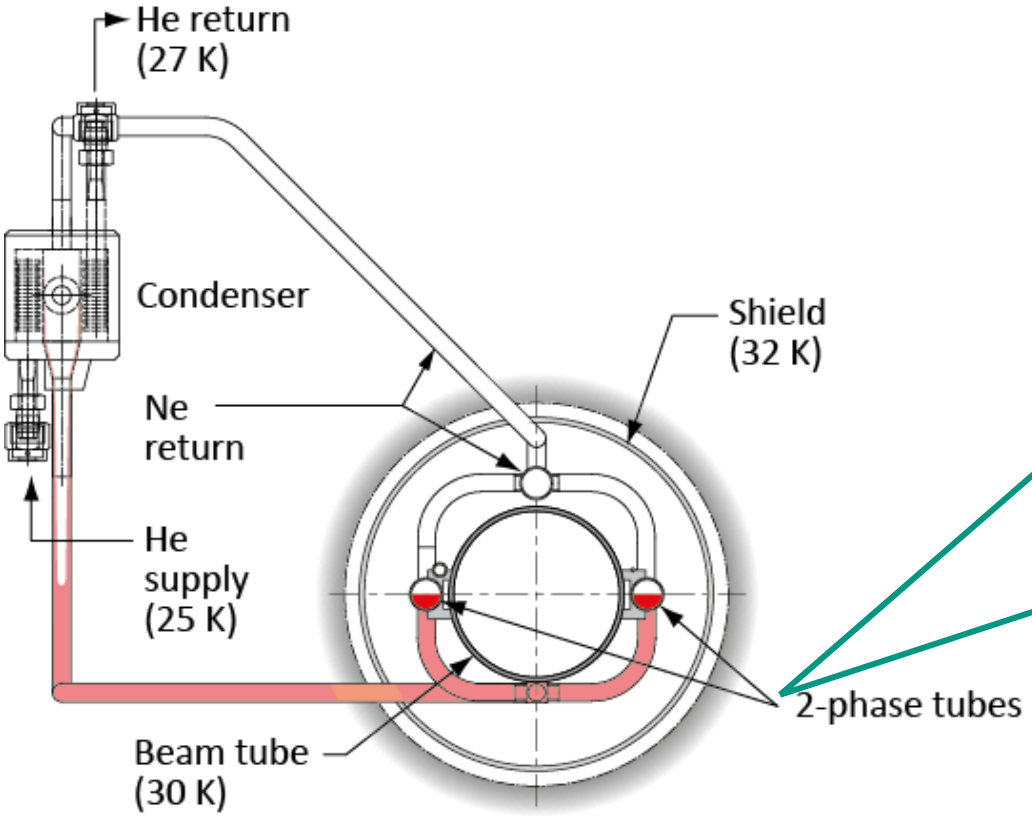
The rear section

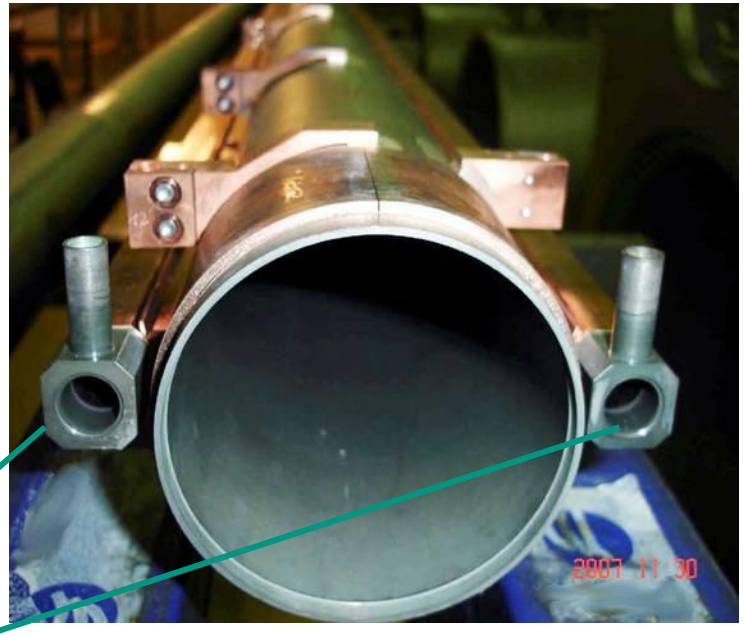
- Purpose: Calibration and monitoring
  - Definition of electrostatic potential of WGTS by rear wall
  - Source activity monitoring
  - Measurement of gas column density with electron gun



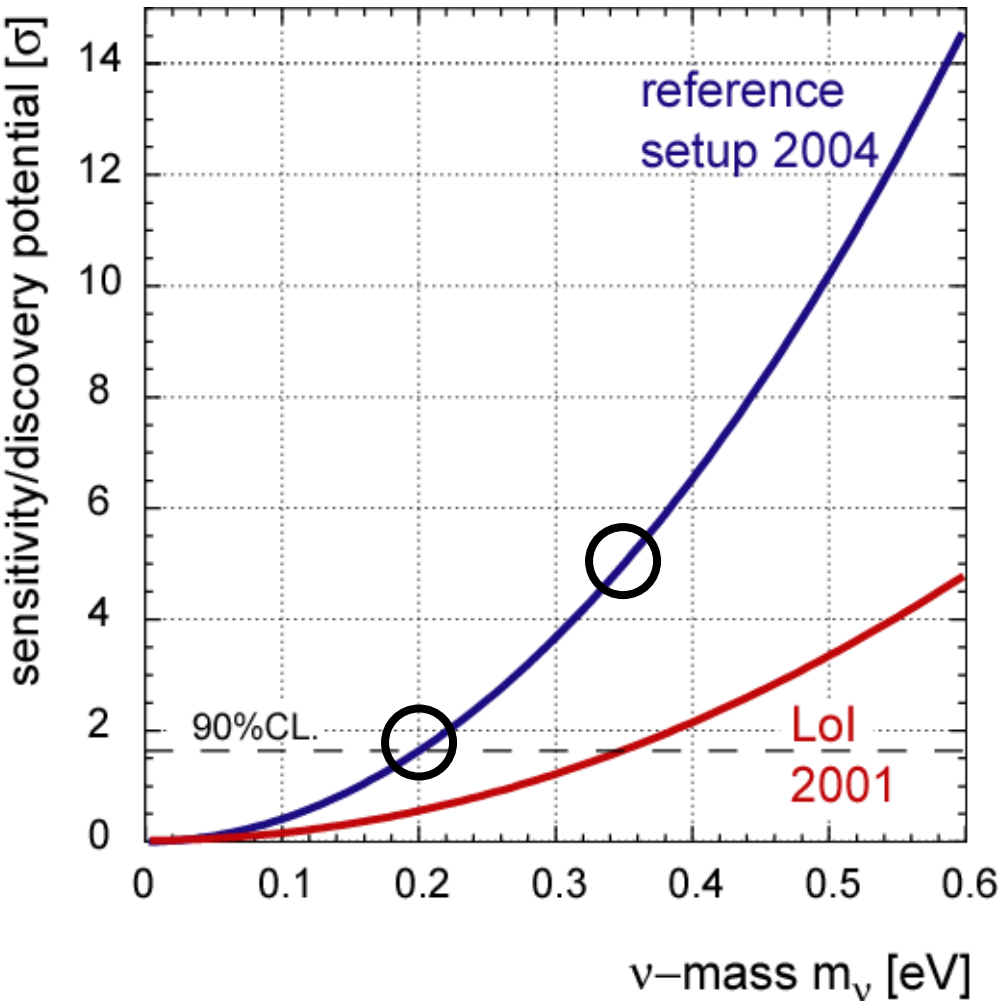
Preliminary design

2 phase Ne cooling cycle





KATRIN Sensitivity



After 3 years data (5y real time):

discovery potential
m(ν) = 0.35 eV (5σ)

sensitivity (90% CL)
m(ν) < 0.2 eV

$$\Delta m_{tot}^2 = (\Delta m_{stat}^4 + \Delta m_{sys,tot}^4)^{1/2}$$

$$\Delta m_{tot}^2 \approx 0.025\ eV^2/c^4$$

and

$$\Delta m_{stat} = \Delta m_{sys,tot}$$

$$\Delta m_{stat}^2 = 0.018\ eV^2/c^4$$

$$\Delta m_{sys,tot}^2 \leq 0.017\ eV^2/c^4$$