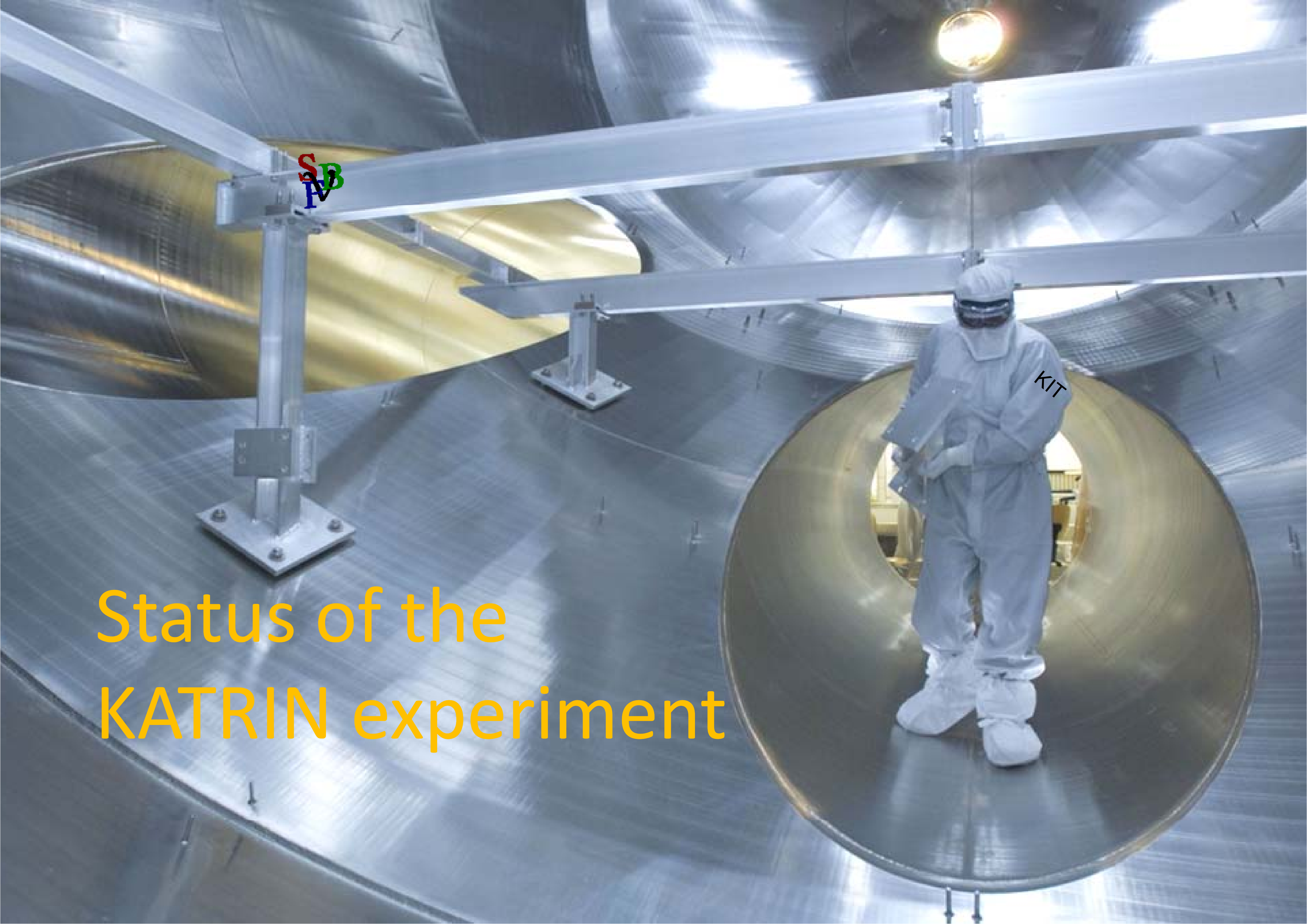
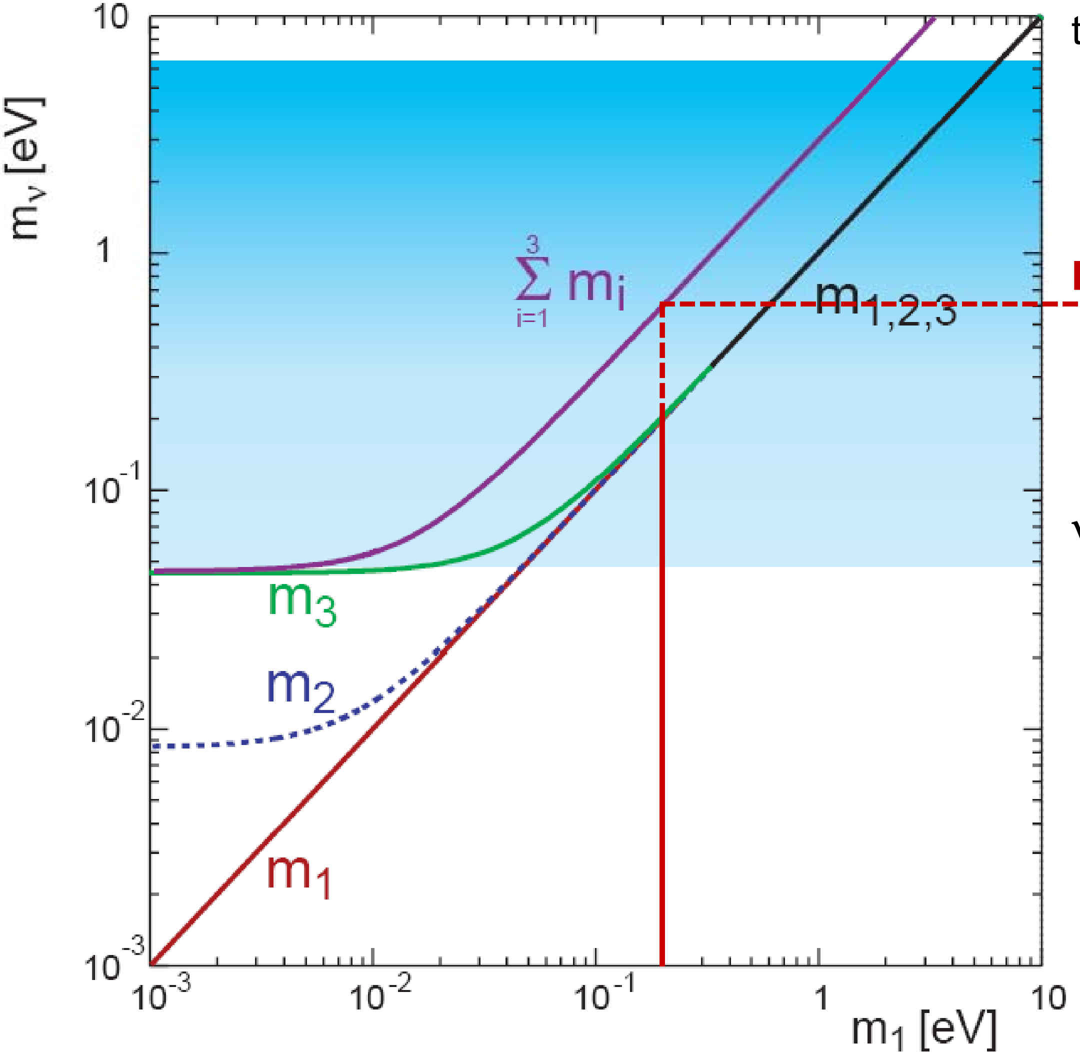
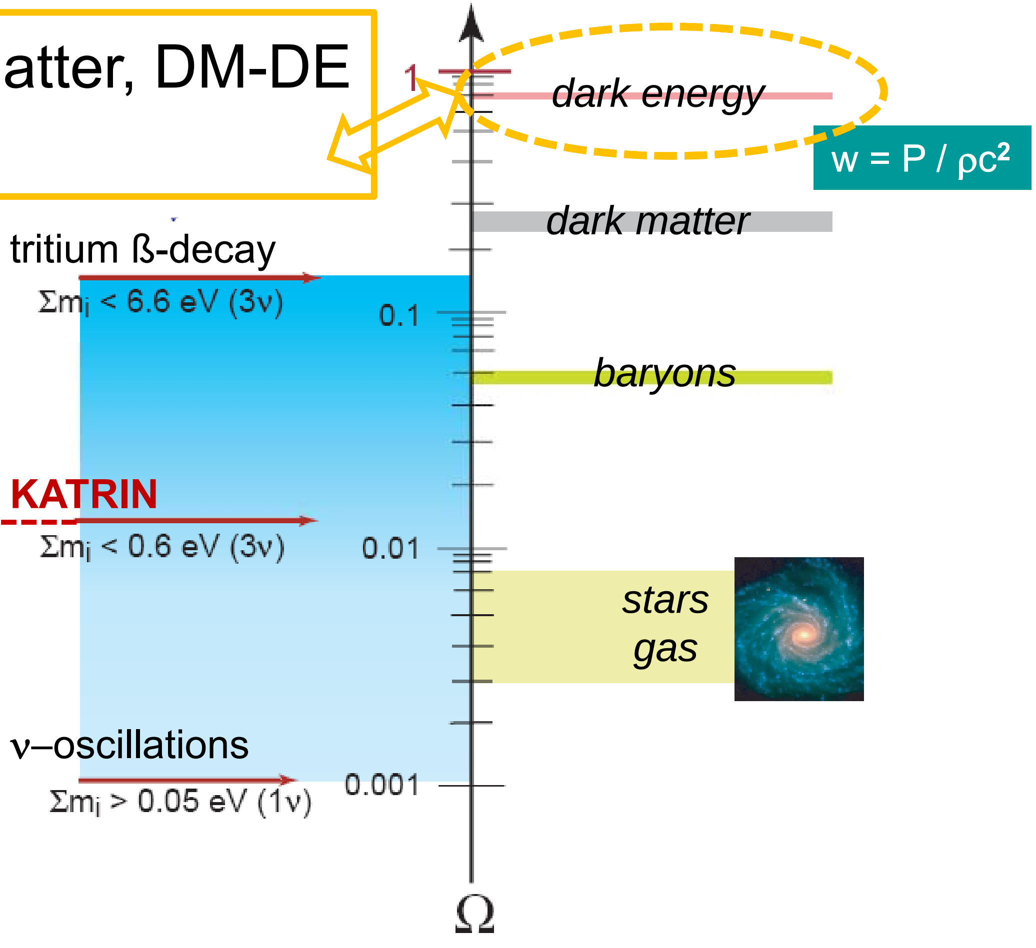


Status of the KATRIN experiment

motivation: ν´s in astroparticle physics

cosmology: role of relic-ν as hot dark matter, DM-DE
particle phyiscs: neutrino mass scale





degeneracy between m_ν and dark energy equation of state w

ß-decay: Fermi´s theory & ν-mass

a model-independent measurement of m(ν_e)
based on kinematics & energy conservation

$$m(\nu_e) = \sqrt{\sum_{i=1}^{3} \left|U_{ei}^2\right| \cdot m_i^2}$$

incoherent sum

$$\frac{d\Gamma_i}{dE} = C\cdot p\cdot(E+m_e)\cdot(E_0-E)\cdot\sqrt{(E_0-E)^2-m_i^2}\cdot F(E,Z)\cdot\theta(E_0-E-m_i)$$

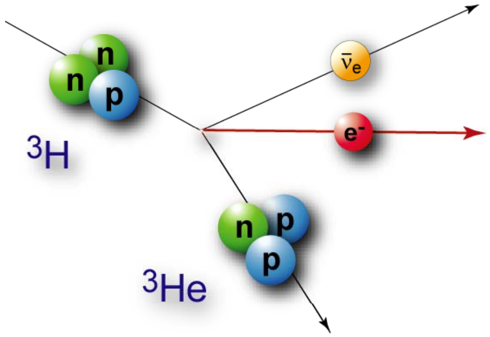
Fermi´s theory

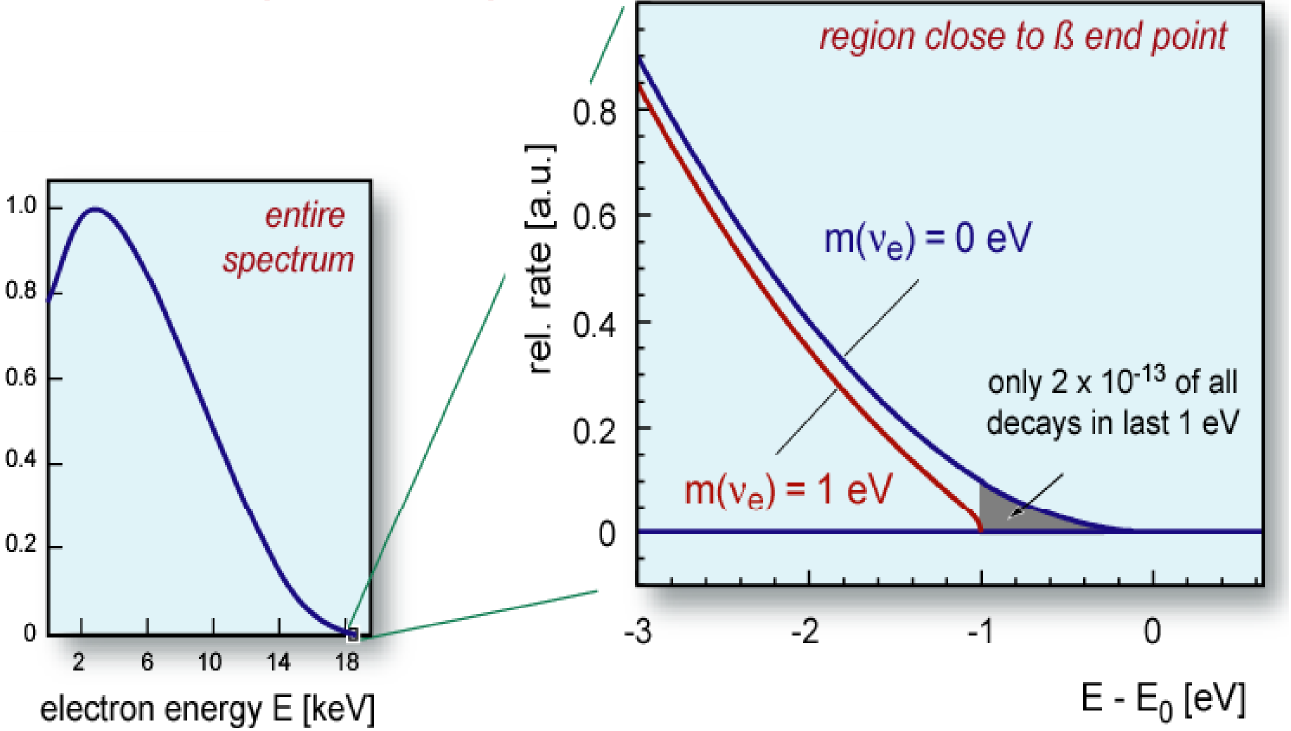
why tritium?

(ν– mass)^2

^{3}H: super-allowed	
E_0	18. 6 keV
$t_{1/2}$	12.3 y

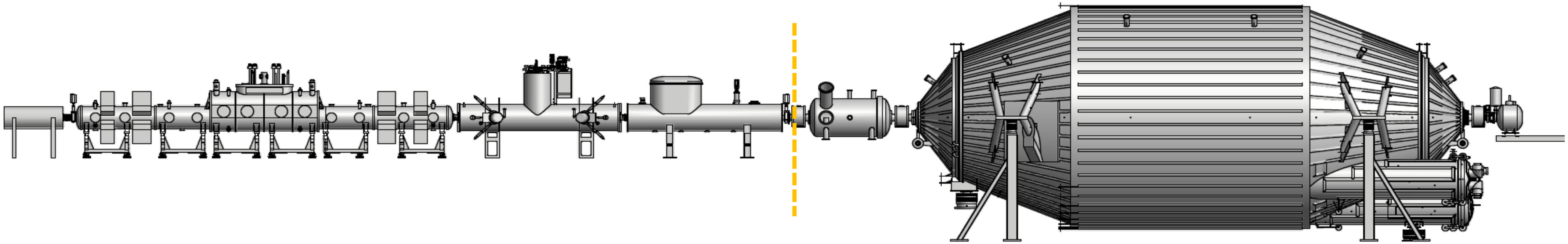
$$^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$$





only 2 x 10^{-13} of all decays in last 1 eV

ß-decay: Fermi´s theory & ν-mass

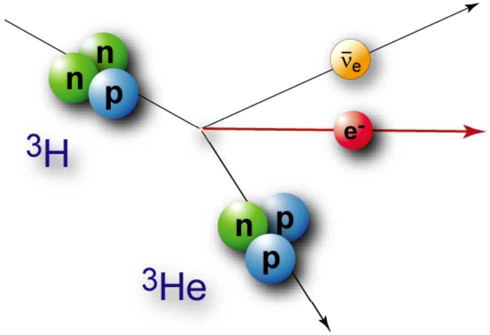


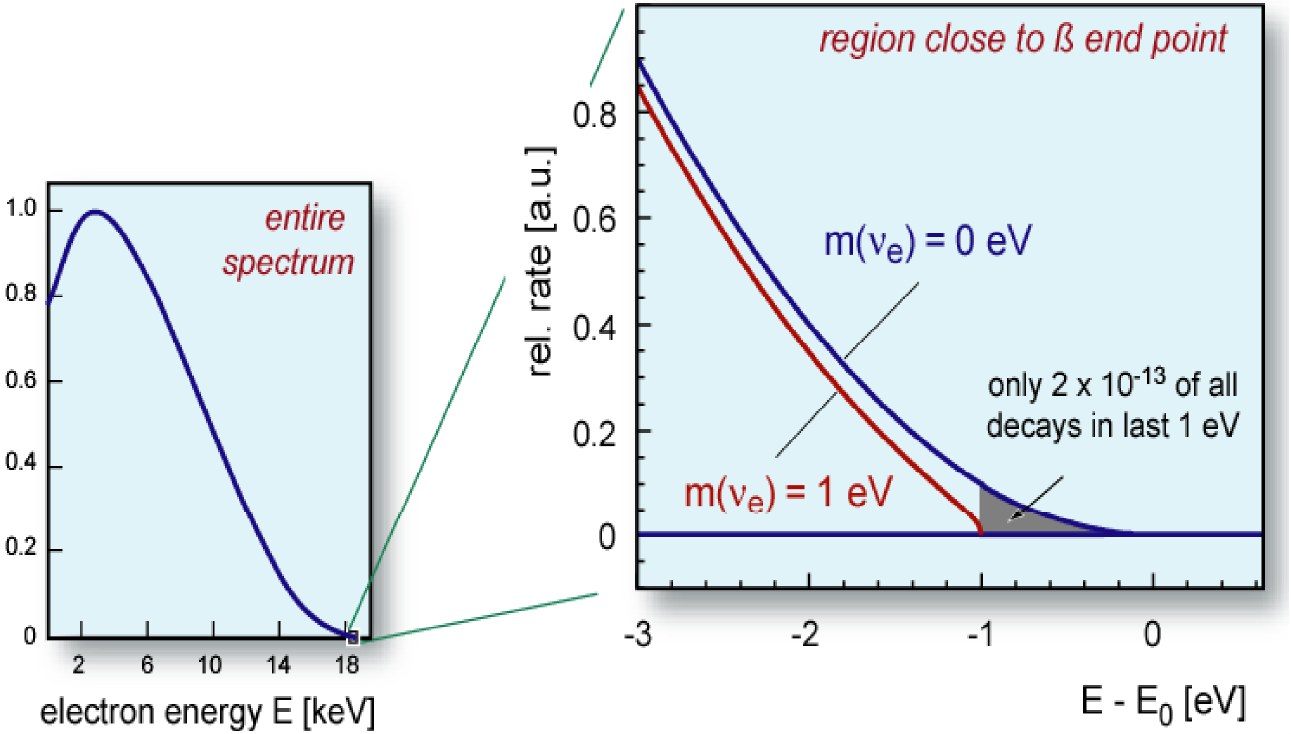
tritium-bearing components

electrostatic spectrometers & detector

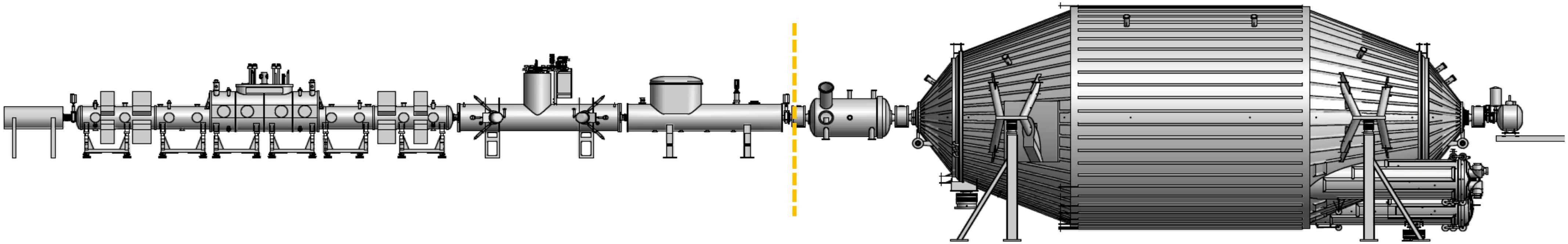
^{3}H: super-allowed	
E_0	18. 6 keV
$t_{1/2}$	12.3 y

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





KATRIN experiment - overview



tritium-bearing components

⇩

10^{11} Bq tritium source

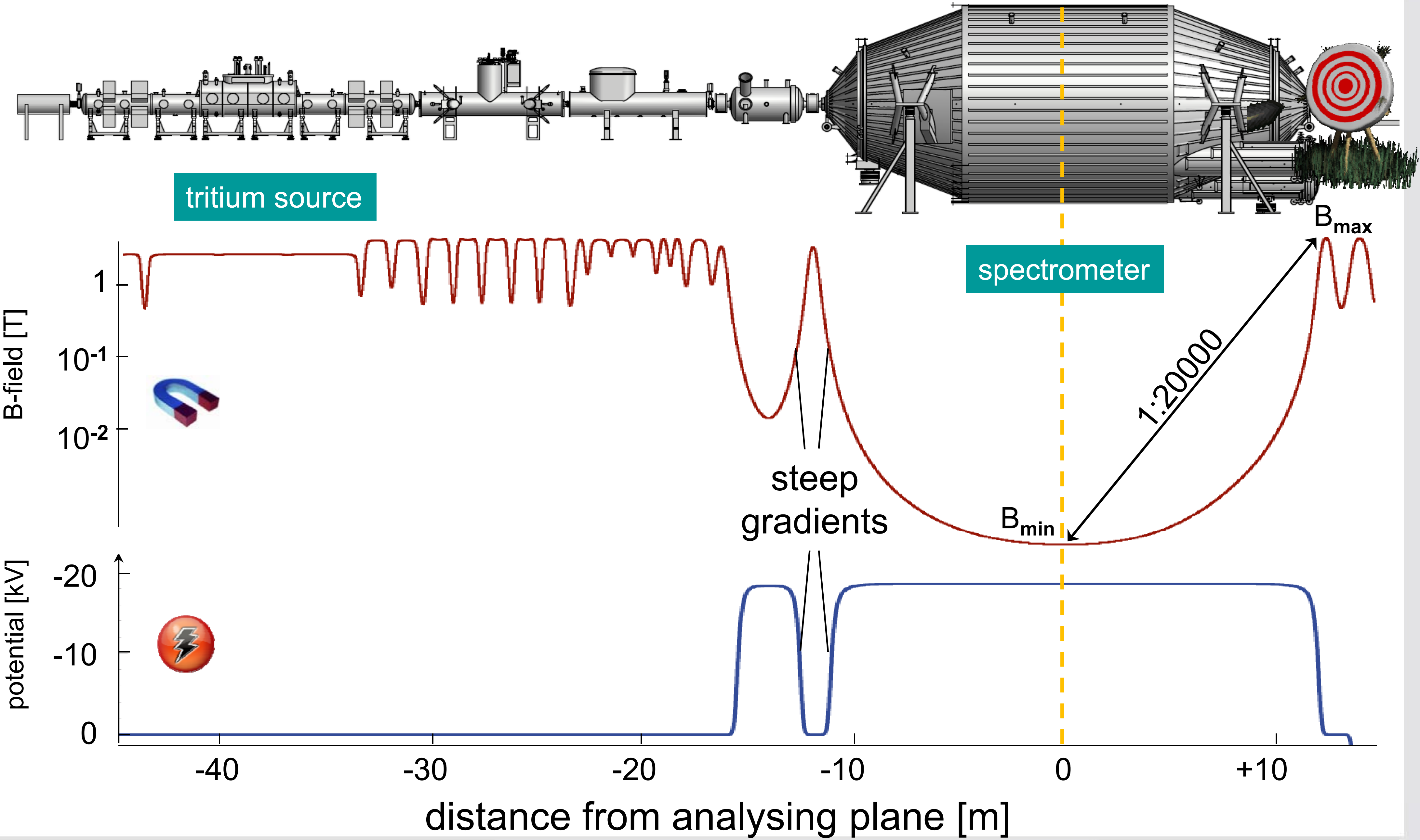
electrostatic spectrometers & detector

⇩

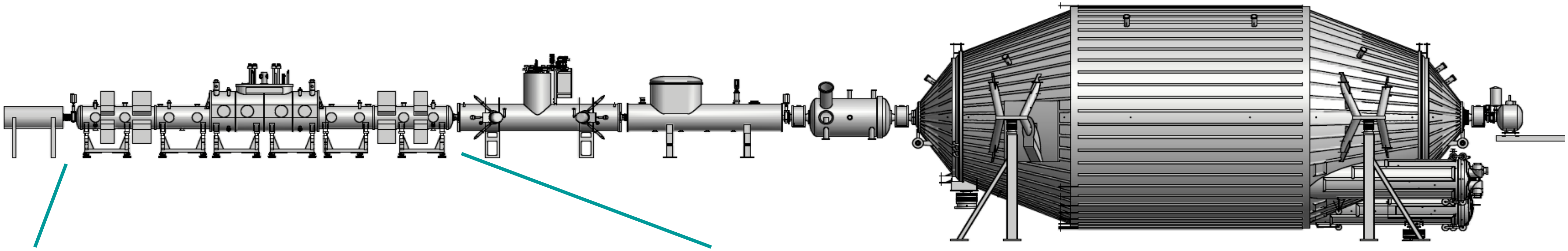
10^{-2} Bq total background

- ↳ 10^{-3} stability of tritium source column density ρd
- ↳ retention factor for molecular tritium R = 10^{14}
- ↳ effective removal of ions
- ↳ fully adiabatic (meV-Skala) transport of electrons over > 50 m
- ↳ avoid particle storage in Penning traps

KATRIN – B-field & electrostatic potential



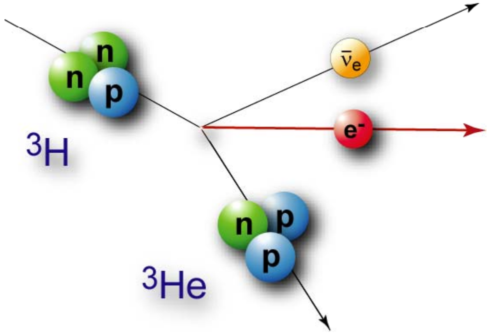
KATRIN – closed tritium cycle & TLK

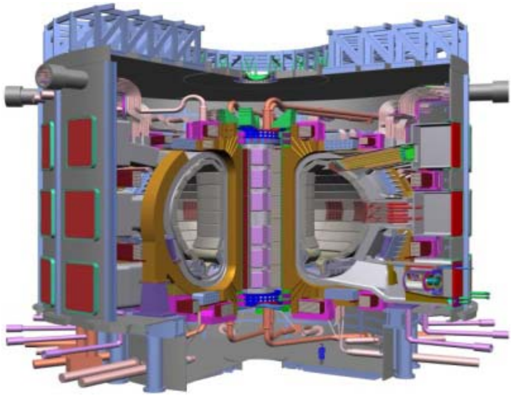


KATRIN tritium throughput per year equivalent to fusion facility ITER

KATRIN closed cycle operational in 2012

⇔ first D-T operation of ITER in 2026

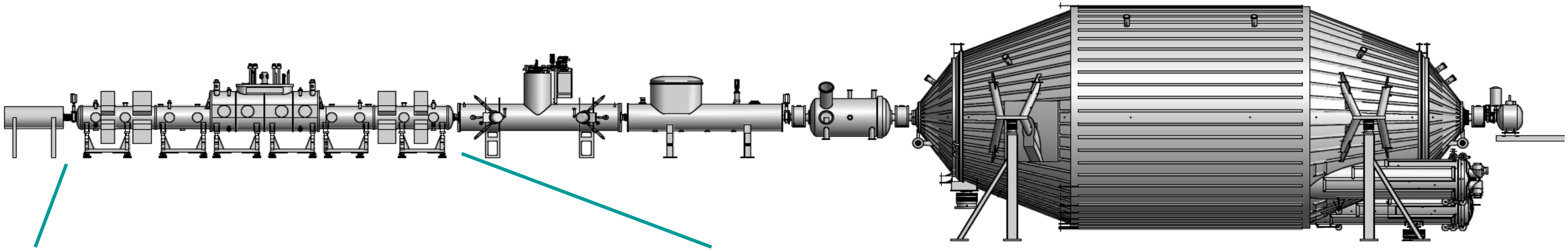


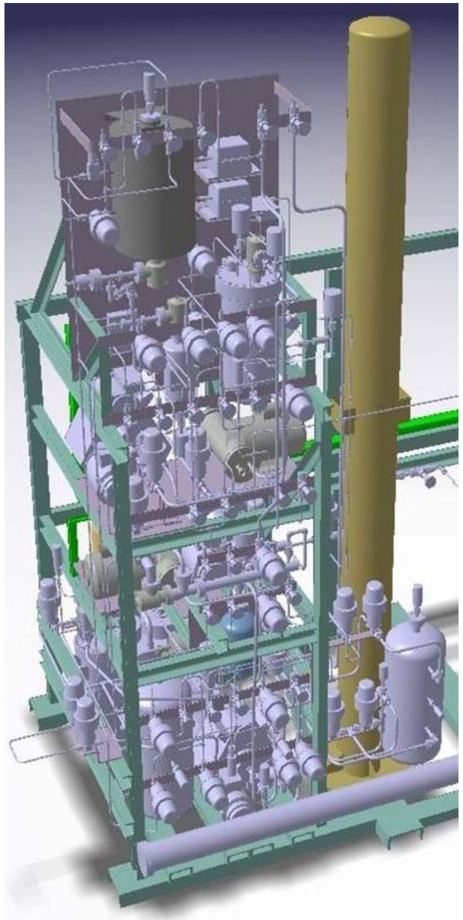


TLK – Tritium Laboratory Karlsruhe

a unique research facility in Europe
licensed for storage of 20 g tritium

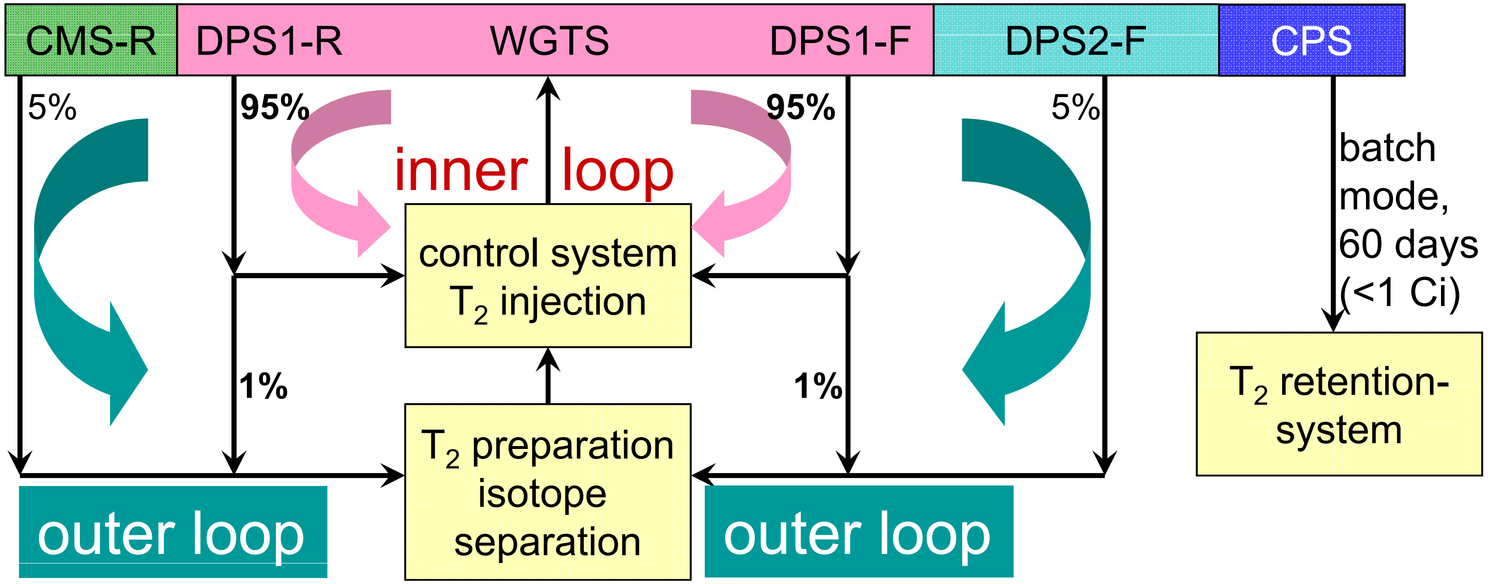
KATRIN – closed tritium cycle





KATRIN tritium loop system

27 pumps, 109 valves, 62 sensors,
6 buffer vessels, 2 permeators



CMS-R | DPS1-R | WGTS | DPS1-F | DPS2-F | CPS

5% | 95% | 95% | 5%

inner loop

control system
T_2 injection

1% | 1%

T_2 preparation
isotope
separation

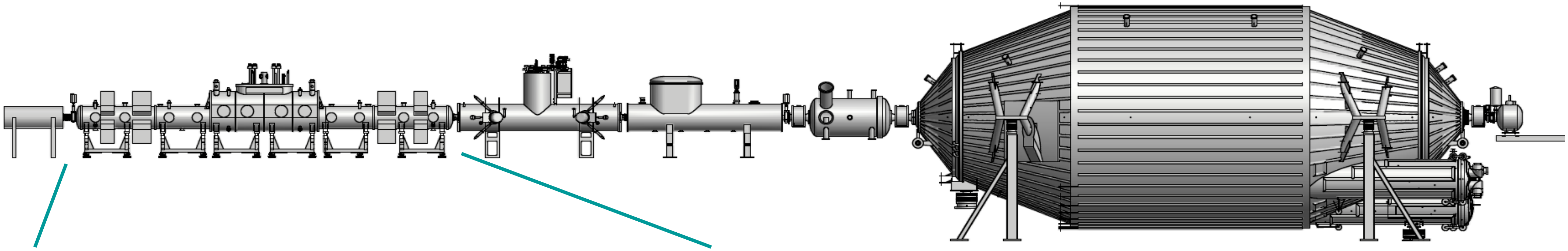
outer loop

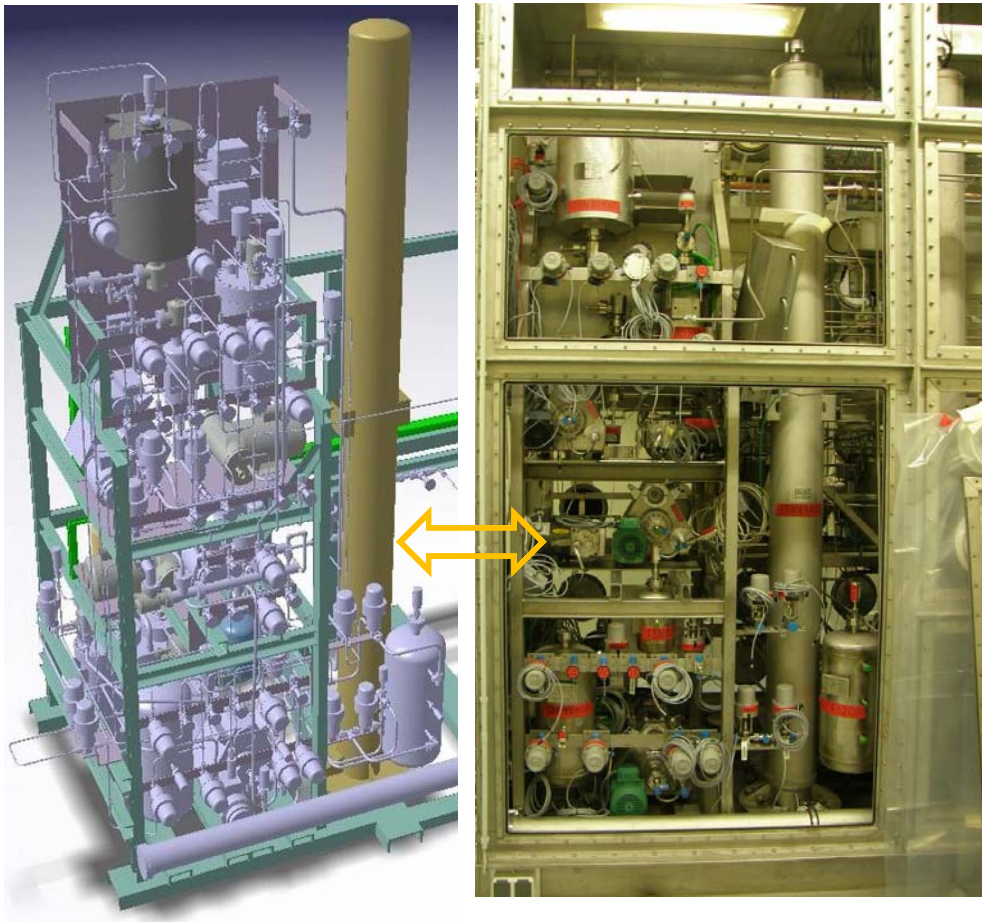
outer loop

batch mode,
60 days
(<1 Ci)

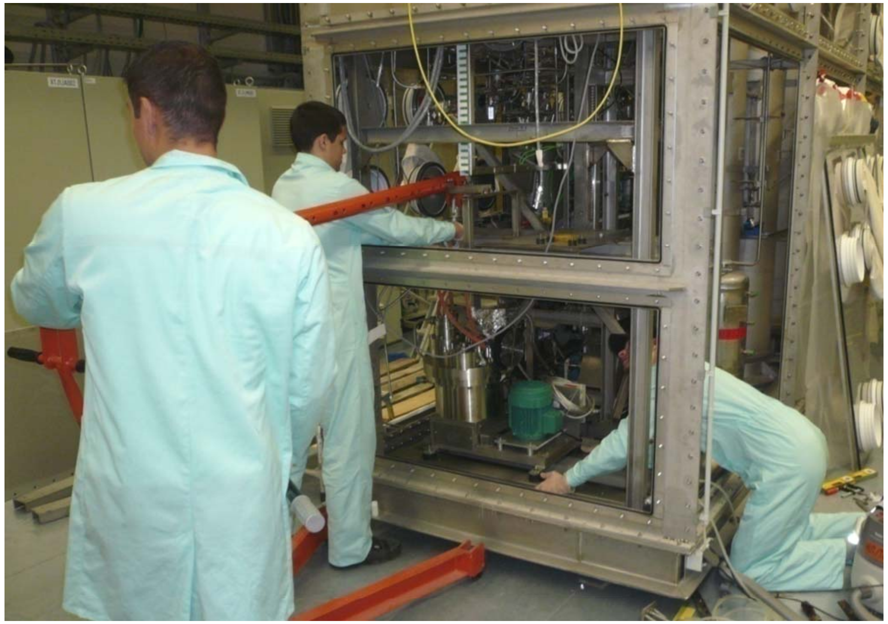
T_2 retention-system

KATRIN – closed tritium cycle & SFB



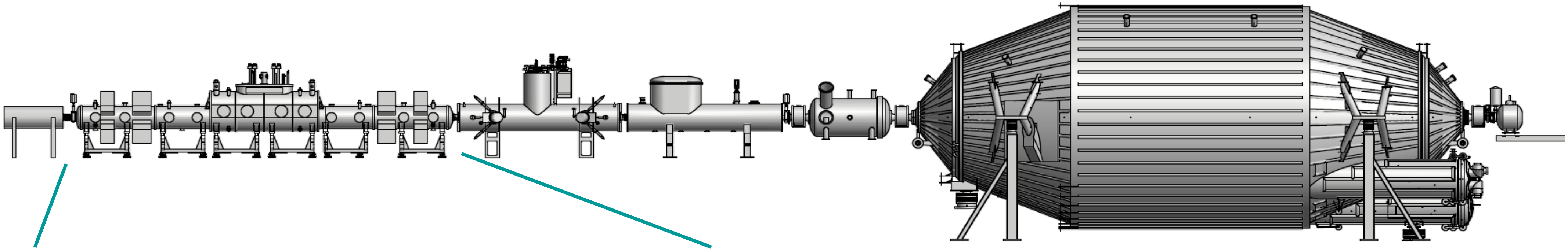


A1 personnel is coordinating and optimising the set-up of the closed tritium loop system of KATRIN

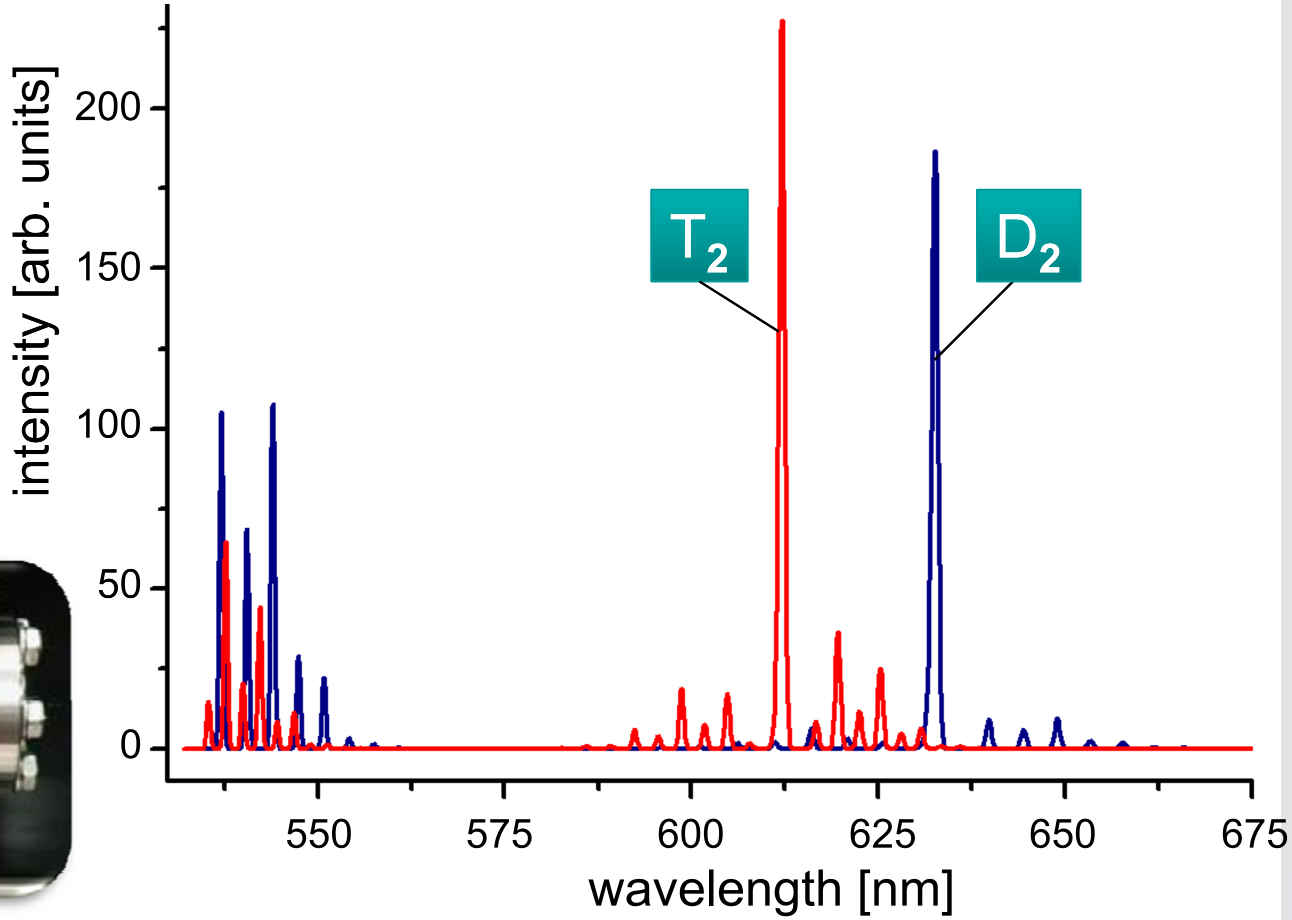


M. Sturm
A1 – graduate student

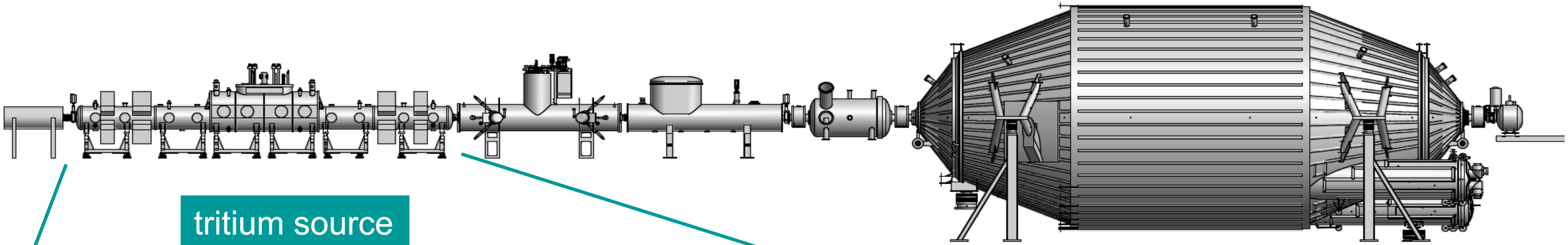
KATRIN – Laser Raman Spectroscopy



high-precision (~0.1%)
in-situ measurement of
actual H-isotopologue
composition in the WGTS
(see talk by Magnus Schlösser
Friday, July 10, 16:00)



WGTS – windowless gaseous source

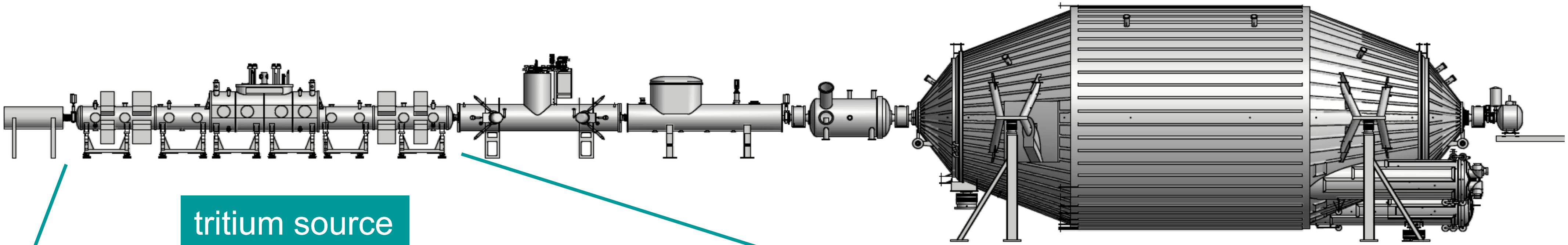


tritium source

16 m long cryostat

WGTS	design value	precision
luminosity	1.7 × 10^{11} Bq	
injection rate	5 × 10^{19} mol/s	±0.1 %
column density ρd	5 × 10^{17} mol/cm^2	±0.1 %
tritium purity	> 95%	±0.1 %
magnetic field	3.6 T	± 2%

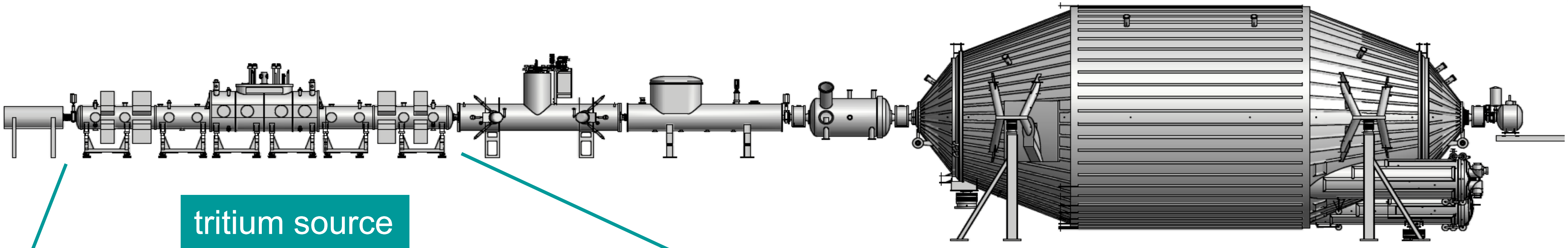
WGTS – windowless gaseous source



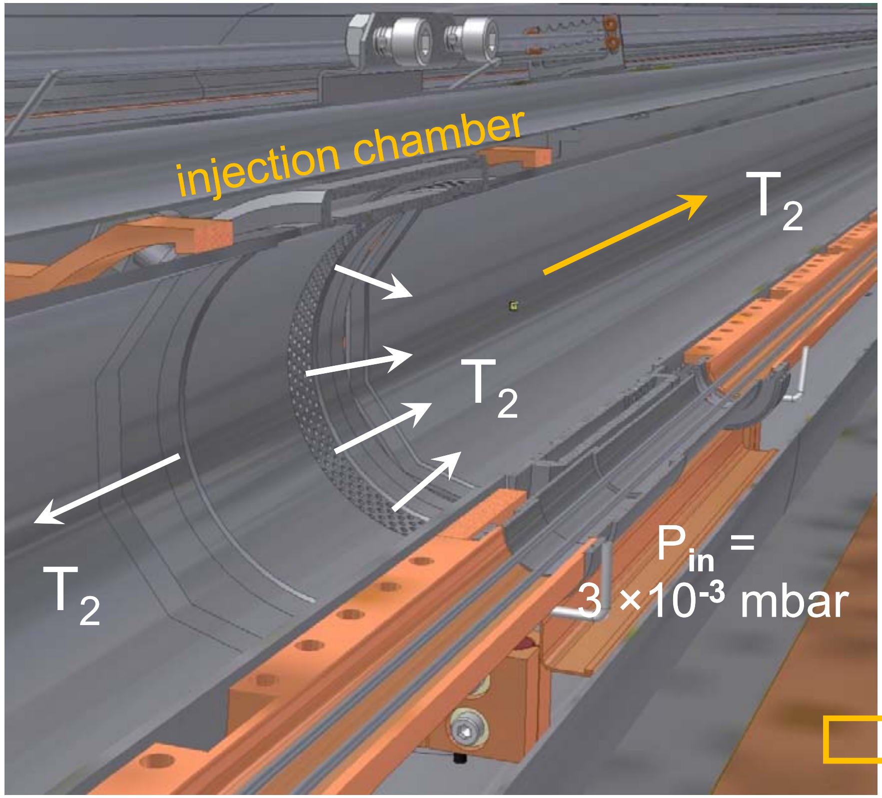
16 m long cryostat

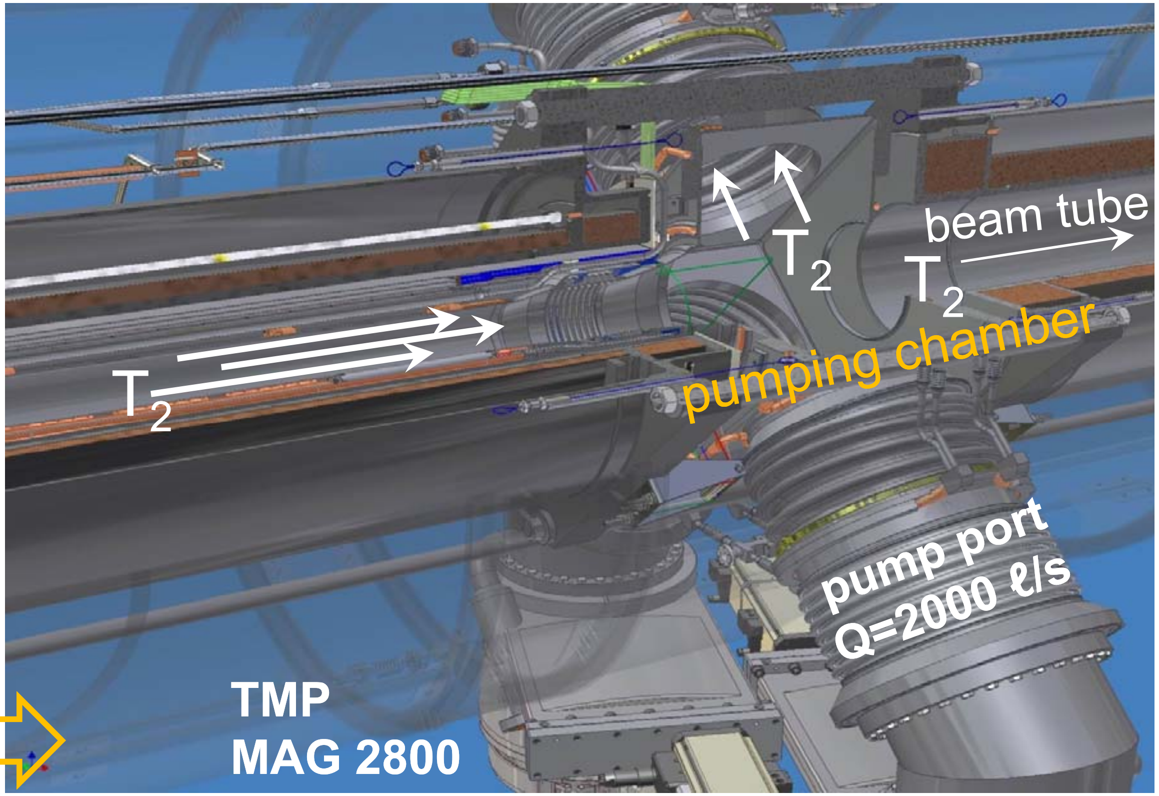
12 cryogenic circuits
6 cryogenic fluids
- instrumentation:
~ 500 sensors for temperature (4 – 600 K), B-field, pressure, gas flow, liquid levels

KATRIN – windowless gaseous source

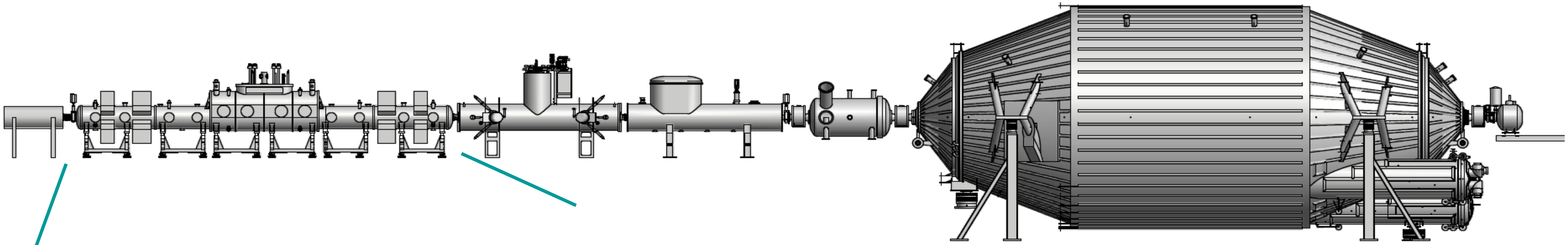


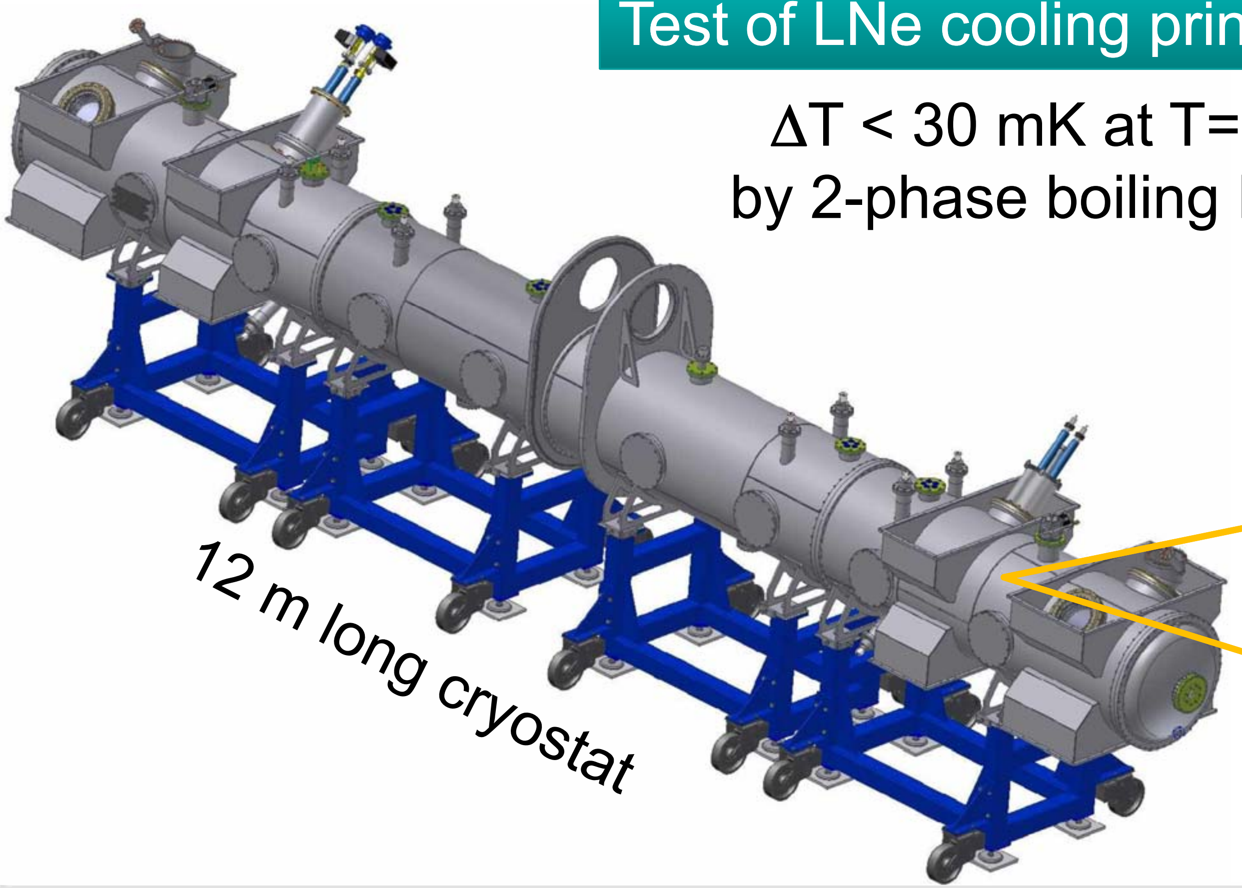
WGTS gasdynamics: see talk by Denize Kalempa (KIT guest scientist)





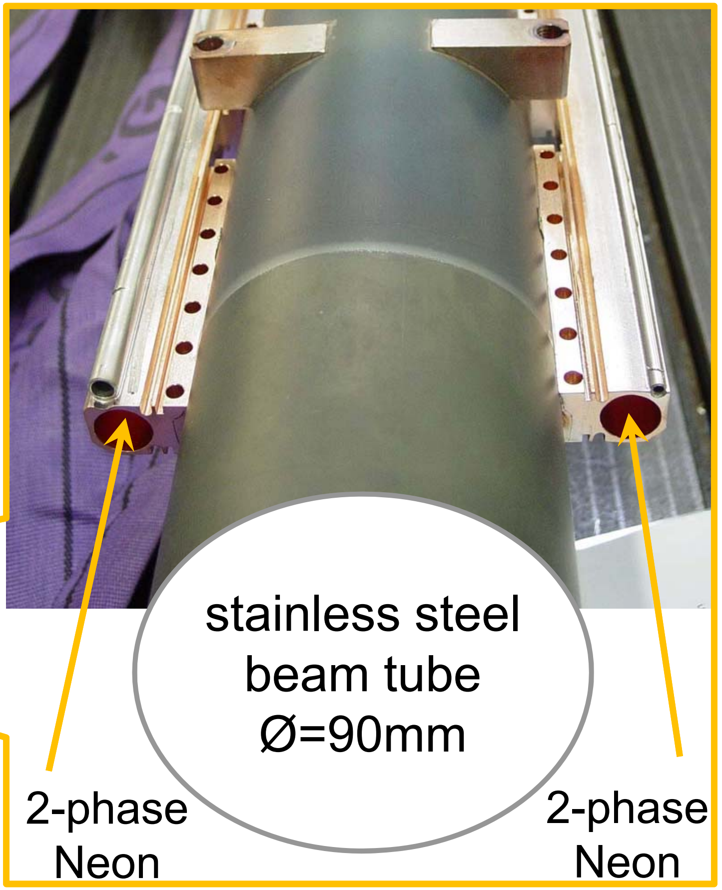
WGTS – demonstrator



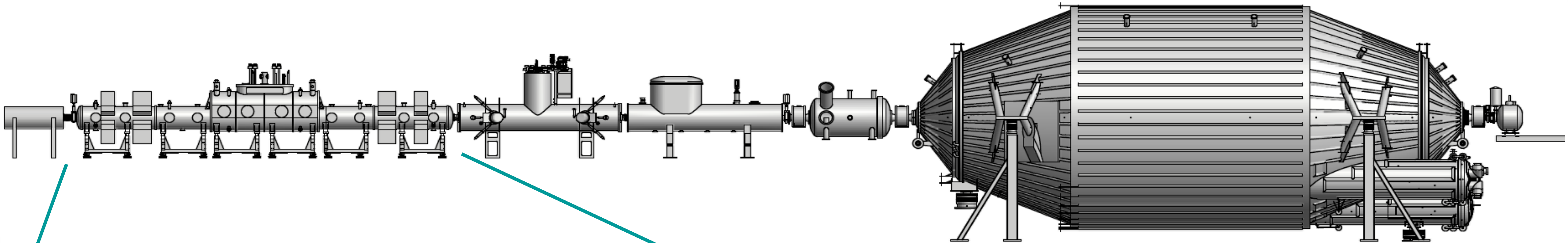


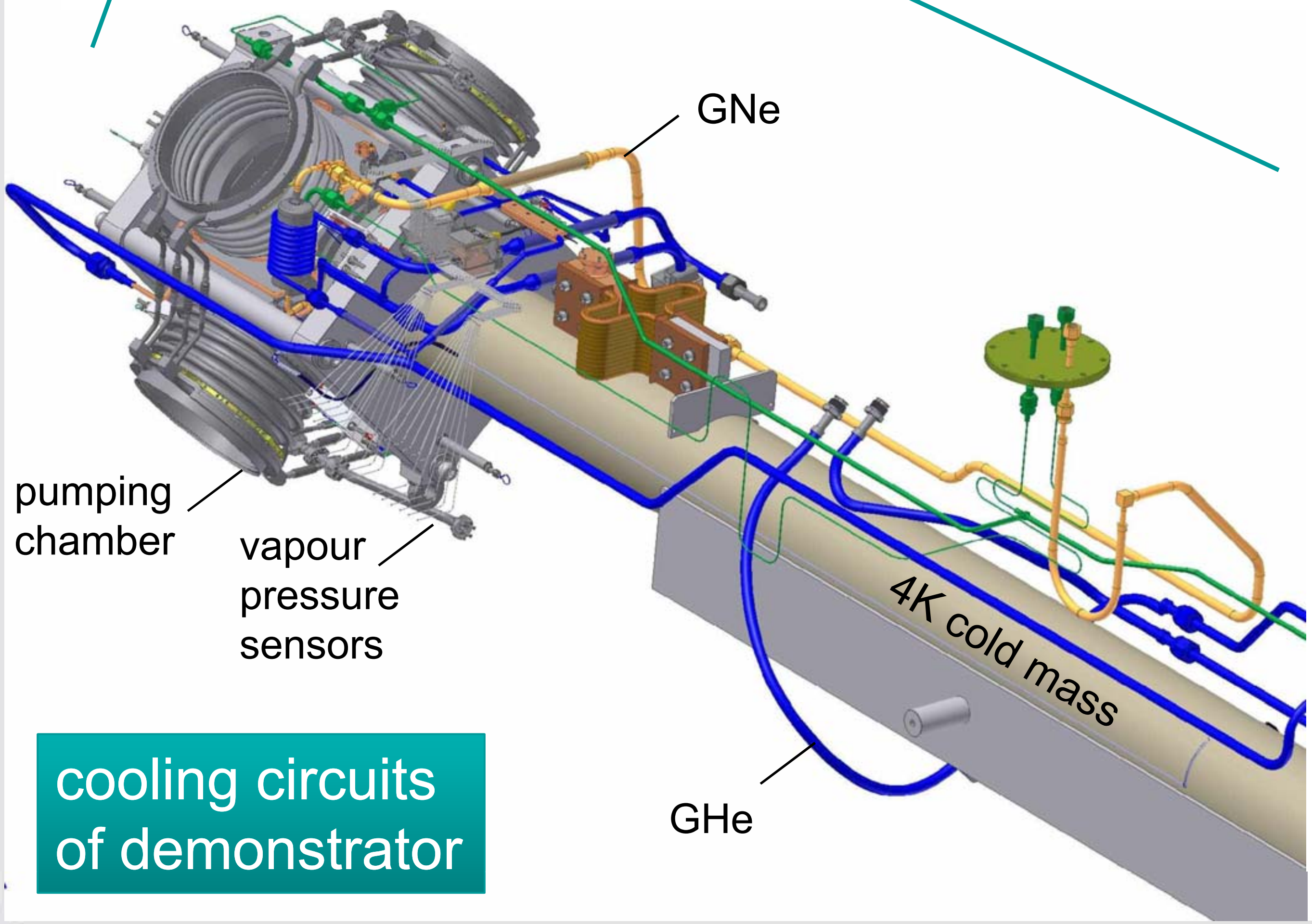
Test of LNe cooling principle

$\Delta T < 30$ mK at T= 30 K
by 2-phase boiling Neon



WGTS – demonstrator



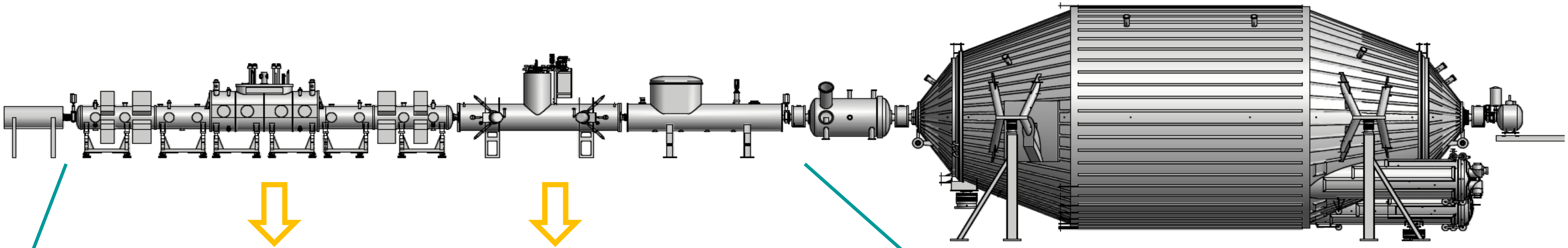


cooling circuits of demonstrator

demonstrator/WGTS status

- beam tube and pumping chambers leak tested
- demonstrator assembly finished in 10/2009
- 3 months test of LNe circuit & ΔT profiles
- reassembly to WGTS until mid-2011
- WGTS operational by end 2011, then system integration

KATRIN – cryo infrastructure

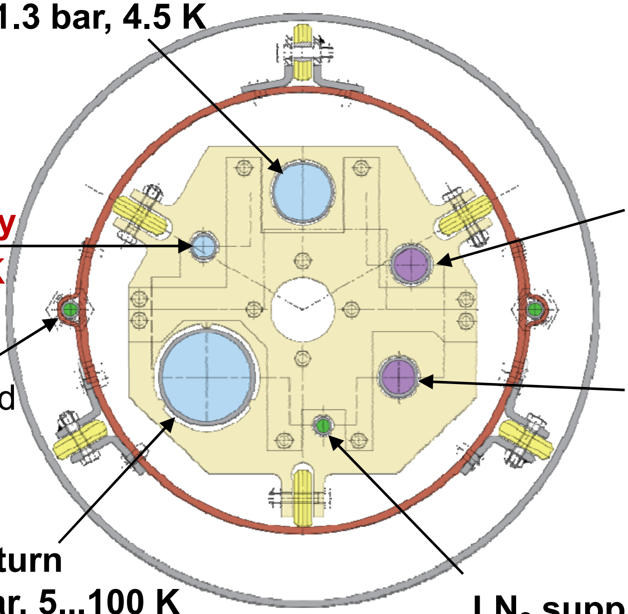


WGTS box in the TLK

Section II in transport hall

successful commissioning in 2008

cryo transfer line



He return
1.3 bar, 4.5 K

He supply
5 bar, 5 K

LN$_2$ shield
cooling

He return
1.3 bar, 5...100 K

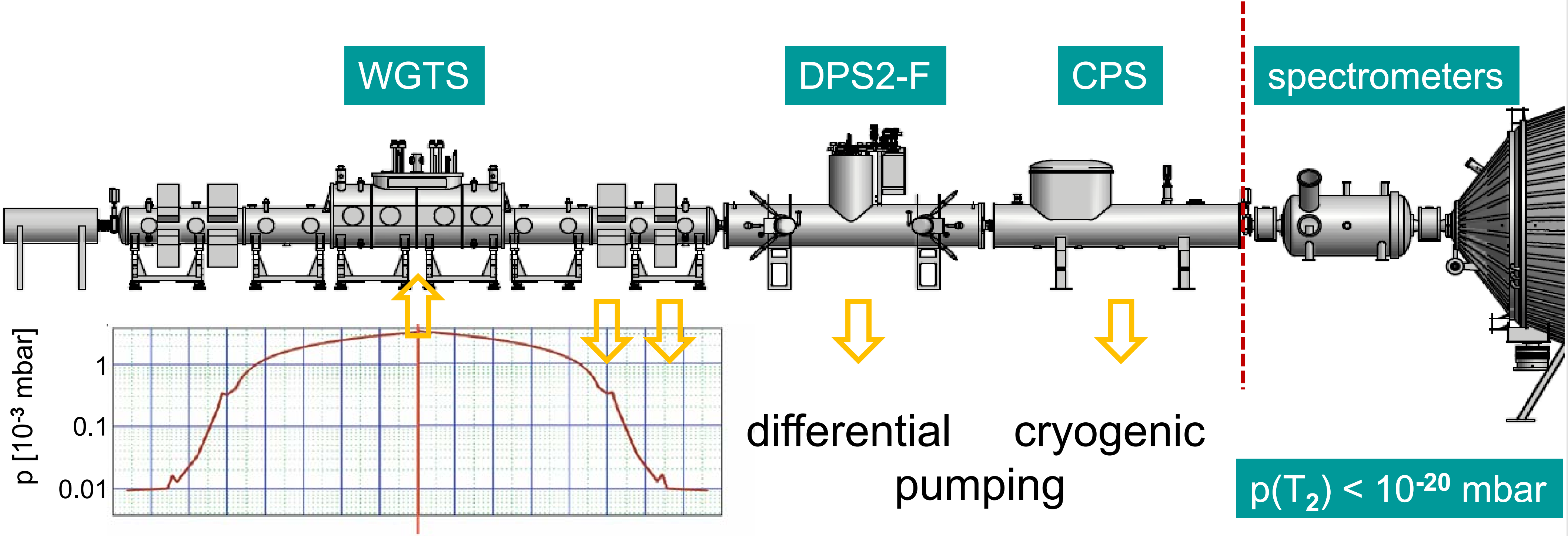
WGTS BT
supply
12 bar,
25/115 K

WGTS BT
return
6 bar,
27/117 K

LN$_2$ supply
4 bar, 80 K

KATRIN – tritium retention

the tritium flow out of the WGTS has to be reduced by **factor ~10^{14}**



tritium bearing components

tritium free

WGTS

DPS2-F

CPS

spectrometers

differential cryogenic

pumping

$p(T_2) < 10^{-20}$ mbar

injection rate = 1.8 mbar ℓ / s

R>10^7

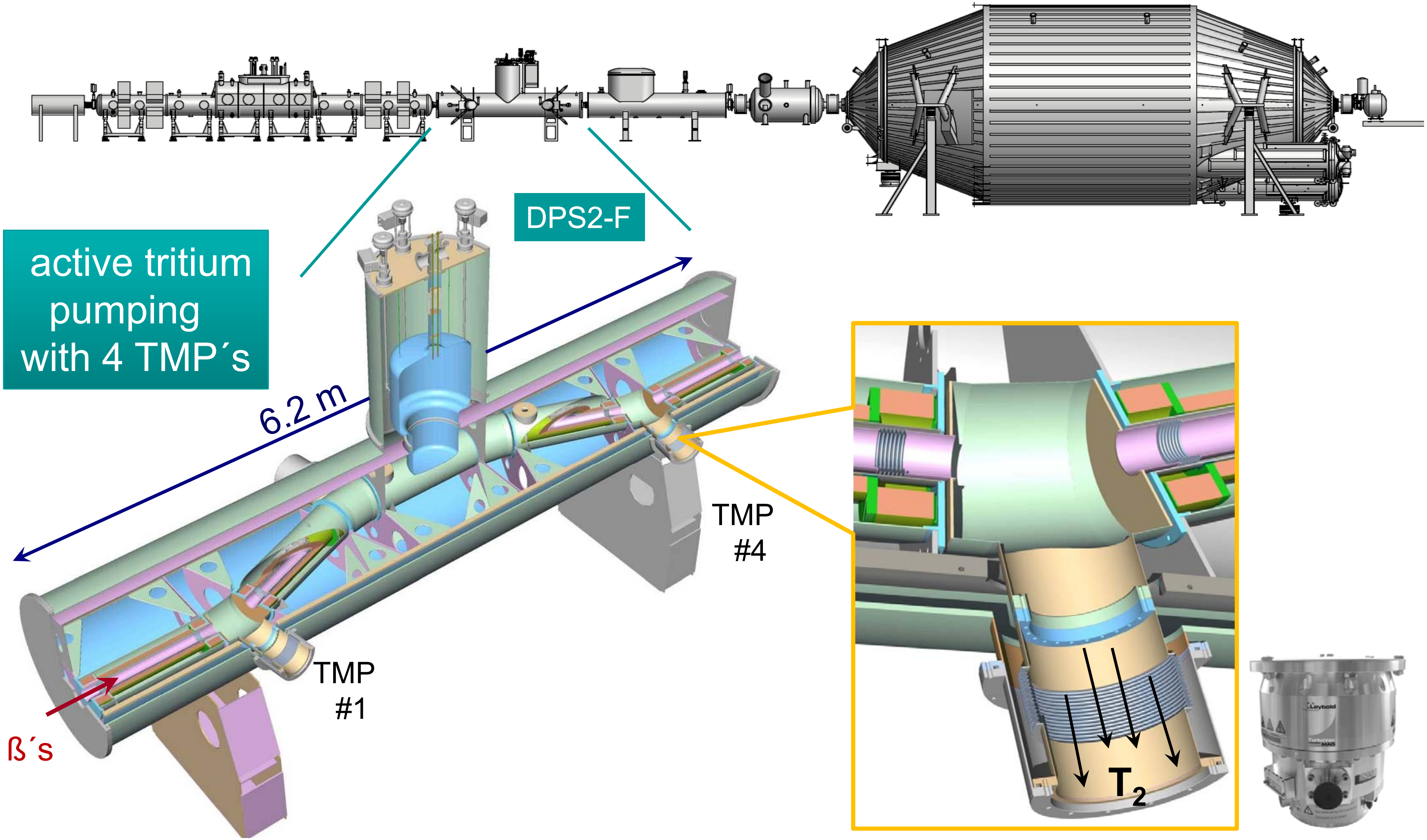
10^{-7} mbar ℓ/s

R>10^7

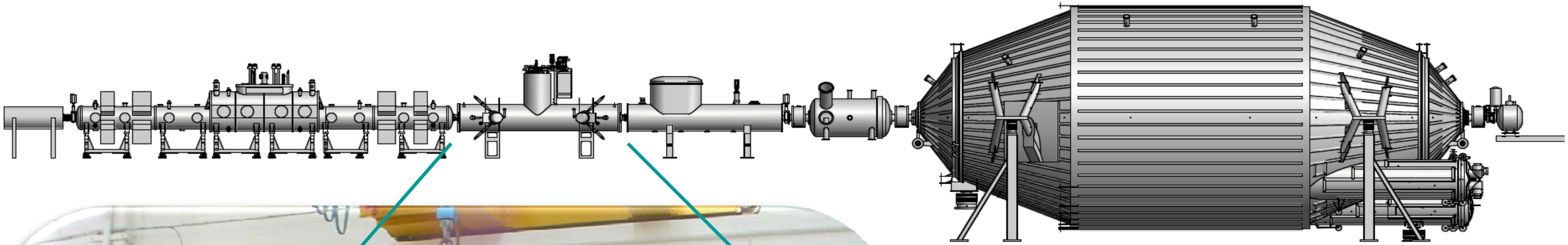
10^{-14} mbar ℓ/s

differential pumping section DPS2-F

active tritium pumping with 4 TMP´s



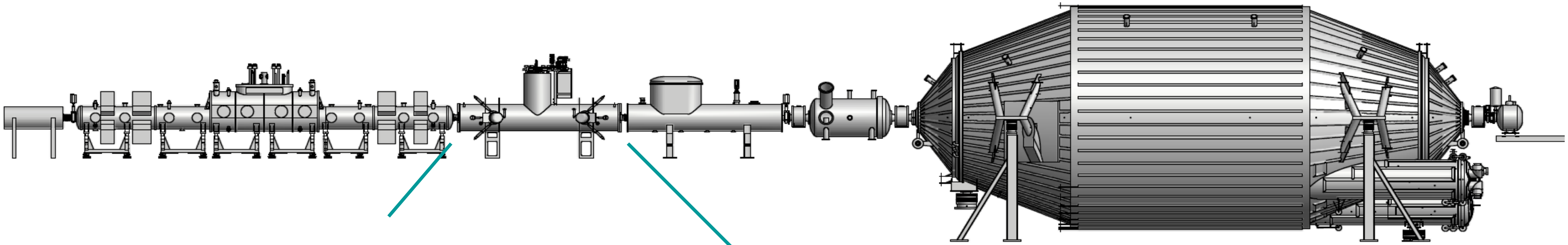
differential pumping section DPS2-F

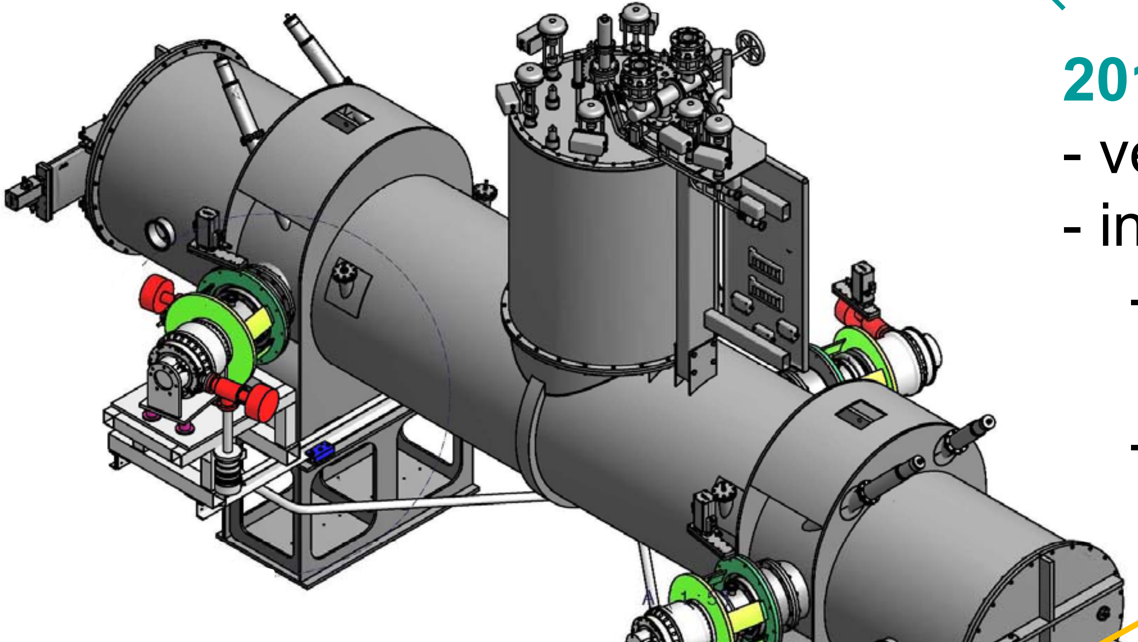


DPS2-F status

- successful cold tests at ASG
- arrival at TLK: July 15, 2009
- acceptance tests → 12/2009

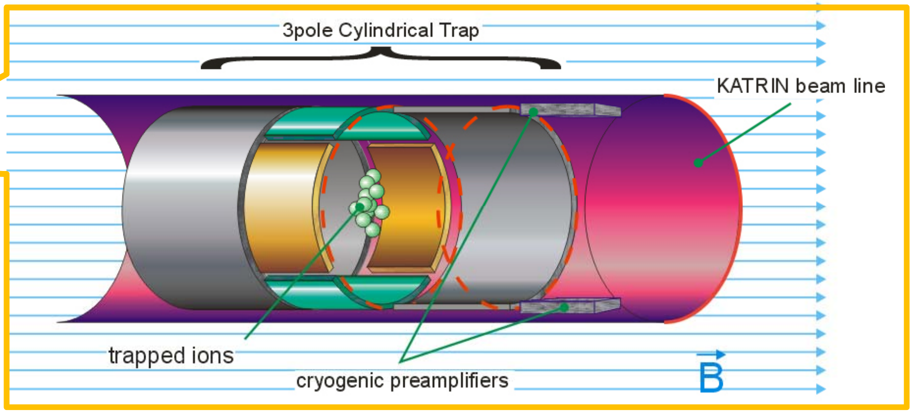
differential pumping section DPS2-F





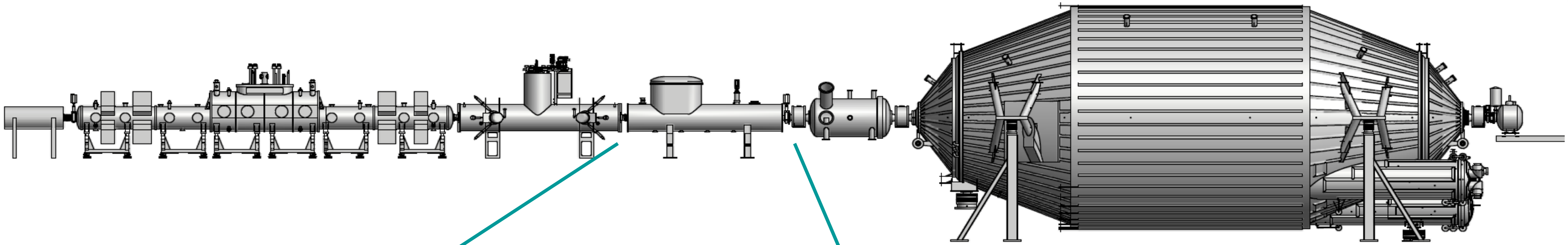
2010 DPS2-F experimental programme

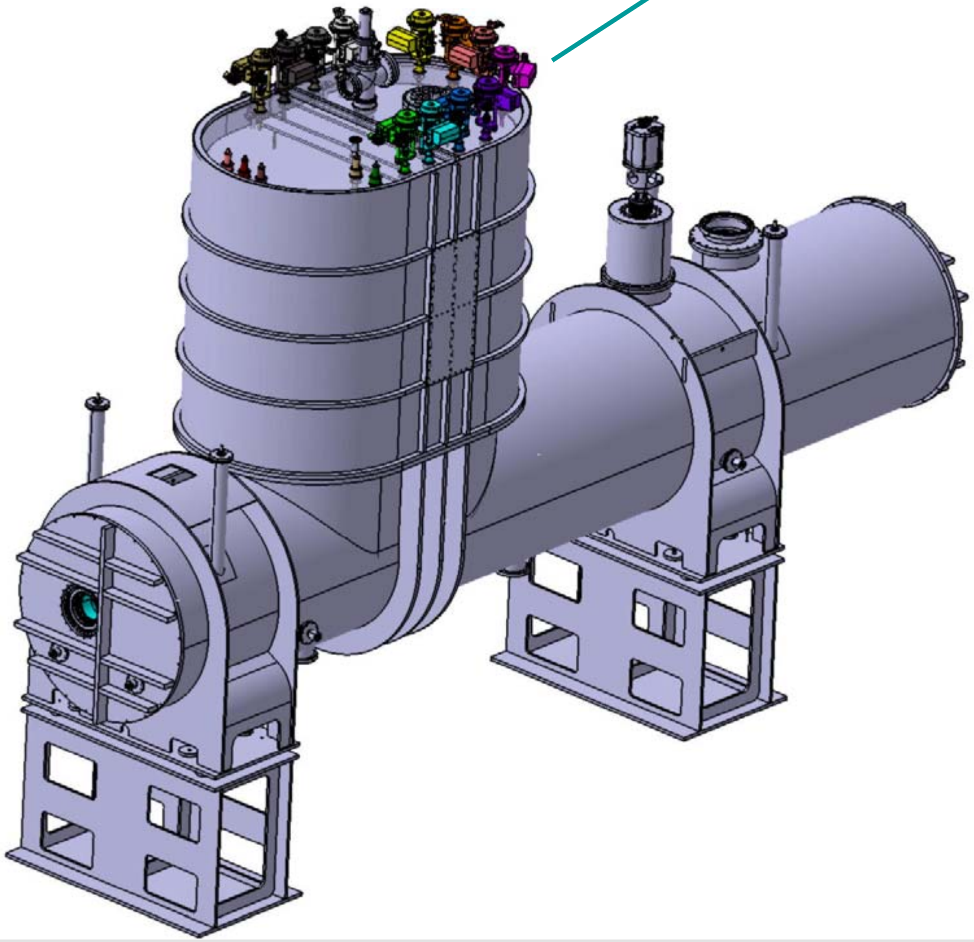
- verify H-isotopologue retention R = 10^5
- investigations of ion properties:
  - diagnostics with FT-ICR measurements (with K. Blaum- MPIK)
  - suppression with dipoles



Strahinja Lukic
A1 – post-doctoral researcher

cryogenic pumping section CPS





objective:

reduction of T_2-flux by factor 10^7 :

10^{-7} mbar ℓ/s → 10^{-14} mbar ℓ/s

method:

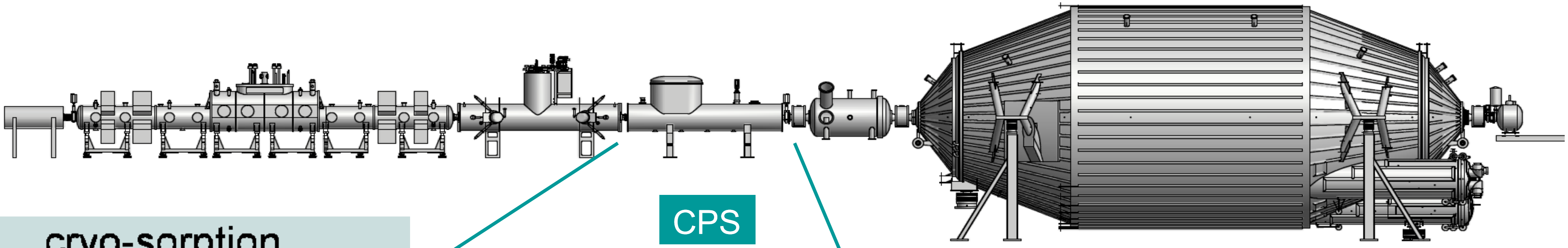
cryo-sorption on condensing Ar-frost

T_2-rate:

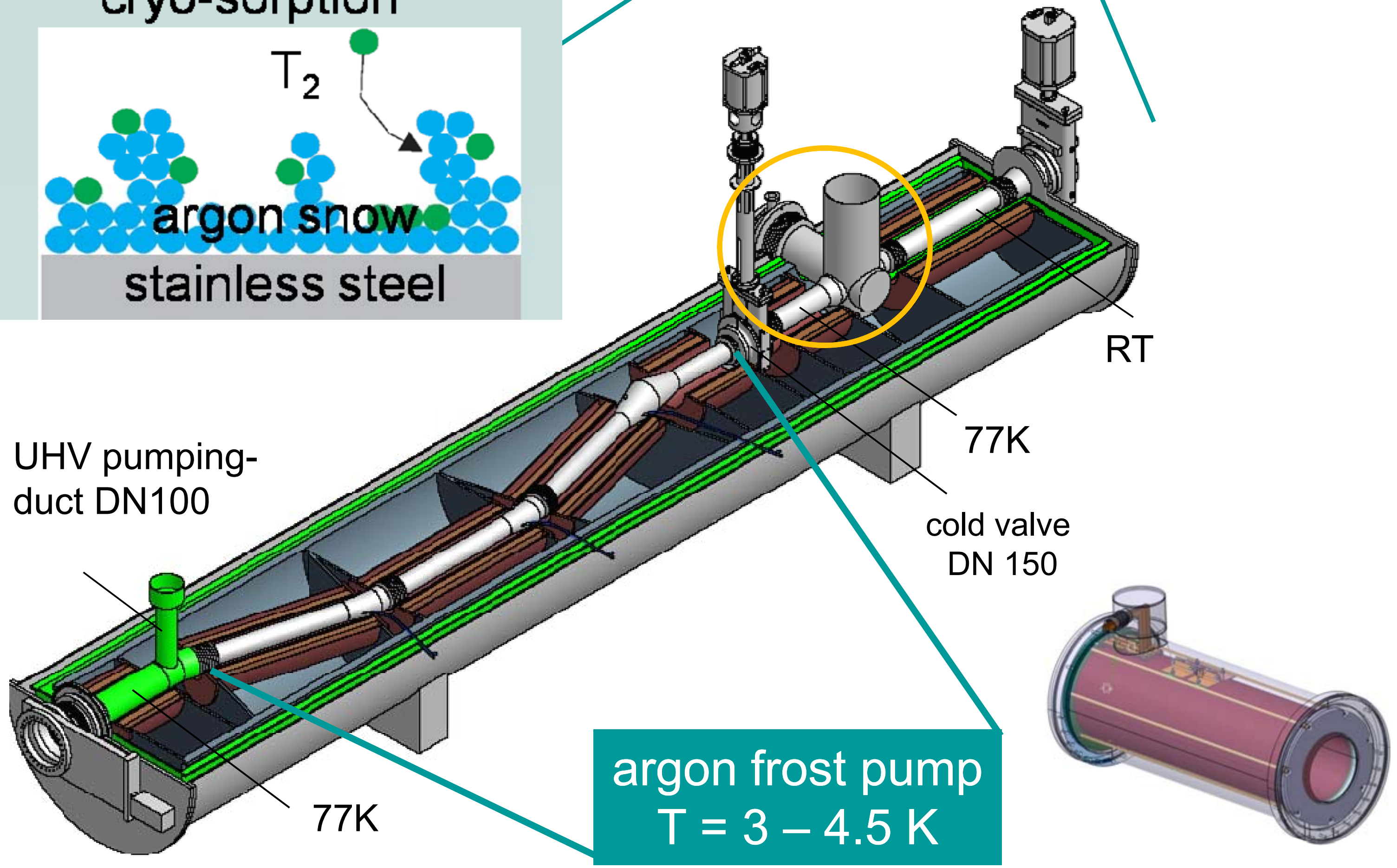
<1 Ci T_2 in 60 days (= 1 KATRIN run)

(regeneration with warm He-gas)

cryogenic pumping section CPS

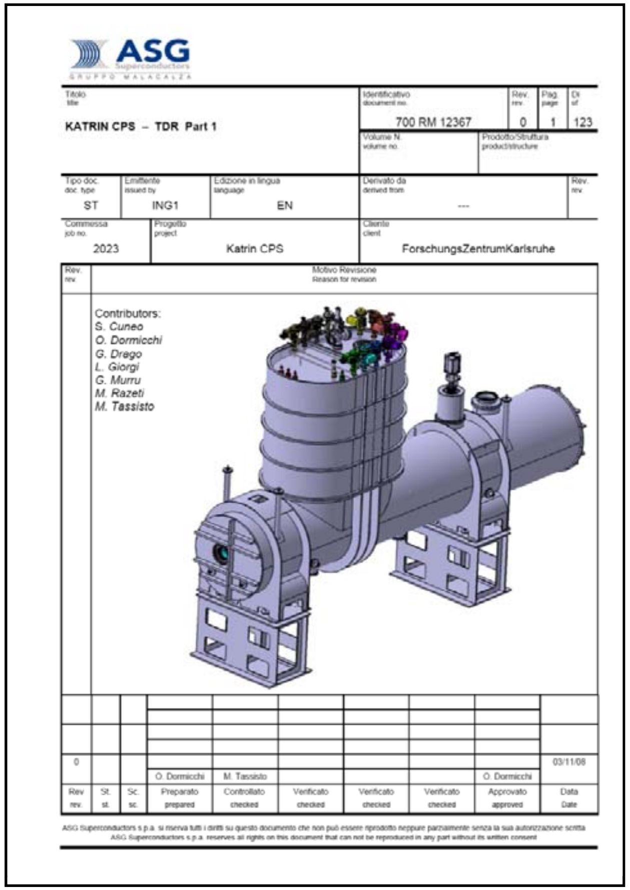


CPS



cryo-sorption

argon frost pump
T = 3 – 4.5 K



ASG Superconductors
GRUPPO MALACALZA

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Progetto / project: Katrin CPS
Cliente / client: ForschungsZentrumKarlsruhe
Rev. / rev.
Motivo Revisione / Reason for revision

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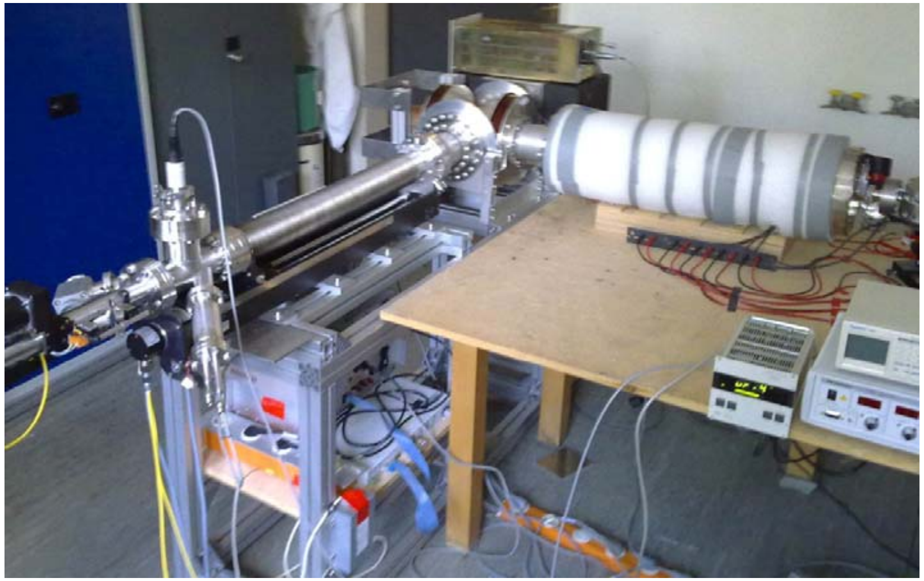
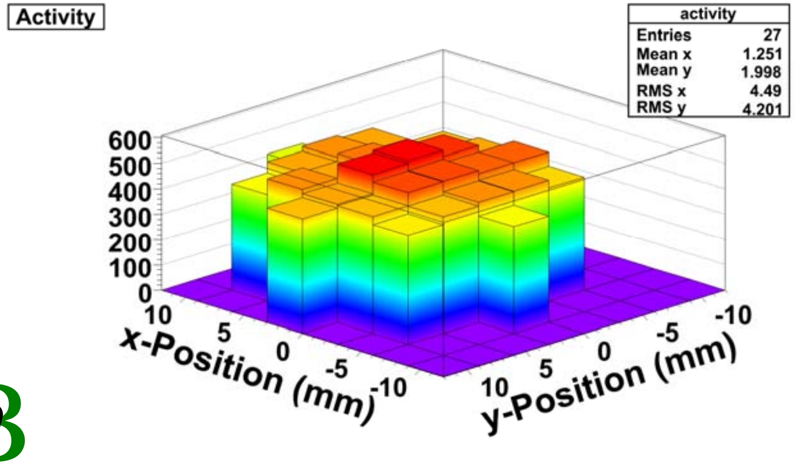
Rev rev.	St. st.	Sc. sc.	Preparato prepared	Controllato checked	Verificato checked	Verificato checked	Verificato checked	Approvato approved	Data Date
0			O. Dormicchi	M. Tassisto				O. Dormicchi	03/11/08

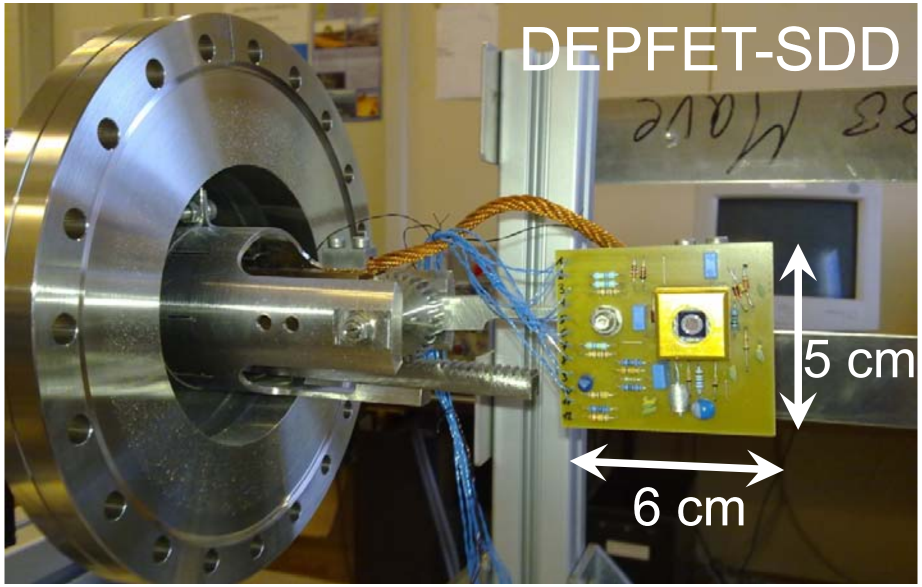
Forward Beam Monitoring

Tasks:

- permanent monitoring of WGTS luminosity in outer flux tube at the CPS (before spectrometers)
- movable into flux tube for diagnostics
- detector types: DEPFET, SDD
- tested with X-rays and electrons

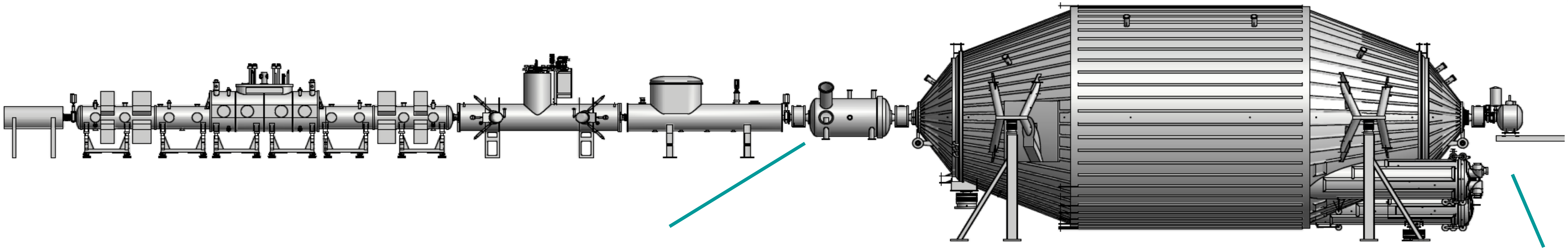






Udo Schmitt
A2 – post-doctoral researcher

electrostatic spectrometers



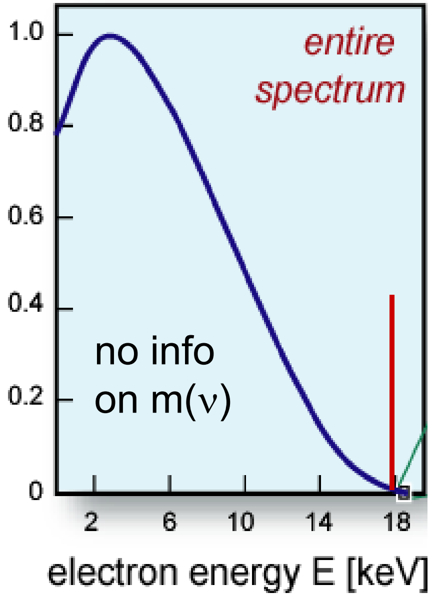
pre-filter

fixed retarding potential

U_0 = - 18.3 kV

$\Delta E \sim 100$ eV

- filter out all ß-decay electrons without m(ν)-info
- reduce background from ionising collisions

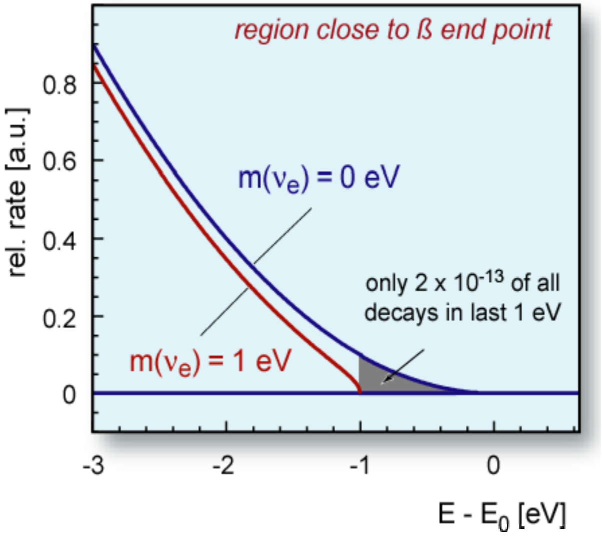


precision filter - scanning

variable retarding potential

U_0 = - 18.4 … -18.6 kV

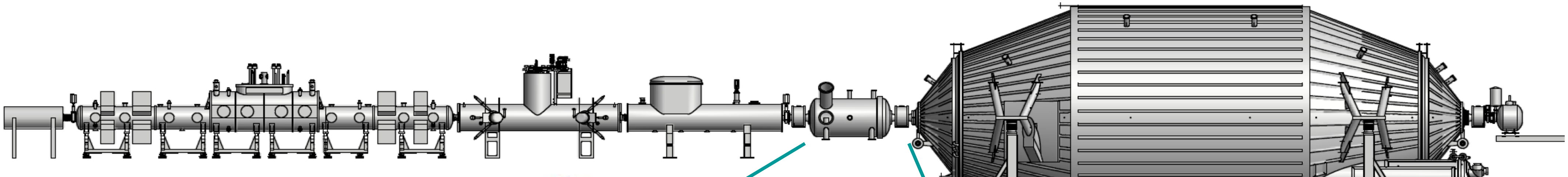
$\Delta E \sim 0.93$ eV (100% transmission)

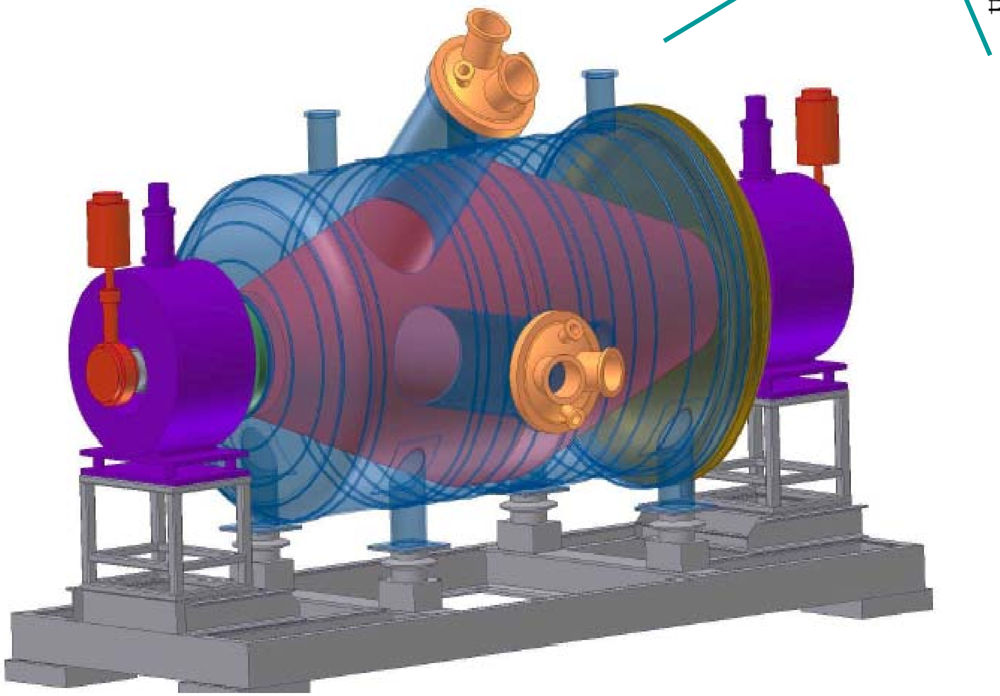


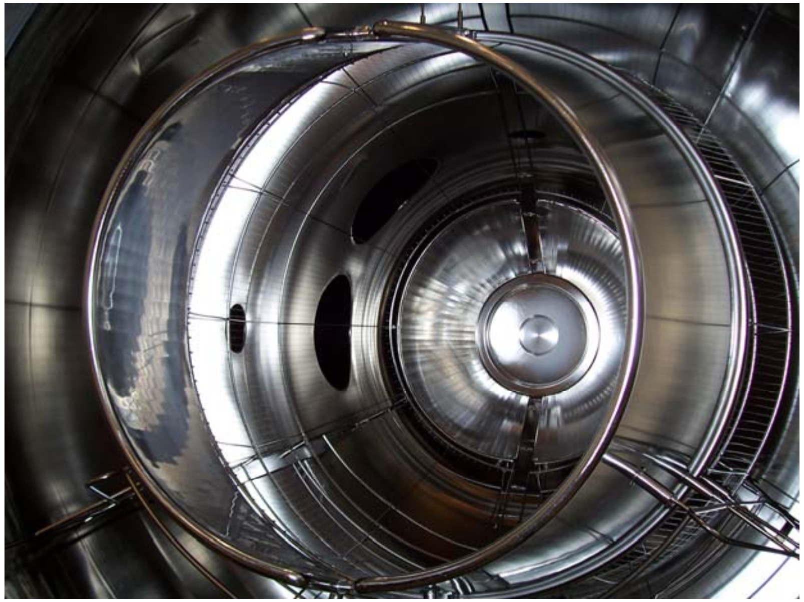
tandem design: pre-filter & energy analysis

10^{11} electrons/s ⇨ 10^3 electrons/s

pre-spectrometer





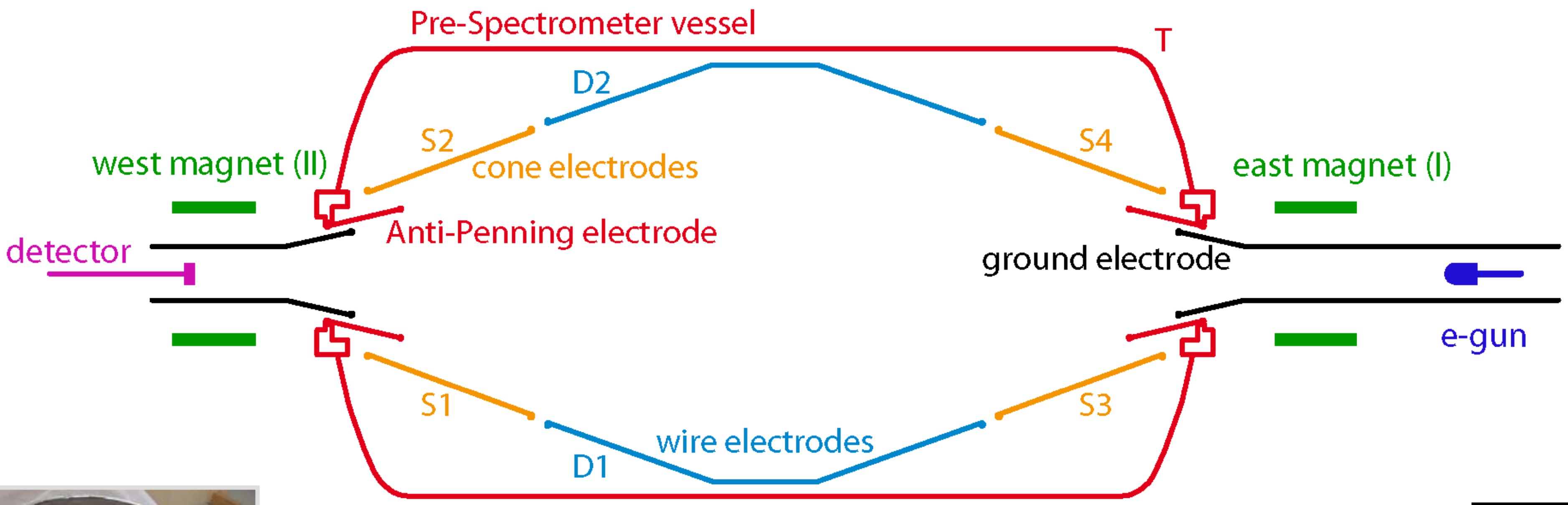


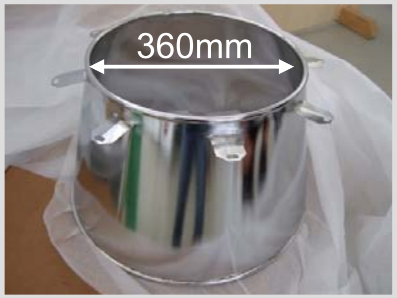
inner wire electrode system

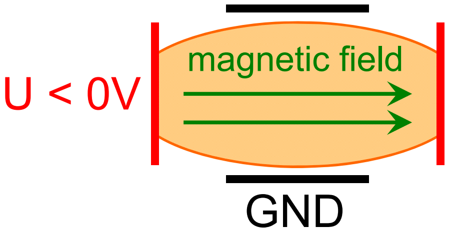
optimisation of electromagnetic design

- minimisation of Penning traps
- background reduction techniques (dipole fields)
- important testbed for main spectrometer layout

pre-spectrometer: electromagnetic tests



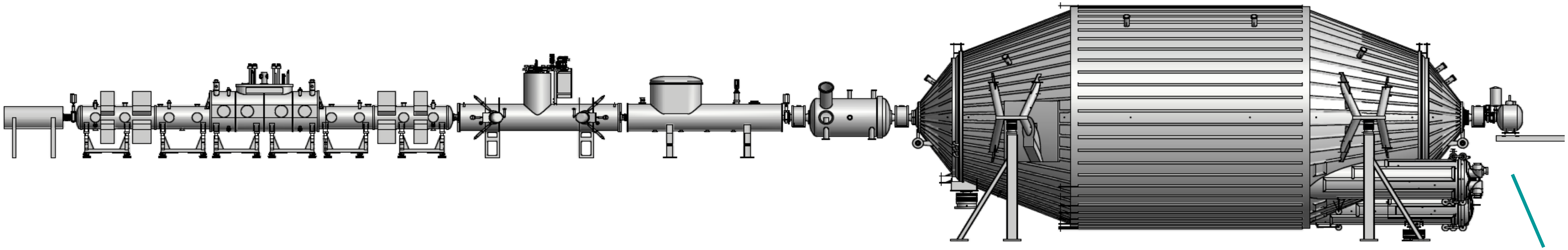


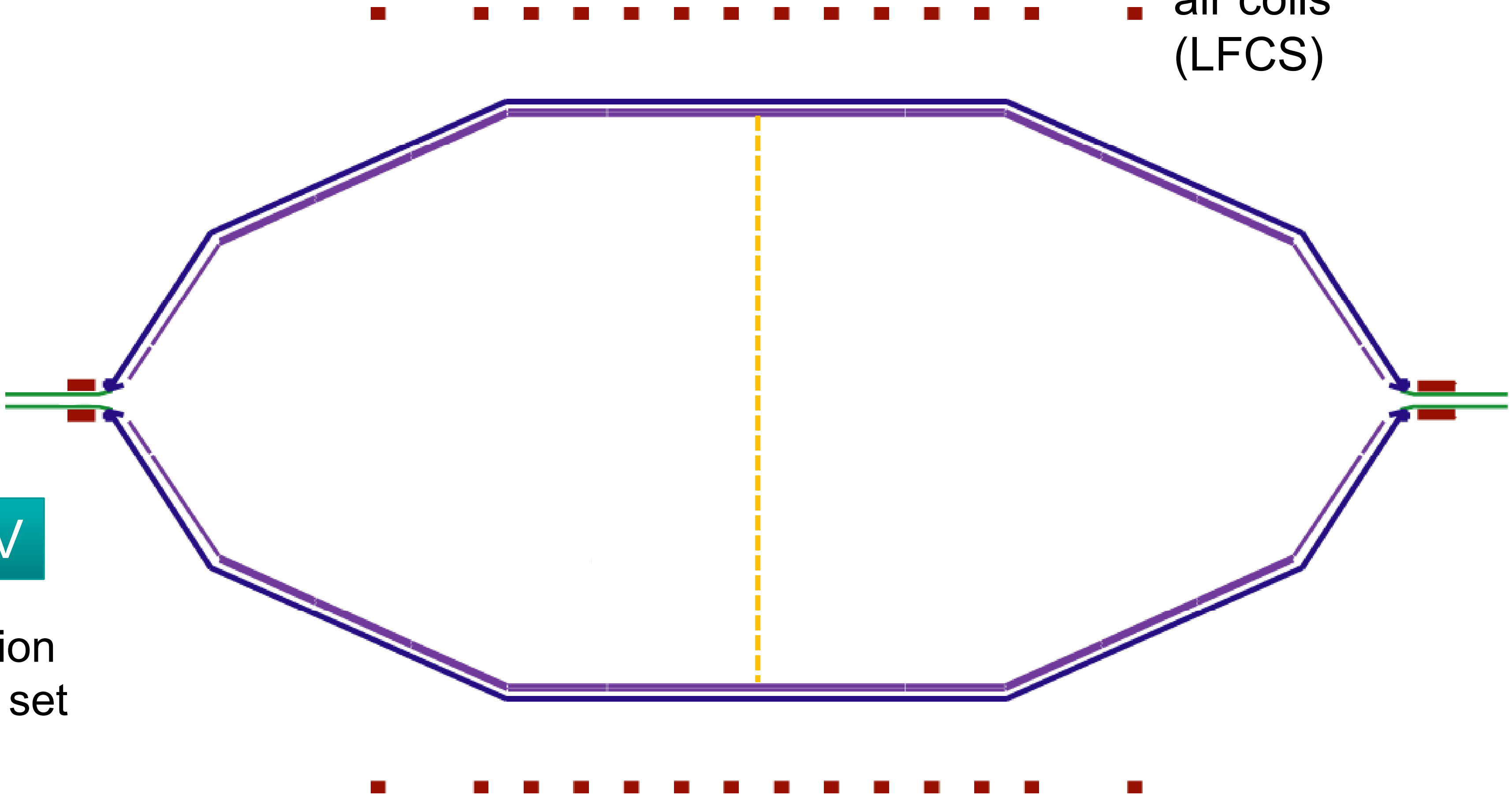


optimisation of electromagnetic design

- design of geometry of ground & Anti-Penning electrodes
- detailed study of characteristics of Penning traps as function of electrostatic potential, B-field, pressure
- 3rd generation layout is being implemented

main spectrometer

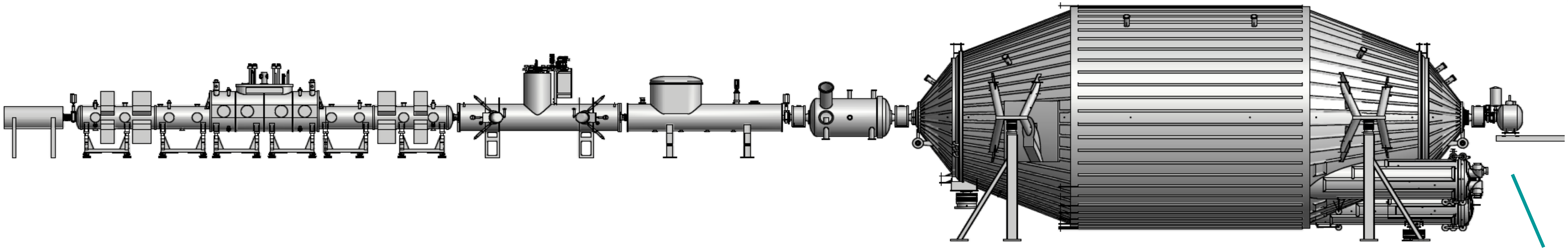


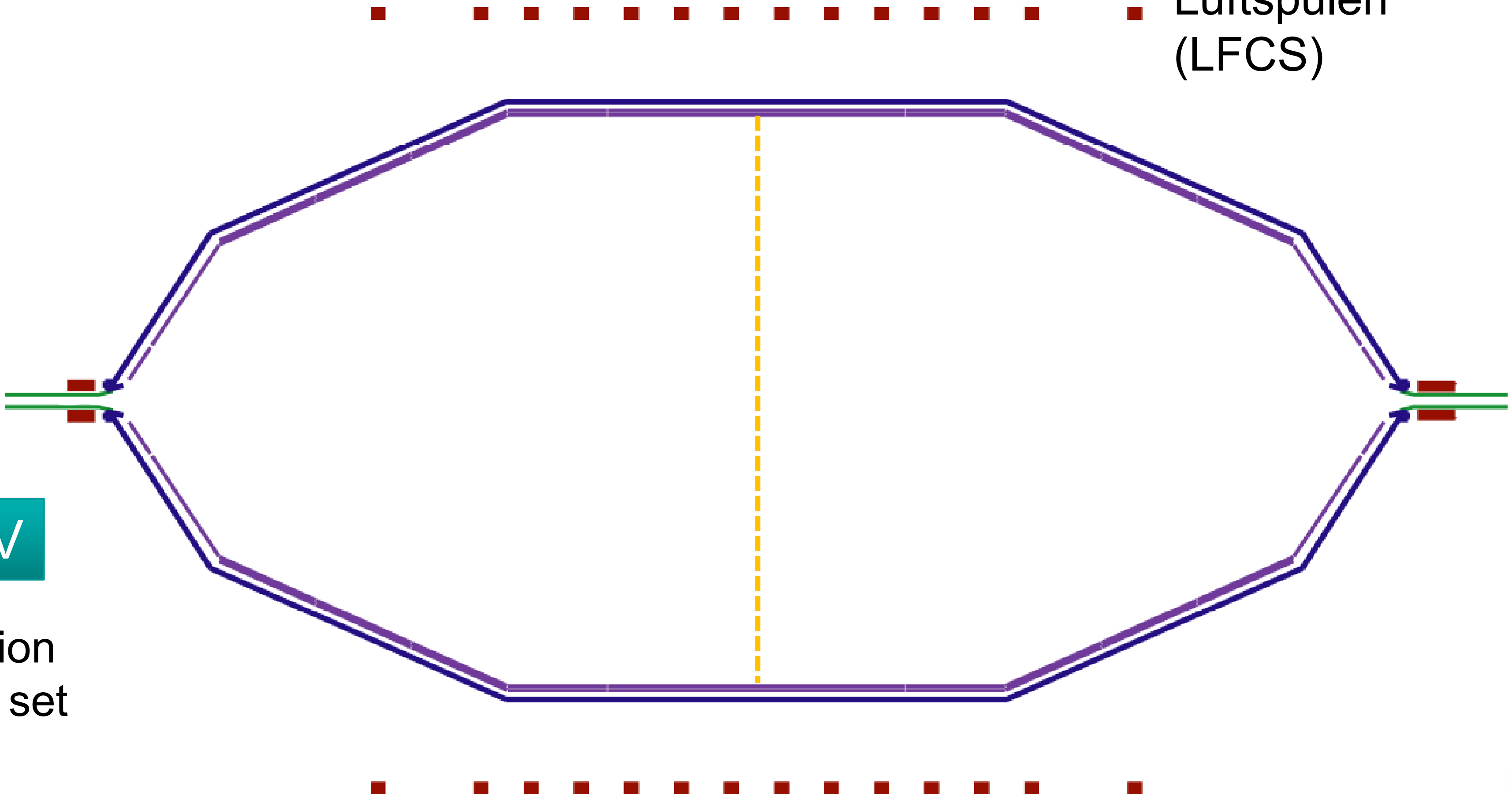


$E(e^-) = U_0 - 1\ \mathrm{eV}$

for better visualisation
of cyclotron motion set
$m_e = 0.01\ m_e$

main spectrometer



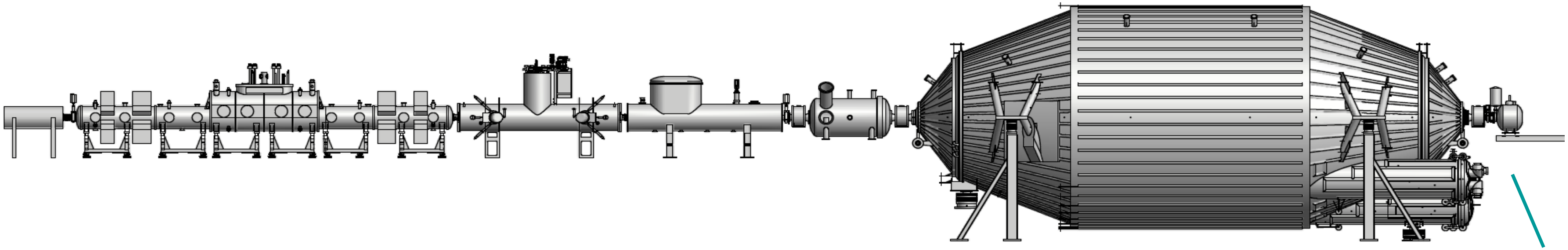


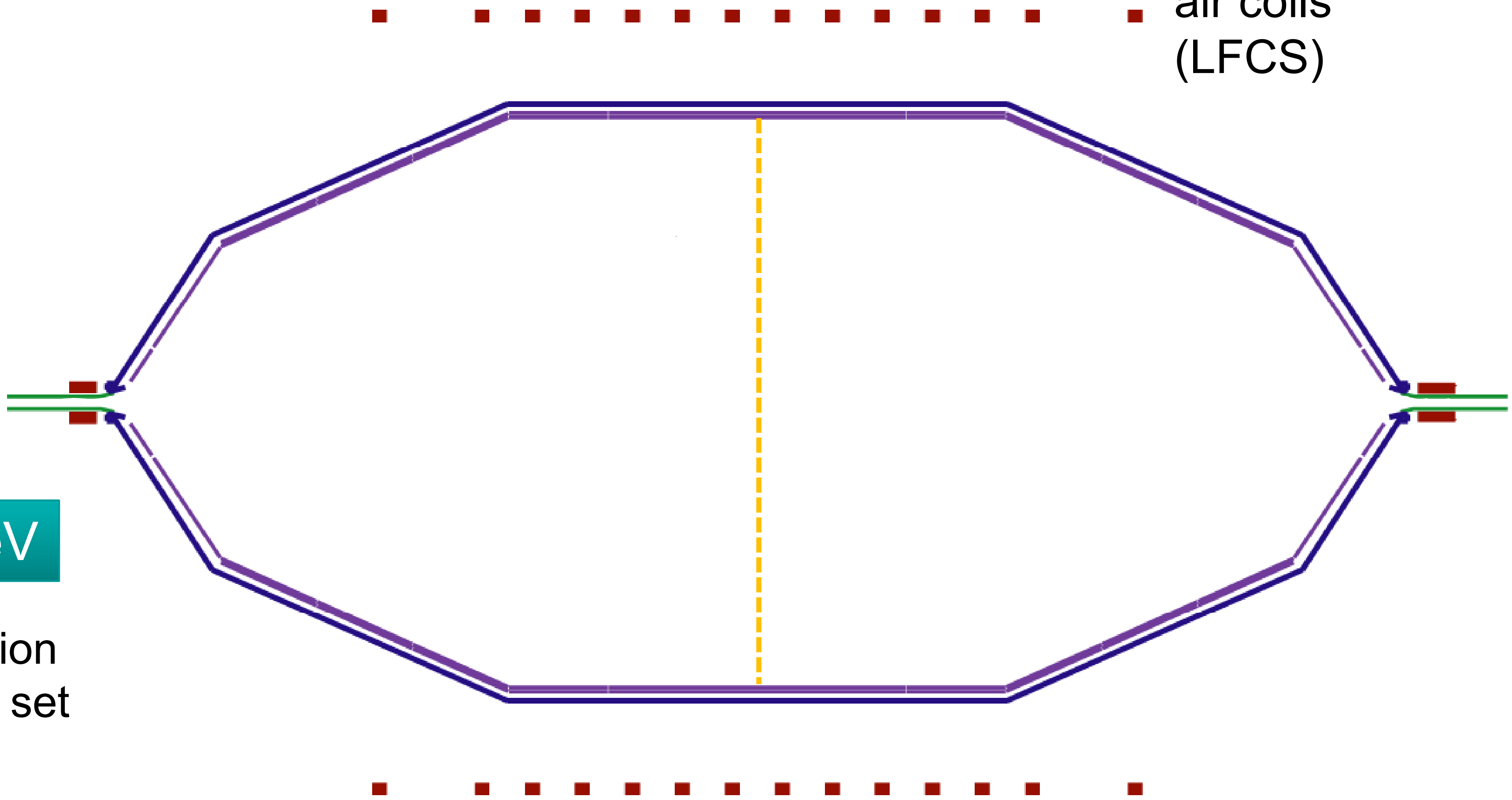
Luftspulen (LFCS)

$E(e^-) = U_0 - 1\ \text{eV}$

for better visualisation
of cyclotron motion set
$m_e = 0.01\ m_e$

main spectrometer



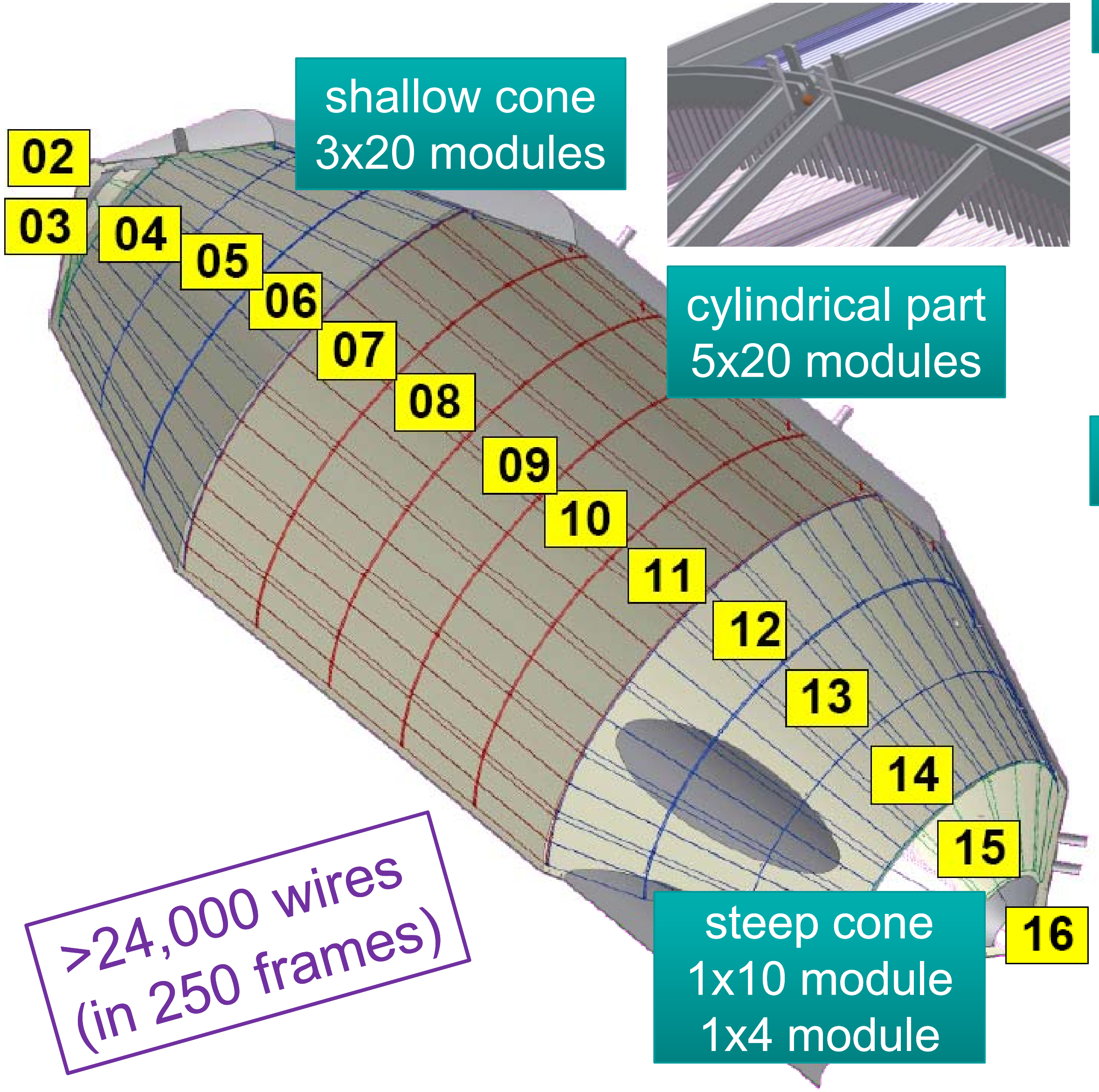


E(e$^-$) = U_0 + 1 eV

for better visualisation
of cyclotron motion set
$m_e = 0.01\ m_e$

temperature stabilised spectrometer hall

inner electrodes: overall system layout



shallow cone
3x20 modules

cylindrical part
5x20 modules

steep cone
1x10 module
1x4 module

>24,000 wires
(in 250 frames)

#1: fine forming of retarding field

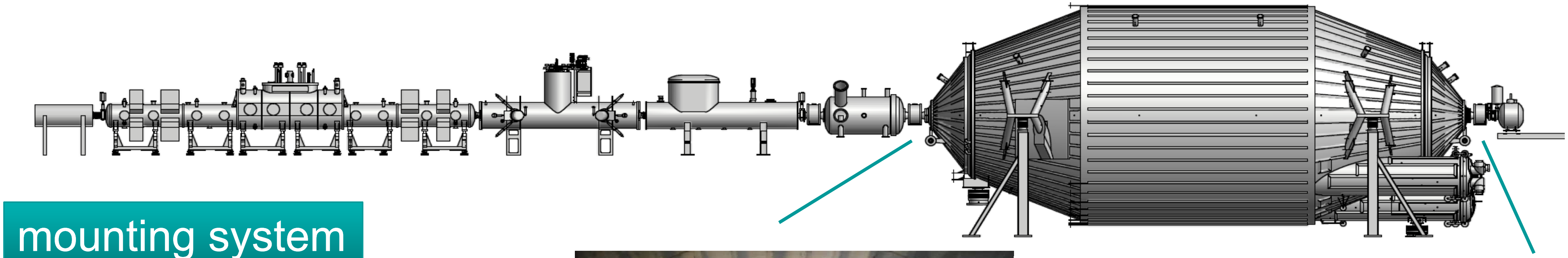
- precision HV power supplies:
  intrinsic HV precision ~1 ppm
- dipole mode: emptying of particles
  stored in Penning traps

#2: background suppression

inelastic reactions of cosmic muons
↳ low-energy secondary electrons
from the 690 m² inner surface

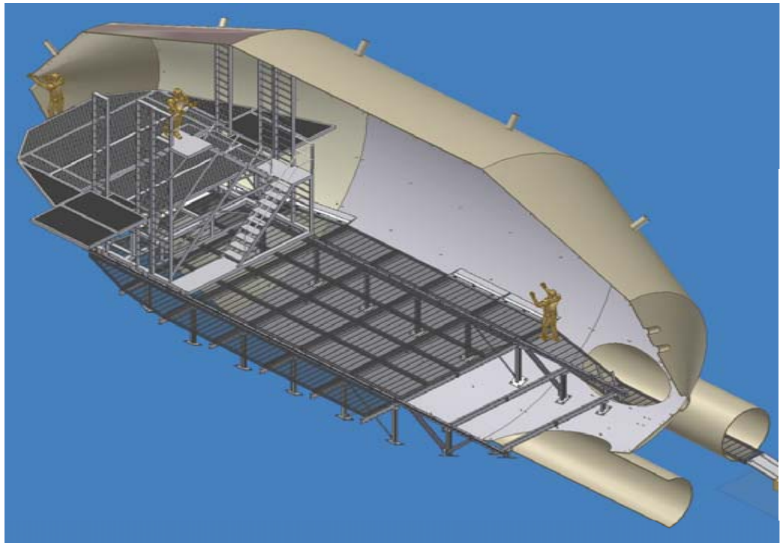
manufacture
at U Münster

inner electrodes: mounting system



mounting system

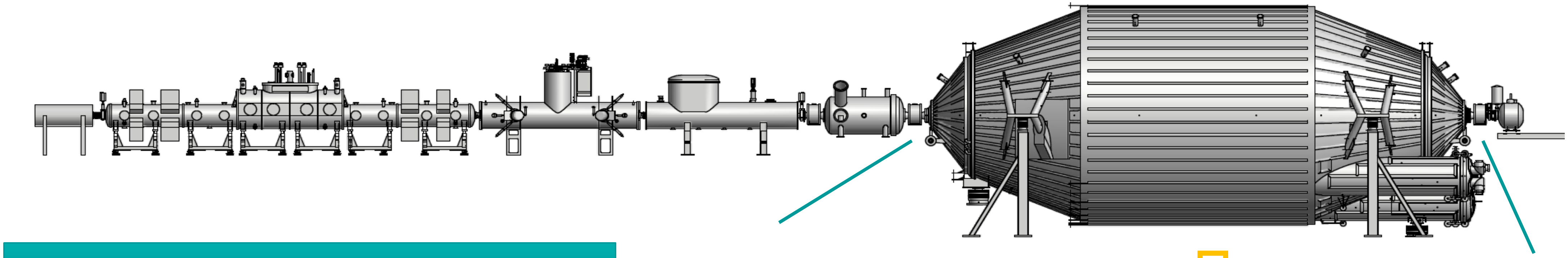
- access via 85 m² clean room at rear end
- electropolished mounting system for precise mounting



- laser tracker alignment with 100 µm over entire inner surface

July 2009: first wire modules installed successfully

main spectrometer: Helmholtz coil system



LFCS – Low Field Coil System

radial coils

tasks:

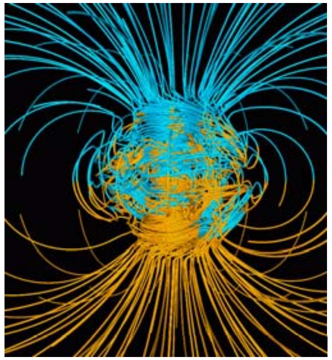
- constrain magnetic flux tube (2.4 G→3.4 G)
- reduce field inhomogeneities (33%→13%)

EMCS – Earth Magnetic Field Coil System

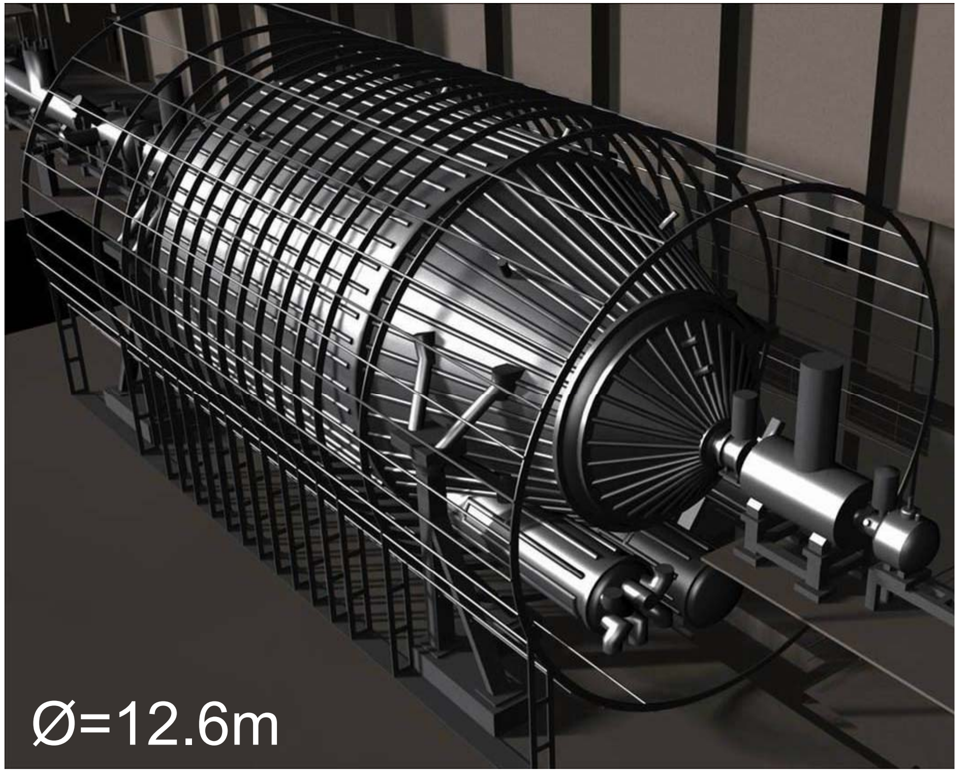
´cosine´ coils

tasks:

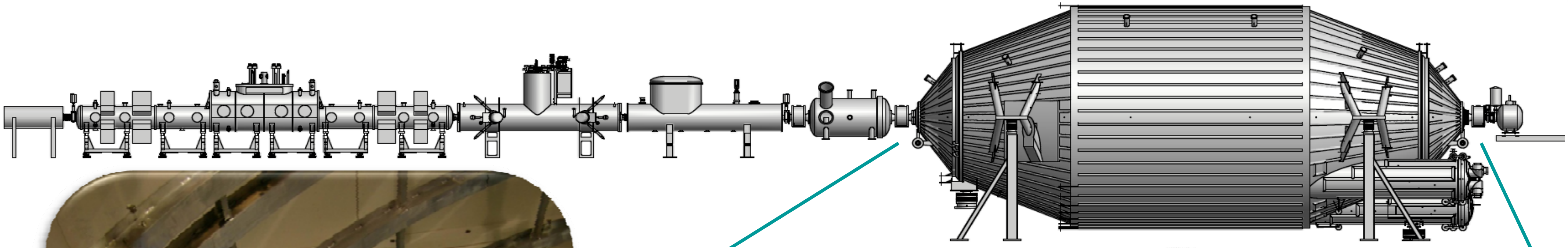
- compensate earth magnetic field (500 mG) or B-field distortions

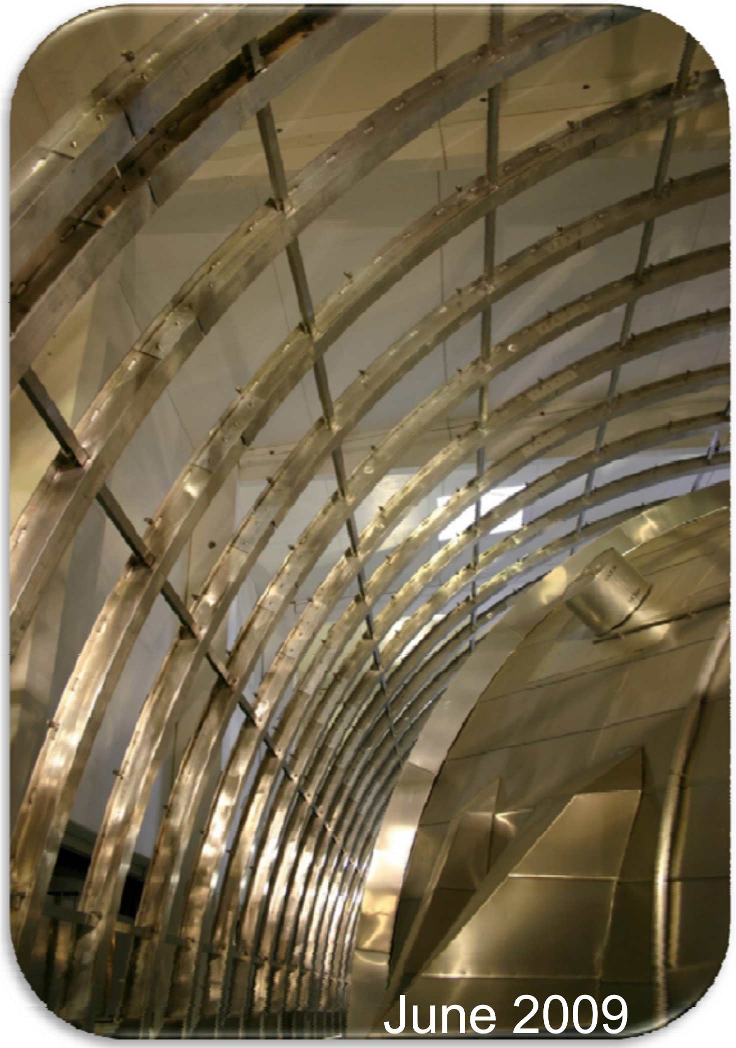


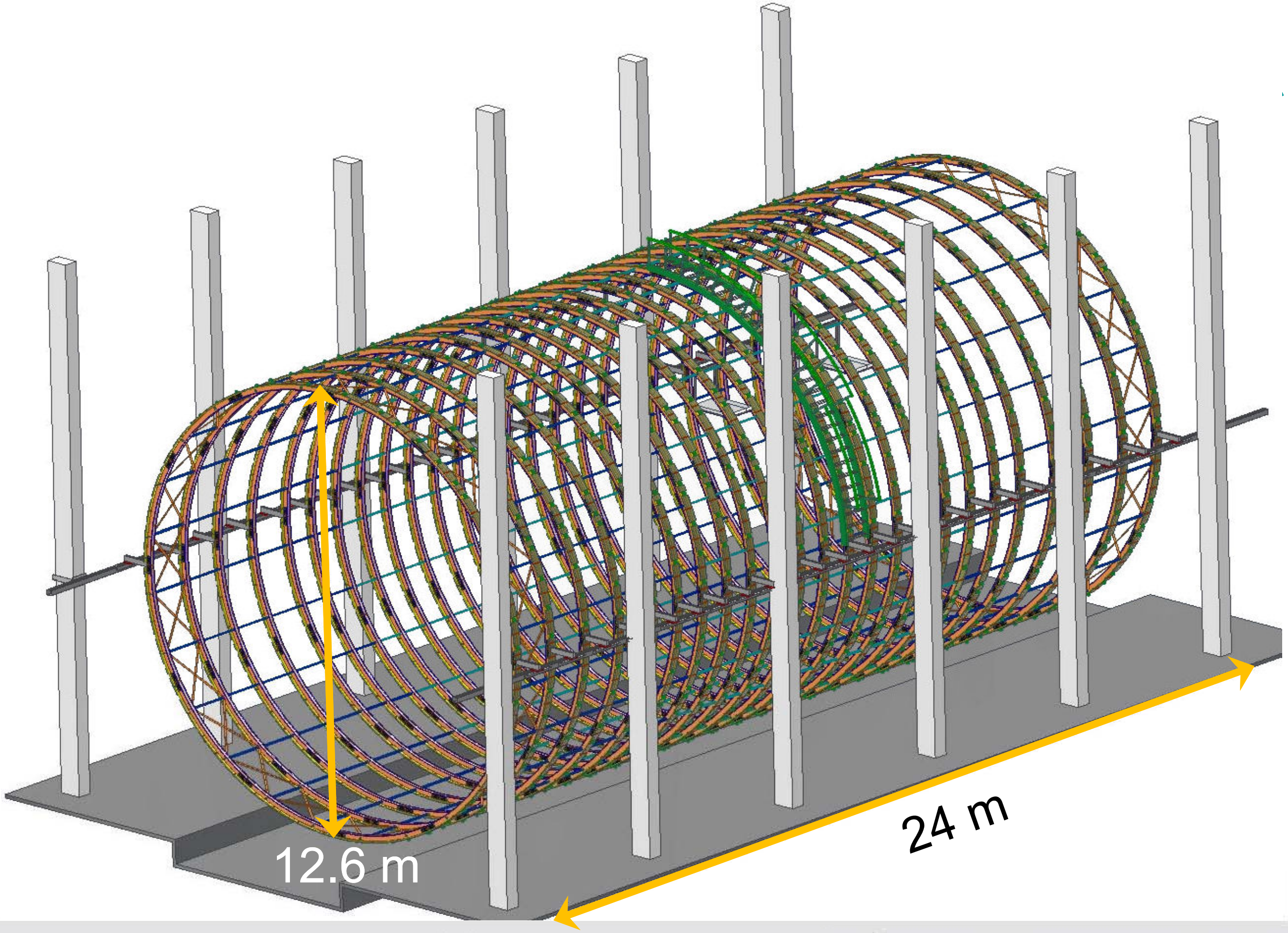
02/09-08/09: ⇩ assembly



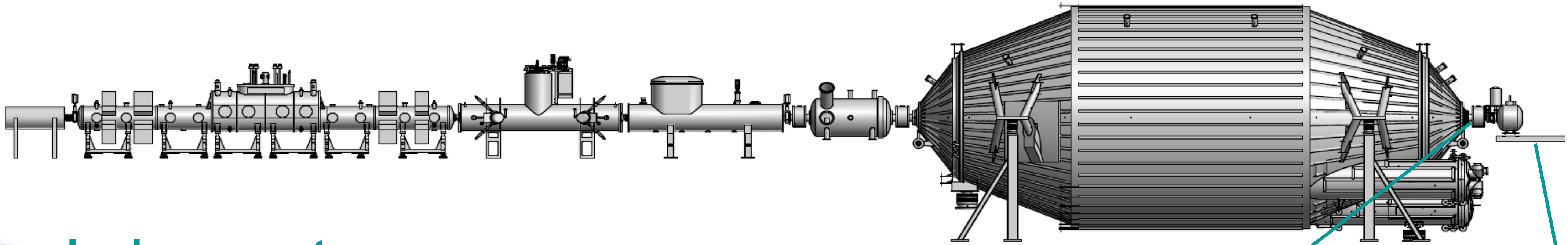
Helmholtz coil system – status







focal plane system



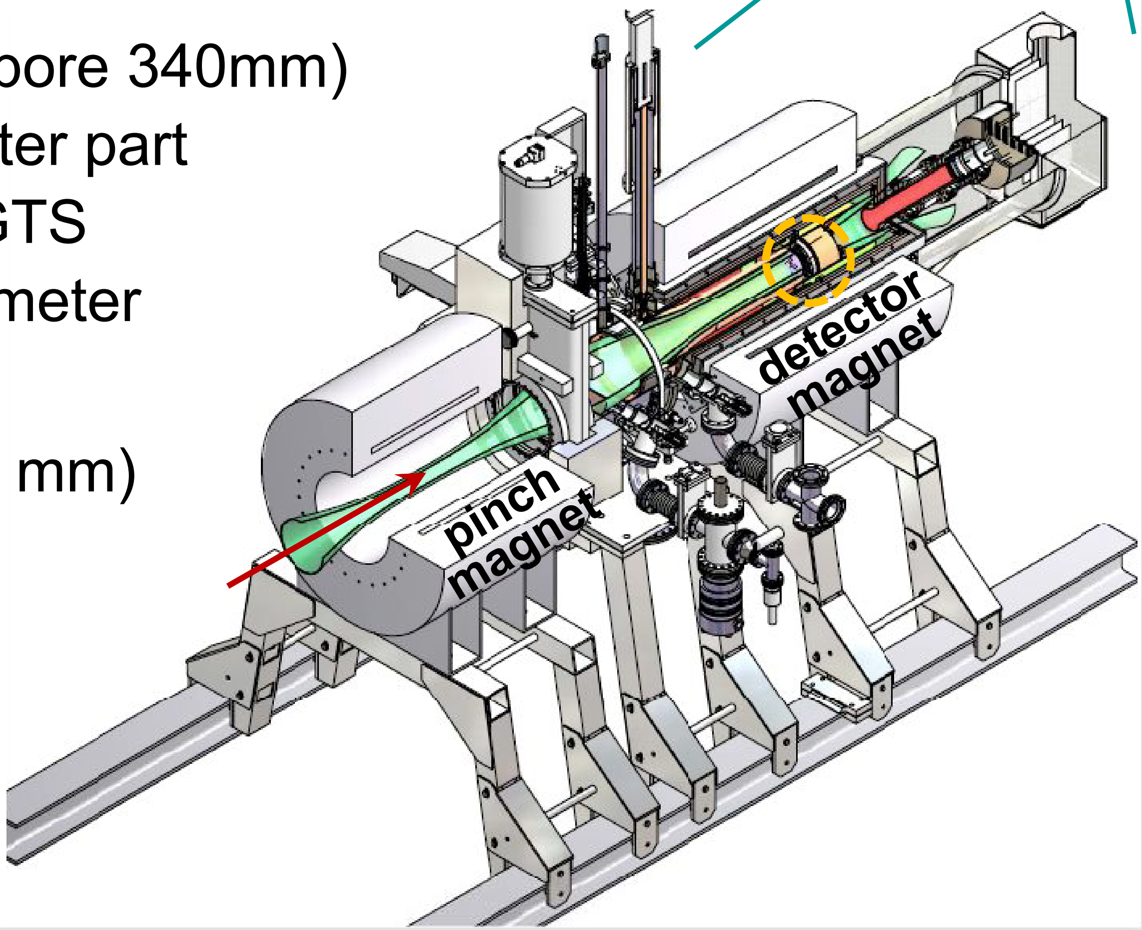
- **pinch magnet**

  provide maximum field B_{max} = 6 T (bore 340mm)
  - guiding B-field in rear spectrometer part
  - define θ_{max} for ß-electrons in WGTS
  - define energy resolution spectrometer
- **detector magnet**

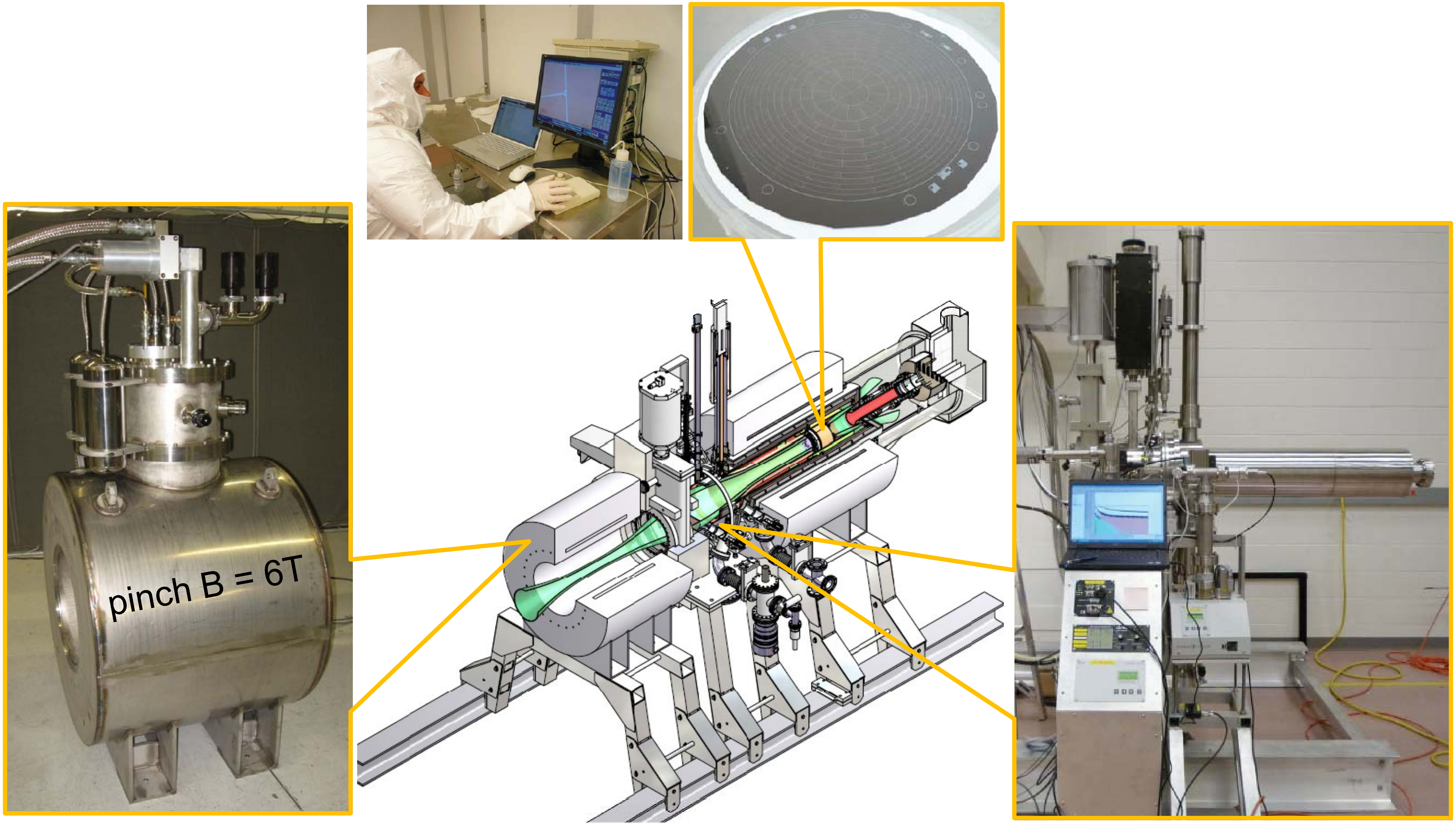
  strong field B_{det} = 3 – 6 T (bore 440 mm)
  - optimised focusing of analysing plane inhomogeneities (B, U_0)
- **focal plane detector**

  segmented Si-PIN diode array

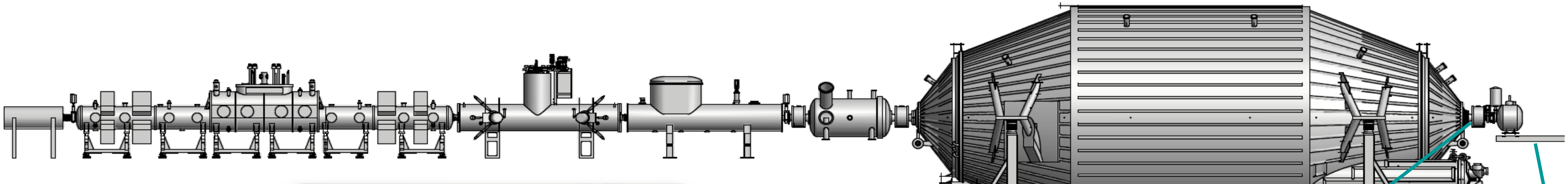
  read-out electronics

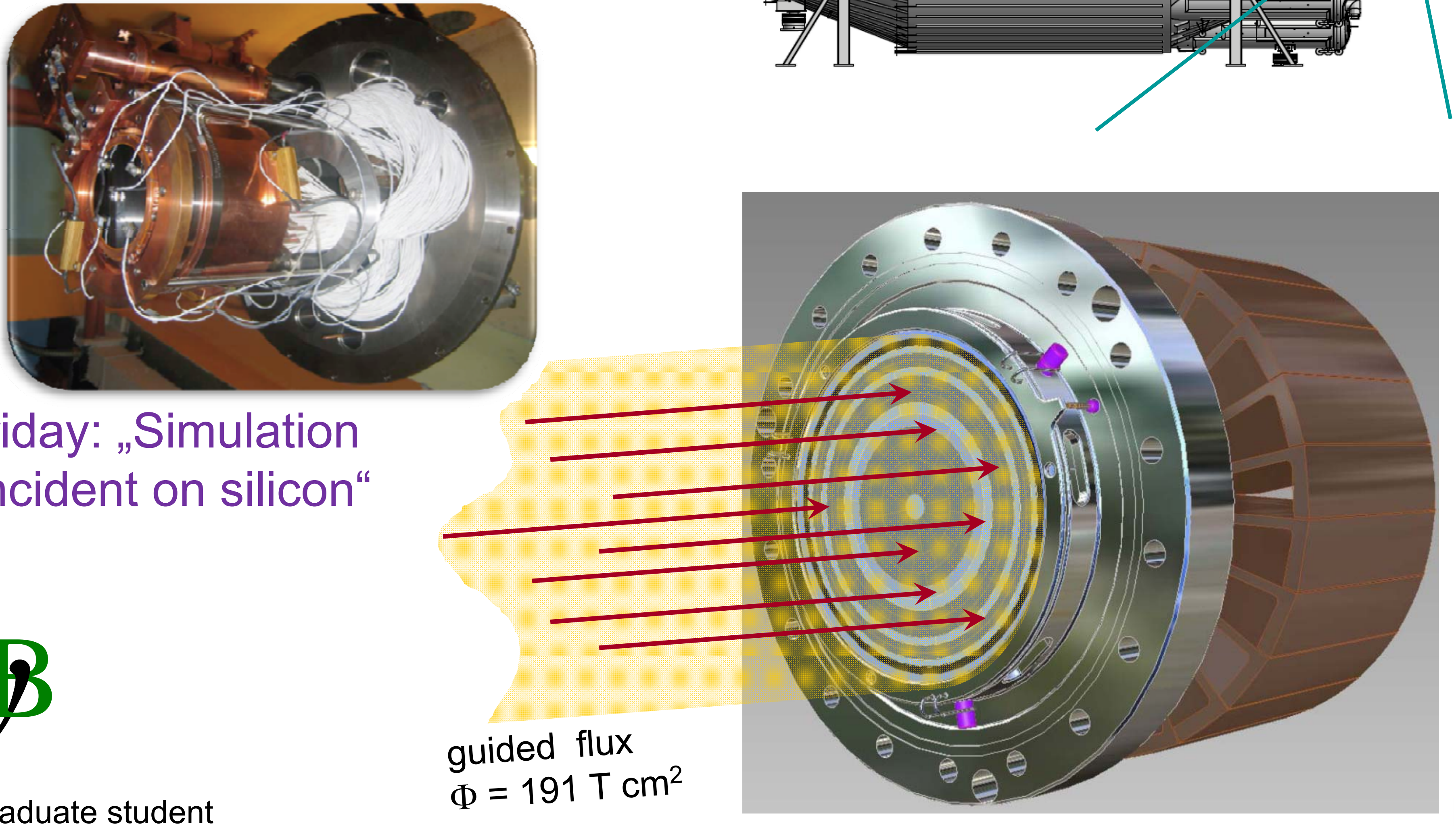


detector system – hardware status



focal plane detector

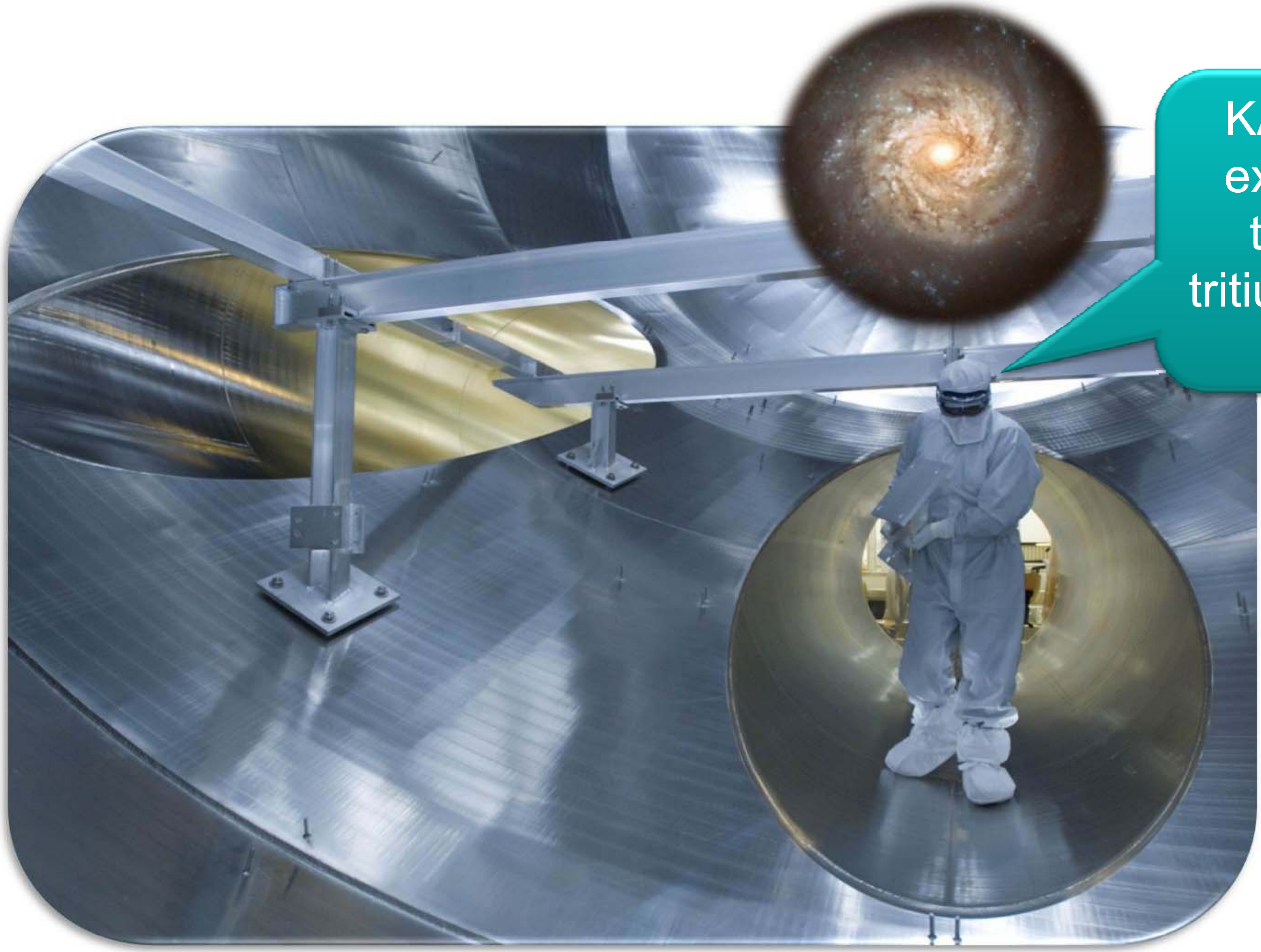




see talk on Friday: „Simulation of electrons incident on silicon“

P. Renschler A2 – graduate student

Inside KATRIN



KATRIN is making excellent progress towards the first tritium measurements in mid-2012

thanks to the