Direct neutrino mass searches

KATRIN and other approaches

MARE

Neutrino Oscillation Workshop - NOW 2012

Guido Drexlin, Institut für Experimentelle Kernphysik

Karlsruhe Institute of Technology

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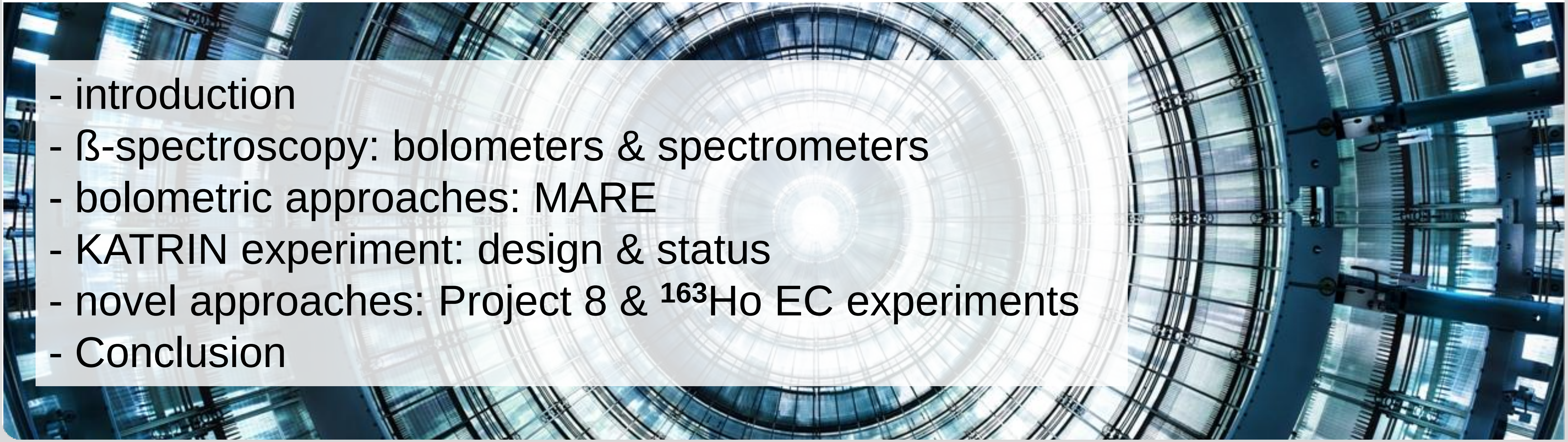


- introduction
- ß-spectroscopy: bolometers & spectrometers
- bolometric approaches: MARE
- KATRIN experiment: design & status
- novel approaches: Project 8 & ^{163}Ho EC experiments
- Conclusion

in memoriam

Jochen Bonn

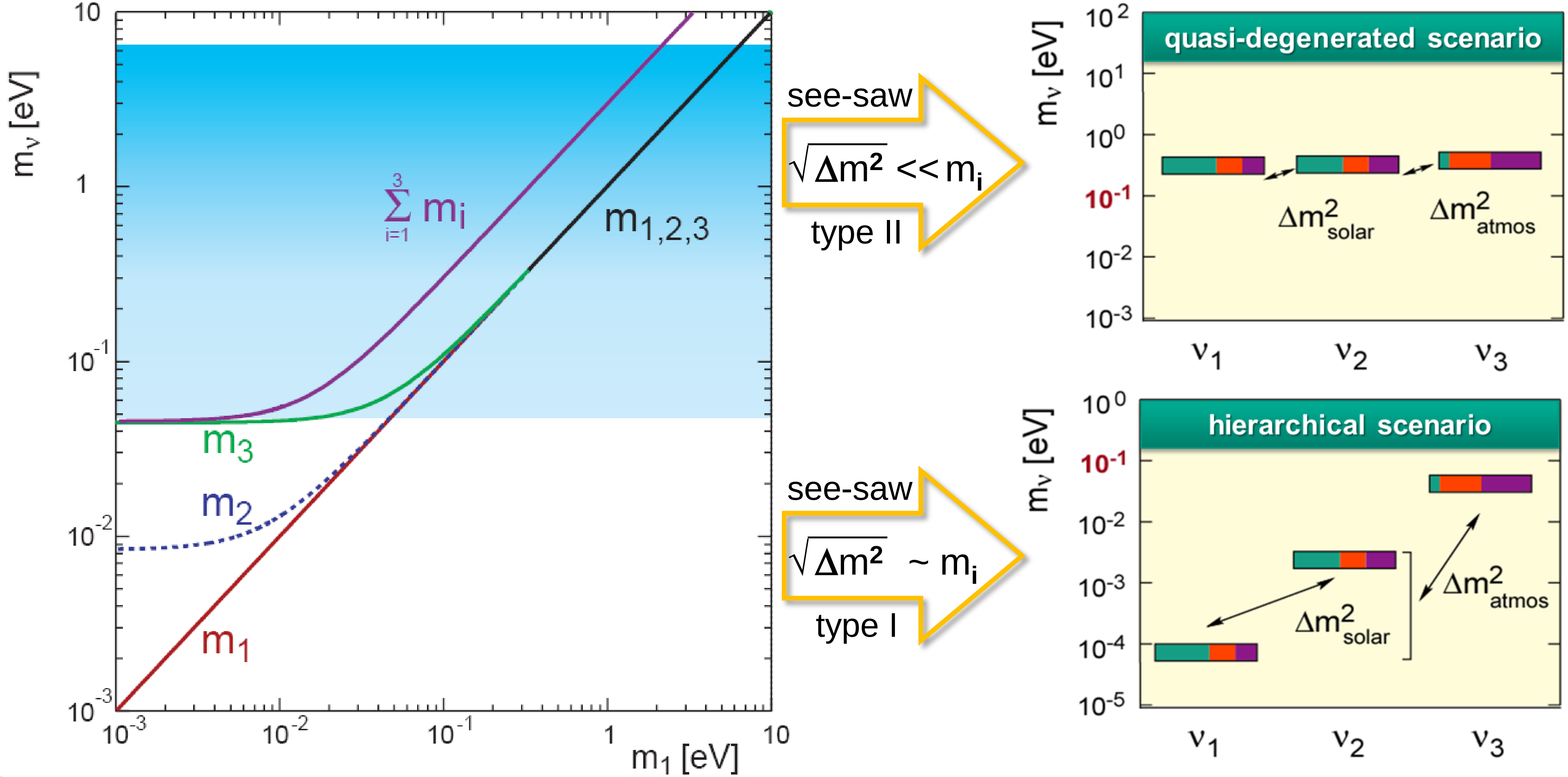
experimental physicist par excellence

1944 - 2012

Introduction & ß-spectroscopy

motivation: ν´s in astroparticle physics

particle physics: absolute neutrino mass scale (m_ν)



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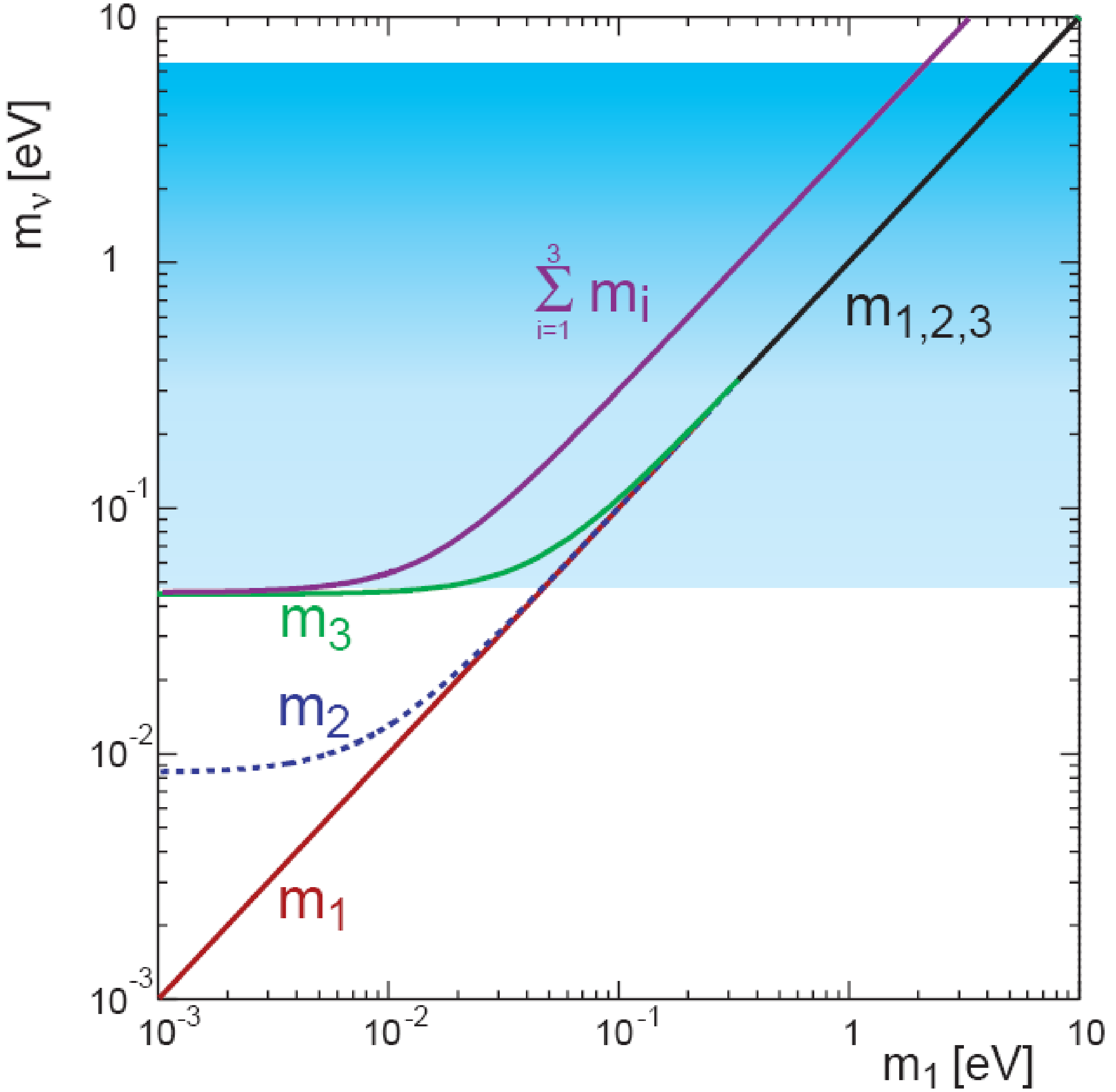
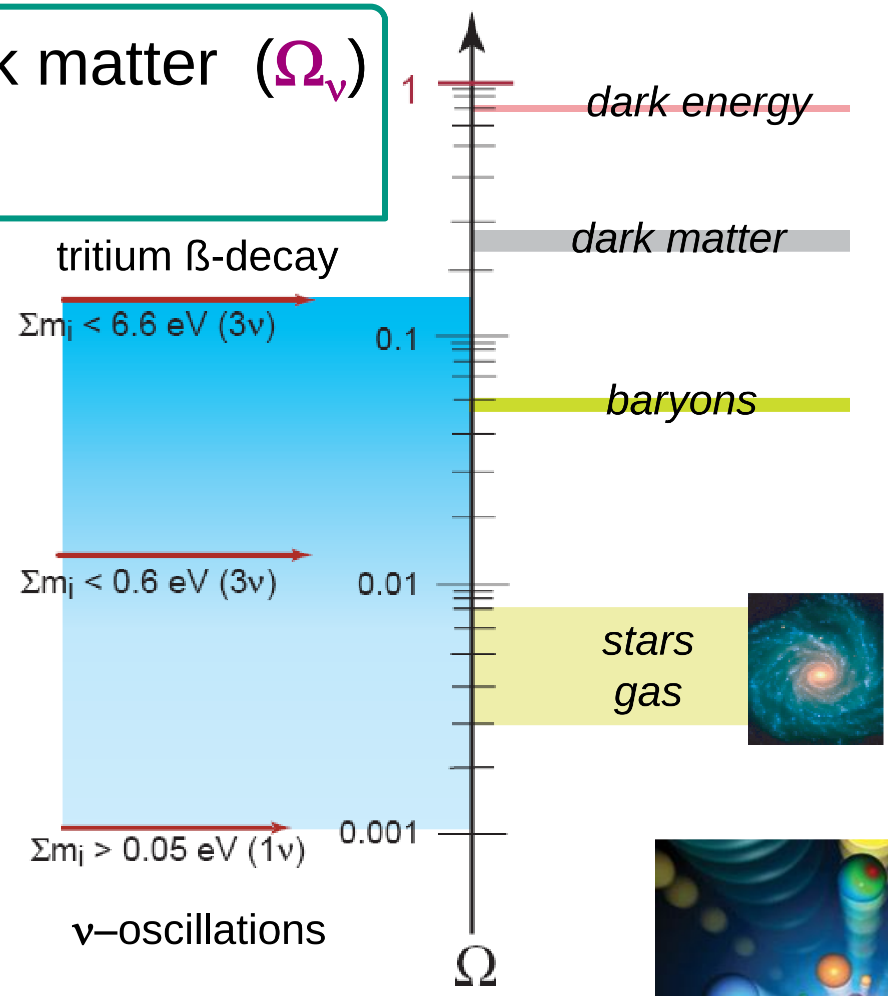
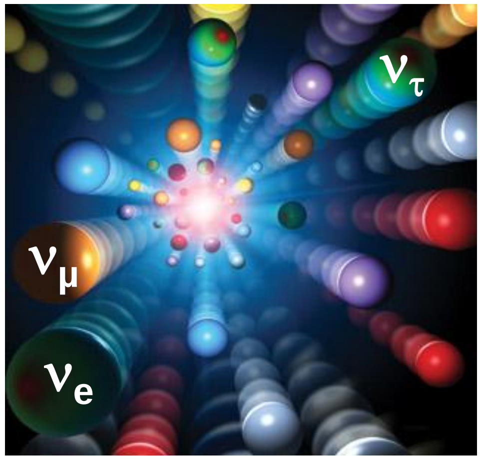
cosmology: role of relic-ν´s as hot dark matter (Ω_ν)



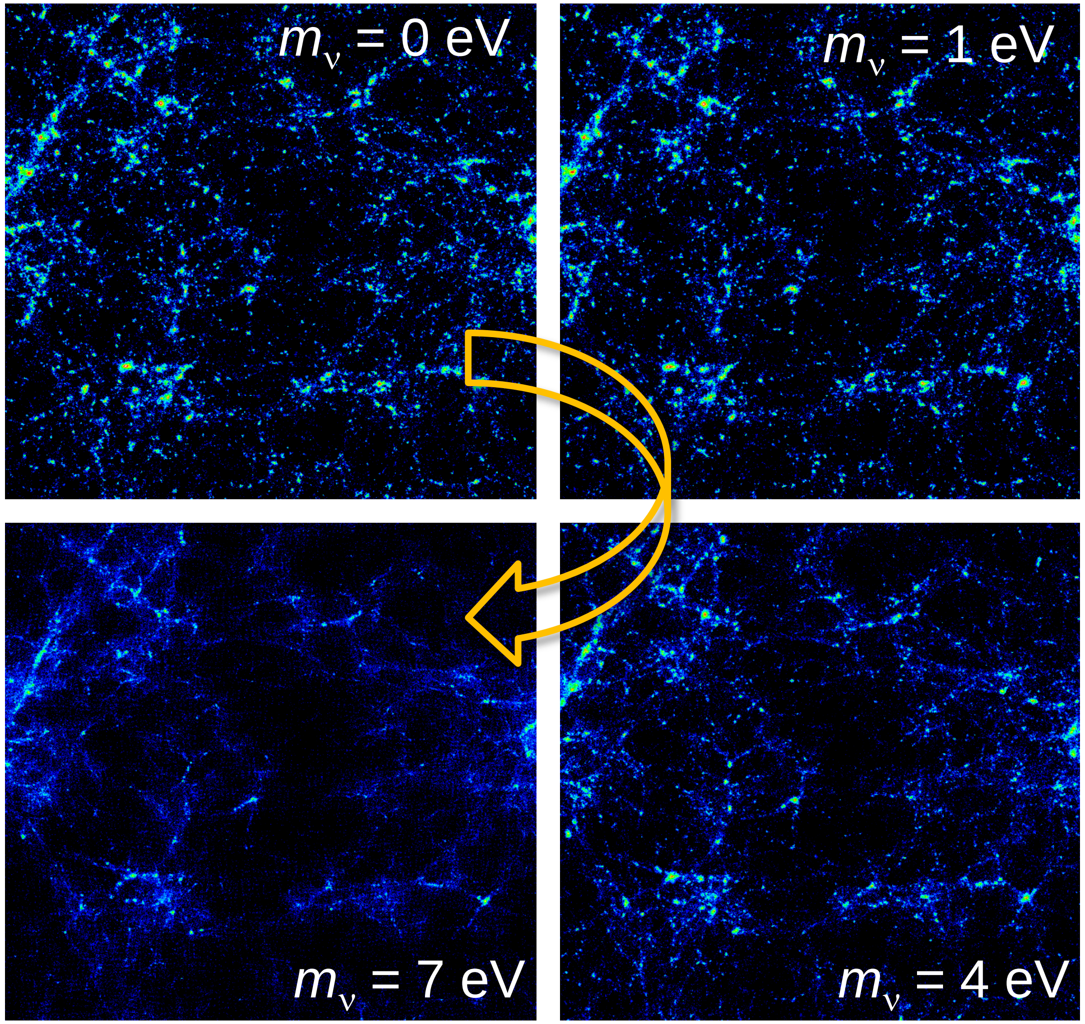


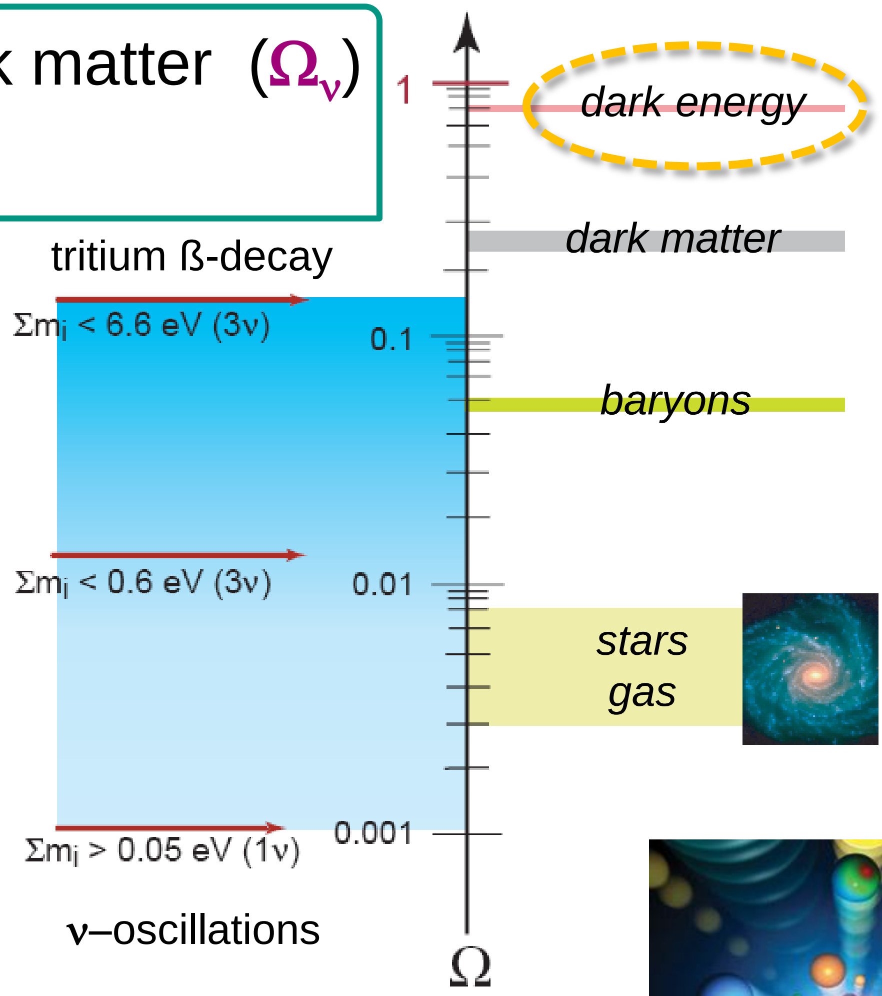


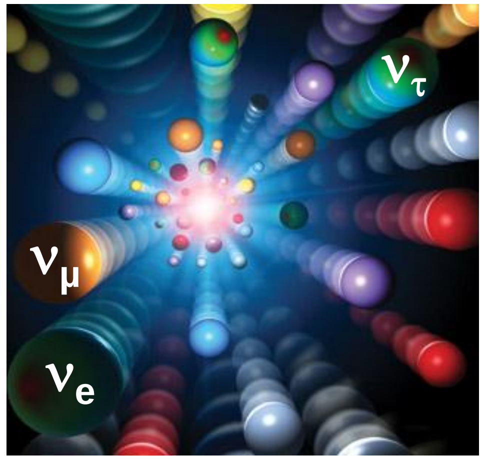
motivation: ν´s in astroparticle physics

cosmology: role of relic-ν´s as hot dark matter (Ω_ν)

$w = P / \rho c^2$







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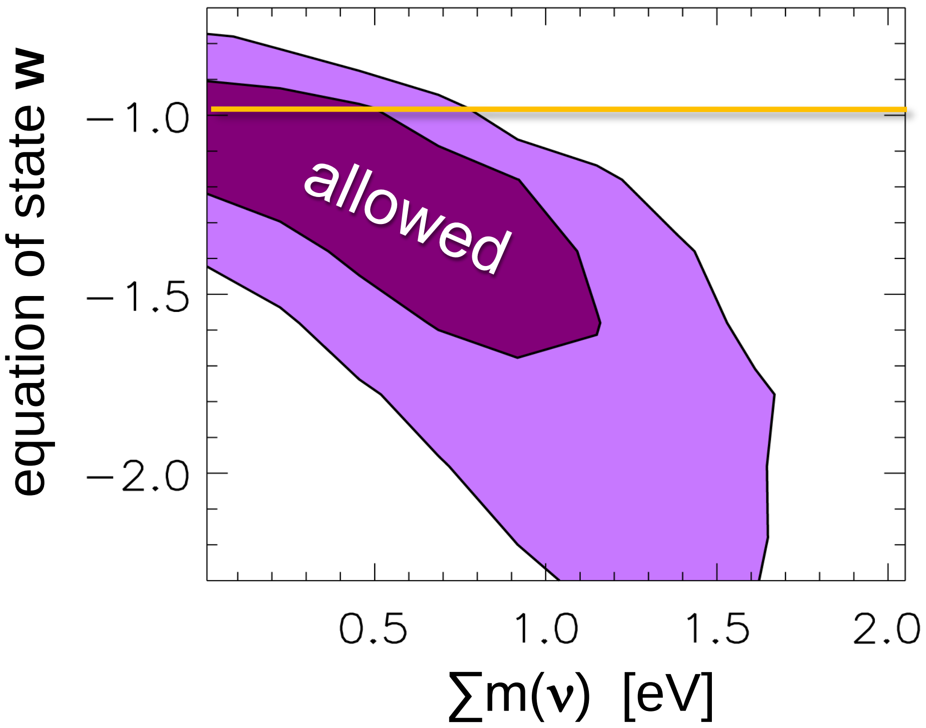

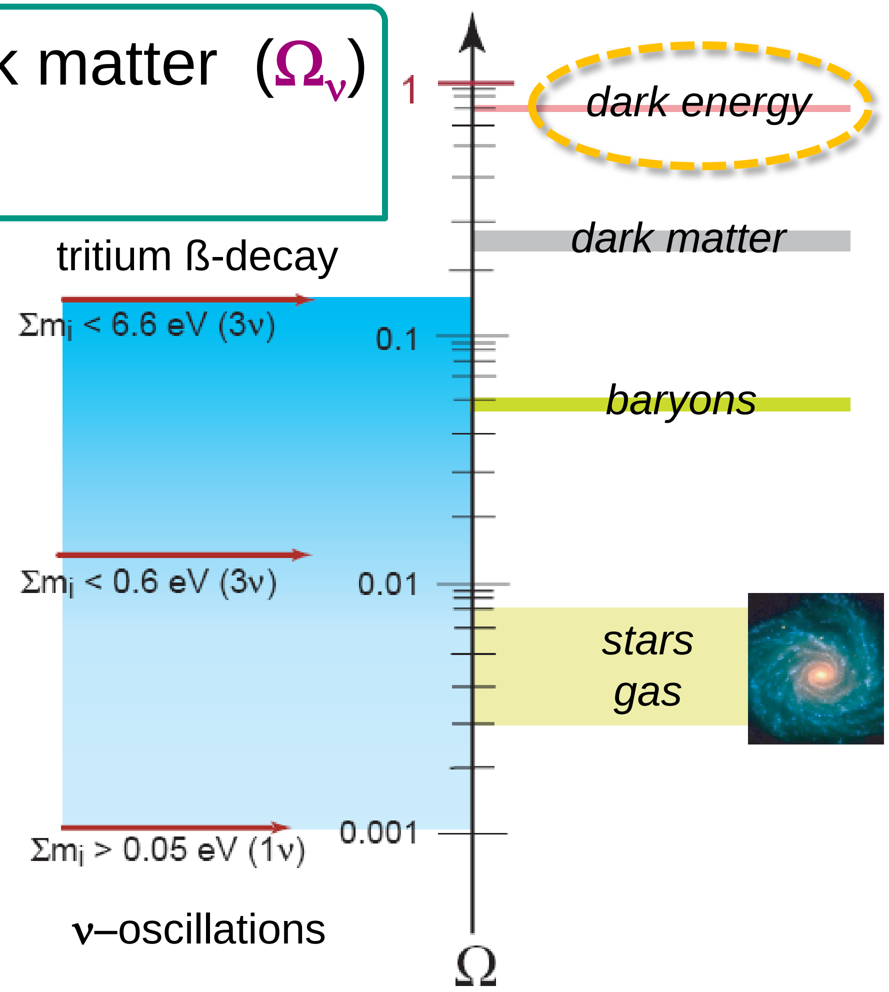

$w = P / \rho c^2$

degeneracy between m_ν and dark energy equation of state *w*

motivation: ν´s in astroparticle physics

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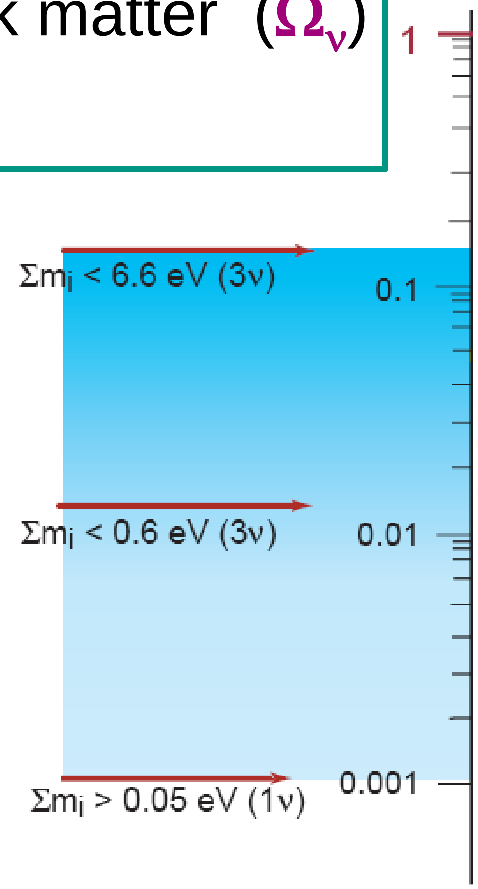
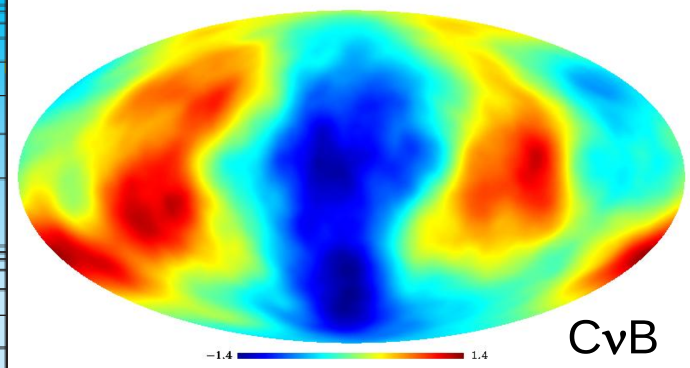
cosmology: role of relic-ν´s as hot dark matter (Ω_ν)



calculated anisotropies of the CνB for m_ν = 10 meV (S. Hannestad, 2009)

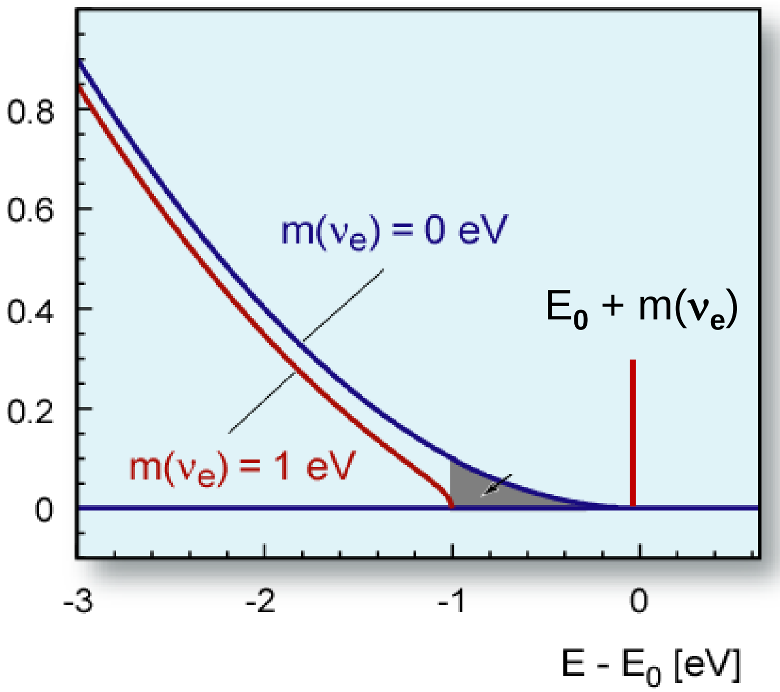


CνB dipole

- idea: capture of relic neutrinos on ß-unstabile isotope (^{3}H, ^{187}Re):

  e.g. $\nu_e + {}^3H \rightarrow {}^3He + e^-$

  advantage: no threshold!



- **experimental challenges in case of ^{3}H:**

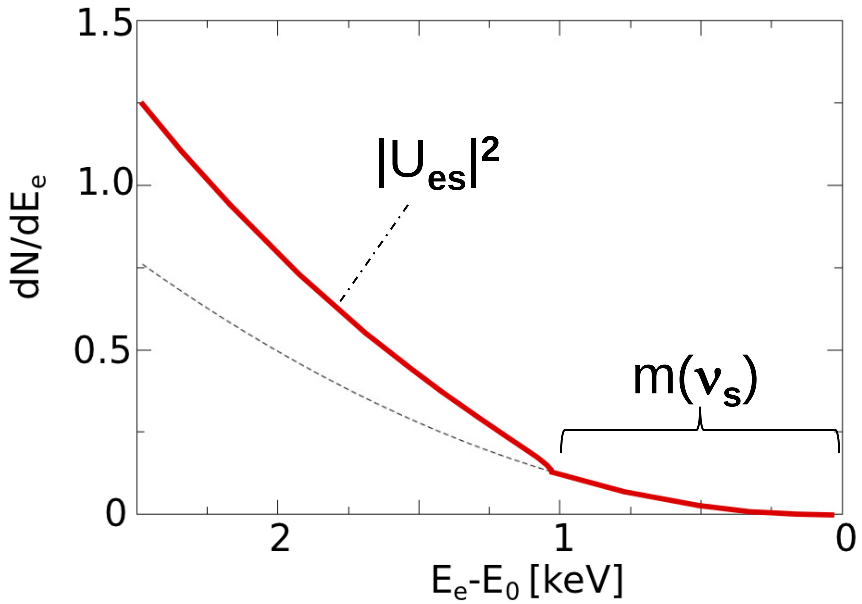
  a) >10^6 KATRIN T_2 target mass required (~100 g), 24 g T_2 are on site at TLK

  b) resolution ΔE < 50 meV for 18.6 keV ß´s would severely cut solid angle of source

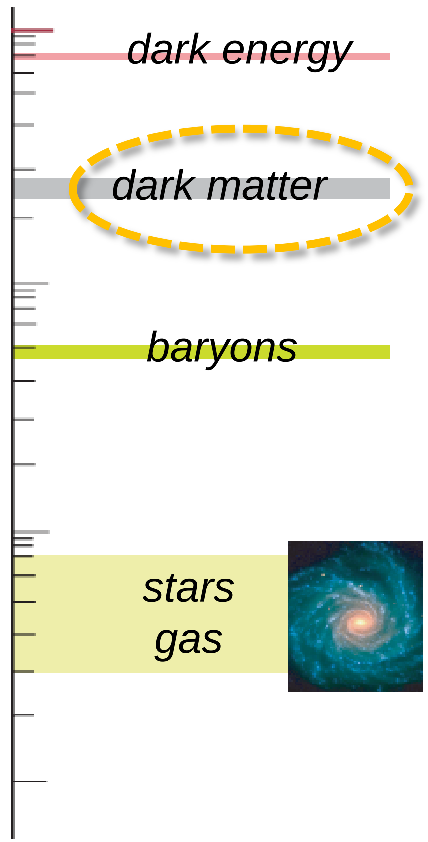
motivation: ν´s in astroparticle physics

cosmology: role of sterile ν´s as warm dark matter (see talk by M. Lindner)

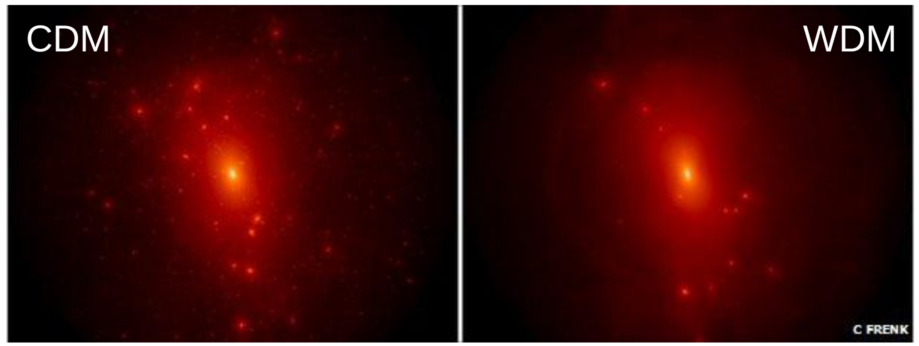
- idea: sterile ν´s in the 1-10 keV mass regime would constitute warm dark matter (WDM)



- sterile neutrino ν_s would manifest itself as a tiny kink (10^{-7}-10^{-10}) deep in the ß-spectrum
  ↳ need reliable calculation of spectral shape



DM & dwarf statellites



ß-decay – Fermi theory & ν-mass

- ß-decay kinematics close to endpoint E_0: model independent measurement of $m(\nu_e)$, based solely on **kinematic parameters & energy conservation**

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

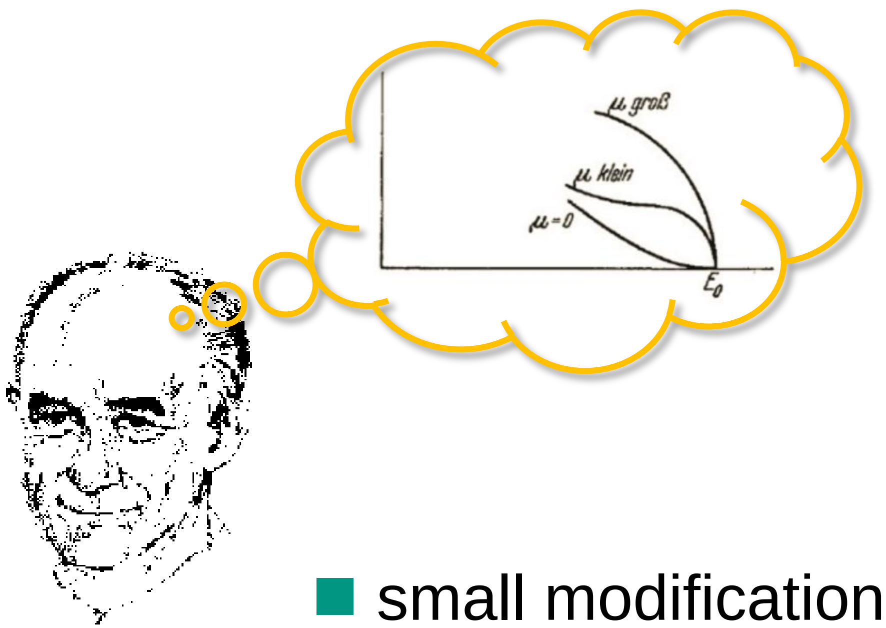
$$G_F^2 \cdot \frac{m_e^5}{2\pi^3} \cdot \cos^2\theta_C \cdot |M|^2$$

observable $m^2(\nu_e)$: effective ´electron-ν-mass´

Fermi function F(E,Z)

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

´incoherent´ sum of the mass eigenstates m_i



- small modifications by final states, radiative & recoil corrections

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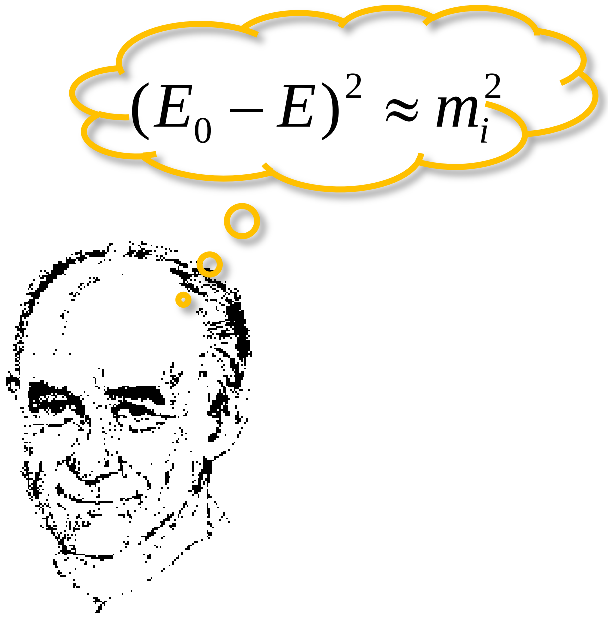

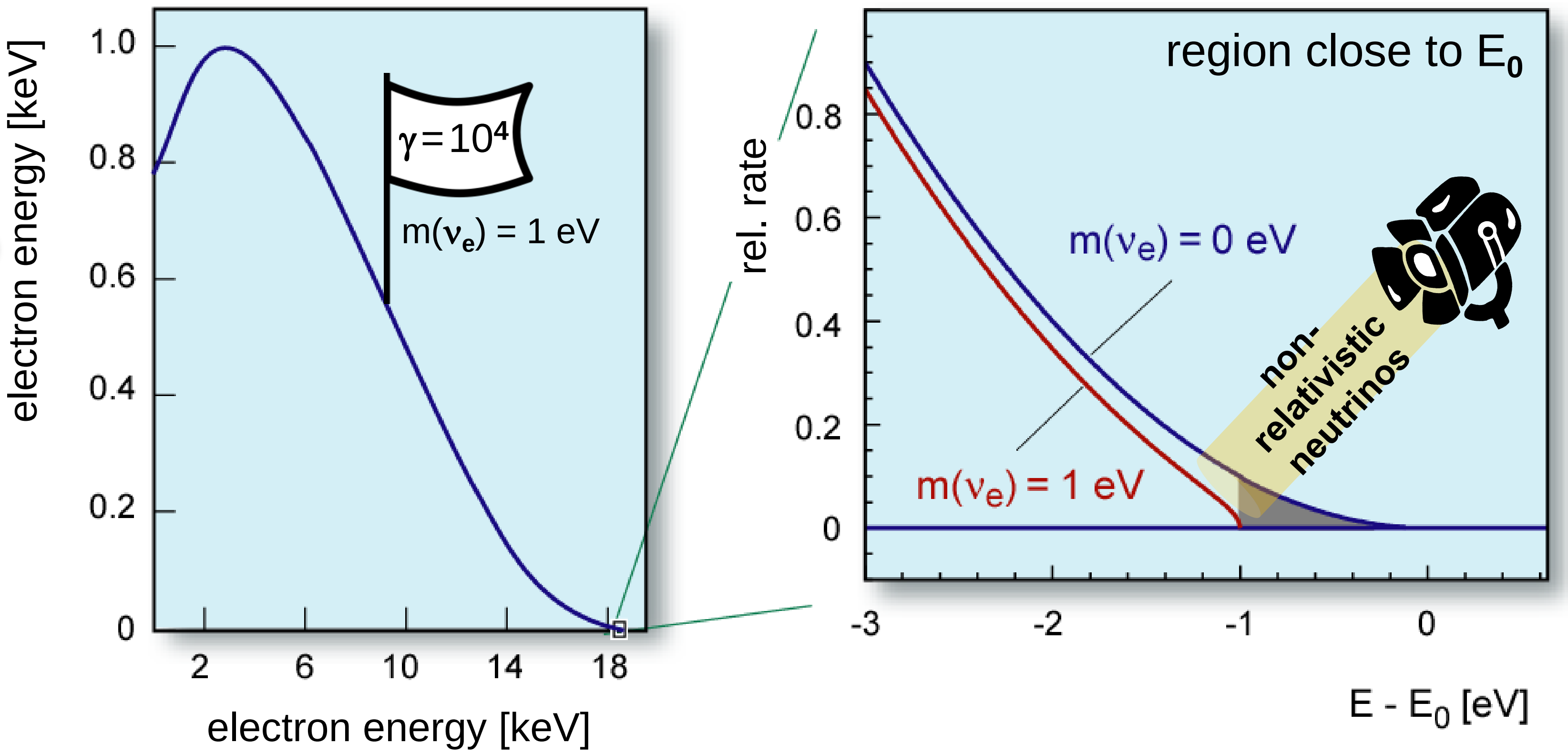

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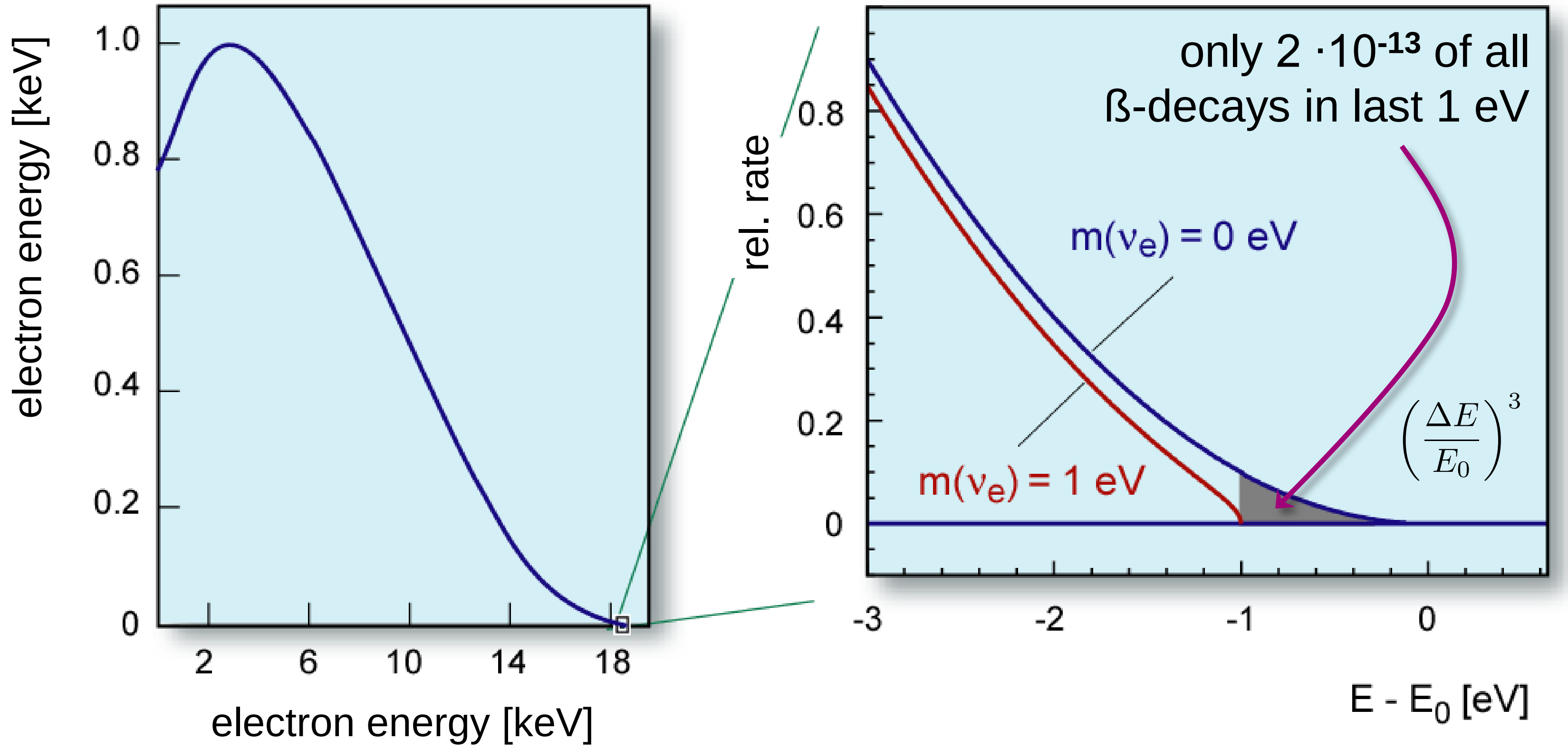
which isotope yields the highest ß-intensity & ν-mass sensitivity?



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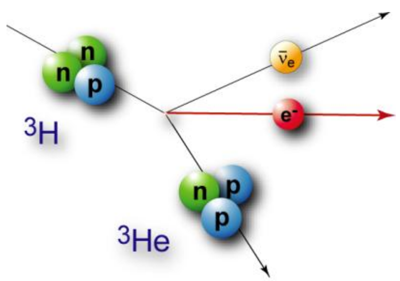
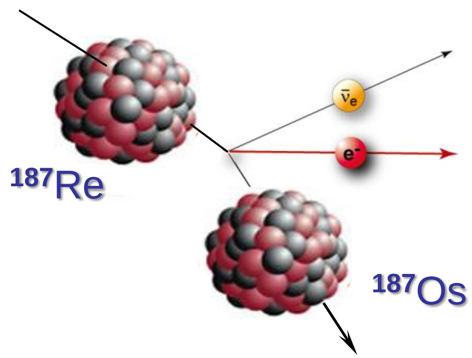
ß-source requirements
short half life $t_{1/2}$ ⇒ high luminosity
low endpoint energy E_0
superallowed/allowed transition
simple atomic/molecular structure



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

^{3}H: super-allowed	
E_0	18.6 keV
$t_{1/2}$	12.3 y

^{187}Re: unique 1st	
E_0	2.47 keV
$t_{1/2}$	43.2 Gy



$^{187}Re \rightarrow {}^{187}Os + e^- + \bar{\nu}_e$

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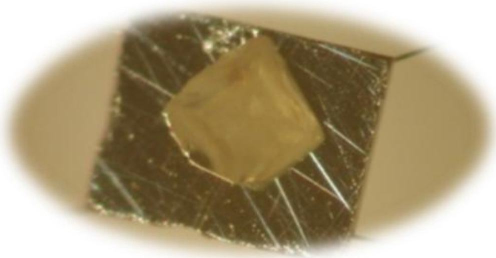
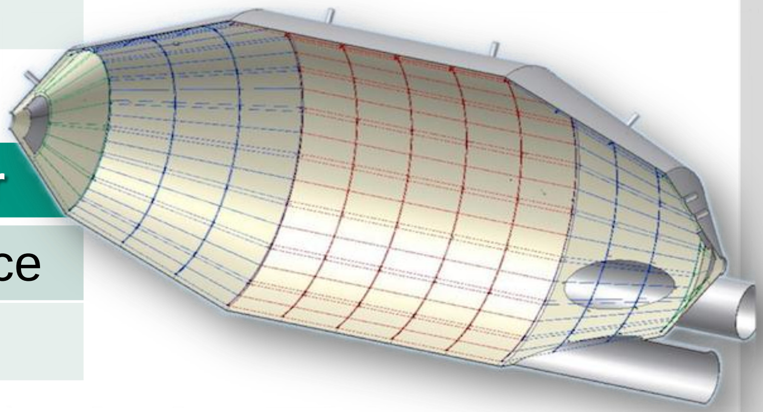
which detector?

ß-detection requirements
large solid angle (~2π)
low background rate
high energy resolution (~eV)
short dead time, no pile up



calorimeter	spectrometer
ß-source = detector	external ß-source
ß-source: ^{187}Re, ^{163}Ho	ß-source: ^{3}H



ß-spectroscopy

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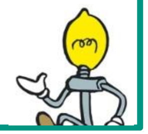
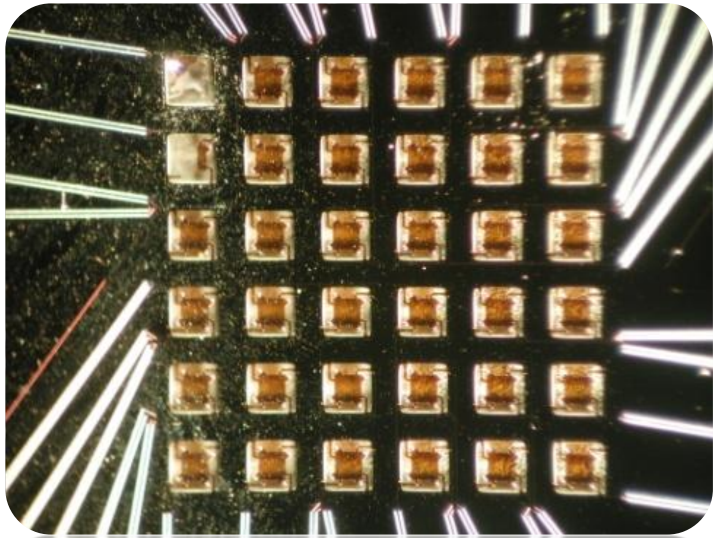
- experimental challenges, requirements and characteristics of micro-bolometers and electrostatic spectrometers for high-precision ß-spectrocopy



	calorimeters	**spectrometers**
source	metallic Re, dielectric $AgReO_4$	high-purity molecular gaseous T_2
ß-energy	arrays of crystal bolometers	MAC-E filter: electrostatic retardation
activity	low: **$<10^5$ ß/s**	high: **$\sim10^{11}$ ß/s**
response	entire decay energy	(longitudinal) kinetic energy of electrons
interval	entire ß-decay spectrum	very narrow interval close to E_0
method	differential spectrum	integral spectrum (ToF mode possible)
set-up	modular, size can be upscaled	integral design, spectrometer size limits
resolution	ΔE ~ few eV (FWHM)	ΔE = 0.93 eV (100%)

spectrometer & calorimeter techniques complementary (different systematics)

bolometric approaches: MARE



PS-1, Wed. 18.00-18.20 Elena Ferri *Nu mass with 187-Re and 163-Ho in MARE*

bolometer experiments for ^{187}Re

^{187}Re-experiments (MANU, MIBETA, MARE)

^{187}Re as ß-emitter: natural isotope content = 62.8 %

$$^{187}_{85}\mathrm{Re} \rightarrow ^{187}_{86}\mathrm{Os} + e^- + \bar{\nu}_e$$

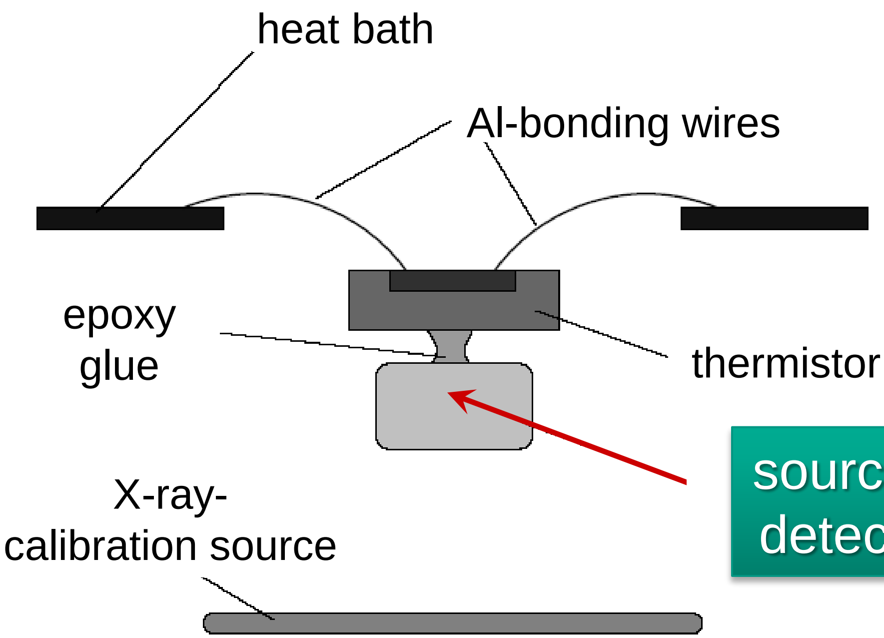
$5/2^+ \rightarrow 1/2^-$ ´unique´ 1st forbidden transition (shape factor), BEFS

^{187}Re: unique 1st	
E_0	2.47 keV
$t_{1/2}$	43.2 Gy

previous ^{187}Re-experiments MANU, MIBETA

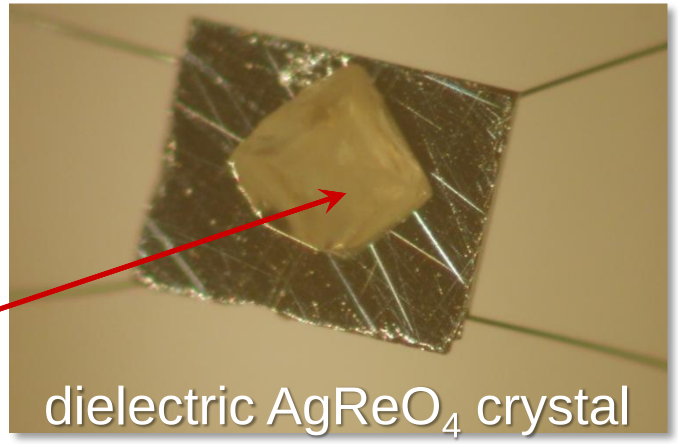
MANU: metallic Rhenium — group in Genova

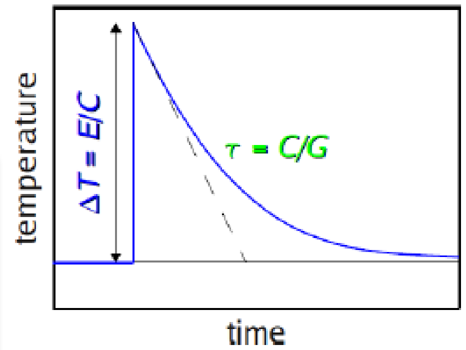
MIBETA: dielectric $AgReO_4$ crystals — group in Milano



source = detector

measure entire ß-decay energy





MIBETA:
10 crystals

bolometer experiments

■ ^{187}Re-experiments (MANU, MIBETA, MARE)

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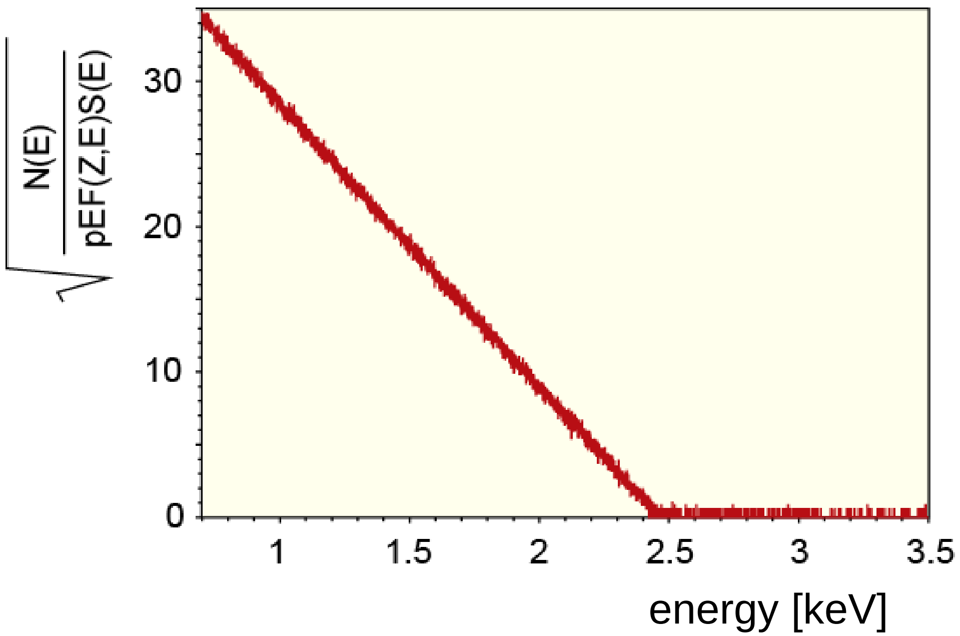


- analysis of ^{187}Re-Kurie plot

$6.2 \cdot 10^6$ ^{187}Re ß-decays:
m(ν) < 15 eV (2004)

- several months of measuring time

MARE experiment

- **M**icrocalorimeter **A**rrays for a **R**henium **E**xperiment

- **general strategy to increase sensitivity to sub-eV regime**:
  - deploy large arrays of cryogenic micro-bolometers
    up-scaling of source intensity with 1 mg Re ≈ 1 decay/s
  - avoid pulse pile-up: develop faster detectors
  - develop multiplexed read-out technologies
  - improve energy resolution to 1 eV-level

MARE-I ~ 10^9-10^{10} ß-decays

- set-up small bolometer array: ν-mass sensitivity $m(\nu_e)$ ~ few eV
- test & select different isotopes (^{163}Ho-EC/^{187}Re-ß-decay)
  and read-out/sensor techniques (TES, Si-thermistor, MMC, …)

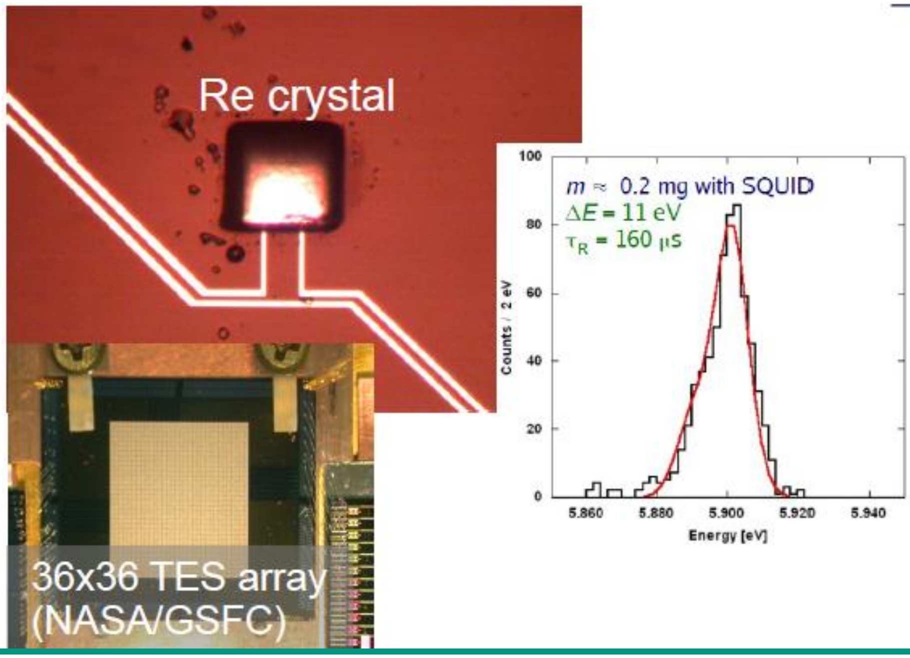
MARE-II ~ 10^{14} ß-decays

- full set-up, large bolometer array with 10^4-10^5 pixels
- aim for statistical ν-mass sensitivity $m(\nu_e)$ ~ 0.1-0.2 eV

MARE experiment: phase-I

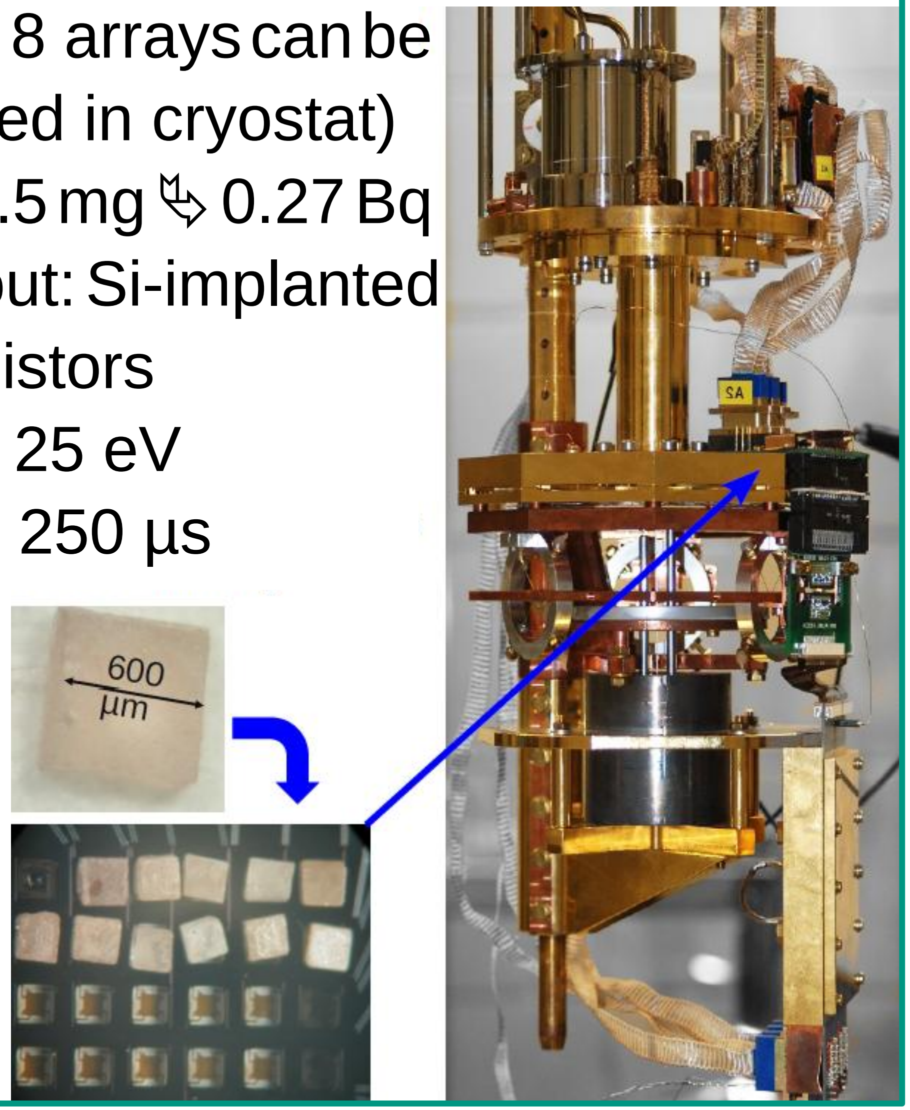
Genova m(ν_e) ~ 2 eV

- metallic Re absorbers, up to 300
- m = (0.2-0.3) g ⇨ ~0.25 Bq
- TES sensors (Ir-Au bi-layer), multiplexed SQUID read-out
- ΔE ~ 11 eV
- τ_{rise} ~ 160 µs



Milano-Bicocca m(ν_e) ~ 3-4 eV

- 6x6 arrays of AgReO4 crystals (up to 8 arrays can be housed in cryostat)
- m = 0.5 mg ⇨ 0.27 Bq
- readout: Si-implanted thermistors
- ΔE ~ 25 eV
- τ_{rise} ~ 250 µs

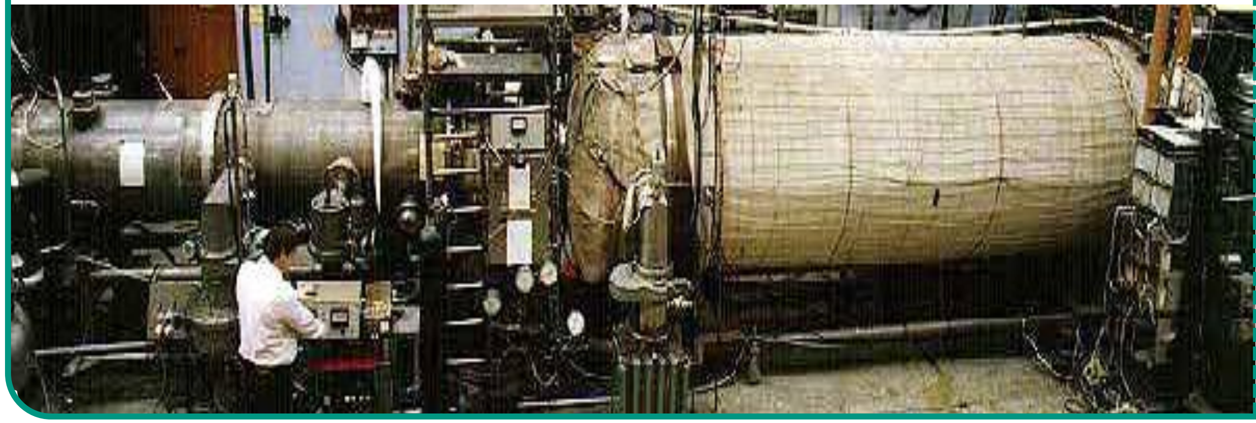


KATRIN – design & status

Troitsk & Mainz experiments

Troitsk experiment

- windowless gaseous tritium source



- 2011 re-analysis of selected data from 1994-2004: no evidence for Troitsk anomaly

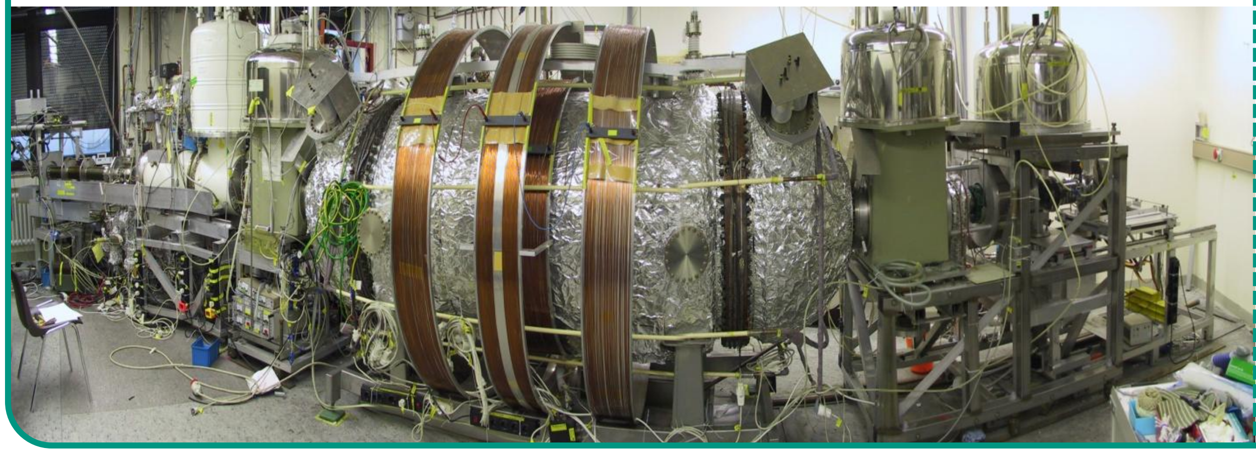
$$m^2(\nu_e) = (-0.67 \pm 1.89 \pm 1.68)\ eV^2$$

$$m(\nu_e) < 2.05\, eV$$

V.N. Aseev et al., Phys. Rev. D 84 (2011) 112003

Mainz experiment

- quench condensed tritium source



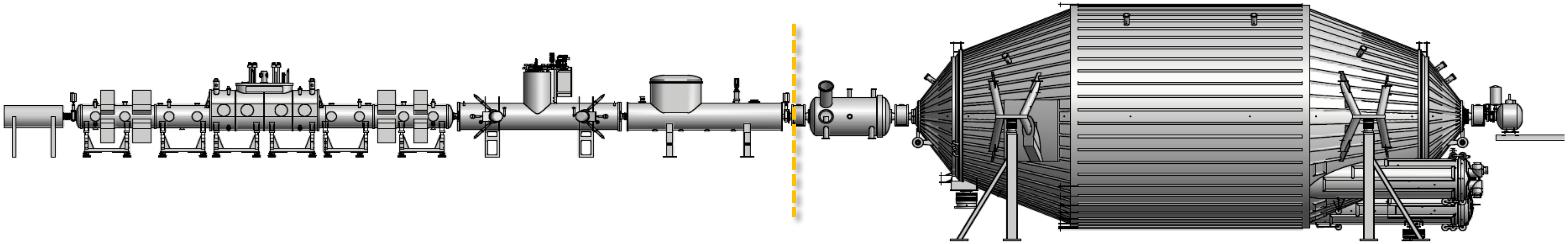
- 2004 final analysis of Mainz phase II data from 1998-2001: analysis of last 70 eV

$$m^2(\nu_e) = (-0.6 \pm 2.2 \pm 2.1)\ eV^2$$

$$m(\nu_e) < 2.3\, eV$$

C. Kraus et al., Eur. Phys. J. C 40 (2005) 447

KATRIN experiment



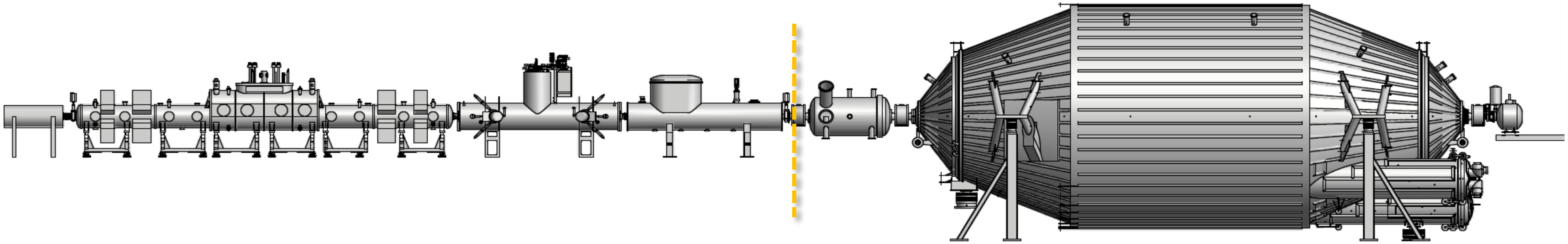
tritium-bearing components

electrostatic spectrometers & detector

KArlsruhe TRItium Neutrino experiment

- a large-scale, next-generation direct neutrino mass experiment
- currently being installed at Tritium Laboratory Karlsruhe at KIT
- push spectrometer technology to limits, sensitivity $m(\nu_e)$ = 200 meV

KATRIN experiment - overview



tritium-bearing components

tritium source: 10^{11} ß-decays/s

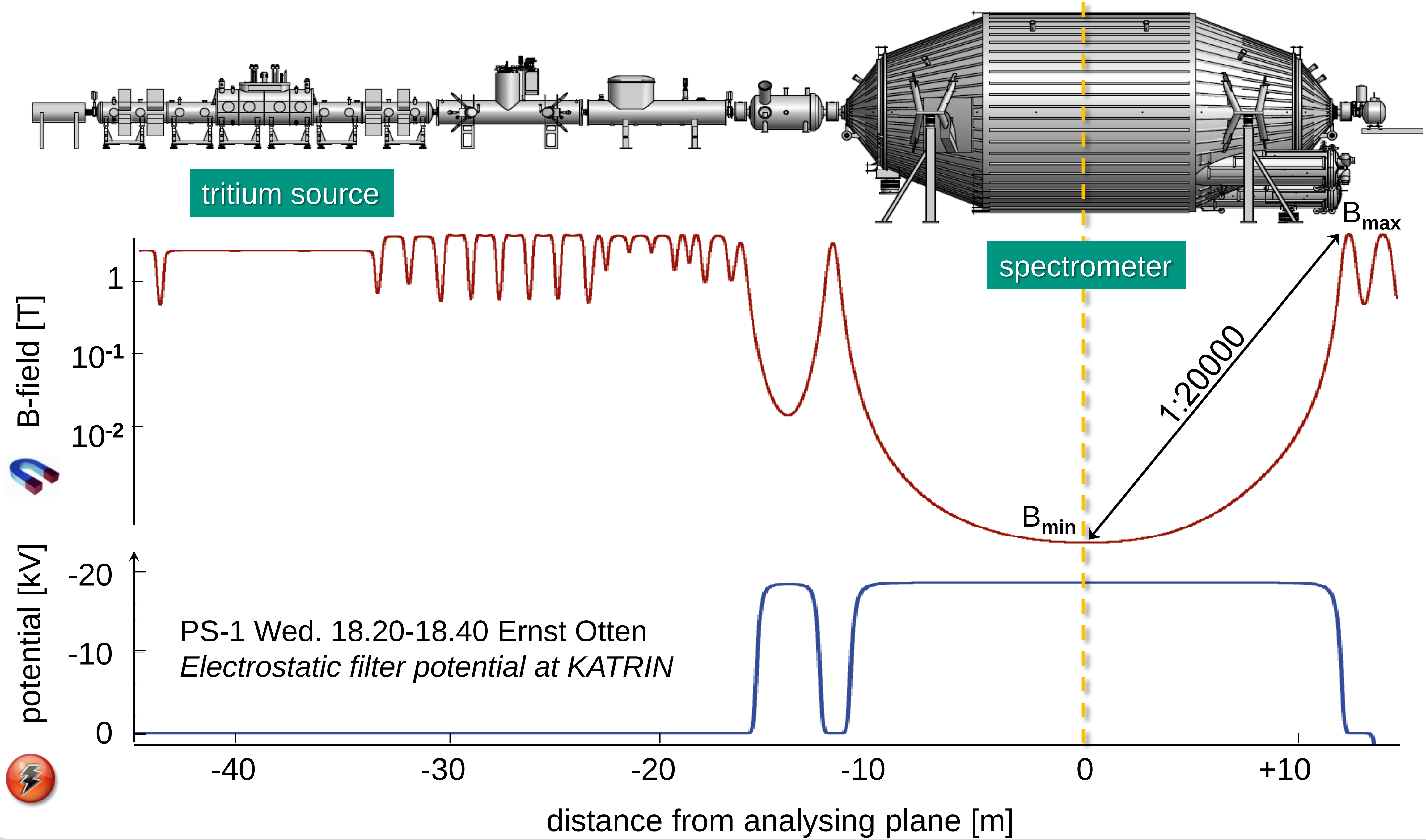
electrostatic spectrometers & detector

total background: 10^{-2} cps

experimental challenges

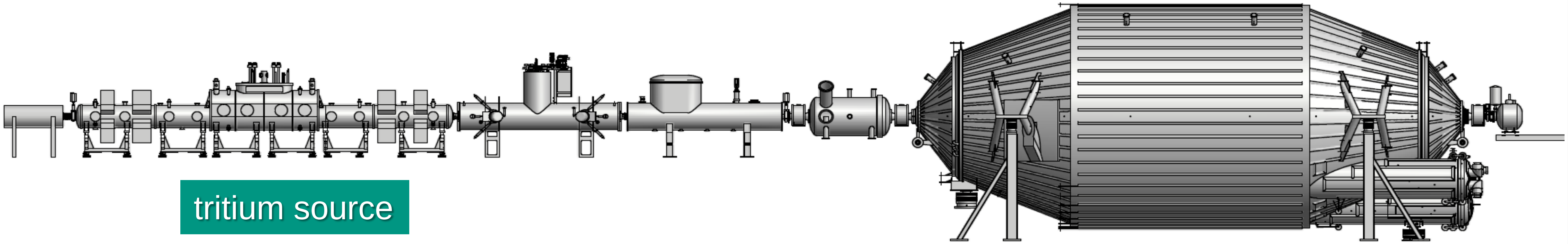
- 10^{-3} stability of tritium source column density ρd (T, p_{in})
- on-line & in-situ measurement (10^{-3}) of isotope content in source
- retention factor of flux of molecular tritium R > 10^{14}
- effective removal of ions R = 10^{8}
- fully adiabatic (meV-scale) transport of electrons over > 50 m
- avoid particle storage in Penning traps, UHV in spectrometer
- precise monitoring of HV on ppm-scale

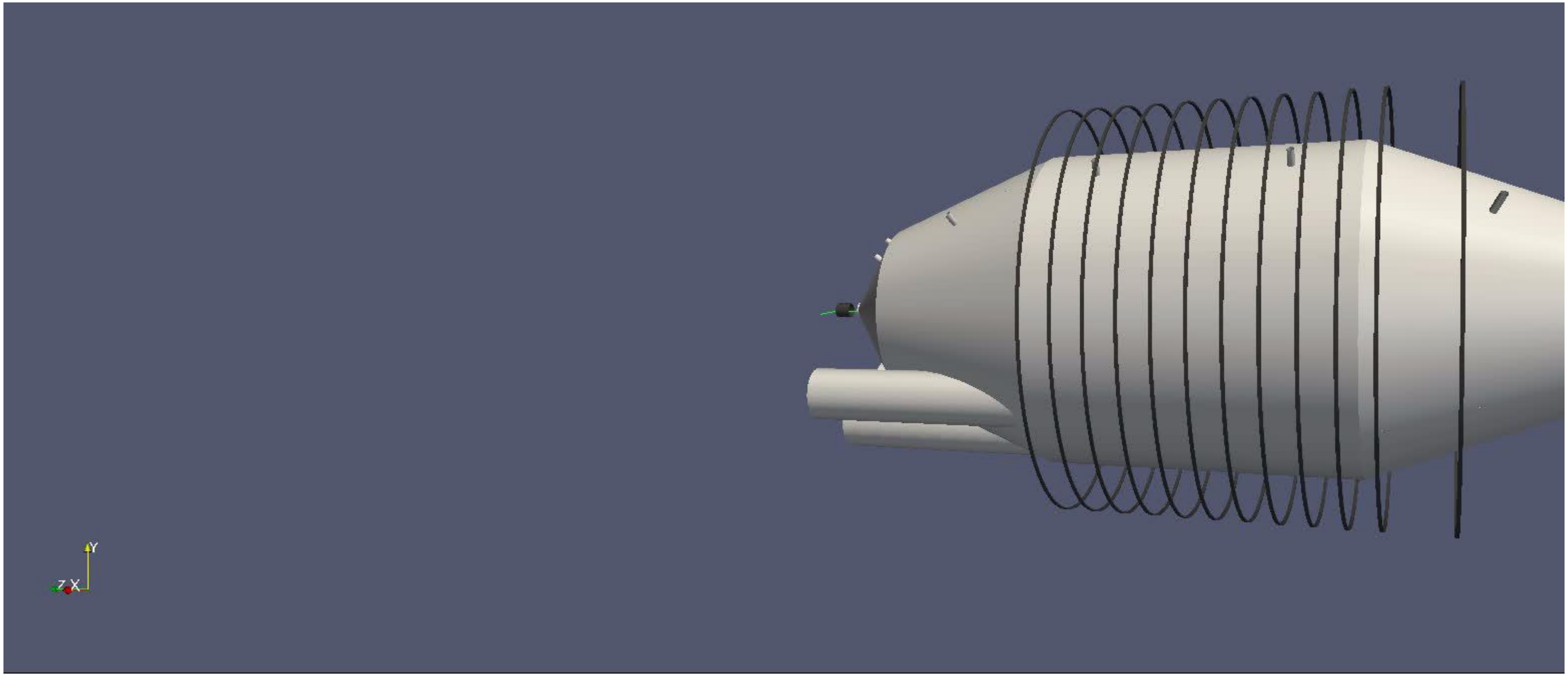
magnetic field & electrostatic potential



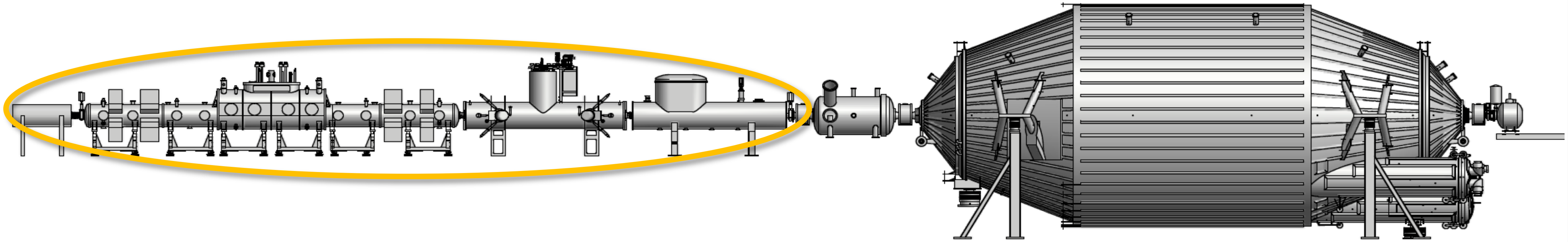
PS-1 Wed. 18.20-18.40 Ernst Otten
Electrostatic filter potential at KATRIN

magnetic field & electrostatic potential





tritium source

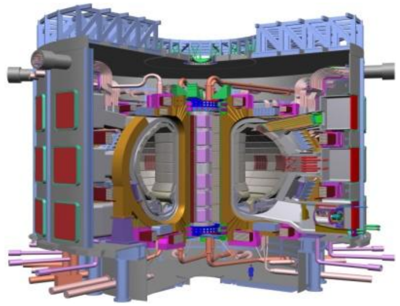


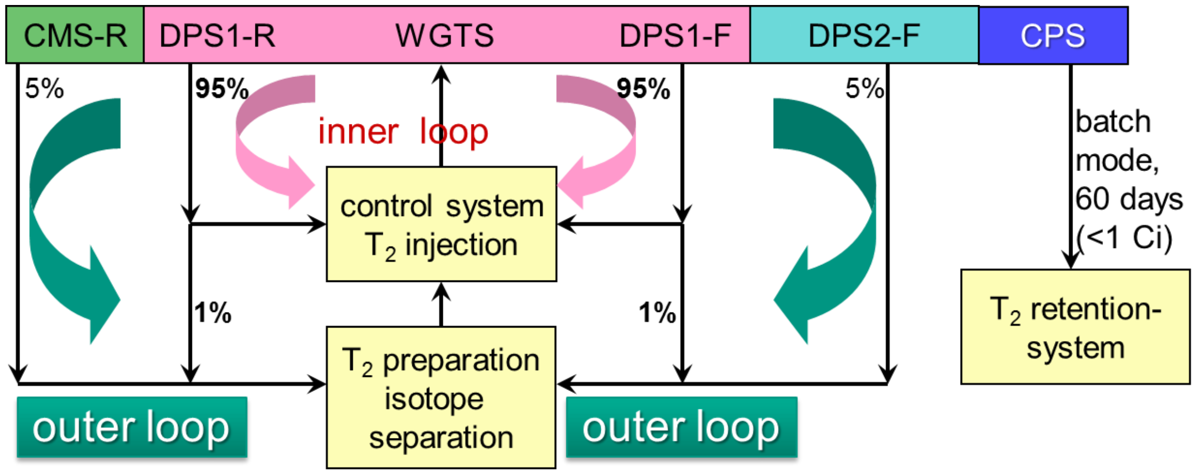
■ **KATRIN tritium throughput per year is equivalent to ITER fusion facility**

tritium source is operated as closed cycle:

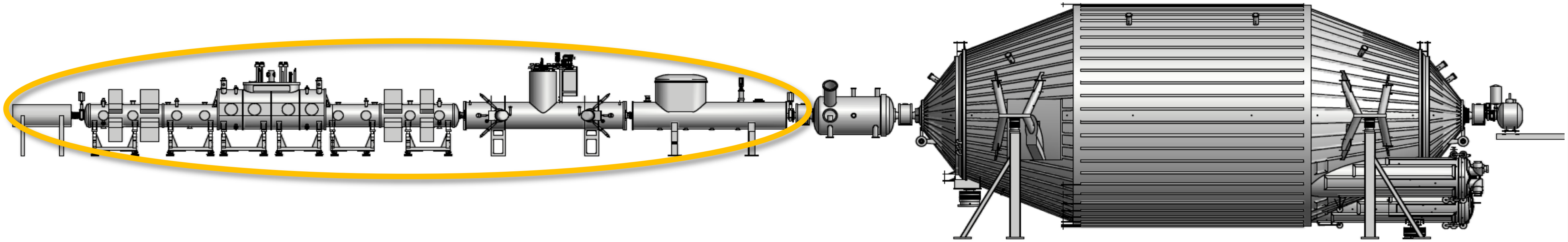
thoughput of 40 kg/year

TLK – a unique research facility



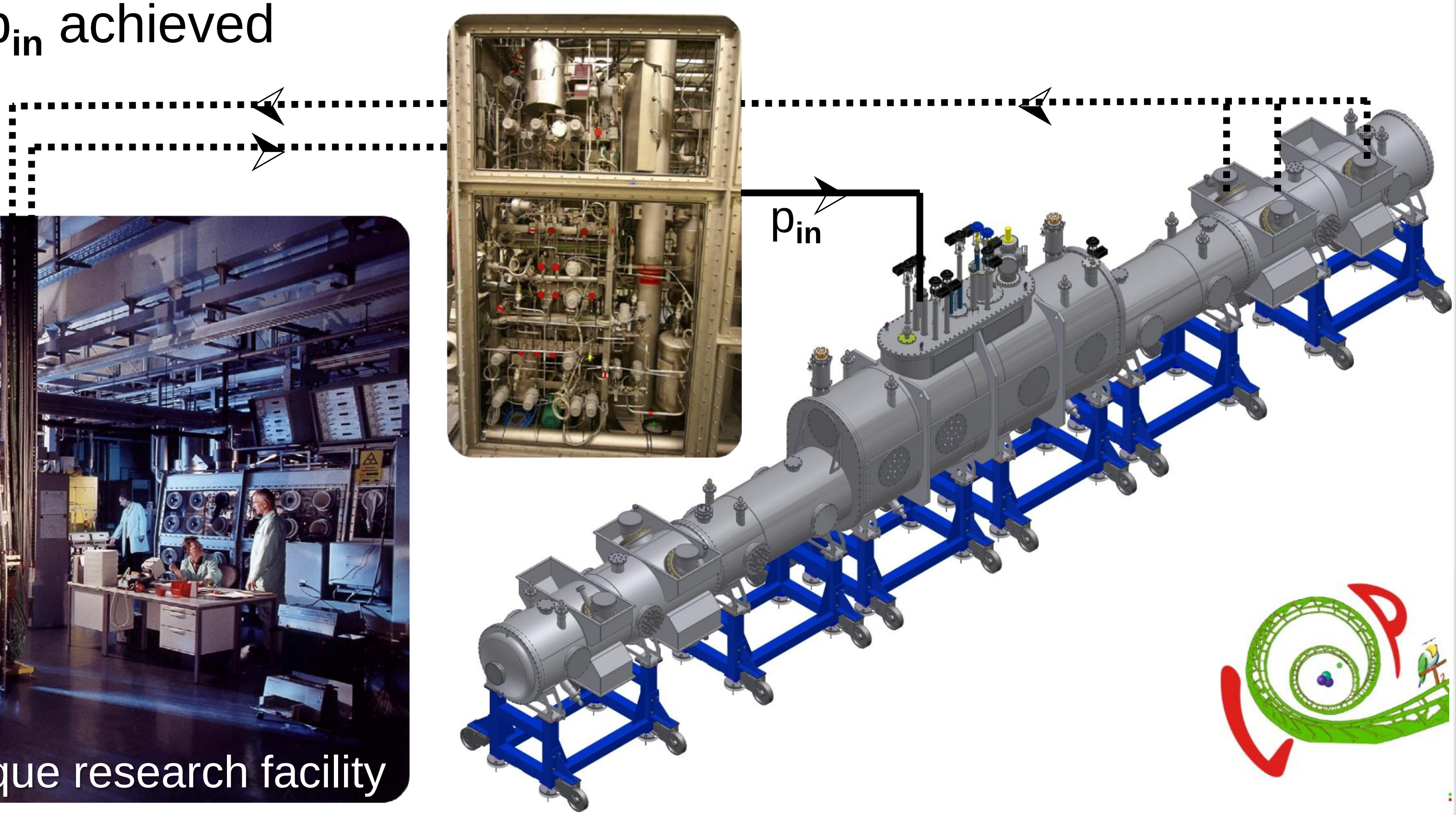


tritium source: loop system

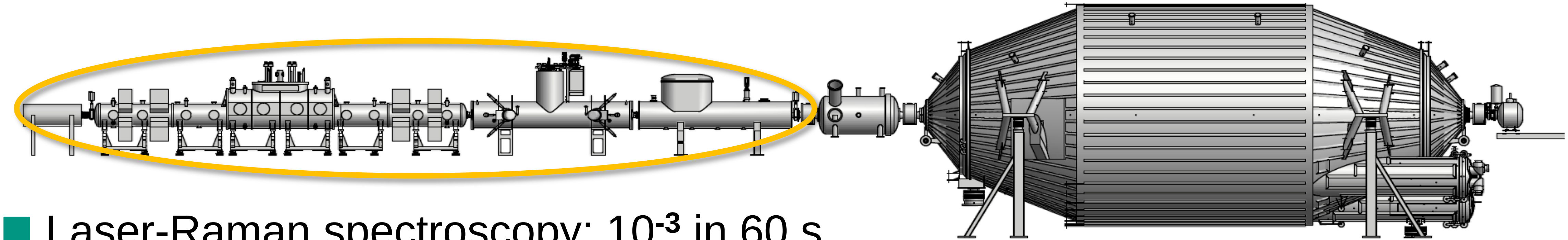


- 10^{-4} stability for p_{in} achieved in test set-up

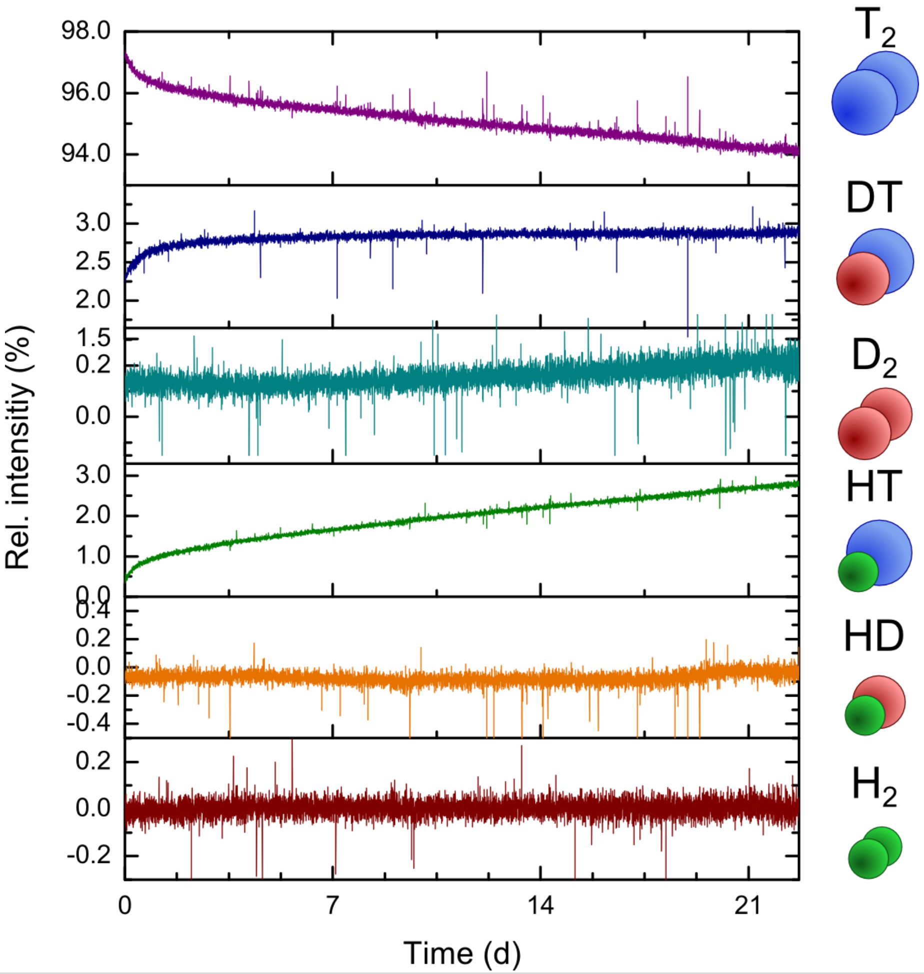
TLK – a unique research facility

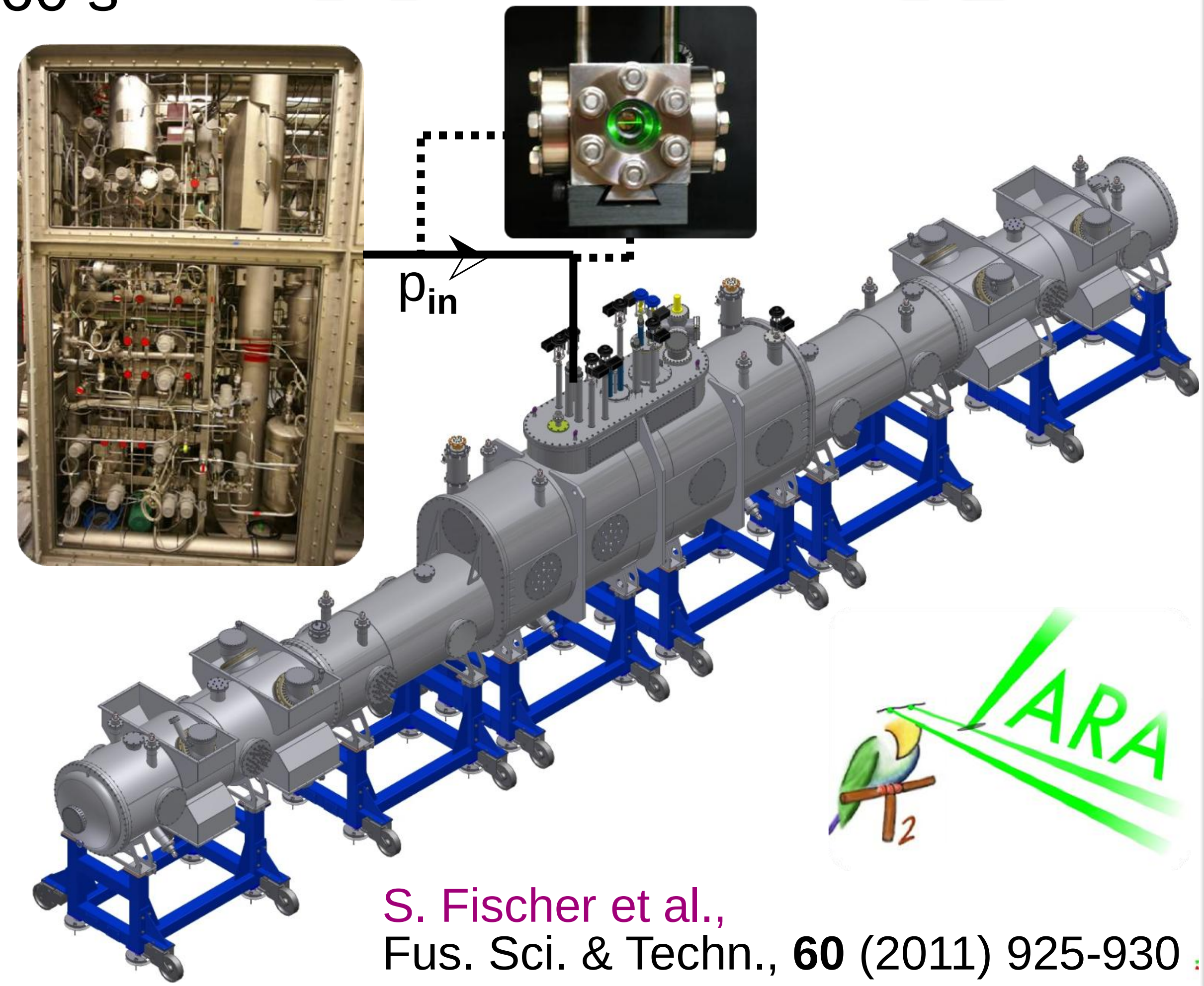


tritium source: loop system



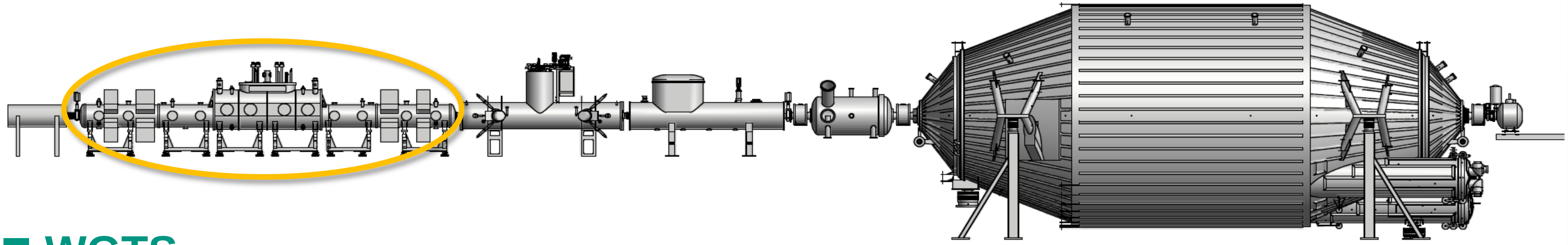
- Laser-Raman spectroscopy: 10^{-3} in 60 s





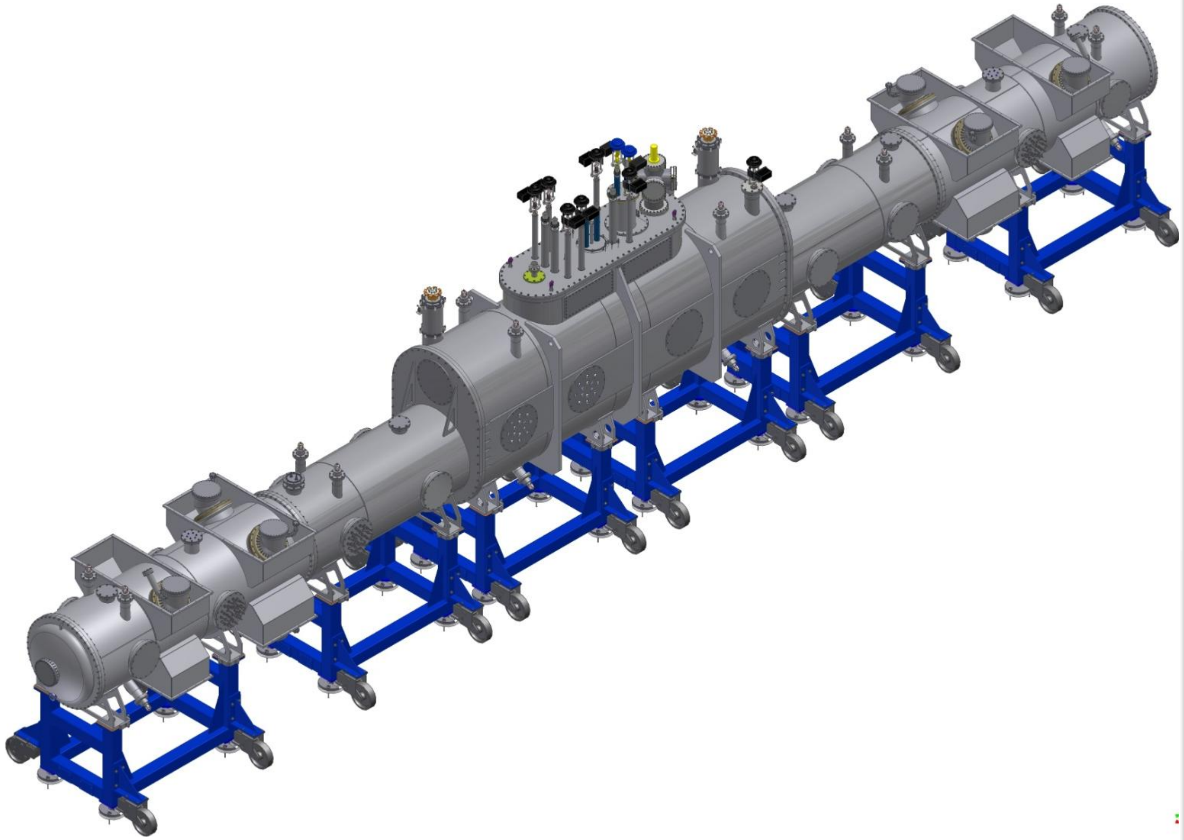
S. Fischer et al.,
Fus. Sci. & Techn., **60** (2011) 925-930

WGTS – windowless gaseous tritium source

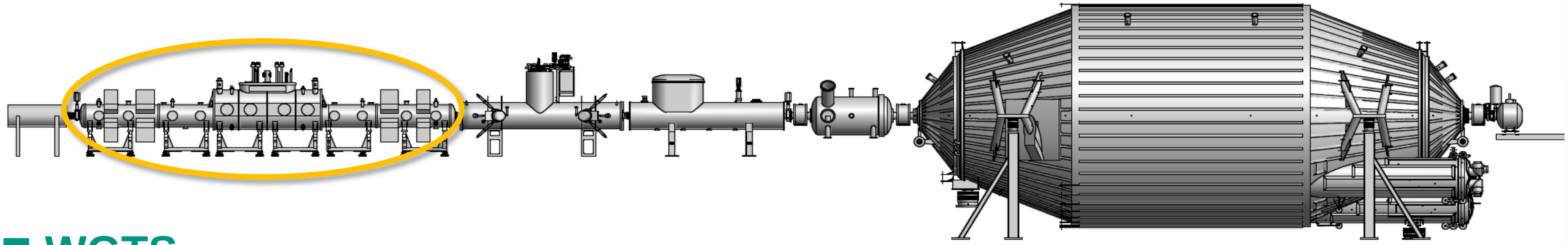


- **WGTS**
  - a molecular tritium source of
    highest luminosity
    highest stability

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 tritium source

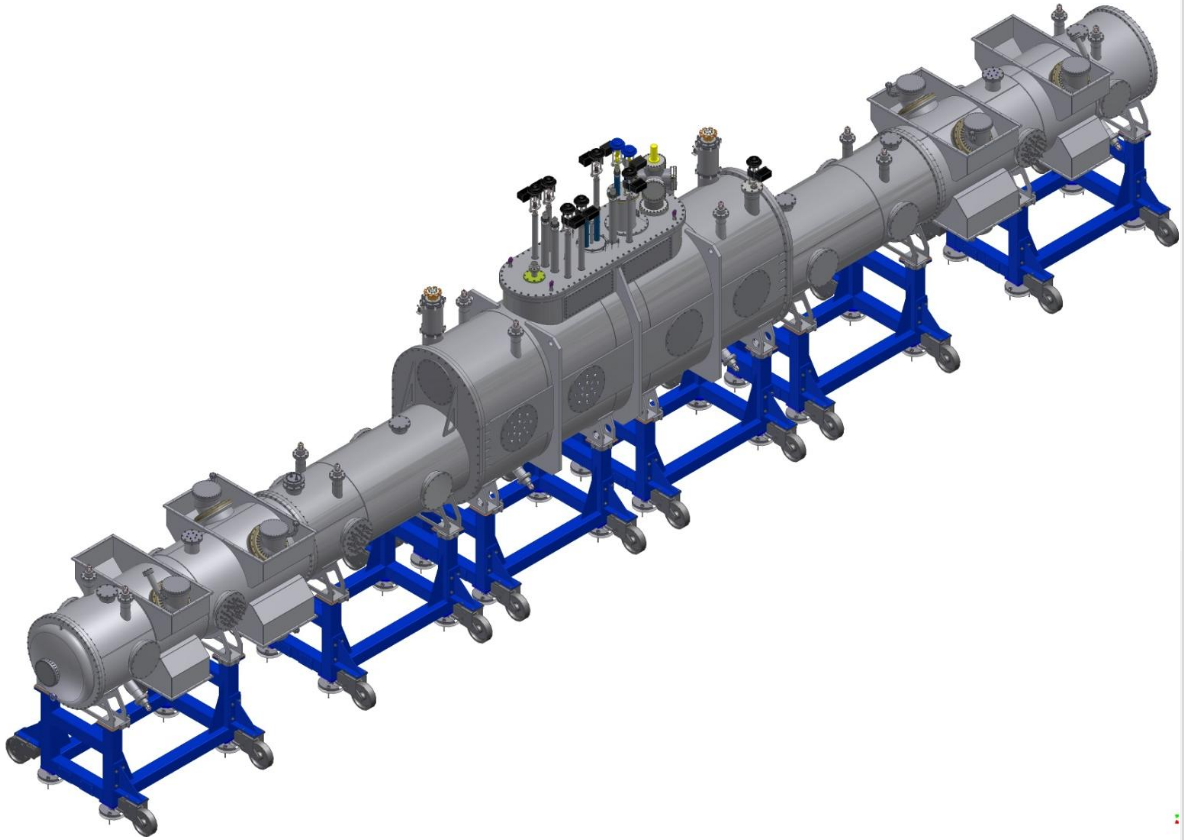


- **WGTS**

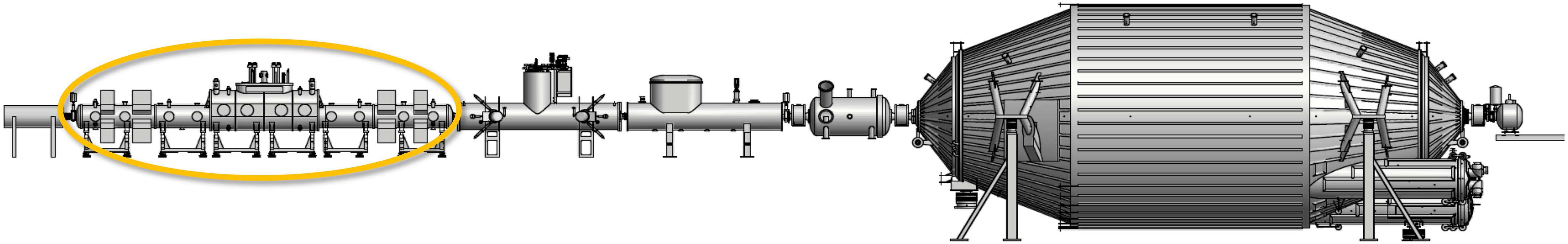
  one of the world´s most complex cryostats:
  tritium – cryo – magnet issues

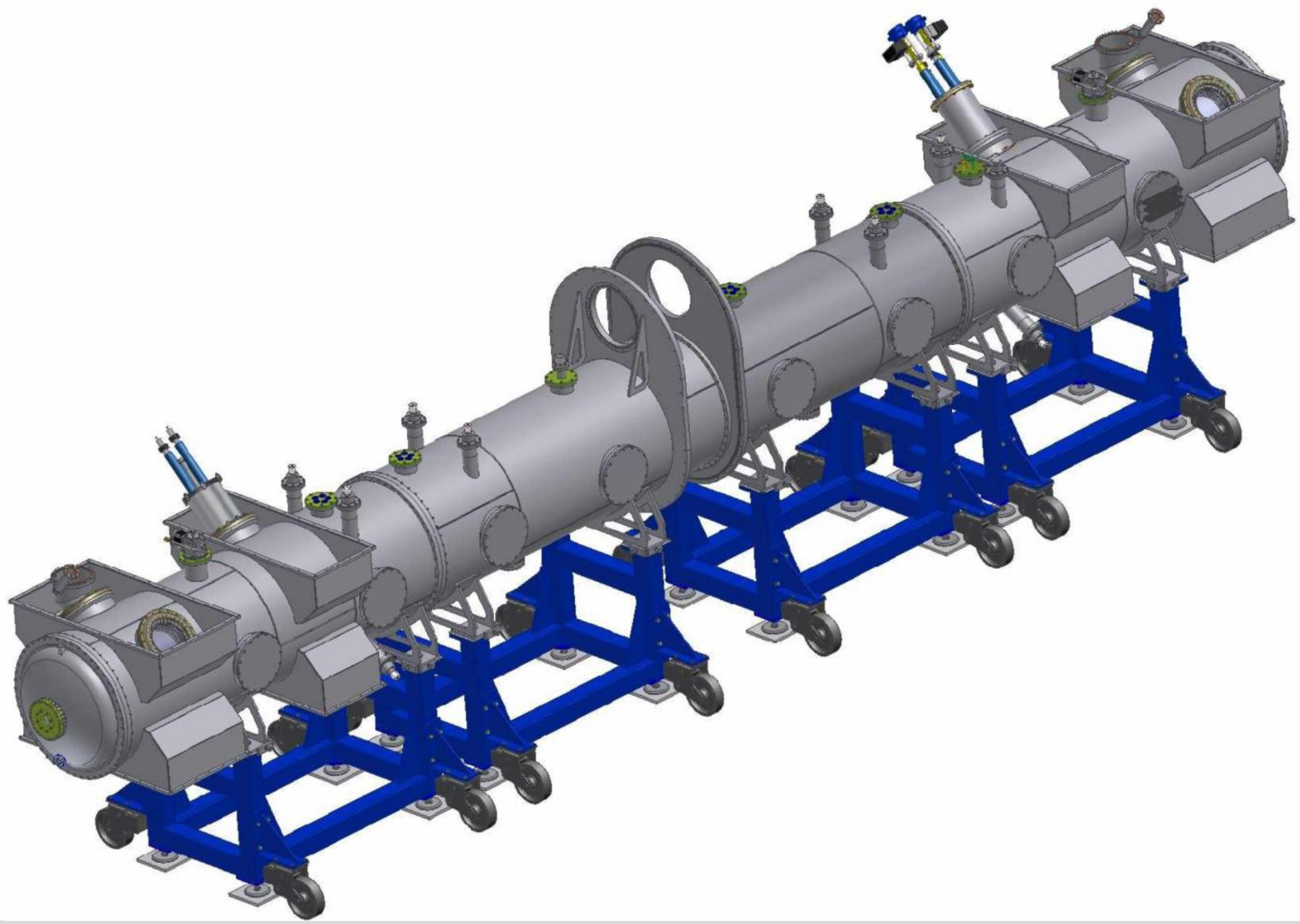
  12 cryogenic circuits
  6 cryogenic fluids

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



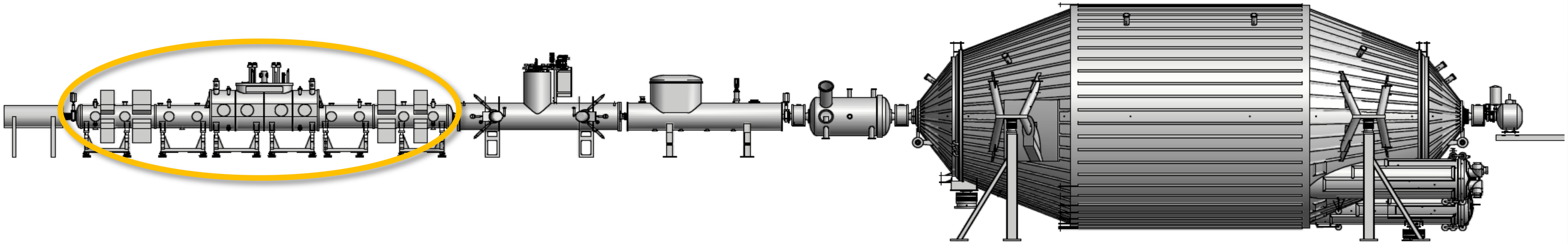
WGTS – demonstrator





- **objectives of measurements**
  - demonstrate feasibility of novel 2-phase (LNe/GNe) beam tube cooling system
  - WGTS-BT requirements:
    a) operation at T_{BT} = 28-32 K
    b) $\Delta T = \pm$ **30 mK**
      - stability (1h)
      - homogeneity (10 m)

WGTS – demonstrator



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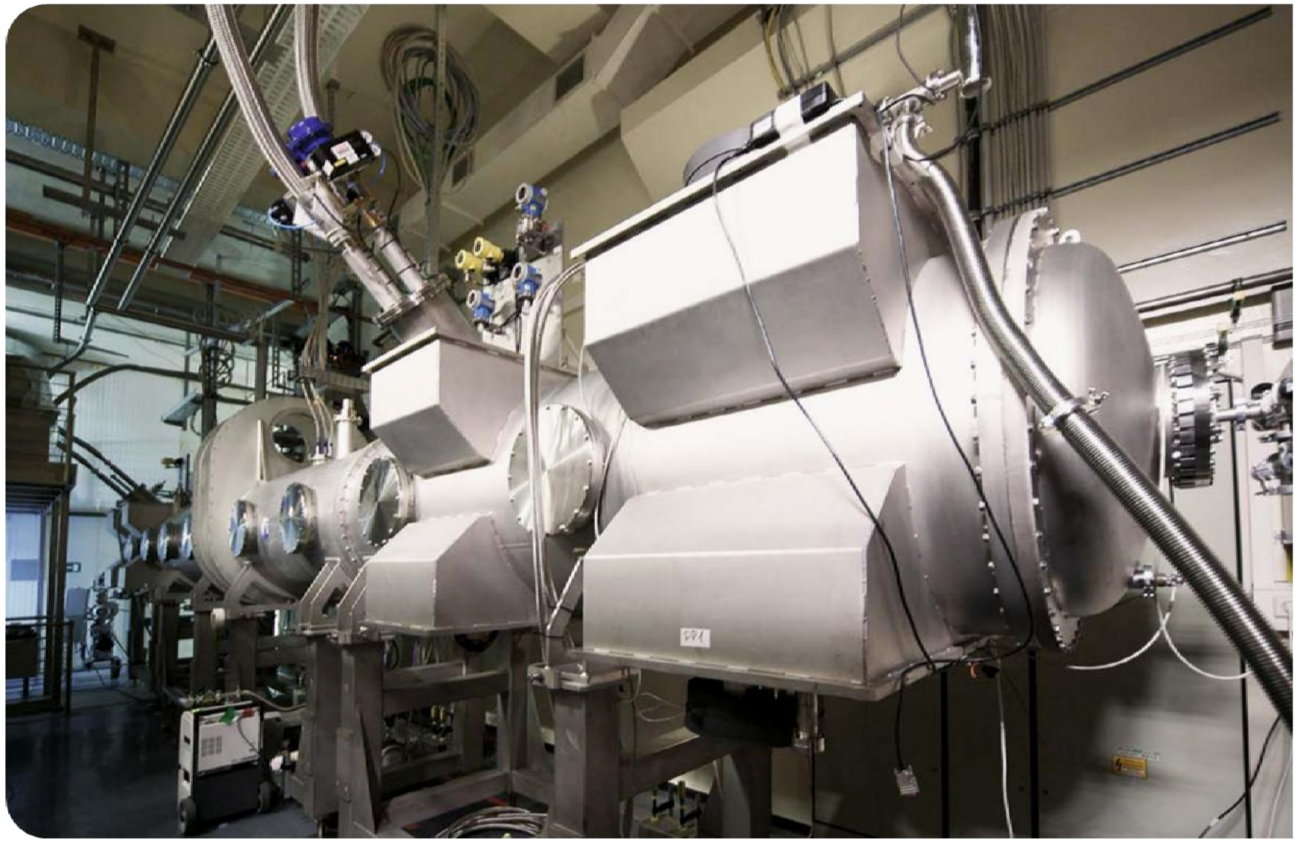
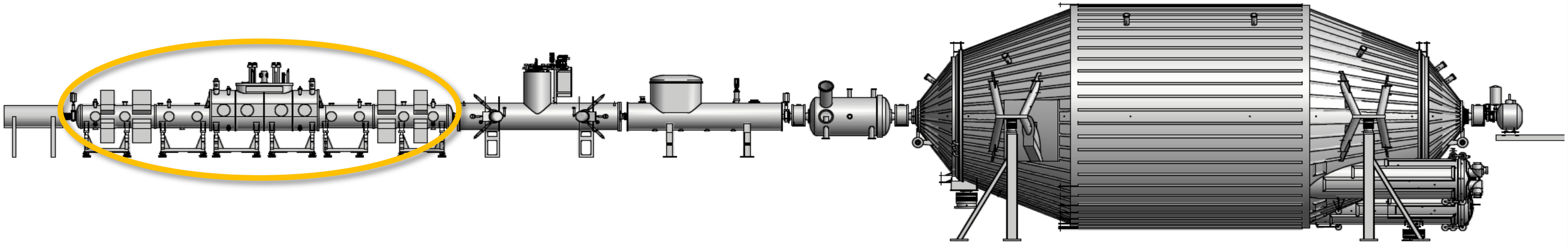
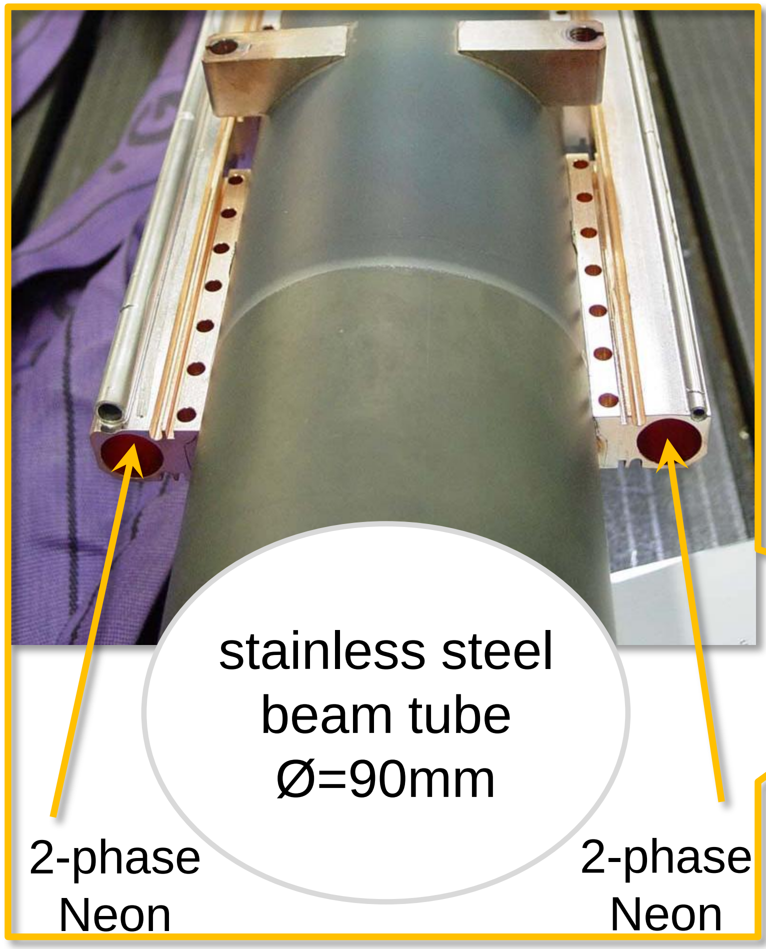
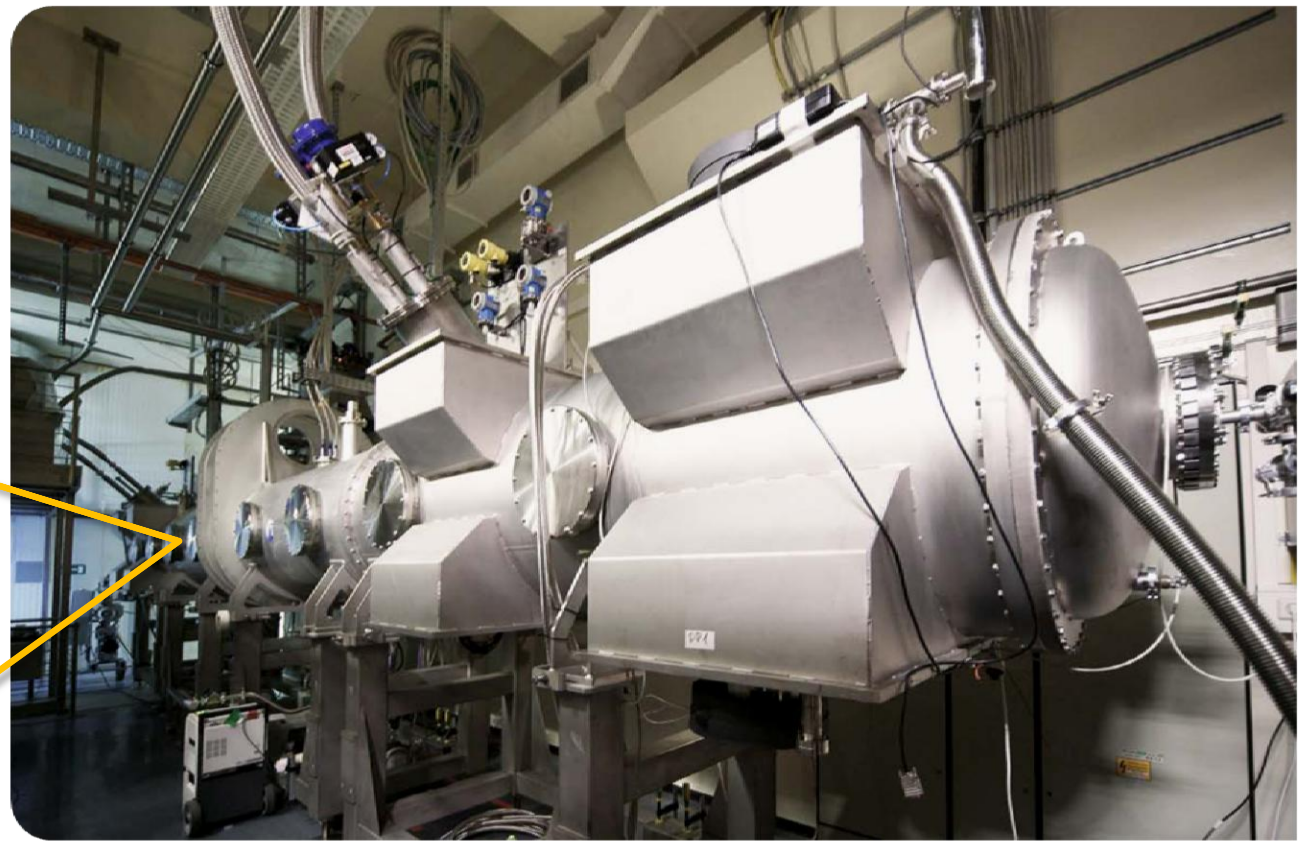


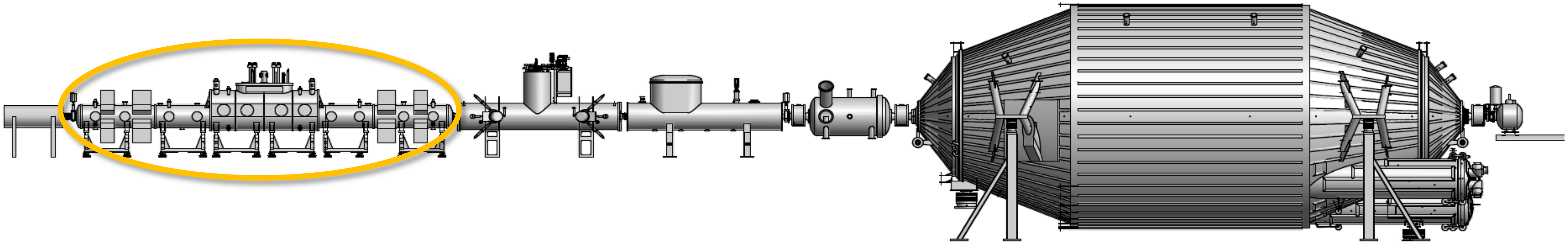
WGTS – demonstrator

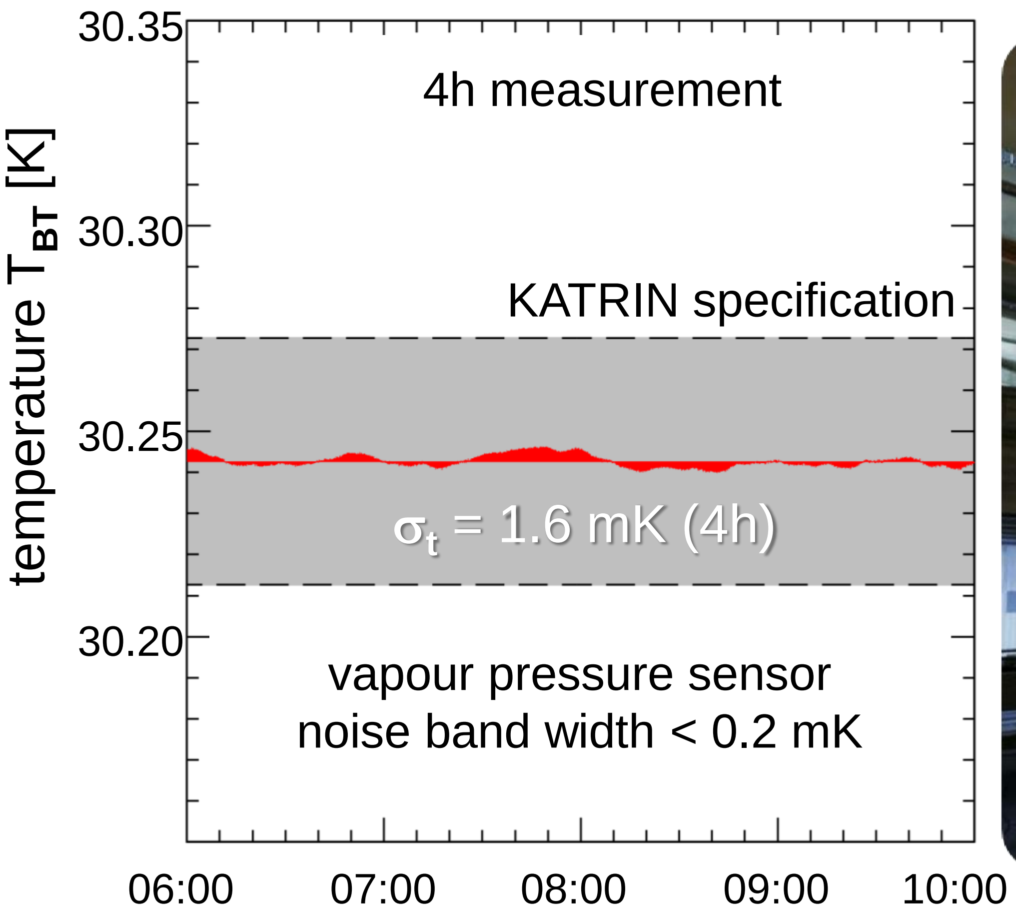


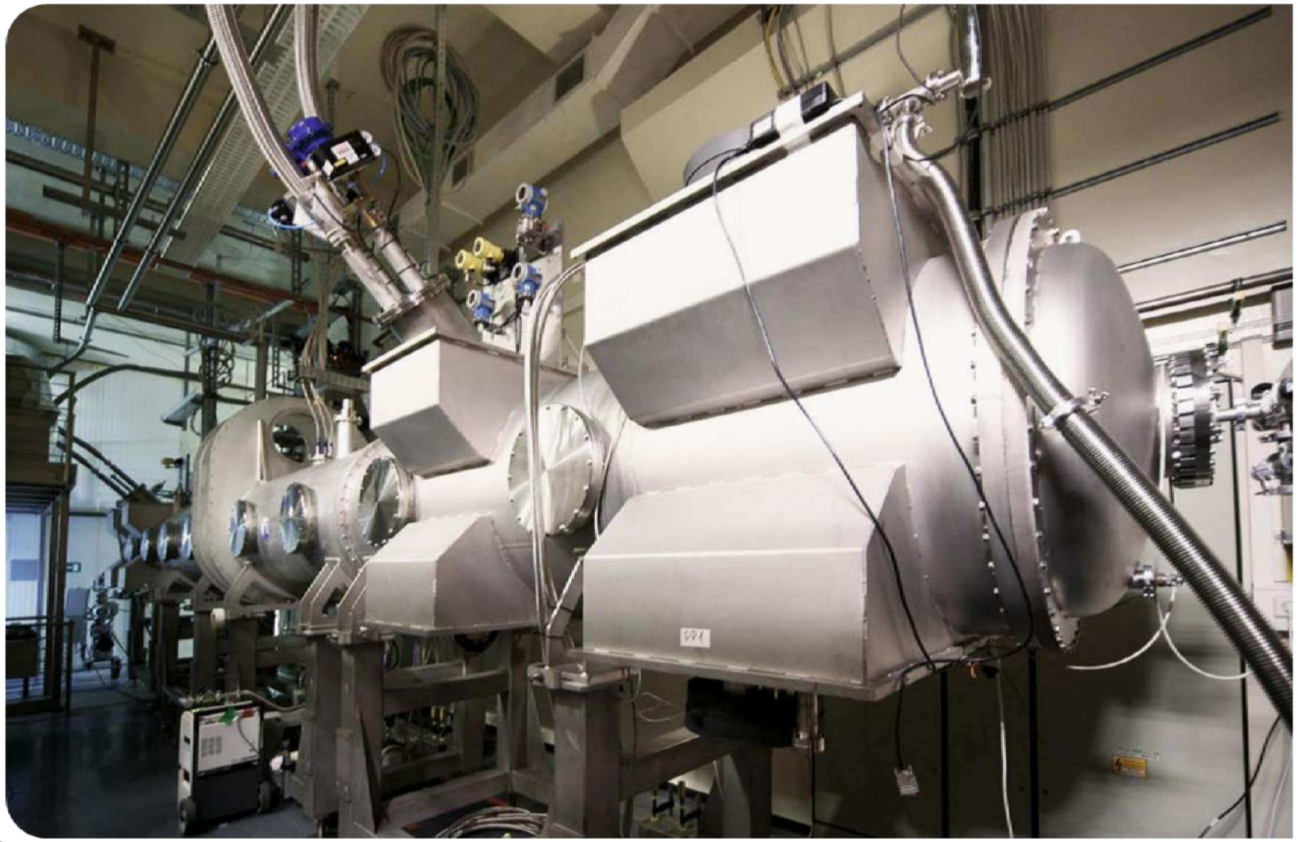




WGTS – demonstrator

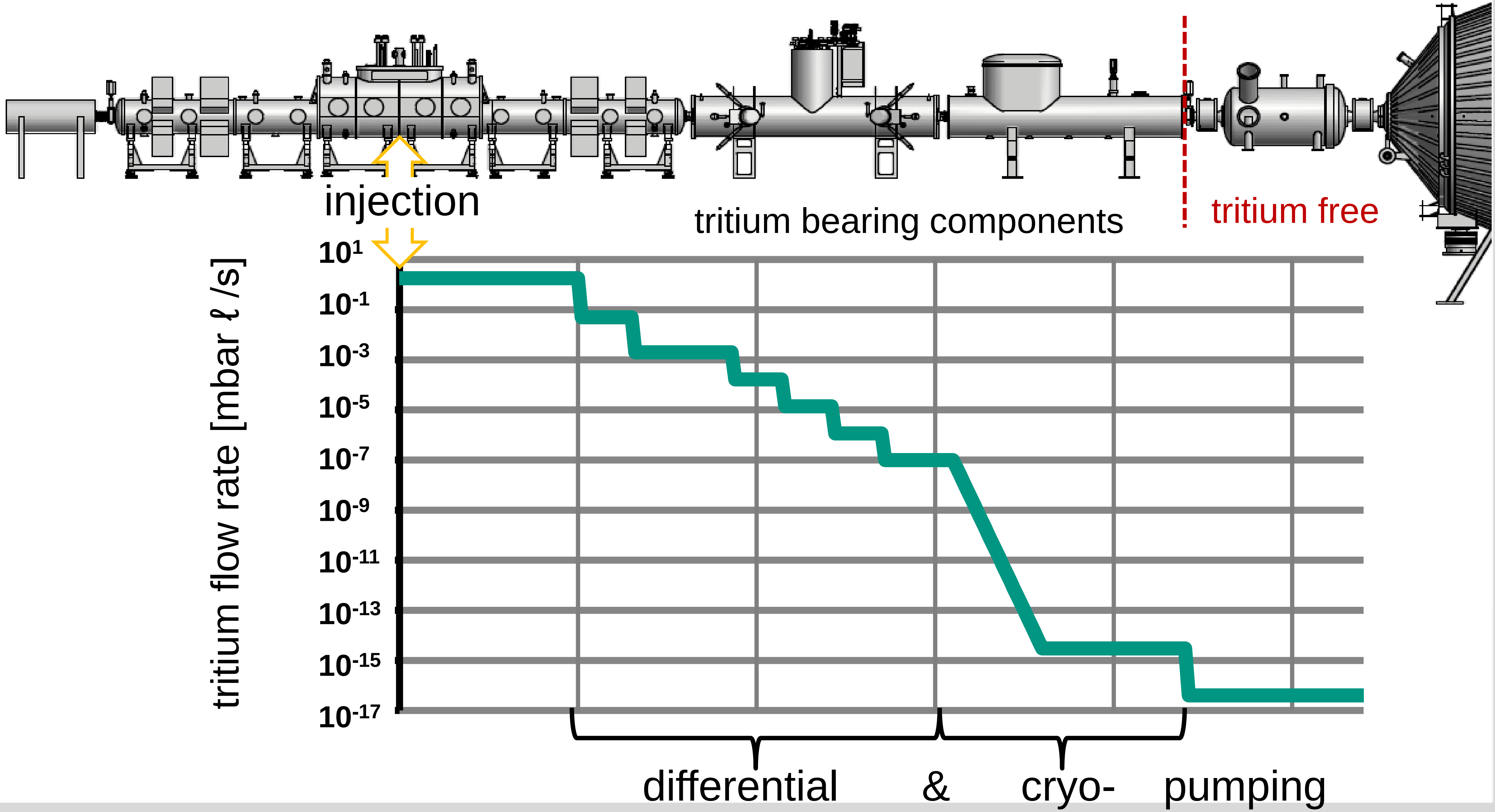






tritium retention techniques

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



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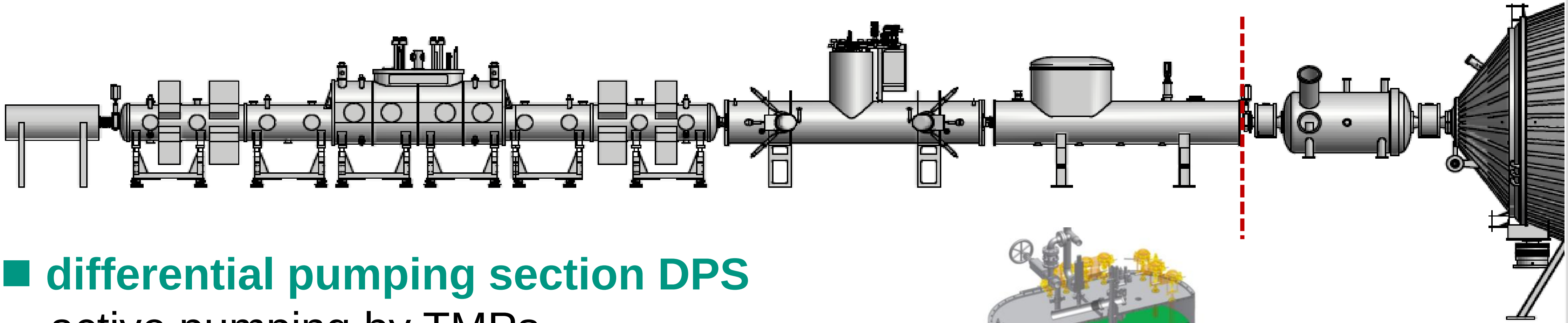
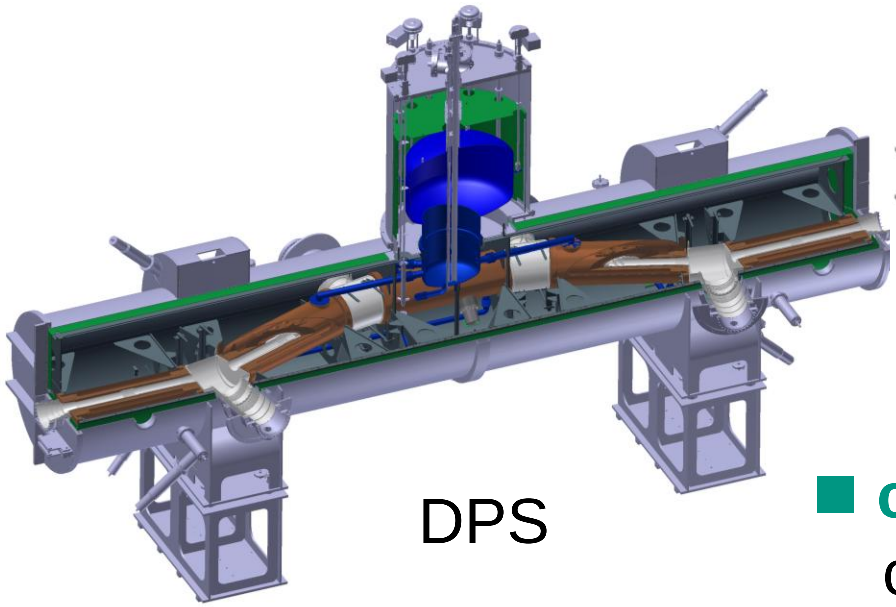
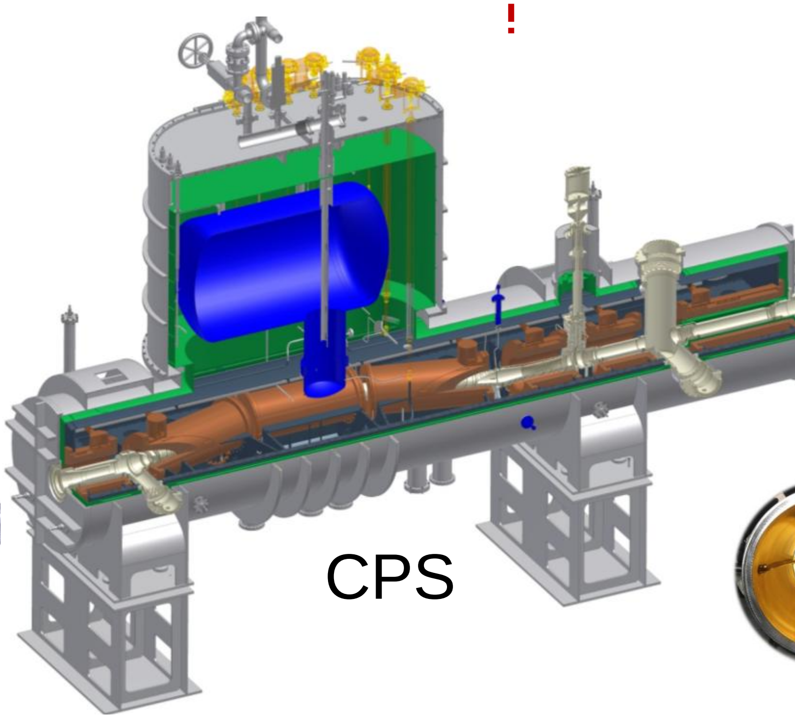


- **differential pumping section DPS**
  active pumping by TMPs
  reduction R = $2.5 \cdot 10^4$ achieved @RT



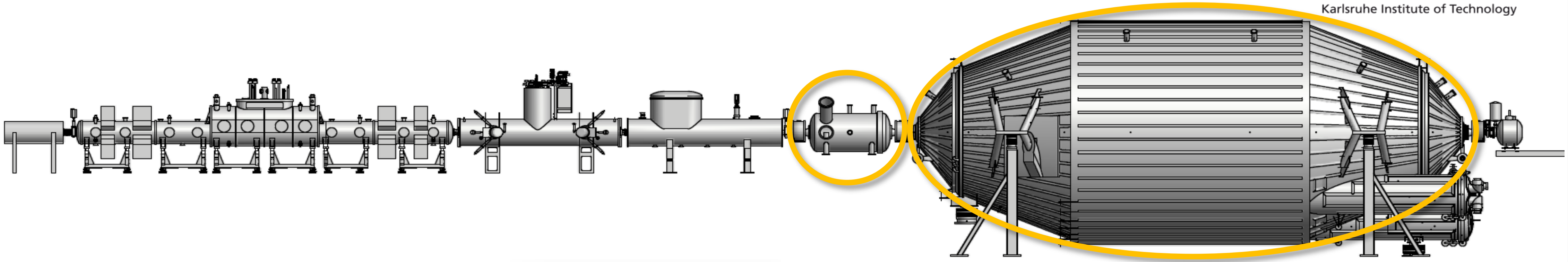
DPS



CPS

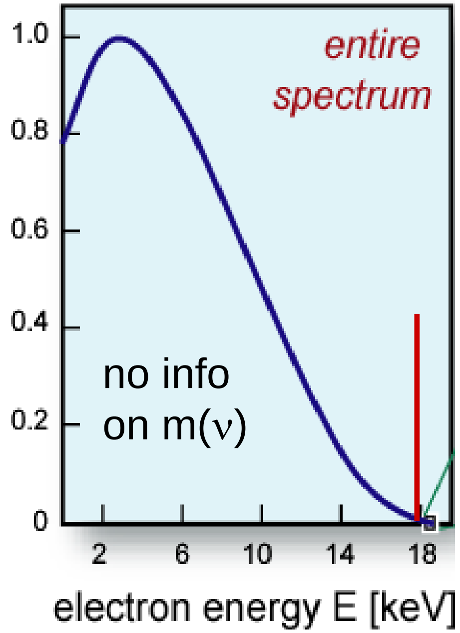
- **cryogenic pumping section CPS**
  cryosorption on Ar-frost

electrostatic spectrometers



pre-filter option

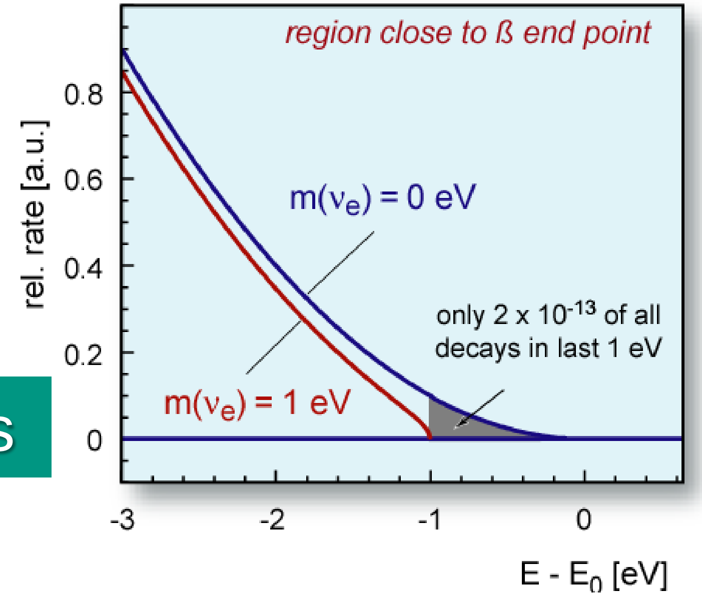
fixed retarding potential
U_0 = - 18.3 kV
ΔE ~ 100 eV



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

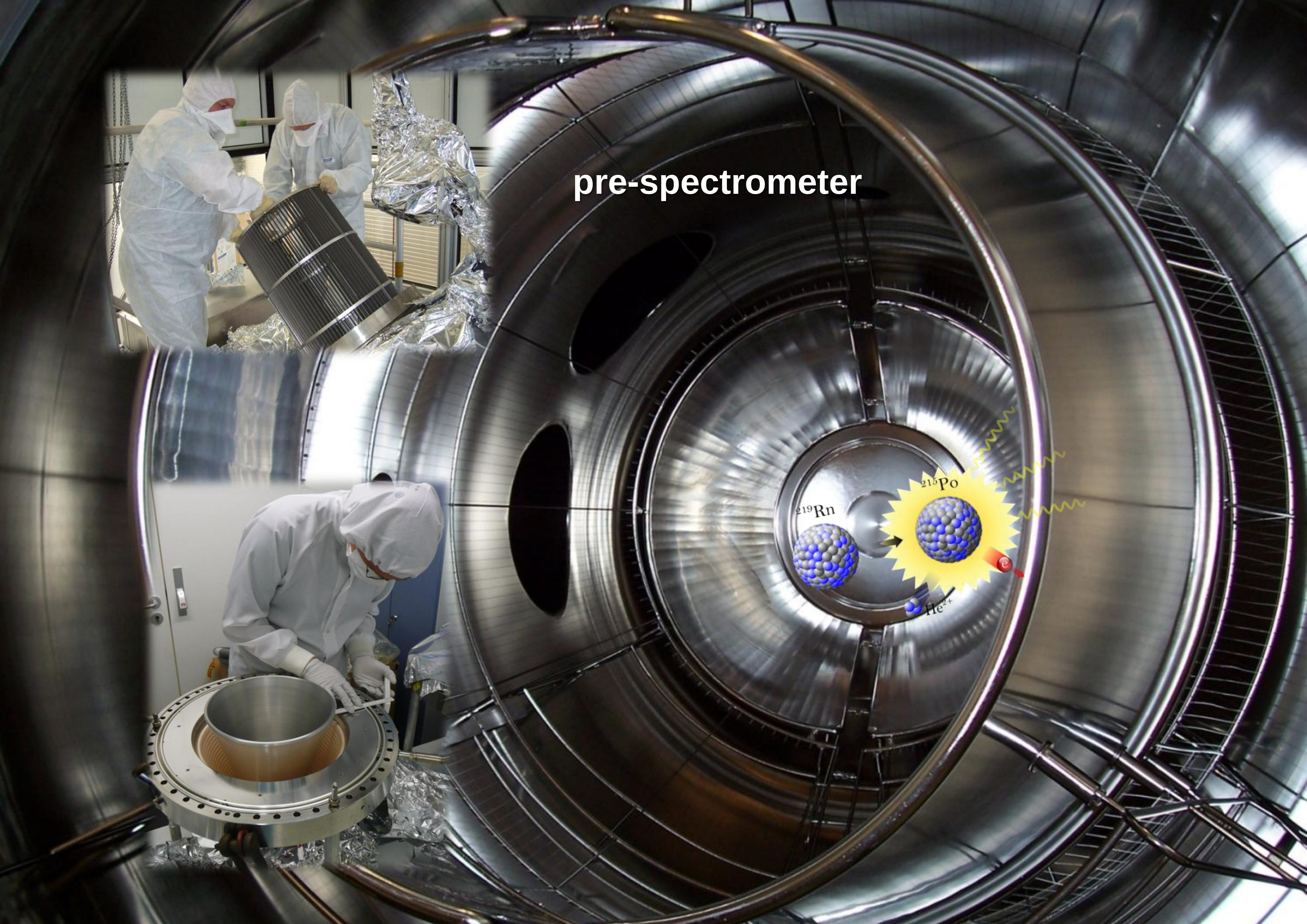
precision filter - scanning

variable retarding potential
U_0 = - 18.4 … -18.6 kV
ΔE ~ 0.93 eV (100% transmission)



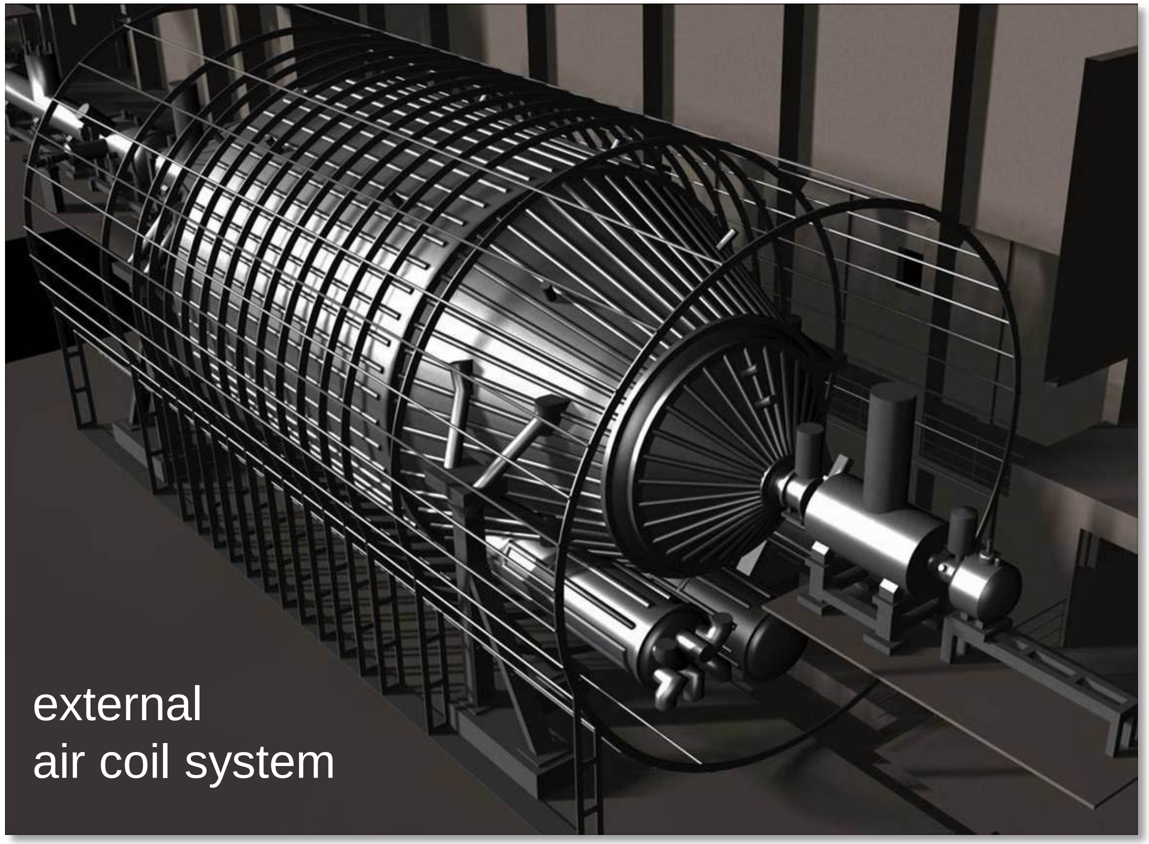
tandem design: pre-filter & energy analysis

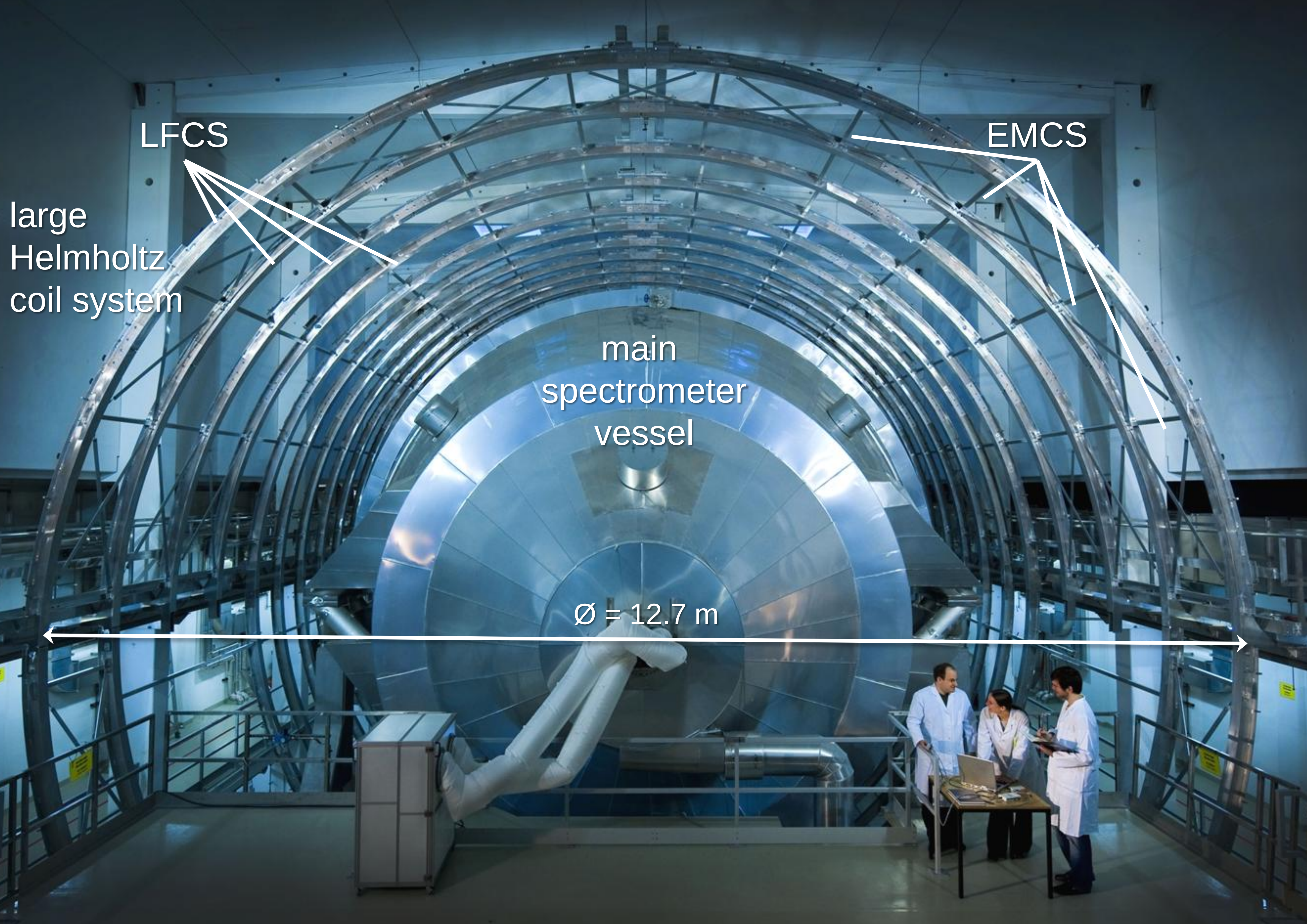
10^{11} electrons/s ⇨ 10^{3} electrons/s


pre-spectrometer
219Rn
215Po
He2+

main spectrometer

- **ultra-precise energy analysis** of ß-decay electrons close to endpoint E_0 with ´energy resolution´ **$\Delta E = 0.93$ eV** (0% → 100% transmission)
- **features:** Ø = 10 m, length = 24 m, surface = 690 m^2, volume = 1240 m^3, $p < 10^{-11}$ mbar (world´s largest UHV recipient) inner electrode system & external Helmholtz-type air coil system

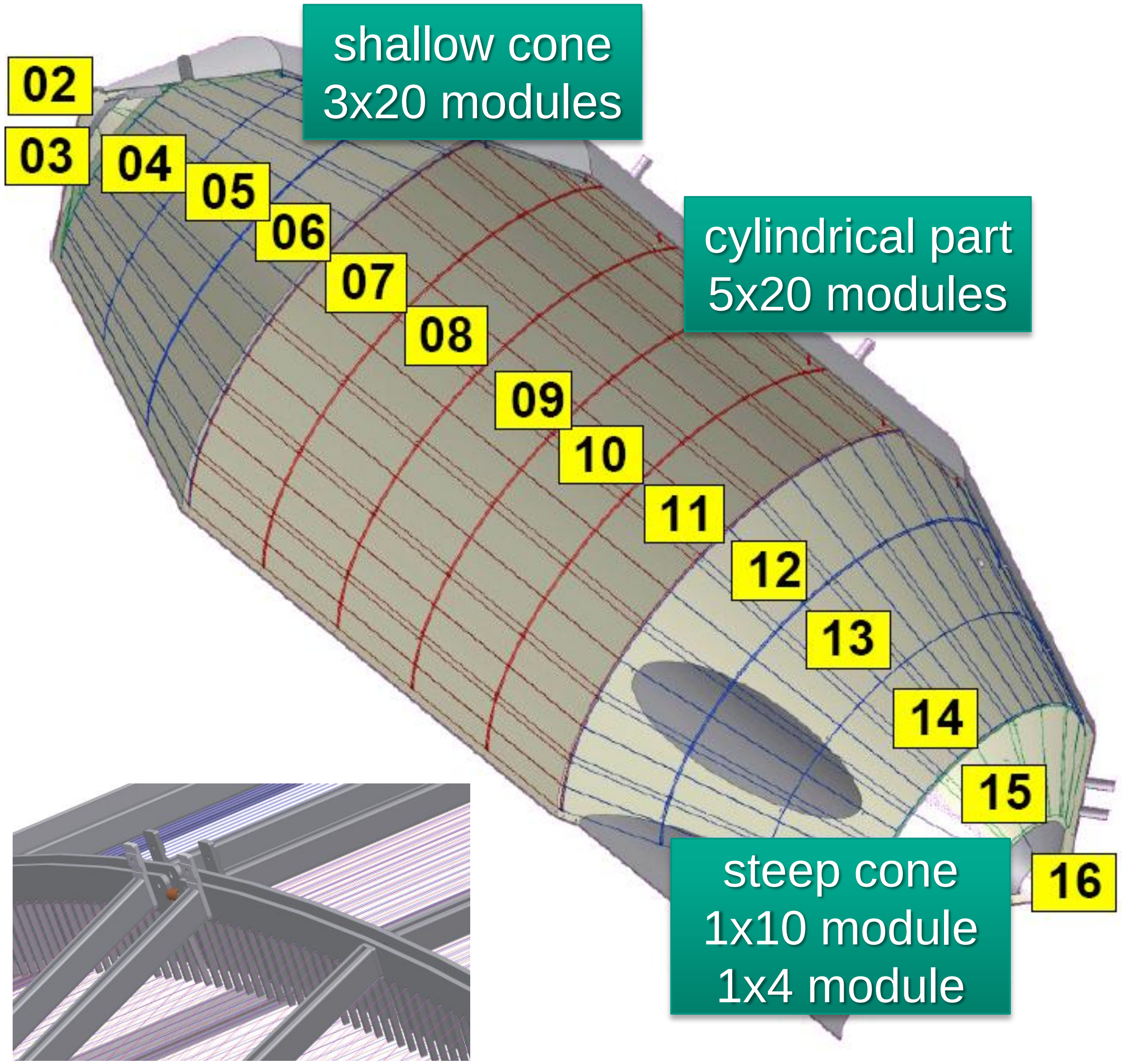



LFCS
EMCS
large Helmholtz coil system
main spectrometer vessel
Ø = 12.7 m

inner electrode system – objectives

- a double-layered inner electrode system for ß-spectroscopy

>24,000 wires
(in 250 frames)



#1: background suppression

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

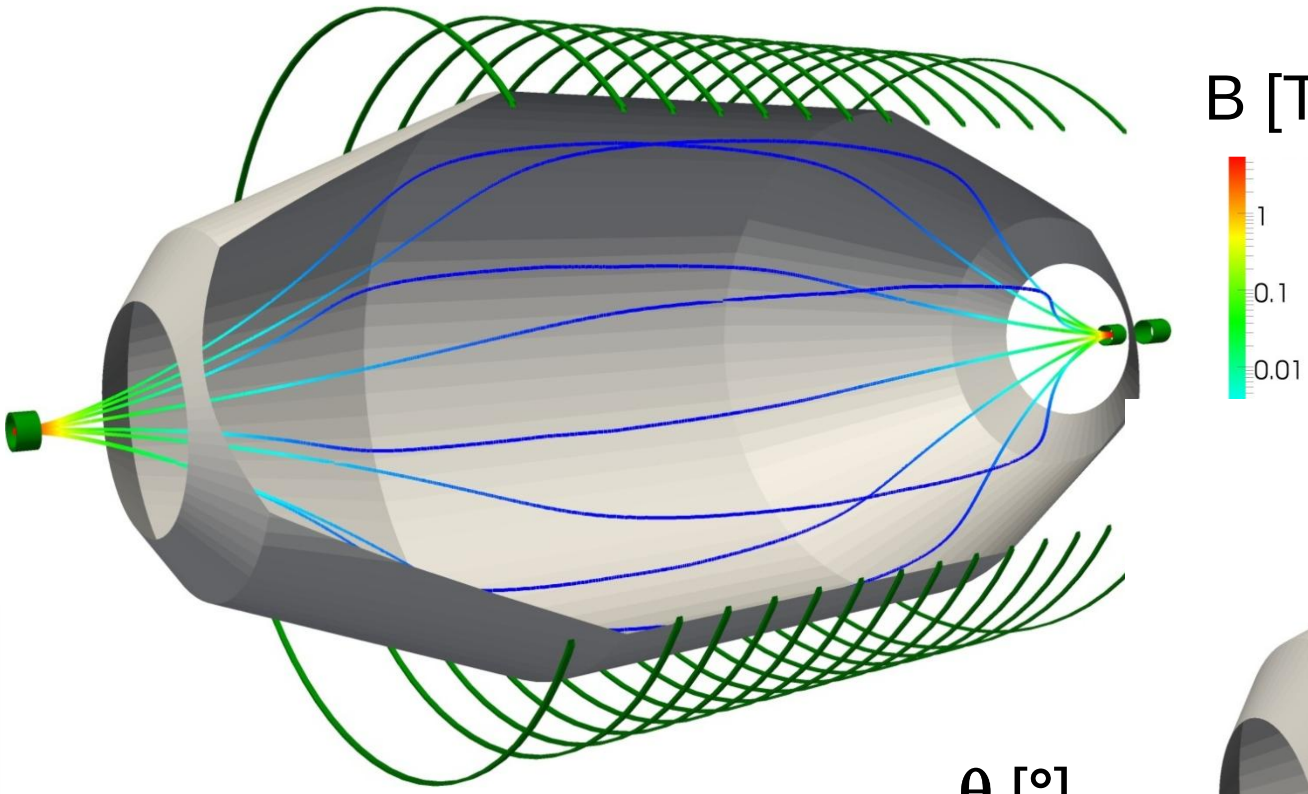
#2: fine forming of retarding field

- precision HV power supplies: intrinsic HV precision ~1 ppm
- dipole/ECR mode: eject particles stored in Penning traps


SDS Commissioning Measurements
KATRIN Collaboration
2011-10-07, Revision 10835
1

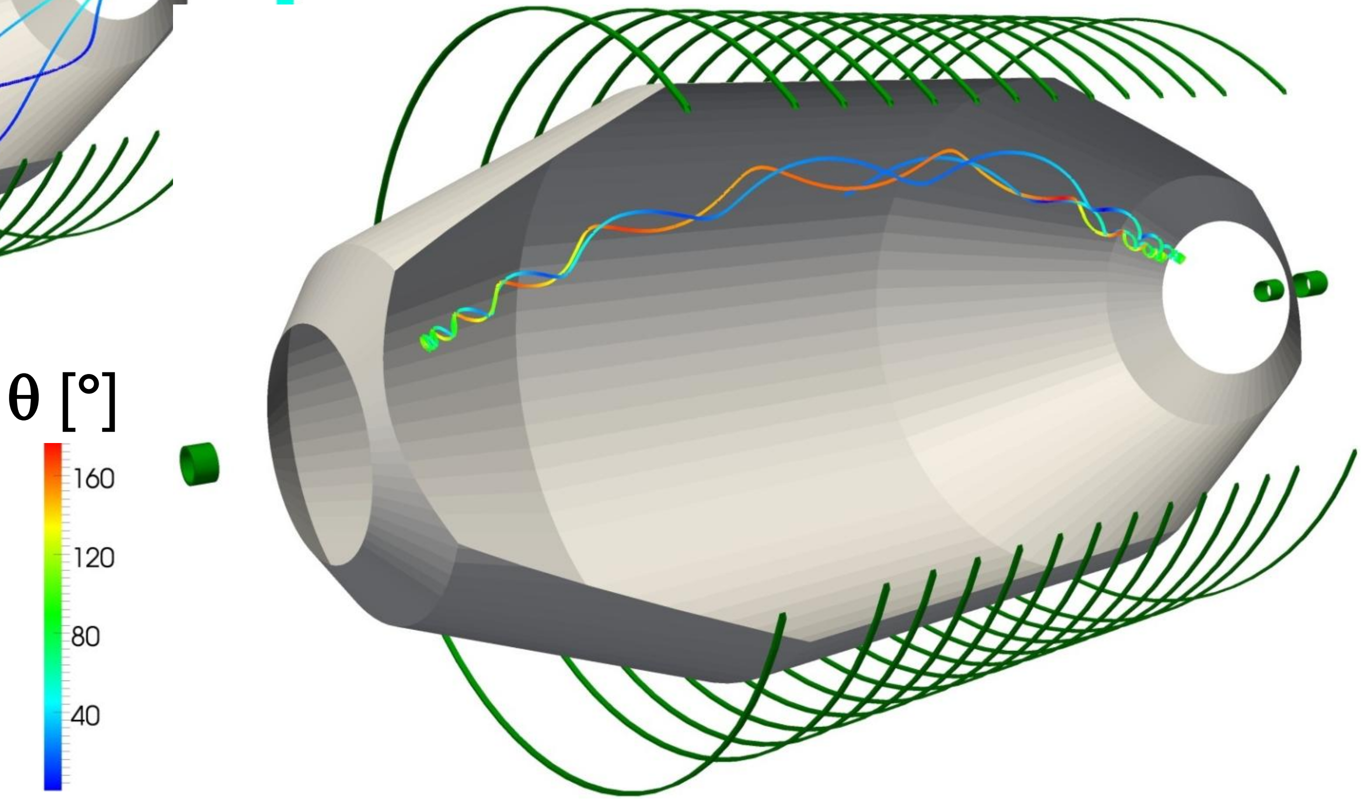
KASSIOPEIA: signal & background

- **KASSIOPEIA:** detailed simulation of electron trajectories



- **transmission of ß-electrons**:
  magnetic guiding &
  electrostatic retardation

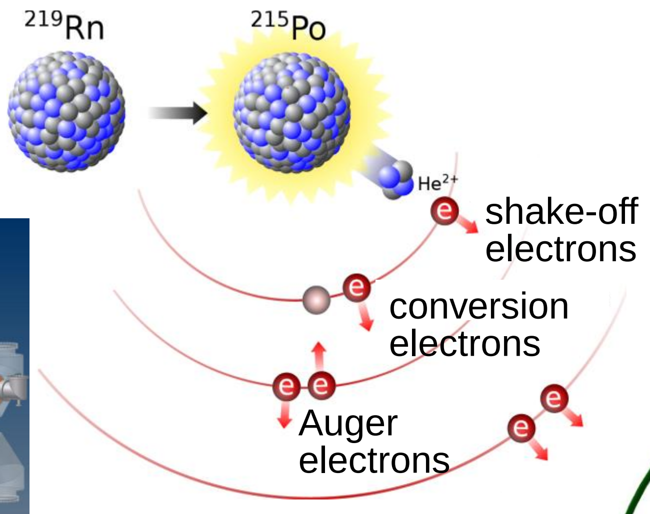
- **trapping of bg-electrons**:
  spectrometer acts as
  a magnetic bottle,
  long storage (h)



radon induced background

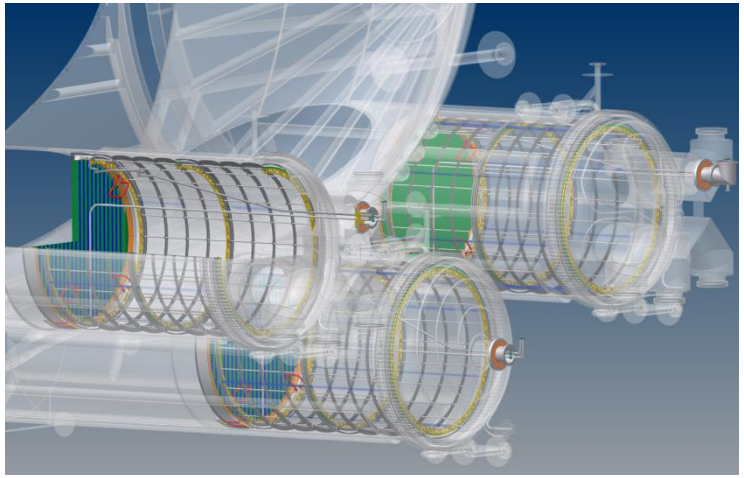
Karlsruhe Institute of Technology

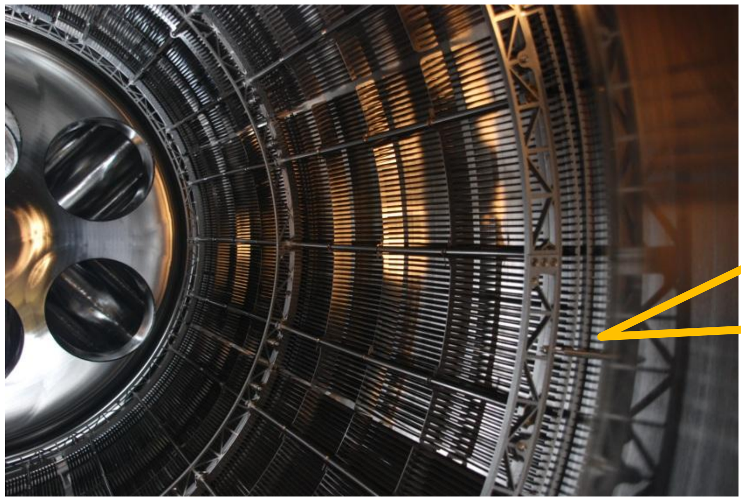
- ^{219}Rn emanation from St707 NEG getter strips (3 · 1 km) in pump ports of spectrometers

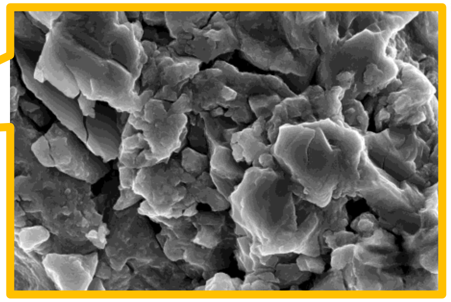


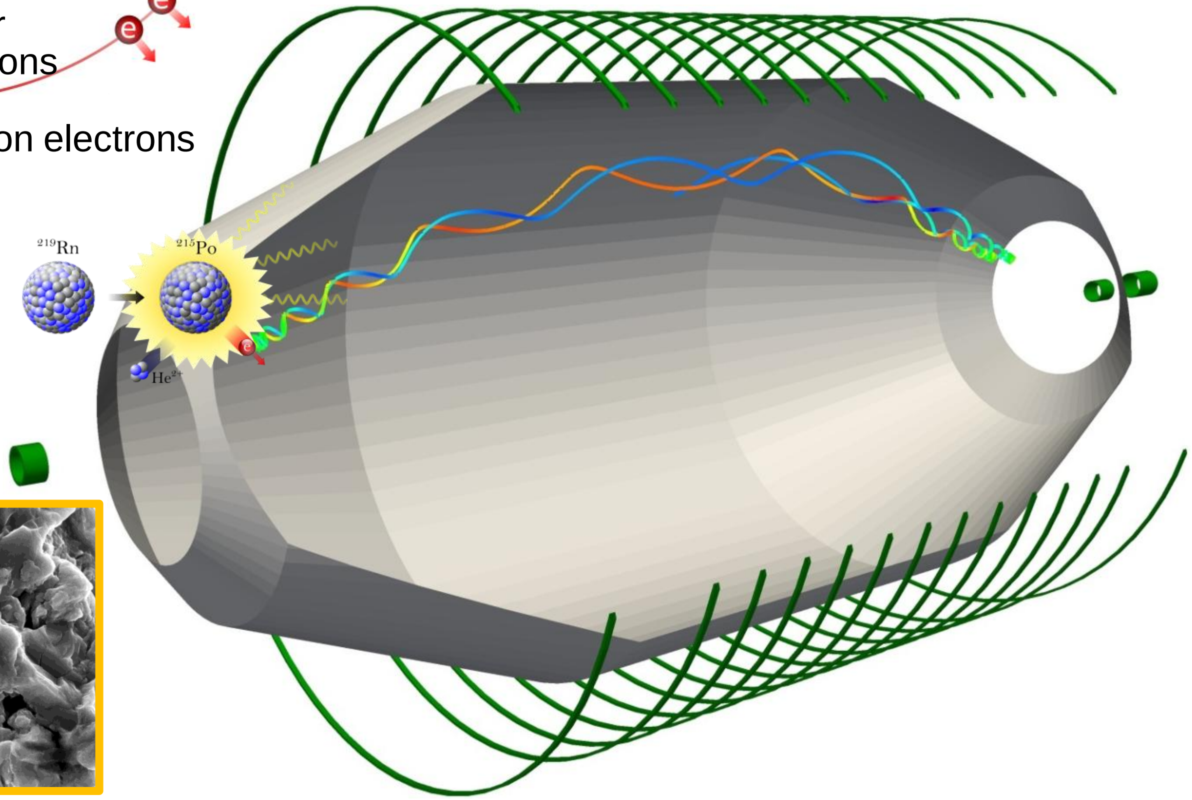
F.M. Fränkle et al., Astropart. Phys. **35** (2011) 128

S. Mertens, PhD thesis KIT (2012)



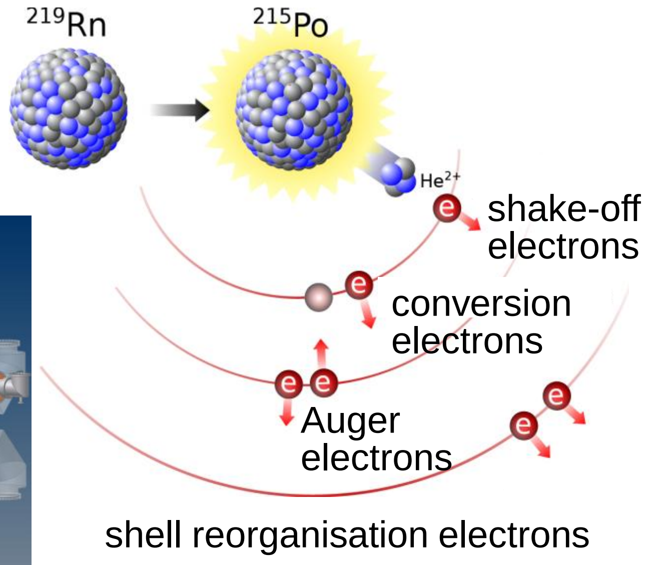


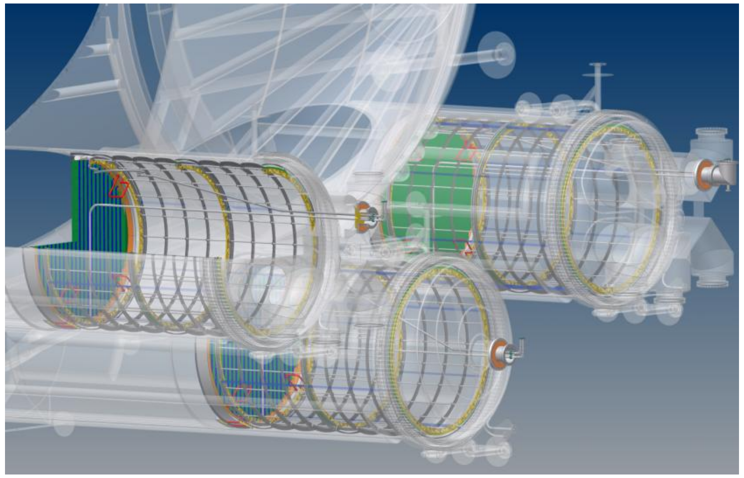


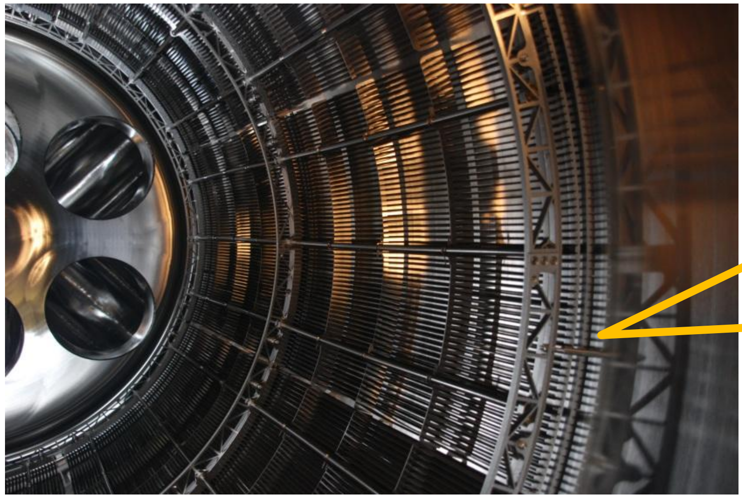


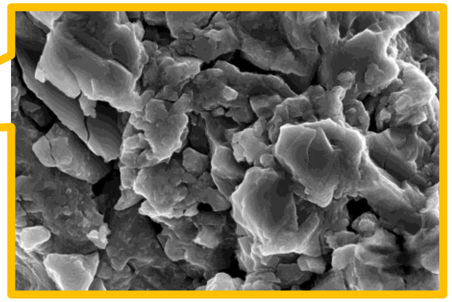
KASSIOPEIA: signal & background

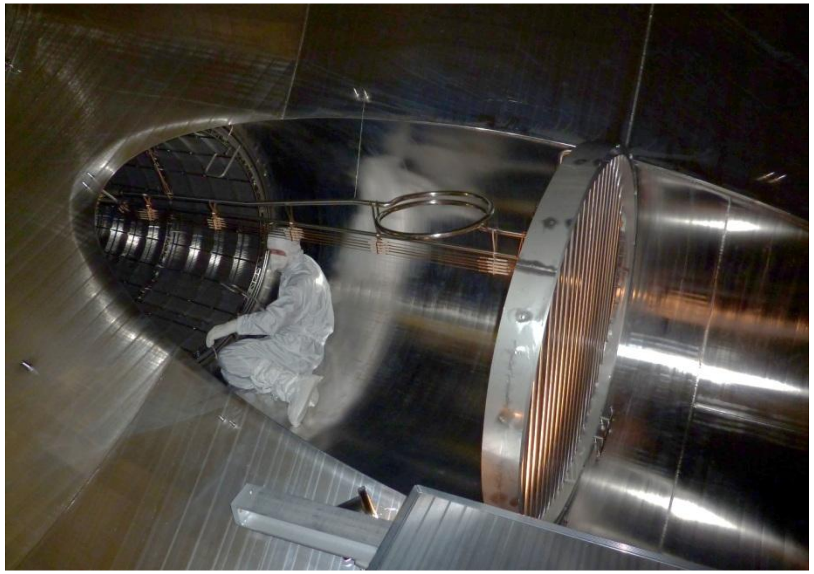
- passive background reduction: **LN2-cooled baffles** to cryocondense ^{219}Rn

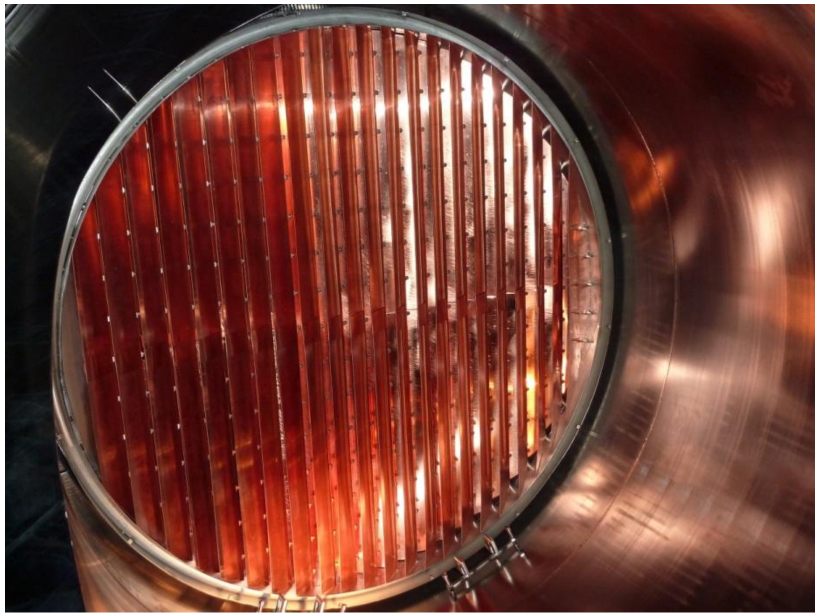






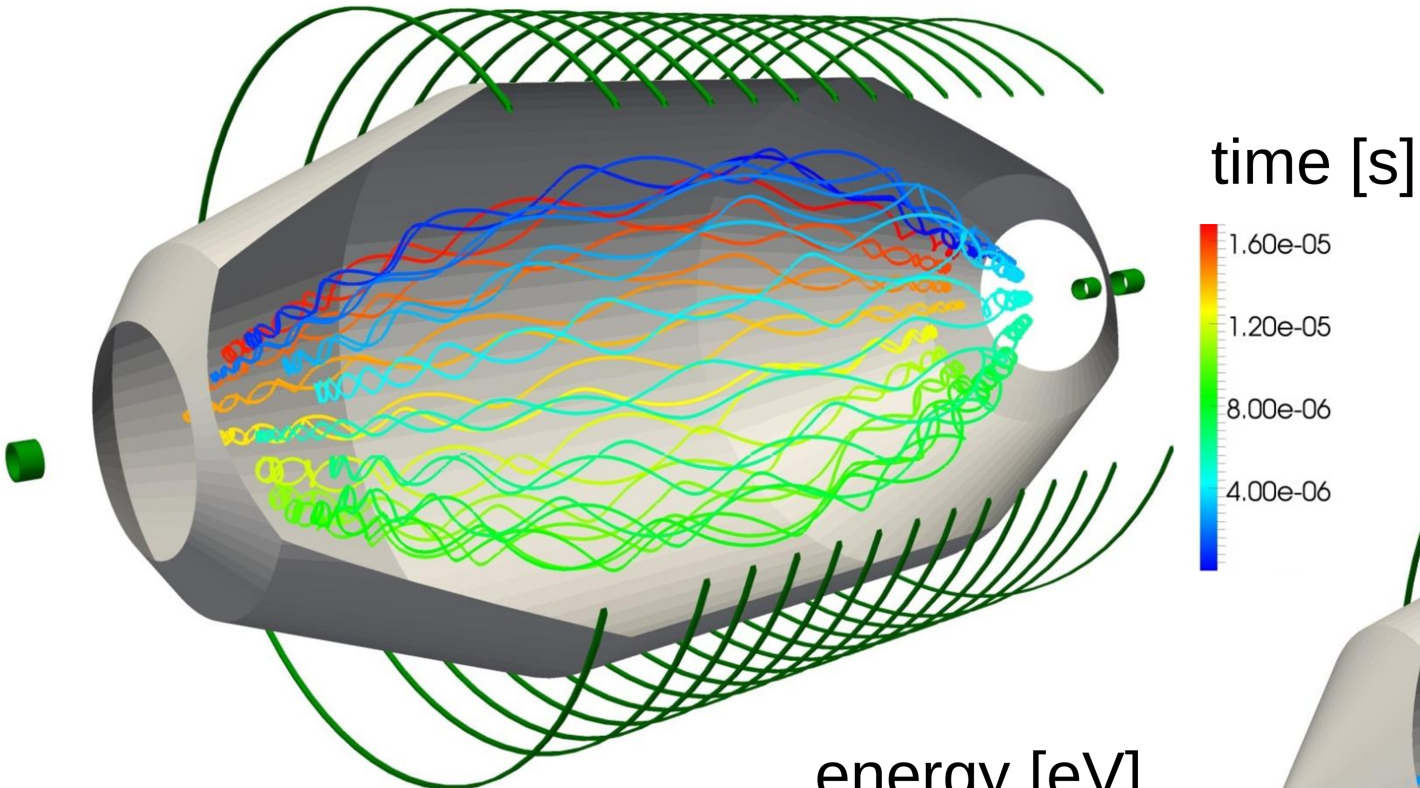






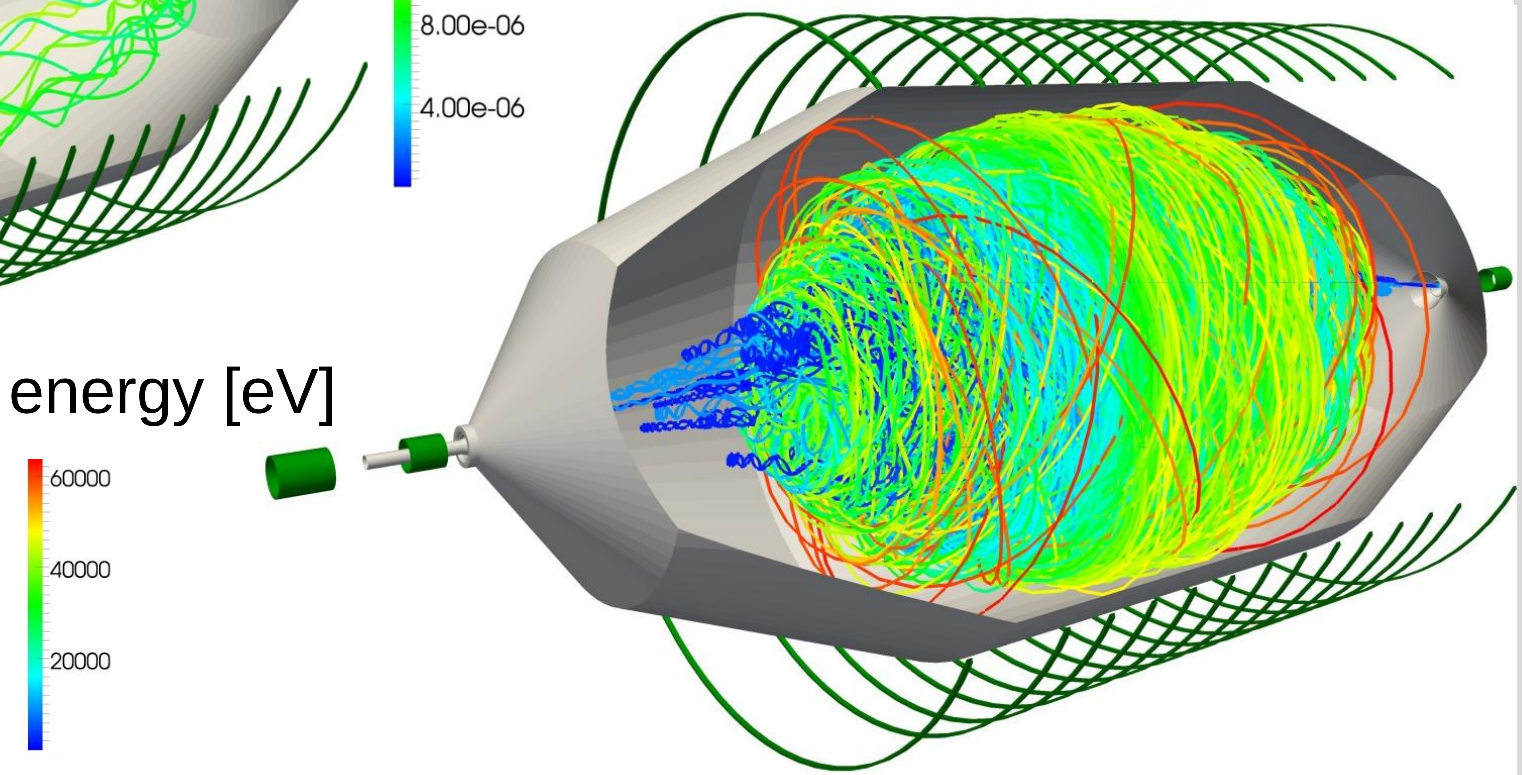
KASSIOPEIA: background reduction

- ^{219,220}Rn emanation from bulk material of vessel: need active bg-suppression



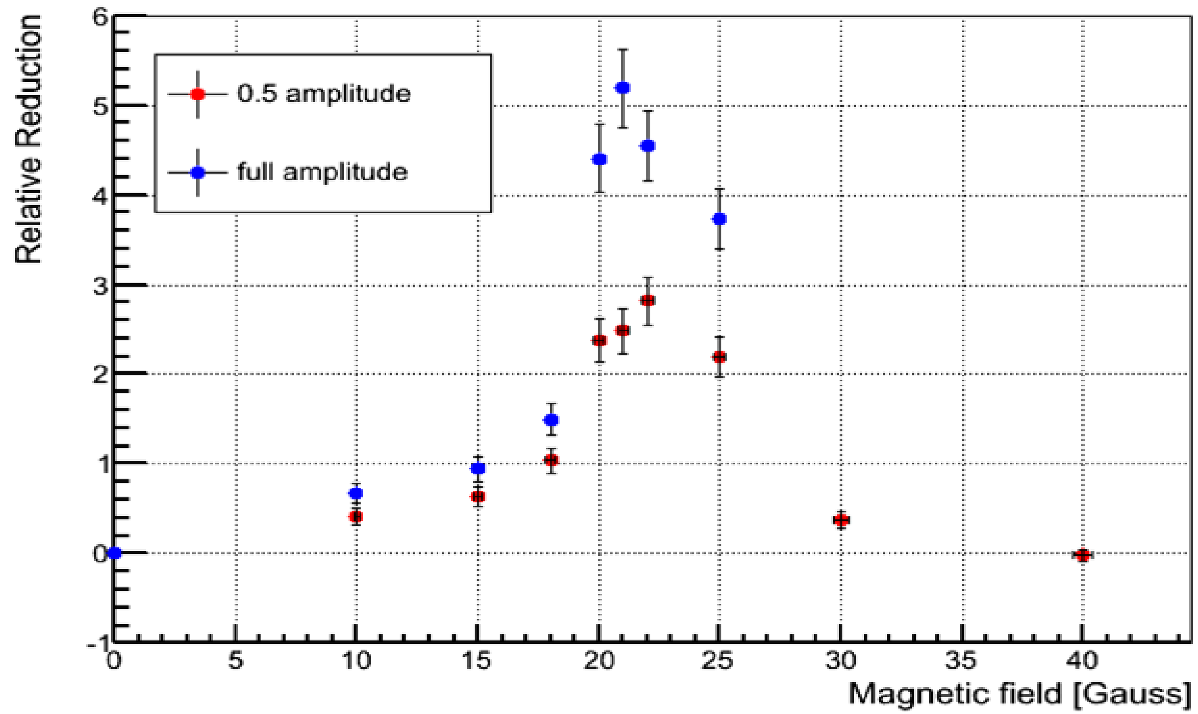
- **stored multi-keV electrons**:
  rapid cyclotron motion
  intermediate axial oscillation
  slow magnetron drift

- **ECR technique**:
  stochastic heating
  by short RF pulses
  with $\omega_{RF} = \omega_{cycl}$



KASSIOPEIA: background reduction

- ECR-tests at pre-spectrometer very successful: promise of low bg!



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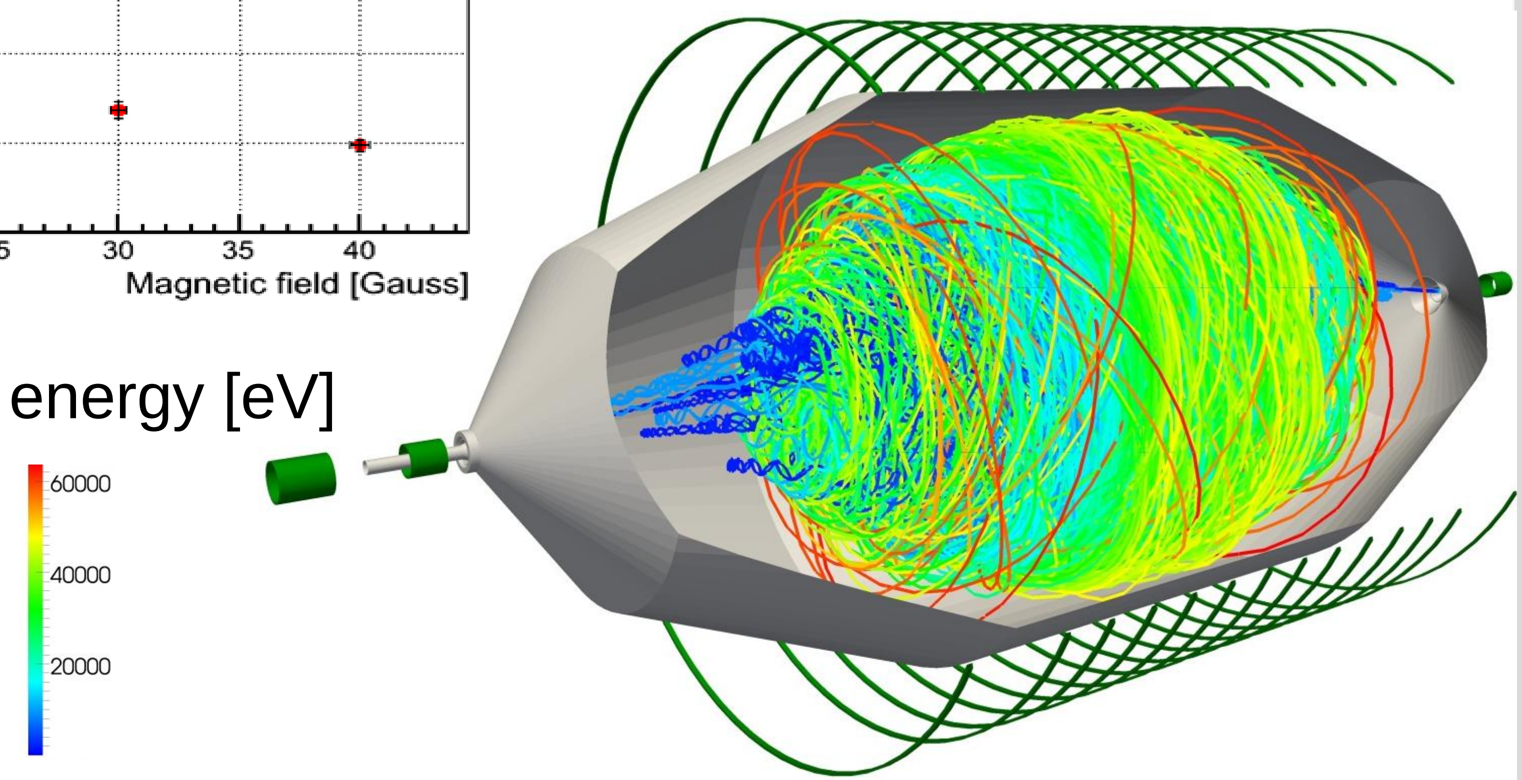

- **ECR technique**:
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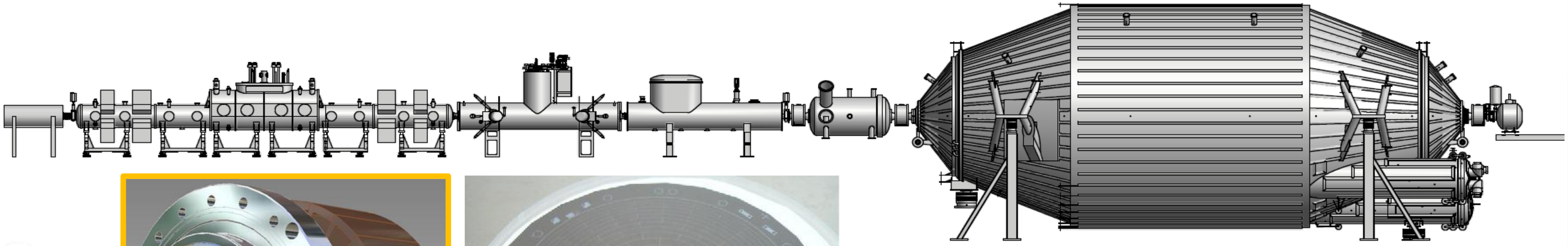
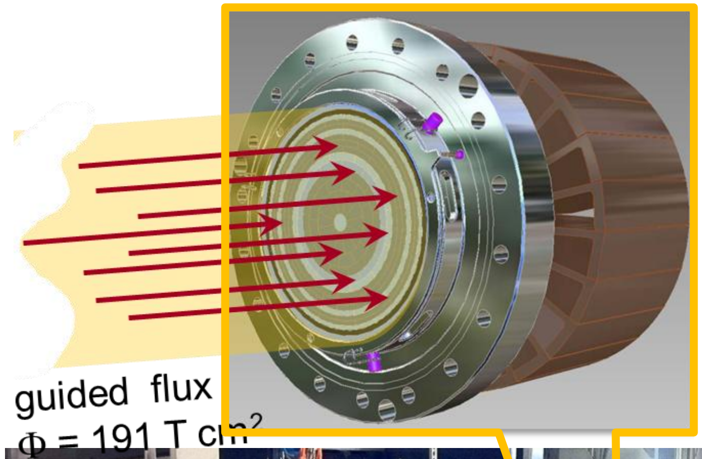
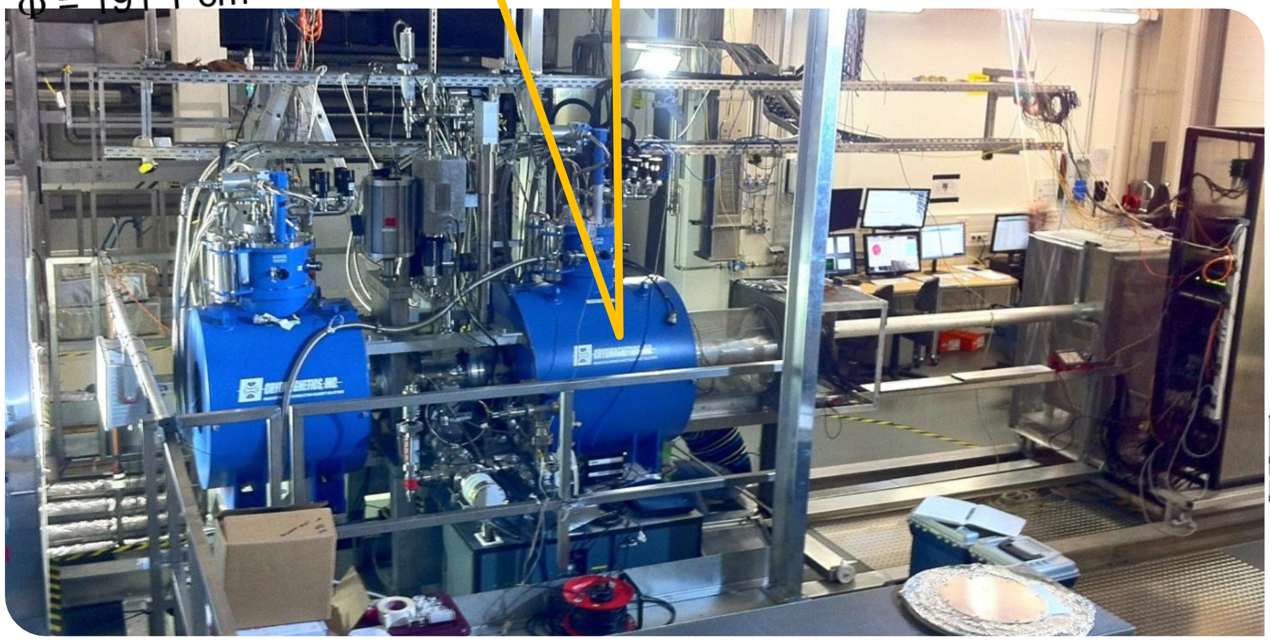
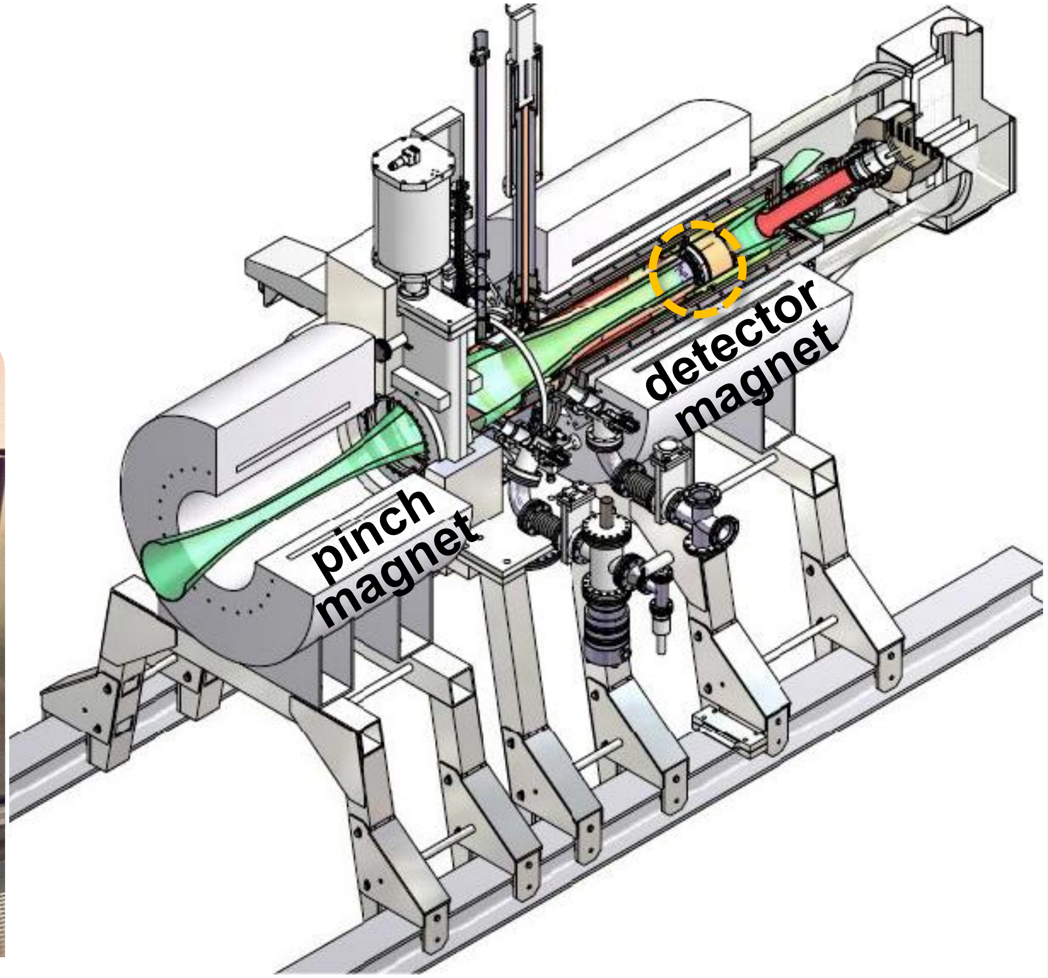
  with $\omega_{RF} = \omega_{cycl}$

focal plane system – final commissioning







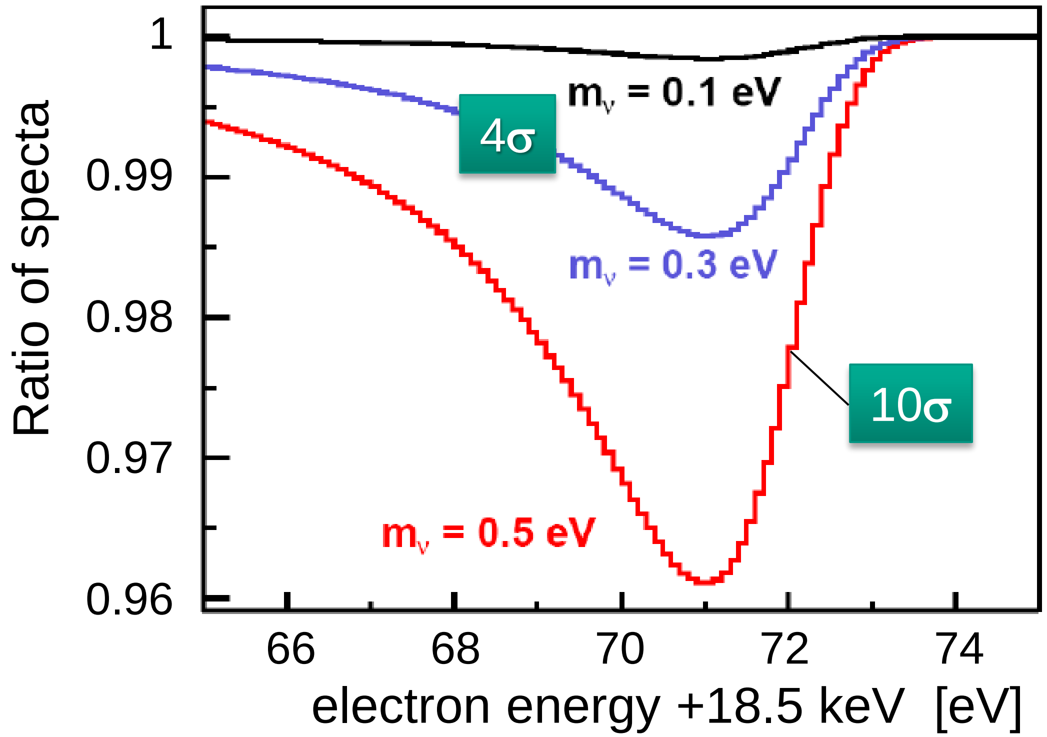


KATRIN sensitivity

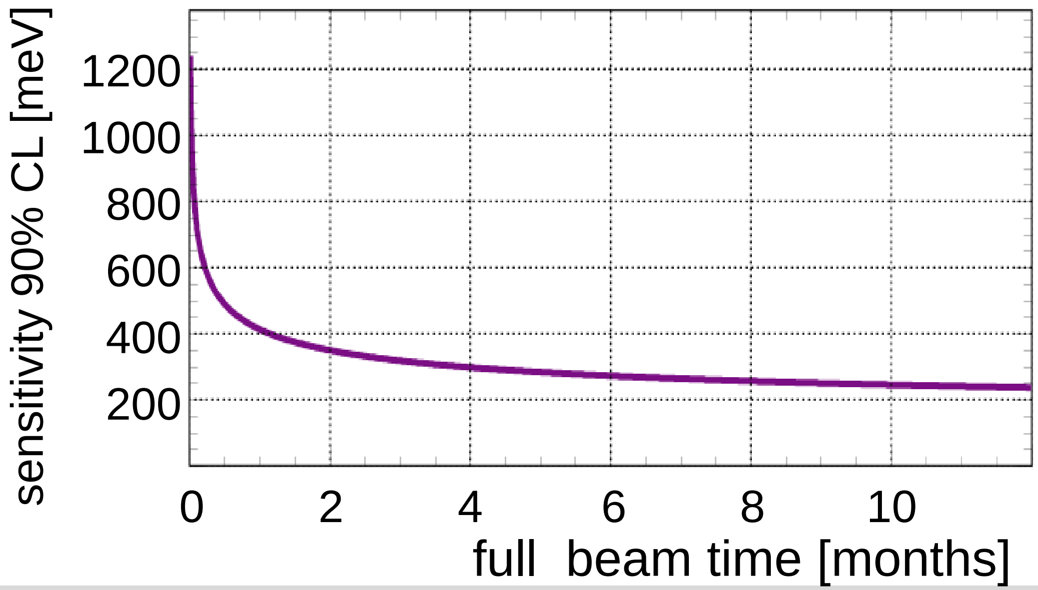
- **reference ν-mass sensitivity**
  for 3 ´full beam´ years:
  - statistical & systematic errors contribute equally:
    statistics σ_{stat} = 0.018 eV²
    systematics σ_{syst} < 0.017 eV²

sensitivity m(ν) = 200 meV (90% CL)

350 meV (5σ)

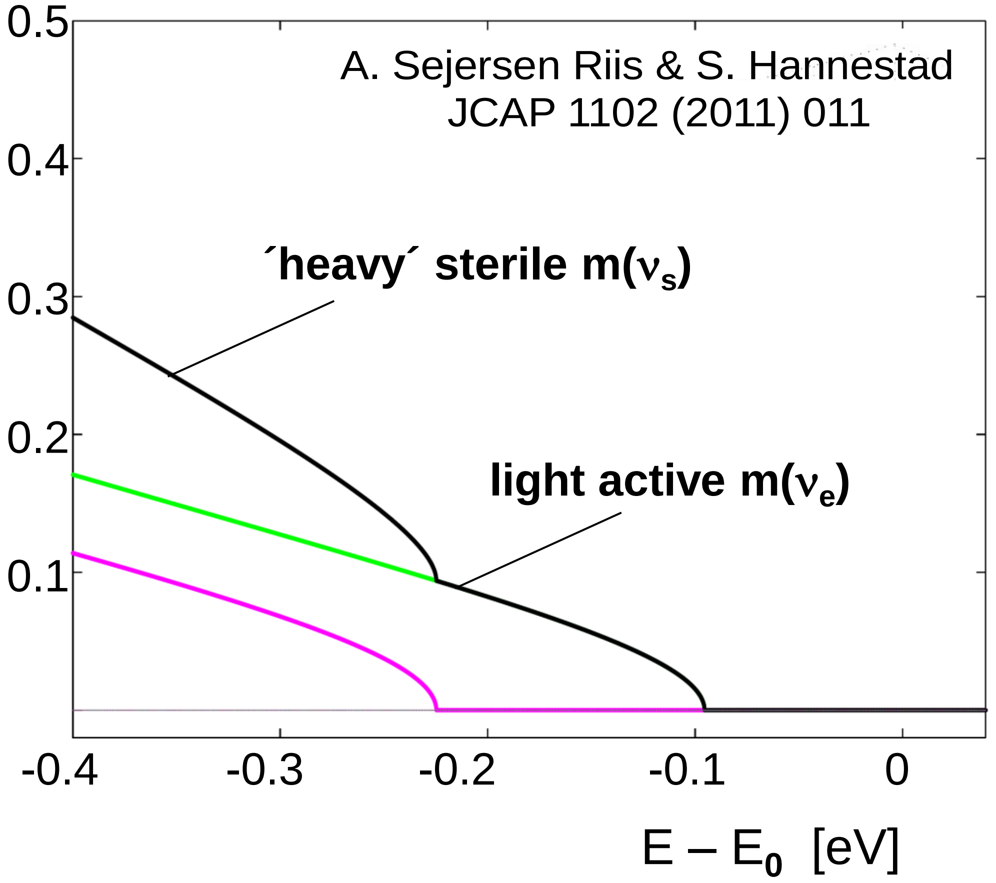


- **plans for a later KATRIN phase II:**
  - differential ß-energy spectrum:
    cryo-bolometer array with ΔE ~ 1eV?
    synchrotron emission (GHz-range)?
  - precision external value end point E_0
  - atomic tritium source?

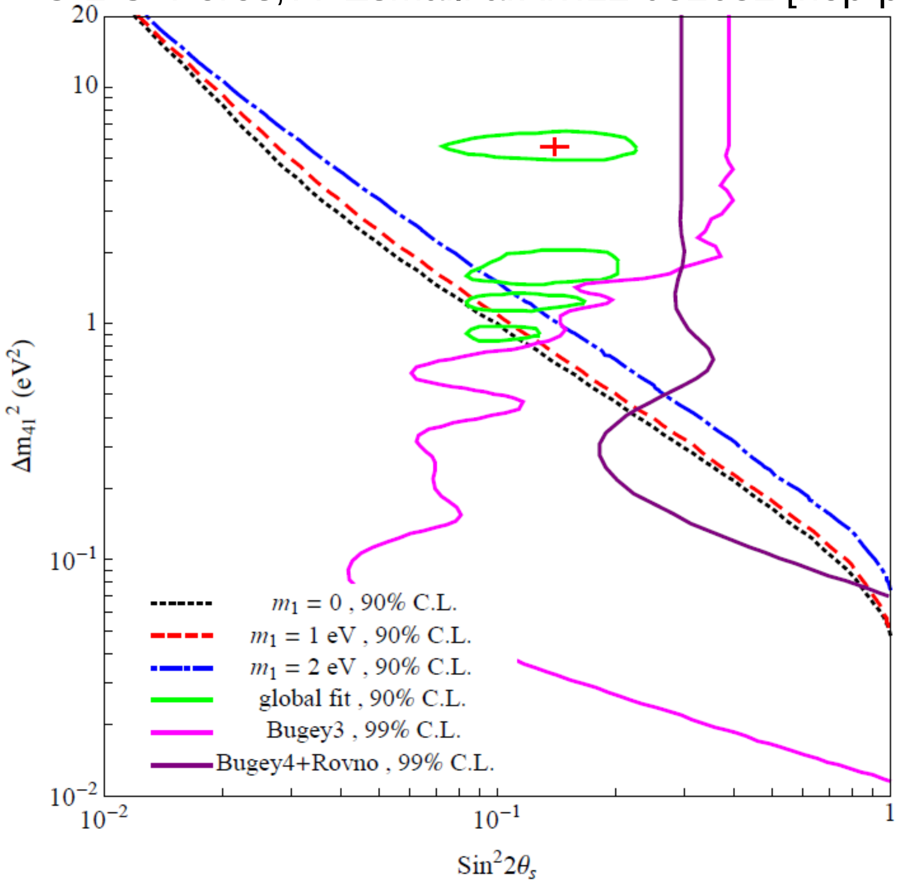


sterile neutrinos: (sub-)eV scale

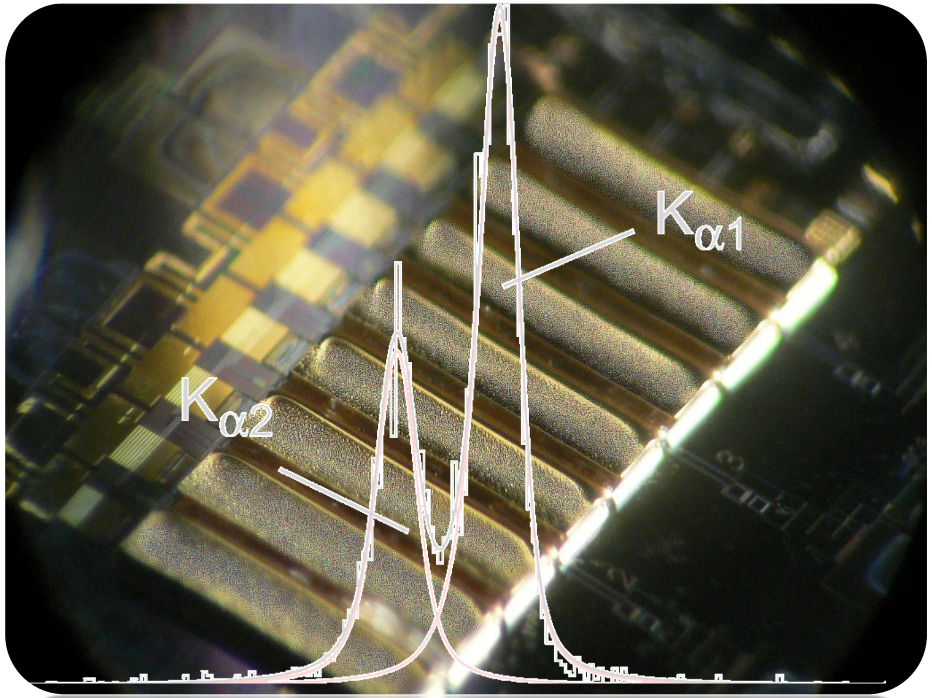
- Hannestad et al. - initial estimates of KATRIN sensitivity for sterile ν´s
  assume very light active neutrinos m(ν_e) ~ 0 eV, mixed with sterile m (ν_s)
- 3 σ detection of ´kink´ by $m_{sterile}$ if active-sterile mixing **$|U_{es}|^2 \geq 0.055$**
  3+2 scenarios can also be disentangled, **measure absolute value m (ν_s)**



O.L.G. Peres, A. Esmaili arXiv:12.032632 [hep-ph]



novel approaches: Project 8 & ^{163}Ho EC experiments



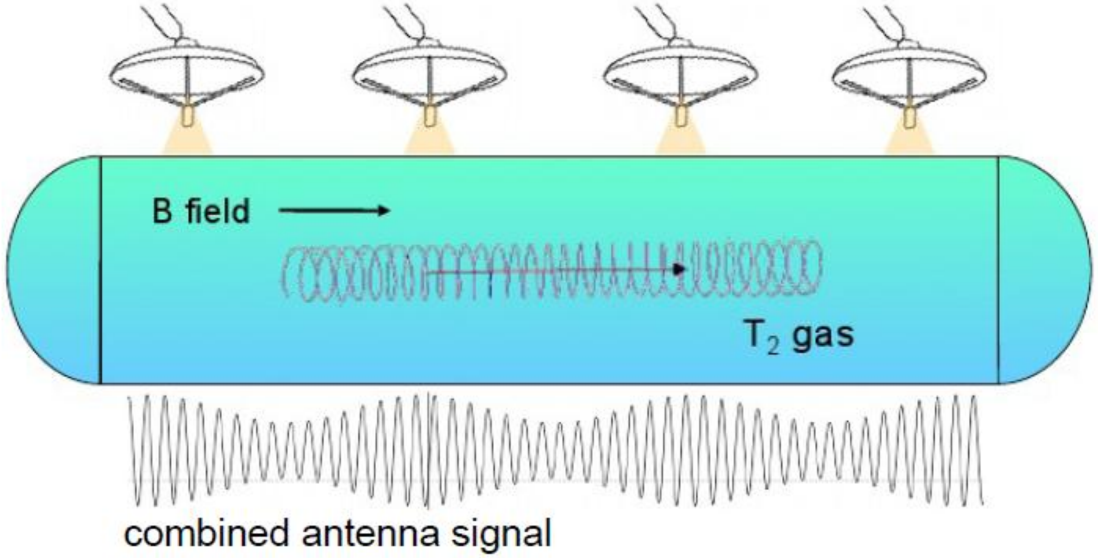
Project 8 – a novel technology ansatz

Karlsruhe Institute of Technology

- **basic concept** (J. Formaggio, B. Monreal et al.)
  - source: WGTS in an NMR-type constant B-field
    max. ß-intensity: ~10^9 Bq (~10^{-2} of KATRIN)
  - spectroscopy: array of microwave antennae to pick up **coherent cyclotron radiation** of single electrons
    as $\Delta\omega \sim 1/t_s$ ⇘ long sampling time $t_s \sim 40\ \mu s$ for $\Delta E = 1$ eV
    ⇘ trapping in magnetic bottle

MIT HAYSTACK OBSERVATORY

Doppler effect: array picks up blue- & red-shifted signals



B. Monreal, J. Formaggio, Phys. Rev. D 80, 051301(R) (2009)

- **basic parameters**:

$$\omega(\gamma) = \frac{\omega_0}{\gamma} = \frac{e \cdot B}{m_e + E_{e,kin}}$$

- precise measurement of ω yields electron kinetic energy
- B = 1 T & $E_{e,kin}$ = 18.575 keV
  ⇘ $f_0 = \mathbf{w_0} / 2\pi \approx$ 27 GHz

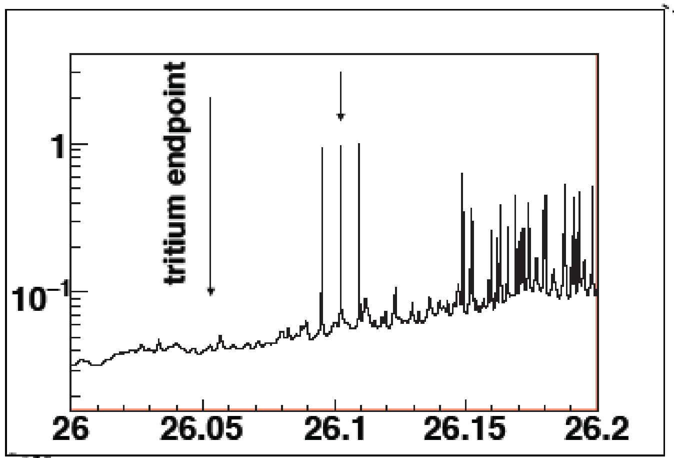
Project 8 – a novel technology ansatz

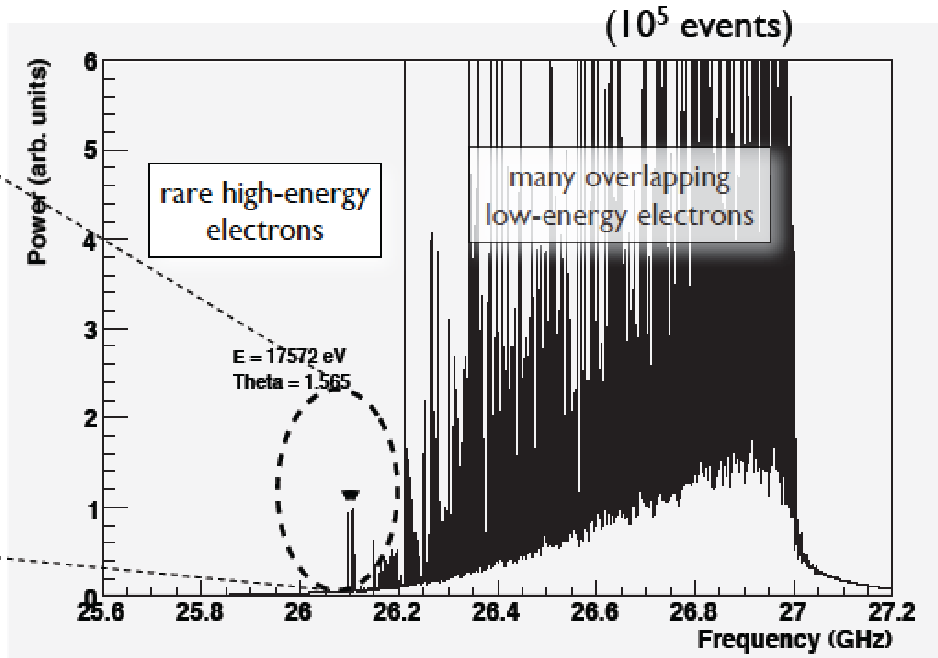
- **experimental challenges**:
  - very small power P of emitted synchrotron radiation by ***single*** keV-electron, requires adequate antennae & amplifier technologies

$$P(\beta,\gamma) = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2e^2\cdot\omega_0^2}{3c}\cdot\frac{\beta^2\cdot\sin^2\theta}{1-\beta^2}$$

P_{signal} ~ 10^{-15} W (1T, 18.6 keV)
P_{noise} ~ 10^{-17} W (thermal noise ampl.)

- **MC simulation**: 30 µs measuring interval with 10^5 ß-decay electrons





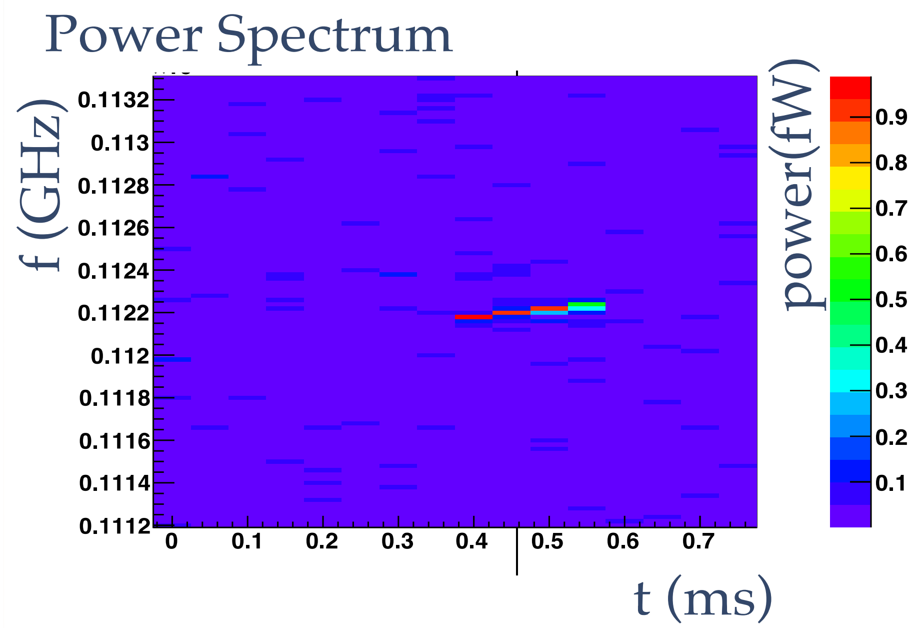
signal: 3 lines (triplet)
1 unshifted (central) coherent line
2 side bands (incoherent Doppler)

Project 8 – a novel technology ansatz

Karlsruhe Institute of Technology

- **experimental status**:
  - prototype experiment running at UW Seattle
  - aim: detect cyclotron emission from ***single*** electron
  - source: 17.8 keV electrons from ^{83m}Kr (K32-line)
  - cryostat: B = 1T, small magnetic bottle (V = 1 mm³)

- **R&D on**:
  - antenna technology
  - receiver & DAQ technology
  - study Doppler shifts



- Project 8 aims for

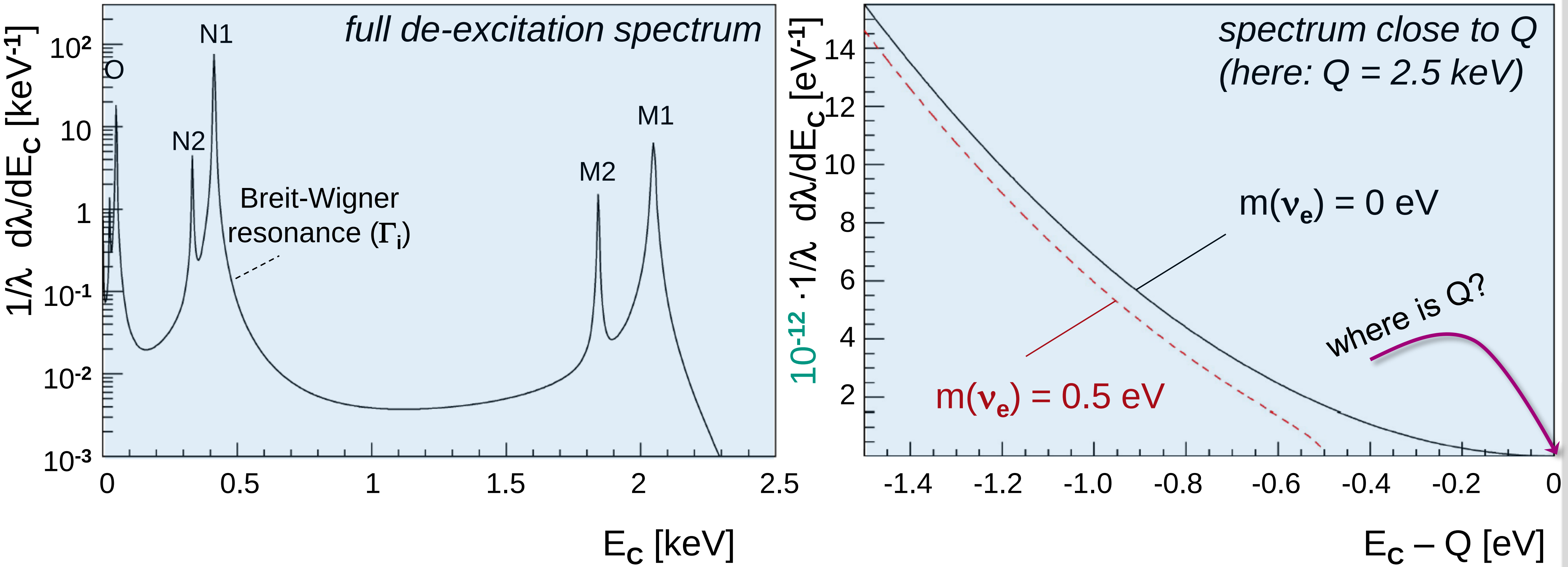
  sensitivity m(ν) = 100 meV (90% CL)

- **a lot of R&D work still to be performed**

electron capture & ν-mass

- electron capture: non-zero $m(\nu_e)$ value affects the EC de-excitation spectrum
  EC of ^{163}Ho is suitable candidate: $^{163}\text{Ho} + e^- \rightarrow \nu_e + {}^{163}\text{Dy}^* \rightarrow {}^{163}\text{Dy} + E_C$

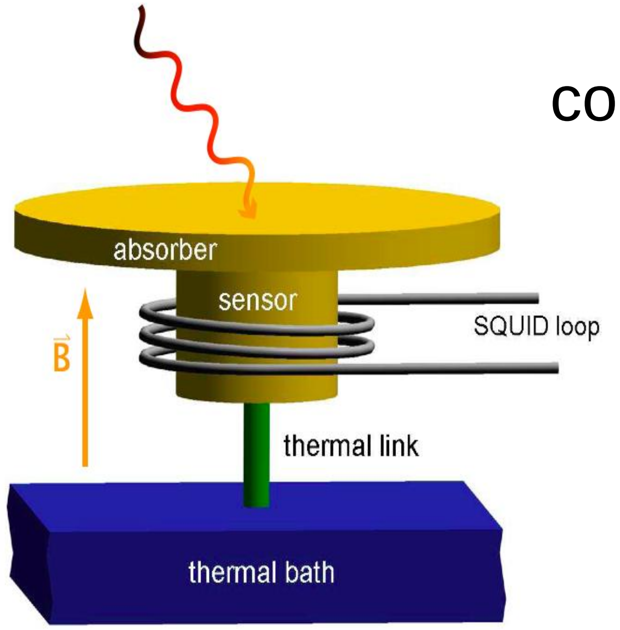
$$\frac{d\lambda_{EC}}{dE_C} \sim (Q-E_C)\cdot\sqrt{(Q-E_C)^2 - m^2(\nu_e)}\cdot\sum_i n_i\cdot C_i\cdot\beta_i^2\cdot B_i\cdot\frac{\Gamma_i}{2\pi}\cdot\frac{1}{(E_C-E_i)^2+\Gamma_i^2/4}$$



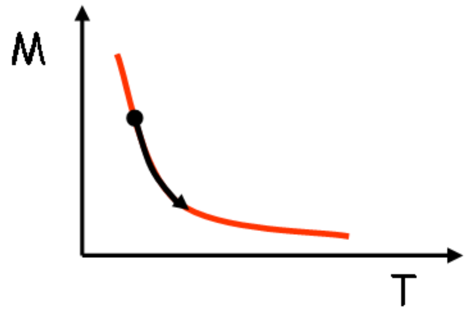
^{163}Ho experiments

- ^{163}Ho EC-decay parameters: Q_{EC} ~ 2.5 keV, $t_{1/2}$ = 4570 y
  detection of de-excitation of ^{163}Dy* (Dysprosium) by micro-calorimeters
  - **MARE groups** in Genova and Milano (& collaborators)
  - **ECHO collaboration** (**E**lectron **C**apture ^{163}**Ho** experiment):
    Uni Hd, MPIK, Saha Inst. of Nucl. Phys., CERN – ISOLDE, Petersburg

- interesting and promising new detector technology:
  MMC: **m**agnetic **m**icro-**c**alorimeters with paramagnetic sensor Au:Er



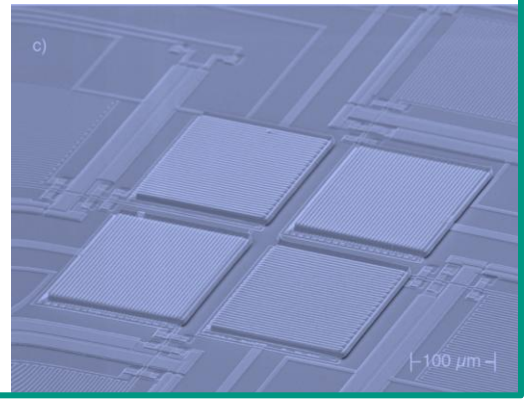
concept: δT in absorber from EC-decay
⇨ change in magnetism δM of sensor



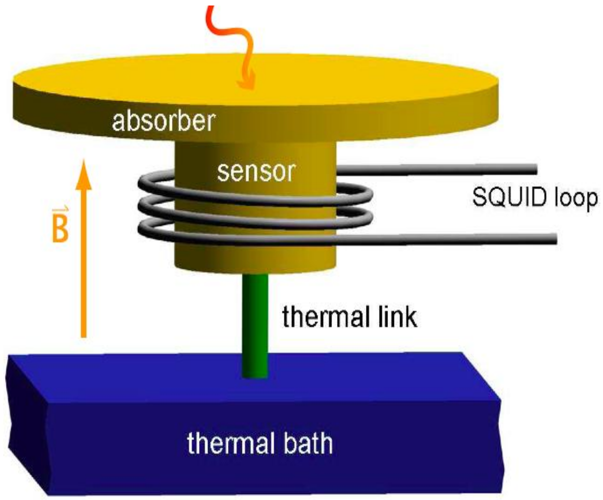
calorimeter signal: $$\delta\Phi_S \sim \frac{\partial M}{\partial T} \cdot \Delta T \sim \frac{\partial M}{\partial T} \cdot \frac{1}{C_{tot}} \cdot \delta E$$

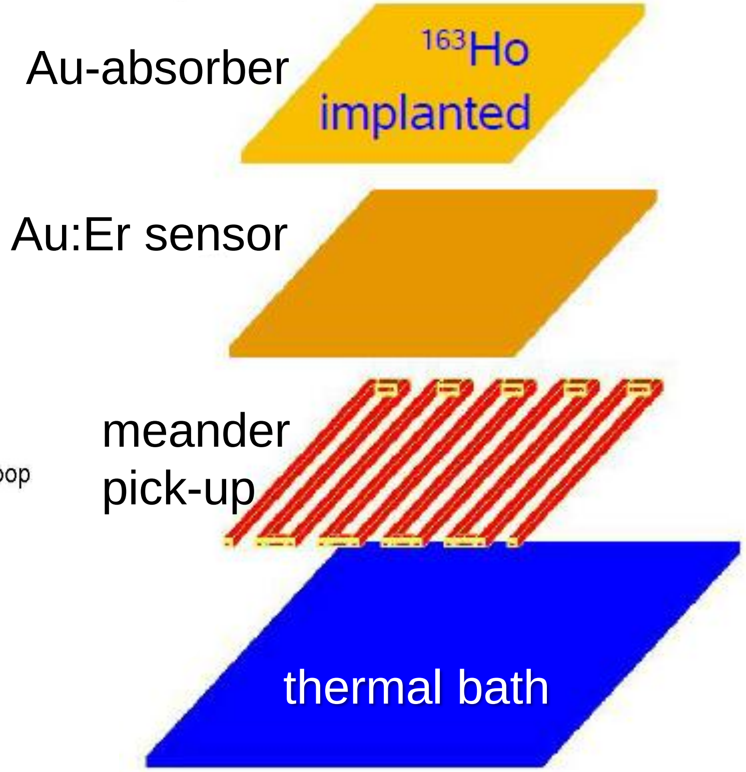
^{163}Ho experiments

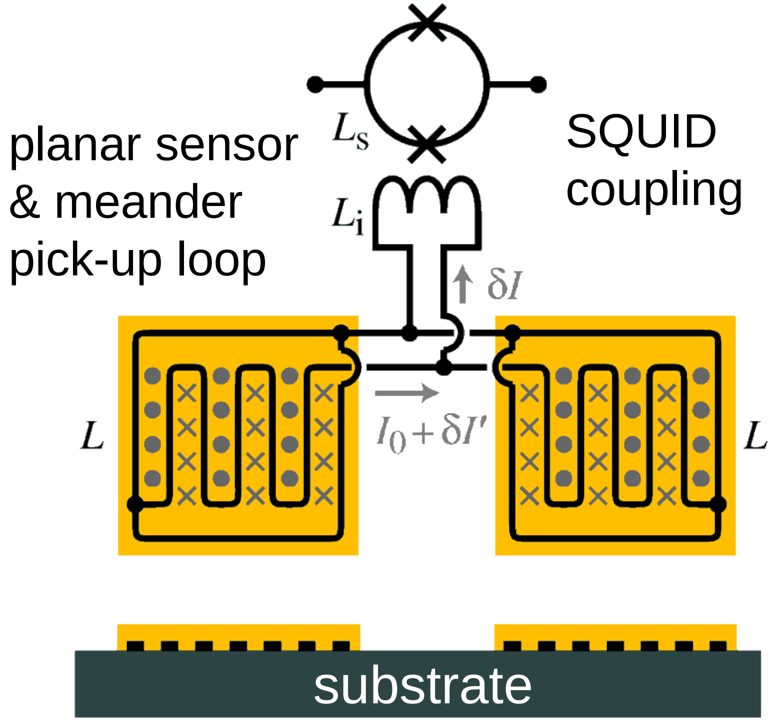
- **micro-fabrication of MMC detectors**
  - absorber: ^{163}Ho ion implantation at CERN – ISOLDE



early design:



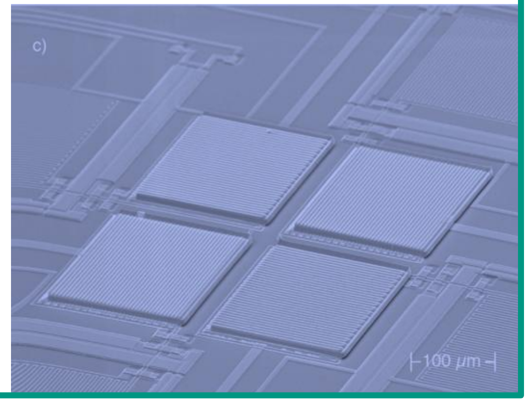


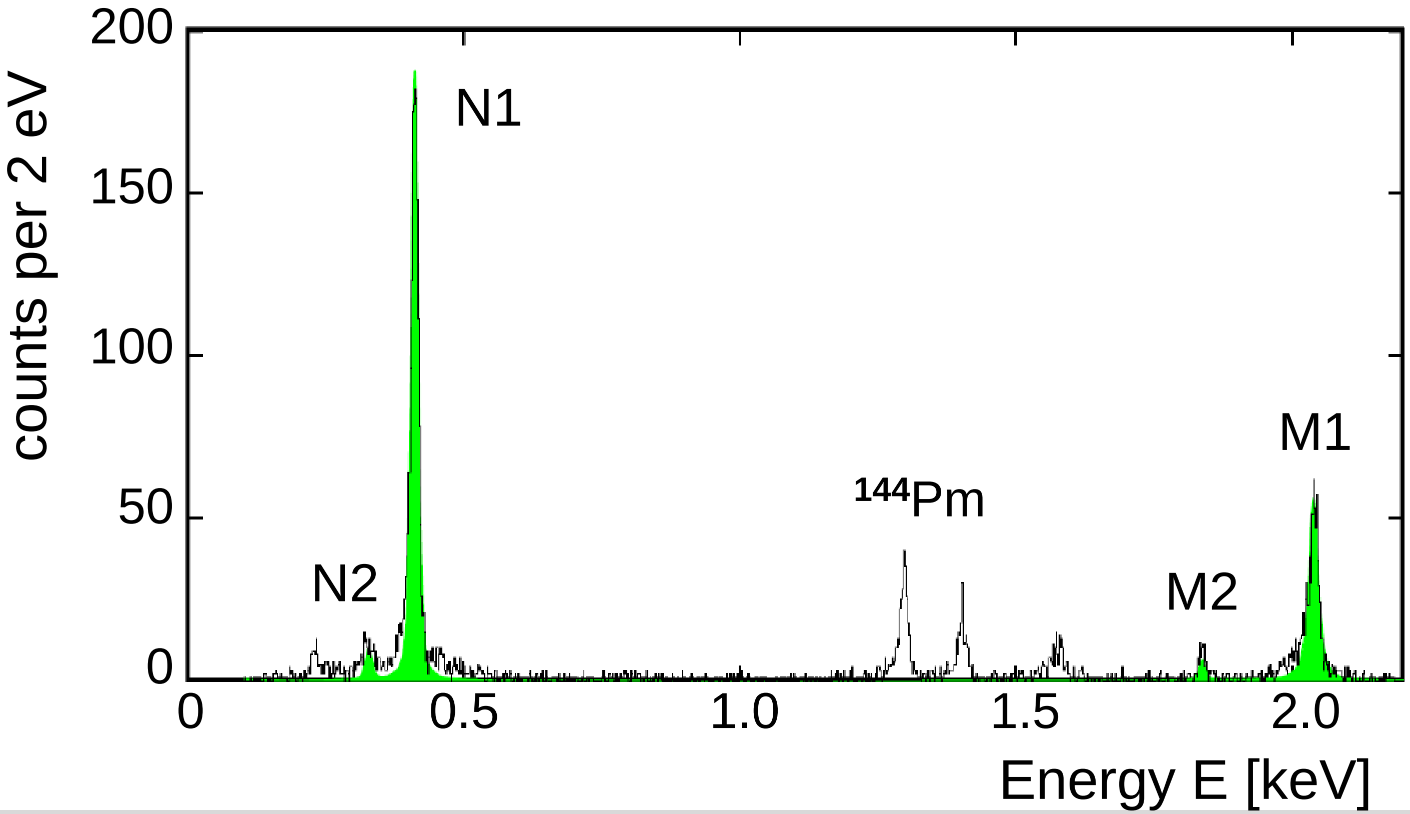


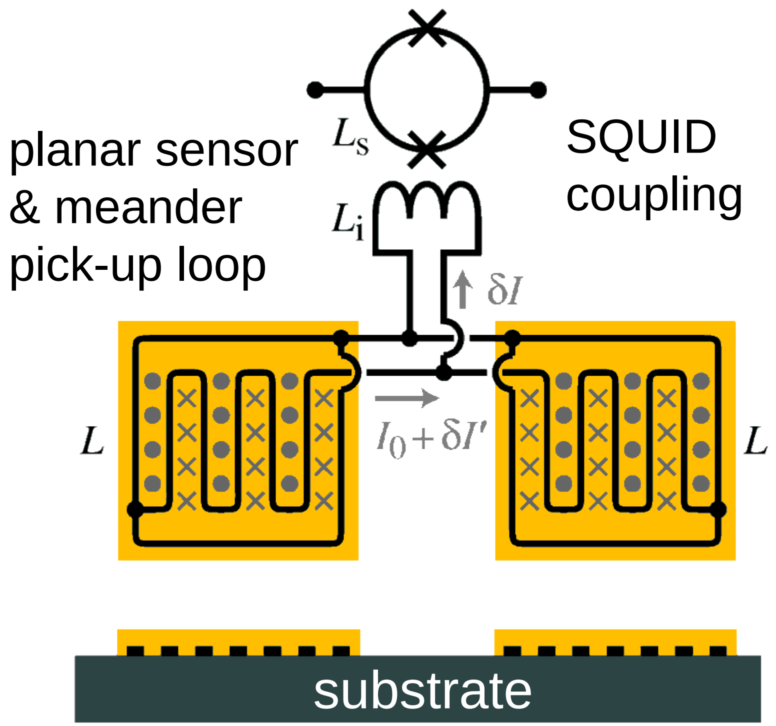
^{163}Ho experiments

■ micro-fabrication of MMC detectors

- absorber: ^{163}Ho ion implantation at CERN – ISOLDE
- test results: magnetic & thermal properties as expected
  ΔE_{FWHM} = 11.8 eV, latest designs ΔE_{FWHM} < 3 eV
  fast rise-time: τ_R = 90 ns
- extracted end-point value Q_{EC} = (2.8 ± 0.1) keV







Conclusions

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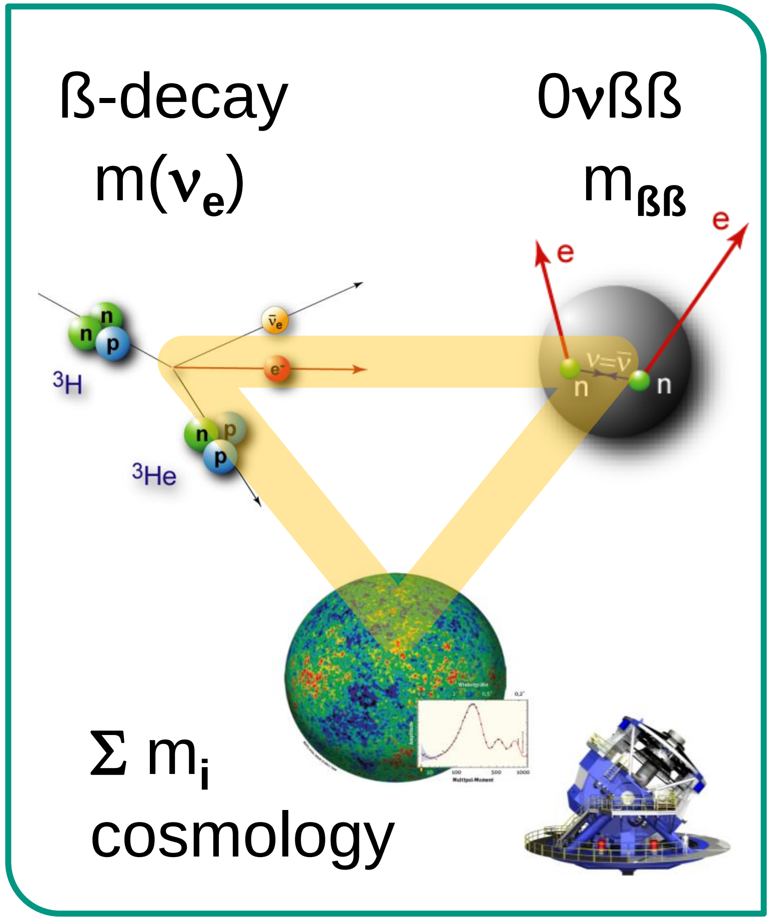
- studies of ß-decay/EC kinematics – the only model-independent method to determine absolute ν-mass scale
- KATRIN will probe cosmologically relevant scale down to $m(\nu_e) = 200$ meV
  studies for phase II to go beyond this value

- calorimetric experiments (MARE, ECHO) will provide an independent check
  advantage: scalable approach, still a lot of R&D work for $m(\nu_e) = 200$ meV
  new ideas: Project 8 and others
- KATRIN next steps:
  - electromagnetic tests of main spectrometer
  - commissioning of CPS (end of 2013) and WGTS (end of 2014)

Conclusions

the complete picture of neutrino masses is obtained only
by comparing high-precision results from direct neutrino mass searches
with 0νßß experiments and cosmological studies



backup slides

history of tritium ß-decay experiments

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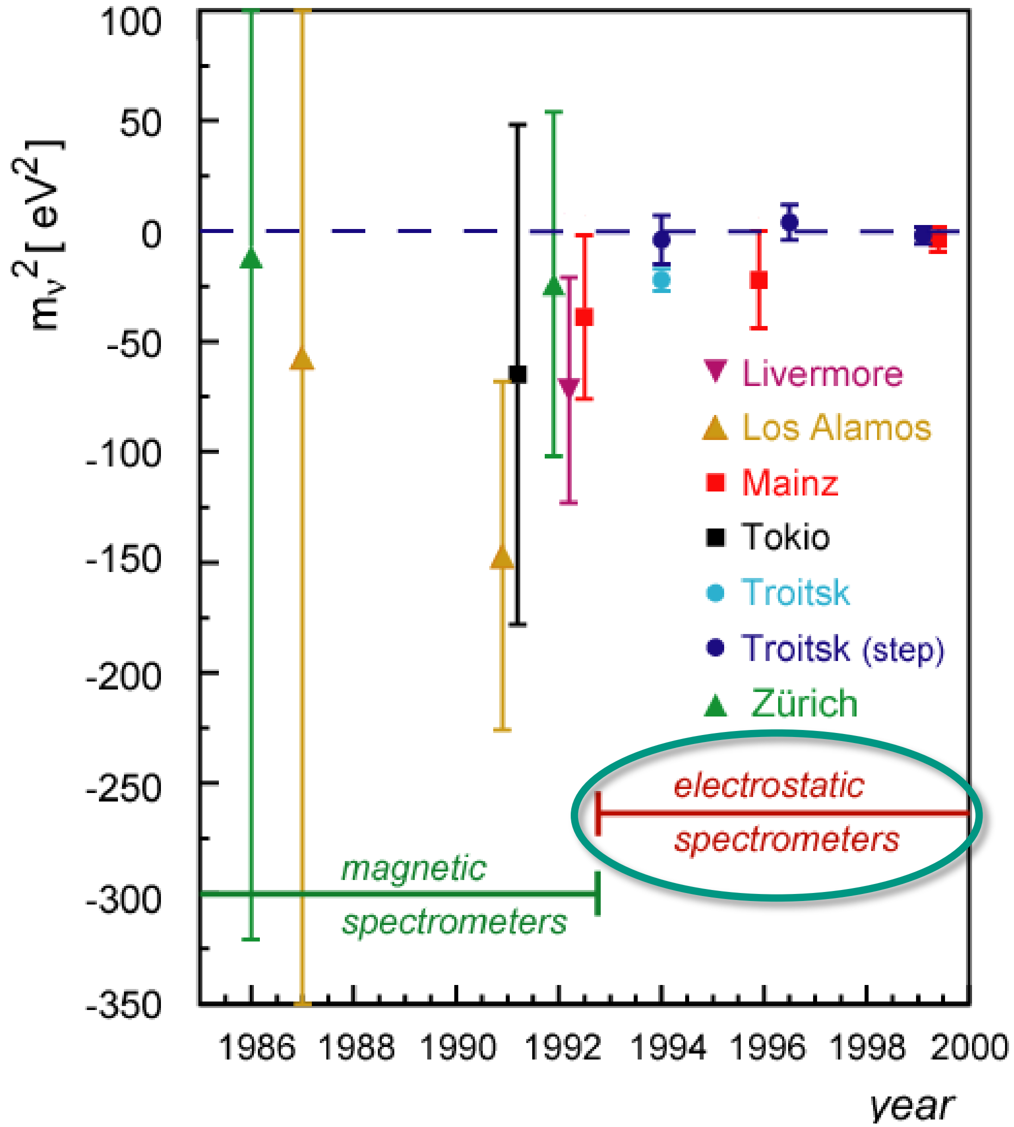
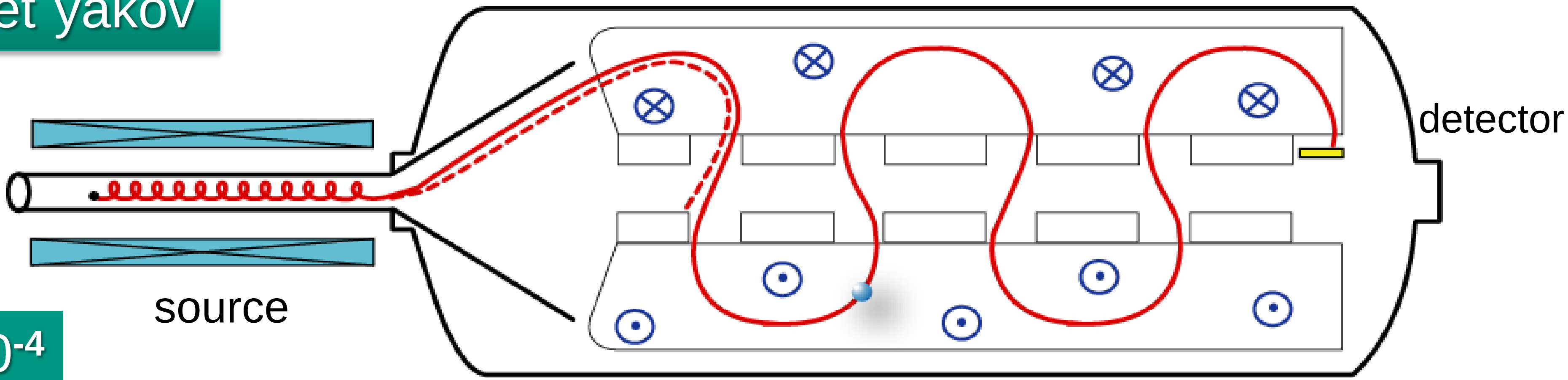
	m_ν
ITEP *T_2 in complex molecule* *magn. spectrometer (Tret'yakov)*	17-40 eV
Los Alamos *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 9.3 eV
Tokio *T - source* *magn. spectrometer (Tret'yakov)*	< 13.1 eV
Livermore *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 7.0 eV
Zürich *T_2 - source impl. on carrier* *magn. spectrometer (Tret'yakov)*	< 11.7 eV
Troitsk (1994-today) *gaseous T_2 - source* *electrostat. spectrometer*	< 2.05 eV
Mainz (1994-today) *frozen T_2 - source* *electrostat. spectrometer*	< 2.3 eV

experimental results for m_ν^2



techniques in ß-spectroscopy

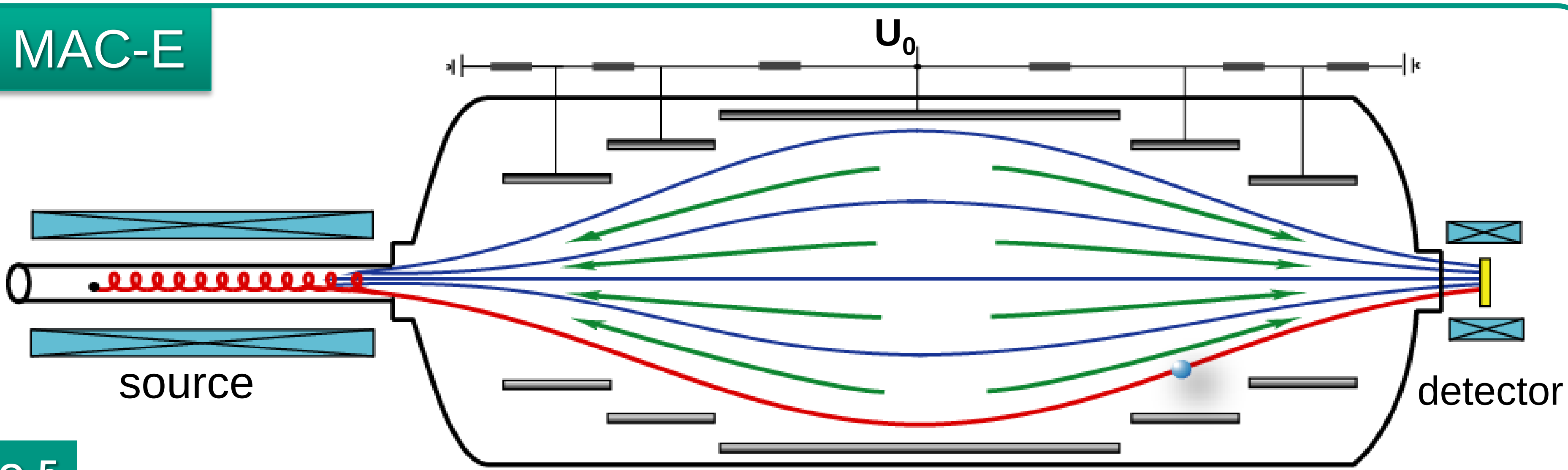
magnetic: Tret´yakov



$\Delta p/p = 7 \times 10^{-4}$
$\delta\Omega = 10^{-3}$

principle: analysis of electron ***momentum*** by magnetic field

electrostatic: MAC-E



$\Delta E/E = 1 \times 10^{-5}$
$\delta\Omega \sim 2\pi$

principle: analysis of electron ***energy*** by electrostatic retardation

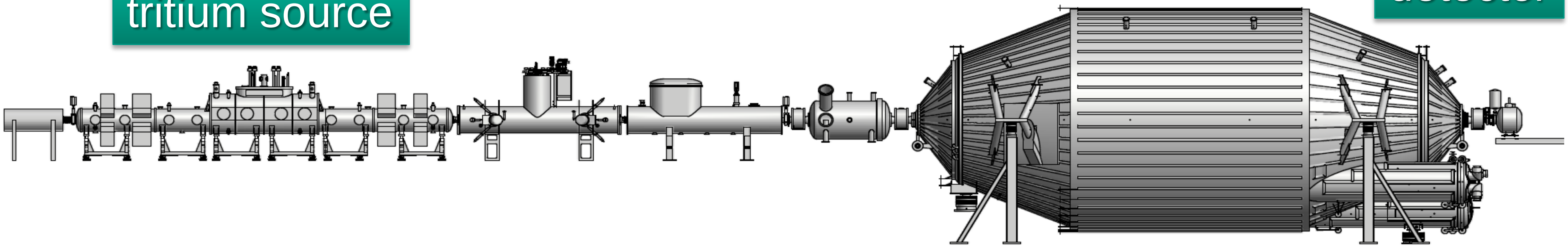
background sources

- ß-decay electrons from areas with different electrostatic potentials
- ß-decays from T^-/T^+ ions, clusters

- X-rays, gammas & electrons from natural radioactivity or scattered ß-decay electrons (beam-halo)

tritium source

detector



spectrometer

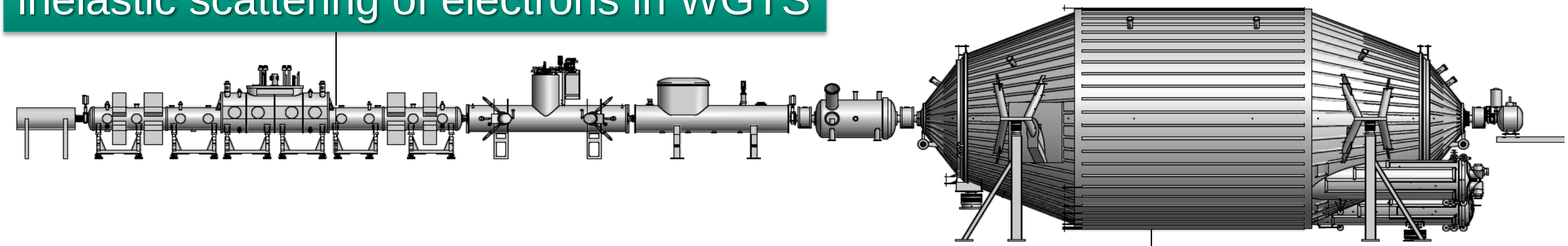
total bg - rate
$R_{bg} < 10^{-2}$ cps

- stored ß-electrons (Penning traps, scattering)
- trapped electrons from $^{219,220}Rn$ α-decays / T_2-ß-decays in central spectrometer area
- cosmic µ-induced secondary electrons

systematic effects – I

- precise measurement of experimental response function
- special unfolding technique to derive cross section σ_{inel} at E = 18.6 keV
- narrow analysis window around E_0 to maximise no-loss electron fraction

inelastic scattering of electrons in WGTS



fluctuations of spectrometer retarding HV potential

$$\Delta m_\nu^2 = -2\sigma_{syst}^2$$

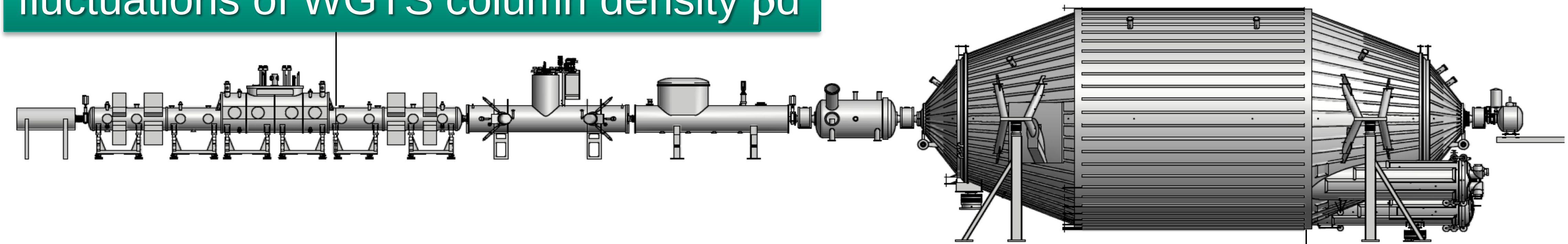
general relation for tritium-ß-decay

- stabilisation of HV: precision HV units
- monitoring of HV:
  1. ultra-stable HV-divider & precise digital voltmeter
  2. Rb/Kr-source & separate monitor spectrometer

systematic effects – II

- stabilisation of ρd: injection pressure, beam tube T = 27K, Laser-Raman
- cyclic scans of ρd: high-intensity electron gun
- monitoring of ρd: rear detector/system, forward beam monitor

fluctuations of WGTS column density ρd



hysteresis effects from HV and ρd scanning

- minimisation of trapped particles from scanning of column density ρd
- optimised scanning strategy
- randomized steps of HV

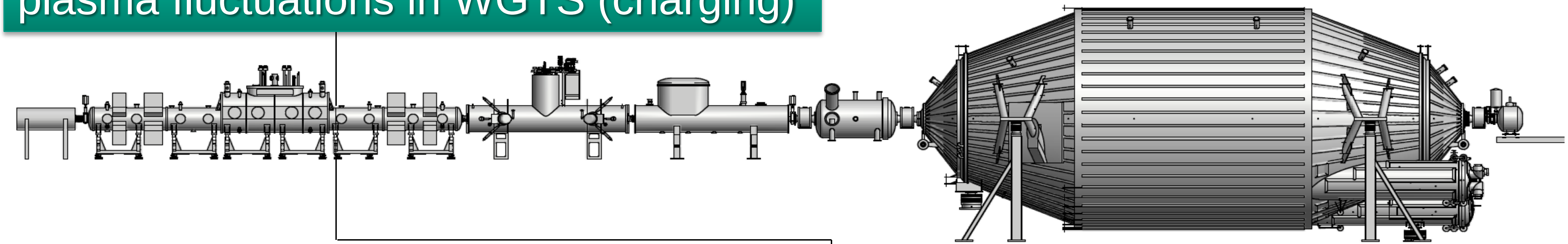
$$\Delta m_\nu^2 = -2\sigma_{syst}^2$$

general relation for tritium-ß-decay

systematic effects – III

- stabilisation of plasma: neutralise ions (Φ < 20 mV), injection of meV-e^-
- cyclic scans of plasma: high-intensity electron gun runs at different ρd
- monitoring of plasma: rear detector/system

plasma fluctuations in WGTS (charging)



final states (molecular excitations in $^3H^3He$)

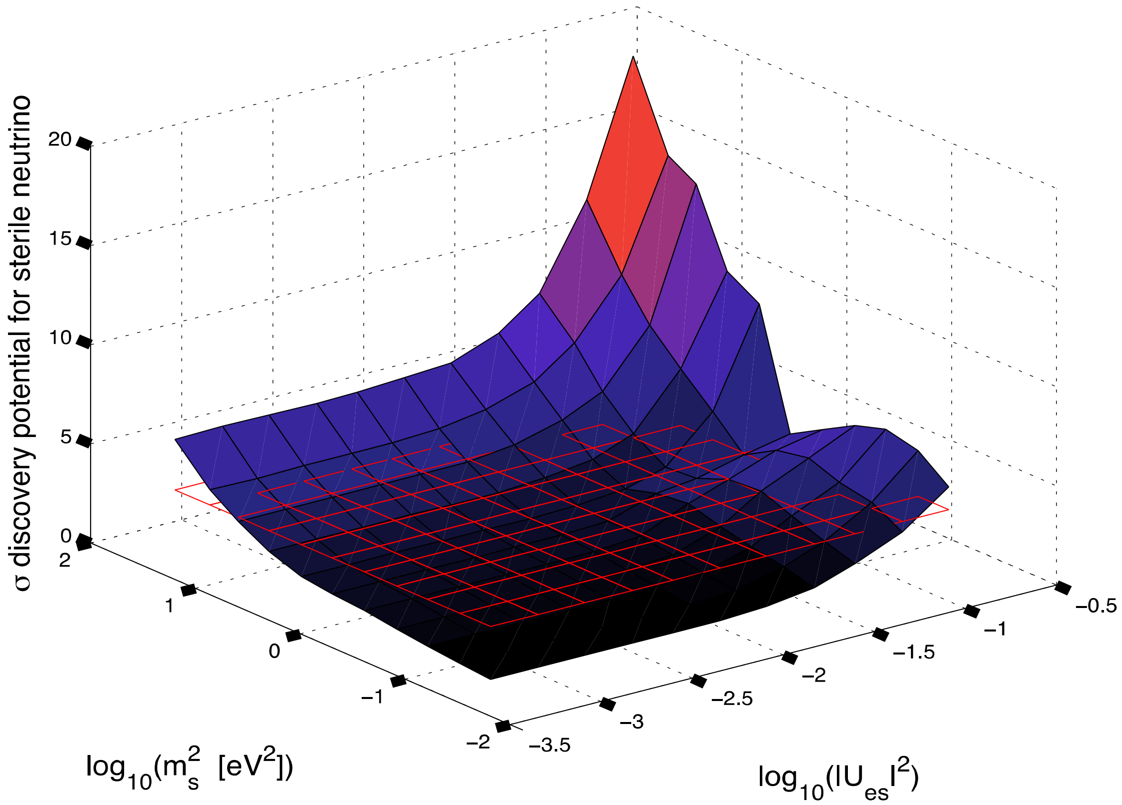
$$\Delta m_\nu^2 = -2\sigma_{syst}^2$$

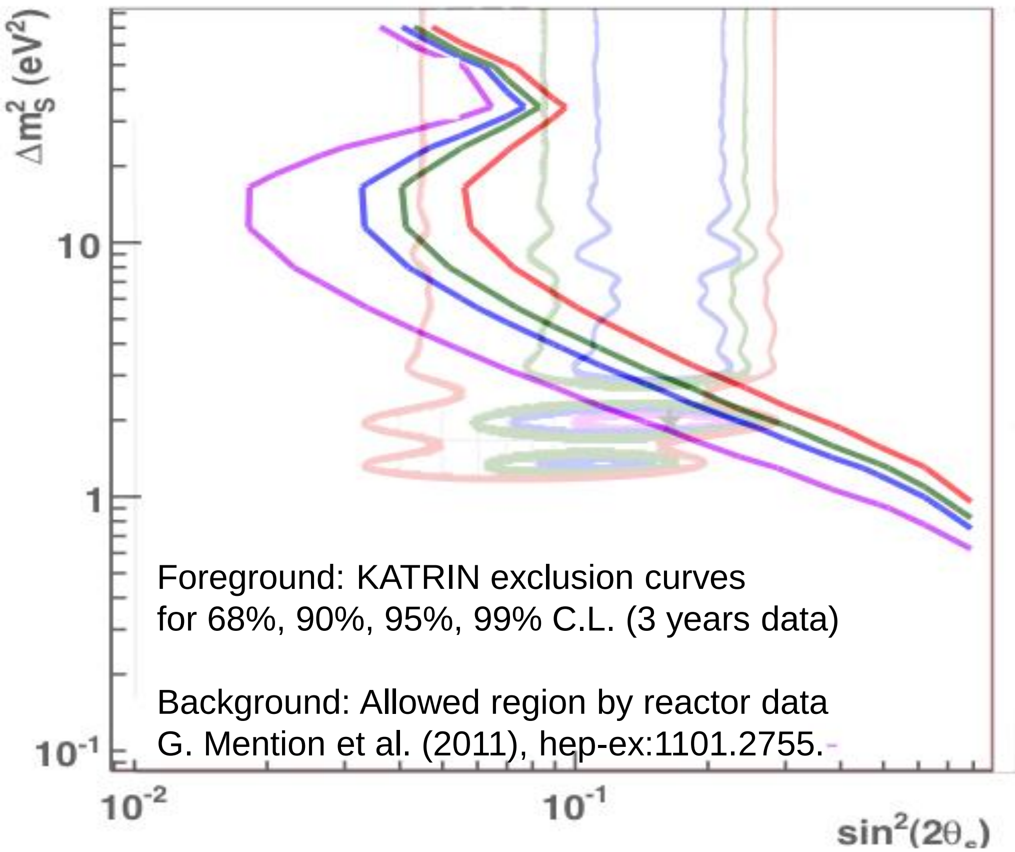
general relation for tritium-ß-decay

- reliable quantum-chemical calculations for all isotopologues available (up to continuum)
- very good agreement among the different calculations, sum rules correct

sterile neutrinos: (sub-)eV scale

J. A. Formaggio, J. Barret, arXiv:1105.1326





- Single β decay experiments (MARE, Project8, KATRIN) can detect a sterile neutrinos signature.
- KATRIN: for $m_{sterile}$ > 3.2 eV a 3σ detection could be made for any mixing angle.
- Single β decay offers a complementary input, independent of CP phases.

- Use TES arrays with 32x32 pixels
- Resolution 1 – 2 eV FWHM
- Need 5 TES arrays for 0.2 eV/c^2 sensitivity
  - Makes **5000 pixels** (vs. 50000 for Re)

- ^{163}Ho production has been demonstrated
- Embedding process is under investigation
- Readout developed and tested as prototype
- Next: TDR for funding

F. Gatti, ISAPP 2011 and
J Low Temp Phys (2008) 151