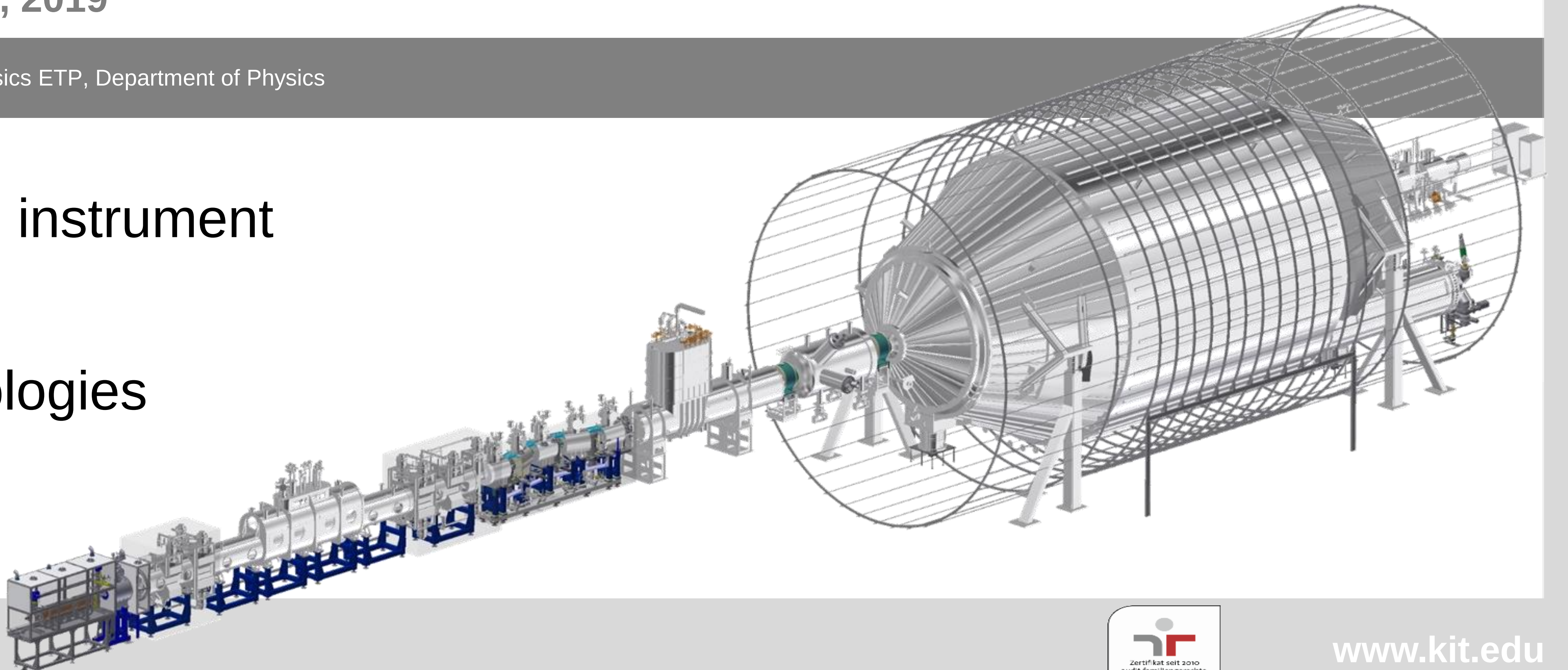
Karlsruher Institut für Technologie

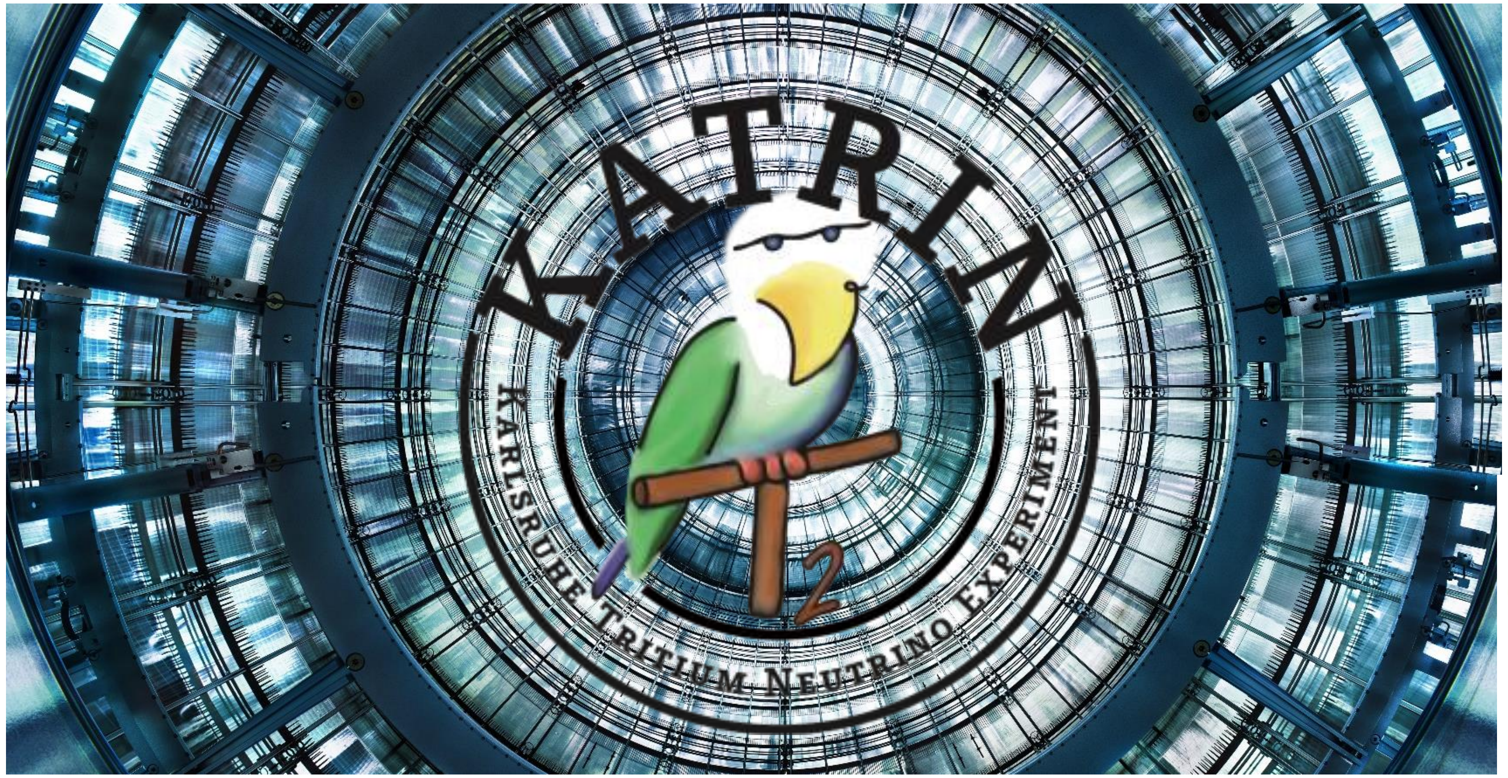

# KATRIN experiment – technologies at the cutting edge

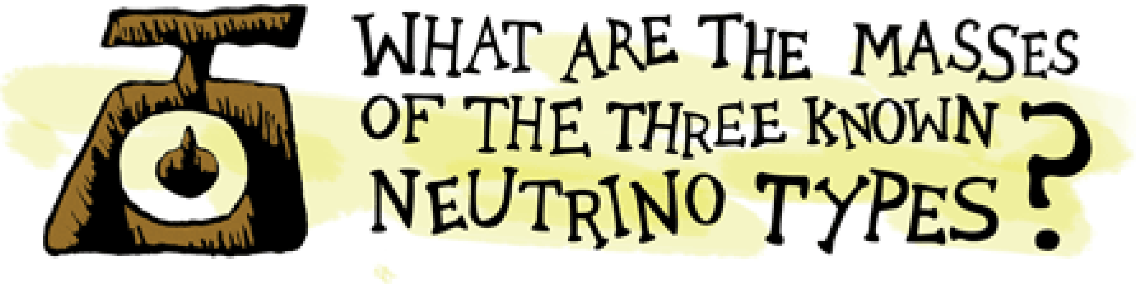
## Science Colloquium "First Neutrino Mass Result from KATRIN"
## KIT, FTU Aula, September 16, 2019

Guido Drexlin, Institute of Experimental Particle Physics ETP, Department of Physics

- KATRIN: a high-tech instrument
- source technologies
- spectrometer technologies
- conclusion



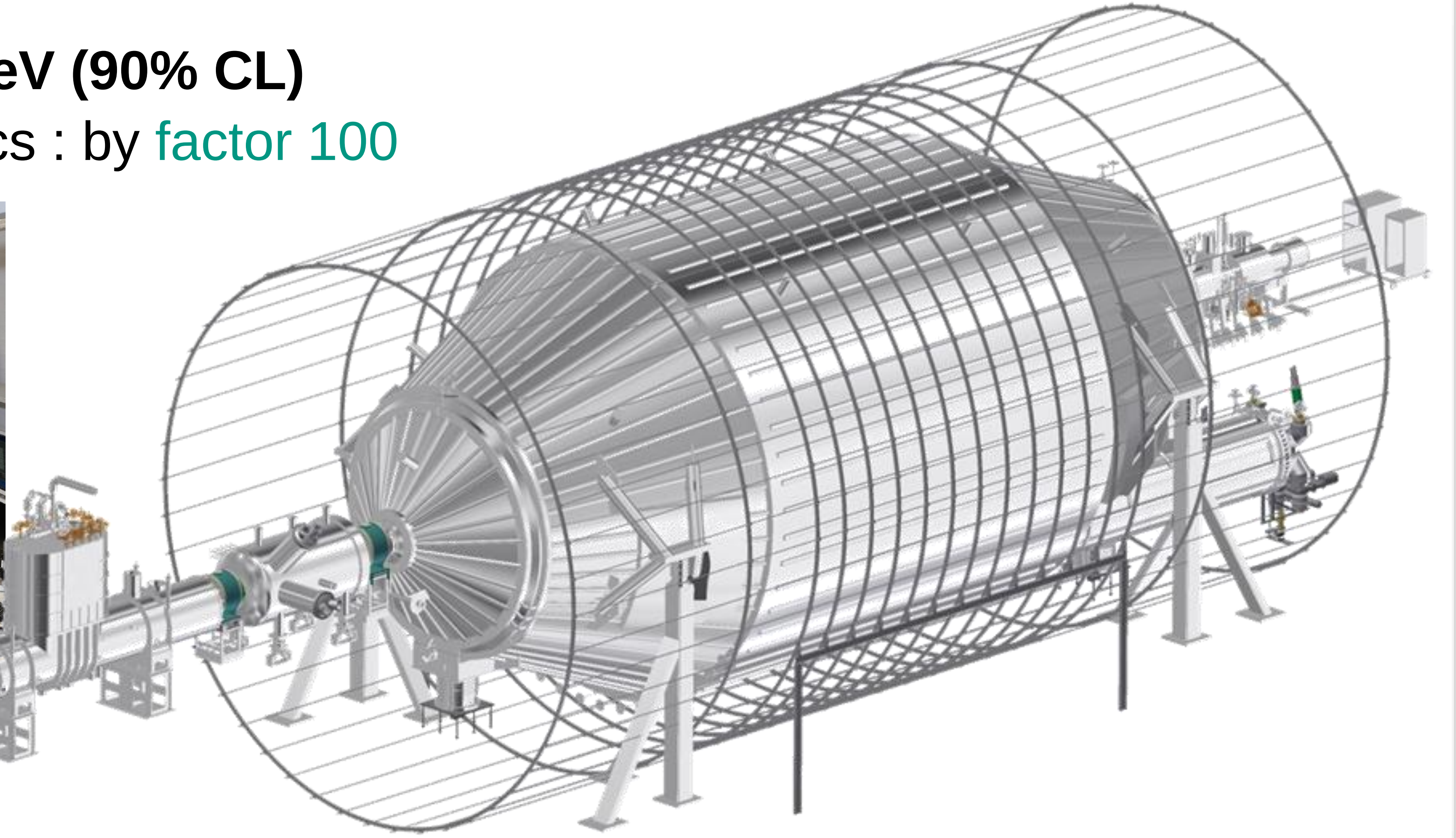


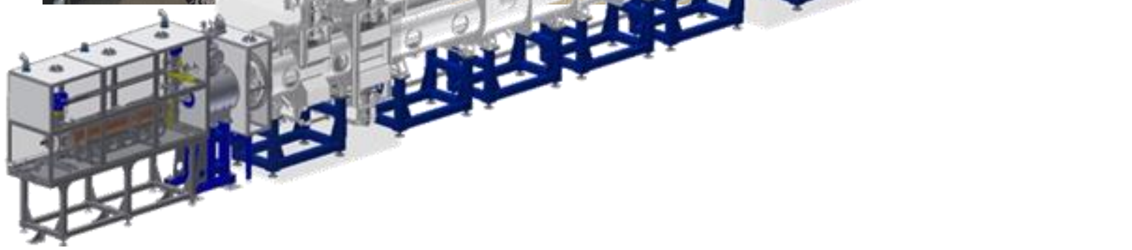




# KATRIN – A HIGH TECH INSTRUMENT

# KATRIN overview

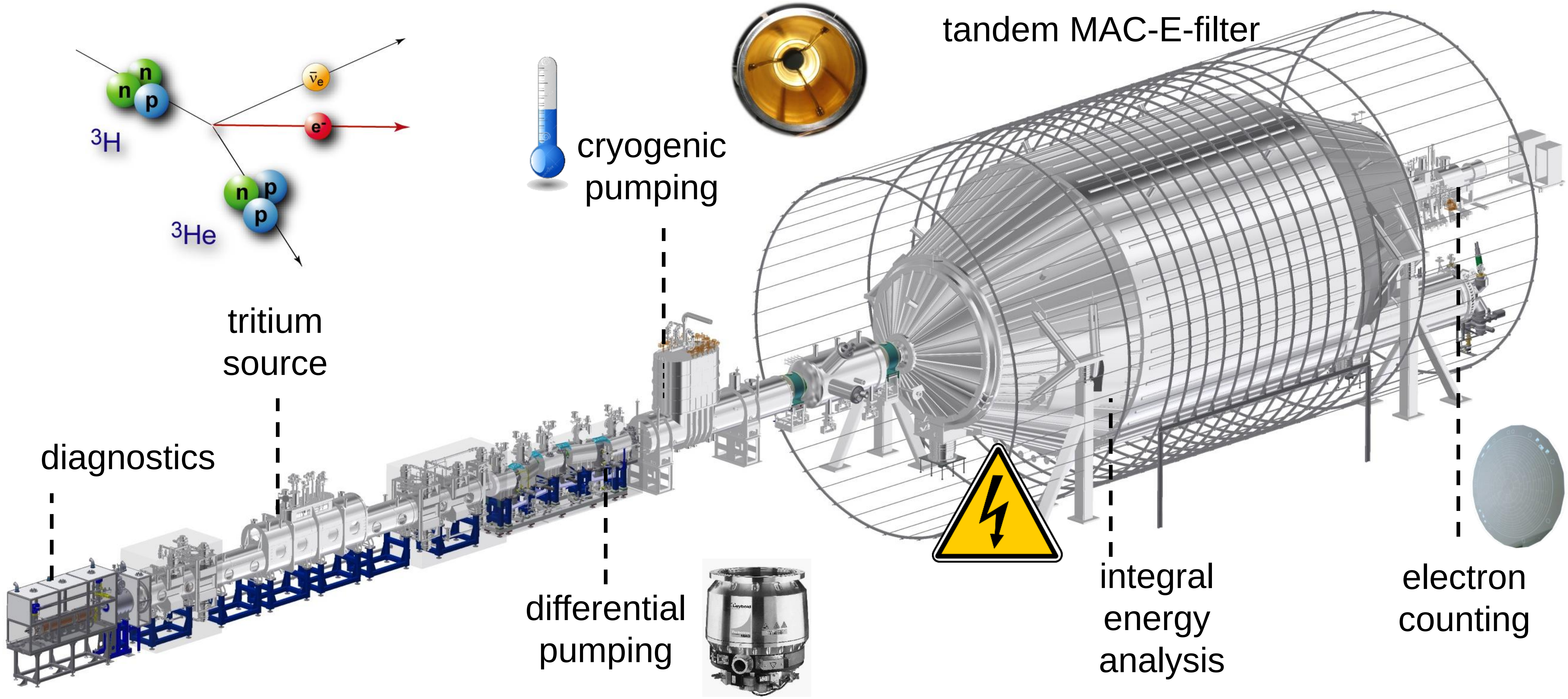
- **world´s most precise scale**:
  - measure neutrino mass down to **0.2 eV (90% CL)**
  - improve statistics / reduce systematics : by factor 100



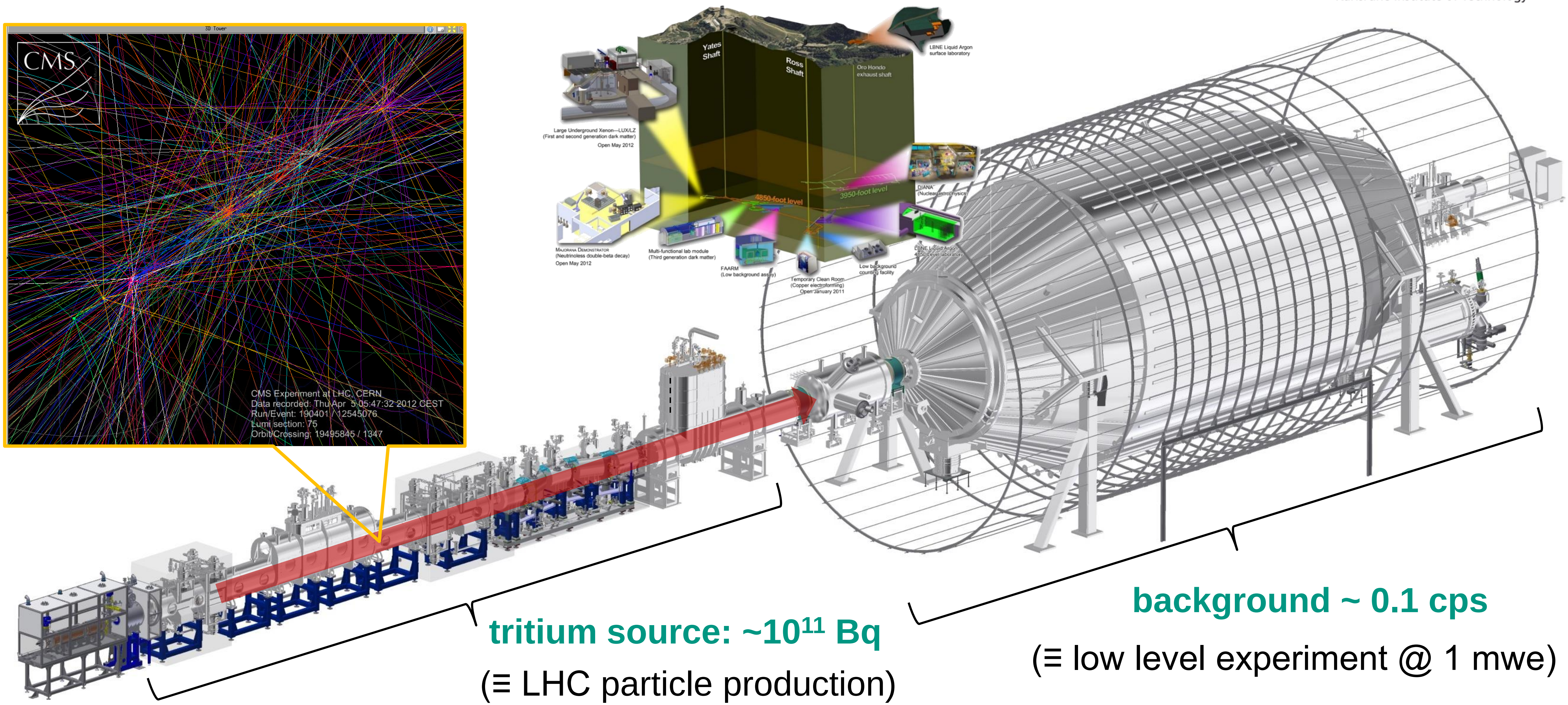


- **enabling technologies**:
  - we have pioneered many cutting-edge technologies
  - continued R&D works to further improve science reach

# KATRIN overview: 70 m long beamline



# KATRIN challenges – particle intensities




**tritium source: ~$10^{11}$ Bq**

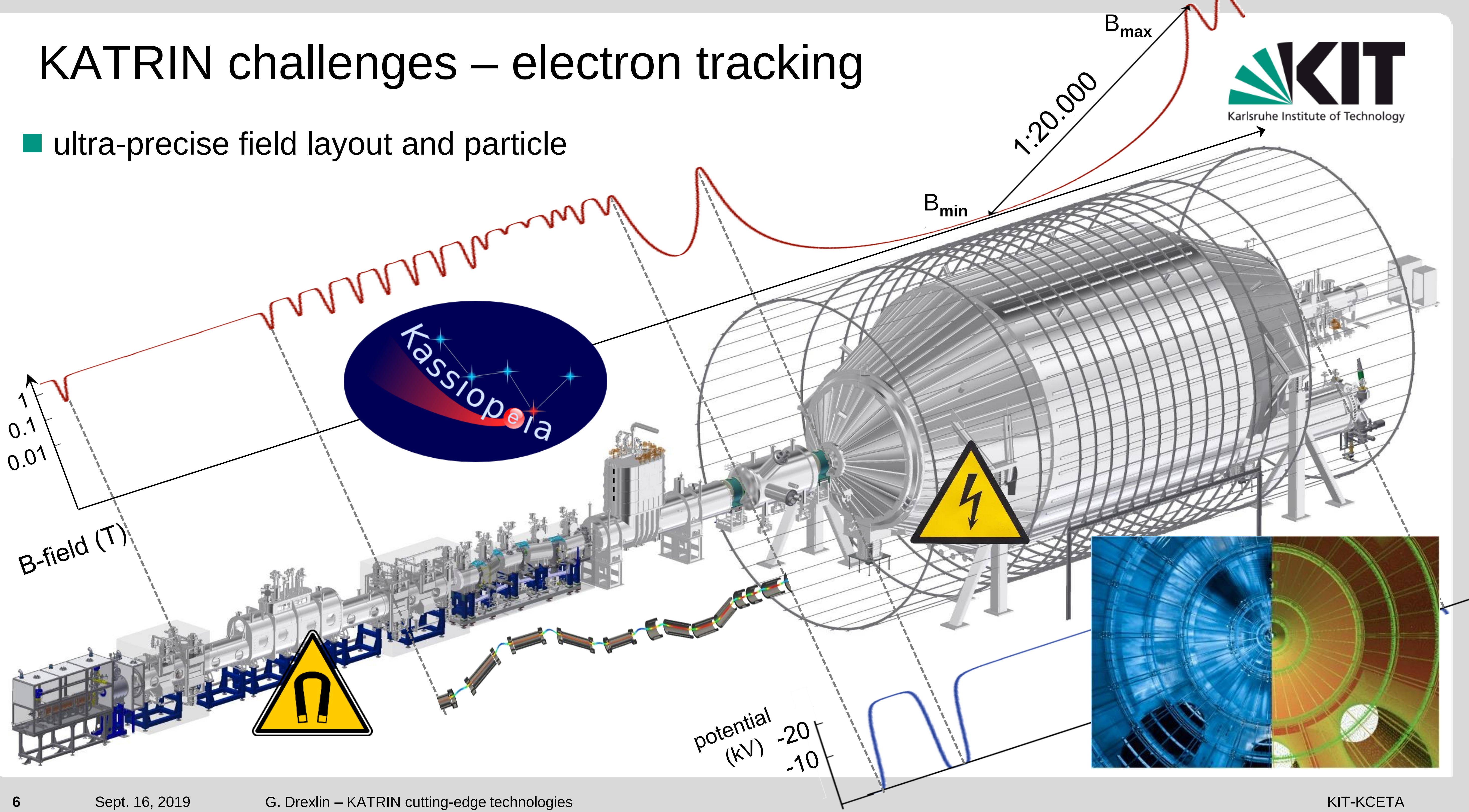
(≡ LHC particle production)

**background ~ 0.1 cps**

(≡ low level experiment @ 1 mwe)

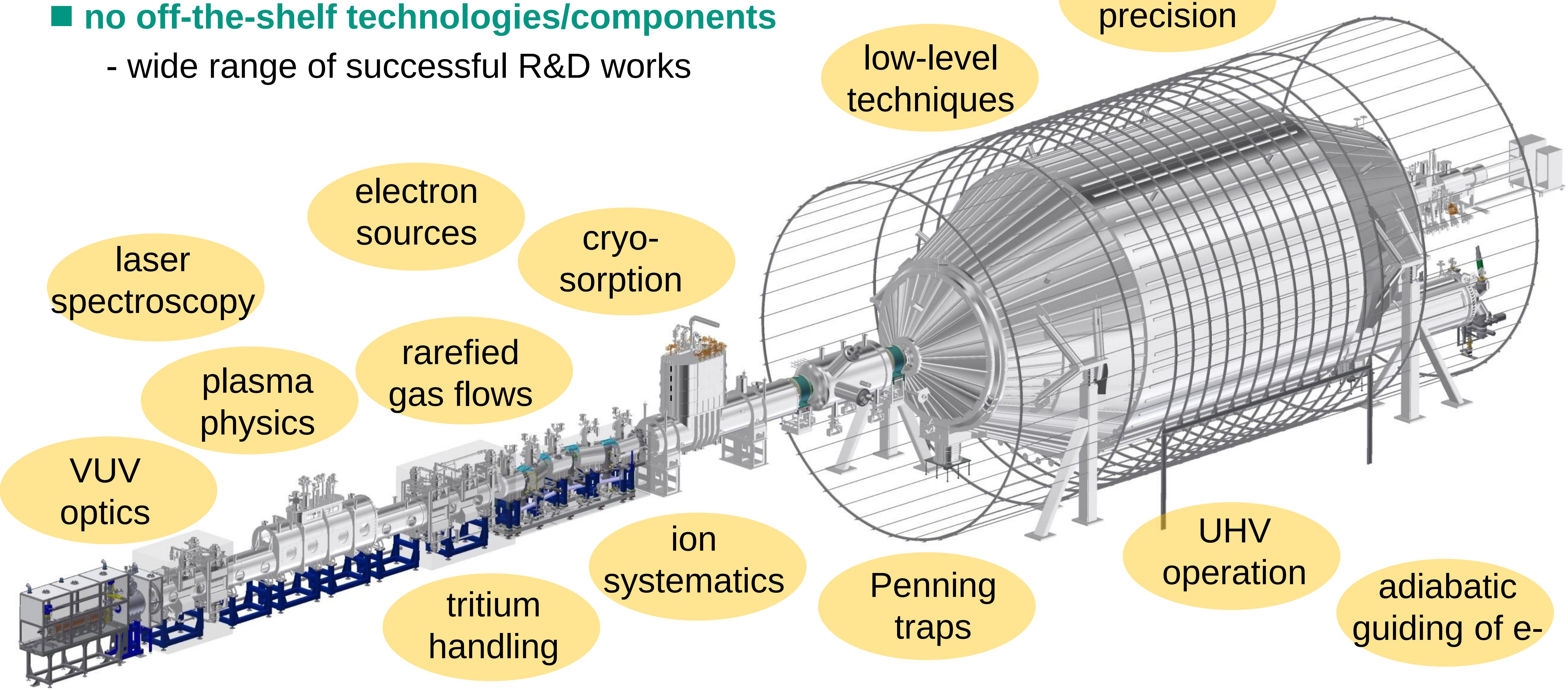
# KATRIN challenges – electron tracking

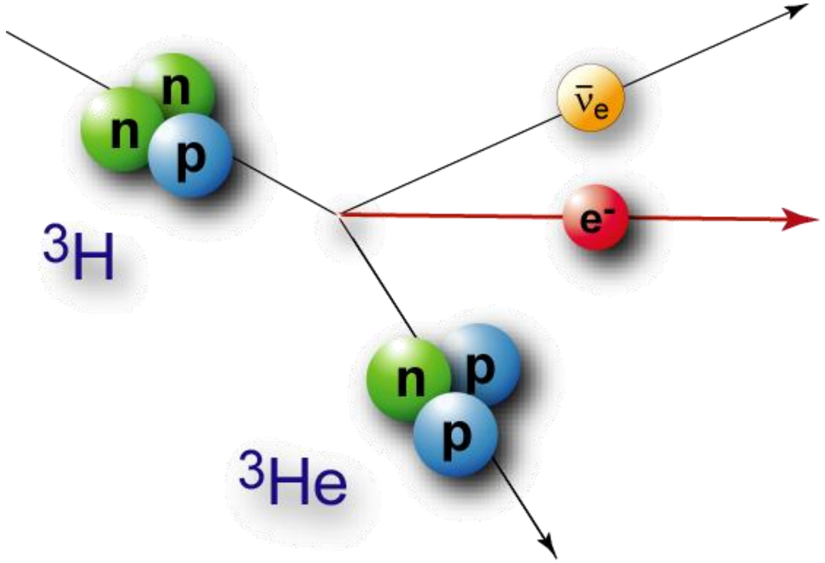
- ultra-precise field layout and particle



# KATRIN: cutting-edge echnologies

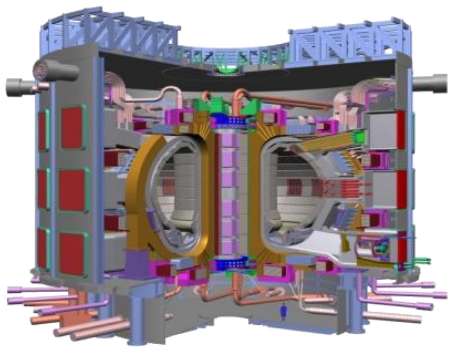
- **no off-the-shelf technologies/components**
  - wide range of successful R&D works



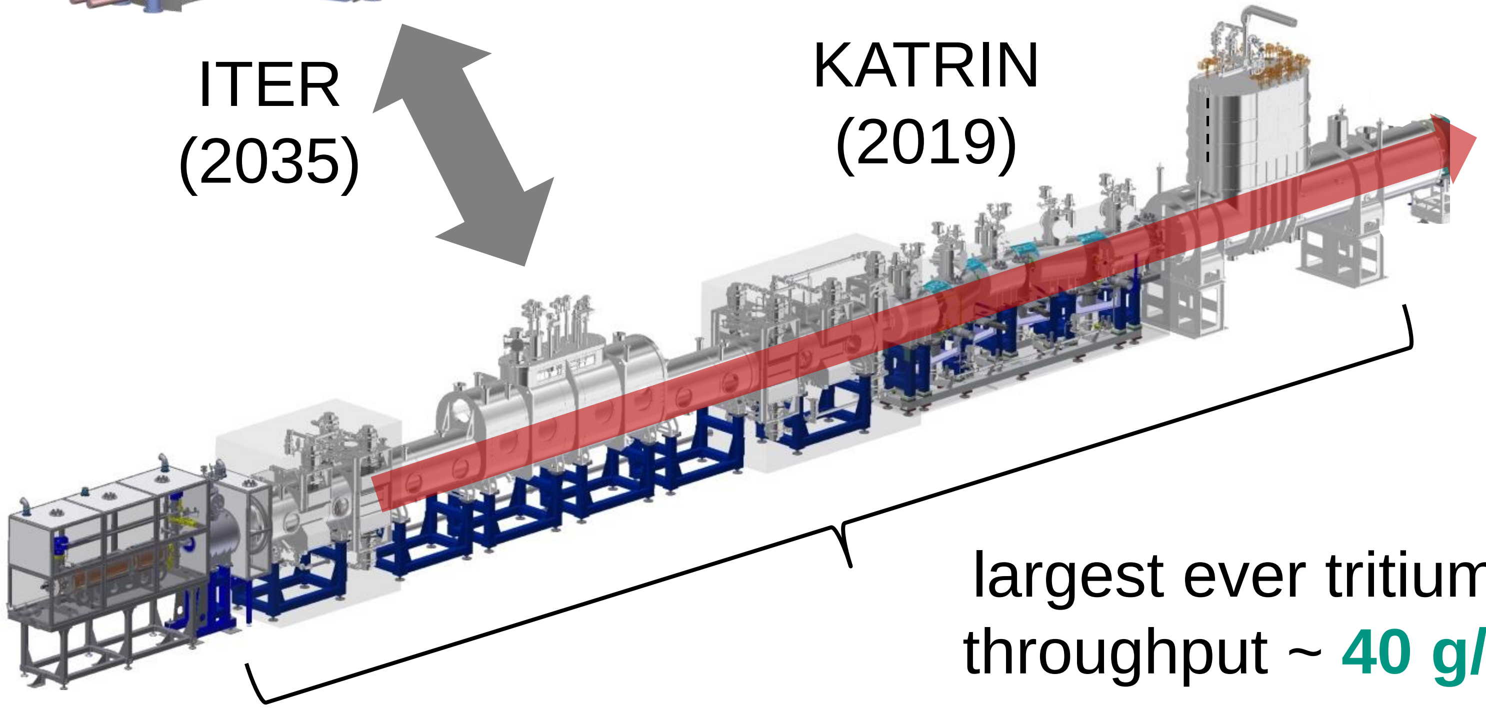




# SOURCE TECHNOLOGIES

# closed tritium cycle at 40g/d throughput

ITER
(2035)



KATRIN
(2019)

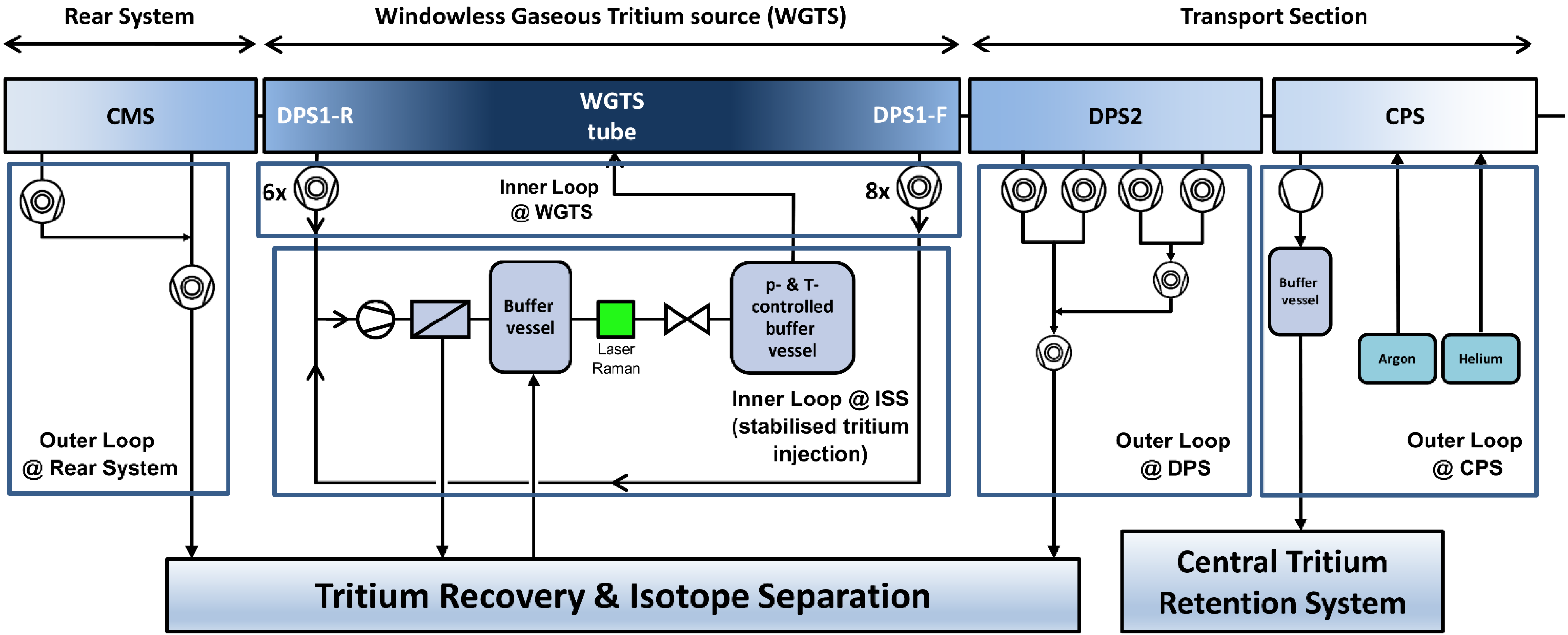
largest ever tritium throughput ~ **40 g/d**

**$A_{\beta}$ = $10^{11}$ ß-decay electrons / s**
**$\rho d$ = 5 · $10^{17}$ molecules / $cm^2$**

- **TLK** – a unique research infrastructure
  30+ scientists, engineers, technicians, PhDs & students:
  ⇨ **high-purity tritium at high throughput**

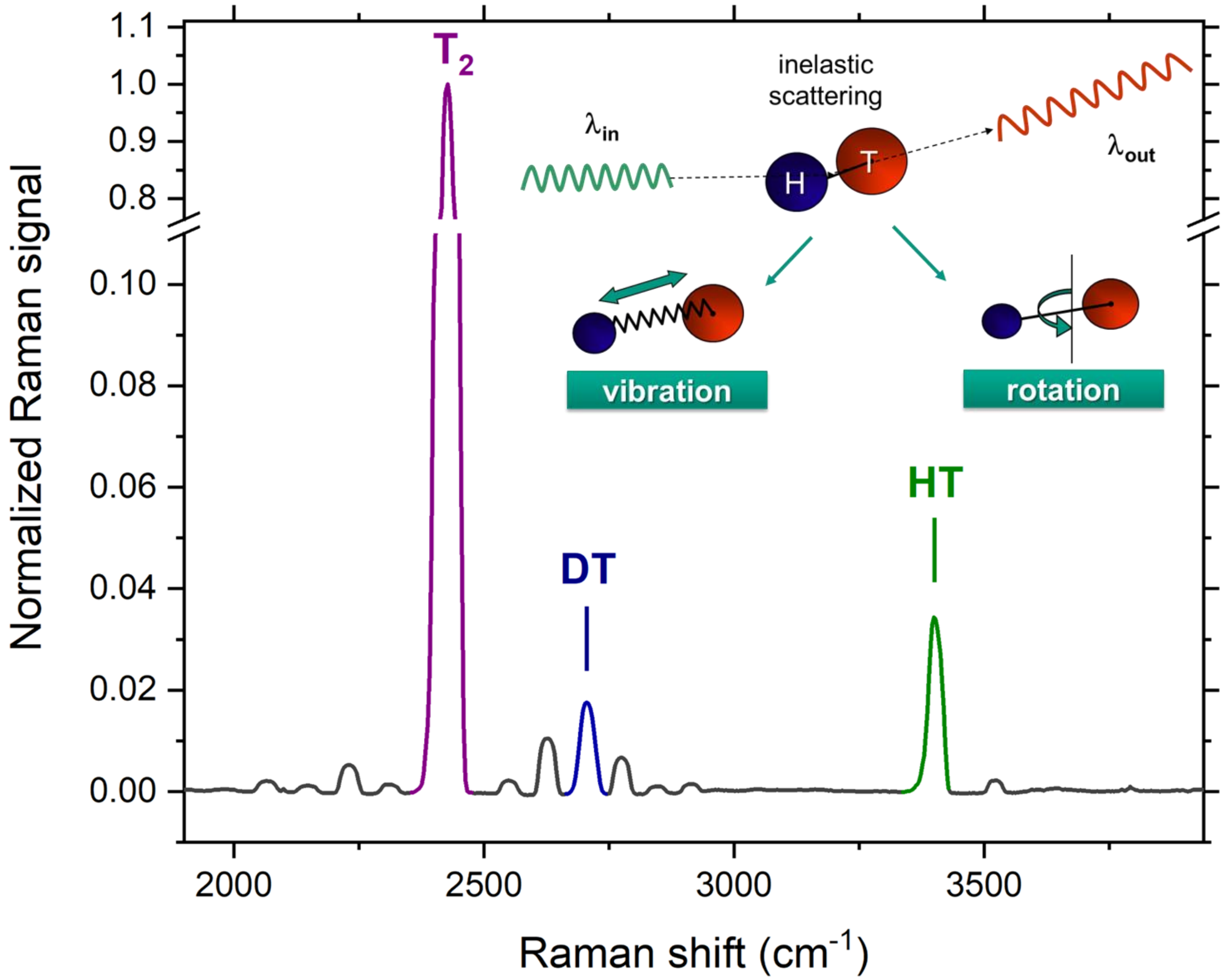
# a closed tritium cycle of 40g/day

- **tritium technologies for high-purity tritium at unprecedented throughput**

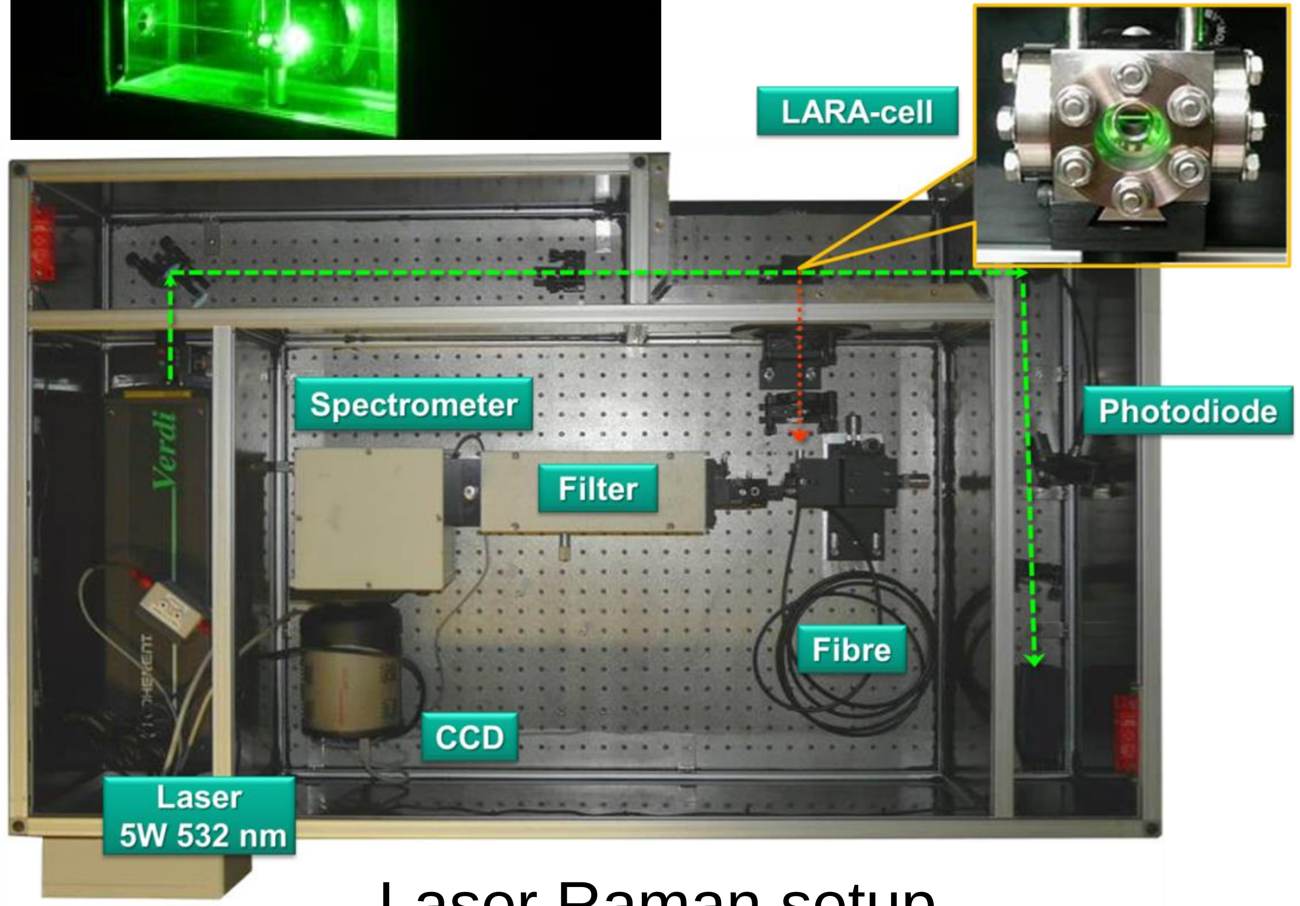


# Laser Raman spectroscopy for hydrogen isotopologues

- **Laser Raman (LARA) spectroscopxy**
  - sampling of hydrogen isotopologes
  - $\Delta t < 60$ s for 0.1% precision ☑







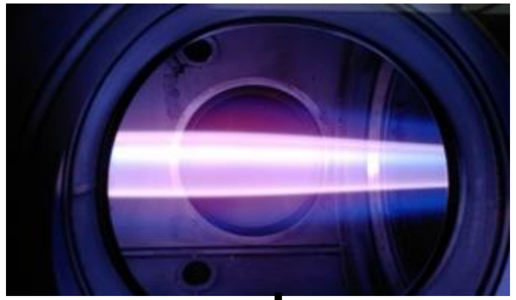

Laser Raman setup

# source stability: overview

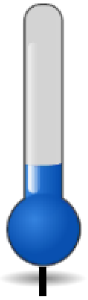
injection pressure (± 0.1%)
isotopic content (0.1% in < 60 s)

source potential (mV-scale)

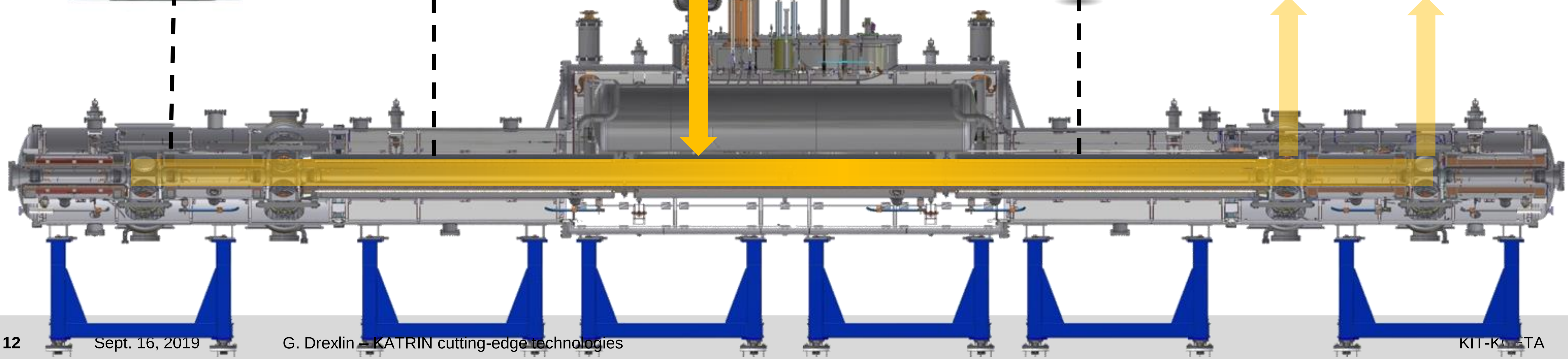

plasma properties ($10^{11}$ T-ions/s)




beamtube temperature (± 0.1%) (27-100 K)

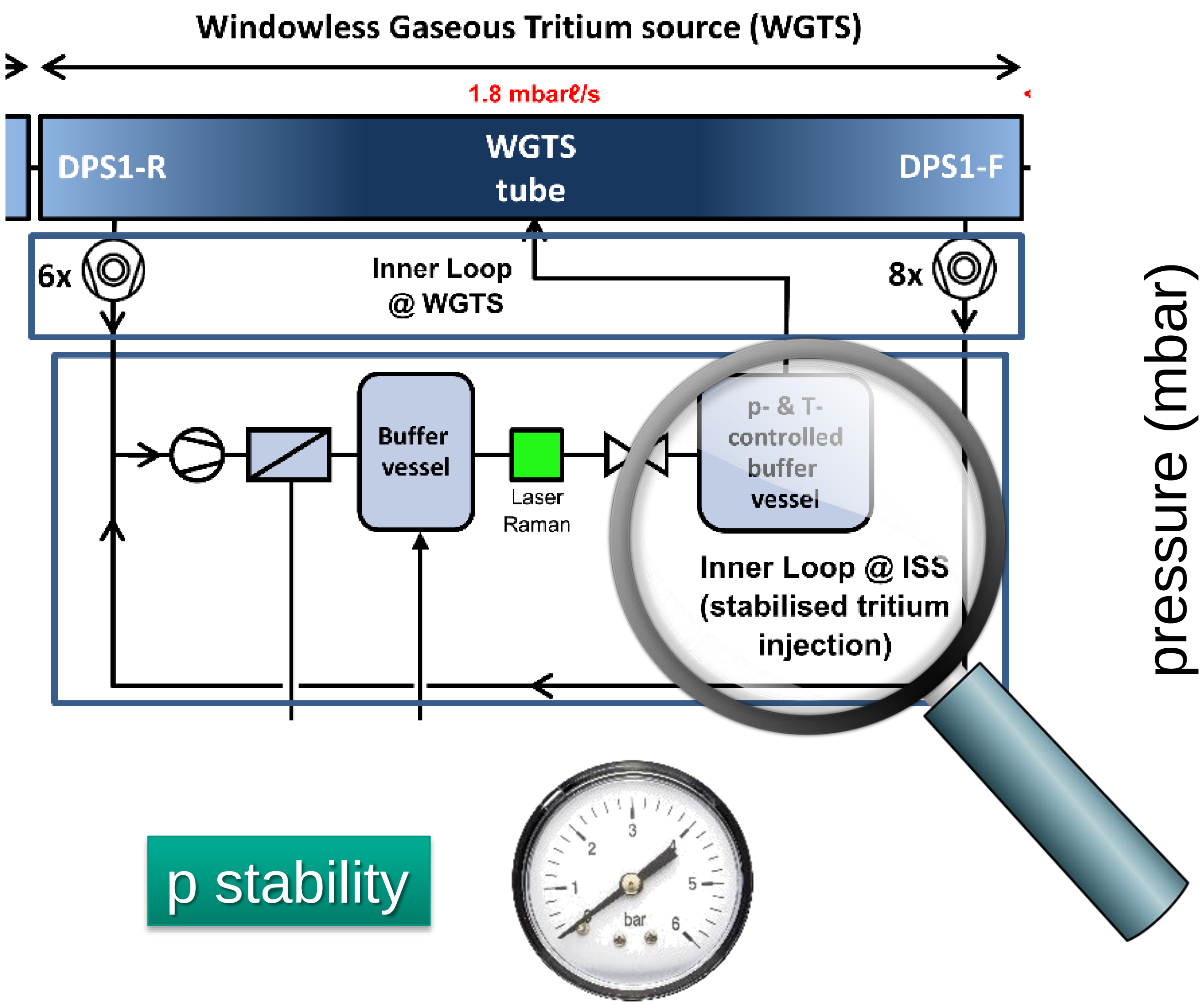


active pumping (12 TMPs)



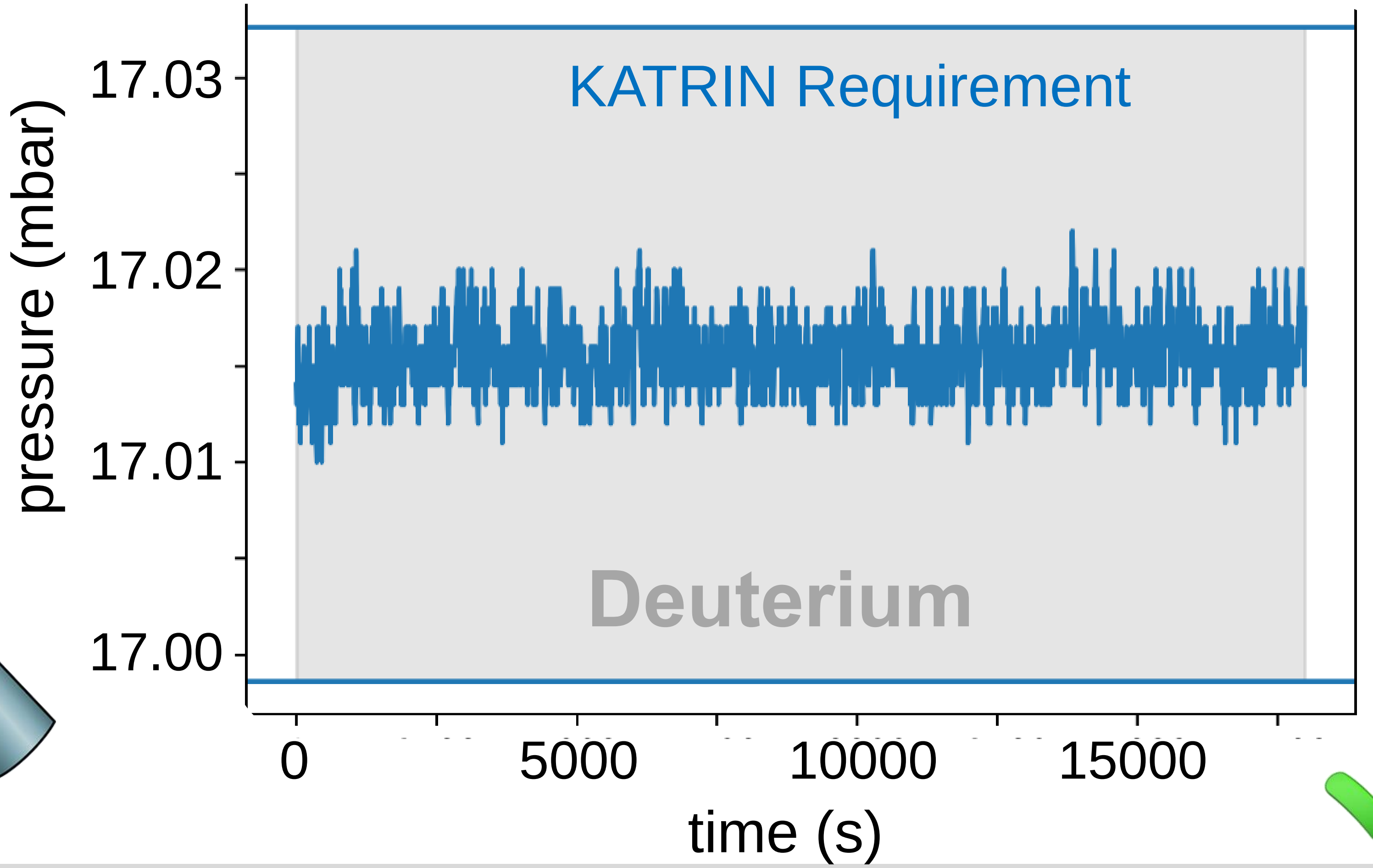
# injection pressure stability

- **loop system:** exceeds specifications for D2, excellent pressure stability ⇨ **stable ρd**



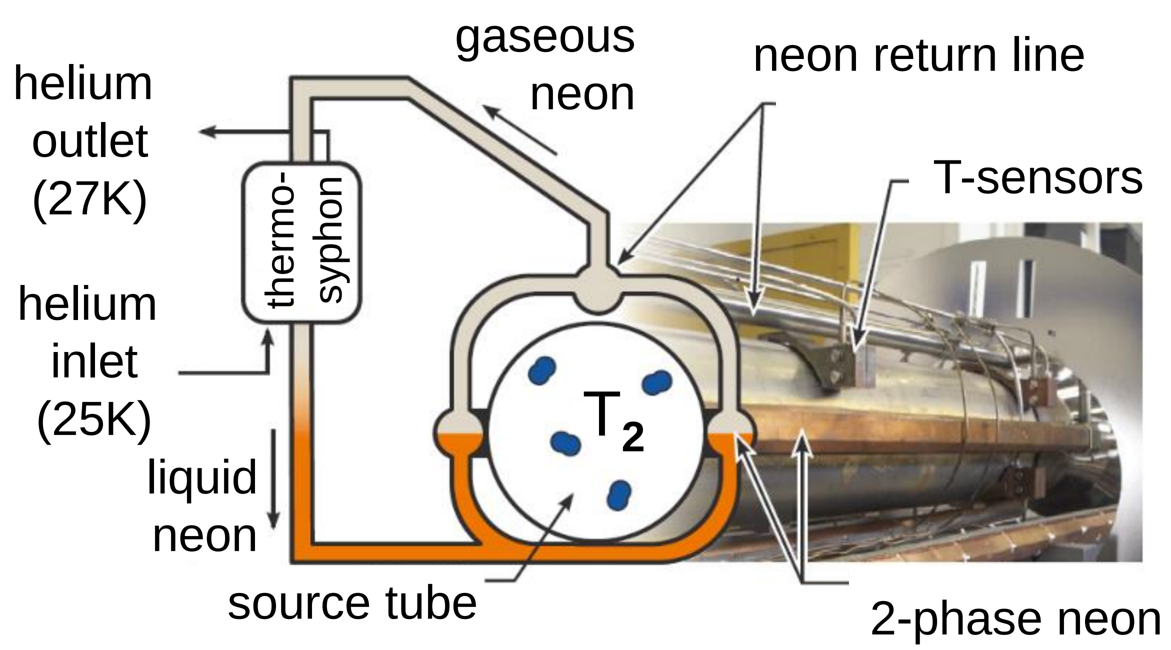

specified: $\Delta p = \pm 0.1\% / h$

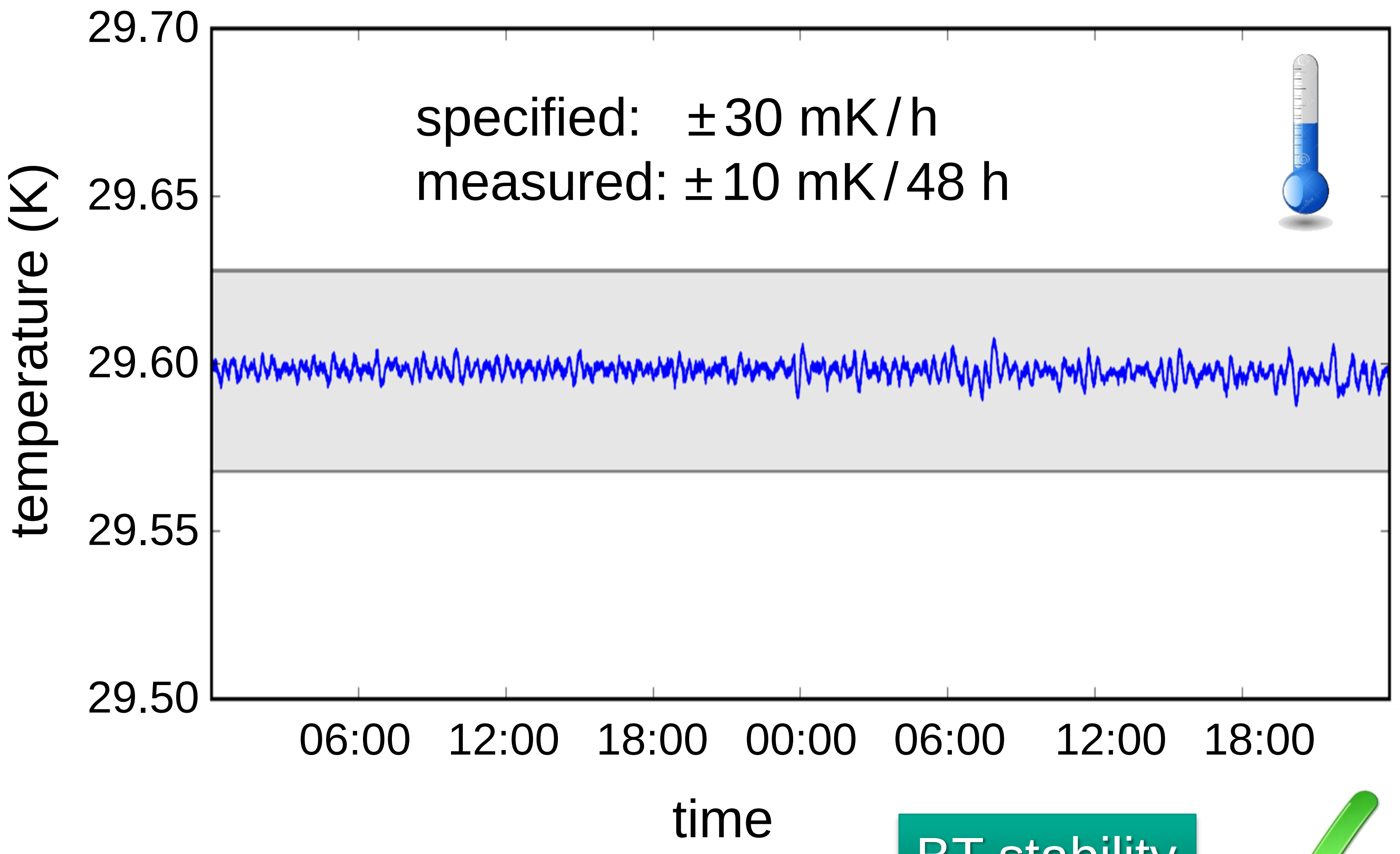
measured: $\Delta p < \pm 0.1\%$ over longer times



# beam tube temperature

- **beam tube cooling system**: exceeds specifications, excellent temperature stability
  ⇨ stable column density ρd in source tube

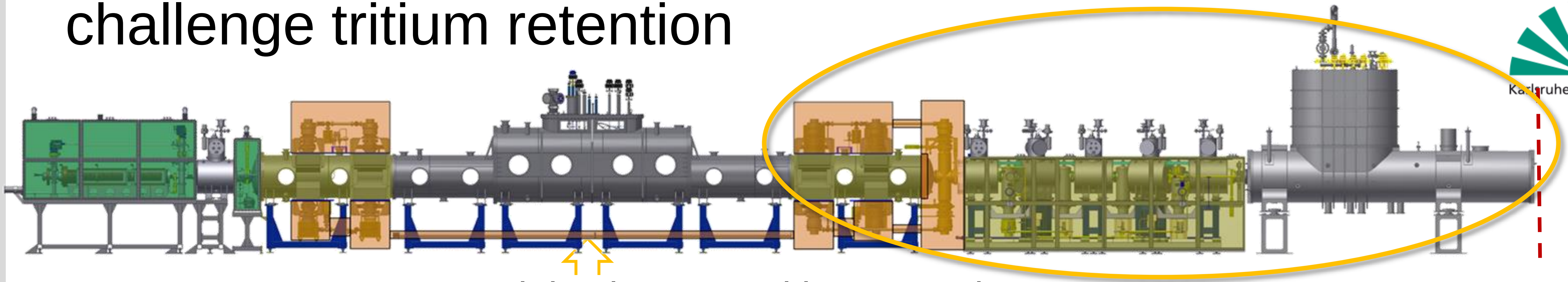



- long-term stable cryogenic operation
- thermosyphon principle

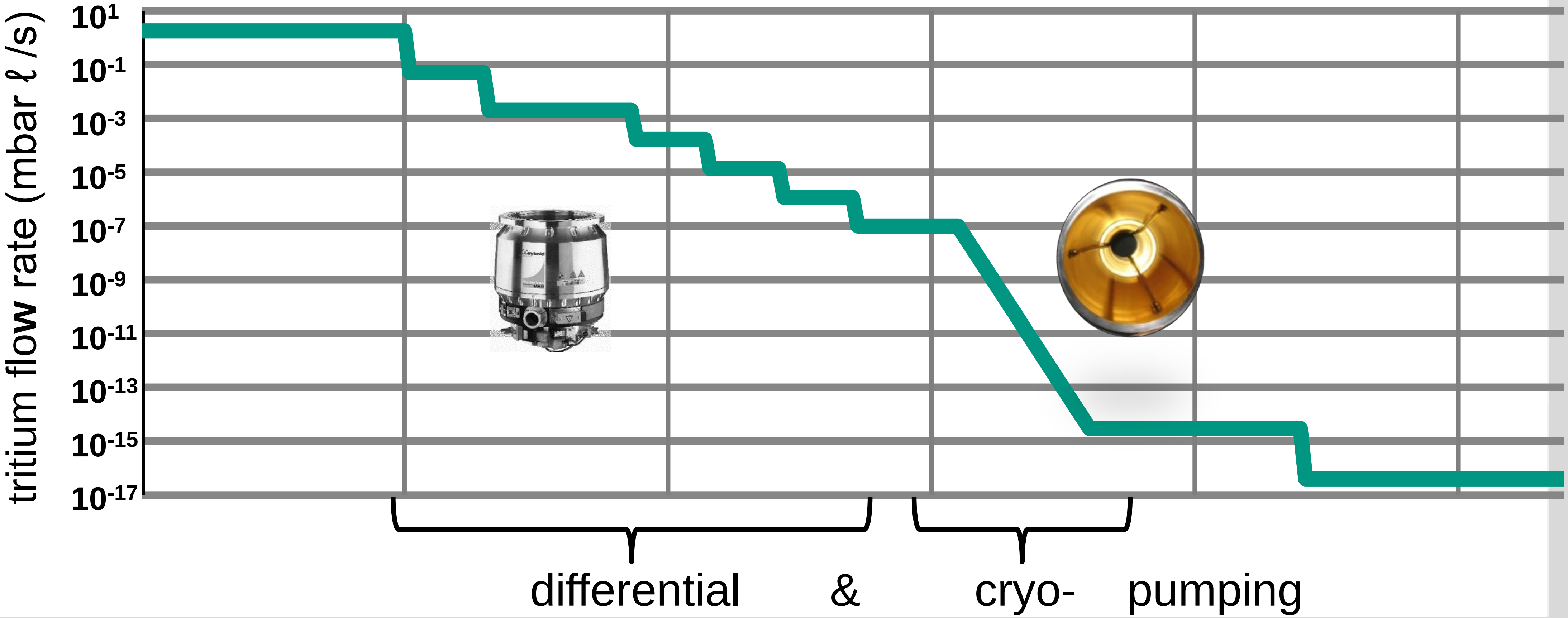
BT stability ✓

# challenge tritium retention




- overall retention
  **factor > $10^{14}$**

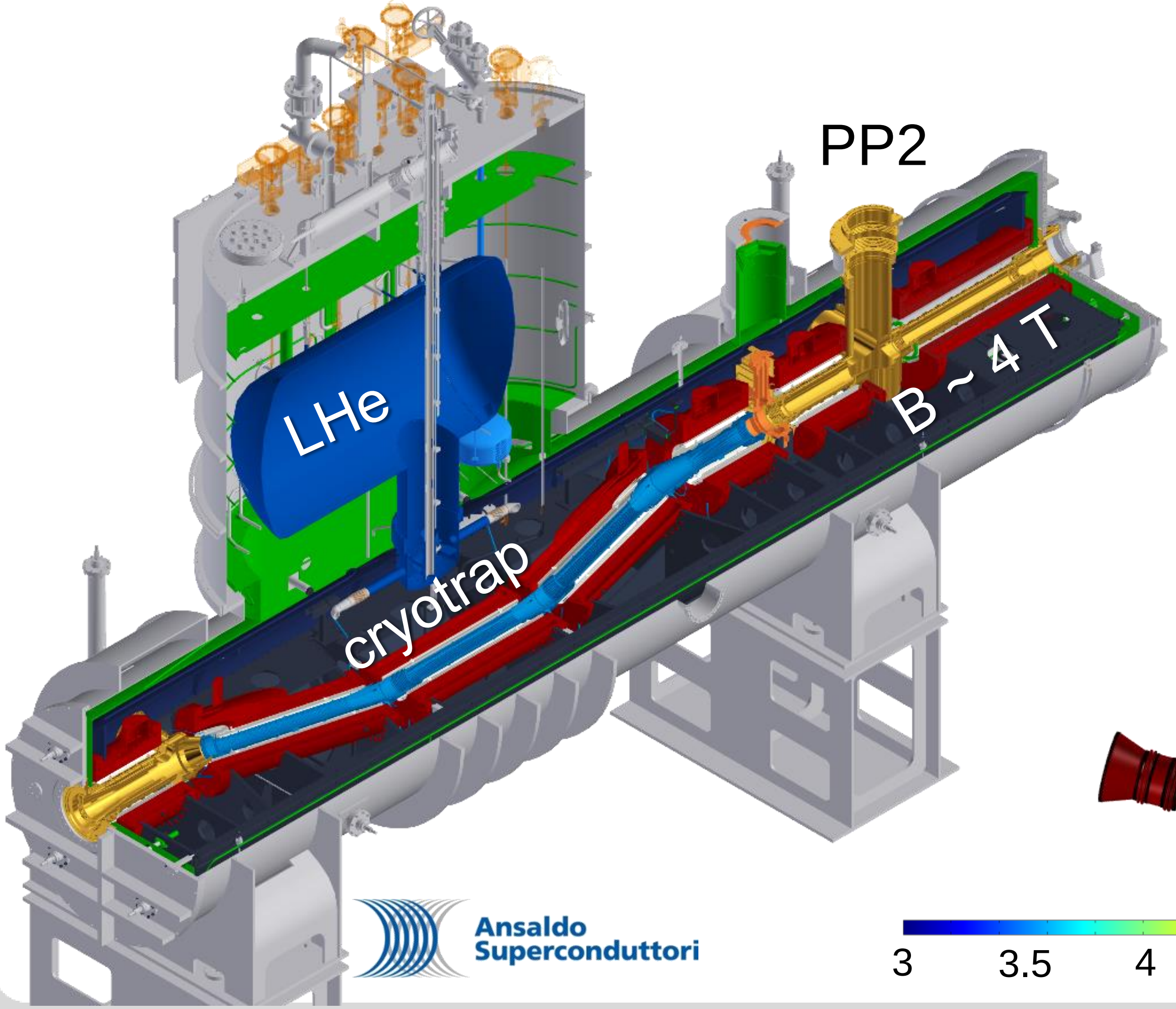
for overall **factor > $10^{14}$**

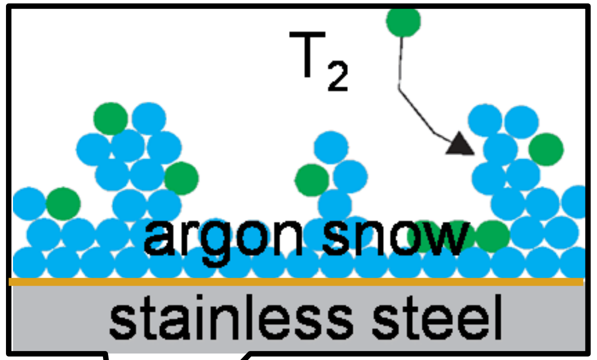



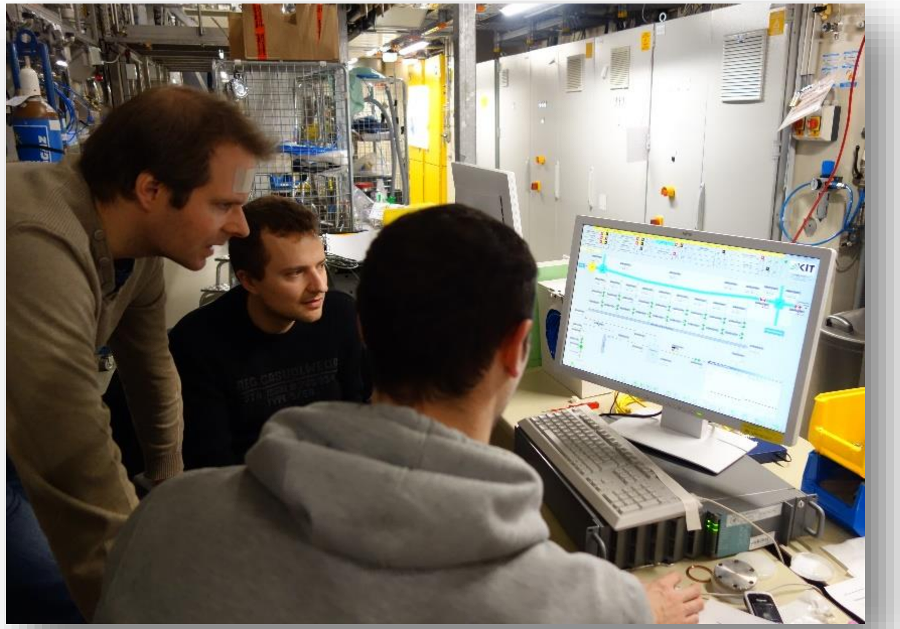

theoretical expecation
from TDR

# a lage-scale cryotrap

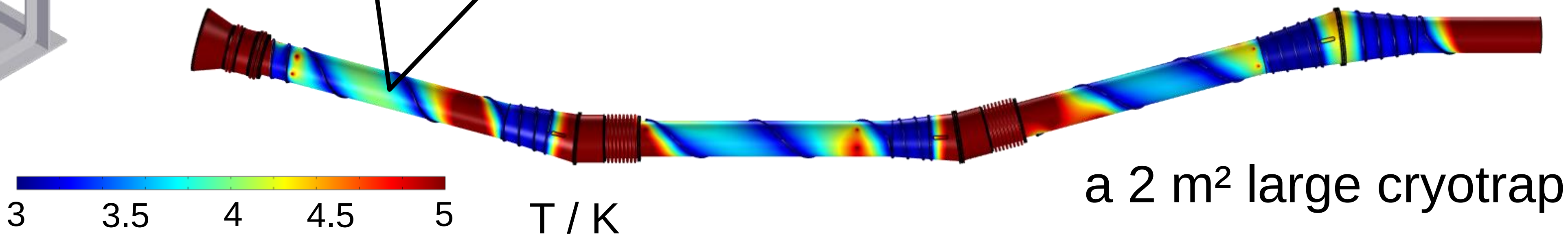
- **cryogenic pumping section CPS:**
  - 3K section with Ar-frost layer → > $10^7$ reduction of HT/$T_2$



$E_B$ ~ 1590 J/mol
multi-year capacity




a 2 m² large cryotrap

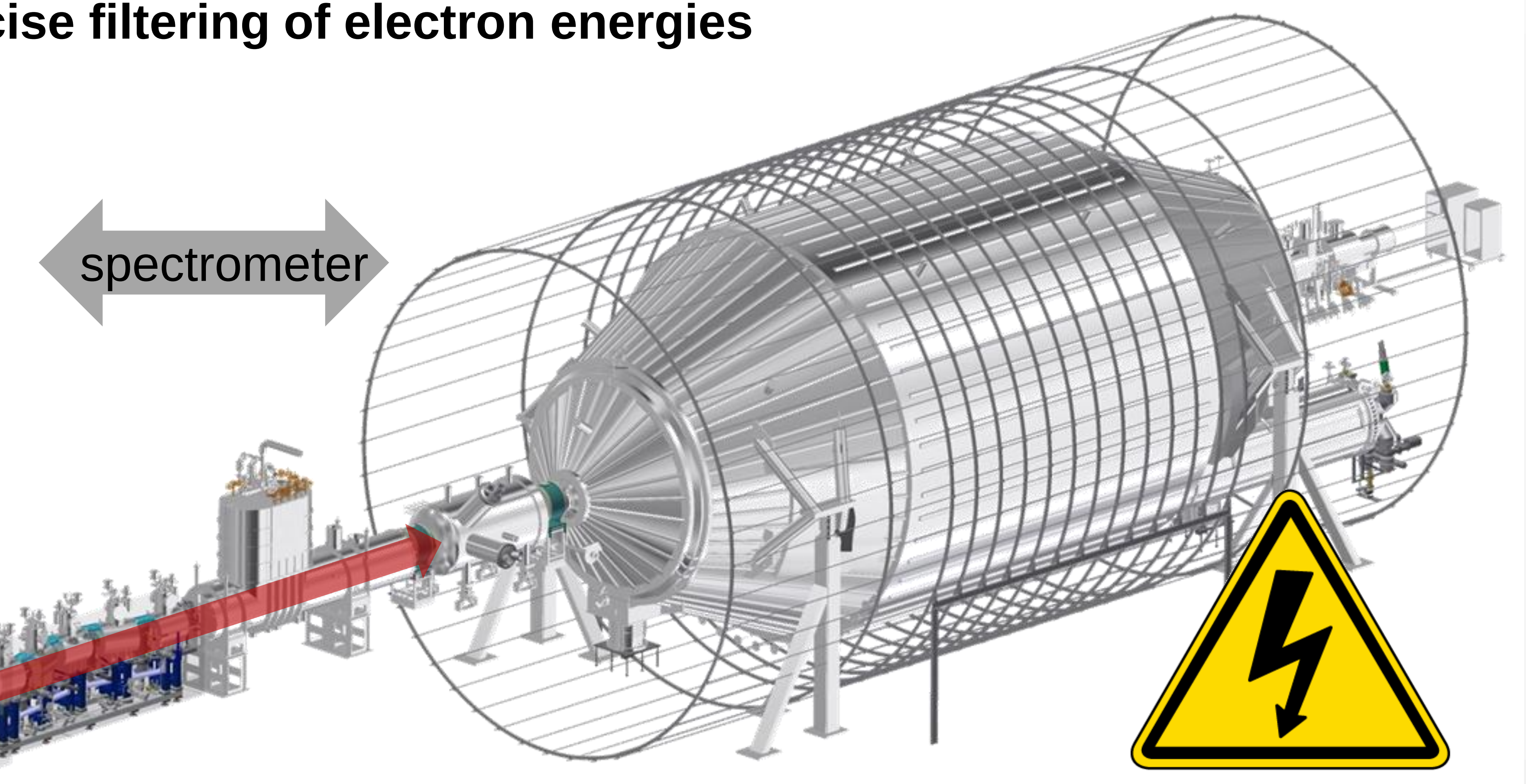


# SPECTROMETER TECHNOLOGIES

# electrostatic retarding spectrometers

- KATRIN needs a very **precise filtering of electron energies**


spectrometer

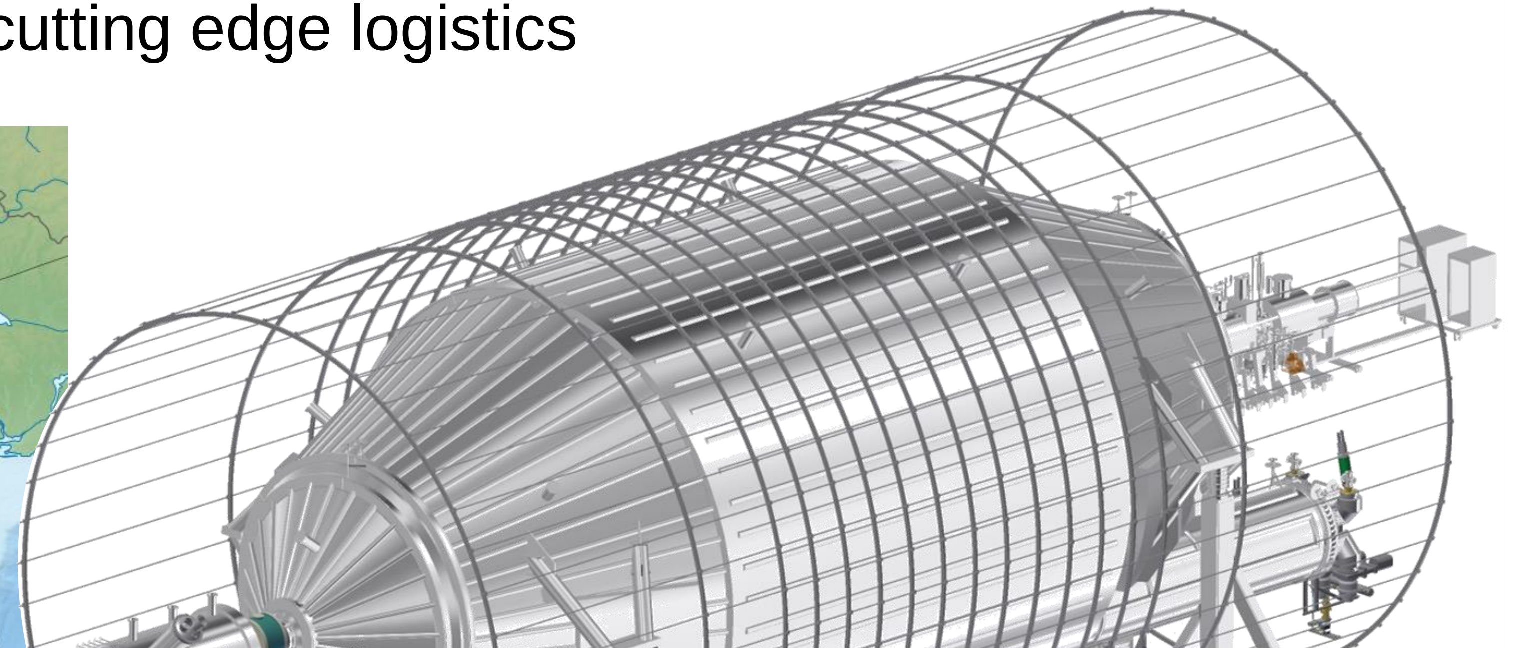


world´s most precise High Voltage at ppm-scale
(see next talk)

# electrostatic retarding spectrometers

- an 8000 km spectrometer voyage in 2006 – cutting edge logistics

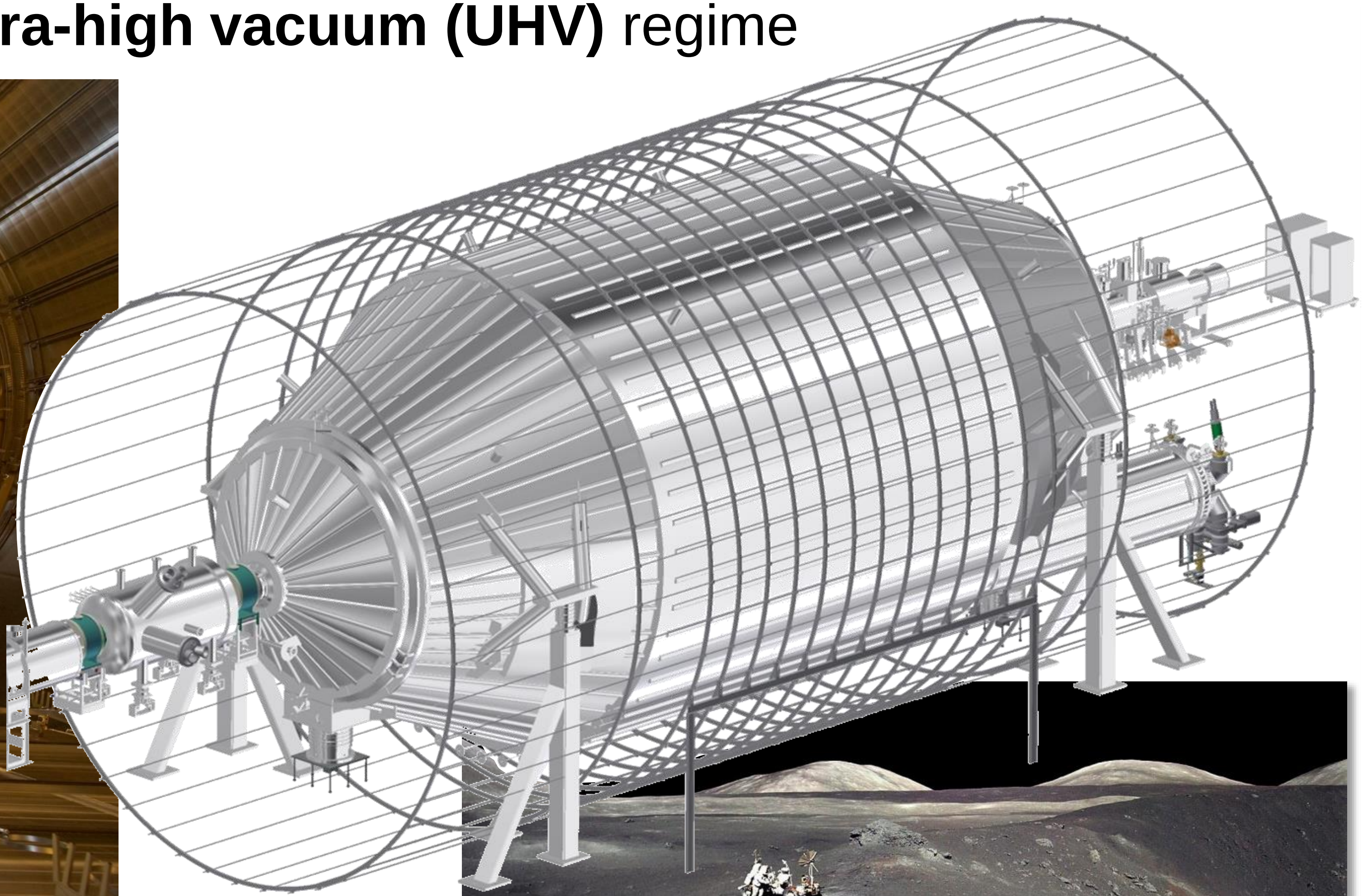

spectrometer transport – the first few thousand km

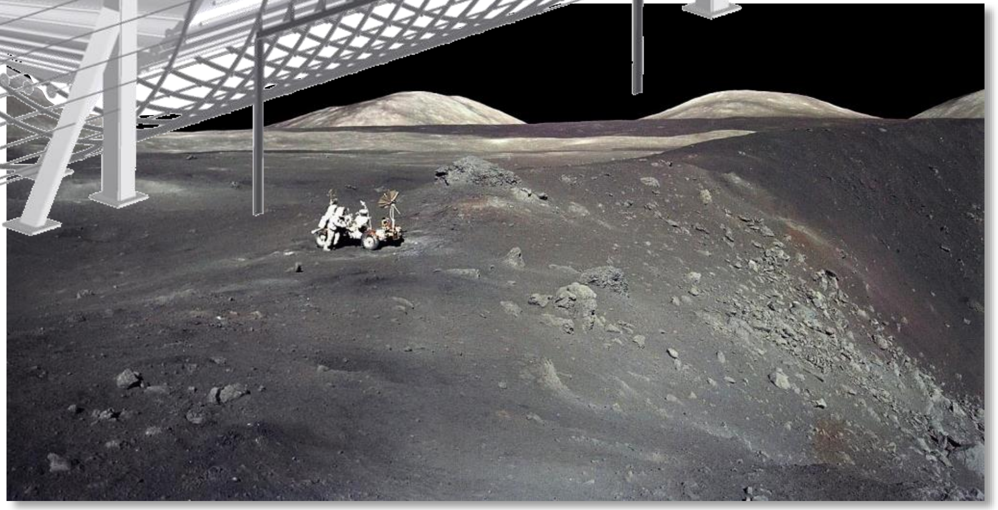


the final few km

# electrostatic retarding spectrometers

- spectrometers to be operated at stringent **ultra-high vacuum (UHV)** regime





the largest UHV vessel in the world

vacuum equivalent to lunar surface

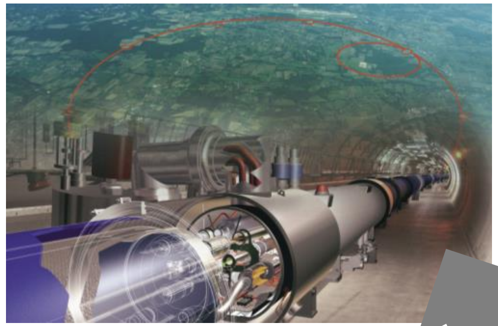
# largest ever ultra-high vacuum recipient

- **UHV-environment**

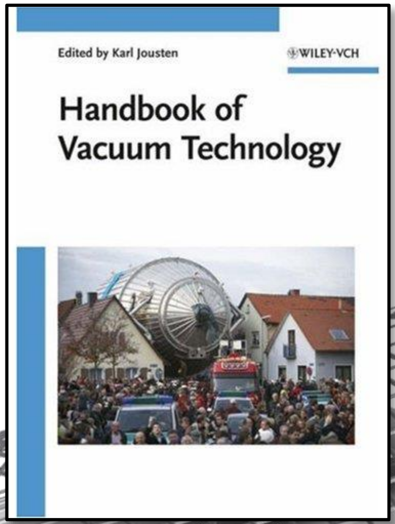
  p ~ $10^{-11}$ mbar range

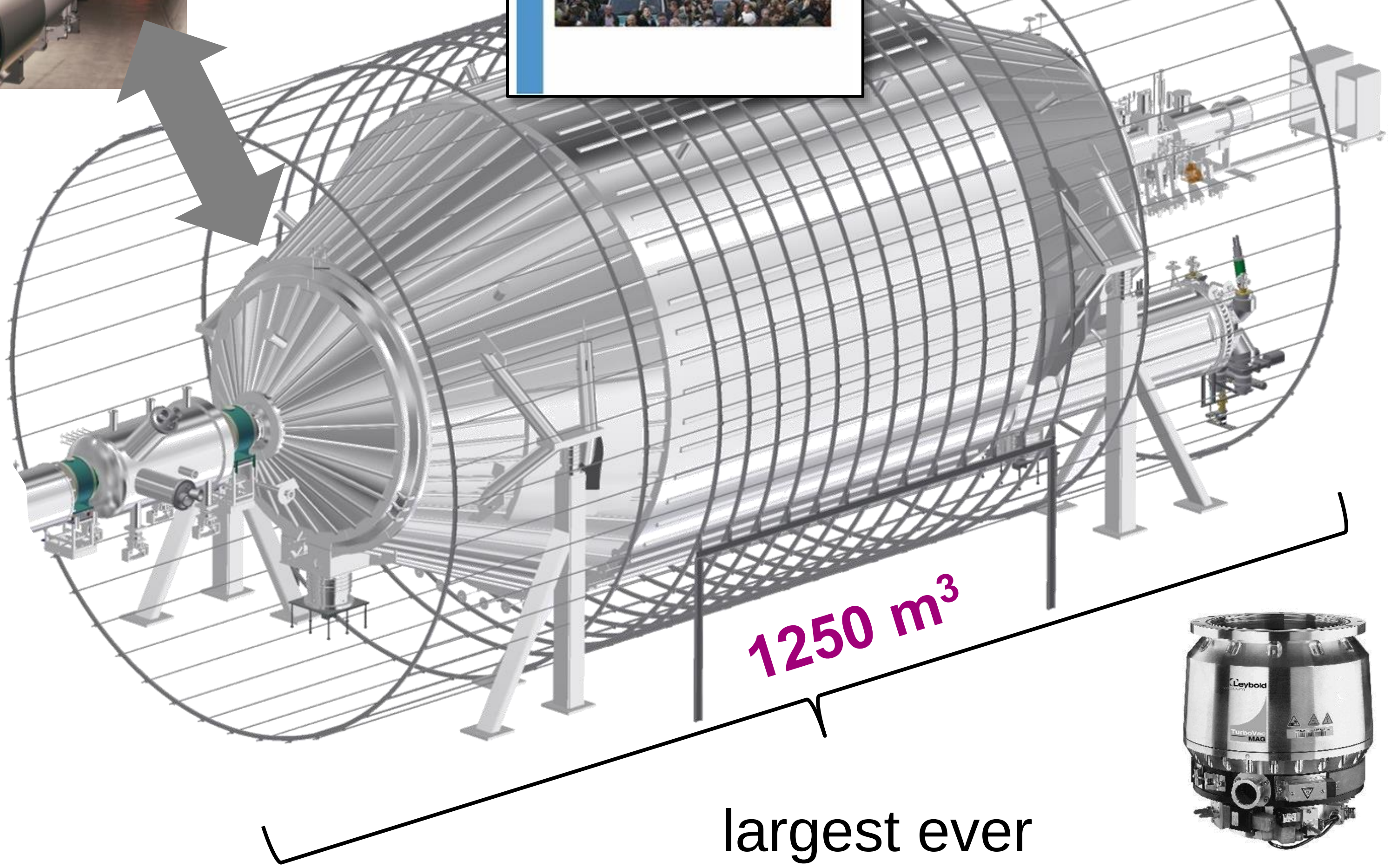
  - 2 large NEG strips (Σ = 2 km)

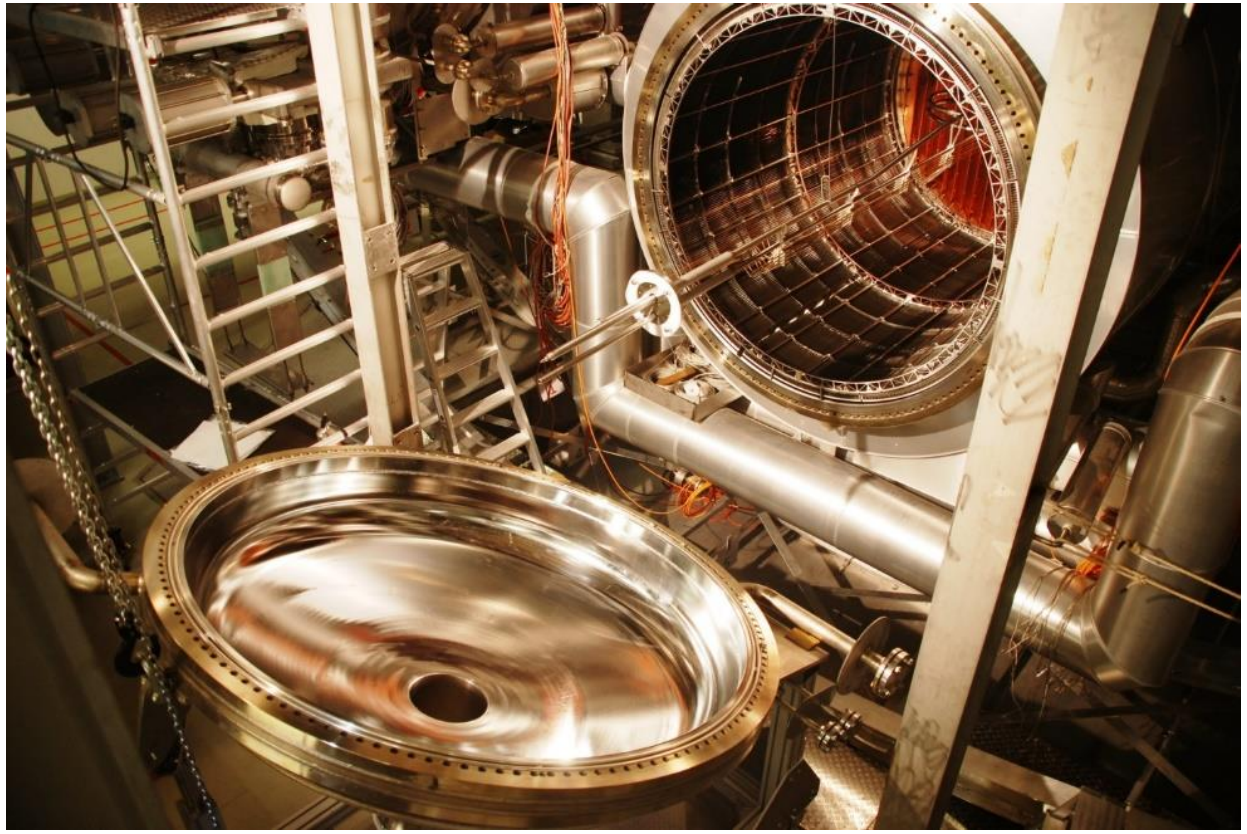
  - 6 TMPs (Leybold MAG W2800)



LHC
154 m³



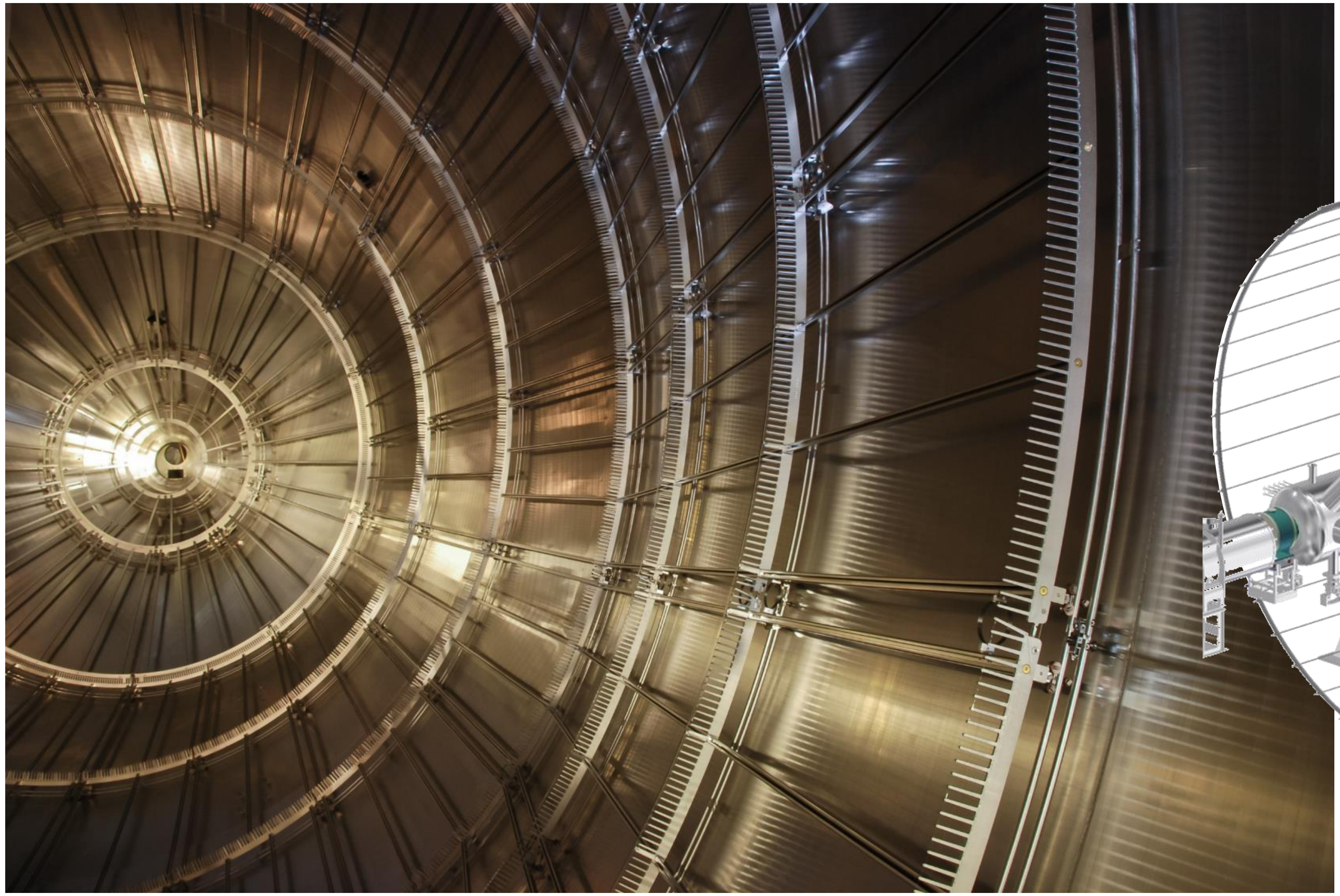



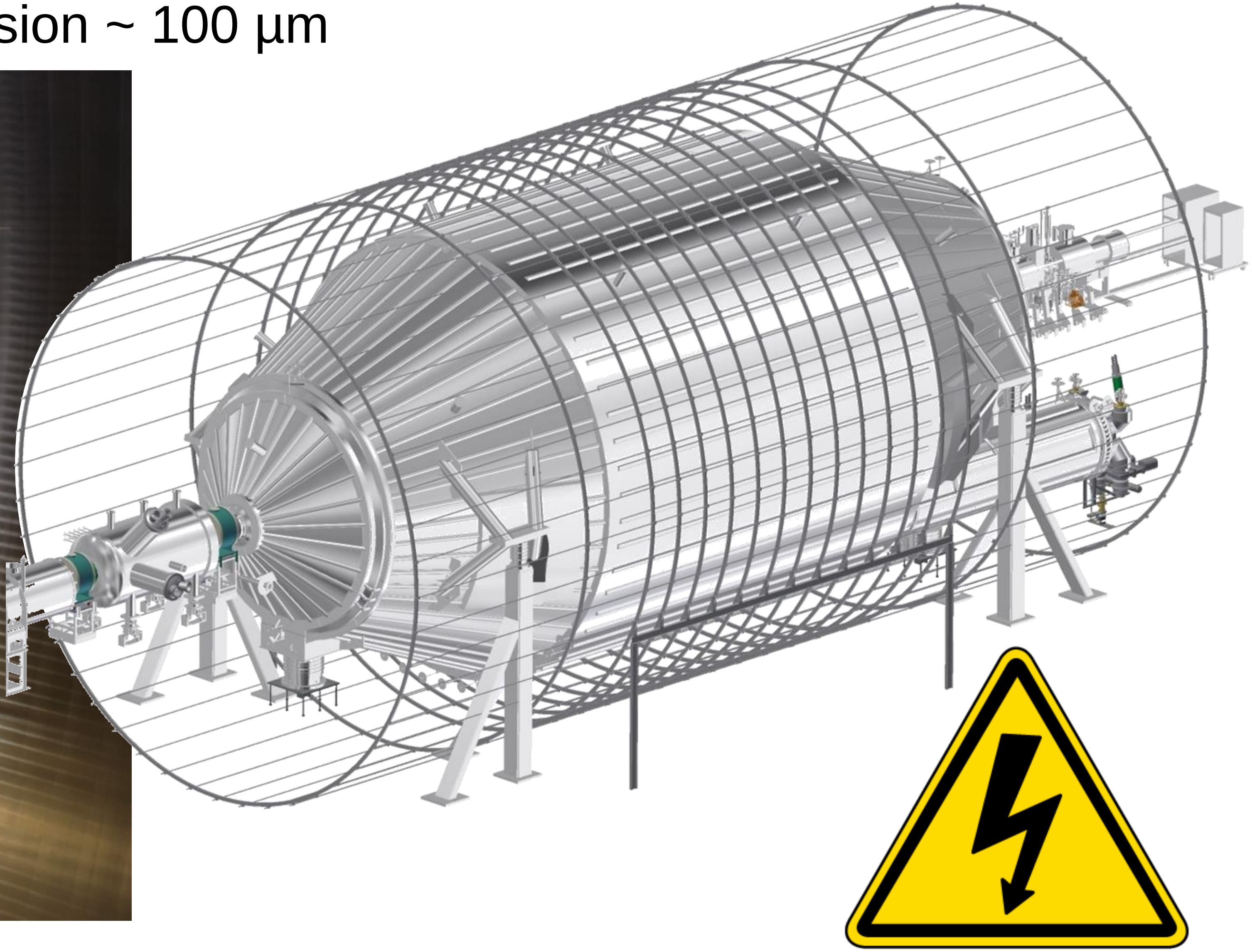



largest ever
UHV recipient
(since 2013)

# Precision electromagnetic layout – inner electrode

- multi-year installation phase, mechnical precision ~ 100 µm

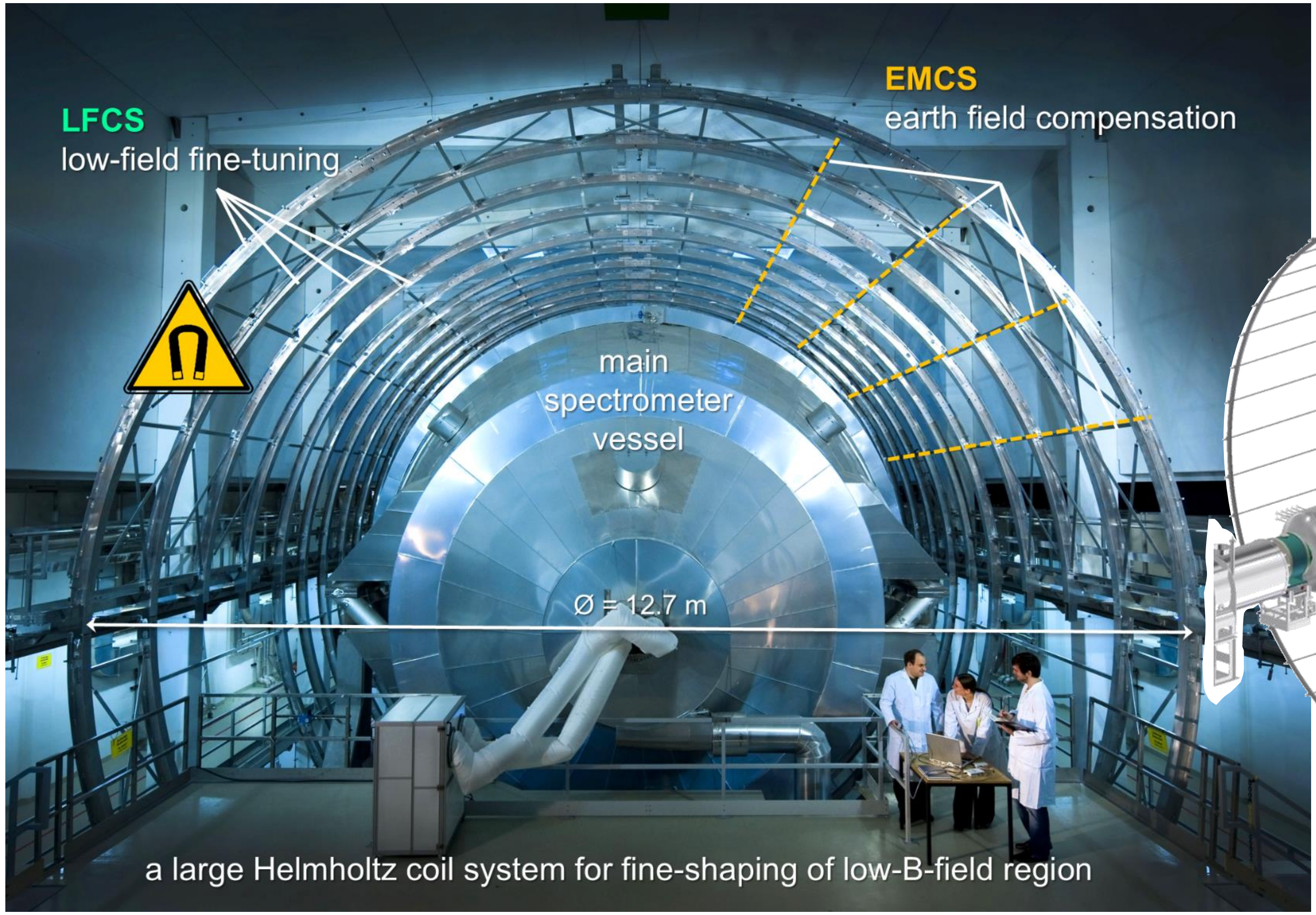


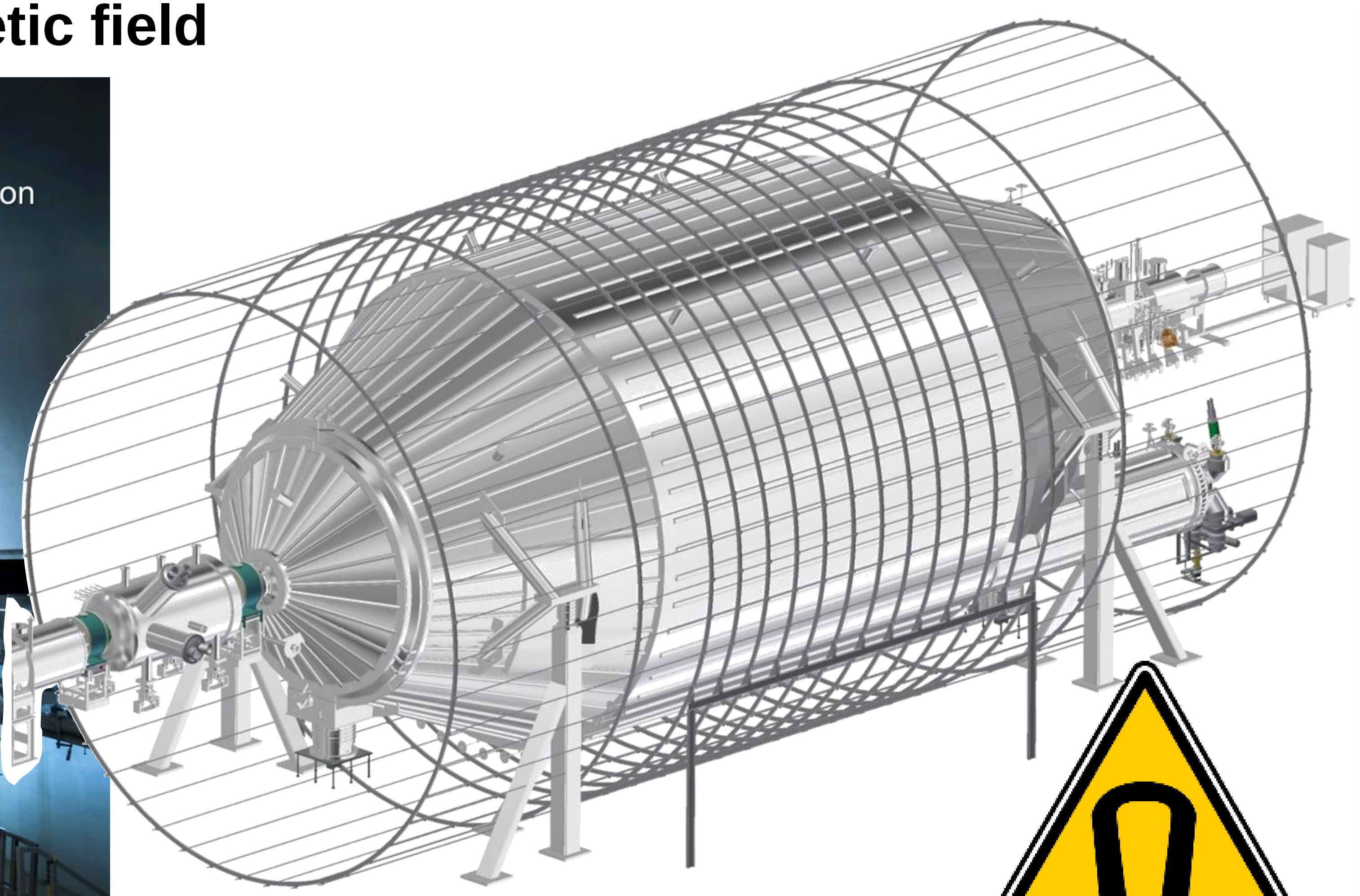


large inner electrode system in the spectrometer

# Precision electromagnetic layout

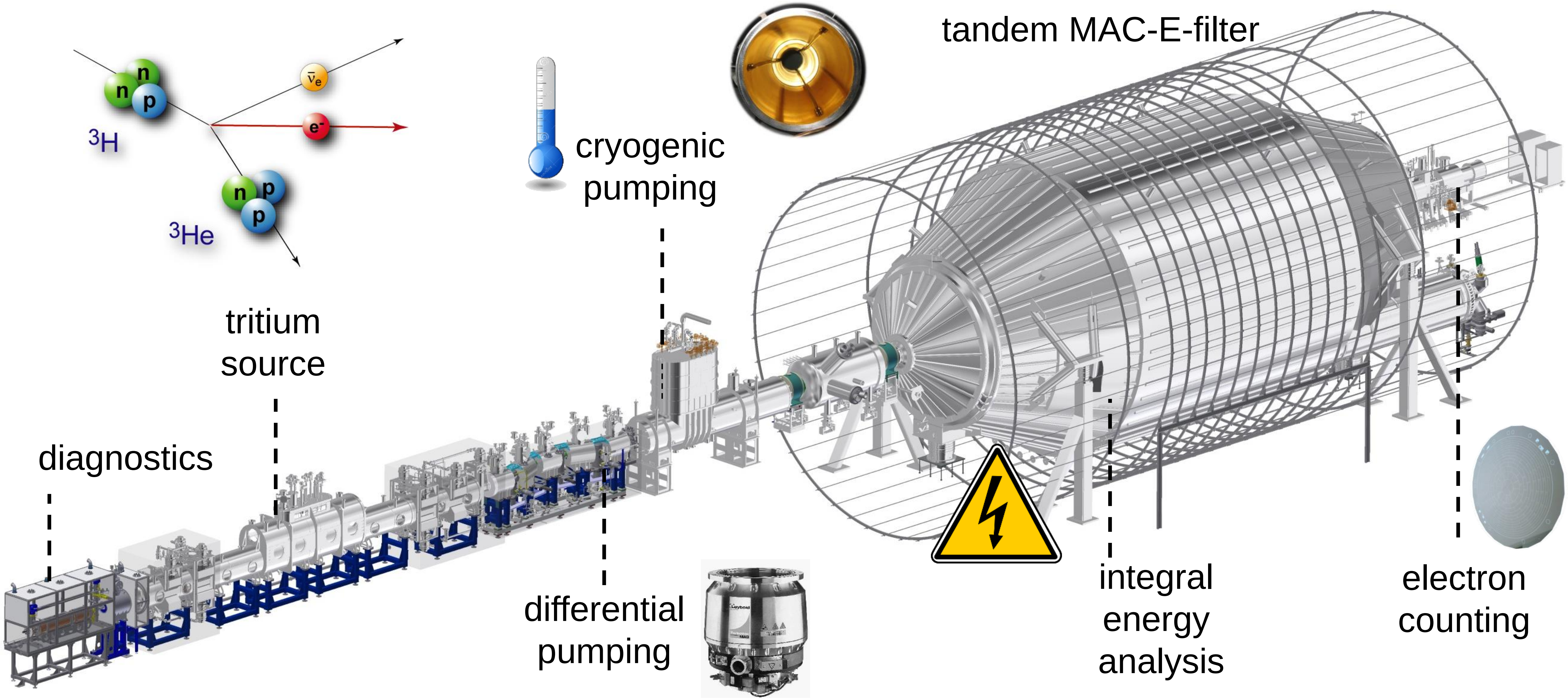
- **precision compensation of earth magnetic field**



a large aircoil system around the spectrometer to fine-tune magnetic flux-tube
no background from cosmic muons and environmental gammas

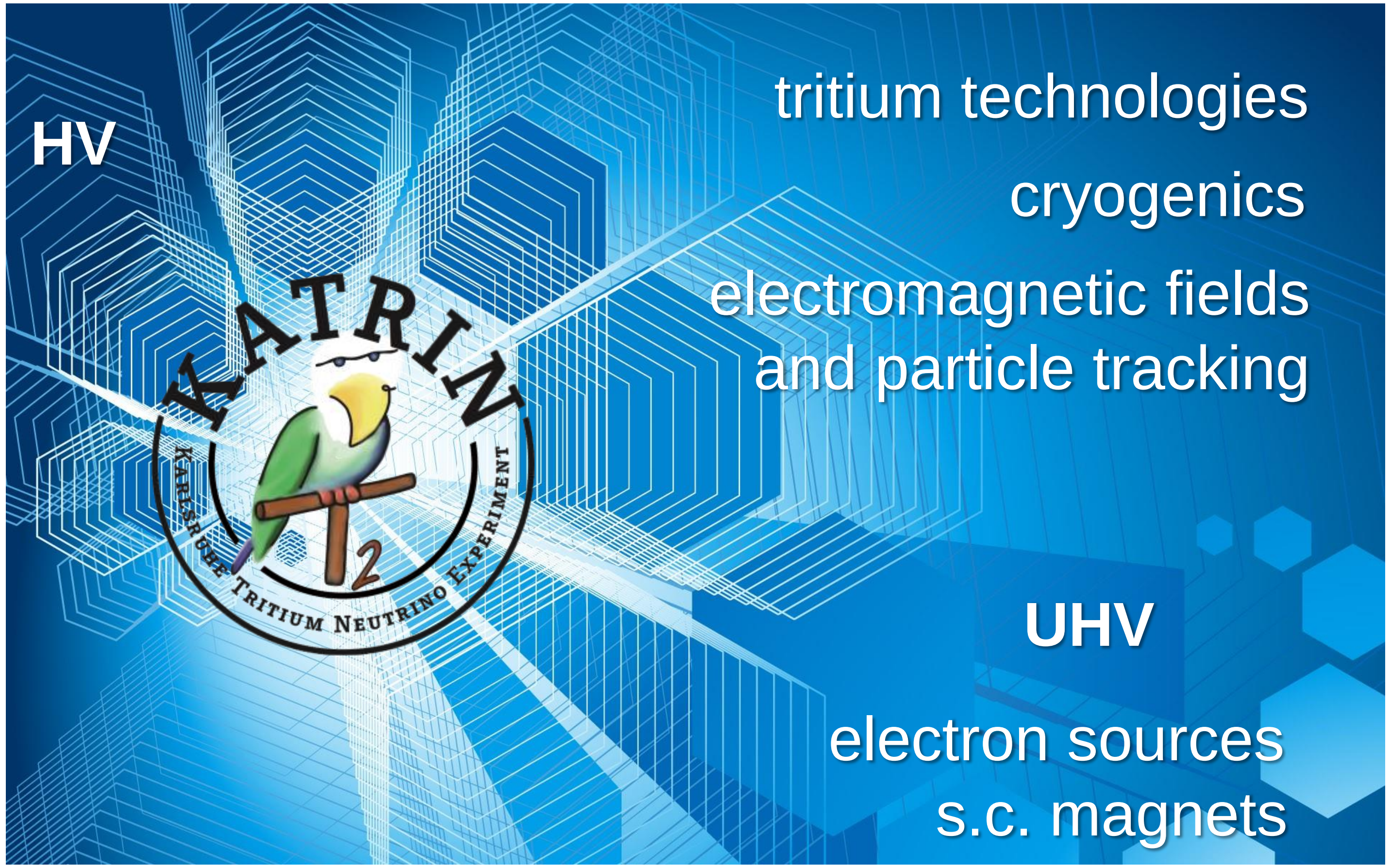
# KATRIN – a unique instrument at work (following talks)



# KATRIN – a bona fide technology driver

Karlsruhe Institute of Technology

- **neutrino mass measurement only possible due to cutting-edge technologies**




**CONCLUSION**

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