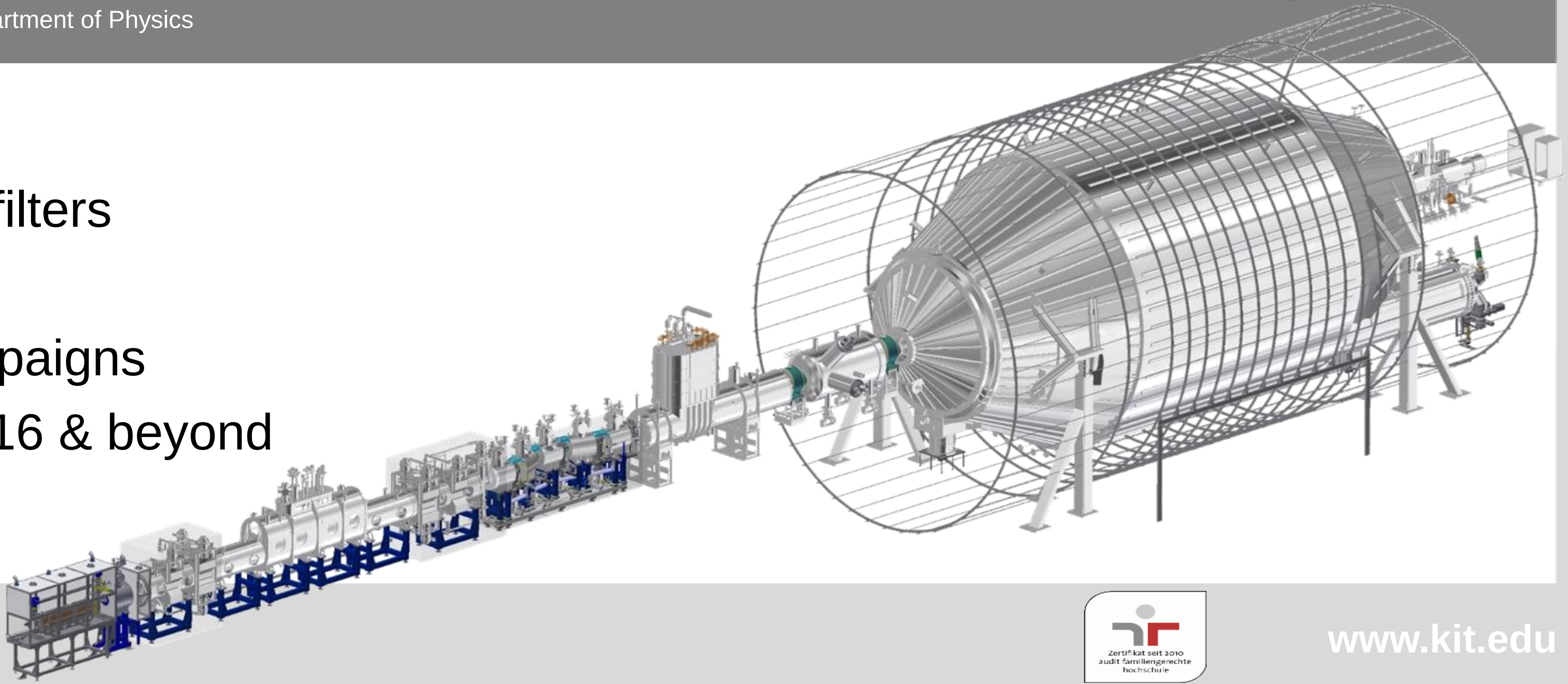
Karlsruher Institut für Technologie

KATRIN

Neutrino Oscillation Workshop – NOW2016
Otranto, September 4-11, 2016

Guido Drexlin, Institute for Experimental Nuclear Physics, Department of Physics

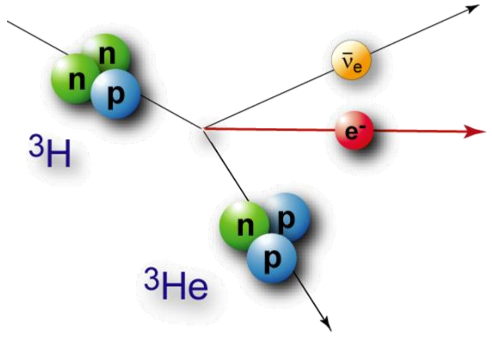
- Introduction
- ß-spectroscopy with MAC-E-filters
- KATRIN components
- Results of 2014/15 SDS campaigns
- First Light measurements 2016 & beyond
- Conclusions

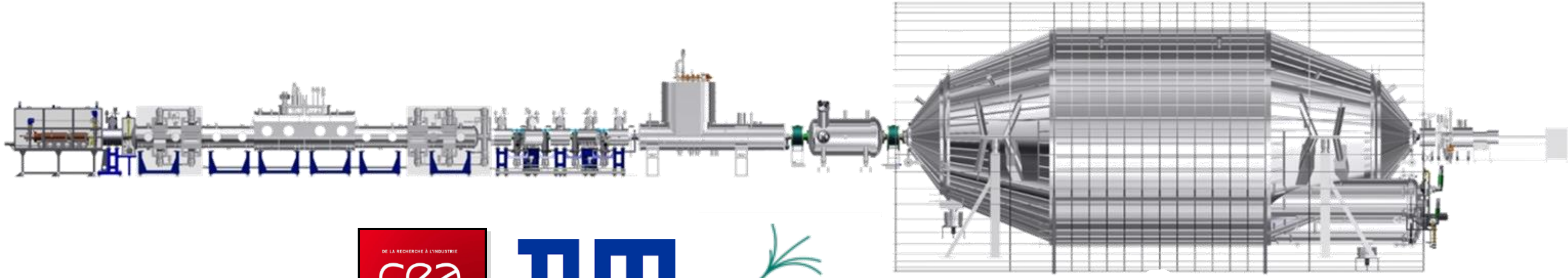


KATRIN experiment

Karlsruhe Tritium Neutrino Experiment

- **direct ν–mass experiment** at Tritium Laboratory (TLK) of KIT
- international collaboration: ~130 members
  from 6 countries: D, US, CZ, RUS, F, ES



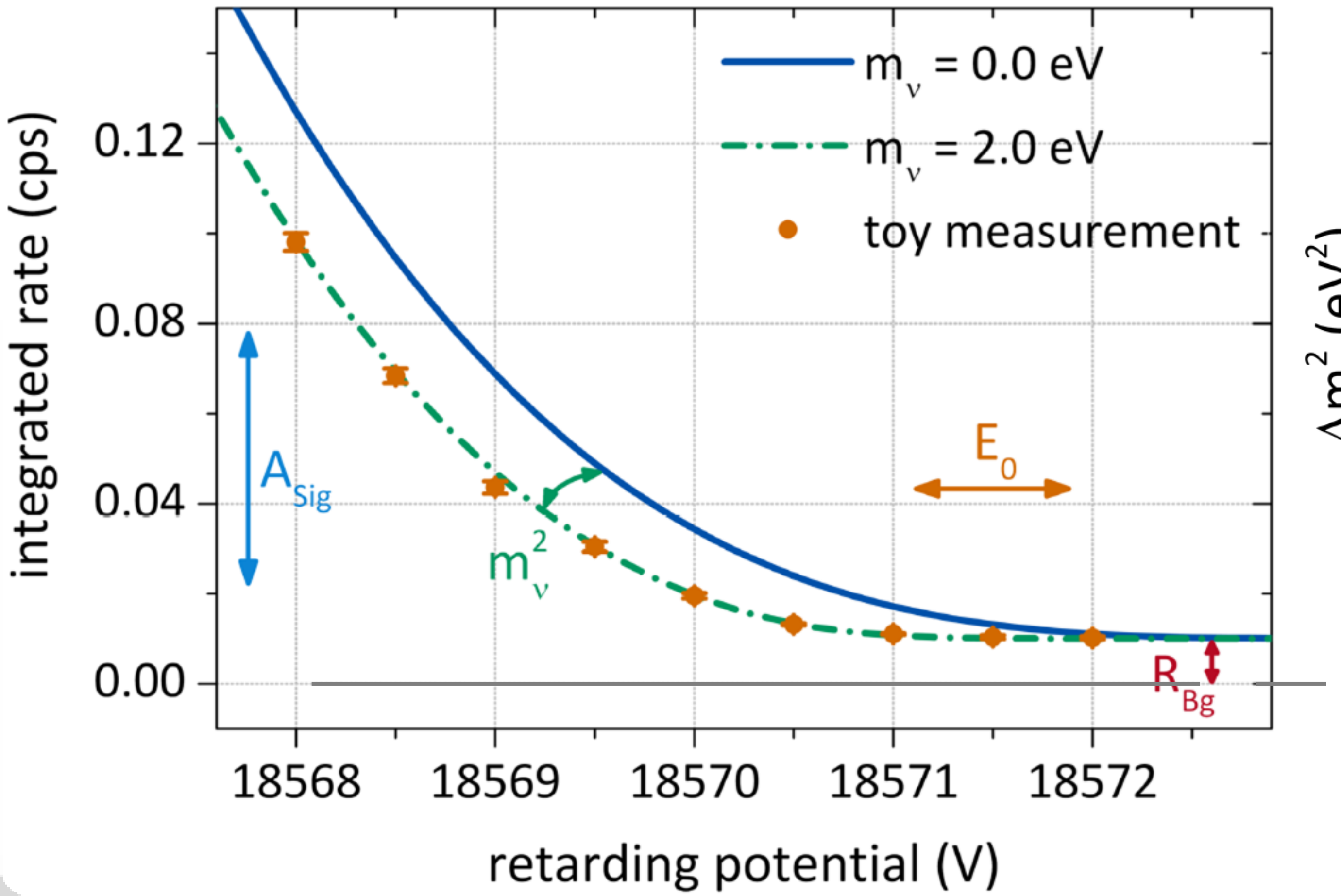


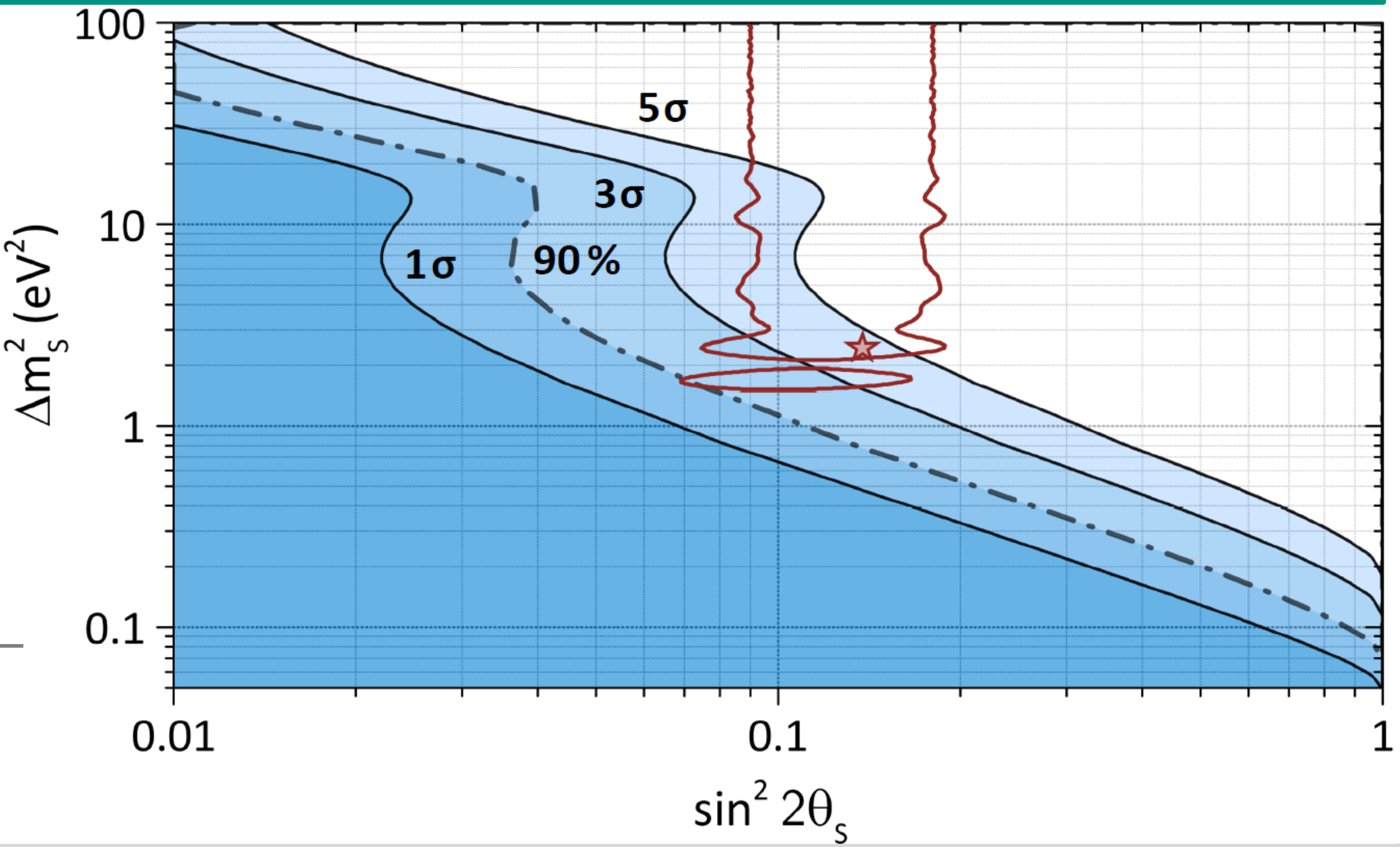
18 institutions:

KATRIN experiment – science case

■ physics programme

- model-independent effective electron (anti-)neutrino mass: **$m(\nu_e)$ = 200 meV** (90% CL)
- search for light… heavy sterile neutrinos: sub-eV … keV mass scale
- constrain local relic-ν density, search for Lorentz violation, exotic currents, BSM physics …





KATRIN overview: 70 m long beamline

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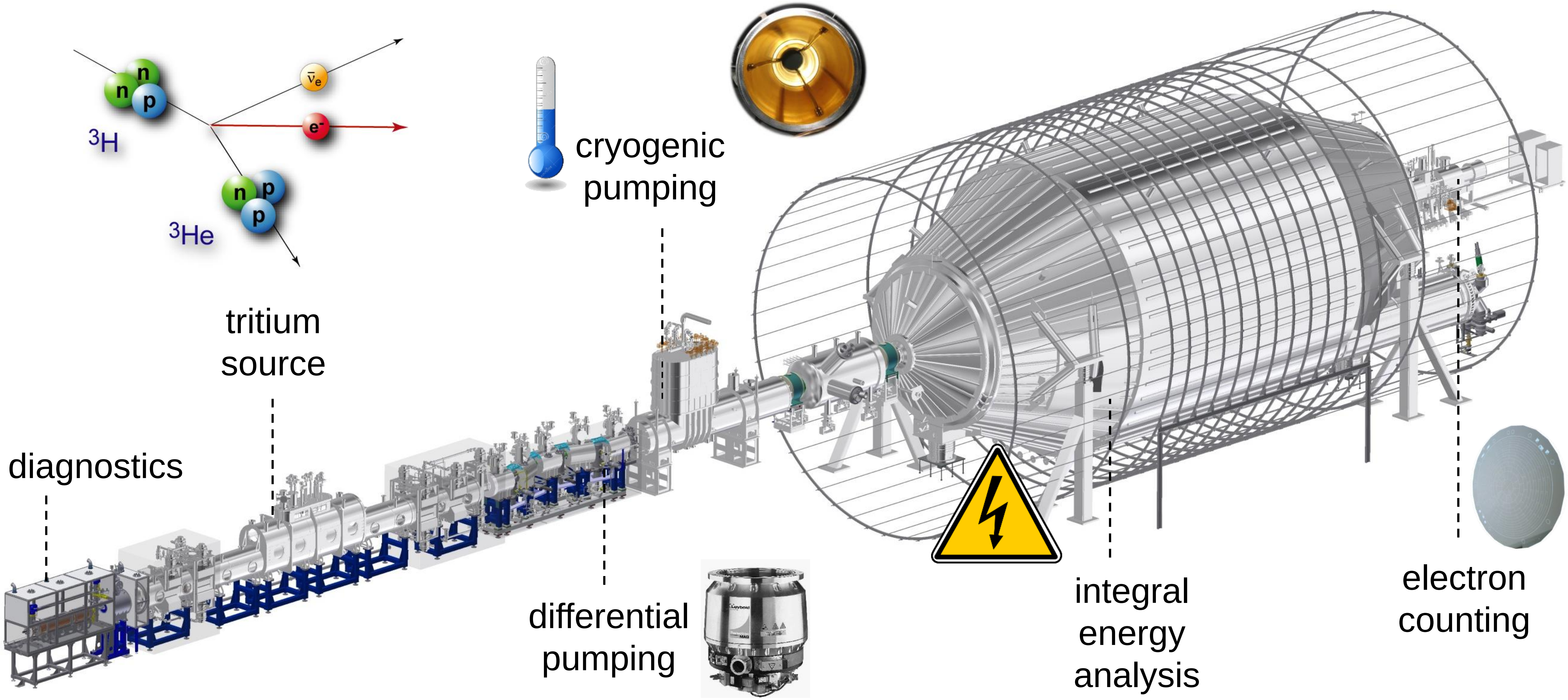
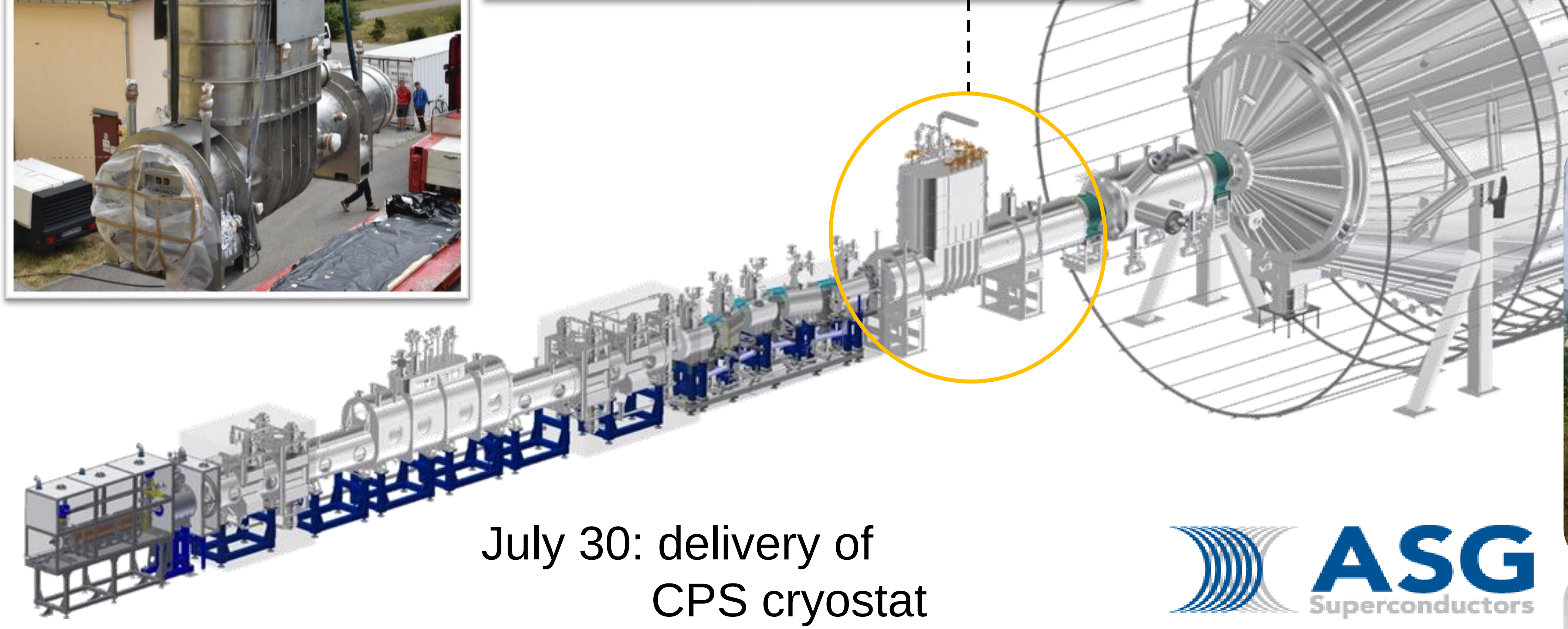


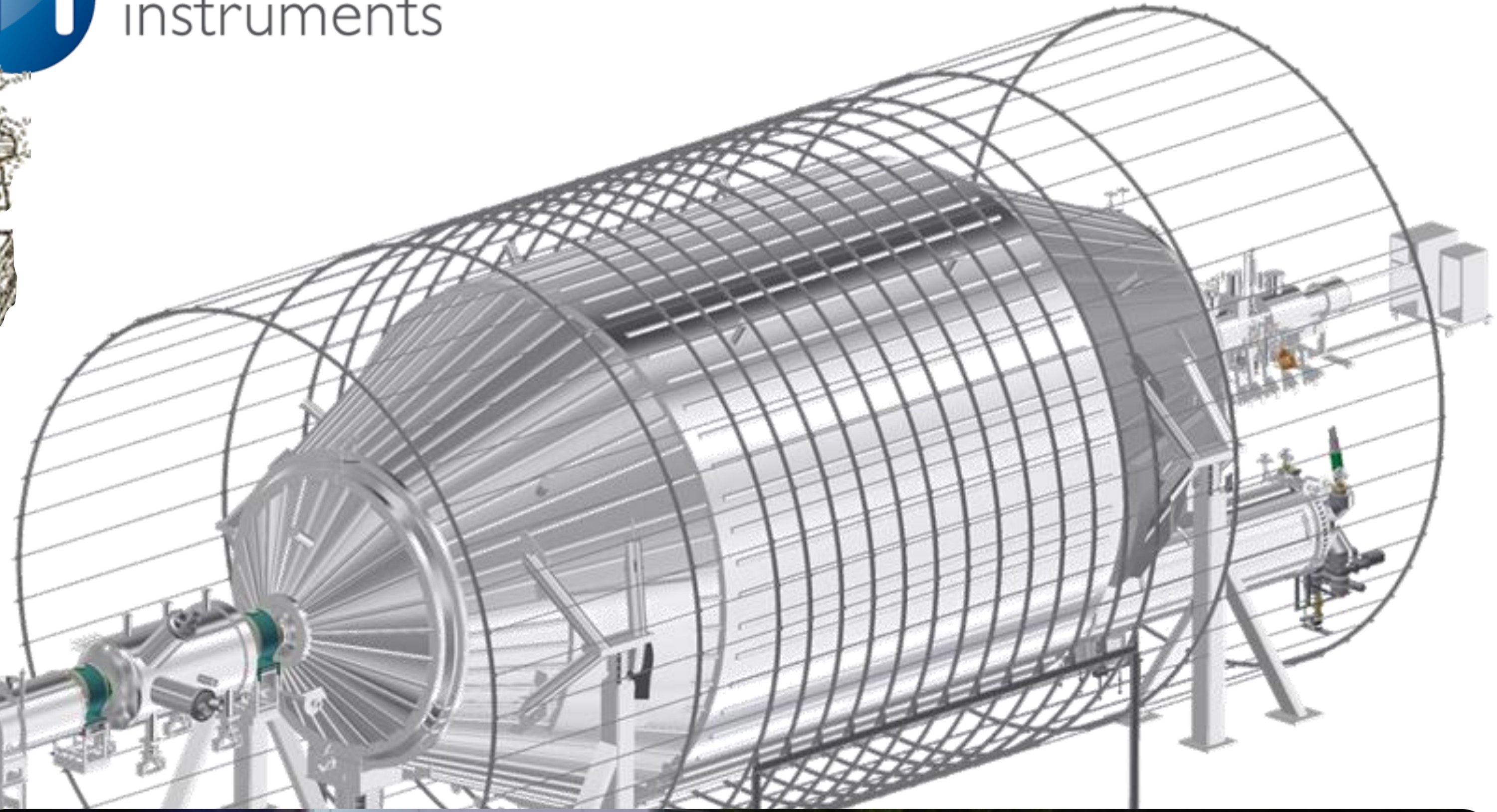
Project milestones 2015 - CPS

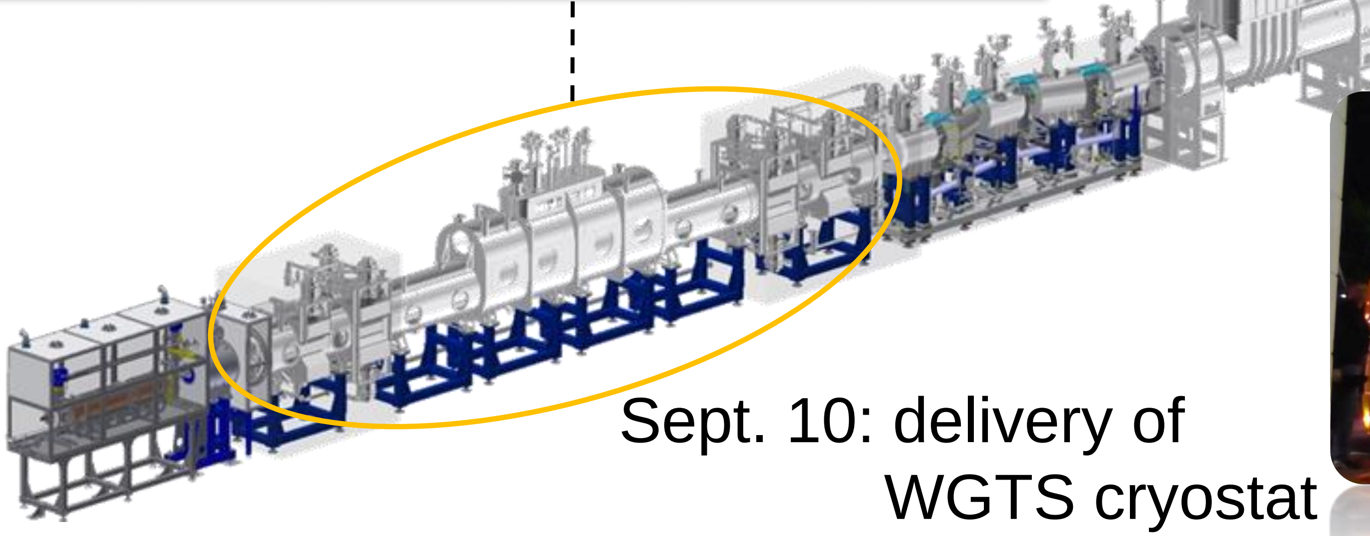


July 30: delivery of
CPS cryostat

ASG Superconductors

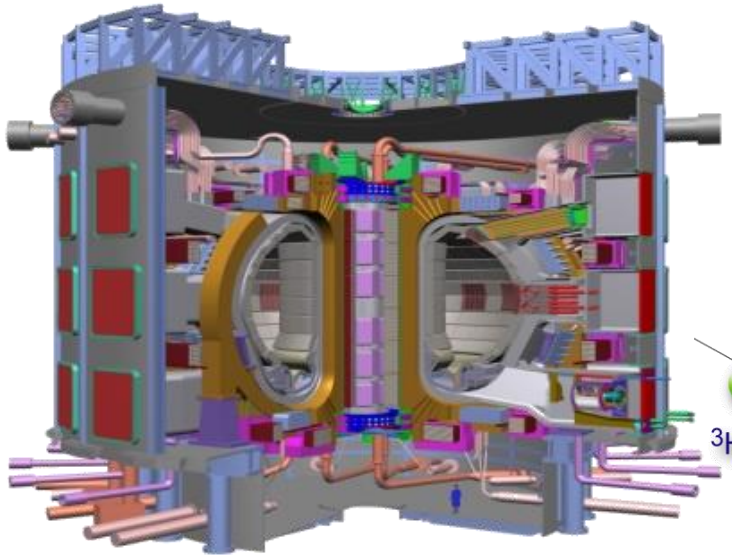
Project milestones 2015 - WGTS

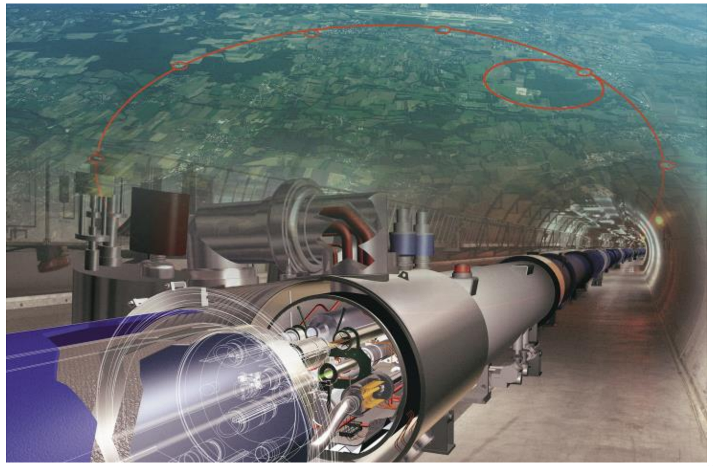


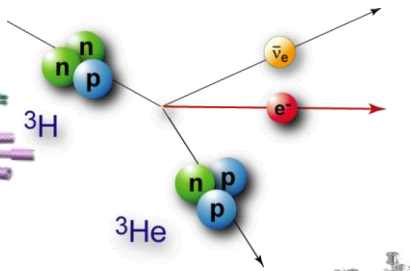


Sept. 10: delivery of
WGTS cryostat

KATRIN overview: challenges-I

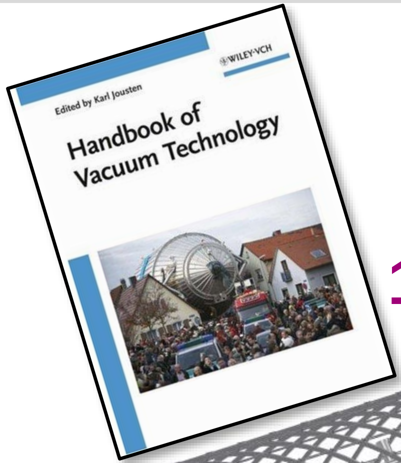




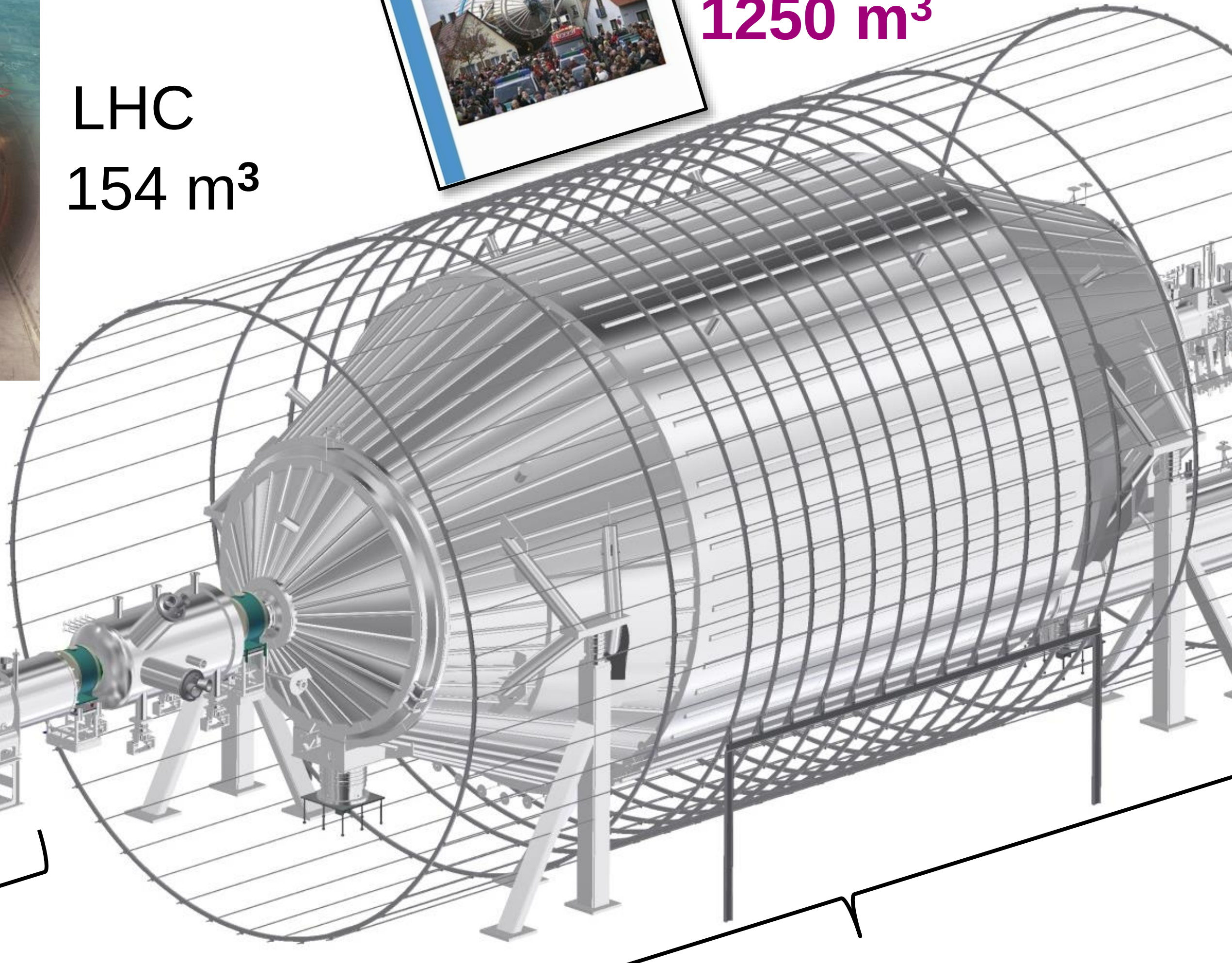


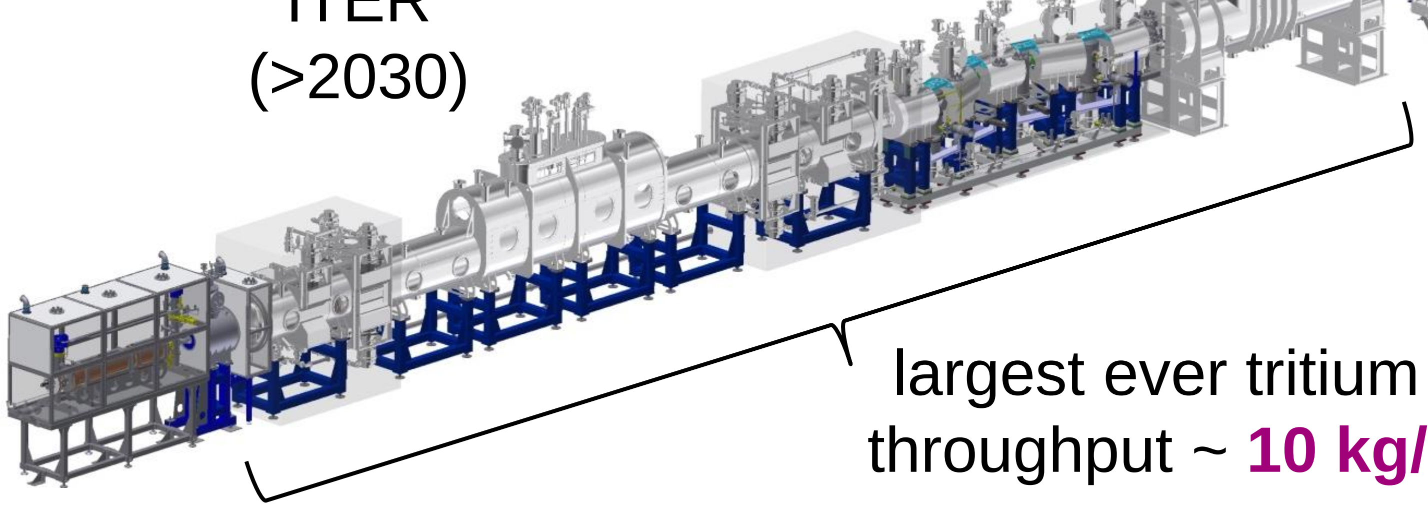
ITER
(>2030)

LHC
154 m³



1250 m³





largest ever tritium
throughput ~ **10 kg/a**

largest ever UHV
recipient (<10^{-11} mbar)

KATRIN overview: challenges-II

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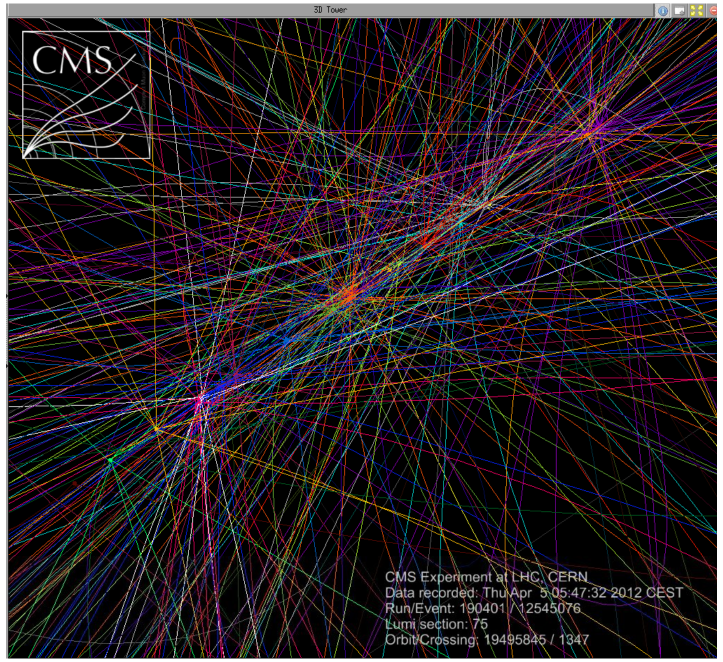
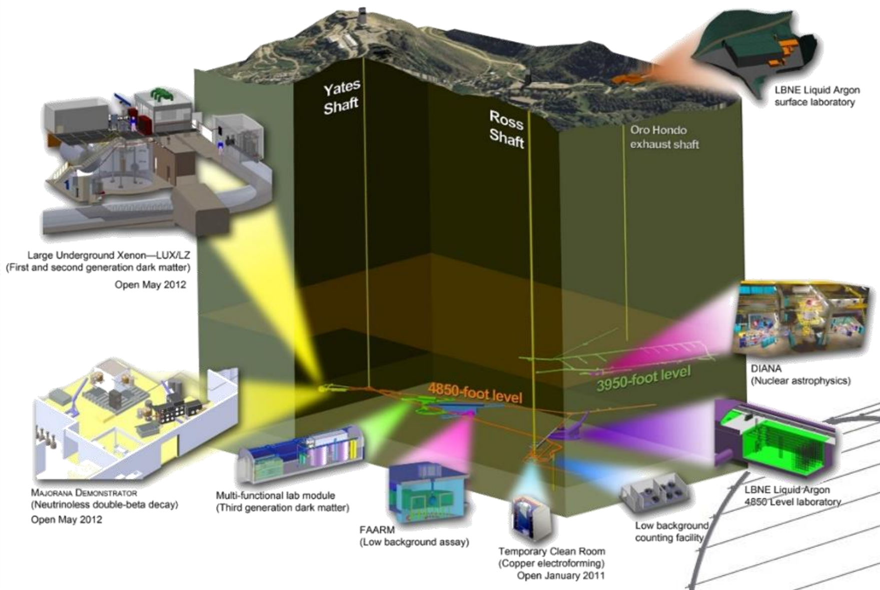
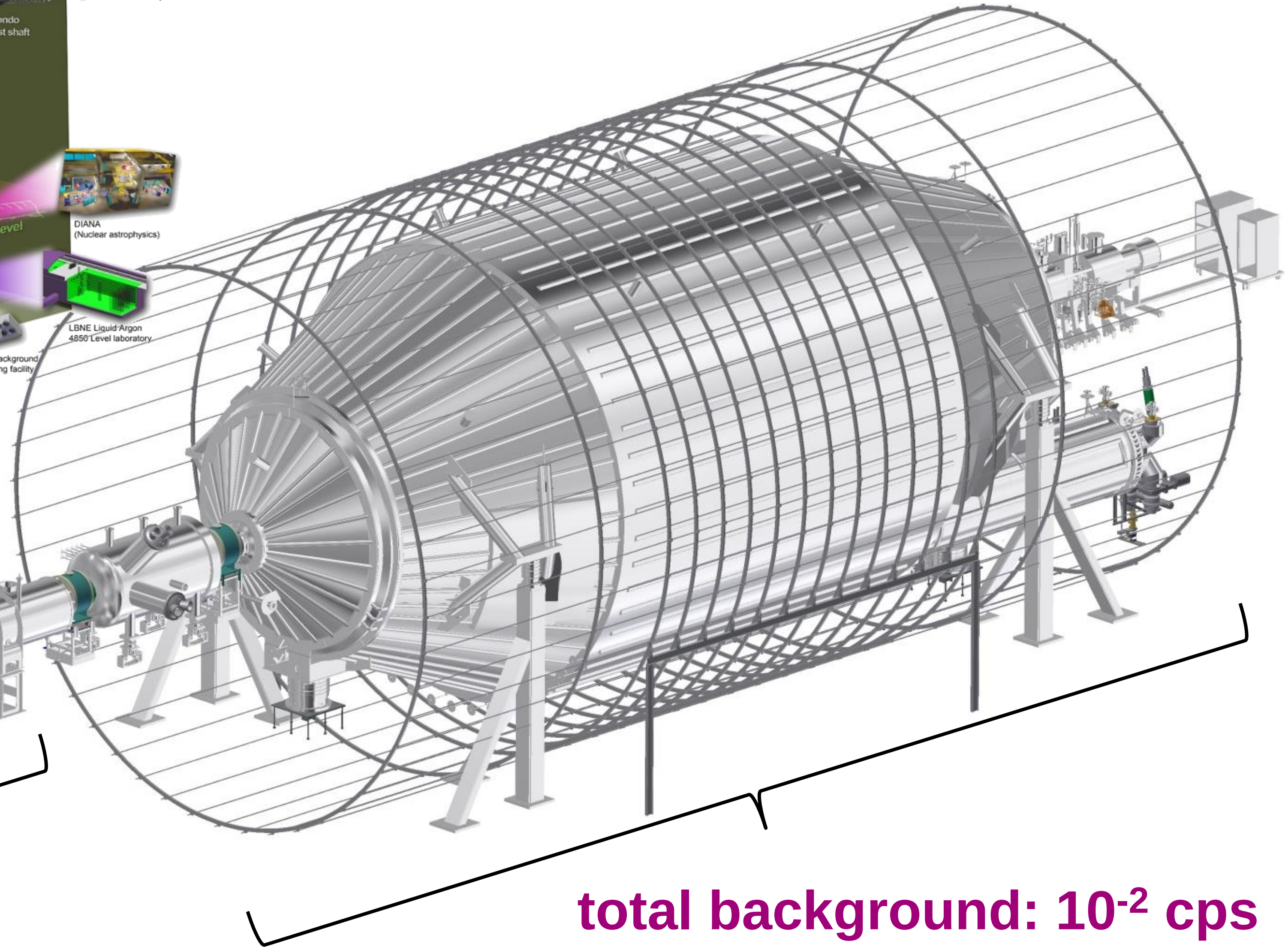






total background: 10^{-2} cps

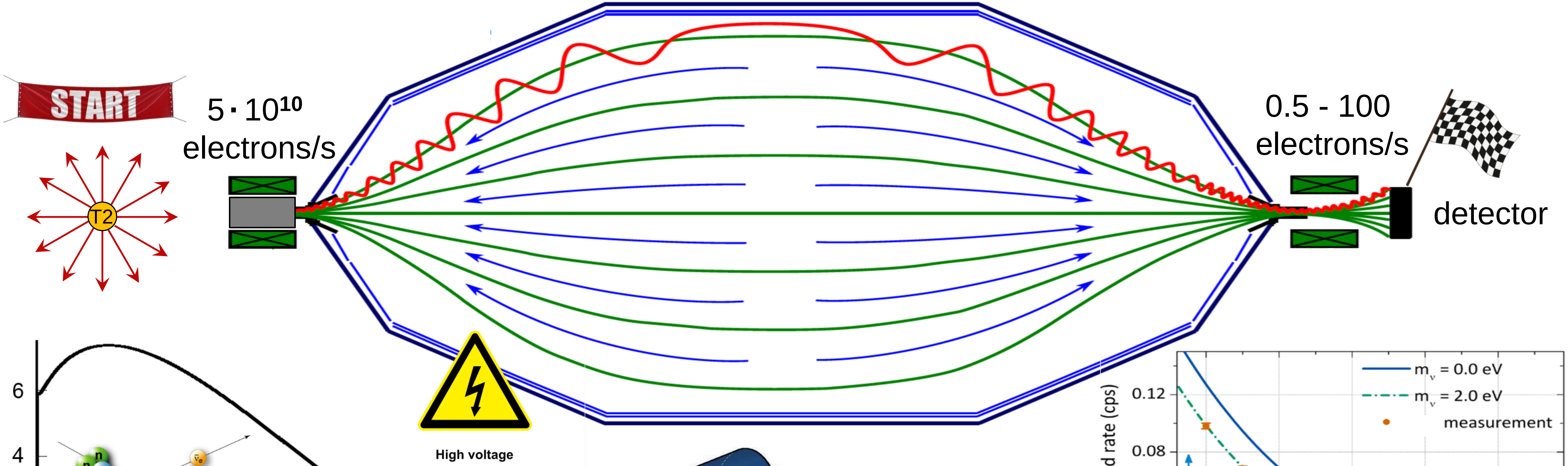
(≡ low level @ 1 mwe)

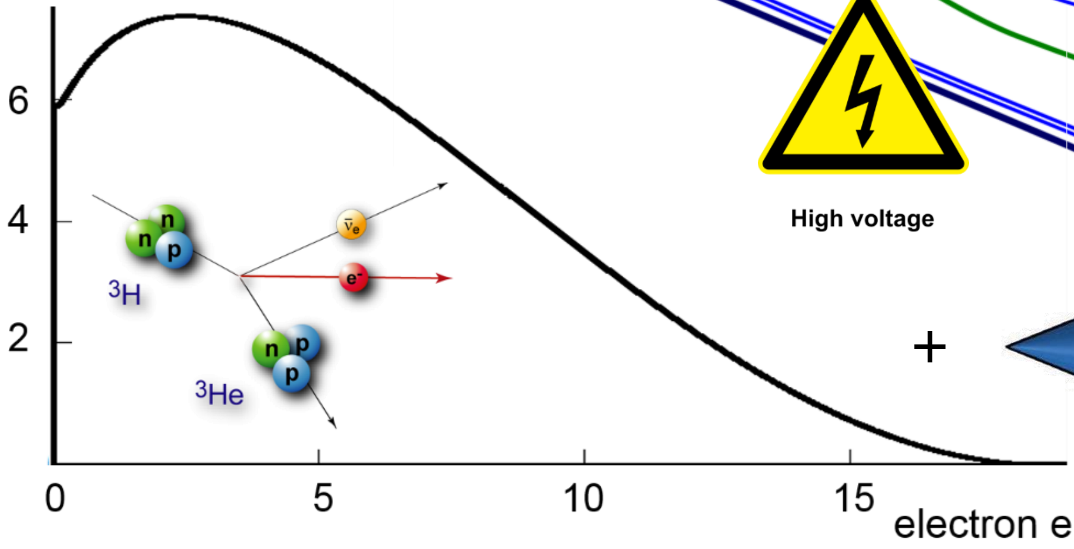
tritium source: 10^{11} ß-decays/s

(≡ LHC particle production)

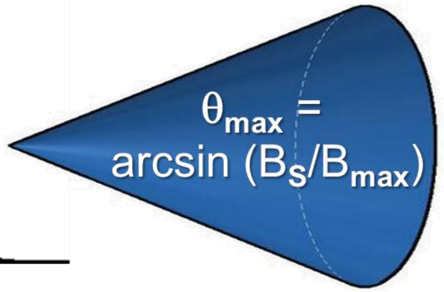
MAC-E principle: high-intensity tritium ß-spectroscopy

- **Magnetic Adiabatic Collimation & Electrostatic Filter:** scan high-intensity T2 source

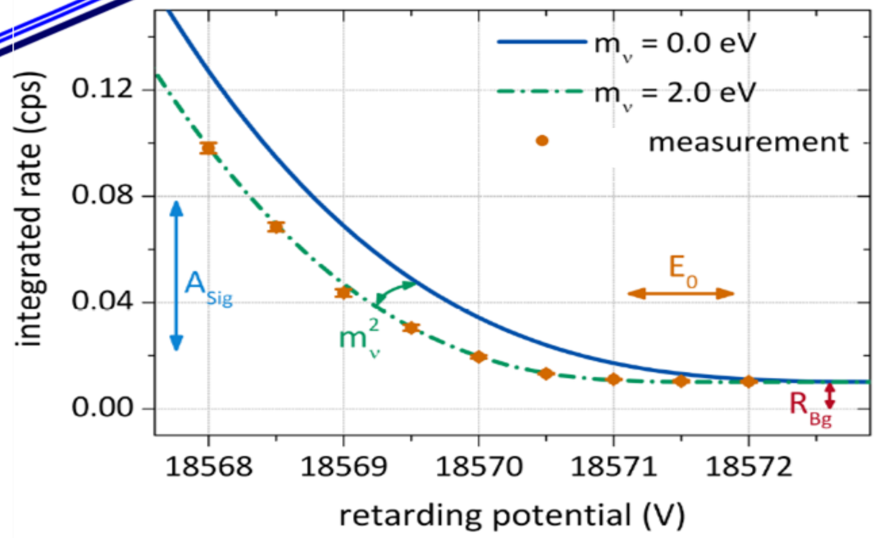




+

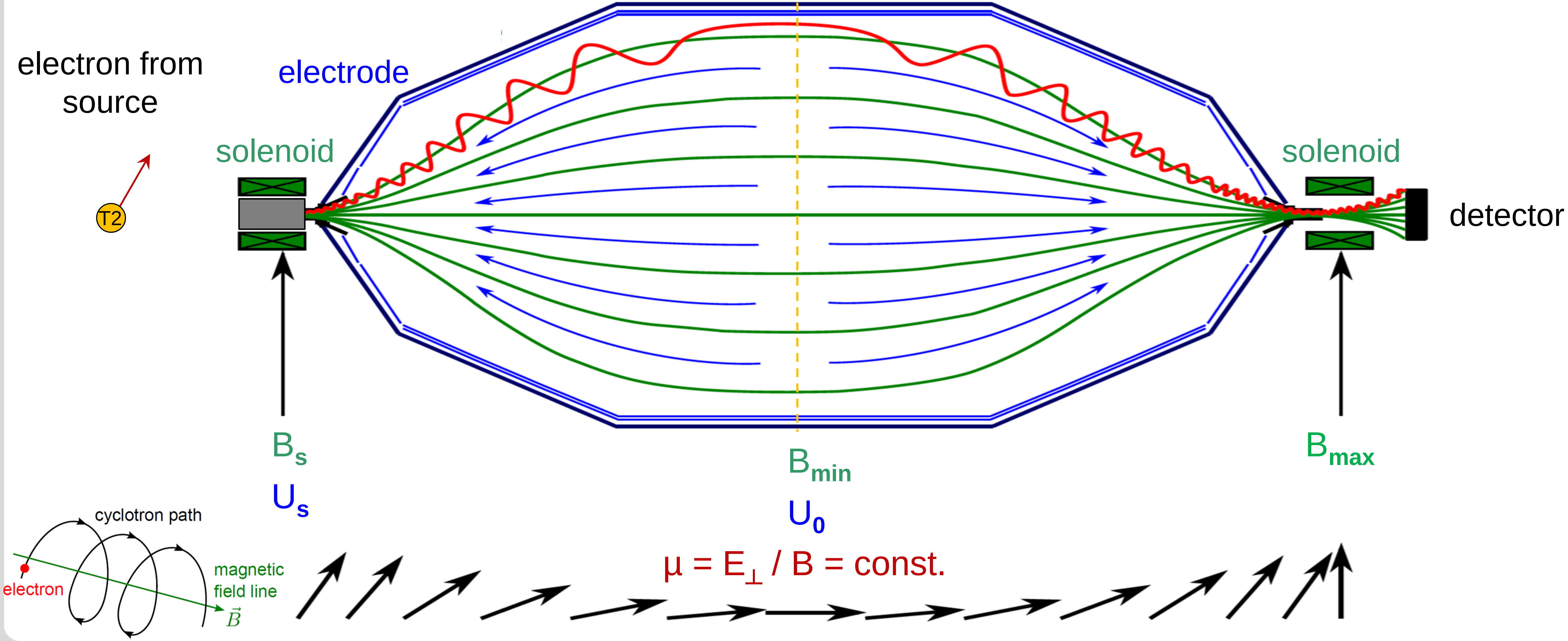


large acceptance angle ⇨



MAC-E principle: high-resolution tritium ß-spectroscopy

- **Magnetic Adiabatic Collimation & Electrostatic Filter:** adiabatic conversion $E_\perp \rightarrow E_\parallel$



MAC-E principle: high-resolution tritium ß-spectroscopy

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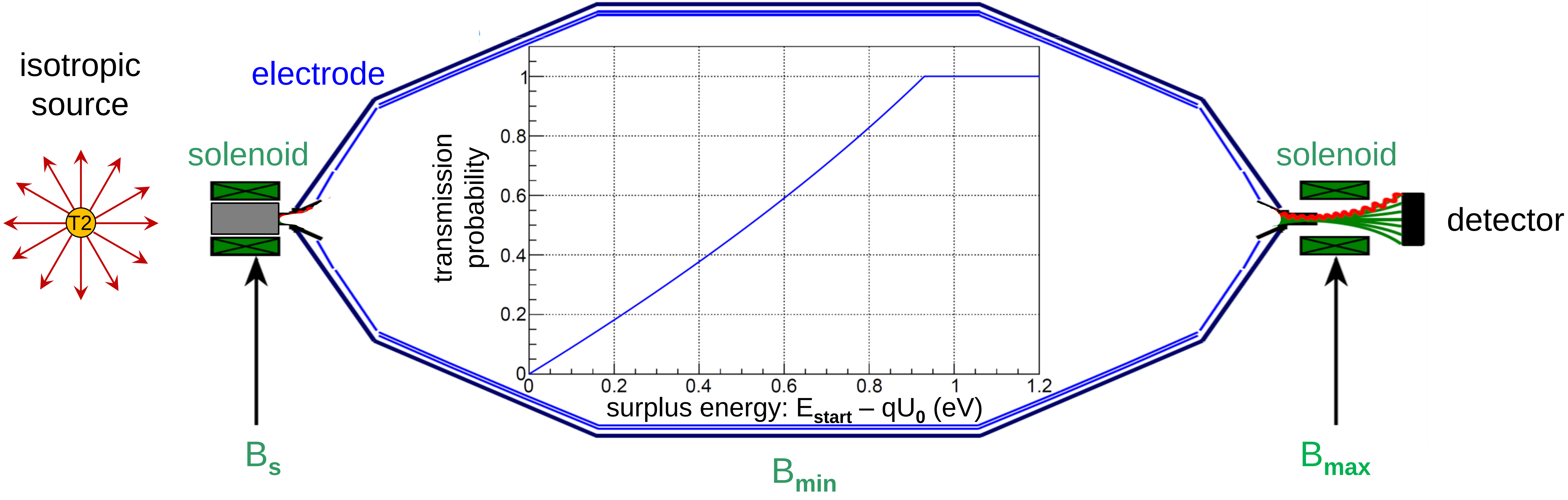
- **Magnetic Adiabatic Collimation & Electrostatic Filter:** *analytic* transmission function T



$\Delta E / E = B_{min} / B_{max}$ ⇨ $\Delta E = 0.93$ eV

3×10^{-4} T / 6 T @18.6 keV

- $T(B_{min}, B_{max}, U_0)$: **no Gaussian tails**
  but: U_0 on ppm-scale for sub-eV $m(\nu_e)$!

MAC-E principle: integrated ß-spectrum close to E0

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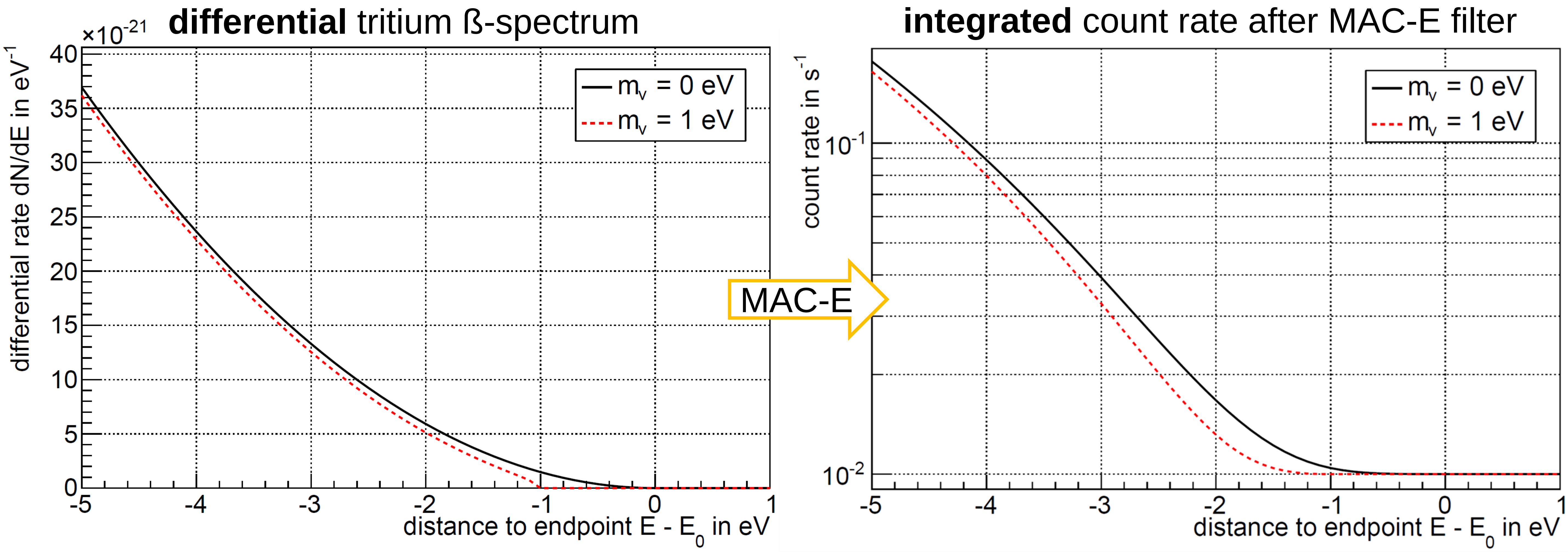
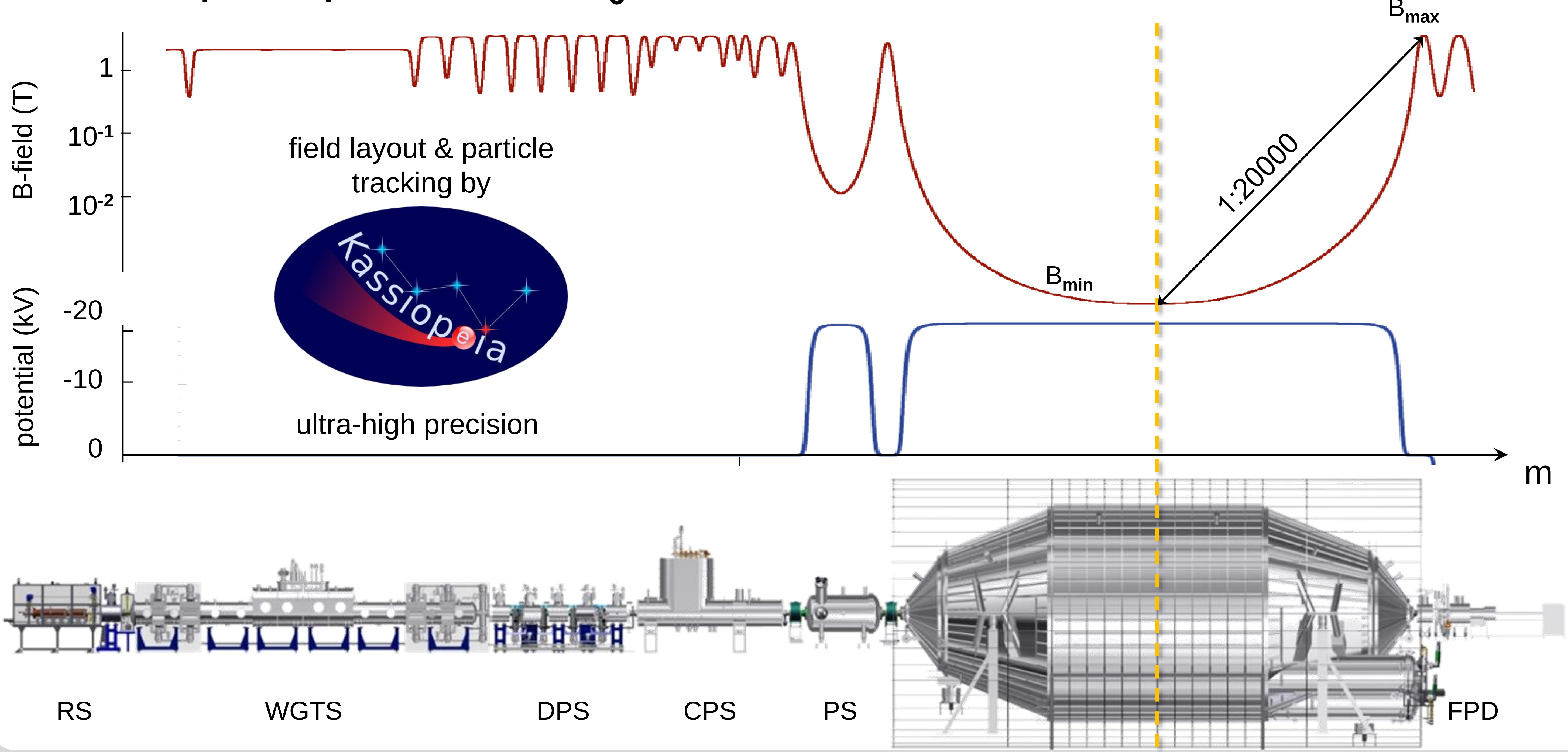
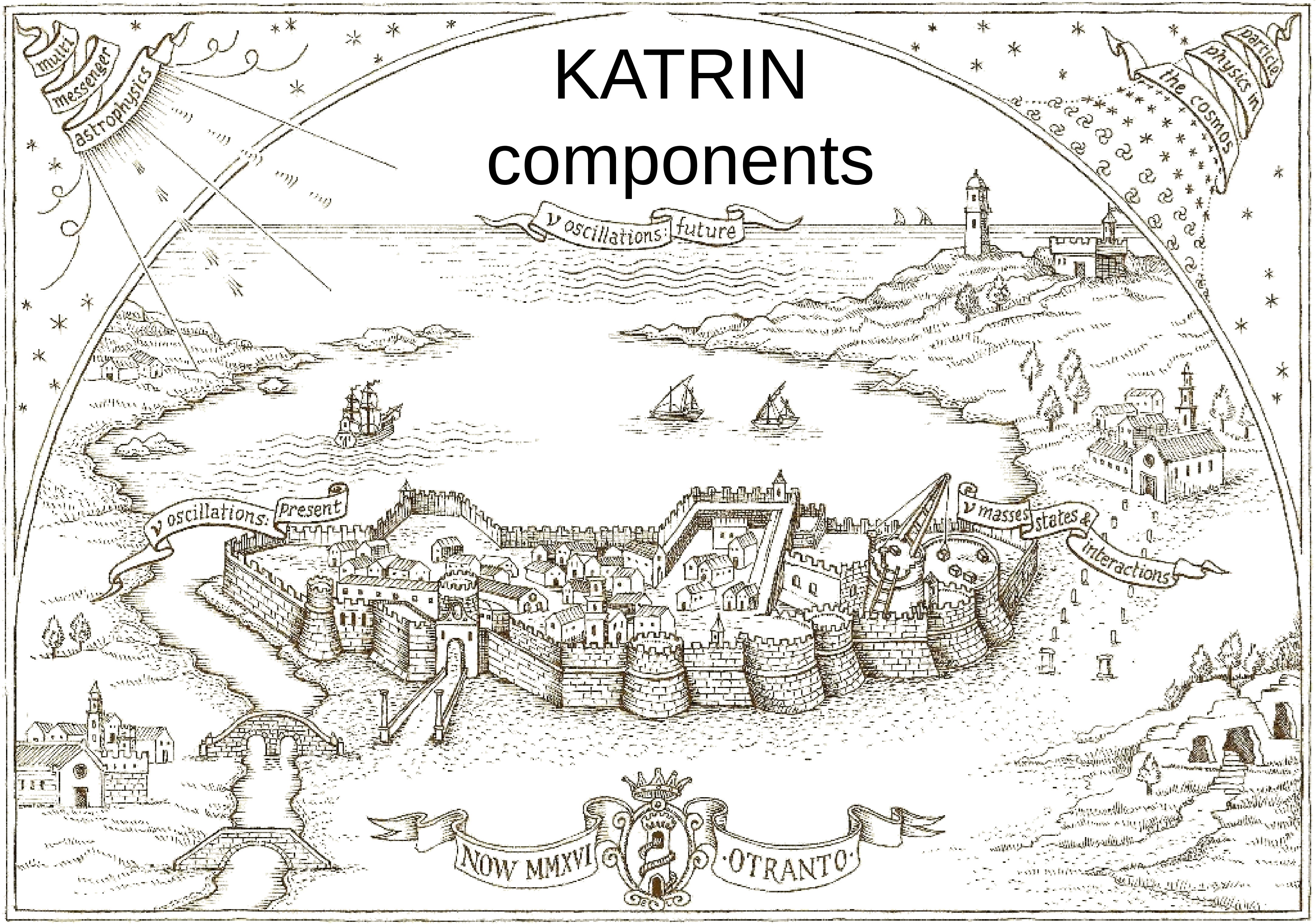
- **MAC-E filter**: count all ß-decay electrons with E > U_0 in focal plane detector
  - requires excellent source stability (and diagnostics), **R&D on differential read-out ongoing**



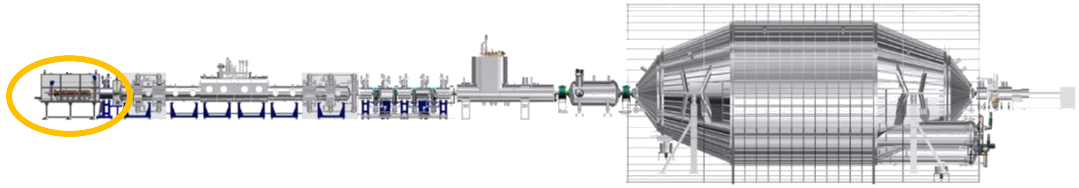
MAC-E principle: B and U_0 from source to detector



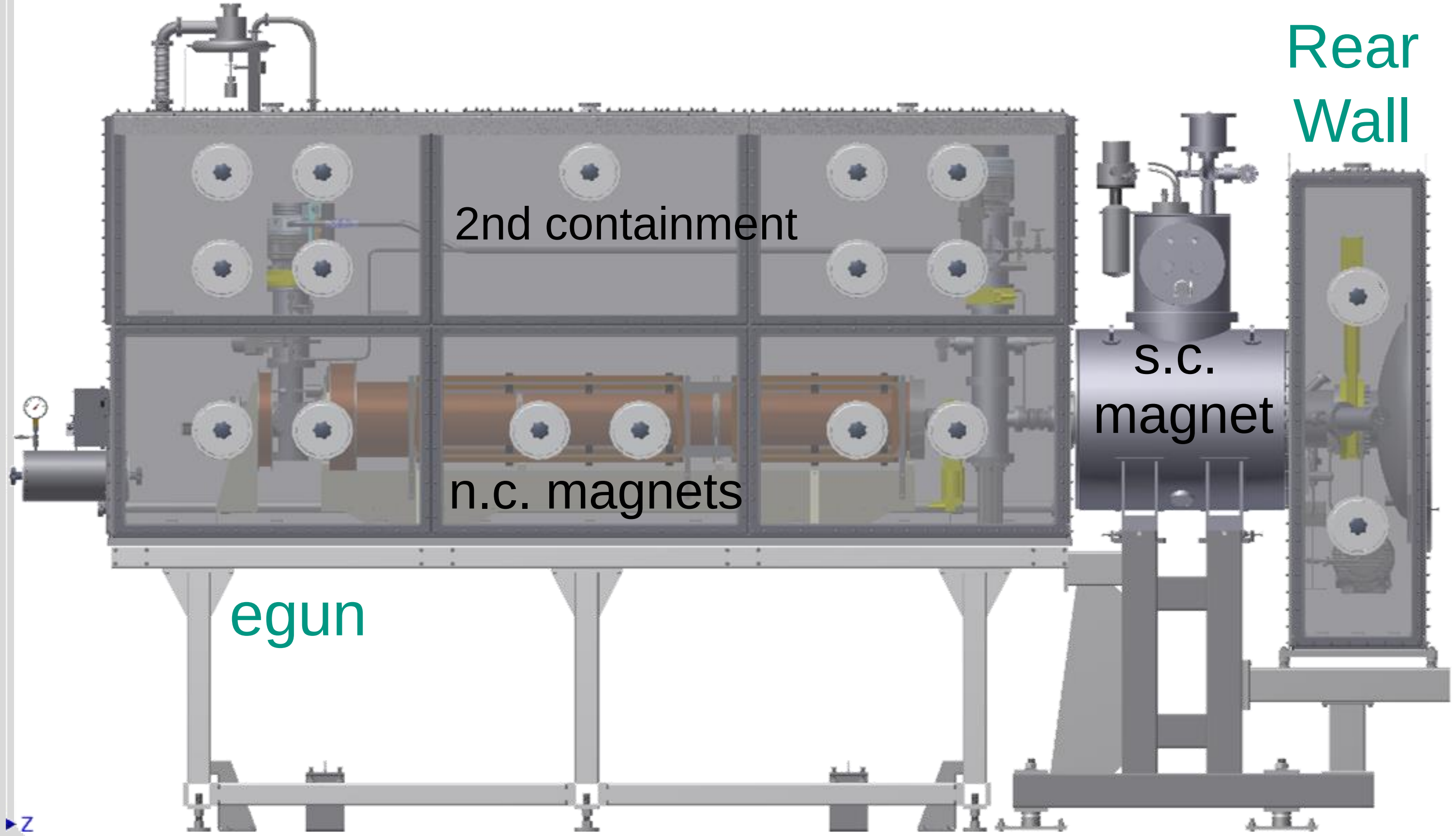
KATRIN components

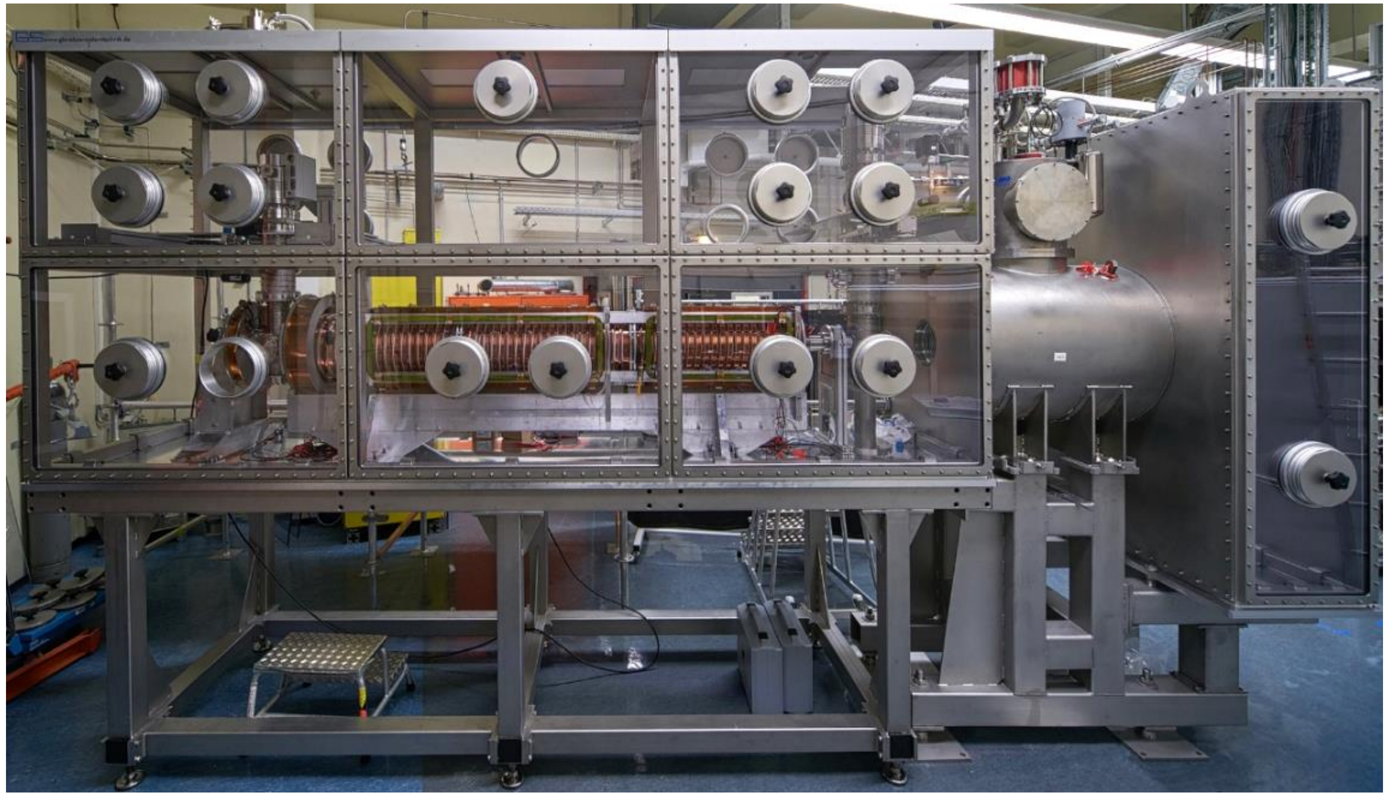


Rear Section for diagnostics

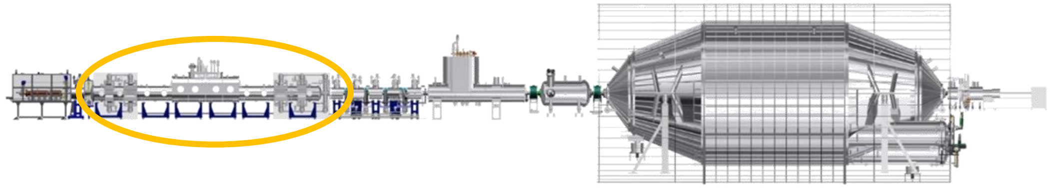


- **Rear Section:** an indispensible tool for diagnostics of source & spectrometer
  - **angular selective photoelectron gun**: spectrometer transmission & energy losses in source
  - **Rear Wall**: definition of source potential, neutralization of cold WGTS tritium plasma, online monitoring of tritium ß-decay activity via X-rays (BIXS)





WGTS – source cryostat



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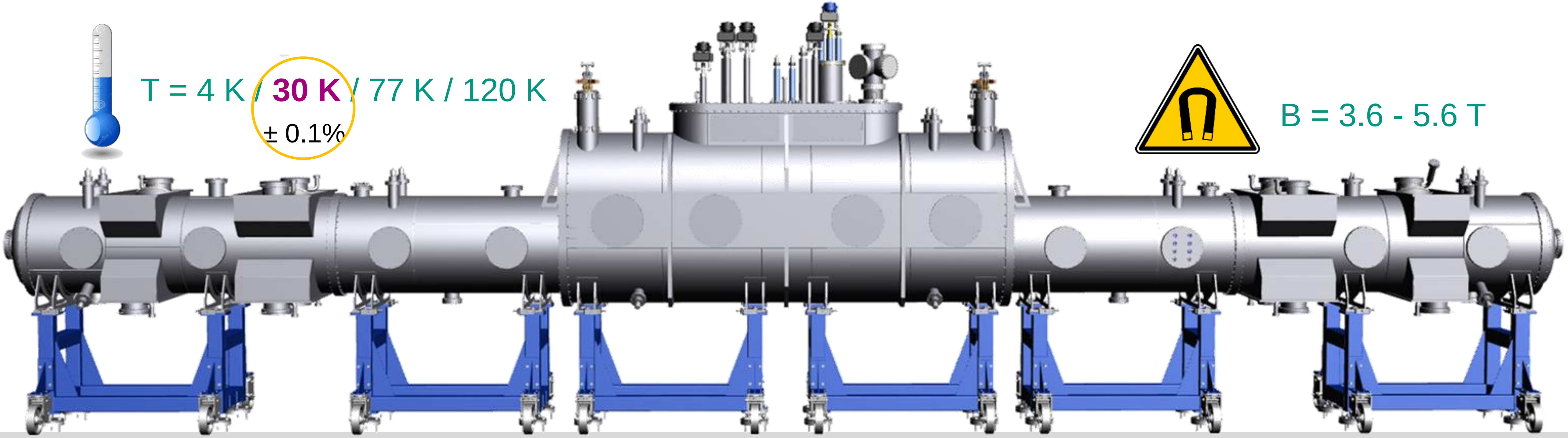
WGTS – source cryostat

- **complex tritium source cryostat**: 16 m length, 27 t total weight, ~ 40.000 pieces
  - 7 s.c. solenoids for adiabatic guiding of ß-decay electrons (3.6 – 5.6 T)
  - 7 cryogenic fluids for tritium operation (BT: 30-120K) & liquid He bath for magnets (4 K)
  - tritium beam tube @30K with stability and homogeneity of 0.1%
  - extensive instrumentations: >800 sensors (B, T, p, level, flow, …)



source-related challenges - overview

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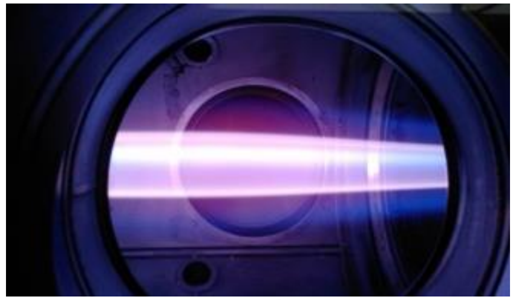
① injection pressure (± 0.1%)
② isotopic content (0.1% in < 60 s)
(also: add ^{83m}Kr)

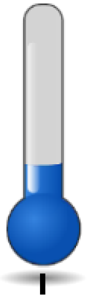
④ source potential (mV-scale)

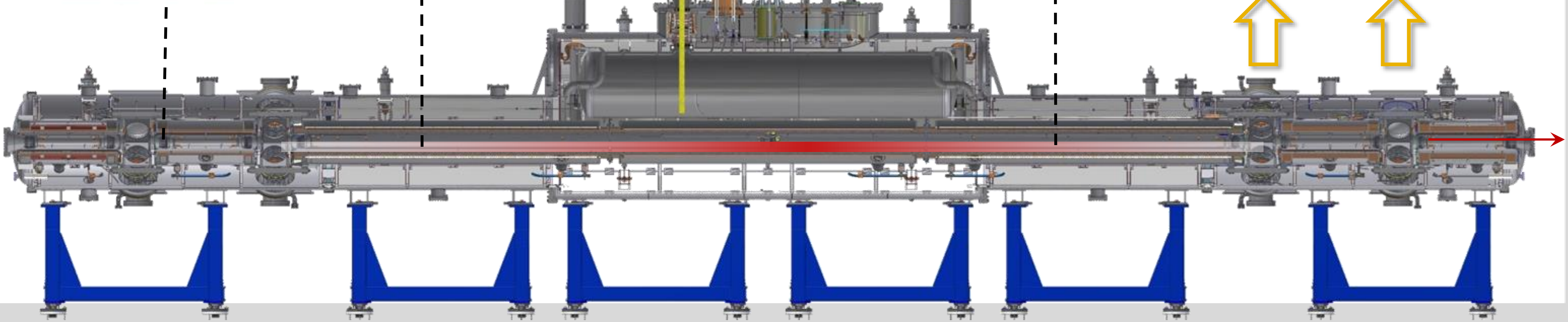
⑤ plasma properties (10^{11} T-ions/s)

③ beamtube temperature (27-125 K)

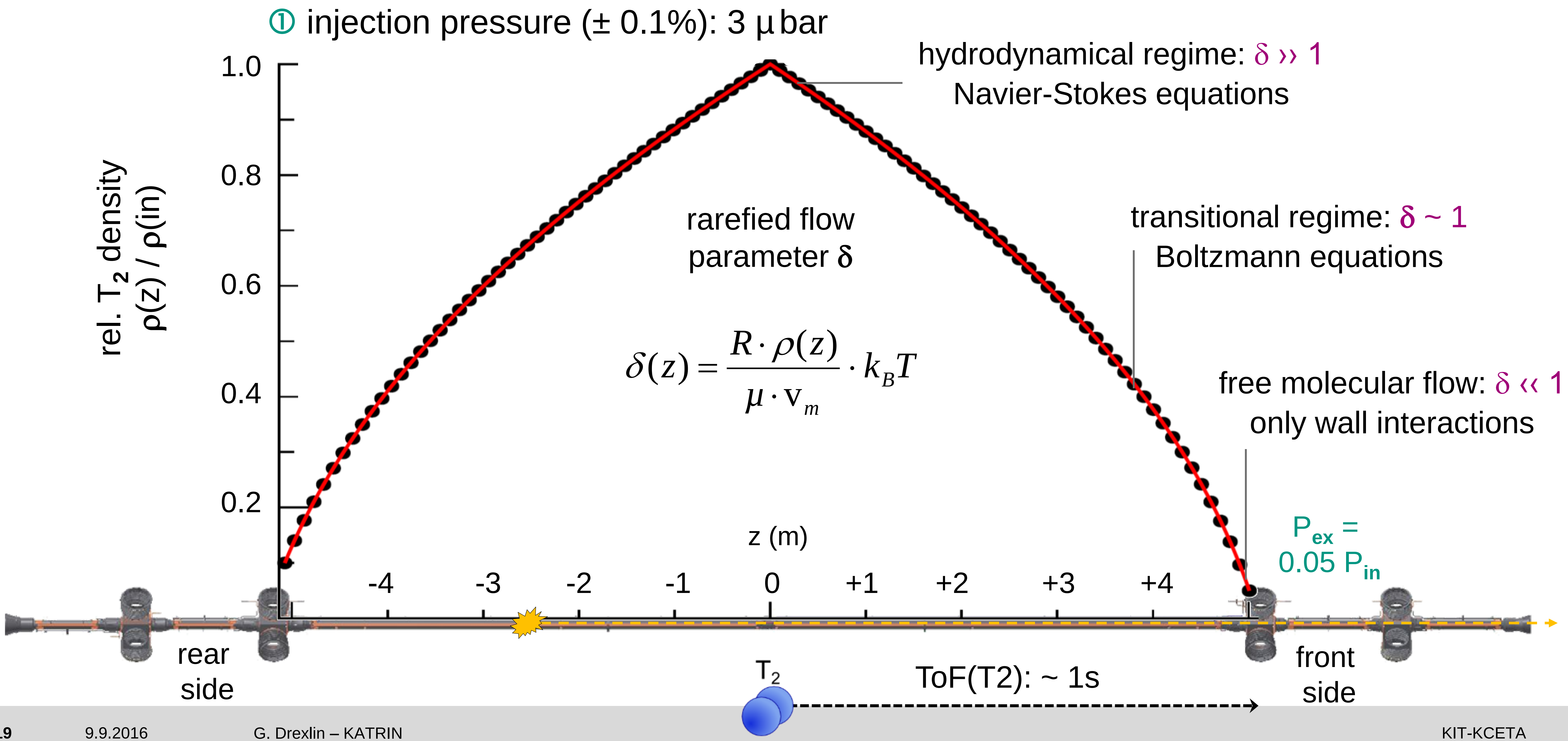
⑥ tritium retention (12 TMPs)



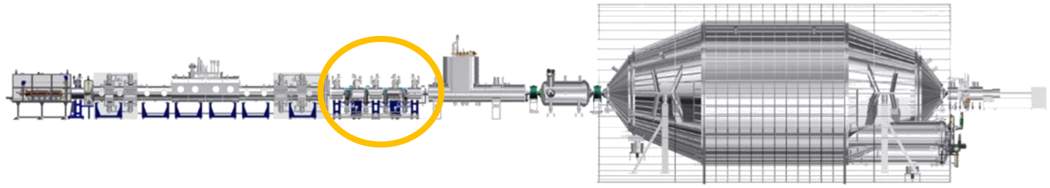




source challenges: injection & gas flow calculation

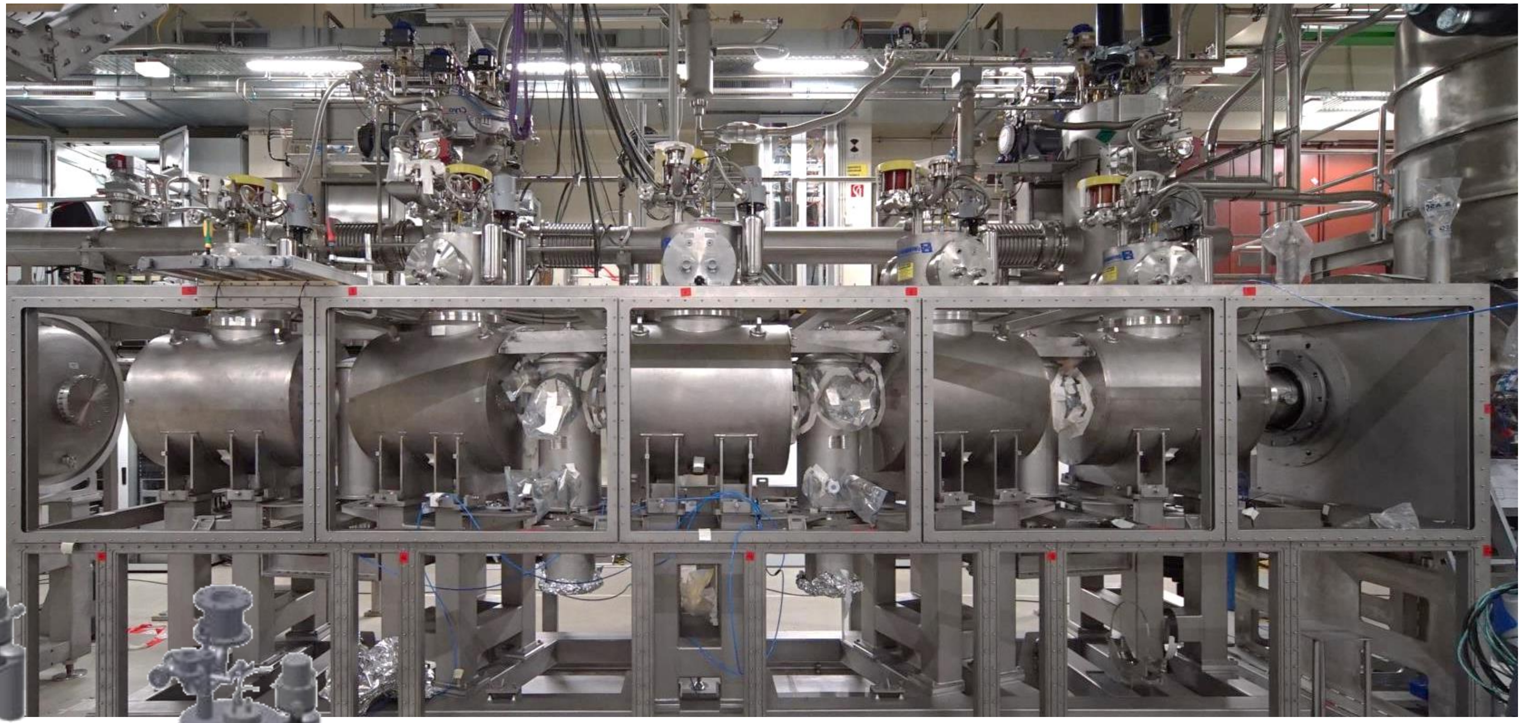


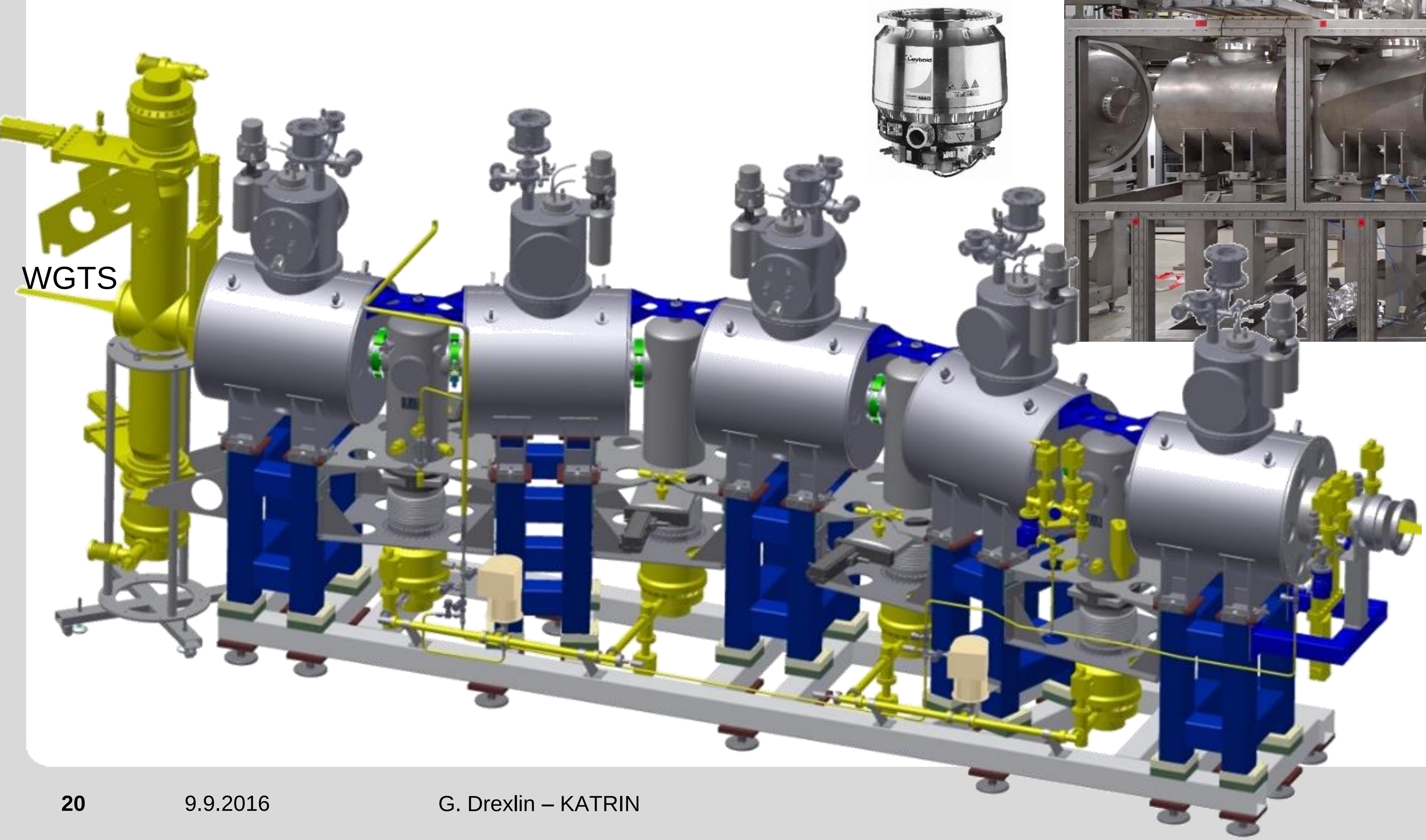
differential pumping - DPS



■ differential pumping section DPS2-F:

- serial pumping with TMPs → 10^5 reduction
- ion elimination with E × B → 10^7 reduction

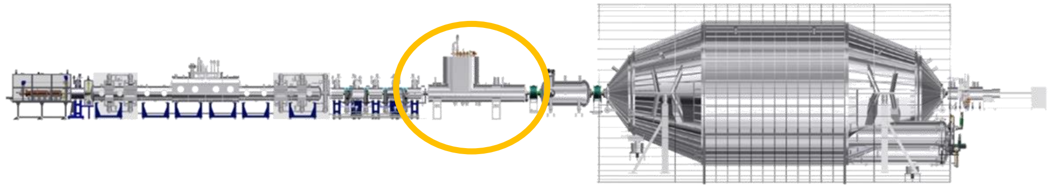




■ DPS instrumentation for ions:

- FT-ICR (ion diagnostics)
- dipoles (ion elimination)
- ring electrode (ion blocking)

cryogenic pumping - CPS



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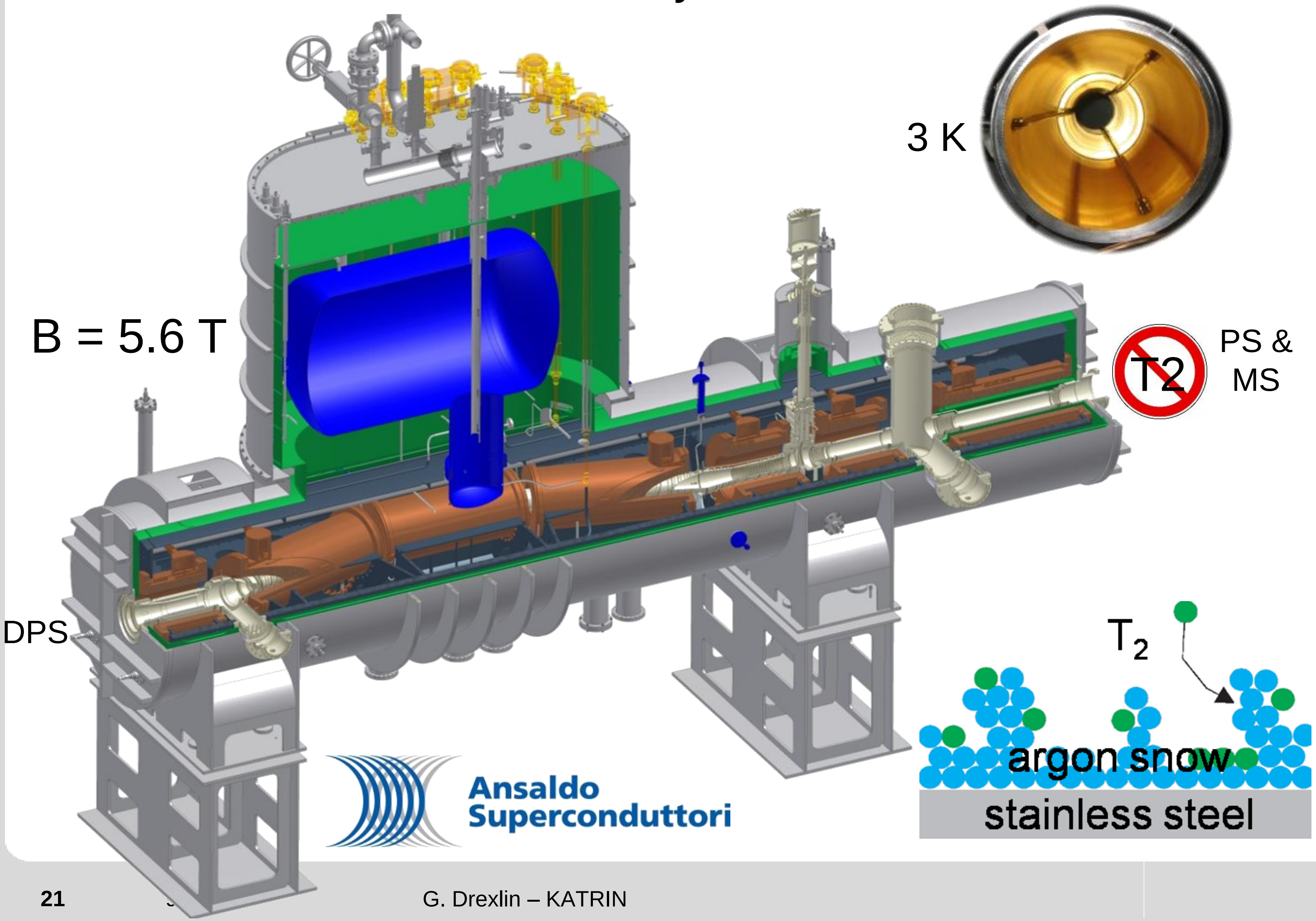
cryogenic pumping section CPS:

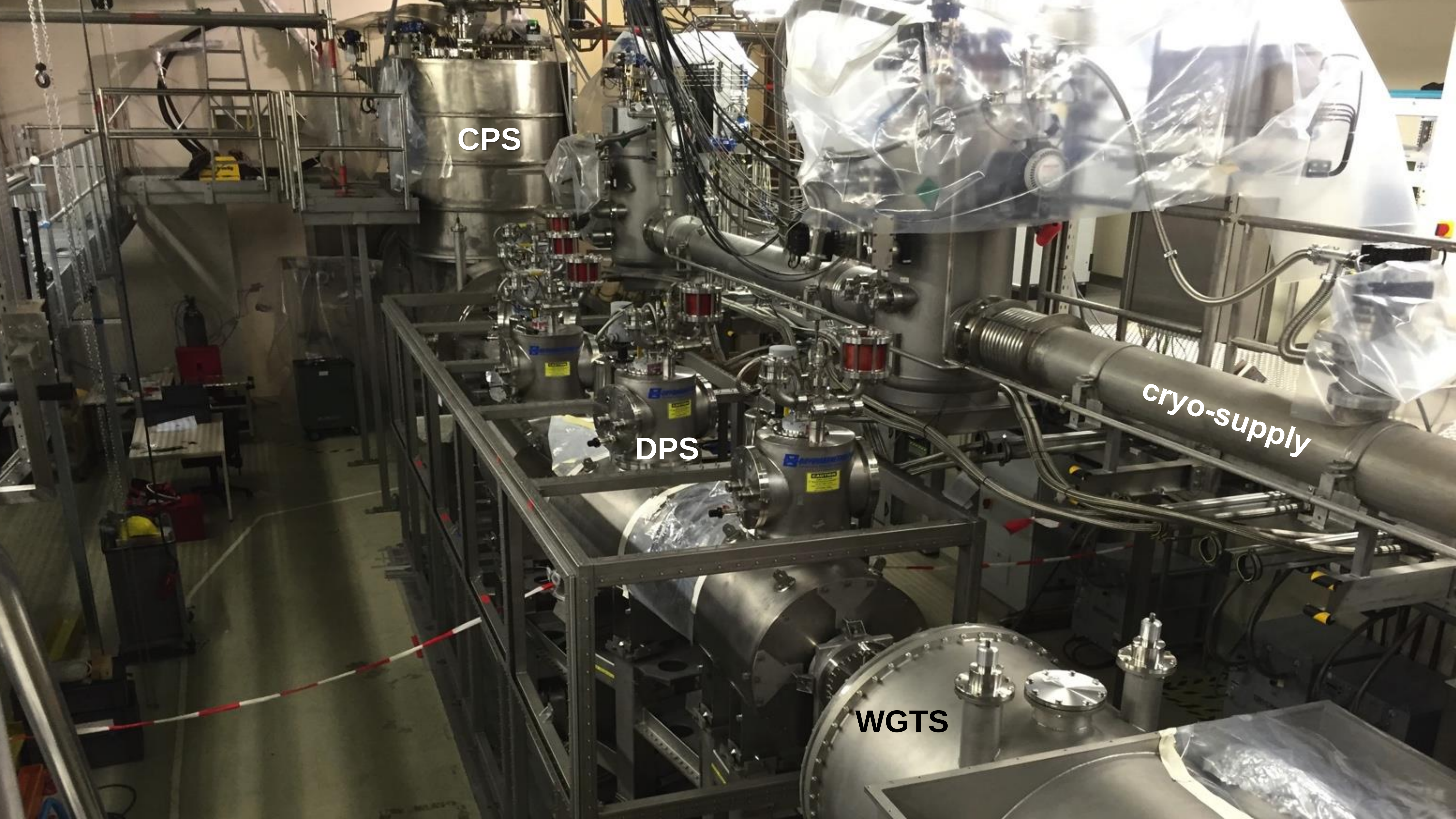
- 3K section with Ar-frost layer → >10^7 reduction of T_2



Ansaldo Superconduttori

CPS instrumentation:

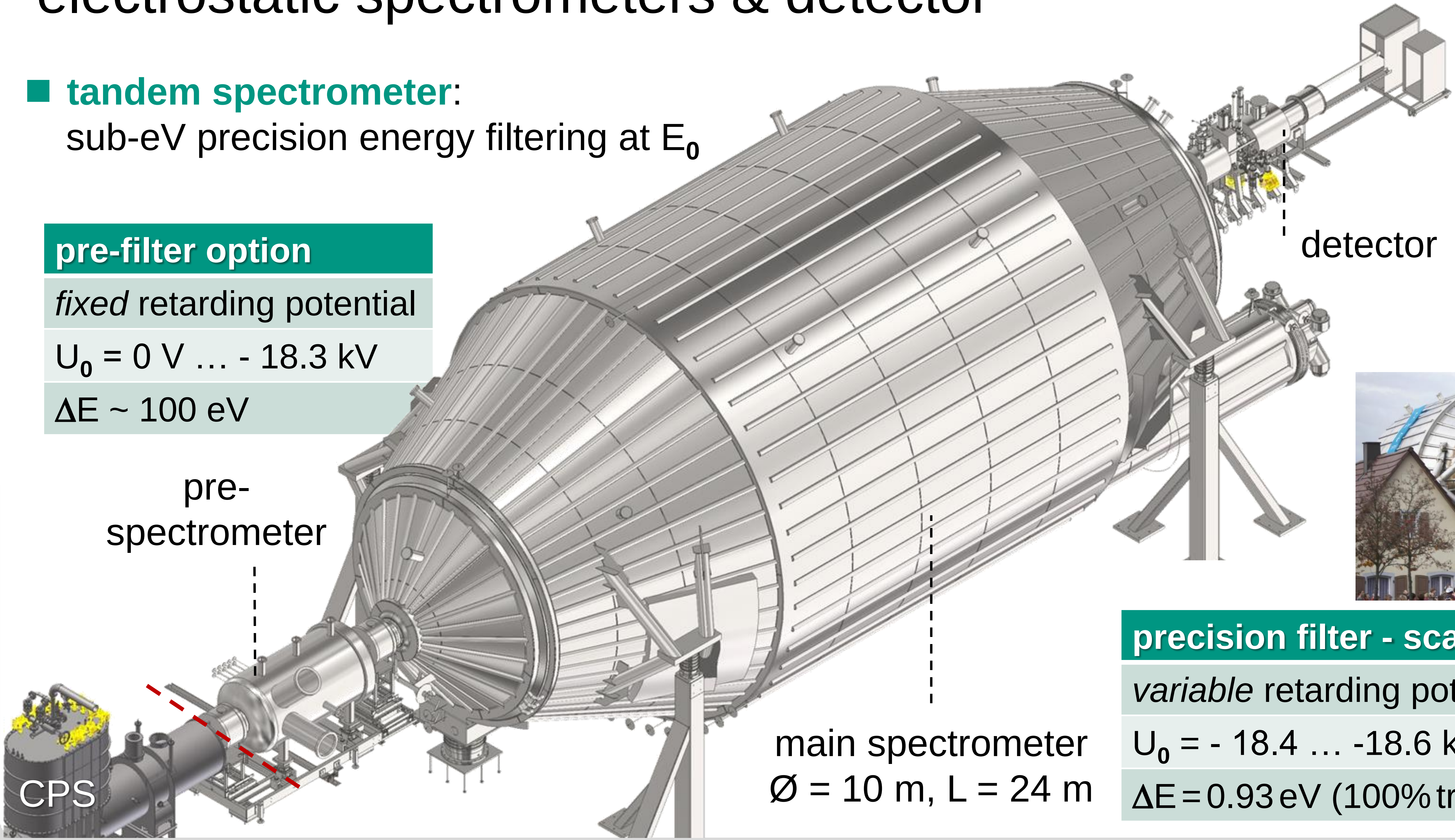
- condensed ^{83m}Kr-source (calibration)
- forward beam monitor (ß-activity)


CPS
DPS
cryo-supply
WGTS

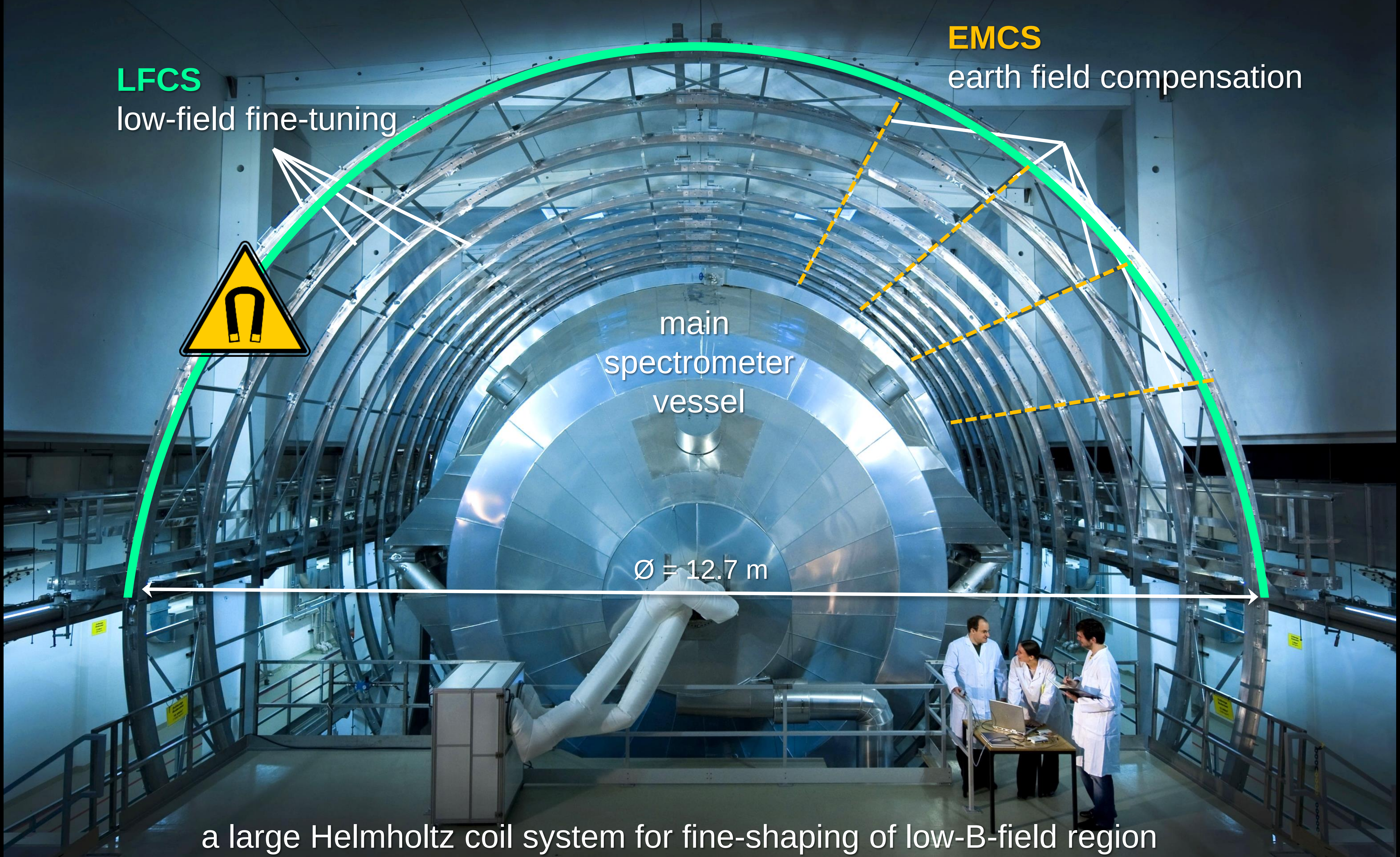
electrostatic spectrometers & detector

- **tandem spectrometer**:
  sub-eV precision energy filtering at E_0

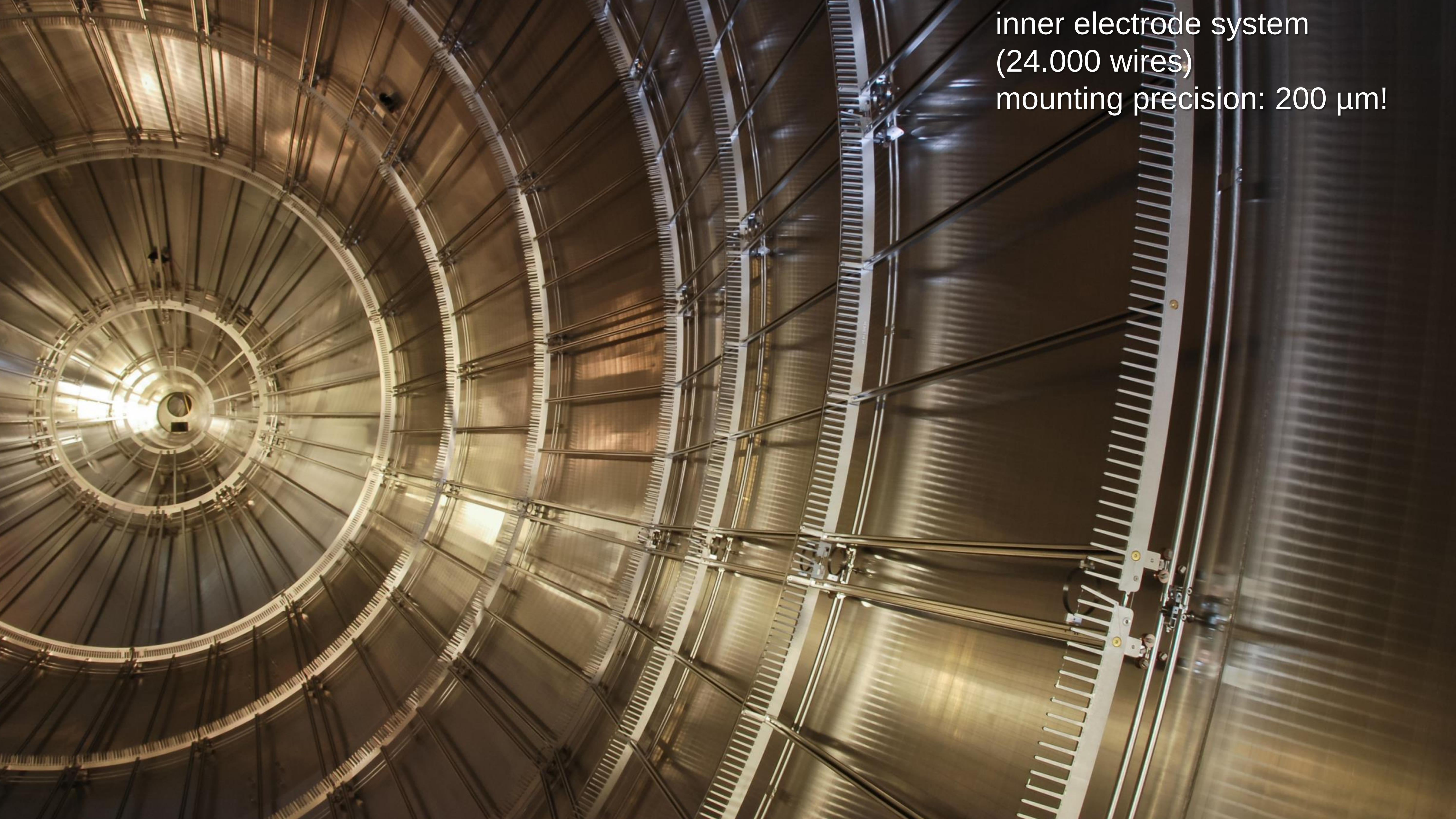
pre-filter option
fixed retarding potential
U_0 = 0 V … - 18.3 kV
ΔE ~ 100 eV



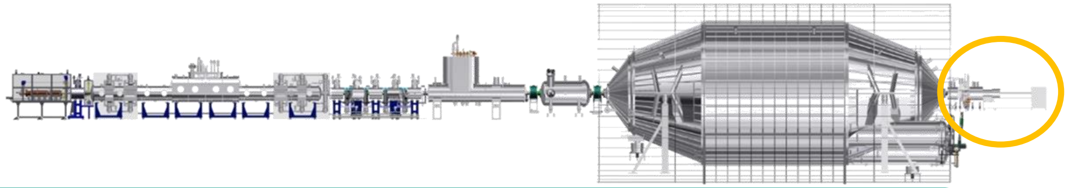
precision filter - scanning
variable retarding potential
U_0 = - 18.4 … -18.6 kV (ppm-scale)
ΔE = 0.93 eV (100% transmission)

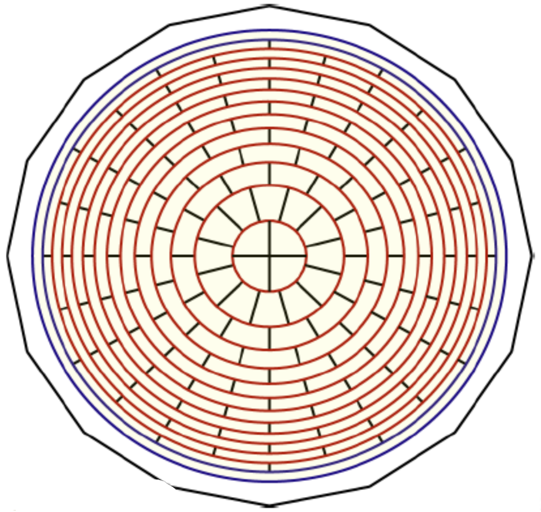


a large Helmholtz coil system for fine-shaping of low-B-field region

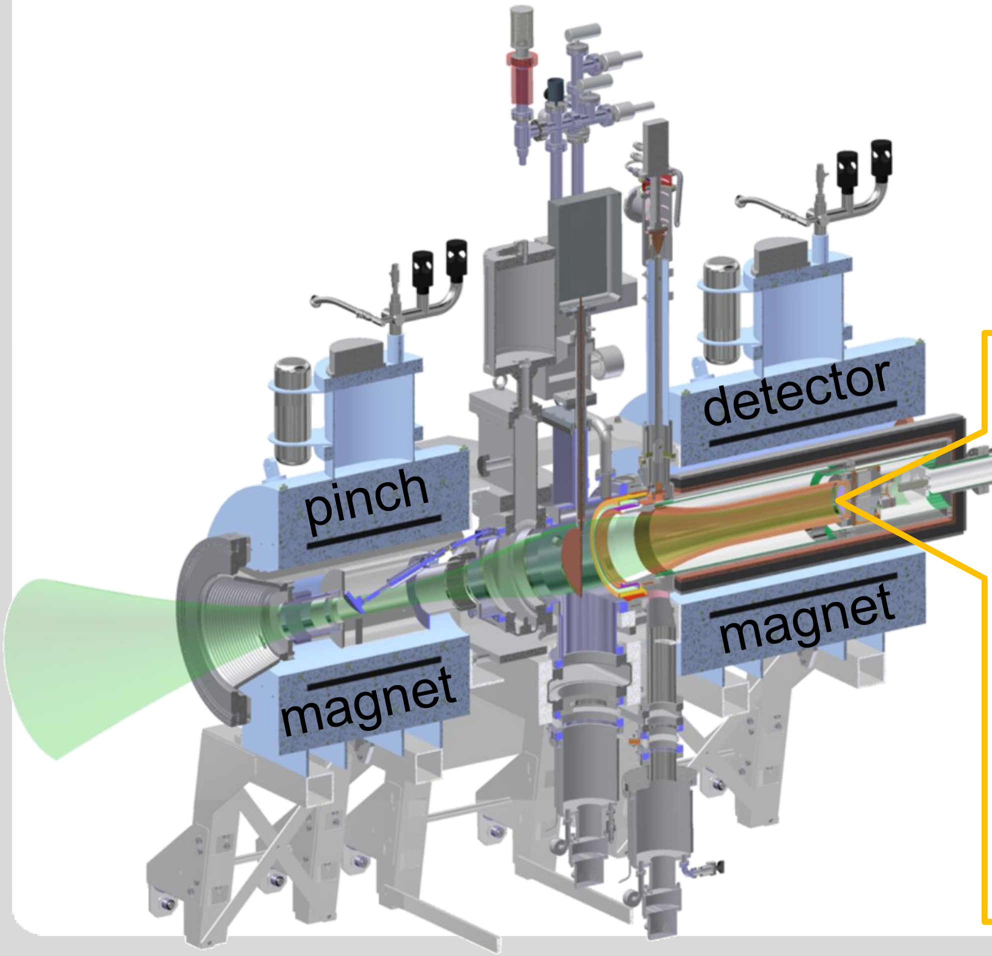

inner electrode system
(24.000 wires)
mounting precision: 200 µm!

Focal Plane Detector system

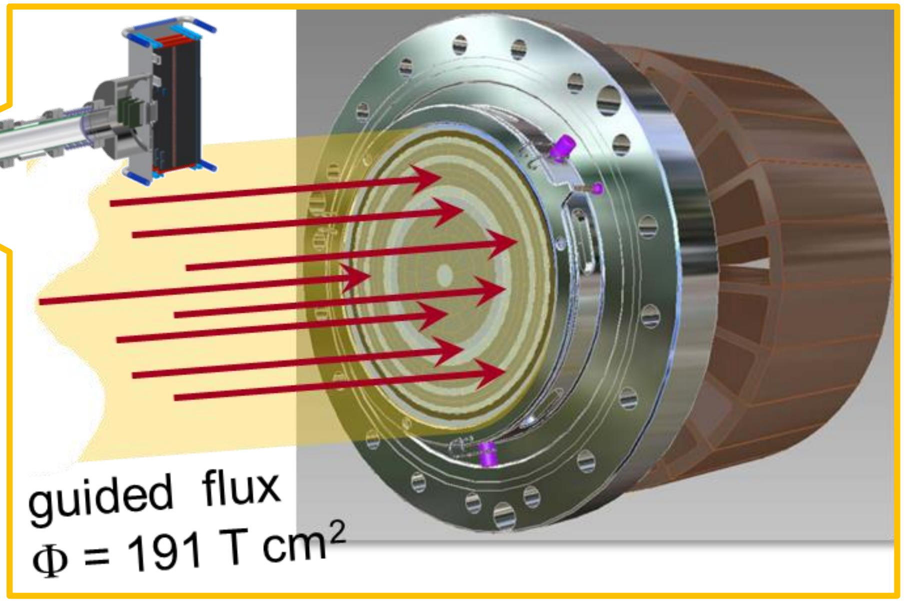




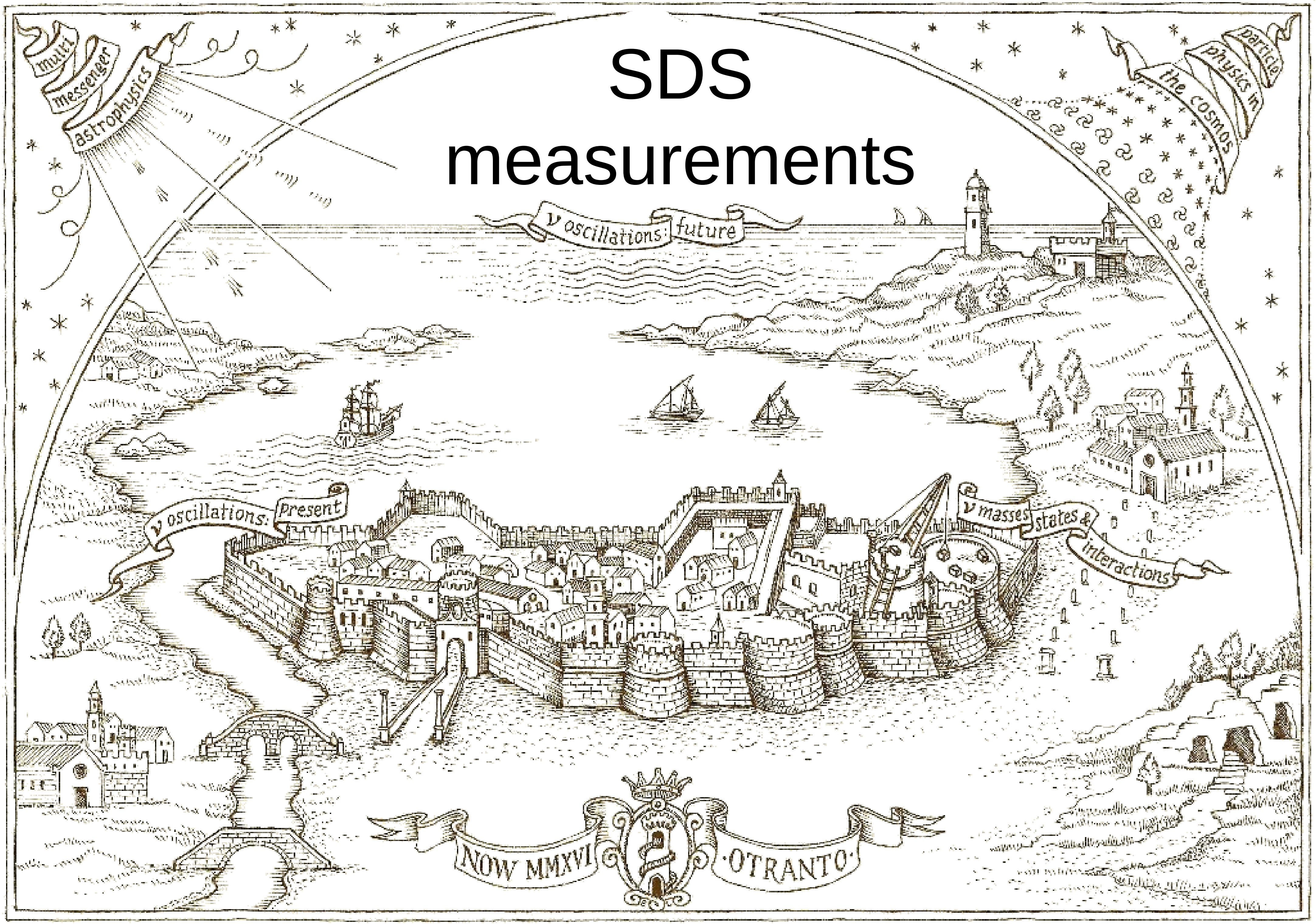
- Detection of transmitted electrons with **Si-PIN detector array**
  - 148 pixels (A = 44 mm² each) with ~ 100 nm top deadlayer in 500 µm wafer
  - 12 rings, each consisting of 12 pixels each, central 4-pixel bullseye
  - active scintillator µ-veto & passive (Pb, Cu) shielding, PAE: + 10 kV



position resolution over entire flux tube (radius, azimuth)

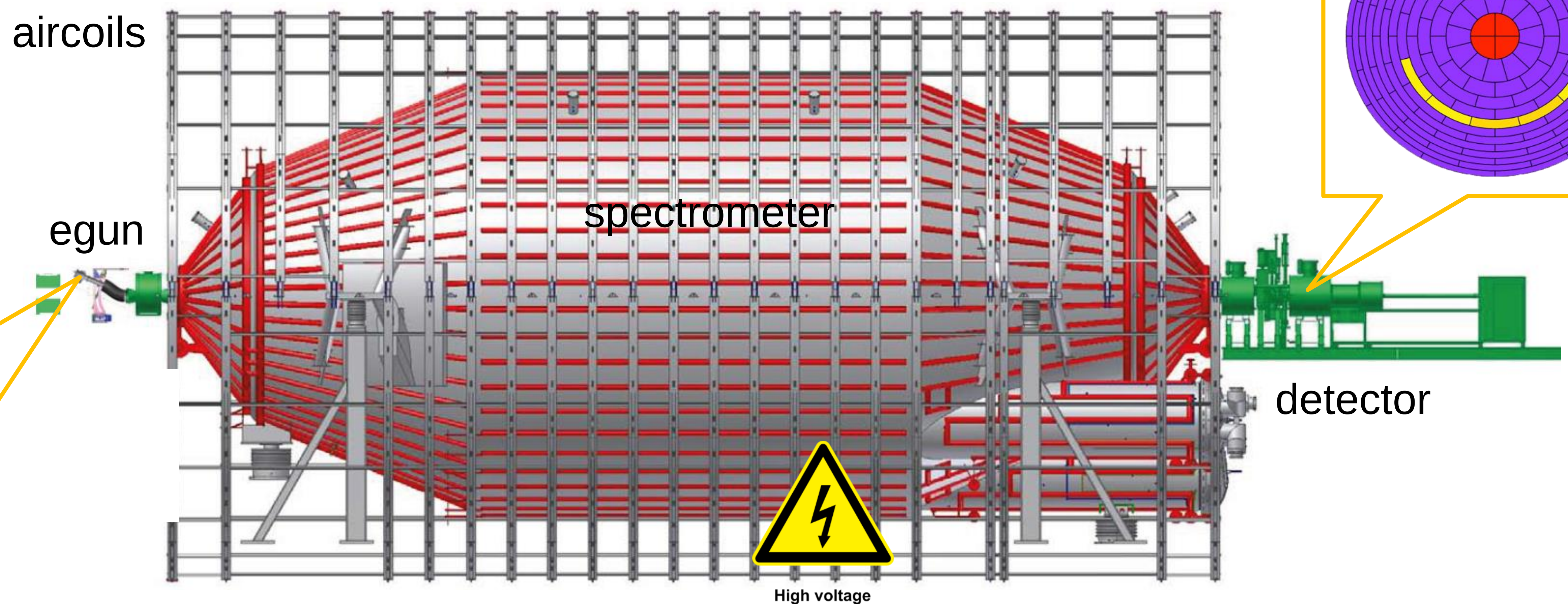


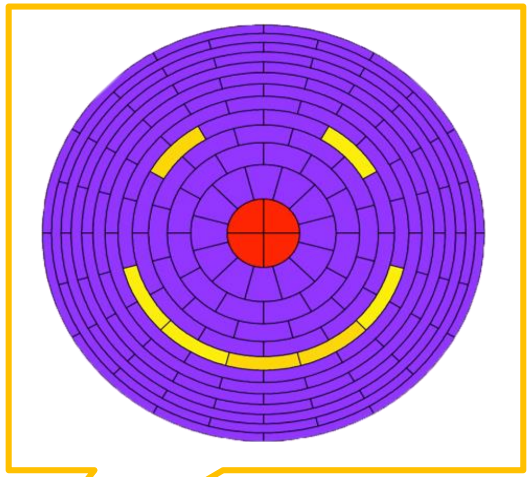
SDS measurements



spectrometer commissionng measurements 2013-15

- **over 12 months of continuous spectrometer measurements** to verify:
  - functionality of all components: UHV, HV, B-fields, SC, DAQ,…
  - MAC-E filter characteristics via egun transmission studies
  - refine background model & optimisation of bg-reduction methods

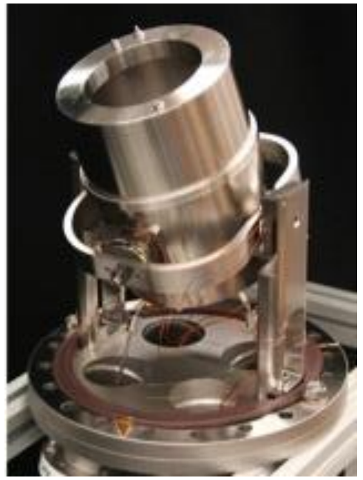


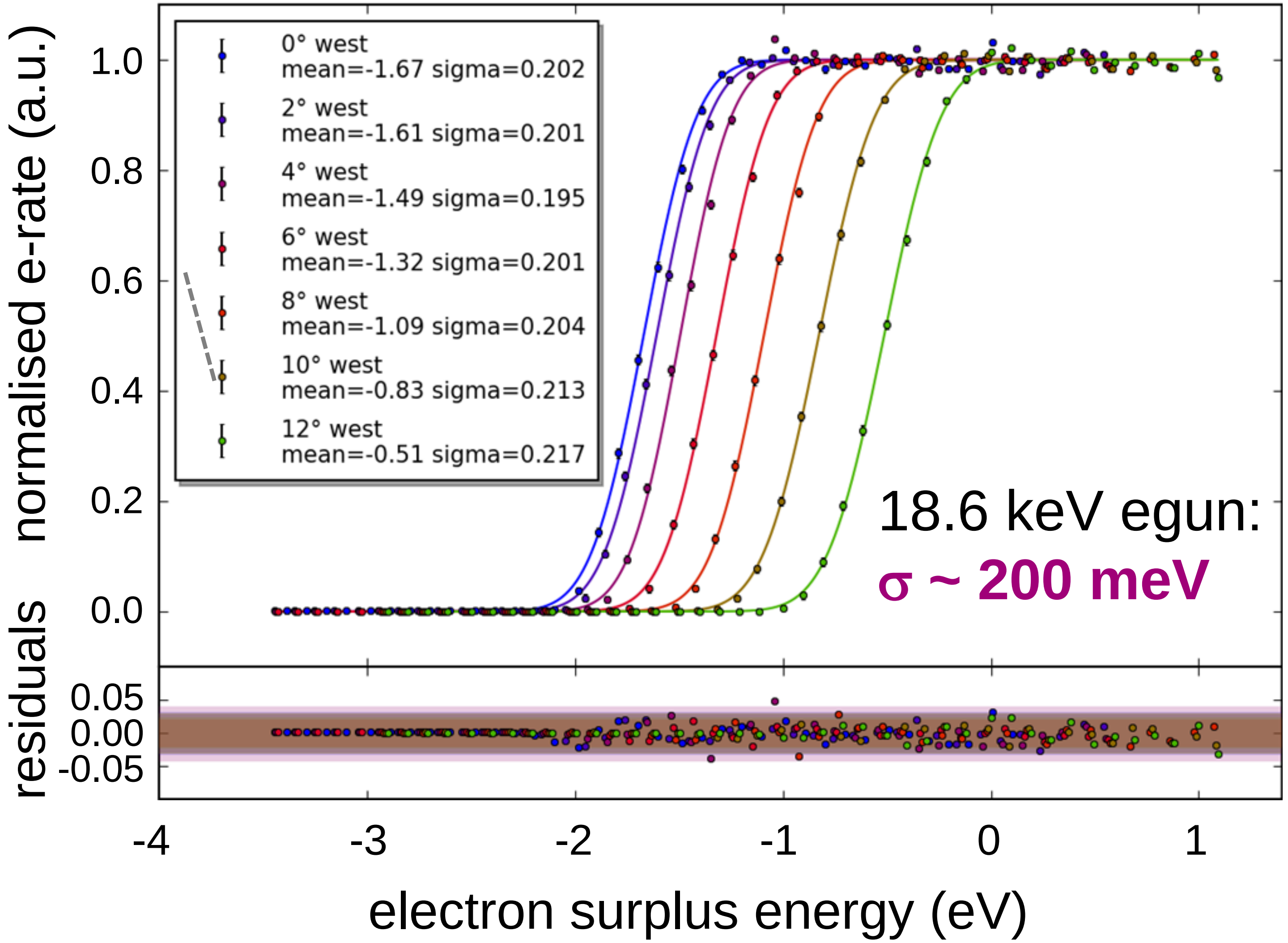


Main spectrometer: MAC-E characteristics

- **Main spectrometer** works as high-resolution MAC-filter:
  - sharp transmission function for 18.6 keV electrons from egun, HV precision on 10 mV scale

small angular spread

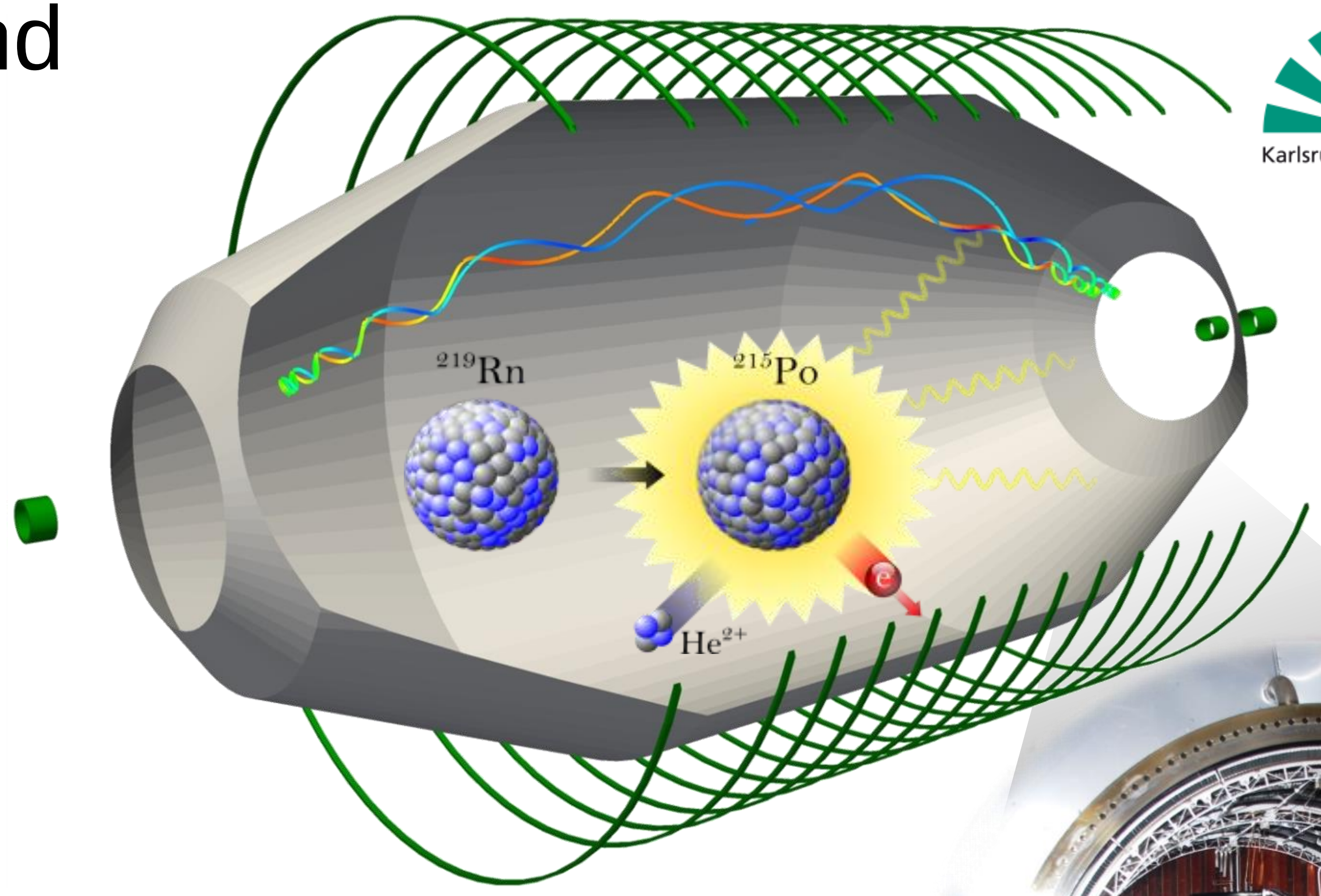


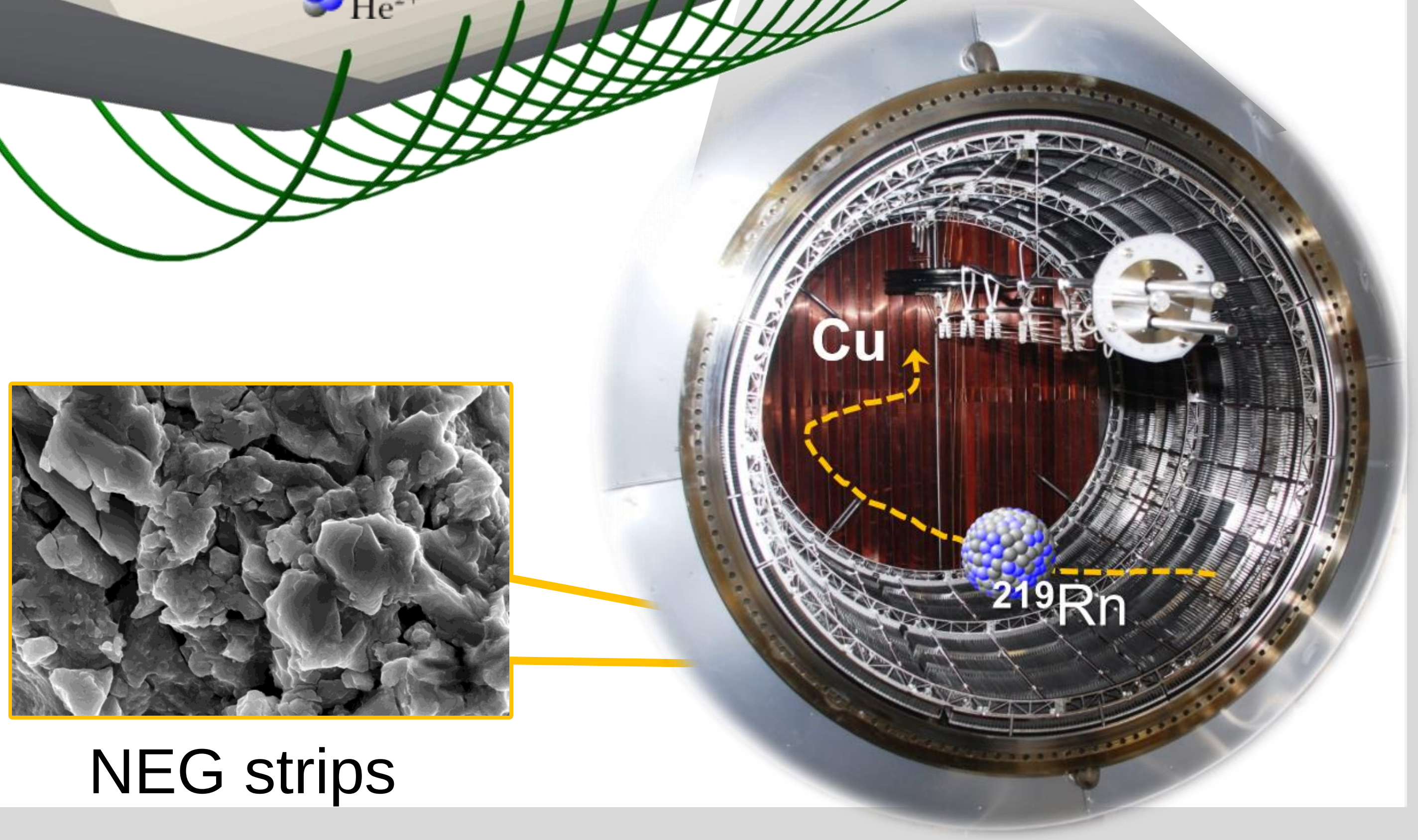


width still limited by finite egun emission energy spectrum

Radon-induced baclground

- **main spectrometer** background:
  no contributions observed from
  - µ-induced secondaries
  - environmental γ´s
- Background stems only from
  neutral, unstable atoms in UHV
- ^{219}Rn atoms emanate from large
  surface of NEG pumps (2 km strips)
  - eV…keV electrons from α-decay
  - correspnding bg-rate: ~0.5 cps
- countermeasure (factor 20):
  - 3 LN2-cooled Cu-baffles in front of NEG
  - cryotrap eliminates ^{219}Rn-propagation
  - remaining bg level: ~0.5 cps

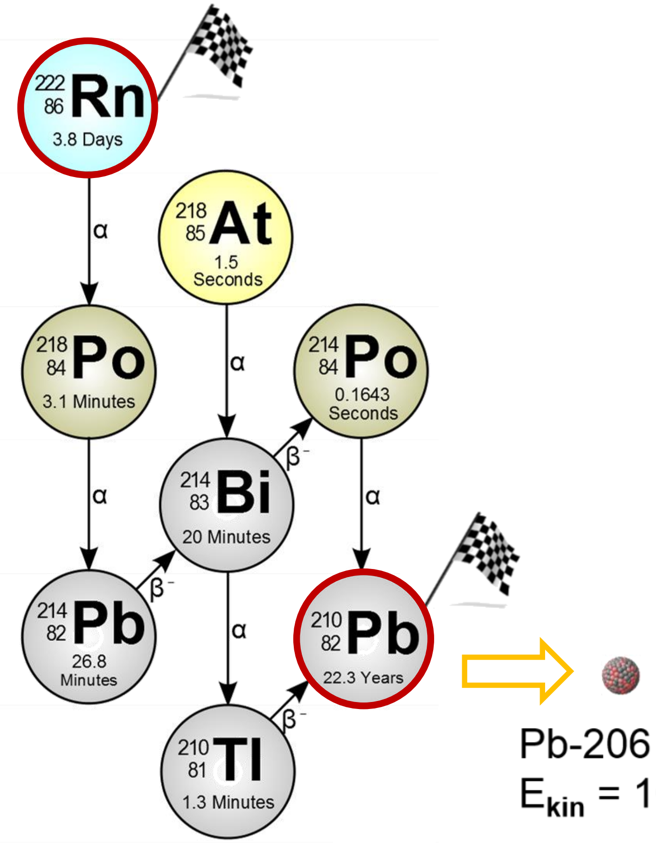




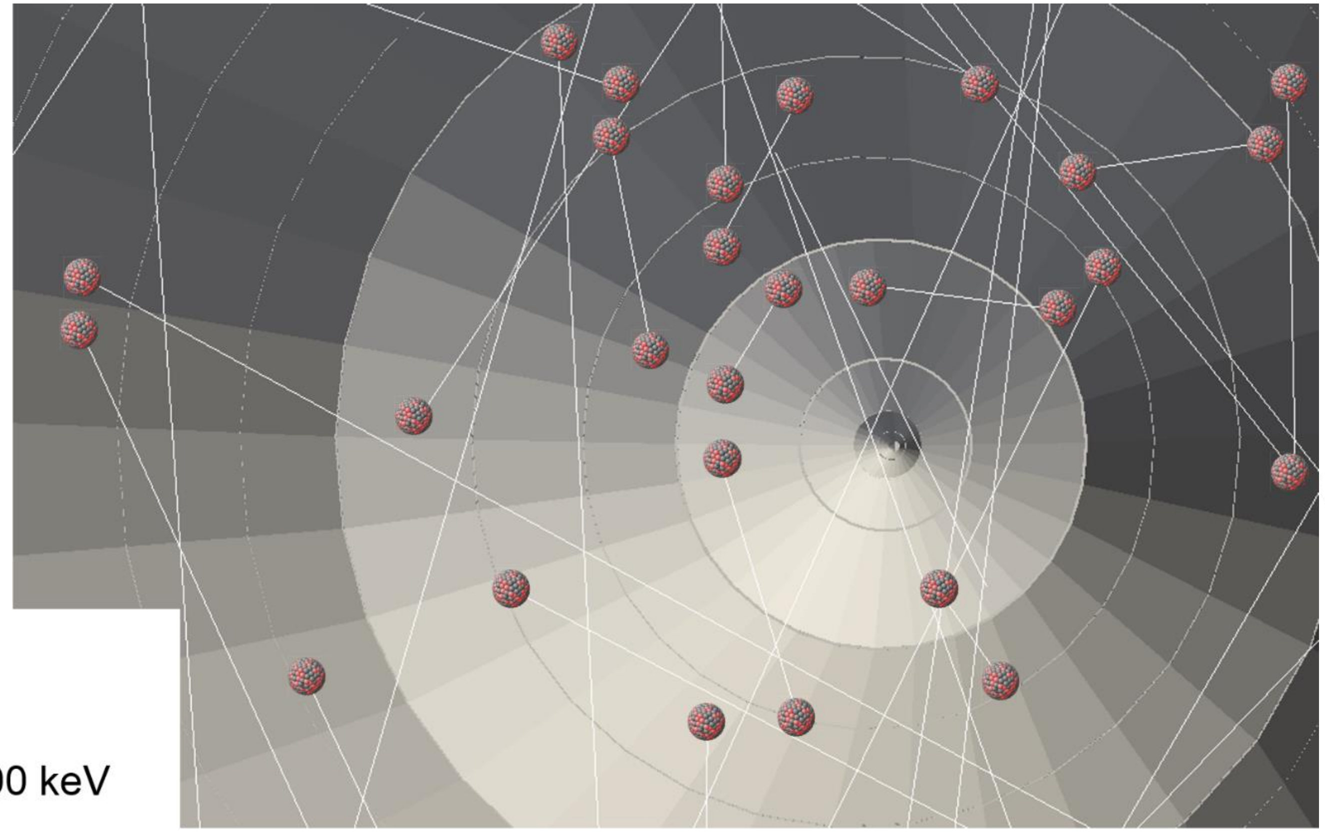
NEG strips

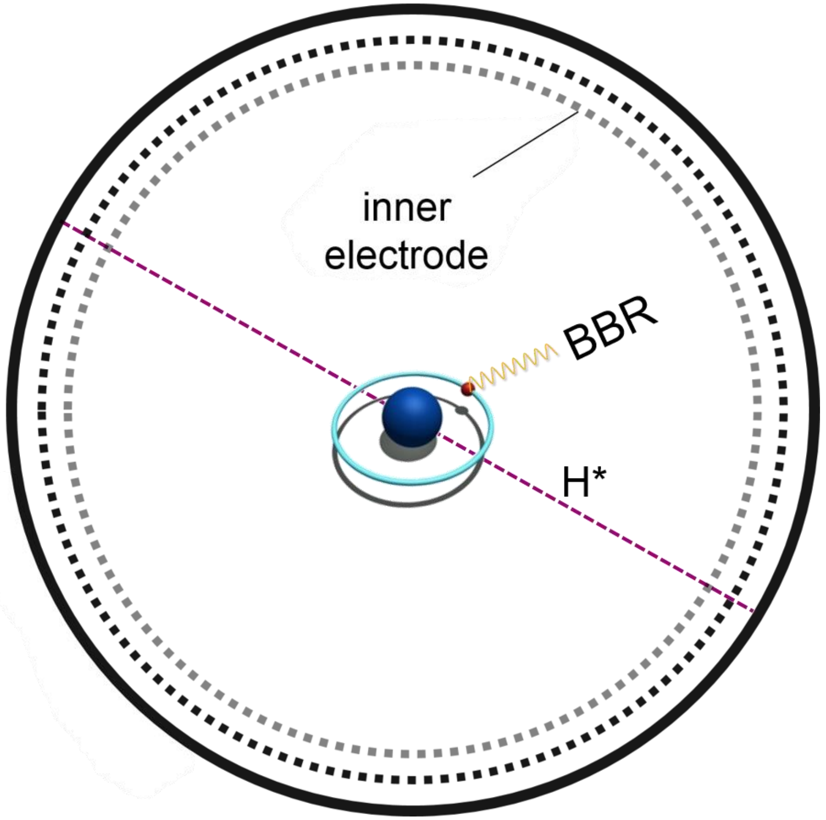
^{206}Pb-recoil induced H-Rydberg states

- **highly excited H-atoms (Rydberg states) produced by Pb-206 recoils**
  - long-term forced ventilation of spectrometer, ^{222}Rn α-decays results in ^{210}Pb implantation
  - single ^{206}Pb recoil ions generate large clouds of H-Rydberg states, which propagte in UHV
  - small number of H*- atoms is ionized in UHV by thermal BBR from spectrometer
  - isotropic generation of low-energy (<1 eV) electrons in active flux tube volume (0.5 cps)



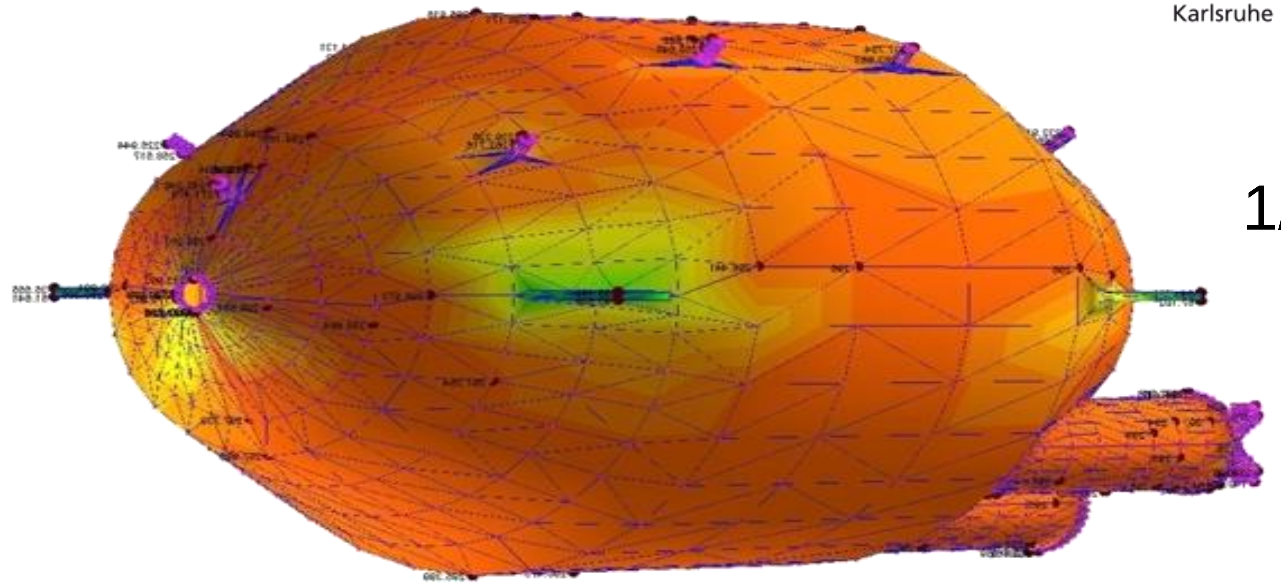
Pb-206
E_{kin} = 100 keV





Rydberg-background: mitigation strategies

- **extended bake-out phase of MS**:
  ~3 weeks of bake-out at 470-500 K
  reduce number of H2O & H-atoms
  on inner spectrometer surface to
  reduce number of H-Rydberg states
  (already successful in SDS2 in 2015)

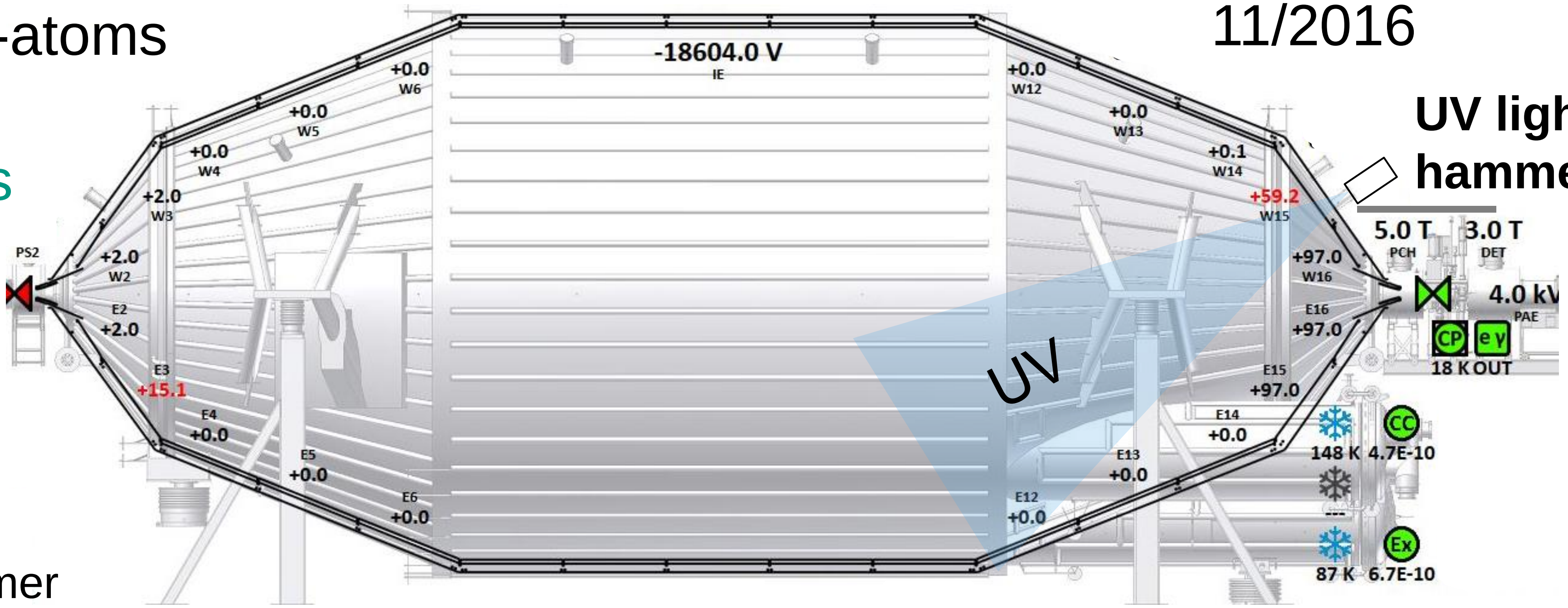


1/2017

- **intense extended UV-illumination of MS**:
  UV-induced desorption of H2O & H-atoms
  from inner spectrometer walls to
  reduce number of H-Rydberg states

11/2016

Heraeus Lighthammer



UV light hammer

KATRIN
first light & future

Source and Transport System – STS

- **Commissioning of source components**:

RS: assembly of egun, preparing for „First Light“ via UV-illumination of Rear Wall

WGTS: active cool-down, ongoing preparations for tests of s.c. magnet system (4 K today!!) & long-term tests of 2-phase BT cooling system

DPS: magnet filling with LHe & pumping of BT-vacuum, test of instrumentation

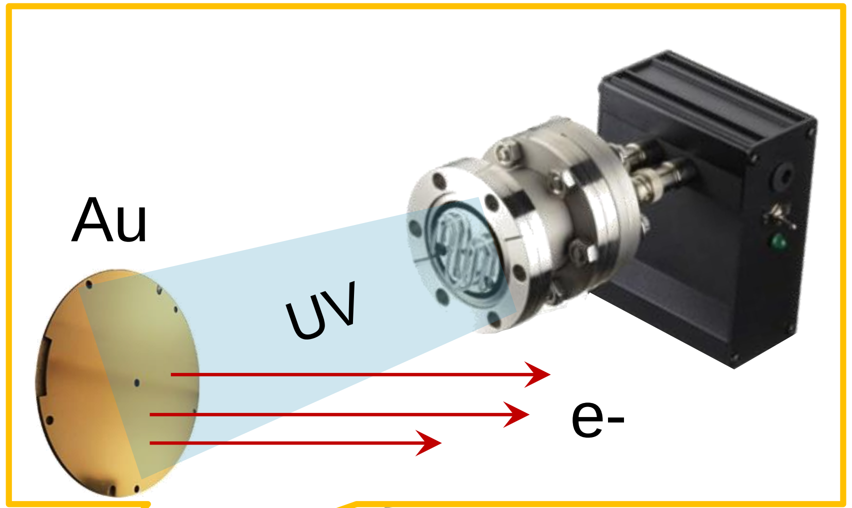
CPS: successful cryogenic & magnet commissioning, full thermal cycle RT → 3K → RT

Loops: ongoing manufacture of piping & PCS7 control

October 2016: all STS components ready for „First Light“ measurements

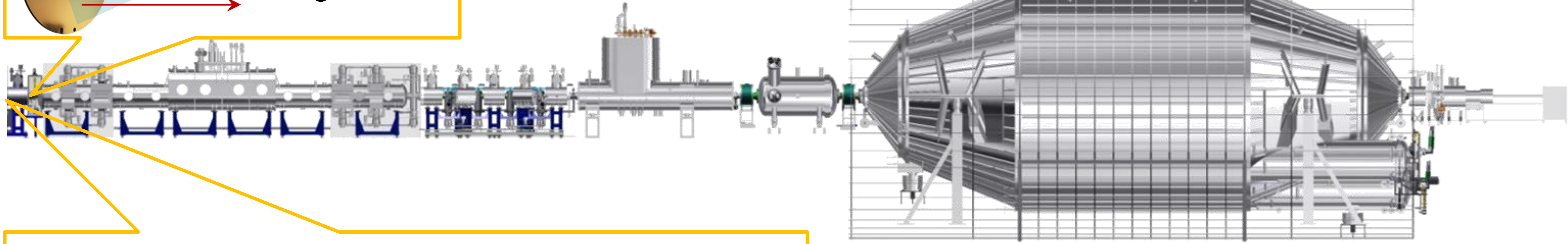
KATRIN First Light: Alignment & Ion Systematics

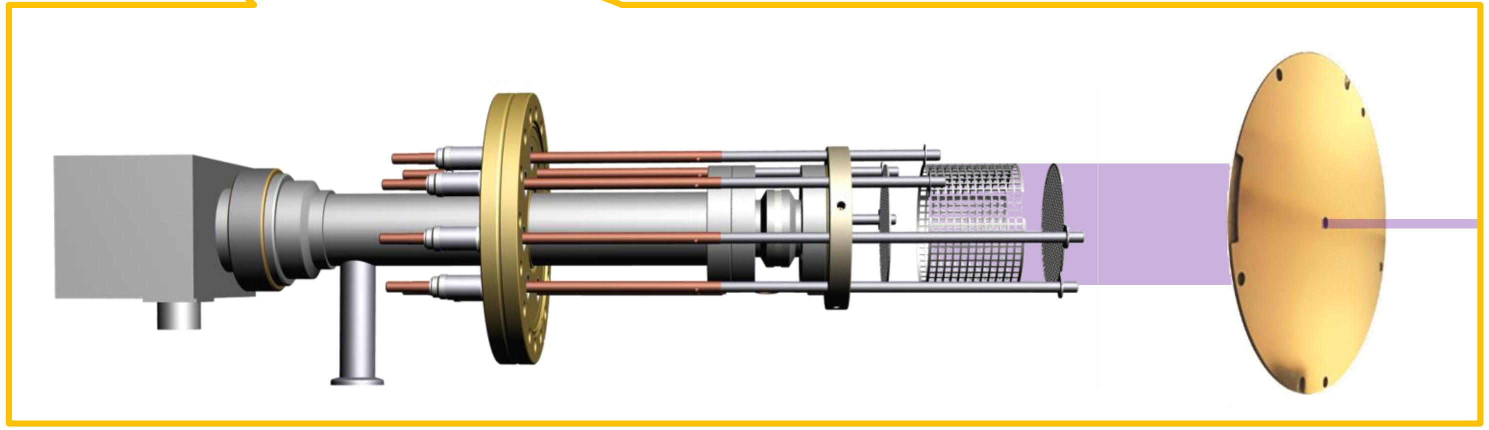
Karlsruhe Institute of Technology



- **Alignment Measurements:** collisionless & adiabatic transport of low-energy electrons in flux-tube of 191 T cm² (start: Oct, 14 2016)

FirstLight

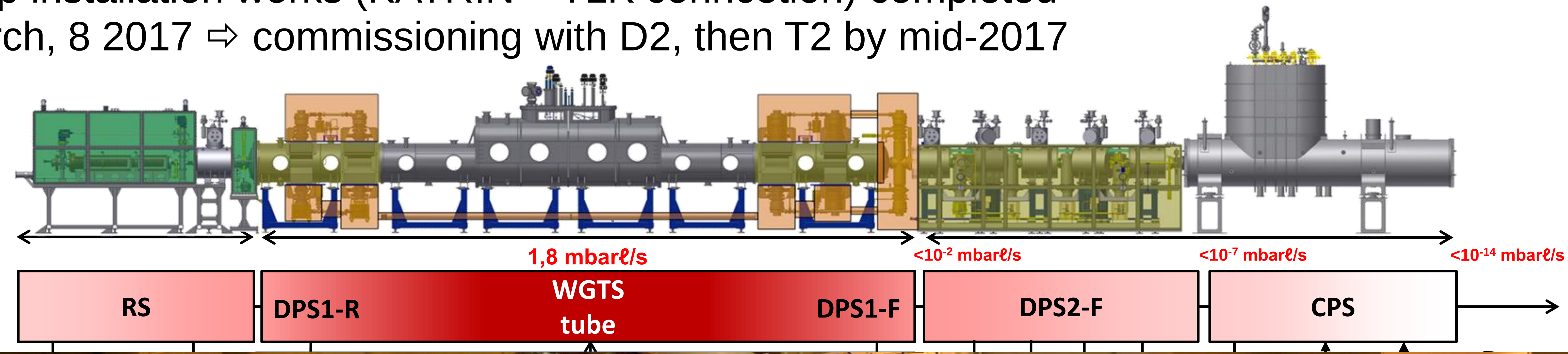




- **Ion systematics:** low-energy pencil beam of deuterium ions to study ion blocking & ion removal via $E \times B$ drift

KATRIN future: tritium loops in Q1-Q2/2017

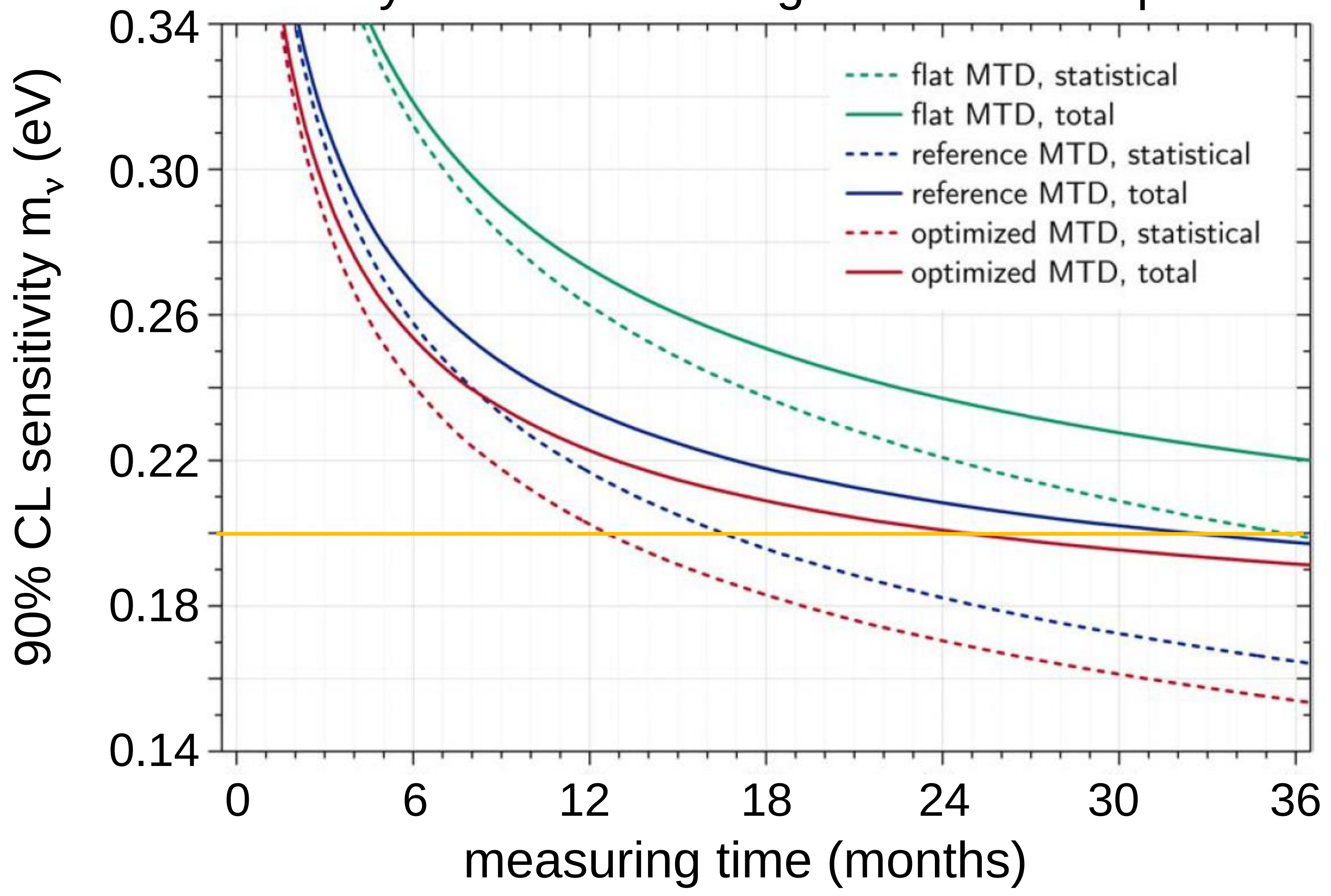
- Loop installation works (KATRIN – TLK conncetion) completed March, 8 2017 ⇨ commissioning with D2, then T2 by mid-2017



KATRIN - reference neutrino mass sensitivity

- **KATRIN reference ν-mass sensitivity** for 3 ´full beam´ (5 calendar) years:

analysis for nominal bg-level of 10 mcps



sensitivity $m(\nu_e)$ = 0.2 eV (90% CL)

0.35 eV (5σ)

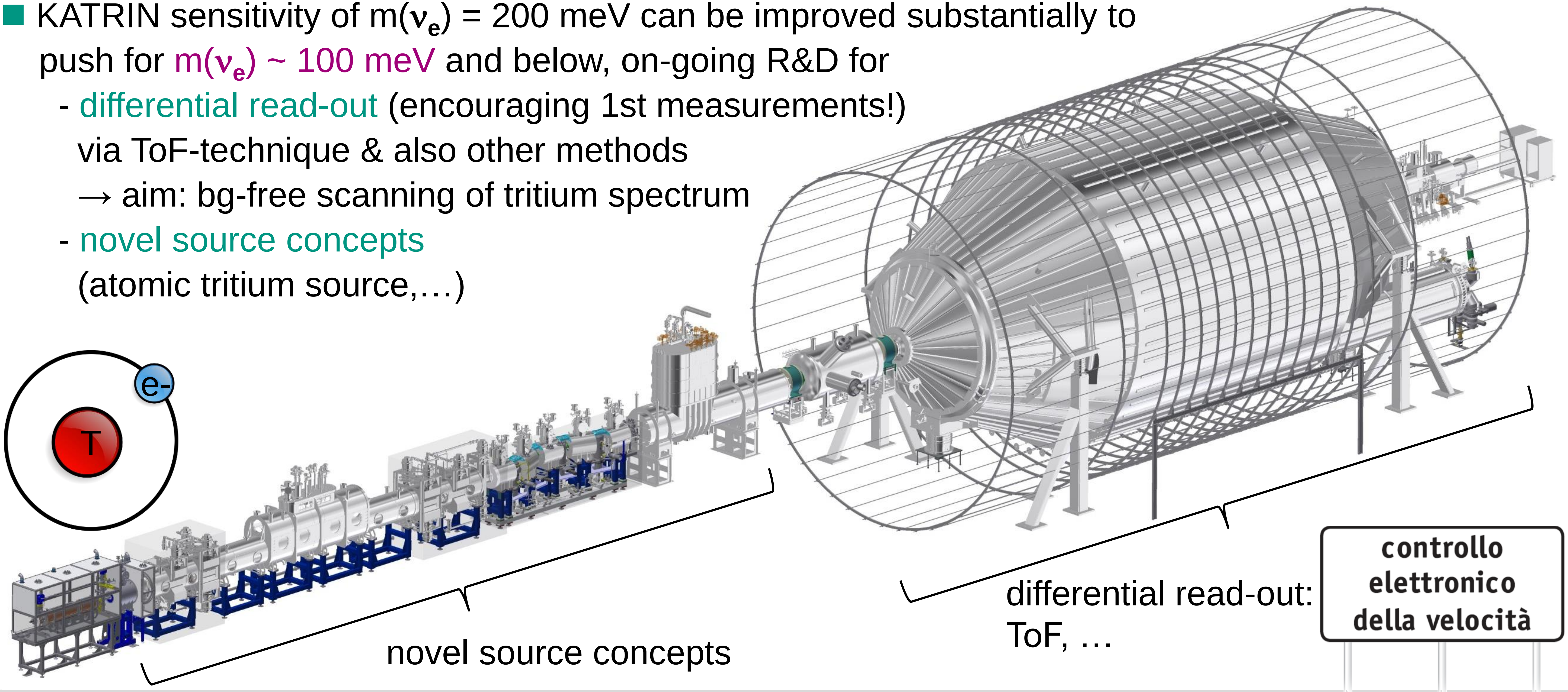
- very moderate impact of an enhanced background level due to shape analysis and specific coutermeasures:
  - optimized scanning strategy
  - range of spectral analysis
  - reduced flux tube volume

  for bg-level of 2015 with 0.5 cps:
  $m(\nu_e)$ = 0.24 eV (90%) CL
  expect further bg-reduction!

KATRIN: Upgrade plans to improve sensitivity for m(ν_e)

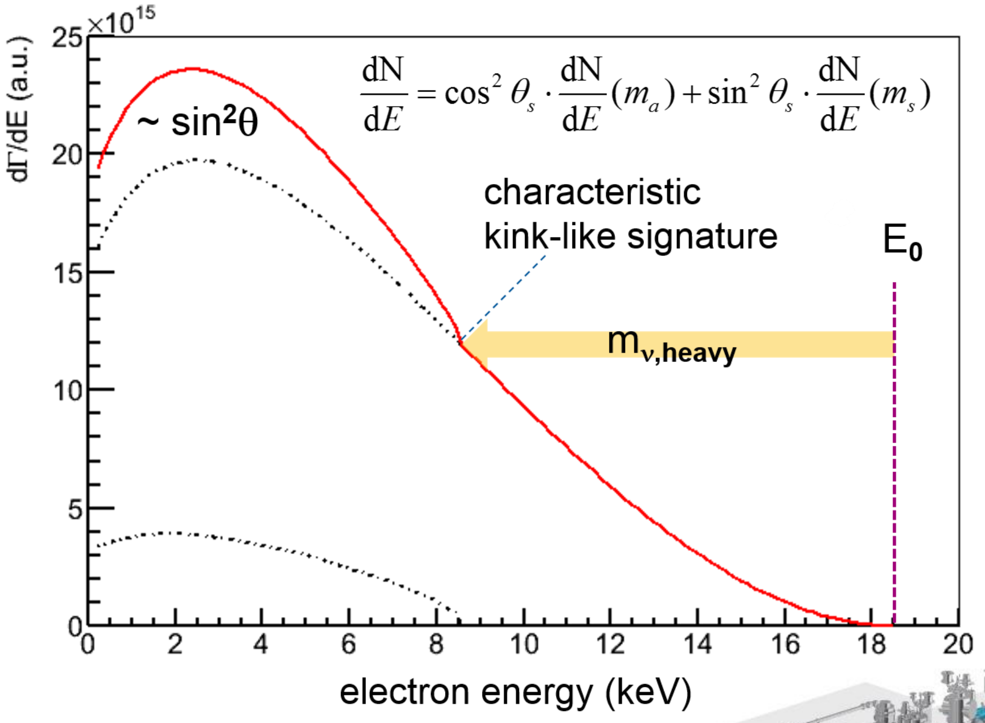
Karlsruhe Institute of Technology

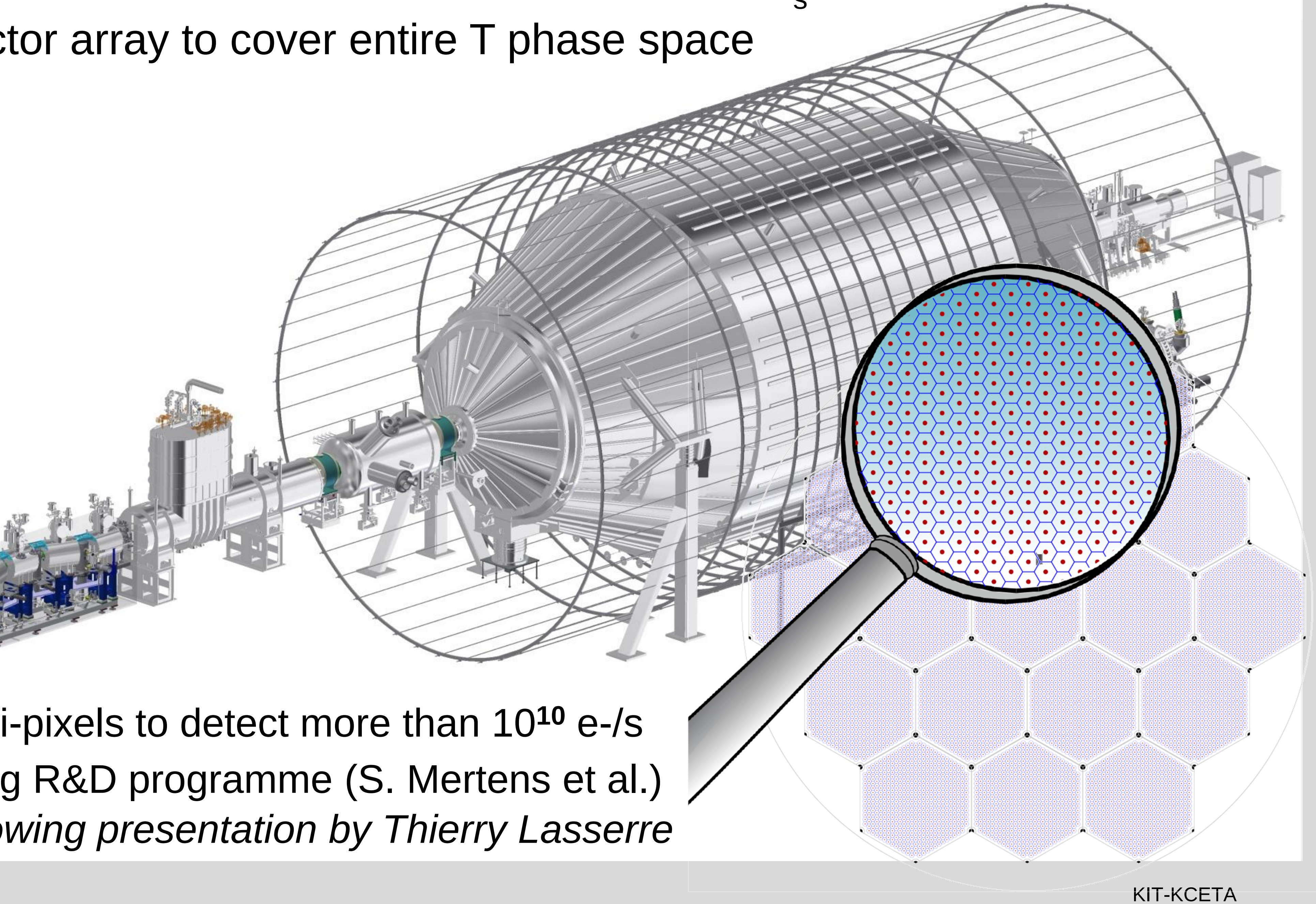
- KATRIN sensitivity of m(ν_e) = 200 meV can be improved substantially to push for m(ν_e) ~ 100 meV and below, on-going R&D for
  - differential read-out (encouraging 1st measurements!) via ToF-technique & also other methods → aim: bg-free scanning of tritium spectrum
  - novel source concepts (atomic tritium source,…)



KATRIN: Upgrade plans to hunt for keV-scale ν´s

- ß-decay shape modification by **keV-mass sterile neutrinos** with mass m_s
  TRISTAN: a novel Si-pixel detector array to cover entire T phase space





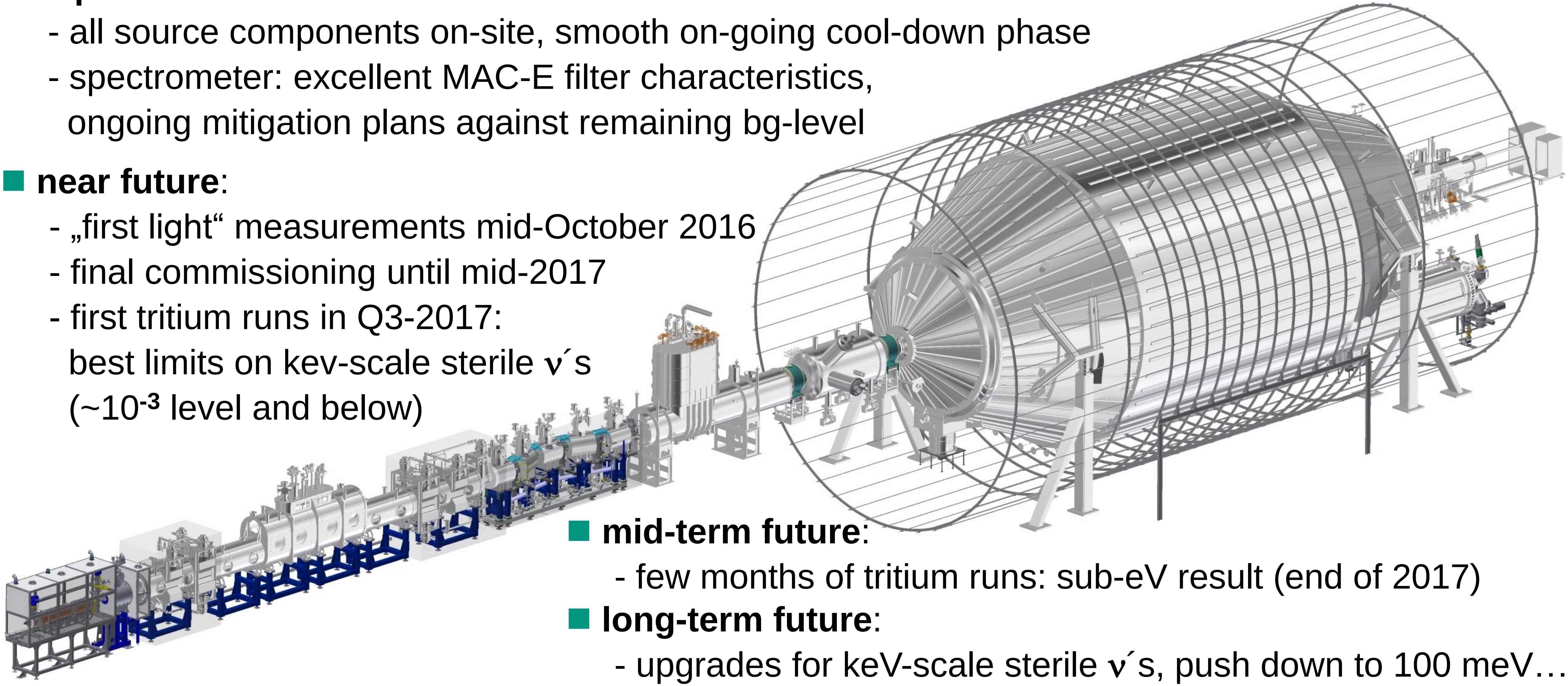
- $\sim 10^4$ Si-pixels to detect more than 10^{10} e-/s
- ongoing R&D programme (S. Mertens et al.)

see following presentation by Thierry Lasserre

Conclusions & Outlook

- **experimental status**:
  - all source components on-site, smooth on-going cool-down phase
  - spectrometer: excellent MAC-E filter characteristics, ongoing mitigation plans against remaining bg-level

- **near future**:
  - „first light“ measurements mid-October 2016
  - final commissioning until mid-2017
  - first tritium runs in Q3-2017: best limits on kev-scale sterile ν´s ($\sim 10^{-3}$ level and below)



- **mid-term future**:
  - few months of tritium runs: sub-eV result (end of 2017)
- **long-term future**:
  - upgrades for keV-scale sterile ν´s, push down to 100 meV…

grazie


multi messenger astrophysics
particle physics in the cosmos
ν oscillations: future
ν oscillations: present
ν masses states & interactions
NOW MMXVI
·OTRANTO·