An update on the KATRIN experiment

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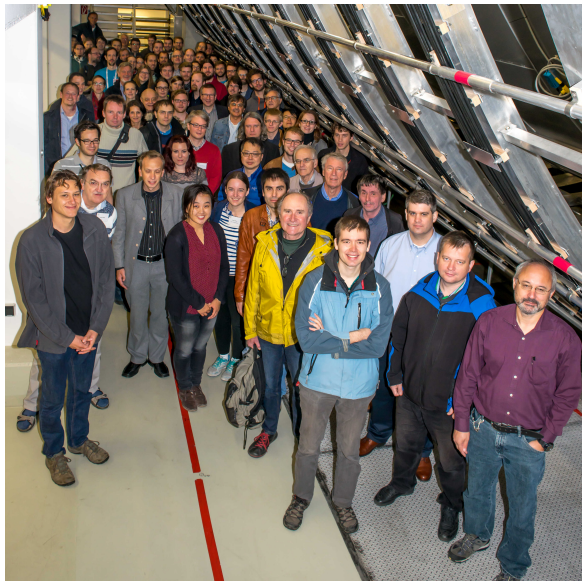
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

Outline

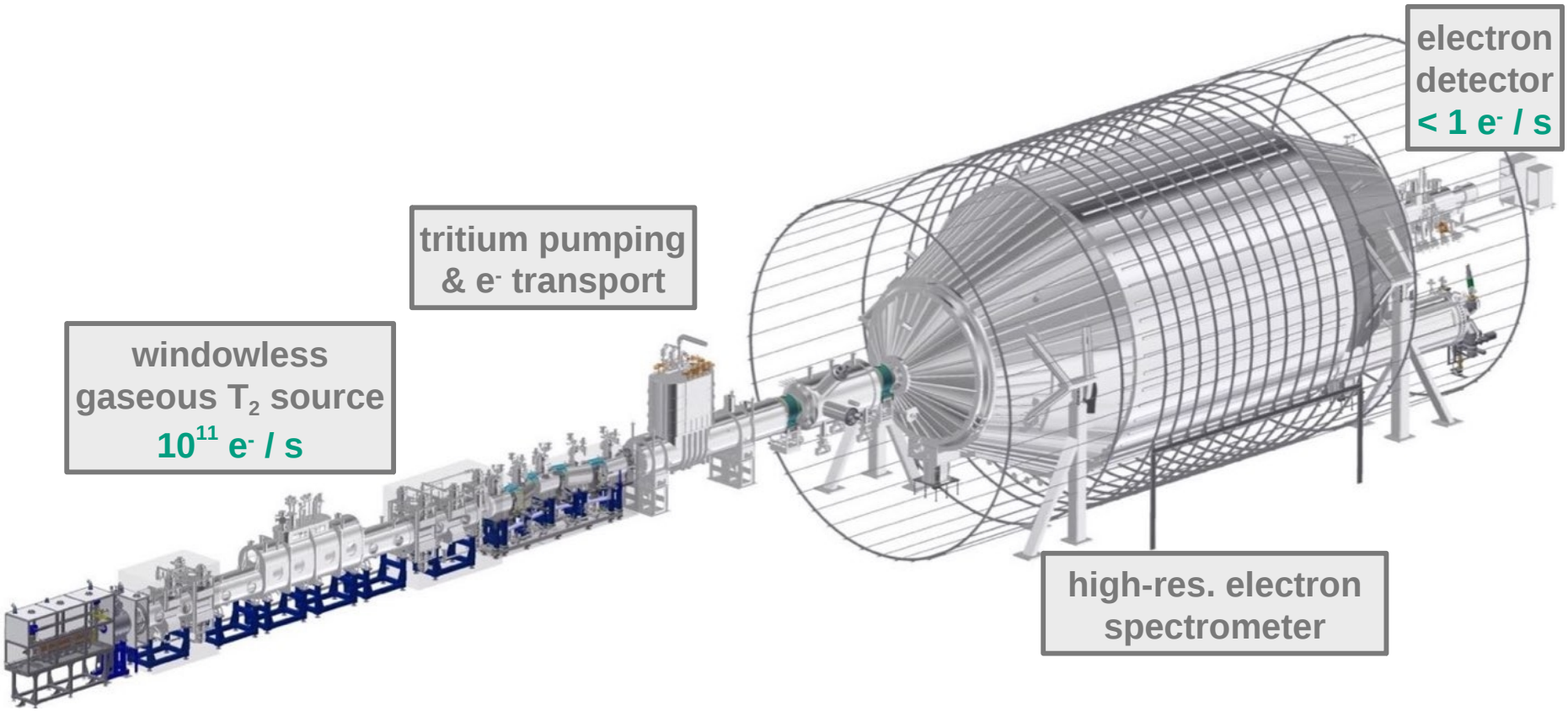
The **KA**rlsruhe **TRI**tium **N**eutrino experiment

- international collaboration with $\approx$ 130 members in 6 countries
- located at Karlsruhe Institute of Technology



KATRIN in a nutshell

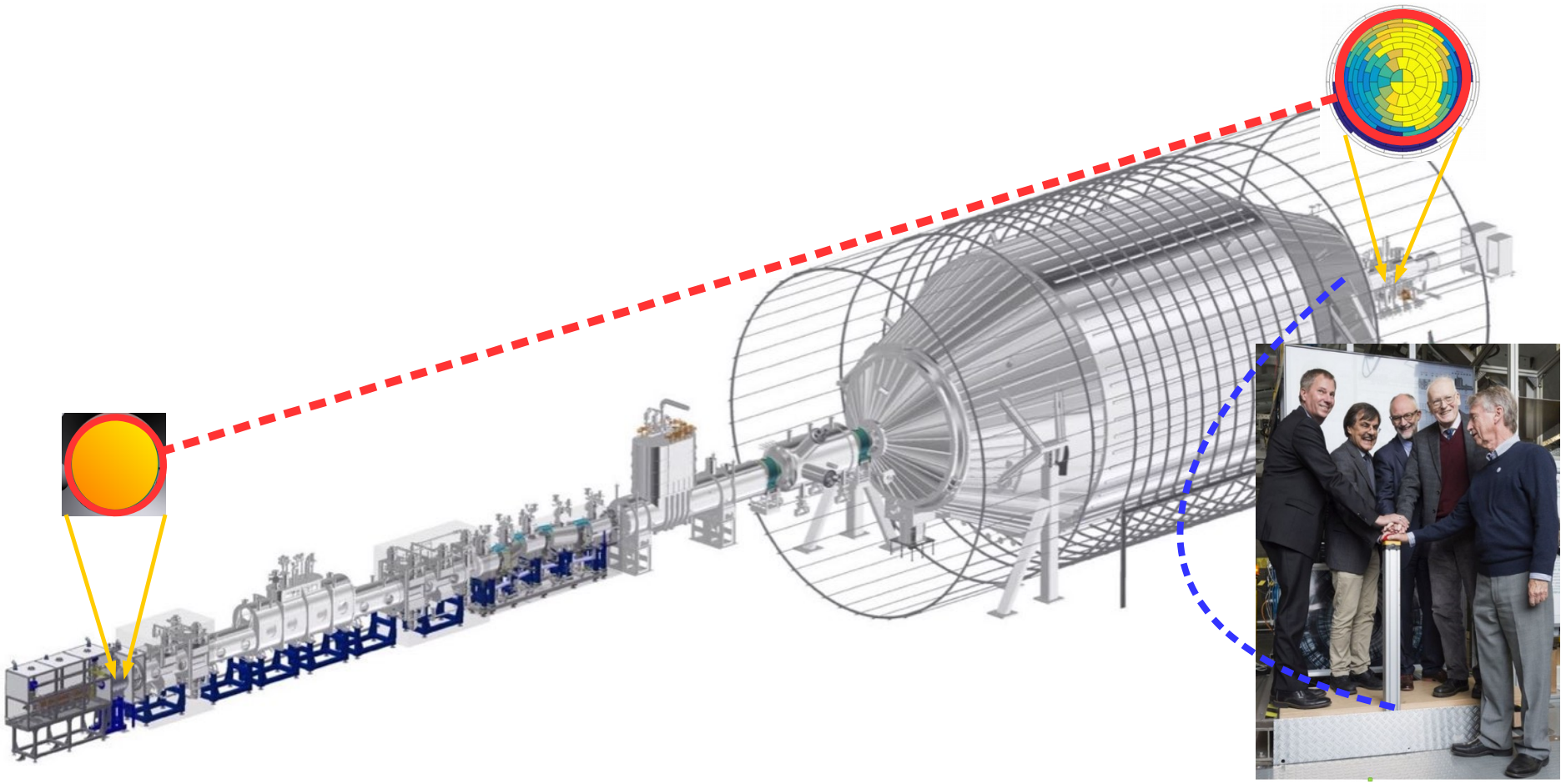
- improvement from 2 eV $\rightarrow$ 0.2 eV sensitivity
  - requires 100x improved statistics and systematics
  - 70 m long beamline
  - high energy resolution: MAC-E-filter
  - high activity and stability of the source



KATRIN - First Light

technical inauguration - 14th October 2016

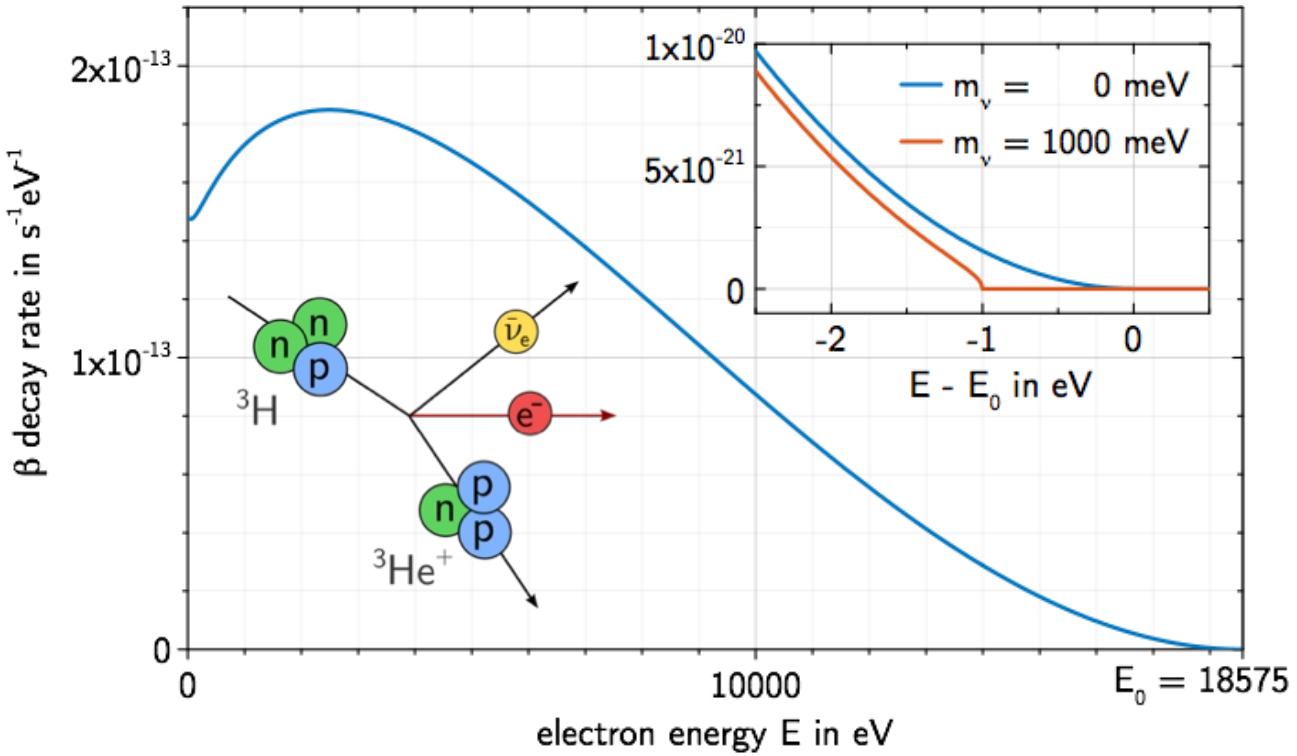
- illuminate rear wall with UV light
- photo-electric electrons are magnetically guided through entire beam line



The direct determination of m_ν

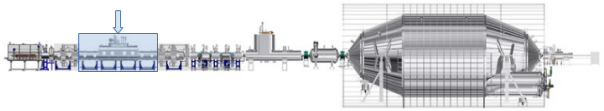
$$\frac{d\Gamma}{dE} = C \times F(Z,E)p(E+m_e)(E_0-E)\sum_i |U_{ei}|^2 \sqrt{(E_0-E)^2 - m^2(\nu_i)}$$

Spectral distortion $m^2(\nu_e) = \sum_i |U_{ei}|^2 m_i^2$

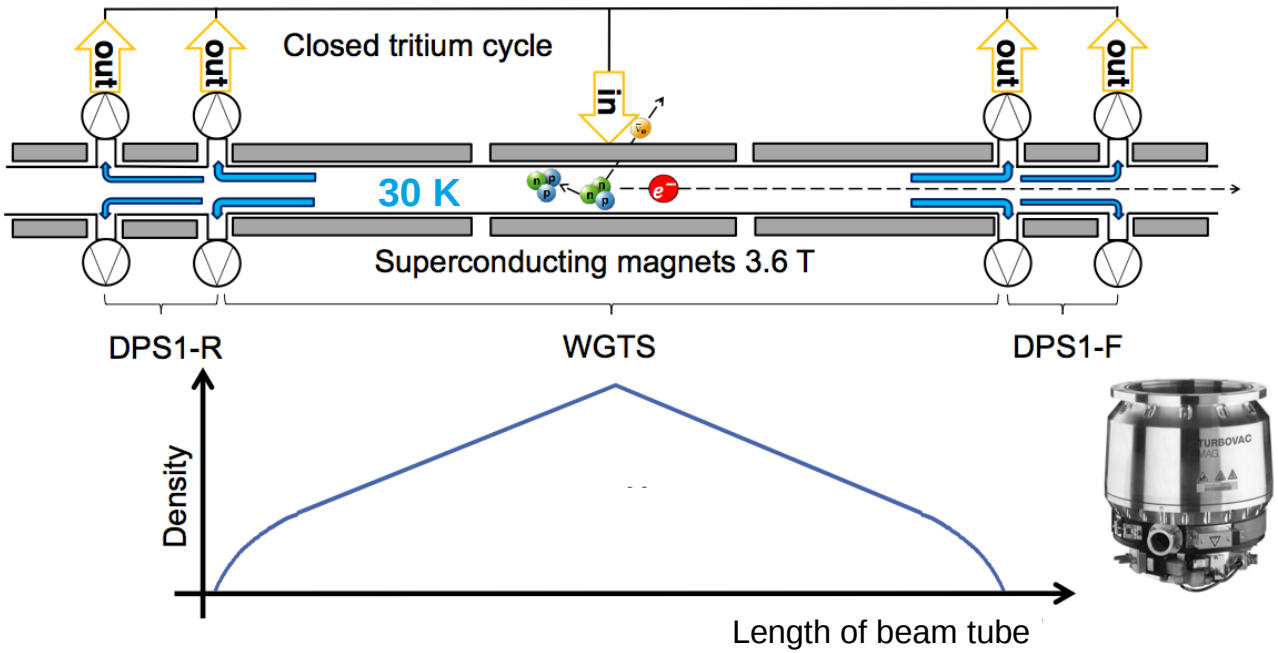


The **W**indowsless **G**aseous **T**ritium **S**ource

- 10 m long beam tube with 90 mm diameter
- 7 solenoids with 3.6 T to 5.6 T
- Gaseous Molecular Tritium
  - high activity $\approx$ 170 GBq
  - high isotopic purity $\epsilon_t > 95$ %
  - high stability 0.1 %



September 2015



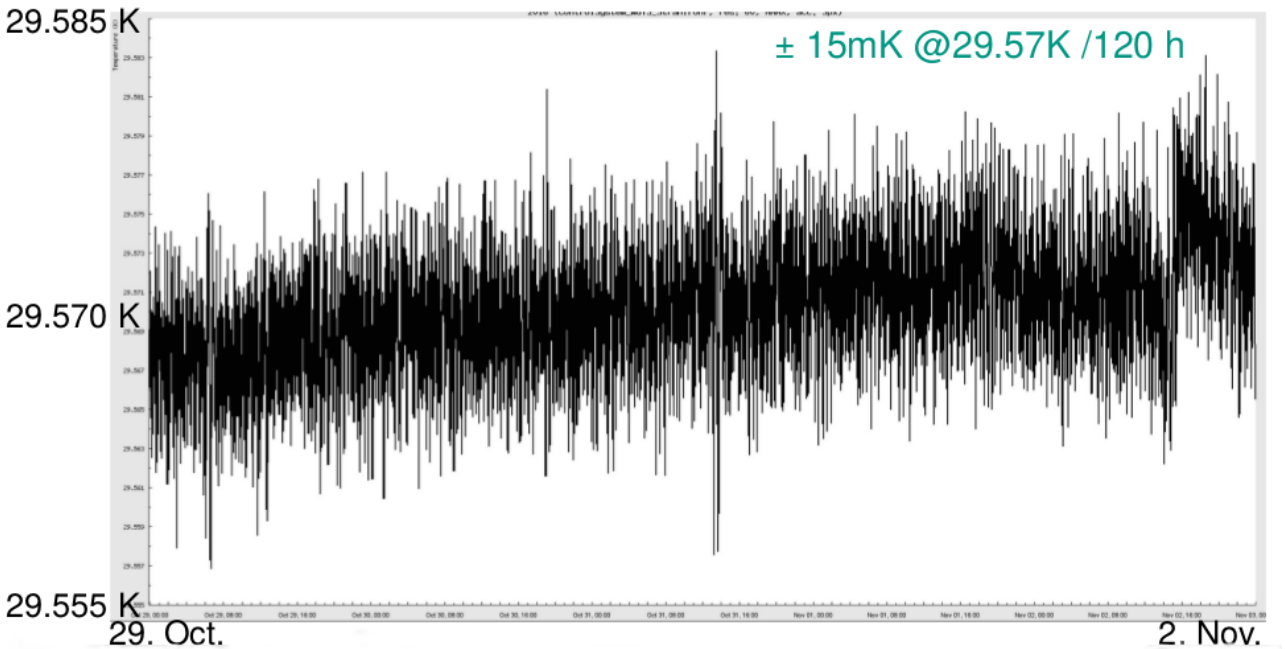
Requirements on the WGTS cryostat

- tritium beam tube cooled to 30 K
  - homogeneity and stability of 0.1 %
- check of leakage rate primary system and second containment ✓

homogeneity (✓)

- towards front side $<$ 0.1 %
- towards rear side $\leq$ 1 %

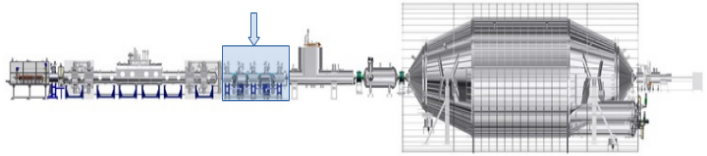
The inhomogeneity is known!



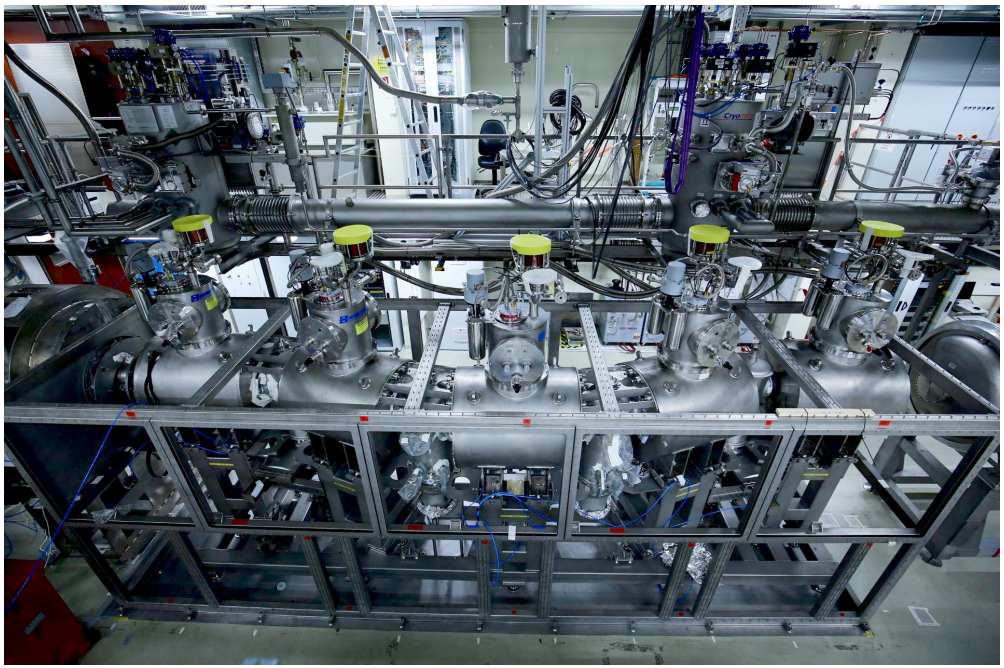
stability ✓

WGTS beam tube ready for T_2 operation!

The Differential Pumping Section



- reduction of tritium flow by 10^5
  - 4 turbo pumps
  - electrons and ions are guided magnetically through chicane



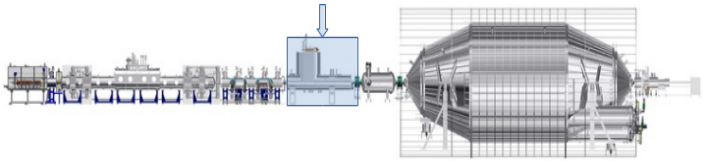
ion removal

- dipole and ring electrodes ✓
- FT-ICR ✗

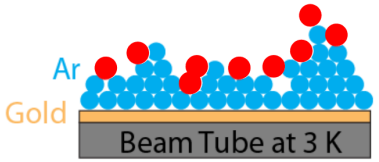
First Light results:

- **no** collision of the 191 Tcm^2 e^- flux with beam tube
- ions can be **drifted** with the dipole electrodes
- ions can be **blocked** with the ring electrodes

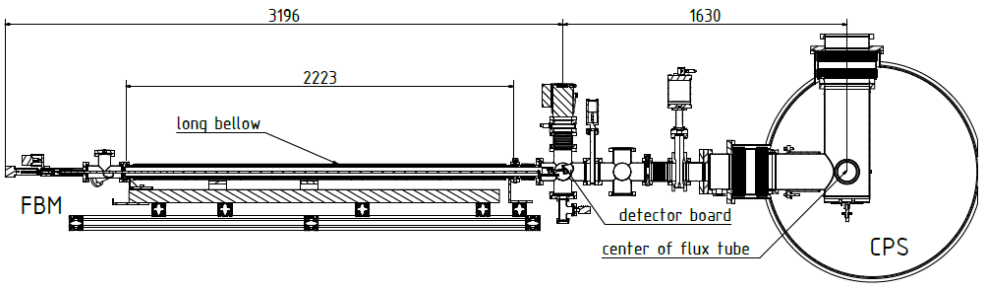
The **C**ryogenic **P**umping **S**ection



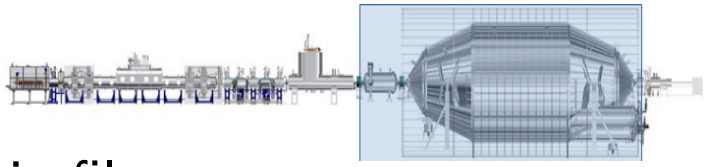
- reduction of tritium flow by 10^7
  - cryosorption on the pre-condensed Argon frost layer
  - tilted beam line
- **F**orward **B**eam **M**onitor attached to CPS
  - monitoring and scanning of the column density



T_2 -cryosorption

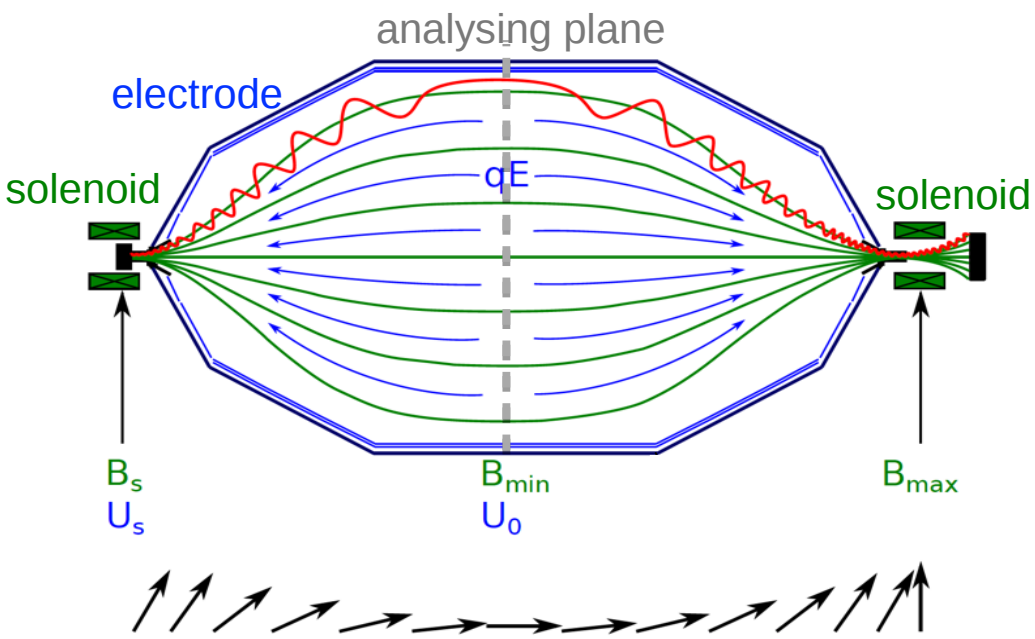


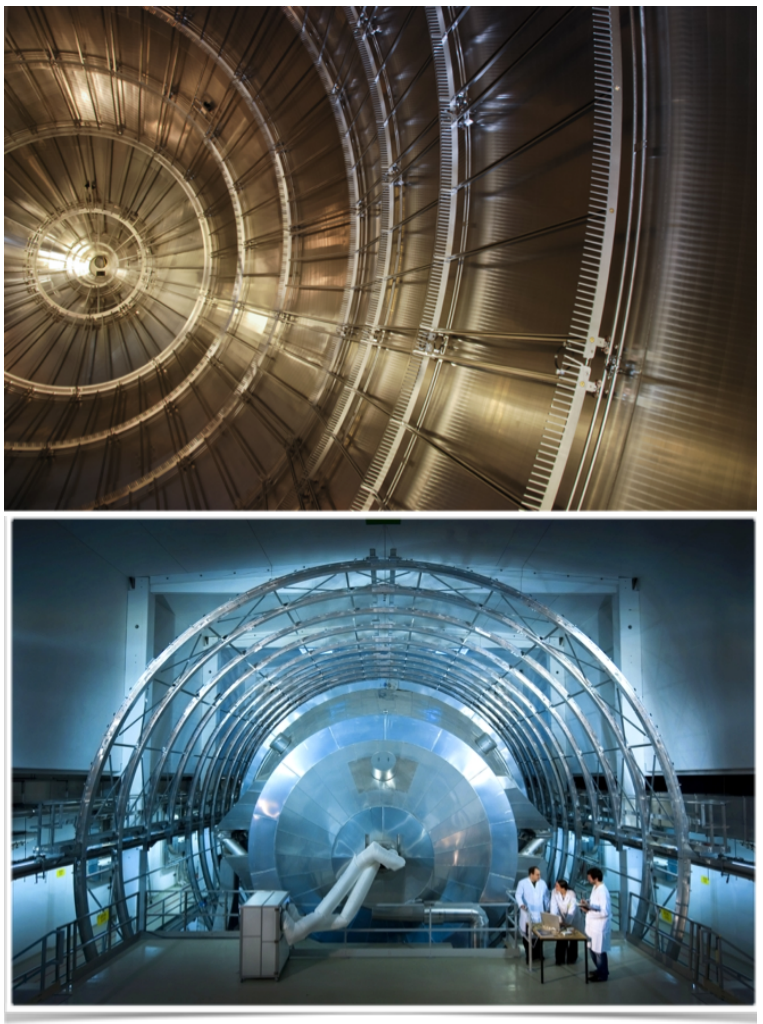
The MAC-E-filter



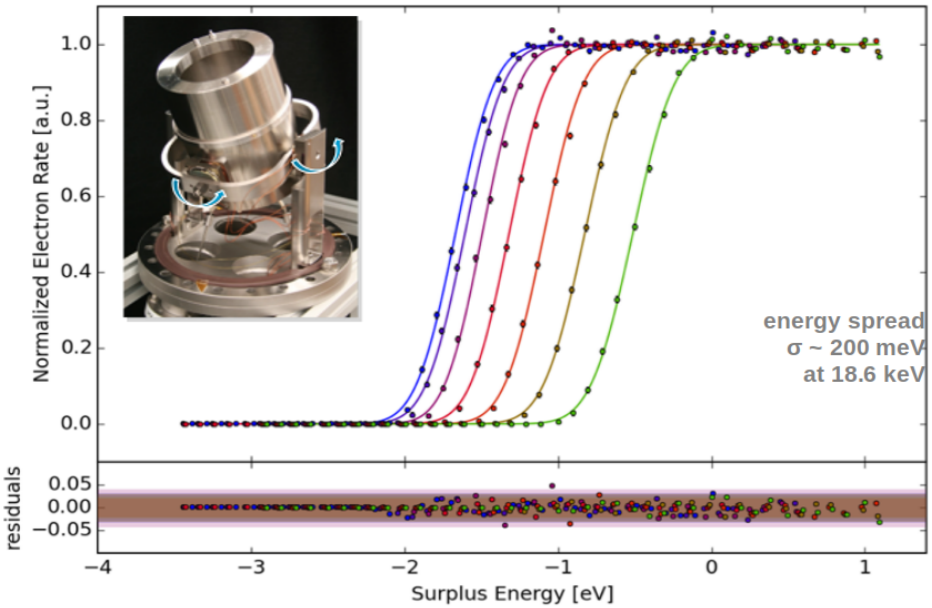
Magnetic **A**diabatic **C**ollimation and **E**lectrostatic filter

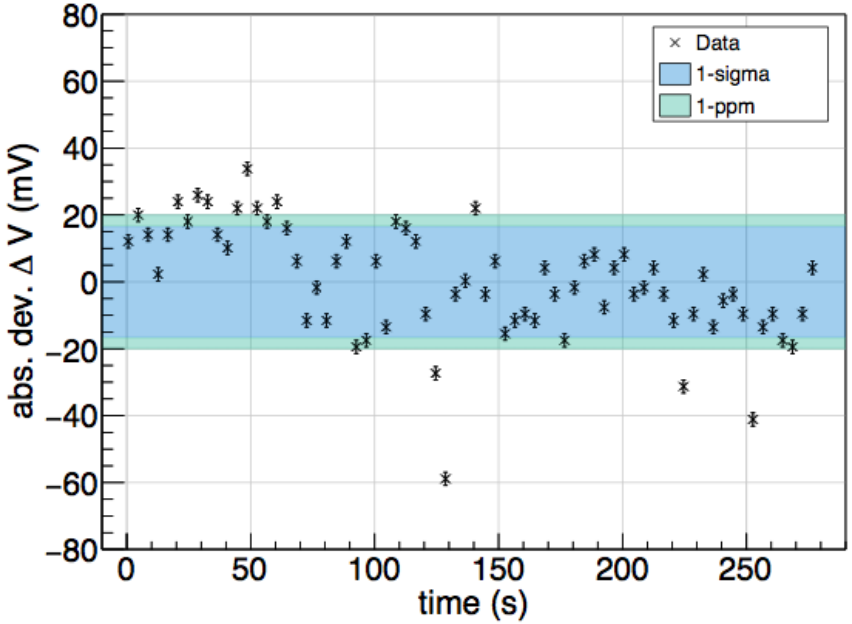
- energy resolution
  $\Delta E = \frac{B_{min}}{B_{max}} \cdot E = \frac{3 \cdot 10^{-4}\ \mathrm{T}}{6\ \mathrm{T}} \cdot 18600\ \mathrm{eV}$
- volume of 1500 m^3 and mass of $\approx$ 200 t





Main spectrometer: MAC-E-filter characteristics

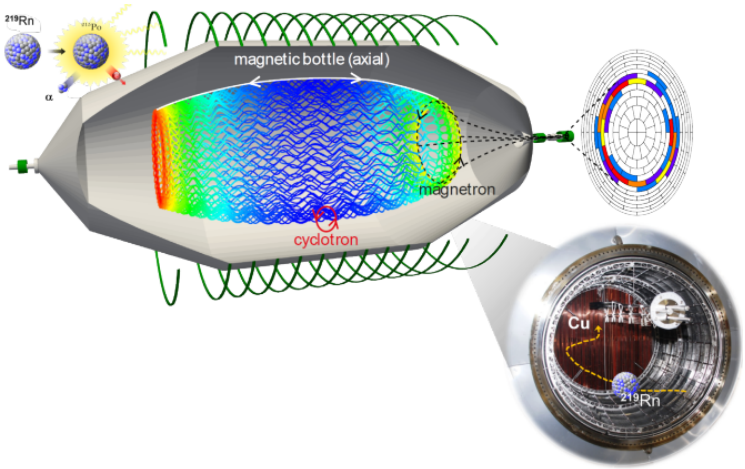


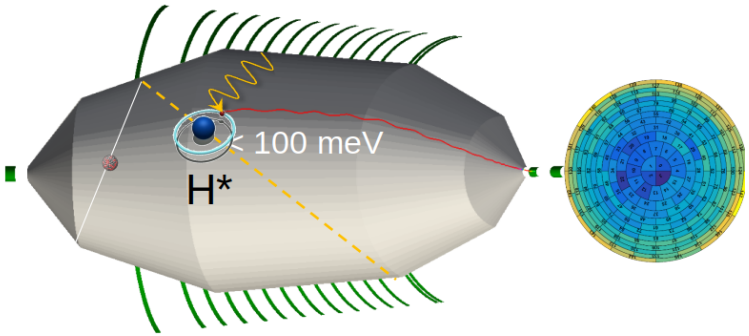


- sharp transmission for electrons at 18.6 keV
- width limited by e-gun transmission spectrum

- HV-stability on ppm level
- long term stability monitoring with ^{83m}Kr

Main spectrometer background





^{219}Rn atoms

- ^{219}Rn emanates from NEG
- background rate: $\approx$ 0.5 cps

H* Rydberg atoms

- desorbed due to ^{206}Pb recoil ions
- background rate: $\approx$ 0.5 cps

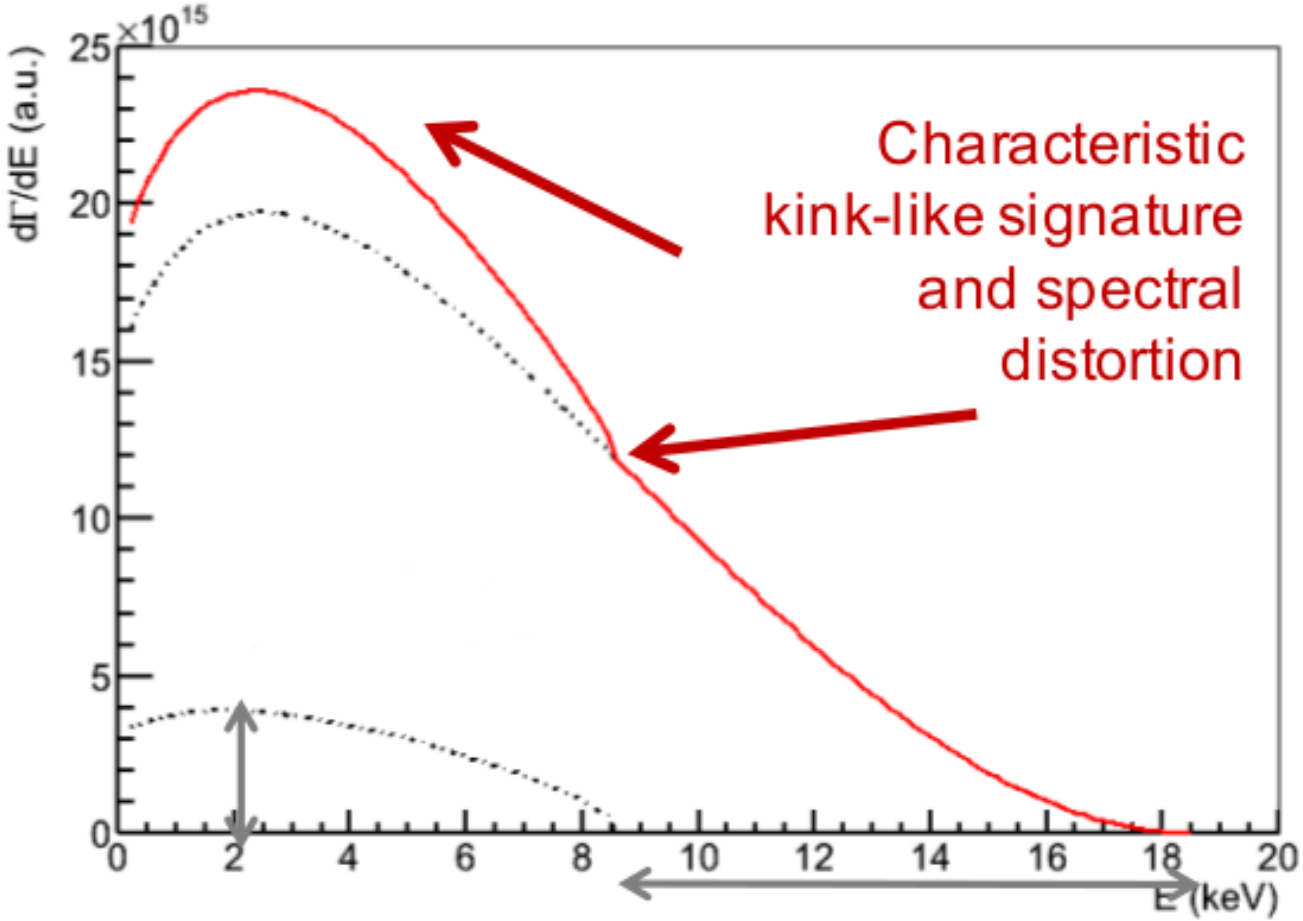
countermeasure

- cryotraps in front of NEG
  - 3 LN_2 cooled Cu-baffles

countermeasure

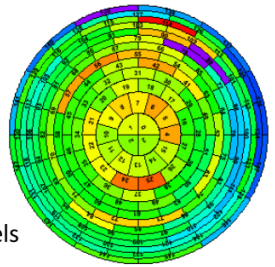
- reduction H-atom surface coverage
  - extended bake-out phase
  - strong UV illumination source

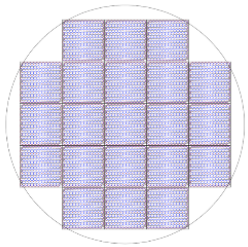
Hunting keV sterile neutrinos with KATRIN

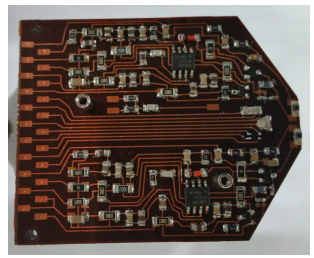


The measurement phases

1. pre KATRIN measurement phase
   - reduced count rate at the detector $\approx 10^6$ cps
     - ★ low count rate in standard KATRIN operation
     - ★ energy resolution of 2 keV (FWHM)
   - quick measurement to improve current limits
2. post KATRIN measurement phase
   - new detector and read-out system $\approx 10^8$ cps
     - ★ energy resolution of 300 eV (FWHM)
3. upgrade of the FBM
   - replace PIN diode with SDD planed for post KATRIN
     - ★ current energy resolution of 2 keV (FWHM)


148 pixels


3528 pixels



pre KATRIN Phase

How to decrease count rate?

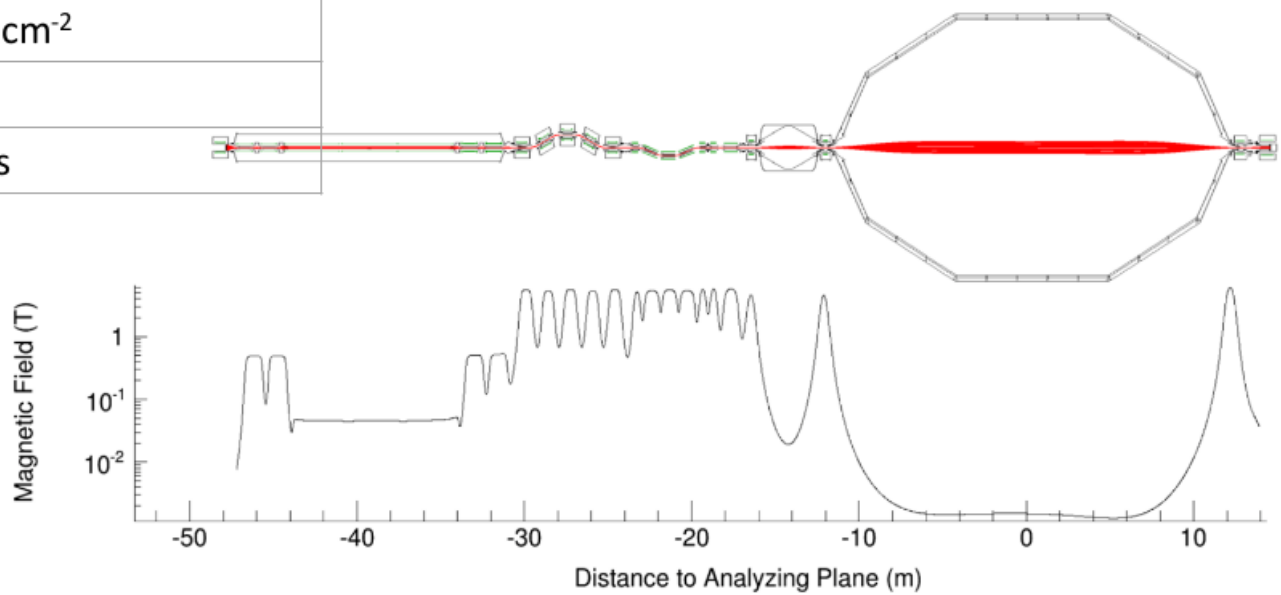
1. decrease column density
   - less scattering in the source
2. decrease magnetic field in the source
   - reduced acceptance angle

crucial systematics

- rear wall / detector scattering
- adiabaticity
- pile-up

parameter	value
Source magnetic field	0.045 T
Acceptance angle	4.97 degree
Column density	$3 \cdot 10^{15}$ cm^{-2}
Reduction of rd	167
Rate at detector	10^6 cps

Plot by Anton Huber

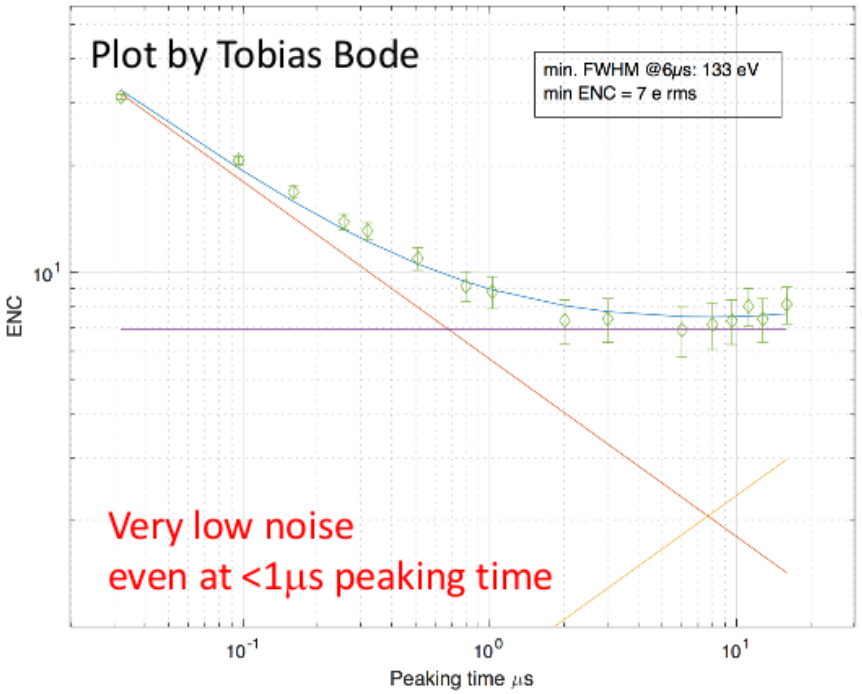


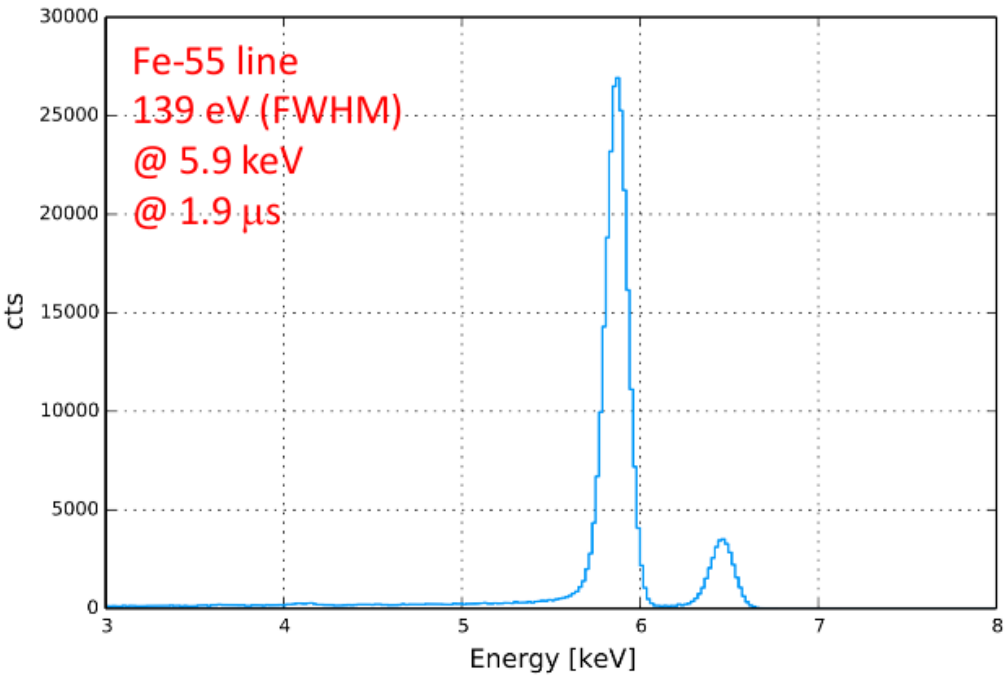
post KATRIN Phase

1. after ν mass measurement
2. upgraded detector and read-out system
3. detailled source model is necessary
   - MC simulations not feasible

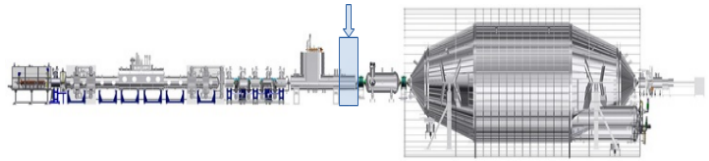
required characteristics

- $1\,000 - 10\,000$ pixel
- thin dead layer < 10 nm
- energy resolution 300 eV (FWHM) at 20 keV

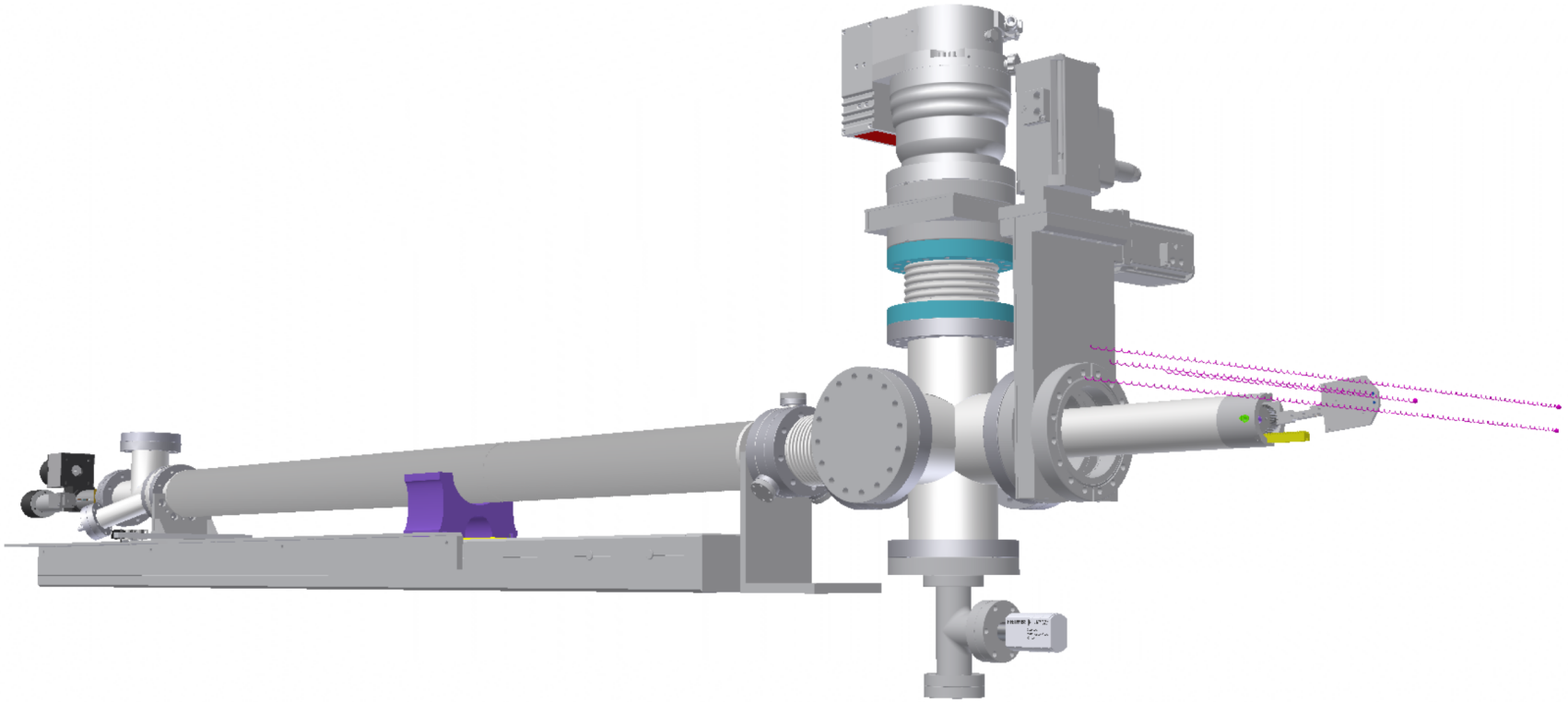




Forward Beam Monitor



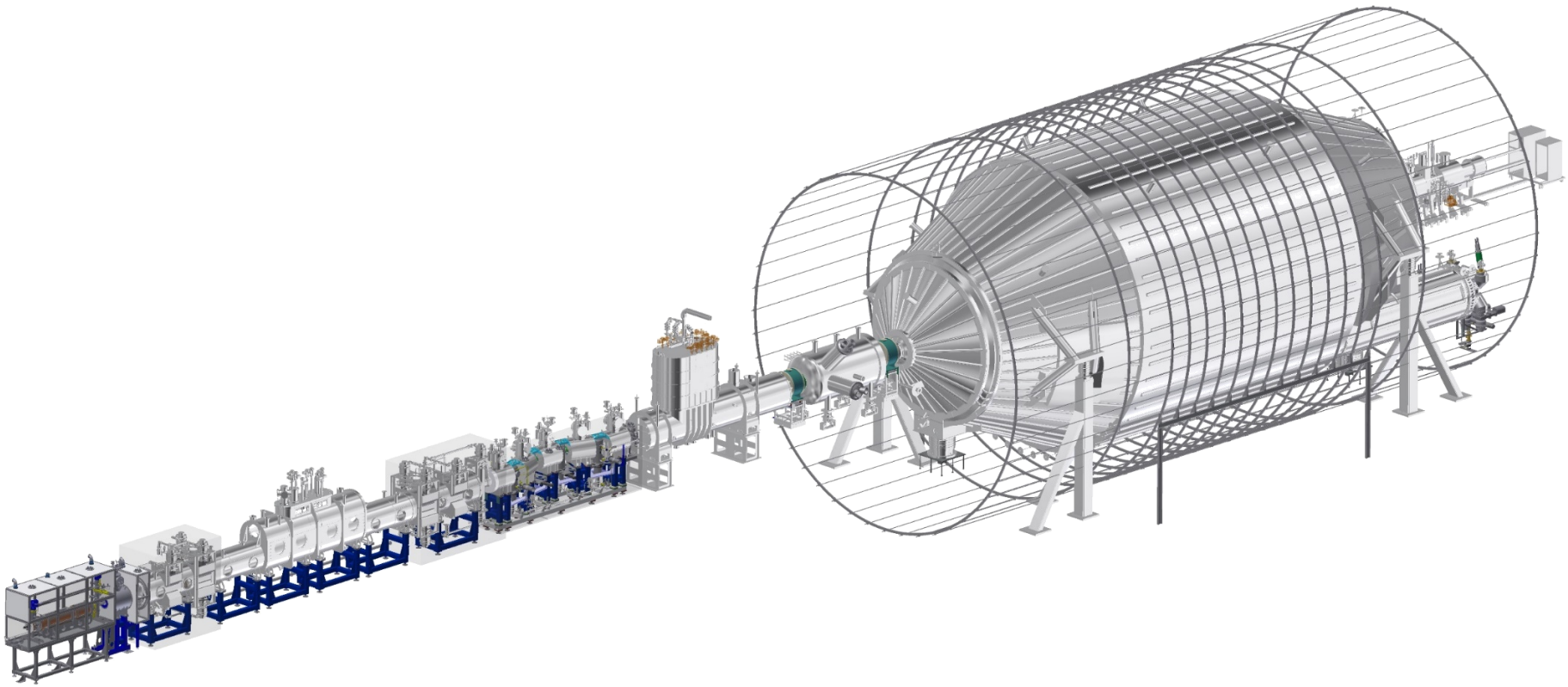
- PIN diodes: monitor the source during KATRIN operation
- replace PIN diode with Silicon Drift Detector
  - small deadlayer
  - high energy resolution
  - record differential β-spectrum



Outlook

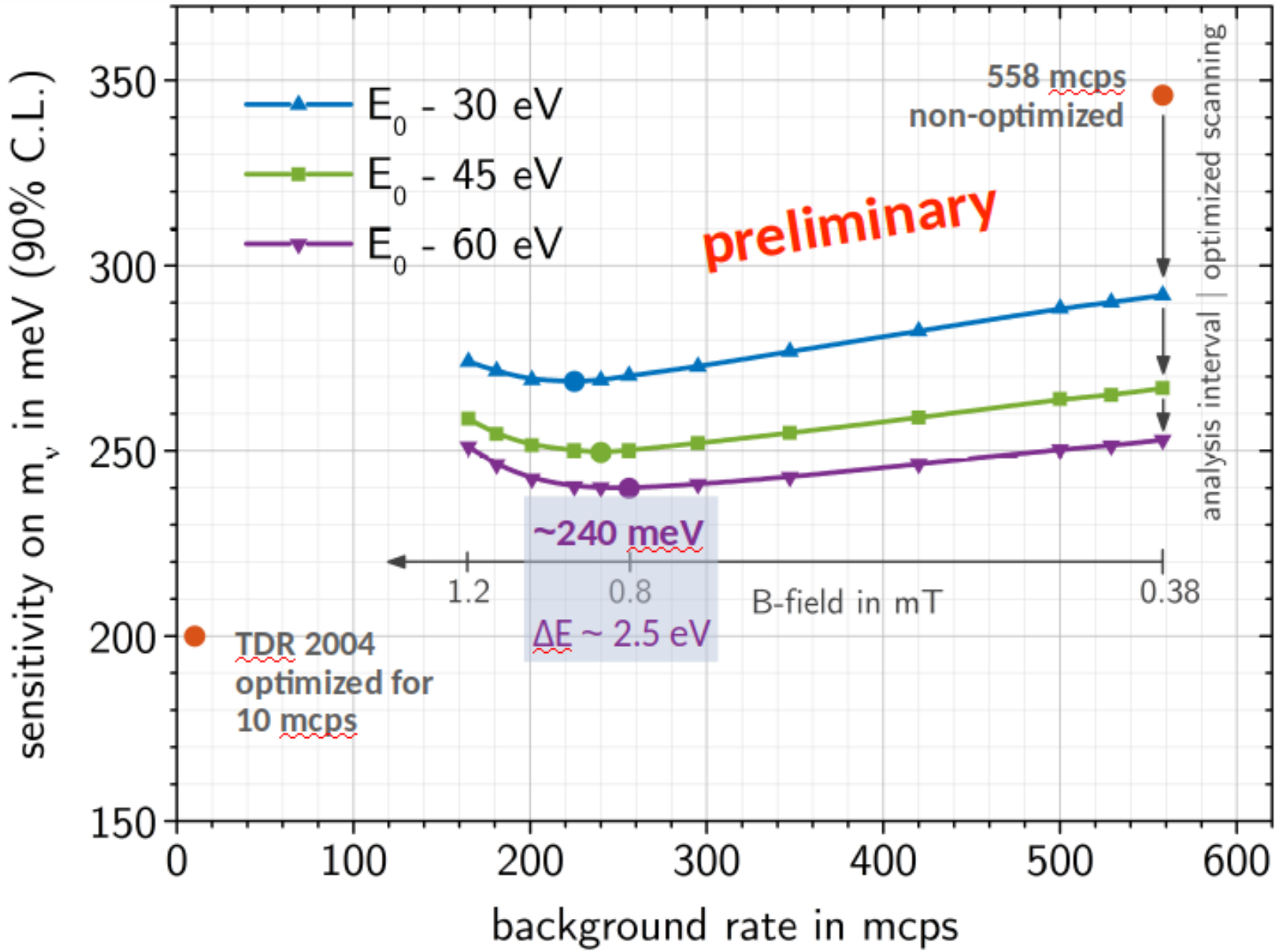
Next steps:

- deuterium and Kr in the source
- electrons: energy losses in source and transmission function
- first traces active tritium: commissioning and safety checks
- pre KATRIN sterile neutrino measurement

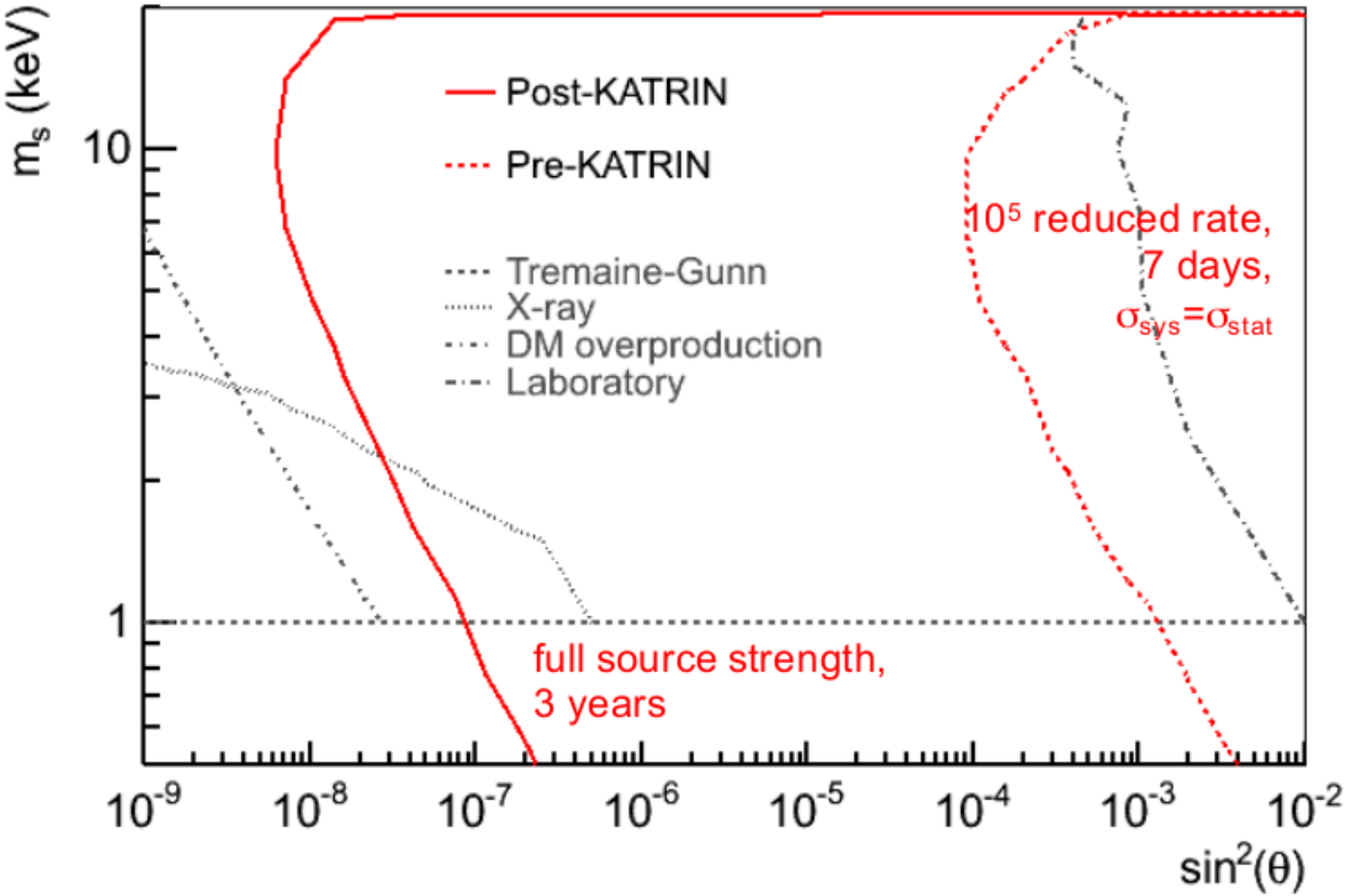


Backup slides

KATRIN sensitivity



Sterile Neutrino sensitivity



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Direct probes of neutrino mass

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KATRIN Design Report

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WINDOWLESS GASEOUS TRITIUM SOURCE - Status and Outlook

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References

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