Gaseous tritium source rear wall contribution to tritium beta-spectrum in search for sterile neutrinos by Troitsk nu-mass experiment

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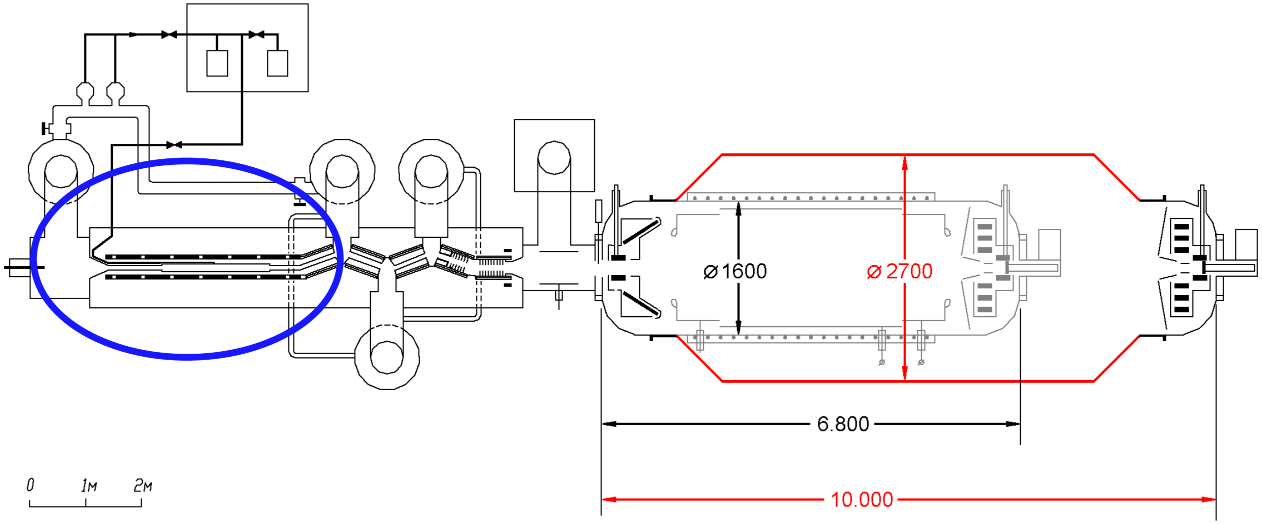
Troitsk nu-mass experiment

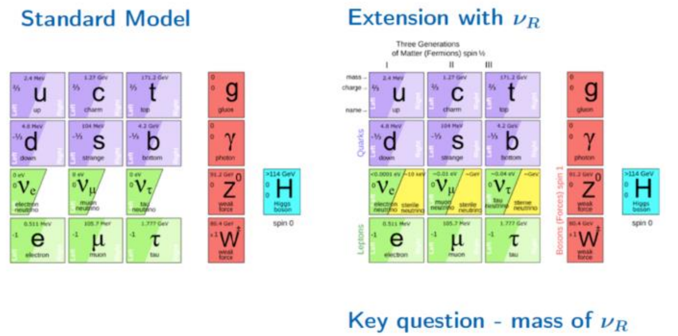
Windowless Gaseous Tritium source. Gas is freely circulating there, no window.

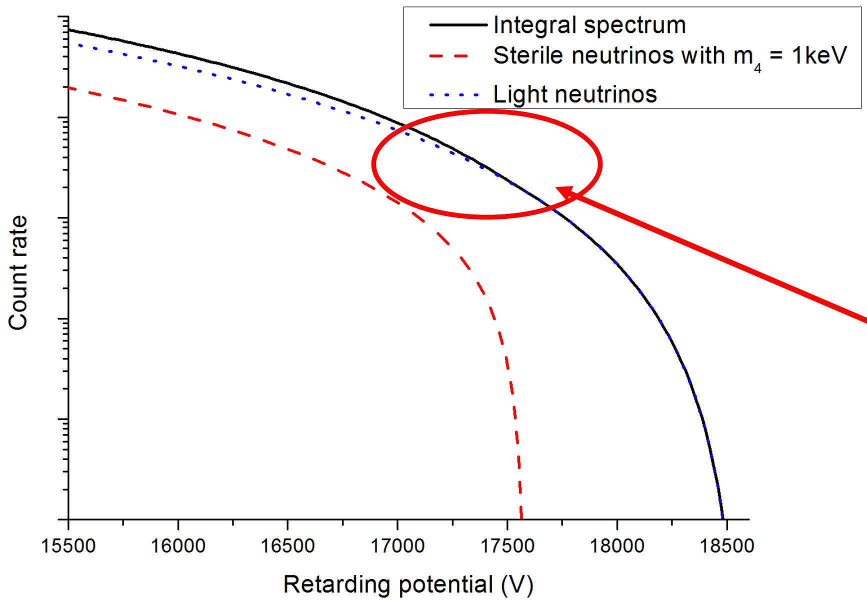
Magnetic bottle for decay electrons

Electrostatic spectrometer and detector



Search for keV Sterile neutrino in Tritium β-spectrum





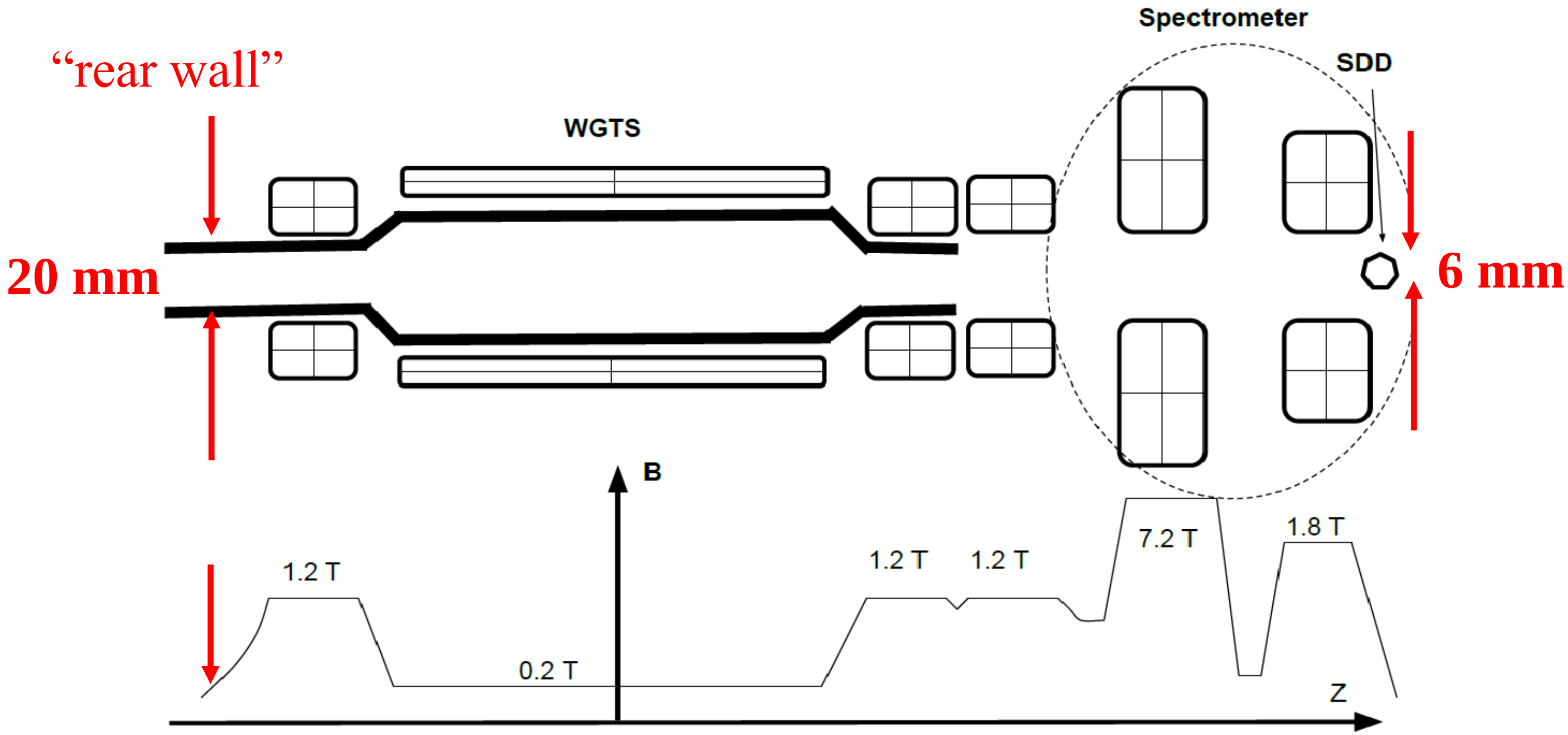
Task: to measure β-spectrum in wide energy range10-19 keV - Search for spectrum distortion, kink

Problem – there could be other sources for such distortion, like rear wall

Spectrum should have 2 components: ***sterile*** and ***regular*** neutrinos

$$S(E) = U_{ex}^2 S(E, m_x) + (1 - U_{ex}^2) S(E, 0)$$

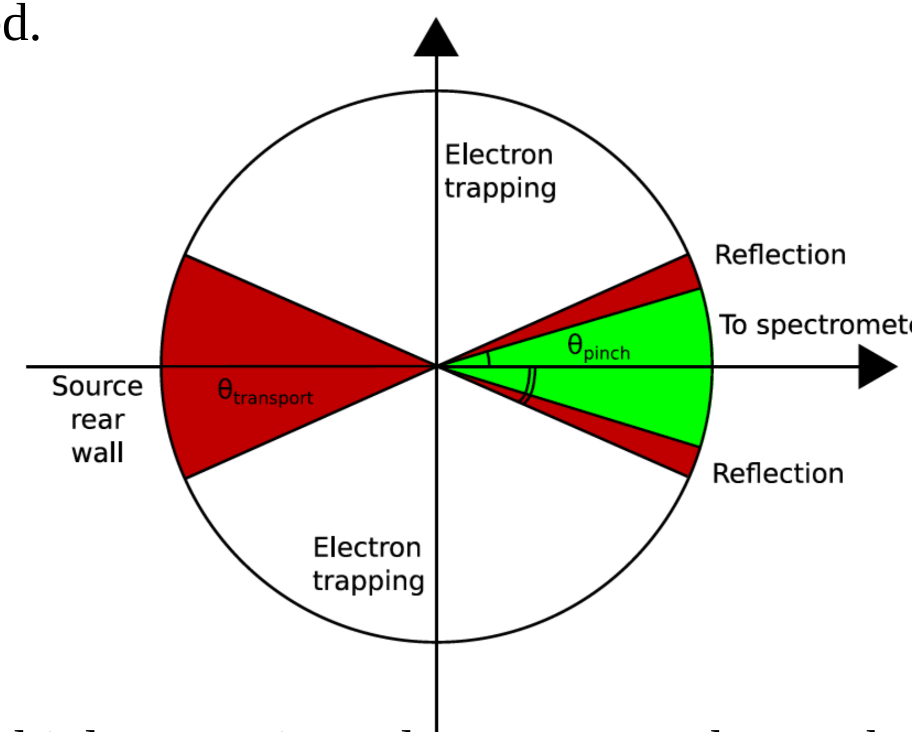
Magnetic map. Superconducting solenoids



Magnetic flux at 6 mm detector in B=1.8 T defines the field of 0.162 T and location in 20 mm pipe, "rear wall", where electrons may scatter back and reach detector

Magnetic trap in tritium source

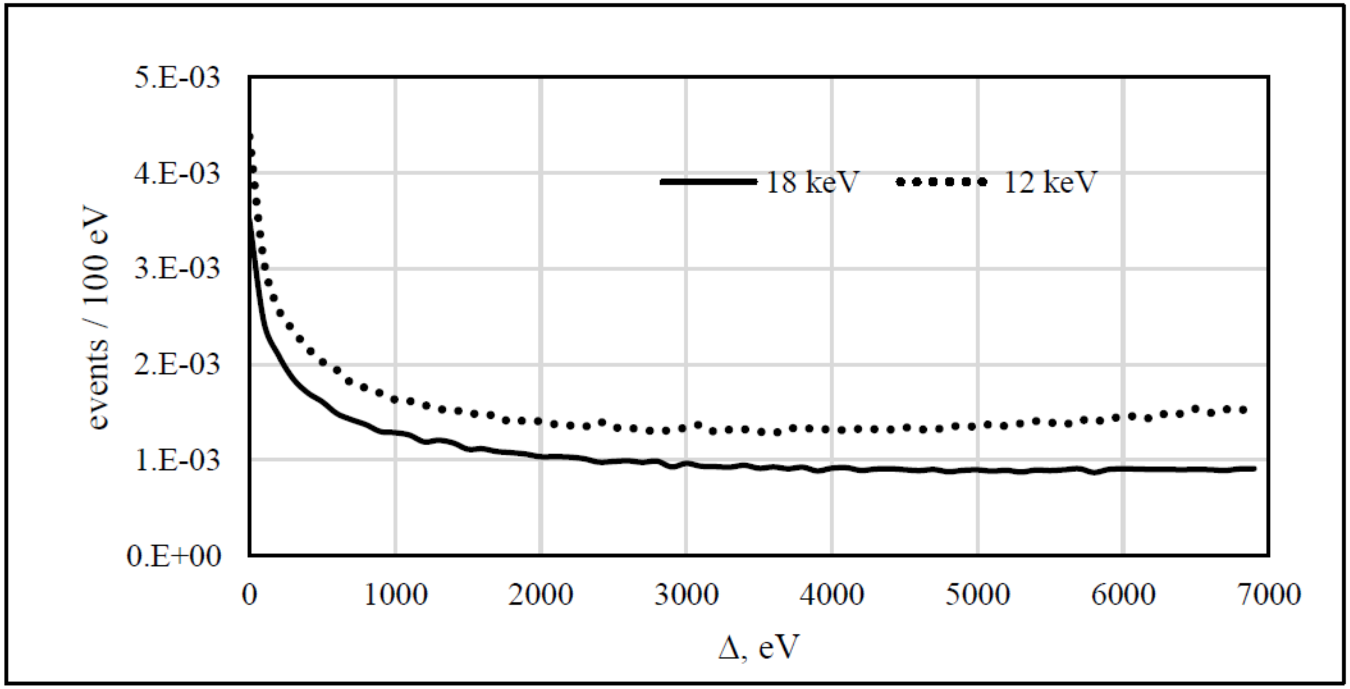
Because of high magnetic field of 1.2 T at edges of the source and 0.2 T in the middle, big portion of decay electrons ***at large azimuthal angle*** are trapped.



After multiple scatterings electrons may change the angle and escape to the spectrometer or (mostly) to the rear wall.
Energy spectrum of such electrons differs from the original one.

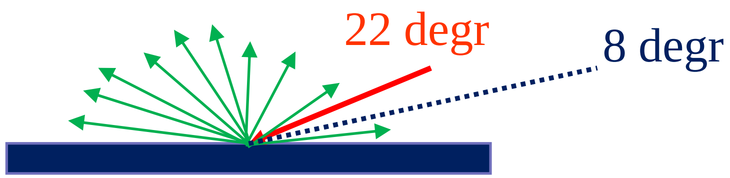
Trapping contribution

- We simulate electron scattering in working gas
- Estimate energy loss, Δ, before escaping to the rear wall direction

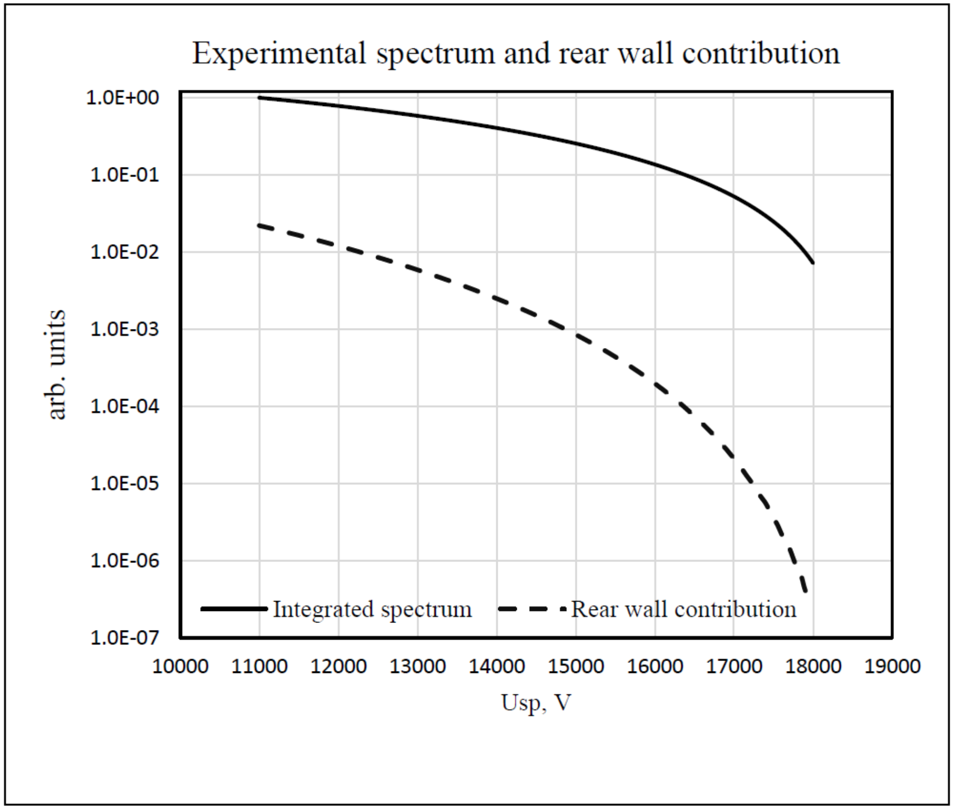


Final rear wall simulation, GEANT4

- Electron energy spectrum at the rear wall = original differential + contribution from the trap convoluted with original spectrum
- From magnetic field configuration estimate the maximum *angular impact* relative to the wall surface, **22 degrees**
- Estimate the back scattered angle, at which electron will pass through the ***gaseous source***, ***pitch magnet*** and ***spectrometer*** to the ***detector***, **8.6 degrees**
- For each spectrometer potential estimate number of electrons which satisfy the ***energy*** and ***angular*** cuts to scatter back to detector

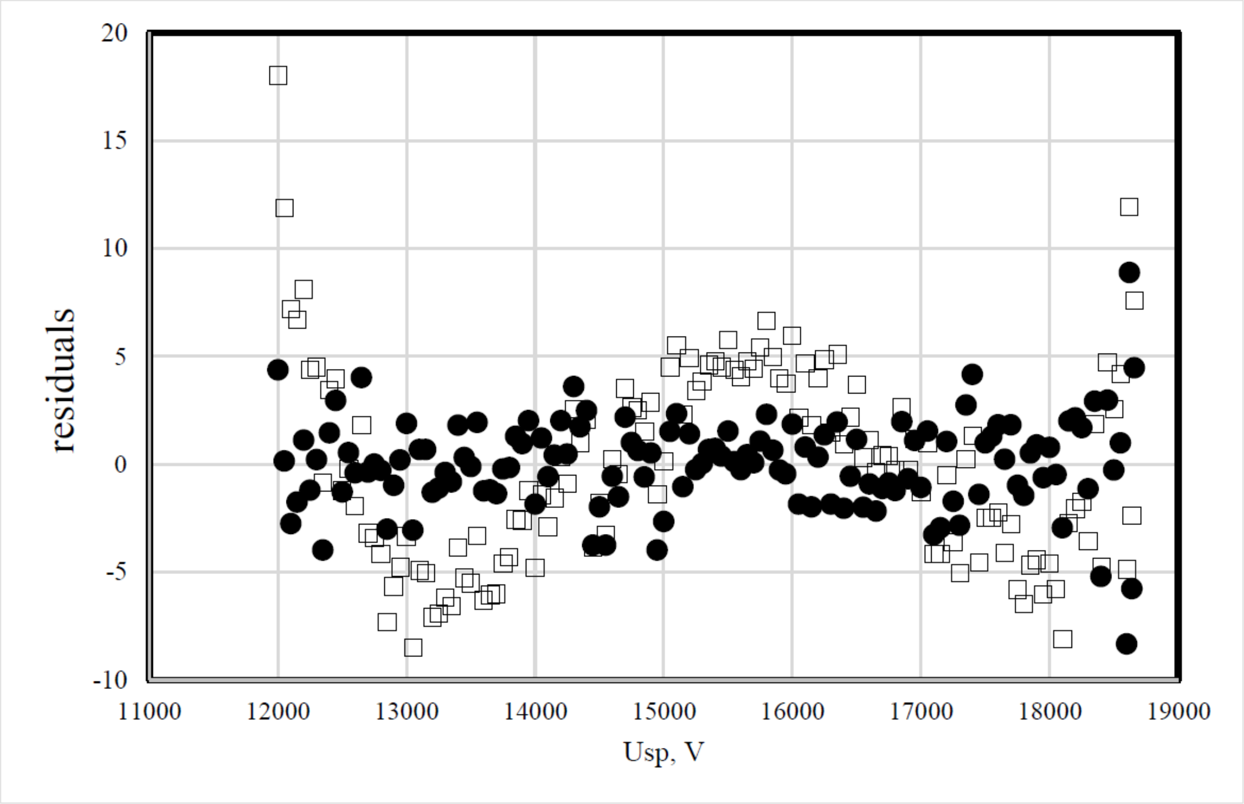


Rear wall contribution. Results.



- Measurements at the spectrum right edge of 18500 eV are not influenced by rear wall.
- This is why all previous measurements in search for **electron anti-neutrino** mass are valid.
- Going down by measurement points gets larger and reaching 2% at 11000 eV.
- Selection of rear wall material could be critical.
- Beryllium?

Influence to the spectrum fit



Open squares – fit results without rear wall contribution.
Black circles – with rear wall contribution.

Effect of rear wall will be much more critical for upcoming extension of KATRIN experiment after 2025 - project TRISTAN to search for sterile neutrino in a similar way

NATURE PHYSICS ARTICLES

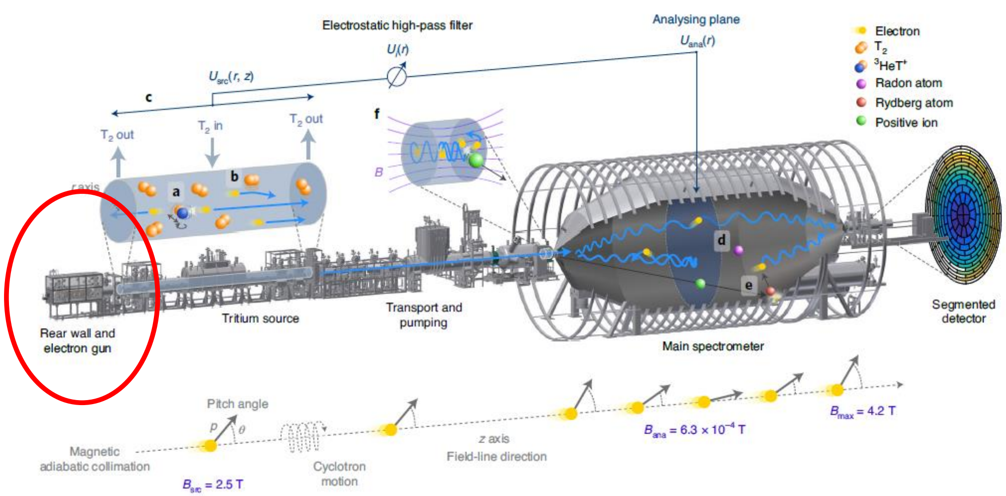


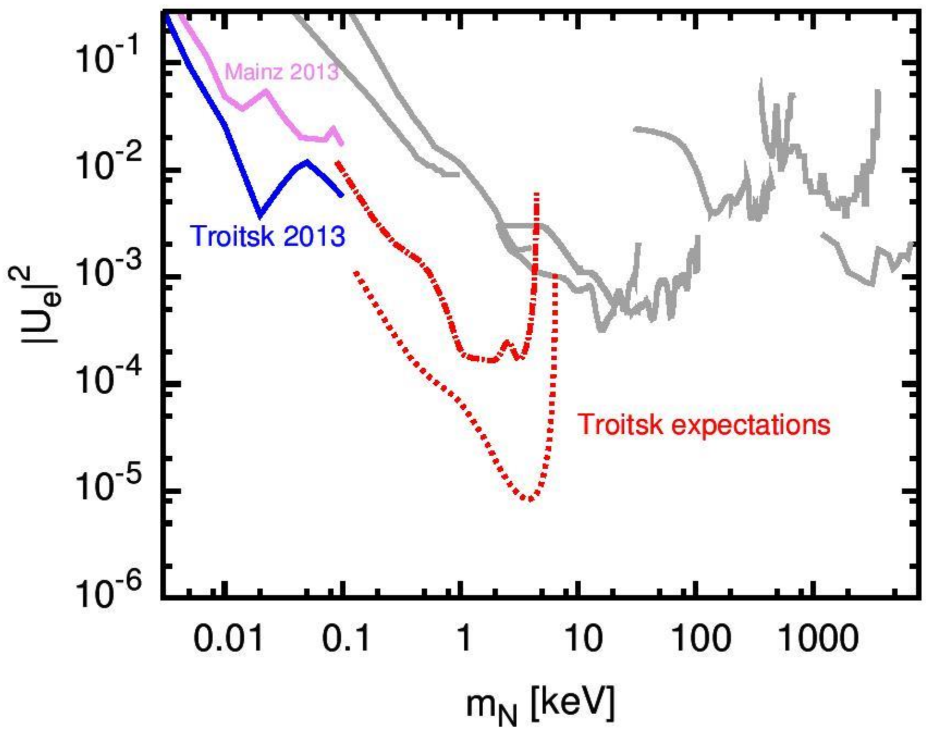
Fig. 1 | Illustration of the 70-m-long KATRIN beamline. The main components are labelled. The transport of β-electrons and magnetic adiabatic collimation of their momenta p are illustrated. **a–f**, View into the tritium source depicts three systematic effects: molecular excitations during β-decay (**a**), scattering of electrons off the gas molecules (**b**) and spatial distribution of the electric potential in the source $U_{src}(r,z)$ (**c**). The view into the spectrometer illustrates the main background processes arising from radon decays inside the volume of the spectrometer[47–49] (**d**), highly excited Rydberg atoms sputtered off from the structural material via α-decays of ^{210}Po (refs. [44–46]) (**e**) and positive ions created in a Penning trap between the two spectrometers[57] (**f**). Low-energy electrons, created in the volume as a consequence of radon decays or Rydberg-atom ionizations, can be accelerated by qU_{ana} towards the focal-plane detector, making them indistinguishable from signal electrons[66].

As of now, in KATRIN there is no magnetic plug at the rear wall direction.
As a material – flat gold plate.
There is a long discussion now what to use as a Rear Wall for TRISTAN – modified magnetic field, electrostatics, material?

Conclusion

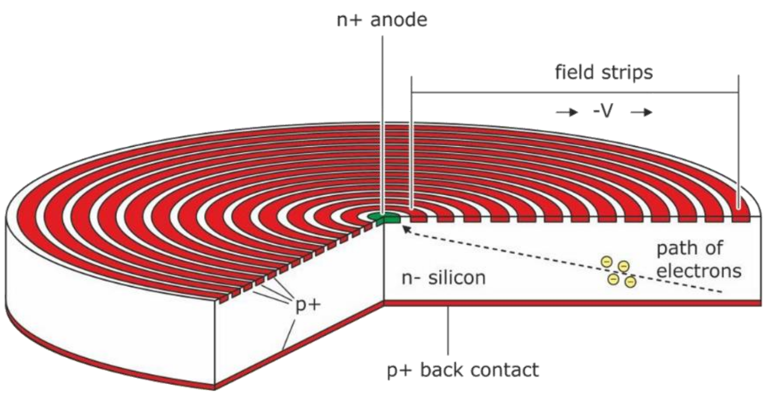
- Despite of elegant idea of geometry and magnetic bottle field configuration in our setup (*which for years was successfully used for electron neutrino mass measurements and search for sterile neutrino in the mass range under 1-2 keV*), effect of the Rear Wall scattering becomes significant in search for sterile neutrino in 2-10 keV mass range.
- To extend the measured mass range it would be useful to replace rear wall material
- Our experience will be useful for upcoming TRISTAN project

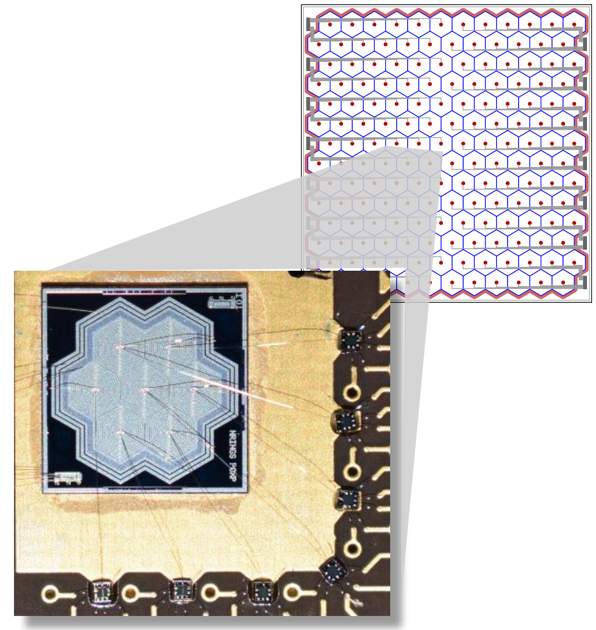
Back-up


Mainz 2013
Troitsk 2013
Troitsk expectations
$|U_e|^2$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.01
0.1
1
10
100
1000
m_N [keV]

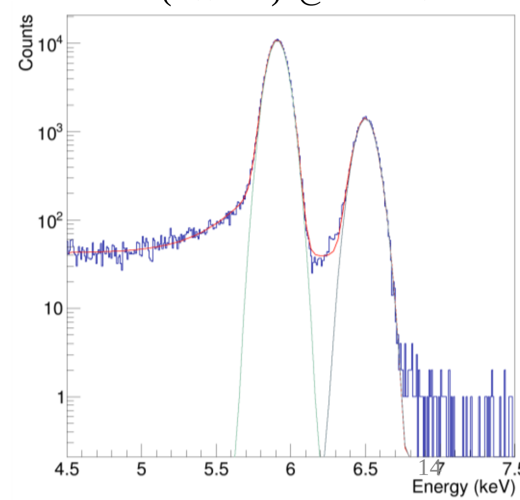
TRISTAN Detector R&D

- Silicon Drift Detector design
- Novelty: extremely thin entrance window (< 100 nm)
- Final system: ~4000 pixels (21 x **166** pixel modules)
- Prototype: 7 pixel





Fe-55 line 139 eV
(FWHM) @ 5.9 keV



Extremely low anode capacitance on the order of 20-40 fF
Very low noise level about 100-150 eV
Usage of signal digital filtering
Controlled electronics “live” time

TRISTAN in Troitsk