bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

Status and Perspectives of the KATRIN Experiment

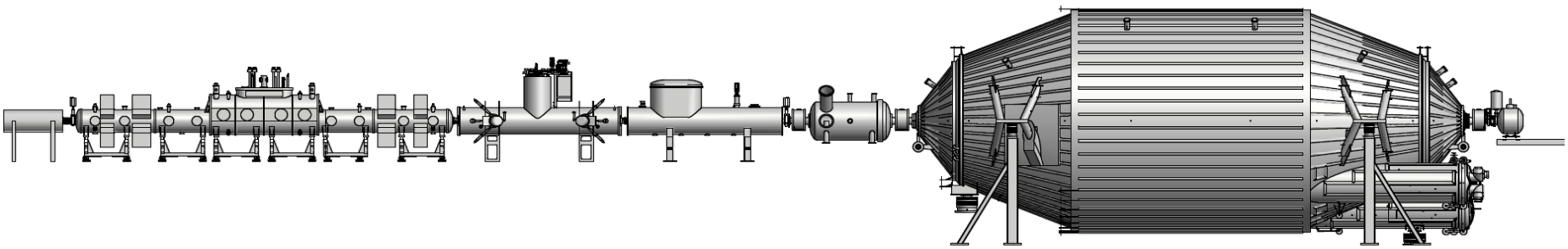
Susanne Mertens for the KATRIN collaboration

Outline

- Why are we interested in the absolute neutrino mass scale ?
- How does KATRIN work and what is the status ?

- Background at KATRIN
- Perspective of KATRIN

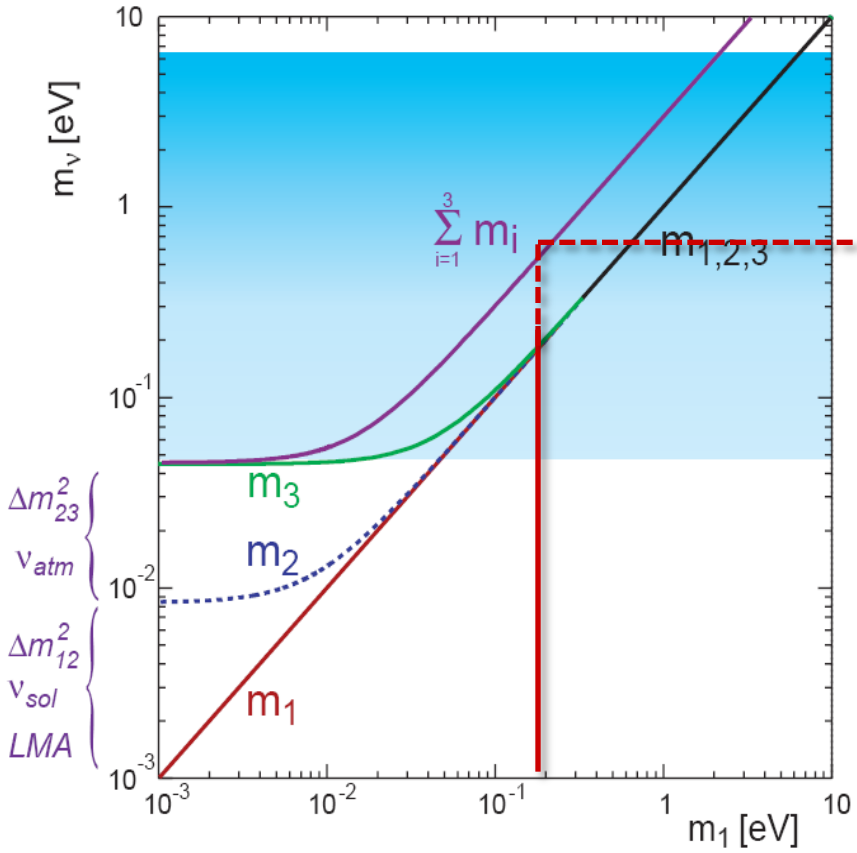
- Conclusion

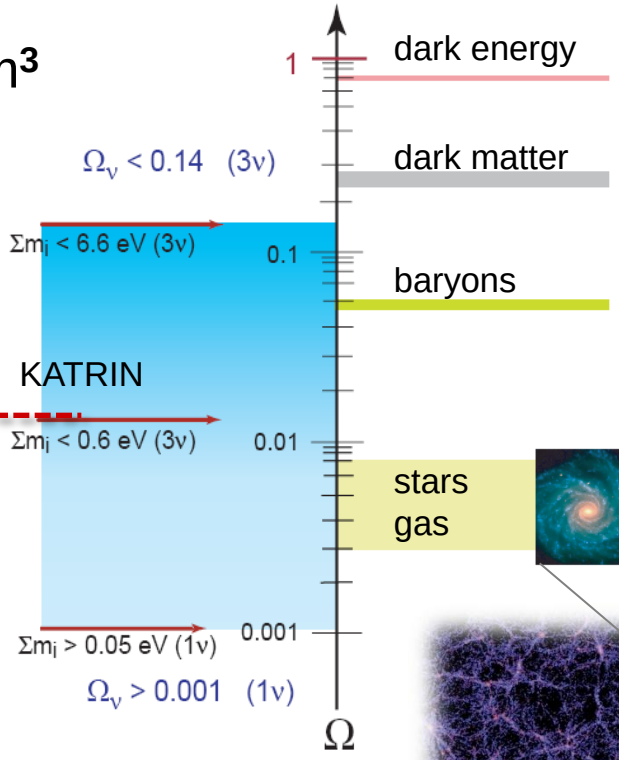


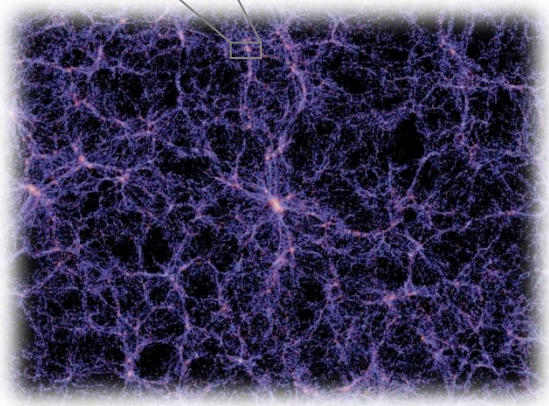
Absolute neutrino mass scale

Particle Physics

Cosmology 336 relic ν´s/cm³







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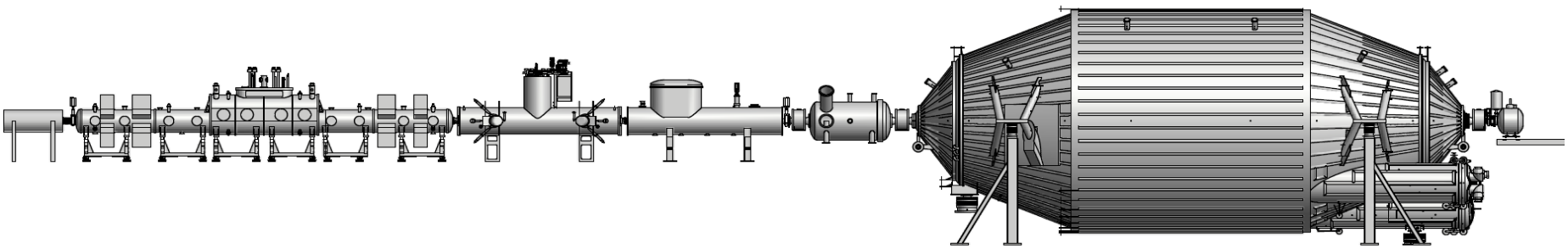
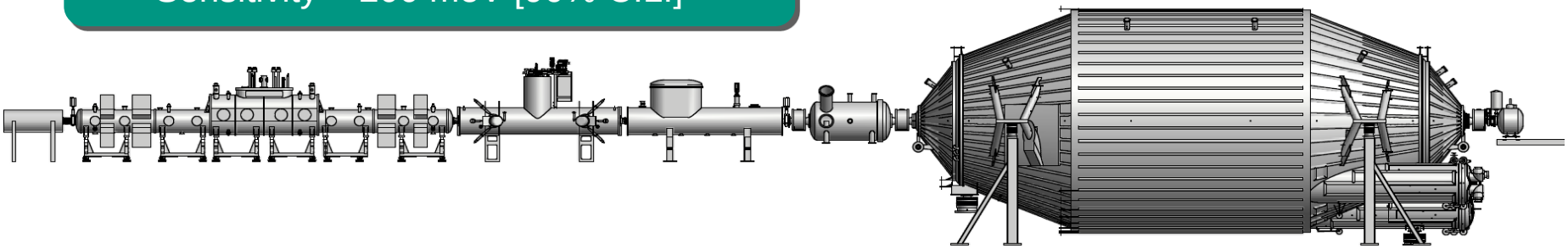
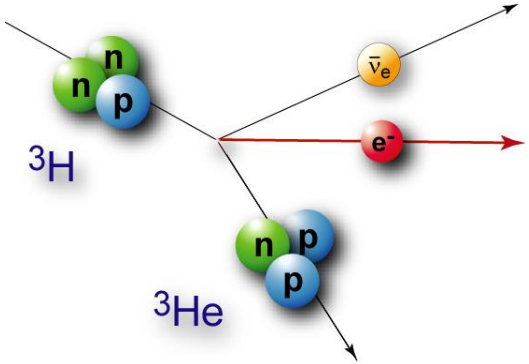


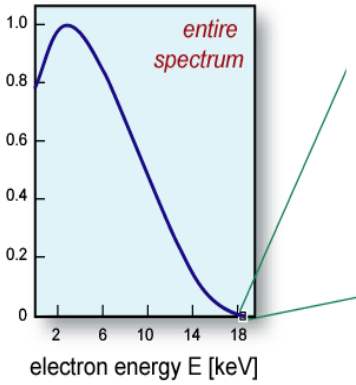
KATRIN experiment - overview

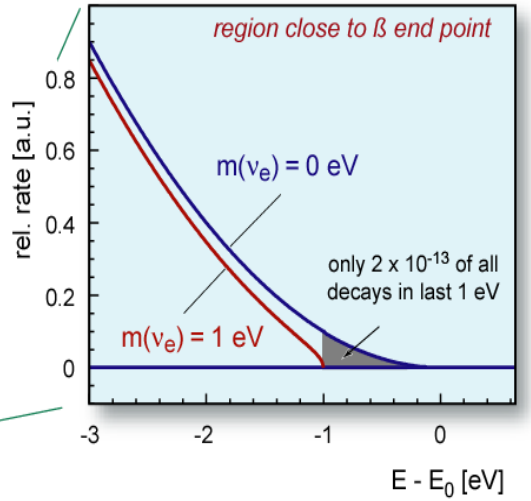
Goal: Direct neutrino mass measurement
Sensitivity = 200 meV [90% C.L.]





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

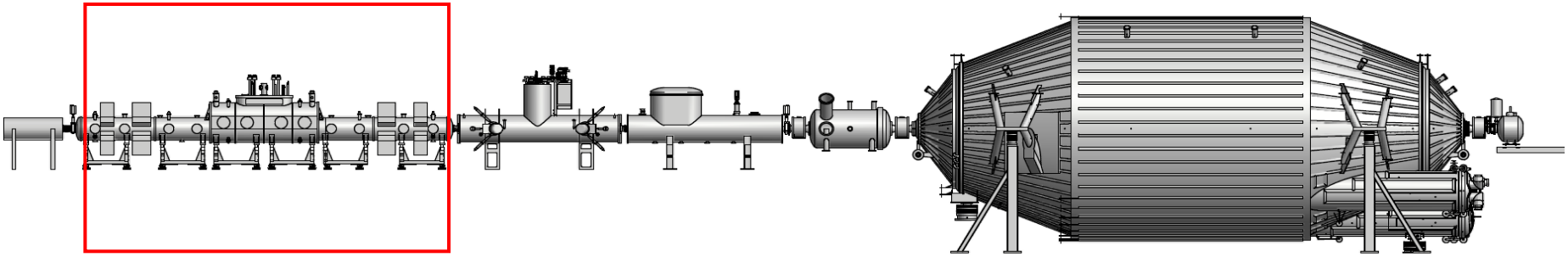




$$m^2(\bar{\nu}_e) = \sum_{i=1}^{3} \left| U_{ei}^2 \right| \cdot m_i^2$$

KATRIN experiment - overview

WGTS: Windowless gasseous tritium source



- **Source mass:**
  - 0.3 mg of T_2
- **Yearly throughput**
  - 10 kg (≡ ITER)
- **ß- intensity:**
  - 1.7×10^{11} electrons per second

KATRIN experiment - overview

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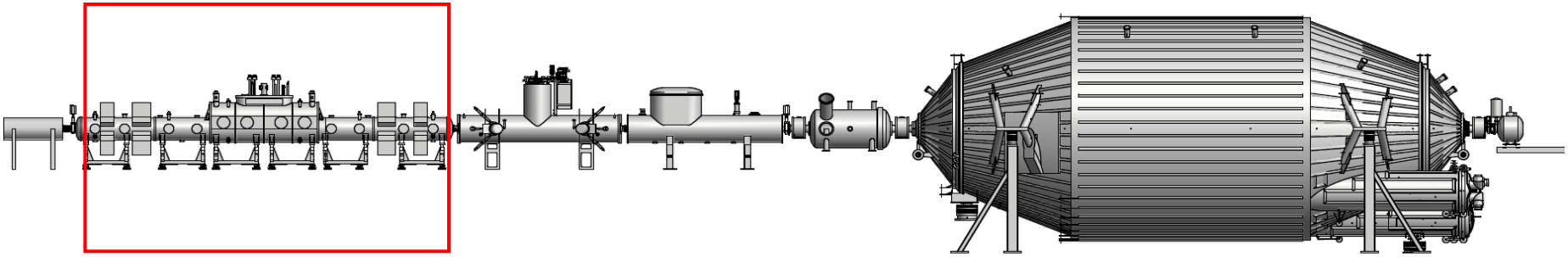
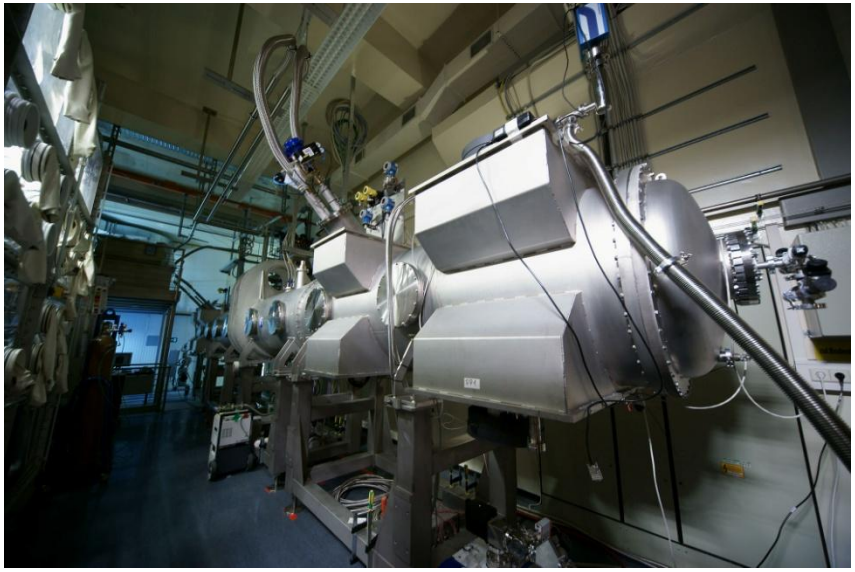
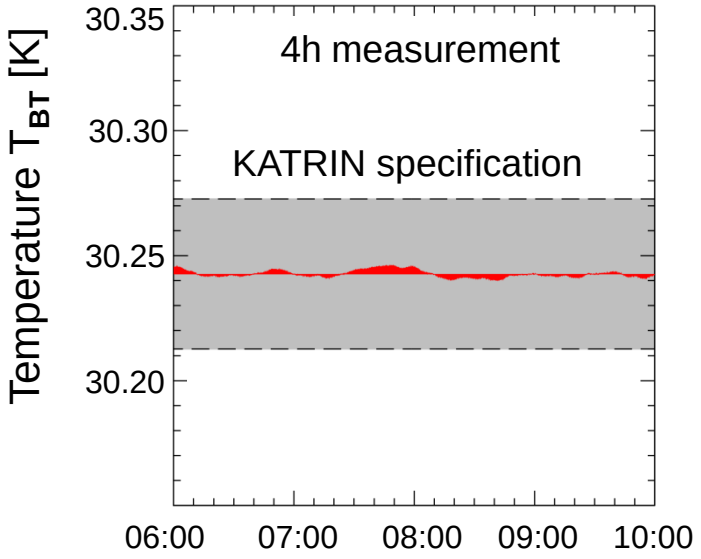


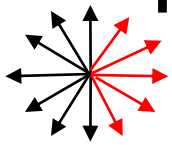


WGTS Demonstrator

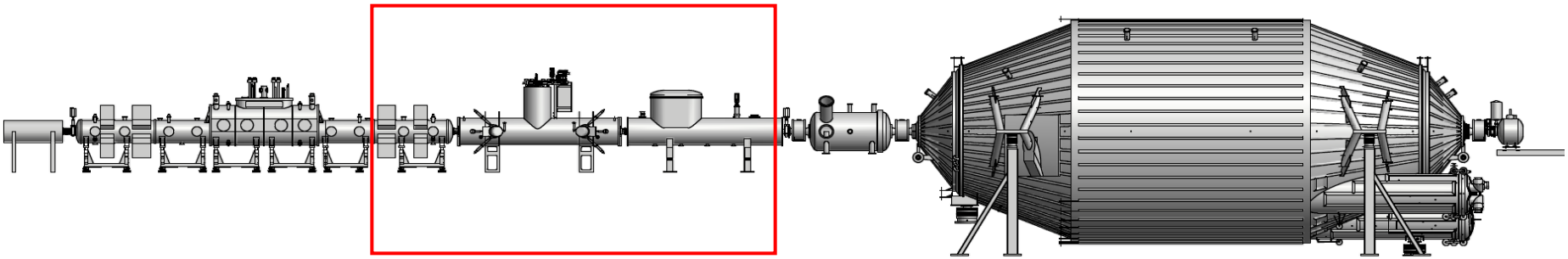


arXiv:1205.5421v1

KATRIN experiment - overview



Transport section



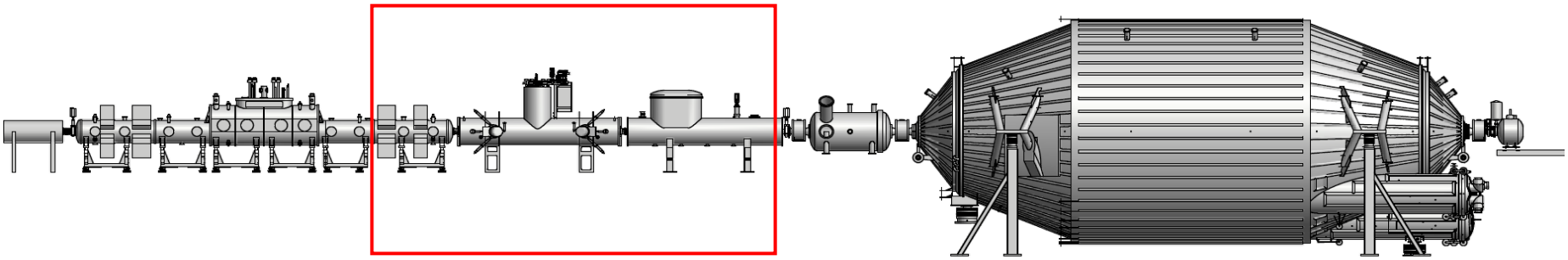
Adiabatic guidance of beta electrons

Transport section:
12 solenoids at 5.7 T

Total KATRIN system:
37 solenoids

KATRIN experiment - overview

Transport section



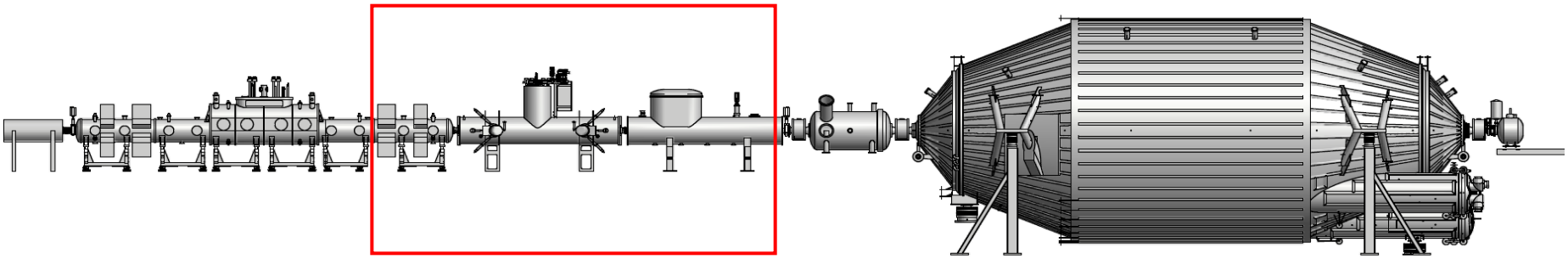
R>10⁷ **R>10⁷**

Reduction of tritium flow by 14 orders of magnitude

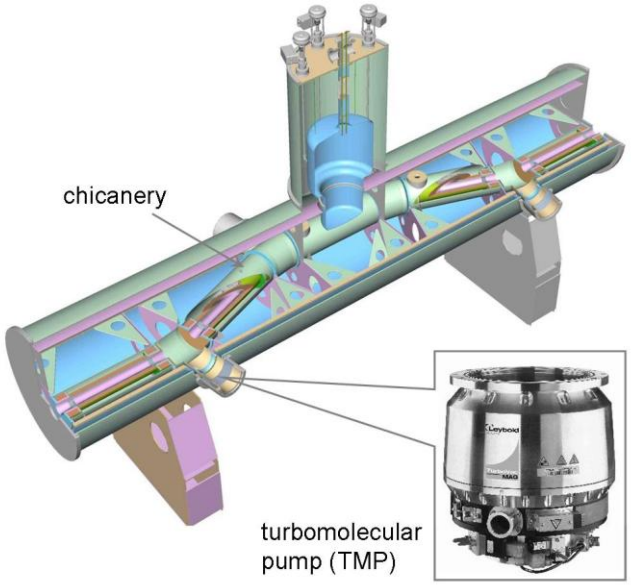
$p(T_2) < 10^{-20}$ mbar
$p = 10^{-11}$ mbar

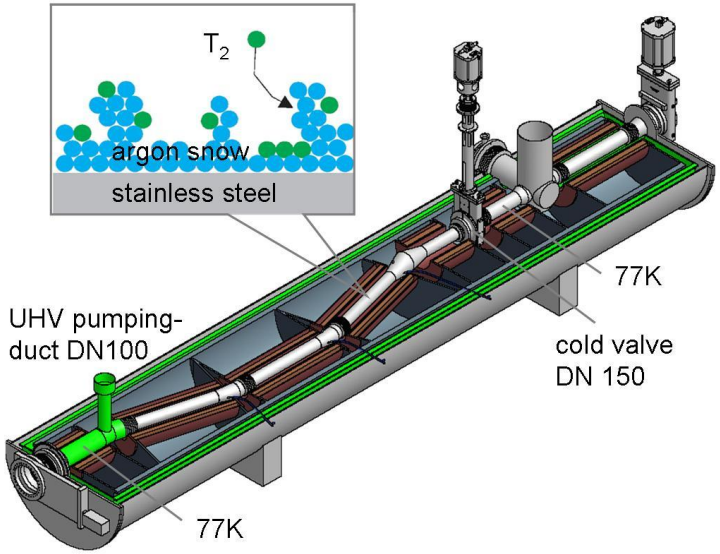
KATRIN experiment - overview

Transport section



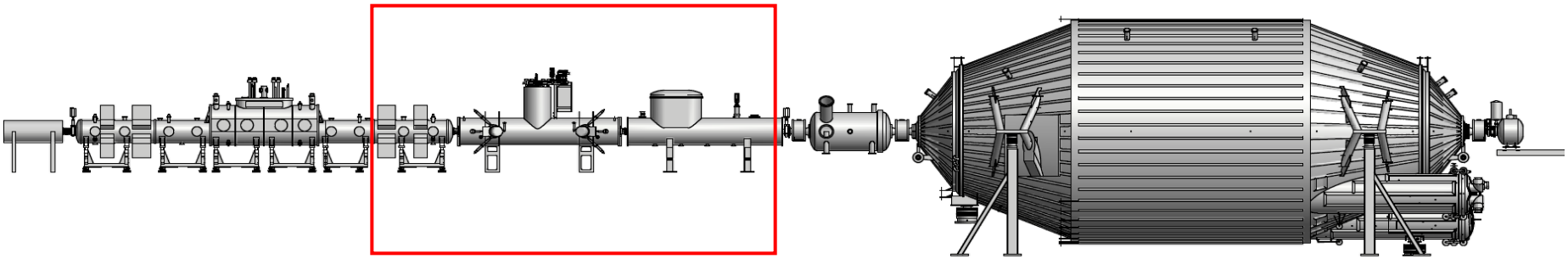
Differential pumping section + Cryogenic pumping section





KATRIN experiment - overview

Transport section

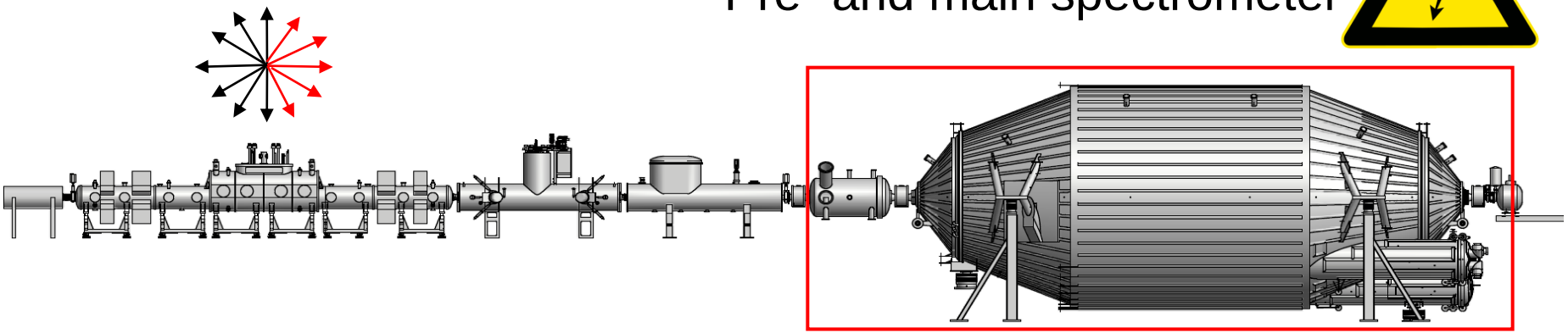


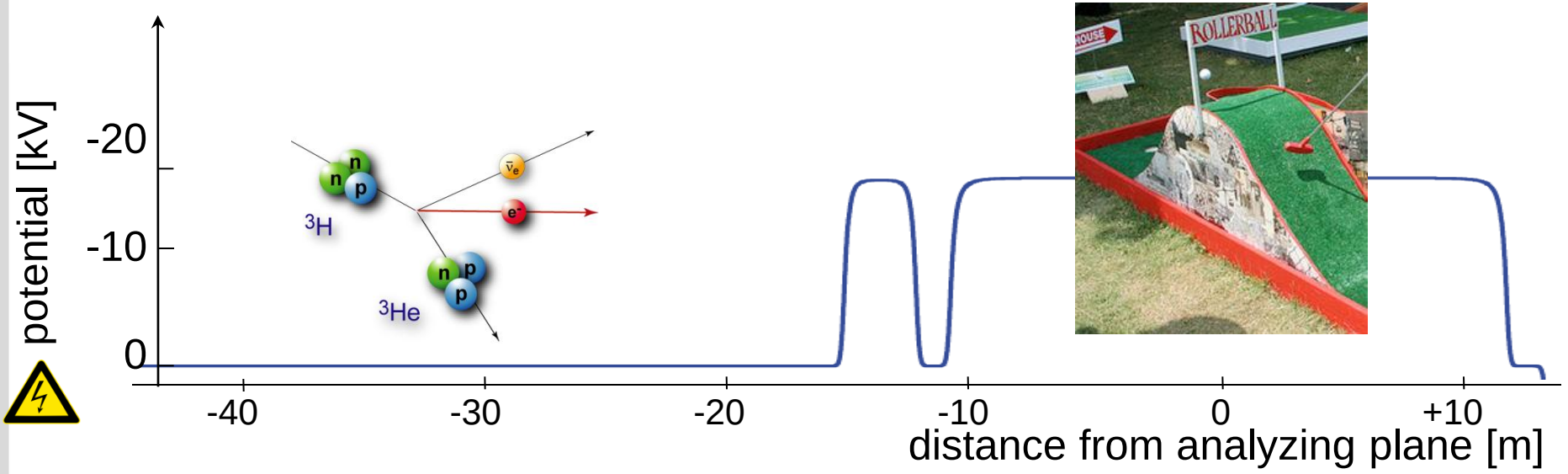
Differential pumping section + Cryogenic pumping section

http://dx.doi.org/10.1016/j.vacuum.2011.10.017

KATRIN experiment - overview

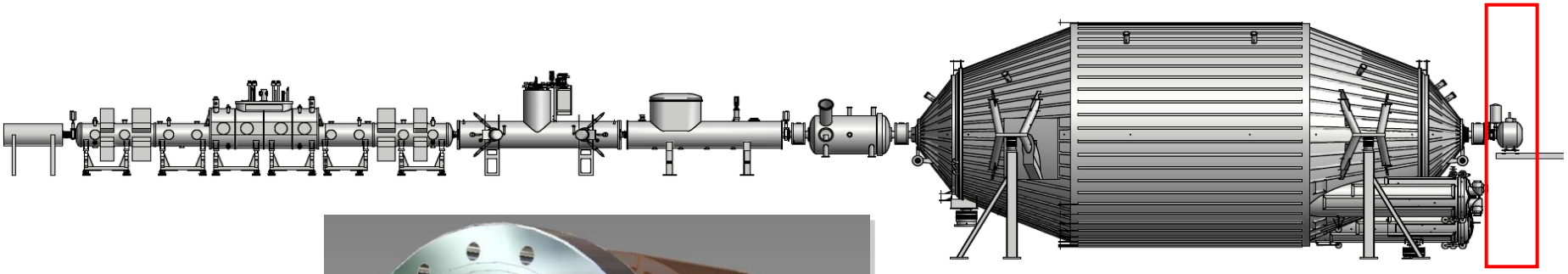
Pre- and main spectrometer

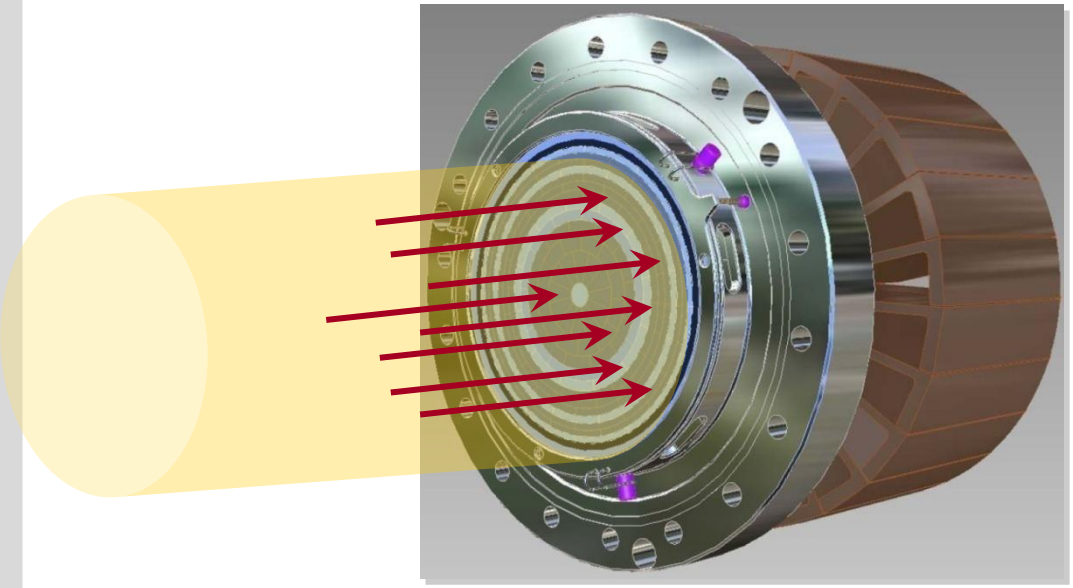


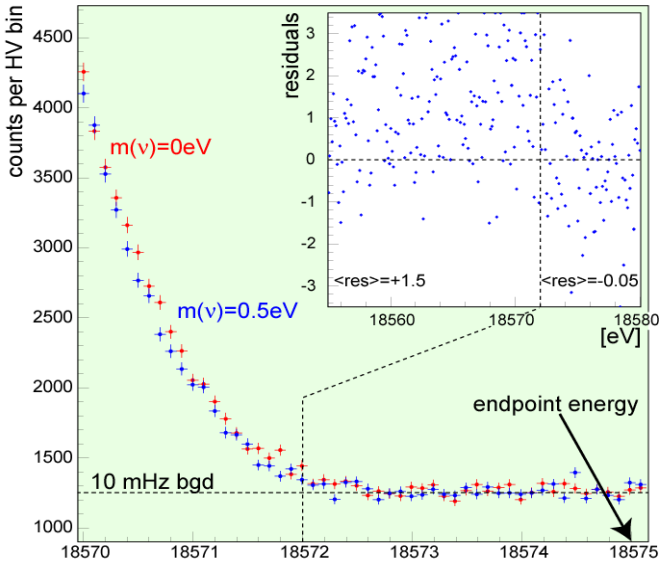


KATRIN experiment - overview

Detector







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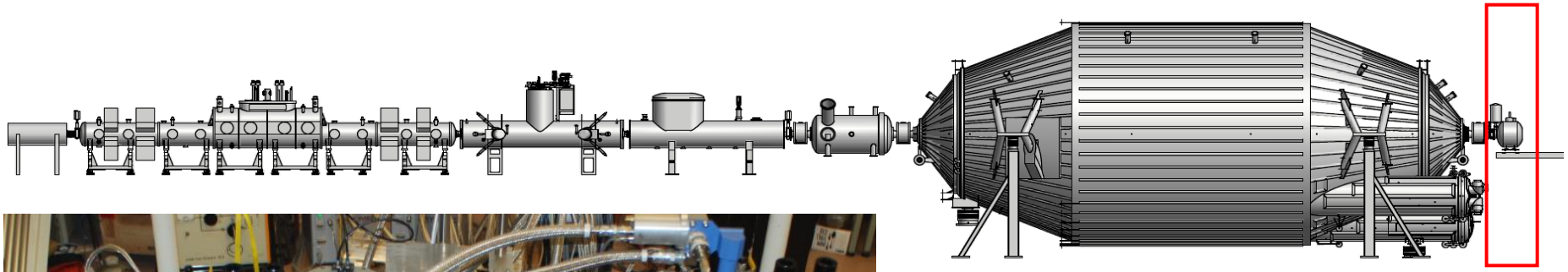
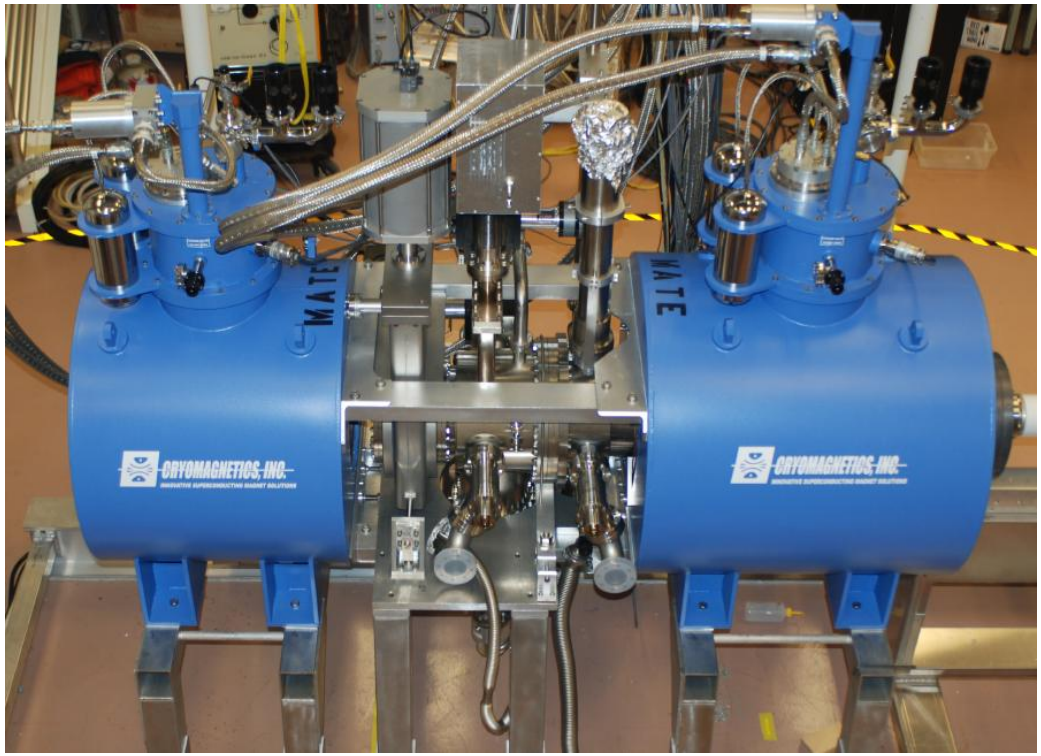
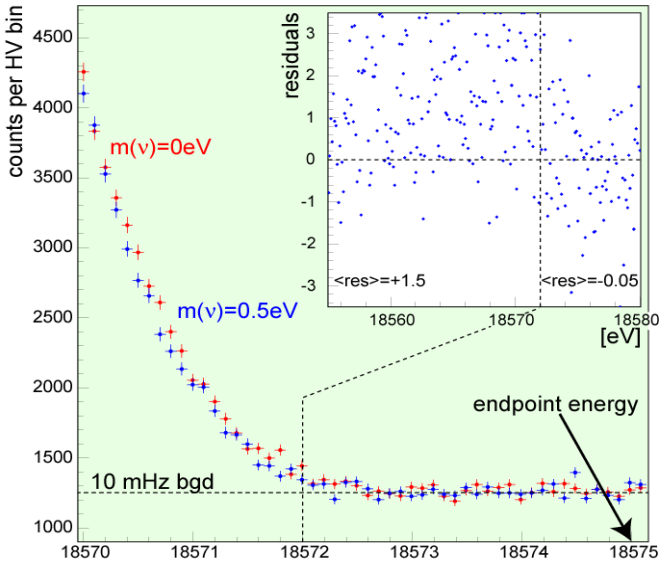
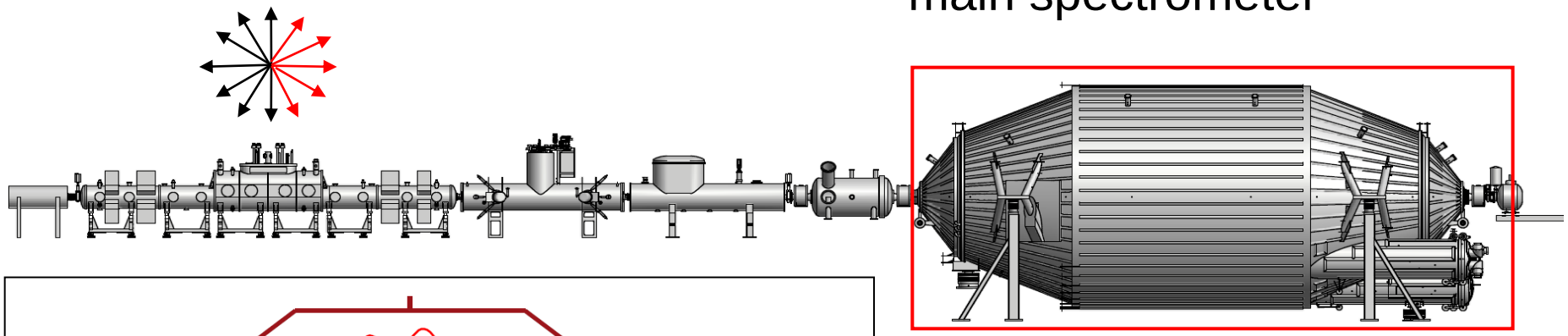


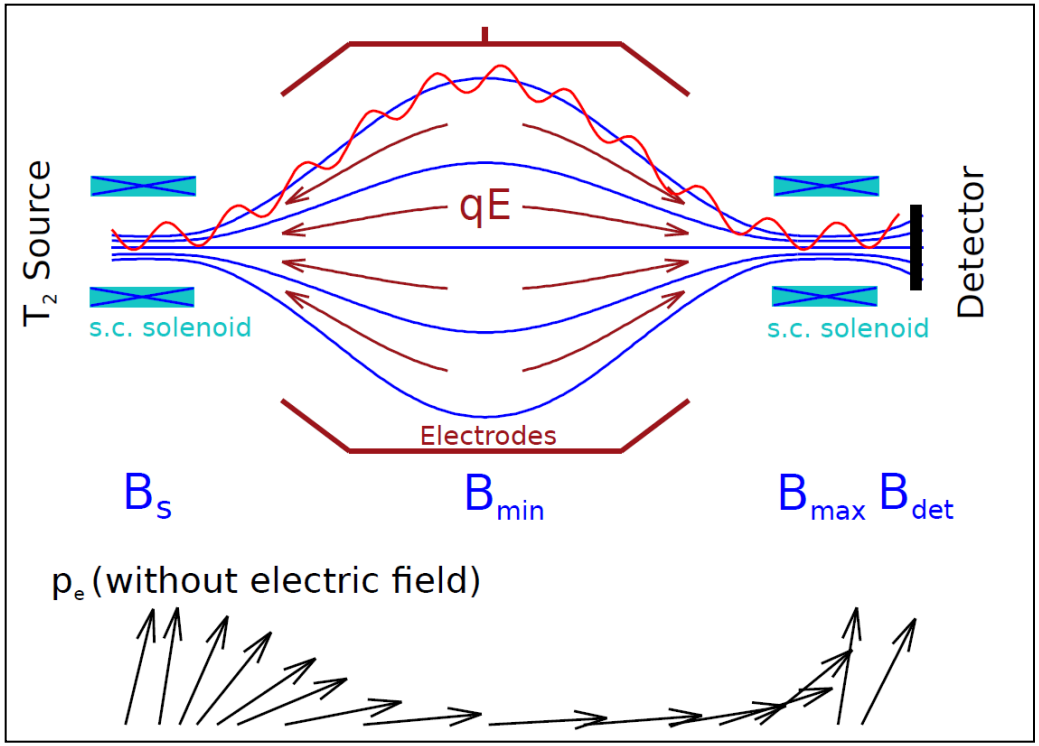




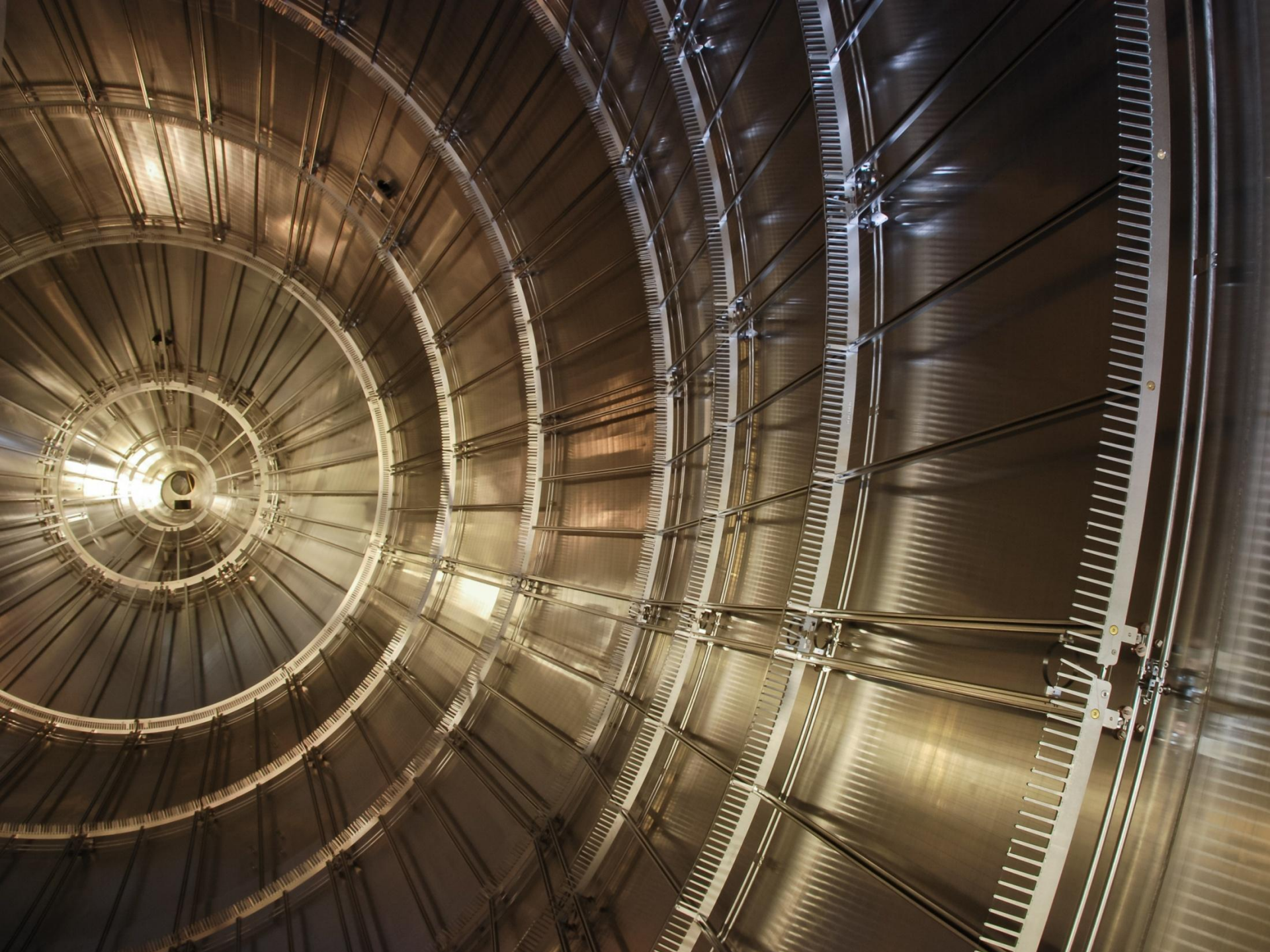
KATRIN experiment - overview

main spectrometer





MAC-E Principle:
Large angle acceptance
+ High energy resolution
(0.93 eV)



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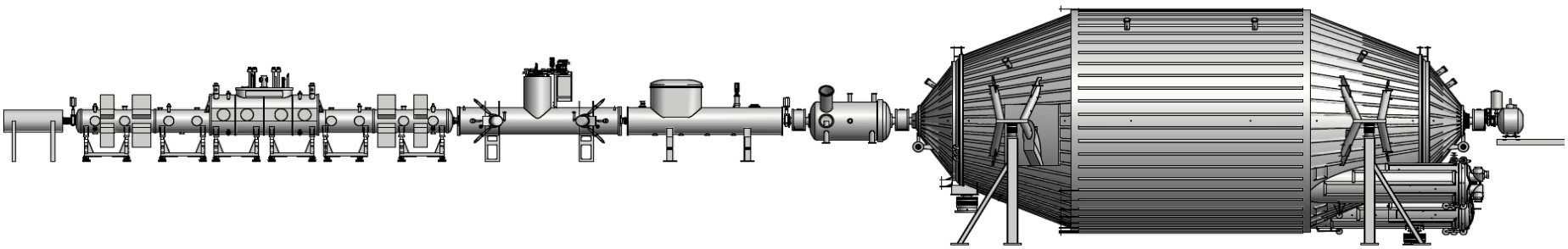
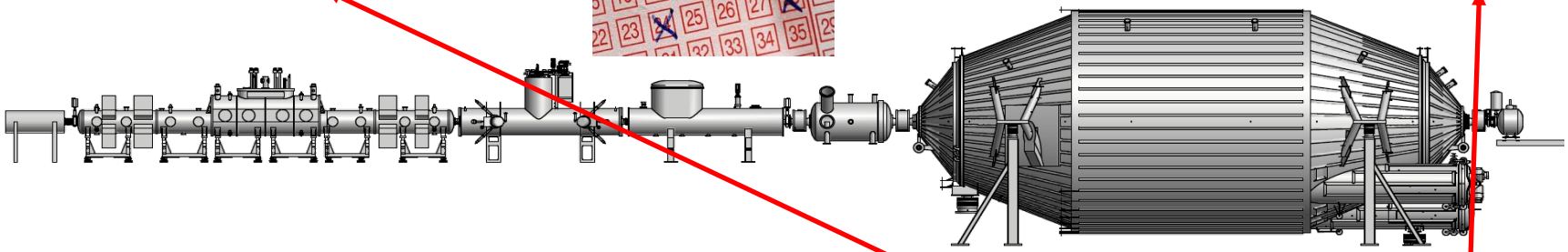


Why is background an issue for KATRIN ?

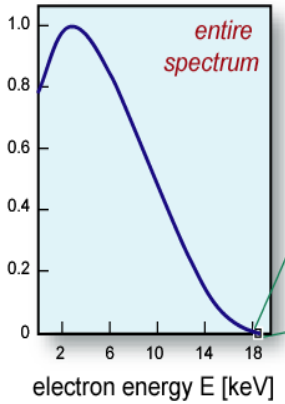
10^{11} electrons/s

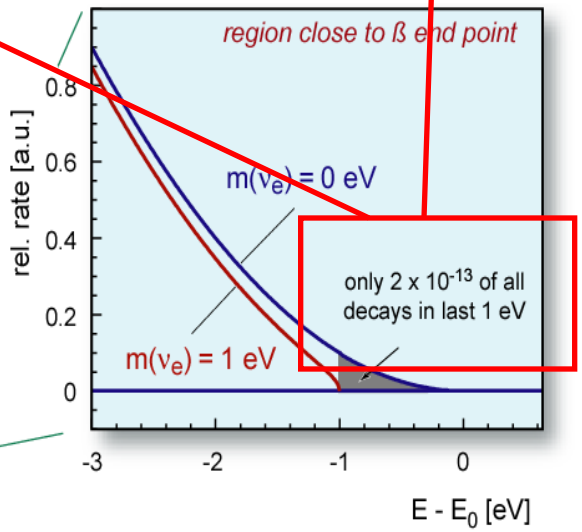
Probability = 10^{-7}

10^{-2} electrons/s
≈1 electron/min

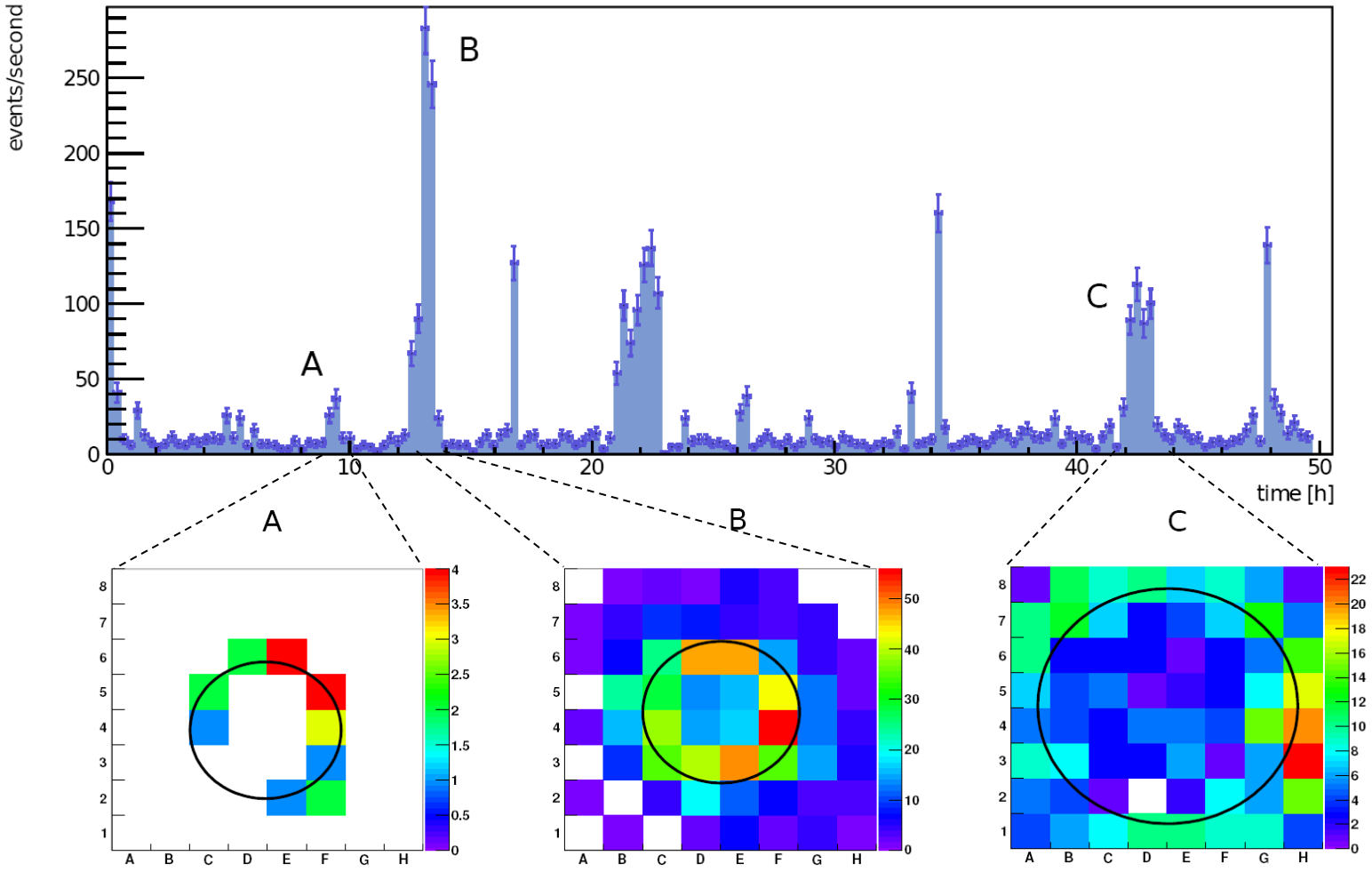


Desired background rate: = 10 mHz





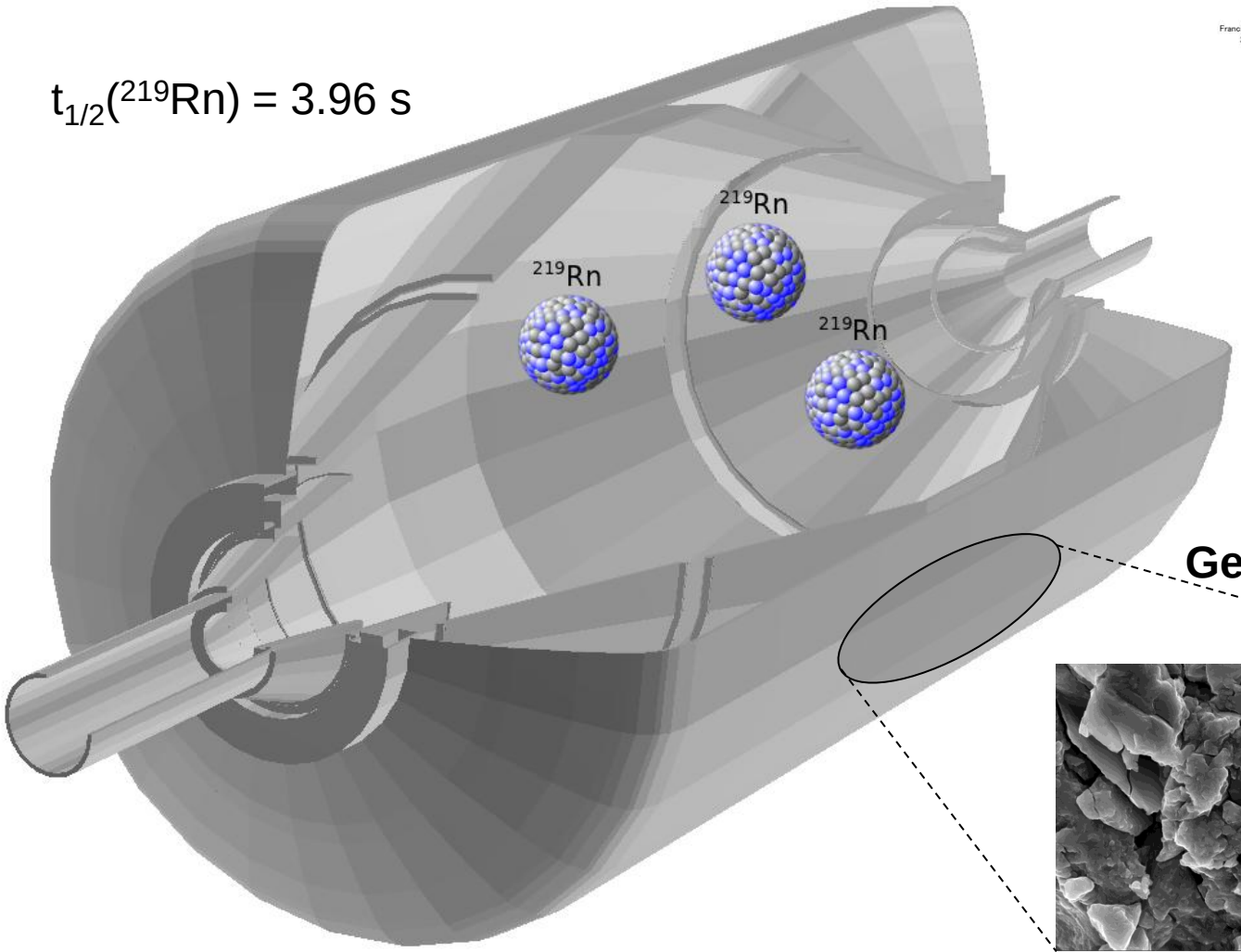
Background measurement at the prespectrometer

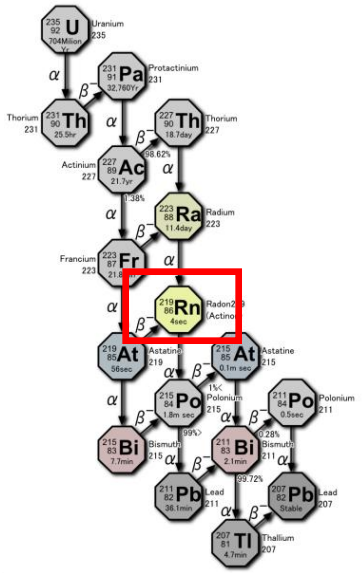


http://dx.doi.org/10.1016/j.astropartphys.2011.06.009

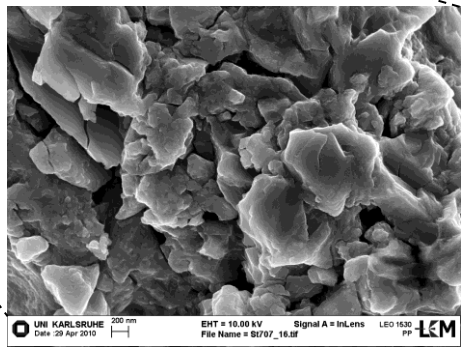
Background production mechanism

$t_{1/2}(^{219}Rn) = 3.96$ s

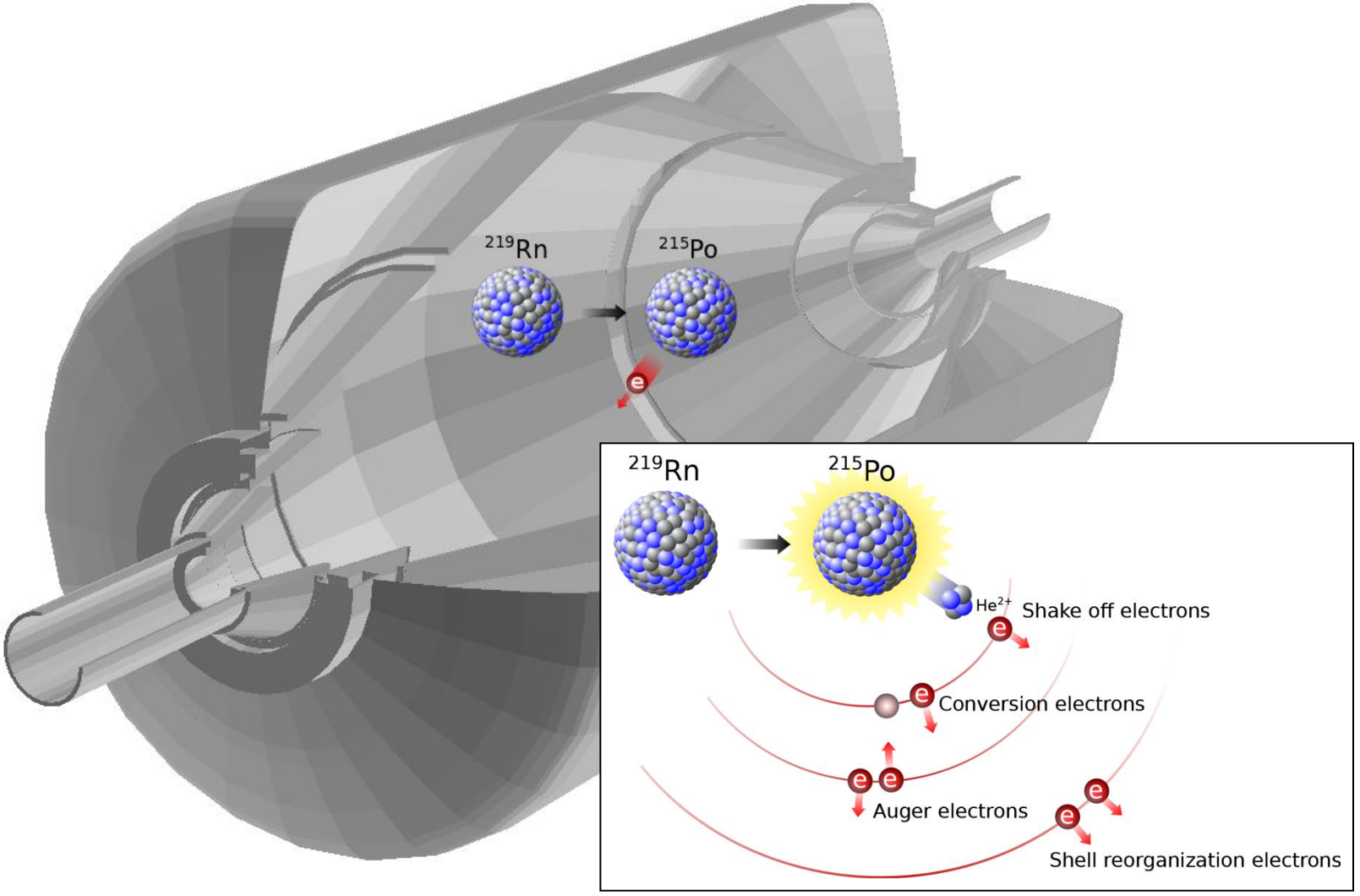




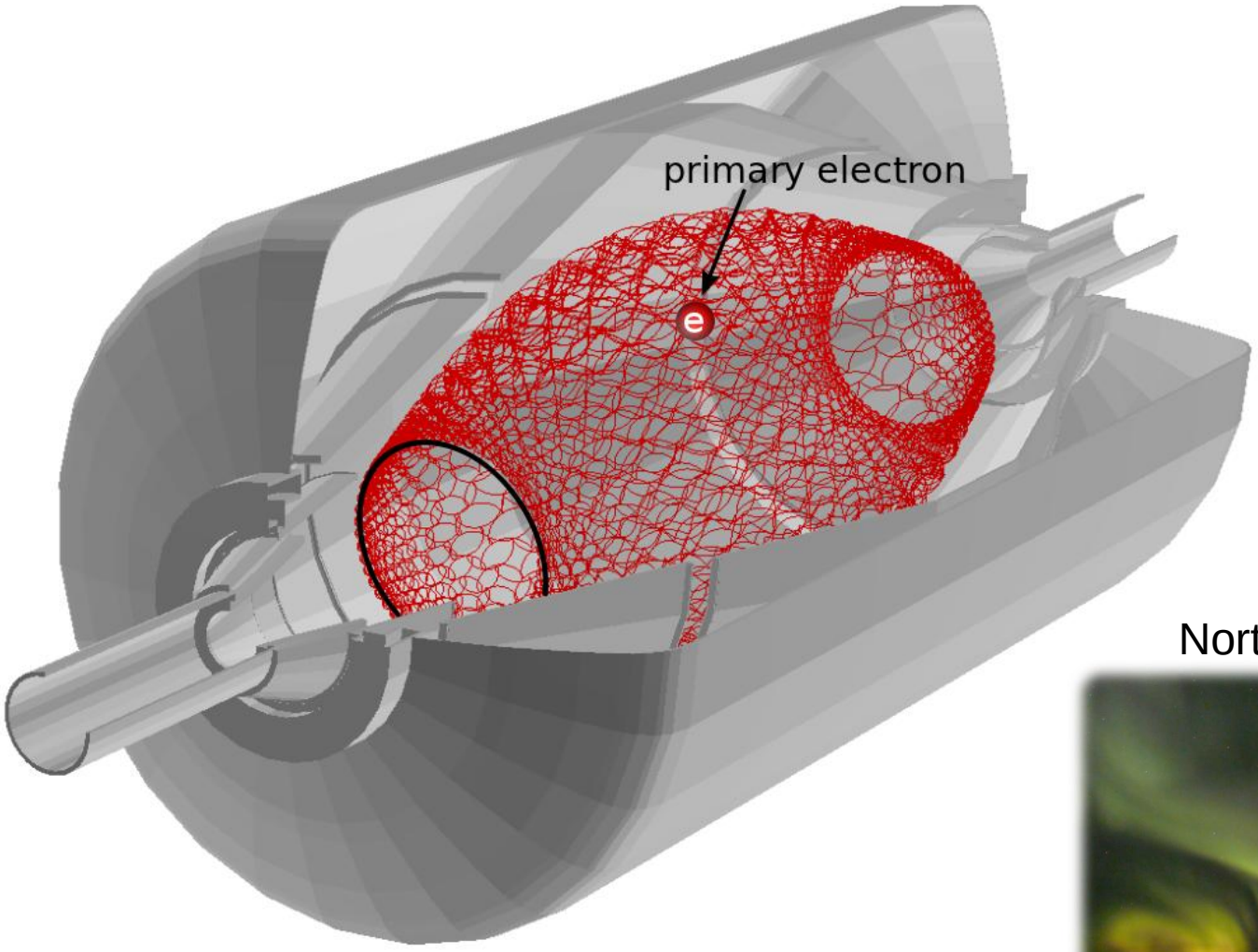
Getter pump



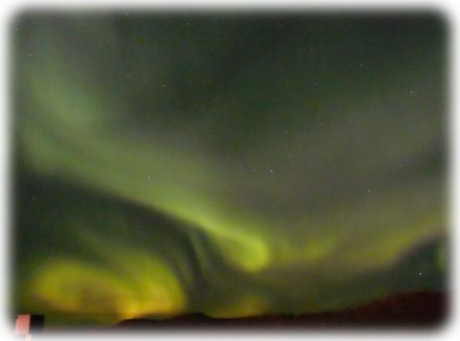
Background production mechanism



Background production mechanism

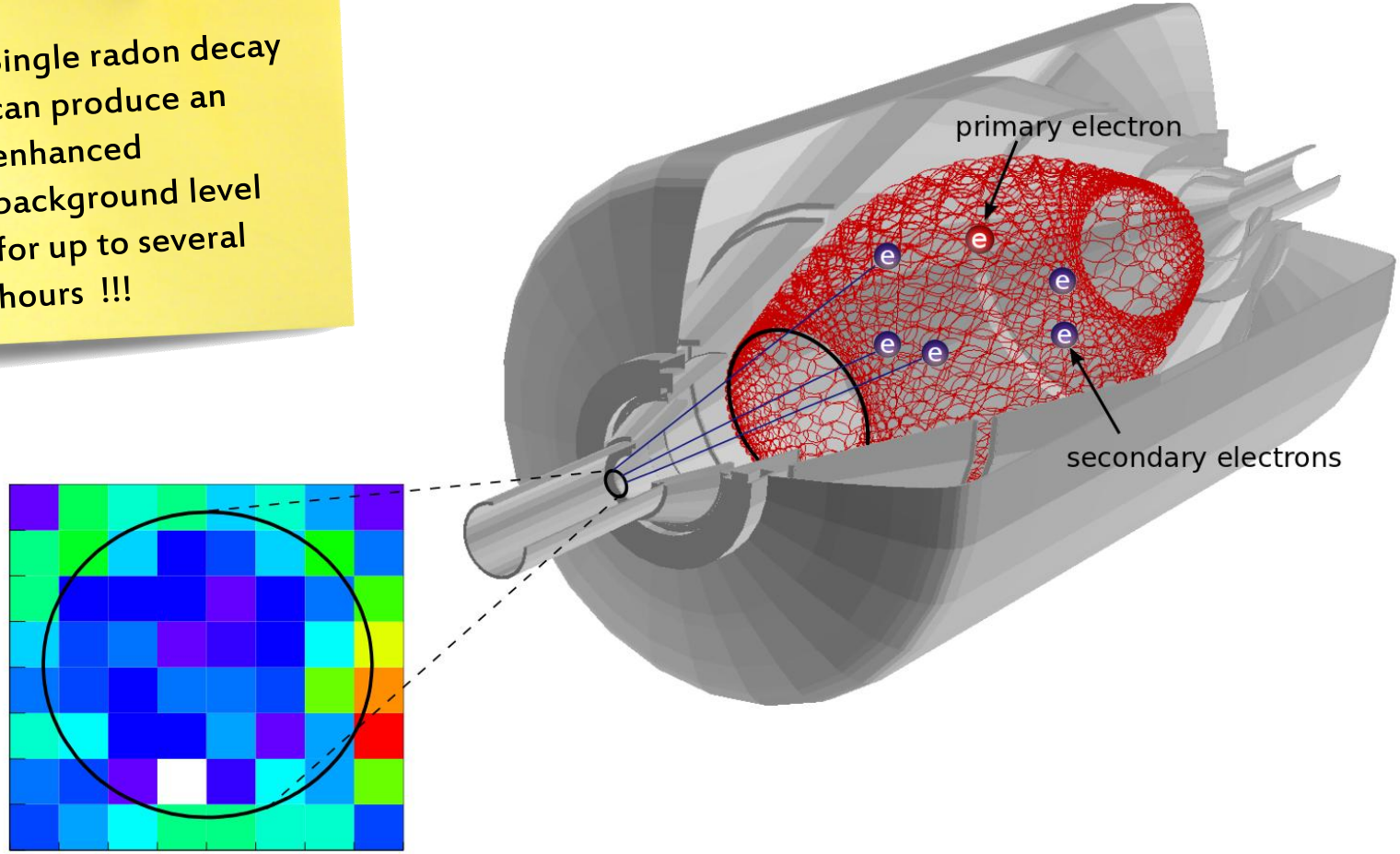


Northern lights



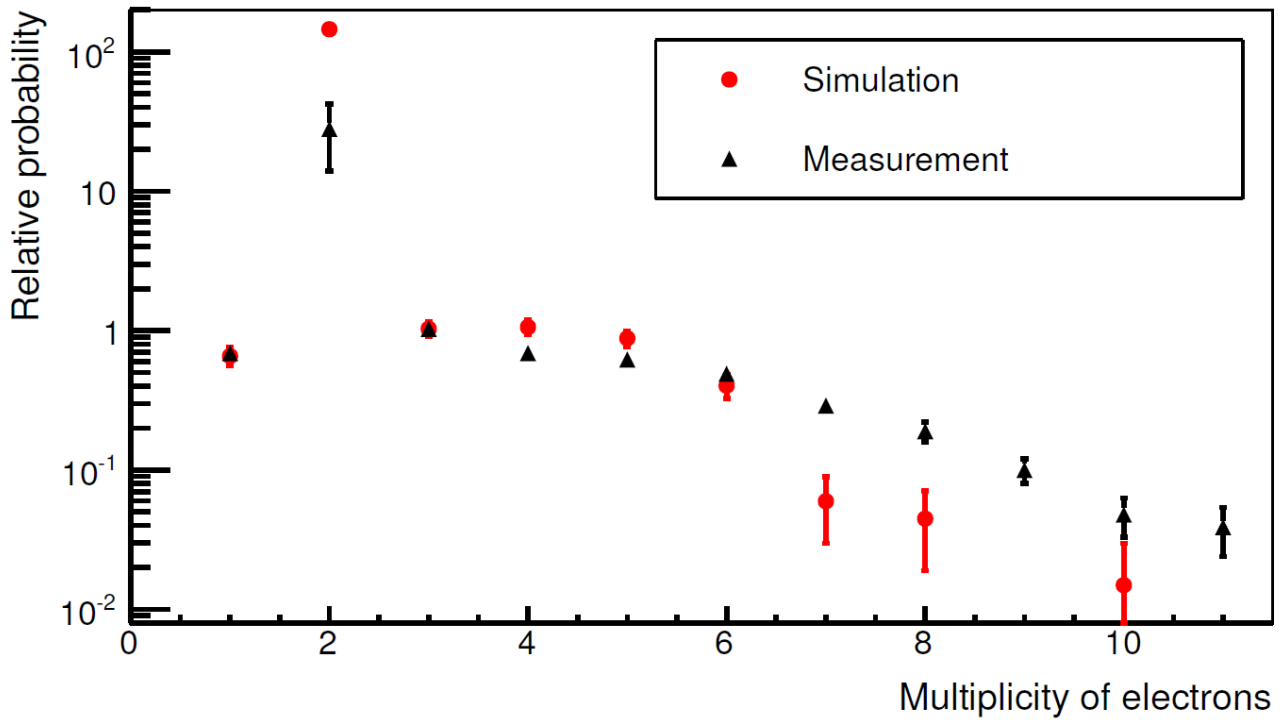
Background production mechanism

Single radon decay can produce an enhanced background level for up to several hours !!!



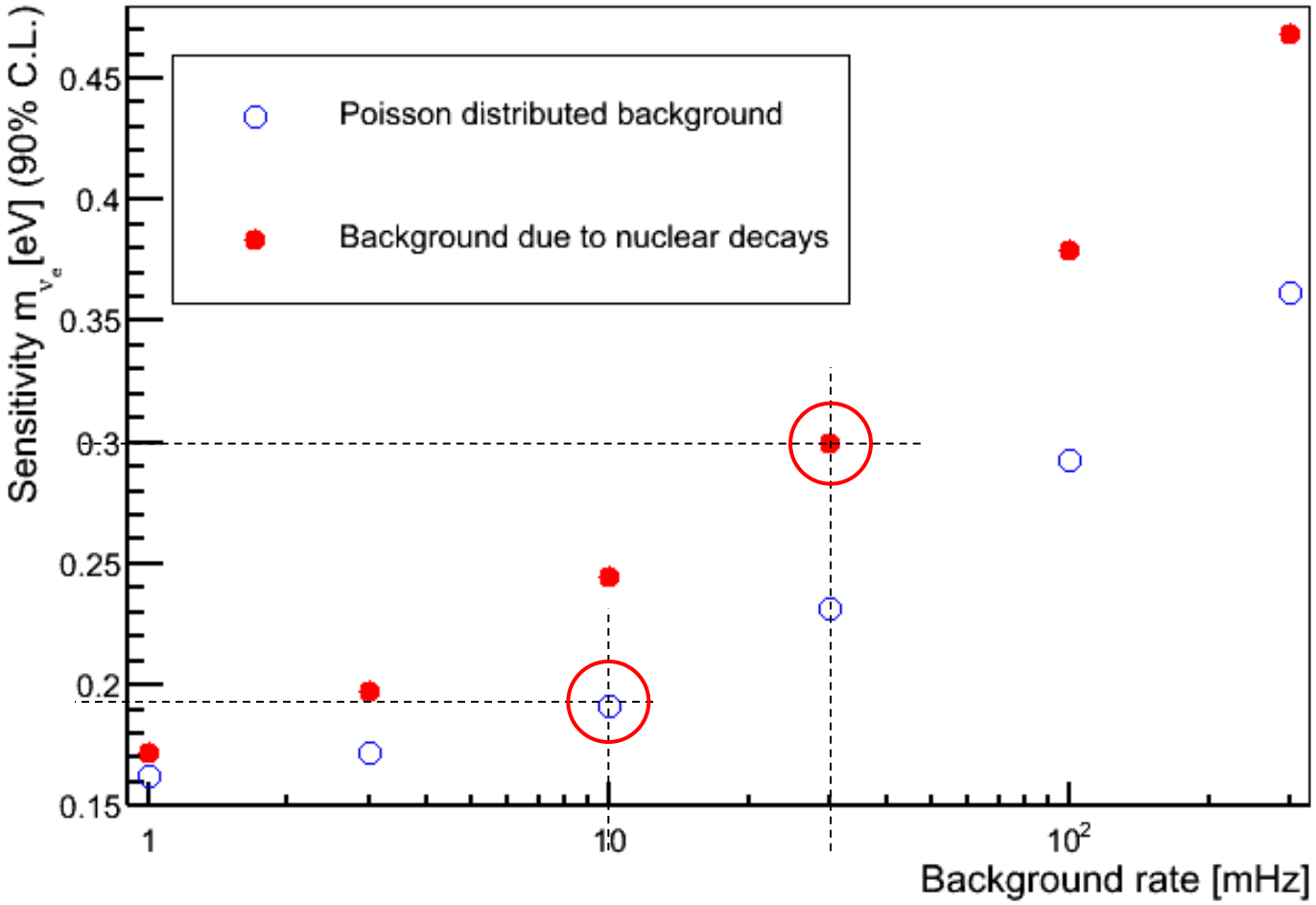
Verification of background model

- Comparison to independent measurement



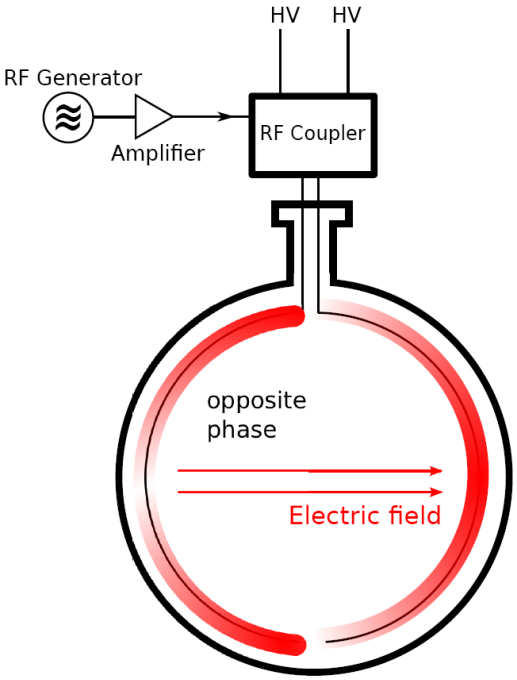
http://link.aps.org/doi/10.1103/PhysRevLett.15.163

Impact of background on KATRIN sensitivity

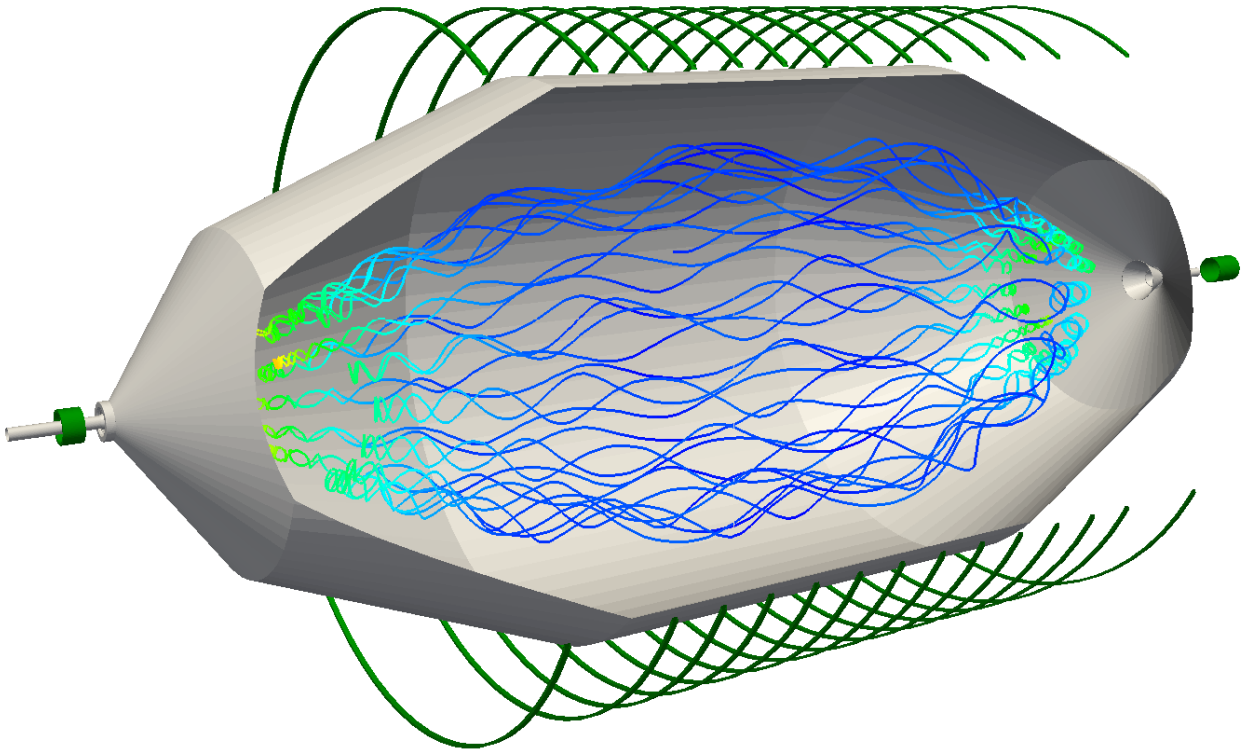


arXiv:1204.6213v1

Solution: Electron Cyclotron Resonance (ECR)



$$\omega_{\mathrm{RF}} = \omega_{\mathrm{cycl}} = \frac{eB}{m\gamma}$$



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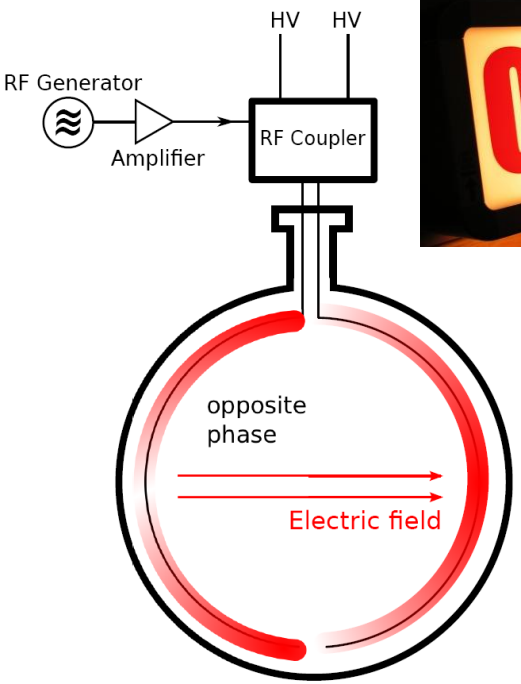

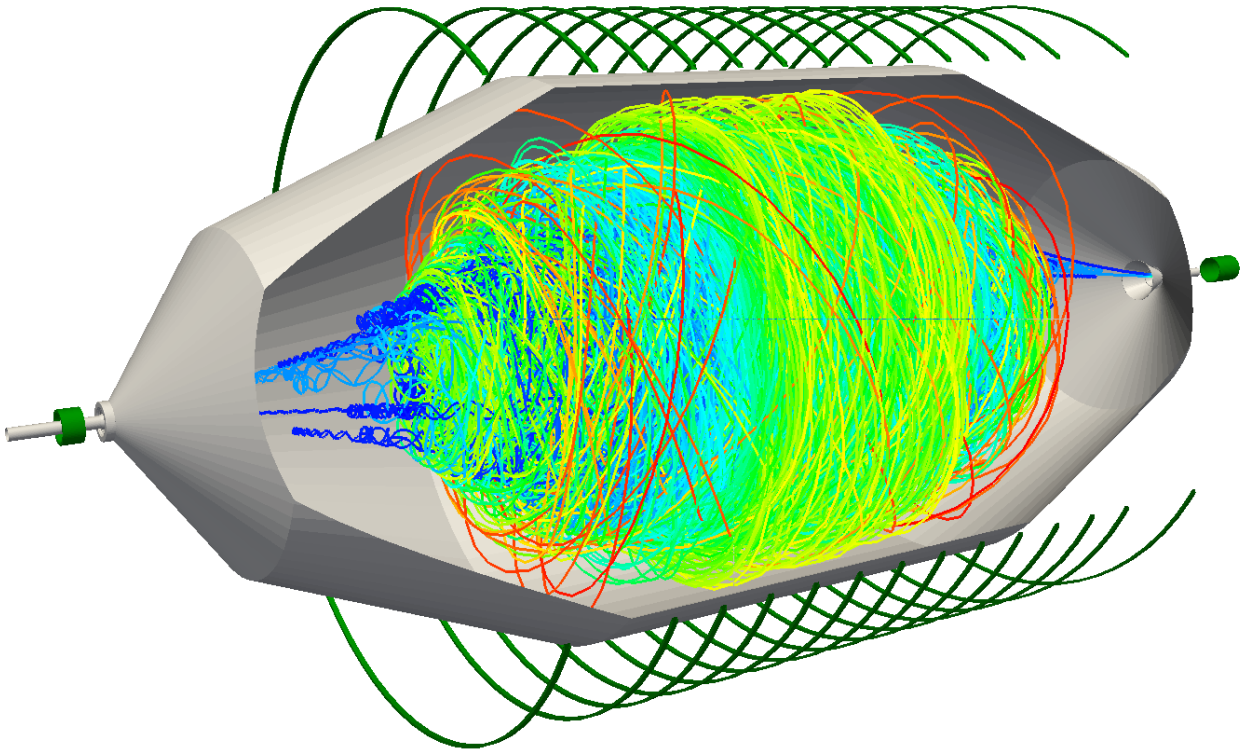

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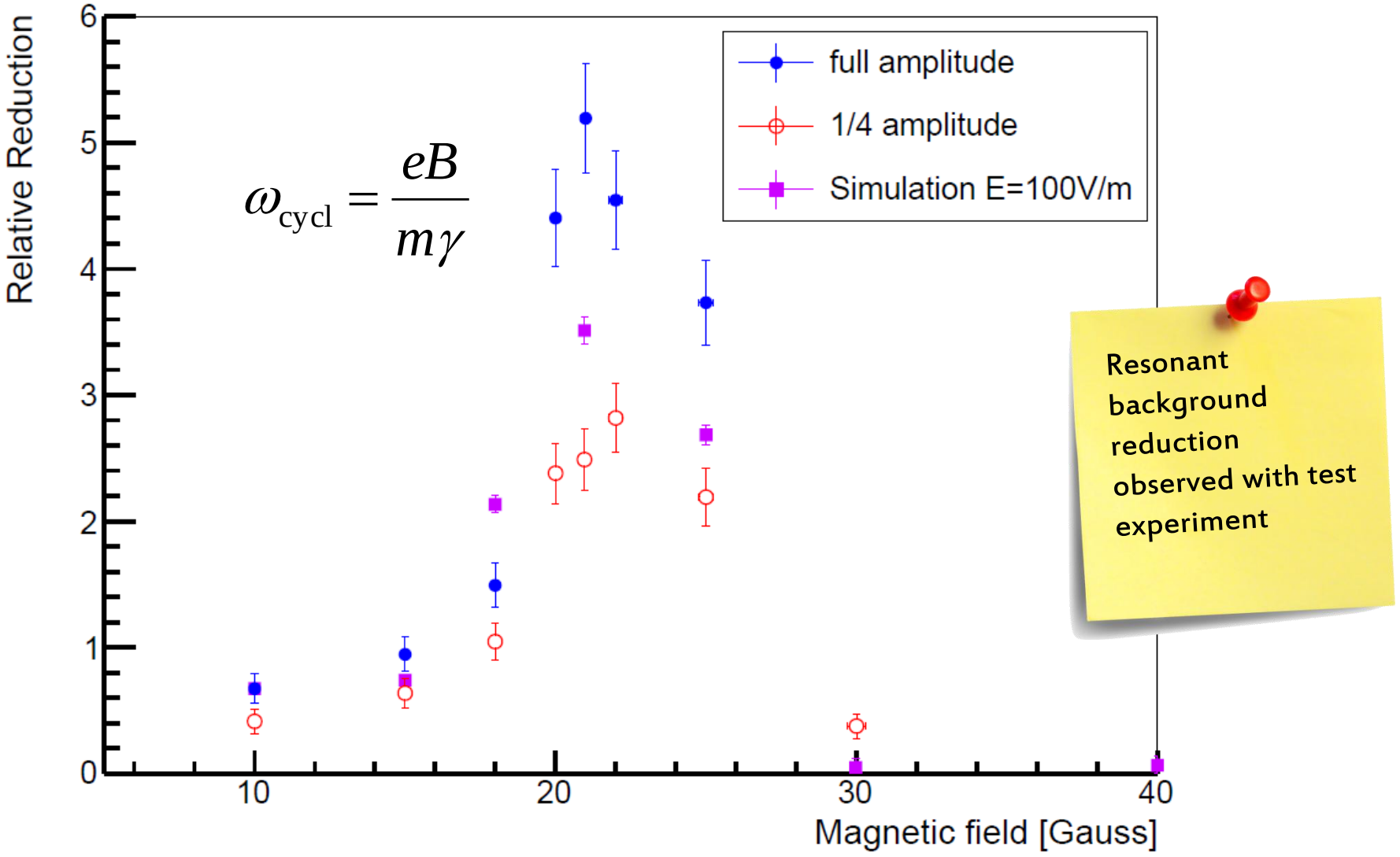

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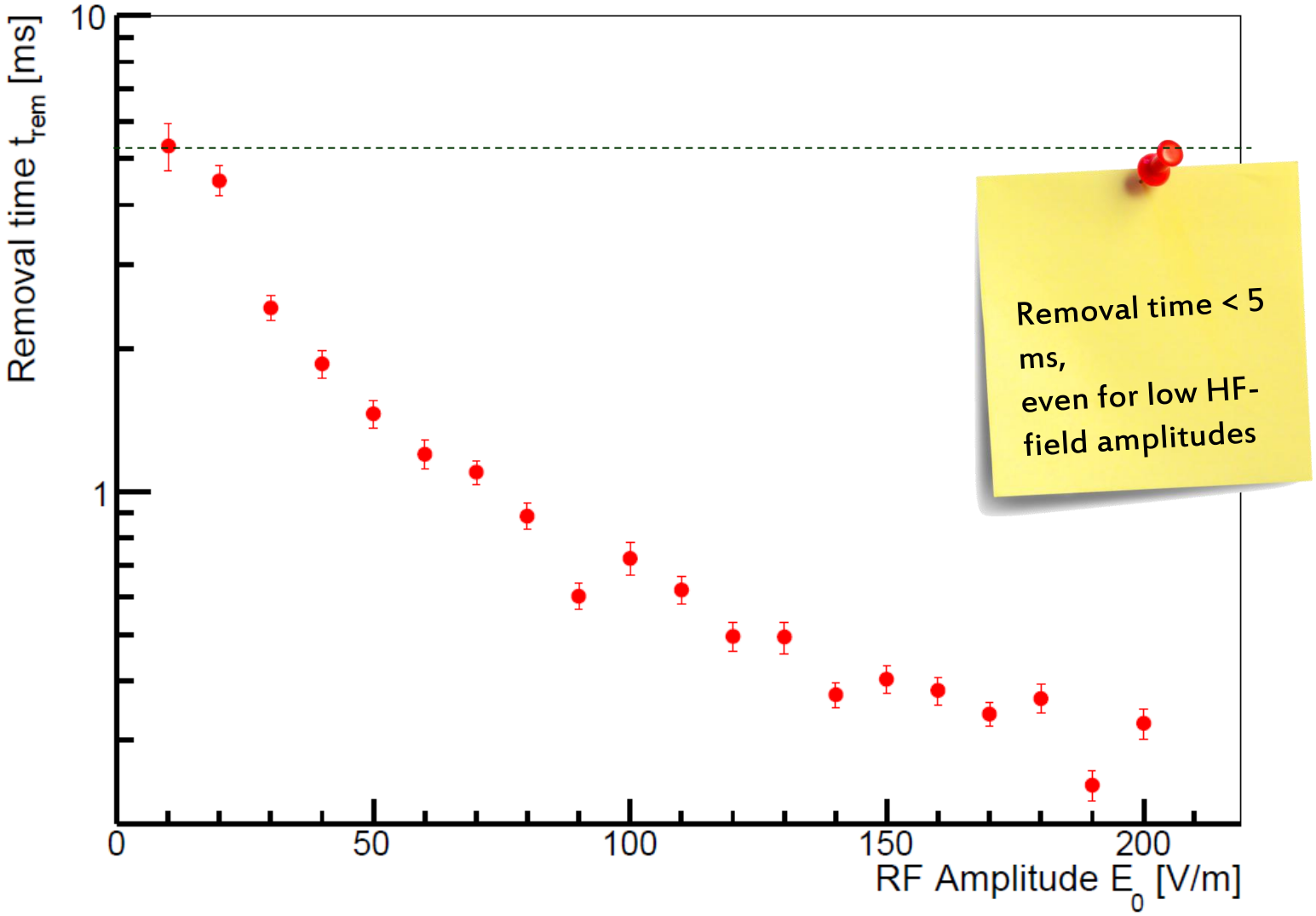

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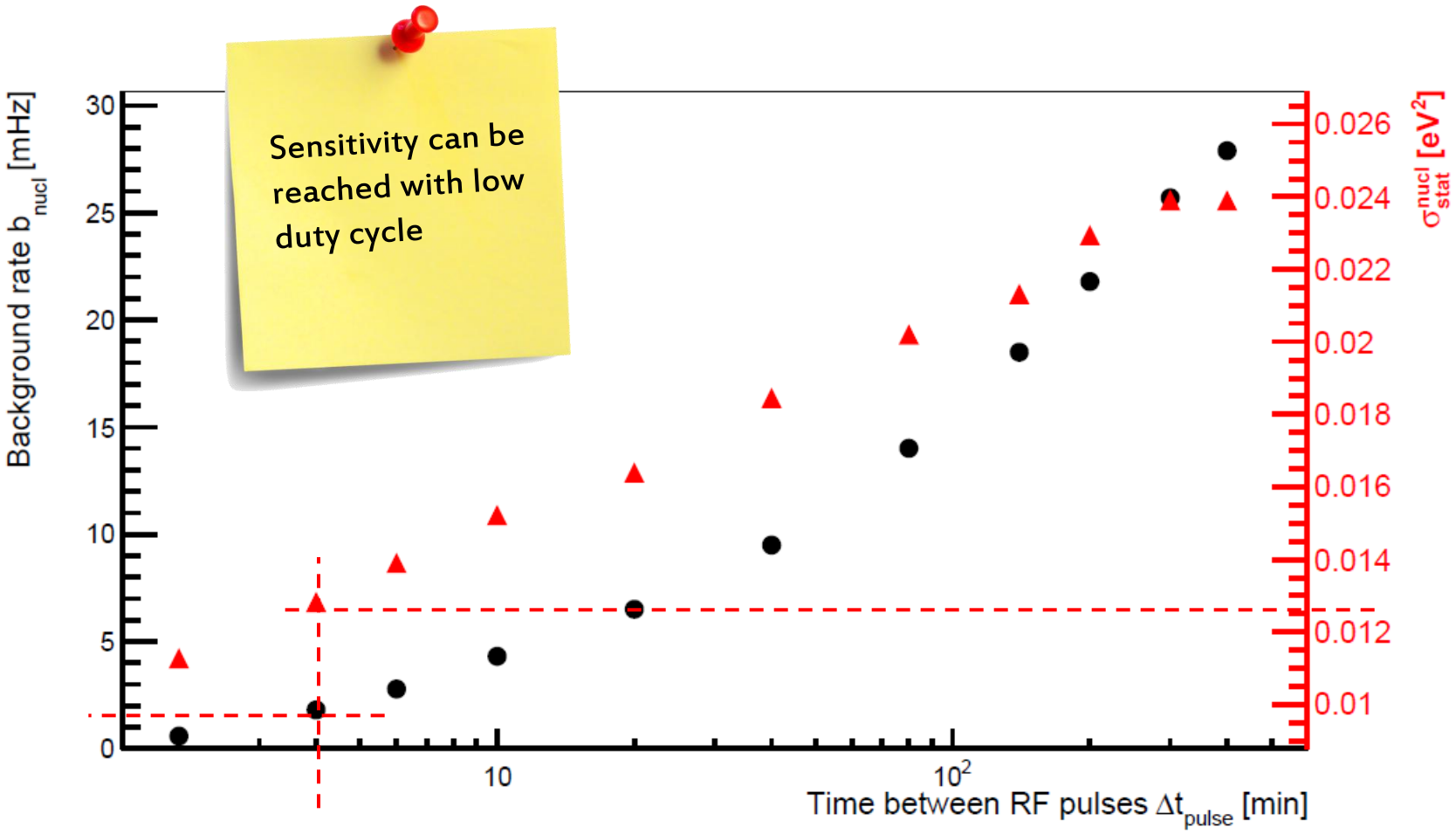

arXiv:1205.3729v1

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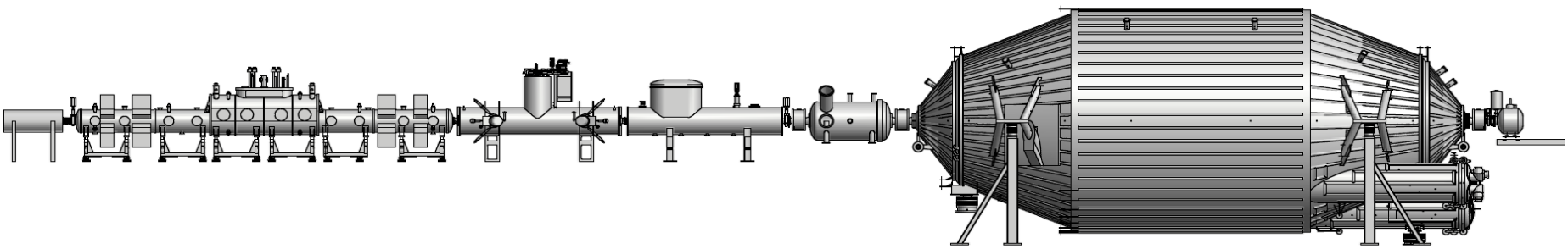
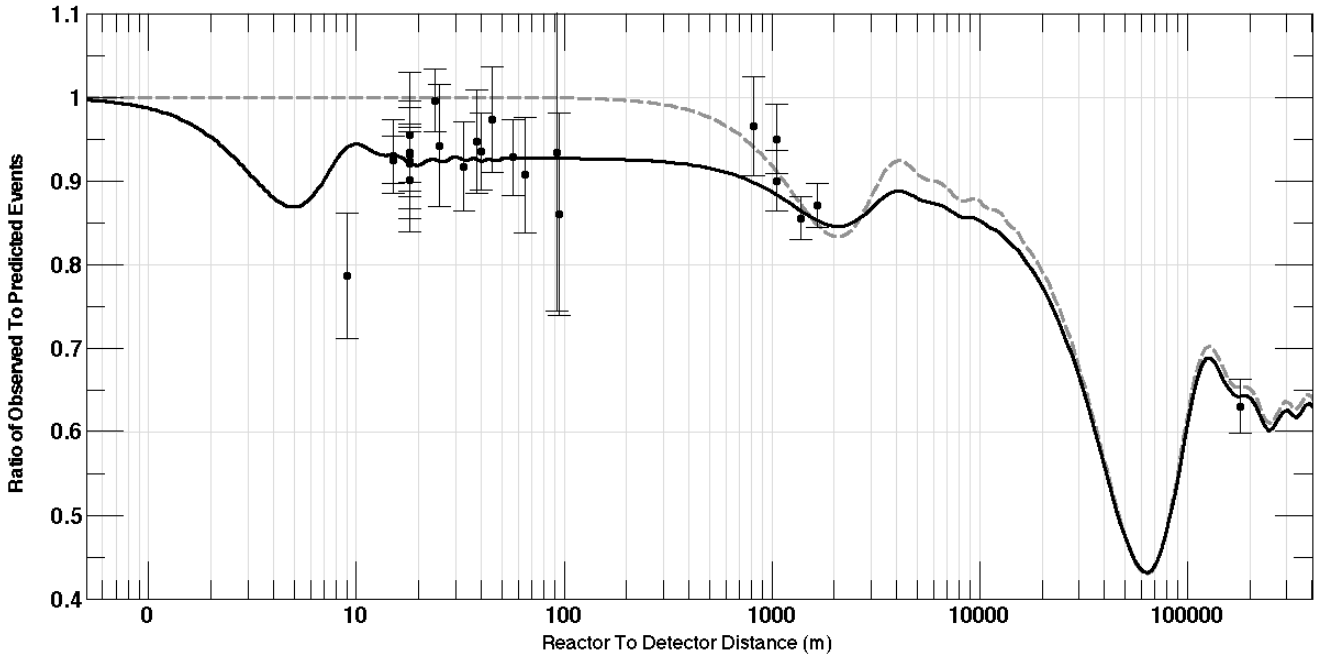


KATRIN and eV sterile neutrinos

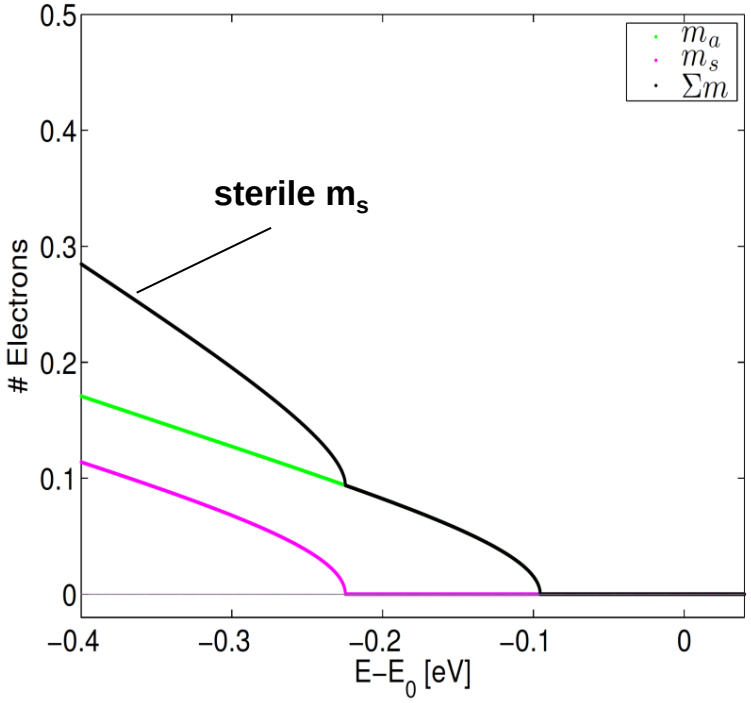
- Reactor anomaly
- Gallium anomaly
- Short base line accelerator results

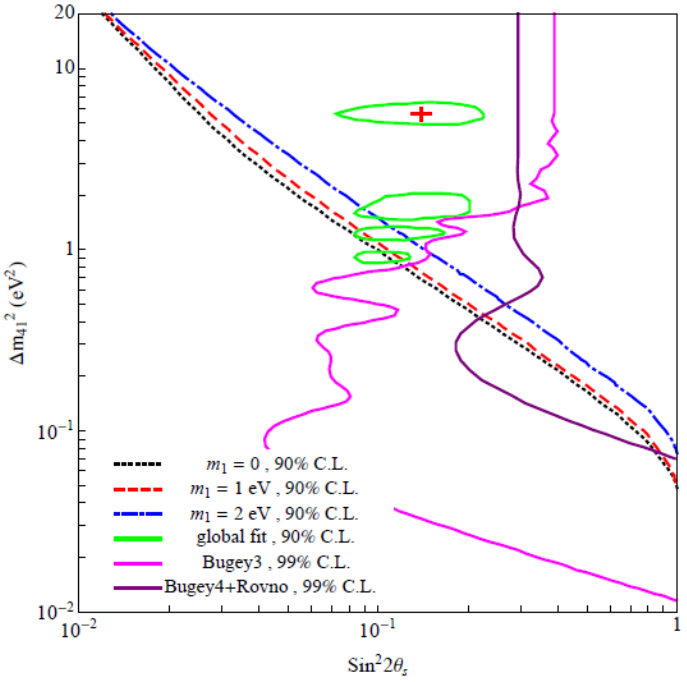


http://link.aps.org/doi/10.1103/PhysRevD.83.073006

KATRIN and eV sterile neutrinos

- Reactor anomaly
- Gallium anomaly
- Short base line accelerator results

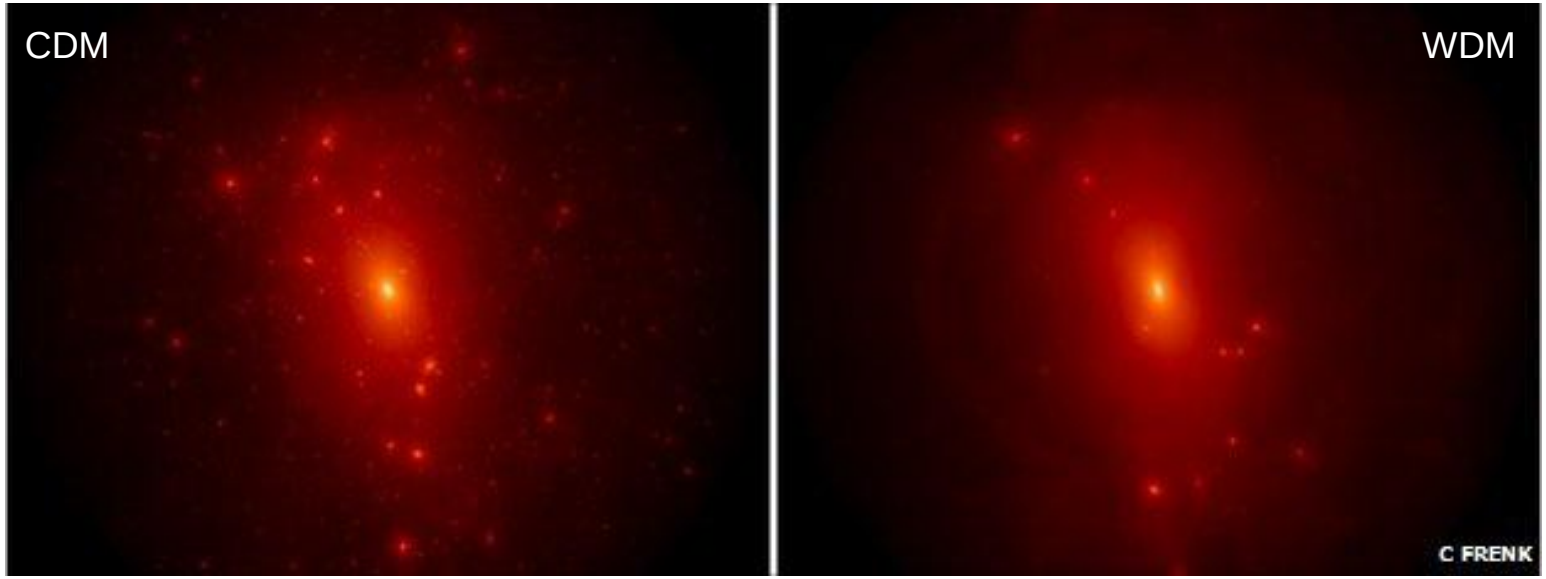




arXiv:1203.2632v1

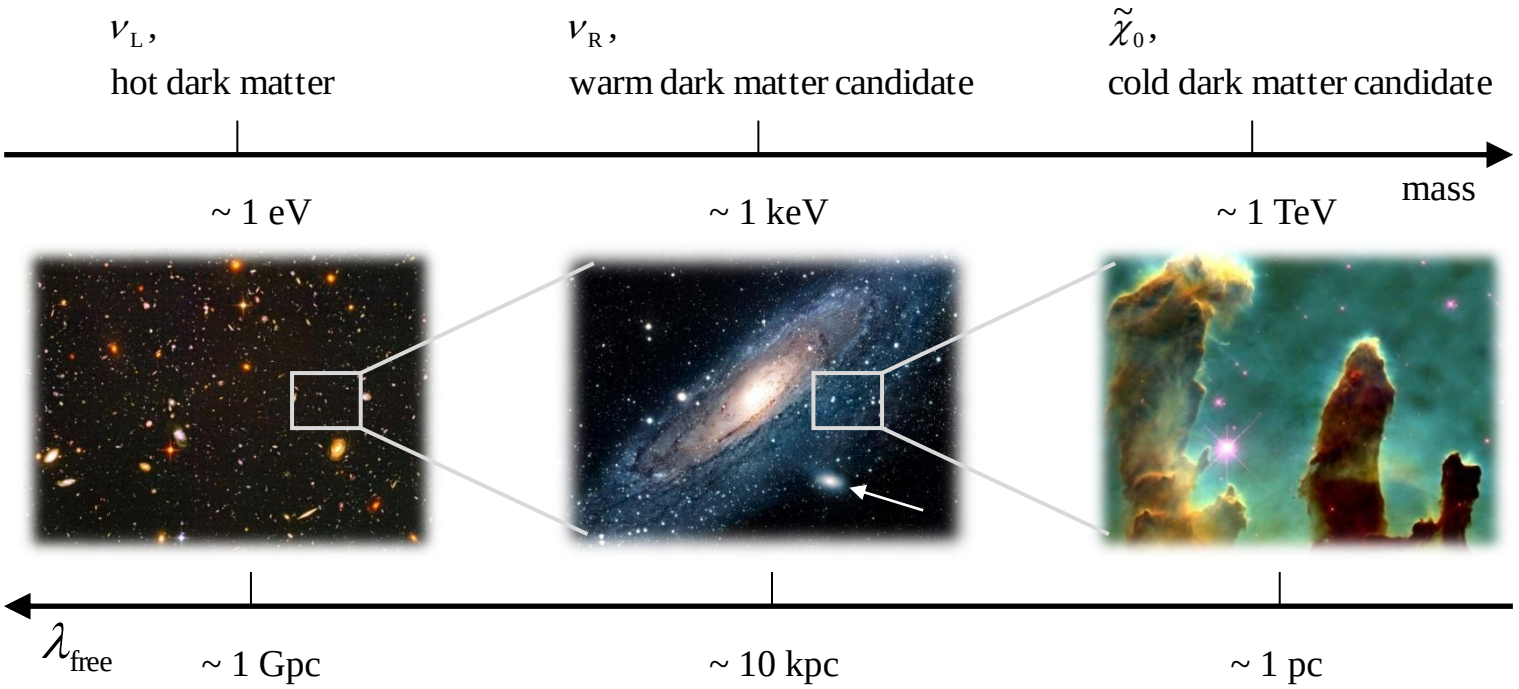
KATRIN and keV sterile neutrinos

- CDM predict too many satellite dwarf galaxies
- …

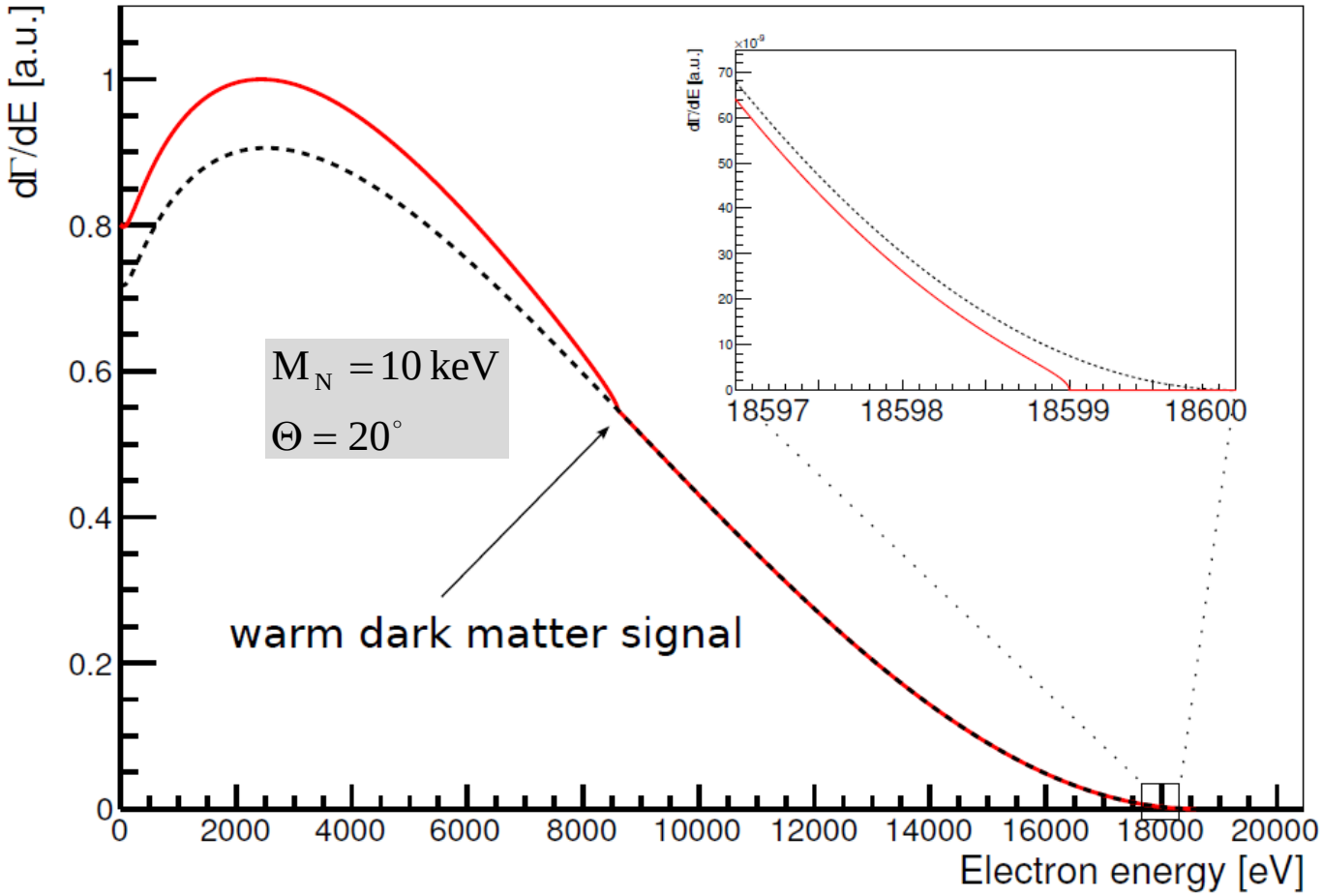


KATRIN and keV sterile neutrinos

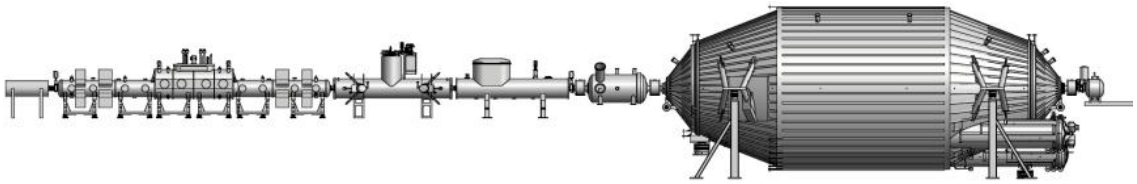
- CDM predict too many satellite dwarf galaxies
- …



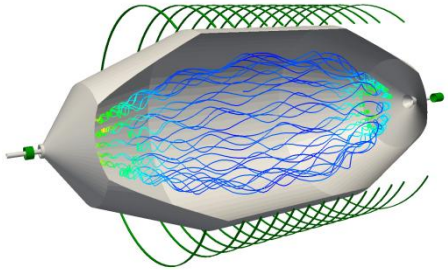
KATRIN and keV sterile neutrinos



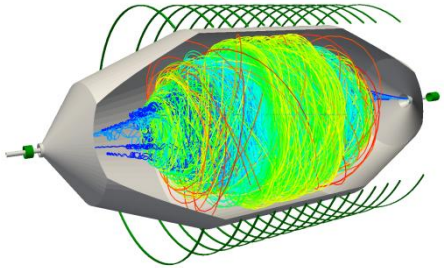
Conclusion



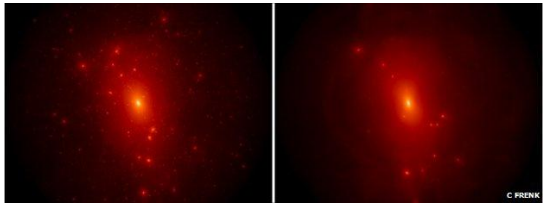
- KATRIN
  - Sensitivity of 200 meV
  - Many major steps have been achieved
  - Data taking will start in 2015



- Background
  - Stored electrons are a serious background source
  - Electron Cyclotron Resonance to mitigate the problem



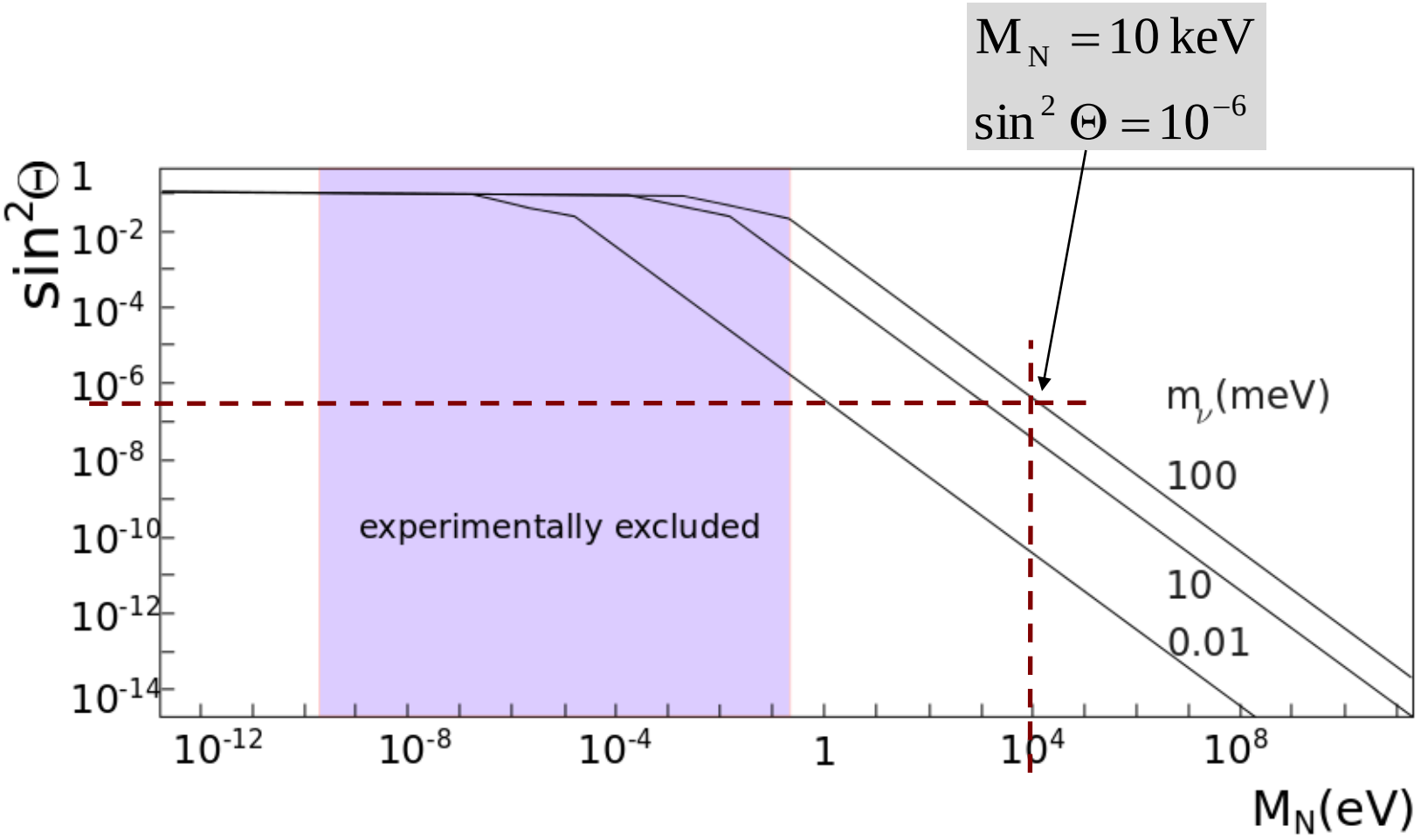
- Physics reach from sub-eV to keV neutrinos




Thank you for your attention

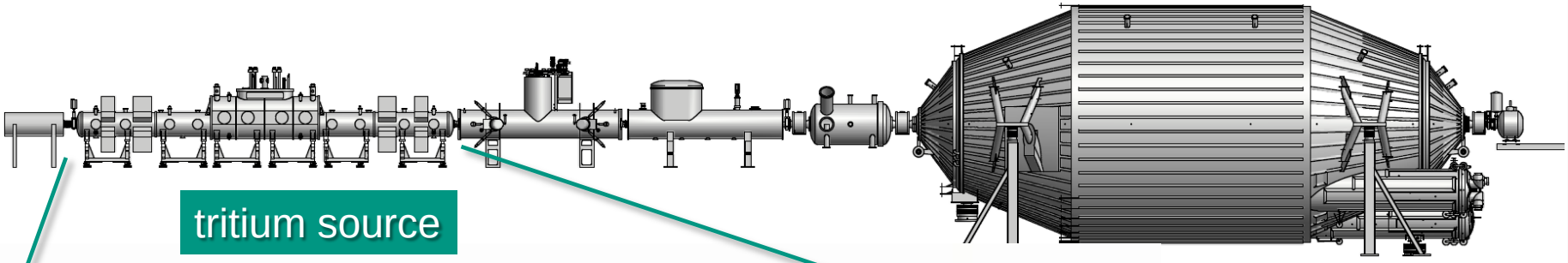
Backup slides

KATRIN and keV sterile neutrinos

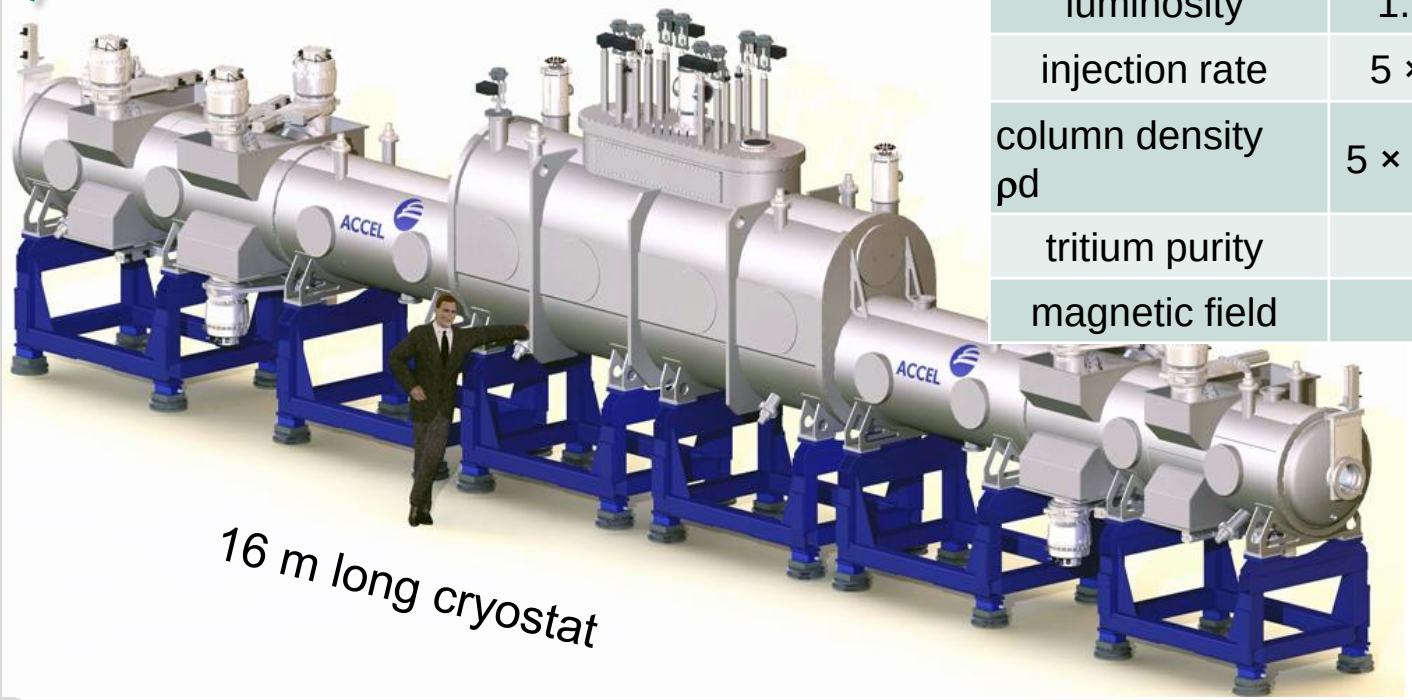


arXiv:1204.5379v1

WGTS – windowless gaseous source

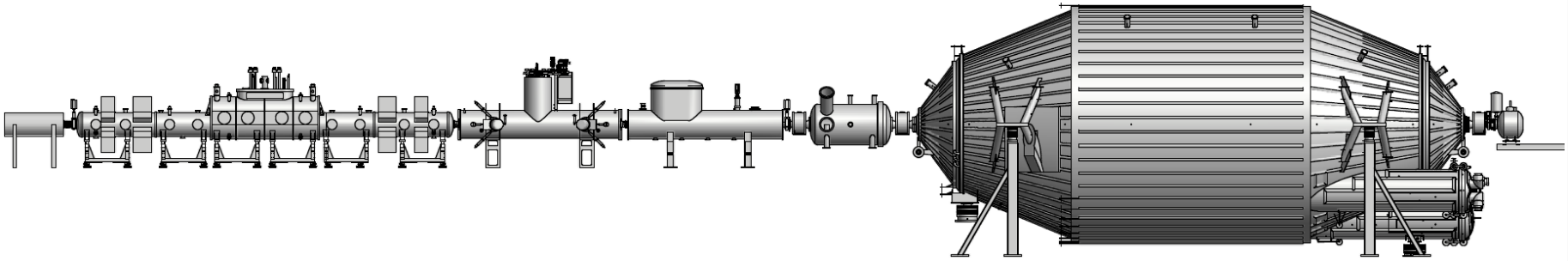


WGTS precision	design value	
luminosity	1.7×10^{11} Bq	
injection rate	5×10^{19} mol/s	± 0.1 %
column density ρd	5×10^{17} mol/cm^2	± 0.1 %
tritium purity	> 95%	± 0.1 %
magnetic field	3.6 T	± 2%



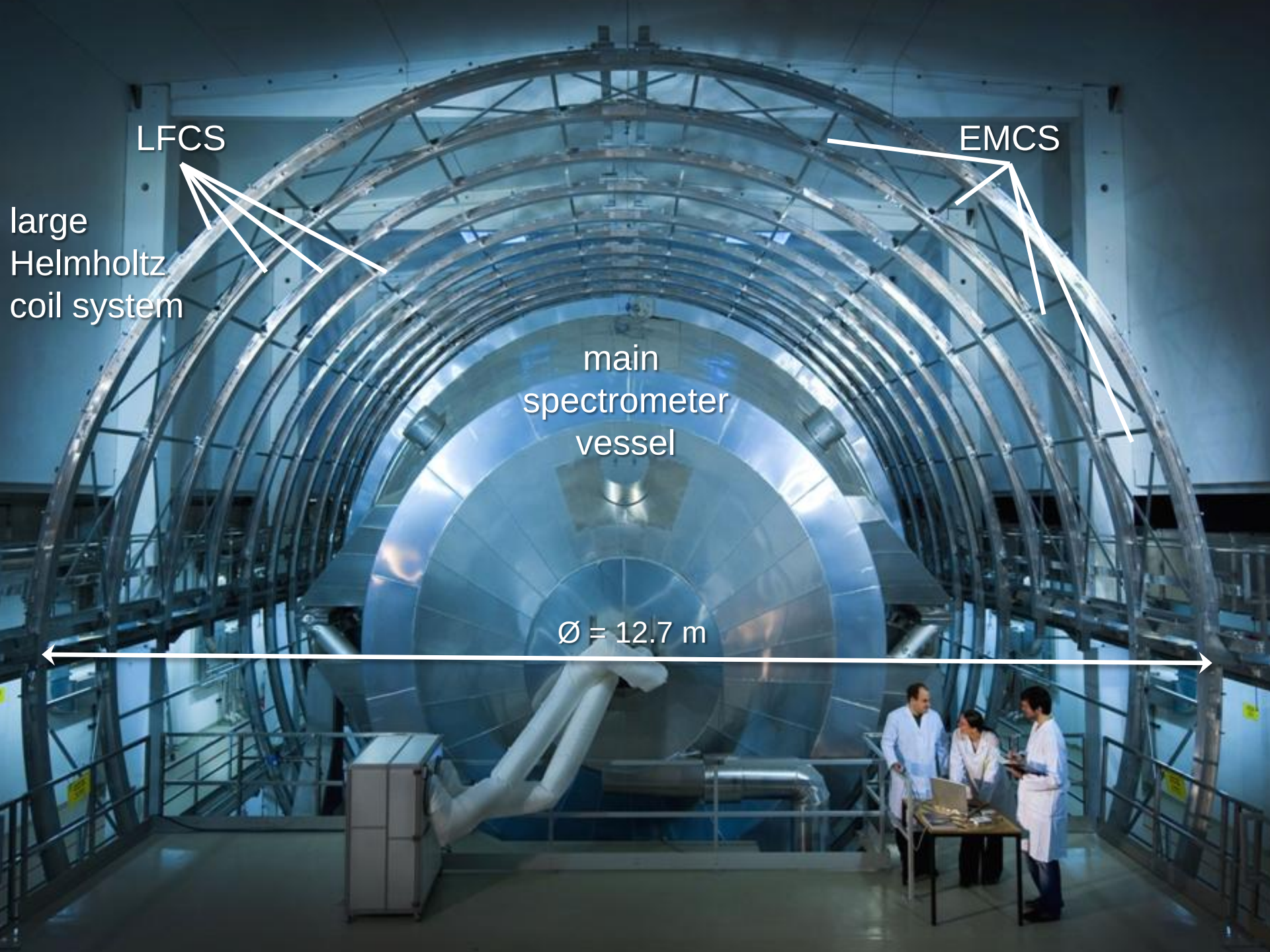
16 m long cryostat

main spectrometer – transport



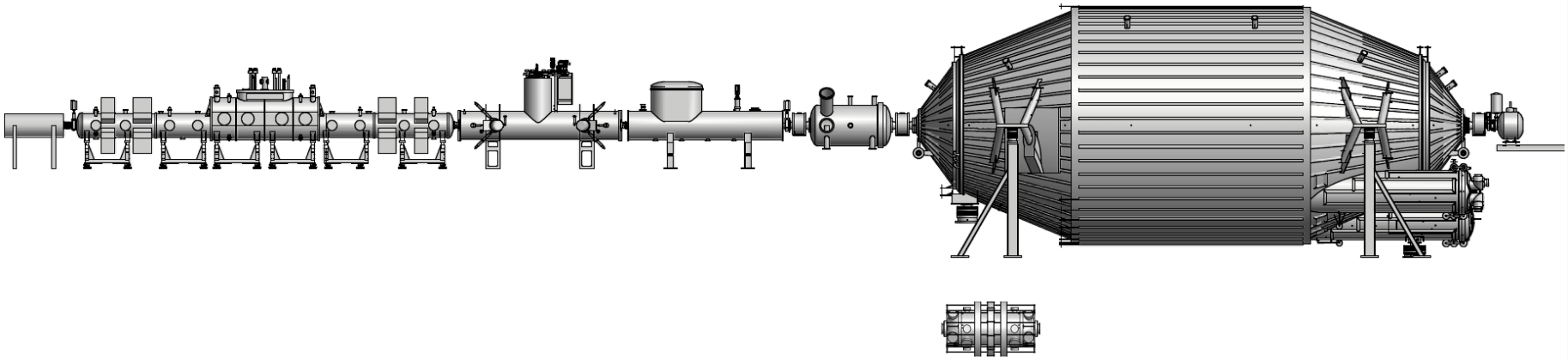
November 25, 2006

8.800 km voyage around Europe


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

HV for KATRIN

- HV issues are of central importance for KATRIN:
  actual HV value defines the retarding potential for ß-decay electrons
  - HV fluctuations I: separate monitor beamline with nuclear standard ^{83m}Kr
  - HV fluctuations II: ultra-precise HV divider with digital voltmeter



	RS, WGTS, DPS	PS	MS / MOS	FPD
Voltage	-1 kV	-35 kV	-35 kV	+25 kV
Stability	± 20 mV	uncritical	± 20 mV	uncritical

KATRIN HV divider

- **ultra-precise HV divider for up to 65 kV**
  U Münster and PTB Braunschweig
  (stored in steel cylinder in dry nitrogen gas)

Westfälische Wilhelms-Universität Münster

PTB

ppm-precision

properties:

- four scale factors:
  100:1, 500:1, 1818:1, 3636:1
- 165 selected 880kW resistors (VISHAY)
- resistors are pre-aged to reduce the long-term drift
- temperature stabilisation $\Delta T < 0.1$ K
  improved temperature regulation
- HF-probe implemented

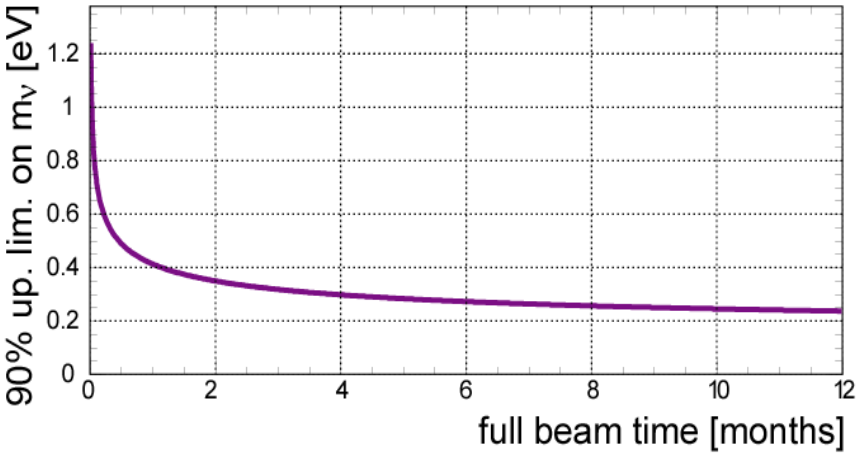
KATRIN HV divider – mark II

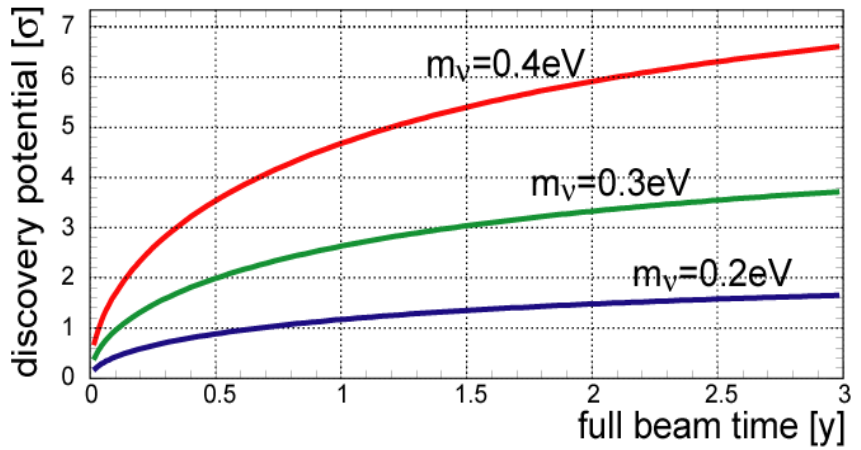
KATRIN sensitivity

- **neutrino mass sensitivity:** detailed investigations of of reference design, requirements: highest luminosity, high energy resolution, low background, control/monitoring of fluctuations near on-line MC of experim. data
- **statistical & systematic errors** are expected to contribute equally
  - statistical error $\sigma_{stat} = 0.018\ eV^2$
  - systematic error $\sigma_{syst} < 0.017\ eV^2$
- **reference sensitivity (3 fb years)**

sensitivity (90% CL)
m(ν) < 200 meV

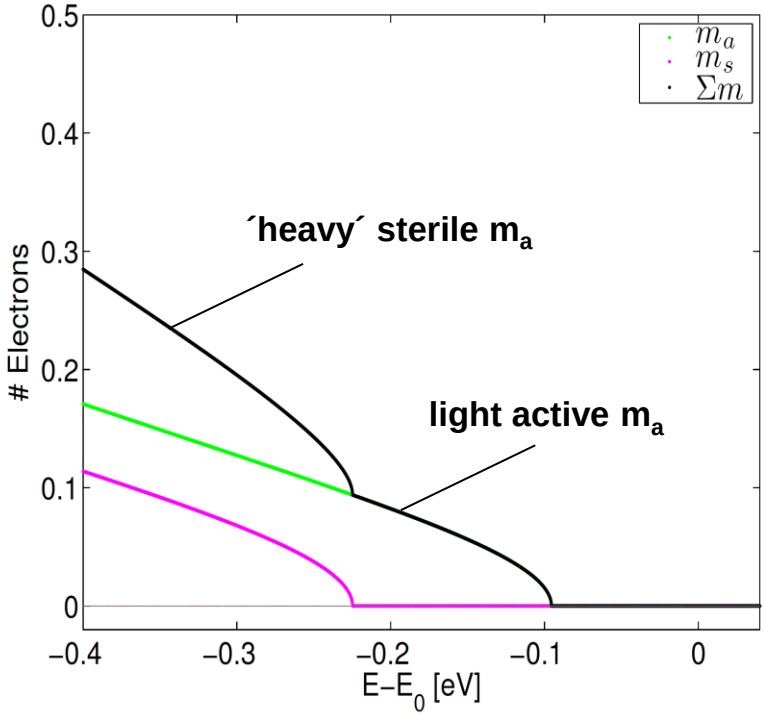
discovery potential
m(ν) = 350 meV (5σ)





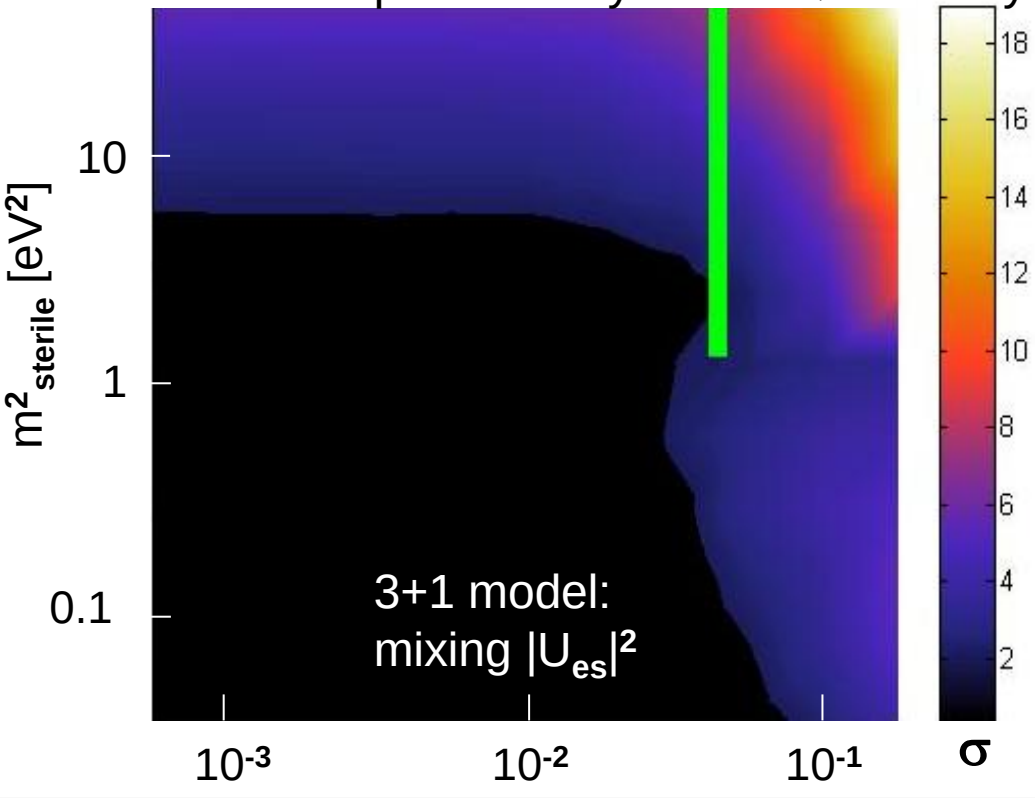
KATRIN sensitivity for sterile neutrinos

- Hannestad et al: initial estimates of KATRIN sensitivity for sterile ν´s assume very light active neutrinos $m_a(\nu) \sim 0$ eV, mixed with sterile $m_s(\nu)$
- 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



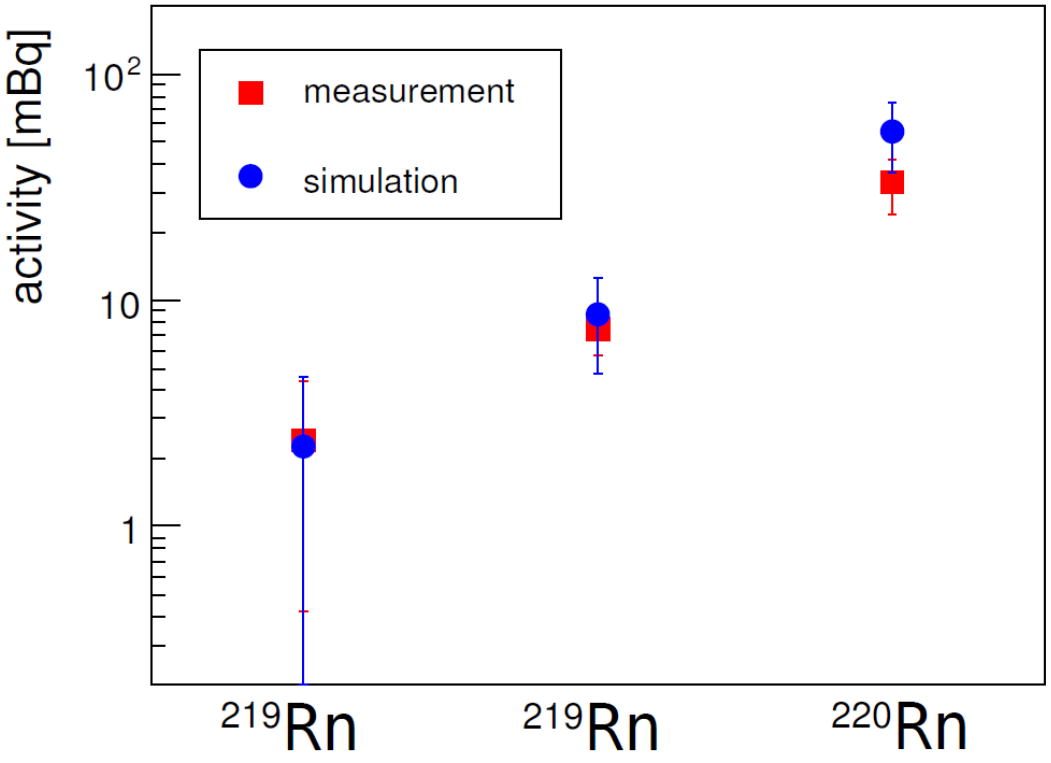
A.S. Riis, S. Hannestad,
arXiv: 1008.1495v2, JCAP02(2011)011

preferred by reactor ν anomaly



Verification of background model

- Comparison to pre-spectrometer measurement



Good agreement between measurement and simulation