Status and Perspectives of the KATRIN Experiment

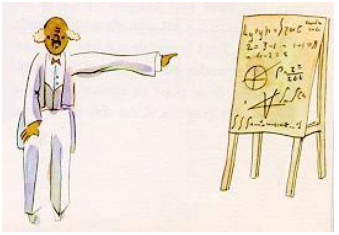
Susanne Mertens
for the KATRIN Collaboration

Overview

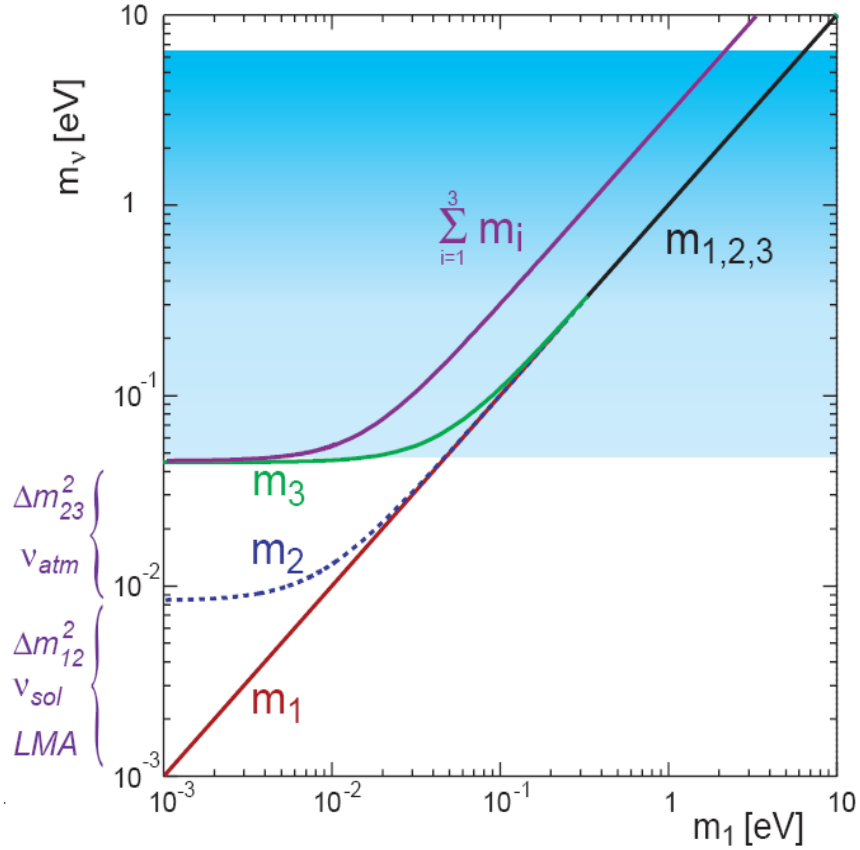
- Why is a direct neutrino mass measurement so important?
- How does KATRIN work?

- Present: Main Spectrometer Commissioning
- Future: Search for heavy sterile Neutrinos

Why neutrino mass?



Particle Physics: mass creation mechanism



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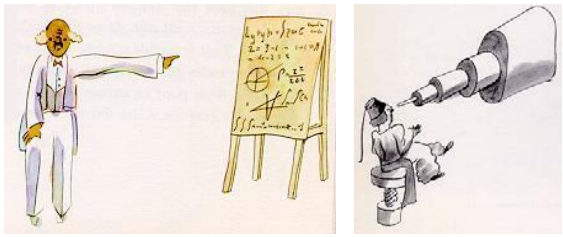
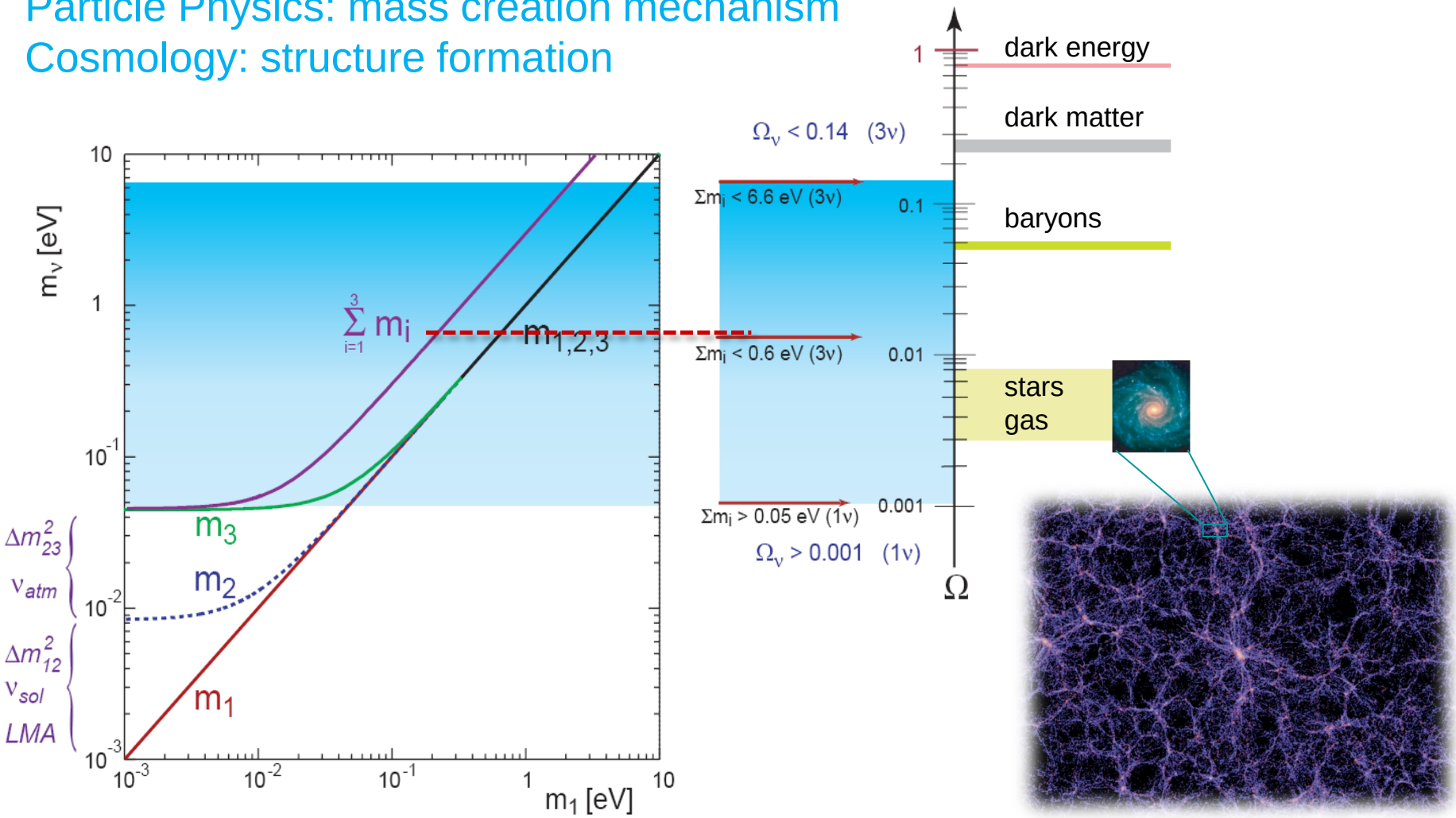
Why neutrino mass?



Particle Physics: mass creation mechanism

Cosmology: structure formation



Why a direct measurement?

Cosmology

model-dependent
potential: Σm_i = 20-50 meV
e.g. Planck

$$m_\nu = \sum_i m_i$$

Search for 0νßß

model-dependent
potential: $m_{ßß}$ = 20-50 meV
e.g. MAJORANA

$$m_{\beta\beta} = \left| \sum_{\mathrm{i}} U_{\mathrm{ei}}^2 \cdot m_{\nu_{\mathrm{i}}} \right|$$

Kinematics of ß-decay

model-independent
potential: m_ν = 200 meV
e.g. KATRIN

$$m_{\nu_{\mathrm{e}}}^2 = \sum_{\mathrm{i}} |U_{\mathrm{ei}}|^2 \cdot m_{\nu_{\mathrm{i}}}^2$$

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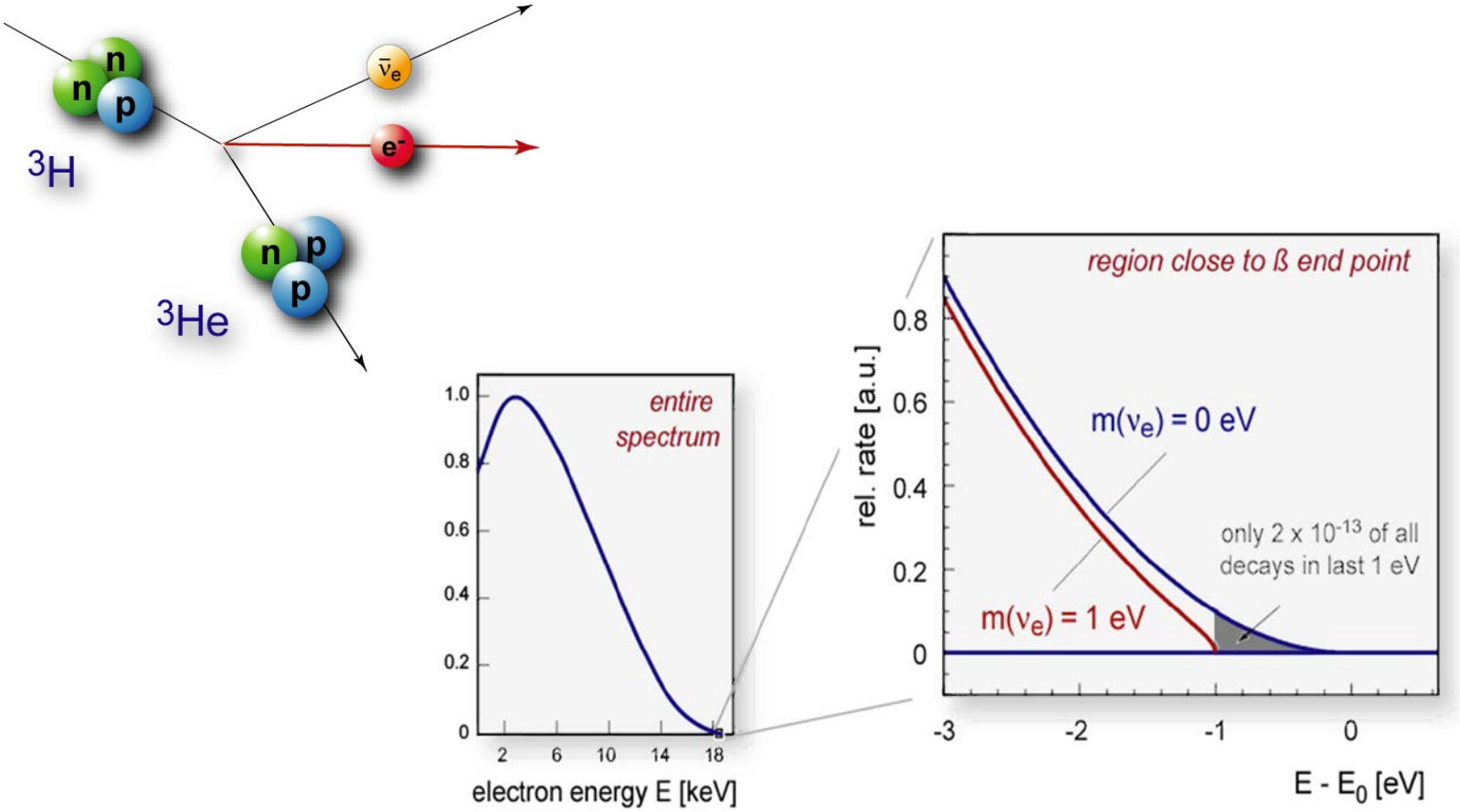
Karlsruhe Tritium Neutrino Experiment

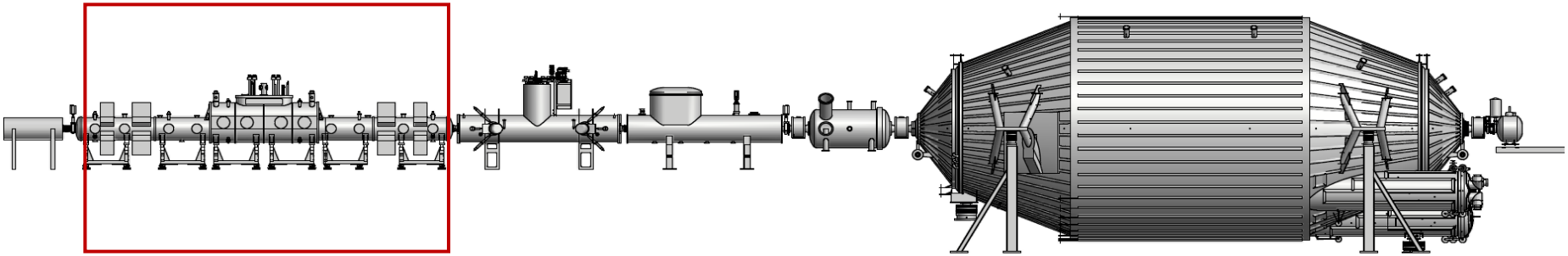
- Next-generation direct ν-mass experiment
- International Collaboration: 120 members
- 15 institutions in 5 countries: D, US, UK, CZ, RUS
- Reference ν-mass sensitivity: $m(\nu_e)$ = 200 meV, after 3 years

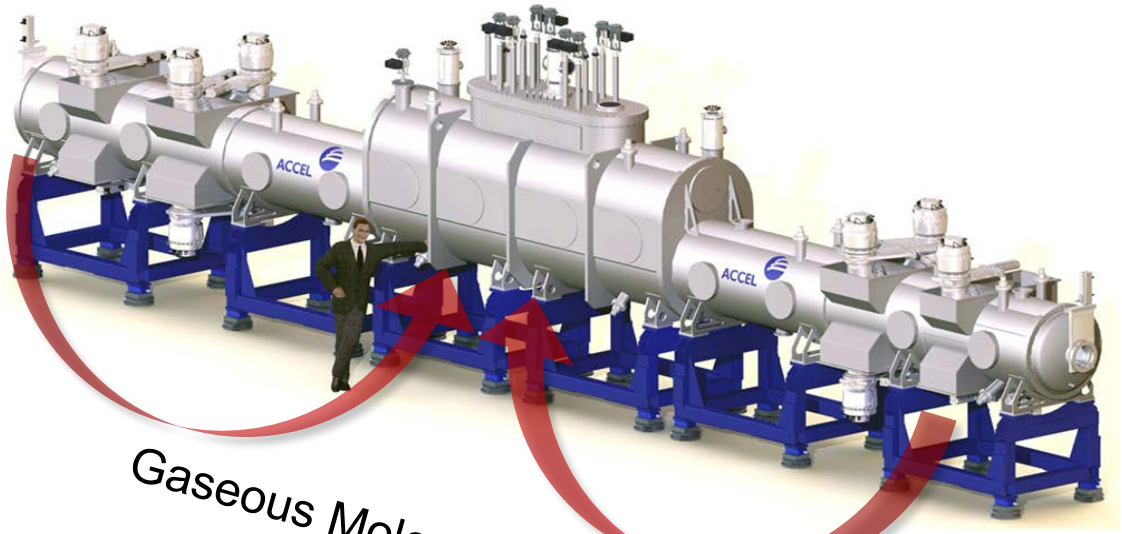
KATRIN Overview



KATRIN Overview

Source Section





Gaseous Molecular Tritium

Yearly throughput:

10 kg (≡ ITER)

ß- intensity:

10^{11} electrons/s

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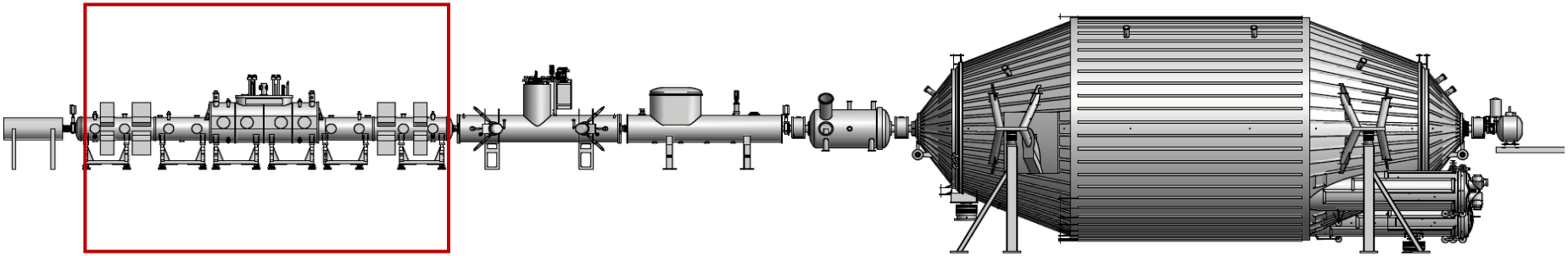
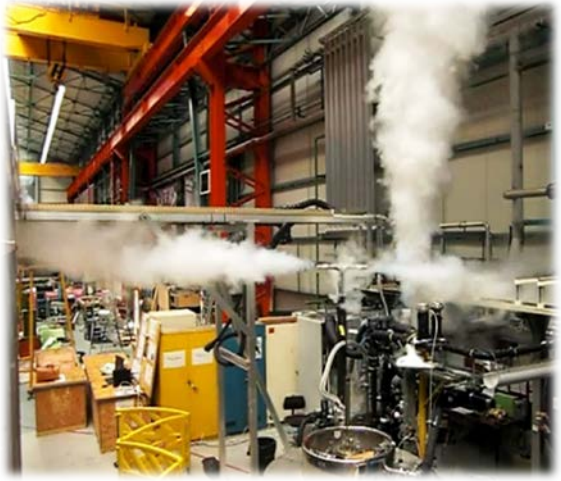
KATRIN Overview

Source Section

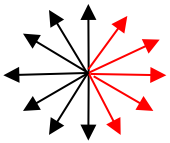




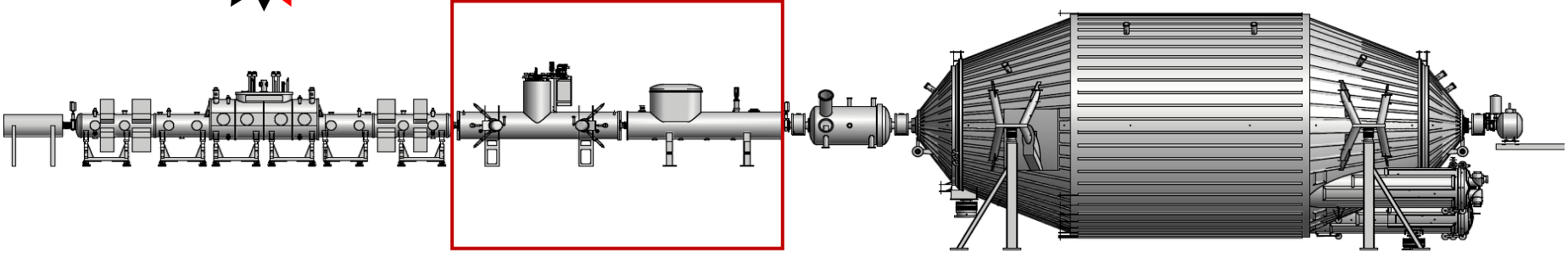
WGTS magnet tests at Saclay

Final assembly finished Summer 2015

The KATRIN experiment

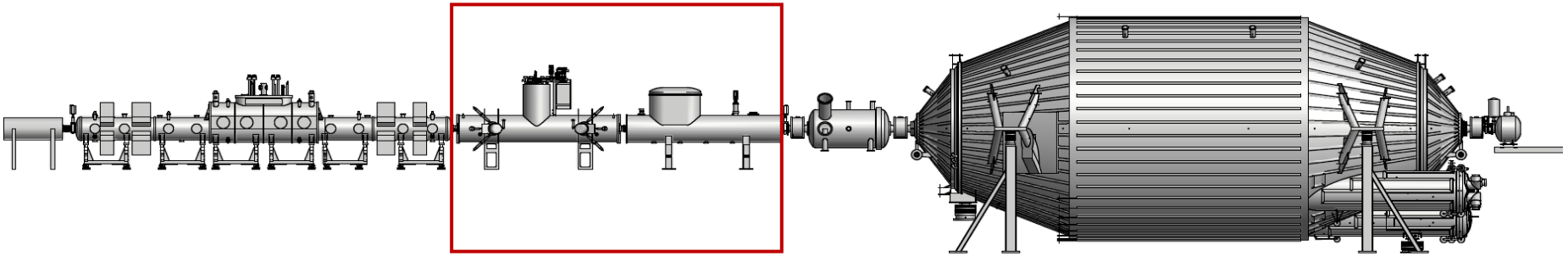


Transport Section



Adiabatic guidance of beta electrons

The KATRIN experiment



R>10⁷ **R>10⁷**

Reduction of tritium flow by 14 orders of magnitude

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

$p = 10^{-11}$ mbar

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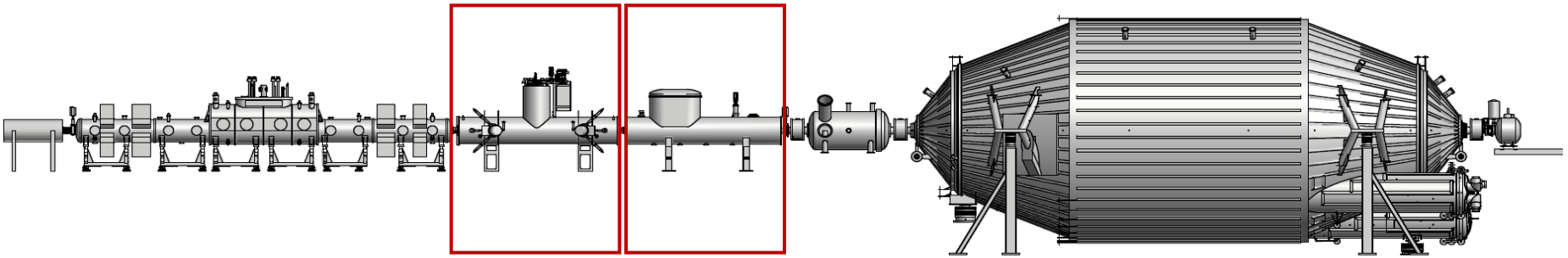
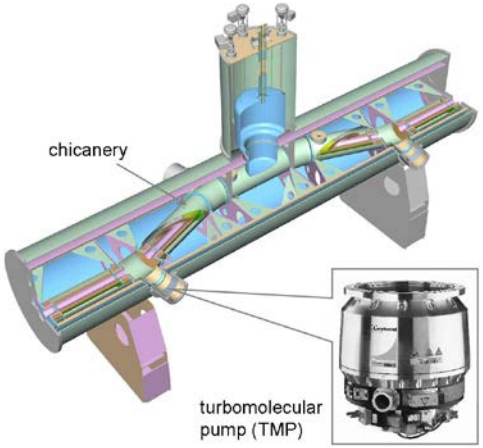
KATRIN Overview

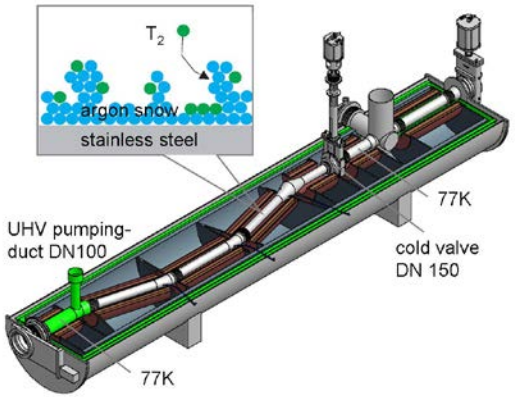
Transport Section



Differential pumping section



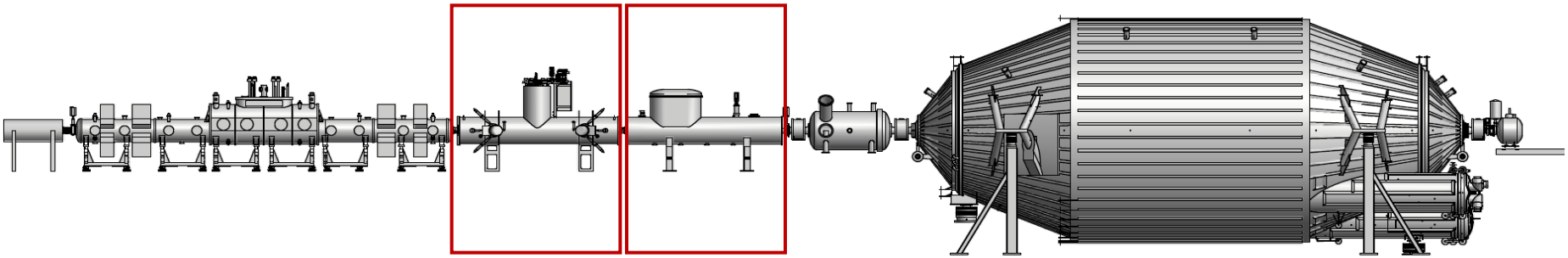
Cryogenic pumping section



S. Lukić, Vacuum 86 (2012) 8

KATRIN Overview

Transport Section

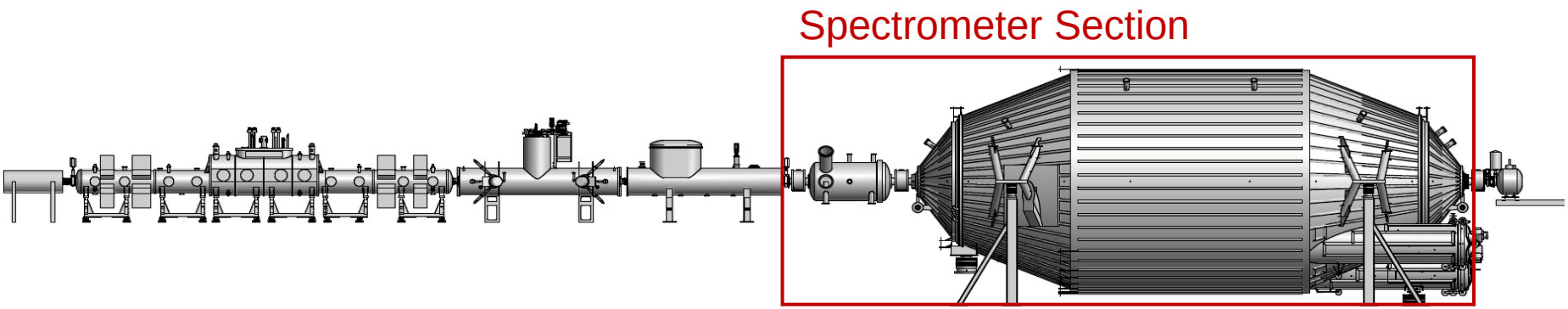


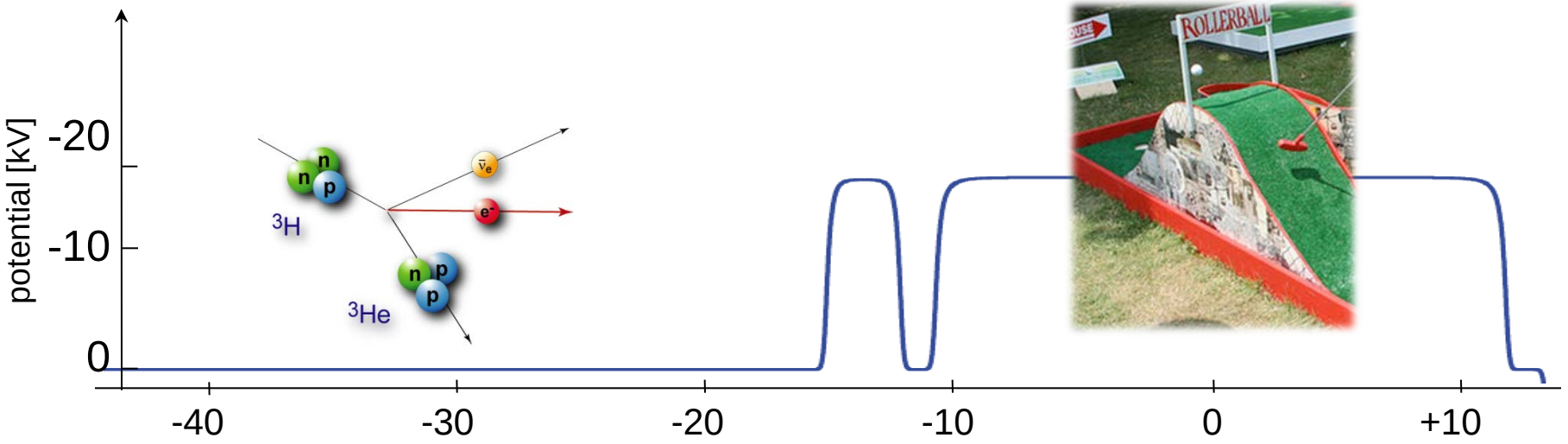
Differential pumping section

Cryogenic pumping section

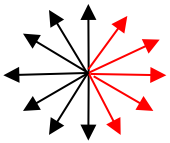
Final assembly finished Summer 2015

KATRIN Overview

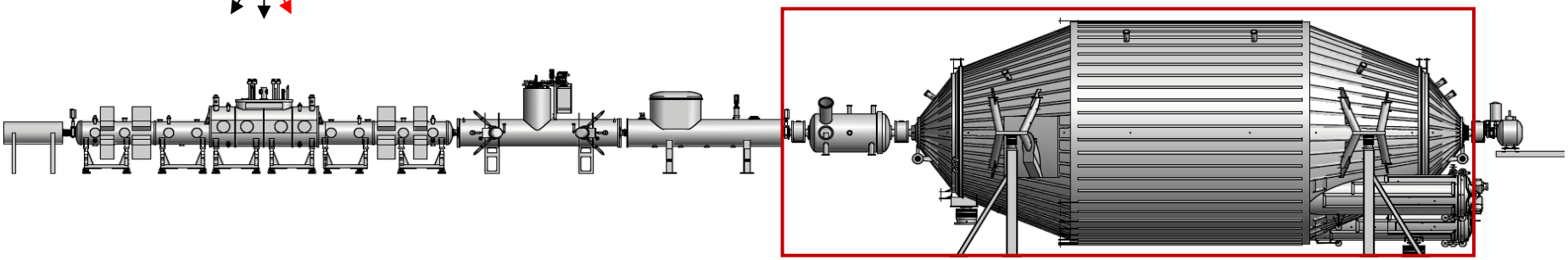


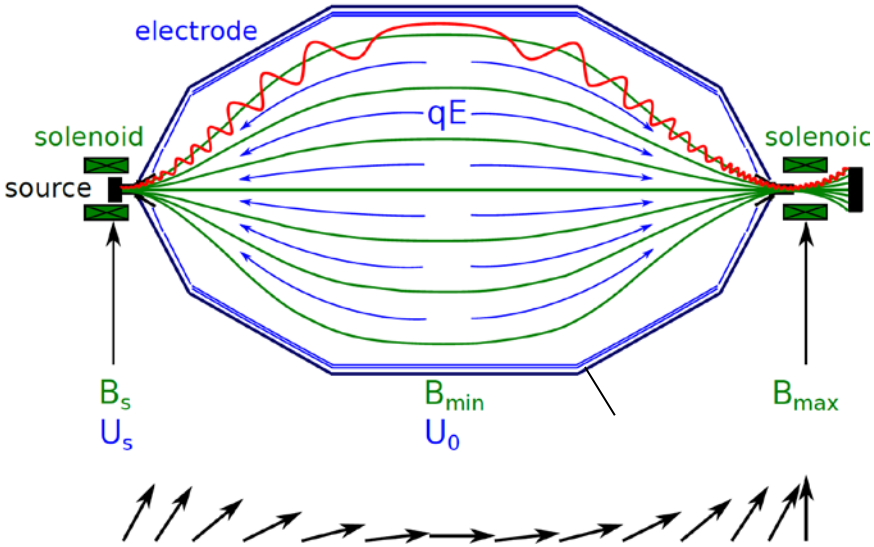


KATRIN Overview



Spectrometer Section





MAC-E Principle:

Large angle acceptance

High energy resolution (0.93 eV)

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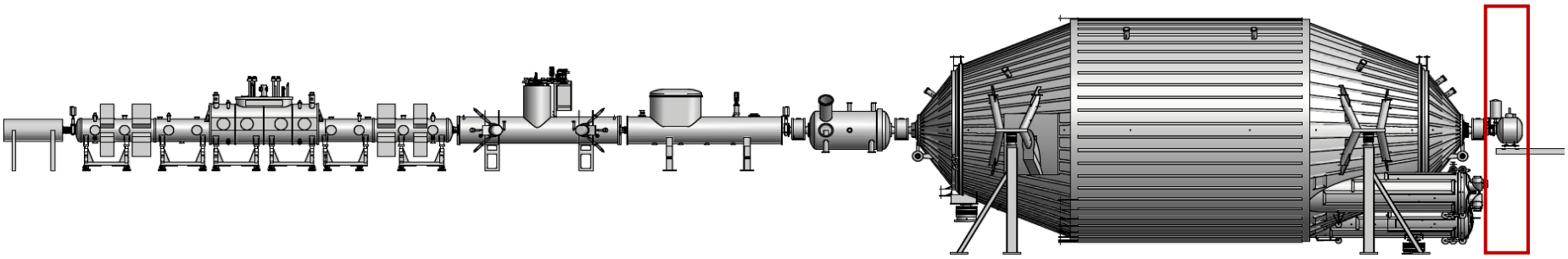
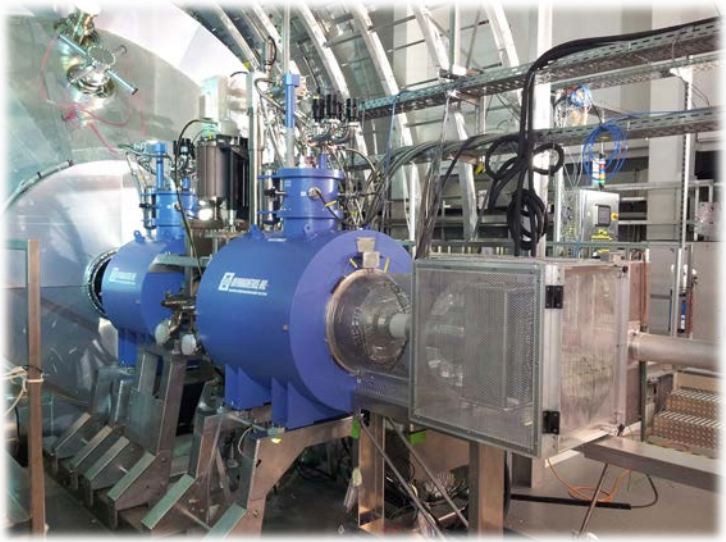
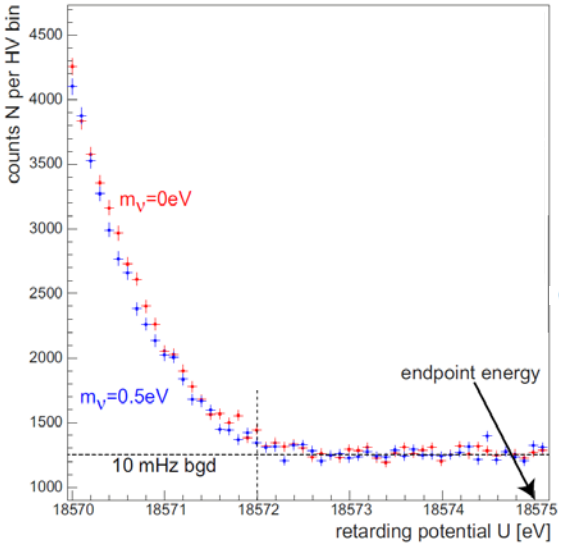
KATRIN Overview

Detector Section







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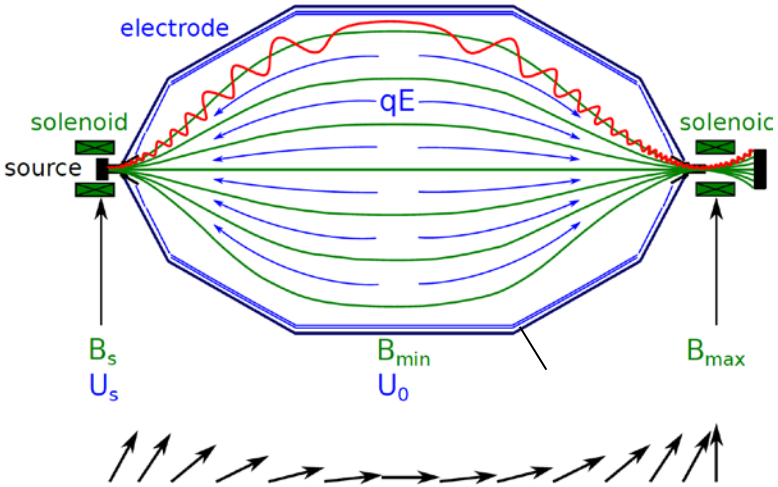
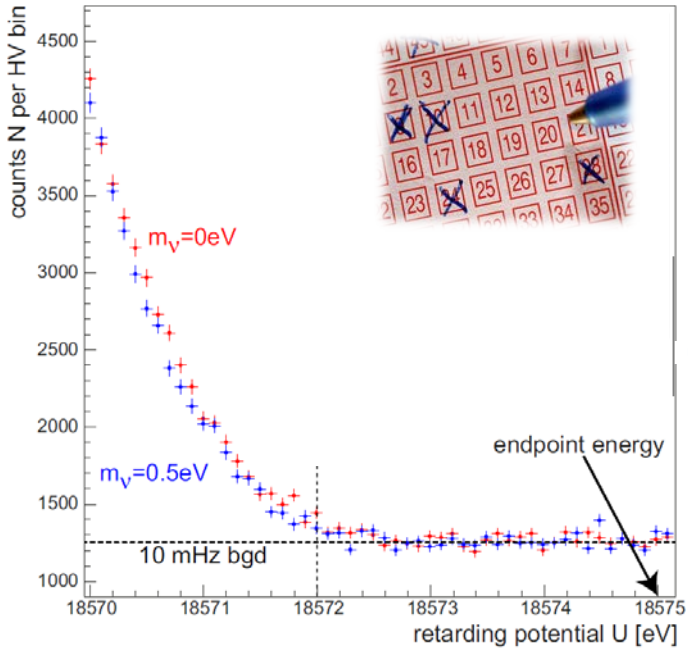
- Future: Search for heavy sterile Neutrinos

Commissioning goals

- Adiabatic transmission of electrons
- Low Background Level





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2006: Arrival of
Main Spectrometer
at KIT

2011: fully commissioned
Aircoil system

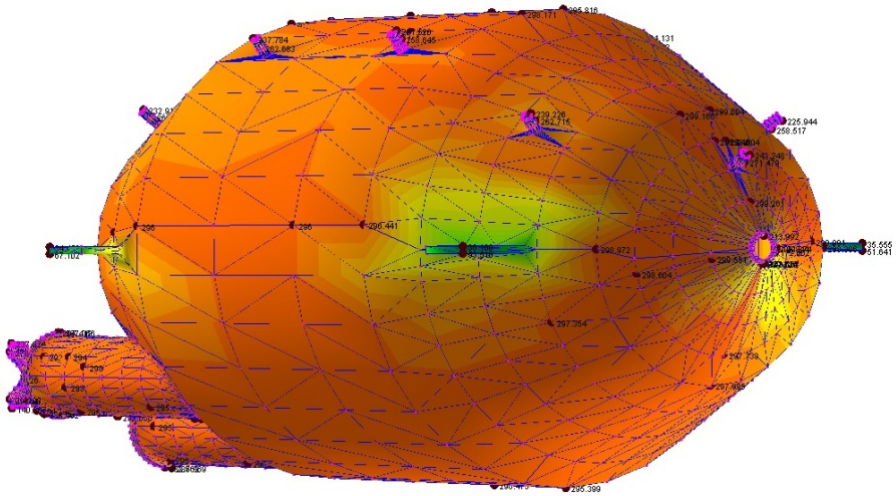

January 2012:
Inner electrode system
(24.000 wires)
completely mounted
(precision: 200 µm!)


May 8, 2012 14:11
spectrometer pump ports are closed

Commissioning of main spectrometer

- Successful bake-out of spectrometer vessel at 300° C
- NEG pump activated: pressure at 5×10^{-11} mbar
- Inner electrode system: no broken wire (but: wire layers shorted)

- “First light” last summer



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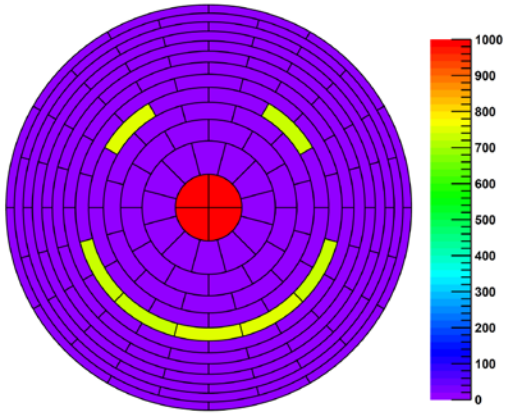
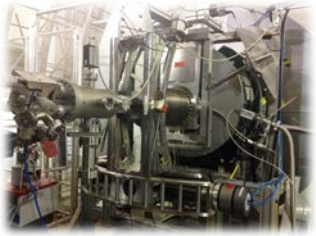
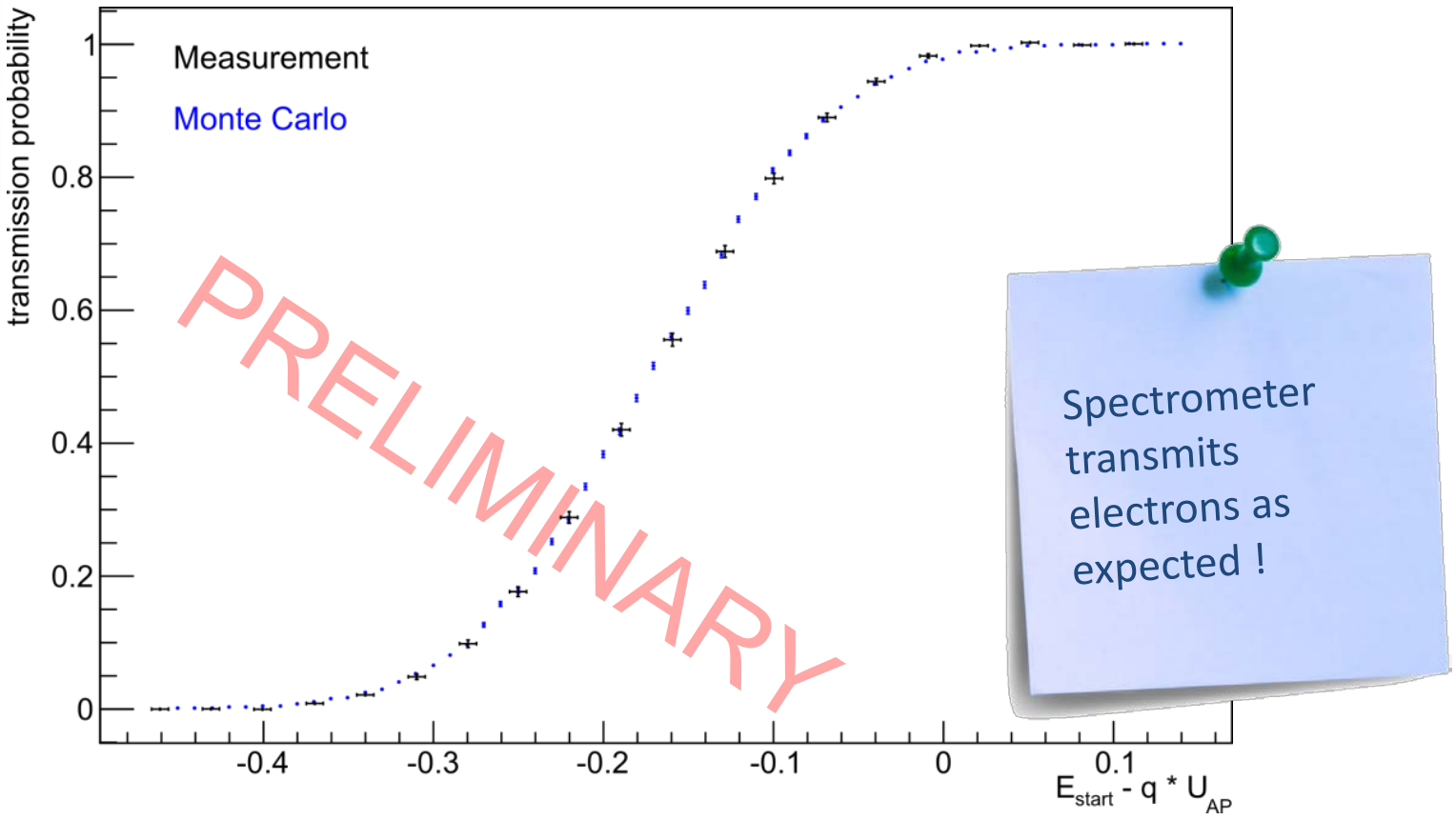


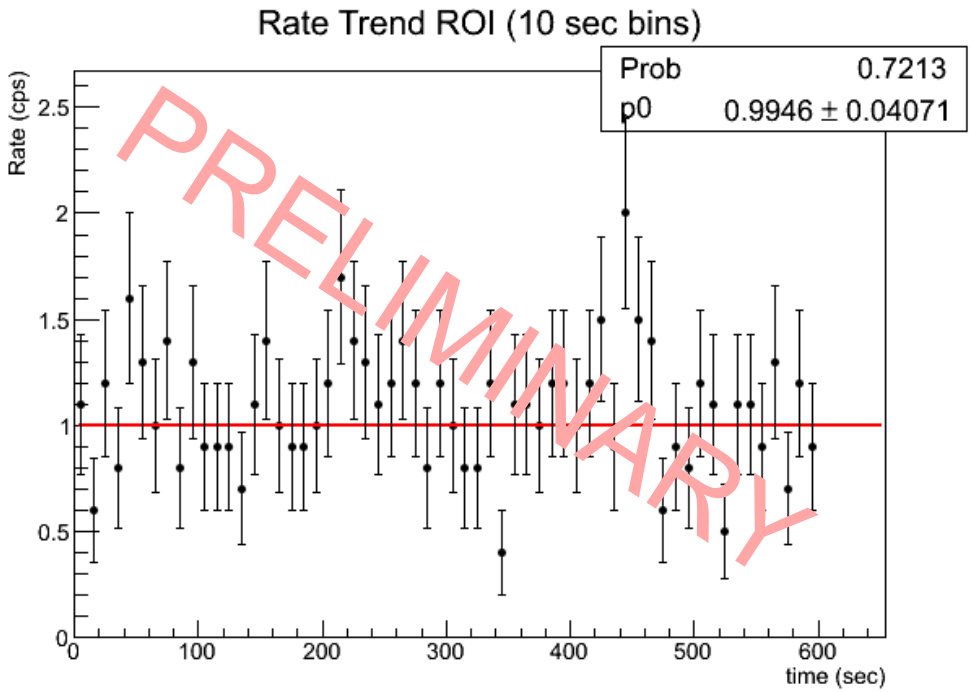
First Transmission Measurement

angular selective egun





First Background Measurement



Desired background rate: 10 mcps

Initial measured rate: 1 cps

No Penning discharge !!!

Magnetic shielding works !

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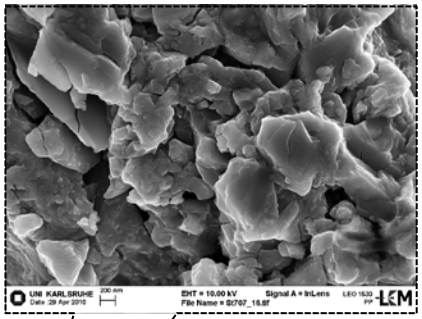
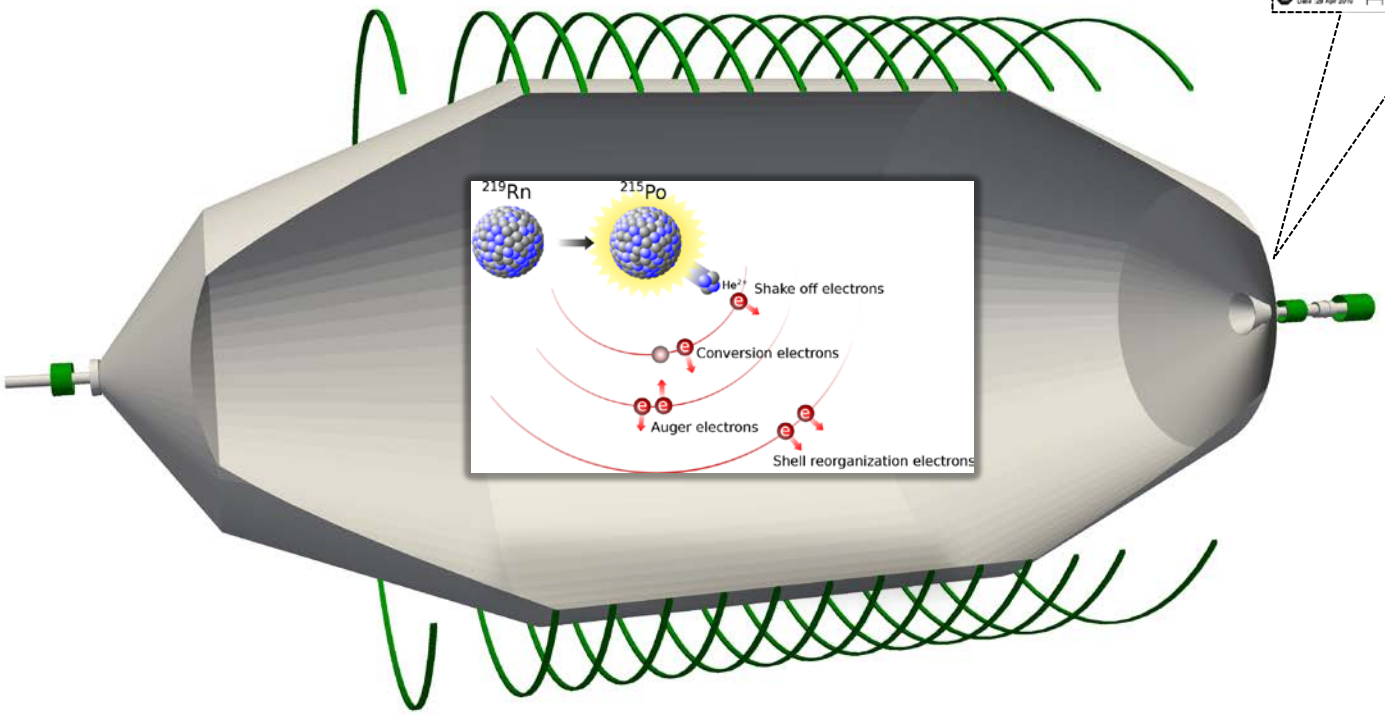
Radon induced Background

Radon induced Background

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

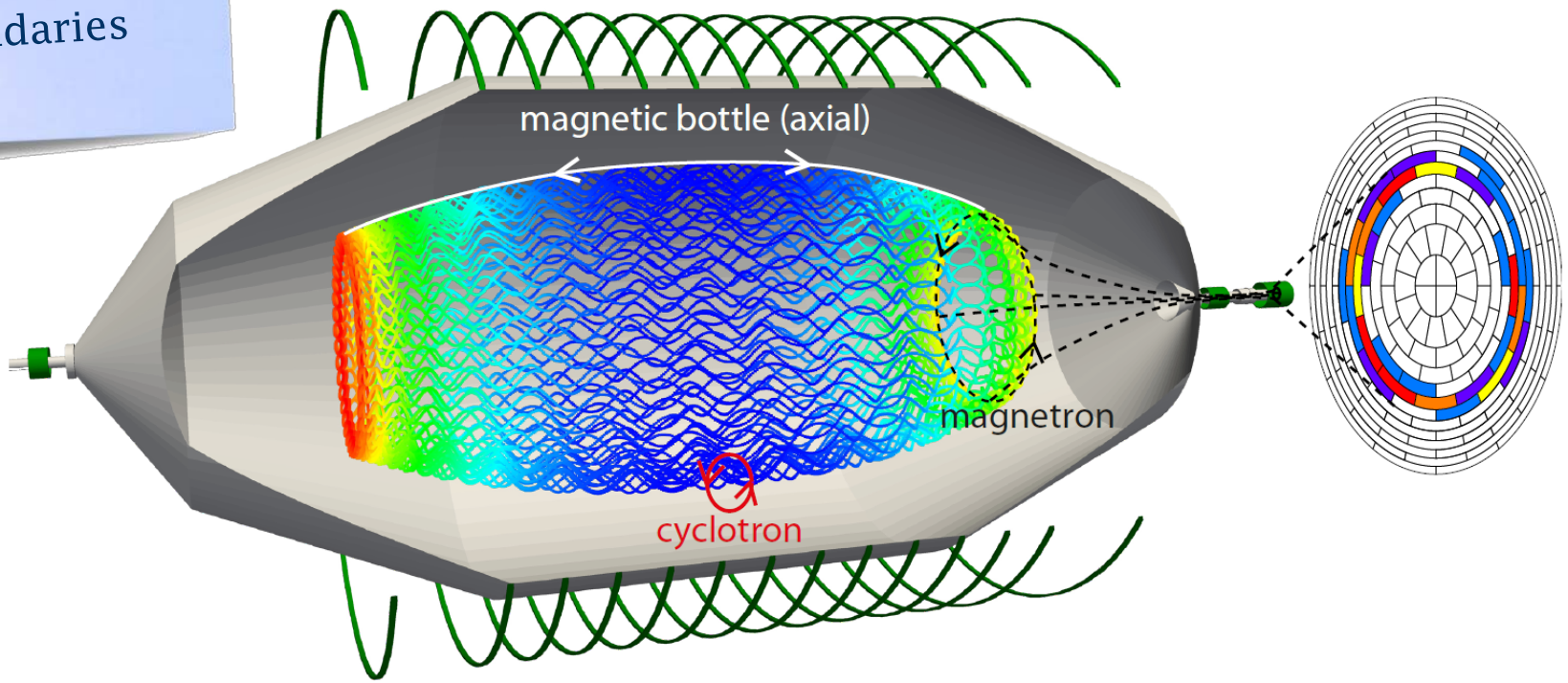
Getter pump





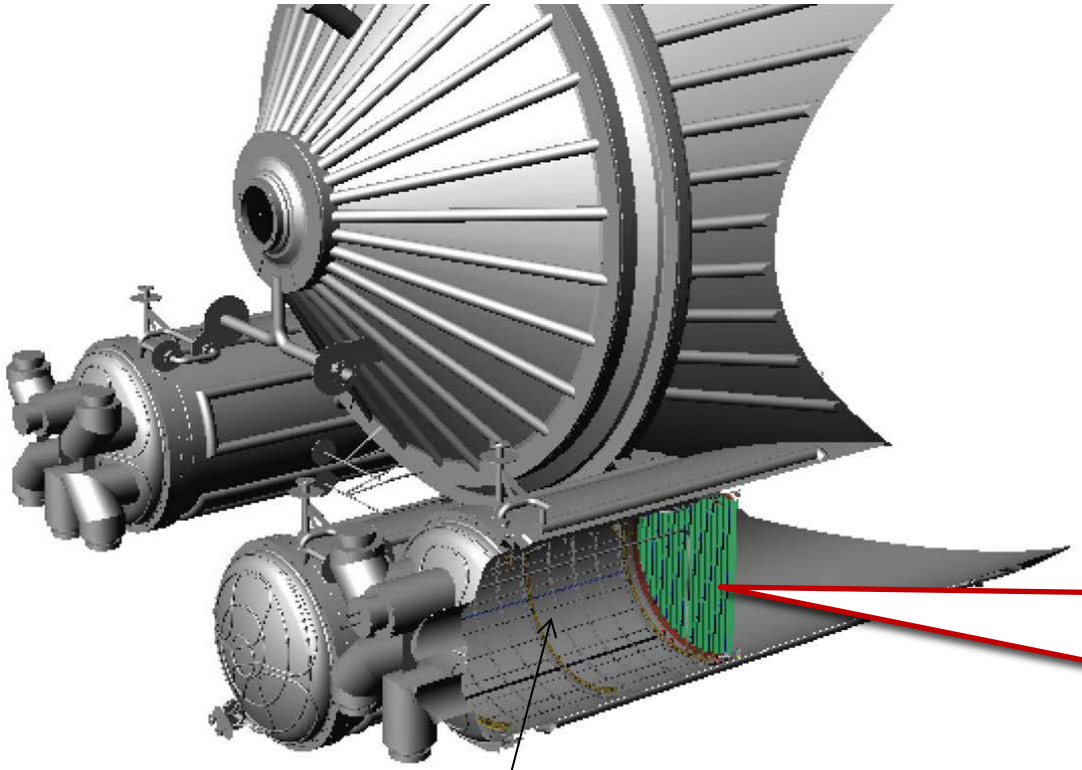
Radon induced Background

Single Radon decay produces hundreds of secondaries

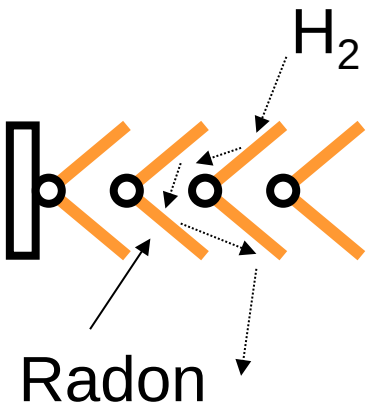


N. Wandkowsky et al., New J. Phys. 15 (2013) 083040
N. Wandkowsky et al., J. Phys. G 40 (2013) 8
S. M. et al., Astropart. Phys. 41 (2013) 52

Passive Reduction Technique

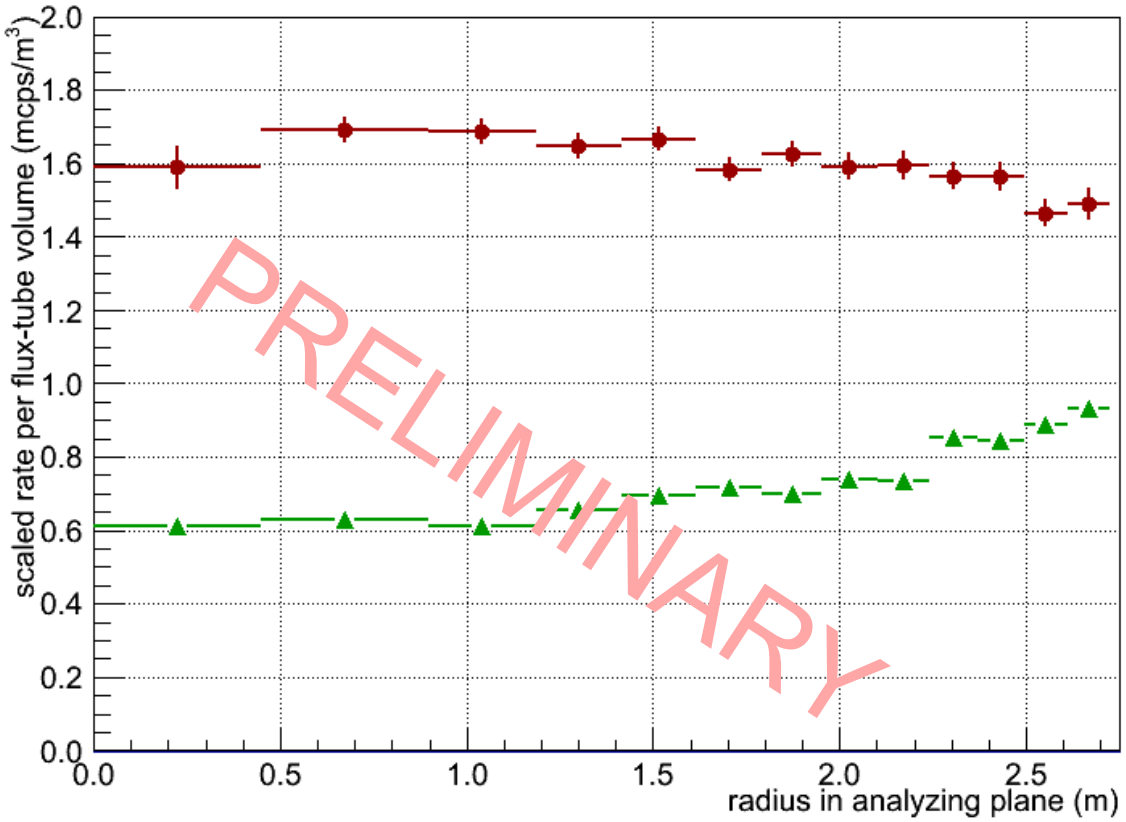


Getter pump



LN2 cooled baffle

Passive Reduction Technique



Total background with warm baffle

Single events (not due to Radon)

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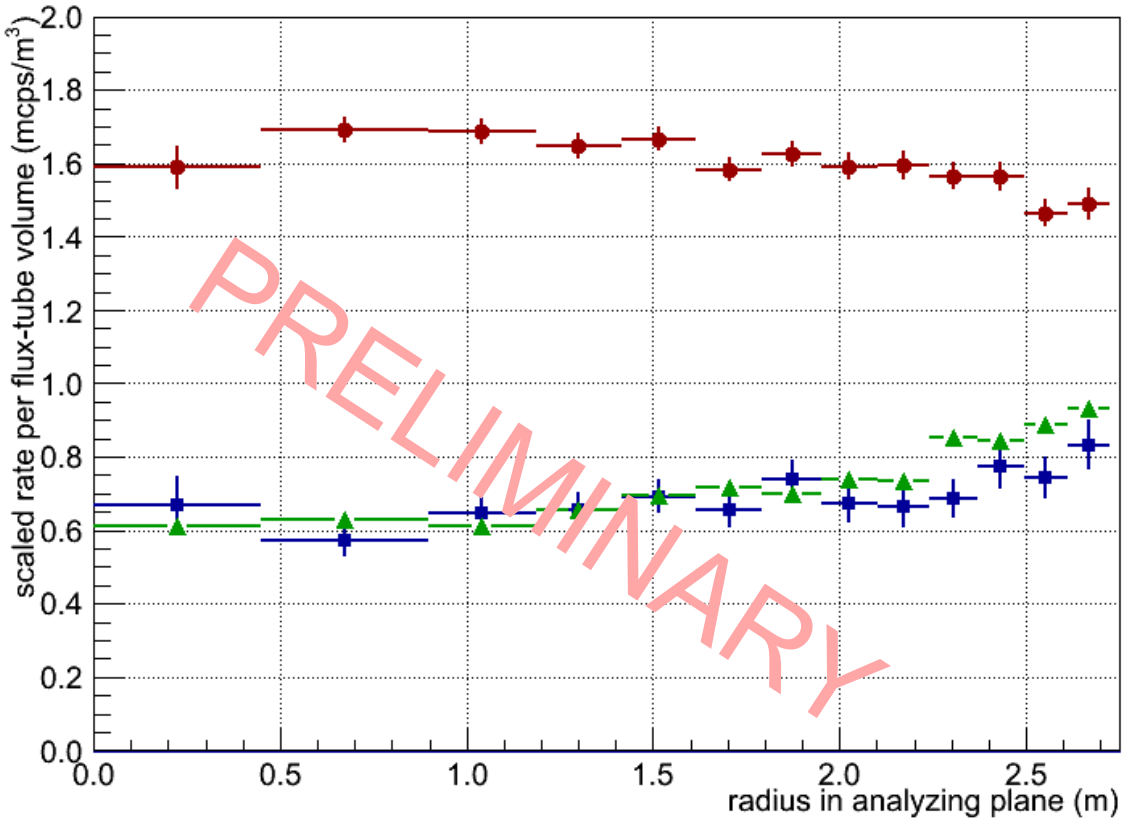
Passive Reduction Technique



Total background with warm baffle

Single events (not due to Radon)

Total background with cold baffle

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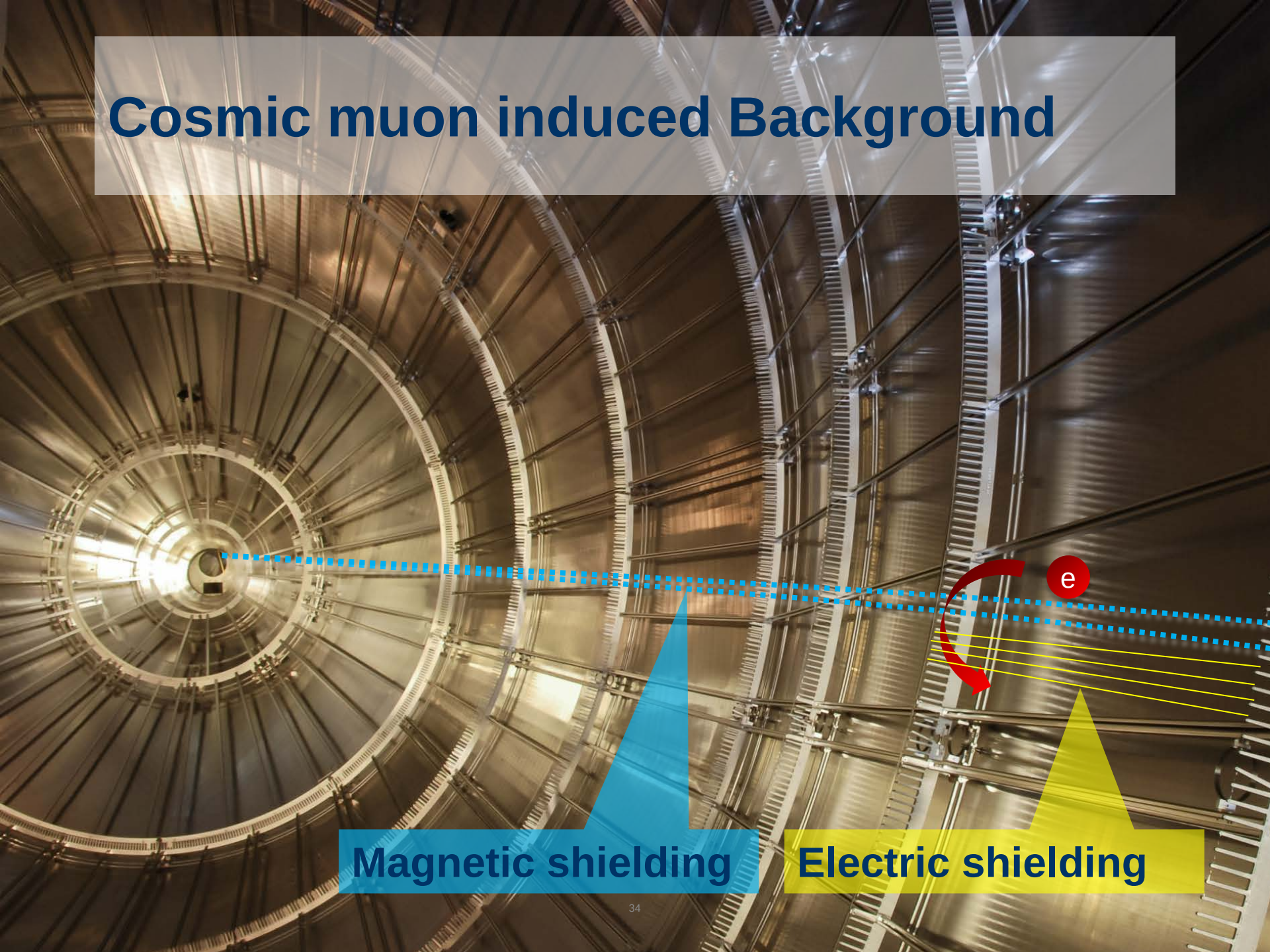
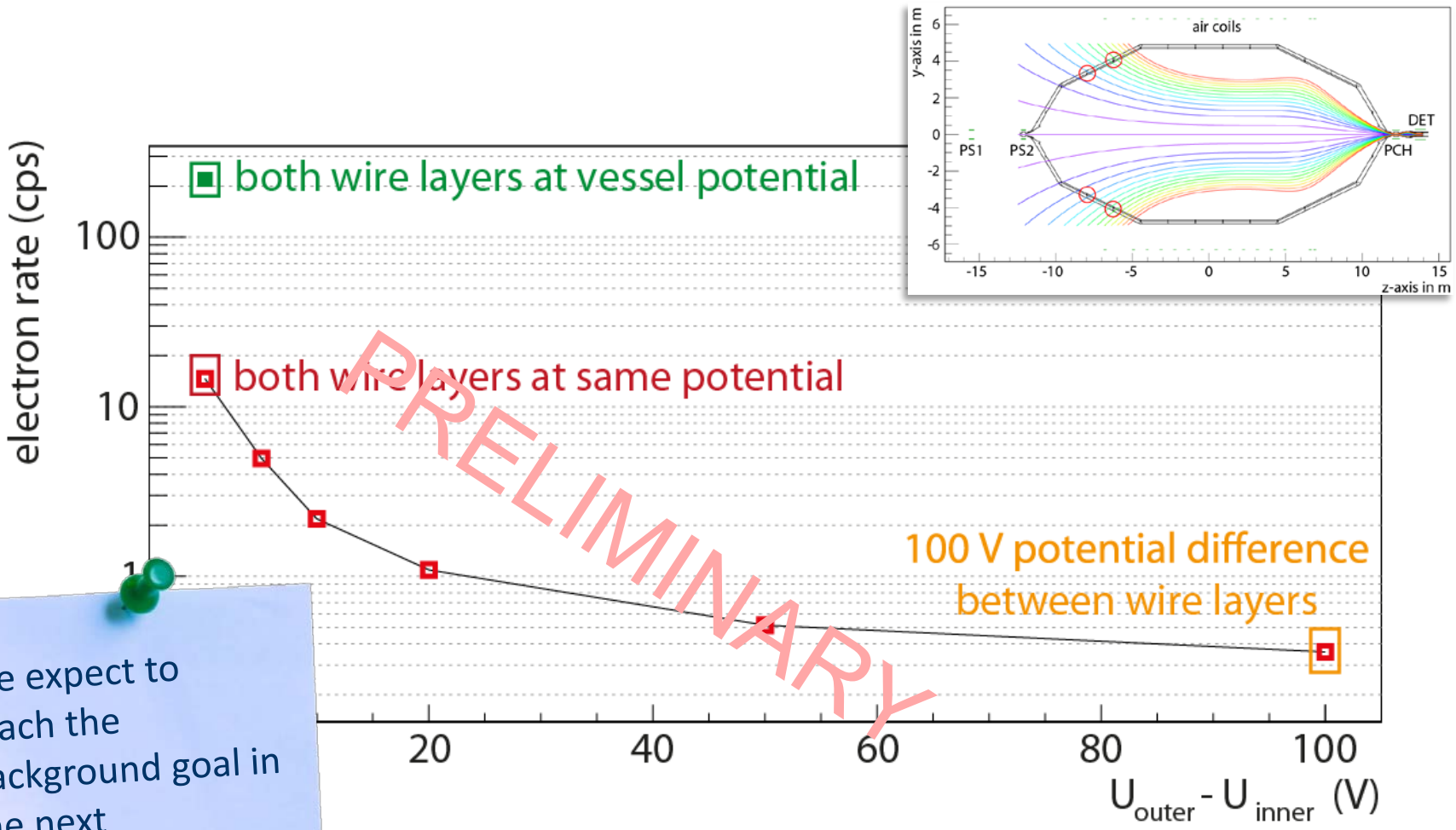
Cosmic muon induced Background



Passive Reduction Technique



We expect to reach the background goal in the next measurement phase!

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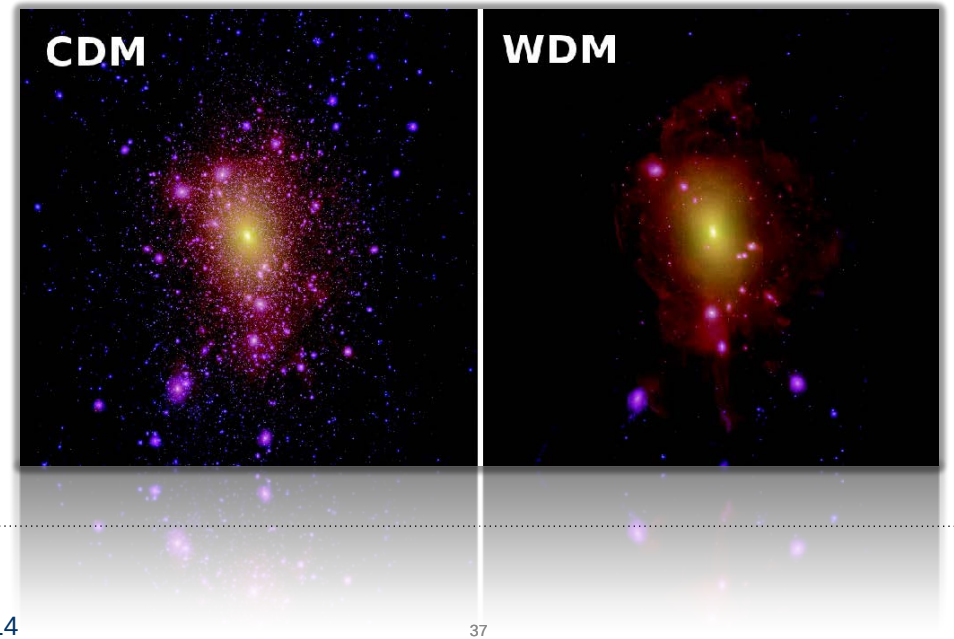
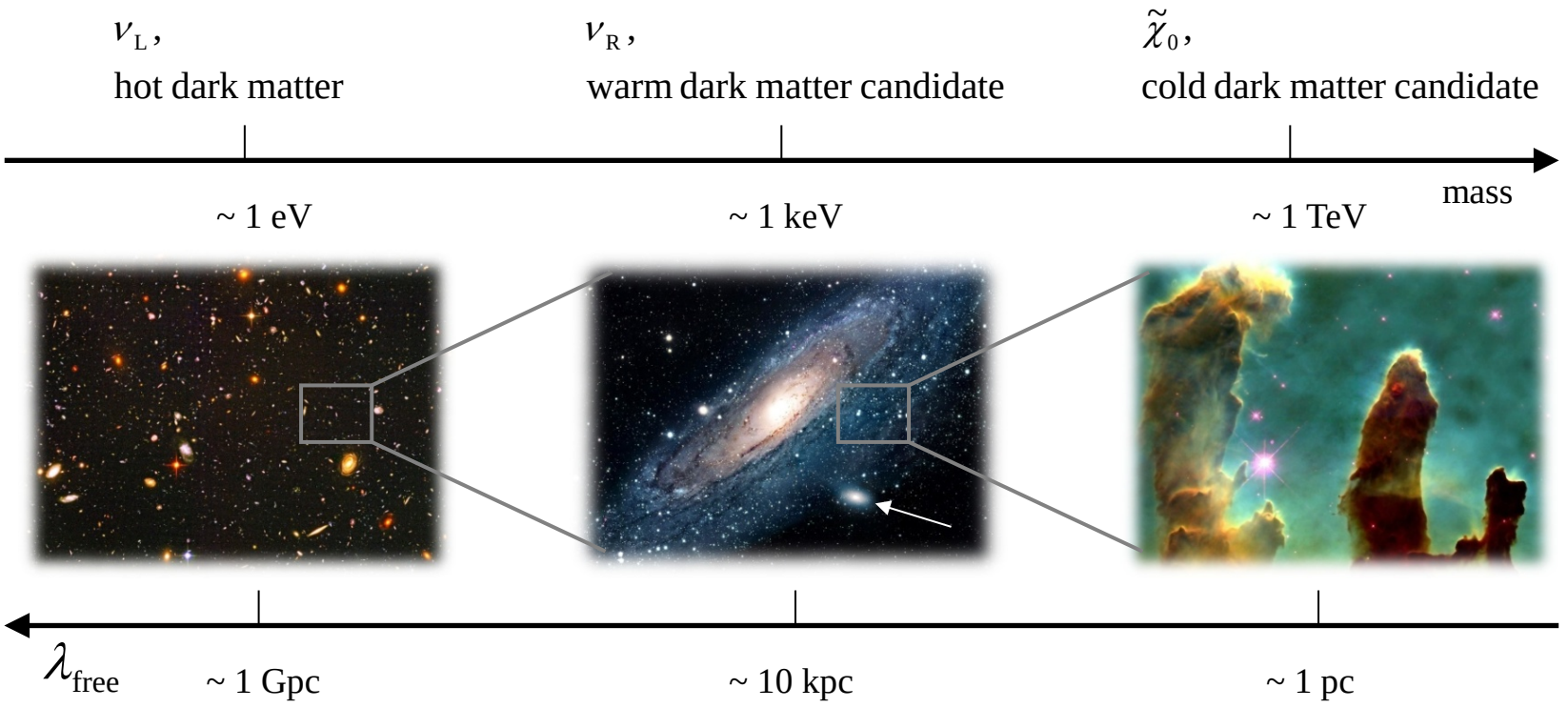
Why heavy sterile neutrinos?

”Simple” Λ-CDM models predict:

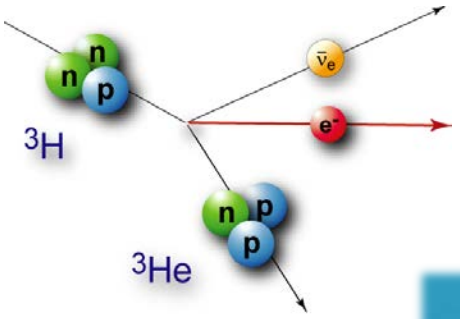
- many small scale structures (dwarf galaxies)
- cuspy density profiles of galaxies



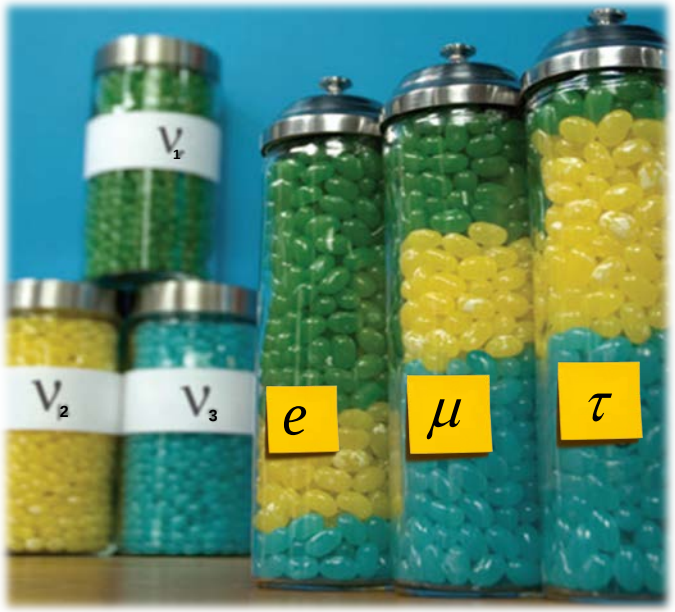
keV neutrinos as WDM candidate



Imprint of keV neutrinos on ß-spectrum



$$|U_{e1}|^2 \nu_1 + |U_{e2}|^2 \nu_2 + |U_{e3}|^2 \nu_3$$



keV neutrino

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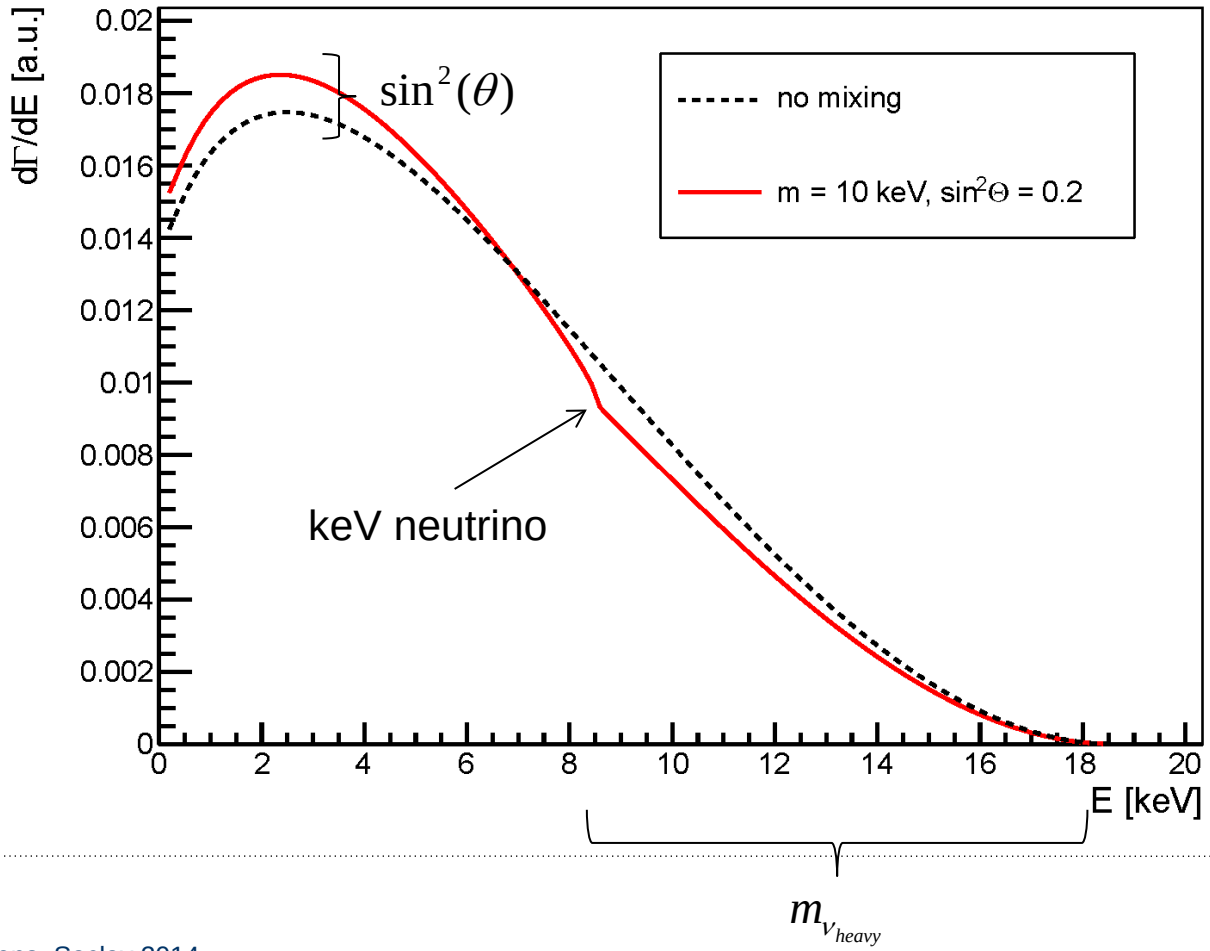
Imprint of keV neutrinos on ß-spectrum



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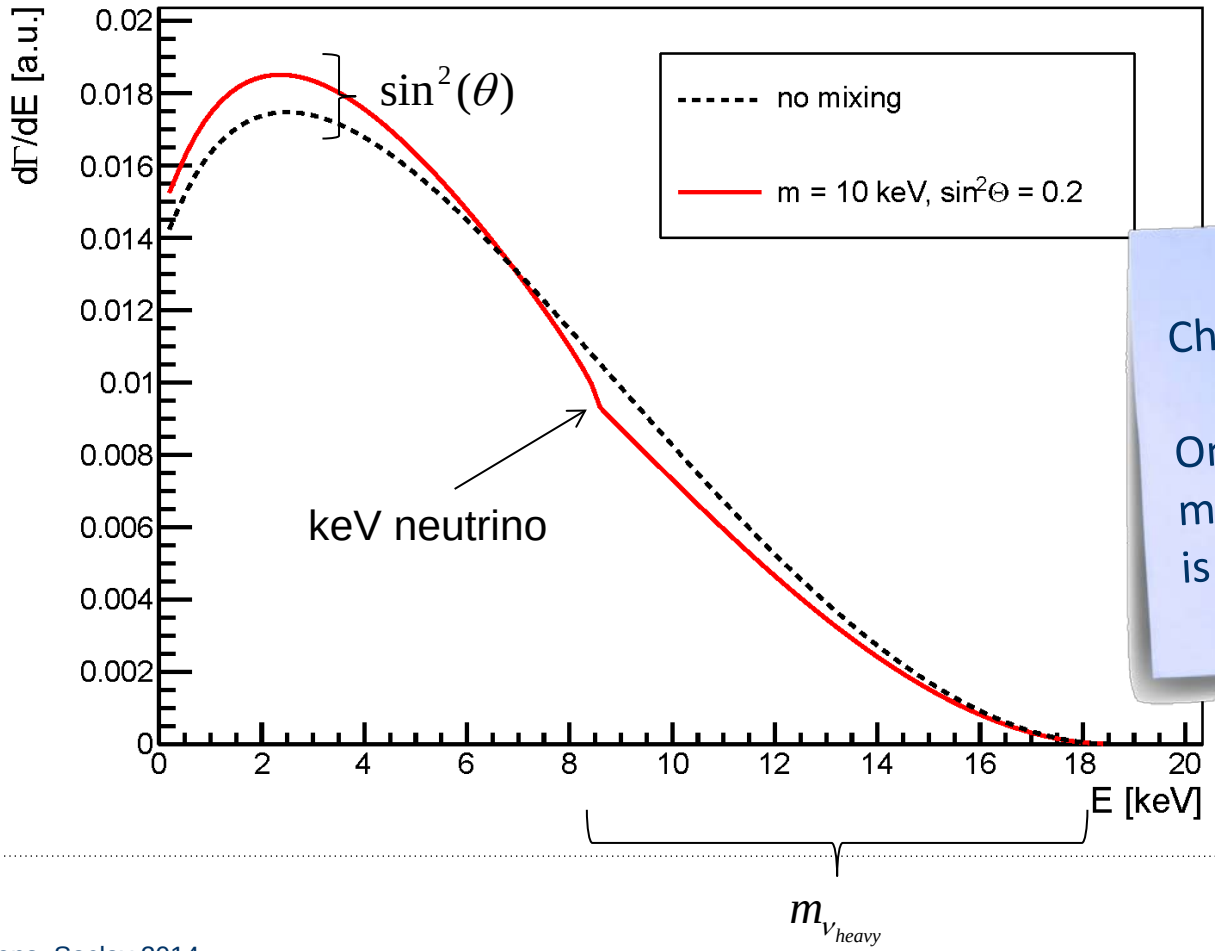
Imprint of keV neutrinos on ß-spectrum



Challenge:

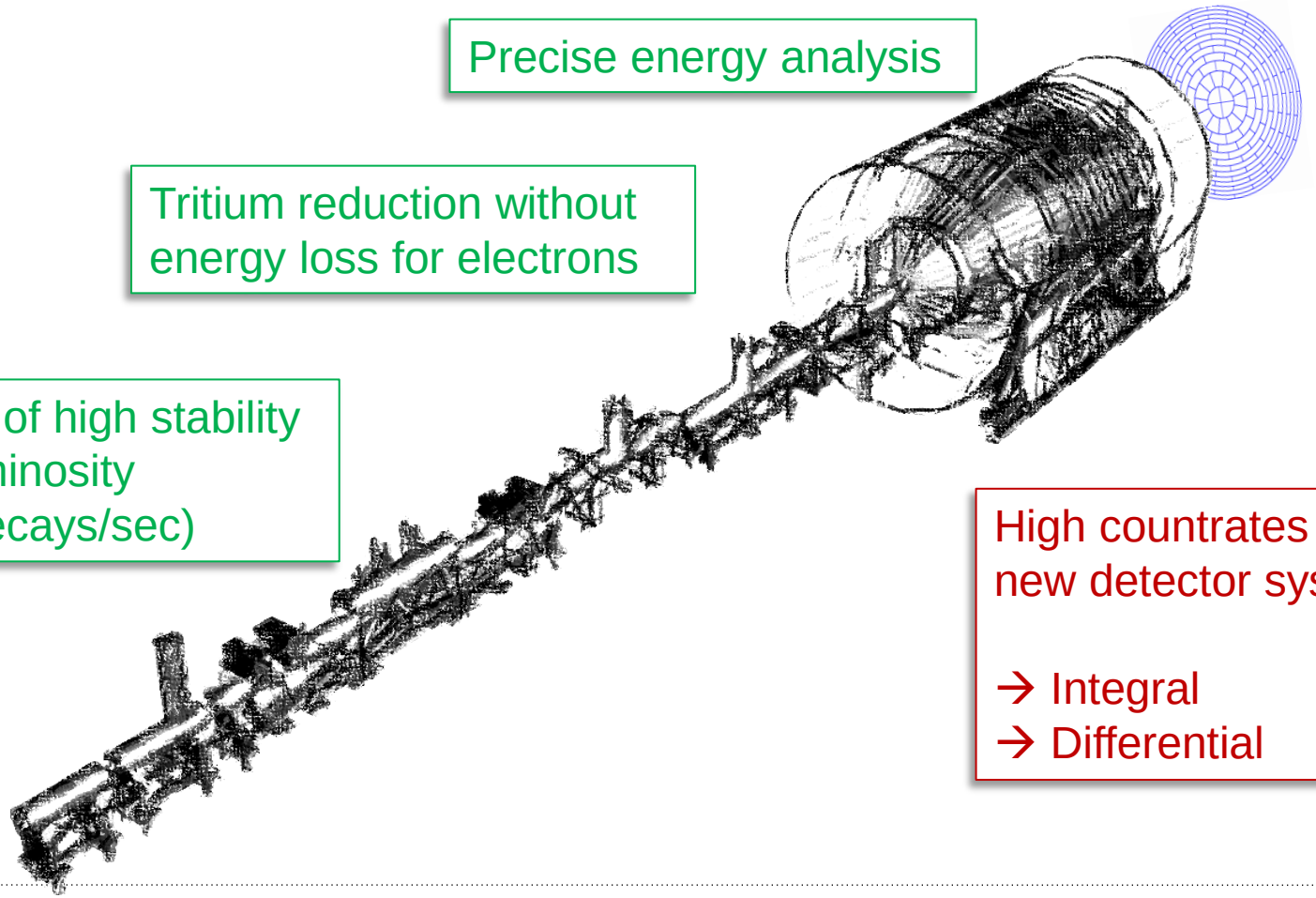
Only one in 10 million jelly beans is red!

How to make use of KATRIN?

Precise energy analysis

Tritium reduction without energy loss for electrons

Source of high stability and luminosity (10^{11} decays/sec)

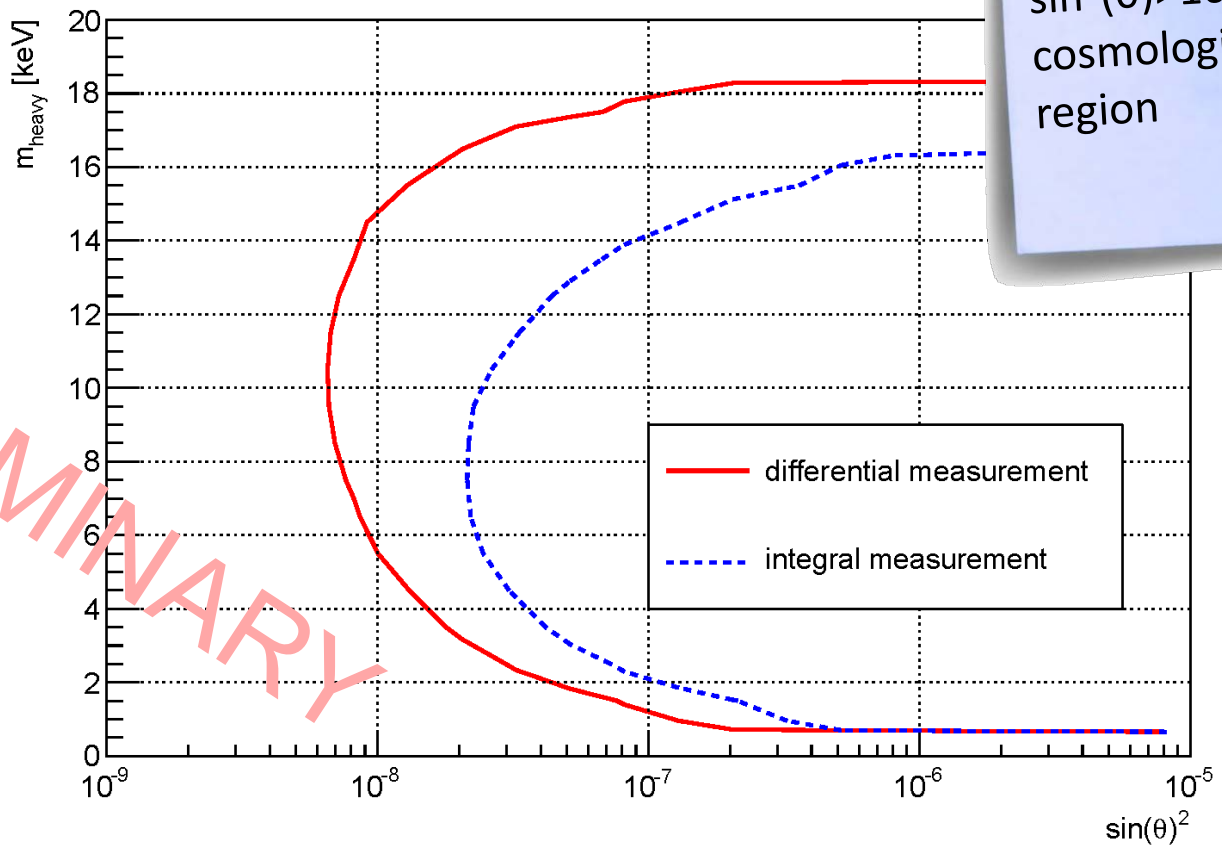


High countrates require a new detector system

→ Integral
→ Differential

Statistical Sensitivity

Upgraded KATRIN provide great statistical sensitivity of up to $\sin^2(\theta)>10^{-8}$, probing the cosmological favored region



PRELIMINARY

KATRIN source strength, 3 years measurement time

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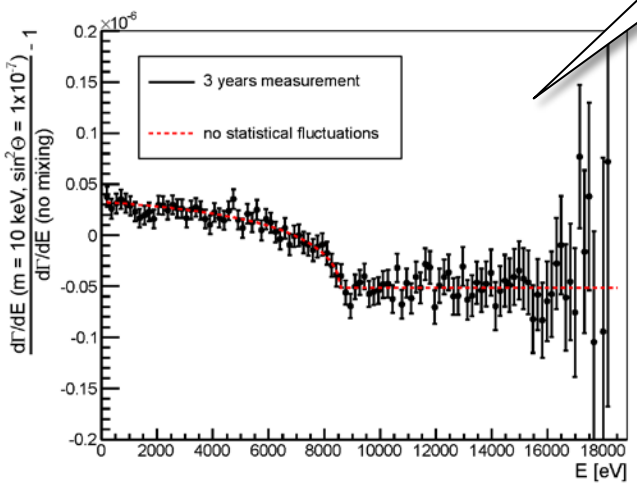
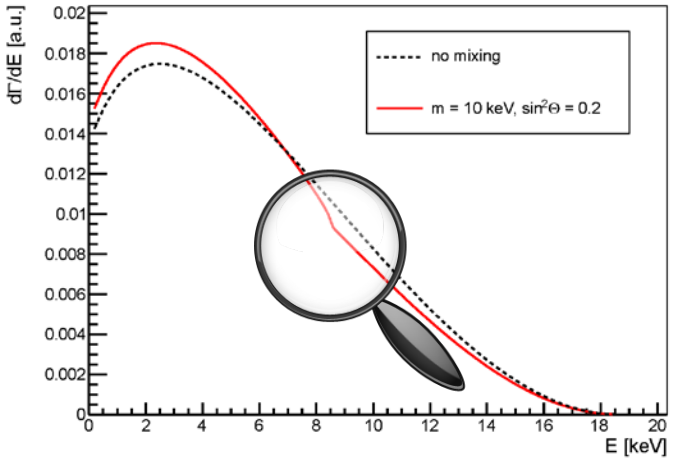
Theoretical uncertainty

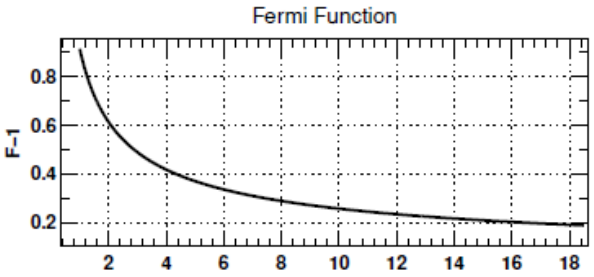
1. Spectral Fit Approach
2. Wavelet Approach

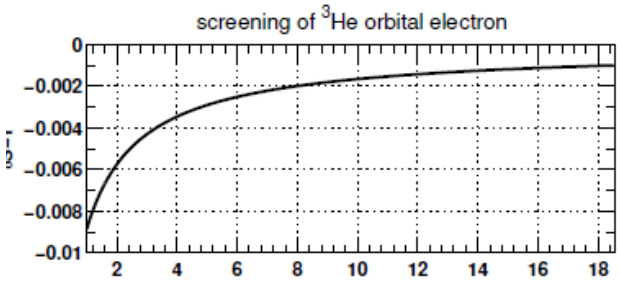
Idea:
Parametrize uncertainties and let these parameters free in the fit, to allow them to fake a keV neutrino signature

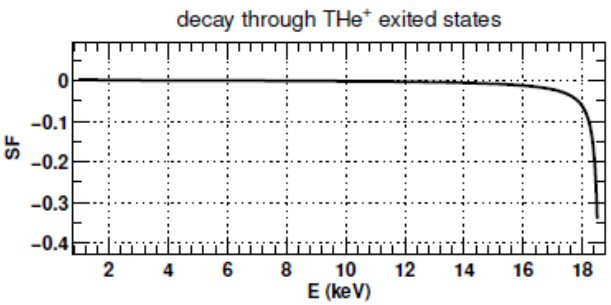


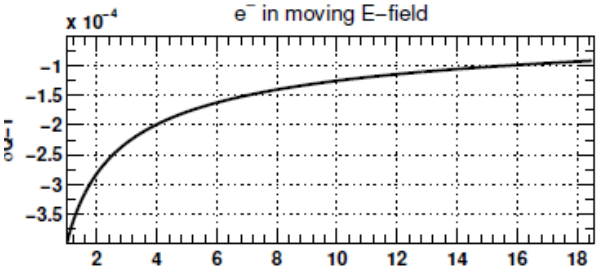


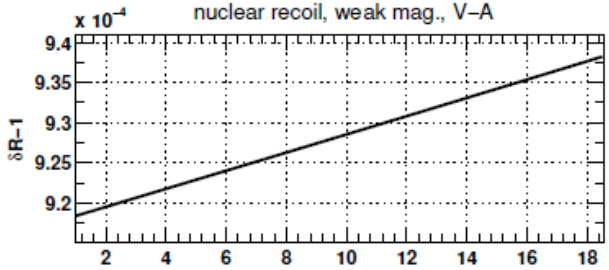
Spectral Fit Approach

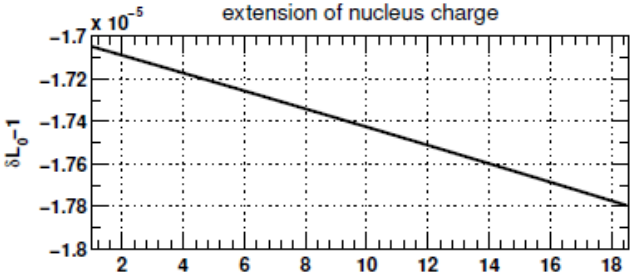


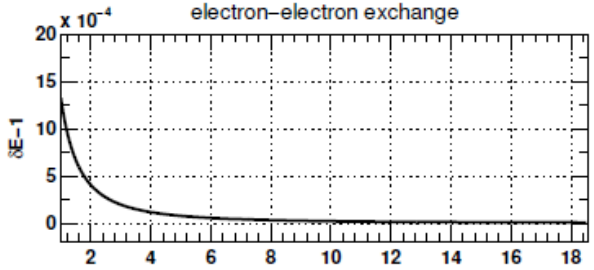


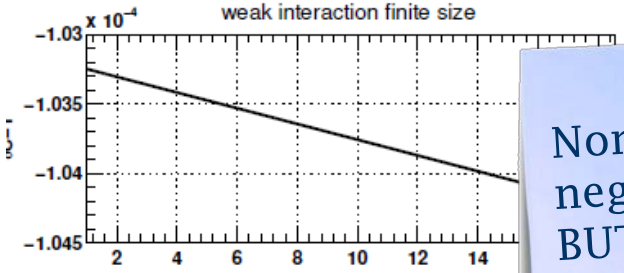


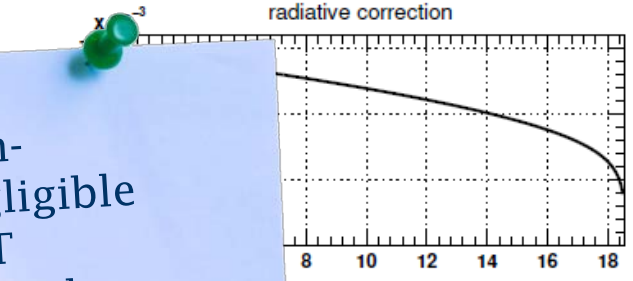












Non-negligible BUT smooth in energy

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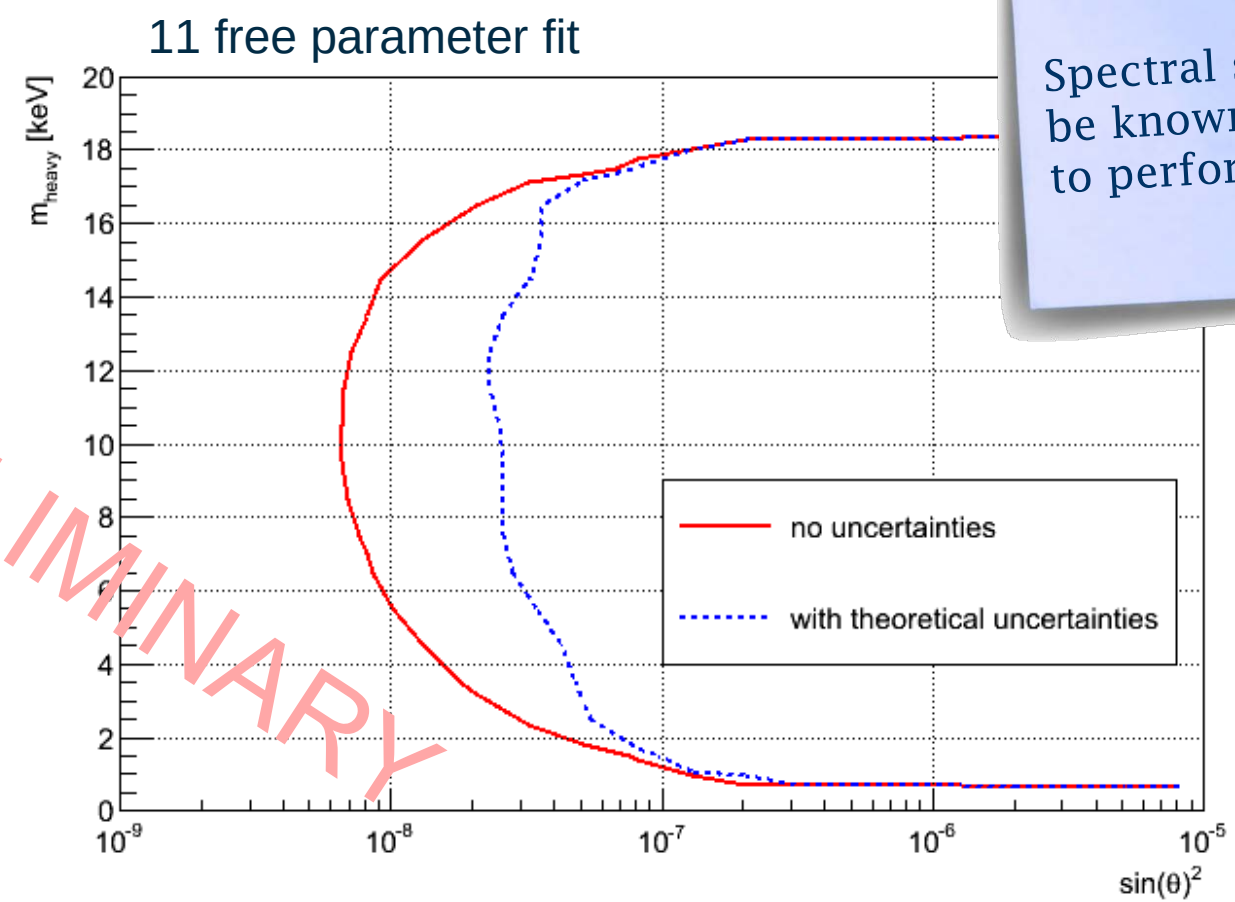
Spectral Fit Approach

Smooth corrections do not fake a kink signal $\sin^2(\theta) > 10^{-7}$

Spectral shape has to be known to be able to perform a fit



PRELIMINARY

KATRIN source strength, 3 years measurement time

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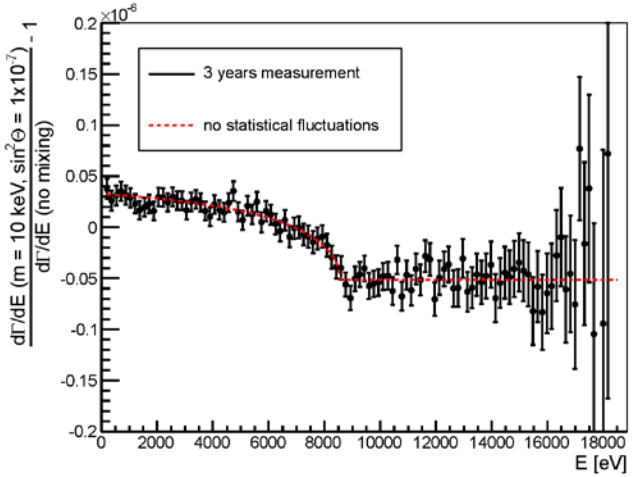
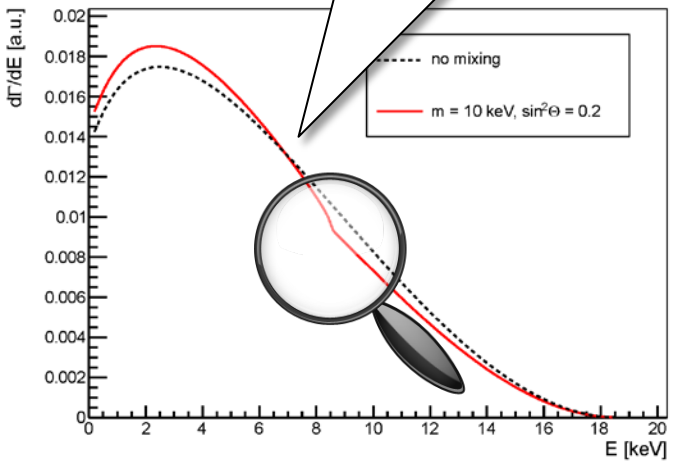
Theoretical uncertainty

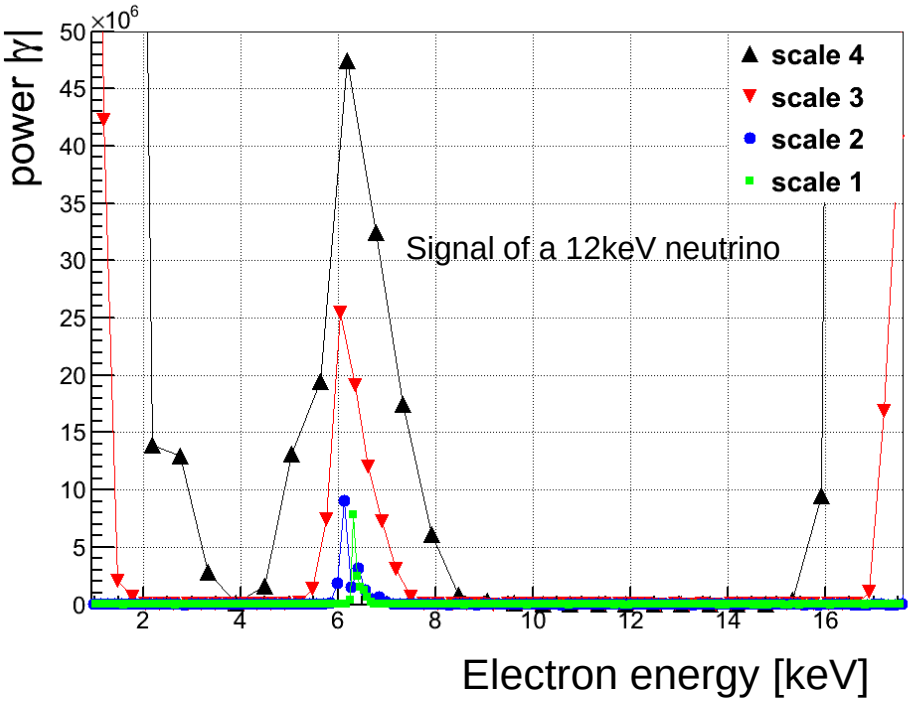
1. Spectral Fit Approach
2. Wavelet Approach

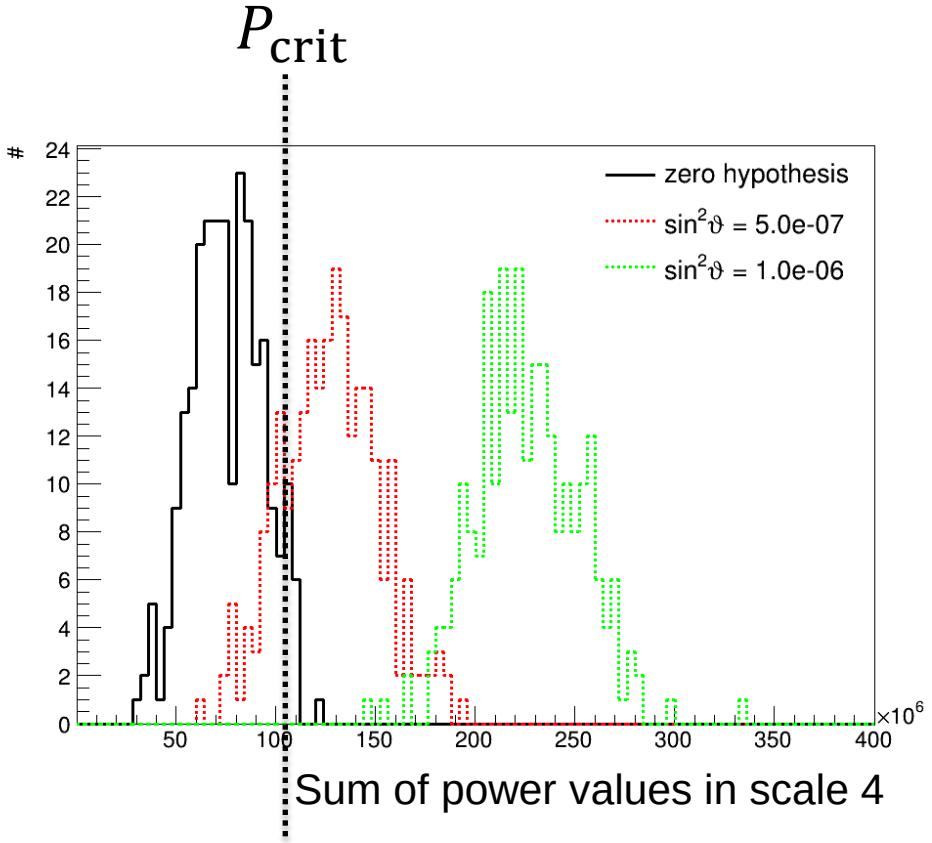
Idea:
Use wavelet transformation to detect „kink“ feature in the spectrum, in order to be be insensitive to the exact knowledge of the true spectrum



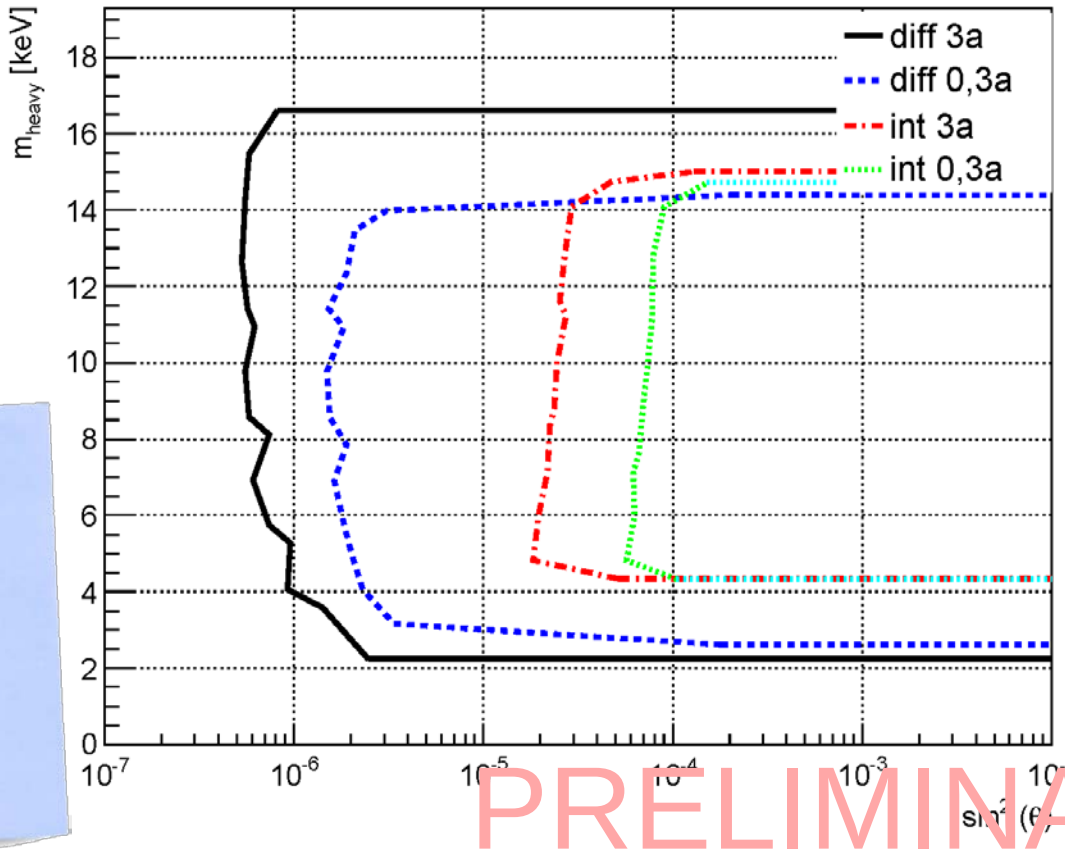


Wavelet Approach





Wavelet Approach

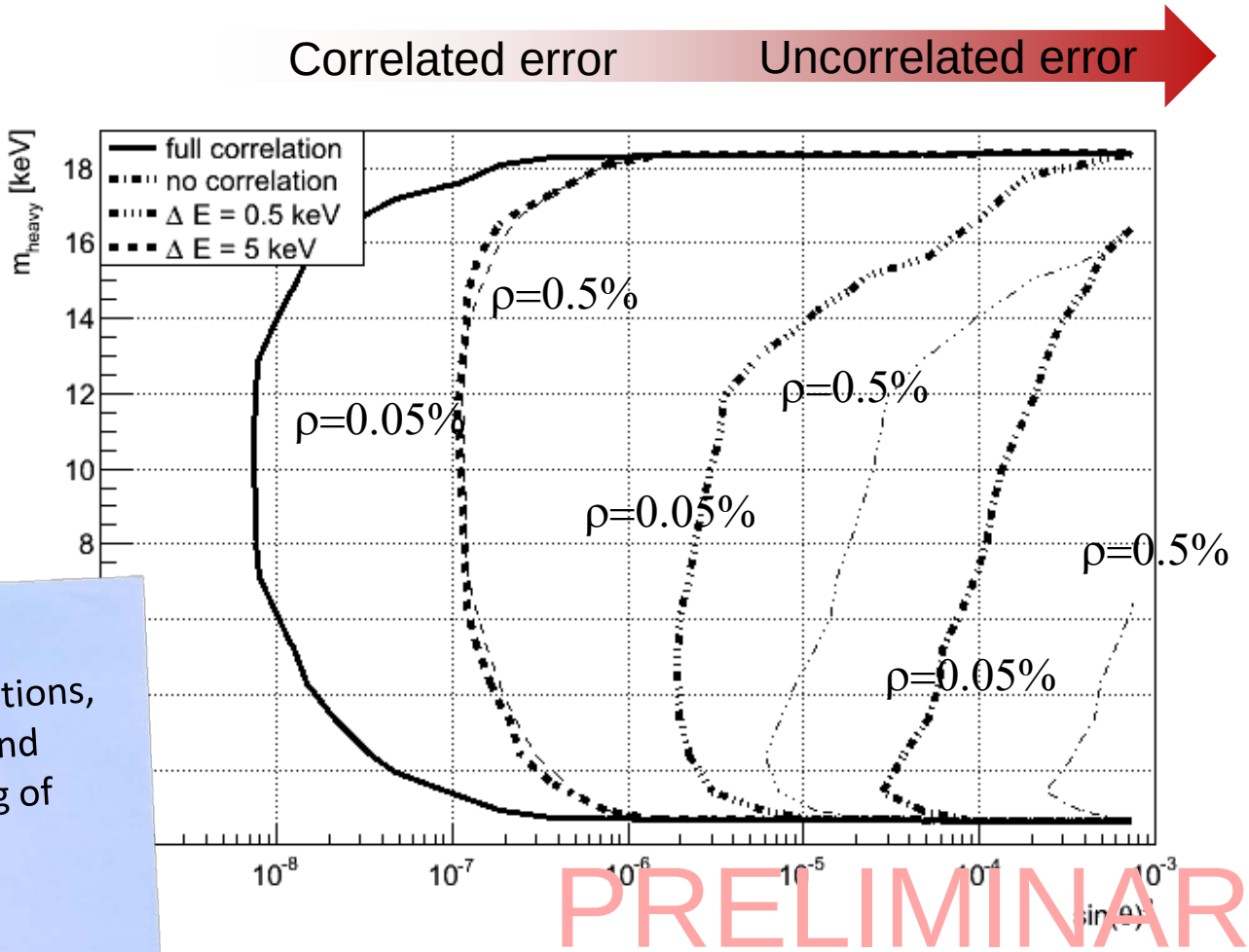


Kink search can be powerful, but differential measurement with good energy resolution is required

PRELIMINARY

KATRIN source strength, 3 years measurement time

Experimental uncertainties



Precise calibrations, simulations, and understanding of correlations are needed

Summary

- KATRIN is designed to directly measure the neutrino mass with a sensitivity of 200meV (90%CL) after 3 years of measurement time
- Successful commissioning of main spectrometer
- Start of Tritium measurements: fall 2015
- Promising potential for sterile neutrino search


Thank you for your attention