STERILE NEUTRINOS IN β AND $0\nu\beta\beta$

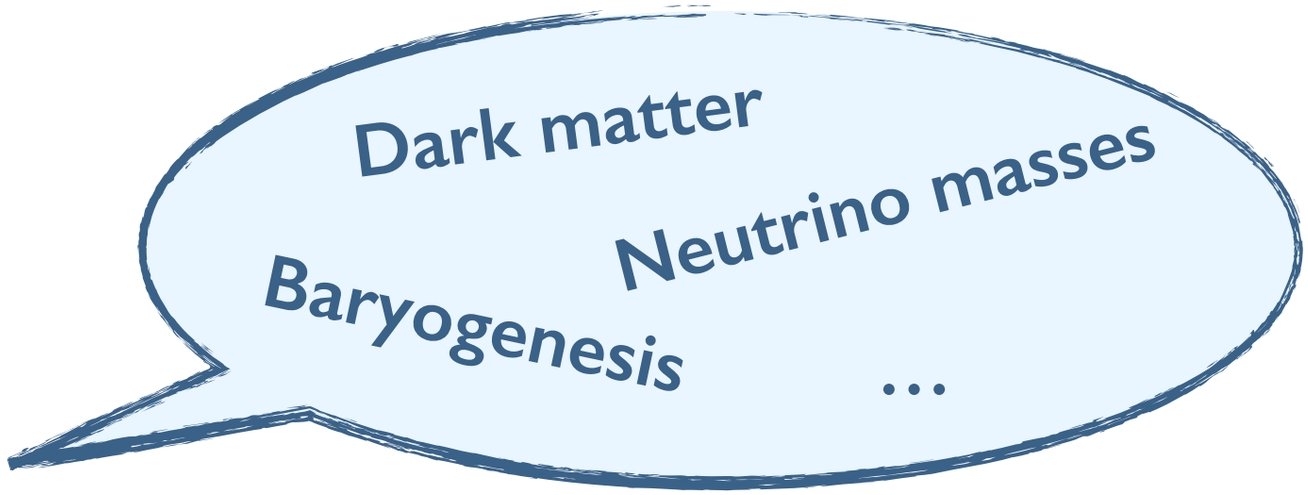
Xabier Marcano
LPT, Orsay

Based on 1807.01331 with
Asmaa Abada and Álvaro Hernández-Cabezudo

KIT - Invisibles 18 Workshop - September 18

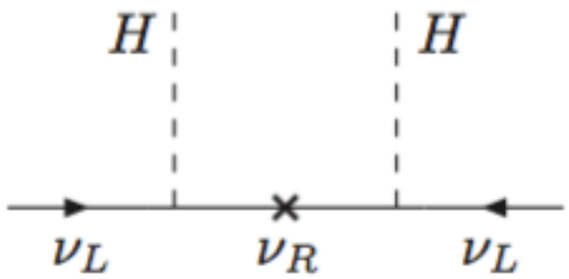
Why sterile neutrinos

- Open problems in the SM

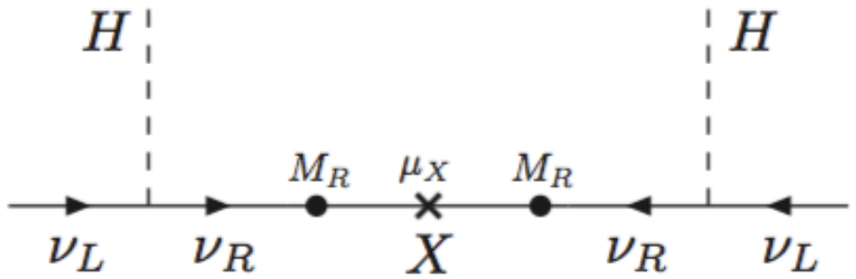


- **New Physics is needed** to solve these issues

- Many BSM extensions consider **Sterile Neutrinos**, e.g. ***type-I and type-III seesaws, and its variants νMSM, linear seesaw, inverse seesaw…***



Type-I seesaw



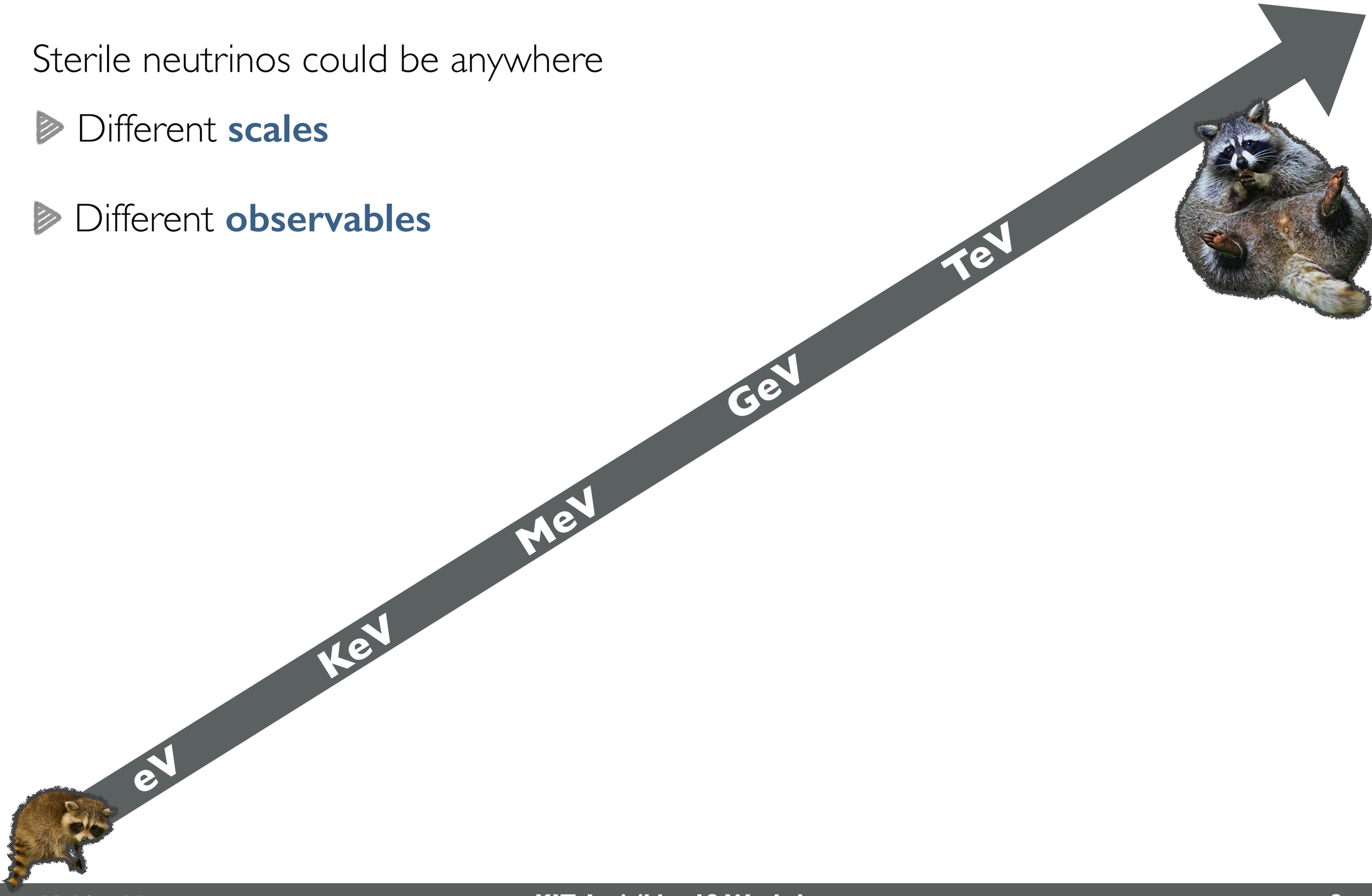
Inverse seesaw

- **Sterile neutrinos:** SM singlets, **only via mixing** to active neutrinos

Broad phenomenology

Sterile neutrinos could be anywhere

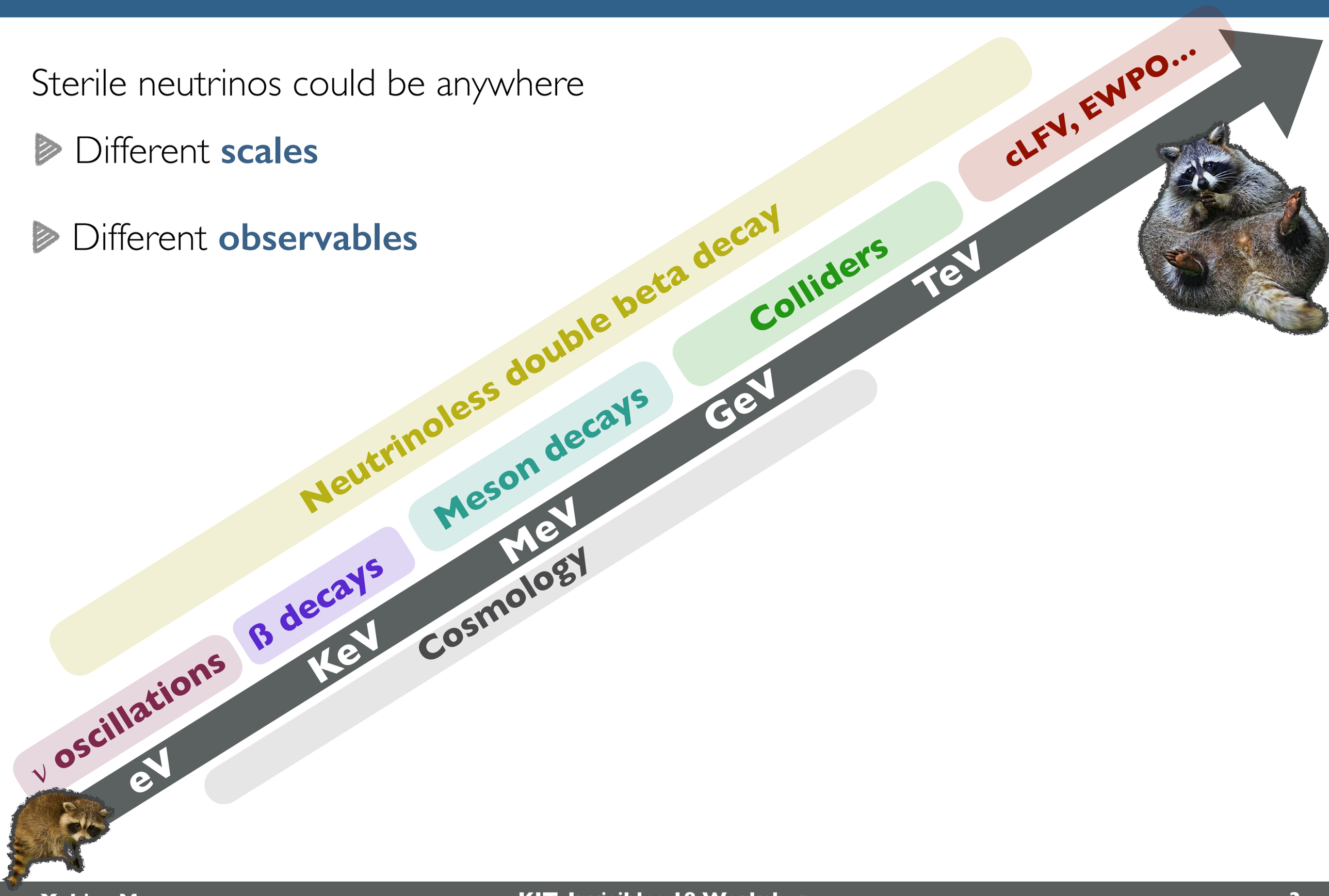
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

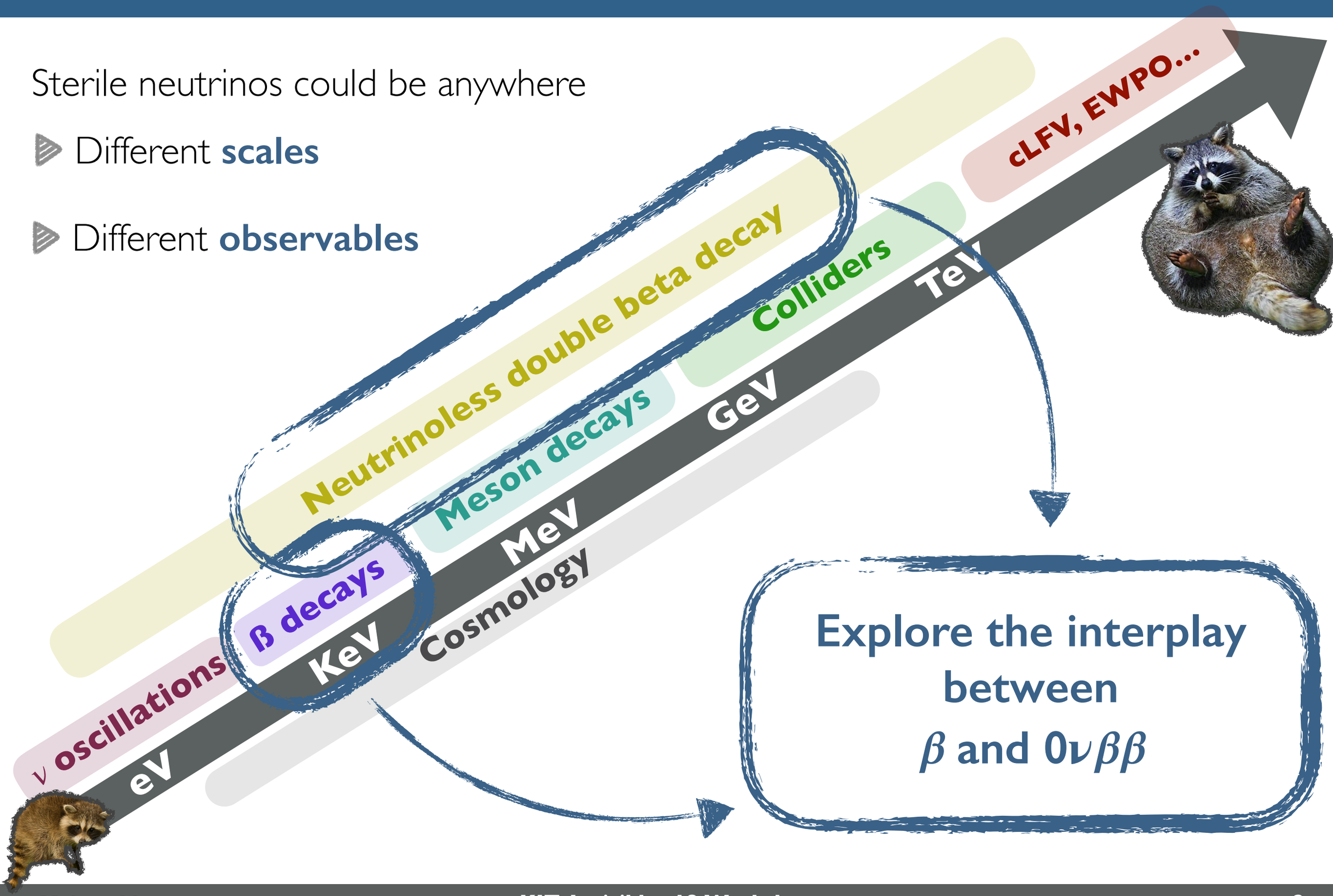
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

- Different **scales**
- Different **observables**

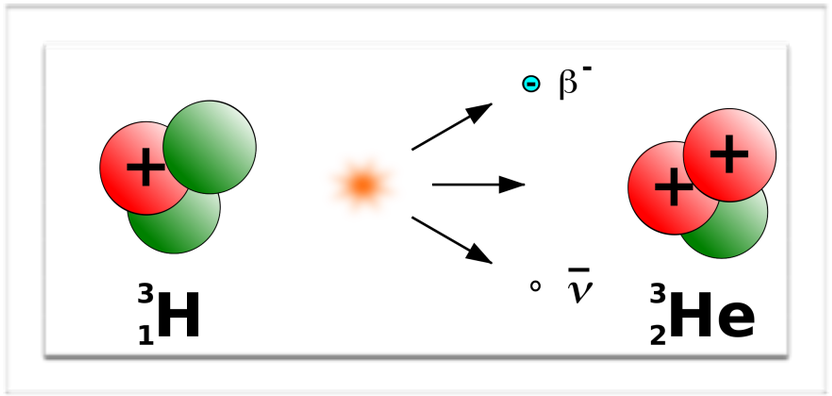


Outline

- **Experimental status** for β and $0\nu\beta\beta$ decays
- The **role of sterile neutrinos** in β and $0\nu\beta\beta$ decays
- **Implications** for type-I seesaw models

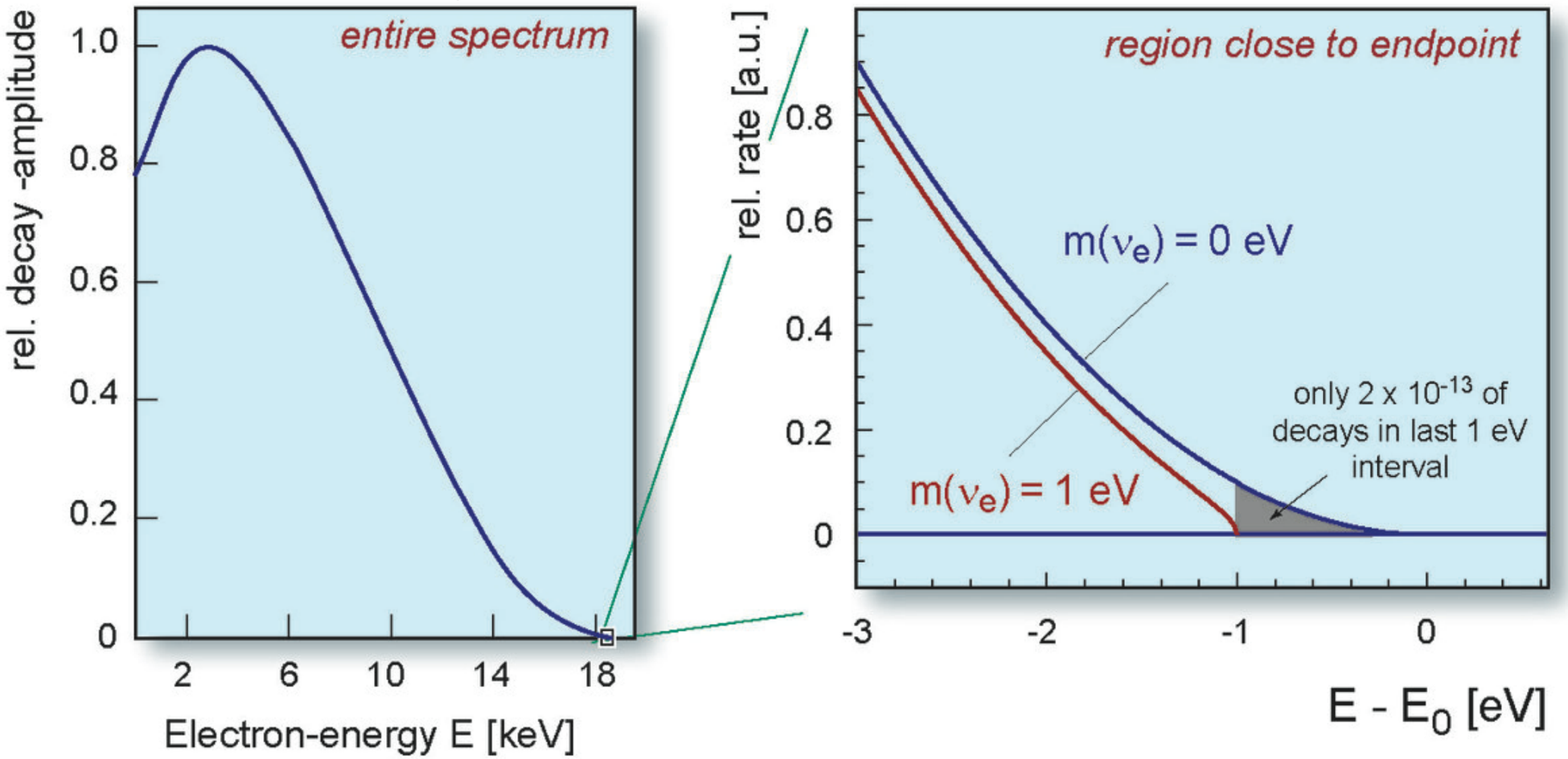
Experimental status of β decays

- Measure the end-point spectrum of **tritium β decay (E$_0$ = 18.6 keV)**



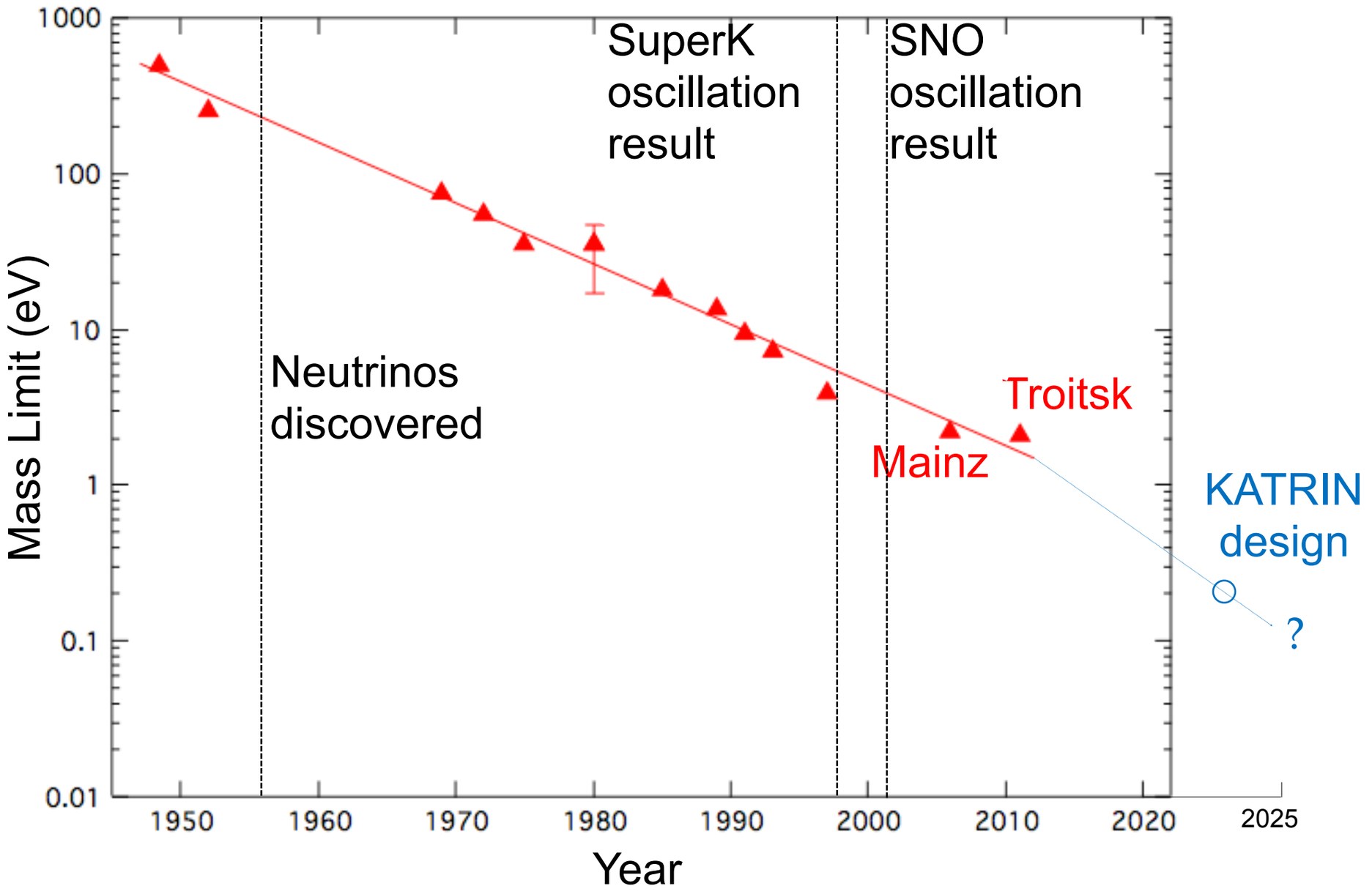
$$m_\beta^2 = \sum_{i=1}^{3} m_i^2 |U_{ei}|^2$$

Source: KATRIN experiment



$m_{\nu,eff}^2$: A Brief History in Tritium

**Talk by Diana Parno in Neutrino 2018*



Adapted from J. Wilkerson, Neutrino 2012

The KATRIN Experiment

Image credit Laura Baudis

The KATRIN Experiment

elusives
neutrinos, dark matter & dark energy physics

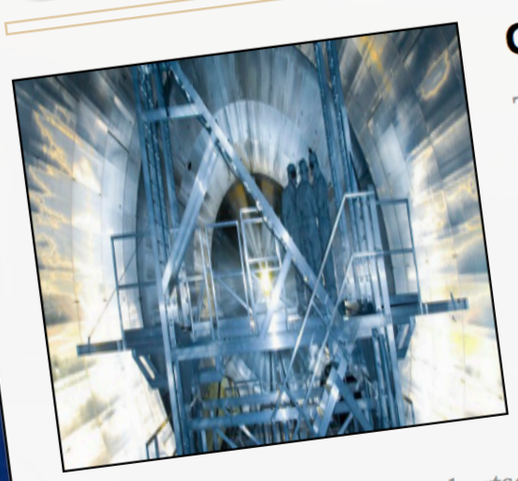
Search in Elusives | Search

THE NETWORK | JOBS | OUTREACH | VIRTUAL INSTITUTE | PUBLICATIONS

Home » News & Events » Official inauguration of the KATRIN experiment ...

News & Events

Official inauguration of the KATRIN experiment at KIT



Today, June 11 2018 the KATRIN experiment has been inaugurated at 11.46 a.m. at the Karlsruhe Institute of Technology (KIT).

The KATRIN collaboration started commissioning four weeks ago on May 18 2018, making the first tritium injection, and today it has been finally inaugurated, marking the start of the data taking with the aim of measuring the absolute mass of the neutrinos or set the lowest upper bound with an unprecedented sensitivity of 0.2 eV.

During the ceremony, the two Nobel Laureates Takaaki Kajita and Arthur McDonald gave lectures on "Atmospheric Neutrinos and their Oscillations" and "Flavor Change for Solar Neutrinos" respectively, and later the professors R.G.H. Robertson, C. Weinheimer and G. Drexlin laid out the history of the KATRIN experiment from its incep

prospects for the future.

After the ceremony all the participants are invited to a barbecue to celebrate this important and beautiful event.

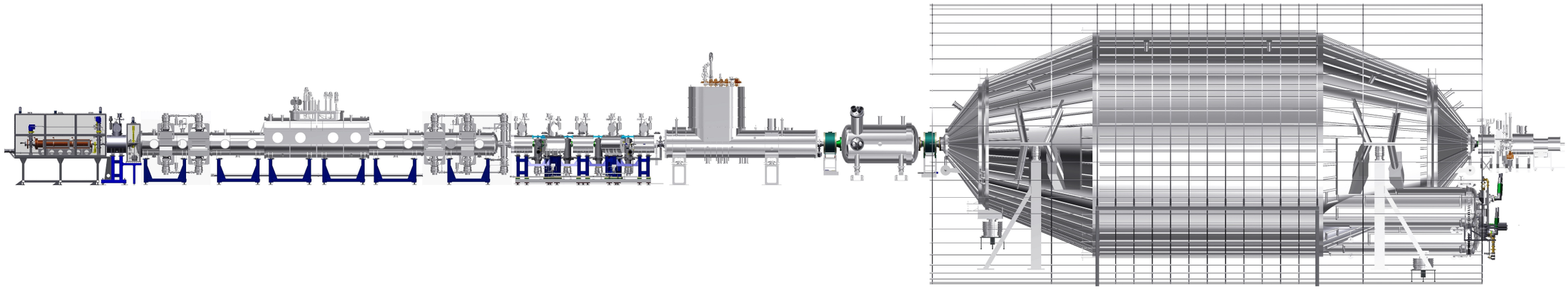
Text by Álvaro Hernández-Cabezudo

KIT, 11th June 20

Image credit Laura Baudis

The KATRIN Experiment

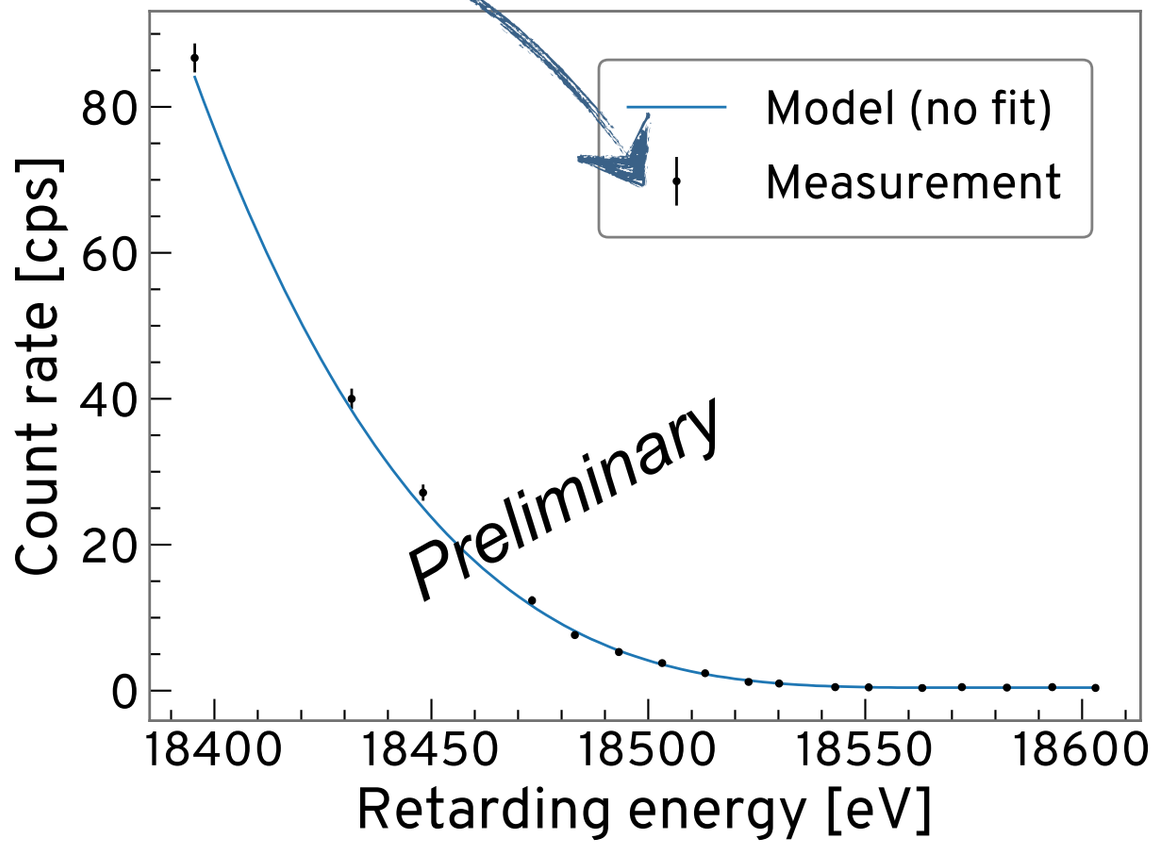
- The **KA**rlsruhe **TRI**tium **N**eutrino experiment



- **First Tritium** data in May'18!!!
- Large luminosity of **10^{11} decays/s**
- Good **energy resolution 0.93 eV**
- **Expected sensitivity**

$$m_\beta < 0.2 \text{ eV}$$

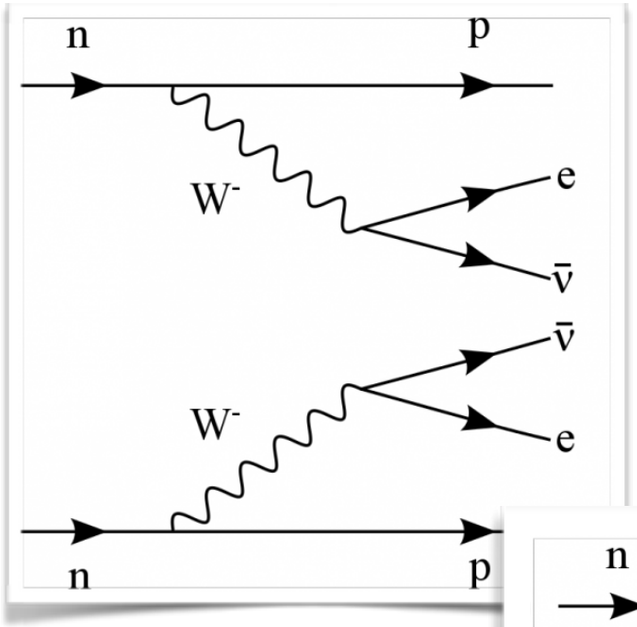
Diana Parno, Neutrino 2018



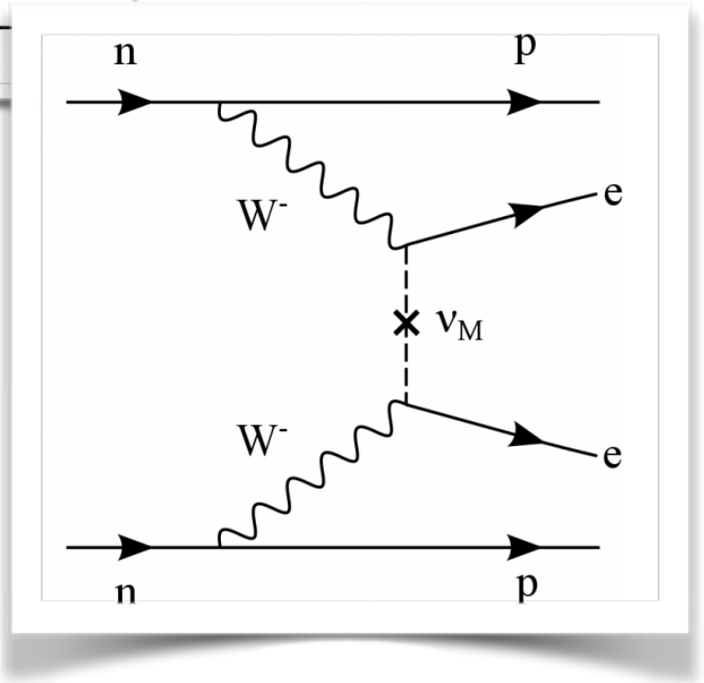
Neutrinoless double beta decay

- Learn about **neutrinos** looking for **no neutrinos**

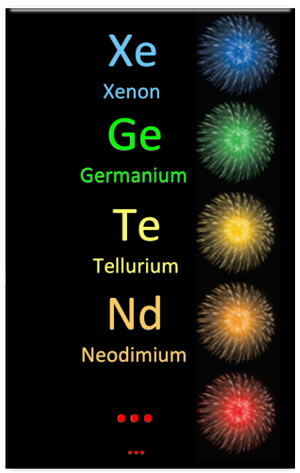
$$m_{ee} = \left| \sum_i m_i U_{ei} \right|^2$$

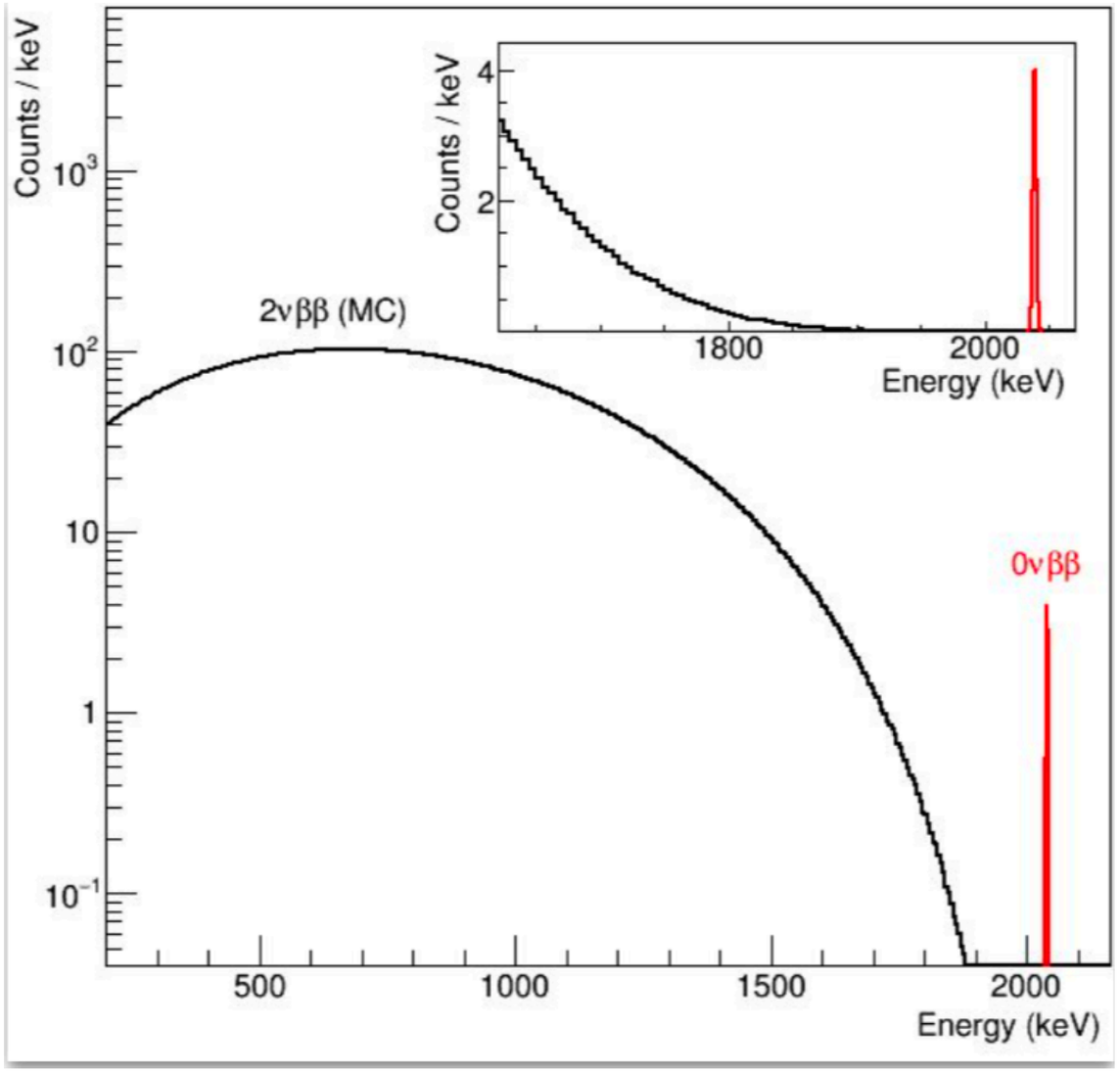


$2\nu\beta\beta$



$0\nu\beta\beta$





Anna Julia Zsigmond (GERDA), Neutrino 2018

Experimental status of $0\nu\beta\beta$

- **Current bounds** on neutrinoless double beta decays **after Neutrino 2018**
- Depend on the **studied isotope**

Experiment	Isotope	$T_{1/2}^{\min}(y)$	$m_{ee}^{\max}(meV)$
EXO-200	^{136}Xe	1.8×10^{25}	147-398
KamLAND-Zen	^{136}Xe	1.07×10^{26}	62-165
GERDA	^{76}Ge	0.9×10^{26}	110-260
MAJORANA DEMONSTRATOR	^{76}Ge	2.7×10^{25}	200-433
CUORE	^{130}Te	1.5×10^{25}	110-520
CUPID-0	^{82}Se	2.4×10^{24}	376-770

- More in talk by **Chiara Brofferio**

Experimental status of $0\nu\beta\beta$

- **Current bounds** on neutrinoless double beta decays **after Neutrino 2018**
- Depend on the **studied isotope**

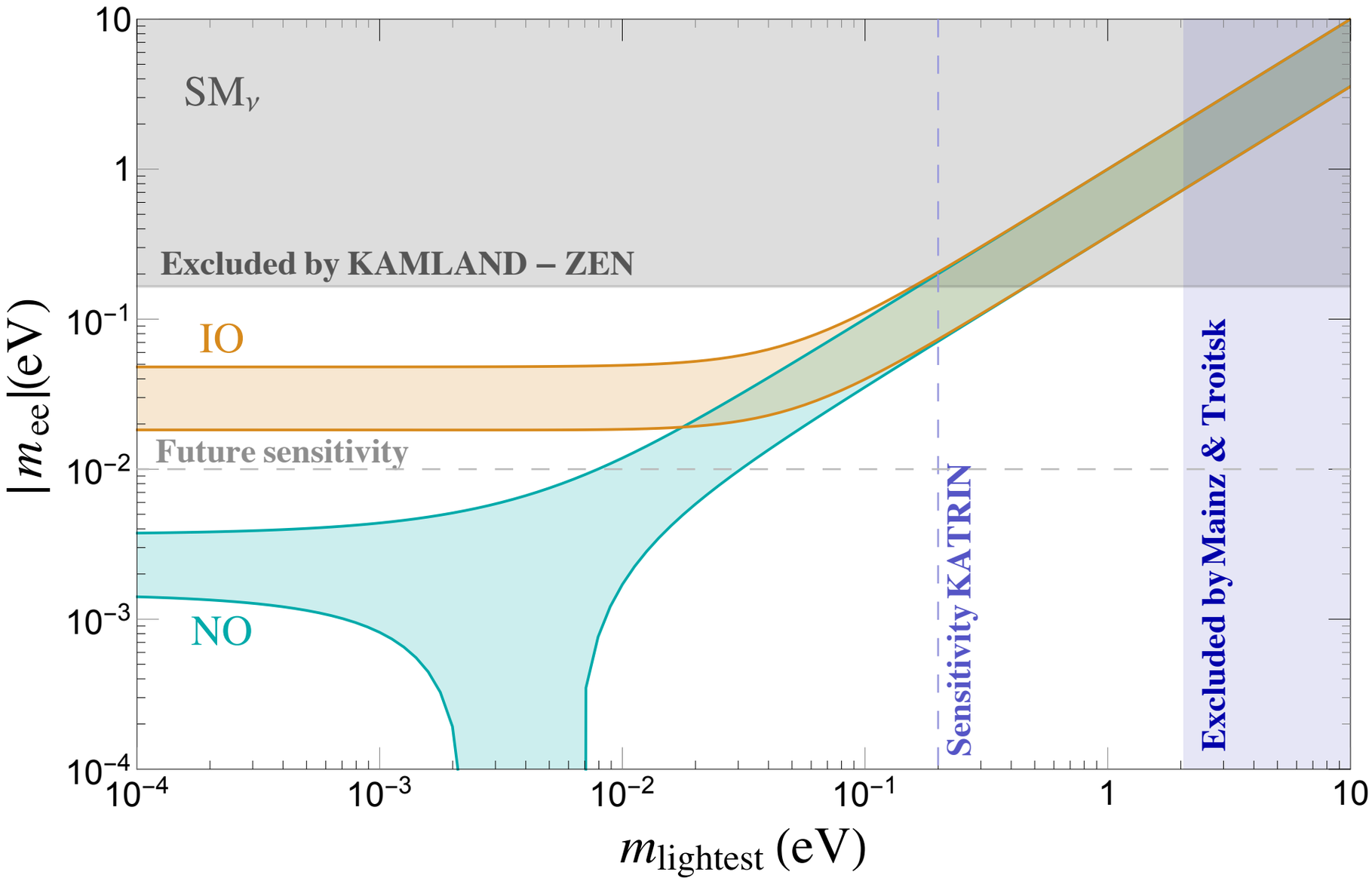
Experiment	Isotope	$T_{1/2}^{\min}(y)$	$m_{ee}^{\max}(meV)$
EXO-200	^{136}Xe	1.8×10^{25}	147-398
KamLAND-Zen	^{136}Xe	1.07×10^{26}	62-165
GERDA	^{76}Ge	0.9×10^{26}	110-260
MAJORANA DEMONSTRATOR	^{76}Ge	2.7×10^{25}	200-433
CUORE	^{130}Te	1.5×10^{25}	110-520
CUPID-0	^{82}Se	2.4×10^{24}	376-770

NEW!!!

- More in talk by **Chiara Brofferio**

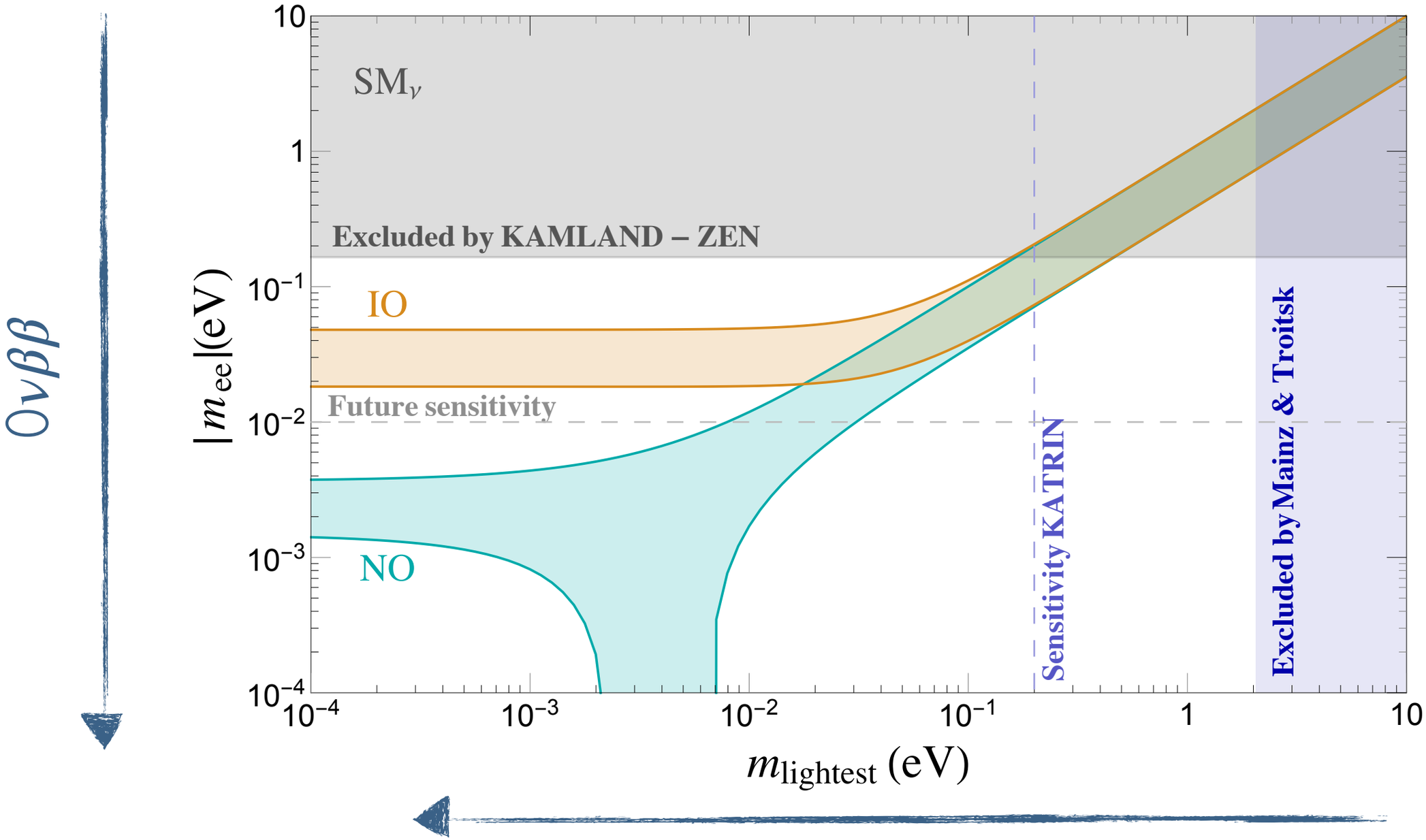
β AND $0\nu\beta\beta$ IN THE SMν

- The standard picture for **3 light Majorana neutrinos (SMν)**



β AND $0\nu\beta\beta$ IN THE SMν

- The standard picture for **3 light Majorana neutrinos (SMν)**

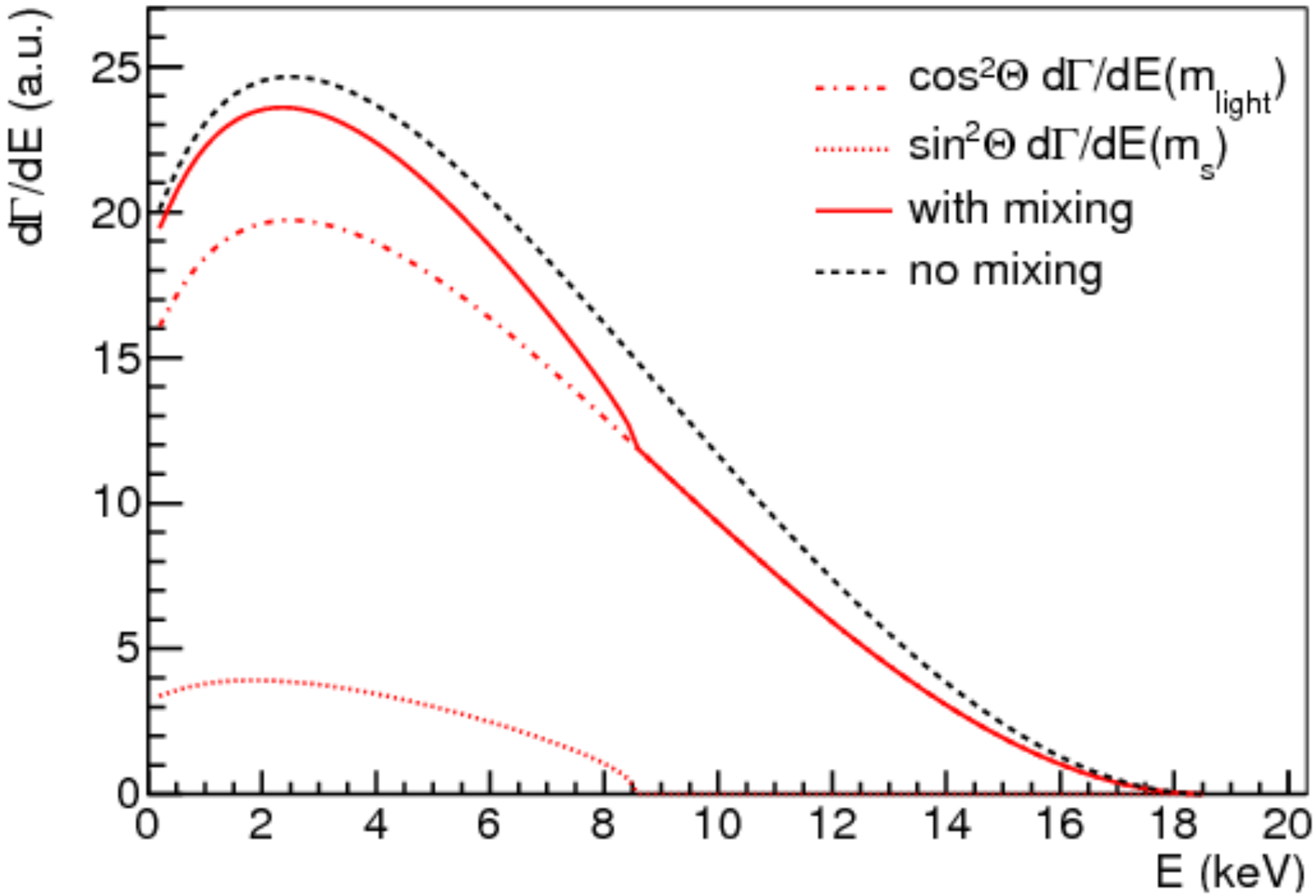


WHERE IS THE STERILE NEUTRINO IN ALL THIS STORY?

STERILE NEUTRINOS IN β DECAYS

- It could be seen as a **kink** in the electron spectrum

$$\frac{d\Gamma}{dE} = \cos^2(\theta)\frac{d\Gamma}{dE}(m_{\text{light}})\,\Theta(E_0 - E - m_{\text{light}}) + \sin^2(\theta)\frac{d\Gamma}{dE}(m_{\text{heavy}})\,\Theta(E_0 - E - m_{\text{heavy}})$$

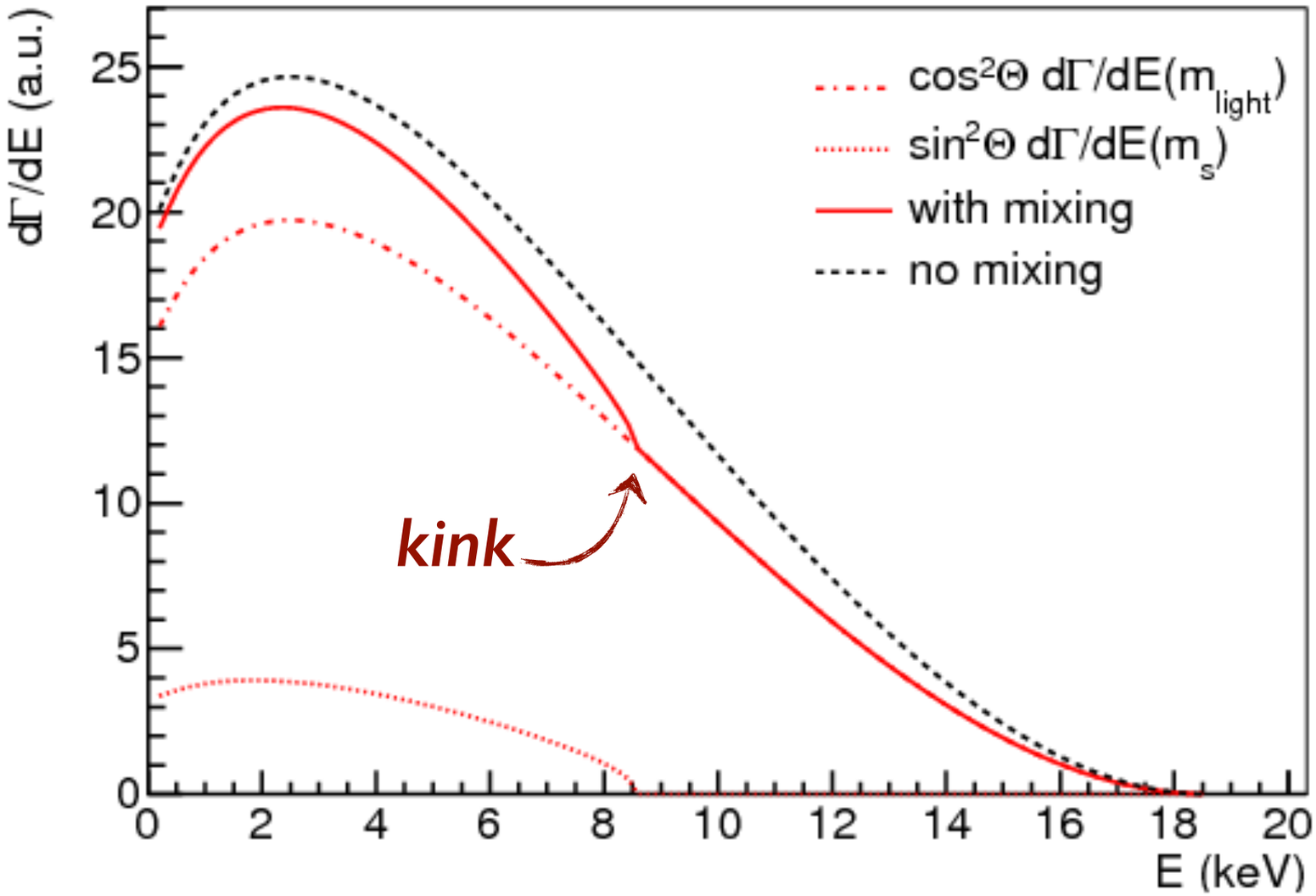


S. Mertens et al, Phys.Rev. D91 (2015) 042005

STERILE NEUTRINOS IN β DECAYS

- It could be seen as a **kink** in the electron spectrum

$$\frac{d\Gamma}{dE} = \cos^2(\theta)\frac{d\Gamma}{dE}(m_{\text{light}})\,\Theta(E_0 - E - m_{\text{light}}) + \sin^2(\theta)\frac{d\Gamma}{dE}(m_{\text{heavy}})\,\Theta(E_0 - E - m_{\text{heavy}})$$

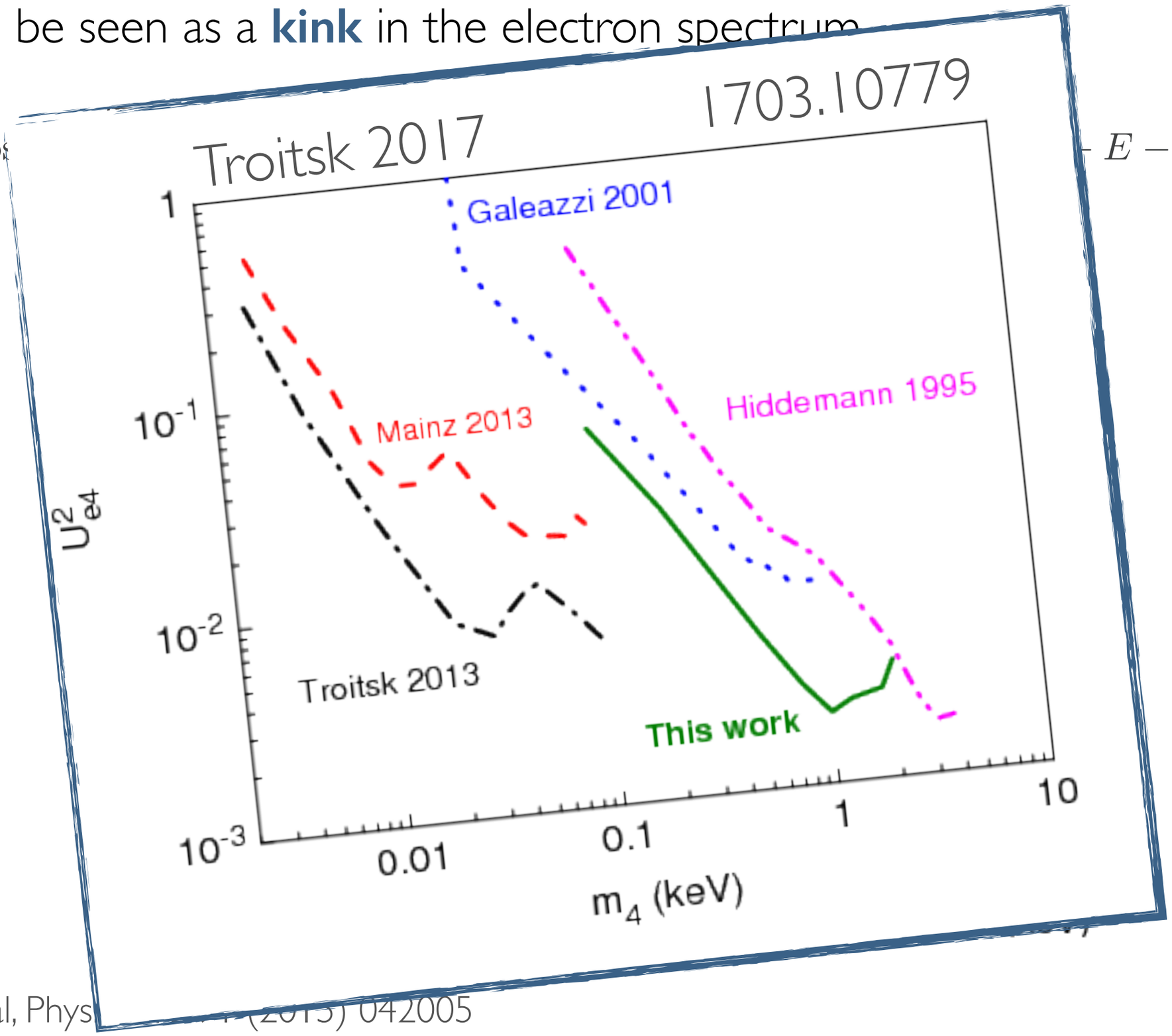


S. Mertens et al, Phys.Rev. D91 (2015) 042005

STERILE NEUTRINOS IN β DECAYS

- It could be seen as a **kink** in the electron spectrum

$$\frac{d\Gamma}{dE} = \cos$$

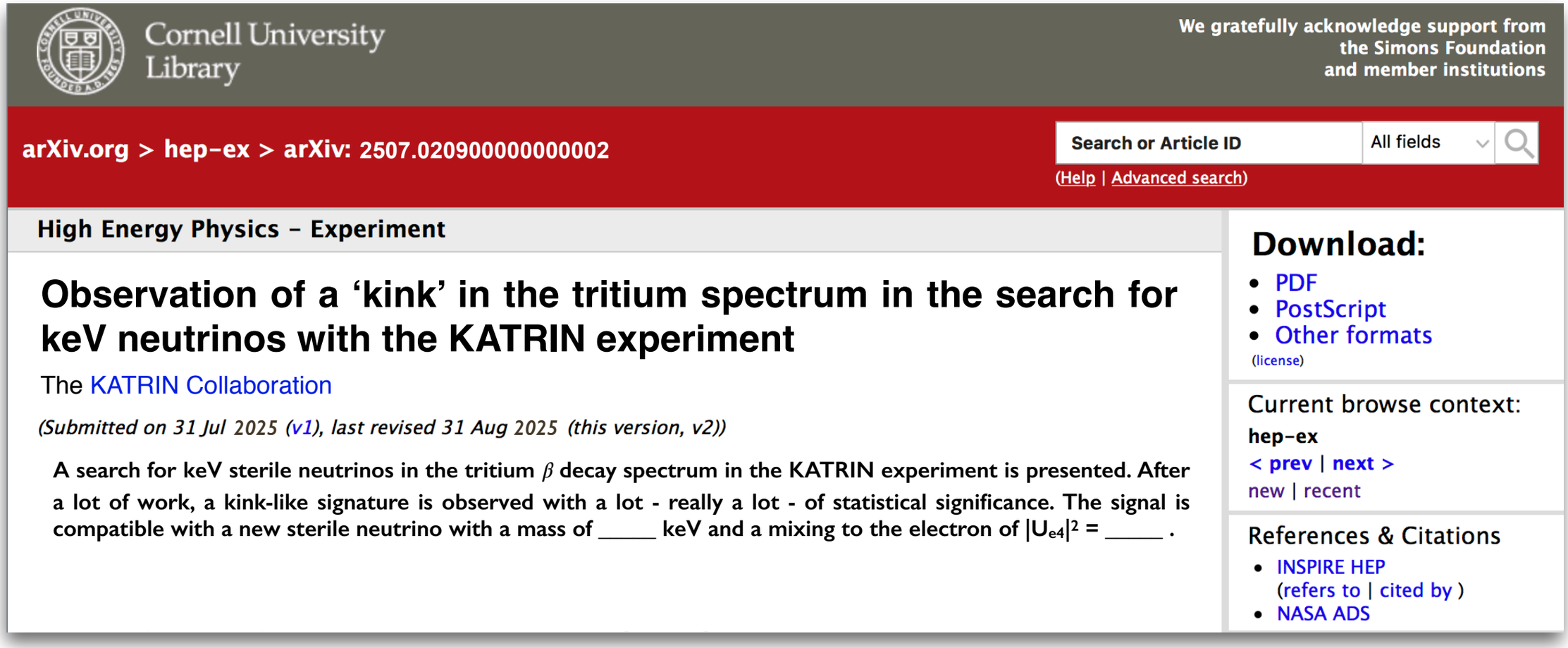


$E - m_{\mathrm{heavy}})$

S. Mertens et al, Phys (2015) 042005

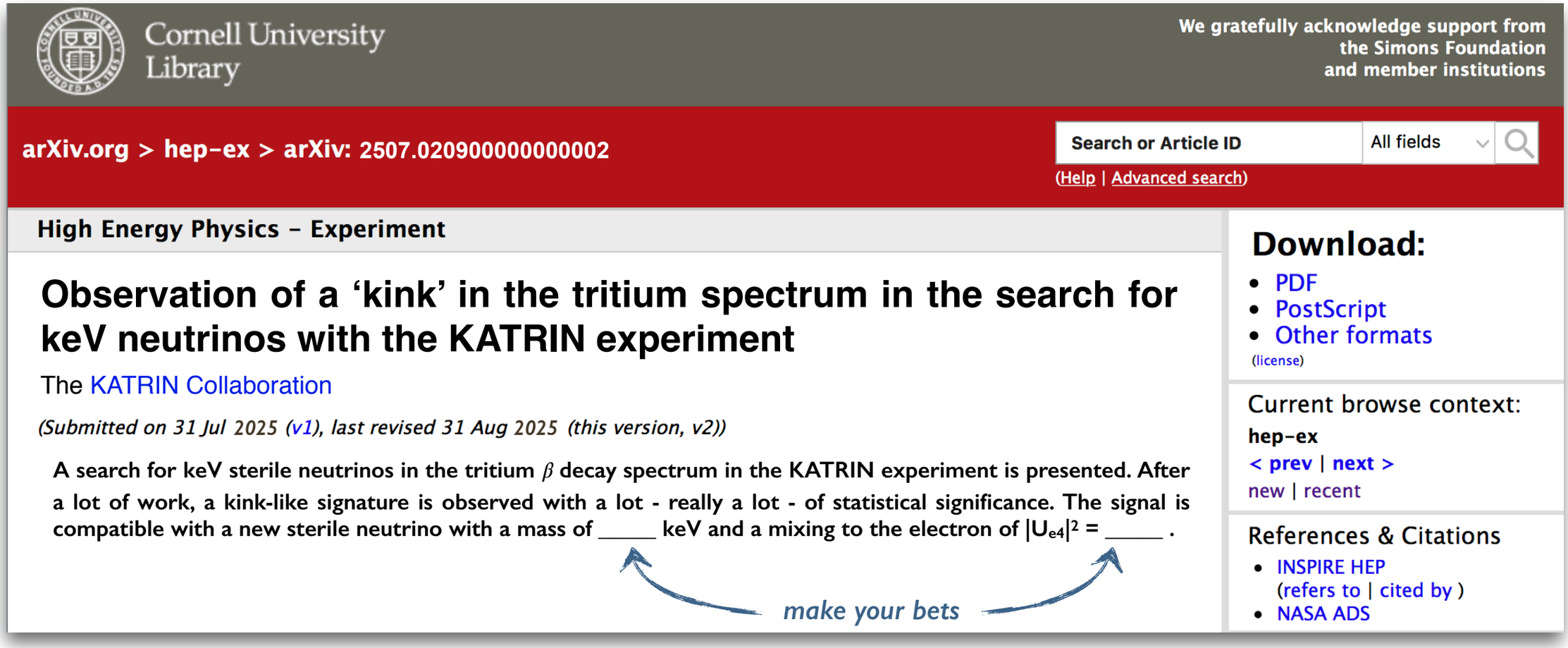
What if...

*Disclaimer: not a real arXiv entry (yet)



What if...

*Disclaimer: not a real arXiv entry (yet)



What if...

*Disclaimer: not a real arXiv entry (yet)

Cornell University Library

We gratefully acknowledge support from the Simons Foundation and member institutions

arXiv.org > hep-ex > arXiv: 2507.020900000000002

Search or Article ID | All fields

(Help | Advanced search)

High Energy Physics – Experiment

Observation of a 'kink' in the tritium spectrum in the search for keV neutrinos with the KATRIN experiment

The KATRIN Collaboration

(Submitted on 31 Jul 2025 (v1), last revised 31 Aug 2025 (this version, v2))

A search for keV sterile neutrinos in the tritium β decay spectrum in the KATRIN experiment is presented. After a lot of work, a kink-like signature is observed with a lot - really a lot - of statistical significance. The signal is compatible with a new sterile neutrino with a mass of _____ keV and a mixing to the electron of $|U_{e4}|^2$ = _____ .

make your bets

Download:

- PDF
- PostScript
- Other formats

(license)

Current browse context:
hep-ex
< prev | next >
new | recent

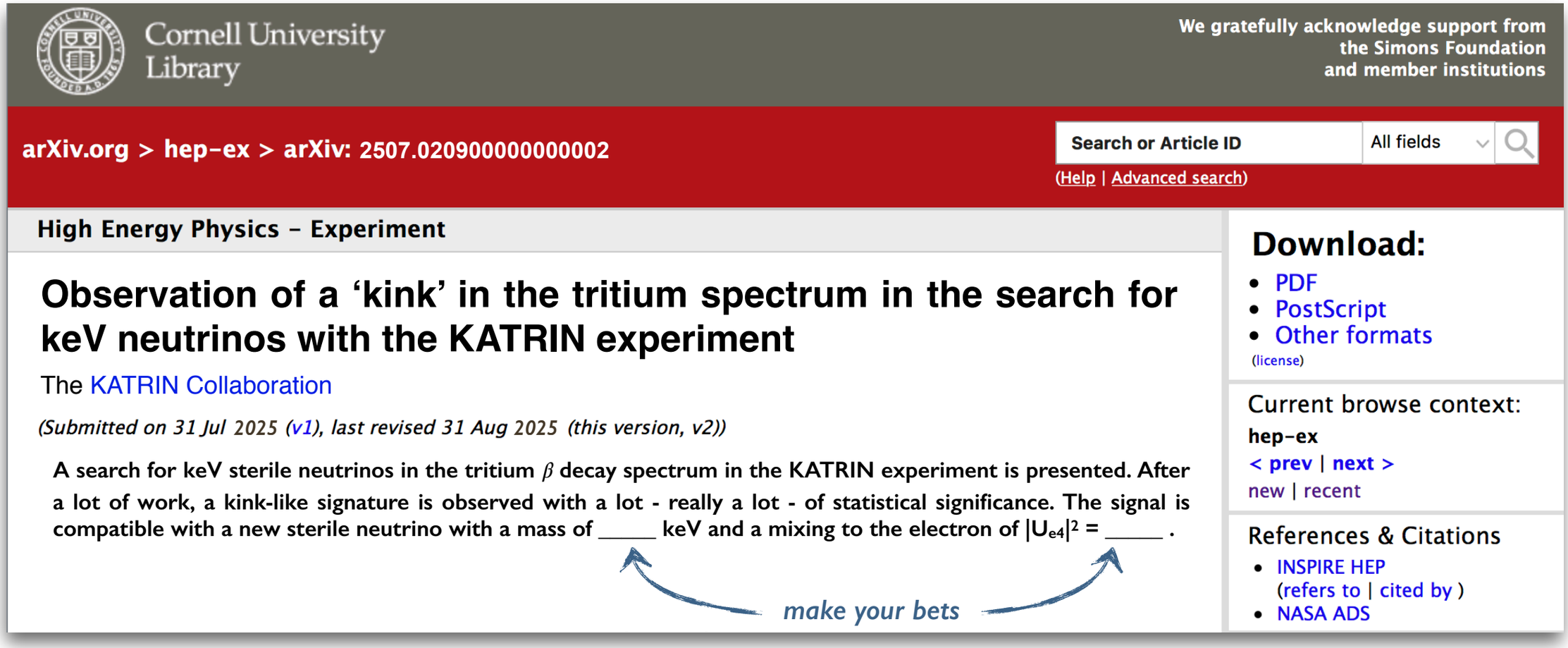
References & Citations
- INSPIRE HEP (refers to | cited by)
- NASA ADS

What would be the implications?

A new neutrino?

What if...

*Disclaimer: not a real arXiv entry (yet)



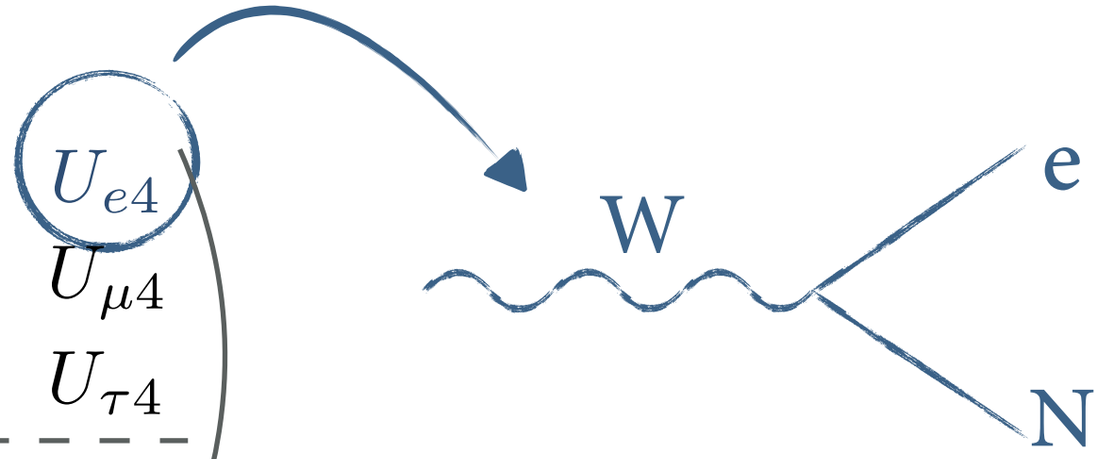
What would be the implications?

A new neutrino? → **A new Majorana neutrino?**

The 3+1 scenario

- Simplest **bottom-up** approach
- **4 masses** $m_\nu = (m_1, m_2, m_3, m_4)$
- **4x4 mixing matrix**

$$U^{\nu}_{4\times 4} = \left(\begin{array}{c|c} \tilde{U}_{\rm PMNS} & \begin{matrix} U_{e4} \\ U_{\mu 4} \\ U_{\tau 4} \end{matrix} \\ \hline \begin{matrix} \\ \\ \end{matrix} & \end{array}\right)$$



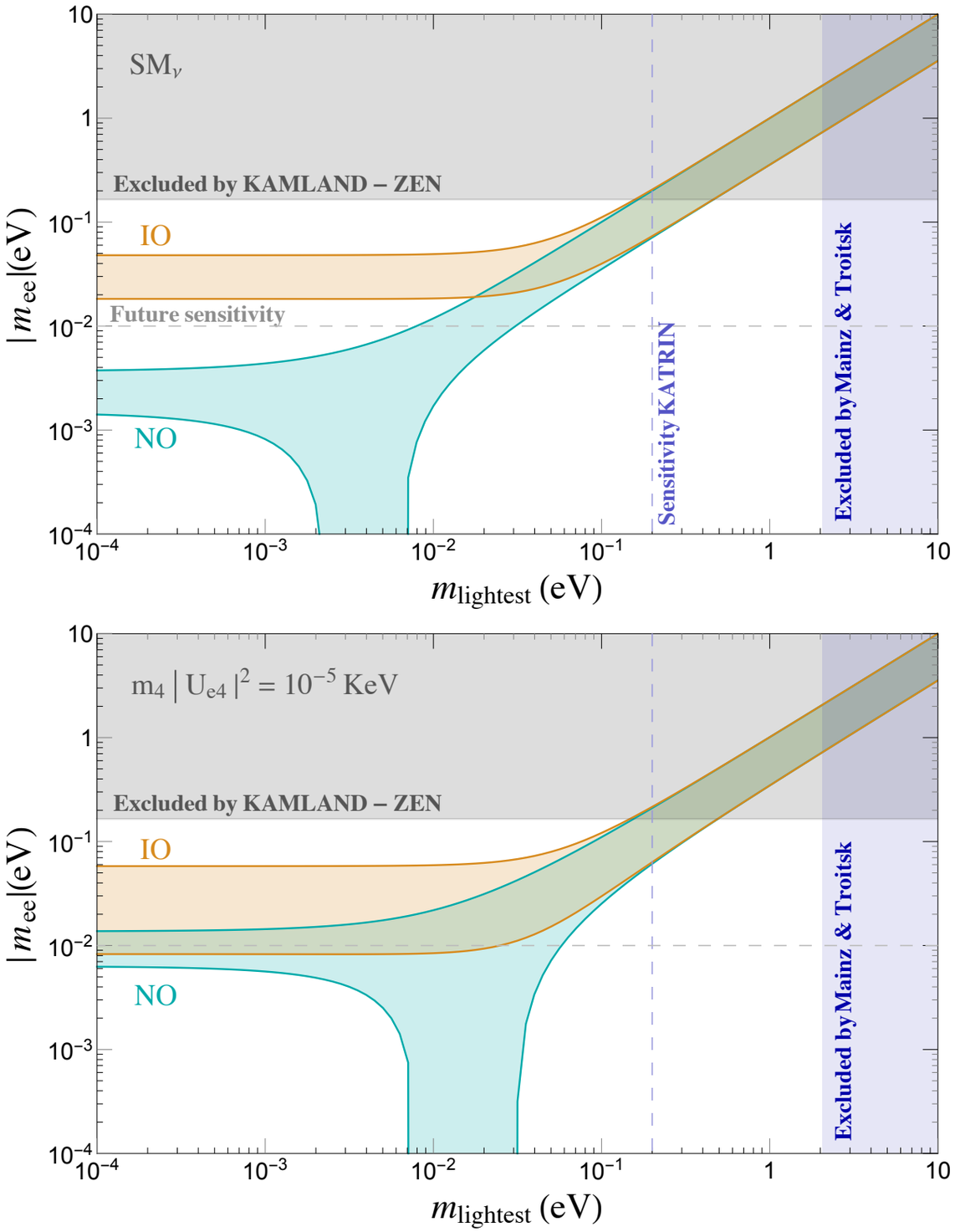
a kink in KATRIN

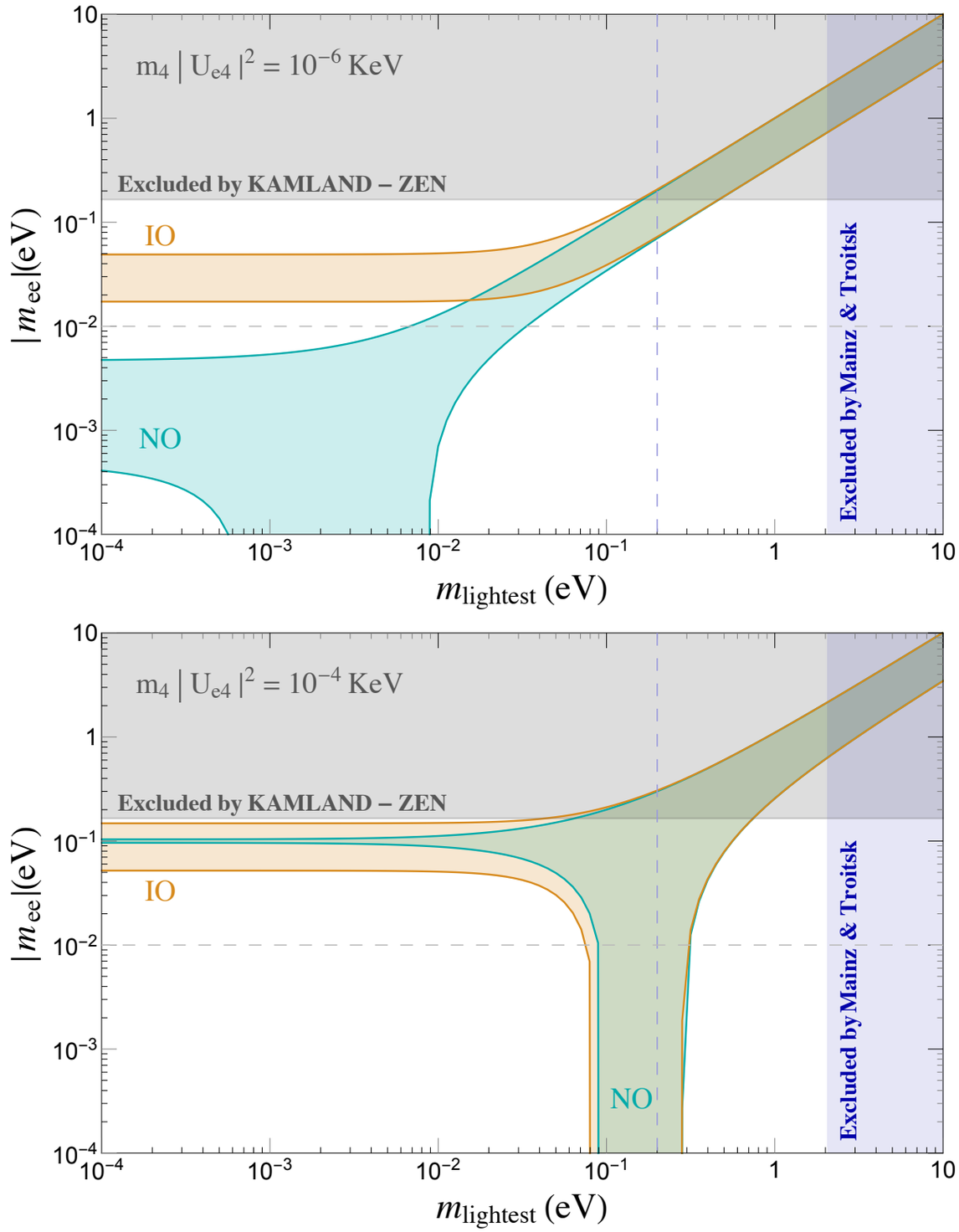
$$\begin{cases} m_4 \sim (1 - 18)\ KeV \\ |U_{e4}|^2 \gtrsim 10^{-8} - 10^{-6} \end{cases}$$

S. Mertens et al, JCAP 1502 (2015) no.02, 020
S. Mertens et al, PRD91 (2015) 042005
N. M.N. Steinbrink et al, EPJC 78 (2018) no.3, 212

$0\nu\beta\beta$ IN THE 3+1 SCENARIO

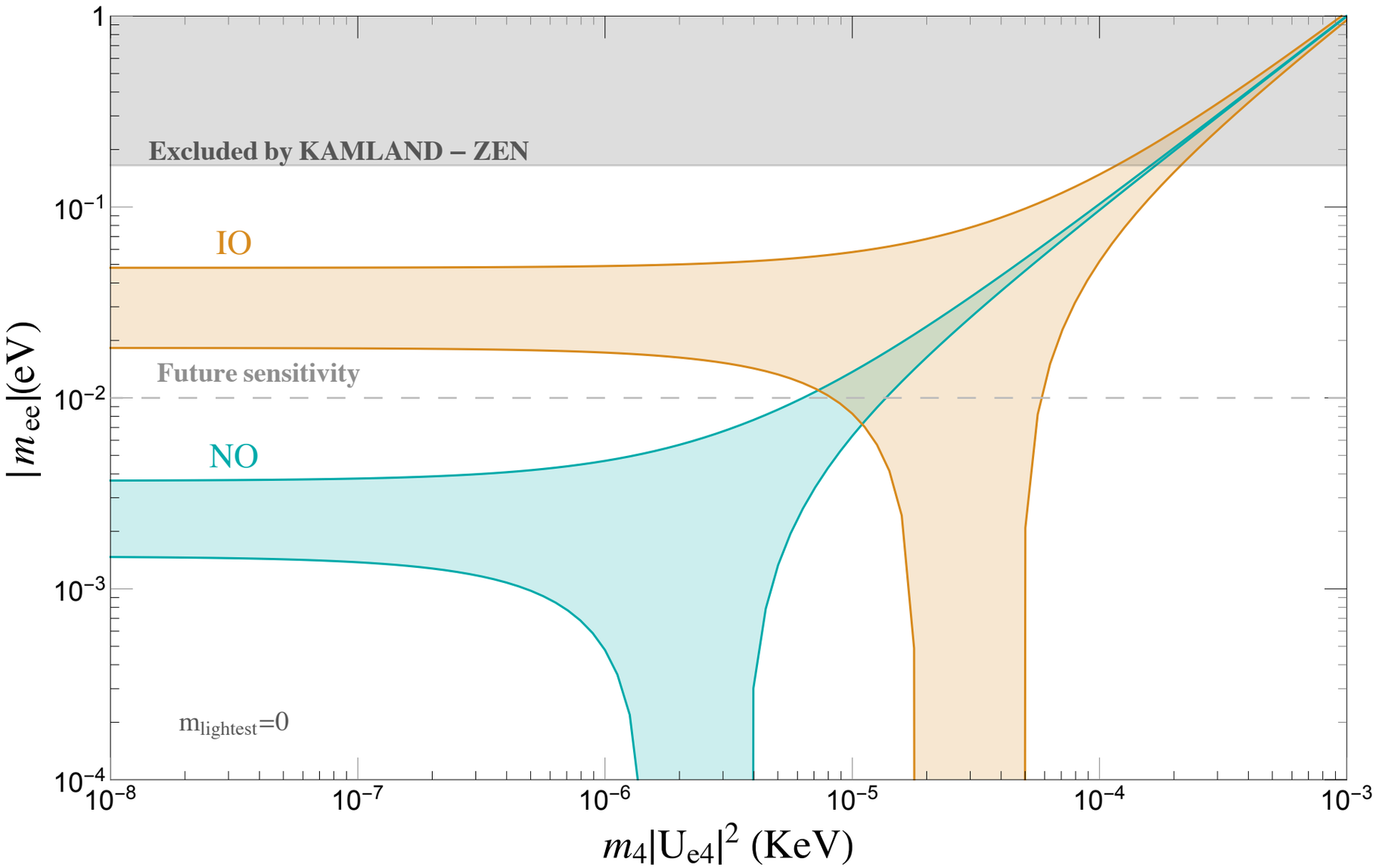
- A **new Majorana neutrino in the KeV** could change the standard picture





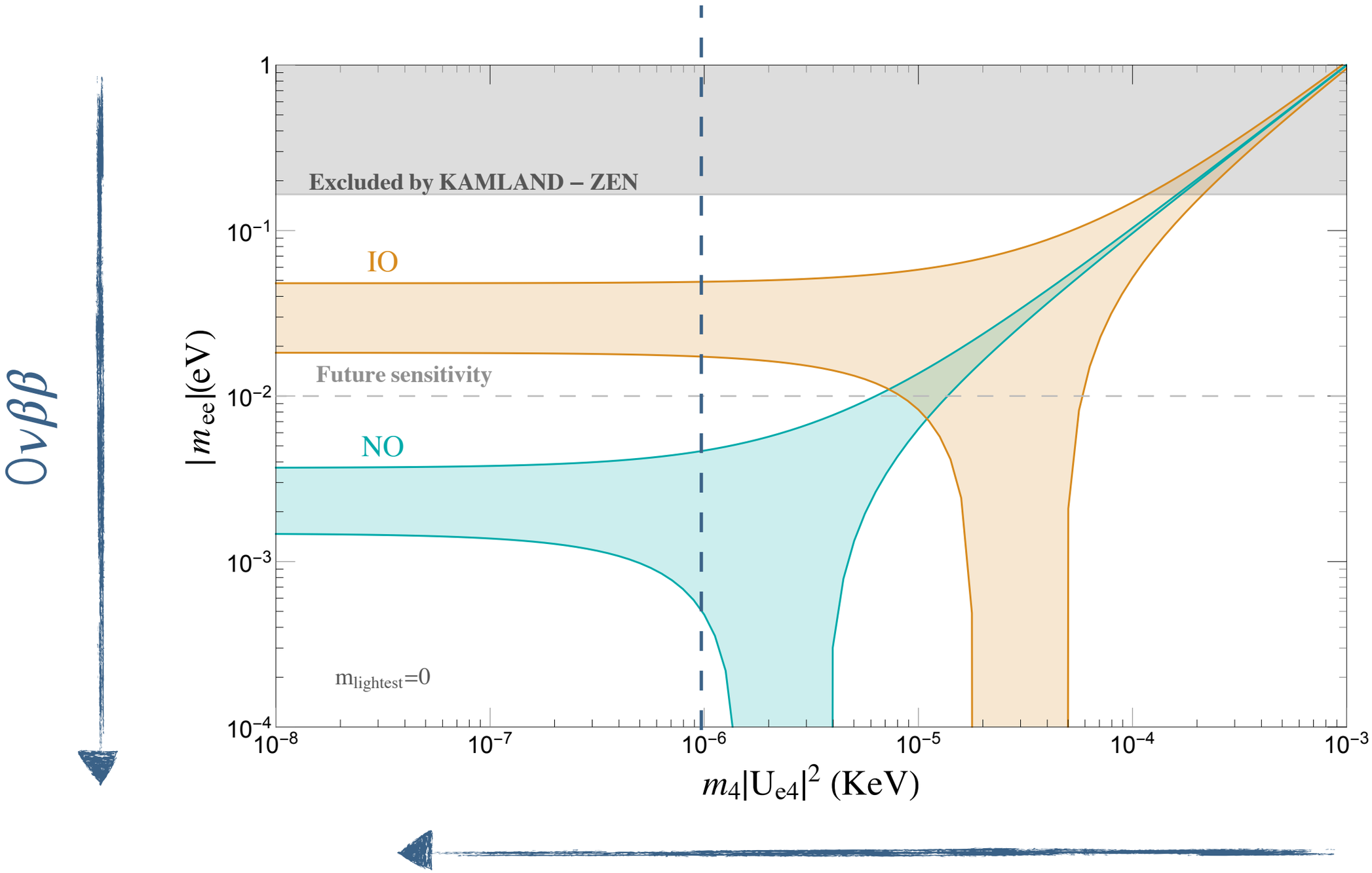
$0\nu\beta\beta$ IN THE 3+1 SCENARIO

- A **new Majorana neutrino in the KeV** could change the standard picture



$0\nu\beta\beta$ IN THE 3+1 SCENARIO

- A **new Majorana neutrino in the KeV** could change the standard picture

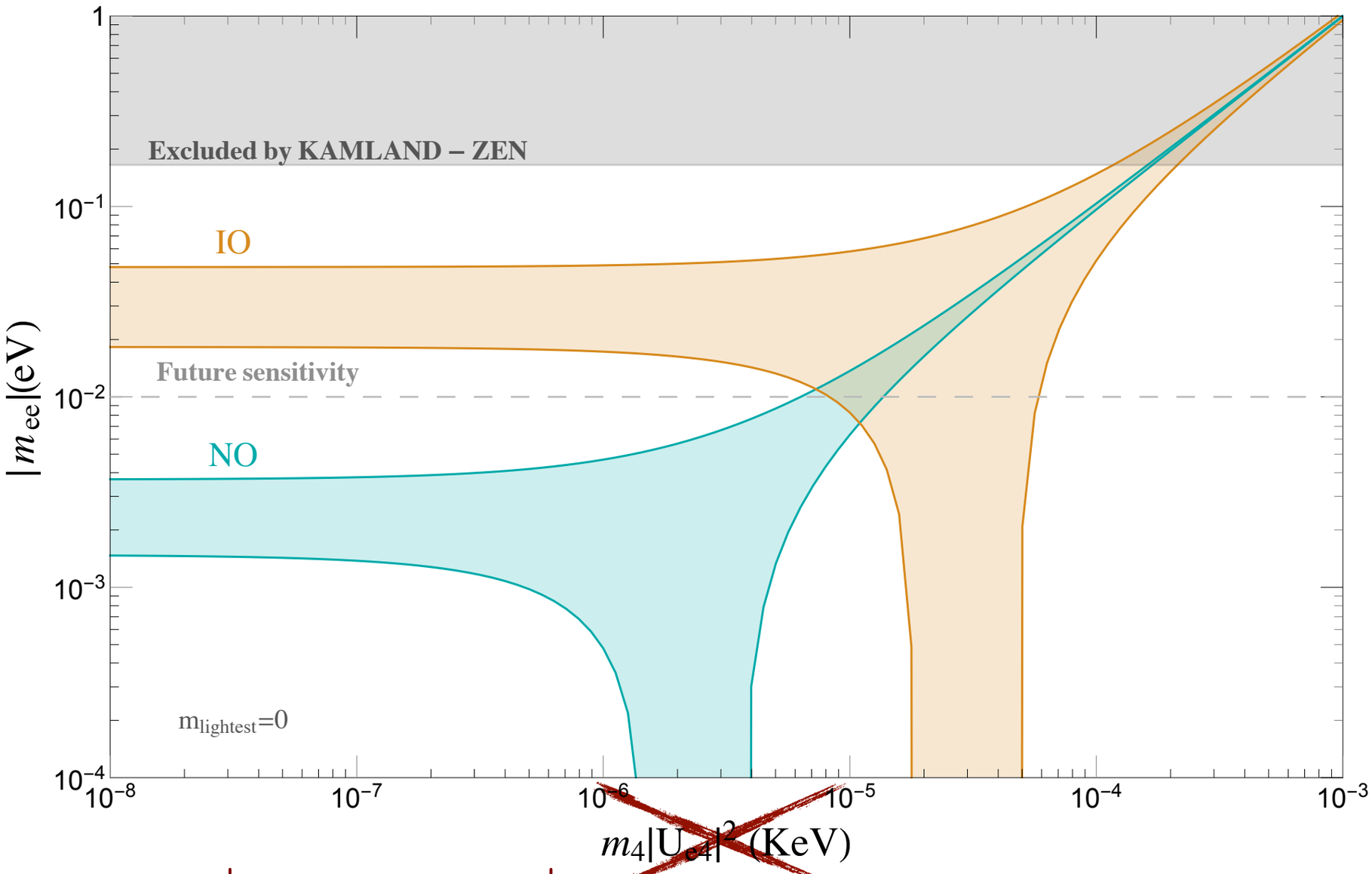


$0\nu\beta\beta$

Kinks in β decays

$0\nu\beta\beta$ IN THE 3+N SCENARIO

- If there are more **light** sterile neutrino (**$m_i^2 \ll p^2 \sim (100\ \mathrm{MeV})^2$**)



$$\left| \sum_i m_i U_{ei}^2 \right|$$

Type I seesaw models

- Add right-handed neutrinos with **Dirac** and **Majorana** terms

$$\mathcal{L} = \mathcal{L}_{\rm SM} + i\overline{N_I}\partial\!\!\!/ N_I - \left(Y_{\alpha I}\overline{\ell_\alpha}\tilde{\phi}N_I + \frac{M_{IJ}}{2}\overline{N_I^c}N_J + h.c. \right),$$

- The **minimal** realization needs **2 right-handed** neutrinos

- After the EW symmetry breaking

$$M_{\text{type I}} = \begin{pmatrix} 0 & m_D \\ m_D^T & M \end{pmatrix}$$

$$\downarrow$$

$$m_{\rm light} \simeq -m_D \frac{1}{M} m_D^T$$

Type I seesaw models

- Explaining m_{light} imposes **relations between the parameters**

- In the type-I seesaw, these relations may lead to **cancellations in m_{ee}**

M. Blennow et al, JHEP 1007 (2010) 096

Type I seesaw models

- Explaining m_{light} imposes **relations between the parameters**

- In the type-I seesaw, these relations may lead to **cancellations in m_{ee}**

M. Blennow et al, JHEP 1007 (2010) 096

- The cancellation in a nutshell:

- Neutrino mass **diagonalization** relations:

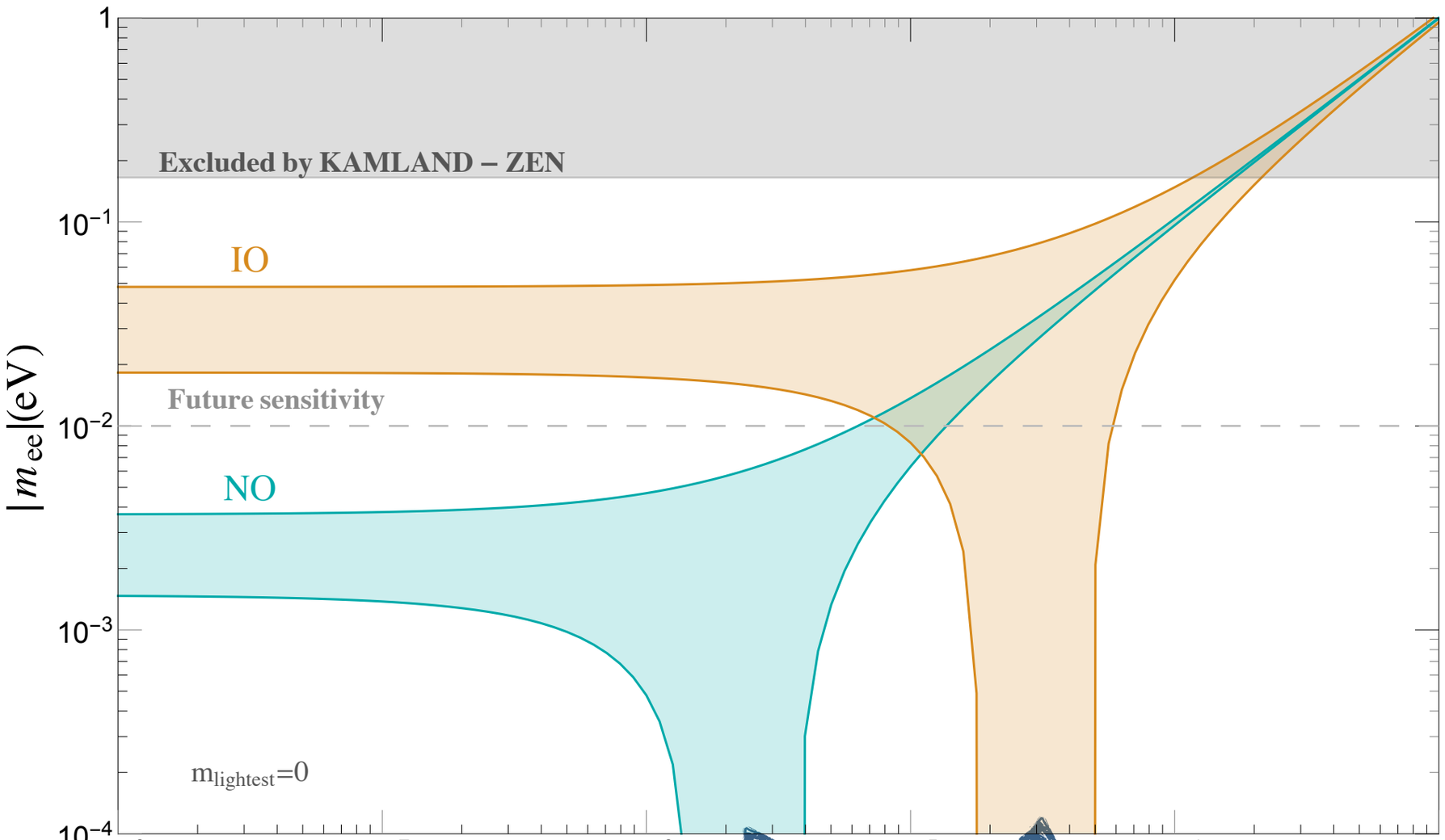
$$\left(M_{\rm type-I}\right)_{ee} = \left(U M_{\rm diag} U^T\right)_{ee} = \sum_{i=1}^{3+N} U_{ei}^2 m_i \equiv 0$$

- m_{ee} **if all the neutrinos are lighter** than the $p^2 \sim (100\ \text{MeV})^2$:

$$m_{ee} \simeq \sum_{i=1}^{3+N} U_{ei}^2 p^2 \frac{m_i}{p^2 - m_i^2} \approx \sum_{i=1}^{3+N} U_{ei}^2 m_i \approx 0$$

Type I seesaw models

- Cancellations in the type I seesaw with ***light*** **right-handed neutrinos**



$$\left| \sum_i m_i U_{ei}^2 \right|$$

They live here

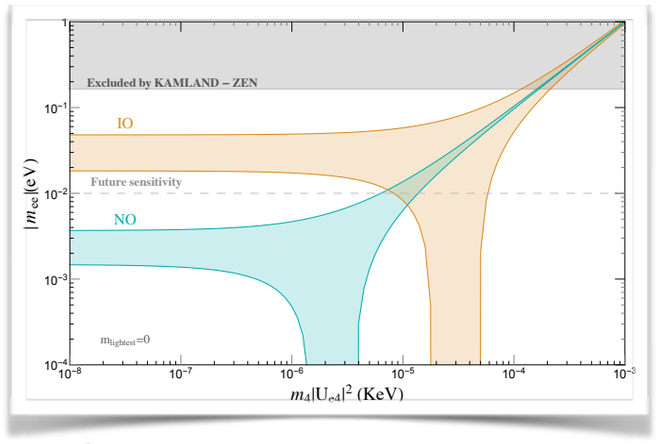
Minimal type-I seesaw with 2 RH

- **Minimal** realization needs **2 right-handed** neutrinos
- Fix ν_4 **to the KATRIN** regime and let ν_5 **free**

$$m_{ee} = \sum_{i=1}^{N} U_{ei}^2 \, p^2 \, \frac{m_i}{p^2 - m_i^2} \approx m_{ee}^{(3+1)} \left[1 - \frac{p^2}{p^2 - m_5^2} \right]$$

Minimal type-I seesaw with 2 RH

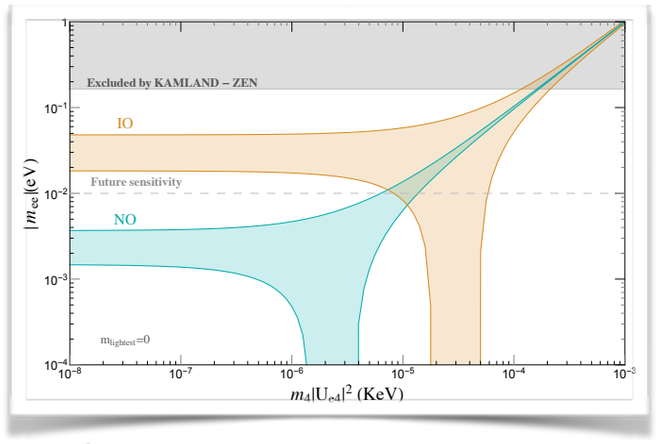
- **Minimal** realization needs **2 right-handed** neutrinos
- Fix ν_4 **to the KATRIN** regime and let ν_5 **free**



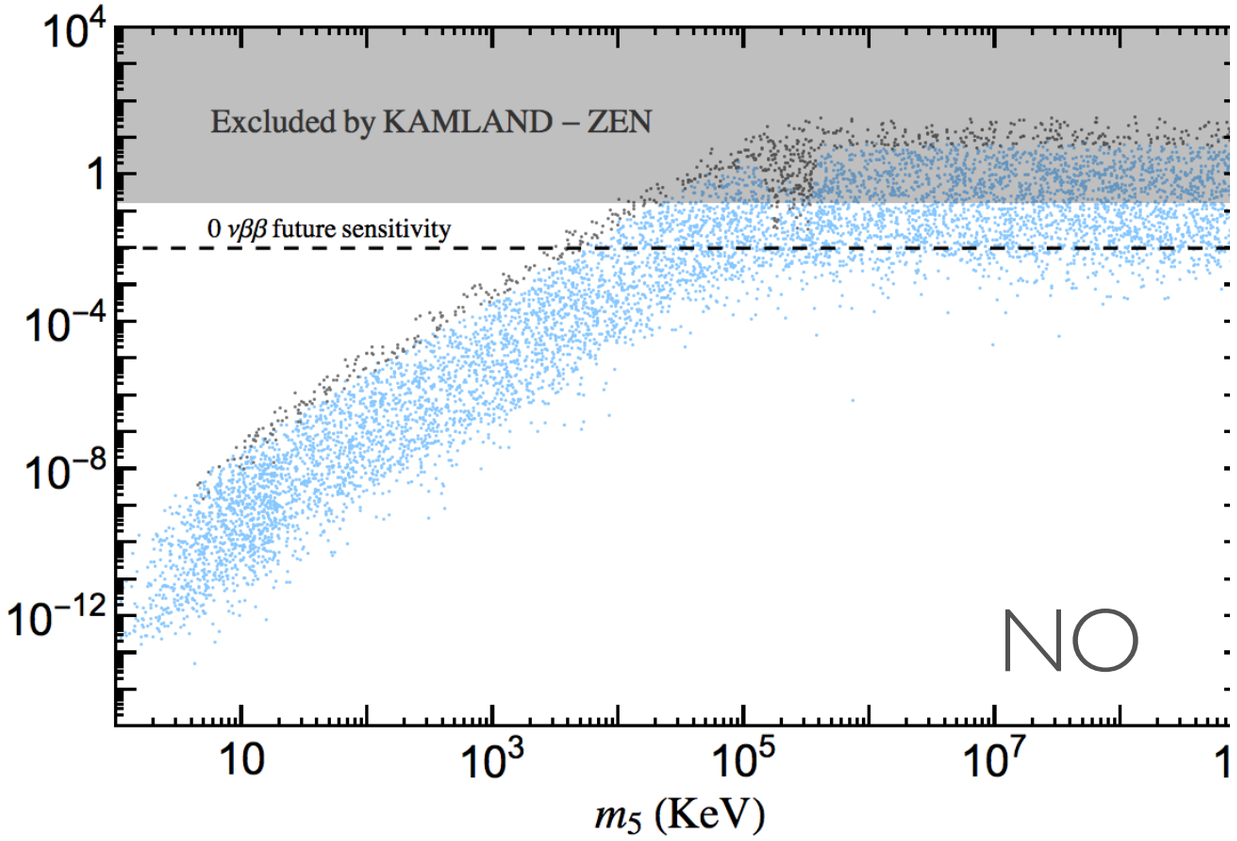
$$m_{ee} = \sum_{i=1}^{N} U_{ei}^2\, p^2\, \frac{m_i}{p^2 - m_i^2} \approx m_{ee}^{(3+1)} \left[1 - \frac{p^2}{p^2 - m_5^2}\right]$$

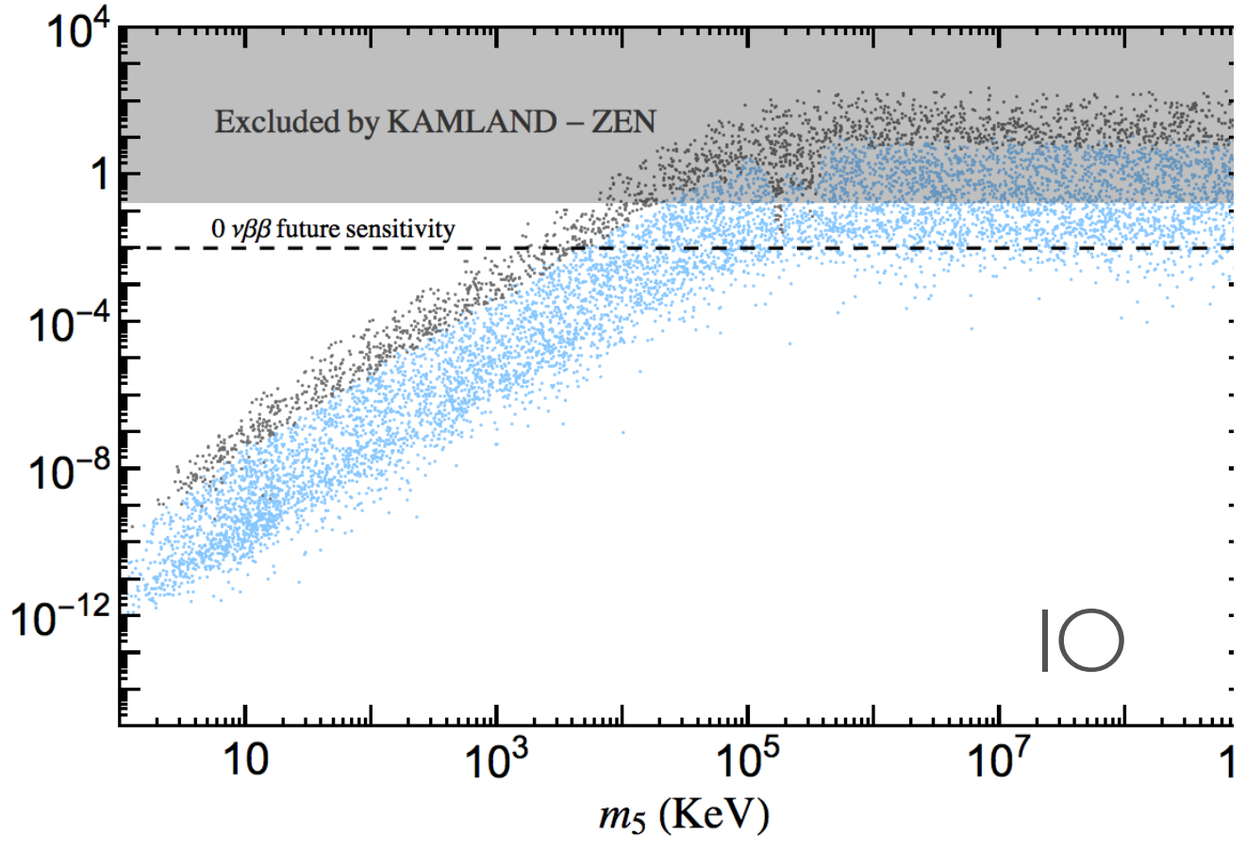
Minimal type-I seesaw with 2 RH

- **Minimal** realization needs **2 right-handed** neutrinos
- Fix ν_4 **to the KATRIN** regime and let ν_5 **free**



$$m_{ee} = \sum_{i=1}^{N} U_{ei}^2\, p^2\, \frac{m_i}{p^2 - m_i^2} \approx m_{ee}^{(3+1)} \left[1 - \frac{p^2}{p^2 - m_5^2}\right]$$





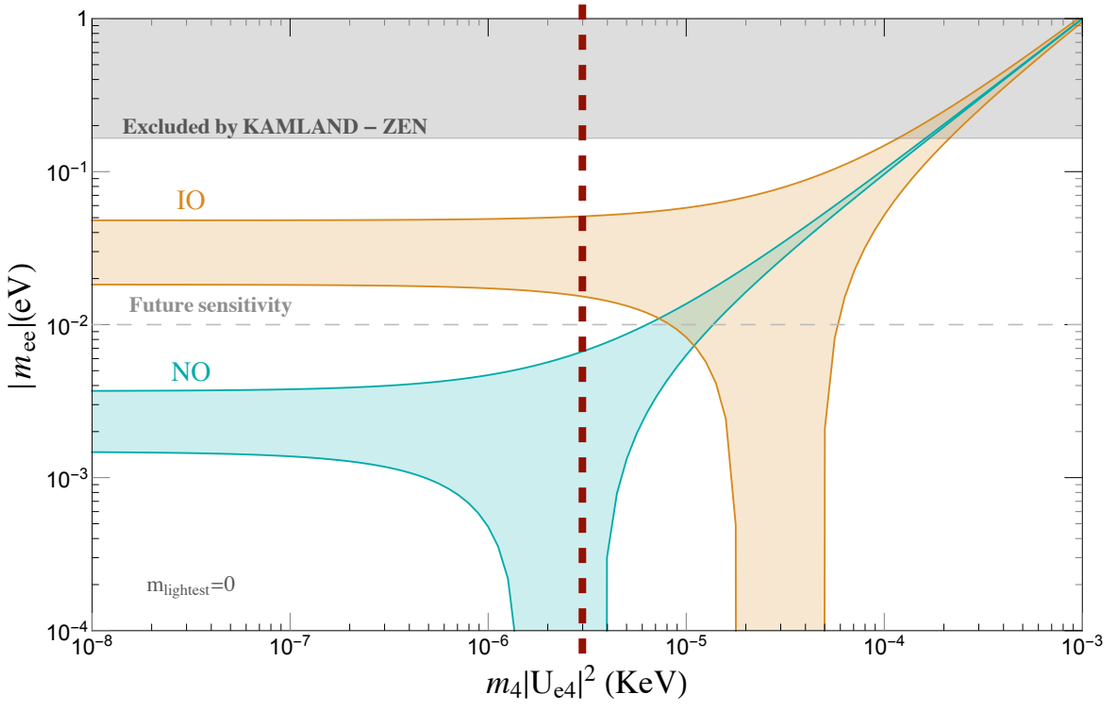
Minimal type-I seesaw with 2 RH

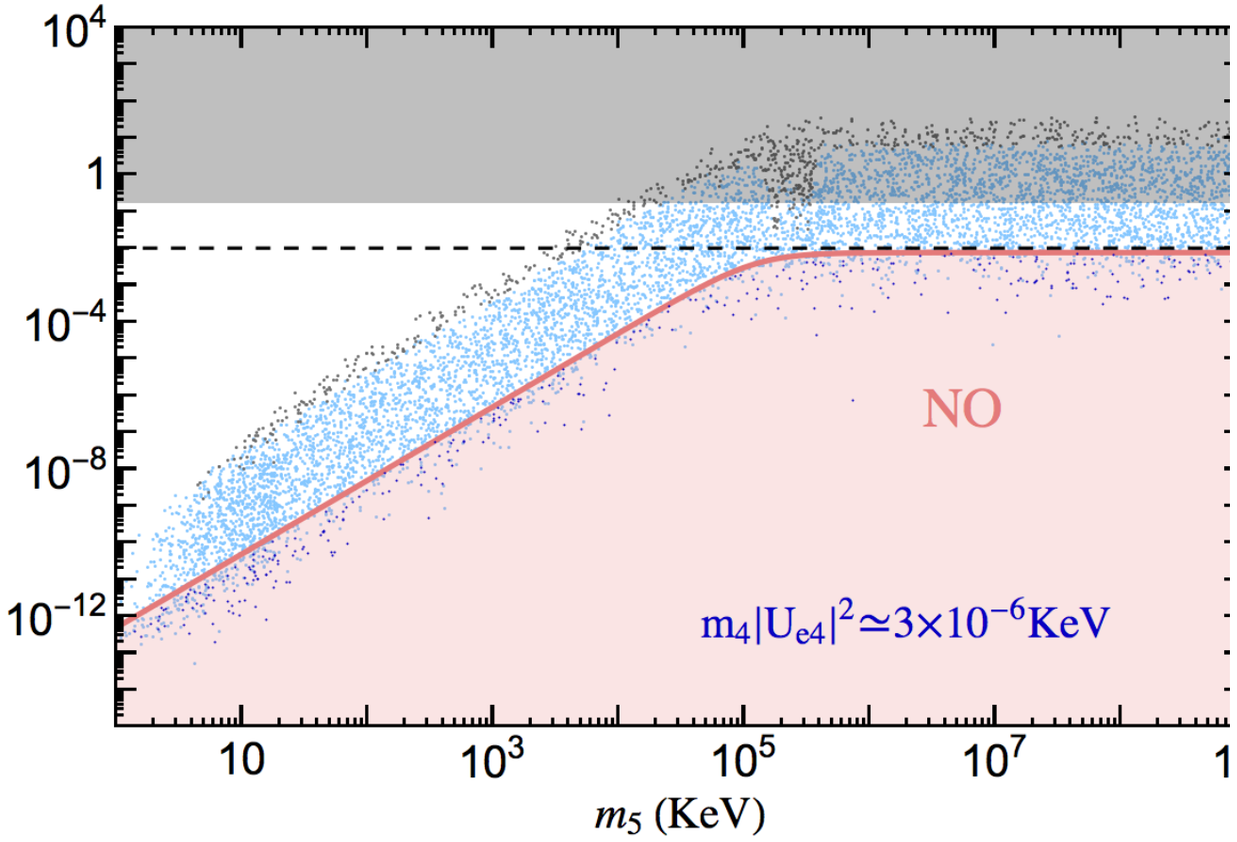
if KATRIN says…

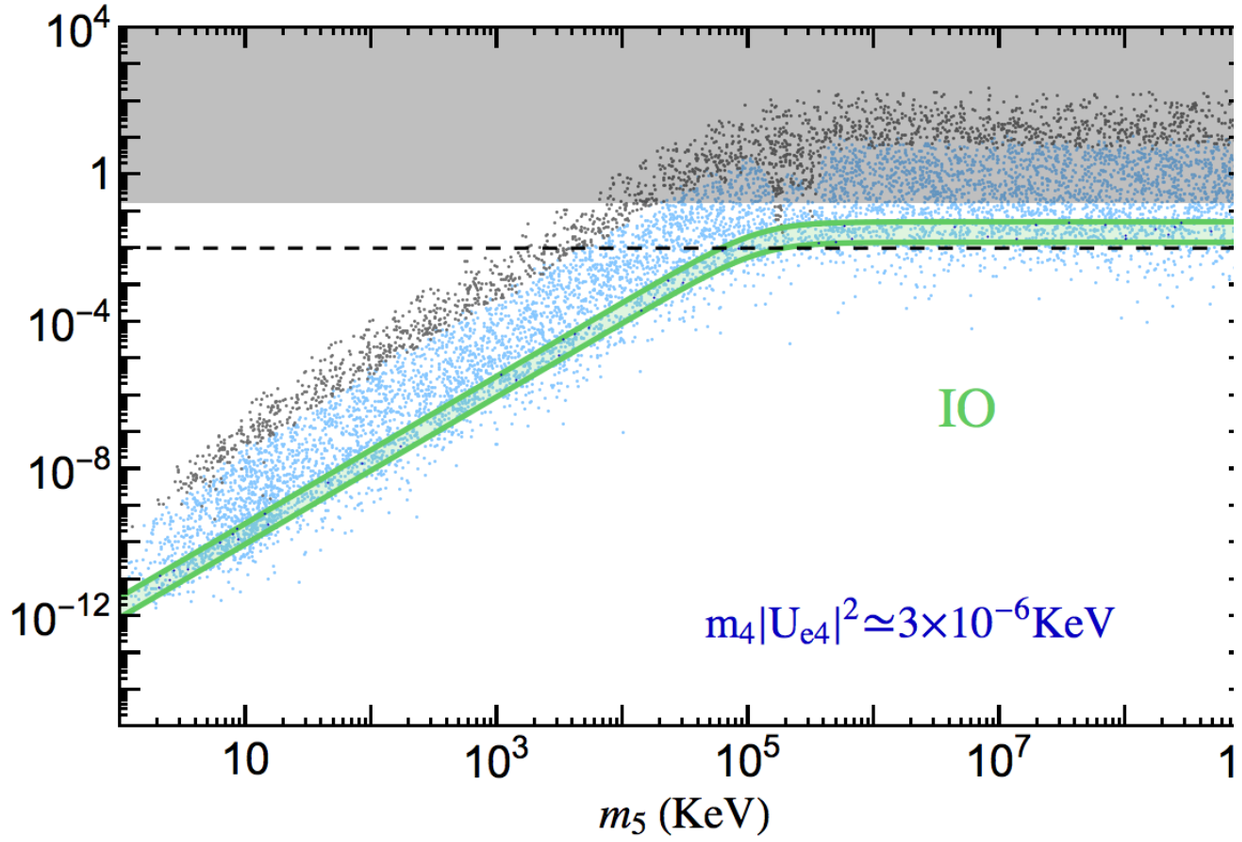
$a)\ m_4|U_{e4}|^2 \sim 10^{-6}\ KeV$

$b)\ m_4|U_{e4}|^2 \sim 10^{-5}\ KeV$

$c)\ m_4|U_{e4}|^2 \sim 10^{-4}\ KeV$







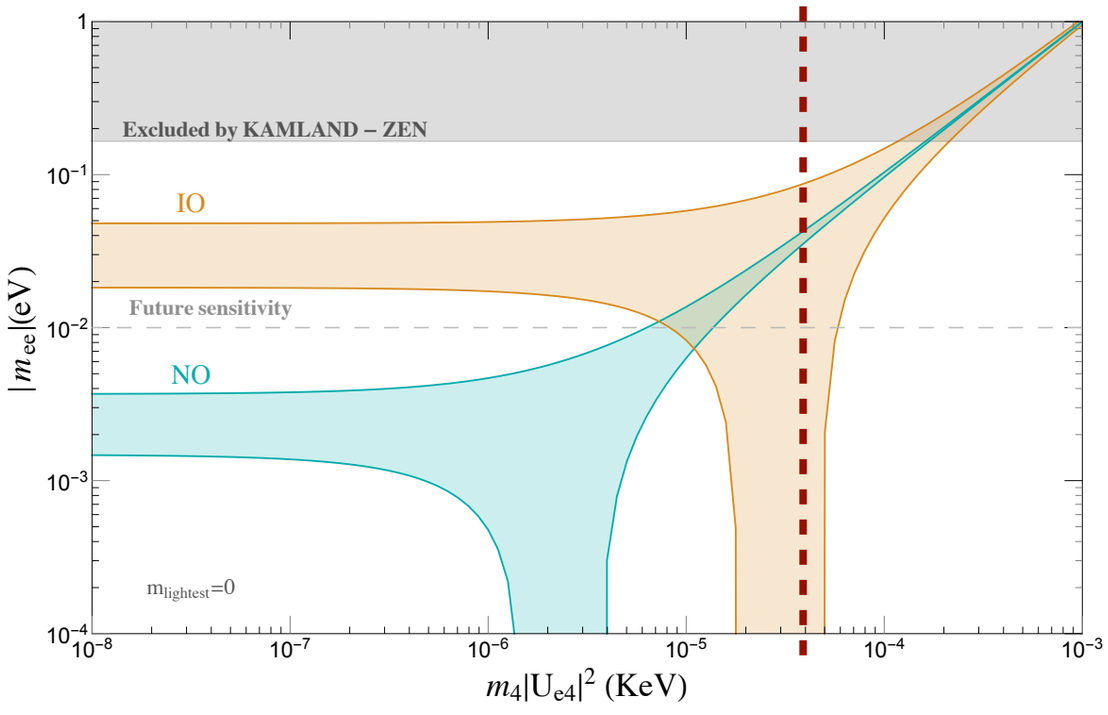
Minimal type-I seesaw with 2 RH

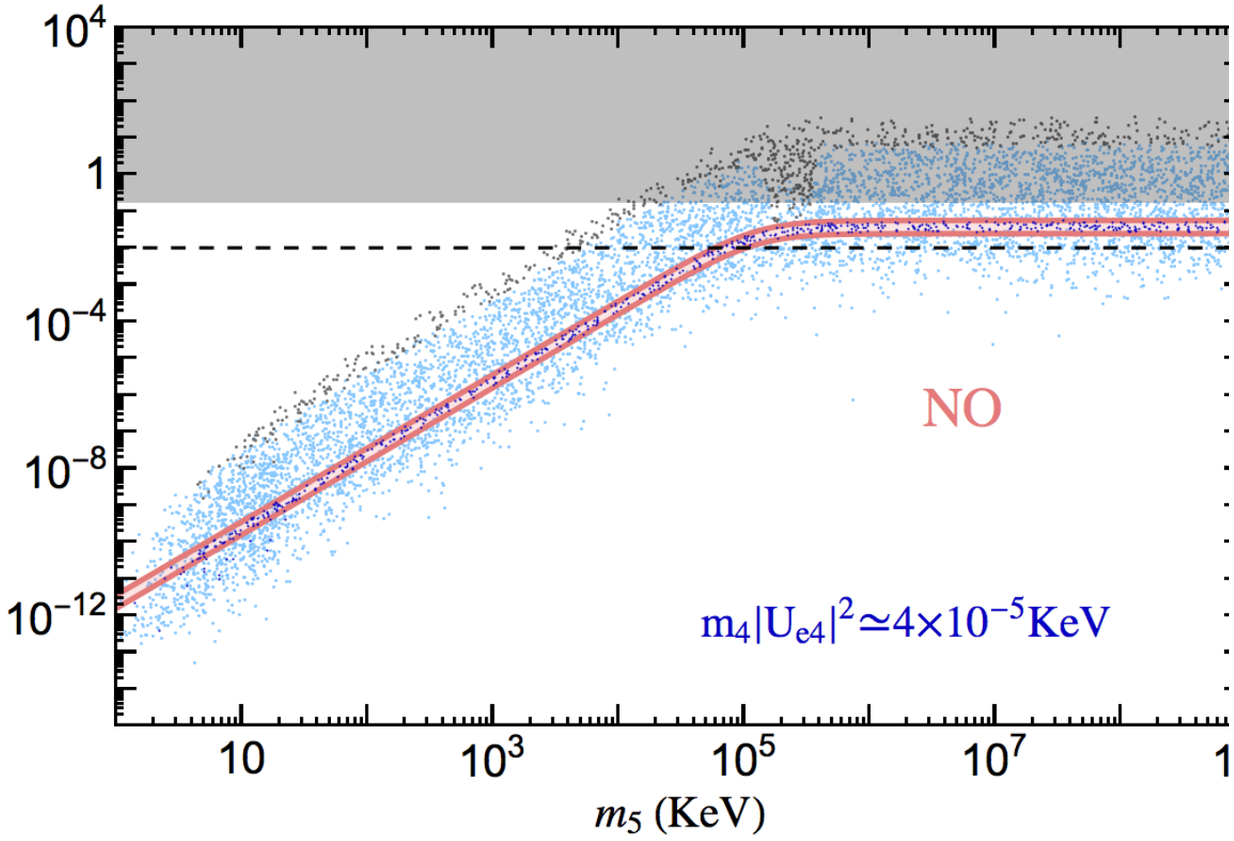
if KATRIN says…

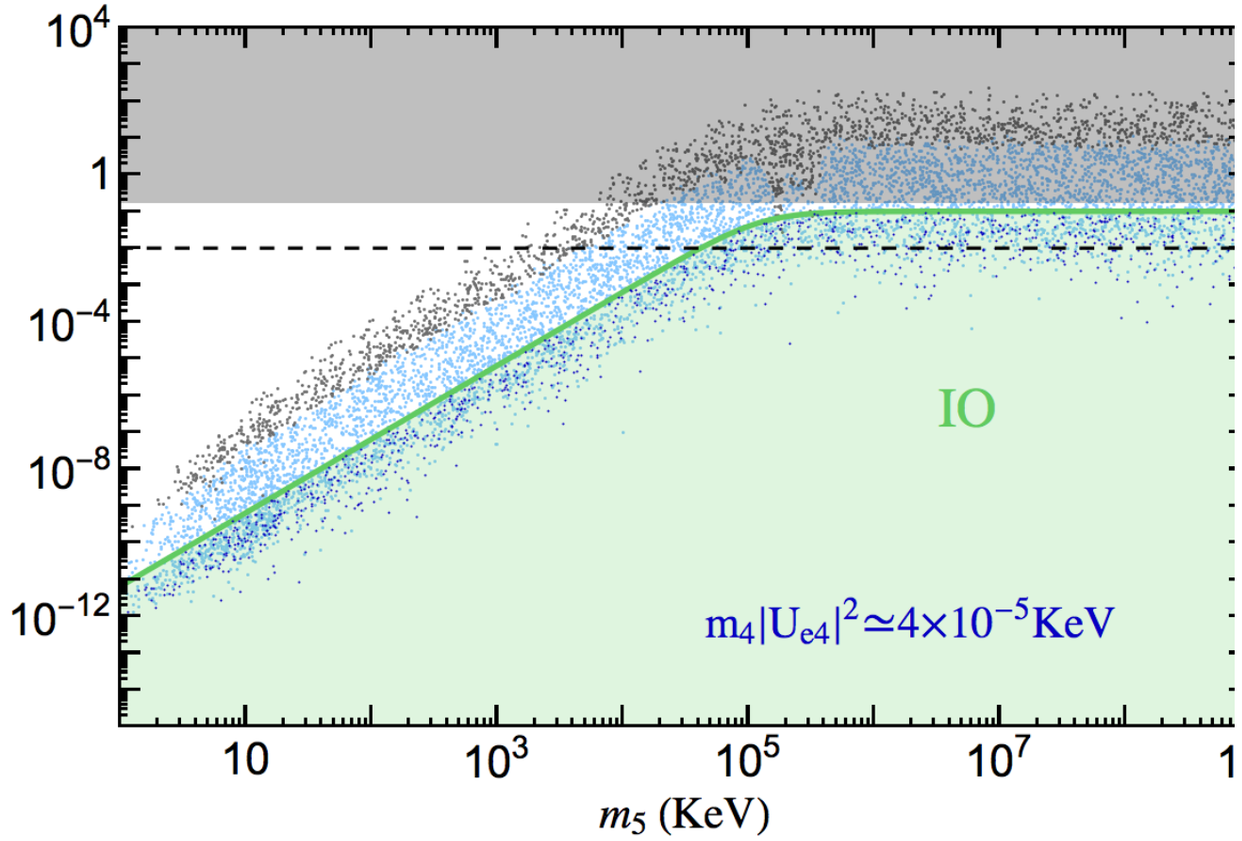
$a)\ m_4|U_{e4}|^2 \sim 10^{-6}\ KeV$

$b)\ m_4|U_{e4}|^2 \sim 10^{-5}\ KeV$

$c)\ m_4|U_{e4}|^2 \sim 10^{-4}\ KeV$







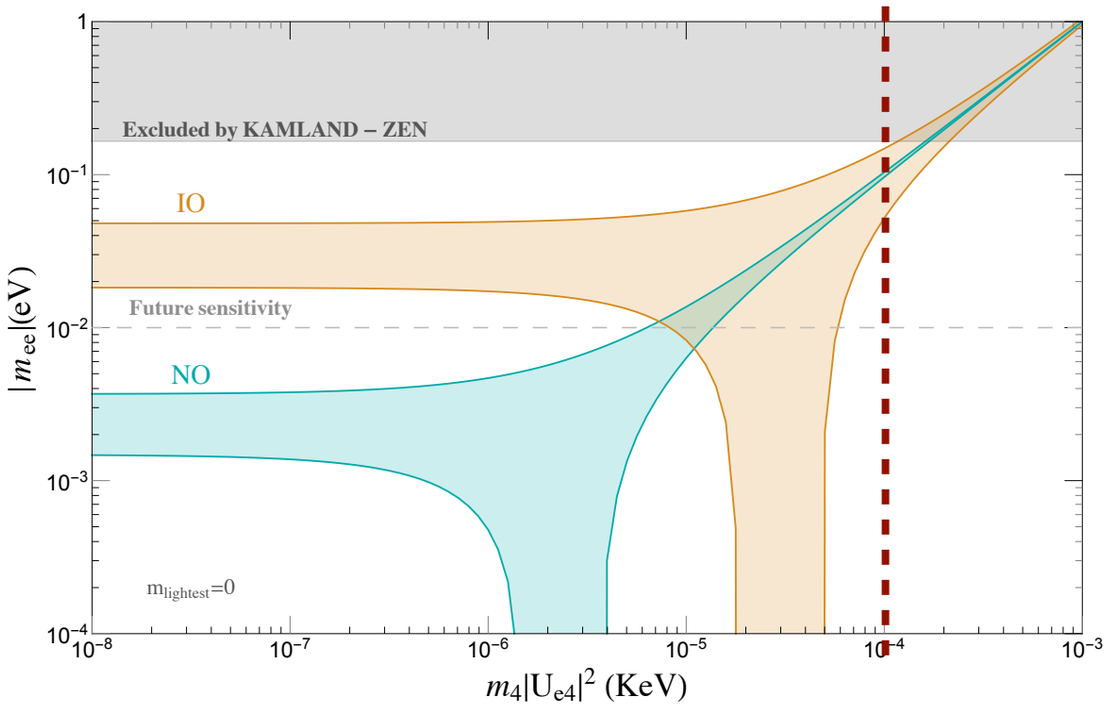
Minimal type-I seesaw with 2 RH

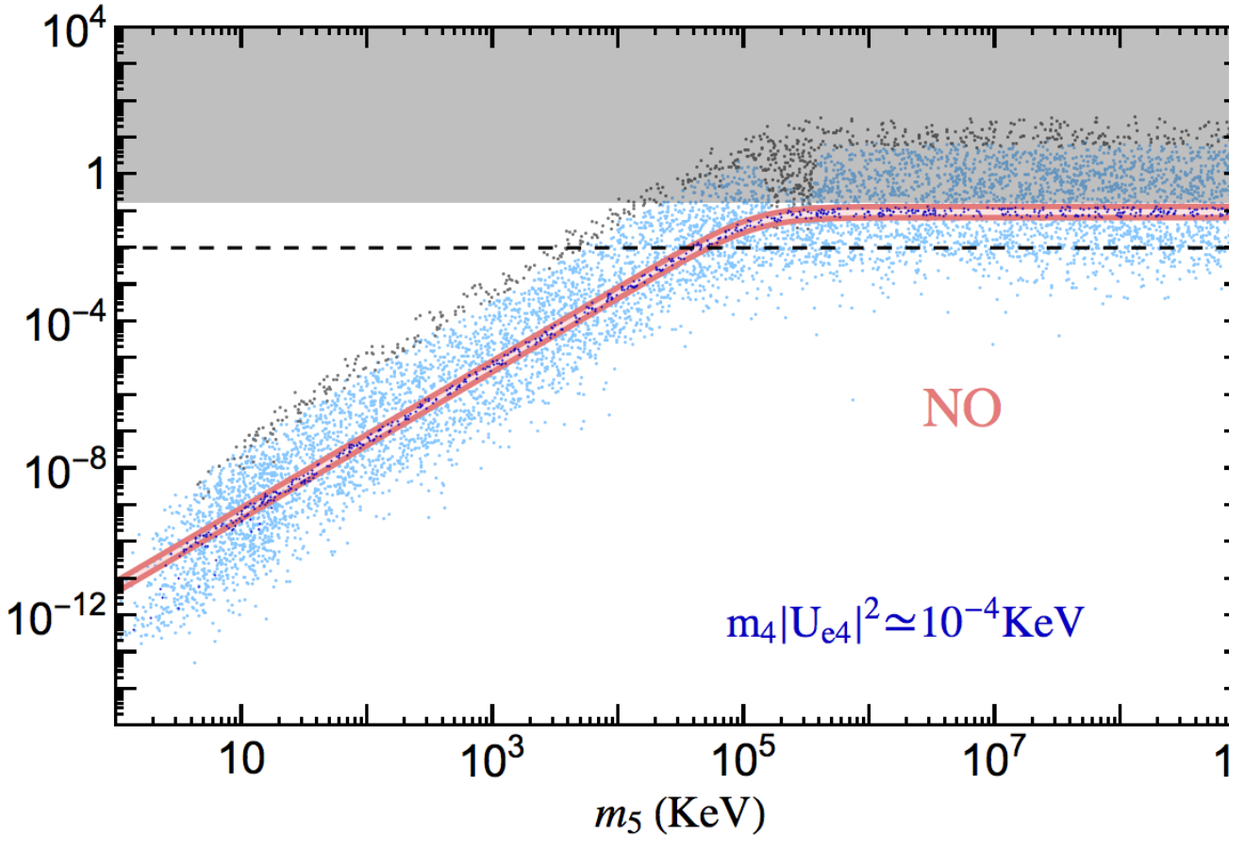
if KATRIN says…

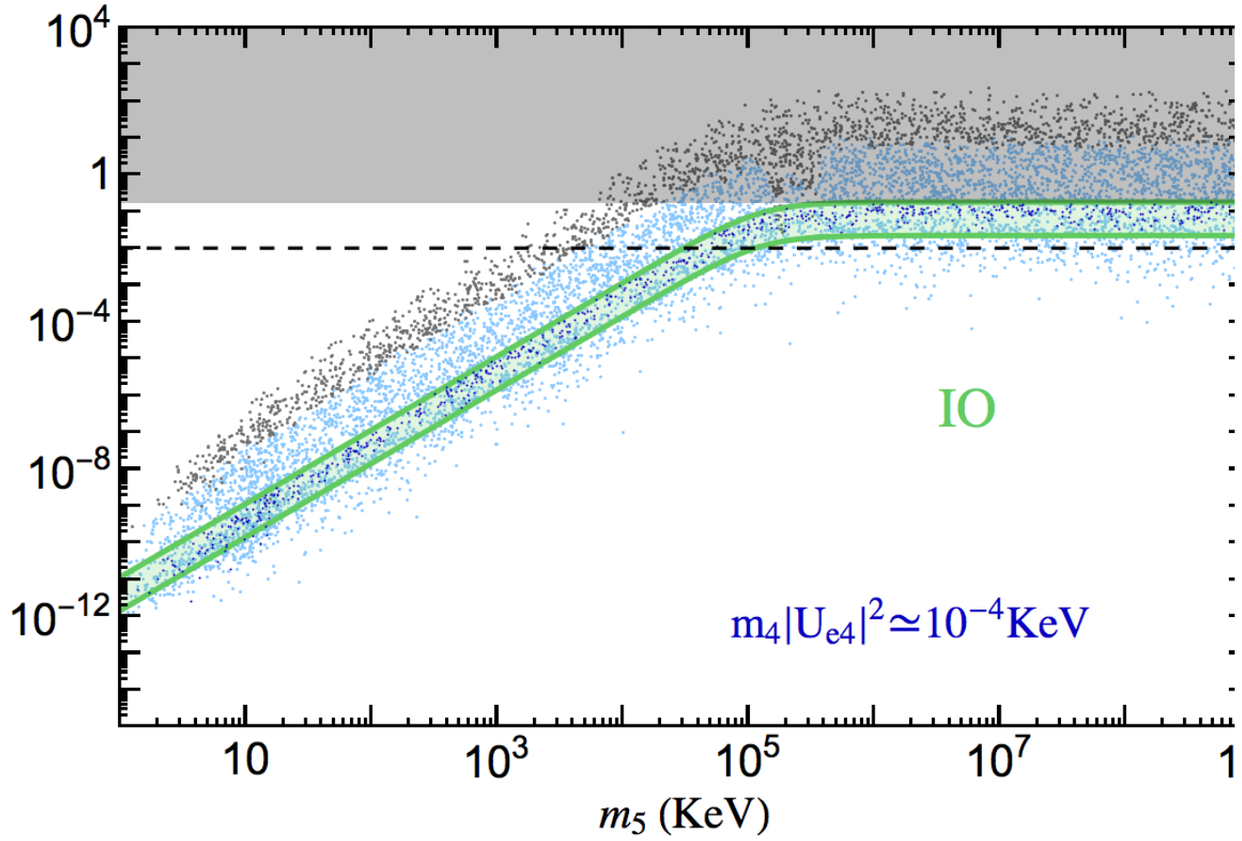
$a)\ m_4|U_{e4}|^2 \sim 10^{-6}\ KeV$

$b)\ m_4|U_{e4}|^2 \sim 10^{-5}\ KeV$

$c)\ m_4|U_{e4}|^2 \sim 10^{-4}\ KeV$







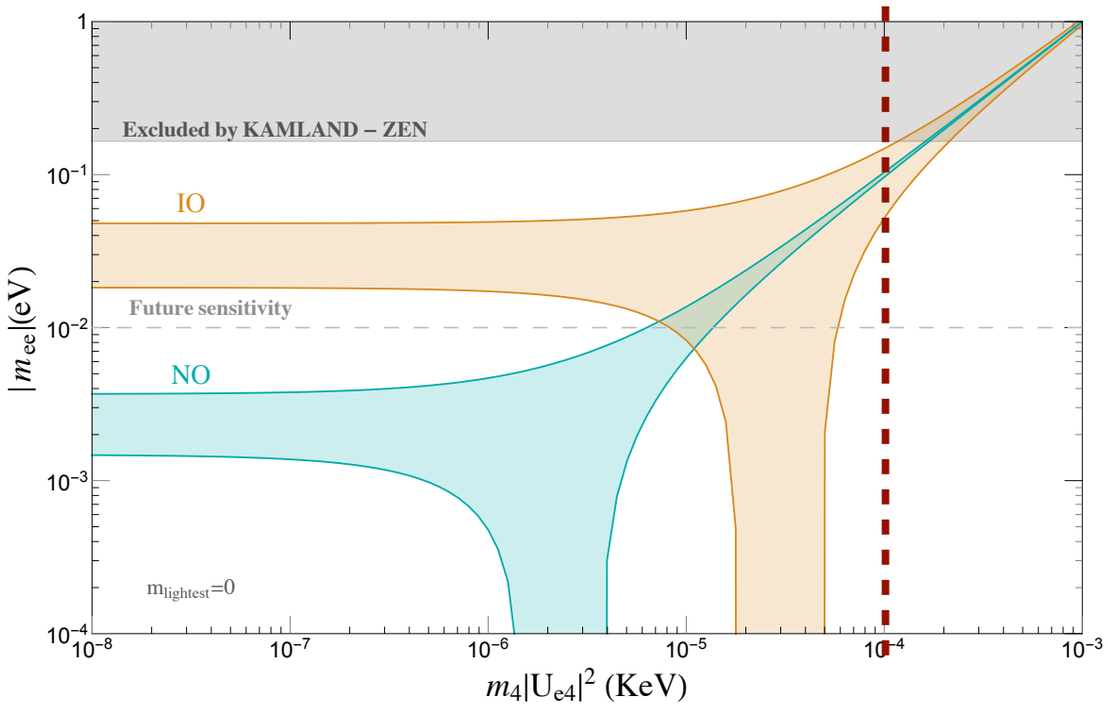
Minimal type-I seesaw with 2 RH

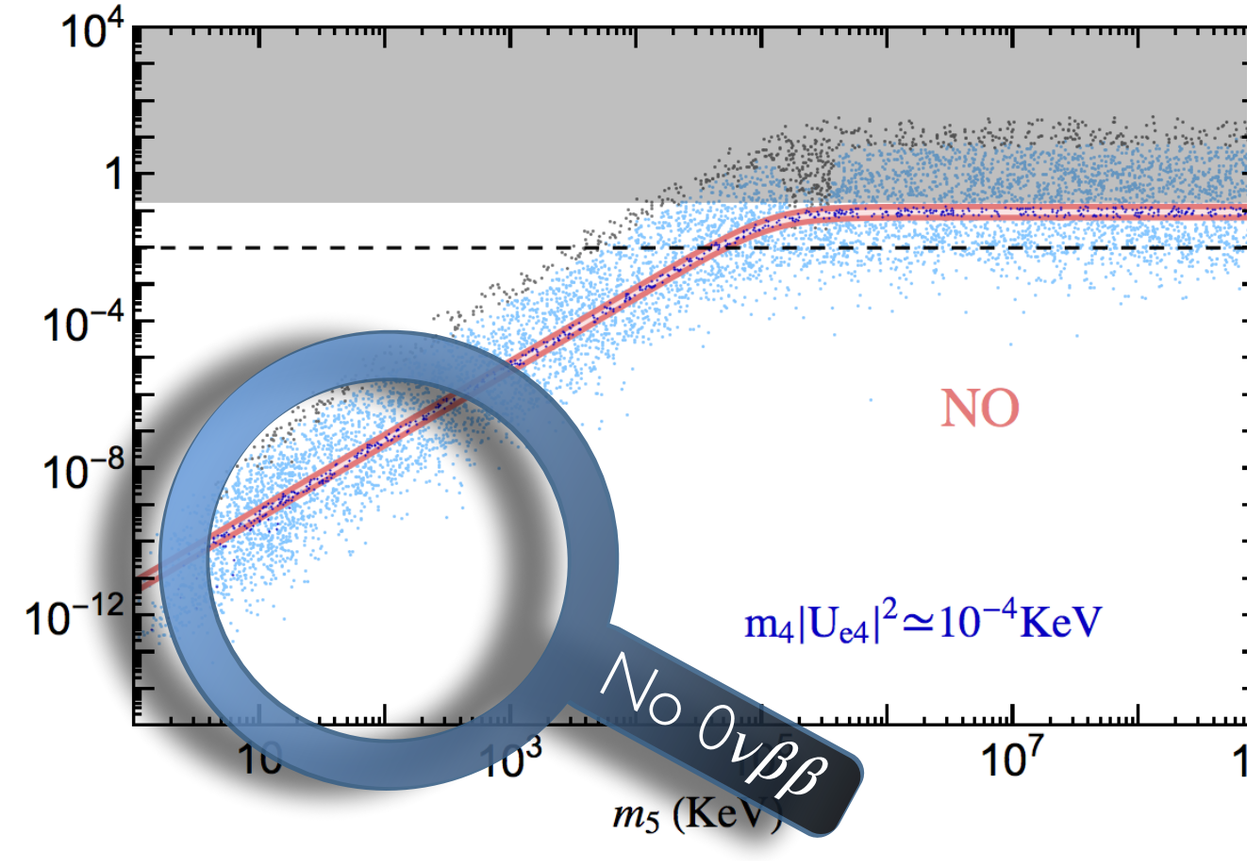
if KATRIN says…

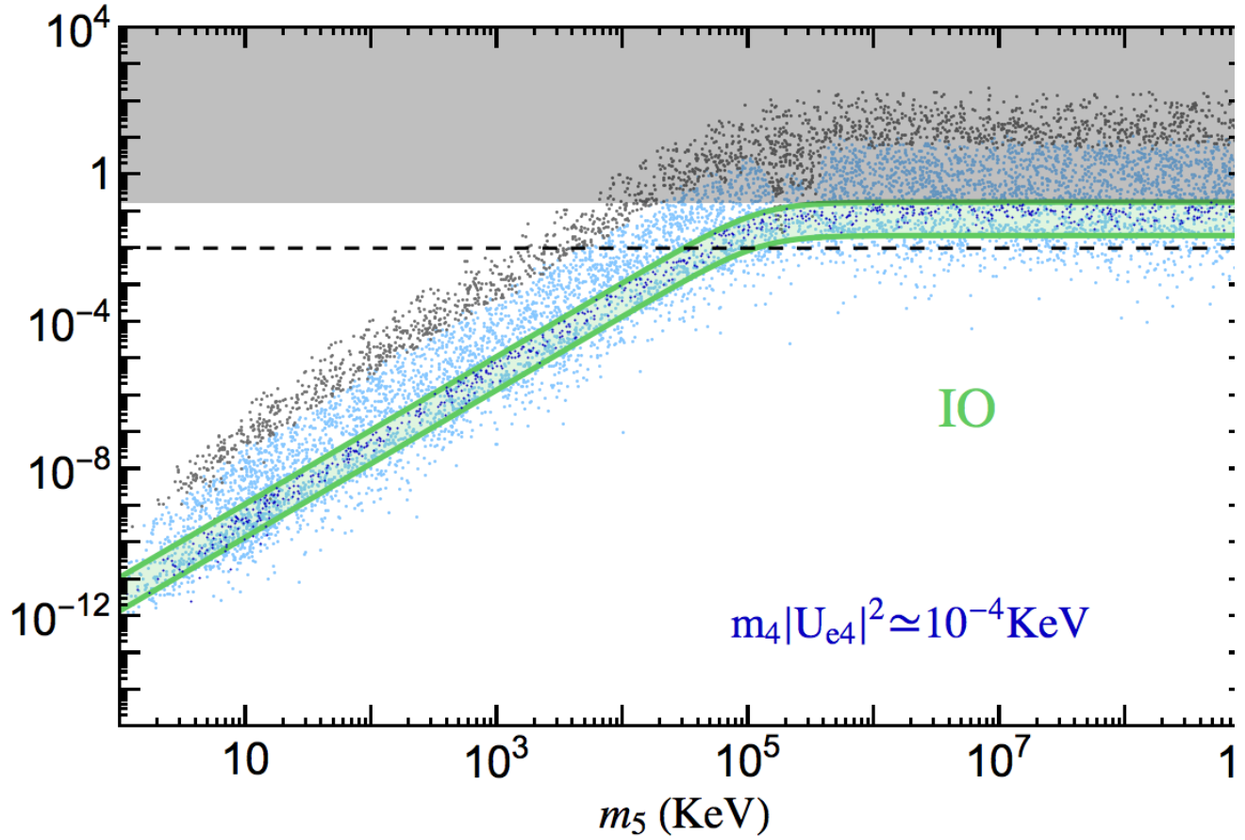
$a)\ m_4|U_{e4}|^2 \sim 10^{-6}\ KeV$

$b)\ m_4|U_{e4}|^2 \sim 10^{-5}\ KeV$

$c)\ m_4|U_{e4}|^2 \sim 10^{-4}\ KeV$

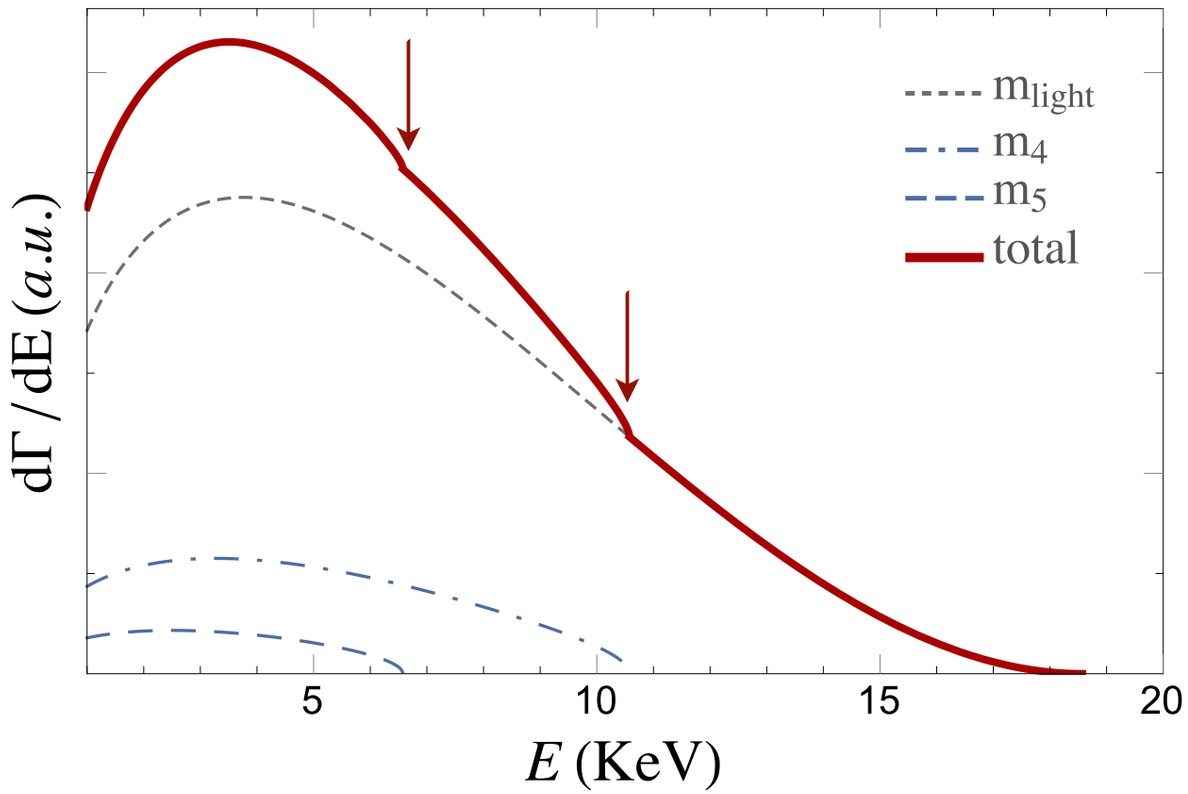


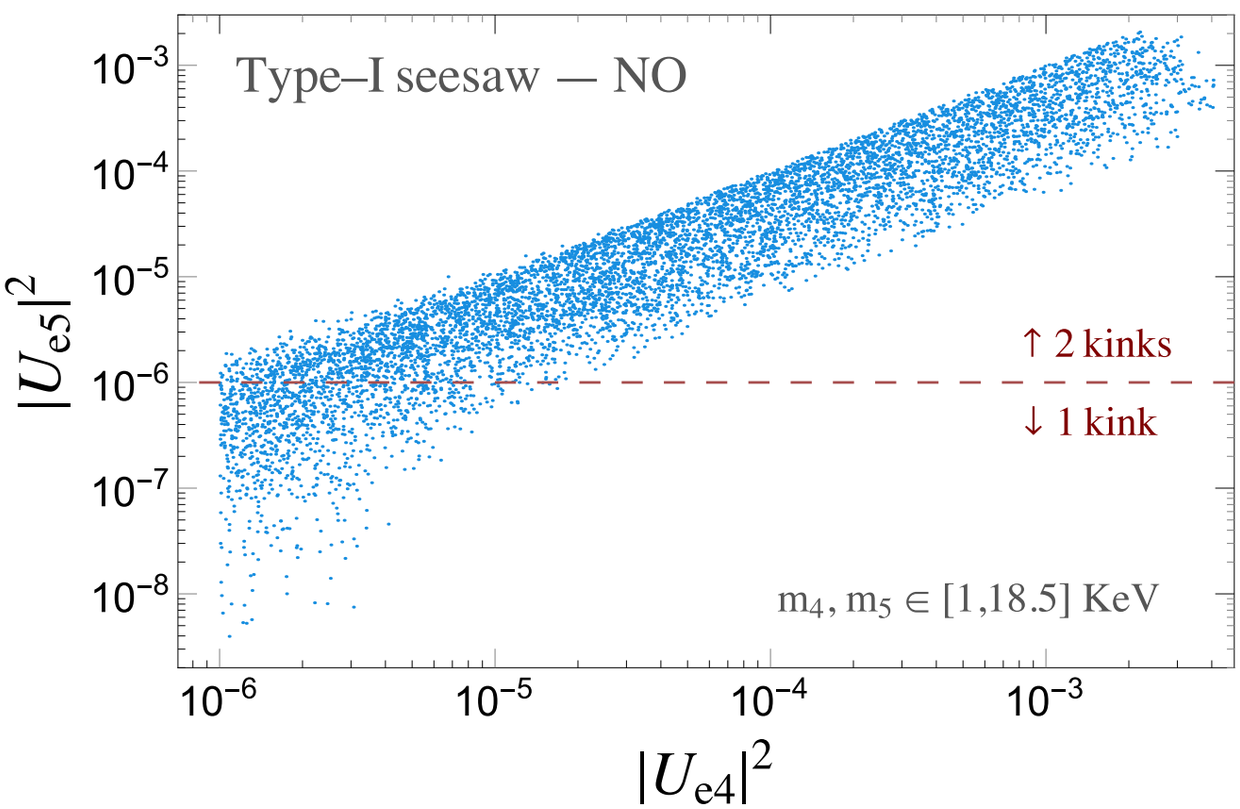




Double kink in KATRIN?

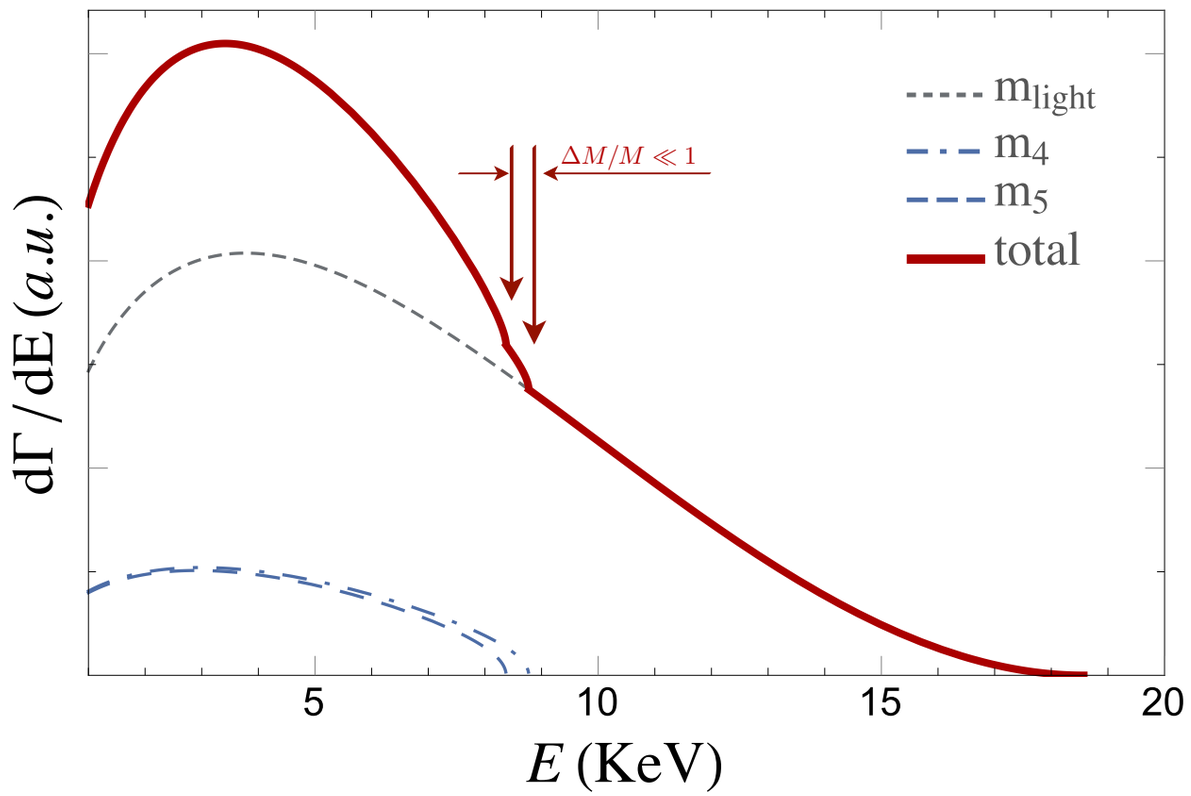
- **Lack** of signal in $0\nu\beta\beta$ naturally pushes **m_5 to also be light**
- It opens the possibility of a **second kink** in the KATRIN spectrum

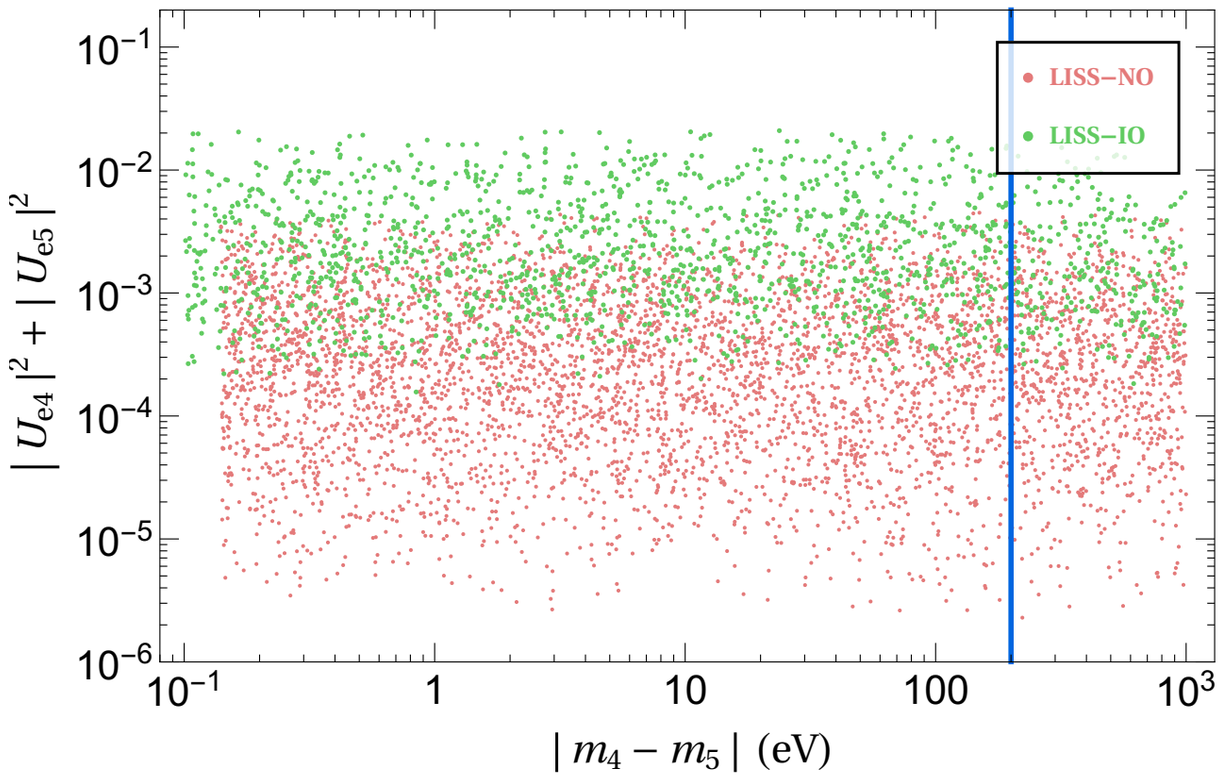




Double kink in KATRIN?

- **Lack** of signal in $0\nu\beta\beta$ naturally pushes **m_5 to also be light**
- It opens the possibility of a **second kink** in the KATRIN spectrum
- If they are close **(double-kink)** point towards Lepton Number Conservation





Conclusions

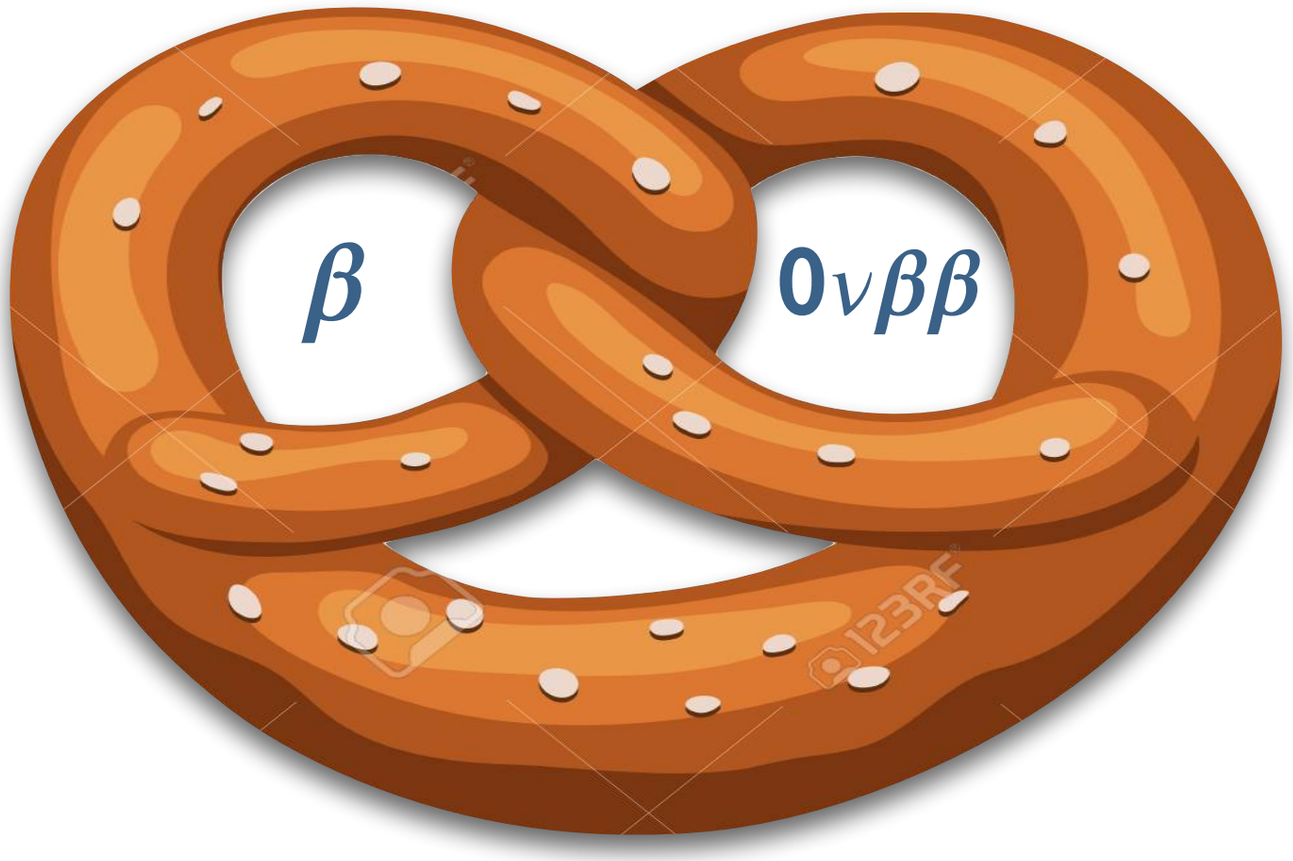
- **Intense experimental programme** for β and $0\nu\beta\beta$ decays
- Could be extended to **kink searches** in β decays

Under the assumption of an experimental 'kink' observation:

- We explored the **implications** for several seesaw models
  - We **showed results** for type-I seesaw models
  - If no signal is observed in $0\nu\beta\beta$, **double-kink** searches could probe these model

The interplay between β and $0\nu\beta\beta$ decays could help disentangling the various possible models for neutrino masses

Thank you!



This project has received funding/support from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 674896.