



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

**Xabier Marcano**  
**LPT, Orsay**

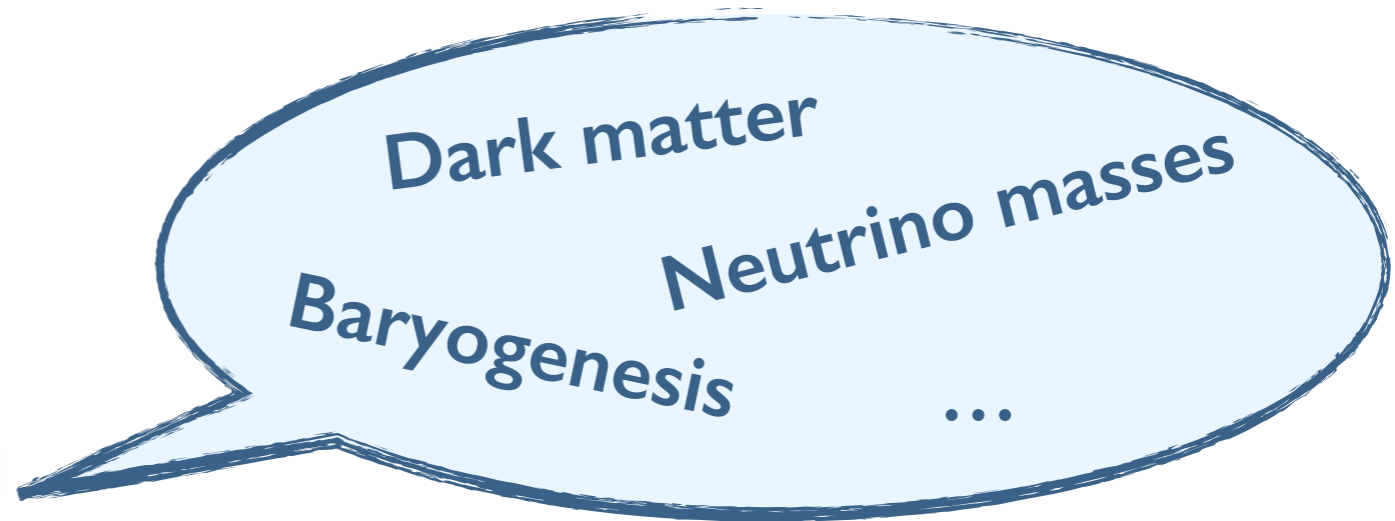
Based on I807.01331 with  
**Asmaa Abada and Álvaro Hernández-Cabezudo**

A photograph of the Karlsruhe Institute of Technology (KIT) building at night, illuminated with warm lights, set against a dark sky with some distant lights.

**KIT - Invisibles 18 Workshop - September 18**

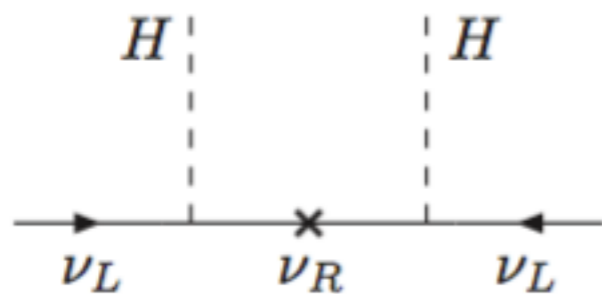
# WHY STERILE NEUTRINOS

- ▶ Open problems in the SM

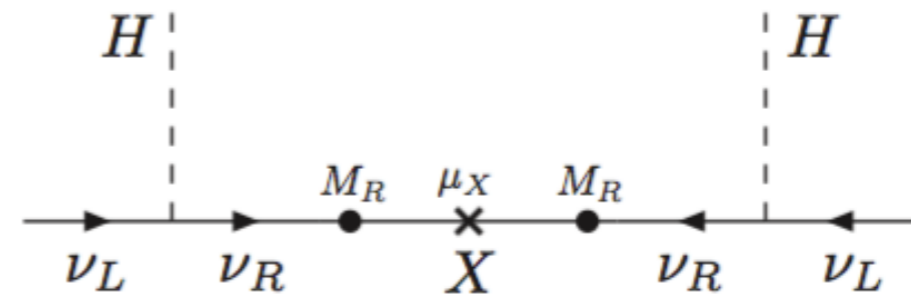


- ▶ **New Physics is needed** to solve these issues

- ▶ Many BSM extensions consider **Sterile Neutrinos**, e.g. *type-I and type-III seesaws, and its variants  $\nu$ MSM, linear seesaw, inverse seesaw...*



Type-I seesaw



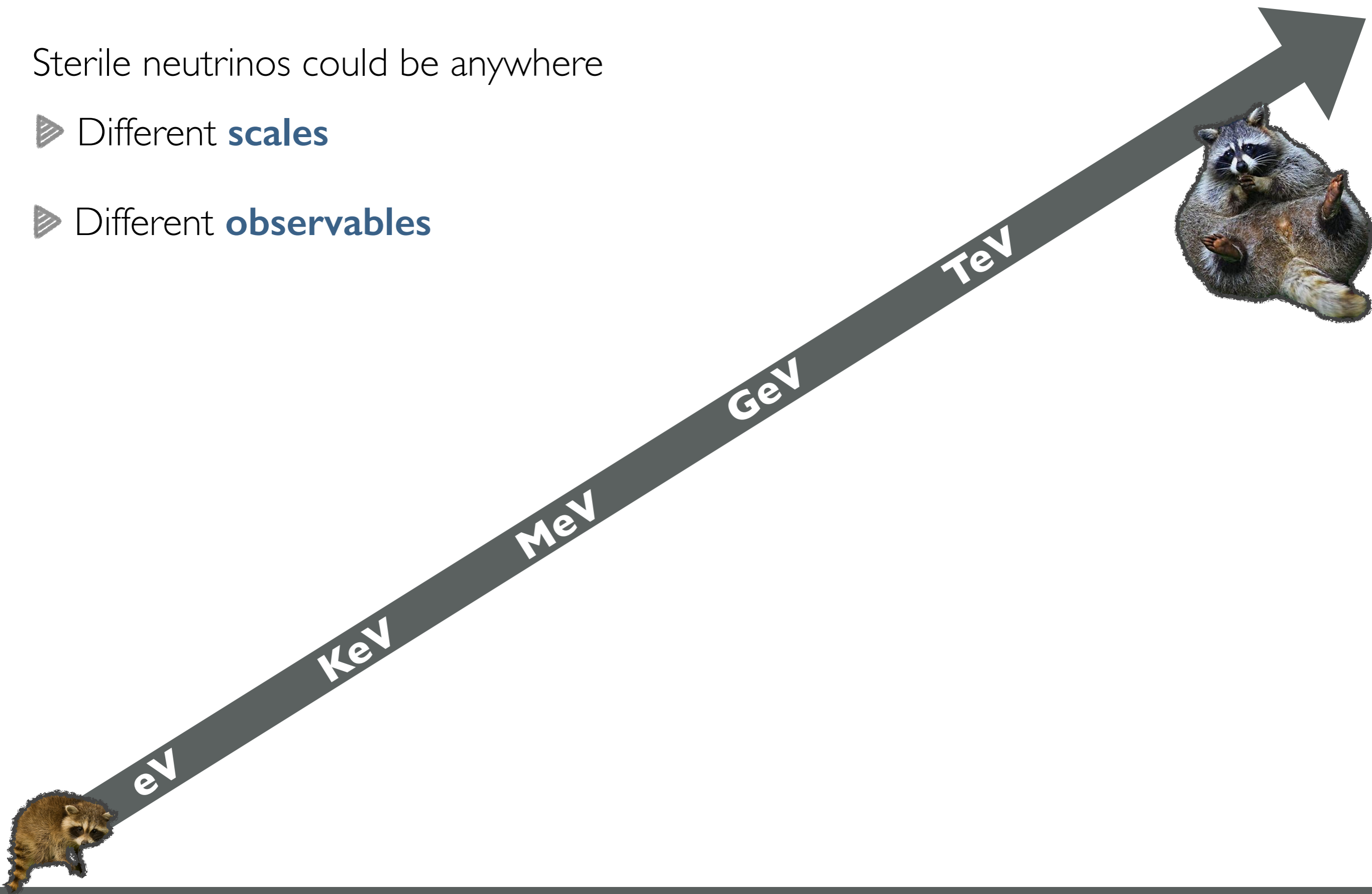
Inverse seesaw

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

# BROAD PHENOMENOLOGY

Sterile neutrinos could be anywhere

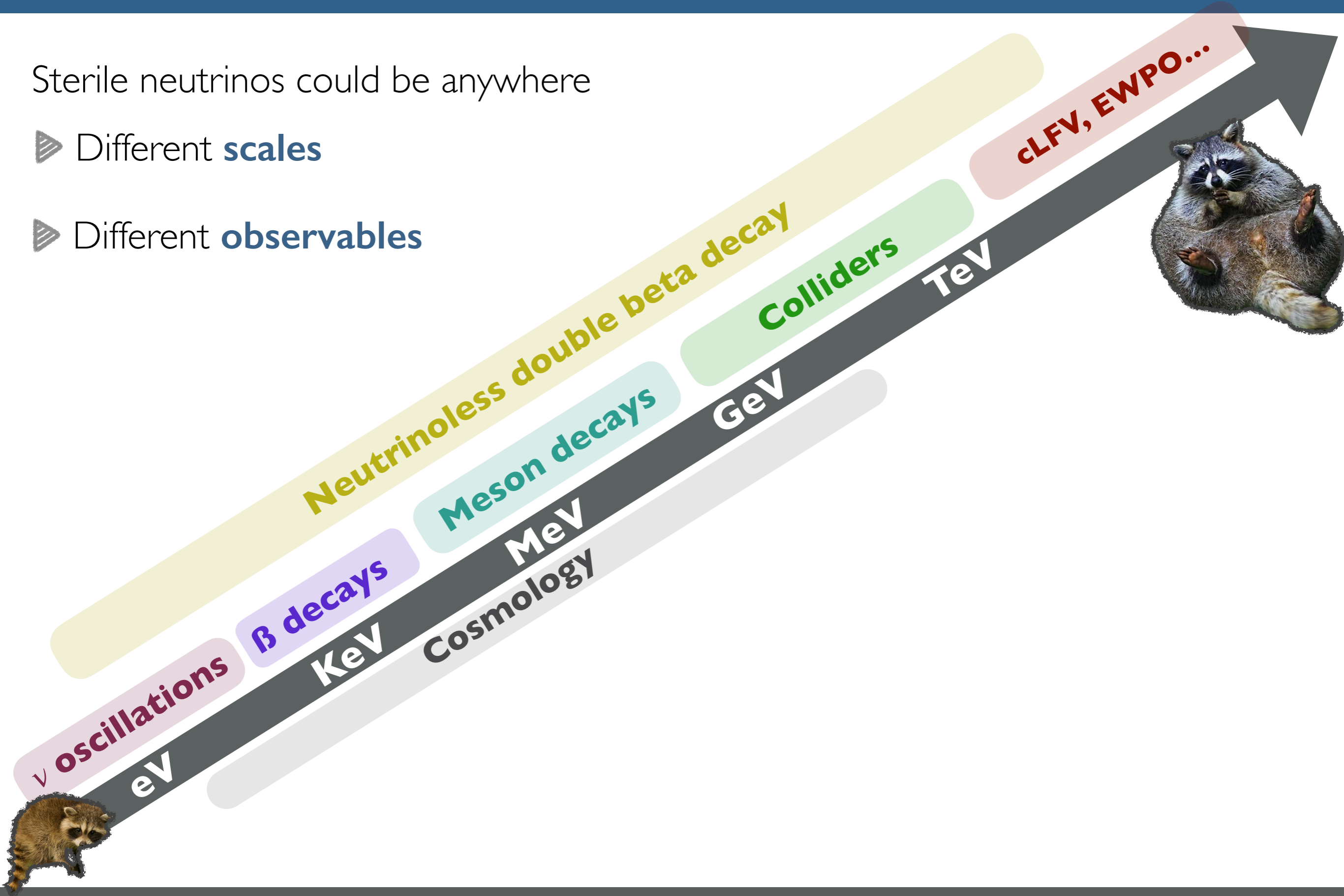
- ▶ Different **scales**
- ▶ Different **observables**



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Sterile neutrinos could be anywhere

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

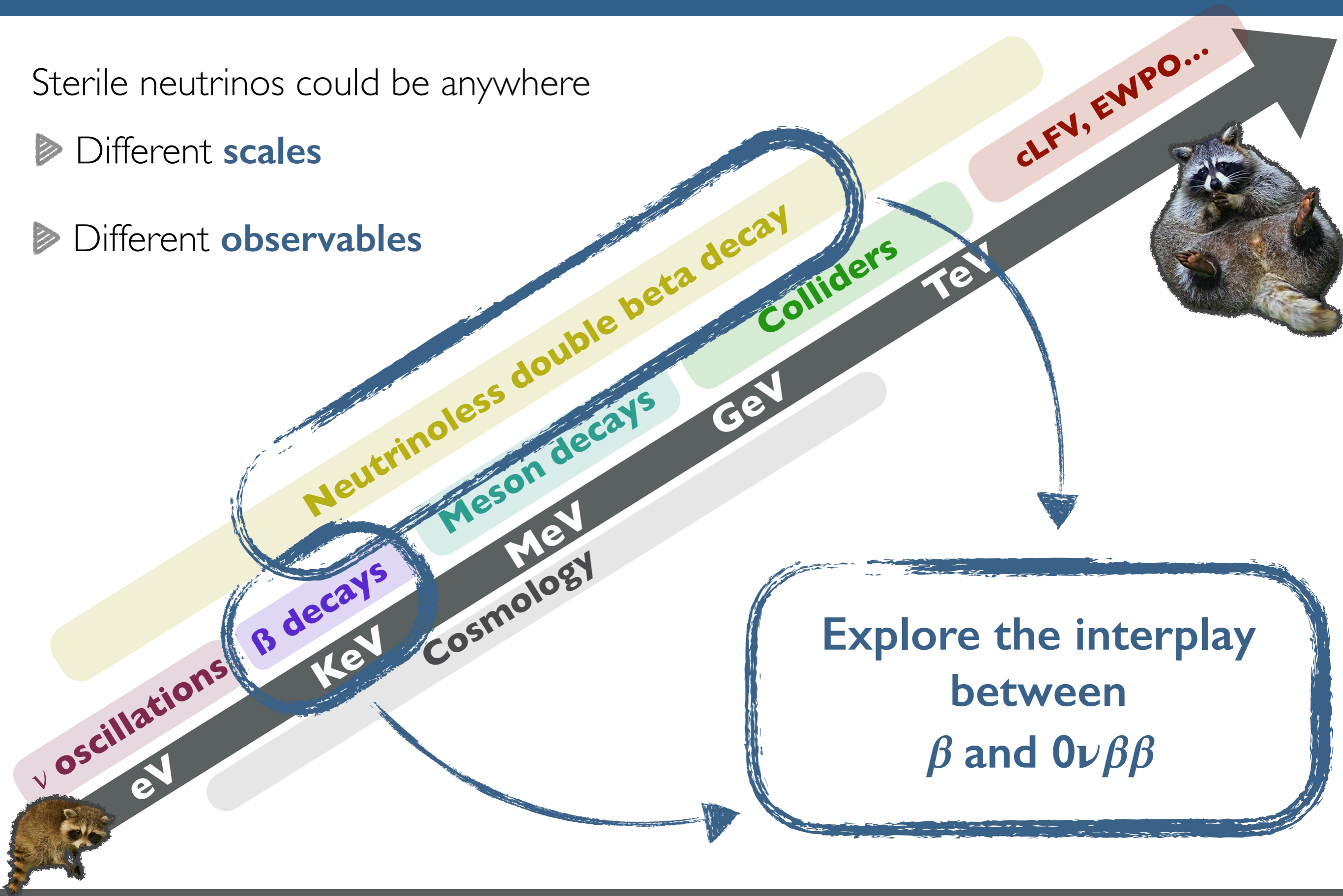




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- ▶ Different **scales**
- ▶ Different **observables**

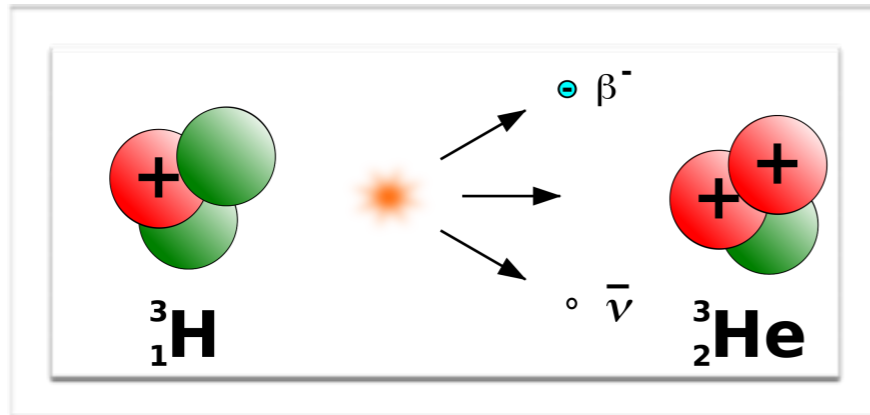


# OUTLINE

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

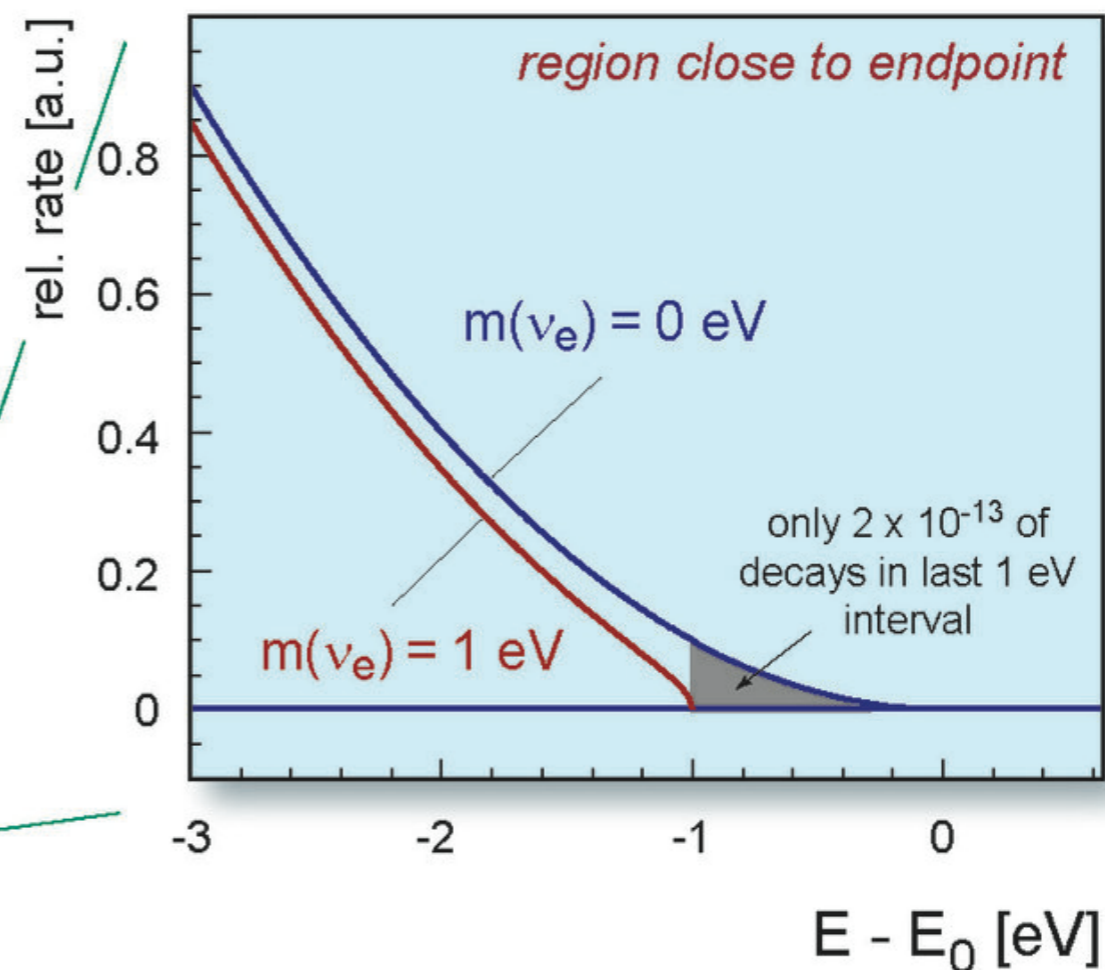
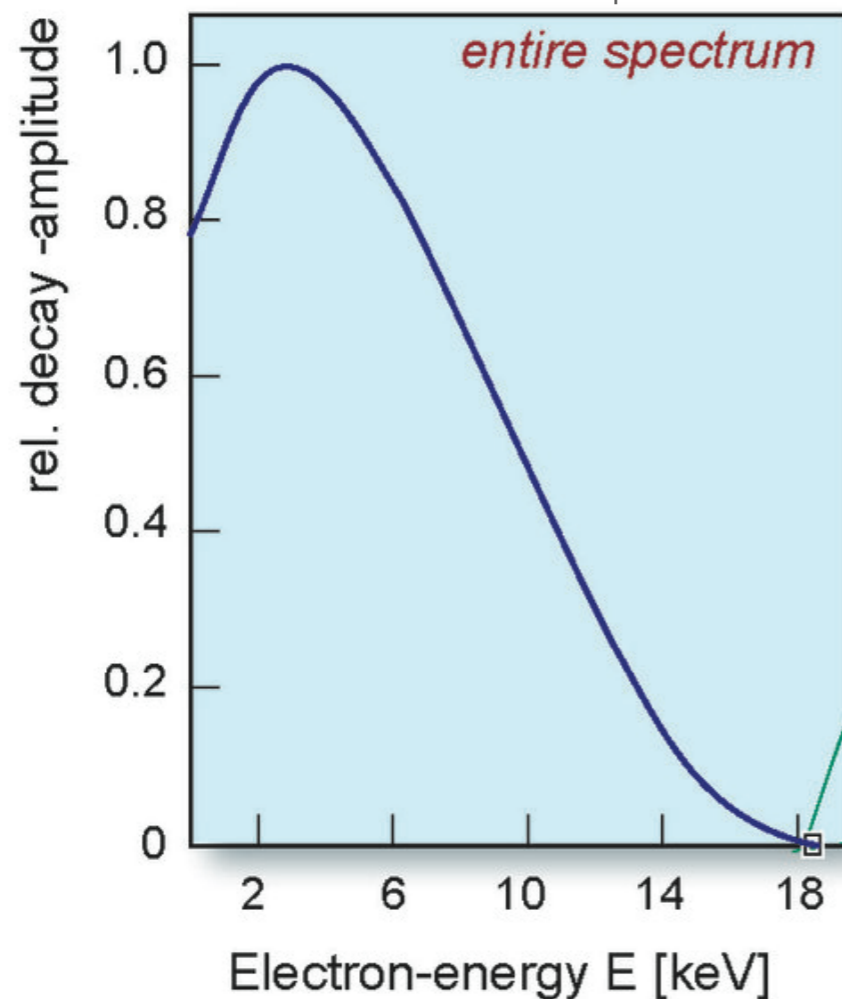
# EXPERIMENTAL STATUS OF $\beta$ DECAYS

► Measure the end-point spectrum of **tritium  $\beta$  decay** ( $E_0 = 18.6$  keV)



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

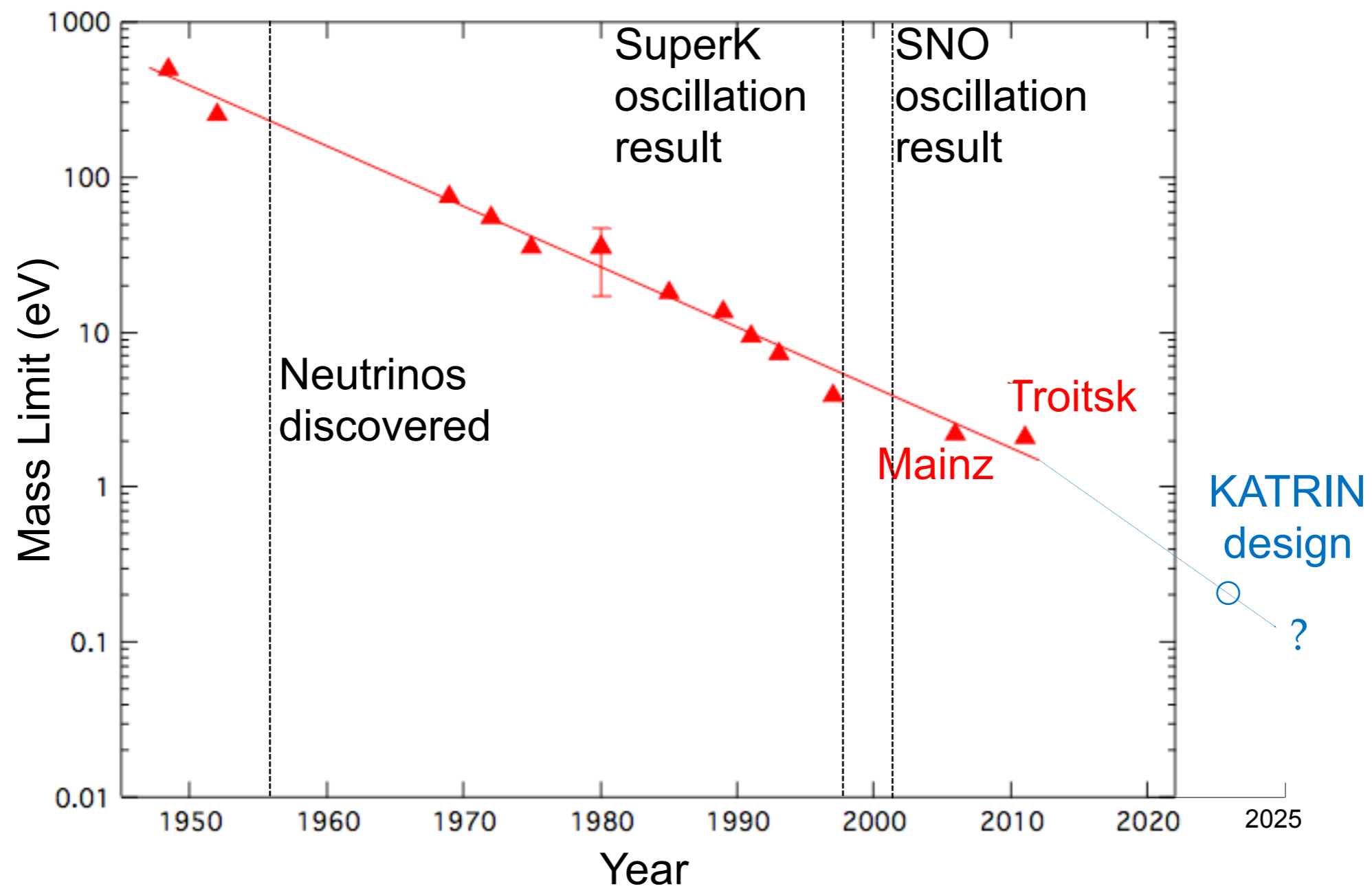
Source: KATRIN experiment





# $m_{\nu, \text{eff}}^2$ : 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

KIT, Invisibles I8 Workshop



# THE KATRIN EXPERIMENT

The screenshot shows the website for 'elusives', which focuses on 'neutrinos, dark matter & dark energy physics'. The navigation menu includes 'THE NETWORK', 'JOBS', 'OUTREACH', 'VIRTUAL INSTITUTE', and 'PUBLICATIONS'. The main content area features a news article titled 'Official inauguration of the KATRIN experiment at KIT'. The article includes a photograph of the experimental setup and a portrait of a young man. The text describes the inauguration on June 11, 2018, and mentions the collaboration's start on May 18, 2018. It also notes that the experiment aims to measure the absolute mass of neutrinos and set a new upper bound. The article concludes with an invitation to a barbecue and credits the text to Álvaro Hernández-Cabezudo.

Search in Elusives Search

THE NETWORK JOBS OUTREACH VIRTUAL INSTITUTE PUBLICATIONS

elusives  
neutrinos, dark matter & dark energy physics

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

## News & Events

### Official inauguration of the KATRIN experiment at KIT


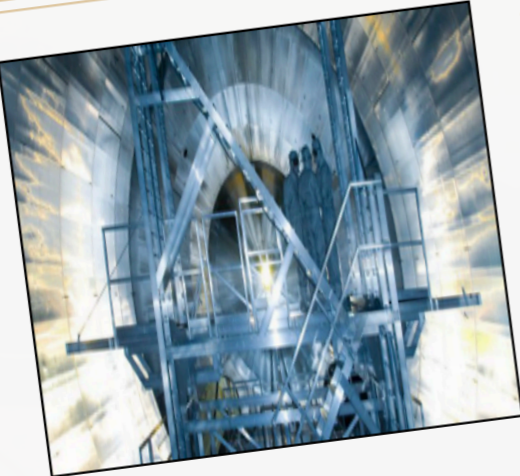
Today, June 11 2018 the [KATRIN](#) experiment has been inaugurated at 11.46 a.m. at the Karlsruhe Institute of Technology (KIT).

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 inception 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

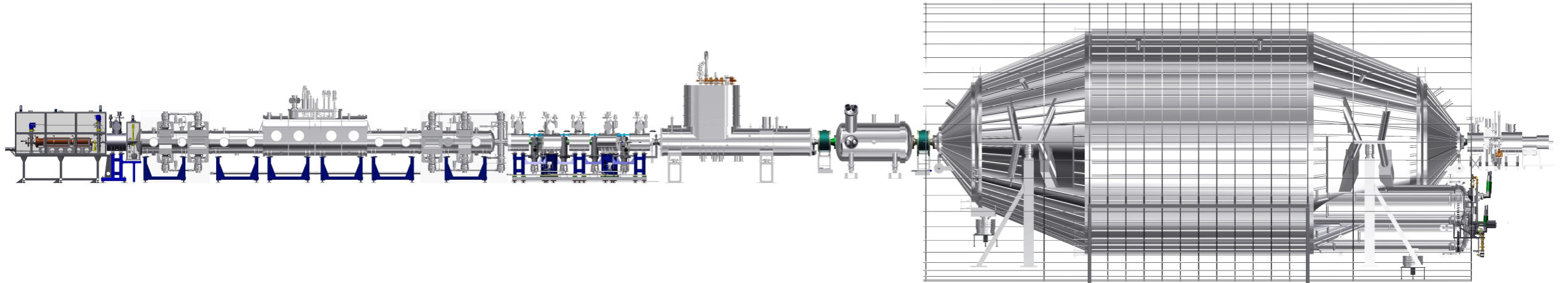


...ATION KIT, 11<sup>th</sup> June 20

Image credit Laura Baudis

# THE KATRIN EXPERIMENT

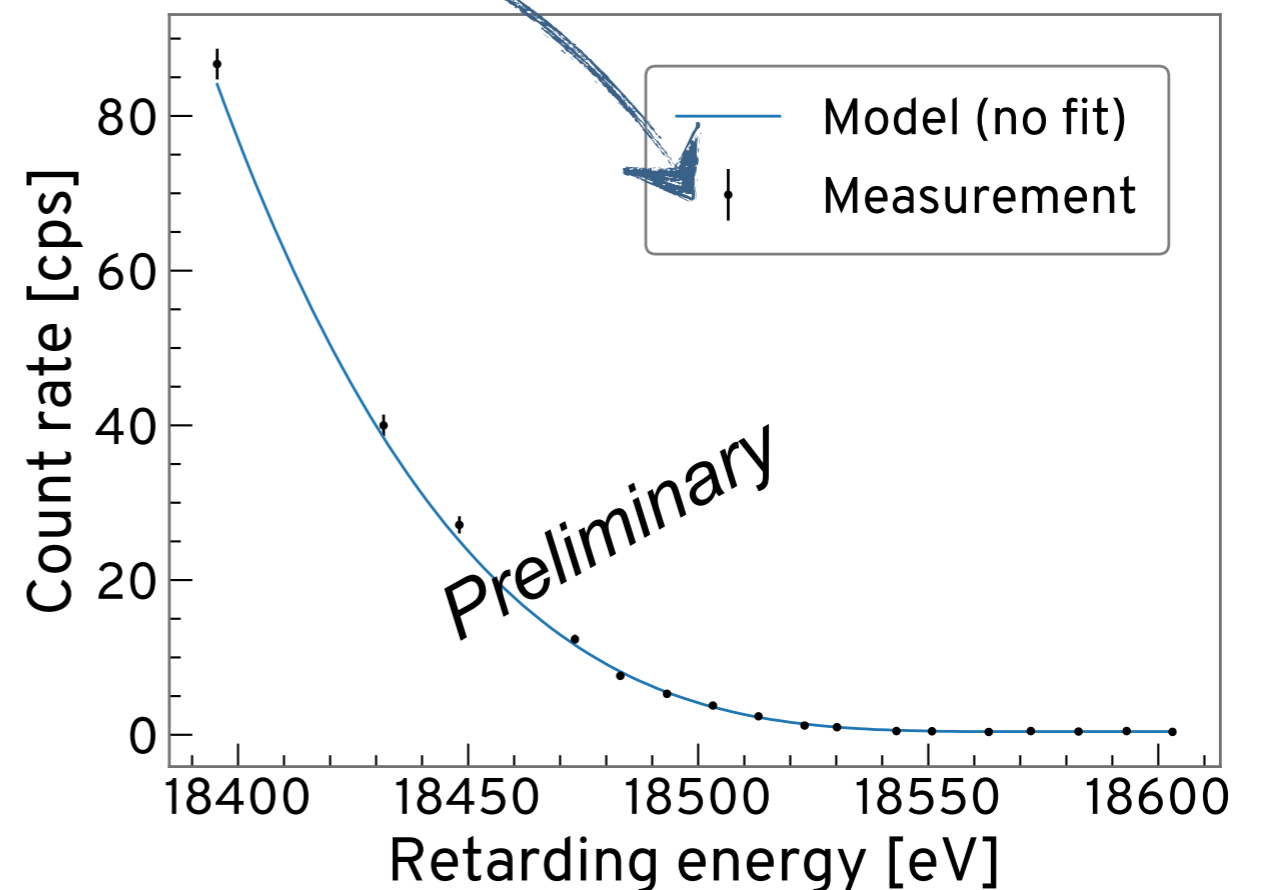
► The **KA**rlsruhe **TR**itium **N**eutrino experiment



- **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*

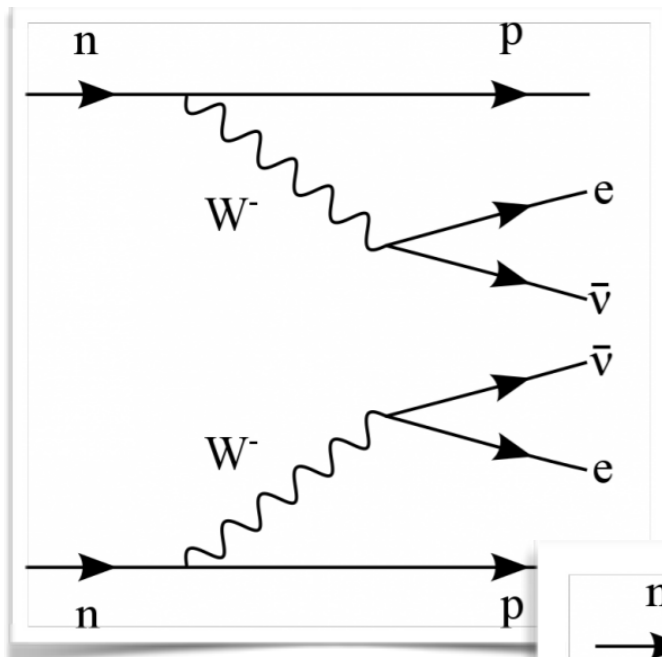




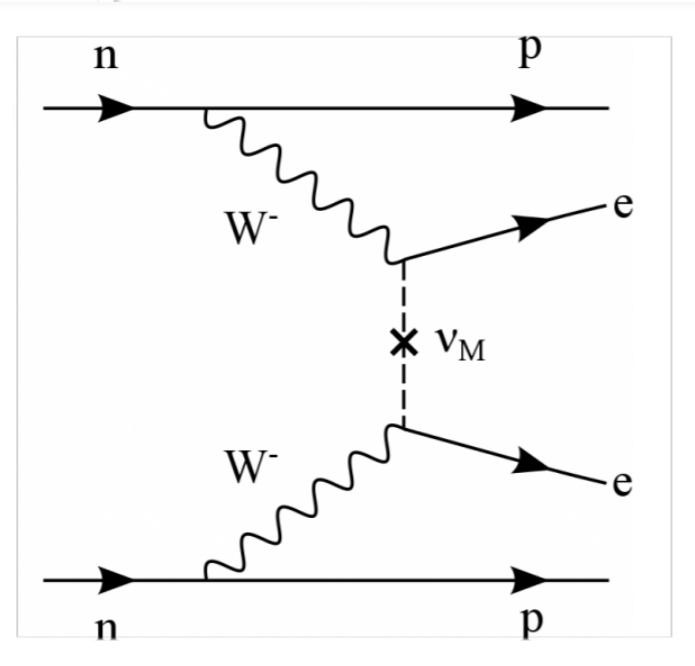
# NEUTRINOLESS DOUBLE BETA DECAY

► Learn about **neutrinos** looking for **no neutrinos**

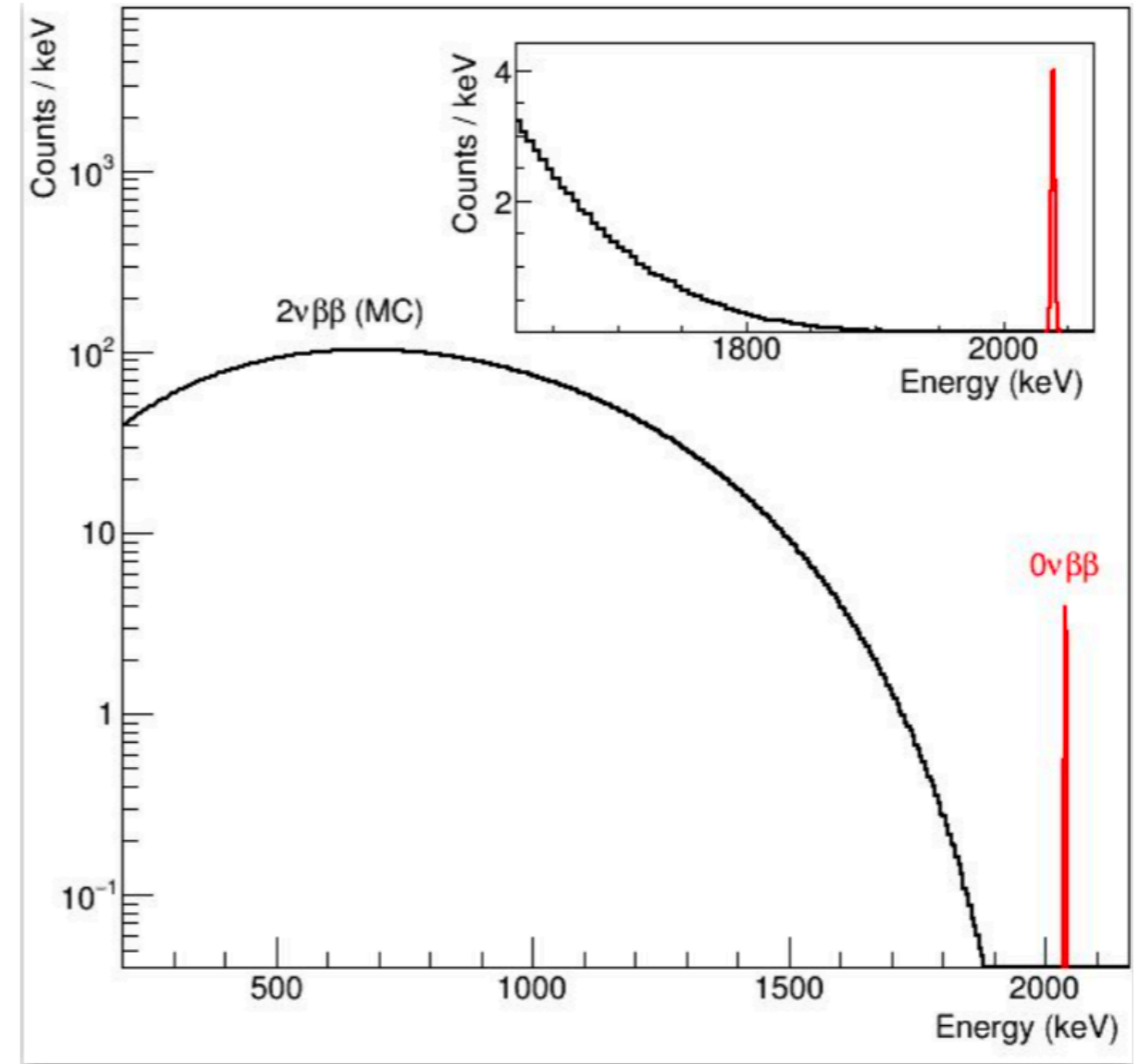
$$m_{ee} = \left| \sum_i m_i U_{ei} \right|^2$$



$2\nu\beta\beta$



$0\nu\beta\beta$



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	$^{136}\text{Xe}$	$1.8 \times 10^{25}$	147-398
KamLAND-Zen	$^{136}\text{Xe}$	$1.07 \times 10^{26}$	62-165
GERDA	$^{76}\text{Ge}$	$0.9 \times 10^{26}$	110-260
MAJORANA DEMONSTRATOR	$^{76}\text{Ge}$	$2.7 \times 10^{25}$	200-433
CUORE	$^{130}\text{Te}$	$1.5 \times 10^{25}$	110-520
CUPID-0	$^{82}\text{Se}$	$2.4 \times 10^{24}$	376-770

- ▶ More in talk by **Chiara Brofferio**

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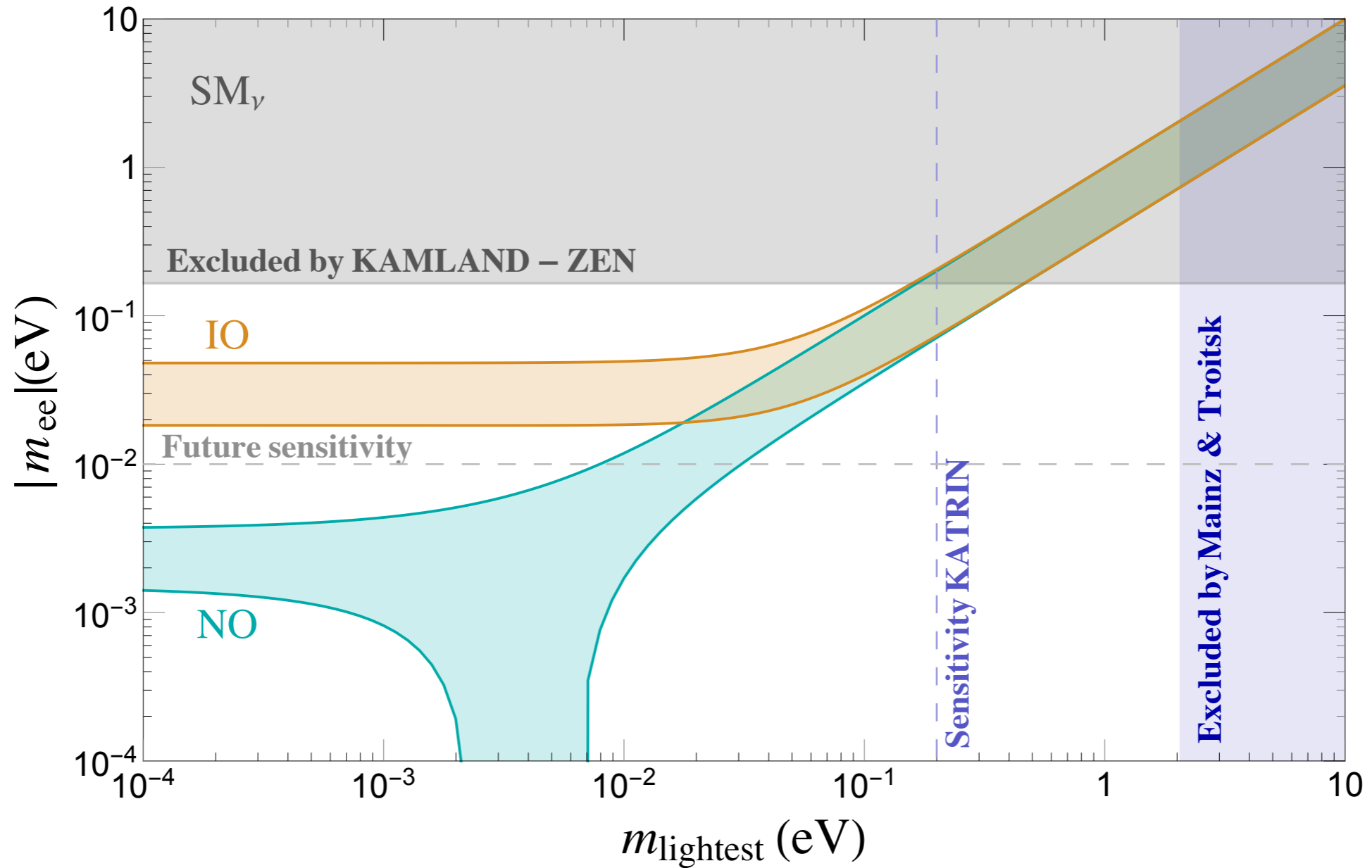
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**NEW!!!**

- ▶ More in talk by **Chiara Brofferio**

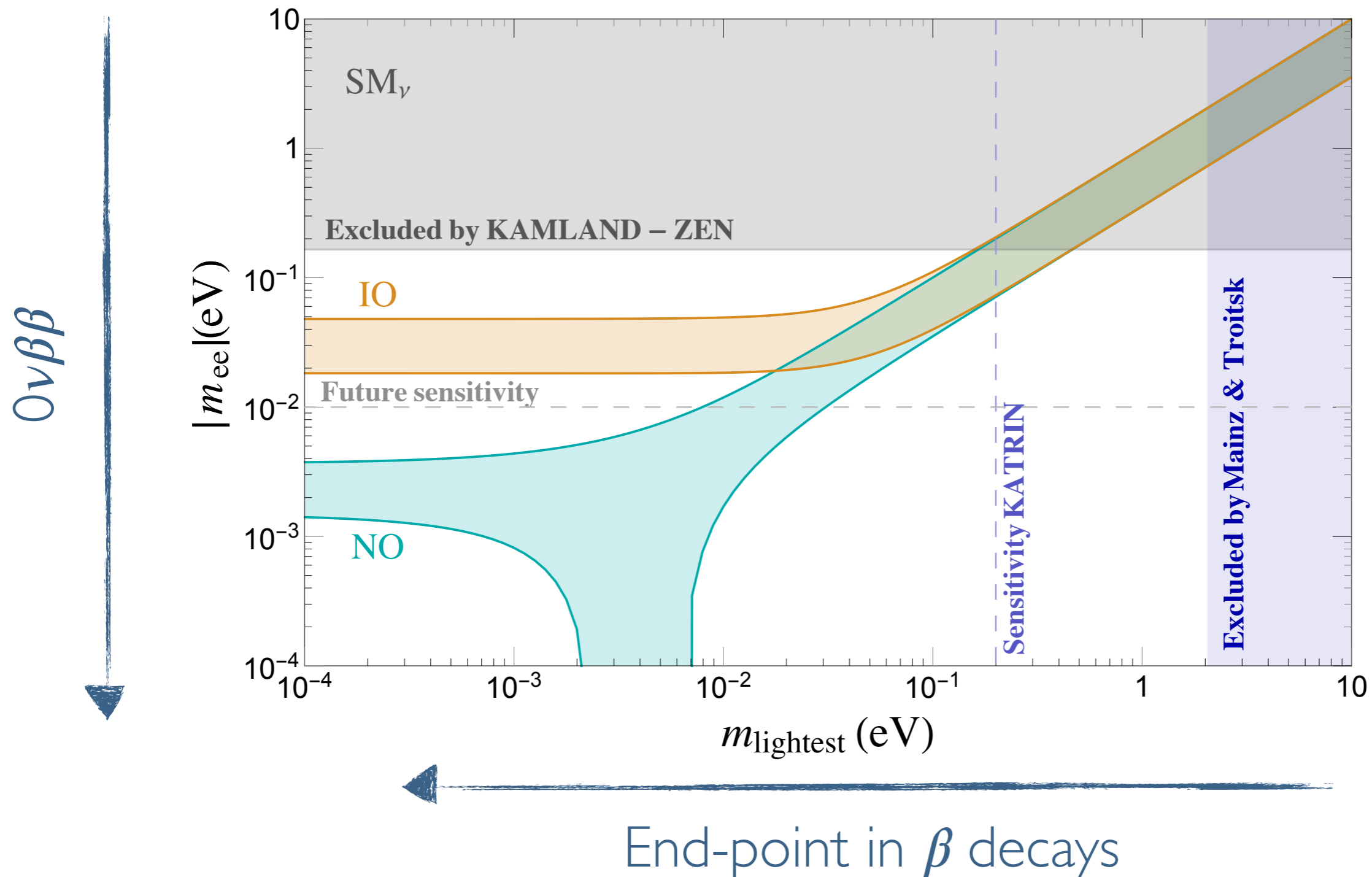
# $\beta$ AND $0\nu\beta\beta$ IN THE $SM_\nu$

► The standard picture for **3 light Majorana neutrinos ( $SM_\nu$ )**



# $\beta$ AND $0\nu\beta\beta$ IN THE $SM_\nu$

► The standard picture for **3 light Majorana neutrinos ( $SM_\nu$ )**



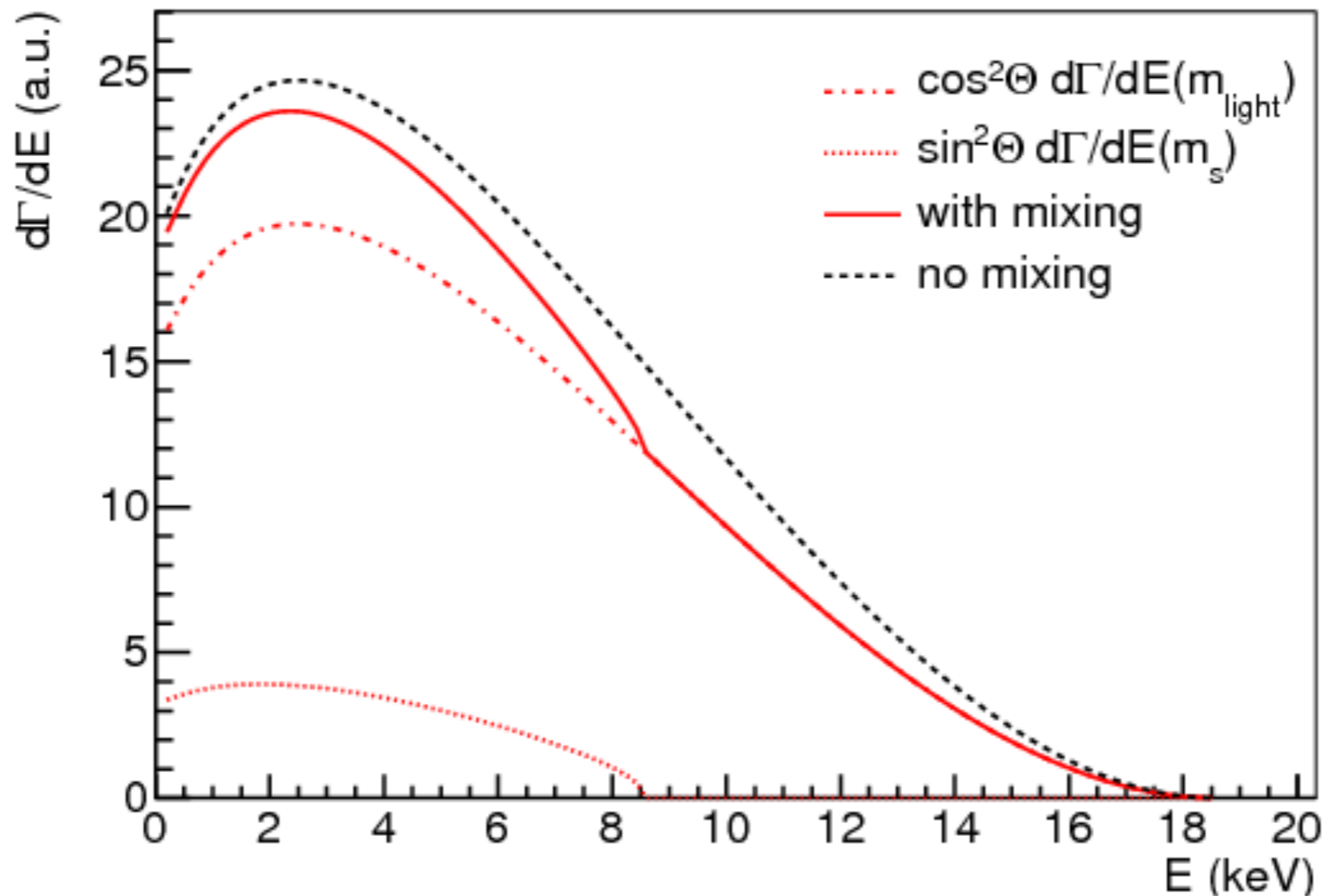


# **WHERE IS THE STERILE NEUTRINO IN ALL THIS STORY?**

# STERILE NEUTRINOS IN $\beta$ DECAYS

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

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

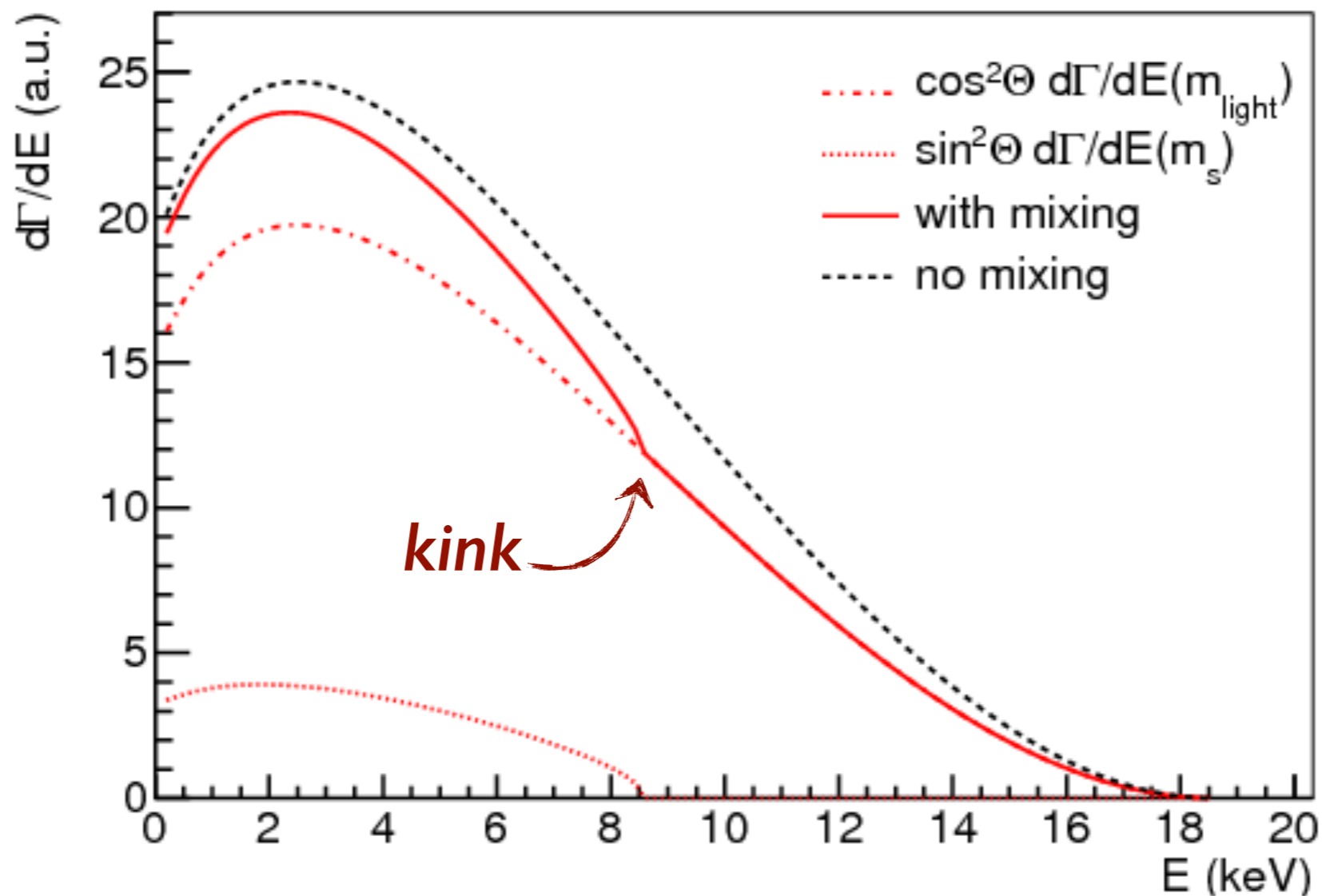


S. Mertens et al, Phys.Rev. D91 (2015) 042005

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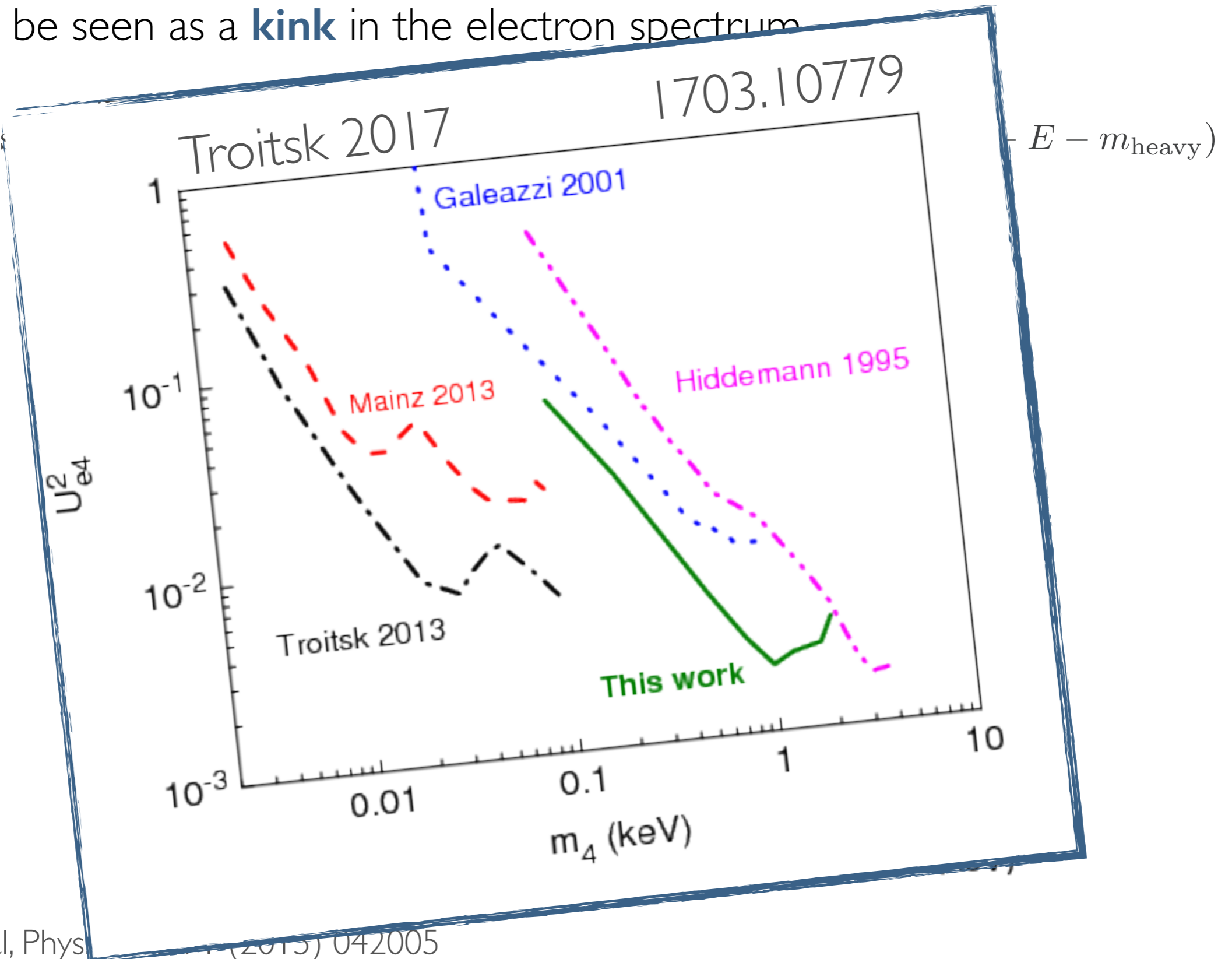


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$$\frac{d\Gamma}{dE} = \cos^2 \theta$$



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



# WHAT IF...

\*Disclaimer: not a real arXiv entry (yet)

The screenshot shows a simulated arXiv entry page. At the top left is the Cornell University Library logo. At the top right is a disclaimer: "We gratefully acknowledge support from the Simons Foundation and member institutions". Below this is a navigation bar with "arXiv.org > hep-ex > arXiv: 2507.020900000000002" and a search box containing "Search or Article ID" and "All fields". Below the navigation bar is a header "High Energy Physics - Experiment". The main content area features the title "Observation of a 'kink' in the tritium spectrum in the search for keV neutrinos with the KATRIN experiment" and the author "The KATRIN Collaboration". Below the title is the submission information: "(Submitted on 31 Jul 2025 (v1), last revised 31 Aug 2025 (this version, v2))". The abstract text reads: "A search for keV sterile neutrinos in the tritium  $\beta$  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  $|U_{e4}|^2 = \text{_____}$  .". On the right side, there is a "Download:" section with links for "PDF", "PostScript", and "Other formats (license)". Below that is the "Current browse context:" section showing "hep-ex" and navigation links "< prev | next >" and "new | recent". At the bottom right is the "References & Citations" section with links for "INSPIRE HEP (refers to | cited by)" and "NASA ADS".

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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  $\beta$  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  $|U_{e4}|^2 = \text{_____}$  .

*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)
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What would be the implications?

A new neutrino?

# WHAT IF...

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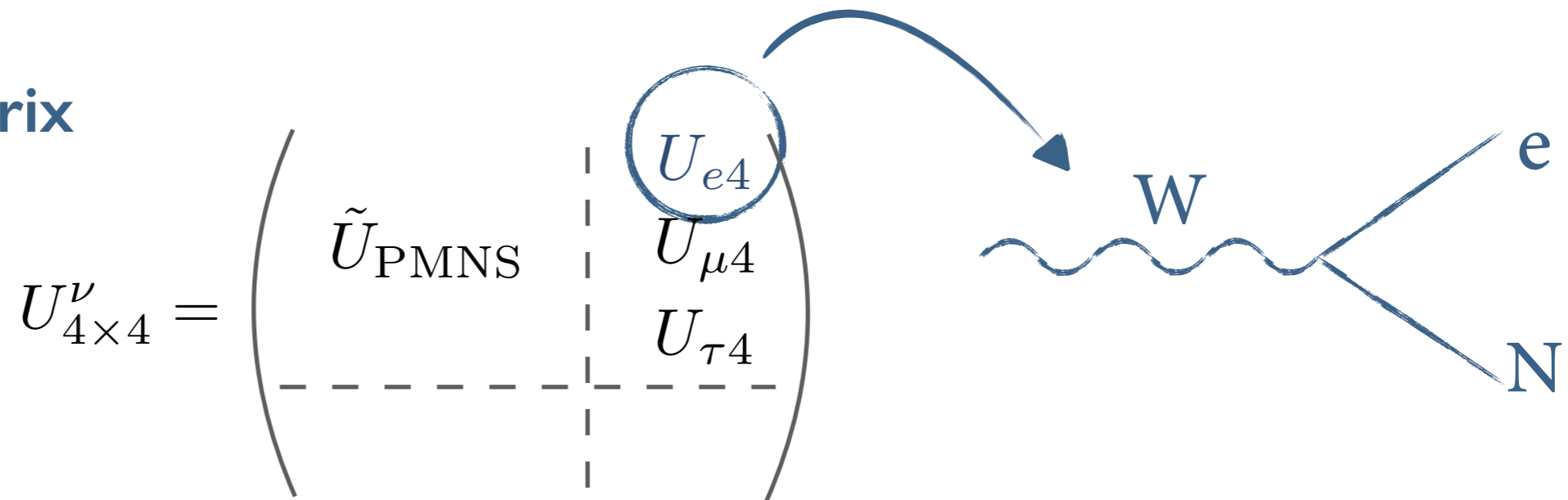
What would be the implications?



# THE 3+1 SCENARIO

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

- ▶ **4x4 mixing matrix**



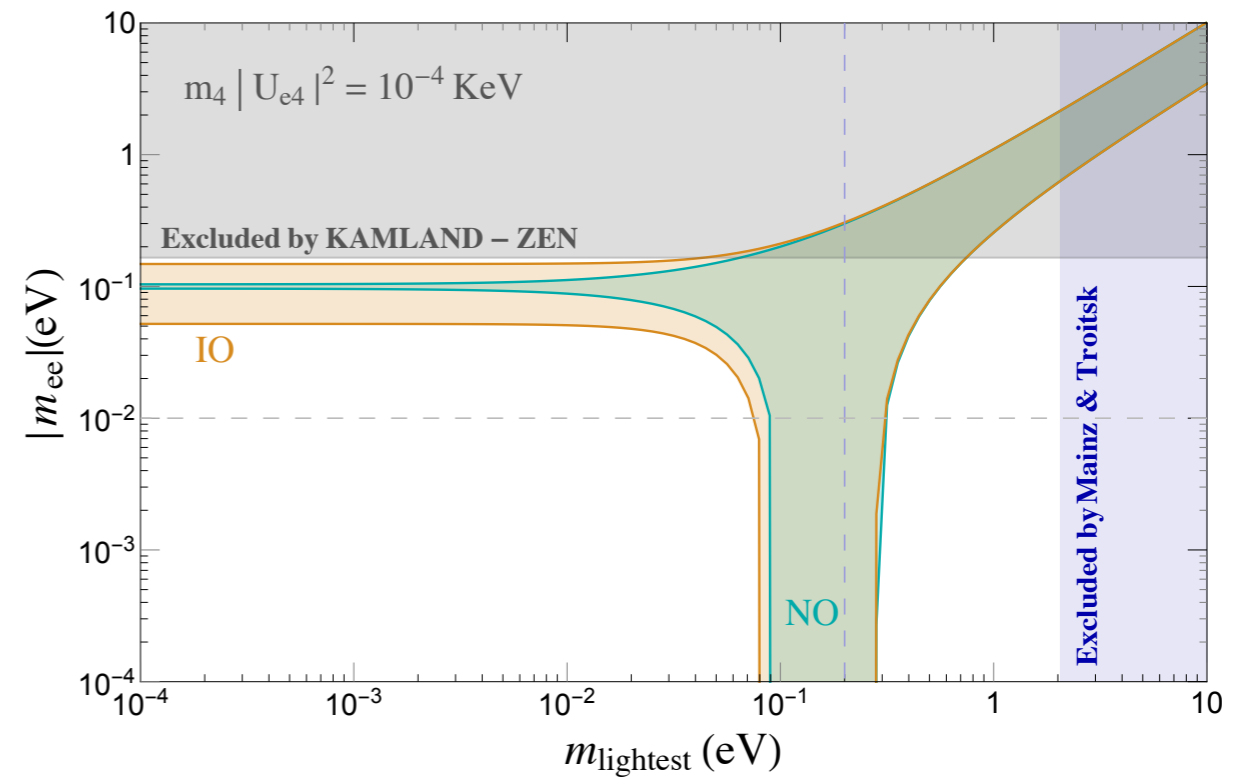
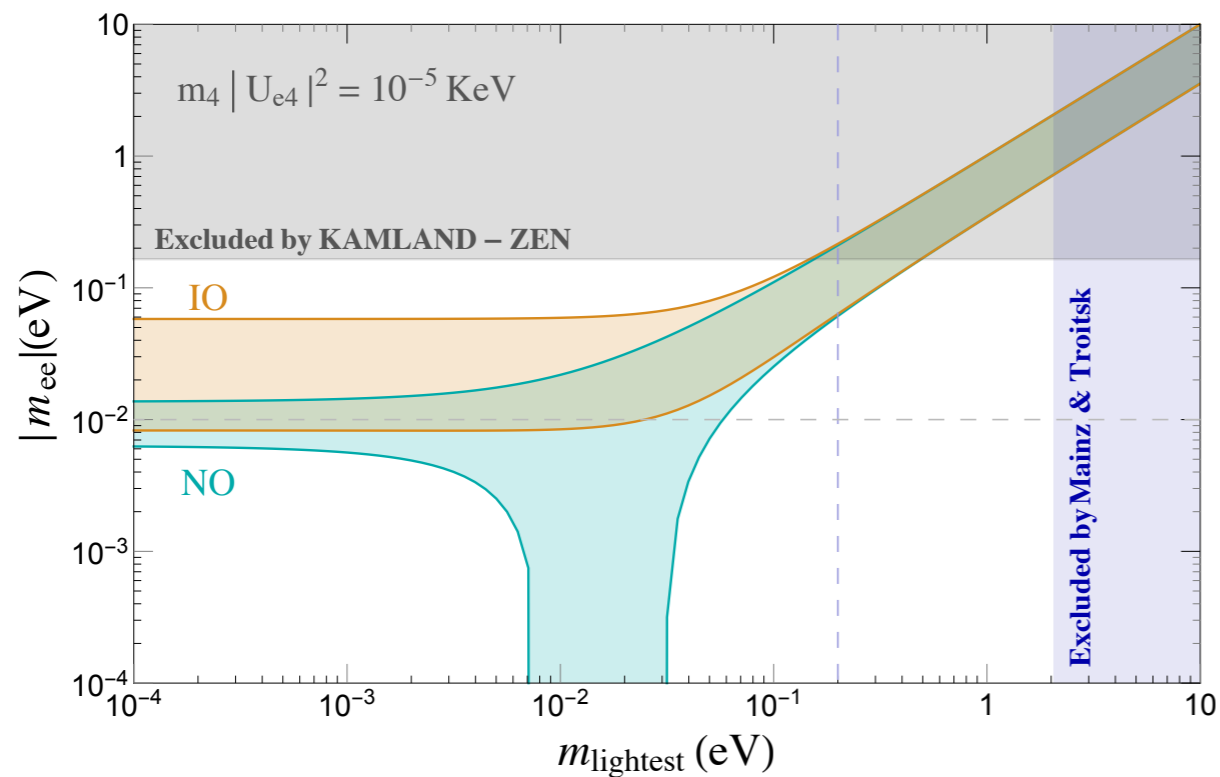
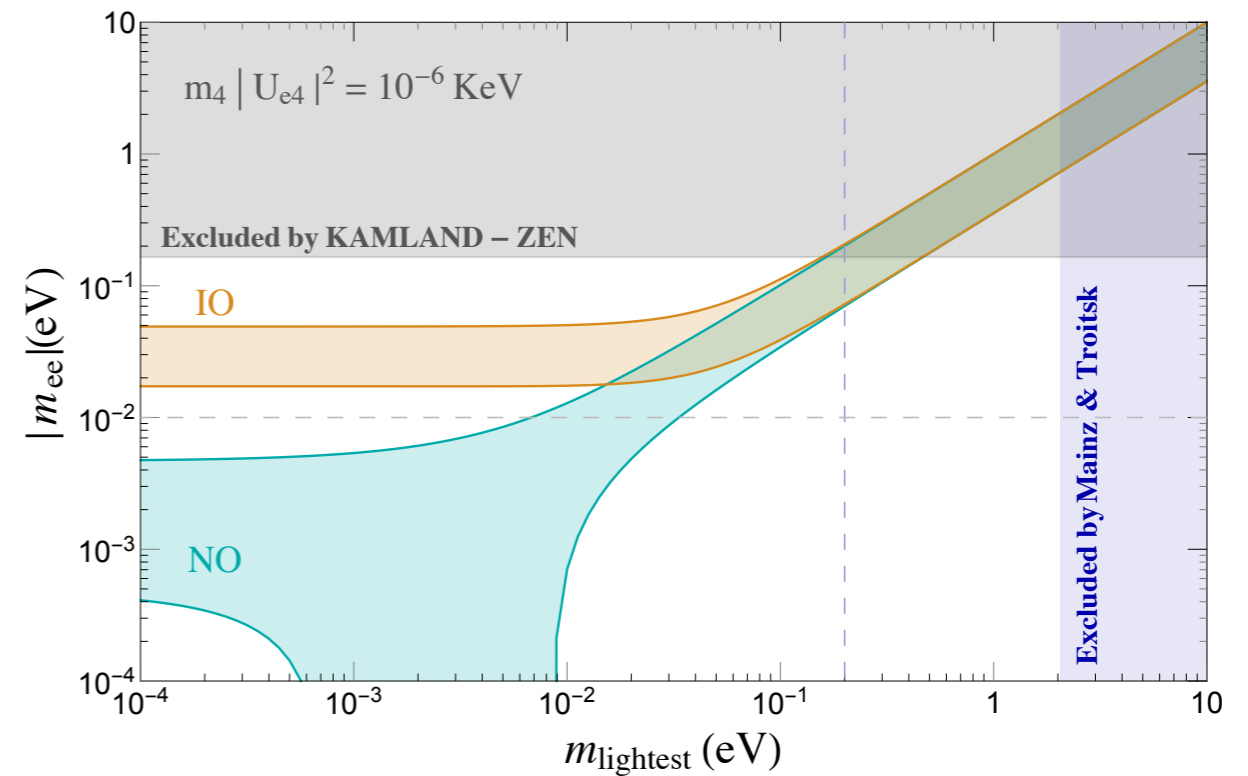
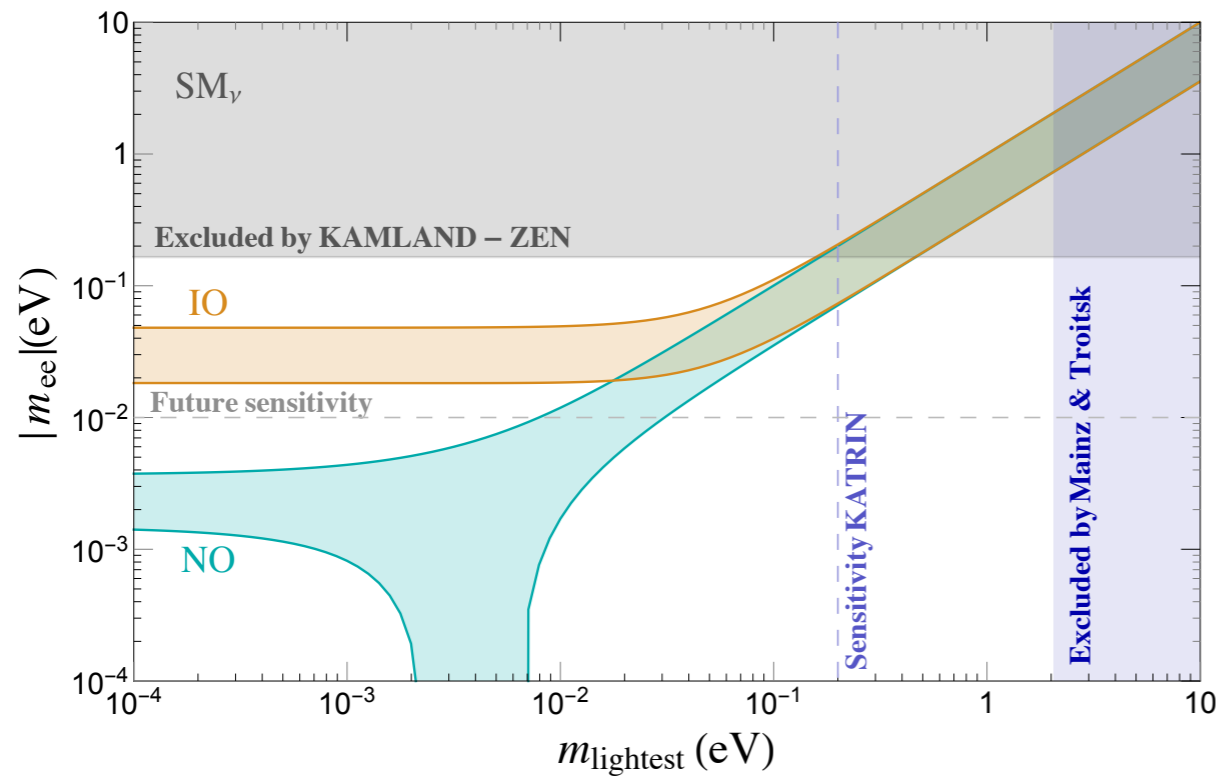
**a kink in KATRIN**

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

$$\left\{ \begin{array}{l} m_4 \sim (1 - 18) \text{ KeV} \\ |U_{e4}|^2 \gtrsim 10^{-8} - 10^{-6} \end{array} \right.$$

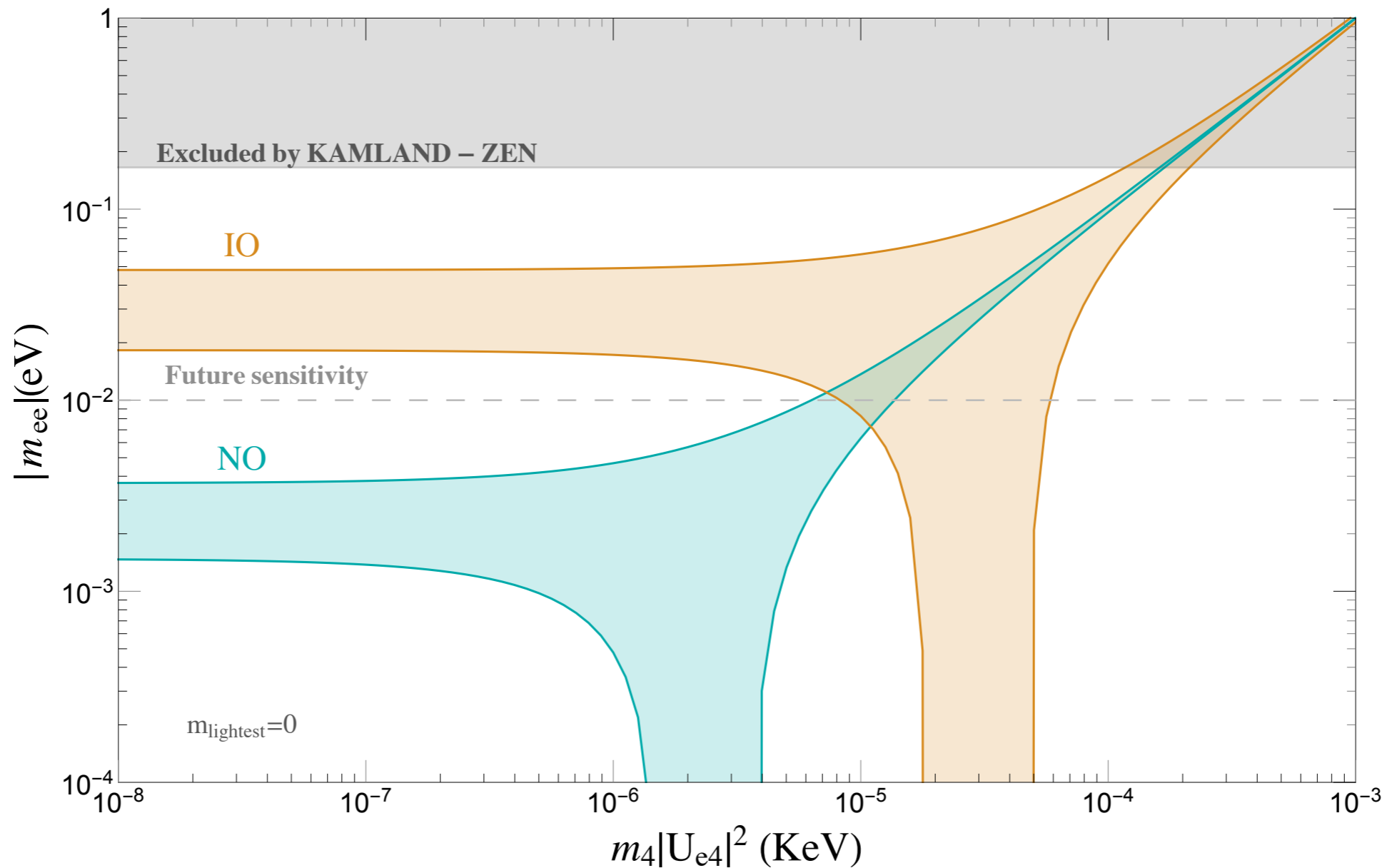
# $0\nu\beta\beta$ IN THE 3+1 SCENARIO

► A new Majorana neutrino in the KeV could change the standard picture



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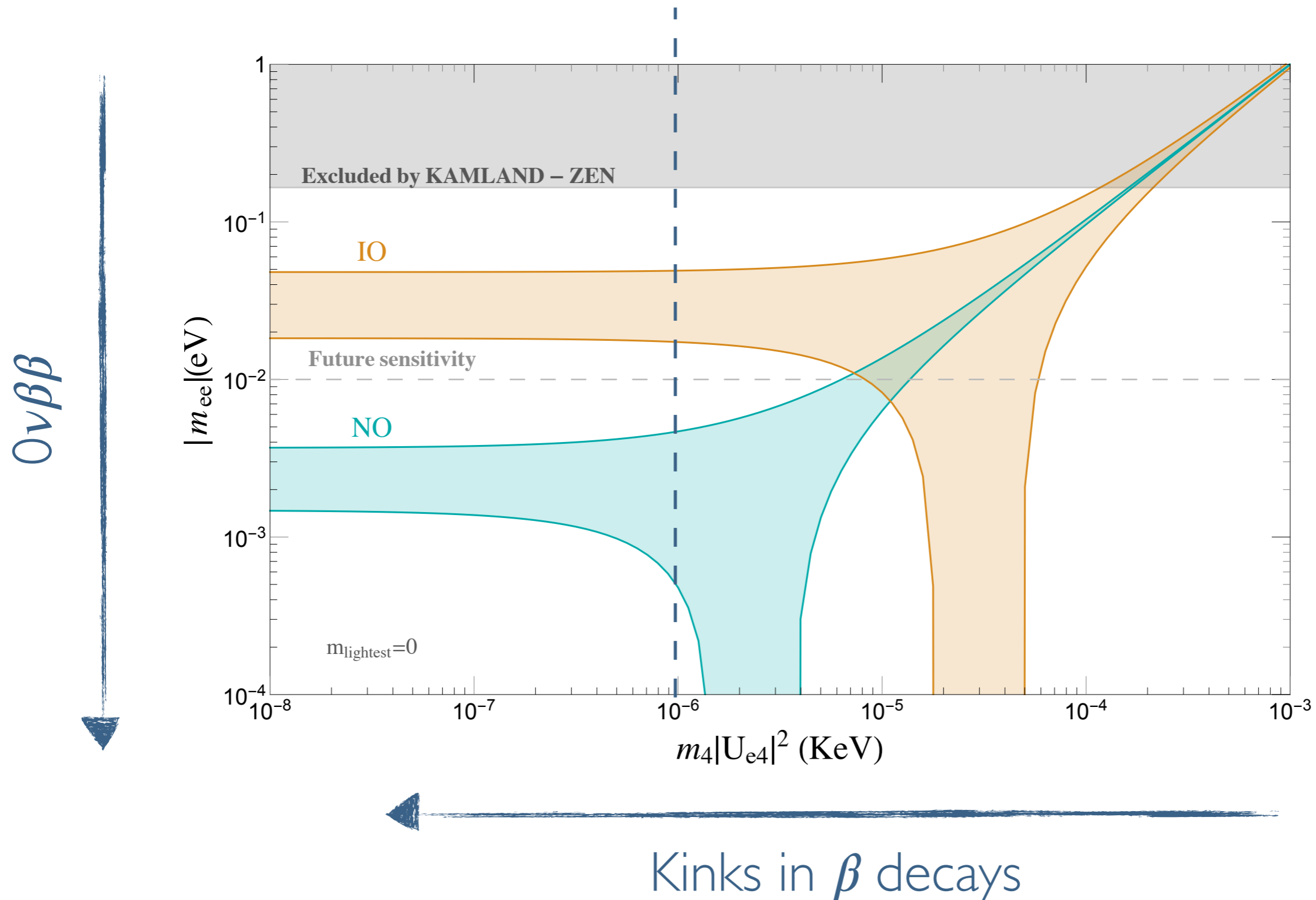
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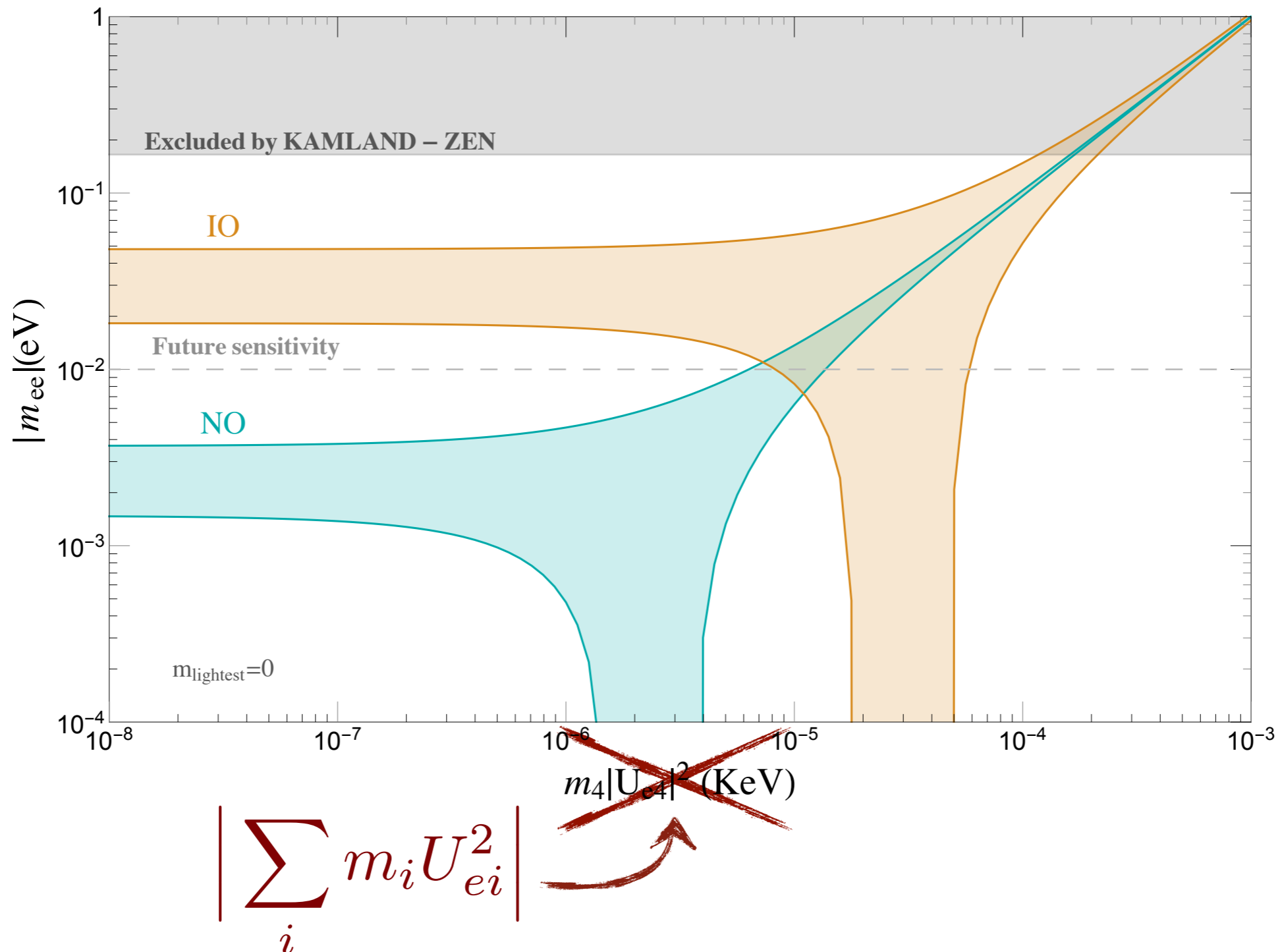
# $0\nu\beta\beta$ IN THE 3+1 SCENARIO

► A new Majorana neutrino in the KeV could change the standard picture



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

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



# TYPE I SEESAW MODELS

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

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + i\bar{N}_I \not{\partial} N_I - \left( Y_{\alpha I} \bar{\ell}_\alpha \tilde{\phi} N_I + \frac{M_{IJ}}{2} \bar{N}_I^c N_J + h.c. \right),$$

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

- ▶ After the EW symmetry breaking

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



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



# TYPE I SEESAW MODELS

► Explaining  $m_{\text{light}}$  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*

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

► The cancellation in a nutshell:

◆ Neutrino mass **diagonalization** relations:

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

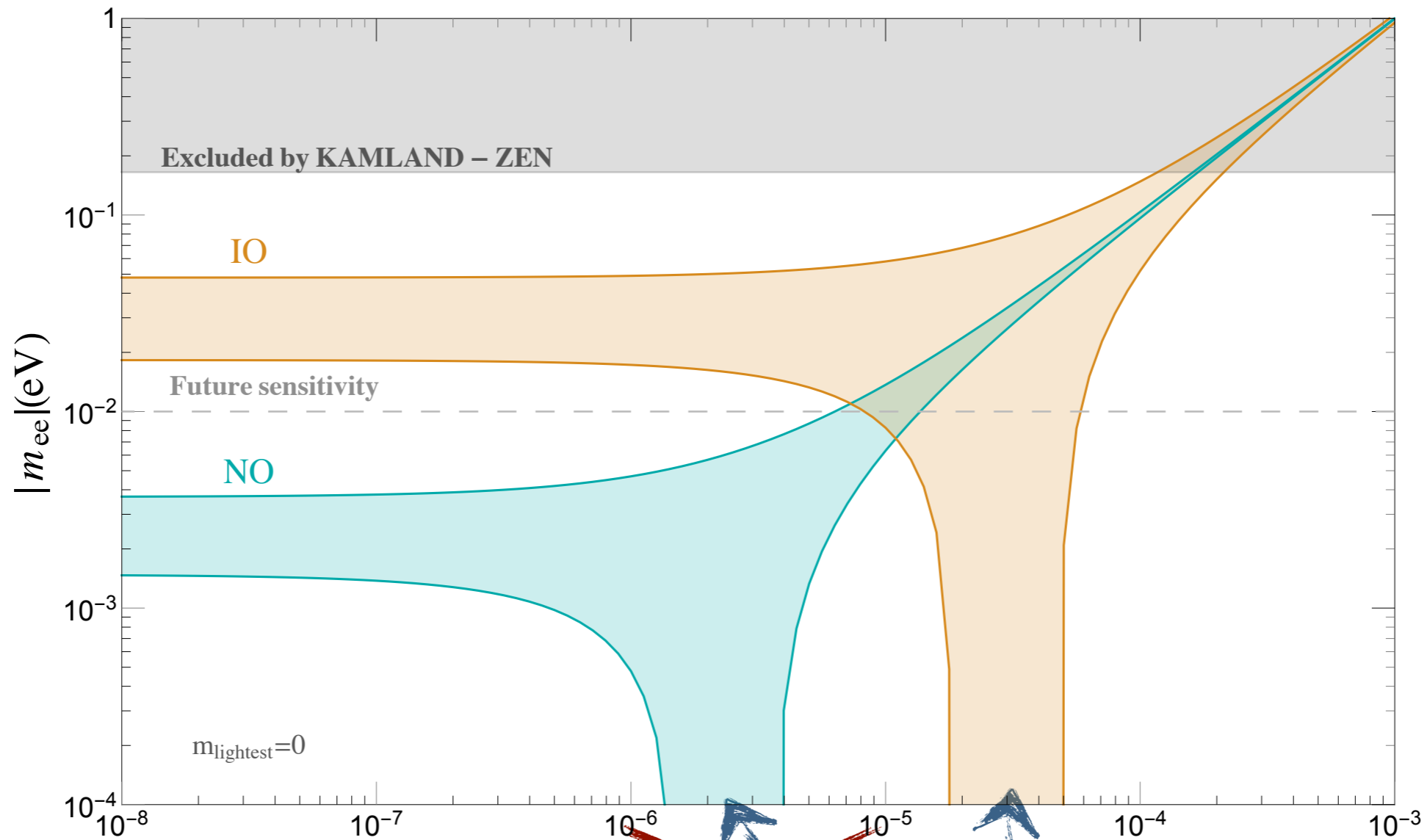
◆  $m_{ee}$  **if all the neutrinos are lighter** than the  $p^2 \sim (100 \text{ MeV})^2$ :

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



# TYPE I SEESAW MODELS

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



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

~~$m_4 |U_{e4}|^2$  (KeV)~~

They live here

# MINIMAL TYPE-I SEESAW WITH 2 RH

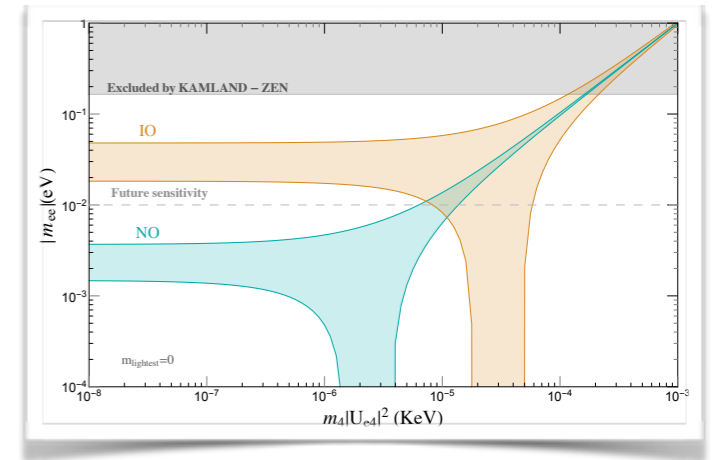
- ▶ **Minimal** realization needs **2 right-handed** neutrinos
- ▶ Fix  $\nu_4$  to the **KATRIN** regime and let  $\nu_5$  **free**

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

# MINIMAL TYPE-I SEESAW WITH 2 RH

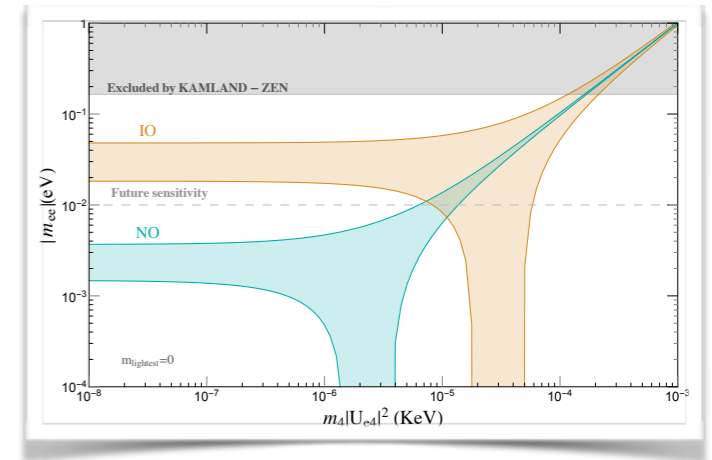
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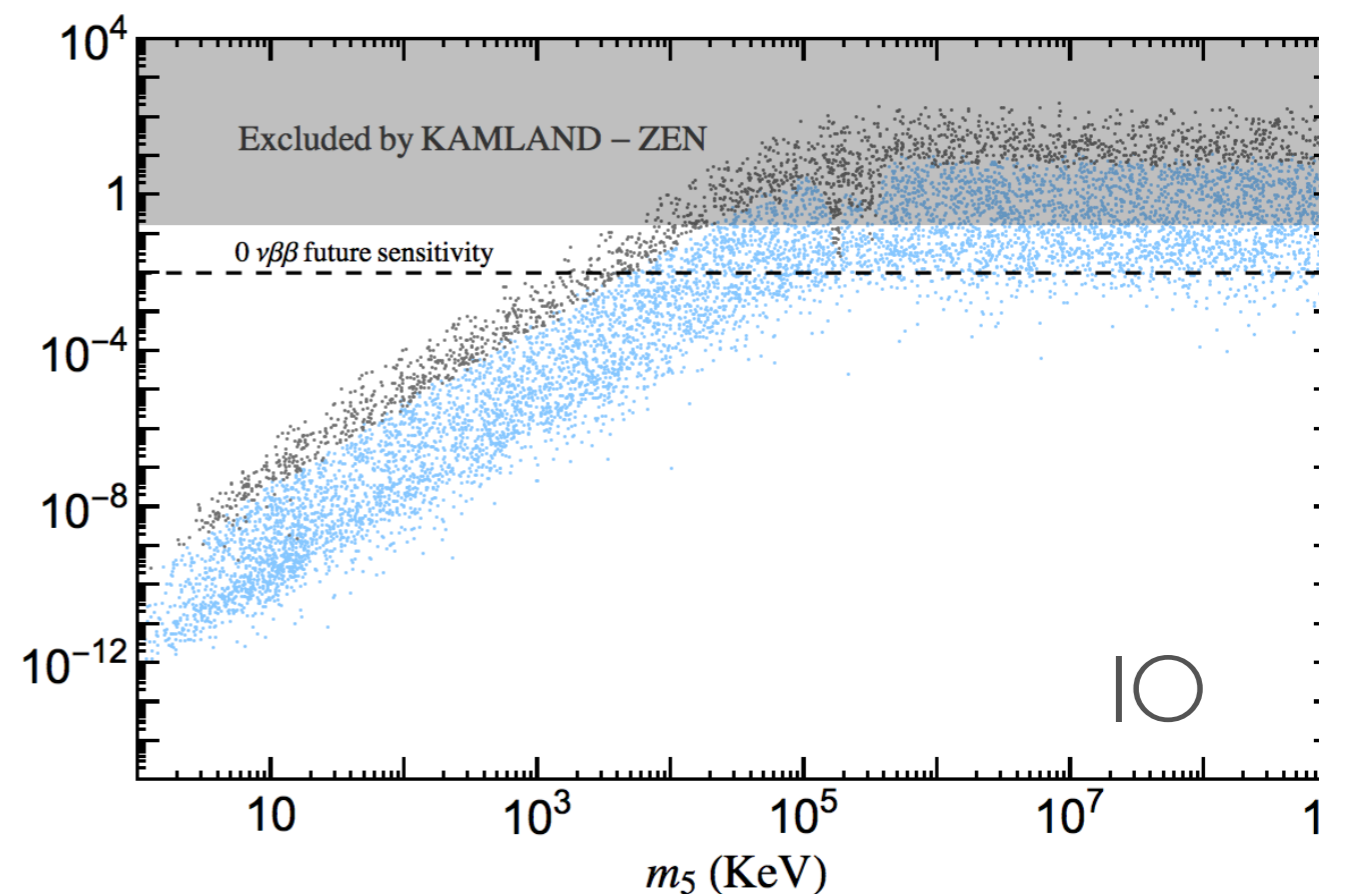
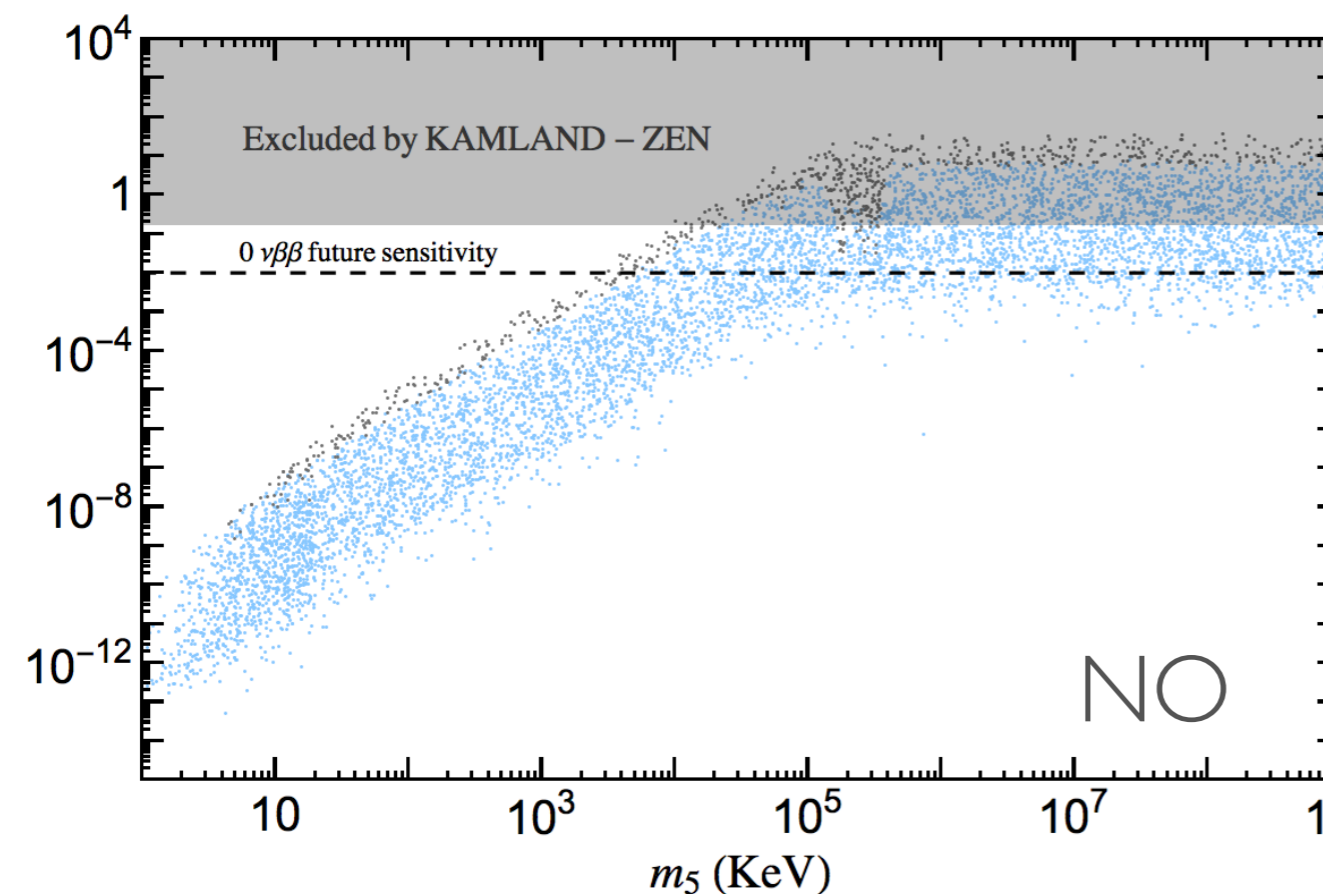


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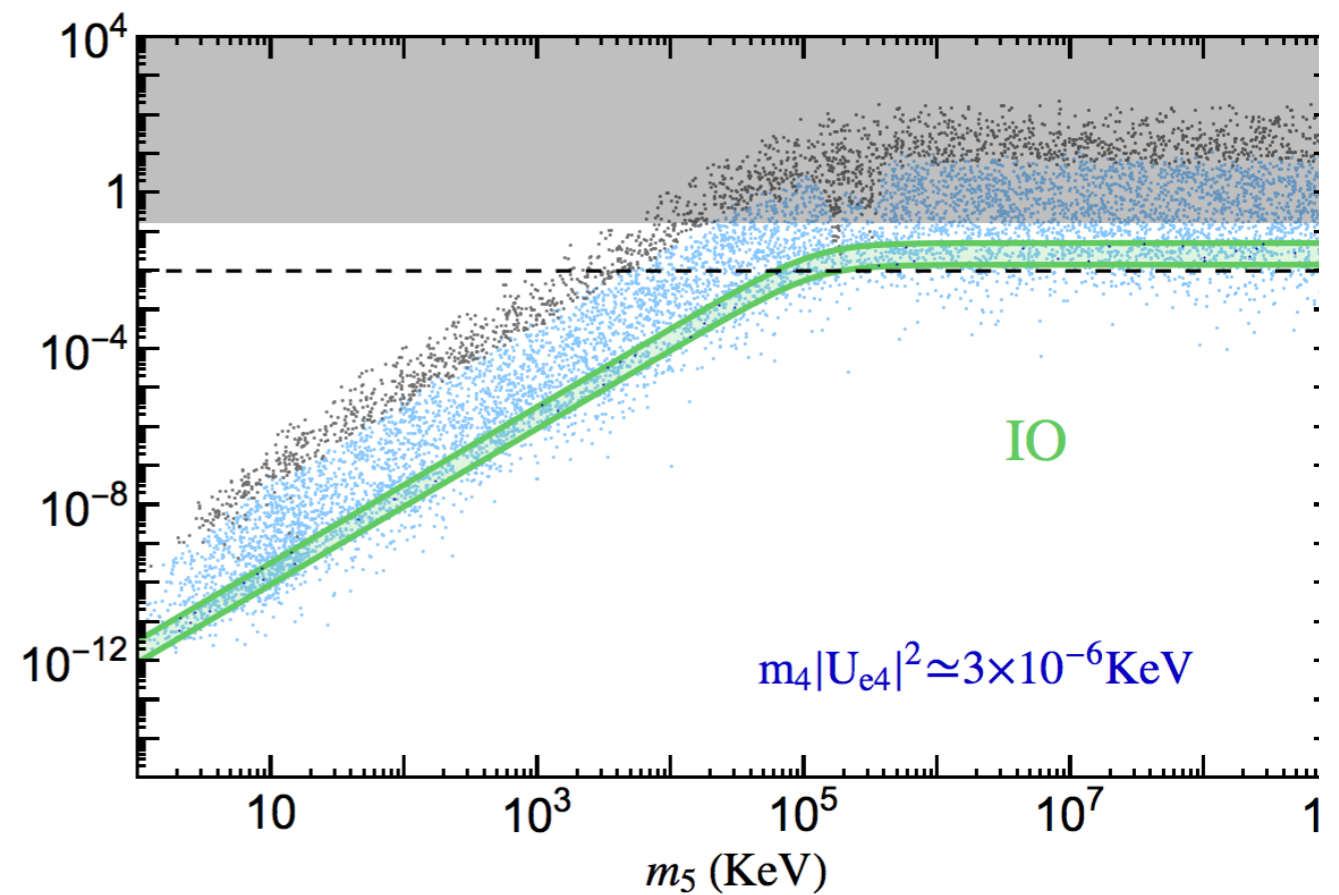
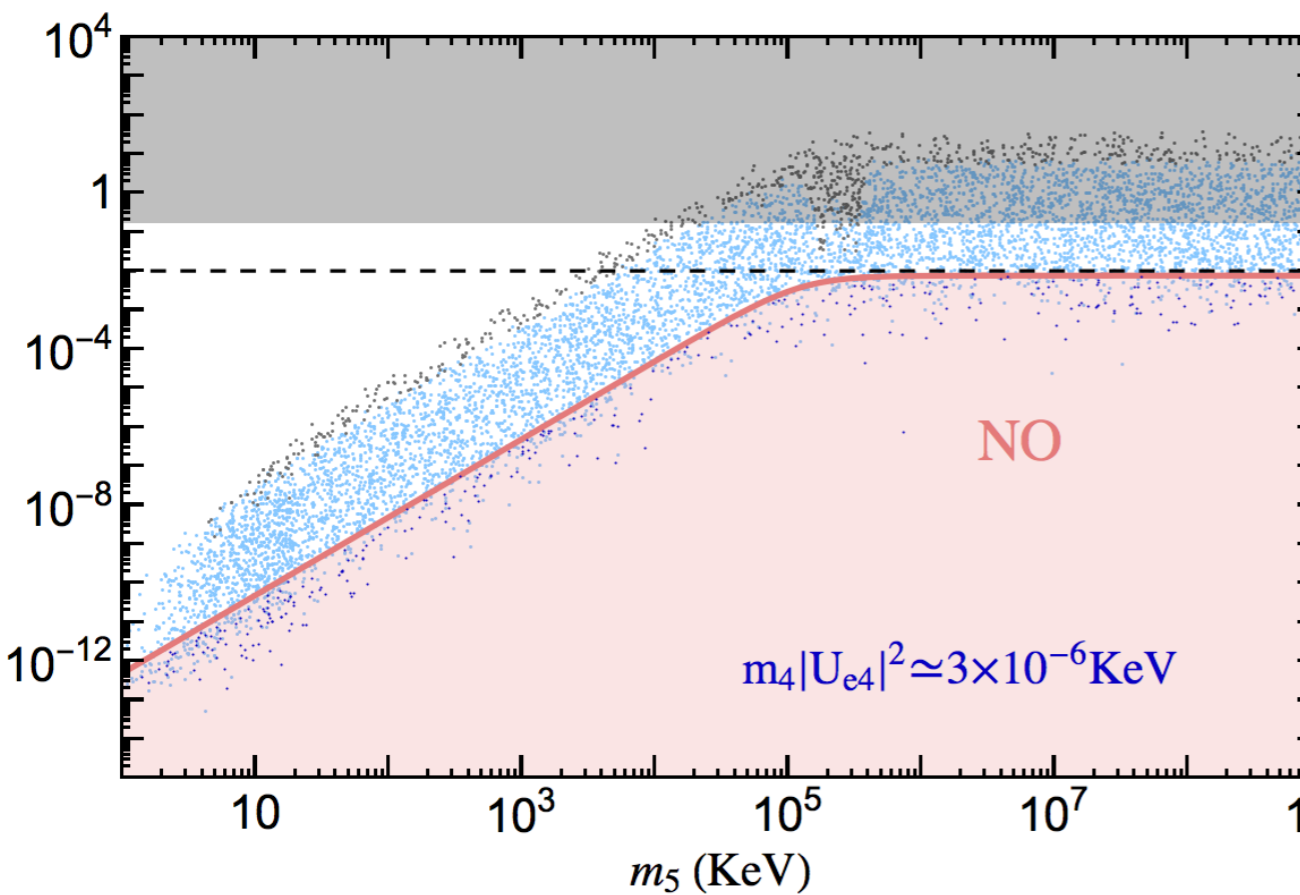
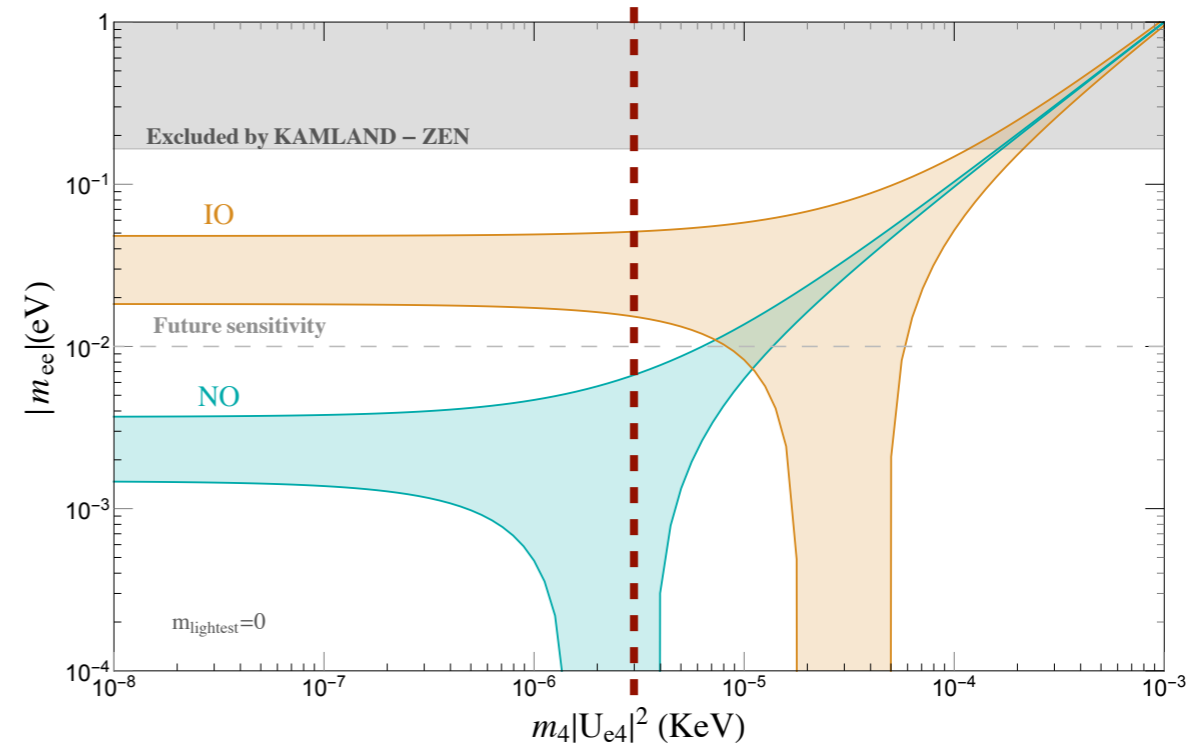
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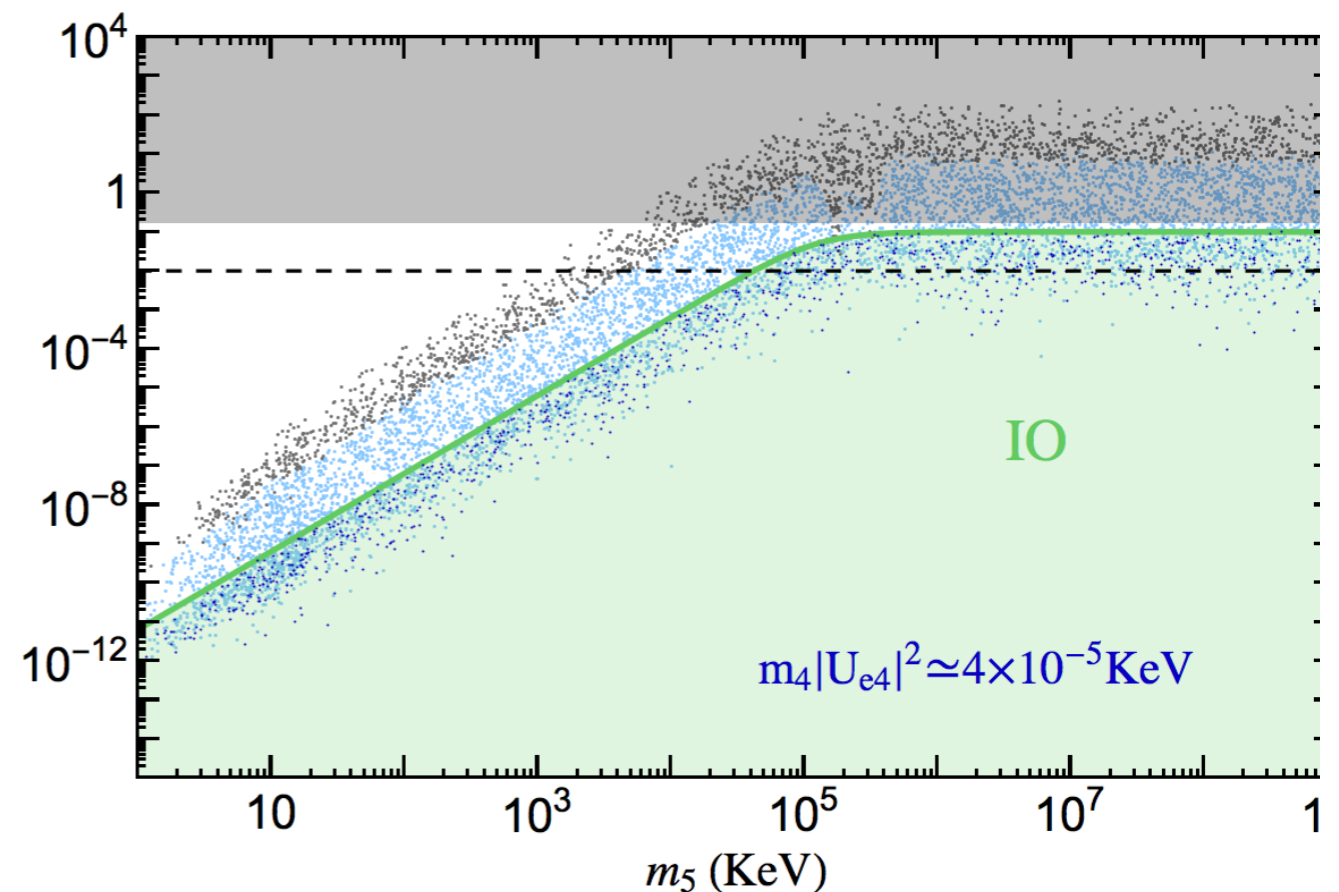
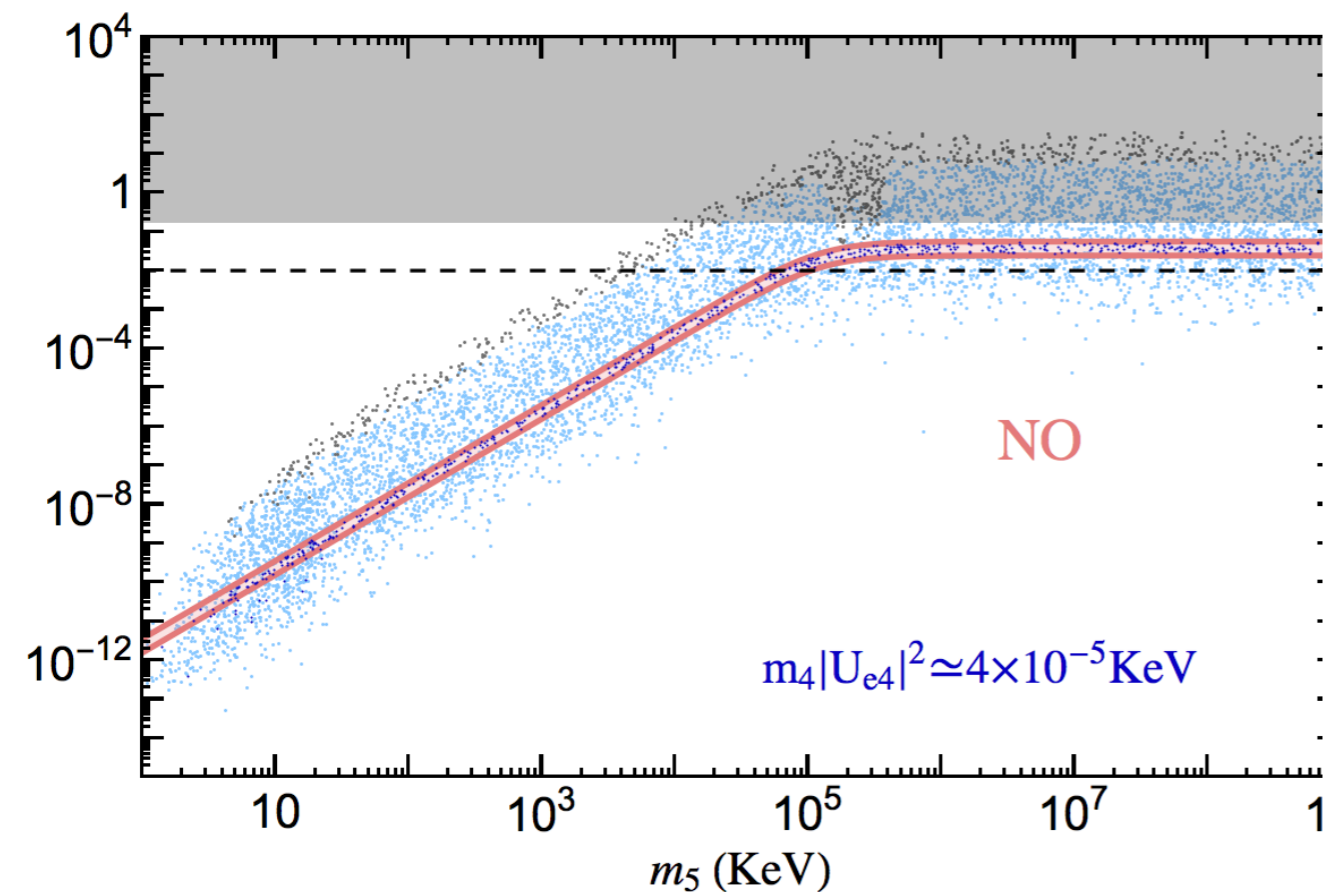
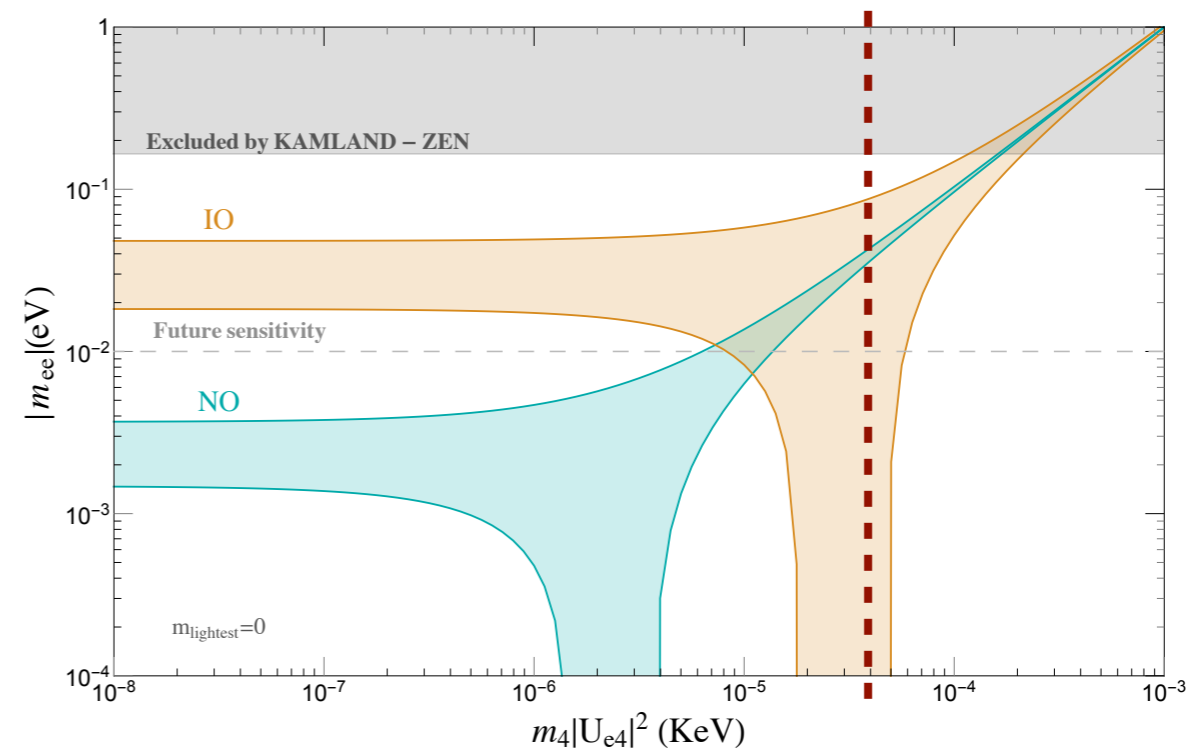
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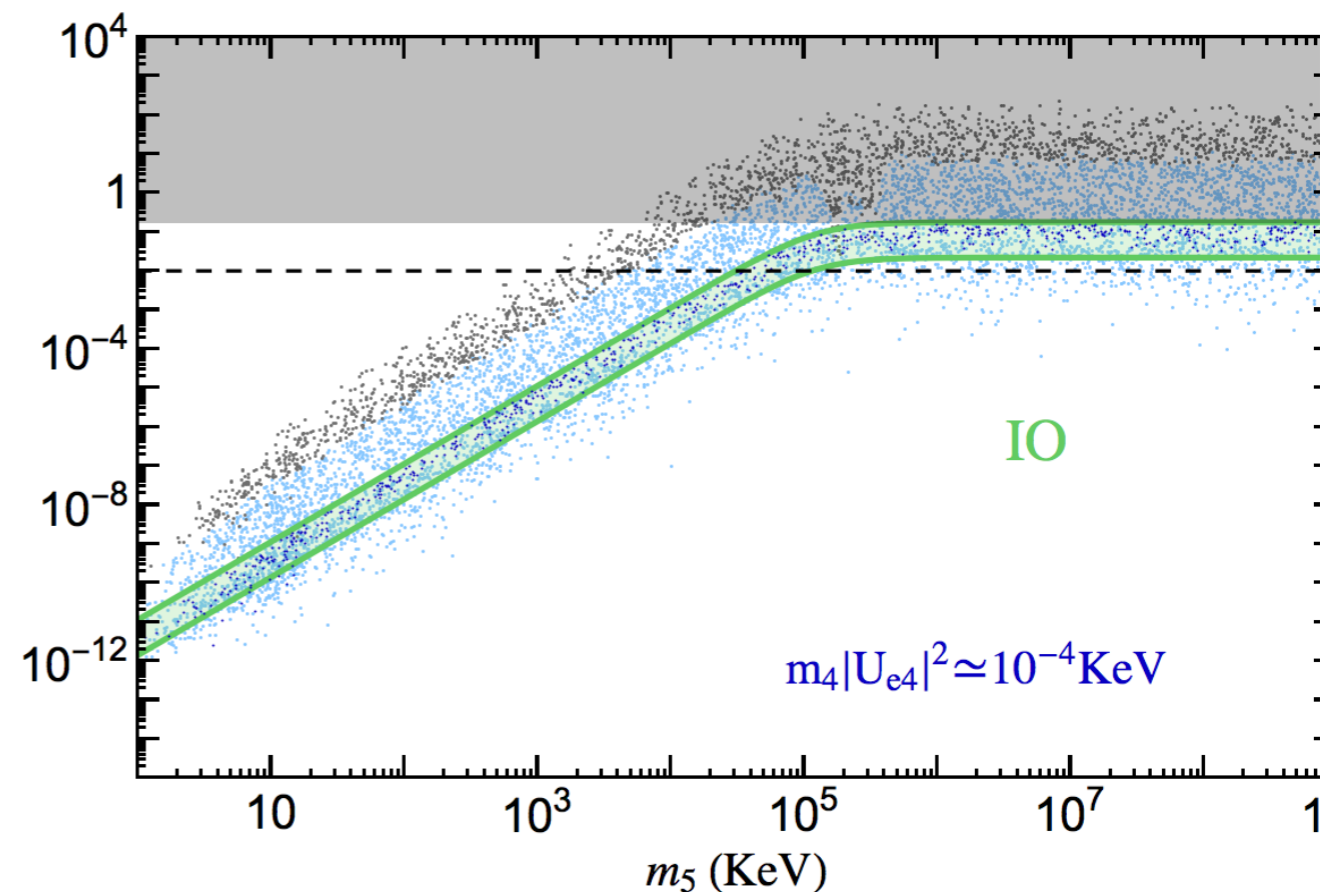
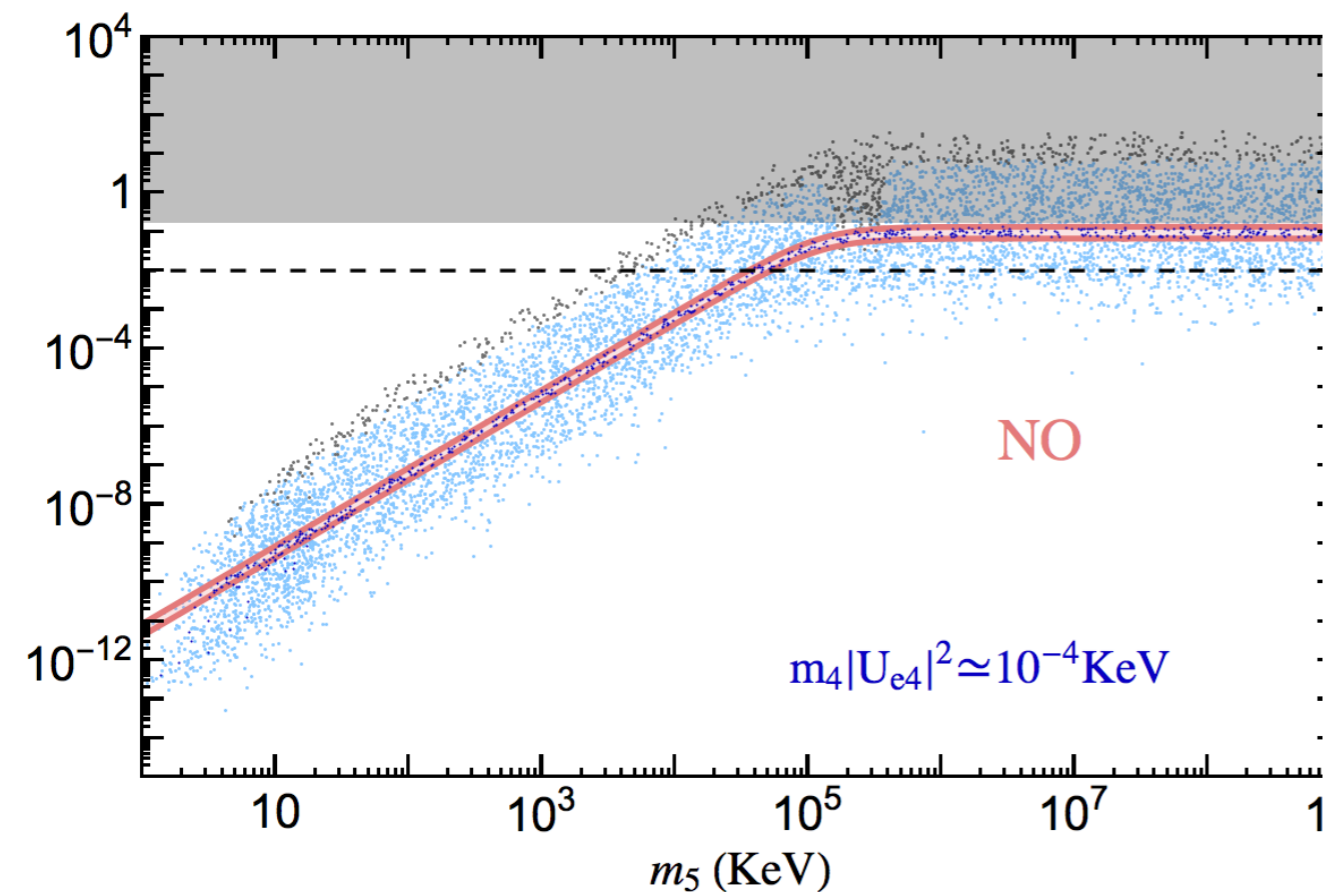
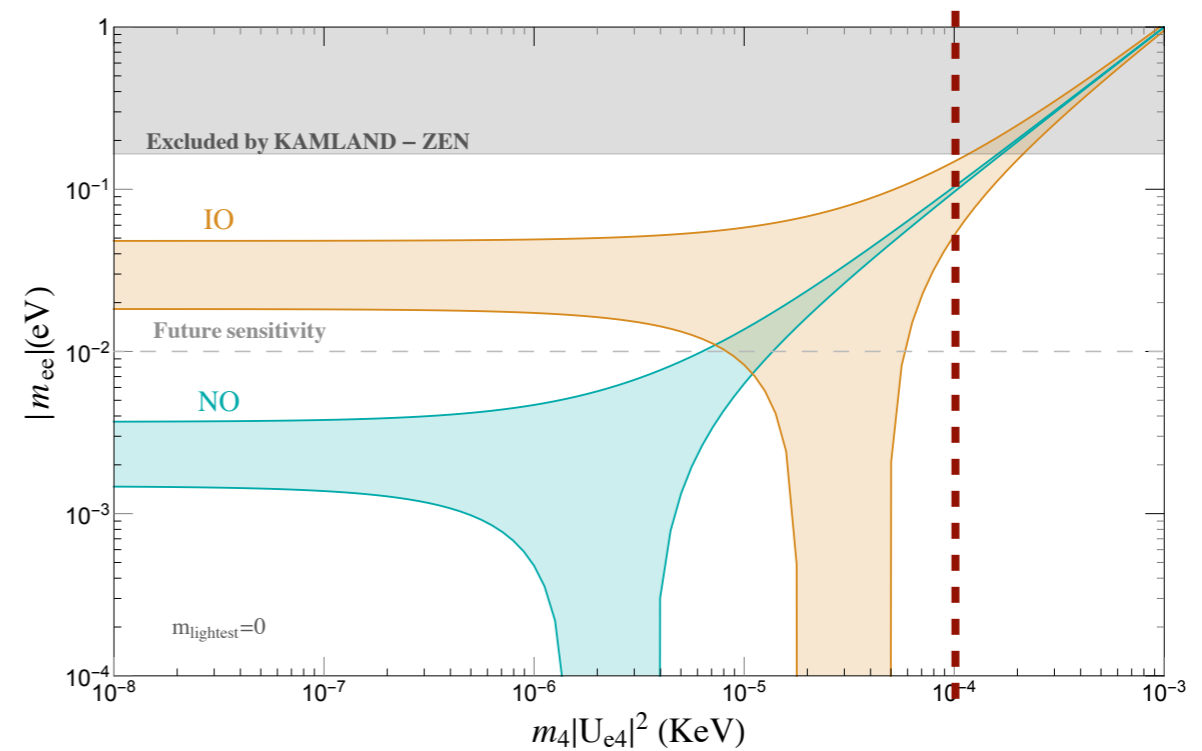
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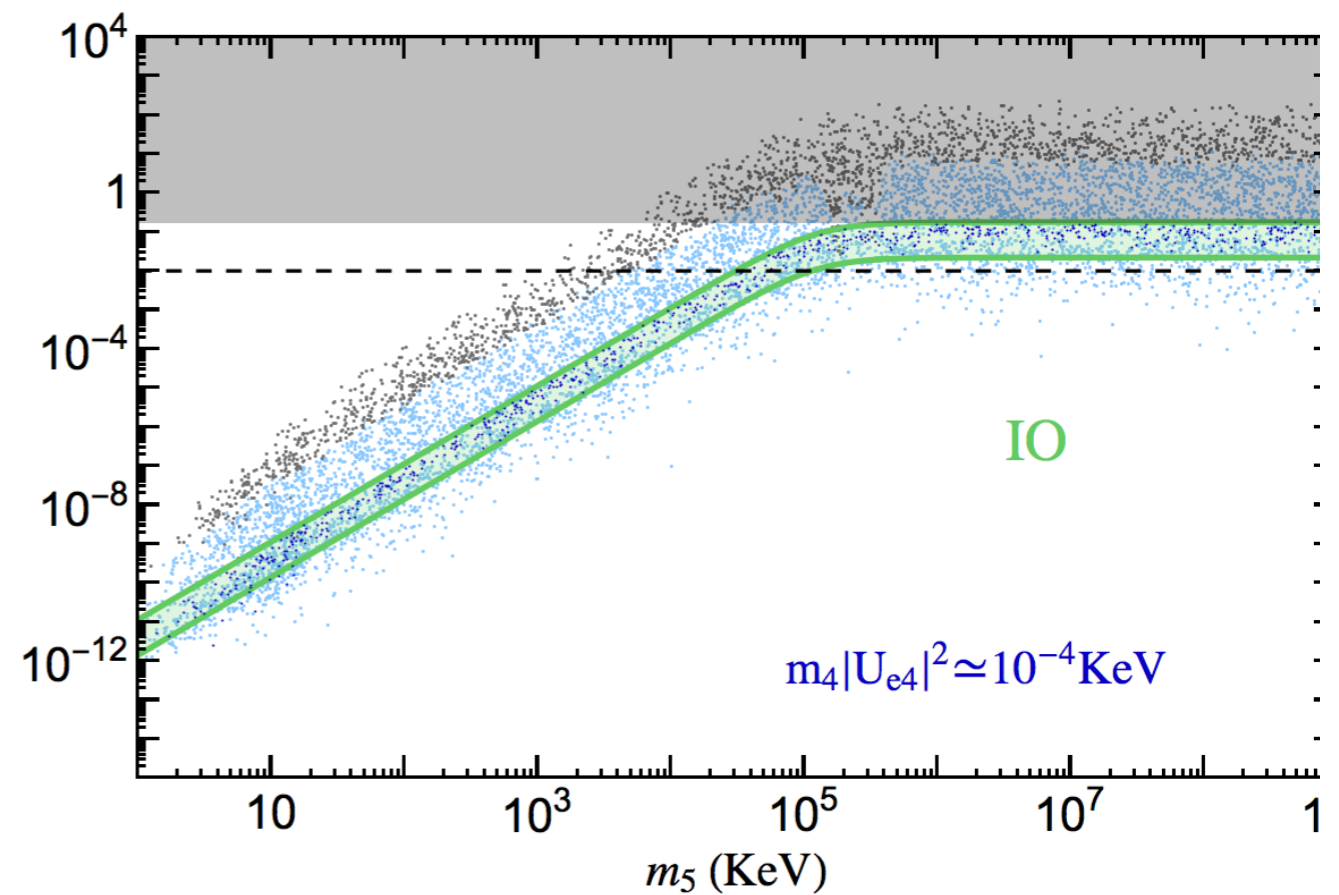
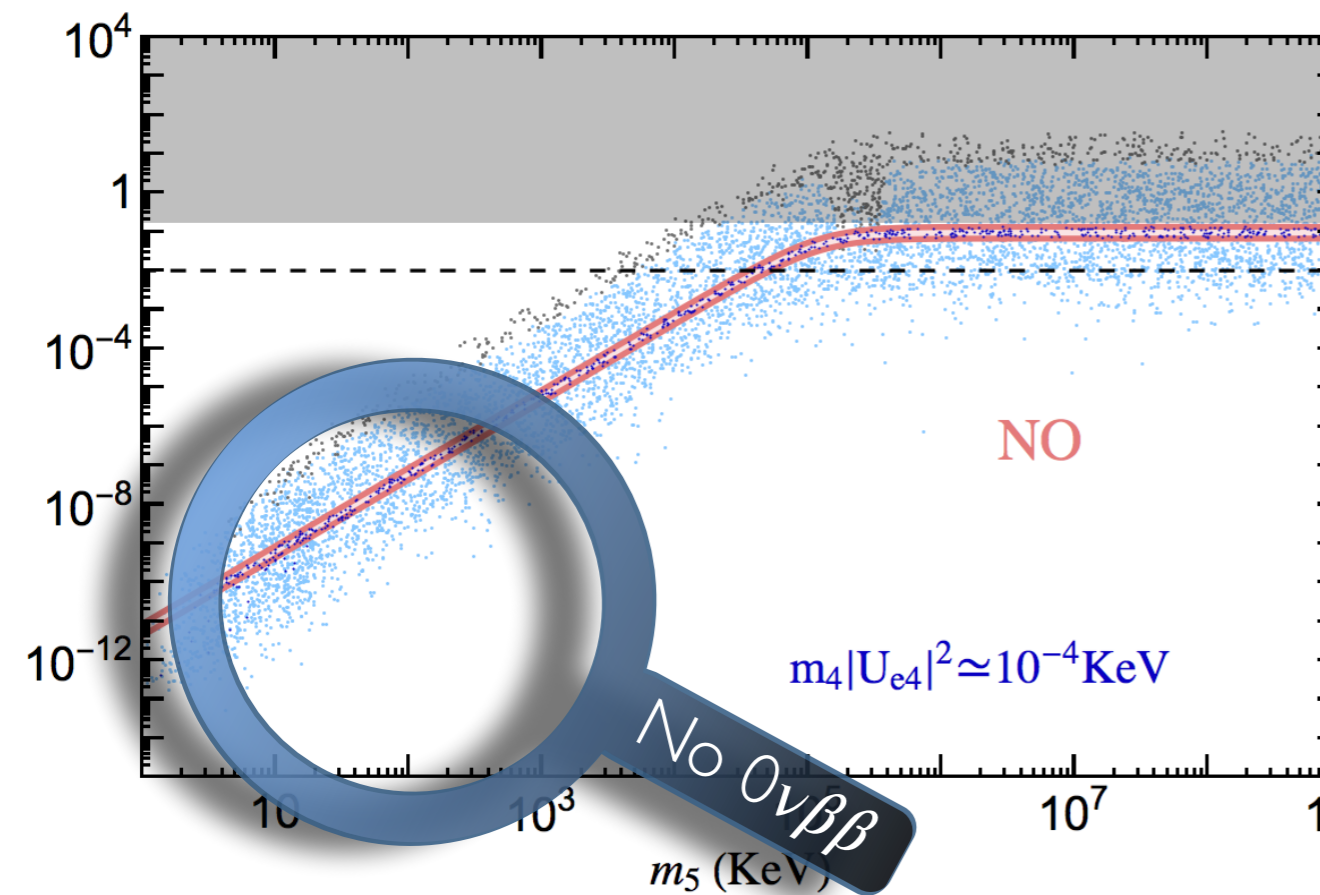
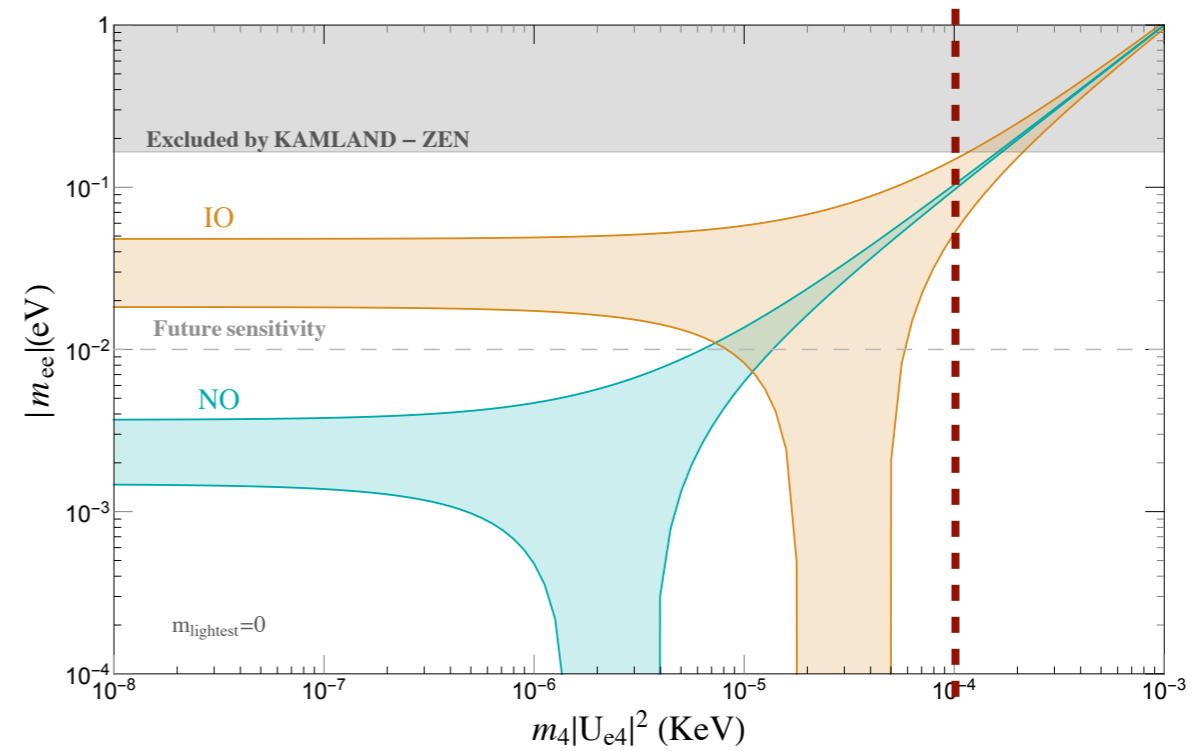
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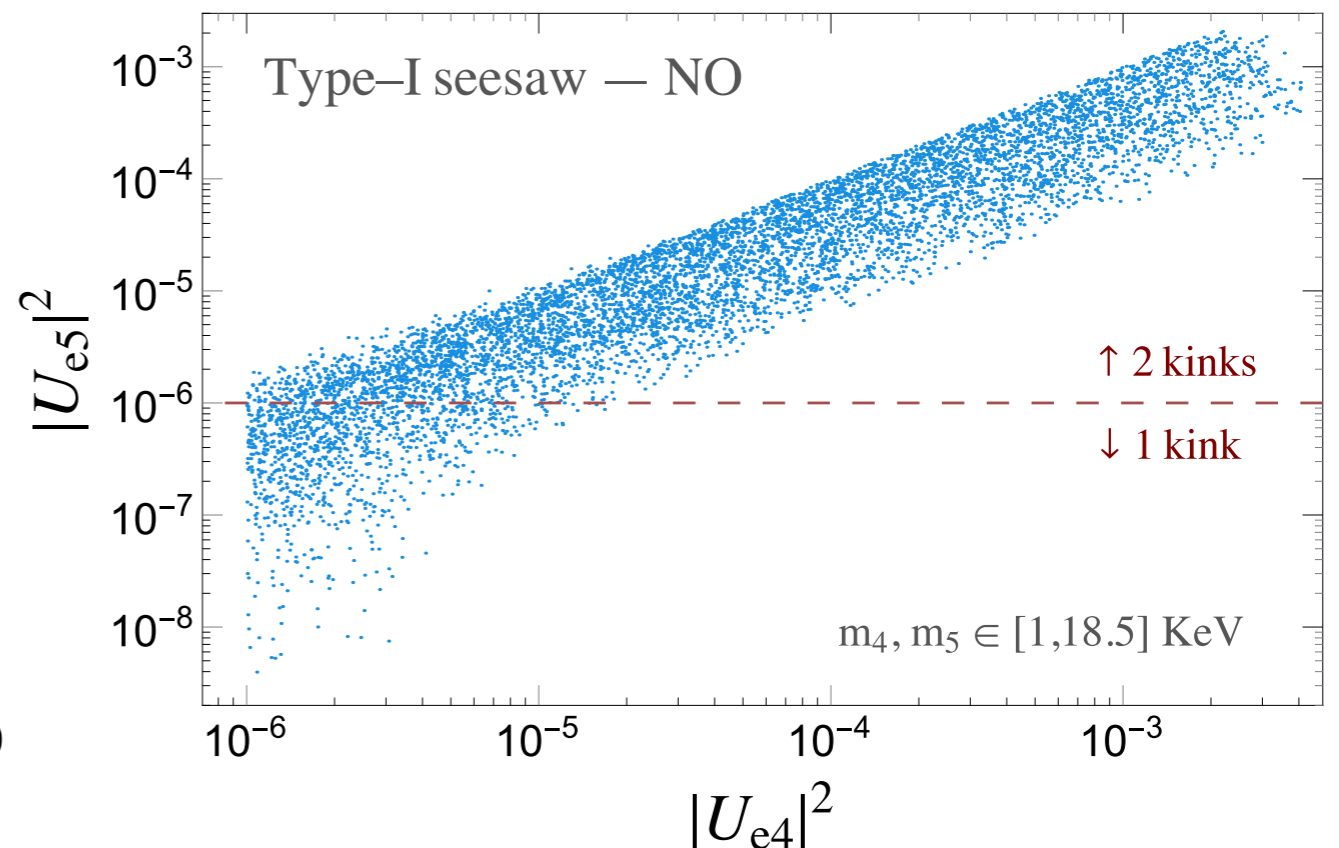
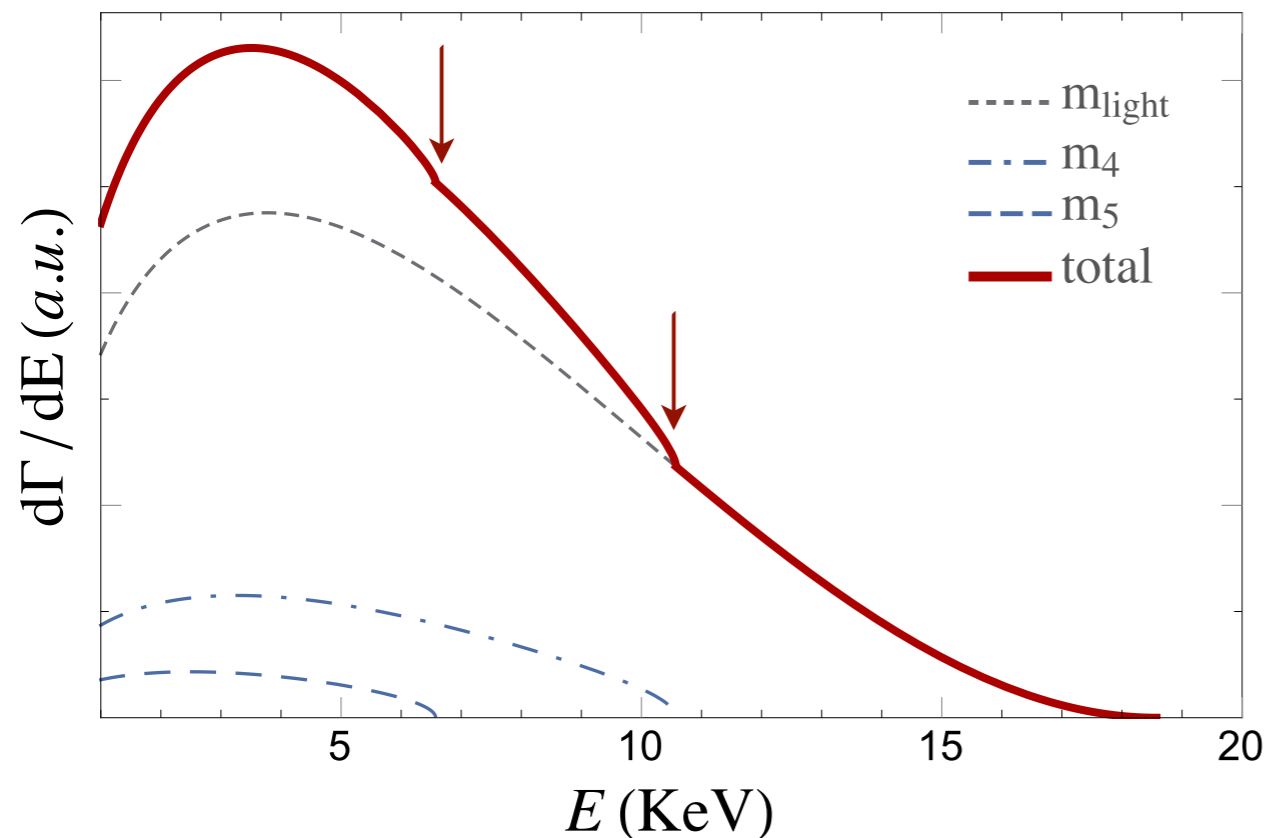
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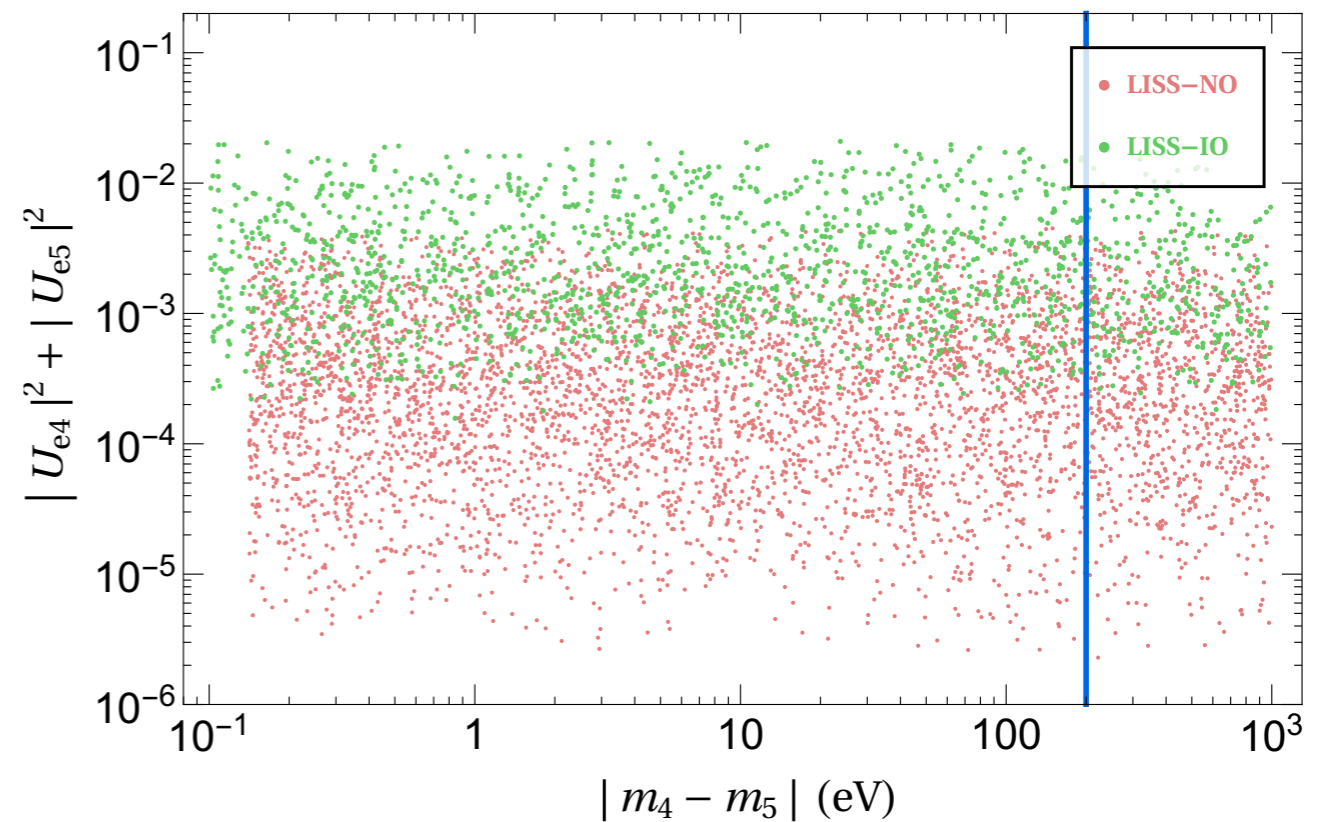
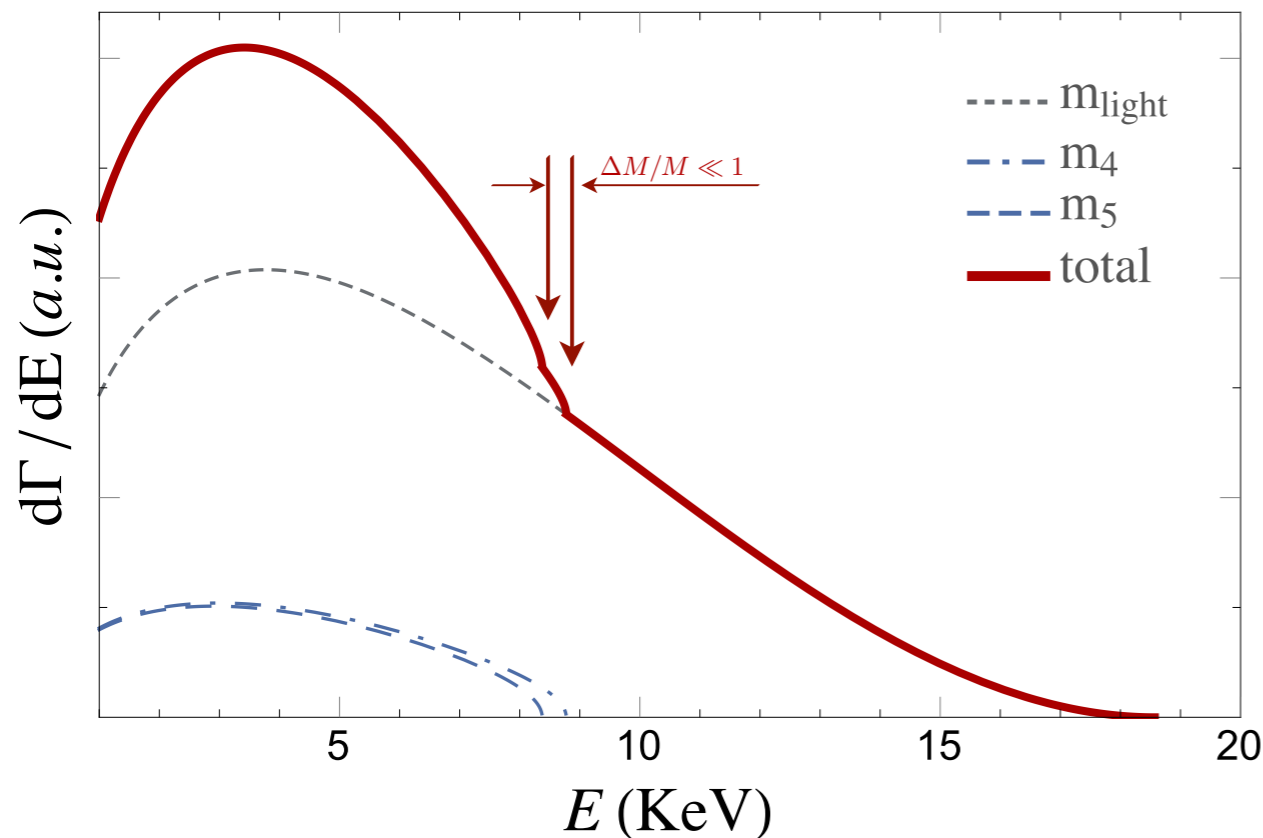
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- ▶ If they are close (**double-kink**) point towards Lepton Number Conservation





# CONCLUSIONS

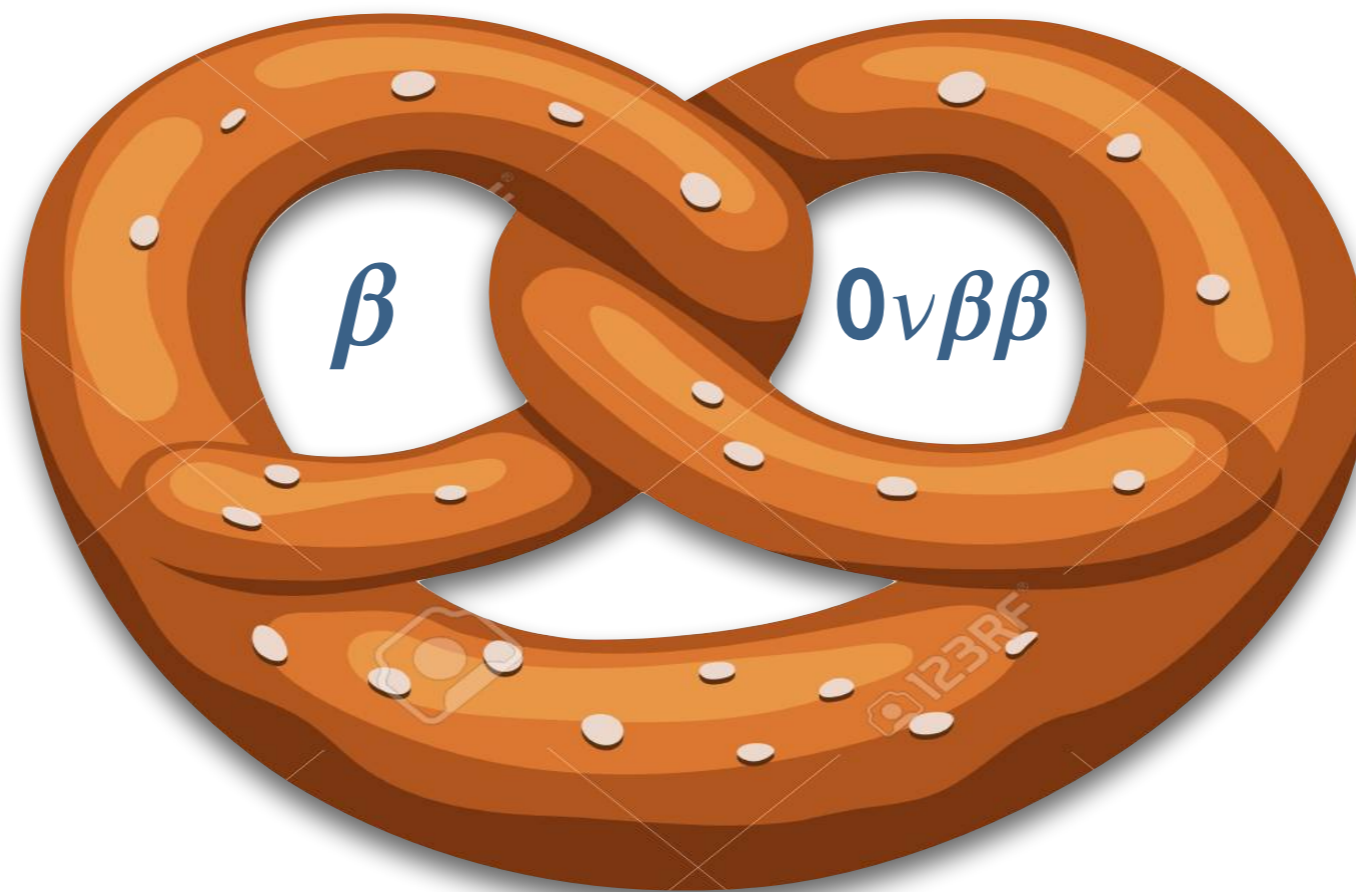
- ▶ **Intense experimental programme** for  $\beta$  and  $0\nu\beta\beta$  decays
- ▶ Could be extended to **kink searches** in  $\beta$  decays

## 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  $\beta$  and  $0\nu\beta\beta$  decays could help disentangling the various possible models for neutrino masses**

# THANK YOU!



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