β AND $0\nu\beta\beta$ DECAYS WITH STERILE NEUTRINOS

LPT, Orsay

xabier.marcano@th.u-psud.fr

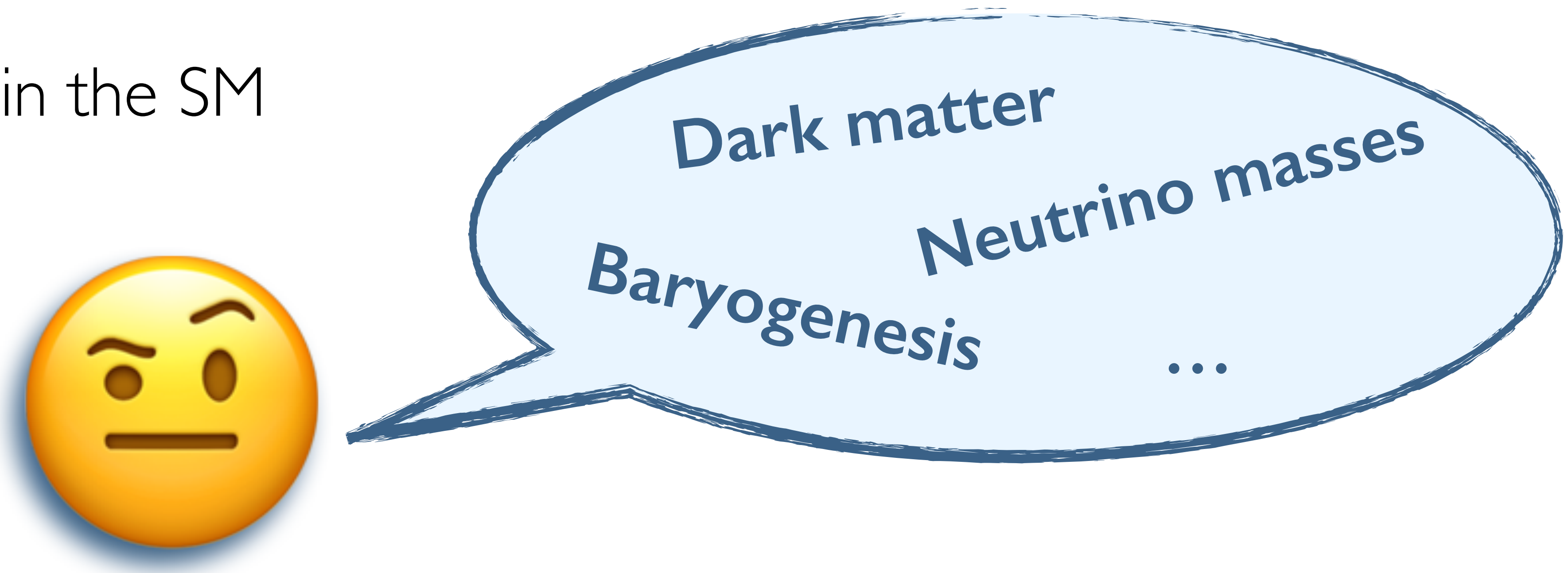
Work in progress with

Asmaa Abada and Alvaro Hernandez-Cabezudo

APC Paris, GDR Neutrino meeting June18

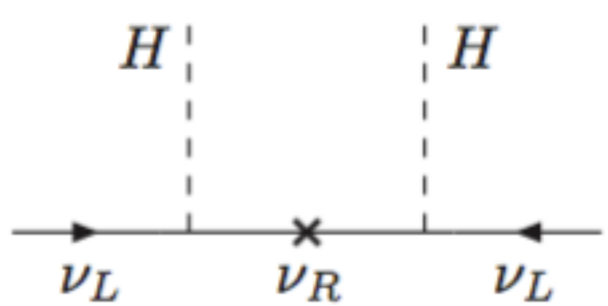
WHY STERILE NEUTRINOS

- Open problems in the SM

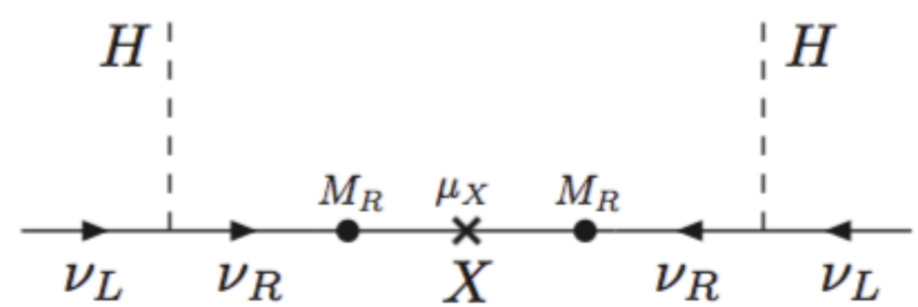


- **New Physics is needed** to solve these issues

- 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

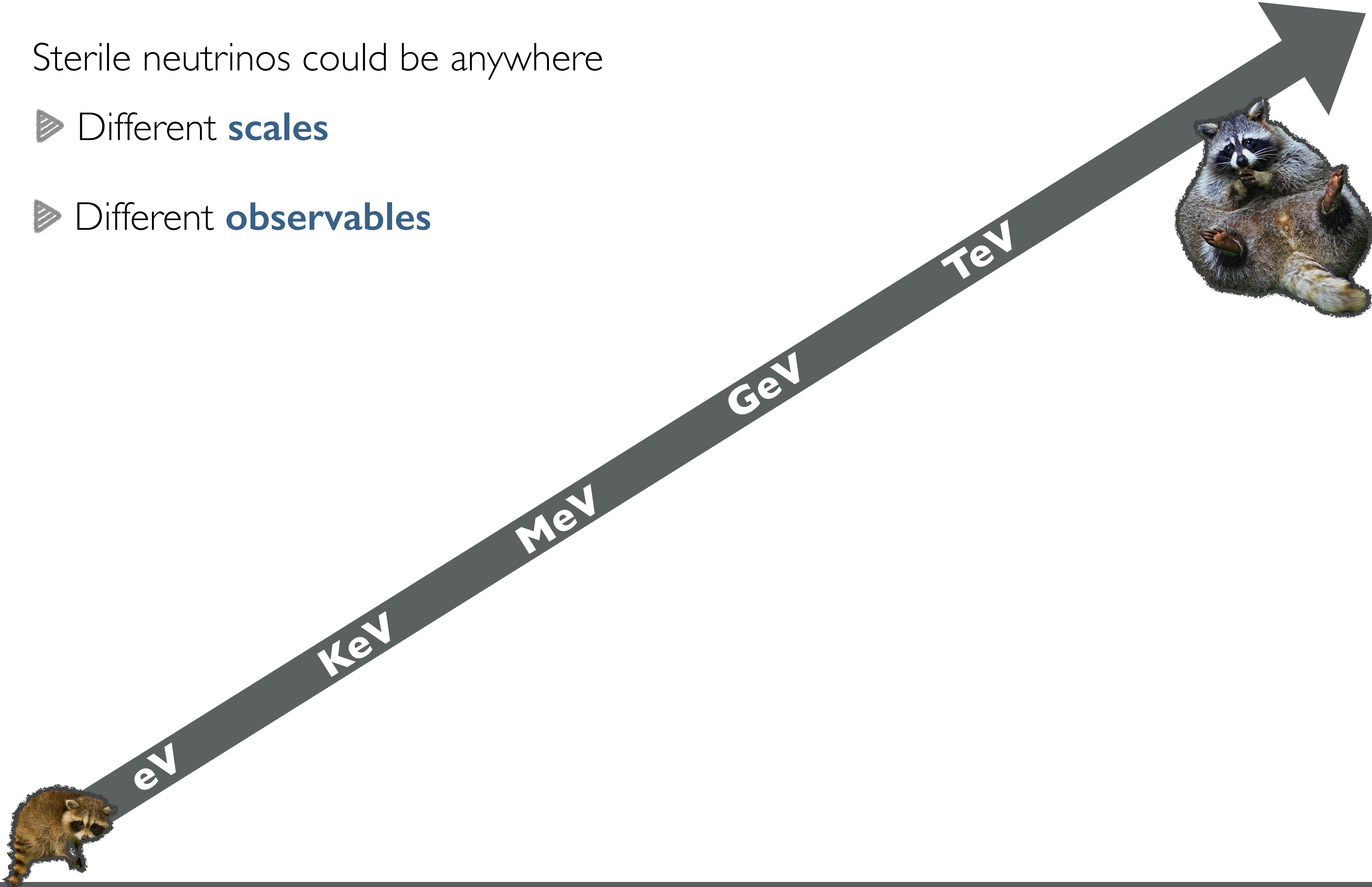
- **Sterile neutrinos:** SM singlets, **only via mixing** to active neutrinos

Broad phenomenology

Sterile neutrinos could be anywhere

- Different **scales**

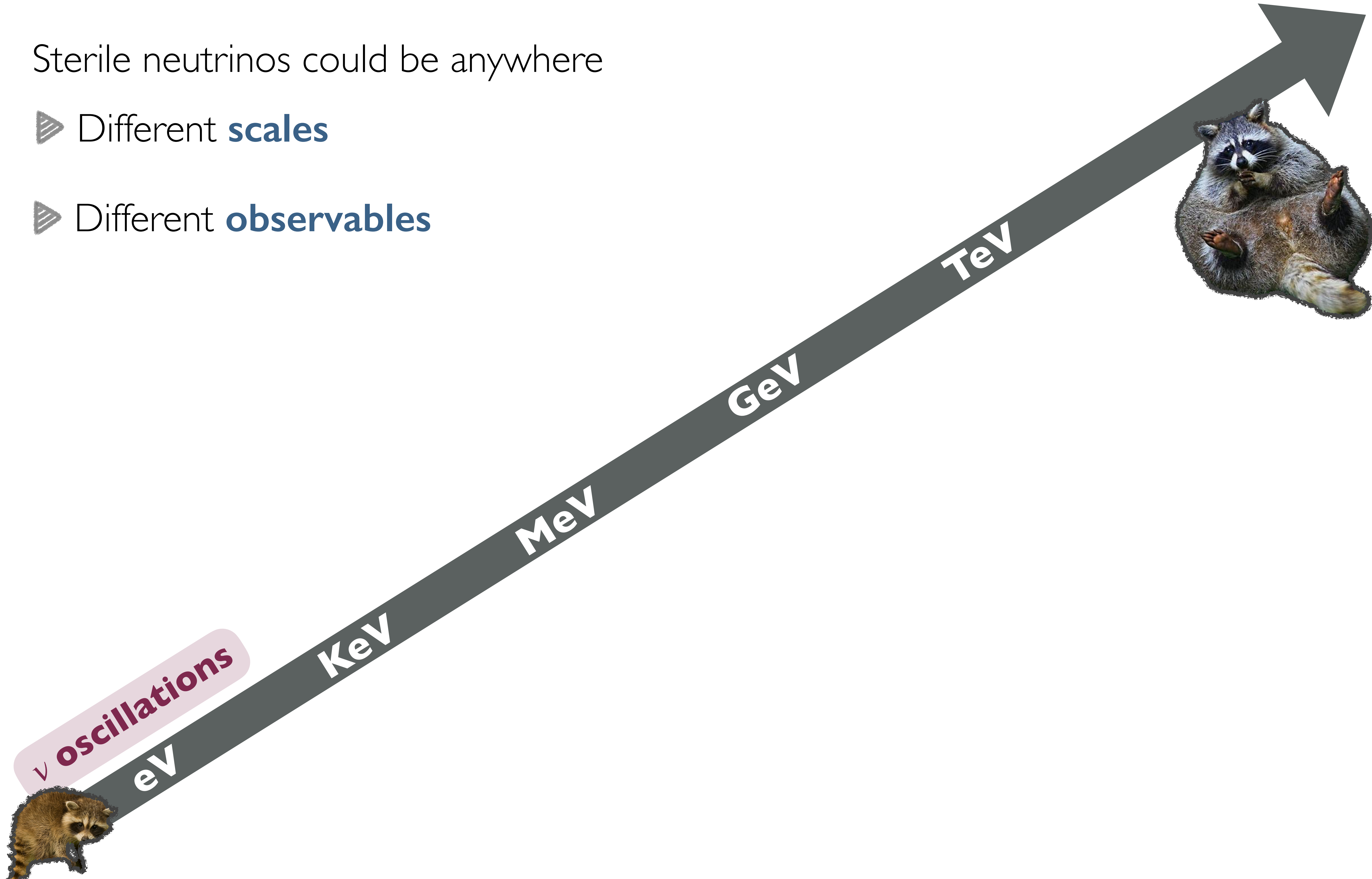
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

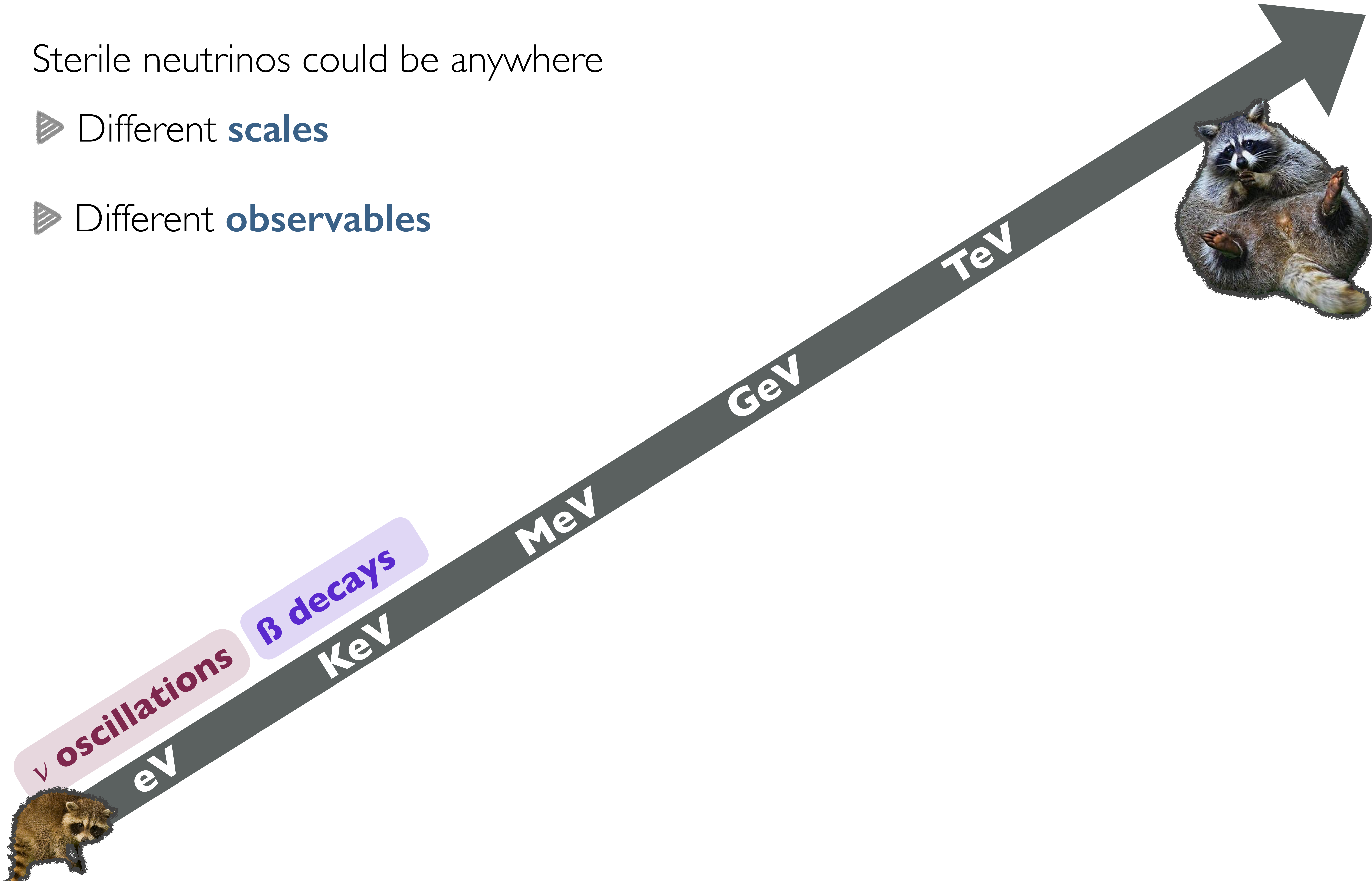
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

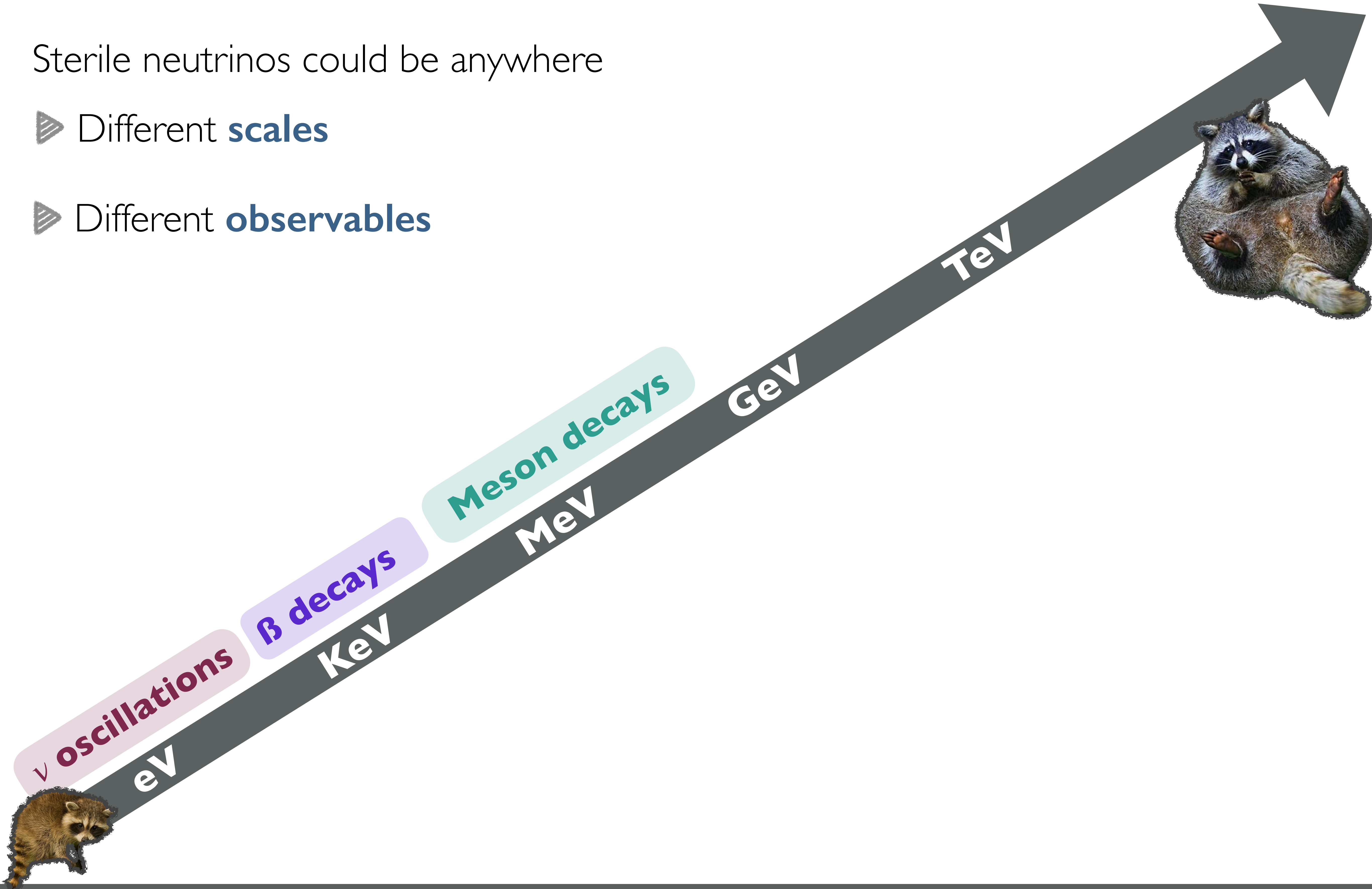
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

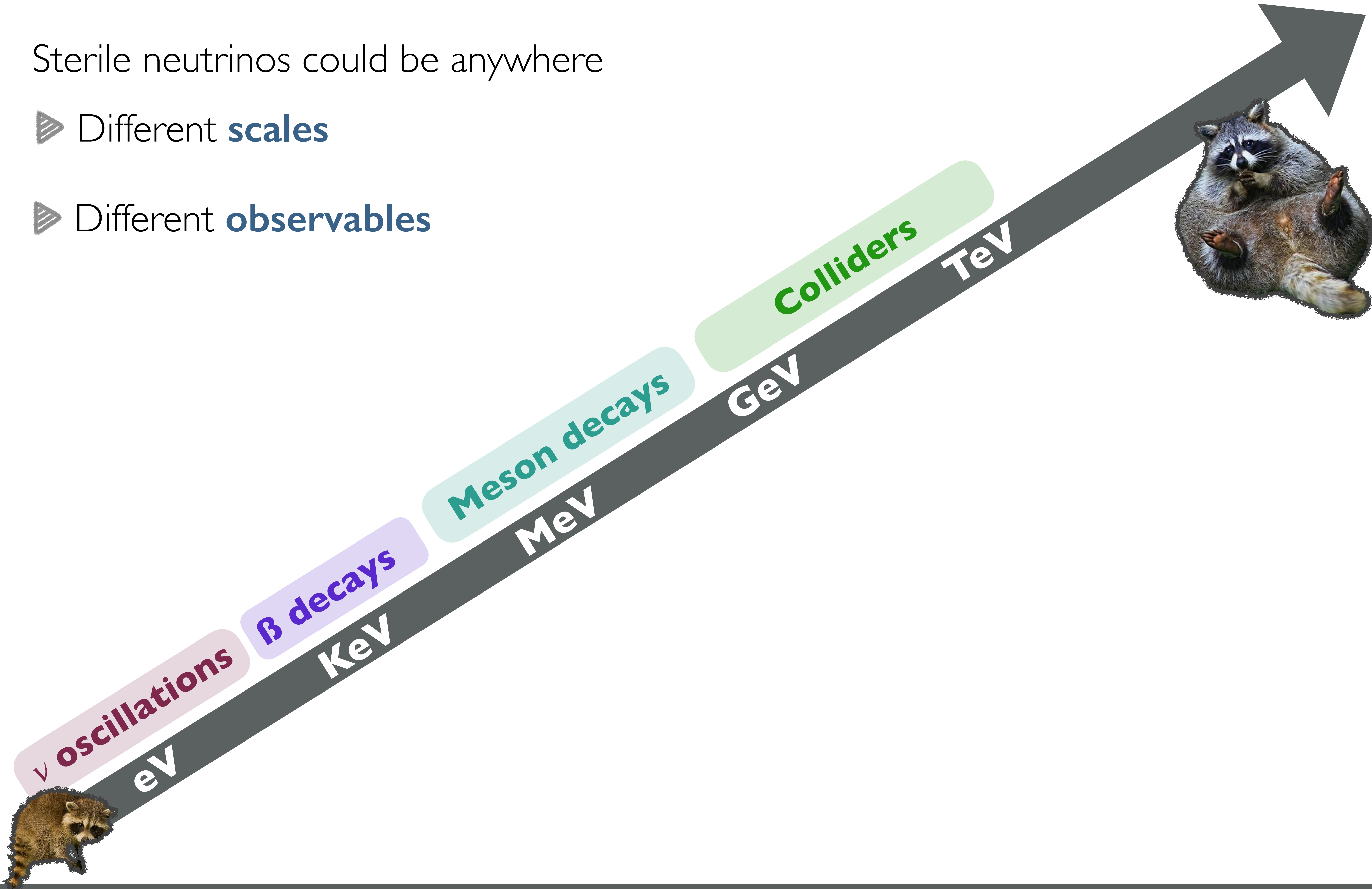
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

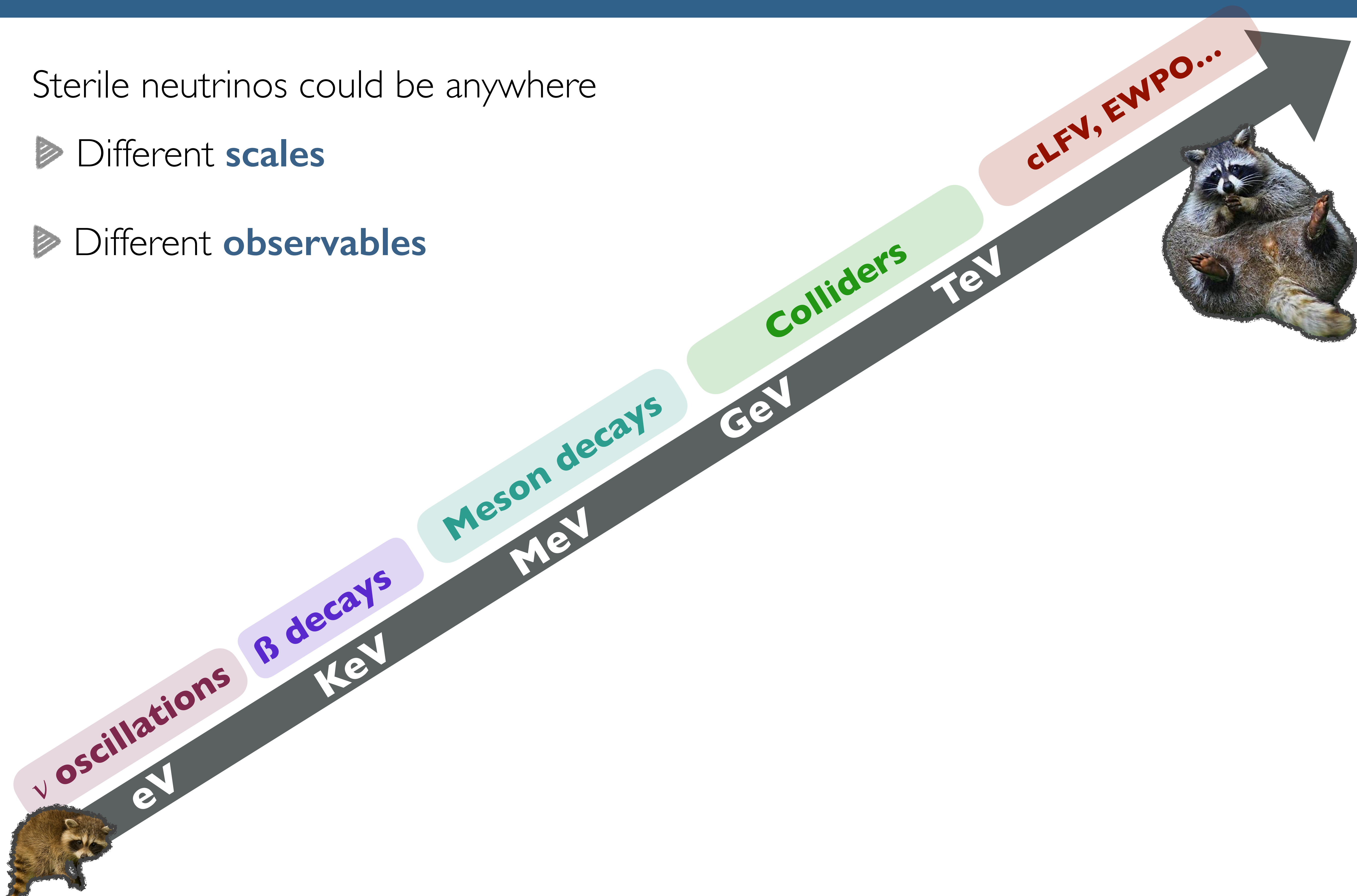
- Different **scales**
- Different **observables**



BROAD PHENOMENOLOGY

Sterile neutrinos could be anywhere

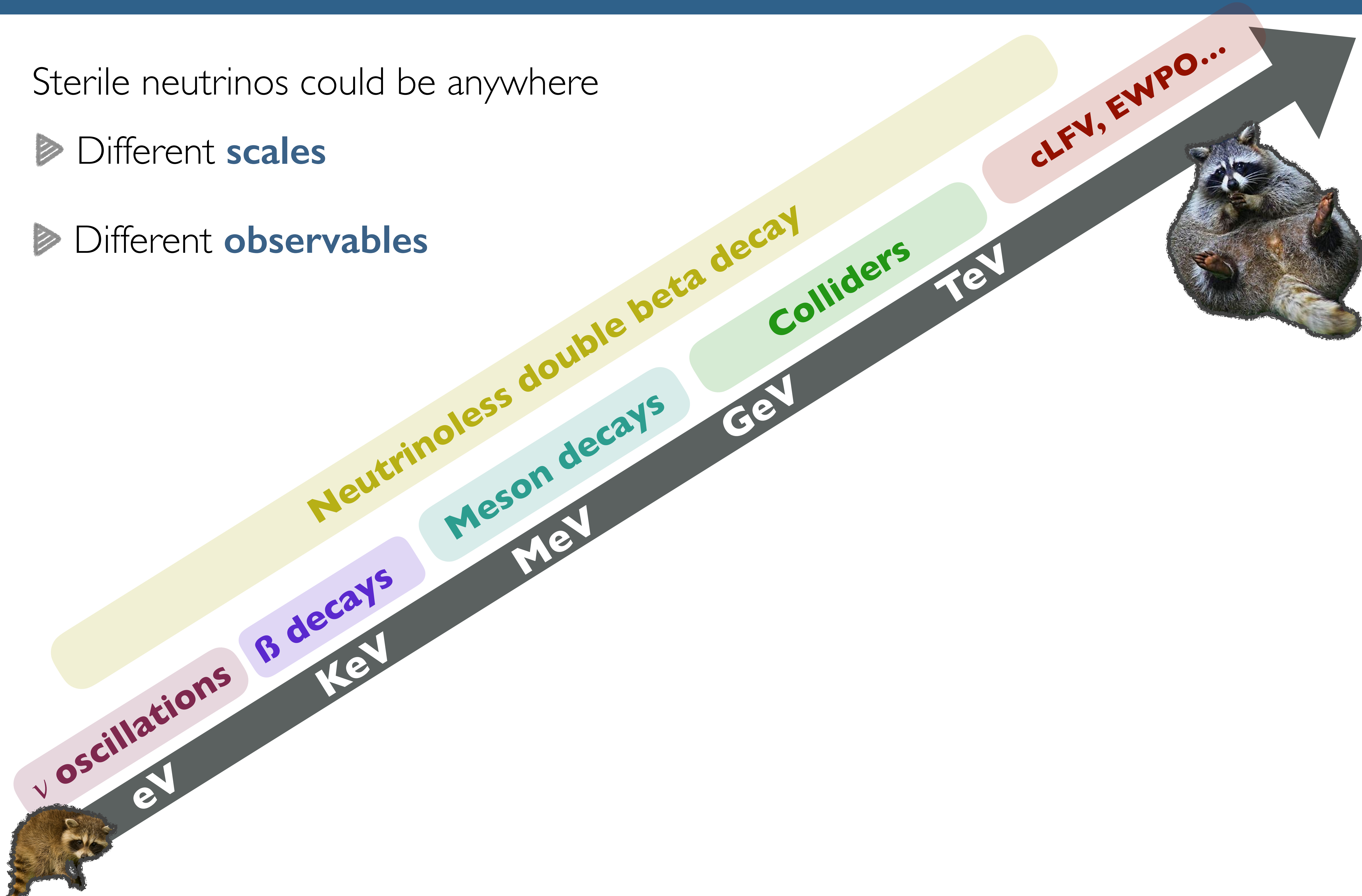
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

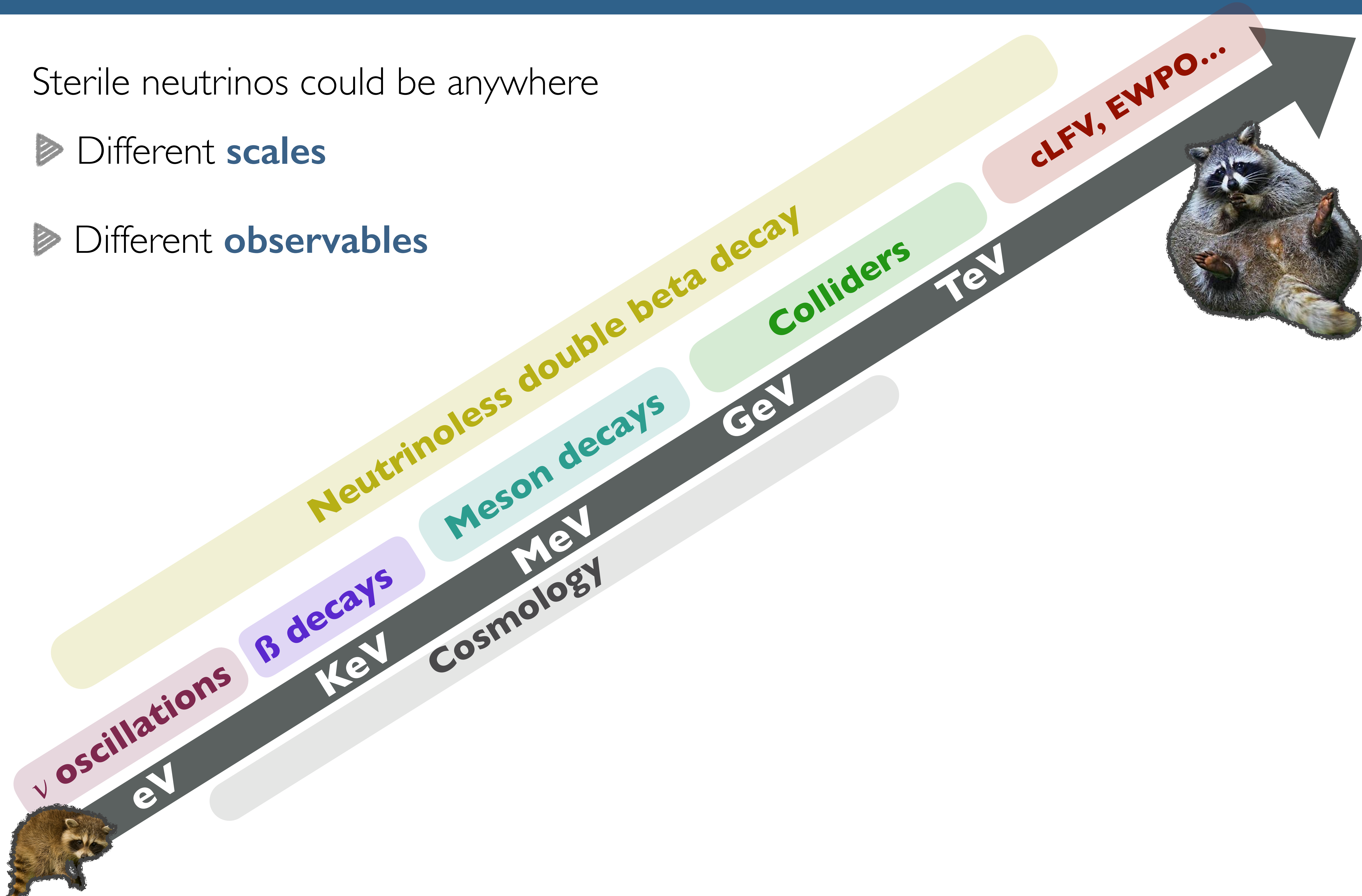
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

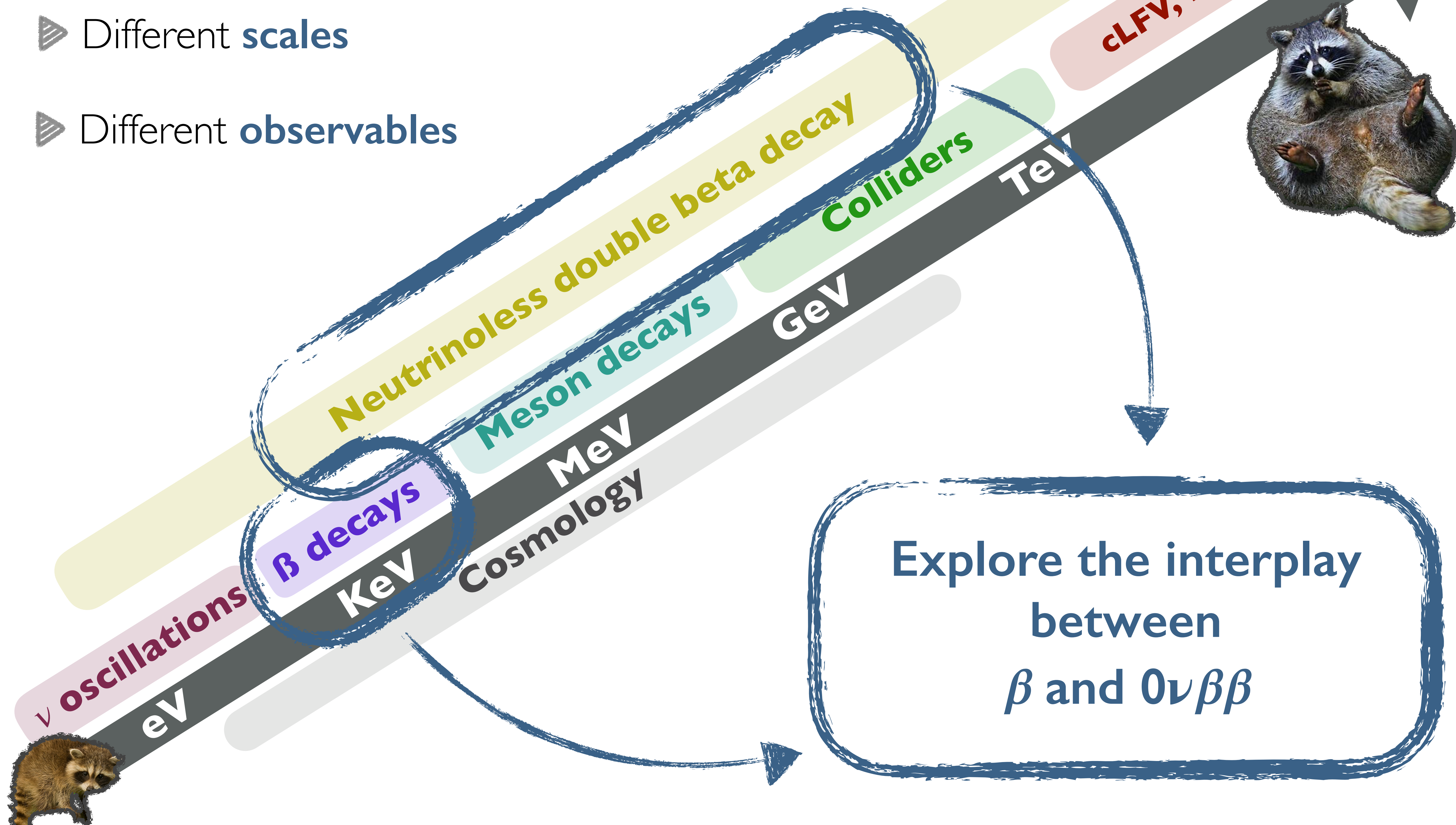
- Different **scales**
- Different **observables**



Broad phenomenology

Sterile neutrinos could be anywhere

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



Explore the interplay between β and $0\nu\beta\beta$

Outline

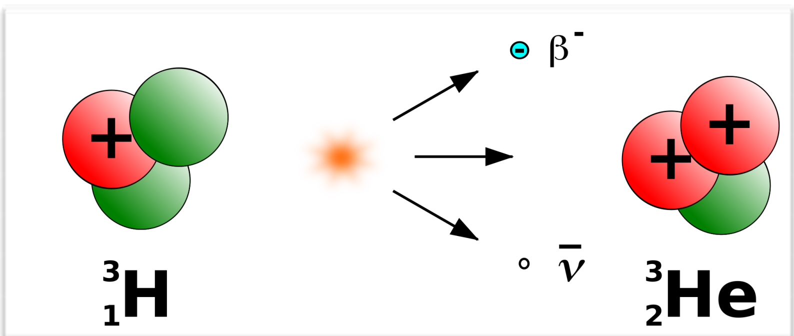
- **Experimental status** for β and $0\nu\beta\beta$ decays

- The **role of sterile neutrinos** in β and $0\nu\beta\beta$ decays

- **Implications** for type-I seesaw models

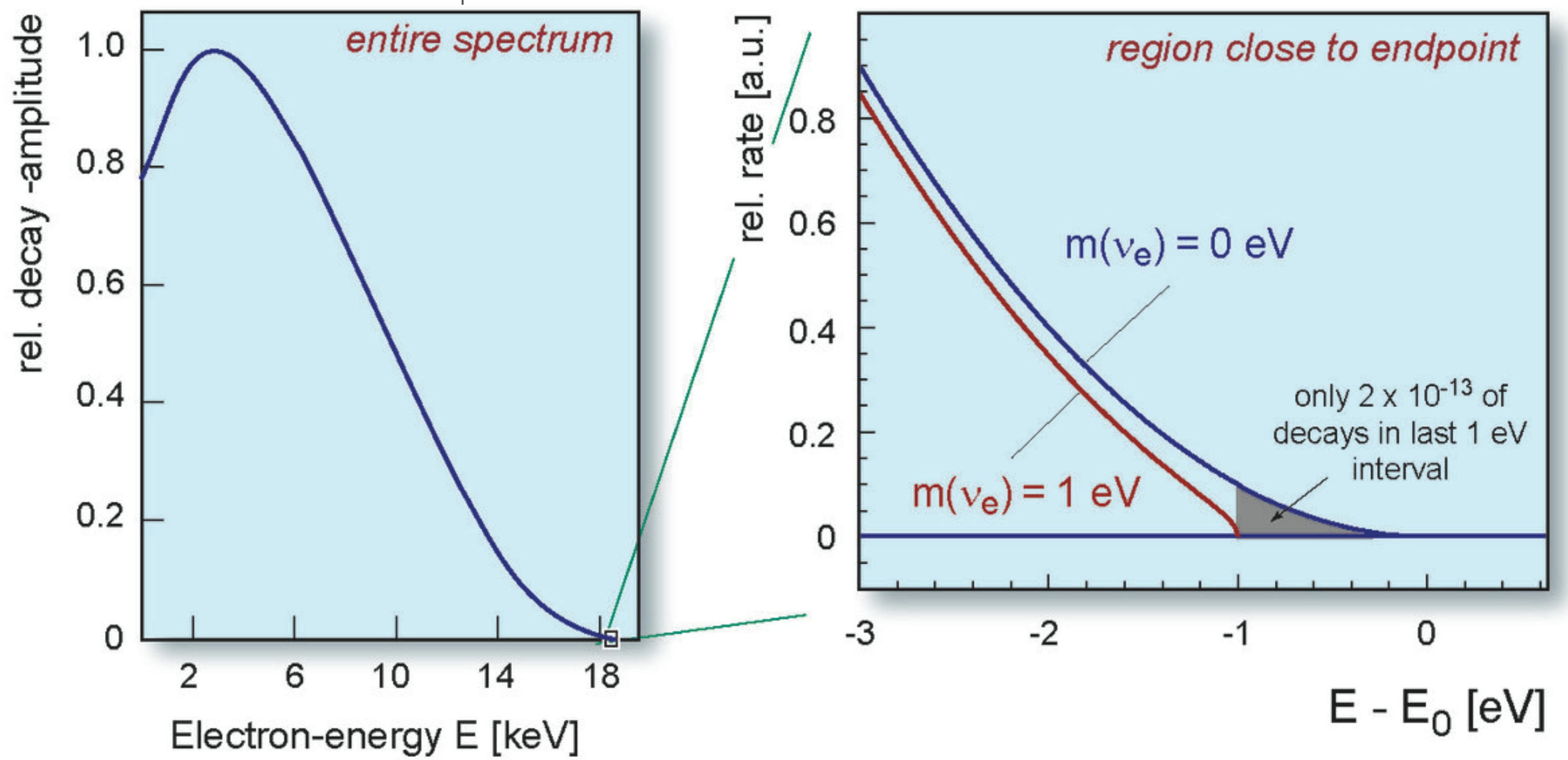
EXPERIMENTAL STATUS OF β DECAYS

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



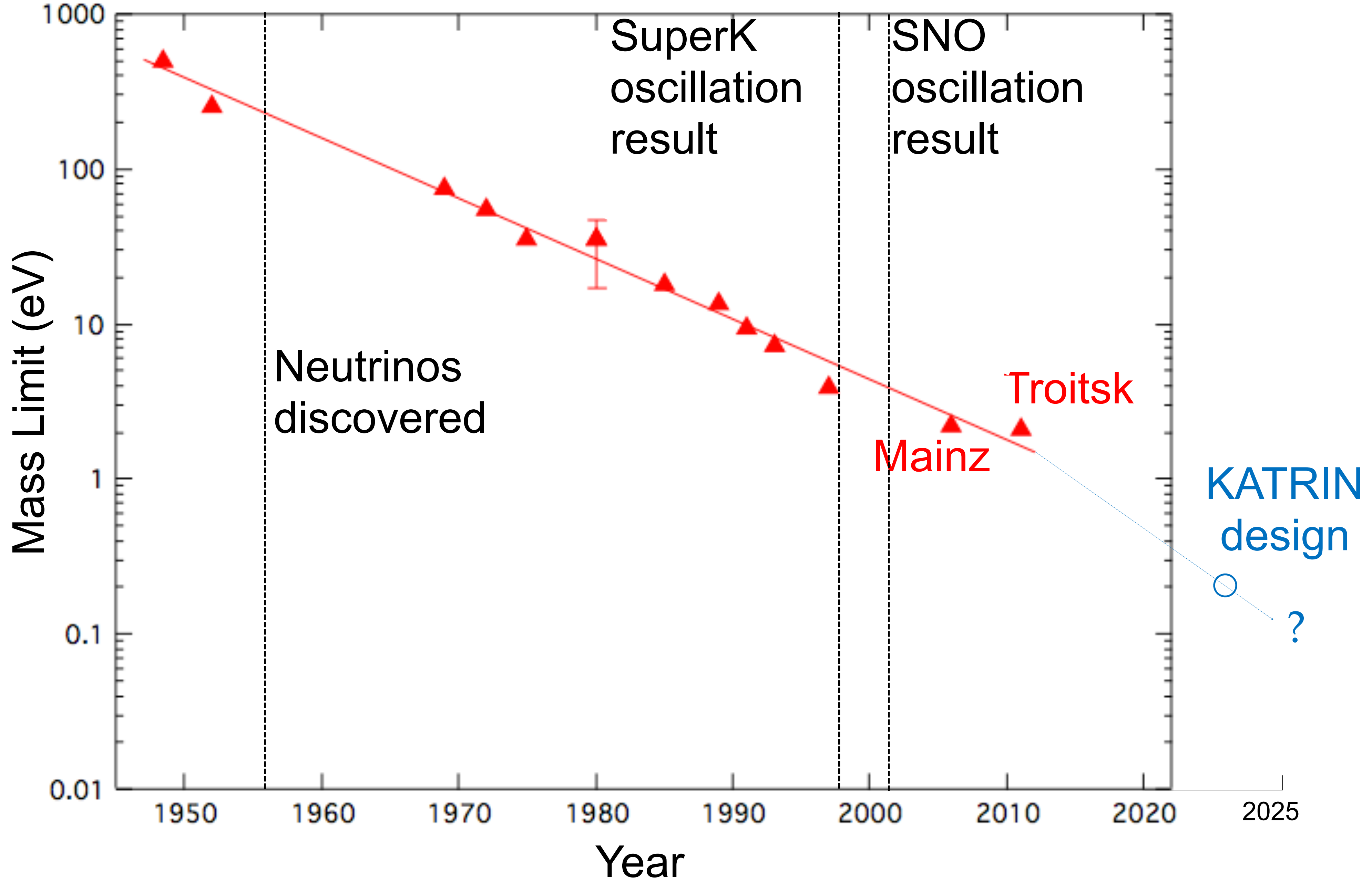
$$m_\beta^2 = \sum_{i=1}^{3} m_i^2 |U_{ei}|^2$$

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

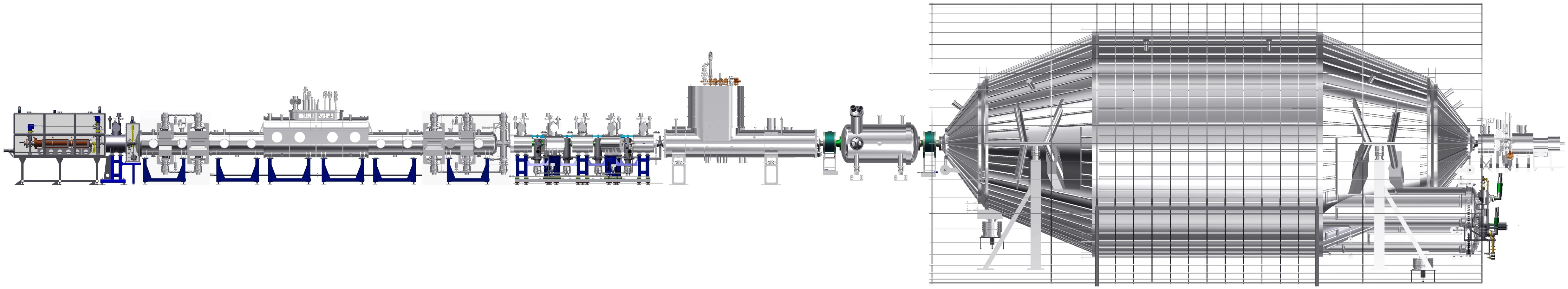
Image credit Laura Baudis

The KATRIN Experiment

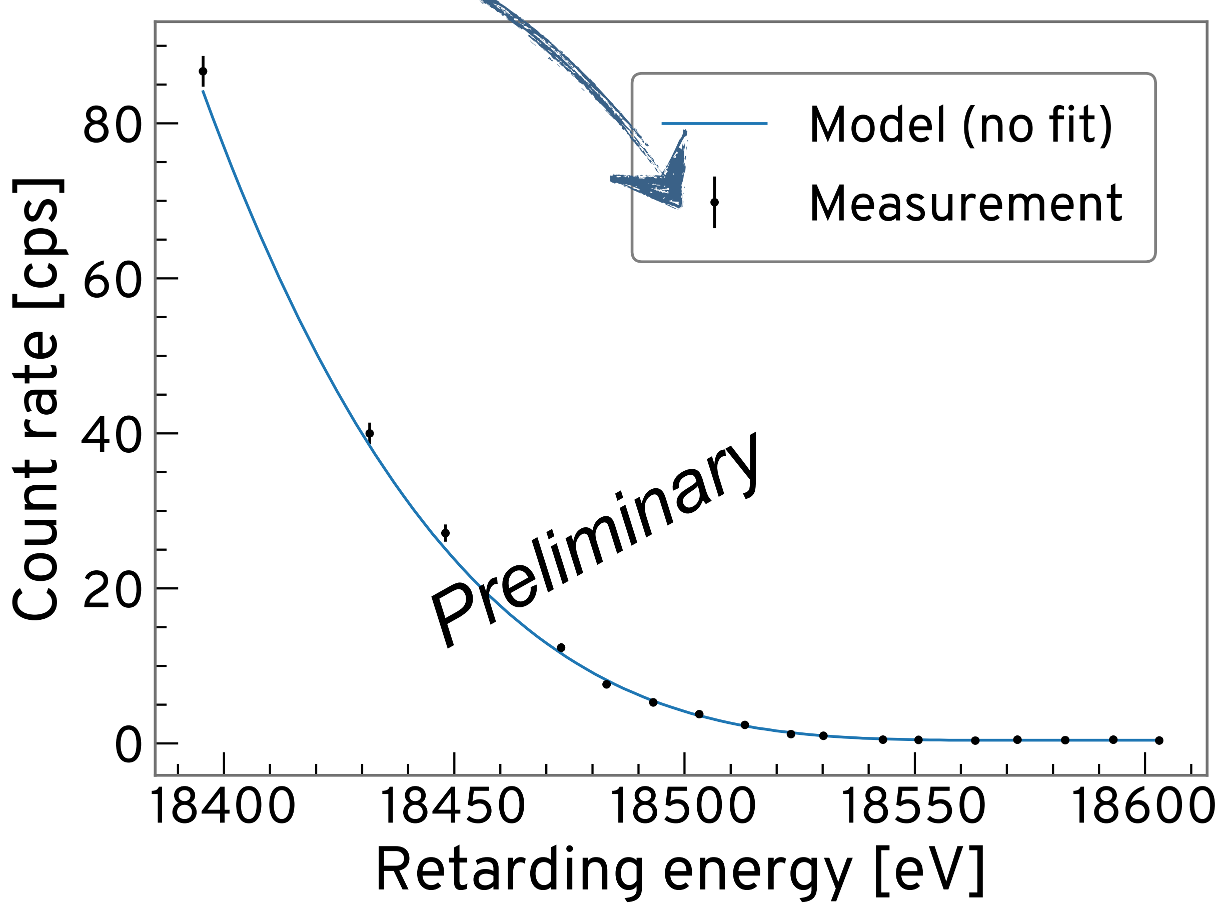
Image credit Laura Baudis

The KATRIN Experiment

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



Diana Parno, Neutrino 2018



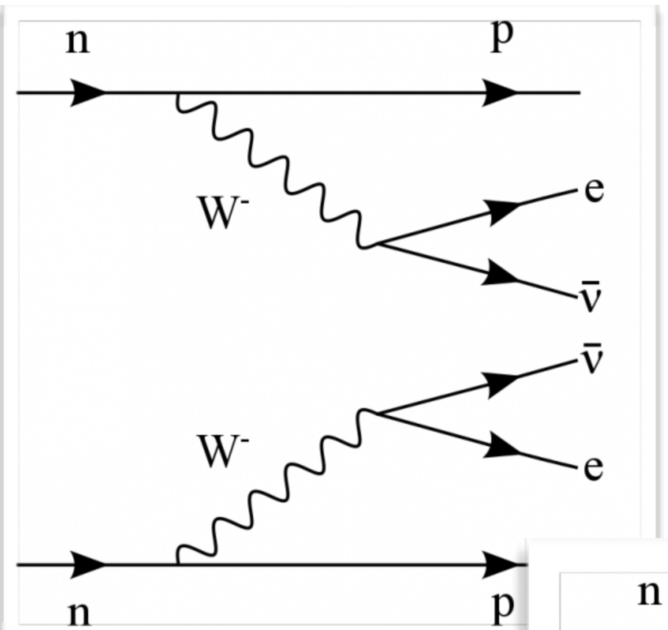
- **First Tritium** data 3 weeks ago!!!
- Large luminosity of **10^{11} decays/s**
- Good **energy resolution 0.93 eV**
- **Expected sensitivity**

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

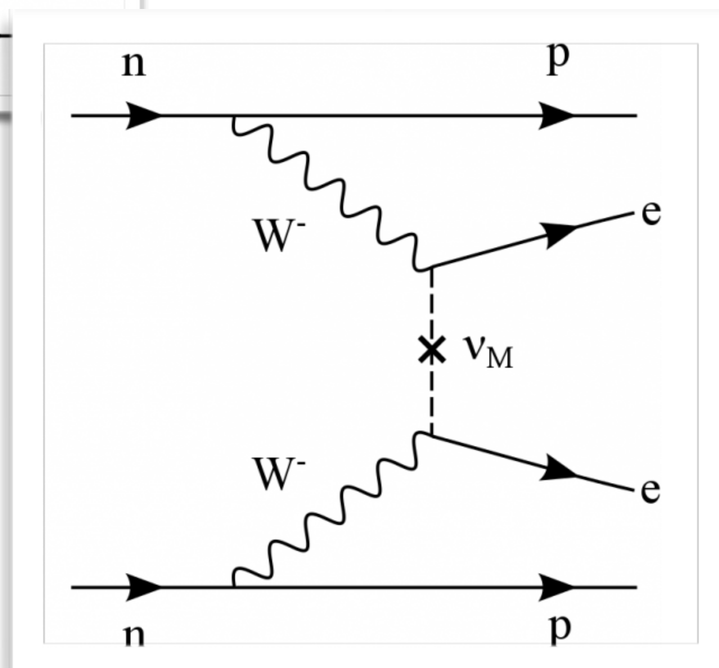
NEUTRINOLESS DOUBLE BETA DECAY

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

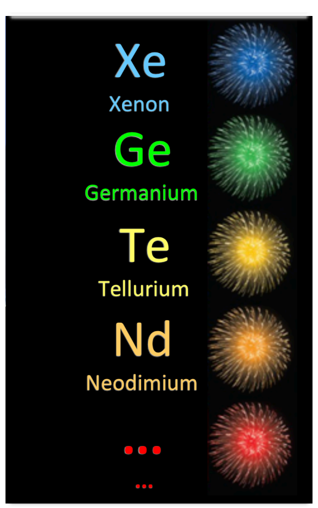
$$m_{ee} = \left| \sum_i m_i U_{ei} \right|^2$$

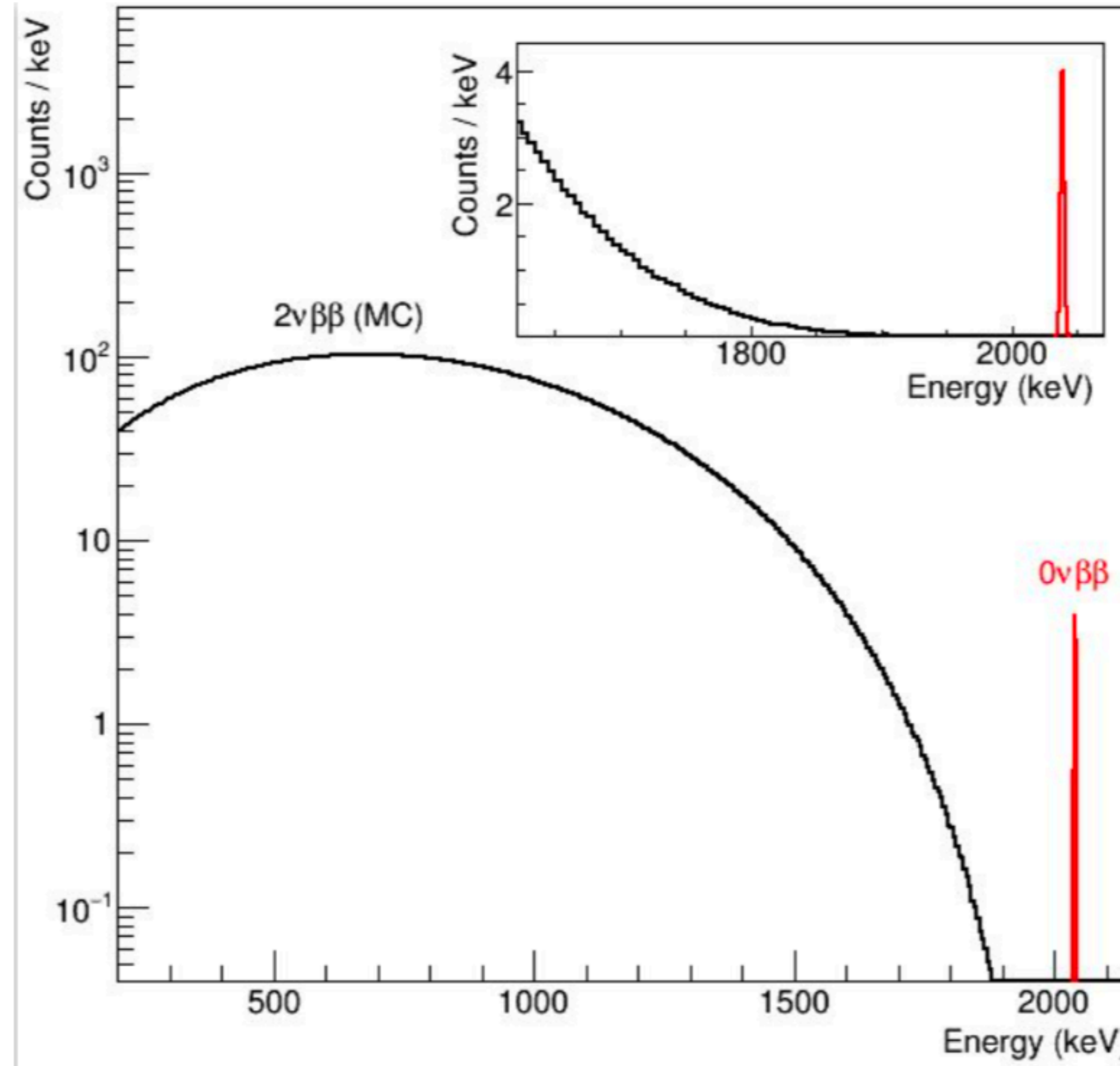


$2\nu\beta\beta$



$0\nu\beta\beta$





Anna Julia Zsigmond (GERDA), Neutrino 2018

Approaches and experiments

source = detector

			NOW	MID-TERM	LONG-TERM
Scalability	Fluid embedded source	Xe-based TPC	EXO-200		nEXO
			NEXT-10	NEXT-100 PandaX-III	NEXT-2.0 PandaX-III 1t
		Liquid scintillator as a matrix	KamLAND-Zen 800		KamLAND2-Zen
			SNO+ phase I		SNO+ phase II
High ΔE and ε	Crystal embedded source	Germanium diodes	GERDA-II MJD	LEGEND 200	LEGEND 1000
		Bolometers	AMoRE pilot, I	AMoRE II	
			CUORE CUPID-0, CUPID-Mo		CUPID

**Talk by Andrea Giuliani in 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	$T_{1/2}^{\text{min}}(y)$	$m_{ee}^{\text{max}}(meV)$
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

EXPERIMENTAL STATUS OF $0\nu\beta\beta$

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

NEW!!!

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

EXPERIMENTAL STATUS OF $0\nu\beta\beta$

- **Current bounds** on neutrinoless double beta decays **after Neutrino 2018**

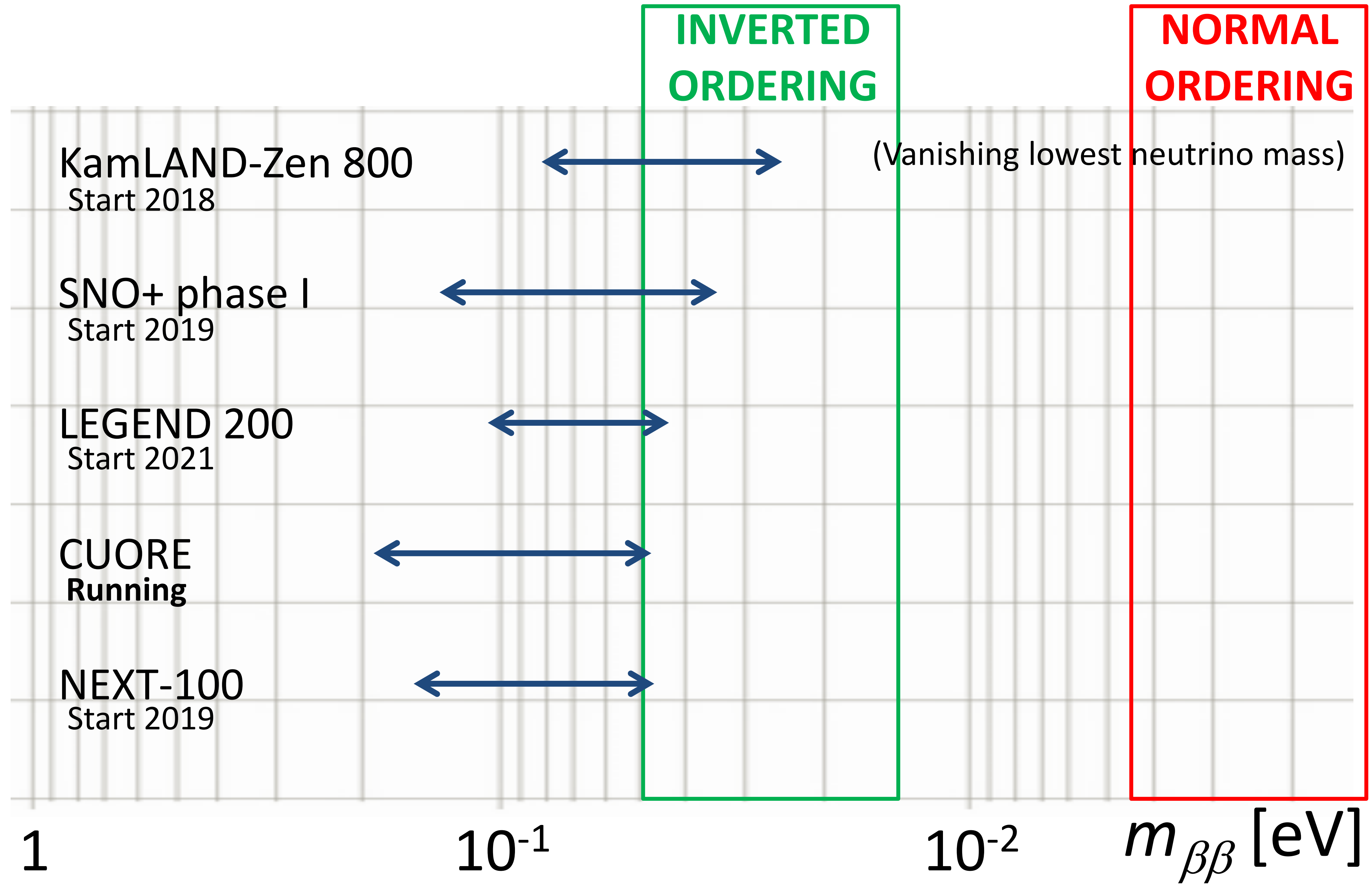
- Depend on the **studied isotope**

NEW!!!

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

Possible scenario in 2024

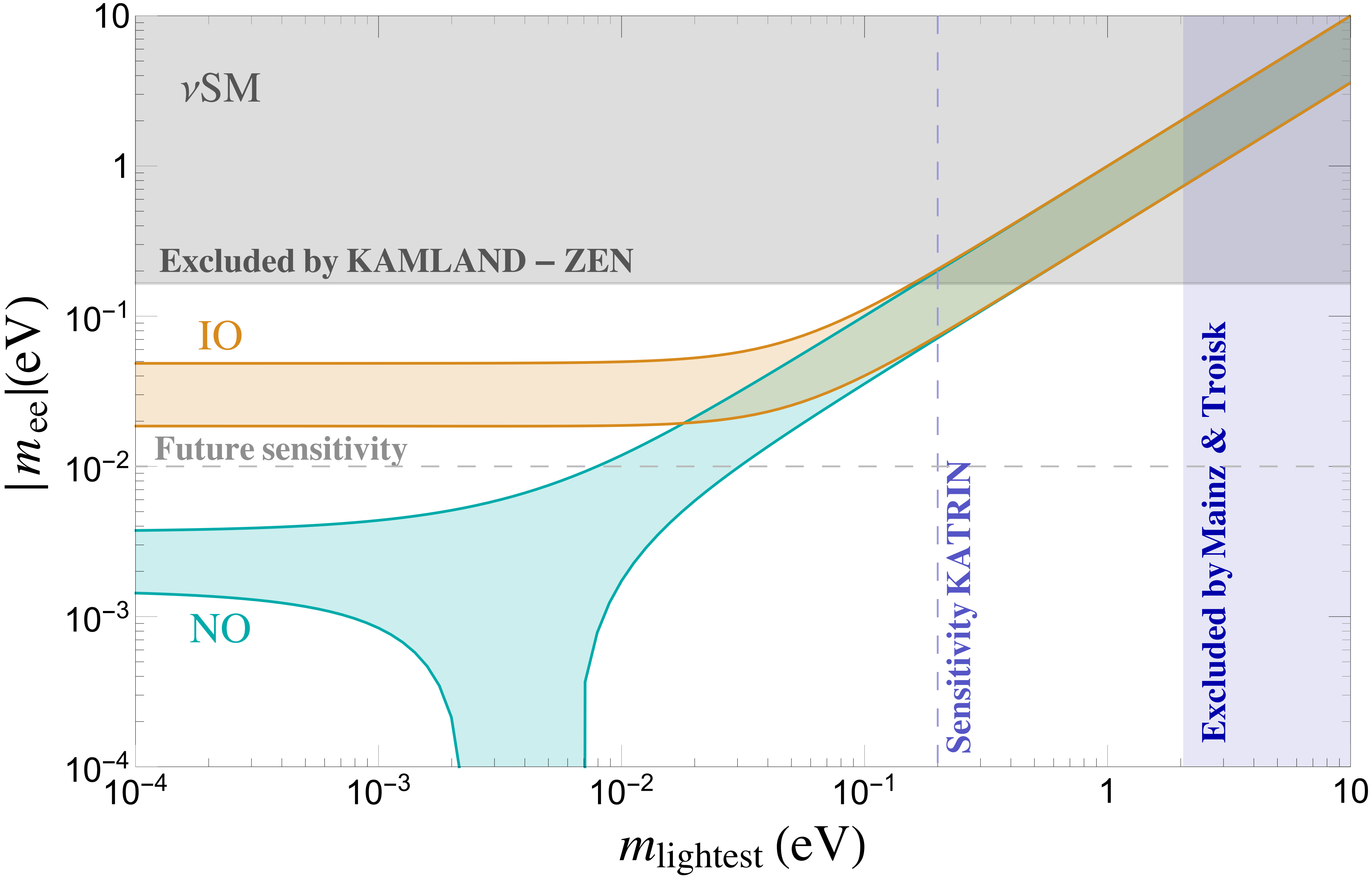
Considering running or well advanced projects (for results, funding and infrastructures)



**Talk by Andrea Giuliani in Neutrino 2018*

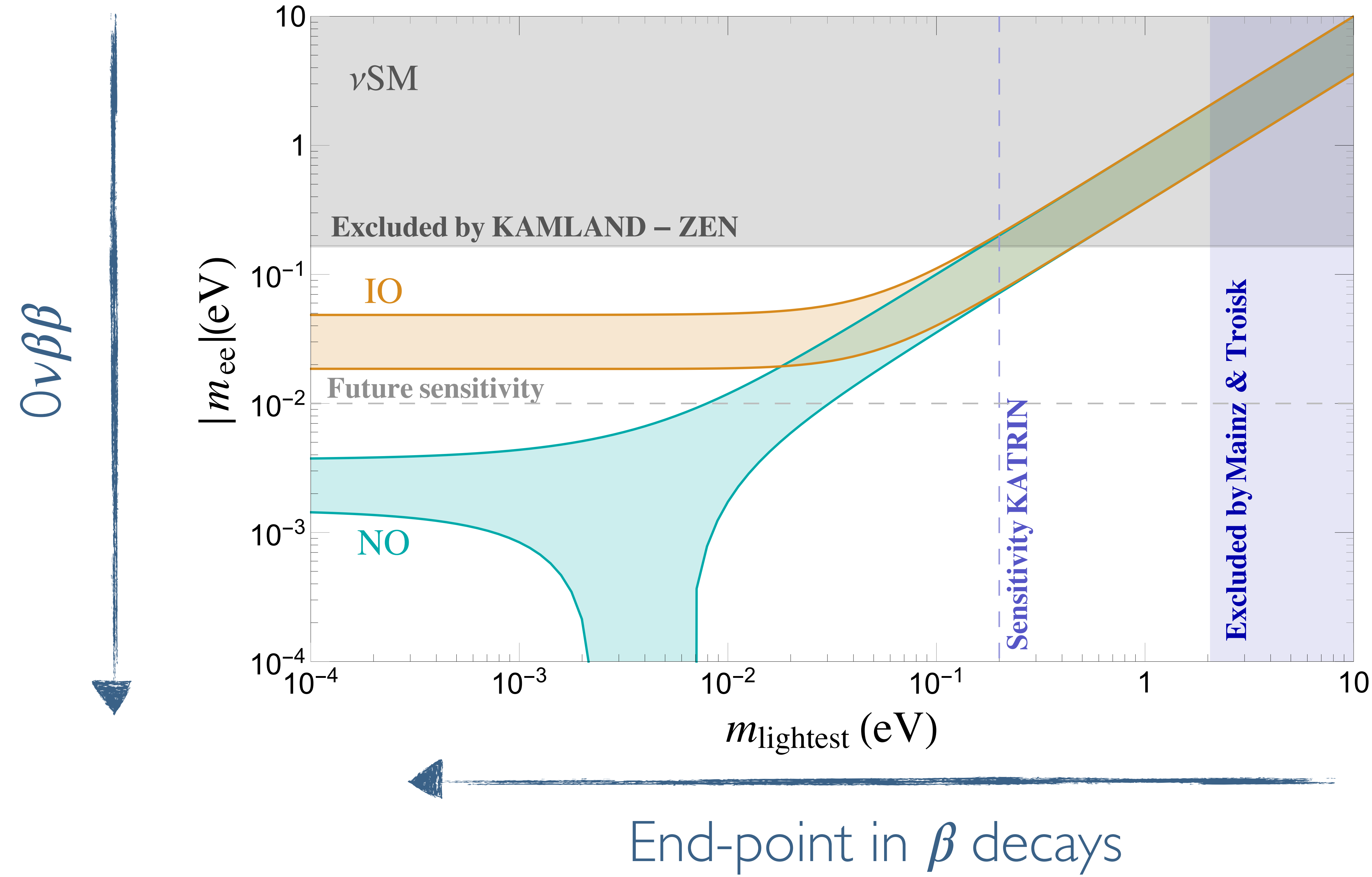
β AND $0\nu\beta\beta$ IN THE νSM

- The standard picture for **3 light Majorana neutrinos**



β AND $0\nu\beta\beta$ IN THE νSM

- The standard picture for **3 light Majorana neutrinos**

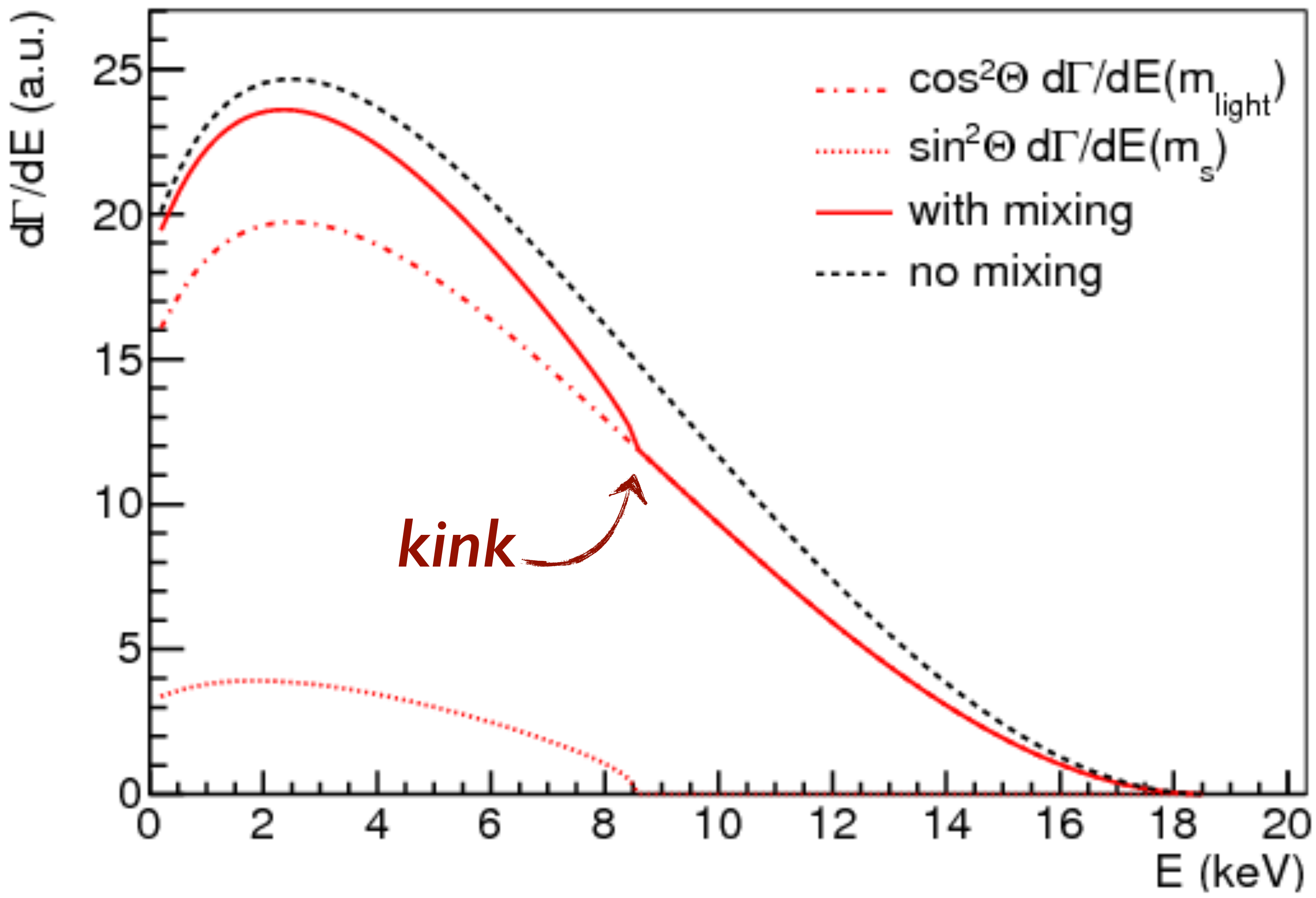


Where is the sterile neutrino in all this story?

STERILE NEUTRINOS IN β DECAYS

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

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

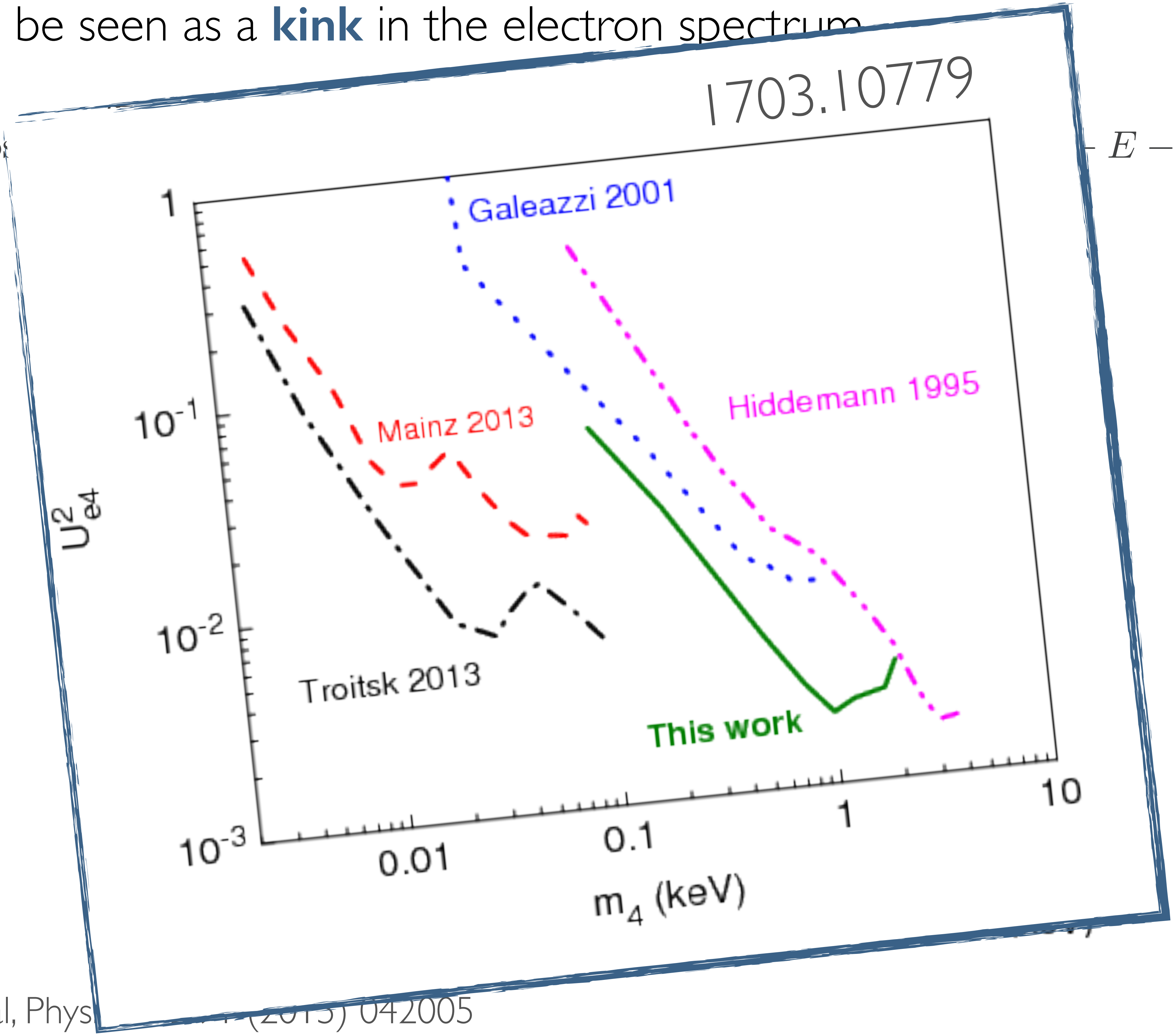


S. Mertens et al, Phys.Rev. D91 (2015) 042005

STERILE NEUTRINOS IN β DECAYS

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

$$\frac{d\Gamma}{dE} = \text{co} \ldots - E - m_{\text{heavy}})$$



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

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 $|U_{e4}|^2$ = _____ .

Download:

- PDF
- PostScript
- Other formats

(license)

Current browse context:

hep-ex

< prev | **next >**

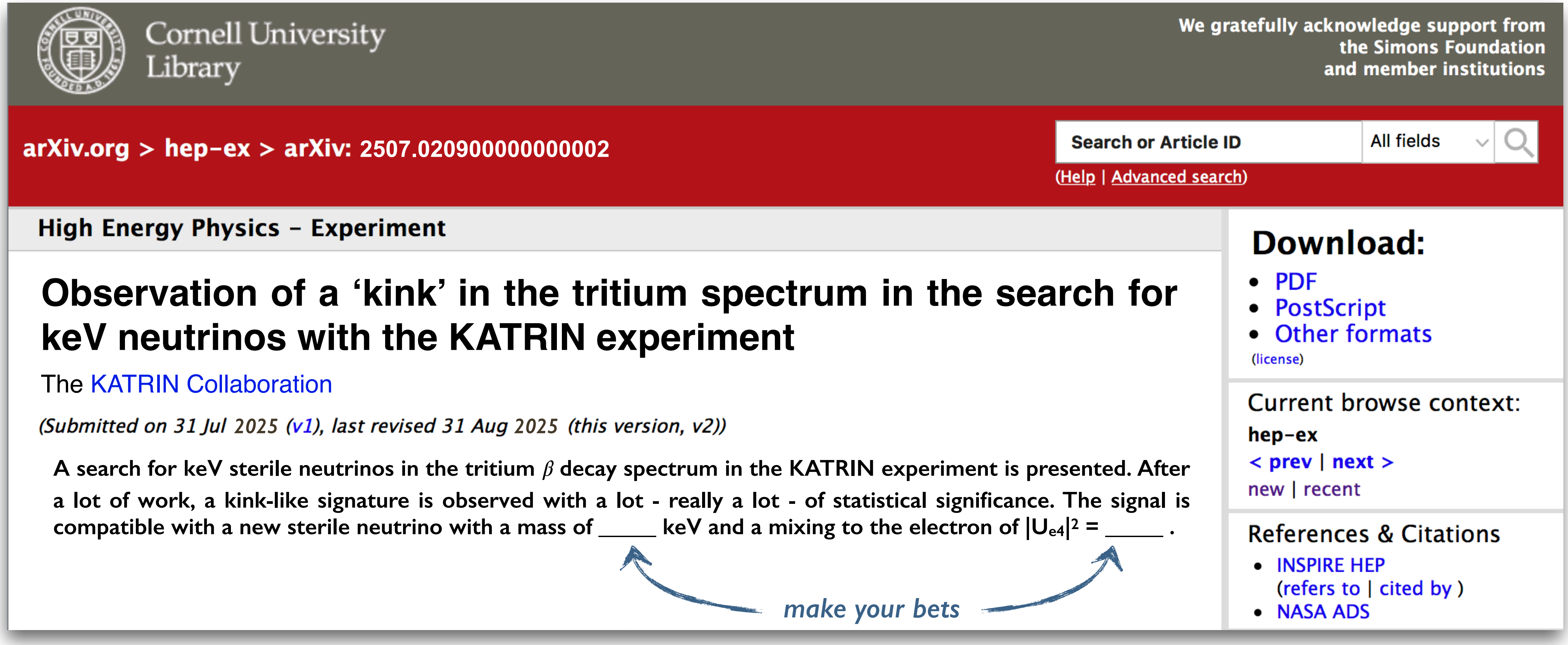
new | recent

References & Citations

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

WHAT 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 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)

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

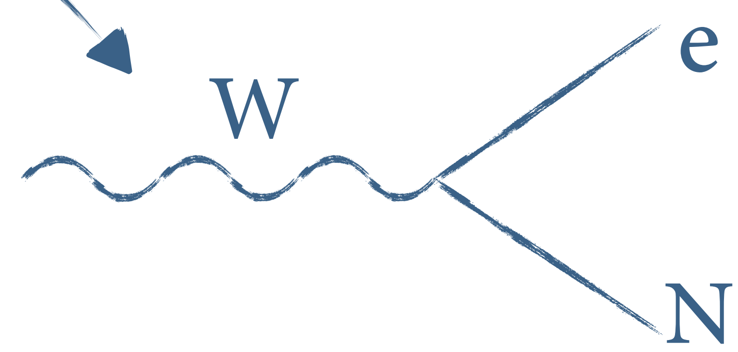
What would be the implications?

A new neutrino? → **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**

$$U^{\nu}_{4\times4} = \left(\begin{array}{c|c} \tilde{U}_{\rm PMNS} & \begin{array}{c} U_{e4} \\ U_{\mu 4} \\ U_{\tau 4} \end{array} \\ \hline & \end{array}\right)$$



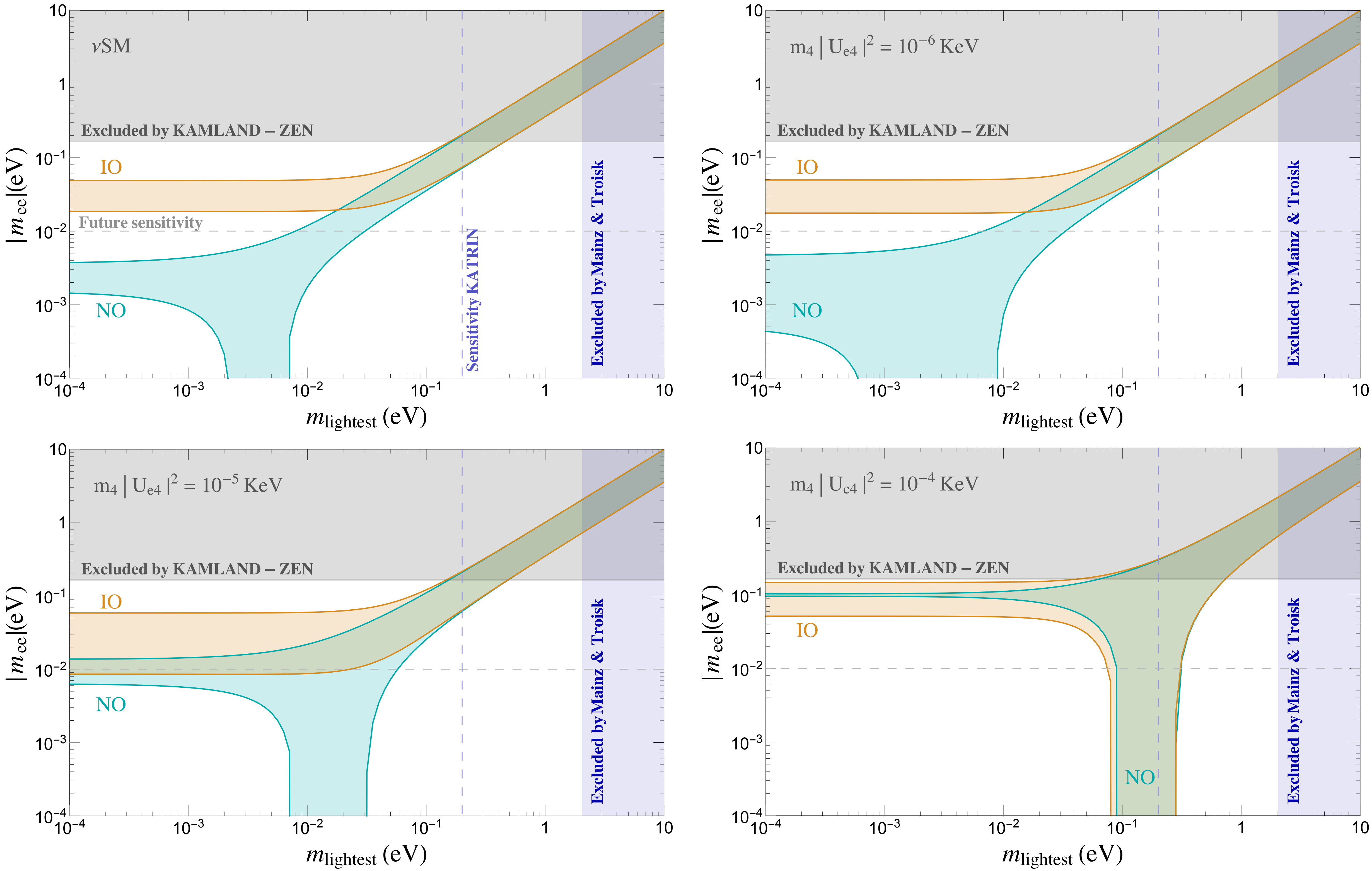
a kink in KATRIN

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

S. Mertens et al, JCAP 1502 (2015) no.02, 020
S. Mertens et al, Phys.Rev. D91 (2015) 042005

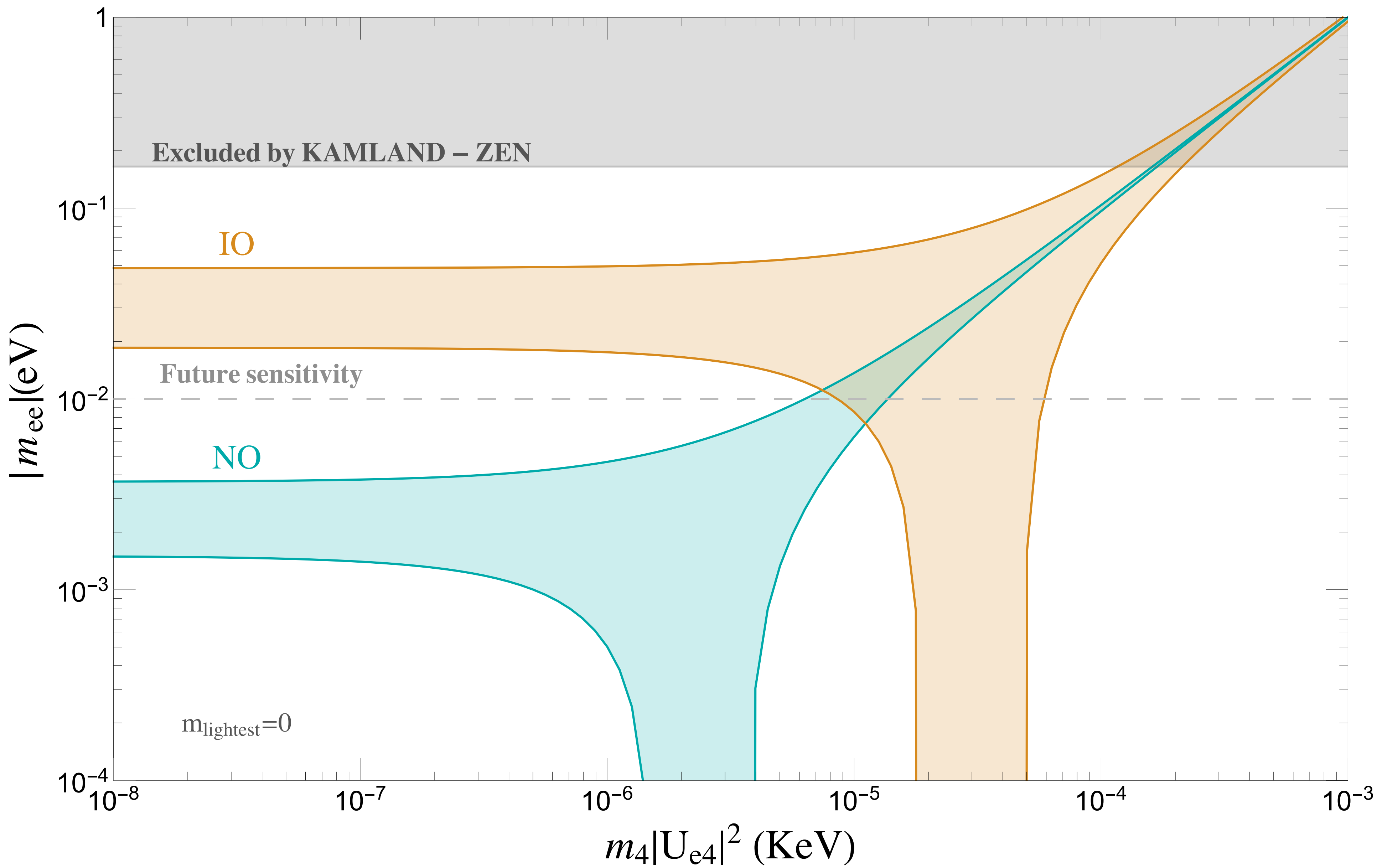
$0\nu\beta\beta$ IN THE 3+1 SCENARIO

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



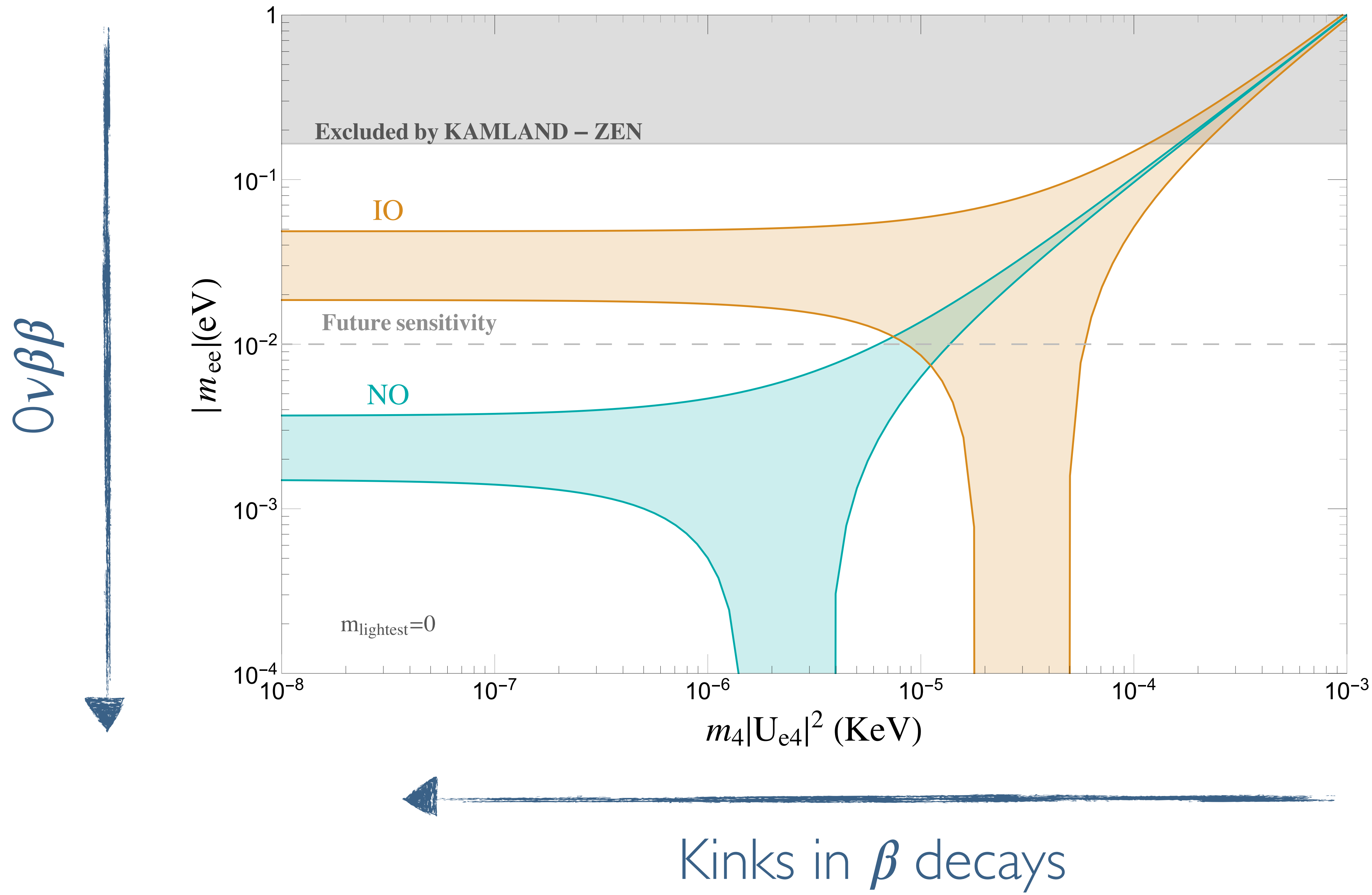
$0\nu\beta\beta$ IN THE 3+1 SCENARIO

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



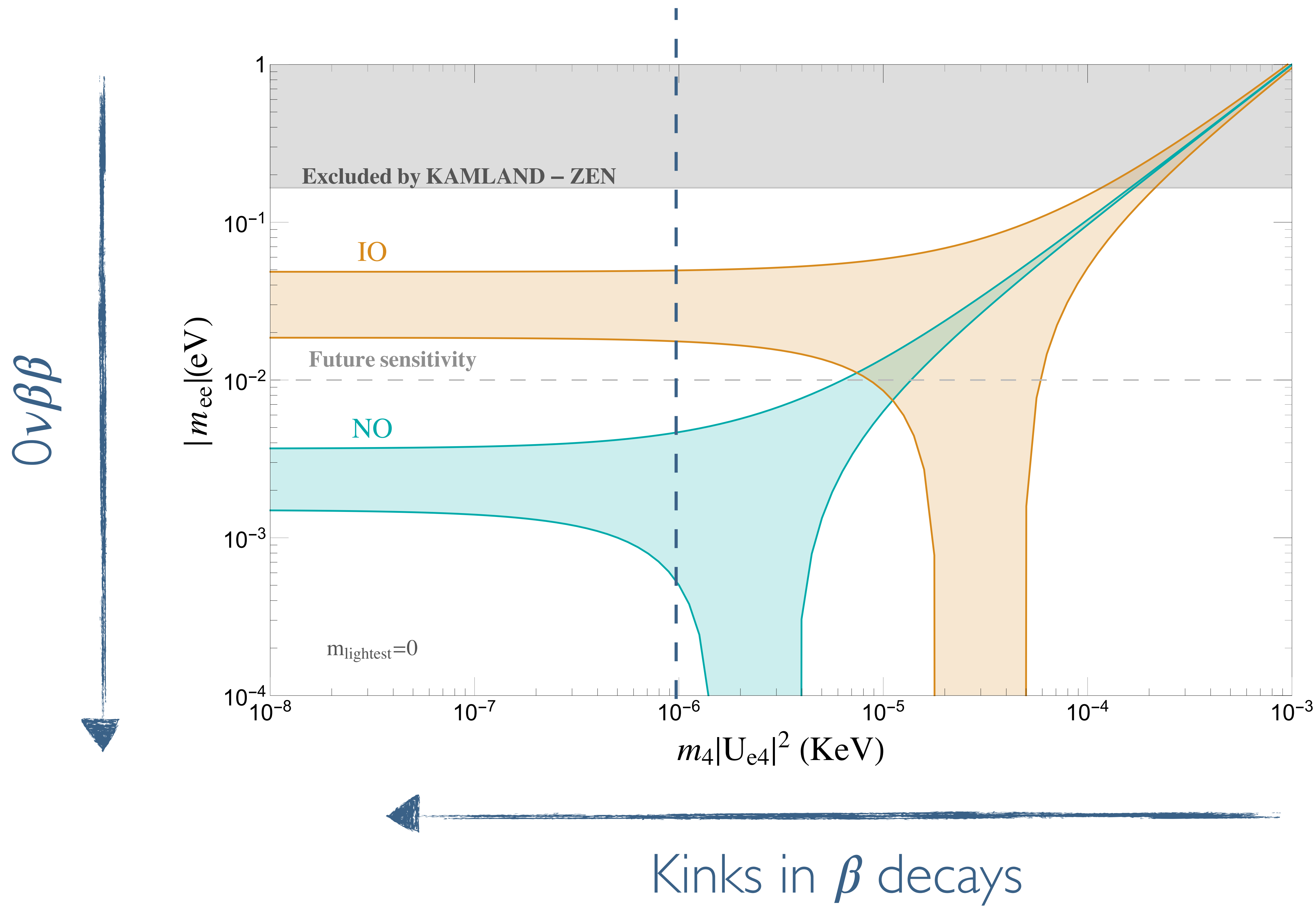
$0\nu\beta\beta$ IN THE 3+1 SCENARIO

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



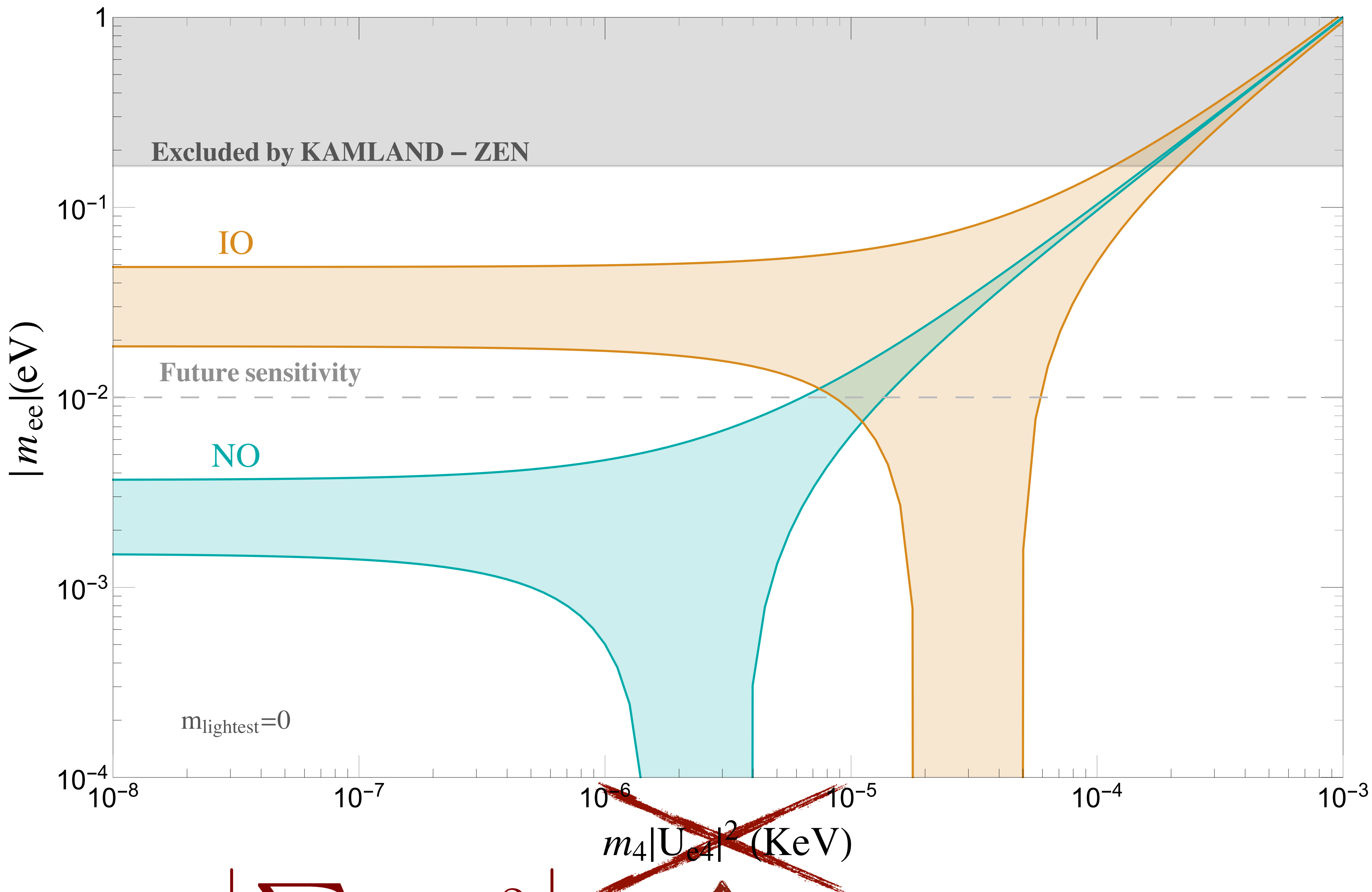
$0\nu\beta\beta$ IN THE 3+1 SCENARIO

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 (**$m_i^2 \ll p^2 \sim (100\ \mathrm{MeV})^2$**)



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

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:

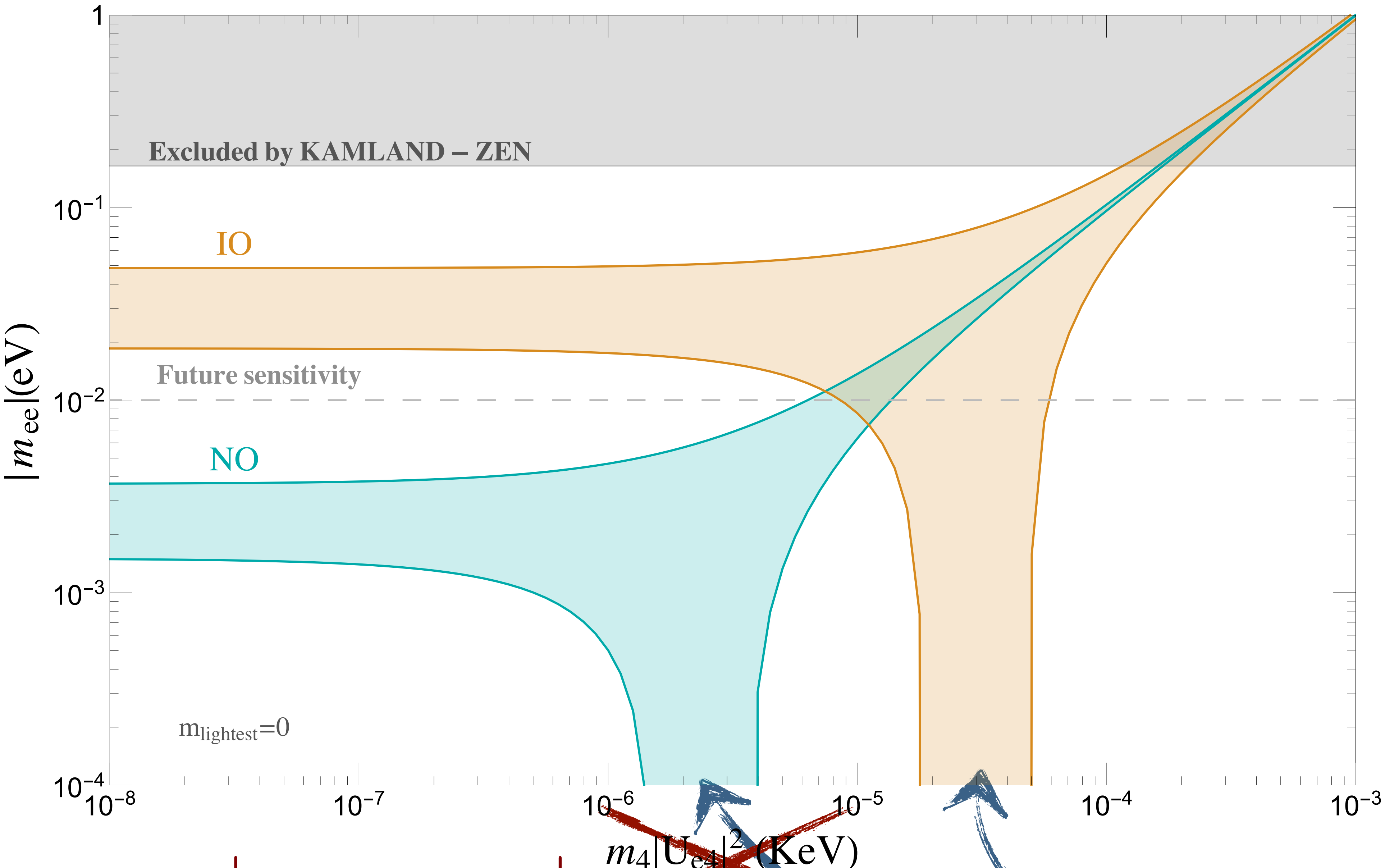
  - Neutrino mass **diagonalization** relations:

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

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

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

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



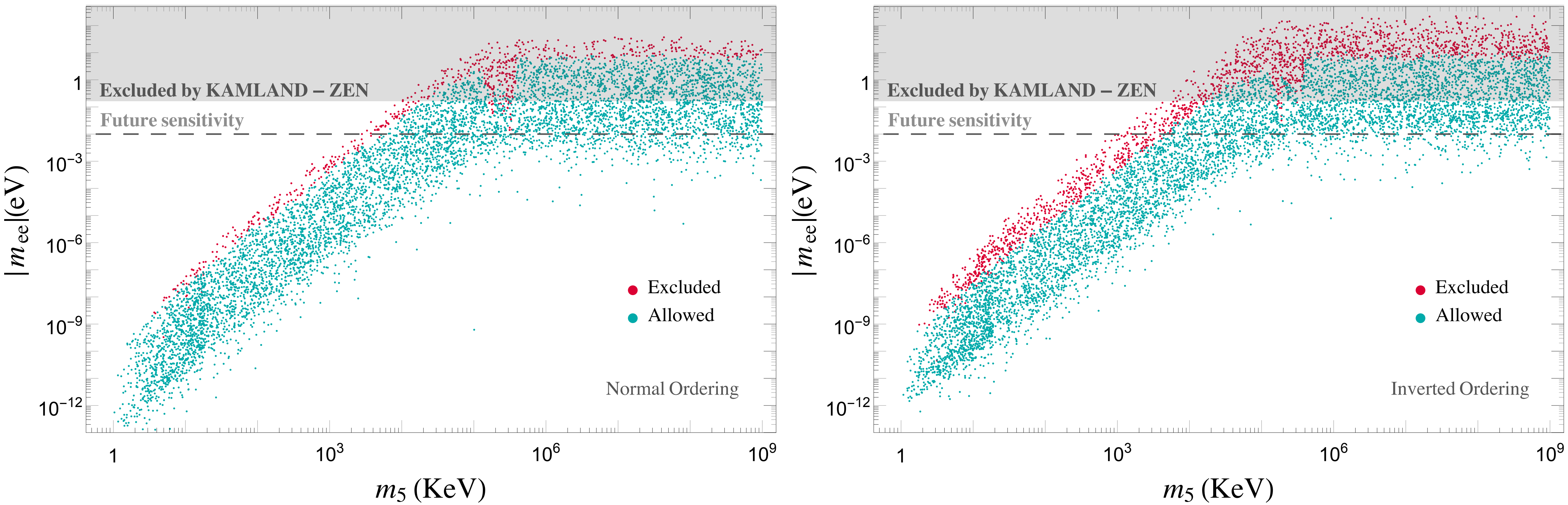
$$\left|\sum_i m_i U_{ei}^2\right|$$

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**

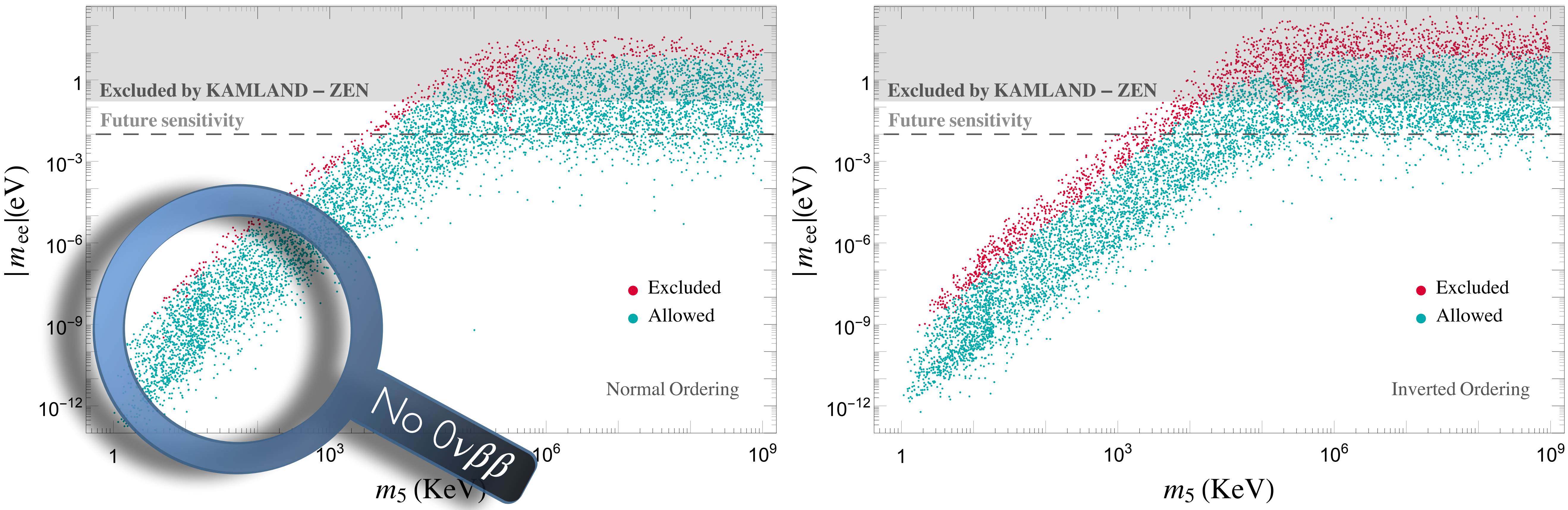
$$m_{ee} = \sum_{i=1}^{N} U_{ei}^2\, p^2 \frac{m_i}{p^2 - m_i^2} \approx m_{ee}^{(3+1)} \left[1 - \frac{p^2}{p^2 - m_5^2}\right]$$



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**

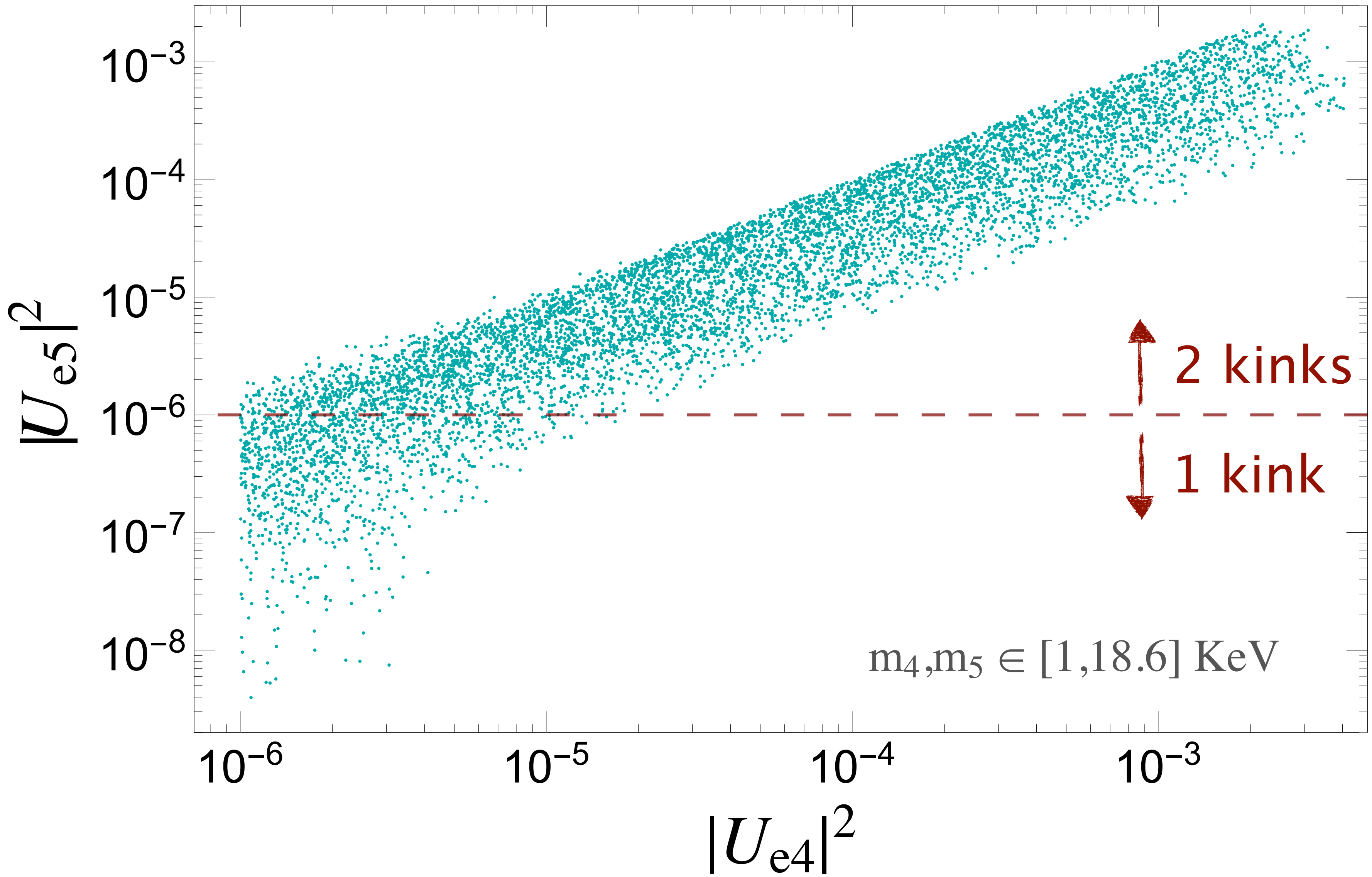
$$m_{ee} = \sum_{i=1}^{N} U_{ei}^2\, p^2 \frac{m_i}{p^2 - m_i^2} \approx m_{ee}^{(3+1)} \left[1 - \frac{p^2}{p^2 - m_5^2}\right]$$



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



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!

BACK UP

Isotopes for double beta decay (Q-value > 2MeV)

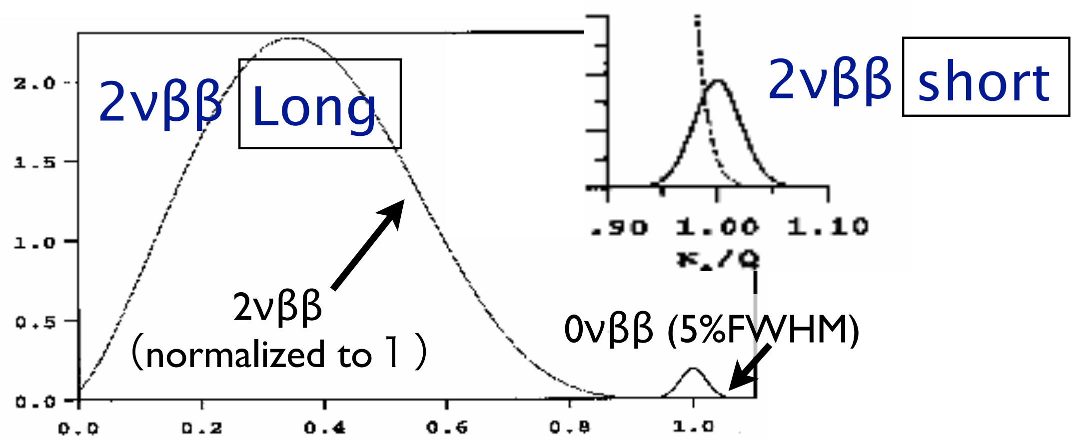
- No perfect isotope for double beta decay

Isotopes	Q-value (keV)	N.A. (%)	$T^{2\nu}_{1/2}$ (year) measurement PDG2015, no error included	$T^{0\nu}_{1/2}(50\,\mathrm{meV})$ calculation PRC 79, 055501 (2009), (R)QRPA (CCM SRC)	Pros & Cons
^{48}Ca	4273.6 ± 4	0.19	4.4 × 10^{19}	-	Q-value **highest**, N.A. **small**, enrichment **difficult**
^{76}Ge	2039.006 ± 0.050	7.6	1.84 × 10^{21}	(2.99-7.95)×10^{26}	2v **long**, enrichment **~90%**
^{82}Se	2995.50 ± 1.87	8.7	9.6 × 10^{19}	(0.85-2.38)×10^{26}	enrichment **>90%**
^{96}Zr	3347.7 ± 2.2	2.8	2.35 × 10^{19}	(3.16-6.94)×10^{26}	
^{100}Mo	3034.40 ± 0.17	9.4	7.11 × 10^{18}	(0.59-2.15)×10^{26}	2v**short**, enrichment **>90%**
^{110}Pd	2017.85 ± 0.64	7.5	-	-	
^{116}Cd	2813.50 ± 0.13	7.5	2.8 × 10^{19}	(0.98-3.17)×10^{26}	enrichment **80~90%**
^{124}Sn	2287.80 ± 1.52	5.8	-	-	
^{130}Te	2527.01 ± 0.32	34.1	7.0 × 10^{20}	(7.42-2.21)×10^{26}	N.A. **high**
^{136}Xe	2457.83 ± 0.37	8.9	2.165 × 10^{21}	(1.68-7.17)×10^{26}	2v **long**, enrichment **~90%**
^{150}Nd	3317.38 ± 0.20	5.7	9.11 × 10^{18}	-	2v **short**, enrichment **difficult**

2vββ → Background of 0vββ

$$T^{0\nu}/T^{2\nu}$$

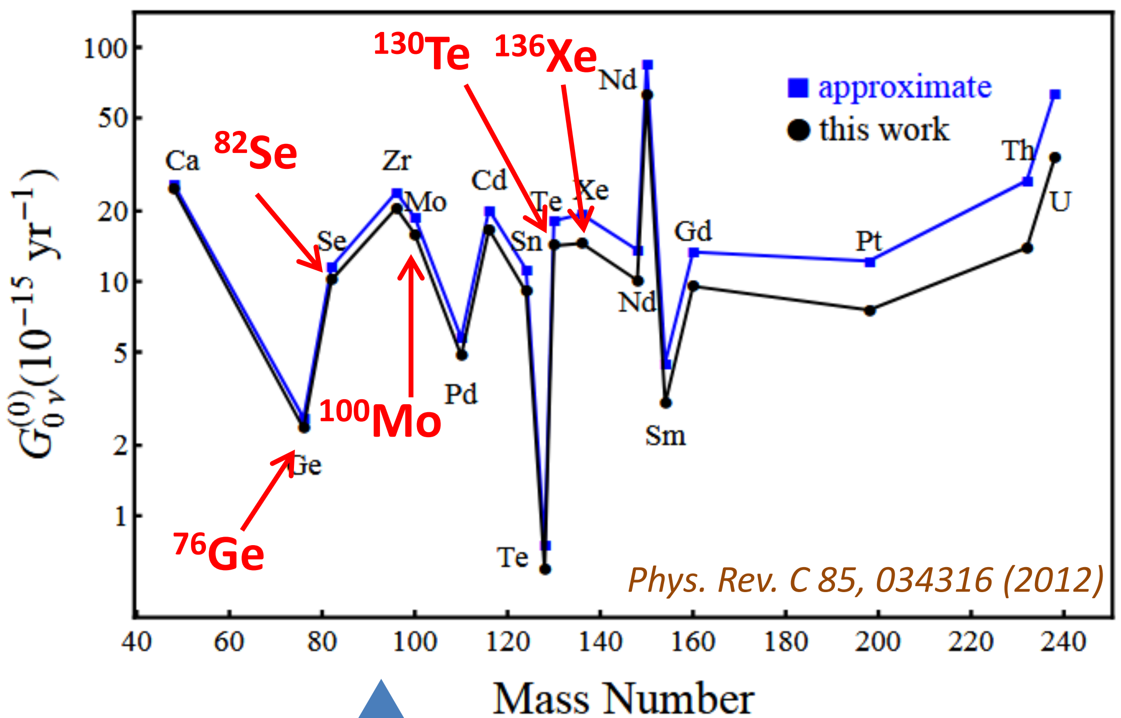
If ratio is big
→ Energy resolution is important



*Talk by Azusa Gando (KamLAND-Zen),Neutrino 2018

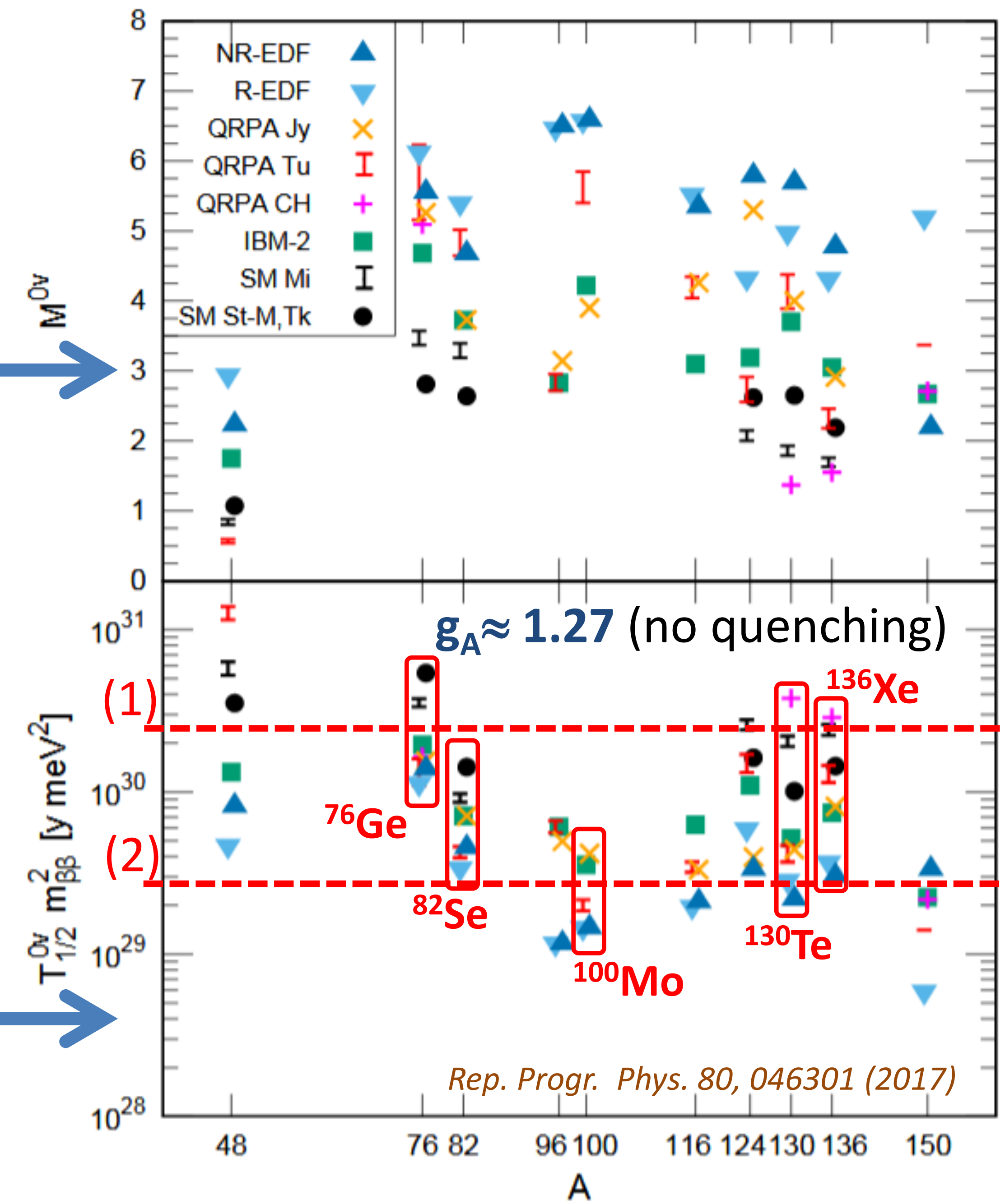
How difficult is it?

Phase space: exactly calculable



*See next talk by **Jouni Suhonen***

Nuclear matrix elements: several models



$$1/\tau = G(Q,Z)\, g_A^{\,4}\, |M_{nucl}|^2\, m_{\beta\beta}^{\,2}$$

**Talk by Andrea Giuliani in Neutrino 2018*

Cosmology

K. Abazajian, arXiv:1705.01837