Low-Scale Leptogenesis in the νSMEFT

Sascha Weber

JGU Mainz

In collaboration with
Kaori Fuyuto (LANL) and Julia Harz (JGU)
[In preparation]

MPA MAINZ PHYSICS ACADEMY

Mainz Institute for Theoretical Physics

Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter PRISMA

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Another paper

Asymgenesis

Martin A. Mojahed[1,2,*] and Sascha Weber[2,†]

[1] *Physics Department T70, Technical University of Munich, 85748 Garching, Germany*
[2] *PRISMA$^+$ Cluster of Excellence & Mainz Institute for Theoretical Physics, FB 08 - Physics, Mathematics and Computer Science, Johannes Gutenberg-Universität Mainz, Staudingerweg 9, 550099 Mainz, Germany*

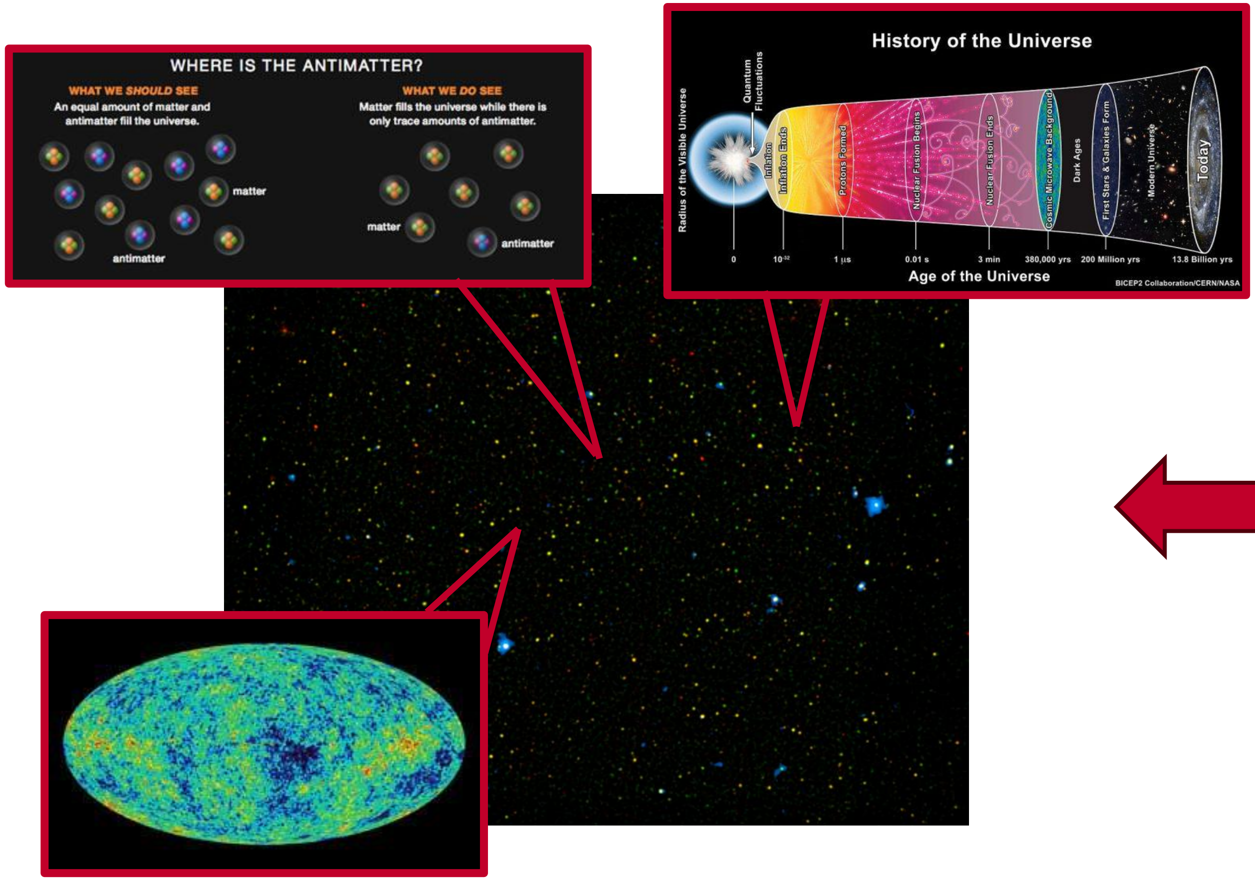
(Dated: July 16, 2025)

We present a framework based on the standard type-I seesaw model that relates the baryon asymmetry of the universe to the dark matter (DM) density. The framework, which we name *Asymgenesis*, relies on the presence of primordial charge asymmetries seeded either in the dark sector or in the visible sector. A higher-dimensional portal operator reshuffles this initial asymmetry into both sectors, eventually resulting in a nonzero $B-L$ asymmetry and an asymmetric DM component. Compared to conventional asymmetric-dark-matter (ADM) schemes, our framework imposes far milder requirements on the portal interaction. In particular, the portal interaction need not violate $B-L$, and the temperature scales of efficient $B-L$ violation and efficient charge-transfer interaction mediated by the portal operator can be separated. We develop the formalism in detail and argue that the flexibility of our framework enlarges the model-building landscape for ADM.

[M.Mojahed and S.W. arXiv:2507.10655]

Motivation

[https://www.pinterest.de/pin/planet-earth-featuring-europe-and-european-union-countries-including-france-ger-sponsored-countries-union-f--850969292074858684/]
[https://www.mpi-hd.mpg.de/gerda/]
[https://www-project.slac.stanford.edu/exo/about.html]
[https://cerncourier.com/a/kamland-experiment-discovers-that-reactor-antineutrinos-disappear/]



[https://www.universetoday.com/tag/223-aas/]
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[https://www.astroblogs.nl/2013/03/23/wordt-het-universum-geregeerd-door-anti-neutrinos/baryon-asymmetry/]
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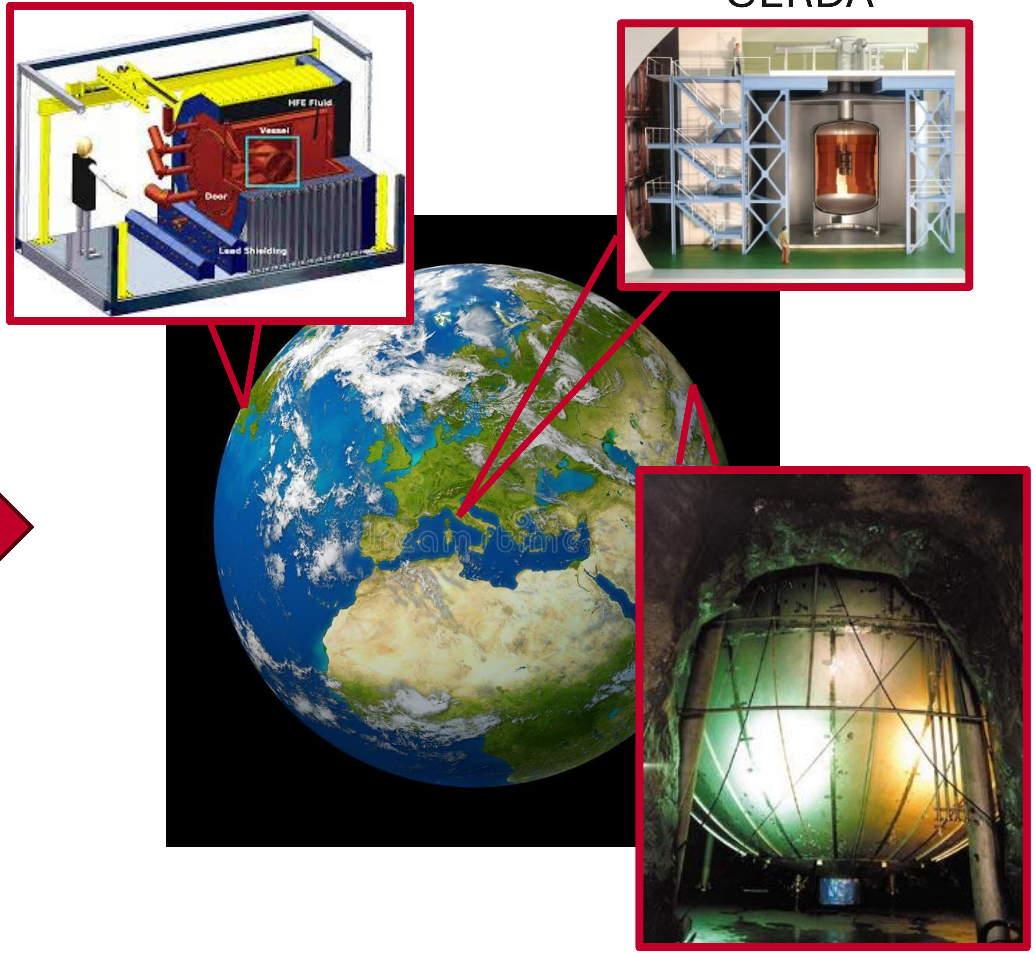
EXO

GERDA



KamLAND-Zen

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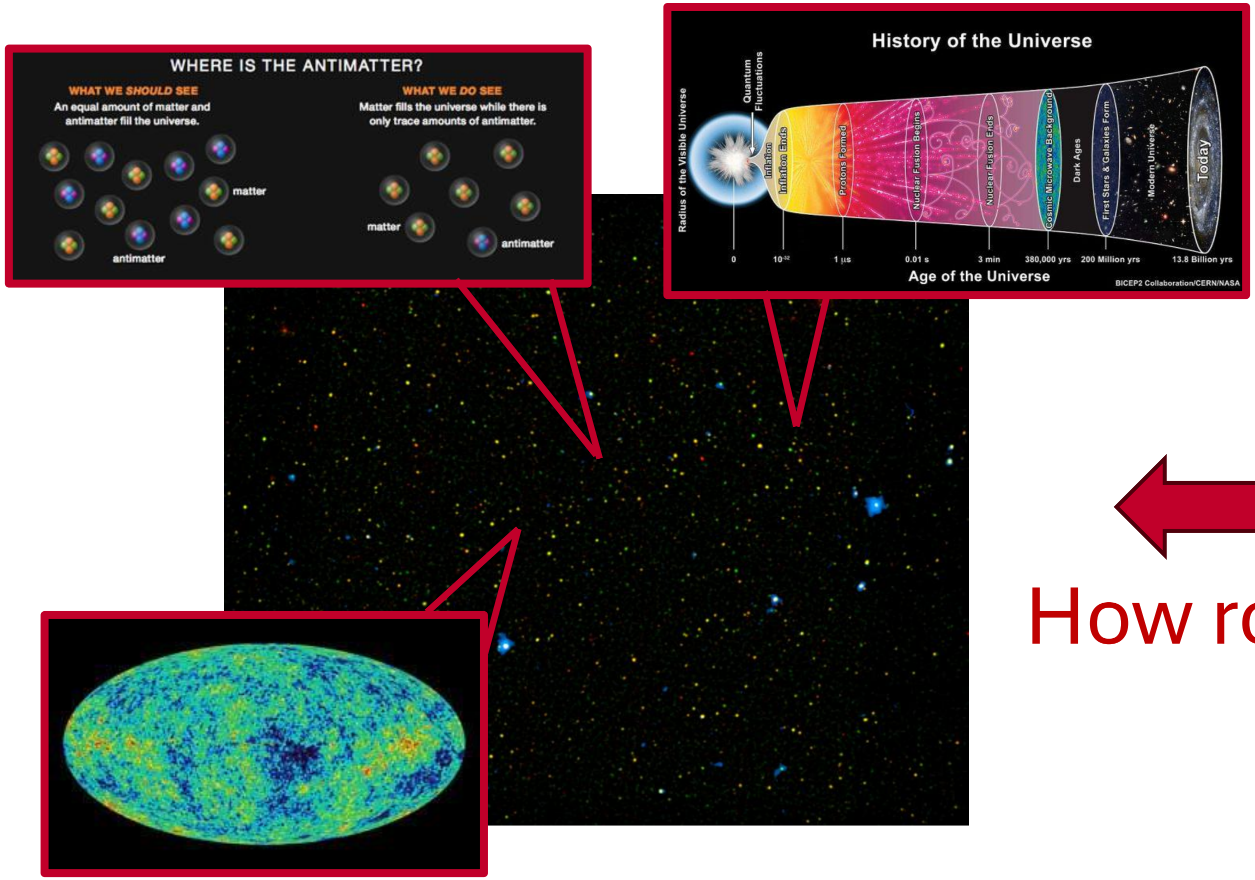

How robust?

EXO

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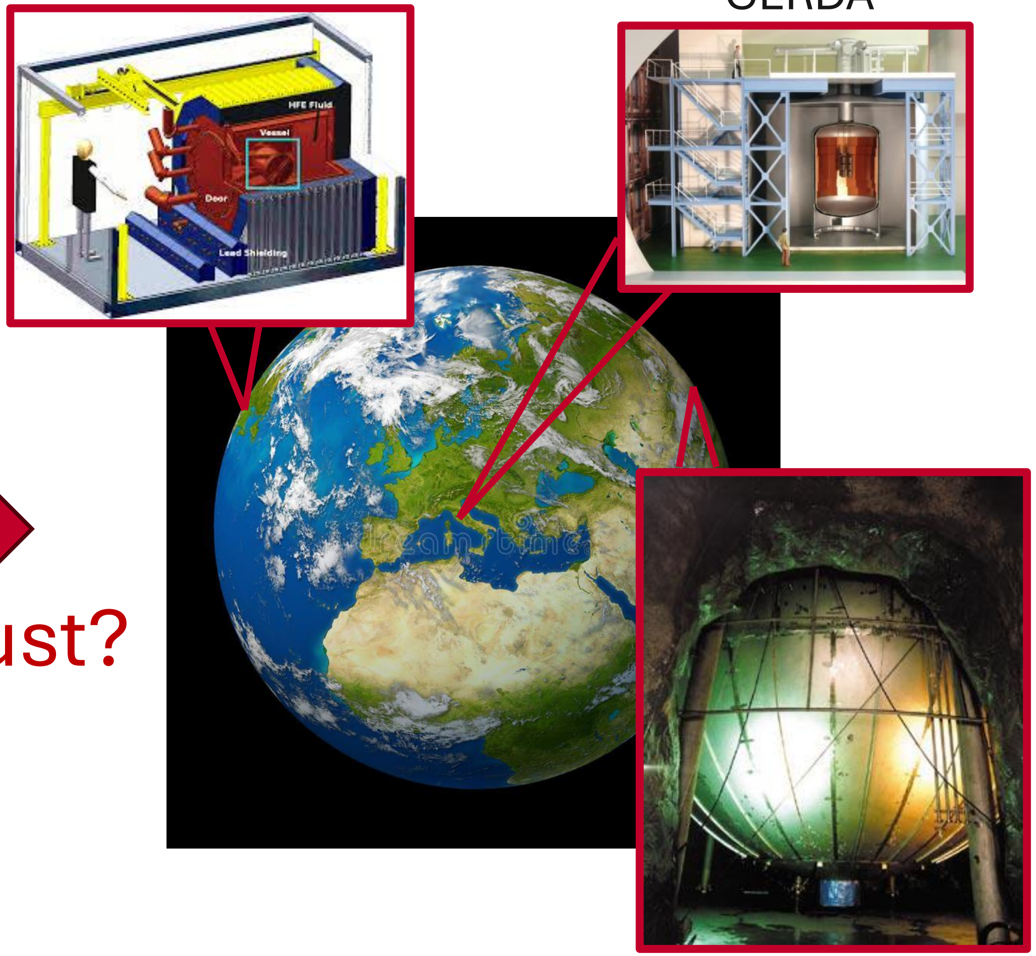

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JHEP

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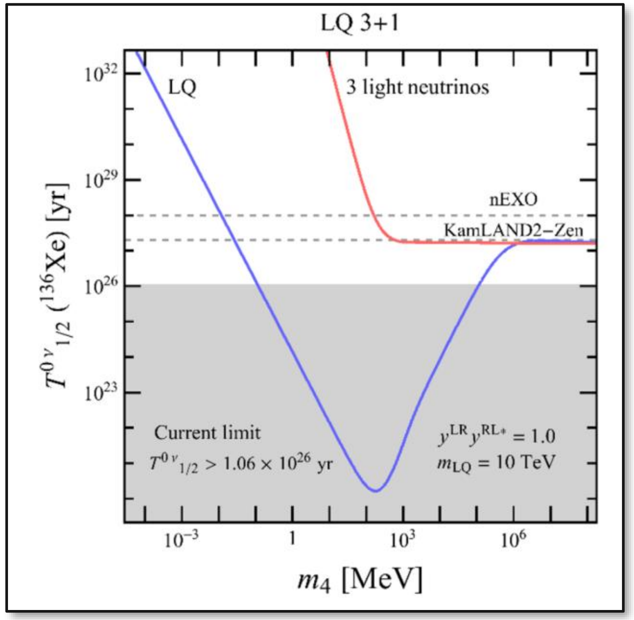
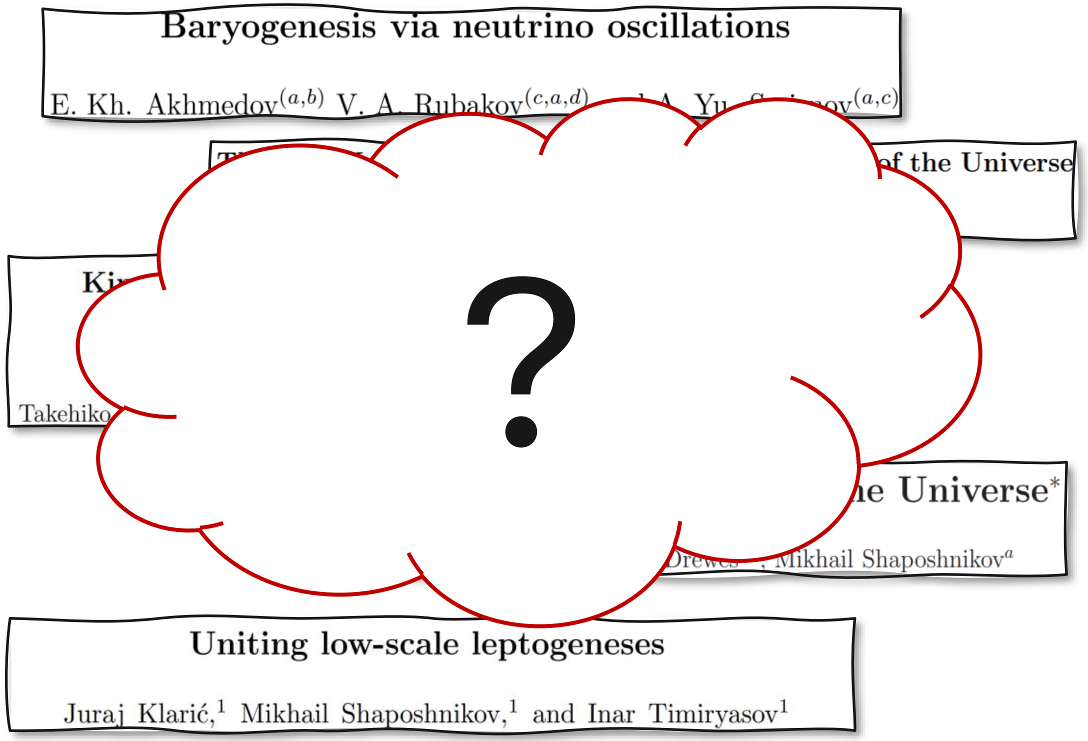


How robust?

Low-Scale Leptogenesis

[Dekens et. al. JHEP 2020]



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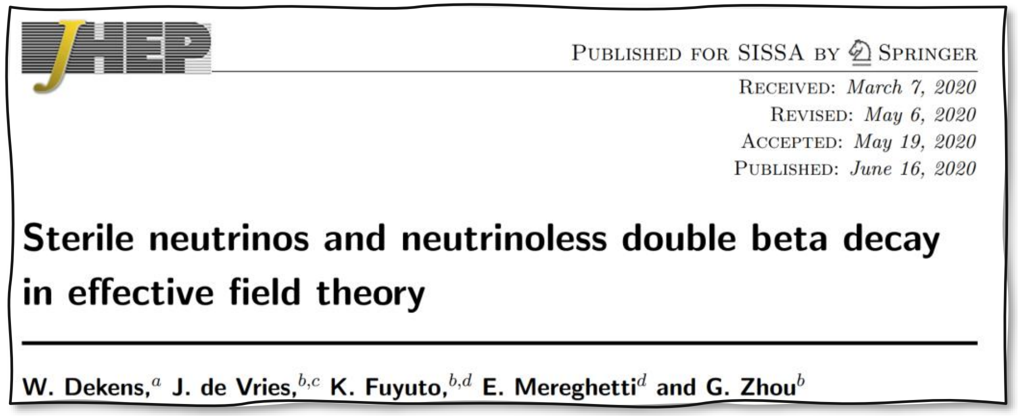

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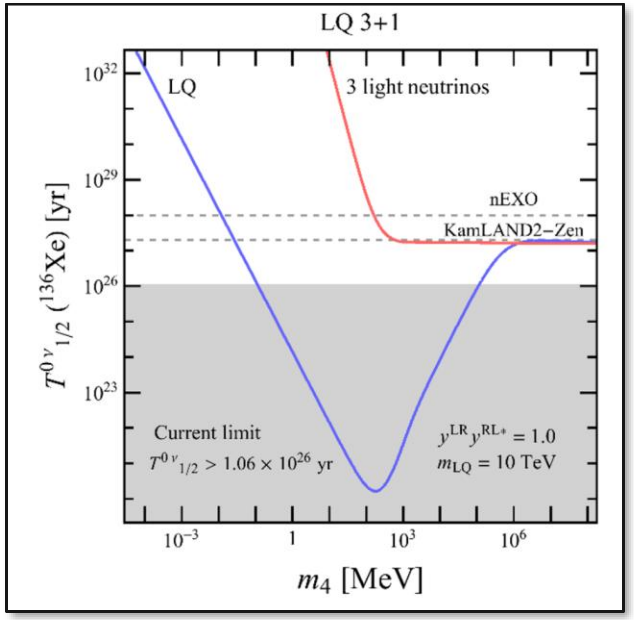
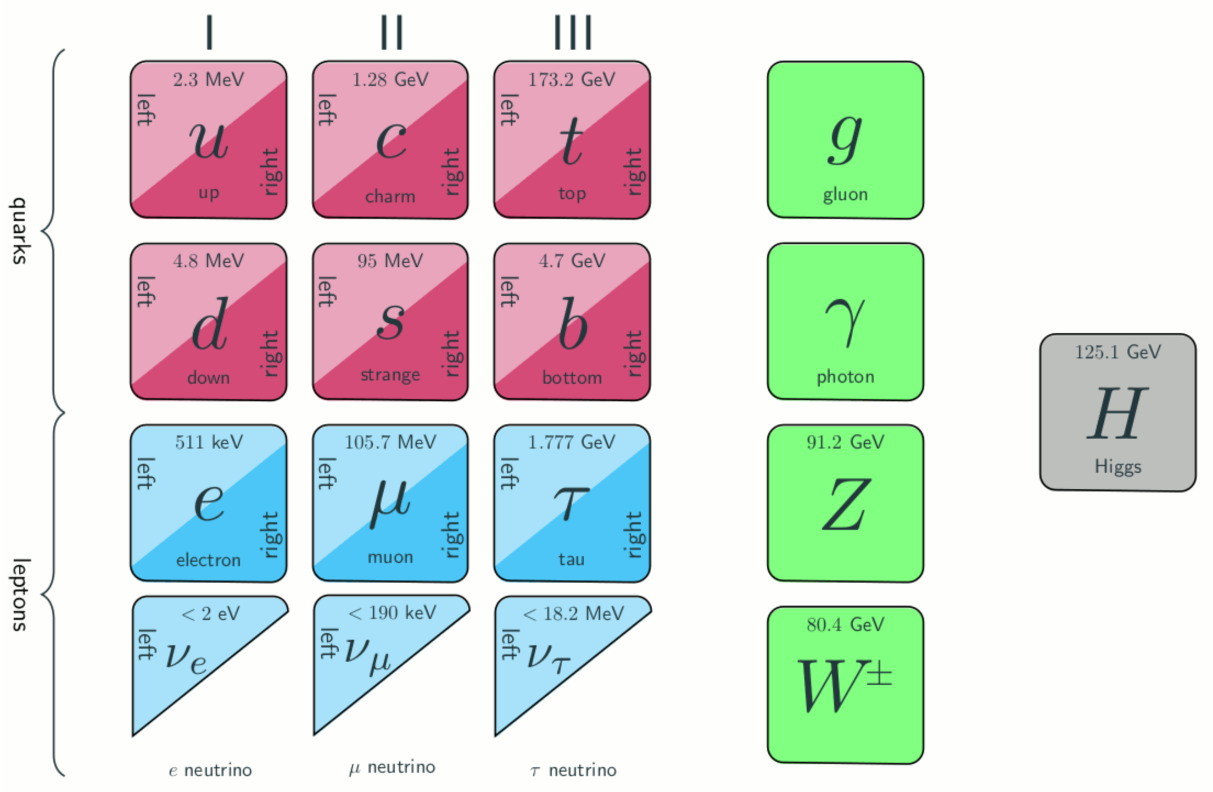


How robust?

Standard Case

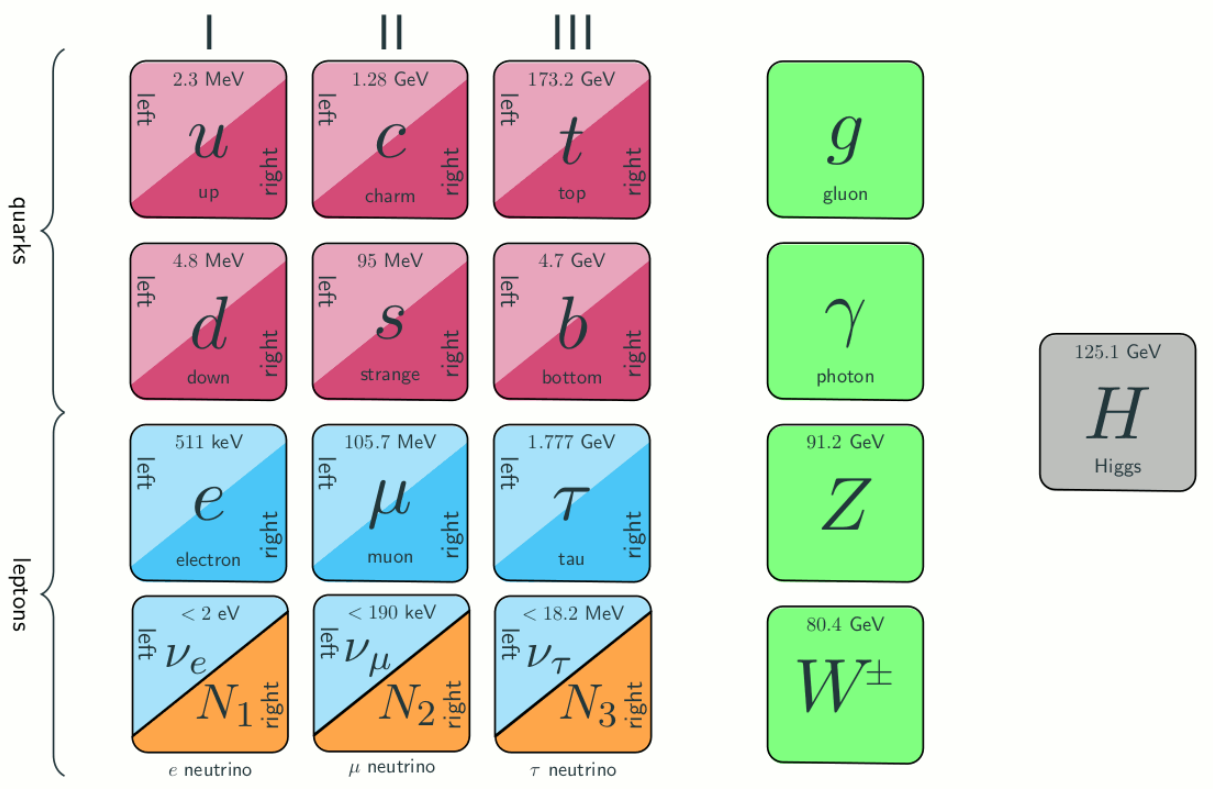
Underlying model



[https://ep-news.web.cern.ch/uniting-leptogeneses]

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}}$$

Underlying model



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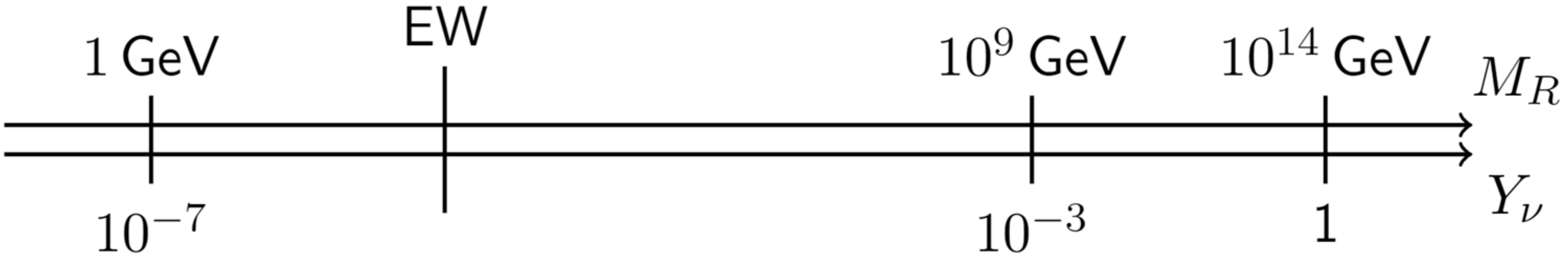
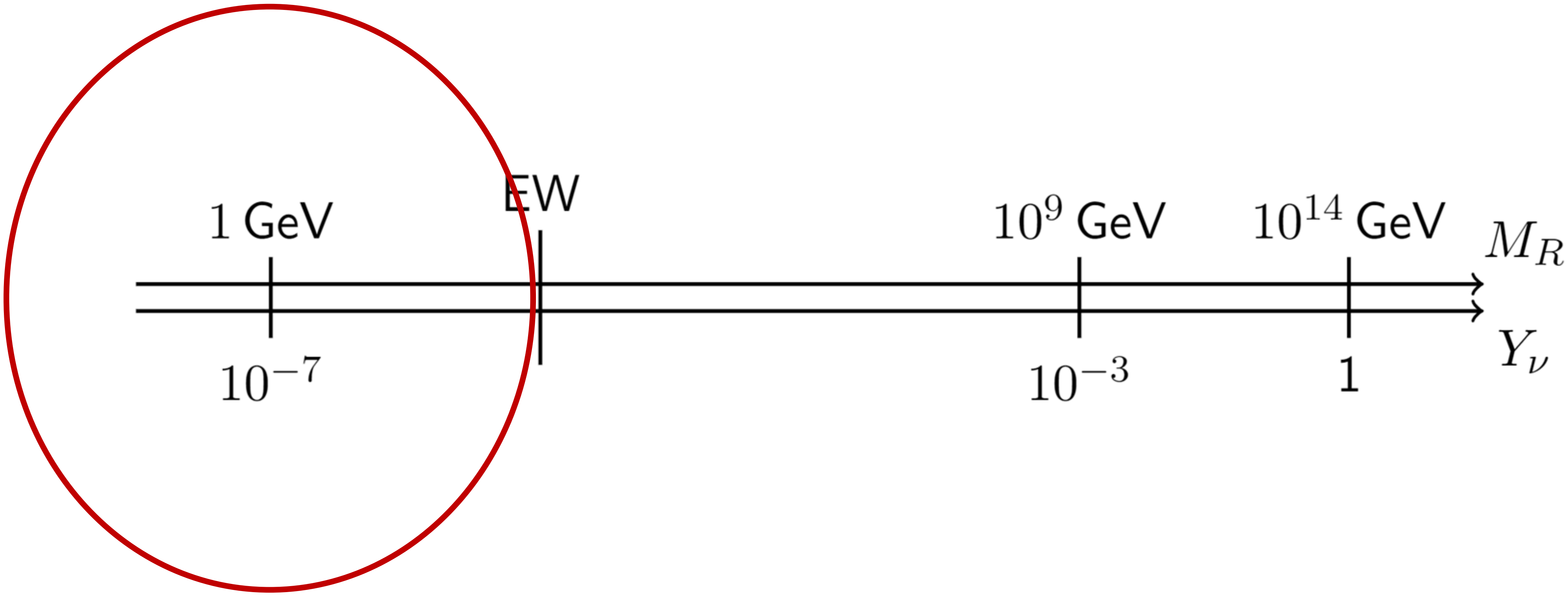
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}}$$

$$+\mathcal{L}_N \begin{cases} +\bar{N}(i\partial\!\!\!/)N \\ -Y_{i\alpha}\bar{N}_i H L_\alpha + \text{h.c.} \\ -\bar{N}_i^c M_i N_i + \text{h.c.} \end{cases}$$

Mass Range

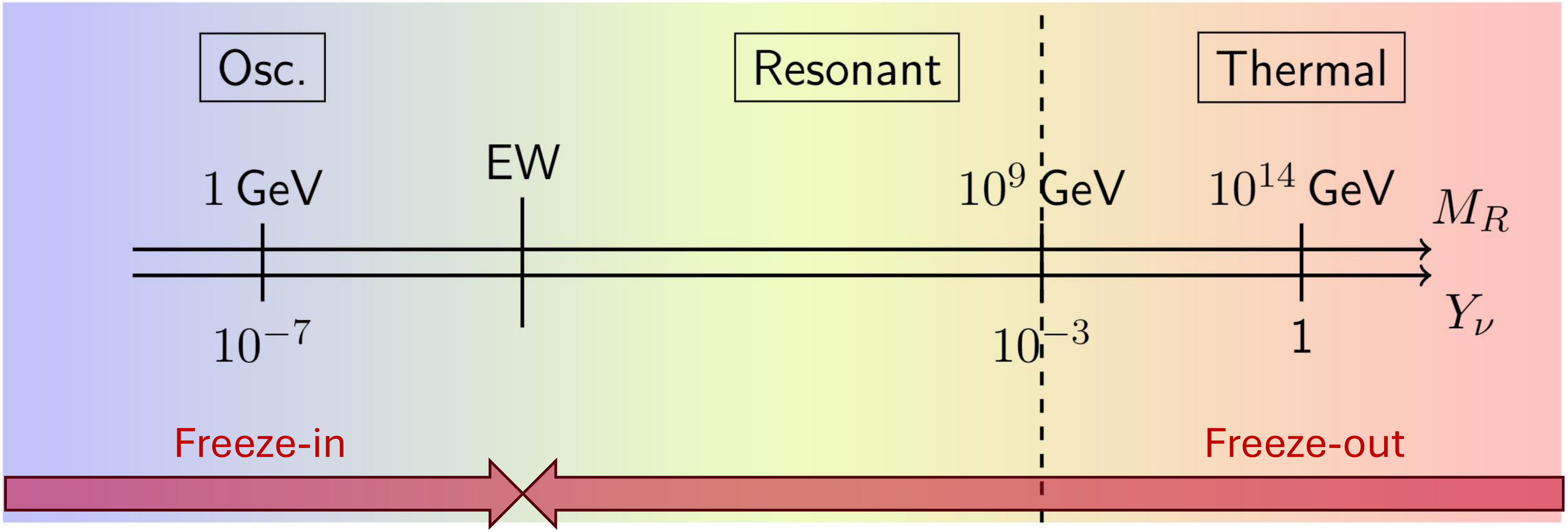


Mass Range

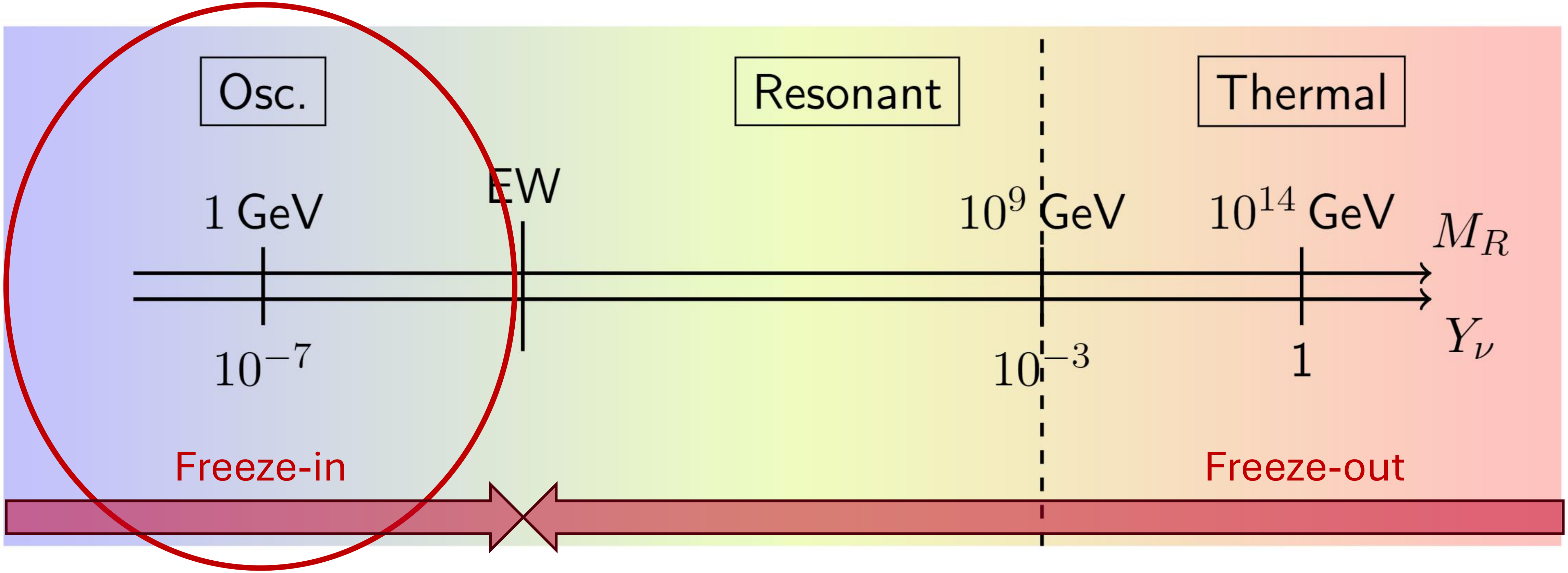


"Low-Scale"

Leptogenesis regimes

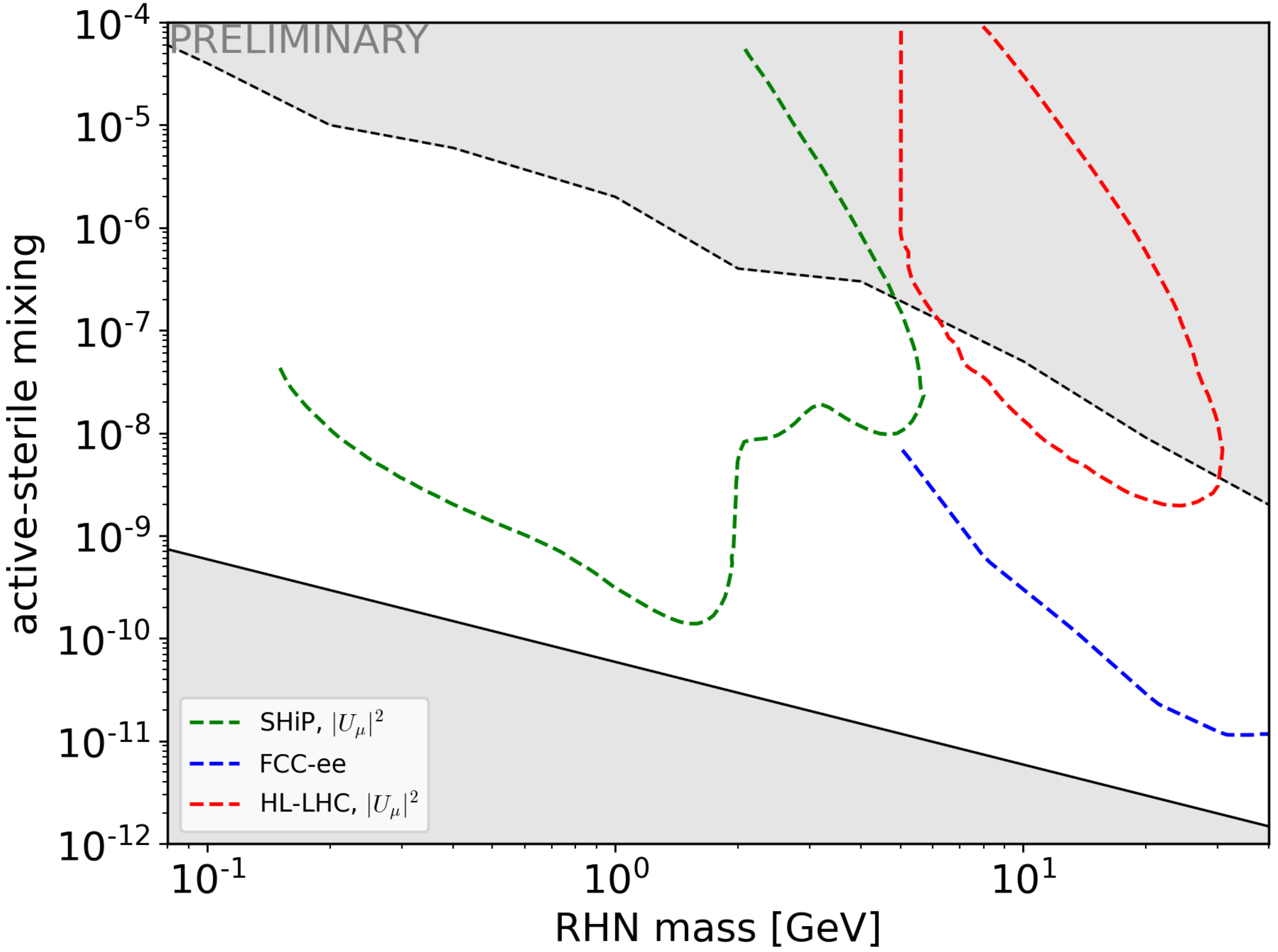


Leptogenesis regimes



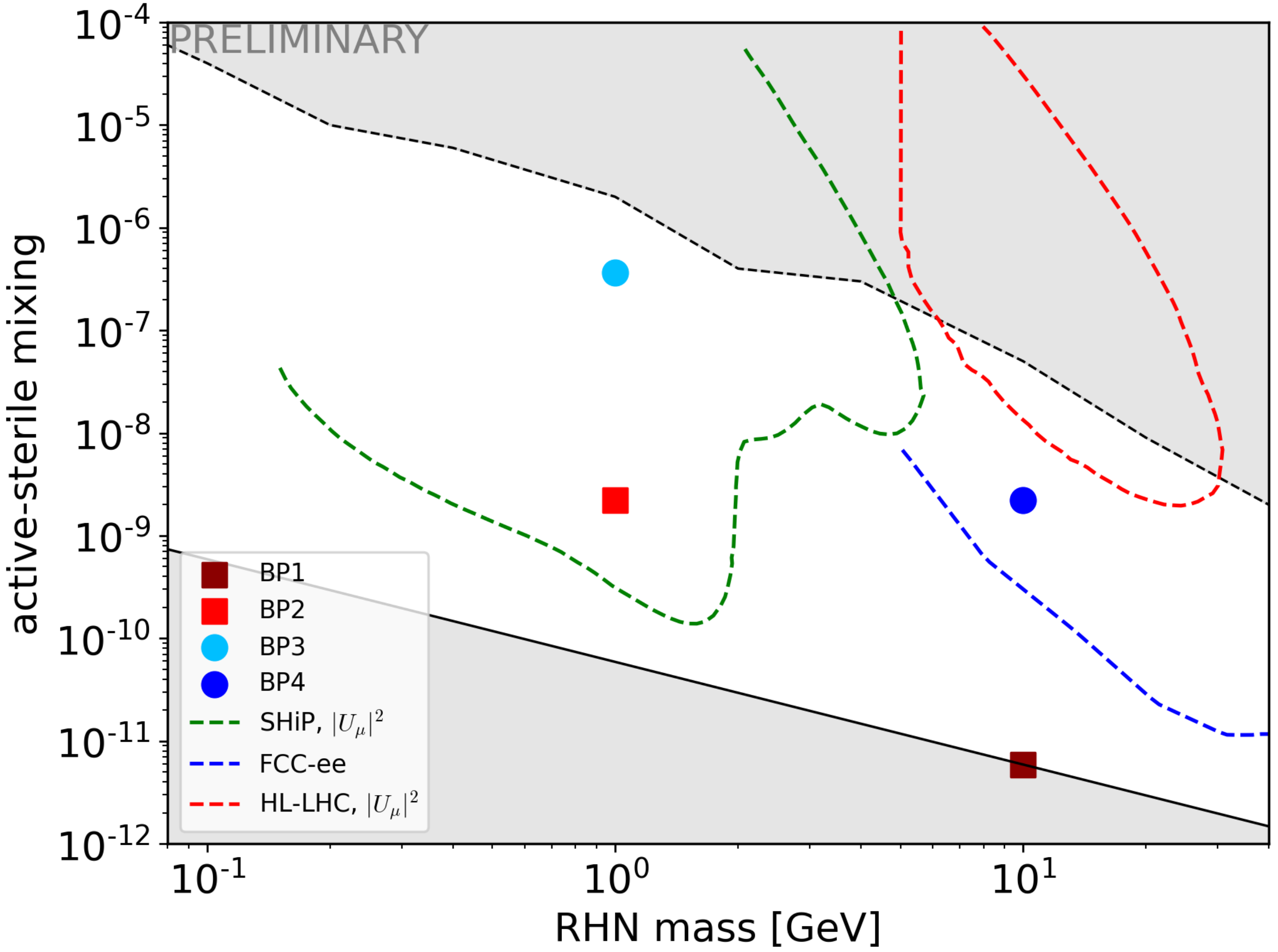
Low-Scale Leptogenesis

Available parameter space



[Fuyuto, Harz, SW in preparation]

Available parameter space



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Non-Standard Case

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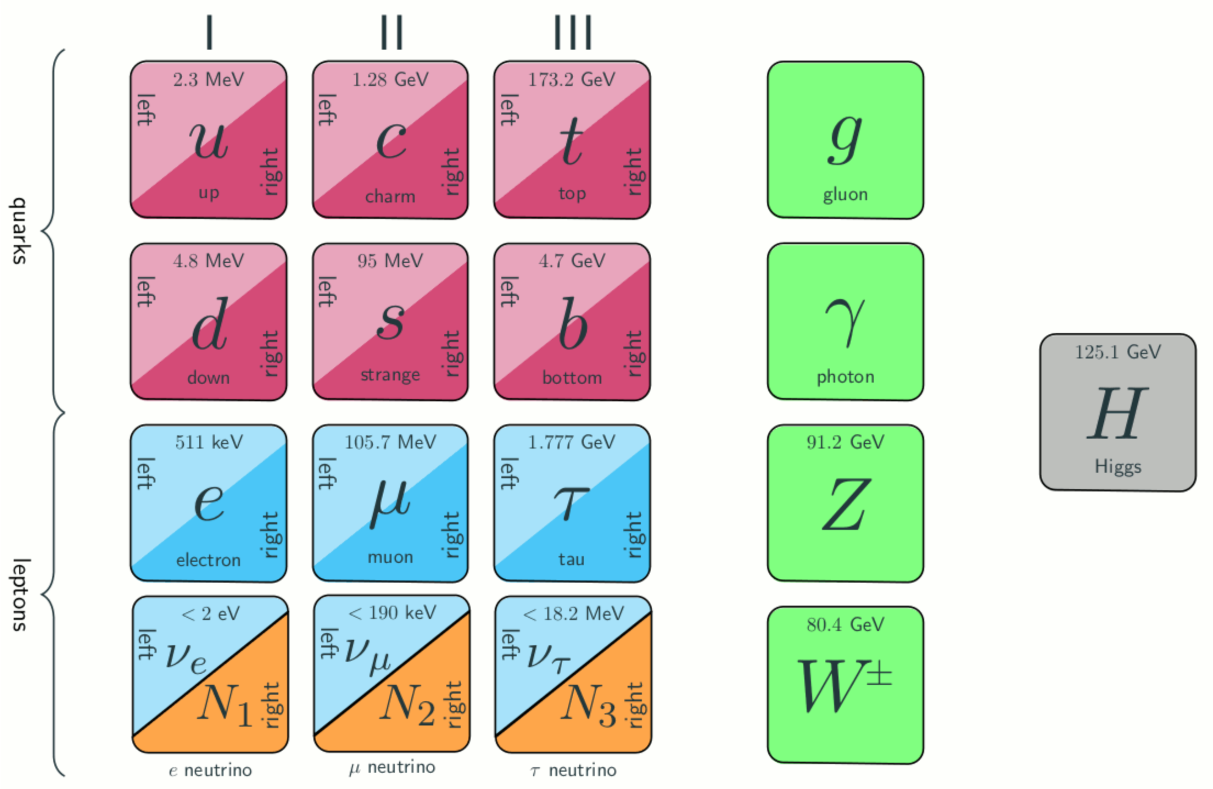

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$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}}$$

$$+ \mathcal{L}_N \begin{cases} + \bar{N}(i\partial\!\!\!/)N \\ - Y_{i\alpha}\bar{N}_i H L_\alpha + \text{h.c.} \\ - \bar{N}_i^c M_i N_i + \text{h.c.} \end{cases}$$

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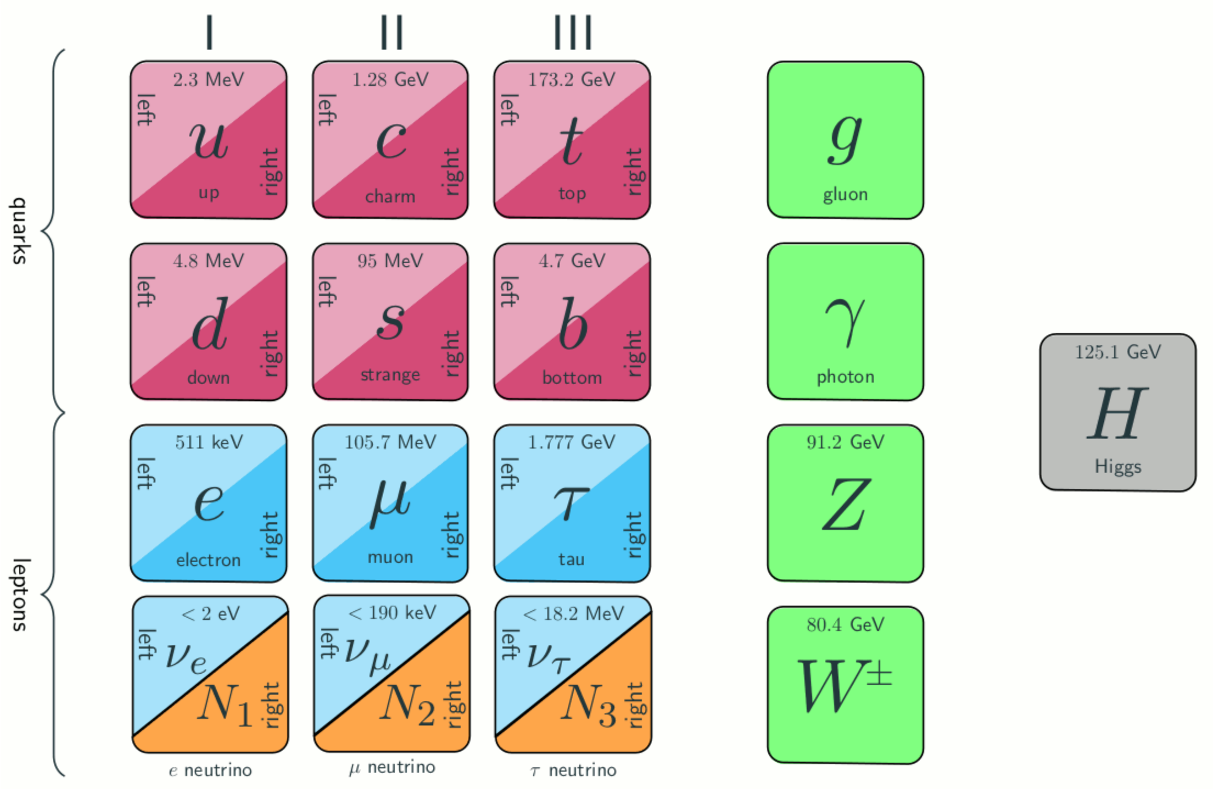

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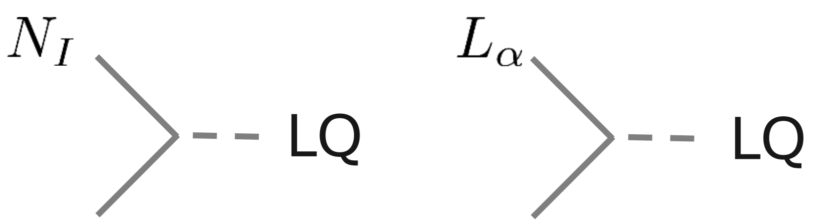
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}}$$

$$+\,\mathcal{L}_N \left\{ \begin{array}{l} +\,\bar{N}(i\partial\!\!\!/)N \\ -\,Y_{i\alpha}\bar{N}_i H L_\alpha + \mathrm{h.c.} \\ -\,\bar{N}_i^c M_i N_i + \mathrm{h.c.} \end{array} \right.$$

+ more?

Non-Standard Case



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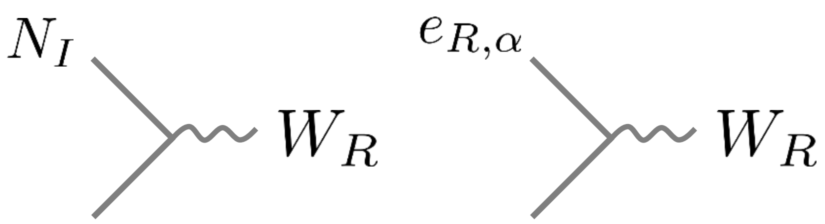
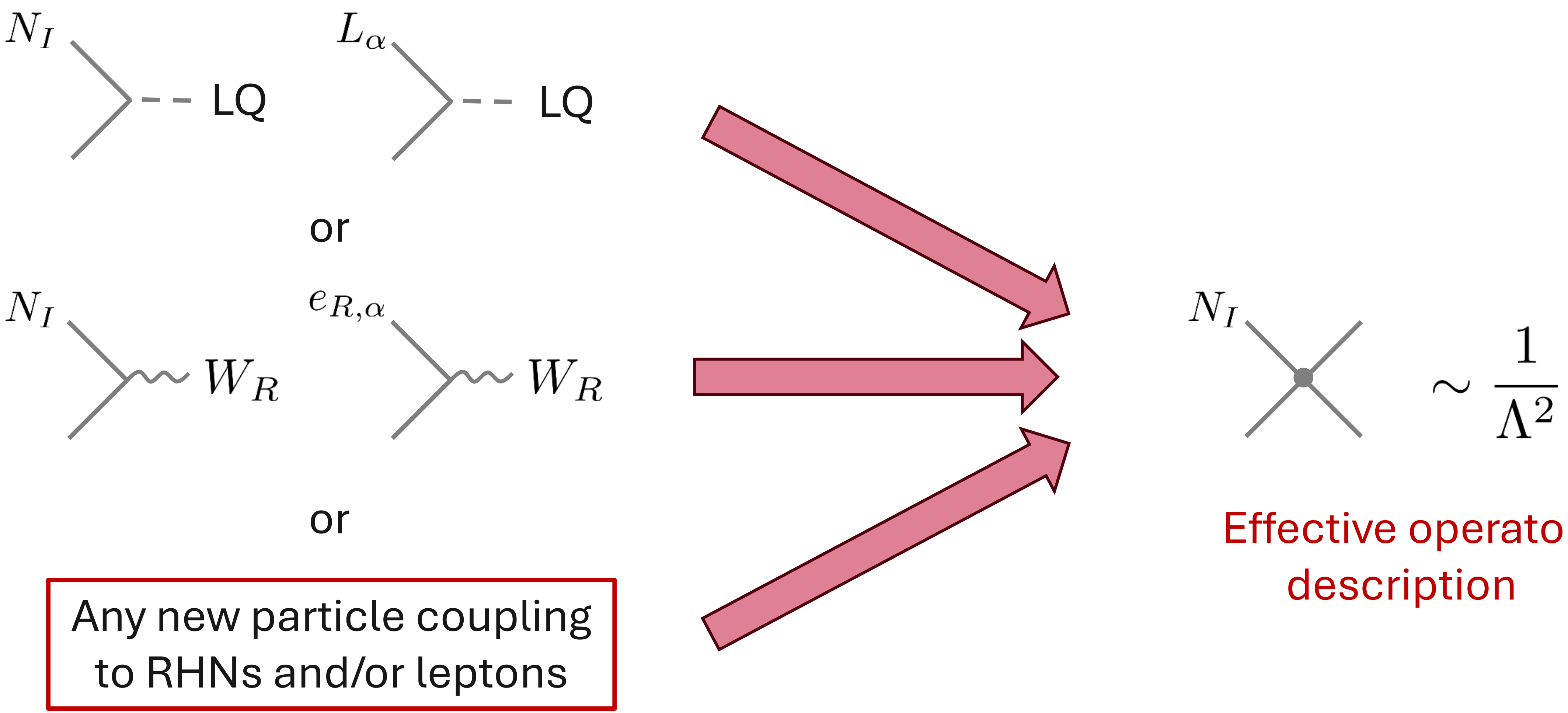


or

Any new particle coupling to RHNs and/or leptons

Non-Standard Case



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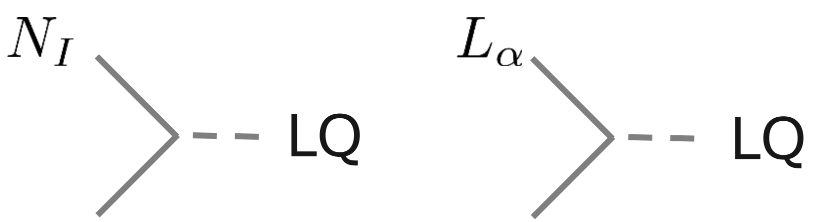

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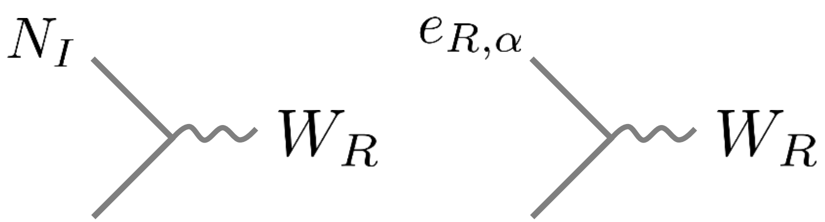

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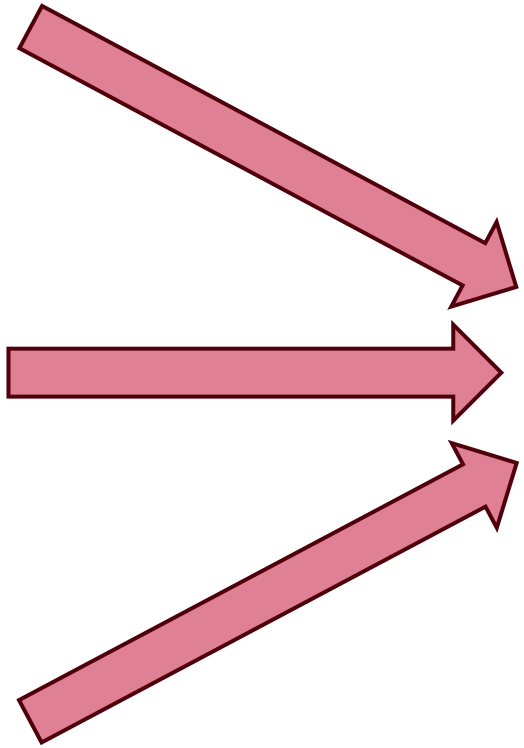
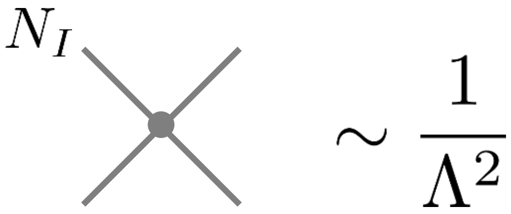
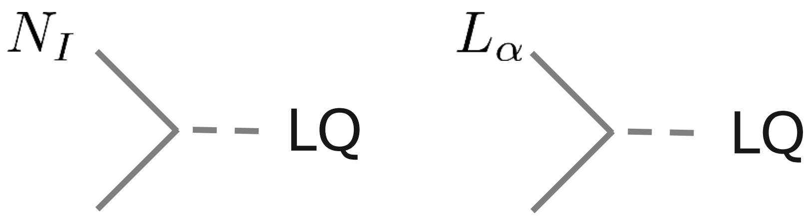




Effective operator description

νSMEFT

Non-Standard Case



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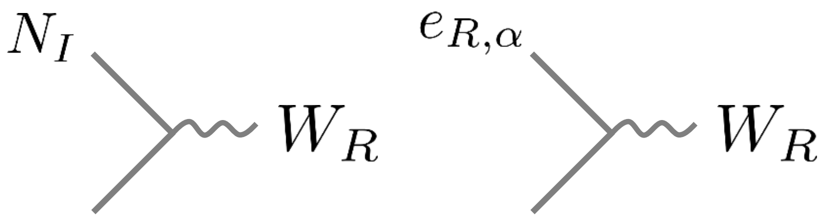

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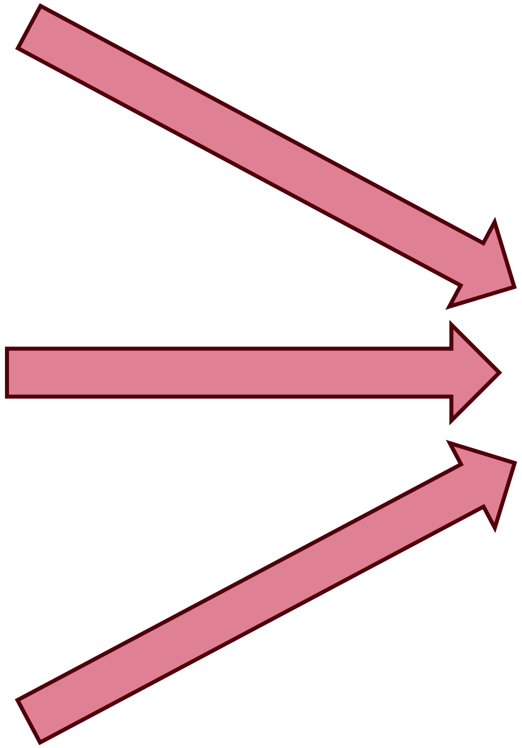
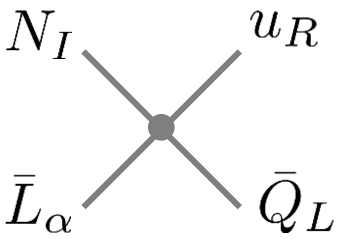
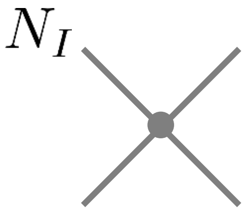


Example operator:





$\sim \frac{1}{\Lambda^2}$

Effective operator description

νSMEFT

Lepton Number Violation

- Assignment of LN: $\mathcal{L} \supset -Y_{i\alpha}\overline{N_i} H L_\alpha - \overline{N_i^c} M_i N_i + \text{h.c.}$

  $\underbrace{-Y_{i\alpha}\overline{N_i} H L_\alpha}_{\text{LNC}}$ $\underbrace{- \overline{N_i^c} M_i N_i}_{\text{LNV}}$

$$L(L_\alpha) = 1$$
$$L(H) = 0$$
$$L(N_i) = 1$$

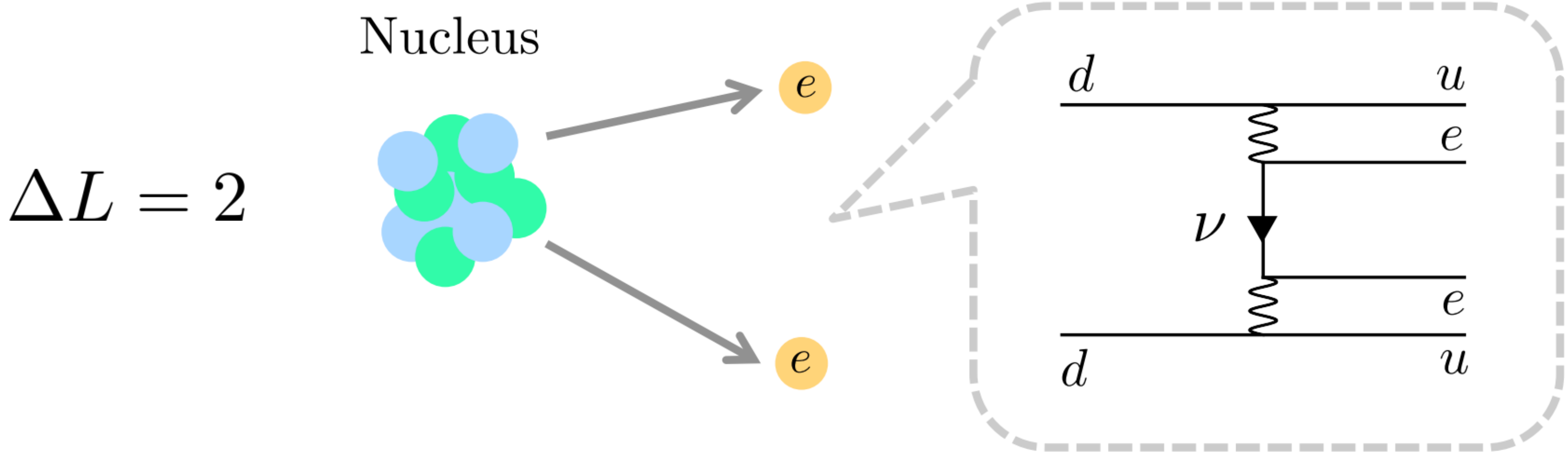
Lepton Number Violation

- Assignment of LN: $\mathcal{L} \supset -Y_{i\alpha}\overline{N_i}HL_\alpha - \overline{N_i^c}M_iN_i + \text{h.c.}$

  LNC LNV

  $L(L_\alpha) = 1$
  $L(H) = 0$
  $L(N_i) = 1$

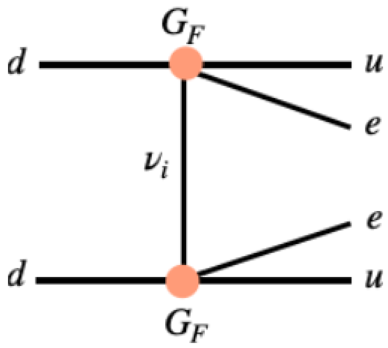
- "Most" promising observable: $0\nu\beta\beta$ decay

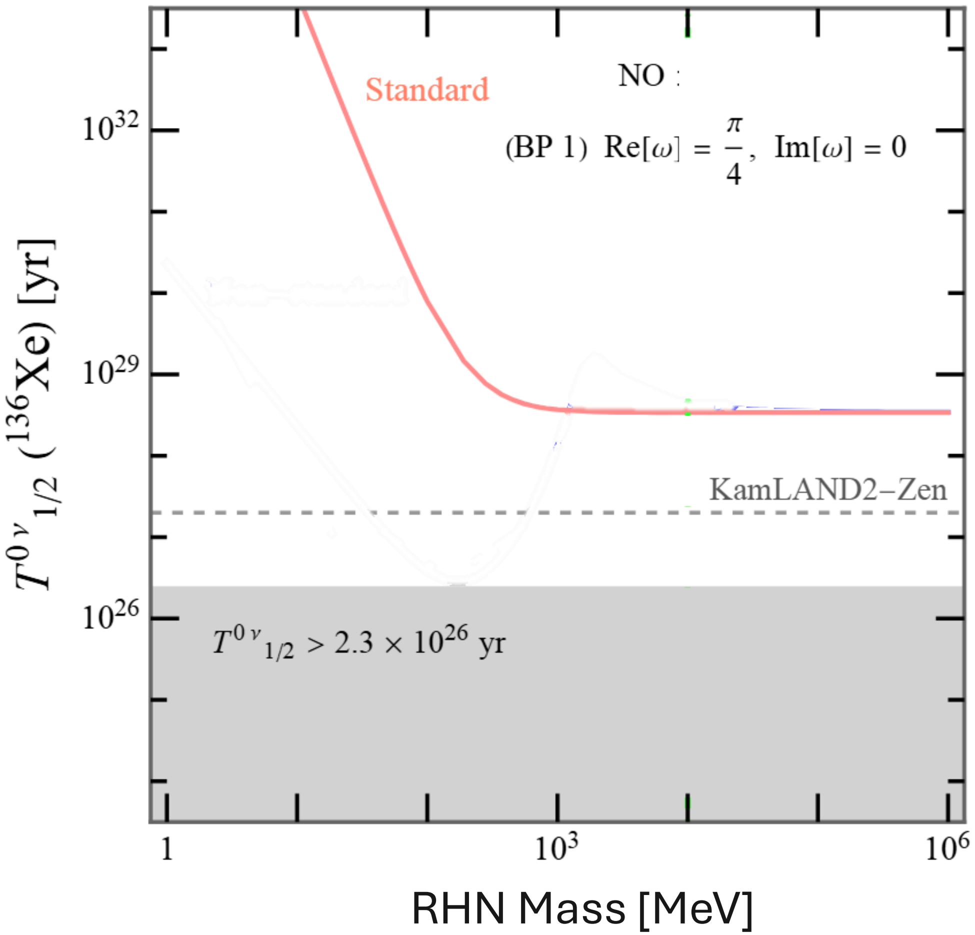


[by K. Fuyuto]

$0\nu\beta\beta$ decay

- 4-fermion interaction at low scales

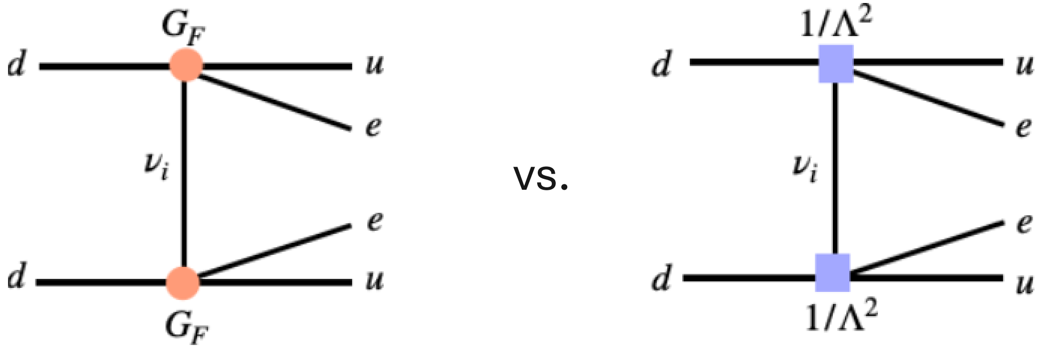




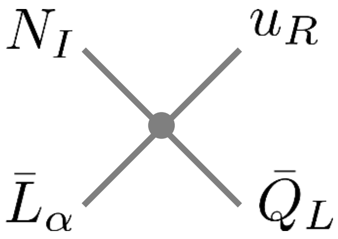
[Fuyuto, Harz, SW in preparation]

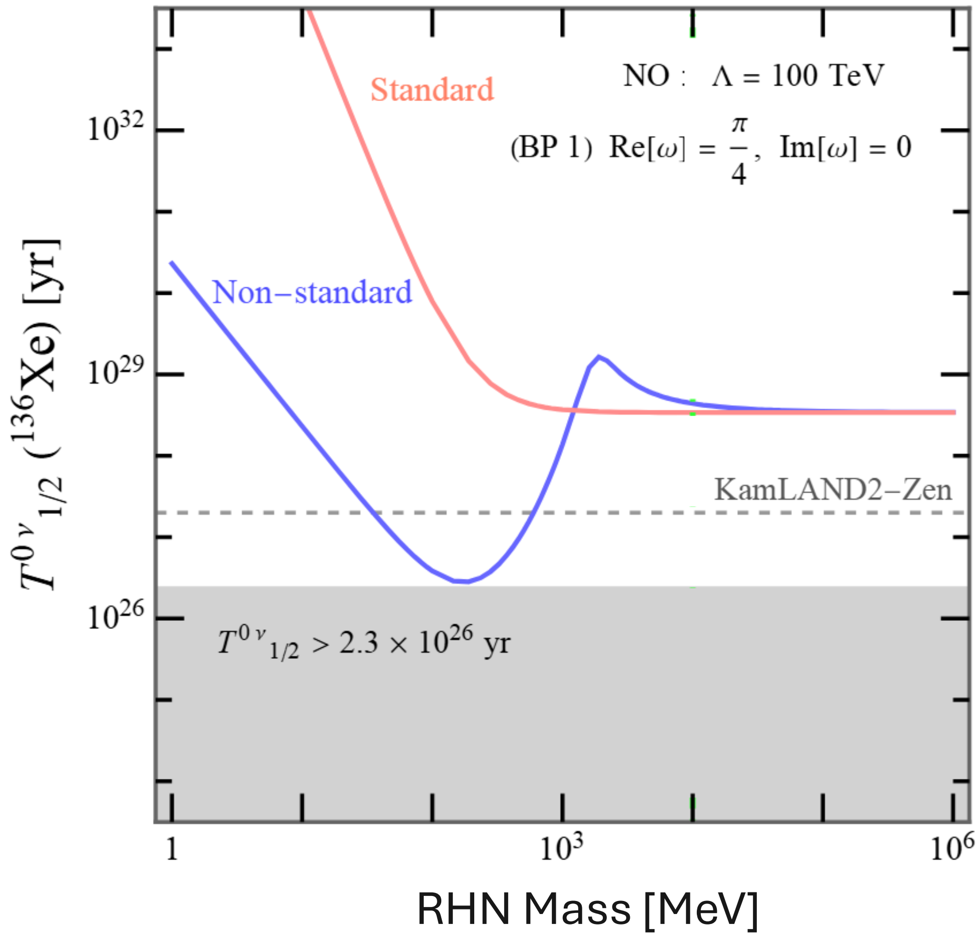
$0\nu\beta\beta$ decay

- See also [Dekens et. al. JHEP 2020]



LNC operator:





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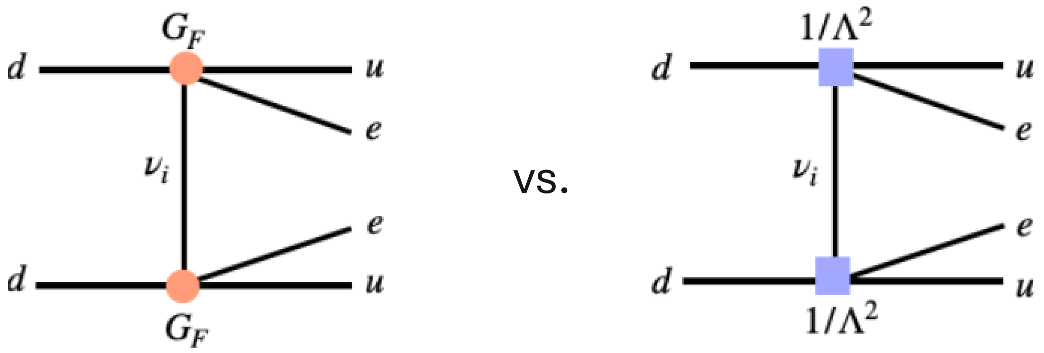
$0\nu\beta\beta$ decay

Order of magnitude effect!

- See also [Dekens et. al. JHEP 2020]



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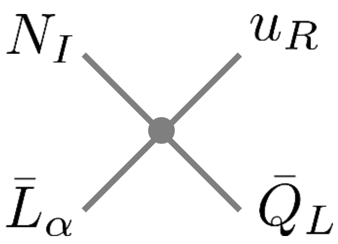

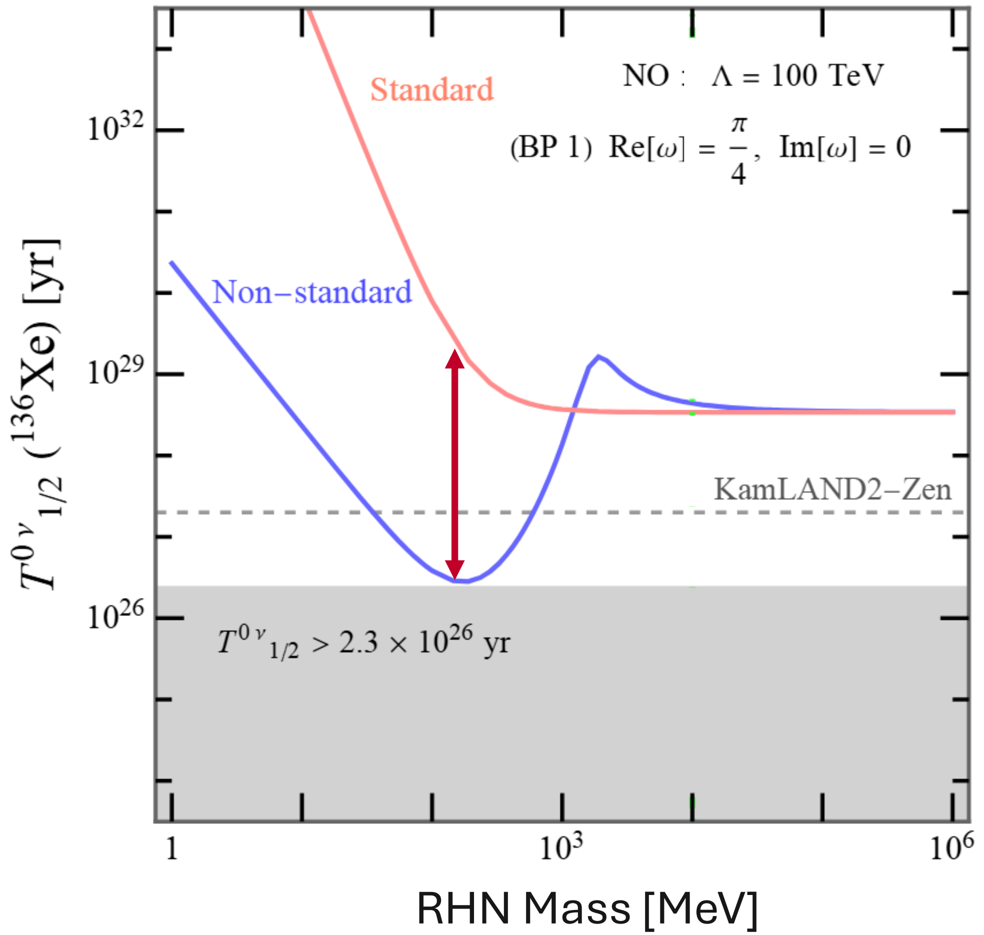

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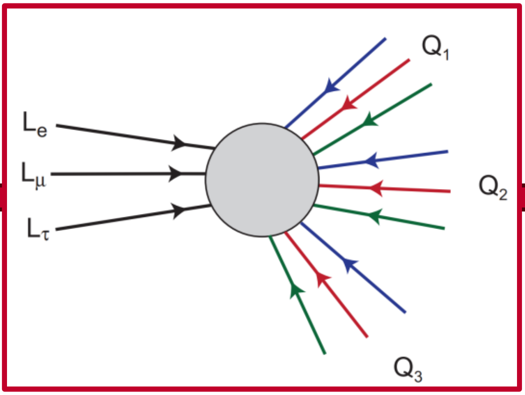
Baryon Asymmetry

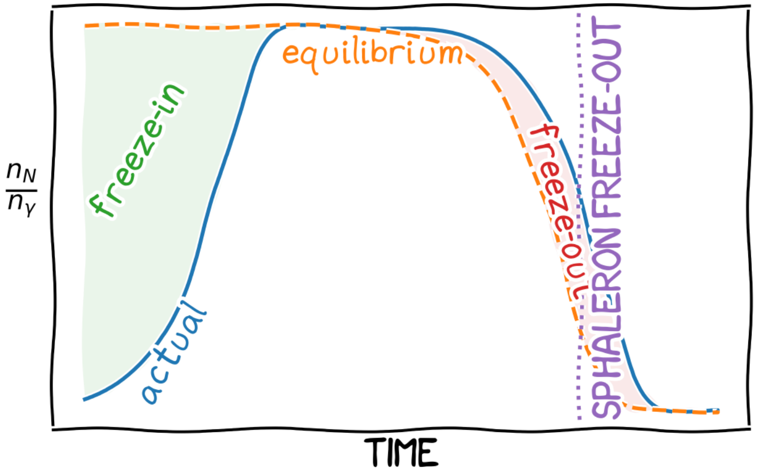
EW Sphalerons

ΔL →  → ΔB

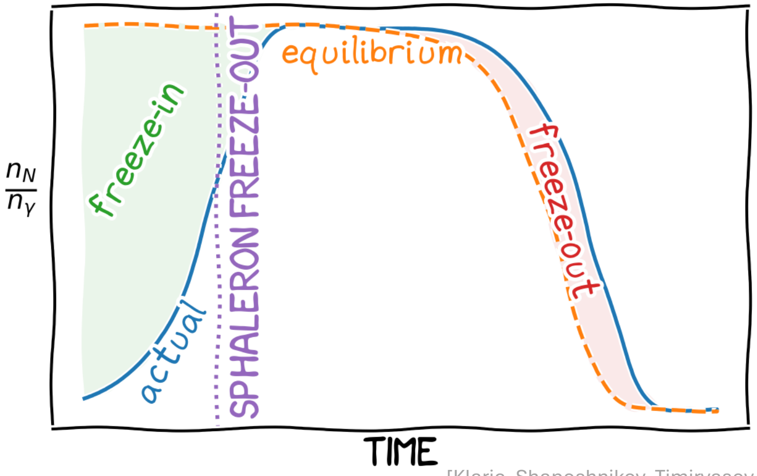
[Nir 2009]

Baryon Asymmetry

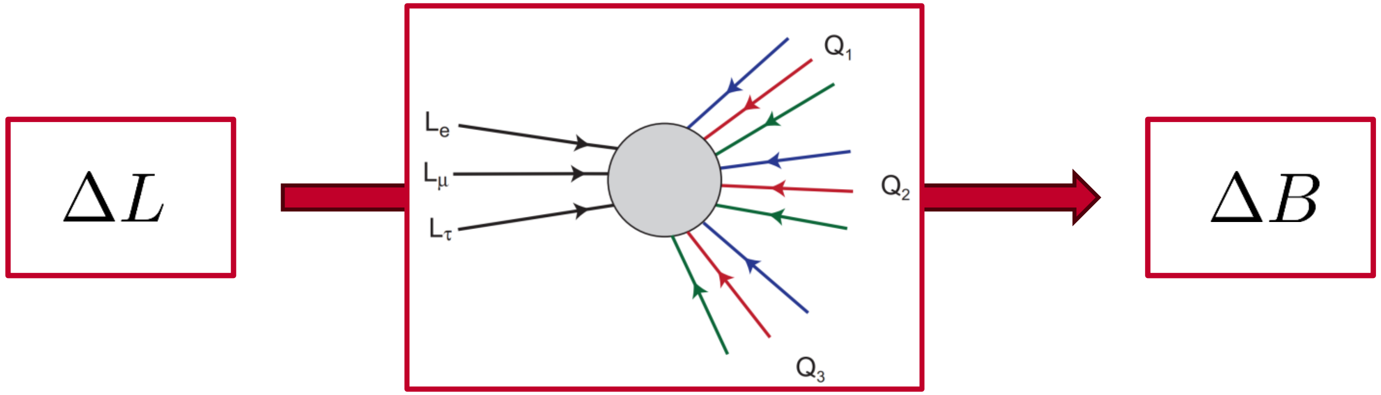
Thermal/Resonant



Via Oscillations



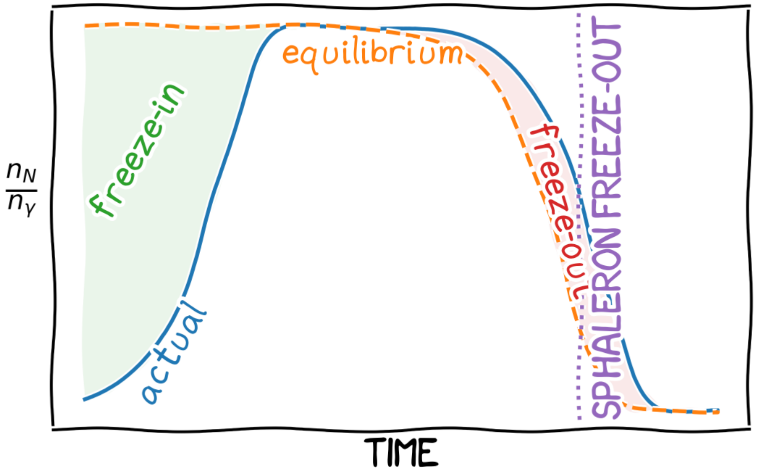
[Klaric, Shaposhnikov, Timiryasov 2103.16545]



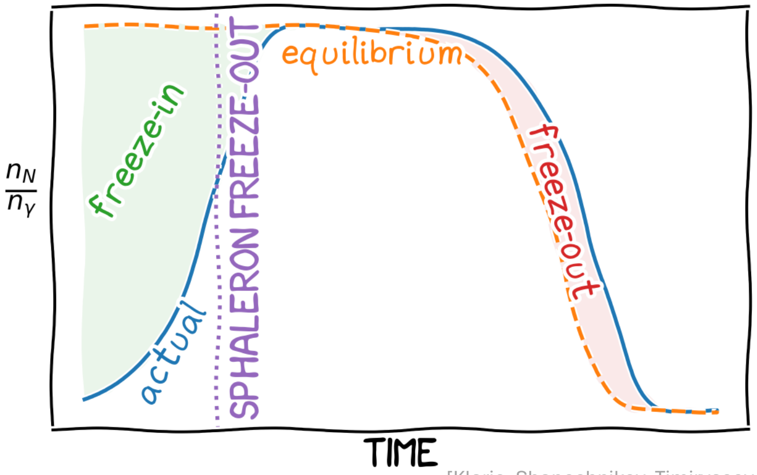
[Nir 2009]

Baryon Asymmetry

Thermal/Resonant

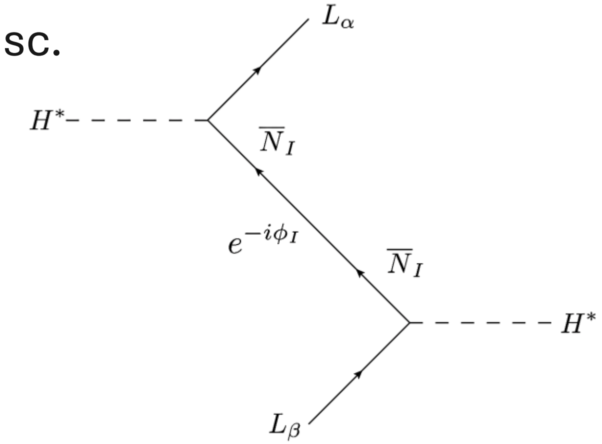


Via Oscillations



[Klaric, Shaposhnikov, Timiryasov 2103.16545]

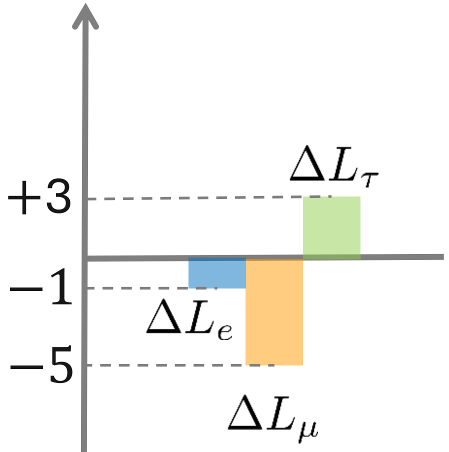
Osc.



[Flood et. al. PRD 2022]

Coherent oscillations

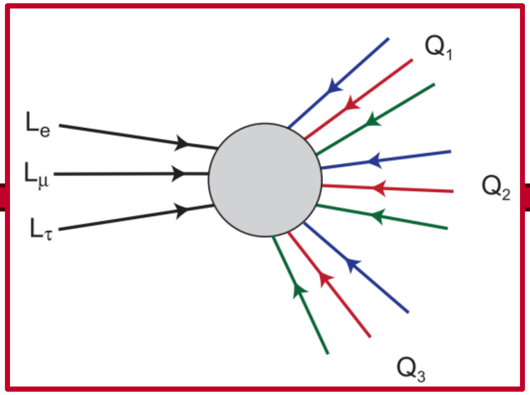
Scatterings



$\Delta L_{\mathrm{SM}} \neq 0$

EW Sphalerons

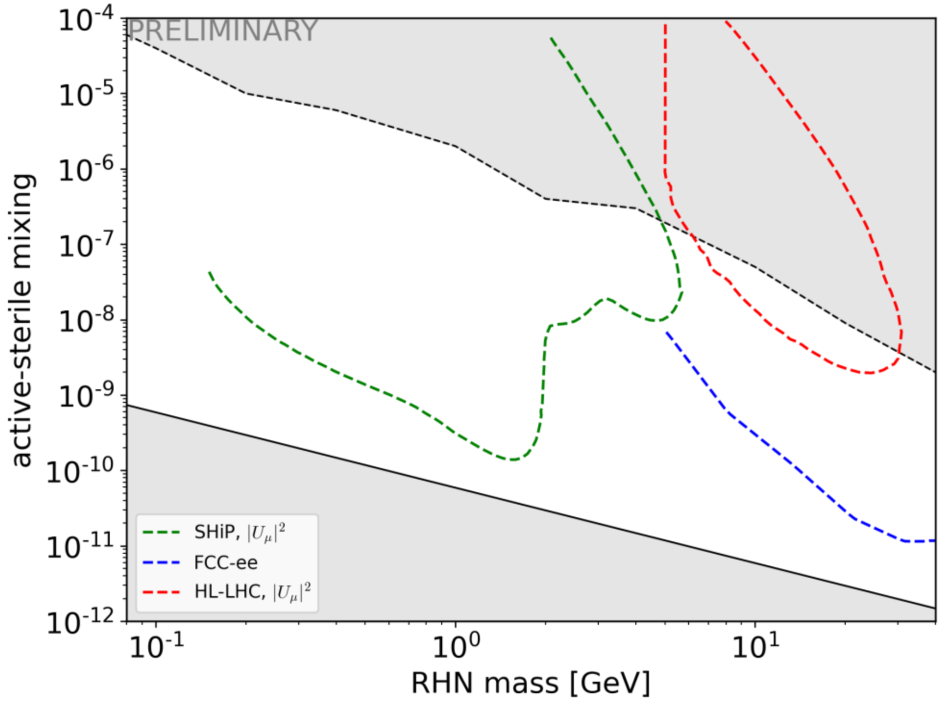
ΔL

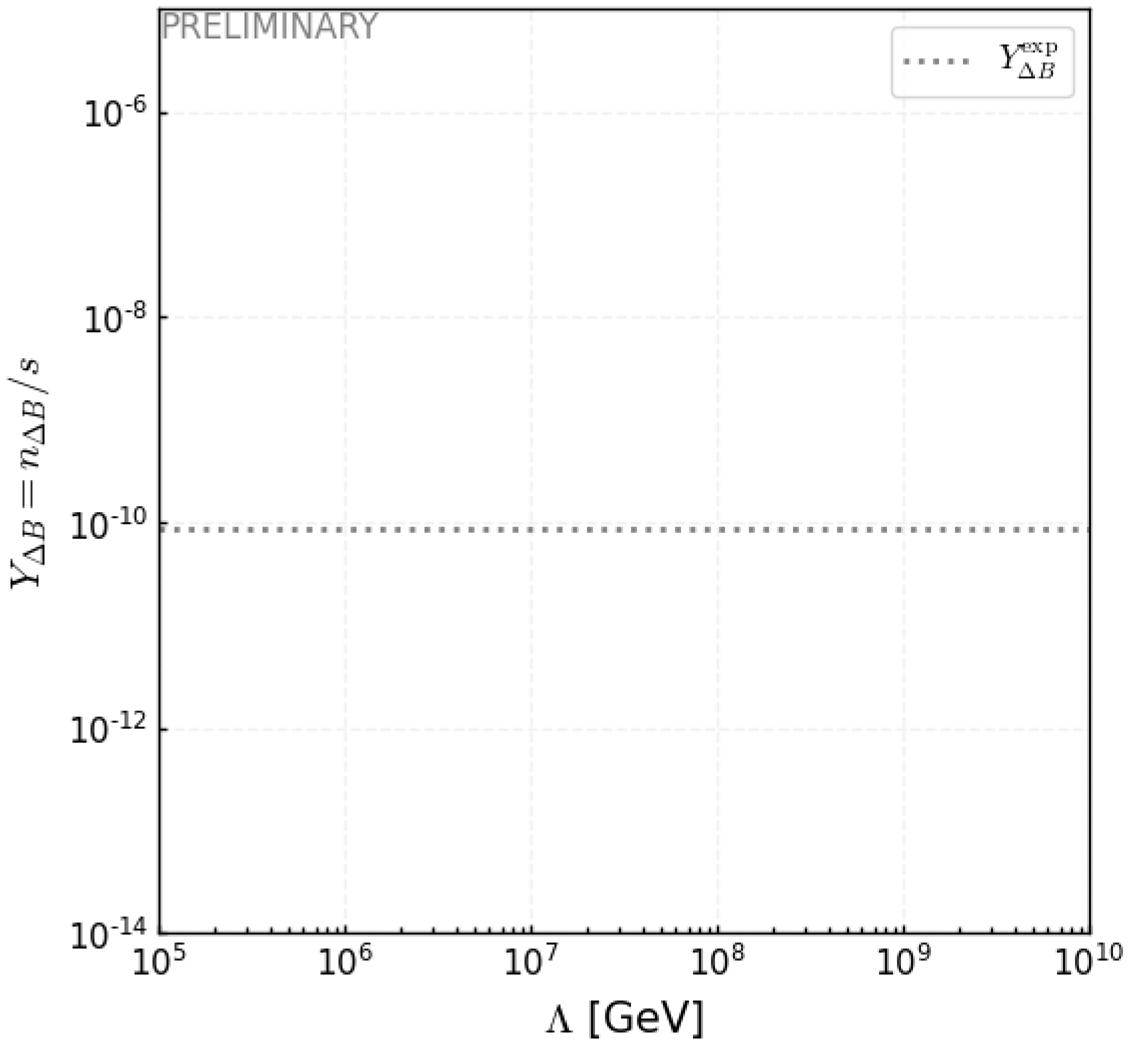


ΔB

[Nir 2009]

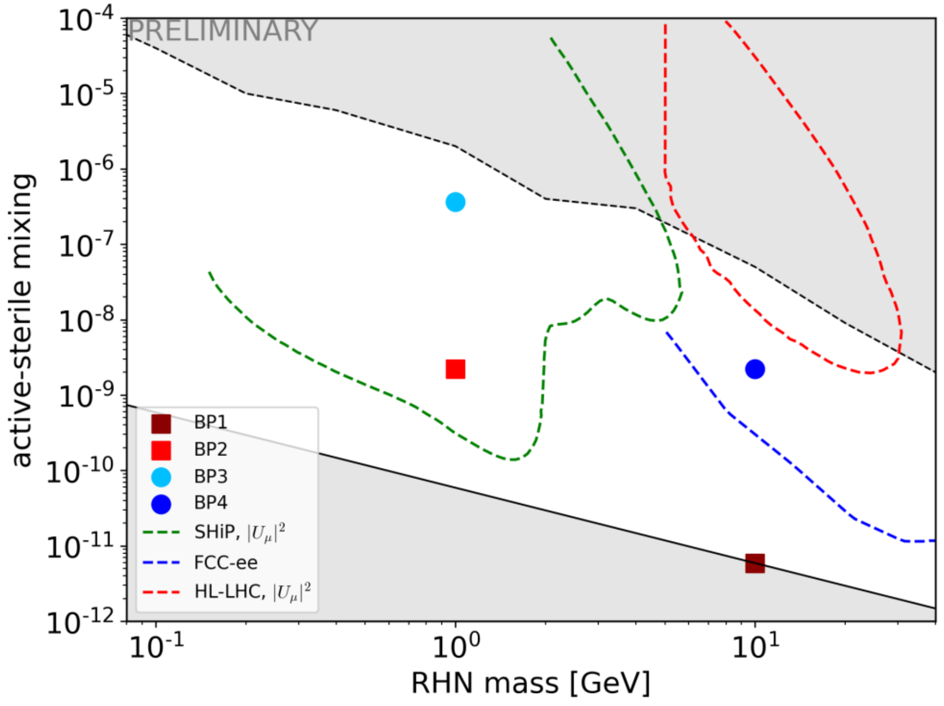
Low-Scale Leptogenesis in the νSMEFT

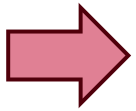


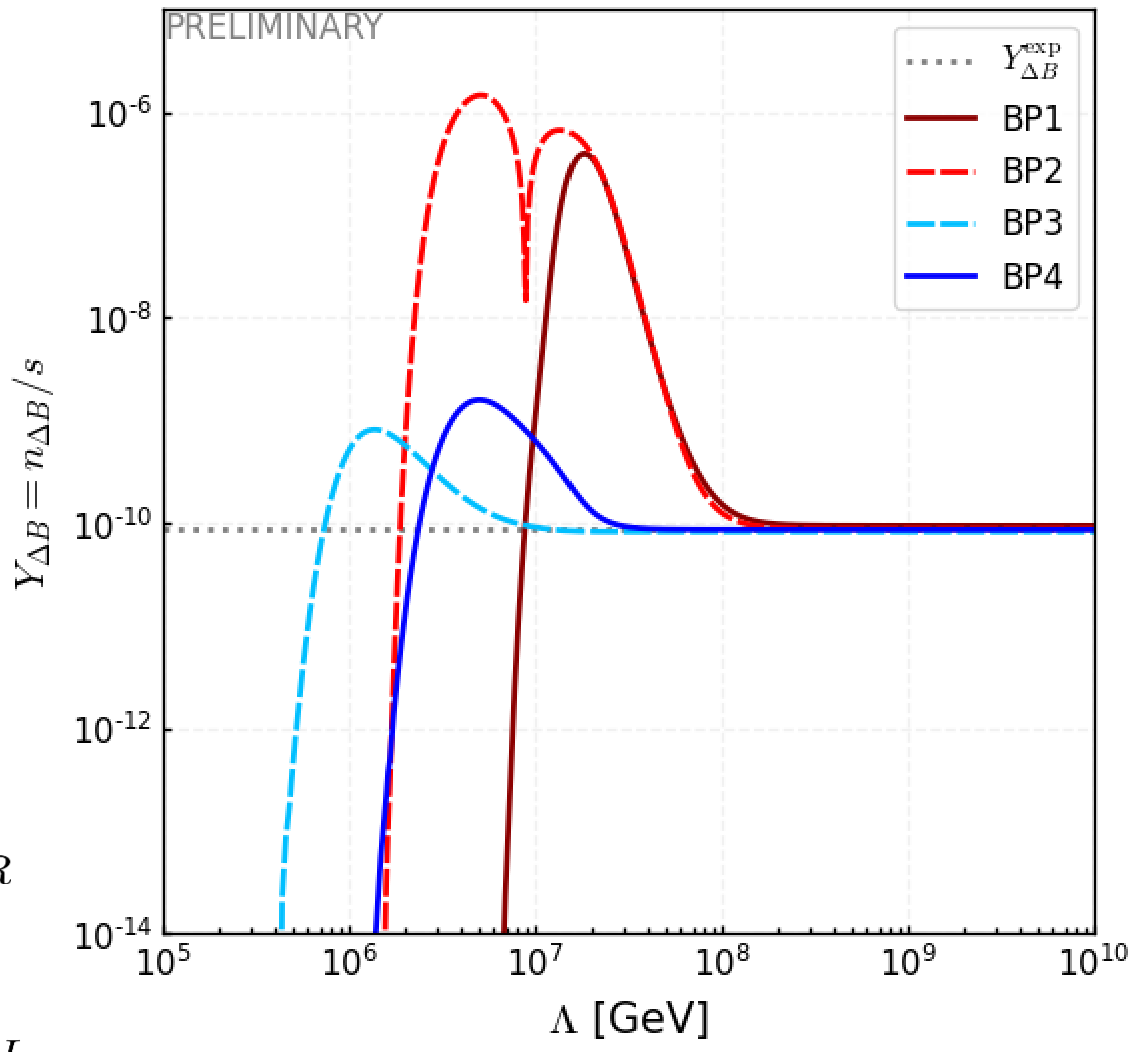


[Fuyuto, Harz, SW in preparation]

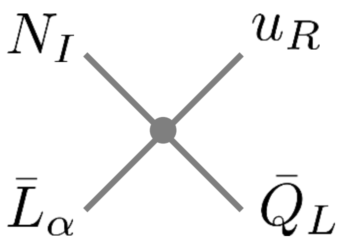
Low-Scale Leptogenesis in the νSMEFT





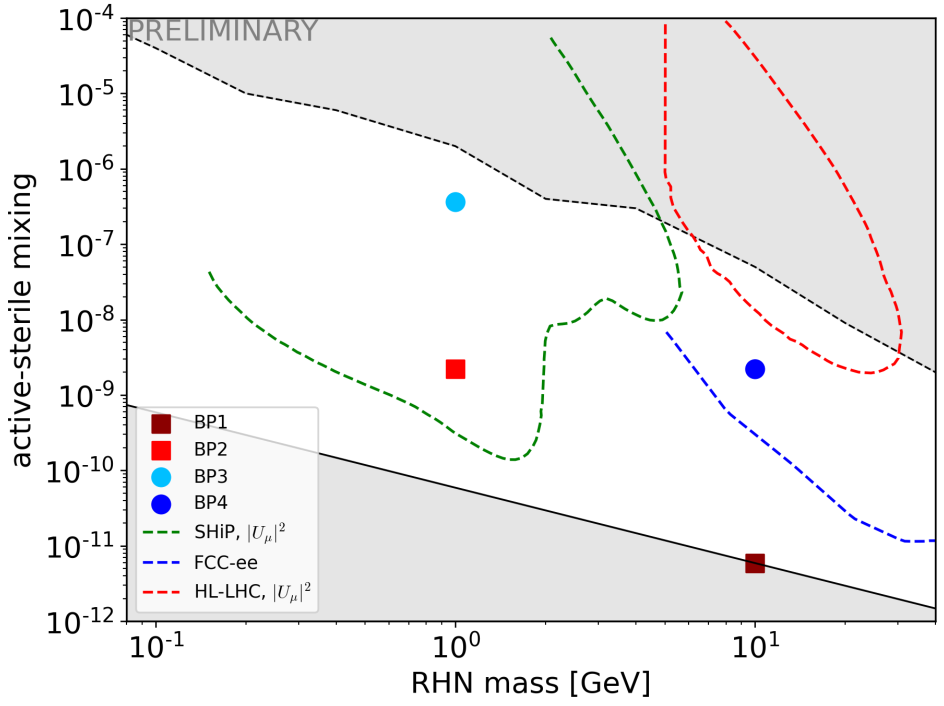


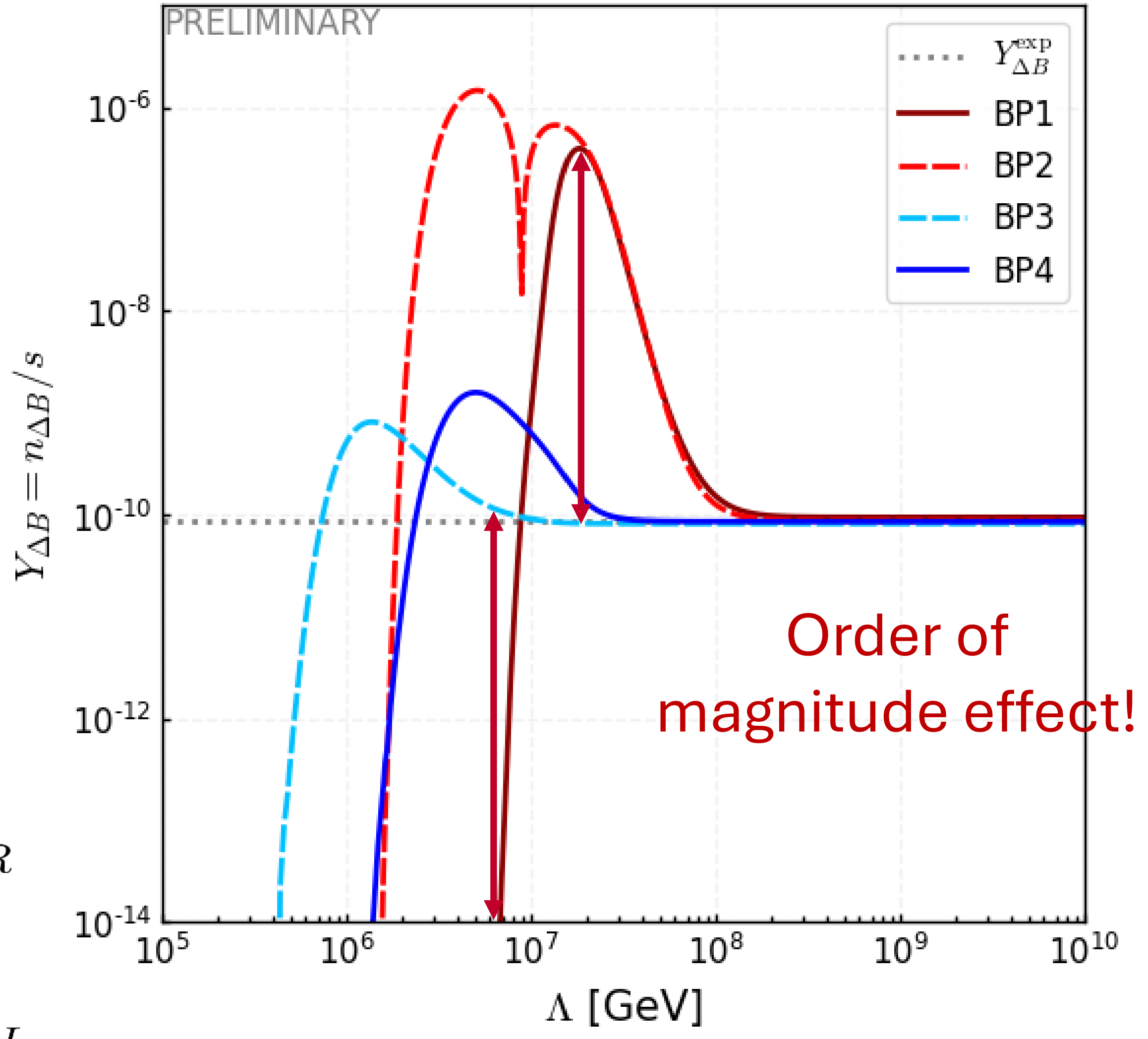
LNC operator:



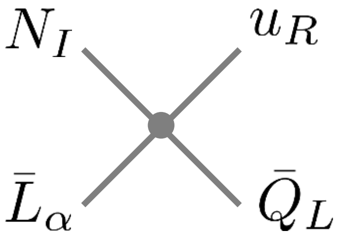
[Fuyuto, Harz, SW in preparation]

Low-Scale Leptogenesis in the νSMEFT





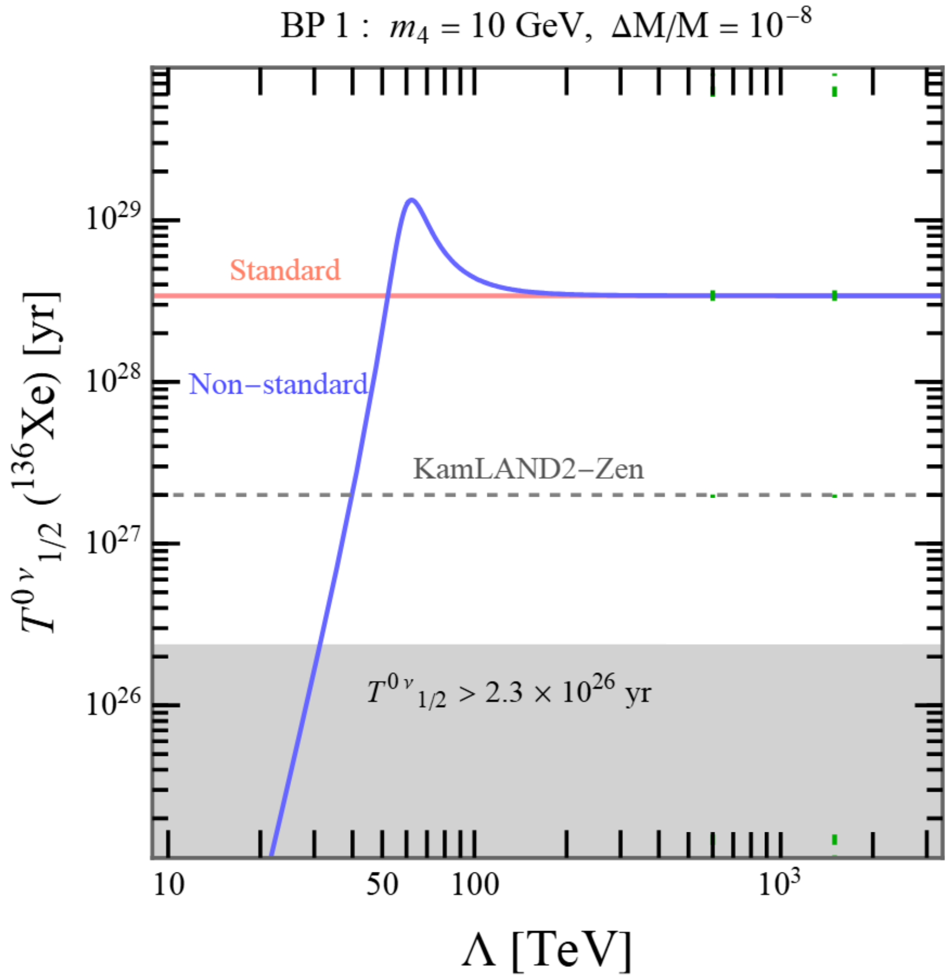
LNC operator:



[Fuyuto, Harz, SW in preparation]

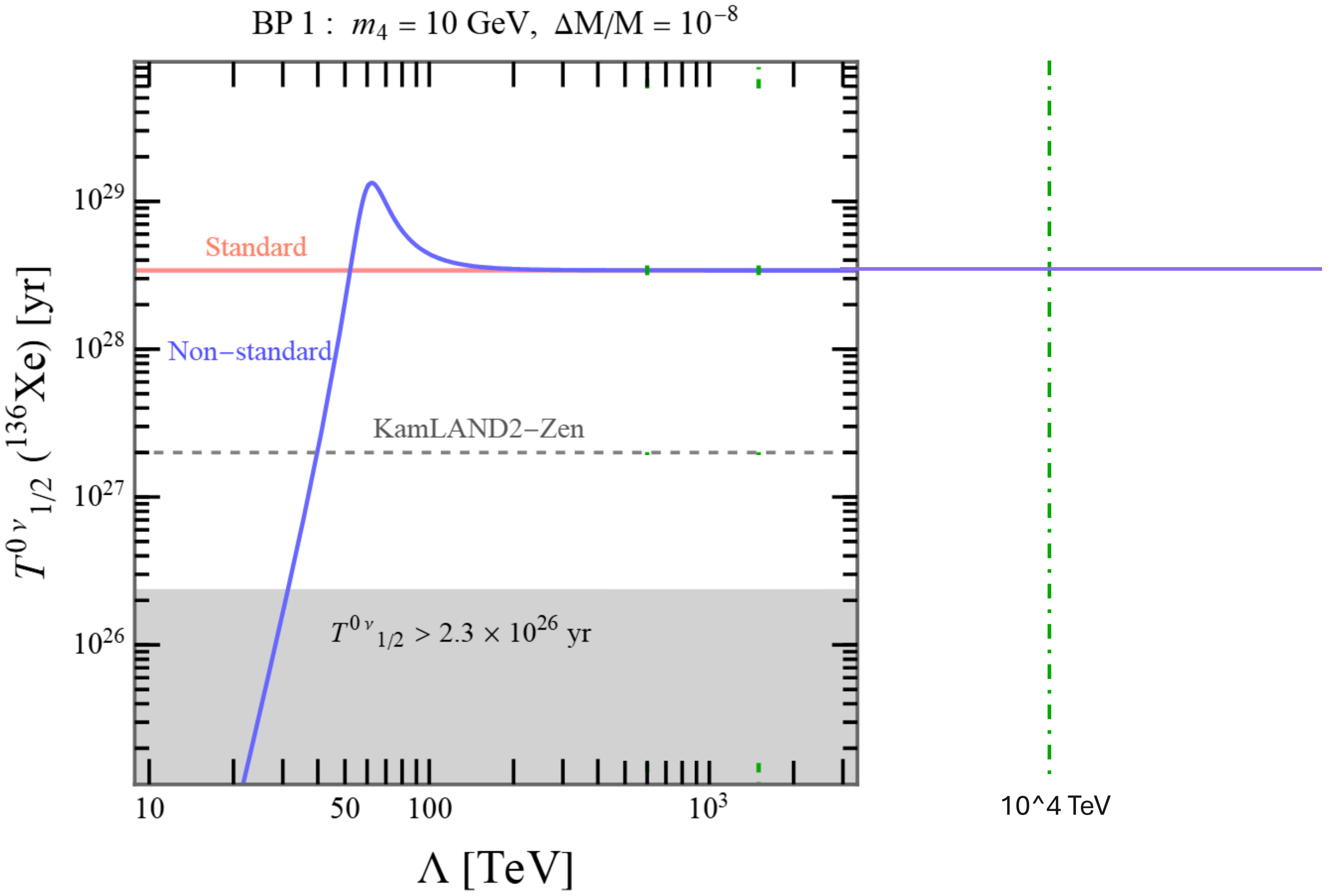
Combine Leptogenesis
&
$0\nu\beta\beta$ decay

Falsifying Low-Scale Leptogenesis?



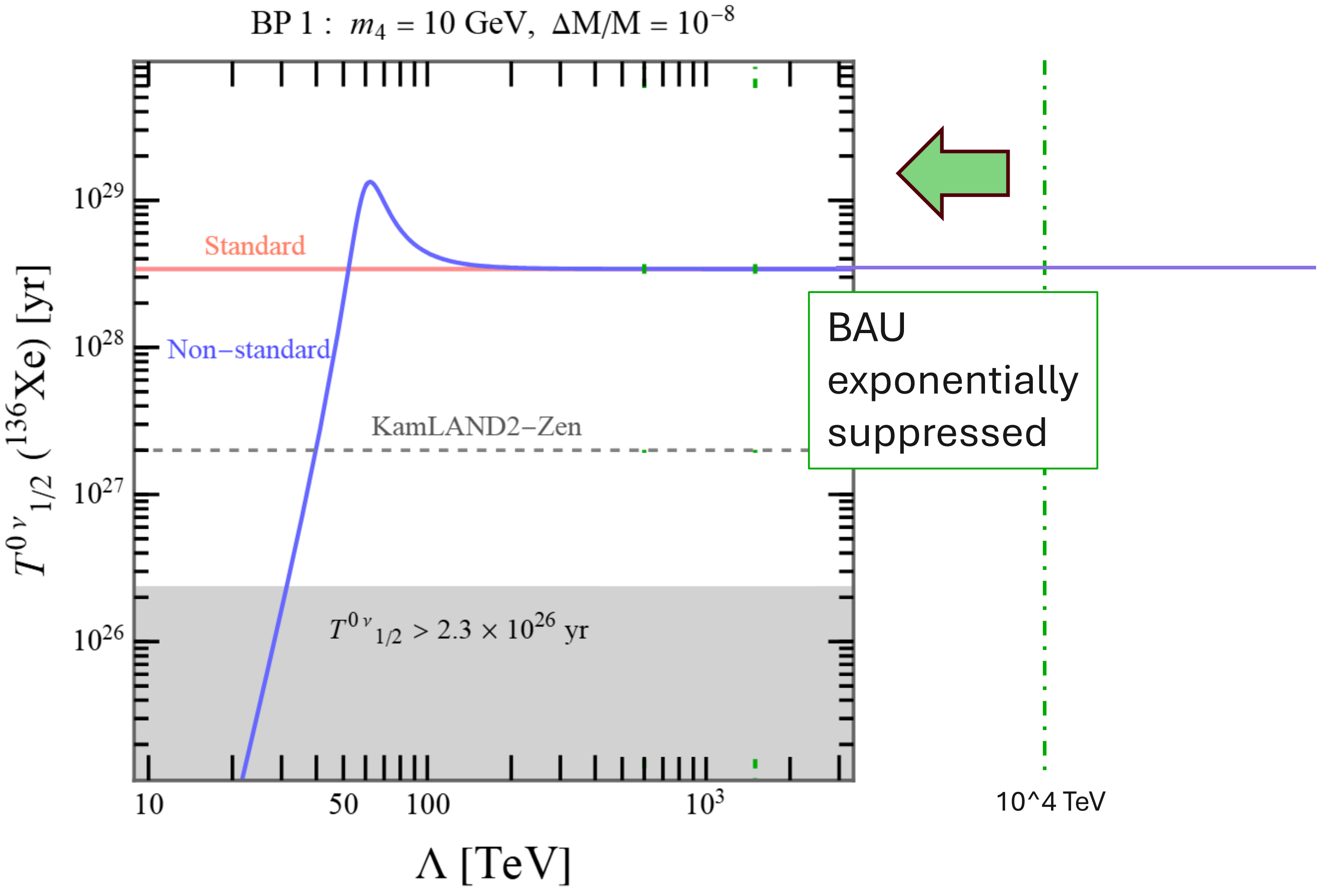
[Fuyuto, Harz, SW in preparation]

Falsifying Low-Scale Leptogenesis?



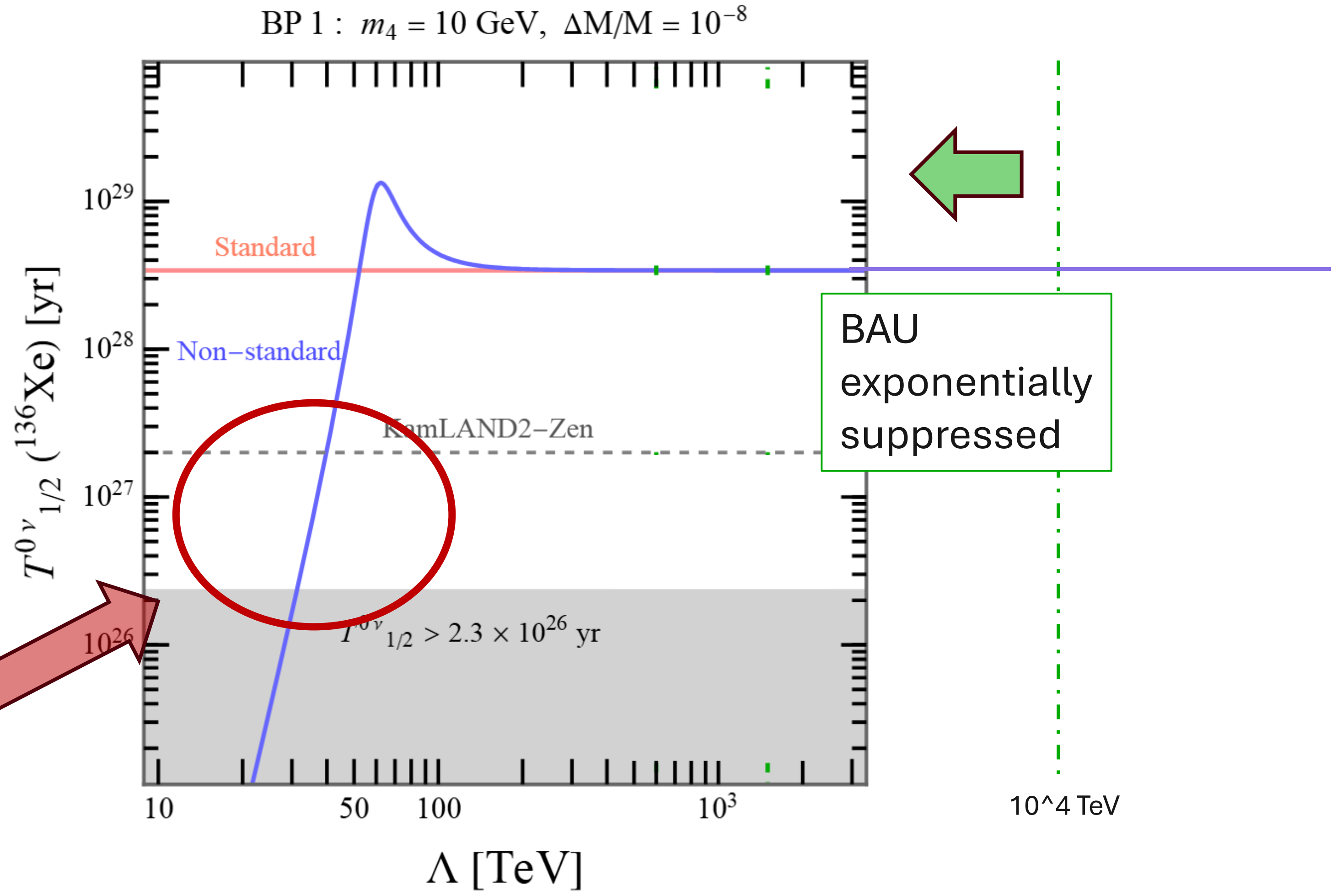
[Fuyuto, Harz, SW in preparation]

Falsifying Low-Scale Leptogenesis?



[Fuyuto, Harz, SW in preparation]

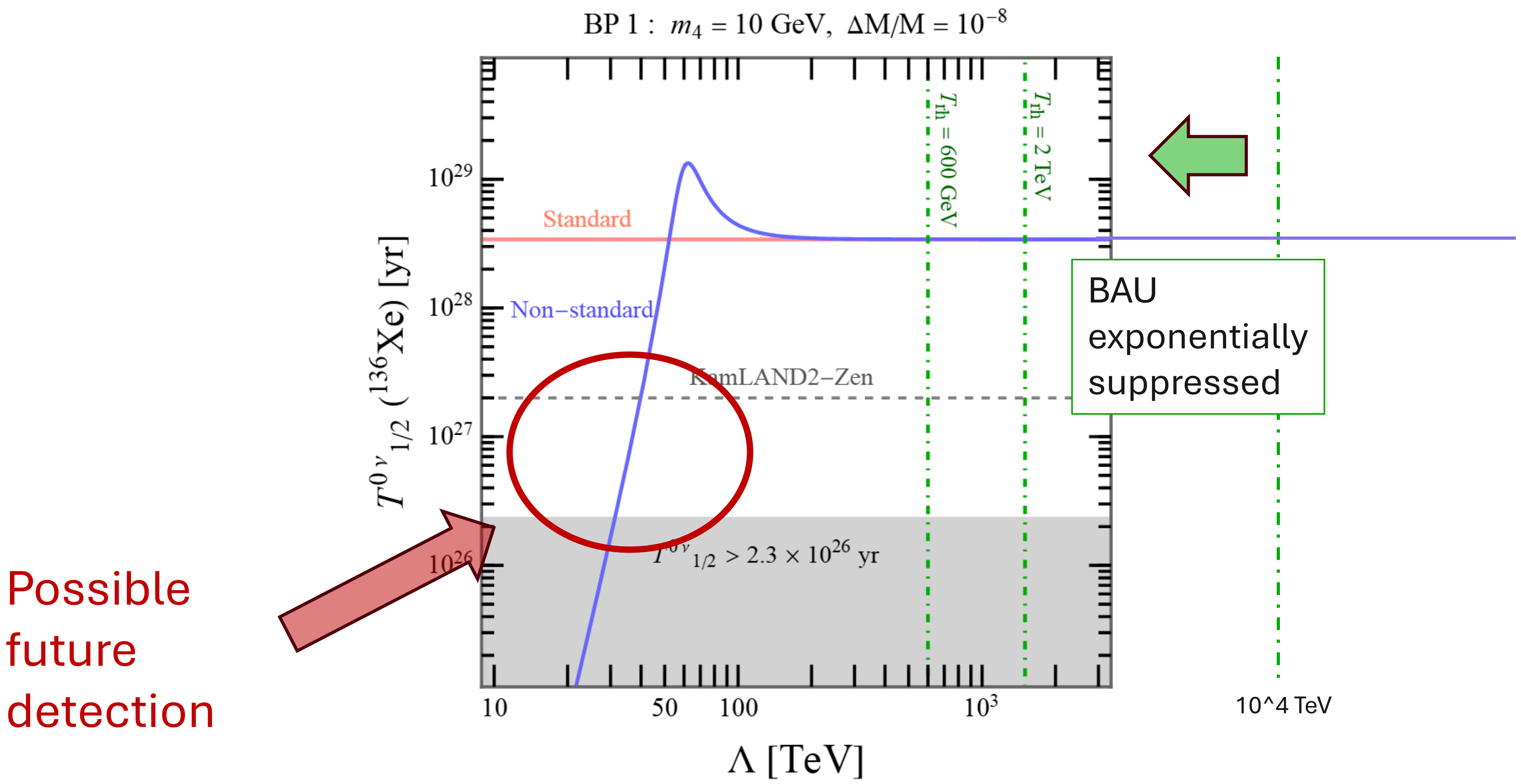
Falsifying Low-Scale Leptogenesis?



Possible future detection

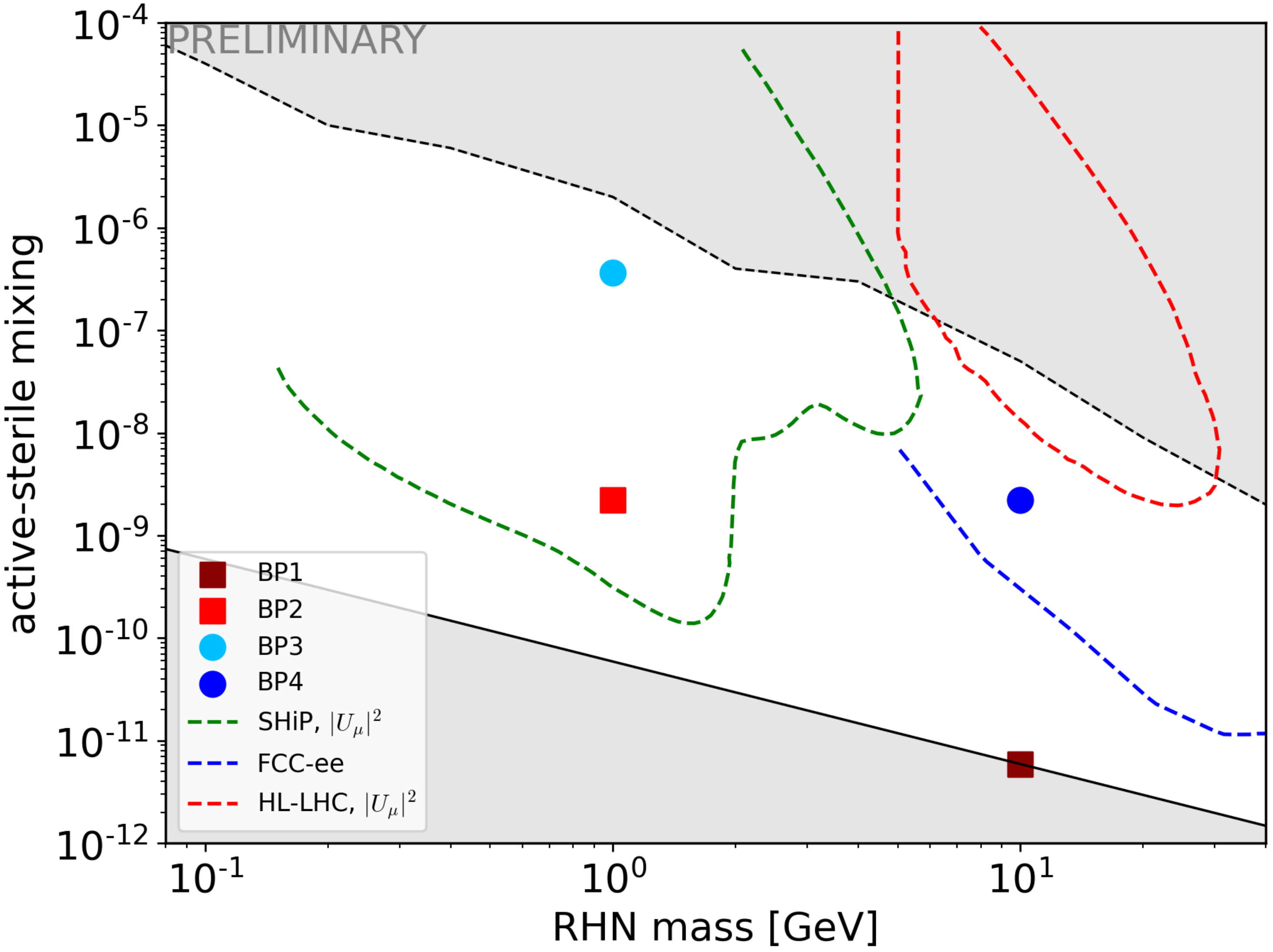
[Fuyuto, Harz, SW in preparation]

Falsifying Low-Scale Leptogenesis?



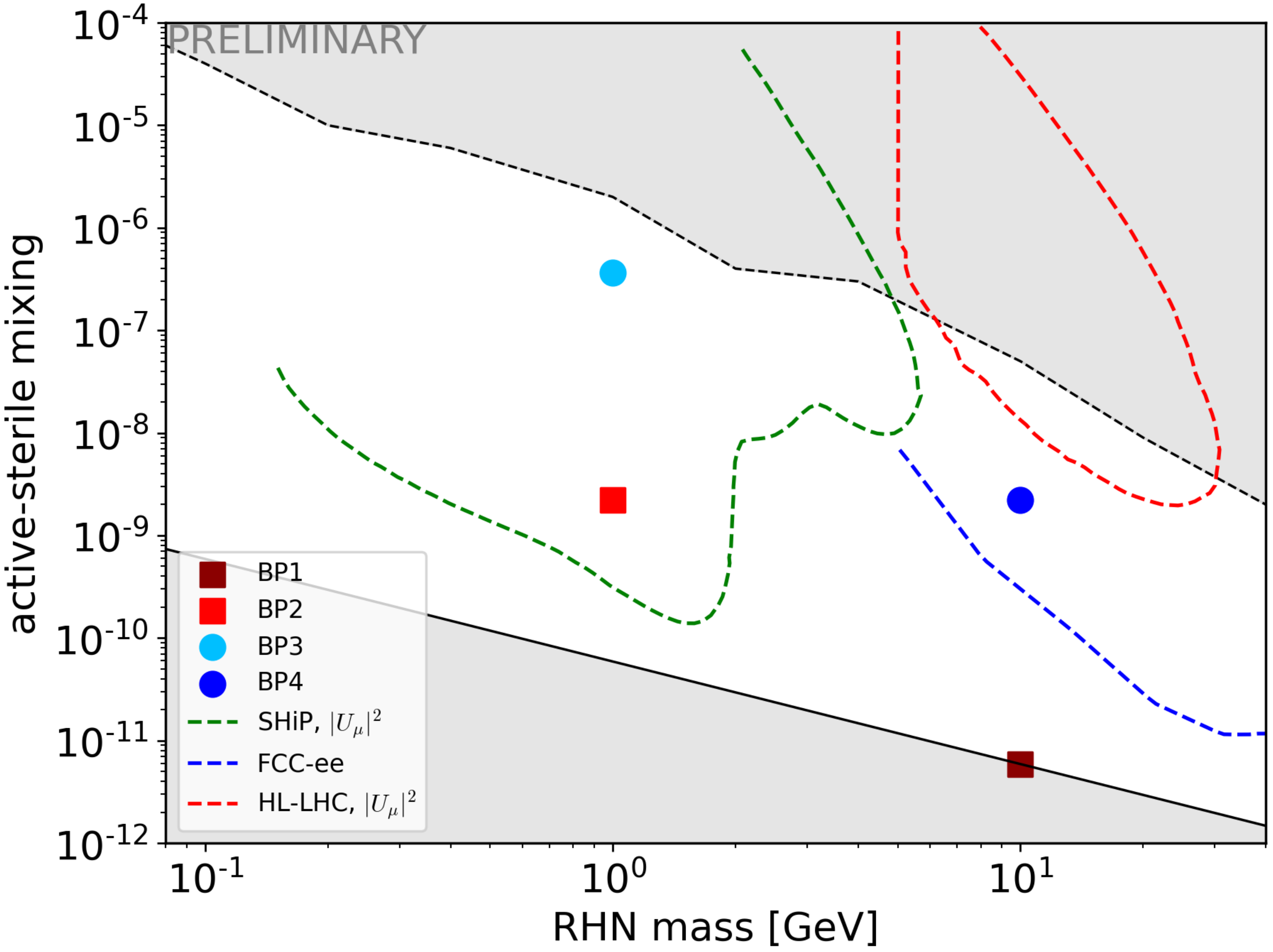
[Fuyuto, Harz, SW in preparation]

Always True?



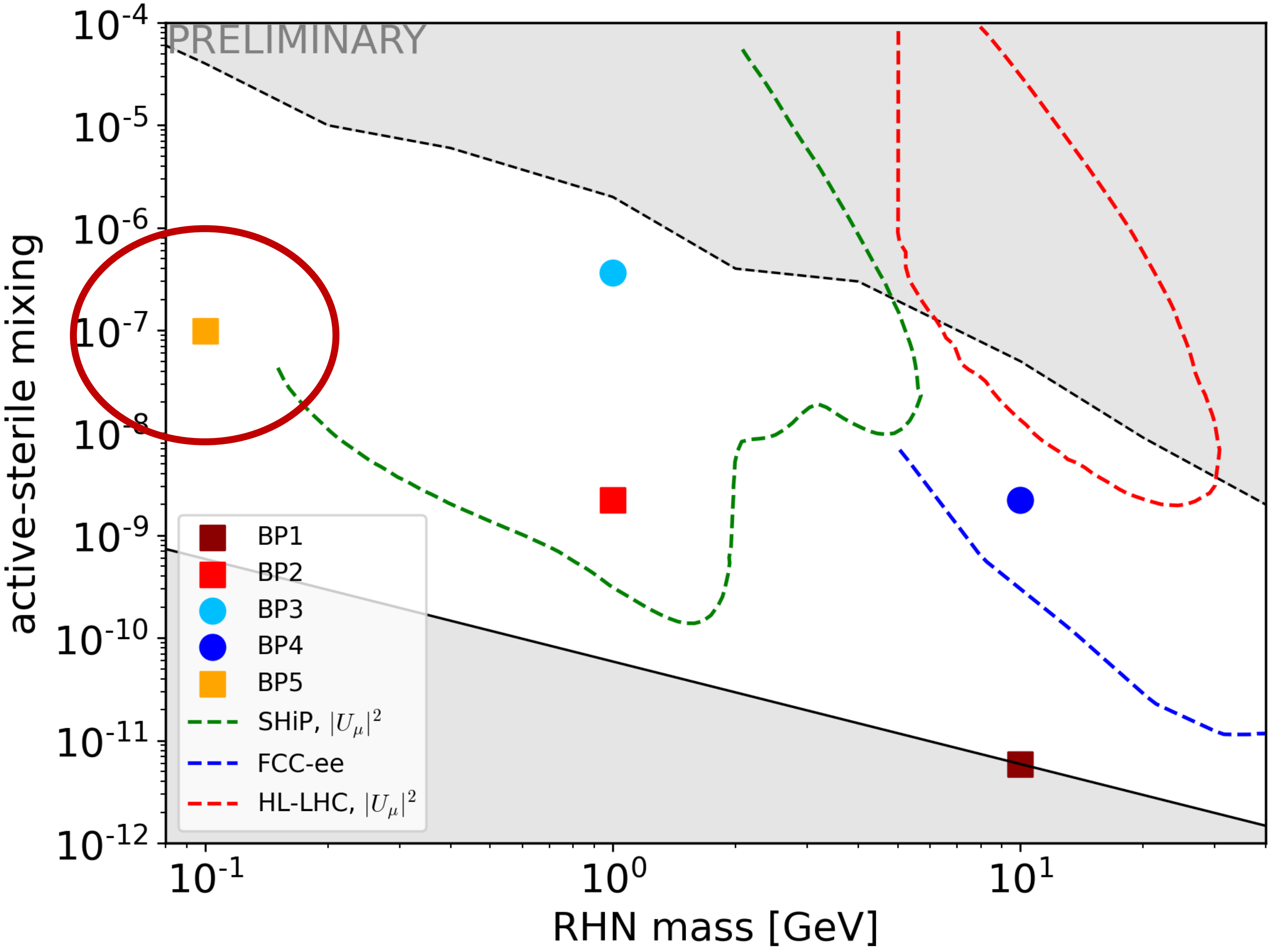
[Fuyuto, Harz, SW in preparation]

Always True?



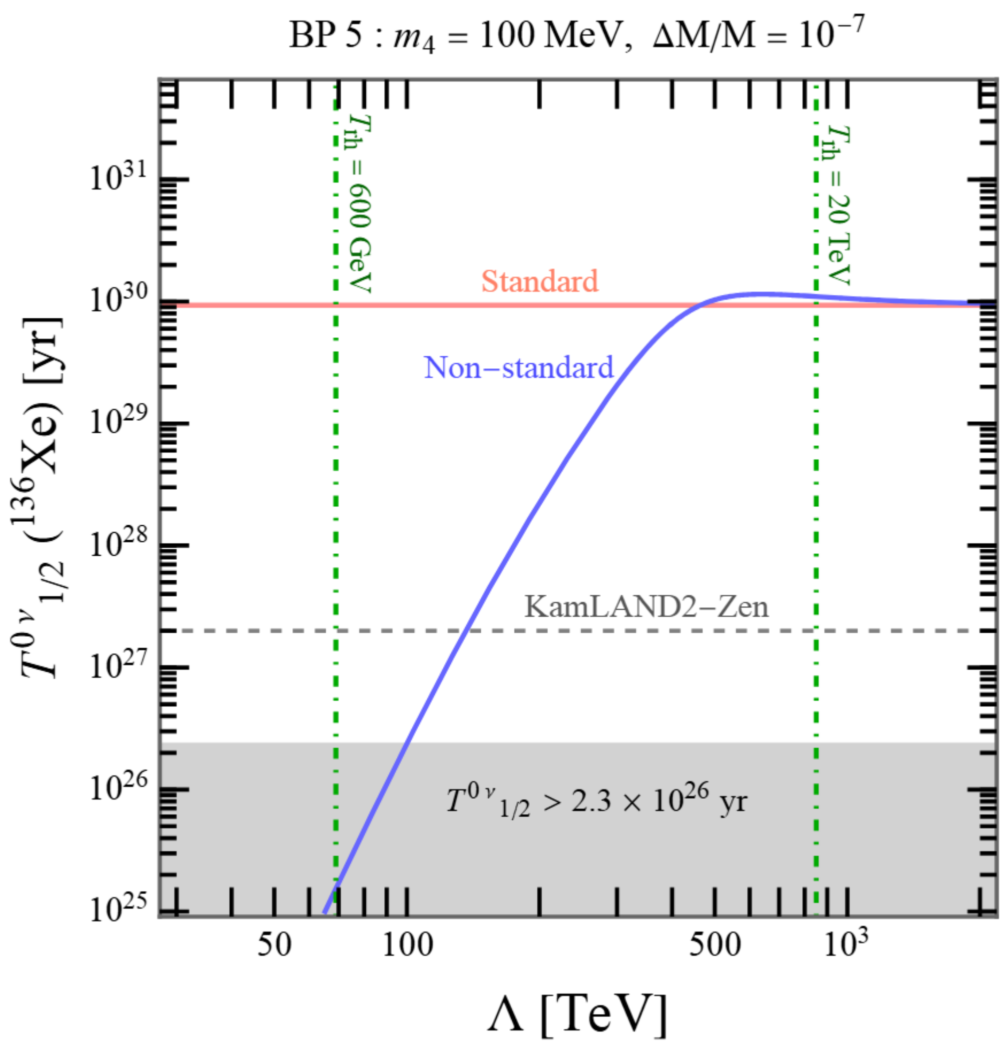
[Fuyuto, Harz, SW in preparation]

Always True?



[Fuyuto, Harz, SW in preparation]

Falsifying Low-Scale Leptogenesis? – No

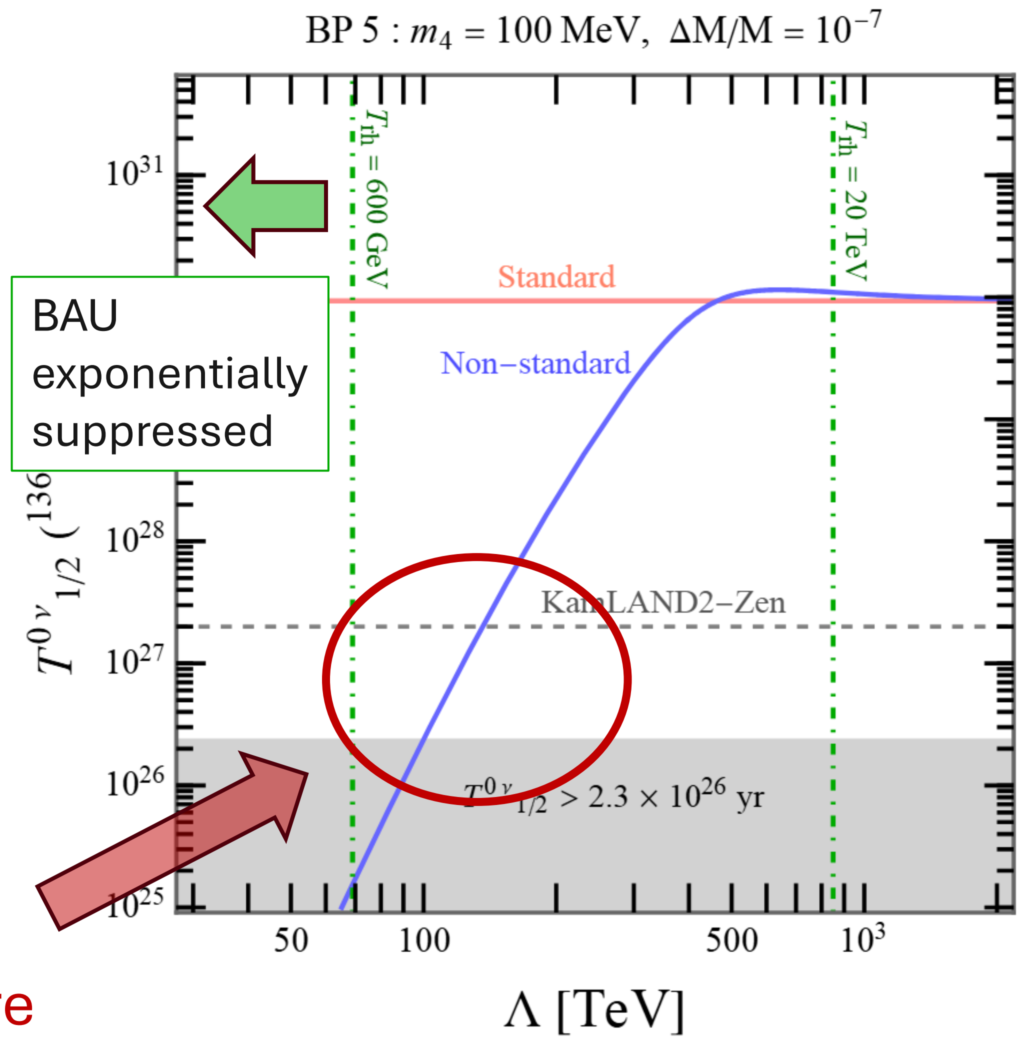


But still exciting!

[Fuyuto, Harz, SW in preparation]

Falsifying Low-Scale Leptogenesis? – No

But still exciting!



BAU exponentially suppressed

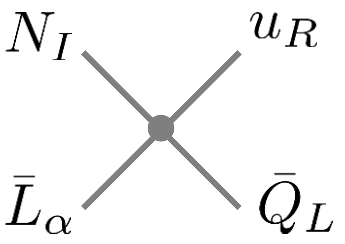
Need low reheating temperature

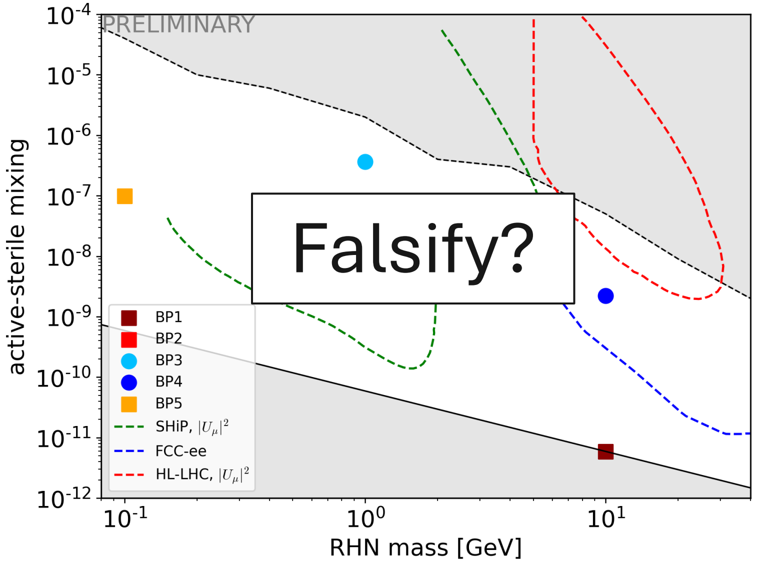
[Fuyuto, Harz, SW in preparation]

[Fuyuto, Harz, SW in preparation]

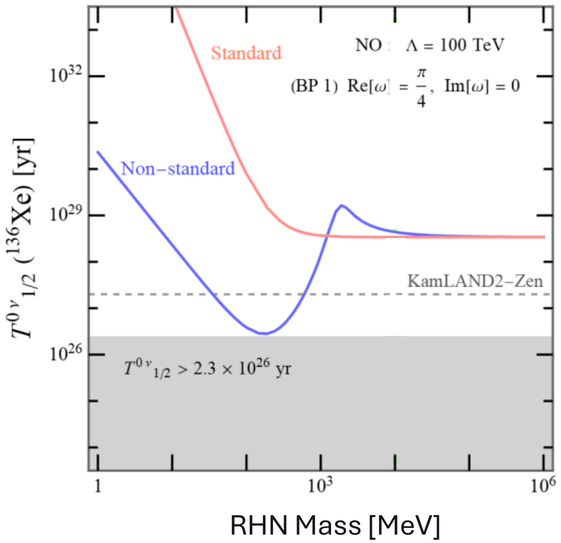
Conclusion

Example operator:

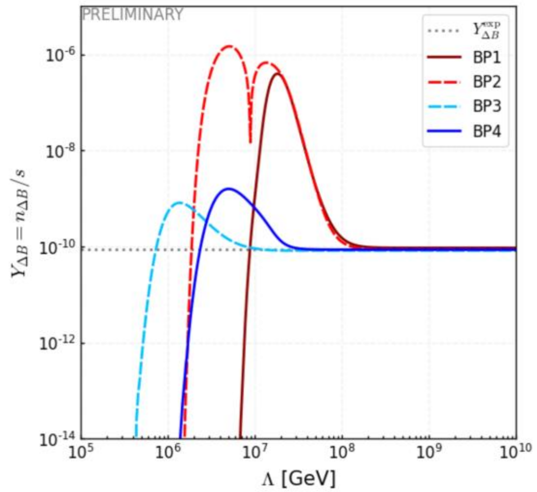


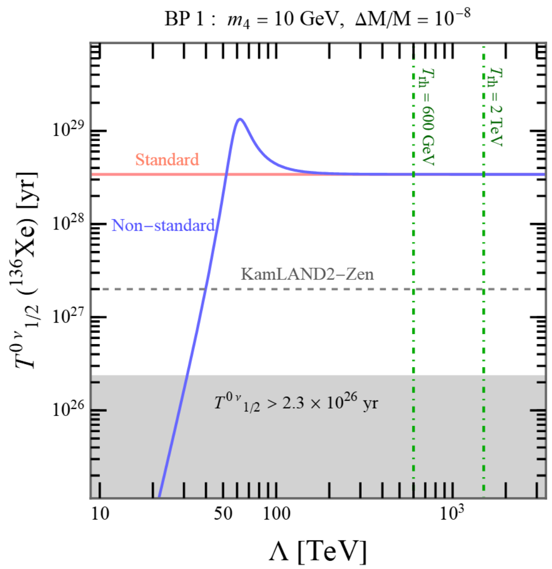


Falsify?

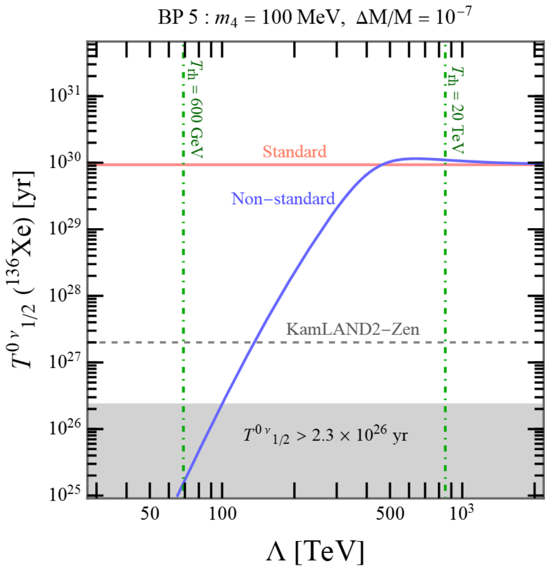


+





BUT



Thank You

Backup

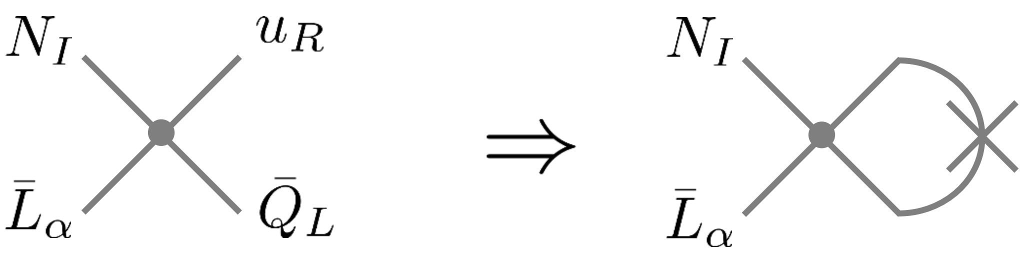
Key predictions

1 Neutrino masses – Seesaw mechanism

2 Lepton number violation – $0\nu\beta\beta$ decay

3 Baryon Asymmetry of the Universe - Leptogenesis

1) Contribution to neutrino mass?



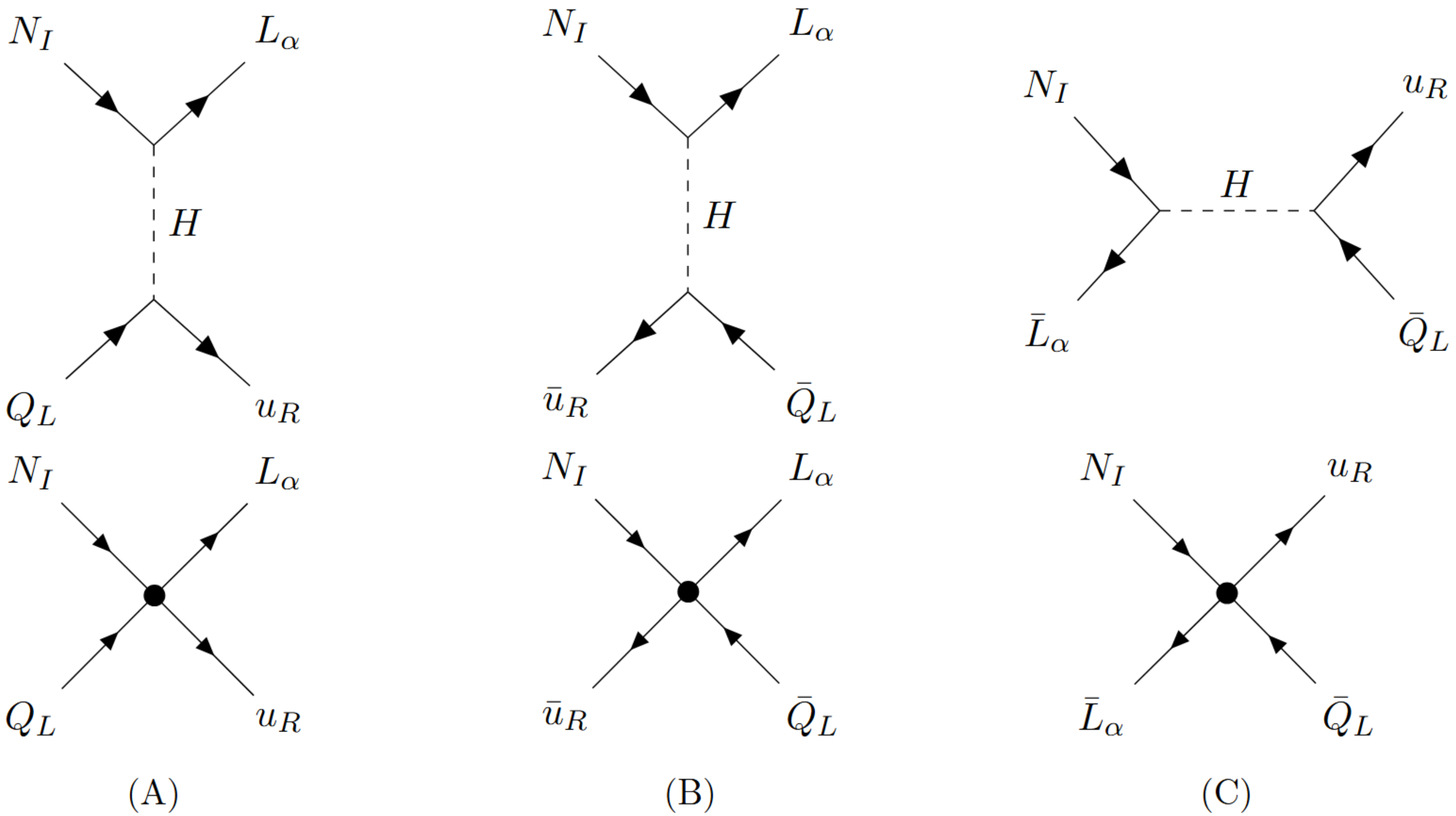
$$\Delta F_{\alpha I} \sim 1.8 \times 10^{-12} \left(\frac{1 \times 10^5 \, \mathrm{GeV}}{\Lambda} \right)^2 \left(\frac{[Y_u]_{aa}}{1.3 \times 10^{-5}} \right) [G_{\alpha I}]_{aa}$$

Quantum Kinetic Equations

$$
\begin{aligned}
zH\frac{\mathrm{d}R_N}{\mathrm{d}z} &= -i\left[\langle H_{\text{eff}}\rangle, R_N\right] - \frac{1}{2}\sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(0),XY}\right\rangle\left\{X^\dagger Y, R_N - 1\right\} \\
&\quad + \sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(1),XY}\right\rangle X^\dagger \mu Y - \frac{1}{2}\sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(2),XY}\right\rangle\left\{X^\dagger \mu Y, R_N\right\} \qquad (4.5)
\end{aligned}
$$

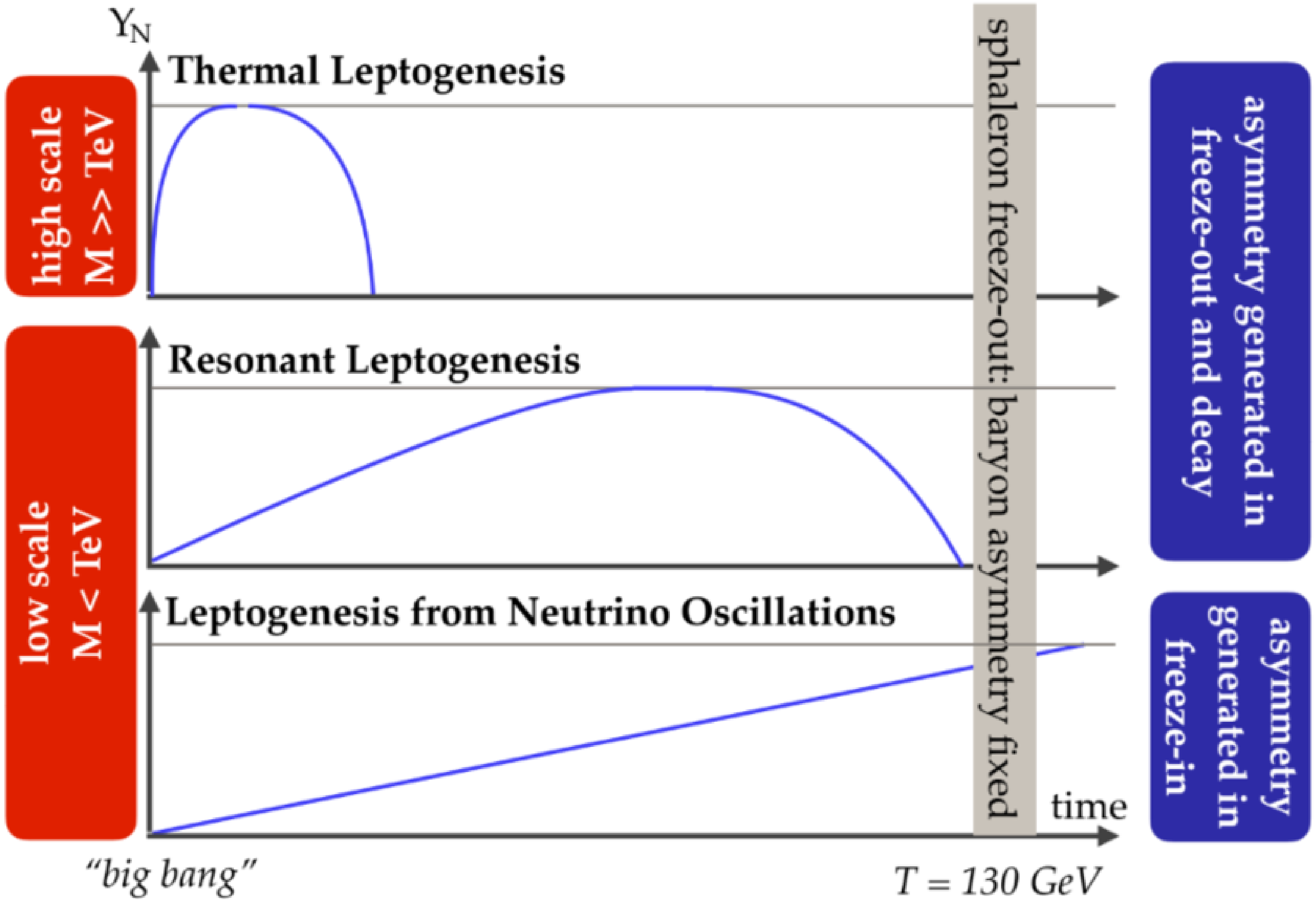
$$
\begin{aligned}
zH\frac{\mathrm{d}R_{\bar N}}{\mathrm{d}z} &= -i\left[\langle H_{\text{eff}}\rangle, R_{\bar N}\right] - \frac{1}{2}\sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(0),XY}\right\rangle\left\{X^T Y^*, R_{\bar N} - 1\right\} \\
&\quad - \sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(1),XY}\right\rangle X^T \mu Y^* + \frac{1}{2}\sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(2),XY}\right\rangle\left\{X^T \mu Y^*, R_{\bar N}\right\} \qquad (4.6)
\end{aligned}
$$

$$
\begin{aligned}
zH\frac{\mathrm{d}\mu_\alpha}{\mathrm{d}z} &= \frac{1}{2N_D}\sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(0),XY}\right\rangle\left[Y R_N X^\dagger - Y^* R_{\bar N} X^T\right]_{\alpha\alpha} \\
&\quad - \frac{1}{N_D}\sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(1),XY}\right\rangle\left[Y X^\dagger\right]_{\alpha\alpha}\mu_\alpha \\
&\quad + \frac{1}{2N_D}\sum_{X,Y\in\{F,G\}}\left\langle \gamma_N^{(2),XY}\right\rangle\left[Y R_N X^\dagger + Y^* R_{\bar N} X^T\right]_{\alpha\alpha}\mu_\alpha\,, \qquad (4.7)
\end{aligned}
$$

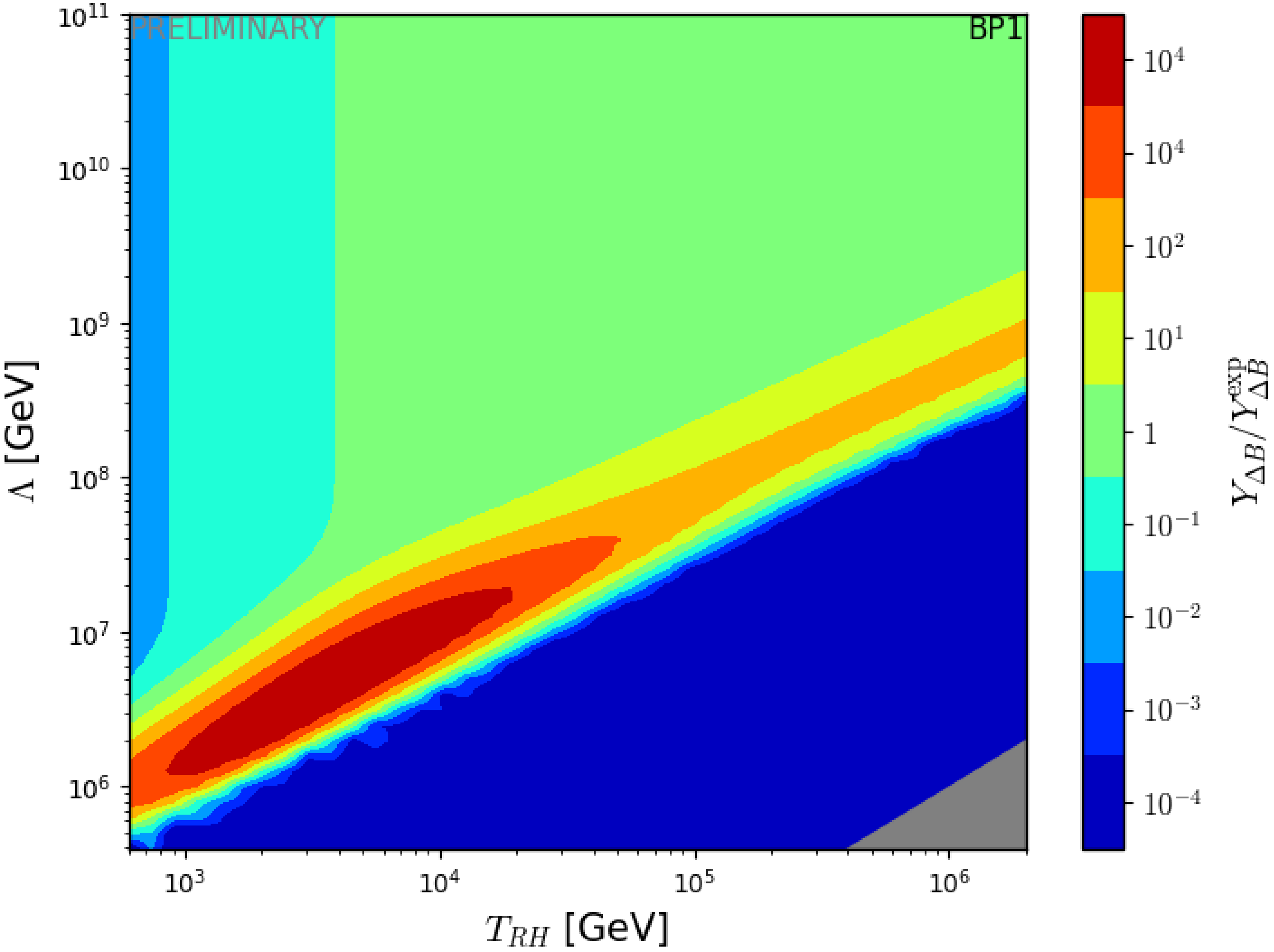


N_I
L_α
H
Q_L
u_R
N_I
L_α
Q_L
u_R
(A)
N_I
L_α
H
$\bar{u}_R$
$\bar{Q}_L$
N_I
L_α
$\bar{u}_R$
$\bar{Q}_L$
(B)
N_I
u_R
H
$\bar{L}_\alpha$
$\bar{Q}_L$
N_I
u_R
$\bar{L}_\alpha$
$\bar{Q}_L$
(C)

Types of Leptogenesis

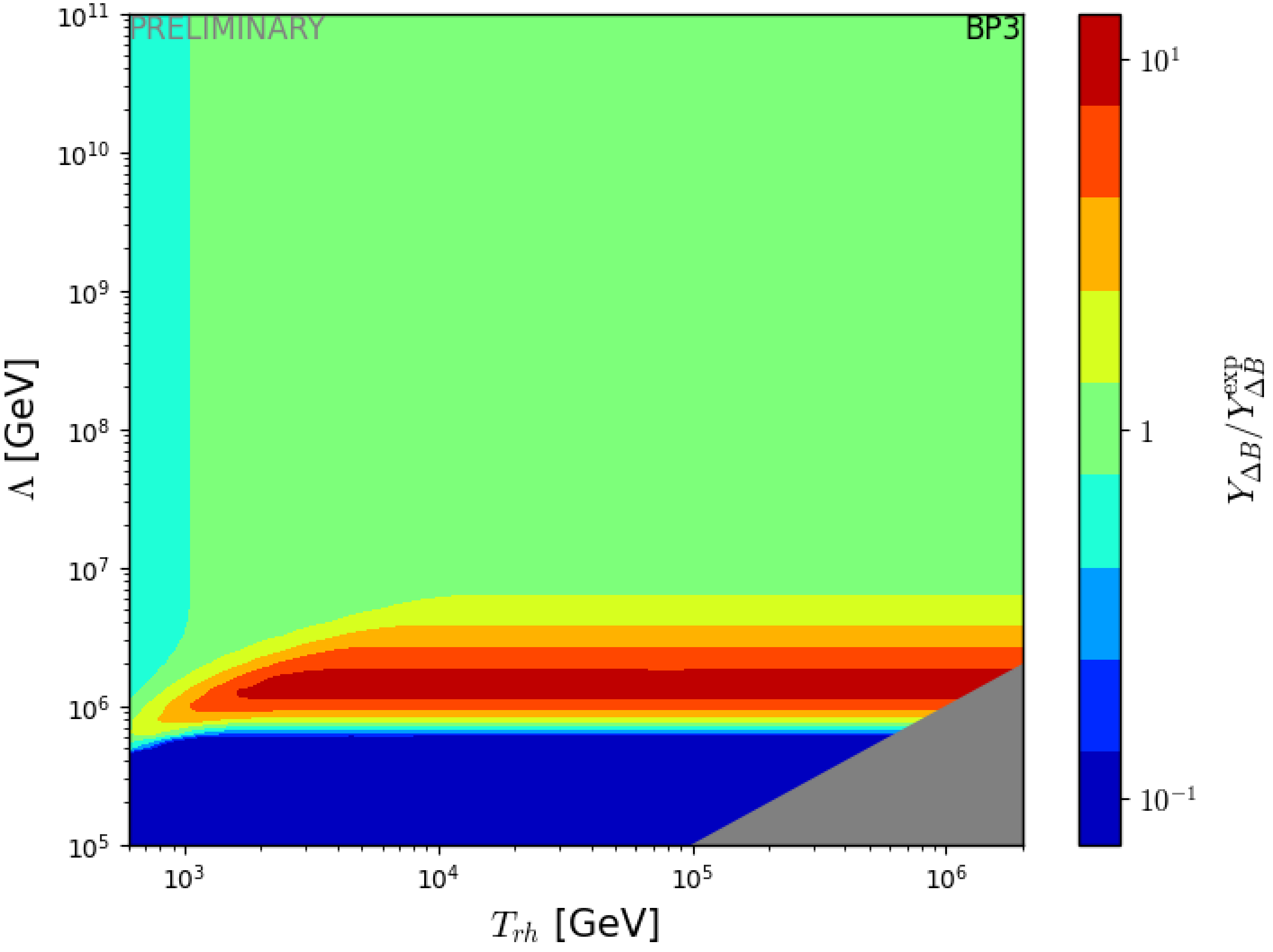


Dependence on reheating temperature



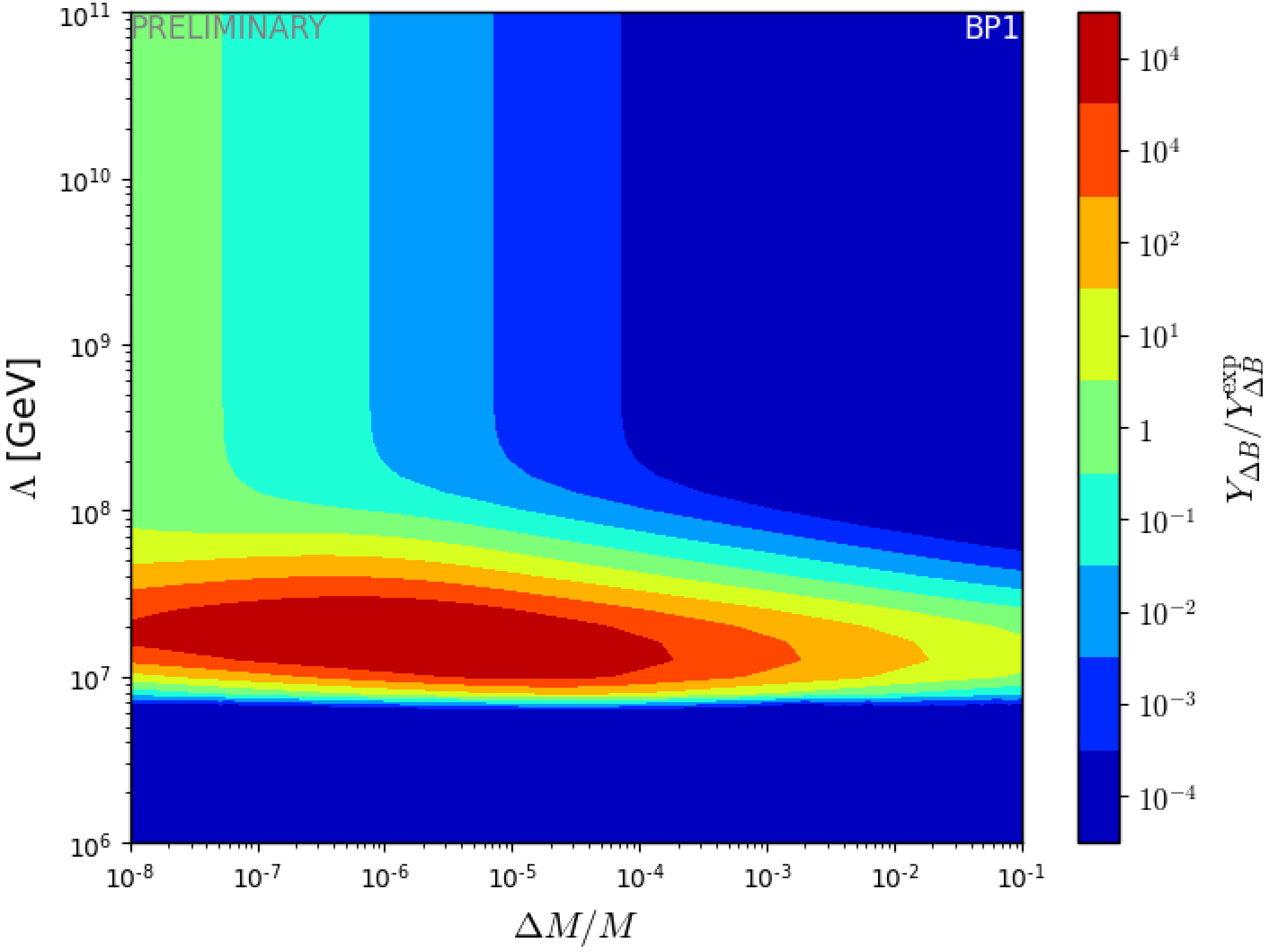
[Fuyuto, Harz, SW in preparation]

Dependence on reheating temperature



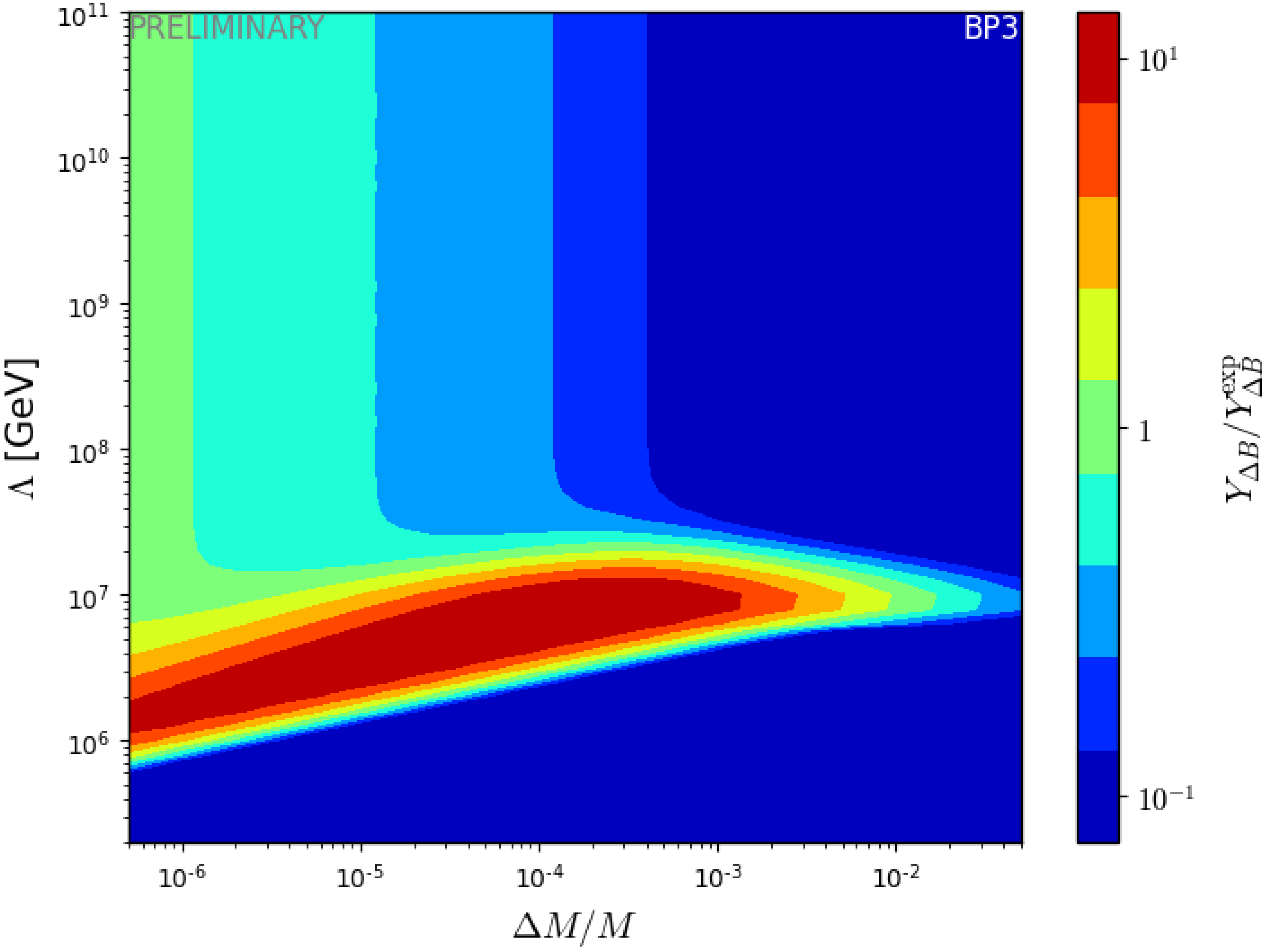
[Fuyuto, Harz, SW in preparation]

Lifting mass degeneracy

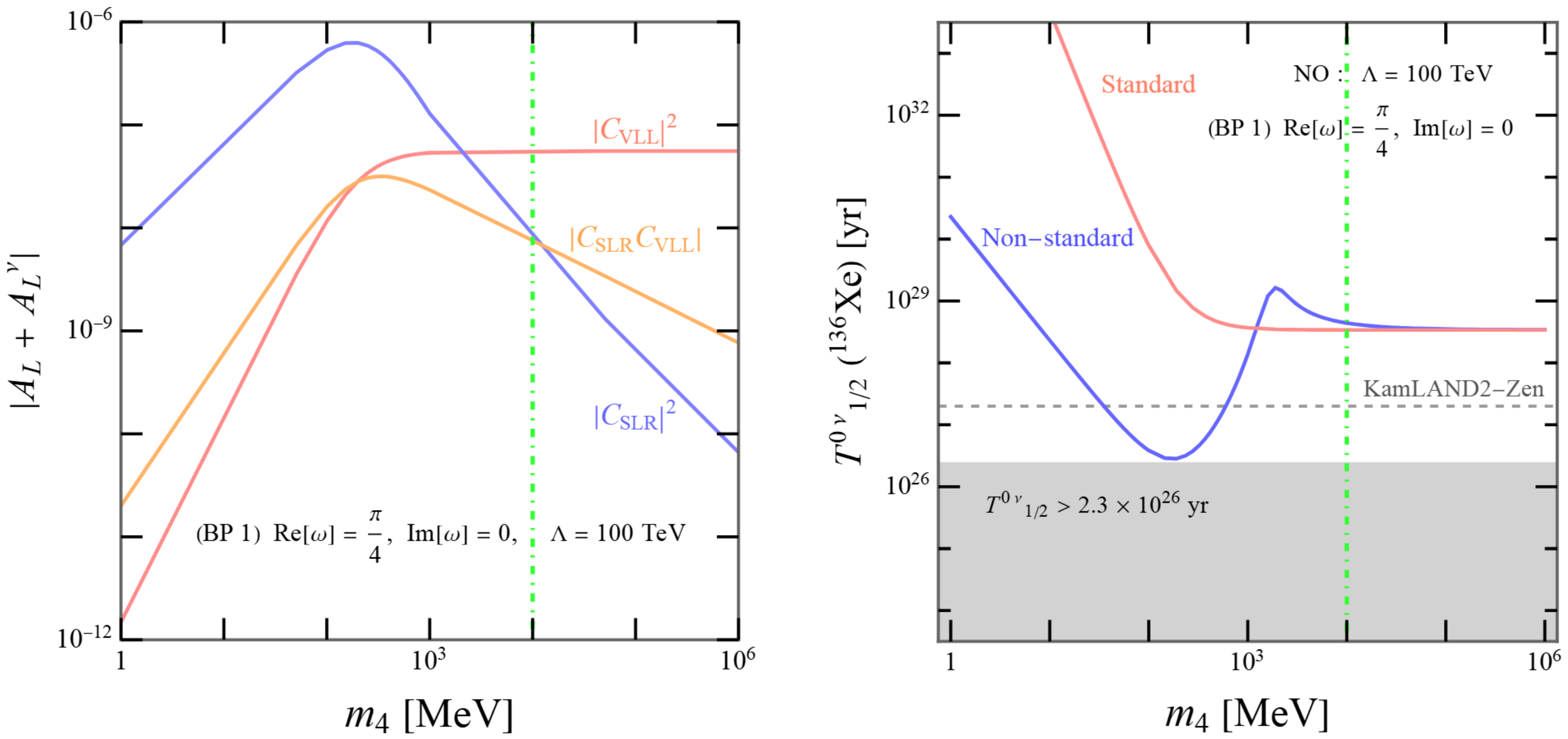


[Fuyuto, Harz, SW in preparation]

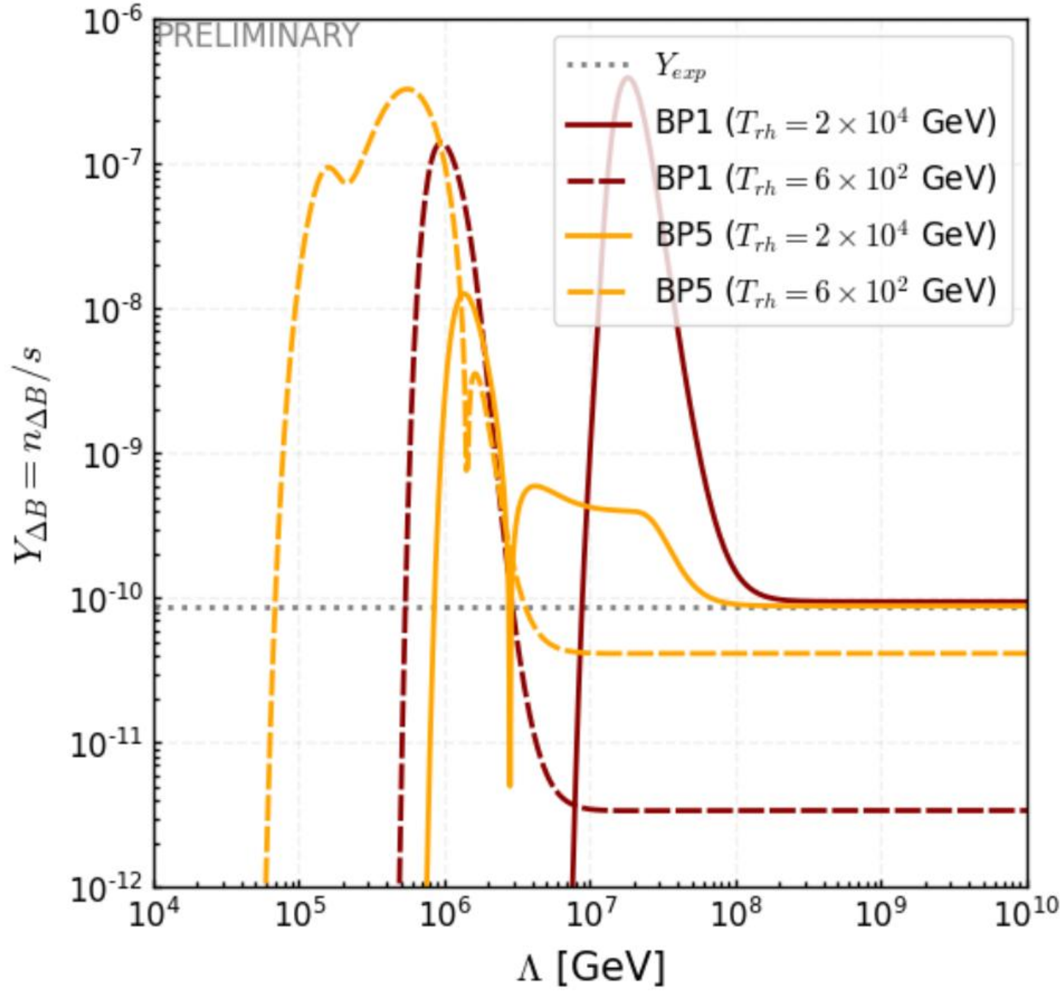
Lifting mass degeneracy



[Fuyuto, Harz, SW in preparation]



[Fuyuto, Harz, SW in preparation]



[Fuyuto, Harz, SW in preparation]