MPA
MAINZ PHYSICS ACADEMY

mitp Mainz Institute for Theoretical Physics

Impact of non-standard interactions on low-scale leptogenesis and neutrinoless double beta decay

Sascha Weber

JGU Mainz

In collaboration with

Kaori Fuyuto (LANL) and Julia Harz (JGU)

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

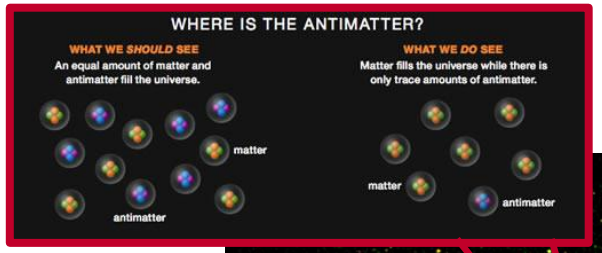
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

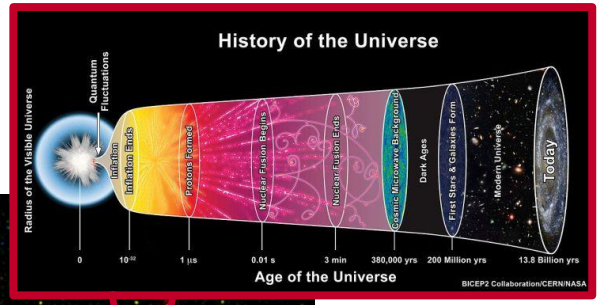
JG|U

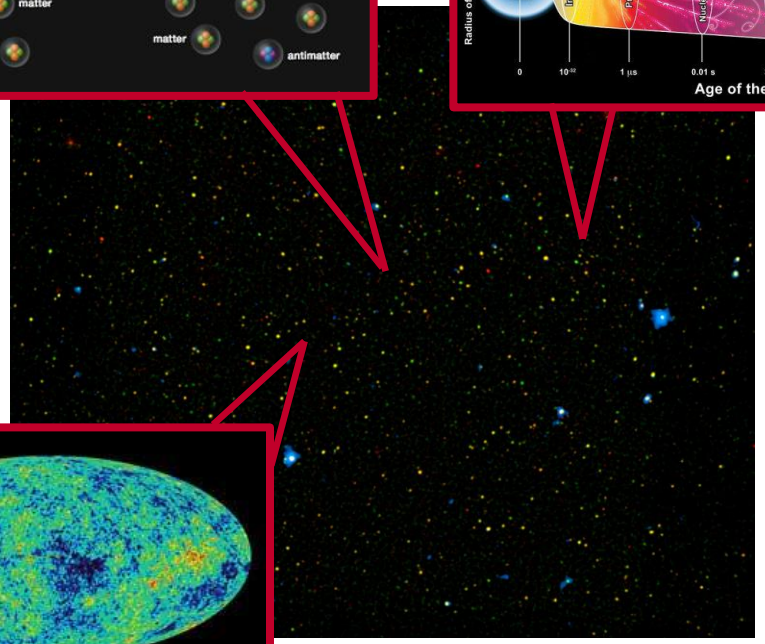
PLANCK 2024 - June 6th 2024 - IST Lisbon

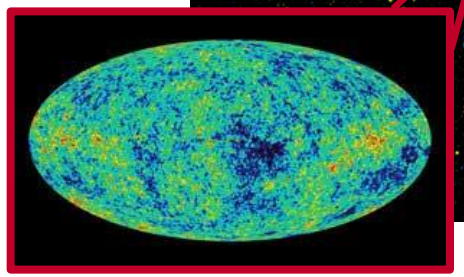
[https://www.pinterest.de/pin/planet-earth-featuring-europe-and-european-union-countries-including-france-ger-sponsored-countries-union-f--850969292074858684/]
[https://www.mpi-hd.mpg.de/gerda/]
[https://www-project.slac.stanford.edu/exo/about.html]
[https://cerncourier.com/a/kamland-experiment-discovers-that-reactor-antineutrinos-disappear/]

Motivation









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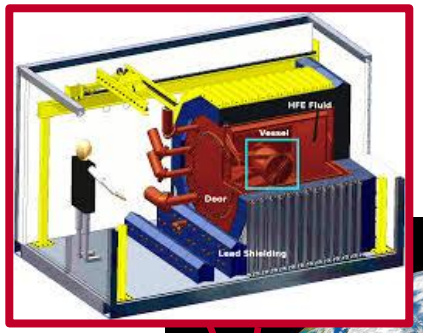
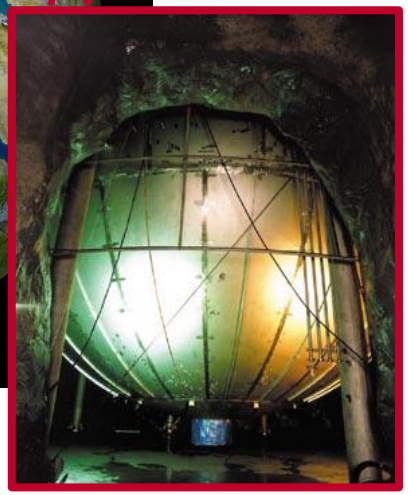
EXO



GERDA



KamLAND-Zen

Motivation

Baryogenesis via neutrino oscillations

E. Kh. Akhmedov[(a,b)] V. A. Rubakov[(c,a,d)] and A. Yu. Smirnov[(a,c)]

The νMSM, Dark Matter and Baryon Asymmetry of the Universe

Takehiko Asaka* and Mikhail Shaposhnikov†

Kinetic Equations for Baryogenesis via Sterile Neutrino Oscillation

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Matter and Antimatter in the Universe*

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Uniting low-scale leptogeneses

Juraj Klarić,[1] Mikhail Shaposhnikov,[1] and Inar Timiryasov[1]

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How robust?

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[Dekens et. al. JHEP 2020]

JHEP

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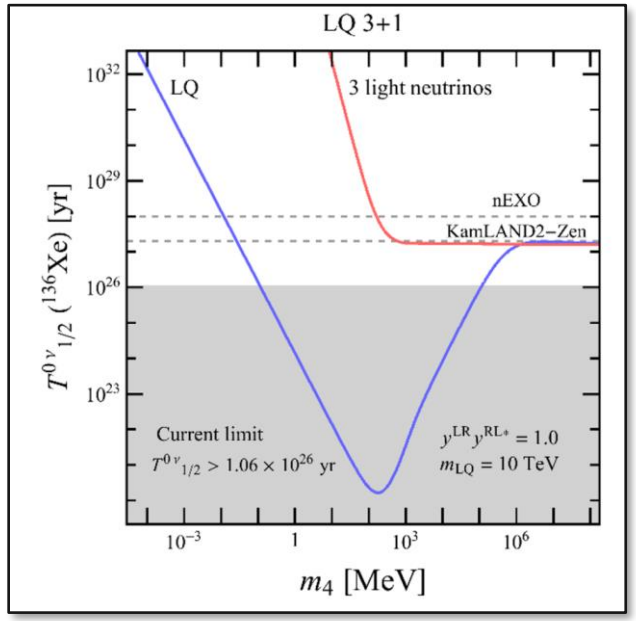
Sterile neutrinos and neutrinoless double beta decay in effective field theory

W. Dekens,[a] J. de Vries,[b,c] K. Fuyuto,[b,d] E. Mereghetti[d] and G. Zhou[b]



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[illegible] of the Universe

Ki[illegible]

Takehiko[illegible]

?

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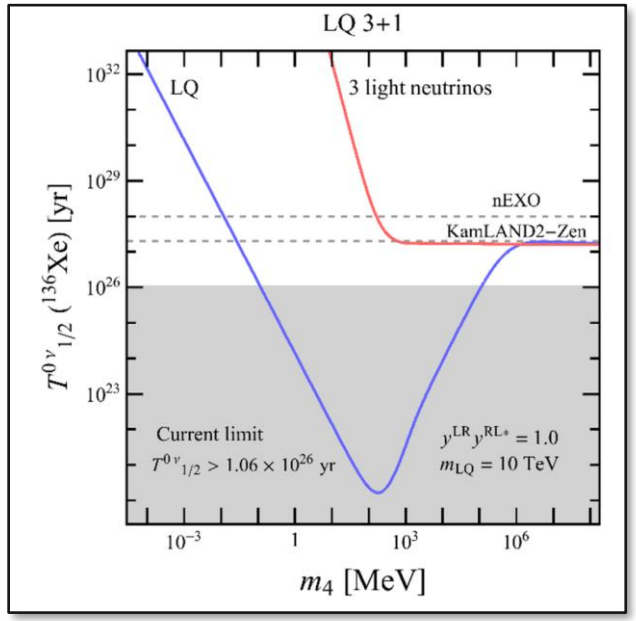


Outline

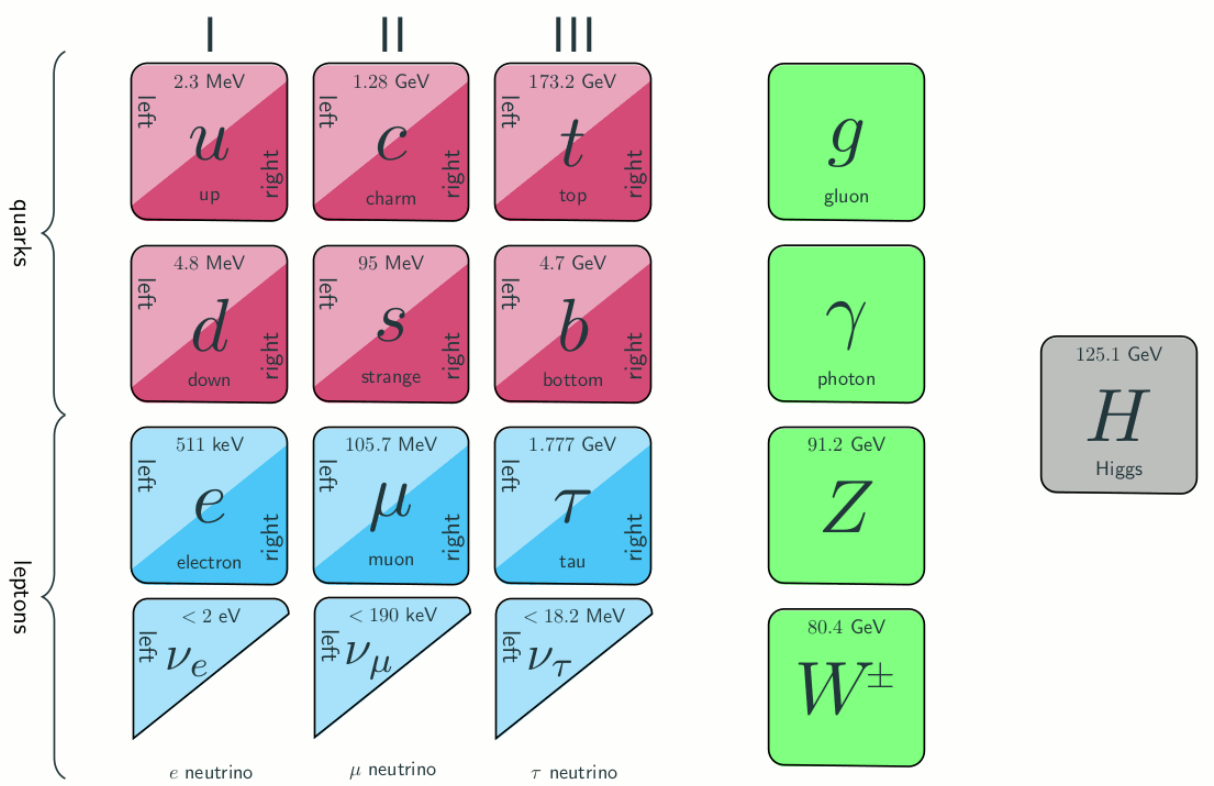
0 Right-handed neutrinos (RHN) and non-standard interactions (NSI)

1 Neutrino masses – Seesaw mechanism

2 Lepton number violation – 0vbb decay

3 Baryon Asymmetry of the Universe - Leptogenesis

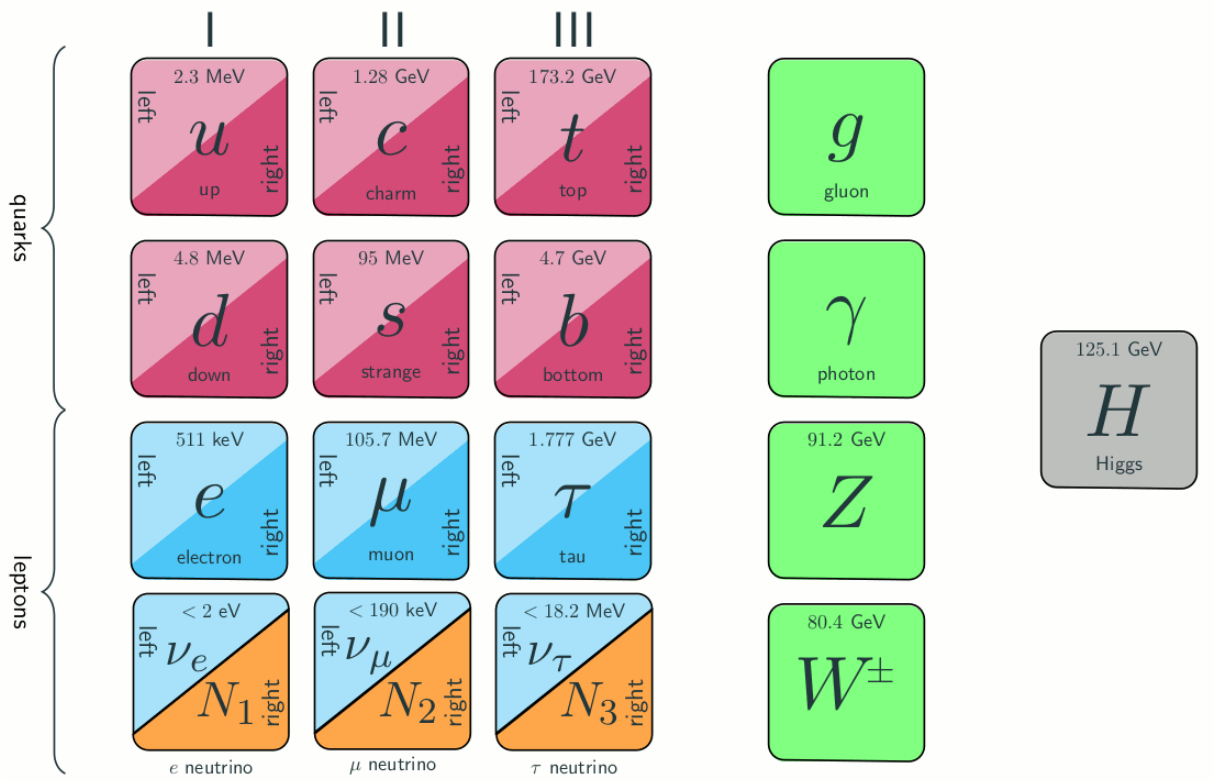
The Standard Case



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

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

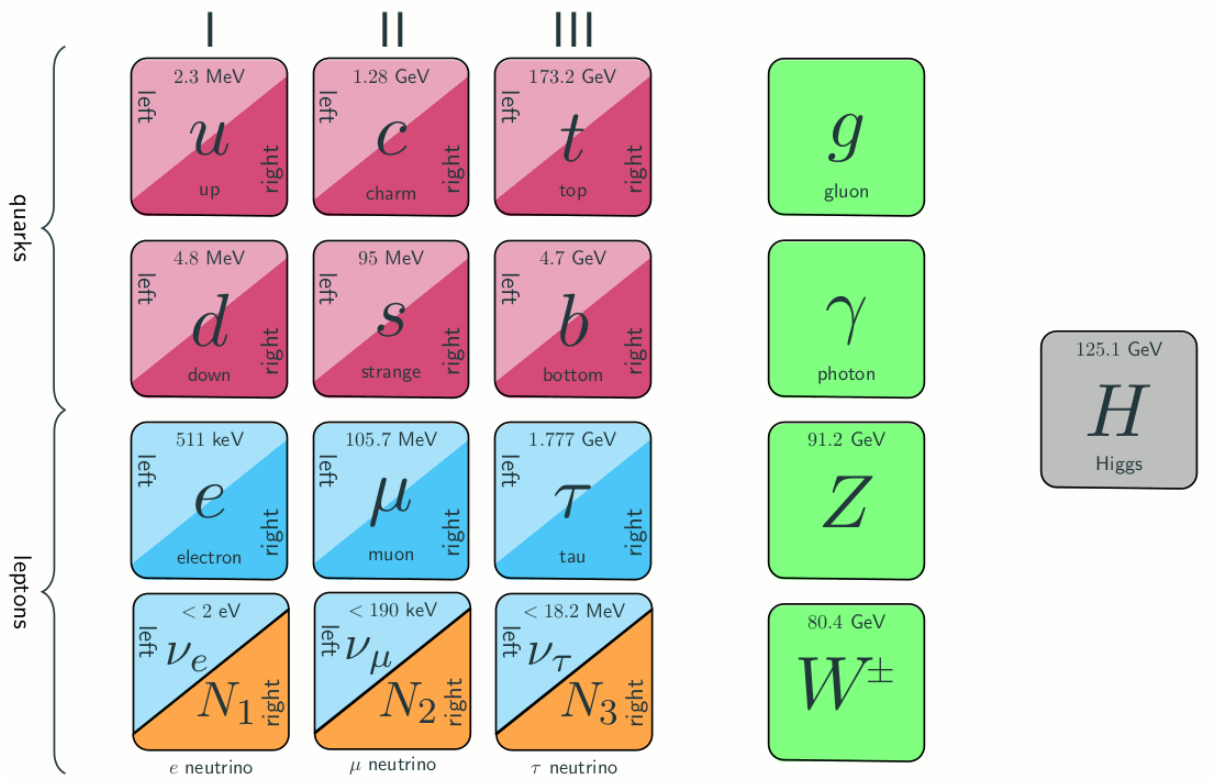
The Standard Case



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

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

Non-Standard Case?



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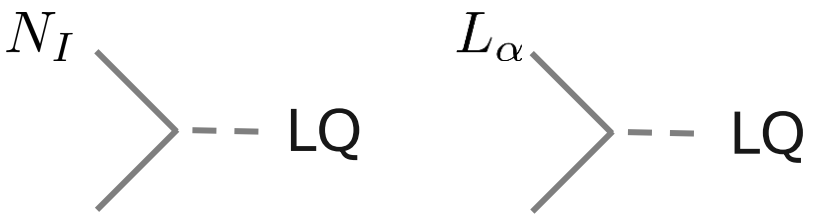
+ more?

Non-Standard Case



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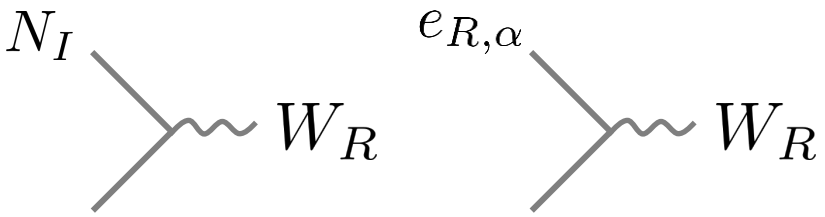
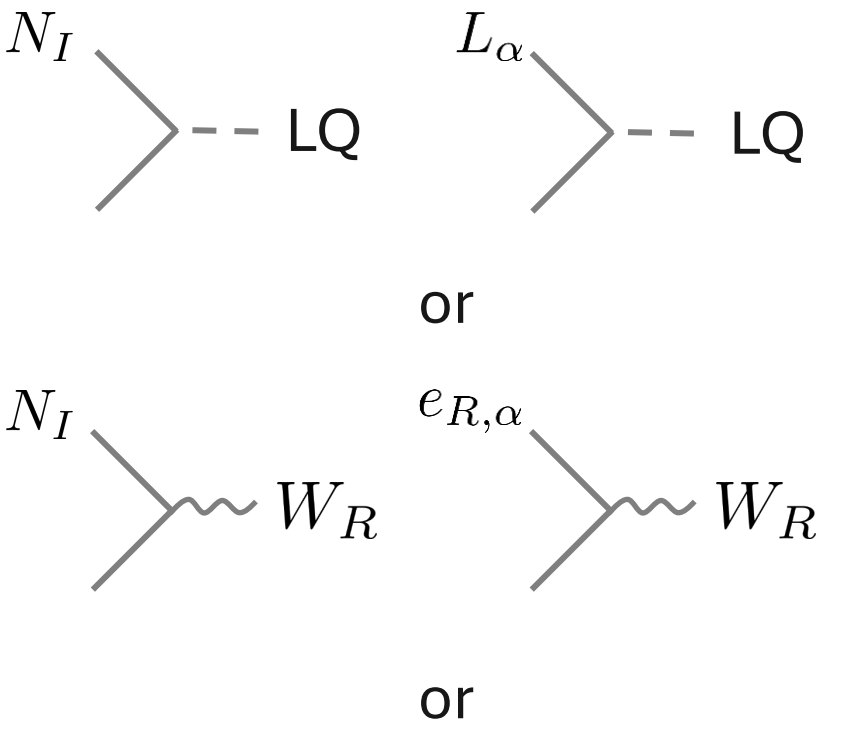


or

Any new particle coupling to RHNs and/or leptons

Non-Standard Case



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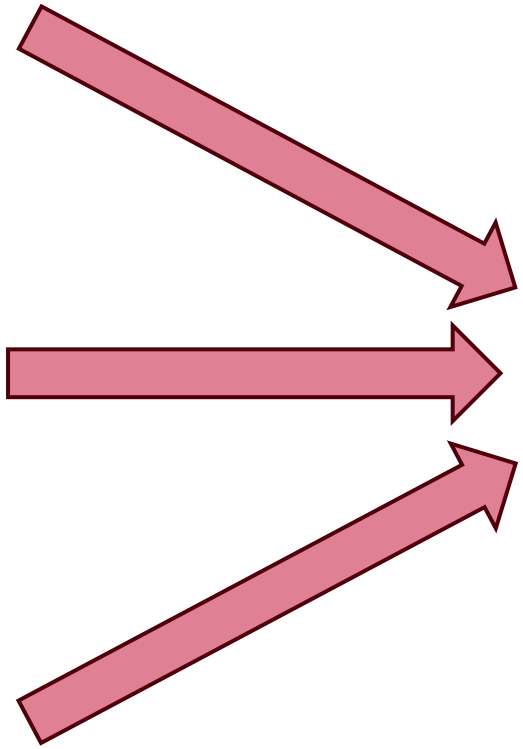
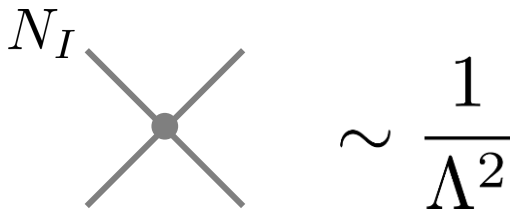
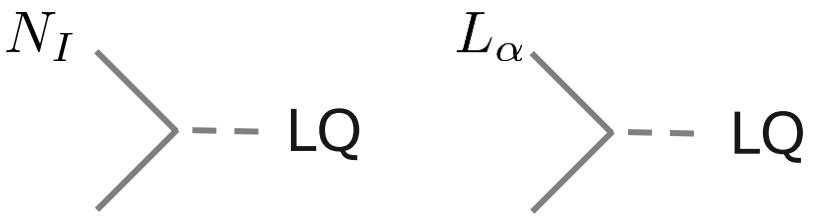




Effective operator description

Non-Standard Case



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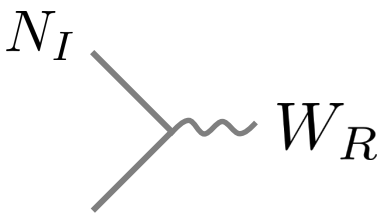

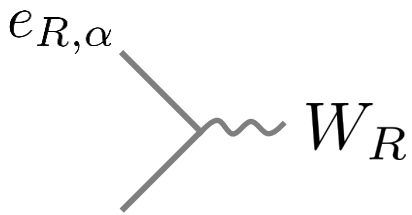

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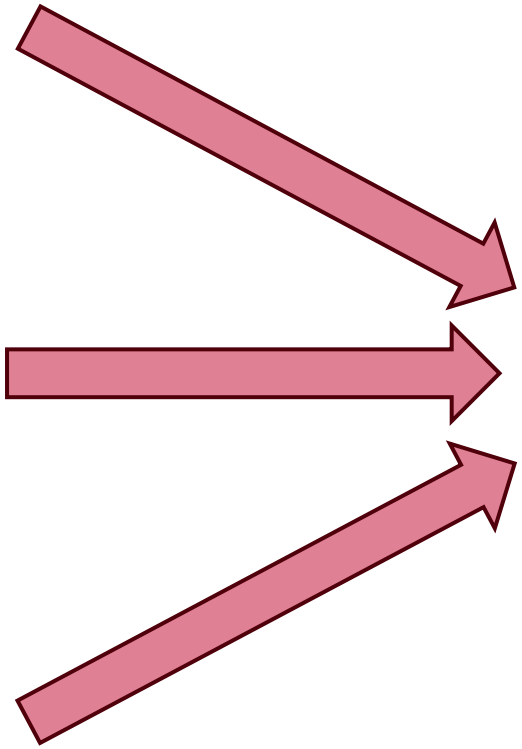
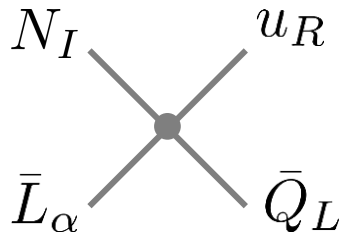
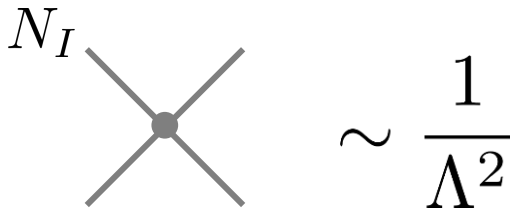


Example operator:





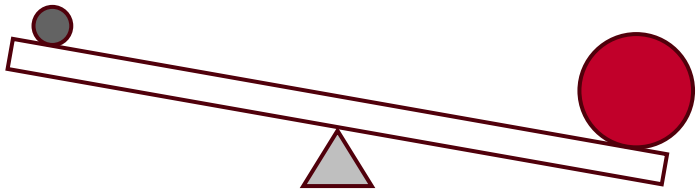
Effective operator description

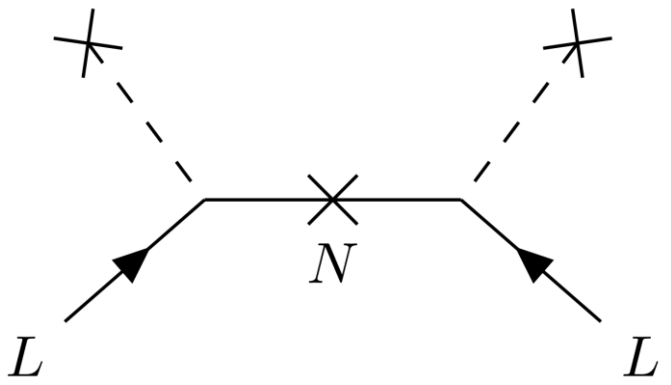
1) Neutrino masses – Standard Case

$$\mathcal{L} \supset -\underbrace{(Y v_{\mathrm{EW}})}_{m_D} \bar{N} \nu_L - M_N \bar{N}^c N$$

Seesaw mechanism: $M_N \gg m_D$

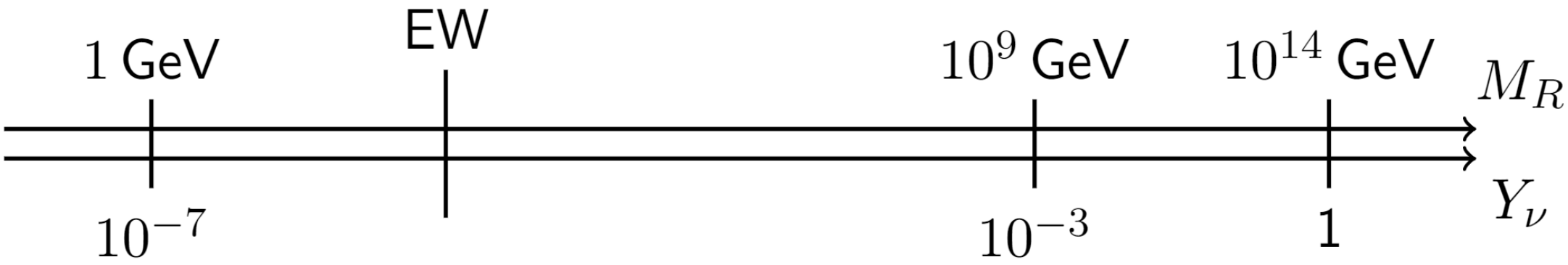
$$\frac{v^2 Y^2}{M_N} \approx m_\nu \qquad m_N \approx M_N$$





[Fridell PhD 2022]

Range of scales



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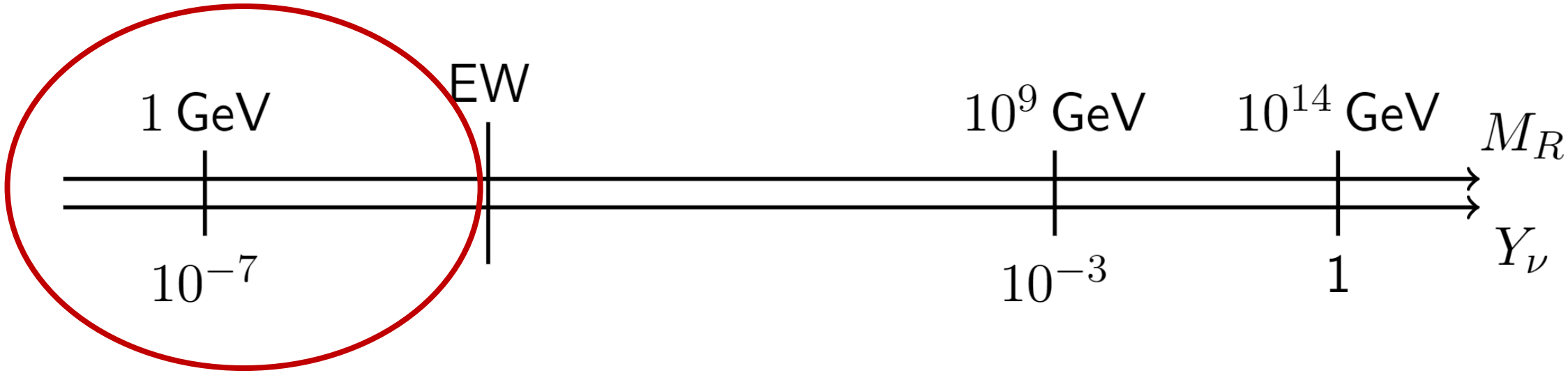
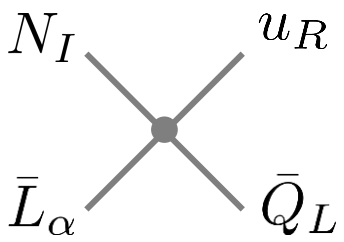


“Low Scale”

Neutrino masses – Non-Standard Case



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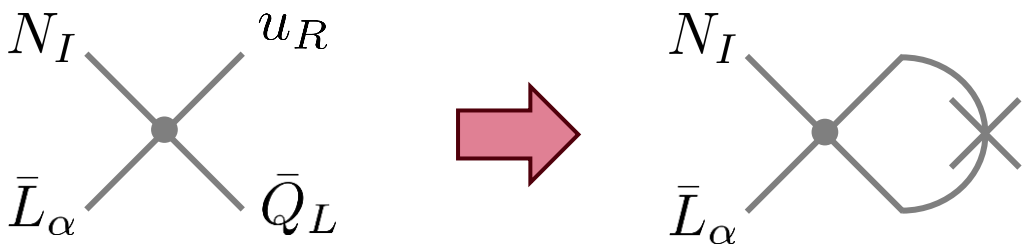

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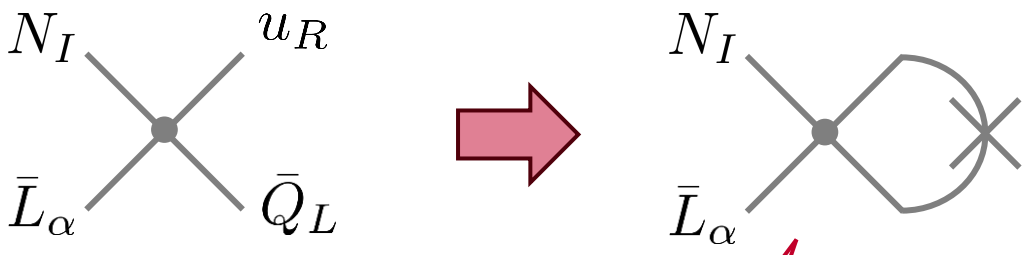
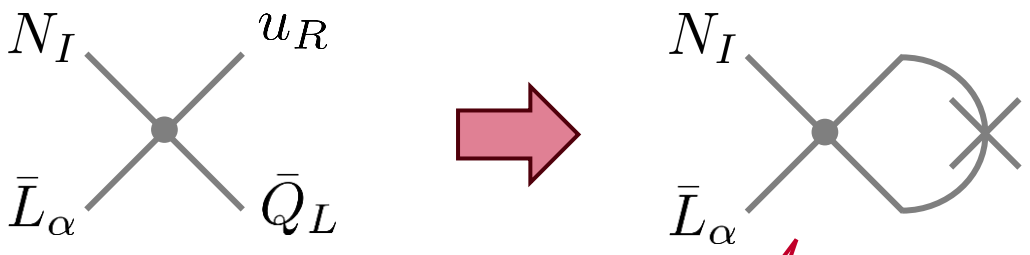


Diagonalize Mass matrix $M = \begin{pmatrix} M_L & M_D^* \\ M_D^\dagger & M_R^\dagger \end{pmatrix}$

Need to satisfy upper bound on m_υ

Neutrino masses – Non-Standard Case



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Need to satisfy upper bound on m_υ

→ Lower bound on Λ

2) 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

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

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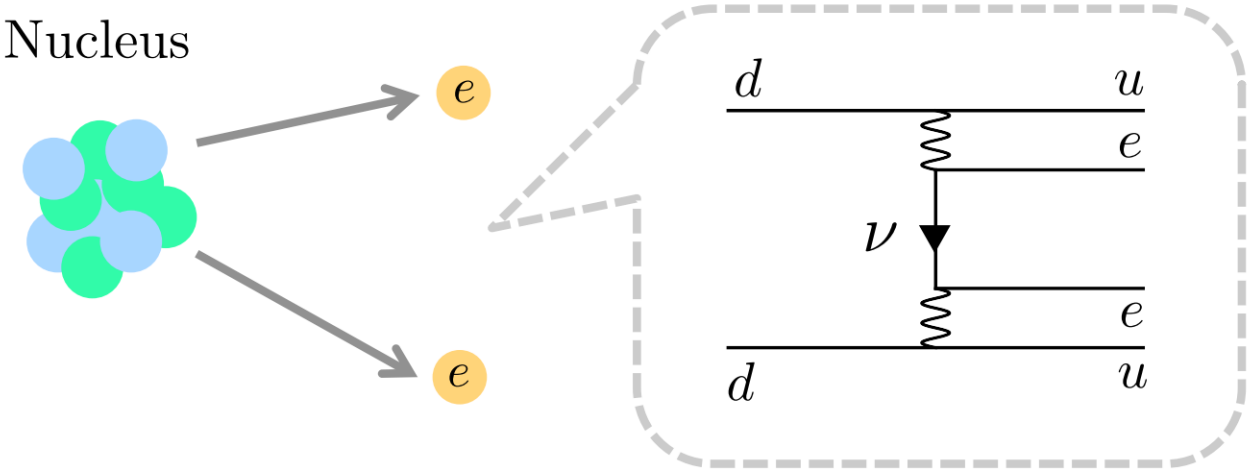
- Assignment of LN: $\mathcal{L} \supset -Y_{i\alpha}\overline{N_i}HL_\alpha - \overline{N_i^c}M_iN_i + \text{h.c.}$

LNC LNV

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

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

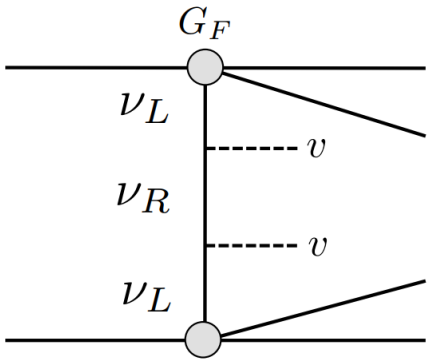
$\Delta L = 2$



[by K. Fuyuto]

LNV – Standard Case

- 4-fermion interaction at low scales



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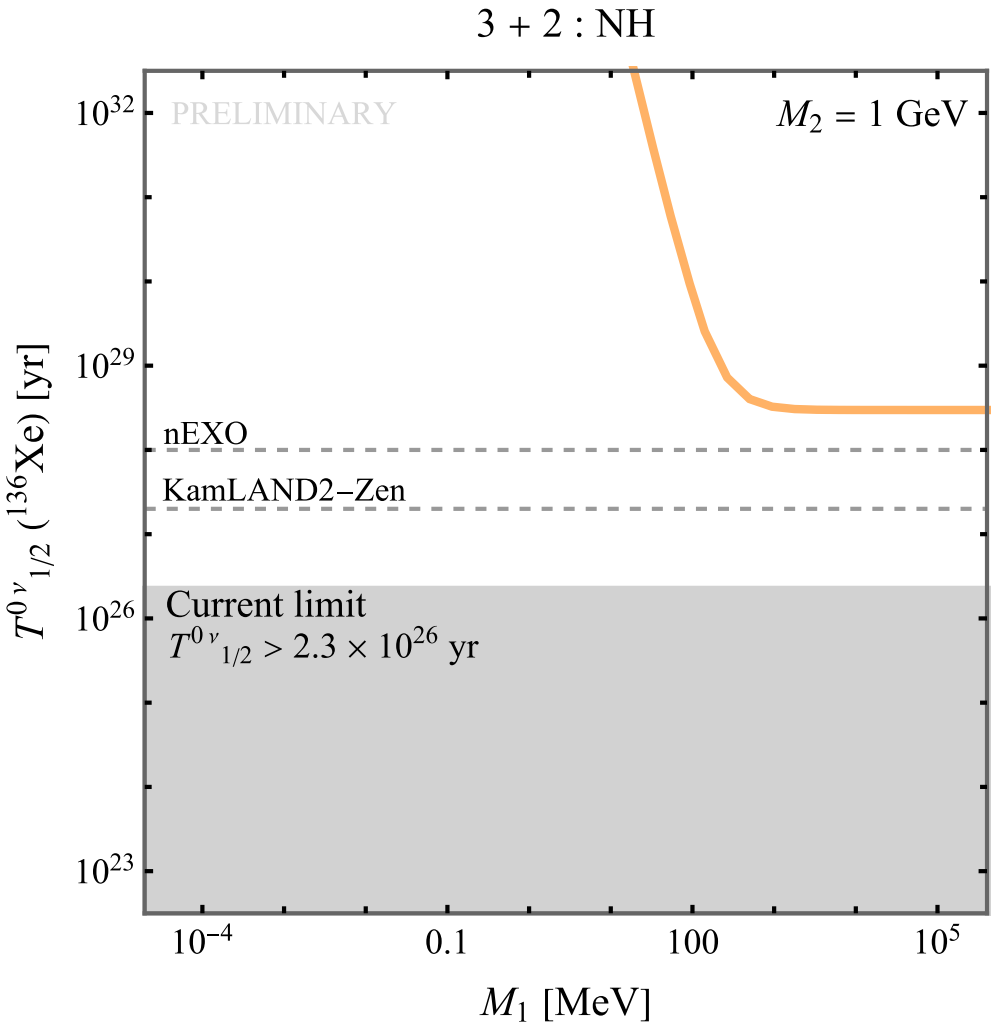
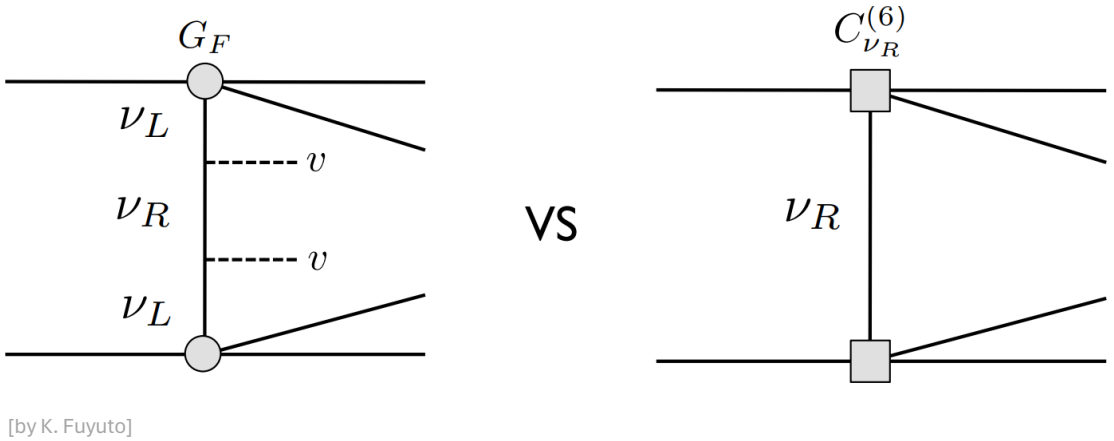


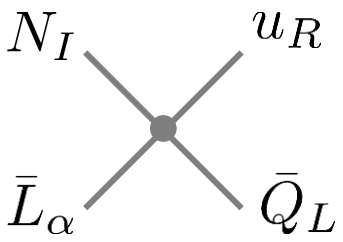
LNV – Non-Standard Case

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

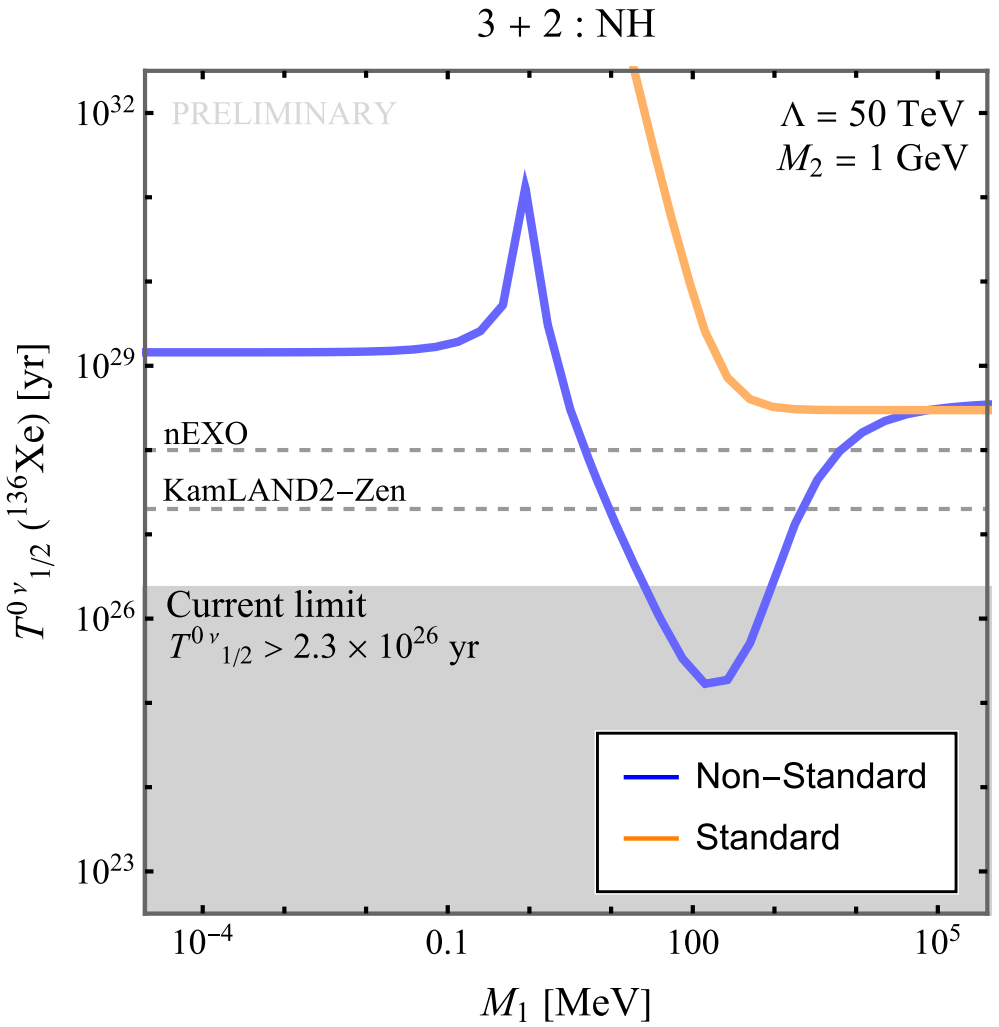


[by K. Fuyuto]

LNC operator:



Order of magnitude effect!

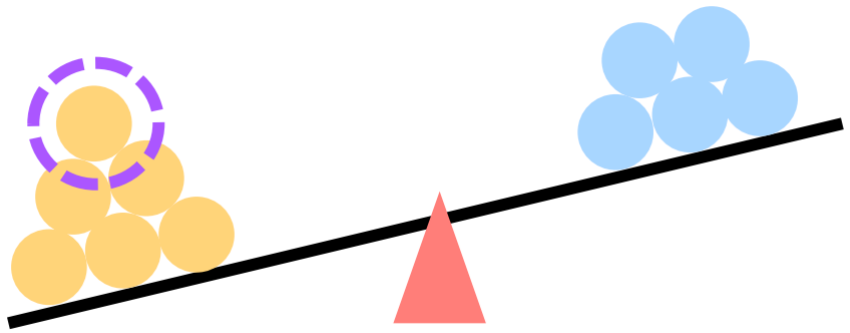


3) Baryon Asymmetry

- Matter-Antimatter asymmetry

$$\eta_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 6 \times 10^{-10}$$

- Sakharov conditions
  1) B violation
  2) C and CP violation
  3) Out-of-equilibrium

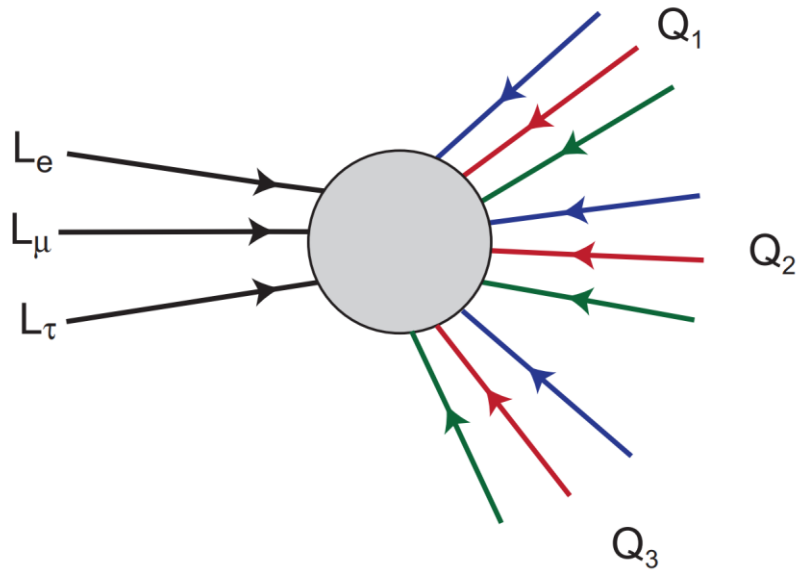


[by K. Fuyuto]

Leptogenesis (LG)

Above EW scale:

- SM sphaleron processes → $B + L$ violation
- Non-perturbative



[Nir 2009]

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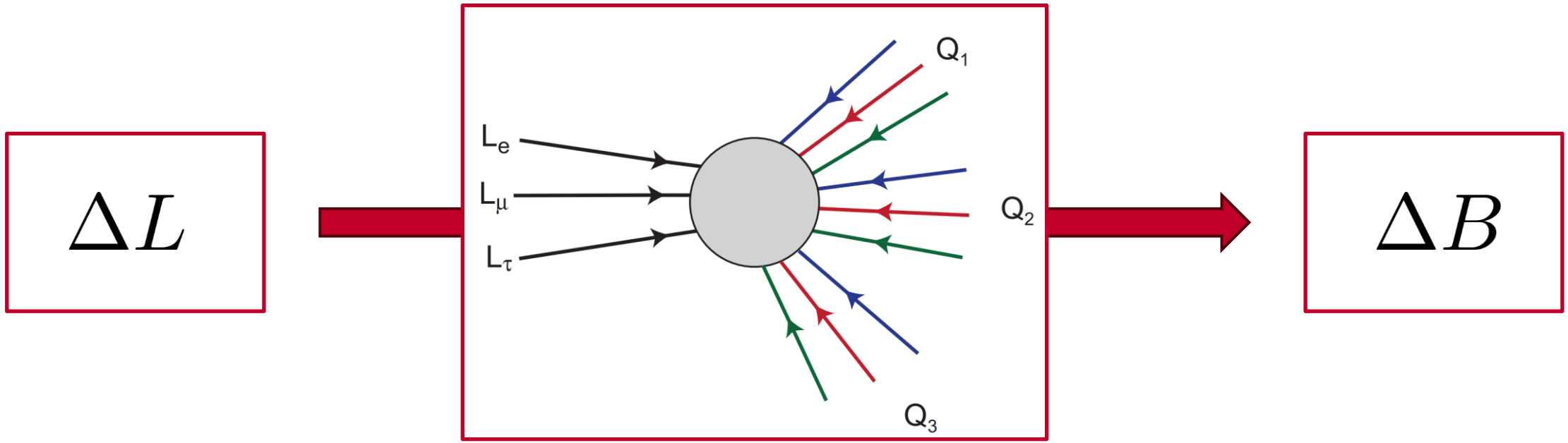
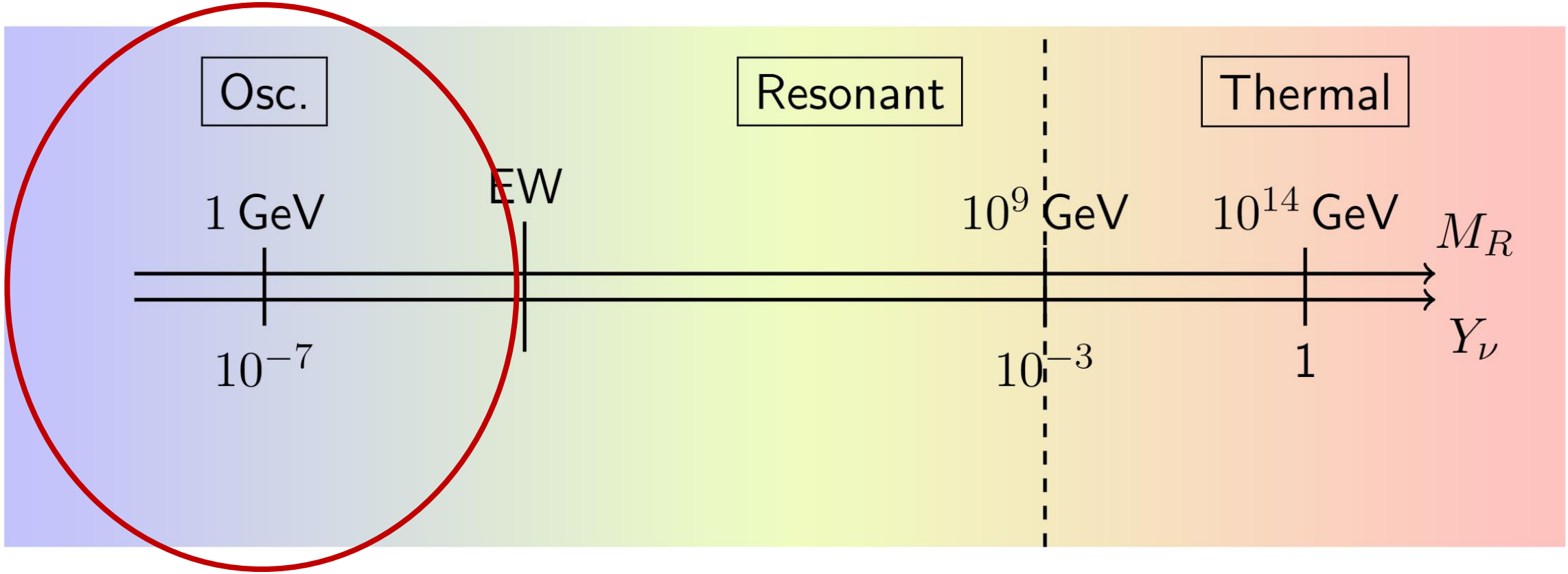
- SM sphaleron processes → $B + L$ violation
- Non-perturbative

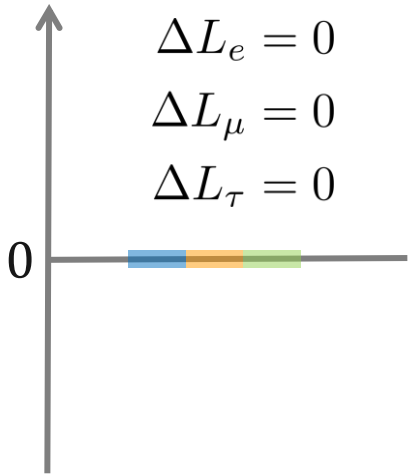


[Nir 2009]

Leptogenesis regimes

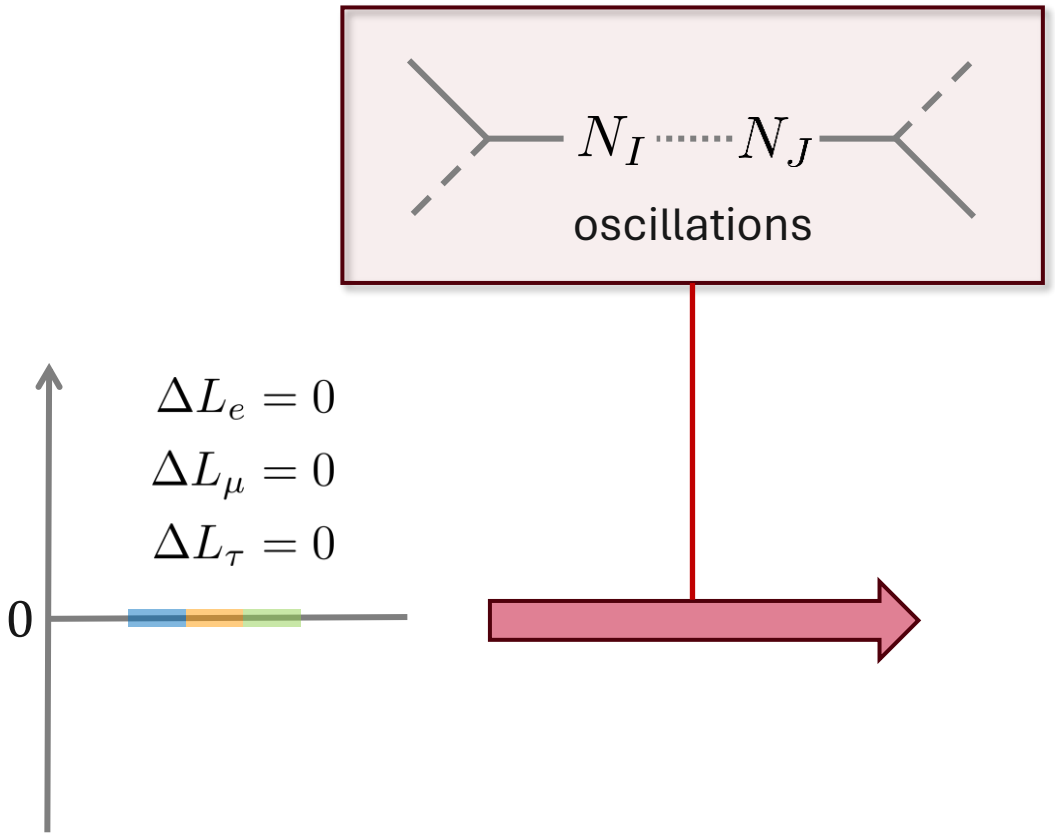


BAU via Neutrino Oscillation – Standard Case

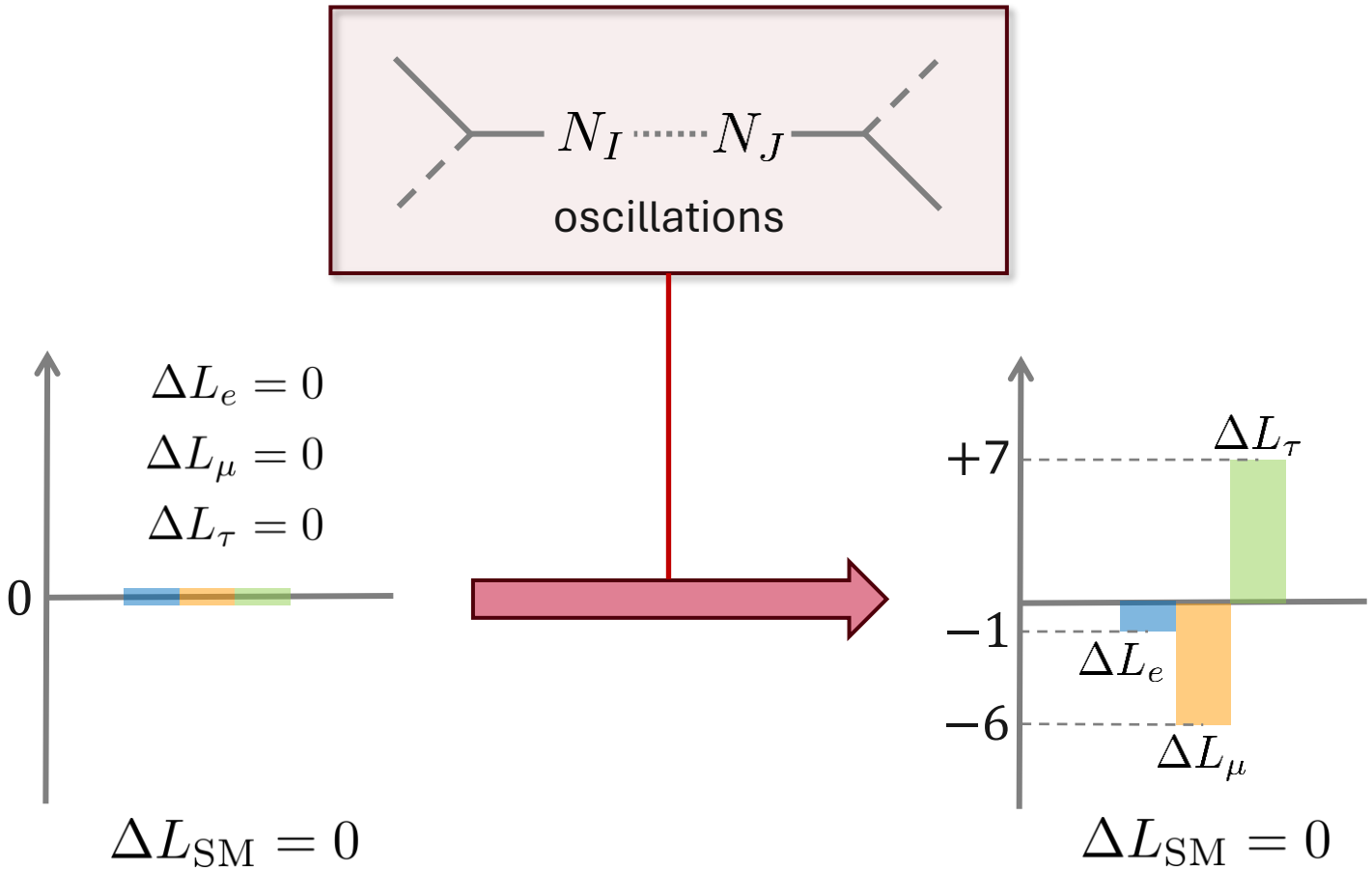


$$\Delta L_{\mathrm{SM}} = 0$$

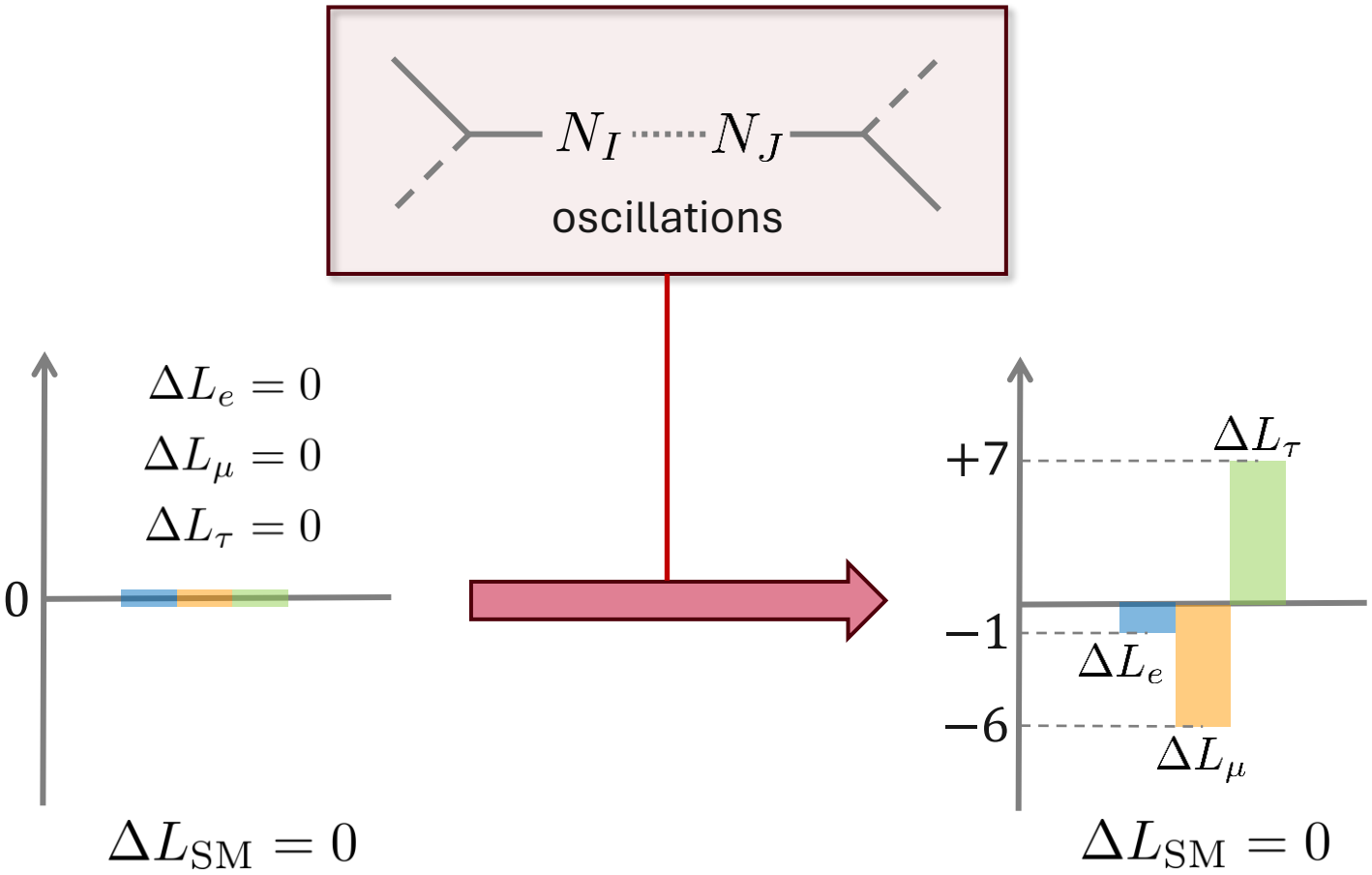
BAU via Neutrino Oscillation – Standard Case

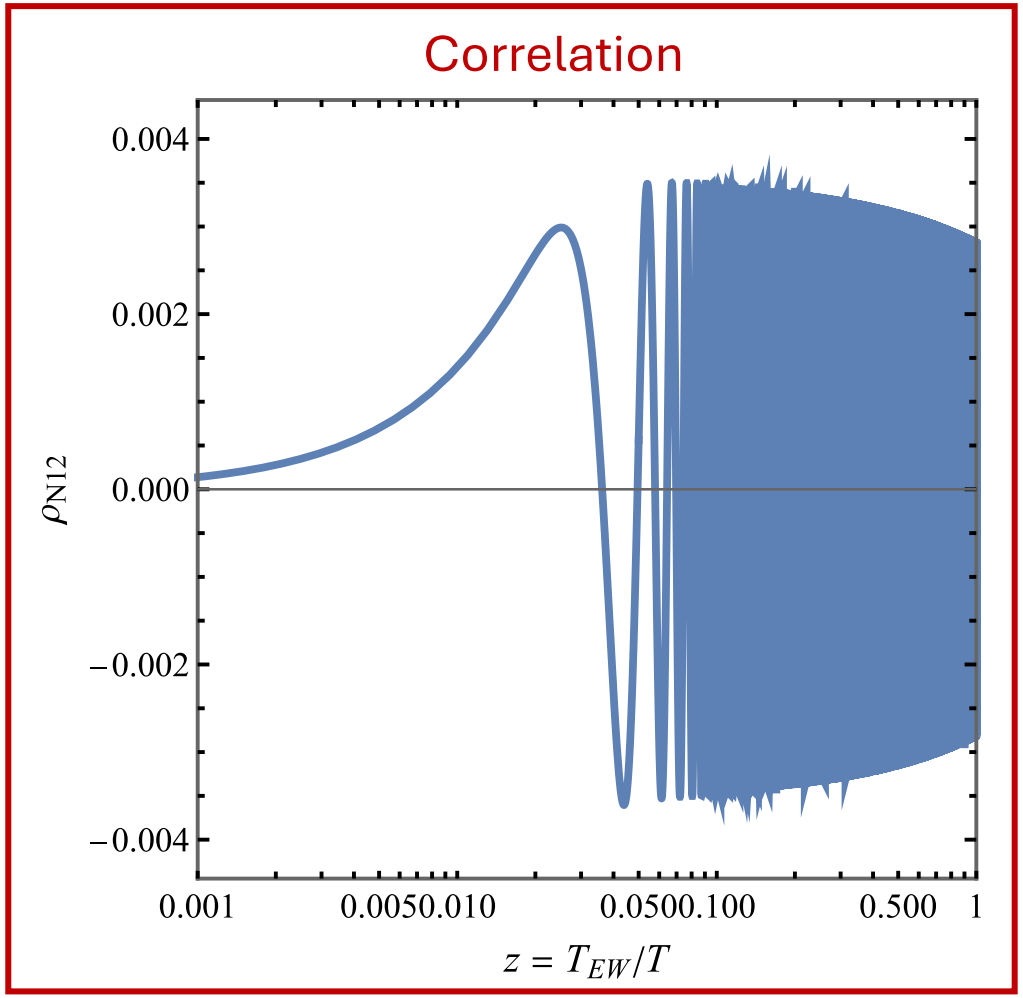


BAU via Neutrino Oscillation – Standard Case



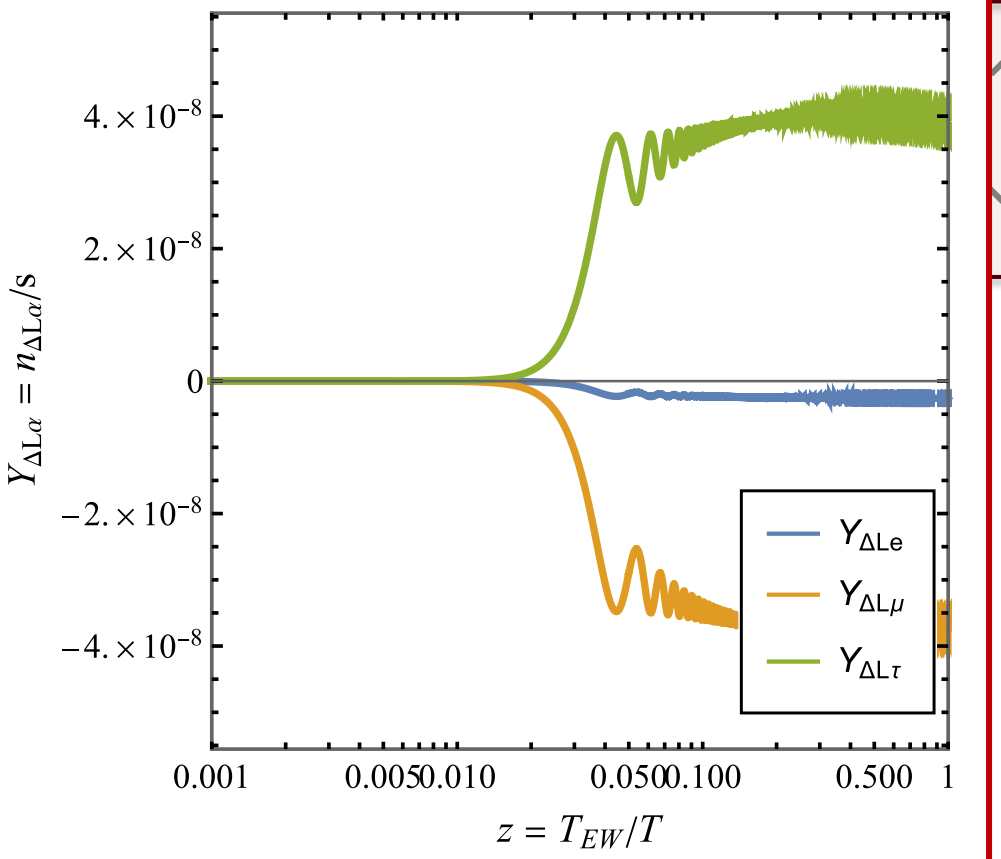
BAU via Neutrino Oscillation – Standard Case

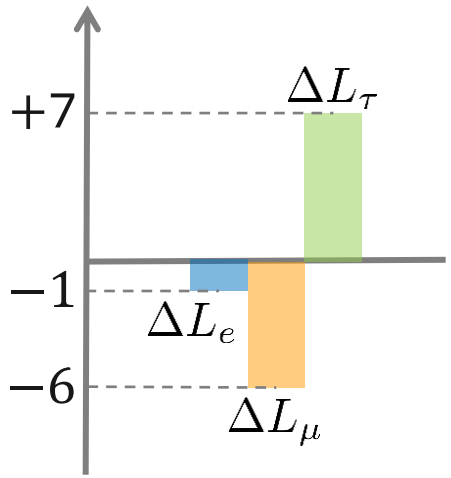




BAU via Neutrino Oscillation – Standard Case

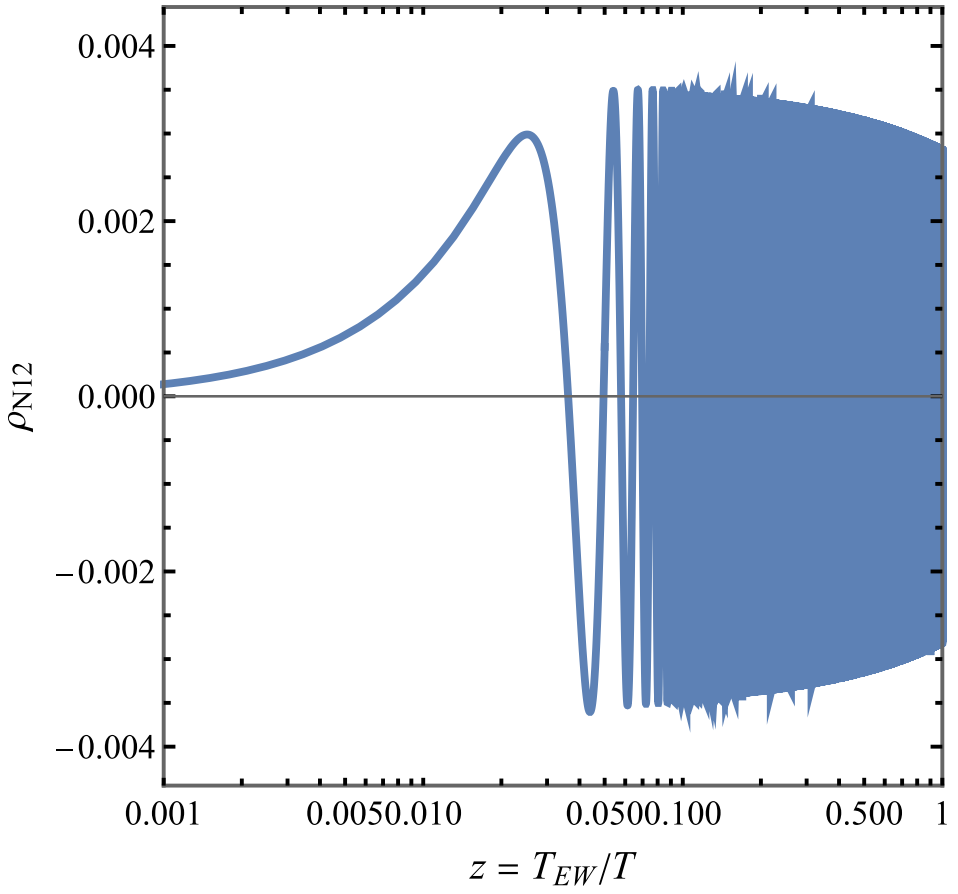
Lepton Flavor Asymmetries





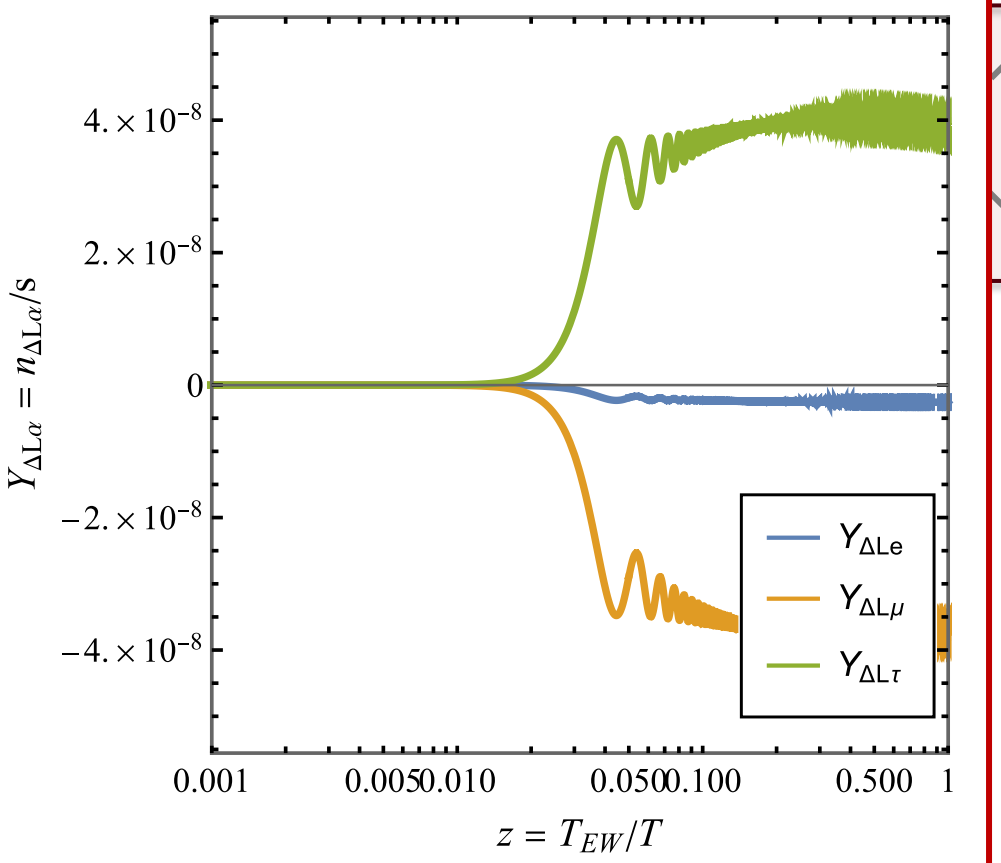
$$\Delta L_{\rm SM} = 0$$

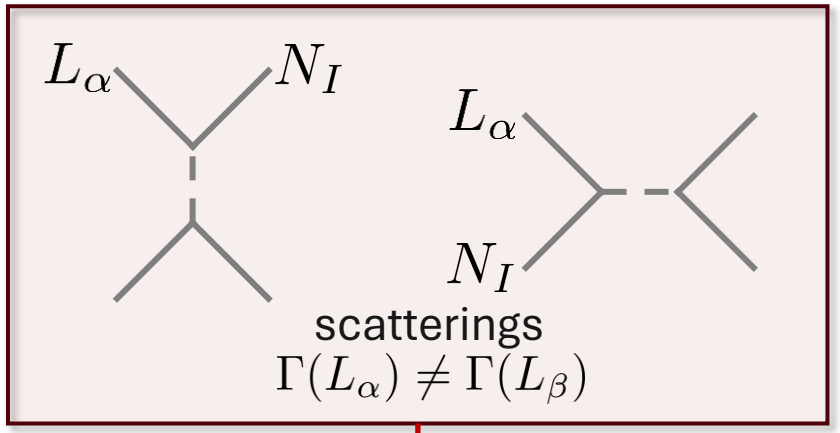
Correlation

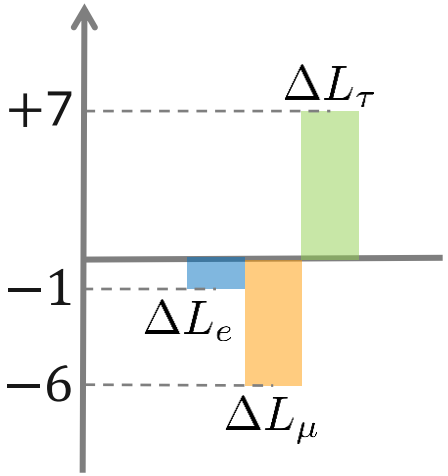


BAU via Neutrino Oscillation – Standard Case

Lepton Flavor Asymmetries



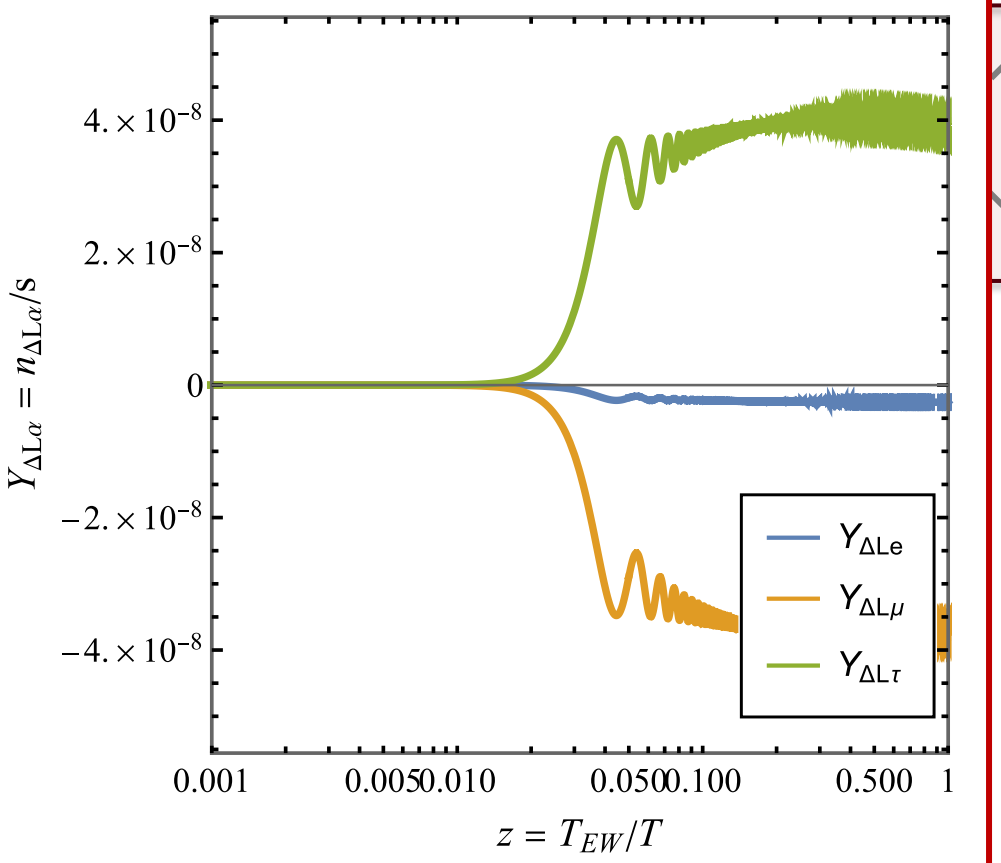


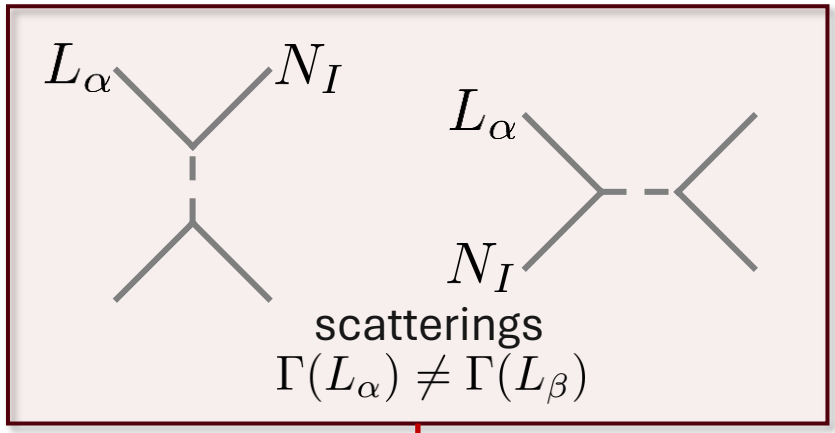


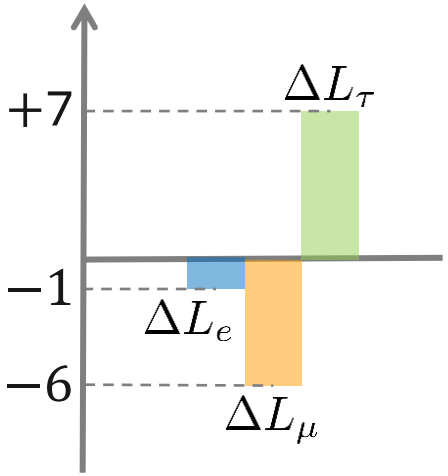
$\Delta L_{\rm SM} = 0$

BAU via Neutrino Oscillation – Standard Case

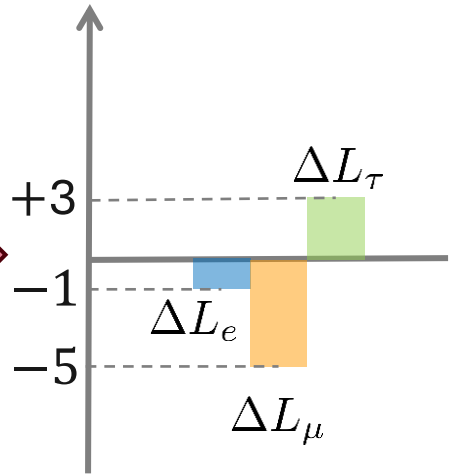
Lepton Flavor Asymmetries





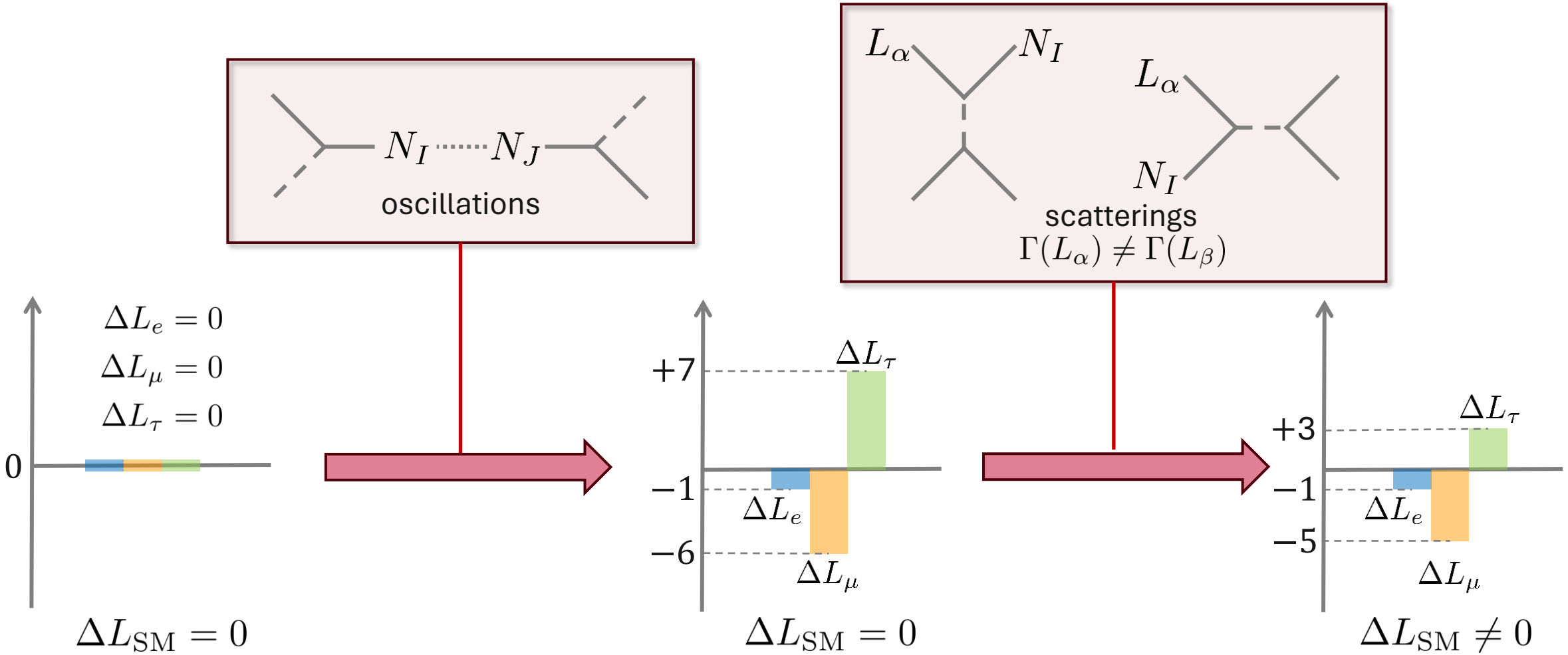


$\Delta L_{\rm SM} = 0$

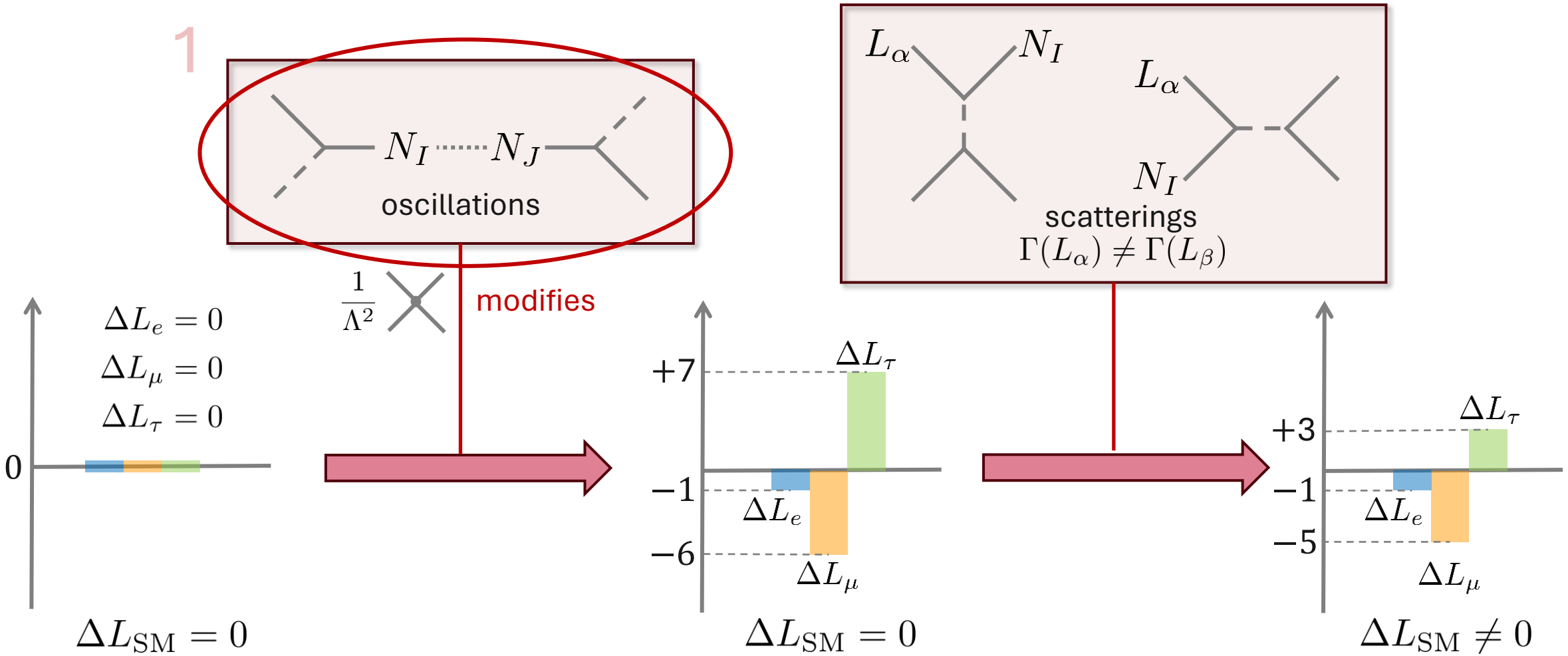


$\Delta L_{\rm SM} \neq 0$

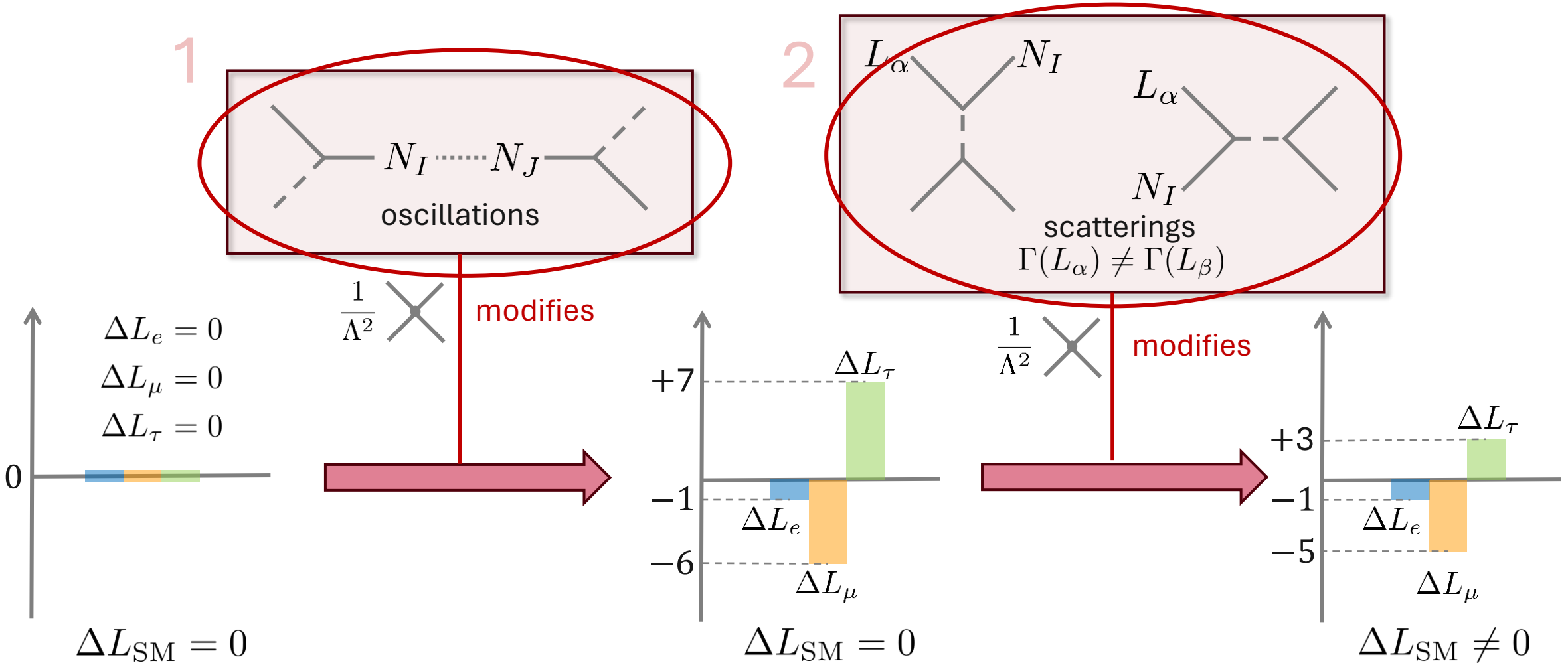
BAU via Neutrino Oscillation – Standard Case



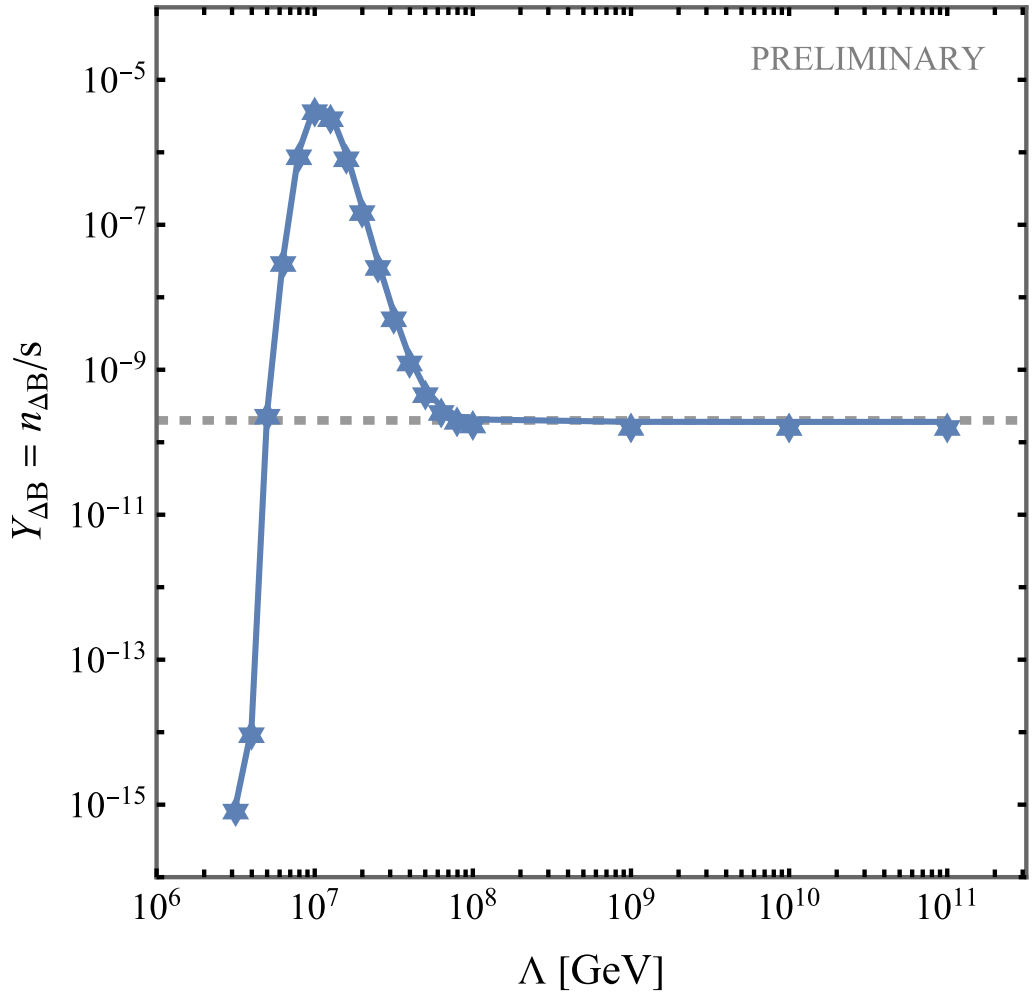
BAU via Neutrino Oscillation – Non-Standard Case



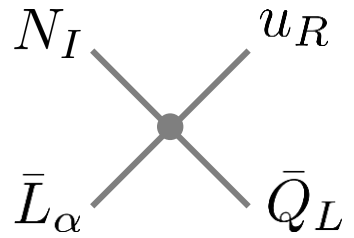
BAU via Neutrino Oscillation – Non-Standard Case



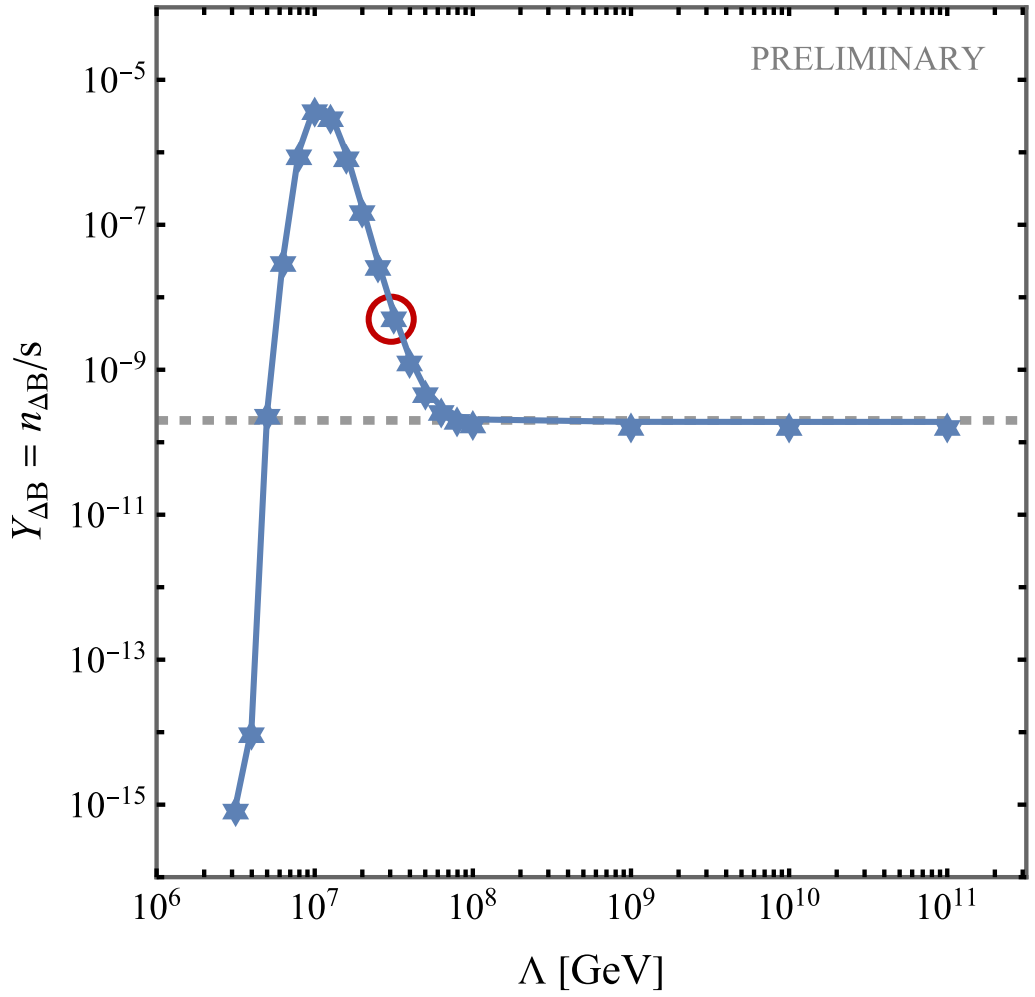
Low scale Leptogenesis – Non-Standard Case



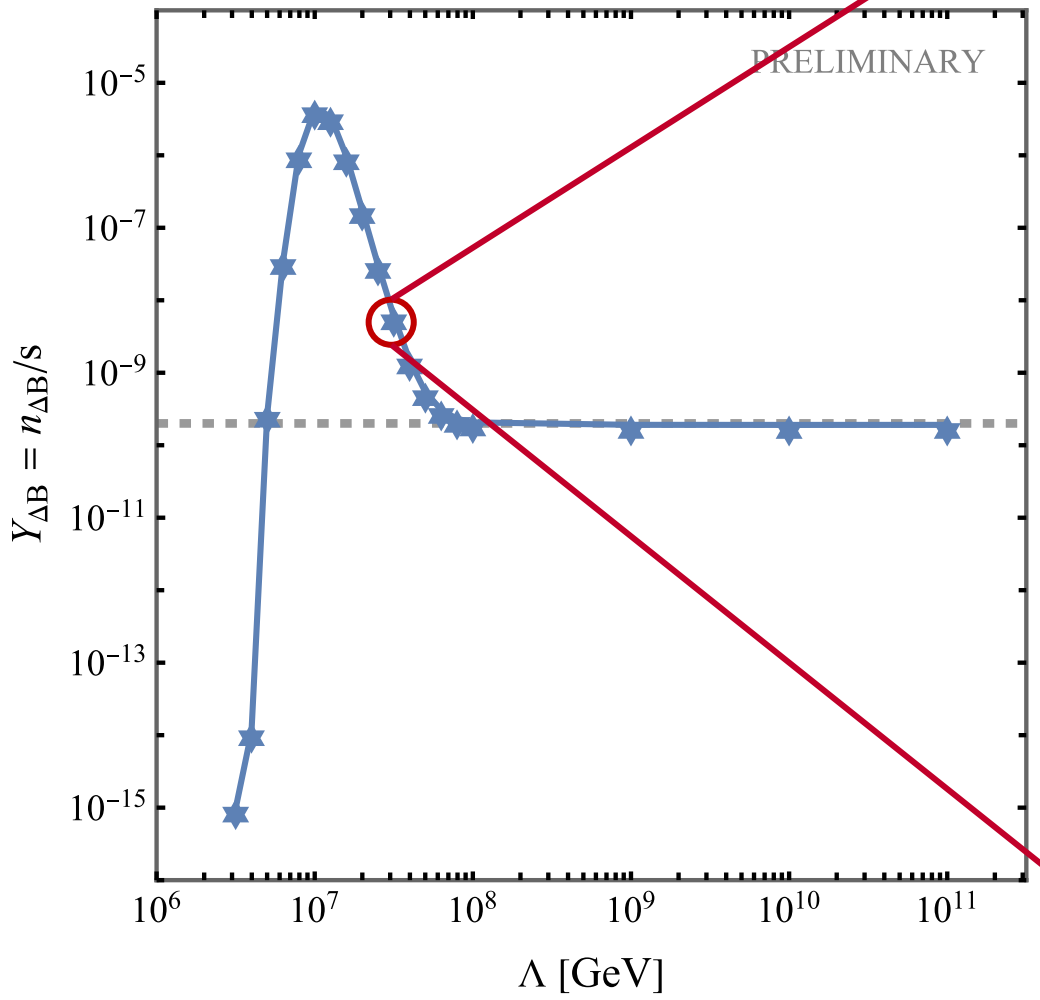
LNC operator:

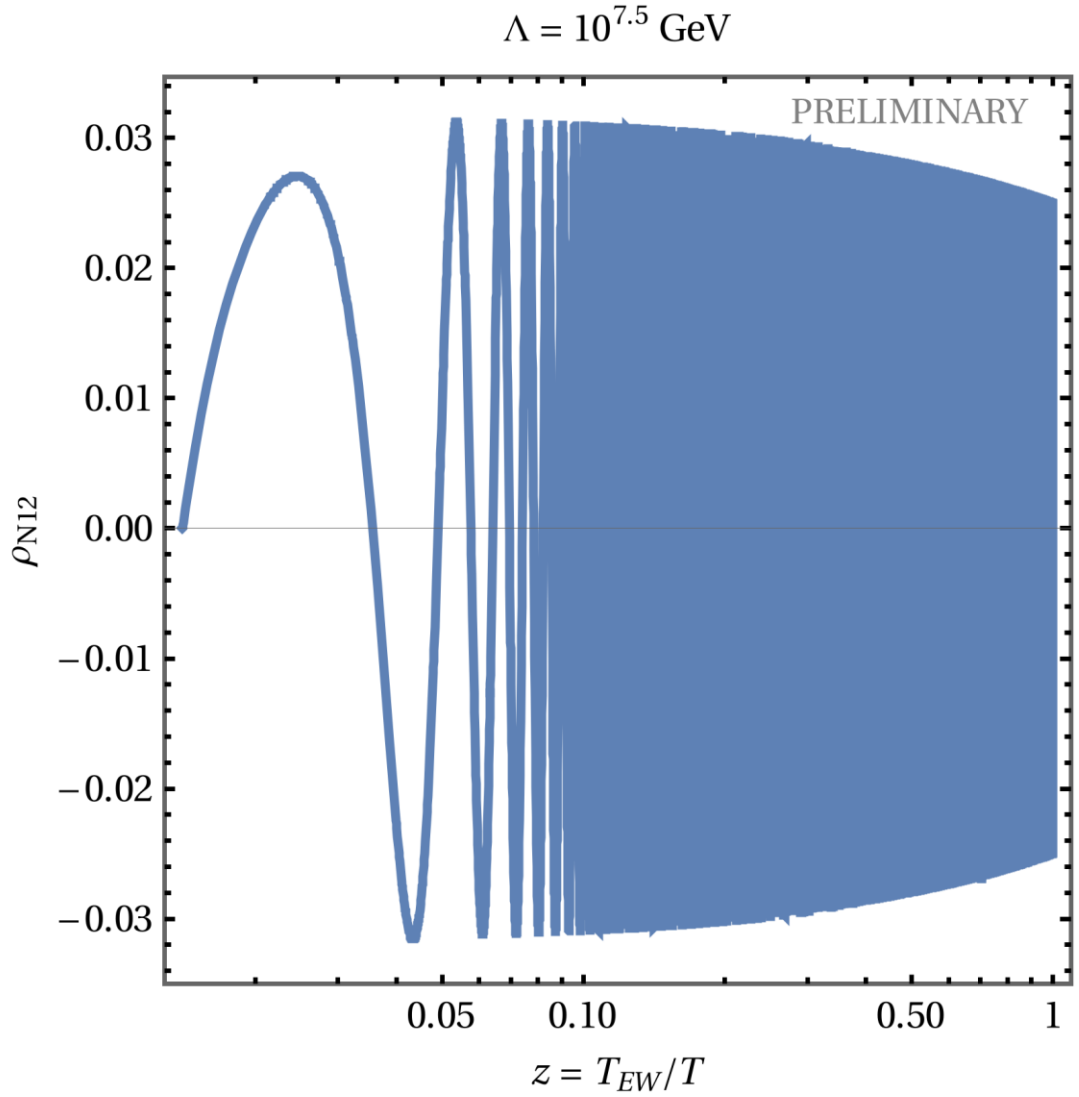


Low scale Leptogenesis – Non-Standard Case

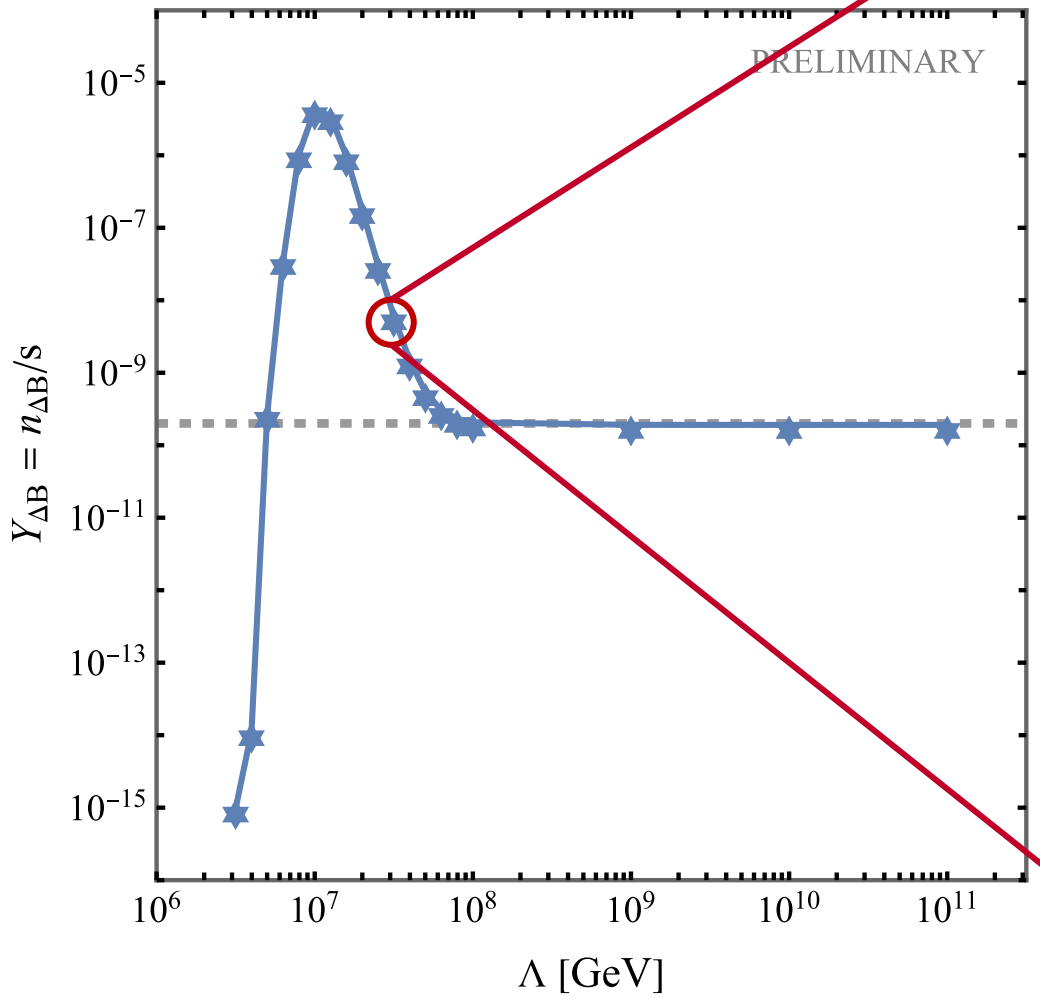


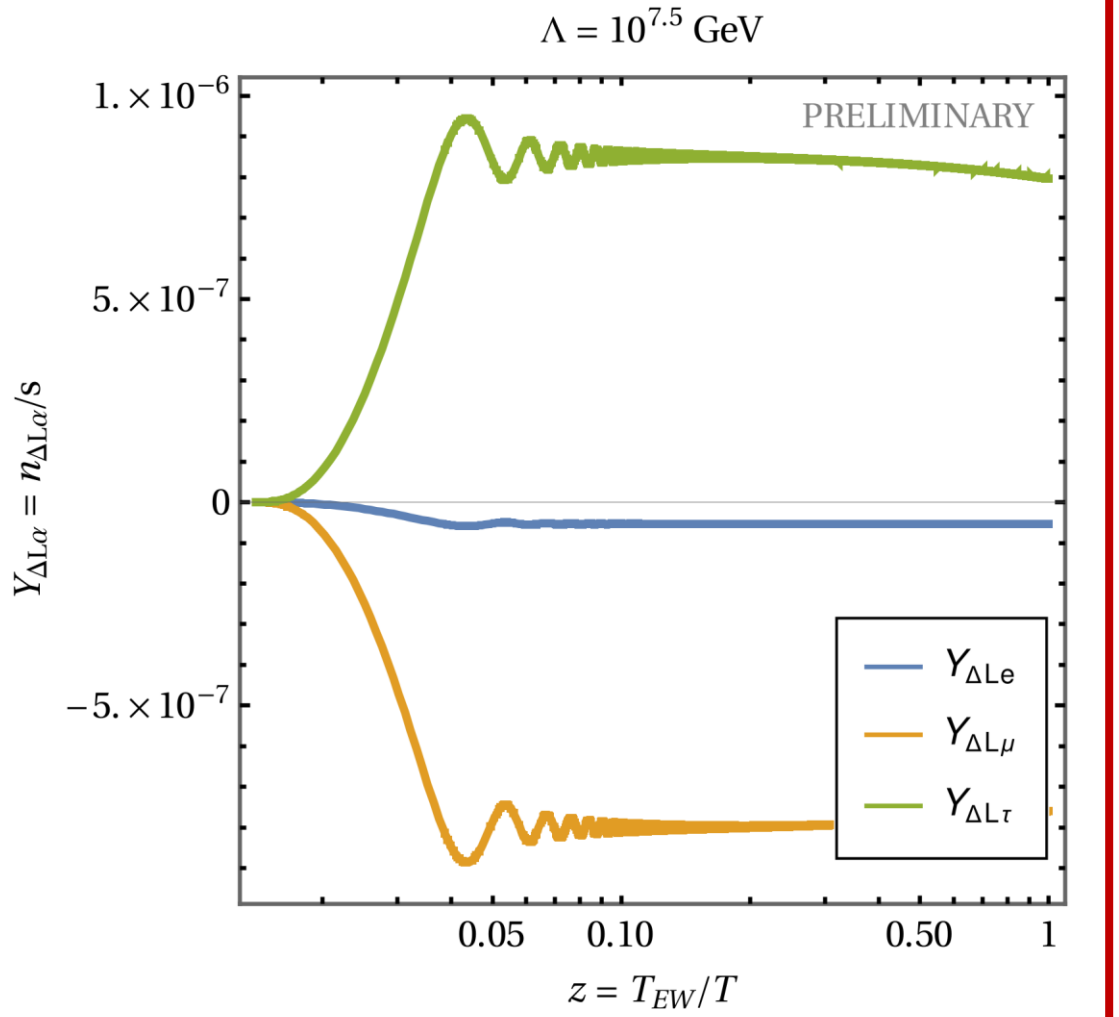
Low scale Leptogenesis – N



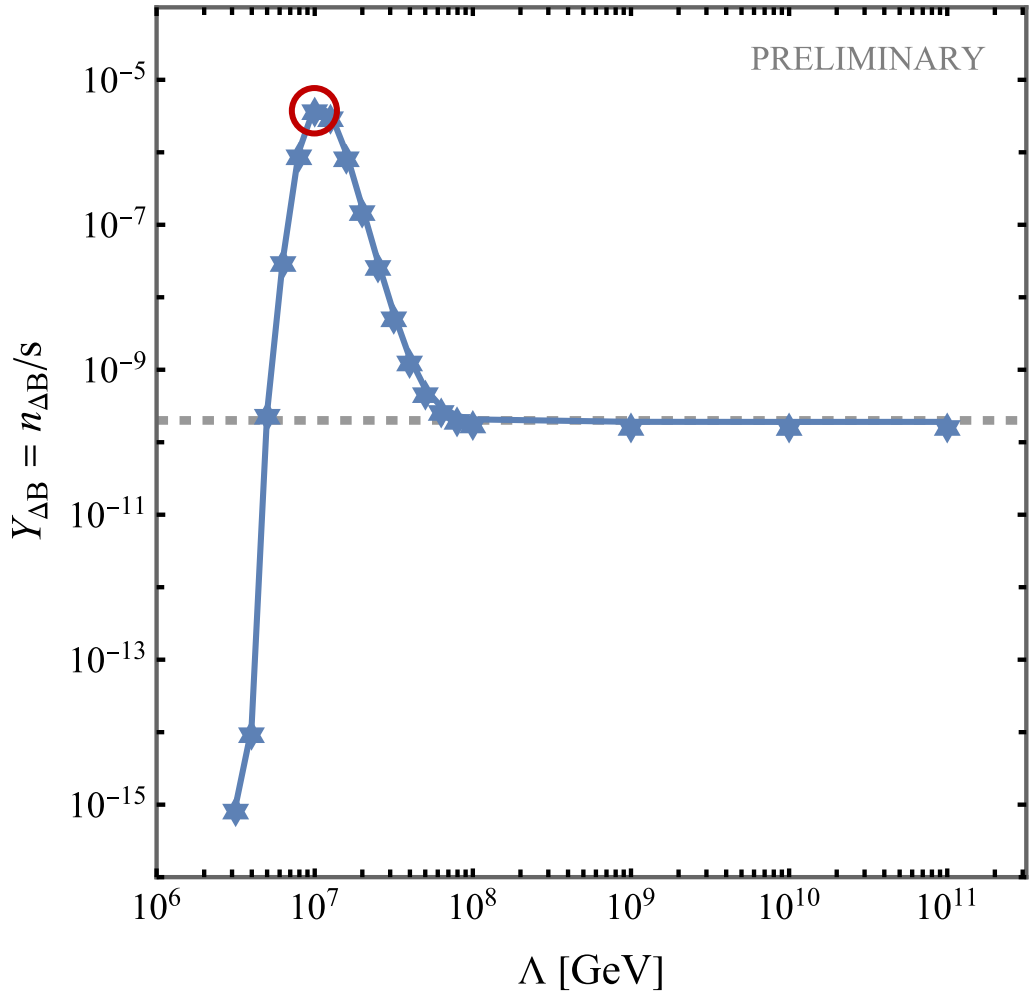


Low scale Leptogenesis – N

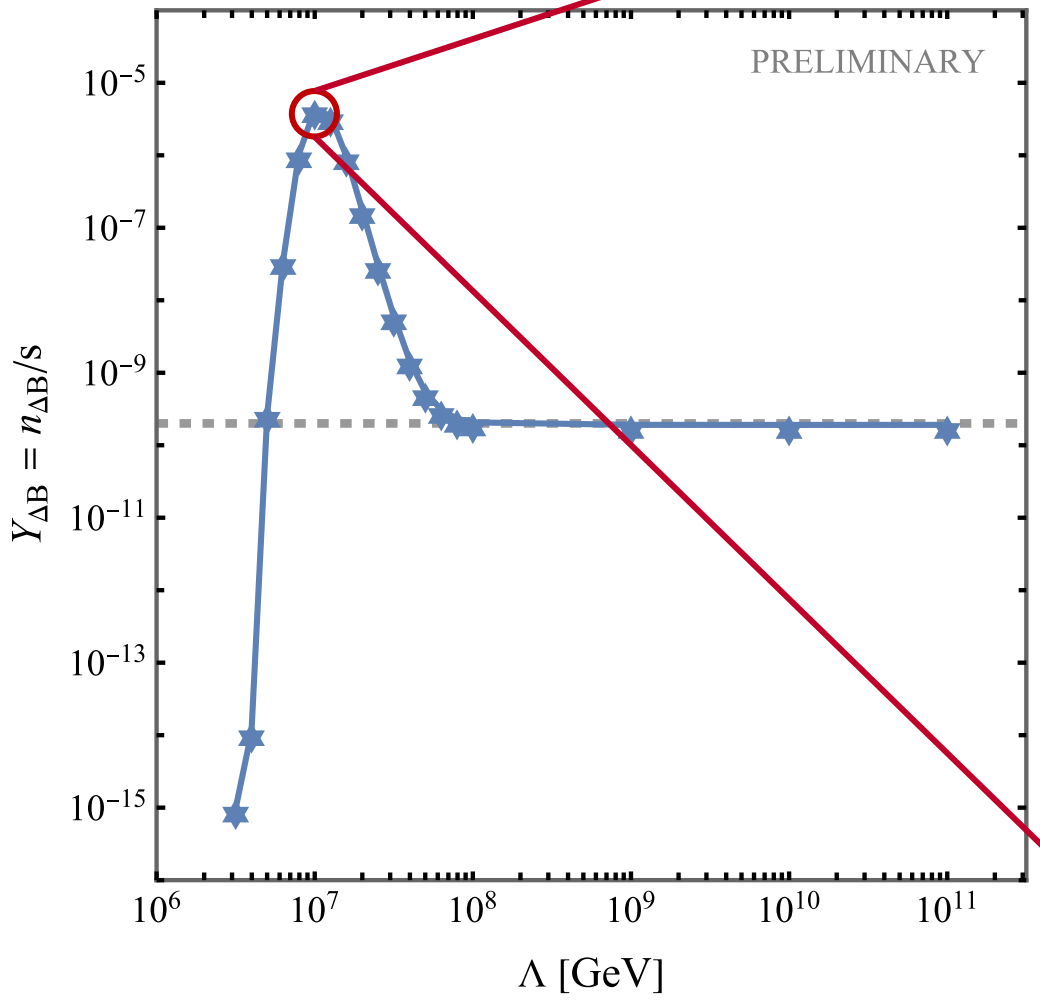


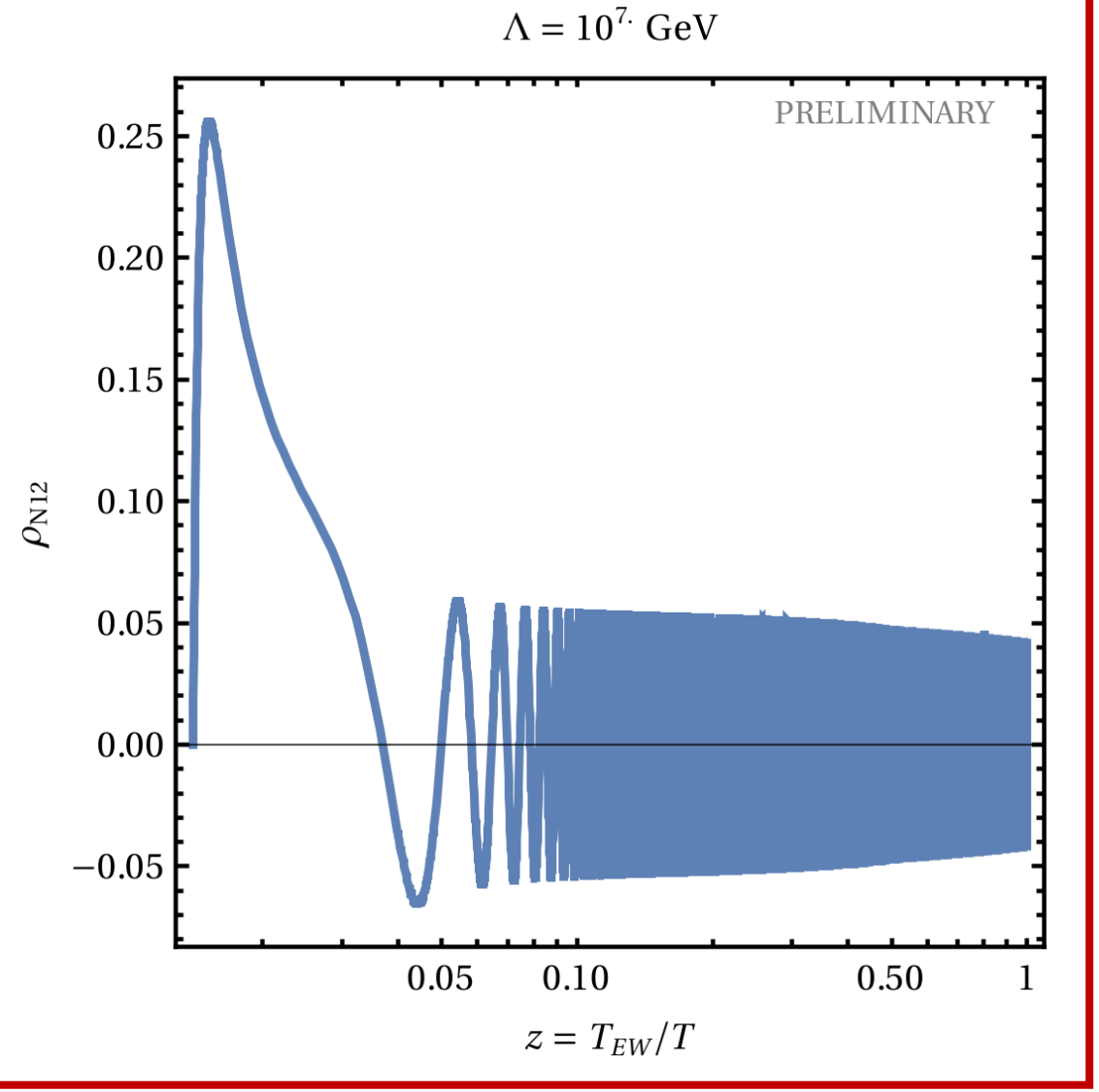


Low scale Leptogenesis – Non-Standard Case

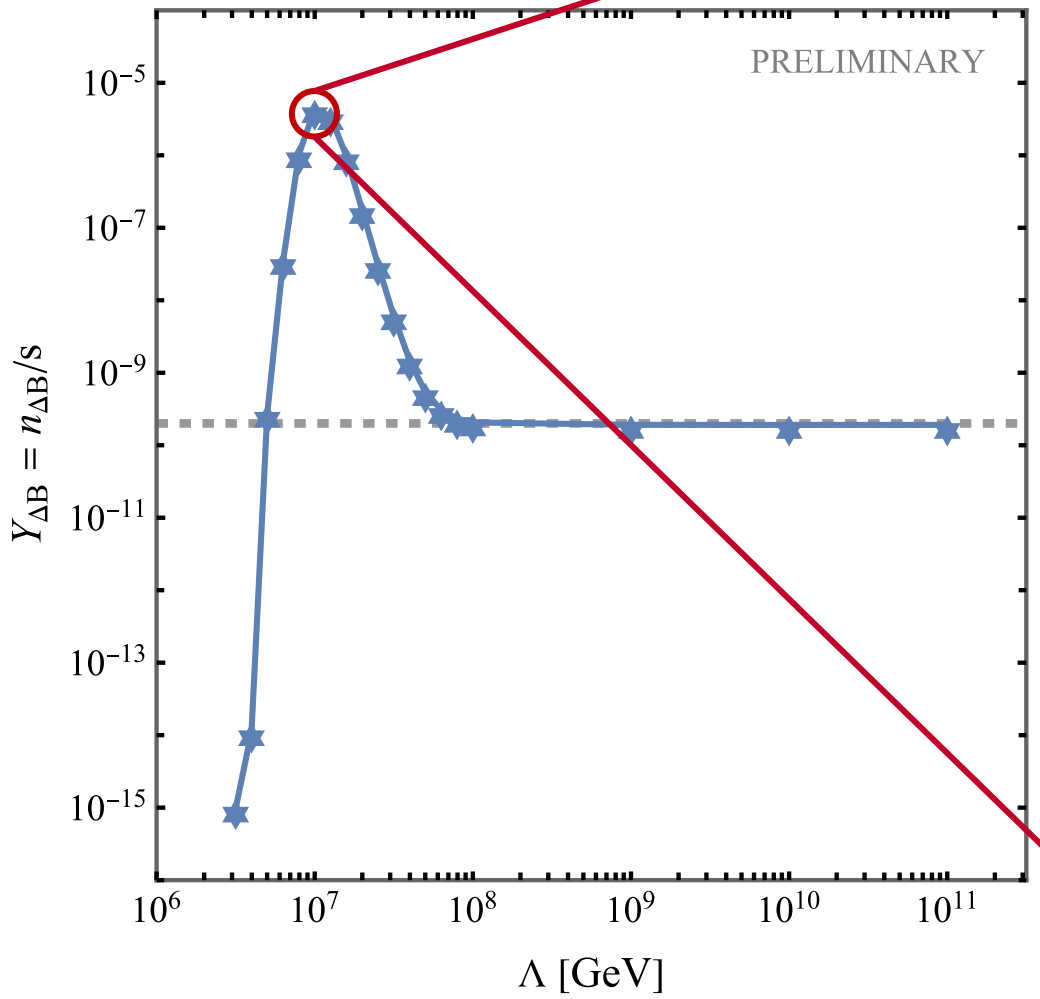


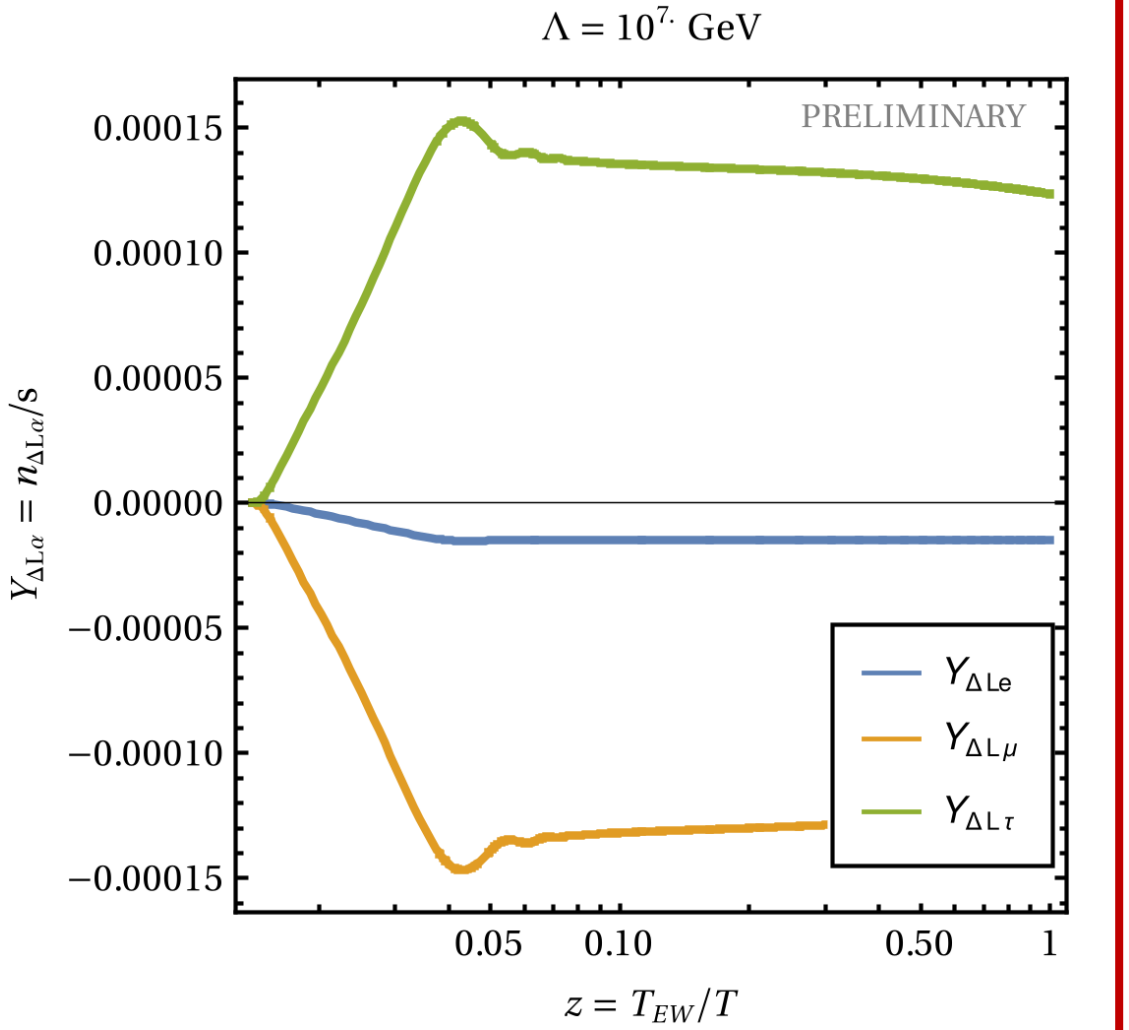
Low scale Leptogenesis – N



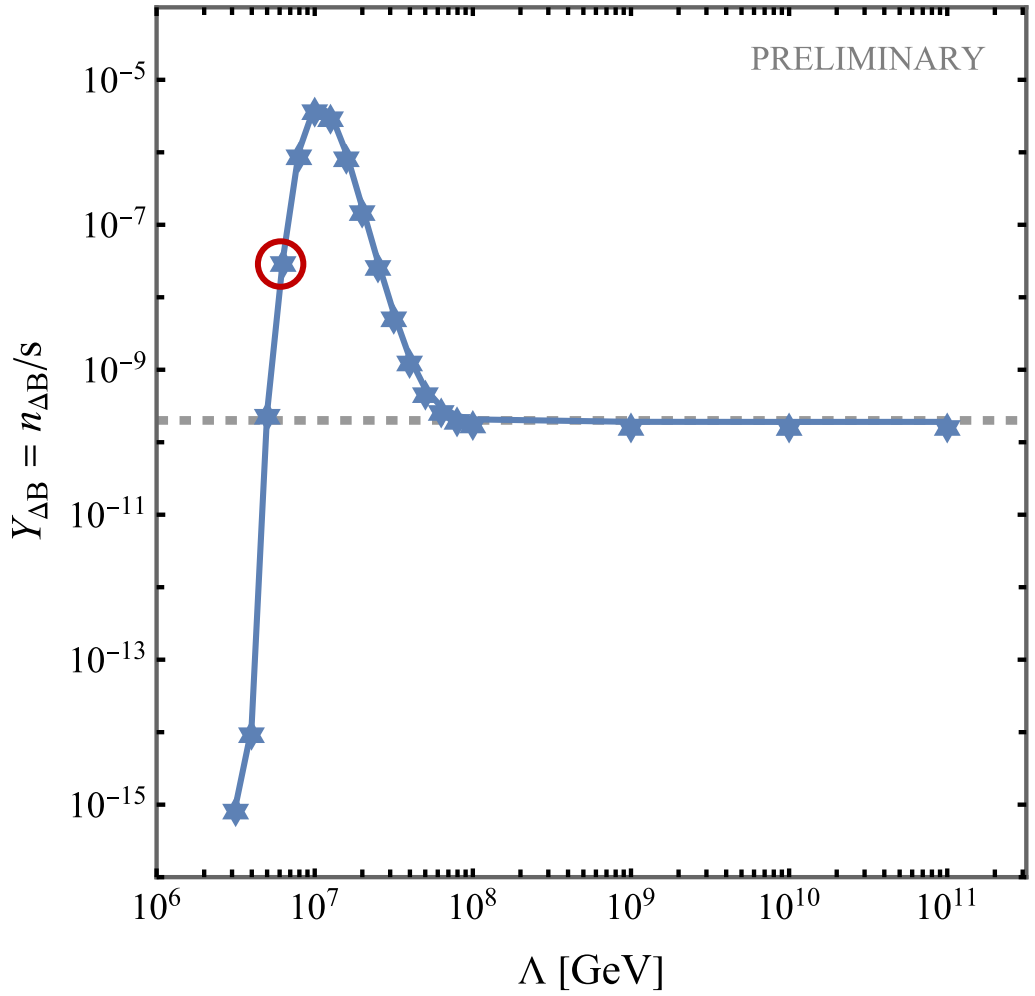


Low scale Leptogenesis – N

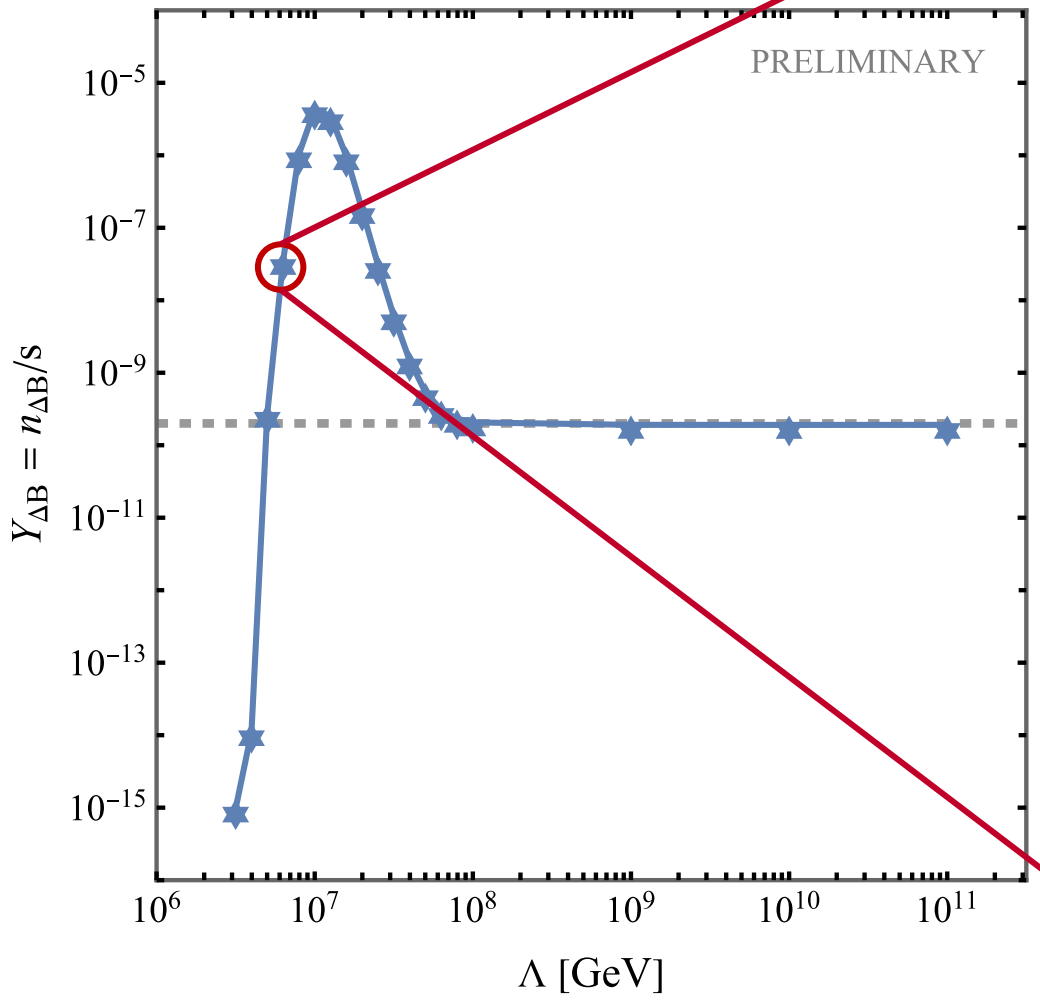


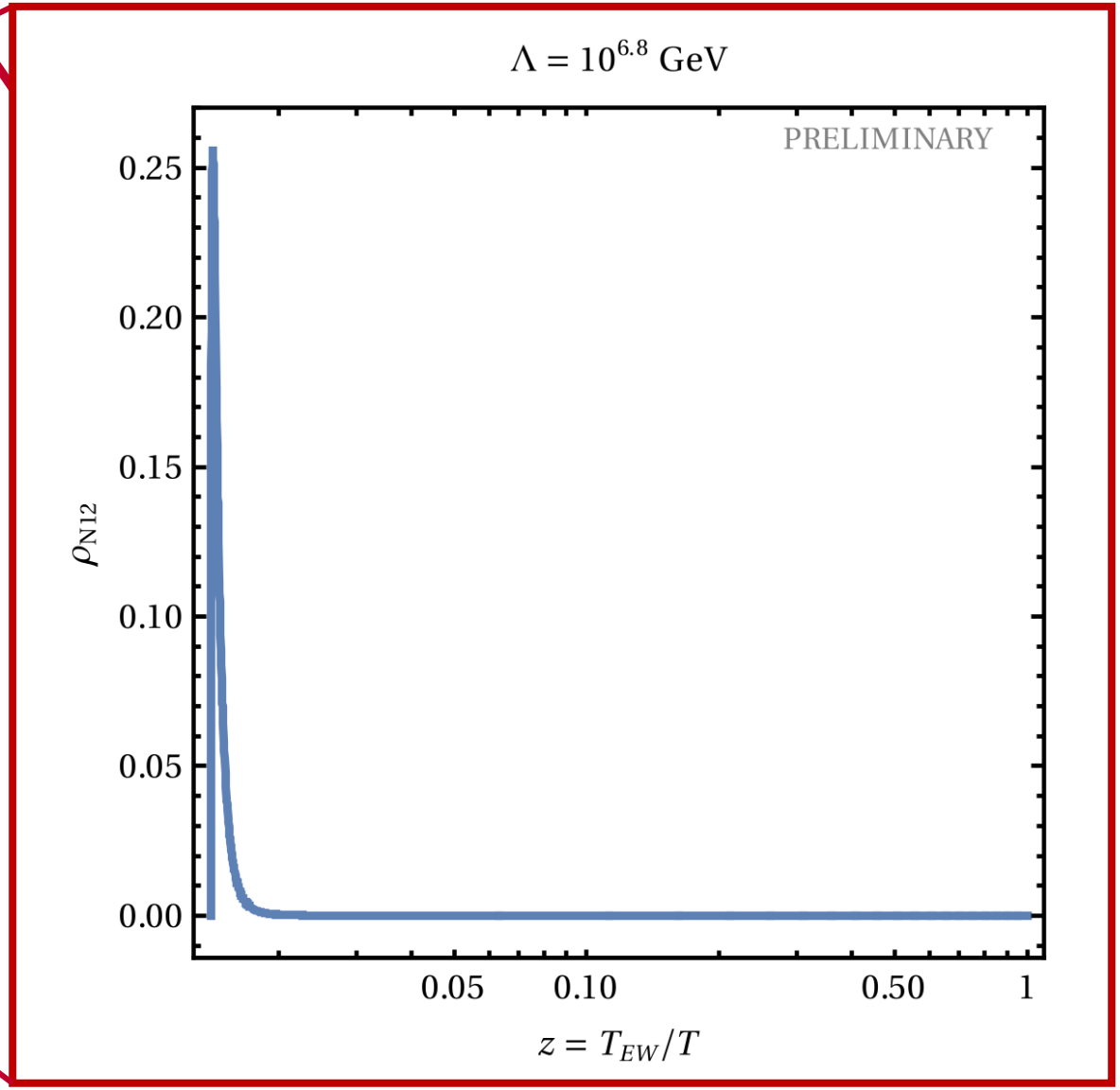


Low scale Leptogenesis – Non-Standard Case

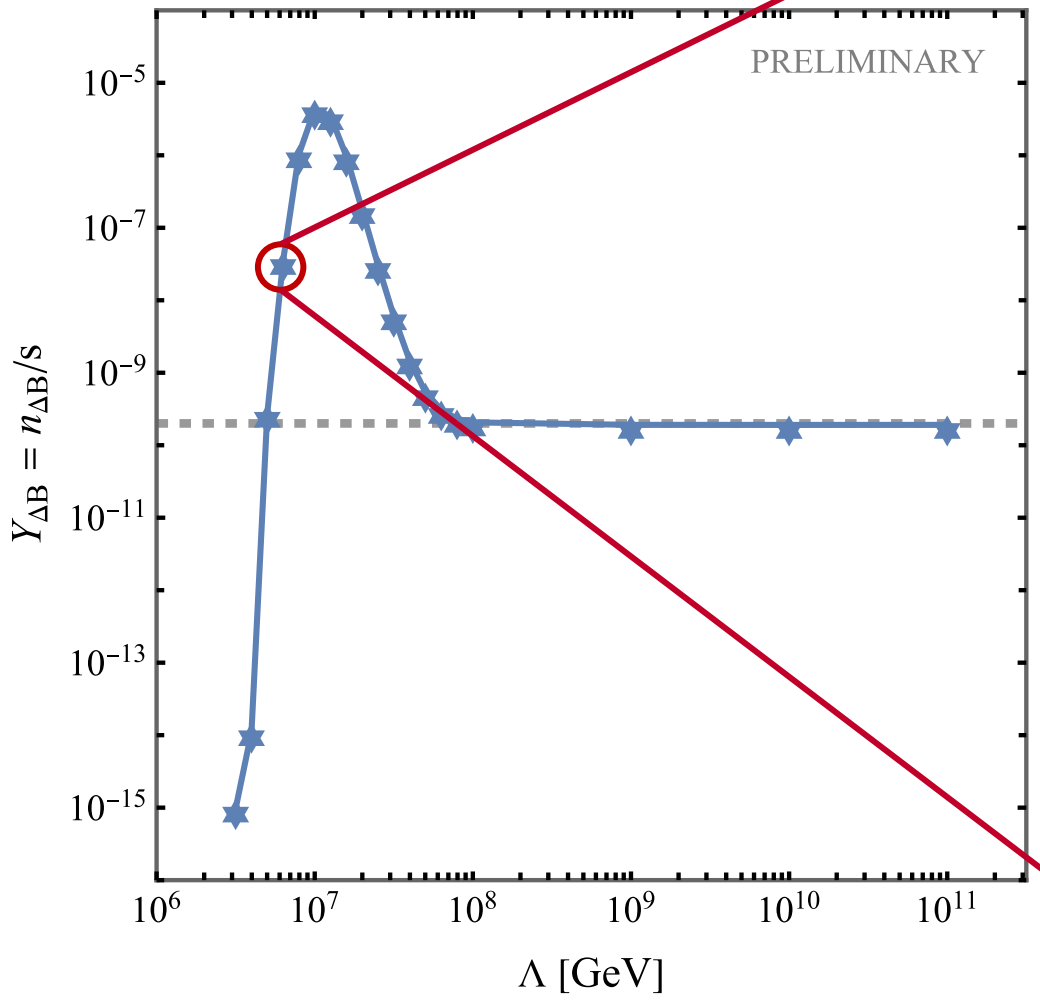


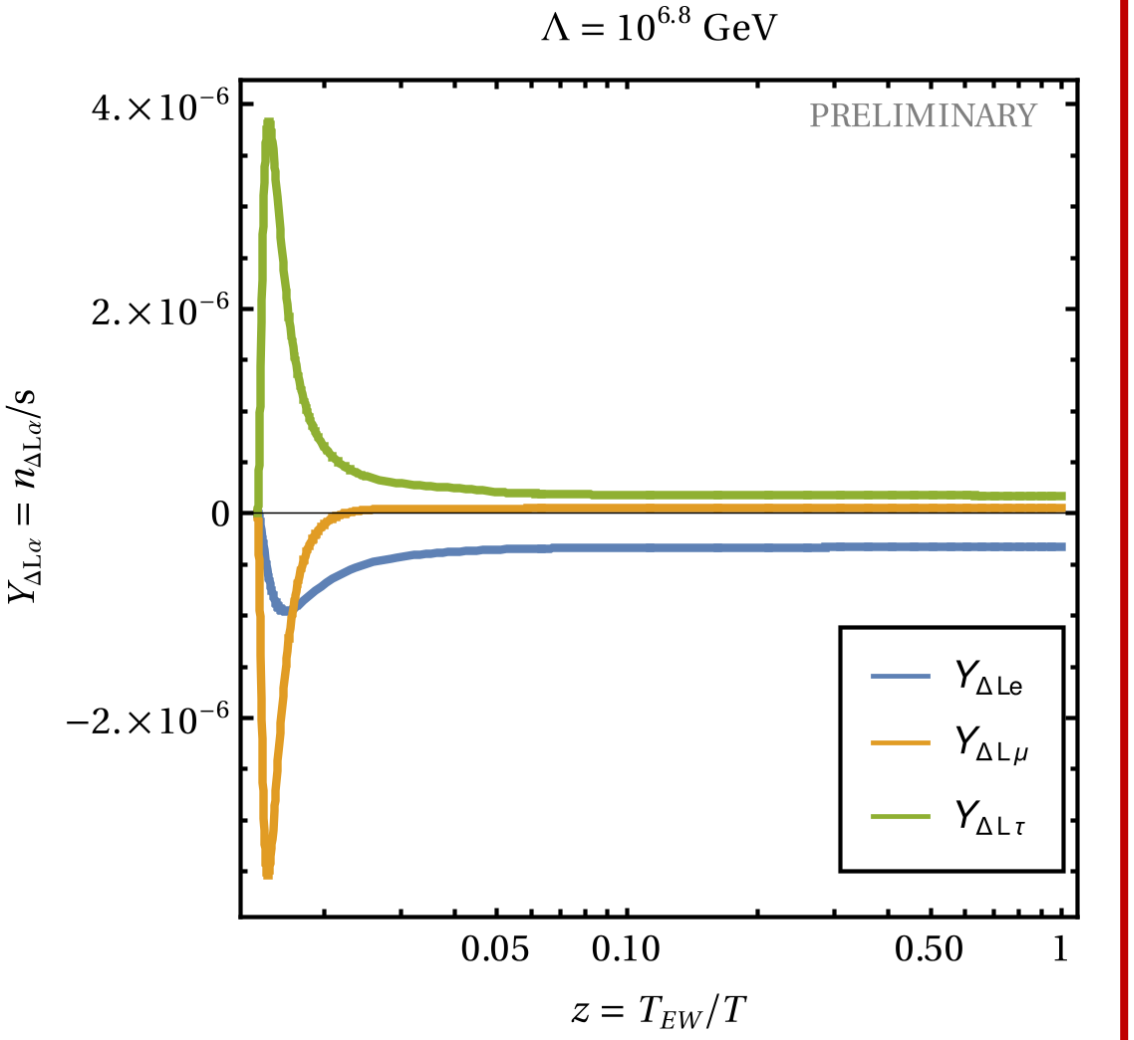
Low scale Leptogenesis – N



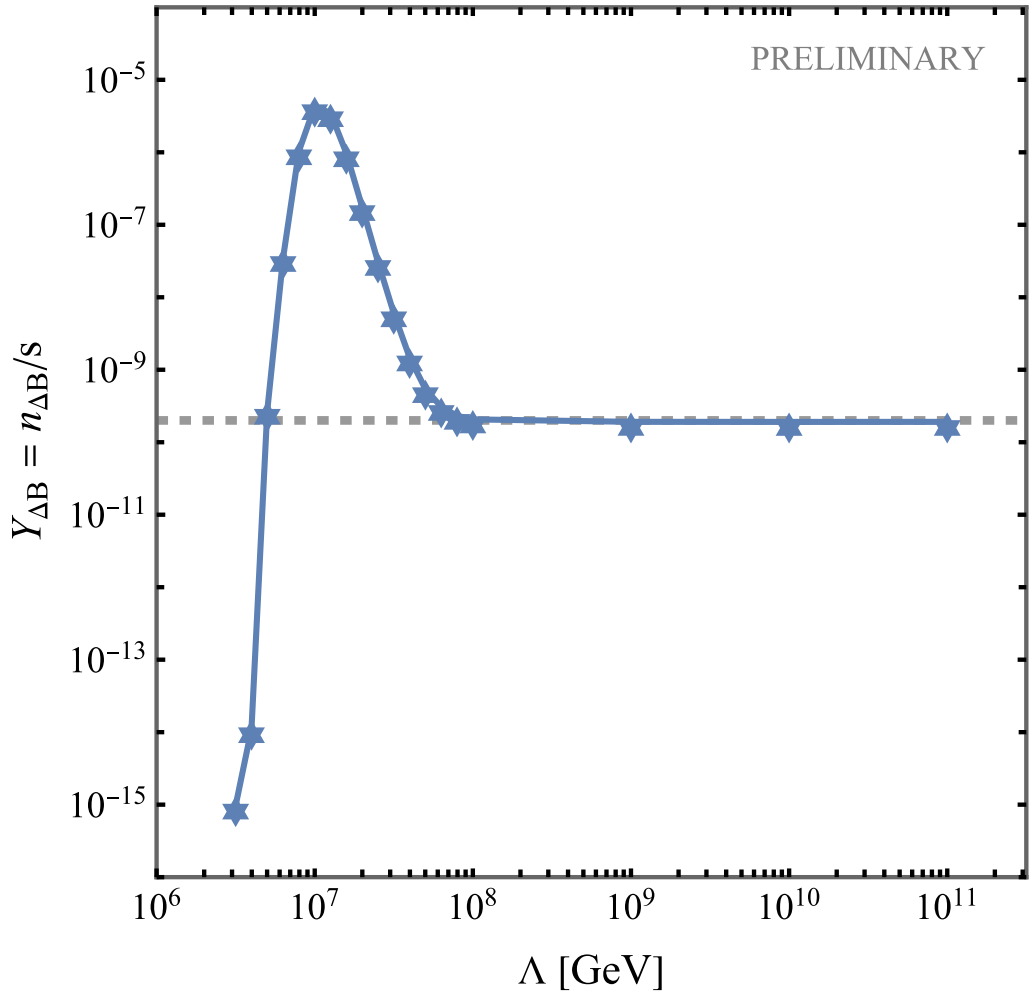


Low scale Leptogenesis – N



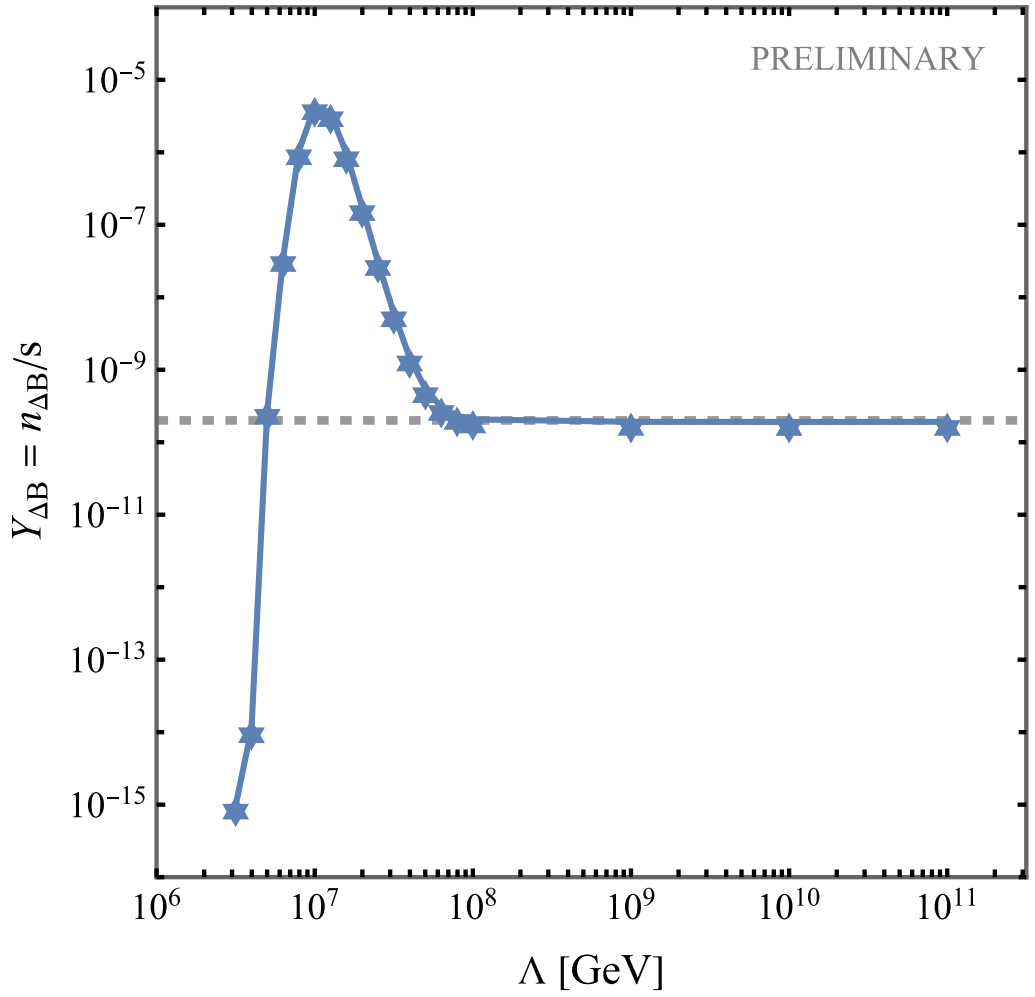


Low scale Leptogenesis – Non-Standard Case



Order of magnitude effect!

Low scale Leptogenesis – Non-Standard Case



Order of magnitude effect!

Work in progress!

Conclusion & Outlook

- Non-standard interactions can change
  - → $0\nu\beta\beta$ decay
  - → Low-Scale Leptogenesis

  by orders of magnitude

Conclusion & Outlook

- Non-standard interactions can change
  - → $0\nu\beta\beta$ decay
  - → Low-Scale Leptogenesis

  by orders of magnitude

- Conduct full parameter scan
- Go beyond effective operator approach to study the effect of T_{RH}


Thank You
[https://pxhere.com/de/photo/1371657]

Neutrinoless double beta decay and the baryon asymmetry of the Universe

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Non-standard cases

e.g. in connection to Unification