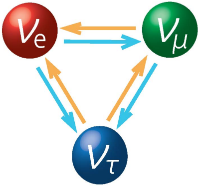
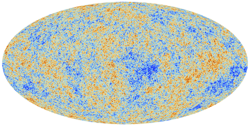
Mapping the viable parameter space for testable leptogenesis

Yannis Georis
based on work in collaboration with M. Drewes and J. Klarić
[2106.16226]

Dark Matters 2022
December 1, 2022

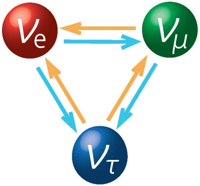


Neutrino masses



[Planck]

Baryon asymmetry



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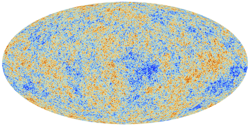

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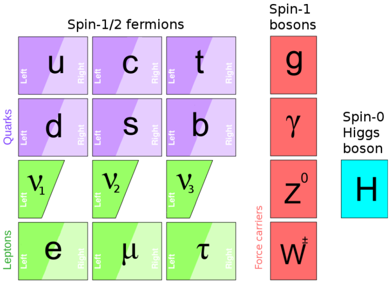
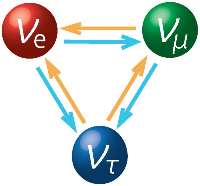
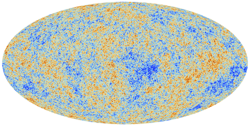


Right-handed neutrinos (RHN)



Type-I seesaw mechanism



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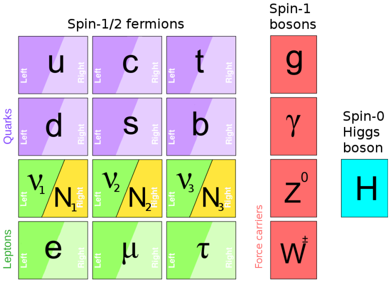

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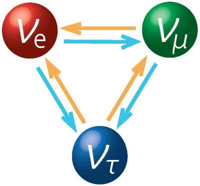

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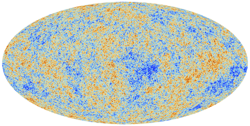

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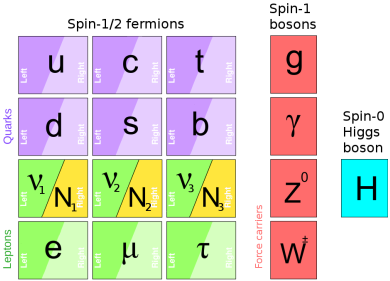

In this work: 3 RHN generations

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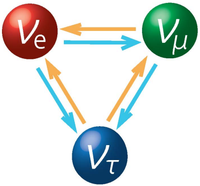

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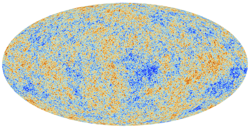

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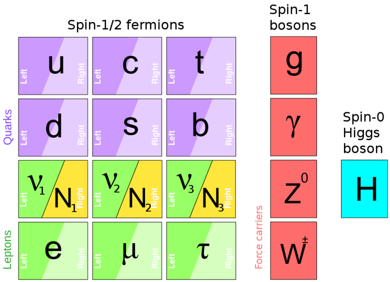
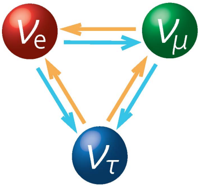


Why relevant for Dark Matter ?



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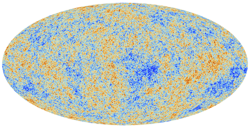

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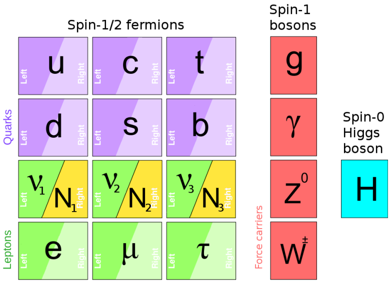

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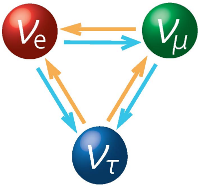

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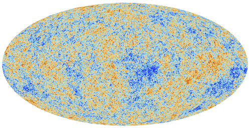

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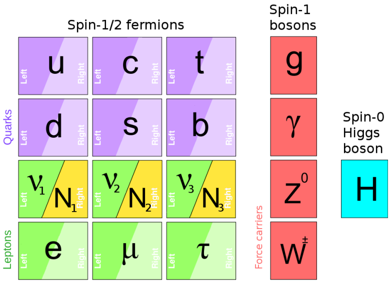

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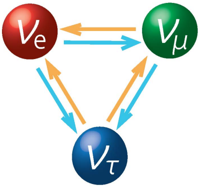

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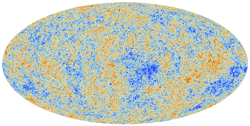

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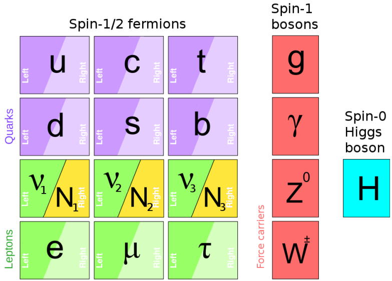

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- *Sterile neutrinos*
- *Theoretical methods*
- *Large lepton asymmetry influence many processes, e.g. Shi – Fuller*

Leptogenesis

Sakharov conditions:

- C- and CP-violation
- Deviation from thermal equilibrium
- Baryon number violation

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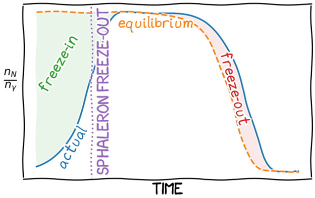

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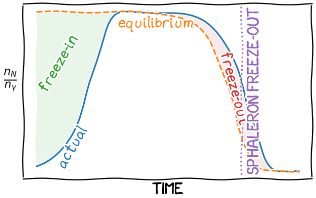

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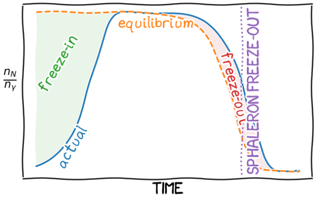

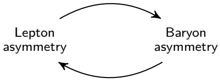

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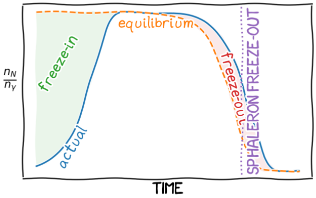

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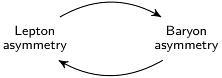

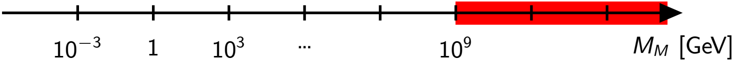

Thermal leptogenesis
[Fukugita/Yanagida '86]

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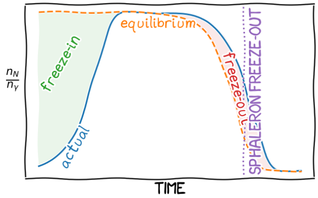

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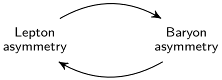
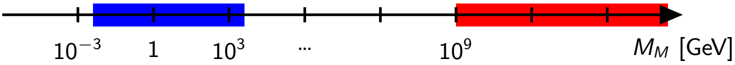




Low-scale leptogenesis
[Akhmedov/Rubakov/Smirnov '98, Asaka/Shaposhnikov '05]

Thermal leptogenesis
[Fukugita/Yanagida '86]

Quantum kinetic equations

$$i\frac{\mathrm{d}\rho}{\mathrm{d}t} = [\mathbf{H}, \delta\rho] - \frac{i}{2}\{\Gamma, \delta\rho\} - i \sum_{a\in\{e,\mu,\tau\}} \tilde{\Gamma}_a \frac{\mu_a}{T} f_F(1-f_F),$$

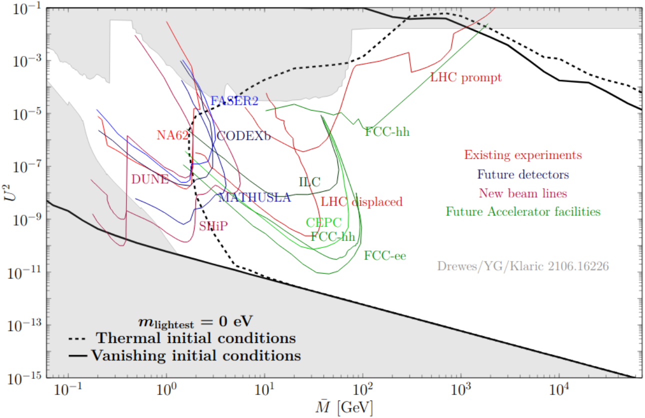
$$i\frac{\mathrm{d}\bar{\rho}}{\mathrm{d}t} = -[\mathbf{H}, \delta\bar{\rho}] - \frac{i}{2}\{\Gamma, \delta\bar{\rho}\} + i \sum_{a\in\{e,\mu,\tau\}} \tilde{\Gamma}_a \frac{\mu_a}{T} f_F(1-f_F),$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{n}_{\Delta_a} = -\frac{2i\mu_a}{T}\int \frac{\mathrm{d}^3\vec{k}}{(2\pi)^3}\mathrm{Tr}[\Gamma_a] f_F(1-f_F) + i\int \frac{\mathrm{d}^3\vec{k}}{(2\pi)^3}\mathrm{Tr}[\tilde{\Gamma}_a(\delta\bar{\rho} - \delta\rho)].$$

Density matrix/**Matter-antimatter asymmetry**
Effective Hamiltonian/**Interaction rates**

- Momentum-averaged rates from Klaric/Shaposhnikov/Timiryasov [2103.165451]
- Cover a mass range from 50 MeV to 70 TeV.

Viable parameter space



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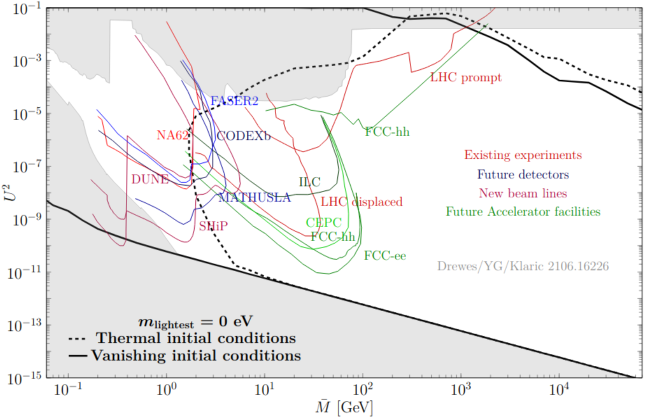

- Experiments will cut deep into $n = 3$ parameter space.

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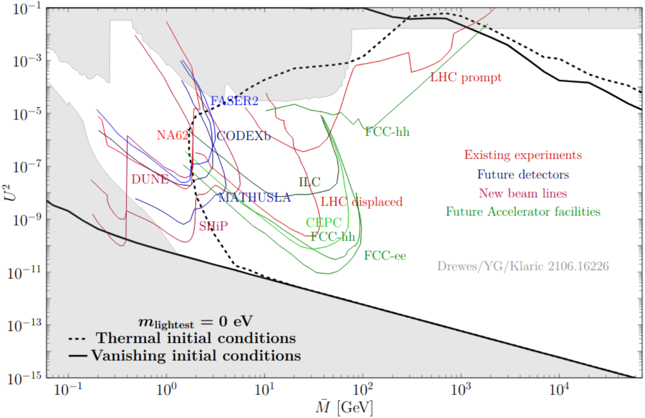

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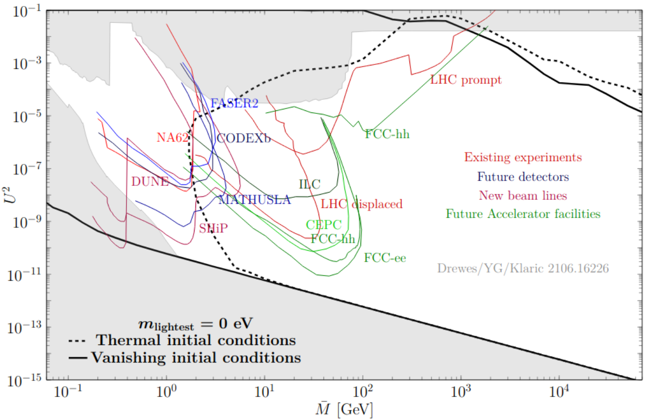


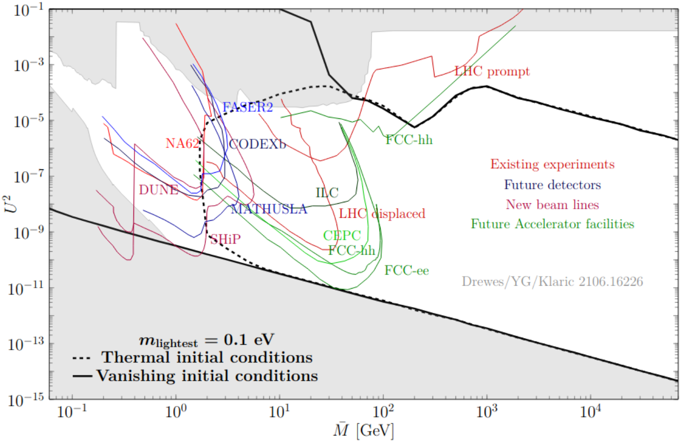
- Experiments will cut deep into $n = 3$ parameter space.
- Can expect to produce thousands of displaced vertices at HL-LHC: Testability !
- Leptogenesis with thermal initial conditions works for masses as low as $\mathcal{O}(1.7)$ GeV: testable at *e.g.* NA62.

Conclusion

- Extending the SM with right-handed neutrinos is a minimal solution to the problem of neutrino masses and baryon asymmetry.
- Large part of the parameter space will be probed in the next few years.
- Potential not only to discover but also comprehensively test the model.
- Large lepton asymmetries can also play a role for DM production, ...

Backup slides

Results for $m_{\text{lightest}} = 0.1$ eV



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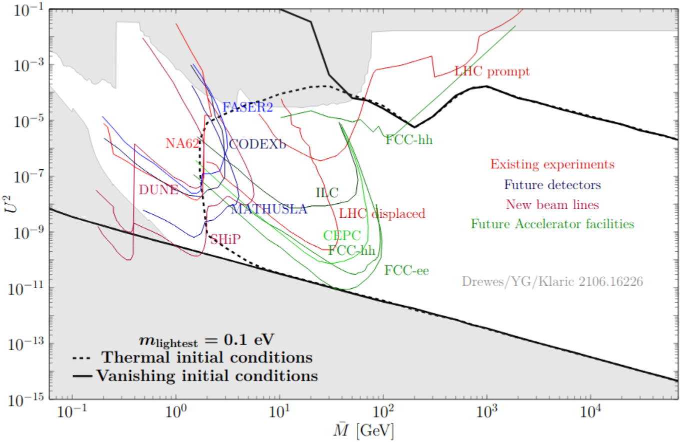
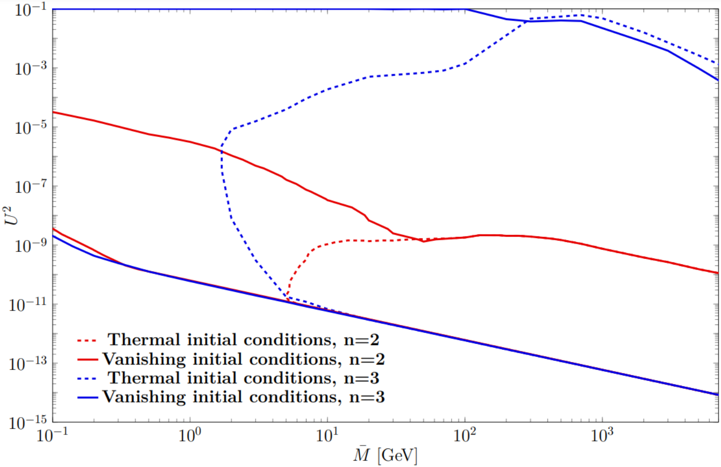


- Parameter space smaller for $m_{\rm lightest} = 0.1$ eV.

$$F = \frac{i}{v} U_\nu \sqrt{m_\nu^{diag}} R \sqrt{M_M}$$

Comparing $n = 2$ and $n = 3$.



n=2 lines from Klaric/Shaposhnikov/Timiryasov [2008.13771]

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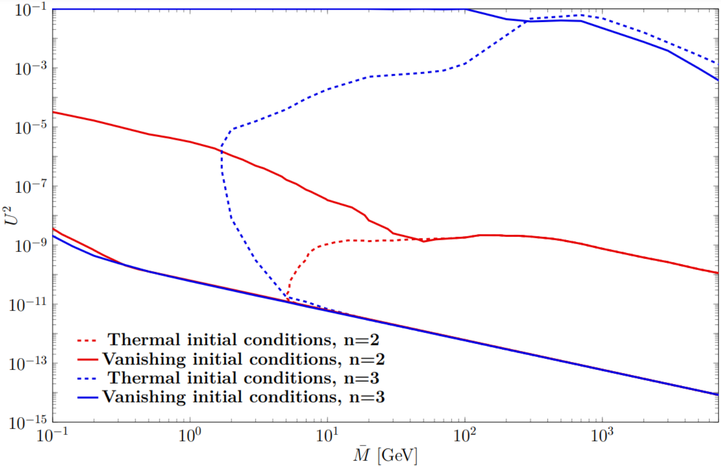
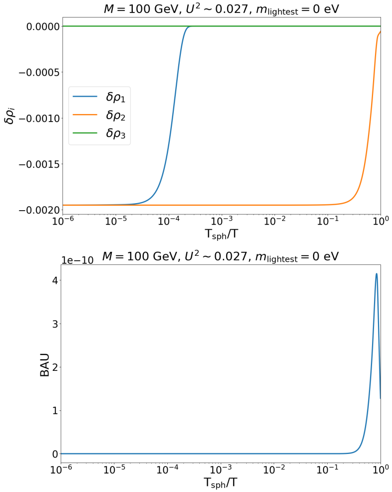


n=2 lines from Klaric/Shaposhnikov/Timiryasov [2008.13771]

- Parameter space way larger than in the $n = 2$ scenario: Late BAU production.

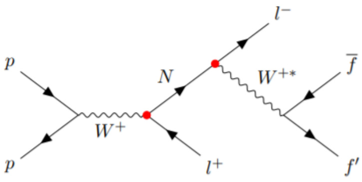
Late equilibration



- Large mixing angles allow late equilibration of one heavy neutrino $U_i^2 \propto \epsilon'^2$.

- Implies late BAU production.

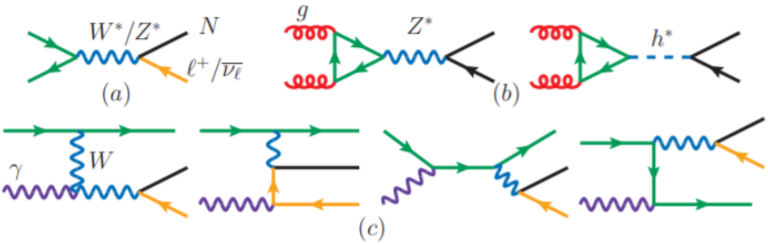
Displaced vertices



(a) Charged current decay. (b) Neutral current decay.

Drewes/Hajer 1903.06100

Production processes



Pascoli/Ruiz/weiland 1812.08750

B-$\bar{\text{L}}$ approximate symmetry

Naive seesaw bound

$$U_i^2 \sim \frac{\sqrt{\Delta m_{atm}^2 + m_{light}^2}}{M} \lesssim 10^{-10}\frac{\text{GeV}}{M_i}$$

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B-$\bar{\text{L}}$ approximate symmetry

Majorana mass

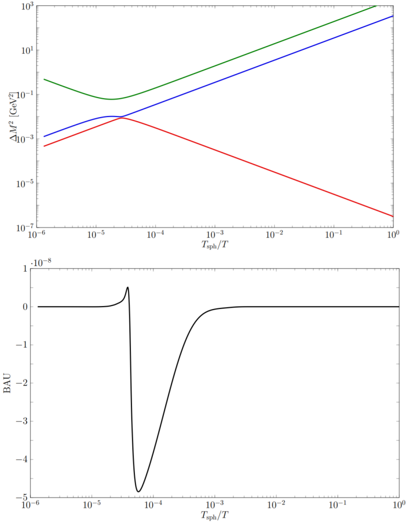
$$\bar{M} \cdot \begin{pmatrix} 1-\mu & 0 & 0 \\ 0 & 1+\mu & 0 \\ 0 & 0 & \mu' \end{pmatrix}$$

Yukawa coupling

$$\begin{pmatrix} f_e(1+\epsilon_e) & if_e(1-\epsilon_e) & f_e\epsilon'_e \\ f_\mu(1+\epsilon_\mu) & if_\mu(1-\epsilon_\mu) & f_\mu\epsilon'_\mu \\ f_\tau(1+\epsilon_\tau) & if_\tau(1-\epsilon_\tau) & f_\tau\epsilon'_\tau \end{pmatrix}$$

Smallness of light neutrino masses from the smallness of the symmetry breaking parameters $\mu, \epsilon, \epsilon' \ll 1$.

Resonant enhancement

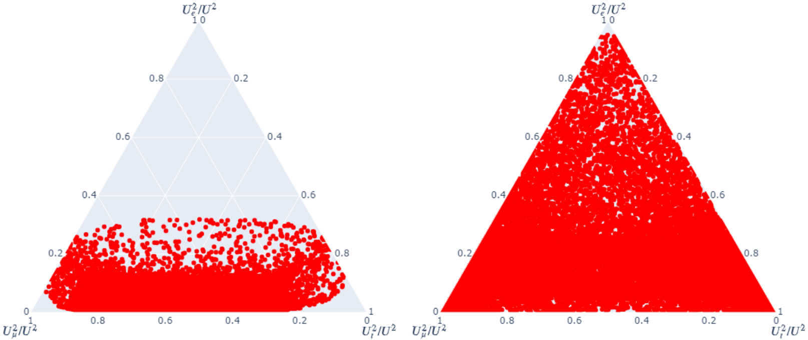


Thermal corrections can dynamically generate small mass splittings

↓

Resonant enhancement

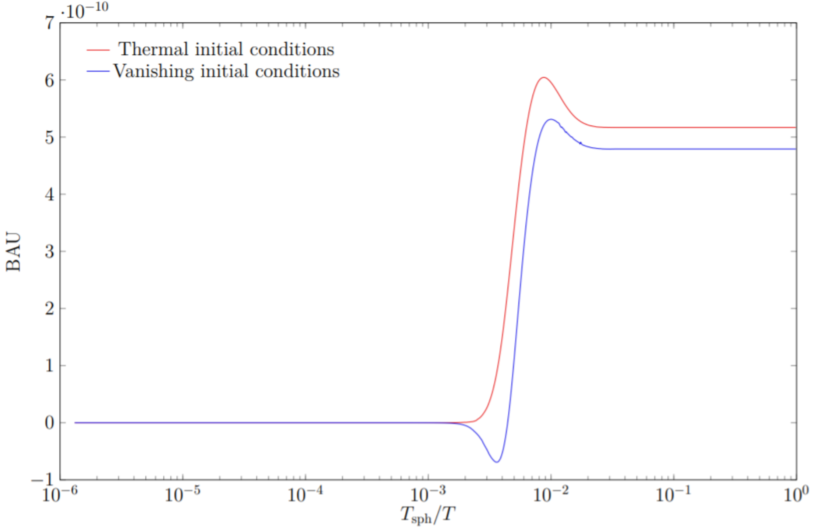
Branching ratios



$m_{\text{lightest}} = 0$ eV

$m_{\text{lightest}} = 0.1$ eV

Thermal vs vanishing initial conditions



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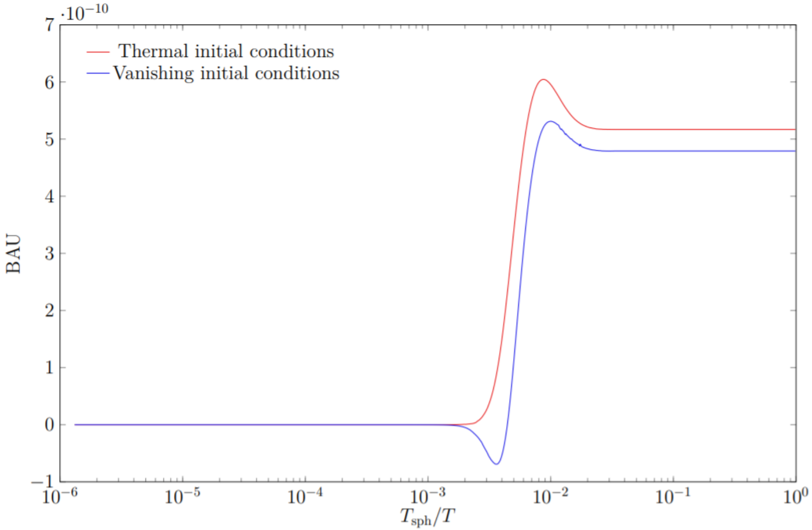

- Asymmetries generated during freeze-in and freeze-out have opposite signs.

Constraints

- Normal ordering and $m_{\mathrm{lightest}} \in \{0, 0.1\}$ eV.

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- Theoretical constraints:

1. Perturbative unitarity $\Gamma < \frac{M}{2}$
2. Seesaw expansion $U^2 < 0.1$
3. No large radiative corrections $(1 - ||\frac{m_{tree}}{m_{loop}}||)^2 < \frac{1}{4}$.