Scalar triplet leptogenesis without RH neutrino decoupling

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Based on

NPB, 858, 196 and **arXiv:1205.6134**

F. Bazzocchi (SISSA), I. de Medeiros Varzielas, (Dortmund)

Motivation
- Baryon asymmetry
- Origin of the BA
- Baryogenesis in the SM
- Possible approaches

Neutrino masses

Leptogenesis in type-I seesaw

Leptogenesis in type-II seesaw

Conclusions

Motivation

Baryon asymmetry

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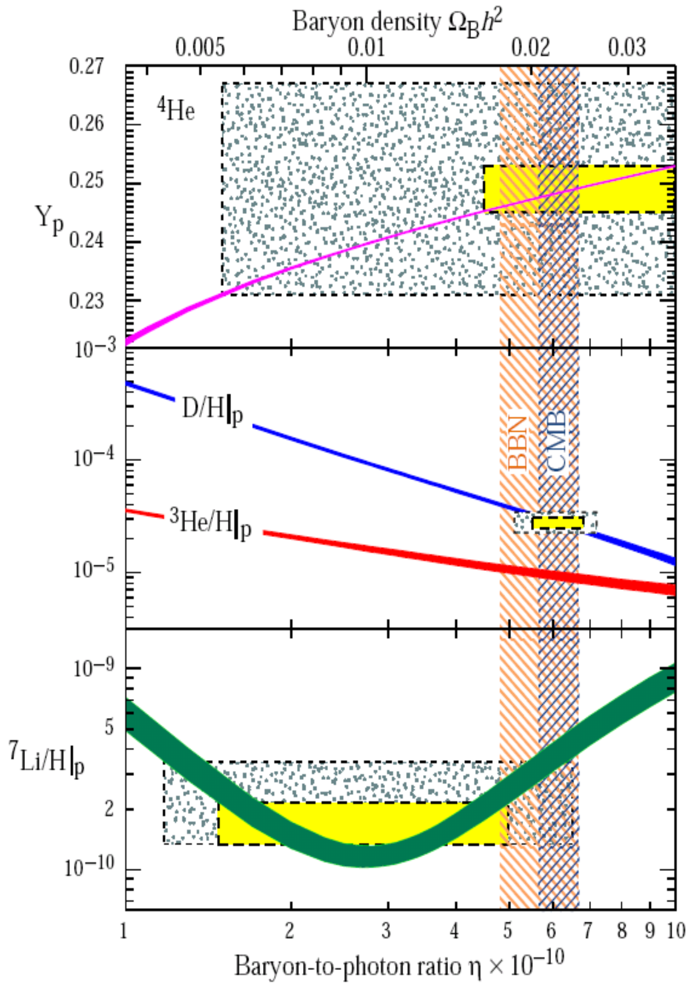
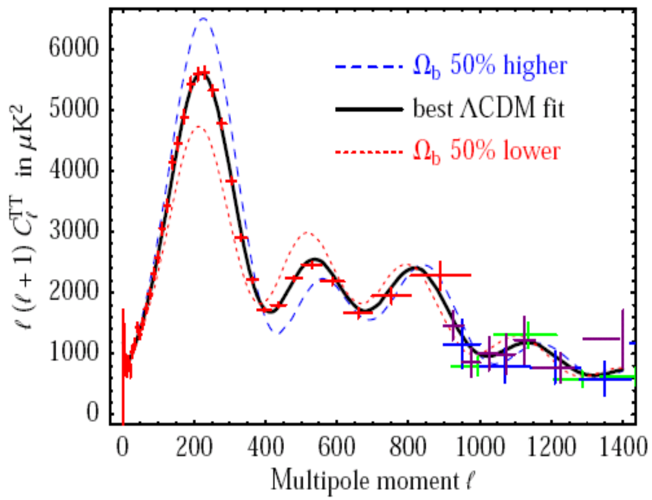
The cosmic Baryon Asymmetry (BA) is derived from measurements of light elements abundances (D, ^{3}He, ^{4}He, ^{7}Li) and the CMB





$$\eta = \frac{n_B - n_{\bar{B}}}{n_\gamma} \simeq (6.21 \pm 0.16) \times 10^{-10}$$

$$\eta = 2.74 \times 10^{-8} \Omega_B h^2$$

$$Y_{\Delta_B} = \frac{n_B - n_{\bar{B}}}{s} \simeq \frac{\eta}{7.04}$$

$$\boxed{Y_{\Delta_B} \simeq (8.75 \pm 0.23) \times 10^{-11}}$$

7-year WMAP, arXiv:1001.4538

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- Could be an initial condition?... A crucial ingredient of ΛCDM is inflation... Any primordial B asymmetry would be diluted.
- The origin of the Baryon Asymmetry should be dynamic (Baryogenesis):

Sakharov Conditions

Pisma Zh.Eksp.Teor.Fiz. 5 (1967) 32-35

1. The Baryon Asymmetry generating interations must violate B.
2. The Baryon Asymmetry generating interactions must break CP.
3. The Baryon Asymmetry generating interactions must departure -at some point- from Thermodynamical Equilibrium.

Any model satisfying these conditions -in principle- constitutes a framework for baryogenesis

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Baryogenesis in the SM

Qualitatively

- B is broken at the non-perturbative level (sphalerons processes)
- CP violation is provided by the CKM quark mixing matrix
- Departure from TEQ provided by the electro-weak phase transition.

Quantitatively

- CP violation to small ✘
- Succesful baryogenesis requires strongly $1^{\underline{st}}$ order phase transition $\Rightarrow$

$m_h < 40$ GeV while LEP: $m_h > 115$ GeV **(Kajantie et. al. PRL,77,2887)** ✘

The SM fails at the quantitative level

Explanation of $Y_{\Delta B}$ requires BSM physics

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Possible approaches

A large number of mechanisms (models) for baryogenesis exist. Among them two of the most widely studied are:

EW baryogenesis **(Cohen, Kaplan, Nelson, PLB,245,561)**

EW baryogenesis models "cure" the SM pitfalls via extended scalar sectors

$$V_{\text{SM}}(\Phi) \longrightarrow V(S_i,\Phi_i) \Rightarrow \begin{cases} \text{Strongly } 1^{\text{st}} \text{ order EWPT: relaxing } m_h^{\max} \\ \text{Additional CP violating sources} \end{cases}$$

SM+S, 2HDMs, MSSM... EWB testable at the LHC!

Leptogenesis: **(Fukugita, Yanagida, PLB,174,45)**

$$Y_{\Delta_L} \to Y_{\Delta_B}$$

$B+L$ violating EW sphalerons interactions

$$\mathcal{O}_{B+L} = \prod_{i=1,2,3} (q_{L_i} q_{L_i} q_{L_i} \ell_{L_i})$$

Qualitatively (quantitatively in some cases) viable in models of Majorana neutrino masses. Linked with the origin of neutrino masses!

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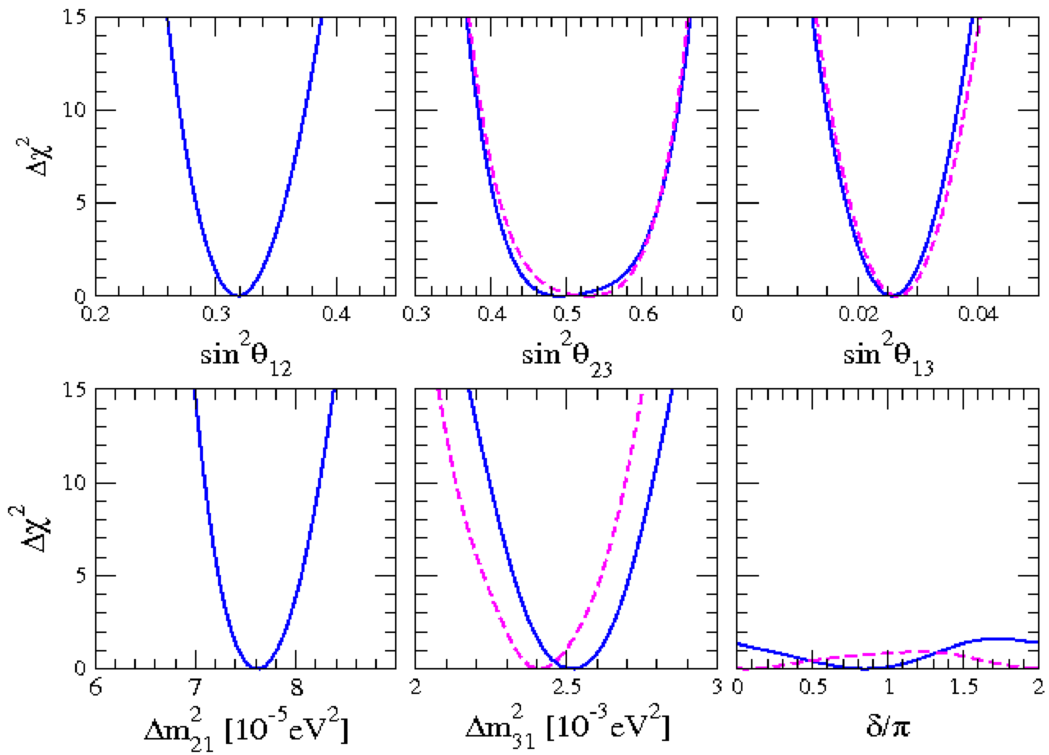
Parameters are extracted from solar, atmospheric, reactor and long-baseline experiments:

Forero et. al. [arXiv:1205.4018]

Fogli et. al. [arXiv:1205.5254]

Gonzalez-Garcia, et. al. [1001.4524]



Forero, Tortola, Valle [1205.4018]

Normal spectrum

Parameter	2σ
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.27-8.01
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\text{eV}^2]$	2.34-2.69
$\sin^2\theta_{12}$	0.29-0.35
$\sin^2\theta_{23}$	0.41-0.62
$\sin^2\theta_{13}$	0.019-0.033
δ	0-2π

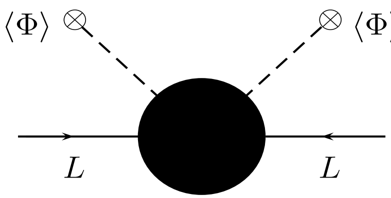
$\boxed{\theta_{13} = 0 \text{ excluded @ } 8\sigma}$

Neutrinos are massive
with non-vanishing mixing angles

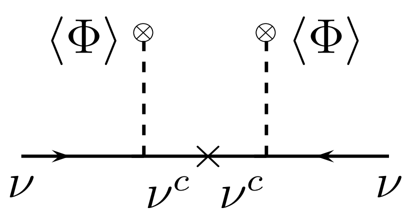
Neutrino mass generation

An effective dimension-five operator $\mathcal{O}_5 \sim L\Phi L\Phi$ can be added to the SM. Once the EW symmetry breaks through the vev of Φ neutrino Majorana masses are induced

S. Weinberg, Phys. Rev. D **22**, 1694 (1980)

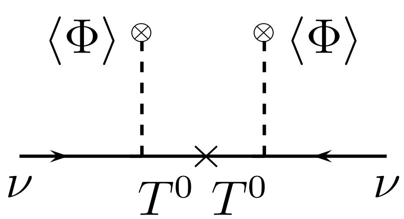


Tree level realizations



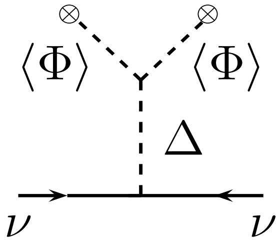
Type-I

P. Minkowski, R. Mohapatra & G. Senjanovic, T. Yanagida, Schechter & Valle...



Type-III

R. Foot, H. Lew *et. al.*



Type-II

J. Schechter & J.W.F. Valle, G. Lazarides *et. al.*, C. Wetterich

$\mathcal{O}_5$ can be model independently classified:

One-loop order: **(E. Ma (1998) & Bonnet, Hirsch *et. al* (2012))**)

Two-loop: **Challenging!** **(In progress)**

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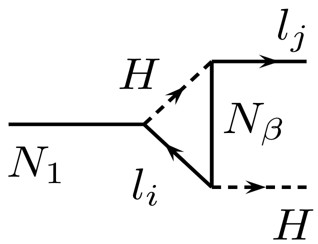
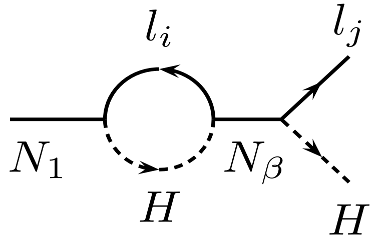
Standard leptogenesis

The **Sakharov** conditions are readily satisfied **[Fukugita & Yanagida (1986)]**:

- Majorana mass term $\boldsymbol{M_N}$ is a L violating source ($\Delta L = 2$).
- $\lambda_{i\alpha} \longrightarrow$ contain new physical CPV phases. CPV asymmetries arise at the one-loop level **(Covi, Roulet, Vissani, PLB384, 169)**

$$\boxed{\epsilon_{N_1}^{\ell_i} = \frac{\Gamma_i - \bar{\Gamma}_i}{\Gamma_i + \bar{\Gamma}_i}}$$





- Departure from thermal equilibrium provided by the expansion.
$\Gamma_D \lesssim H(z = M/T = 1)$

Non-flavored LG

$Y_{\Delta_B}^{\rm LG} \sim \epsilon_{N_1} \eta$

Flavored LG

$Y_{\Delta_B}^{\rm LG} \sim \sum_{i=e,\mu,\tau} \epsilon_{N_1}^{\ell_i} \eta_i$

$Y_{\Delta_B}^{\rm LG}(\underbrace{v_{\rm seesaw}}_{\text{Seesaw param}})$

\# of N_1 decaying OTEQ

Amount of CP violation

Generation of the asymmetry

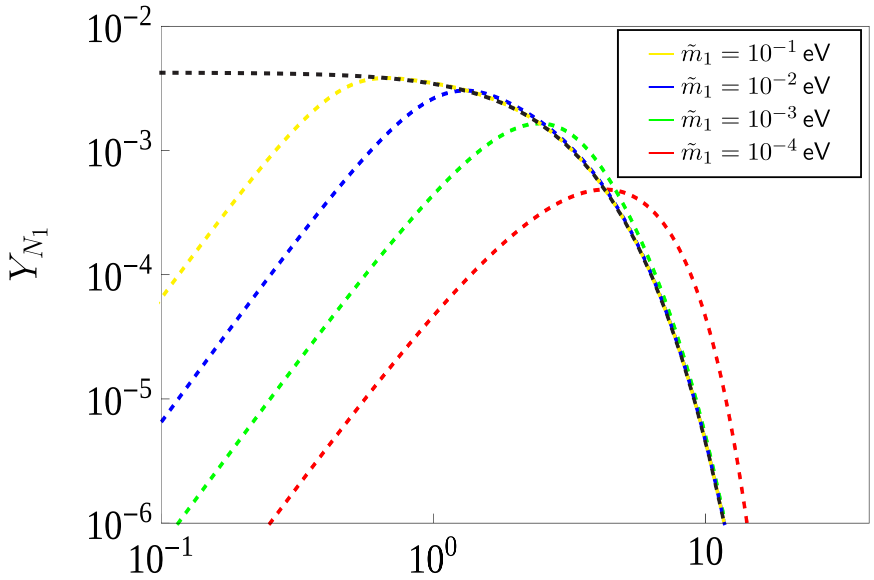
A precise determination of the $B-L$ asymmetry requires solving the kinetic equations. At leading order in $\boldsymbol{\lambda}$ $[\mathcal{O}(\boldsymbol{\lambda}^2)]$(**unflavored regimen**):

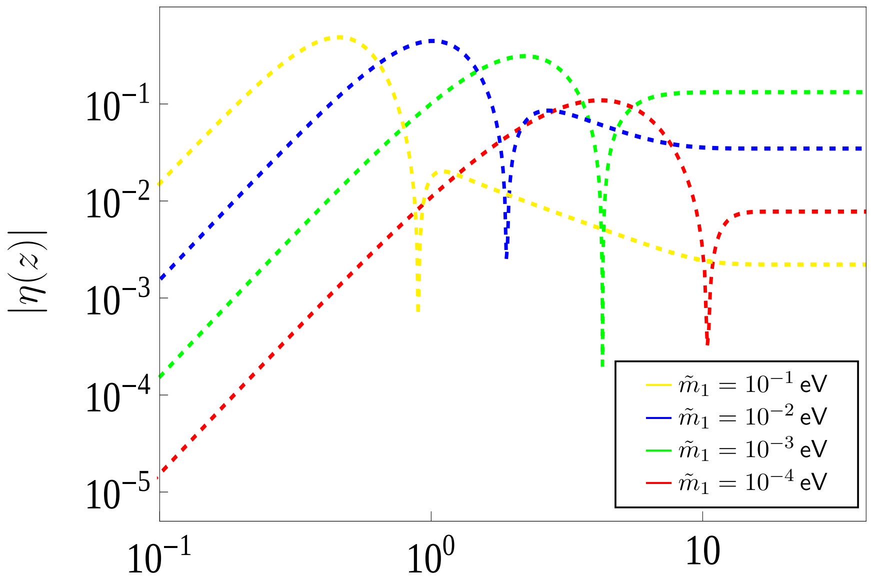
$$\frac{dY_{N_1}}{dz} = -\frac{1}{sHz}\left(\frac{Y_{N_1}}{Y_{N_1}^{\rm Eq}} - 1\right)\gamma_D$$

$$\frac{dY_{\Delta_{B-L}}}{dz} = -\frac{1}{sHz}\left[\left(\frac{Y_{\Delta_{N_1}}}{Y_{N_1}^{\rm Eq}} - 1\right)\epsilon_{N_1} + \frac{Y_{\Delta_{B-L}}}{2Y_\ell^{\rm Eq}}\right]\gamma_D$$

$$\gamma_D = \frac{1}{8\pi^3}\frac{M_{N_1}^5}{v^2}\frac{K_1(z)}{z}\tilde{m}_1$$

Problem determined by $\boxed{\epsilon_{N_1}, \tilde{m}_1}$





The generation of the correct amount of $B-L$

it is just a quantitative problem

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Leptogenesis in type-II seesaw

Generalities

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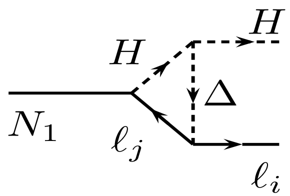
The SM scalar sector extended with scalar $SU(2)$ triplets $\boldsymbol{\Delta}$

- Single $\boldsymbol{\Delta}$ sufficient for $m_\nu \neq 0$.
- Not sufficient for leptogenesis: $\begin{cases} \textbf{A.} & \text{Additional } \boldsymbol{\Delta}. \\ \textbf{B.} & \text{Presence of RHN or fermion triplets.} \end{cases}$

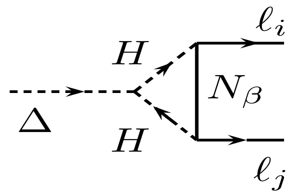
$$\boxed{\mathcal{L}=\mathcal{L}^{\rm I}+\mathcal{L}^{\rm II} \quad \Rightarrow \quad \begin{cases}\mathcal{L}^{(\rm I)} & = -\lambda^*_{i\alpha}\bar{\ell}_i N_\alpha \tilde{H} - \frac{1}{2}\bar{N}_\alpha M_{N_\alpha} N^c_\alpha + \text{h.c} \\ \mathcal{L}^{(\rm II)} & = -Y_{ij}\ell_i^T C i\tau_2 \boldsymbol{\Delta}\ell_j - M^2_{\boldsymbol{\Delta}}\,\mathrm{Tr}\,\boldsymbol{\Delta}^\dagger\boldsymbol{\Delta} + \mu H^T i\tau_2 \boldsymbol{\Delta} H + \text{h.c.}\end{cases}}$$

- $M_{N_1} \ll M_{\boldsymbol{\Delta}}$, resembles conventional picture.
- $M_{N_1} \gg M_{\boldsymbol{\Delta}}$, triplet dynamics responsible for leptogenesis **[Hambye,Raidal Strumia (2005)]**.
- $M_{N_1} \sim M_{\boldsymbol{\Delta}}$ triplet and singlet dynamics responsible for leptogenesis **[DAS, Bazzocchi,Medeiros (2011)]**.

$$\epsilon^{\rm tot}_{N_1} = \epsilon_{N_1} + \epsilon^{\Delta}_{N_1}$$
$$\epsilon^{\Delta}_{N_1} = -\frac{3}{2\,\pi\,M_\Delta}\frac{1}{(\boldsymbol{m_D}\,\boldsymbol{m_D}^\dagger)_{11}}\mathfrak{Im}\left[\left(\boldsymbol{m_D}\,\boldsymbol{Y}^*\boldsymbol{m_D}^T\right)_{11}\,\mu\right]\,h(M^2_\Delta/M^2_{N_1})\,.$$



$$\epsilon_\Delta = -\frac{1}{8\,\pi\,v^2}\frac{1}{M_\Delta}\frac{\sum_\beta \mathfrak{Im}\left[\left(\boldsymbol{m_D}\,\boldsymbol{Y}^*\,\boldsymbol{m_D}^T\right)_{\beta\beta}\,\mu\right]}{\mathrm{Tr}\left[\boldsymbol{Y}\,\boldsymbol{Y}^\dagger\right]+\mu^2/M^2_\Delta}\,H(M^2_\Delta/M^2_{N_\alpha})$$



Generation of the asymmetry

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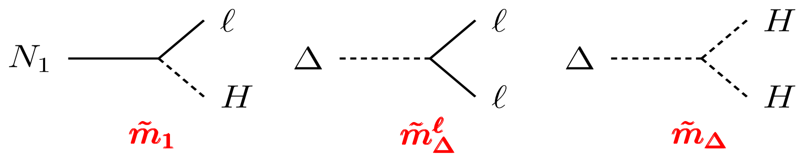
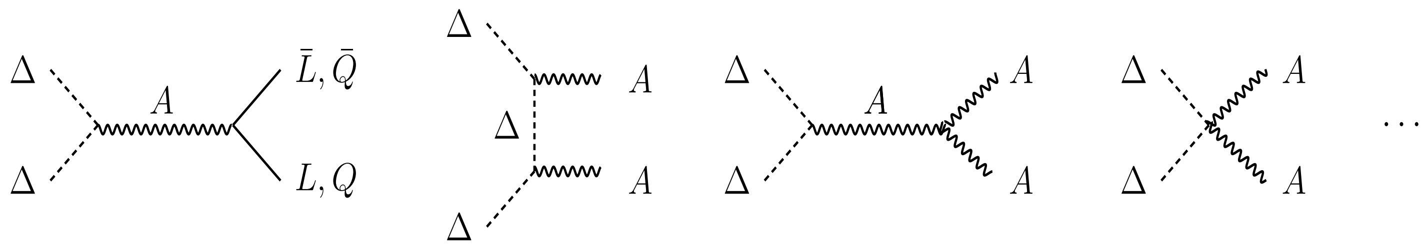
A treatment based on kinetic equations is needed. The L asymmetry proceeds via:



- Y_{N_1} distribution
- Y_Σ with $\Sigma = \Delta + \Delta^\dagger$
- Asymmetries $Y_{\Delta_L}, Y_{\Delta_H}, Y_{\Delta_\Delta}$.
- Hypercharge neutrality $\Rightarrow$ $Y_{\Delta_L}, Y_{\Delta_H}, Y_{\Delta_\Delta}$ related

Gauge reactions must be included:



- Gauge reactions $\Rightarrow$ dependence with M_Δ
- Mild hierarchy $M_\Delta \sim M_{N_1}$ $\Rightarrow$ dependence with M_{N_1}

Determination of Y_{Δ_L} is a five parameter problem

$$\tilde{m}_1, \tilde{m}^\ell_\Delta, \tilde{m}_\Delta, M_\Delta, r = M_{N_1}/M_\Delta$$

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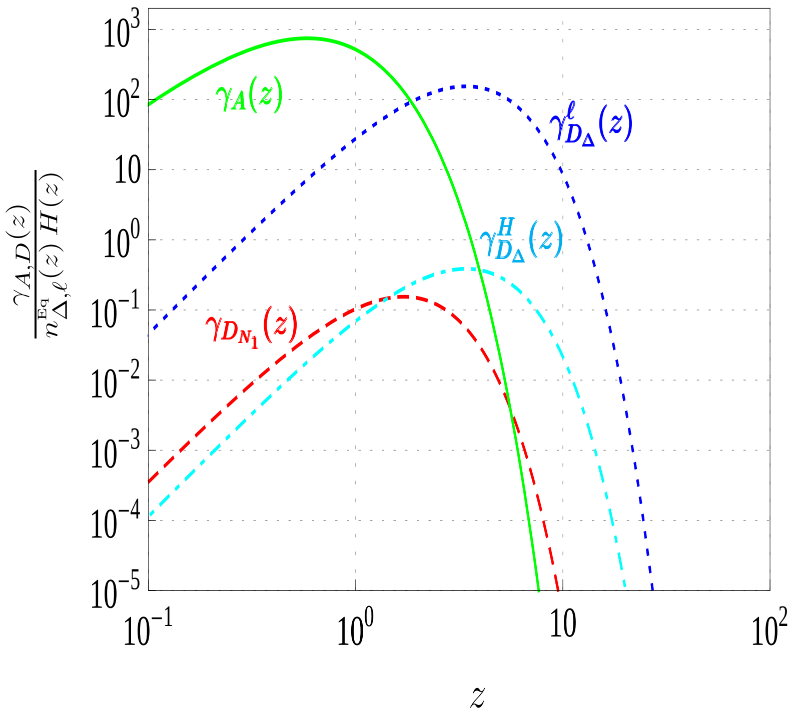
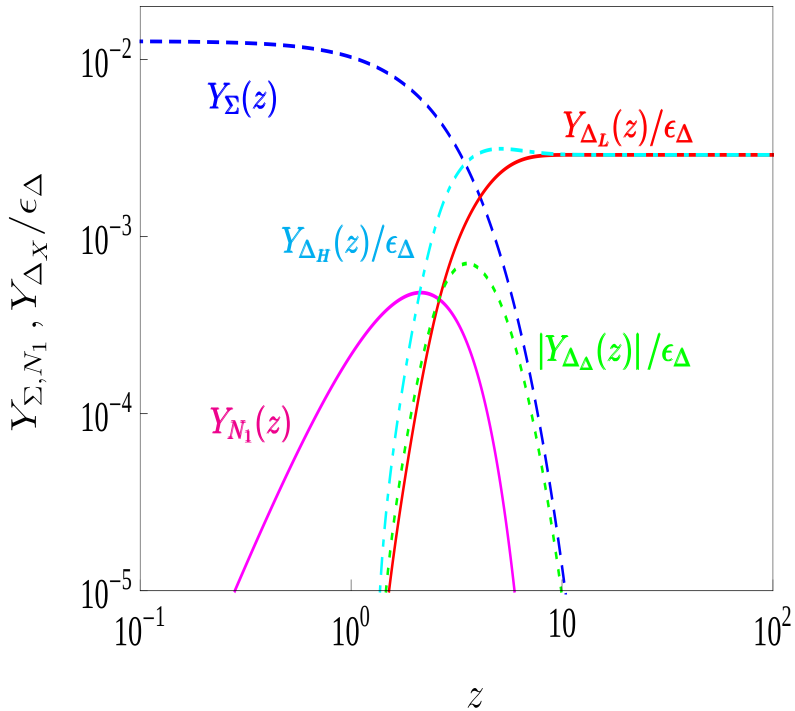
- **Purely triplet leptogenesis:** $\tilde{m}_1 \ll \tilde{m}^\ell_\Delta, \tilde{m}_\Delta$. The $B-L$ asymmetry determined by $\Delta \to \ell\ell$ and $\Delta \to HH$
- **Singlet dominated leptogenesis:** $\tilde{m}_1 \gg \tilde{m}^\ell_\Delta, \tilde{m}_\Delta$. The asymmetry produced mainly via N_1 dynamics.
- **Mixed leptogenesis:** $\tilde{m}_1 \sim \tilde{m}^\ell_\Delta \sim \tilde{m}_\Delta$. A net $B-L$ asymmetry is built from N_1 and Δ dynamics.

$(\tilde{m}_1, \tilde{m}_\Delta, \tilde{m}^\ell_\Delta, M_\Delta, r)$ =(10^{-4} eV, 10^{-2} eV, 10^{-1} eV, 10^{10} GeV,2)





Possible scenarios (II)

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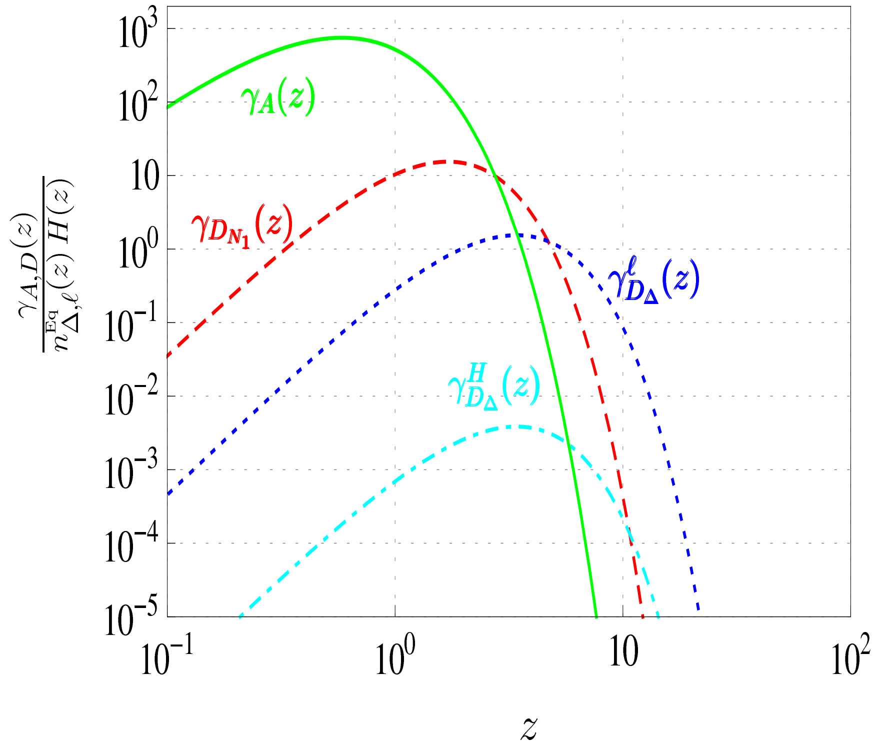
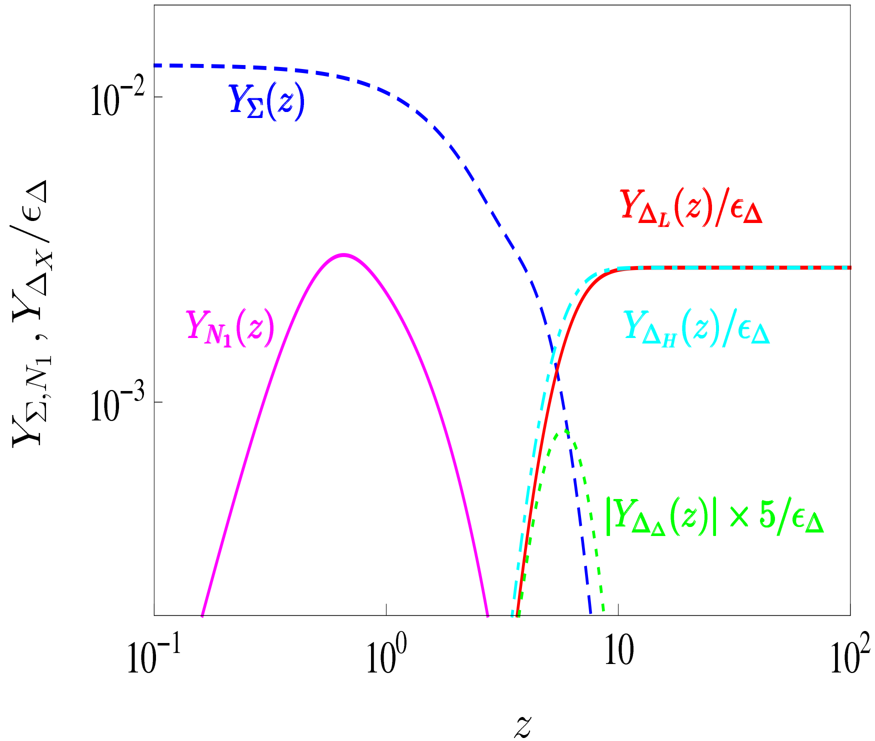
$(\tilde{m}_1, \tilde{m}_\Delta, \tilde{m}_\Delta^\ell, M_\Delta, r) = (10^{-2}$ eV, 10^{-4} eV, 10^{-3} eV, 10^{10} GeV,2)





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Final Remarks

- Models for Majorana neutrino masses are intrinsic playgrounds for baryogenesis via leptogenesis.
- Type-I seesaw is the most well analysed scenario for leptogenesis. But other scenarios arising e.g. from type-II ot III seesaws could be considered.
- Leptogenesis in these kind of frameworks involves gauge reactions that *naively* can be thought to make leptogenesis not-viable.
- In type-II seesaw different possibilities–depending on the aditional d.o.f– can arise. If the extra d.o.f correspond to RHNs several scenarios can be identified.
- The presence of the RHN either open windows in parameter space (that otherwise are closed) or enhances the resulting lepton asymmetry.