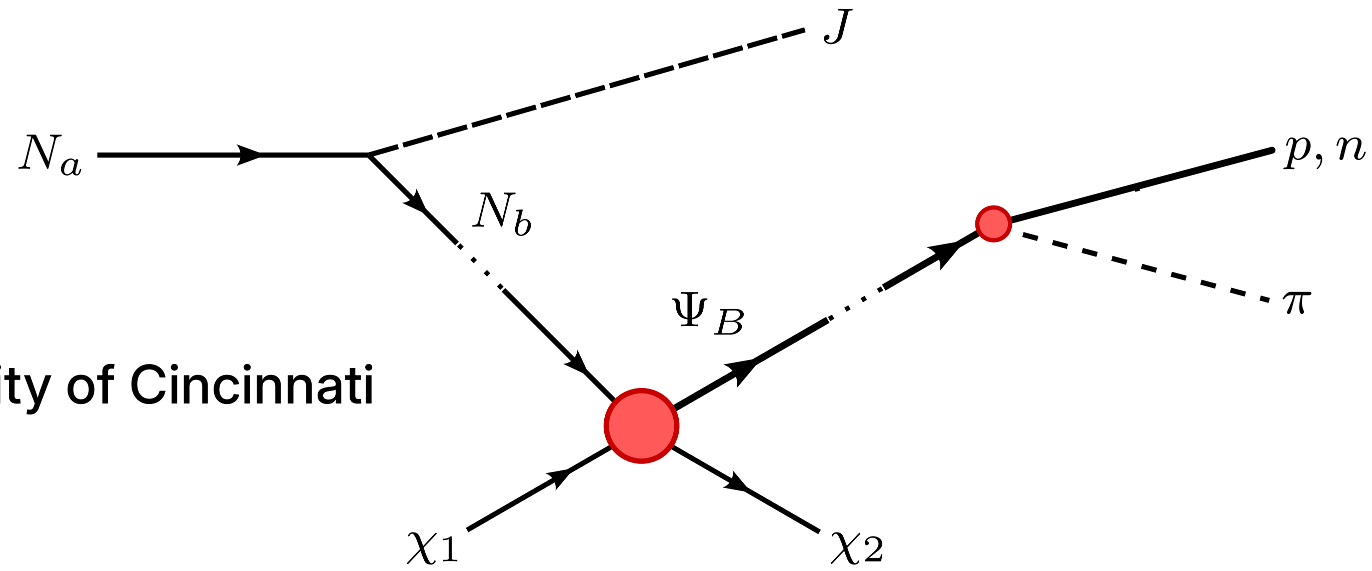
A flavorful and dark cascade for low-scale leptogenesis



Tony Menzo

PhD candidate, University of Cincinnati

In collaboration with ***Julia Gehrlein*** and ***Jure Zupan*** (25xx.xxxx)

Lore: matter-$\overline{\text{matter}}$ asymmetry

$$\eta \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma}$$ **~constant after BBN**

Measured value: $\eta = (6.12 \pm 0.04) \times 10^{-10}$

Naive estimate: **Consider η = 0 and compute ratio at freeze out (T_{FO} ~ 20 MeV).**

$$\frac{n_B}{n_\gamma} \simeq \frac{n_{\bar{B}}}{n_\gamma} \simeq \left(\frac{m_p}{T}\right)^{3/2} e^{-m_p/T} \simeq 10^{-18}$$

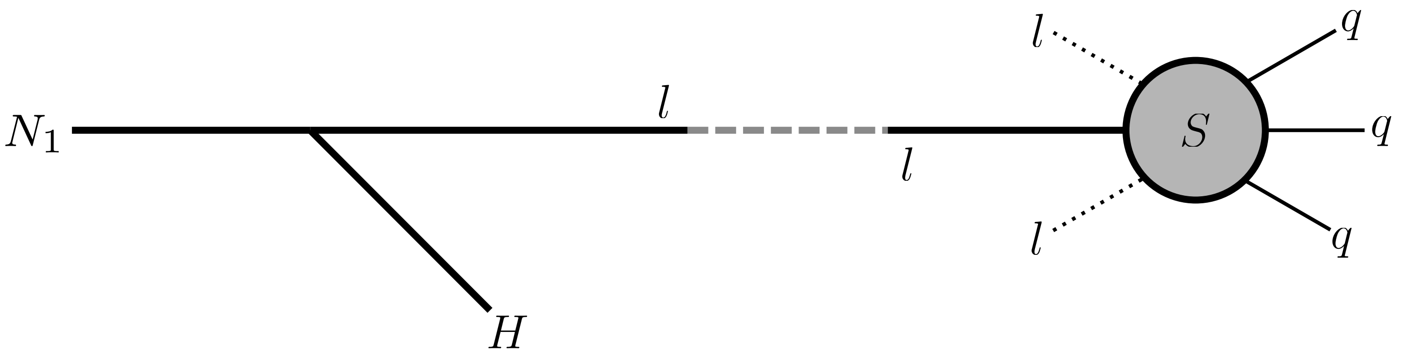
Lore: matter-$\overline{\text{matter}}$ asymmetry

What about electroweak baryogenesis with SM ingredients?

Requires strong 1st order phase transition bubbles i.e. m_H < 72 GeV.

BSM required!

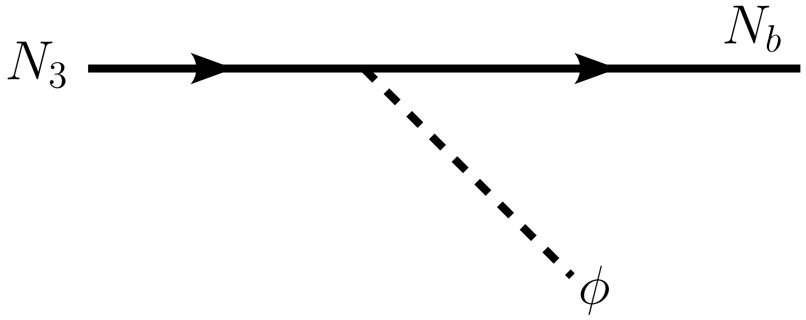
Many models… for example high scale (> 100 GeV) leptogenesis + sphalerons



The mechanism

Our mechanism: low-scale (< 100 GeV) leptogenesis + DM scattering

1. Production of lepton asymmetry



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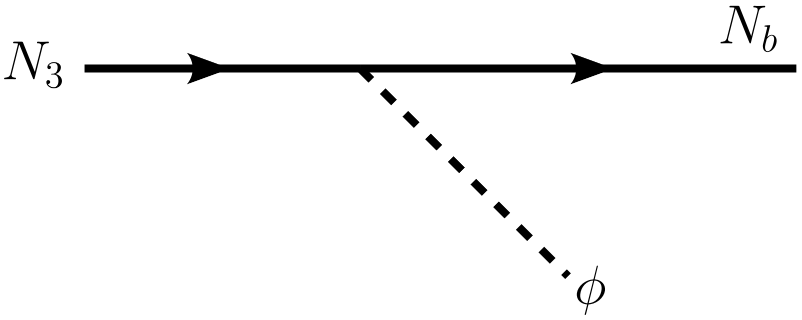

<u>Toy model</u>

Consider n sterile Dirac neutrinos:

$$\mathcal{L} \supset -y_{ij}\overline{N}_i P_L N_j \phi + \text{h.c.}$$

- Lepton number is conserved
- CPT tells us:

$$\Gamma_{\text{total}}(N_i) = \Gamma_{\text{total}}(\bar{N}_i)$$

$\longrightarrow$ n ≥ 3 for non-trival CPV

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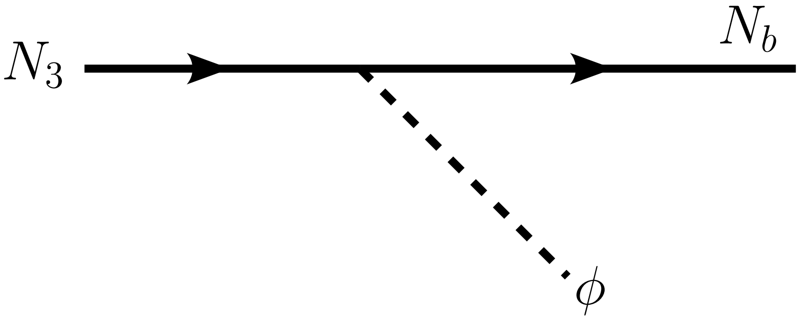

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$$\Delta\Gamma(N_3 \to N_2\phi) = -\Delta\Gamma(N_3 \to N_1\phi)$$

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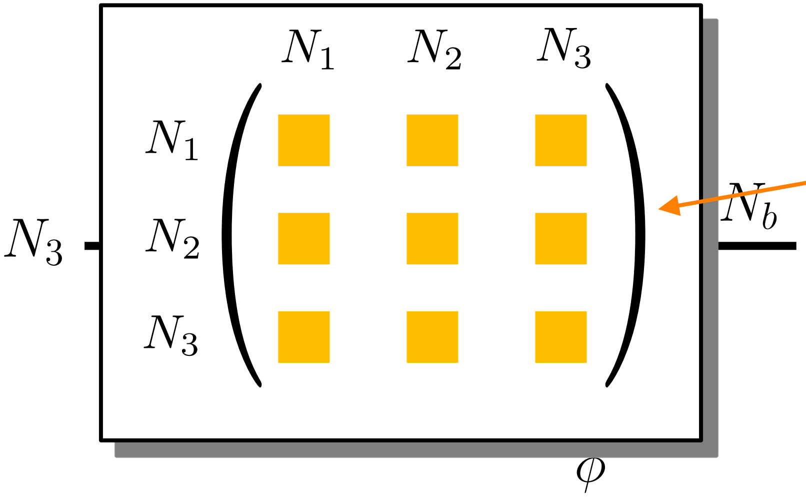

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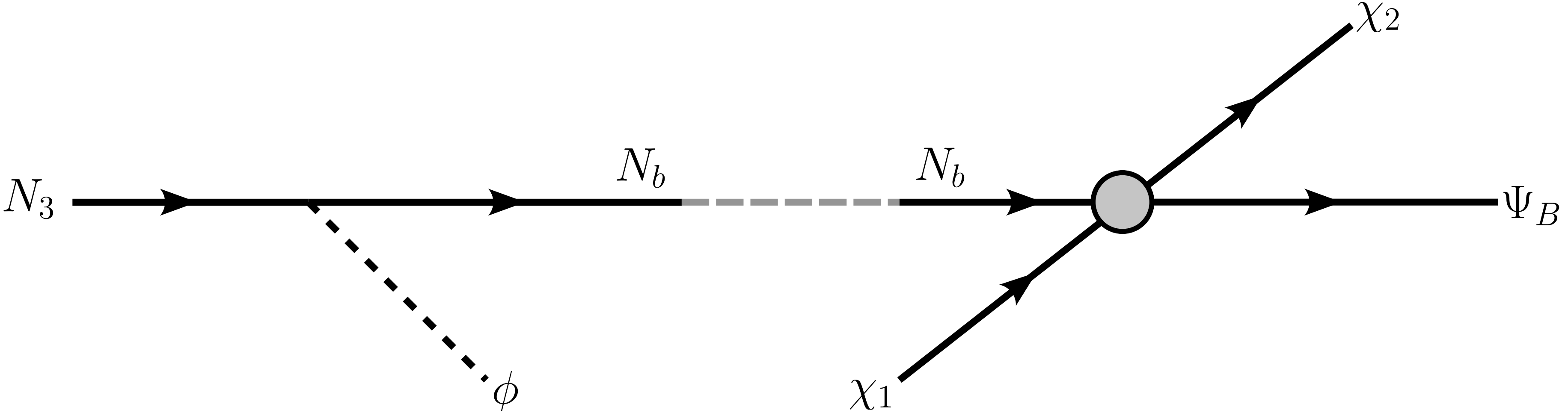
1. Production of lepton asymmetry 2. Transfer to baryon asymmetry



The mechanism

Our mechanism: **low-scale (< 100 GeV) leptogenesis + DM scattering**

1. Introduce dark sector:

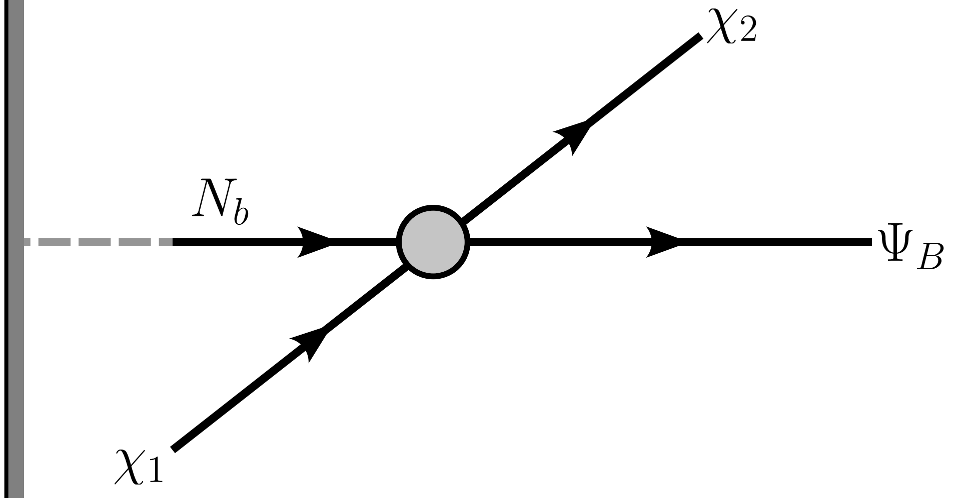
$$\mathcal{L} \supset -\lambda \overline{N}_1 \Psi_B X - \lambda' \bar{\chi}_1 \chi_2 X + \mathrm{h.c.}$$

Need to preferentially scatter on $N_{1,2}$ – either kinematically forbid

$$m_{N_1} + m_{\chi_1} < m_{N_2} + m_{\chi_2}$$

or introduce generation-philic flavor structure.

2. Transfer to baryon asymmetry



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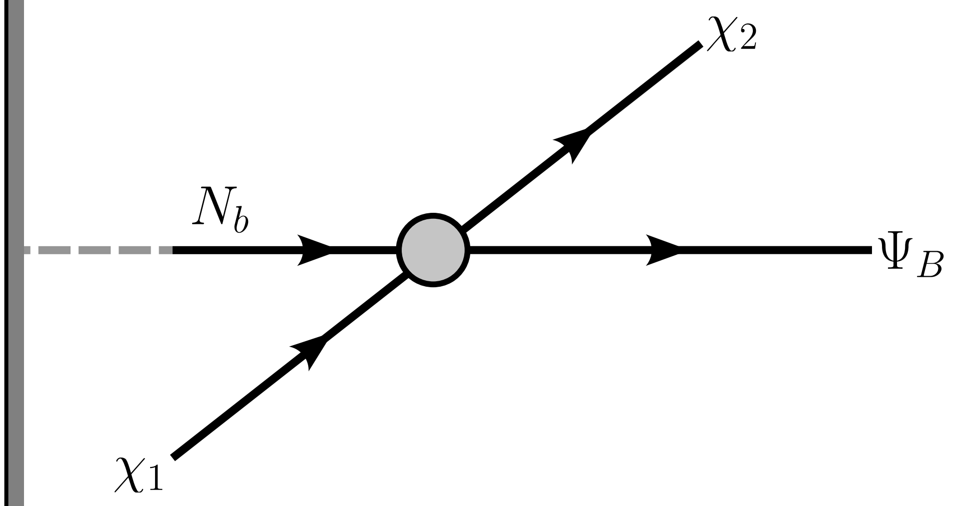
1. Introduce dark sector:

$$\mathcal{L} \supset -\lambda \overline{N}_1 \Psi_B X - \lambda' \bar{\chi}_1 \chi_2 X + \text{h.c.}$$

- Note we can arrange for baryon and lepton number conserved

	X	Ψ_B	χ_1	χ_2
L	1	0	2	1
B	-1	1	1	2
spin	0	1/2	1/2	1/2

2. Transfer to baryon asymmetry



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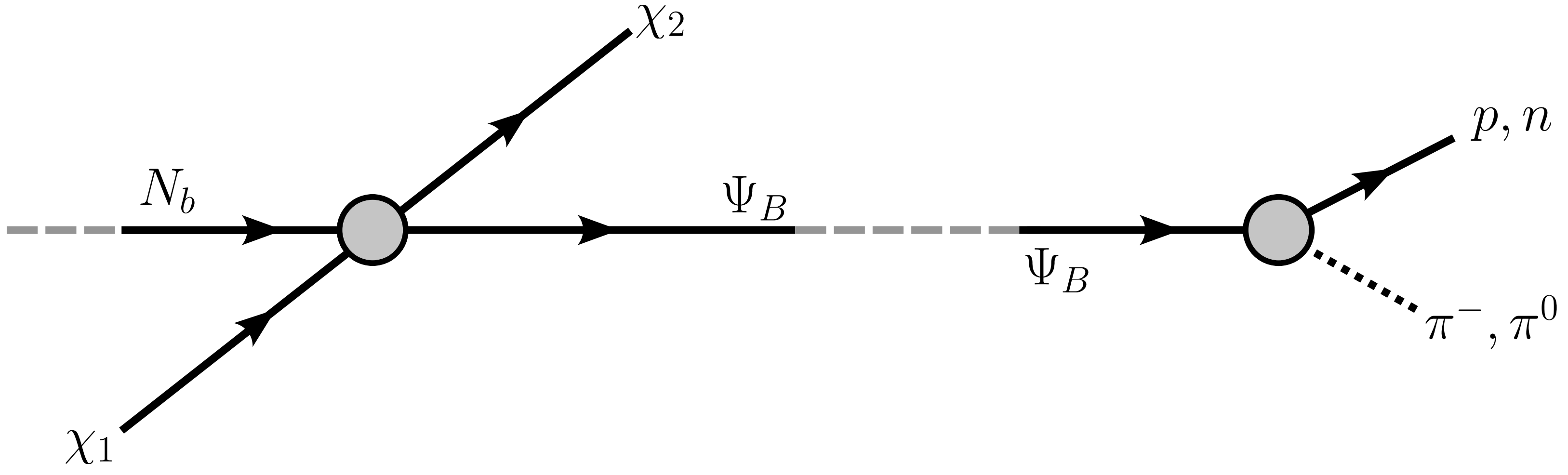
2. Transfer to baryon asymmetry

3. Heavy dark baryon decay



The mechanism

Our mechanism: **low-scale (< 100 GeV) leptogenesis + DM scattering**

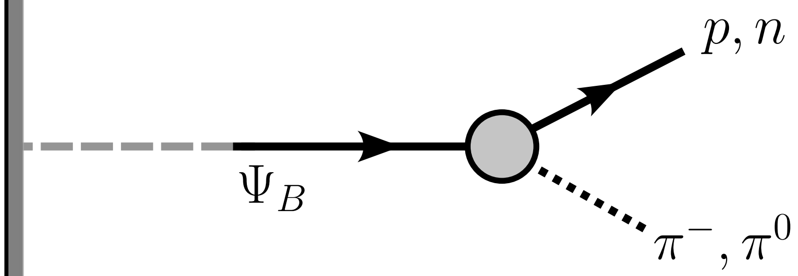
Neutron portal:

$$\mathcal{L} \supset -\frac{1}{\Lambda^2}\overline{\Psi}_B P_R d\, \bar{u}^c P_R d + \text{h.c.}$$

Match

$$\mathcal{L} \supset -\frac{C\Lambda^3_{\text{QCD}}}{f_\pi \Lambda^2}\bar{\Psi}_B p \pi^- + \text{h.c.} + \cdots$$

3. Heavy dark baryon decay



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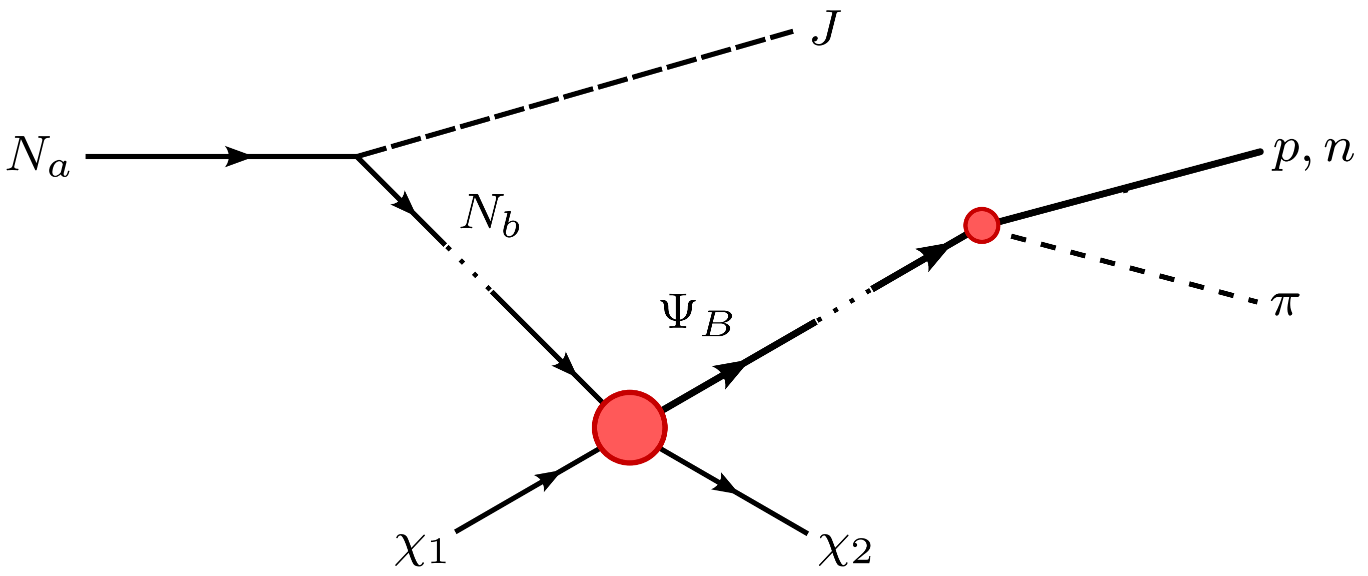


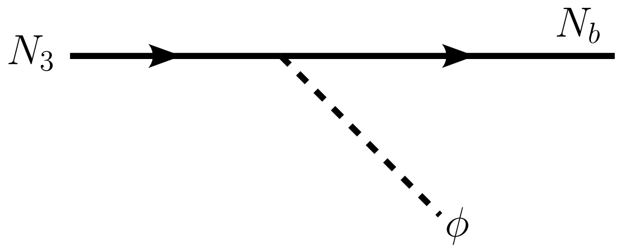
- **Baryon and lepton number are conserved, *visible* baryon number is violated**

Constraints

- **Out of equilibrium after EWPT, but before BBN**

$$H = \frac{\dot{a}}{a} \simeq 1.66\sqrt{g_*}\frac{T^2}{M_{\rm Pl}}$$

$$H_{\rm BBN} < \Gamma_{N_3} < H_{\rm EWPT}$$



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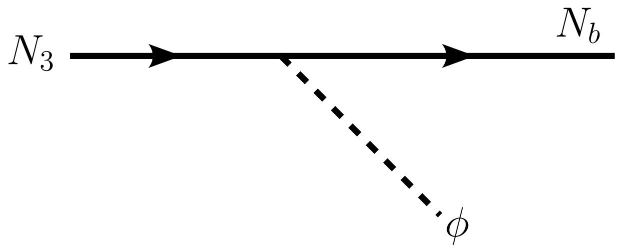


$$H = \frac{\dot{a}}{a} \simeq 1.66\sqrt{g_*}\frac{T^2}{M_{\rm Pl}}$$

$$10^{-25}\ \text{GeV} \lesssim \Gamma_{N_3} \lesssim 10^{-14}\ \text{GeV}$$

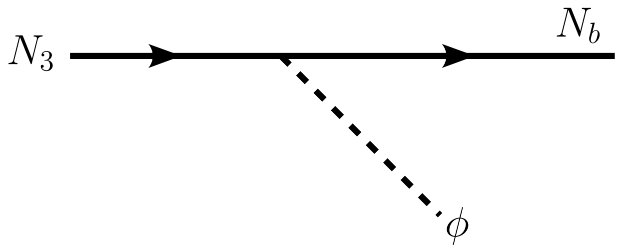
$T \sim 1\ \text{MeV}$ $\quad$ $T \sim 100\ \text{GeV}$

$$\Gamma(N_3 \to N_b\phi) \simeq \frac{|y_{b3}|^2}{8\pi} m_{N_3}$$

Constraints

- **Out of equilibrium after EWPT, but before BBN**

$$10^{-12} \lesssim |y_{b3}| \left(\frac{m_{N_3}}{10\,\mathrm{GeV}} \right)^{1/2} \lesssim 2 \times 10^{-7}$$



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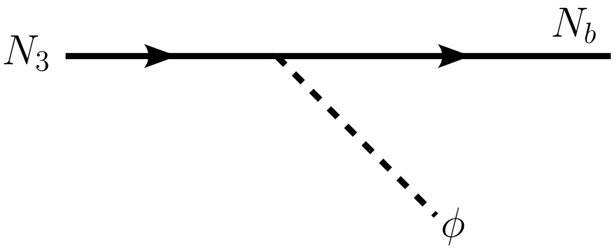

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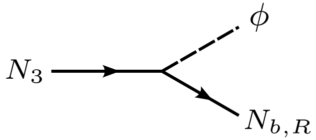
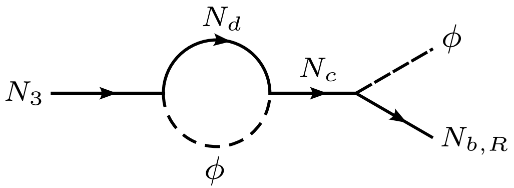
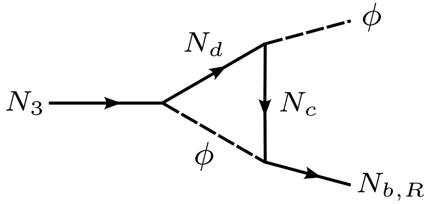
- **CP asymmetry need to be large enough:** $Y_L \gtrsim Y_B \approx 10^{-10}$







$$\epsilon = \frac{\Delta\Gamma}{\Gamma_{N_3}}$$

$$\simeq \sum_{c,d} \frac{1}{16\pi^2} \frac{\mathrm{Im}(y_{cd} y^*_{d3} y^*_{2c} y_{23})}{|y_{23}|^2 + |y_{13}|^2}$$

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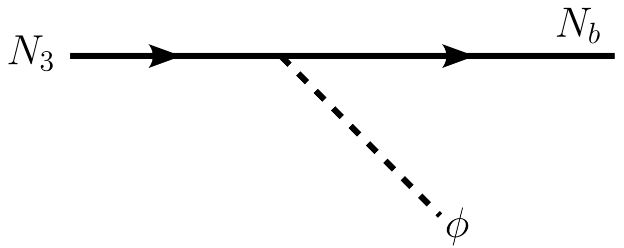

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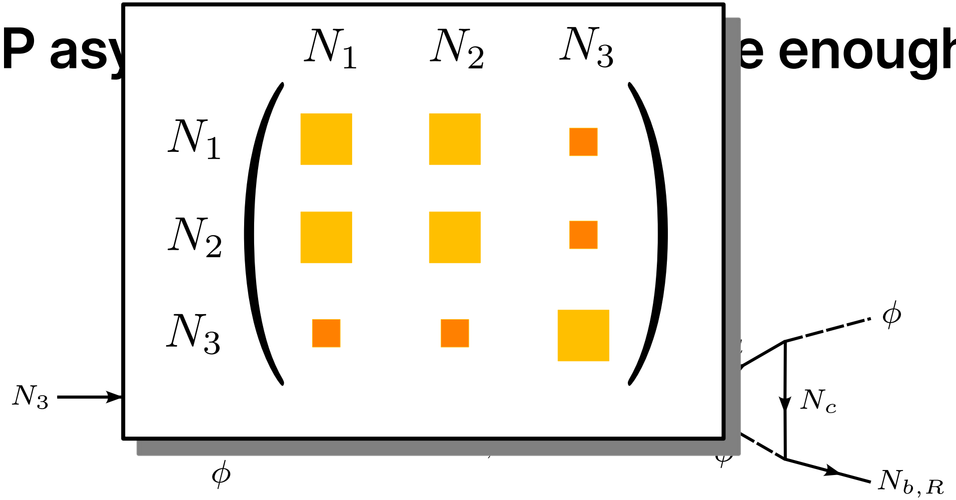

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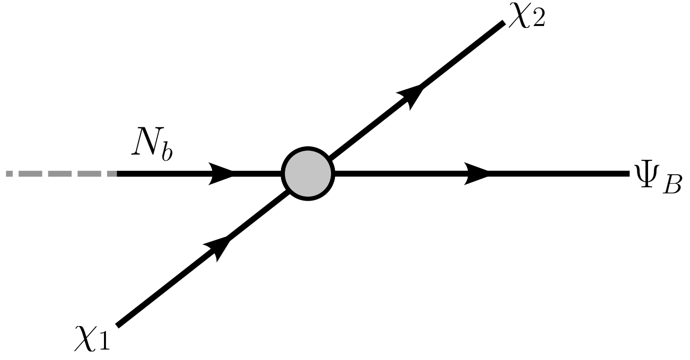
Constraints

- **$N_{2/1}$ need to live long enough to scatter**

$$\Gamma_{N_{1,2}} \ll \Gamma_{\text{scatter}}$$



Constraints

- **$N_{2/1}$ need to live long enough to scatter**

$$\Gamma_{N_{1,2}} \ll \Gamma_{\text{scatter}}$$

- **No inverse scattering**

$$m_{N_2} + m_{\Psi_B} > m_{\chi_2} + m_{\chi_2}$$

- **No new decay channels**

$$m_X + m_{\Psi_B} > m_{N_2}$$

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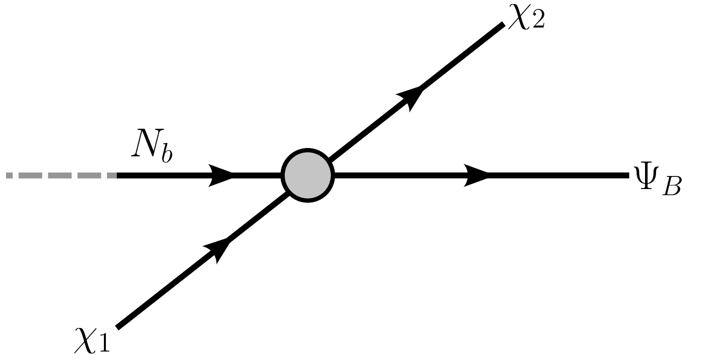
- **Stable DM**

$$m_{\chi_1} + m_X > m_{\chi_2}$$



- **Correct relic abundance**

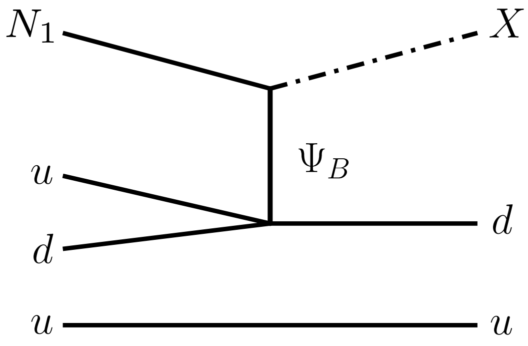
$$m_{\chi_1} + m_{\chi_2} \sim 5 m_p$$

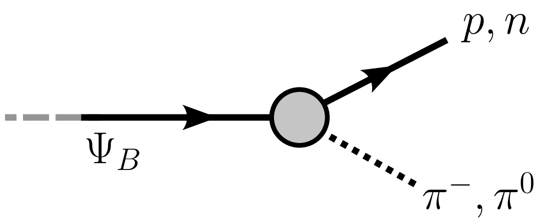
- **Evolution of DM abundance**

$$\frac{s_{\text{late}}}{s_{\text{early}}}\left(\frac{\Omega_{1,\text{early}}}{m_{\chi_1}} + \frac{\Omega_{2,\text{early}}}{m_{\chi_2}}\right) = \frac{\Omega_{1,\text{late}}}{m_{\chi_1}} + \frac{\Omega_{2,\text{late}}}{m_{\chi_2}}$$

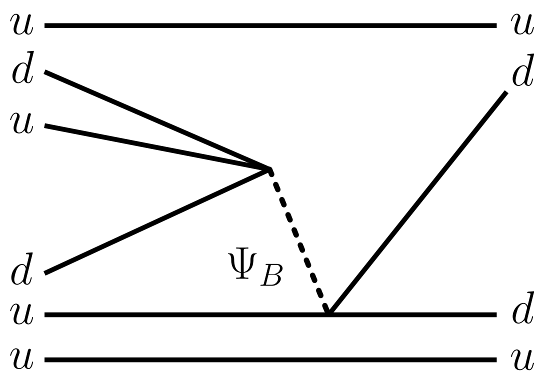
Constraints

- **Induced nucleon decay** $p \to \pi^+ + \not{E}$





- **Dinucleon decay** $pp \to \pi^+\pi^+$



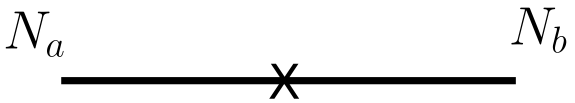
- **LHC constraints** $\dfrac{\lambda_{udd}}{\Lambda^2} \lesssim 0.07\ \mathrm{TeV}^{-2}$

- **Neutron stars** $m_{\Psi_B} \gtrsim 1.2\ \mathrm{GeV}$

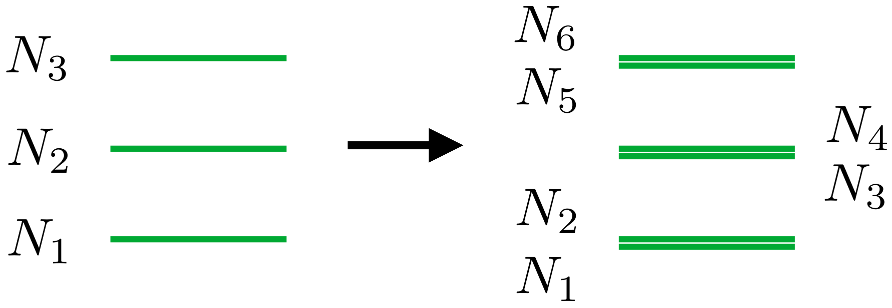
Majorana neutrinos?

Connect lepton asymmetry to smallness of neutrino masses

$$\mathcal{L} \supset -\mu_{ab} N_a N_b$$



- **Need psuedo-Dirac states:**



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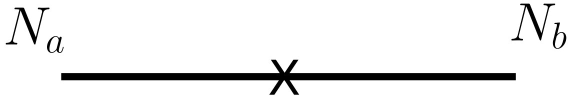


- **Oscillation period needs to be slower than the relevant time-scales in the problem**

$$\Delta m_{N_3} \ll \Gamma(N_3 \to N_b \phi)$$

$$\Delta m_{N_1} \ll \Gamma_{\text{scatter}}(N_1 \chi_1 \to \Psi_B \chi_2)$$

Inverse seesaw

Neutrino sector (extended inverse seesaw): $\lambda f \ll m_D \ll m,$

$$\mathcal{L}_M = -\frac{1}{2}\begin{pmatrix}\overline{\nu_R^C} & \overline{\mathcal{N}_R} & \overline{\mathcal{N}_R'}\end{pmatrix}\begin{pmatrix}0 & m_D^\top & 0\\ m_D & \lambda\sigma^* & m^\top \\ 0 & m & \lambda'\sigma\end{pmatrix}\begin{pmatrix}\nu_L\\ \mathcal{N}_L^C \\ \mathcal{N}_L'^C\end{pmatrix} + \text{h.c.}$$

Spontaneous symmetry breaking of $\mathrm{U(1)_L}$ at the scale f

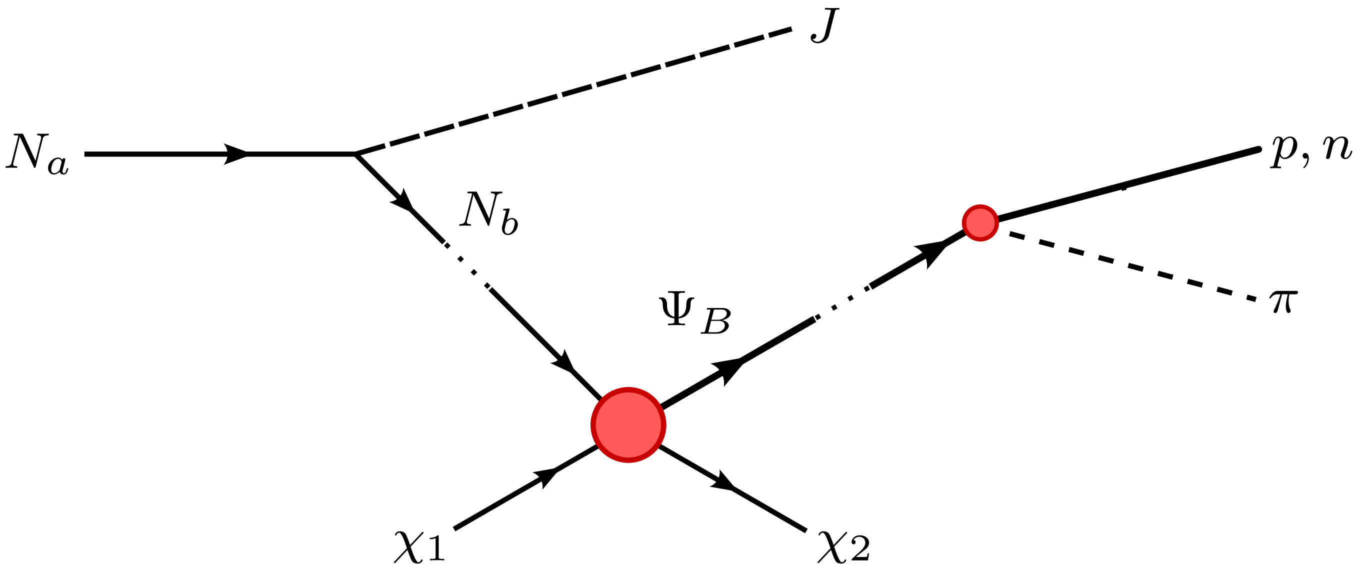
$$\sigma \to \frac{1}{\sqrt{2}}(f + \sigma_0 + iJ)$$

Neutrinos acquire hierarchical masses:

$$m_\nu \simeq \frac{\mu m_D^2}{m^2}, \quad m_{N_1,N_2} \simeq m \mp \frac{\mu}{2}$$

Conclusion

Phenomenologically promising model of low-scale leptogenesis.



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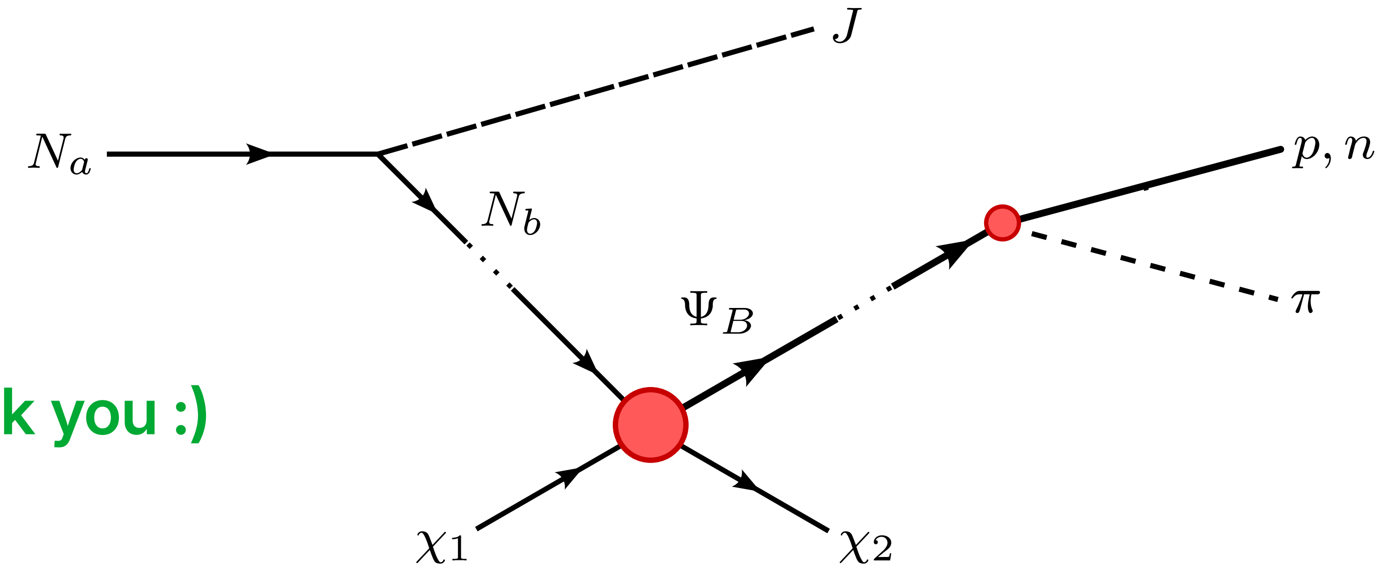
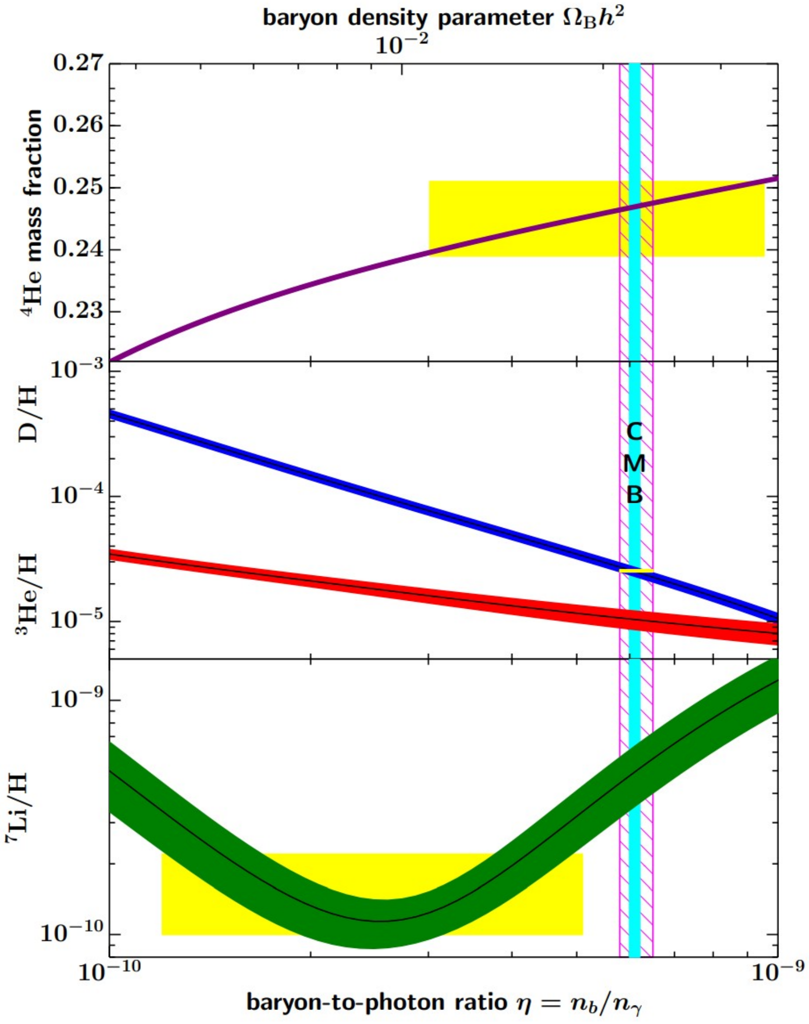


Thank you :)

BACK-UPS

Primordial abundances as predicted by the standard model of BBN (1912.01132)



The mechanism - details

1. Lepton asymmetry

Introduce SM singlets:

	$\mathcal{N}_i$	$\mathcal{N}_i'$	σ
L	1	-1	2
spin	1/2	1/2	0

Neutrino sector (extended inverse seesaw):

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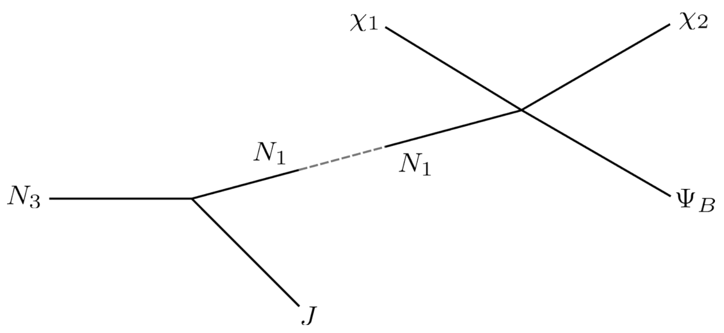
Evolution

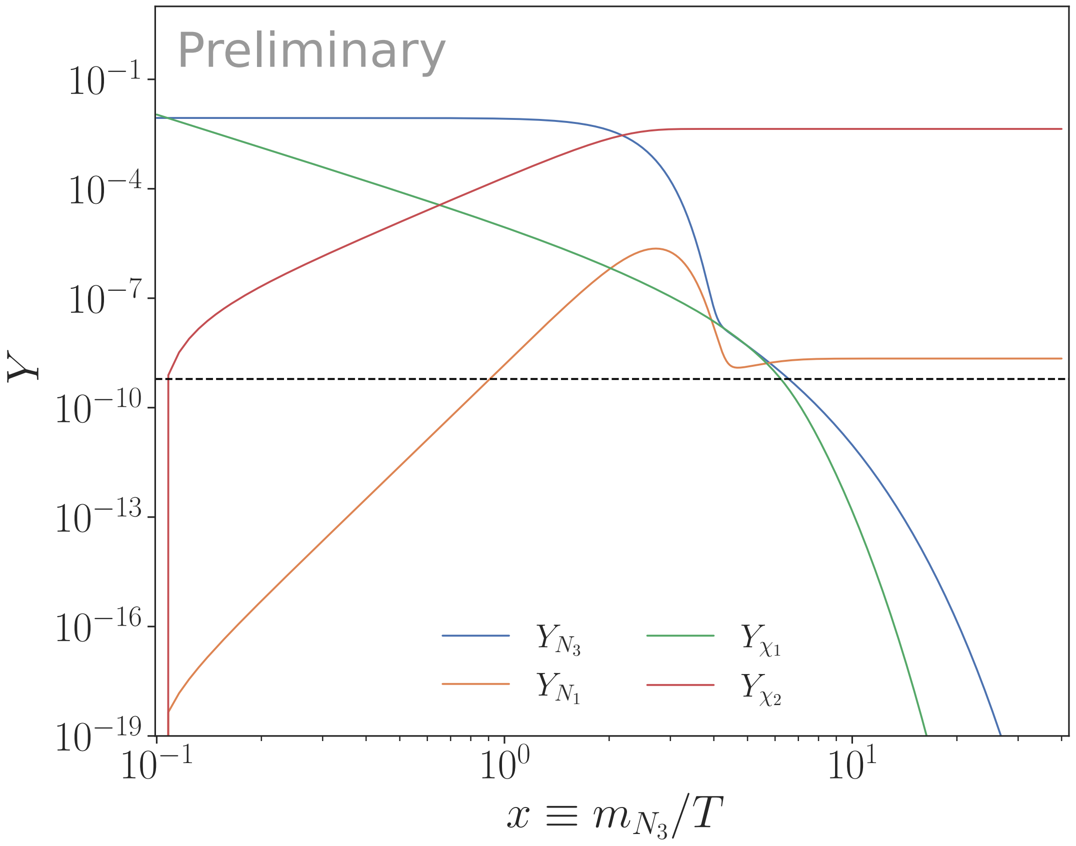
$m_{N3} = 20$ GeV

$m_{\chi 1} = 0.5$ GeV

$m_{\chi 2} = 0.3$ GeV

$m_{\psi B} = 1.2$ GeV





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