UNIVERSITY OF Southampton

Dark Matter and Leptogenesis in the Type Ib Seesaw Model

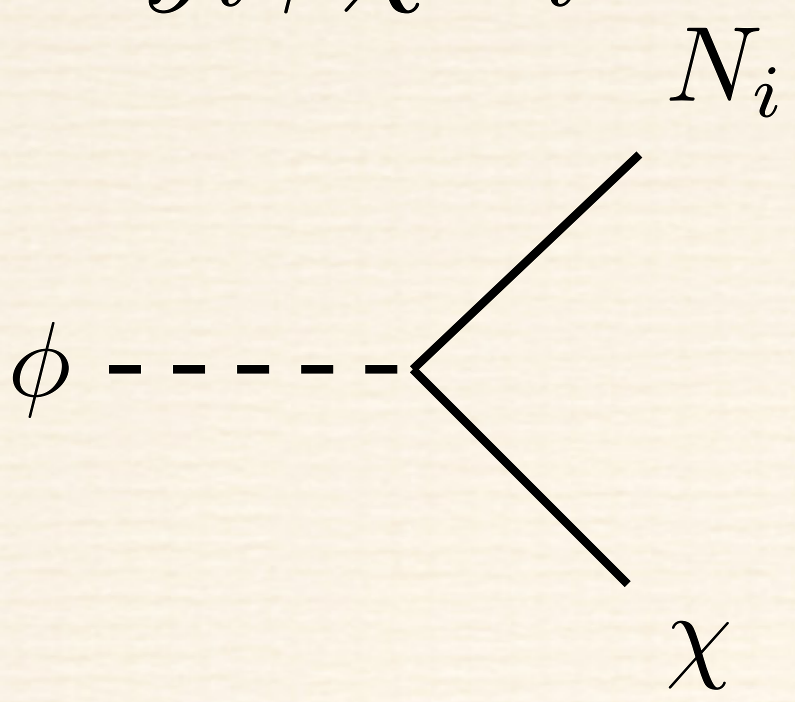
Bowen Fu
with Marco Chianese and Stephen F. King

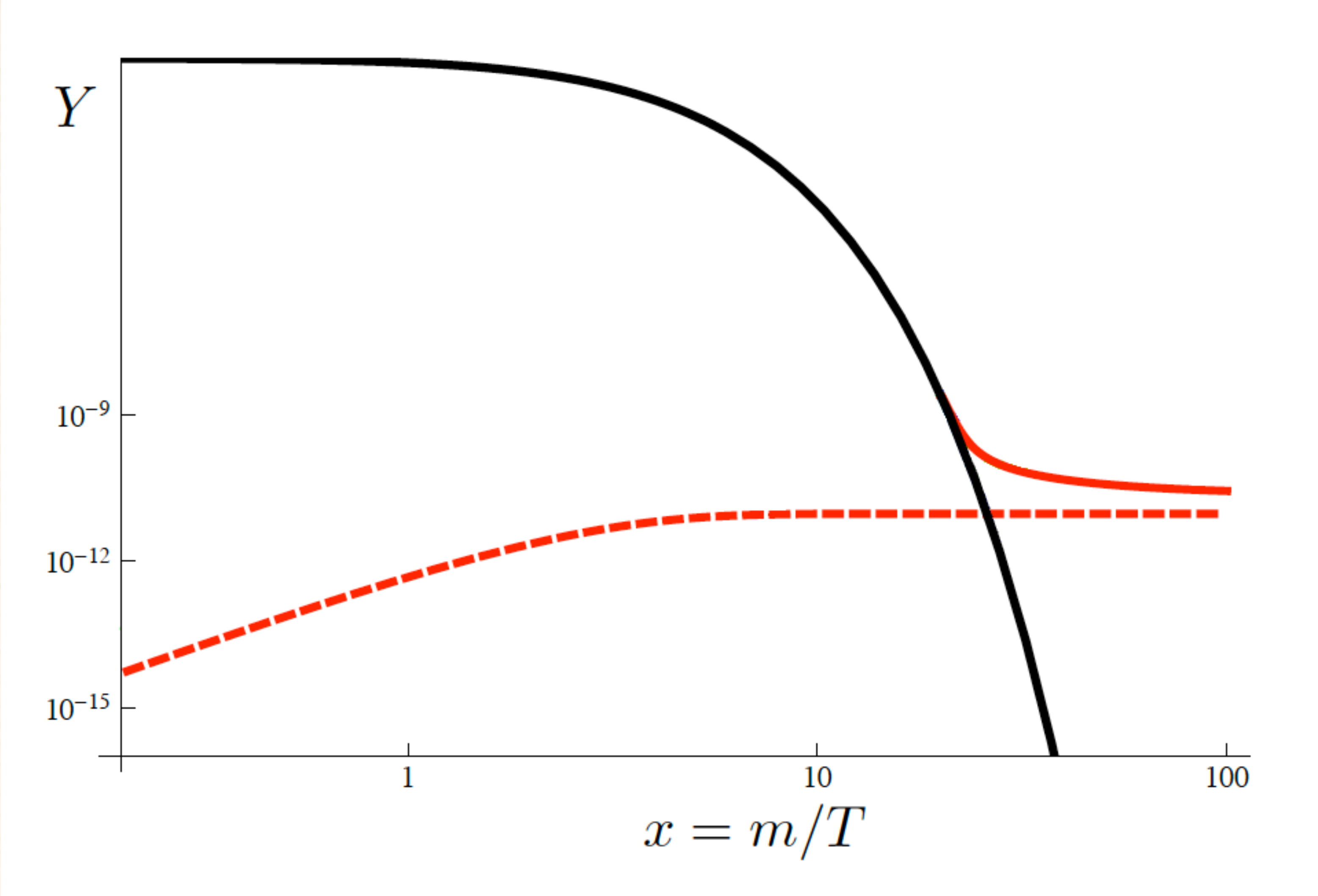
arXiv:2102.07780 [hep-ph], arXiv:2107.01486 [hep-ph]

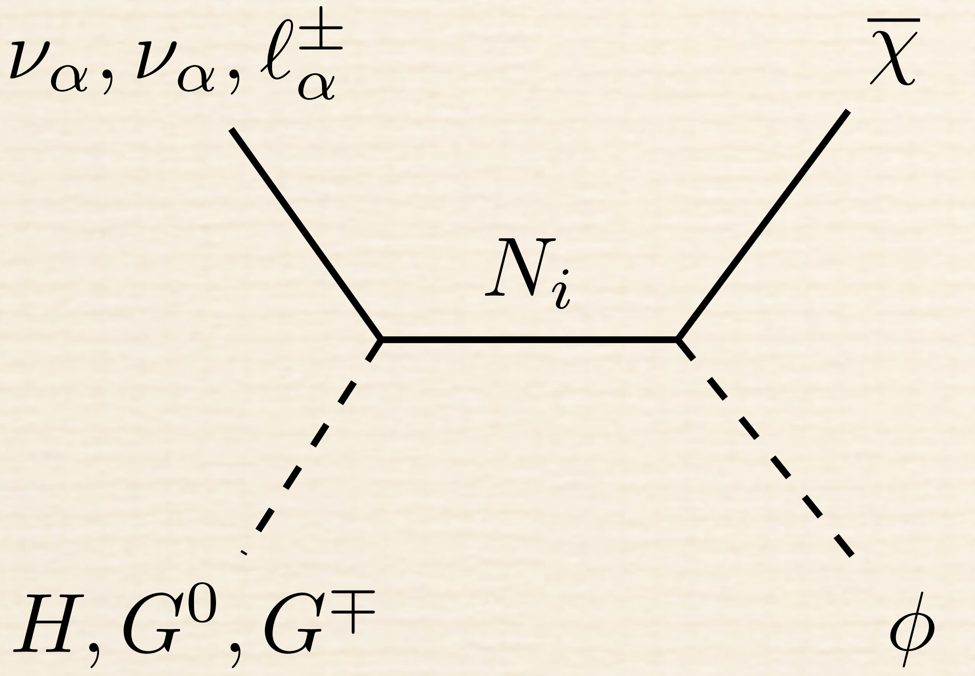
The XXVIII International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2021)
24 Aug 2021

Neutrino Portal

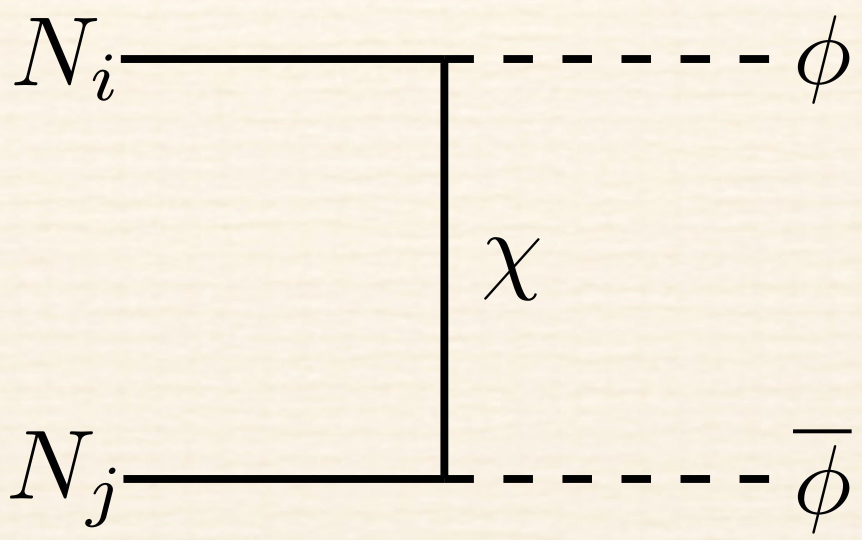
- General neutrino portal $y_i \phi \overline{\chi} N_i$
- heavy scalar scenario
- Dark matter producing process

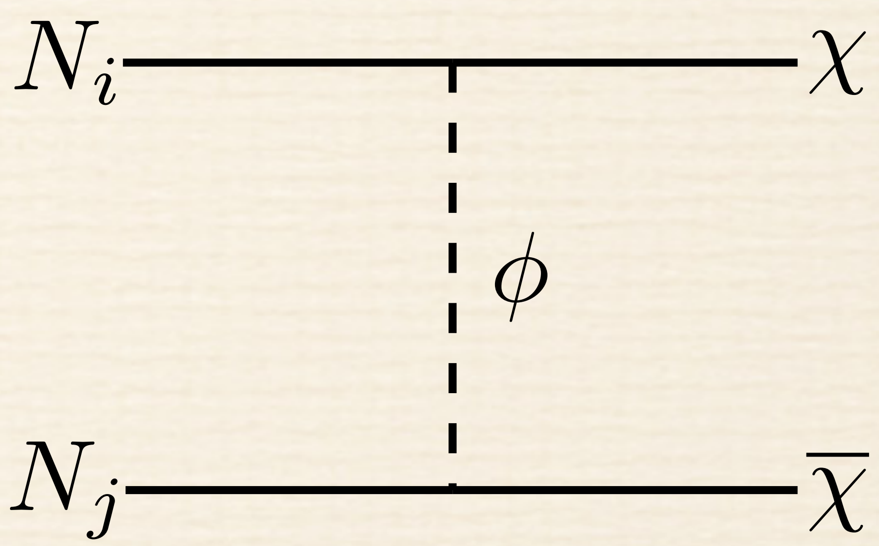






ν-Yukawa process $\propto Y^2 y^2$

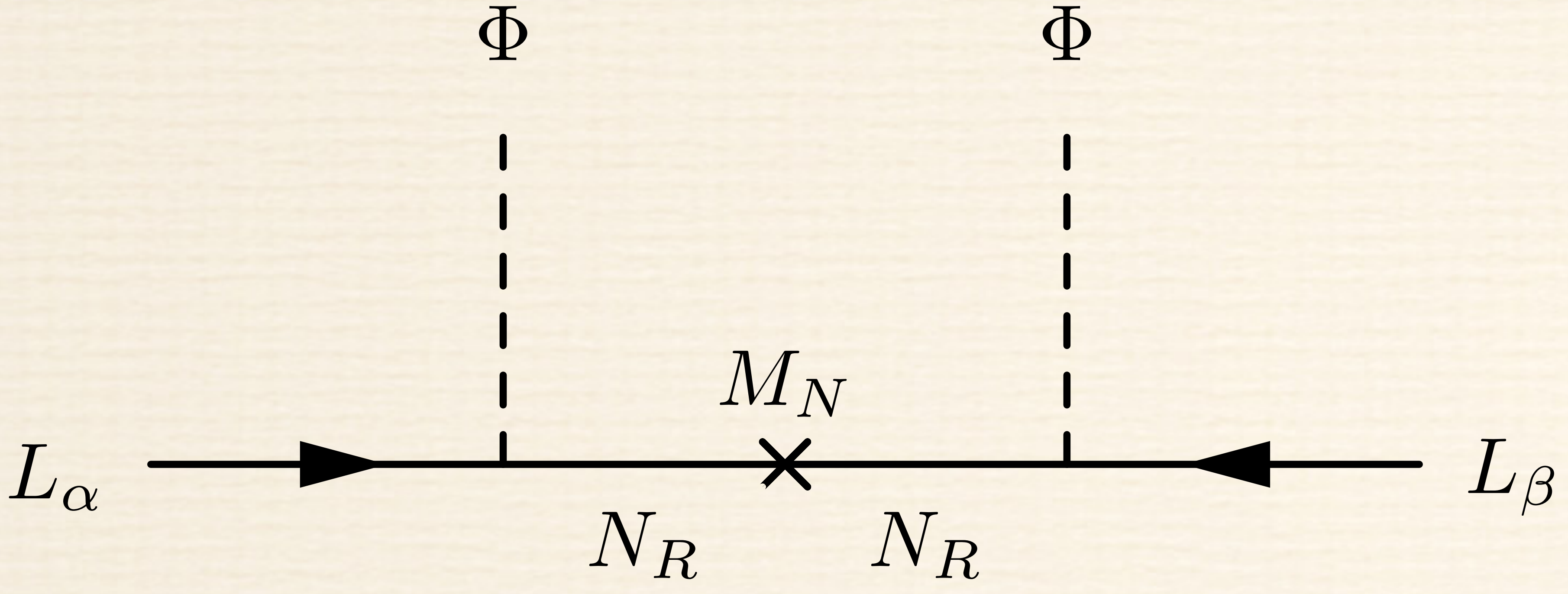




dark sector process $\propto y^4$

Why Type Ib Seesaw Model?

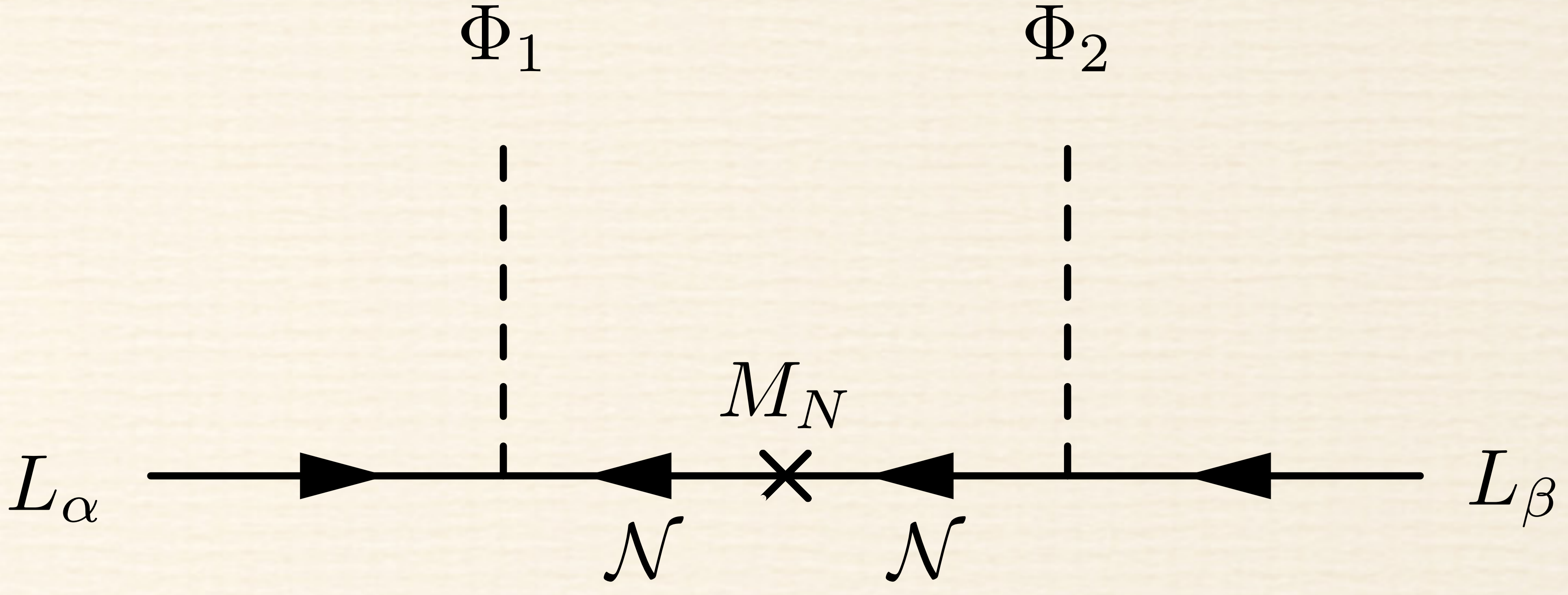
- Traditional type I seesaw mechanism (type Ia)



$$m \propto \frac{Y^2 v^2}{M_N}$$

- M_N~1GeV → Y~10^{-7}: too small to play roles in dark matter production

- Type Ib seesaw mechanism



$$m \propto \frac{Y_1 Y_2 v_1 v_2}{M_N}$$

- One of Y_1, Y_2 can be small while the other one is large

Type Ib Seesaw Model with a Neutrino Portal

- Particles and symmetries

	Q_α	$u_{R\beta}$	$d_{R\beta}$	L_α	$e_{R\beta}$	Φ_1	Φ_2	$N_{\rm R1}$	$N_{\rm R2}$	ϕ	$\chi_{L,R}$
$SU(2)_L$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$U(1)_Y$	$\frac{1}{6}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	$-\frac{1}{2}$	0	0	0	0
Z_3	1	ω	ω	1	ω	ω	ω^2	ω^2	ω	ω	ω^2
Z_2	$+$	$+$	$+$	$+$	$+$	$+$	$+$	$+$	$+$	$-$	$-$

- Seesaw Lagrangian and neutrino portal

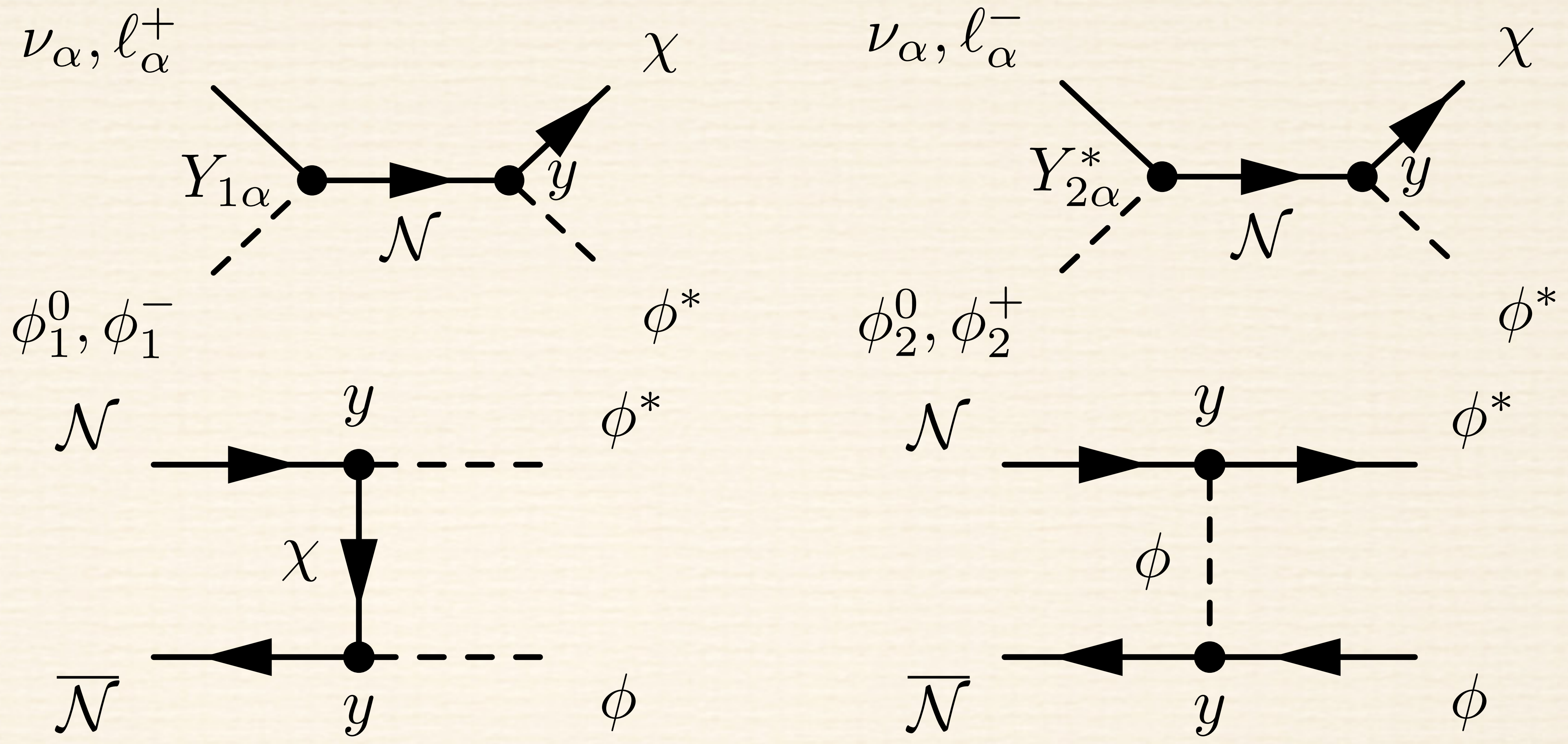
$$\mathcal{L}_{\rm seesawIb} = -Y_{1\alpha}\overline{L}_\alpha\Phi_1 N_{R1} - Y_{2\alpha}\overline{L}_\alpha\Phi_2 N_{R2} - M_N\overline{N^c_{R1}}N_{R2} + \text{h.c.}$$
$$\mathcal{L}_{\rm N_R portal} = y_1\phi\,\overline{\chi_R}N^c_{R1} + y_2\phi\,\overline{\chi_L}N_{R2} + \text{h.c.}$$

- The two RH neutrinos form a Dirac pair $\mathcal{N} = (N^c_{R1}, N_{R2})$

$$\mathcal{L}_{\rm seesawIb} = -Y^*_{1\alpha}\overline{L^c}_\alpha\Phi^*_1\mathcal{N}_L - Y_{2\alpha}\overline{L}_\alpha\Phi_2\mathcal{N}_R - M_N\overline{\mathcal{N}_L}\mathcal{N}_R + \text{h.c.}$$
$$\mathcal{L}_{\rm N_R portal} = y\phi\,\overline{\chi}\mathcal{N} + \text{h.c.}$$

Dark Matter Production

- Dark matter producing processes
    - ν-Yukawa processes
    - dark sector processes



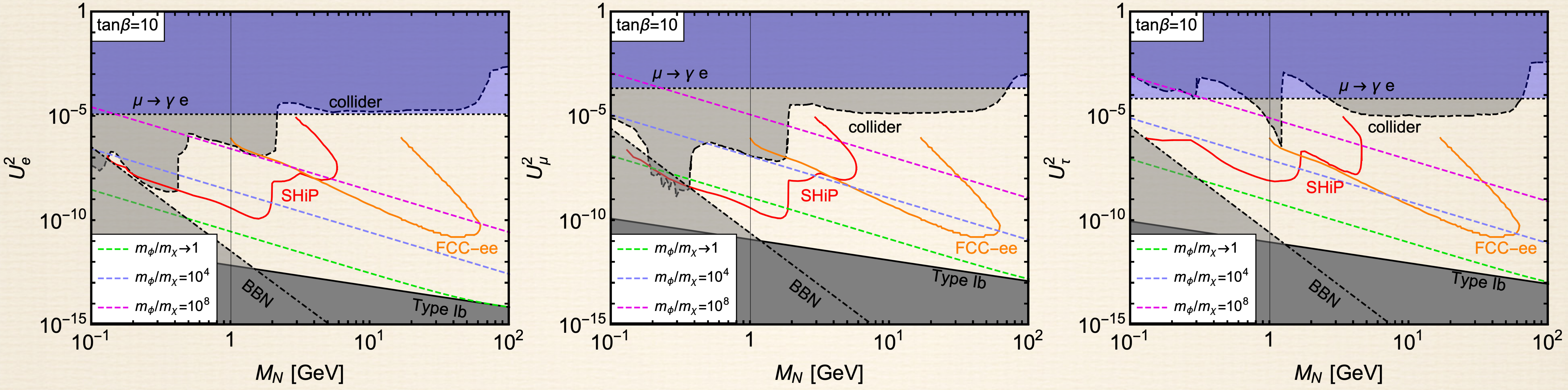
- If $m_\phi >> m_\chi$, M_N, the dark matter production only depends on m_ϕ/m_χ
    - ν-Yukawa dominance $\quad y^2\left(Y_1^2+Y_2^2\right) \simeq 2.1 \times 10^{-22}\frac{m_\phi}{m_\chi}$
    - dark sector dominance $\quad y^4 \simeq 3.9 \times 10^{-23}\frac{m_\phi}{m_\chi}$

equal contribution

$$\left(Y_1^2+Y_2^2\right)^2 \simeq 5.5 \times 10^{-22}\frac{m_\phi}{m_\chi}$$

- Condition for ν-Yukawa dominance $\quad \frac{m_\phi}{m_\chi} \gtrsim 6.9 \times 10^{-9}\left(\frac{M_N}{1\mathrm{GeV}}\right)^2\frac{1}{\sin^2 2\beta} \qquad \tan\beta = v_2/v_1$

Results



- ν-Yukawa dominance is allowed above the coloured dashed lines
- More constrained as m_ϕ/m_χ increases
- The strongest constraint is given by ν_μ mixing

Leptogenesis

Extended Type Ib Seesaw Mechanism

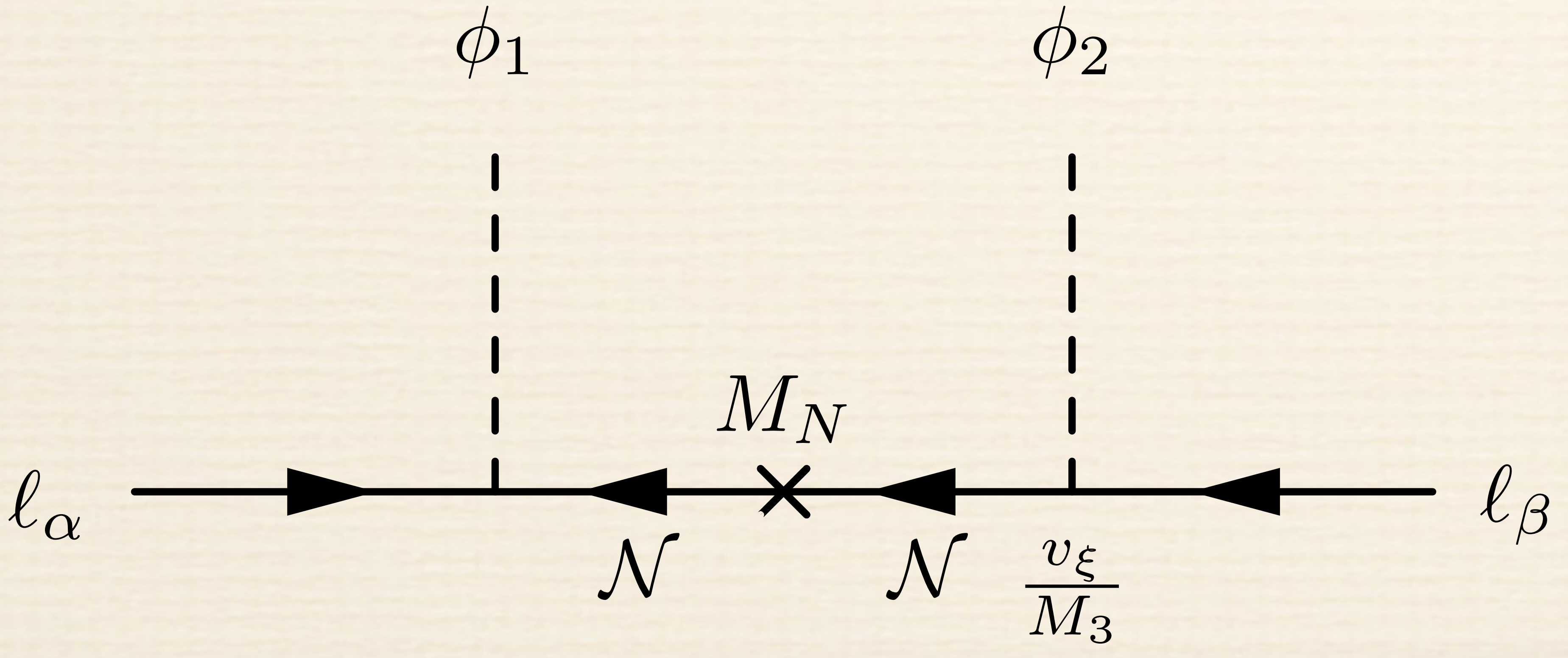
- Particles and symmetries

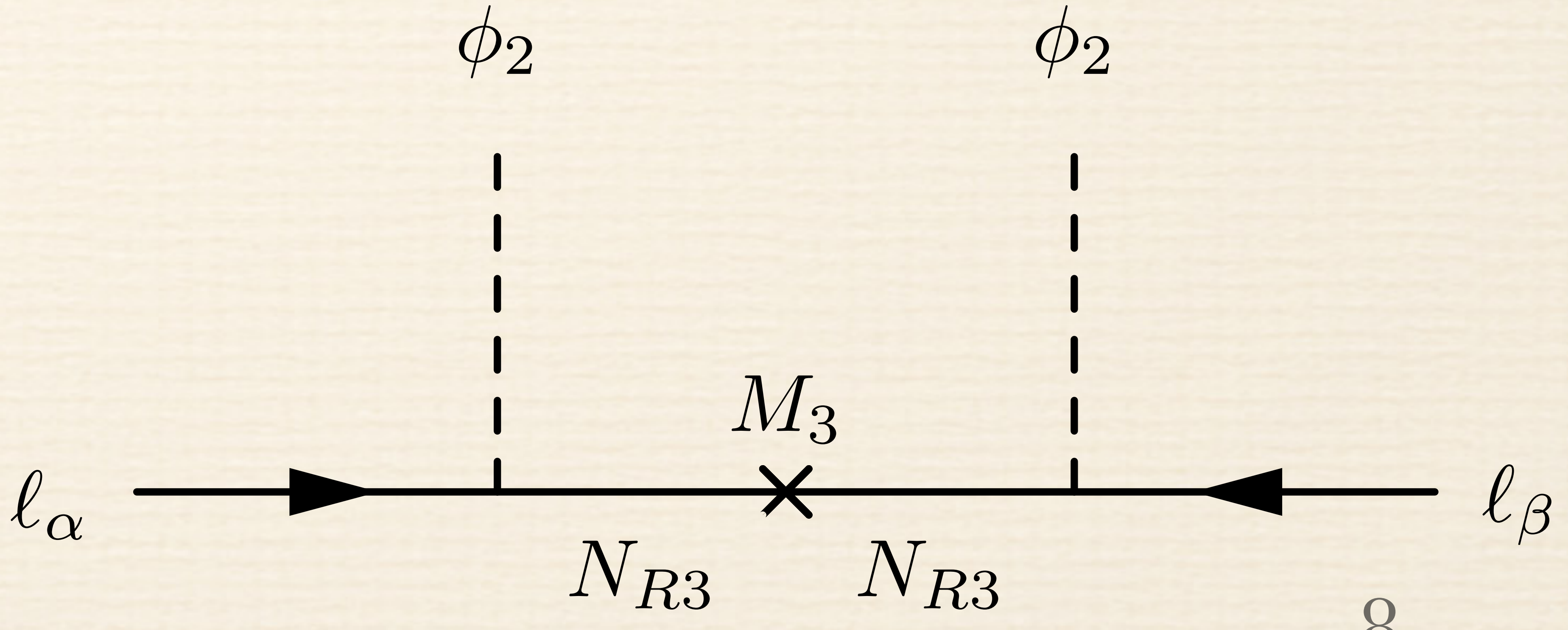
	q_α	$u_{R\beta}$	$d_{R\beta}$	ℓ_α	$e_{R\beta}$	ϕ_1	ϕ_2	$N_{\rm R1}$	$N_{\rm R2}$	$N_{\rm R3}$	ξ
$SU(2)_L$	**2**	**1**	**1**	**2**	**1**	**2**	**2**	**1**	**1**	**1**	**1**
$U(1)_Y$	$\frac{1}{6}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	$-\frac{1}{2}$	0	0	0	0
Z_4	1	ω^2	ω	1	ω	ω	ω^2	ω^3	ω	ω^2	ω

- Seesaw Lagrangian

$$\begin{aligned}\mathcal{L}_{\rm seesaw} \quad = \quad & -Y_{1\alpha}\overline{\ell}_\alpha\phi_1 N_{R1} - Y_{3\alpha}\overline{\ell}_\alpha\phi_2 N_{R3} - 2Y_{13}\overline{\xi}\,\overline{N_{R3}^c}N_{R1} - 2Y_{23}\xi\overline{N_{R3}^c}N_{R2} \\ & -M\overline{N_{R1}^c}N_{R2} - \frac{1}{2}M_3\overline{N_{R3}^c}N_{R3} + \text{h.c.}\end{aligned}$$

- Type Ib seesaw mechanism can be realised effectively





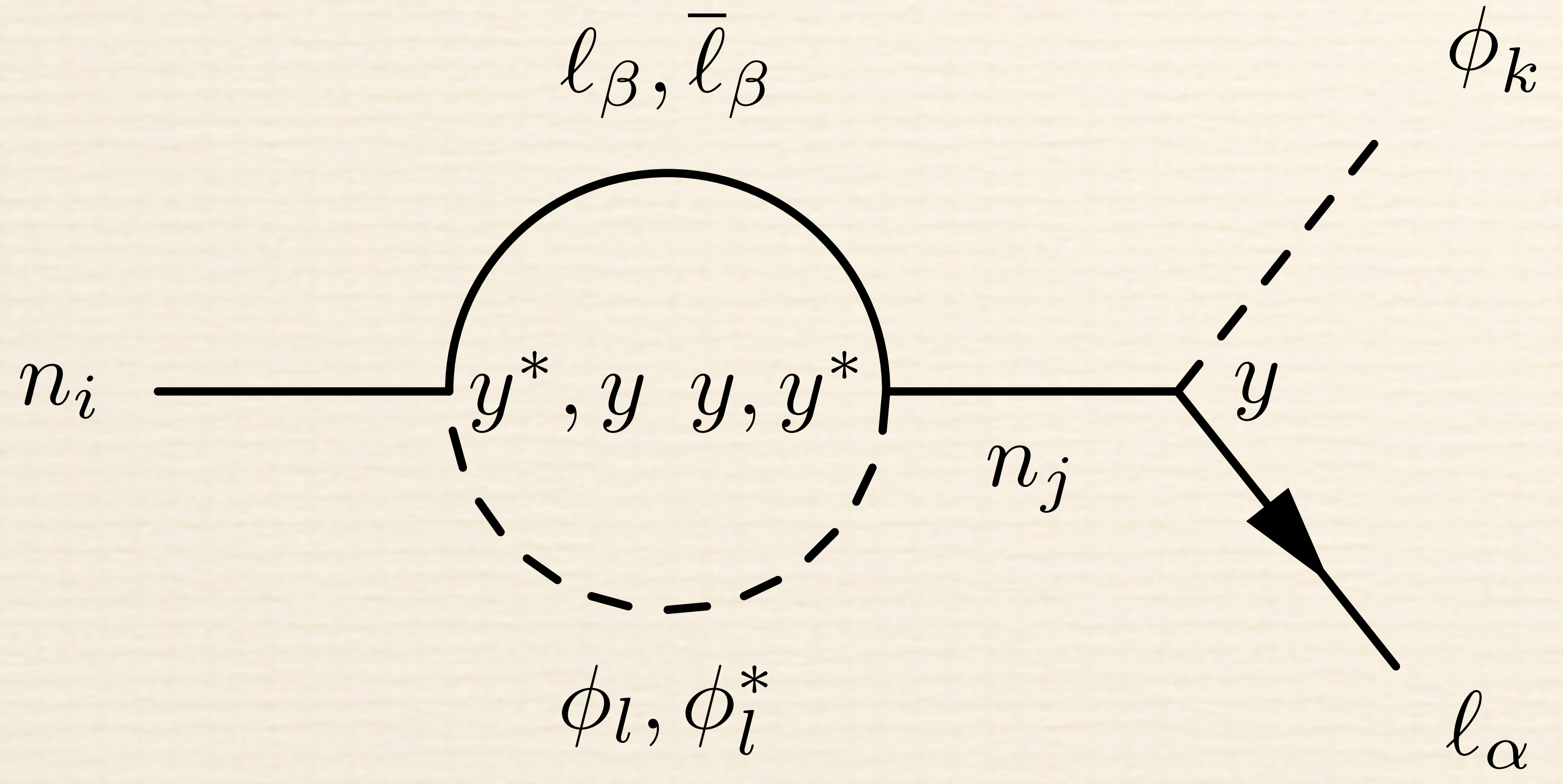
Resonant Leptogenesis

- N_{R1} and N_{R2} gain mass splitting through mixing with N_{R3}

$$\begin{pmatrix} N_{R1} \\ N_{R2} \\ N_{R3} \end{pmatrix} \to \begin{pmatrix} n_{R1} \\ n_{R2} \\ n_{R3} \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}}\left(1-\frac{M_{13}^2-M_{23}^2}{4MM_3}\right)^* & \frac{1}{\sqrt{2}}\left(1+\frac{M_{13}^2-M_{23}^2}{4MM_3}\right)^* & -\frac{M_{13}^*+M_{23}^*}{M_3} \\ \frac{i}{\sqrt{2}}\left(1+\frac{M_{13}^2-M_{23}^2}{4MM_3}\right)^* & -\frac{i}{\sqrt{2}}\left(1-\frac{M_{13}^2-M_{23}^2}{4MM_3}\right)^* & -i\frac{M_{13}^*-M_{23}^*}{M_3} \\ \frac{M_{13}}{\sqrt{2}M_3} & \frac{M_{23}}{\sqrt{2}M_3} & 1 \end{pmatrix} \begin{pmatrix} N_{R1} \\ N_{R2} \\ N_{R3} \end{pmatrix}$$

$$m_1 \simeq M - \frac{(M_{13}+M_{23})^2}{2M_3}, \quad m_2 \simeq M + \frac{(M_{13}-M_{23})^2}{2M_3}, \quad m_3 \simeq M_3$$

- Lepton number violation

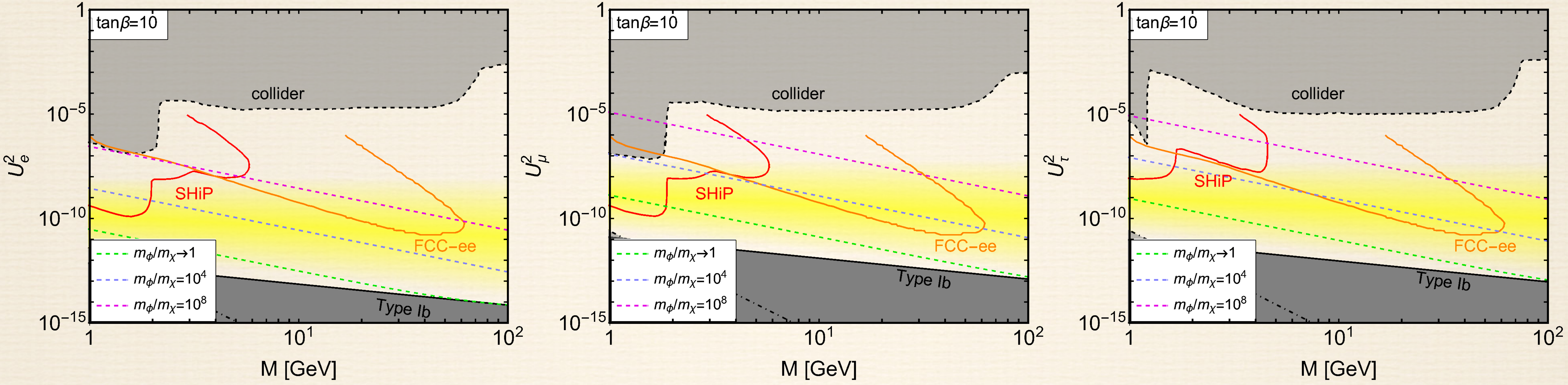


$$\left(\epsilon_{n_1}^{\rm wave}\right)_{1\alpha} = \left(\epsilon_{n_2}^{\rm wave}\right)_{1\alpha} \simeq \frac{Y_{1\alpha}Y_{1\alpha}^*}{2Y_1^2}\frac{\Im\left(M_{13}^2+M_{23}^2\right)}{MM_3}$$

$$Y_{\Delta_\alpha} \simeq \sum_i \epsilon_{i\alpha} Y_{n_i}^{\rm eq} \frac{z_{sph}}{2\,\mathcal{C}_2 \kappa_{i\alpha}|A_{\alpha\alpha}|}$$

$$\mathcal{C}_2 \sim 0.1$$
$$z_{sph} \equiv M/T_{sph}$$

Results



- Theoretical and experimental constraints
  - type Ib seesaw dominant
  - pseudo-Dirac neutrino
  - oscillation data
  - observed baryogenesis

- Allowed region of mixing strength

$$1.0 \times 10^{-6} \cos^2\beta \gg U_e^2 \gg 1.5 \times 10^{-14} \frac{v}{M} \cot\beta$$

$$7.3 \times 10^{-6} \cos^2\beta \gg U_\mu^2 \gg 6.3 \times 10^{-13} \frac{v}{M} \cot\beta$$

$$5.7 \times 10^{-6} \cos^2\beta \gg U_\tau^2 \gg 4.3 \times 10^{-13} \frac{v}{M} \cot\beta$$

Summary

- We discussed dark matter production in a minimal extension of type Ib seesaw model with a neutrino portal
- The DM-ν relation is constrained by experimental results when the heavy neutrino is 1-100 GeV
- The results can be further constrained by future experiments
- The type Ib seesaw mechanism can be realised effectively to produce BAU through resonant leptogenesis
- Leptogenesis and dark matter can be realised simultaneously in the type Ib seesaw model for GeV scale heavy neutrino

Thank You!