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# Dark Matter in the Type Ib Seesaw Model

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付博文

*Based on M. Chianese, B. Fu, and S. F. King, (2021), arXiv:2102.07780 [hep-ph]*

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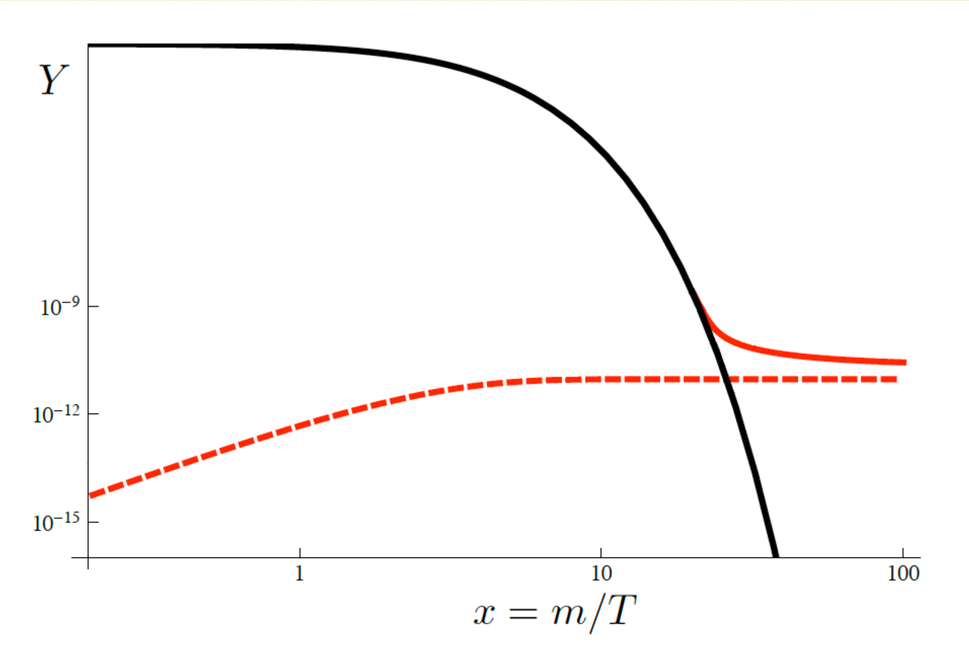
# Dark Matter Production

- Freeze-out: Thermal equilibrium
- Freeze-in: Never in thermal equilibrium




- The observed DM relic abundance gives a constraint to DM yield

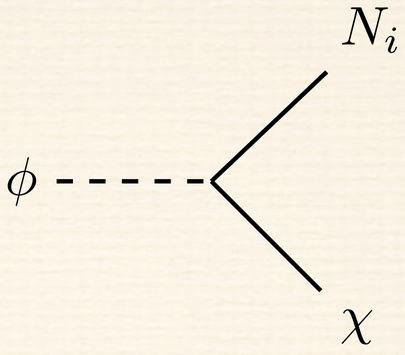
$$\Omega_{\rm DM}^{\rm obs} h^2 = 0.120 \pm 0.001$$

N. Aghanim et al. (Planck), (2018), arXiv:1807.06209

# Neutrino Portal

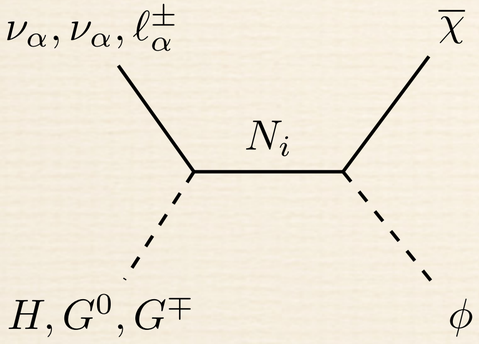
- General neutrino portal

$$y_i \phi \overline{\chi} N_i$$

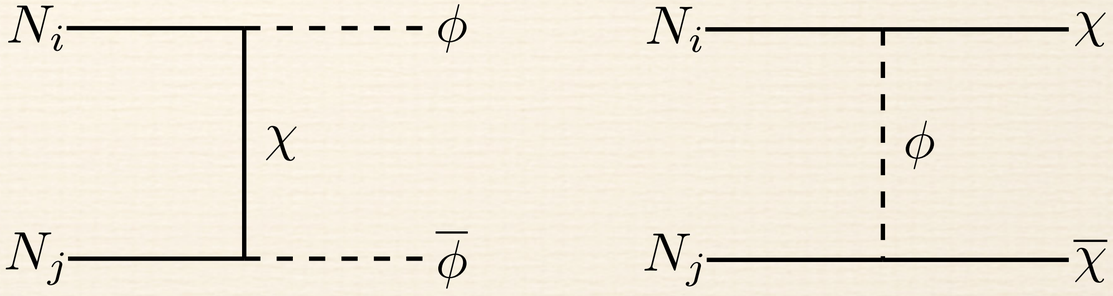



- heavy scalar scenario

- Dark matter producing process



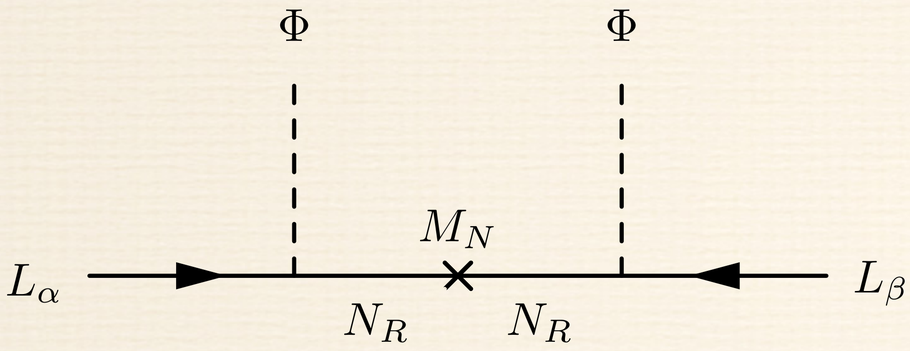

$\nu$-Yukawa process $\propto Y^2 y^2$




dark sector process $\propto y^4$

# Why Type Ib Seesaw Model?

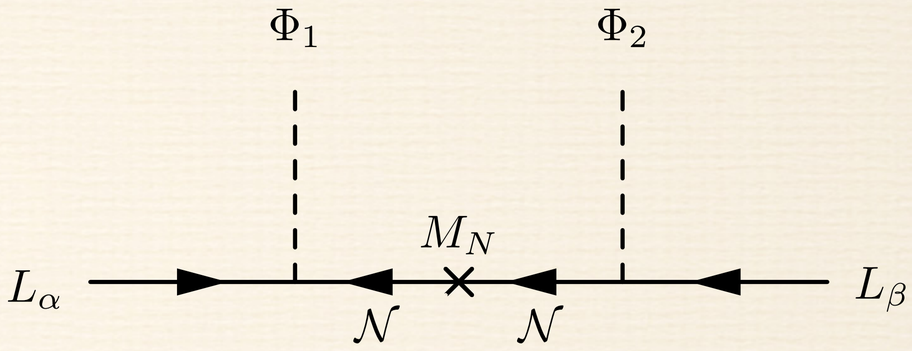
- Traditional type I seesaw mechanism (type Ia)




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

- m~0.1eV, $M_N$~1GeV → Y~$10^{-7}$
- $M_N$>4TeV for ν-Yukawa dominance

- 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

| | $Q_\alpha$ | $u_{R\beta}$ | $d_{R\beta}$ | $L_\alpha$ | $e_{R\beta}$ | $\Phi_1$ | $\Phi_2$ | $N_{\rm R1}$ | $N_{\rm R2}$ | $\phi$ | $\chi_{L,R}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SU(2)_L$ | $\mathbf{2}$ | $\mathbf{1}$ | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{2}$ | $\mathbf{1}$ | $\mathbf{1}$ | $\mathbf{1}$ | $\mathbf{1}$ |
| $U(1)_Y$ | $\frac{1}{6}$ | $\frac{2}{3}$ | $-\frac{1}{3}$ | $-\frac{1}{2}$ | $-1$ | $-\frac{1}{2}$ | $-\frac{1}{2}$ | $0$ | $0$ | $0$ | $0$ |
| $Z_3$ | $1$ | $\omega$ | $\omega$ | $1$ | $\omega$ | $\omega$ | $\omega^2$ | $\omega^2$ | $\omega$ | $\omega$ | $\omega^2$ |
| $Z_2$ | $+$ | $+$ | $+$ | $+$ | $+$ | $+$ | $+$ | $+$ | $+$ | $-$ | $-$ |

- 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 $\mathcal{N} = (N^c_{R1}, N_{R2})$

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

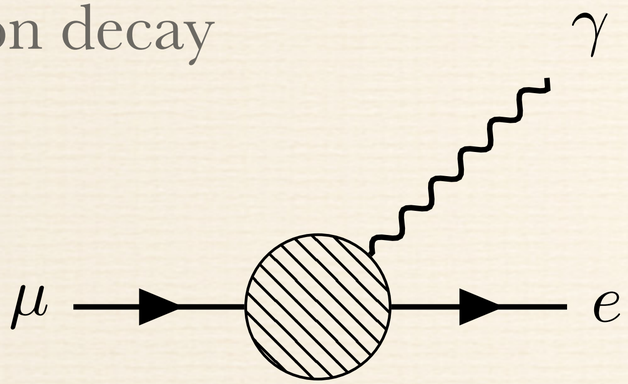
$$\mathcal{L}_{\rm N_R portal} = y \phi\, \overline{\chi}\mathcal{N} + \text{h.c.}$$

# Constraints

- Oscillation data

$$Y_{1\alpha} \to Y_1 \qquad Y_{2\alpha} \to Y_2 \qquad \frac{Y_1 Y_2 v_1 v_2}{M_N} = 3.0 \times 10^{-11}\,\mathrm{GeV}$$

- Muon decay



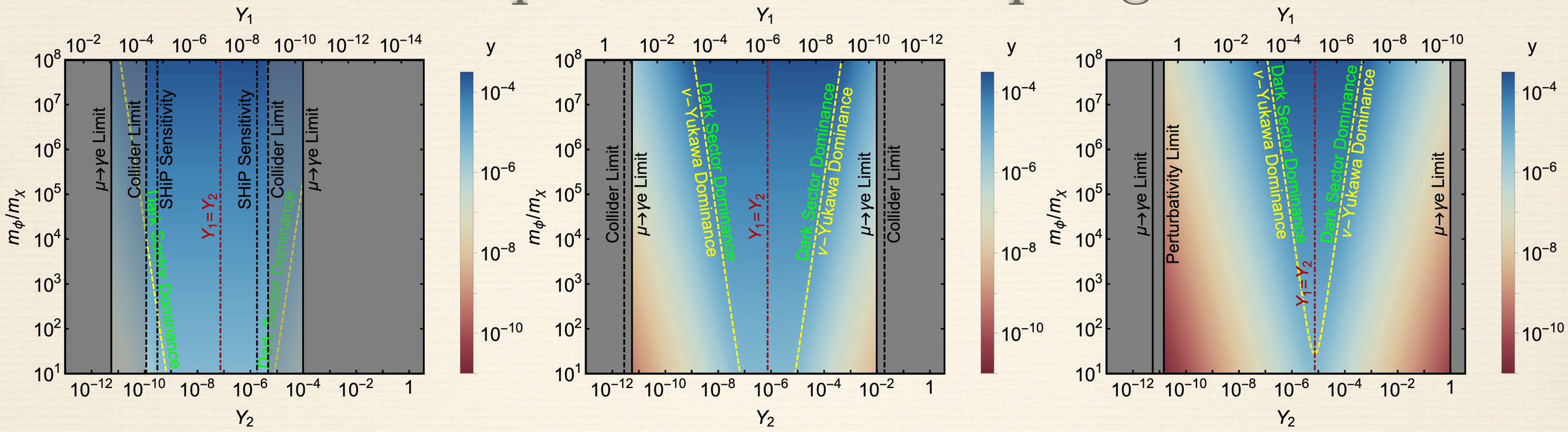

$$|\eta_{e\mu}| = \frac{\left|Y_{1e}Y_{1\mu}^* v_1^2 + Y_{2e}Y_{2\mu}^* v_2^2\right|}{4M_N^2} \lesssim 8.4 \times 10^{-6}$$

- Collider data on neutrino mixing

$$U_\alpha^2 = \sum_{i=L,R} |U_{\alpha i}|^2\,, \quad \alpha = e, \mu, \tau \qquad U_\alpha^2 = (a_\alpha + b_\alpha \cos\delta_M)\frac{v_1^2 Y_1^2}{M_N^2} + (a_\alpha - b_\alpha \cos\delta_M)\frac{v_2^2 Y_2^2}{M_N^2}$$

$$M_{\mathrm{diag}}^\nu = U^T M^\nu U \qquad U_\alpha^2 \geq \sqrt{a'_\alpha - b'_\alpha \cos\delta_M}\,\frac{1\,\mathrm{GeV}}{M_N}$$

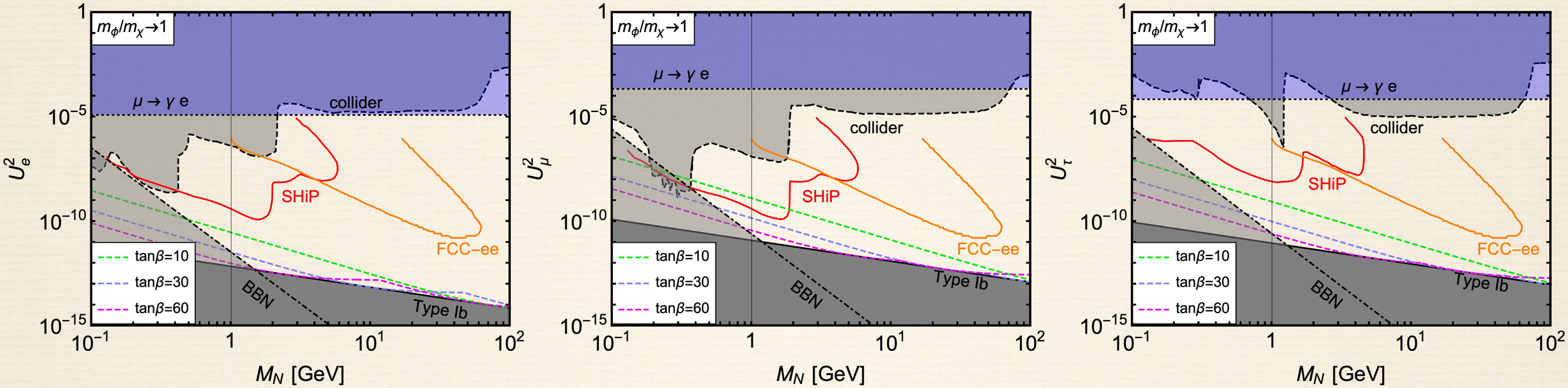
# Required Portal Coupling




- $\tan\beta = v_2/v_1 = 10$
- If $m_\phi >> m_\chi$, $M_N$, then the dark matter production only depends on $m_\phi/m_\chi$ instead of $m_\phi$ or $m_\chi$
  - dark sector dominance $y^4 \simeq 3.9 \times 10^{-23} \frac{m_\phi}{m_\chi}$
  - ν-Yukawa dominance $\left(Y_1^2 + Y_2^2\right)^2 \simeq 5.5 \times 10^{-22} \frac{m_\phi}{m_\chi}$
- $M_N$ is 1, $10^2$, $10^4$ GeV
- For heavier $M_N$, the ν-Yukawa dominance is favoured in most of the parameter space

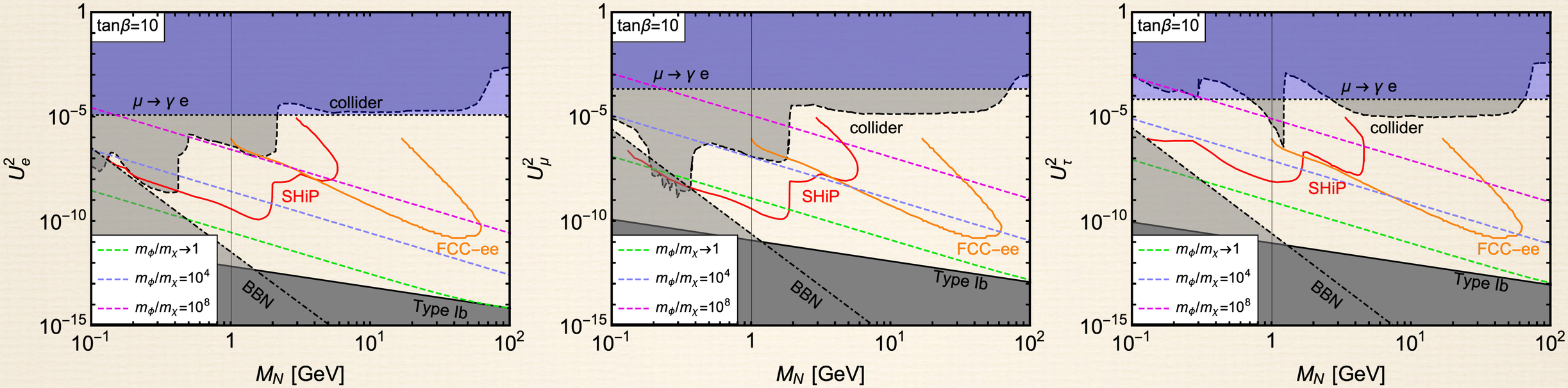
$$\frac{m_\phi}{m_\chi} \gtrsim 6.9 \times 10^{-9} \left(\frac{M_N}{1\text{GeV}}\right)^2 \frac{1}{\sin^2 2\beta}$$

# Relation to Experiments




- ν-Yukawa dominance is allowed above the coloured dashed lines
- Less constrained as tanβ increases
- The strongest constraint is given by $\nu_\mu$ mixing

# Relation to Experiments




- ν-Yukawa dominance is allowed above the coloured dashed lines
- More constrained as $m_\phi/m_\chi$ increases
- The strongest constraint is given by $\nu_\mu$ mixing

# Summary

- We discussed dark matter production in a minimal extension of type Ib seesaw model
- The DM-ν relation is constrained by experimental results when the heavy neutrino is GeV scale
- The results can be further constrained by future experiments
- The type Ib seesaw mechanism can be realised effectively to produce leptogenesis

Thank You!