Dark Matter in the Type Ib Seesaw Model

UNIVERSITY OF Southampton

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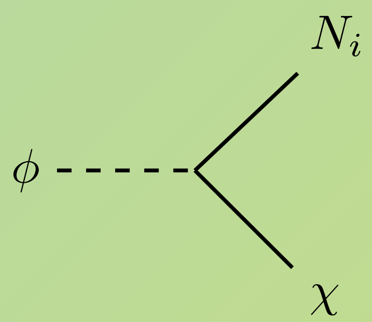
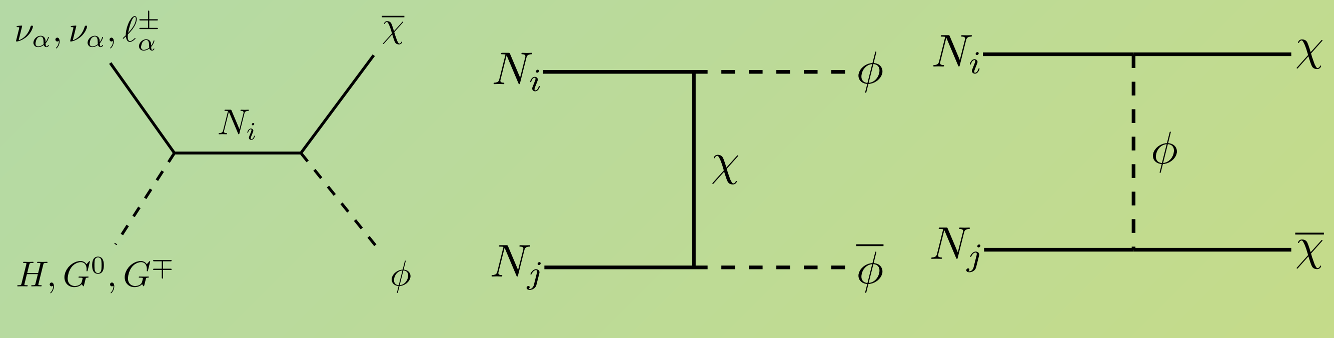
Neutrino Portal

- General neutrino portal: a dark scalar, a dark fermion and a heavy neutrino $y_i \phi \overline{\chi} N_i$
- heavy scalar scenario: dark scalar is heaviest and can decay



- Dark matter producing process

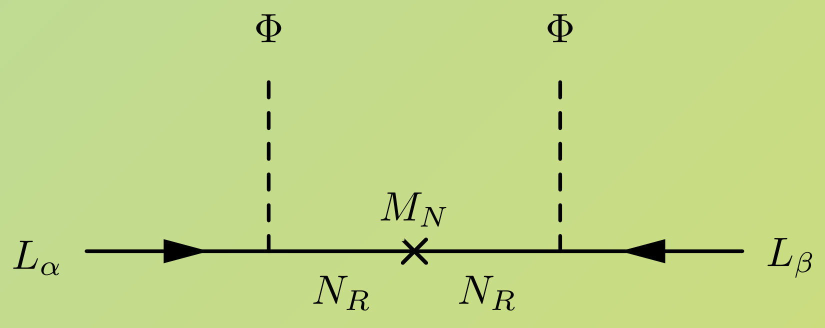


ν-Yukawa process $\propto Y^2 y^2$ dark sector process $\propto y^4$

- To have a connection between neutrino physics and dark matter, we are more interested in neutrino-Yukawa processes

Why Type Ib Seesaw Model?

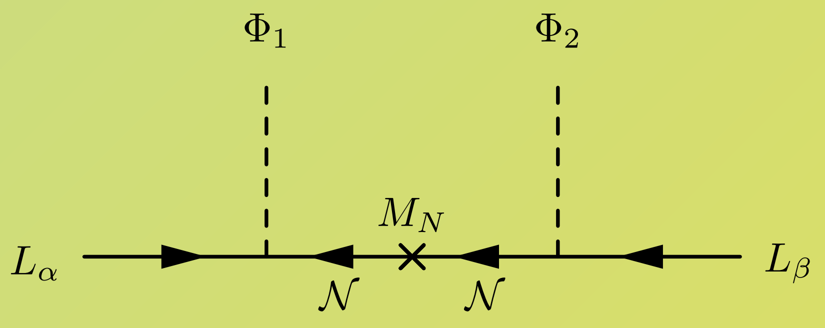
- Traditional type I seesaw mechanism (type Ia)



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

- To have a GeV scale heavy neutrino, the seesaw Yukawa coupling has to be roughly of order Y~10-7
- In the case of two RH neutrinos, the seesaw coupling would be too small to play a role in DM production if M_N is below 4 TeV

- Type Ib seesaw mechanism



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

- In type Ib seesaw model, the neutrino mass is generated by 2 different Higgs doublets, and there are 2 Yukawa couplings Y_1 and Y_2
- One of Y_1, Y_2 can be small while the other one is large which can play a role in DM production

Required Portal Coupling

- If $m_\phi \gg m_\chi$, MN, the dark matter production only depends on m_ϕ/m_χ instead of mφ or mχ
  - dark sector dominance

$$y^4 \simeq 3.9 \times 10^{-23} \frac{m_\phi}{m_\chi}$$

  - ν-Yukawa dominance

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

- For heavy MN, the ν-Yukawa dominance is favoured in most of the parameter space as there is a lower bound on m_ϕ/m_χ for ν-Yukawa dominance

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

The Model

- Particles and symmetries:
  - The Z_3 symmetry ensures the SM fermion mass is generated through type II 2HDM
  - the Z_2 symmetry ensures the dark fermion stable

	Q_α	$u_{R\beta}$	$d_{R\beta}$	L_α	$e_{R\beta}$	Φ_1	Φ_2	N_{R1}	N_{R2}	ϕ	$\chi_{L,R}$
$SU(2)_L$	**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_3	1	ω	ω	1	ω	ω	ω^2	ω^2	ω	ω	ω^2
Z_2	+	+	+	+	+	+	+	+	+	−	−

- Seesaw Lagrangian and neutrino portal

$$\mathcal{L}_{\text{seesawIb}} = -Y_{1\alpha} \overline{L}_\alpha \Phi_1 N_{R1} - Y_{2\alpha} \overline{L}_\alpha \Phi_2 N_{R2} - M_N \overline{N_{R1}^c} N_{R2} + \text{h.c.}$$

$$\mathcal{L}_{\text{N}_\text{R}\text{portal}} = y_1 \phi \,\overline{\chi_R} N_{R1}^c + y_2 \phi \,\overline{\chi_L} N_{R2} + \text{h.c.}$$

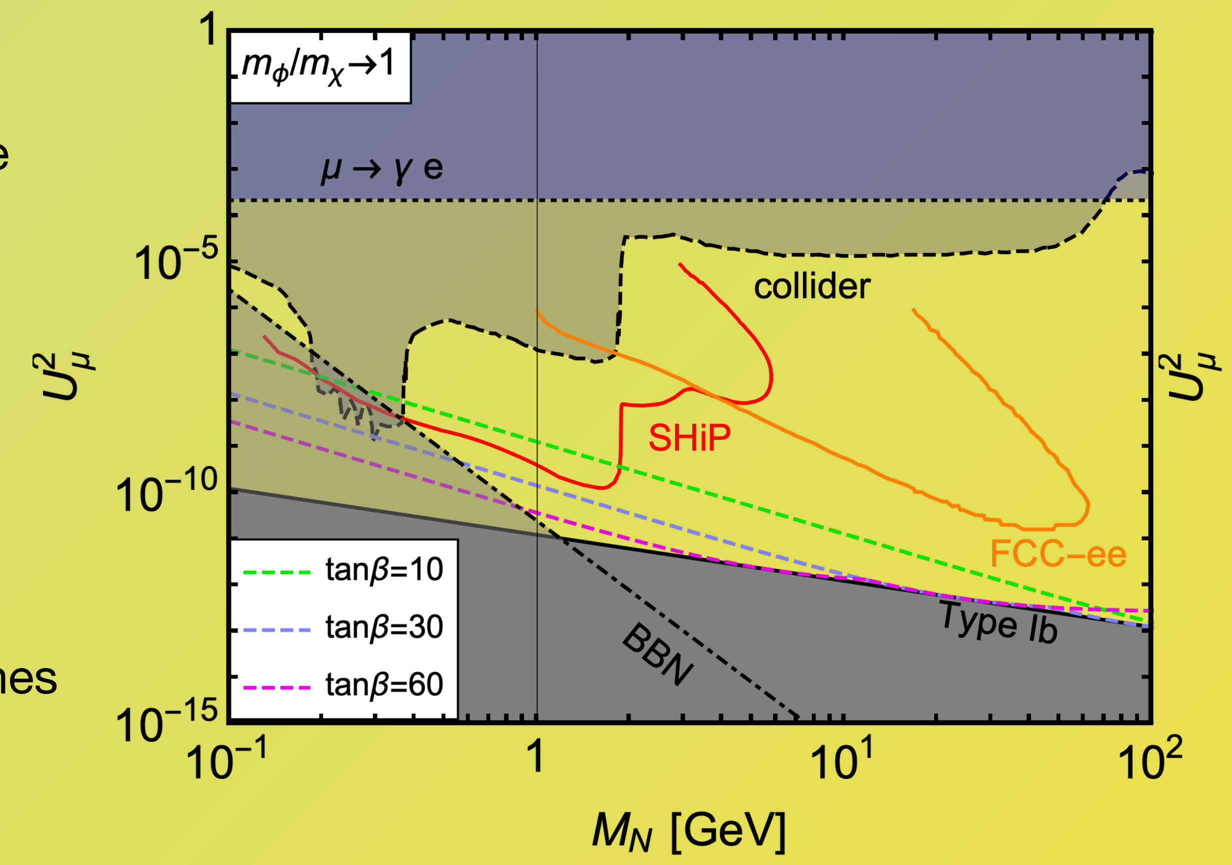
- The two RH neutrinos form a Dirac pair $\mathcal{N} = (N_{R1}^c, N_{R2})$

Relation to Experiments

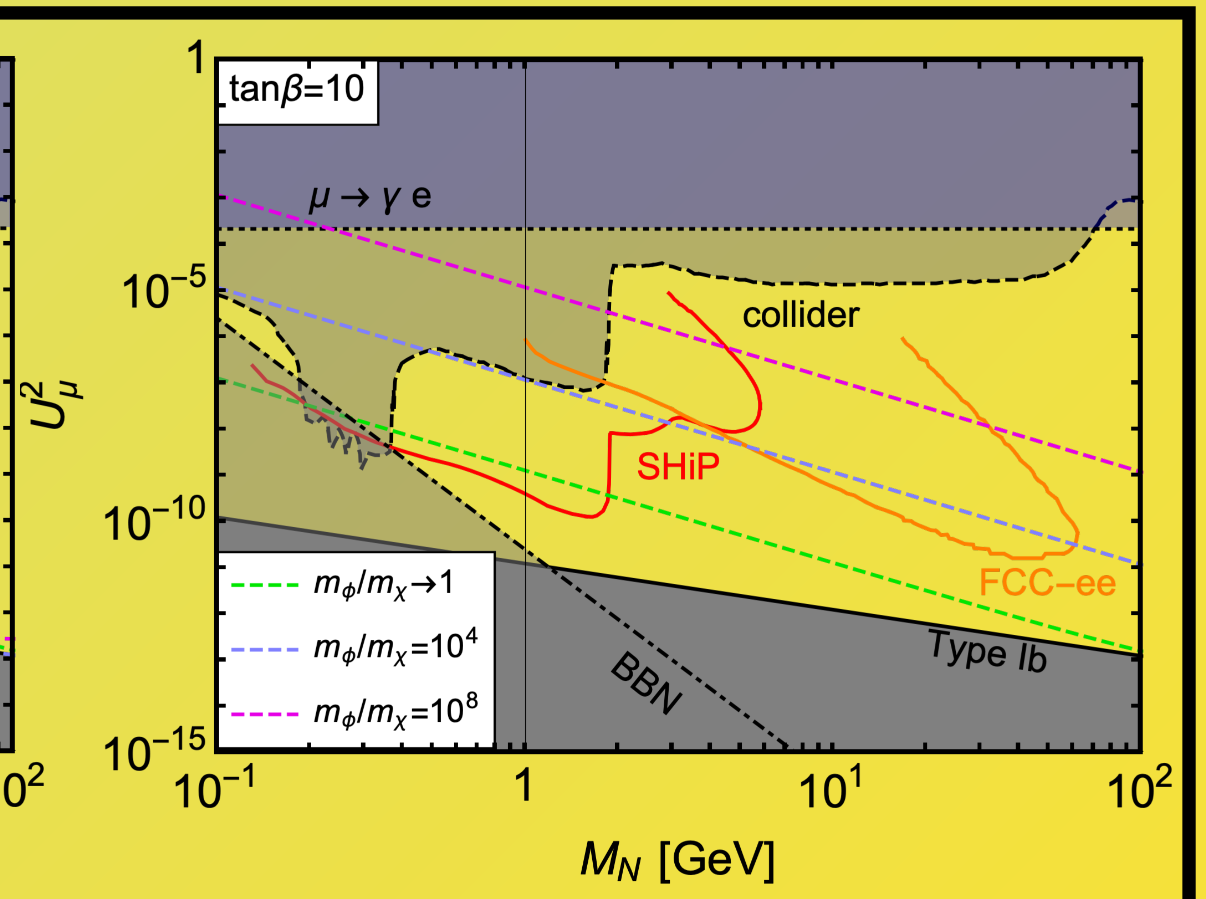
- tanβ is defined as the ratio of two VEVs in the 2HDM
- ν-Yukawa dominance is allowed above the coloured dashed lines for the corresponding conditions
- The sensitivity of future experiment SHiP and FCC-ee are marked out by red and orange lines
- U^2 is the strength of active-sterile neutrino mixing which takes the expression

$$U_\alpha^2 = (a_\alpha + b_\alpha \cos\delta_M) \frac{v_1^2 Y_1^2}{M_N^2} + (a_\alpha - b_\alpha \cos\delta_M) \frac{v_2^2 Y_2^2}{M_N^2}$$

- The strongest constraint is given by ν_μ mixing



- When the value of tanβ increases, the dashed coloured line moves downwards, which means the parameter space is less constrained



- When the value of the mass ratio m_ϕ/m_χ increases, the line moves upwards and the parameter space is more constrained