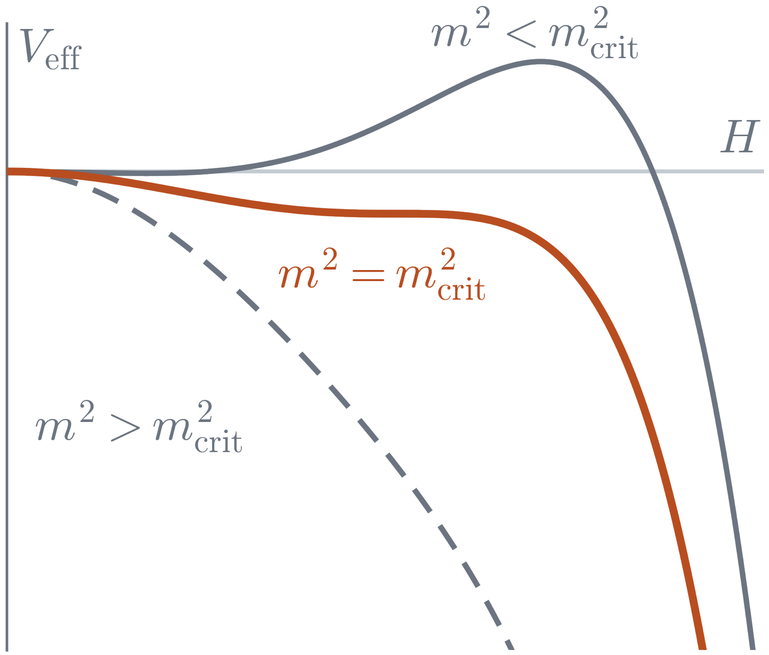
VAST 2026: From Vacuum Stability to Gravitational Waves · Real Jardín Botánico, CSIC 21-23 Oct 2026

Linking Neutrino Masses, Dark Matter, and Higgs Criticality via Gauged $U(1)_{B-L}$



In a metastable vacuum, the new fermions, not the Standard Model, set the bound on the Higgs mass

Eduardo Peinado

Instituto de Física, UNAM

work in progress in collaboration with P. Fitzpatrick and T. Steingasser

Dirección General de Asuntos del Personal Académico

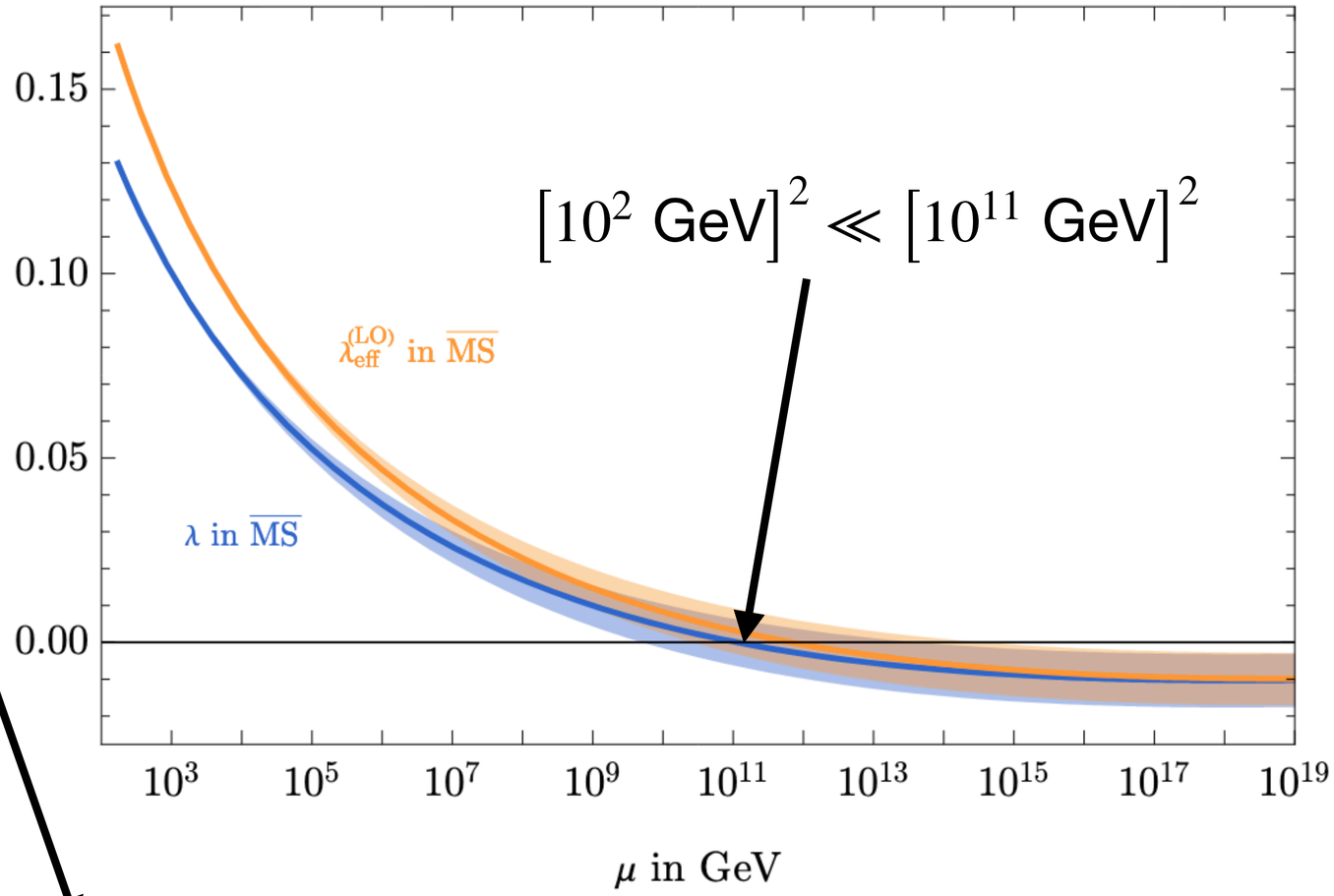
física teórica IFUNAM

Motivation

D. Buttazzo et al. 1307.3536

$$m_h^2 \lesssim |\beta_\lambda(\mu_I)|\,\mu_I^2 \ll \Lambda_{UV}^2$$

lowered by BSM physics?



Courtesy of T. Steingasser

VLFs
[2105.08617]
[2502.07876]
[2408.10297]

ALPs
[2412.03542]

Sparticles
[2502.07876]

Majoron
[2503.03825]

WIMPs
[2512.04158]

The low scale Majoron model

$$\mathcal{L}_{\nu_R} = \sum_i \overline{\nu_{R_i}} \partial\!\!\!/ \nu_{R_i} - \sum_{a,i} \boldsymbol{Y}_\nu^{ai} \bar{\ell}_L^a \tilde{H} \nu_{R_i} - \frac{1}{2} \sum_{i,j} \boldsymbol{Y}_R^{ij} S \overline{\nu_{R_i}^c} \nu_{R_j} + \text{h.c.}\,,$$

$$\boldsymbol{M_\nu} \equiv \frac{v^2}{\sqrt{2}} \boldsymbol{Y}_\nu \frac{1}{\boldsymbol{M_N}} \boldsymbol{Y}_\nu^T \qquad \boldsymbol{Y}_R = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & Y_R \\ 0 & Y_R & 0 \end{pmatrix}, \qquad \boldsymbol{Y}_\nu = \begin{pmatrix} 0 & Y_{12} & 0 \\ 0 & Y_{22} & 0 \\ 0 & Y_{32} & 0 \end{pmatrix}$$

$$\text{Tr}(\boldsymbol{Y}_\nu^\dagger \boldsymbol{Y}_\nu \boldsymbol{Y}_\nu^\dagger \boldsymbol{Y}_\nu) = \text{Tr}(\boldsymbol{Y}_\nu^\dagger \boldsymbol{Y}_\nu)^2 = |Y_\nu|^4 \qquad \Theta_\nu^a = \frac{\boldsymbol{Y}_\nu^{*a2}}{\sqrt{2}} \frac{v}{M_N} \qquad \text{and} \qquad |\Theta_\nu|^2 \equiv \sum_a |\Theta^a|^2$$

Enguita, Gavela, Steingasser arXiv:2503.03825

Low scale seesaw - gauge B-L

ϕ

Breaking scale to rule them all

M

heavy fermions

v_{B-L}

$M_{Z'}$

gauge boson

M_ϕ

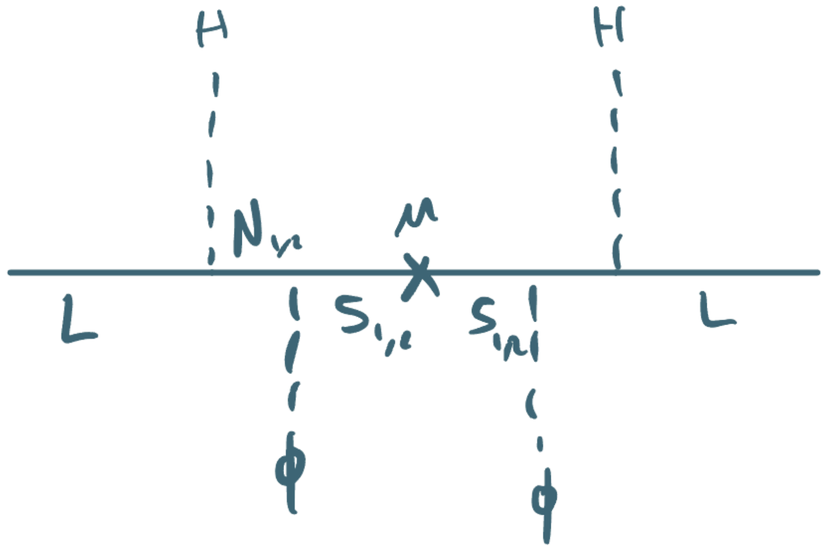
scalar mass

Fitzpatrick, EP, Steingasser (2026)

The inverse seesaw

$$(\nu_{L_i}, N_k^c, S_l)$$
$$L = (1, -1, 1)$$

$$M_\nu = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M \\ 0 & M^T & \mu \end{pmatrix}$$



$$m_\nu^{inv} = m_D (M^T)^{-1} \mu M^{-1} m_D^T$$

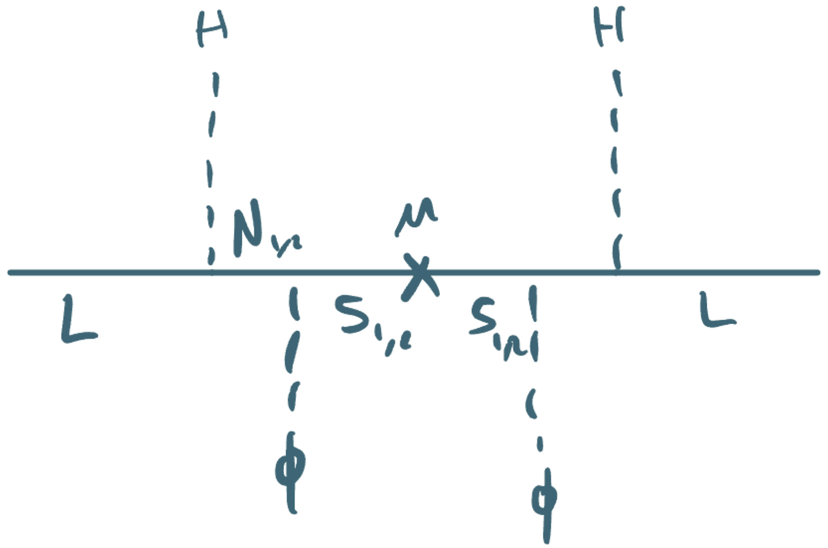
Mohapatra, Valle, PRD34(1986)1642

The inverse seesaw

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$$L = (1, -1, 1)$$

$$M_\nu = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M \\ 0 & M^T & \mu \end{pmatrix}$$

Breaking lepton number



$$m_\nu^{inv} = m_D (M^T)^{-1} \mu M^{-1} m_D^T$$

Mohapatra, Valle, PRD34(1986)1642

Gauging B–L: one N per family cancels the anomalies, and S stays neutral

	L_i	$N_{1,2,3}$	$S_{1,2,3}$	H	ϕ
$\mathrm{SU}(2)_L$	2	1	1	2	1
$\mathrm{U}(1)_Y$	$-\frac{1}{2}$	0	0	$\frac{1}{2}$	0
$\mathrm{U}(1)_{B-L}$	-1	-1	0	0	-1

$$\mathscr{L} \supset y_{ik}\,\bar{L}_i\tilde{H}N_k + Y_{kl}\,\bar{N}_k S_l\,\phi + \mu_{kl}\,\bar{S}^c_k S_l + \text{h.c.}, \qquad k,l = 1,2,3$$

anomaly cancelation

as in Type I seesaw

Anomalies per family (left-handed fields)

$$\sum q \;=\; \sum q^3 \;=\; \underbrace{0}_{\text{quarks}}\;\underbrace{-1}_{L,\,e^c}\;\underbrace{+1}_{N^c} \;=\; 0$$

Fitzpatrick, EP, Steingasser, in preparation

$U(1)_{B-L}$ gauge model

anomaly cancelation as in Type I seesaw

	L_i	$N_{1,2}$	$S_{1,2}$	N_3	S_3	H	η	ϕ
$\mathrm{SU}(2)_L$	2	1	1	1	1	2	2	1
$\mathrm{U}(1)_Y$	$-\frac{1}{2}$	0	0	0	0	$\frac{1}{2}$	$\frac{1}{2}$	0
$\mathrm{U}(1)_{B-L}$	-1	-1	0	-1	0	0	0	-1
$\mathbb{Z}_2$	$+$	$+$	$+$	$-$	$-$	$+$	$-$	$+$

$$\mathscr{L} = y_{ik}\bar{L}_i\tilde{H}N_k + Y_{kl}\bar{N}_k S_l\phi + \mu_{kl}\bar{S}_k^c S_l$$

$$+\tilde{Y}_3\bar{N}_3 S_3\phi + \tilde{\mu}_3\bar{S}_3^c S_3 + \tilde{y}_{i3}\bar{L}_i\tilde{\eta}N_3 + \text{h.c.}$$

Fitzpatrick, EP, Steingasser In preparation

$U(1)_{B-L}$ gauge model

anomaly cancelation as in Type I seesaw

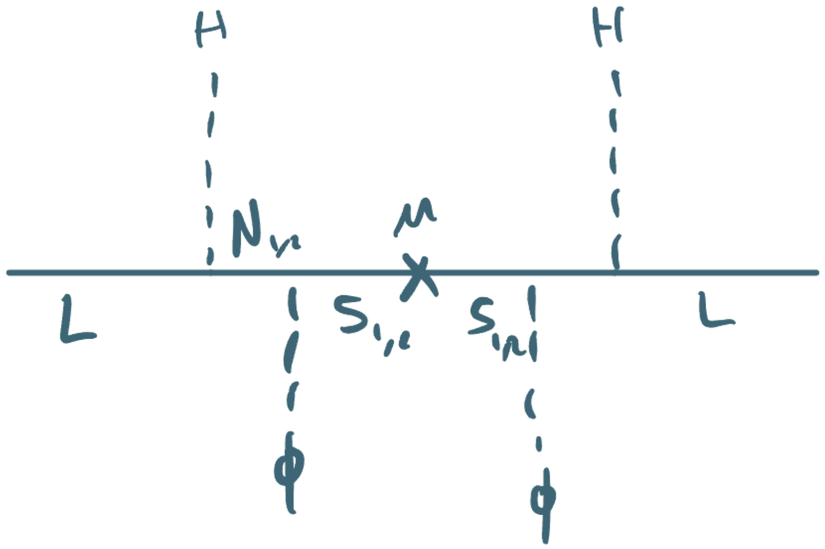
	L_i	$N_{1,2}$	$S_{1,2}$	N_3	S_3	H	η	ϕ
$\mathrm{SU}(2)_L$	2	1	1	1	1	2	2	1
$\mathrm{U}(1)_Y$	$-\frac{1}{2}$	0	0	0	0	$\frac{1}{2}$	$\frac{1}{2}$	0
$\mathrm{U}(1)_{B-L}$	-1	-1	0	-1	0	0	0	-1
$\mathbb{Z}_2$	$+$	$+$	$+$	$-$	$-$	$+$	$-$	$+$

$$\mathscr{L} = y_{ik}\bar{L}_i\tilde{H}N_k + Y_{kl}\bar{N}_k S_l\phi + \mu_{kl}\bar{S}_k^c S_l$$

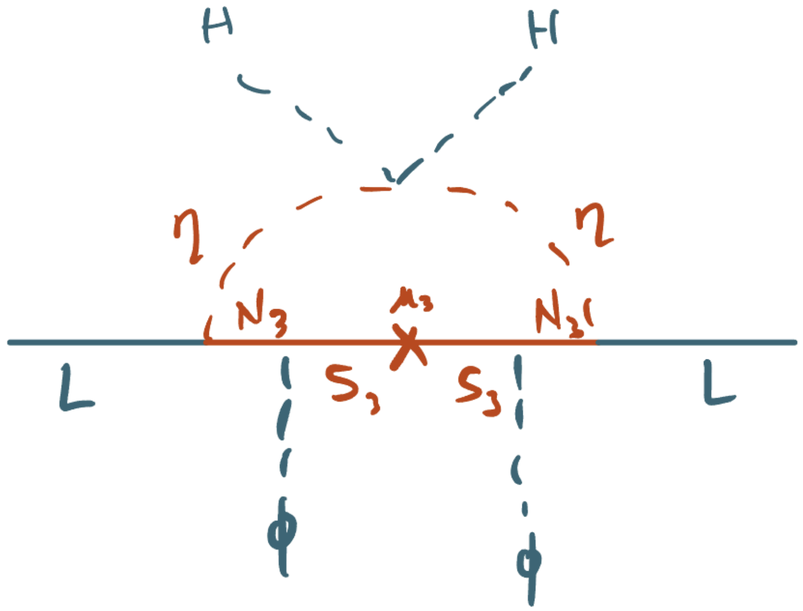
$$+\tilde{Y}_3\bar{N}_3 S_3\phi + \tilde{\mu}_3\bar{S}_3^c S_3 + \tilde{y}_{i3}\bar{L}_i\tilde{\eta}N_3 + \text{h.c.}$$

Fitzpatrick, EP, Steingasser In preparation

ν masses

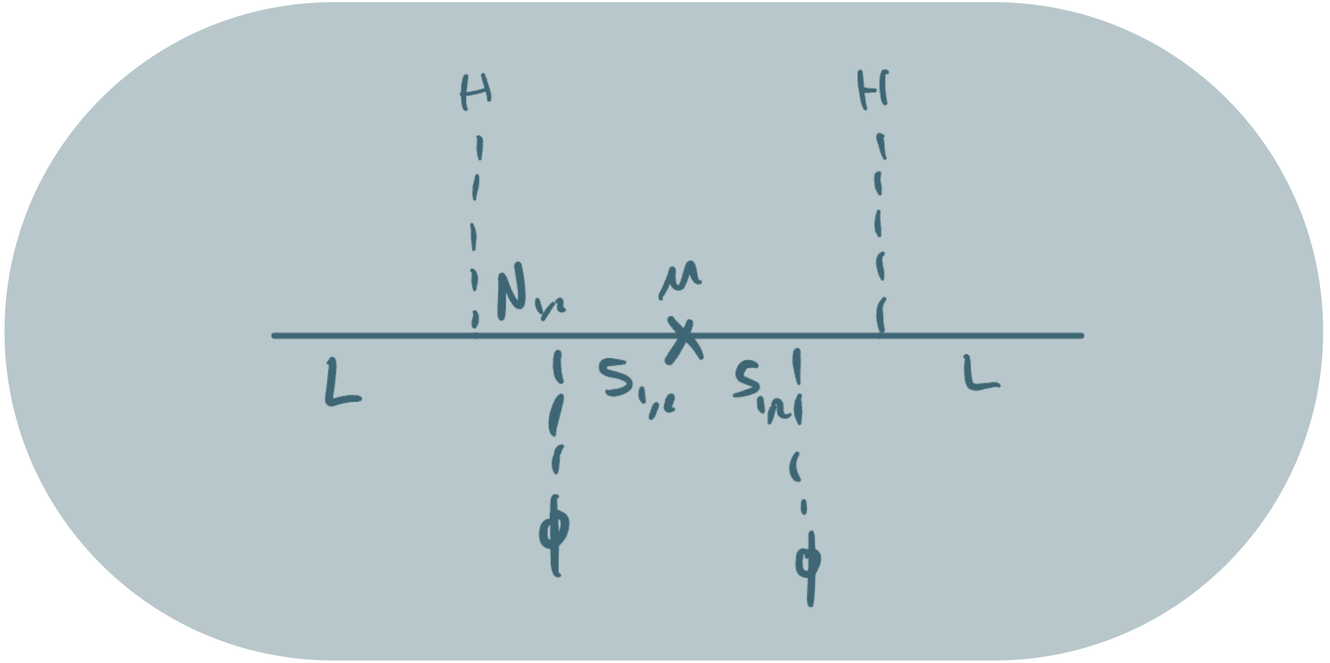


$$m_\nu^{inv} = m_D (M^T)^{-1} \mu M^{-1} m_D^T$$

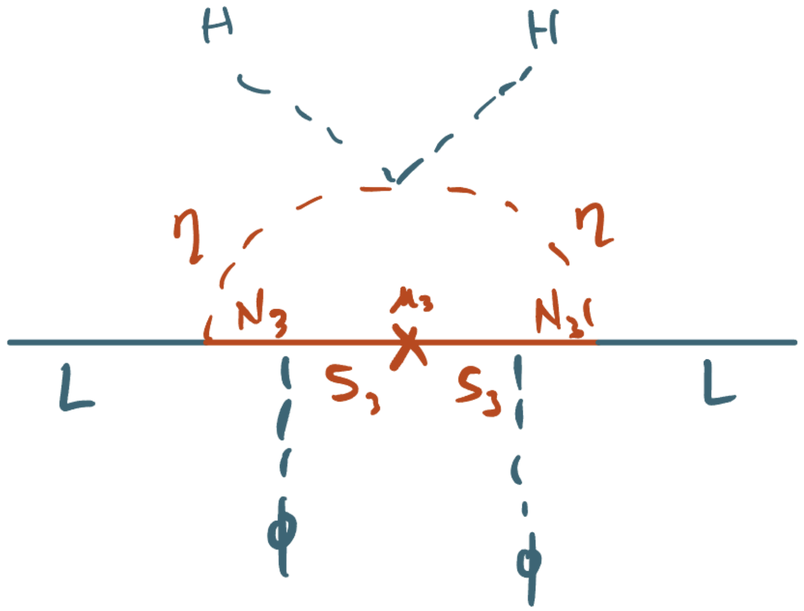


$$m_\nu^{sct} \simeq \frac{\lambda_5 \tilde{y}_{i3} \tilde{y}_{j3} v^2}{16\pi^2} \frac{\tilde{\mu}_3}{m_0^2},$$

ν masses



$$m_\nu^{inv} = m_D (M^T)^{-1} \mu M^{-1} m_D^T$$

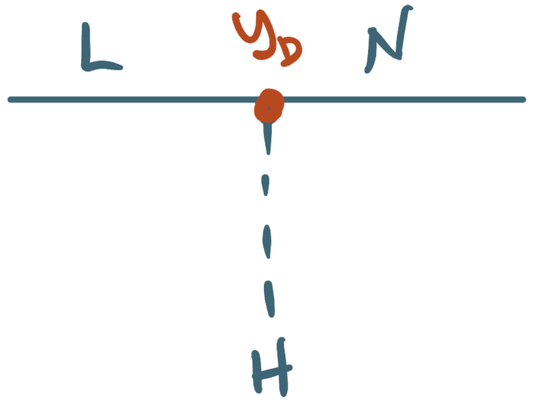


$$m_\nu^{sct} \simeq \frac{\lambda_5 \tilde{y}_{i3} \tilde{y}_{j3} v^2}{16\pi^2} \frac{\tilde{\mu}_3}{m_0^2},$$

Yukawa couplings

$$y_{ik}\bar{L}_i\tilde{H}N_k$$

$$m_\nu \sim y_D^2 \quad \frac{v^2}{M^2} \quad \mu$$

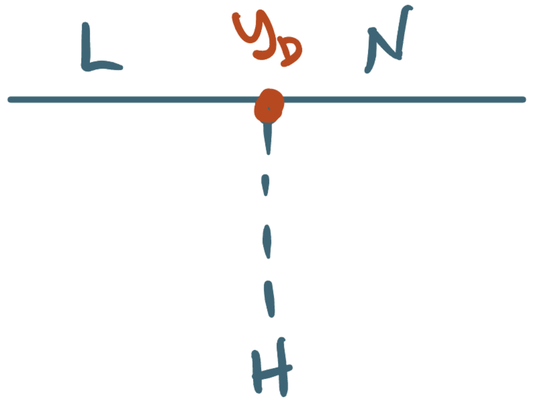


Yukawa couplings

$$y_{ik}\bar{L}_i\tilde{H}N_k$$

$$m_\nu \sim y_D^2 \quad \frac{v^2}{M^2} \quad \mu$$

eV $O(1)$ $10\ TeV$ KeV



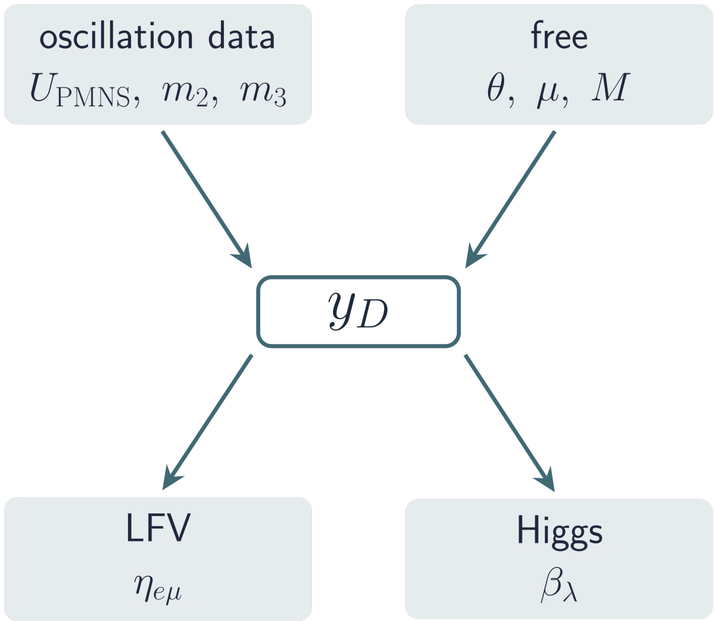
Casas–Ibarra: any μ, M and θ fit the data, and small μ means large Yukawas

$$y_D = \frac{1}{v_{SM}} U_{\rm PMNS} \sqrt{\hat{m}_\nu}\, R\, \mu^{-1/2}\, M^T$$

$$\hat{m}_\nu = \mathrm{diag}(0,\, m_2,\, m_3), \qquad R = \begin{pmatrix} 0 & 0 \\ \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}, \quad R^T R = \mathbf{1}_{2\times 2}$$

$$|y_D| \sim \frac{M}{v_{SM}} \sqrt{\frac{m_\nu}{\mu}}$$

small μ: large Yukawas and large mixing



Casas & Ibarra, Nucl. Phys. B 618 (2001) 171 · Fitzpatrick, Peinado, Steingasser, in preparation

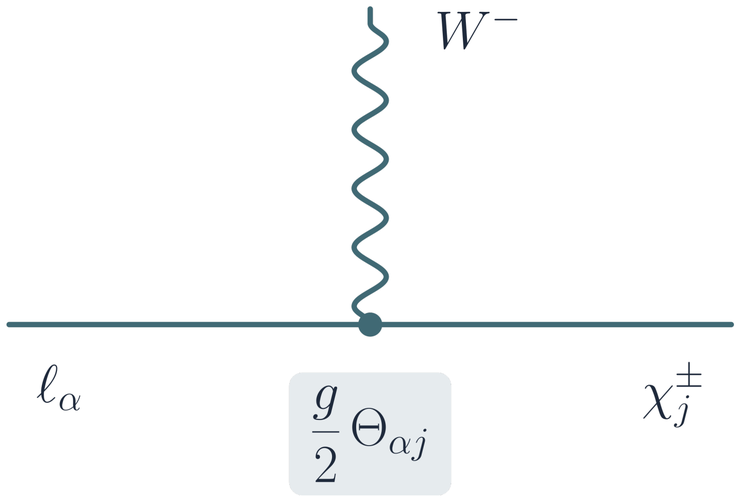
Light–heavy mixing is set by m_D/M, not by μ, so it can be large

$$m_\nu \simeq m_D\,(M^T)^{-1}\,\mu\,M^{-1}\,m_D^T$$ vanishes as μ → 0

$$\Theta \simeq m_D\,M^{-1}$$ no μ: set by the Yukawas and M

$$U_{\rm PMNS} \;\to\; (1-\eta)\,U_{\rm PMNS}, \qquad \eta = \tfrac{1}{2}\Theta\Theta^\dagger$$

the light mixing matrix is no longer unitary

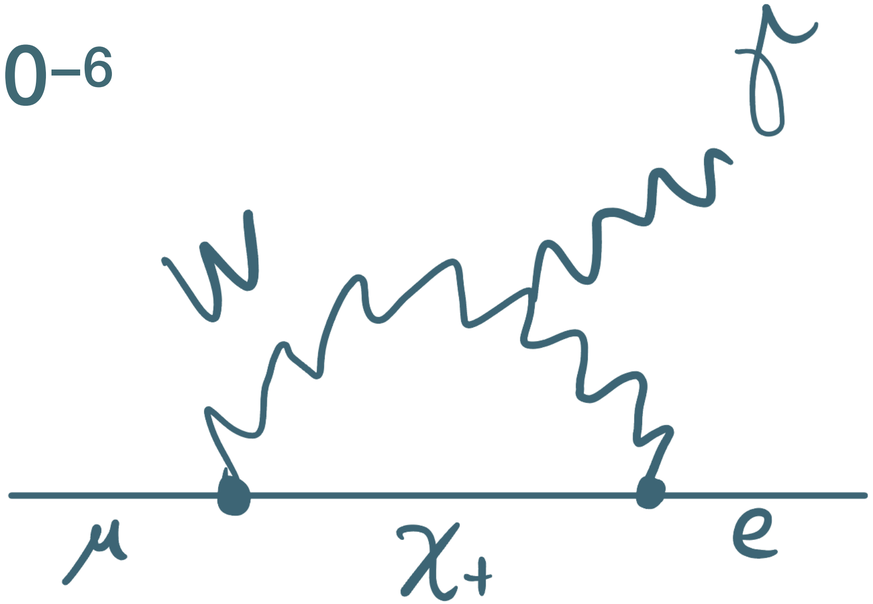


$$\chi^\pm \simeq \tfrac{1}{\sqrt{2}}(N \pm S), \qquad m_{\chi^\pm} \simeq M \pm \tfrac{\mu}{2}$$

μ → eγ measures $\eta_{e\mu}$: MEG II now requires $|\eta_{e\mu}| < 7 \times 10^{-6}$

$$\mathrm{BR}(\mu \to e\gamma) = \frac{3\alpha}{2\pi}\left|\left(\Theta\,\hat{G}_\gamma\,\Theta^\dagger\right)_{e\mu}\right|^2 \simeq \frac{3\alpha}{2\pi}\left|\eta_{e\mu}\right|^2 \qquad (M \gg M_W)$$

$$\hat{G}_\gamma = \mathrm{diag}\, G_\gamma\left(M_k^2/M_W^2\right) \;\to\; \tfrac{1}{2}, \qquad \eta = \tfrac{1}{2}\Theta\Theta^\dagger$$

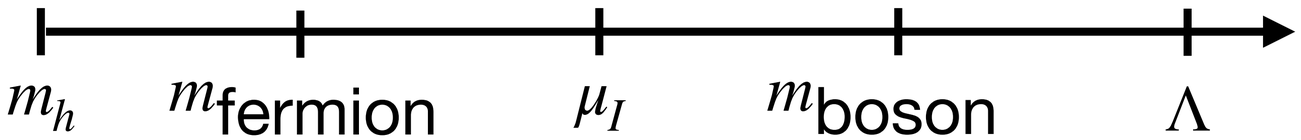


MEG II: $\mathrm{BR} < 1.5 \times 10^{-13} \quad \Rightarrow \quad \left|\eta_{e\mu}\right| < 7 \times 10^{-6}$

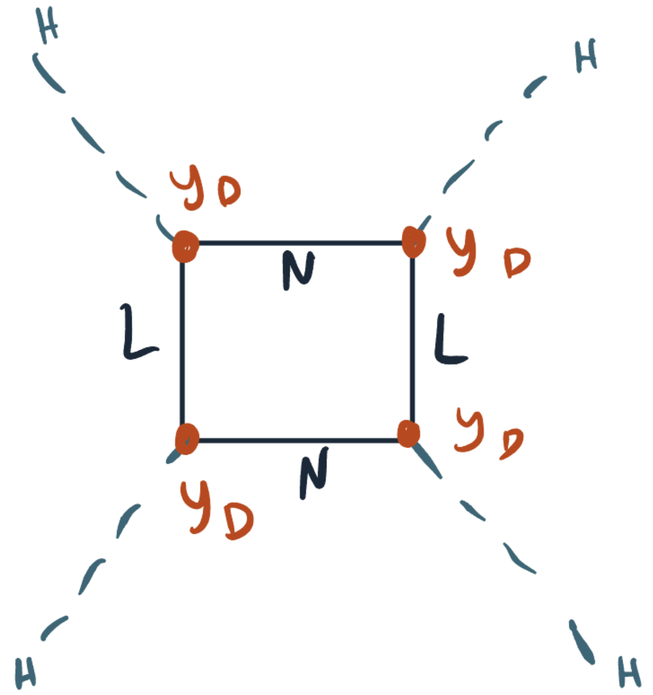
It bounds the off-diagonal mixing: flavour-aligned Yukawas can stay large

MEG II (2025), 2021–2022 data: BR(μ⁺ → e⁺γ) < 1.5 × 10⁻¹³ at 90 % CL

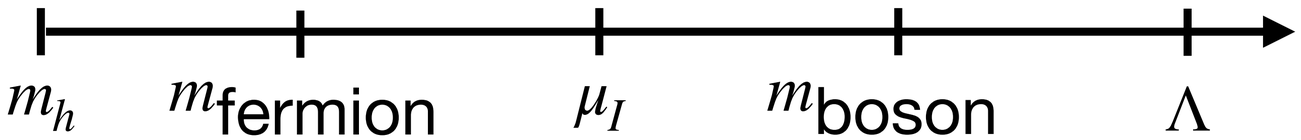
Higgs



$$\Delta\beta_\lambda^{(1)} = \frac{1}{(4\pi)^2}\left[-2\mathrm{Tr}(Y^\dagger Y Y^\dagger Y) + 4\lambda\mathrm{Tr}(Y^\dagger Y)\right]$$

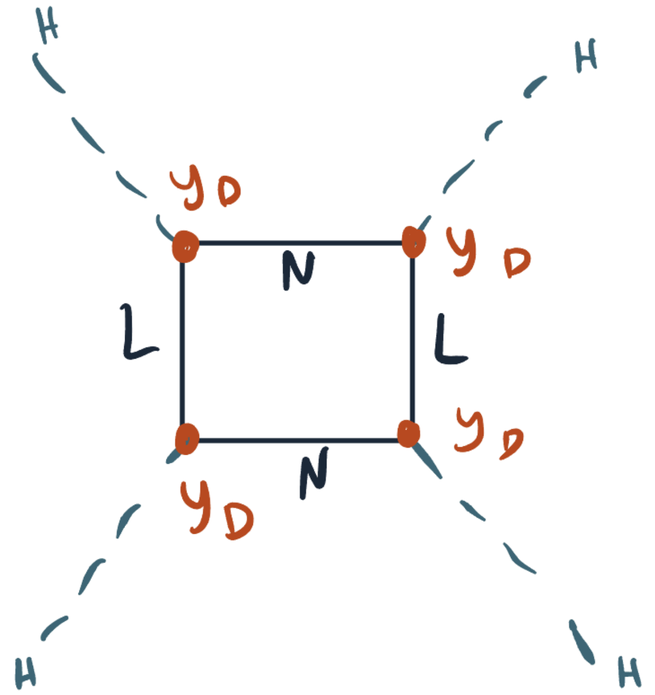


Higgs

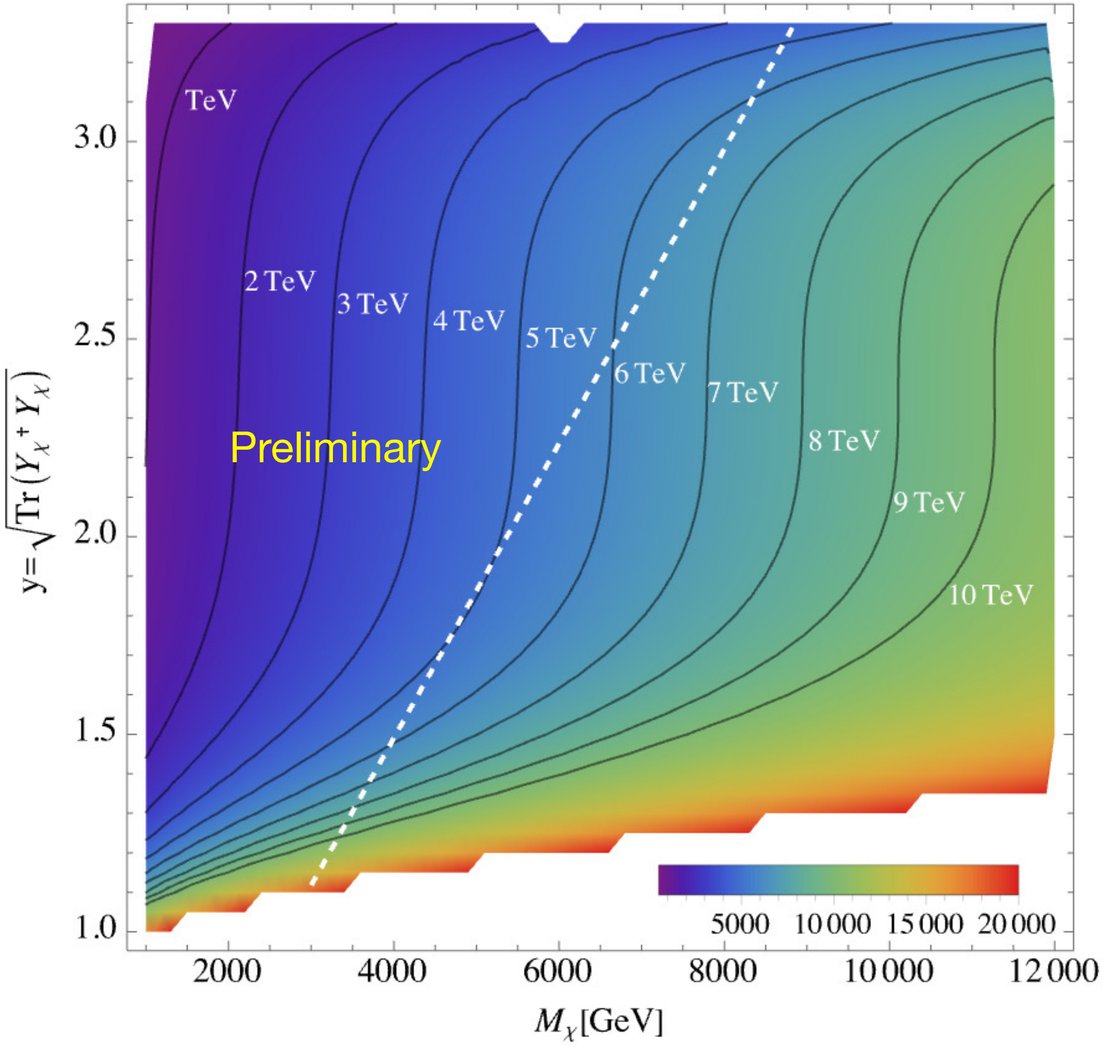


$$\Delta\beta_\lambda^{(1)} = \frac{1}{(4\pi)^2}\left[-2\mathrm{Tr}(Y^\dagger Y Y^\dagger Y) + 4\lambda\mathrm{Tr}(Y^\dagger Y)\right]$$

$$\Delta\beta_\lambda^{(1)} \simeq -\frac{2}{(4\pi)^2}\left[\mathrm{Tr}(Y^\dagger Y Y^\dagger Y)\right]$$

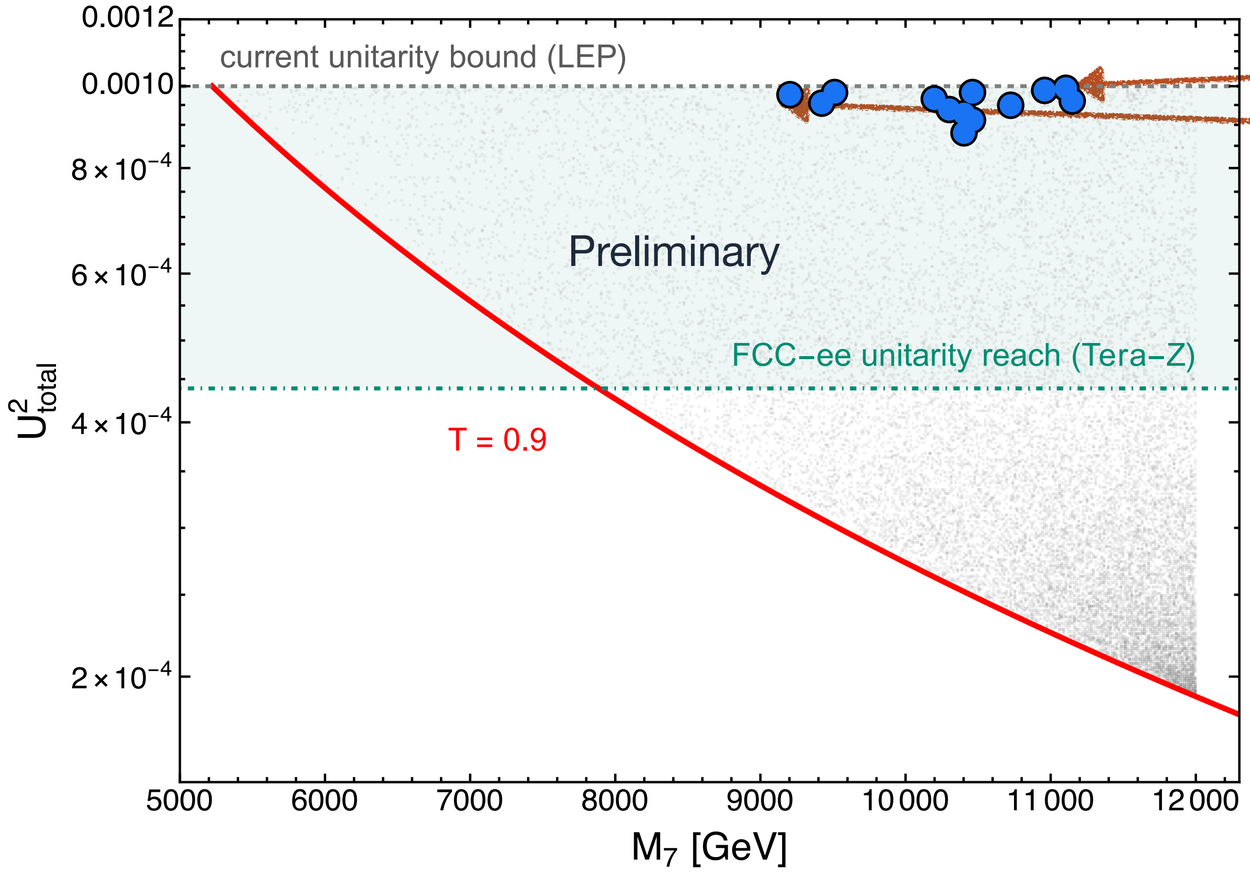


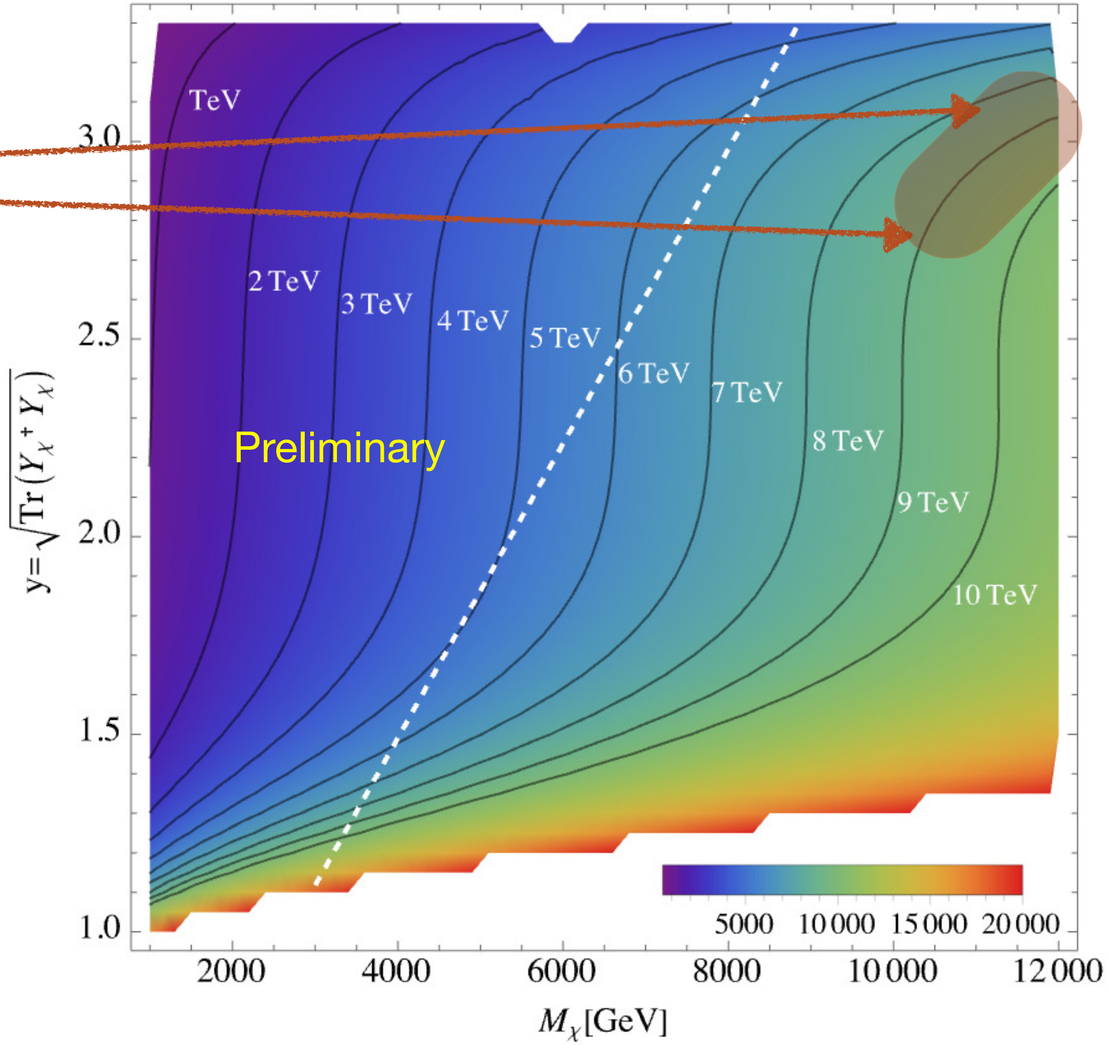
Higgs mass bound heavy-light



Fitzpatrick, EP, Steingasser (2026)

Higgs mass bound heavy-light





Fitzpatrick, EP, Steingasser (2026)

Near the Z′ resonance, χ^- gets $\Omega h^2 \approx 0.12$ with a small g_{B-L}

After B–L breaking, the dark fermions form a pseudo-Dirac pair

$$m_{\chi^\pm} \simeq M \pm \tfrac{1}{2}\,\tilde{\mu}_3, \qquad \chi^- = \mathrm{DM}$$

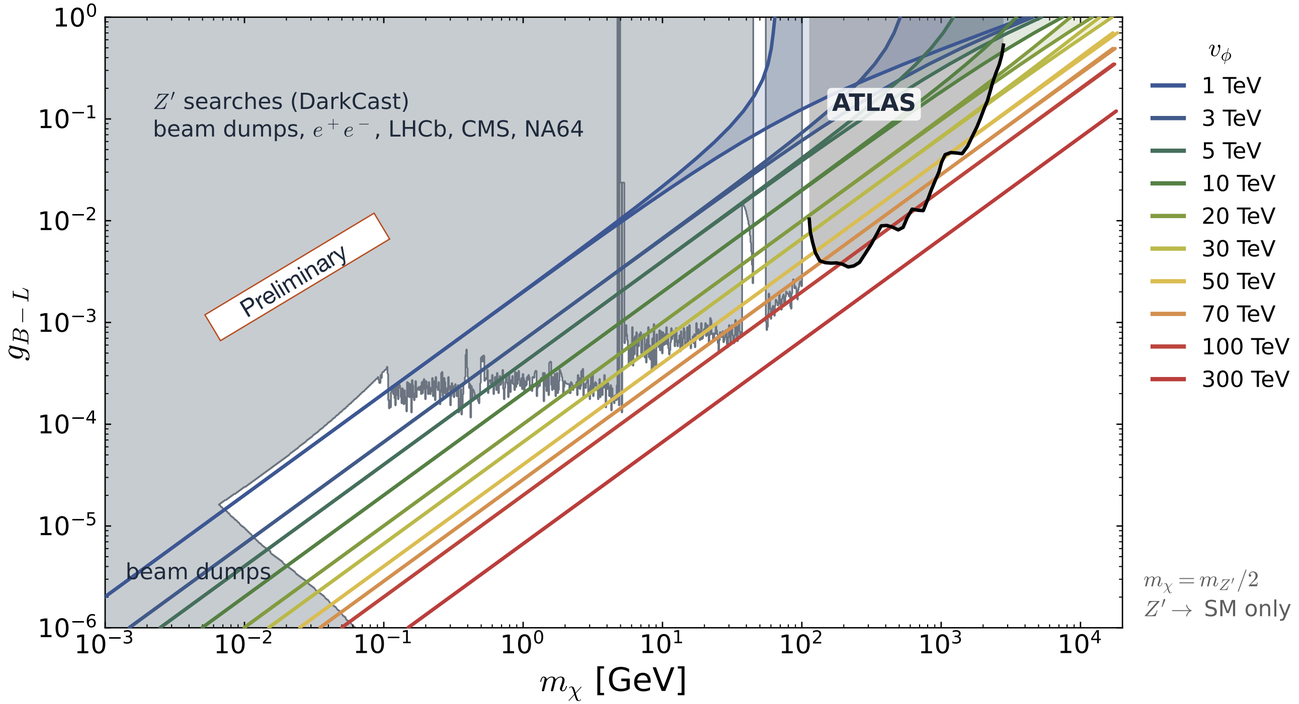
At freeze-out ($T_f \sim M/20$, far above the splitting): one Dirac fermion with a chiral Z′ coupling

$$\mathcal{L} \supset -\,g_{B-L}\,Z'_\mu\,\bar{\Psi}\gamma^\mu P_R \Psi, \qquad \Psi = N_3 + S_3$$

The observed abundance sits on the Z′ resonance

$$2\,m_\chi \simeq m_{Z'} = g_{B-L}\,v_\phi$$

Fitzpatrick, Peinado, Steingasser, in preparation



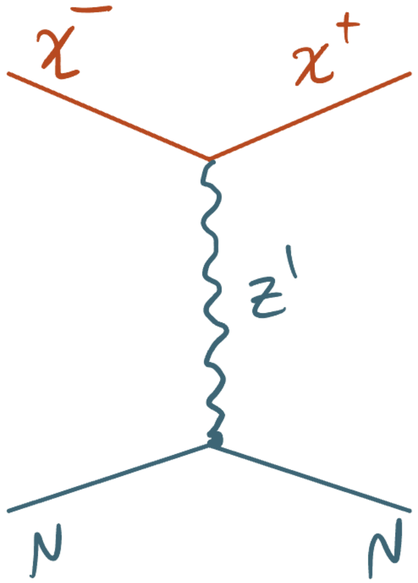
Solid: $\Omega h^2 \approx 0.12$ · shaded: $\Omega h^2 < 0.12$ · v_ϕ from 1 to 300 TeV

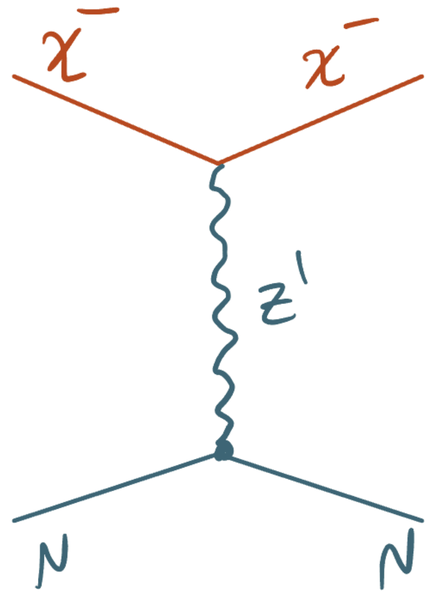
Direct detection: the splitting closes the inelastic Z′ channel

Z′ inelastic
$\chi^- N \to \chi^+ N$

$$\delta m = \tilde{\mu}_3 > \tfrac{1}{2}\,\mu_{\chi A}\,(v_{\rm esc} + v_E)^2 \simeq 410\ \text{keV}\ (\text{Xe})$$

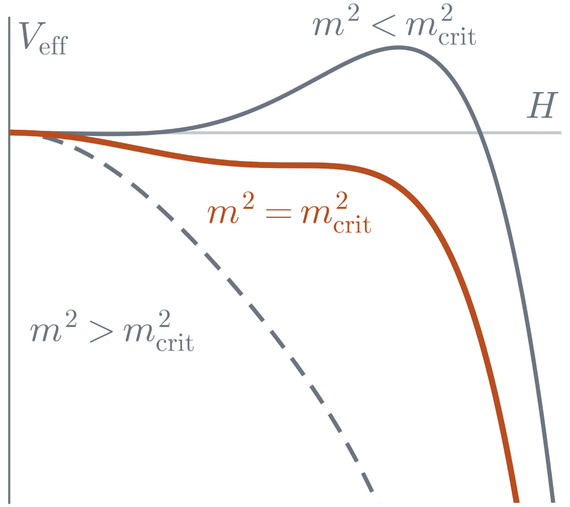
closed for the benchmark splitting of 500 keV





One gauged $U(1)_{B-L}$ links neutrino masses, dark matter and Higgs criticality

1. Neutrino masses come from a tree-level inverse seesaw plus a scotogenic-like loop
2. In a metastable vacuum, the sterile fermions, not the SM, **set the Higgs-mass bound**
3. The Z_2-odd fermion is the dark matter, with the observed abundance near the Z′ resonance



Fitzpatrick, Peinado, Steingasser, in preparation