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Dark matter and the elusive Z' in a dynamical ISS scenario

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Low scale Inverse Seesaw (ISS)

(Mohapatra & Valle, 1986)

- Add three generations of SM singlet pairs, N_R and N'_R
- Inverse seesaw basis (ν_L, N_R, N'_R):

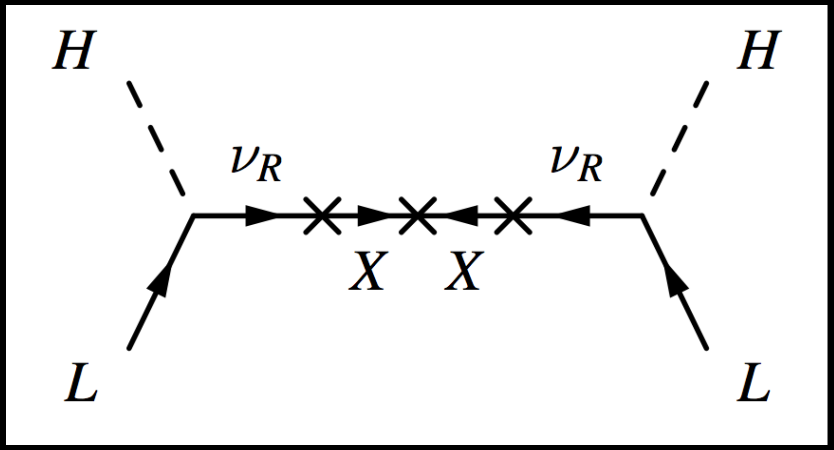
$$M^{\nu} = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M_R \\ 0 & M_R^T & \mu_X \end{pmatrix}$$

$$\Rightarrow \begin{cases} \text{3 light } \nu : m_\nu \approx \frac{(Y_\nu v)^2}{(Y_\nu v)^2 + M_R^2} \mu_X \\ \text{3 pseudo-Dirac pairs} : m_{N^\pm} \approx M_R \pm \mu_X \end{cases}$$

- Y_ν~O(1) and M_R ~ 1TeV testable at the colliders and low energy experiments.
- Large mixings (active-sterile) and light sterile neutrinos are possible

M_R = (0.1 MeV, 10^6 GeV)

μ_X = (0.01 eV, 1 MeV)



- Original ISS embedded in superstring (E6) models. Other explanations to the smallness of μ_X from SUSY or GUT

(Bazzocchi et al. 2010, Malinsky et al. 2005)

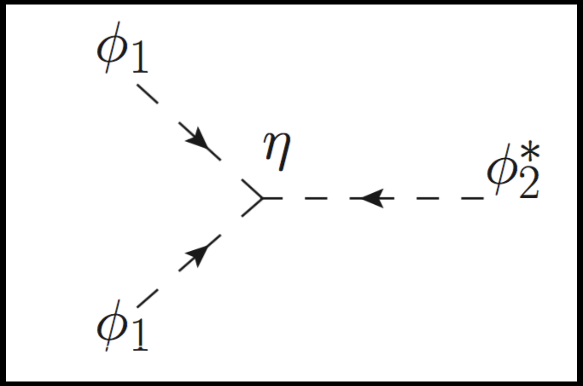
Scalar sector

- Promote μ_X to a dynamical quantity by gauging B–L
- B–L spontaneously broken by two new scalars ϕ_1, ϕ_2

(Bazzocchi, 2011
Khalil, 2010
Basso et al. 2012
Ma and Srivastava, 2014)

- Seesaw in the scalar sector: $m_{\phi_1} \sim m_{\phi_2} \sim O$ (TeV), $\langle \phi_1 \rangle \gtrsim$ TeV

$$v_2 \simeq \frac{\sqrt{2}\eta v_1^2}{m_2^2}$$ ~ keV



$$V = \frac{m_H^2}{2} H^\dagger H + \frac{\lambda_H}{2}(H^\dagger H)^2 + \frac{m_1^2}{2}\phi_1^*\phi_1 + \frac{m_2^2}{2}\phi_2^*\phi_2 + \frac{\lambda_1}{2}(\phi_1^*\phi_1)^2 + \frac{\lambda_2}{2}(\phi_2^*\phi_2)^2 \quad (2.7)$$
$$+ \frac{\lambda_{12}}{2}(\phi_1^*\phi_1)(\phi_2^*\phi_2) + \frac{\lambda_{1H}}{2}(\phi_1^*\phi_1)(H^\dagger H) + \frac{\lambda_{2H}}{2}(\phi_2^*\phi_2)(H^\dagger H) - \eta(\phi_1^2\phi_2^* + \phi_1^{*2}\phi_2).$$

Leptonic sector

$$-\mathcal{L}_\nu = \bar{L} Y_\nu \widetilde{H} N_R + \overline{N_R^c} M_N N_R' + \phi_2 \overline{N_R^c} Y_N N_R + \phi_2^* \overline{(N_R')^c} Y_N' N_R' + \phi_1^* \overline{\chi_L} Y_\chi \chi_R + \text{h.c.},$$

- Chiral pattern in neutrino sector dictates the existence of extra fields to cancel triangle anomalies ($U(1)_{B-L}{}^3$ and $U(1)_{B-L}$-gravity)

Particle	ϕ_1	ϕ_2	ν_L	N_R	N_R'	χ_R	χ_L	ω
$U(1)_{B-L}$ charge	$+1$	$+2$	-1	-1	$+1$	$+5$	$+4$	$+4$
Multiplicity	1	1	3	3	3	1	1	1

basis $(\nu_L^c, N_R, N_R', \chi_L^c, \chi_R)$:

$$M = \left(\begin{array}{ccc|cc} 0 & Y_\nu \widetilde{H} & 0 & 0 & 0 \\ Y_\nu^T \widetilde{H}^\dagger & Y_N \phi_2 & M_N & 0 & 0 \\ 0 & M_N^T & Y_N' \phi_2^* & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & Y_\chi \phi_1^* \\ 0 & 0 & 0 & Y_\chi^T \phi_1 & 0 \end{array}\right).$$

- After EWSB:
  - 3 active neutrinos
  - 3 pseudo-Dirac pairs ~ TeV
  - 1 new gauge boson Z' ~ TeV
  - 1 Dirac pair $\chi = (\chi_L, \chi_R)$ ~TeV (DM)
  - 1 massless ω

Interesting phenomenology

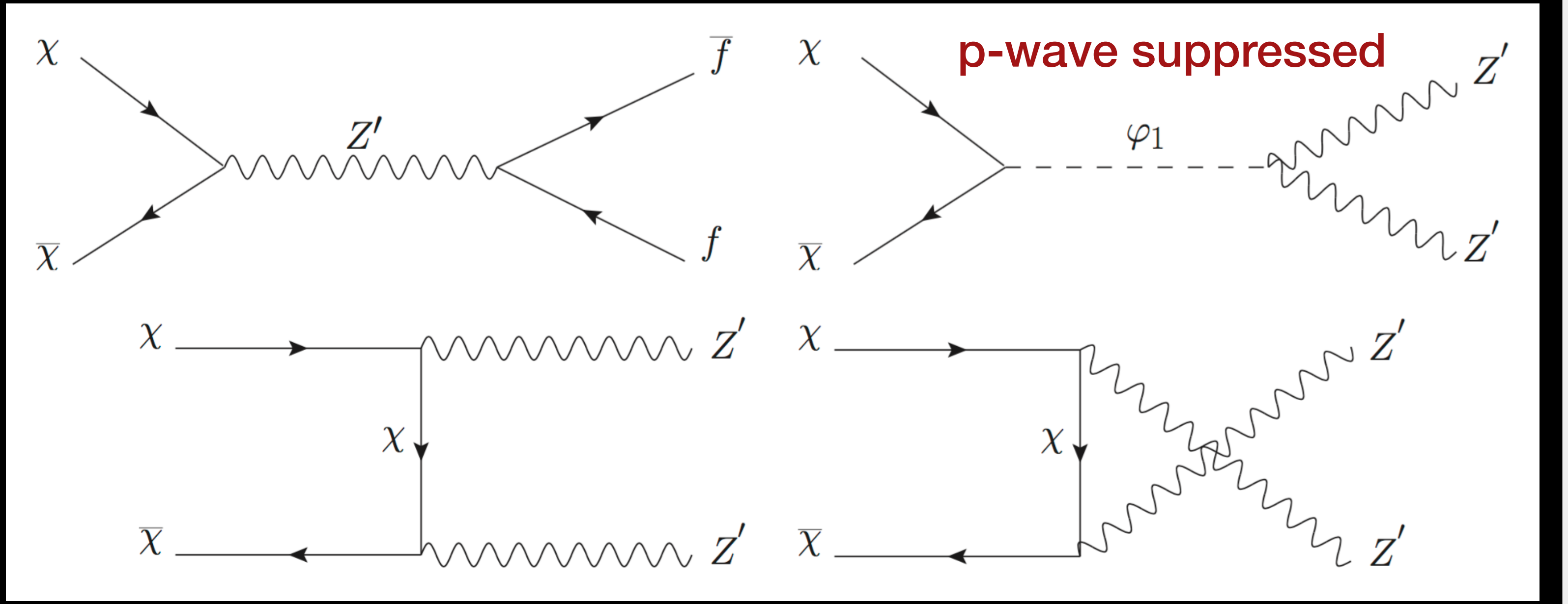
- Deviations in Higgs observables: limit on mixing angle between H^0 and ϕ_1
- Additional Z' boson at the TeV scale: strong B-L couplings to leptons.
  - Typical BRs: ~70% (87%) invisible, ~12% quarks, ~18% charged leptons
  - $Z' \rightarrow e^+ e^-$, $\mu^+ \mu^-$ resonant searches
  - compare to SSM, O(1) difference
- Perturbativity limit: $g_{BL} \cdot q_{max} \leq 2\pi$
- Dark sector with a thermal DM candidate which can yield the correct relic density and passes the DM direct and indirect detection constraints
- Massless fermion which contributes to ΔN_{eff}

Dark sector

$$\mathcal{L}_{DM} = -g_{\rm BL}\bar{\chi}\gamma^\mu(5P_R + 4P_L)\chi Z'_\mu + \frac{1}{2}M^2_{Z'}Z'_\mu Z'^\mu - m_\chi\bar{\chi}\chi,$$

▶ Indirect detection / relic density: Main annihilation channels are

- $\chi\,\chi \to f\,f$
- $\chi\,\chi \to Z'\,Z'$

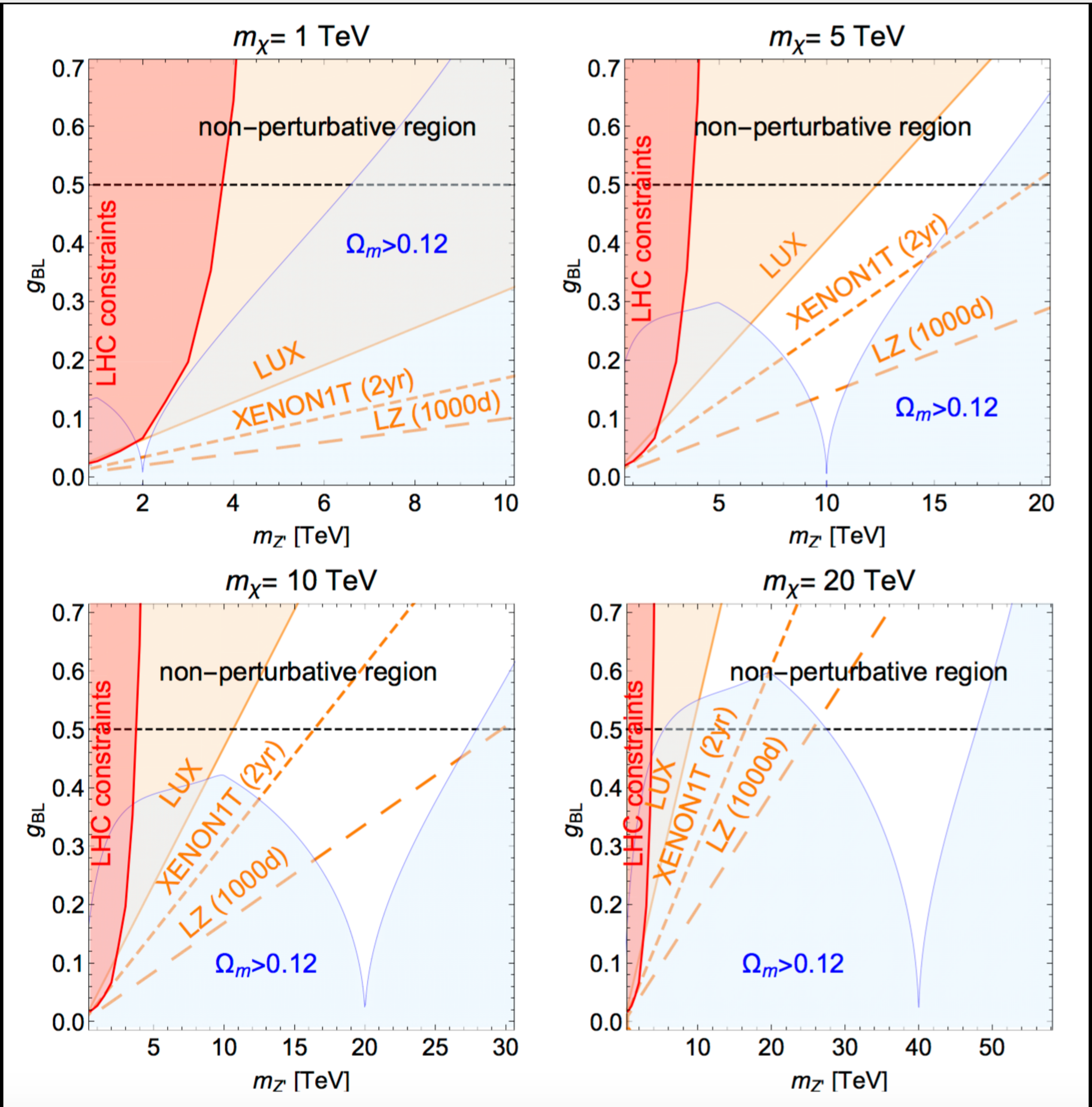


▶ Direct detection:

- DM - SM interactions: vector-vector (SI cross-section) or axial-vector (-> no signal in direct detection).

▶ Neff:

- ω contributes (via Z' interactions) to the number of relativistic degrees of freedom in the early Universe
- mZ' ~ 10 TeV, gBL~0.1, ω would freeze out at ~ 4 GeV, before QCD phase transition: ΔNeff ~ 0.03. Maybe within EUCLID sensitivity?



m_χ= 1 TeV
non–perturbative region
LHC constraints
Ω_m>0.12
LUX
XENON1T (2yr)
LZ (1000d)
g_{BL}
$m_{Z'}$ [TeV]
m_χ= 5 TeV
non–perturbative region
LHC constraints
LUX
XENON1T (2yr)
LZ (1000d)
Ω_m>0.12
m_χ= 10 TeV
non–perturbative region
LHC constraints
LUX
XENON1T (2yr)
LZ (1000d)
Ω_m>0.12
m_χ= 20 TeV
non–perturbative region
LHC constraints
LUX
XENON1T (2yr)
LZ (1000d)
Ω_m>0.12