SILAFAE 2014

Ruta N, Medellin -Colombia
November 24th -28th 2014

X Latin American Symposium of High Energy Physics

SILAFAE is one of the most important events in High Energy Physics in Latin America, where theorists and experimentalists meet to discuss recent advances of different topics in High Energy Physics.

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More information and registration:
http://gfif.udea.edu.co/xsilafae

Registration deadline: 14 July 2014
The proceedings will be published as a separate volume of Nuclear Physics B - Proceedings Supplements

Scientific secretariat (UdeA):
Dilia Portillo
Marta Sánchez
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Avalaibe finanancial help for students and youth researchers

Opening talk
John Ellis. (King's College)

Dark matter
Alejandro Ibarra. (TUM)

Flavor and CP Violation
Yosef Nir. (Weizmann)

SUSY and BSM
Alberto Casas. (IFT, UAM)

Higgs Physics
Cristophe Grojean (CERN)

Cosmology
Leonardo Senatore (MIT)

Neutrino Physics
Gianluigi Fogli (Bari U.)

Perturbative QCD
Frank Petriello. (Stanford U.)

Nonperturbative QCD
Boris Z. Kopeliovich (USM)

Amplitudes in the LHC era
Pierpaolo Mastrolia (CERN)

Quantum Gravity
Esperanza Lopez (UAM)

Dark Matter direct detection experiments
Elena Aprile. (Columbia U.)

AMS-02 and DM searches in space
Javier Berdugo (CIEMAT)

LHCb results
To be confirmed (TBC)

SUSY and BSM LHC results.
TBC

Higgs LHC results
TBC

Cosmology results (Planck)
Martin Bucher (Orsay, LPT)

Neutrino Experiments
Juan José Gómez Cadenas. (UV)

Dark Energy results
Juan Estrada (Fermilab)

Auger Experiment results
Esteban Roulet. (CAB/CNEA)

Alice results.
TBC

ANDES
Osvaldo Civitarese. (UNLP)

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Universidad del Valle

Universidad del Tolima

ITM Institución Universitaria

Dark matter realization of the Weinberg neutrino mass operator

Diego Restrepo[1]

[1]Instituto de Física
Universidad de Antioquia
Phenomenology Group (GFIF: 4+1+4+2+$\cdots$)
http://gfif.udea.edu.co

Focus on
arXiv:1308.3655
In collaboration with
Carlos Yaguna (Münster University) & Oscar Zapata (UdeA)

UNIVERSIDAD DE ANTIOQUIA
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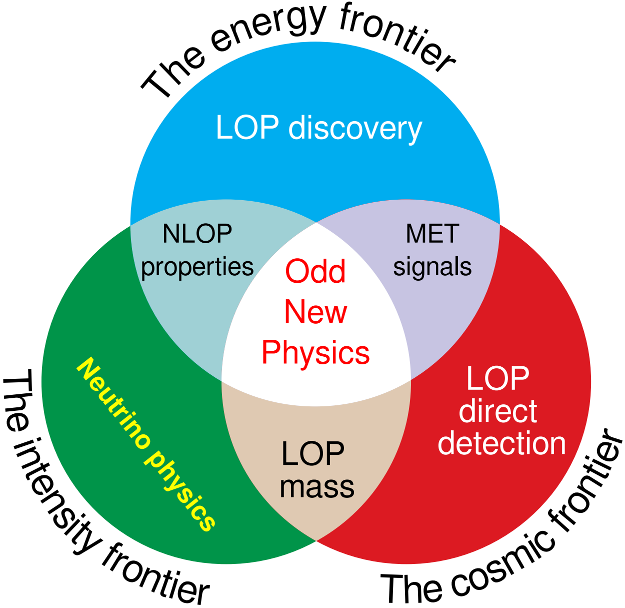
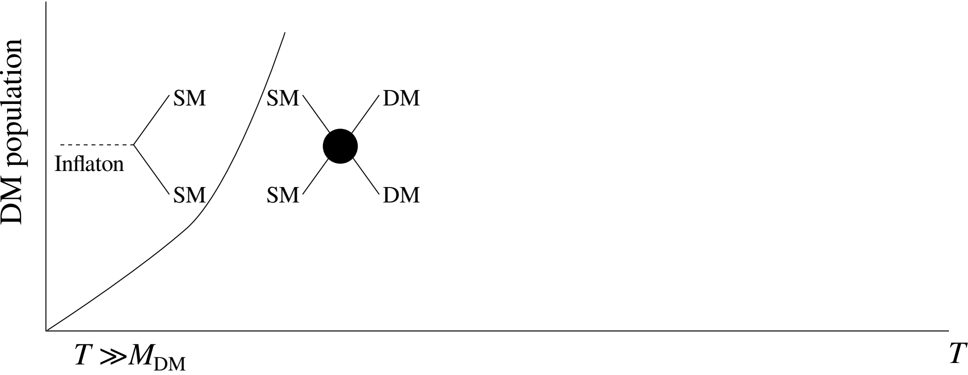


Standard Model Z_2-Even particles + New Z_2-Odd new particles

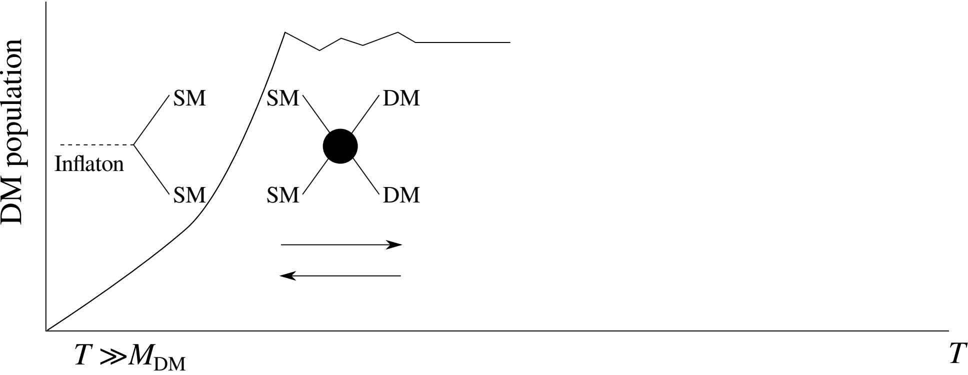
Lightest Odd Particle (LOP) may be a suitable dark matter candidate

I - Production

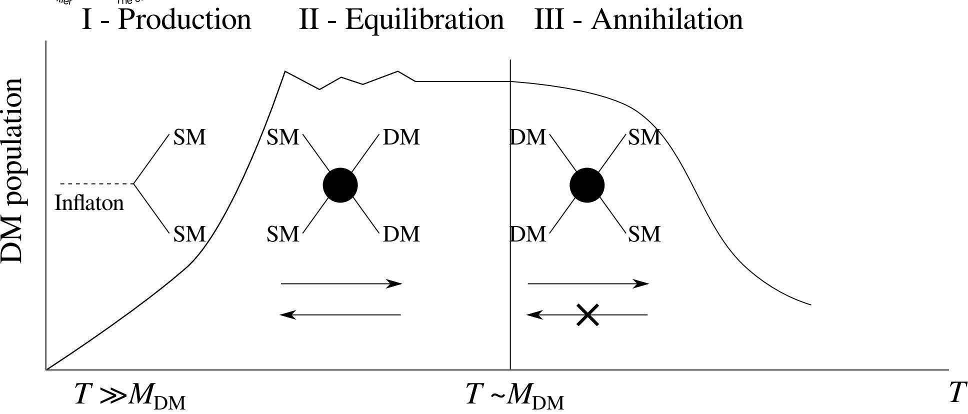


A. Ibarra, DM course, Valencia Sep/2013

I - Production II - Equilibration

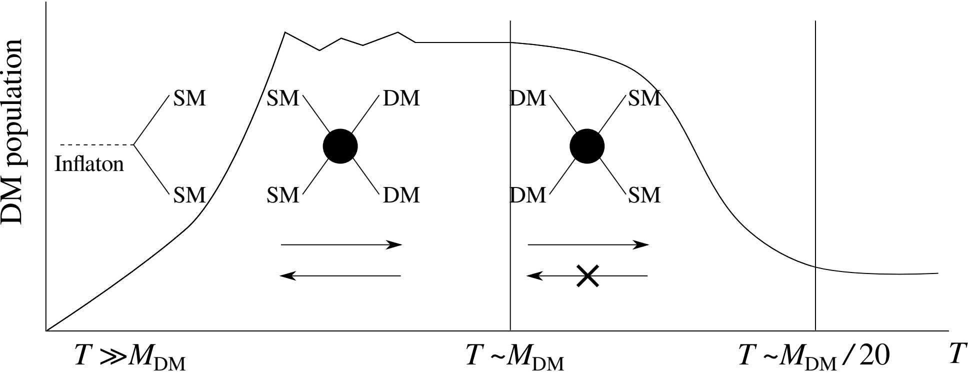


A. Ibarra, DM course, Valencia Sep/2013

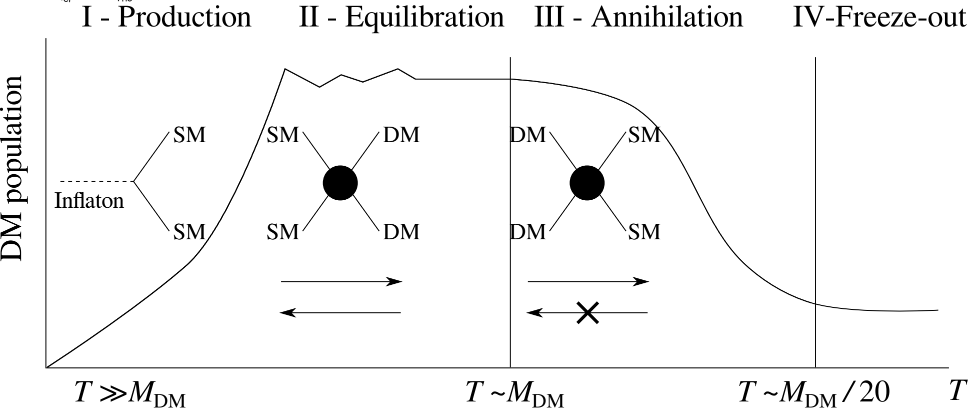


A. Ibarra, DM course, Valencia Sep/2013

I - Production II - Equilibration III - Annihilation IV-Freeze-out



A. Ibarra, DM course, Valencia Sep/2013



A. Ibarra, DM course, Valencia Sep/2013

Parámetro	1σ
$\Delta m^2_{32}[10^{-3}\mathrm{eV}^2]$	$2.50^{+0.09}_{-0.16}$
$\Delta m^2_{21}[10^{-5}\mathrm{eV}^2]$	$7.59^{+0.20}_{-0.18}$

Parámetro	1σ
$\sin^2\theta_{23}$	$0.52^{+0.06}_{0.07}$
$\sin^2\theta_{12}$	$0.312^{+0.017}_{-0.015}$
$\sin^2\theta_{13}$	$0.013^{+0.007}_{-0.005}$

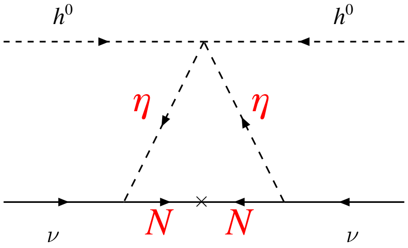
Electroweak searches

No new physics with strong production at LHC Run-I.
Many possibilities for new physics with EW production.
For example: SM $SU(2)_L$-triplet fermion with zero hypercharge: $\mathbf{\Sigma}_0$ (or $\widetilde{\boldsymbol{W}}$ in SUSY)

Not large missing E_T	Large missing E_T	
Type-III Seesaw	Simplified SUSY model with only M_1, M_2 below 1 TeV and $M_1 < M_2$	Scotogenic Type-III Seesaw
CMS arXiv:1207.6079	CMS arXiv:1309.7509	In progress (see Poster Session)
$pp \to \Sigma^\pm \Sigma^0$	$pp \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0$	$pp \to \Sigma^\pm + \Sigma^0$
$\Sigma^\pm \to Z l^\pm$	$\tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0$	$\Sigma^\pm \to H^0 l^\pm$
$\Sigma^0 \to W^\pm l^\mp$	$\tilde{\chi}_2^0 \to Z \tilde{\chi}_1^0$	$\Sigma^0 \to H^\pm l^\mp$
$W^\pm \to l^\pm \nu$	$W^\pm \to l^\pm \nu$	$H^\pm \to W^\pm H^0$
$(Z \to jj, \nu\nu)$	$Z \to l^\pm l^\mp$	$W^\pm \to l^\pm \nu$
Trilepton	Trilepton + $\not{E}_T$	
Neutrinos	DM?	Neutrinos + DM

Radiative type-I seesaw

E. Ma, hep-ph/0601225 (PRD)

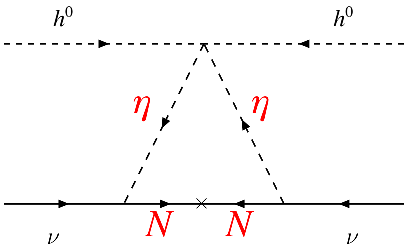


$$
\begin{aligned}
-\mathcal{L} \supset & \frac{M_i}{2} \bar{N}_i^c P_R N_i - h_{\alpha i} \bar{\ell}_\alpha \eta^\dagger P_R N_i + \text{h.c.}, \\
& + \mu_2^2 \eta^\dagger \eta + \lambda_3 \left(H^\dagger H\right)\left(\eta^\dagger \eta\right) \\
& + \lambda_4 \left(H^\dagger \eta\right)\left(\eta^\dagger H\right) \\
& + \frac{\lambda_5}{2}\left(H^\dagger \eta\right)^2 + \text{h.c.},
\end{aligned}
$$

$$
\begin{aligned}
M_{H^\pm}^2 &= \mu_2^2 + \lambda_3 v^2, \\
M_{H^0}^2 &= \mu_2^2 + (\lambda_3 + \lambda_4 + \lambda_5) v^2, \\
M_{A^0}^2 &= \mu_2^2 + (\lambda_3 + \lambda_4 - \lambda_5) v^2,
\end{aligned}
$$

Radiative type-I seesaw

E. Ma, hep-ph/0601225 (PRD)



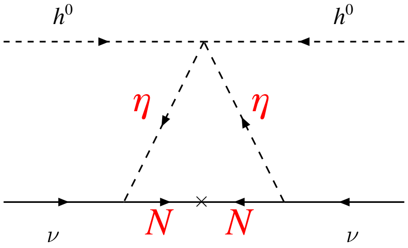
$$-\mathcal{L} \supset \frac{M_i}{2} \bar{N}_i^c P_R N_i - h_{\alpha i} \bar{\ell}_\alpha \eta^\dagger P_R N_i + \text{h.c.},$$
$$+ \mu_2^2 \eta^\dagger \eta + \lambda_3 \left(H^\dagger H\right)\left(\eta^\dagger \eta\right)$$
$$+ \lambda_4 \left(H^\dagger \eta\right)\left(\eta^\dagger H\right)$$
$$+ \frac{\lambda_5}{2} \left(H^\dagger \eta\right)^2 + \text{h.c.},$$

$$(m_\nu)_{\alpha\beta} \simeq \sum_{i=1}^{3} \frac{2\lambda_5 h_{\alpha i} h_{\beta i} v^2}{(4\pi)^2 M_i} I\left(\frac{M_i^2}{M_0^2}\right),$$
$$I(x) = \frac{x}{1-x}\left(1 + \frac{x \log x}{1-x}\right)$$
$$M_0^2 \simeq \mu_2^2 + (\lambda_3 + \lambda_4) v^2$$

$$M_{H^\pm}^2 = \mu_2^2 + \lambda_3 v^2,$$
$$M_{H^0}^2 = \mu_2^2 + (\lambda_3 + \lambda_4 + \lambda_5) v^2,$$
$$M_{A^0}^2 = \mu_2^2 + (\lambda_3 + \lambda_4 - \lambda_5) v^2,$$

Radiative type-I seesaw

E. Ma, hep-ph/0601225 (PRD)



$$
\begin{aligned}
-\mathcal{L} \supset & \frac{M_i}{2}\bar{N}_i^c P_R N_i - h_{\alpha i}\bar{\ell}_\alpha \eta^\dagger P_R N_i + \text{h.c.}, \\
& + \mu_2^2 \eta^\dagger \eta + \lambda_3 \left(H^\dagger H\right)\left(\eta^\dagger \eta\right) \\
& + \lambda_4 \left(H^\dagger \eta\right)\left(\eta^\dagger H\right) \\
& + \frac{\lambda_5}{2}\left(H^\dagger \eta\right)^2 + \text{h.c.},
\end{aligned}
$$

$$
(m_\nu)_{\alpha\beta} \simeq \sum_{i=1}^{3} \frac{2\lambda_5 h_{\alpha i} h_{\beta i} v^2}{(4\pi)^2 M_i} I\left(\frac{M_i^2}{M_0^2}\right),
$$

$$
I(x) = \frac{x}{1-x}\left(1 + \frac{x\log x}{1-x}\right)
$$

$$
M_0^2 \simeq \mu_2^2 + (\lambda_3 + \lambda_4)v^2
$$

$$
\begin{aligned}
M_{H^\pm}^2 &= \mu_2^2 + \lambda_3 v^2, \\
M_{H^0}^2 &= \mu_2^2 + (\lambda_3 + \lambda_4 + \lambda_5)v^2, \\
M_{A^0}^2 &= \mu_2^2 + (\lambda_3 + \lambda_4 - \lambda_5)v^2,
\end{aligned}
$$

$$100\ \text{GeV} < M_{H^0} < 1\ \text{TeV} \qquad M_{H^0} < M_{A^0} < M_{H^0} + 40\ \text{GeV}$$

$$M_{H^0} < M_{H^\pm} < M_{H^0} + 40\ \text{GeV} \qquad M_{H^0} < M_{N_i} < M_{H^0} + 40\ \text{GeV}$$

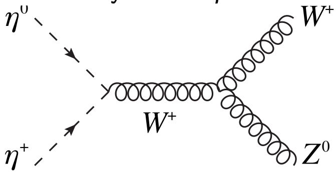
$$10^{-5} < \lambda < 10^{-1} \qquad 10^{-6} < h_2 < 10^{-1}.$$

Coannihilations

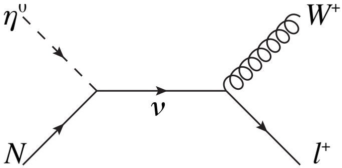
When another particle lies near in mass to the relic particle and shares a quantum number with it, the effects or their coannihilations can either suppress or *increase* the relic abundance.

Increase example: the lightest odd particle is a neutral scalar and coannihilate with right-handed neutrinos.

Right-handed neutrinos annihilate less efficiently than the neutral-charged scalar system, and therefore right-handed neutrino coannihilations effectively act as *parasite degrees of freedom* at freeze-out.



efficient

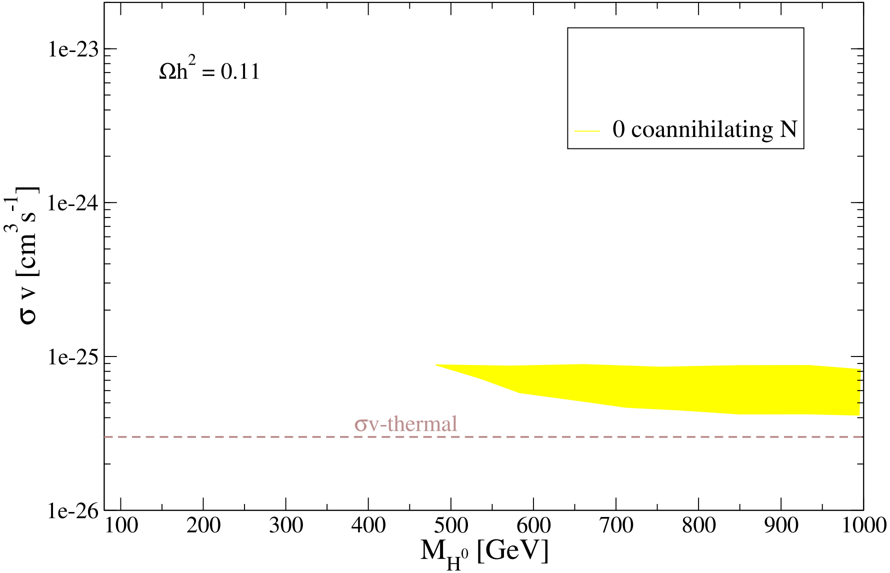


suppressed by small Yukawas couplings

$$\sigma_{\text{eff}}^{N_i} \sim \sigma_{\text{eff}} \left(\frac{g_{\text{eff}}^{0}(x_{\text{f.o.}})}{g_{\text{eff}}^{N_i}(x_{\text{f.o.}})} \right)^2 \qquad \sigma_{\text{eff}}^{N_i} \text{ decrease} \rightarrow \Omega_{\text{DM}} \text{ increase}$$

Radiative type-I seesaw

Klansen, D.R, Yaguna, Ruiz, Zapata,
arXiv:1302.5298 (JCAP)



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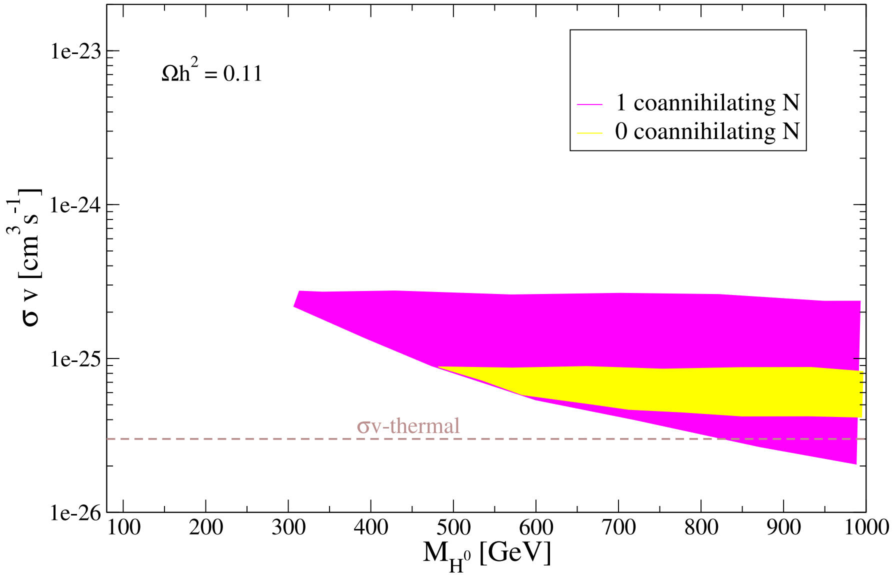

Radiative type-I seesaw

Klansen, D.R, Yaguna, Ruiz, Zapata,
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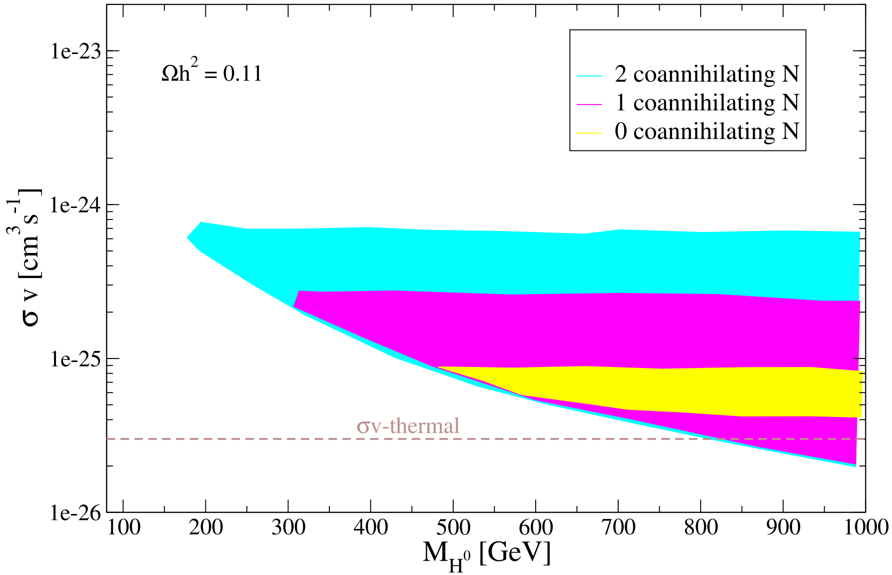

Radiative type-I seesaw

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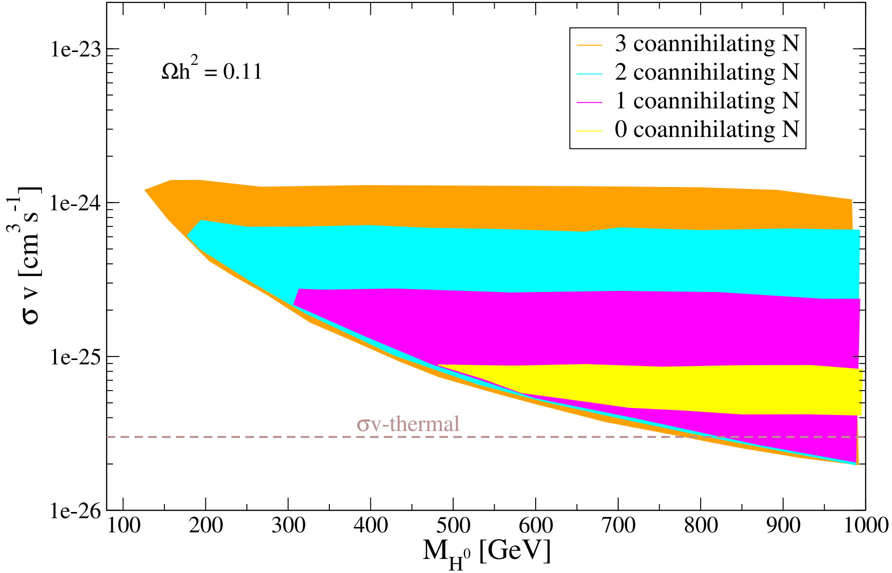

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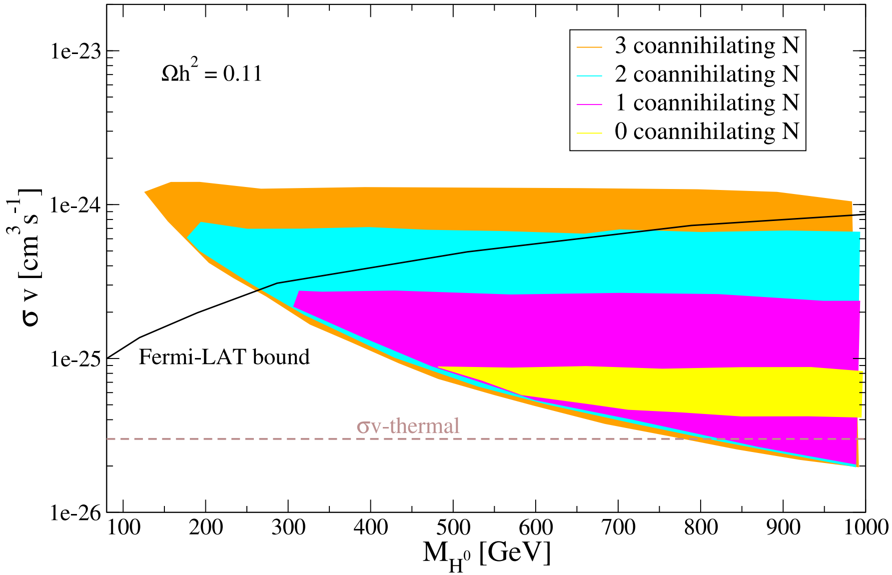
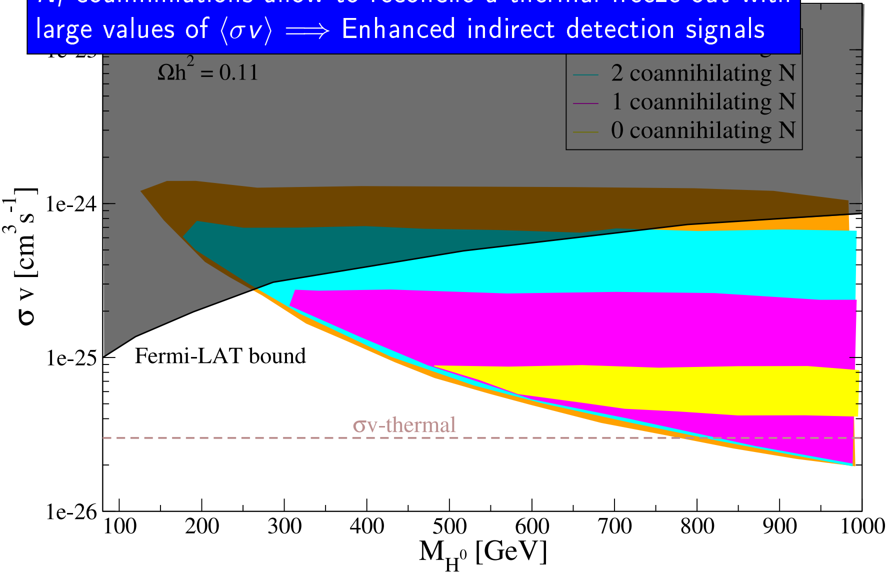


Radiative type-I seesaw

Klansen, D.R, Yaguna, Ruiz, Zapata, arXiv:1302.5298 (JCAP)

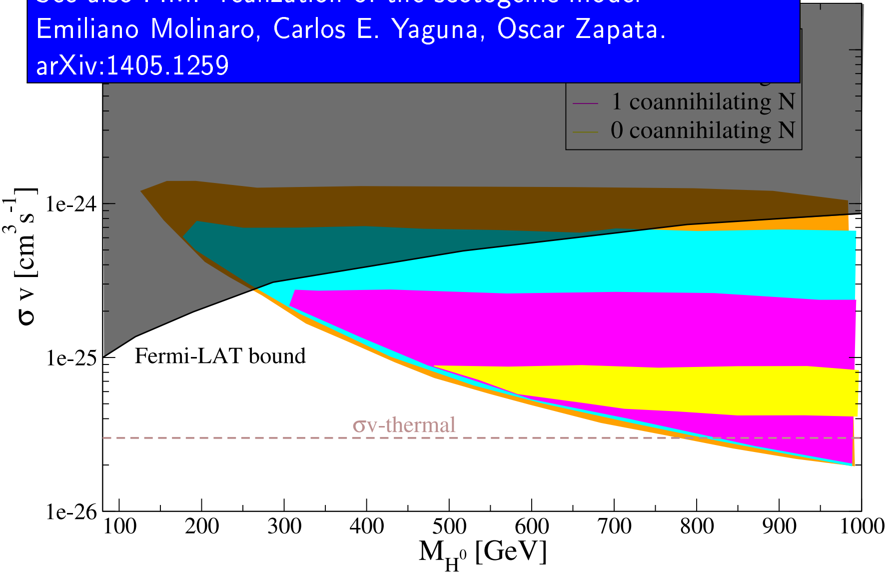
N_i coannihilations allow to reconcile a thermal freeze-out with large values of $\langle \sigma v \rangle \implies$ Enhanced indirect detection signals



Radiative type-I seesaw

Klansen, D.R, Yaguna, Ruiz, Zapata, arXiv:1302.5298 (JCAP)

See also FIMP realization of the scotogenic model
Emiliano Molinaro, Carlos E. Yaguna, Oscar Zapata.
arXiv:1405.1259



Tree level possibilities: I

Akhmedov, hep-ph/0001264; Langacker, arXiv:1112.5992

The Majorana mass term should be of the form $\overline{\nu_L^c}\nu_L$. Since ν_L has $I_3 = 1/2$, the Majorana mass term has $I_3 = 1$ With $L = \begin{pmatrix}\nu_L & e_L\end{pmatrix}^T$

$$\overline{L^c}\boldsymbol{\tau} i\tau_2 L \sim (3, -2) \ .$$

One would need an isotriplet scalar field $\Delta \sim (3, 2)$, which either elemental or composite. The term

$$H^T \boldsymbol{\tau} i\tau_2 H \sim (3, -2) \, ,$$

can play the role of the composite triplet, where $H = \begin{pmatrix}H^+ & H^0\end{pmatrix}^T$

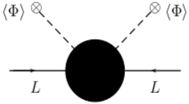
We have the Weinberg operator

$$\begin{aligned}\mathcal{L} =& -\frac{f}{2M}\left(\overline{L^c}\boldsymbol{\tau} i\tau_2 L\right)\cdot\left(H^T\boldsymbol{\tau} i\tau_2 H\right)+\text{h.c}\\ =&\frac{f}{M}\left(\overline{L^c}\widetilde{H}^*\right)\left(\widetilde{H}^\dagger L\right)+\text{h.c}\\ =&\frac{f}{M}\overline{L^c_a}H_c L_b H_d \epsilon_{ac}\epsilon_{bd}+\text{h.c}\,.\end{aligned}$$

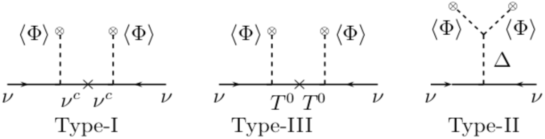
Weinberg, PRL43(1979)1566

Model independent approach: induced by $\mathcal{O}_5 \sim LL\Phi\Phi \Rightarrow \Delta L = 2$

S. Weinberg, Phys. Rev. D **22**, 1694 (1980)



Tree-level UV completions



Minkowski, 1977

Mohapatra & Senjanovic, 1980

Schechter & JWFV, 1980 ...

Foot, Lew, He & Joshi, 1989

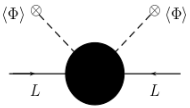
Schechter & JWFV, 1980 ...

Diego Aristizabal @ FestiValle (2013)

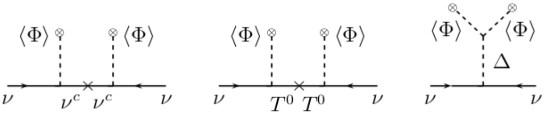
Majorana neutrino masses

Model independent approach: induced by $\mathcal{O}_5 \sim LL\Phi\Phi \Rightarrow \Delta L = 2$

S. Weinberg, Phys. Rev. D **22**, 1694 (1980)



Tree-level UV completions



Finite number of models with fixed hypercharges and representations

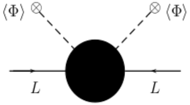
(Even with $\langle\Phi\rangle \to \langle S_{1,2}\rangle$ McDonald, arXiv:1303.4573 (JHEP))

Diego Aristizabal @ FestiValle (2013)

Majorana neutrino masses

Model independent approach: induced by $\mathscr{O}_5 \sim LL\Phi\Phi \Rightarrow \Delta L = 2$

S. Weinberg, Phys. Rev. D **22**, 1694 (1980)



One-loop UV completions

Arbitrary number of models:
Multiple hypercharges and representations.

Diego Aristizabal @ FestiValle (2013)

Weinberg operator at one-loop

Bonnet, Hirsch, Ota, Winter, arXiv:1204.5862 (JHEP)

Notations

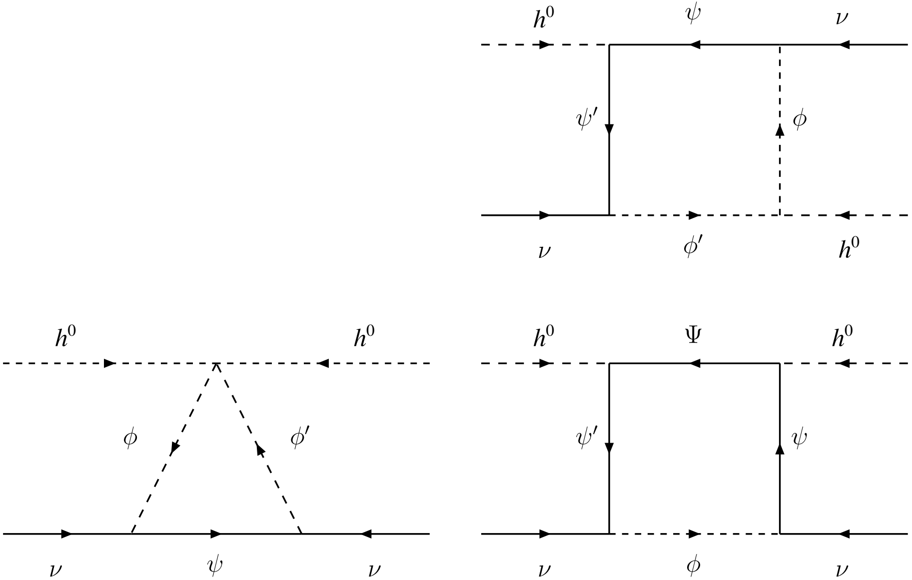
$$\mathbf{X}^{\mathcal{L}}{}_{\mathbf{Y}}$$

- $\mathcal{L}$ Lorentz nature: scalar (S) or fermion (F),
- $Y \equiv 2(Q - I_3)$ hypercharge: α arbitrary rational-number
- **X** $SU(2)$ nature: singlet **1**, doublet **2**, triplet **3**
  - quadruplet **4**, quintuplet **5**, ...

Law, McDonald, arXiv:1305.6467

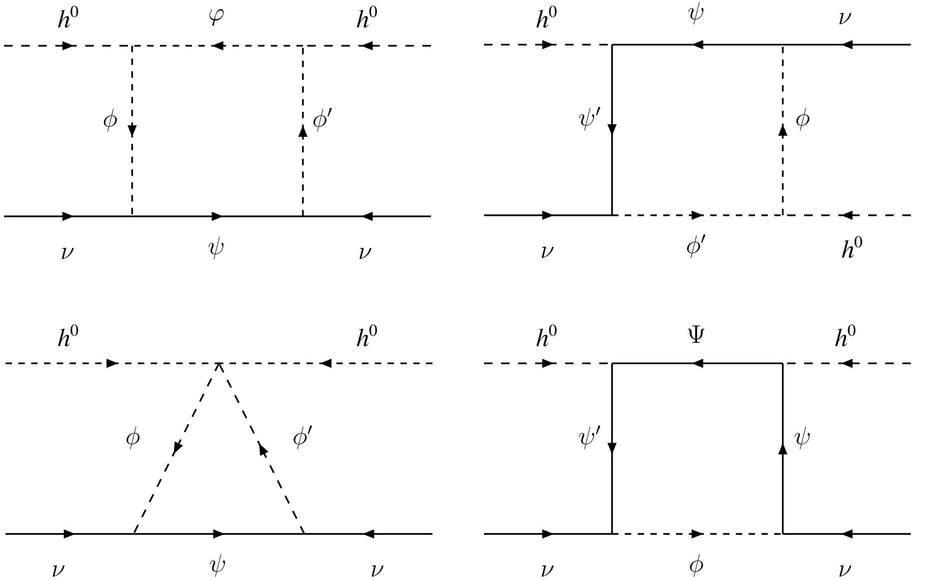
Weinberg operator at one-loop

Ma, hep-ph/9805219 (PRL)



Weinberg operator at one-loop

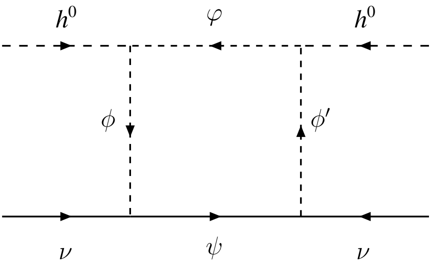
Bonnet, Hirsch, Ota, Winter,
arXiv:1204.5862 (JHEP)

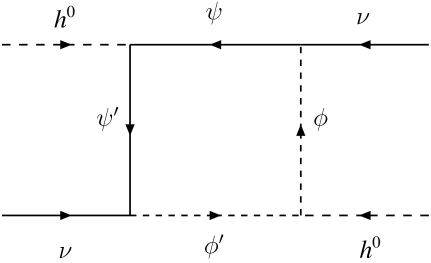


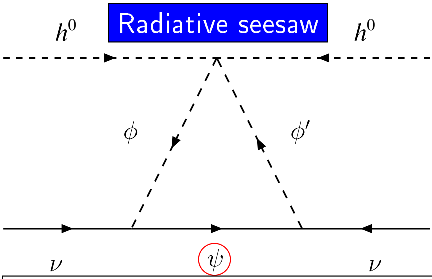
and reducible and divergent topologies

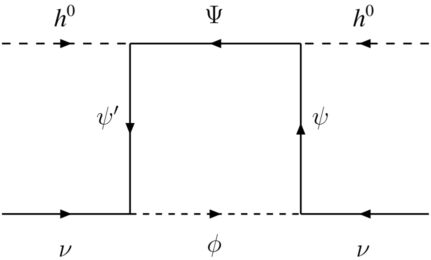
Weinberg operator at one-loop

Bonnet, Hirsch, Ota, Winter,
arXiv:1204.5862 (JHEP)





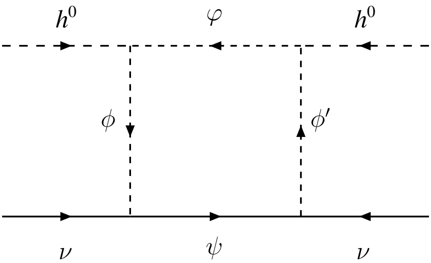


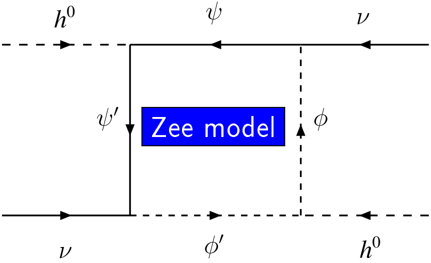


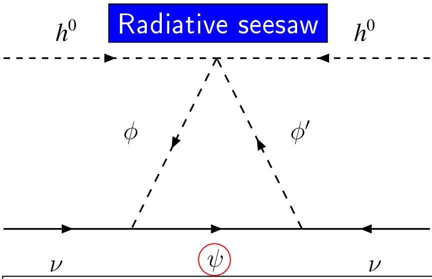
$1^F_{1+\alpha}, 2^F_{1+\alpha}, 3^F_{1+\alpha}, 4^F_{1+\alpha}, 5^F_{1+\alpha}, \ldots$

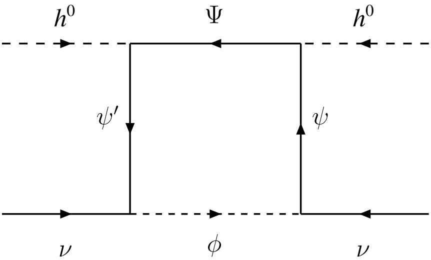
Weinberg operator at one-loop

Bonnet, Hirsch, Ota, Winter,
arXiv:1204.5862 (JHEP)





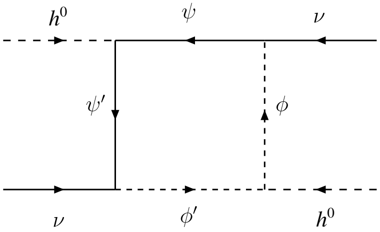




$1^F_{1+\alpha}, 2^F_{1+\alpha}, 3^F_{1+\alpha}, 4^F_{1+\alpha}, 5^F_{1+\alpha}, \ldots$

Generalized Zee model

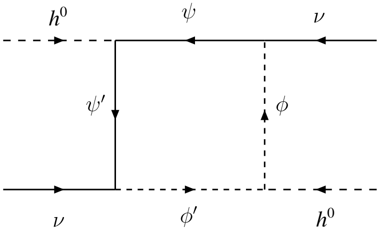
A. Zee, Phys.Lett.B93(1980)389 .



ψ	ϕ	ϕ'	ψ'	
$2_1^F : \overline{e_L}$	$1_2^S : \eta^+$	$2_1^S : \phi$	$1_2^F : \overline{e_R}$	

Generalized Zee model

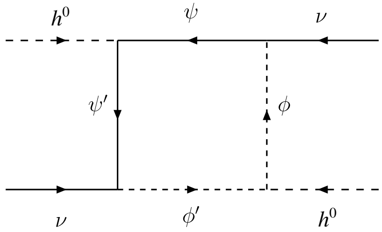
E. Ma, hep-ph/9805219 (PRL)



ψ	ϕ	ϕ'	ψ'	
2^F_α	$1^S_{1+\alpha}$	2^S_α	$1^F_{1+\alpha}$	
2^F_α	$3^S_{1+\alpha}$	2^S_α	$1^F_{1+\alpha}$	
2^F_α	$3^S_{1+\alpha}$	2^S_α	$3^F_{1+\alpha}$	
2^F_α	$1^S_{1+\alpha}$	2^S_α	$3^F_{1+\alpha}$	

Generalized Zee model

Bonnet, Hirsch, Ota, Winter, arXiv:1204.5862 (JHEP)

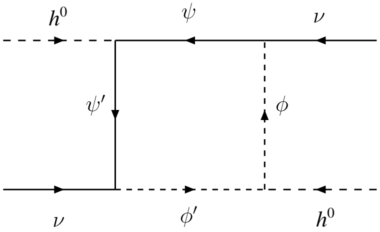


$$\alpha \to -\alpha - 1$$

ψ	ϕ	ϕ'	ψ'	
1^F_α	$2^S_{1+\alpha}$	1^S_α	$2^F_{1+\alpha}$	
2^F_α	$1^S_{1+\alpha}$	2^S_α	$1^F_{1+\alpha}$	
1^F_α	$2^S_{1+\alpha}$	3^S_α	$2^F_{1+\alpha}$	
2^F_α	$3^S_{1+\alpha}$	2^S_α	$1^F_{1+\alpha}$	
2^F_α	$3^S_{1+\alpha}$	2^S_α	$3^F_{1+\alpha}$	
3^F_α	$2^S_{1+\alpha}$	3^S_α	$2^F_{1+\alpha}$	
2^F_α	$1^S_{1+\alpha}$	2^S_α	$3^F_{1+\alpha}$	
3^F_α	$2^S_{1+\alpha}$	1^S_α	$2^F_{1+\alpha}$	

Generalized Zee model

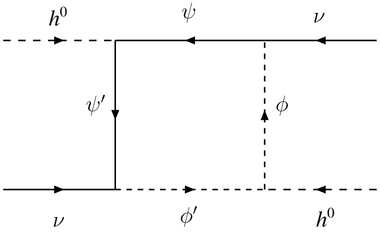
[?]



ψ	ϕ	ϕ'	ψ'	
1^F_α	$2^S_{1+\alpha}$	1^S_α	$2^F_{1+\alpha}$	
2^F_α	$1^S_{1+\alpha}$	2^S_α	$1^F_{1+\alpha}$	
1^F_α	$2^S_{1+\alpha}$	3^S_α	$2^F_{1+\alpha}$	
2^F_α	$3^S_{1+\alpha}$	2^S_α	$1^F_{1+\alpha}$	
2^F_α	$3^S_{1+\alpha}$	2^S_α	$3^F_{1+\alpha}$	
3^F_α	$2^S_{1+\alpha}$	3^S_α	$2^F_{1+\alpha}$	
2^F_α	$1^S_{1+\alpha}$	2^S_α	$3^F_{1+\alpha}$	
3^F_α	$2^S_{1+\alpha}$	1^S_α	$2^F_{1+\alpha}$	
Larger $SU(2)_L$ multiplets				

Generalized Zee model

D.R, Yagunga, Zapata, arXiv:1308.3655



Dark matter filter

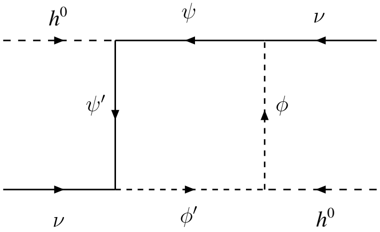
- Impose Z_2 symmetry
  - SM particles are even
  - New particles are odd
- Lightest odd particle (LOP)
  - Color and electrically neutral
  - Consistent with direct detection constraints
- Odd fermions must be vector-like

$Y = -2T_3$ for at least one particle

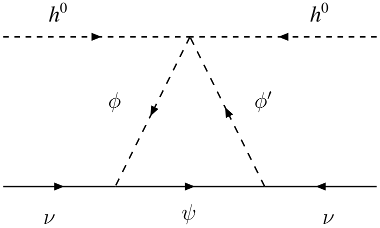
ψ	ϕ	ϕ'	ψ'	α
$\mathbf{1}_0^F$	$\mathbf{2}_1^S$	$\mathbf{1}_0^S$	2_1^F	
2_{-1}^F	1_{-2}^S	$\mathbf{2}_{-1}^S$	1_{-2}^F	
$\mathbf{1}_0^F$	$\mathbf{2}_1^S$	3_0^S	2_1^F	
2_{-1}^F	3_{-2}^S	$\mathbf{2}_{-1}^S$	1_{-2}^F	
2_1^F	3_2^S	$\mathbf{2}_1^S$	3_2^F	
$\mathbf{3}_0^F$	$\mathbf{2}_{-1}^S$	$\mathbf{3}_0^S$	2_{-1}^F	
2_1^F	1_2^S	$\mathbf{2}_1^S$	3_2^F	
$\mathbf{3}_0^F$	$\mathbf{2}_{-1}^S$	$\mathbf{1}_0^S$	2_{-1}^F	
Larger $SU(2)_L$ multiplets				

Generalized Zee model

D.R, Yagunga, Zapata, arXiv:1308.3655



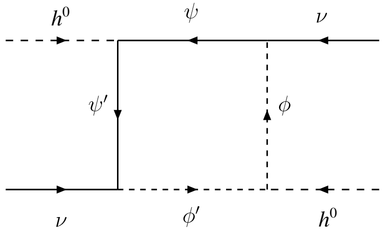
Radiative type-I/III seesaw
with additional contribution
to neutrino masses.



ψ	ϕ	ϕ'	ψ'	α
$\mathbf{1}^F_0$	$\mathbf{2}^S_1$	$\mathbf{1}^S_0$	2^F_1	$\boxed{0}$
2^F_{-1}	1^S_{-2}	$\mathbf{2}^S_{-1}$	1^F_{-2}	
$\mathbf{1}^F_0$	$\mathbf{2}^S_1$	3^S_0	2^F_1	$\boxed{0}$
2^F_{-1}	3^S_{-2}	$\mathbf{2}^S_{-1}$	1^F_{-2}	
2^F_1	3^S_2	$\mathbf{2}^S_1$	3^F_2	
$\mathbf{3}^F_0$	$\mathbf{2}^S_{-1}$	$\mathbf{3}^S_0$	2^F_{-1}	$\boxed{-1}$
2^F_1	1^S_2	$\mathbf{2}^S_1$	3^F_2	
$\mathbf{3}^F_0$	$\mathbf{2}^S_{-1}$	$\mathbf{1}^S_0$	2^F_{-1}	$\boxed{-1}$
Larger $SU(2)_L$ multiplets				

Generalized Zee model

D.R, Yagunga, Zapata, arXiv:1308.3655



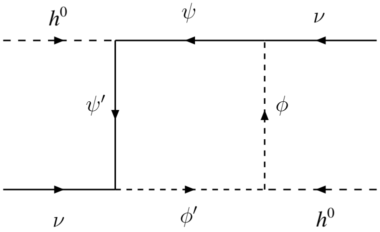
Inert doublet model with one-loop neutrino masses (susy-like)

ψ	ϕ	ϕ'	ψ'	α
$\mathbf{1}^F_0$	$\mathbf{2}^S_1$	$\mathbf{1}^S_0$	2^F_1	0
2^F_{-1}	1^S_{-2}	$\mathbf{2}^S_{-1}$	1^F_{-2}	$\boxed{-2}$
$\mathbf{1}^F_0$	$\mathbf{2}^S_1$	3^S_0	2^F_1	0
2^F_{-1}	3^S_{-2}	$\mathbf{2}^S_{-1}$	1^F_{-2}	$\boxed{-2}$
2^F_1	3^S_2	$\mathbf{2}^S_1$	3^F_2	$\boxed{1}$
$\mathbf{3}^F_0$	$\mathbf{2}^S_{-1}$	$\mathbf{3}^S_0$	2^F_{-1}	-1
2^F_1	1^S_2	$\mathbf{2}^S_1$	3^F_2	$\boxed{1}$
$\mathbf{3}^F_0$	$\mathbf{2}^S_{-1}$	$\mathbf{1}^S_0$	2^F_{-1}	-1

Larger $SU(2)_L$ multiplets

Generalized Zee model

D.R, Yagunga, Zapata, arXiv:1308.3655

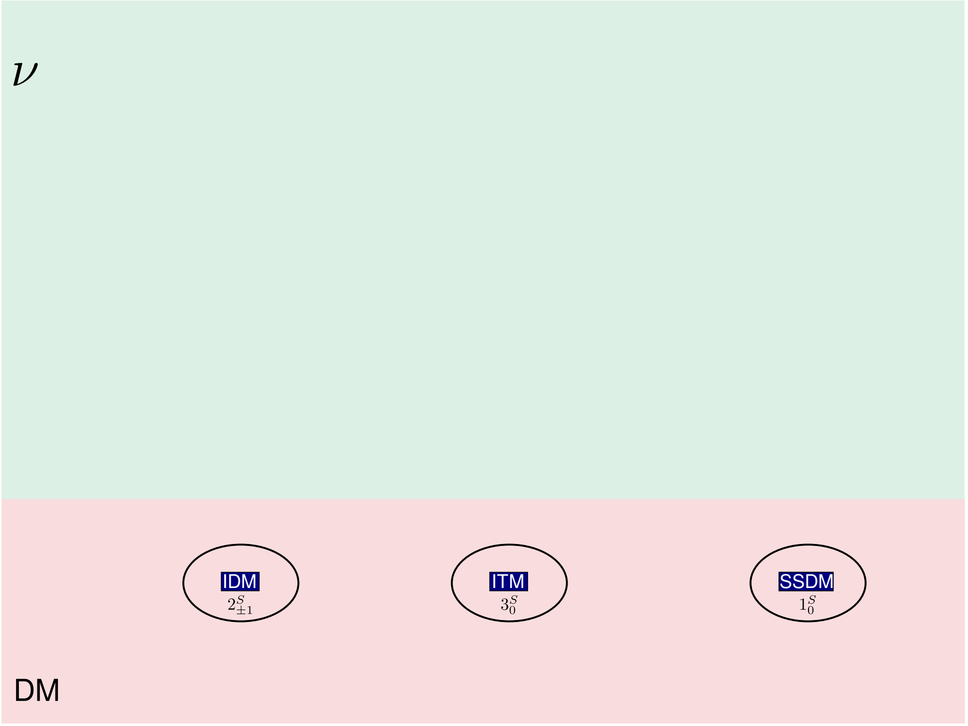


Inert doublet model with one-loop neutrino masses (susy-like)

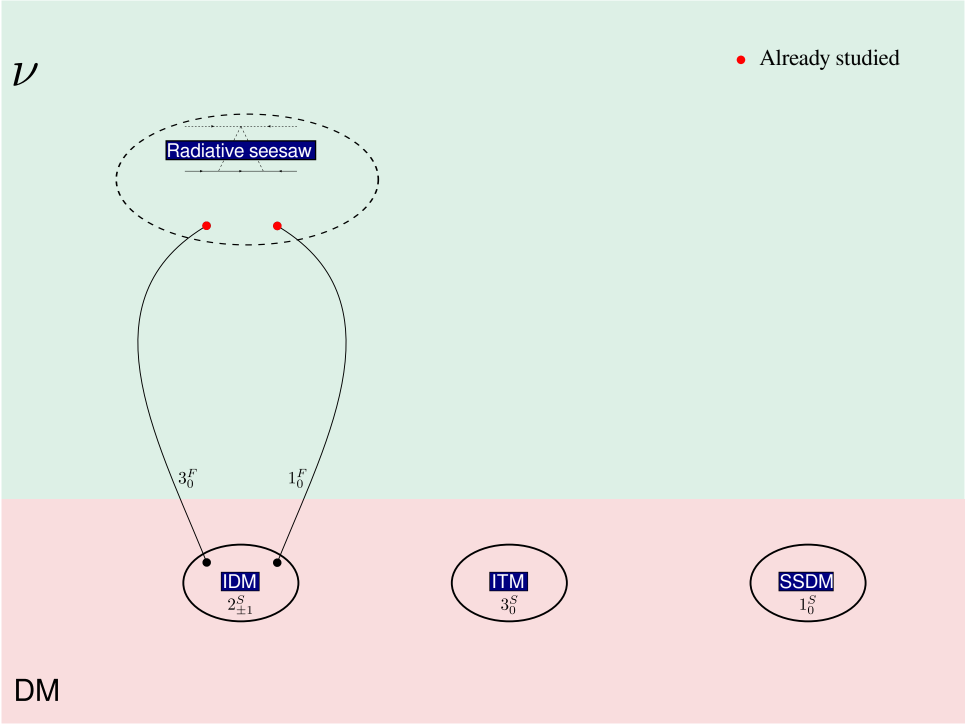
and exotic charges

ψ	ϕ	ϕ'	ψ'	α
$\mathbf{1}^F_0$	$\mathbf{2}^S_1$	$\mathbf{1}^S_0$	2^F_1	0
2^F_{-1}	1^S_{-2}	$\mathbf{2}^S_{-1}$	1^F_{-2}	-2
$\mathbf{1}^F_0$	$\mathbf{2}^S_1$	3^S_0	2^F_1	0
2^F_{-1}	3^S_{-2}	$\mathbf{2}^S_{-1}$	1^F_{-2}	$\boxed{-2}$
2^F_1	3^S_2	$\mathbf{2}^S_1$	3^F_2	$\boxed{1}$
$\mathbf{3}^F_0$	$\mathbf{2}^S_{-1}$	$\mathbf{3}^S_0$	2^F_{-1}	-1
2^F_1	1^S_2	$\mathbf{2}^S_1$	3^F_2	$\boxed{1}$
$\mathbf{3}^F_0$	$\mathbf{2}^S_{-1}$	$\mathbf{1}^S_0$	2^F_{-1}	-1

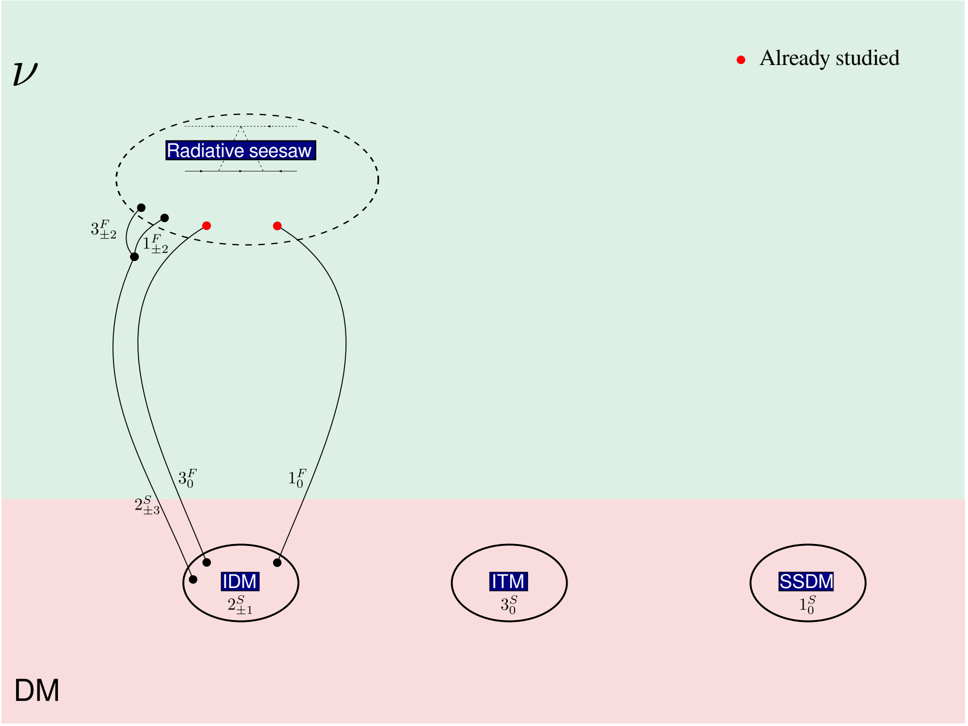
Larger $SU(2)_L$ multiplets



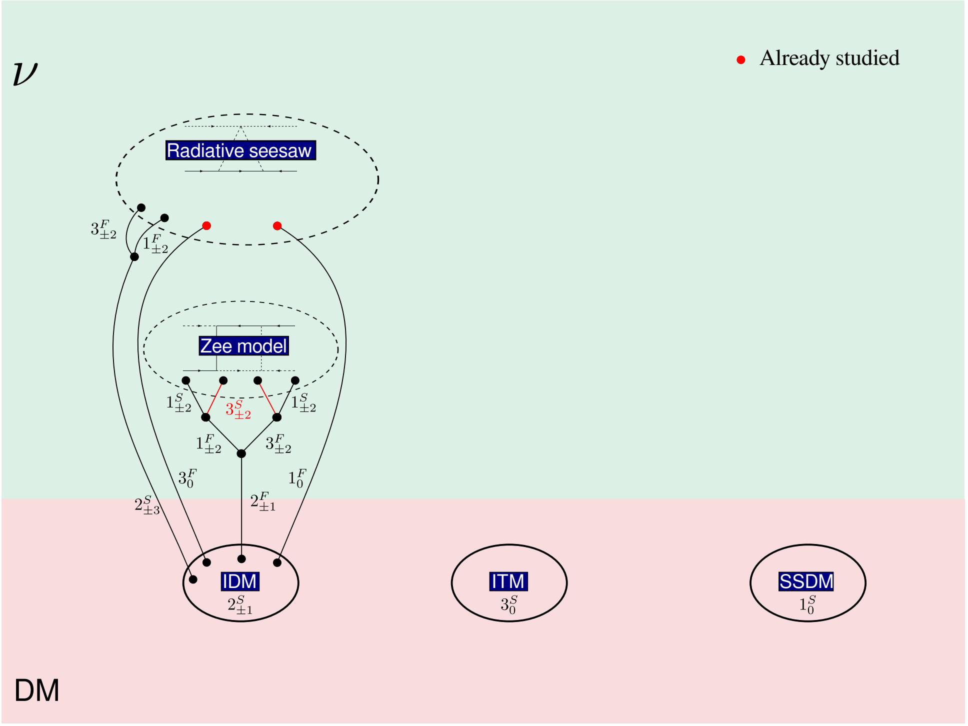
ν
IDM
$2^S_{\pm 1}$
ITM
3^S_0
SSDM
1^S_0
DM



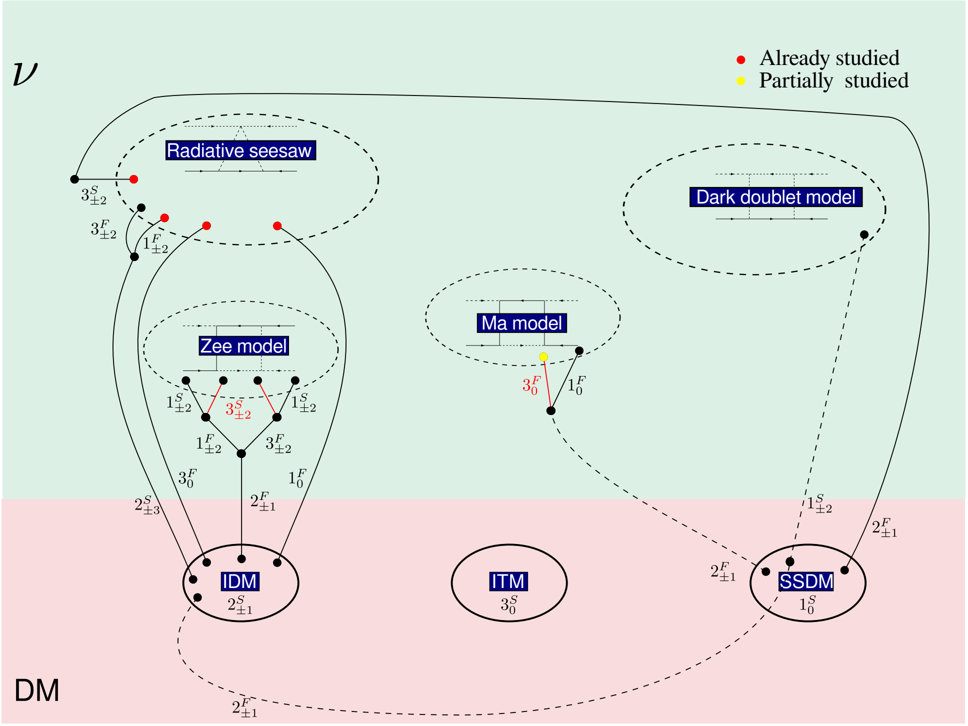
ν
Already studied
Radiative seesaw
3^F_0
1^F_0
IDM
$2^S_{\pm1}$
ITM
3^S_0
SSDM
1^S_0
DM



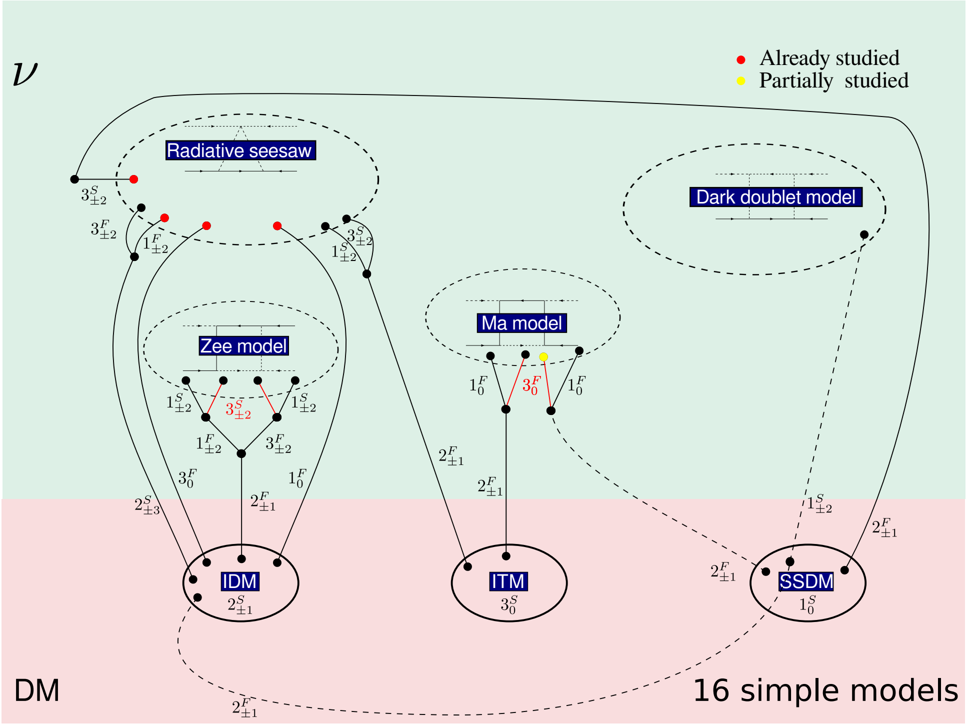
ν
Already studied
Radiative seesaw
$3^F_{\pm2}$
$1^F_{\pm2}$
3^F_0
1^F_0
$2^S_{\pm3}$
IDM
$2^S_{\pm1}$
ITM
3^S_0
SSDM
1^S_0
DM



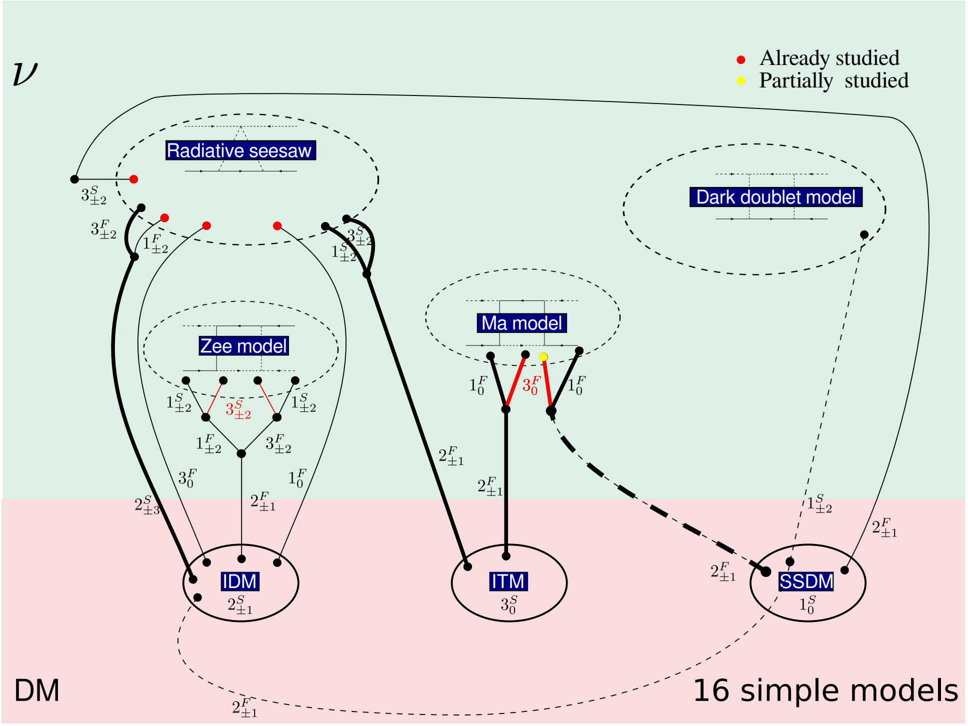
ν
Already studied
Radiative seesaw
$3^F_{\pm 2}$
$1^F_{\pm 2}$
Zee model
$1^S_{\pm 2}$
$3^S_{\pm 2}$
$1^S_{\pm 2}$
$1^F_{\pm 2}$
$3^F_{\pm 2}$
3^F_0
1^F_0
$2^S_{\pm 3}$
$2^F_{\pm 1}$
IDM
$2^S_{\pm 1}$
ITM
3^S_0
SSDM
1^S_0
DM



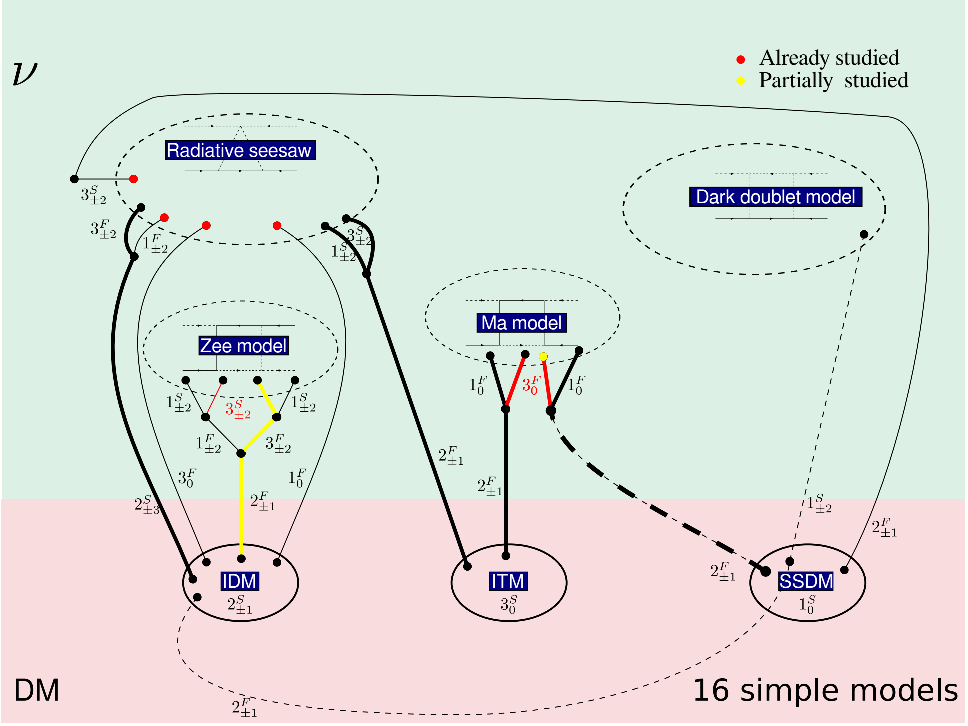
ν
Already studied
Partially studied
Radiative seesaw
Dark doublet model
Zee model
Ma model
$3^S_{\pm2}$
$3^F_{\pm2}$
$1^F_{\pm2}$
$1^S_{\pm2}$
$3^S_{\pm2}$
$1^S_{\pm2}$
$1^F_{\pm2}$
$3^F_{\pm2}$
3^F_0
1^F_0
3^F_0
1^F_0
$2^S_{\pm3}$
$2^F_{\pm1}$
$1^S_{\pm2}$
$2^F_{\pm1}$
$2^F_{\pm1}$
IDM
$2^S_{\pm1}$
ITM
3^S_0
SSDM
1^S_0
DM
$2^F_{\pm1}$



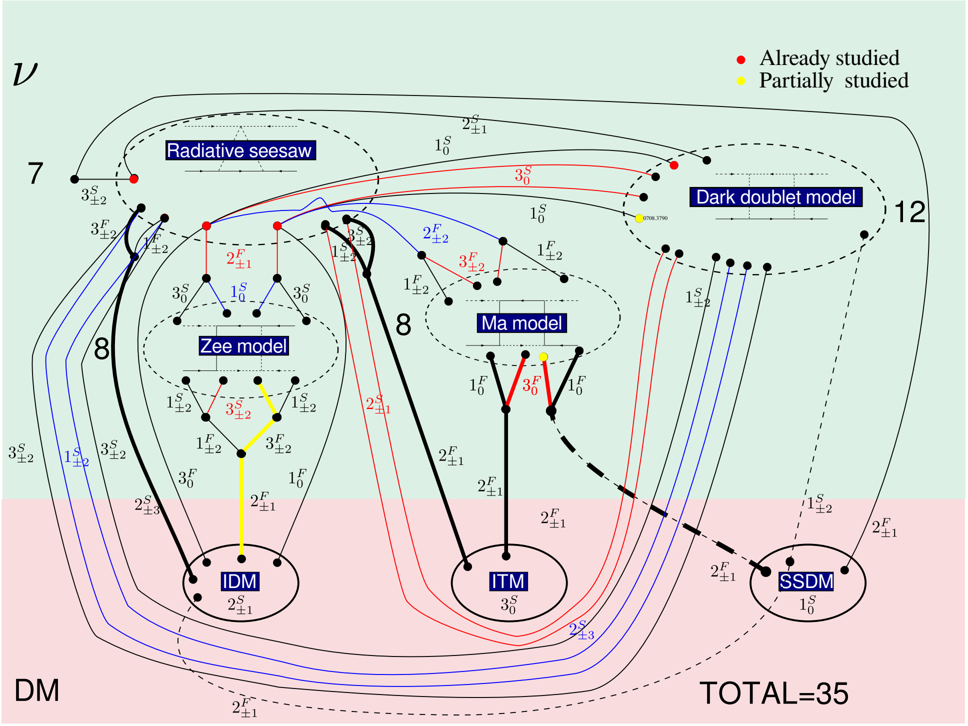
ν
Already studied
Partially studied
Radiative seesaw
Dark doublet model
Zee model
Ma model
$3^S_{\pm 2}$
$3^F_{\pm 2}$
$1^F_{\pm 2}$
$3^S_{\pm 2}$
$1^S_{\pm 2}$
$1^S_{\pm 2}$
$3^S_{\pm 2}$
$1^S_{\pm 2}$
$1^F_{\pm 2}$
$3^F_{\pm 2}$
1^F_0
3^F_0
1^F_0
$2^F_{\pm 1}$
$2^F_{\pm 1}$
3^F_0
1^F_0
$2^F_{\pm 1}$
$2^S_{\pm 3}$
$1^S_{\pm 2}$
$2^F_{\pm 1}$
$2^F_{\pm 1}$
IDM
$2^S_{\pm 1}$
ITM
3^S_0
SSDM
1^S_0
$2^F_{\pm 1}$
DM
16 simple models



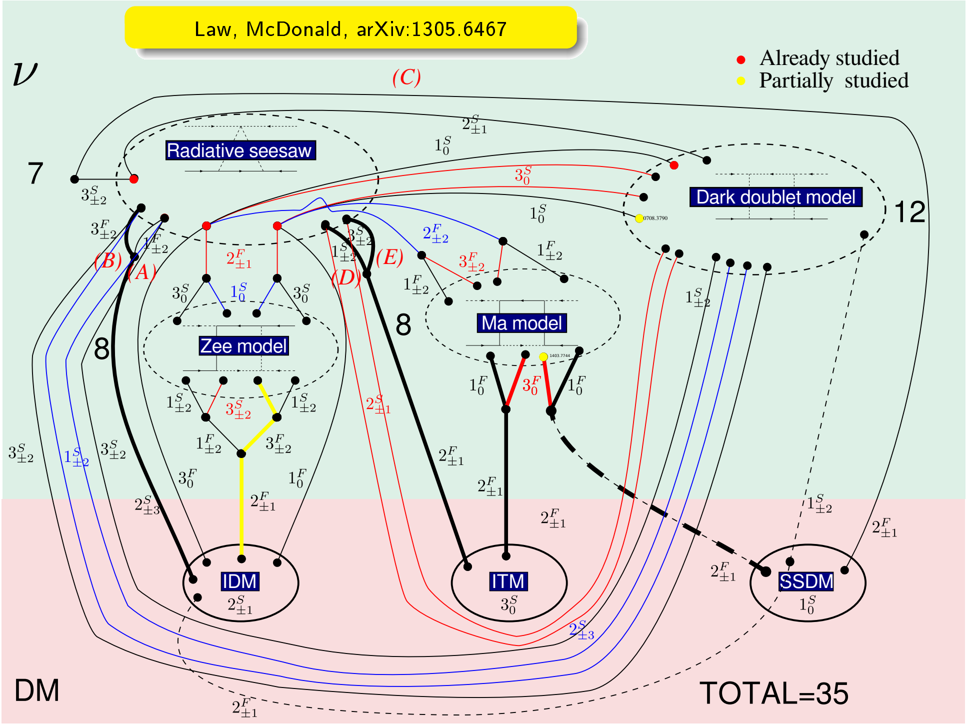
ν
Already studied
Partially studied
Radiative seesaw
Dark doublet model
Zee model
Ma model
$3^S_{\pm 2}$
$3^F_{\pm 2}$
$1^F_{\pm 2}$
$3^S_{\pm 2}$
$1^S_{\pm 2}$
$1^S_{\pm 2}$
$3^S_{\pm 2}$
$1^S_{\pm 2}$
$1^F_{\pm 2}$
$3^F_{\pm 2}$
1^F_0
3^F_0
1^F_0
3^F_0
$2^F_{\pm 1}$
$2^F_{\pm 1}$
$2^F_{\pm 1}$
$2^S_{\pm 3}$
1^F_0
$1^S_{\pm 2}$
$2^F_{\pm 1}$
$2^F_{\pm 1}$
IDM
$2^S_{\pm 1}$
ITM
3^S_0
SSDM
1^S_0
$2^F_{\pm 1}$
DM
16 simple models



ν
Already studied
Partially studied
Radiative seesaw
Dark doublet model
Zee model
Ma model
IDM
ITM
SSDM
DM
16 simple models
$3^S_{\pm2}$
$3^F_{\pm2}$
$1^F_{\pm2}$
$3^S_{\pm2}$
$1^S_{\pm2}$
$1^S_{\pm2}$
$3^S_{\pm2}$
$1^S_{\pm2}$
$1^F_{\pm2}$
$3^F_{\pm2}$
3^F_0
1^F_0
$2^S_{\pm3}$
$2^F_{\pm1}$
$2^F_{\pm1}$
1^F_0
3^F_0
1^F_0
$2^F_{\pm1}$
$1^S_{\pm2}$
$2^F_{\pm1}$
$2^F_{\pm1}$
$2^S_{\pm1}$
3^S_0
1^S_0
$2^F_{\pm1}$

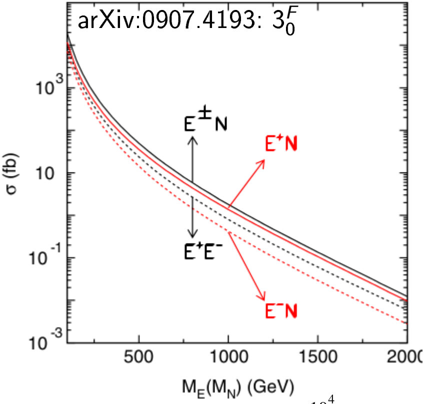


Already studied
Partially studied
ν
7
Radiative seesaw
Dark doublet model
12
Zee model
Ma model
8
8
IDM
ITM
SSDM
DM
TOTAL=35
0708.3790

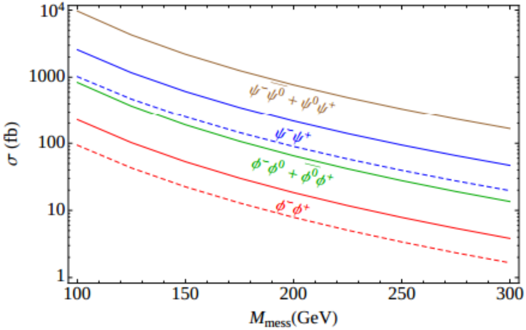


Law, McDonald, arXiv:1305.6467
Already studied
Partially studied
ν
(C)
Radiative seesaw
Dark doublet model
Zee model
Ma model
IDM
ITM
SSDM
7
8
8
12
(A)
(B)
(D)
(E)
0708.3790
1403.7744
$3^S_{\pm2}$
$3^F_{\pm2}$
$1^F_{\pm2}$
$2^F_{\pm1}$
1^S_0
3^S_0
$2^S_{\pm1}$
$2^F_{\pm2}$
$1^S_{\pm2}$
3^F_0
1^F_0
$2^S_{\pm3}$
3^S_0
1^S_0
DM
TOTAL=35

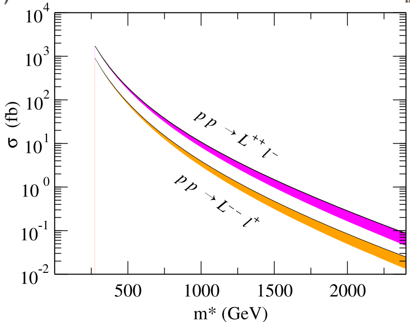
arXiv:0907.4193: 3_0^F

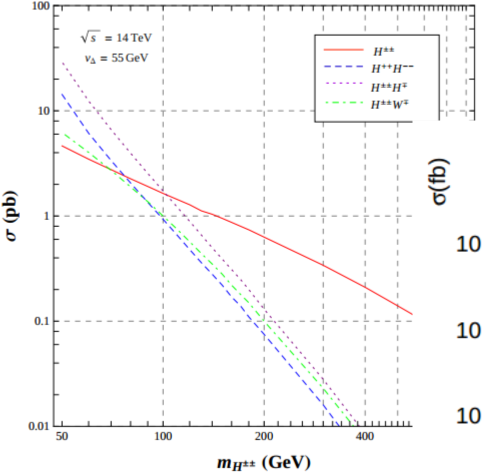


arXiv:1303.4404: $2_{\pm1}^{F,S}$ (solid) $1_{\pm2}^{F,S}$ (dashed)

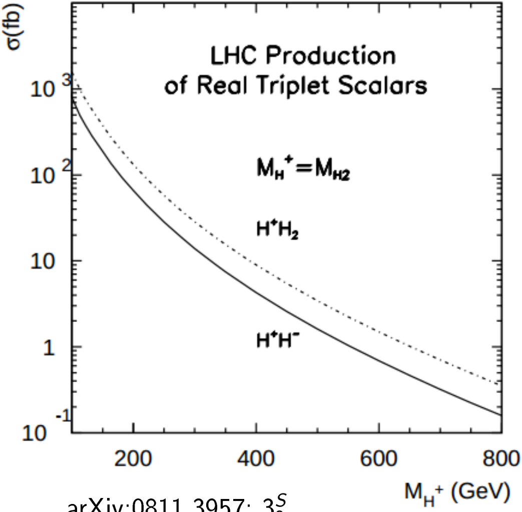


arXiv:1201.3764 $3_{\pm2}^F$





arXiv:1202.2014: $3^S_{\pm 2}$



arXiv:0811.3957: 3^S_0

Discussion

FeynRules/SARAH

micrOMEGAS (CalcHEP) MadGraph(UFO)

DM LHC

- The collider and dark matter phenomenology of many of these viable models have yet to be studied in detail.
- We have only qualitatively described the particle content and the dark matter candidates of each model. A more specific analysis of some of these models is certainly desirable.
- Some strategies to systematically search for this kind of models at colliders would be designed.
- New particles allowed to be even under Z_2 could give rise to new possibilities.