WIMP dark matter as radiative neutrino mass messenger

Joaquim Palacio
Thursday 7th November, 2013

9th MultiDark Consolider Workshop
Alcalá de Henares

M. Hirsch, R.A. Lineros, S. Morisi, J. Palacio, N. Rojas, J.W.F. Valle.
10.1007JHEP10(2013)149

Outline

Dark Matter Evidences

(Radiative) Neutrino Mass Models

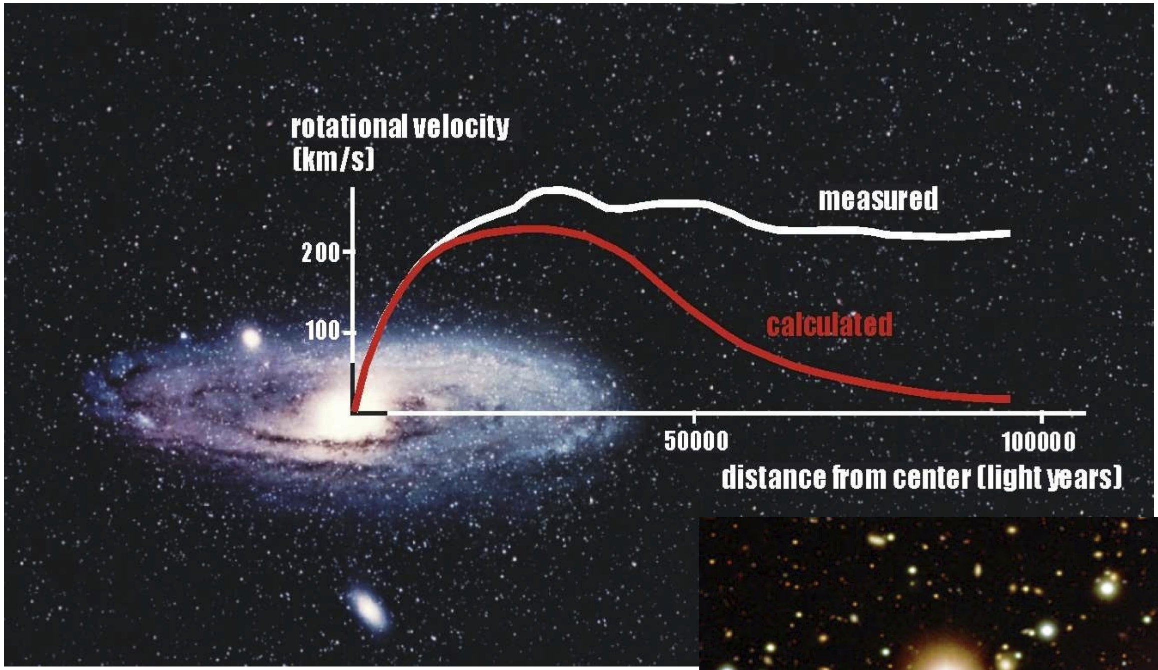
Dark Matter & Neutrino Masses

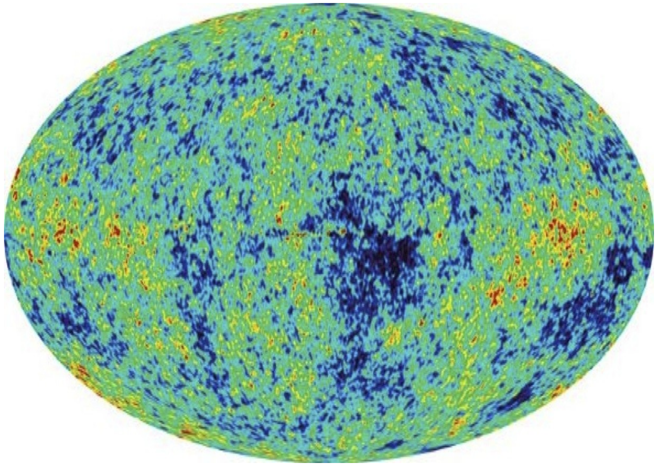
The Model

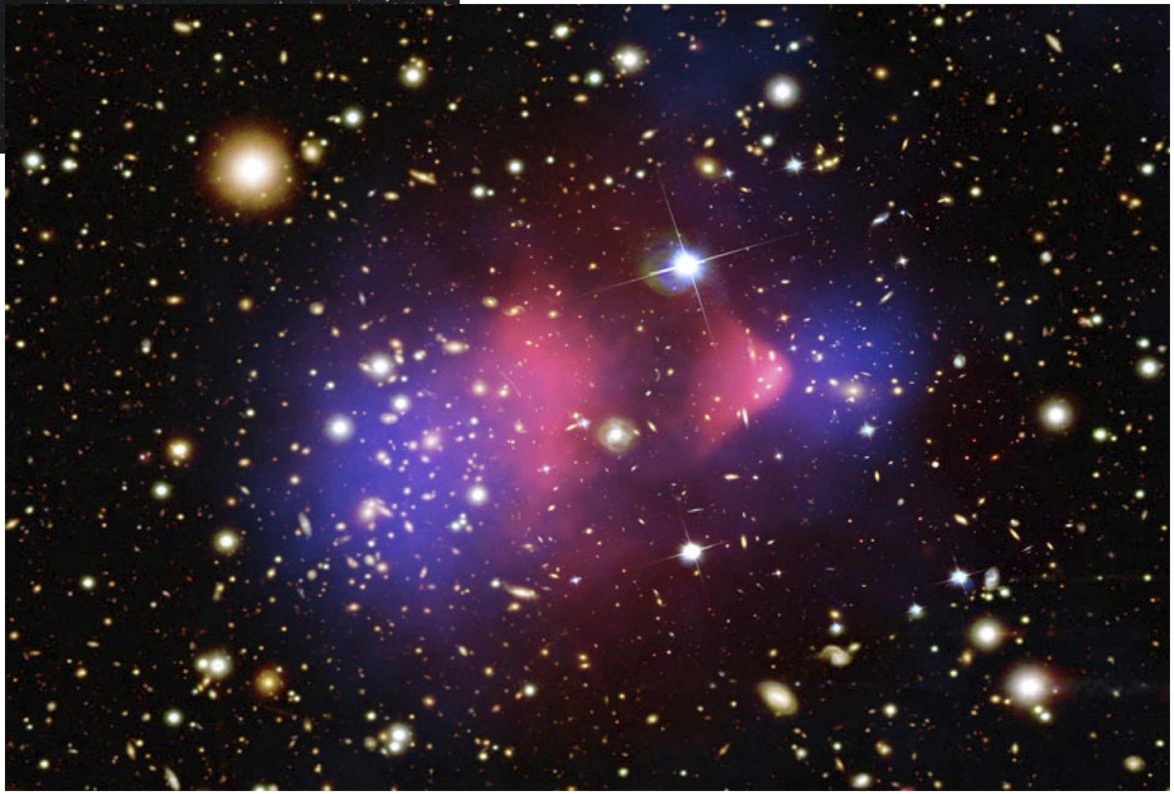
- Particle content
- Study of the Model
- Detection prospects

Conclusions

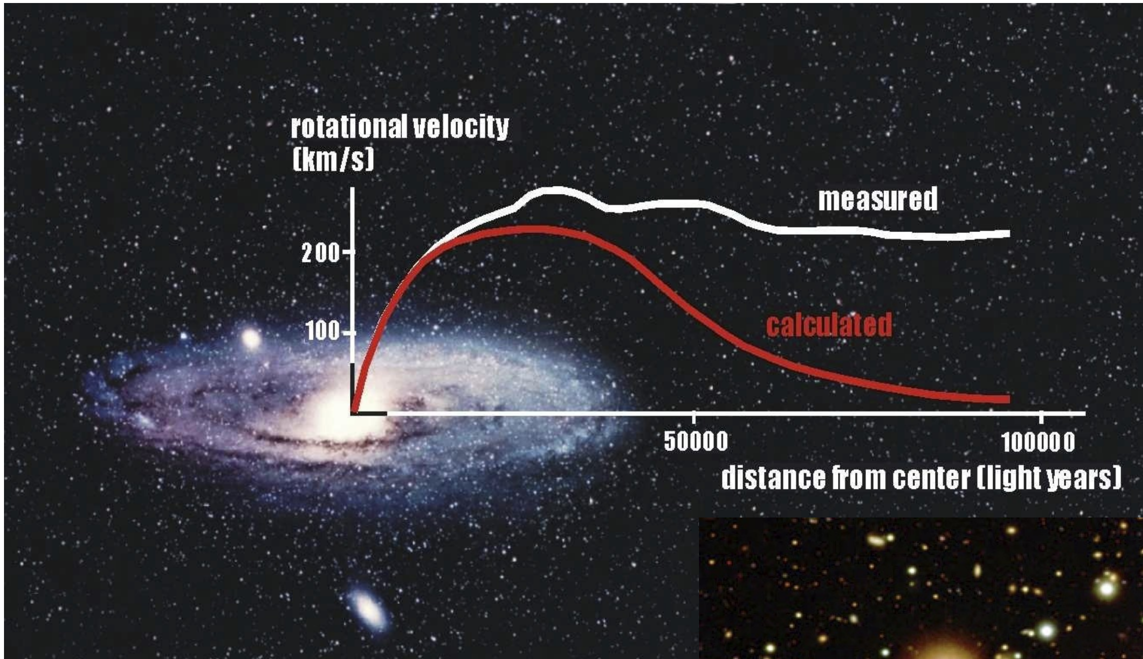
DM evidences





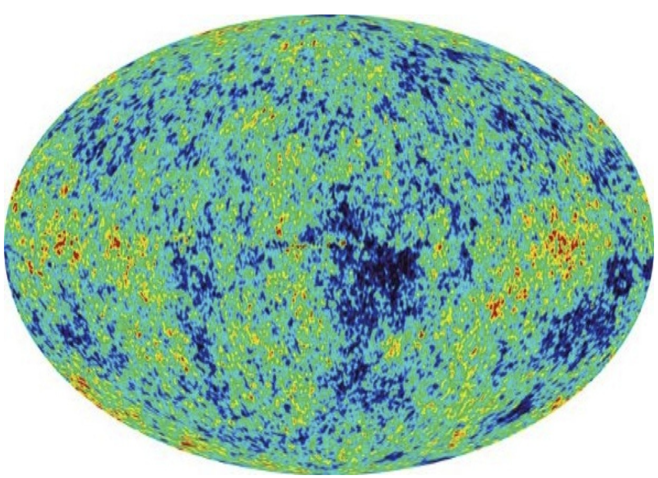


DM evidences



Need of extra matter

→¿WIMP?



Neutrino mass models

Neutrinos are massless in the SM

FORERO-TORTOLA-VALLE
Phys. Rev. D 86, 073012 (2012)

parameter	best fit	1σ range	2σ range	3σ range
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.62	7.43–7.81	7.27–8.01	7.12–8.20
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\text{eV}^2]$	2.55 2.43	2.46 – 2.61 2.37 – 2.50	2.38 – 2.68 2.29 – 2.58	2.31 – 2.74 2.21 – 2.64
$\sin^2\theta_{12}$	0.320	0.303–0.336	0.29–0.35	0.27–0.37
$\sin^2\theta_{23}$	0.613 (0.427)[a] 0.600	0.400-0.461 & 0.573–0.635 0.569–0.626	0.38–0.66 0.39–0.65	0.36–0.68 0.37–0.67
$\sin^2\theta_{13}$	0.0246 0.0250	0.0218–0.0275 0.0223–0.0276	0.019–0.030 0.020–0.030	0.017–0.033
δ	0.80π -0.03π	$0 - 2\pi$	$0 - 2\pi$	$0 - 2\pi$

dirac mass term require a very small yukawa...

¿small masses = new physics?

Neutrino mass models

Effective dim 5 operator:Weinberg Operator $(\mathcal{O}_{ij}) = \frac{1}{\Lambda} L^c_{iL} \quad \widetilde{\phi}^* \widetilde{\phi}^\dagger L_{jL}$

$\text{where } L_i = (\nu_e, e), (\nu_\mu, \mu), (\nu_\tau, \tau);$

	Field	Spin	SU(2)	Y
Type 1	N	1/2	1	0
Type 2	Δ	0	3	-2
Type 3	Σ	1/2	3	0

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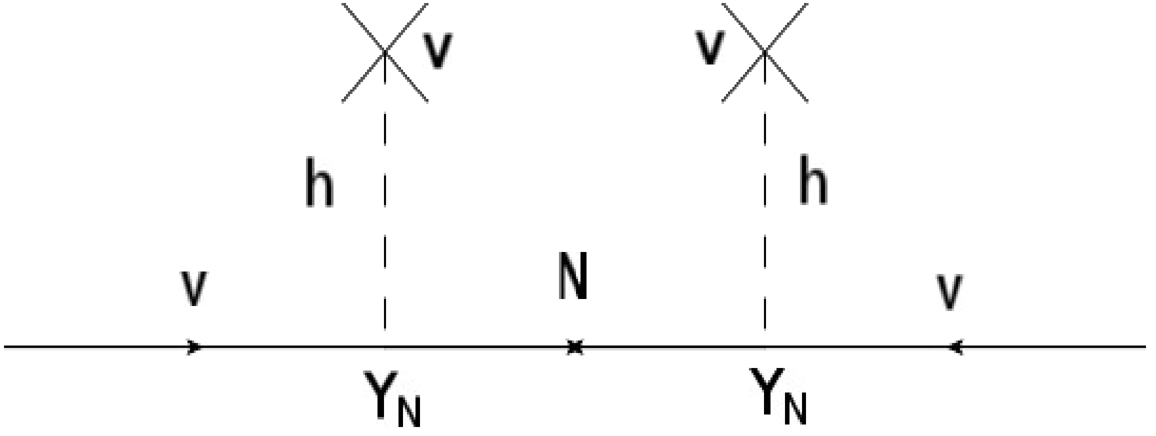

Neutrino mass models

Effective dim 5 operator:Weinberg Operator

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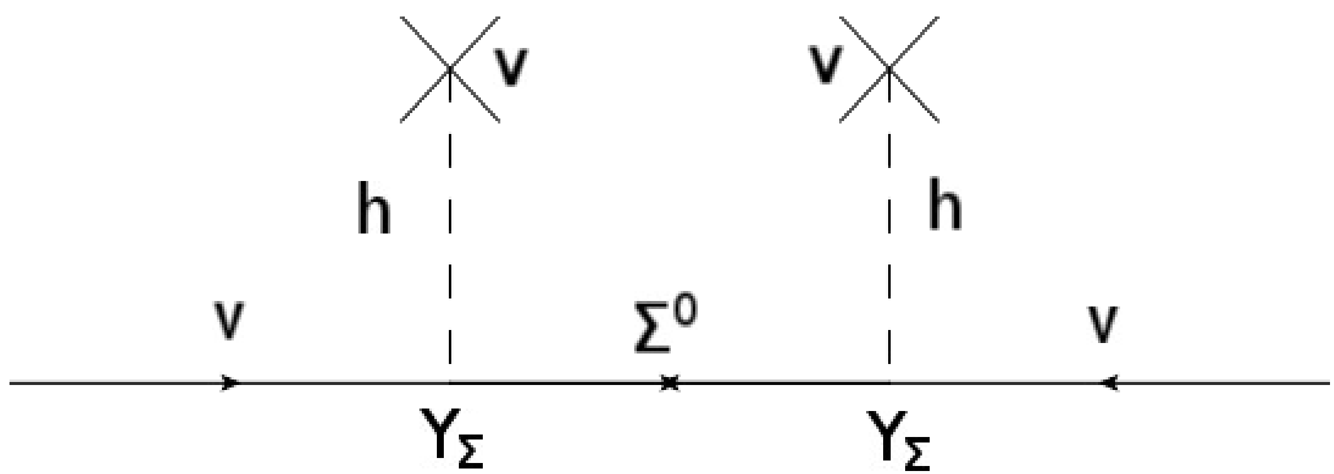

Neutrino mass models

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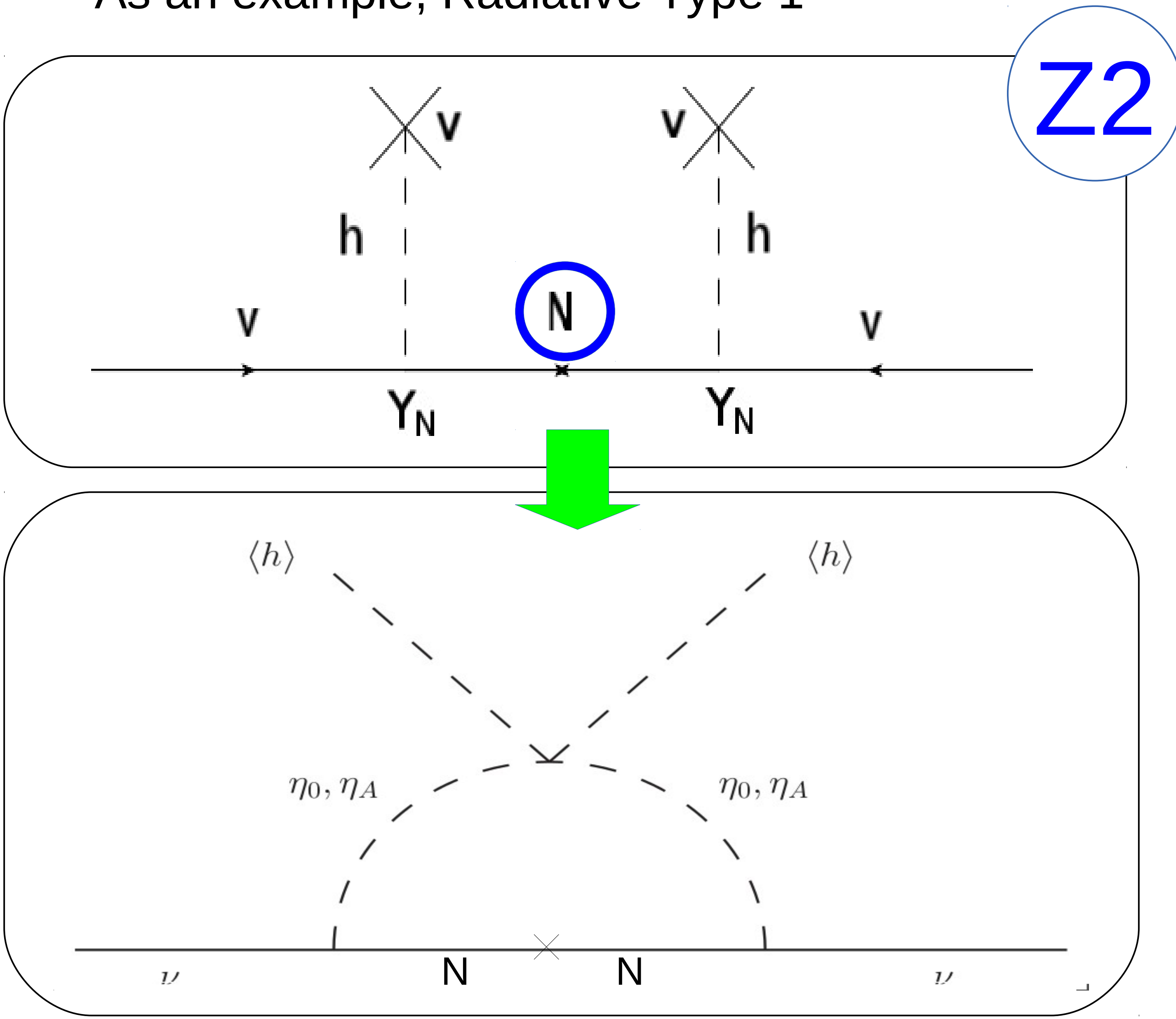
It was then realised that based on the same matter content, neutrino masses could arise at loop level, providing an interesting link between Dark Matter and Neutrino masses generating mechanism.

Neutrino mass models

As an example, Radiative Type 1

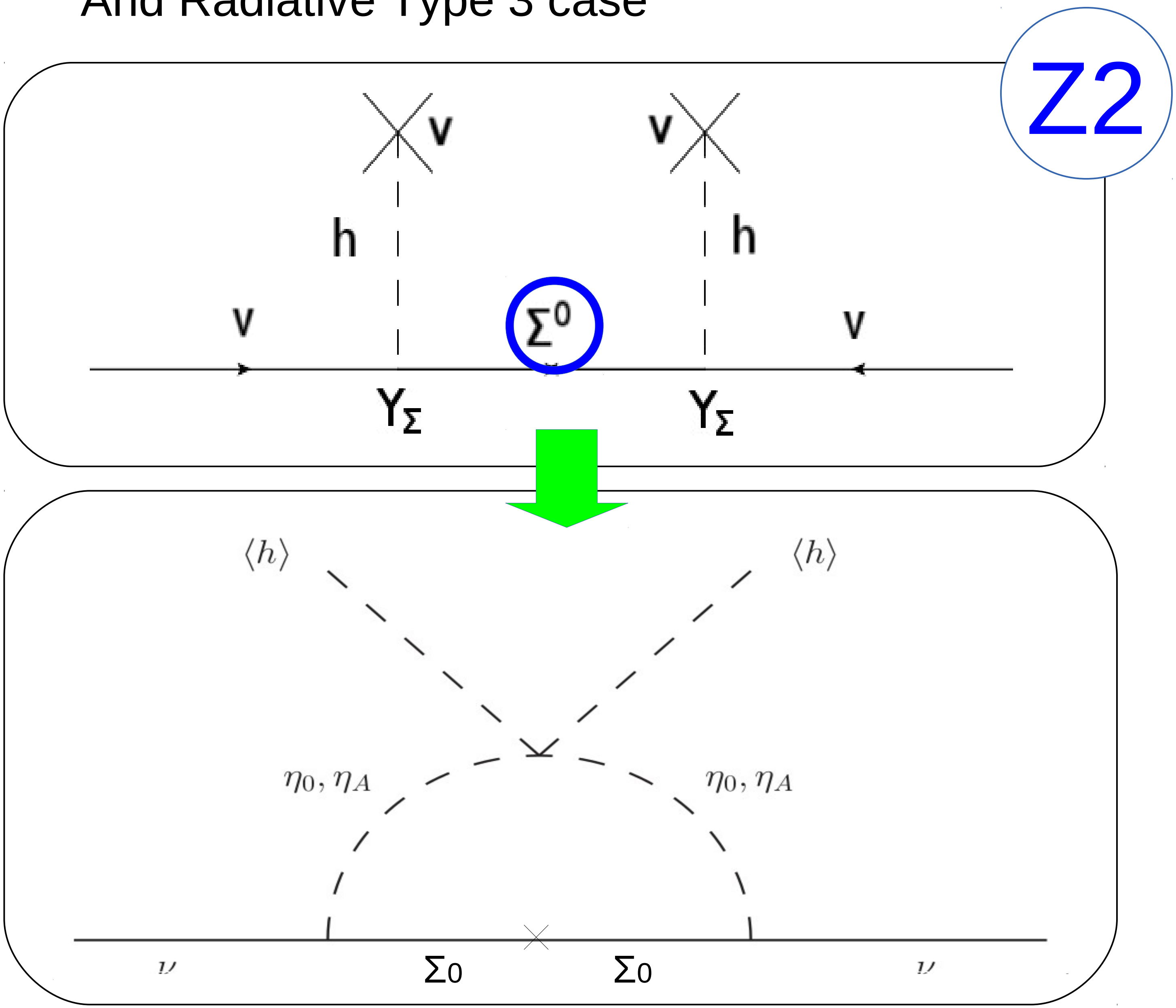


Scalar:
-lot of freedom

Fermion:
-easy light DM
-poor phenomenology

Neutrino mass models

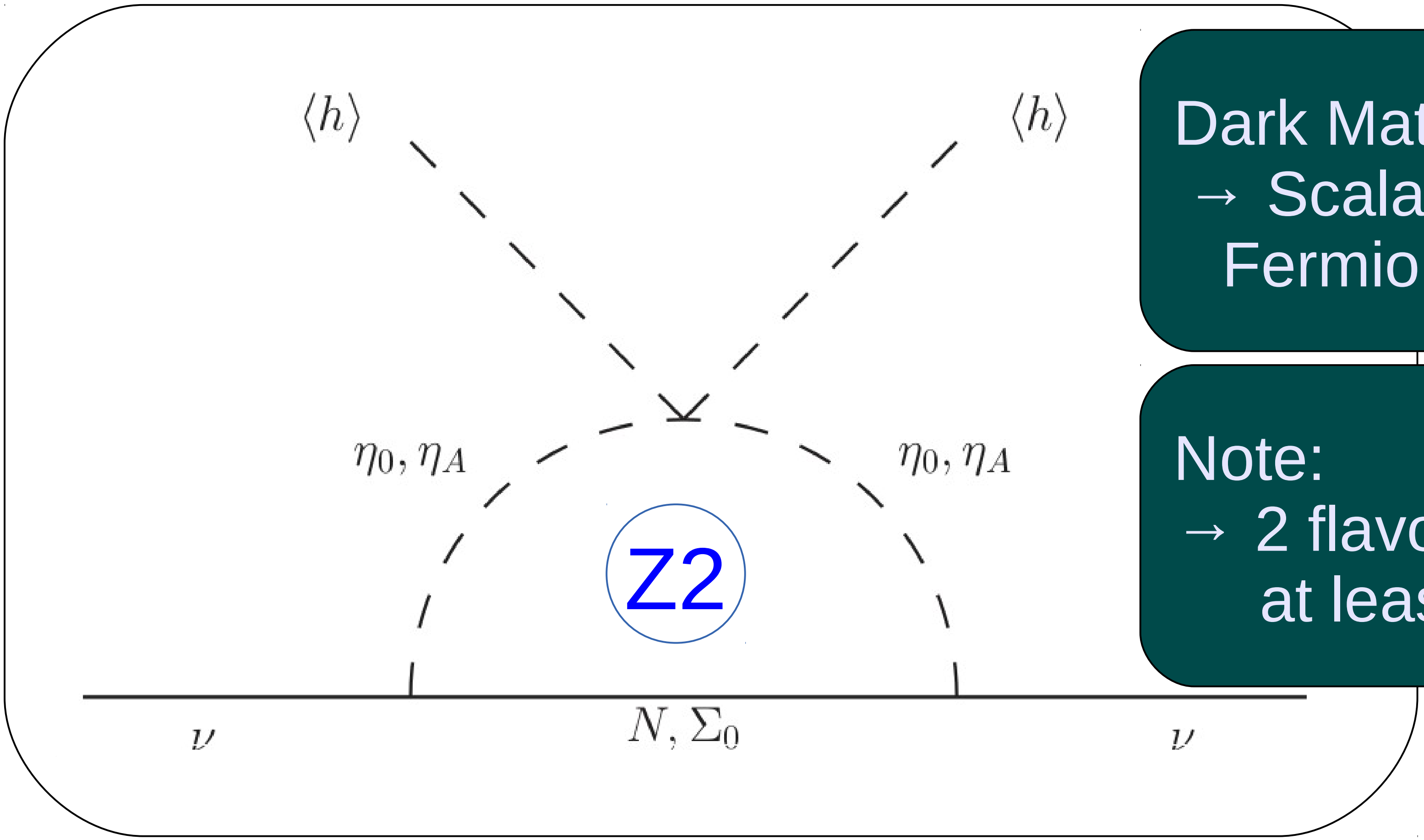
And Radiative Type 3 case



Scalar:
-lot of freedom

Fermion:
-rich phenomenology
-very constrained
DM mass

Neutrino mass models



Dark Matter:
→ Scalar or Fermionic

Note:
→ 2 flavours at least

We would like to join de advantatges of both scenario:

->Light DM for the singlet
->Rich phenomenology

The Model

M. Hirsch, R.A. Lineros, S. Morisi, J. Palacio, N. Rojas, J.W.F. Valle.
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Z2

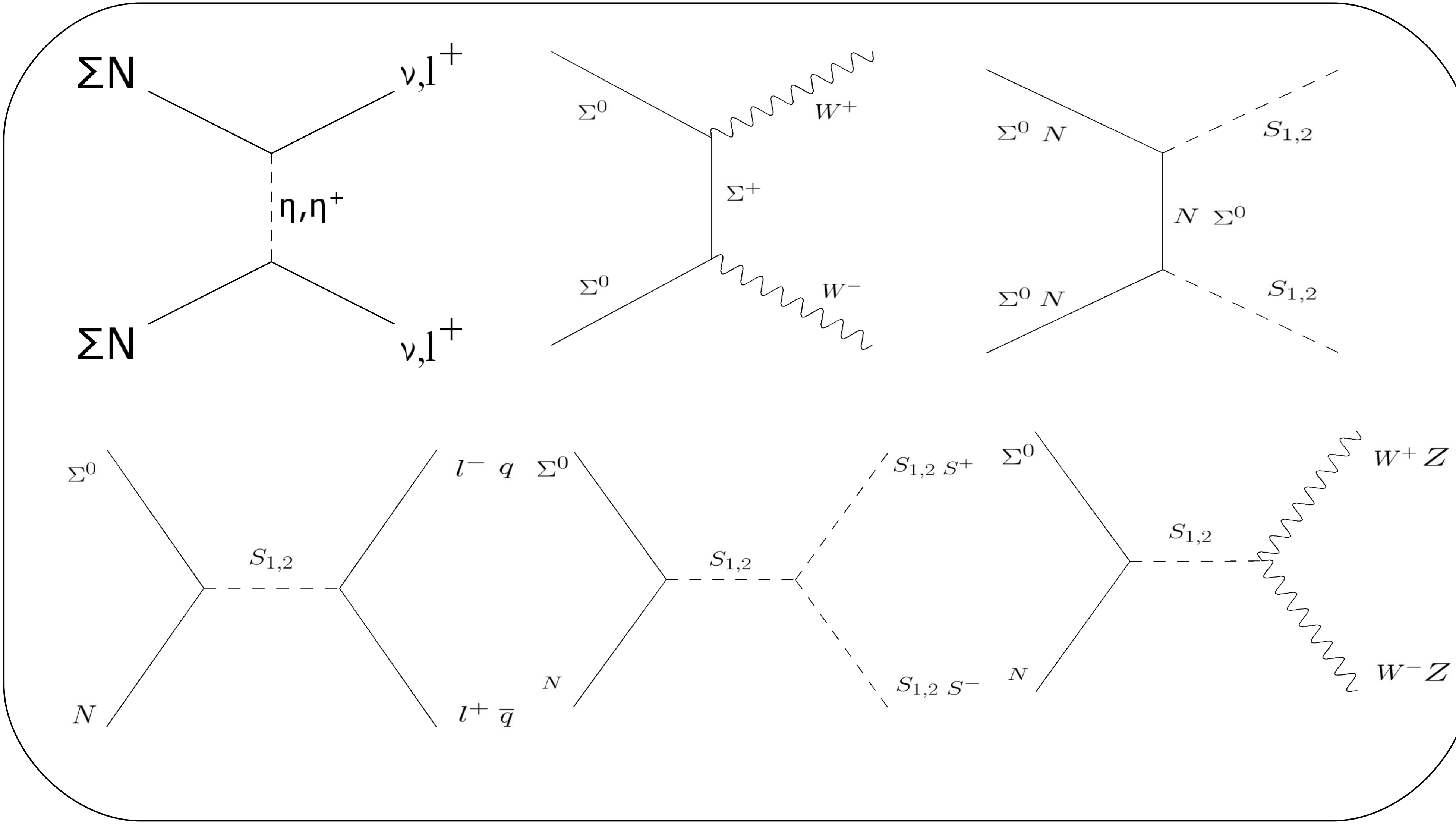
Fields	Standard Model			Fermions		Scalars	
	L	e	ϕ	Σ	N	η	Ω
$SU(2)$	2	1	2	3	1	2	3
Y	-1	-2	1	0	0	1	0
Z_2	$+$	$+$	$+$	$-$	$-$	$-$	$+$

$$\mathcal{L} = -Y_{\alpha\beta}\,\overline{L}_\alpha e_\beta \phi - Y_{\Sigma_\alpha}\overline{L}_\alpha C\Sigma^\dagger\tilde{\eta} - \frac{1}{4}M_\Sigma \mathrm{Tr}\left[\overline{\Sigma}^c\Sigma\right] + $$
$$-Y_\Omega \mathrm{Tr}\left[\overline{\Sigma}\Omega\right] N - Y_{N_\alpha}\overline{L}_\alpha\tilde{\eta}N - \frac{1}{2}M_N\overline{N^c}N + h.c.$$

where $\alpha, \beta = 1, 2, 3$;

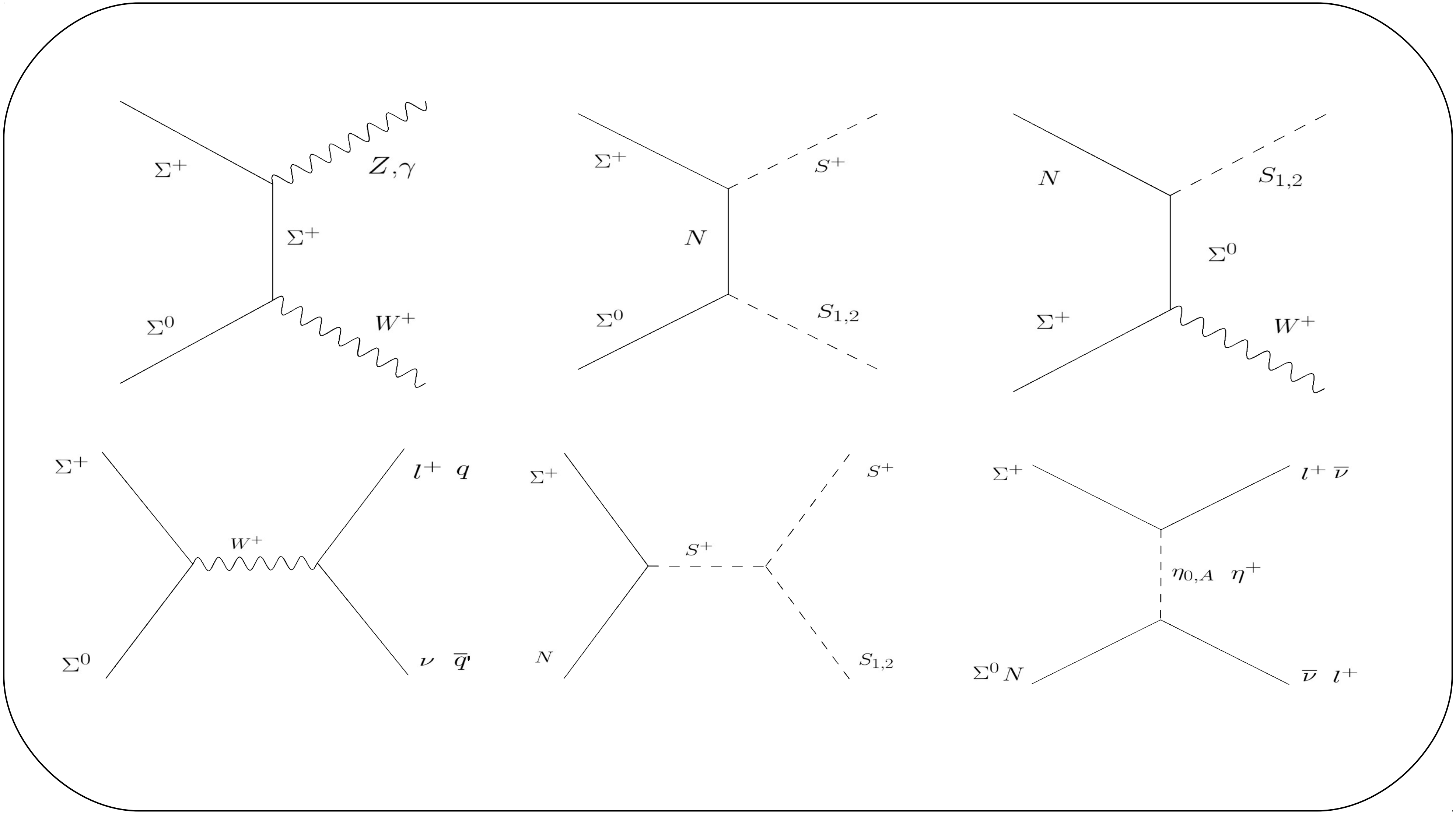
The Model

(Co-)Annihilation diagrams



The Model

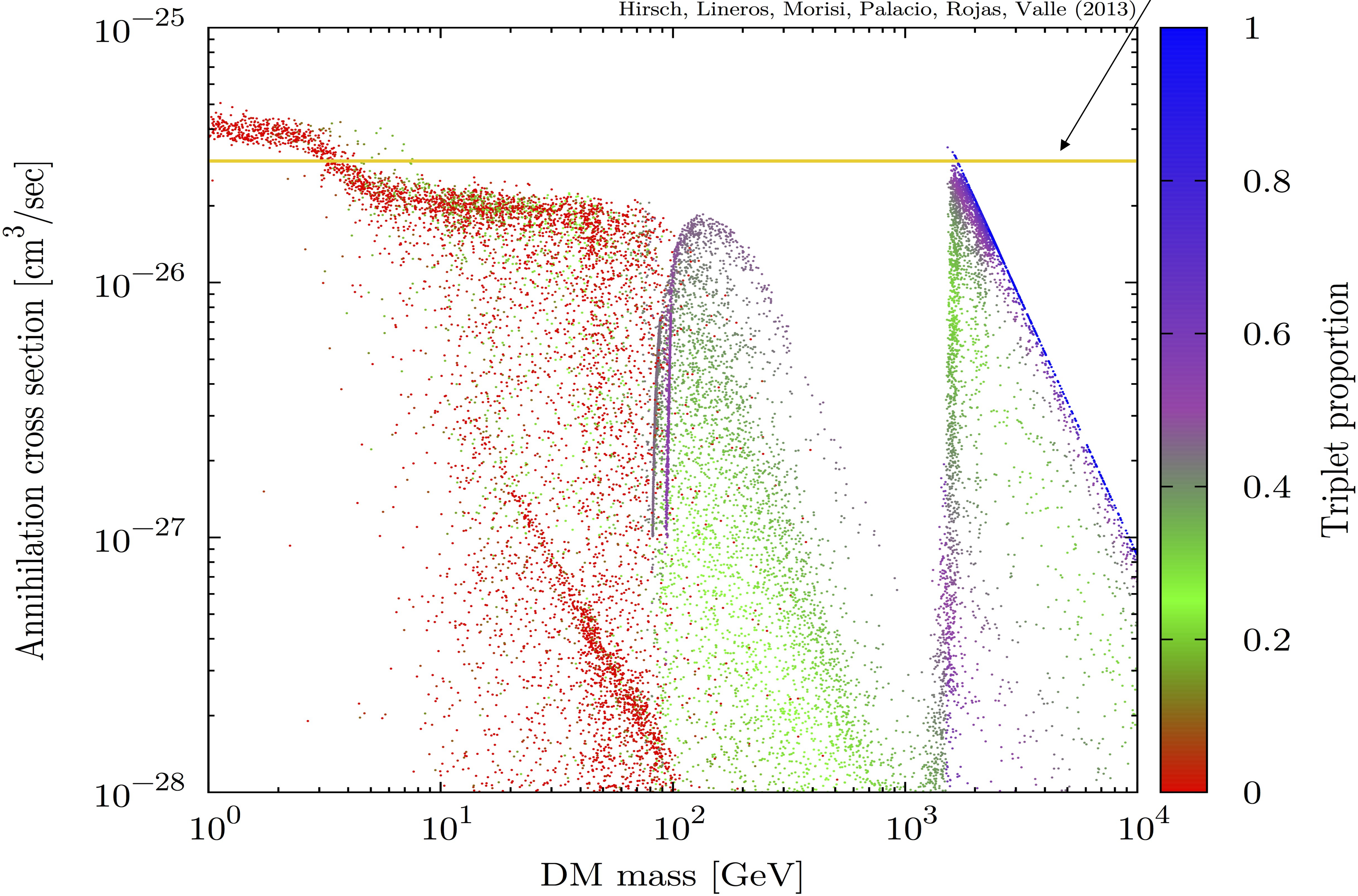
Charged co-Annihilation diagrams



The Model

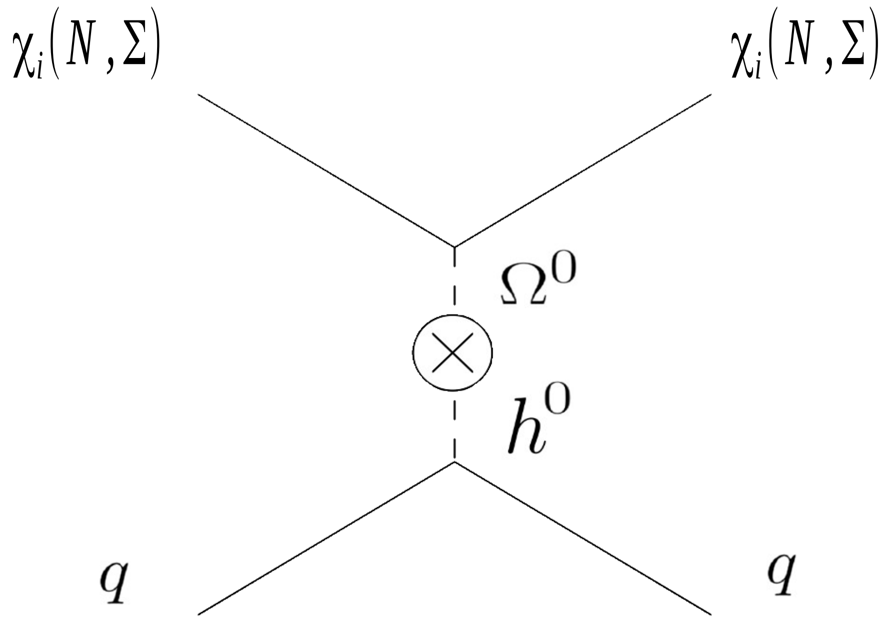
$$\Omega_{CDM} h^2 \approx 0.1 \frac{3 \cdot 10^{-26} cm^3 s^{-1}}{\langle \sigma v \rangle_{f.o.}}$$

Annihilation cross section



The Model

Direct detection

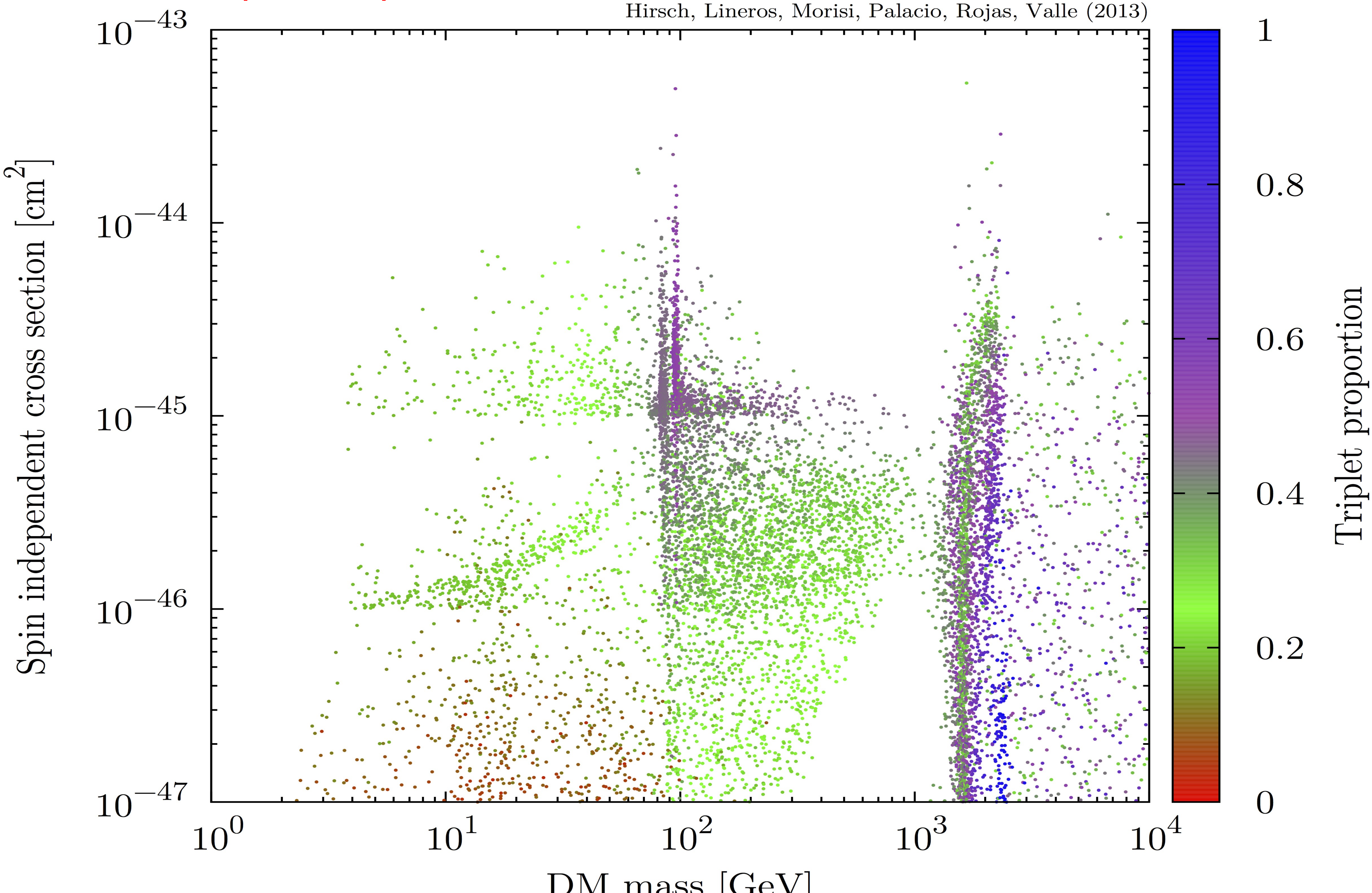


Z2

$$
\begin{aligned}
V \;=\; & -m_1^2\phi^\dagger\phi + m_2^2\eta^\dagger\eta + \frac{\lambda_1}{2}\left(\phi^\dagger\phi\right)^2 + \frac{\lambda_2}{2}\left(\eta^\dagger\eta\right)^2 + \lambda_3\left(\phi^\dagger\phi\right)\left(\eta^\dagger\eta\right) \\
& + \lambda_4\left(\phi^\dagger\eta\right)\left(\eta^\dagger\phi\right) + \frac{\lambda_5}{2}\left(\phi^\dagger\eta\right)^2 + h.c. - \frac{M_\Omega^2}{4}Tr\left(\Omega^\dagger\Omega\right) + \left(\mu_1\phi^\dagger\Omega\phi + h.c.\right) \\
& + \lambda_1^\Omega\phi^\dagger\phi\, Tr\left(\Omega^\dagger\Omega\right) + \lambda_2^\Omega\left(Tr(\Omega^\dagger\Omega)\right)^2 + \lambda_3^\Omega Tr(\left(\Omega^\dagger\Omega\right)^2) + \lambda_4^\Omega\left(\phi^\dagger\Omega\right)\left(\Omega^\dagger\phi\right) \\
& + \left(\mu_2\eta^\dagger\Omega\eta + h.c.\right) + \lambda_1^\eta\eta^\dagger\eta\, Tr\left(\Omega^\dagger\Omega\right) + \lambda_4^\eta\left(\eta^\dagger\Omega\right)\left(\Omega^\dagger\eta\right) .
\end{aligned}
$$

The Model

Spin independent cross section



Conclusions

Dark Matter and neutrino oscillations are the most robust evidence of physics beyond de Standard Model

We linked both phenomenas in this model: Neutrino mass-generating mechanism also stabilizes the Dark Matter.

The mixture scenario, Ω, gain the nice thinks of both pure Models: light DM with a rich phenomenology

The same mechanism that produces the fermion mixing also predicts a high interaction with quarks

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Thanks

Back-up slides

The Scan

We used micrOMEGAs to do a parameter scan
G. Bélanger, F. Boudjema, A. Pukhov, A. Semenov, arXiv:1305.0237 [hep-ph]

Constraints: - Ω is an triplet of SU(2)

$$M_W = \frac{g}{2}\sqrt{v_h^2 + v_\Omega^2}.$$

⇒ $V_\Omega < 7\text{GeV}$

- searches of new physics

Parameter	Range
M_N (GeV)	$1 - 10^5$
M_Σ (GeV)	$100 - 10^5$
$m_{\eta^\pm}$ (GeV)	$100 - 10^5$
m_{η^0} (GeV)	$1 - 10^5$
$M_\pm$ (GeV)	$100 - 10^4$
$\|\lambda_i\|$	$10^{-4} - 1$
$\|Y_i\|$	$10^{-4} - 1$

Scalar sector

$$\mathcal{M}_s^2 = \begin{pmatrix} \lambda_1 v_h^2 + \frac{t_h}{v_h} & -2\mu_1 v_h + 4 v_h v_\Omega \left(\lambda_1^\Omega + \frac{\lambda_4^\Omega}{2}\right) \\ -2\mu_1 v_h + 4 v_h v_\Omega \left(\lambda_1^\Omega + \frac{\lambda_4^\Omega}{2}\right) & \frac{\mu_1 v_h^2}{v_\Omega} + 16 v_\Omega^2 \left(2\lambda_2^\Omega + \lambda_3^\Omega\right) + \frac{t_\Omega}{v_\Omega} \end{pmatrix}$$

$$\begin{aligned} M_{S1}^2 &= v_h^2 \lambda_1 \cos(\theta_0)^2 + 4 v_h \left[-v_\Omega \left(2\lambda_1^\Omega + \lambda_4^\Omega\right) + \mu_1\right] \cos(\theta_0)^2 \sin(\theta_0)^2 \\ &\quad + \left[16 v_\Omega^2 \left(2\lambda_2^\Omega + \lambda_3^\Omega\right) + \mu_1 v_h^2 / v_\Omega\right] \sin(\theta_0)^2 \\ M_{S2}^2 &= v_h^2 \lambda_1 \sin(\theta_0)^2 + 4 v_h \left[v_\Omega \left(2\lambda_1^\Omega + \lambda_4^\Omega\right) - \mu_1\right] \cos(\theta_0)^2 \sin(\theta_0)^2 \\ &\quad + \left[16 v_\Omega^2 \left(2\lambda_2^\Omega + \lambda_3^\Omega\right) + \mu_1 v_h^2 / v_\Omega\right] \cos(\theta_0)^2 \\ &\quad \text{where } \tan(2\theta_0) = \frac{4 v_h \left[v_\Omega \left(2\lambda_1^\Omega + \lambda_4^\Omega\right) - \mu_1\right]}{16 v_\Omega^2 \left(2\lambda_2^\Omega + \lambda_3^\Omega\right) - v_h^2 \left(\lambda_1 - \mu_1 / v_\Omega\right)} \end{aligned}$$

Scalar sector

-Z2

$$
\begin{aligned}
m^2_{\eta 0} &= m_2^2 + \frac{1}{2}\left(\lambda_3 + \lambda_4 + \lambda_5\right) v_h^2 + \left(2\lambda_1^\eta + \lambda_4^\eta\right) v_\Omega^2 - 2\mu_2 v_\Omega \,, \\
m^2_{\eta A} &= m_2^2 + \frac{1}{2}\left(\lambda_3 + \lambda_4 - \lambda_5\right) v_h^2 + \left(2\lambda_1^\eta + \lambda_4^\eta\right) v_\Omega^2 - 2\mu_2 v_\Omega \,, \\
m^2_{\eta\pm} &= m_2^2 + \frac{1}{2}\lambda_3 v_h^2 + 2\mu_2 v_\Omega + \left(2\lambda_1^\eta + \lambda_4^\eta\right) v_\Omega^2 \,.
\end{aligned}
$$

λ5 plays an important role in ν masses

The Model

$$
\begin{aligned}
\mathcal{L} \;=\; & -Y_{\alpha\beta}\,\overline{L}_\alpha e_\beta \phi - Y_{\Sigma_\alpha}\overline{L}^{c}_\alpha{}'\Sigma^\dagger\tilde{\eta} - \frac{1}{4}M_\Sigma \mathrm{Tr}\left[\overline{\Sigma}^c\Sigma\right] + \\
& -Y_\Omega \mathrm{Tr}\left[\overline{\Sigma}\Omega\right] N - Y_{N_\alpha}\overline{L}_\alpha\tilde{\eta}N - \frac{1}{2}M_N\overline{N^c}N + h.c.
\end{aligned}
$$

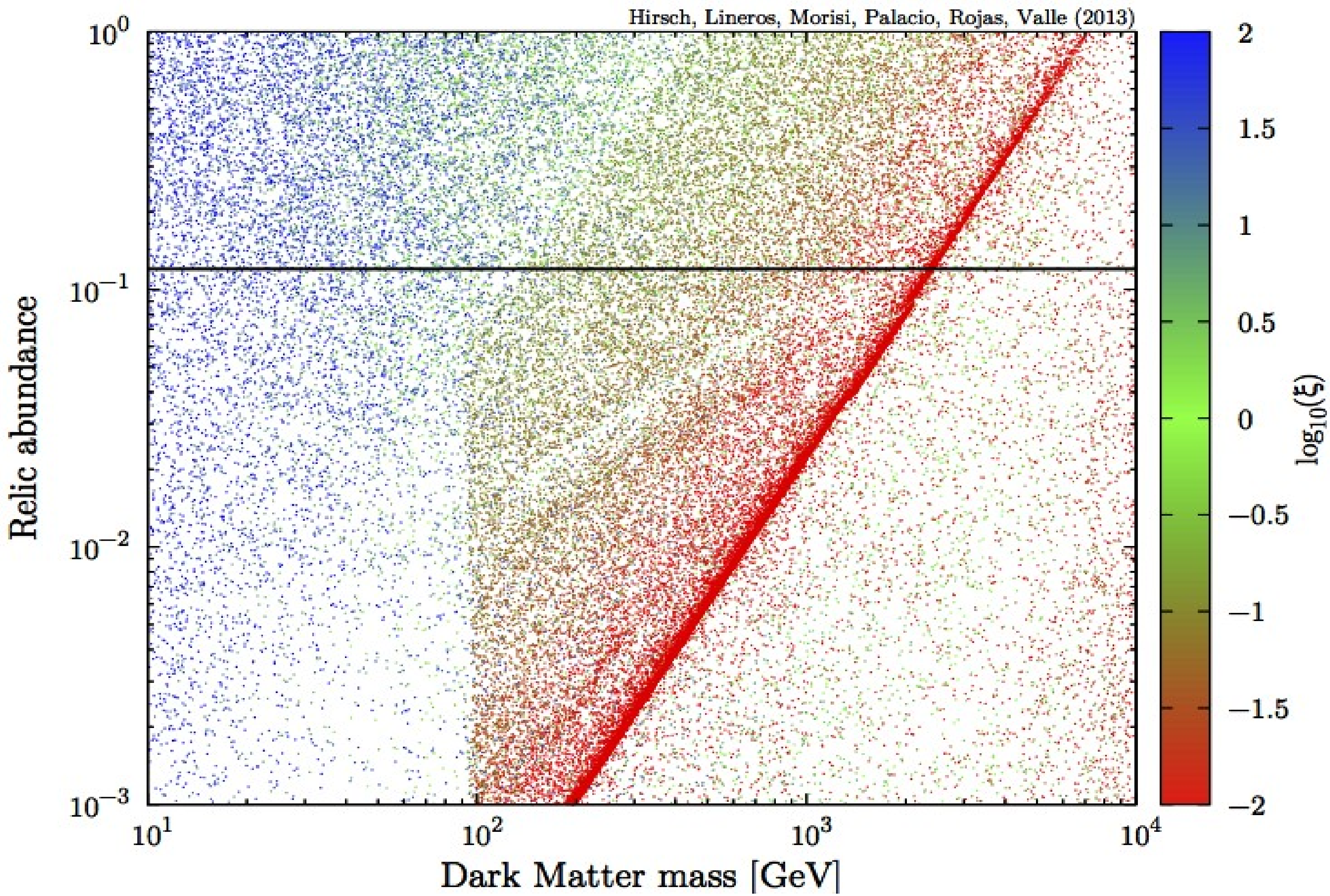
where $\alpha, \beta = 1, 2, 3$;

$$
M_\chi = \begin{pmatrix} M_\Sigma & 2Y_\Omega v_\Omega \\ 2Y_\Omega v_\Omega & M_N \end{pmatrix}
$$

$$
\begin{aligned}
M_{\chi 1} &= \sin(\theta_f)^2 M_N + \cos(\theta_f)^2 M_\Sigma - 2v_\Omega Y_\Omega \cos(\theta_f)\sin(\theta_f) \\
M_{\chi 2} &= \cos(\theta_f)^2 M_N + \sin(\theta_f)^2 M_\Sigma + 2v_\Omega Y_\Omega \cos(\theta_f)\sin(\theta_f)
\end{aligned}
$$

where $\tan(2\theta_f) = \dfrac{-4Y_\omega v_\Omega}{M_\Sigma - M_N}$

Scan constrains



Scan constrains