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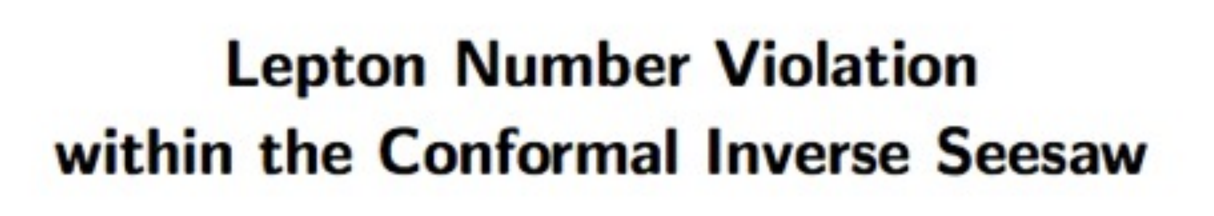
HEIDELBERG

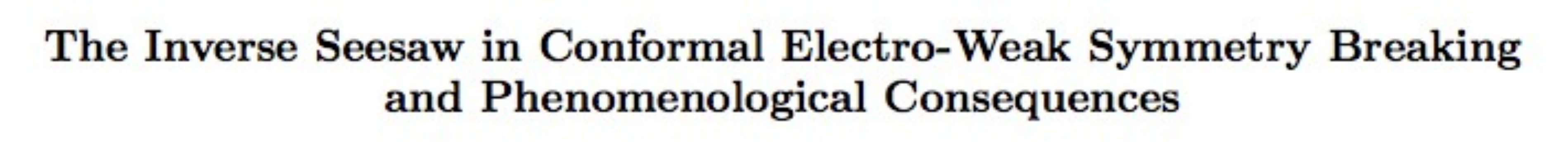
Conformal inverse Seesaw
LNV and Dark Matter

Juri Smirnov


Lepton Number Violation
within the Conformal Inverse Seesaw

1505.07453

JHEP


The Inverse Seesaw in Conformal Electro-Weak Symmetry Breaking
and Phenomenological Consequences

1503.
03066

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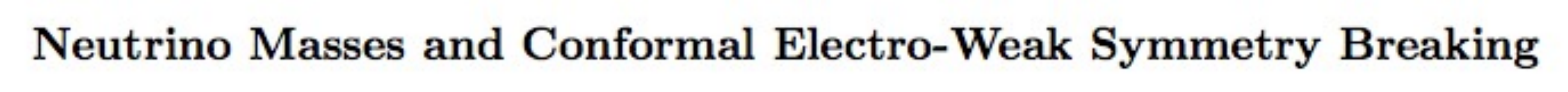
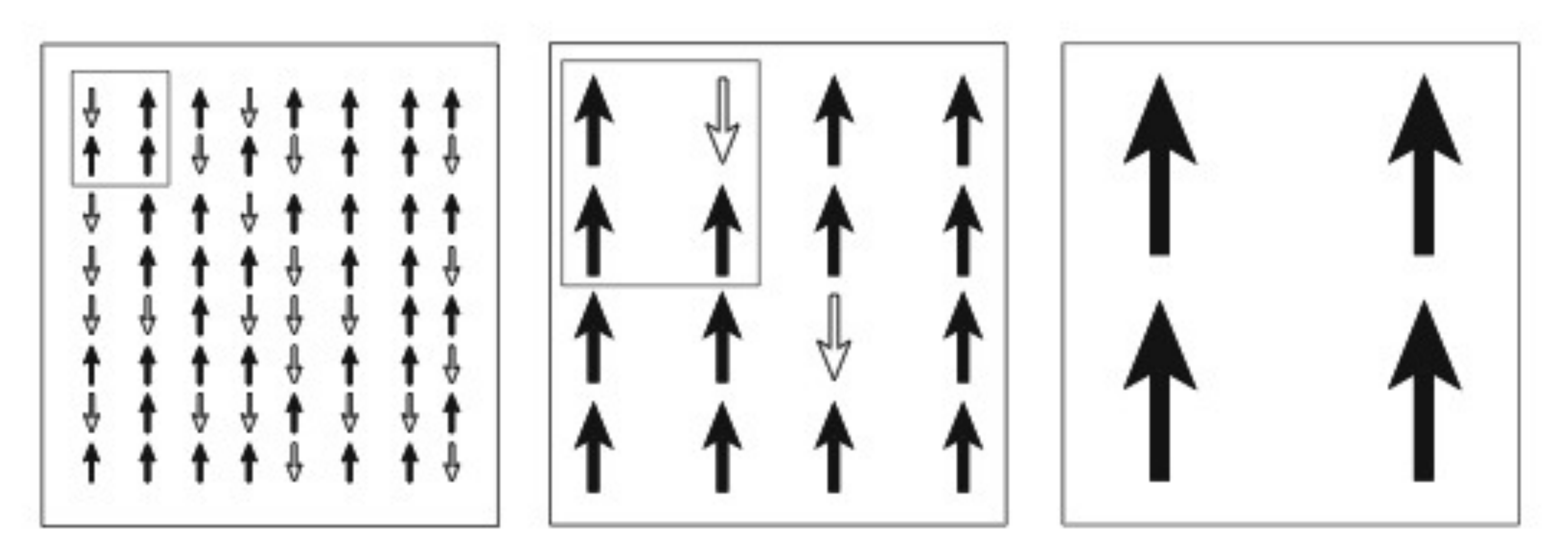

Neutrino Masses and Conformal Electro-Weak Symmetry Breaking

1405.
6204

with M. Lindner, P. Humbert, S. Schmidt, S. Patra

Self similarity

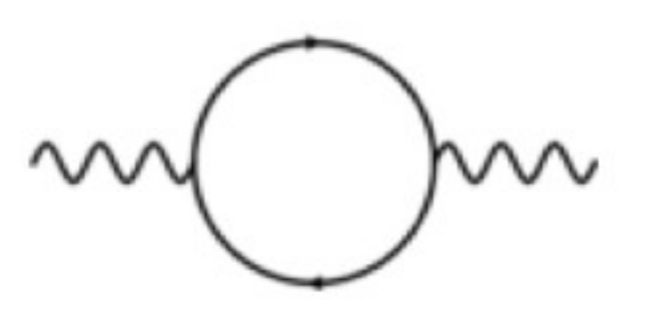
- Self similarity near a critical point (idea goes back to Leo Kadanoff)

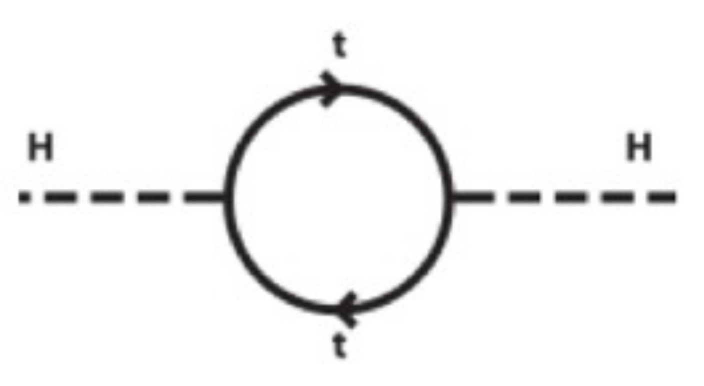


- Can we apply the ideas to QFT ?

Conformal model

- Gauge boson masses are protected by gauge symmetry i.e. no power divergence
- Higgs mechanism is non linear realization of gauge symmetry
- Now introduce conformal symmetry:
- Scale dependence trough trace of energy momentum tensor
- Beta function responsible for the log running





Portals to the Hidden Sector

1) Higgs Portal

$$\langle\phi^\dagger\phi\rangle \Rightarrow \lambda(\phi^\dagger\phi)(H^\dagger H) \to \mu H^\dagger H$$

2) Neutral Lepton Portal

$$\mathcal{L}_{NP} = -h_{\alpha i}\bar{\ell}_\alpha \tilde{H} N_i - h^\dagger_{i\alpha}\bar{N}_i\tilde{H}^\dagger \ell_\alpha$$

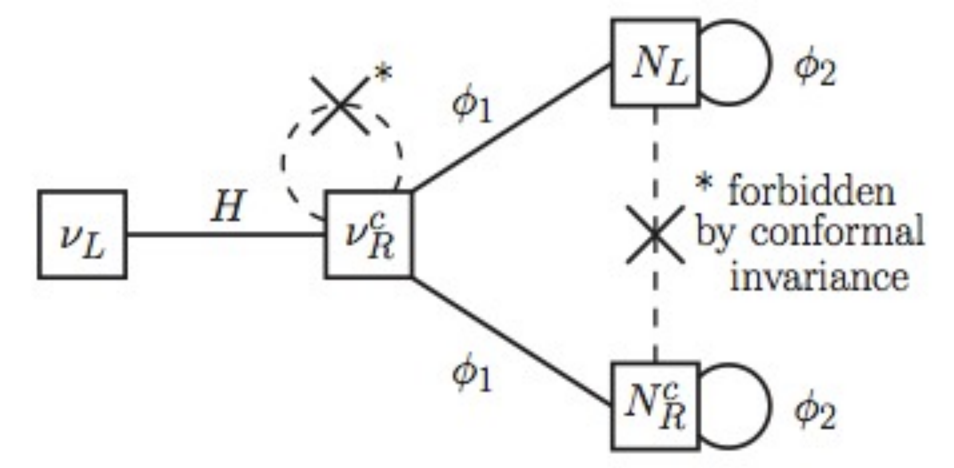
3) New gauge sector

$$g_X \bar{\Psi}\gamma_\mu \Psi X^\mu \quad \kappa \tilde{F}_{\mu\nu}F^{\mu\nu}$$

Explicit breaking or local symmetry

- Not possible in conformal framework: $\cancel{M\,\bar{\nu}_R\nu_R^c}$
- Possible to construct interactions violating L
- Introduce U(1)$_X$ in the HS and fermions:

$$\nu_R : (1_{SU(2)}, 0_Y, 0_X)\,;\; N_L : (1_{SU(2)}, 0_Y, n_X)\,;\; N_R : (1_{SU(2)}, 0_Y, n_X)$$



$$\bar{N}_L \nu_R \phi_1$$
$$\bar{N}_R^c \nu_R \phi_1^*$$

Violate L
as N is vector
like

Explicit breaking by interaction
in addition breaking of U(1)$_X$ transferred to L

I) Gauged Symmetry X & Explicitly broken L

$$\mathcal{M} = \begin{pmatrix} 0 & y_D\,\langle H\rangle & 0 & 0 \\ y_D\,\langle H\rangle & 0 & y_1\,\langle\phi_1\rangle & \tilde{y}_1\,\langle\phi_1\rangle \\ 0 & y_1\,\langle\phi_1\rangle & y_2\,\langle\phi_2\rangle & 0 \\ 0 & \tilde{y}_1\,\langle\phi_1\rangle & 0 & \tilde{y}_2\,\langle\phi_2\rangle \end{pmatrix} = \begin{pmatrix} 0 & m_D & 0 & 0 \\ m_D & 0 & M_1 & M_2 \\ 0 & M_1 & \mu_1 & 0 \\ 0 & M_2 & 0 & \mu_2 \end{pmatrix}$$

Type I)

$$N^T = (\nu_L, \nu_R^c, N_L, N_R^c)$$

II) Gauged B-L & Spontaneously broken

$$\begin{pmatrix} 0 & m_D & 0 & 0 \\ m_D & M_R & M_1 & M_2 \\ 0 & M_1 & \mu_1 & 0 \\ 0 & M_2 & 0 & \mu_2 \end{pmatrix}$$

Type II)

Explicit breaking vs. local B-L

Explicit L breaking and PD states (I)

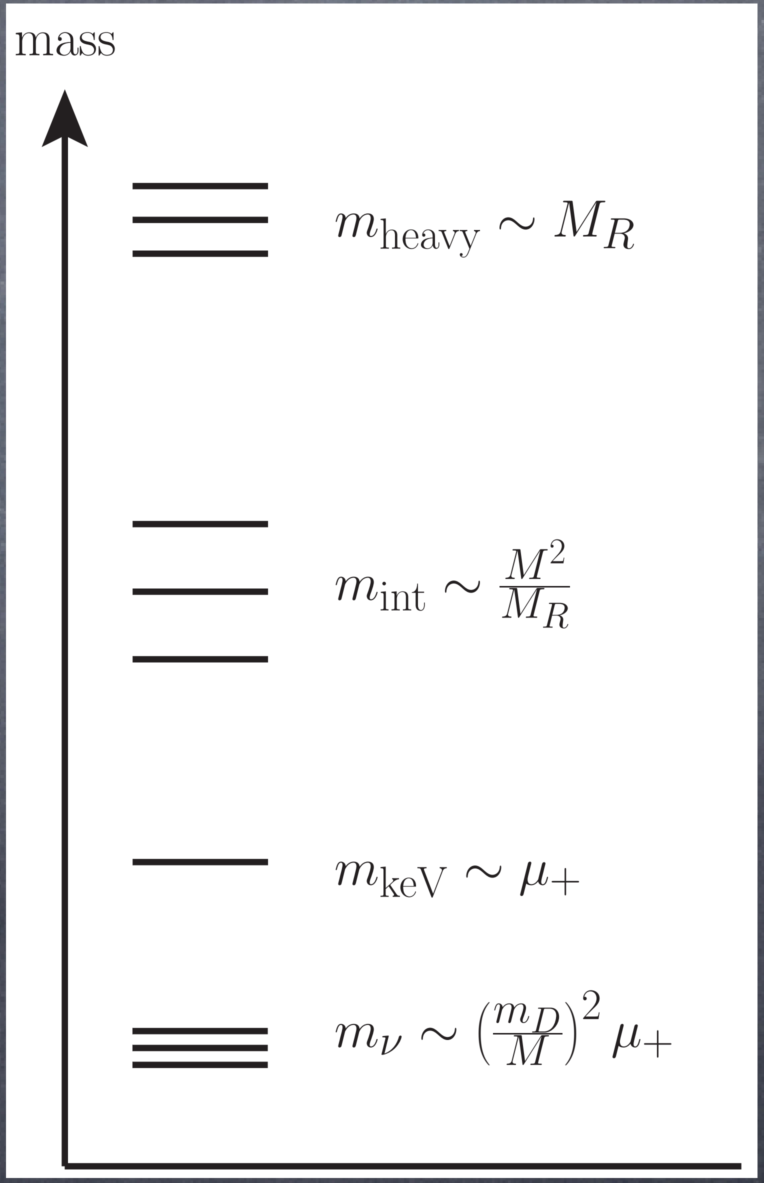
$$M_{1\text{heavy}} \approx M + \mu \approx \text{TeV}$$

$$M_{2\text{heavy}} \approx -M + \mu \approx \text{TeV}$$

$$m_{DM} \approx \mu_+ \approx \text{keV}$$

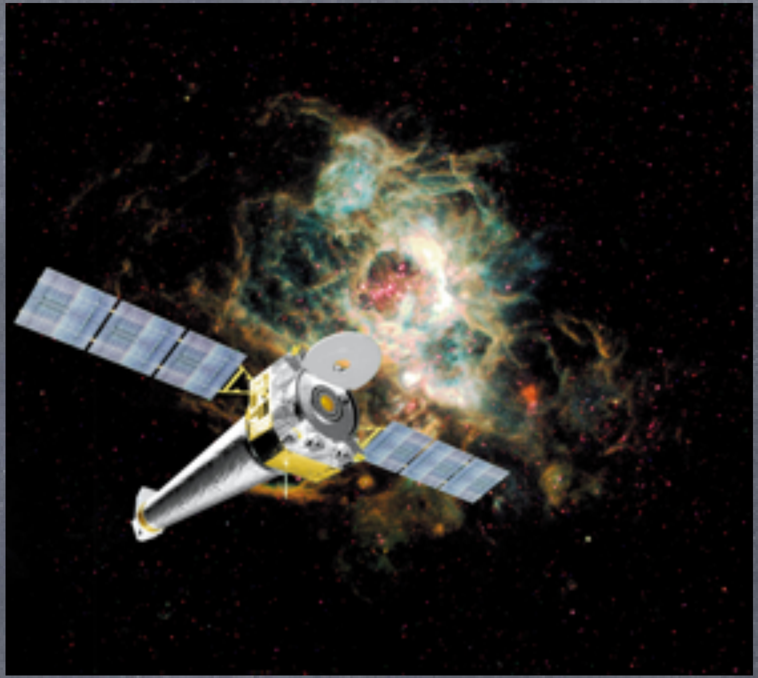
$$m_\nu \approx \left(\frac{m_D}{M}\right)^2 \mu_+ \approx \text{eV}$$

Local B-L and Majorana states (II)



Hidden Sector Relics II

New state needed for anomaly cancellation Majorana state at intermediate mass scale



$$m_1 = \mu_+ \frac{m_D^2}{\mathbf{M}^2} - \frac{\bar{\mu}^2}{\mu_+} \frac{m_D^2}{\mathbf{M}^2} + \frac{\bar{\mu}^2}{\mu_+} \approx \mu_+ \frac{m_D^2}{\mathbf{M}^2} + \frac{\bar{\mu}^2}{\mu_+} \tag{10}$$

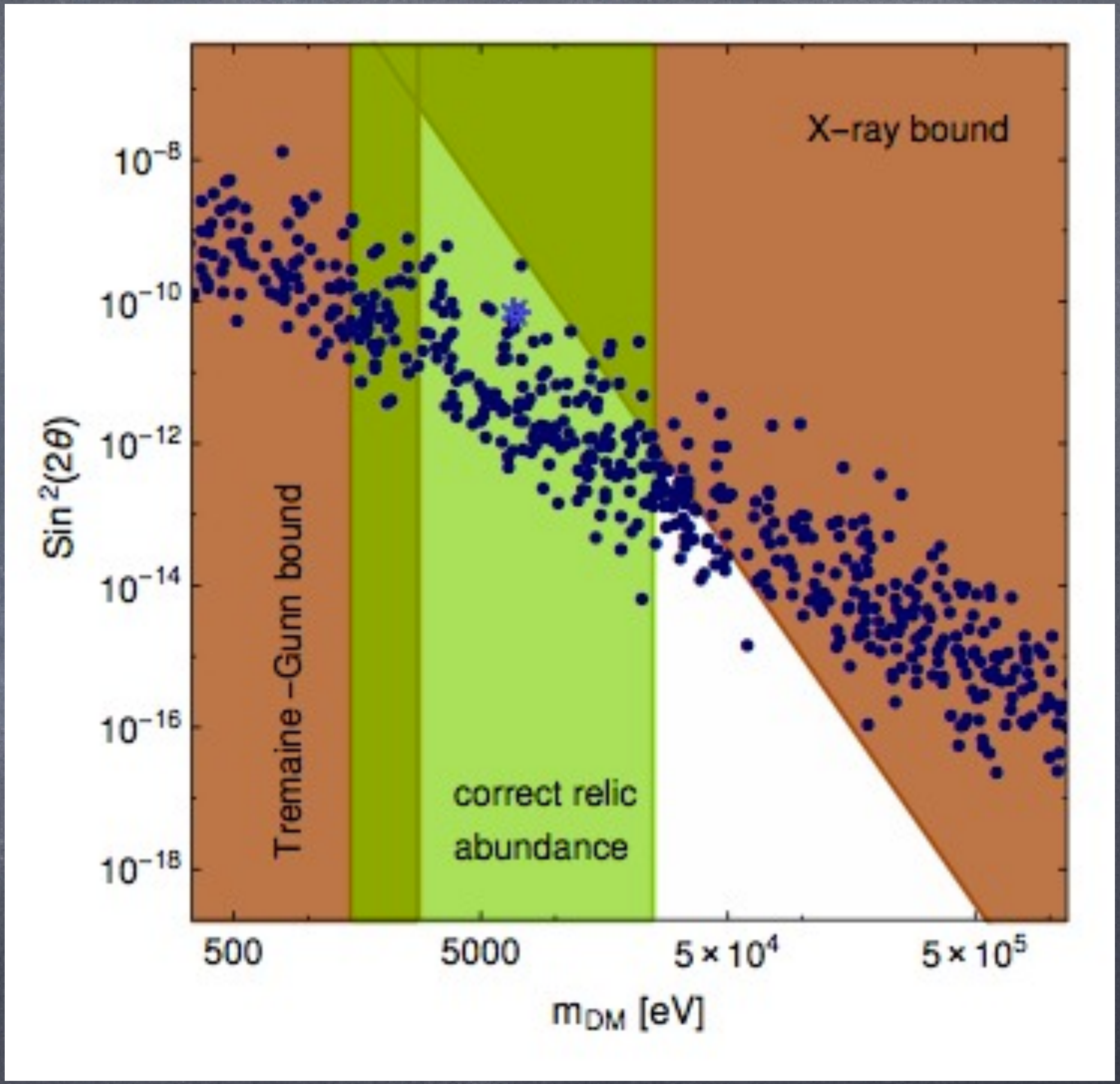
$$m_2 = \mu_+ + \frac{\bar{\mu}^2}{\mu_+} \frac{m_D^2}{\mathbf{M}^2} - \frac{\bar{\mu}^2}{\mu_+} \approx \mu_+ - \frac{\bar{\mu}^2}{\mu_+} . \tag{11}$$

$$\tilde{\theta} \approx \frac{m_D}{M} \frac{\mu_1 - \mu_2}{\mu_1 + \mu_2}$$

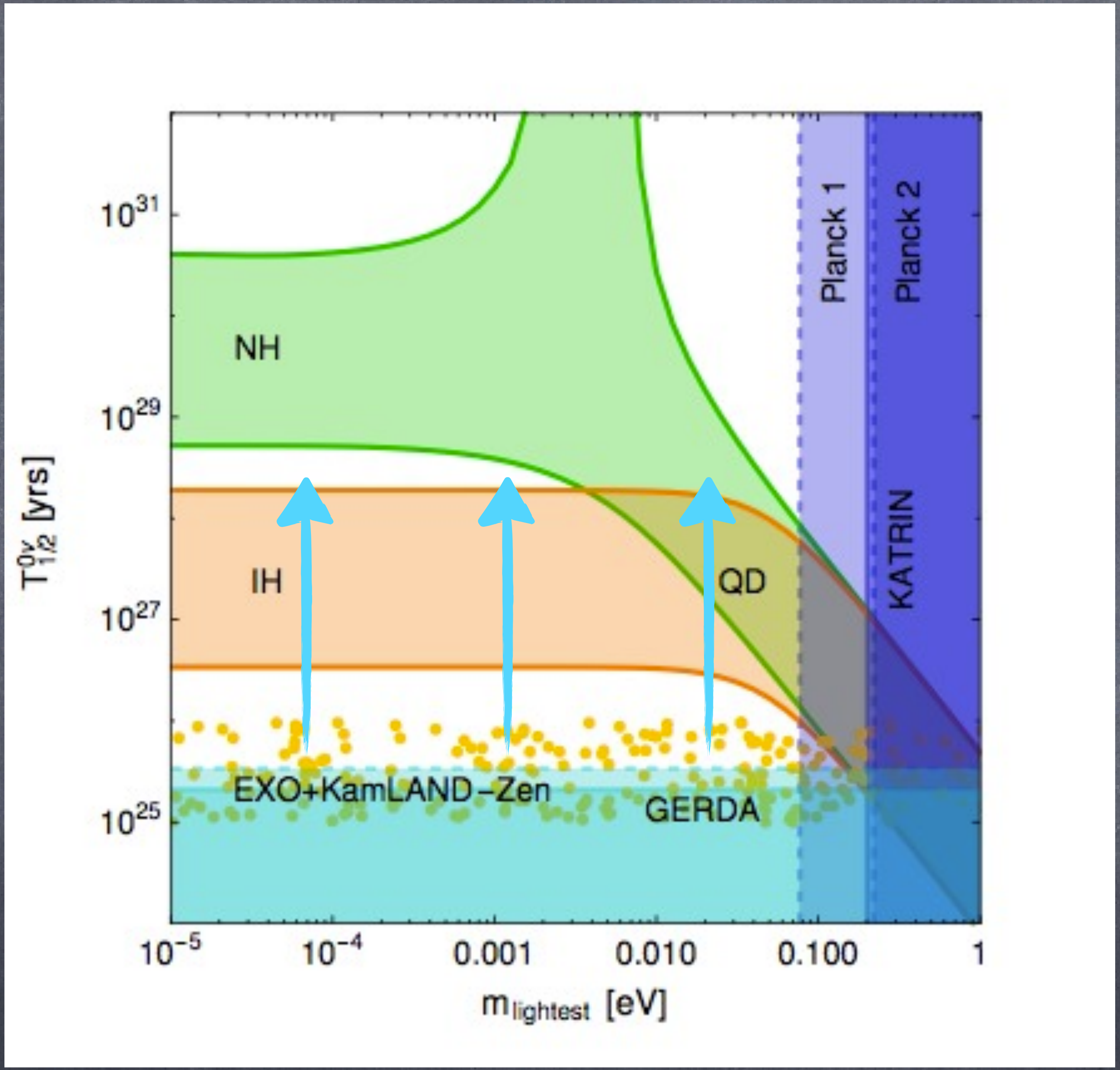
TeV Seesaw scale induces keV Dark Matter scale

Low energy constraints and cosmology

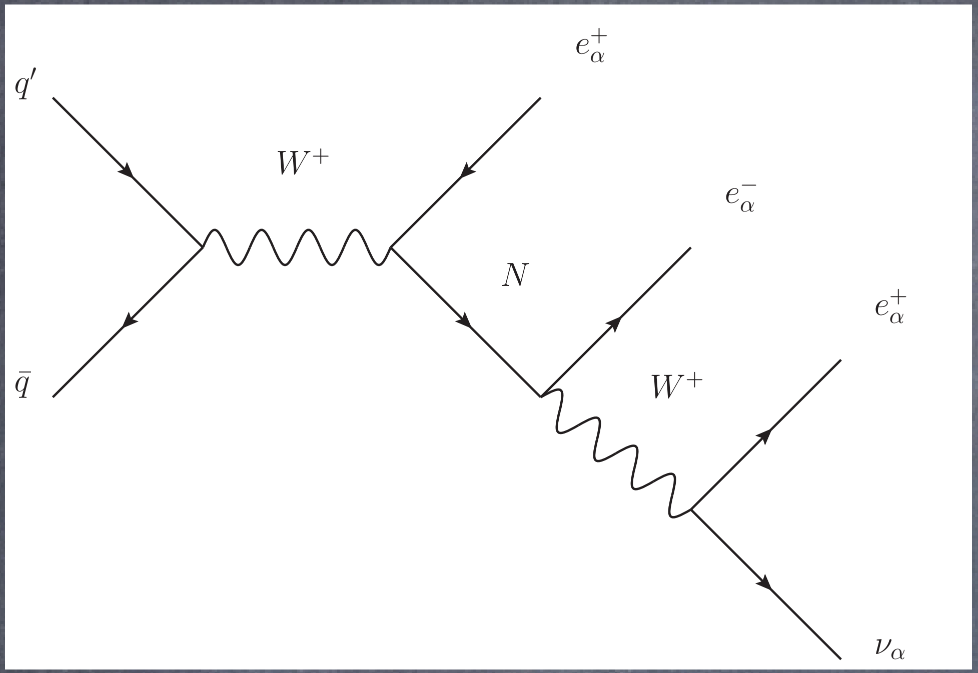
- Active neutrino masses
- Lepton universality
- Lepton flavour constraints
- Non-Unitarity
- Lepton Number violation
- Freeze-in



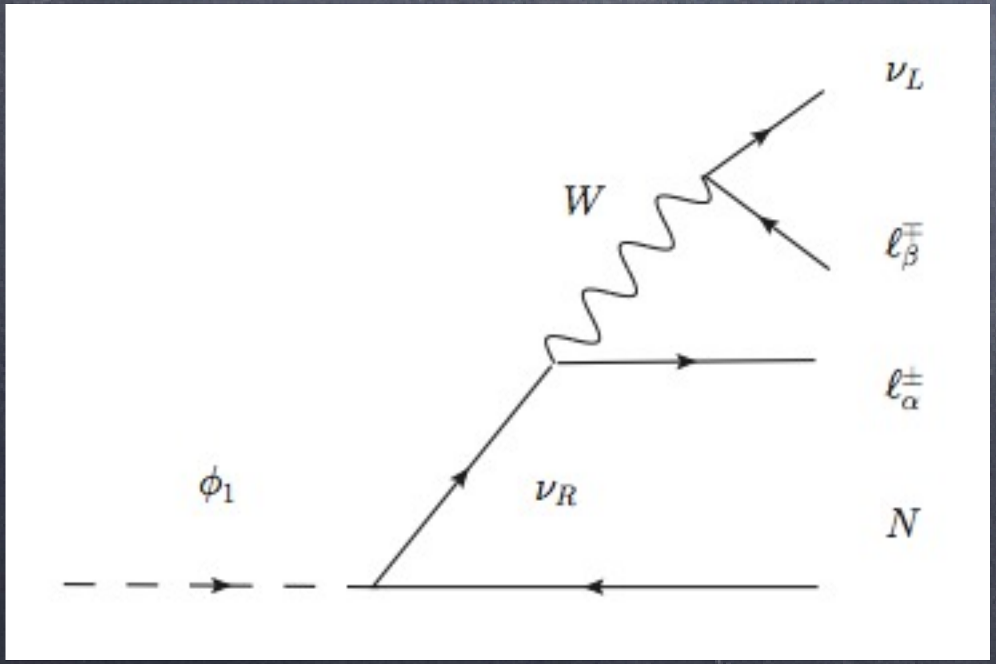
How to distinguish scenarios?

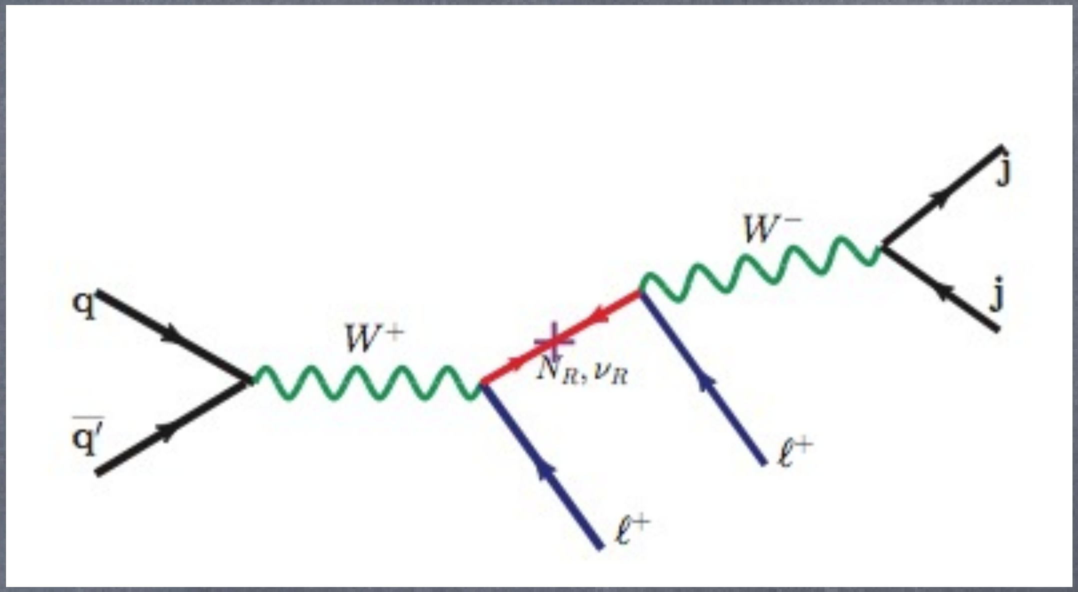


Distinguishing the models

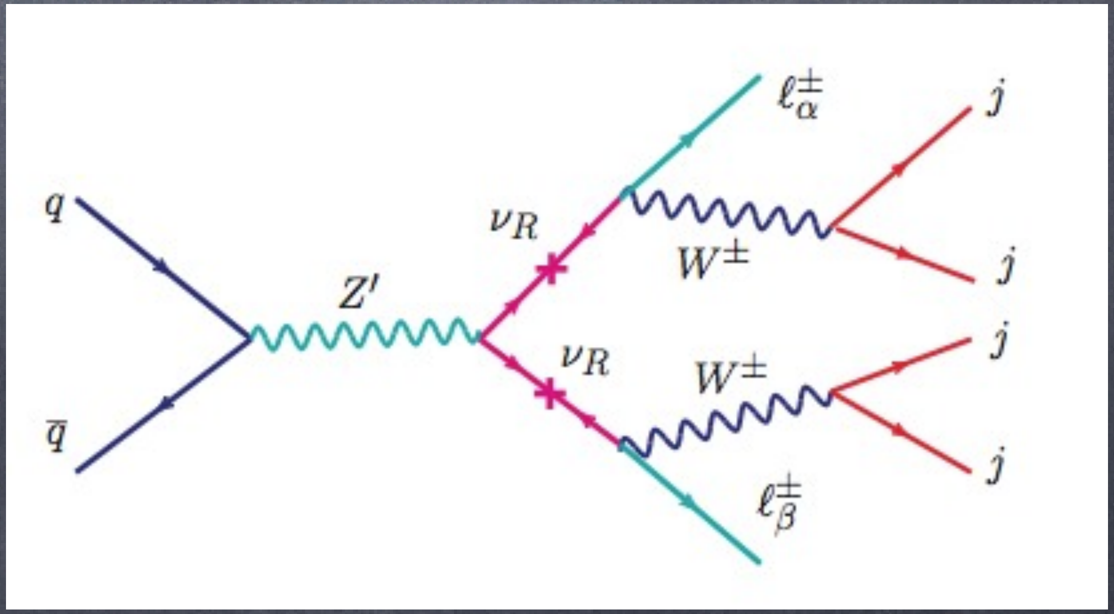


Pseudo Dirac (I)

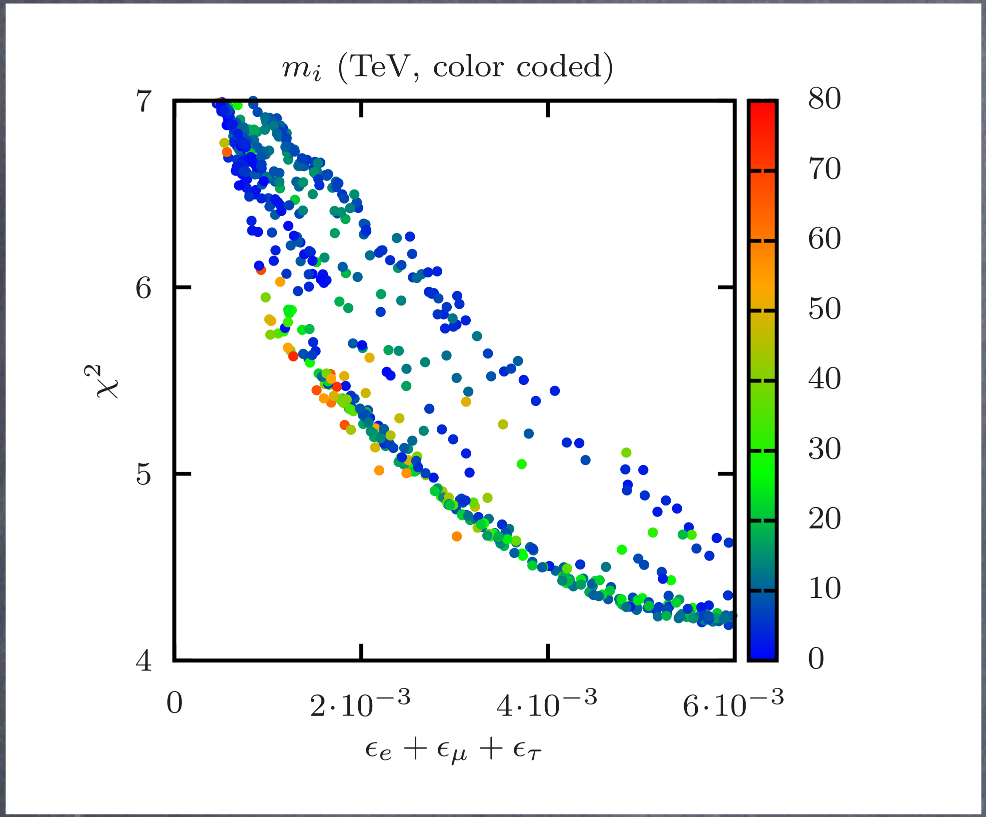


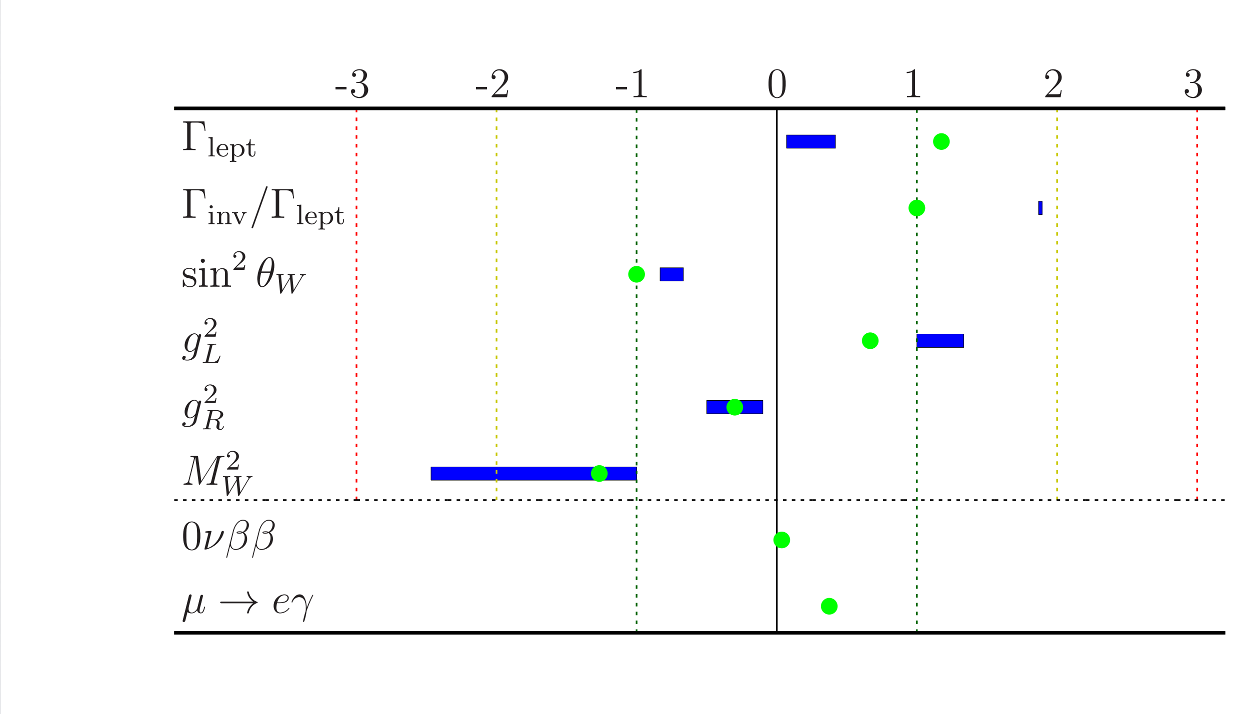


Majorana (II)



The Electroweak Fit





$$\ell^\pm + \ell^\mp + \text{Jets} \;\; (30 \pm 10)$$

$$\ell^\pm + \ell^\mp + \text{Jets} + \not{E}_T \;\; (130 \pm 50)$$

$$\ell^\pm + \text{Jets} + \not{E}_T \;\; 2.6\,\sigma$$

Reports: CMS-PAS-SUS-12-019

CMS: 1407.3683

CMS-EXO-12-041

Improving Electro-Weak Fits with TeV-scale Sterile Neutrinos

E. Akhmedov (Heidelberg, Max Planck Inst.), A. Kartavtsev (Munich, Max Planck Inst.), M. Lindner, L. Michaels, J. Smirnov (Heidelberg, Max Planck Inst.). Feb 7, 2013. 16 pp.

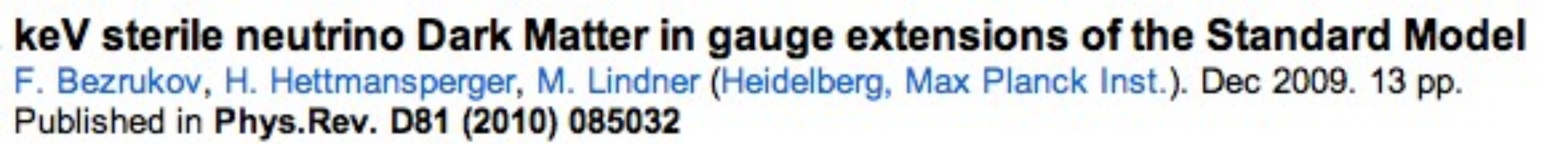
Published in **JHEP 1305 (2013) 081**

Summary

- We studied spontaneous generation of scales via dimensional transmutation
- Models with explicitly broken L or local B-L can lead to low energy Seesaw
- Scenarios can be distinguished at LHC
- New states required for anomaly cancellation are candidates for Dark Matter
- There is more work required to study non linear realization of conformal symmetry

Production mechanisms

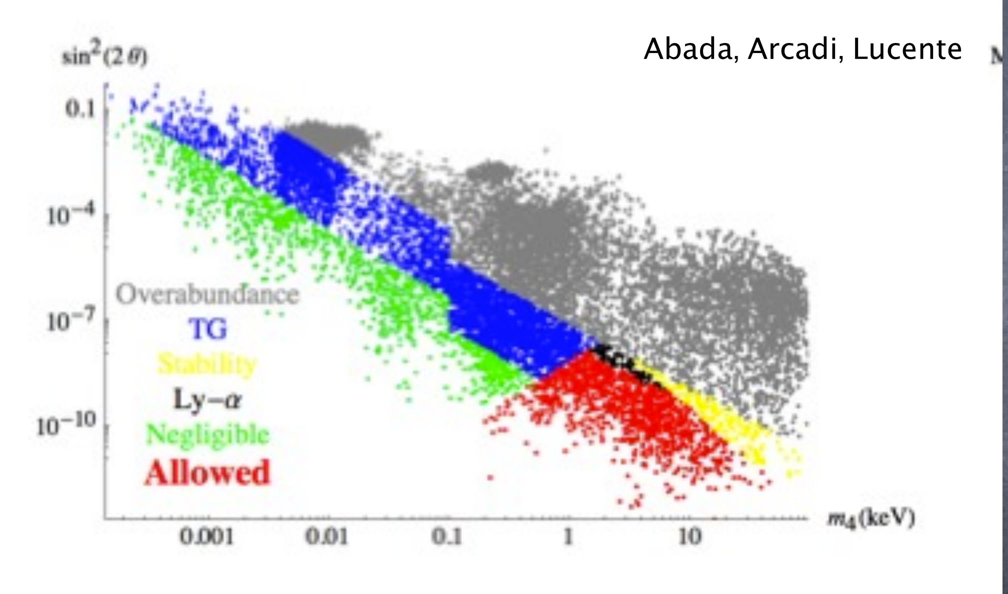
- I) DW mechanism
- II) Thermalisation and entropy injection



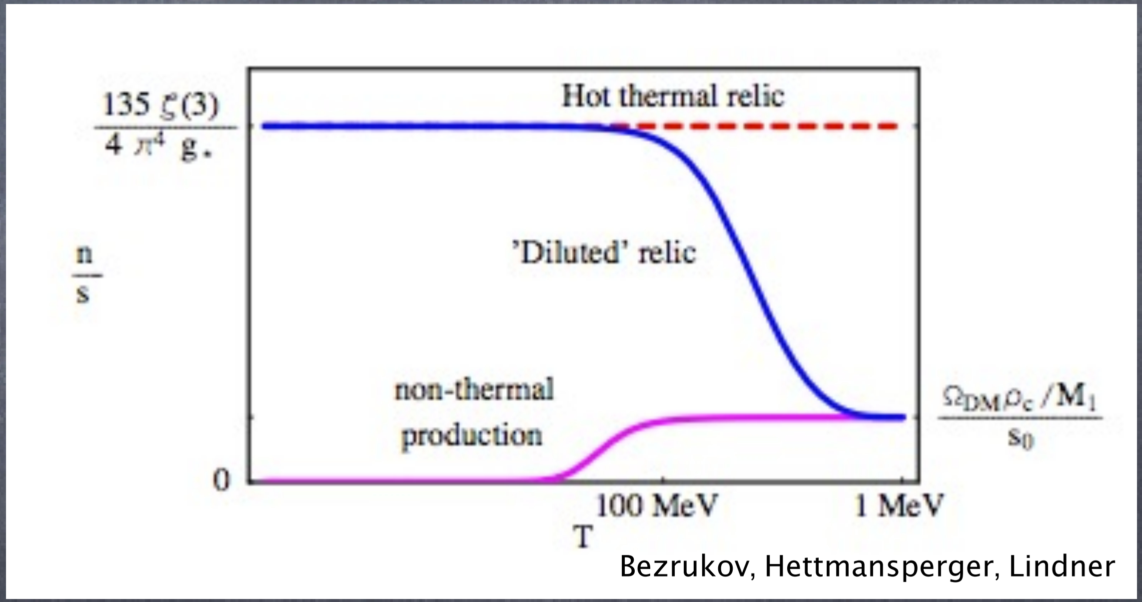
keV sterile neutrino Dark Matter in gauge extensions of the Standard Model
F. Bezrukov, H. Hettmansperger, M. Lindner (Heidelberg, Max Planck Inst.). Dec 2009. 13 pp.
Published in **Phys.Rev. D81 (2010) 085032**

- III) Freeze-In

New Production Mechanism for keV Sterile Neutrino Dark Matter by Decays of Frozen-In Scalars
Alexander Merle (Southampton U.), Viviana Niro (Barcelona U., ECM & ICC, Barcelona U.), Daniel Schmidt (Heidelberg, Max Planck Inst.). Jun 17, 2013. 28 pp.
Published in **JCAP 1403 (2014) 028**

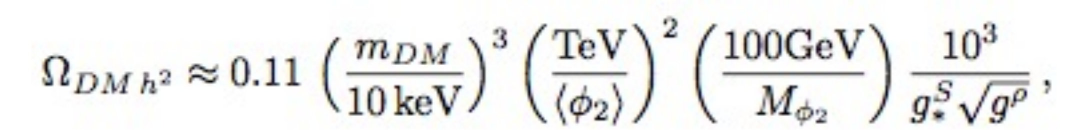


Abada, Arcadi, Lucente



Bezrukov, Hettmansperger, Lindner

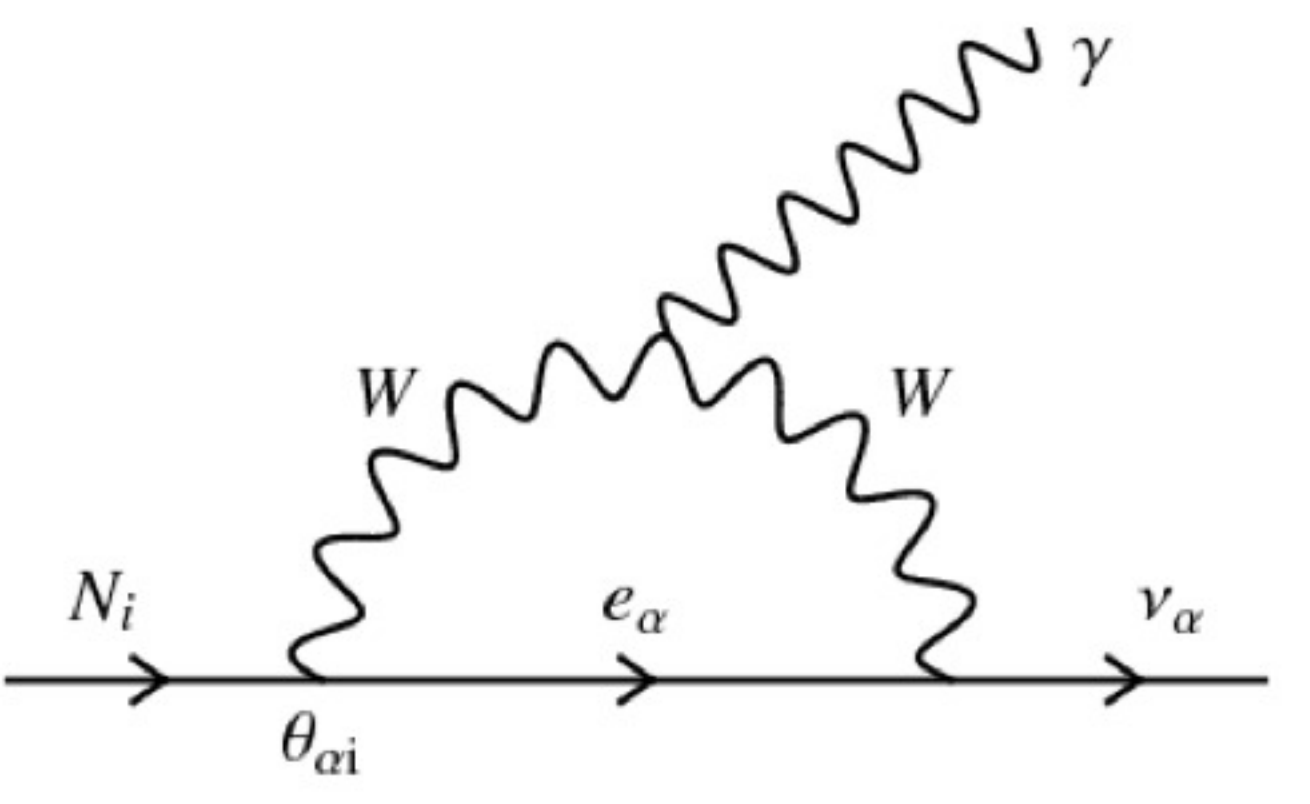
Relic density



$$\Omega_{DM\,h^2} \approx 0.11 \left(\frac{m_{DM}}{10\,\mathrm{keV}}\right)^3 \left(\frac{\mathrm{TeV}}{\langle\phi_2\rangle}\right)^2 \left(\frac{100\mathrm{GeV}}{M_{\phi_2}}\right) \frac{10^3}{g_*^S\sqrt{g^\rho}},$$

Not hot! $\lambda_{fs} < 0.1$ Mpc.

Decay of the Singlet



- Decay proportional to m^5 and to $\sin^2(2\theta)$
- keV Mass and $\sin^2(2\theta) < 10^{-8}$ imply a magnetic moment of $\mu_D < 10^{-22}\,\mu_B$
- Direct detection improbable