INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

PTFS FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

MAX-PLANCK-GESELLSCHAFT

On arXiv today!

Neutrino Masses and Conformal Electro-Weak Symmetry Breaking

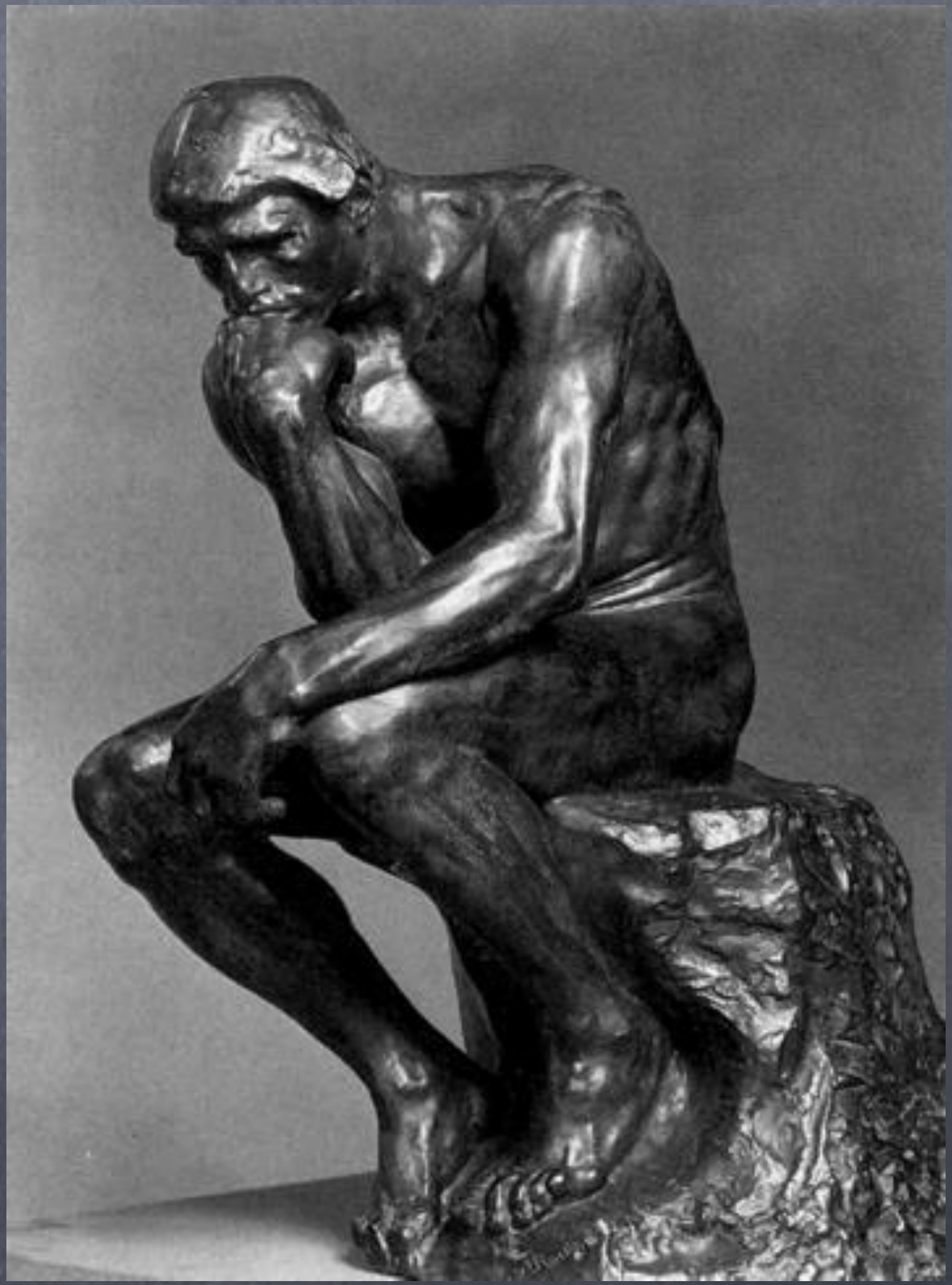
Manfred Lindner,* Steffen Schmidt,† and Juri Smirnov‡
Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Dimensional transmutation in classically conformal invariant theories may explain the electroweak scale and the fact that so far nothing but the Standard Model (SM) particles have been observed. We discuss in this paper implications of this type of symmetry breaking for neutrino mass generation.

Juri Smirnov
Max-Planck Institut für Kernphysik
Heidelerg, Germany

Scalar Mass Naturalness

- New Particles @ TeV
- New Symmetries @ TeV
- So far only SM seen
- What now?
- It is just around the corner...
- Conformal Symmetry in classical Lagrangian -> dim. trans. via CW



Dimensional Transmutation and Coleman Weinberg

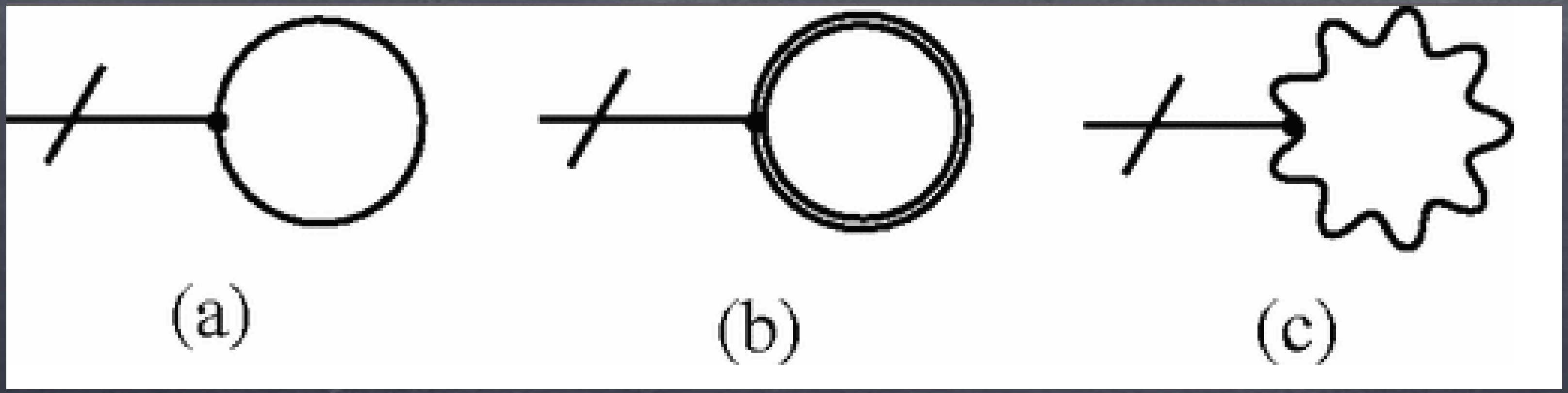
- No tree level mass term in the SM:

$$\text{if } m_t < 79\text{GeV} \rightarrow m_h \approx 9\text{GeV}$$

- Portals to additional bosonic sector

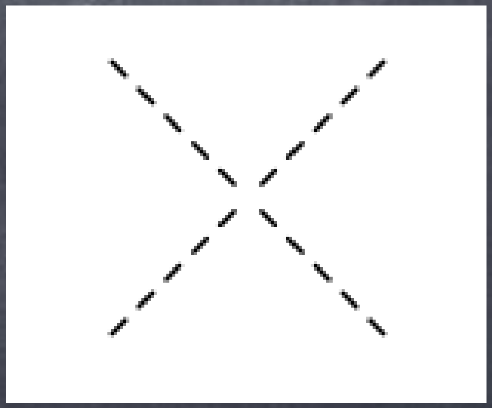
$$\langle\phi^\dagger\phi\rangle \Rightarrow \lambda(\phi^\dagger\phi)(H^\dagger H) \rightarrow \mu H^\dagger H$$

- TeV-ish VEV induces correct Higgs mass



Classical Conformal Symmetry

- No explicit mass scales in the Lagrangian, no μ term in Higgs potential
- Generically only two scales, symmetry breaking around TeV and EW scale
- Fermion masses only via Yukawa*VEV
- Building Rules:



Strategies for Neutrino Masses

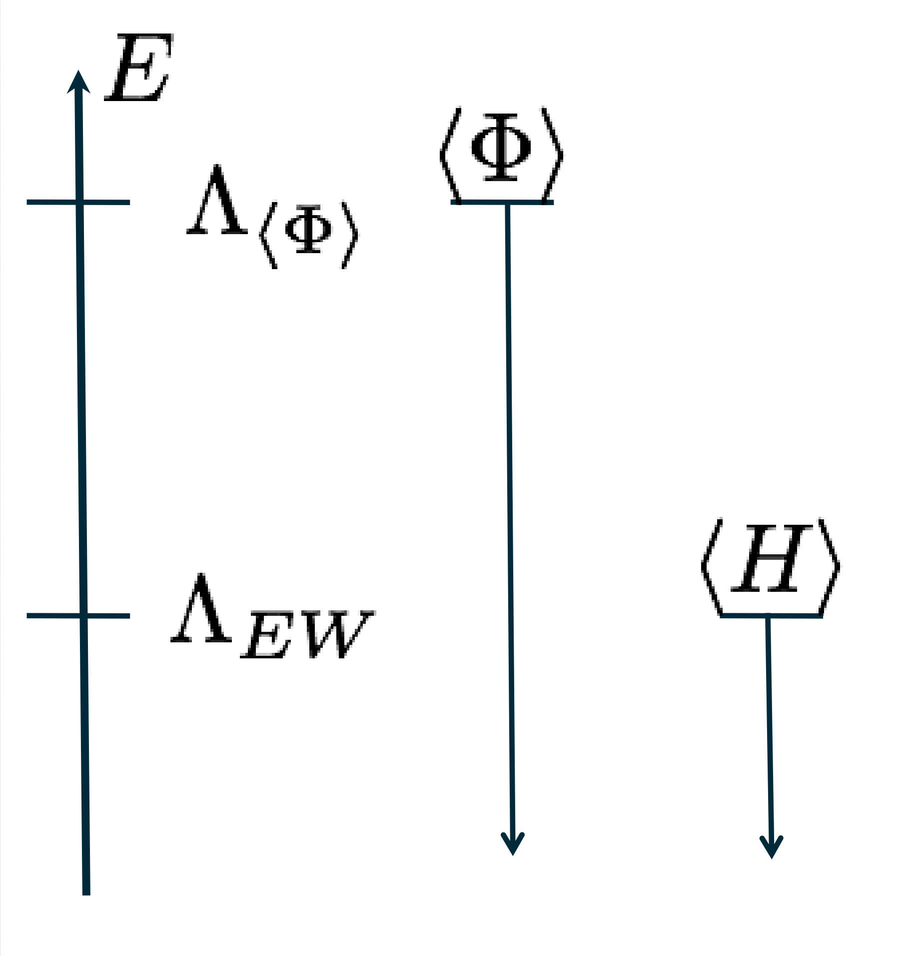
- **Hard fact: SM is not complete**
- Enlarge the Standard Model field spectrum
  arXiv:0706.1829
- Add a direct product group SM $\otimes$ HS
- Embed the SM in larger gauge group SM$\subset$G
  arXiv:0911.0710
- Focus on first two options, embedding causes a “little” hierarchy problem

Reasons for Scale Separation

1) Yukawa Seesaw SM + Φ + ν_R

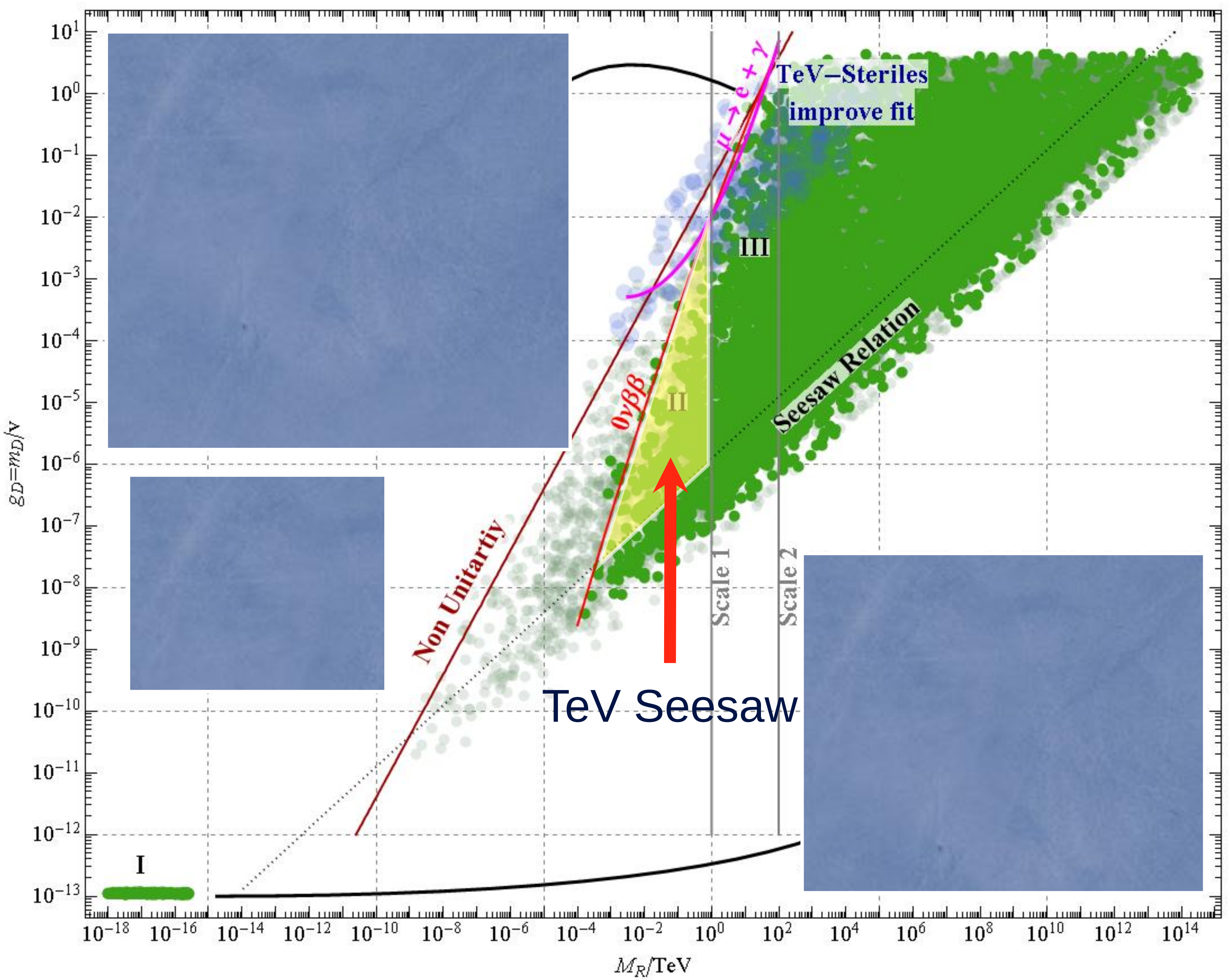
$$\mathcal{M} = \begin{pmatrix} 0 & y_D \langle H \rangle \\ y_D^T \langle H \rangle & y_M \langle \phi \rangle \end{pmatrix}$$

$$\langle \phi \rangle \approx \text{TeV}$$
$$\langle H \rangle \approx 1/4\, \text{TeV}$$
$$\text{and } y_D \ll y_M$$



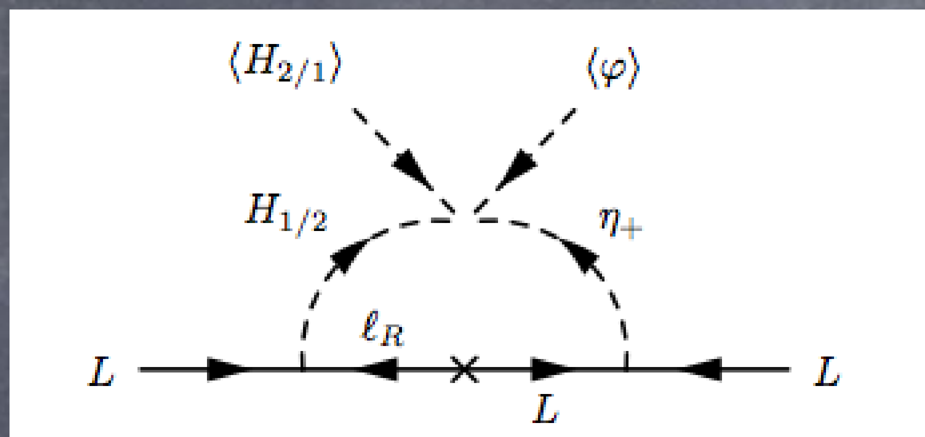
Dirac Yukawa couplings in the same range as known in SM

Neutrino Mass Map

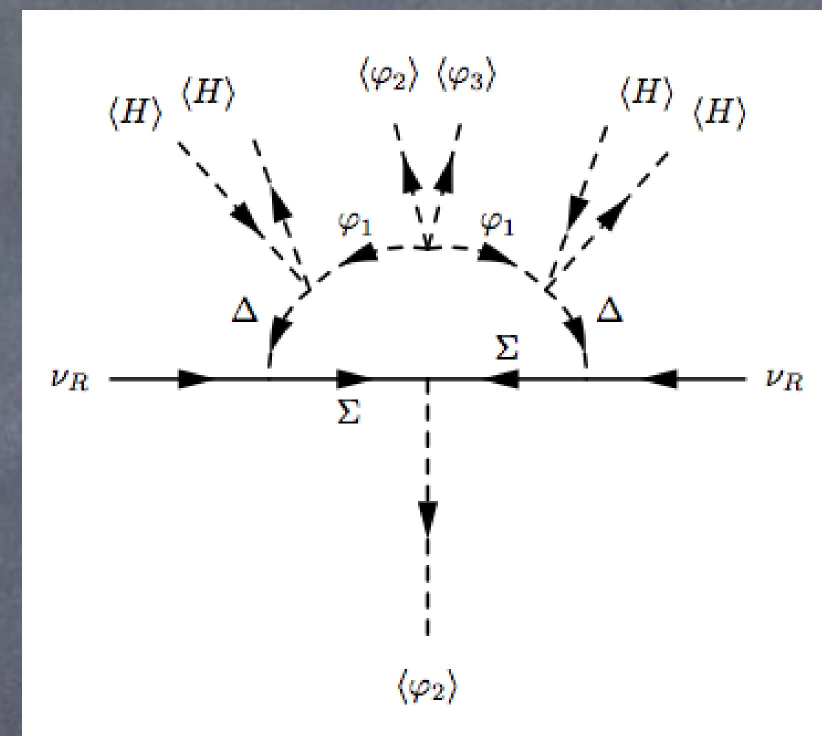


Reasons for Scale Separation

2) Radiative Mass Generation & LNV



Potential: $V = \lambda_L \eta H_1^\dagger H_2 \varphi + h.c. + ...$



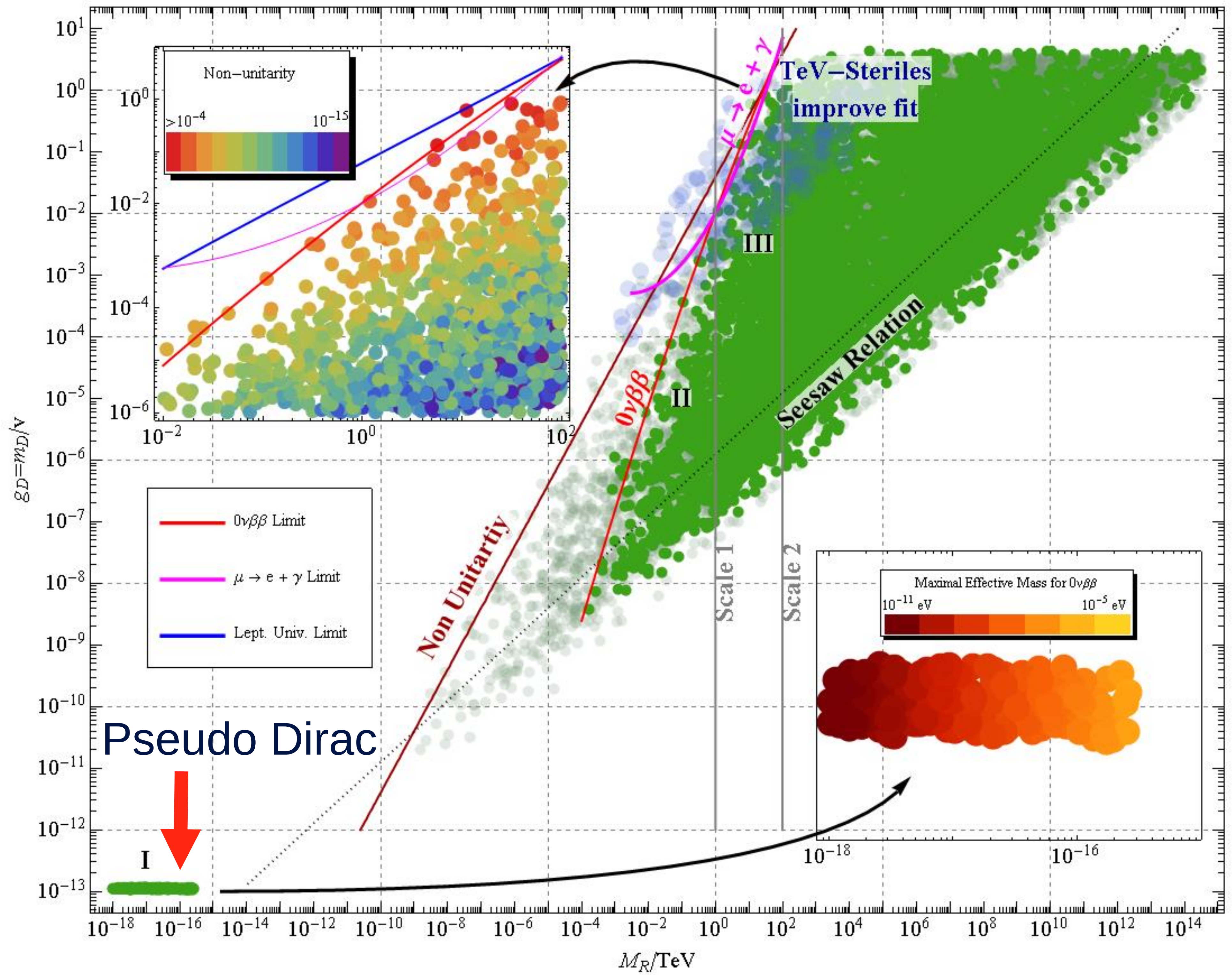
Potential: $V = \lambda \varphi_1 H^T i\sigma_2 \mathbf{\Delta}^\dagger \tilde{H} + \lambda' \varphi_1^2 \varphi_2 \varphi_3 + h.c. + ...$

$$\mathcal{M} = m_L$$

or

$$\mathcal{M} = \begin{pmatrix} \mu_1 & y_D \langle H \rangle \\ y_D^T \langle H \rangle & \mu_2 \end{pmatrix}$$

Neutrino Mass Map



Reasons for Scale Separation

3) Seesaw & LNV

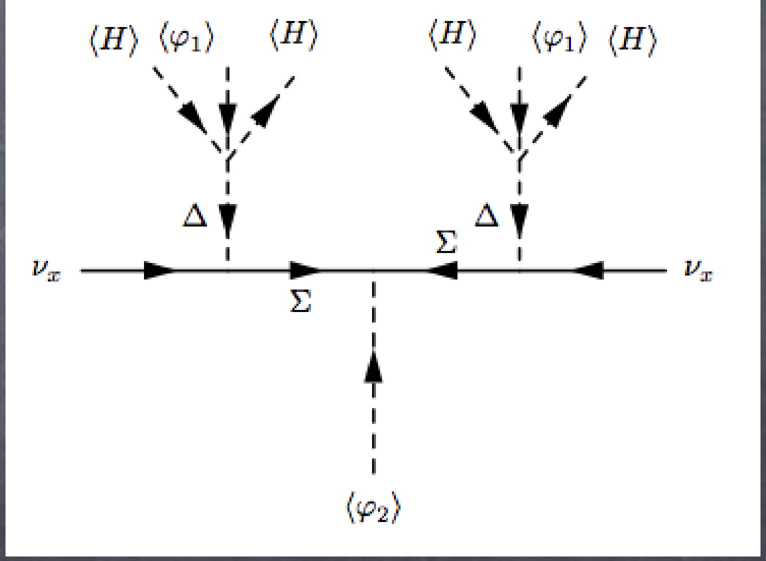
Framework: SM $\otimes$ HS

$$\nu_R \; : \; (1_{SU(2)}, 0_Y, 0_{HS})$$
$$\nu_x \; : \; (1_{SU(2)}, 0_Y, n_{HS})$$

$$\mathcal{M} = \begin{pmatrix} 0 & y_D \langle H \rangle & 0 \\ y_D^T \langle H \rangle & 0 & y_{Rx} \langle \phi \rangle \\ 0 & y_{Rx}^T \langle \phi \rangle & \mu \end{pmatrix}$$

$$\epsilon = \frac{1}{2} y_D^\dagger (y_{Rx}^{-1})^* (y_{Rx}^{-1})^T y_D \cdot \frac{\langle H \rangle^2}{\langle \phi \rangle^2}$$

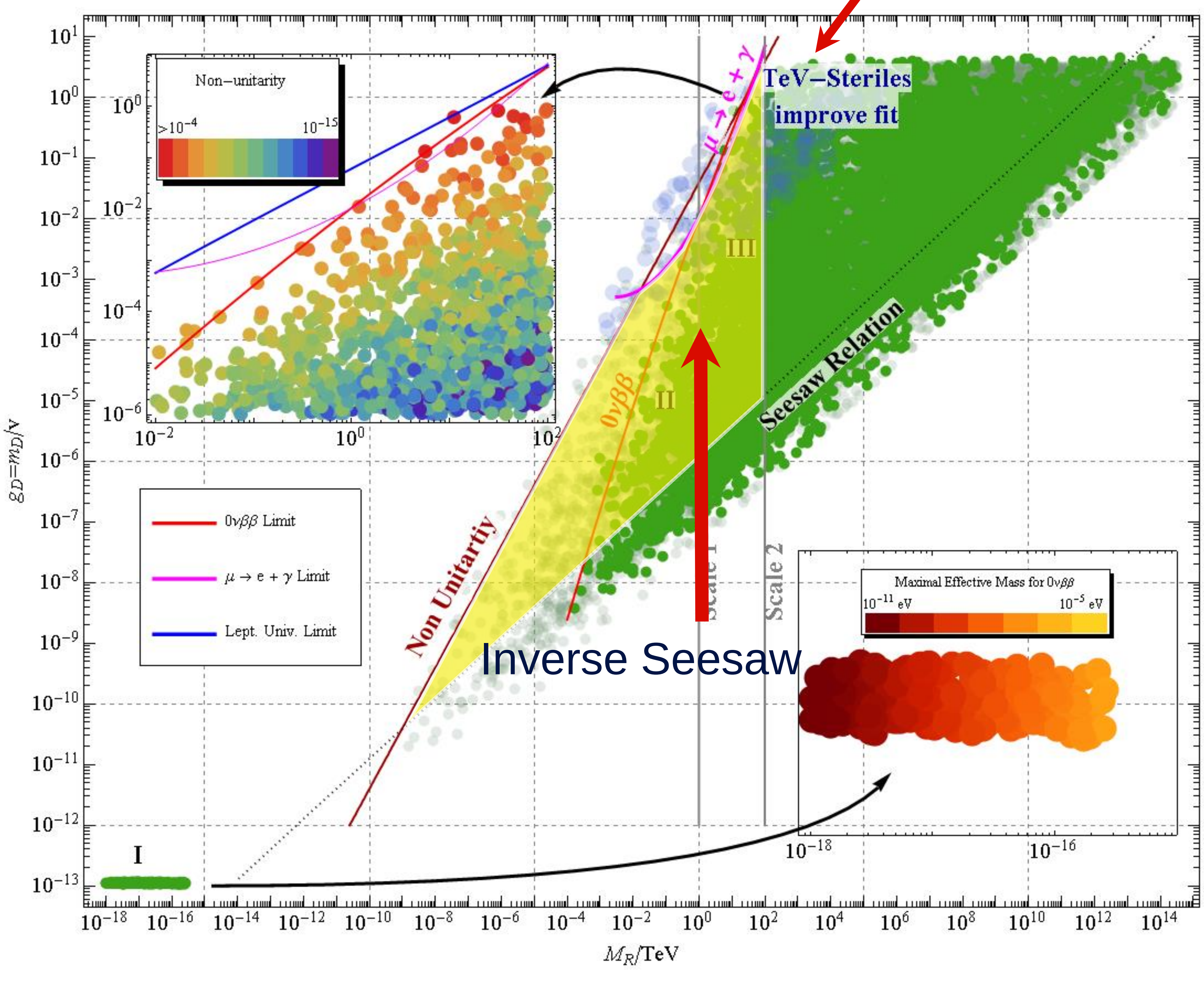
$$\langle \phi \rangle > \langle H \rangle \text{ and } m_\nu \approx \mu \, \epsilon$$



μ is suppressed (LNV) natural scale keV

Neutrino Mass Map

E. Akhmedov, A. Kartavtsev, M. Lindner, L. Michaels, and J. Smirnov, JHEP **1305**, 081 (2013), 1302.1872.



Hidden Sector and Dark Sector

$$\mathcal{M} = \begin{pmatrix} 0 & y_D^{3\times3}\langle H\rangle & 0 & 0 \\ y_D^T\langle H\rangle & 0 & y_{Rx}^{3\times3}\langle\phi\rangle & y_{Ry}^{3\times1}\langle\phi\rangle \\ 0 & y_{Rx}^T\langle\phi\rangle & \mu_1 & 0 \\ 0 & y_{Ry}^T\langle\phi\rangle & 0 & \mu_2 \end{pmatrix}$$

For Free: Additional SM singlet is a Majorana state at the keV mass scale with small mixing to active Neutrinos

TeV and Neutrino mass scales induce warm Dark Matter scale

A. Dolgov and S. Hansen, Astropart.Phys. **16**, 339 (2002), hep-ph/0009083.
F. Bezrukov, H. Hettmansperger, and M. Lindner, Phys.Rev. **D81**, 085032 (2010), 0912.4415.

Conformal Mass Models within the SM Gauge Group

#	particle content	non-conformal motivation	neutrino masses	correct Higgs mass	phenomenological note
		Left-Handed Majorana Masses			
1A	Conformal SM (CSM)	⁄	**No**	**No**	This theory does not yield neutrino masses.
2A	CSM + $\nu_R : (1,0)$	See-saw type I	**Yes**	**No**	Neutrinos in this theory are of Dirac type.
3A	CSM + $\nu_R : (1,0)$ + $\varphi : (1,0)$	See-saw type I	**Yes**	**Yes**	In dependence of the coupling constants this theory can yield Sub TeV or Pseudo-Dirac neutrinos.
4A	CSM + $\Delta : (3,-2)$	See-saw type II	**Yes**	**No**	This theory yields pure left-handed Majorana neutrinos.
5A	CSM + $\Delta : (3,-2)$ + $\varphi : (1,0)$	See-saw type II	**Yes**	**Yes**	This theory yields pure left-handed Majorana neutrinos as well.
6A	CSM + $\nu_R : (1,0)$ + $\varphi : (1,0)$ + $\Delta : (3,-2)$	See-saw type I/II	**Yes**	**Yes**	Sub TeV and Pseudo-Dirac neutrinos are possible.
7A	CSM + $\delta_- : (1,-2)$	⁄	**No**	**No**	Neutrinos remain massless.
8A	CSM + $\delta_- : (1,-2)$ + $\Delta : (3,-2)$	⁄	**Yes**	**No**	The additional δ_- only contributes corrections to the masses.
9A	CSM + $\Sigma : (3,0)$	See-saw type III	**No**	**No**	Neutrinos remain massless.
10A	CSM + $\Sigma : (3,0)$ + $\varphi : (1,0)$	See-saw type III	**Yes**	**Yes**	This theory yields the same neutrino phenomenology like the conformal See-saw type I.
11A	CSM + $\delta_- : (1,-2)$ + $\epsilon_{++} : (1,4)$ + $\varphi : (1,0)$	Zee-Babu	**Yes**	**Yes**	Pure left-handed Majorana neutrino masses suppressed by 2 loops.
12A	CSM + $H_2 : (2,1)$ + $\eta_+ : (1,2)$ + $\varphi : (1,0)$	Zee Model	**Yes**	**Yes**	Pure left-handed Majorana neutrino masses suppressed by 1 loop.
13A	CSM + $\phi_1 : (2,3)$ $H_2 : (2,1)$ $\eta : (1,-4)$; $\phi_2 : (1,0)$	Law-McDonald	**Yes**	**Yes**	Pure left-handed Majorana neutrino masses suppressed by 2 loops.
		Right-Handed Majorana Masses			
1B	CSM + $\nu_R : (1,0)$ + $\Sigma : (3,0)$ + $\Delta : (3,0)$ + $\varphi : (1,0)$	⁄	**Yes**	**Yes**	This theory can generate conditions for the Pseudo-Dirac and the Sub TeV see-saw.
2B	CSM + $\nu_R : (1,0)$ + $\nu_x : (1,0)$ + $\varphi : (1,0)$	⁄	**Yes**	**Yes**	The extension by further sterile neutrinos is trivial if they cannot be distinguished from the original sterile neutrinos.

Conformal Mass Models with Additional U(1) Symmetry

#	particle content	$U(1)_H$	VEV structure	phenomenological note
	ν_R Majorana Masses			
1C	$\nu_R : (1,0)$ $\nu_x : (1,0)$ $\varphi_1 : (1,0)$ $\varphi_2 : (1,0)$	0 1 1 2	all scalars get a VEV	The double see-saw mass structure is implied. Pseudo-Dirac and sub TeV scenarios are possible .
2C	$\nu_R : (1,0)$ $\nu_x : (1,0)$ $\varphi_1 : (1,0)$ $\varphi_2 : (1,0)$	0 2 0 -2	all scalars get a VEV	The minimal extended see-saw structure is implied. Light sterile neutrinos with large active-sterile mixing .
3C	theory 1C + $\varphi_3 : (1,0)$	theory 1C -4	φ_1 gets no VEV	radiative model, implies Pseudo-Dirac scenario
4C	$\nu_R : (1,0)$ $\Sigma : (3,0)$ $\Delta : (3,0)$ $\varphi_1 : (1,0)$ $\varphi_2 : (1,0)$	0 1 1 1 2	all scalars get a VEV	Pseudo-Dirac and sub TeV scenarios are possible.
5C	theory 3C + $\varphi_3 : (1,0)$	theory 3C -4	φ_1 gets no VEV	radiative model, implies Pseudo-Dirac scenario
	ν_x Majorana Masses			
1D	$\nu_R : (1,0)$ $\nu_x : (1,0)$ $\Sigma : (3,0)$ $\Delta : (3,0)$ $\varphi_1 : (1,0)$ $\varphi_2 : (1,0)$ $\varphi_4 : (1,0)$	0 1 -2 -3 -3 -4 1	all scalars get a VEV	generates small ν_x mass, implies the inverse see-saw scenario
2D	theory 1D + $\varphi_3 : (1,0)$	theory 1D 10	φ_1 gets no VEV	radiative model, implies the inverse see-saw scenario

Summary

- Motivated by Scalar Hierarchy problem we considered classical scale invariance
- Mass scales are no longer independent
- Mechanisms for small Neutrino mass: Yukawa See-Saw, Loop suppression with LNV
- Elektro-Weak and Neutrino scale lead naturally to a warm Dark Matter scale
- Dark Energy needs to be accessed with this paradigm

Further Questions

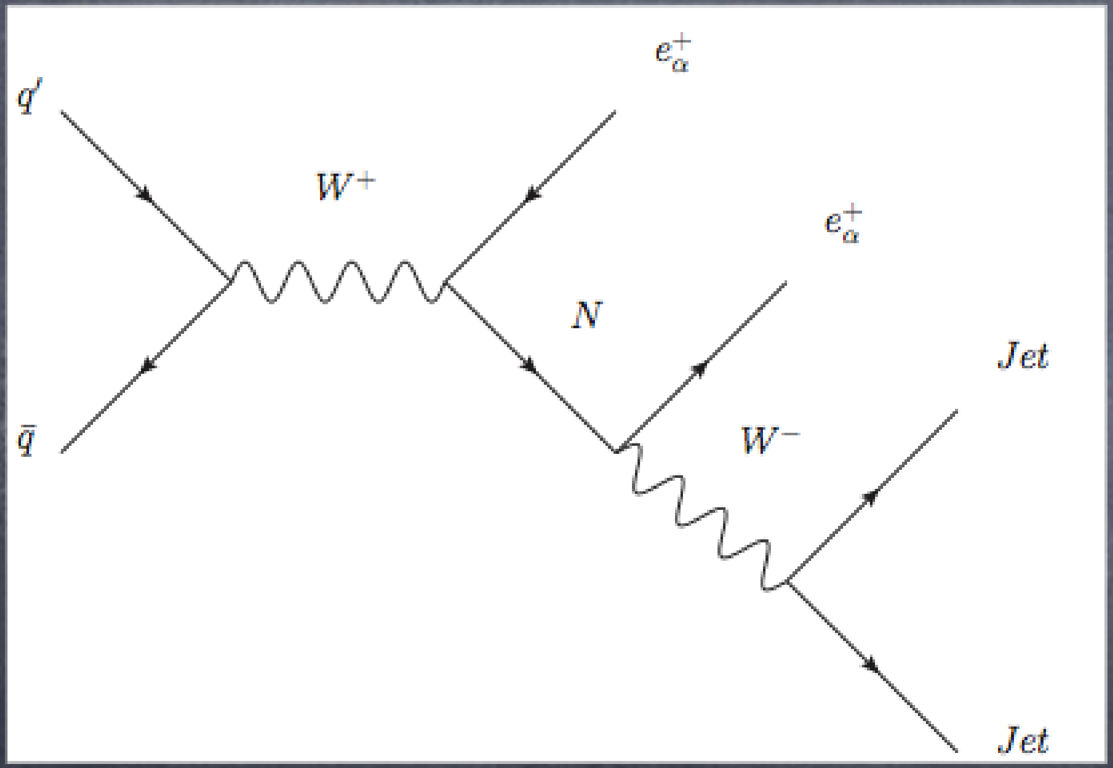
- What about Planck-Scale physics?
  conformal gravity = non-linear realization
  see e.g. 1403.4226 A. Salvio and A. Strumia
  or K. Hamada, 1109.6109, 0811.1647, 0907.3969

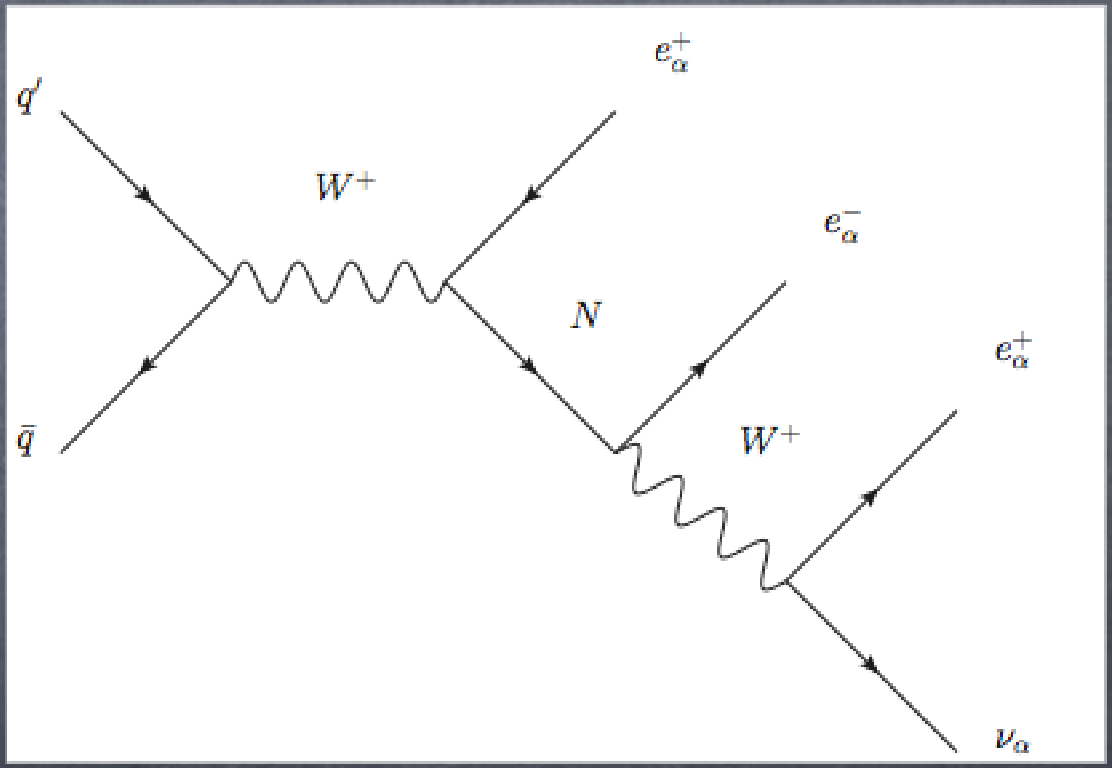
- What about inflation?
  see e.g. 1405.3987 by K. Kannike, A. Racioppi, M. Raidal

- Cosmological Constant as a Scale?
  1012.4848 R. Foot, A. Kobakhidze, R. Volkas

Collider Signatures

VS





arXiv:1405.0177
A. Das, B. Dev, N. Okada