

Dynamical Conformal and Electro-Weak Symmetry Breaking

Manfred Lindner

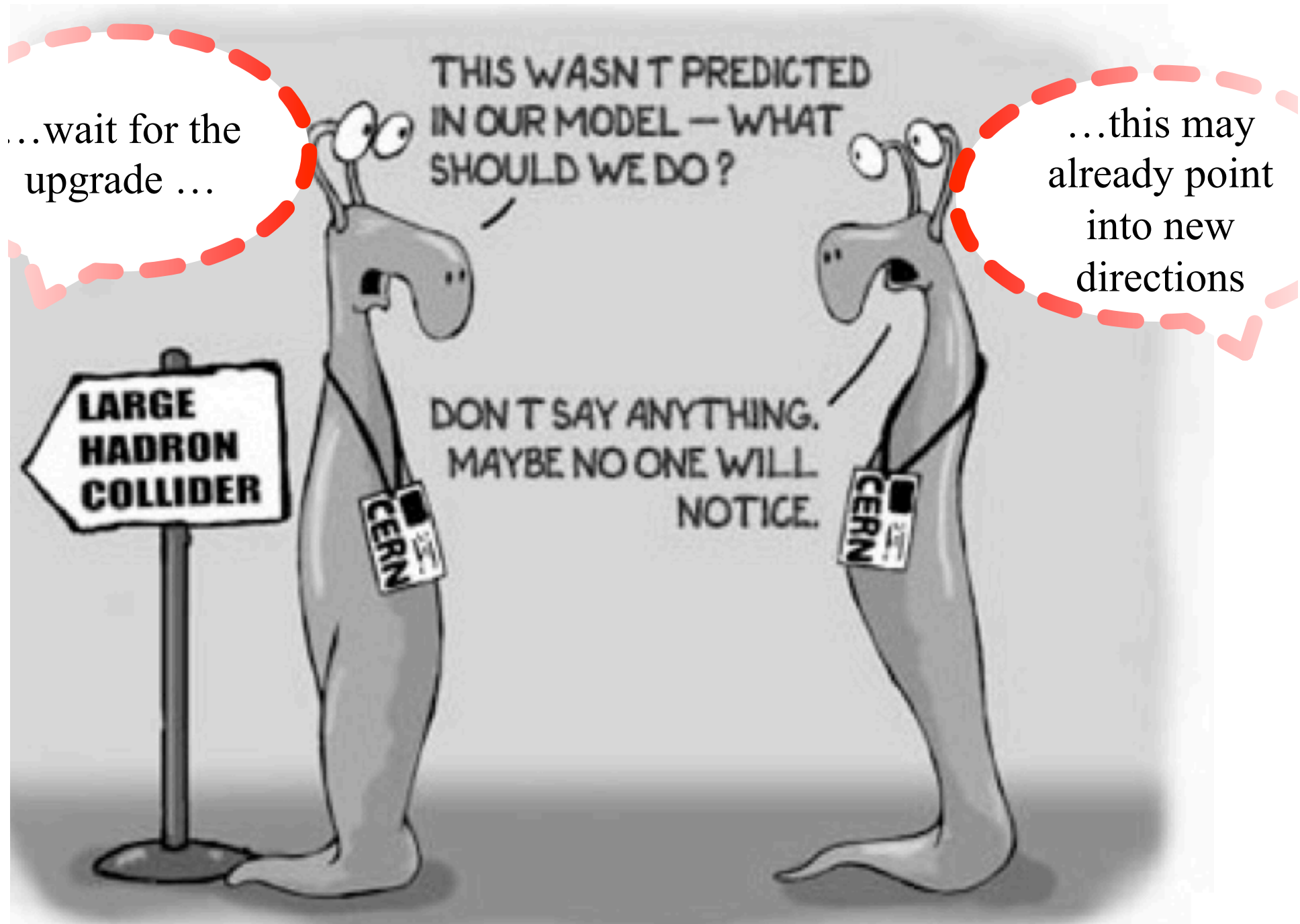


574. Wilhelm und Else Heraeus Seminar

STRONG INTERACTIONS IN THE LHC ERA

Physikzentrum Bad Honnef, Germany, November 12-14, 2014





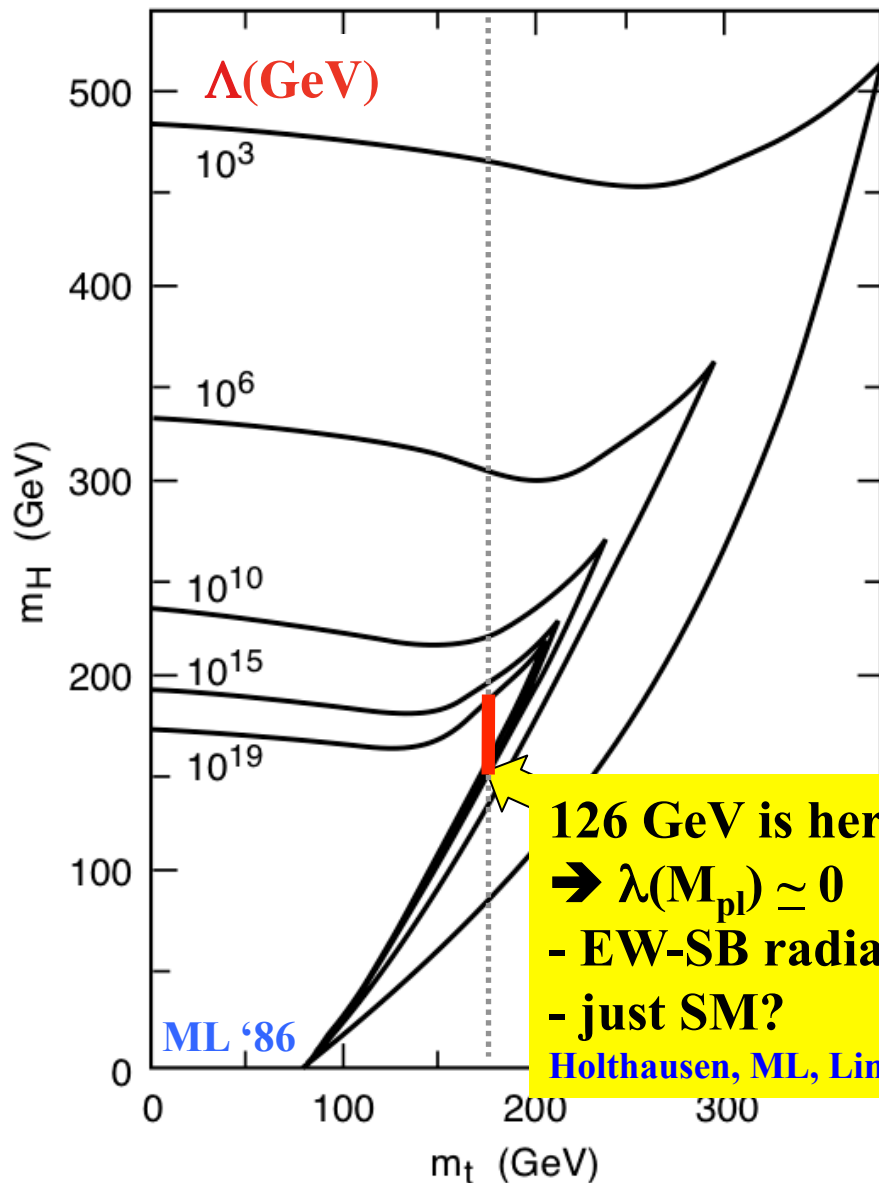
Look again carefully at the SM as QFT

- **The SM itself (without embedding) is a QFT like QED**
 - infinities, renormalization \rightarrow only differences are calculable
 - SM itself is perfectly OK \rightarrow many things unexplained...
- **Has (like QED) a triviality problem (Landau poles \leftrightarrow infinite λ)**
 - running $U(1)_Y$ coupling (pole well beyond Planck scale... - like in QED)
 - running Higgs / top coupling \rightarrow **upper bounds on m_H and m_t**
 - \rightarrow requires some scale Λ where the SM is embedded
 - \rightarrow the physics of this scale is unknown
- **Another potential problem is vacuum instability (\leftrightarrow negative λ)**
 - does occur in SM for large top mass > 79 GeV \rightarrow **lower bounds on m_H**

SM as QFT (without an embedding):

- **a hard cutoff Λ and the sensitivity towards Λ has no meaning**
- **renormalizable, calculable ... - just like QED**

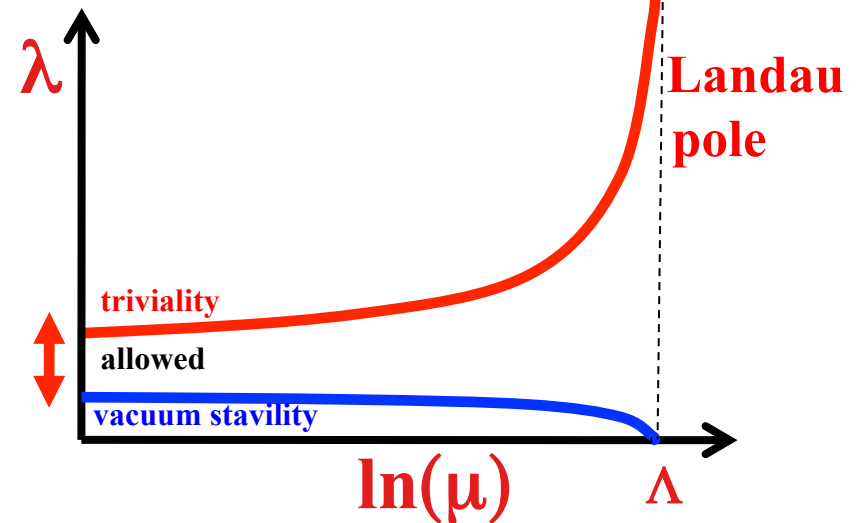
SM: Triviality and Vacuum Stability Bounds



126 GeV is here!
 $\rightarrow \lambda(M_{\text{pl}}) \simeq 0$
 - EW-SB radiative
 - just SM?
 Holthausen, ML, Lim (2011)

$$126 \text{ GeV} < m_H < 174 \text{ GeV}$$

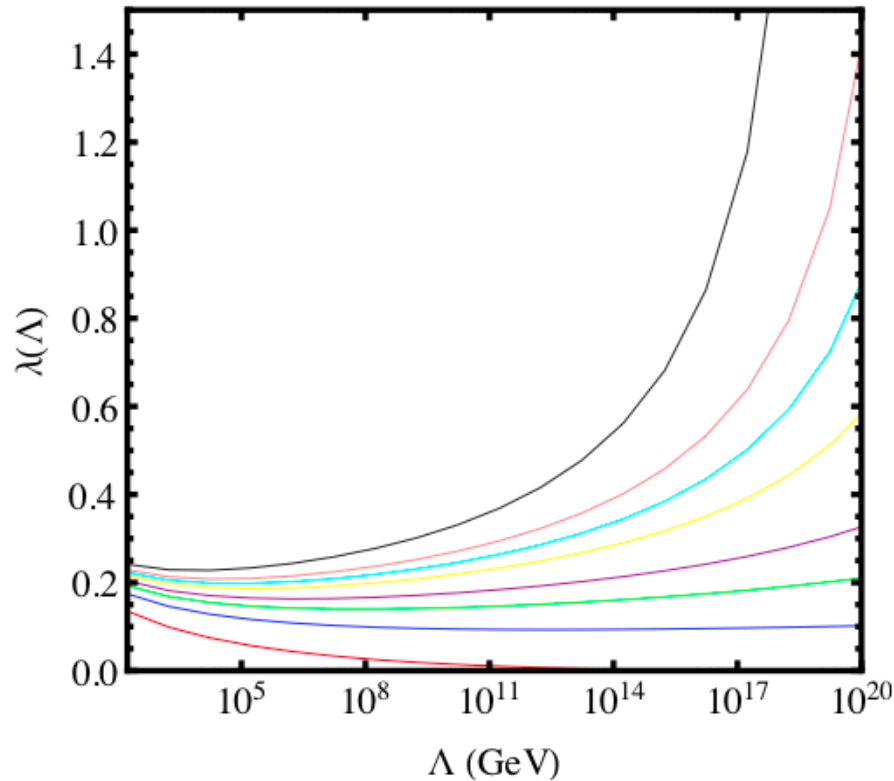
SM does not exist w/o embedding
 - U(1) coupling, Higgs self-coupling



\rightarrow RGE arguments seem to work
 \rightarrow we need some embedding
 \leftrightarrow no BSM physics observed!
 \rightarrow just a SM Higgs

A special Value of λ at M_{planck} ?

ML '86



downward flow of RG trajectories
→ IR QFP → random λ flows to $m_H > 150$ GeV
→ $m_H \simeq 126$ GeV flows to tiny values at M_{Planck} ...

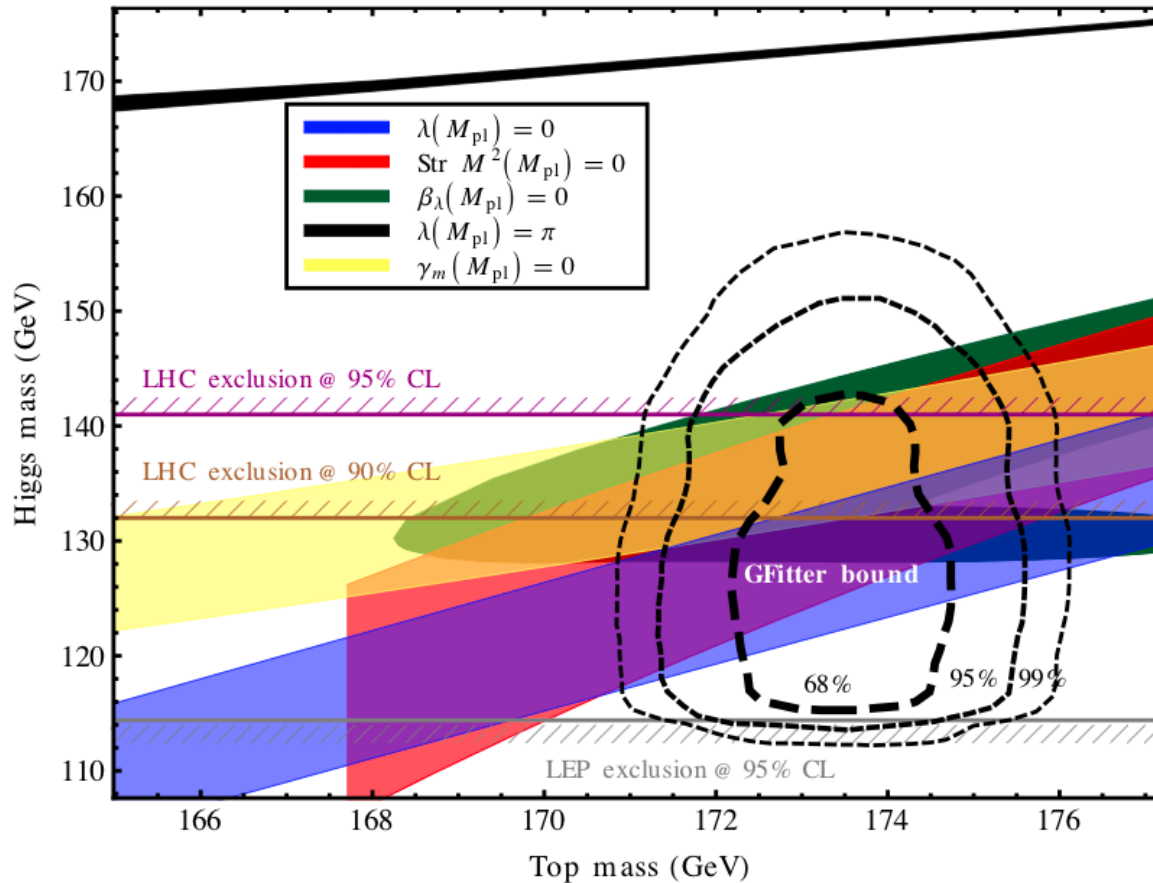
Holthausen, ML Lim (2011)

Different conceivable special conditions:

- Vacuum stability
 $\lambda(M_{pl}) = 0$ [7-12]
- vanishing of the beta function of λ
 $\beta_\lambda(M_{pl}) = 0$ [9, 10]
- the Veltman condition [13-15] $\text{Str}\mathcal{M}^2 = 0$,

$$\begin{aligned} \delta m^2 &= \frac{\Lambda^2}{32\pi^2 v^2} \text{Str}\mathcal{M}^2 \\ &= \frac{1}{32\pi^2} \left(\frac{9}{4}g_2^2 + \frac{3}{4}g_1^2 + 6\lambda - 6\lambda_t^2 \right) \Lambda^2 \end{aligned}$$

- vanishing anomalous dimension of the Higgs mass parameter
 $\gamma_m(M_{pl}) = 0, m(M_{pl}) \neq 0$



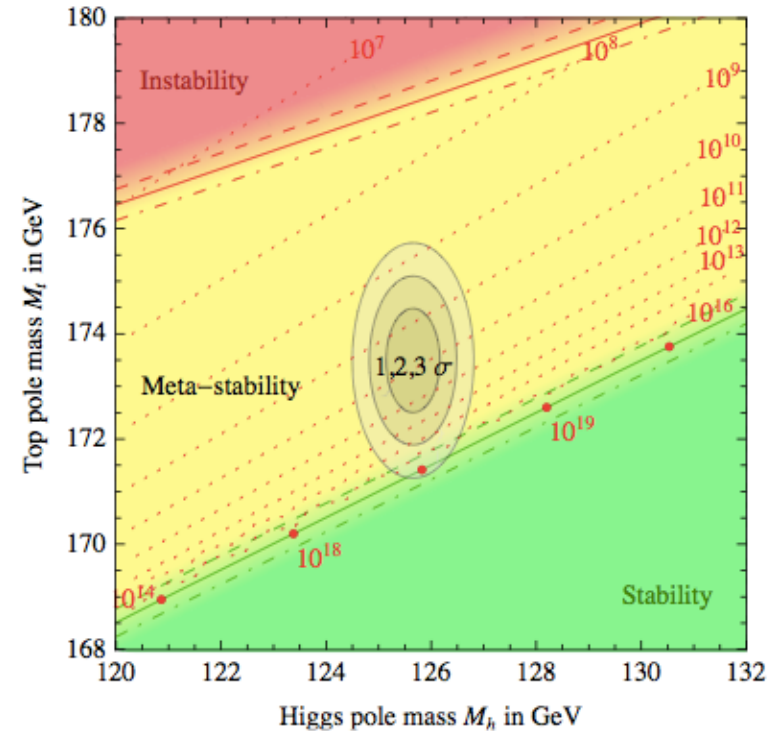
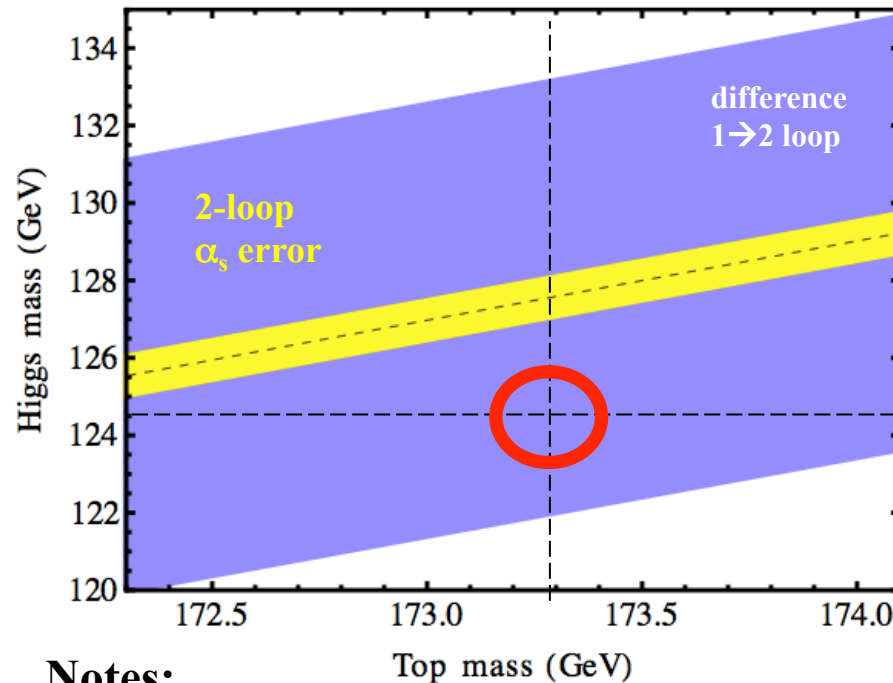
$m_H < 150 \text{ GeV}$
 \rightarrow random $\lambda = O(1)$
 excluded

- Why do all these boundary conditions work?
 - suppression factors compared to random choice = $O(1)$
 - $\lambda = F(\lambda, g_i^2, \dots) \rightarrow$ loop factors $1/16\pi^2$
 - top loops \rightarrow fermion loops \rightarrow factors of (-1)
- \rightarrow scenarios 'predicting' sufficiently suppressed (small/tiny) λ at M_{planck} are OK
- \rightarrow more precision \rightarrow selects options ; e.g. $\gamma_m = 0$ now ruled out

Is the Higgs Potential at M_{Planck} flat?

Buttazzo, Degrandi, Giardino, Giudice, Sala, Salvio, Strumia

Holthausen, ML, Lim



Notes:

- remarkable relation between weak scale, m_t , couplings **and** $M_{\text{Planck}} \leftrightarrow$ precision
- strong cancellations between Higgs and top loops
 - \rightarrow very sensitive to exact value and error of $m_H, m_t, \alpha_s = 0.1184(7) \rightarrow$ currently 1.8σ in m_t
- other physics, ... Planck scale thresholds... Lalak, Lewicki, Olszewski,
 - \rightarrow important: watch central values & errors \rightarrow important: new physics \leftrightarrow DM, m_ν
 - \rightarrow what if the SM were metastable...? \rightarrow 1st bubble... \rightarrow thermal history...

Interpretating special Conditions: E.g. $\lambda(M_{\text{Planck}}) = 0$

$\lambda\phi^4 \rightarrow 0$ at the Planck scale \rightarrow **no Higgs self-interaction (V is flat)**
 $\rightarrow m_H$ at low E radiatively generated - value related to m_t and g_i
 \rightarrow **SM emdeded directly into gravity ...!?**

- **What about the hierarchy problem?**

\rightarrow GR is different: **Non-renormalizable!**

\rightarrow requires new concepts beyond QFT/gauge theories: ... ?

\rightarrow **BAD:** We have no facts which concepts are realized by nature

\rightarrow **Two GOOD aspects:**

1) QFTs cannot explain absolute masses and couplings

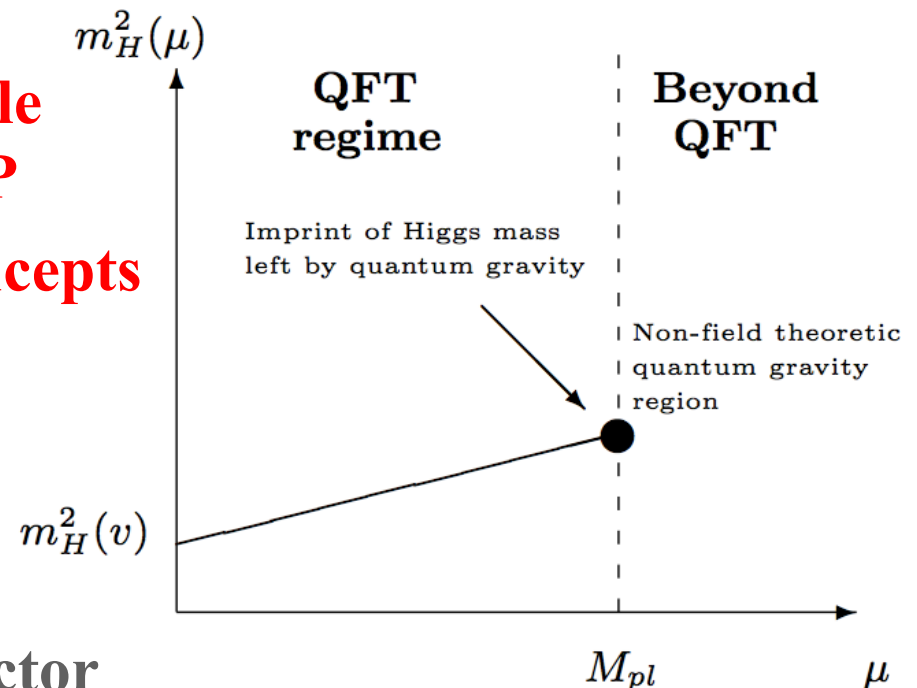
- **QFT embeddings = shifting the problem only to the next level**

\rightarrow **new concepts beyond QFT might explain absolute values**

2) Asymmetry $SM \leftrightarrow$ Planck scale
may allow new solutions of the HP

→ new non-QFT Planck-scale concepts
could have mechanism which
explain hierarchies

→ lost in effective theory = SM



Anaology: Type II superconductor

Ginzburg-Landau effective QFT \leftrightarrow BCS theory

$$E \approx \alpha|\phi|^2 + \beta|\phi|^4 + \dots \quad \leftrightarrow \quad \alpha, \beta, \text{ dynamical details lost}$$

→ The hierarchy problem may be an artefact of the
bottom-up QFT perspective. New concepts beyond QFT
at the Planck-scale could explain things top-down.

The Hierarchy Problem: Specify Λ

- Renormalizable QFTs with two scalars φ , Φ with masses m , M and a mass hierarchy $m \ll M$
- These scalars must interact since $\varphi^+\varphi$ and $\Phi^+\Phi$ are singlets
→ $\lambda_{\text{mix}}(\varphi^+\varphi)(\Phi^+\Phi)$ must exist in addition to φ^4 and Φ^4
- Quantum corrections $\sim M^2$ drive both masses to the (heavy) scale
→ two vastly different scalar scales are generically unstable

Therefore: If (=since) the SM Higgs field exists

→ problem: embedding with a 2nd scalar with much larger mass

→ usual solutions:

- a) new scale @TeV
- b) protective symmetry @TeV

} → LHC !

b) is usually SUSY, but SUSY & gauge unification = SUSY GUT →

→ doublet-triplet splitting problem → hierarchy problem back

Conformal Symmetry as Protective Symmetry

- Exact (unbroken) CS

- absence of Λ^2 and $\ln(\Lambda)$ divergences
- no preferred scale and therefore no scale problems

- Conformal Anomaly (CA): Quantum effects explicitly break CS

existence of CA → CS preserving regularization does not exist

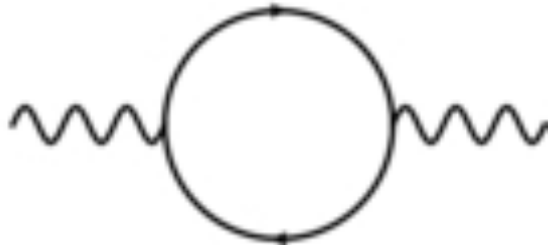
- dimensional regularization is close to CS and gives only $\ln(\Lambda)$
- cutoff reg. → Λ^2 terms; violates CS badly → Ward Identity

→ **Bardeen: maybe CS still forbids Λ^2 divergences**

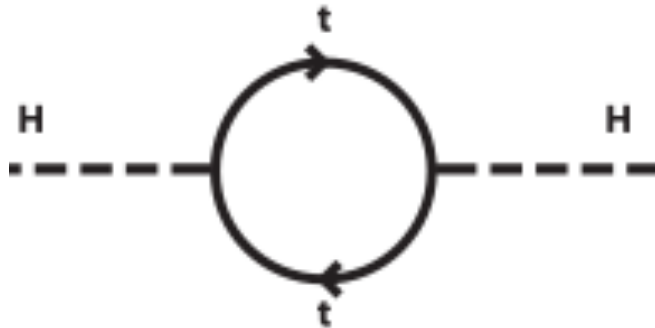
- CS breaking \leftrightarrow β -functions \leftrightarrow $\ln(\Lambda)$ divergences
- anomaly induced spontaneous EWSB

IMPORTANT: The conformal limit of the SM (or extensions) may have no hierarchy problem!

Implications



Gauge invariance \rightarrow only log sensitivity



Relics of conformal symmetry \rightarrow only log sensitivity

- With CS there no hierarchy problem, even though it has anomaly
- Dimensional transmutation due to log running like in QCD
 - \rightarrow scalars can condense and set scales like fermions
 - \rightarrow use this in Coleman Weinberg effective potential calculations
 - \leftrightarrow most attractive channels (MAC) \leftrightarrow β -functions

Why the minimalistic SM does not work

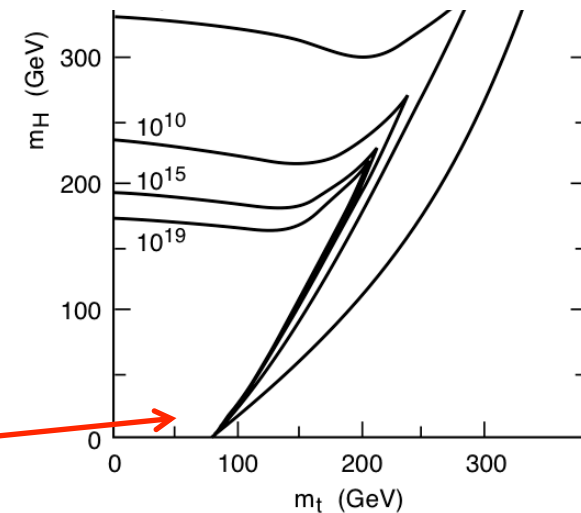
Minimalistic:

SM + choose $\mu=0 \leftrightarrow$ CS

Coleman Weinberg: effective potential

→ CS breaking (dimensional transmutation)

→ induces for $m_t < 79 \text{ GeV}$
a Higgs mass $m_H = 8.9 \text{ GeV}$

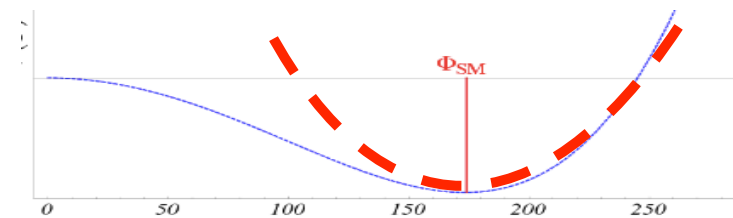


This would conceptually realize the idea, but:

Higgs too light and the idea does not work for $m_t > 79 \text{ GeV}$

Reason for $m_H \ll v$: V_{eff} flat around minimum

$\leftrightarrow m_H \sim \text{loop factor} \sim 1/16\pi^2$



AND: We need neutrino masses, dark matter, ...

Realizing the Idea via Higgs Portals

- SM scalar Φ plus some new scalar φ (or more scalars)
- CS \rightarrow no scalar mass terms
- the scalars interact $\rightarrow \lambda_{\text{mix}}(\varphi^+\varphi)(\Phi^+\Phi)$ must exist

\rightarrow a condensate of $\langle\varphi^+\varphi\rangle$ produces $\lambda_{\text{mix}}\langle\varphi^+\varphi\rangle(\Phi^+\Phi) = \mu^2(\Phi^+\Phi)$
 \rightarrow effective mass term for Φ

- CS anomalous ... \rightarrow breaking \rightarrow only $\ln(\Lambda)$
 \rightarrow implies a TeV-ish condensate for φ to obtain $\langle\Phi\rangle = 246$ GeV
- Model building possibilities / phenomenological aspects:
 - φ could be an effective field of some hidden sector DSB
 - further particles could exist in hidden sector; e.g. confining...
 - extra hidden U(1) potentially problematic \leftrightarrow U(1) mixing
 - avoid Yukawas which couple visible and hidden sector \rightarrow phenomenology safe due to Higgs portal, but there is TeV-ish new physics!

Realizing this Idea: Left-Right Extension

M. Holthausen, ML, M. Schmidt

Radiative SB in conformal LR-extension of SM

(use isomorphism $SU(2) \times SU(2) \simeq Spin(4) \rightarrow$ representations)

particle	parity \mathcal{P}	Z_4	$Spin(1,3) \times (SU(2)_L \times SU(2)_R) \times (SU(3)_C \times U(1)_{B-L})$
$\mathbb{L}_{1,2,3} = \begin{pmatrix} L_L \\ -iL_R \end{pmatrix}$	$P\mathbb{P}L(t, -x)$	$L_R \rightarrow iL_R$	$\left[\left(\frac{1}{2}, \underline{0} \right) (\underline{2}, \underline{1}) + \left(\underline{0}, \frac{1}{2} \right) (\underline{1}, \underline{2}) \right] (\underline{1}, -1)$
$\mathbb{Q}_{1,2,3} = \begin{pmatrix} Q_L \\ -iQ_R \end{pmatrix}$	$P\mathbb{P}Q(t, -x)$	$Q_R \rightarrow -iQ_R$	$\left[\left(\frac{1}{2}, \underline{0} \right) (\underline{2}, \underline{1}) + \left(\underline{0}, \frac{1}{2} \right) (\underline{1}, \underline{2}) \right] (\underline{3}, \frac{1}{3})$
$\Phi = \begin{pmatrix} 0 & \Phi \\ -\tilde{\Phi}^\dagger & 0 \end{pmatrix}$	$P\Phi^\dagger P(t, -x)$	$\Phi \rightarrow i\Phi$	$(\underline{0}, \underline{0}) (\underline{2}, \underline{2}) (\underline{1}, 0)$
$\Psi = \begin{pmatrix} \chi_L \\ -i\chi_R \end{pmatrix}$	$P\Psi(t, -x)$	$\chi_R \rightarrow -i\chi_R$	$(\underline{0}, \underline{0}) [(\underline{2}, \underline{1}) + (\underline{1}, \underline{2})] (\underline{1}, -1)$

→ the usual fermions, one bi-doublet, two doublets

→ a Z_4 symmetry

→ no scalar mass terms \leftrightarrow CS

→ Most general gauge and scale invariant potential respecting Z_4

$$\mathcal{V}(\Phi, \Psi) = \frac{\kappa_1}{2} (\bar{\Psi}\Psi)^2 + \frac{\kappa_2}{2} (\bar{\Psi}\Gamma\Psi)^2 + \lambda_1 (\text{tr}\Phi^\dagger\Phi)^2 + \lambda_2 (\text{tr}\Phi\Phi + \text{tr}\Phi^\dagger\Phi^\dagger)^2 + \lambda_3 (\text{tr}\Phi\Phi - \text{tr}\Phi^\dagger\Phi^\dagger)^2 + \beta_1 \bar{\Psi}\Psi\text{tr}\Phi^\dagger\Phi + f_1 \bar{\Psi}\Gamma[\Phi^\dagger, \Phi]\Psi,$$

→ calculate V_{eff}

→ Gildner-Weinberg formalism (RG improvement of flat directions)

- anomaly breaks CS

- spontaneous breaking of parity, Z_4 , LR and EW symmetry

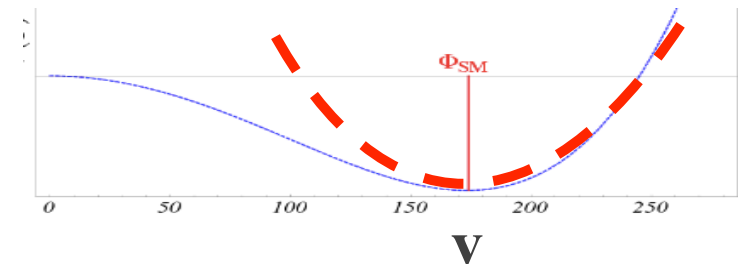
- $m_H \ll v$; typically suppressed by 1-2 orders of magnitude

Reason: V_{eff} flat around minimum

↔ $m_H \sim \text{loop factor} \sim 1/16\pi^2$

→ generic feature → predictions

- everything works nicely...



→ requires moderate parameter adjustment for the separation of the LR and EW scale... PGB...?

Phenomenology

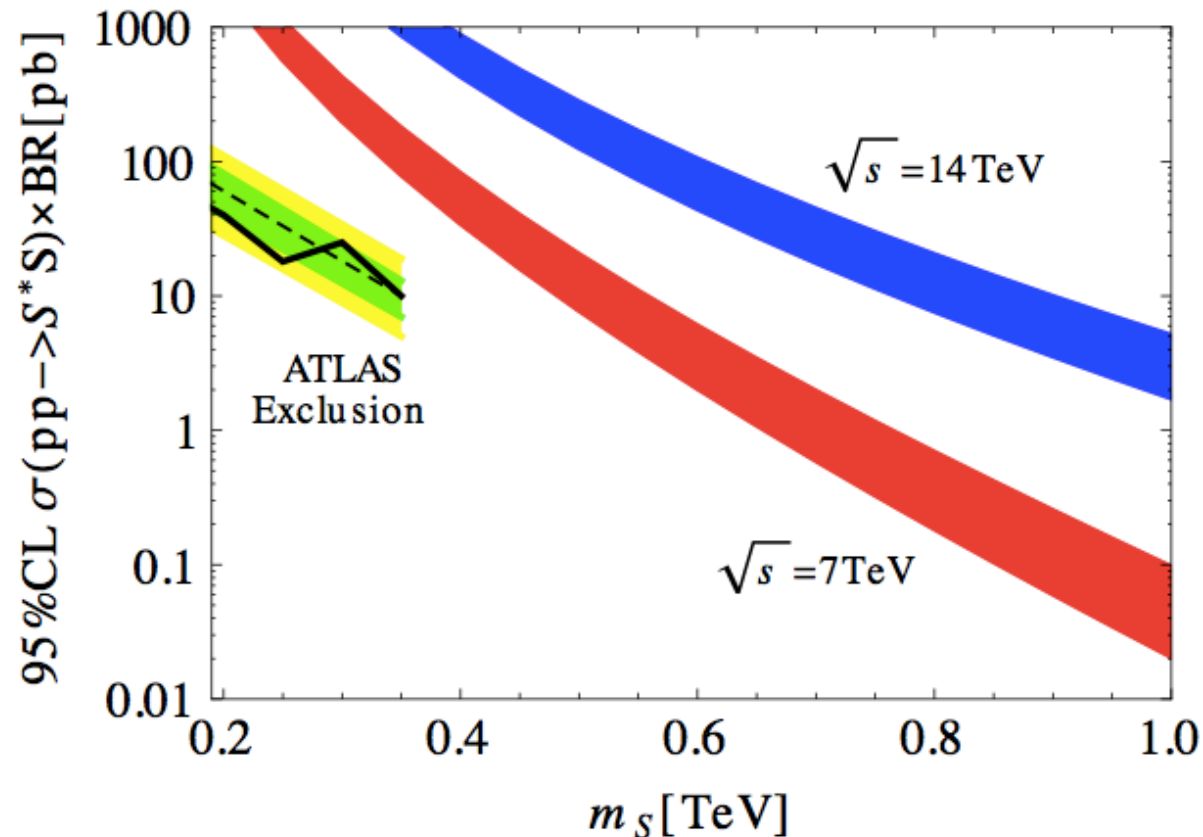


Figure 3. The S pair production cross section from gluon fusion channel is calculated for different value of m_S . The 95% confidence level exclusion limit on $\sigma \times BR$ for $\sqrt{s} = 7$ TeV by ATLAS is plotted. We assume 100% BR of $\langle S^\dagger S \rangle$ into two jets.

Realizing the Idea: Other Directions

SM + extra singlet: Φ, φ

Nicolai, Meissner, Farzinnia, He, Ren, Foot, Kobakhidze, Volkas

SM + extra $SU(N)$ with new N -plet in a hidden sector

Ko, Carone, Ramos, Holthausen, Kubo, Lim, ML

SM embedded into larger symmetry (CW-type LR)

Holthausen, ML, M. Schmidt

SM + colored scalar which condenses at TeV scale

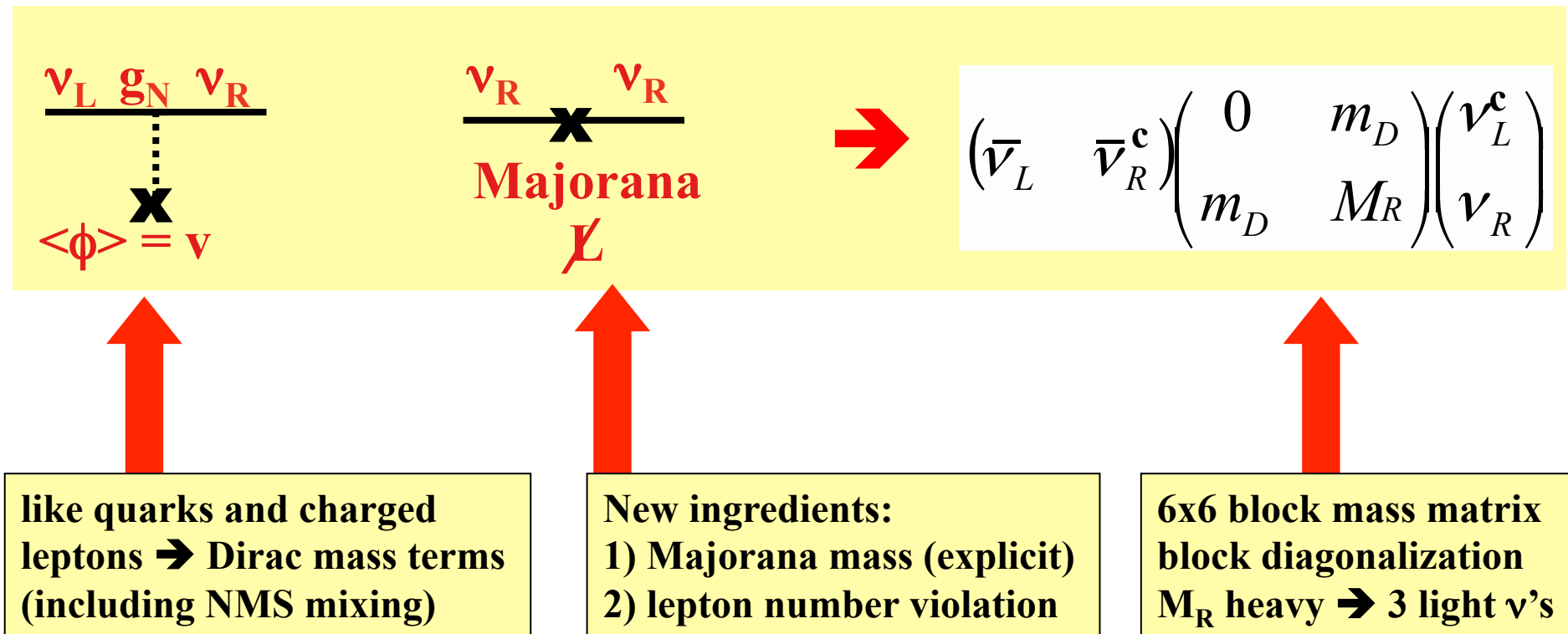
Kubo, Lim, ML

Since the SM-only version does not work \rightarrow observable effects:

- Higgs coupling to other scalars (singlet, hidden sector, ...)**
- dark matter candidates \leftrightarrow hidden sectors & Higgs portals**
- consequences for neutrino masses**

Neutrino Masses = New Physics...

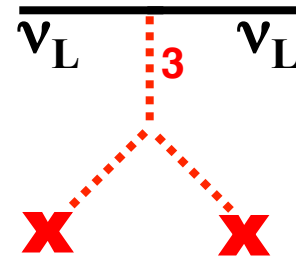
Simplest possibility: add 3 right handed neutrino fields



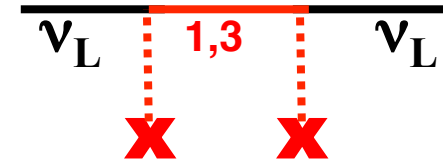
NEW ingredients, 9 parameters \rightarrow SM+

Are right-handed neutrinos established?

New scalar triplets (3_L)
or fermionic 1_L or 3_L



→ left-handed Majorana mass term:



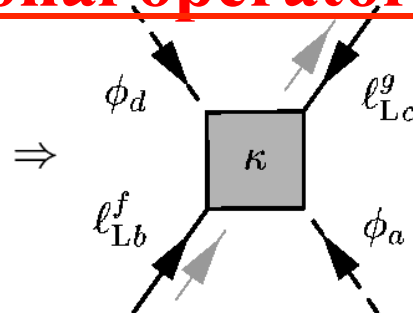
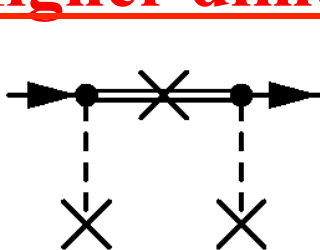
→ $M_L \bar{L} L^c$

Both ν_R and new singlets / triplets:

→ see-saw type II, III

$$m_\nu = M_L - m_D M_R^{-1} m_D^T$$

Higher dimensional operators: $d=5, \dots$

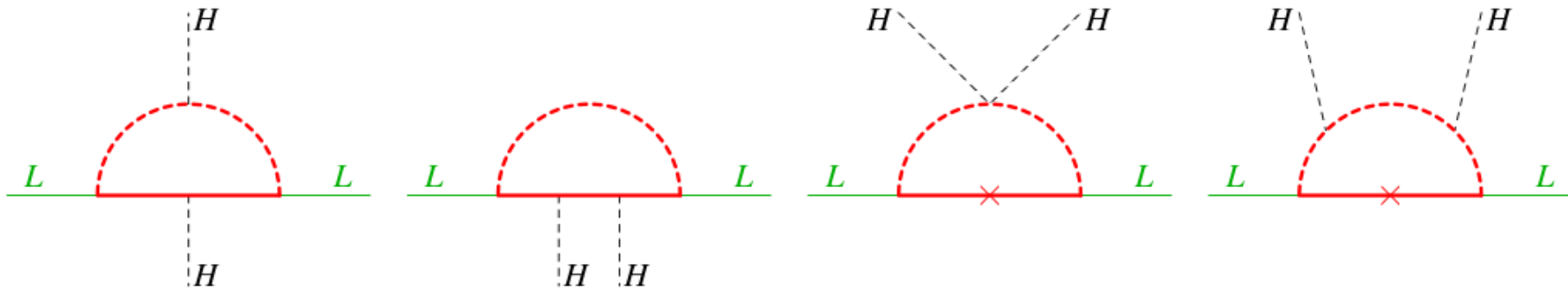


⇔

$$\mathcal{L}_{mass} = \kappa \cdot \bar{\nu}_L^C \nu_L \Phi^T \Phi$$

→ $M_L \bar{L} L^c$

Radiative neutrino mass generation



SUSY, extra dimensions, ...

- inspiring options, many questions, connections to LFV, LHC, ...
- SM+ → can/may solve two of the SM problems:
 - Leptogenesis as **explanation of BAU**
 - keV sterile neutrinos as **excellent warm dark matter candidate**
- progress:
 - new experimental results ...waiting...
 - theoretical guidance ...guessing...

Guidance by the larger Picture: GUTs

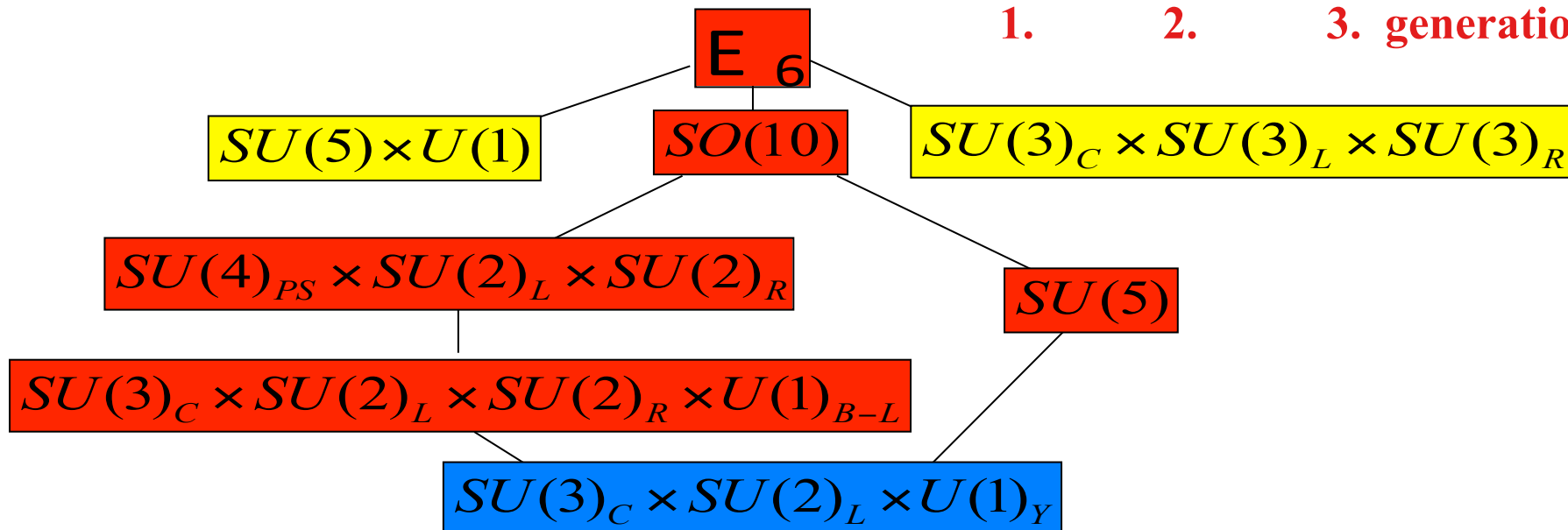
Gauge unification suggests GUTs

Ingredients:

- unified gauge group
- unified particle multiplets $\leftrightarrow \nu_R$
 \rightarrow Q,L Yukawa couplings connected
-
- \rightarrow proton decay , ...
- generations are just copies

Quarks	u	2/3	c	2/3	t	2/3
	~5		~1350		175000	
Leptons	d	-1/3	s	-1/3	b	-1/3
	~9		~175		~4500	
	ν_1	0?	ν_2	0?	ν_3	0?
	e	0.511	μ	105.66	τ	1777.2

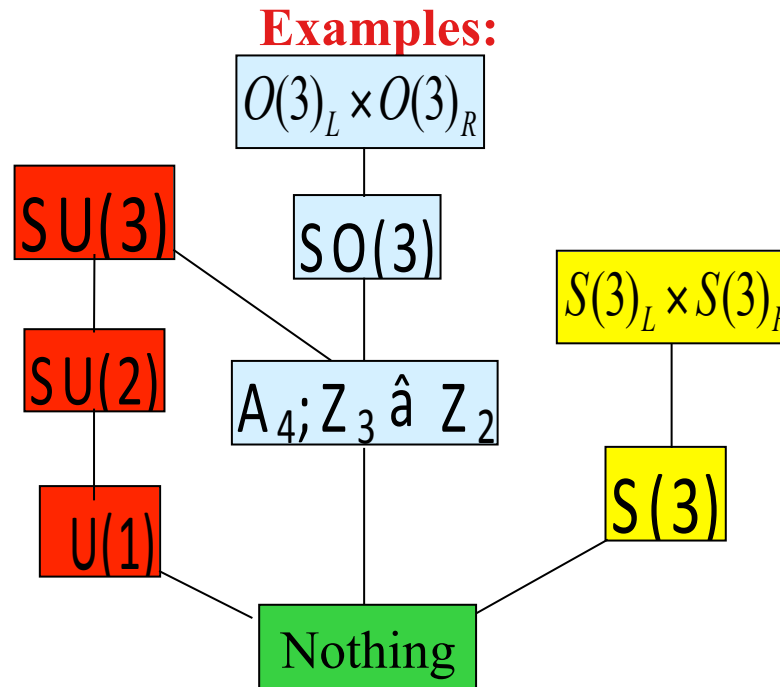
1. 2. 3. generation



Flavour Unification

- so far **no understanding of flavour, 3 generations**
- apparant regularities in quark and lepton parameters
- ➔ flavour symmetries (finite number for limited rank)
- ➔ **symmetry** not texture zeros

Quarks	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$
	u ~ 5	c ~ 1350	t 175000
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$
	d ~ 9	s ~ 175	b ~ 4500
Leptons	0?	0?	0?
	ν_1	ν_2	ν_3
	0.511	105.66	1777.2
	e	μ	τ
	1.	2.	3.
	generation		



GUT & Flavour Unification

$SO(10)$	Quarks	$\frac{2}{3}$ u ~5	$\frac{2}{3}$ c ~1350	$\frac{2}{3}$ t 175000
		$-\frac{1}{3}$ d ~9	$-\frac{1}{3}$ s ~175	$-\frac{1}{3}$ b ~4500
	Leptons	ν_1 0?	ν_2 0?	ν_3 0?
		e 0.511	μ 105.66	τ 1777.2
		1.	2.	3.
		generation		
		$SO(3)_F$		

→ GUT group x flavour group

example: $SO(10) \times SU(3)_F$

- SSB of $SU(3)_F$ between Λ_{GUT} and Λ_{Planck}

- all flavour Goldstone Bosons eaten

- discrete sub-groups survive \leftrightarrow SSB

e.g. $Z_2, S_3, D_5, A_4, \dots$

→ structures in flavour space

→ compare with data

→ aim: distinguish models by future precision and learn about the origin of flavour

→ reality so far: many models get killed by data (see e.g. $\theta_{13} \dots$)

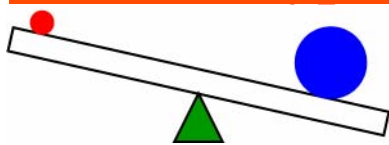
Generic & Suggestive See-Saw Features

QFT: natural value of mass operators \leftrightarrow scale of symmetry

$m_D = g_D * v$; $v \simeq$ electro-weak scale ; $0 \leq g_D \leq 2 \rightarrow 0 \leq m_D \leq 2*v$

$M_R \sim$ L violation scale $\leftarrow ? \rightarrow$ embedding (GUTs, ...)

See-saw (type I)



$$m_\nu = m_D M_R^{-1} m_D^T$$

$$m_h = M_R$$

Numbers: For $m_3 \sim (\Delta m_{\text{atm}}^2)^{1/2}$, $m_D \sim$ leptons $\rightarrow M_R \sim 10^{11} - 10^{16} \text{ GeV}$

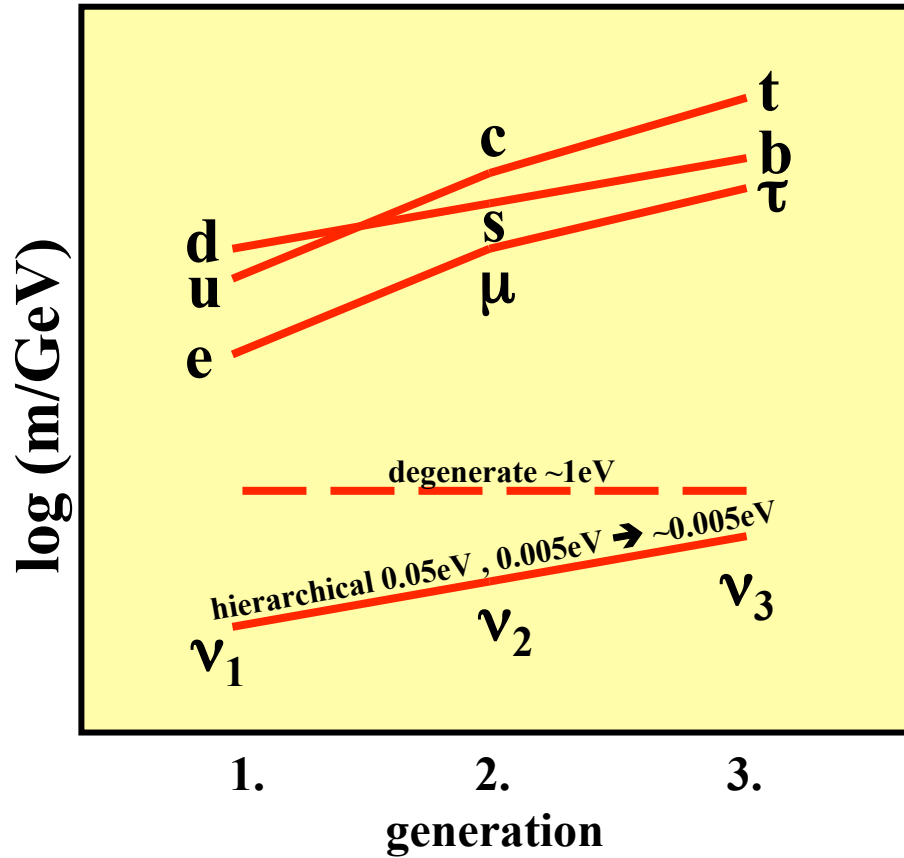
M_R suggests **that sterile neutrinos must be very heavy** – really?

\rightarrow are there indications / arguments for light sterile states?

\rightarrow theoretical arguments in favour of light steriles

2nd Look Questions

Quarks & charged leptons → hierarchical masses → neutrinos?



Quarks and charged leptons:

$$m_D \sim H^n ; n = 0,1,2 \rightarrow H \geq 20 \dots 200$$

Neutrinos:

$$m_\nu \sim H^n \rightarrow H \leq \sim 10$$

See-saw:

$$m_\nu = -m_D^T M_R^{-1} m_D$$

	↑	↑	↑	↑
H	~ 10	≥ 20	?	≥ 20

- inversely correlated hierarchy in M_R ? → not related!
- other version of see-saw? → type II, III, ...? Dirac masses?
- b.t.w: see-saw may explain tiny masses, but what about mixings...?

Hints / Arguments / ... for Sterile Neutrinos

Particle Physics: LSND, Gallium, MiniBooNE, reactor anomaly, ...

CMB: $N_\nu = 3.3 \pm 0.27 \rightarrow$ extra eV-ish ν 's possible PLANCK 2013

BBN: $N_\nu = 3-4 \rightarrow$ possible e.g. Coc

Astrophysics: keV-ish sterile neutrinos could explain pulsar kicks

Kusenko, Segre, Mocioiu, Pascoli, Fuller et al., Biermann & Kusenko, Stasielak et al., Loewenstein et al., Dodelson, Widrow, Dolgov, ...

Dark matter: keV sterile neutrinos are excellent WDM

Asaka, Blanchet, Shaposhnikov, ... ML, Bezrukov, Hettmanperger



claims

Sterile ν 's and improved EW fits: TeV-ish ν 's improve χ^2

Akhmedov, Kartavtsev, ML, Michaels and J. Smirnov

Most likely not all true, but one is enough:

VERY IMPORTANT IMPLICATIONS \rightarrow new direct experiments

Options for Neutrino Mass Spectra

$$\begin{array}{c}
 \begin{array}{cc}
 3 & 0 \dots N \\
 \downarrow & \downarrow \\
 \left(\begin{array}{cc} \bar{\nu}_L & \bar{\nu}_R^c \end{array} \right) & \left(\begin{array}{cc} M_L & m_D \\ m_D & M_R \end{array} \right) & \left(\begin{array}{c} \nu_L^c \\ \nu_R \end{array} \right)
 \end{array} \\
 \begin{array}{c}
 \text{3x3 matrix} \\
 \text{3xN} \quad \text{NxN}
 \end{array}
 \end{array}$$

M_L, m_D, M_R may have almost any form / values:

- zeros (symmetries)
- 0 + tiny corrections
- scales: M_W, M_{GUT}, \dots
- diagonalization: 3+N EV
- 3x3 active almost unitary

$M_L=0, m_D = M_W,$
 $M_R=\text{high: see-saw}$

M_R singular
 singular-SS

$M_L = M_R = 0$
 Dirac

$M_L = M_R = \epsilon$
 pseudo Dirac

sterile



active



Conformal Symmetry & Neutrino Masses

ML, S. Schmidt and J. Smirnov, arXiv:1405.6204

- **No explicit scale \rightarrow no explicit (Dirac or Majorana) mass term
 \rightarrow only Yukawa couplings \otimes generic scales**
- **Enlarge the Standard Model field spectrum
like in 0706.1829 - R. Foot, A. Kobakhidze, K.L. McDonald, R. Volkas**
- **Consider direct product groups: SM \otimes HS**
- **Two scales: CS breaking scale at O(TeV) + EW scale**
 - \rightarrow spectrum of Yukawa couplings \otimes TeV or EW scale
 - \rightarrow many possibilities

Examples

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

Yukawa seesaw:

SM + ν_R + singlet

$$\langle \phi \rangle \approx \text{TeV}$$

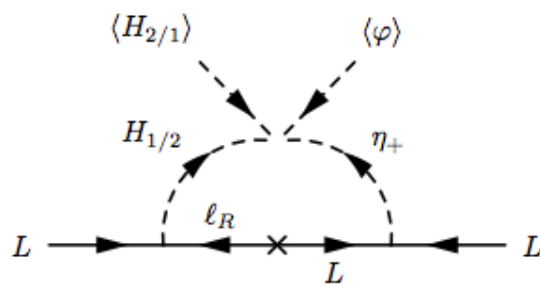
$$\langle H \rangle \approx 1/4 \text{ TeV}$$

→ generically expect a TeV seesaw

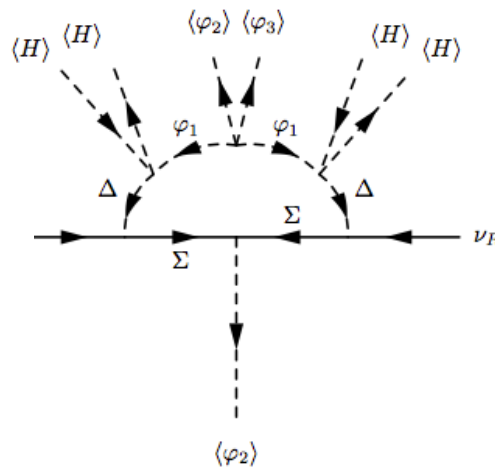
BUT: y_M might be tiny

→ wide range of sterile masses → includes pseudo-Dirac case

Radiative masses



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



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

$$\mathcal{M} = m_L$$

or

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

→ pseudo-Dirac case

More Examples: Inverse Seesaw

Seesaw & LNV

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

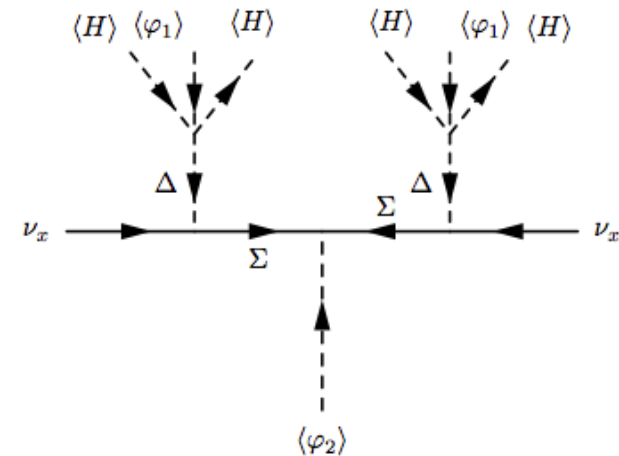
$$\nu_x : (1_{SU(2)}, 0_Y, n_{HS})$$

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

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

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

μ is suppressed (LNV) natural scale keV

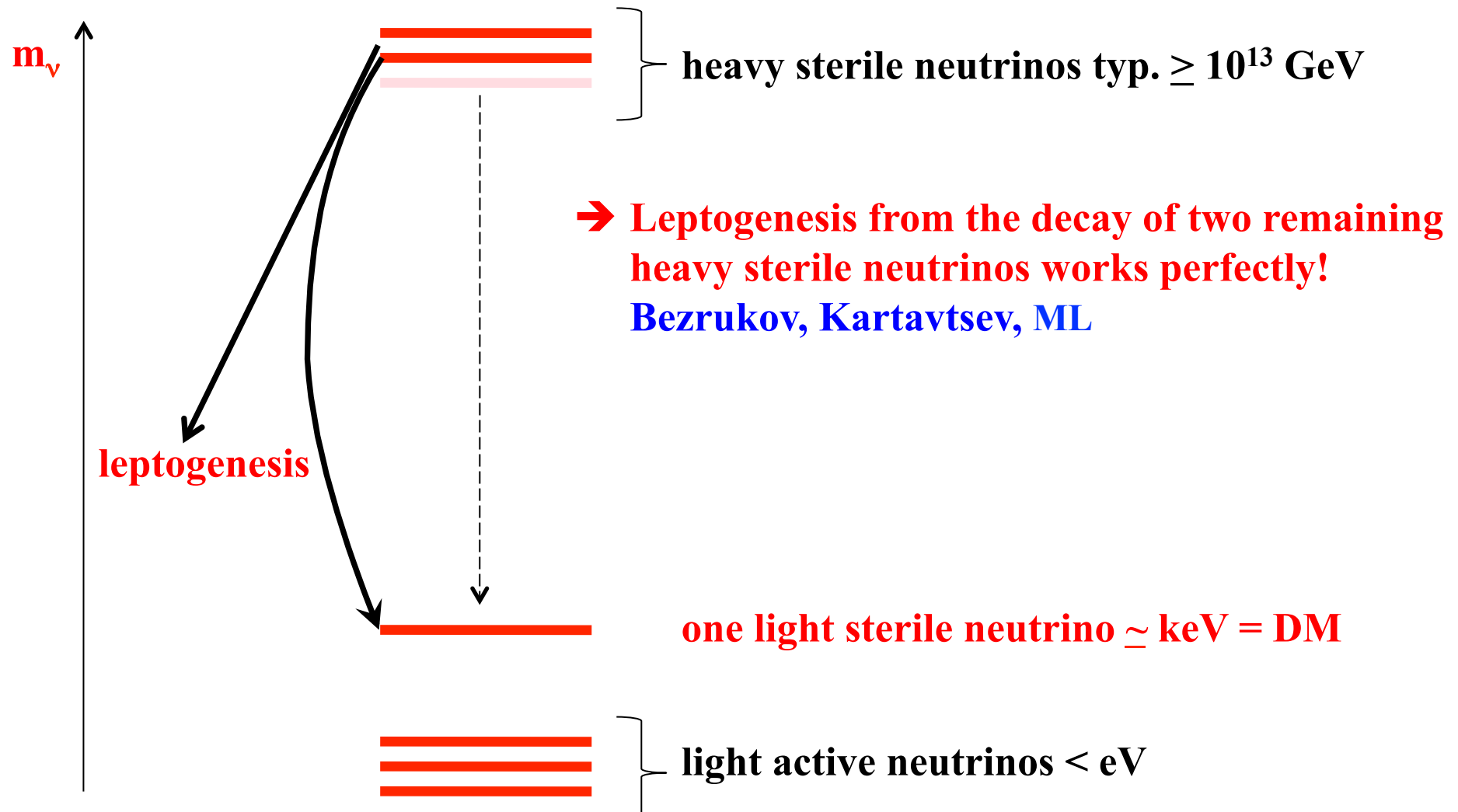


The punch line:

- all usual neutrino mass terms can be generated
- No explicit masses \rightarrow all via Yukawa couplings \rightarrow different numerical expectations

→ More Flexible Neutrino Mass Spectrum

...see-saw spectrum may be rather different than usual. E.g. ...



Further Comments

- Having a new (hidden) sector → not surprisingly DM
- ... or keV-ish sterile neutrinos as warm DM ...
- Question: Isn't the Planck-Scale spoiling things?
 - conformal gravity = non-linear realization
 - or ...

see e.g. 1403.4226 by A. Salvio and A. Strumia → 'Agravity'
or K. Hamada, 1109.6109, 0811.1647, 0907.3969
- Question: What about inflation?
 - see e.g. 1405.3987 by K. Kannike, A. Racioppi, M. Raidal
or 1308.6338 by V. Khoze
- Further questions: What about unification, UV-FPs,

Summary

- **SM (+ m_ν +DM) works perfectly; no signs of new physics**
- **The standard hierarchy problem suggests TeV scale physics ... which did (so far...) not show up**
- **Revisit how the hierarchy problem may be solved**
 - $\lambda(M_{\text{Planck}}) = 0$? \leftrightarrow **precise value for m_t**
 - Embeddings into QFTs with classical conformal symmetry
 - SM: Coleman Weinberg effective potential – excluded
 - extended versions \rightarrow work!
 - \rightarrow **implications for Higgs couplings, dark matter, ...**
 - \rightarrow **implications for neutrino masses**
 - \rightarrow **testable consequences @ LHC, DM search, neutrinos**