The Mirage of the Fermi scale

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Outline

1. Introduction: abandon the current paradigms?

2. Brief overview of a new paradigm

3. Some recent model building examples

based on work done with

T. Alanne, H. Gertov, A. Meroni, F. Sannino, T. Tenkanen (in various combinations)

1411.6132

1511.01910

1611.04932

1. Introduction

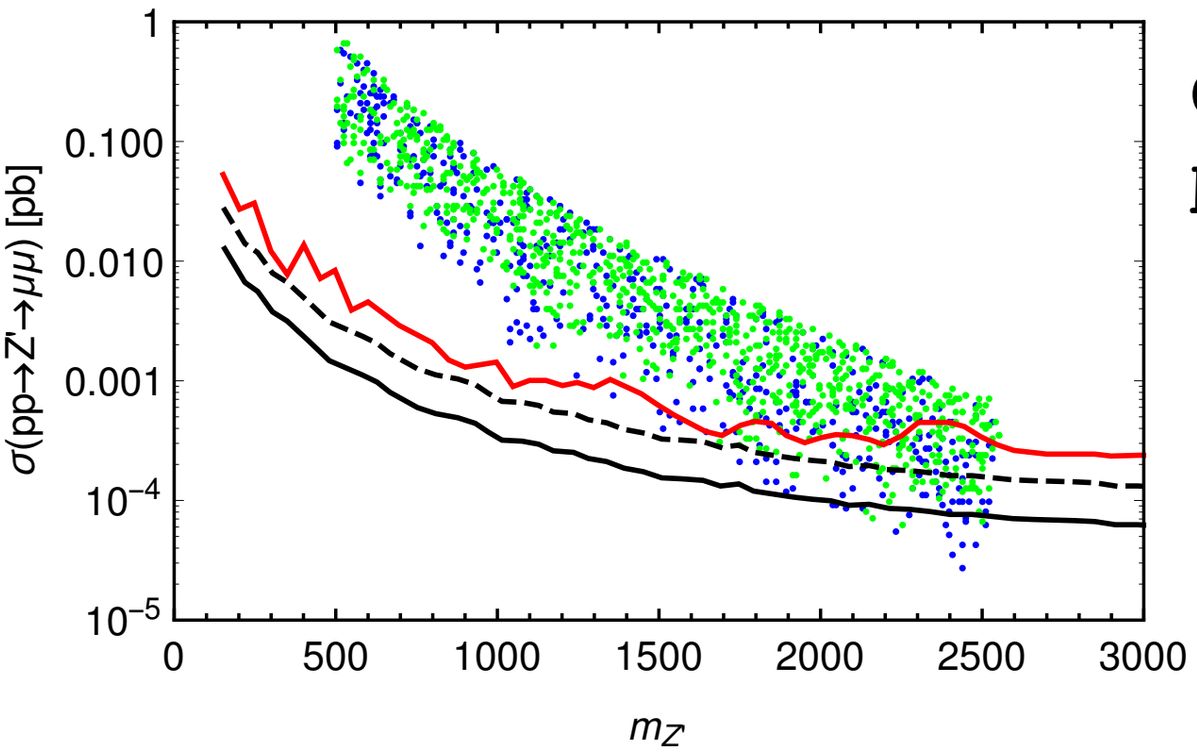
Past 30+ years: the naturalness paradigm

- Technicolor, (tumbling)
- SUSY, (not well)
- Extra dims, (dead)

…

Expected:

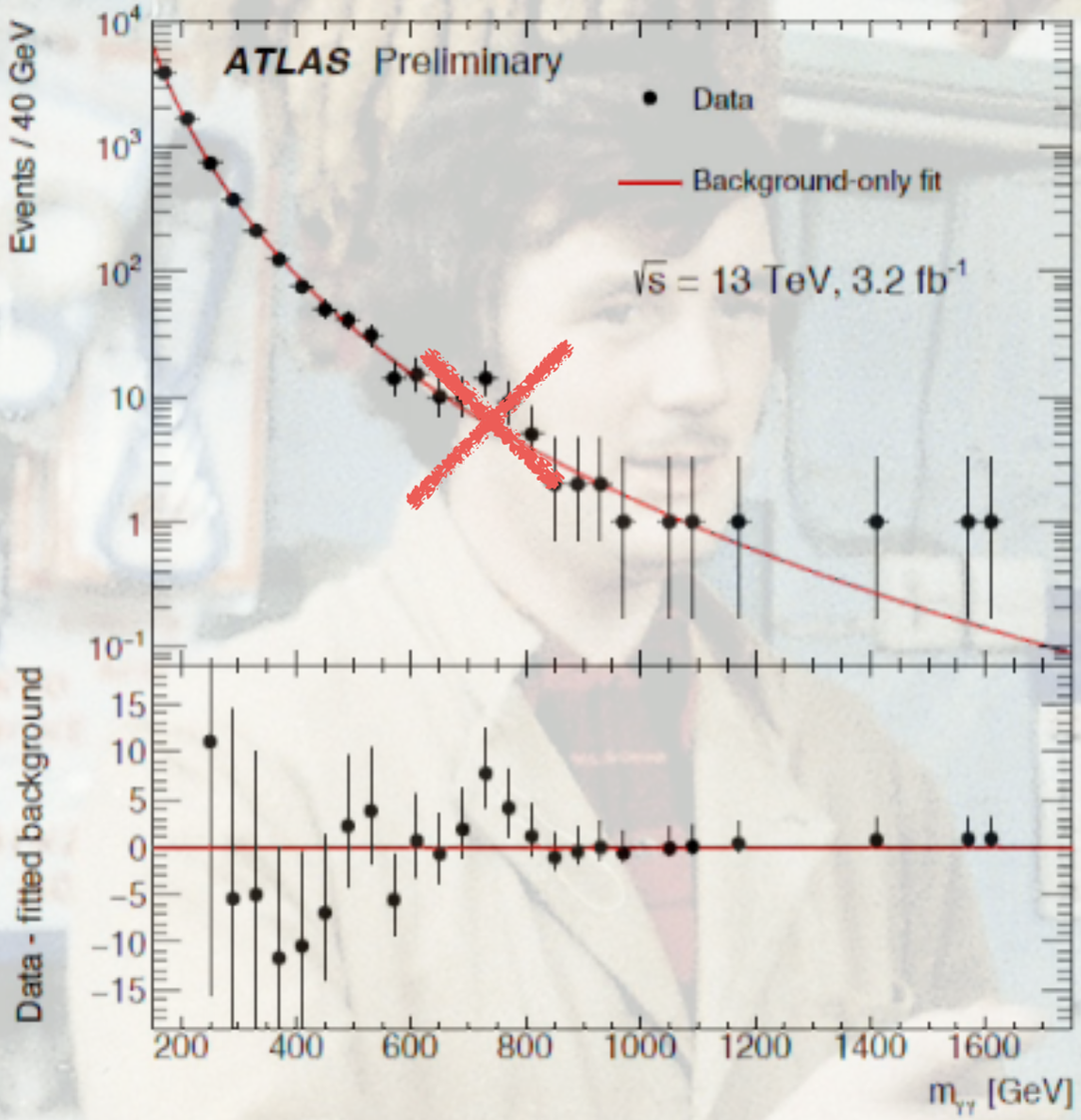
A zoo of new particles at the terascale (just behind the corner…)



Constraint on Z′ of Minimal Technicolor

(S. Di Chiara, M. Heikinheimo & KT)

Never buy a Norwegian Blue from an LHC experimentalist just before Christmas…



"This excess is no more.
It has ceased to be.
It's expired and gone to meet its maker.
It's a stiff.
Bereft of life, it rests in peace.
It's pushing up the daisies.
It's rung down the curtain
and joined the choir invisible.

This is an ex-excess."

The usual argument of naturality:

$$v_{\rm weak} = 264\,{\rm GeV} \longrightarrow \Lambda_{\rm NP} = 4\pi v_{\rm weak} = 3\,{\rm TeV}$$

Fails, so need to rethink the BSM premises.

- No new states at LHC energies.
- Dark matter, baryon asymmetry, neutrinos?
- Particle physics context of inflation?

Instead, start from: $\Lambda_{\rm NP} = 10^4 \ldots 10^9\,{\rm GeV}$

Consider larger scalar sector than in SM.
See if EW scale could come out somehow…

2. The new paradigm

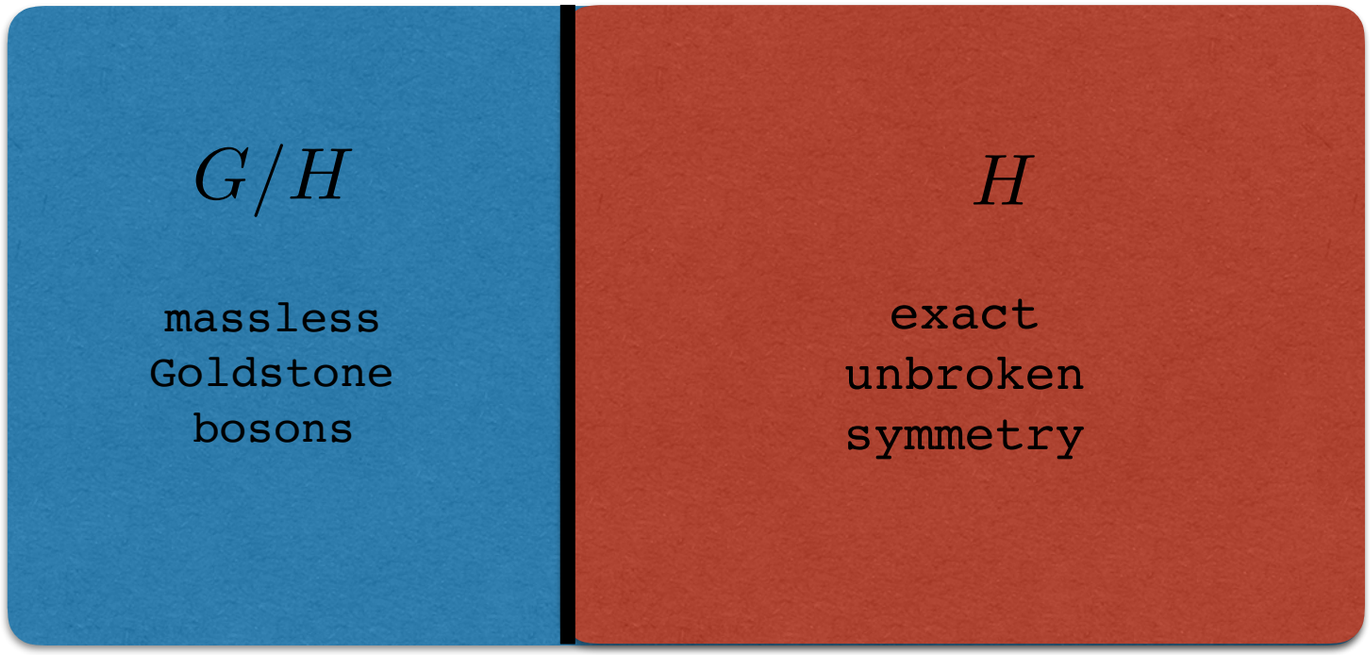
$$\mathcal{L} = -\frac{1}{4} \sum_{V=G,W,B} F^2_{\mu\nu}(V) + i \sum_{\psi=Q,u,d,L,e} \bar{\psi} \not{D} \psi$$

$$+ |D\Phi|^2 + V(\Phi) + \mathcal{L}_{\text{Yuk}}$$

- No new QCD dofs,
- Scalars are elementary, global symmetry G
- EW & scalars perturbative.

SSB and Higgs mechanism:

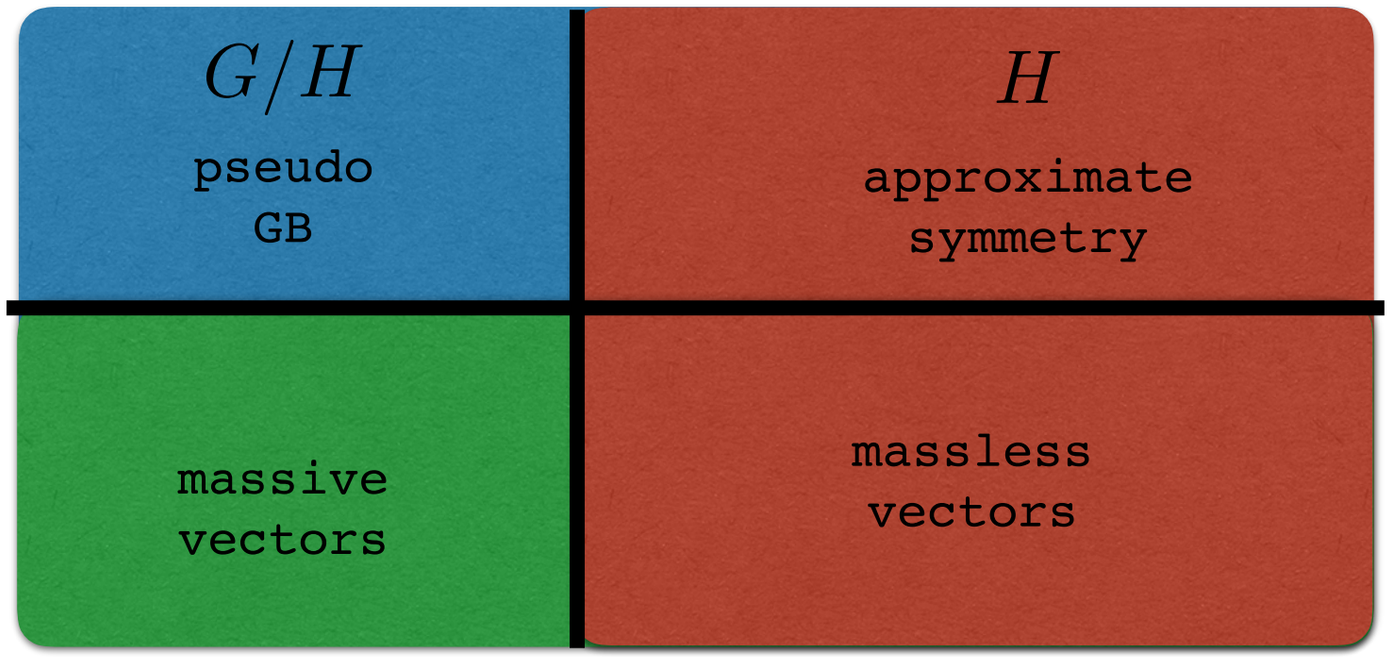
G broken by vacuum condensate to $H \subset G$



The Minimal Standard Model:

$$G = SO(4) \xrightarrow{v = v_{\text{weak}} = 246\,\text{GeV}} SO(3) = H$$

SSB and Higgs mechanism: Gauged $G' \subset G$



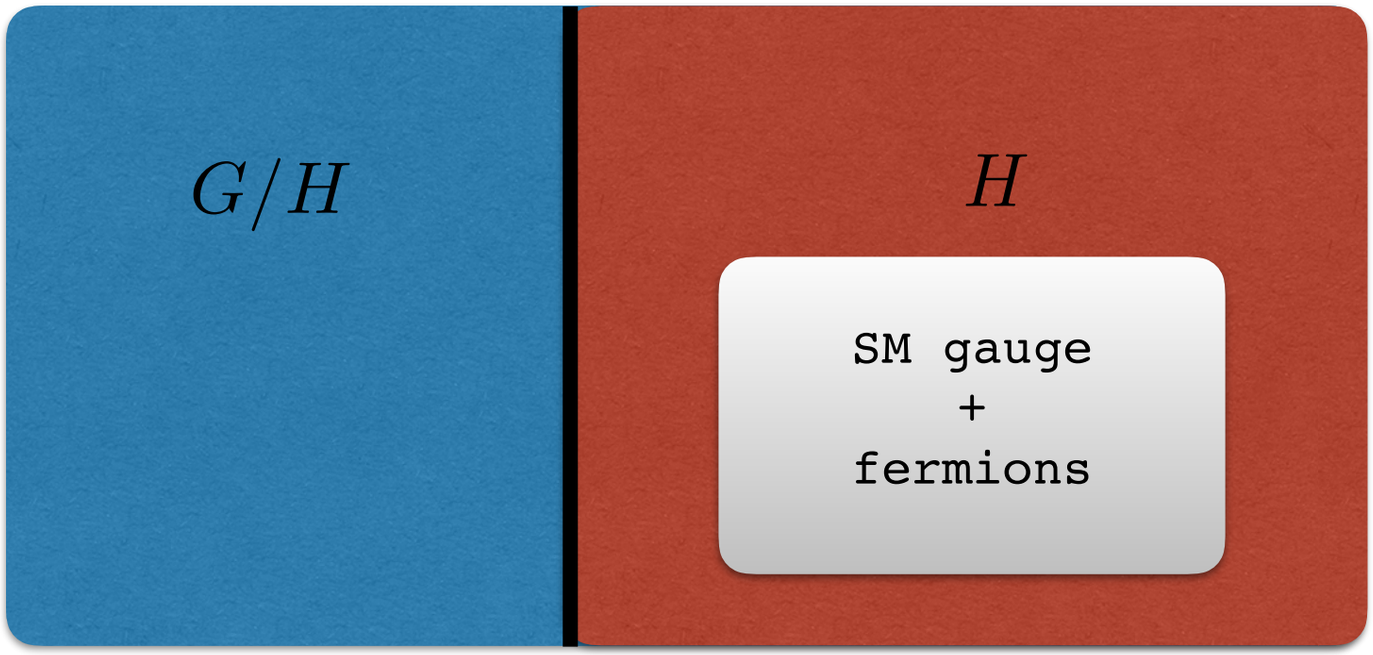
The Minimal Standard Model:

$$\begin{array}{ccc} G = SO(4) & \xrightarrow{v = v_{\rm weak} = 246\,{\rm GeV}} & SO(3) = H \\ \cup & & \cup \\ G' = [SU(2)_L \times U(1)_Y] & \longrightarrow & [U(1)_{\rm em}] \end{array}$$

3 GBs eaten by 3 massive vectors

Extend to a larger scalar sector

$$V_0 = \frac{m^2}{2}\Phi^\dagger\Phi + \frac{\lambda}{4!}(\Phi^\dagger\Phi)^2 \qquad \Phi = (\sigma + i\Pi^a X^a)E$$



$4 \oplus (N-1)$ singlets under $SO(4)$

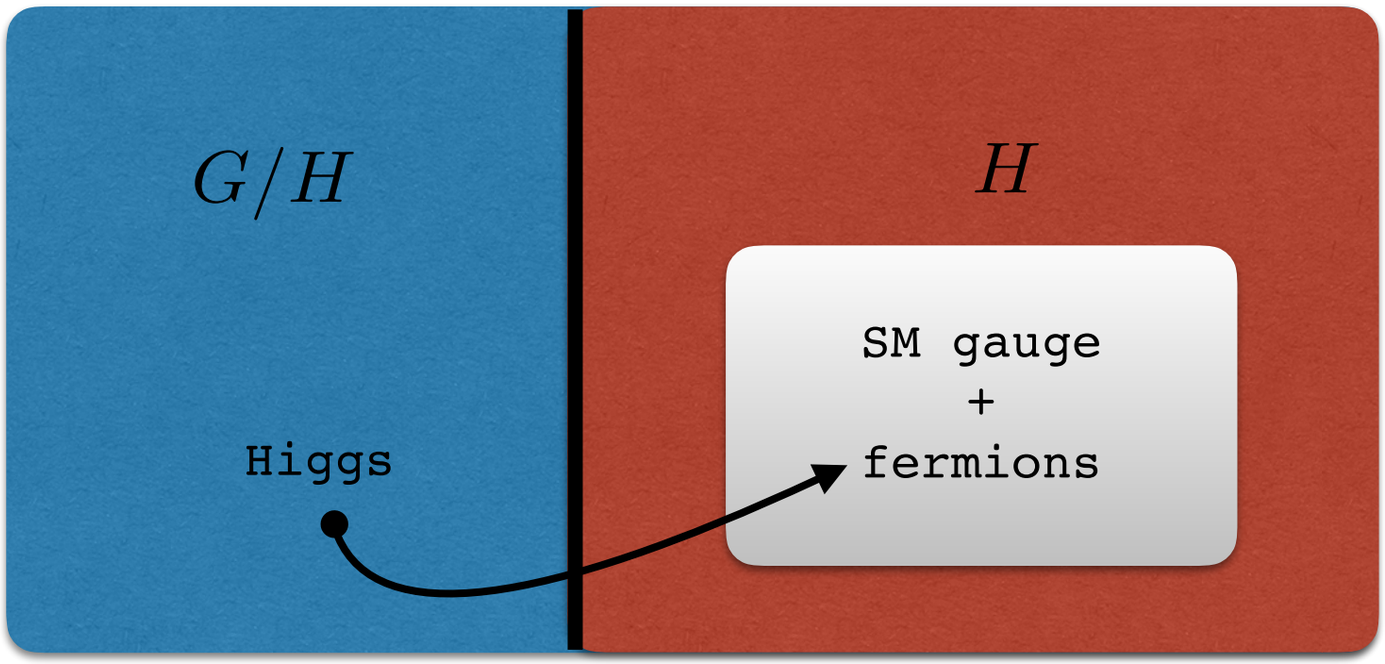
$$SO(N) \xrightarrow[v \neq 0]{} SO(N-1) \qquad N > 4$$
$$\cup$$
$$[SU(2)_L \times U(1)_Y]$$

Good: The value of v can be anything.

Bad: looks like EW does not break at all…

EW breaks as a secondary effect:

Vacuum misalignment by quantum corrections.



Full perturbative control.

$$M_W = \sin\theta v$$

$$v \gg v_{\rm weak} \;\; \Rightarrow \;\; \sin\theta \ll 1$$

Elementary Goldstone Higgs

Basic predictions:

No new particles around EW scale.
Only the Higgs

Almost like SM, but not quite:

$$m_h \sim \lambda v \qquad v \gg v_{\rm weak} \qquad \lambda \ll 1$$

Test by measuring the Higgs self-couplings

1. Examples

Simplest extension: $SO(5) \to SO(4)$

1-loop potential: EW not broken

Fixed by adding a singlet scalar

$$V_0 = \frac{1}{2}m^2\Phi^\dagger\Phi + \frac{1}{2}m_S^2 S^2 + \frac{\lambda}{4!}(\Phi^\dagger\Phi)^2 + \frac{\lambda_{\Phi S}}{4}(\Phi^\dagger\Phi)S^2 + \frac{\lambda_S}{4!}S^4.$$

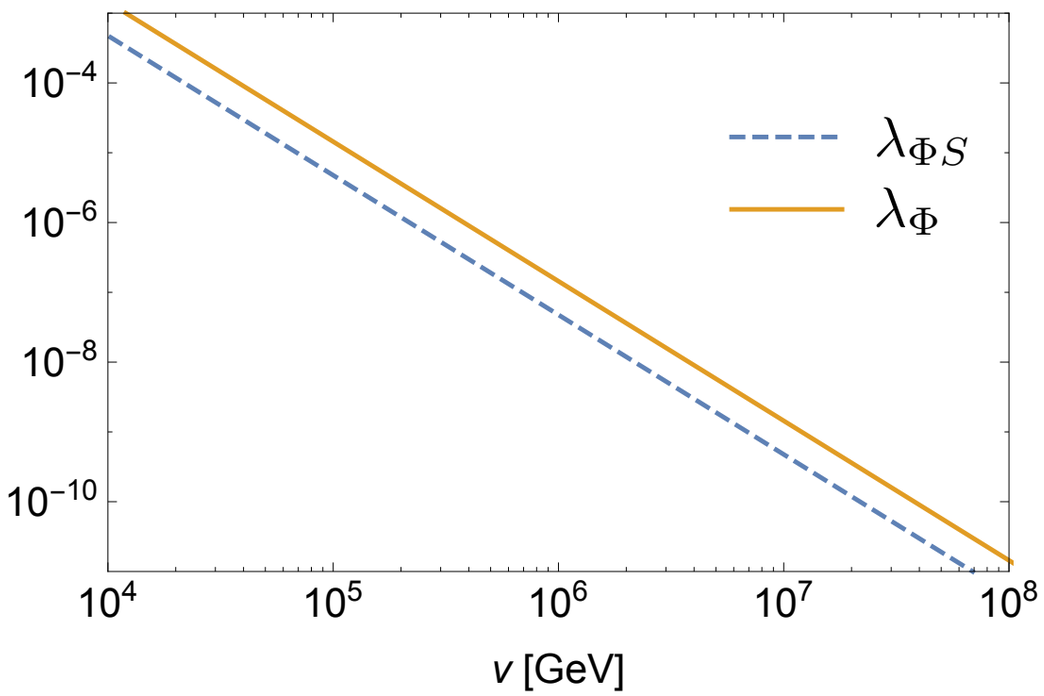
Leads to the pGB Higgs via 1-loop corrections

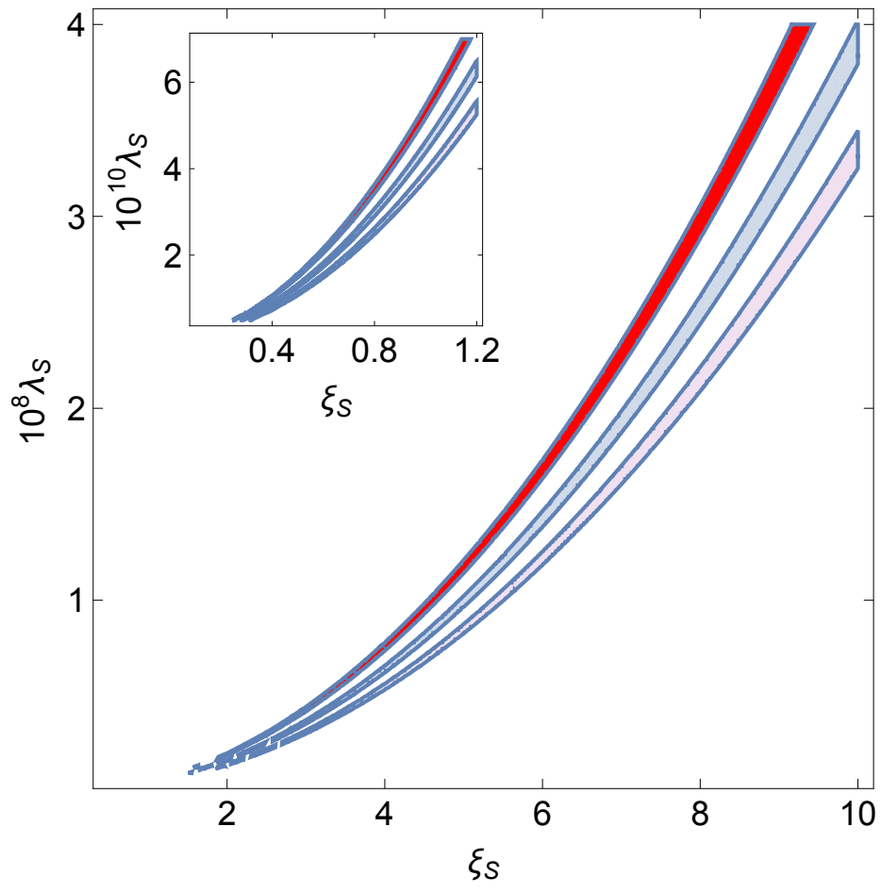
Include gravity, non-minimally coupled

$$V_\xi = \xi_\Phi(\Phi^\dagger\Phi)R + \frac{1}{2}\xi_S S^2 R \qquad \xi_\Phi < \xi_S = \mathcal{O}(1)$$

Succesfull inflation.

Avoids problems of Higgs inflation.





Next to minimal extension:

$$SU(4) \simeq SO(6) \longrightarrow SO(5) \simeq Sp(4)$$

More scalar fields,

Allows for dark matter,

Inflation,

Right-handed neutrinos,

Unification

Conclusions/ Outlook

1. LHC may not discover any BSM resonances
2. Model building paradigms need to be revised
3. **Elementary Goldstone Higgs:**
    a. High scale physics & emergent EW scale
    b. Provides a context for inflation
    c. Dark matter
    d. EW transition & Baryogenesis
    e. (gauge) unification