Inflation and Electroweak vacuum stability after LHC, PLANCK and BICEP2

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Discoveries

- Large Hadron Collider :

Higgs Particle ⟶ Mass 122-127 GeV

- PLANCK :

Precision measurements of scalar spectral index and primordial non-Gaussinity ⟶ Hinting towards single-field inflationary scenarios

- BICEP2 :

Claimed (dust ?) to have measured (primordial) large tensor-to-scalar ratio ⟶ Puts inflationary scale close to GUT scale

Open issues

- Observed Higgs and top masses may lead to unstable electroweak vacuum at higher energy scales (around 10^{10} GeV)
- We still do not know the particle physics origin of inflaton
- Large tensor-to-scalar ratio observation by BICEP2 might claim that Higgs is not inflaton

Aims

- To include inflaton in a particle physics model
- To stablilize the Electroweak vacuum all the way upto the Planck scale

Model

- Symmetry Group :

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{B-L}$$

- 3 extra right handed neutrinos to cancel all the gauge as well as gravitational anomalies, 1 extra gauge boson and 1 extra heavy scalar field
- Electroweak symmetry breaks at 256 GeV and B-L symmetry breaks at GUT scale

- Scalar Lagrangian :

$$\mathcal{L} = (\mathcal{D}_\mu S)^\dagger(\mathcal{D}^\mu S) + (\mathcal{D}_\mu \Phi)^\dagger(\mathcal{D}^\mu \Phi) + m_s^2(S^\dagger S) + m_\phi^2(\Phi^\dagger\Phi) - \lambda_1(S^\dagger S)^2 - \lambda_2(\Phi^\dagger\Phi)^2 - \lambda_3(S^\dagger S)(\Phi^\dagger\Phi)$$

- The full symmetry group and the low energy effective SM are well separated in energy scales

- Decoupling theorem ⟶ presence of new heavy particles of the extended theory would not affect the quartic coupling of the SM Higgs at low scales ⟶ No Vacuum Stability ??

Threshold effect

- Threshold effect : modifies the evolution of Higgs quartic coupling at lower scale due to presence of a heavy scalar below the instability scale

- Scalar potential :

$$V(S,\Phi) = \lambda_1 (S^\dagger S)^2 - m_s^2 (S^\dagger S) + \lambda_2 \left(\Phi^\dagger \Phi - \tfrac{1}{2} v_\phi^2\right)^2 + \lambda_3 (S^\dagger S)\left(\Phi^\dagger \Phi - \tfrac{1}{2} v_\phi^2\right)$$

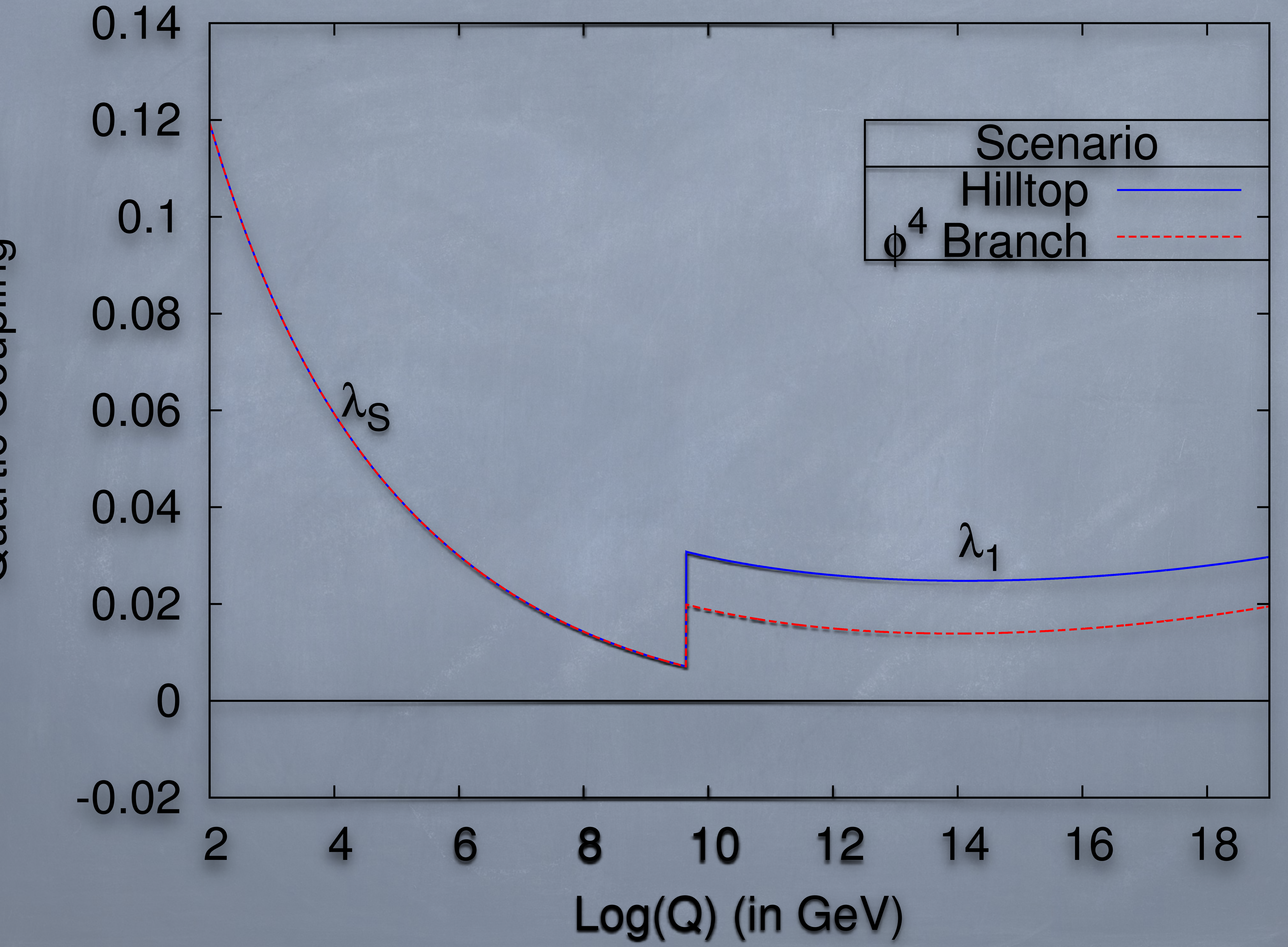
- The EOM of the heavy scalar at its minima

$$\Phi^\dagger \Phi = \tfrac{1}{2} v_\phi^2 - \frac{\lambda_3}{2\lambda_2} S^\dagger S$$

- Effective scalar potential below the heavy scalar's mass-scale :

$$V(S)|_{\rm eff} = \left(\lambda_1 - \frac{\lambda_3^2}{4\lambda_2}\right)(S^\dagger S)^2 - m_s^2(S^\dagger S)$$
$$\equiv \lambda_S (S^\dagger S)^2 - m_s^2(S^\dagger S)$$

- The Electroweak vacuum is stable all the way upto the Planck scale



0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
2
4
6
8
10
12
14
16
18
Log(Q) (in GeV)
Scenario
Hilltop
ϕ^4 Branch
λ_S
λ_1

Inflation

- Inflation is driven by the radiatively corrected quartic inflaton potential

$$V(\phi_0) = \frac{1}{4}\lambda_2(\phi_0^2 - v_\phi^2)^2 + a\lambda_2 \log\left(\frac{\phi_0}{v_\phi}\right)\phi_0^4$$

- Where the radiatively corrected term has the coefficient

$$a \equiv \frac{1}{16\pi^2\lambda_2}\left(20\lambda_2^2 + 2\lambda_3^2 + 2\lambda_2\left(\sum_i (Y_i^{N_R})^2 - 24 g_{B-L}^2\right) + 96 g_{B-L}^4 - \sum_i (Y_i^{N_R})^4\right)$$

- Define : $u = (1 + a + 4a\ln\phi_0/v_\phi)/a$
- The observables are

$$r = \frac{128M_{\rm Pl}^2}{\phi_0^2}\frac{u^2}{(u-1)^2}$$

$$n_s = 1 - \frac{8M_{\rm Pl}^2}{\phi_0^2}\frac{3u^2 - u + 4}{(u-1)^2}$$

$$\frac{dn_s}{d\ln k} = -\frac{64M_{\rm Pl}^4}{\phi_0^4}\left[\frac{u(3u^3 - 4u^2 + 15u + 10)}{(u-1)^4}\right]$$

$$\mathcal{P}_{\mathcal{R}} = \frac{\lambda_2}{768\pi^2}\left(\frac{\phi_0}{M_{\rm Pl}}\right)^6\frac{a(u-1)^3}{u^2}$$

Hilltop inflation

$$
\begin{aligned}
u_* &= -0.333 \\
r_* &= 0.015 \\
\lambda_2 &\sim 1.89 \times 10^{-13} \\
m_\phi &\sim 4.3 \times 10^9 \,\mathrm{GeV} \\
\left.\frac{dn_s}{d\ln k}\right|_{k_*} &\sim 1.07 \times 10^{-4}
\end{aligned}
$$

In accordance with PLANCK observations

ϕ^4-branch Inflation

$$
\begin{aligned}
u_* &= -11.001 \\
r_* &= 0.203 \\
\lambda_2 &\sim 3.6 \times 10^{-13} \\
m_\phi &\sim 6.0 \times 10^9\,\mathrm{GeV} \\
\left.\frac{dn_s}{d\ln k}\right|_{k_*} &\sim -5.6 \times 10^{-4}
\end{aligned}
$$

- In accordance with PLANCK & BICEP2

Summary

- Aims : to stabilize the electroweak vacuum all the way upto Planck scale and accommodate inflaton in the particle picture
- We extend the SM by $U(1)_{B-L}$ symmetry
- Due to presence of an extra heavy scalar Higgs quartic coupling receives a threshold correction which helps keep the vacuum stable till the Planck scale
- The real part of the new heavy scalar is the inflaton
- Inflation can occur in two different branches which are in accordance with observation.

Thank You !!