Matching and running: predictions in non-renormalizable inflationary models

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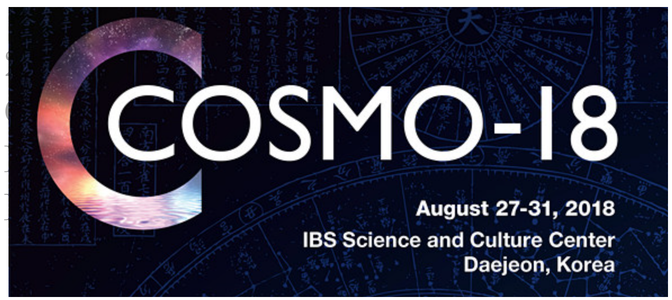


Based on

J.F., S. Mooij and M. Postma. JHEP 1803 (2018) 038.

J.F., M. Postma, M. Van de Bout in preparation.

Can we connect low energy physics to inflation?

How we connect low energy physics to inflation?

MINIMAL

CONSISTENT

$\longleftrightarrow$

PREDICTIVE

#Parameters $<$ # Predictions

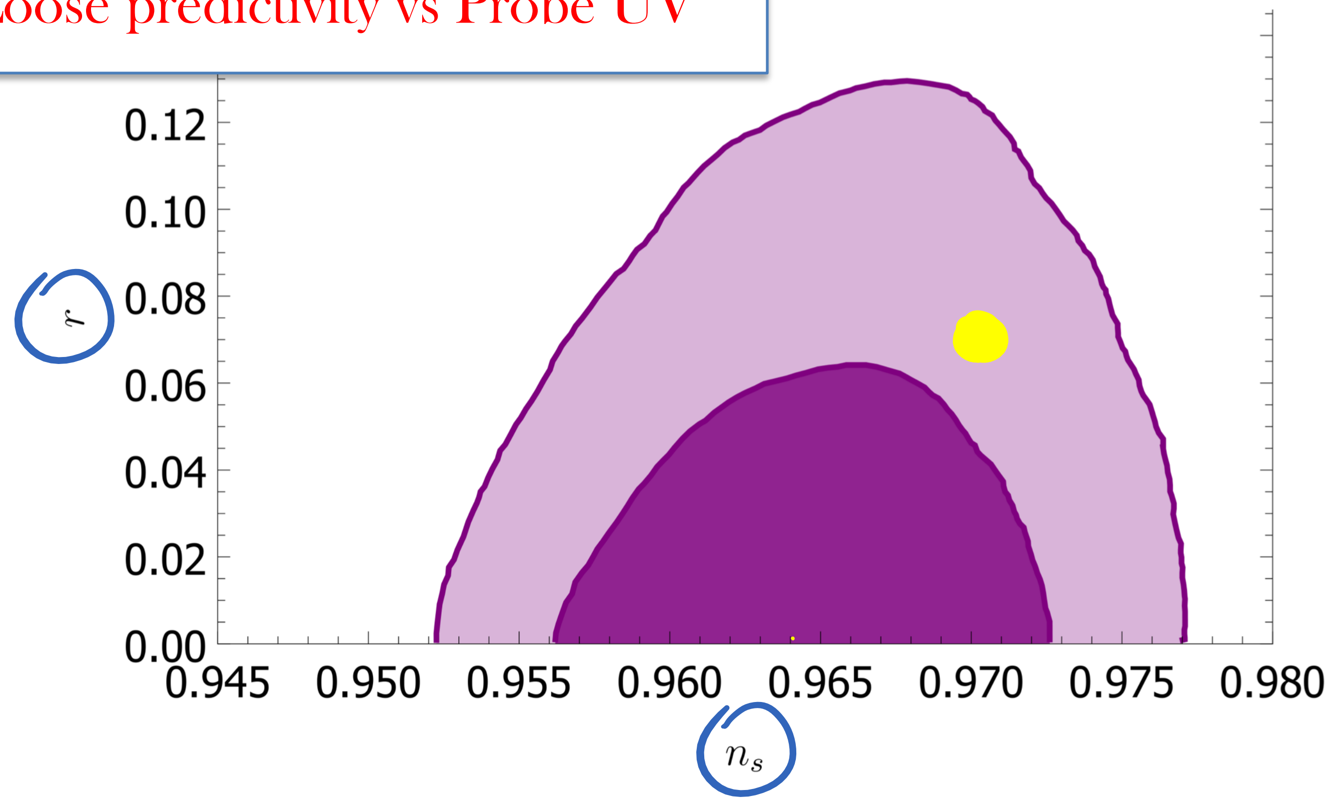
Requiring consistency can affect the predictiveness?

UV sensitivity $\longleftrightarrow$ Non-renormalizability

UV sensitivity

$$\langle 0 | |\mathcal{R}(x)|^2 | 0 \rangle \longrightarrow \mathcal{P}_s \propto \overset{\sim 10^{-9}}{\left(\frac{V}{\epsilon}\right)} \left(\frac{k}{k_\star}\right)^{n_s - 1} \longrightarrow (n_s, r)_{\text{new}}$$

Loose predictivity vs Probe UV



New Higgs Inflation

C. Germani, A. Kehagias '10

$$\mathcal{L} = \frac{M_{\rm pl}^2}{2} R - \left(g^{\mu\nu} - \frac{G^{\mu\nu}}{M^2}\right) D_\mu \mathcal{H}^\dagger D_\nu \mathcal{H} - V \sim \boxed{\left(1 + \frac{V}{\mathcal{M}^4}\right) D^\mu \mathcal{H}^\dagger D_\mu \mathcal{H} - V}$$

$$G^{tt} \simeq 3H^2$$

Gravitationally Enhanced friction

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}\sum \left(g^{\alpha\mu} g^{\beta\nu} - \alpha_A \frac{3G^{\mu\nu\alpha\beta}}{M^2}\right) F^a_{\mu\nu} F^a_{\alpha\beta} \sim -\frac{1}{4}\sum \left(1 + \alpha_A \frac{V}{\mathcal{M}^4}\right) F^a_{\mu\nu} F^{a,\mu\nu}$$

$$\mathcal{L}_{\rm fermion} = -\sum_i \left(g^{\alpha\beta} - \alpha_\psi \frac{G^{\alpha\beta}}{M^2}\right) \bar{\psi}_i \gamma_\alpha D_\beta \psi_i \sim -\sum_i \left(1 + \alpha_\psi \frac{V}{\mathcal{M}^4}\right) \bar{\psi}_i i \gamma^\mu D_\mu \psi_i$$

Disformal Transformation

C. Germani, S.Di Vita '16

$$g_{\alpha\beta} \to g_{\alpha\beta} + 2\frac{\mathcal{D}_\mu \mathcal{H}^\dagger \mathcal{D}^\mu \mathcal{H}}{\mathcal{M}^4}$$

$$\boxed{\mathcal{M}^4 = M^2 m_{\rm pl}^2}$$

$$\boxed{\varepsilon = \frac{\dot{\phi}^2}{\mathcal{M}^4}}$$

New Higgs Inflation

$$\mathcal{L} = \frac{M_{\rm pl}^2}{2} R - \left(g^{\mu\nu} - \frac{G^{\mu\nu}}{M^2} \right) D_\mu \mathcal{H}^\dagger D_\nu \mathcal{H} - V \quad \sim \boxed{\left(1 + \frac{V}{\mathcal{M}^4} \right) D^\mu \mathcal{H}^\dagger D_\mu \mathcal{H} - V}$$

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4} \sum \left(g^{\alpha\mu} g^{\beta\nu} - \alpha_A \frac{3\mathcal{G}^{\mu\nu\alpha\beta}}{M^2} \right) F^a_{\mu\nu} F^a_{\alpha\beta} \sim -\frac{1}{4} \sum \left(1 + \alpha_A \frac{V}{\mathcal{M}^4} \right) F^a_{\mu\nu} F^{a,\mu\nu}$$

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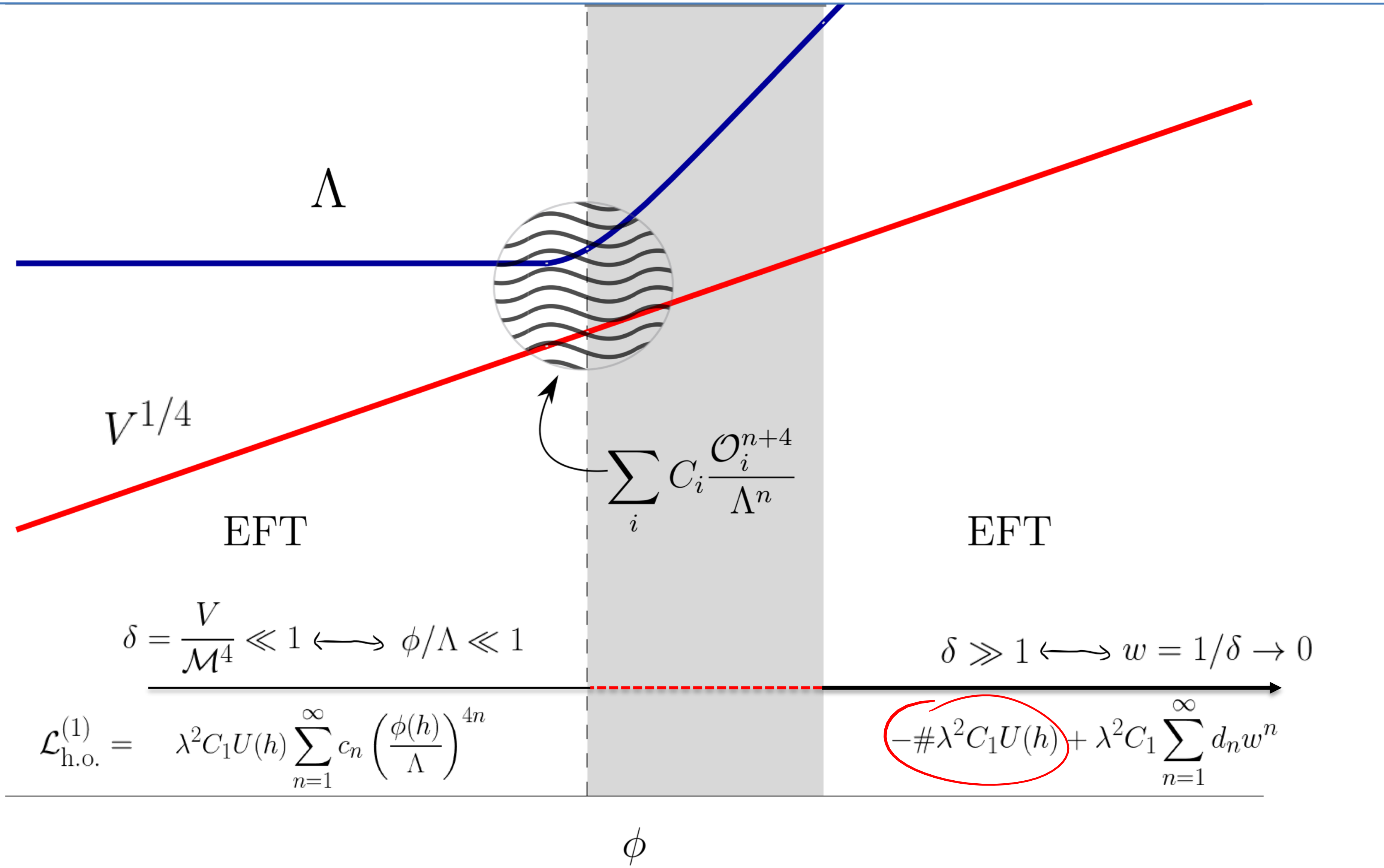
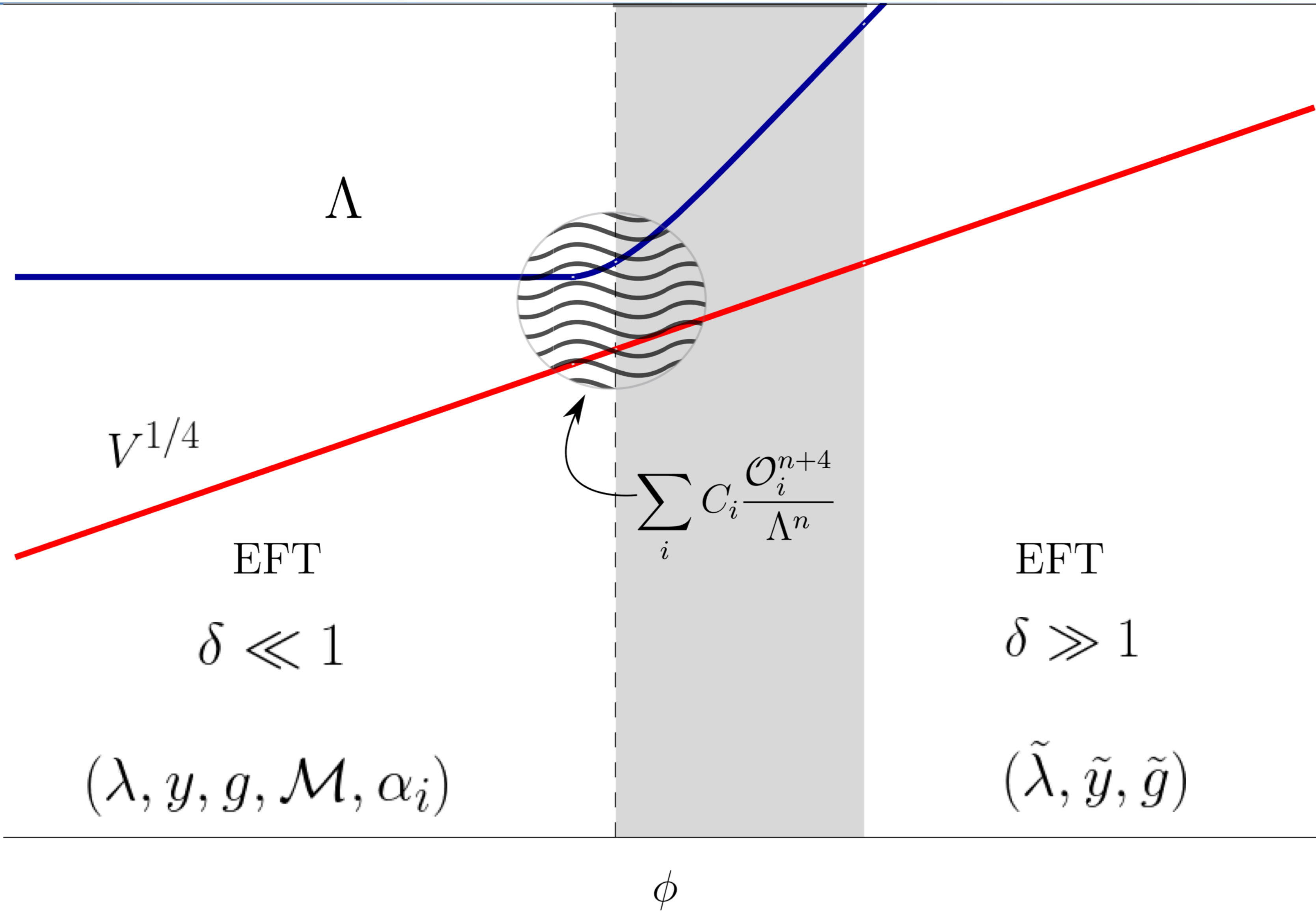
$$\delta \equiv \frac{V}{\mathcal{M}^4} = \frac{\lambda \phi^4}{4\mathcal{M}}$$

small field : $\delta \ll 1,$ large field : $\delta \gg 1$

Non renormalizability/EFT



Relevant parameters



How compute loop corrections with non-trivial fields-space manifold?

Unique effective action   Vilkovinsky-De Witt '84

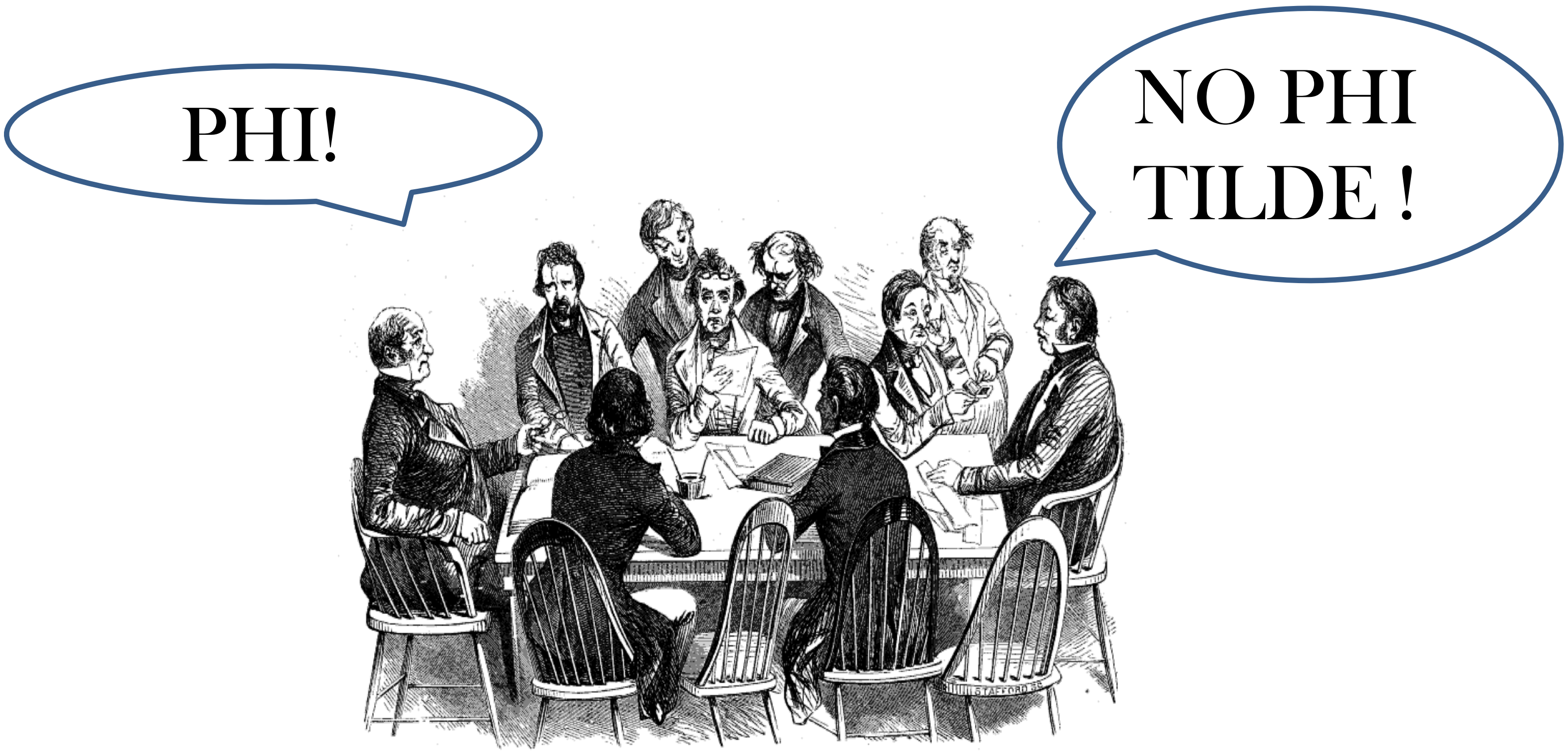
$$
\begin{array}{ccc}
S[\phi] & \xrightarrow{\tilde{\phi} = f(\phi)} & \tilde{S}[\tilde{\phi}] \\
\downarrow & & \downarrow \\
\Gamma[\phi_0] & \xrightarrow{\phi_0 = f^{-1}(\tilde{\phi}_0)} & \tilde{\Gamma}[\tilde{\phi}_0]
\end{array}
$$

$$\phi_0 = \langle \phi \rangle, \quad \tilde{\phi}_0 = \langle f(\phi) \rangle$$

Unique effective action

Vilkovinsky-De Witt '84

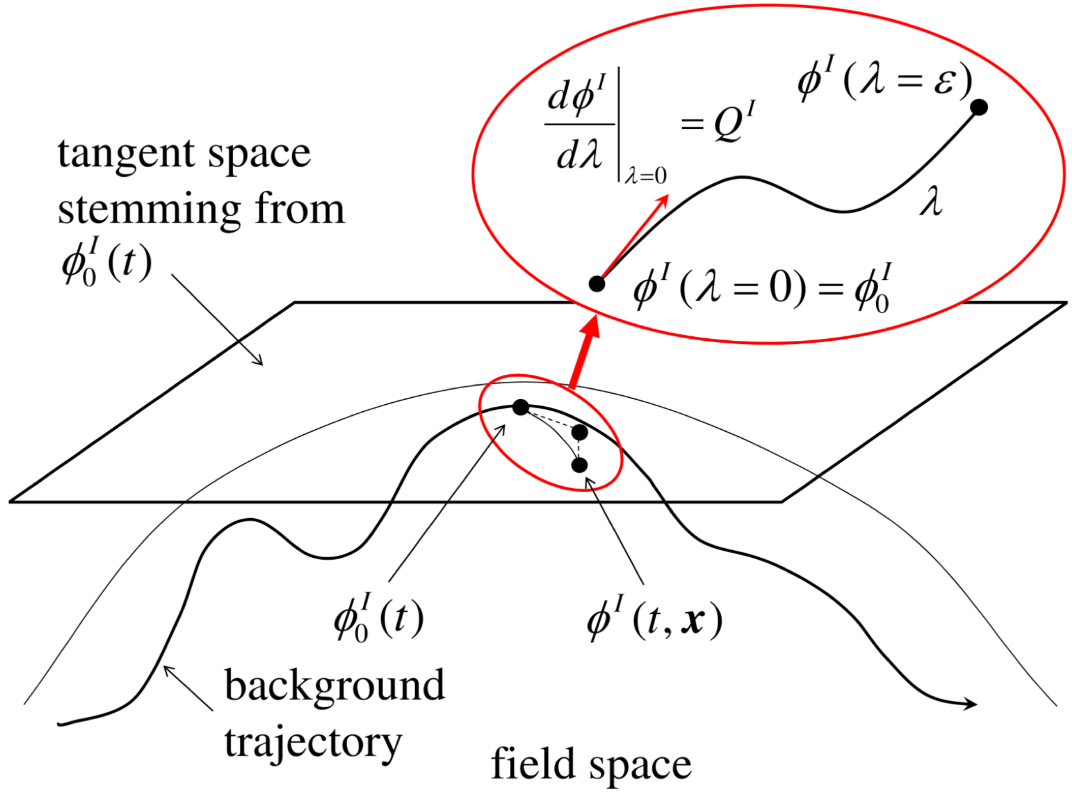
$$\delta\phi^I = \phi^I - \phi_0^I \longrightarrow Q^I$$



Covariant formalism

Vilkovinsky-De Witt '84
Gong, Tanaka '12

$$\mathcal{L}_{\mathrm{k}} = -\frac{1}{2} G_{IJ}(\phi^I) \partial\phi^I \partial\phi^J \qquad \phi_0^I + \delta\phi^I = \{\phi, \theta, A\}$$



$$\delta\phi^a = Q^a - \frac{1}{2!}\Gamma^a_{bc} Q^b Q^c + \frac{1}{3!}\left(\Gamma^a_{be}\Gamma^e_{cd} - \Gamma^a_{bc,d}\right) Q^b Q^c Q^d + \ldots$$

Covariant formalism

Vilkovinsky-De Witt '84
Gong, Tanaka '12

$$\mathcal{L}_{\rm k} = -\frac{1}{2} G_{IJ}(\phi^I)\partial\phi^I\partial\phi^J \qquad \phi_0^I + \delta\phi^I = \{\phi, \theta, A\}$$

$$R[G_{IJ}] = 0 \qquad G_{ij}\partial\phi^i\partial\phi^j = \delta_{ij}\partial\tilde{\phi}^i\partial\tilde{\phi}^j$$

Covariant formalism

Vilkovinsky-De Witt '84
Gong, Tanaka '12

$$\mathcal{L}_\mathrm{k} = -\frac{1}{2} G_{IJ}(\phi^I)\partial\phi^I\partial\phi^J \qquad \phi_0^I + \delta\phi^I = \{\phi, \theta, A\}$$

$$R[G_{IJ}] \neq 0 \qquad \{(1+\delta)\delta_{ij}, (1+\alpha_A\delta)\eta_{\mu\nu}\}$$

Beta-functions

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{V}{\mathcal{M}^4} D^\mu \mathcal{H}^\dagger D_\mu \mathcal{H} + \alpha_A \frac{V}{\mathcal{M}^4} F^a_{\mu\nu} F^{a,\mu\nu} + \alpha_\psi \frac{V}{\mathcal{M}^4} \bar{\psi}_i i \gamma^\mu D_\mu \psi_i$$

$$\beta_{\tilde{y}} = \beta_{\tilde{g}^2} = \gamma_\psi = \gamma_{\tilde{\phi}} = \gamma_A = \mathcal{O}(\delta^{-1})$$

$$\beta_{\tilde{\lambda}} = \frac{1}{8\pi^2} 6^{4/3} \left(-3\tilde{y}_t^4 \qquad\qquad\qquad\qquad \right)$$

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Beta-functions

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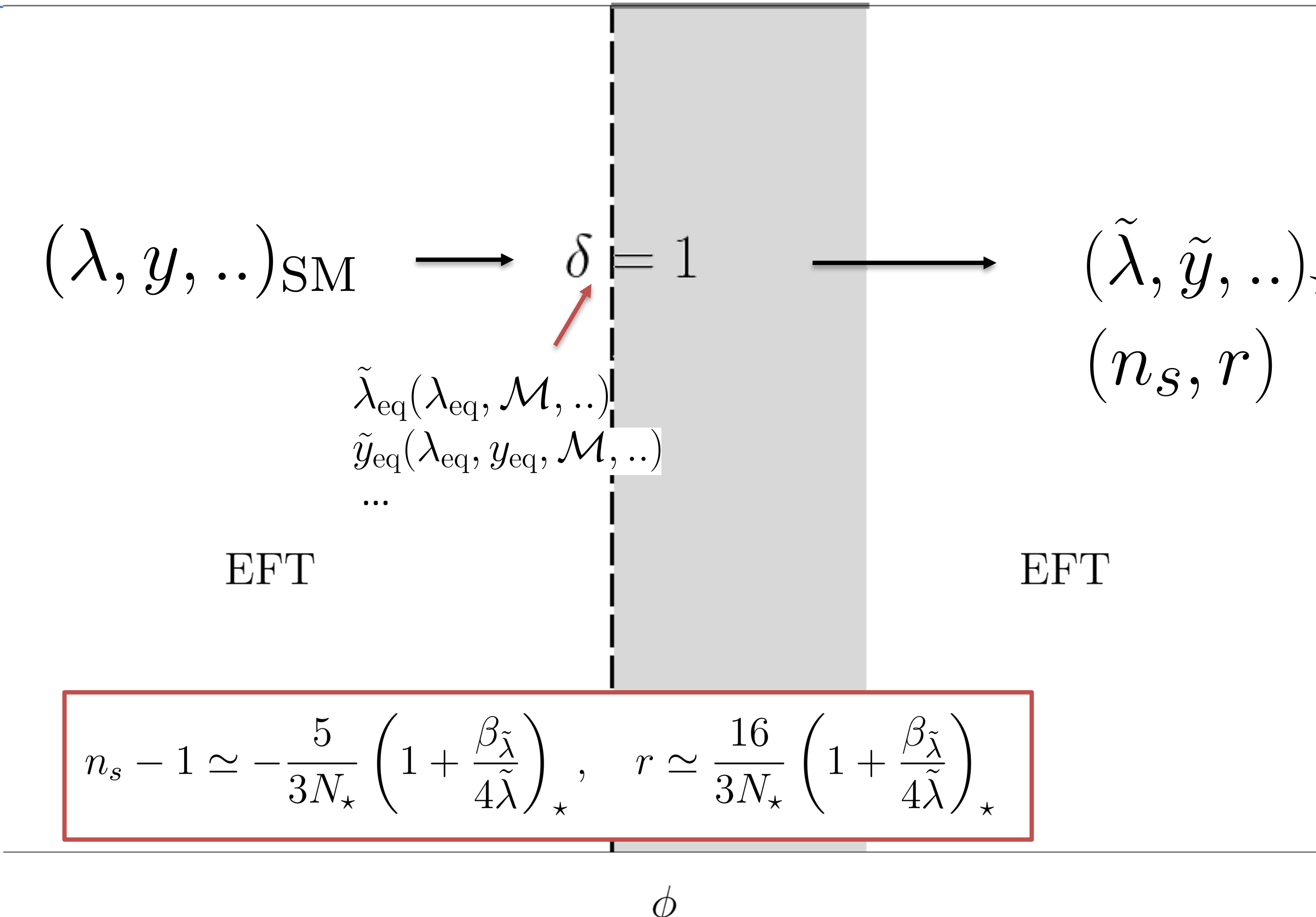
$$\alpha_i \propto \delta^{n_i/2}$$

$$\beta_{\tilde{y}} = \beta_{\tilde{g}^2} = \gamma_\psi = \gamma_{\tilde{\phi}} = \gamma_A = \mathcal{O}(\delta^{-1})$$

$$\beta_{\tilde{\lambda}} = \mathcal{O}(\delta^{-1})$$

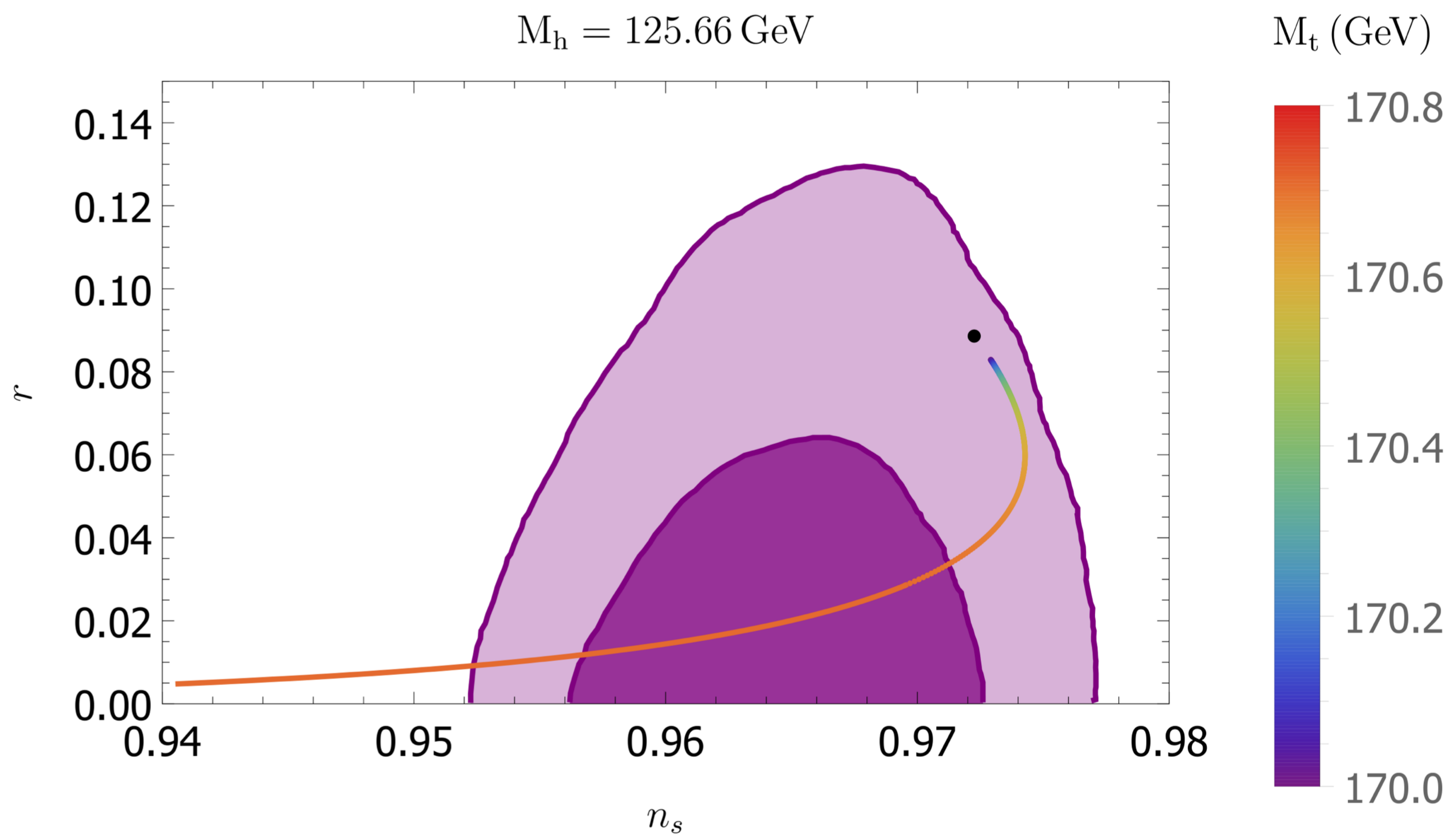
$\Longrightarrow$ No Running – no sensitivity

Matching and running



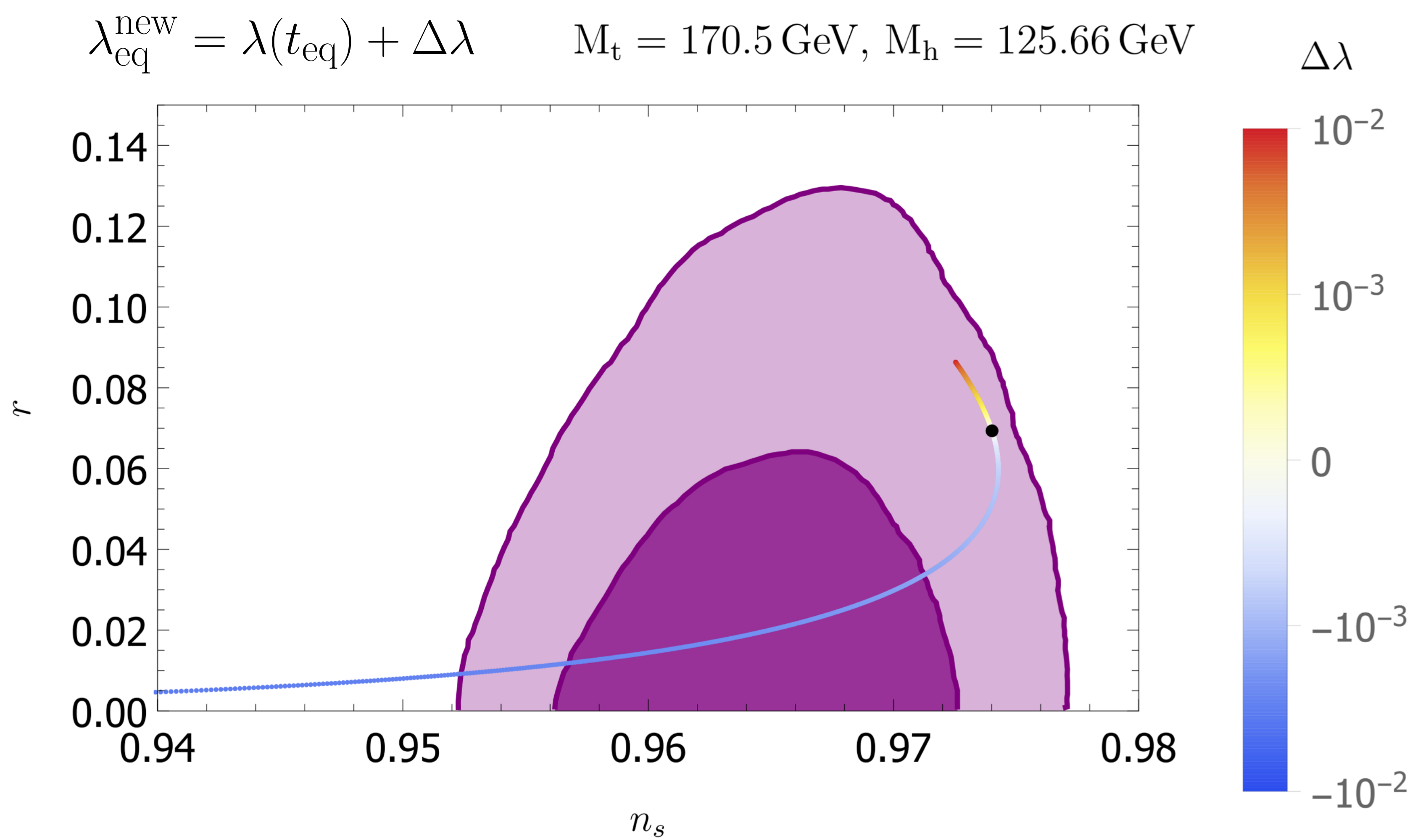
$$\boxed{n_s - 1 \simeq -\frac{5}{3N_\star}\left(1 + \frac{\beta_{\tilde\lambda}}{4\tilde\lambda}\right)_\star\,, \quad r \simeq \frac{16}{3N_\star}\left(1 + \frac{\beta_{\tilde\lambda}}{4\tilde\lambda}\right)_\star}$$

NHI predictiveness



J.F. , Postma, M. van den Bout in prep.

NHI predictiveness with threshold



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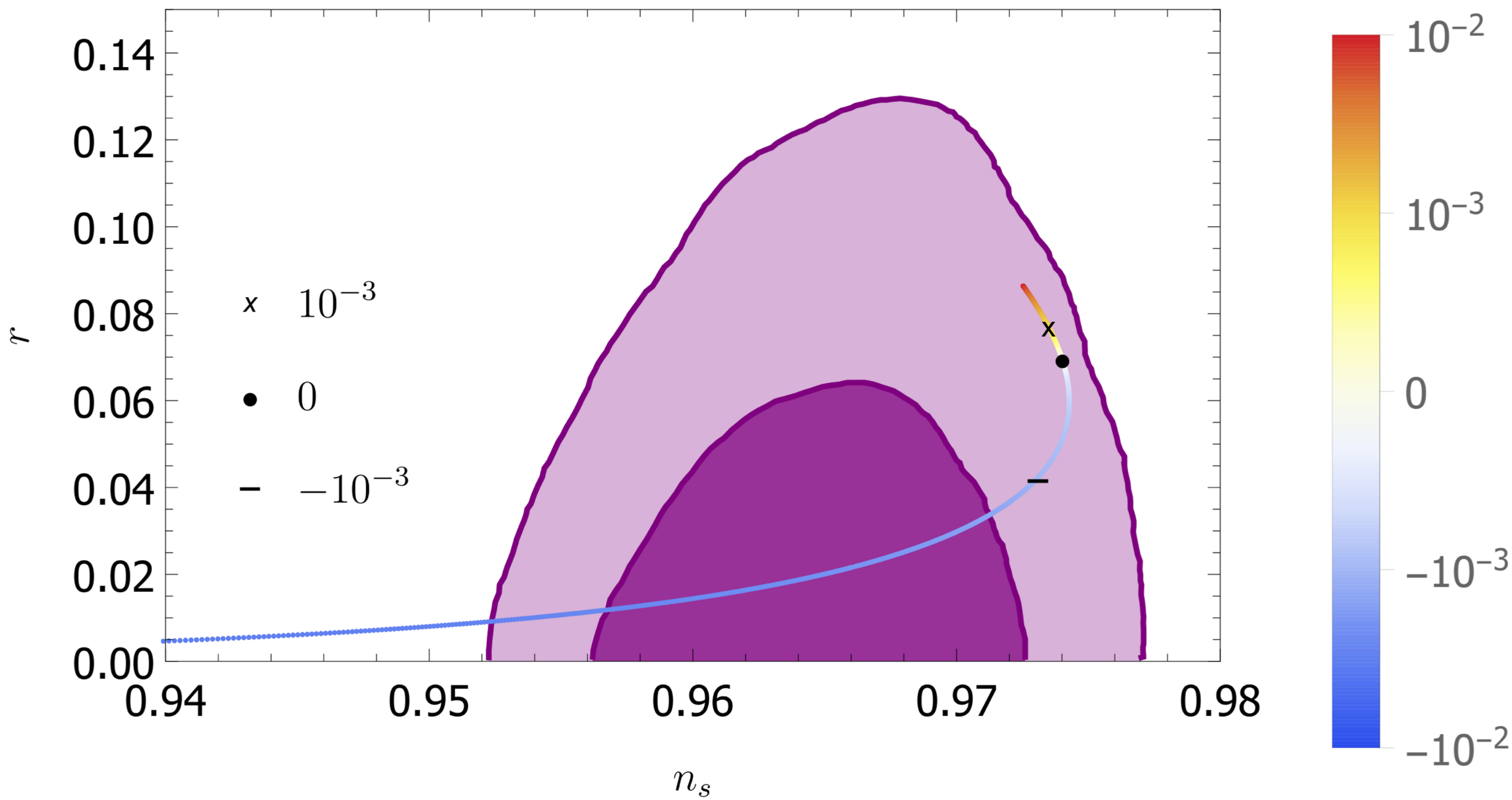
NHI predictiveness with threshold

$$\lambda_{\rm eq}^{\rm new} = \lambda(t_{\rm eq}) + \Delta\lambda \qquad \mathrm{M_t} = 170.5\,\mathrm{GeV},\ \mathrm{M_h} = 125.66\,\mathrm{GeV}$$



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Conclusions

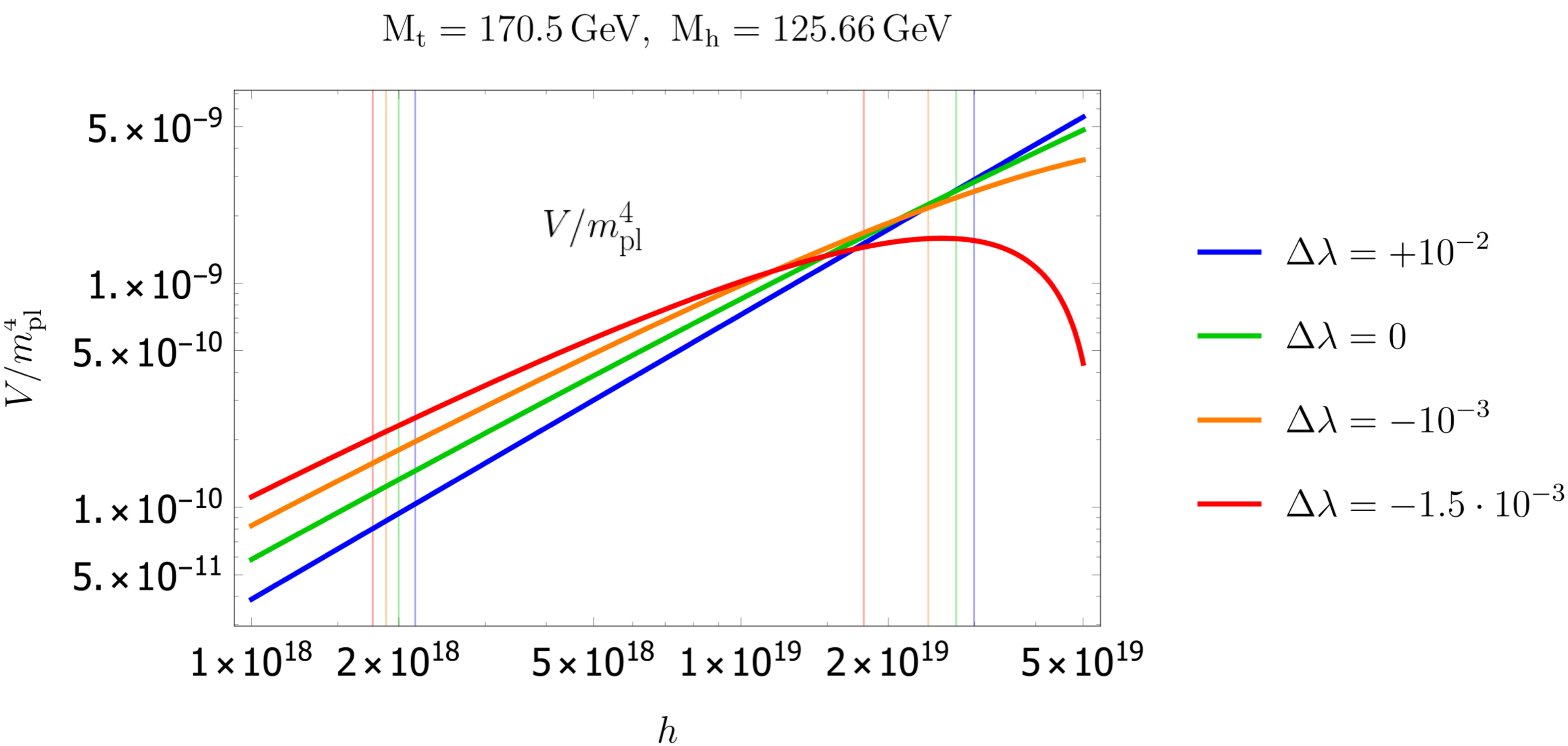
General lessons:

- The classical description might not be enough to sensibly compare the model to the Planck data.
- You need extra ingredients to describe inflation

Outlook

- UV sensitivity that might affect non renormalizable models
- Problem of predictivity vs virtue
- Beta functions with covariant methods – further investigations

NHI predictiviness with threshold



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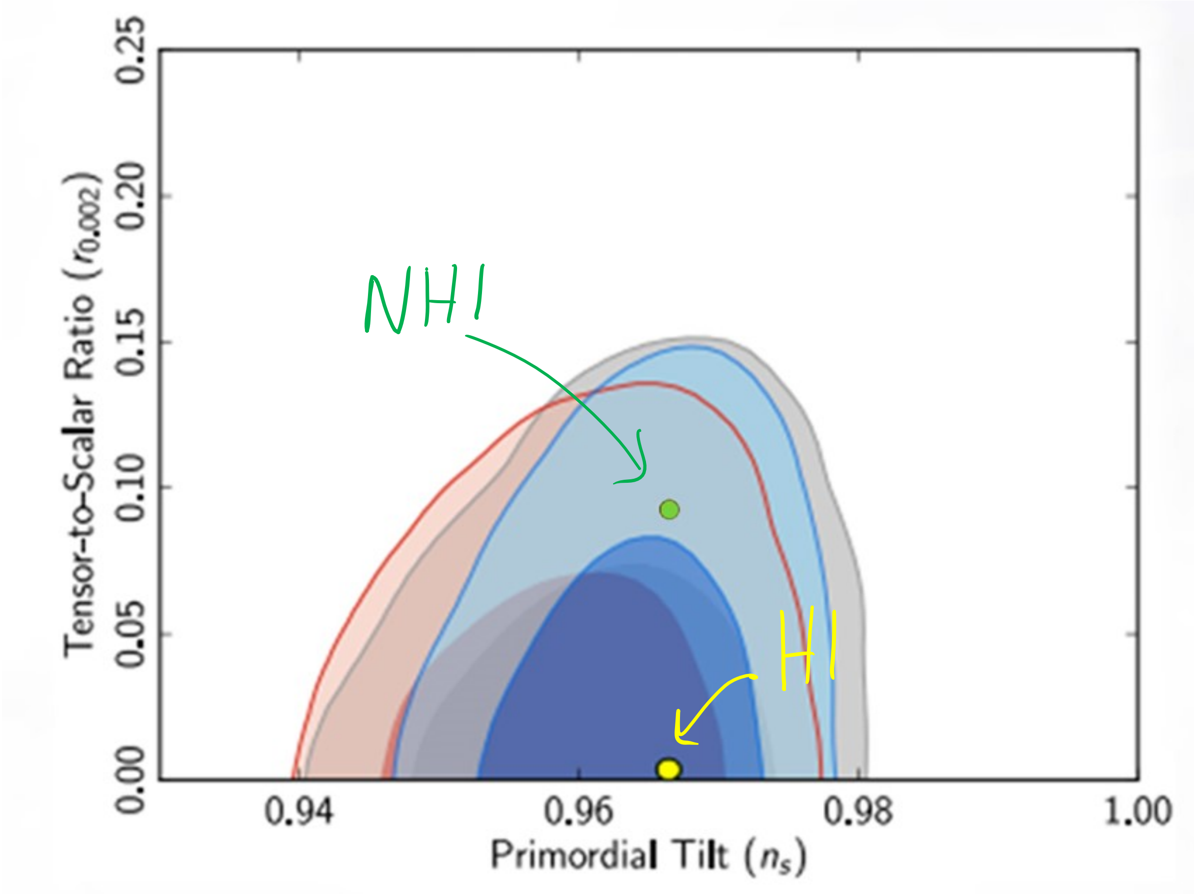
New Higgs Inflation

$$\Delta_s \implies M \simeq 1.5 \cdot 10^{-8} M_{\rm pl} \lambda^{-1/4}$$

$n_s \simeq 0.97$

$r \simeq 0.09$



Matching and running