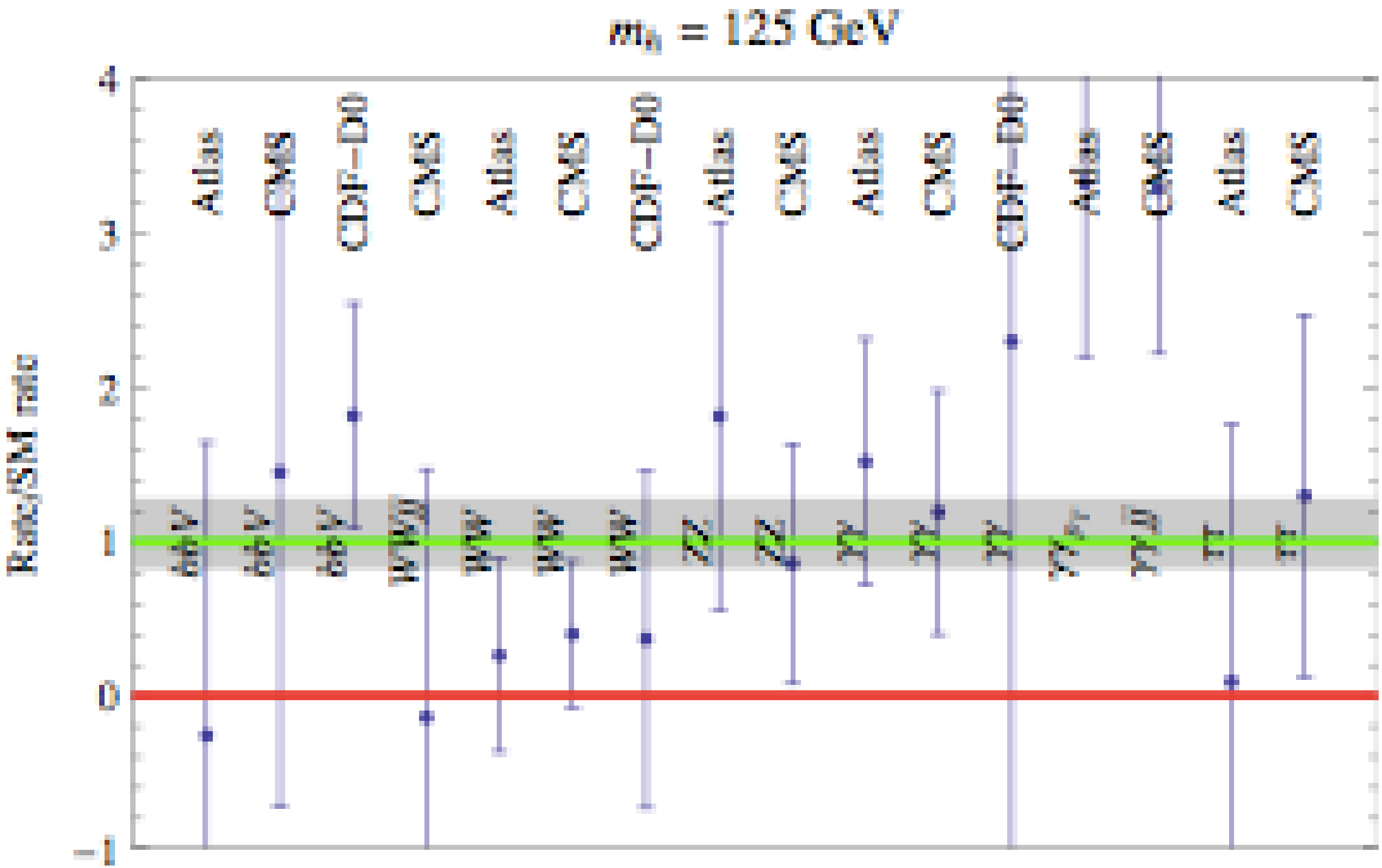
125GeV Higgs Boson --Cosmological viewpoint--

Harigaya, Nagata, Hisano, Kikukawa,
Takayama, Tanabashi, Yamanaka

ルール

- 125GeVヒッグスを宇宙論の観点で考える
  「？？？」という問題を真剣に考えると次に見えるのは「？？？」実験で「？？？」である。

- Higgs Portal Dark Matter (Nagata)
- Higgs Portal(?) Dark Radiation (Harigaya)
- Electroweak Baryogenesis (Hisano)
- Higgs Inflation (Yamanaka)

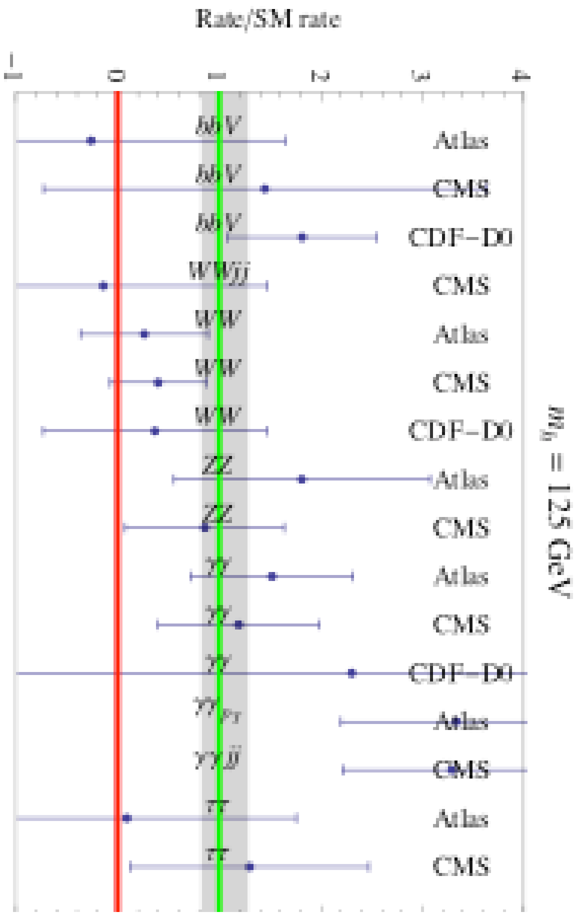


P.Giardino, K.Kannike, M.Raidal, A.Strumia, arXiv: 1203. 4254

Invisible decay width

$$\mathcal{L}_S = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial\phi)^2 - \frac{M_S^2}{2}\phi^2 - \frac{c_S}{2}|H|^2\phi^2 - \frac{d_S}{4!}\phi^4$$

ϕ : Scalar DM



Partial Decay Width

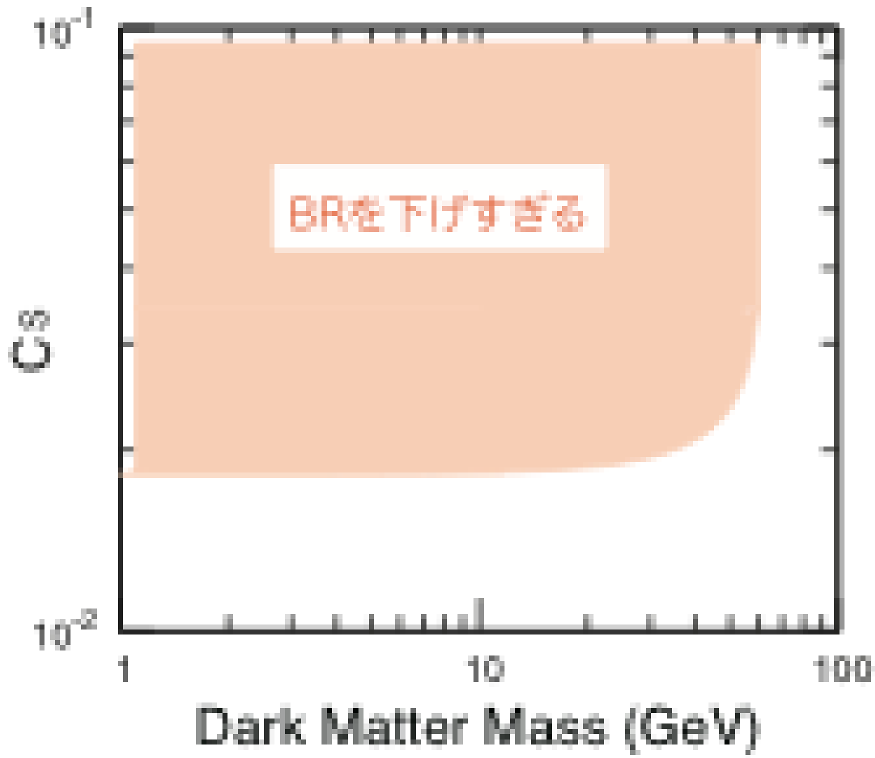
$$\Gamma(H \to \phi\phi) = \frac{c_S^2 v^2}{32\pi m_h}\sqrt{1 - \frac{4m_S^2}{m_h^2}}$$

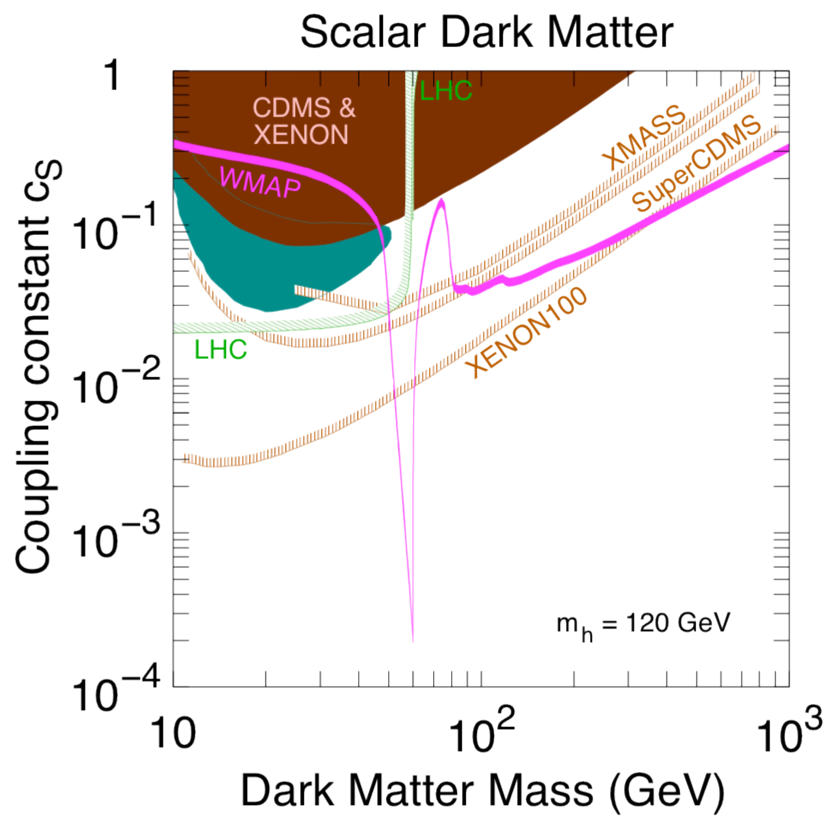
SMのGlobal fitから2σまでずれてもよいとする

$$\Gamma(H \to \phi\phi) < 2 \times 0.2 \times 4 \ \mathrm{MeV}$$

P.Giardino, K.Kannike, M.Raidal, A.Strumia, arXiv: 1203. 4254

Couplingに対する制限





S.Kanemura, S.Matsumoto, T. Nabeshima, and N.Okada (2010)

Dark Radiation

Dark Radiation

WMAP7 + ACBAR + ACT + SPR + SDSS-DR7

M. Archidiacono, E. Calabrese and A. Melchiorri hep-ph 1109.2767

背後にあるエネルギースケールを知りたい

とりあえずMeV scaleでのeffective operatorを書いてみる

scalar

$$\frac{1}{\Lambda^2}\phi^2 F_{\mu\nu}F^{\mu\nu} \qquad \frac{m_f}{\Lambda^2}\phi^2\bar{f}f \qquad \frac{m_f}{\Lambda}\phi\bar{f}f$$

$$\frac{1}{\Lambda^4}(\partial\phi)^2 F_{\mu\nu}F^{\mu\nu} \quad \frac{1}{\Lambda}\phi F_{\mu\nu}F^{\mu\nu}$$

fermion

$$\frac{1}{\Lambda^2}\bar{\psi}\gamma_\mu\gamma_5\psi\bar{f}\gamma^\mu f \qquad \frac{m_\psi}{\Lambda^2}\bar{\psi}\gamma^{\mu\nu}\psi F_{\mu\nu} \qquad \frac{m_f m_\phi}{\Lambda^4}\bar{\psi}\psi\bar{f}f$$

etc.

Thermal abundanceを仮定して、 cut off はいくらか？

エネルギースケール

Decoupling temperature ~10MeV, $f = e, m_\psi = 0.1\text{eV}$

Oparators	Λ
$\frac{1}{\Lambda^2}\phi^2 F_{\mu\nu}F^{\mu\nu}$	TeV
$\frac{m_f}{\Lambda^2}\phi^2 \bar{f}f$	TeV
$\frac{m_f}{\Lambda}\phi \bar{f}f$	10^15 GeV
$\frac{1}{\Lambda^4}(\partial\phi)^2 F_{\mu\nu}F^{\mu\nu}$	10 GeV
$\frac{1}{\Lambda}\phi F_{\mu\nu}F^{\mu\nu}$	10^8 GeV
$\frac{1}{\Lambda^2}\bar{\psi}\gamma_\mu\gamma_5\psi\bar{f}\gamma^\mu f$	TeV
$\frac{m_f}{\Lambda^3}\bar{\psi}\psi\bar{f}f$	10 GeV
$\frac{m_\psi}{\Lambda^2}\bar{\psi}\gamma^{\mu\nu}\psi F_{\mu\nu}$	eV

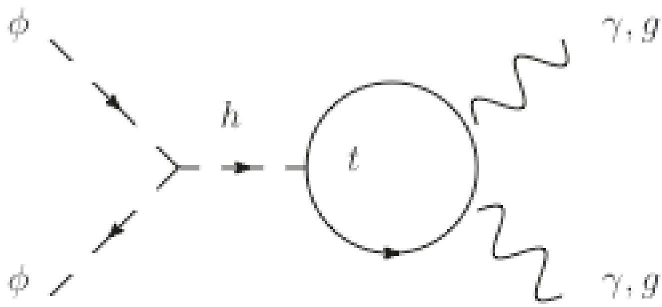
TeV -> Higgs ?

$$\frac{1}{\Lambda^2}\phi^2 F_{\mu\nu}F^{\mu\nu}$$

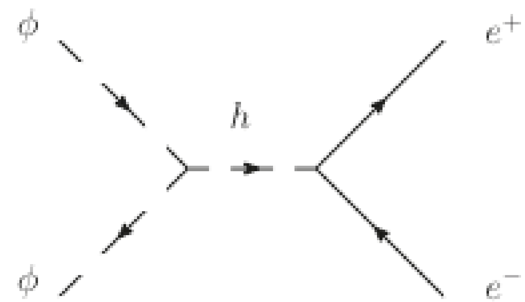
$$\frac{m_f}{\Lambda^2}\phi^2 \bar{f} f$$

$$\lambda_{\phi H}\phi^2(|H|^2 - v^2)$$

質量が出ない様に全オーダーでtune



$\lambda_{\phi H} \gtrsim 1000$



$\lambda_{\phi H} \gtrsim 0.01$

Higgs invisible decayからの制限

$$\lambda_{\phi H} \gtrsim 0.01$$

$$\Rightarrow \Gamma(h \to \psi\psi) \gtrsim 0.001(\mathrm{GeV})$$

ずれが見えるかも!?

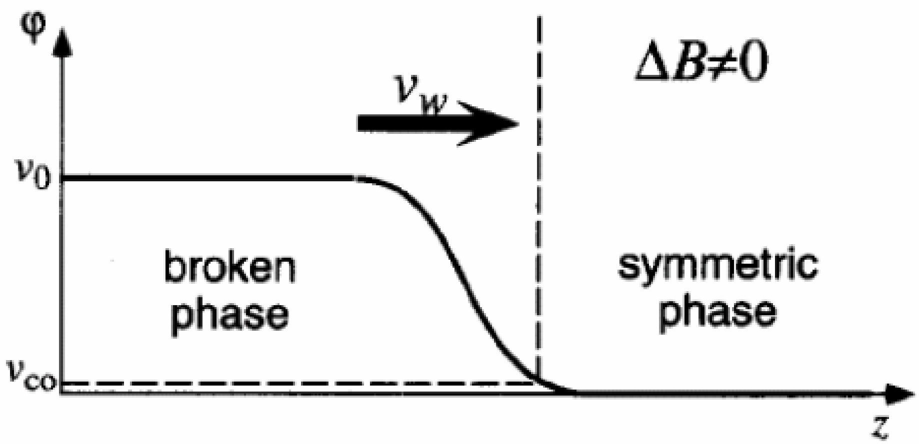
Electroweak baryogenesis

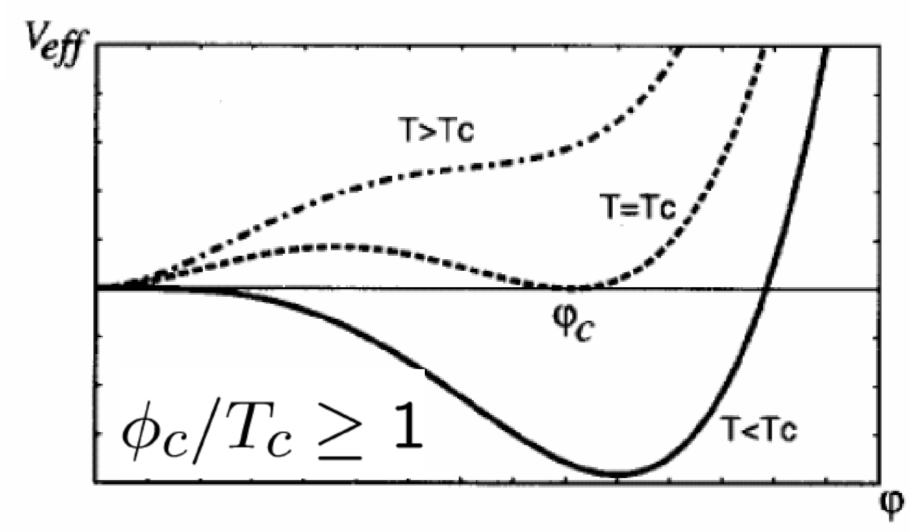
サハロフの3条件

１，バリオン数の破れ　←　電弱量子異常

２，CPの破れ　←　とりあえず新物理を仮定

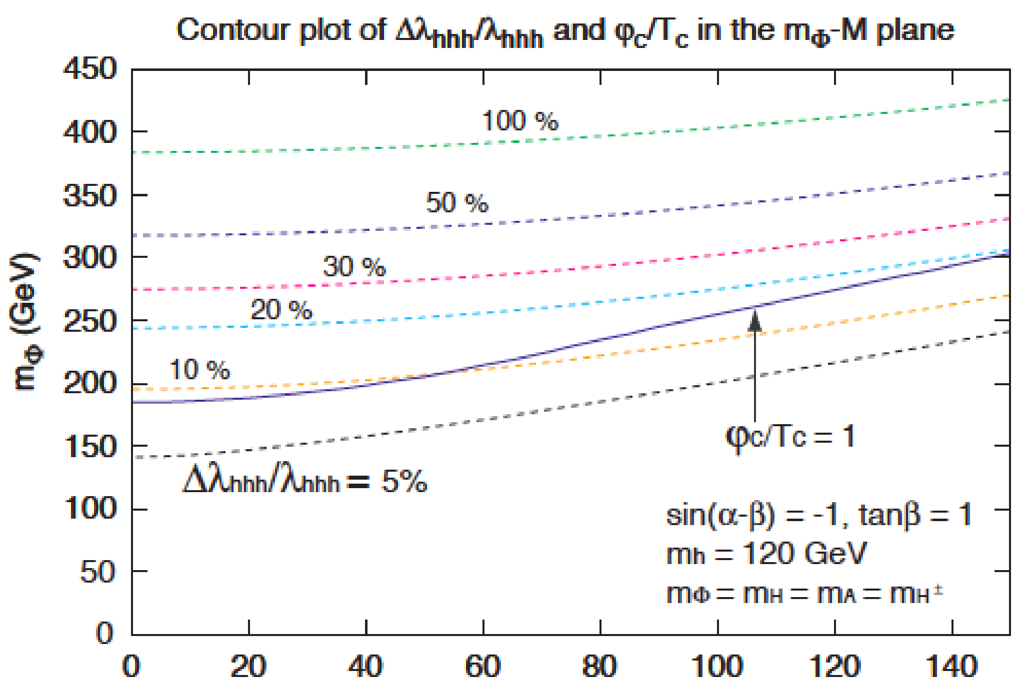
３，熱平衡からのズレ　←　一次の電弱相転移





Triple vertex in 2HDM

$$V_{\text{tree}} = m_1^2|\Phi_1|^2 + m_2^2|\Phi_2|^2 - (m_3^2\Phi_1^\dagger\Phi_2 + \text{h.c.})$$
$$+\frac{\lambda_1}{2}|\Phi_1|^4 + \frac{\lambda_2}{2}|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \left[\frac{\lambda_5}{2}(\Phi_1^\dagger\Phi_2)^2 + \text{h.c.}\right],$$



$M^2\ (= m_3^2/\sin\beta\cos\beta)$

Kanemura et al, Phys.Lett. B606 (2005) 361-366

FIG. 1: The straight line stands for the critical line which satisfied the condition, $\varphi_c/T_c = 1$. The dashed lines are the deviation of hhh coupling from the SM value, where $\Delta\lambda_{hhh}^{\rm THDM} \equiv \lambda_{hhh}^{\rm eff}(\text{THDM}) - \lambda_{hhh}^{\rm eff}(\text{SM})$

Color assisted EWBG

Cohen et al
1203.2924 [hep-ph]

$$-\mathscr{L} \supset M_X^2|X|^2 + \frac{K}{6}|X|^4 + Q|X|^2|H|^2,$$

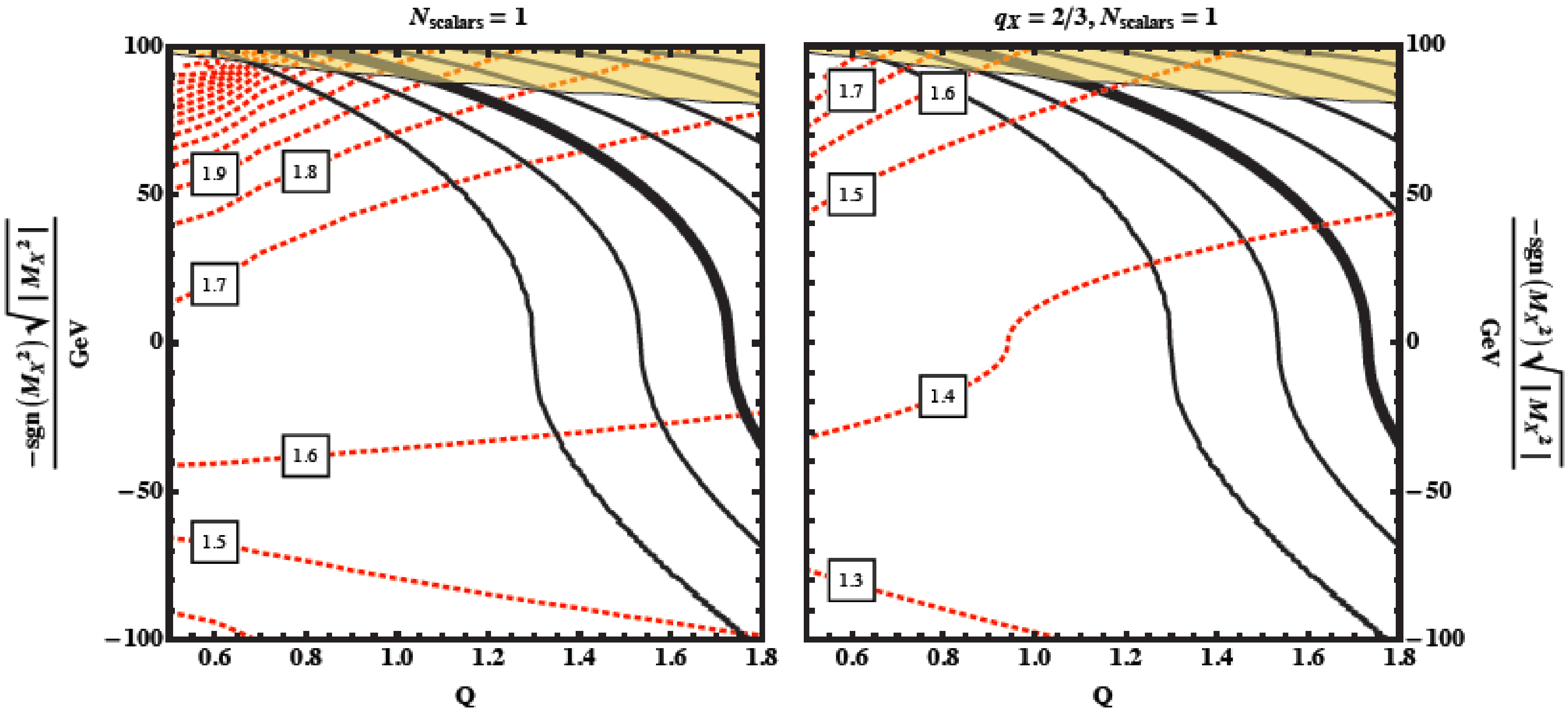


Figure 1: Contours of ϕ_C/T_C [black, solid lines] in the $-\text{sgn}\left(M_X^2\right)\sqrt{|M_X^2|}$ vs. Q plane for one new color-triplet scalar. (The most negative mass squared values are at the top of the plot.) The bolded line corresponds to $\phi_C/T_C = 0.9$ and the adjacent solid lines delineate steps of $\Delta(\phi_C/T_C) = 0.2$. The yellow shaded region is excluded because for these parameters the Universe would have evolved to a charge-color breaking minimum. In the *left* plot we also show contours of the ratio of the gluon fusion cross section to the SM value [red, dotted lines]. In the *right* plot we show contours of the ratio of the gluon fusion cross section times the branching ratio to di-photons to the SM value [red, dotted lines] when the charge of the colored scalar is taken to be $q_X = 2/3$.

Higgs inflationとは？

「Higgs = inflaton」としたslow-roll型inflation scenario

Action $$S=\int d^4x\sqrt{-g}\left[\frac{1}{2}m_{\rm Pl}^2 f(\phi)\mathcal{R}-\frac{1}{2}k(\phi)(\partial\phi)^2-V(\phi)\right]$$

$\mathcal{R}$: Ricci scalar

重力との大きな値を持つnon-minimal couplingを導入することにより、
slow-rollingと初期揺らぎの生成を実現

[F. Bezrukov and M.Shaposhinikov, arXiv:0710.3755]

メリット1: SM particle contentsのみで説明可能

メリット2: Higgsの物理を明らかにすることで地上実験にて検証可能

125GeV Higgs massとの相性は？

Tree level Higgs inflationでは、n_s は標準模型パラメーターに依存せず一

→ Higgs massに予言与えず、地上実験での検証も困難

SM couplingのrunningを含めて、effective Planck massやPotentialのrunning

→ $n_s < 0.99$ を出せるHiggs mass (実際にはl) の領域に予言

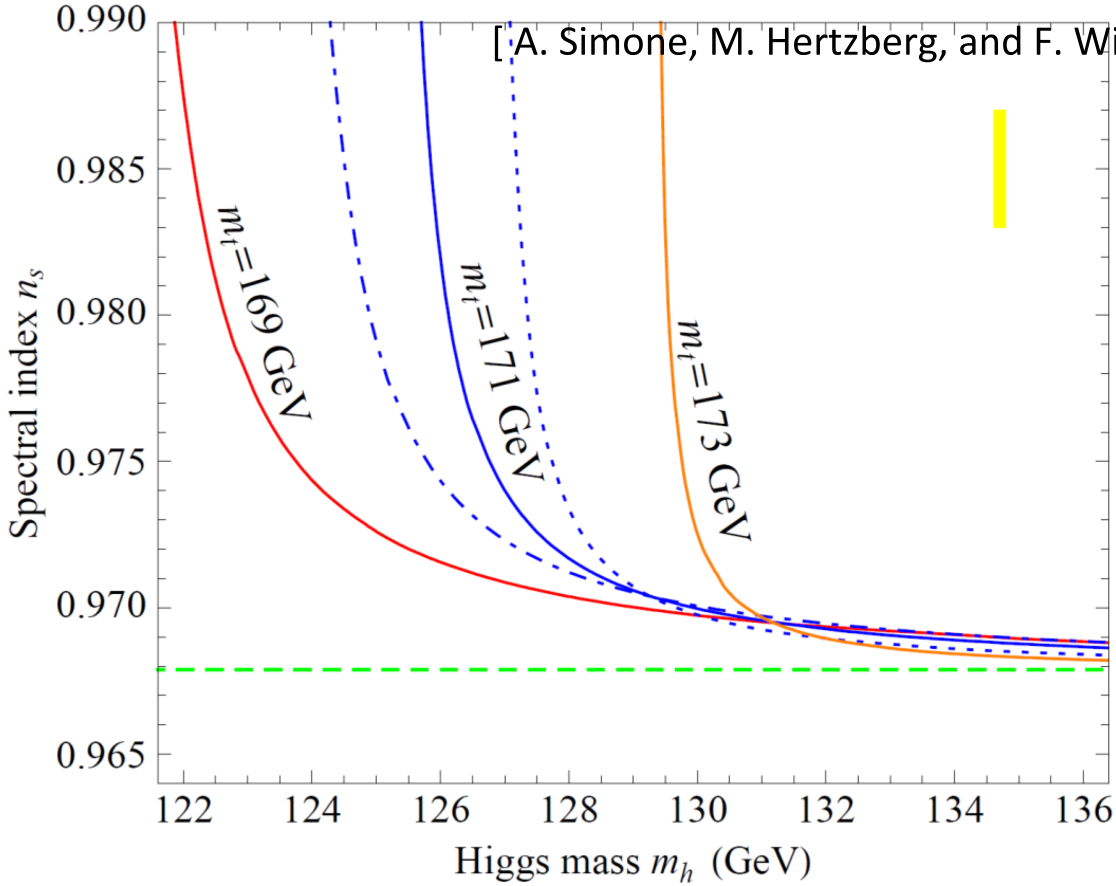
$$m_h > 125.7\,\mathrm{GeV} + 3.8\,\mathrm{GeV}\left(\frac{m_t - 171\,\mathrm{GeV}}{2\,\mathrm{GeV}}\right) - 1.4\,\mathrm{GeV}\left(\frac{\alpha_s(m_Z) - 0.1176}{0.0020}\right) \pm \delta$$

$\delta \sim 2\,\mathrm{GeV}$: theoretical uncertainty from higher order corrections

125GeV HiggsはギリギリOK

125GeV Higgs massとの相性は？

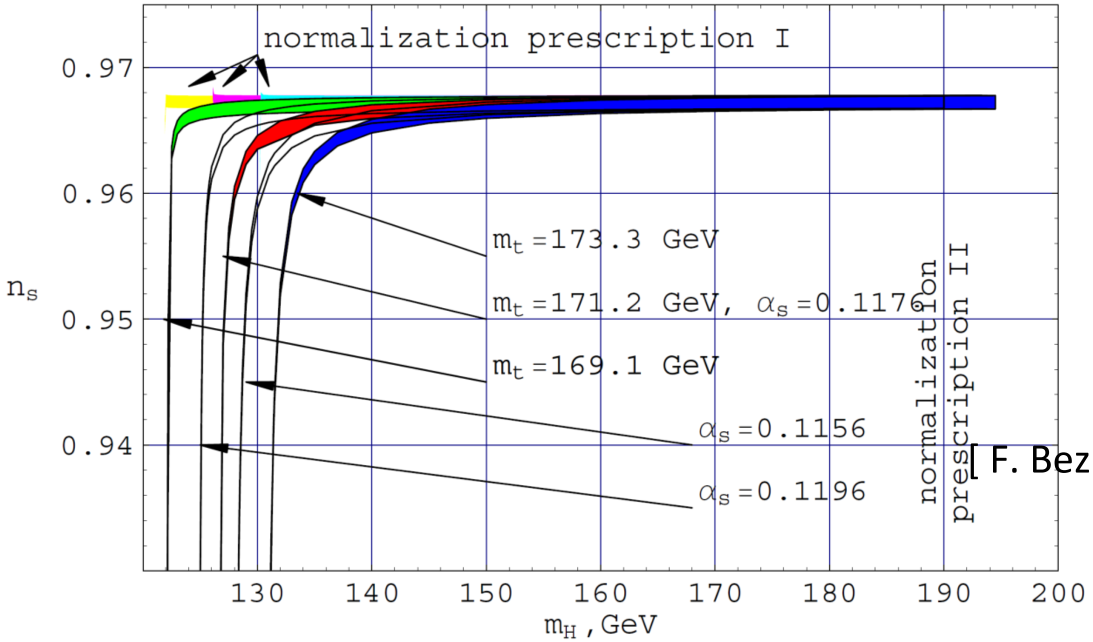
[A. Simone, M. Hertzberg, and F. Wilczek , arXiv:0812.4946]



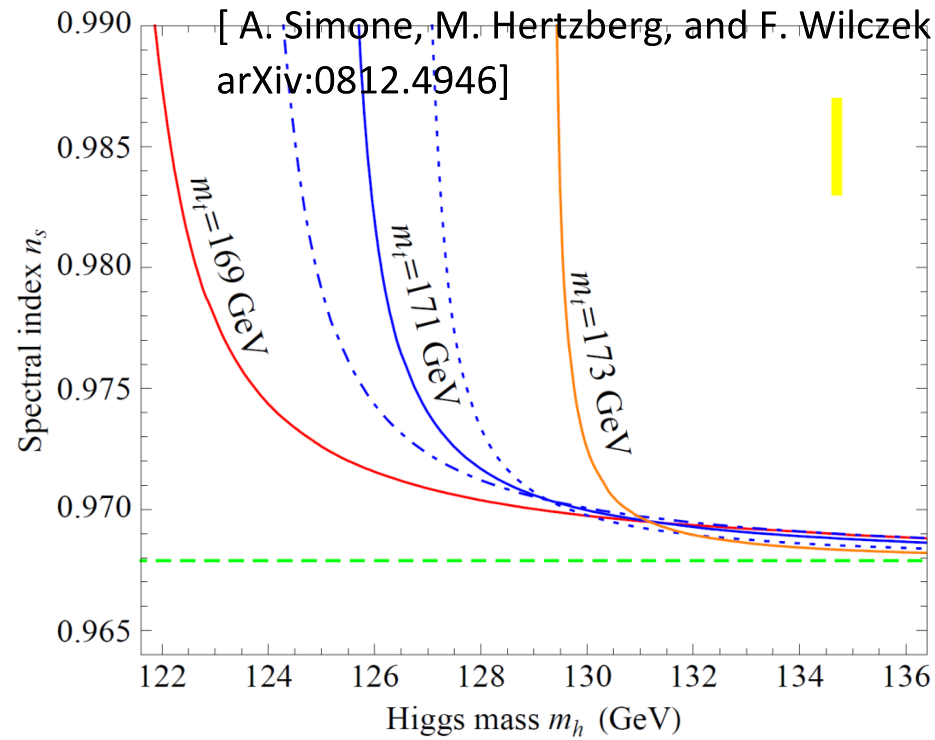
宇宙観測から課されている制限

$$0.93 < n_s < 0.99 \text{ and } r < 0.22 \text{ (at 95\% confidence level)}$$

Spectral index とHiggs mass



[F. Bezrukov and M. Shaposhnikov arXiv:0904.1537]



[A. Simone, M. Hertzberg, and F. Wilczek arXiv:0812.4946]

- ☑ Running orderや繰り込みの手法に大きく依存し、結果が全く異なる
- ☑ 125GeV Higgsがconfirmされ、Higgs inflationを信じるなら、計算方法を詰めるべき

補足(n_s計算の両者の違い)

Comment from A. Simone, M. Hertzberg, and F. Wilczek arXiv:0812.4946

In our analysis, we computed the full RG improved effective potential. We did this including (i) 2-loop beta functions, (ii) the effect of curvature in the RG equations (through the function s), (iii) wave-function renormalization, and (iv) accurate specification of the initial conditions through proper pole matching. On the other hand, [32] did not compute the full effective potential or include any of the items (i)–(iv).[9] Instead Ref. [32] approximated the potential at leading log order with couplings evaluated at an inflationary scale after running them at 1-loop (this is one step beyond [18] where couplings were not run).

Ref. [32] = [F. Bezrukov and M. Shaposhnikov arXiv:0904.1537]