

Coleman-Weinberg Higgs

: Radiatively Generated Electroweak Symmetry Breaking

SKKI seminar

2014. Mar. 12

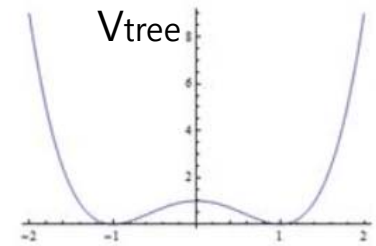
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arXiv:[1308.0891](#) Radovan Dermisek, Tae Hyun Jung, Hyung Do Kim

Higgs!

- Discovery of 126 GeV Higgs Particle
- Time to see details of EW symmetry breaking
- Is EW symmetry breaking in a radiative manner possible?
- What are the consequences of it?



RG improved effective potential

- Effective potential is obtained from the effective action
- Effective potential is of the form

$$V_{eff}(\phi) = V_{cl}(\phi) + \sum_a \frac{1}{16\pi^2} (m_a(\phi))^4 \left(\ln \frac{m_a(\phi)^2}{\mu^2} - C_a \right) + \text{higher order}$$

- Large logarithm resummation

$\mu \sim \xi m_{heaviest}$ where ξ is of order one

$$\begin{aligned} \Rightarrow V_{eff} &\approx V_{cl}(\phi) + \frac{1}{16\pi^2} m(\phi)^4 (-\ln \xi^2 - C_a) + \text{higher order} \\ &= \frac{1}{4} \left(\lambda_h + \frac{1}{16\pi^2} \lambda_a^2 (-\ln \xi^2 - C_a) + \dots \right) \phi^4 = \frac{1}{4} \widetilde{\lambda}_h(\phi) \phi^4 \end{aligned}$$

Vacuum conditions

$$V_{eff} = \frac{1}{4} \widetilde{\lambda}_h(\phi) \phi^4$$

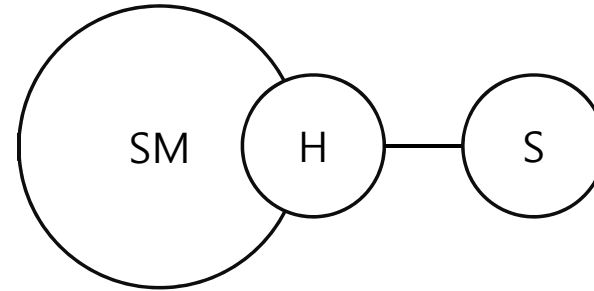
$$V'_{eff} = \left(\widetilde{\lambda}_h + \frac{1}{4} \beta_{\widetilde{\lambda}_h} \right) \phi^3 \quad (= 0 \quad \text{at } \phi = v)$$

$$V''_{eff} = \left(3\widetilde{\lambda}_h + \frac{7}{4} \beta_{\widetilde{\lambda}_h} + \frac{1}{4} \beta'_{\widetilde{\lambda}_h} \right) \phi^2 \quad (\approx m_h^2 \quad \text{at } \phi = v)$$

- In one loop level, $V''_{eff} = \left(3(-\frac{1}{4} \beta_{\widetilde{\lambda}_h}) + \frac{7}{4} \beta_{\widetilde{\lambda}_h} \right) v^2 \approx m_h^2$, $\therefore \beta_{\widetilde{\lambda}_h} \sim \frac{1}{4}$
- SM : $\beta_{\lambda_h} = \frac{1}{16\pi^2} (24\lambda_h^2 + 12y_t^2\lambda_h - 6y_t^4) \ll \frac{1}{4}$

New Scalars

- We need large beta!

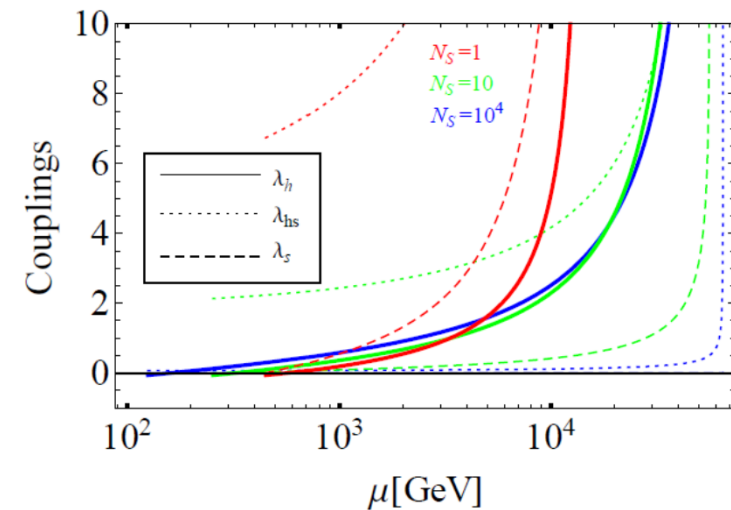


- N_s complex scalars with $V = \lambda_h (H^\dagger H)^2 + \lambda_{hs} (H^\dagger H)(S^\dagger S) + \lambda_s (S^\dagger S)^2$

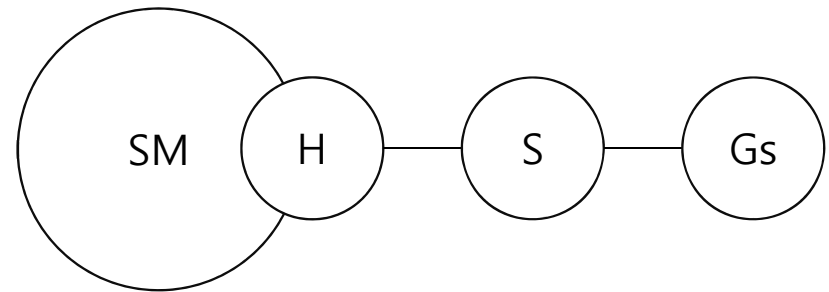
$$\Rightarrow \beta_{\lambda_h} = \frac{1}{16\pi^2} (24\lambda_h^2 + N_s \lambda_{hs}^2 + 12y_t^2 \lambda_h - 6y_t^4)$$

$$\therefore \frac{N_s \lambda_{hs}^2}{16\pi^2} \sim \frac{1}{4}$$

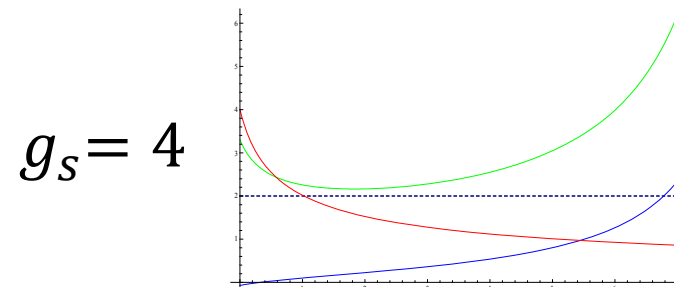
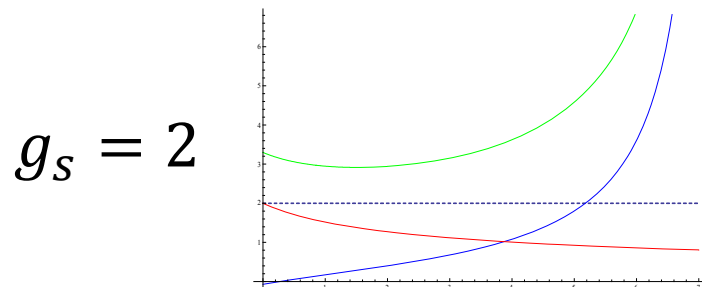
- Mass : $m_s = \sqrt{(\frac{\lambda_{hs}}{2} \phi^2)} \sim \frac{440}{N^{1/4}} \text{ GeV}$
- Landau pole appears at 10 TeV



New Gauge Group

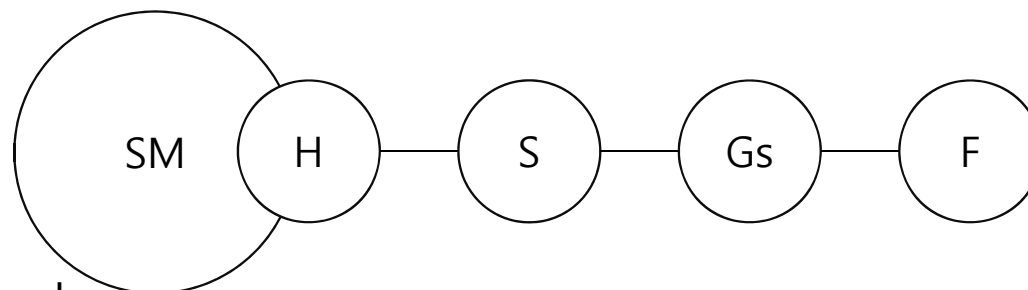


- Dropping λ_{hs} gives farther Landau pole
 - Introduce SU(N_s) gauge group (the new scalars are charged)
- $$\beta_{hs} = \frac{1}{16\pi^2} \lambda_{hs} (4\lambda_{hs} + 12\lambda_h + (4N_s + 4)\lambda_s - \frac{3(N_s^2 - 1)}{N_s} g_s^2 + 6y_t^2)$$



- g_s large and stay large \rightarrow Landau pole at higher energy

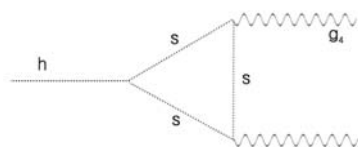
New fermions



- Adding fermions helps move Landau pole
- N_f fermions charged under G_s

$$\Rightarrow \beta_{g_s} = \frac{1}{16\pi^2} g_s^3 \left(-\frac{11}{3} N_s + \frac{1}{3} N_f + \frac{1}{6} \right)$$

- Fermions need to be massive
 - (a) Fermion dark radiation
 - (b) Higgs invisible decay to glueball
 - : Massive fermion \rightarrow Integrated out \rightarrow Large negative $\beta_{g_s} \rightarrow$ Confinement



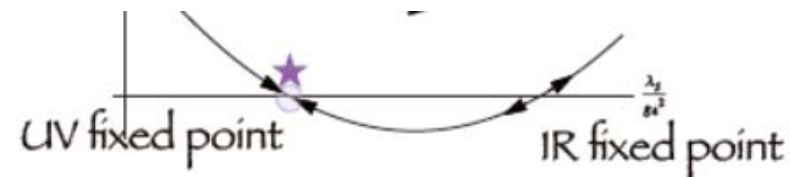
$\sigma(h \rightarrow \text{invisibles}) = 0$ if the hidden glueballs are heavier than 63 GeV.

- One easiest way is to have a scalar with v.e.v. of M_{Pl} and Yukawa of M_W/M_{Pl}

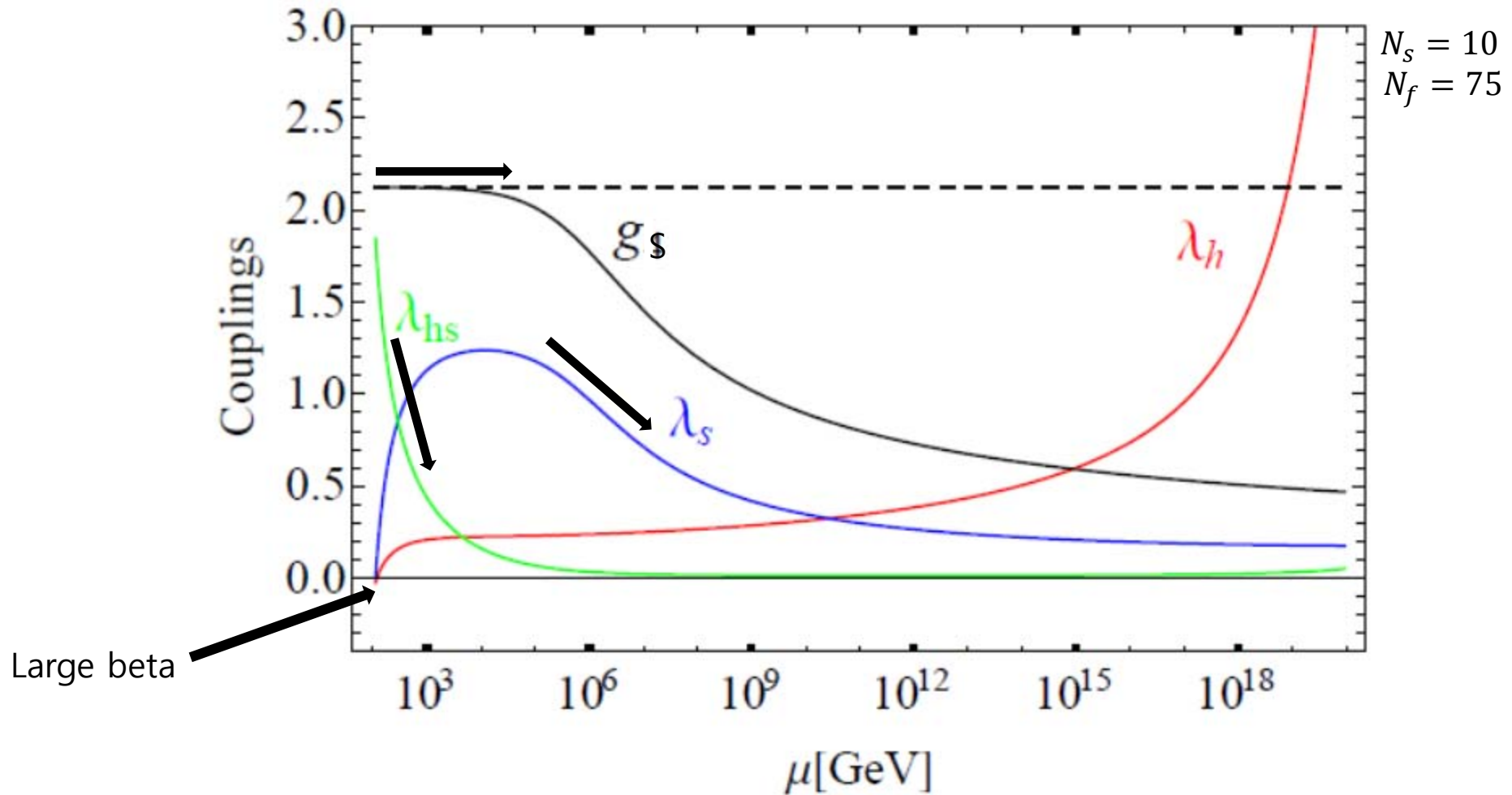
Fixed point behavior of λ_s

- λ_s UV quasi-fixed

$$\beta_s = \frac{1}{16\pi^2} g_s^4 \left\{ 4(4 + N_s) \left(\frac{\lambda_s}{g_s^2} \right)^2 - \frac{6(N_s^2 - 1)}{N_s} \left(\frac{\lambda_s}{g_s^2} \right) + \frac{2\lambda_{hs}^2}{g_s^4} + \frac{3}{4} \frac{(N_s^3 + N_s^2 - 4N_s + 2)}{N_s^2} \right\}$$



- Discriminant plot



- To achieve Landau pole above M_{Pl} , large gauge coupling is necessary. Thus, one loop calculation is not enough.
- Observables directly coupled to the gauge group might get big uncertainty. (e.g. m_s)

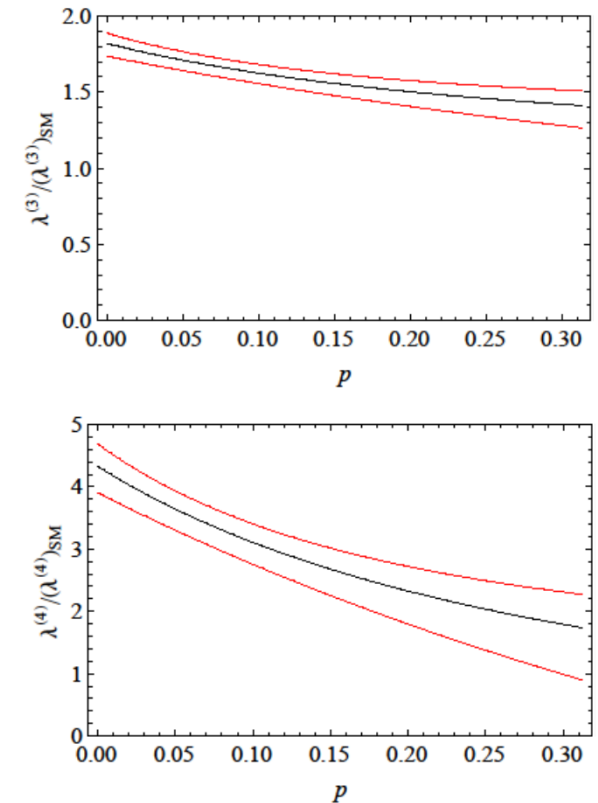
Higgs Cubic Coupling

$$V(h) = \frac{1}{2}m_h^2 h^2 + \lambda^{(3)} v h^3 + \frac{1}{4}\lambda^{(4)} h^4$$

- SM : $\lambda^{(3)} = \lambda^{(4)} = \frac{m_h^2}{2v^2}$
- CW Higgs : $\lambda^{(3)} = \frac{5}{6} \frac{m_h^2}{v^2} + \frac{1}{6} \beta'_{\lambda_h} = \frac{5}{3} \lambda_{SM}^{(3)} + \frac{1}{6} \beta'_{\lambda_h}$
 $\lambda^{(4)} = \frac{11}{6} \frac{m_h^2}{v^2} + \beta'_{\lambda_h} = \frac{11}{3} \lambda_{SM}^{(4)} + \beta'_{\lambda_h}$

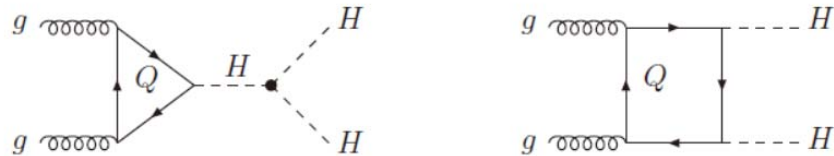
- $p \equiv \frac{N_s g_S^2}{16\pi^2}$, $\beta'_{\lambda_h} \approx \frac{N_s \lambda_{hs}^2}{16\pi^2} (-6p)$

- **Uncertainty** from the scale choice ξ

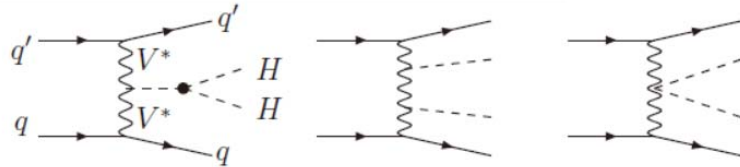


LHC

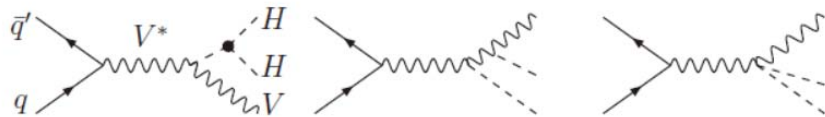
(a) gg double-Higgs fusion: $gg \rightarrow HH$



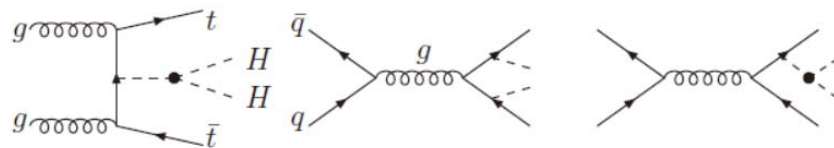
(b) WW/ZZ double-Higgs fusion: $qq' \rightarrow HHqq'$



(c) Double Higgs-strahlung: $q\bar{q}' \rightarrow ZHH/WHH$



(d) Associated production with top-quarks: $q\bar{q}/gg \rightarrow t\bar{t}HH$



$$\bullet \frac{\sigma(gg \rightarrow HH)}{\sigma(gg \rightarrow H)}, 14 \text{ TeV } 3000 \text{ fb}^{-1}$$

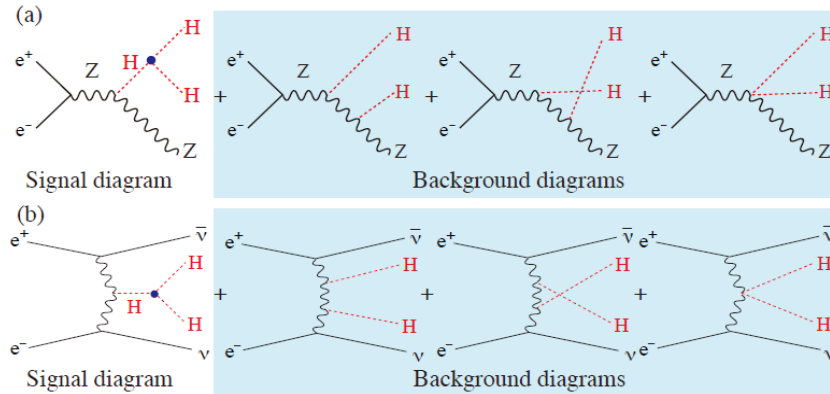
$$\Rightarrow \frac{\delta\lambda^{(3)}}{\lambda^{(3)}} \sim +30\% \sim -20\%$$

Ref.[1] J. Baglio *et al.* **JHEP 1304 (2013) 151**

Ref.[2] F. Goertz *et al.* **JHEP 1306 (2013) 016**

e^+e^- Collider

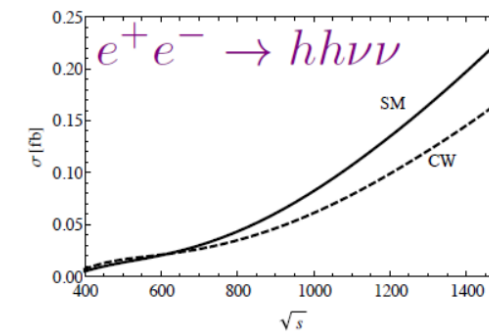
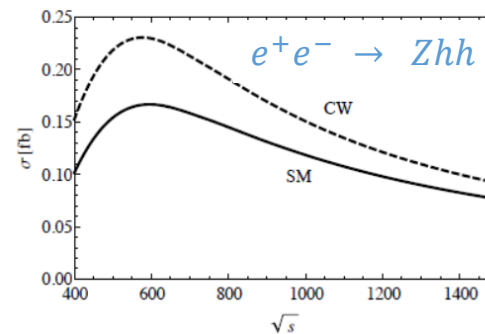
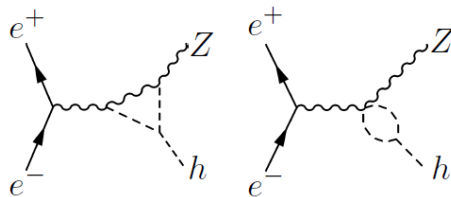
• ILC



$\Delta g/g$	Baseline			LumiUP		
	250 GeV	+ 500 GeV	+ 1 TeV	250 GeV	+ 500 GeV	+ 1 TeV
g_{HZZ}	1.3%	1.0%	1.0%	0.61%	0.51%	0.51%
g_{HWW}	4.8%	1.2%	1.1%	2.3%	0.58%	0.56%
g_{Hbb}	5.3%	1.8%	1.1%	2.5%	0.83%	0.60%
Γ_H	11%	5.0%	4.6%	5.4%	2.5%	2.3%
λ_{HHH}	-	83%	21%	-	46%	13%

Ref.[3] J. Tian, K. Fujii arXiv: 1311.6528

• TLEP



$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{3!} \delta_h A_{h,SM} h^3 \Rightarrow \delta_h \sim 28\% \text{ for } 240 \text{ GeV } 10 \text{ ab}^{-1}$$

Ref.[4] M. McCullough arXiv: 1312.3322

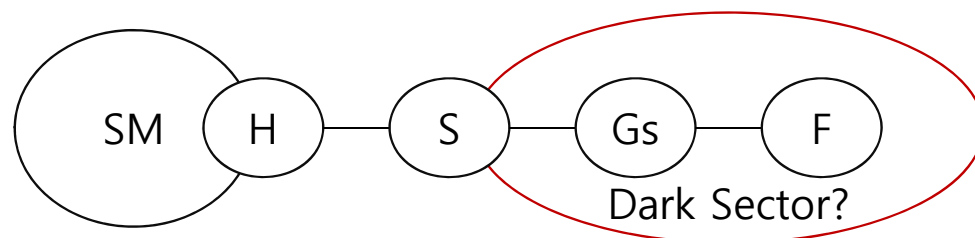
Dark Matter & Baryogenesis (Future work)

- Dark Matter

Strong coupling to SM

⇒ fail to explain Relic density

One of D.M. constituents (detectable, but not abundant)



- Baryogenesis

(a) Strong 1st order phase transition

(b) $G_{\mu\nu}\tilde{G}^{\mu\nu}H^+H$ additional CP violation

Conclusion

- We get working examples of radiatively generated EW sym. breaking with a valid perturbativity to a high energy.
- These models predict measureable cubic coupling significantly different from that of SM.