Dilaton portal to composite twin Higgs

Aqeel Ahmed

Vrije Universiteit Brussel

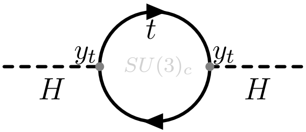
with B. Dillon and S. Najjari, arXiv:1909.0nnnn

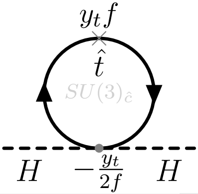
Scalars 2019 – Warsaw

September 13, 2019

- Electroweak Hierarchy Problem is one of the main theoretical motivations to go beyond the SM.
- Notable examples include SUSY, extra dimensions, and composite Higgs which solve the hierarchy problem by new physics (top-partners) close to the EW scale.
- However LHC null results have pushed these scenarios to relatively fine tuned parameter space.

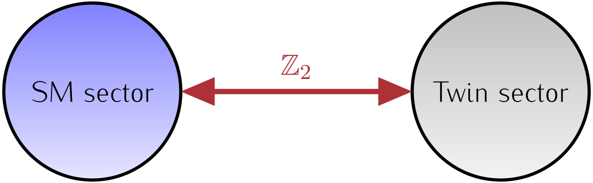
- Electroweak Hierarchy Problem is one of the main theoretical motivations to go beyond the SM.
- Notable examples include SUSY, extra dimensions, and composite Higgs which solve the hierarchy problem by new physics (top-partners) close to the EW scale.
- However LHC null results have pushed these scenarios to relatively fine tuned parameter space.
- An interesting possibility to avoid strong LHC bounds on the top-partners is offered by the Neutral Naturalness paradigm, where the top-partners are SM neutral states.





- Twin Higgs model is the prime example of Neutral Naturalness, where the Hierarchy Problem is solved by SM neutral 'top partners'.

[Chacko-Goh-Harnik,hep-ph/0506256]

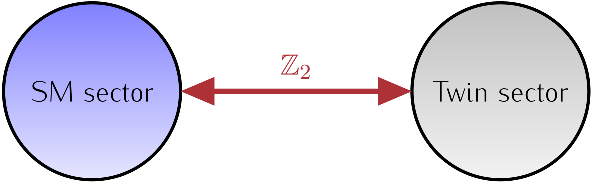


$SU(3)_c \times SU(2)_L \times U(1)_Y$ $SU(3)_{\hat{c}} \times SU(2)_{\hat{L}} \times U(1)_{\hat{Y}}$

Twin Higgs model

- Twin Higgs model is the prime example of Neutral Naturalness, where the Hierarchy Problem is solved by SM neutral 'top partners'.

[Chacko-Goh-Harnik,hep-ph/0506256]

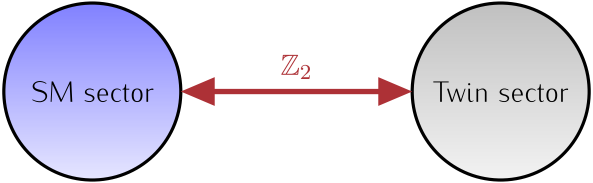


$SU(3)_c \times SU(2)_L \times U(1)_Y$ $\qquad$ $SU(3)_{\hat{c}} \times SU(2)_{\hat{L}} \times U(1)_{\hat{Y}}$

- Twin Higgs mechanism employs spontaneous breaking of a global symmetry at scale f such that the resulting Goldstone bosons include the SM Higgs doublet H.

Twin Higgs model

- Twin Higgs model is the prime example of Neutral Naturalness, where the Hierarchy Problem is solved by SM neutral 'top partners'.
  [Chacko-Goh-Harnik,hep-ph/0506256]



$SU(3)_c \times SU(2)_L \times U(1)_Y$ $\qquad$ $SU(3)_{\hat{c}} \times SU(2)_{\hat{L}} \times U(1)_{\hat{Y}}$

- Twin Higgs mechanism employs spontaneous breaking of a global symmetry at scale f such that the resulting Goldstone bosons include the SM Higgs doublet H.

- Requiring minimal fine tuning implies relatively small scale f, which implies that at scale $\Lambda = 4\pi f$ a UV completion of twin Higgs models becomes necessary!

Composite twin Higgs model

- Most natural UV completion of twin Higgs mechanism is realized by composite/holographic twin Higgs models.
  [Barbieri-Greco-Rattazzi-Wulzer,1501.07803] [Low-Tesi-Wang,1501.07890] [Geller-Telem,1411.2974]

- Composite twin Higgs employs approximate $SO(8)$ global symmetry which is spontaneously broken to $SO(7)$ at scale f.

- The $SO(8)/SO(7)$ coset gives seven Goldstone bosons, which include the SM Higgs doublet H.

Composite twin Higgs model

- Most natural UV completion of twin Higgs mechanism is realized by composite/holographic twin Higgs models.
  [Barbieri-Greco-Rattazzi-Wulzer,1501.07803] [Low-Tesi-Wang,1501.07890] [Geller-Telem,1411.2974]
- Composite twin Higgs employs approximate $SO(8)$ global symmetry which is spontaneously broken to $SO(7)$ at scale f.
- The $SO(8)/SO(7)$ coset gives seven Goldstone bosons, which include the SM Higgs doublet H.
- The weak groups $SU(2)_L \times SU(2)_{\hat{L}} \subset SO(8)$ of the two sectors are gauges.
- In the unitary gauge out of 7 Goldstone bosons, 6 are 'eaten' by the SM and twin weak gauge bosons ($W^{\pm}, Z, \hat{W}^{\pm}, \hat{Z}$) and the remaining Goldstone serve as the SM Higgs boson h.

- The mass of radial mode $\hat{h}$ in CTH is of the order $\sim 4\pi f$ and hence can be integrated out in the effective theory.
- The mass scale of new states associated with the strongly coupled dynamics is

$$m_* = g_* f, \qquad \text{where} \quad 1 \lesssim g_* \lesssim 4\pi$$

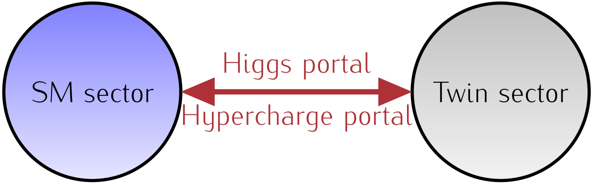
Hence, they are also integrated out in the effective theory.

- The mass of radial mode $\hat{h}$ in CTH is of the order $\sim 4\pi f$ and hence can be integrated out in the effective theory.
- The mass scale of new states associated with the strongly coupled dynamics is

$$m_* = g_* f, \qquad \text{where} \quad 1 \lesssim g_* \lesssim 4\pi$$

  Hence, they are also integrated out in the effective theory.
- Therefore the effective theory contains only SM and its twin copy. The natural portals to the connect the two sectors are:
  - Higgs portal: $\frac{v}{f} h \bar{\hat{\psi}} \hat{\psi}$
  - Hypercharge portal: $\epsilon B_{\mu\nu} \hat{B}_{\mu\nu}$

[see S. Najjari's talk]



Dilaton portal composite twin Higgs

- We present a strongly coupled approximate scale invariant UV completion of the twin Higgs mechanism, where the scale invariance is spontaneously broken at scale $\mathcal{F} \gtrsim f$.
- The spontaneous breaking of approximate scale invariance gives rise to a light pseudo-Goldstone boson, the dilaton $\phi(x)$.

Dilaton portal composite twin Higgs

- We present a strongly coupled approximate scale invariant UV completion of the twin Higgs mechanism, where the scale invariance is spontaneously broken at scale $\mathcal{F} \gtrsim f$.
- The spontaneous breaking of approximate scale invariance gives rise to a light pseudo-Goldstone boson, the dilaton $\phi(x)$.
- Below the scale $\mathcal{F}$ the approximate scale invariance is non-linearly realized, such that,

$$x^\mu \to x'^\mu = e^{-\lambda} x^\mu, \qquad \phi(x) \to \phi'(x') = \phi(x) + \lambda \mathcal{F}$$

Dilaton portal composite twin Higgs

- We present a strongly coupled approximate scale invariant UV completion of the twin Higgs mechanism, where the scale invariance is spontaneously broken at scale $\mathcal{F} \gtrsim f$.
- The spontaneous breaking of approximate scale invariance gives rise to a light pseudo-Goldstone boson, the dilaton $\phi(x)$.
- Below the scale $\mathcal{F}$ the approximate scale invariance is non-linearly realized, such that,

$$x^\mu \to x'^\mu = e^{-\lambda} x^\mu, \qquad \phi(x) \to \phi'(x') = \phi(x) + \lambda \mathcal{F}$$

- We assume the mass of the dilaton as a free parameter and require $m_\phi \ll \mathcal{F}$, such that an effective theory below scale $\mathcal{F}$ is

$$\mathcal{L} = \mathcal{L}_{\mathsf{SM}} + \hat{\mathcal{L}}_{\mathsf{TS}} + \mathcal{L}_{\text{dilaton}} + \mathcal{L}_{\text{portal}}$$

$$\boxed{\mathcal{L}_{\text{portal}} = -\frac{\phi}{\mathcal{F}}\left[T^\mu_\mu + \hat{T}^\mu_\mu\right]}$$

Holographic treatment

- We employ holographic duality to realize a 4D strongly coupled nearly scale invariant twin Higgs model in 5D anti-de Sitter geometry:

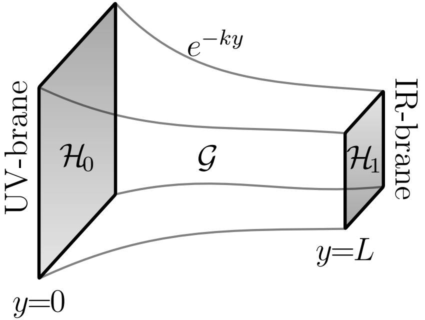
$$\boxed{ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2}$$

[Geller-Telem,1411.2974]

- We employ holographic duality to realize a 4D strongly coupled nearly scale invariant twin Higgs model in 5D anti-de Sitter geometry:

$$\boxed{ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2}$$

[Geller-Telem,1411.2974]

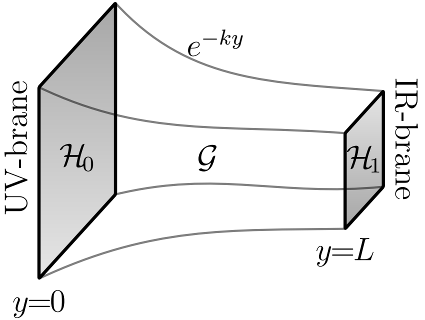


$$\mathcal{G} = SU(7)\times SO(8)\times \mathbb{Z}_2$$
$$\mathcal{H}_1 = SU(7)\times SO(7)\times \mathbb{Z}_2$$
$$\mathcal{H}_0 = \mathcal{G}_{\text{SM}}\times \mathcal{G}_{\text{twin}}\times \mathbb{Z}_2$$
$$\mathcal{G}_{\text{SM}} = SU(3)_c\times SU(2)_L\times U(1)_Y$$
$$\mathcal{G}_{\text{twin}} = SU(3)_{\hat{c}}\times SU(2)_{\hat{L}}\times U(1)_{\hat{Y}}$$

- We employ holographic duality to realize a 4D strongly coupled nearly scale invariant twin Higgs model in 5D anti-de Sitter geometry:

$$\boxed{ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2}$$

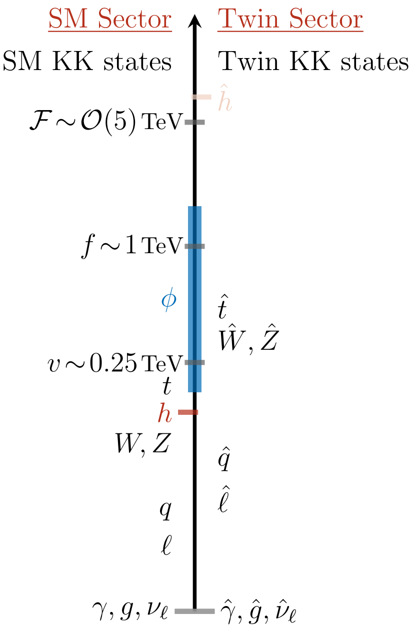
[Geller-Telem,1411.2974]

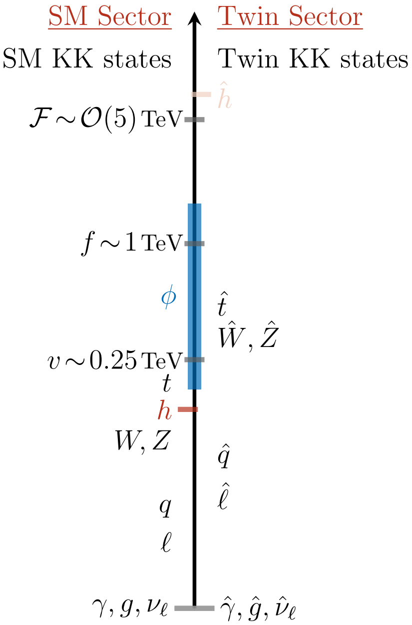


$$\mathcal{G} = SU(7) \times SO(8) \times \mathbb{Z}_2$$
$$\mathcal{H}_1 = SU(7) \times SO(7) \times \mathbb{Z}_2$$
$$\mathcal{H}_0 = \mathcal{G}_{\text{SM}} \times \mathcal{G}_{\text{twin}} \times \mathbb{Z}_2$$
$$\mathcal{G}_{\text{SM}} = SU(3)_c \times SU(2)_L \times U(1)_Y$$
$$\mathcal{G}_{\text{twin}} = SU(3)_{\hat{c}} \times SU(2)_{\hat{L}} \times U(1)_{\hat{Y}}$$

- In holographic picture, the dilaton is identified as the radion.

Dilaton portal composite/holographic twin Higgs





- Useful dictionary

$$m_{\mathrm{KK}} = g_* f\,, \qquad g_* \equiv g\sqrt{kL}$$

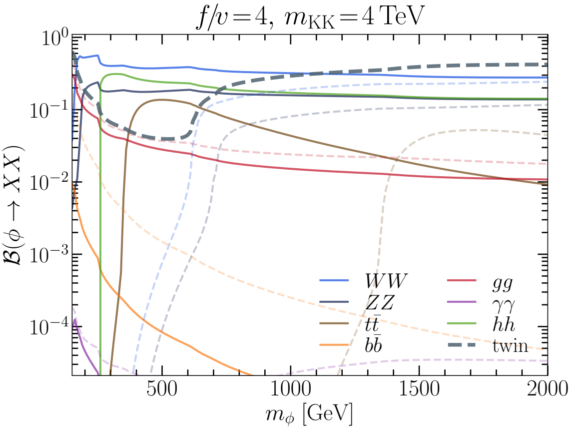
$$\boxed{\mathcal{F} = \sqrt{\frac{3}{2}}\frac{M_{\mathrm{Pl}}}{k}\, g_* f}$$

$$m_{\mathrm{twin}} \simeq \frac{f}{v} m_{\mathrm{SM}}$$

$$\boxed{\mathcal{L}_{\mathrm{portal}} = -\frac{\phi}{\mathcal{F}}\left[T^\mu_\mu + \hat{T}^\mu_\mu\right]}$$

- Phenomenology is fixed by:

$$\boxed{m_\phi,\ \mathcal{F},\ f,\ m_{\mathrm{KK}}}$$

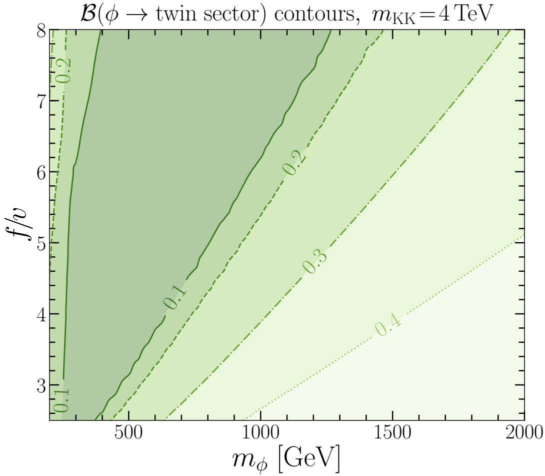


For $m_\phi \in [2m_V - 2m_{\hat{V}}]$ the dominant BRs channels for the dilaton are the SM gauge and Higgs bosons, $WW/ZZ/hh$.

- For $m_\phi \gtrsim 2m_{\hat{V}}$ thanks to Goldstone equivalence theorem,

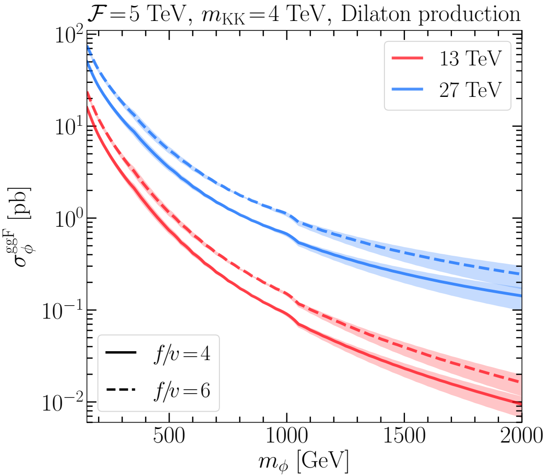
$$\boxed{\mathcal{B}(\phi \to hh) \simeq \mathcal{B}(\phi \to VV) \simeq \mathcal{B}(\phi \to \hat{V}\hat{V}) \simeq \frac{1}{7}}$$

- Massless bosons BRs are enhanced due to the trace anomalous and bulk contributions, while the fermions BRs are proportional to their masses.

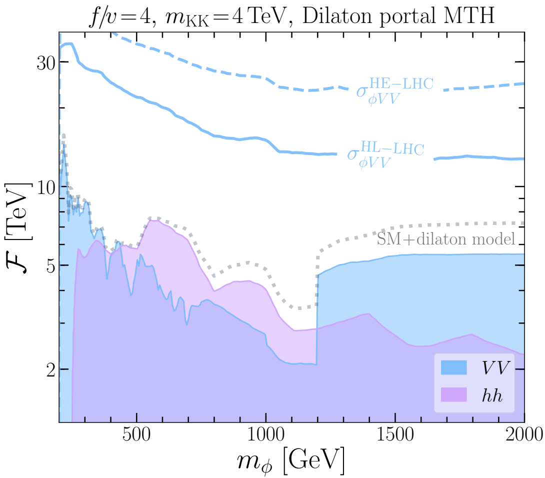


- The twin sector (invisible) branching fraction of the dilaton.
- Dilaton branching ratios are independent of $\mathcal{F}$.

Dilaton phenomenology: production at the LHC

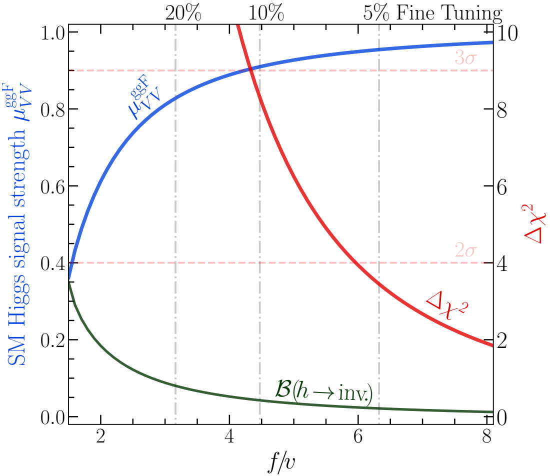


- Dilaton production cross section at the LHC is dominated by the ggF, we calculate at order $\mathrm{N^3LO}$ adopting `SusHi-1.7` with `PDF4LHC15_nnlo_mc`.
- Naively, one expects the VBF to be comparable of ggF but the large anomalous coupling of dilaton to gluons makes the later dominant.



- LHC run2 direct searches of heavy scalars to dibosons place the most stringent bounds, excluding $\mathcal{F} \lesssim 6$ TeV.
- HL-LHC (HE-LHC) with 3000/fb would exclude $\mathcal{F} \lesssim 10(20)$ TeV.

Global fit to the twin Higgs parameters

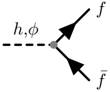
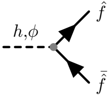
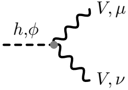
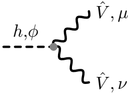
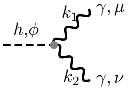
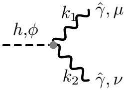
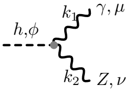
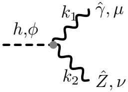
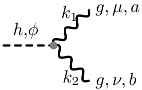
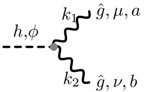
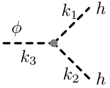


- Global χ^2 fit is performed employing all the LHC run-2 Higgs data.
- χ^2 fit with LHC run-2 data excludes $f/v \lesssim 4$ at 3σ.
  This result is independent of the presence of the dilaton portal!

Conclusions

- Twin Higgs mechanism offers an interesting possibility to solve the little hierarchy problem by SM neutral top-partners.
- We considered strongly coupled nearly scale invariant UV completions of the twin Higgs models where a light dilaton state can provide a natural portal between the SM and twin (hidden) sectors.
- The effective theory of a twin Higgs dilaton portal can be described by four parameters, $m_\phi, \mathcal{F}, f, m_{\rm KK}$.
- Phenomenological study of this model at the LHC which implies for $m_\phi \in [200 - 2000]$ GeV, $\mathcal{F} \gtrsim 5$ TeV, $f/v \gtrsim 4$ with $m_{\rm KK} \sim 5$ TeV.
- The projected reach of HL-LHC and HE-LHC with 3000/fb could probe all the natural (FT up to 1%) parameter space of this model.

Appendix

SM SECTOR		TWIN SECTOR	
	$-i\,\frac{m_f}{v}\,g_{h,\phi}$		$-i\,\frac{m_{\hat f}}{\hat v}\,\hat g_{h,\phi}$
	$i\frac{m_V^2}{v}\,g_{h,\phi}\,\eta^{\mu\nu}$		$i\frac{m_{\hat V}^2}{\hat v}\,\hat g_{h,\phi}\,\eta^{\mu\nu}$
	$i\frac{\alpha}{2\pi v}c_\gamma^{h,\phi}\left(\eta^{\mu\nu}k_1\cdot k_2 - k_1^\nu k_2^\mu\right)$; $c_\gamma^{h,\phi}\equiv g_\phi\left(b_{\rm EM}+\frac{2\pi}{\alpha k L}\right)-g_{h,\phi}\left(e_i^2 N_c^i F_{1/2}+F_1\right)$		$i\frac{\hat\alpha}{2\pi \hat v}c_{\hat\gamma}^{h,\phi}\left(\eta^{\mu\nu}k_1\cdot k_2 - k_1^\nu k_2^\mu\right)$; $c_{\hat\gamma}^{h,\phi}\equiv \hat g_\phi\left(\hat b_{\rm EM}+\frac{2\pi}{\hat\alpha k L}\right)-\hat g_{h,\phi}\left(\hat e_i^2 N_c^i \hat F_{1/2}+\hat F_1\right)$
	$i\frac{\alpha}{2\pi v}c_{Z\gamma}^{h,\phi}\left(\eta^{\mu\nu}k_1\cdot k_2 - k_1^\nu k_2^\mu\right)$; $c_{Z\gamma}^{h,\phi}\equiv 2g_\phi\left(\frac{b_2}{t_\theta}-b_Y t_\theta\right)-g_{h,\phi}\left(A_{1/2}+A_1\right)$		$i\frac{\hat\alpha}{2\pi \hat v}c_{\hat Z\hat\gamma}^{h,\phi}\left(\eta^{\mu\nu}k_1\cdot k_2 - k_1^\nu k_2^\mu\right)$; $c_{\hat Z\hat\gamma}^{h,\phi}\equiv 2\hat g_\phi\left(\frac{\hat b_2}{t_{\hat\theta}}-\hat b_Y t_{\hat\theta}\right)-\hat g_{h,\phi}\left(\hat A_{1/2}+\hat A_1\right)$
	$i\delta^{ab}\frac{\alpha_s}{4\pi v}c_g^{h,\phi}\left(\eta^{\mu\nu}k_1\cdot k_2 - k_1^\nu k_2^\mu\right)$; $c_g^{h,\phi}\equiv 2\,g_\phi\left(b_3+\frac{2\pi}{\alpha_s kL}\right)-g_{h,\phi}F_{1/2}$		$i\delta^{ab}\frac{\hat\alpha_s}{4\pi \hat v}c_{\hat g}^{h,\phi}\left(\eta^{\mu\nu}k_1\cdot k_2 - k_1^\nu k_2^\mu\right)$; $c_{\hat g}^{h,\phi}\equiv 2\,\hat g_\phi\left(\hat b_3+\frac{2\pi}{\hat\alpha_s kL}\right)-\hat g_{h,\phi}\hat F_{1/2}$
	$ig_{\phi hh} = i\frac{m_\phi^2}{\mathcal{F}}\left(1+\frac{2m_h^2}{m_\phi^2}\right)$	with $g_h\equiv\frac{\hat v}{f}$, $\hat g_h\equiv-\frac{v}{f}$, $g_\phi\equiv\frac{v}{\mathcal{F}}$, $\hat g_\phi\equiv\frac{\hat v}{\mathcal{F}}$, $\hat v\equiv\sqrt{f^2-v^2}$	