NLO Corrections to Higgs production and decay in BSM Models

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INFN

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DIPARTIMENTO DI FISICA EDOARDO AMALDI

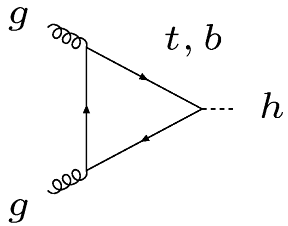
Outline

- Higgs production and decay in SM.
- NP contributions in $\Gamma(h \to \gamma\gamma),\ \sigma(gg \to h)$:
  colored scalars, QCD corrections
- NP contributions in $\sigma(gg \to h/H)$
  top/stop/gluino contributions in the MSSM
- Conclusions

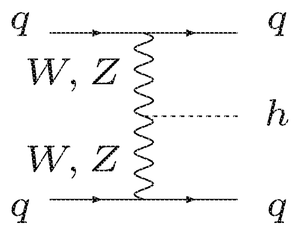
Higgs production and decay in the SM

SM Higgs production at LHC

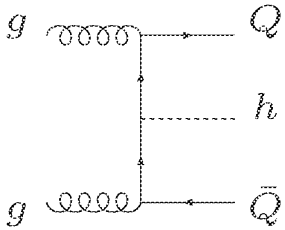
Gluon fusion



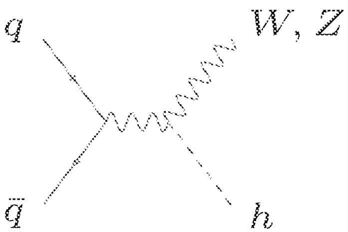
VBF

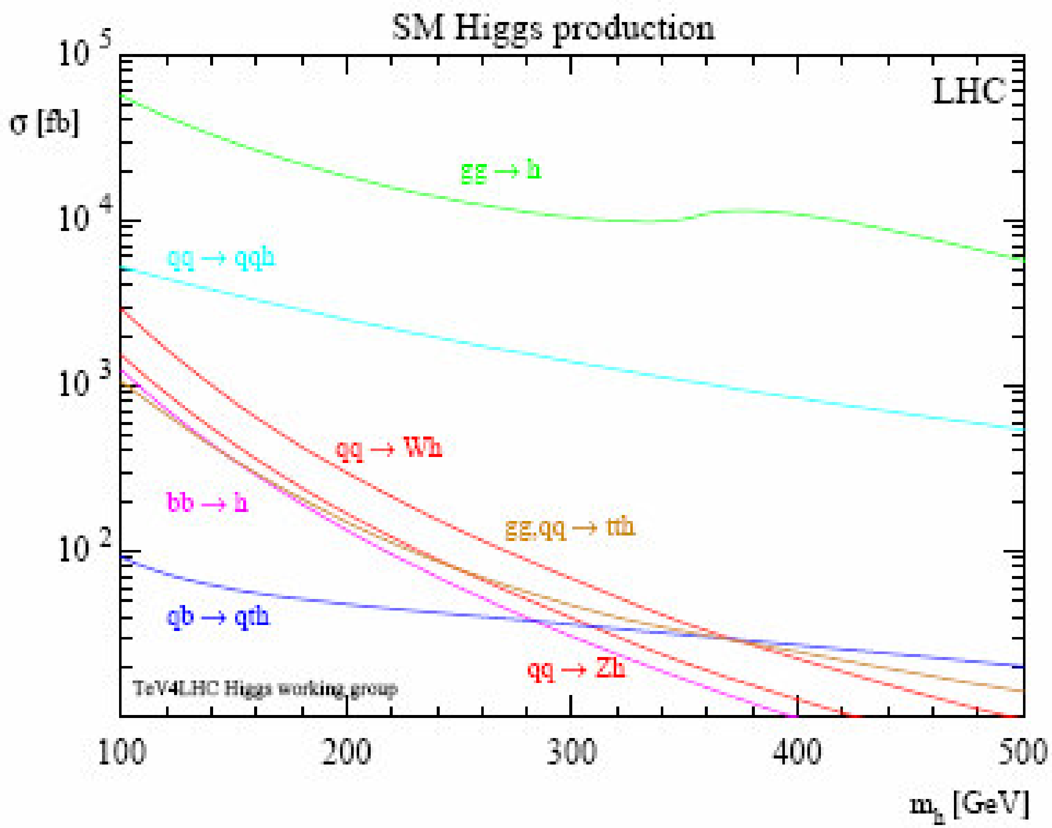


Associate production with $Q\bar{Q}$



Associate production with W,Z





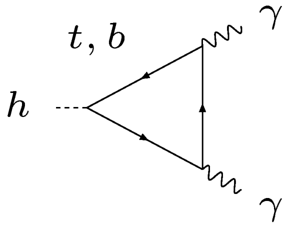
SM Higgs decays (BR)

$M_h \lesssim 140$ GeV

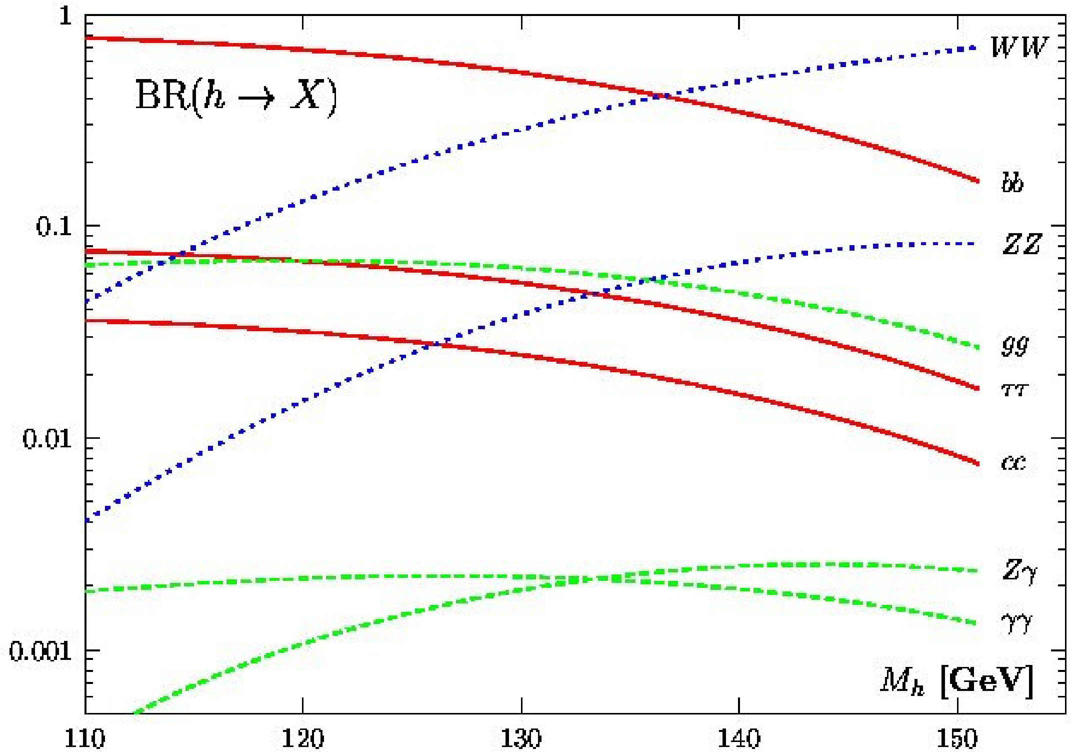
$h \longrightarrow b\bar{b}$ dominant

huge QCD background

$h \longrightarrow \gamma\gamma$

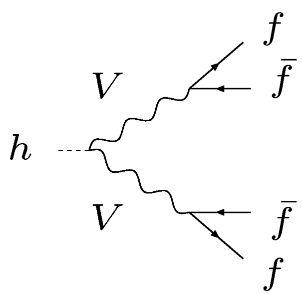


small BR
exp. clean



$M_h \gtrsim 140$ GeV

$h \longrightarrow WW$
$h \longrightarrow ZZ$



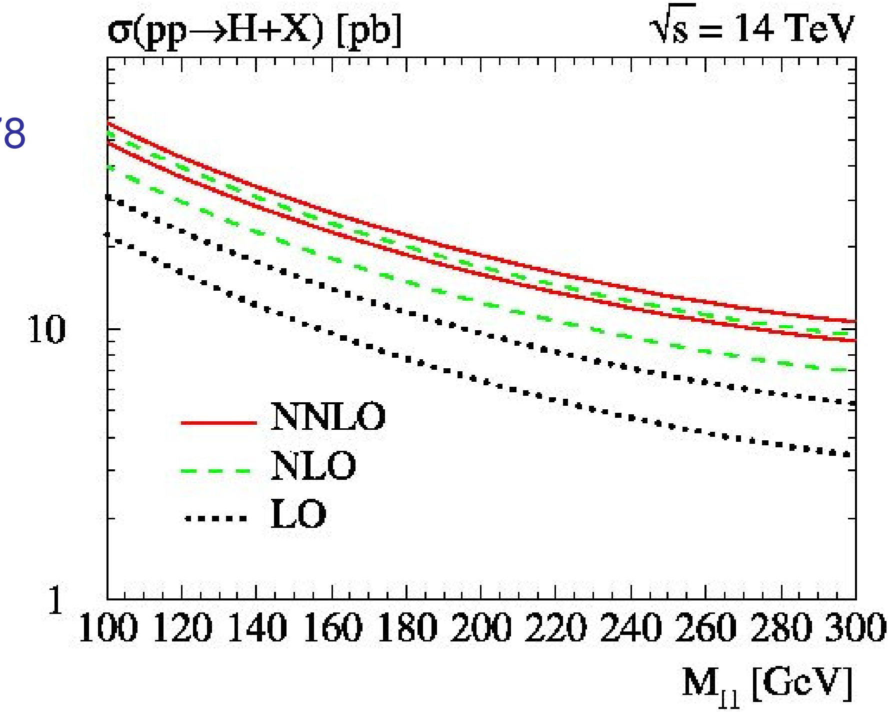
dominant

Gluon fusion Higgs production in the SM

- LO
  Georgi, Glashow, Machacek, Nanopoulos (78

QCD corrections exact

- NLO corrections at large p_T
  Ellis, Hinchliffe, Soldate, van der Bij (88),
  Baur, Glover (90)
- NLO corrections to production rate
  (LO X-sect. 60-70%↑)
  Djouadi, Graudens, Spira, Zerwas (91-95),
  Dawson (91),



QCD corrections $M_t \to \infty$

- NNLO corrections to production rate (NLO X-sect. 15-20% ↑)
  Harlander, Kilgore (01-02), Catani, de Florian, Grazzini (01),
  Anastasiou, Melnikov (02), Ravindran, Smith, van Neerven (03)

- NNLO corrections +softgluon NNLL resummation (NNLO X-sect. 6-15%↑)
  Catani, de Florian, Grazzini, Nason (03), Moch, Vogt (05)

- Higher order p_T and rapidity distributions
  de Florian, Grazzini, Kunszt (99), Del Duca et al. (01), Bozzi, Catani, de Florian, Grazzini (03-07),
  Anastasiou, Dixon, Melnikov (03), Anastasiou, Melnikov, Petriello (03), Catani, Grazzini (07)

Gluon fusion Higgs production in the SM

Electroweak corrections $\mathrm{M_t} \rightarrow \infty$

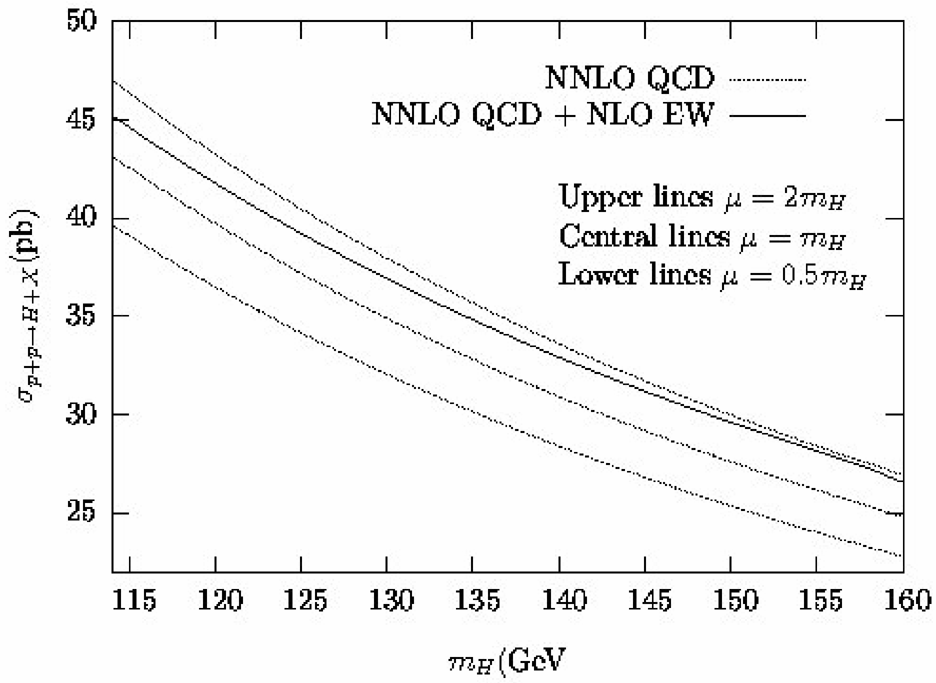
- LO X-sect. 0.4%↑

  Djouadi, Gambino (94), Djouadi, Gambino, Kniehl (98)

Electroweak corrections exact

- Light fermion + top (NNLO QCD X-sect. 5% ↑)

  Aglietti, Bonciani, Vicini, G.D. (04),
  F. Maltoni, G.D. (04),
  Actis, Passarino, Sturm, Uccirati (07-08)



Mixed QCD-EW to l.f. contr.

- estimate of the violation of the c.f. approximation

  Anastasiou, Boughezal, Petriello (08)

Higgs decay in two photons in the SM

- LO (largest contribution is bosonic, W exchange)
  Ellis, Gaillard, Nanopoulos (76), Shifman et al. (79)

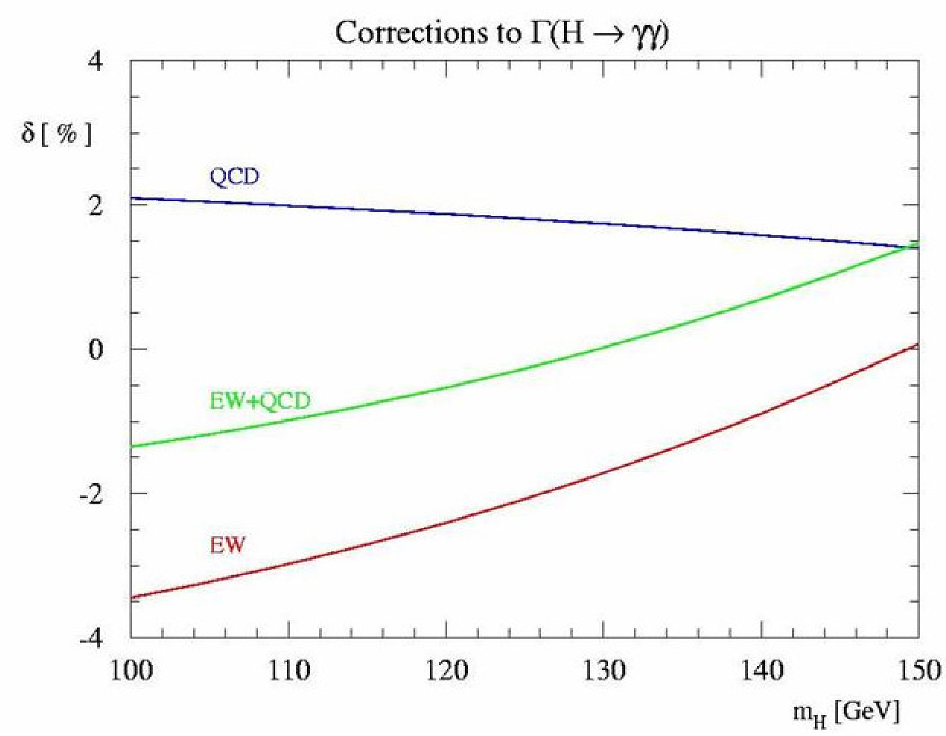
QCD corrections

- QCD corrections to the top-bottom contribution
  Zheng,Wu (90), Djouadi, Spira, Zerwas, van der Bij, Graudens (91-94), Dawson , Kauffman (93), Melnikov, Yakolev (93), Steinhauser (96)

  Analytic results available
  Fleischer, Tarasov, Tarasov (04), Harlander, Kant (05), Anastasiou et al. (06), Aglietti, Bonciani, Vicini, G.D. (06)

Electroweak corrections

- $\mathcal{O}(G_\mu M_t^2)$
  Liao, Li (97), Fugel, Kniehl, Steinhauser (04)
- $\mathcal{O}(G_\mu M_h^2)$
  Korner, Melnikov, Yakovlev (96)
- complete
  Aglietti, Bonciani, Vicini, G.D. (04), F. Maltoni, G.D. (05), Actis, Passarino, Sturm, Uccirati (07-08)



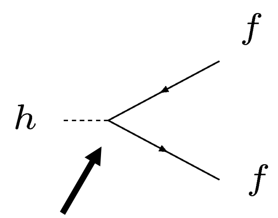
Colored scalar contribution to

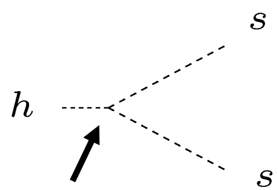
$$\Gamma(h \to \gamma\gamma), \sigma(gg \to h)$$

$\Gamma(h \to \gamma\gamma)$

Try to make a (as much as possible) model independent analysis of the contribution of one generic colored fermion and one generic colored scalar

Vertices:





$$h_t \to g\lambda_{1/2}\frac{m_{1/2}}{M_w} \qquad\qquad M \to g\lambda_0\frac{A^2}{M_w} \quad ([A] = M)$$

Amplitude: $$T^{\mu\nu} = [q_1^\nu\, q_2^\mu \; - (q_1 \cdot q_2)\, g^{\mu\nu}\,]\,\mathcal{F}$$

Decay width: $$\Gamma(h \to \gamma\gamma) = \frac{G_\mu \alpha^2 M_h^3}{128\sqrt{2}\pi^3}\,|\mathcal{F}|^2$$

$$\mathcal{F} = \lambda_1\, Q_1^2\, N_1\, \mathcal{F}_1 + \lambda_{1/2}\, Q_{1/2}^2\, N_{1/2}\mathcal{F}_{1/2} + \lambda_0\, Q_0^2\, N_0\, \frac{A^2}{m_0^2}\, \mathcal{F}_0\,,$$

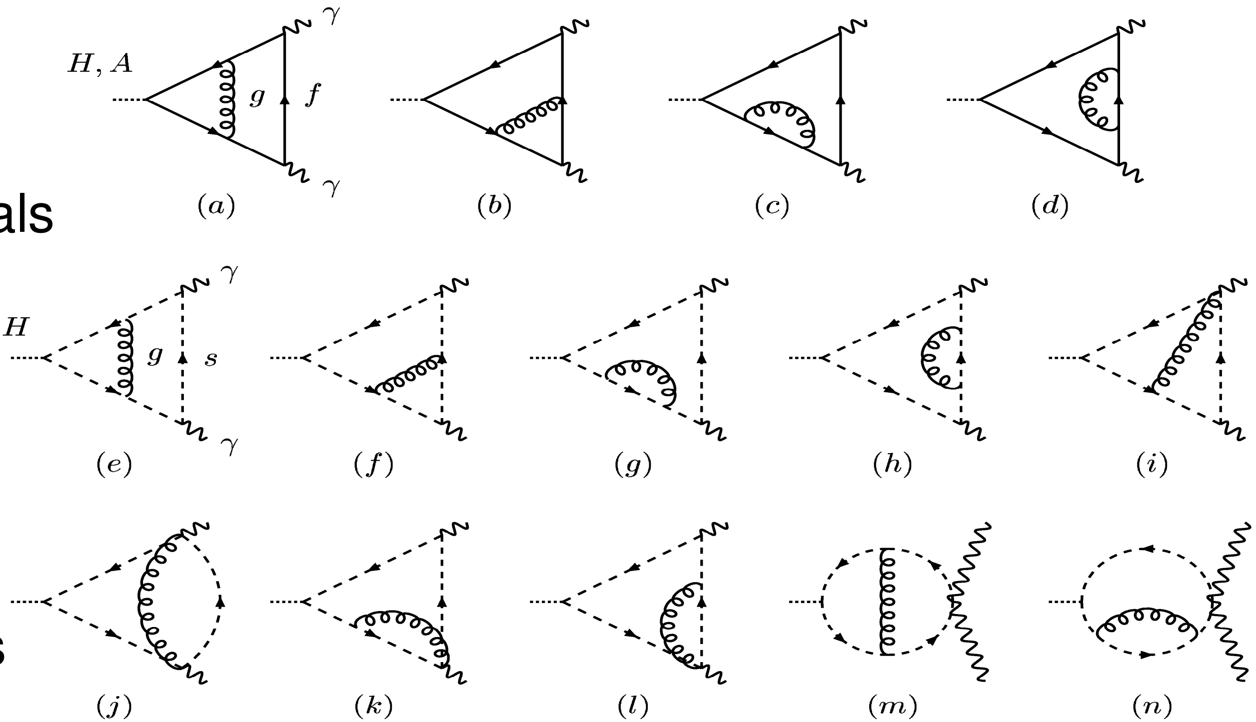
$$\mathcal{F}_1^{1l} \to 7 \qquad\qquad \mathcal{F}_{1/2}^{1l} \to -\frac{4}{3} \qquad\qquad \mathcal{F}_0^{1l} \to -\frac{1}{3}$$

$\Gamma(h \to \gamma\gamma)$: QCD Corrections

Aglietti, Bonciani, Vicini, G.D. (06)

Reduction of loop integrals
to MI via IBP (LI)
(Laporta algorithm)

Computation of MI
via differential equations



Analytic solution of MI expressed in terms of Harmonic Polylogarithms (HPL)
thresholds at $0, \; 4\, m^2$

$\Gamma(h \to \gamma\gamma)$: QCD Corrections

$$\mathcal{F}^{(2l)}_{QCD} = \frac{\alpha_S}{\pi} \sum_{i=(0,1/2)} C(R_i)\, \mathcal{F}^{(2l)}_i \,,$$

Fermion, on-shell mass:

$$\mathcal{F}^{(2l)}_{1/2} = \mathcal{F}^{(2l,a)}_{1/2}(x_{1/2}) + \frac{4}{3}\mathcal{F}^{(2l,b)}_{1/2}(x_{1/2})$$

$$\begin{aligned}
\mathcal{F}^{(2l,a)}_{1/2}(x) \quad = \quad & \frac{36x}{(x-1)^2} - \frac{4x\left(1-14x+x^2\right)}{(x-1)^4}\,\zeta_3 - \frac{4x(1+x)}{(x-1)^3}\,H(0,x) \\
& - \frac{8x\left(1+9x+x^2\right)}{(x-1)^4}\,H(0,0,x) + \frac{2x\left(3+25x-7x^2+3x^3\right)}{(x-1)^5}\,H(0,0,0,x) \\
& + \frac{4x\left(1+2x+x^2\right)}{(x-1)^4}\left[\zeta_2 H(0,x) + 4\,H(0,-1,0,x) - H(0,1,0,x)\right] \\
& + \frac{4x\left(5-6x+5x^2\right)}{(x-1)^4}\,H(1,0,0,x) - \frac{8x\left(1+x+x^2+x^3\right)}{(x-1)^5}\,\mathcal{H}_1(x)\,, \\
\mathcal{F}^{(2l,b)}_{1/2}(x) \quad = \quad & -\frac{12x}{(x-1)^2} - \frac{6x(1+x)}{(x-1)^3}\,H(0,x) + \frac{6x\left(1+6x+x^2\right)}{(x-1)^4}\,H(0,0,x)\,,
\end{aligned}$$

Complete agreement with Spira, Djoudi, Graudenz, Zerwas (numerical) and Harlander, Kant (analytical)

Scalar, on-shell mass, $\overline{MS}\ A$ coupling

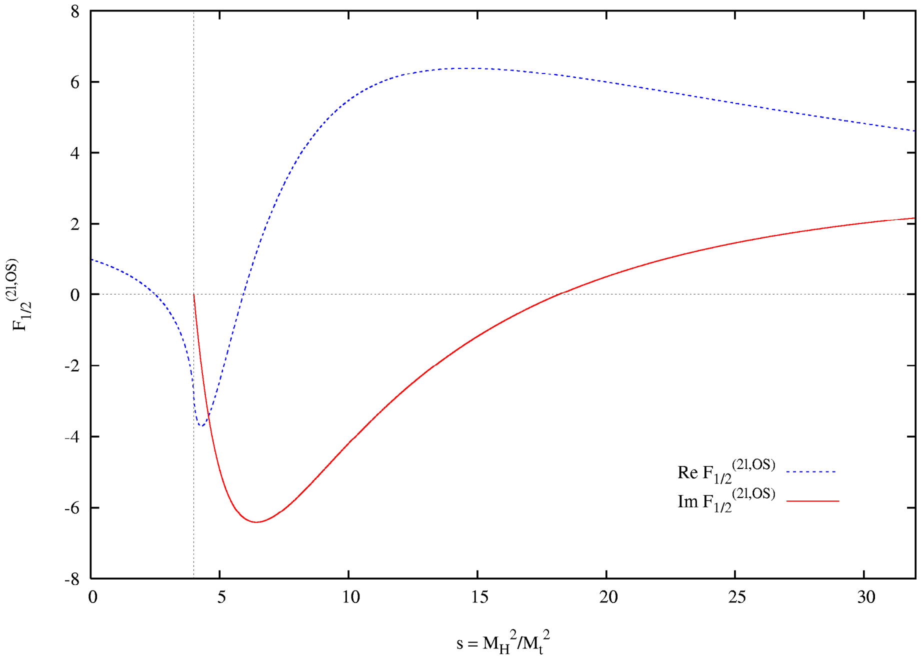
$$\mathcal{F}_0^{(2l)} = \mathcal{F}_0^{(2l,a)}(x_0) + \frac{7}{3}\,\mathcal{F}_0^{(2l,b)}(x_0) + \mathcal{F}_0^{(2l,c)}(x_0)\ln\left(\frac{m_0^2}{\mu^2}\right) \ .$$

$$\begin{aligned}
\mathcal{F}_0^{(2l,a)}(x) \quad &= \quad -\frac{14x}{(x-1)^2} - \frac{24x^2}{(x-1)^4}\,\zeta_3 + \frac{x\left(3-8x+3x^2\right)}{(x-1)^3(x+1)}\,H(0,x) + \frac{34x^2}{(x-1)^4}\,H(0,0,x) \\
&\quad -\frac{8x^2}{(x-1)^4}\left[\zeta_2 H(0,x) + 4H(0,-1,0,x) - H(0,1,0,x) + H(1,0,0,x)\right] \\
&\quad -\frac{2x^2(5-11x)}{(x-1)^5}\,H(0,0,0,x) + \frac{16x^2\left(1+x^2\right)}{(x-1)^5(x+1)}\,\mathcal{H}_1(x)\,, \\
\mathcal{F}_0^{(2l,b)}(x) \quad &= \quad \frac{6x^2}{(x-1)^3(x+1)}\,H(0,x) - \frac{6x^2}{(x-1)^4}\,H(0,0,x)\,, \\
\mathcal{F}_0^{(2l,c)}(x) \quad &= \quad -\frac{3}{4}\,\mathcal{F}_0^{(1l)}\,.
\end{aligned}$$

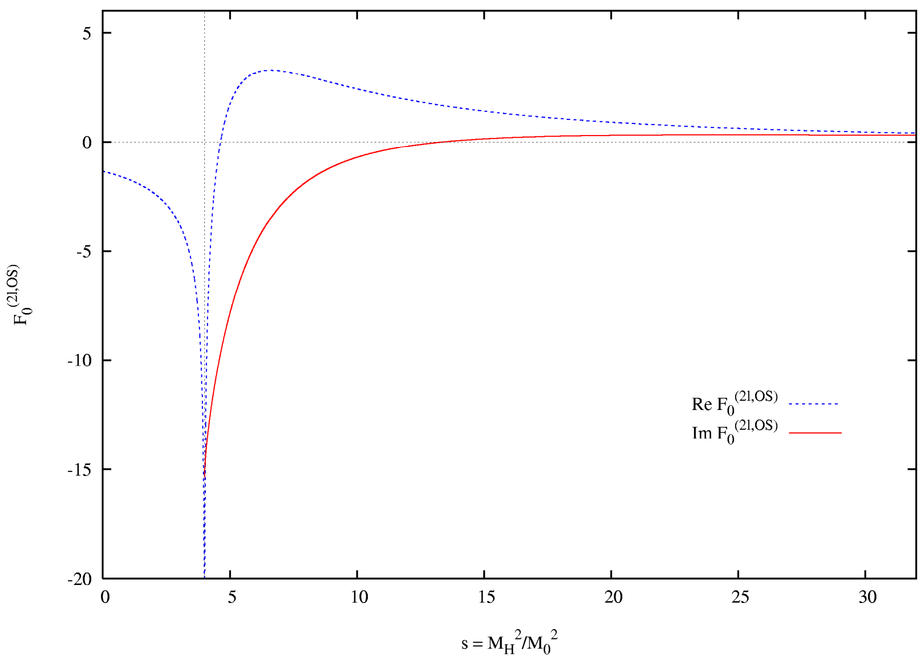
Similar analysis by Anastasiou et al. (06)
Complete agreement (numerical) with Muehlleitner, Spira (06)

Real and Imaginary parts of $\mathcal{F}_{1/2}^{(2l)}$, $\mathcal{F}_0^{(2l)}$

fermion



scalar



Scalar contribution shows a logarithmic singularity at the threshold $4\, m_0^2$

1PI scalar diagrams contain square root singularity at the threshold

$\sigma(gg \to h)$

$$\begin{aligned}\sigma(h_1 + h_2 \to H + X) &= \sum_{a,b} \int_0^1 dx_1 dx_2 f_{a,h_1}(x_1, \mu_F^2) f_{b,h_2}(x_2, \mu_F^2) \\ &\times \int_0^1 dz\, \delta\left(z - \frac{\tau_H}{x_1 x_2}\right) \hat{\sigma}_{ab}(z)\end{aligned}$$

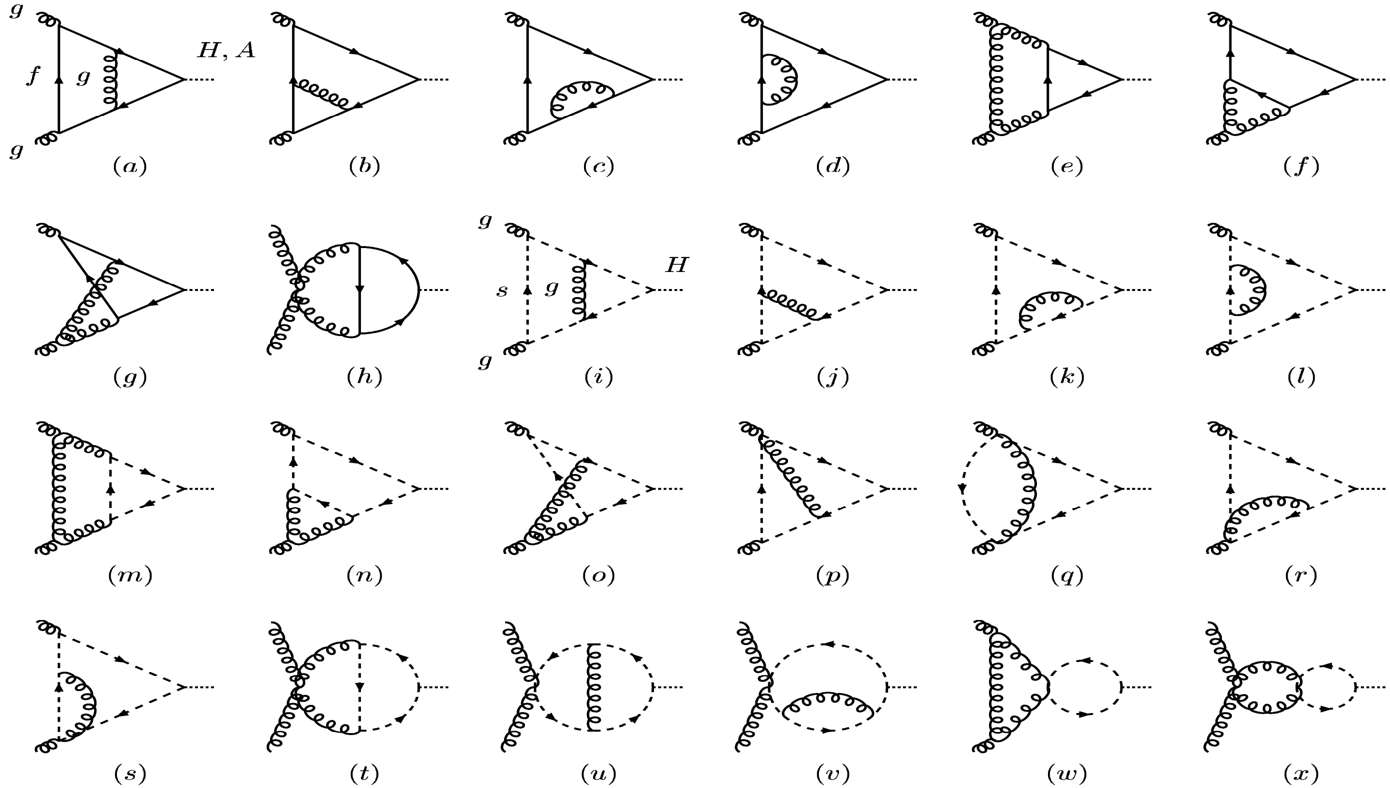
$$\hat{\sigma}_{ab}(z) = \sigma^{(0)}\, z\, G_{ab}(z); \;\; \sigma^{(0)} = \frac{G_\mu \alpha_S^2(\mu_R^2)}{128\sqrt{2}\,\pi} \left| \sum_{i=0,1/2} \lambda_i \left(\frac{A^2}{m_0^2}\right)^{1-2i} T(R_i)\, \mathcal{G}_i^{(1l)} \right|^2$$

Born: $\mathcal{G}_i^{1l} = \mathcal{F}_i^{1l}$, $G_{ab}^{(0)}(z) = \delta(1-z)\,\delta_{ag}\,\delta_{bg}$

NLO: $G_{ab}(z) = G_{ab}^{(0)}(z) + \dfrac{\alpha_s(\mu_R^2)}{\pi} G_{ab}^{(1)}(z)$

$$\begin{aligned}G_{gg}^{(1)}(z) &= \delta(1-z)\left[C_A \frac{\pi^2}{3} + \beta_0 \ln\left(\frac{\mu_R^2}{\mu_F^2}\right) + \sum_{i=0,1/2} \mathcal{G}_i^{(2l)}\right] \\ &+ P_{gg}(z) \ln\left(\frac{\hat{s}}{\mu_F^2}\right) + C_A \frac{4}{z}(1-z+z^2)^2 \mathcal{D}_1(z) + C_A \mathcal{R}_{gg} \\ G_{q\bar{q}}^{(1)}(z) &= \mathcal{R}_{q\bar{q}}, \quad G_{qg}^{(1)}(z) = P_{gq}(z)\left[\ln(1-z) + \frac{1}{2}\ln\left(\frac{\hat{s}}{\mu_F^2}\right)\right] + \mathcal{R}_{qg}\end{aligned}$$

Virtual Corrections



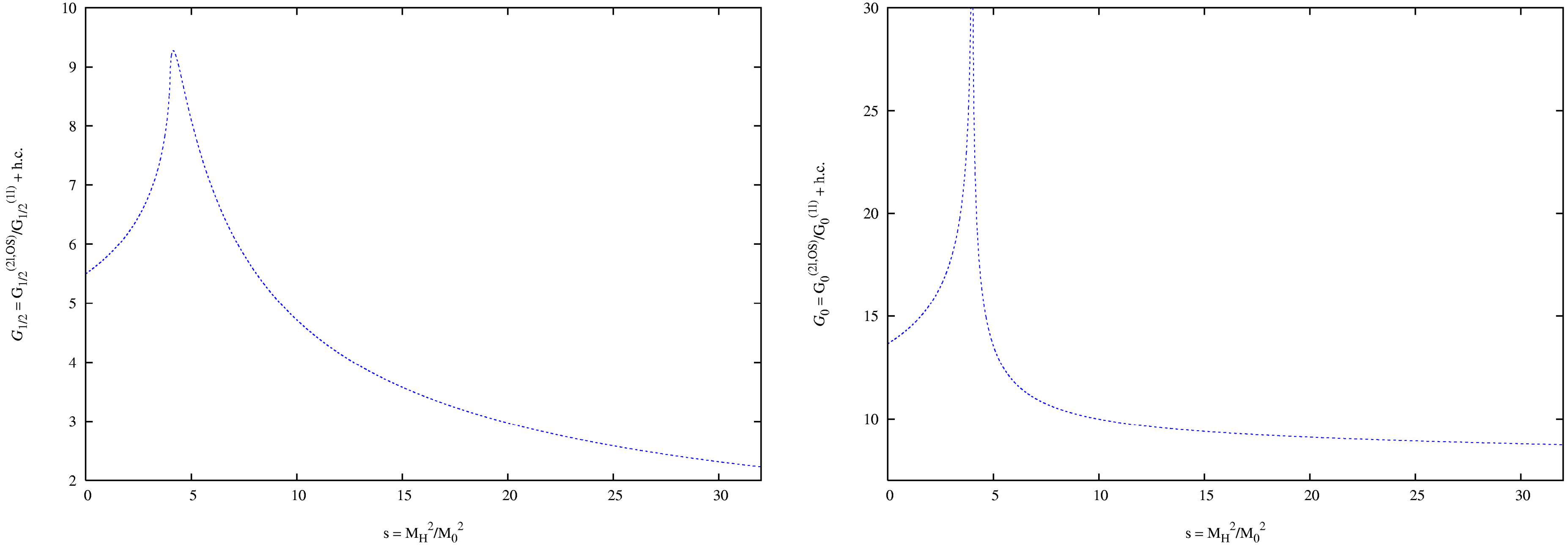
$$\mathcal{G}_i^{(2l)} = \lambda_i \left(\frac{A^2}{m_0^2}\right)^{1-2i} T(R_i)\left(C(R_i)\,\mathcal{G}_i^{(2l,C_R)}(x_i) + C_A\,\mathcal{G}_i^{(2l,C_A)}(x_i)\right)$$

$$\times \left(\sum_{j=0,1/2} \lambda_j \left(\frac{A^2}{m_0^2}\right)^{1-2j} T(R_j)\,\mathcal{G}_j^{(1l)}\right)^{-1} + h.c.$$

$$\mathcal{G}_i^{(2l,C_R)} = \mathcal{F}_i^{(2l)}$$

$$\mathcal{G}_{1/2}^{(2l,C_A)}(x) = \frac{4x}{(x-1)^2}\left[3 + \frac{x(1+8x+3x^2)}{(x-1)^3}\,H(0,0,0,x) - \frac{2(1+x)^2}{(x-1)^2}\,\mathcal{H}_2(x) + \zeta_3 - H(1,0,0,x)\right]$$

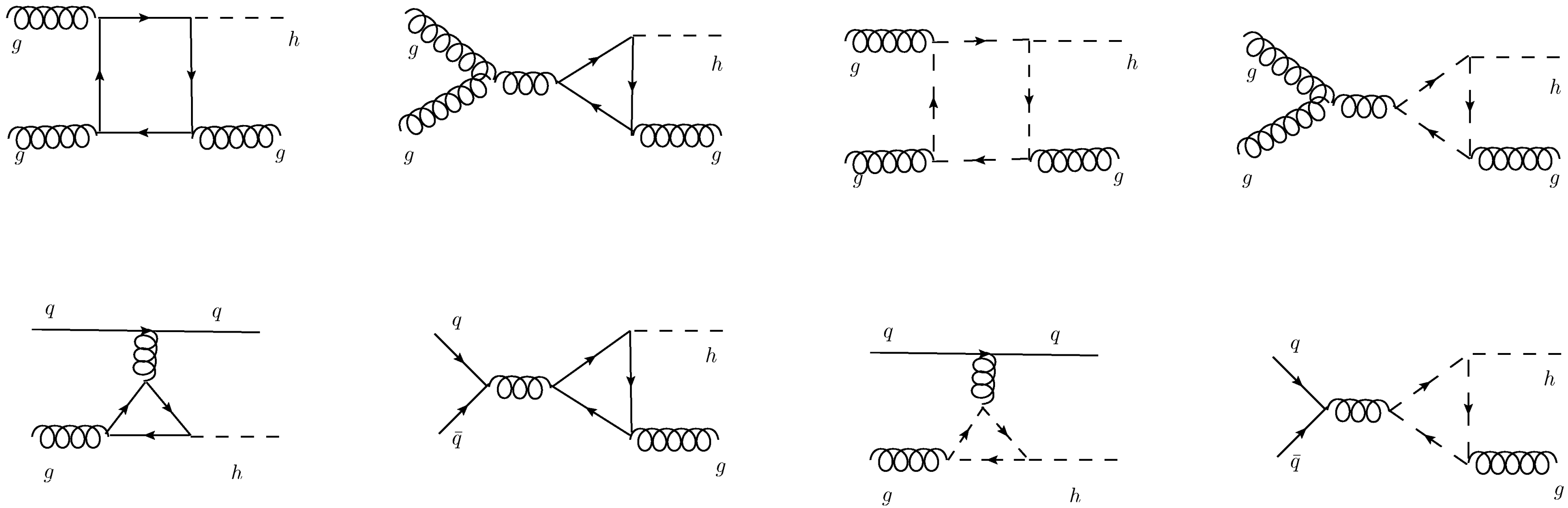
$$\mathcal{G}_0^{(2l,C_A)}(x) = \frac{4x}{(x-1)^2}\left[-\frac{3}{2} + \frac{x(1-7x)}{(x-1)^3}H(0,0,0,x) + \frac{4x}{(x-1)^2}\mathcal{H}_2(x)\right]$$



Similar analysis by Anastasiou et al. (06)
Complete agreement (numerical) with Muehlleitner, Spira (06)

Real radiation

Bonciani, Vicini, G.D. (07)



$$\mathcal{R}_{gg} = \frac{1}{z(1-z)}\int_0^1 \frac{dv}{v(1-v)}\left\{\frac{8\,z^4\left|\mathcal{A}_{gg}(\hat{s},\hat{t},\hat{u})\right|^2}{\left|\sum_{j=0,1/2}\lambda_j\left(\frac{A^2}{m_0^2}\right)^{1-2j}\;T(R_j)\,\mathcal{G}_j^{(1l)}\right|^2} - (1-z+z^2)^2\right\}$$

$$\mathcal{R}_{q\bar{q}} = \frac{128}{27}\frac{z\,(1-z)\;\left|\mathcal{A}_{q\bar{q}}(\hat{s},\hat{t},\hat{u})\right|^2}{\left|\sum_{j=0,1/2}\lambda_j\left(\frac{A^2}{m_0^2}\right)^{1-2j}\;T(R_j)\,\mathcal{G}_j^{(1l)}\right|^2}$$

$$\mathcal{R}_{qg} = C_F\int_0^1 \frac{dv}{(1-v)}\left\{\frac{1+(1-z)^2v^2}{[1-(1-z)v]^2}\frac{2\,z\left|\mathcal{A}_{qg}(\hat{s},\hat{t},\hat{u})\right|^2}{\left|\sum_{j=0,1/2}\lambda_j\left(\frac{A^2}{m_0^2}\right)^{1-2j}T(R_j)\,\mathcal{G}_j^{(1l)}\right|^2} - \frac{1+(1-z)^2}{2z}\right\} + \frac{1}{2}C_F z$$

K-factor

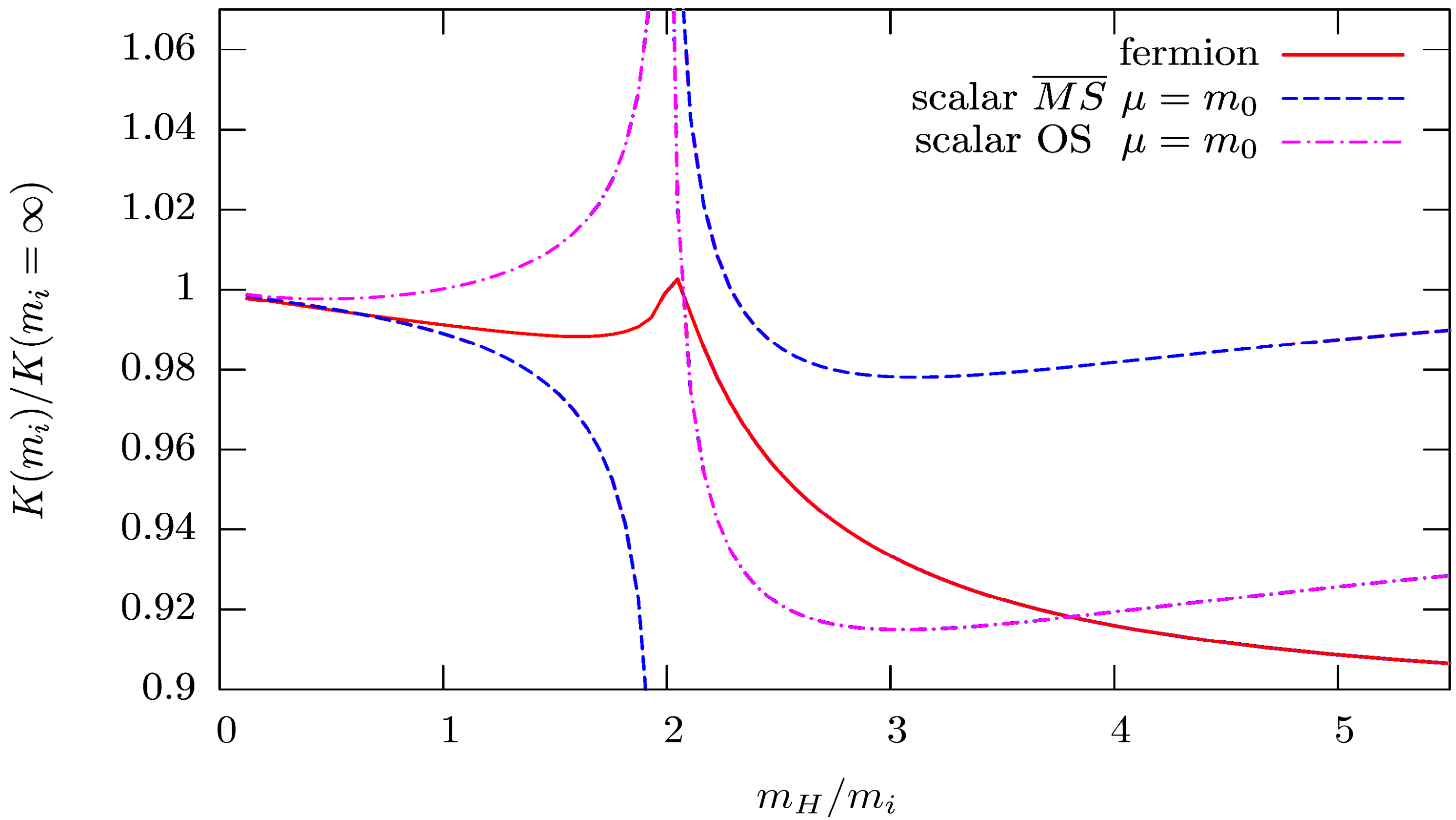
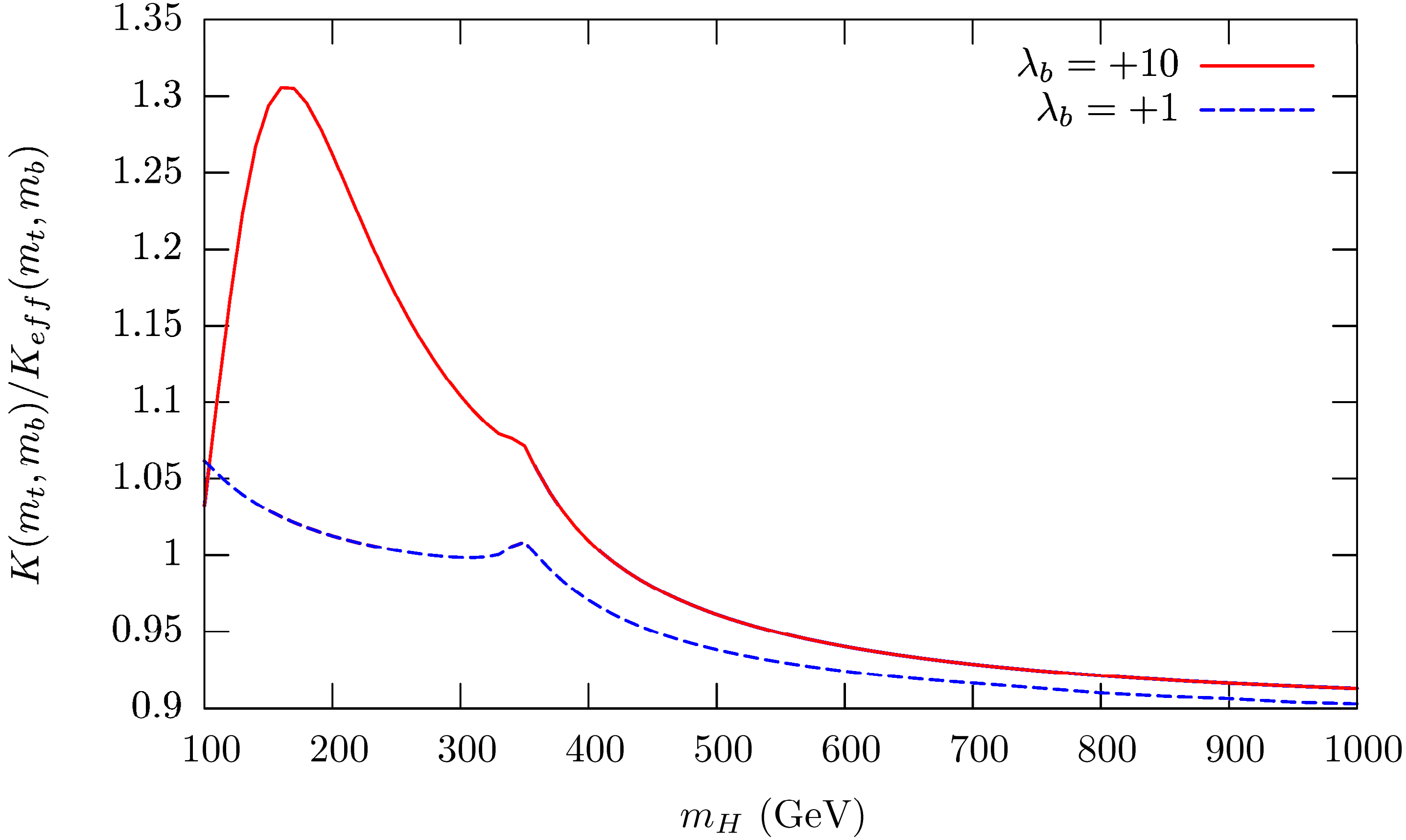


Figure 1: Exact K-factor normalized to the effective one. The different lines represent a single heavy fermion (solid line) and a single heavy scalar whose mass is renormalized in the $\overline{\mathrm{MS}}$ (dashed line) or in the on-shell scheme (dashed-dotted line).

K-factor



$\lambda_b = +10$
$\lambda_b = +1$
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
100
200
300
400
500
600
700
800
900
1000
$K(m_t, m_b)/K_{eff}(m_t, m_b)$
m_H (GeV)

The Manohar-Wise Model

Manohar, Wise. (06)

- Scalar sector of the SM augmented with a $(8,2)_{1/2}$ scalar multiplet.
- $(1,2)_{1/2}$, $(8,2)_{1/2}$ are the only representations which have couplings to quarks with natural flavor conservation
- Fields: $S^a = \begin{pmatrix} S^a_+ \\ S^a_0 \end{pmatrix} = \begin{pmatrix} S^a_+ \\ \frac{S^a_{0R}+iS^a_{OI}}{\sqrt{2}} \end{pmatrix}$
- Yukawa coupling: $\mathcal{L}_Y = -\eta_U Y^U_{ij} \bar{U}_{R_i} T^a Q_j S^a - \eta_D Y^D_{ij} \bar{d}_{R_i} T^a Q_j S^{a\dagger} + h.c.$
- Scalar Potential: $(S = S^a T^a)$

$$\begin{aligned} V &= \frac{\lambda}{4}\left(H^{\dagger i} H_i - \frac{v^2}{2}\right)^2 + 2m_S^2 \, TrS^{\dagger i} S_i \\ &+ \lambda_1 H^{\dagger i} H_i Tr S^{\dagger j} S_j + \lambda_2 H^{\dagger i} H_j Tr S^{\dagger j} S_i + \left(\lambda_3 H^{\dagger i} H^{\dagger j} Tr S_i S_j + h.c.\right) + \cdots \end{aligned}$$

- Spectrum:

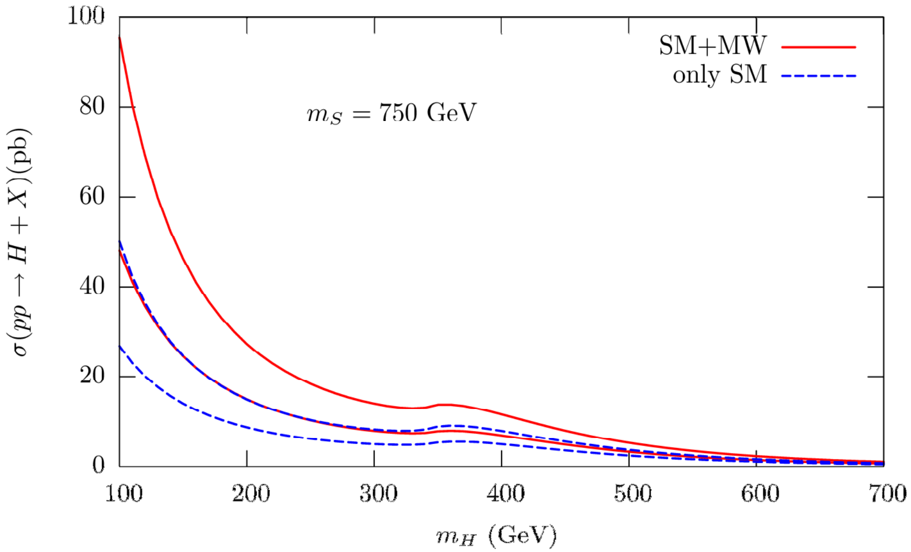
$$\begin{aligned} m^2_{S_+} &= m_S^2 + \lambda_1 \frac{v^2}{4} \\ m^2_{S_0 R} &= m_S^2 + (\lambda_1 + \lambda_2 + 2\lambda_3) \frac{v^2}{4} \\ m^2_{S_0 I} &= m_S^2 + (\lambda_1 + \lambda_2 - 2\lambda_3) \frac{v^2}{4}. \end{aligned}$$

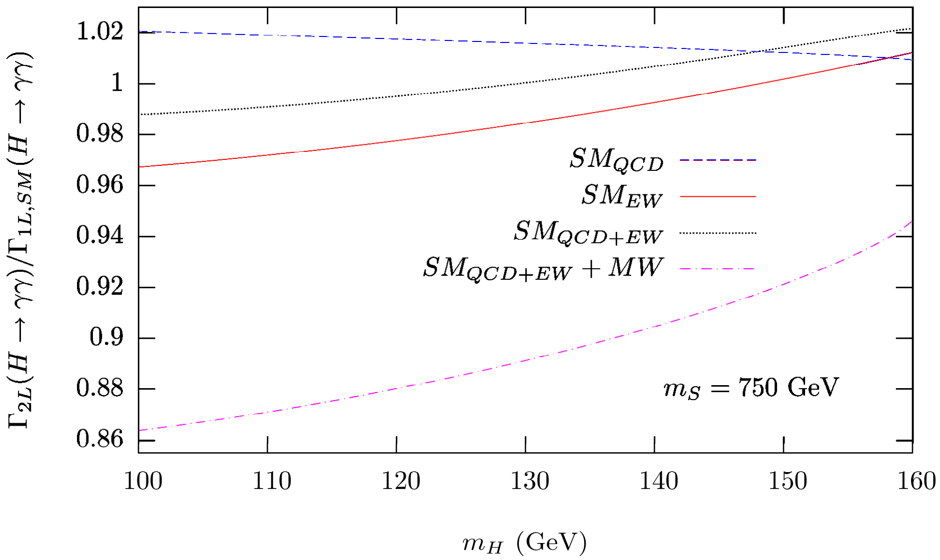
Couplings:

$$\begin{aligned} H S^a_+ S^b_- &= g \frac{\lambda_1}{4} \frac{v^2}{M_W} \delta^{ab} \\ H S^a_{0R} S^b_{OR} &= g \frac{\lambda_1 + \lambda_2 + 2\lambda_3}{8} \frac{v^2}{M_W} \delta^{ab} \\ H S^a_{0I} S^b_{0I} &= g \frac{\lambda_1 + \lambda_2 - 2\lambda_3}{8} \frac{v^2}{M_W} \delta^{ab} . \end{aligned}$$

Corrections to $\Gamma(h \to \gamma\gamma), \sigma(gg \to h)$

$$m_S = 750 \text{ GeV}, \ \frac{A^2}{m_S^2} \sim 0.1$$





- Colored scalars can double the SM NLO production cross section
- The decay width in two photon is reduced up to 15 %

Top/stop/gluino contribution to

$$\sigma(gg \longrightarrow h/H)$$

$\sigma(gg \to h, H)$ in the MSSM

Higgs sector: $H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}$, $H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} \Longrightarrow h, H, A, H^{\pm}$

Higgs coupling to gluons mediated by quarks and squarks

partonic X-sect.: $\hat{\sigma}^h_{ab}(z) = \sigma^{(0)}\, z\, G_{ab}(z)$; $\sigma^{(0)} = \dfrac{G_\mu\, \alpha_s^2(\mu_R)}{128\,\sqrt{2}\,\pi} \left| T_F \left(-\sin\alpha\, \mathcal{H}_1^{1\ell} + \cos\alpha\, \mathcal{H}_2^{1\ell}\right)\right|^2$

$$\hat{\sigma}^H_{ab}(z) = \hat{\sigma}^h_{ab}(z)(-\sin\alpha \to \cos\alpha,\ \cos\alpha \to \sin\alpha)$$

$\mathcal{H}_1, \mathcal{H}_2$ related to the structure of the Higgs-(s)quark-(s)quark couplings

$$\begin{aligned}
\mathcal{H}_1 &= \lambda_t \left[m_t\, \mu\, s_{2\theta_t}\, F_t + m_Z^2\, s_{2\beta}\, D_t\right] + \lambda_b \left[m_b\, A_b\, s_{2\theta_b}\, F_b + 2\, m_b^2\, G_b + 2\, m_Z^2\, c_\beta^2\, D_b\right] , \\
\mathcal{H}_2 &= \lambda_b \left[m_b\, \mu\, s_{2\theta_b}\, F_b - m_Z^2\, s_{2\beta}\, D_b\right] + \lambda_t \left[m_t\, A_t\, s_{2\theta_t}\, F_t + 2\, m_t^2\, G_t - 2\, m_Z^2\, s_\beta^2\, D_t\right] .
\end{aligned}$$

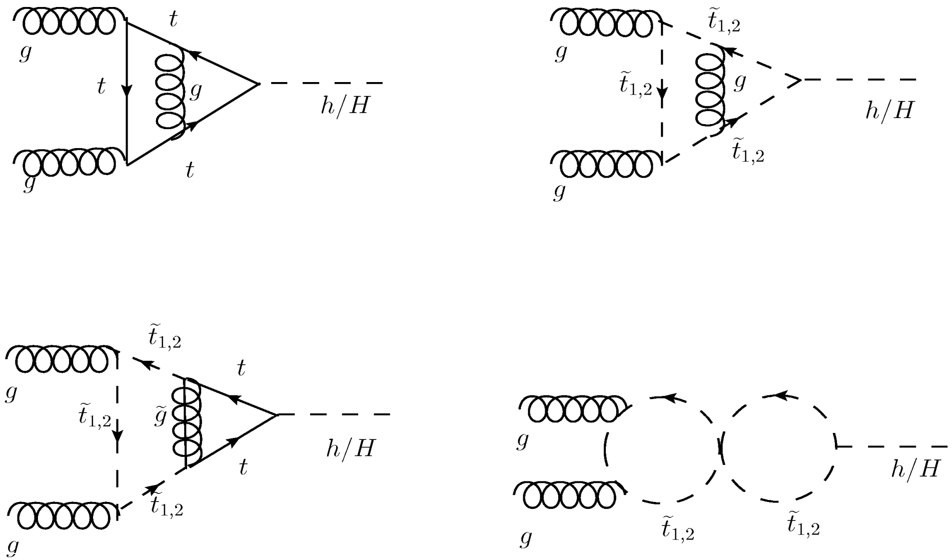
$\lambda_t = 1/\sin\beta,\ \lambda_b = 1/\cos\beta,$

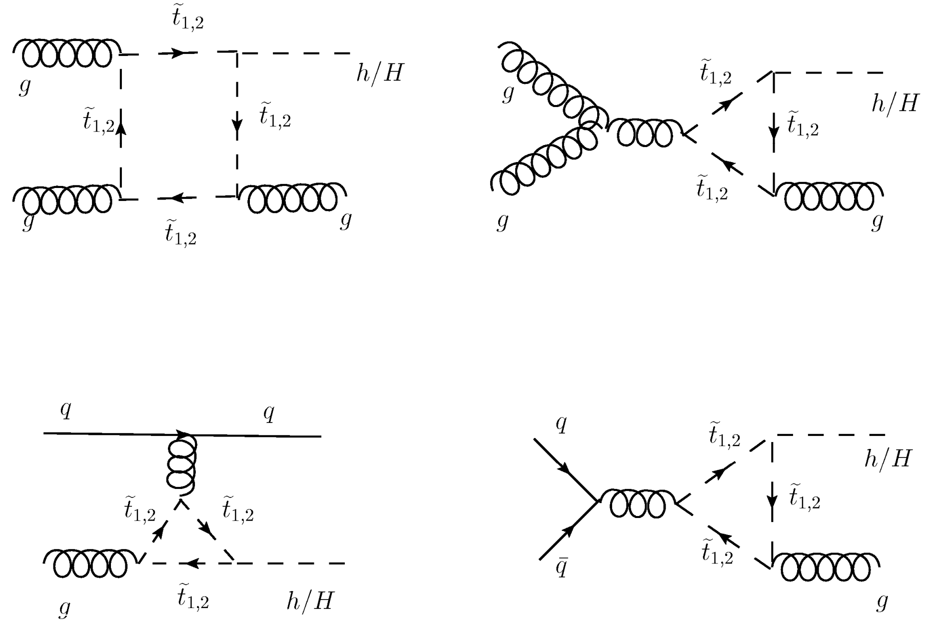
Yukawa $\longrightarrow$ $F_q,\ G_q$

D-term $\longrightarrow$ $D_q = \dfrac{I_{3q}}{2}\, \widetilde{G}_q + c_{2\theta_{\tilde{q}}} \left(\dfrac{I_{3q}}{2} - Q_q\, s^2_{\theta_W}\right) \widetilde{F}_q$

$\sigma(gg \to h, H)$ @ NLO in the MSSM

virtual





real

$\sigma(gg \to h, H)$ @ NLO in the MSSM

- Gluon-squark virtual & real contribution in the vanishing Higgs-mass limit (VHML)
  Dawson, Djouadi, Spira (96)

- Gluon-squark virtual & real contribution complete (analytic)
  Anastasiou, Beerli, Bucherer, Daleo, Kunszt (07), Aglietti, Bonciani, Vicini, G.D. (07)
  Muehlleitner, Spira (07), Bonciani, Vicini, G.D. (07)

- Gluino-stop-top virtual contribution in the vanishing Higgs-mass limit
  $\Longrightarrow$ computer code evalcsusy.f
  Harlander, Steinhauser (03-04)

- Gluino-quark-squark virtual contribution complete
  $\Longrightarrow$ not yet available to the public as computer code
  Anastasiou, Beerli,Daleo (08)

- Alternative derivation of the gluino-stop-top virtual contribution in the vanishing Higgs-mass limit based on the Low-Energy Theorem
  $\Longrightarrow$ explicit analytic result, easy to implement in any computer code
  Slavich, G.D. (08)

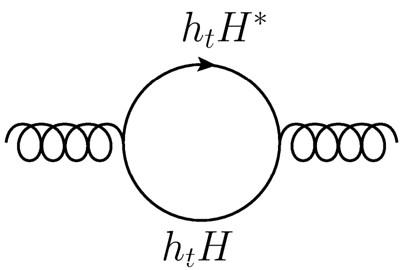
Low-Energy Theorem

Shifman et al. (79), Kniehl, Spira (95)

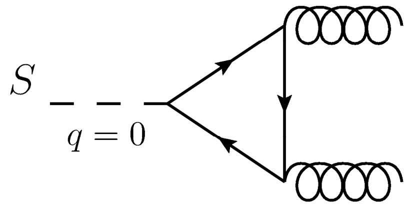
Gluon self-energy in BFG as a field dependent quantity :

$$\left(q^\nu q^\mu - q^2 g^{\mu\nu}\right) \Pi(q^2, H) \qquad\qquad H = \frac{v+S+iP}{\sqrt{2}}$$

$$\frac{\partial}{\partial S}$$

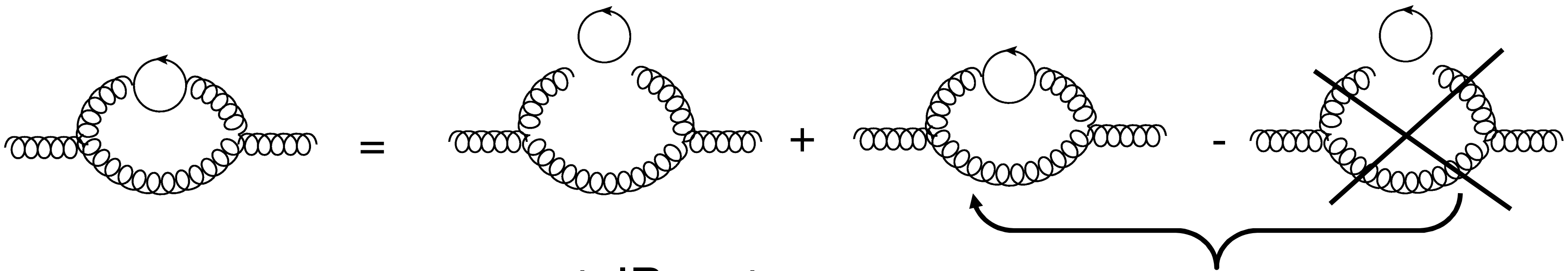


$$\Big|_{<H>=\frac{v}{\sqrt{2}}} \Rightarrow$$



$$\Rightarrow \frac{\partial \Pi(0)}{\partial S} \propto \mathcal{G}\Big|_{q=0}$$

Two-loop:



exact: IR part

Taylor: Wilson Coefficient

Field-dependent mass matrices:

$$\mathcal{M}_t = \begin{pmatrix} 0 & -h_t H_2^{0*} \\ -h_t H_2^0 & 0 \end{pmatrix}$$

$$\mathcal{M}_{\tilde{t}}^2 = \begin{pmatrix} m_Q^2 + h_t^2 \, |H_2^0|^2 + d_{\tilde{t}_L} \left(|H_1^0|^2 - |H_2^0|^2\right) & h_t \, \left(A_t \, H_2^0 - \mu H_1^{0\,*}\right) \\ h_t \, \left(A_t \, H_2^{0\,*} - \mu H_1^0\right) & \hat{m}_U^2 + h_t^2 \, |H_2^0|^2 + d_{\tilde{t}_R} \left(|H_1^0|^2 - |H_2^0|^2\right) \end{pmatrix}$$

$$H_i = \tfrac{v_i + S_i + i P_i}{\sqrt{2}}, \quad d_{\tilde{q}} = \tfrac{1}{2} \, \left(T_{3q} \, g^2 - Y_q \, g'^{\,2}\right)$$

$\mathcal{M}_t, \mathcal{M}_{\tilde{t}}^2$ can be made real via a a field redefinition
$\Longrightarrow$ phase factor difference in the $\tilde{g}\tilde{t}t$ vertex

Gluon self-energy depends on five field-dependent parameters:

$m_t, \, m_{\tilde{t}_1}^2, \, m_{\tilde{t}_2}^2, \, c_{2\theta_t}^2, \, c_{\varphi\tilde{\varphi}}$

relevant only for derivatives w.r.t. CP-odd fields

Application of the L.E.T. to the MSSM

Top:

$$\mathcal{H}_i \Big|^{\rm top/stop}_{m_\phi^2=0} = \frac{2\pi v}{\alpha_s\, T_F}\, \frac{\partial \Pi^t(0)}{\partial S_i}\,,$$

$$F_t^{2\ell} = \frac{\partial Z}{\partial m^2_{\tilde{t}_1}} - \frac{\partial Z}{\partial m^2_{\tilde{t}_2}} - \frac{4\, c^2_{2\theta_t}}{m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2}}\, \frac{\partial Z}{\partial c^2_{2\theta_t}}\,, \qquad Z \equiv (2/T_F)\, \Pi^{2\ell,\,t}(0)$$

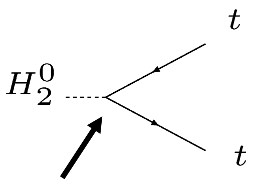
$$G_t^{2\ell} = \frac{\partial Z}{\partial m^2_{\tilde{t}_1}} + \frac{\partial Z}{\partial m^2_{\tilde{t}_2}} + \frac{\partial Z}{\partial m^2_t}\,,$$

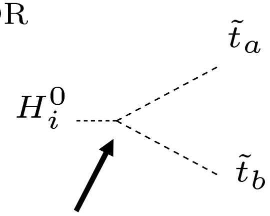
$$\ldots$$

$\Pi^{2\ell,\,t}(0)$ computed using DREG and $\overline{\rm MS}$ $\longrightarrow$ $\overline{\rm DR}$ (DRED)

Martin, Vaughn (93)

$h_t^{\overline{\rm DR}} = \tilde{h}_t^{\overline{\rm DR}}$





$h_t^{\overline{\rm MS}} = h_t^{\overline{\rm DR}} + \mathcal{O}(\alpha_s)$

$\tilde{h}_t^{\overline{\rm MS}} = \tilde{h}_t^{\overline{\rm DR}}$

but $\Pi^{1\ell}_{top}(0)$ independent on h_t

no correction factor needed

$\overline{\mathrm{DR}}$ results:

$$\frac{\partial Z^g}{\partial m_t^2} = \frac{1}{2\, m_t^2}\left(C_F - \frac{5\, C_A}{3}\right),$$

$$\frac{\partial Z^g}{\partial m_{\tilde{t}_i}^2} = -\frac{1}{2\, m_{\tilde{t}_i}^2}\left(\frac{3\, C_F}{4} + \frac{C_A}{6}\right),$$

$$\frac{\partial Z^{4\tilde{t}}}{\partial m_{\tilde{t}_1}^2} = -\frac{C_F}{24}\left[\frac{c_{2\theta_t}^2\, m_{\tilde{t}_1}^2 + s_{2\theta_t}^2\, m_{\tilde{t}_2}^2}{m_{\tilde{t}_1}^4} + \frac{s_{2\theta_t}^2}{m_{\tilde{t}_1}^4\, m_{\tilde{t}_2}^2}\left(m_{\tilde{t}_1}^4\, \ln\frac{m_{\tilde{t}_1}^2}{Q^2} - m_{\tilde{t}_2}^4\, \ln\frac{m_{\tilde{t}_2}^2}{Q^2}\right)\right],$$

$$\ldots$$

$$\frac{\partial Z^{\tilde{g}}}{\partial m^2} = \text{3 pages in Appendix NPB}$$

$\overline{\mathrm{DR}}$ $\Rightarrow$ OS

$$F_t^{2\ell} \longrightarrow F_t^{2\ell} + \frac{\pi}{6\,\alpha_s}\left[\frac{\delta m_{\tilde{t}_1}^2}{m_{\tilde{t}_1}^4} - \frac{\delta m_{\tilde{t}_2}^2}{m_{\tilde{t}_2}^4} - \left(\frac{\delta m_t}{m_t} + \frac{\delta s_{2\theta_t}}{s_{2\theta_t}}\right)\left(\frac{1}{m_{\tilde{t}_1}^2} - \frac{1}{m_{\tilde{t}_2}^2}\right)\right],$$

$$\ldots$$

perfect numerical agreement with evalcsusy.f once their definition of the OS stop mixing angle is enforced: $\delta\theta_t = \dfrac{\Pi_{12}(q_0^2)}{m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2}$

we use: $\delta\theta_t = \dfrac{1}{2}\,\dfrac{\widehat{\Pi}_{12}(m_{\tilde{t}_1}^2) + \widehat{\Pi}_{12}(m_{\tilde{t}_2}^2)}{m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2}$

Bottom:

- only diagrams with sbottom/gluons and quartic sbottom coupling can be approximated by VHML
- diagrams with bottom/gluons are known analytically
- diagrams bottom-sbottom-gluino cannot be computed via L.E.T.

  we expect them $\sim \tan\beta\,(m_b A_b(\mu))/\tilde{m}^2 \log(m_\phi/\tilde{m})$

If $h_b \to 0$, only D-term induced interactions survive

$$D_q = \frac{I_{3q}}{2}\,\widetilde{G}_q + c_{2\theta_{\tilde{q}}}\left(\frac{I_{3q}}{2} - Q_q\, s^2_{\theta_W}\right)\widetilde{F}_q$$

$$\widetilde{F}_b^{2\ell} \;=\; \frac{\partial Z}{\partial m^2_{\tilde{b}_L}} - \frac{\partial Z}{\partial m^2_{\tilde{b}_R}}\,, \qquad \widetilde{G}_b^{2\ell} \;=\; \frac{\partial Z}{\partial m^2_{\tilde{b}_L}} + \frac{\partial Z}{\partial m^2_{\tilde{b}_R}}$$

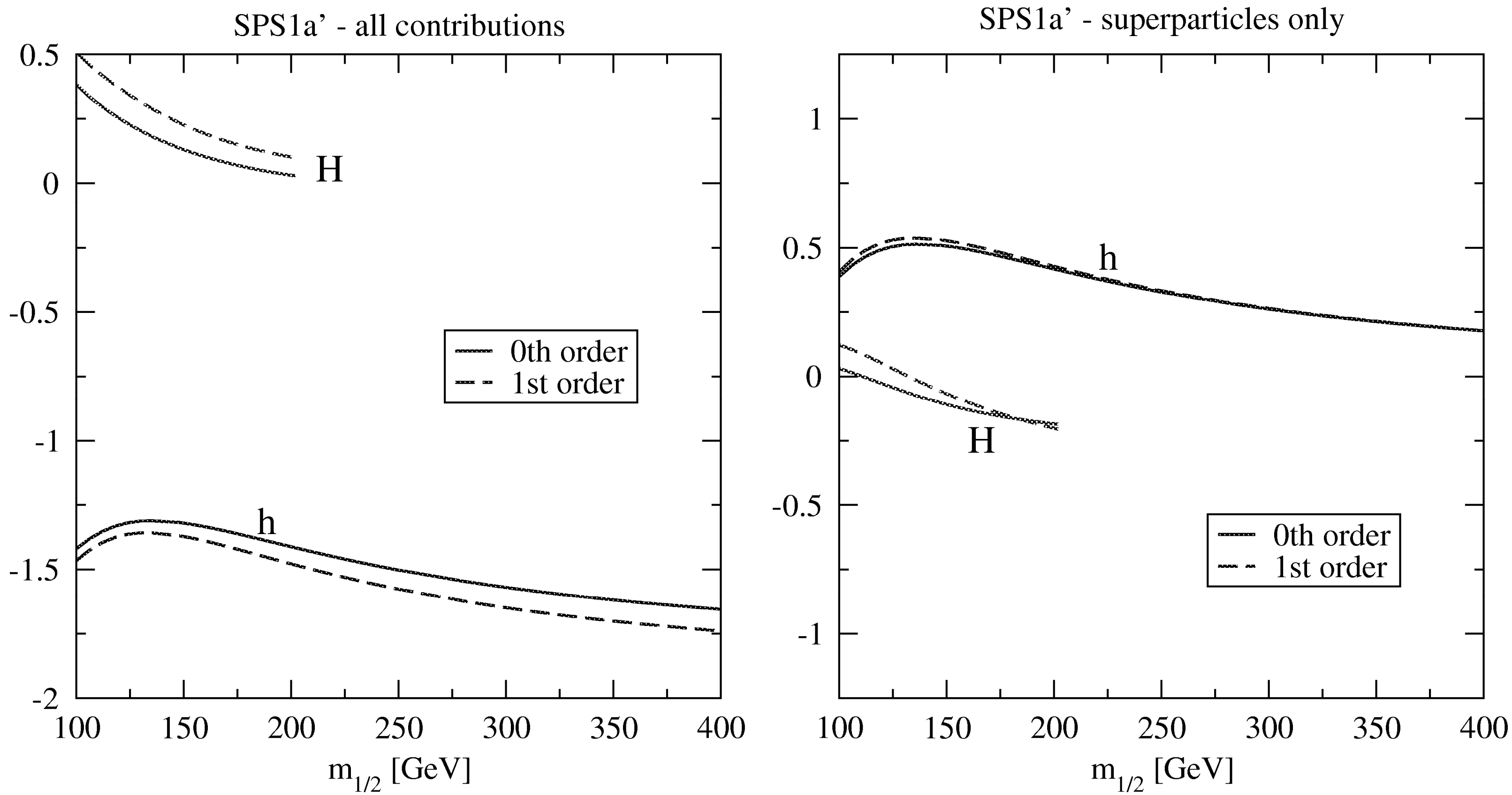
cancellation between up and down squarks

SPS1a'

$m_0 = 0.28\, m_{1/2}\,, \quad A_0 = -1.2\, m_{1/2}\,, \quad \tan\beta = 10\,, \quad \mu < 0$

VHML

$\mathcal{O}(m_\phi^2/M^2)$



Two-loop form factors:

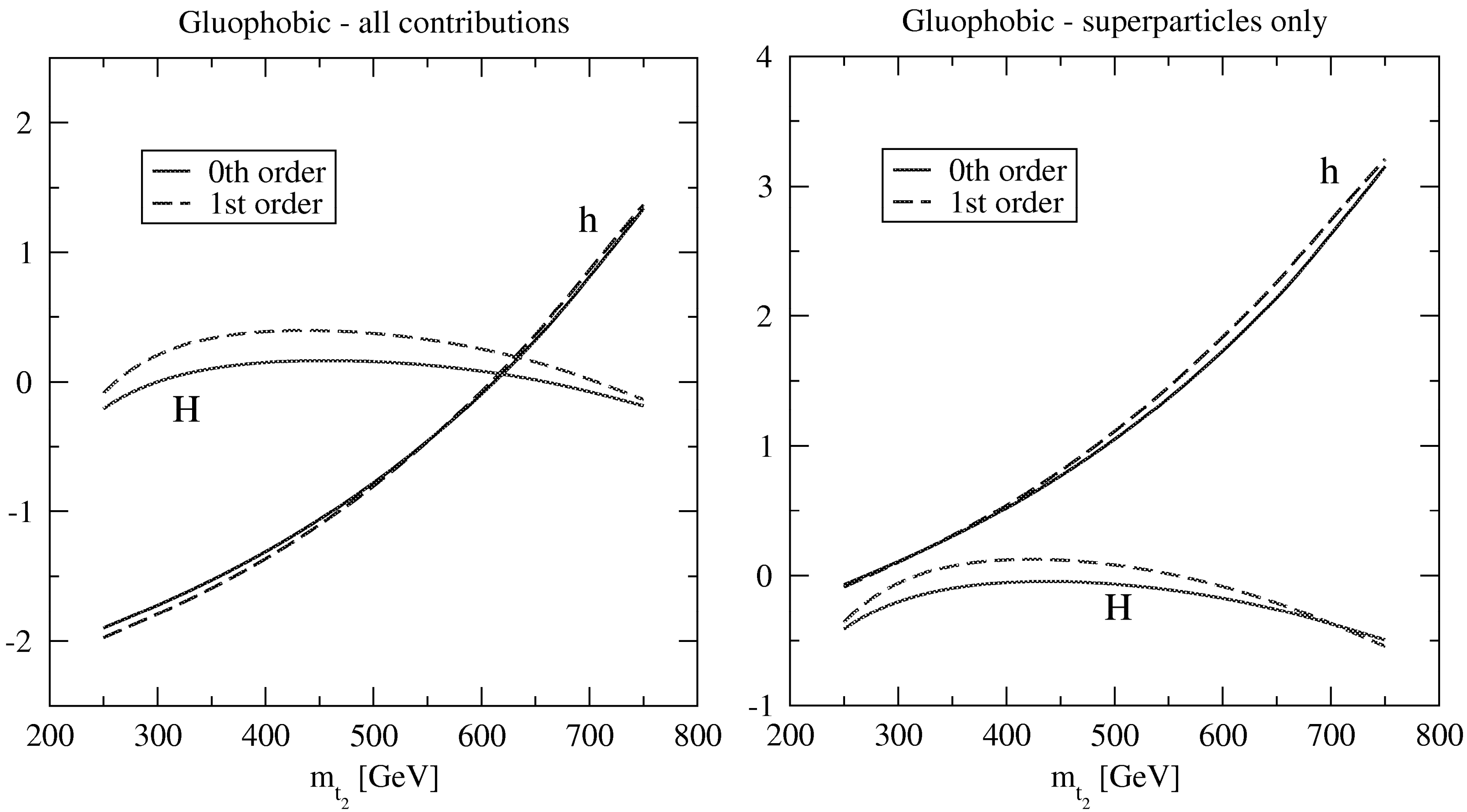
$$\mathcal{H}_h^{2\ell} = T_F\, \left(-\sin\alpha\, \mathcal{H}_1^{2\ell} + \cos\alpha\, \mathcal{H}_2^{2\ell}\right)$$

$$\mathcal{H}_H^{2\ell} = T_F\, \left(\cos\alpha\, \mathcal{H}_1^{2\ell} + \sin\alpha\, \mathcal{H}_2^{2\ell}\right)$$

Gluophobic

Djouadi (98)

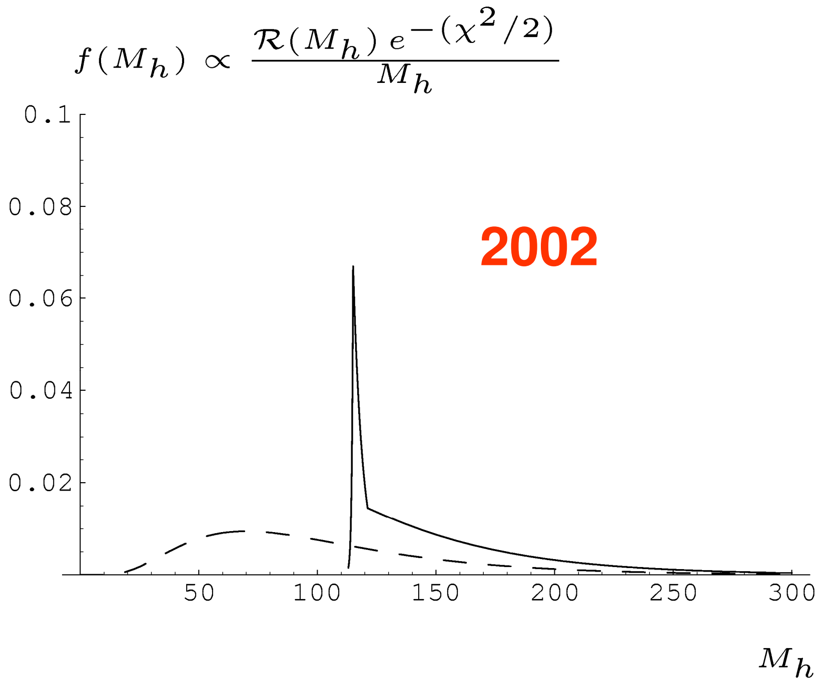
$$\tan\beta = 10, \quad \theta_t = \frac{\pi}{4}, \quad m_A = 300\,\mathrm{GeV}, \quad \mu = -500\,\mathrm{GeV}, \quad m_{\tilde{g}} = 500\,\mathrm{GeV}, \quad m_{\tilde{t}_1} = 200\,\mathrm{GeV}$$

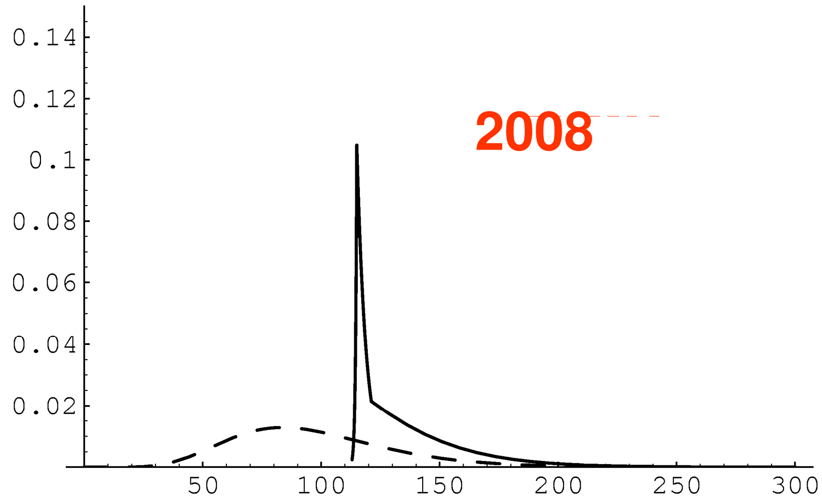


Conclusions

- Theoretical predictions for the SM Higgs boson at LHC are in good shape, QCD@NNLO, EW @NLO +...
- $h \to \gamma\gamma,\ gg \to h$ are affected by NP.
- Colored scalars can significantly modify the gluon-fusion Higgs production cross section and the decay in two photon.
- gluon-fusion Higgs production cross section is fully known at NLO in the MSSM.

Status of the SM Higgs





M_t=174.3±5.1 GeV,

M_W=80.449±0.034 GeV

M_t=172.6±1.4 GeV,

M_W=80.398±0.025 GeV

New values of $M_t,\ M_W$ have significantly reduced the tail

key ingredients: SM couplings HVV, no additional non SM $(\epsilon_1,\ T), (\epsilon_3,\ S)$

A Higgs boson ligther than 220 GeV has no problem with the EW fit.
A Higgs boson heavier than 220 GeV requires NP of non decoupling type