Higgs-Boson Production in Association with Heavy Quarks

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Outline

- Motivation: Quark Yukawa couplings
- SUSY-induced corrections to the b-quark mass
- h^0-production in association with heavy quarks:
  Processes $pp \to b\bar{b}h^0$ and $pp \to t\bar{t}h^0$
- SUSY-QCD corrections
- Numerical Results

Quark Yukawa Couplings

- Coupling between Higgs boson and quarks of Yukawa-type
- proportional to mass of the respective quark
- Size of the Yukawa coupling obtained by comparison with Higgs vacuum expectation value $v = 247$ GeV

$$\Rightarrow \Gamma^{\mathrm{SM}}_{t\bar{t}H} = \frac{m_t}{v} = \frac{172\ \mathrm{GeV}}{247\ \mathrm{GeV}} \simeq 0.7$$
$$\Gamma^{\mathrm{SM}}_{b\bar{b}H} = \frac{m_b}{v} = \frac{4.7\ \mathrm{GeV}}{247\ \mathrm{GeV}} \simeq 0.019$$
$$\Gamma^{\mathrm{SM}}_{c\bar{c}H} = \frac{m_c}{v} = \frac{1.5\ \mathrm{GeV}}{247\ \mathrm{GeV}} \simeq 0.006$$

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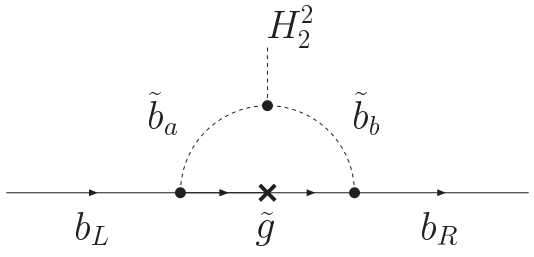
- In the Minimal Supersymmetric Standard Model (MSSM) with $H \to h^0$: (h^0: lighter CP-even neutral Higgs boson)

$$\Gamma^{\text{MSSM}}_{b\bar{b}h^0} = -\frac{\sin\alpha}{\cos\beta}\Gamma^{\text{SM}}_{b\bar{b}H} \overset{(m_A \text{ not too large})}{=} -\tan\beta\,\Gamma^{\text{SM}}_{b\bar{b}H}$$
$$\Gamma^{\text{MSSM}}_{t\bar{t}h^0} = \frac{\cos\alpha}{\sin\beta}\Gamma^{\text{SM}}_{t\bar{t}H} \overset{(m_A \text{ not too large})}{=} \frac{1}{\tan\beta}\,\Gamma^{\text{SM}}_{t\bar{t}H}$$

Corrections to the b-quark mass

[Carena, Garcia, Nierste, Wagner 1999]
[Guasch, Hollik, Penaranda 2001]

In the MSSM the mass of the b-quark receives large SUSY-QCD one-loop corrections, induced by



$$\approx -\frac{2}{3\pi}\,\alpha_s\,\mu\tan\beta\,m_{\tilde{g}}\,C_0(0,0,0,m^2_{\tilde{b}_1},m^2_{\tilde{b}_2},m^2_{\tilde{g}}) \equiv \Delta m_b$$

$$\propto \alpha_s \frac{\mu m_{\tilde{g}}}{M^2_{SUSY}}\tan\beta \quad (\mu : \text{Higgs super field mass term})$$

$$\approx \mathcal{O}(1) \text{ for large } \tan\beta$$

$\Rightarrow$ Regard this corrections as a redefinition of the b-quark Yukawa coupling and write the b-quark mass as

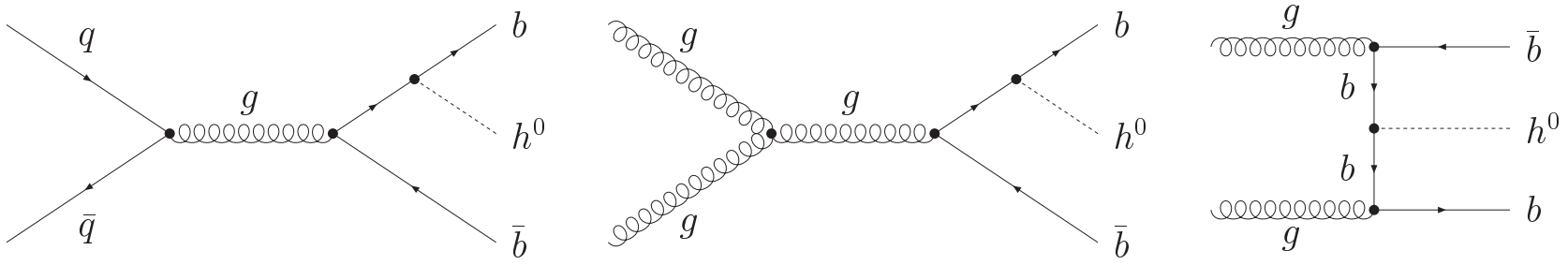
$$m_b \to m_b \frac{1}{1+\Delta m_b}$$

To be able to compare with one-loop results an expansion of the above-mentioned expression up to order α_s is necessary:

$$m_b \to m_b\,(1-\Delta m_b)$$

Tree-level Processes

- Tree-level diagrams appearing in $b\bar{b}h^0$ production

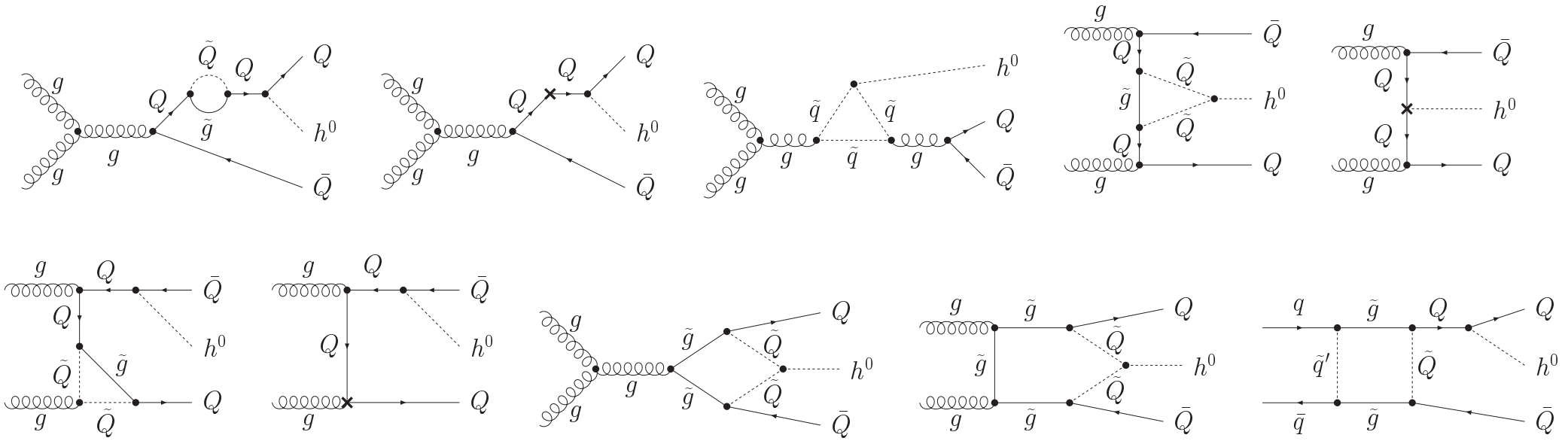


- $t\bar{t}h^0$ diagrams obtained by replacement $b \longrightarrow t$
- t-quark decays rapidly (mainly into $t \longrightarrow bW$) and outgoing b-quarks can be detected via b-tagging
- Process is possible discovery channel for Higgs bosons and important to determine the size of the respective Yukawa coupling
- SM-QCD corrections already known in both cases

[Balazs, He, Yuan; Dicus, Stelzer, Sullivan, Willenbrock 1999]
[Beenakker et al.; Dawson, Orr, Reina, Wackeroth 2001,2003]
[Dittmaier, Krämer, Spira; Dawson, Jackson, Reina, Wackeroth 2004]

SUSY-QCD corrections

- SUSY-QCD corrections partly known in the literature
  $b\bar{b}h^0$: effective $b\bar{b}h^0$ coupling [Gao, Oakes, Yang 2005]
  $t\bar{t}h^0$: complete SUSY-QCD corrections [Peng et al. 2005]
- For both processes complete SUSY-QCD corrections calculated on the one-loop level
- Sample Feynman diagrams:



$b\bar{b}h^0$ production

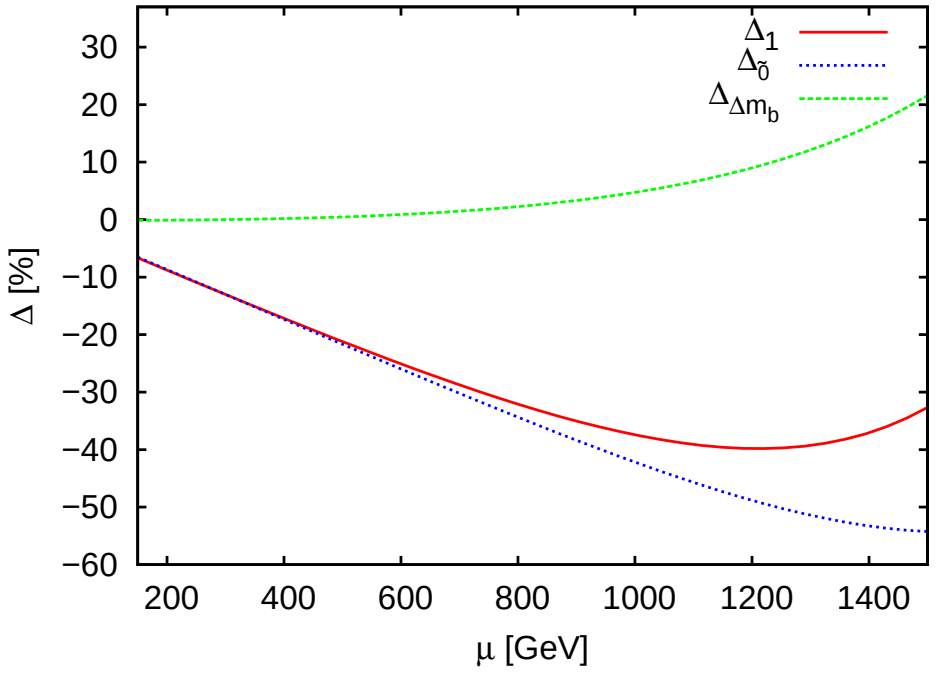
- For the MSSM reference point SPS1a′:

Partonic subprocess	σ_0 [fb]	σ_1 [fb]	Δ_1 [%]	$\Delta_{\tilde{0}}$ [%]
$d\bar{d} \to b\bar{b}h^0$	0.107	0.104	−2.48	−1.95
$u\bar{u} \to b\bar{b}h^0$	0.168	0.164	−2.56	−1.95
$s\bar{s} \to b\bar{b}h^0$	0.028	0.028	−2.26	−1.95
$c\bar{c} \to b\bar{b}h^0$	0.013	0.012	−2.20	−1.95
$gg \to b\bar{b}h^0$	35.647	33.734	−5.37	−1.95
$\sum (pp \to b\bar{b}h^0)$	35.963	34.042	−5.34	−1.95

  where $\Delta_1 = \frac{\sigma_1 - \sigma_0}{\sigma_0}$, $\Delta_{\tilde{0}} = \frac{\sigma_\Delta - \sigma_0}{\sigma_0}$, σ_Δ: Δm_b-corrected tree-level c.s.

- Only t-channel diagram gives significant contribution (s-channel diagrams propagator-suppressed)
- Corrections numerically significant; true one-loop corrections, which are not parametrised by Δm_b, form an important part

SUSY-QCD Corrections to $b\bar{b}h^0$-production



Parameters used in the plot:

$$m_A = 200 \text{ GeV}$$
$$\tan\beta = 30$$
$$A_t = A_b = 0$$
$$M_{\text{SUSY}} \equiv M_{\tilde{Q}} = M_{\tilde{U}} = M_{\tilde{D}} = 250 \text{ GeV}$$
$$m_{\tilde{g}} = 400 \text{ GeV}$$
$$p_T(b, \bar{b}) \geq 20 \text{ GeV}$$

Δ: relative difference between

Δ_1: one-loop and tree-level cross section

$\Delta_{\tilde{0}}$: Δm_b-corrected tree-level and tree-level c.s.

$\Delta_{\Delta m_b}$: one-loop and Δm_b-corrected tree-level c.s.

(i.e. true one-loop corrections)

$t\bar{t}h^0$ production

- For the MSSM reference point SPS1a′:

Partonic subprocess	σ_0 [fb]	σ_1 [fb]	Δ_1 [%]
$d\bar{d} \to t\bar{t}h^0$	42.7	37.6	−11.77
$u\bar{u} \to t\bar{t}h^0$	71.9	63.4	−11.81
$s\bar{s} \to t\bar{t}h^0$	7.5	6.6	−11.58
$c\bar{c} \to t\bar{t}h^0$	2.8	2.5	−11.53
$gg \to t\bar{t}h^0$	273.7	264.7	−3.30
$\sum (pp \to t\bar{t}h^0)$	399.0	374.8	−5.96

  where $\Delta_1 = \frac{\sigma_1 - \sigma_0}{\sigma_0}$

- All diagram types must be taken into account
- S-channel suppression compensated by lower gluon densities at higher x
- Contribution to the total cross section significant

Conclusions

- h^0-production in association with heavy quarks important process:
  - Discovery channel for Higgs bosons
  - Precise measurement of Yukawa couplings
- SUSY-QCD corrections provide significant contribution to the total cross section
- For final-state bottom quarks in certain regions of MSSM parameter space well approximated by Δm_b-corrected tree-level cross section
- When off-diagonal elements of the sbottom mixing matrix become large, other terms also give significant contributions and reduce the overall size of the corrections
- Remaining contribution can still reach up to 40%
- In the top-quark case corrections of the order of several percent appear