

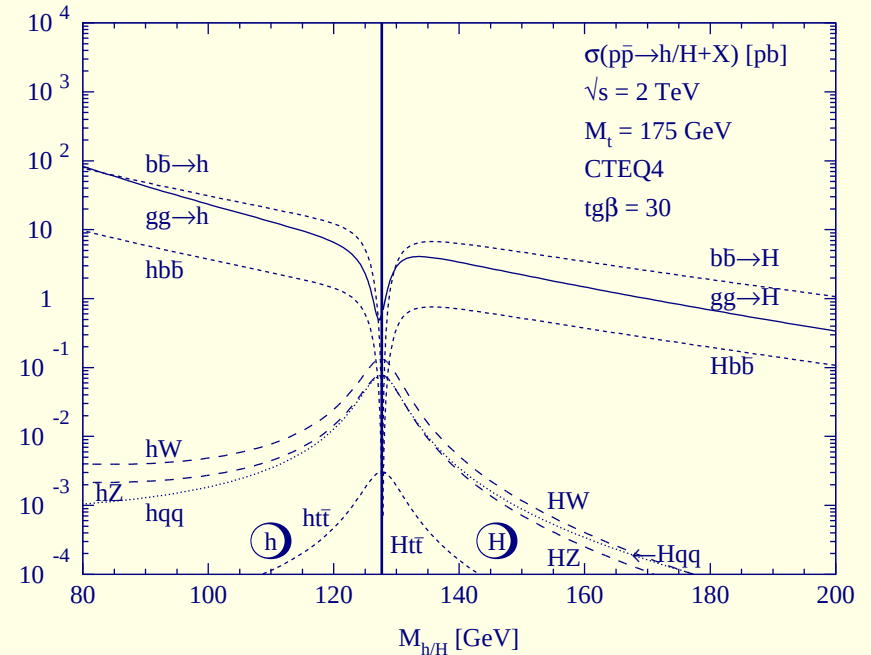
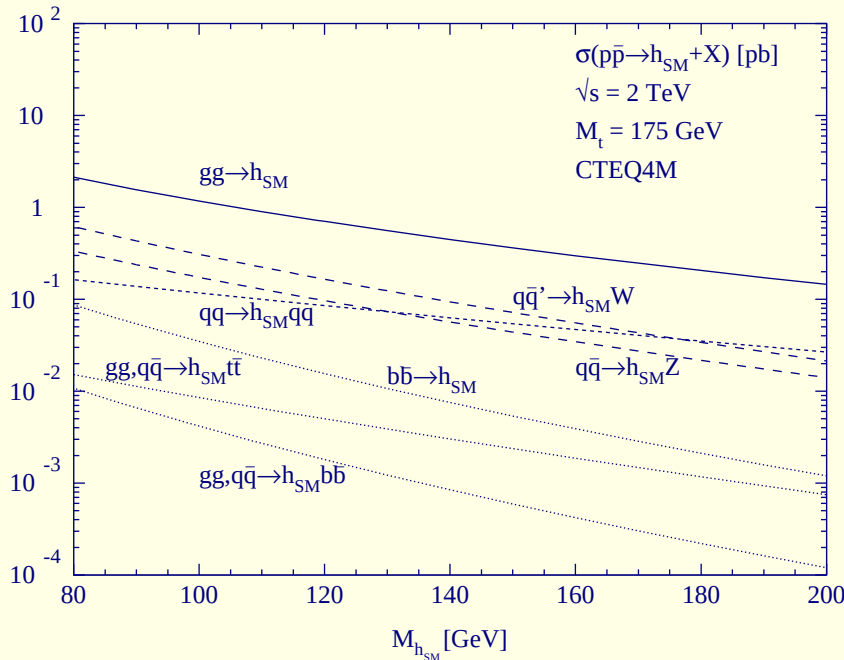
Higgs Boson Production with a Single Bottom Quark at Hadron Colliders

Chris Jackson (Florida State University)

TeV4LHC, September 2004

with S. Dawson (BNL), L. Reina (FSU), and D. Wackeroth (SUNY-Buffalo)

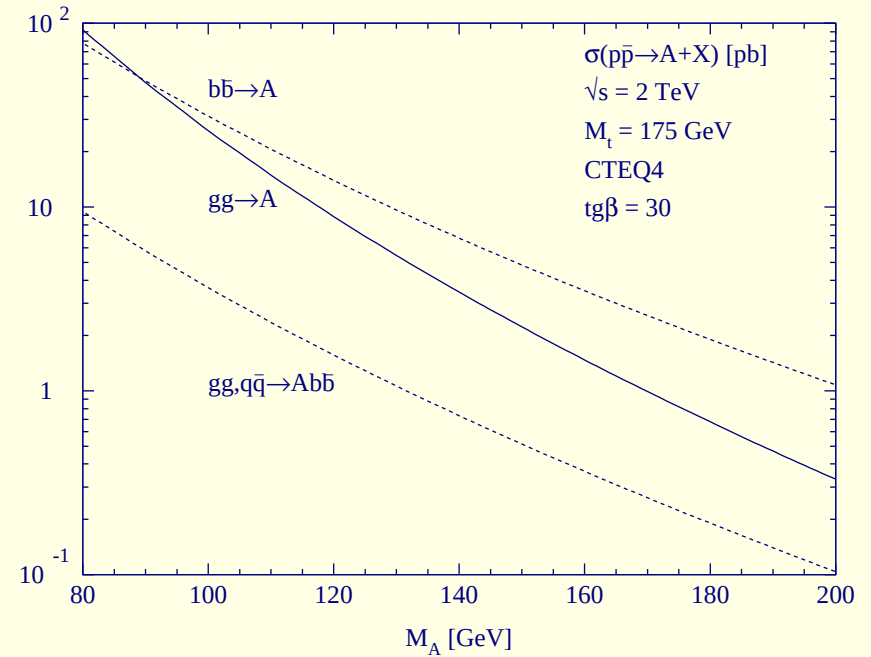
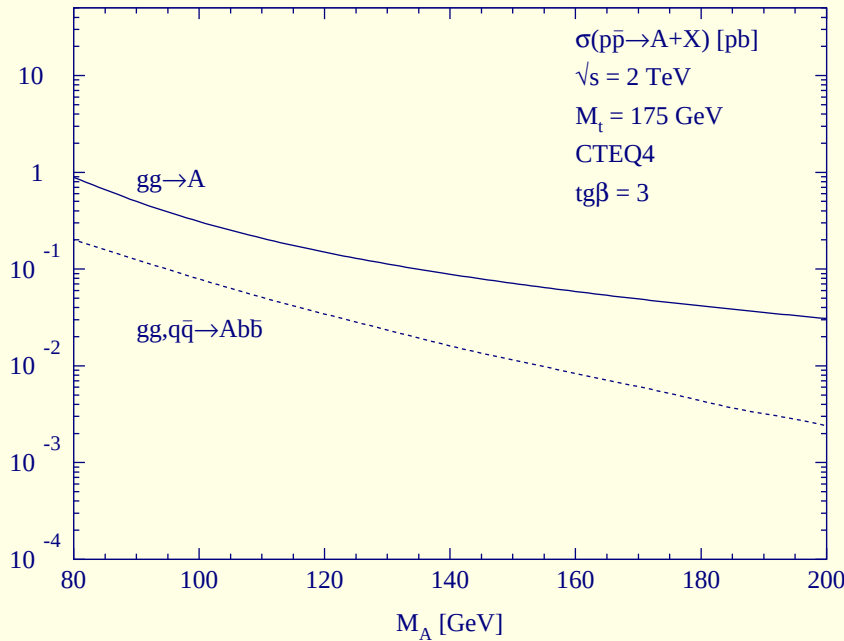
SM vs. MSSM Higgs Production at the Tevatron



(from M. Carena, H. Haber, Prog.Part.Nucl.Phys.50(2003))

- In **SM**, $b\bar{b}h$ suppressed due to smallness of $g_{hb\bar{b}} \sim \frac{m_b}{v}$
- For **MSSM**, Yukawa coupling enhanced: $g_{bb(h^0, H^0)}^{MSSM} = \frac{(-\sin\alpha, \cos\alpha)}{\cos\beta} g_{bbh}$
- $\sigma_{(h^0, H^0)b\bar{b}}$ comparable or larger than $\sigma_{gg \rightarrow (h^0, H^0)}$

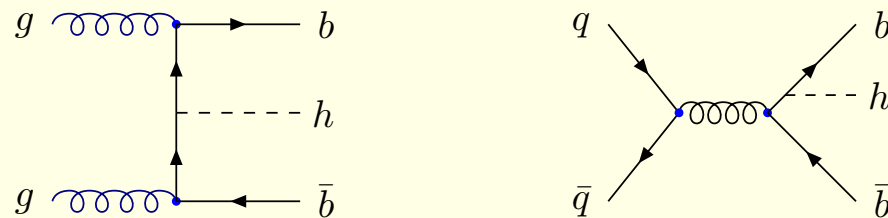
Pseudoscalar Higgs Production at the Tevatron



(from M. Carena, H. Haber, Prog.Part.Nucl.Phys.50(2003))

- For **large $\tan\beta$** , production of A^0 with b quarks enhanced
- In the $m_b = 0$ approximation, $\sigma_{A^0 b\bar{b}} = \sigma_{(h^0, H^0) b\bar{b}}$ (up to **rescaling** of MSSM couplings)

Four Flavor Number Scheme (4FNS)



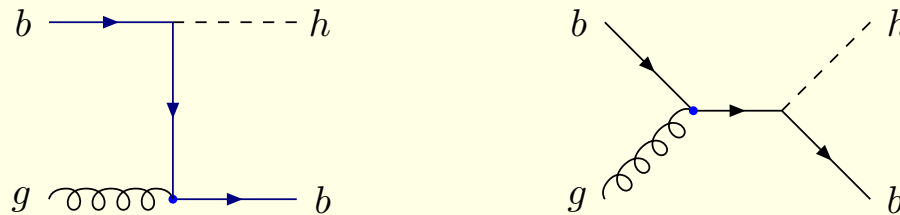
- Two independent calculations of NLO QCD corrections:
 - S. Dittmaier, M. Krämer, M. Spira, hep-ph/0309204
 - S. Dawson, C.J., L. Reina, D. Wackerath , PRD 69 074027 (2004)
- Setup:
 - Require at least one high- p_T b jet in final state: $p_T^{b,\bar{b}} > 20$ GeV and $|\eta_{b,\bar{b}}| < 2(2.5)$ Tevatron (LHC)
 - Radiated g and $b/\bar{b}$ distinct only if $\Delta R > 0.4$

Five Flavor Number Scheme (5FNS)

- Physical process $gg \rightarrow b\bar{b}h$ contains large logs ($\Lambda_b \equiv \log(\frac{Q^2}{m_b^2})$) from **collinear** splitting $g \rightarrow b\bar{b}$
- Introduce (theoretically defined) **b -quark PDF**:

$$\tilde{b}(x, \mu) = \frac{\alpha_s(\mu)}{2\pi} \log\left(\frac{\mu^2}{m_b^2}\right) \int_x^1 \frac{dy}{y} P_{qg}\left(\frac{x}{y}\right) g(y, \mu)$$

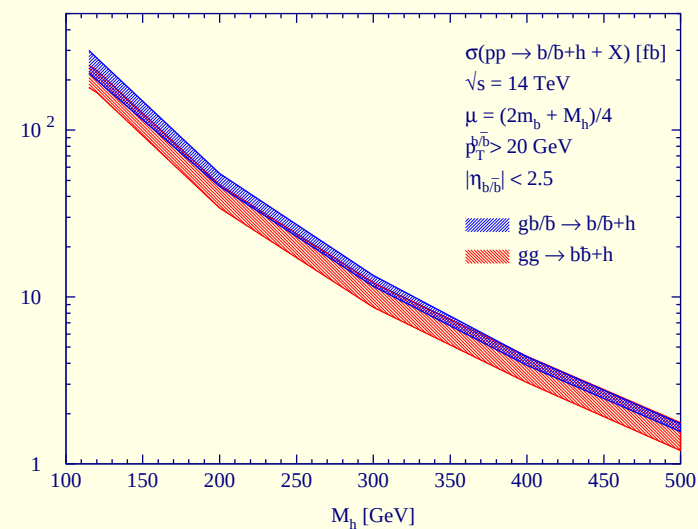
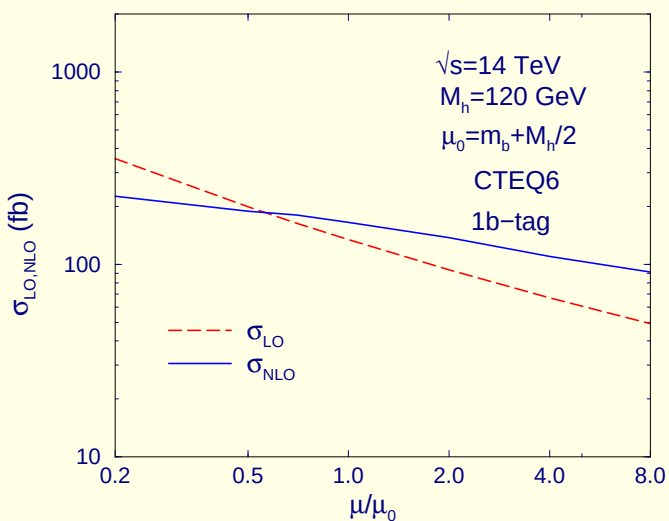
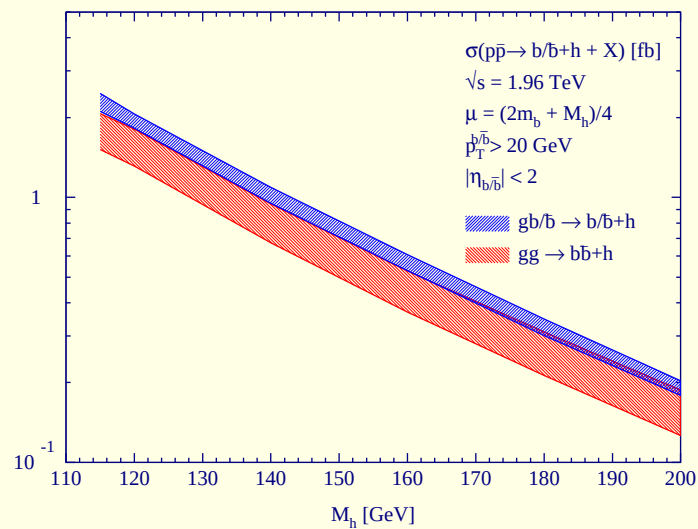
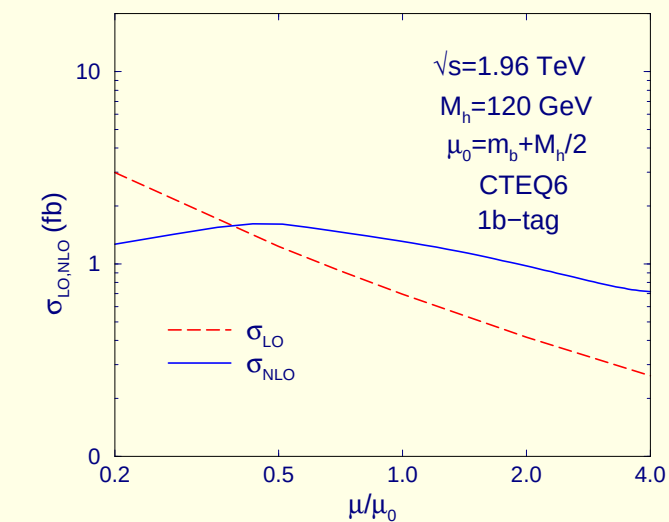
- Leading Process in 5FNS:



(@ NLO: Campbell, Ellis, Maltoni and Willenbrock PRD 67 095002 (2003))

- Important to study **validity/compatibility** of 4FNS/5FNS

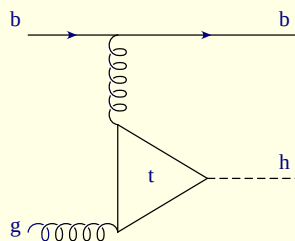
Results for $b\bar{h}$ Production



(from J. Campbell et. al. (Higgs Working Group), Les Houches workshop on Physics at TeV Colliders (2004), hep-ph/0405302)

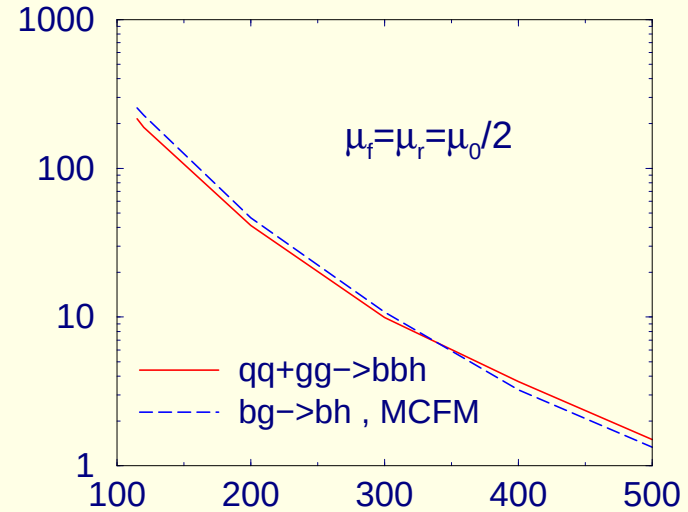
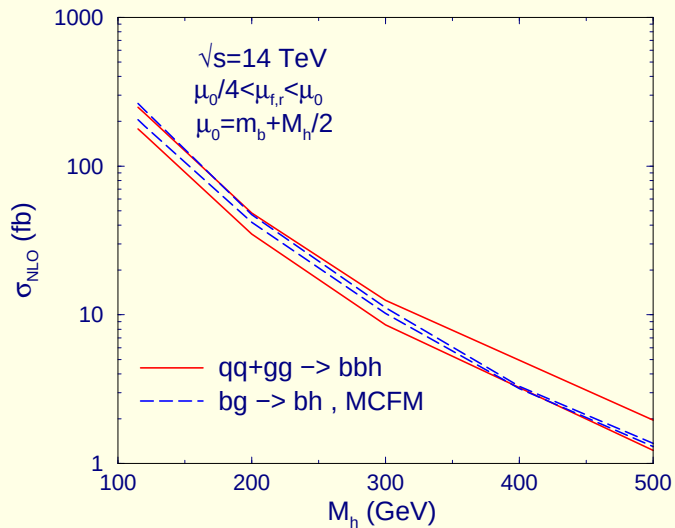
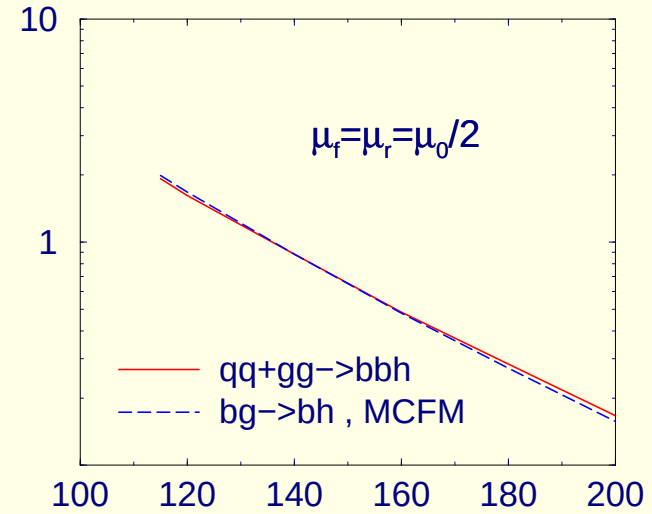
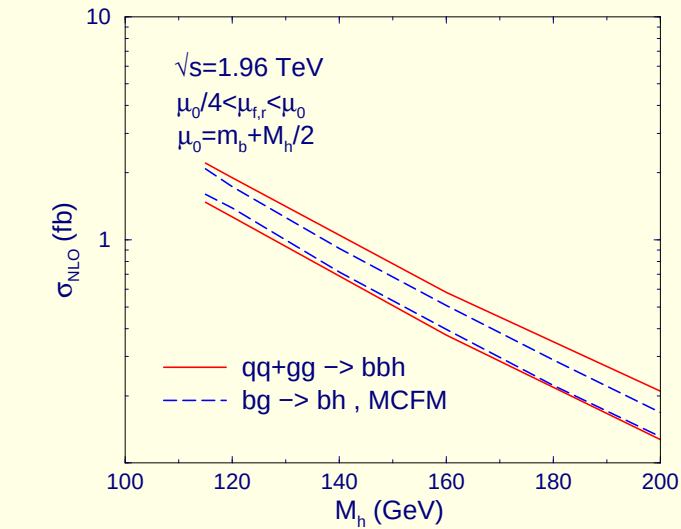
Not the End of the Story

- Diagrams containing loops of top (bottom) quarks **neglected** in 5FNS calculation of SM (MSSM) cross section



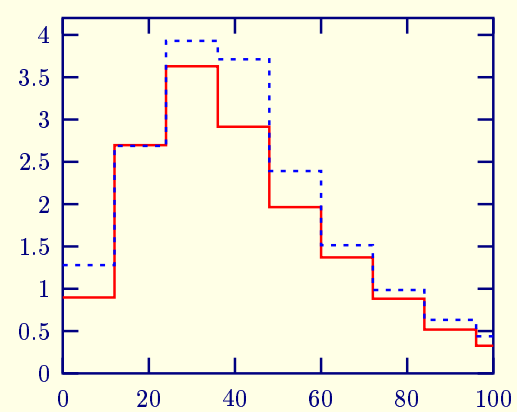
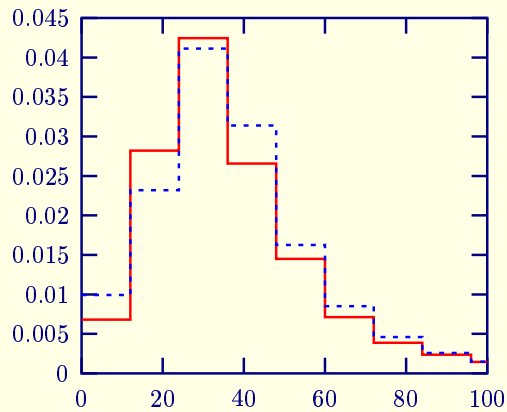
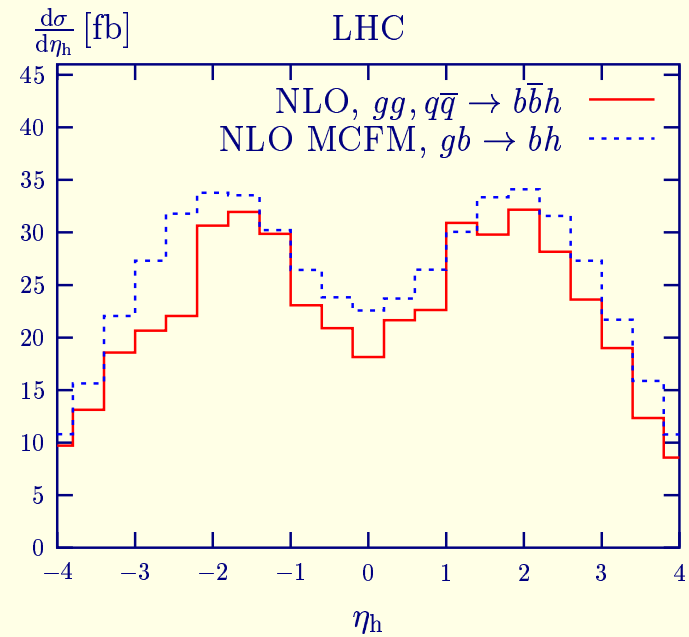
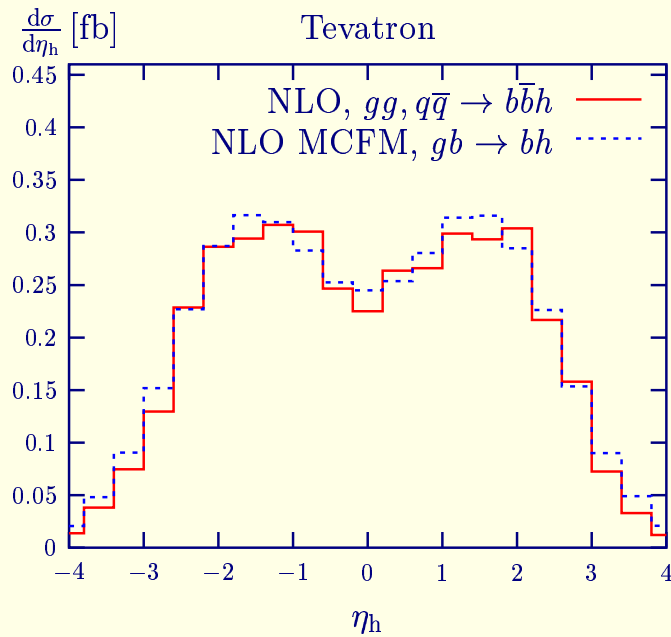
- $bg \rightarrow bh$ @ NLO performed in the $m_b = 0$ approximation:
 - Top (bottom) loop diagrams** neglected since $\sigma_\Delta \propto m_b$
 - In SM, $\sigma_\Delta \sim \mathcal{O}(g_{hbb}g_{htt}\frac{m_b}{m_t}) \sim \mathcal{O}(g_{hbb}^2) \rightarrow$ **could be numerically important!**
- To compare 4FNS and 5FNS for bh production, we coded σ_Δ into **MCFM** (Campbell and Ellis, webpage:mcfm.fnal.gov)
- Including top loop lowers $\sigma_{gb \rightarrow bh}$ by **15%(10%)** at the Tevatron (LHC)

Results for bh Production ...again



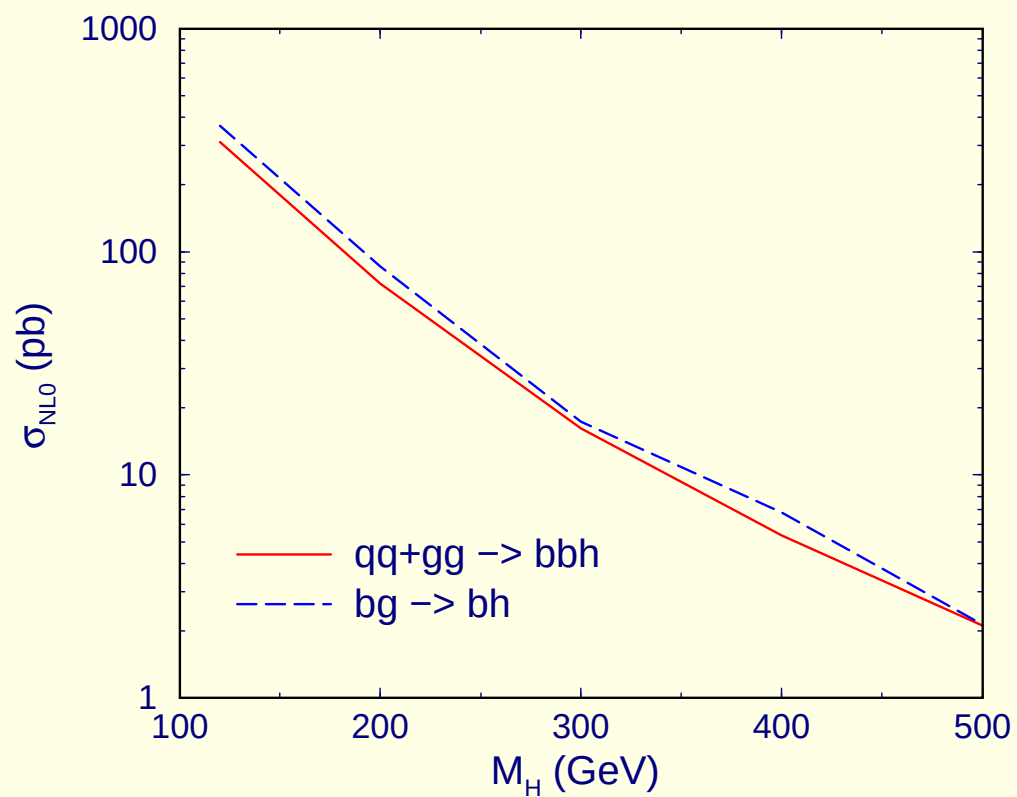
(from S. Dawson, C.J., L. Reina and D. Wackerroth (2004), hep-ph/0408077)

η_h and p_T Distributions for bh Production



(from S. Dawson, C.J., L. Reina and D. Wackerroth (2004), hep-ph/0408077)

MSSM bH^0 Production



- For $\tan \beta = 40$, $\sigma_{\Delta} \leq 0.08\%$ in $gb \rightarrow bH^0$

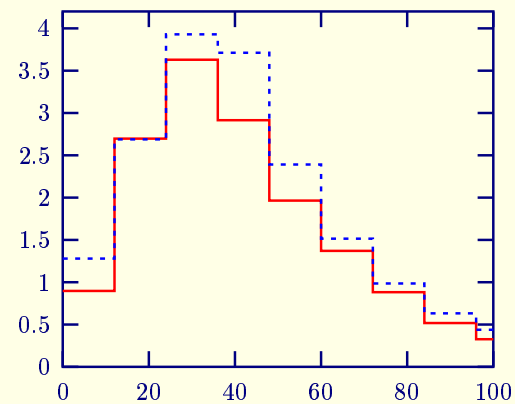
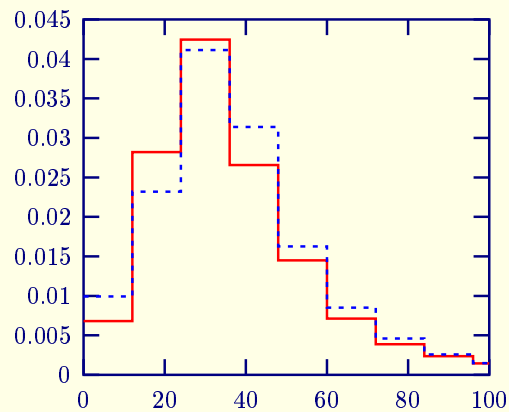
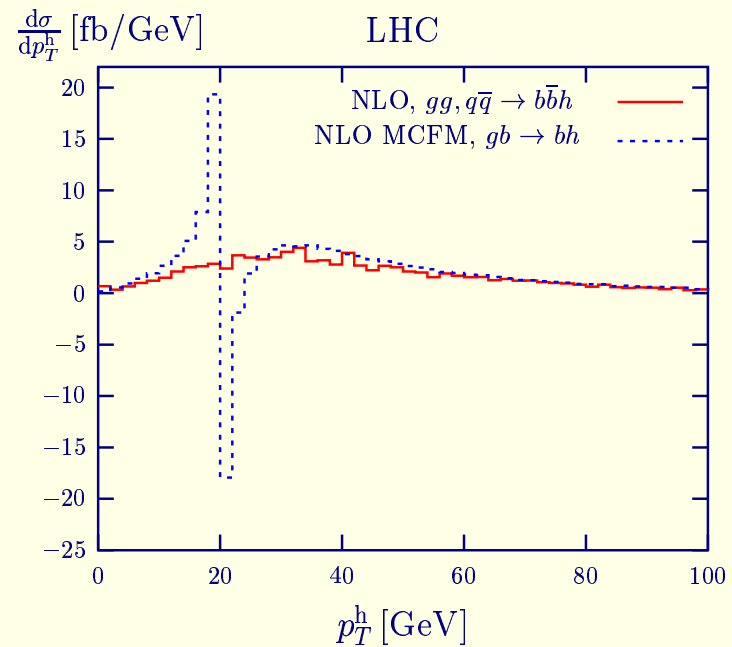
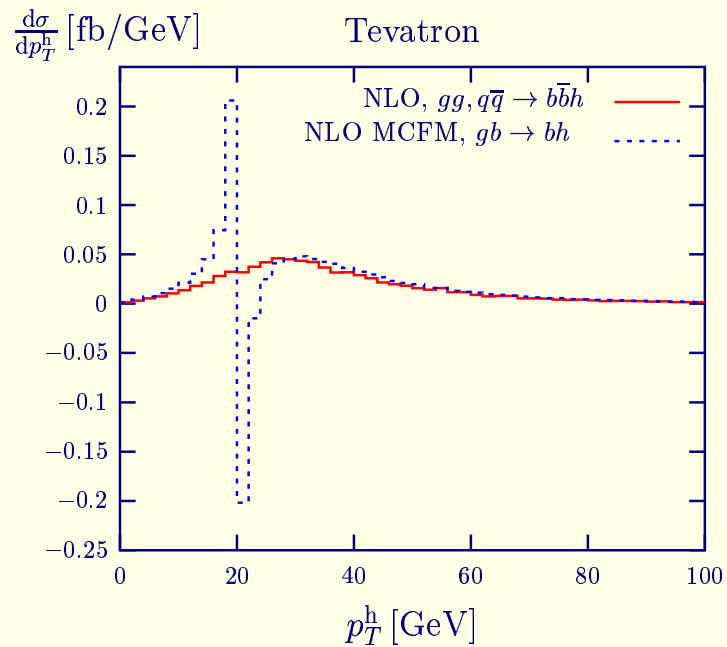
Summary

- Higgs production w/ b quarks can play a **significant role** in the discovery of a Higgs for models w/ enhanced b quark Yukawa couplings (e.g. 2HDM, MSSM)
- **Unique opportunity** to directly probe $g_{(h^0, H^0)b\bar{b}}$ and/or $g_{A^0b\bar{b}}$
- Two independent calculations of NLO QCD corrections for **4FNS** (with good agreement) show drastically reduced renormalization/factorization dependence
- After inclusion of **top-loop diagrams** in **5FNS** calculation, excellent agreement between 4FNS/5FNS for $(h^0, H^0)b$ production

Further Reading

- Exclusive Production:
 - S. Dittmaier, M. Kramer, M. Spira (hep-ph/0309204)
 - S. Dawson, C.J., L. Reina, D. Wackerroth (PRD 69 074027 (2004))
- Inclusive and Semi-inclusive Production:
 - Harlander and Kilgore (PRD 68 013001(2003))
 - J. Campbell et. al. (PRD 67 095002 (2003))
- Comparison between 4FNS/5FNS:
 - LH HWG (hep-ph/0405302)
 - S. Dawson, C.J., L. Reina and D. Wackerroth , hep-ph/0408077

p_T Distributions for Semi-inclusive Production



(from S. Dawson, C.J., L. Reina and D. Wackerroth (2004), hep-ph/0408077)

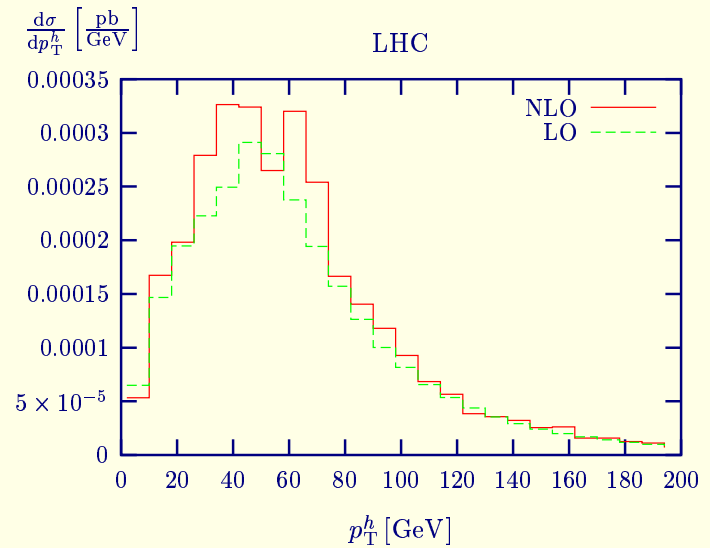
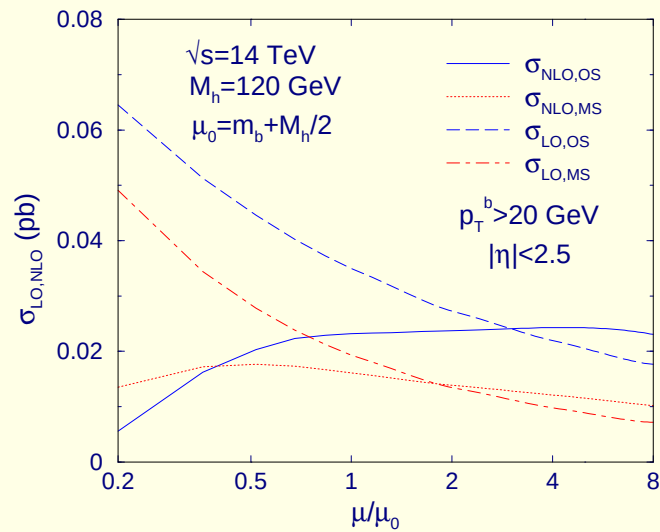
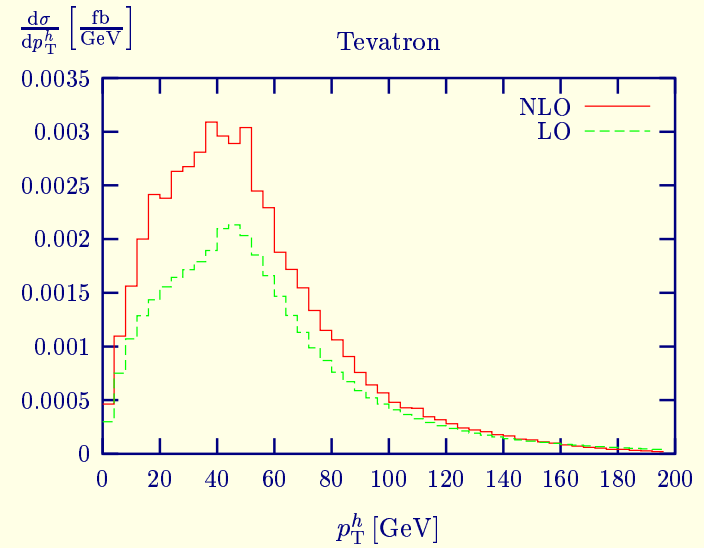
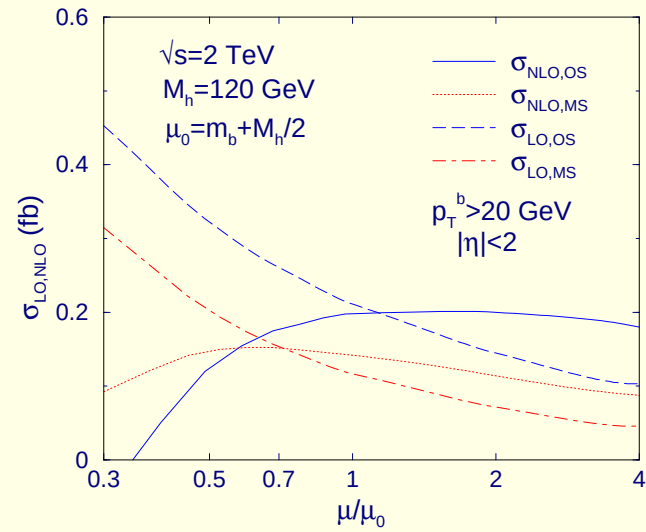
“Divergences” in p_T Distributions

- Similar effects seen in Drell-Yan $Q_\perp$ distributions (for review, see S. Catani and B.R. Webber, hep-ph/9710333)
- At LO, Higgs recoils against b jet:
 - p_T cut on b jet $\implies$ cut on p_T^h
 - $(\frac{d\sigma}{dp_T^h})_{LO} \rightarrow$ “non-smooth” function
- In the region of the “cut” on p_T^h , the NLO c.s. is the convolution of the LO c.s. with a “soft gluon probability”
 - “Soft gluon probability” $\rightarrow$ “plus” distribution
$$\text{“non-smooth” } f(z) = \longrightarrow \int_0^1 dz f(z)[g(z)]_+ = \text{“logarithmic divergences”}$$
- Improvement through resummation techniques (see, e.g. N. Kidonakis, hep-ph/9902484)

Exclusive $b\bar{b}h$ Production

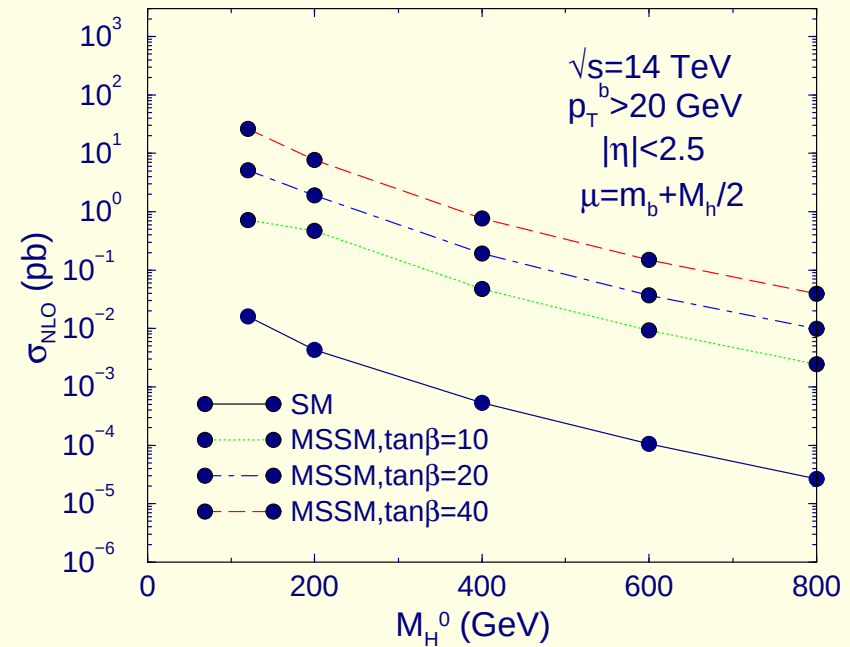
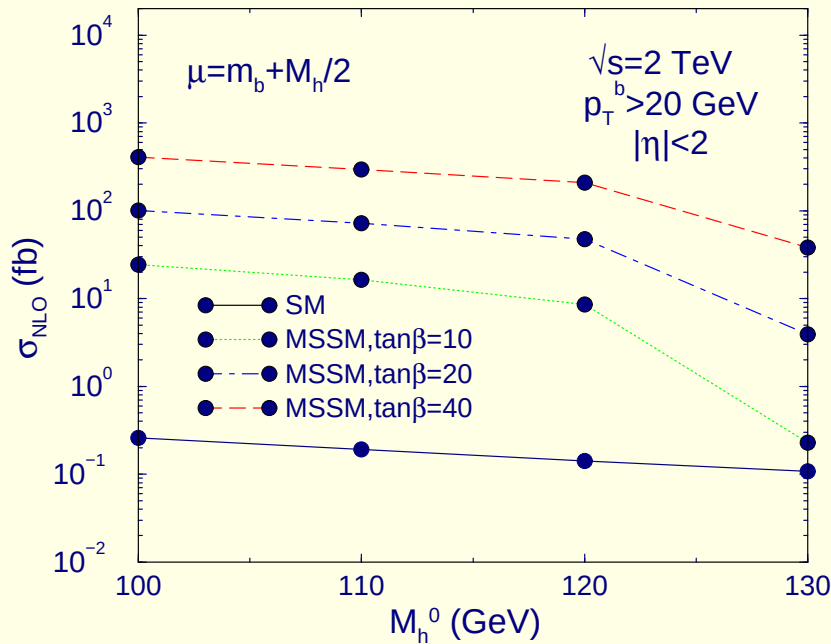
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- Setup:
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 - Radiated g and $b/\bar{b}$ distinct only if $\Delta R > 0.4$
- Cuts reduce signal and background
- Factorization/renormalization scale dependence reduced
- Given large sensitivity of $m_b(\mu_r)$ on μ_r , also investigated renormalization scheme dependence for m_b
 - OS vs. $\overline{MS}$: at $\mathcal{O}(\alpha_s^3)$ both are perturbatively consistent
 - Difference being at higher orders $\rightarrow$ theoretical uncertainty $\approx 15 - 20\%$

Results for Exclusive $b\bar{b}h$ Production



(from S. Dawson, C.J., L. Reina and D. Wackeroth, PRD 69, 074027 (2004))

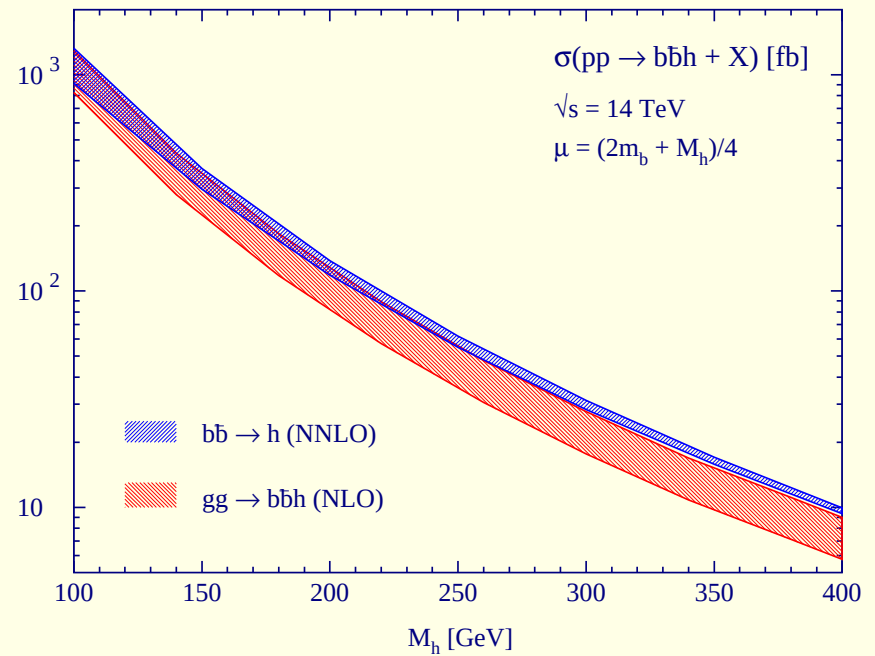
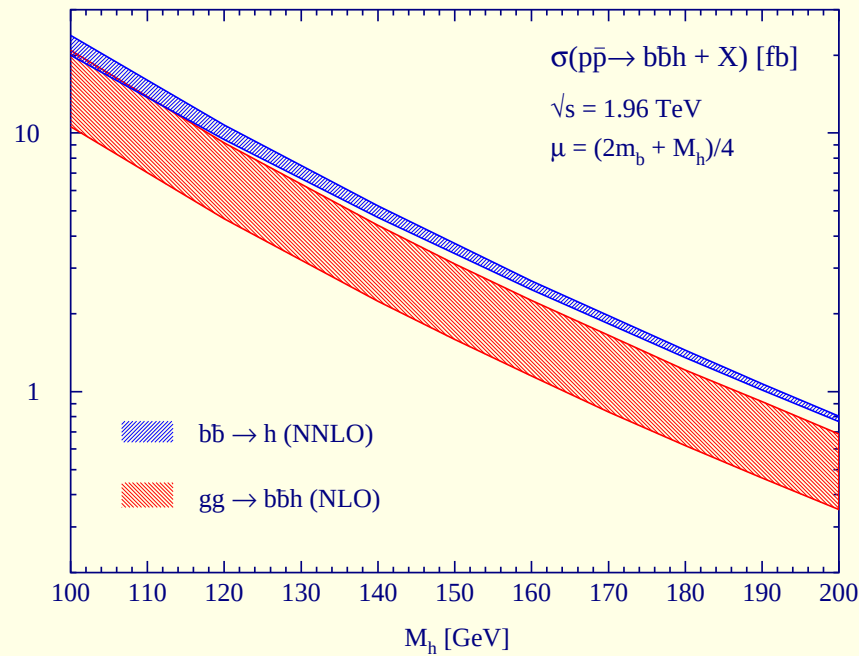
$M_H, \tan \beta$ Dependence for Exclusive $b\bar{b}(h^0, H^0)$



(from S. Dawson, C.J., L. Reina, D. Wackeroth, PRD 69,074027 (2004))

- Large $\tan \beta \rightarrow$ top loop suppressed
- Good approximation: $\sigma_{NLO}(MSSM) \sim \sigma_{NLO}(SM) \left(\frac{g_{bbh}^{MSSM}}{g_{bbh}^{SM}} \right)^2$

Results for Inclusive $(b\bar{b})h$ Production



(from J. Campbell et. al. (Higgs Working Group), Les Houches workshop on Physics at TeV Colliders (2004), hep-ph/0405302)