Higgs Boson Production with Bottom Quarks at Hadron Colliders

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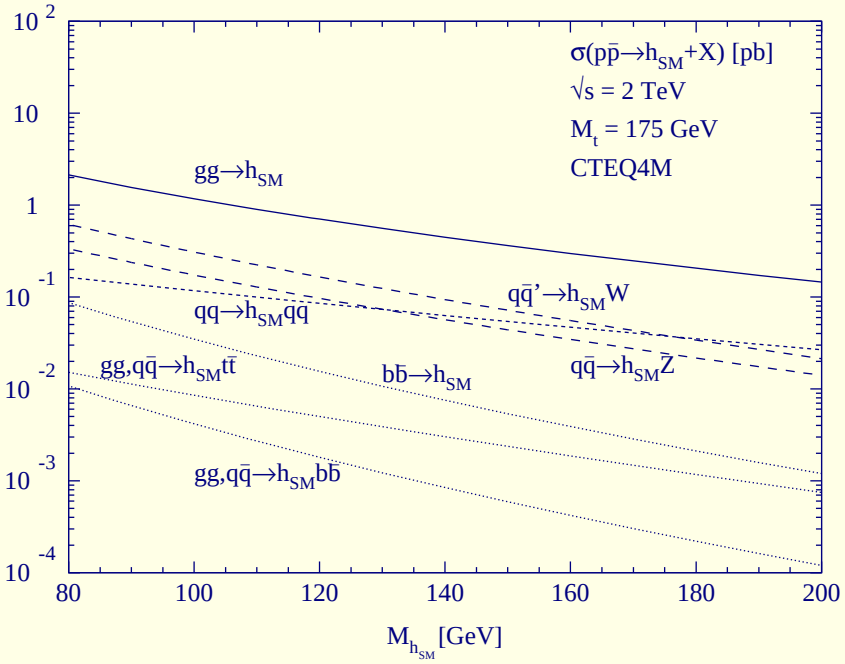
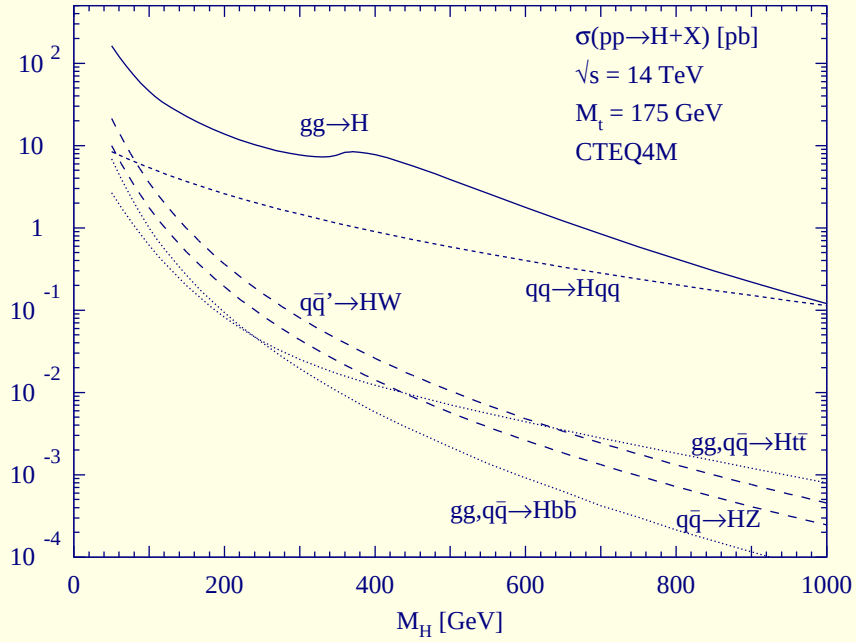
SM Higgs Production at Hadron Colliders

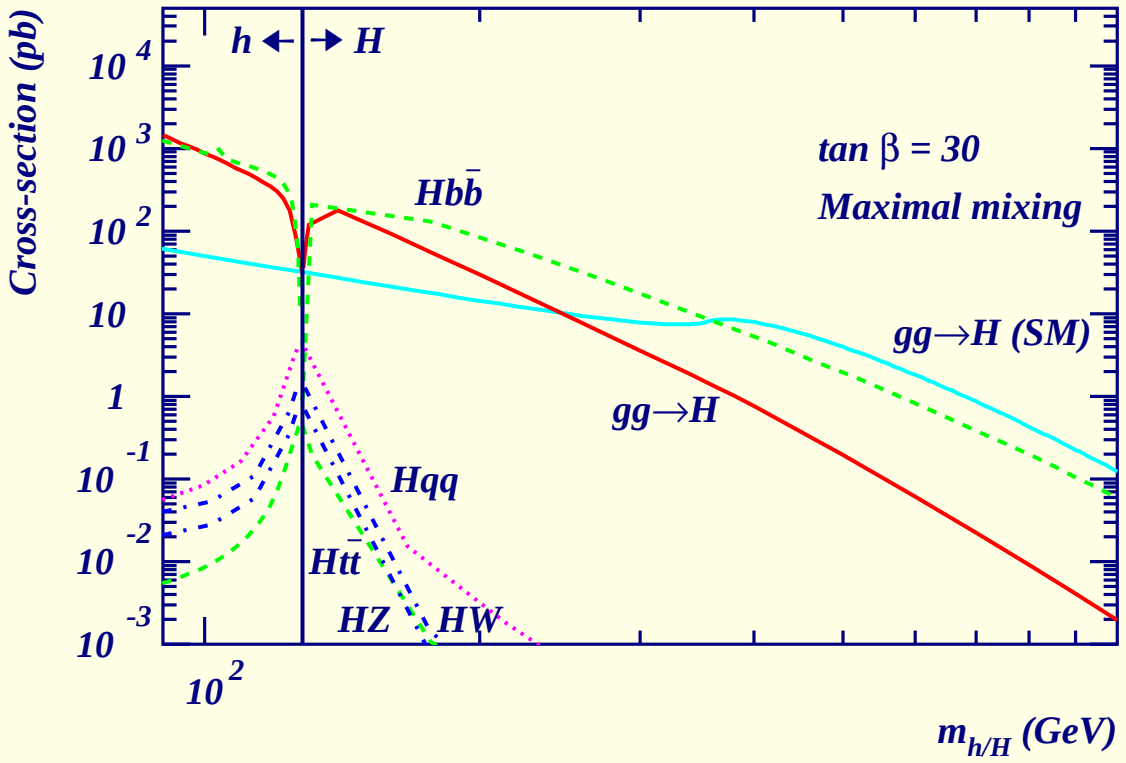




(from M. Carena, H. Haber, Prog.Part.Nucl.Phys.50(2003))

- In SM, Higgs production dominated by $gg \to h$
- $b\bar{b}h$ suppressed due to smallness of $g_{hb\bar{b}} \sim \frac{m_b}{v}$

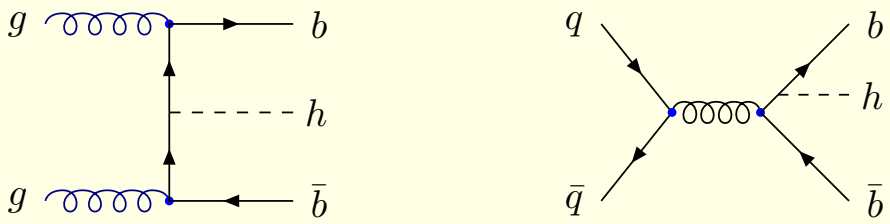
MSSM Higgs Production at Hadron Colliders



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

- Yukawa coupling enhanced: $g^{MSSM}_{bb(h^0,H^0)} = \frac{(-\sin\alpha, \cos\alpha)}{\cos\beta} g_{bbh}$
- $\sigma_{(h^0,H^0)b\bar{b}}$ comparable or larger than $\sigma_{gg\to(h^0,H^0)}$

Four Flavor Number Scheme (4FNS)



- Tagging b jets:
  - inclusive $\equiv$ no cuts on p_T of b's
  - semi-inclusive $\equiv$ one high-p_T b
  - exclusive $\equiv$ two high-p_T b's
- (Semi-)Inclusive c.s. develops potentially large log's ($\Lambda_b \equiv \log(\frac{Q^2}{m_b^2})$) from collinear splitting ($g \to b\bar{b}$)
- Perturbative expansion: $\alpha_s \to \alpha_s \Lambda_b$

Exclusive $b\bar{b}h$ Production

- Two independent calculations of NLO QCD corrections:
  - S. Dittmaier, M. Kramer, M. Spira (hep-ph/0309204)
  - S. Dawson, C.J., L. Reina, D. Wackeroth (PRD 69 074027 (2004))

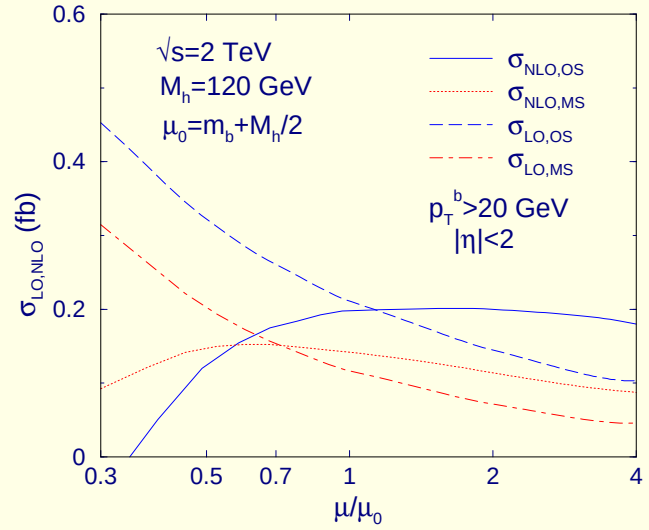
- Setup:
  - Require two high-p_T b jets in final state: $p_T^{b,\bar{b}} > 20$ GeV and $|\eta_{b,\bar{b}}| < 2(2.5)$ Tevatron (LHC)
  - Radiated g and $b/\bar{b}$ distinct only if $\Delta R > 0.4$

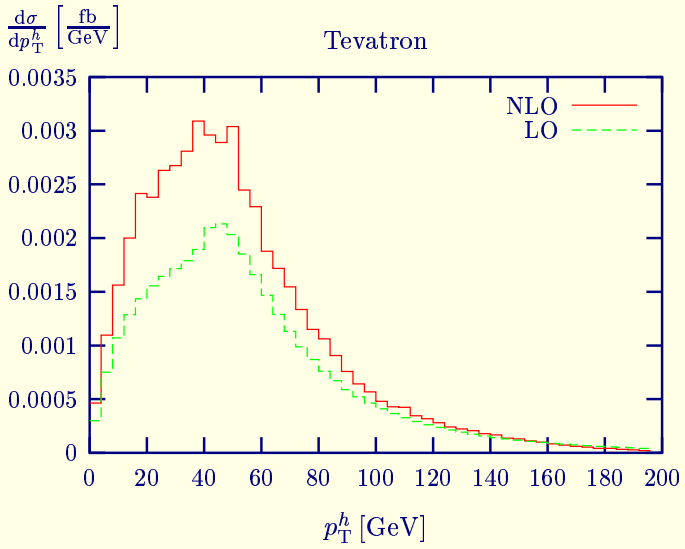
- Cuts reduce signal and background

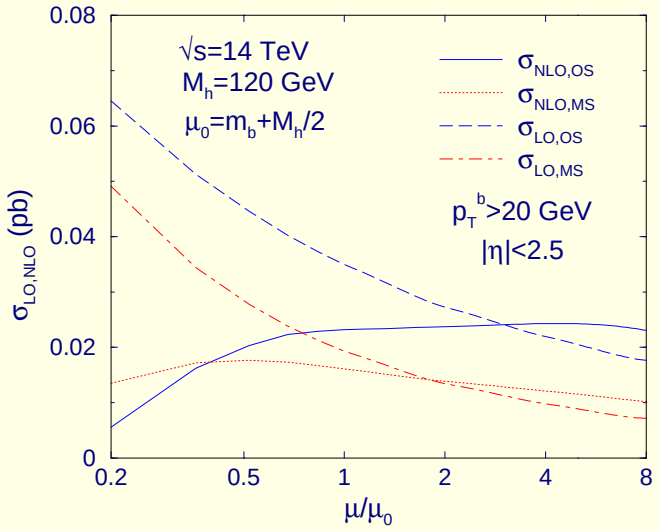
- Factorization/renormalization scale dependence reduced

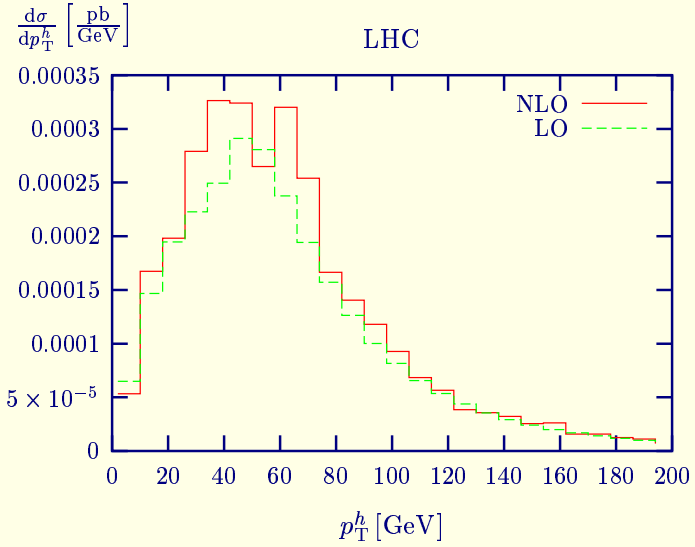
- Given large sensitivity of $m_b(\mu_r)$ on μ_r, also investigated renormalization scheme dependence for m_b
  - OS vs. $\overline{MS}$: at $\mathcal{O}(\alpha_s^3)$ both are perturbatively consistent
  - Difference being at higher orders $\rightarrow$ theoretical uncertainty $\approx 15 - 20\%$

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



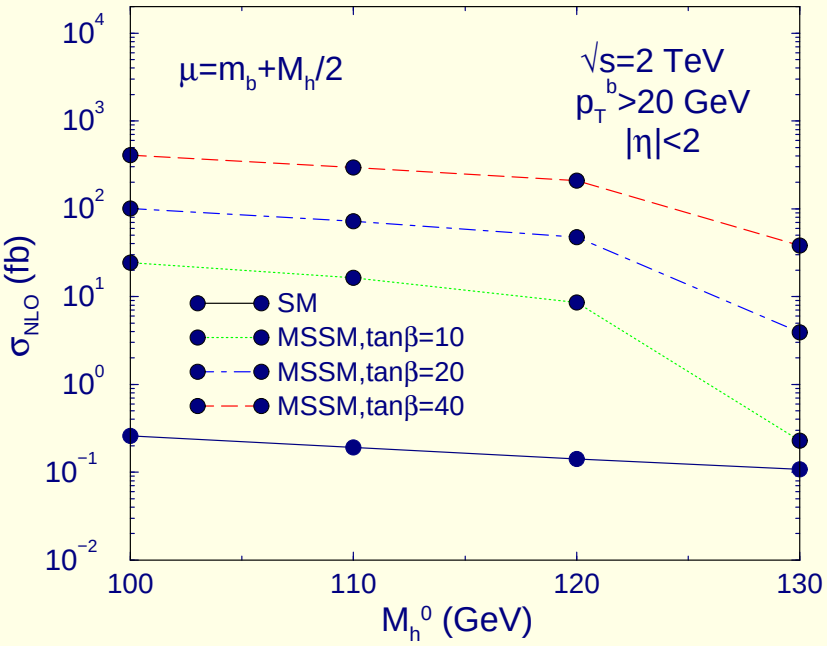


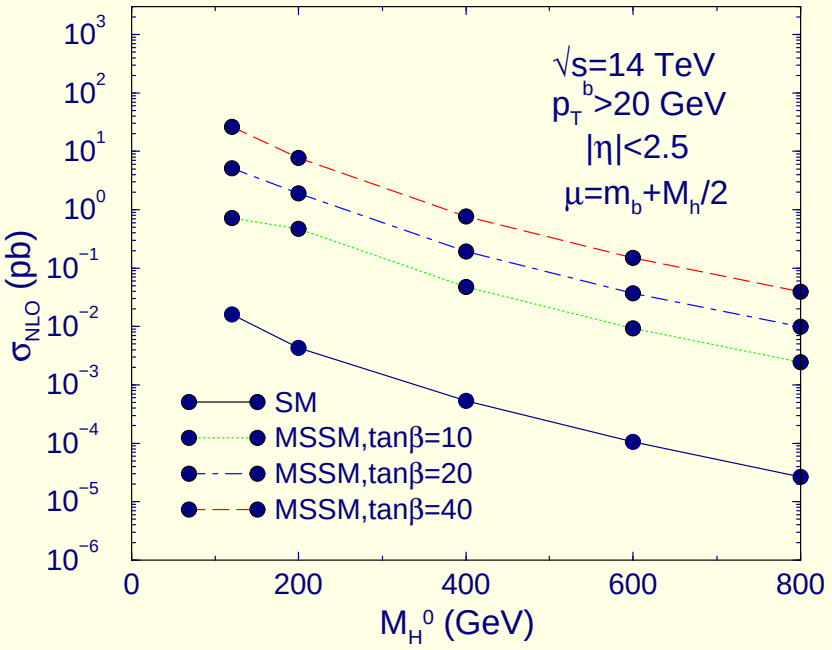




(from S. Dawson, C.J., L. Reina and D. Wackeroth, PRD 69, 074027 (2004)))

$M_H, \tan\beta$ 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: $\sigma_{NLO}(MSSM) \sim \sigma_{NLO}(SM)(\frac{g_{bbh}^{MSSM}}{g_{bbh}^{SM}})^2$

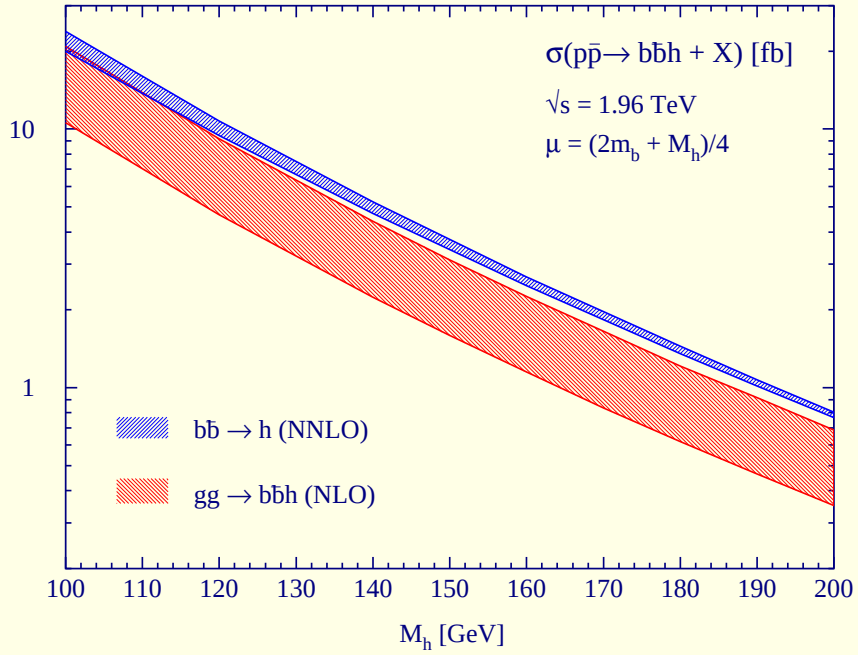
Five Flavor Number Scheme (5FNS)

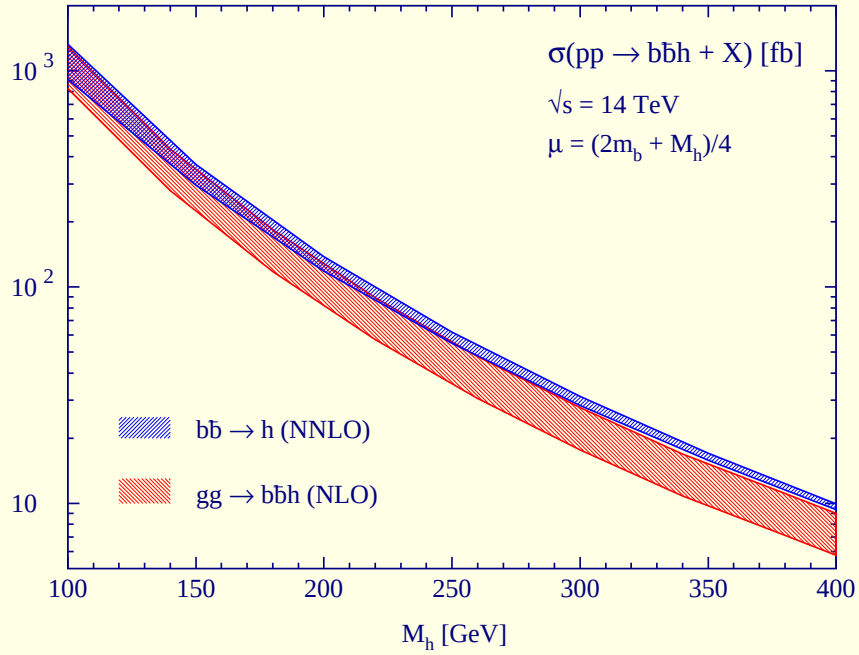
- Physical process $gg \to b\bar{b}h$ contains large logs from (collinear) splitting $g \to b\bar{b}$
- Introduce (theoretically defined) b-quark PDF:

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

- Leading Processes in 5FNS:
  - Inclusive $\equiv b\bar{b} \to h$ (Known at NNLO (see Harlander & Kilgore PRD 68 (2003) 013001))
  - Semi-inclusive $\equiv gb \to bh$ (Known at NLO (see Campbell et.al PRD 67 (2003) 095002))
- Important to study validity/compatibility of 4FNS/5FNS

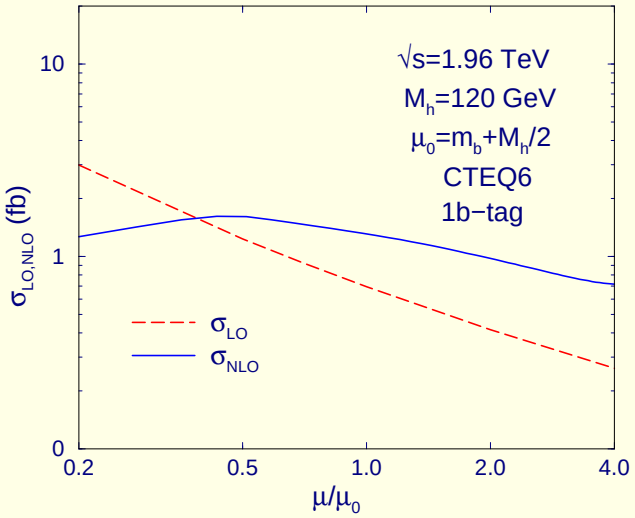
Results for Inclusive $(b\bar{b})h$ Production

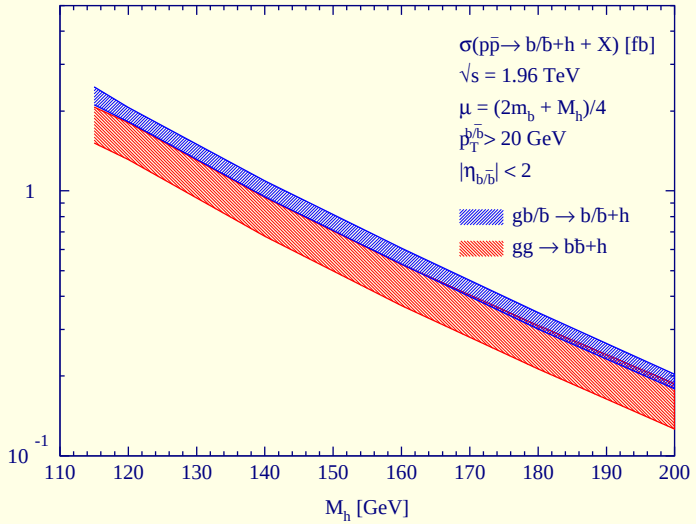


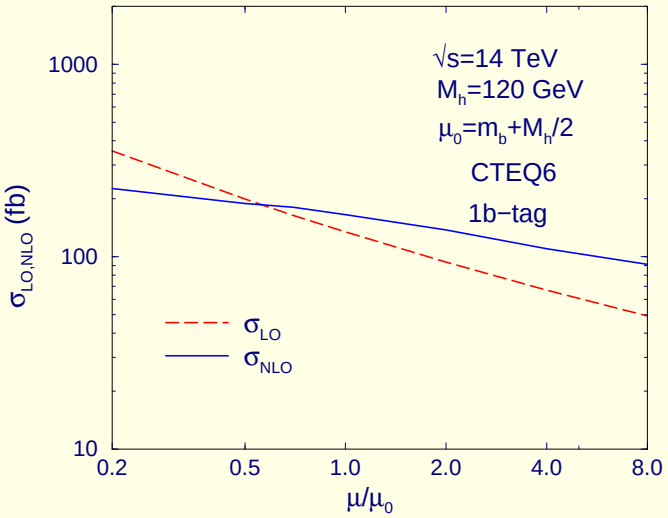


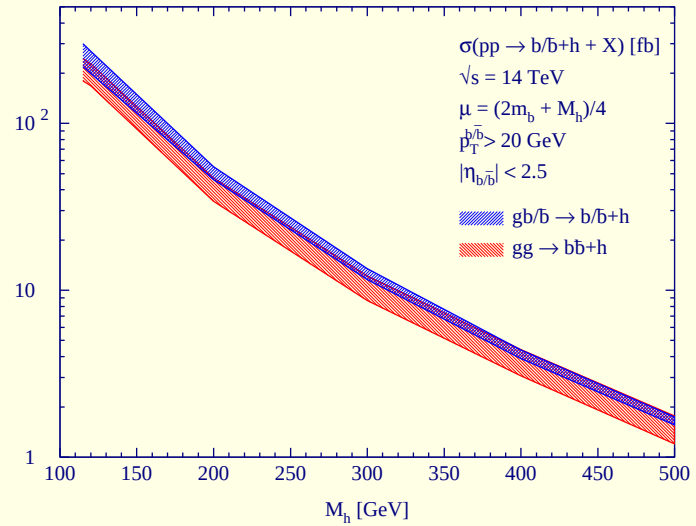
(from J. Campbell et. al. (Higgs Working Group), Les Houches workshop on Physics at TeV Colliders (2004), hep-ph/0405302)

Results for Semi-inclusive $b(\bar{b})h$ Production



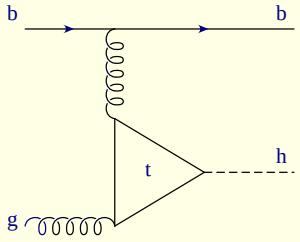






Not the End of the Story

- Diagrams containing loops of quarks neglected in 5FNS

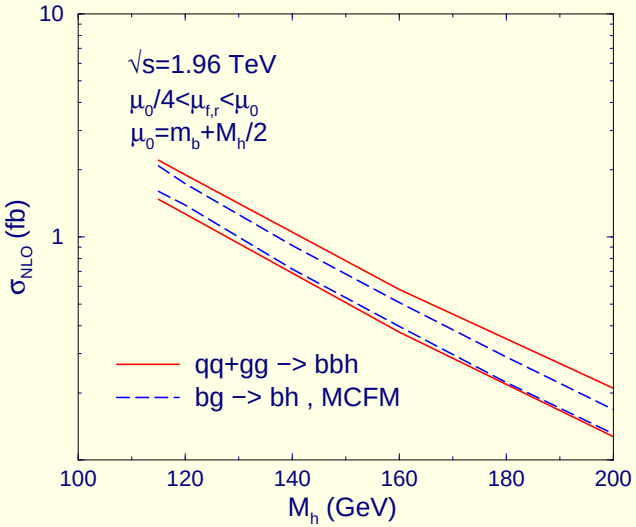


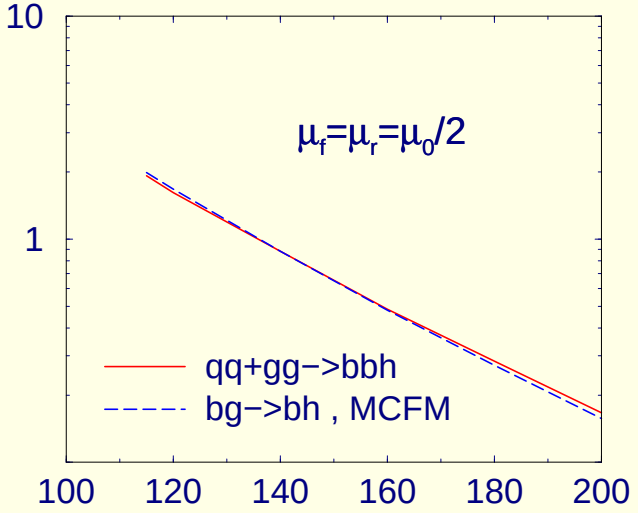
- $bg \to bh$ @ NLO performed in the $m_b = 0$ approximation (except in g_{hbb}):
  - Top quark loop neglected since $g^{MSSM}_{(h^0,H^0)tt} \sim \frac{1}{\tan\beta}$
  - Bottom quark loop neglected since amplitude is $\propto m_b$
  - In SM, this diagram (w/ top quarks) makes a contribution $\sim \mathcal{O}(g^2_{Hbb}) \to$ could be numerically important!

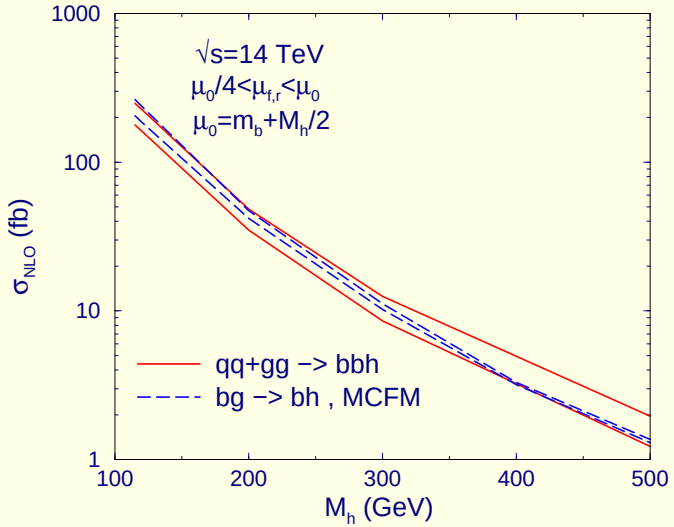
- To compare 4FNS and 5FNS for semi-inclusive process, we utilized MCFM (Campbell and Ellis, webpage:mcfm.fnal.gov) altered to contain the top loop contribution.

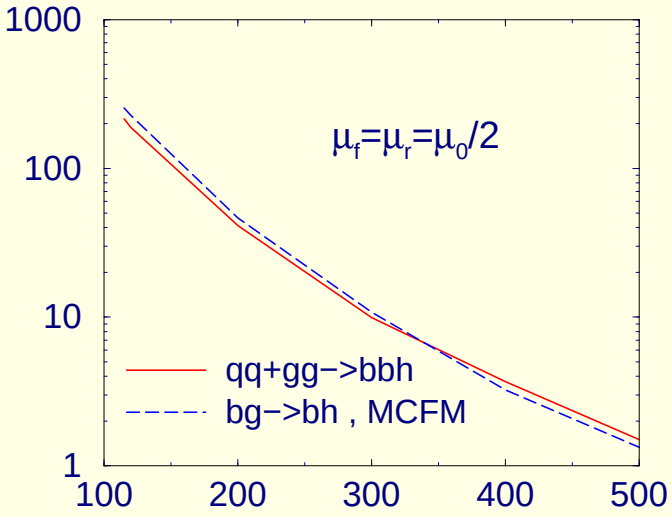
- Including top loop lowers $\sigma_{gb\to bh}$ by 15%(10%) at the Tevatron (LHC)

Results for Semi-inclusive $b(\bar{b})h$ Production ...again



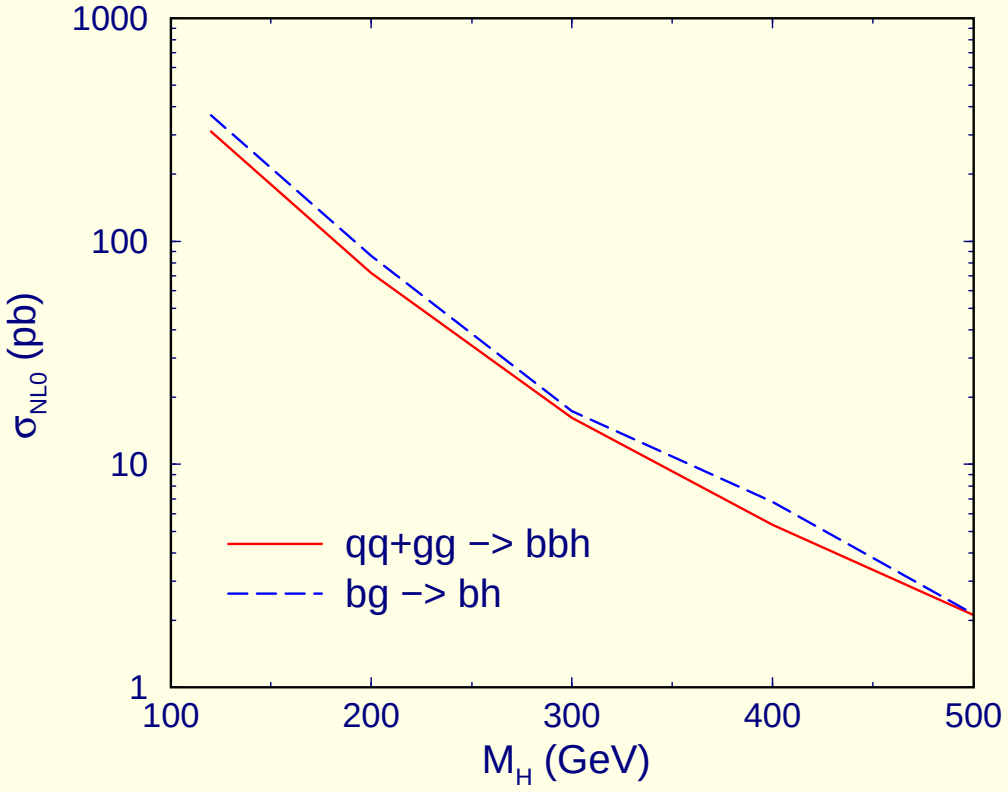






(from S. Dawson, C.J., L. Reina and D. Wackeroth (2004), hep-ph/0408077)

MSSM Semi-Inclusive $b(\bar{b})H^0$



- For $\tan\beta = 40$, top loop contribution $\leq 0.08\%$ in $gb \to bh$

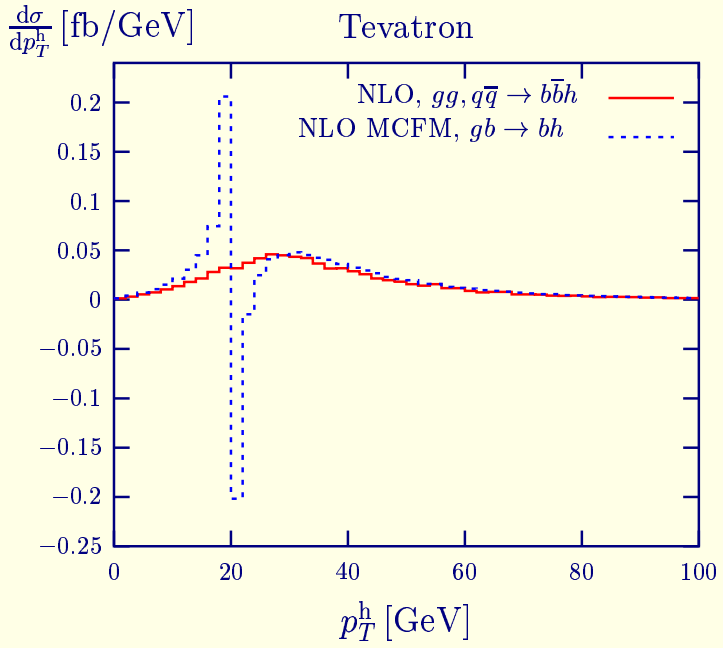
Summary

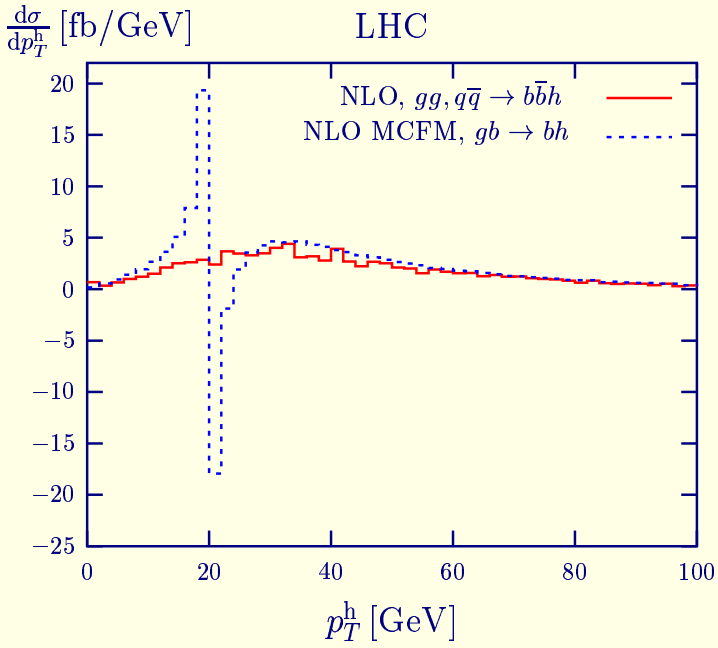
- $b\bar{b}h$ can play important role in Higgs production at Hadron Colliders for models w/ enhanced b quark Yukawa couplings (e.g. 2HDM, MSSM)
- QCD corrections can have large effects on distributions and drastically reduce theoretical uncertainties
- Exclusive Production: agreement between two independent NLO QCD calculations
- Inclusive Production: "good" agreement between 4FNS and 5FNS calculations (top loop diagrams?)
- Semi-inclusive Production:
  - Academically: SM results now agree (spectacularly!) between 4FNS and 5FNS after the inclusion of the top loop diagrams in $gb \to bh$
  - Numerically: MSSM results agree between 4FNS and 5FNS

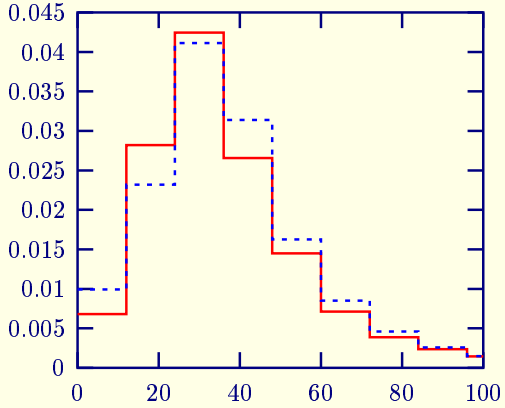
Further Reading

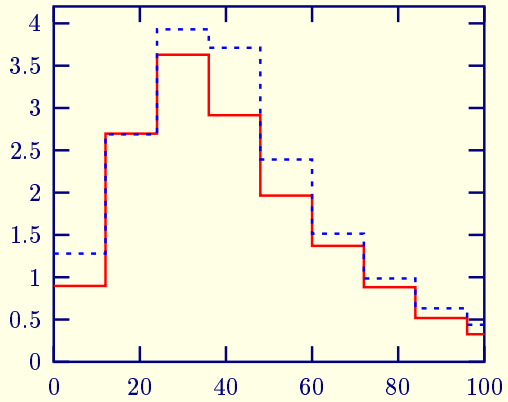
- Exclusive Production:
  - S. Dittmaier, M. Kramer, M. Spira (hep-ph/0309204)
  - S. Dawson, C.J., L. Reina, D. Wackeroth (PRD 69 074027 (2004))
- Inclusive and Semi-inclusive Production:
  - Harlander and Kilgore (PRD 68 013001(2003))
  - J. Campbell et. al. (PRD 67 095002 (2003))
- Comparison between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

p_T Distributions for Semi-inclusive Production









(from S. Dawson, C.J., L. Reina and D. Wackeroth (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 $\Longrightarrow$ 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

"non-smooth" $f(z) = \longrightarrow \int_0^1 dz f(z)[g(z)]_+ =$ "logarithmic divergences"

- Improvement through resummation techniques (see, e.g. N. Kidonakis, hep-ph/9902484)