Bottom Quark PDF Uncertainties and $h + b$ Production

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TeV4LHC, February 2005

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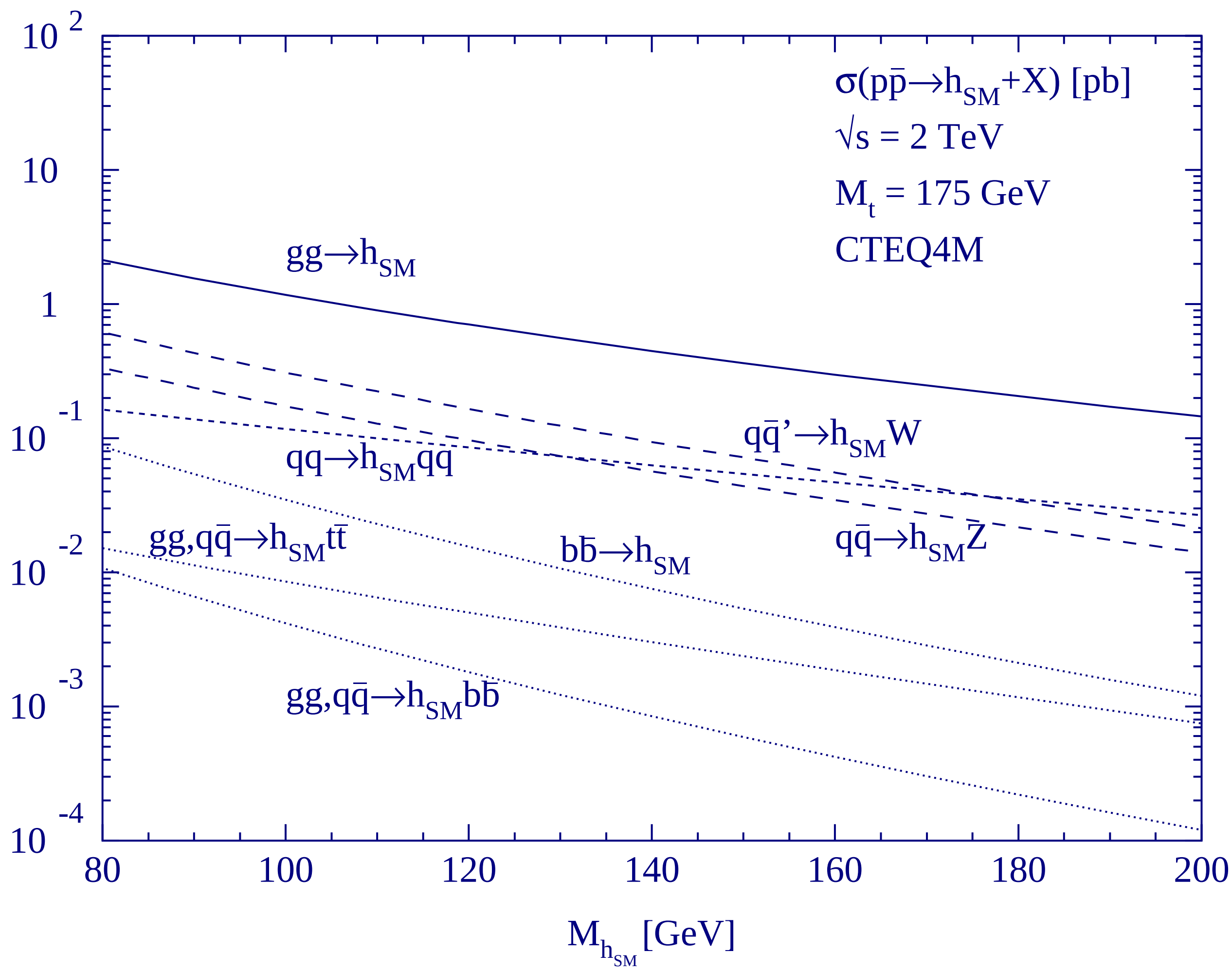
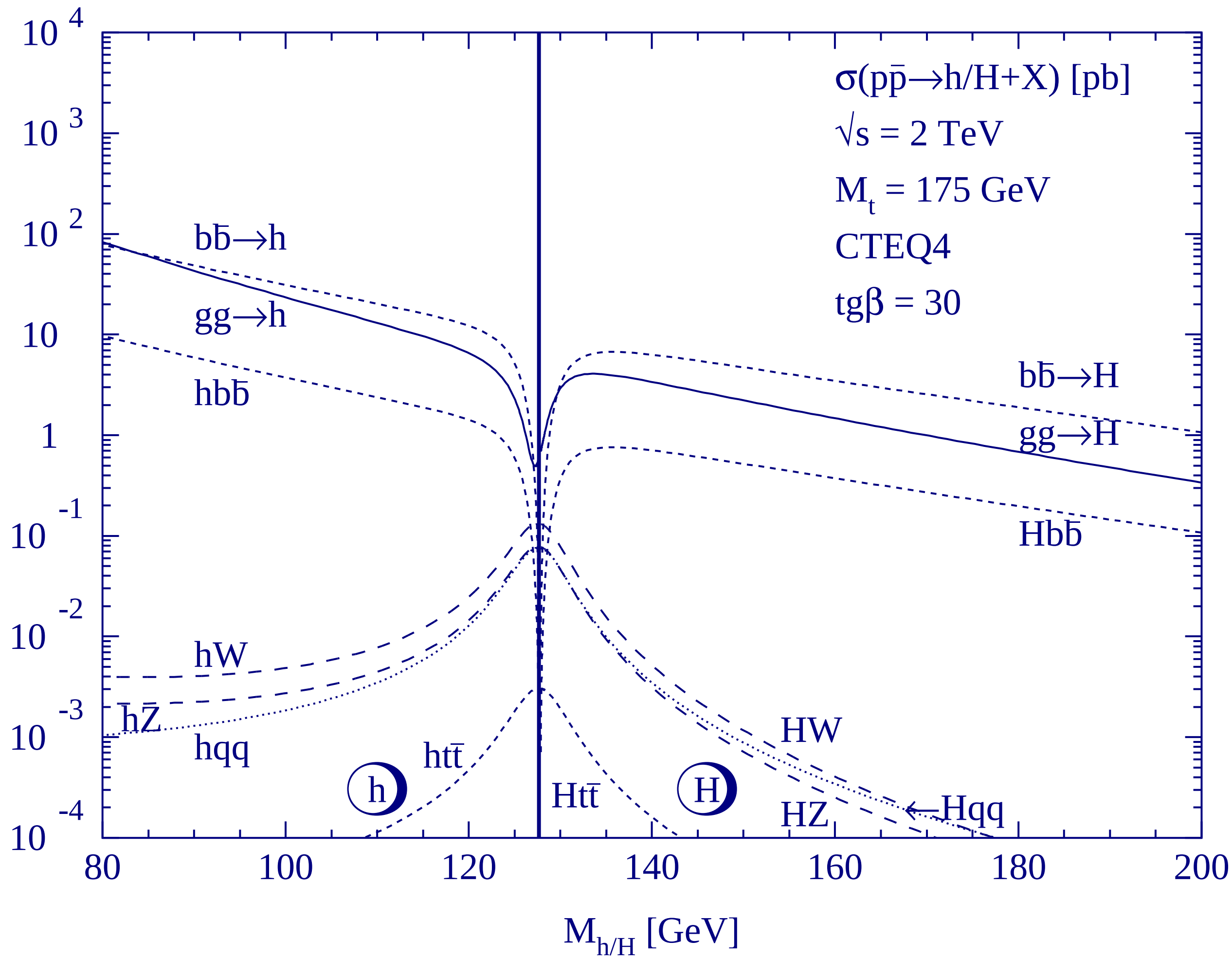
SM vs. MSSM Higgs Production at the Tevatron



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

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

SM vs. MSSM Higgs Production at the Tevatron



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

- For MSSM, 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)

- Two independent calculations of NLO QCD corrections:
  - S. Dittmaier, M. Krämer, M. Spira, PRD 70 (2004) 074010
  - S. Dawson, C.J., L. Reina, D. Wackeroth , PRL 94 (2005) 031802

- Setup:
  - Require at least one high-p_T b jet in final state by placing cuts on $p_T^{b,\bar{b}}$ and $|\eta_{b,\bar{b}}|$
  - Radiated g and $b/\bar{b}$ distinct only if $\Delta R > 0.4$

Five Flavor Number Scheme (5FNS)

- Physical process $gg \to b\bar{b}h$ contains large logs ($\Lambda_b \equiv \log(\frac{Q^2}{m_b^2})$) from collinear splitting $g \to b\bar{b}$

- Introduce (theoretically defined) b-quark PDF:

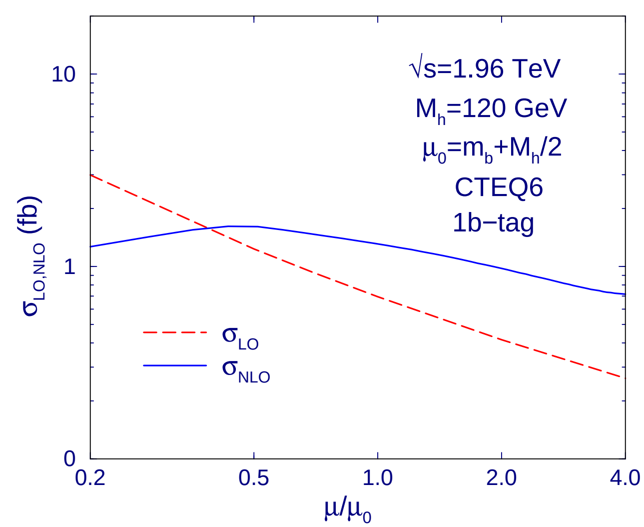
$$\tilde{b}(x,\mu) = \frac{\alpha_s(\mu)}{2\pi}\Lambda_b \int_x^1 \frac{dy}{y} P_{qg}(\frac{x}{y}) g(y,\mu)$$

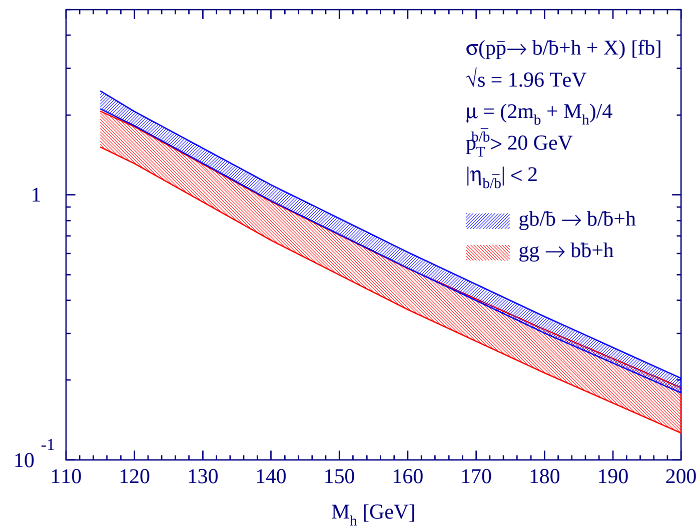
- Leading Process in 5FNS:

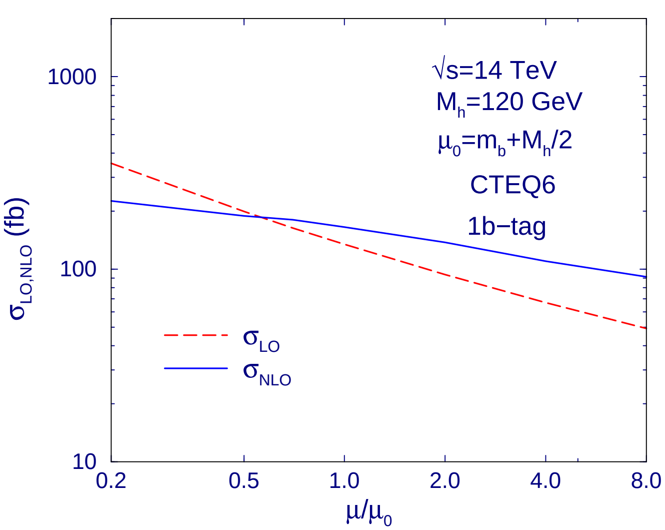
(@ NLO: Campbell, Ellis, Maltoni and Willenbrock PRD 67 095002 (2003))

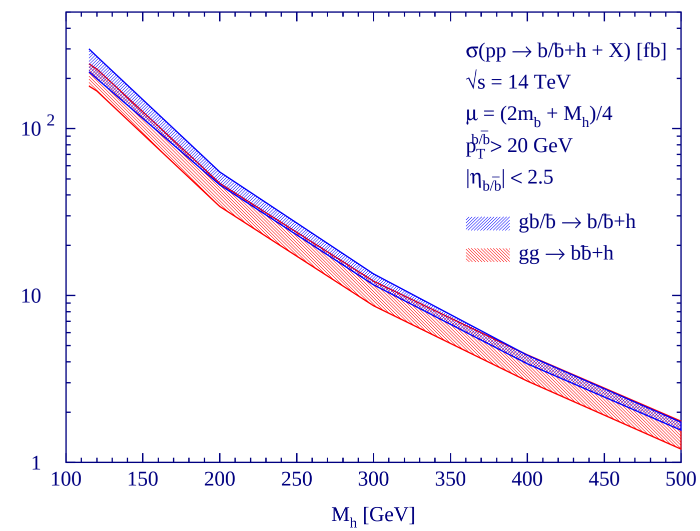
- Important to study validity/compatibility of 4FNS/5FNS

Results for bh Production





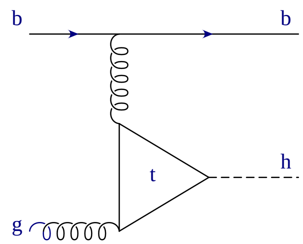




(from J. Campbell et. al. (Higgs Working Group), Les Houches workshop on Physics at TeV Colliders (2004), hep-ph/0405302)

Not the End of the Story

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

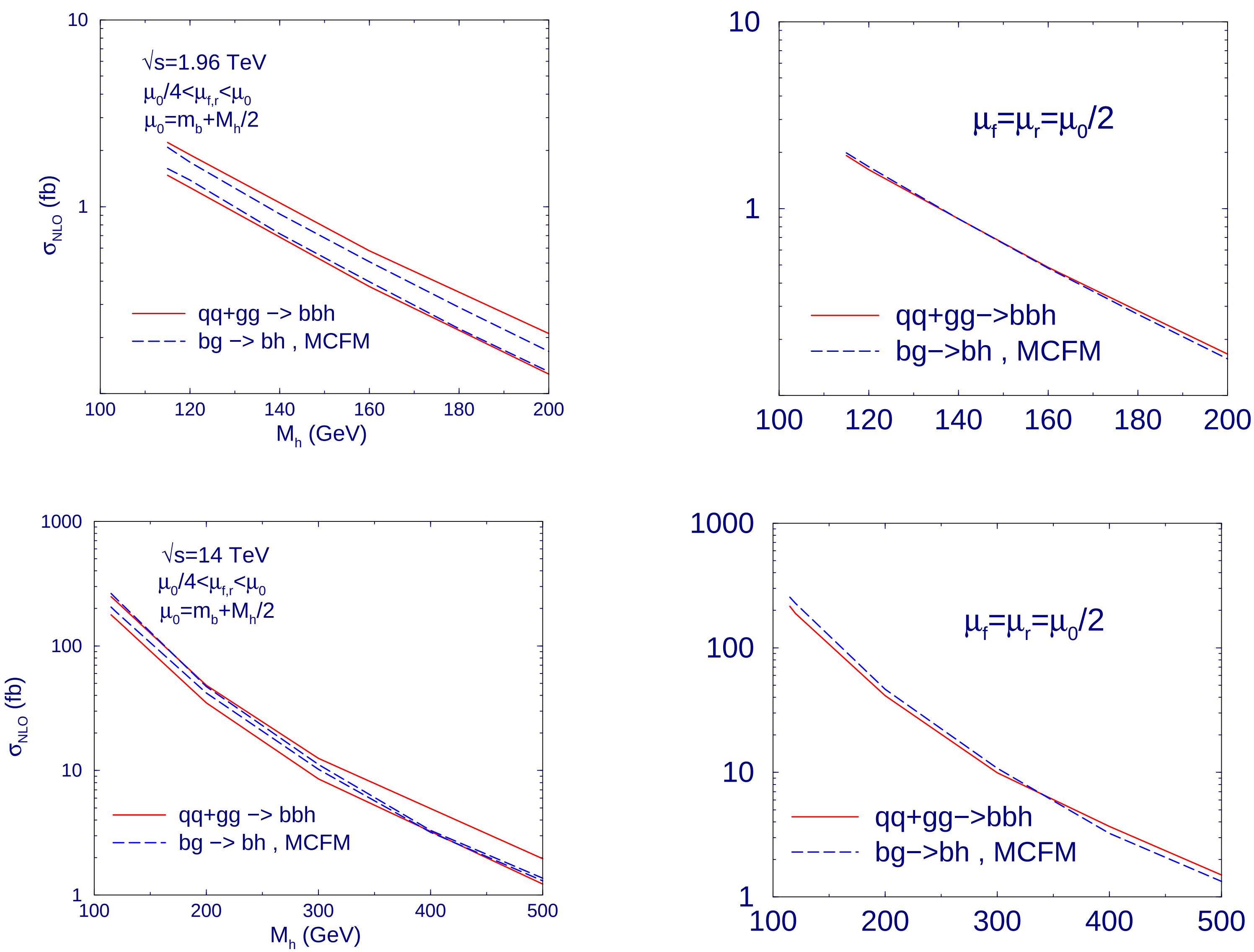


- $bg \to bh$ @ NLO performed in the $m_b = 0$ approximation:
  - Top (bottom) loop diagrams neglected since $\sigma_\Delta \propto m_b$
  - In SM, $\sigma_\Delta \sim \mathcal{O}(g_{hbb} g_{htt} \frac{m_b}{m_t}) \sim \mathcal{O}(g_{hbb}^2) \to$ could be numerically important!

- To compare 4FNS and 5FNS for bh production, we coded σ_Δ into MCFM (Campbell and Ellis, webpage:mcfm.fnal.gov)

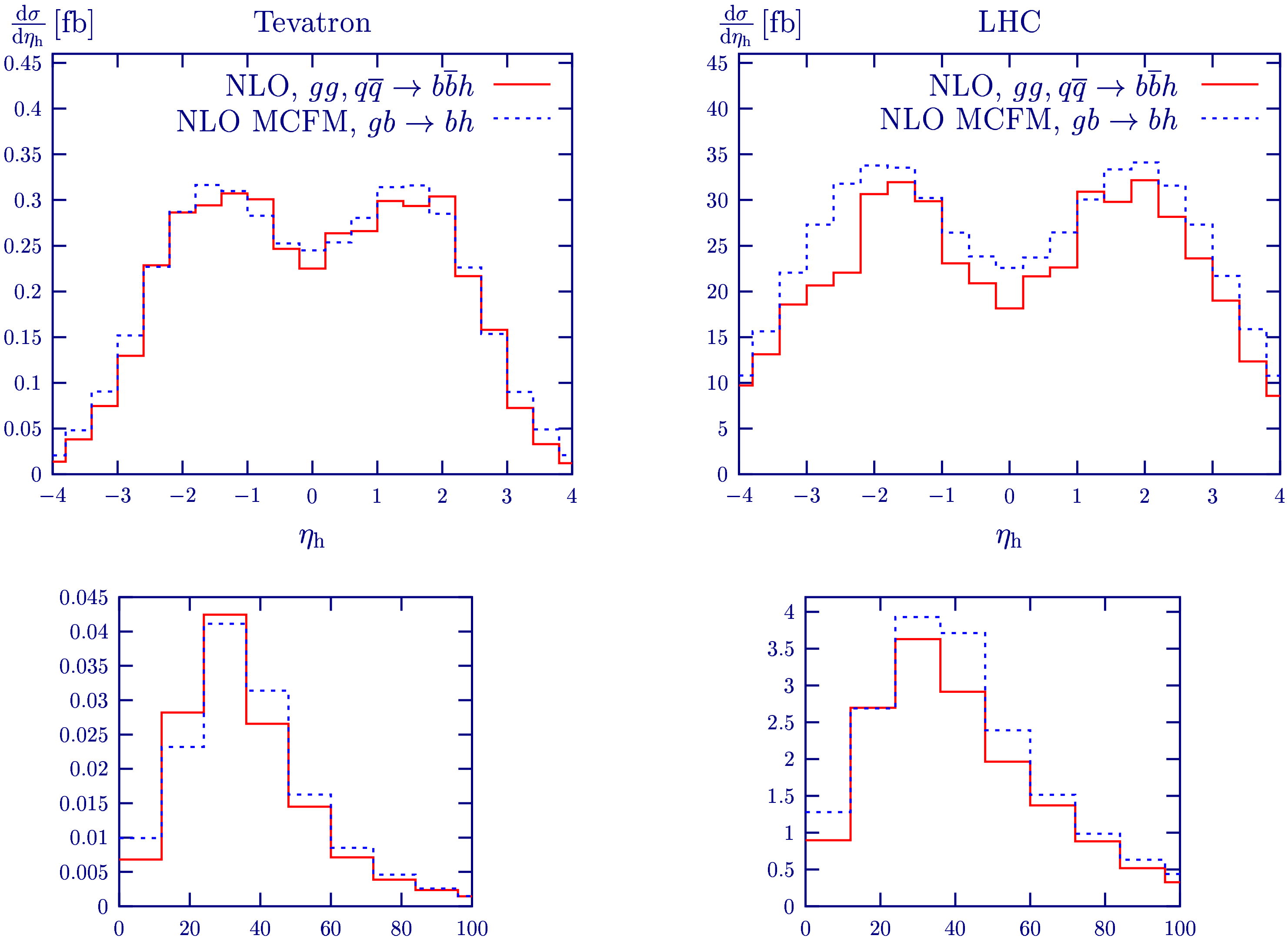
- Including top loop lowers $\sigma_{gb \to bh}$ by 15%(10%) at the Tevatron (LHC)

Results for bh Production ...again



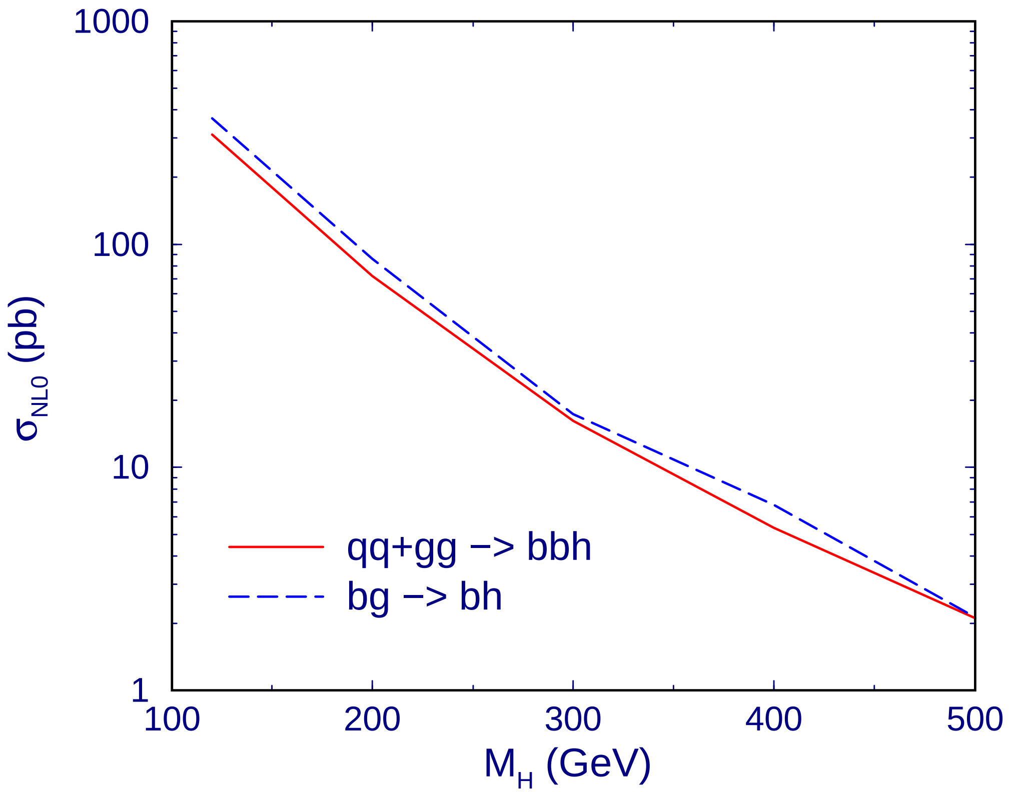
(from S. Dawson, C.J., L. Reina and D. Wackeroth, PRL 94 (2005) 031802)

η_h and p_T Distributions for bh Production



(from S. Dawson, C.J., L. Reina and D. Wackeroth, PRL 94 (2005) 031802)

MSSM bH^0 Production



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

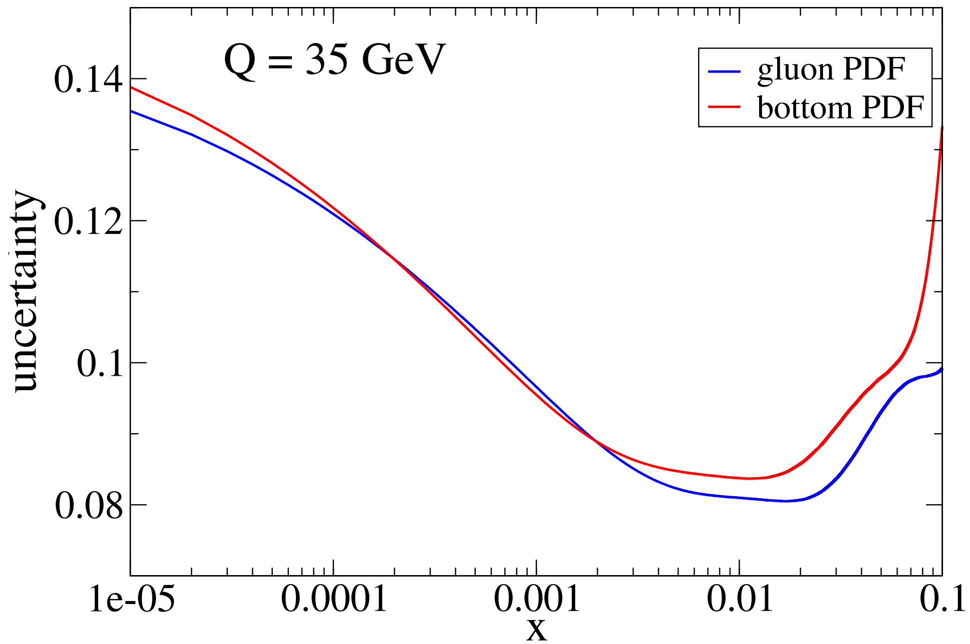
PDF Uncertainties (Light Partons)

- CTEQ (2002): "Hessian Matrix Method"
  - Characterizes parton parameterization in the neighborhood of the global χ^2 minimum fit
  - Gives access to uncertainty estimation through a set of PDF's that describes this neighborhood
  - LHAPDF website: durpdg.dur.ac.uk/lhapdf/

- Procedure:
  - Fit theory to data using $N_{PDF} = 20$ free parameters (from non-perturbative input) $\rightarrow$ "nominal fit" or CTEQ6M
  - Increase global χ^2 of fit by $\Delta\chi^2 = 100 \rightarrow$ "error matrix"
  - Diagonalize error matrix $\rightarrow N_{PDF}$ eigenvectors
  - Up/down excursions in the tolerance gap $\rightarrow 2N_{PDF}$ $(= 40)$ new sets of PDF's.

- Uncertainties (from PDF's) of observables $\rightarrow \Delta\sigma^{\pm} = \sqrt{\sum_i (\sigma_i - \sigma_0)^2}$

Heavy Quark PDF Uncertainties

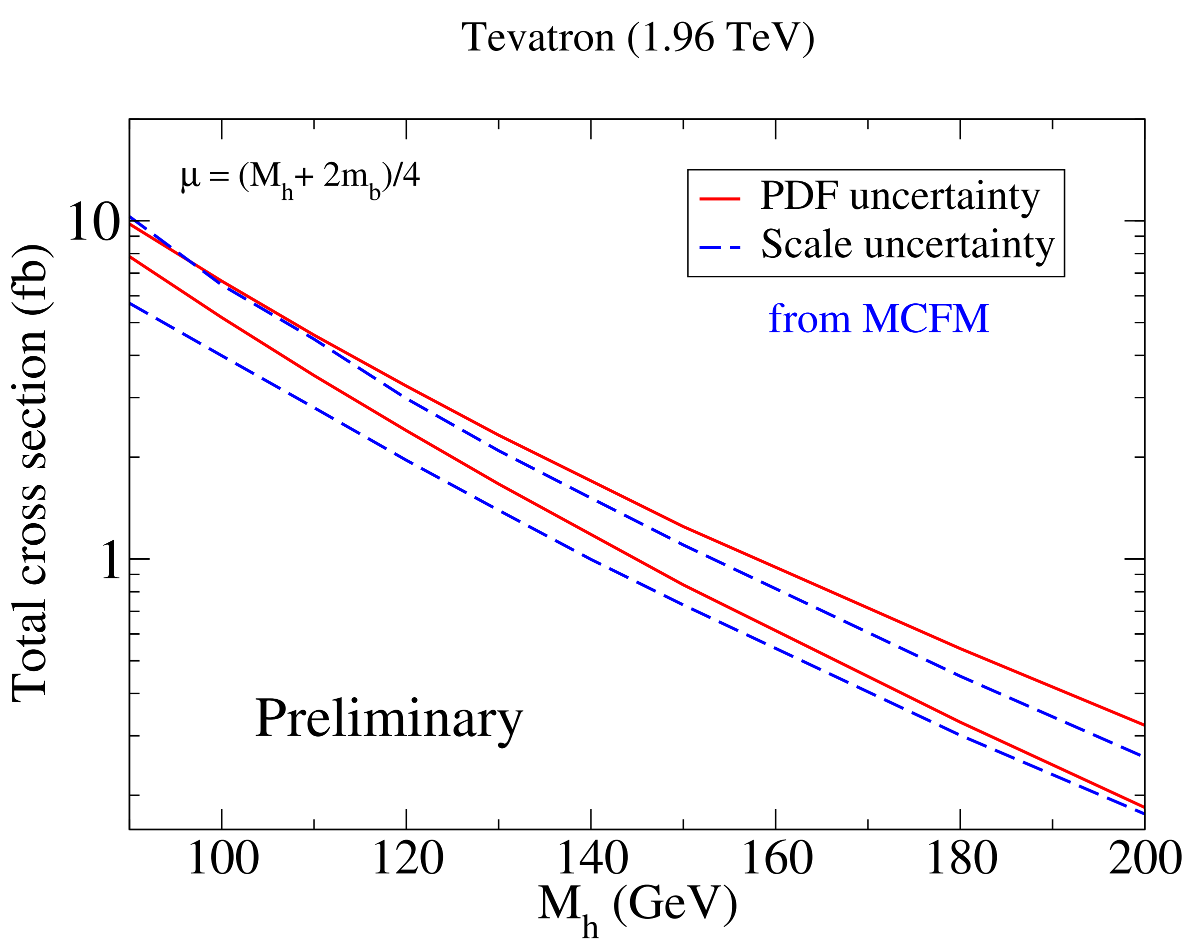


- Not fit to data(!), but arise perturbatively from gluon splitting:

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

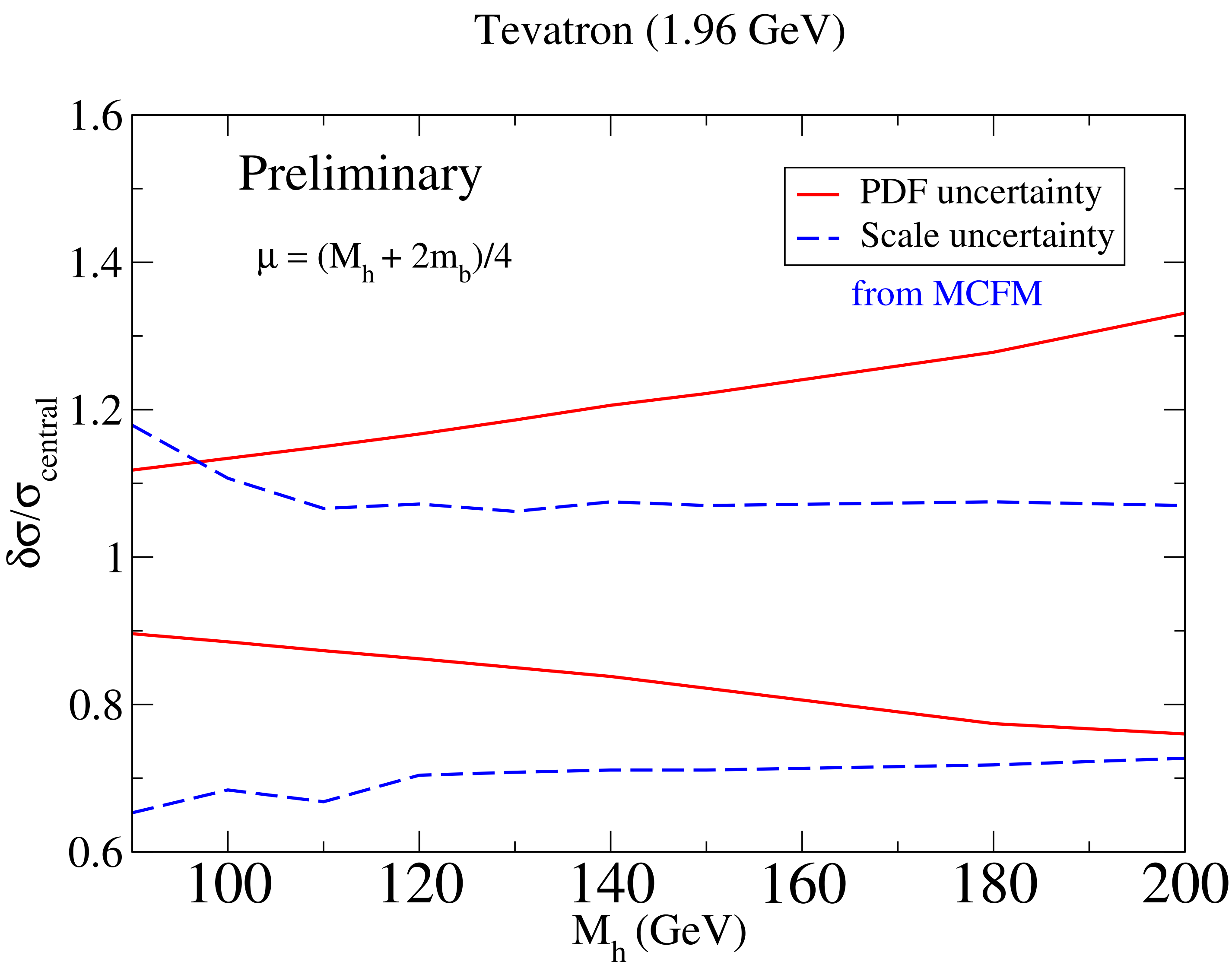
- PDF uncertainties (at lower x) due exclusively to gluon uncertainties (at higher x)

PDF Uncertainties for $gb \to bh$ at the Tevatron



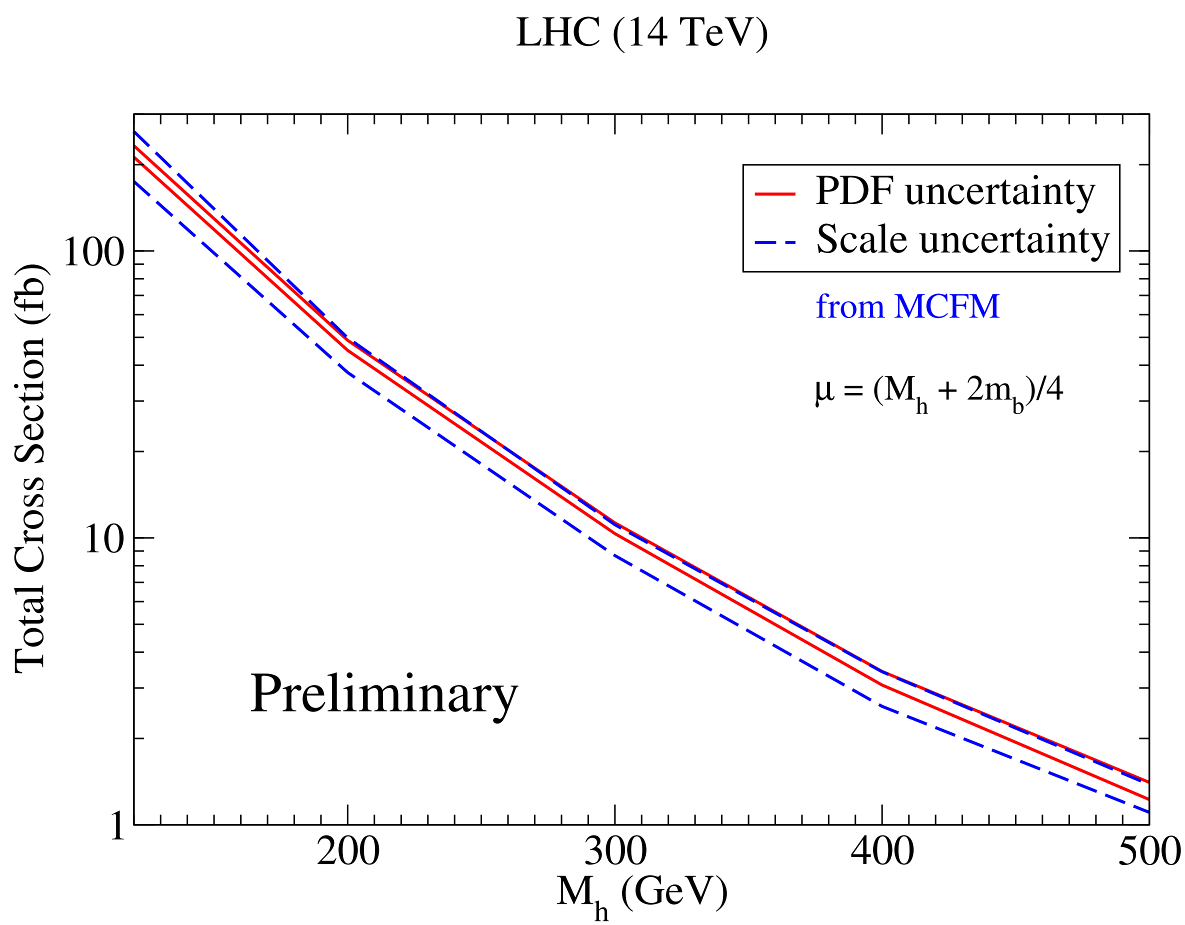
- Due to smallness of c.m. energy, Higgs produced by high-x g's and b's

PDF Uncertainties for $gb \to bh$ at the Tevatron (cont.)



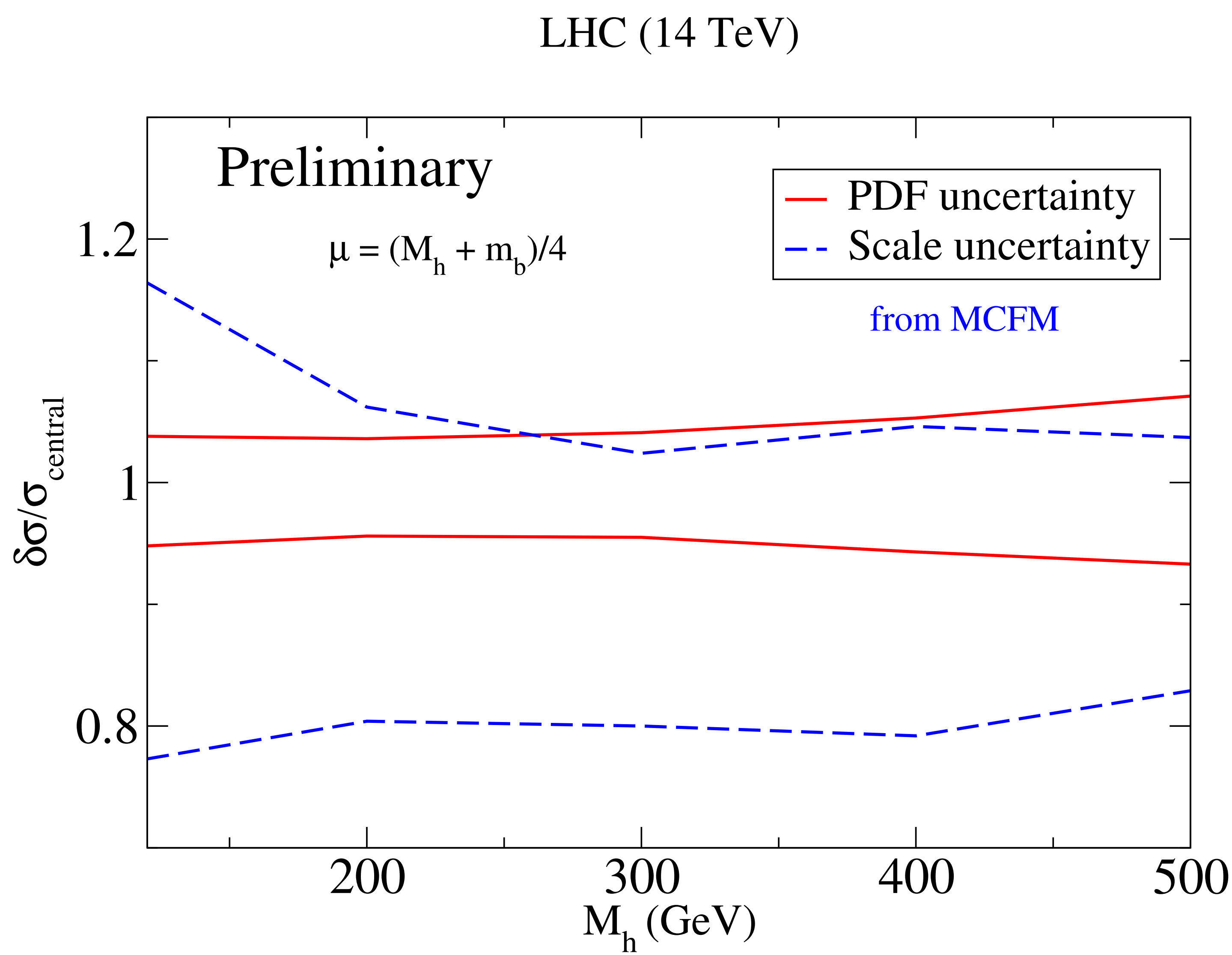
- For larger M_h, PDF uncertainties $\geq$ uncertainties from scale dependence

PDF Uncertainties for $gb \longrightarrow bh$ at the LHC

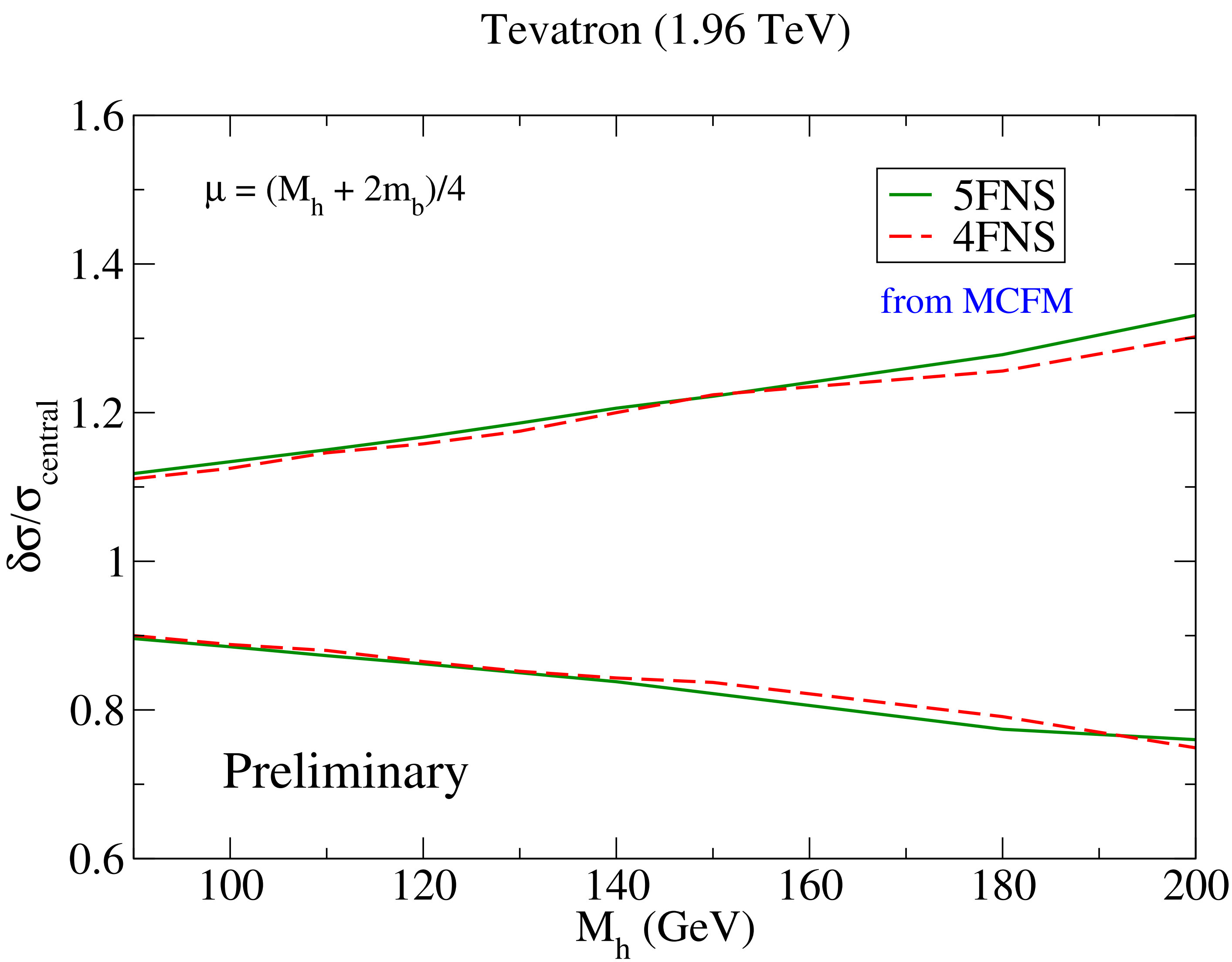


- Larger c.m. energy = lower-x g's and b's

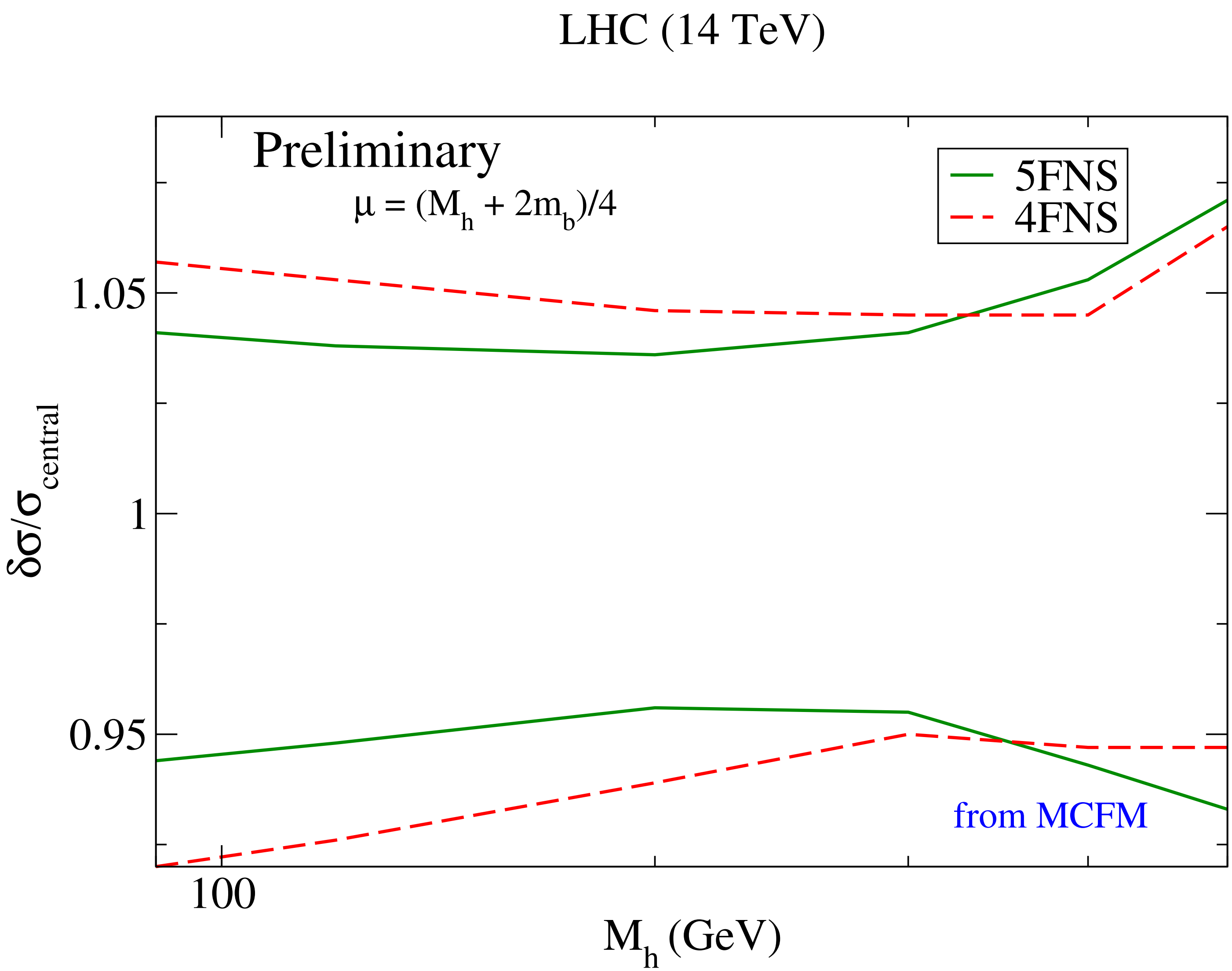
PDF Uncertainties for $gb \to bh$ at the LHC (cont.)



PDF Uncertainties: 4FNS vs. 5FNS



PDF Uncertainties: 4FNS vs. 5FNS



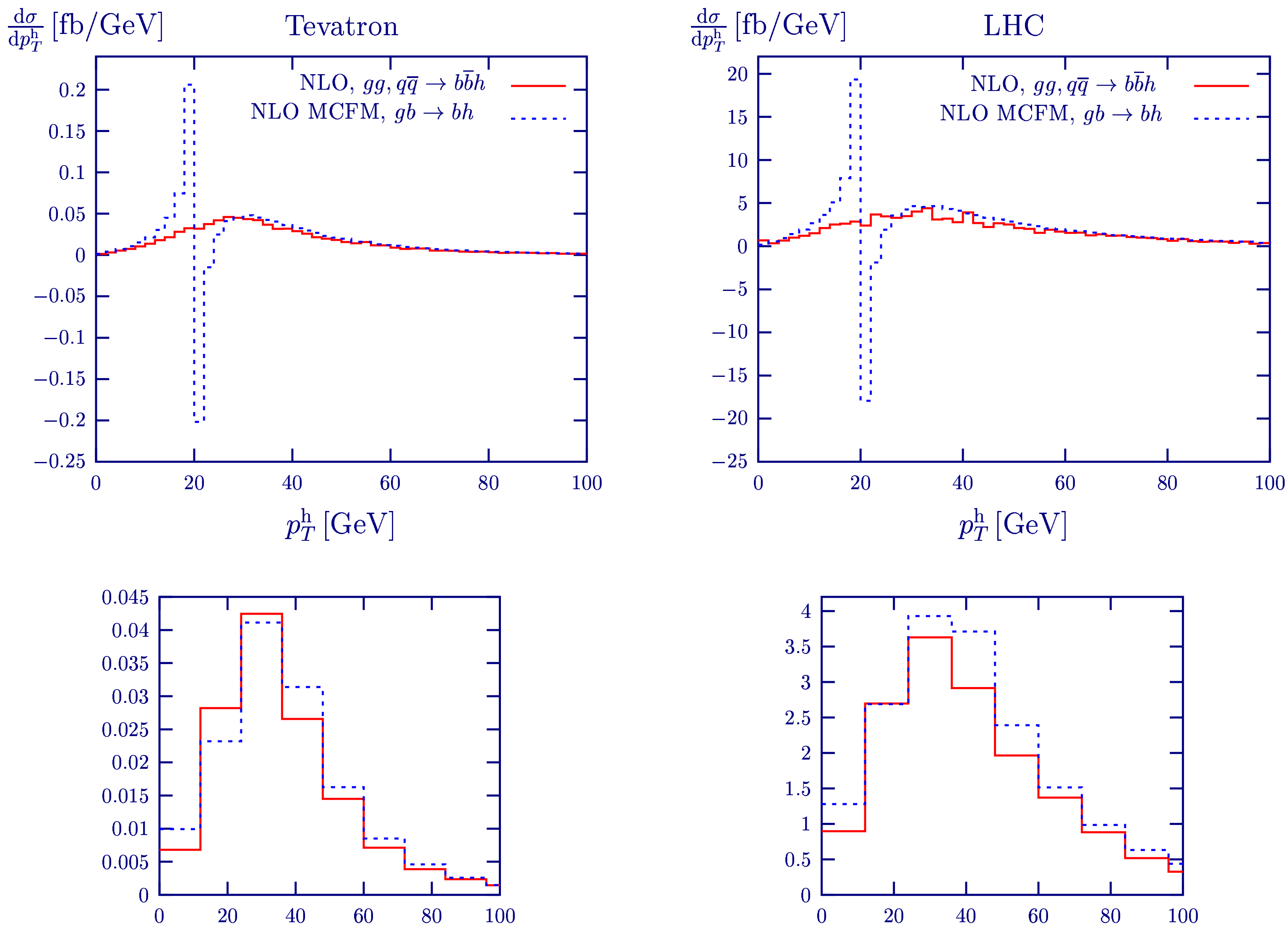
Summary

- $h + b$ production can play a significant role in the discovery of a Higgs for models w/ enhanced b quark Yukawa couplings (e.g. 2HDM, MSSM)
- Excellent agreement between 4FNS and 5FNS calculations of NLO QCD corrections for:
  - SM Higgs once top-loop diagrams are included in 5FNS
  - MSSM Higgs where top loops are negligible
- PDF uncertainties for 5FNS:
  - 10-30% at the Tevatron
  - $\sim$5% at the LHC

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

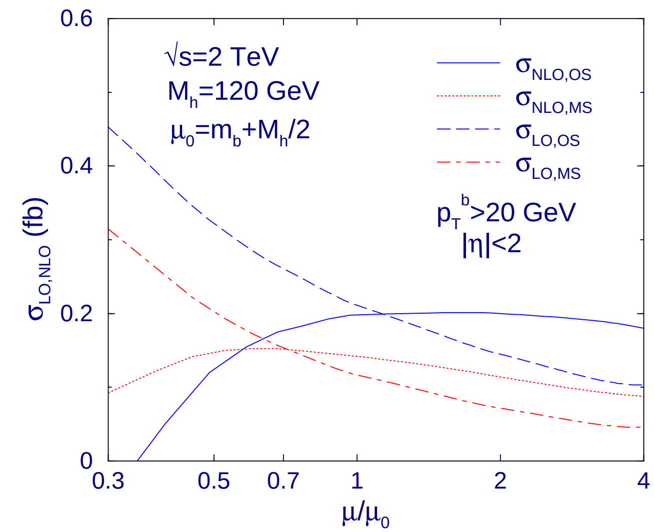
"non-smooth" $f(z) = \longrightarrow \int_0^1 dz f(z)[g(z)]_+ =$ "logarithmic divergences"

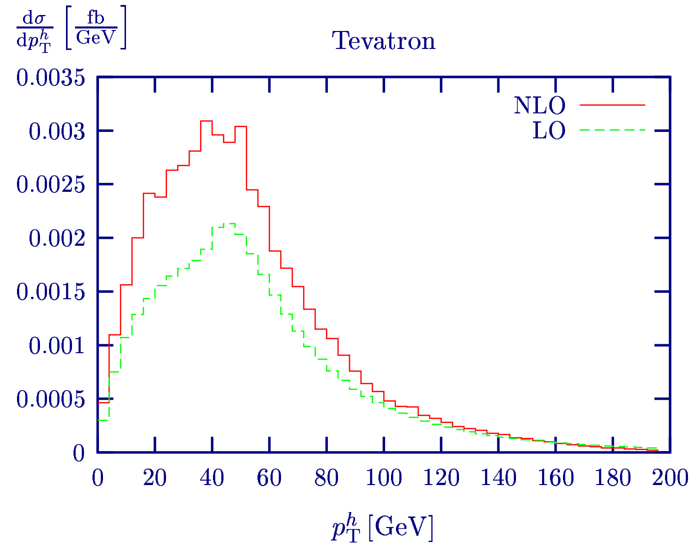
- Improvement through resummation techniques (see, e.g. N. Kidonakis, hep-ph/9902484)

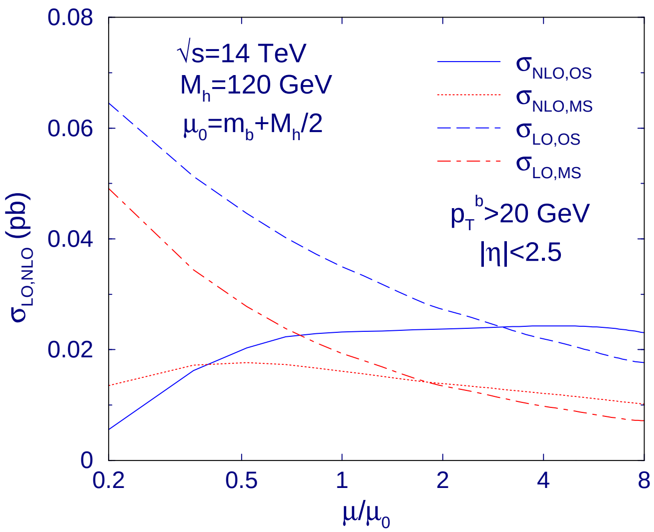
Exclusive $b\bar{b}h$ Production

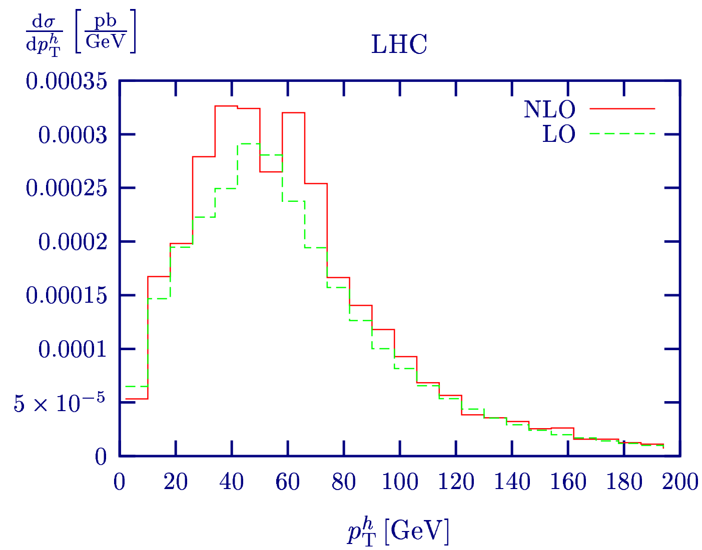
- Two independent calculations of NLO QCD corrections:
  - S. Dittmaier, M. Kramer, M. Spira (hep-ph/0309204)
  - S. Dawson, C.J., L. Reina, D. Wackeroth (PRD 69 074027 (2004))
- Setup:
  - Require two high-p_T b jets in final state: $p_T^{b,\bar{b}} > 20$ GeV and $|\eta_{b,\bar{b}}| < 2(2.5)$ Tevatron (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



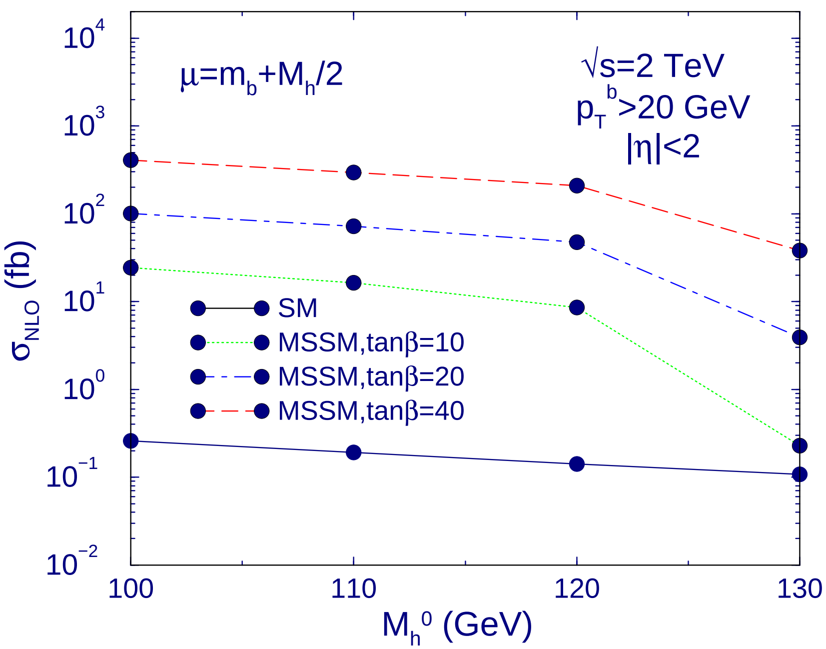


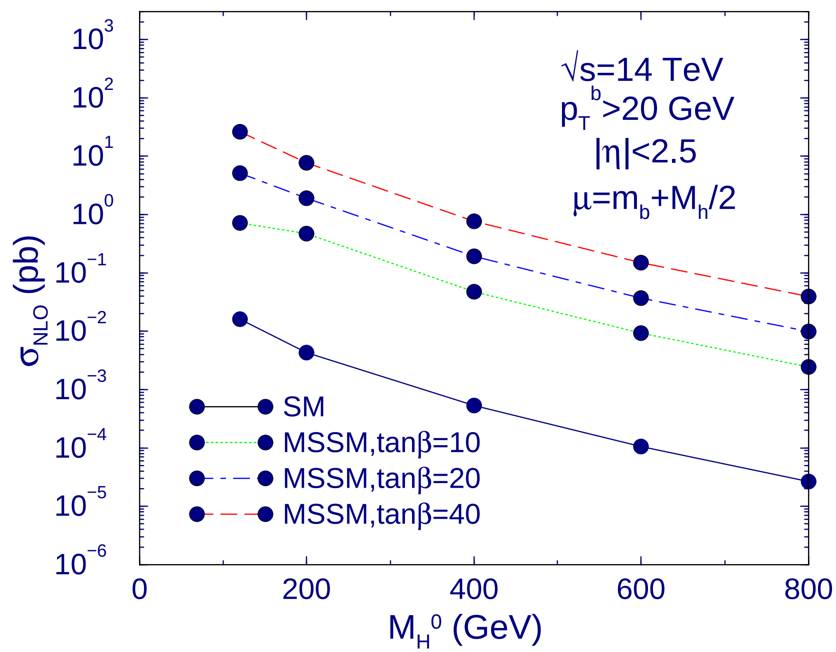




(from S. Dawson, C.J., L. Reina and D. Wackeroth, PRD 69, 074027 (2004))

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

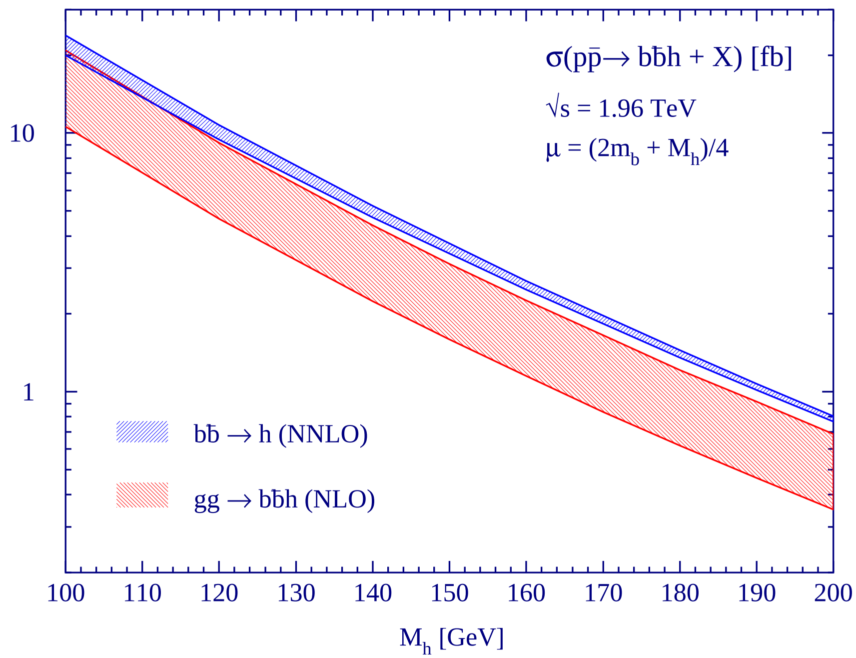


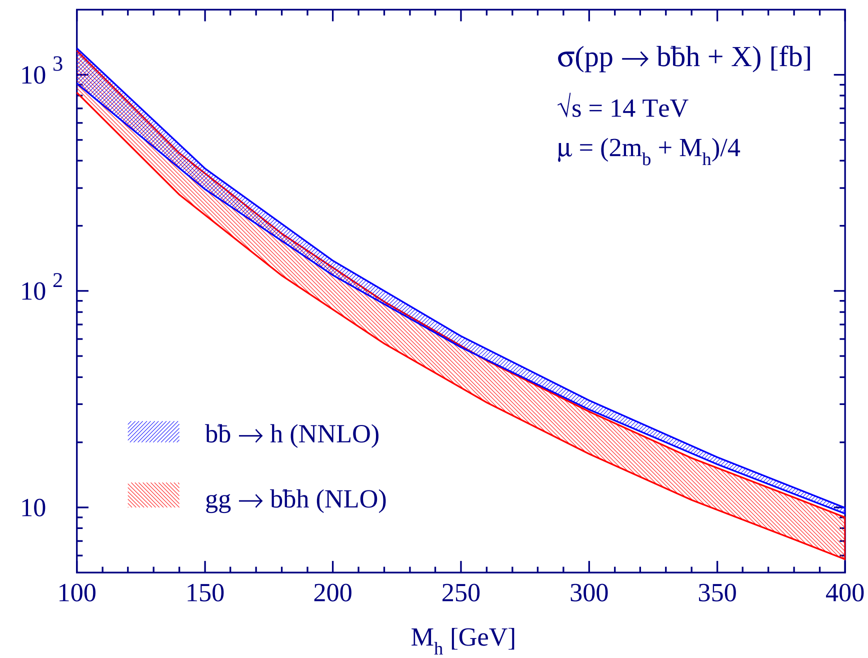


(from S. Dawson, C.J., L. Reina, D. Wackeroth ,PRD 69,074027 (2004))

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

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





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