MSSM Higgs Boson Production with Bottom Quarks

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TeV4LHC
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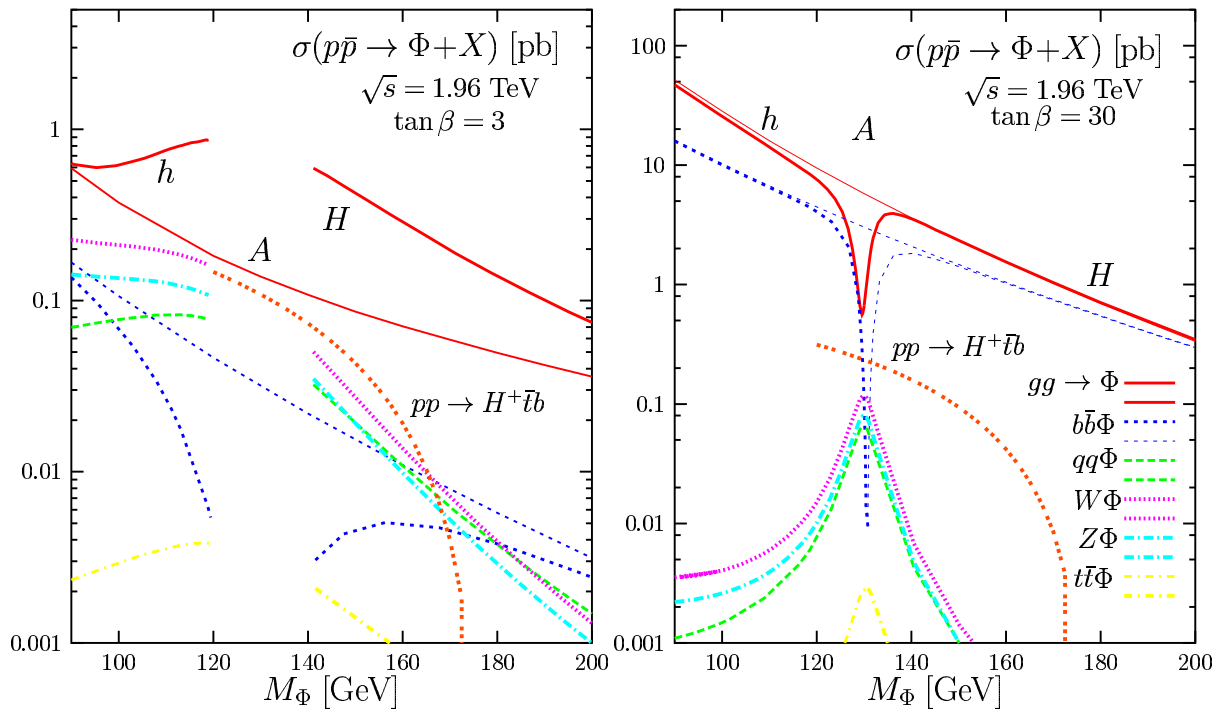
Work with S. Dawson (BNL), L. Reina (FSU) and D. Wackeroth (SUNY-Buffalo)

MSSM Higgs Production at the Tevatron



from A. Djouadi (hep-ph/0503173)

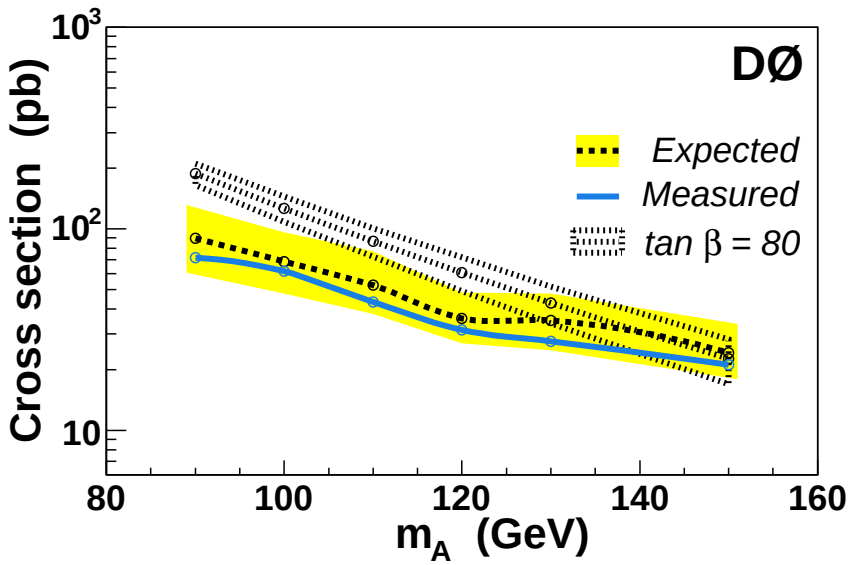
- For large $\tan\beta$, Higgs production w/ b's plays a crucial role for discovery

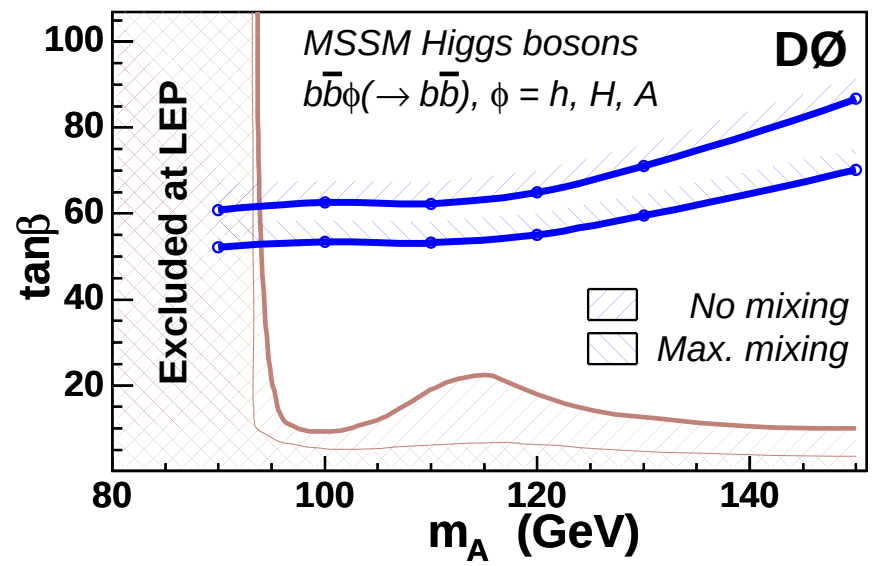
Some Key Points for $b\bar{b}h$ Production

- Experimentally: "Two b's or not two b's", that is the question...

- Theoretically:
  - Assume relevant sub-process is $gg \to b\bar{b}h$ ($\equiv$ "4FNS")
  - Treating b's inclusively (no b-tags) leads to potentially large log's ($\log(\frac{\mu_h^2}{m_b^2})$) from $g \to b\bar{b}$
  - Improve by introducing b PDF and resum log's through DGLAP equation ($\equiv$ "5FNS")...LO subprocesses become $gb \to bh$ and $b\bar{b} \to h$
  - What is μ_h?

In Search Of...





(from DØ Collaboration, hep-ex/0504018)

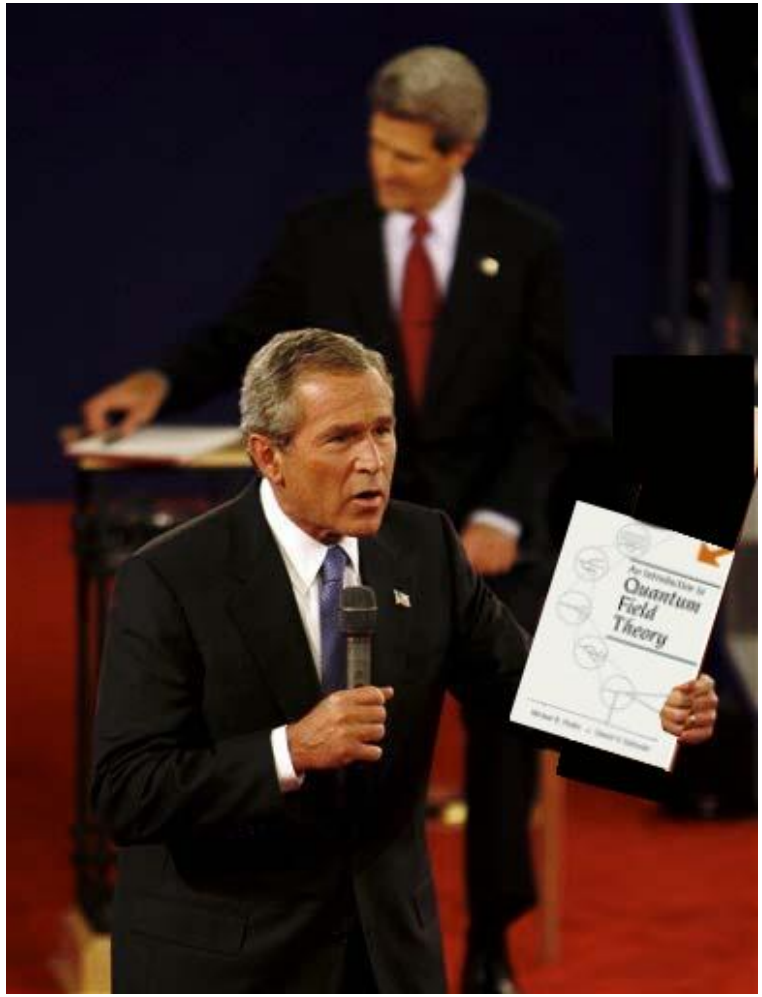
- Search for $h = h^0, H^0, A^0$ in 3 b-tagged events using DØ Run II data
- Significant portion of MSSM parameter space excluded ($\tan\beta \sim 50$)

Higgs + b's Timeline

- 1989/1999: $b\bar{b} \to h$ calculated @ NLO (Dicus/Willenbrock)
- 2001/2002: $gg \to t\bar{t}h$ calculated at NLO (Beenakker et al. and Dawson et al.)
- 2002: $gb \to bh$ calculated at NLO (Willenbrock et al.)
- 2003: Willenbrock et al./Boos and Plehn show $\mu_h \approx \frac{M_h}{4}$
- 2003: $b\bar{b} \to h$ calculated at NNLO (Harlander and Kilgore/Anastasiou and Melnikov)
- 2003/2004: $gg \to b\bar{b}h$ w/ any number of high-p_T b's calculated at NLO (Beenakker et al. and Dawson et al.)
- 2004: Extensive comparison of SM predictions for 4FNS/5FNS (Les Houches HWG)
- 2004: Dawson et al. further improve comparison between 4FNS/5FNS SM predictions for bh production

Higgs Physics in the U.K.

Radiative corrections is *hard work* !!!



Rescaling SM Results to MSSM

- Dominant SUSY radiative corrections $\Longrightarrow$ $b\bar{b}h$ vertex
- Leading, $\tan\beta$ enhanced, radiative corrections from gluino-sbottom and chargino-stop loops...

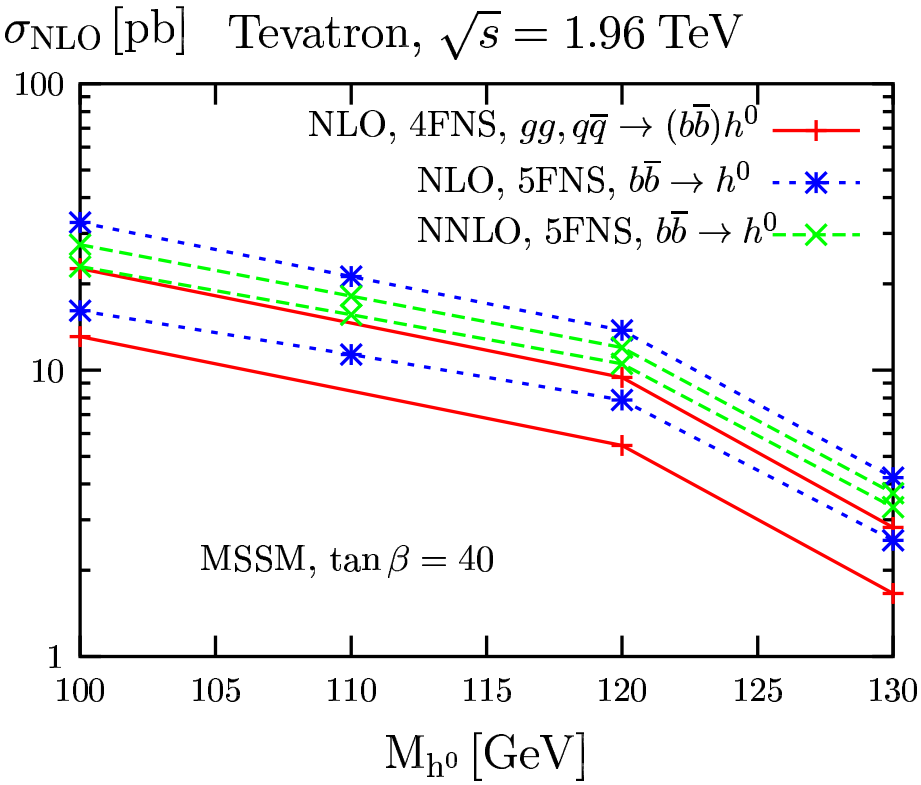
$$g^{MSSM}_{b\bar{b}h^0} = -g^{SM}_{b\bar{b}h}\frac{1}{1+\Delta_b}\left[\frac{\sin\alpha}{\cos\beta} - \Delta_b\frac{\cos\alpha}{\sin\beta}\right]$$

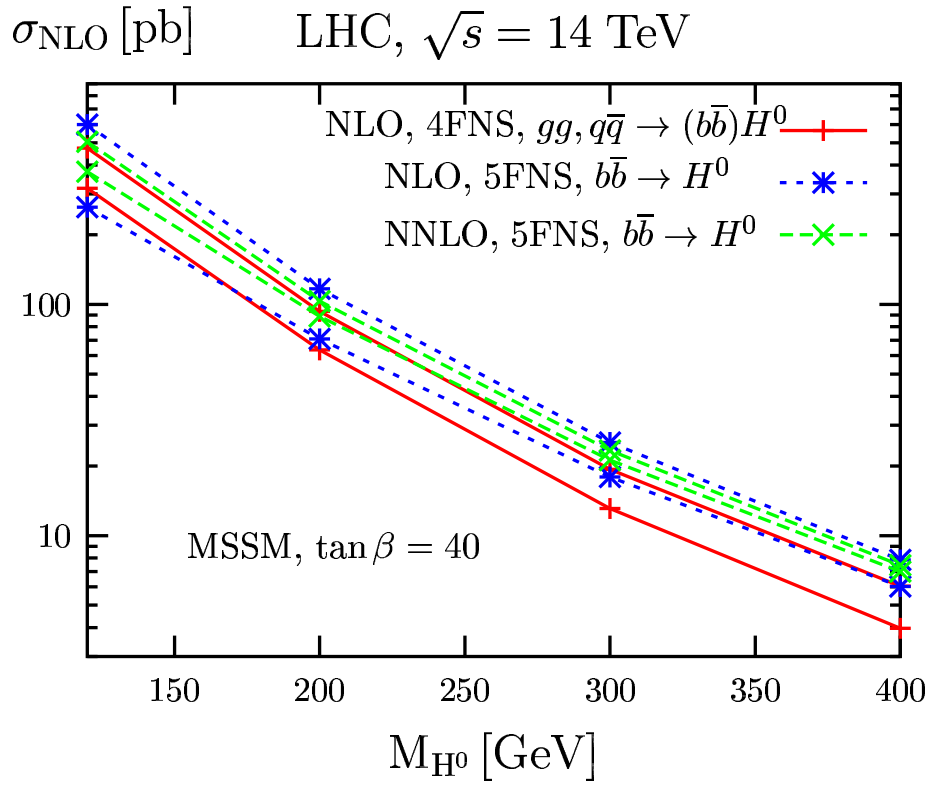
$$g^{MSSM}_{b\bar{b}H^0} = g^{SM}_{b\bar{b}h}\frac{1}{1+\Delta_b}\left[\frac{\cos\alpha}{\cos\beta} + \Delta_b\frac{\sin\alpha}{\sin\beta}\right]$$

$$\Delta_b = \mu\tan\beta\left[\frac{2\alpha_s(m_t)}{3\pi}M_{\tilde{g}}I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}}) + \left(\frac{h_t}{4\pi}\right)^2 A_t I(m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu)\right]$$

$$I(a,b,c) = \frac{[a^2b^2\ln(\frac{a^2}{b^2}) + b^2c^2\ln(\frac{b^2}{c^2}) + a^2c^2\ln(\frac{c^2}{a^2})]}{(a^2-b^2)(b^2-c^2)(a^2-c^2)}$$

Inclusive MSSM Higgs Production with b Quarks

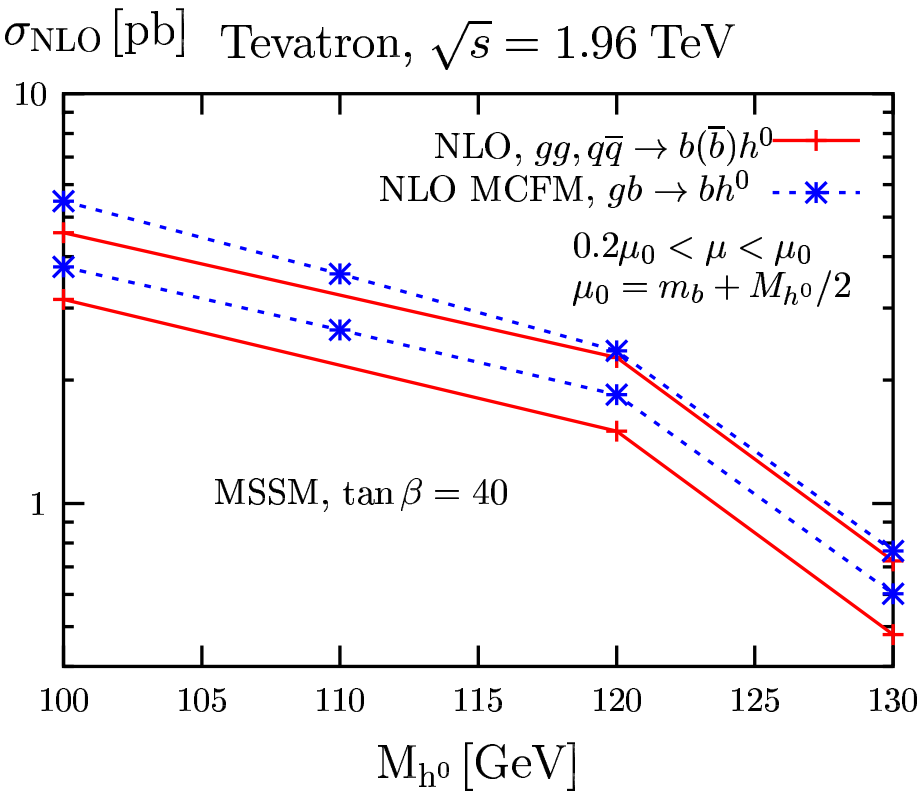


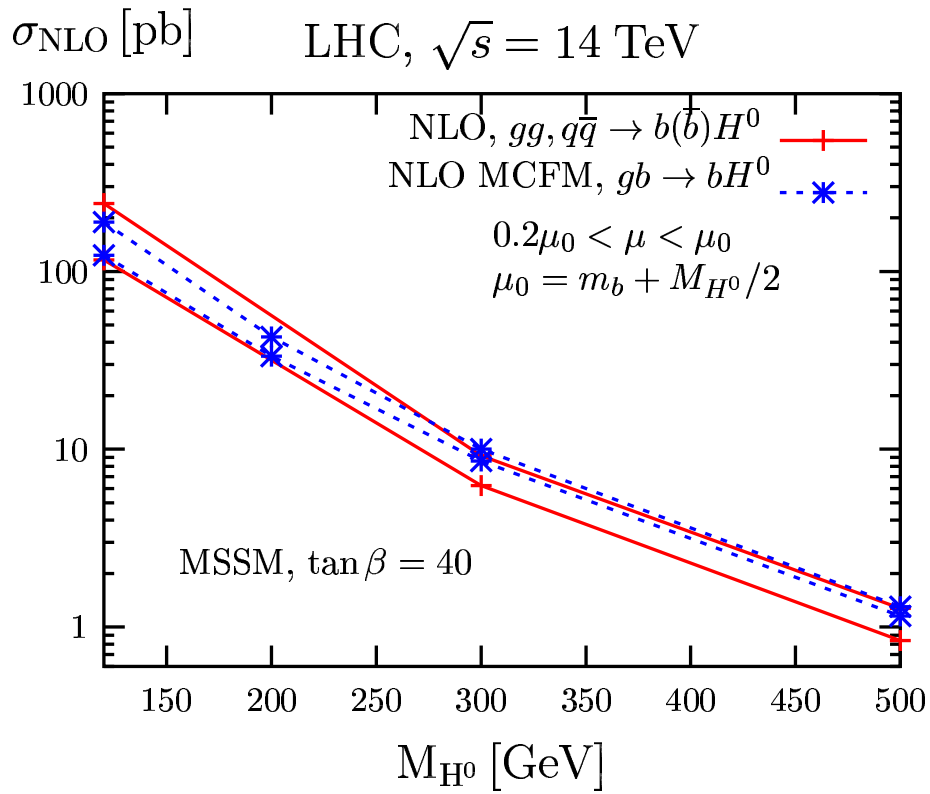


from S. Dawson, C.J., L. Reina and D. Wackeroth (hep-ph/0508293)

5FNS numbers from Harlander and Kilgore (PRD68 013001 (2003))

MSSM Higgs Production with One High-p_T b





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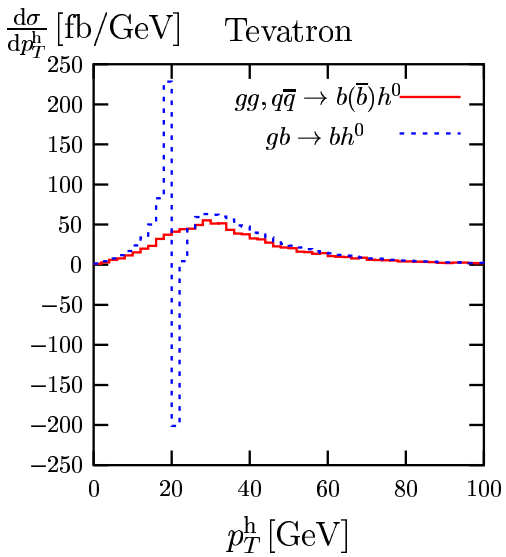
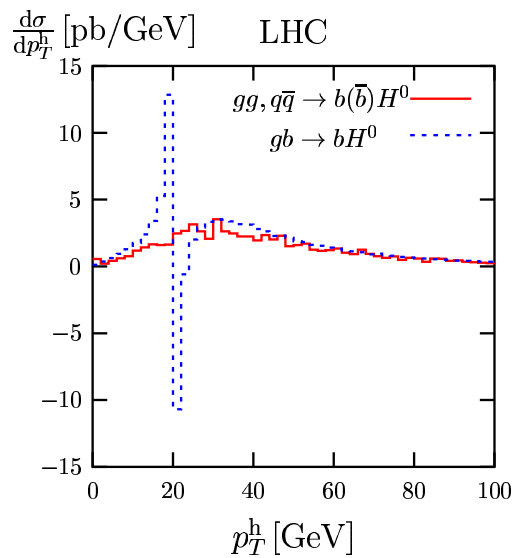
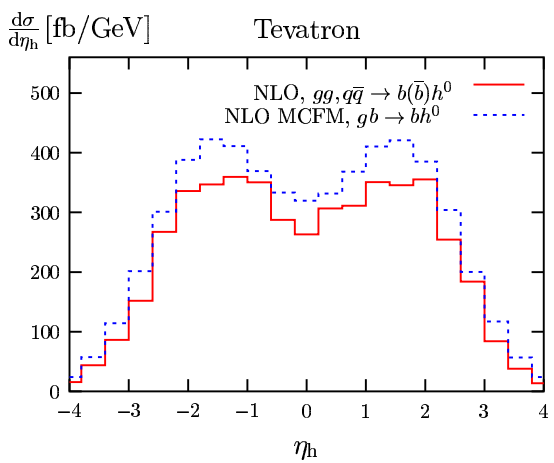
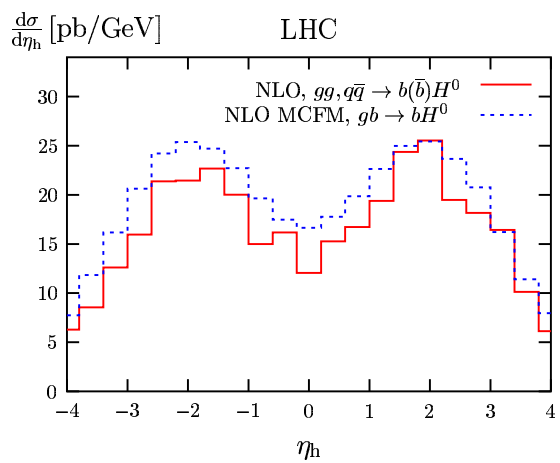
5FNS numbers from MCFM (webpage: mcfm.fnal.gov)

And for the experimentalists...

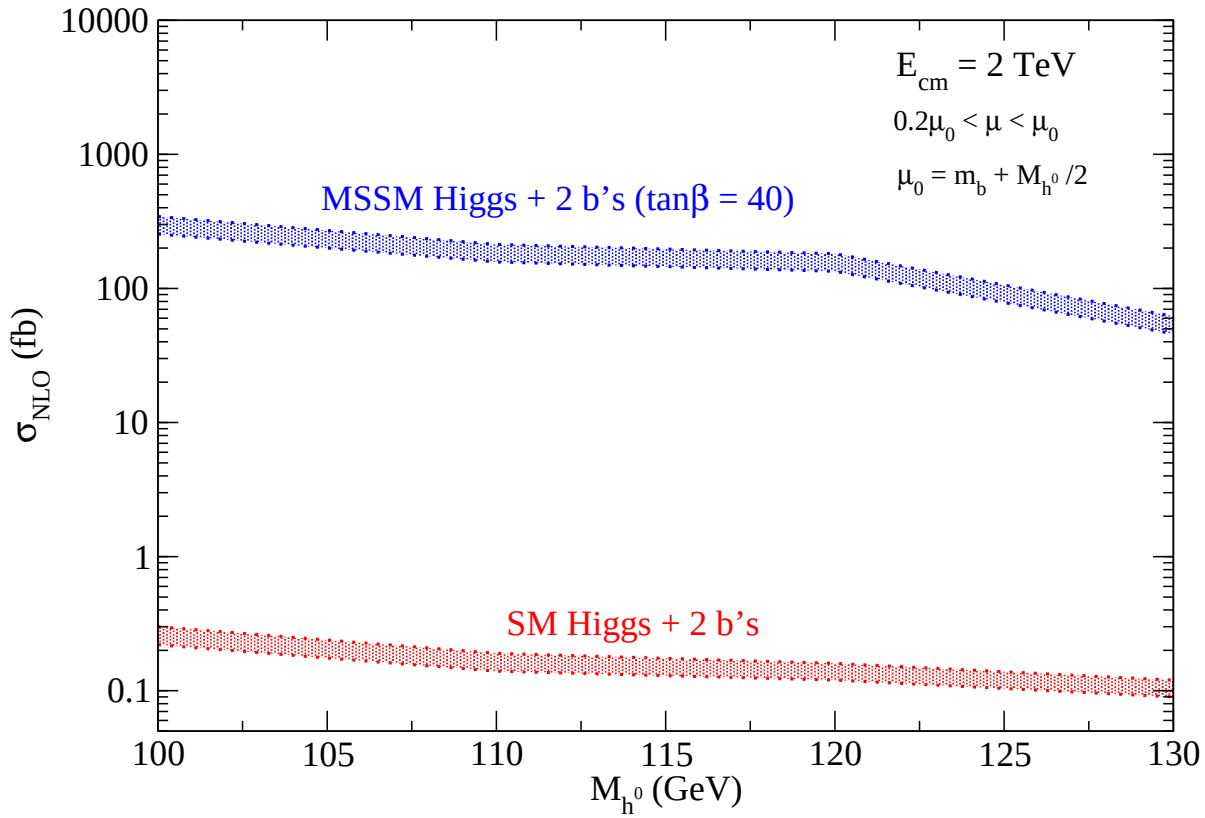




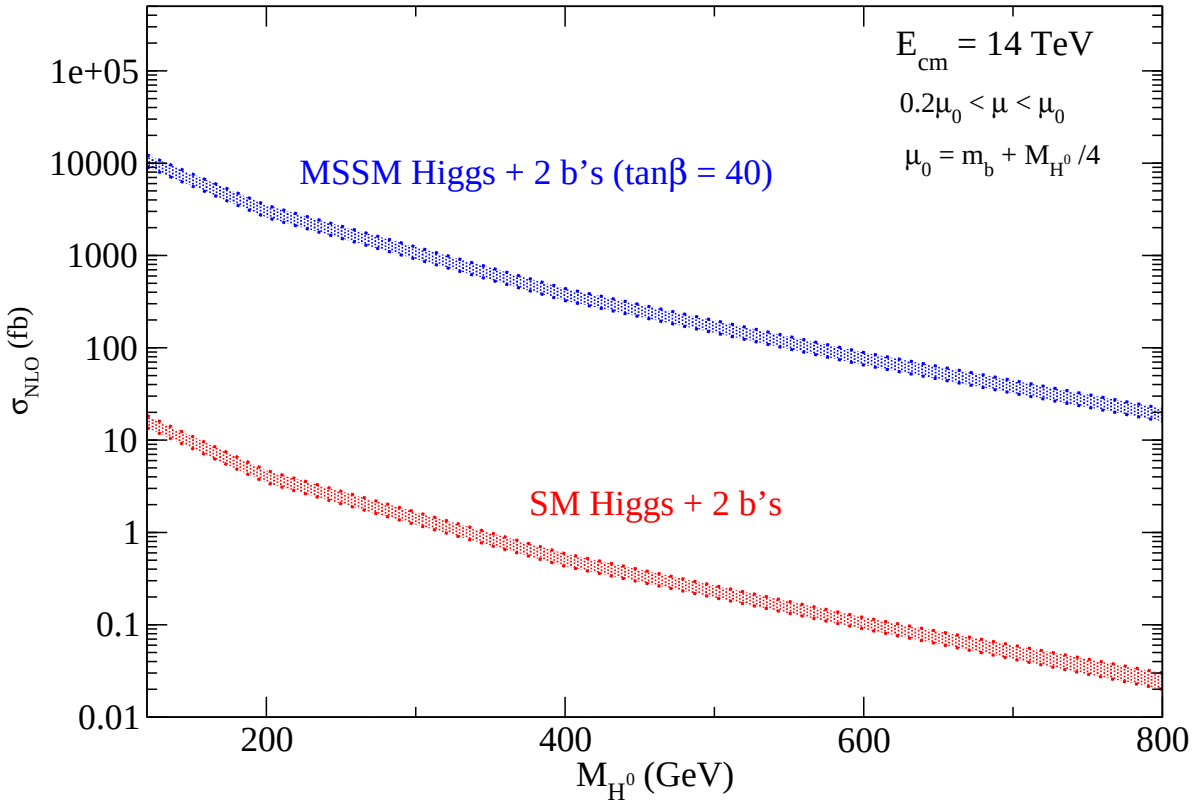




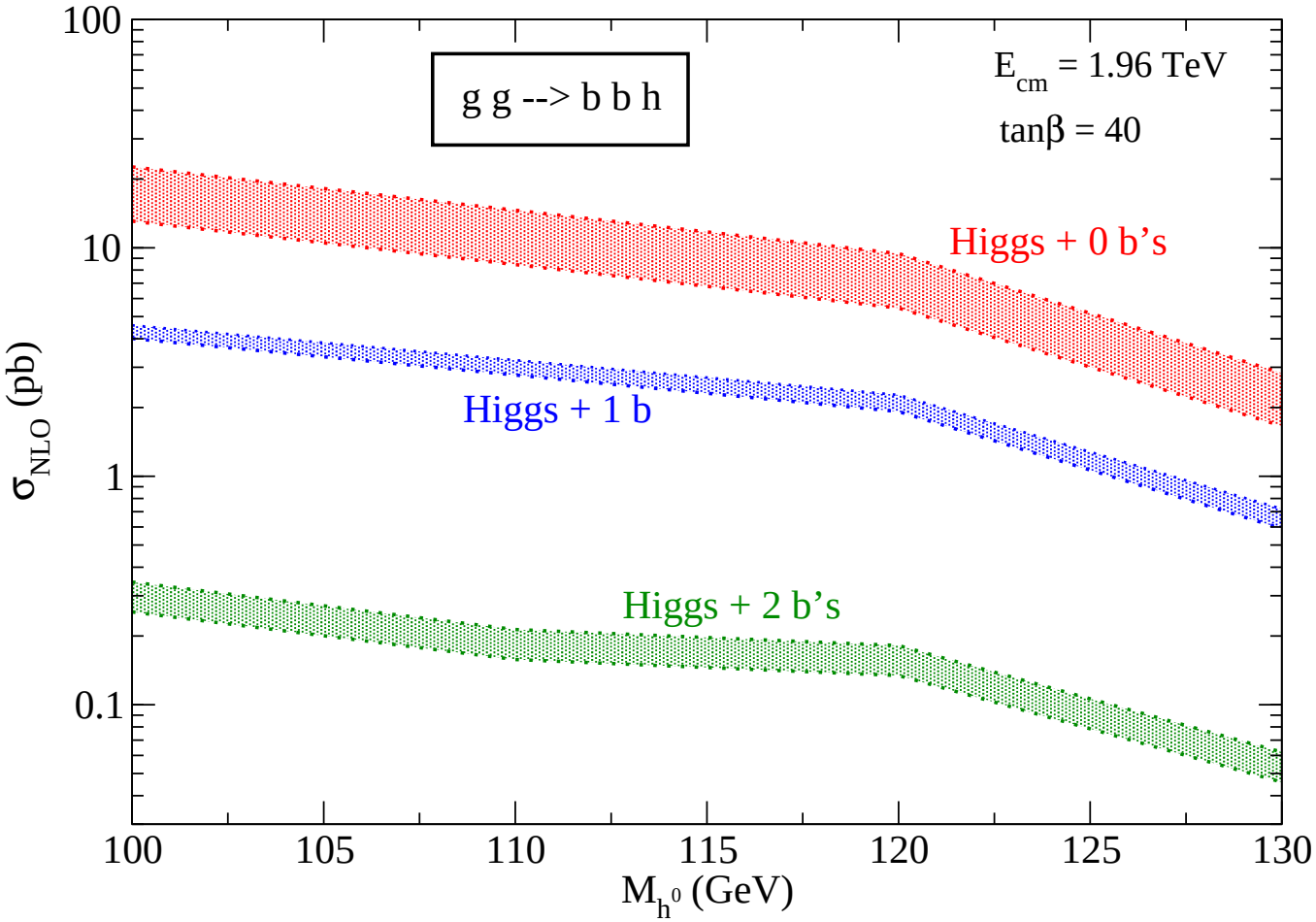
Higgs Production with Two High-p_T b Jets



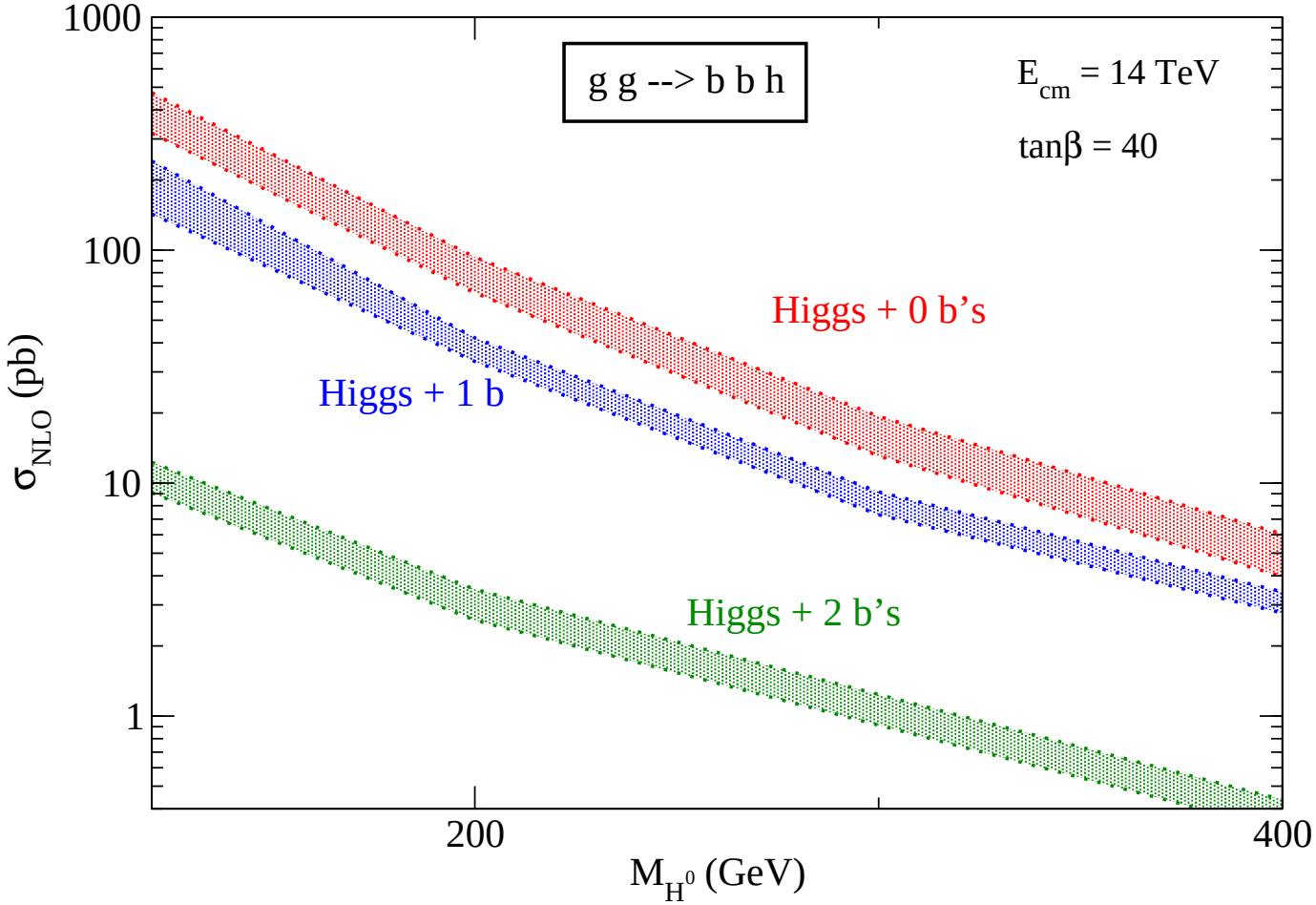
Higgs + 2 b's @ the LHC



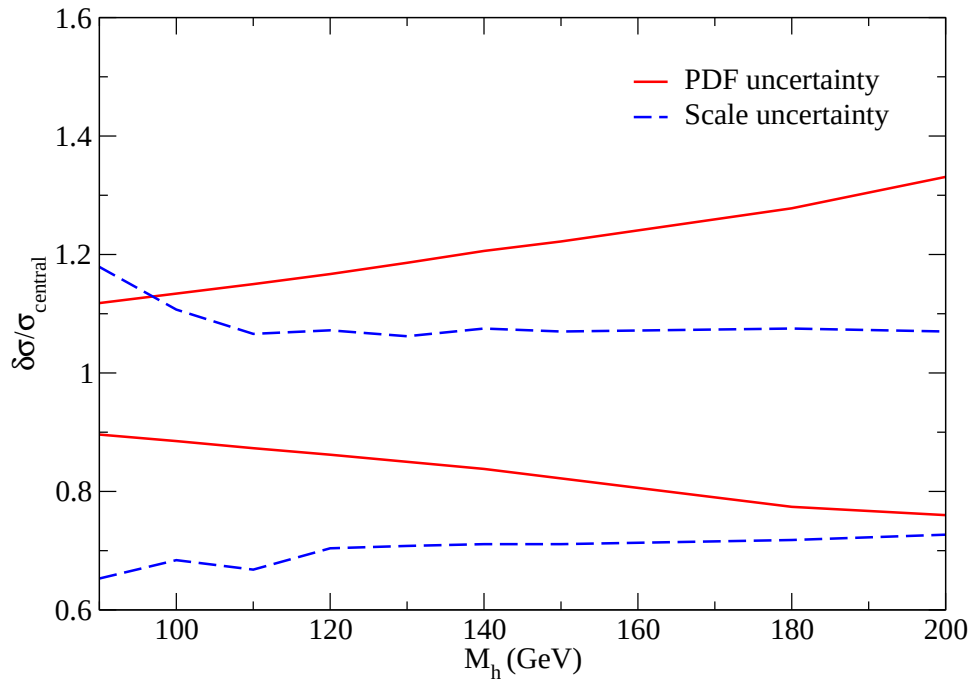
MSSM $b\bar{b}h^0$ at the Tevatron



MSSM $b\bar{b}H^0$ at the LHC

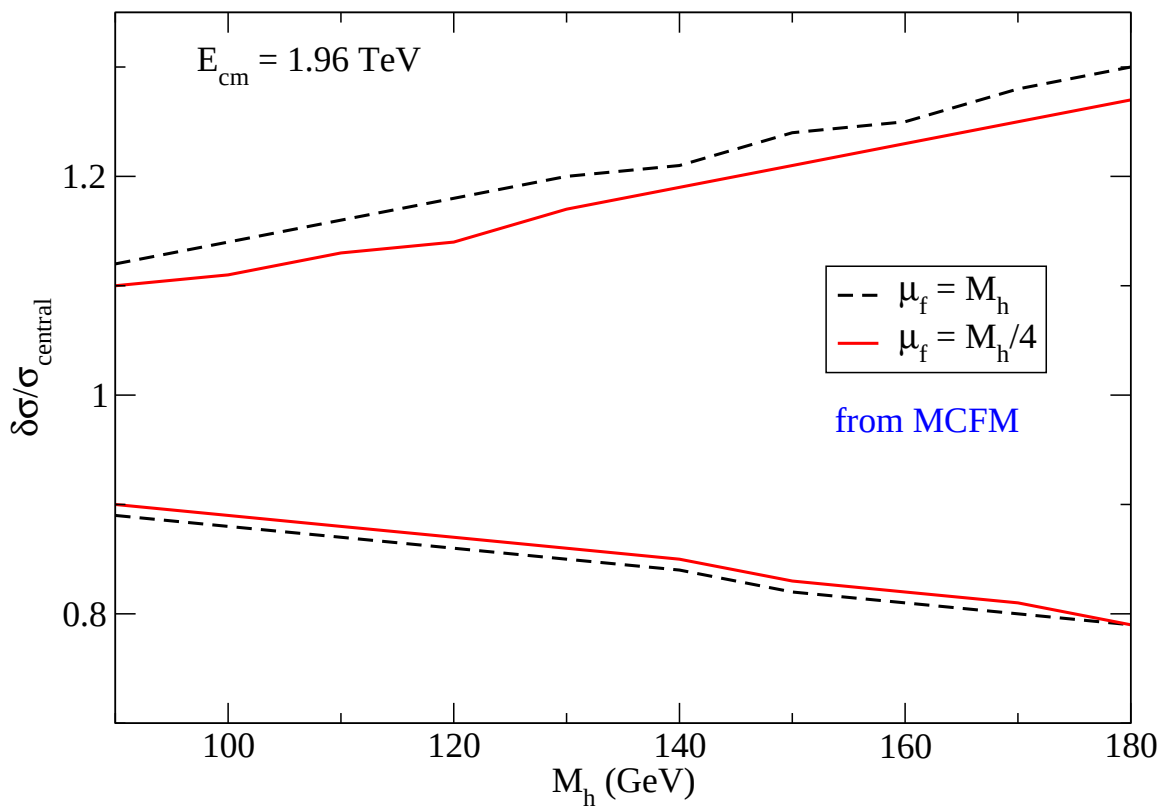


PDF Uncertainties for $gb \to bh$ at the Tevatron



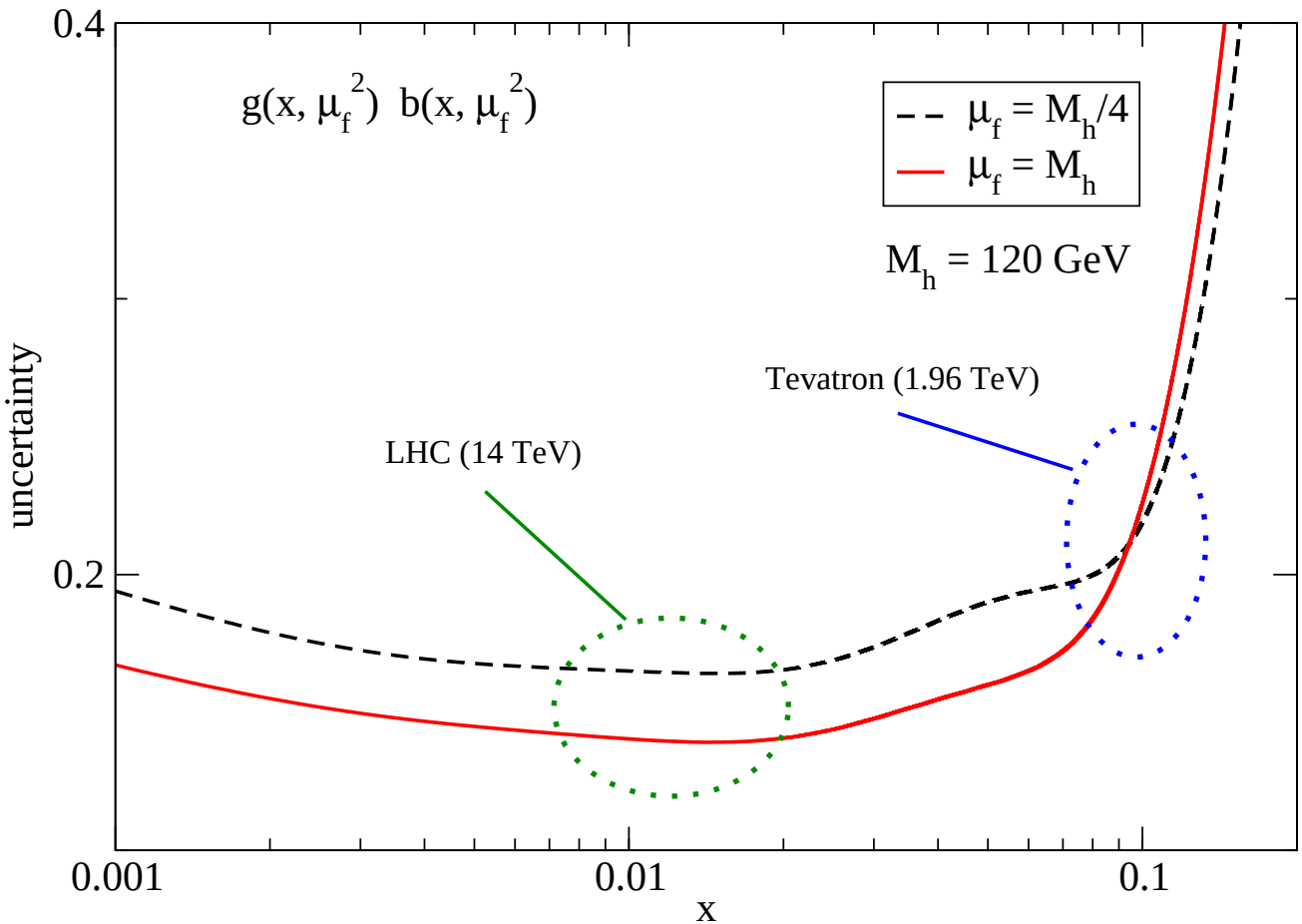
- CTEQ $\Rightarrow$ 40 + 1 Sets (or MRST $\Rightarrow$ 30 + 1 sets)
- Tevatron: Small CM energy $\to$ large x region $\to$ large uncertainties
- Is this due to small(er) scale $\mu_f = \frac{M_h}{4}$?

PDF Uncertainties with $\mu_f = \frac{M_h}{4}$ vs. M_h



- Uncertainties with $\mu_f = \frac{M_h}{4}$ actually smaller...but why?

PDF Uncertainties with $\mu_f = \frac{M_h}{4}$ vs. M_h (cont.)



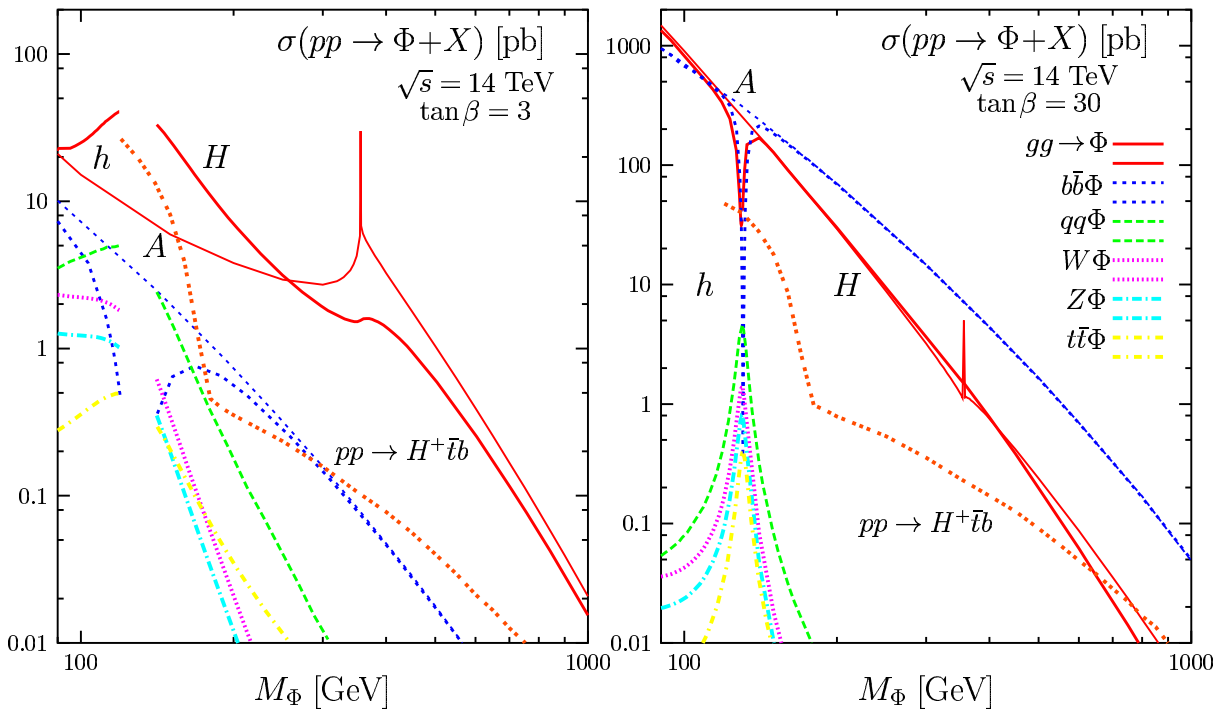
Summary

- $h^0(H^0)$ production with b's is extremely important for discovery at the Tevatron (LHC)
- Two approaches to calculating cross sections: 4FNS and 5FNS
- After years of work, very good agreement between the two
- However, at the Tevatron, both approaches can be plagued by PDF uncertainties ($\pm 20\%$ for $M_{h^0} = 120$ GeV)
- Only thing left to do...find it (minor detail)

The Truth is Out There...

See you at "LHC4ILC"!!!

MSSM Higgs Production at the LHC



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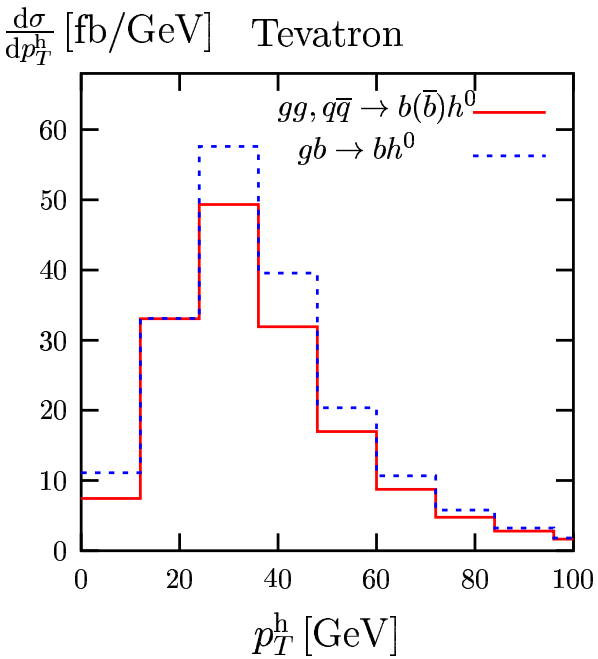
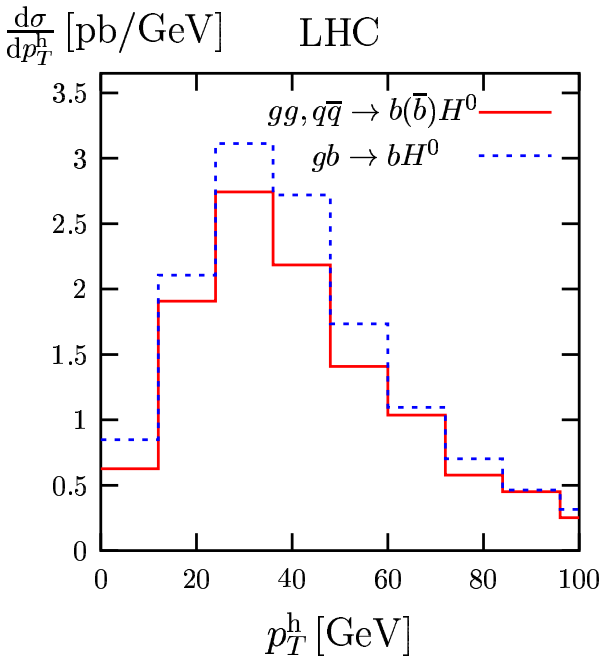
Higgs p_T Distributions





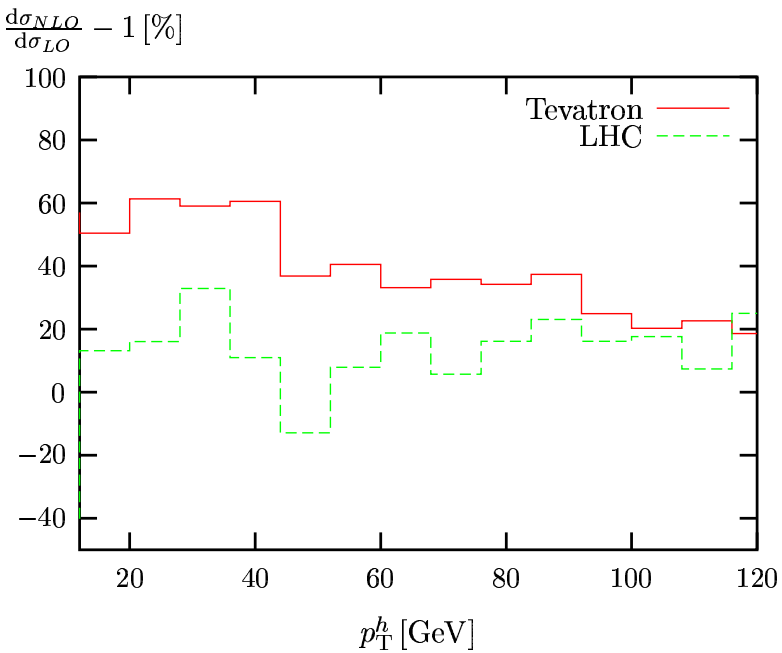
"Divergences" in p_T Distributions

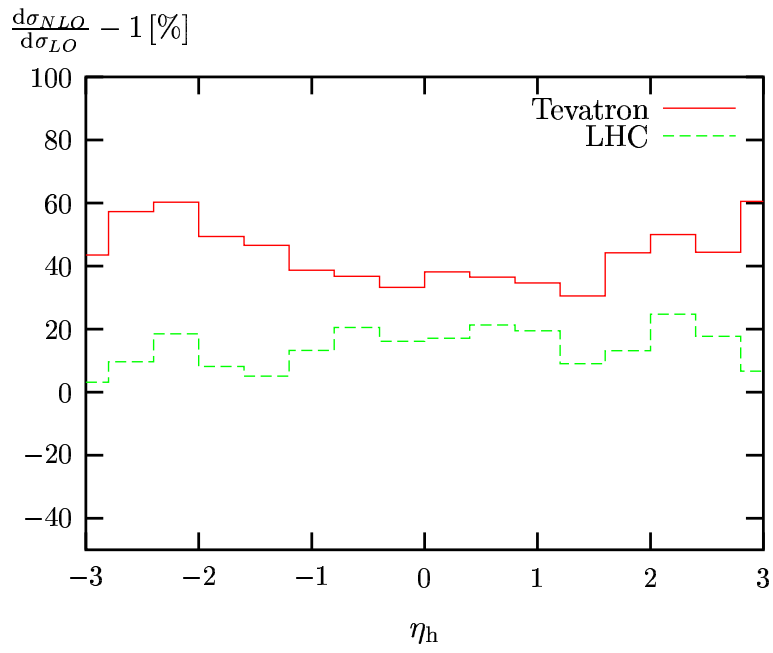
- At LO, Higgs recoils against b jet:
  - p_T cut on b jet $\Longrightarrow$ cut on p_T^h
  - $(\frac{d\sigma}{dp_T^h})_{LO} \rightarrow$ "non-smooth" function
- In the region of the "cut" on p_T^h, the NLO c.s. is the convolution of the LO c.s. with a "soft gluon probability"
  - "Soft gluon probability" $\rightarrow$ "plus" distribution

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

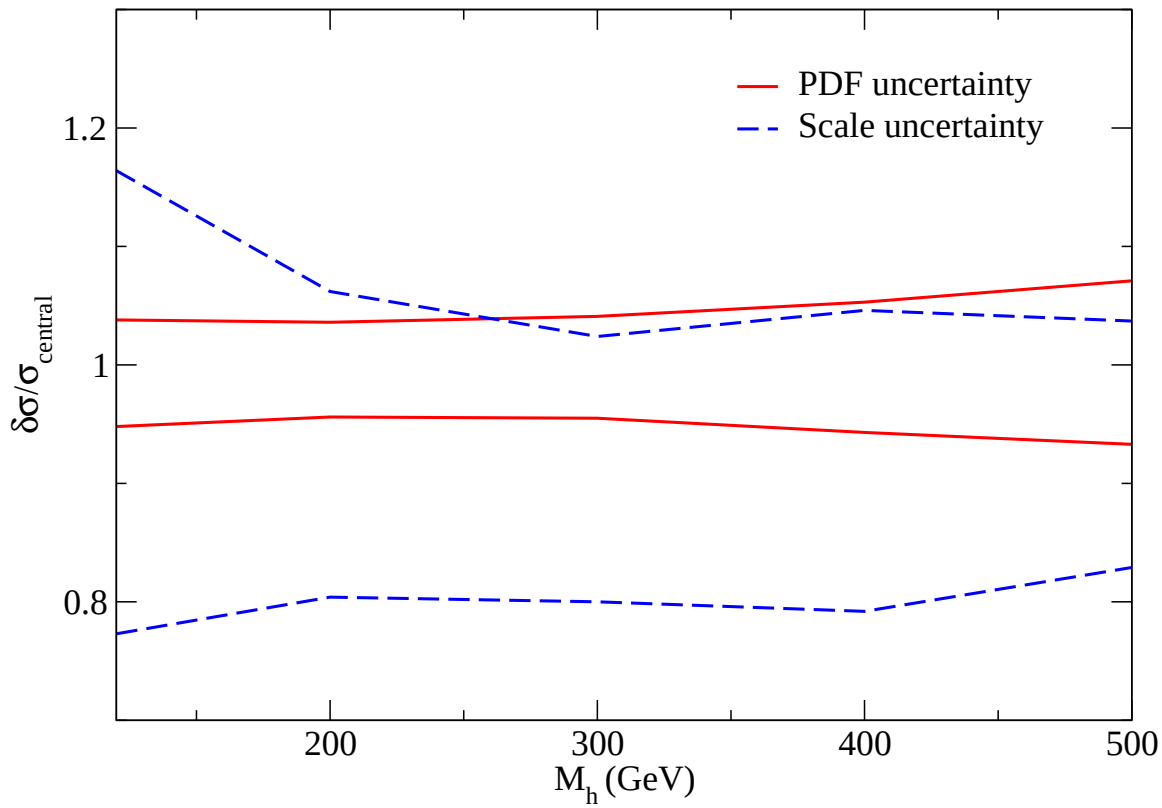
- Improvement through resummation techniques (See B. Field's talk)

Higgs p_T/η Distributions for Exclusive Production





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



PDF Uncertainties

- Nominal set of PDFs (e.g. CTEQ6) obtained by fitting data from low-energy experiments to non-perturbative core equation (20 parameters)

- 20 parameters varied (in a well-defined manner) to *map* out neighborhood around the nominal fit $\longrightarrow$ 40 additional PDF sets

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

- Heavy quark PDFs not fit to data! Calculated perturbatively from gluon PDF $\Rightarrow$ b quark PDF uncertainties intimately related to gluon PDF uncertainties.