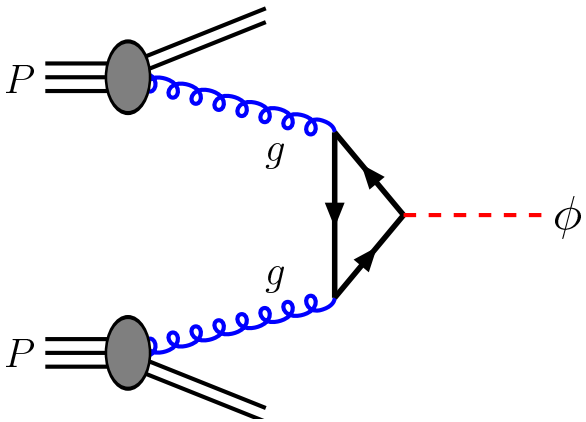
Associated Higgs Production with Bottom Quarks at Hadron Colliders

Michael Krämer (RWTH Aachen)

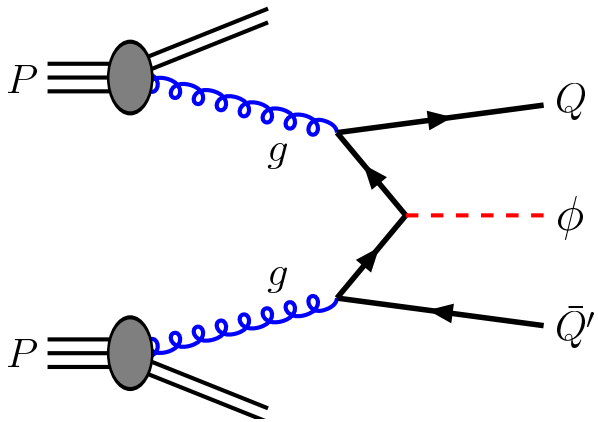
Kickoff Meeting of the working group on Higgs and heavy quarks
Wuppertal 1.-2.3. 2010

Higgs production at hadron colliders through heavy quarks

inclusive



heavy-quark associated

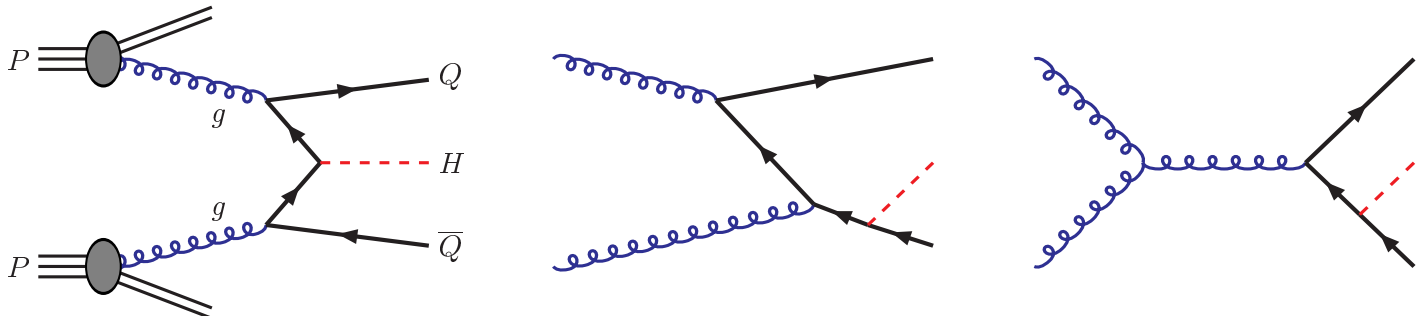


Heavy quarks are special because

- they couple strongly to Higgs
- they are perturbative: $m_Q \gg \Lambda_{\mathrm{QCD}}$

Associate QQH production: two calculational schemes

At leading order



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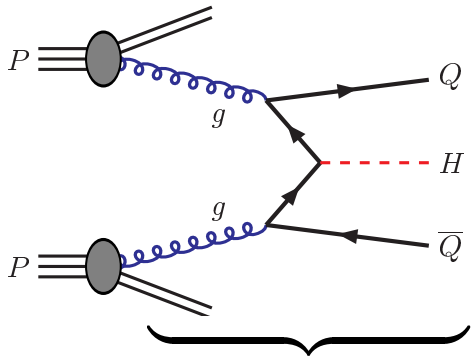

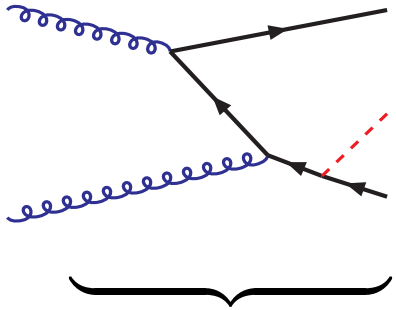

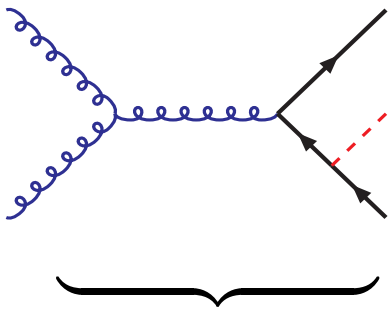

$M_Q \ll M_H$: $\sim \alpha_s^2 \ln^2(M_H/M_Q)$ $\sim \alpha_s^2 \ln(M_H/M_Q)$ $\sim \alpha_s^2$

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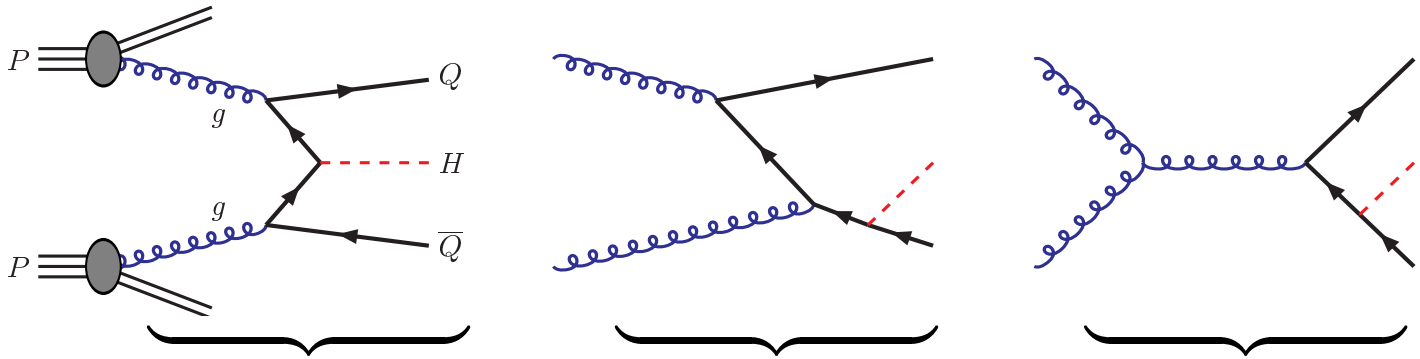

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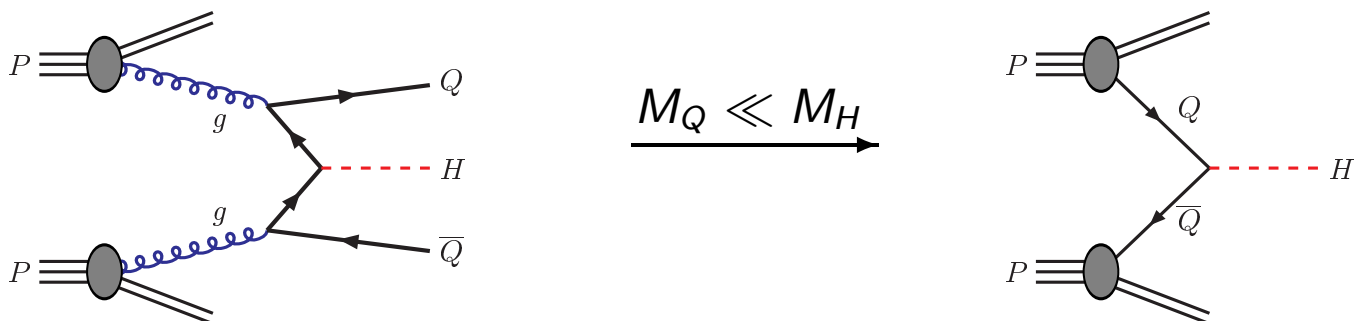
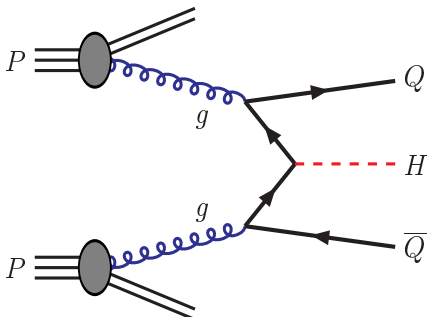
Summation of $\ln(M_H/M_Q)$ terms by using heavy quark PDFs

[Collins, Olness, Tung; Barnett, Haber, Soper; Dicus, Willenbrock,...]



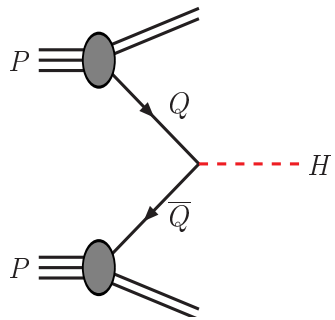
Associate QQH production: two calculational schemes

4-flavour scheme



+ exact $g \to b\bar{b}$ splitting & mass effects
− no summation of $\ln(M_H/M_b)$ terms

5-flavour scheme



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− LL approximation to $g \to b\bar{b}$ splitting

Associate QQH production: two calculational schemes

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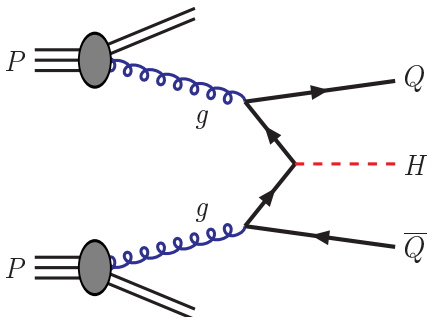

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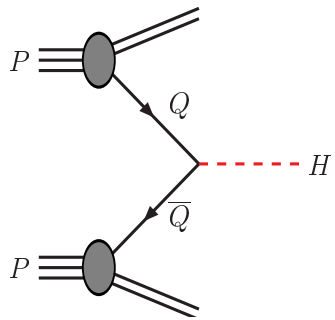


\+ summation of $\ln(M_H/M_b)$ terms

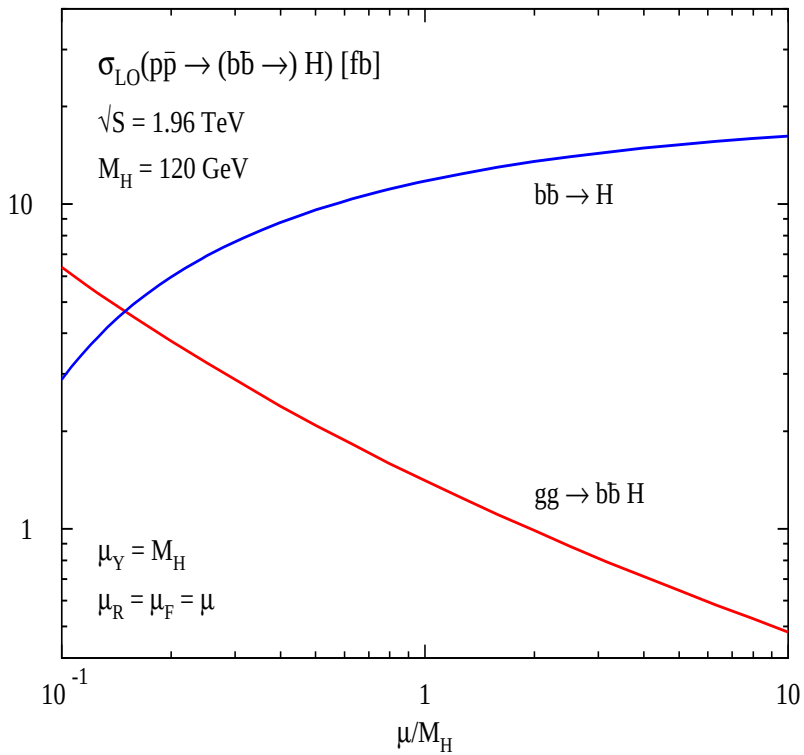
− LL approximation to $g \to b\bar{b}$ splitting

The 4- and 5-flavour schemes

- are both theoretically consistent & well-defined
- represent different ways of ordering perturbation theory
- should agree at sufficiently high order
- do not match exactly at finite order

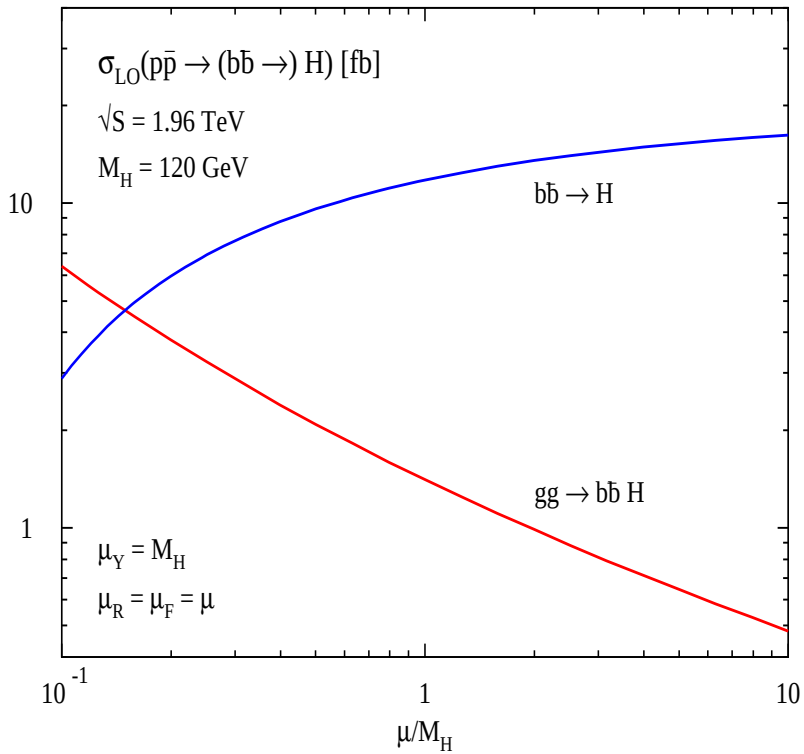
Associate *bbH* production: two calculational schemes

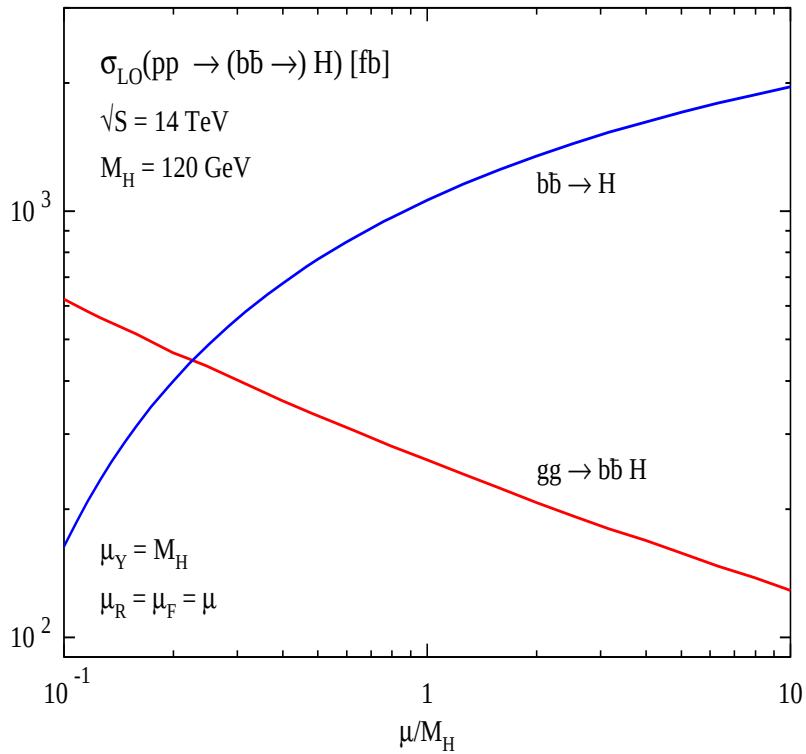
Comparison at leading order



Associate *bbH* production: two calculational schemes

Comparison at leading order





Associate bbH production: two calculational schemes

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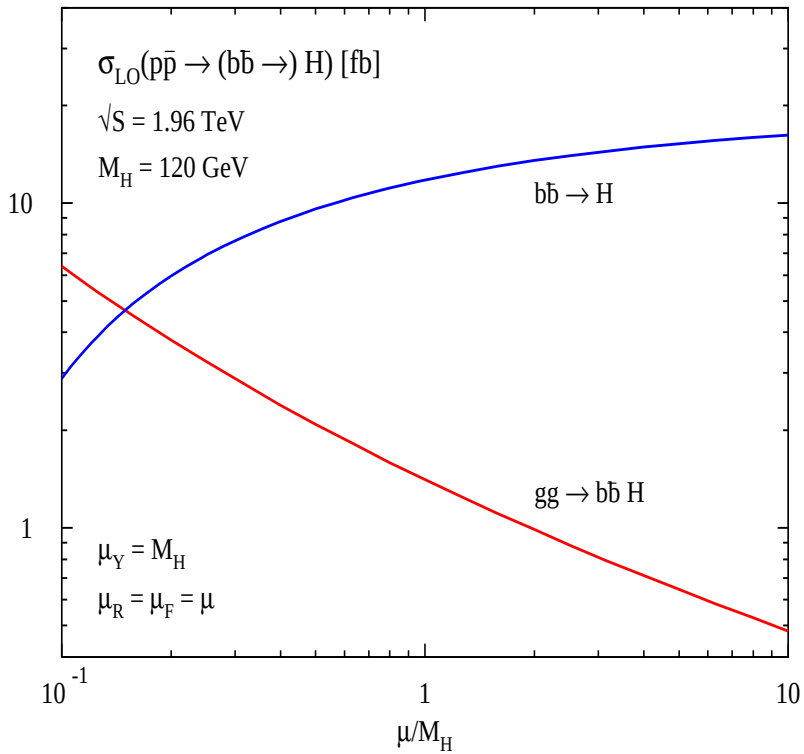
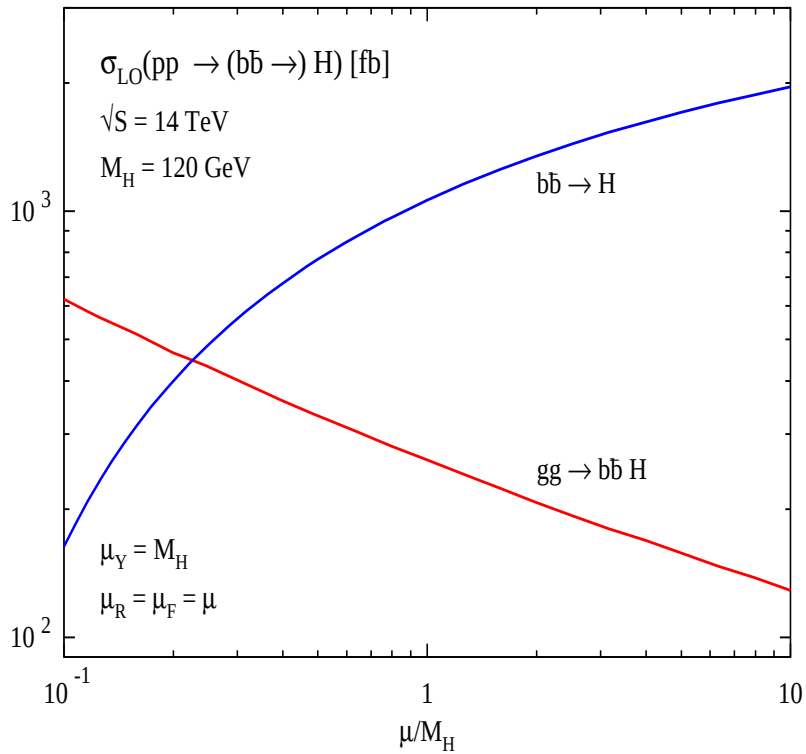




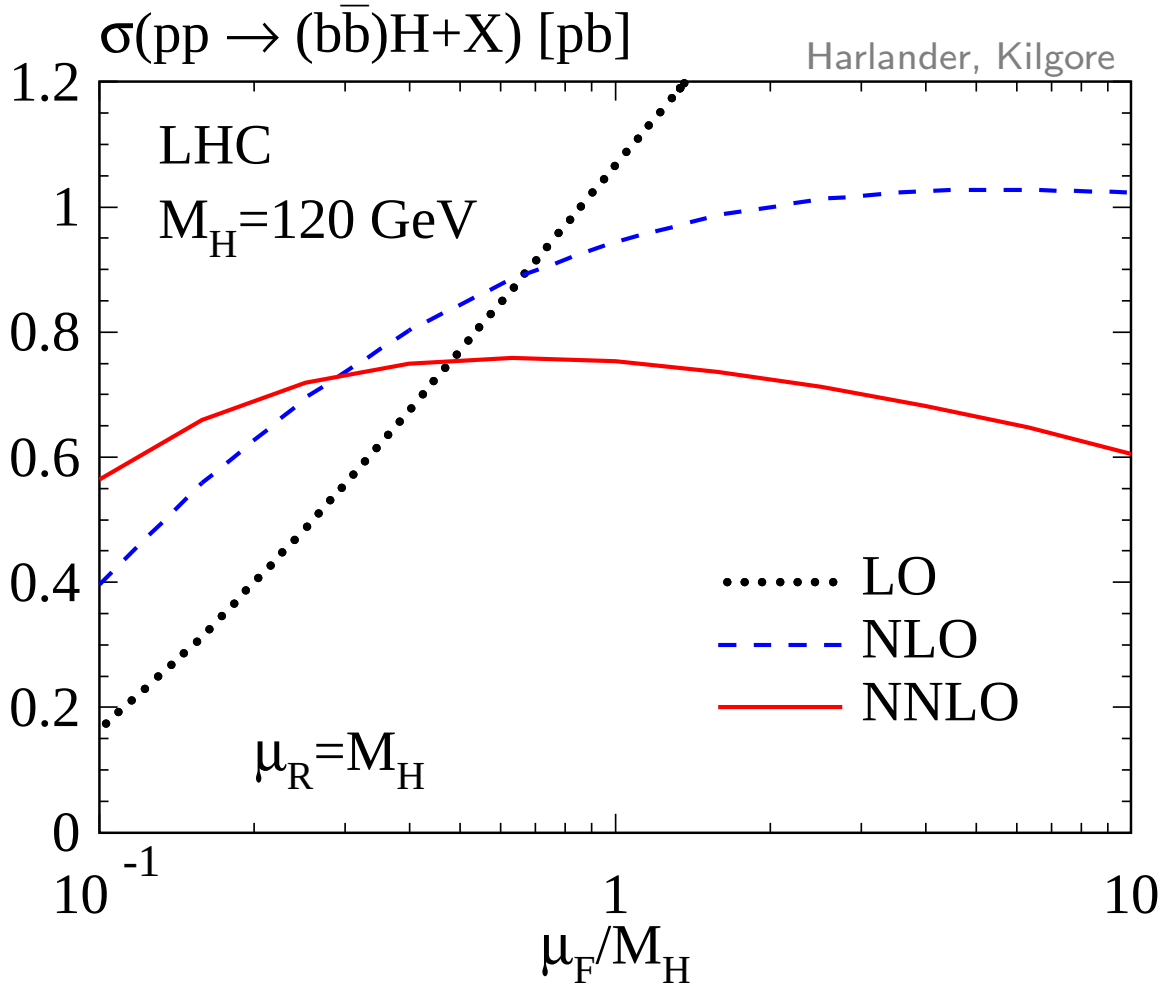
$\longrightarrow$ strong scale dependence

$\longrightarrow$ $\sigma(b\bar{b} \to H) \gg \sigma(gg \to b\bar{b}H)$ at $\mu = M_H$

$\longrightarrow$ discrepancy reduced at $\mu_F = M_H/4$

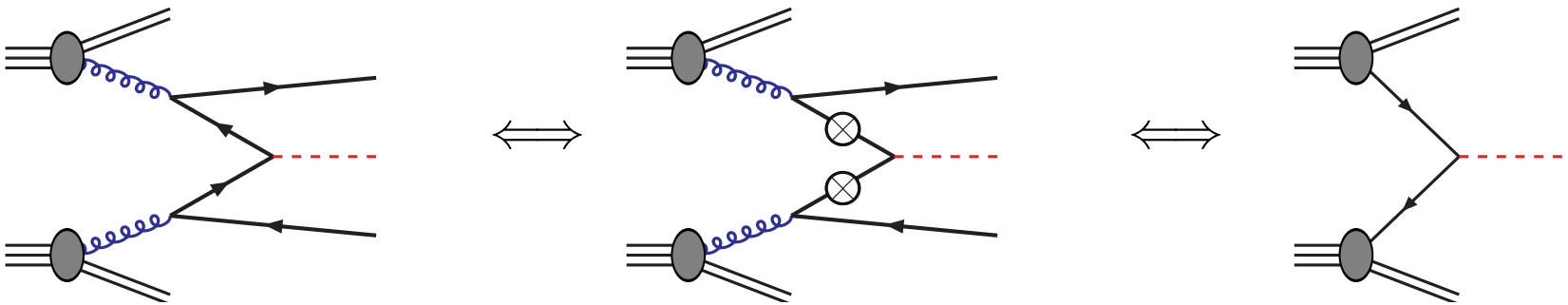
[Harlander, Kilgore; see also Spira; Maltoni, Sullivan, Willenbrock; Boos, Plehn]

NNLO 5FS calculation



Two calculational schemes

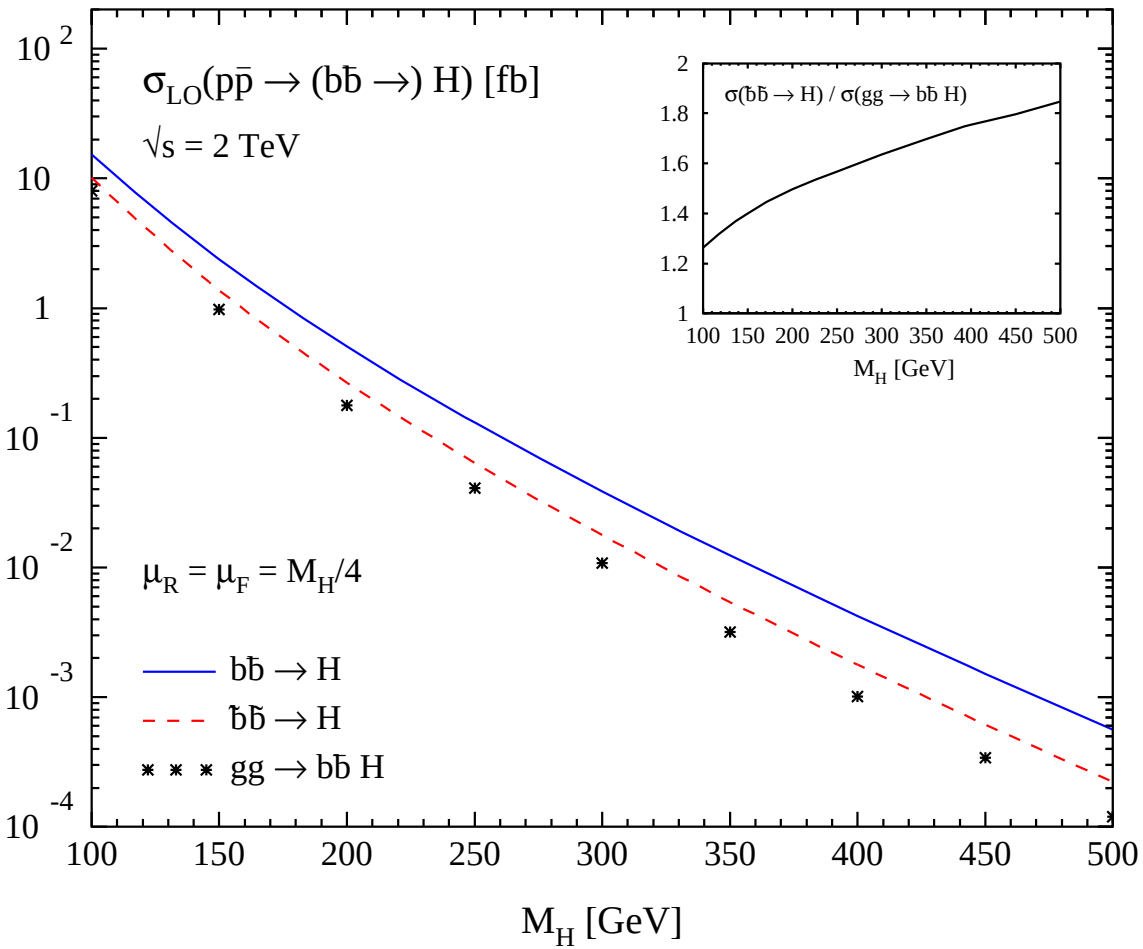
Compare



where $\otimes$ corresponds to α_s^1 contribution to the distribution of heavy quarks in an on-mass shell gluon:

$$\tilde{b}(x,\mu) = \frac{\alpha_s(\mu)}{2\pi} \ln\left(\frac{\mu^2}{m_Q^2}\right) \times \int_x^1 \frac{d\xi}{\xi} P_{qg}^{(1)}\left(\frac{x}{\xi}\right) g(\xi,\mu)\,.$$

Two calculational schemes

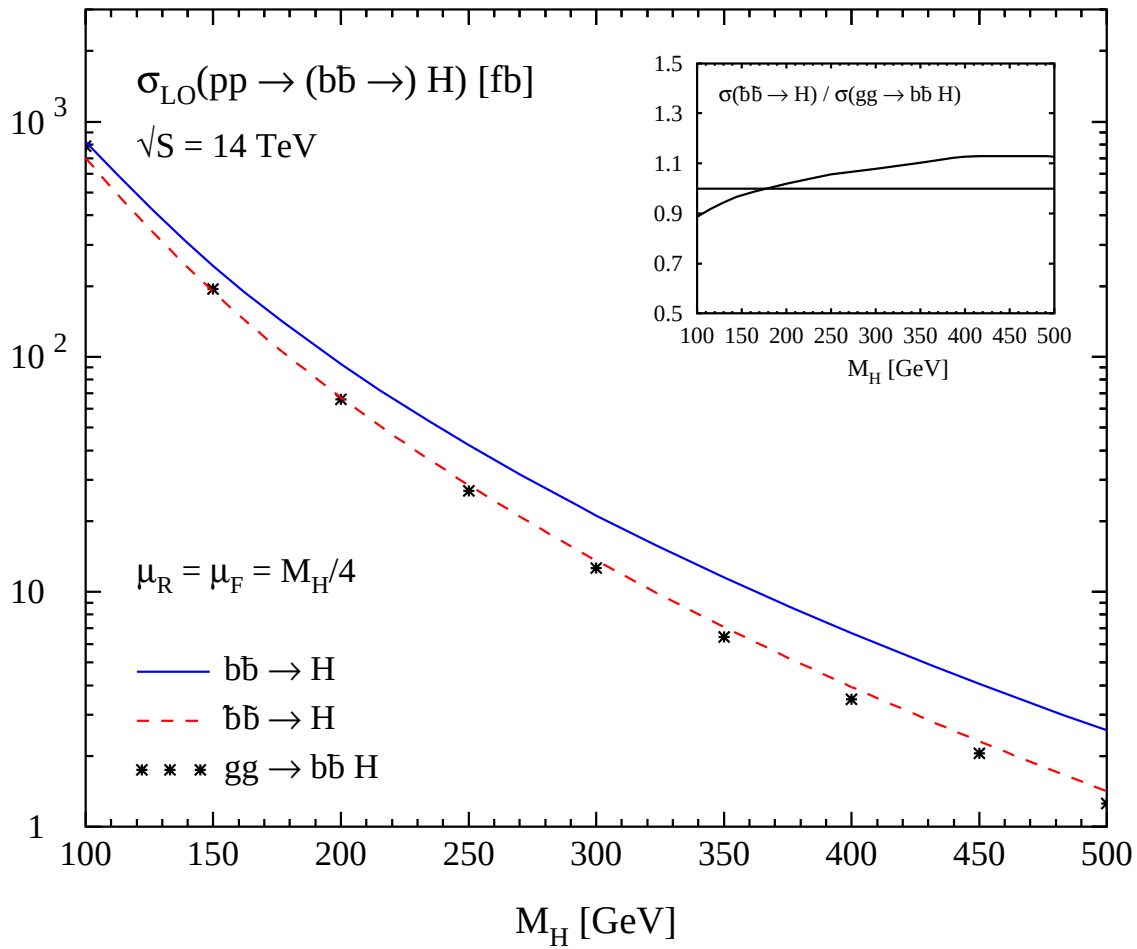


Tevatron

$\to \sigma(\tilde{b}\tilde{b} \to H)/\sigma(gg \to b\bar{b}H) \approx 1.5$

$\to \sigma(bb \to H)/\sigma(\tilde{b}\tilde{b} \to H) \approx 1.7$

Two calculational schemes



LHC

$\rightarrow\ \sigma(\tilde{b}\tilde{b} \to H)/\sigma(gg \to b\bar{b}H) \approx 1.1$

$\rightarrow\ \sigma(bb \to H)/\sigma(\tilde{b}\tilde{b} \to H) \approx 1.4$

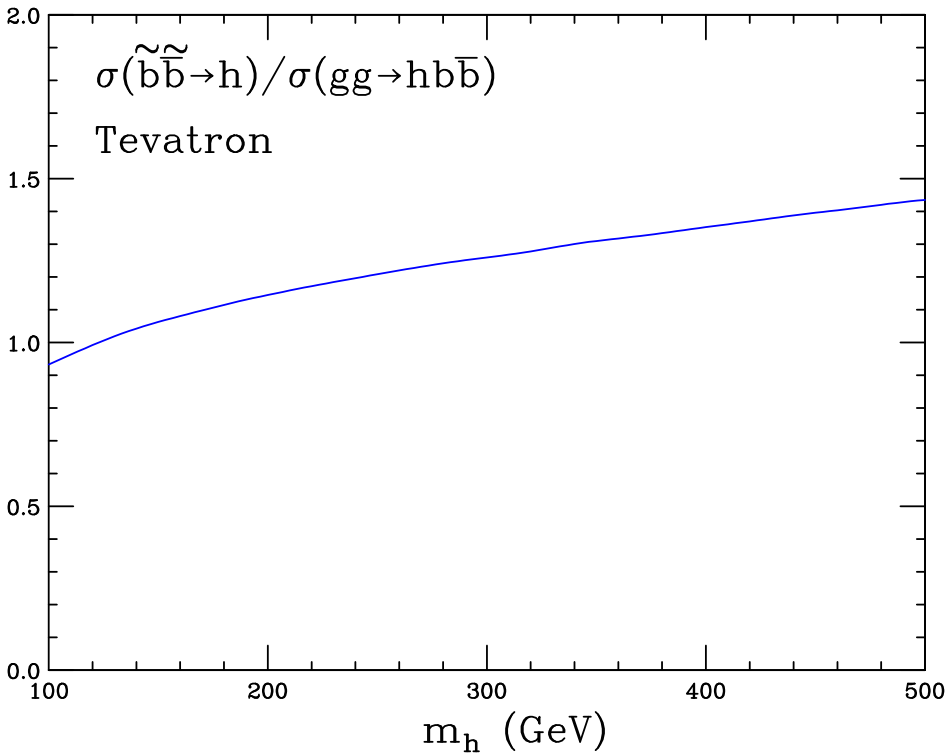
Two calculational schemes

determine factorization scale from collinear region where $d\sigma/dt \sim 1/t$

[Maltoni, McElmurry, Willenbrock]

$\longrightarrow$ $\mu_F \approx m_H/4$ @ $m_H \approx 100$ GeV

$\mu_F \approx m_H/6$ @ $m_H \approx 500$ GeV (Tevatron)



Available calculations for $pp \to bbH$

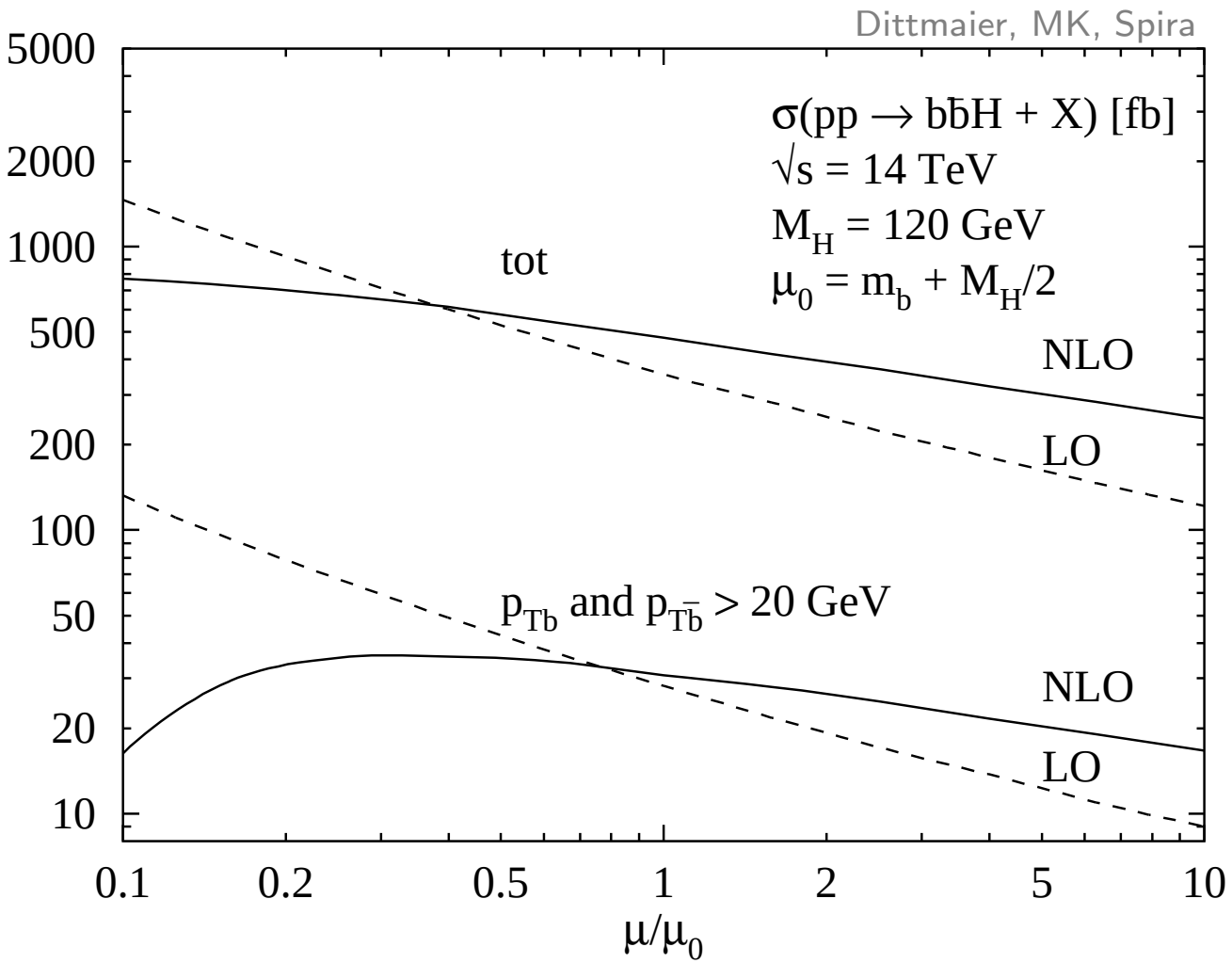
4FS

- NLO-QCD: Dittmaier, MK, Spira, PRD 70 (2004);
  Dawson, Jackson, Reina, Wackeroth, PRD 69 (2004), PRL 94 (2005)

5FS

- $bb \to h$:
  NLO QCD: Dicus, Stelzer, Sullivan, Willenbrock, PRD 59 (1999);
  Balazs, He, Yuan, PRD 60 (1999);
  NNLO-QCD: Harlander, Kilgore, PRD 68 (2003);
  NLO SUSY QCD/EW: Dittmaier, MK, Mück, Schlüter, JHEP03 (2007);
  Hollik, Rauch (2007)
- $bg \to bh$:
  NLO-QCD: Campbell, Ellis, Maltoni, Willenbrock, PRD67 (2003);
  NLO SUSY-QCD: Dawson, Jackson, PRD 77 (2007);
  NLO EW: Dawson, Jaiswal (2010)

NLO 4FS calculation



Inclusive Higgs plus bottom-quark production

Comparison of 4- and 5-flavour schemes at (N)NLO (SM Higgs, LHC)

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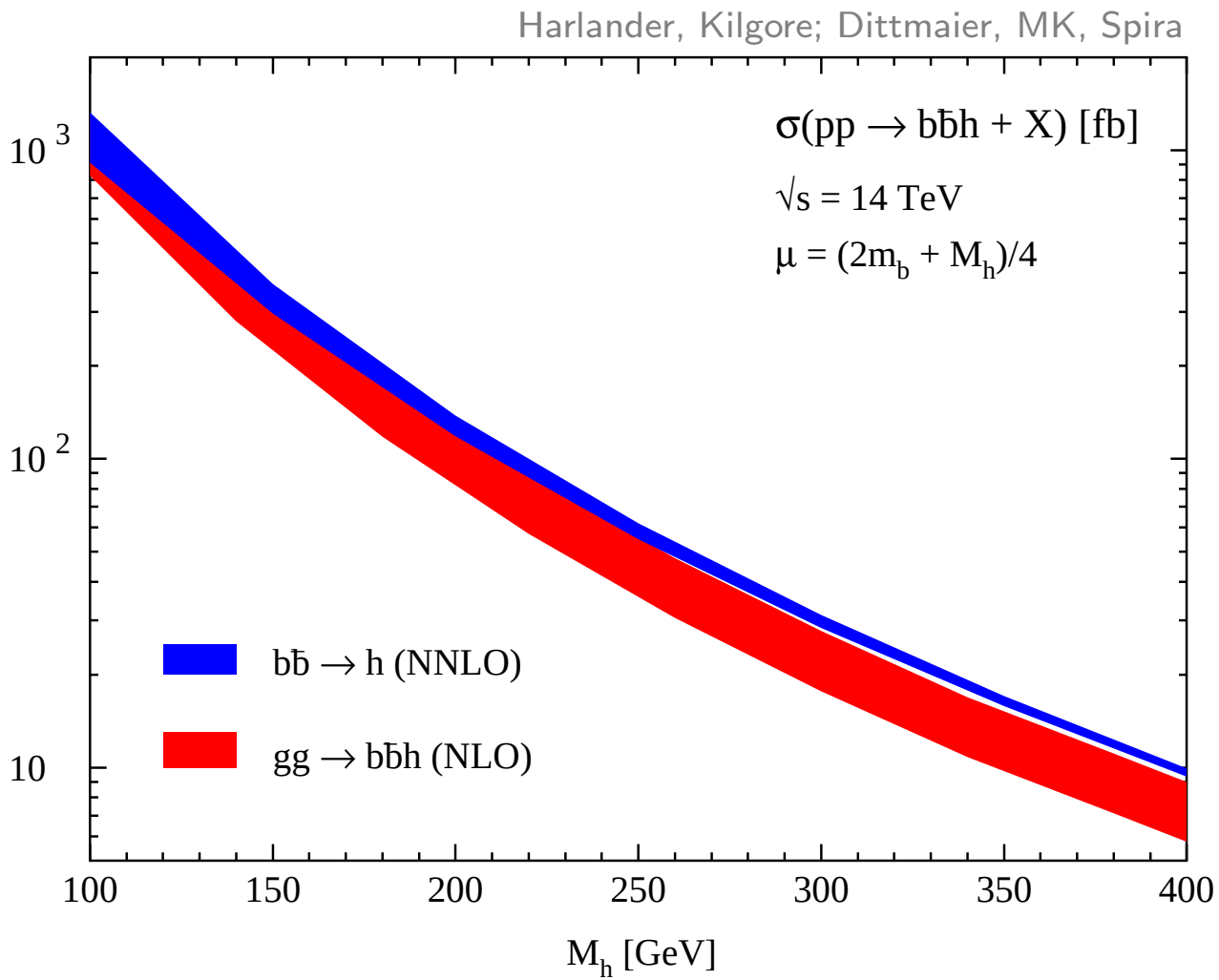


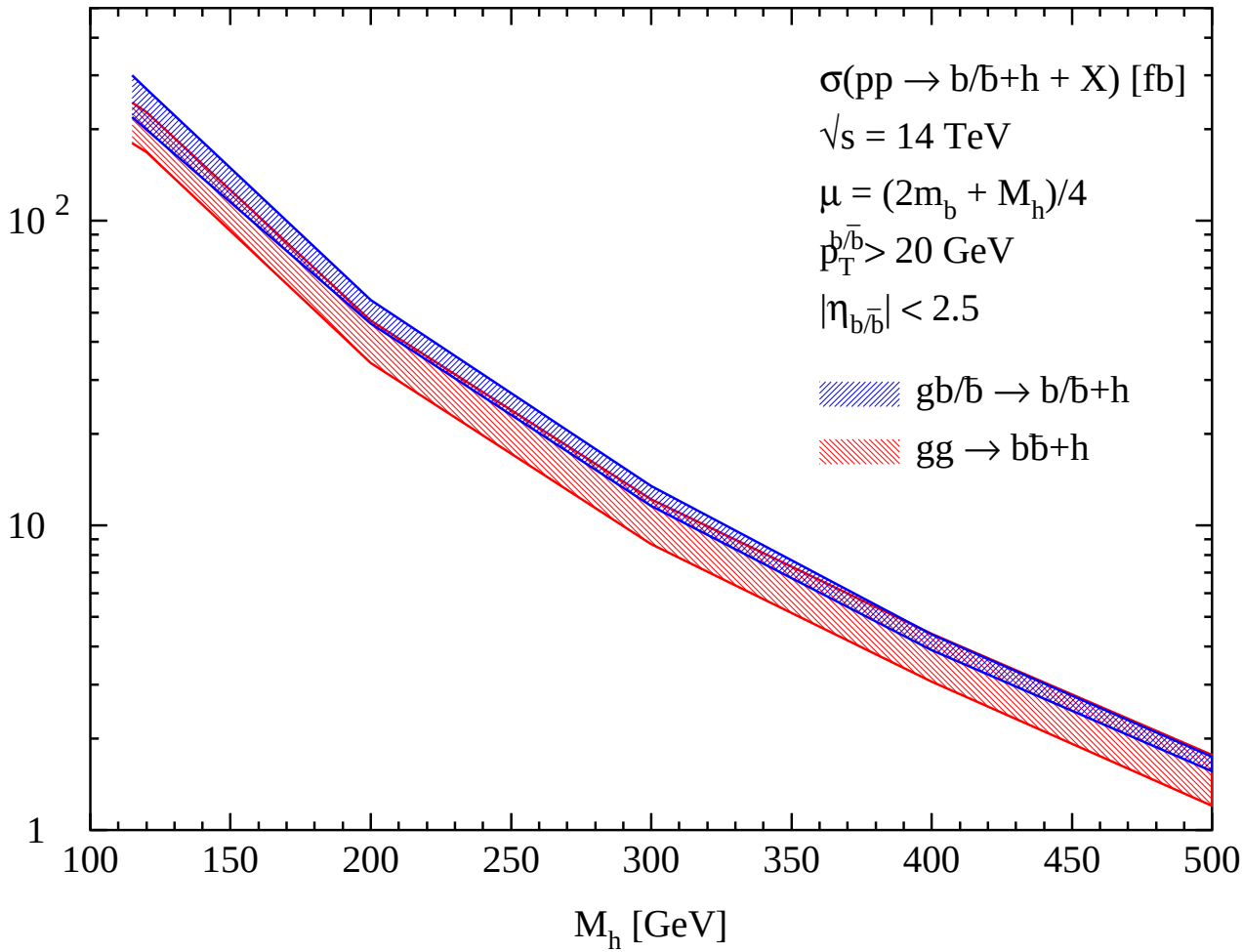
Higgs plus 1 bottom-jet production

Comparison of 4- and 5-flavour schemes at NLO (SM Higgs, LHC)

Higgs plus 1 bottom-jet production

Comparison of 4- and 5-flavour schemes at NLO (SM Higgs, LHC)

Campbell, Ellis, Maltoni, Willenbrock; Dittmaier, MK, Spira; Dawson, Jackson, Reina, Wackeroth



Comments & questions

- 4FS calculation includes Higgs radiation off top loops $\approx -10\%$
- no consistent treatment of pdfs in previous comparisons
  (need pdf with four active flavours $\longrightarrow$ gluon flux larger by 5-10%)

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$\rightarrow$ what is the best estimate for the inclusive cross section?

Maybe the Santander matching [Harlander, MK, Schumacher]:

$$\sigma(\text{best of all worlds}) = \text{weight} \times 5\text{FS} + (1 - \text{weight}) \times 4\text{FS}$$

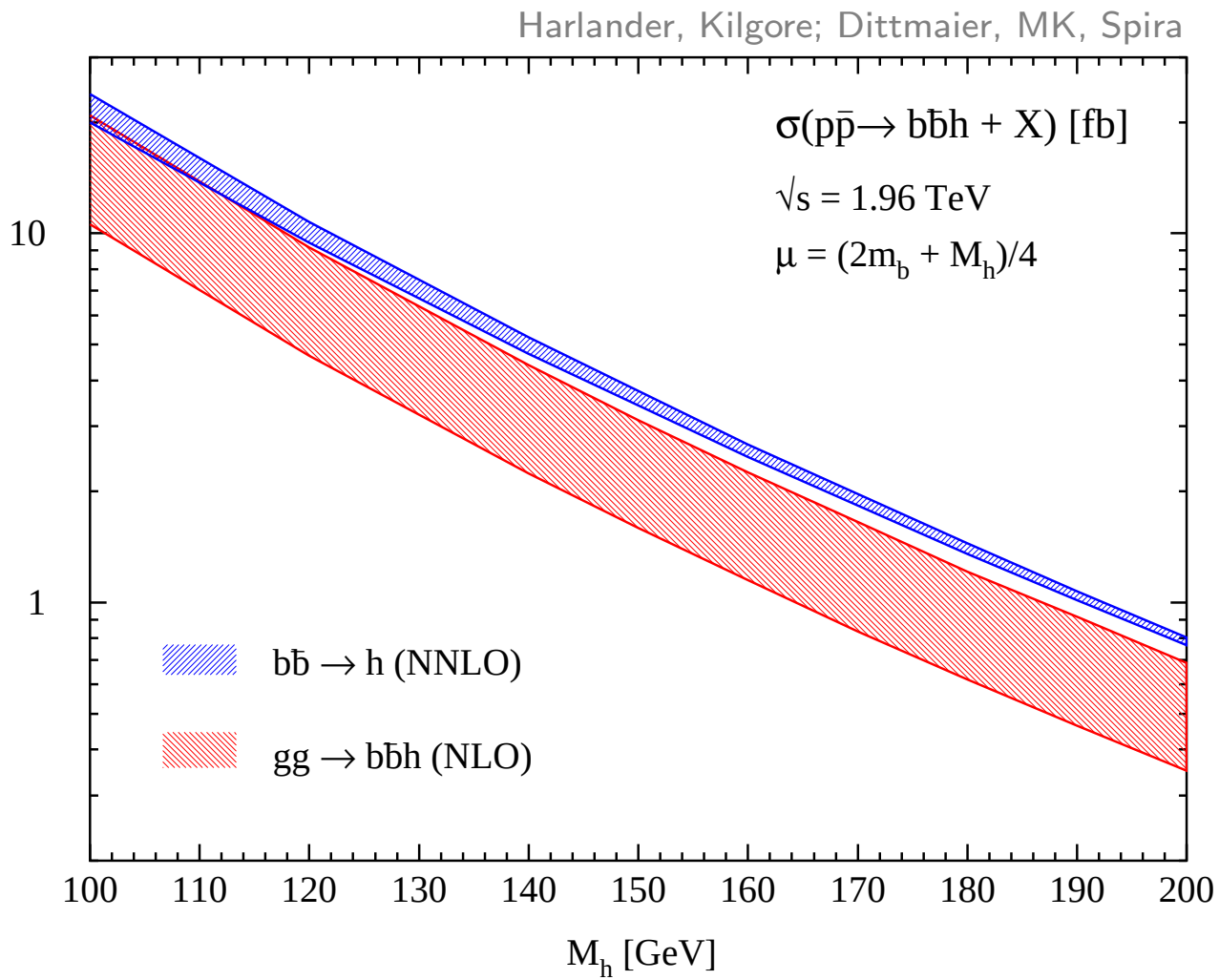
with $\text{weight} = \ln(m_H/37)/(1 + \ln(m_H/37))$

We should be able to do better really, but for the time being...

Backup

Inclusive Higgs plus bottom-quark production

Comparison of 4- and 5-flavour schemes at (N)NLO (SM Higgs, LHC)



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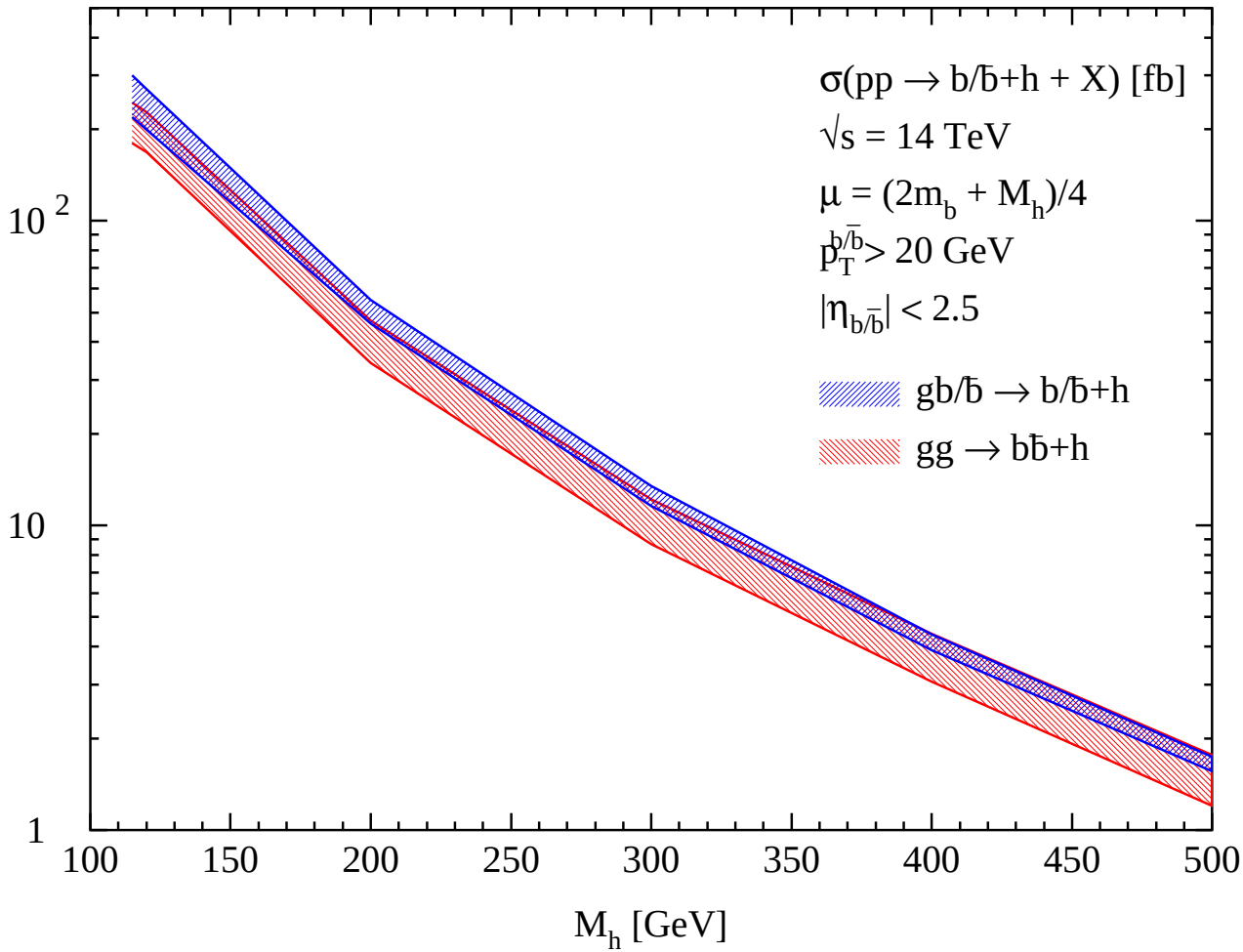

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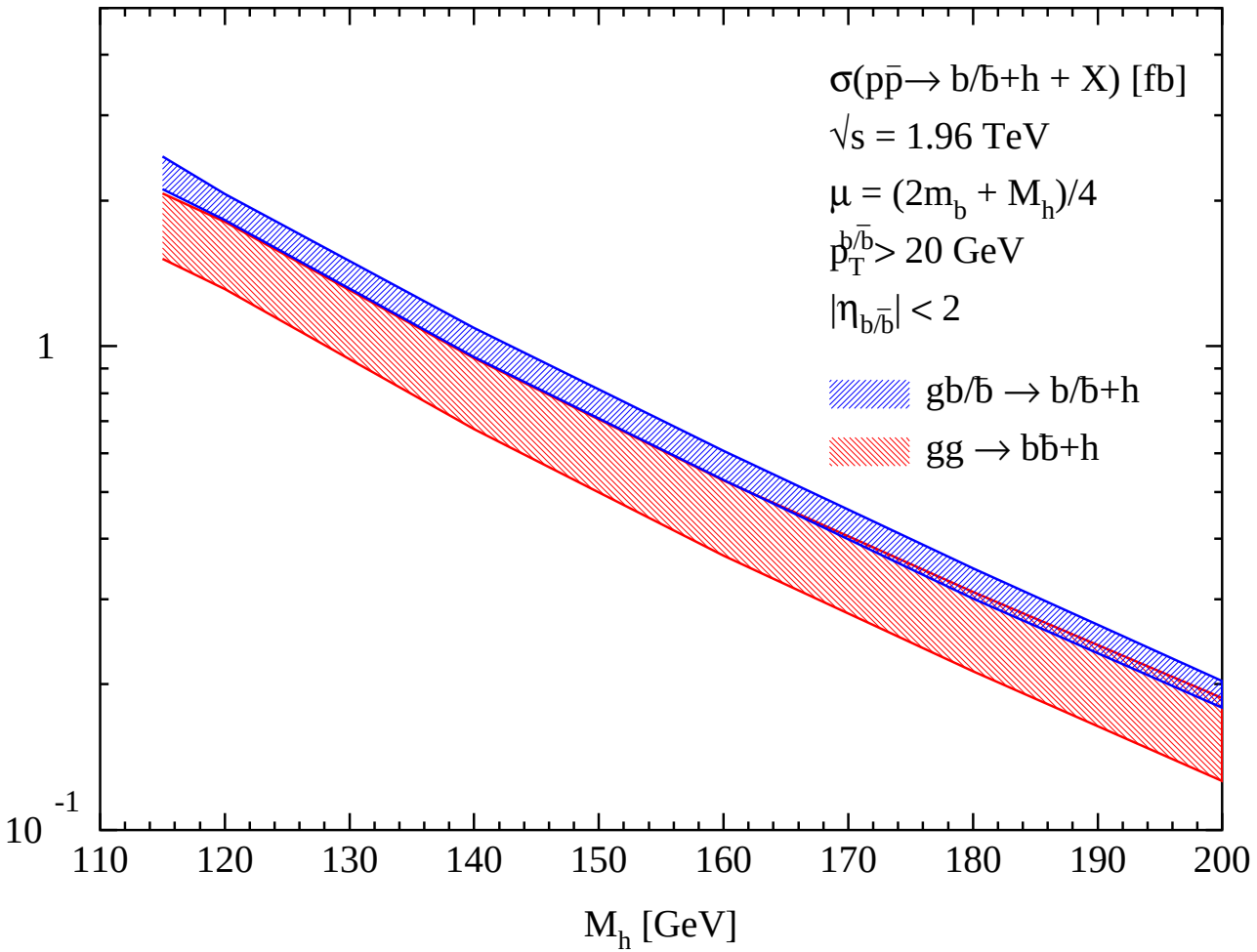

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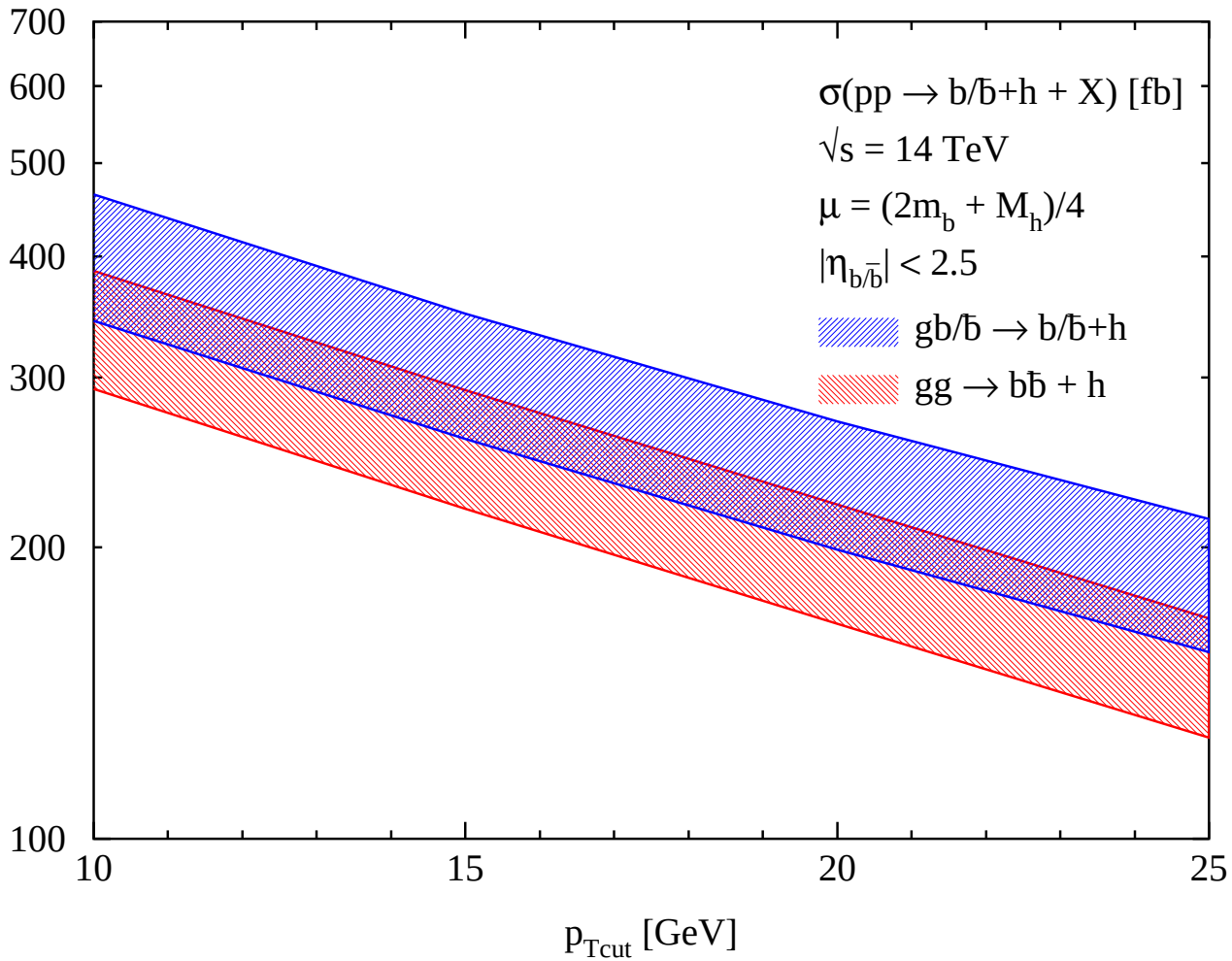

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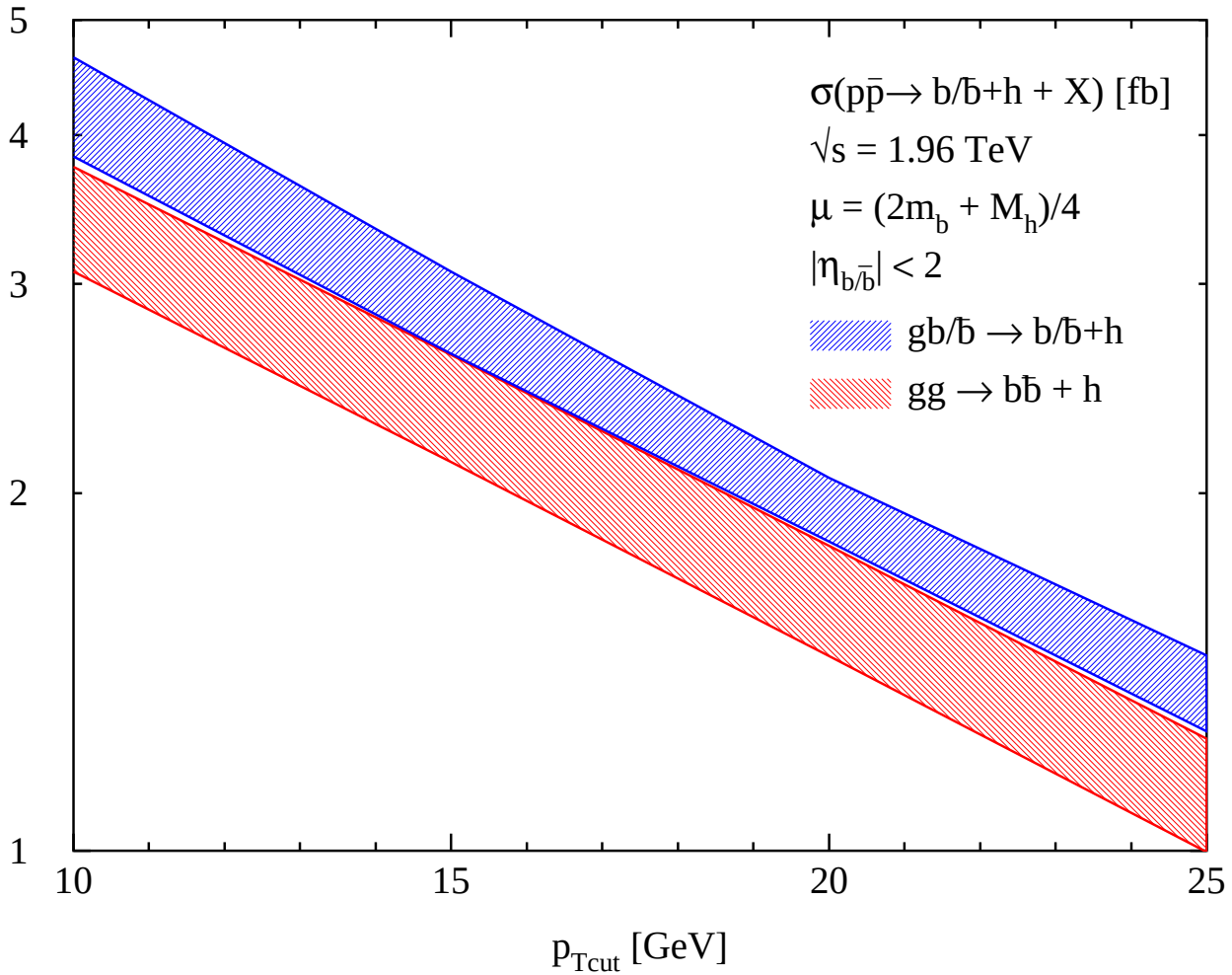

Higgs plus 2 bottom-jet production

Calculation only in 4FS (SM Higgs, LHC)

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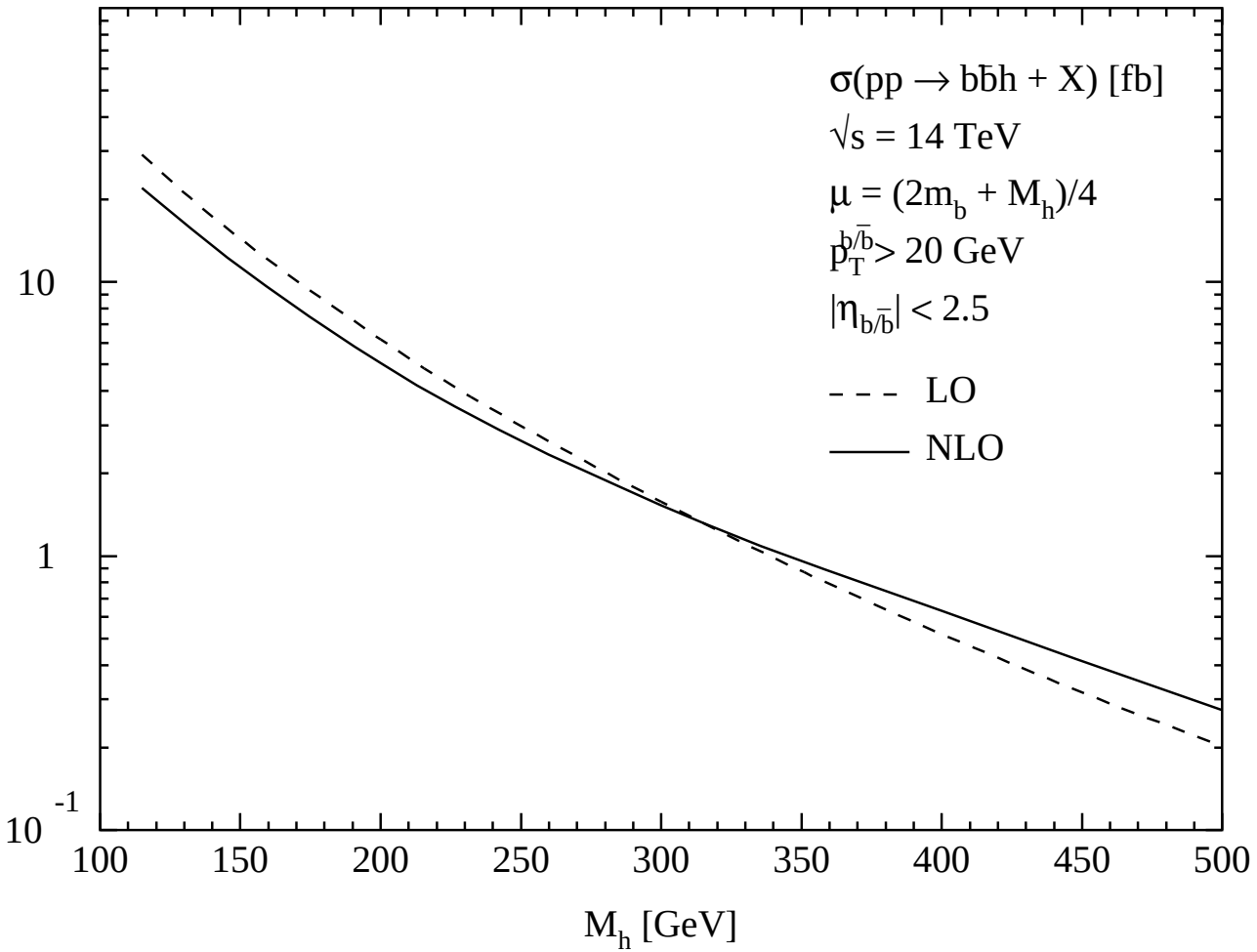

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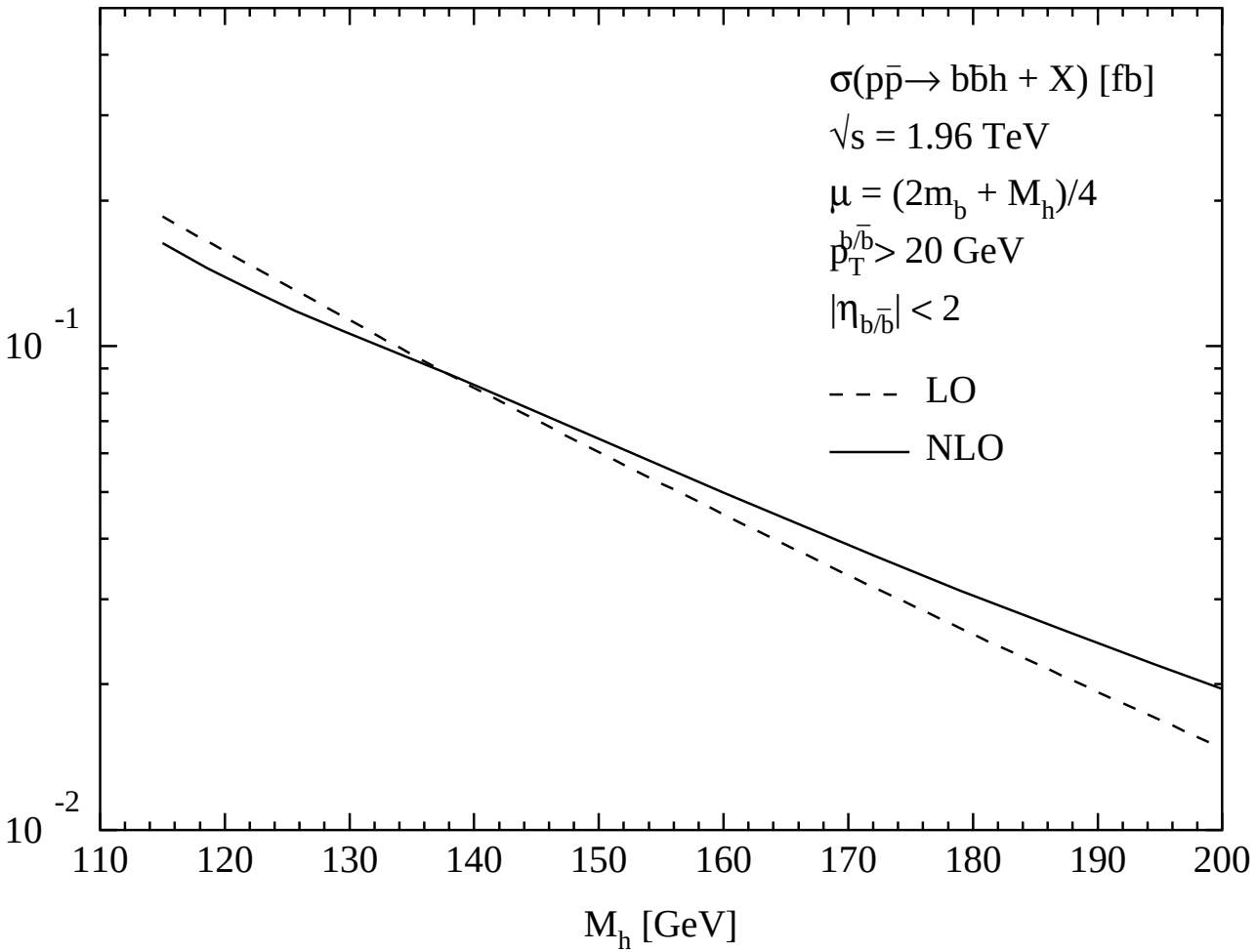

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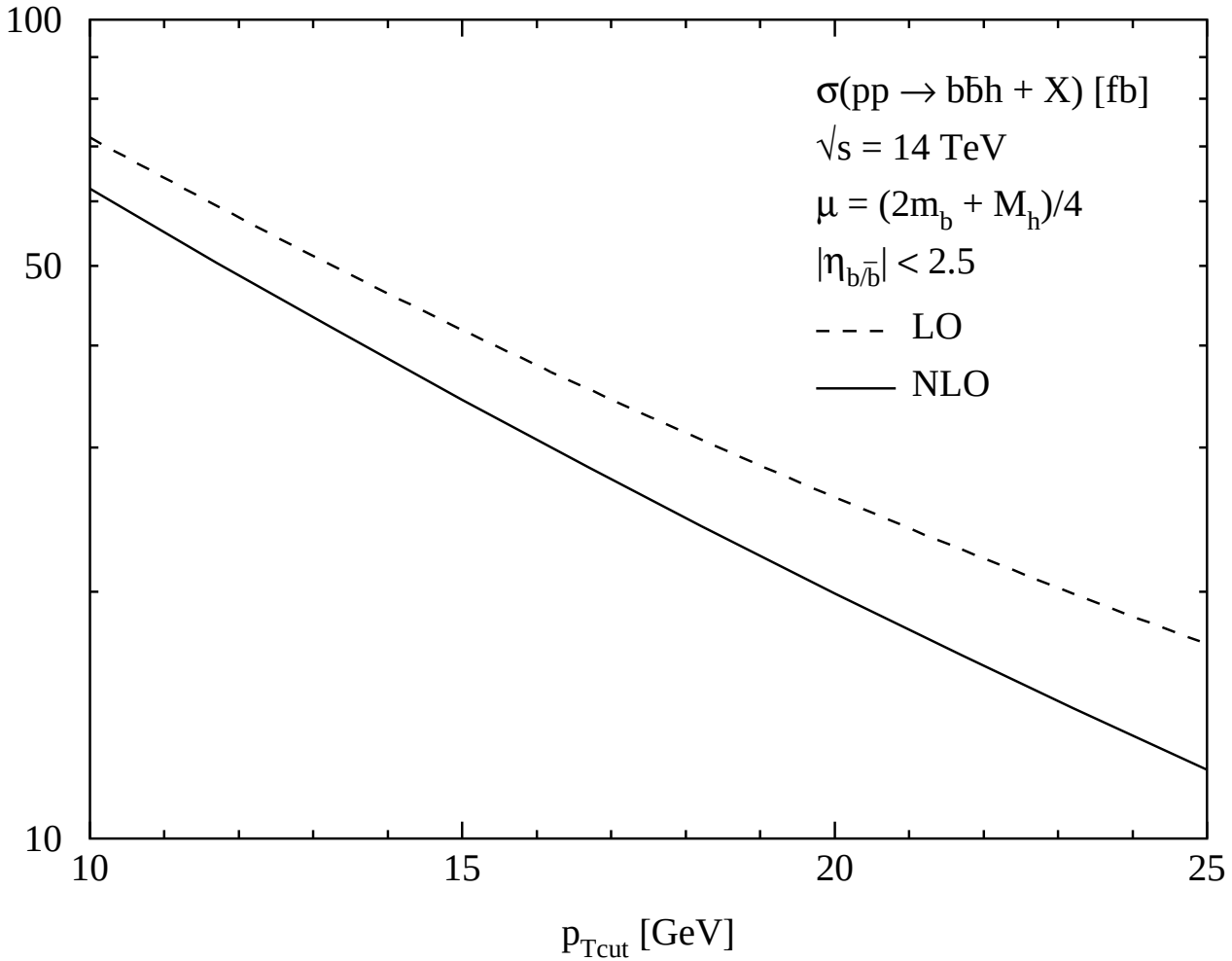

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