HIGGS WG THEORY PART

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I Introduction

II Higgs Boson Production

III Background Processes

IV Summary

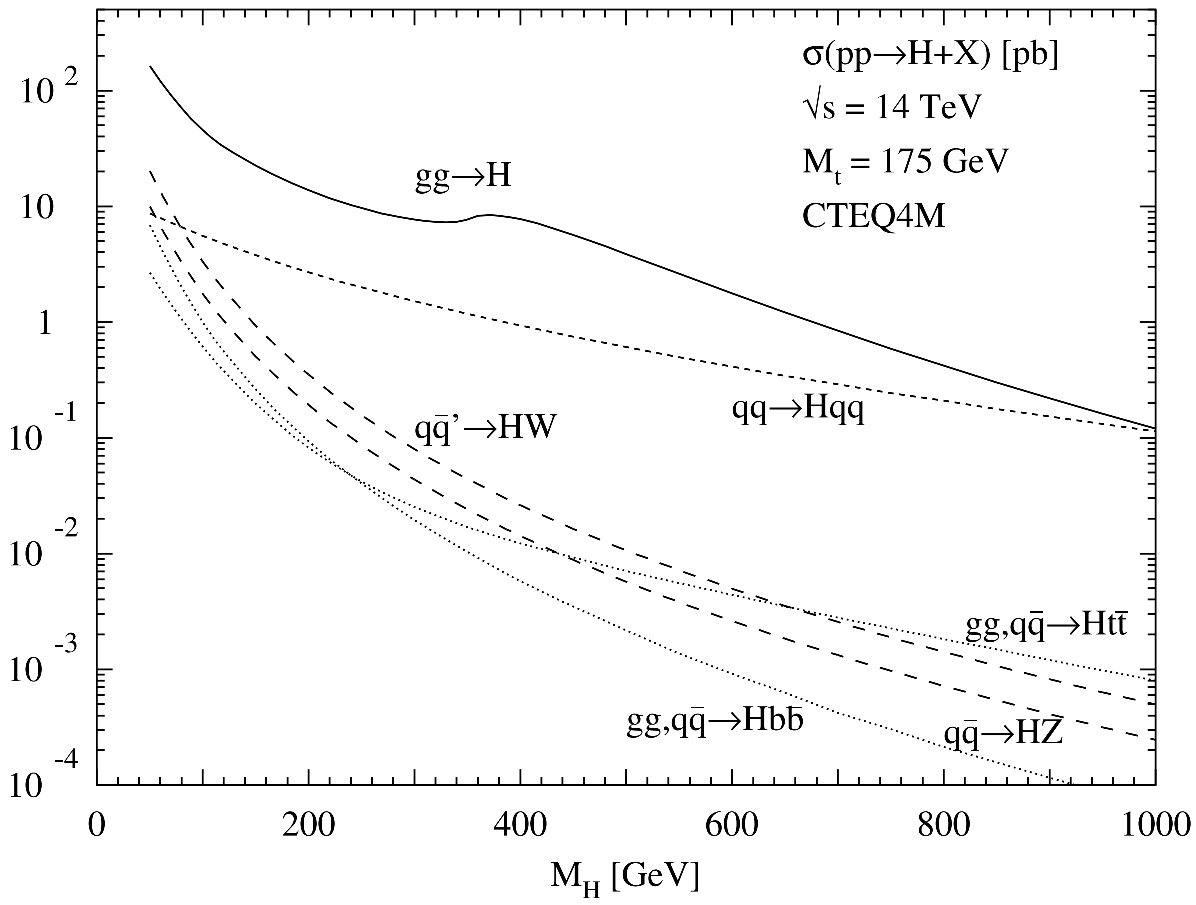
I INTRODUCTION

(i) Standard Model

- Preference for light Higgs: $M_H \lesssim 200$ GeV GUT LEP/LHC

- LHC: $gg \to H$ dominant

- $WW \to H$ important [F/B jet]

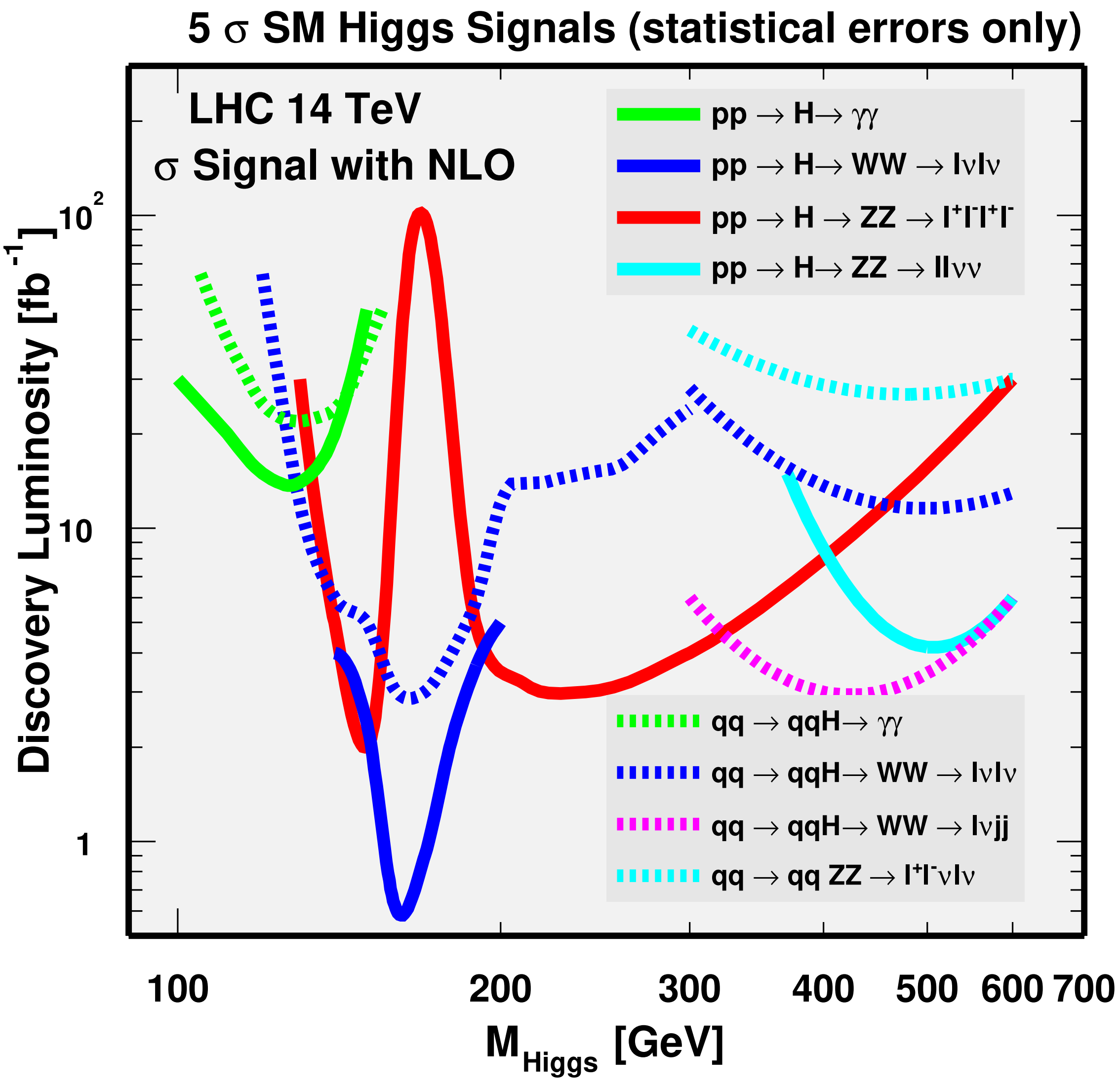


$M_H \lesssim$ 140 GeV: $H \to \gamma\gamma, (b\bar{b})$ F

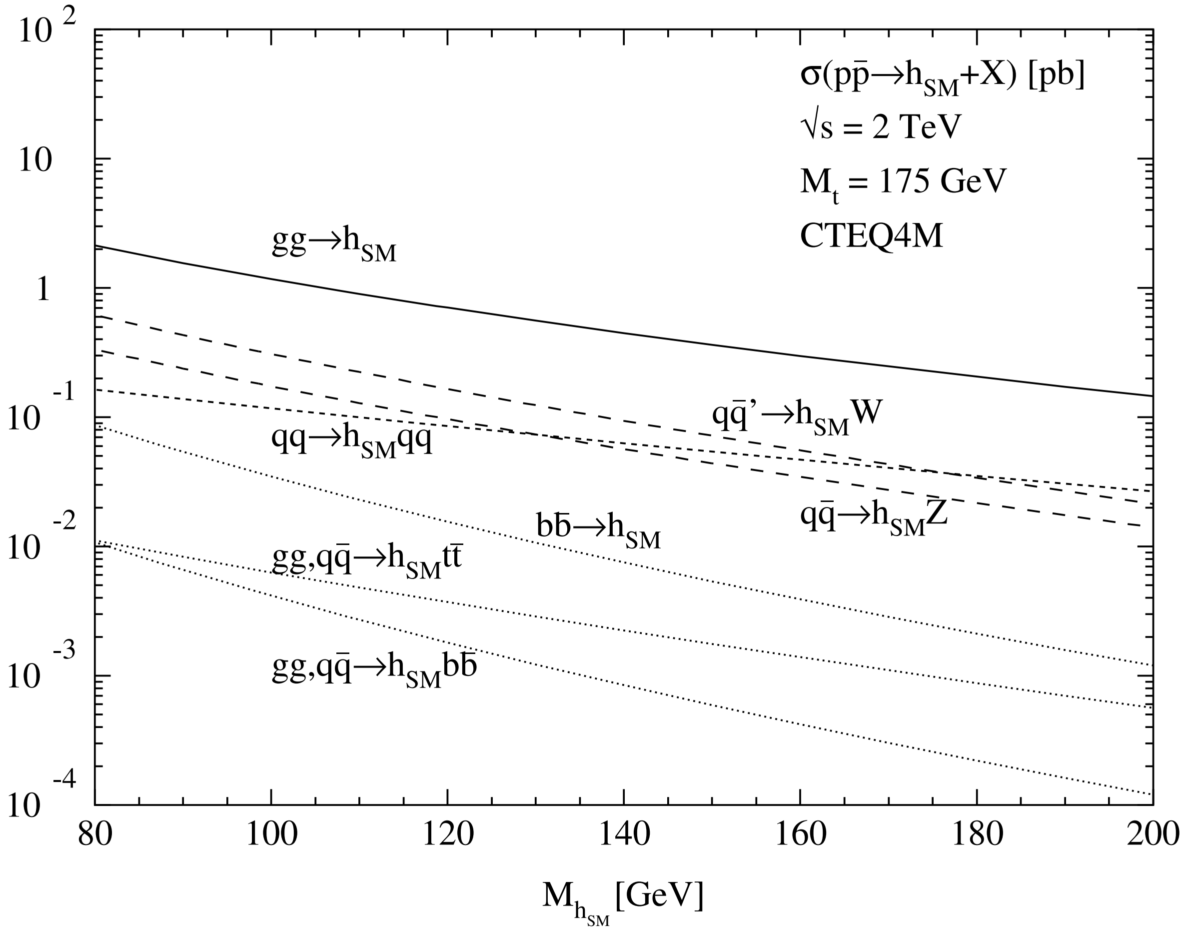
140 GeV $\lesssim M_H \lesssim$ 1 TeV: $H \to ZZ^{(*)} \to 4\ell^{\pm}$

$H \to WW, ZZ \to \ell' s, jets$

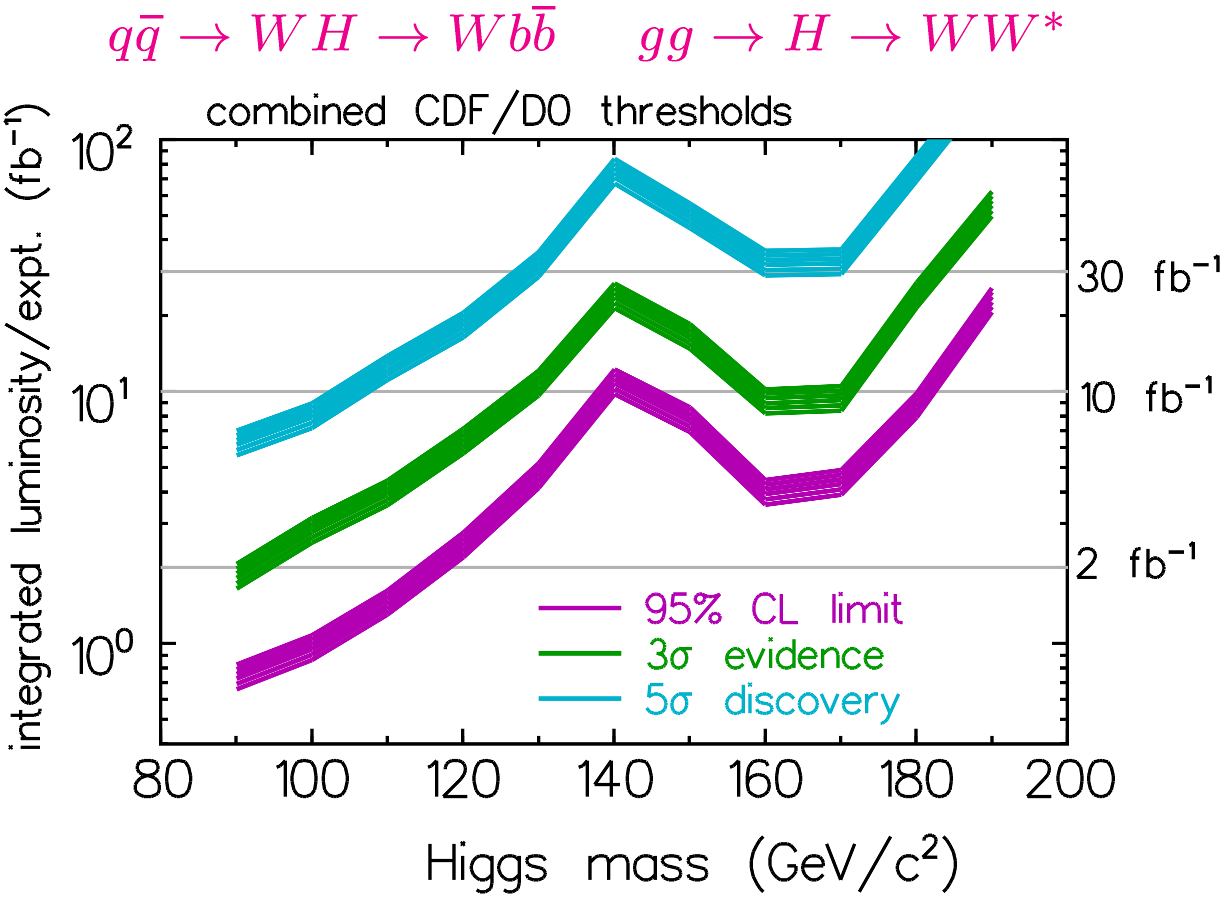
120 GeV $\lesssim M_H \lesssim$ 200 GeV: $H \to WW^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$
[ang. corr.] Dittmar, Dreiner



CMS



σ(pp̄→h_SM+X) [pb]
√s = 2 TeV
M_t = 175 GeV
CTEQ4M
gg→h_SM
qq̄'→h_SM W
qq→h_SM qq̄
qq̄→h_SM Z
bb̄→h_SM
gg,qq̄→h_SM tt̄
gg,qq̄→h_SM bb̄
M_h_SM [GeV]



$q\bar{q} \to WH \to Wb\bar{b}$ $gg \to H \to WW^*$
combined CDF/D0 thresholds
integrated luminosity/expt. (fb⁻¹)
30 fb⁻¹
10 fb⁻¹
2 fb⁻¹
95% CL limit
3σ evidence
5σ discovery
Higgs mass (GeV/c²)

(ii) MSSM

- 2 Higgs doubletts $\xrightarrow{\text{ESB}}$ 5 Higgs bosons: $h, H, A, H^{\pm}$

- radiative corrections $\propto m_t^4 \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}$ $\quad$ Haber, Carena,..., Heinemeyer,..., Zhang, ...

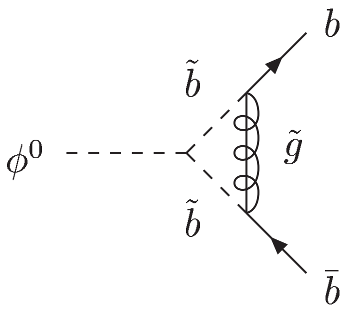
$$\to \boxed{M_h \lesssim 135 \text{ GeV}}$$

- Yukawa couplings: tg$\beta\uparrow \quad \Rightarrow \quad g_u^\phi\downarrow \quad g_d^\phi\uparrow \quad g_V^\phi\downarrow$

- LHC: $gg \to \phi$ dominant for tg$\beta \lesssim 10$
  $gg \to \phi b\bar{b}$ dominant for tg$\beta \gtrsim 10$ $\quad$ F

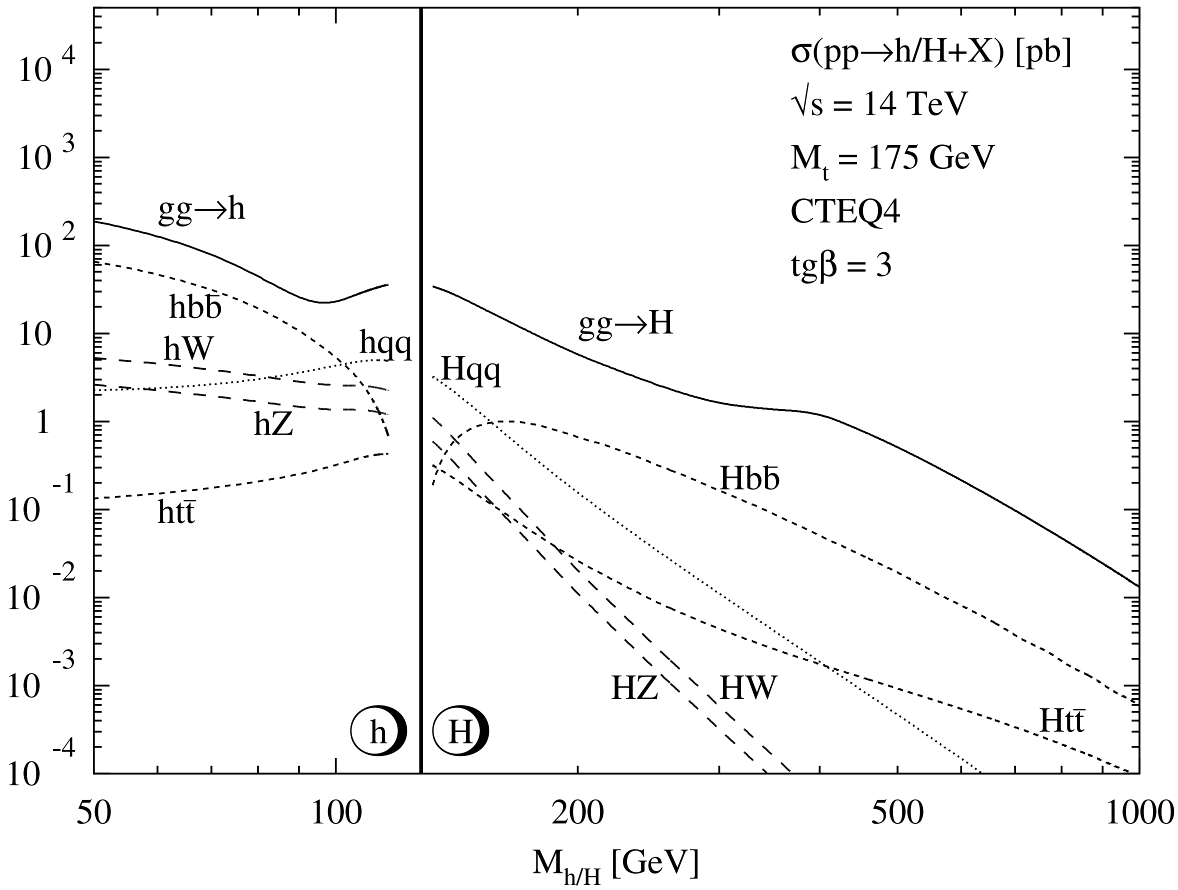
  $h \to \gamma\gamma, b\bar{b}$
  $H, A \to \tau^+\tau^-, \mu^+\mu^-$
  $H^{\pm} \to \tau\nu_\tau$ $\quad$ F
  and $VV \to h, H \to \tau^+\tau^-$ $\quad$ Rainwater, ...

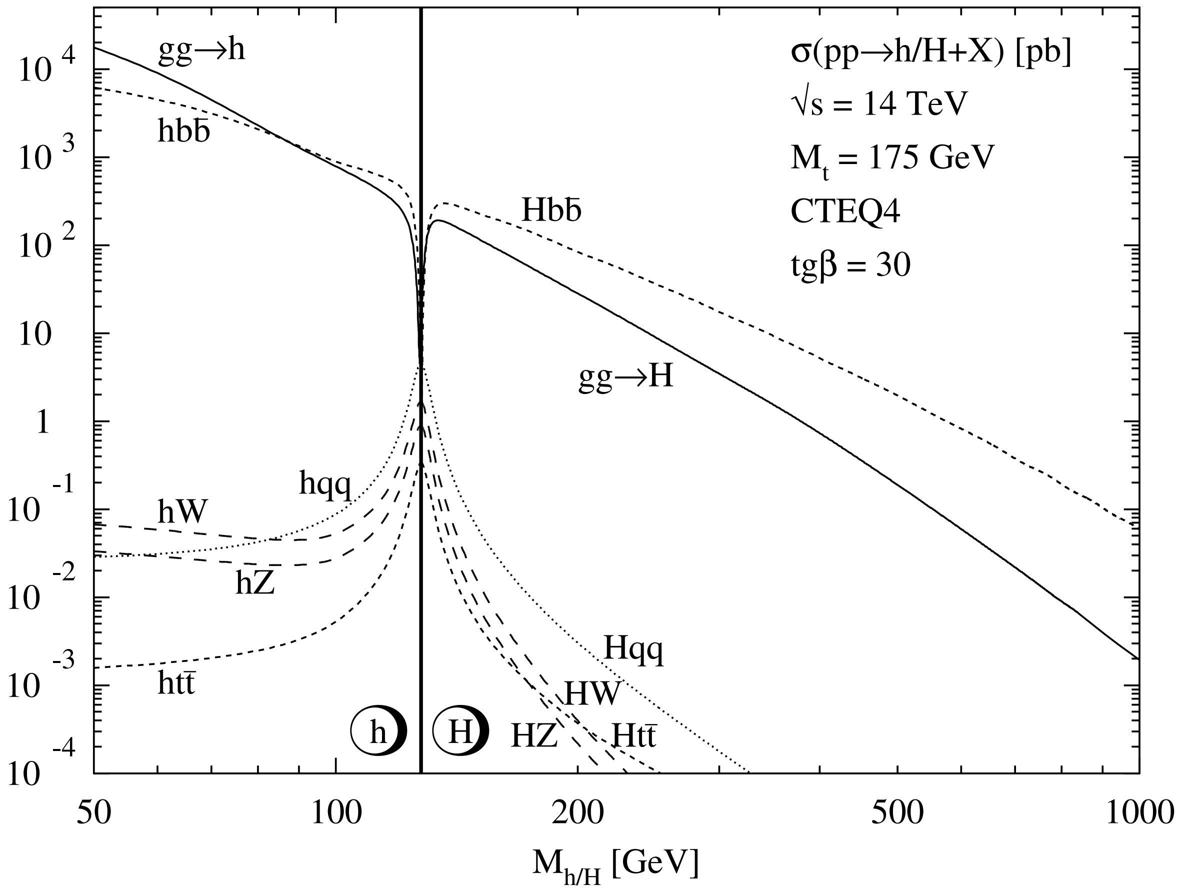
- large tgβ: large MSSM corrections

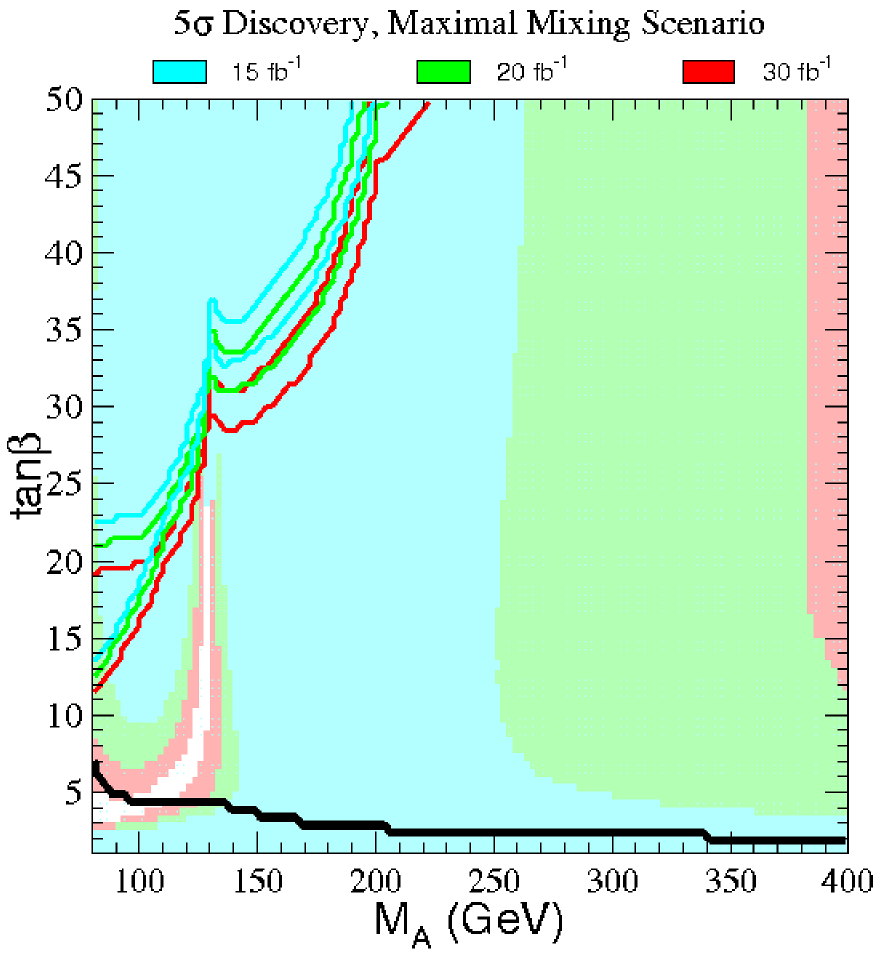


$$+\cdots \qquad \propto \frac{m_{\tilde{g}}\mu \,\text{tg}\beta}{m_{\tilde{b}}^2}$$

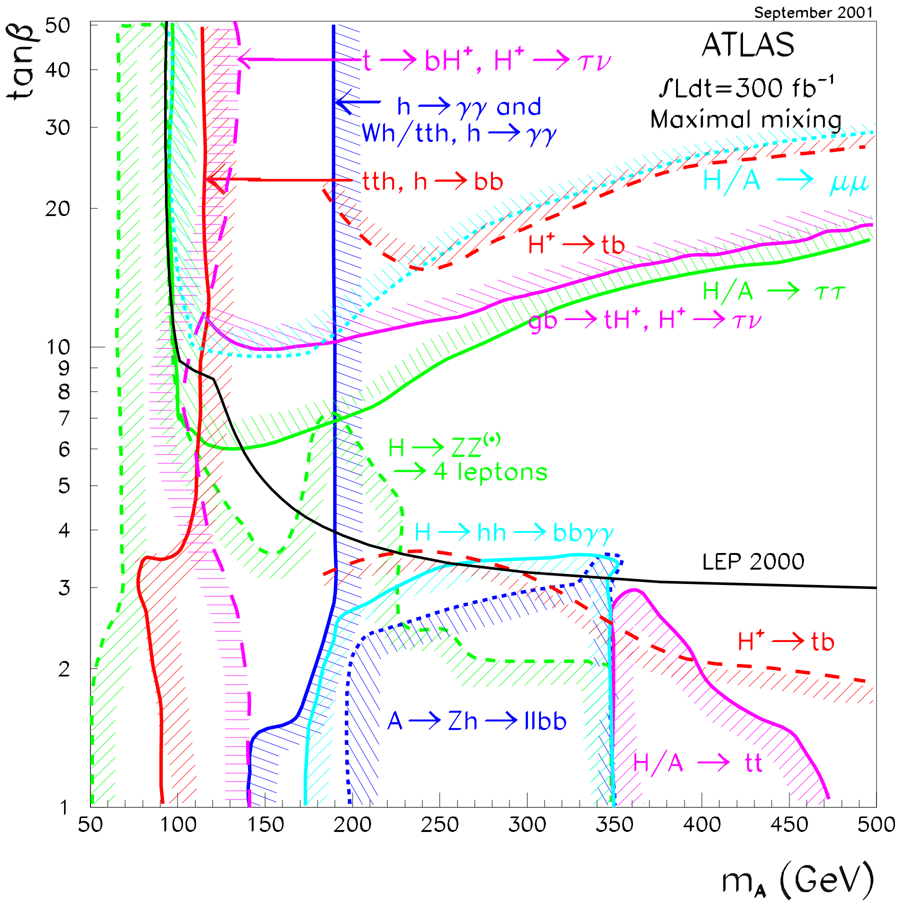
Hall, ..., Carena, ..., ...


σ(pp→h/H+X) [pb]
√s = 14 TeV
M_t = 175 GeV
CTEQ4
tgβ = 3
gg→h
hbb̄
hW
hqq
hZ
htt̄
gg→H
Hqq
Hbb̄
HZ
HW
Htt̄
h
H
M_h/H [GeV]


σ(pp→h/H+X) [pb]
√s = 14 TeV
M_t = 175 GeV
CTEQ4
tgβ = 30
gg→h
hbb̄
Hbb̄
gg→H
hqq
hW
hZ
htt̄
Hqq
HW
HZ
Htt̄
h
H
M_h/H [GeV]



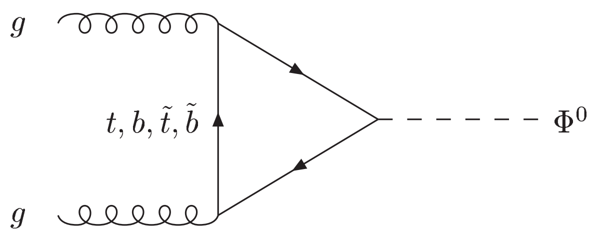
Tevatron



LHC

II *HIGGS BOSON PRODUCTION*

(i) Gluon fusion: $pp \to gg \to h/H/A$



Georgi,...

Gamberini,...

- two-loop QCD corrections: $\sim 10 \ldots 100\%$ — SDGZ
  [moderate for large tg$\beta \leftarrow b$-loop] — Dawson, Kauffman

- NNLO calculated for $m_t \gg M_\phi$
[valid for tg$\beta \lesssim 5$: $\Delta \lesssim 25\%$]
$\Rightarrow$ further increase by 20–30%
scale dependence: $\Delta \lesssim 10 - 15\%$

Harlander, Kilgore
Anastasiou, Melnikov
Ravindran,...

- soft gluon resummation: $\sim 10\%$ — Catani,...

- SUSY decays: $\phi^0 \to \chi_1^0 \chi_1^0$ [LSP]
$\Rightarrow$ invisible Higgs $\longrightarrow \not{E}_T$ if $p_{T\phi} > 0$
$\Rightarrow gg \to \phi^0 g$ dominant
NLO corrections [$m_t \gg M_\phi$]: 60–80%

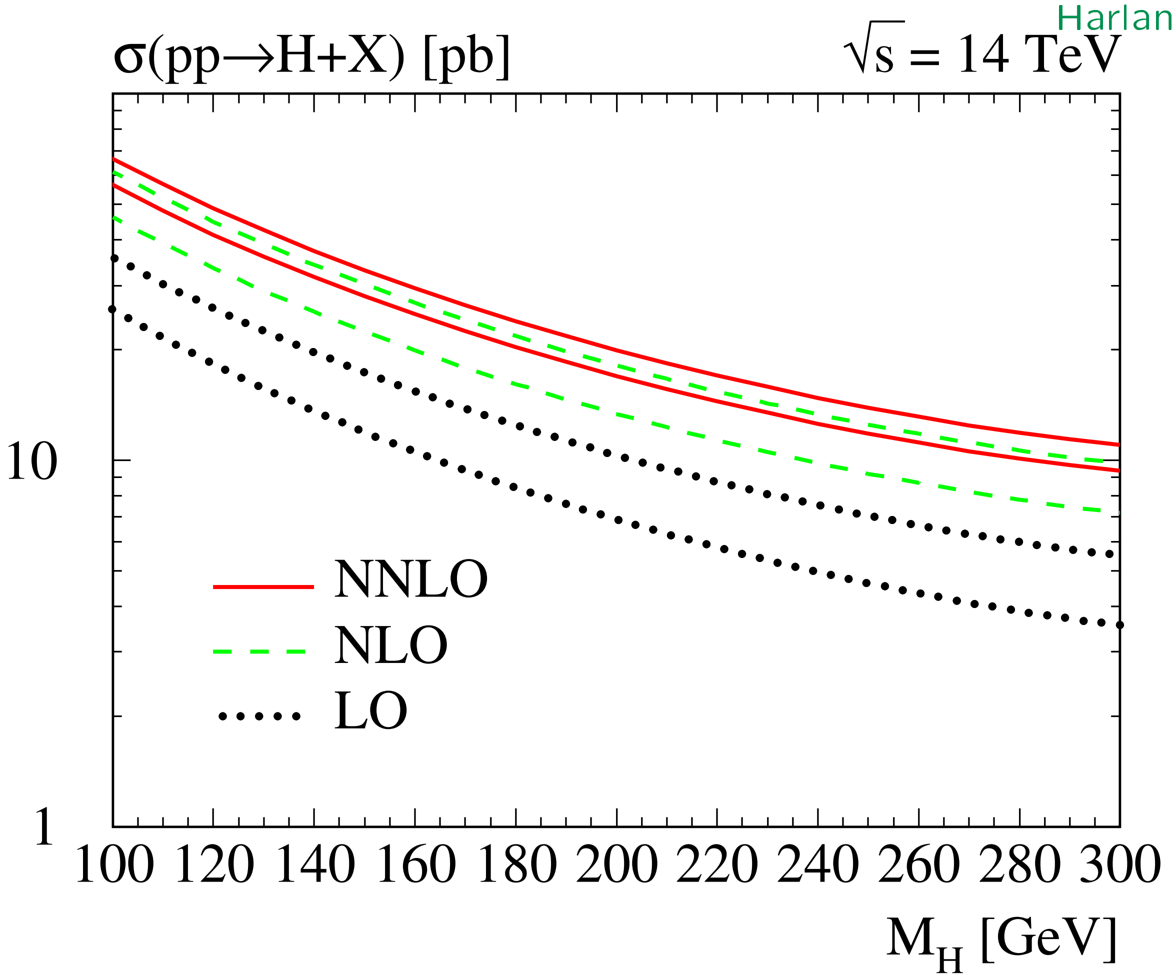
Schmidt
de Florian, ...
Ravindran, ...

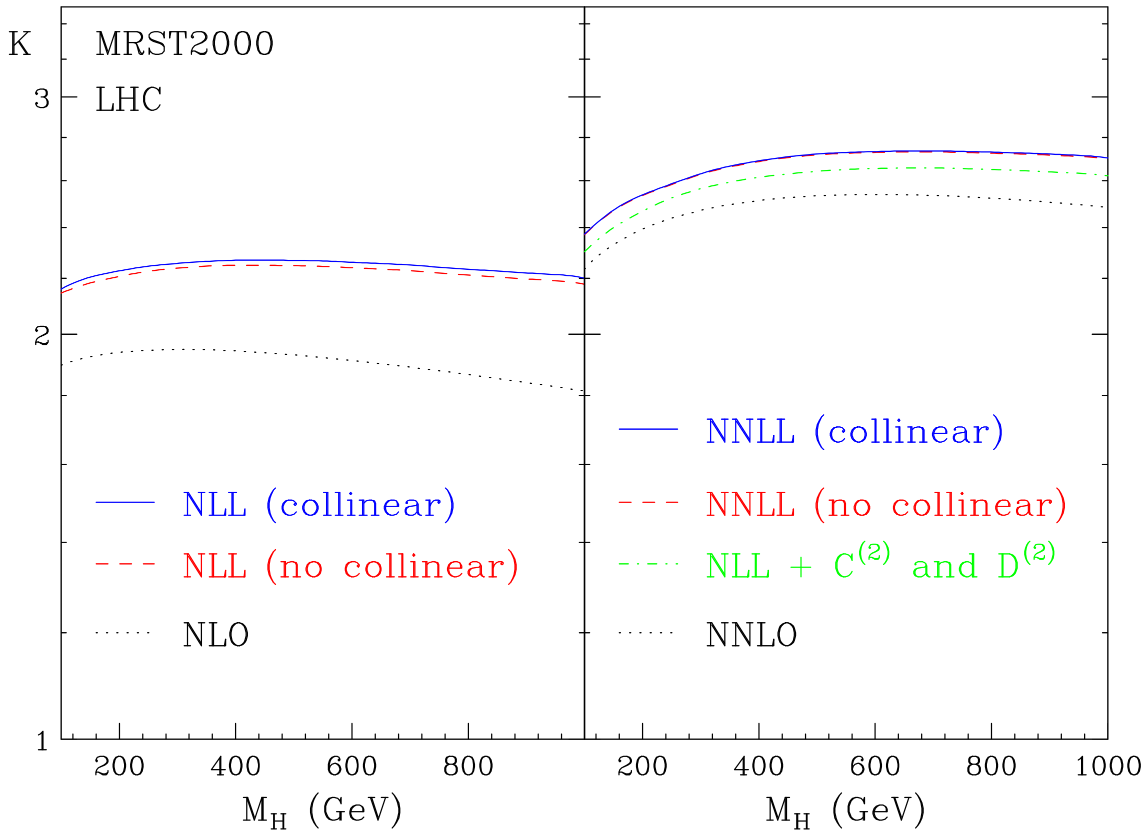
$\longrightarrow$ resummation: $\Delta \lesssim 15\%$

Kauffman
Balazs, Yuan
de Florian

- inclusion in NLO MC?

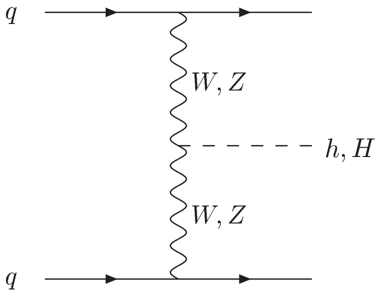
Harlander, Kilgore





Catani, de Florian, Grazzini, Nason

(ii) W/Z fusion: $pp \to W^*W^*/Z^*Z^* \to h/H$



Cahn, Dawson
Hikasa
Atarelli, Mele, Pitolli

- QCD corrections $\sigma_{tot} \leftarrow$ DIS: $\sim 10\%$

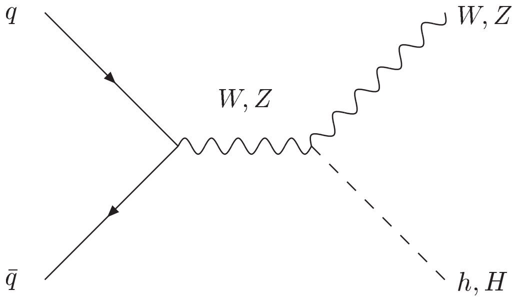
Han, Valencia,
Willenbrock

- jet tagging: exclusive QCD corrections
  $\to$ NLO MC

MCFM
Figy, Oleari, Zeppenfeld

- important alternative Higgs discovery mode
  $\to$ Higgs couplings

(iii) Higgs–strahlung: $pp \to W^*/Z^* \to W/Z + h/H$



Glashow,. . .

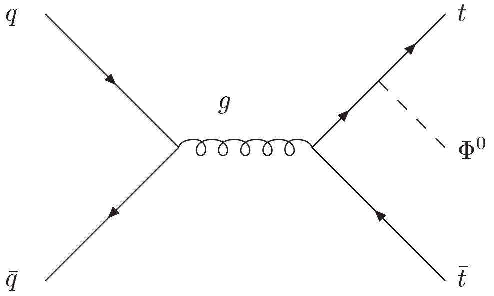
Kunszt,. . .

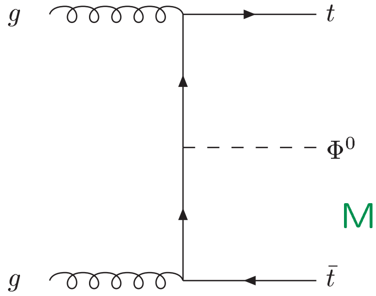
- QCD corrections $\leftarrow$ DY: $\sim 30\%$

Han, Willenbrock

- most important Higgs production mode @ Tevat-
ron

(iv) Bremsstrahlung: $pp \to t\bar{t} + h/H/A$





Kunszt
Gunion
Marciano, Paige

dominant @ Tevatron   dominant @ LHC

- $t\bar{t}h \to t\bar{t}\gamma\gamma, t\bar{t}b\bar{b}$ important signatures

- possibility to measure top Yukawa cplg.

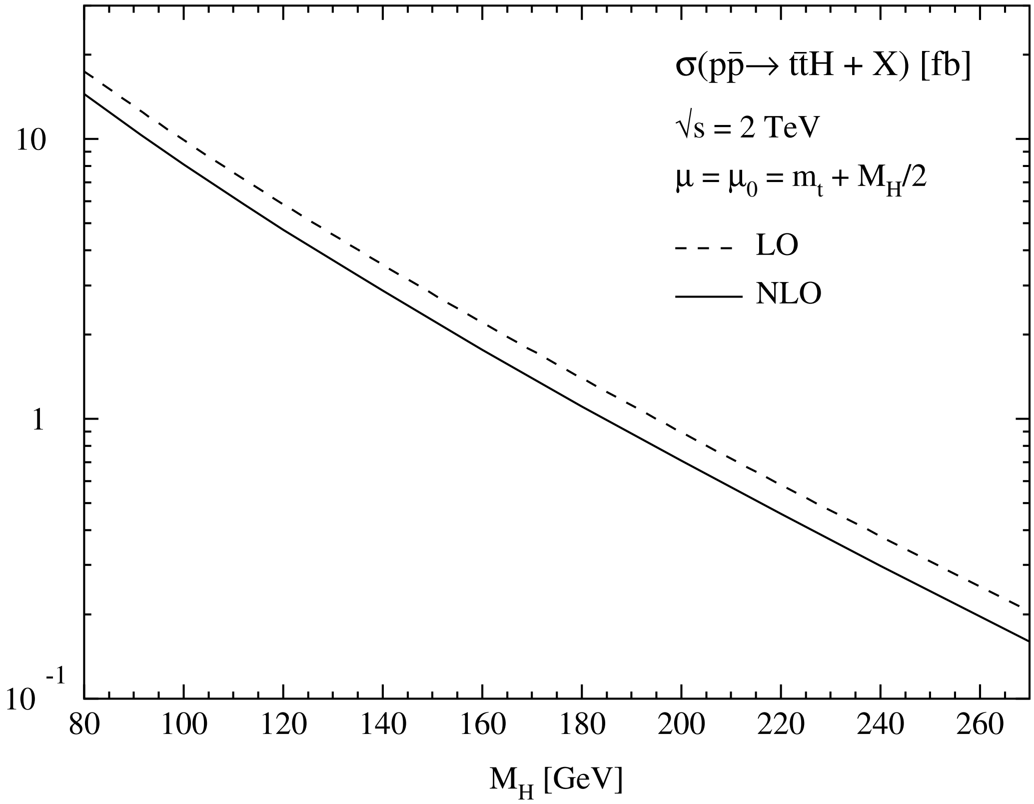
  Gunion,. . .
  Drollinger,. . .
  Dührssen, Jakobs

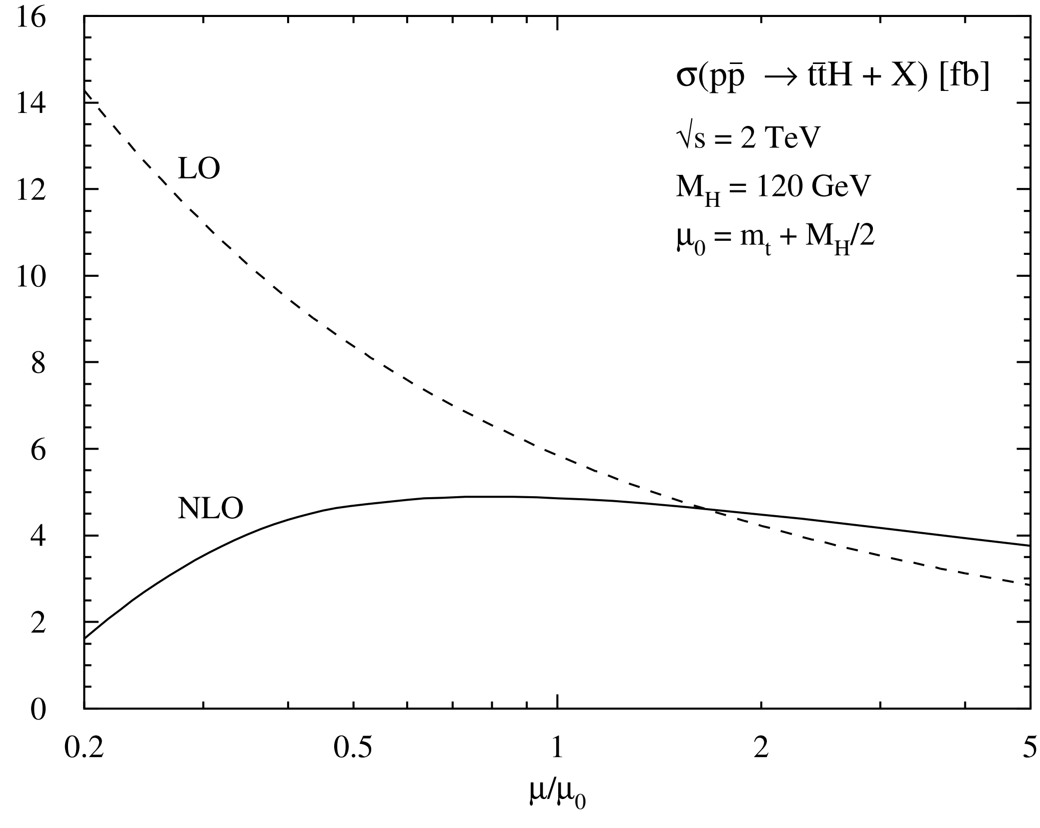
- QCD corrections [SM]: -20% @ Tev
  $+20\%$ @ LHC

  Beenakker,. . .
  Dawson, . . .

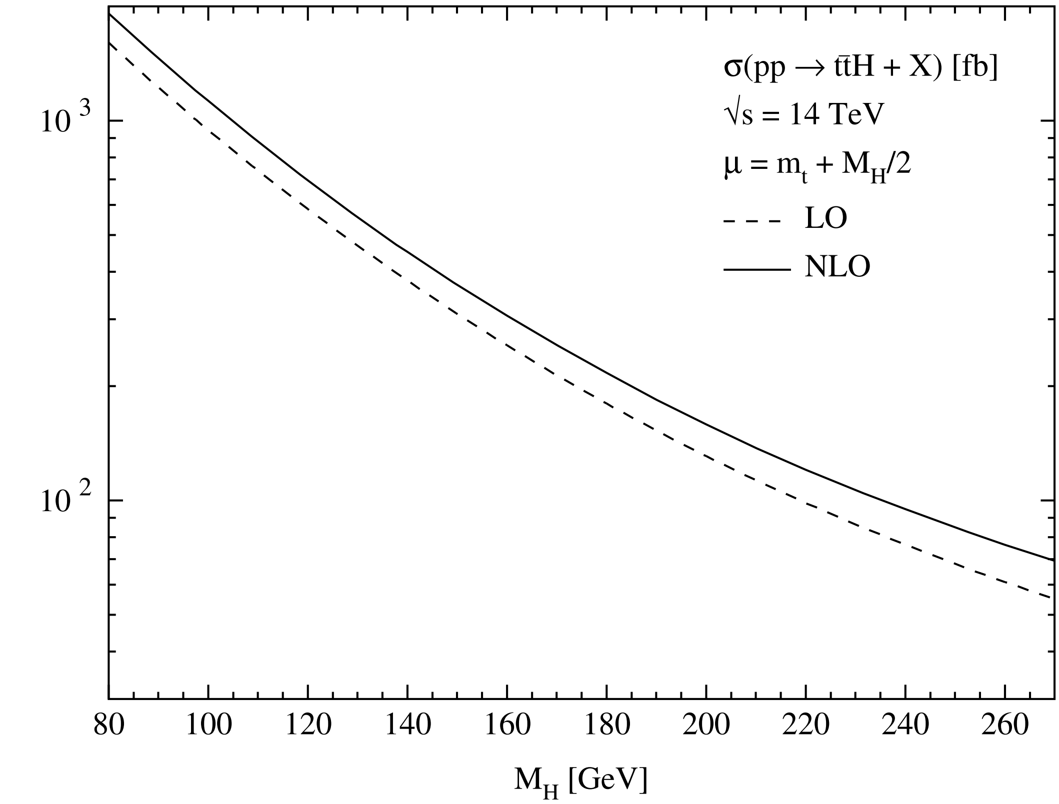
- p_T, y distributions for $t, \bar{t}, H$ available @ NLO

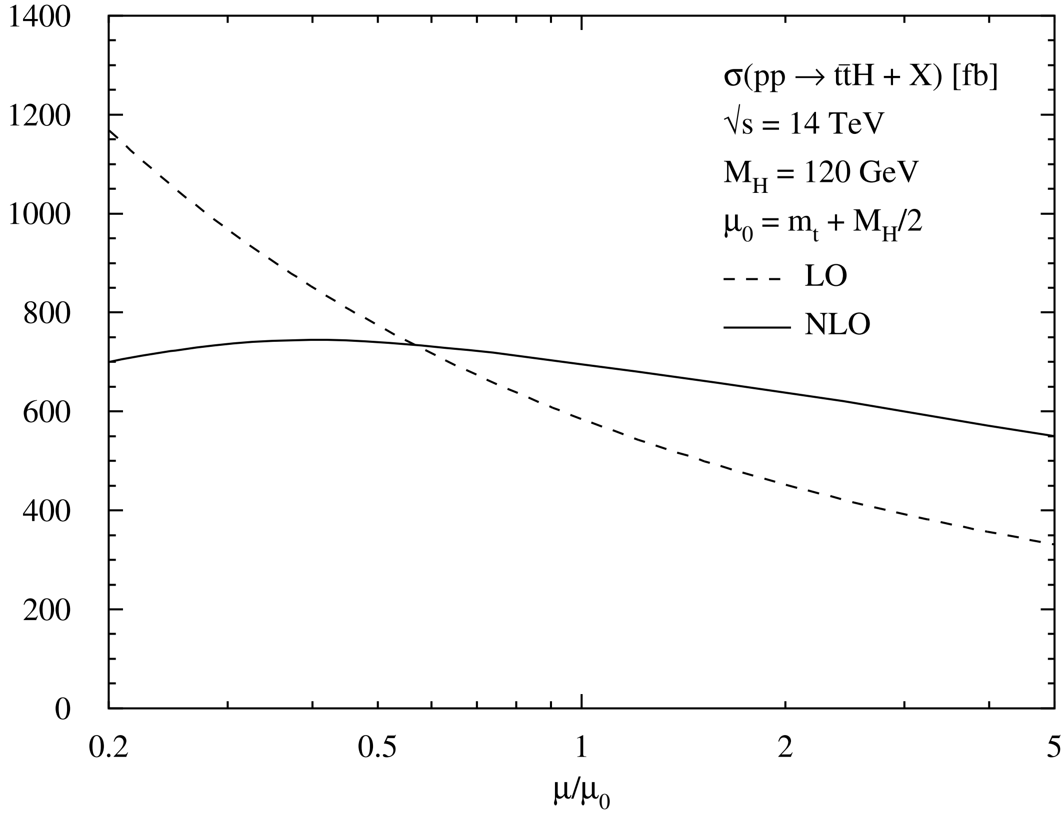
  Beenakker,. . .





Beenakker, Dittmaier, Krämer, Plümper, S., Zerwas

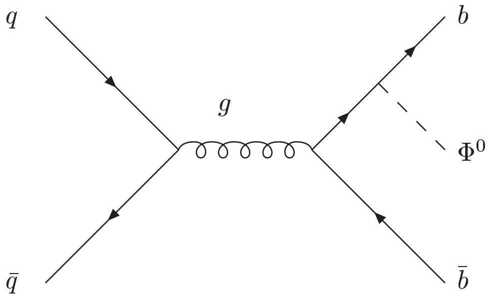




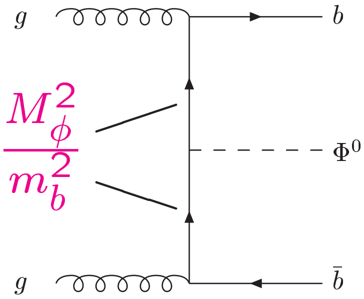
Beenakker, Dittmaier, Krämer, Plümper, S., Zerwas

(v) Bremsstrahlung: $pp \to b\bar{b} + h/H/A$

- $b\bar{b} + H/A$ dominant for large tgβ



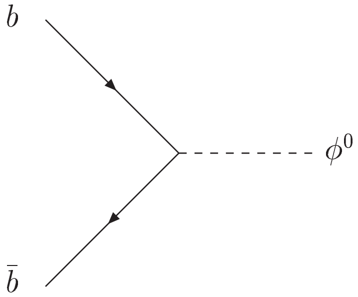
$\log \frac{M_\phi^2}{m_b^2}$



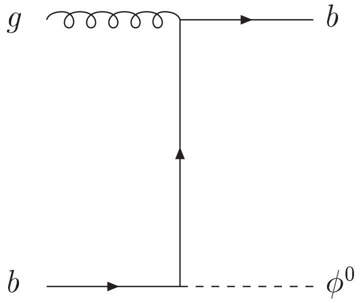
dominant

large logs from phase space integration
$\longrightarrow$ absorbed in bottom PDF
resummation $\equiv$ DGLAP evolution

- new processes:



NNLO



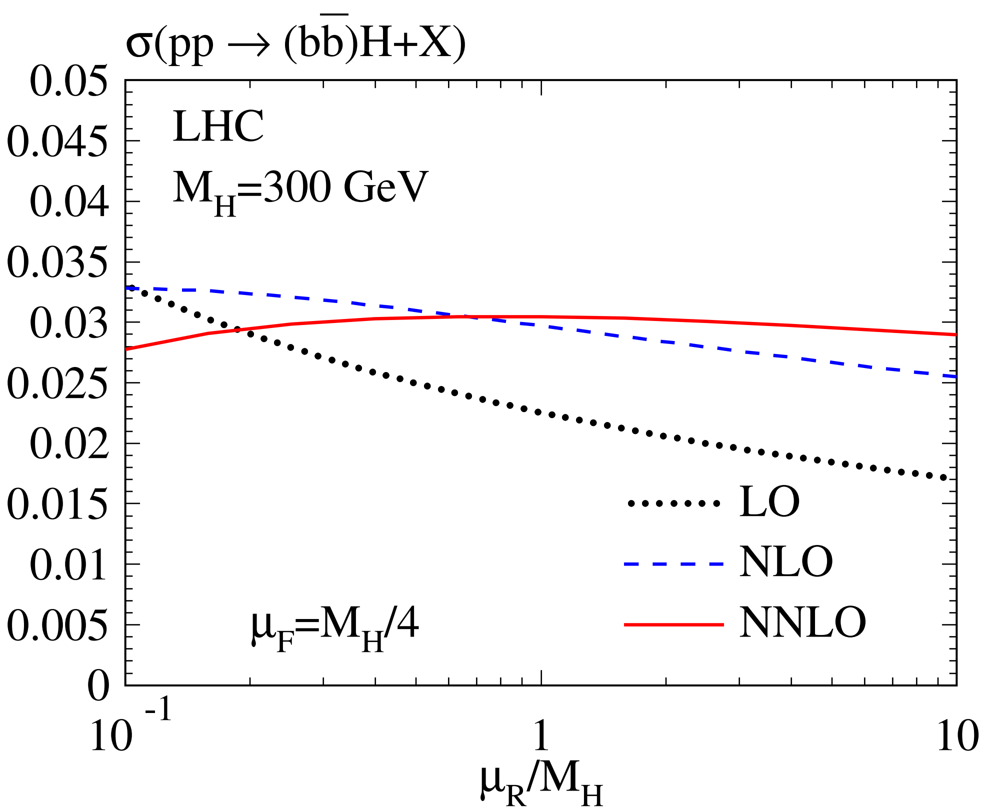
NLO

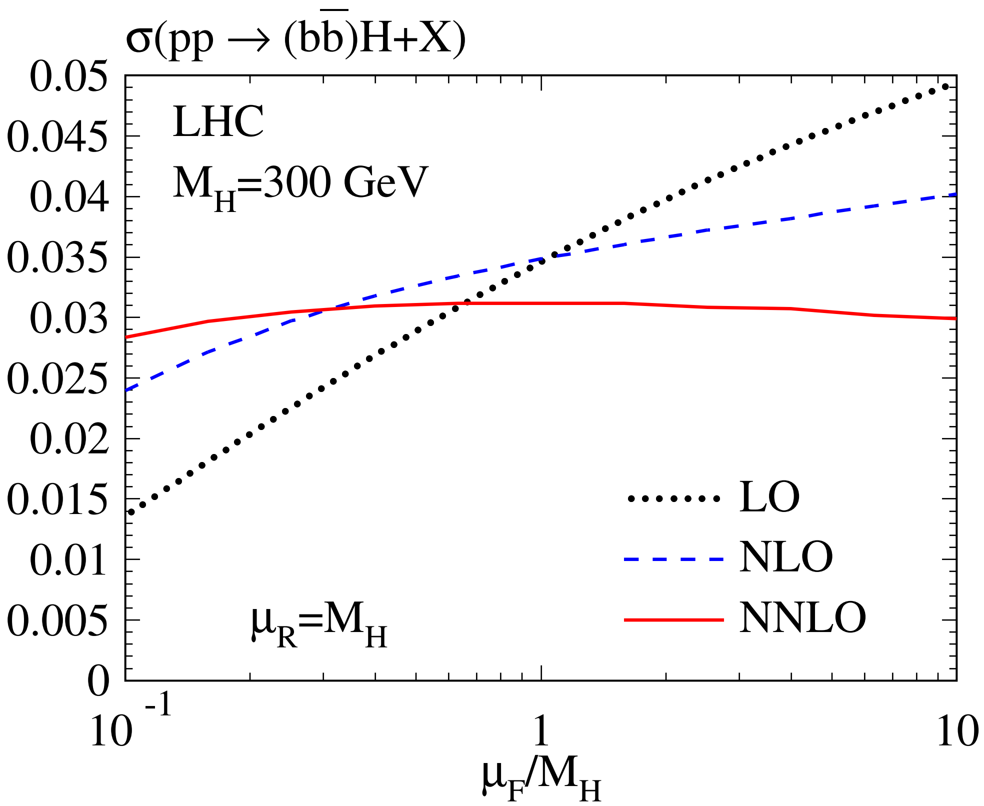
Dicus, Willenbrock
Stelzer, . . .
Balazs, . . .
Campbell, . . .

Harlander, Kilgore

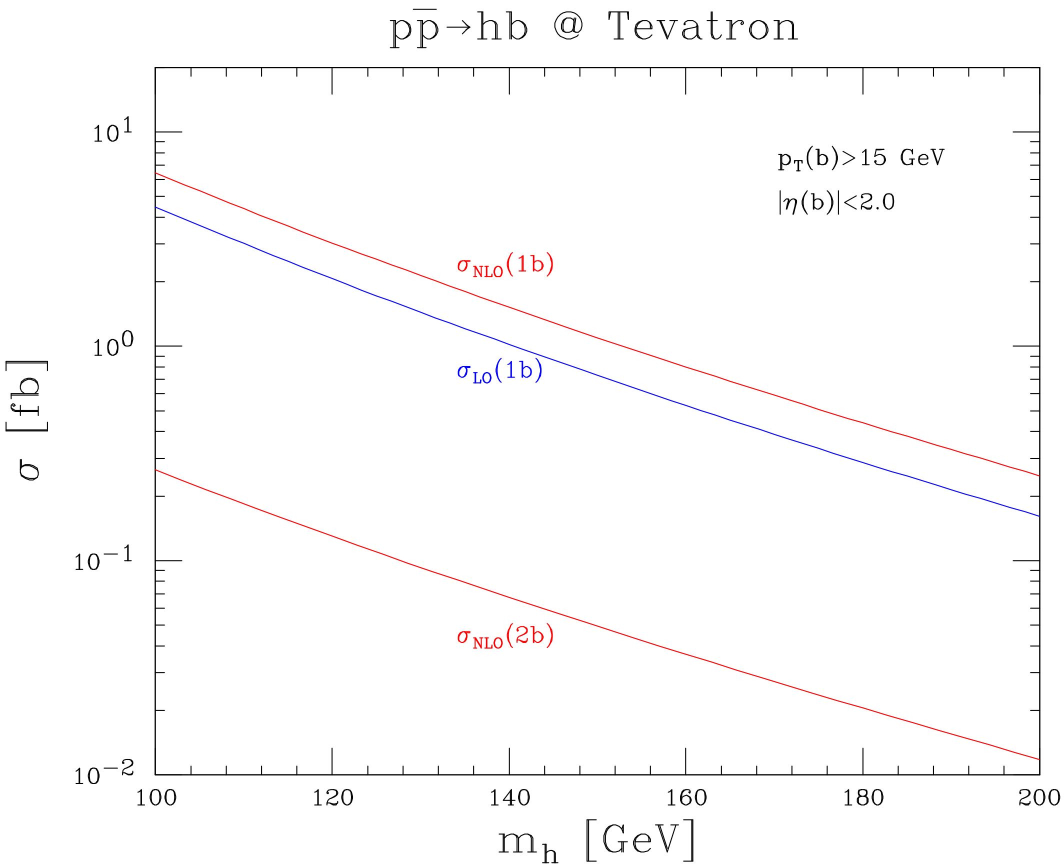
$$b(x,\mu^2) \longrightarrow b(x,\mu^2) - \frac{\alpha_s}{2\pi} P_{qg} \otimes g(x,\mu^2) \log \frac{\mu^2}{m_b^2}$$

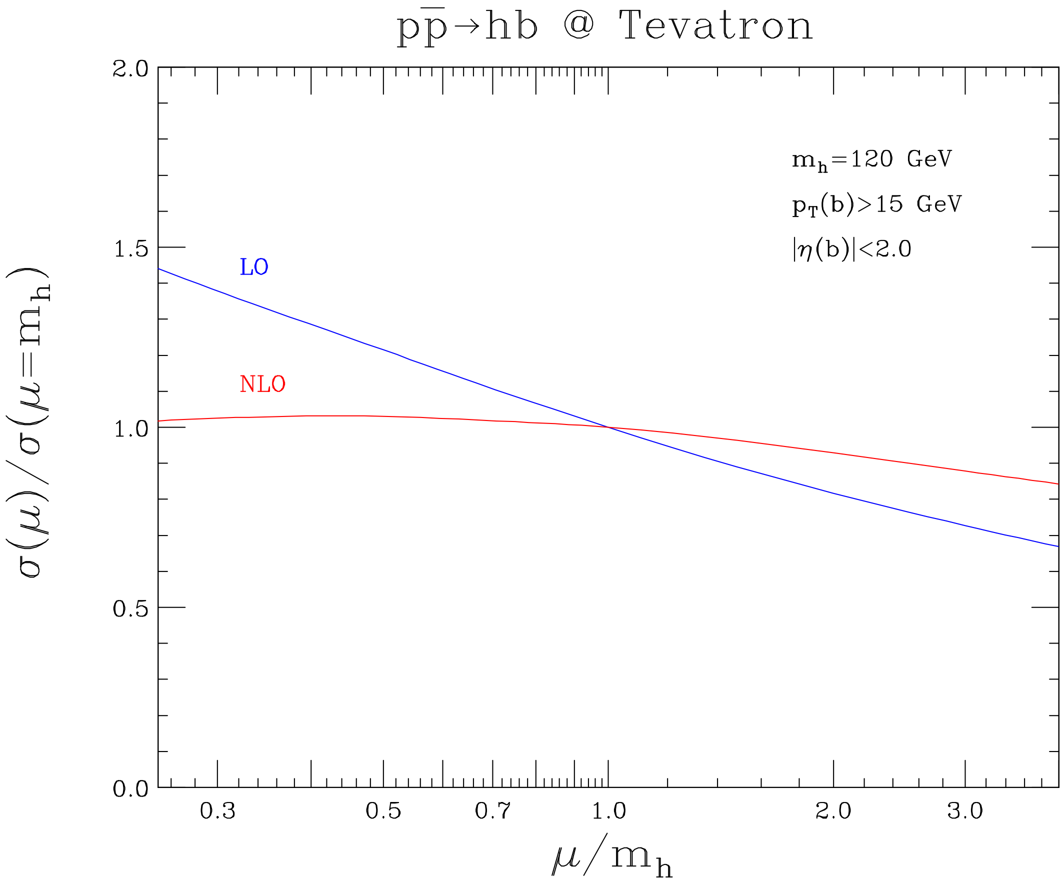
$$\mu \sim M_\phi \Rightarrow \sigma_{tot}$$



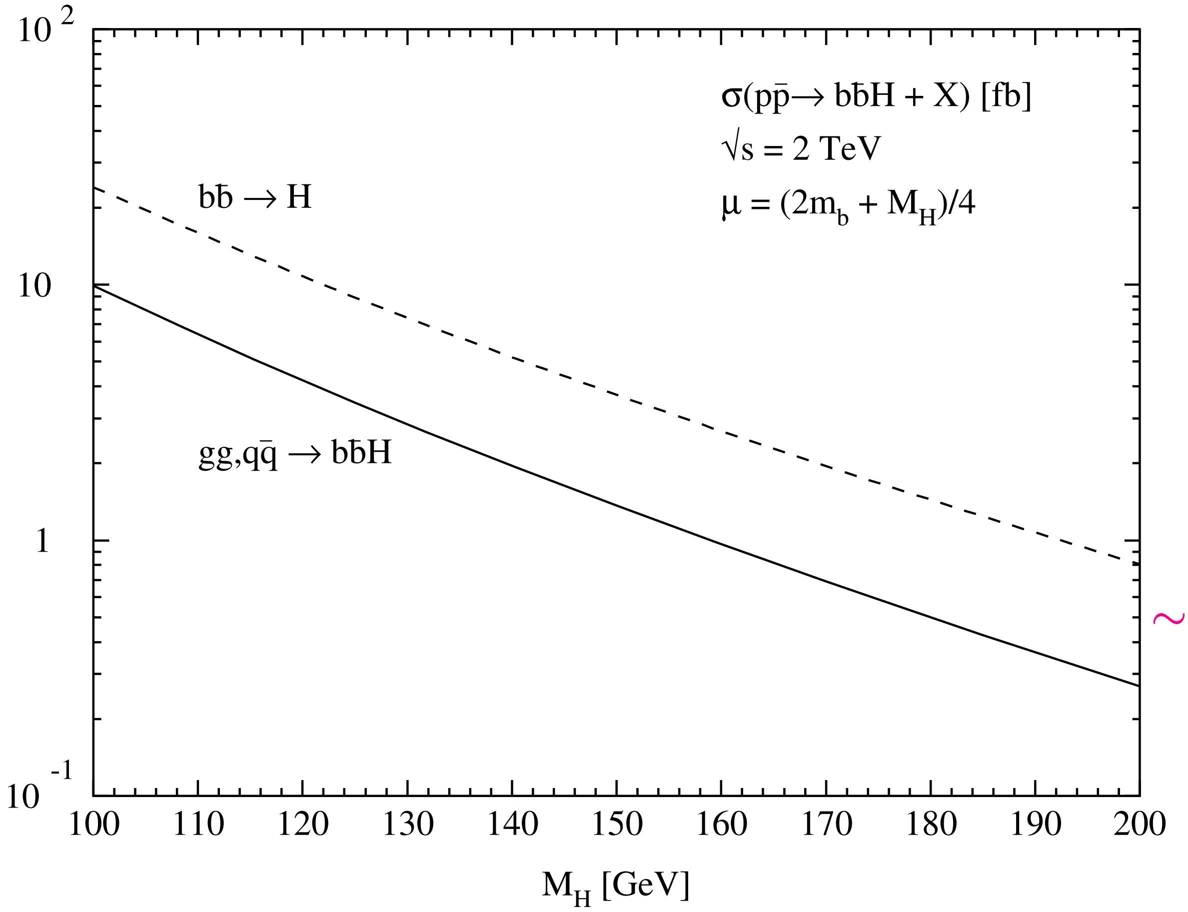


Harlander, Kilgore

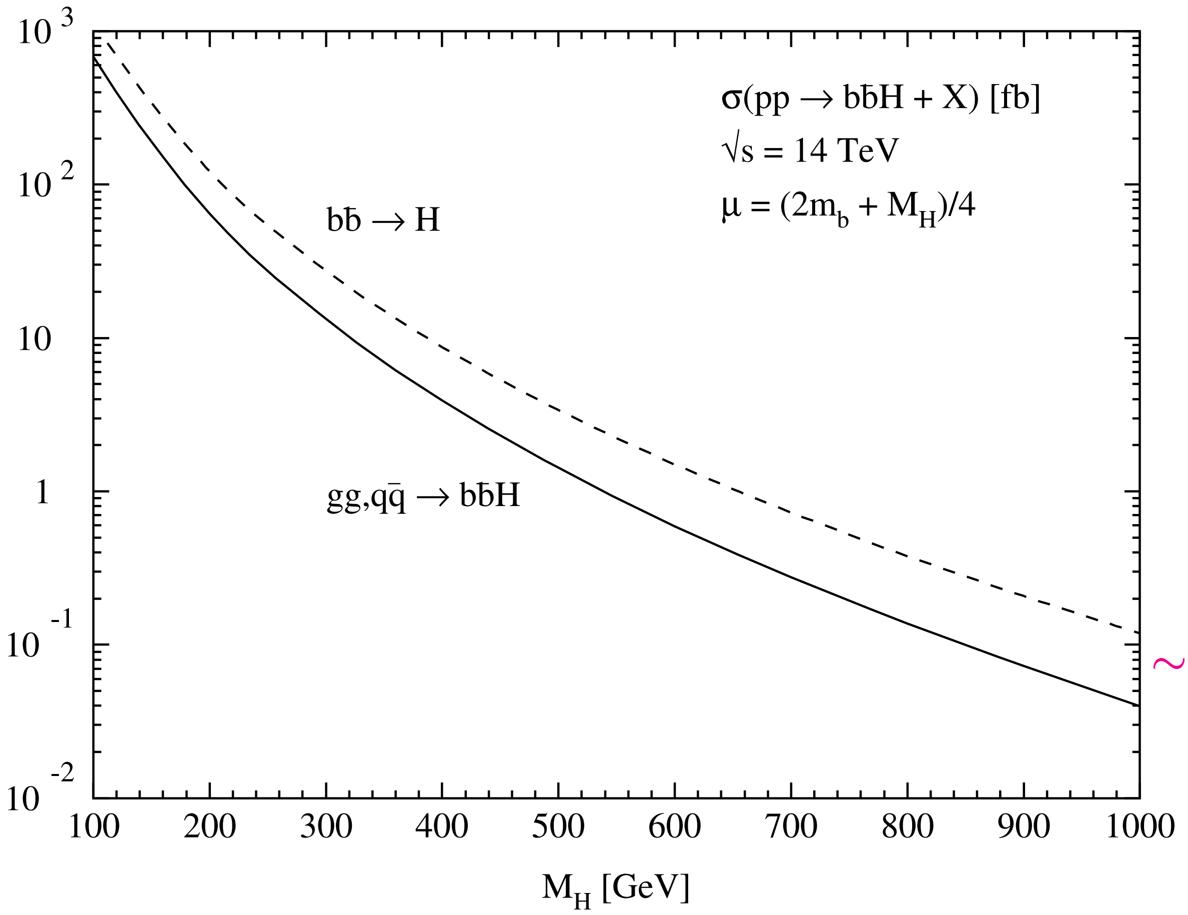




Campbell, Ellis, Maltoni, Willenbrock



~ factor 3



~ factor 3

- factorization in high-energy limit: $[M_{Tb} = \sqrt{p_{Tb}^2 + m_b^2}]$

$$\frac{d\sigma^{(2\to 3)}}{dM_{Tb}^2} = \frac{1}{M_{Tb}^2} \left\{ \frac{\alpha_s}{2\pi} P_{qg} \otimes g \otimes g \otimes \hat{\sigma}_{\bar{b}g} \right\}_{M_{Tb}=m_b\to 0} + \cdots$$

[leading log!]

- total cross section:

$$\sigma = \underbrace{\int_{m_b^2}^{\mu_F^2} \frac{dM_{Tb}^2}{M_{Tb}^2}}_{\log \frac{\mu_F^2}{m_b^2}} \left\{ \frac{\alpha_s}{2\pi} P_{qg} \otimes g \otimes g \otimes \hat{\sigma}_{\bar{b}g} \right\}_{M_{Tb}=m_b\to 0} + \cdots$$

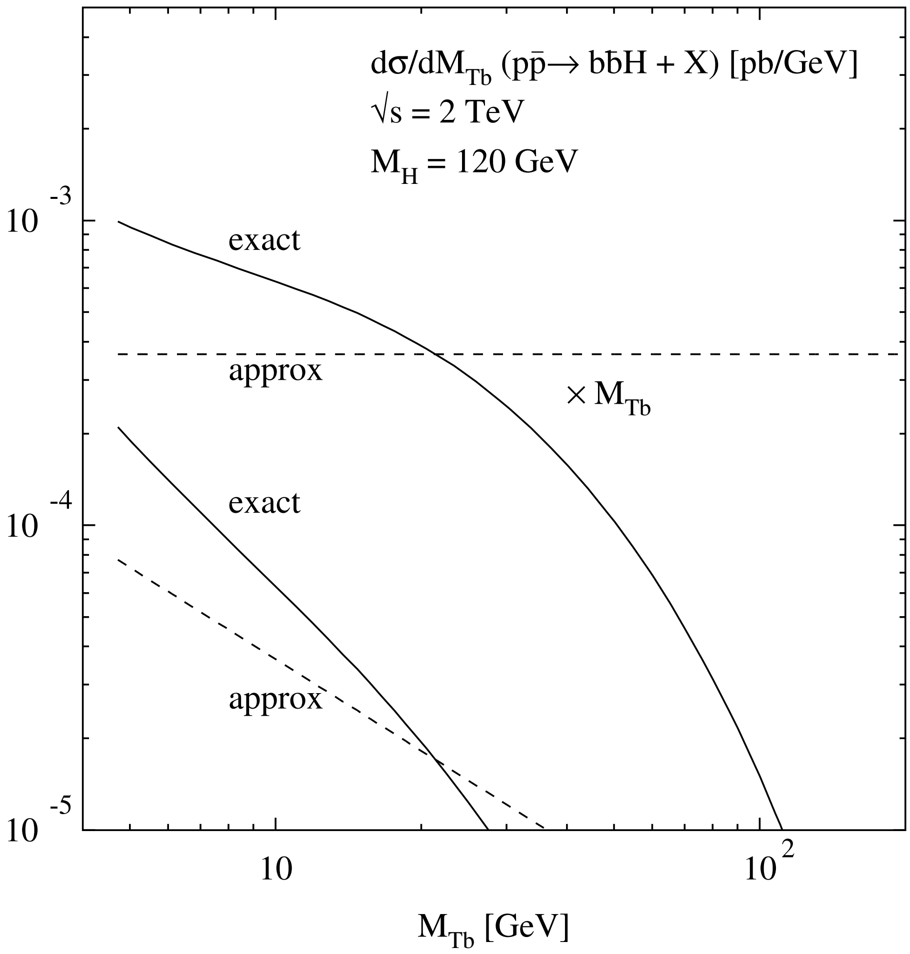
$\Rightarrow$ crucial condition: F

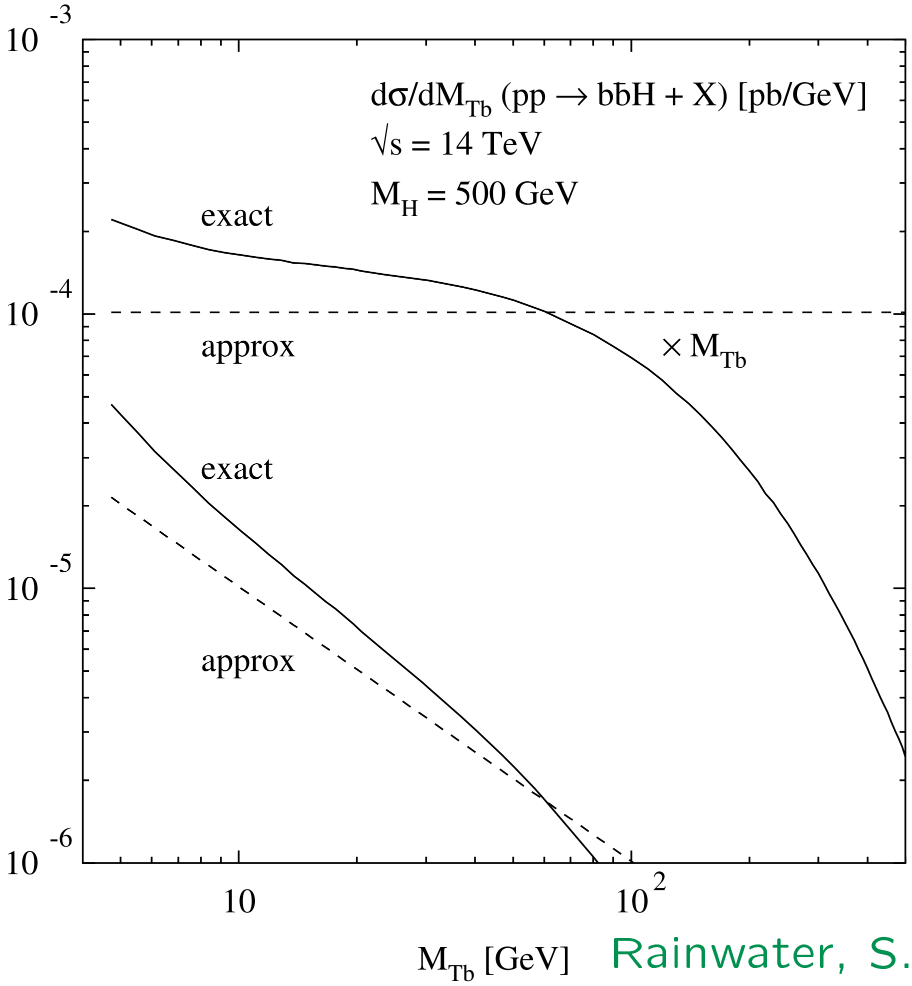
$$\frac{d\sigma^{(2\to 3)}}{dM_{Tb}} \propto \frac{1}{M_{Tb}} \quad \text{up to } M_{Tb} \sim \mu_F$$

- $p_T > p_{Tmin}$: $\log \frac{\mu_F^2}{m_b^2} \to \log \frac{\mu_F^2}{M_{Tmin}^2}$

  $\Rightarrow$ unintegrated PDFs...

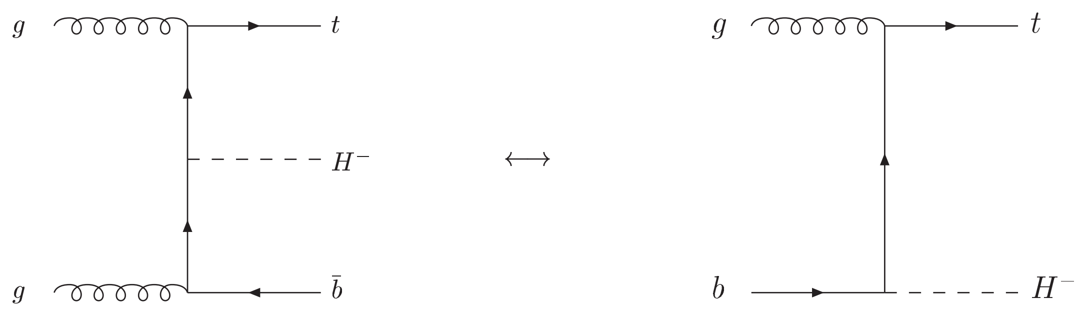
- large corrections to $gg \to b\bar{b}H$?





Rainwater, S., Zeppenfeld

- Charged Higgs:



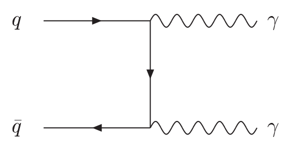
NLO Plehn

- HDECAY: lots of improvements planned
  interface: SUSPECT + SDECAY + HDECAY
  $\longrightarrow$ SSH
  Djouadi, Mühlleitner, S.

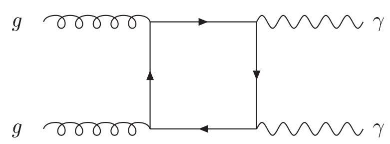
III *BACKGROUND PROCESSES*

- central question: which backgrounds measurable?

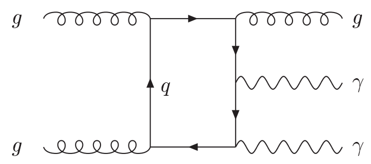
- $pp \to \gamma\gamma + X$: measurable from side-bands



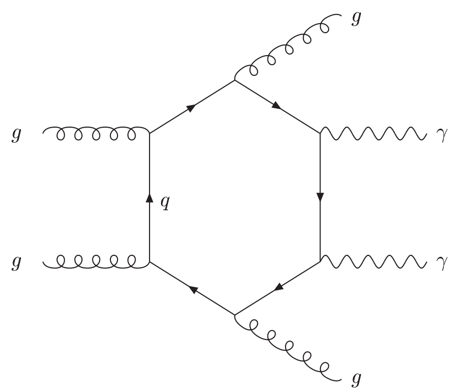
NLO + fragm. Binoth,. . .
$\to$ DIPHOX



NLO recently Bern,. . .



$\gamma\gamma + 1j$: NLO needed?



$\gamma\gamma + 2j$: LO needed
[W fusion]
$\leftarrow$ parton shower reliable???

- $\underline{pp \to t\bar{t} + X}$

background for many processes

$t\bar{t}$: NLO + soft gluon resummation

Dawson,...
Beenakker,...
Catani,...
...

$tt^*, t^*\bar{t}^*$: LO with spin corr. + Γ_t

Kauer, Zeppenfeld

$[Wtb, bbWW]$

$t\bar{t} + jets$: NLO needed [W fusion]

Frixione,...
Baur,...
Dixon,...

- $WW(\to \ell^+\ell^-\nu\bar{\nu})$: NLO with spin corr.

  WW^*/ZZ^*: NLO needed [tails!]

  $WWjj$: NLO needed? [W fusion]

Ellis, Veseli
Campbell

- $Vb\bar{b}$: NLO + soft gluon resummation

  $Vt\bar{t}$: NLO needed

  $[\phi^0 \to W^+W^-]$

- $t\bar{t}b\bar{b}$: LO uncertainties?

  [norm. + shapes]

- $t\bar{t}Vjj$: LO uncertainties?

  $[t\bar{t}\phi^0 \to t\bar{t}W^+W^-]$

- reliability of NLO QCD for jet veto/tagging?

  [NLO MC available?]

•
•
•

IV *SUMMARY*

• reliability of bottom PDFs still not clear [scale choice, approximate kinematics, etc.]
$\Rightarrow$ more [conceptual] work required
[lots of authors: Boos, Campbell, Dicus, Ellis, Harlander, Kilgore, Maltoni, Plehn, Rainwater, Stelzer, Sullivan, Willenbrock, Zeppenfeld $\rightarrow$ different opinions...]

• several background calculations @ LO/NLO missing, but NLO MC's become available for signals and backgrounds
progress expected at Les Houches?

• several exp. analyses have to be updated [e.g. $H \rightarrow \gamma\gamma$]

• coupling measurements set highest requirement on understanding signal and background