ASSOCIATED MSSM HIGGS PRODUCTION WITH HEAVY QUARKS : SUSY – QCD CORRECTIONS

Michael Spira (PSI)

I $t\bar{t}/b\bar{b} + \phi^0$ Production

II $t\bar{b}H^-$ Production

III Conclusions

in collaboration with S. Dittmaier, P. Häfliger, M. Krämer and M. Walser

• minimal model: 2 Higgs doubletts ϕ_1, ϕ_2

$$V_\phi = m_1^2|\phi_1|^2 + m_2^2|\phi_2|^2 - m_{12}^2\left[\phi_1^+\phi_2 + h.c.\right] + \frac{g^2+g'^2}{8}\left[|\phi_1|^2 - |\phi_2|^2\right]^2 + \frac{g^2}{2}|\phi_1^+\phi_2|^2$$

ESB $\rightarrow$ 5 Higgs bosons:

h, H	neutral, $\mathcal{CP}$ even
A	neutral, $\mathcal{CP}$ odd
$H^\pm$	charged

LO: 2 input parameters: $M_A, \text{tg}\beta = \frac{v_2}{v_1}$

$$M_h^2 = \frac{1}{2}\left\{M_A^2 + M_Z^2 + \epsilon - \sqrt{(M_A^2 + M_Z^2 + \epsilon)^2 - 4M_A^2 M_Z^2 c_{2\beta}^2 - 4\epsilon(M_A^2 s_\beta^2 + M_Z^2 c_\beta^2)}\right\}$$

• large radiative corrections:

$$\epsilon = \frac{3G_F}{\sqrt{2}\pi^2}\frac{m_t^4}{s_\beta^2}\left\{\log\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} + \frac{X_t^2}{M_{SUSY}^2}\left[1 - \frac{X_t^2}{12 M_{SUSY}^2}\right]\right\}$$

$$M_h < M_Z \rightarrow \boxed{M_h \lesssim 140 \text{ GeV}}$$

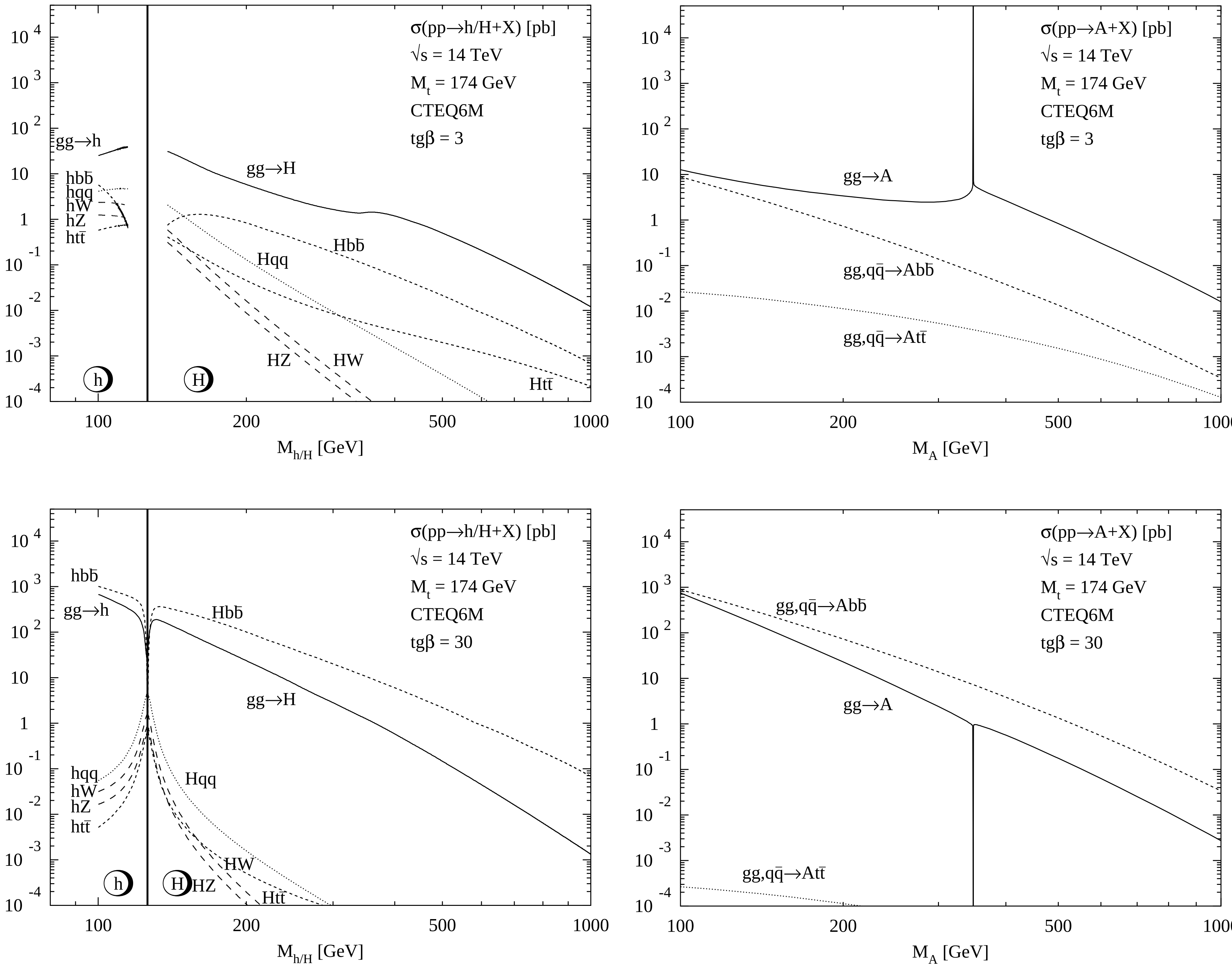
Haber,. . .
Carena,. . .
Heinemeyer,. . .
Zhang
Slavich,. . .
etc.

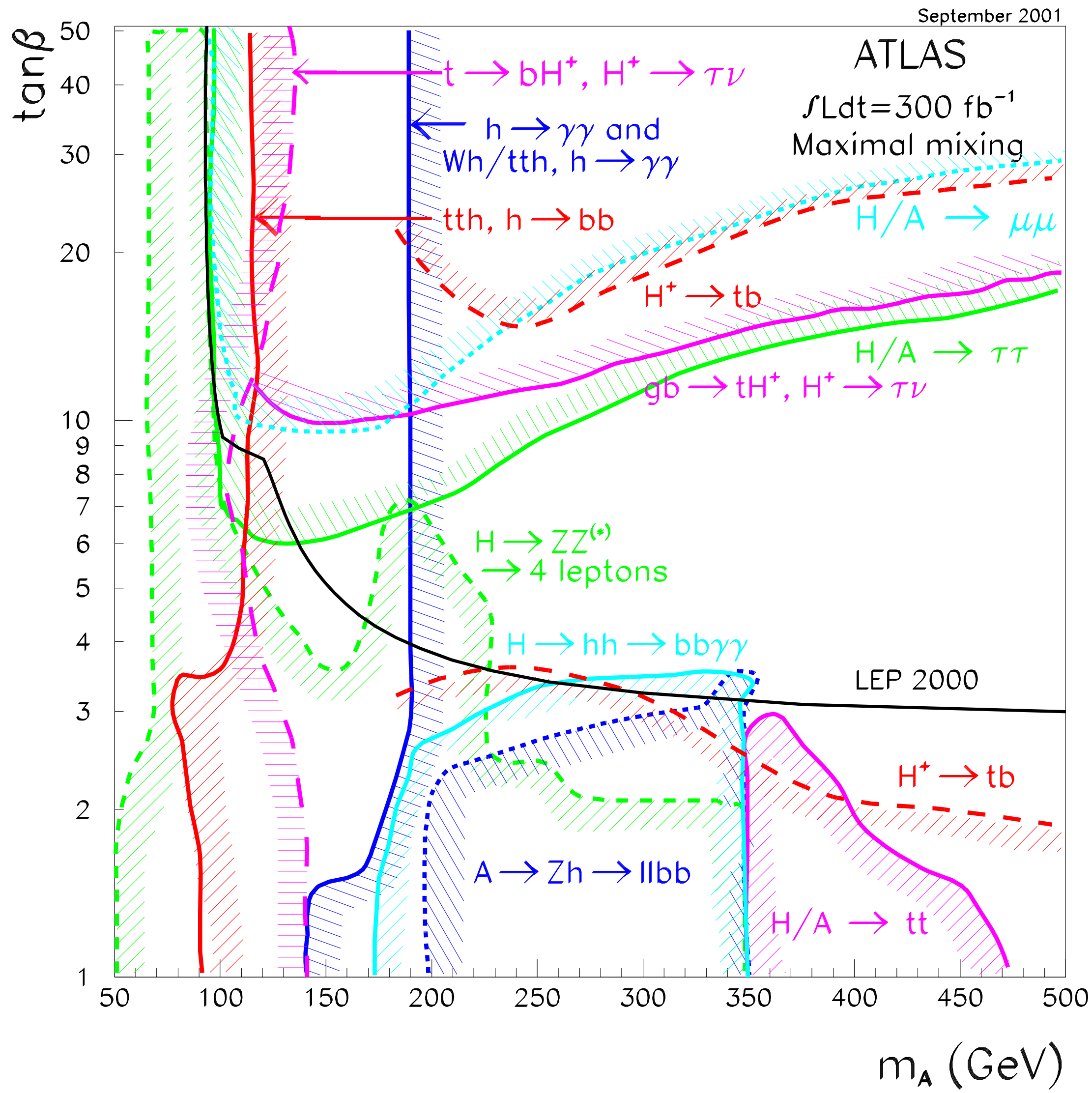
- modified couplings:

ϕ	g_u^ϕ	g_d^ϕ	g_V^ϕ
h	c_α/s_β	$-s_\alpha/c_\beta$	$s_{\beta-\alpha}$
H	s_α/s_β	c_α/c_β	$c_{\beta-\alpha}$
A	ctgβ	tgβ	0

- mixing: $\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} c_\alpha & -s_\alpha \\ s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix}$

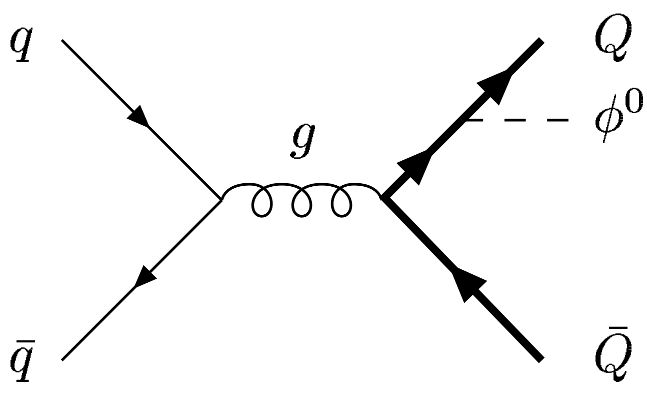
- Yukawa couplings: tg$\beta\uparrow \quad \Rightarrow \quad g_u^\phi\downarrow \quad g_d^\phi\uparrow \quad g_V^\phi\downarrow$

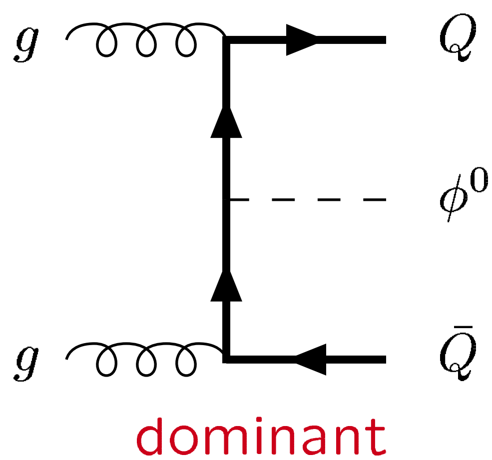

σ(pp→h/H+X) [pb]
√s = 14 TeV
M_t = 174 GeV
CTEQ6M
tgβ = 3
gg→h
hbb̄
hqq
hW
hZ
htt̄
gg→H
Hbb̄
Hqq
HZ
HW
Htt̄
h
H
M_h/H [GeV]
σ(pp→A+X) [pb]
√s = 14 TeV
M_t = 174 GeV
CTEQ6M
tgβ = 3
gg→A
gg,qq̄→Abb̄
gg,qq̄→Att̄
M_A [GeV]
σ(pp→h/H+X) [pb]
√s = 14 TeV
M_t = 174 GeV
CTEQ6M
tgβ = 30
hbb̄
gg→h
Hbb̄
gg→H
hqq
hW
hZ
htt̄
Hqq
HW
HZ
Htt̄
h
H
M_h/H [GeV]
σ(pp→A+X) [pb]
√s = 14 TeV
M_t = 174 GeV
CTEQ6M
tgβ = 30
gg,qq̄→Abb̄
gg→A
gg,qq̄→Att̄
M_A [GeV]



September 2001
ATLAS
∫Ldt=300 fb⁻¹
Maximal mixing
t → bH⁺, H⁺ → τν
h → γγ and
Wh/tth, h → γγ
tth, h → bb
H/A → μμ
H⁺ → tb
H/A → ττ
gb → tH⁺, H⁺ → τν
H → ZZ(*)
→ 4 leptons
H → hh → bbγγ
LEP 2000
H⁺ → tb
A → Zh → llbb
H/A → tt
tanβ
50
40
30
20
10
9
8
7
6
5
4
3
2
1
50
100
150
200
250
300
350
400
450
500
m_A (GeV)

I $t\bar{t}/b\bar{b}+\phi^0$ PRODUCTION

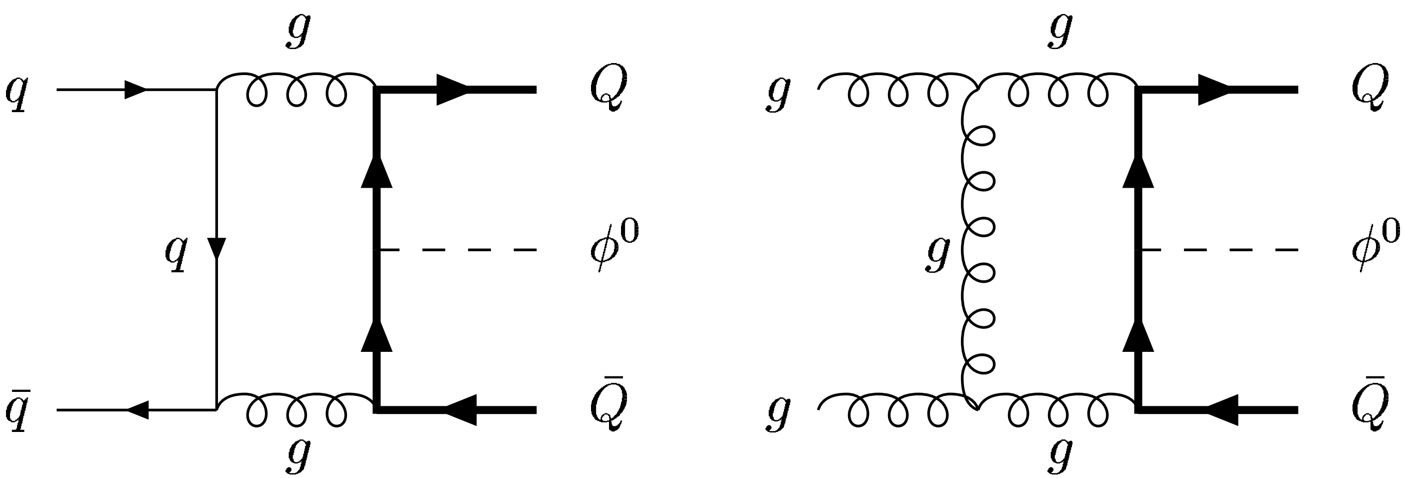




- $gg, q\bar{q} \to t\bar{t}\phi^0$ important for $M_\phi \lesssim 130$ GeV
- crucial for determination of top Yukawa coupling
- $b\bar{b}+H/A$ dominant for large tgβ
- measurement of tgβ
- $t\bar{t}h$: SUSY-QCD corrections computed

Peng, Wen-Gan, Hong-Shen,
Ren-You, Liang
Rauch, Hollik

(i) Virtual Corrections



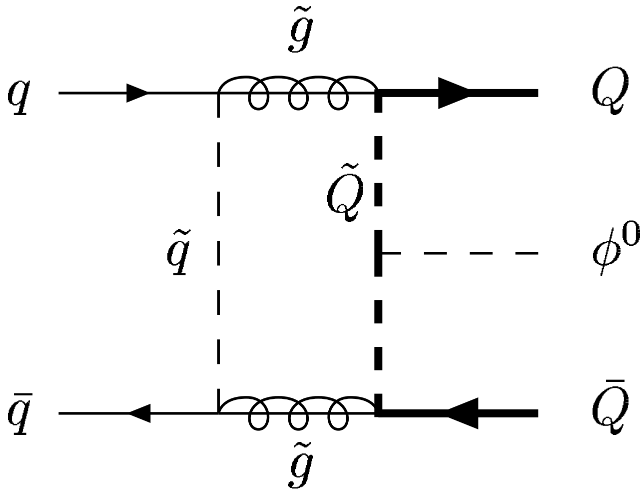
- most difficult part: Pentagon diagrams [infared and collinear divergent]

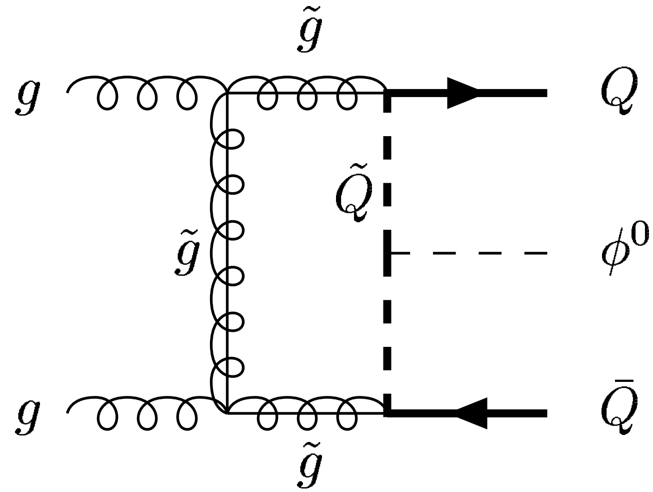
- problematic regions in phase space: avoid inverse Gram determinants

Denner, Dittmaier

- α_s: $\overline{\text{MS}}$ scheme [4/5 flavours], m_Q: on-shell

SUSY-QCD Corrections

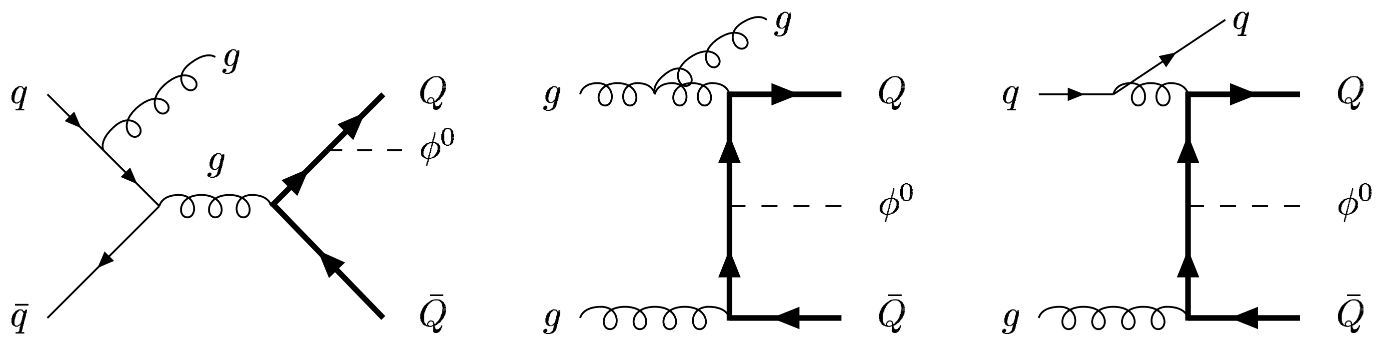




- no infrared singularities

- massive gluinos and squarks decoupled from $\alpha_s \to$ 4/5 active flavours

(ii) Real Corrections



- complex matrix elements

- infrared and collinear singularities cancel against virtual corrections and counter terms of PDFs [mass factorization]

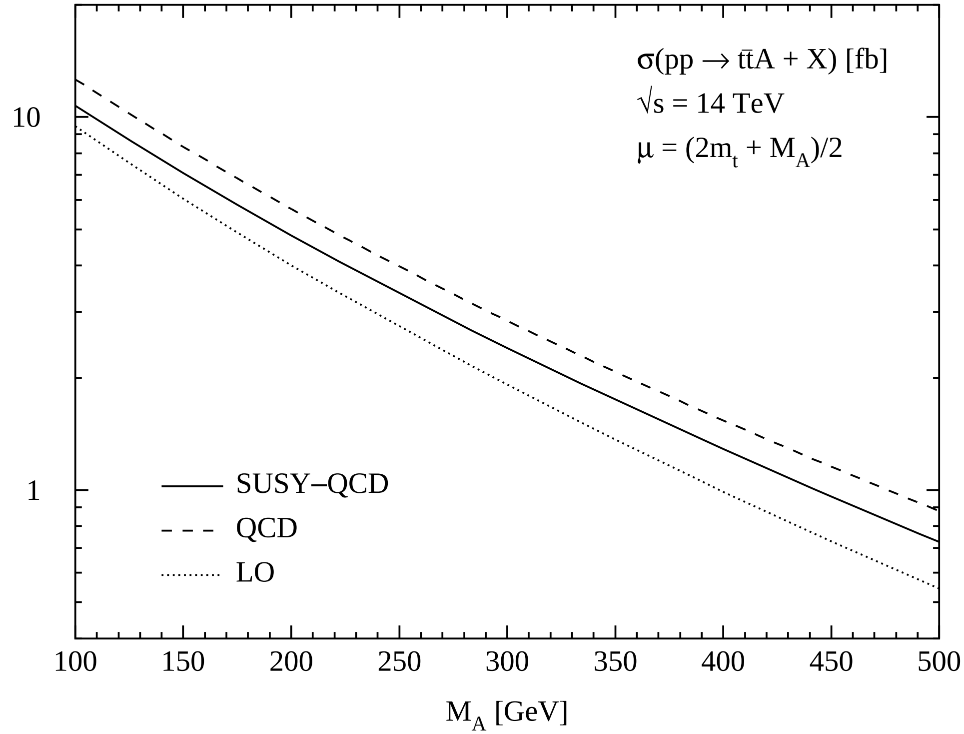
- PDF: $\overline{\text{MS}}$ scheme [4/5 flavours]

- $b\bar{b}\phi$: multi-channel integration

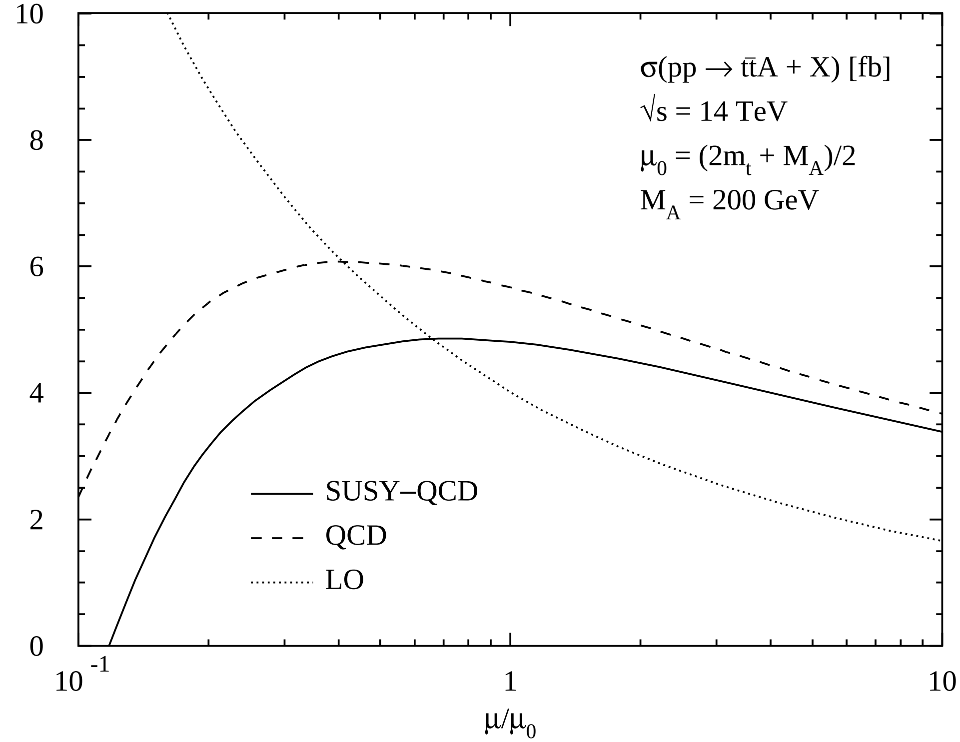
$t\bar{t}\phi^0$: SPS 5

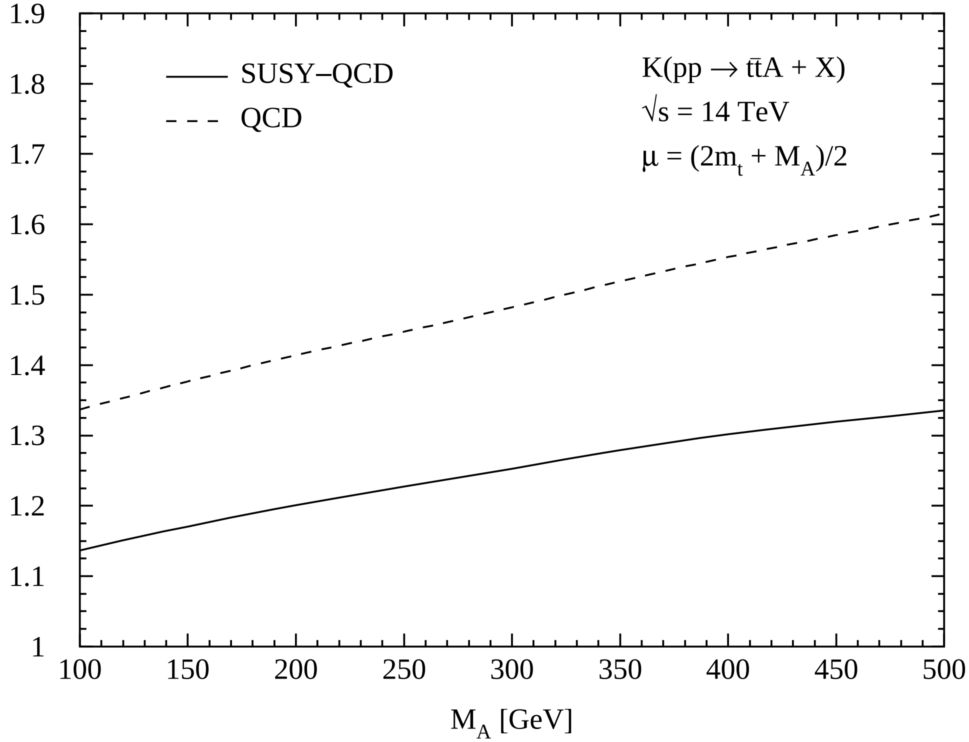
$$
\begin{aligned}
\mathrm{tg}\beta &= 5 \\
\mu &= 639.8 \text{ GeV} \\
A_t &= -1671.4 \text{ GeV} \\
A_b &= -905.6 \text{ GeV} \\
m_{\tilde{g}} &= 710.3 \text{ GeV} \\
m_{\tilde{q}_L} &= 535.2 \text{ GeV} \\
m_{\tilde{b}_R} &= 620.5 \text{ GeV} \\
m_{\tilde{t}_R} &= 360.5 \text{ GeV}
\end{aligned}
$$

$$\longrightarrow m_{\tilde{t}_1} = 230.4 \text{ GeV}, m_{\tilde{t}_2} = 637.8 \text{ GeV}$$



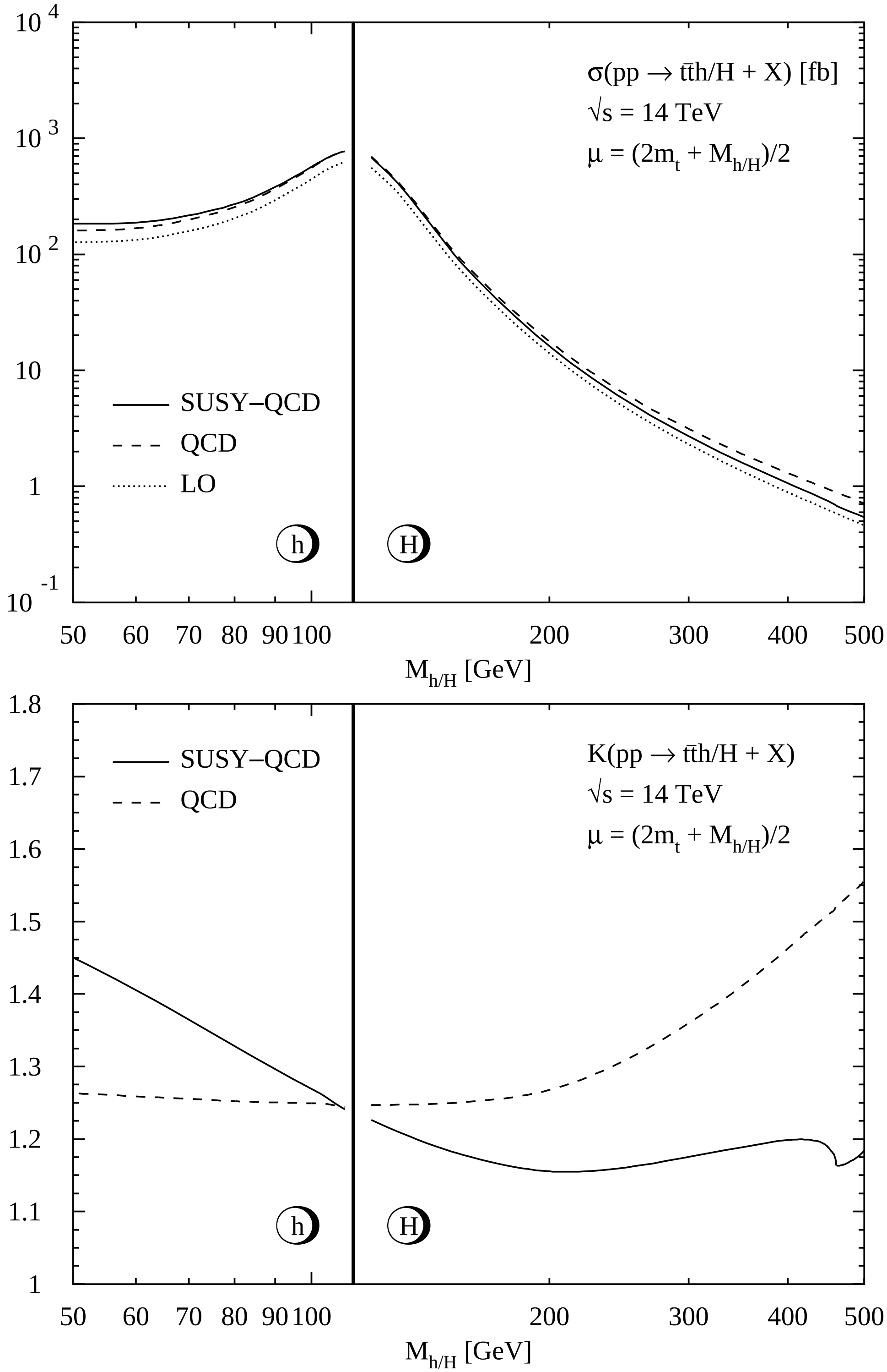
PRELIMINARY



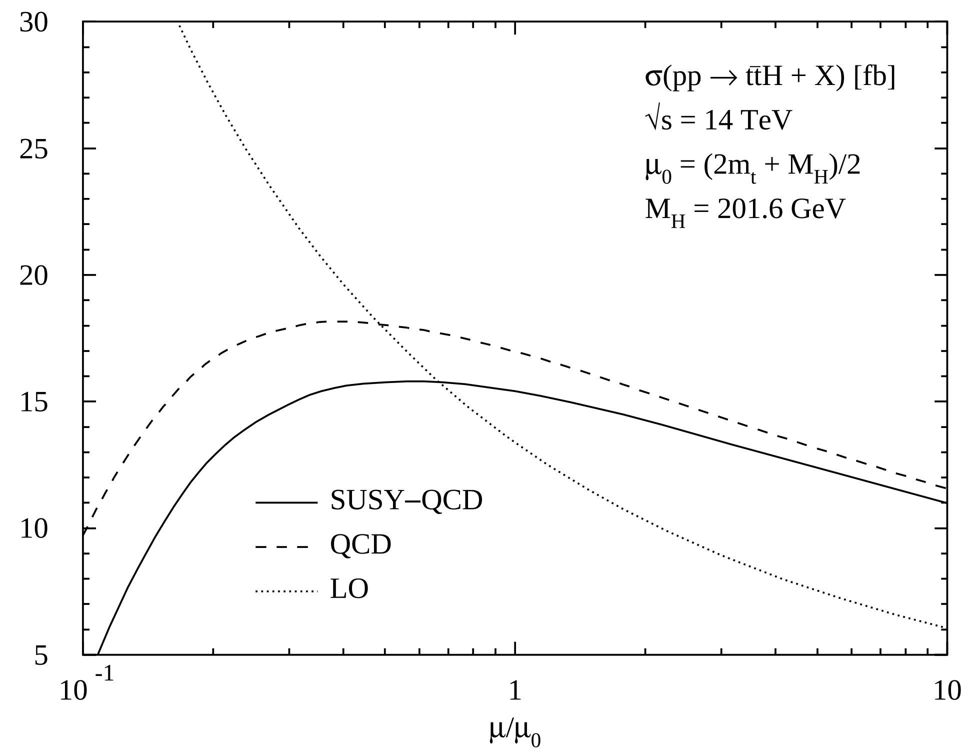


$\Rightarrow \Delta \lesssim 10\%$

Dittmaier, Häfliger,
Krämer, S., Walser



PRELIMINARY



$\Rightarrow \Delta \lesssim 10\%$

Dittmaier, Häfliger,
Krämer, S., Walser

SUSY-QCD Corrections to $b\bar{b}\phi^0$

$$\mathcal{L}_{eff} = -\lambda_b \overline{b_R}\left[\phi_1^0 + \frac{\Delta_b}{\mathrm{tg}\beta}\phi_2^{0*}\right] b_L + h.c. \qquad \text{valid to all orders in } \Delta m_b, \Delta_1$$

$$= -m_b \bar{b}\left[1 + i\gamma_5 \frac{G^0}{v}\right] b - \frac{m_b/v}{1+\Delta_b}\bar{b}\left[g_b^h\left(1 - \frac{\Delta_b}{\mathrm{tg}\alpha\ \mathrm{tg}\beta}\right) h + g_b^H\left(1 + \Delta_b \frac{\mathrm{tg}\alpha}{\mathrm{tg}\beta}\right) H - g_b^A\left(1 - \frac{\Delta_b}{\mathrm{tg}^2\beta}\right) i\gamma_5 A\right] b$$

$$\Delta_b = \frac{\Delta m_b}{1+\Delta_1}$$

$$\Delta m_b = \frac{2}{3}\frac{\alpha_s}{\pi}\, m_{\tilde{g}}\, \mu\ \mathrm{tg}\beta\ I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, m_{\tilde{g}}^2)$$

$$\Delta_1 = -\frac{2}{3}\frac{\alpha_s}{\pi}\, m_{\tilde{g}}\, A_b\ I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, m_{\tilde{g}}^2)$$

$$I(a,b,c) = -\frac{ab\log\frac{a}{b} + bc\log\frac{b}{c} + ca\log\frac{c}{a}}{(a-b)(b-c)(c-a)}$$

$\Rightarrow$ resummed Yukawa couplings

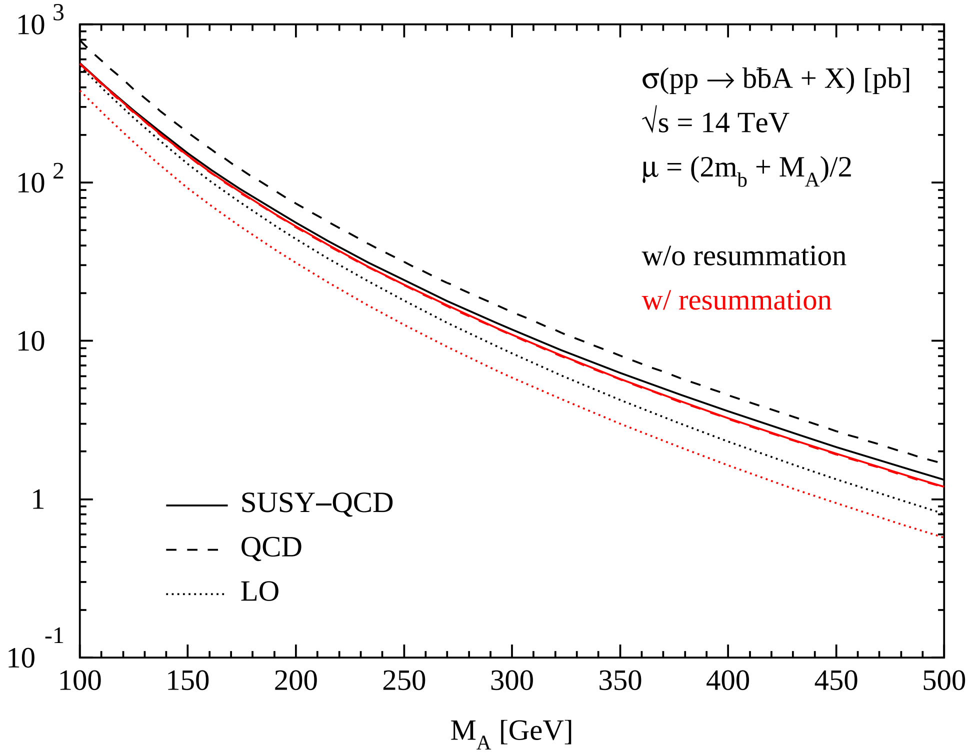
Carena, Garcia, Nierste, Wagner
Guasch, Häfliger, S.

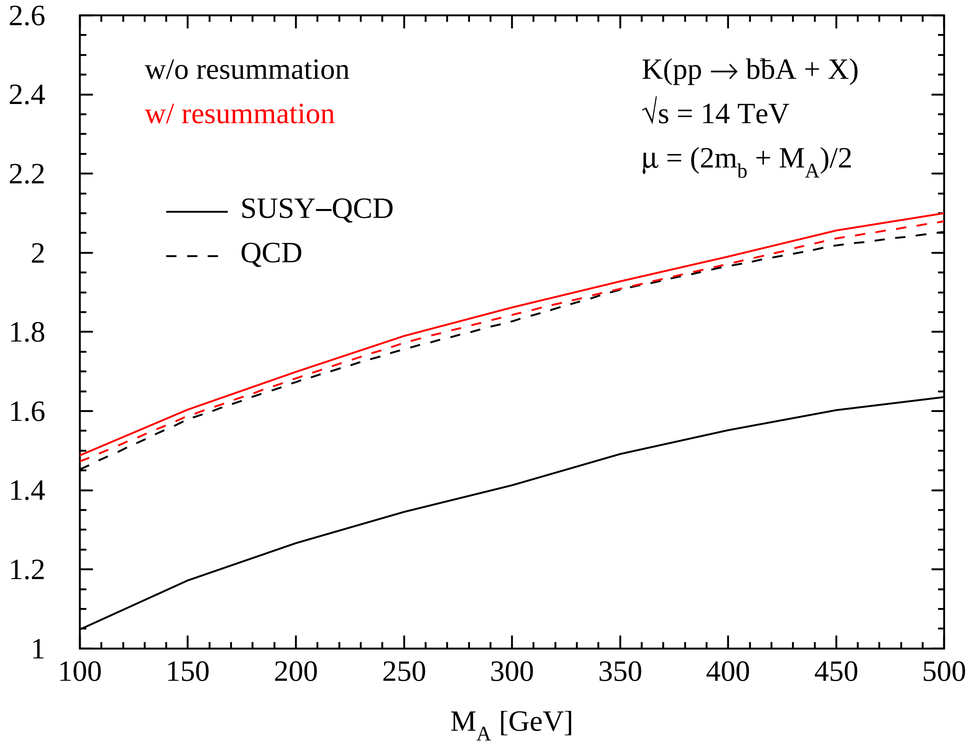
$b\bar{b}\phi^0$: SPS 1b

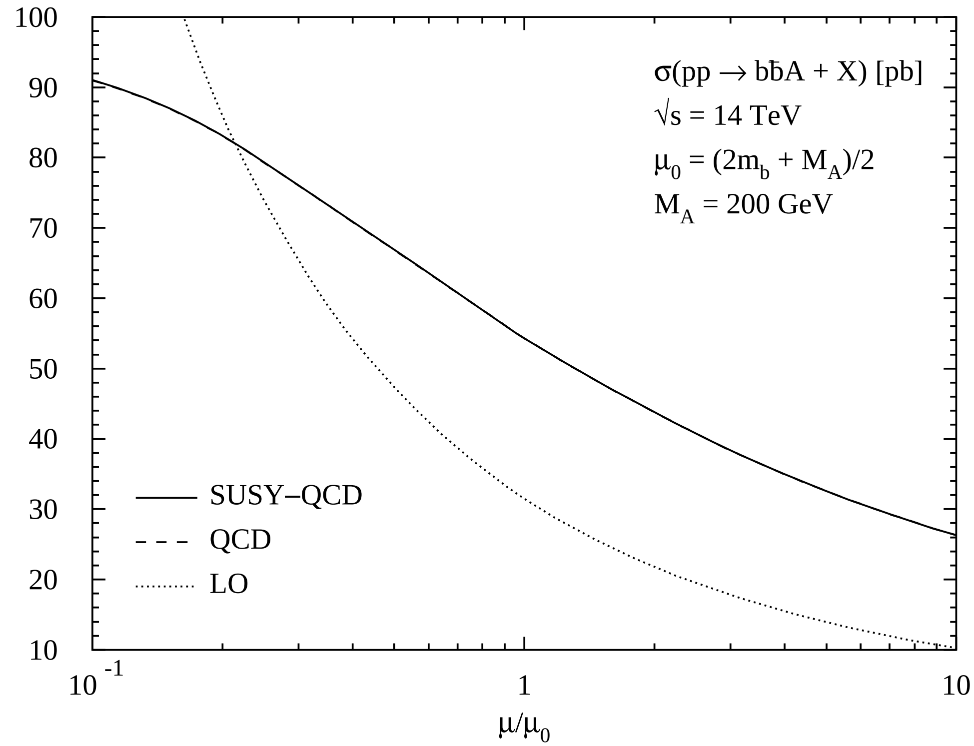
$$
\begin{aligned}
\mathrm{tg}\beta &= 30 \\
\mu &= 495.6 \text{ GeV} \\
A_t &= -729.3 \text{ GeV} \\
A_b &= -987.4 \text{ GeV} \\
m_{\tilde{g}} &= 916.1 \text{ GeV} \\
m_{\tilde{q}_L} &= 762.5 \text{ GeV} \\
m_{\tilde{b}_R} &= 780.3 \text{ GeV} \\
m_{\tilde{t}_R} &= 670.7 \text{ GeV}
\end{aligned}
$$

$$
\longrightarrow m_{\tilde{b}_1} = 745.8 \text{ GeV}, m_{\tilde{b}_2} = 798.9 \text{ GeV}
$$

PRELIMINARY

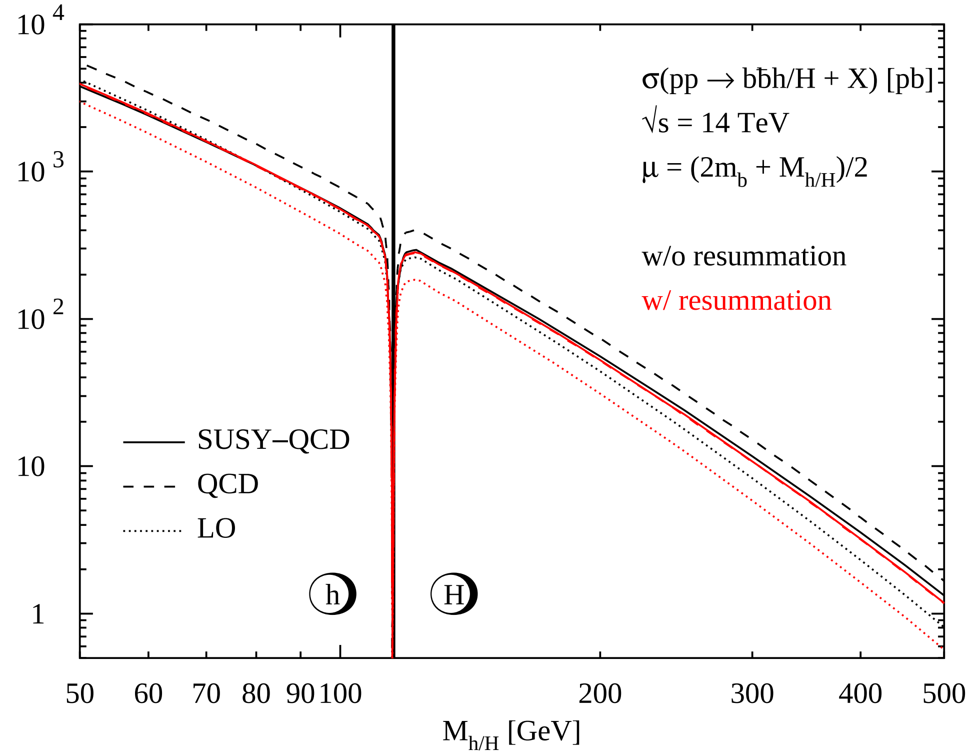


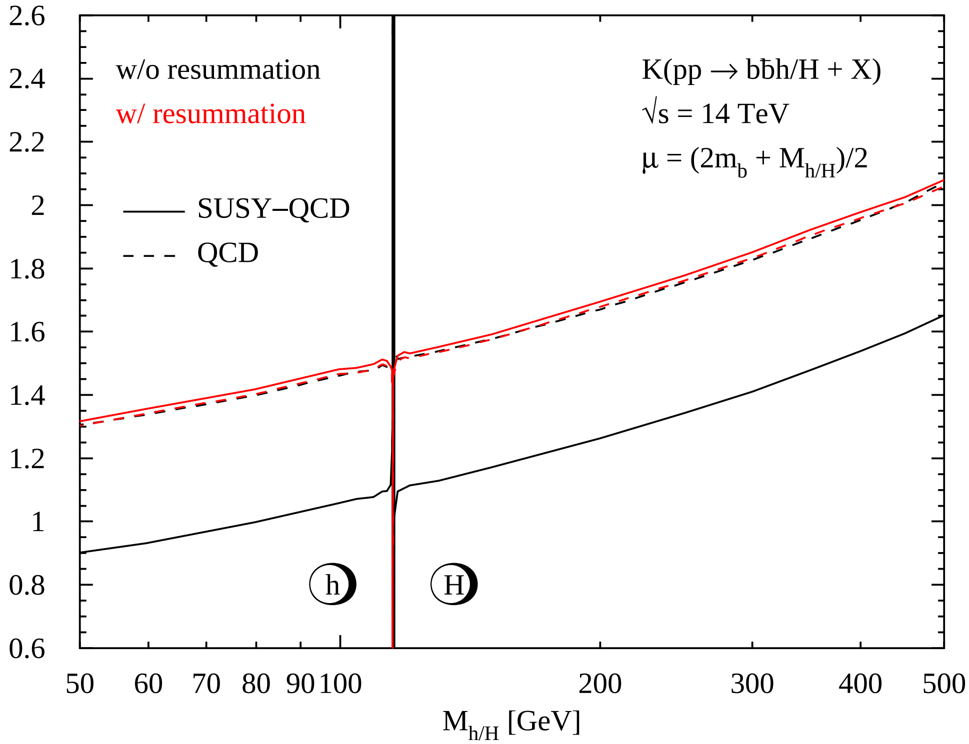




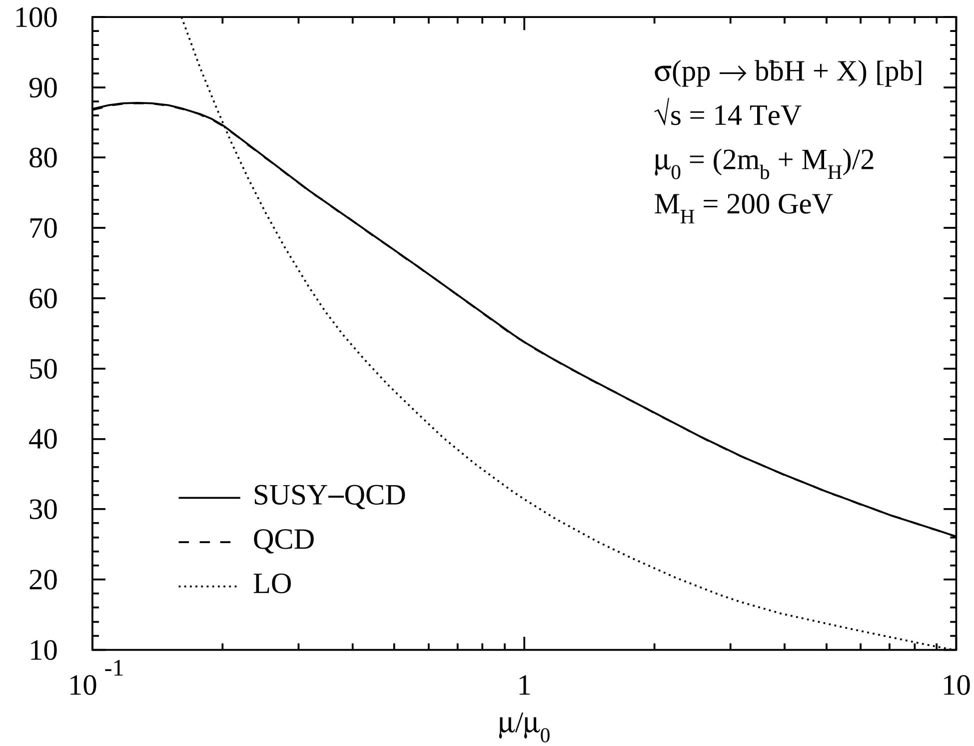
$\Rightarrow \Delta \lesssim 25\%$

Dittmaier, Häfliger,
Krämer, S., Walser





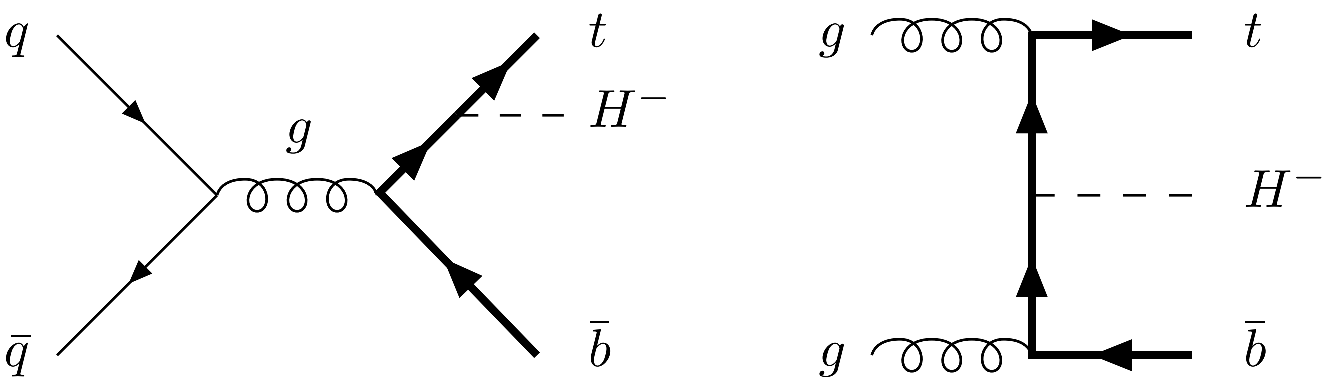
PRELIMINARY



$\Rightarrow \Delta \lesssim 25\%$

Dittmaier, Häfliger,
Krämer, S., Walser

II $t\bar{b}H^-$ PRODUCTION



dominant

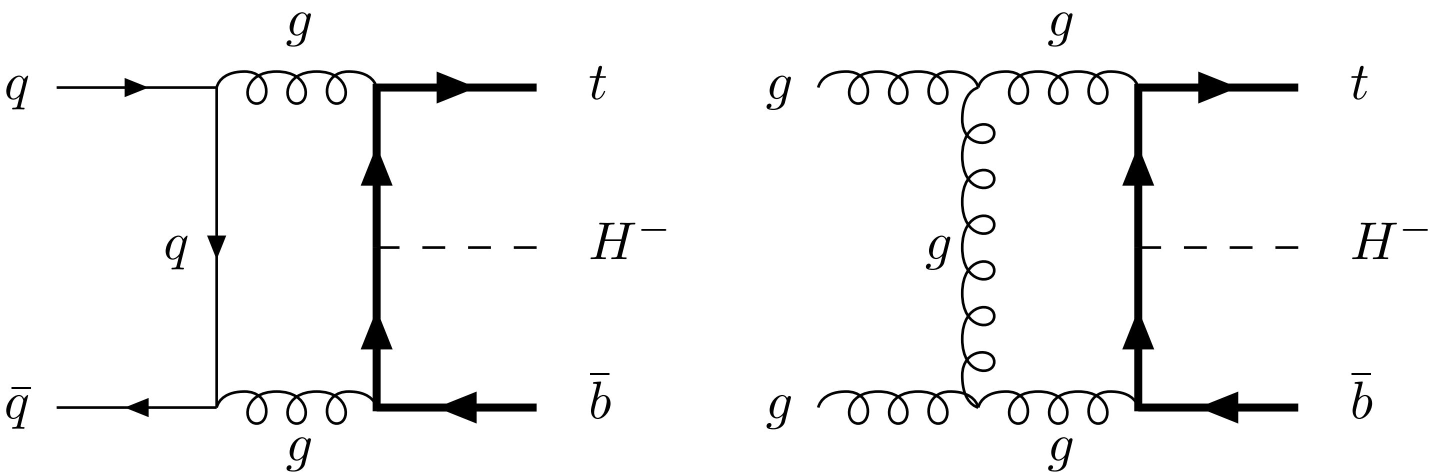
- dominant charged Higgs production process
- clear signal of extended Higgs sector
- continuum calculation $[M_{H^\pm} > m_t - m_b \quad \Rightarrow \quad t \not\to H^+ b]$
- SUSY-QCD corrections calculated

Peng, Wen-Gan, Hong-Shen, Ren-You, Yi, Liang, Lei

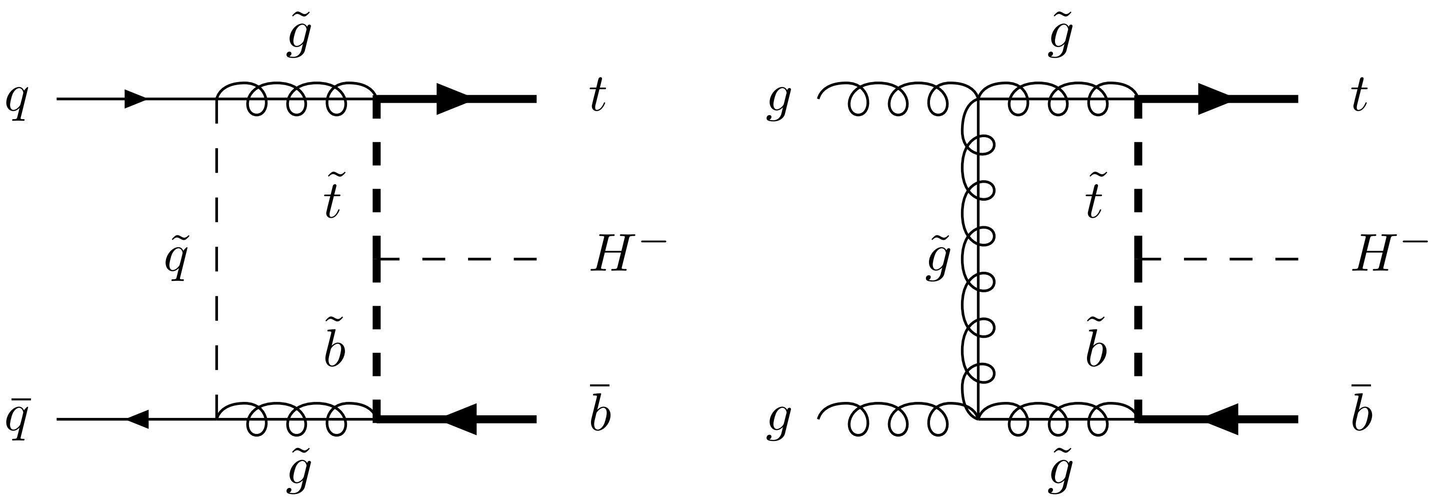
- SUSY-QCD corrections to $bg \to H^- t$ known

Plehn

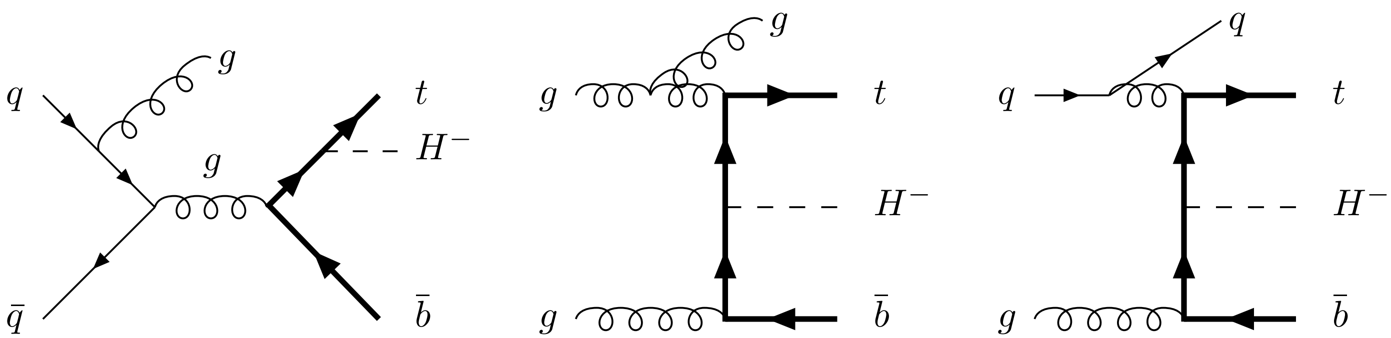
SUSY-QCD Corrections



QCD

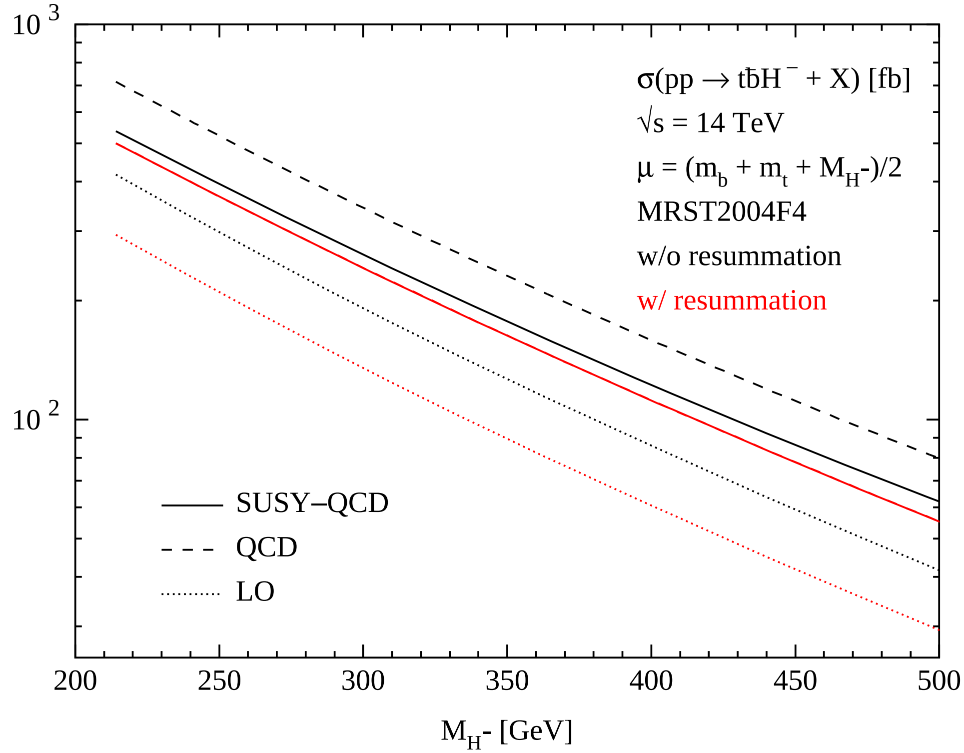


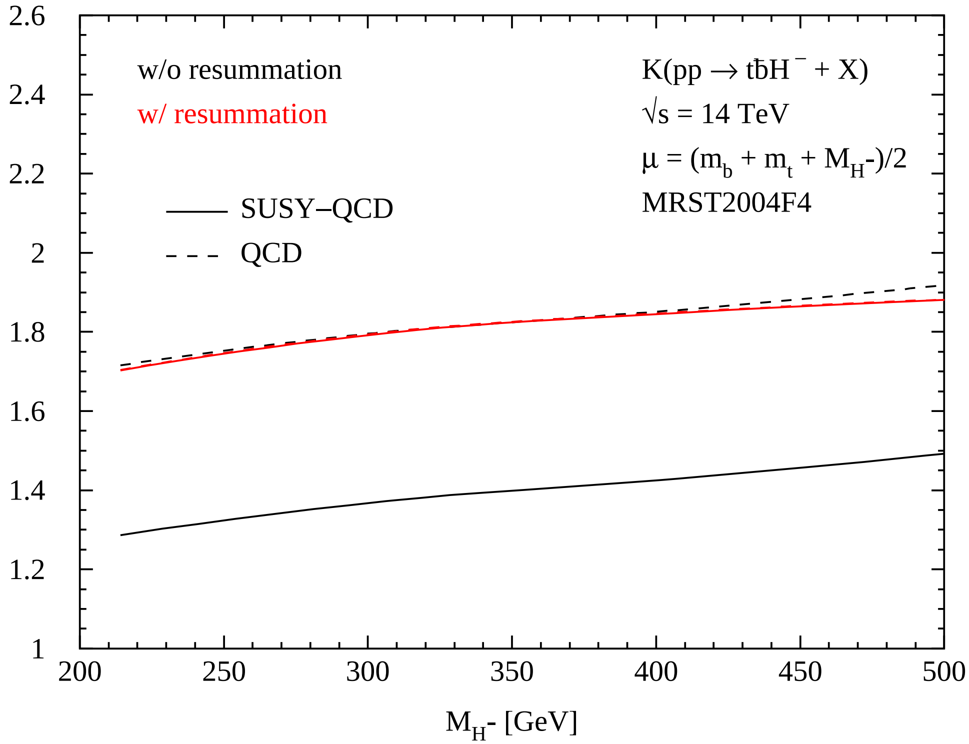
SUSY-QCD

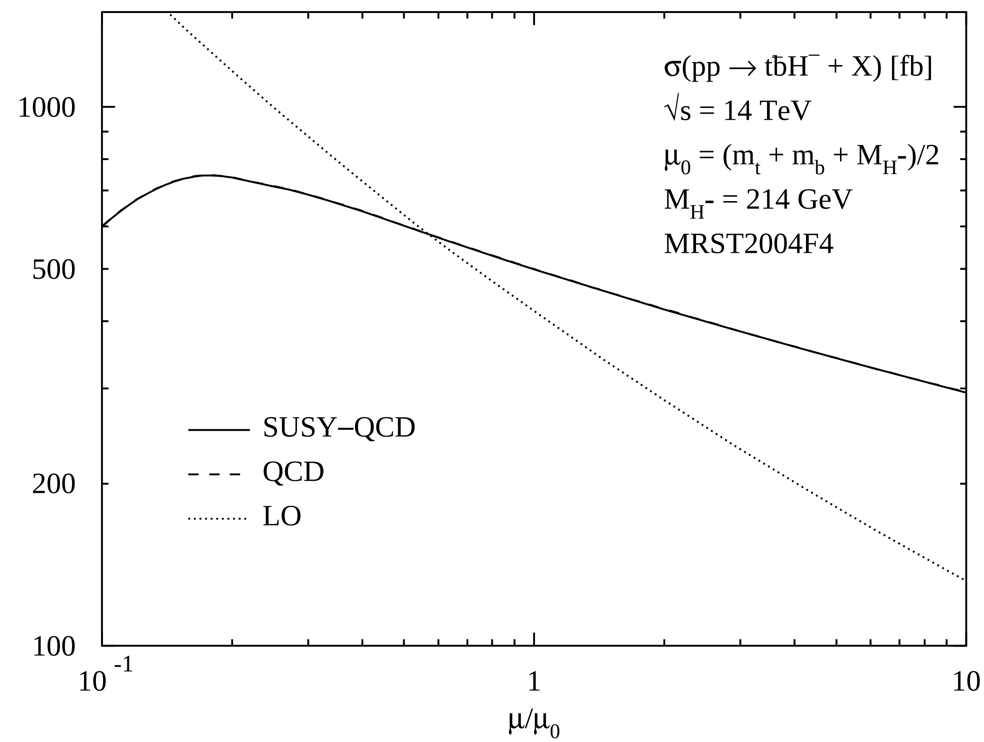


real

PRELIMINARY







$\Rightarrow \Delta \lesssim 25\%$

Dittmaier, Krämer, S., Walser

III *CONCLUSIONS*

(i) $t\bar{t}\phi^0$

- QCD corrections: $\sim (20-60)\%$ @ LHC $\Rightarrow \Delta \lesssim 10-15\%$
- SUSY-QCD corrections: $\sim \pm(20-30)\%$ @ LHC

(ii) $b\bar{b}\phi^0$

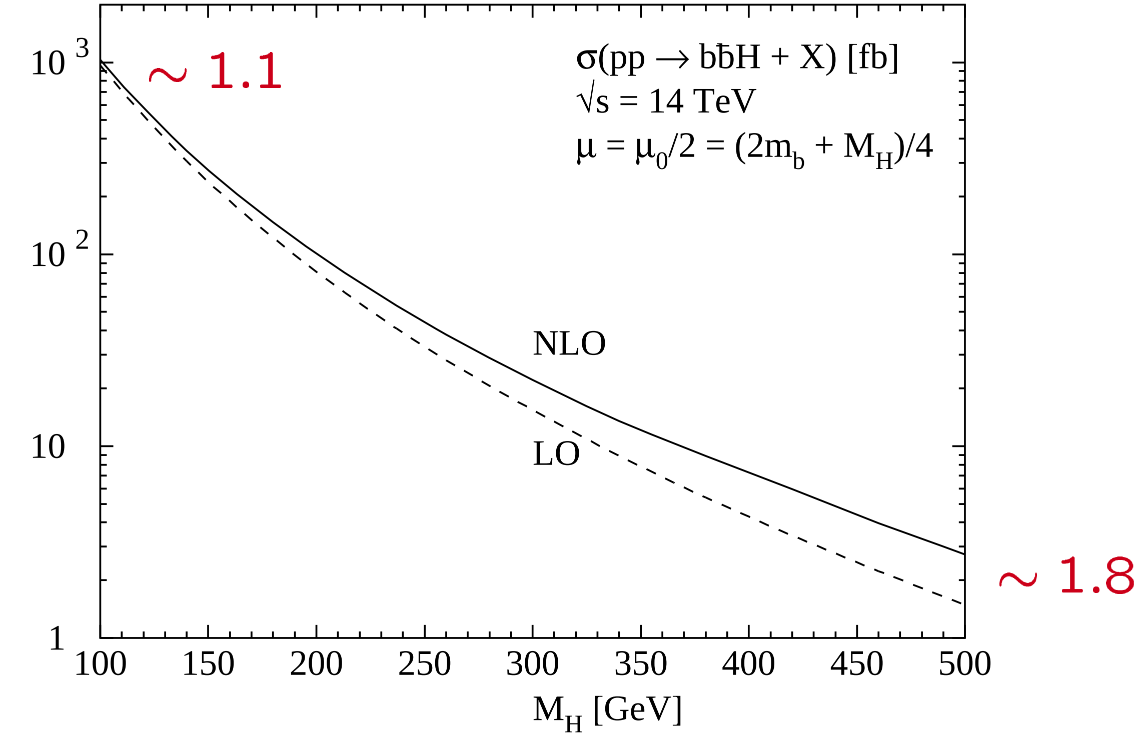
- QCD corrections: $\lesssim 100\%$ for total cxn $\Rightarrow \Delta \lesssim 25\%$
  [moderate for larger p_{Tb}]
- SUSY-QCD corrections: small after resummation [Δm_b]

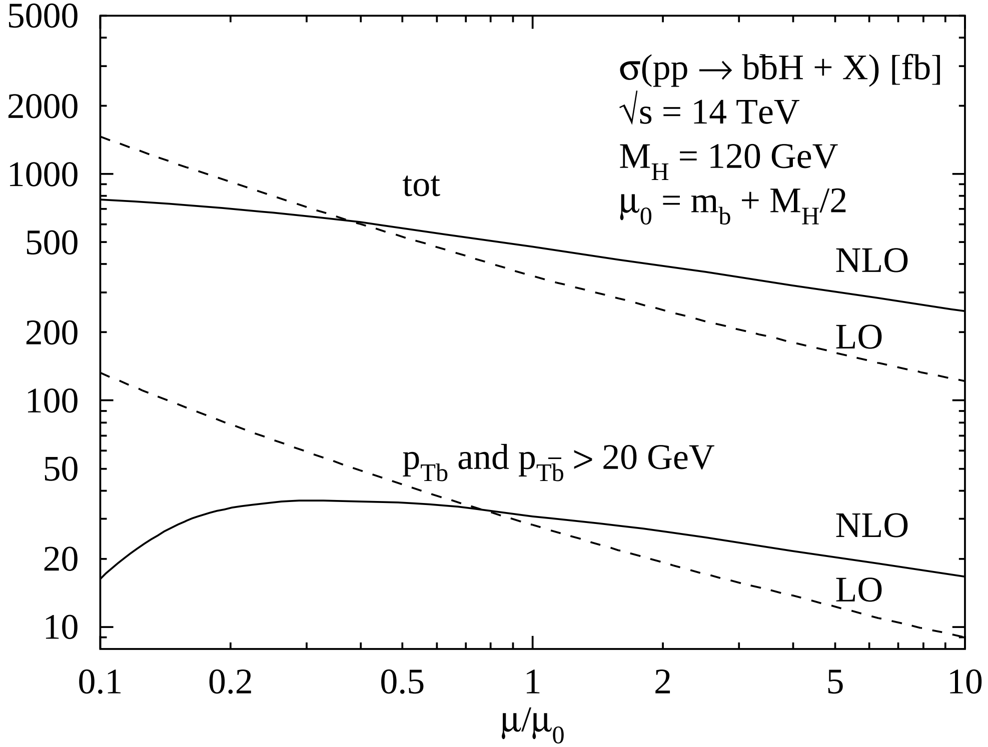
(iii) $t\bar{b}H^-$

- QCD corrections: (60–100)% $\Rightarrow \Delta \lesssim 25\%$
  [moderate for larger p_{Tb}]
- SUSY-QCD corrections: small after resummation [Δm_b]

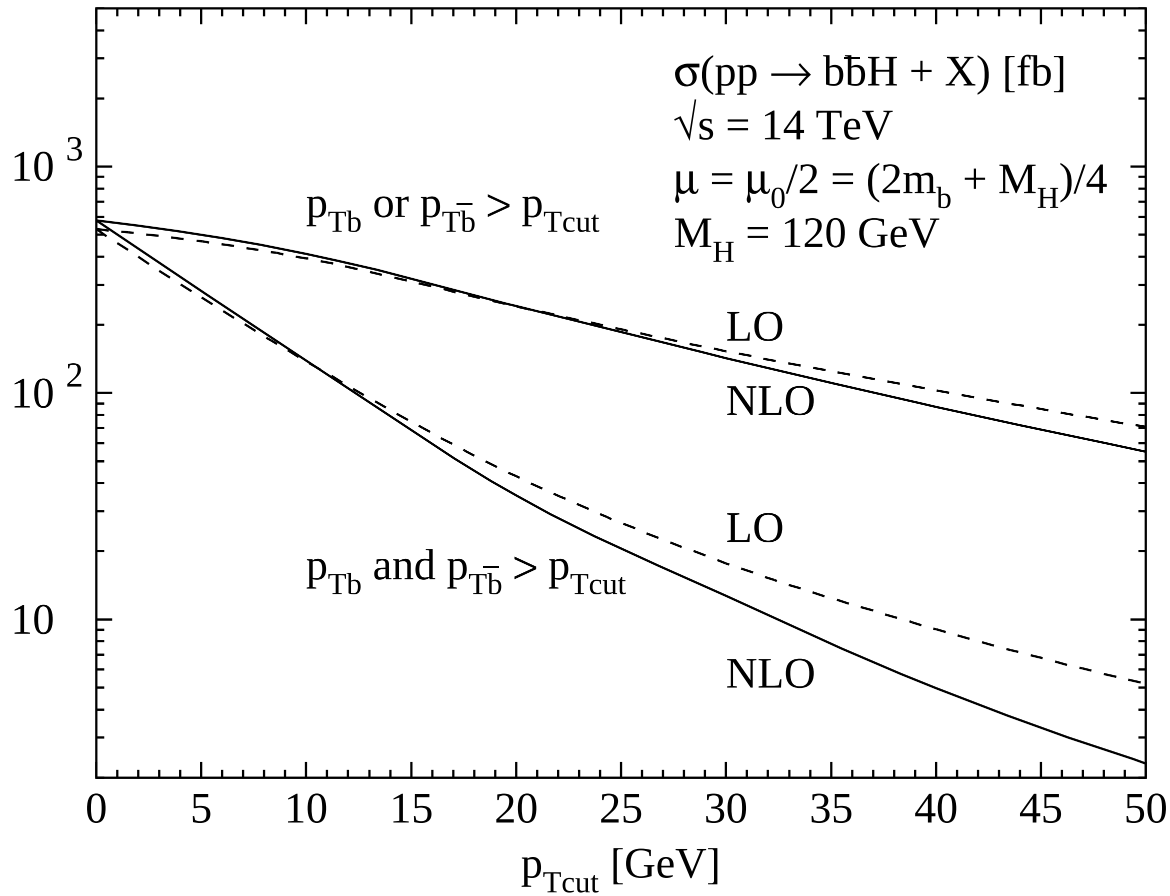
BACKUP SLIDES

Standard Model



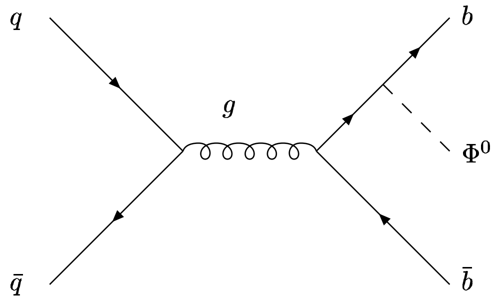


Dittmaier, Krämer, S.

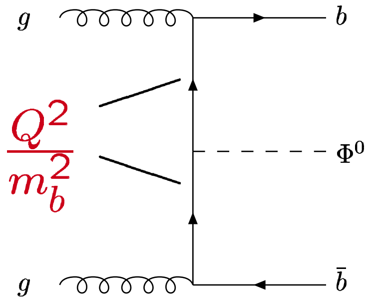


Dittmaier, Krämer, S.

b densities



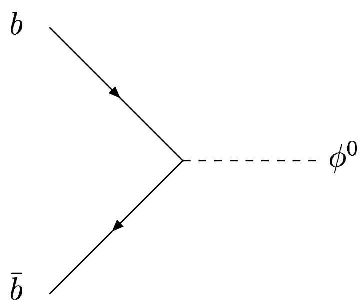
$\log \frac{Q^2}{m_b^2}$



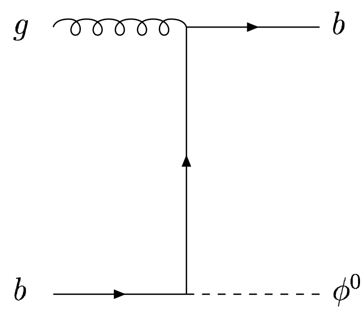
dominant

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

- new processes:



NNLO



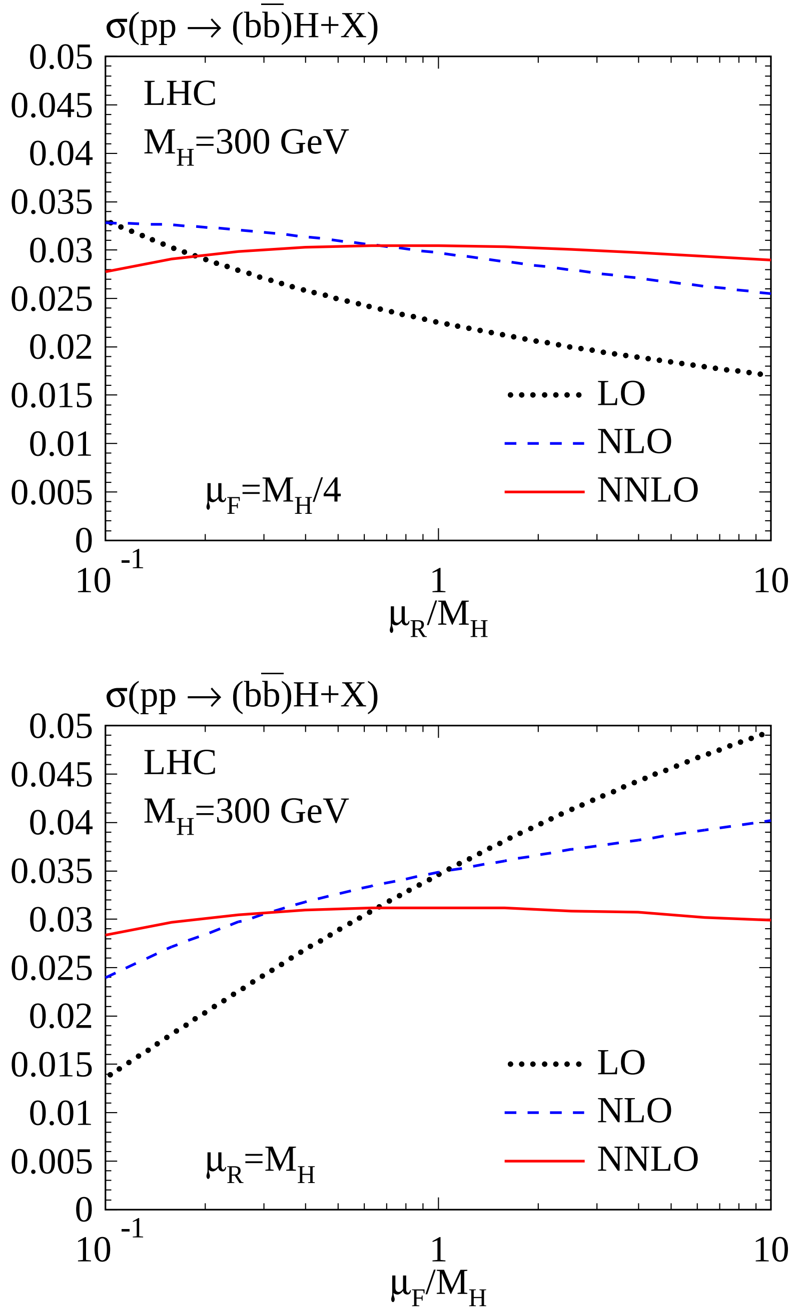
NLO

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

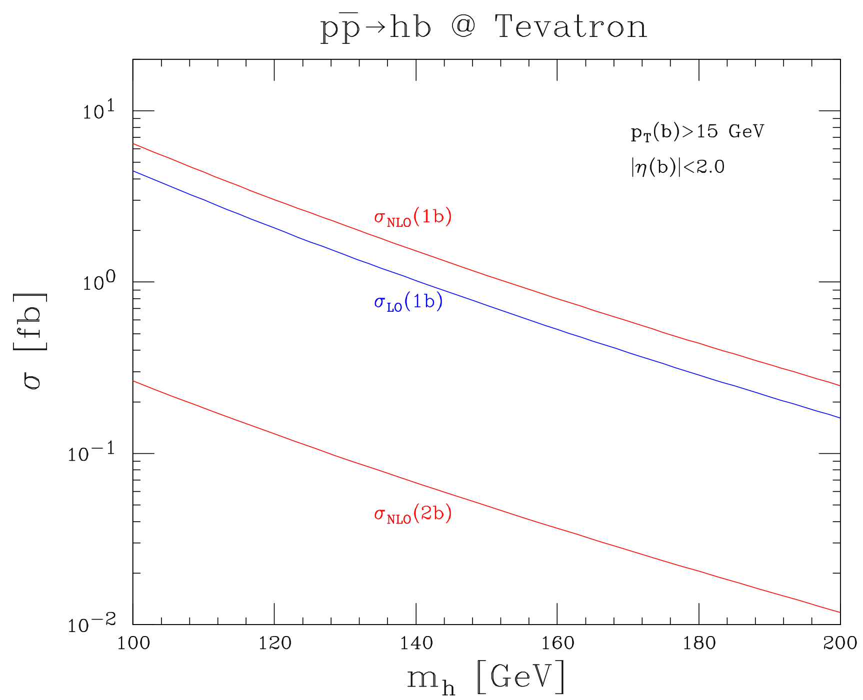
Harlander, Kilgore

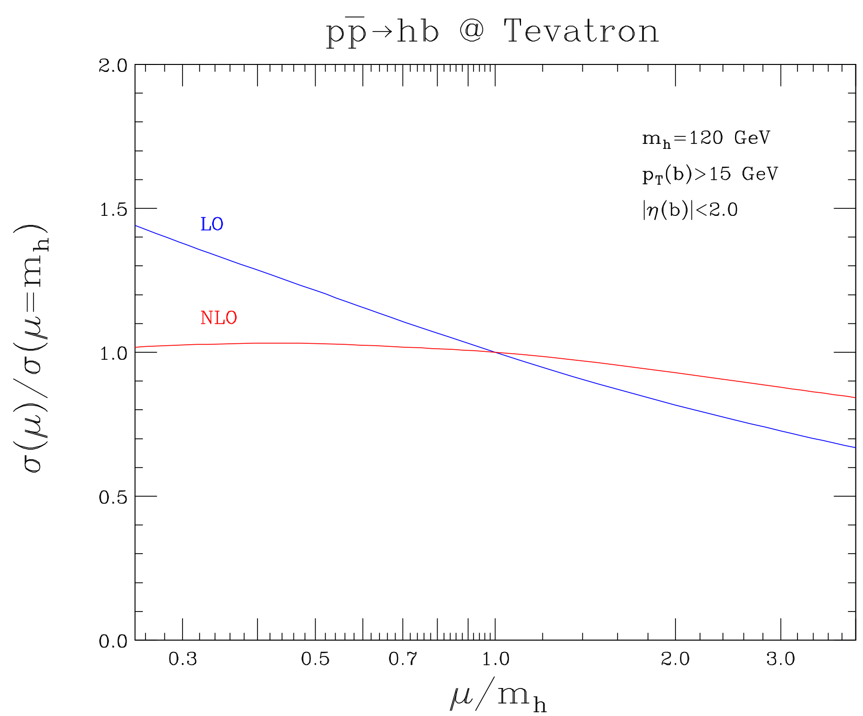
$$b(x,\mu^2) \longrightarrow b(x,\mu^2) - \frac{\alpha_s}{2\pi} P_{qg} \otimes g(x,\mu^2) \log \frac{\mu^2}{m_b^2}$$

$$\mu \sim Q \sim M_\phi/4 \Rightarrow \sigma_{tot}$$

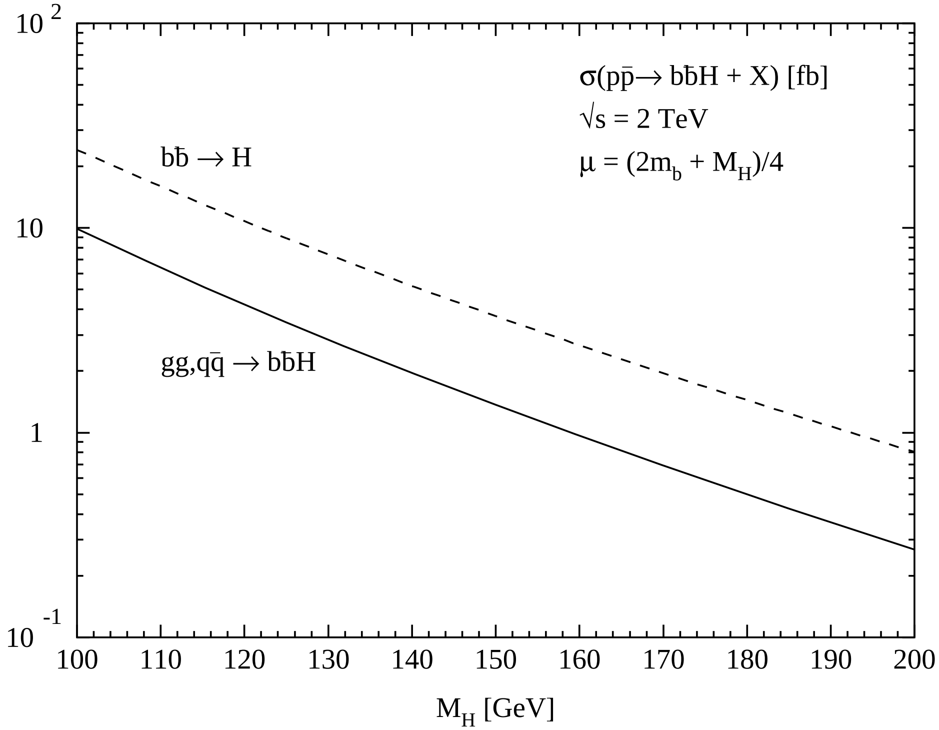


Harlander, Kilgore

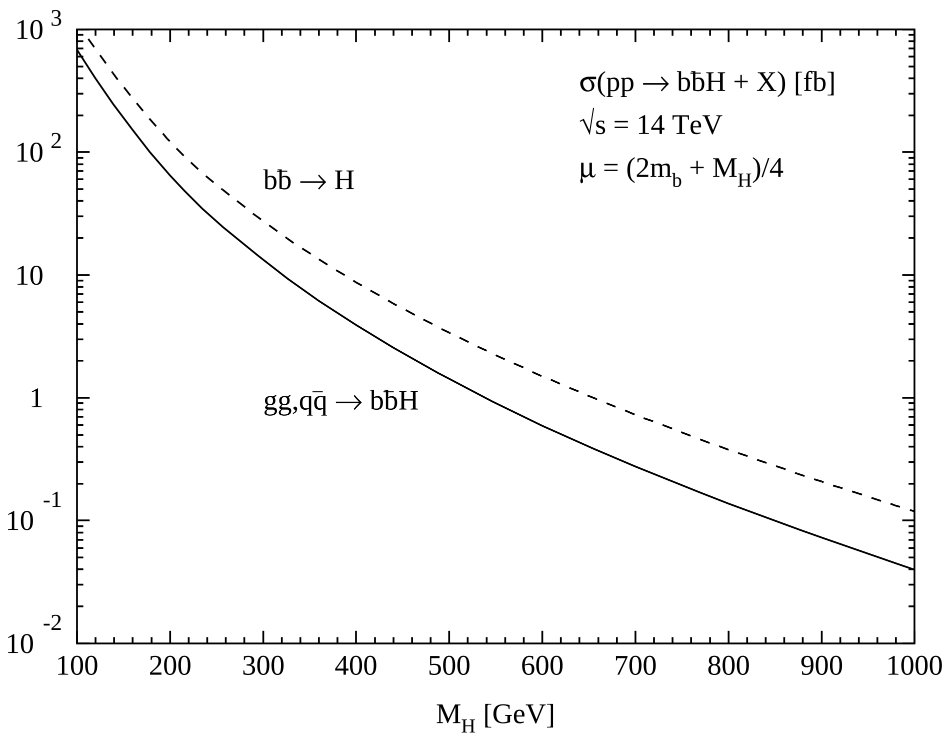




Campbell, Ellis, Maltoni, Willenbrock



$\sim$ factor 3



$\sim$ factor 3

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

$$\frac{d\sigma^{(2\to3)}}{dM_{Tb}^2} = \frac{1}{M_{Tb}^2} \left\{ \frac{\alpha_s}{2\pi} \Delta_{qg} \otimes g \otimes g \otimes \hat{\sigma}_{\bar{b}g} \right\}_{M_{Tb}=m_b\to 0} + \cdots$$

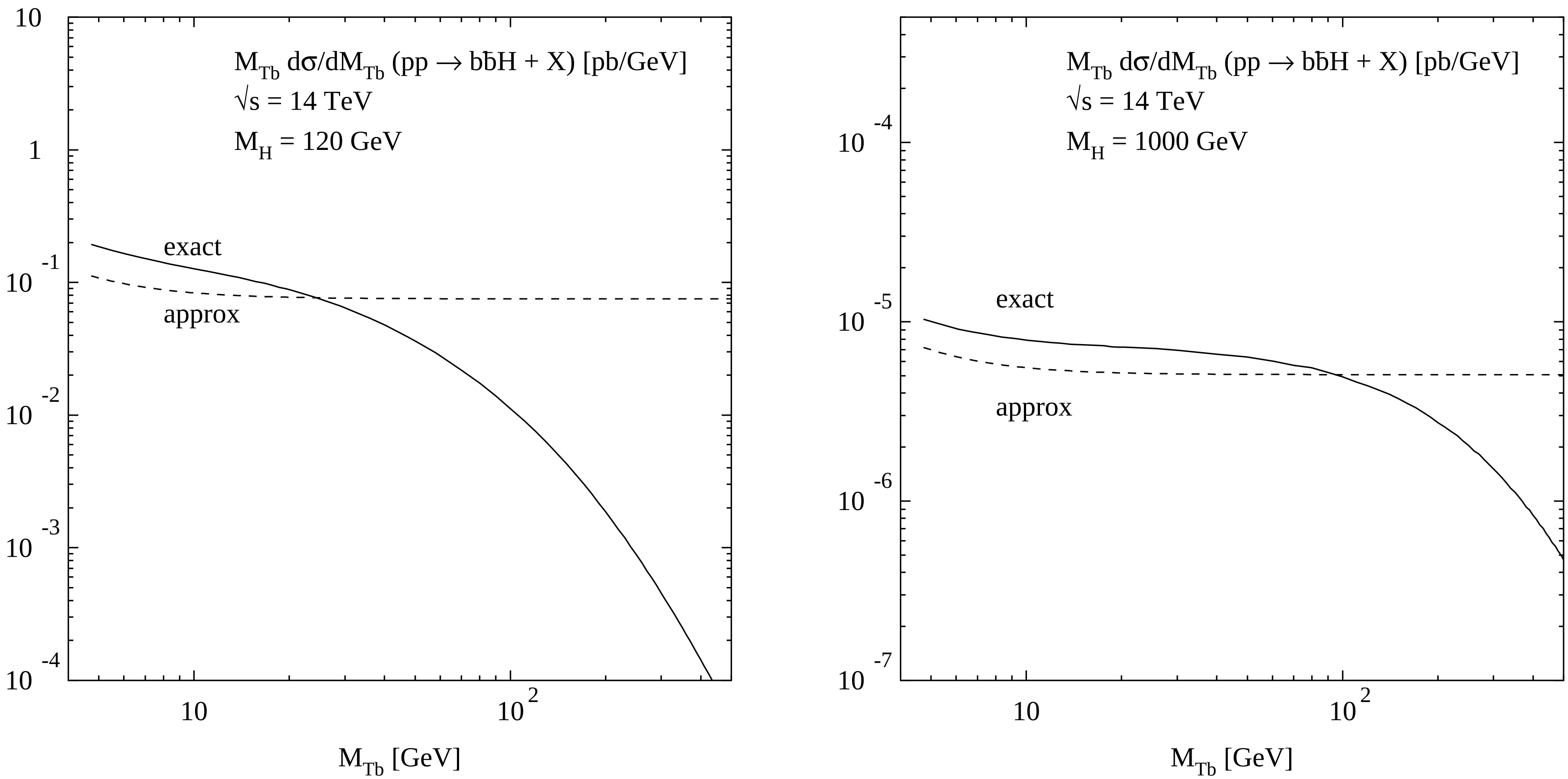
$$\Delta_{qg}(x) = P_{qg}(x) + \frac{m_b^2}{M_{Tb}^2} x(1-x)$$

- total cross section:

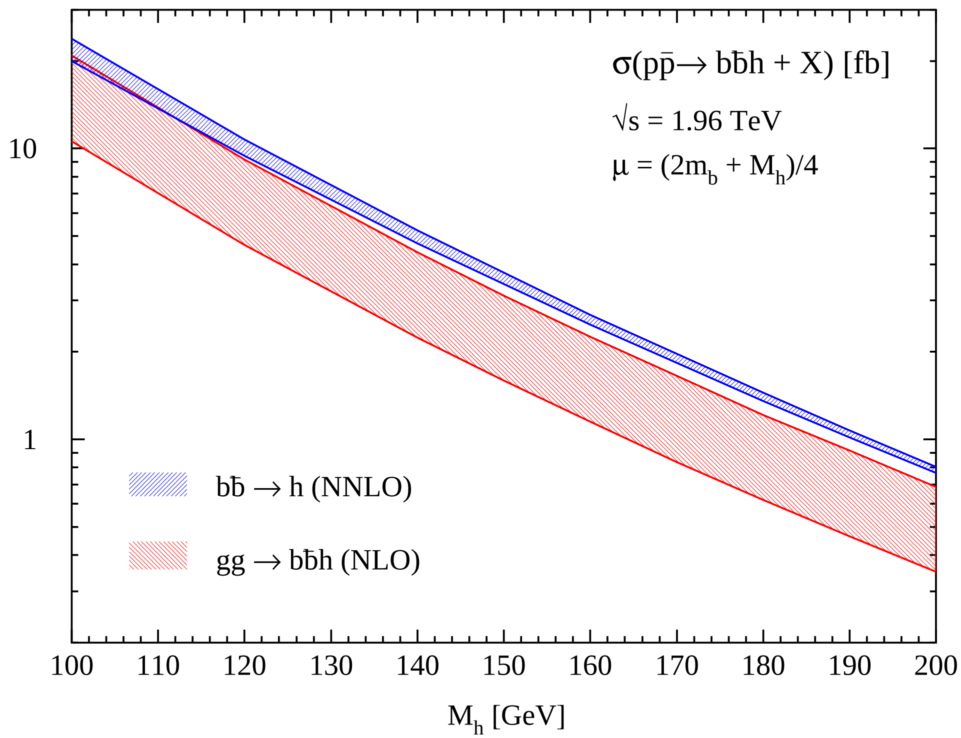
$$\sigma = \underbrace{\int_{m_b^2}^{\mu_F^2} \frac{dM_{Tb}^2}{M_{Tb}^2}}_{\log \frac{\mu_F^2}{m_b^2}} \left\{ \frac{\alpha_s}{2\pi} P_{qg} \otimes g \otimes g \otimes \hat{\sigma}_{\bar{b}g} \right\}_{M_{Tb}=m_b\to 0} + \cdots$$

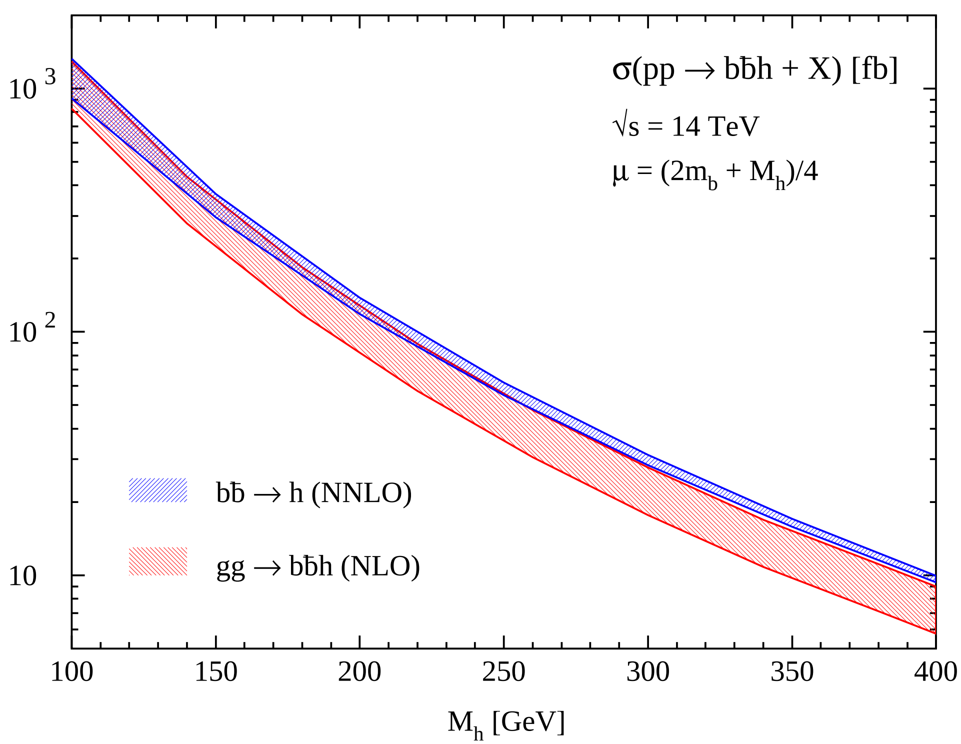
$\Rightarrow$ crucial condition:

$$\frac{d\sigma^{(2\to3)}}{dM_{Tb}} \propto \frac{1}{M_{Tb}} \quad \text{up to } M_{Tb} \sim \mu_F$$

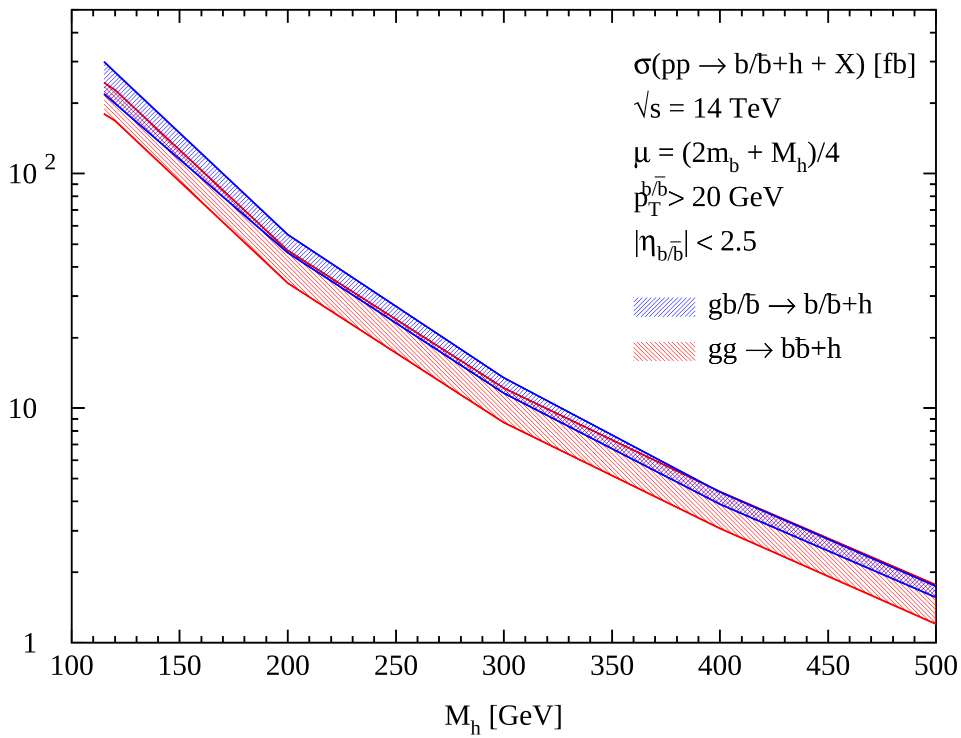


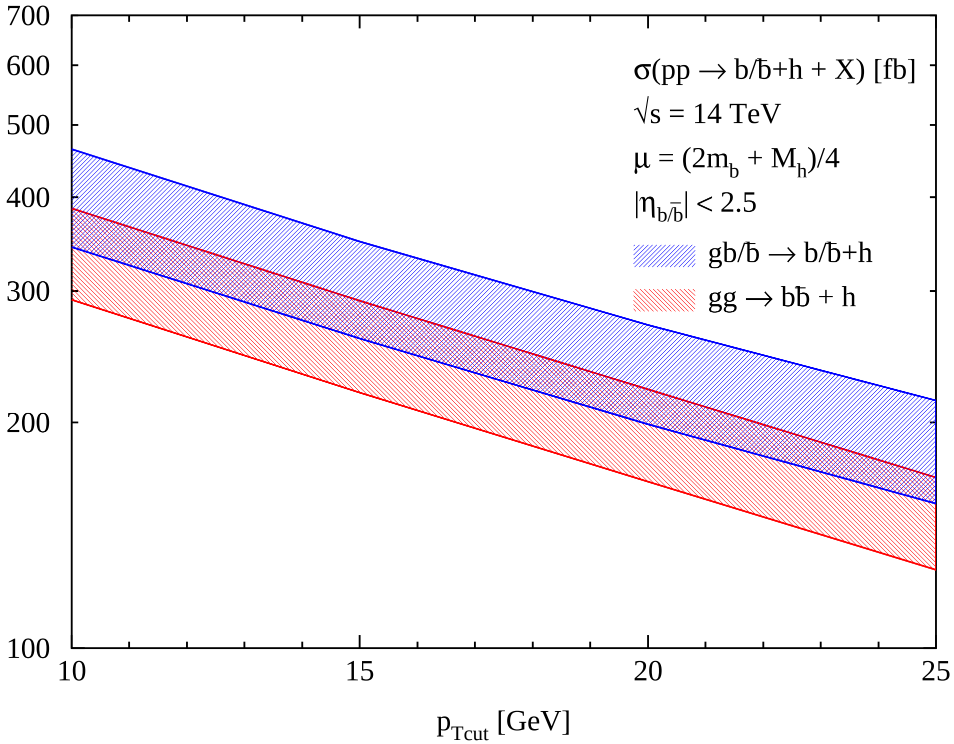
Rainwater, S., Zeppenfeld





Dittmaier, Krämer, S.
Harlander, Kilgore





Campbell, Dawson, Dittmaier, Jackson, Krämer, Maltoni, Reina, S., Wackeroth, Willenbrock