HIGGS PRODUCTION AND PROFILE @ LHC

Michael Spira (PSI)

I Introduction

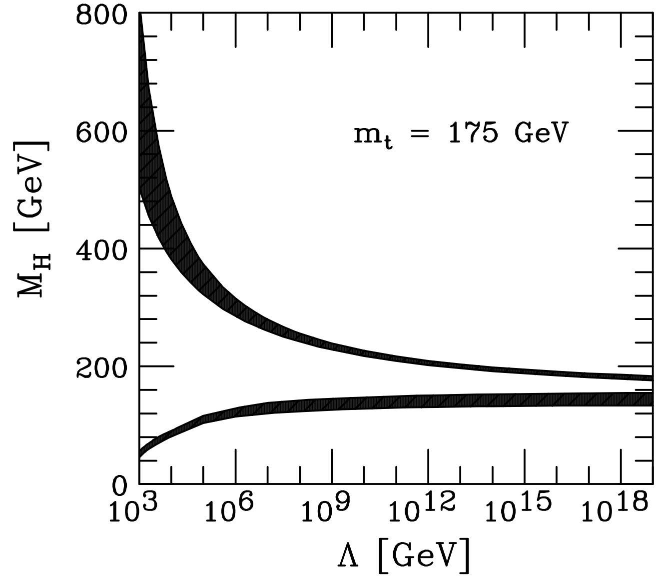
II Higgs Boson Production

III Conclusions

I INTRODUCTION

(i) Standard Model

Hambye, Riesselmann



• LEP2: $M_H > 114.4$ GeV

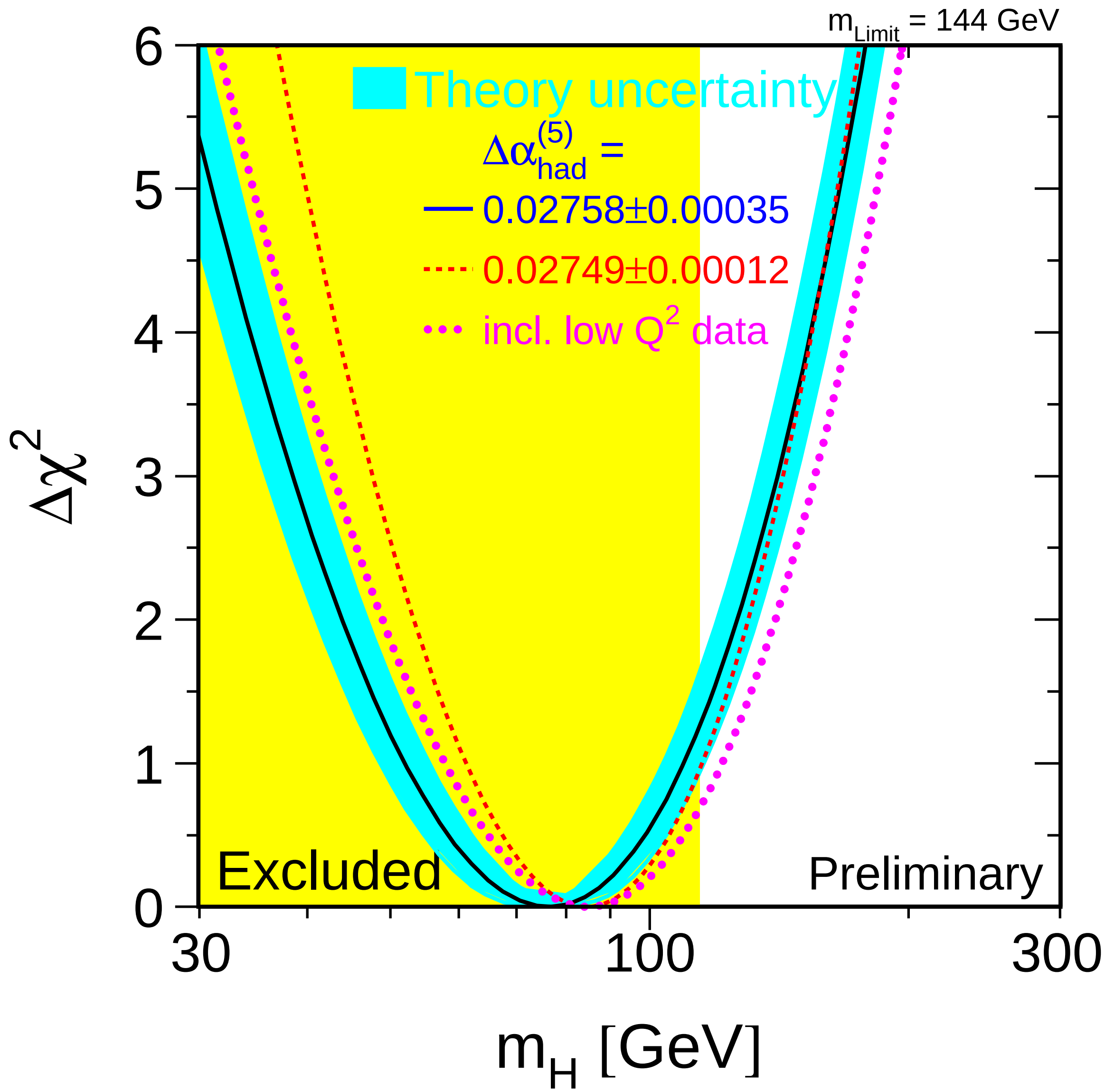
• triviality and vacuum stability:

Cabibbo
Sher
Lindner
Lüscher, Weisz
Hasenfratz,. . .
. . .

$\Rightarrow M_H \lesssim 700$ GeV [$\Lambda \sim 1$ TeV]

130 GeV $\lesssim M_H \lesssim$ 190 GeV [$\Lambda \sim M_{GUT}$]

• electroweak observables: $M_H \lesssim 182$ GeV (95% CL) LEP/SLC/Tevatron



Did you look into the new problem? The plot has to be ready until...yesterday!

$$M_H \quad = \quad 76^{+33}_{-24} \text{ GeV}$$

$$\Rightarrow M_H \quad \lesssim \quad 182 \text{ GeV (95\% CL)}$$

LEP/SLC/Tevatron

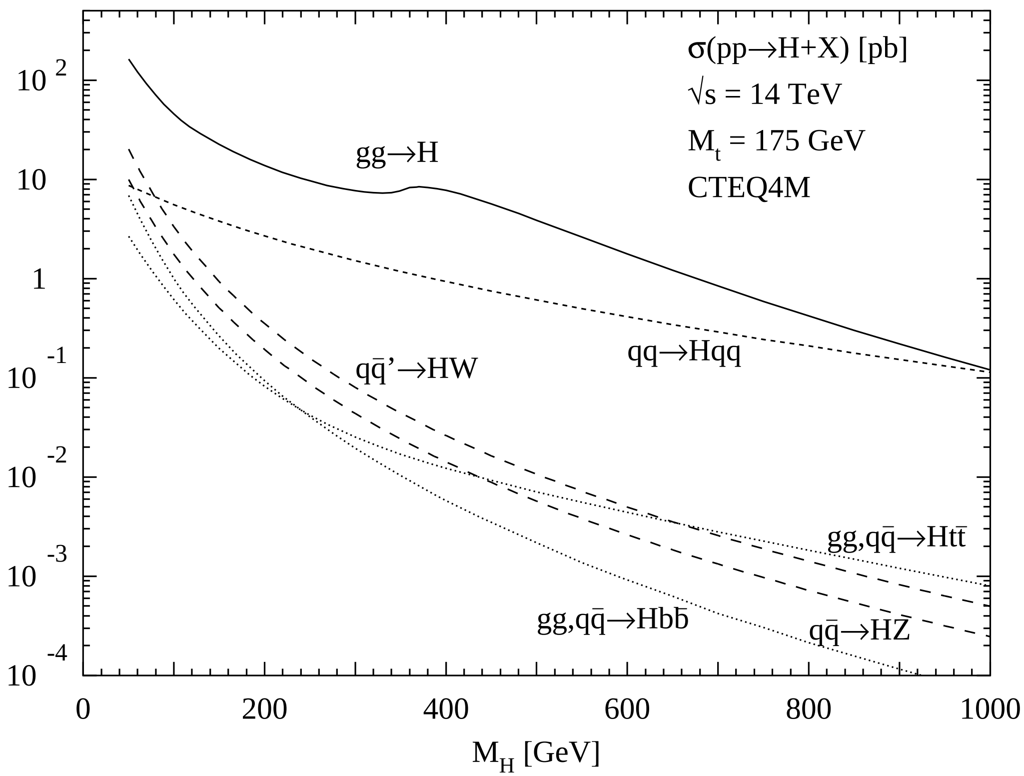
• LHC: $gg \to H$ dominant

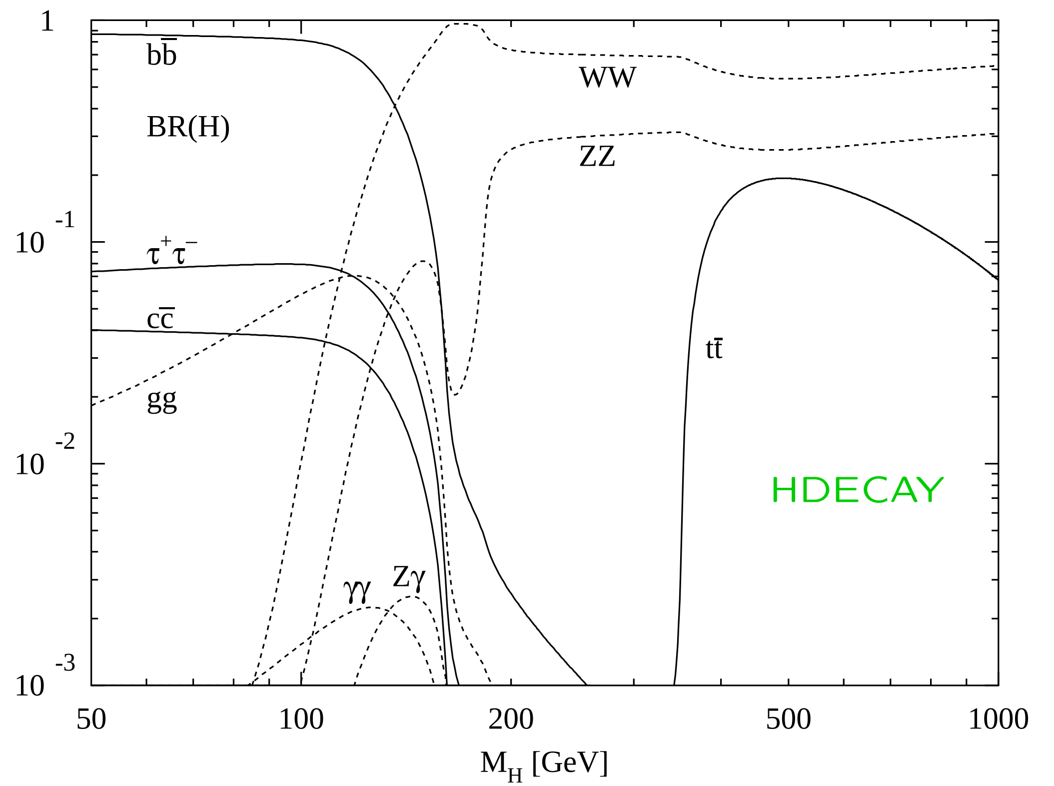
$M_H \lesssim 140$ GeV: $H \to \gamma\gamma, (b\bar{b})$ F

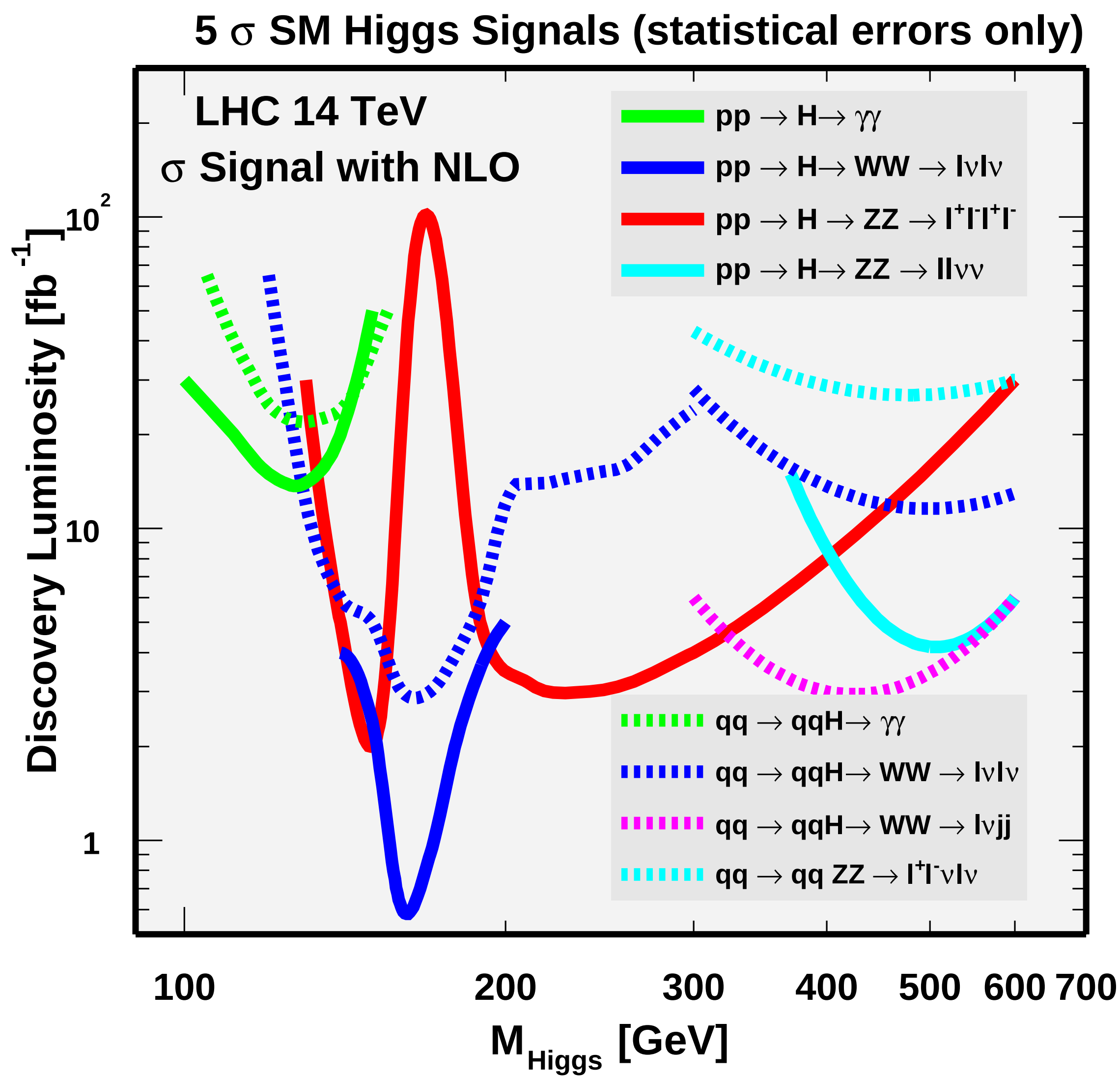
140 GeV $\lesssim M_H \lesssim$ 1 TeV: $H \to ZZ^{(*)} \to 4\ell^{\pm}$
$H \to WW, ZZ \to \ell's, jets$

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

Dittmar, Dreiner







5 σ SM Higgs Signals (statistical errors only)
LHC 14 TeV
σ Signal with NLO
pp → H→ γγ
pp → H→ WW → lνlν
pp → H → ZZ → l+l-l+l-
pp → H→ ZZ → llνν
qq → qqH→ γγ
qq → qqH→ WW → lνlν
qq → qqH→ WW → lνjj
qq → qq ZZ → l+l-νlν
Discovery Luminosity [fb -1]
10^2
10
1
100
200
300
400
500
600
700
M Higgs [GeV]

CMS

(ii) MSSM

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

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

- large radiative corrections:

$$\epsilon = \frac{3G_F}{\sqrt{2}\pi^2} \frac{m_t^4}{s_\beta^2} \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}$$

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

Haber, Hempfling
Carena,. . .
Heinemeyer,. . .
Zhang
etc.

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

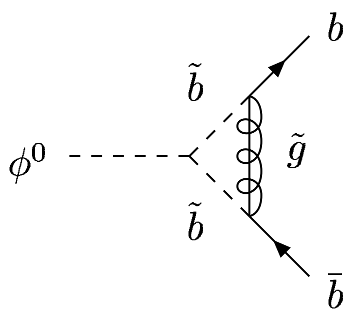
- LEP2: $M_{h/H} \gtrsim$ 91 GeV, $M_A \gtrsim$ 91.9 GeV, $M_{H^\pm} \gtrsim$ 78.6 GeV

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

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

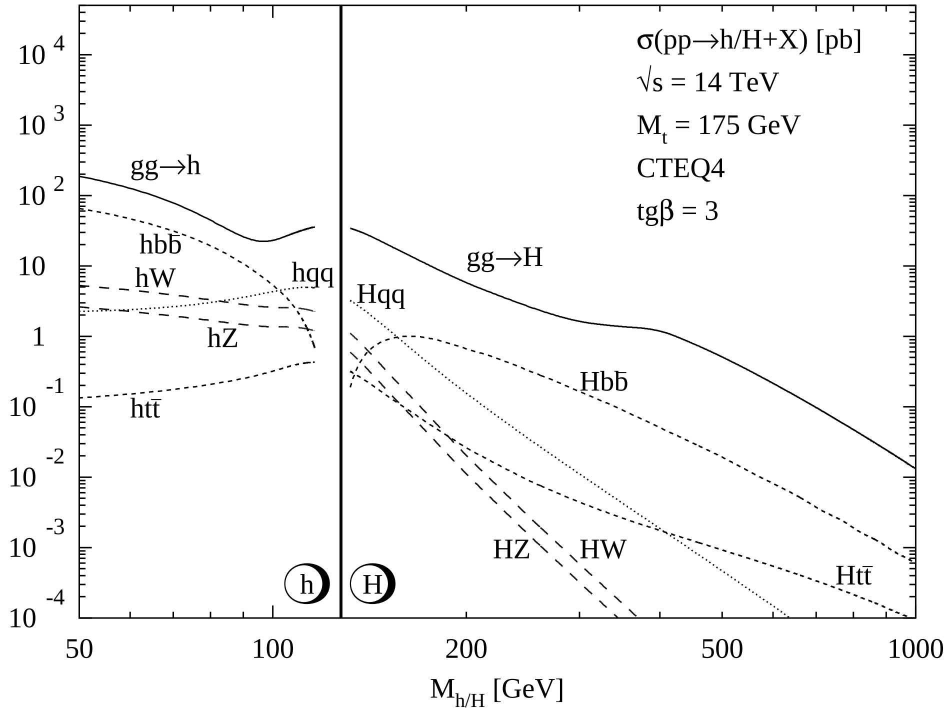
<u>and</u> $VV \to h, H \to \tau^+\tau^-$ Plehn, Rainwater, Zeppenfeld

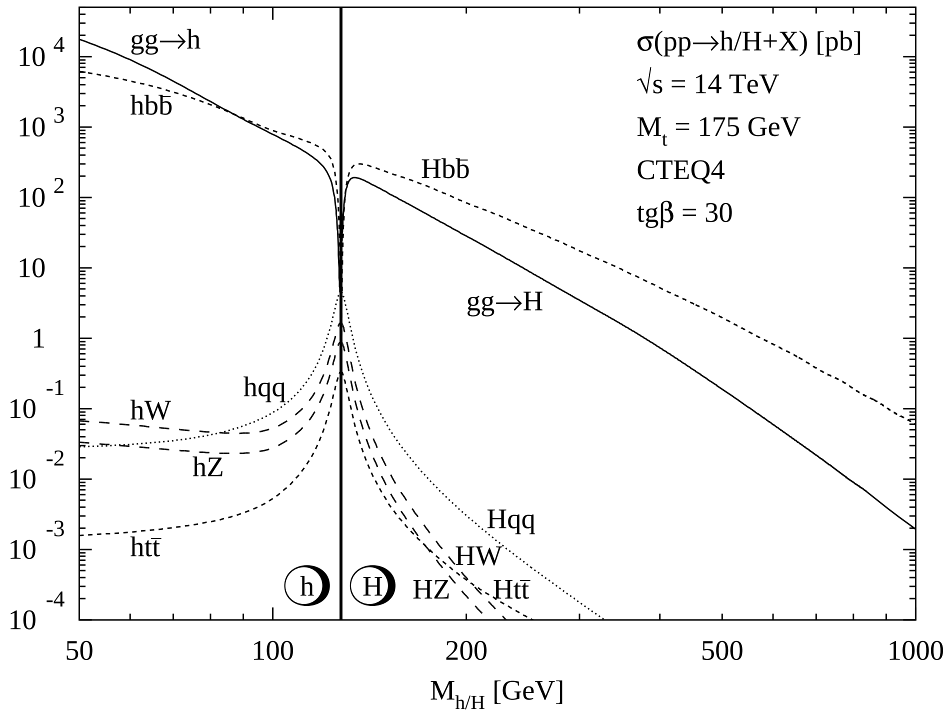
- large tgβ: large MSSM corrections



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

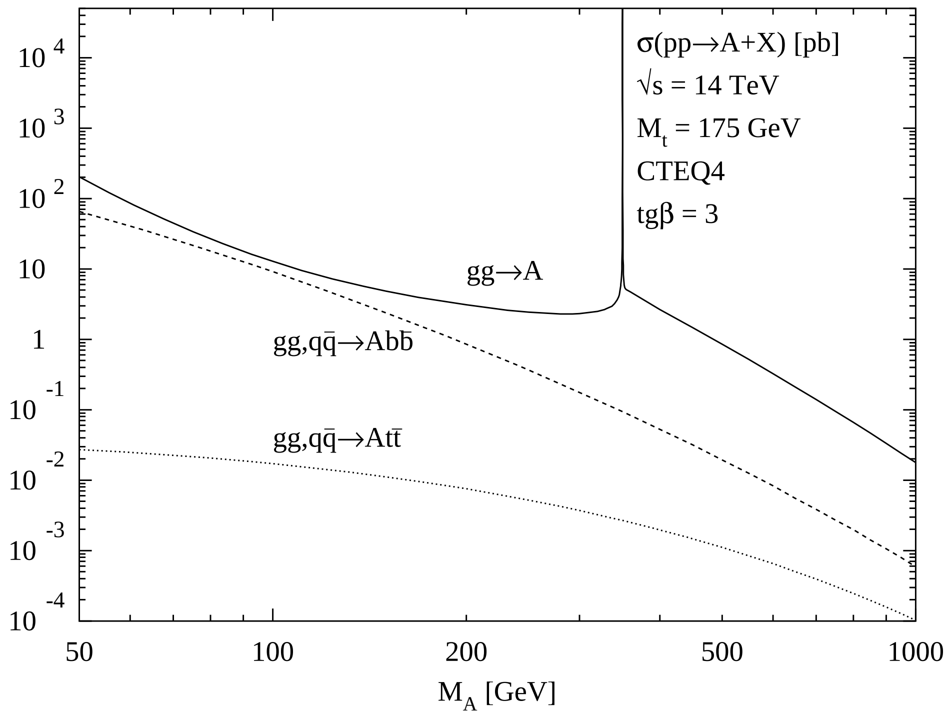
Hall,. . .
Carena,. . .
Häfliger,. . .
. . .

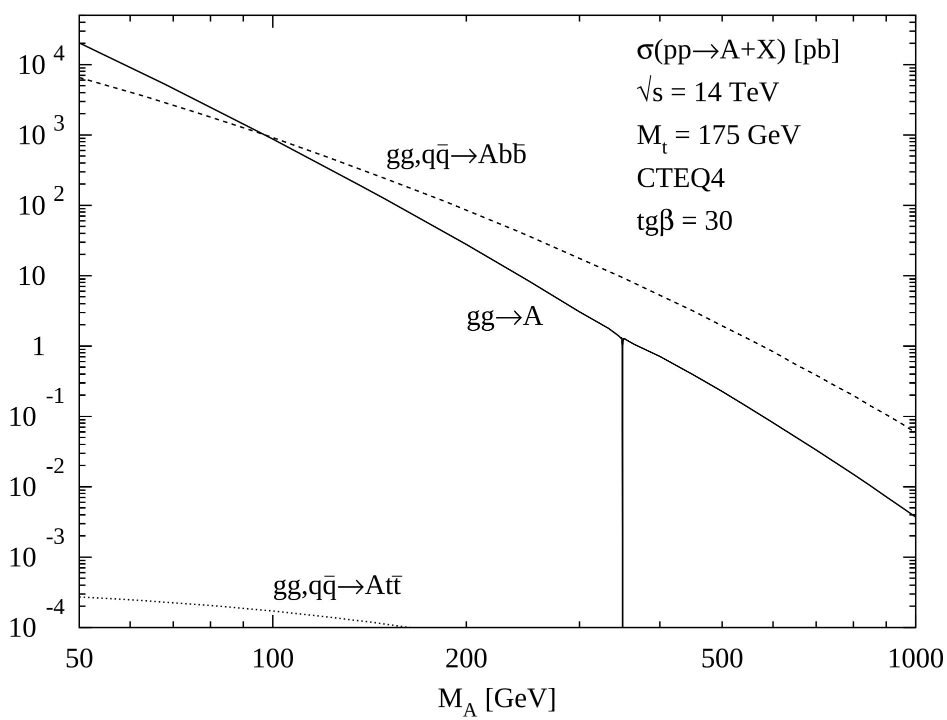


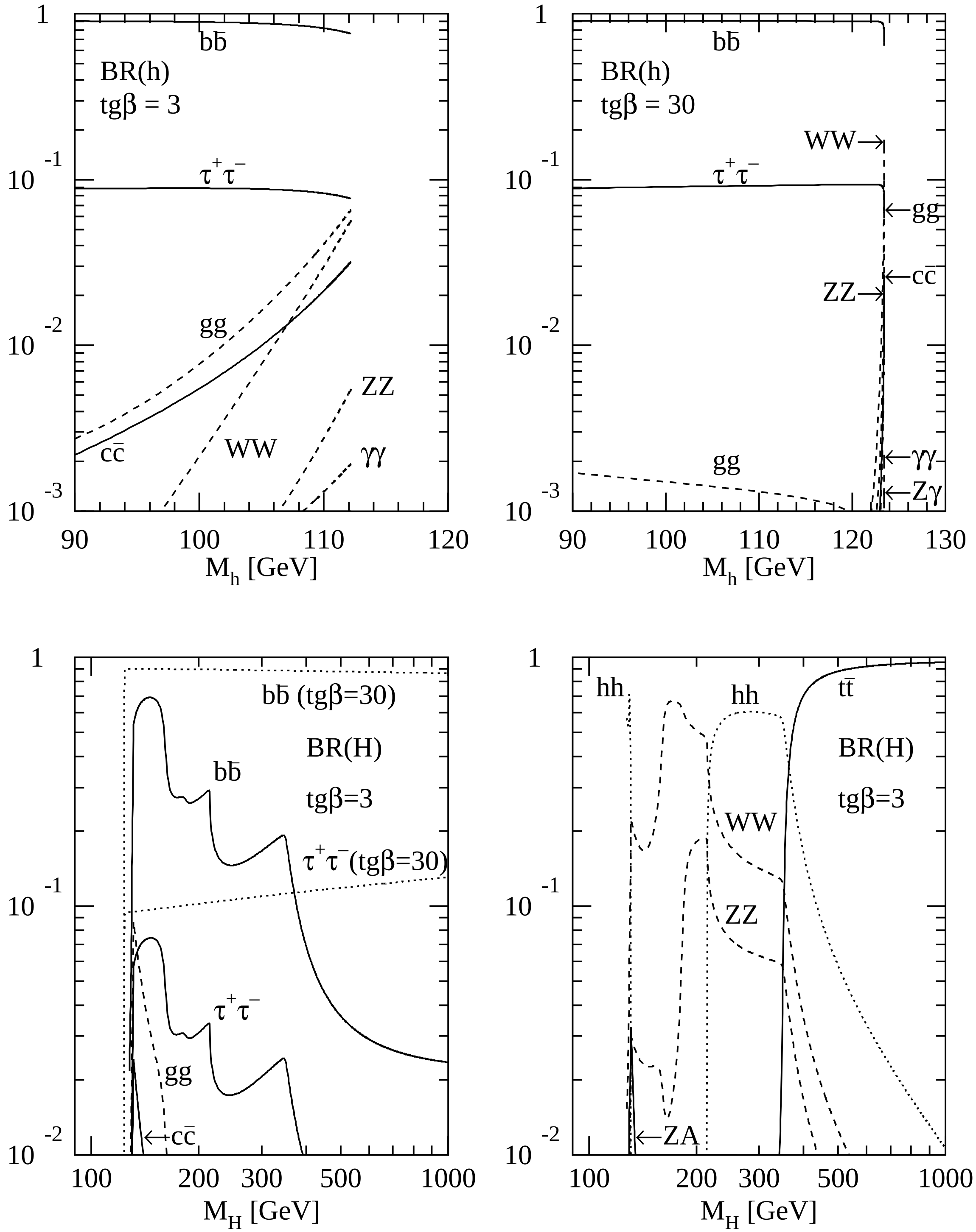


You want to make holidays???

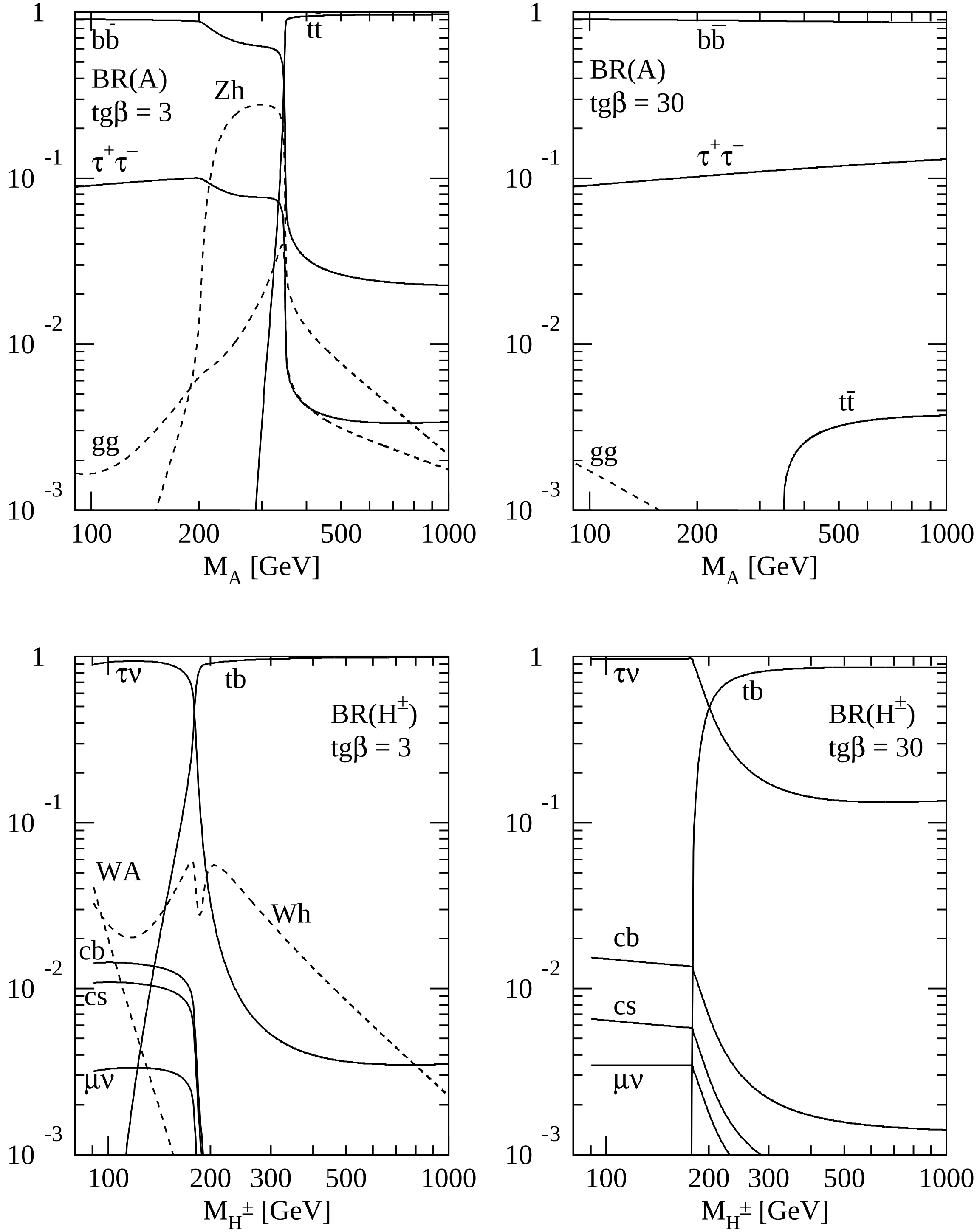
I didn't make holidays since 15 years...


σ(pp→A+X) [pb]
√s = 14 TeV
M_t = 175 GeV
CTEQ4
tgβ = 3
gg→A
gg,qq̄→Abb̄
gg,qq̄→Att̄
M_A [GeV]

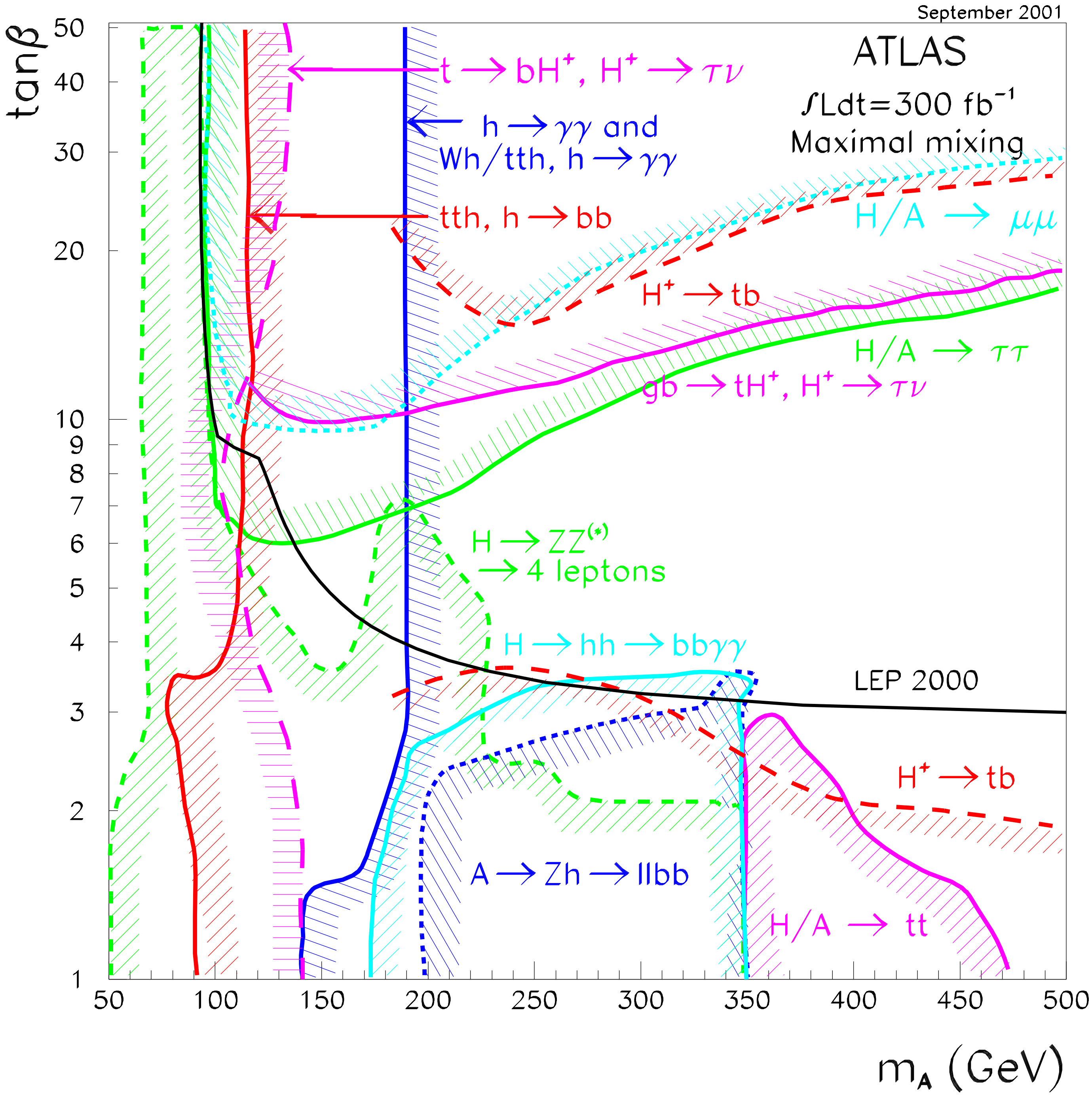

σ(pp→A+X) [pb]
√s = 14 TeV
M_t = 175 GeV
CTEQ4
tgβ = 30
gg,qq̄→Abb̄
gg→A
gg,qq̄→Att̄
M_A [GeV]


BR(h)
tgβ = 3
bb̄
τ+τ−
gg
cc̄
WW
ZZ
γγ
M_h [GeV]
BR(h)
tgβ = 30
bb̄
WW
τ+τ−
gg
cc̄
ZZ
γγ
Zγ
M_h [GeV]
bb̄ (tgβ=30)
BR(H)
tgβ=3
bb̄
τ+τ−(tgβ=30)
τ+τ−
gg
cc̄
M_H [GeV]
hh
hh
tt̄
BR(H)
tgβ=3
WW
ZZ
ZA
M_H [GeV]

HDECAY

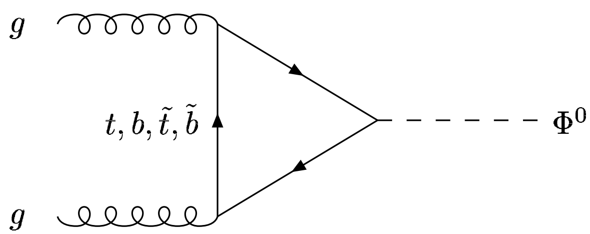

BR(A)
tgβ = 3
bb̄
tt̄
Zh
τ⁺τ⁻
gg
M_A [GeV]
BR(A)
tgβ = 30
bb̄
τ⁺τ⁻
tt̄
gg
M_A [GeV]
BR(H±)
tgβ = 3
τν
tb
WA
Wh
cb
cs
μν
M_H± [GeV]
BR(H±)
tgβ = 30
τν
tb
cb
cs
μν
M_H± [GeV]

HDECAY


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
m$_A$ (GeV)

II *HIGGS BOSON PRODUCTION*

(i) Gluon fusion: $pp \to gg \to \phi^0$



Georgi,. . .

Gamberini,. . .

- third generation dominant [$\tilde{t}, \tilde{b}$: $m_{\tilde{q}} \lesssim$ 400 GeV]

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

F S., Djouadi, Graudenz, Zerwas
Dawson, Kauffman

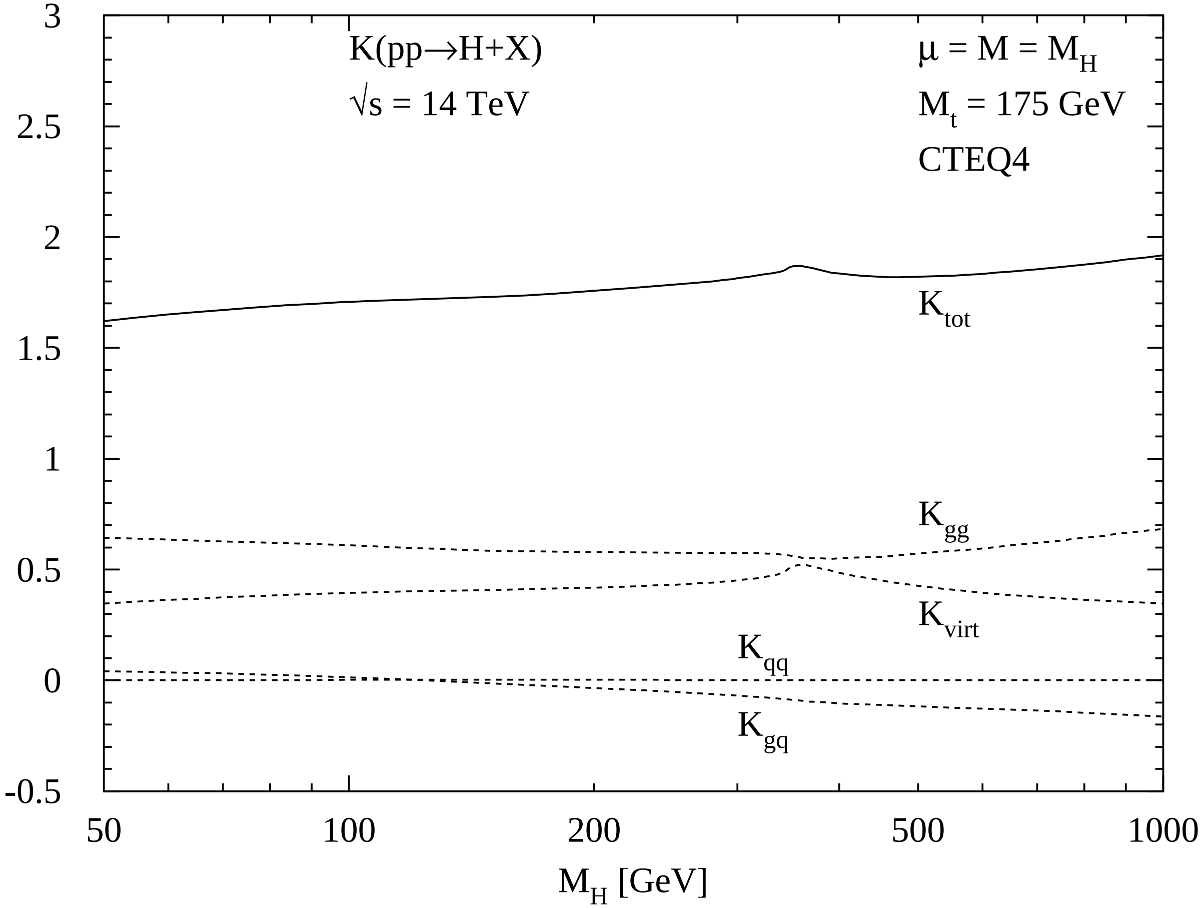
- SM, tg$\beta \lesssim 5$: limit $m_t \gg M_\phi$ approximation for K-factor [$\Delta \lesssim 25\%$]

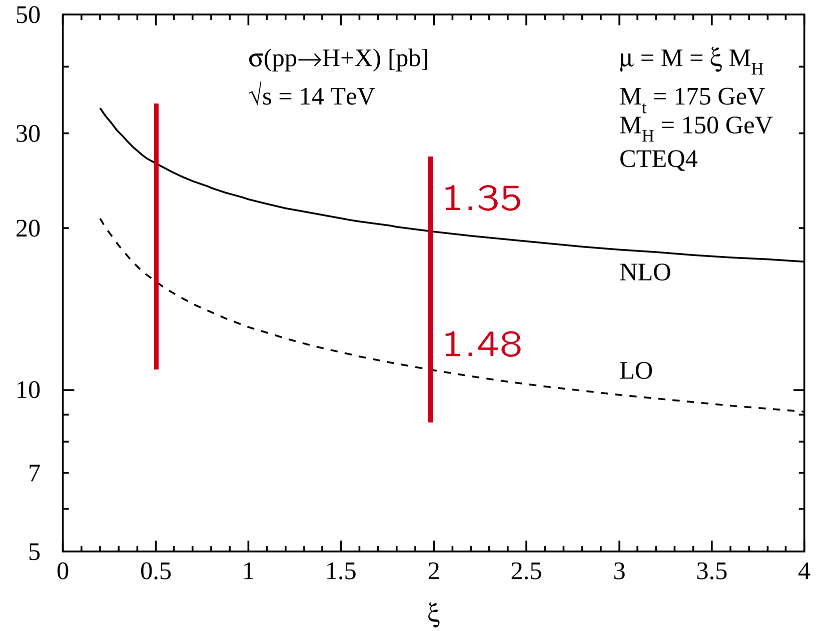
- NNLO calculated for $m_t \gg M_\phi$
$\Rightarrow$ further increase by 20–30%
scale dependence: $\Delta \lesssim 10 - 15\%$

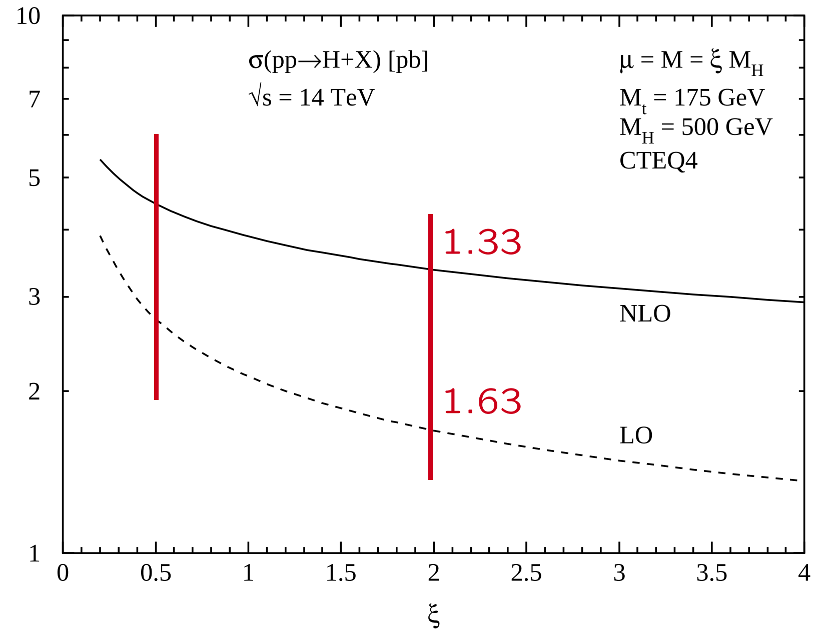
F Harlander, Kilgore
Anastasiou, Melnikov
Ravindran, Smith, van Neerven

- soft gluon resummation: $\sim 10\%$

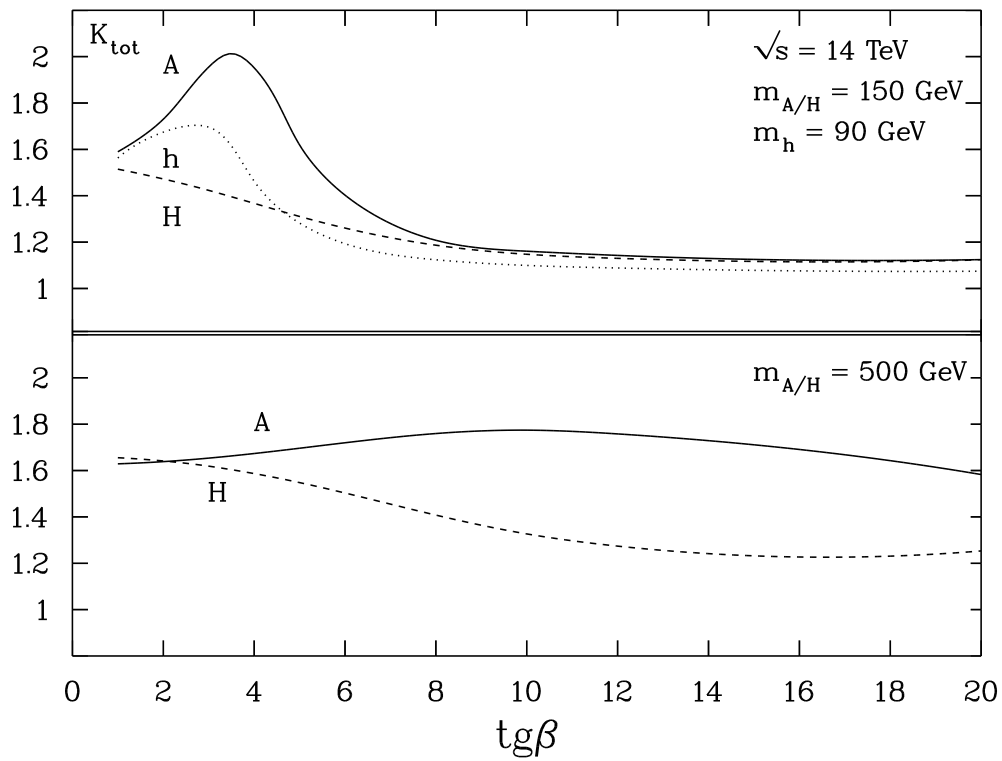
F Catani, de Florian, Grazzini, Nason

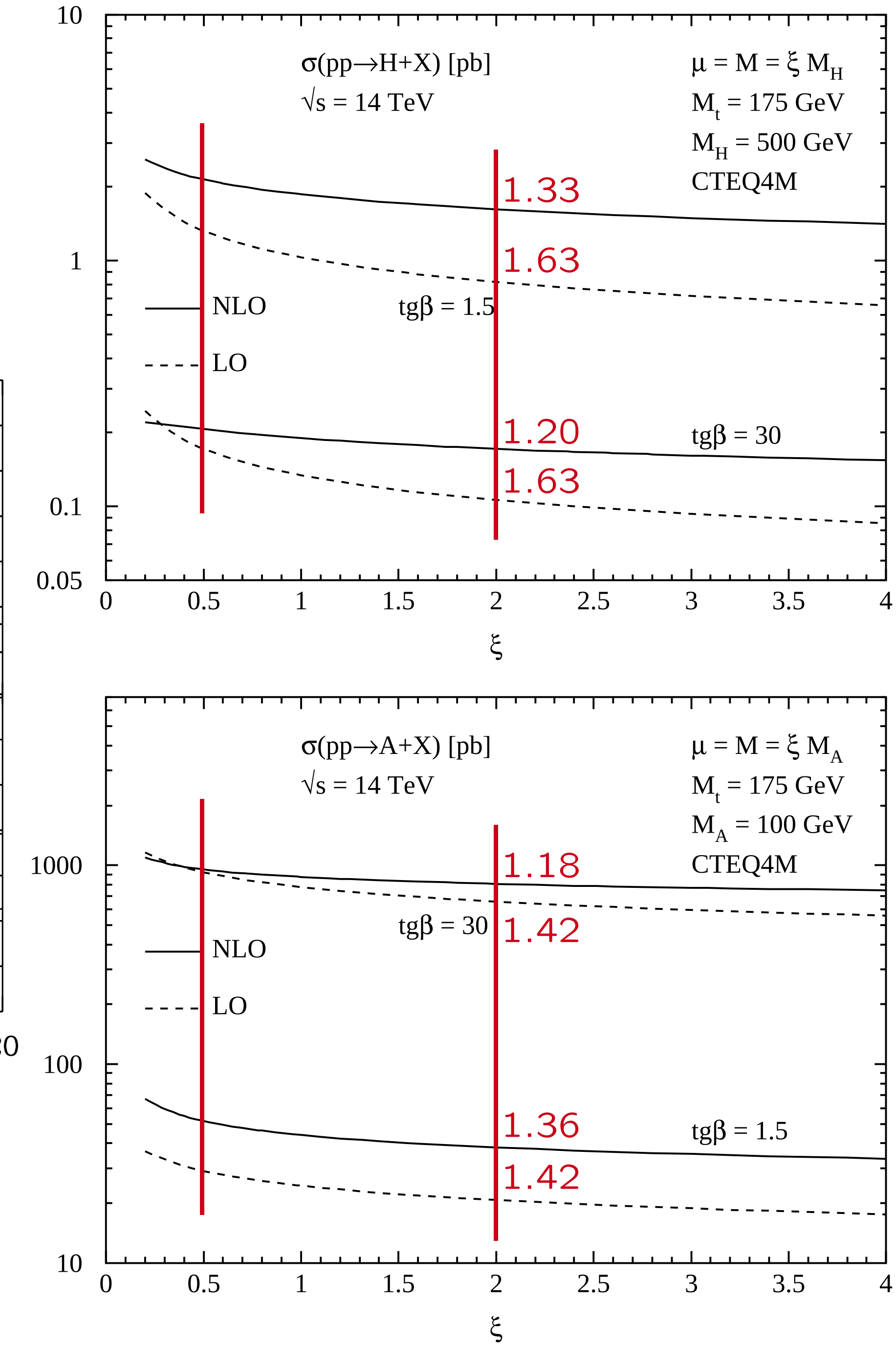




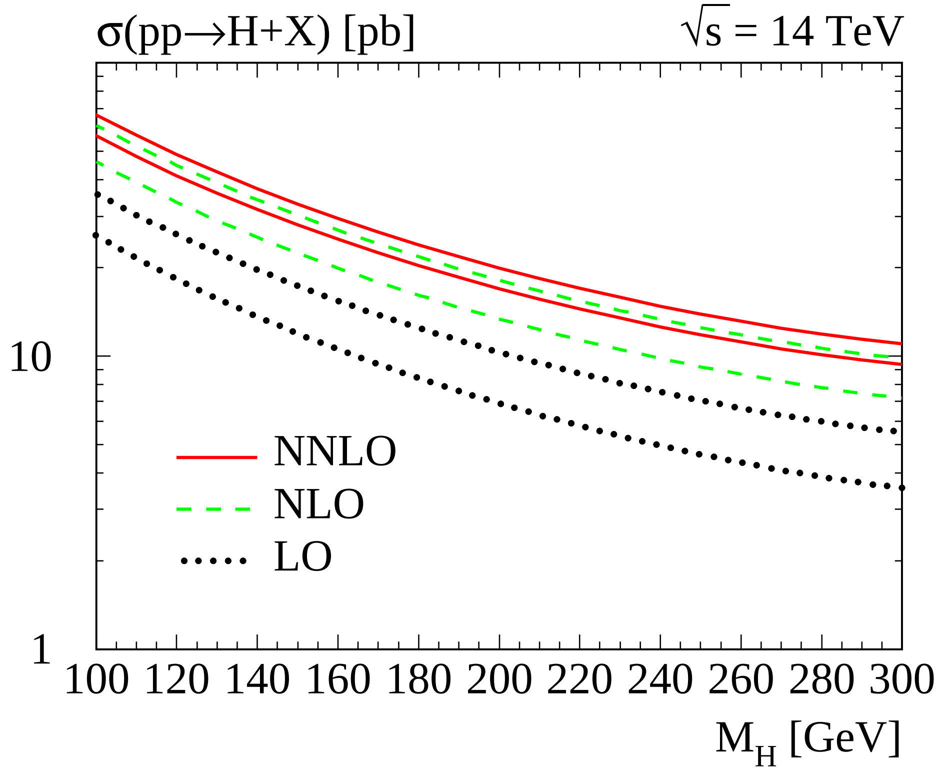


S., Djouadi, Graudenz, Zerwas

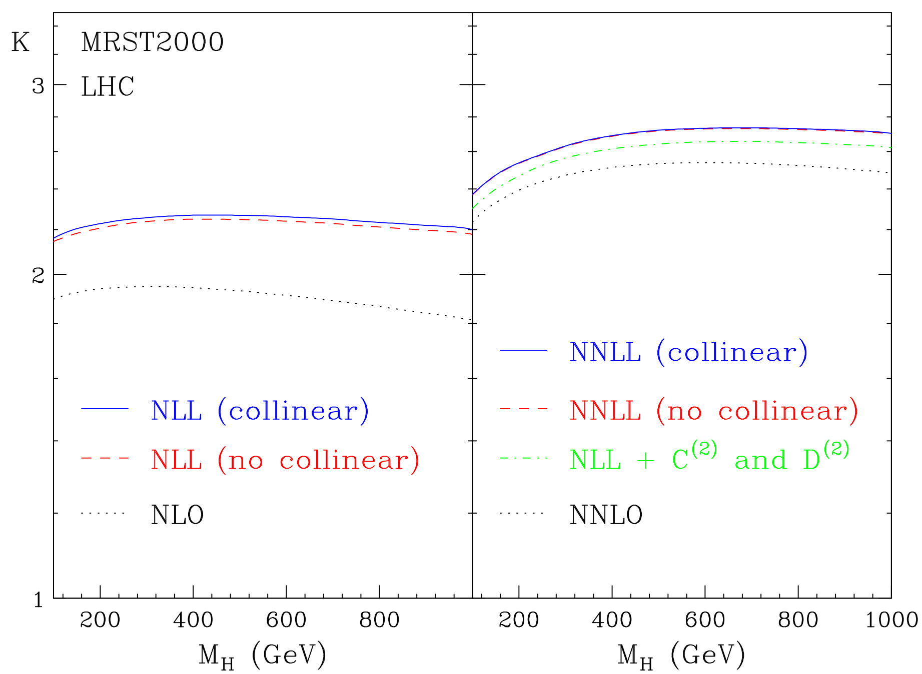




S., Djouadi, Graudenz, Zerwas



Harlander, Kilgore



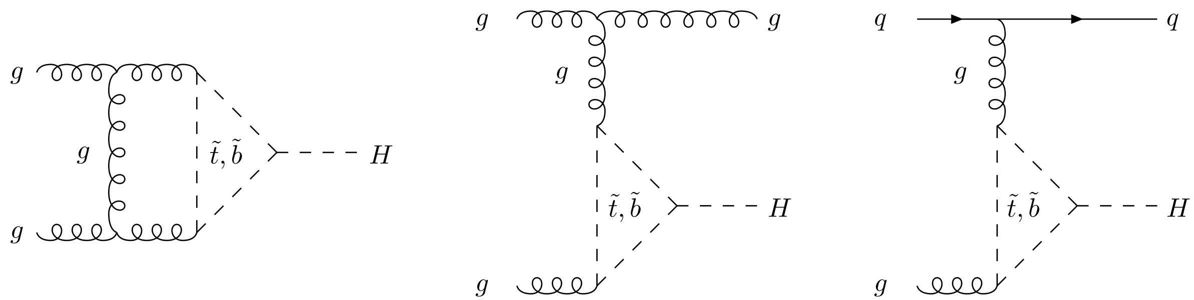
Catani, de Florian, Grazzini, Nason

• SUSY–QCD corrections [gluino-squark-quark loops]: $\sim 5\%$

Harlander, Steinhauser, Hofmann

• QCD corrections to squark loops:

decouple gluino contributions as first step $\longleftarrow$ adjust renormalization

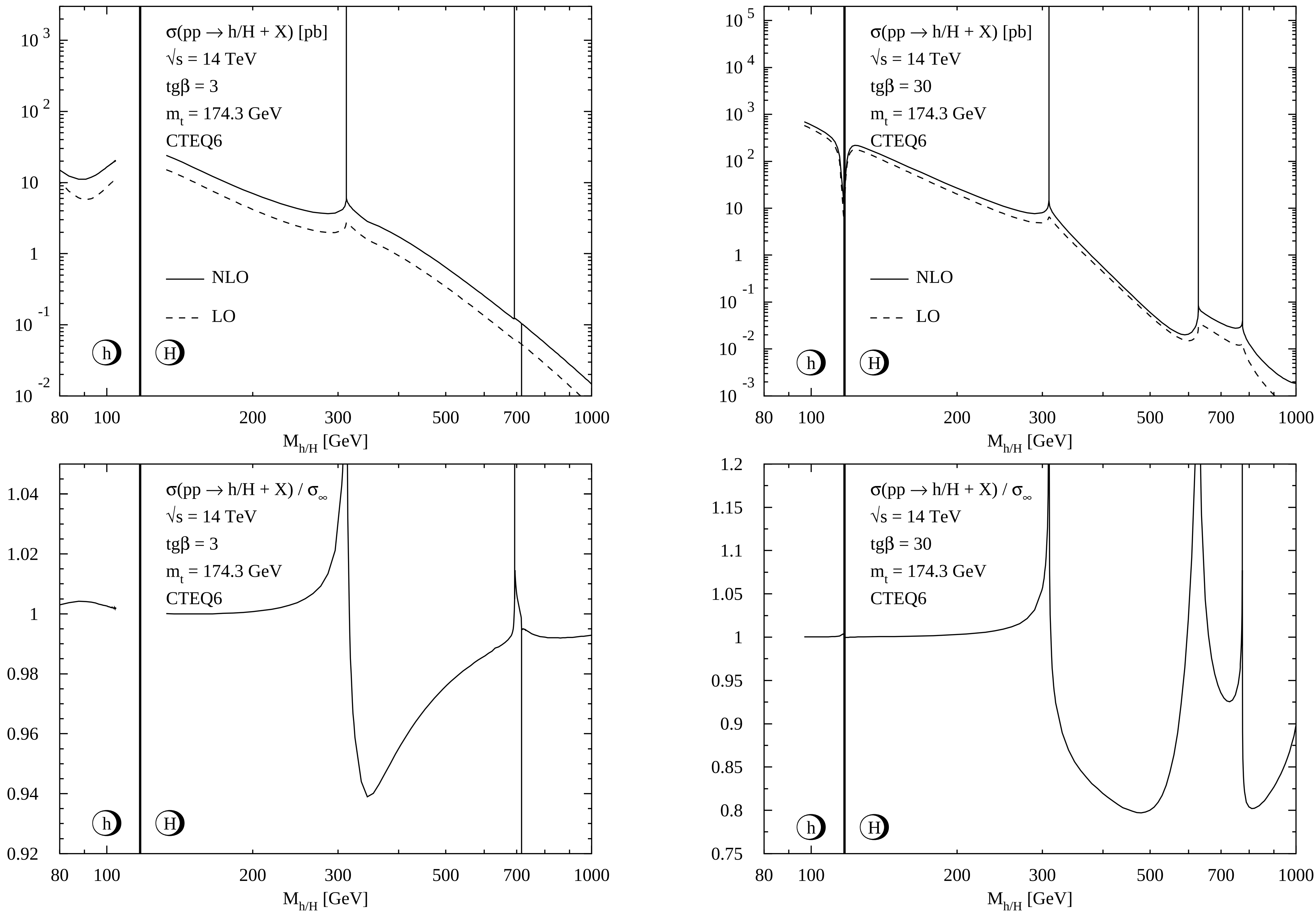


heavy squark limit: effective Lagrangian Dawson, Djouadi, S.

$\longleftarrow$ recovered in massive calculation

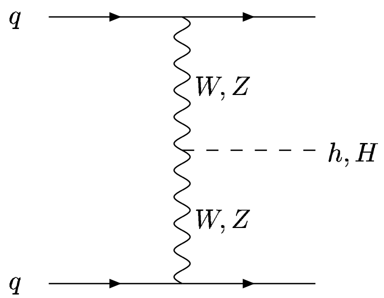
Coulomb singularities at $\tilde{q}\bar{\tilde{q}}$ thresholds $\longrightarrow$ spikes

[$\longleftarrow$ agree with derivation from Sommerfeld factor]



Mühlleitner, S.

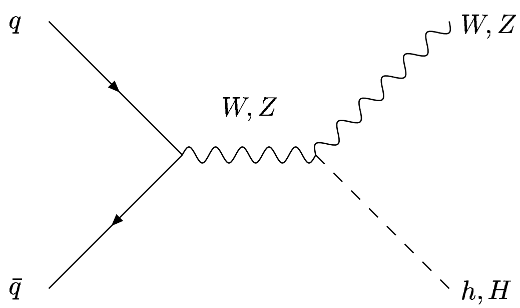
(ii) W/Z fusion: $pp \to W^*W^*/Z^*Z^* \to h/H$



Cahn, Dawson
Hikasa
Atarelli, Mele, Pitolli

- $VV \to h, H \to \tau^+\tau^-$ important @ LHC — Plehn, Rainwater, Zeppenfeld
- QCD corrections $\leftarrow$ DIS: $\sim 10\%$ for σ — Han, Valencia, Willenbrock
  $\lesssim 20\%$ for $d\sigma$ — Figy, Oleari, Zeppenfeld F

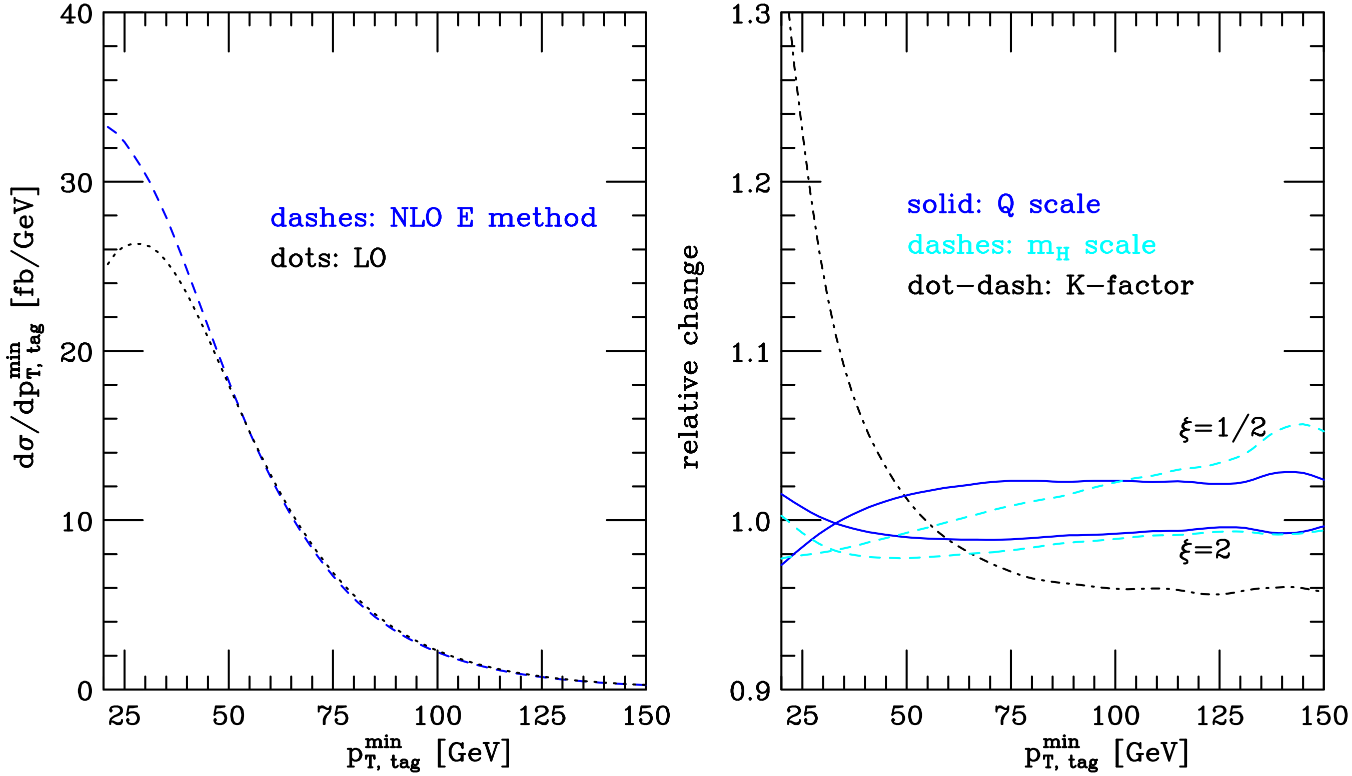
(iii) Higgs–strahlung: $pp \to W^*/Z^* \to W/Z + h/H$



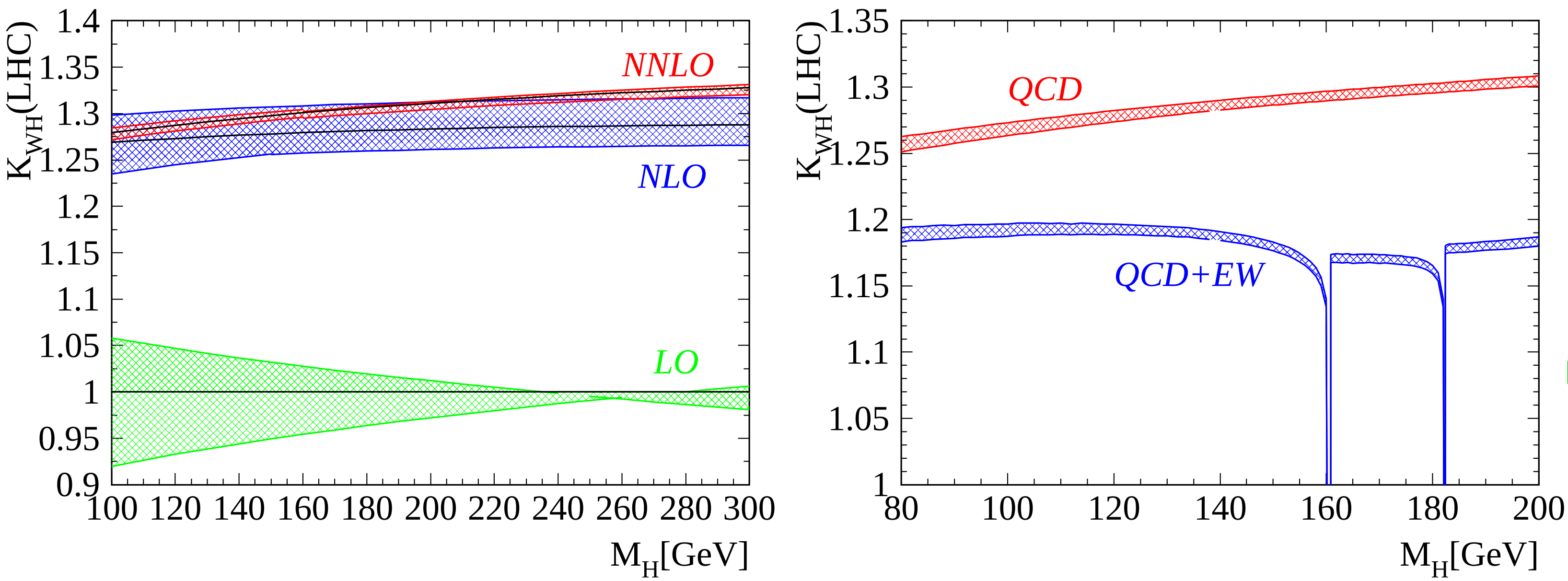
Glashow,. . .
Kunszt,. . .

- QCD corrections $\leftarrow$ DY: $\sim 30\%$ — Han, Willenbrock
  2–loop: $\lesssim 5\%$ — Brein, Djouadi, Harlander F

- electroweak corrections: $\sim -10\%$ — Ciccolini, Dittmaier, Krämer

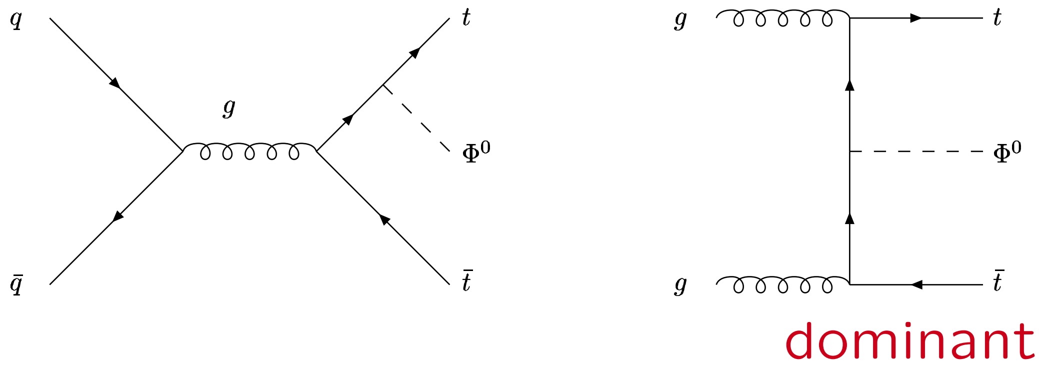


Figy, Oleari, Zeppenfeld



Brein, Ciccolini,
Dittmaier, Djouadi,
Harlander, Krämer

(iv) Bremsstrahlung: $pp \to t\bar{t} + \phi^0$



Kunszt
Gunion
Marciano, Paige

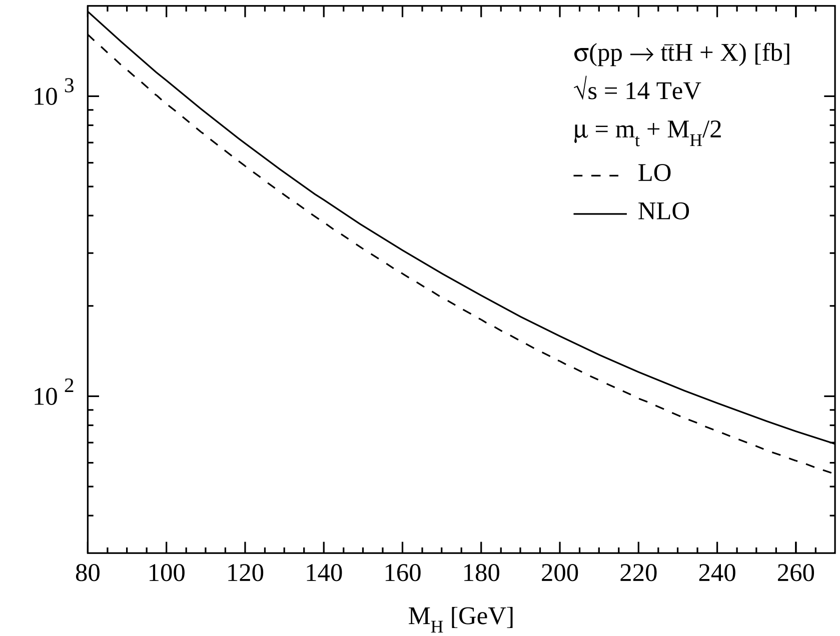
- $t\bar{t}h \to t\bar{t}b\bar{b}$ important @ LHC

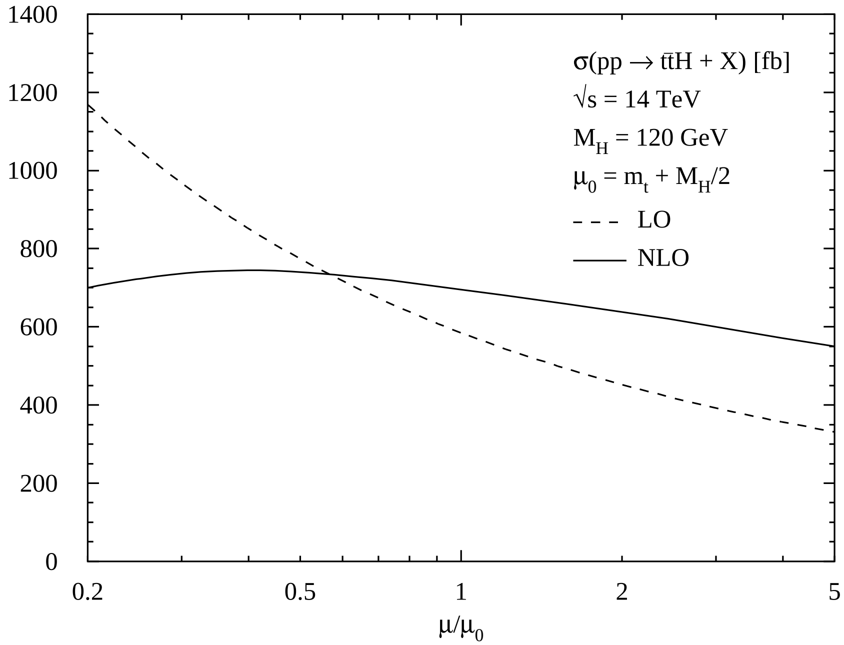
- possibility to measure top Yukawa cplg.

Gunion,. . .
Drollinger,. . .

- QCD corrections [SM]: $\sim 20\%$

Beenakker,. . .
Dawson, . . .

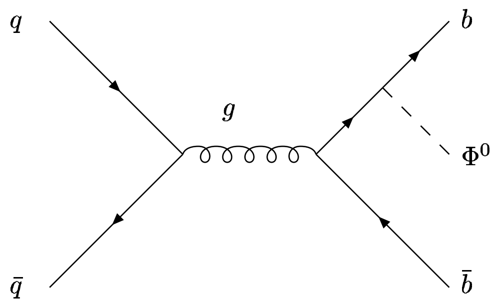


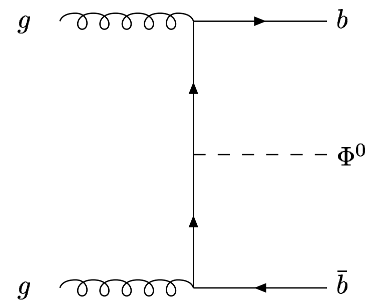


We have seminars on Monday, Tuesday, Thursday and Friday evening. A good idea would be to add another one on Wednesday evening... What? Home? Family???

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

(v) Bremsstrahlung: $pp \to b\bar{b} + \phi^0$





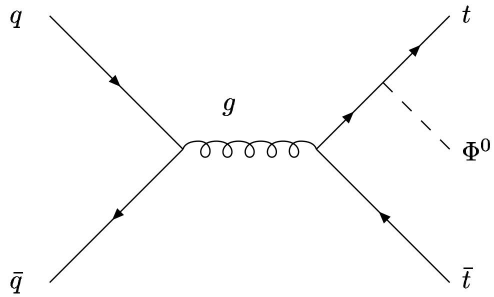
dominant

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

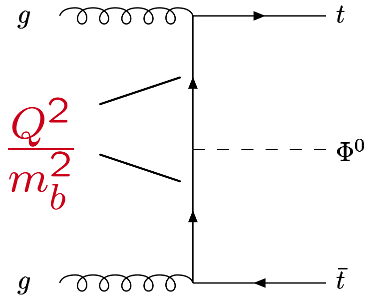
- measurement of tgβ

- QCD corrections large: $\lesssim$ 100%

b densities



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



dominant

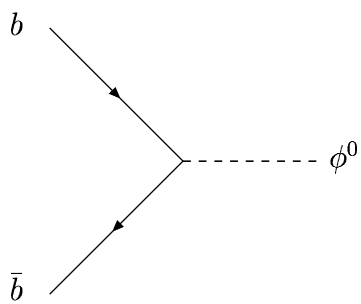
Your family??? My ranking is

1. physics
2. physics
3. physics
4. family

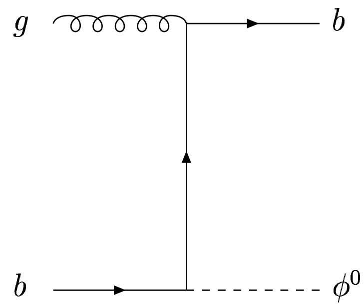
large logs from phase space integration $\longrightarrow$ bottom PDF

resummation $\equiv$ DGLAP evolution

- new processes:



NNLO



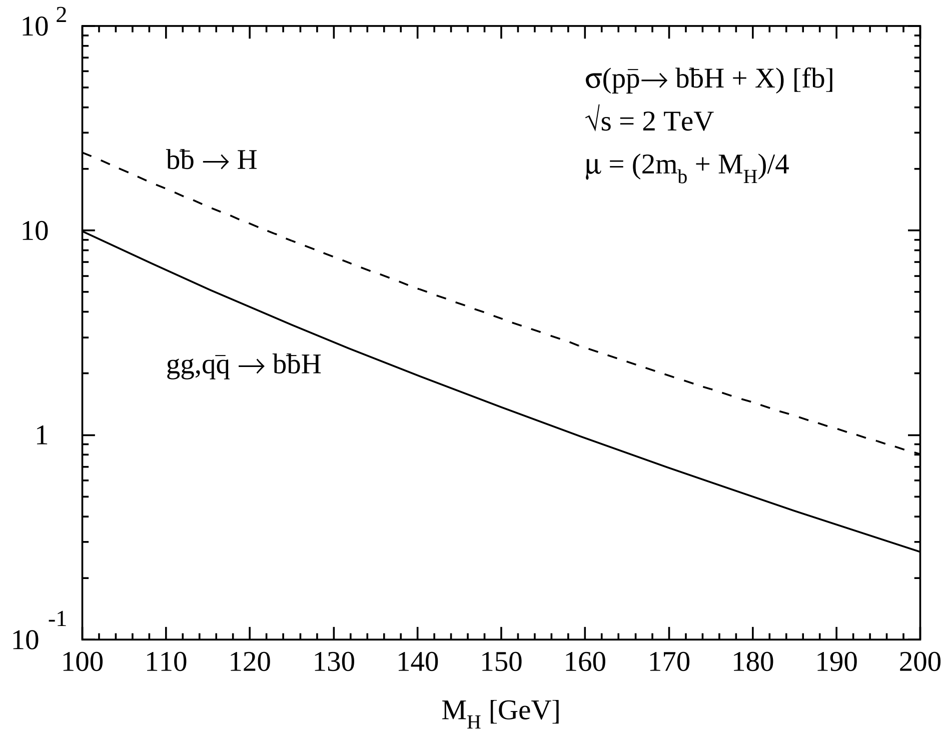
NLO

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

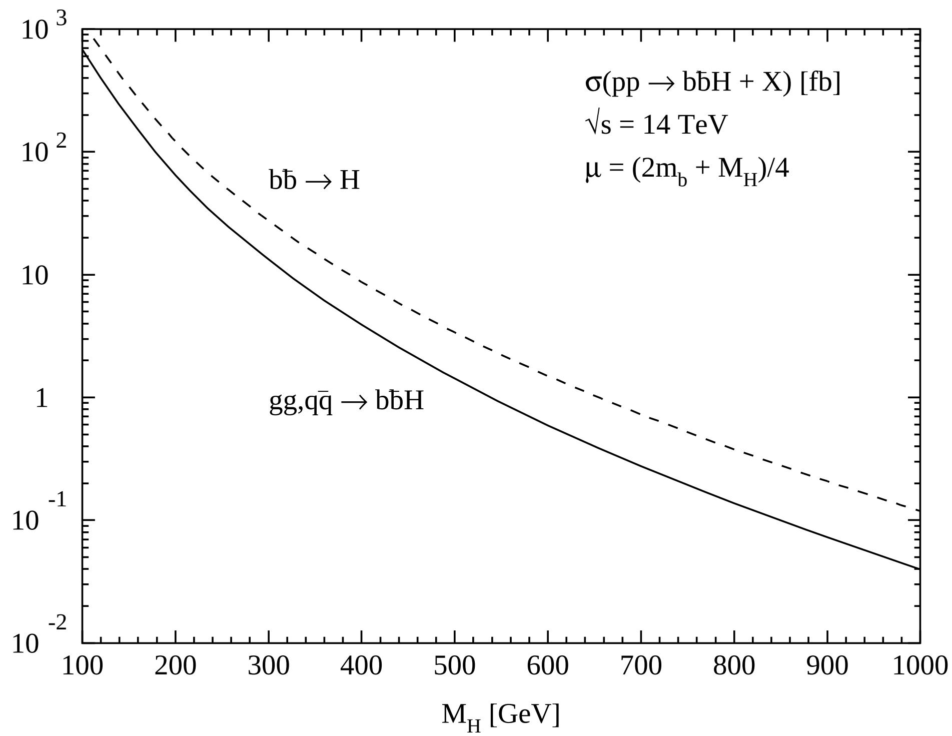
Harlander, Kilgore

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

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



$\sim$ factor 3



$\sim$ factor 3

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

$$\frac{d\sigma^{(2\to3)}}{dM_{Tb}^2} = \frac{1}{M_{Tb}^2}\left\{\frac{\alpha_s}{2\pi}\Delta_{qg}\otimes g\otimes g\otimes\hat{\sigma}_{\bar{b}g}\right\}_{M_{Tb}=m_b\to0} + \cdots$$

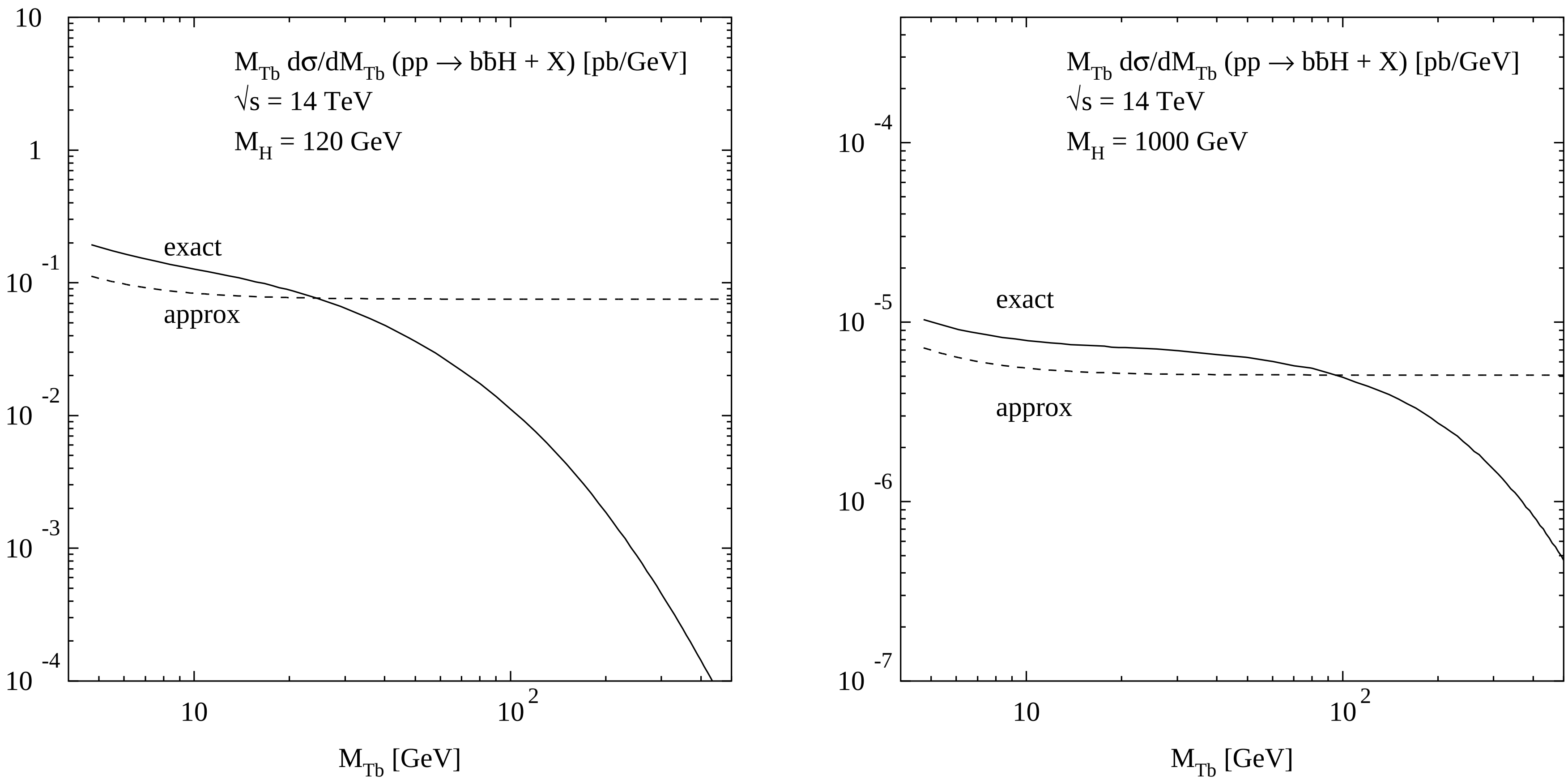
$$\Delta_{qg}(x) = P_{qg}(x) + \frac{m_b^2}{M_{Tb}^2}x(1-x)$$

- total cross section:

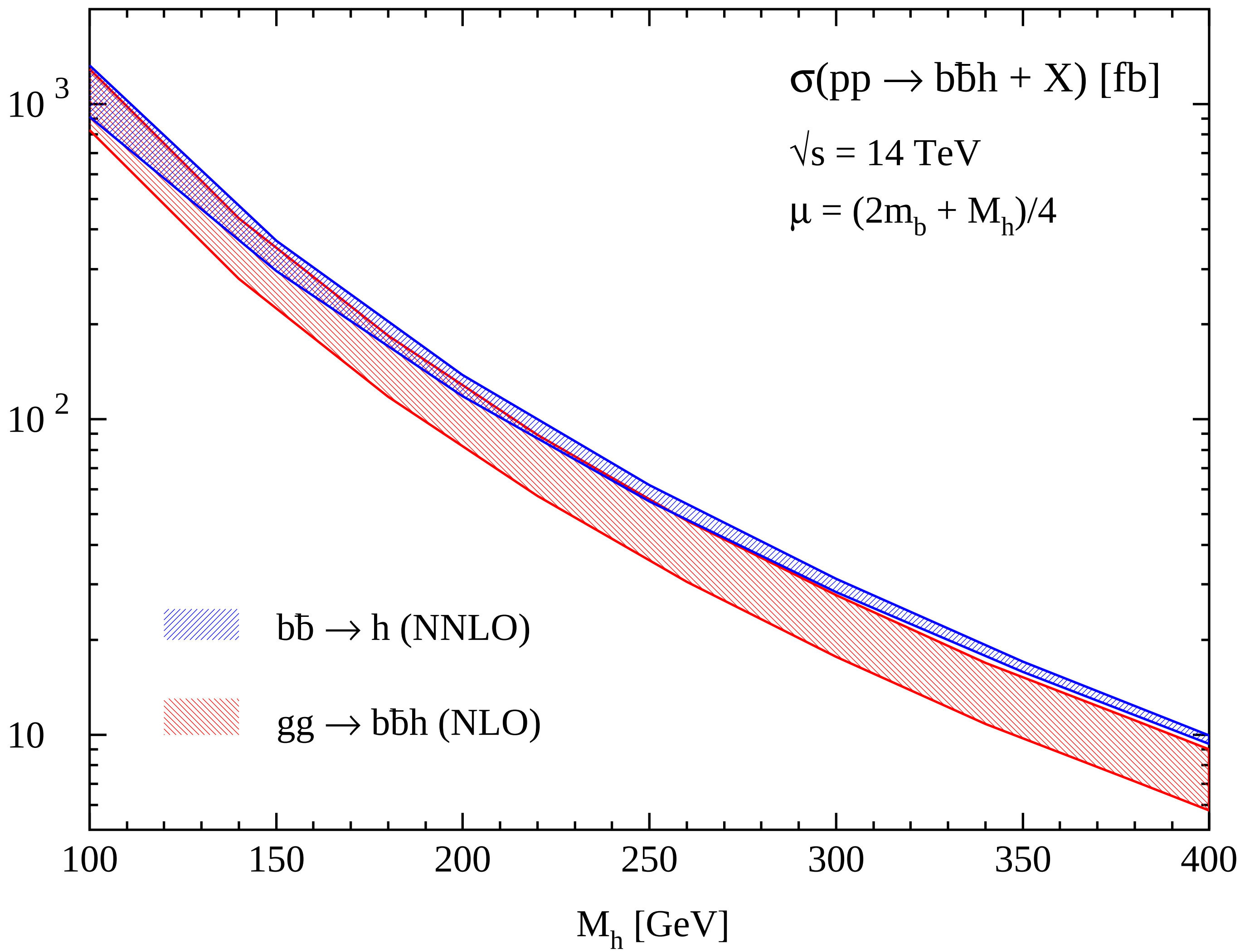
$$\sigma = \underbrace{\int_{m_b^2}^{\mu_F^2}\frac{dM_{Tb}^2}{M_{Tb}^2}}_{\log\frac{\mu_F^2}{m_b^2}}\left\{\frac{\alpha_s}{2\pi}P_{qg}\otimes g\otimes g\otimes\hat{\sigma}_{\bar{b}g}\right\}_{M_{Tb}=m_b\to0} + \cdots$$

$\Rightarrow$ crucial condition:

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

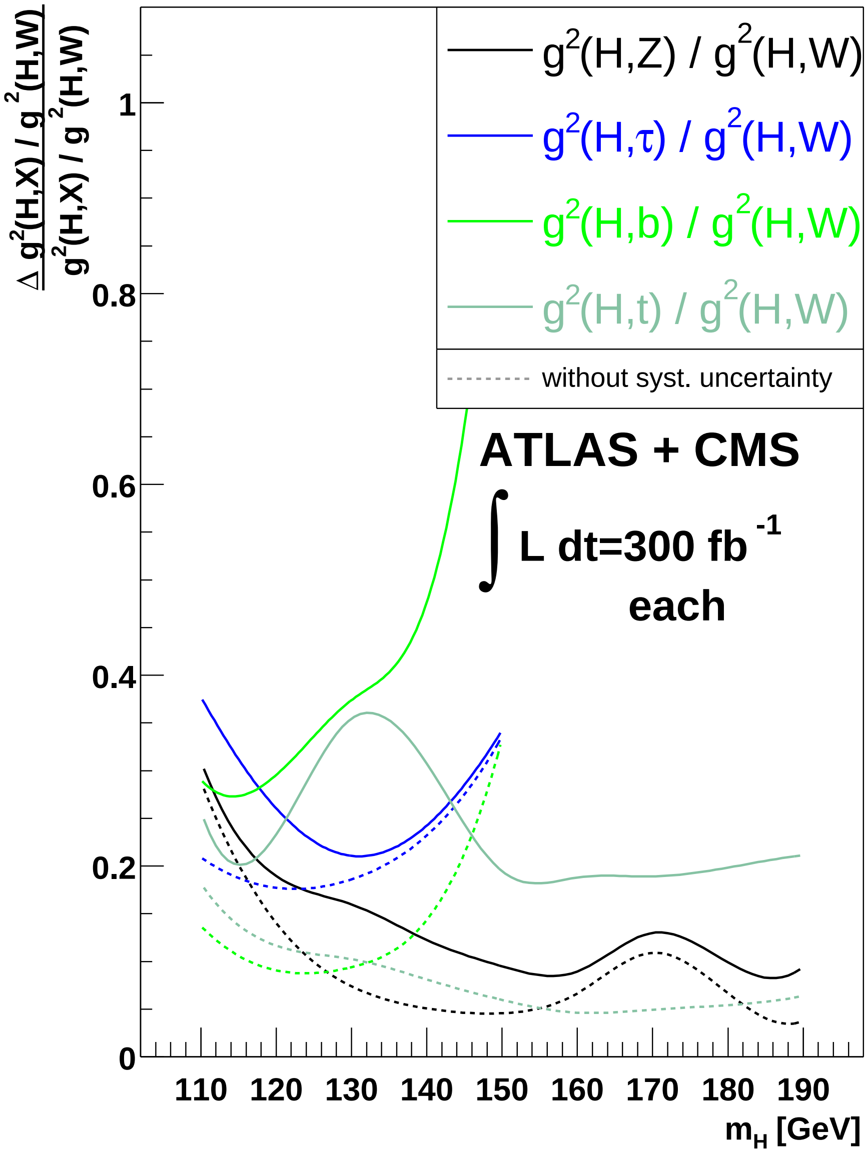


Rainwater, S., Zeppenfeld



Dittmaier, Krämer, S.
Dawson, Jackson, Reina, Wackeroth
Harlander, Kilgore

- accuracies: $\delta M_H/M_H \sim 10^{-3}$, $\delta\Gamma/\Gamma \sim 10\%$, ratios of couplings: $\gtrsim 10\%$



Dührssen,. . .

What's the sense of sports? It's useless. The most beautiful time in my life was at the workshop on physics at future colliders in La Thuile, 1987. We started to discuss about physics at 9 am and finished after midnight each day...

III *CONCLUSIONS*

- Higgs particle searches at the LHC belong to major endeavours

- LHC will find at least one Higgs boson [light scalar]

- most QCD corrections known
  $\Rightarrow$ large corrections in several cases
  remaining theoretical uncertainties:
  $\sim 100\% \longrightarrow \ \lesssim 15\%$

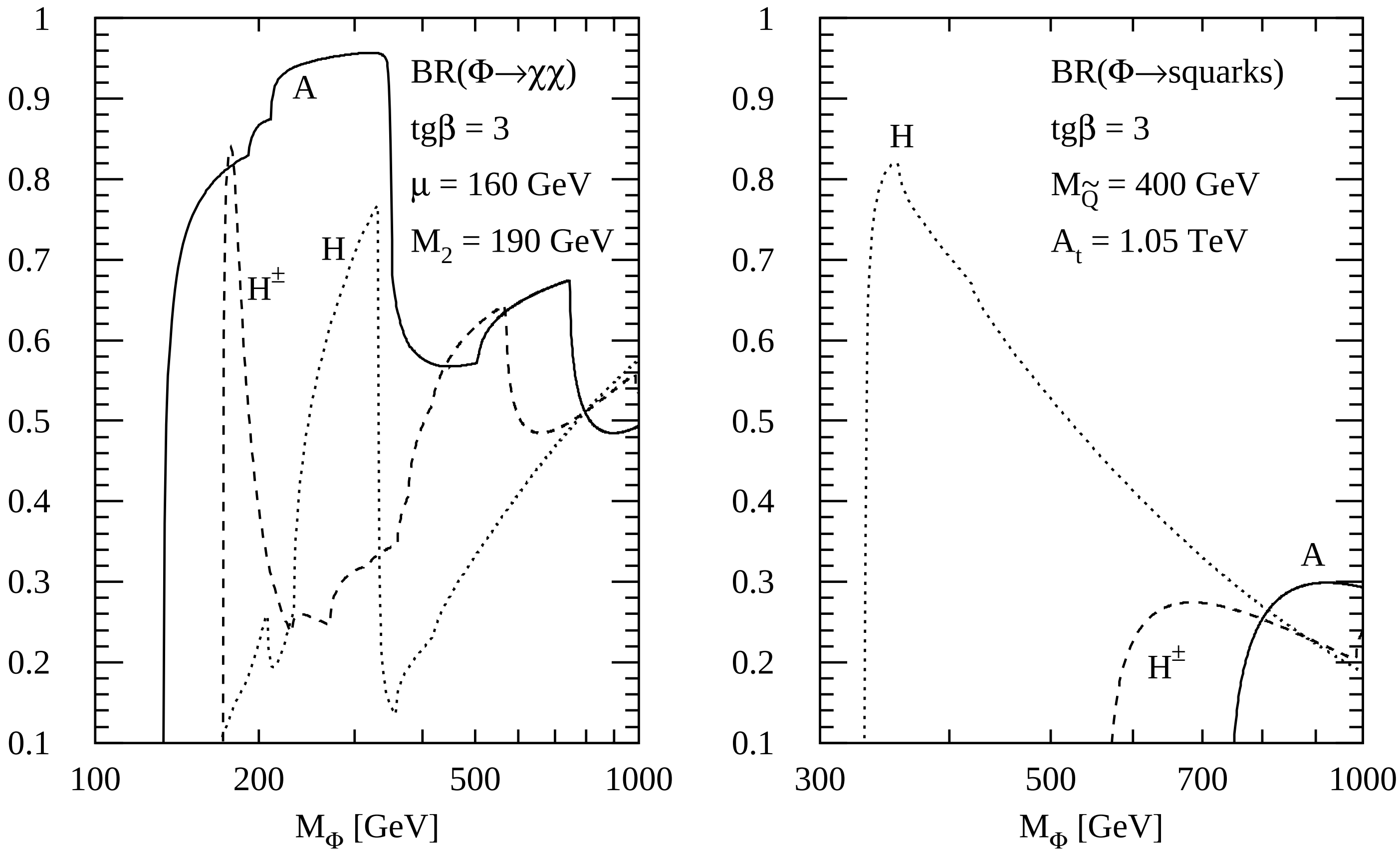
- programs available including the NLO corrections:
  HIGLU, VV2H, V2VH,...

- NLO MC's: MC@NLO, MCFM

include NLO corrections to many background processes, too

SUSY Decays

- new decay modes into SUSY particles: $\phi \to \tilde{\chi}\tilde{\chi}, \tilde{q}\bar{\tilde{q}}$



HDECAY

- if kinematically possible $\to$ important ($\tilde{q}$: 3rd generation)

• SUSY decays: $\phi^0 \to \chi_1^0\chi_1^0$ [LSP] $\Rightarrow$ invisible Higgs $\longrightarrow \not{E}_T$ if $p_{T\phi} > 0$

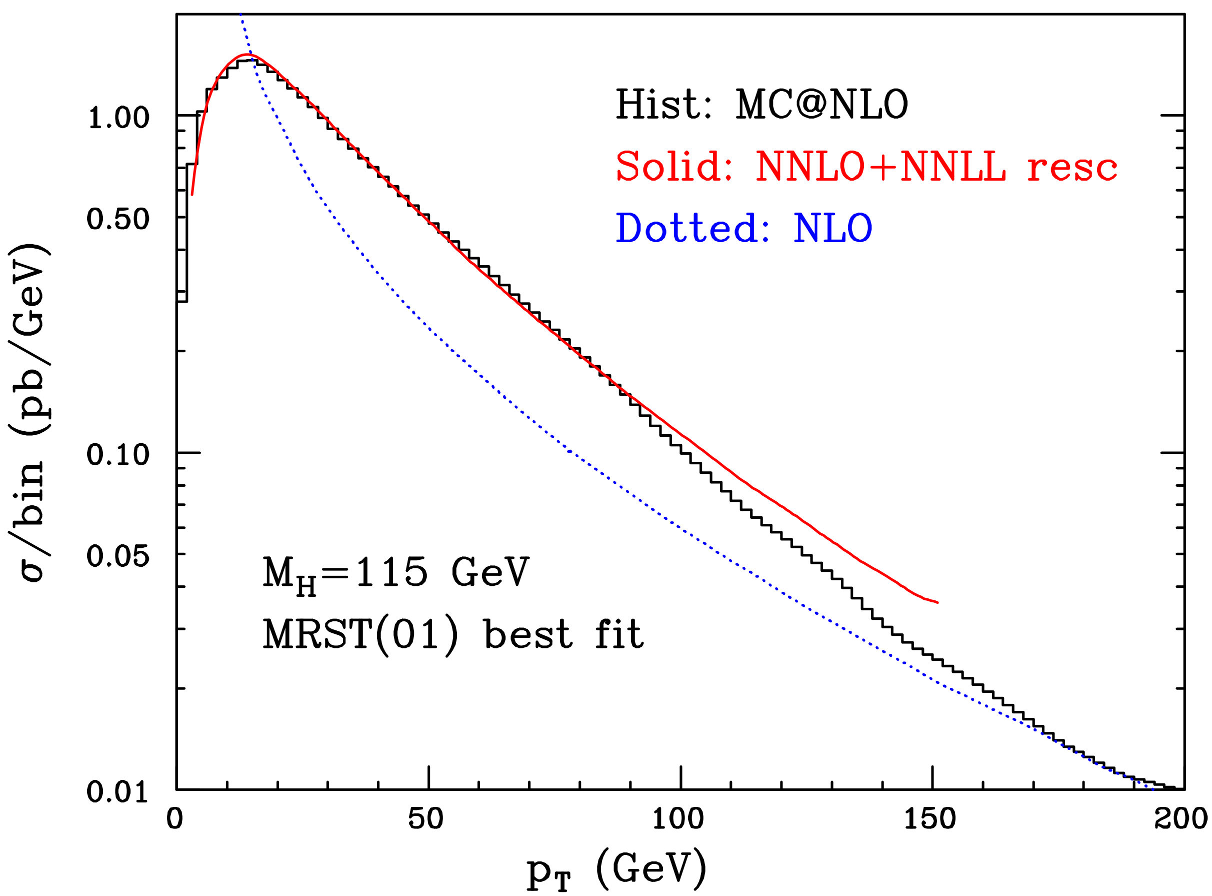
$\Rightarrow gg \to \phi^0 g$ dominant

NLO corrections $[m_t \gg M_\phi, p_{T\phi}]$: 60–80%

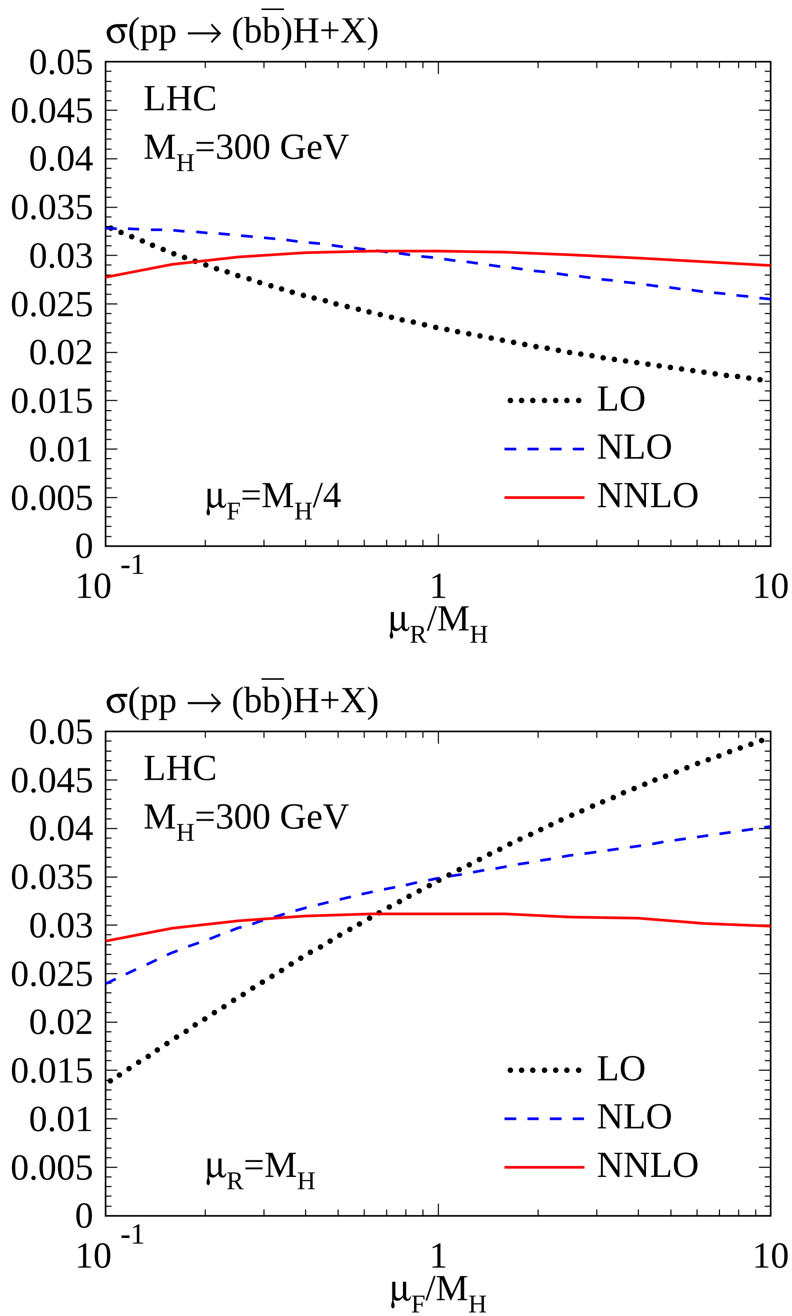
Schmidt
de Florian, Grazzini, Kunszt
Ravindran, Smith, van Neerven

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

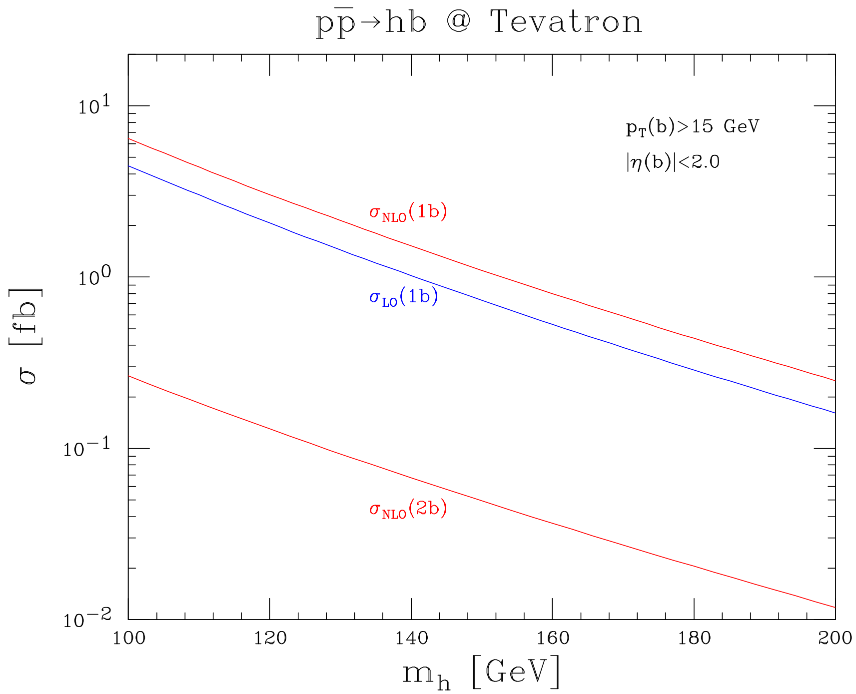
Kauffman
Balazs, Yuan
Bozzi, Catani, de Florian, Grazzini

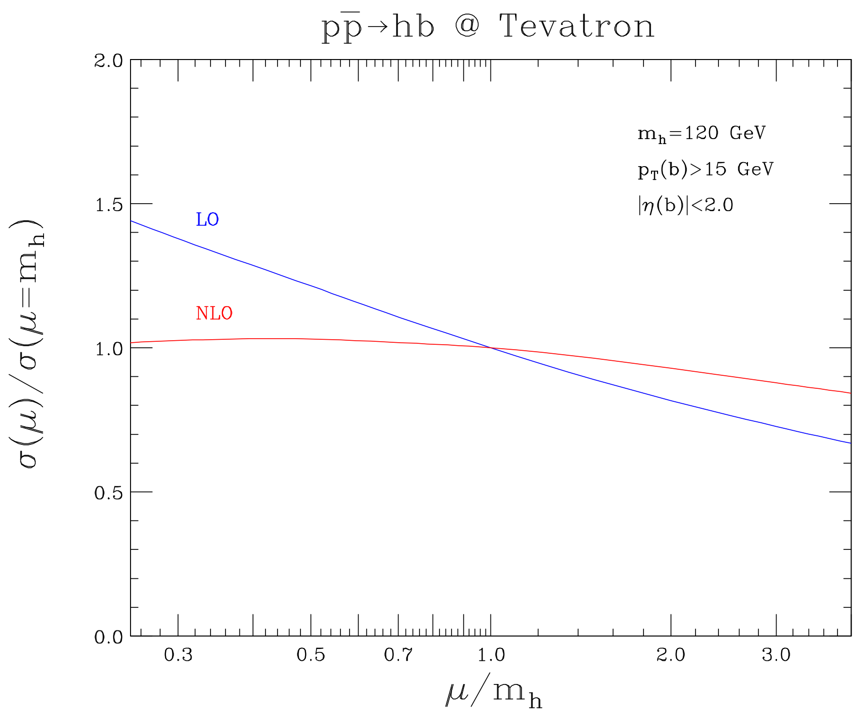


Frixione [MC@NLO]



Harlander, Kilgore





Campbell, Ellis, Maltoni, Willenbrock