PAUL SCHERRER INSTITUT

PARAMETRICALLY ENHANCED CORRECTIONS IN SUPERSYMMETRY : Δ_b

Michael Spira (PSI)

I Introduction

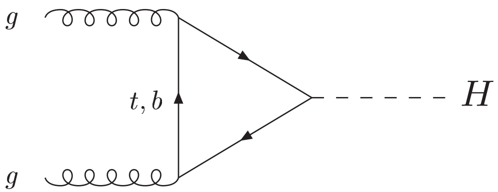
II Δ_b Corrections

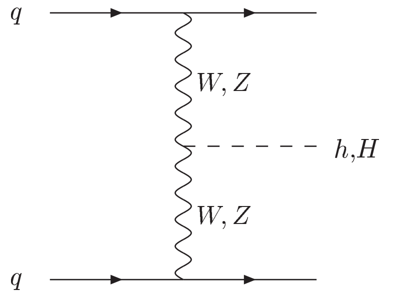
III Higgs Production

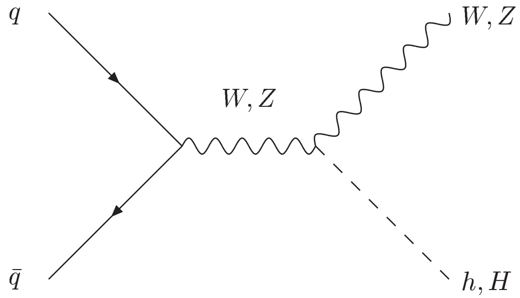
IV Conclusions

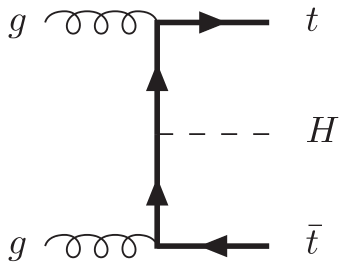
I INTRODUCTION

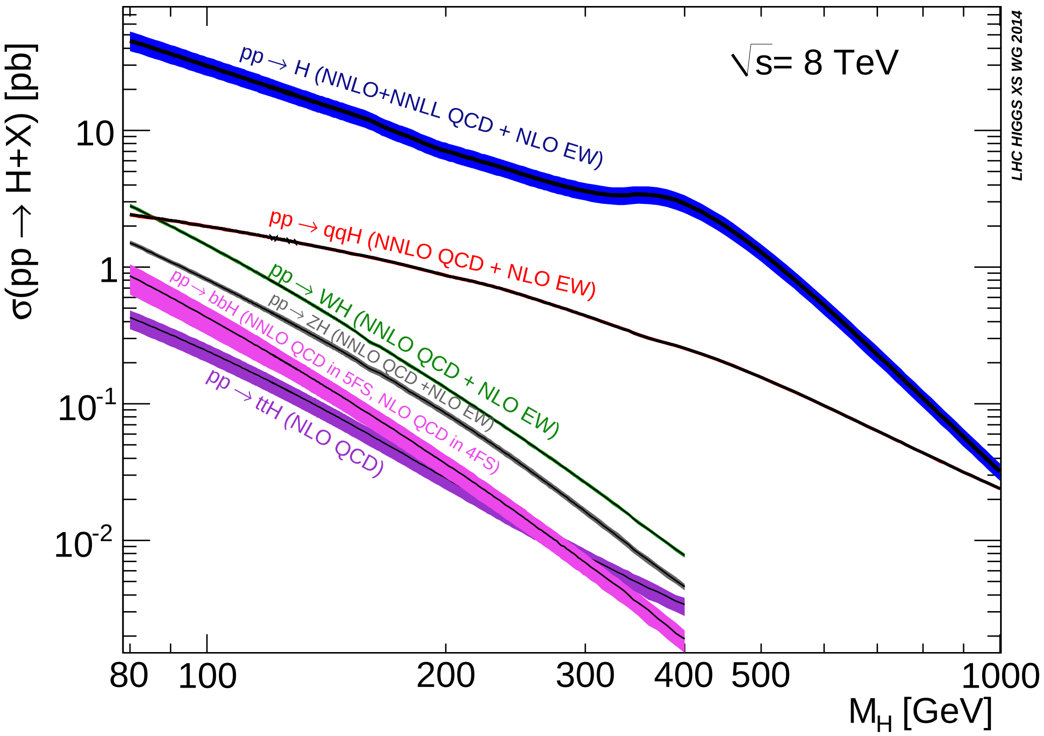
(i) Standard Model

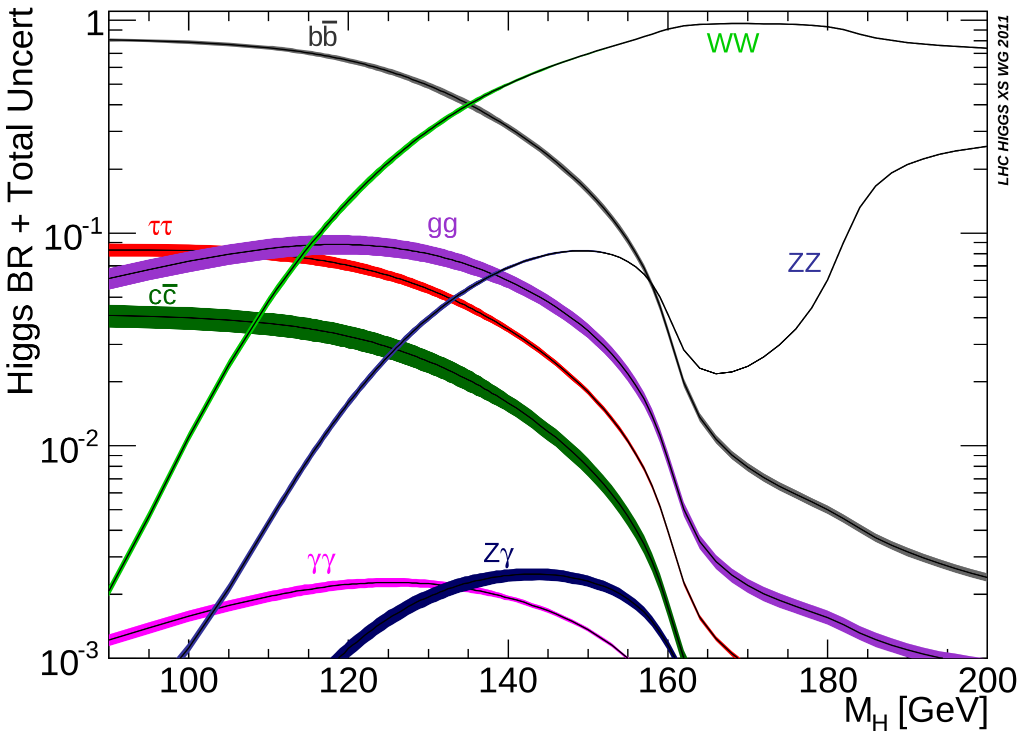












LHC Higgs XS WG

- Discovery: LHC [Tevatron]

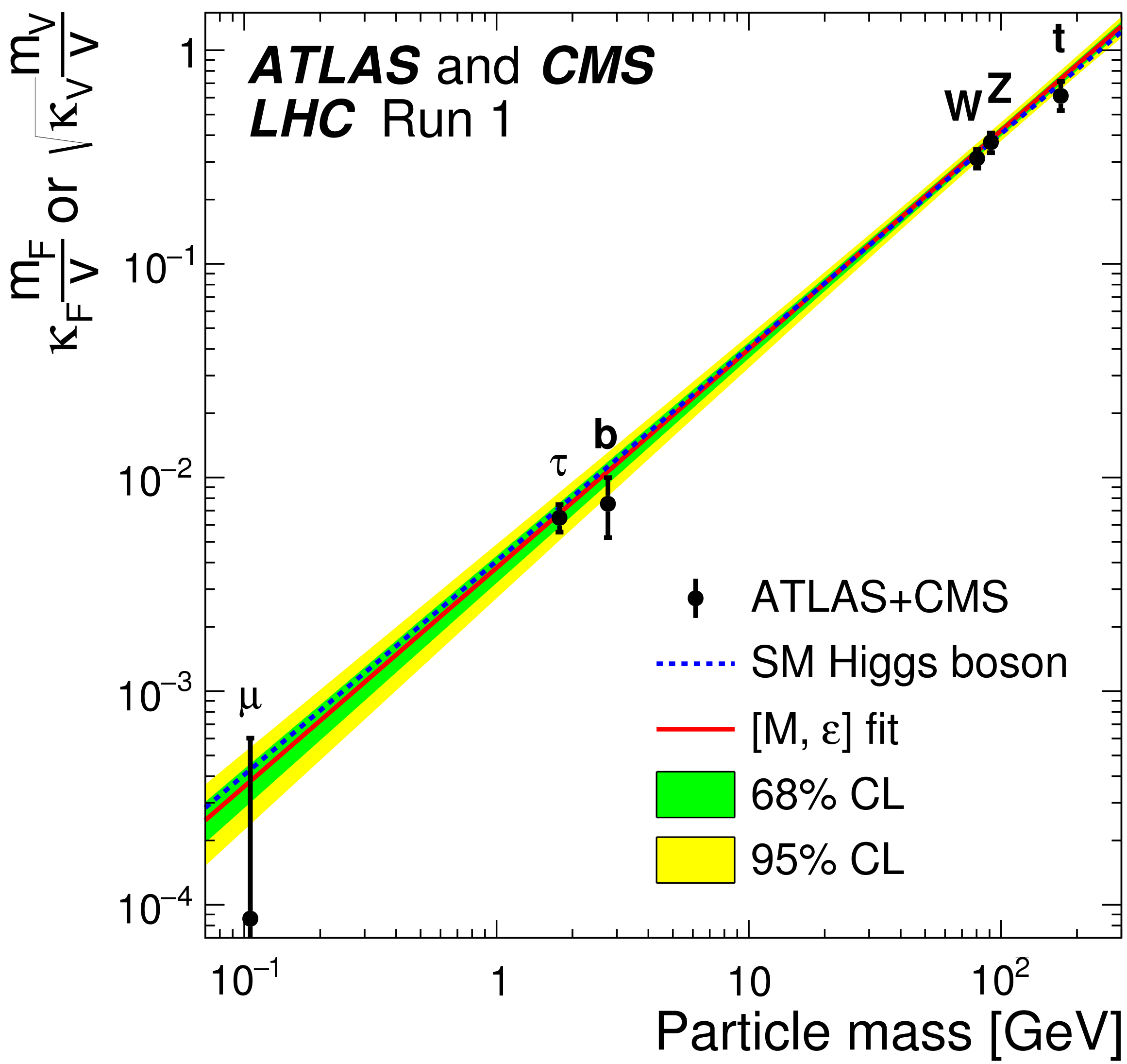
  $\rightarrow$ Higgs mass

  couplings

  spin

  $\mathcal{CP}$

  λ ?



(ii) MSSM

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

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

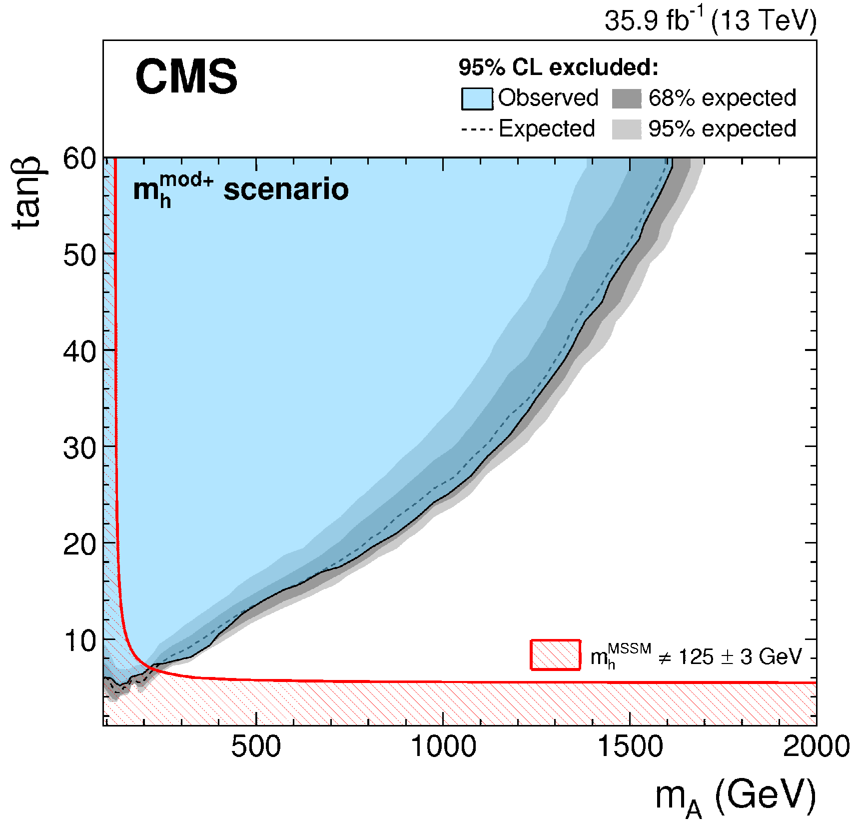
- radiative corrections $\propto m_t^4 \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} \quad \longrightarrow \quad \boxed{M_h \lesssim 135 \text{ GeV}}$

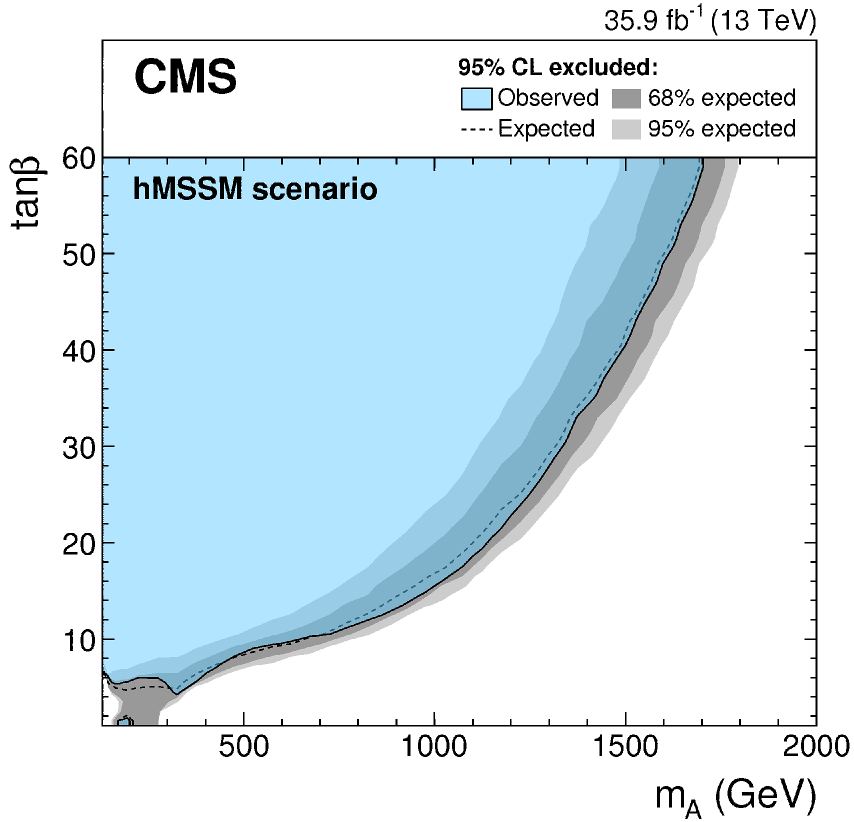
Haber
Carena,. . .
Heinemeyer,. . .
Zhang
Slavich,. . .
. . .

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

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

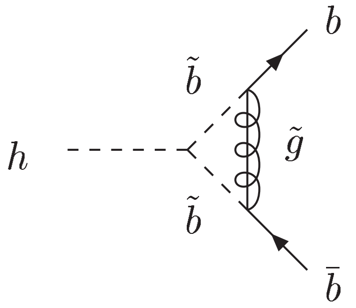
$$gg \to b\bar{b}\phi^0, \;\; gg \to \phi^0 \qquad \phi^0 \to \tau^+\tau^-$$





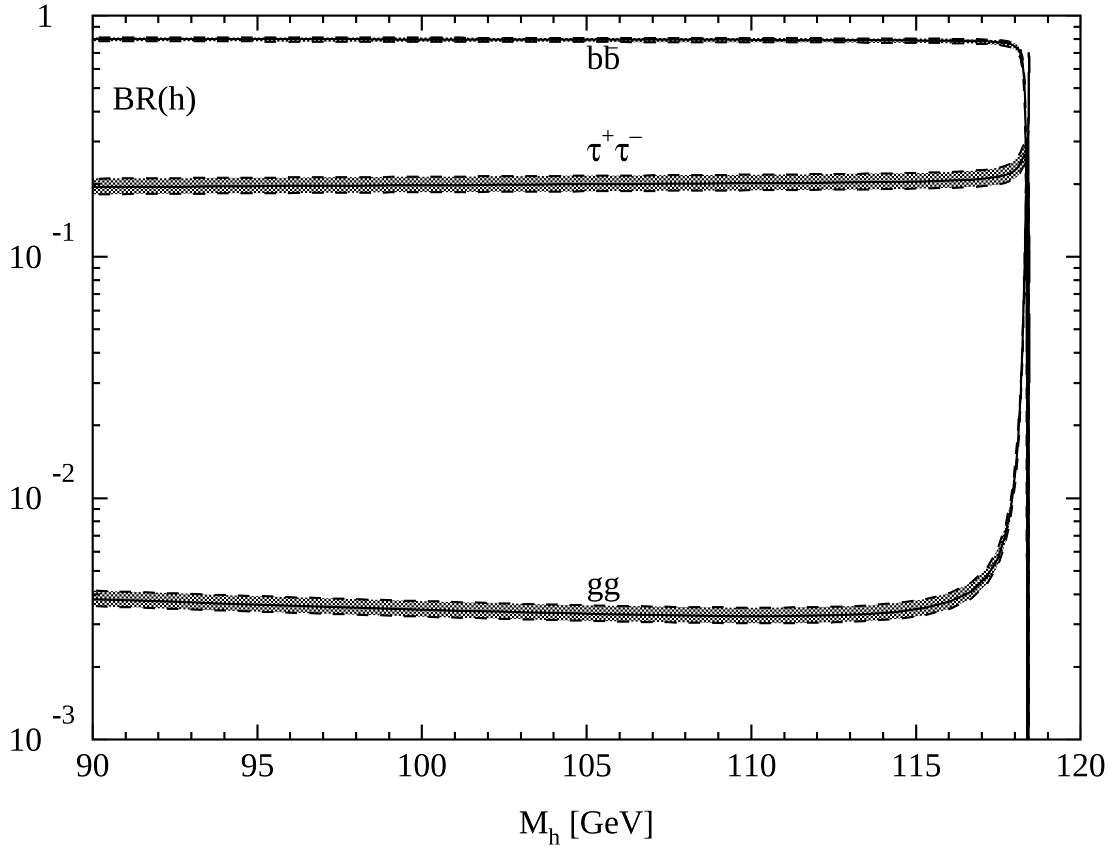
ATLAS: similar results

• large SUSY–QCD corrections to $\phi^0 \to b\bar{b}$



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

Hall,. . .
Carena,. . .
Nierste,. . .
Guasch,. . .
etc.



Guasch, Häfliger, S.

II Δ_b CORRECTIONS

SUSY-QCD Corrections to $b\bar{b}\phi^0$ $\qquad [\Delta \lesssim 1\%]$

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

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

$$\Delta_b = \Delta_b^{QCD(1)} + \Delta_b^{elw(1)}$$

$$\Delta_b^{QCD(1)} = \frac{2}{3} \frac{\alpha_s(\mu_R)}{\pi} M_{\tilde{g}}\ \mu\ \mathrm{tg}\beta\ I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, M_{\tilde{g}}^2)$$

$$\Delta_b^{elw(1)} = \frac{\lambda_t^2(\mu_R)}{(4\pi)^2}\ \mu\ A_t\ \mathrm{tg}\beta\ I(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2)$$

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

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

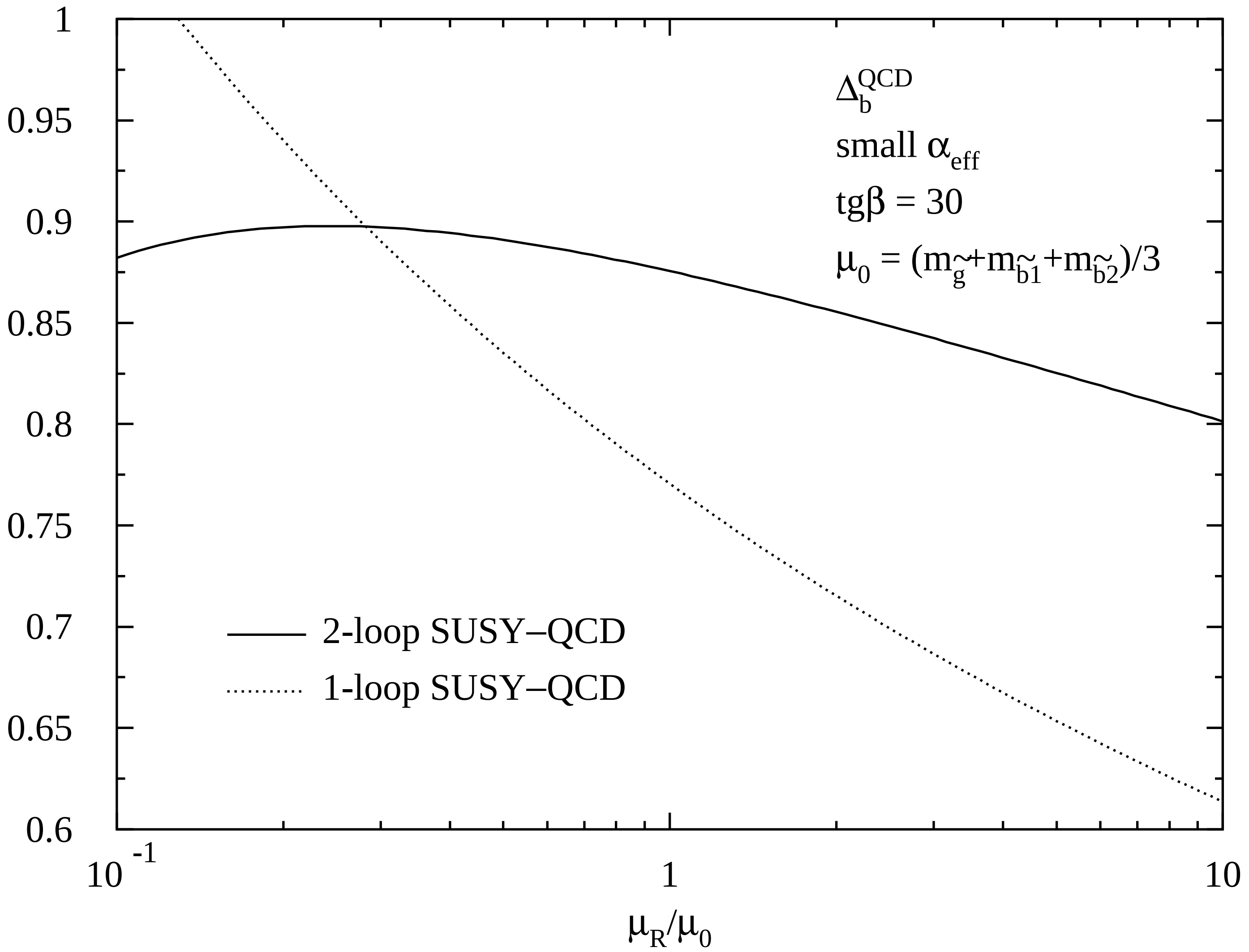
$\Rightarrow$ resummed Yukawa couplings $\tilde{g}_b^\Phi$

small α_{eff} scenario [modified]

$$\begin{aligned} \text{tg}\beta &= 30 \\ M_{\tilde{Q}} &= 800 \text{ GeV} \\ M_{\tilde{g}} &= 1000 \text{ GeV} \quad \longleftarrow \\ M_2 &= 500 \text{ GeV} \\ A_b = A_t &= -1.133 \text{ TeV} \\ \mu &= 2 \text{ TeV} \end{aligned}$$

$$m_{\tilde{t}_1} = 679 \text{ GeV} \qquad m_{\tilde{t}_2} = 935 \text{ GeV}$$

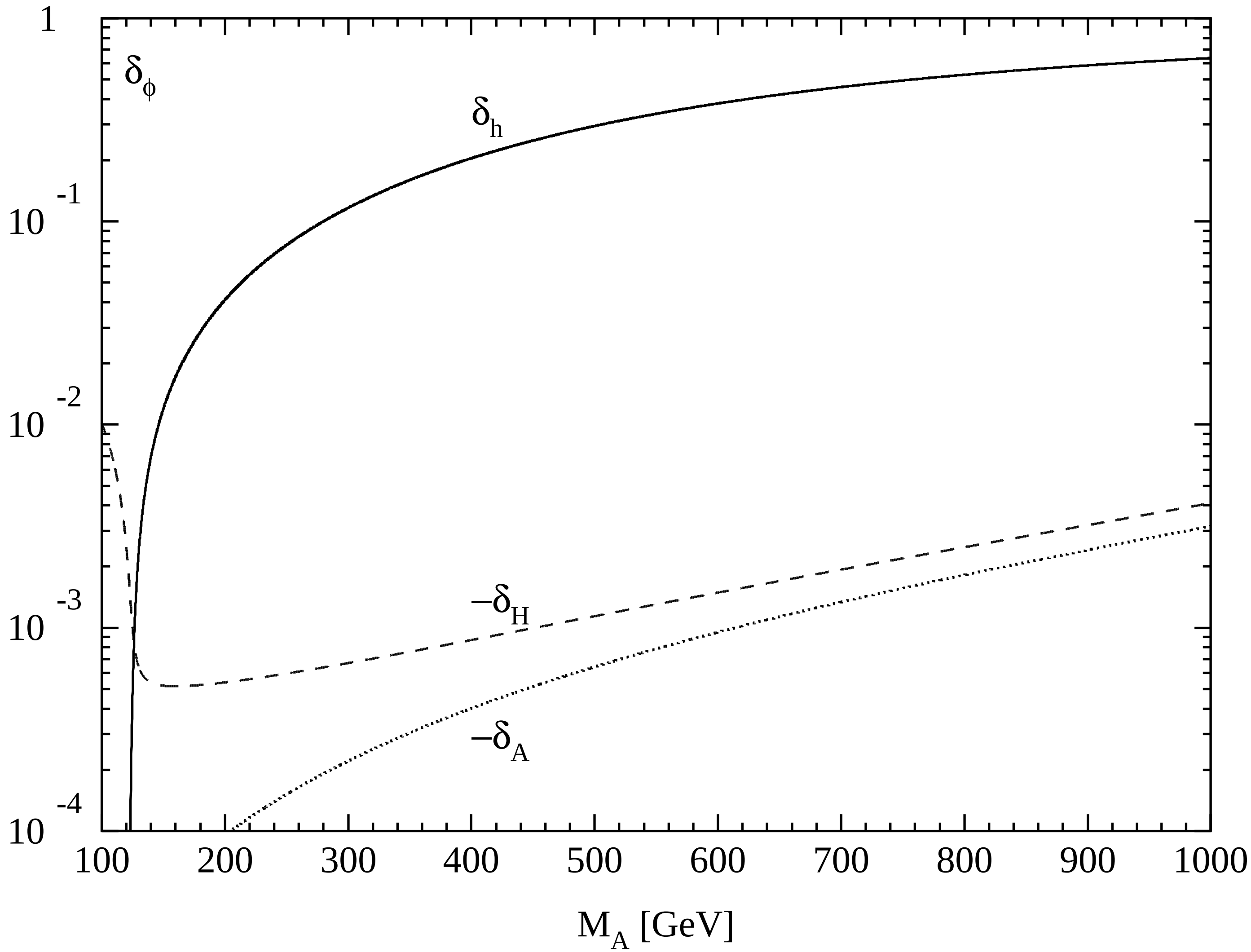
$$m_{\tilde{b}_1} = 601 \text{ GeV} \qquad m_{\tilde{b}_2} = 961 \text{ GeV}$$



Noth, S.
(Mihaila, Reisser)

$$\Gamma[\Phi \to b\bar{b}] = \frac{3G_F M_\Phi}{4\sqrt{2}\pi}\overline{m}_b^2(M_\Phi)\ \Delta_{\rm QCD}\ \tilde{g}_b^\Phi\left[\tilde{g}_b^\Phi + g_b^\Phi \delta_{rem}\right]$$

$$M_A^2 \gg M_Z^2 : {\rm tg}\alpha \to -\frac{1}{{\rm tg}\beta} \quad \Rightarrow \quad \tilde{g}_b^h \to \frac{1}{1+\Delta_b}\left(1 - \frac{\Delta_b}{{\rm tg}\alpha\ {\rm tg}\beta}\right) \to 1$$



$$\delta_\phi = \frac{\delta_{rem}}{\delta_{SQCD}}$$

Guasch, Häfliger, S.

- extension to A_b terms:

$$\mathcal{L}_{eff} = -\lambda_b^0 \overline{b_R} \left[(1+\Delta_{b,1})\phi_1^0 + \frac{\Delta_{b,2}}{\mathrm{tg}\beta}\phi_2^{0*} \right] b_L + h.c.$$

$$\mathcal{L}_{eff} = -\lambda_b \overline{b_R} \left[\phi_1^0 + \frac{\Delta_b}{\mathrm{tg}\beta}\phi_2^{0*} \right] b_L + h.c.$$

$$\Rightarrow \qquad \Delta_b = \frac{\Delta_{b,2}}{1+\Delta_{b,1}}$$

Guasch, Häfliger, S.
Ghezzi, Glaus, Müller, Schmidt, S.

$$\Delta_{b,1} = -\frac{2}{3}\frac{\alpha_s(\mu_R)}{\pi} M_{\tilde{g}} \, A_b \, I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, M_{\tilde{g}}^2) \qquad \to \text{NNLO}$$

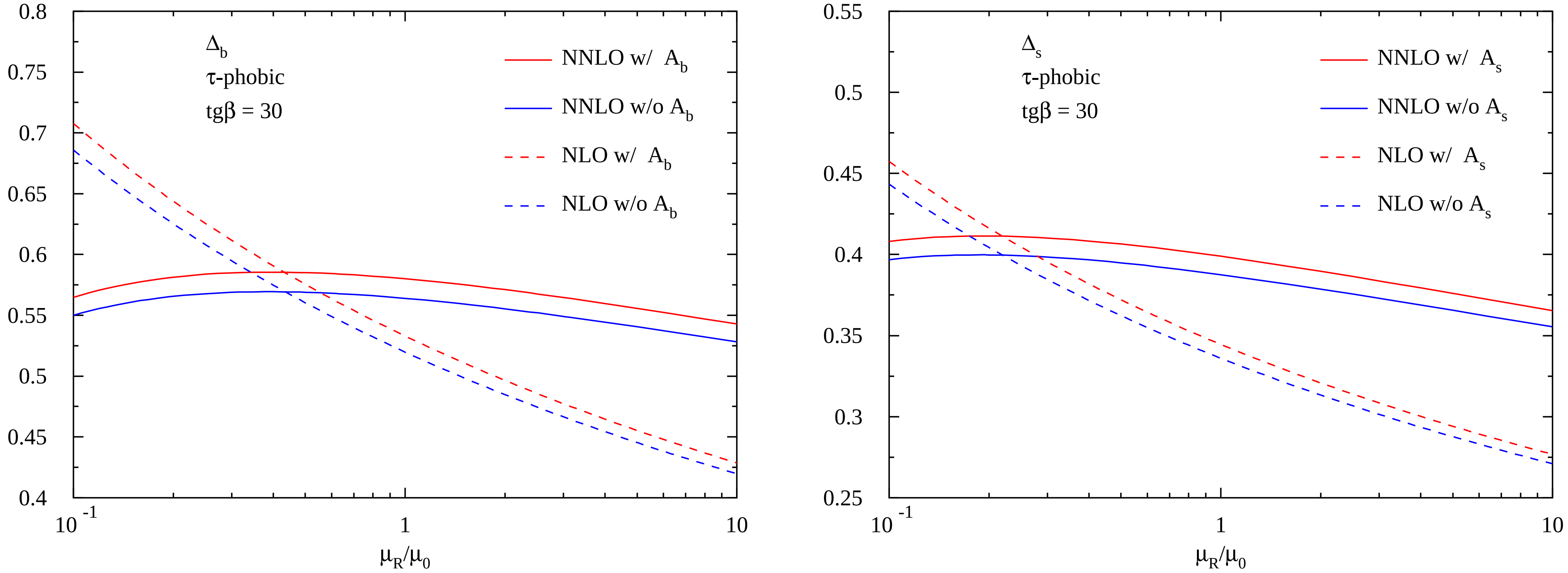
- strange Yukawa couplings:

$$\Delta_{s,1} = -\frac{2}{3}\frac{\alpha_s(\mu_R)}{\pi} M_{\tilde{g}} \, A_s \, I(m_{\tilde{s}_1}^2, m_{\tilde{s}_2}^2, M_{\tilde{g}}^2)$$

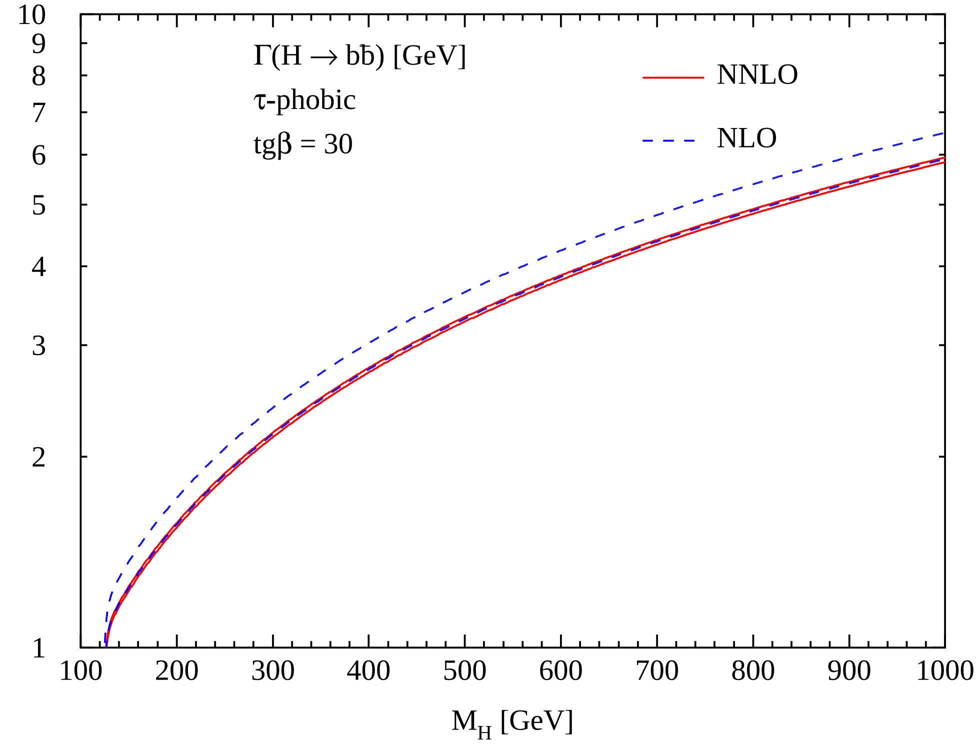
$$\Delta_{s,2} = \frac{2}{3}\frac{\alpha_s(\mu_R)}{\pi} M_{\tilde{g}} \, \mu \mathrm{tg}\beta \, I(m_{\tilde{s}_1}^2, m_{\tilde{s}_2}^2, M_{\tilde{g}}^2)$$

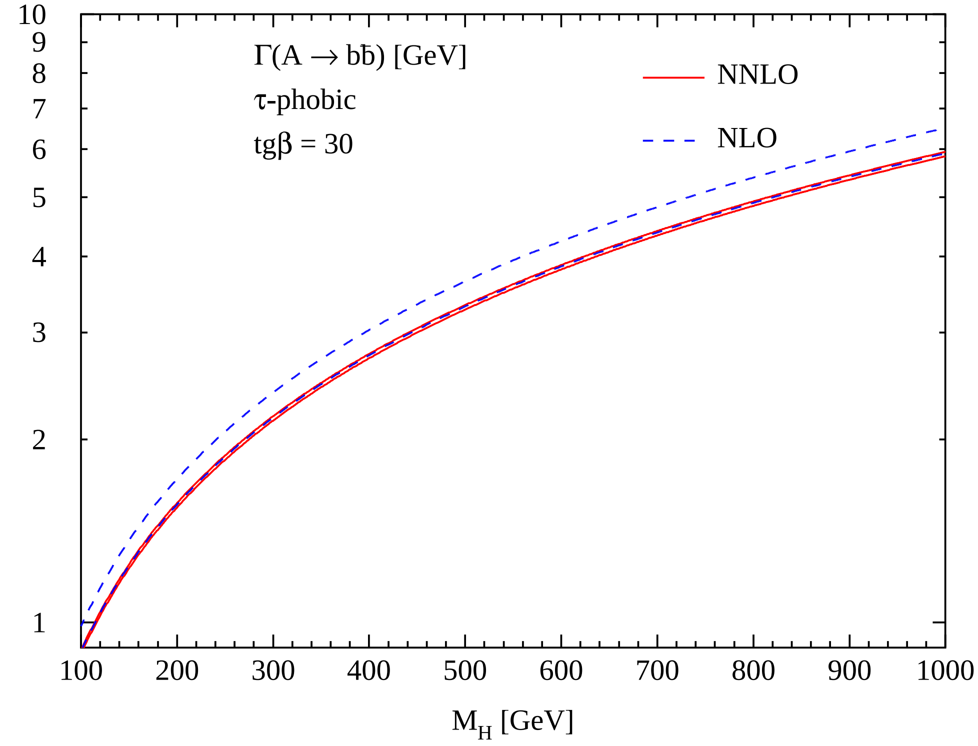
$$\Delta_s = \frac{\Delta_{s,2}}{1+\Delta_{s,1}} \qquad \to \text{NNLO}$$

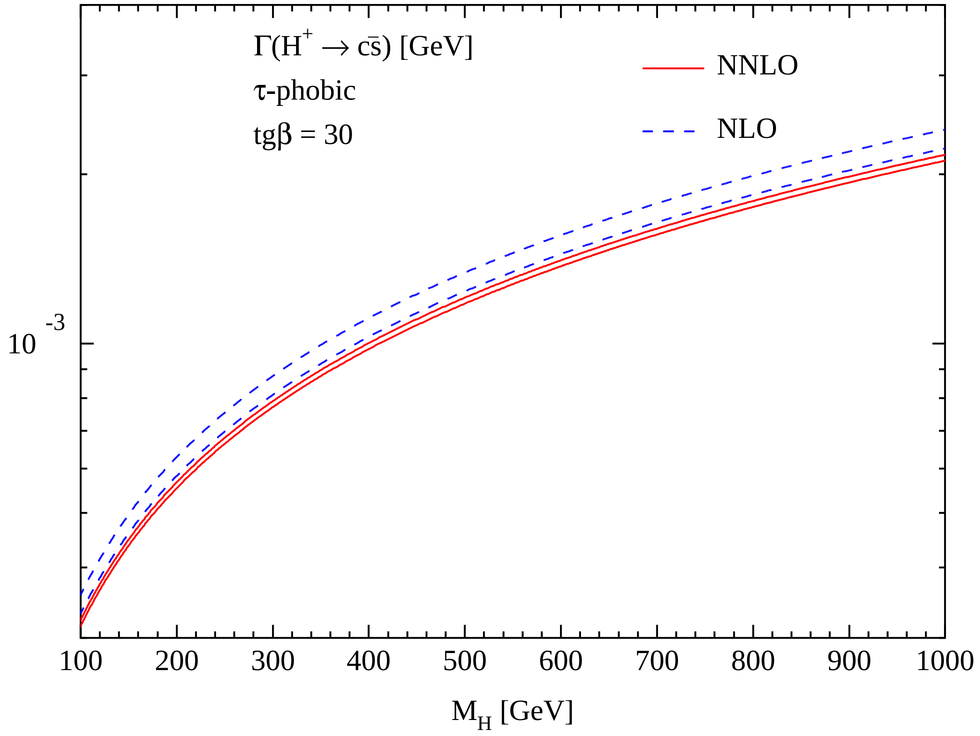
Ghezzi, Glaus, Müller, Schmidt, S.



Ghezzi, Glaus, Müller, Schmidt, S.



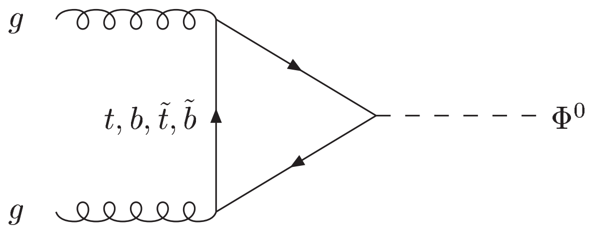




Ghezzi, Glaus, Müller, Schmidt, S.

III *HIGGS BOSON PRODUCTION*

(i) $gg \to h/H/A$



Georgi,. . .

Gamberini,. . .

S., Djouadi, Graudenz, Zerwas
Dawson, Kauffman

- NLO QCD corrections: $\sim 10 \ldots 100\%$

- NNLO calculated for $m_t \gg M_\phi \Rightarrow$ further increase by 20–30%
  [top mass effects small in SM]

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

Marzani, Ball, Del Duca, Forte, Vicini
Harlander, Ozeren
Pak, Rogal, Steinhauser

- N^{3}LO for $m_t \gg M_\phi \quad \Rightarrow$ scale stabilization

scale dependence: $\Delta \lesssim 5\%$

Moch, Vogt
Ravindran
de Florian, Mazzitelli, Moch, Vogt
Anastasiou, Duhr, Dulat, Furlan, Gehrmann, Herzog, Mistlberger
Ball, Bonvini, Forte, Marzani, Ridolfi

- N^3LL soft gluon resummation: $\lesssim 2\%$

Catani, de Florian, Grazzini, Nason
Ravindran
Ahrens, Becher, Neubert, Yang
Ball, Bonvini, Forte, Marzani, Ridolfi
Bonvini, Marzani
Schmidt, S.

- SM + 2HDM elw. corrections: $\sim 5\%$

Aglietti,. . .
Degrassi, Maltoni
Actis, Passarino, Sturm, Uccirati
Jenniches, Sturm, Uccirati

- QCD corrections to squark loops: 10–100%

Mühlleitner, S.
Bonciani, Degrassi, Vicini

- impl. of $gg \to \phi$ in POWHEG including mass effects @ NLO
  (QCD also valid for 2HDM and other Higgs extensions)

Bagnaschi, Degrassi, Slavich, Vicini

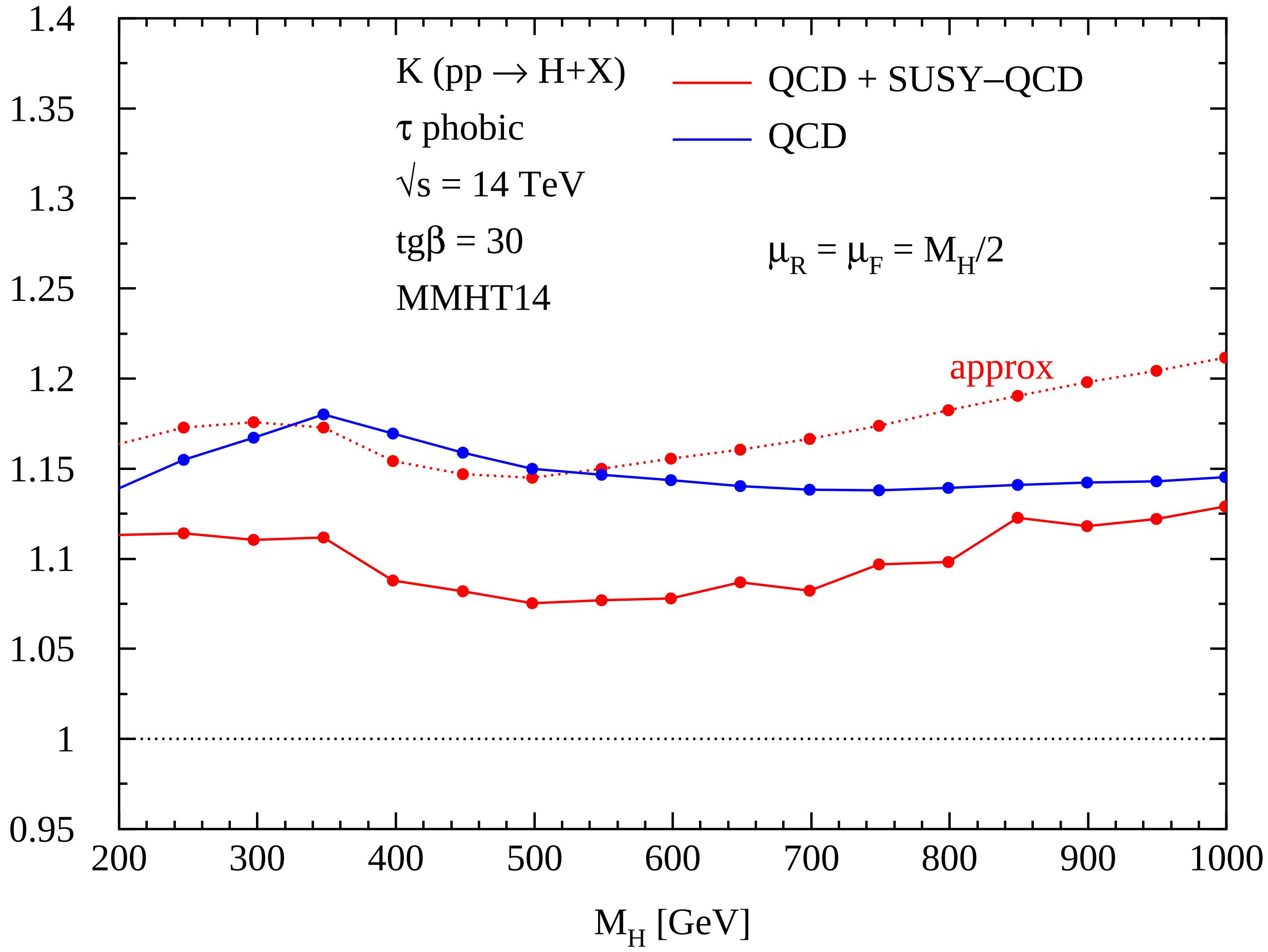
- SUSY-elw. corrections unknown

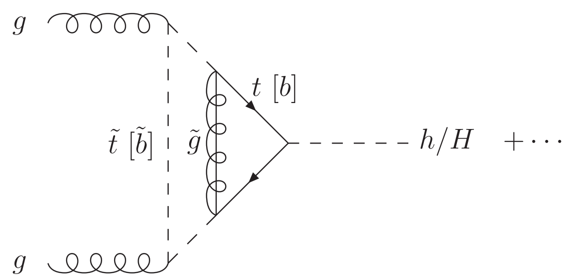
- genuine SUSY–QCD corrections: 10–100%
  [$\leftarrow \Delta_b$ @ large tgβ]

Harlander, Steinhauser, Hofmann
Degrassi, Slavich
Anastasiou, Beerli, Daleo
Mühlleitner, Rzehak, S.

$$\sigma(gg \to \Phi) = \sigma_{LO}(g_t^\Phi, \tilde{g}_b^\Phi)\left[1 + \delta_{QCD} + \delta_{SQCD}\right]$$

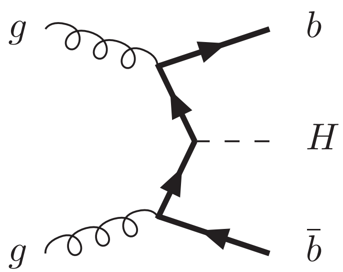
PRELIMINARY



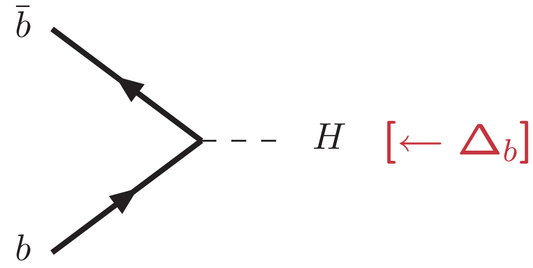


Fritz, Mühlleitner, Rzehak, S.

(ii) $b\bar{b}$+Higgs production



NLO



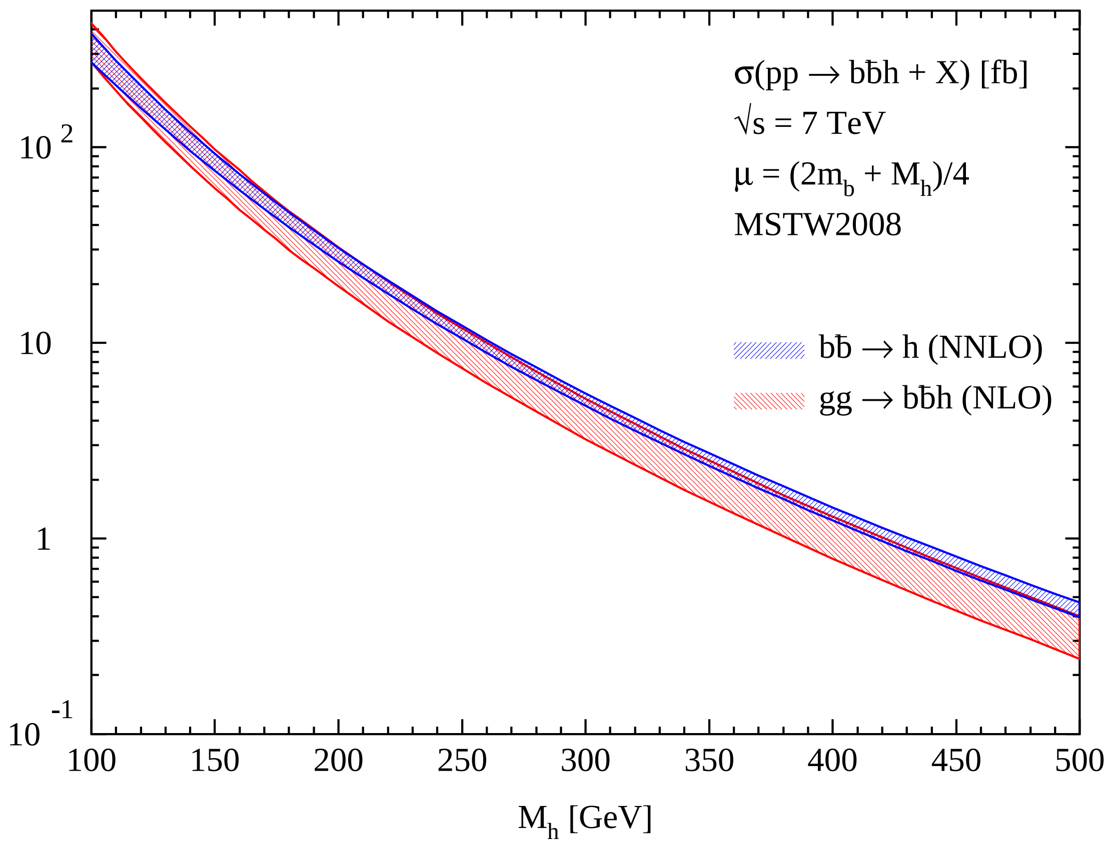
NNLO

exact $g \to b\bar{b}$ splitting & mass/off-shell effects

no resummation of $\log M_H^2/m_b^2$ terms

massless/on-shell b's, no p_{Tb}

resummation of $\log M_H^2/m_b^2$ terms



Santander matching:

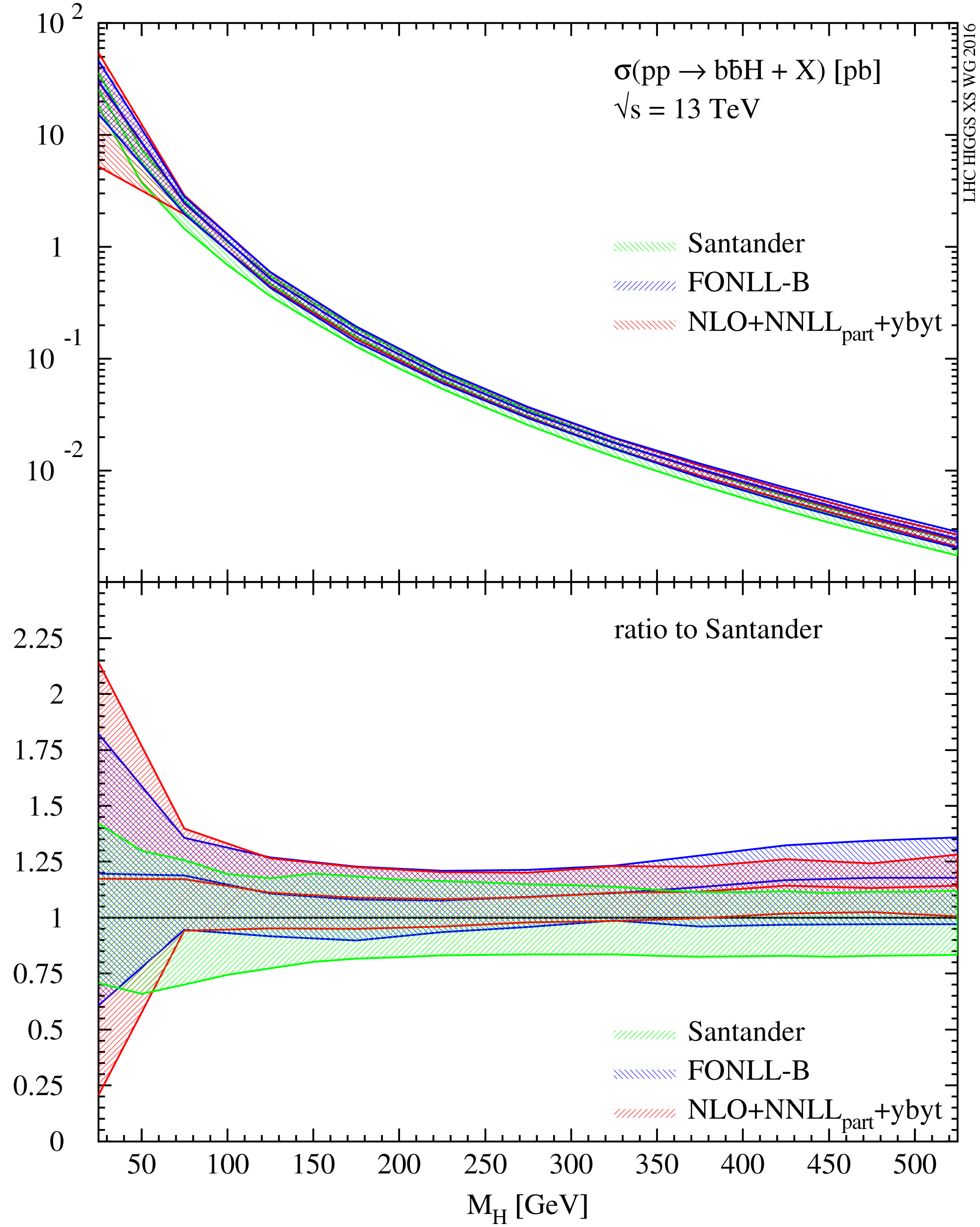
$$\sigma = \frac{\sigma^{4FS} + w\sigma^{5FS}}{1+w}$$

$$w = \log\frac{M_H}{m_b} - 2$$

Harlander, Krämer, Schumacher

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

matching



Bonvini, Papanastasiou, Tackmann

Forte, Napoletano, Ubiali

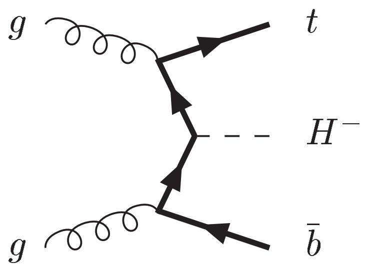
	M_A	M_H [GeV]	δ^A_{QCD}	δ^A_{SUSY}	$\delta^A_{SUSYrem}$	δ^H_{QCD}	δ^H_{SUSY}	$\delta^H_{SUSYrem}$
	100	113.9	0.23	-0.30	0.4×10^{-4}	0.27	-0.38	0.3×10^{-4}
	200	200	0.38	-0.30	2.9×10^{-4}	0.39	-0.30	5.8×10^{-4}
7 TeV	300	300	0.46	-0.30	6.7×10^{-4}	0.47	-0.30	9.3×10^{-4}
	400	400	0.53	-0.30	1.3×10^{-3}	0.53	-0.30	1.5×10^{-3}
	500	500	0.57	-0.30	2.0×10^{-3}	0.59	-0.30	2.2×10^{-3}
	100	113.9	0.14	-0.30	0.4×10^{-4}	0.17	-0.38	0.5×10^{-4}
	200	200	0.28	-0.30	2.7×10^{-4}	0.29	-0.30	5.7×10^{-4}
14 TeV	300	300	0.37	-0.30	6.5×10^{-4}	0.39	-0.30	9.3×10^{-4}
14 TeV	300	300	0.37	-0.30	6.5×10^{-4}	0.39	-0.30	9.3×10^{-4}
	400	400	0.45	-0.30	1.2×10^{-3}	0.45	-0.30	1.5×10^{-3}
	500	500	0.50	-0.30	2.1×10^{-3}	0.49	-0.30	2.3×10^{-3}

	tgβ	M_A	M_H [GeV]	δ^A_{SUSY}	$\delta^A_{SUSYrem}$	δ^H_{SUSY}	$\delta^H_{SUSYrem}$
	3	200	209.7	-0.04	2.1×10^{-4}	-0.04	5.7×10^{-4}
	5	200	204.0	-0.06	2.4×10^{-4}	-0.06	5.3×10^{-4}
	7	200	202.1	-0.08	2.5×10^{-4}	-0.09	3.9×10^{-4}
7 TeV	10	200	200.9	-0.12	2.5×10^{-4}	-0.12	3.8×10^{-4}
	20	200	200.1	-0.21	2.6×10^{-4}	-0.21	4.4×10^{-4}
	30	200	200.0	-0.30	2.9×10^{-4}	-0.30	5.8×10^{-4}
	3	200	209.7	-0.04	2.0×10^{-4}	-0.04	7.2×10^{-4}
	5	200	204.0	-0.06	2.2×10^{-4}	-0.06	5.0×10^{-4}
	7	200	202.1	-0.08	2.4×10^{-4}	-0.09	4.4×10^{-4}
14 TeV	10	200	200.9	-0.12	2.5×10^{-4}	-0.12	4.1×10^{-4}
	20	200	200.1	-0.21	2.7×10^{-4}	-0.21	4.4×10^{-4}
	30	200	200.0	-0.30	2.7×10^{-4}	-0.30	5.7×10^{-4}

SPS1b

(iii) $pp \to t\bar{b}H^- + X$

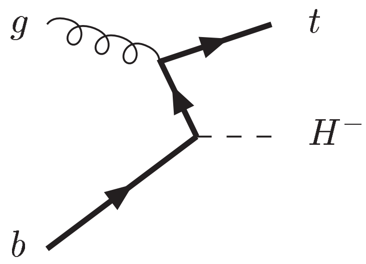
- $M_{H^\pm} < m_t - m_b$: $\sigma_{t\bar{b}H^-} = \sigma_{t\bar{t}} \times BR(\bar{t} \to \bar{b}H^-)$
- $M_{H^\pm} \sim m_t - m_b$: new NLO calculation Degrande, Frederix, Wiesemann, Zaro
- $M_{H^\pm} > m_t - m_b$:



NLO

exact $g \to b\bar{b}$ splitting & mass/off-shell effects

no resummation of $\log M^2_{H^\pm}/m_b^2$ terms



NLO

massless/on-shell b's, no p_{Tb}

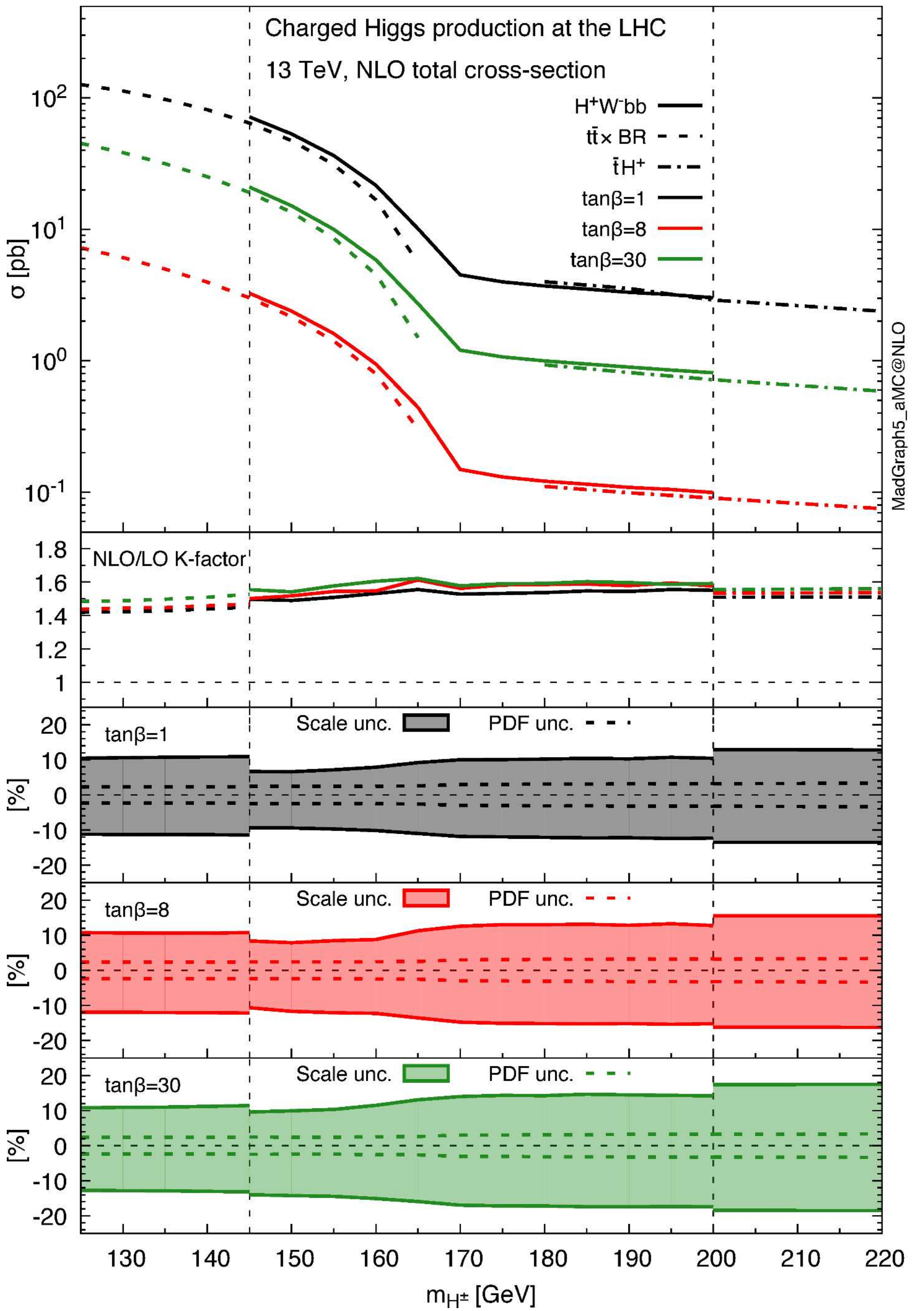
resummation of $\log M^2_{H^\pm}/m_b^2$ terms

$\to$ Santander matching

Dittmaier, Krämer, S., Walser

Plehn

Flechl, Klees, Krämer, Spira, Ubiali



Degrande, Frederix, Wiesemann, Zaro

- charged Higgs: $\tilde{g}_b^{H^\pm} = \frac{\mathrm{tg}\beta}{1+\Delta_b}\left(1 - \frac{\Delta_b}{\mathrm{tg}^2\beta}\right)$

$$\sigma_{NLO} = \sigma_{LO}\big|_{g_b^{H^\pm} \to \tilde{g}_b^{H^\pm}} \times \left\{1 + \delta_{QCD} + \delta_{SQCD}^{rem}\right\}$$

$\mathrm{tg}\beta$	δ_{SUSY}^{rem} [%]
3	-5.7%
5	-7.9%
10	-4.8%
30	-0.13%

$\leftarrow g_t^{H^\pm}$

Dittmaier, Krämer, S., Walser

IV CONCLUSIONS

- genuine SUSY–QCD corrections large @ large tg$\beta \to \Delta_b$
- small remainders beyond Δ_b approximation in most cases
- analogous results for strange Yukawa coupling $\to \Delta_s$

BACKUP SLIDES