Quantum corrections for the MSSM Higgs couplings to SM fermions

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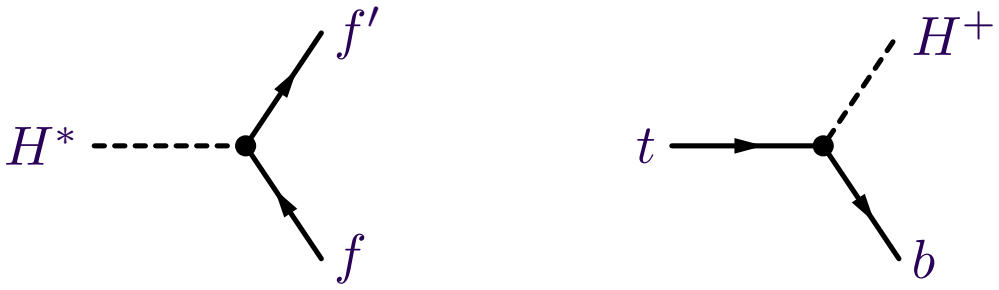
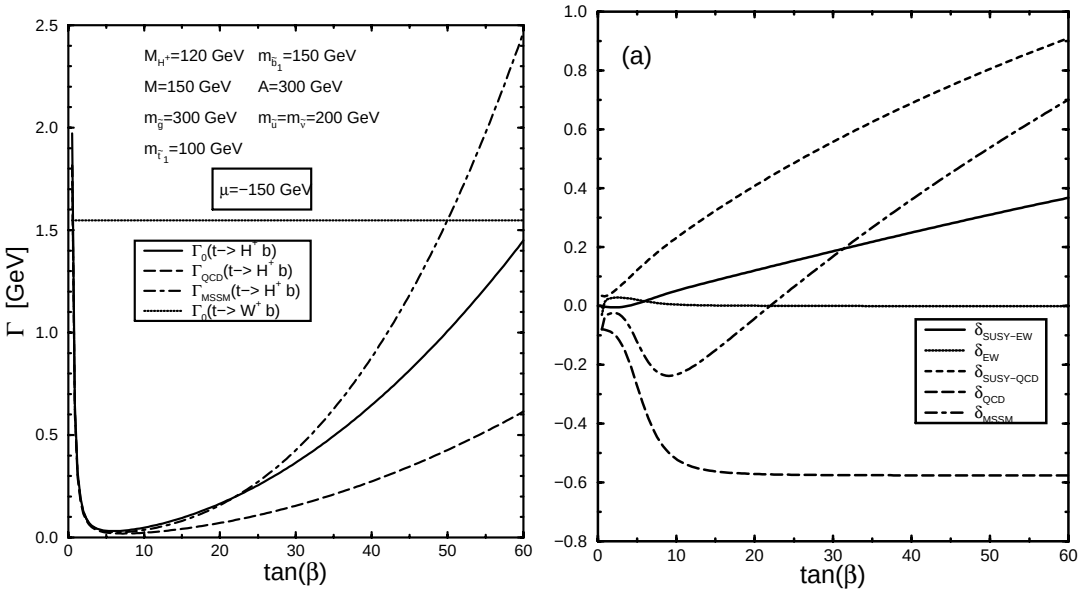
Outline

- Introduction
- Resummation of SUSY corrections
- Applications
  - $pp, p\bar{p} \longrightarrow \bar{t}bH^+$
  - $b \longrightarrow s\gamma$
- Conclusions



- Relevant for most Higgs prod./decay channels
- Large SUSY corr. to such couplings/observables



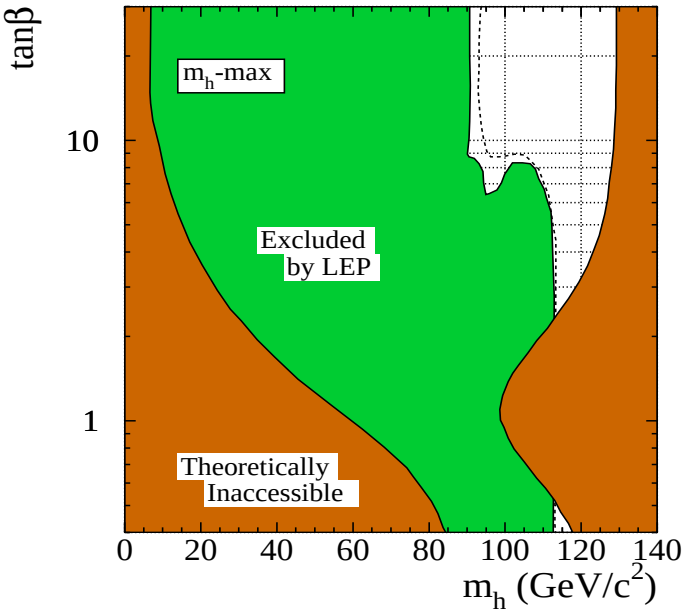
SUSY-QCD: Jiménez, Solà '96; Bartl et al. '96

SUSY-EW: Coarasa, DG, Guasch, Jiménez, Solà '98

- Is the perturbative computation reliable?

Motivation for large $\tan\beta$

Report of the HWG to the LEPC, July '00



- Theoretically appealing:

  top-bottom-[tau] Yukawa unification in minimal SO(10) models require $\tan\beta \sim 30 - 50$

  (Banks '88, Olechowski, Pokorski '88, ...)

For large $\tan\beta \gtrsim 10$, SUSY-QCD, -EW corrections

- are dominated by bottom-mass renormalization effects

- can be $\mathcal{O}(1) \Rightarrow$ need for resummation

Effective lagrangian approach

- Due to the holomorphy of the MSSM superpotential

$$\mathcal{L} = -h_b\, \bar{b}b\, H_1^0 - h_t\, \bar{t}t\, H_2^0 + \cdots$$

"Forbidden" couplings, $\bar{b}bH_2^0$, $\bar{t}tH_1^0$, are radiatively generated by soft-SUSY-breaking interactions.

- In the eff. lagrangian language ($M_{\rm SUSY} > M_H, m_t$)

$$\mathcal{L}_{\rm eff} = -(h_b + \Delta h_b^1)\, \bar{b}bH_1^0 - (0 + \Delta h_b^2)\, \bar{b}bH_2^0 + \cdots$$

After EWSB, for $\tan\beta \gg 1$, Δh_b^2 can induce $\mathcal{O}(1)$ corr. to down-type fermion masses

$$\boxed{m_b = h_b\, v_1\, \left(1 + \Delta h_b^1/h_b + \Delta h_b^2/h_b \tan\beta\right)}$$

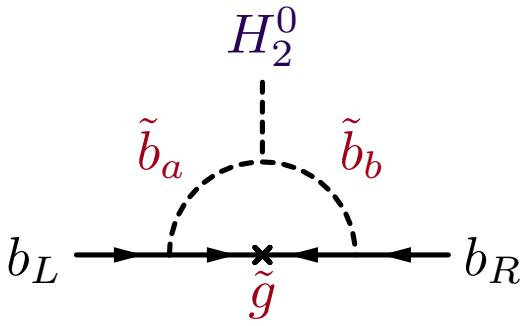
- (Hall, Rattazzi, Sarid '94; Hempfling '94; Carena et al. '94)

$$h_b v_1 = \frac{m_b}{1 + \Delta h_b^1/h_b + \Delta h_b^2/h_b \tan\beta} \sim \frac{m_b}{1 + \Delta m_b}$$

$\Rightarrow$ Well defined pert. bound on the corrections

$\tan\beta$-enhanced SUSY corrections

Δh_b^2 (Δm_b) is SUSY-QCD dominated:



$$\Delta m_b \sim \Delta m_b^{\rm SQCD} = \frac{2\alpha_s}{3\pi}\,\mu M_g\,\tan\beta\, I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}})$$

Important properties of these effects are:

- the relation $g_{hbb}/g_{h\tau\tau} = m_b/m_\tau$ is broken
- they do not vanish for $\mu = M_{\rm SUSY} \to \infty$
- all order SUSY-QCD of the form $(\alpha_s \tan\beta)^n$ are absorbed into the def. of the ren. Yukawa coupling, h_b (Carena, D.G., Nierste, Wagner)

  Reliability of the perturbation series for Yuk. related observables is recovered

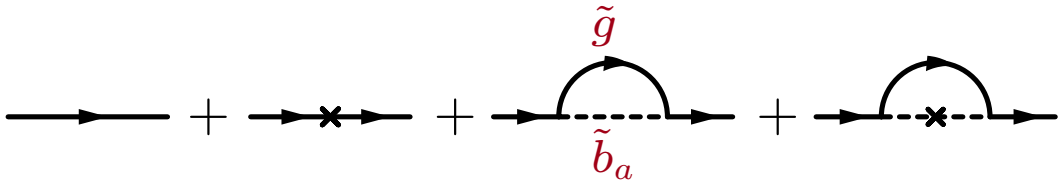
The $\bar{t}bH^+$ interaction reads, for large $\tan\beta$

$$\frac{m_b \tan\beta}{(1+\Delta m_b)\,v}\, H^+ \bar{t}\,{\rm P_R} b$$

Sketch of a proof

- Consider the definition of the renorm. bottom Yuk. coupling, i.e.

  require a zero of the inverse bottom propagator at physical m_b



- "Beyond-one-loop" diagrams suppressed either by $1/\tan\beta$ or $m_b \tan\beta / M_{\rm SUSY}$ with respect to Δm_b

- Translates into

$$h_b v_1 + \delta h_b v_1 + \tilde{h}_b v_1 \, \Delta m_b + \delta \tilde{h}_b v_1 \, \Delta m_b = m_b .$$

- SUSY is restored in the ultraviolet

  $h_b + \delta h_b = \tilde{h}_b + \delta \tilde{h}_b$

$$\Rightarrow \boxed{(h_b + \delta h_b) v_1 = m_b^{\rm R} + \delta m_b = \frac{m_b}{1 + \Delta m_b}}$$

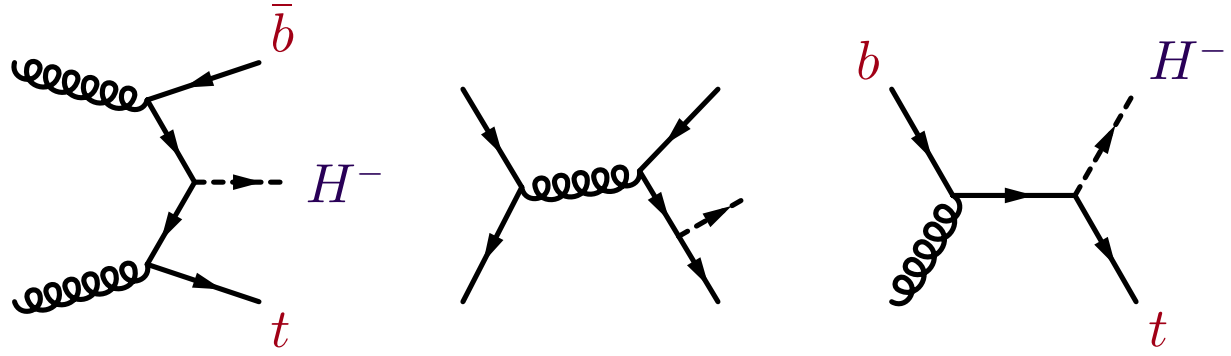
$H^\pm$ production in association with t, b at the Tevatron and the LHC

S. Belyaev, J. Guasch, D.G. and J. Solà, in preparation

- For $m_t > M_{H^+}$, H^+ searches at hadron colliders focus on $t \to H^+ b$
- Beyond that region, the $2 \to 3$ process, $pp, p\bar{p} \to t\bar{b}H^-[\bar{t}bH^+]$, looks promising
- SUSY quantum corr. can enhance [suppress] the signal by $\mathcal{O}(1)$ factors $\Rightarrow$ extended reach in M_{H^+}
- Conversely, H^+ detection would provide info on the nature of the Higgs sector
- Complementarity with neutral Higgs prod. processes, e.g., $W\Phi$ and $b\bar{b}\Phi$
  (Carena, Mrenna, Wagner '98)
- J. Solà talk, Fermilab '98
  Coarasa, Guasch, Solà '99
- Borzumati, Kneur, Polonsky '99; Miller et al. '00, . . .

$$\sigma(pp, p\bar{p} \to t\bar{b}H^-[\bar{t}bH^+])$$

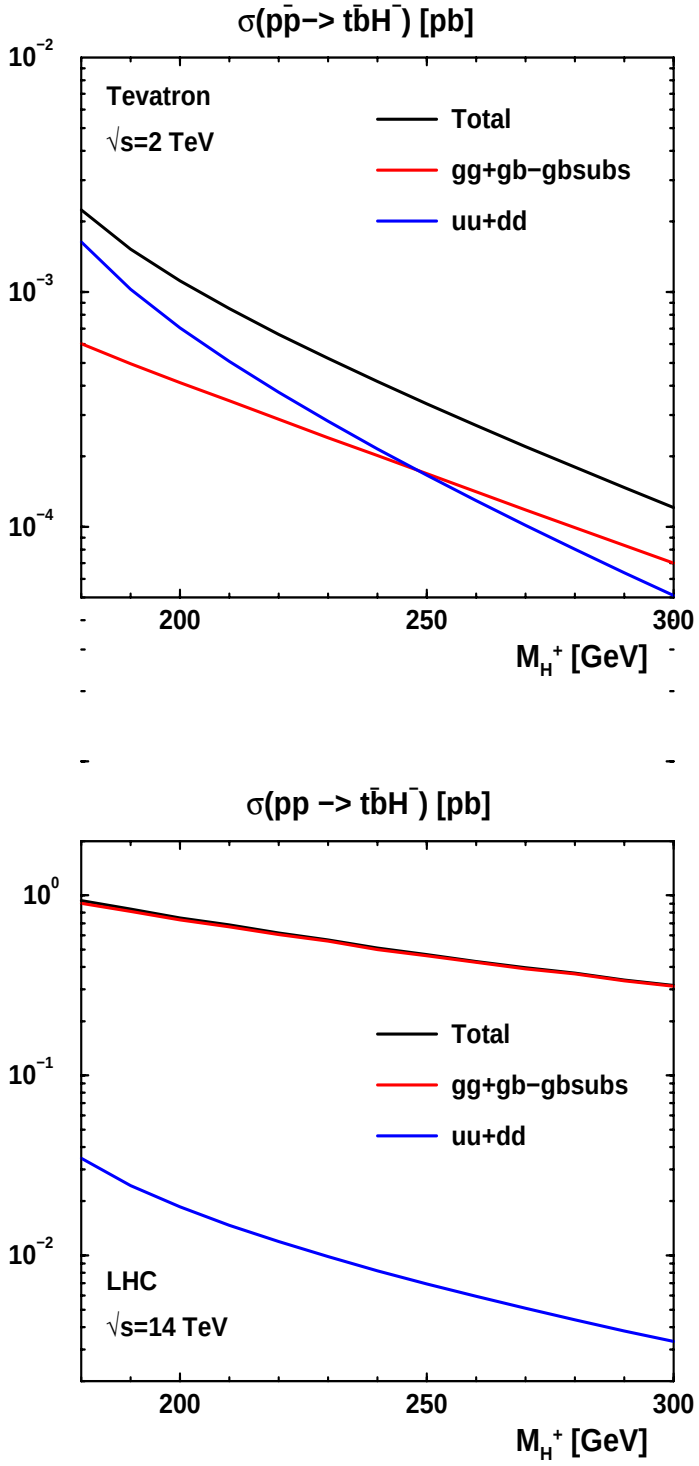
- Parton level subprocesses

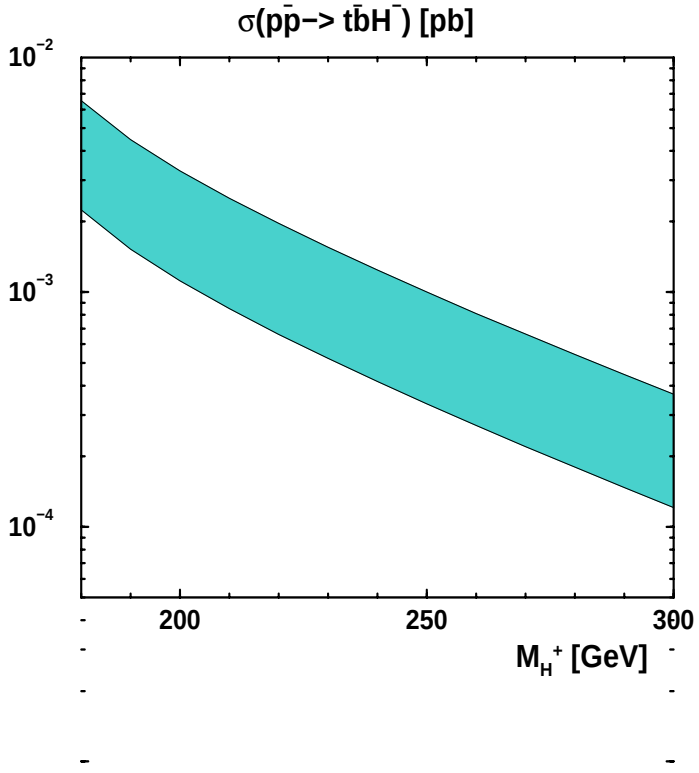


- Proper sum of gg and gb (Dicus et al. '98)
- Use of "improved" h_b Yukawa coupling
- $\overline{\rm MS}$-scheme, with $\overline{m}_b(Q)$, $\alpha_s(Q)$, $Q = m_t + M_{H^-}$
- No SUSY corr. to gqq, ggg couplings, no boxes...
- Off-shell effects: CompHEP + Reduce + analytic expressions for the ren. $t\bar{b}H^-$ vertex and quark propagators
- NLO QCD corrected cross-section yet unknown
- Background analysis in progress

$\mu = -200$ GeV $\quad M_{\tilde{g}} = 500$ GeV $\quad \tan\beta = 30$

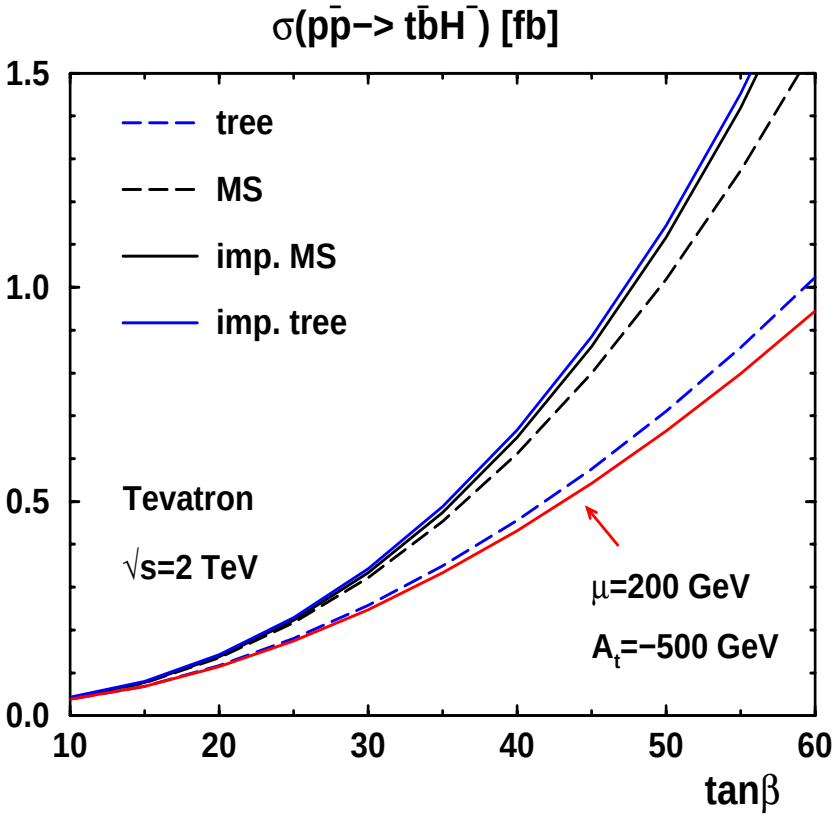
$m_{\tilde{t}_1} = m_{\tilde{b}_1} = A_b = A_t = 500$ GeV




σ(pp̄−> tb̄H⁻) [pb]
10⁻²
10⁻³
10⁻⁴
200
250
300
M_H⁺ [GeV]

$\mu = -200$ GeV $\quad M_{\tilde{g}} = 500$ GeV $\quad \tan\beta = 30$

$m_{\tilde{t}_1} = m_{\tilde{b}_1} = A_b = A_t = 500$ GeV



$\Rightarrow$ all relevant SUSY corrections are reproduced by

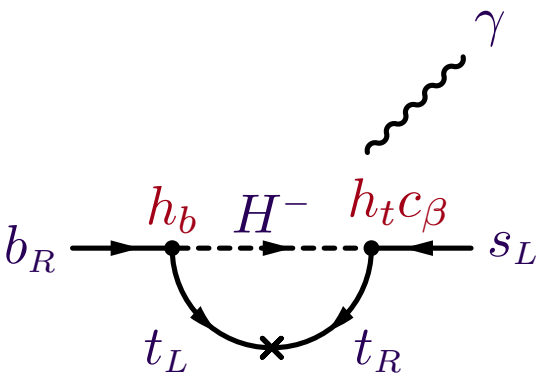
$$\sigma_{\rm tree}[m_b/(1+\Delta m_b)]$$

Improved NLO $\mathcal{BR}(b \to s\gamma)$

M. Carena, D.G., U. Nierste and C.E.M. Wagner, in prep.

NLO formulae from Ciuchini, Degrassi, Gambino, Giudice '98

- Consider the dominant LO corrections to C_7, C_8 in the MSSM (H^-, χ^- diagrams)



- H^- : $h_b h_t c_\beta \propto 1$
- χ^- : $h_b h_t \propto \tan\beta$

- Dominant (in $\tan\beta$) NLO corrections follow from $h_b \to -h_b\,\Delta m_b$ in the LO

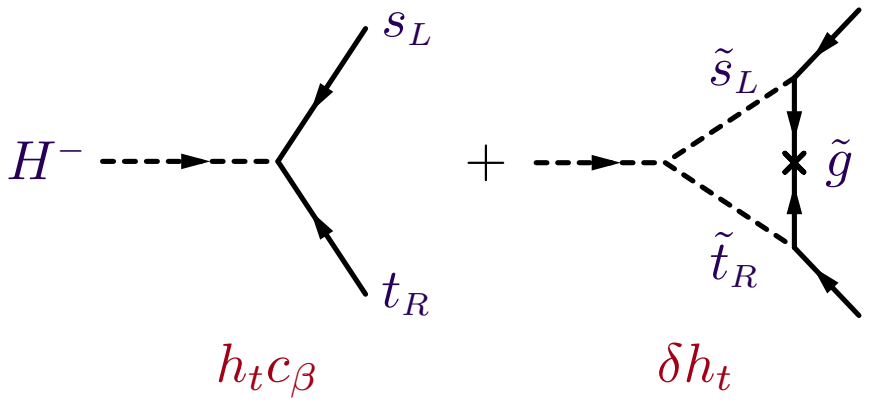
  $\Rightarrow \alpha_s \tan^2\beta$ correction in χ^-
  $\Rightarrow \alpha_s \tan\beta$ correction in H^-

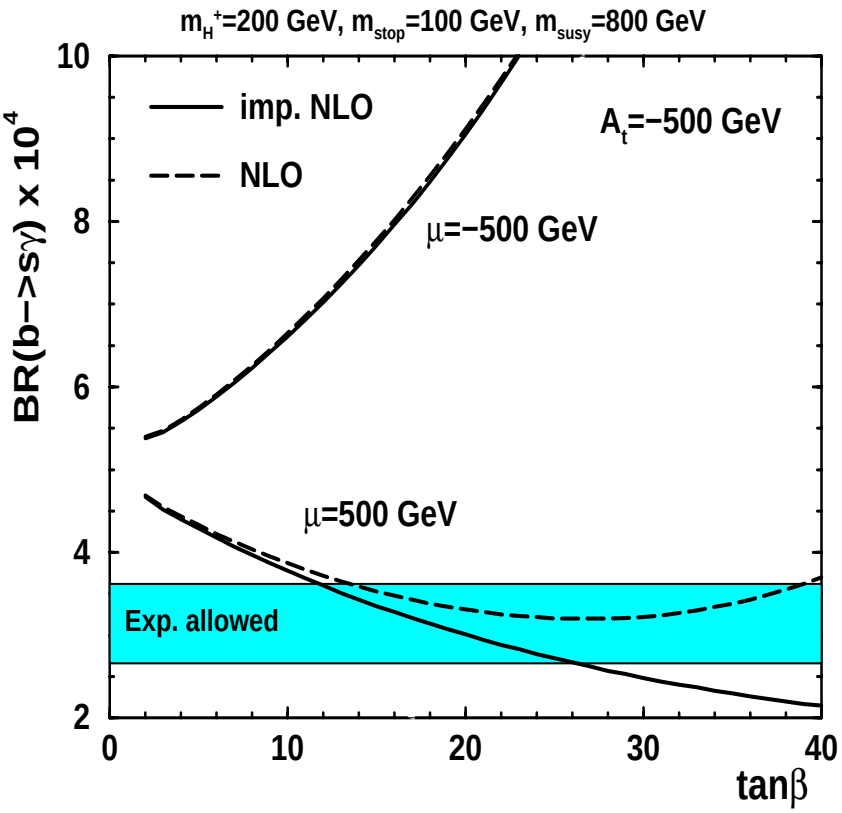
- Improvement:

  - In the LO, replace $h_b \to h_b/(1+\Delta m_b)$
  - In the NLO, remove $-h_b\,\Delta m_b$ terms

$\mathcal{BR}(b \to s\gamma)$

- Extra $\alpha_s \tan\beta$ correction to $h_t c_\beta$





- Both at LO and NLO, $\mu A_t < 0$ is favoured

Conclusions

- Potentially $\mathcal{O}(1)$ SUSY-QCD and SUSY-EW corrections affect Yukawa-related observables in the MSSM

- For large $\tan\beta$ values, leading $(\alpha_s \tan\beta)^n$ terms have to be resummed to all orders, absorbing the corrections into the renormalized bottom Yukawa coupling

- Using this result, we have computed the cross-section for $pp, p\bar{p} \to t\bar{b}H^-[\bar{t}bH^+]$ in the MSSM, including off-shell SUSY corrections to the $t\bar{b}H^-$ vertex and to the quark propagators

- For large $\tan\beta$, $\sigma_{\text{tree}}[m_b/(1+\Delta m_b)]$ gives a good approximation to the full calculation. The cross-section is sizeably enhanced for negative Δm_b, extending the Tevatron reach in M_{H^+} for this channel

- Leading (in $\tan\beta$) NLO corrections to $\mathcal{BR}(b \to s\gamma)$, in the MSSM, come from the SUSY-QCD renormalization of the bottom Yukawa coupling. We have shown how to resum these contributions and the resulting change in the $\mathcal{BR}$ value

- Due to the partial cancellation between H^+ and χ^+ diagrams, the effect is more important for the favoured region of MSSM parameters, with $\mu A_t < 0$