

MSSM HIGGS PRODUCTION

Michael Spira (PSI)

Theory convenors: Robert Harlander, Michael Krämer, Pietro Slavich,
Michael Spira

Experimental convenors: Monica Vazquez Acosta (CMS), Martin Flechl
(ATLAS), Sami Lehti (CMS), Trevor Vickey (ATLAS)

Group members: S. Dittmaier, R. Harlander, S. Heinemeyer, M. Krämer,
P. Slavich, M. Spira, M. Vazquez Acosta, T. Vickey

I INTRODUCTION

MSSM

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

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

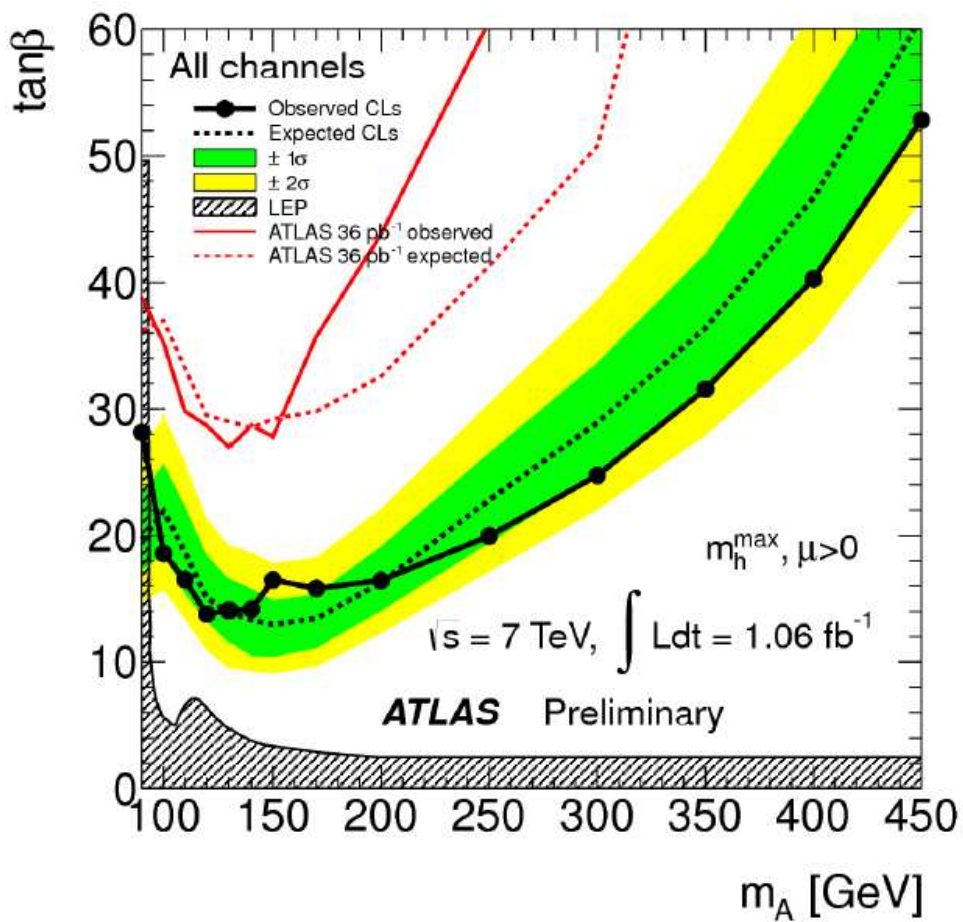
- radiative corrections $\propto m_t^4 \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} \rightarrow \boxed{M_h \lesssim 135 \text{ GeV}}$

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

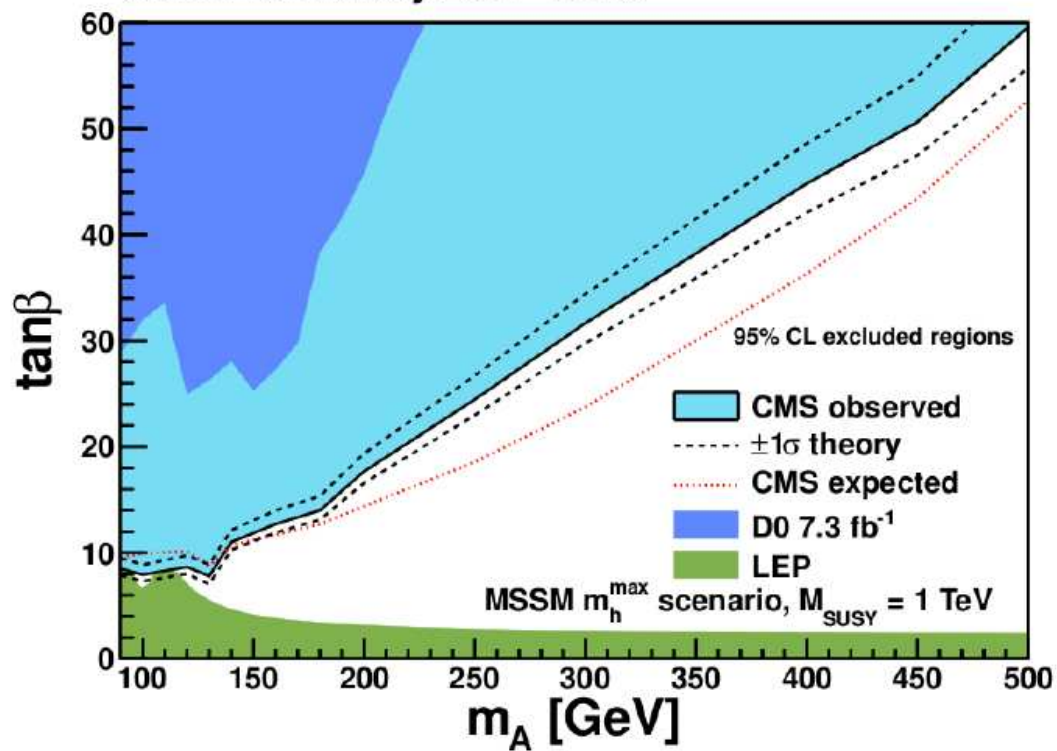
- Yukawa couplings: $\text{tg}\beta \uparrow \Rightarrow g_u^\phi \downarrow \quad g_d^\phi \uparrow \quad g_V^\phi \downarrow$

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

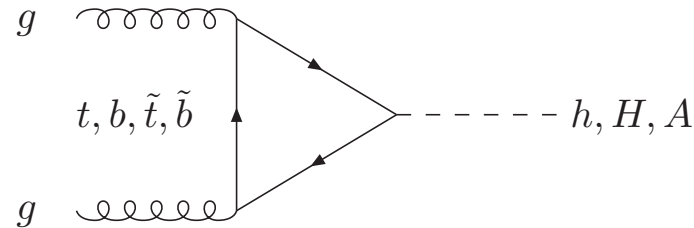
$$gg \rightarrow b\bar{b}\phi^0, \quad gg \rightarrow \phi^0 \quad \phi^0 \rightarrow \tau^+\tau^-$$



CMS Preliminary 2011 1.6 fb⁻¹



Gluon-fusion



$$\begin{aligned} \sigma^{MSSM}(gg \rightarrow \phi) &= \left(\frac{g_t^{MSSM}}{g_t^{SM}} \right)^2 \sigma_{tt}(gg \rightarrow \phi) + \left(\frac{g_b^{MSSM}}{g_b^{SM}} \right)^2 \sigma_{bb}(gg \rightarrow \phi) \\ &+ \frac{g_t^{MSSM}}{g_t^{SM}} \frac{g_b^{MSSM}}{g_b^{SM}} \sigma_{tb}(gg \rightarrow \phi) \end{aligned}$$

$$\begin{aligned} \Delta\sigma_{tt}^{NNLO}(gg \rightarrow \phi) &= \Delta K_{NNLO} \sigma_{tt}^{LO}(gg \rightarrow \phi) \\ \Delta K_{NNLO} &= \frac{\sigma_{NNLO}^0 - \sigma_{NLO}^0}{\sigma_{LO}^0} \end{aligned}$$

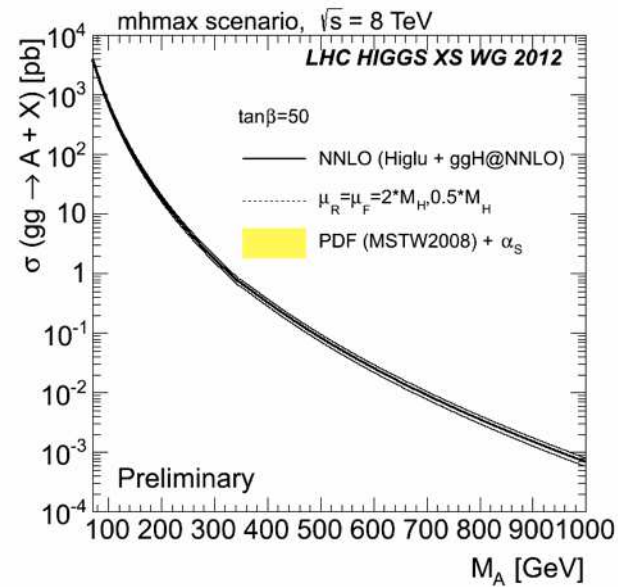
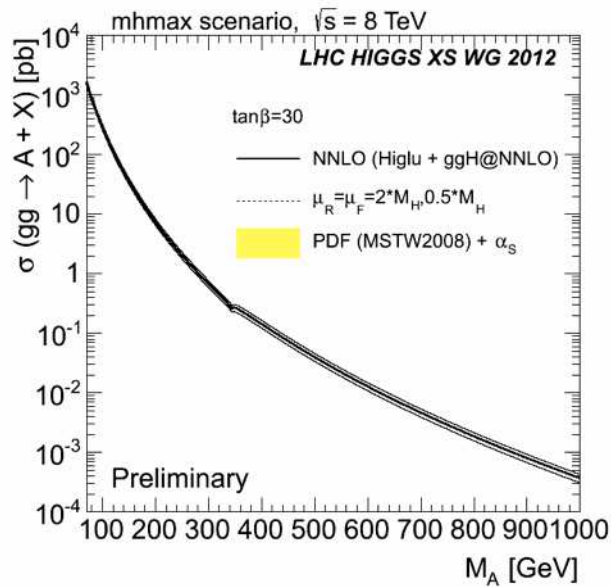
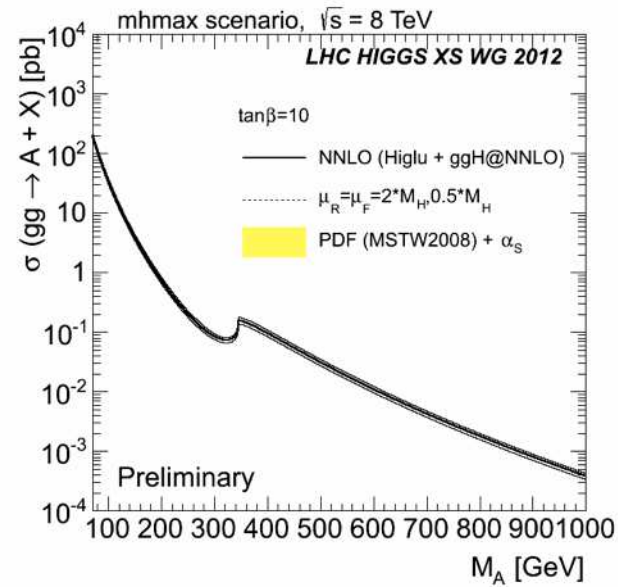
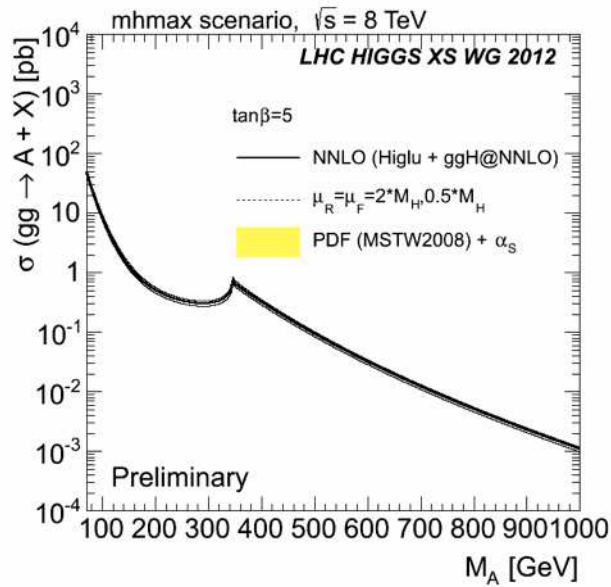
- cross sections: HIGLU & ggh@nnlo

Spira
Harlander, Kilgore

- MSSM couplings: FeynHiggs

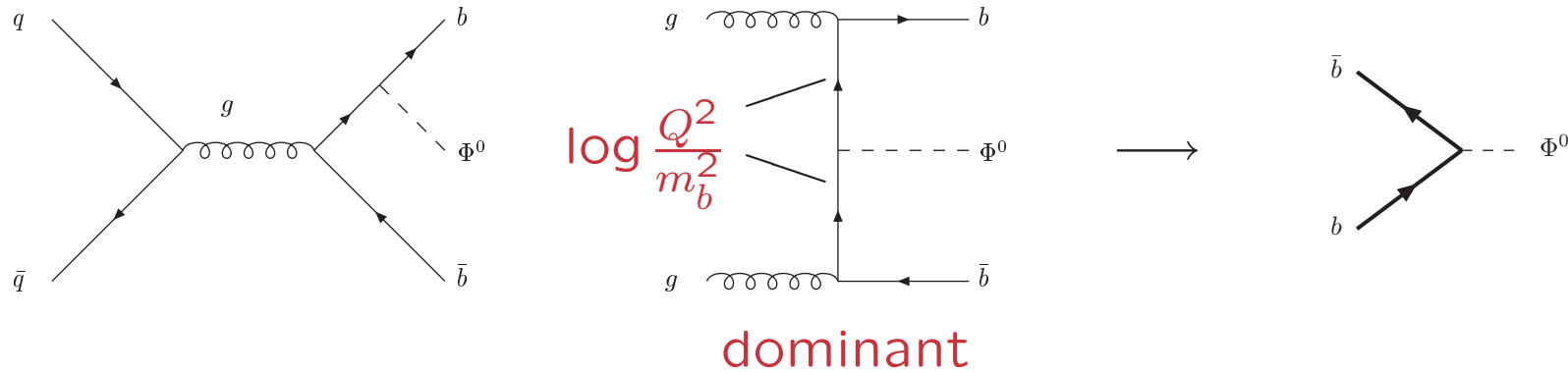
Hahn, Heinemeyer, Hollik, Rzehak, Weiglein

- m_h^{max} scenario: small SUSY contributions



- overall scale + PDF + α_s uncertainties: $\sim 15\%$

$b\bar{b}$ +Higgs production

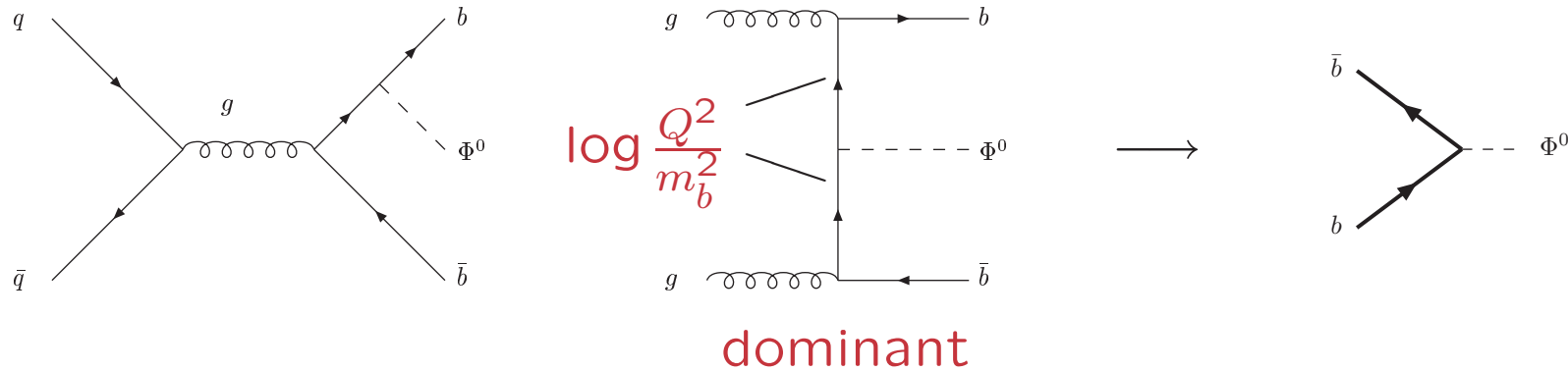


large logs from phase space integration \longrightarrow bottom PDF
 resummation \equiv DGLAP evolution $Q \sim \frac{1}{4} \dots \frac{1}{10} M_H$

5-Flavour Scheme

- massive top, gluinos and squarks decoupled from α_s
 \longrightarrow 5 active flavours
- PDF: $\overline{\text{MS}}$ scheme [5 flavours]
- grids H, A : 80-200 GeV: $\Delta = 5$ GeV, 200-1000 GeV: $\Delta = 20$ GeV
 scale uncertainties, PDF + α_s uncertainties

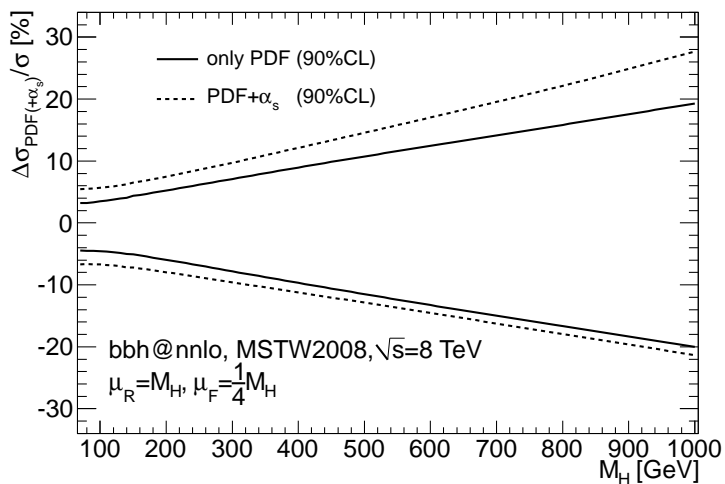
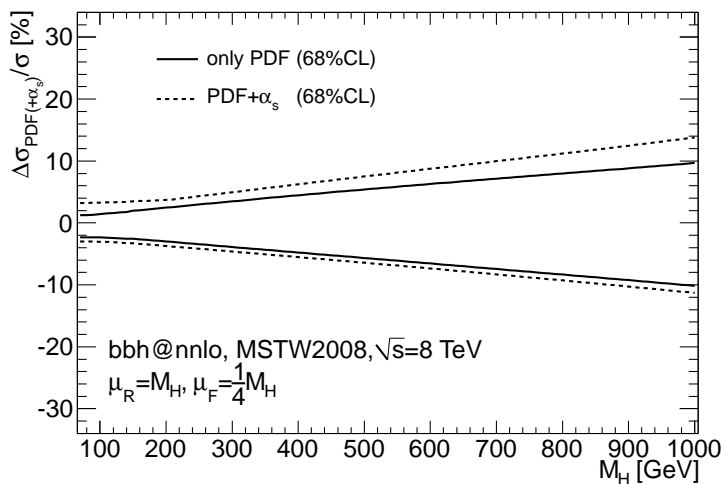
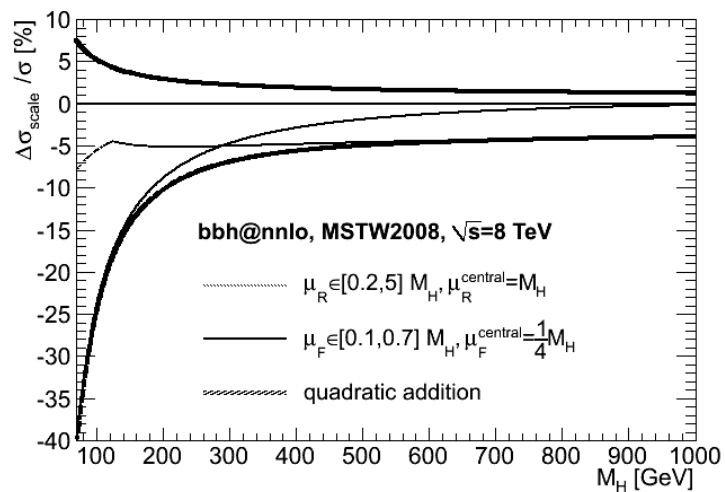
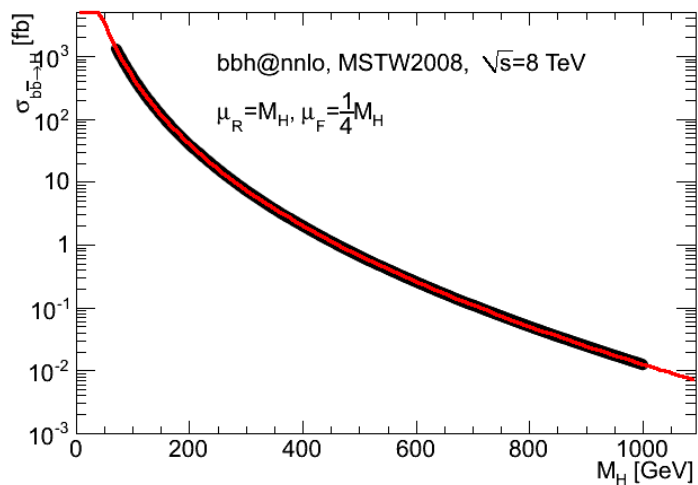
$b\bar{b}$ +Higgs production

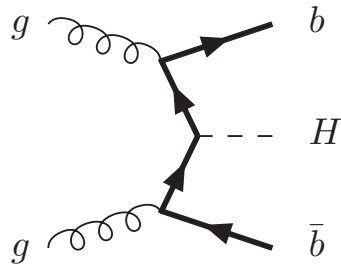


large logs from phase space integration \longrightarrow bottom PDF
 resummation \equiv DGLAP evolution $Q \sim \frac{1}{4} \dots \frac{1}{10} M_H$

4-Flavour Scheme

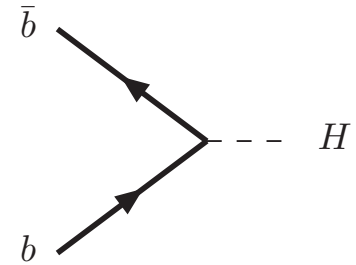
- massive top, bottom, gluinos and squarks decoupled from α_s
 \longrightarrow 4 active flavours
- PDF: $\overline{\text{MS}}$ scheme [4 flavours] \longrightarrow no b -PDF
- grids H, A : 80-200 GeV: $\Delta = 5$ GeV, 200-1000 GeV: $\Delta = 20$ GeV
 scale uncertainties
- error PDFs: not yet done





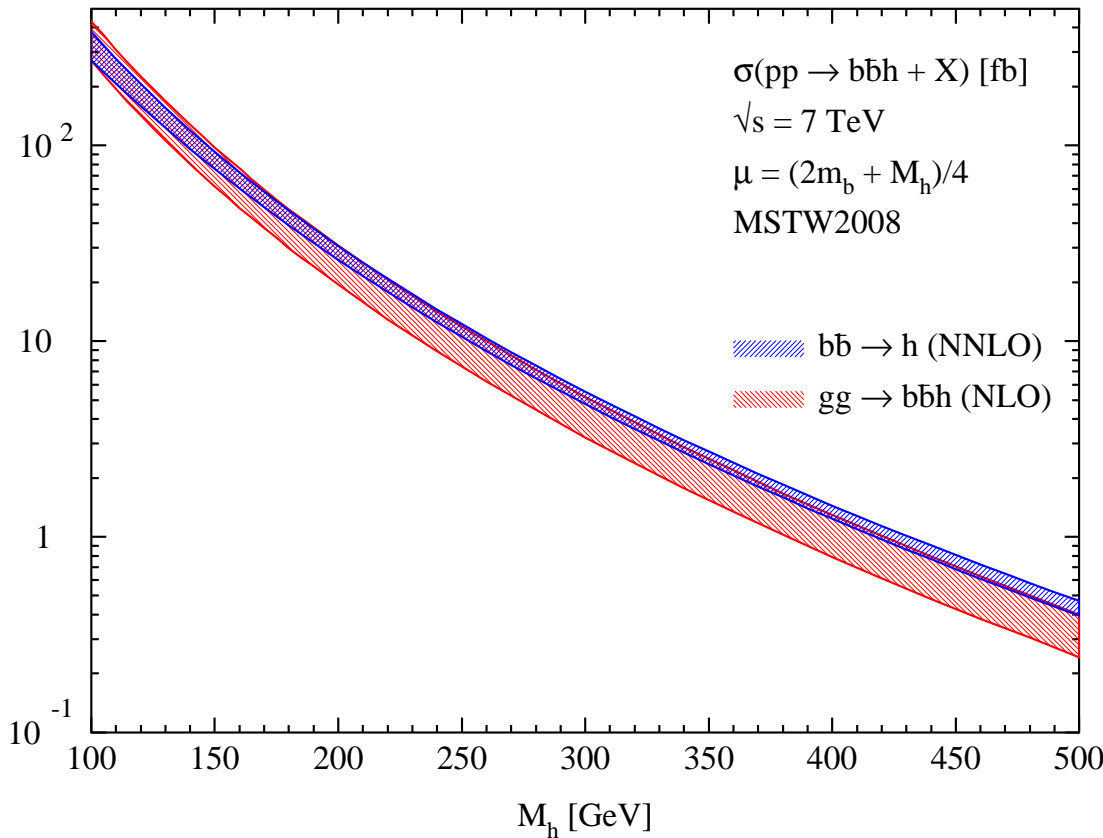
NLO

exact $g \rightarrow b\bar{b}$ splitting & mass/off-shell effects
no resummation of $\log M_H^2/m_b^2$ terms



NNLO

massless/on-shell b 's, no p_{Tb}
resummation of $\log M_H^2/m_b^2$ terms



Santander matching:

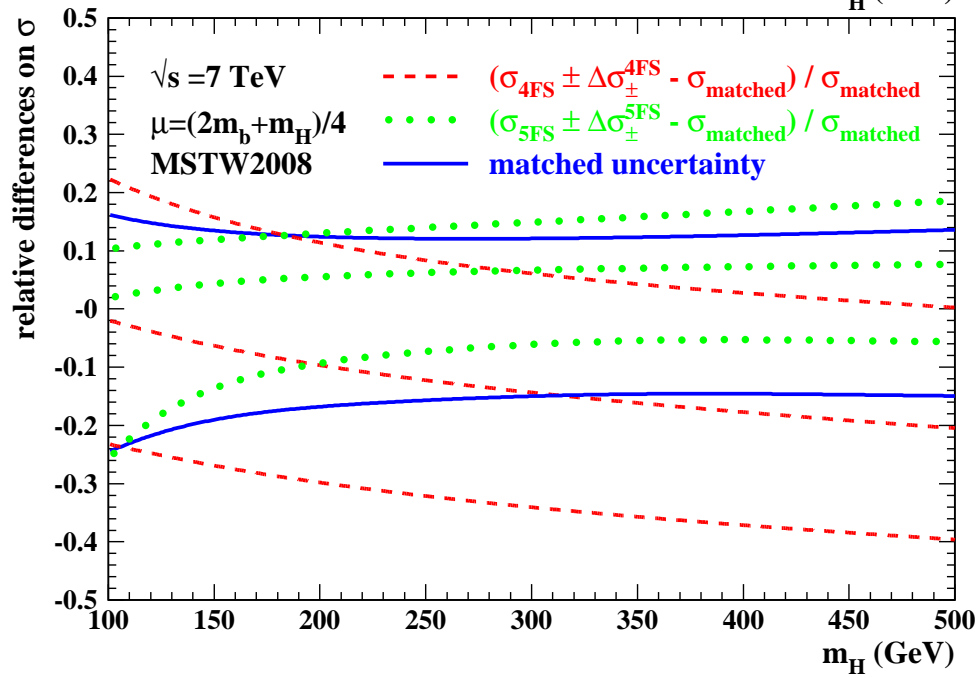
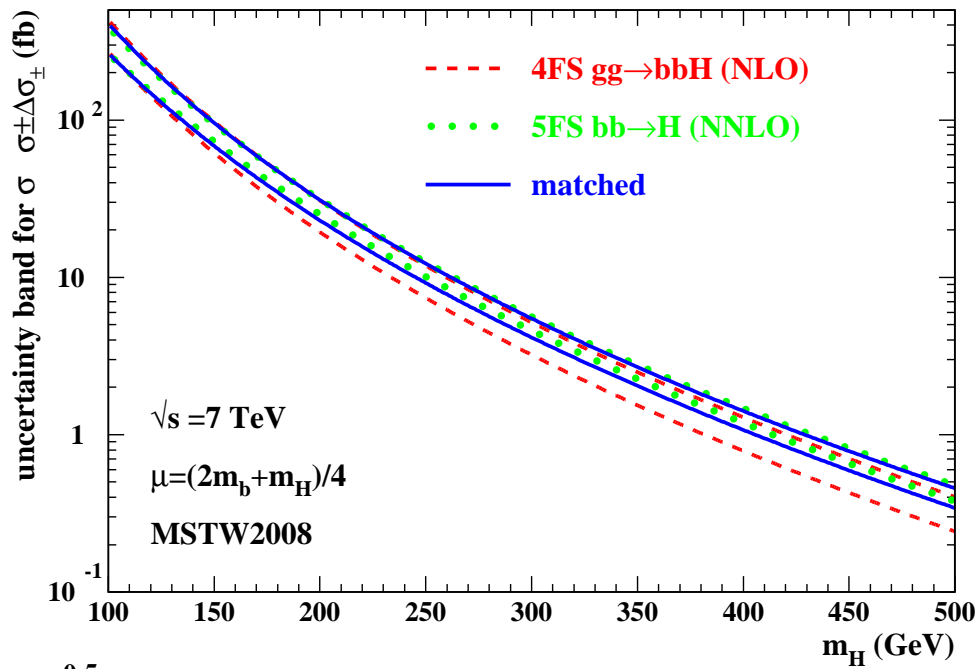
$$\sigma = \frac{\sigma^{4FS} + w\sigma^{5FS}}{1 + w}$$

$$w = \log \frac{M_H}{m_b} - 1$$

Harlander, Krämer, Schumacher

Dittmaier, Krämer, S. Dawson, Jackson, Reina, Wackerroth

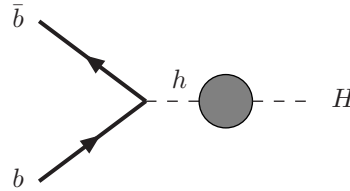
Harlander, Kilgore



Harlander, Krämer, Schumacher

- rescale with Yukawa coefficients

- Z-matrix



Hahn, Heinemeyer, Hollik, Weiglein

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

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

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

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

⇒ resummed Yukawa couplings

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

- NNLO: $\mathcal{O}(10\%)$, $\mu = M_{SUSY}$

Noth, S.
Mihaila, Reisser

- approximation of NLO SUSY-QCD corrections $< 1\%$ @ large $\text{tg}\beta$

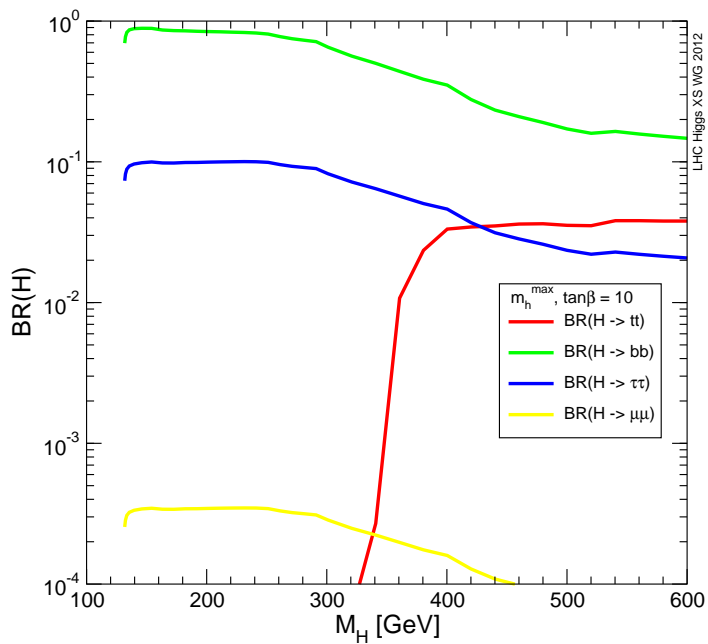
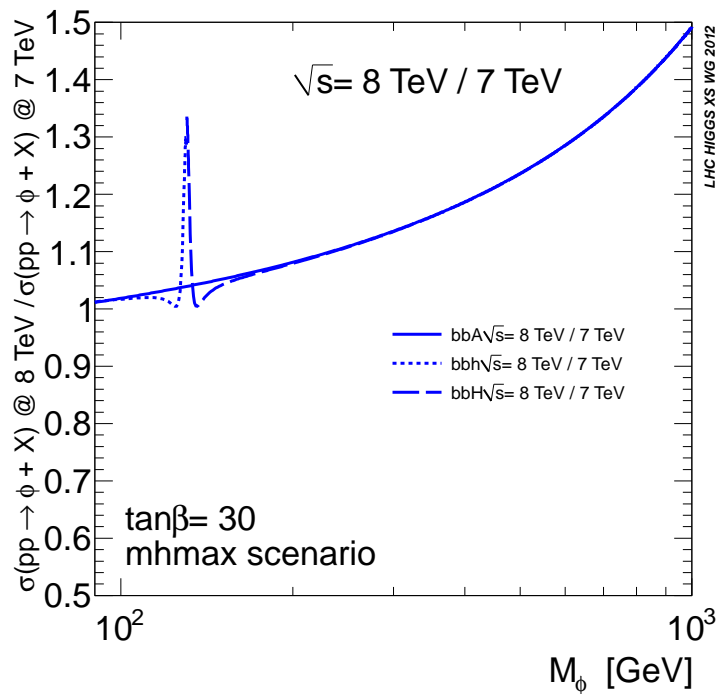
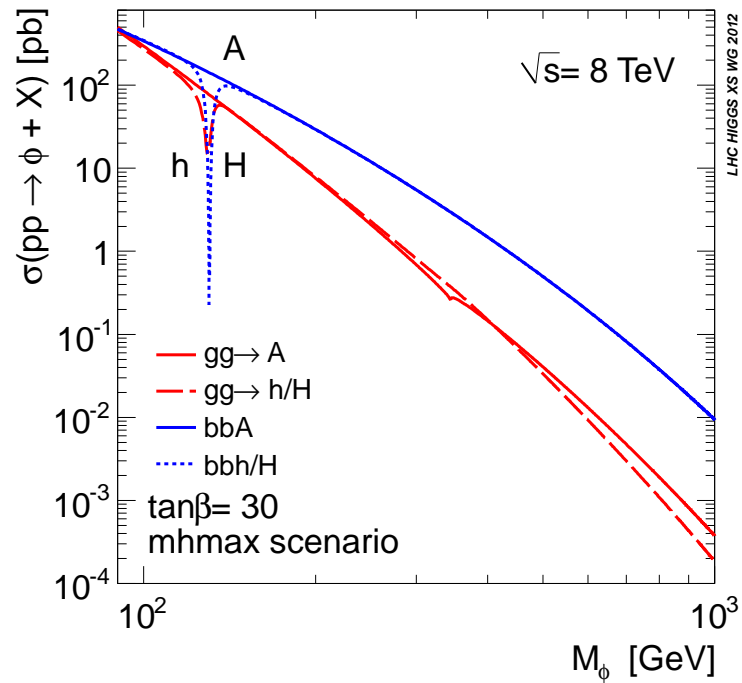
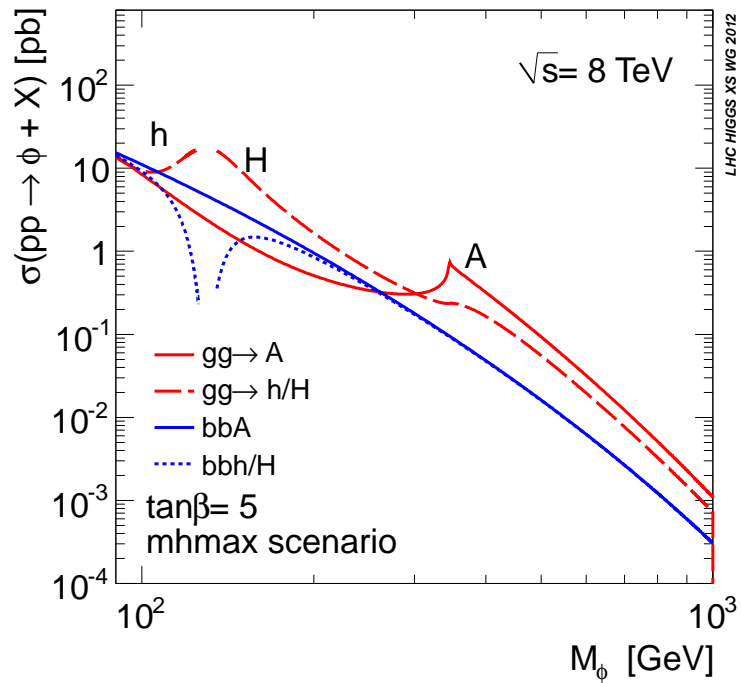
Dittmaier, Häfliger, Krämer, S., Walser

$$\underline{pp \rightarrow b\bar{b}H + X}$$

- virtual top loops $\mathcal{O}(10\%)$ @ small $\text{tg}\beta$

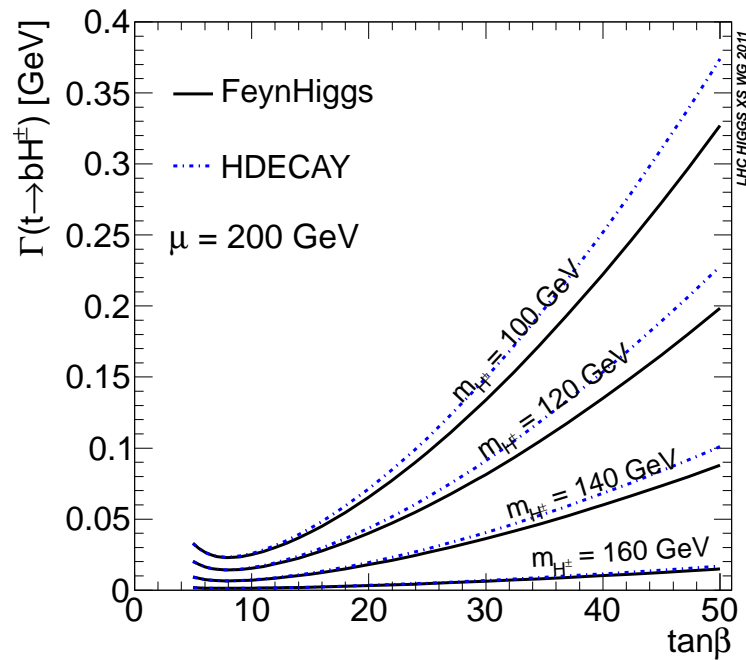
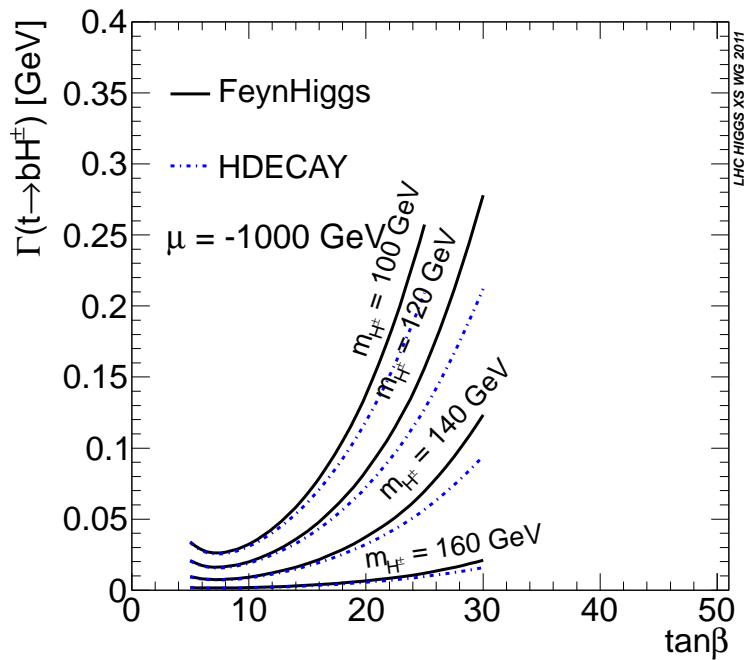
$$\underline{pp \rightarrow t\bar{b}H^- + X}$$

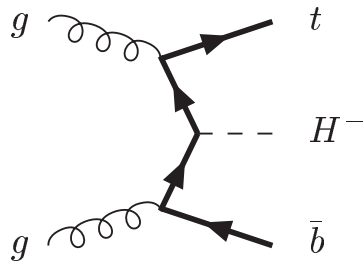
$\text{tg}\beta$	$\delta_{SUSY}^{rem} [\%]$
3	-5.7%
5	-7.9%
10	-4.8%
30	-0.13%



$pp \rightarrow t\bar{b}H^- + X$

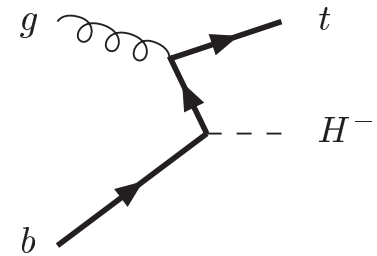
- $M_{H^\pm} < m_t - m_b$: $\sigma_{t\bar{b}H^-} = \sigma_{t\bar{t}} \times BR(\bar{t} \rightarrow \bar{b}H^-)$
- off-shell effects? threshold effects? sufficient for exclusion?





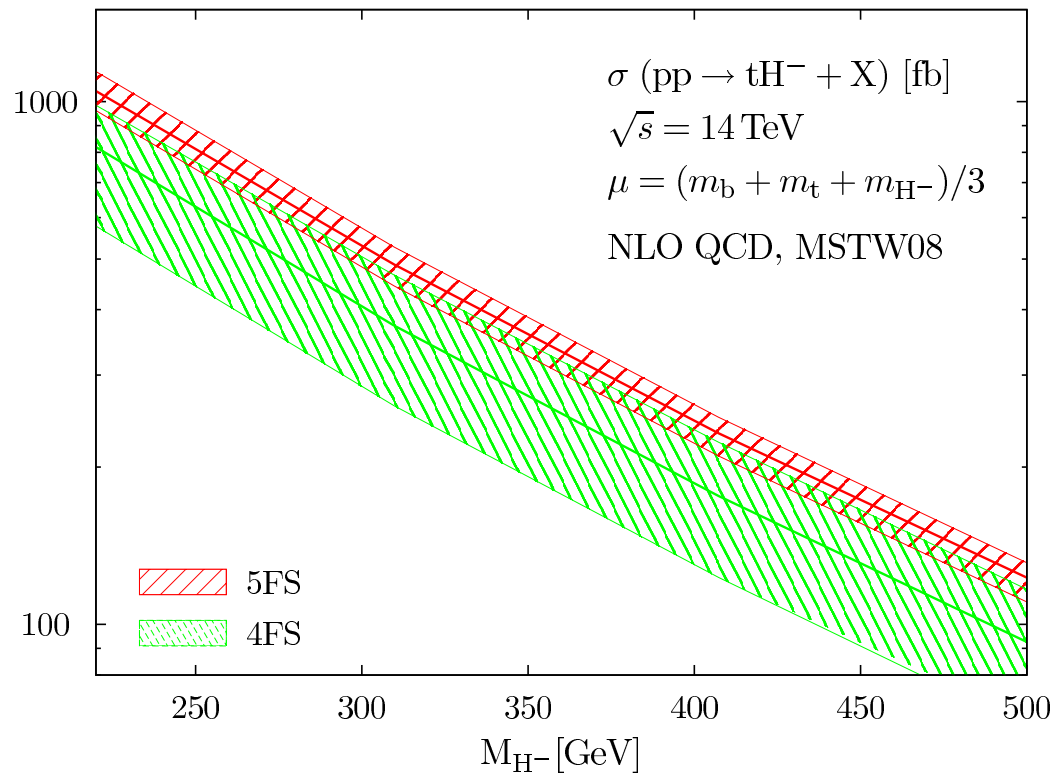
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→ Santander matching

Dittmaier, Krämer, S., Walser
 Plehn

SUMMARY

$gg \rightarrow \phi^0$

- grids for central + errors [scale+PDF+ α_s] available

$b\bar{b}\phi^0$

- 4FS: QCD corrections $\lesssim 100\%$ for total cxn
 $\Rightarrow \Delta \lesssim 30\%$ [only scale]
- SUSY-QCD corrections: small after resummation [Δ_b] for large $\text{tg}\beta$
- grids for 4FS central + scale error available for H and A
- 5FS: QCD corrections moderate for total cxn
 $\Rightarrow \Delta \lesssim 10 - 20\%$ [scale+PDF+ α_s]
- grids/parametrizations for 5FS central + errors [scale+PDF+ α_s] available
- linked to BR calculations