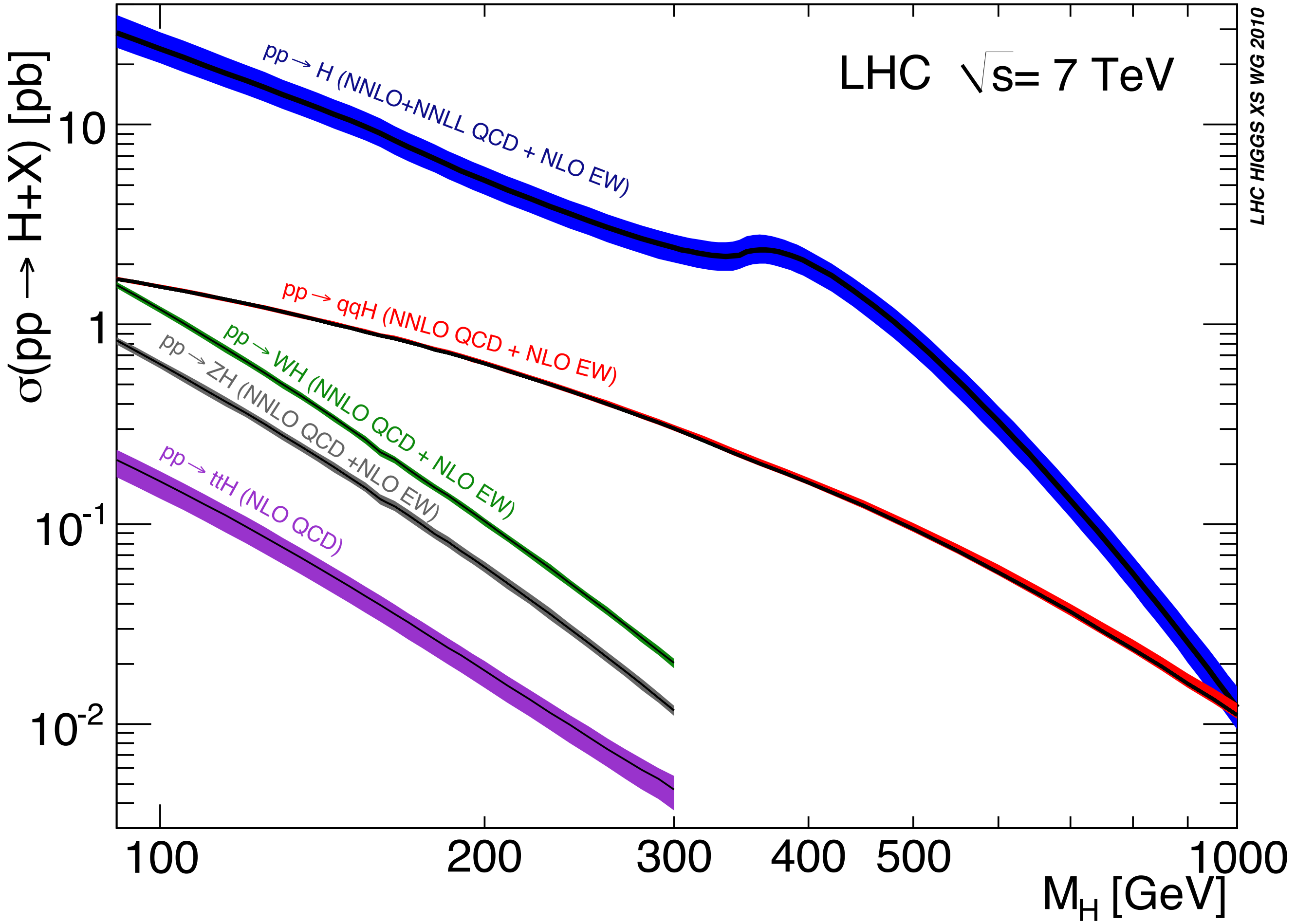
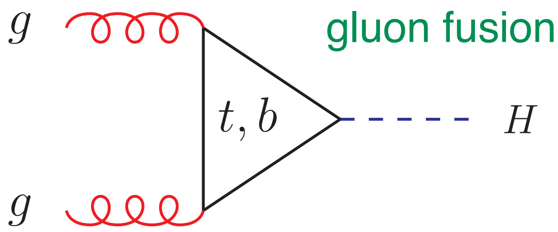
A crash course on Higgs boson production

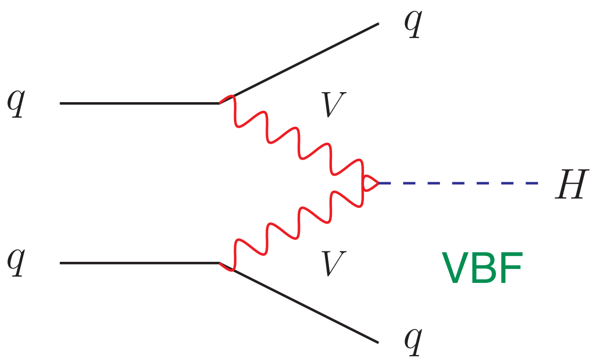
Higgs boson production at hadron colliders

SM predictions for the different channels:

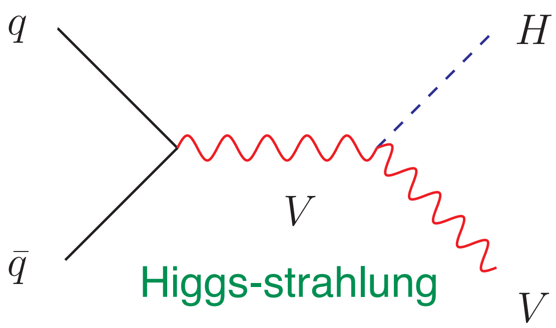




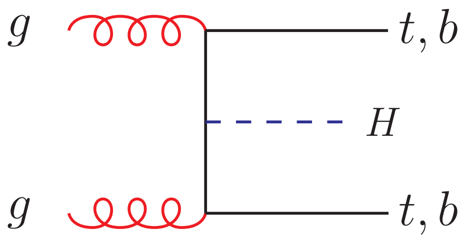
gluon fusion



VBF



Higgs-strahlung



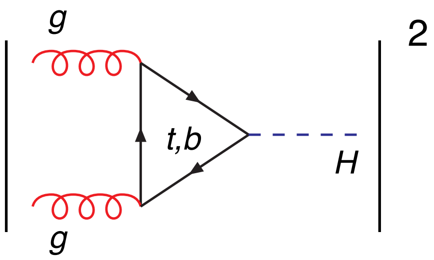
associated prod. with top/bottom

In the SM, gluon fusion is the dominant production channel (in the MSSM, also associated production with bottom)

A precise computation of the cross sections is crucial to the interpretation of the Higgs searches

Higgs boson production in gluon fusion

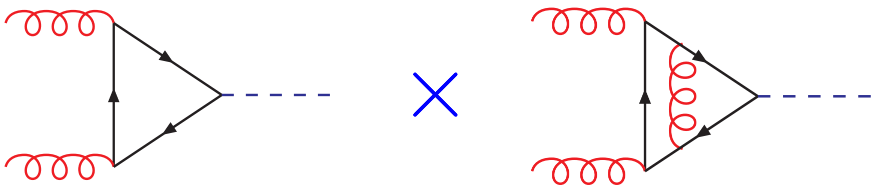
The LO cross section is $\mathcal{O}(\alpha_s^2)$:



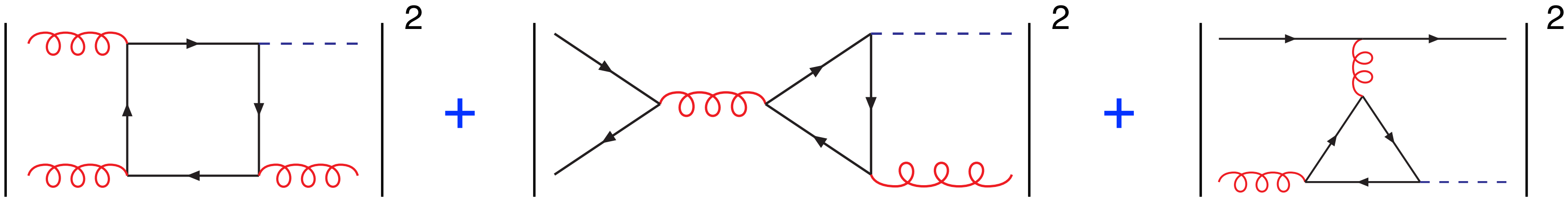
In the SM the top loops give the dominant contribution, bottom loops contribute ≈ 5%

The NLO $\mathcal{O}(\alpha_s^3)$ corrections are crucial, they can be as large as 100%

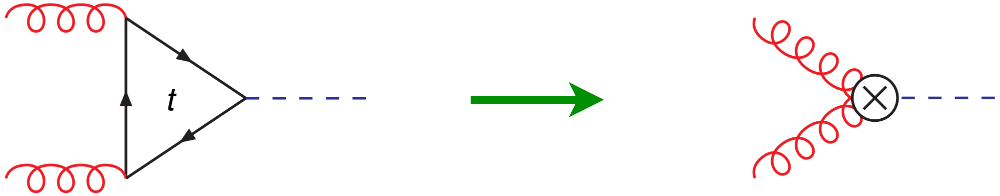
Virtual contribution
(interference term):



Real contributions:

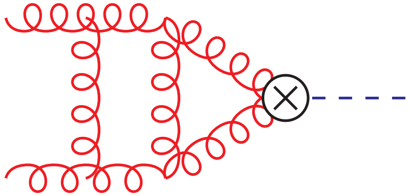


When $m_H << m_t$ (vanishing Higgs-mass limit, or VHML) we can integrate out the top quark



$$\mathcal{L}_{\rm eff} \;=\; -\,C_g\,\frac{H}{v}\,G^{a\,\mu\nu}\,G^{a}_{\mu\nu}$$

The effective *Hgg* vertex is then used in higher-order calculations:



(e.g. NNLO QCD)

For $m_H = 125$ GeV the VHML provides a good approximation of the top-quark contributions (effect of non-infinite top mass estimated to be small)

OTOH, the VHML cannot be applied to the contribution of the bottom quark (because $m_H >> m_b$)

The SM cross section for Higgs production is known exactly at NLO QCD (top+bottom)

\+ NNLO-QCD top contributions in the VHML + EW corrections + NNLL soft-gluon resummation

(uncertainties from scale, α_s and PDFs still large in the SM calculation, of order 15-20%)

However...

DCPT/13/30
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Edinburgh 2012/25
IFUM-1010-FT

Higgs production in gluon fusion beyond NNLO

Richard D. Ball[a], Marco Bonvini[b], Stefano Forte[c], Simone Marzani[d]
and Giovanni Ridolfi[e]

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Durham DH1 3LE, England

[e] *Dipartimento di Fisica, Università di Genova and INFN, Sezione di Genova,*
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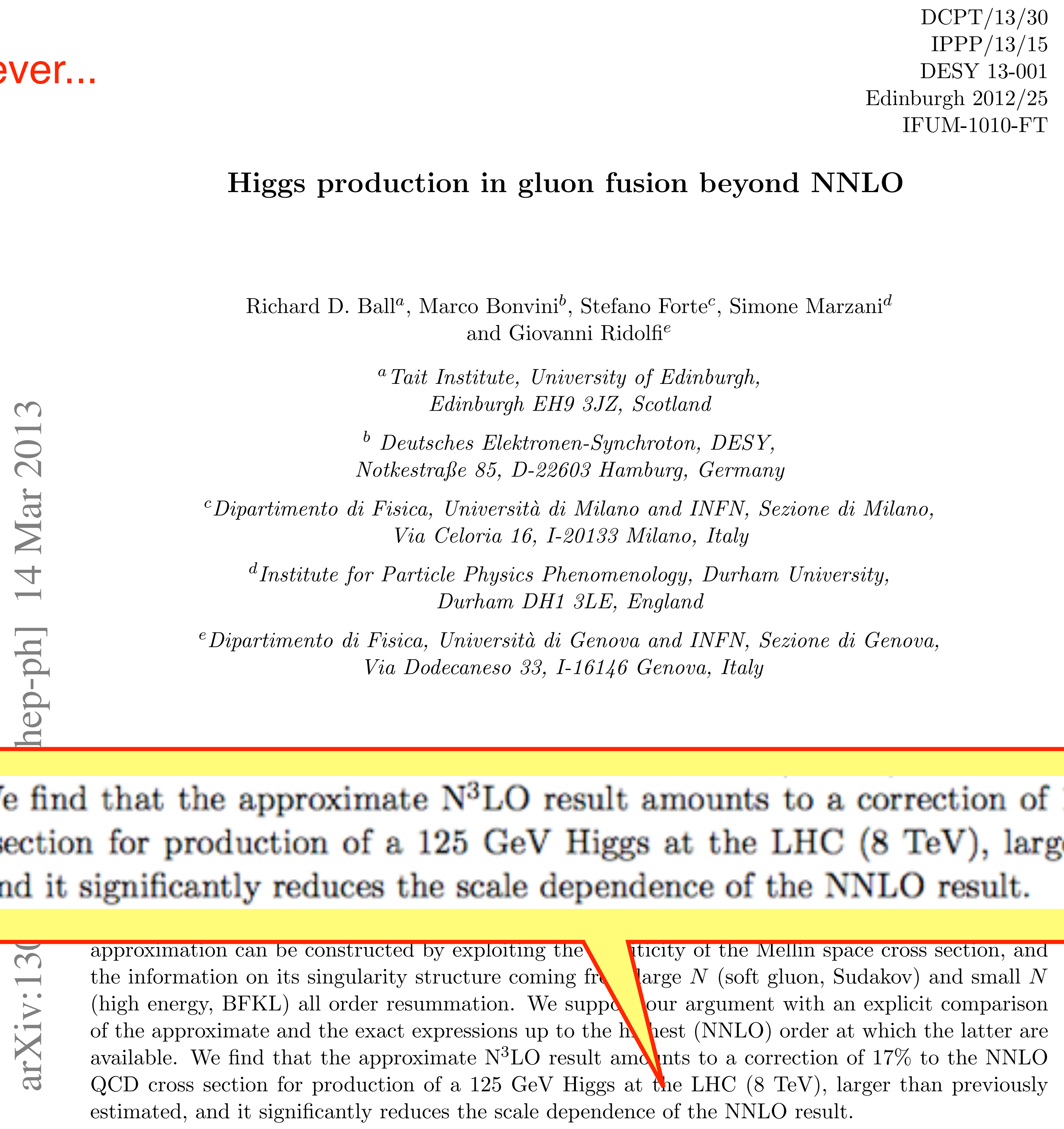
Abstract:

We construct an approximate expression for the cross section for Higgs production in gluon fusion at next-to-next-to-next-to-leading order (N^{3}LO) in α_s with finite top mass. We argue that an accurate approximation can be constructed by exploiting the analiticity of the Mellin space cross section, and the information on its singularity structure coming from large N (soft gluon, Sudakov) and small N (high energy, BFKL) all order resummation. We support our argument with an explicit comparison of the approximate and the exact expressions up to the highest (NNLO) order at which the latter are available. We find that the approximate N^{3}LO result amounts to a correction of 17% to the NNLO QCD cross section for production of a 125 GeV Higgs at the LHC (8 TeV), larger than previously estimated, and it significantly reduces the scale dependence of the NNLO result.

However...



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We find that the approximate N^{3}LO result amounts to a correction of 17% to the NNLO QCD cross section for production of a 125 GeV Higgs at the LHC (8 TeV), larger than previously estimated, and it significantly reduces the scale dependence of the NNLO result.

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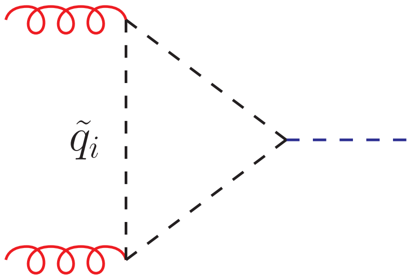
In the MSSM, additional contributions to Higgs production from loops involving superparticles:

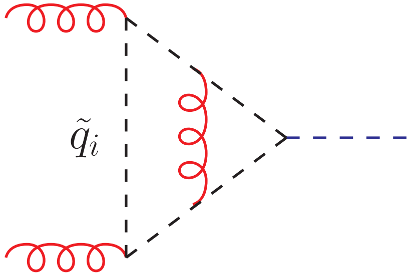
At LO, 1-loop squark contribution:



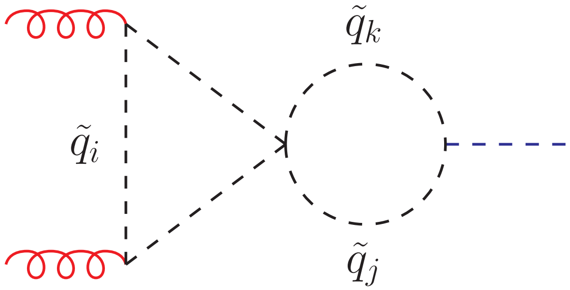
$(\tilde{q} = \tilde{t}\,, \tilde{b})$

At NLO, different classes of 2-loop SUSY contributions:

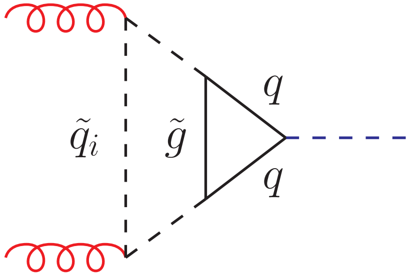
gluon-squark:



quartic squark coupling:



gluino-quark-squark:



Also, squark contributions from 1-loop diagrams with real parton emission

NLO computation of the gluon-fusion cross section in the MSSM

- Gluon-quark virtual & real contribution complete (analytic)
  Spira, Djouadi, Graudenz, Zerwas (95); Harlander, Kant (05)

- Gluon-squark virtual & real contribution complete (analytic)
  Anastasiou, Beerli, Bucherer, Daleo, Kunszt (06); Aglietti, Bonciani, Degrassi, Vicini (06); Muehlleitner, Spira (06); Bonciani, Degrassi, Vicini (07)

- Gluino-quark-squark & four-squark virtual contribution complete (semi-analytic)
  Anastasiou, Beerli, Daleo (08) *(not made available as a public computer code)*
  also Muehlleitner, Rzehak, Spira *(in progress)*

So far, the complete results for the gluino-quark-squark contribution proved too unpractical to be implemented in extensive analyses of the MSSM parameter space *(up to 5 different masses in the 2-loop integrals: huge computing time + instabilities)*

→ *we need at least an approximated result...*

Approximated computation of the gluino contributions

Up to five different masses in a diagram: $m_{\tilde{q}_1},\ m_{\tilde{q}_2},\ m_{\tilde{g}},\ m_q,\ \ p^2 = m_\phi^2$

1) Taylor expansion in the external momentum (or VHML): $m_\phi \ll m_{\tilde{q}_1},\ m_{\tilde{q}_2},\ m_{\tilde{g}},\ m_q$

- ✓ Good for the top-stop-gluino contributions to *h* production
- – From not-so-good to bad for the top-stop-gluino contributions to *H, A*
- – Definitely useless for all bottom-sbottom-gluino contributions

2) Asymptotic expansion in the SUSY masses: $m_\phi,\ m_q \ll m_{\tilde{q}_1},\ m_{\tilde{q}_2},\ m_{\tilde{g}} \approx M$

- ✓ Good for the bottom-sbottom-gluino contributions to *h* production
- ✓ Probably good for the top-stop-gluino contributions to *h* (unless $M \approx m_t$)
- ✦ Might or might not be good for *H, A* production (depending on *M*)

A few approximated calculations in the literature:

- Harlander, Steinhauser (03-04): top-stop-gluino contribution to scalar production for vanishing scalar mass (= zero order in Taylor expansion)

- Harlander, Hofmann (05): top-stop-gluino contribution to pseudoscalar production for vanishing pseudoscalar mass

- Degrassi, Slavich (08): top-stop-gluino contribution to scalar production with a Taylor expansion in the scalar mass (confirming HS result for vanishing mass)

- Degrassi, Slavich (10): bottom-sbottom-gluino contribution to scalar production with an asymptotic expansion in the SUSY masses

- Pak, Steinhauser, Zerf (10): NNLO *(=3-loop!)* top-stop-gluino contribution to scalar production for vanishing scalar mass *(only for* $m_{\tilde{q}_1} = m_{\tilde{q}_2} = m_{\tilde{g}}$ *)*

- Harlander, Hofmann, Mantler (10): quark-squark-gluino contribution to scalar production with an asymptotic expansion in the SUSY masses *(only for* $m_{\tilde{q}_1} = m_{\tilde{q}_2} = m_{\tilde{g}}$*)*

A few approximated calculations in the literature (continued):

- Degrassi, Di Vita, Slavich (11): top-stop-gluino and bottom-sbottom-gluino contribution to pseudoscalar production with either a Taylor expansion in the pseudoscalar mass or an asymptotic expansion in the SUSY masses

- Degrassi, Di Vita, Slavich (12): top-stop-gluino contribution to scalar production with an asymptotic expansion in the SUSY masses
(no hierarchy between top and Higgs masses, applicable to the heavy scalar)

→ *Complete picture for all three neutral Higgs bosons of the MSSM*
Taylor and/or asymptotic expansion for top-stop-gluino
and bottom-sbottom-gluino contributions

- Pak, Steinhauser, Zerf (12): 3-loop top-stop-gluino contributions for vanishing Higgs mass and three different hierarchies of top, stop, gluino masses

The next step: making our results available to the community

- Bagnaschi, Degrassi, Slavich and Vicini, (arXiv:1111.2854):

  Implementation of gluon fusion in POWHEG-BOX, a framework to match NLO-QCD calculations with parton-shower generators (e.g. PYTHIA, HERWIG)

  [SM with quark-mass effects, MSSM with all the available NLO squark effects]

- Pak, Steinhauser, Zerf (arXiv:1208.1588):

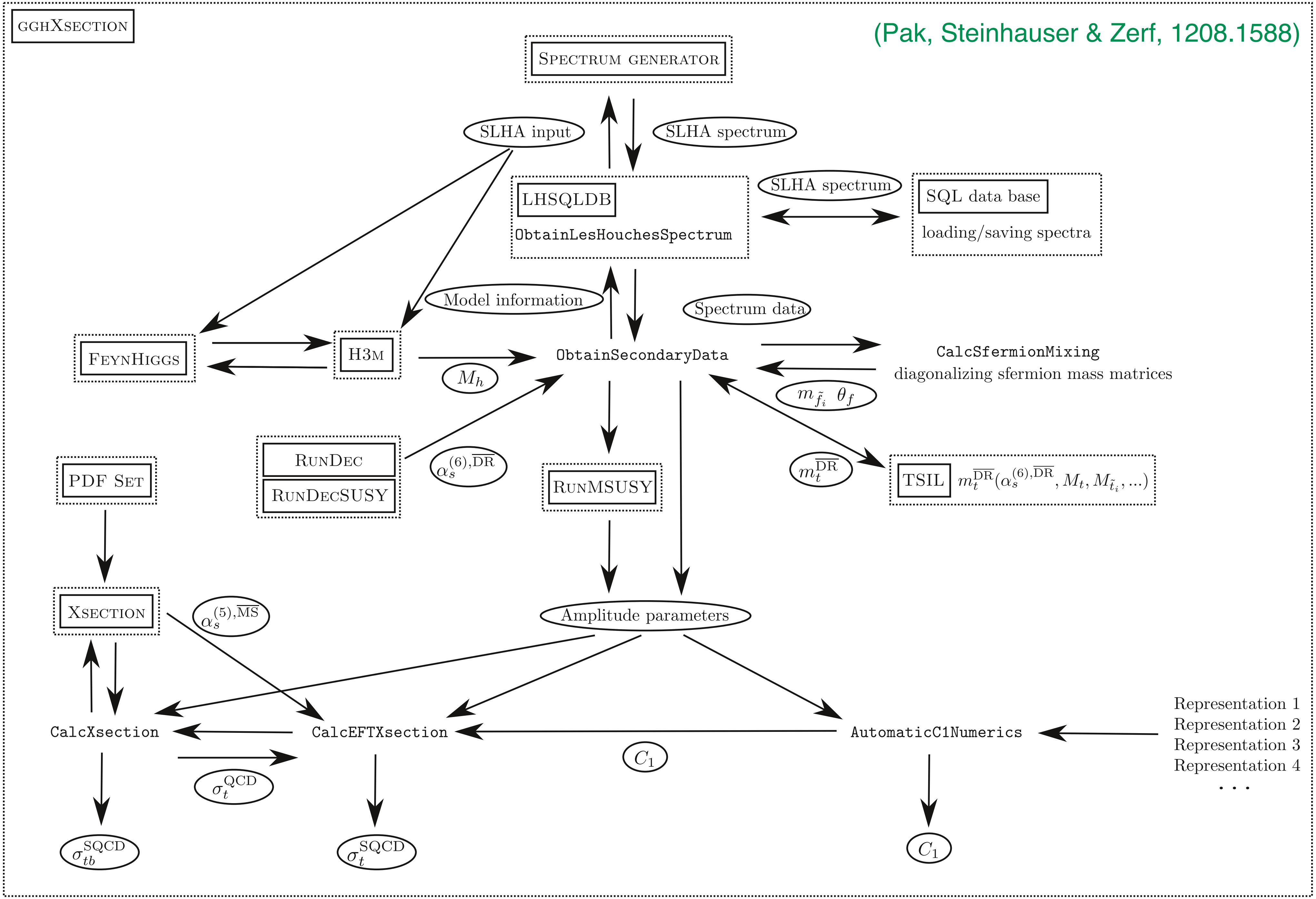
  gghXsection: A program for the NNLO calculation of gluon fusion in the MSSM

  [light scalar only, SUSY mass hierarchies, bottom/sbottom contributions NLO]

- Harlander, Mantler, Liebler (arXiv:1212.3249):

  SusHi: A program for the calculation of Higgs production in gluon fusion and bottom-quark annihilation in the Standard Model and the MSSM

  [SM with quark-mass effects, MSSM with all the available NLO squark effects]



(Pak, Steinhauser & Zerf, 1208.1588)

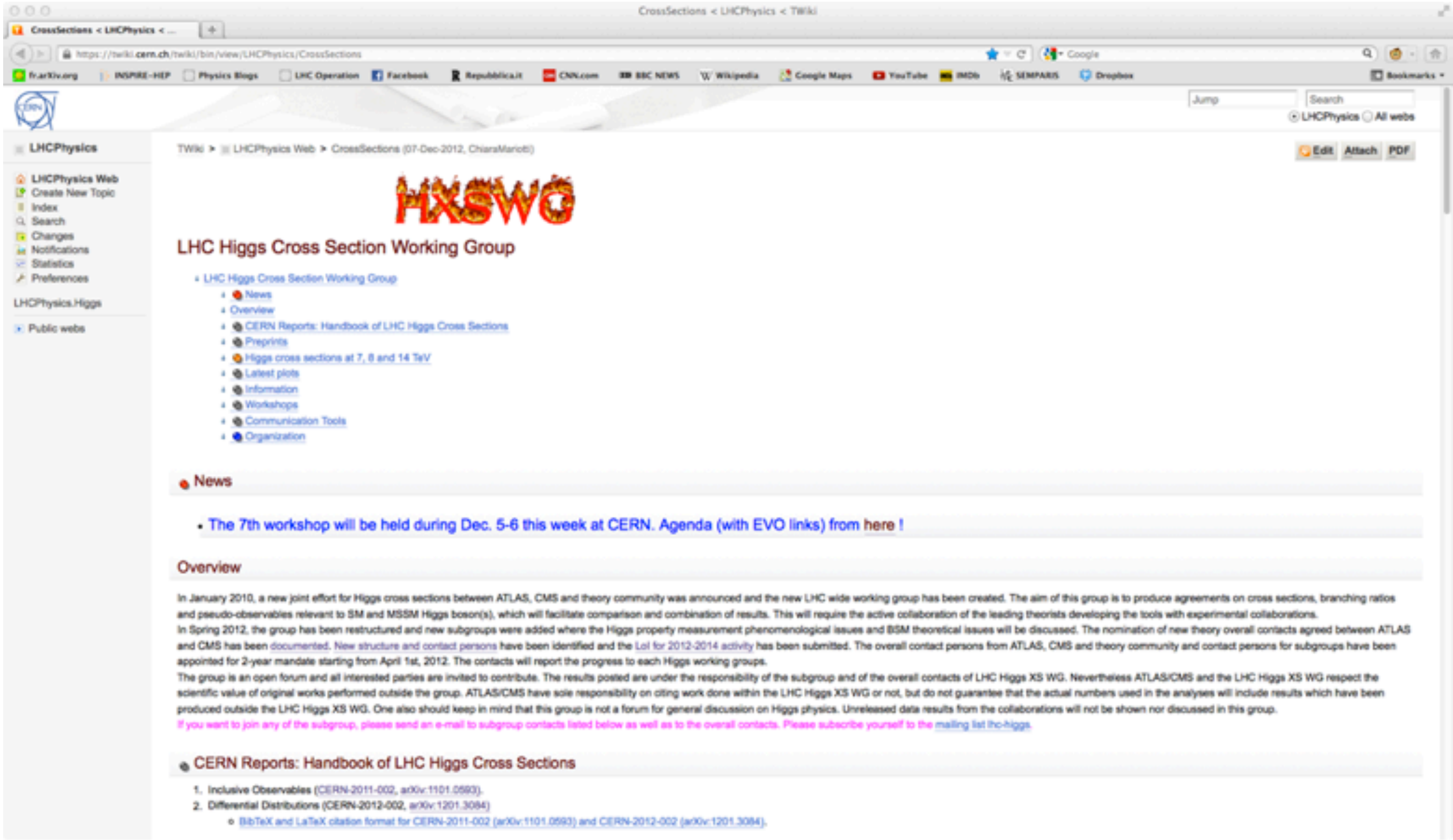
On a mission from the LHC-HXSWG

The LHC Higgs Cross Section Working Group:

“a joint effort for Higgs cross sections between ATLAS, CMS and theory community (....) The aim of this group is to produce agreements on cross sections, branching ratios and pseudo-observables relevant to SM and MSSM Higgs boson(s), which will facilitate comparison and combination of results. This will require the active collaboration of the leading theorists developing the tools with experimental collaborations.”

[quote from the LHC-HXSWG webpage]

On a mission from the LHC-HXSWG



TWiki > LHCPhysics Web > CrossSections (07-Dec-2012, ChiaraMariotti)

LHC Higgs Cross Section Working Group

- LHC Higgs Cross Section Working Group
  - News
  - Overview
  - CERN Reports: Handbook of LHC Higgs Cross Sections
  - Preprints
  - Higgs cross sections at 7, 8 and 14 TeV
  - Latest plots
  - Information
  - Workshops
  - Communication Tools
  - Organization

News

- The 7th workshop will be held during Dec. 5-6 this week at CERN. Agenda (with EVO links) from here !

Overview

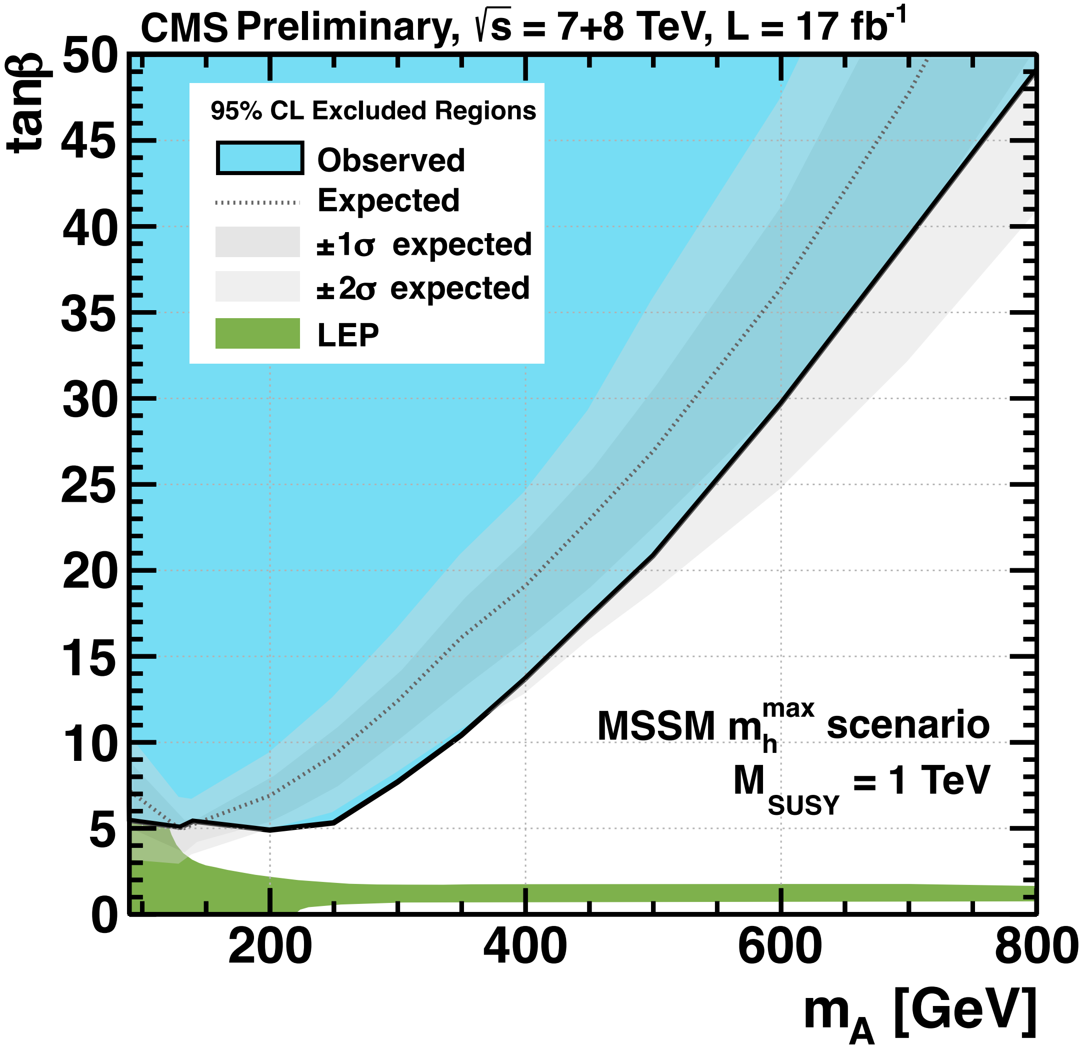
In January 2010, a new joint effort for Higgs cross sections between ATLAS, CMS and theory community was announced and the new LHC wide working group has been created. The aim of this group is to produce agreements on cross sections, branching ratios and pseudo-observables relevant to SM and MSSM Higgs boson(s), which will facilitate comparison and combination of results. This will require the active collaboration of the leading theorists developing the tools with experimental collaborations.
In Spring 2012, the group has been restructured and new subgroups were added where the Higgs property measurement phenomenological issues and BSM theoretical issues will be discussed. The nomination of new theory overall contacts agreed between ATLAS and CMS has been documented. New structure and contact persons have been identified and the LoI for 2012-2014 activity has been submitted. The overall contact persons from ATLAS, CMS and theory community and contact persons for subgroups have been appointed for 2-year mandate starting from April 1st, 2012. The contacts will report the progress to each Higgs working groups.
The group is an open forum and all interested parties are invited to contribute. The results posted are under the responsibility of the subgroup and of the overall contacts of LHC Higgs XS WG. Nevertheless ATLAS/CMS and the LHC Higgs XS WG respect the scientific value of original works performed outside the group. ATLAS/CMS have sole responsibility on citing work done within the LHC Higgs XS WG or not, but do not guarantee that the actual numbers used in the analyses will include results which have been produced outside the LHC Higgs XS WG. One also should keep in mind that this group is not a forum for general discussion on Higgs physics. Unreleased data results from the collaborations will not be shown nor discussed in this group.
If you want to join any of the subgroup, please send an e-mail to subgroup contacts listed below as well as to the overall contacts. Please subscribe yourself to the mailing list lhc-higgs.

CERN Reports: Handbook of LHC Higgs Cross Sections

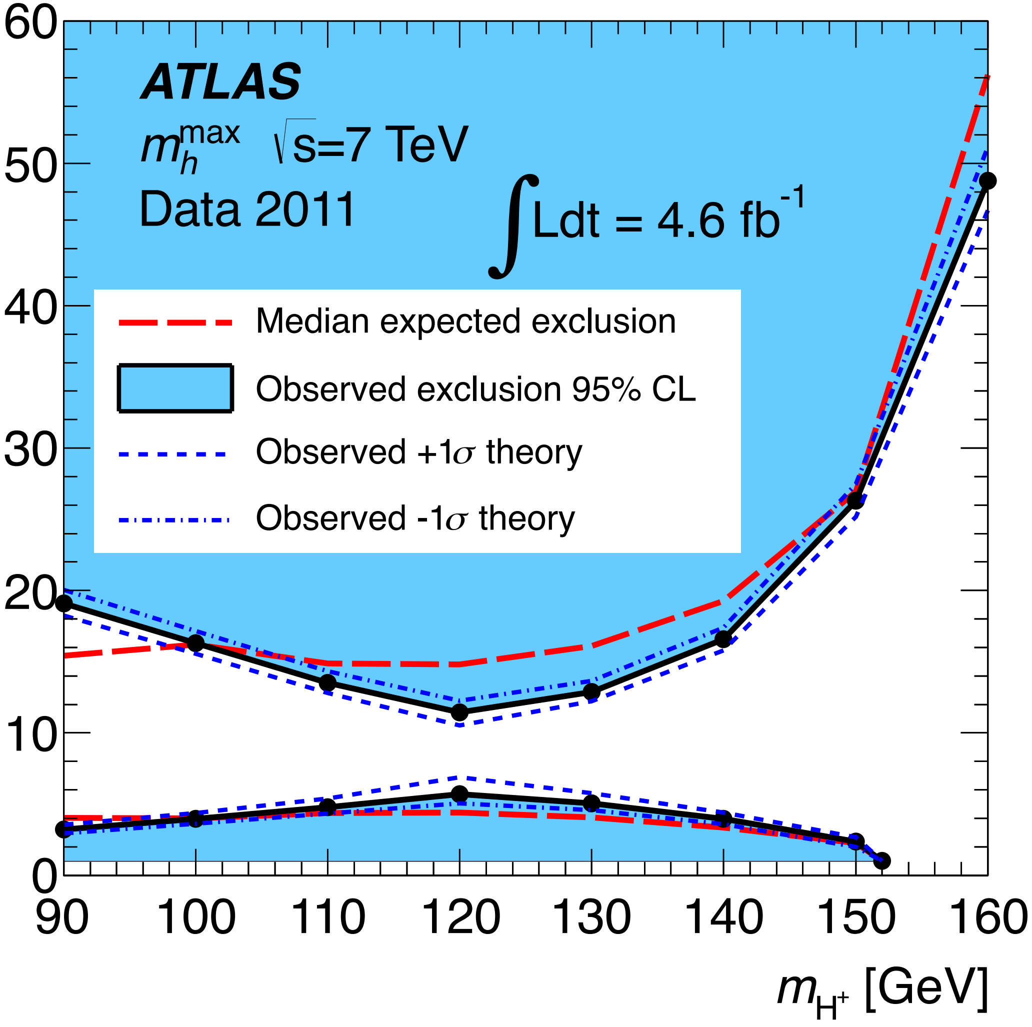
1. Inclusive Observables (CERN-2011-002, arXiv:1101.0593).
2. Differential Distributions (CERN-2012-002, arXiv:1201.3084)
   - BibTeX and LaTeX citation format for CERN-2011-002 (arXiv:1101.0593) and CERN-2012-002 (arXiv:1201.3084).

One task of the MSSM subgroup is to compute cross sections for non-SM Higgs searches:

$gg, b\bar{b} \longrightarrow h, H, A \longrightarrow \tau^+\tau^-$



$gg \longrightarrow t\bar{t} \longrightarrow H^+ X \longrightarrow \tau^+\nu_\tau X$



The exclusion limits require assumptions on the SUSY parameters (e.g. “*m_h^{max} scenario*”)

The old LHC-HXSWG numbers for gluon fusion

NLO top/bottom contributions from HIGLU + NNLO top bit from ggH@NNLO,
rescaled by MSSM Higgs-quark couplings from FeynHiggs:

$$\sigma(gg \to \phi) \;=\; (g_t^\phi)^2\,\left(\sigma^{\rm tt}_{\rm NLO} + \Delta\sigma^{\rm tt}_{\rm NNLO}\right) \;+\; (g_b^\phi)^2\,\sigma^{\rm bb}_{\rm NLO} \;+\; g_t^\phi\,g_b^\phi\,\sigma^{\rm tb}_{\rm NLO}$$

e.g., for *h* :

$$g_t^h \;=\; \frac{\cos\alpha}{\sin\beta}\,, \qquad g_b^h \;=\; -\,\frac{\sin\alpha}{\cos\beta}\,\frac{1}{1+\Delta_b}\left(1 - \frac{\Delta_b}{\tan\alpha\,\tan\beta}\right)$$

$$\Delta_b \;=\; \frac{2\,\alpha_s}{3\pi}\,m_{\tilde g}\,\mu\,\tan\beta\,I(m^2_{\tilde b_1}, m^2_{\tilde b_2}, m^2_{\tilde g}) \;+\; \dots$$

- No stop/sbottom contributions (apart from those implicit in Δ_b)
- No electroweak contributions (not even the known SM ones)

From the first
“Yellow report”:
(1101.0593)

“In further steps we will have to include the full SUSY QCD and SUSY electroweak corrections where available...”

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$$\Delta_b \;=\; \frac{2\,\alpha_s}{3\pi}\, m_{\tilde g}\,\mu\,\tan\beta\, I(m_{\tilde b_1}^2, m_{\tilde b_2}^2, m_{\tilde g}^2) \;+\; \ldots$$

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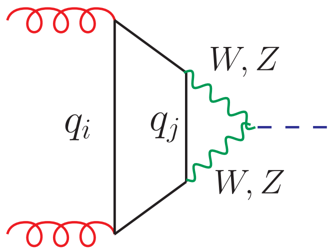

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Towards a state-of-the-art NLO calculation in the MSSM

Two independent computer codes:

➡ Bagnaschi, Degrassi, Slavich, Vicini

➡ Harlander, Mantler, Liebler (SusHi)

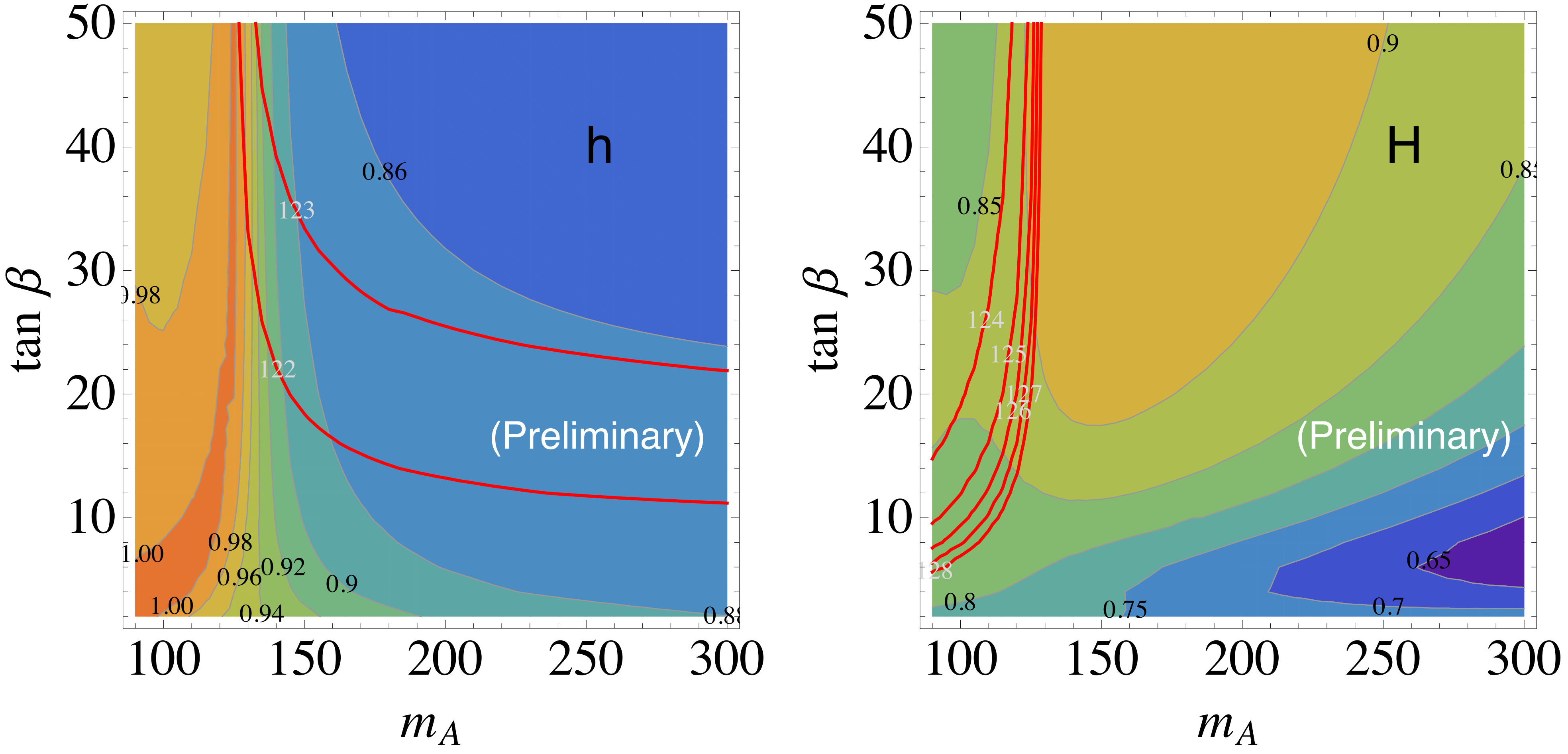
Full NLO top/bottom + expanded NLO stop/sbottom + NNLO top + SM-EW

The road map

- Compare the two codes at pure NLO and understand any discrepancies
- Discuss renormalization schemes for SUSY parameters (esp. for large *tanß*)
- Determine best way to include known NNLO and EW effects from the SM
- Produce new numbers, compare with the old ones used by experimentalists

A benchmark scenario with light stops and large mixing:

$M_S = 0.5 \text{ TeV}, \quad X_t = 1 \text{ TeV}, \quad \mu = M_2 = 350 \text{ GeV}, \quad m_{\tilde{g}} = 1.5 \text{ TeV}$



$\sigma_{gg}^{q+\tilde{q}} \,/\, \sigma_{gg}^{q}$

Stop contribution to Higgs production in gluon fusion

For a SM-like Higgs much lighter than top and stops, the effective *hgg* vertex gets rescaled:

$$\mathcal{L}_{\rm eff} \;=\; \frac{\alpha_s}{12\,\pi\,v}\,h\,G^{a\,\mu\nu}G^a_{\mu\nu} \qquad \longrightarrow \qquad (1+\Delta_{\tilde t})\,\frac{\alpha_s}{12\,\pi\,v}\,h\,G^{a\,\mu\nu}G^a_{\mu\nu}$$

The one-loop stop contribution can enhance or suppress the production cross section:

$$\Delta^{1\ell}_{\tilde t} \;\approx\; \frac{m_t^2}{4}\left(\frac{1}{m^2_{\tilde t_1}}+\frac{1}{m^2_{\tilde t_2}}-\frac{X_t^2}{m^2_{\tilde t_1}\,m^2_{\tilde t_2}}\right)$$

(X_t = LR stop mixing)

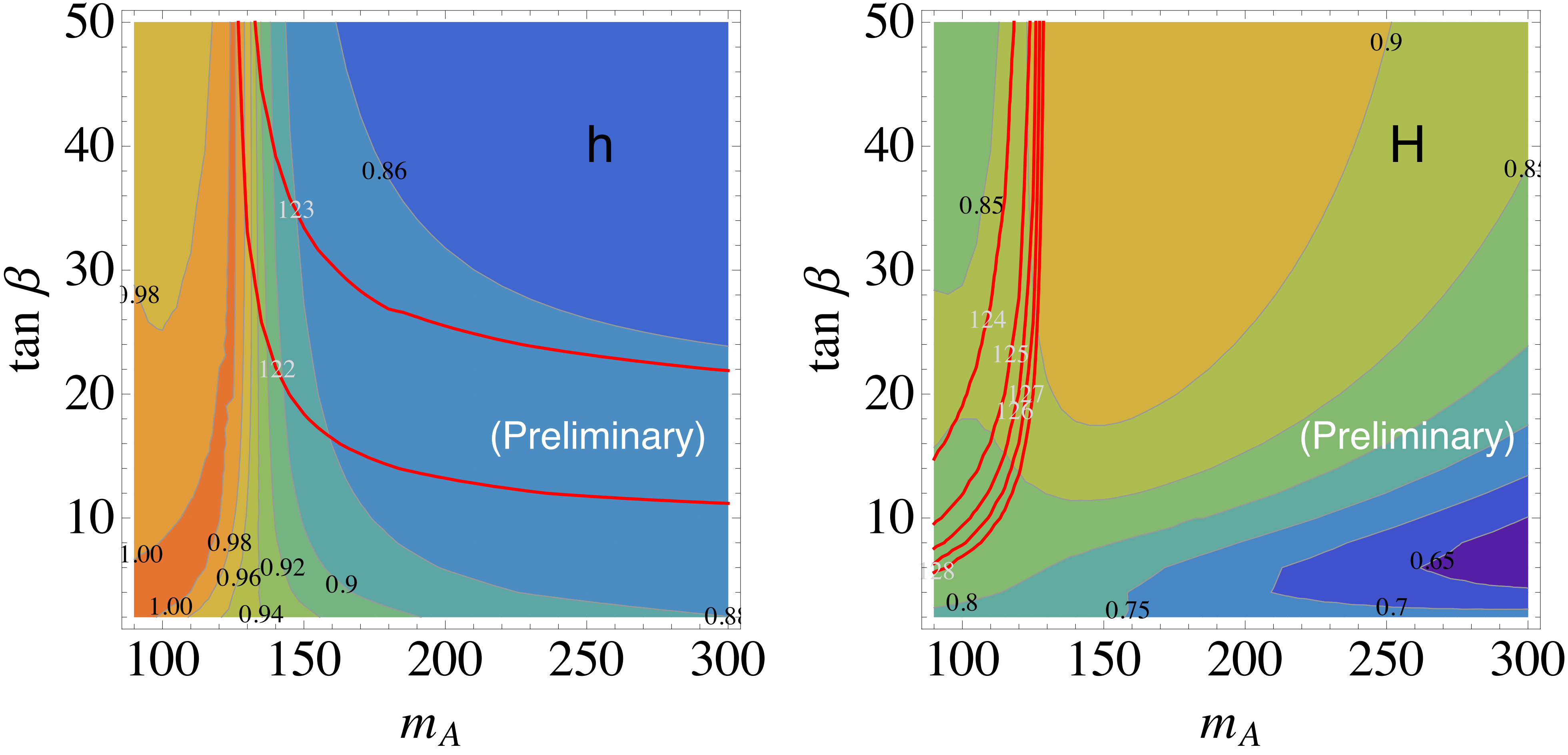
The same rescaling occurs in the top contribution to the $h\gamma\gamma$ vertex.
However, that vertex is dominated by the W loop (opposite sign w.r.t. top loop)

The diphoton rate of a SM-like Higgs is *suppressed* for large X_t (favored by $m_h \approx 125$ GeV)

→ the stop contribution alone cannot explain the *(preliminary)* hint of an enhancement

The EW corrections interfere with the stop contributions

$M_S = 0.5$ TeV, $X_t = 1$ TeV, $\mu = M_2 = 350$ GeV, $m_{\tilde g} = 1.5$ TeV



$\sigma_{gg}^{q+\tilde{q}} \,/\, \sigma_{gg}^{q}$

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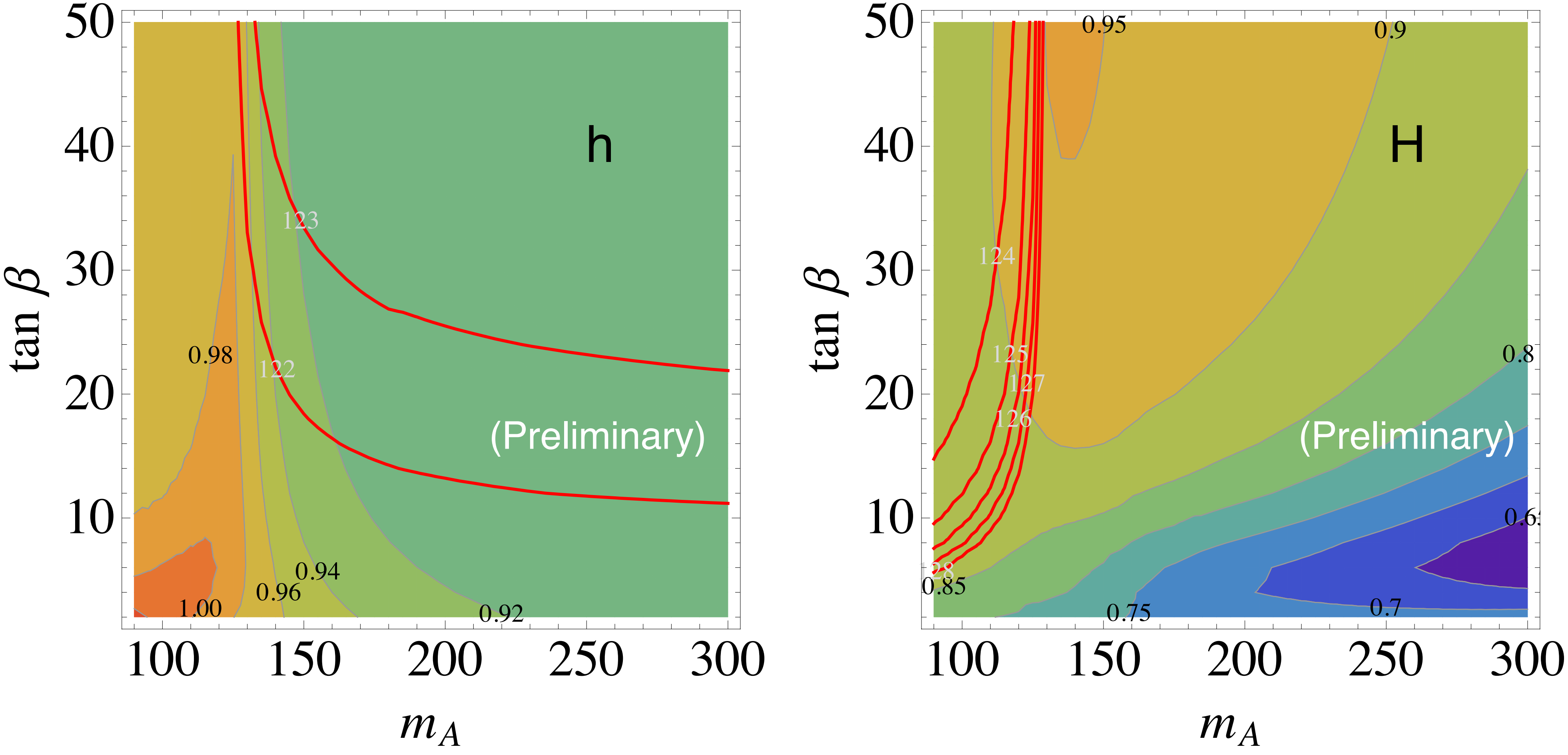
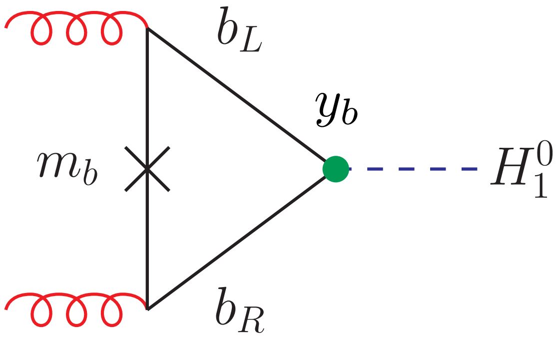


$(1 + \delta_{\rm EW})\, \sigma_{gg}^{q+\tilde{q}} \,/\, \sigma_{gg}^{q}$

A constant headache:

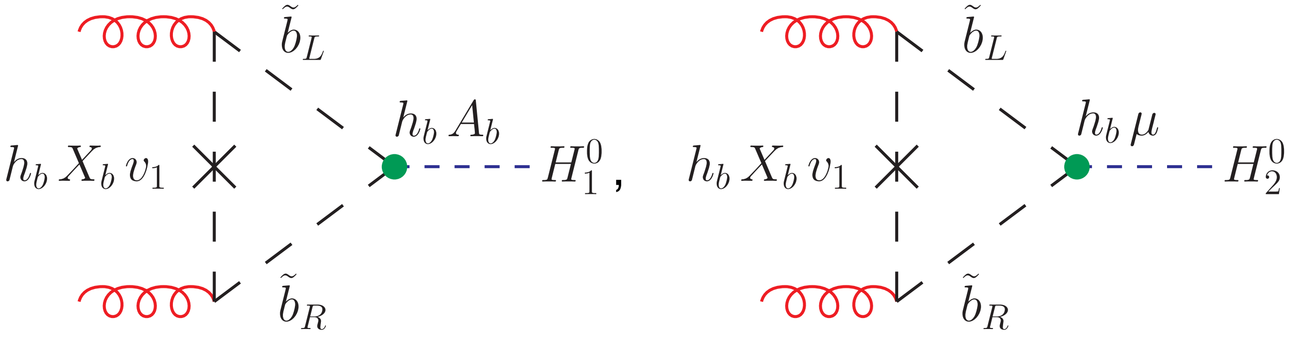
The bottom contributions in the MSSM

Anatomy of 1-loop bottom and (some) sbottom contributions



$$\propto \mathcal{G}^{1\ell}_{1/2}(\tau_b) = -\frac{\tau_b}{2}\left[4 - \ln^2\left(\frac{-4}{\tau_b}\right)\right] + \mathcal{O}(\tau_b^2)$$

$(\tau_b = 4\, m_b^2/m_\phi^2)$



$$\propto m_b s_{2\theta_b} \begin{pmatrix} A_b \\ \mu \end{pmatrix} \left(\frac{1}{m^2_{\tilde b_1}} - \frac{1}{m^2_{\tilde b_2}}\right)$$

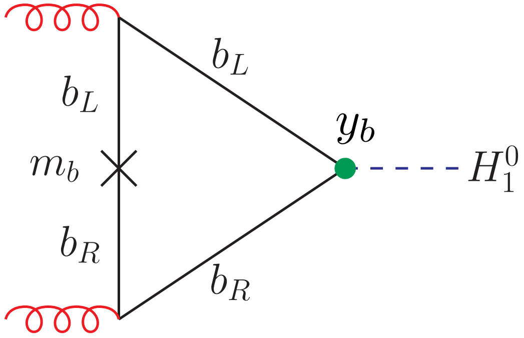
$$\times \left[1 + \mathcal{O}(m_\phi^2/M^2)\right]$$

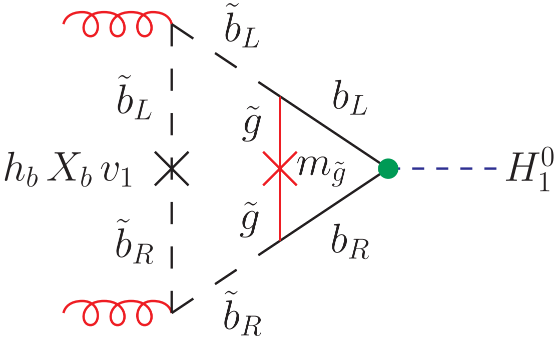
$y_b = h_b$ at tree level, but they may differ at 1-loop in non-SUSY renormalization schemes

In the sbottom sector we will also need renormalization prescriptions for $(m_{\tilde b_i},\ \theta_{\tilde b},\ A_b)$

Renormalization of the Higgs-bottom coupling

The 2-loop diagrams involving gluinos induce large *tanβ*-enhanced contributions





Can be absorbed in the 1-loop amplitude via a redefinition of the Higgs-bottom coupling y_b

Four options in SusHi:

$$y_b^{h,H} \propto m_b^{\mathrm{OS}}$$

"OS coupling"

$$y_b^{h,H} \propto \frac{m_b^{\mathrm{OS}}}{1+\Delta_b}$$

"naive resummation"

$$y_b^{h} \propto \frac{m_b^{\mathrm{OS}}}{1+\Delta_b}\left(1-\Delta_b\frac{\cot\alpha}{\tan\beta}\right)\ , \qquad y_b^{H} \propto \frac{m_b^{\mathrm{OS}}}{1+\Delta_b}\left(1+\Delta_b\frac{\tan\alpha}{\tan\beta}\right)$$

"full resumm."

$$y_b^{h,H} \propto \frac{m_b^{\overline{\mathrm{MS}}}(\mu_b)}{1+\Delta_b}$$

"running coupling"

(note that the bottom mass in the propagators of the 1-loop diagram is always m_b^{OS})

What is the “right” bottom mass?

Input from PDG: $m_b\,(m_b) \approx 4.2\ \mathrm{GeV}$

Convert to pole mass? $m_b^{\mathrm{OS}} \approx\ 4.6\ \mathrm{GeV}$ (1-loop), $4.8\ \mathrm{GeV}$ (2-loop), $4.9\ \mathrm{GeV}$ (3-loop) ...

Evolve to the typical scale of the process? $m_b\,(m_H) \approx\ 3\ \mathrm{GeV}$ for $m_H \approx\ 125\ \mathrm{GeV}$

Formally, a change in the definition of the bottom mass entering the 1-loop amplitude is compensated for (up to higher orders) by a shift in the 2-loop amplitude

However, for such large numerical differences in m_b a fixed-order shift is not enough

→ *LARGE variations in the cross section for Higgses with tanß-enhanced bottom couplings*

The standard choice is to use $m_b\,(m_b)$ or m_b^{OS} , not $m_b\,(m_H)$

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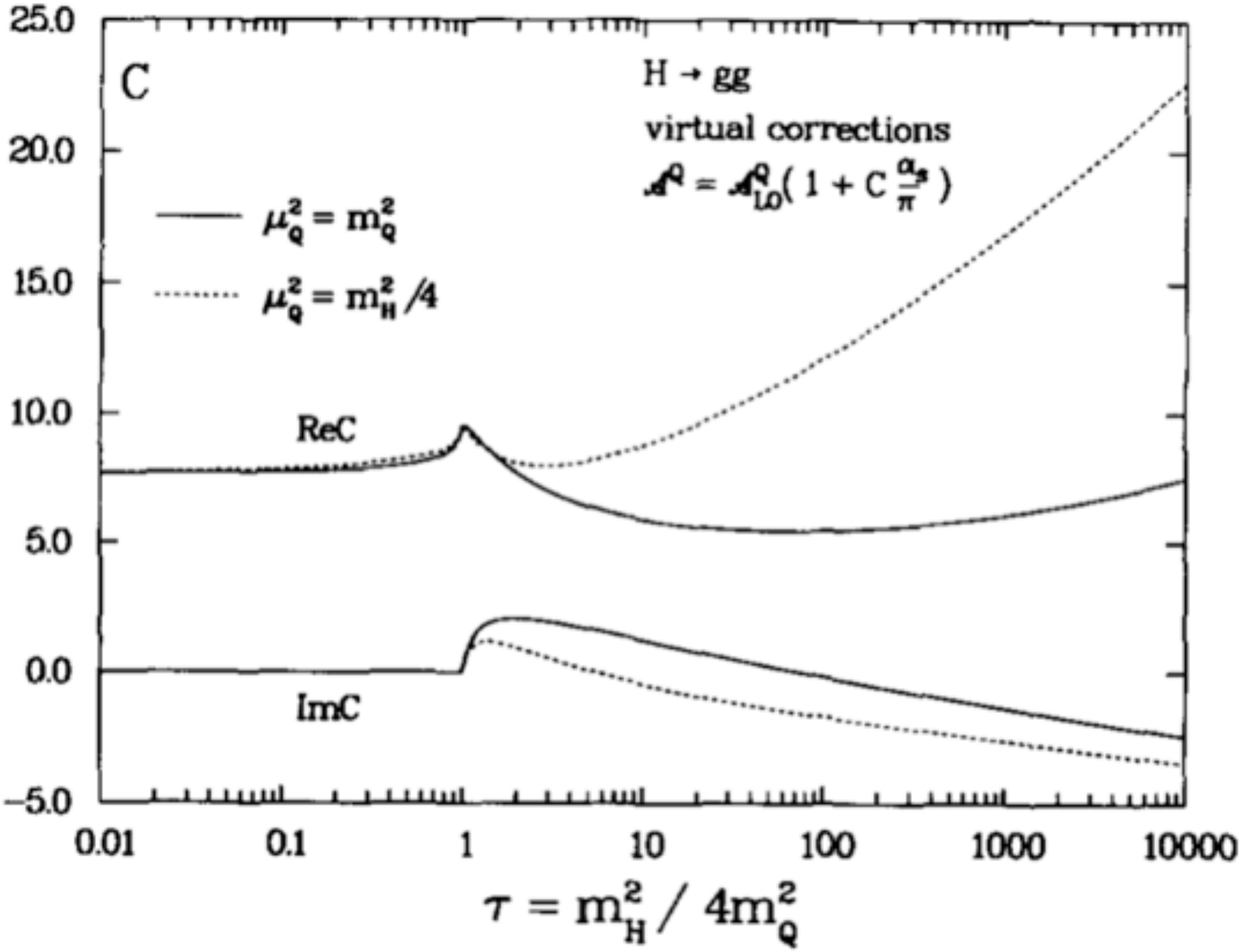
“It turns out a posteriori that the higher order corrections are minimized by choosing the pole mass m_Q for the renormalized quark mass; this is evident from Fig.7a”

Spira, Djouadi, Graudenz & Zerwas (95)



If we identify the bottom Yukawa coupling with $m_b\,(\mu_b)$ the 2-loop amplitude reads:

$$\mathcal{G}^{2\ell}_{1/2}(\tau_b) \;=\; C_F \;\left[\mathcal{F}_{C_F}(\tau_b) + \mathcal{G}^{1\ell}_{1/2}(\tau_b)\left(1-\frac{3}{4}\,\ln\frac{m_b^2}{\mu_b^2}\right)\right] \;+\; C_A\;\mathcal{F}_{C_A}(\tau_b)$$

$$(\tau_b = 4\,m_b^2/m_H^2)$$

Setting $\mu_b = m_b$ does indeed kill potentially large logs. However, not all of them!

$$\mathcal{F}_{C_F}(\tau) = \qquad -\tau\left[5+\frac{9}{5}\,\zeta_2^2-\zeta_3-(3+\zeta_2+4\,\zeta_3)\,\ln(\frac{-4}{\tau})+\zeta_2\,\ln^2(\frac{-4}{\tau}) + \frac{1}{4}\,\ln^3(\frac{-4}{\tau})+\frac{1}{48}\,\ln^4(\frac{-4}{\tau})\right] \;+\; \mathcal{O}(\tau^2),$$

$$\mathcal{F}_{C_A}(\tau) = \qquad -\tau\left[3-\frac{8}{5}\,\zeta_2^2-3\,\zeta_3+3\,\zeta_3\,\ln(\frac{-4}{\tau})-\frac{1}{4}\,(1+2\,\zeta_2)\,\ln^2(\frac{-4}{\tau}) - \frac{1}{48}\,\ln^4(\frac{-4}{\tau})\right] \;+\; \mathcal{O}(\tau^2)$$

There is an accidental cancellation between large logs in terms proportional to C_F and C_A

No guarantee that it persists at higher orders - not motivated by physical arguments

Indeed, Higgs-photon coupling obtained for $C_A = 0$, 2-loop amplitude minimized for $\mu_b = m_H/2$

On the Resummation of Large QCD Logarithms in $H \to \gamma\gamma$

R. Akhoury, H. Wang and O. Yakovlev

Michigan Center for Theoretical Physics
Randall Laboratory of Physics
University of Michigan, Ann Arbor, MI 48109-1120, USA

Abstract

We study the strong corrections to the Higgs coupling to two photons. This coupling is the dominant mechanism for Higgs production in photon-photon collisions. In addition, the two photon decay mode of the Higgs is an important and relatively background free channel of relevance at the LHC and the Tevatron. We develop a method for the resummation of large QCD corrections in the form of Sudakov-like logarithms of the type $\alpha_s^p \ln^{2p}(\frac{m^2}{m_H^2})$ and $\alpha_s^p \ln^{2p-1}(\frac{m^2}{m_H^2})$ (where m is the light quark mass) which can contribute to this process in certain models (for example, the MSSM for large $tan\beta$) up to next-to-leading-logarithmic (NLL) accuracy. The NLL correction is moderate, the substantial part of which comes from terms not related to running coupling effects.

A constant headache:

The bottom contributions in the MSSM

A constant headache:

The bottom contributions in the MSSM

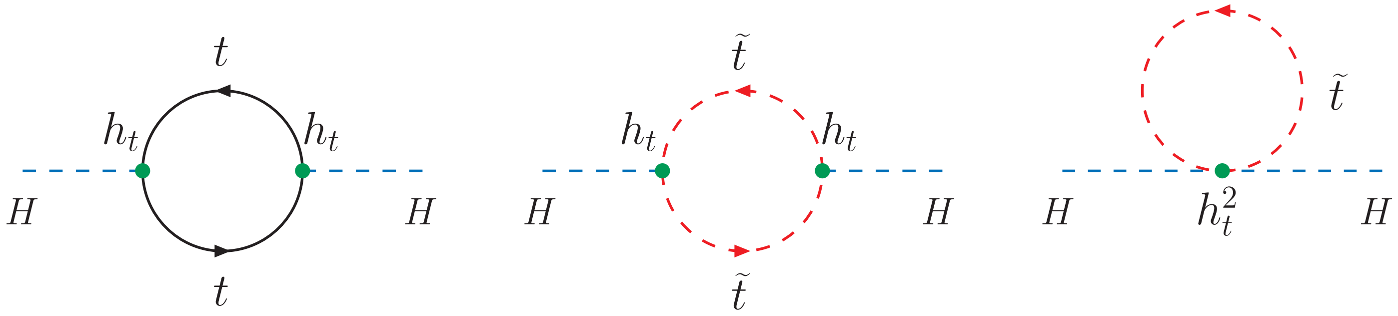
Are we underestimating their uncertainty???

Backup discussion:

Corrections to the light Higgs mass

Radiative corrections to the light Higgs mass

The dominant one-loop corrections to the Higgs masses are due to the particles with the strongest couplings to the Higgs bosons: the top (and bottom) quarks and squarks



$$(\Delta m_h^2)^{1-\mathrm{loop}} \simeq \frac{3\, m_t^4}{4\,\pi^2\, v^2}\left(\ln\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2} - \frac{X_t^4}{12\, M_S^4}\right) - \frac{h_b^4\, \mu^4\, v^2}{16\,\pi^2\, M_S^4}$$

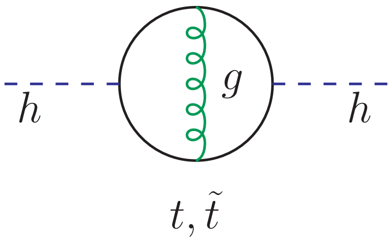
(decoupling limit, M_S = average stop mass, $X_t = A_t - \mu \cot\beta$ = L-R stop mixing)

- Δm_h^2 depends on the SUSY-breaking mismatch between top and stop mass
- It is maximized for large stop masses and large stop mixing ($X_t \simeq \sqrt{6}\, M_S$)
- The negative corrections controlled by h_b are relevant only for large *tanβ*
- Two-loop corrections involving the strong gauge coupling are also important

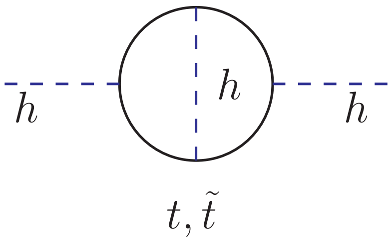
Two-loop corrections to the Higgs masses

- Top corrections (always important)

$\mathcal{O}(\alpha_t\alpha_s)$:

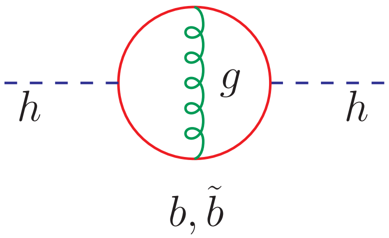


$\mathcal{O}(\alpha_t^2)$:

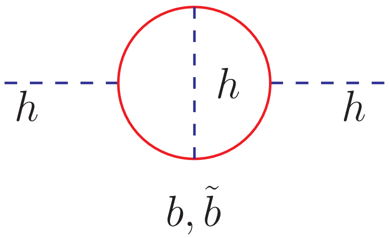


- Bottom corrections (relevant only for large $\tan\beta$)

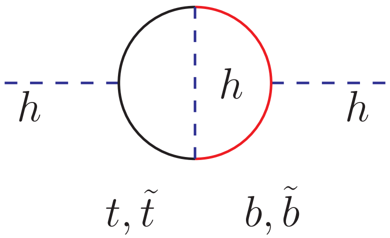
$\mathcal{O}(\alpha_b\alpha_s)$:



$\mathcal{O}(\alpha_b^2)$:

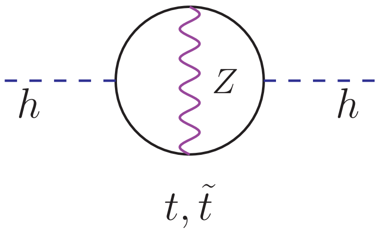


$\mathcal{O}(\alpha_t\alpha_b)$:

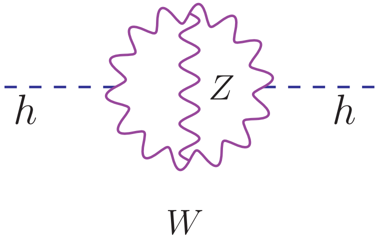


- Electroweak corrections (generally small)

$\mathcal{O}(\alpha_t\alpha)$:

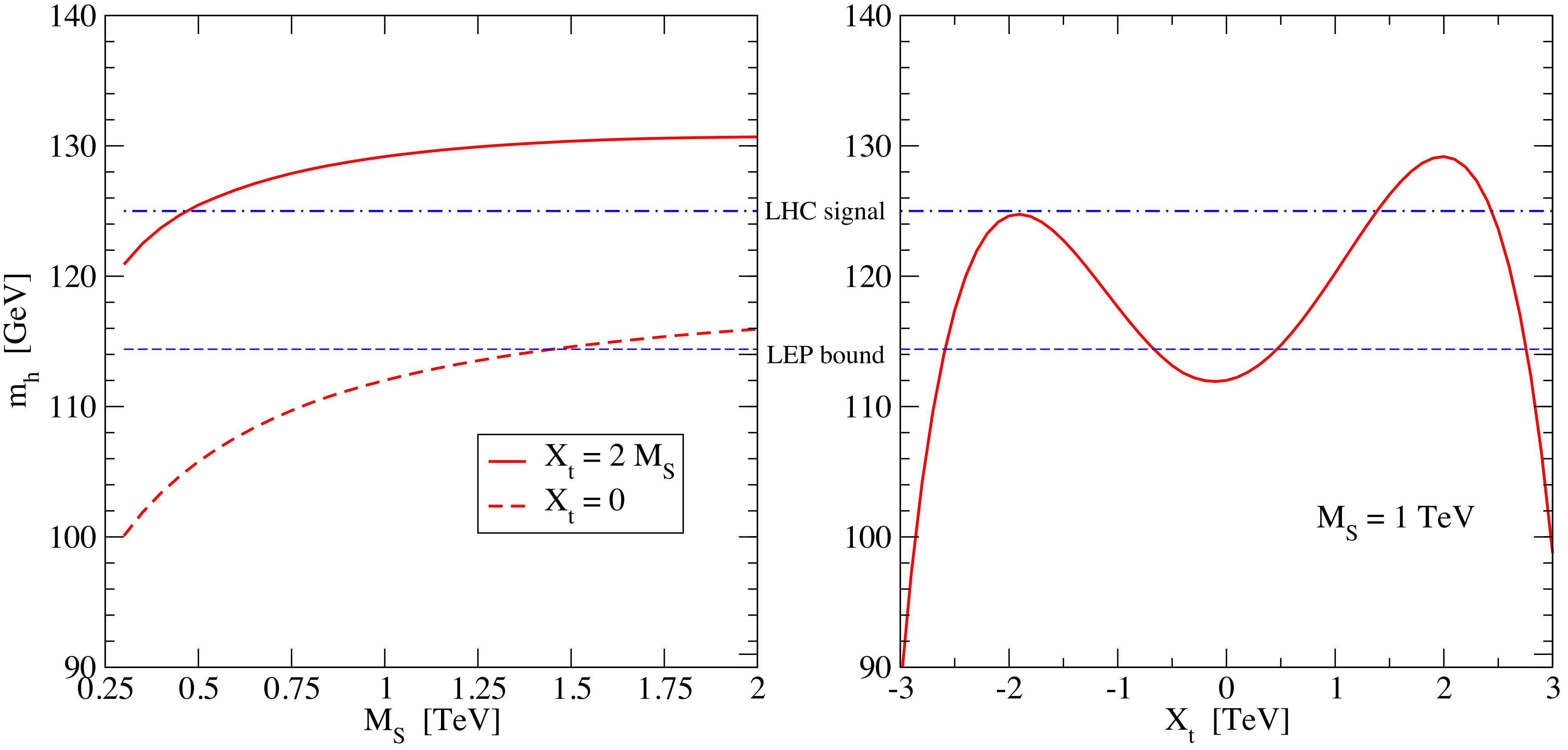


$\mathcal{O}(\alpha^2)$:



$$\mu = M_2 = 200\ \text{GeV}, \quad m_{\tilde{g}} = 0.8\, M_S, \quad m_A = 500\ \text{GeV}, \quad \tan\beta = 10$$

(plots produced with FeynHiggs)



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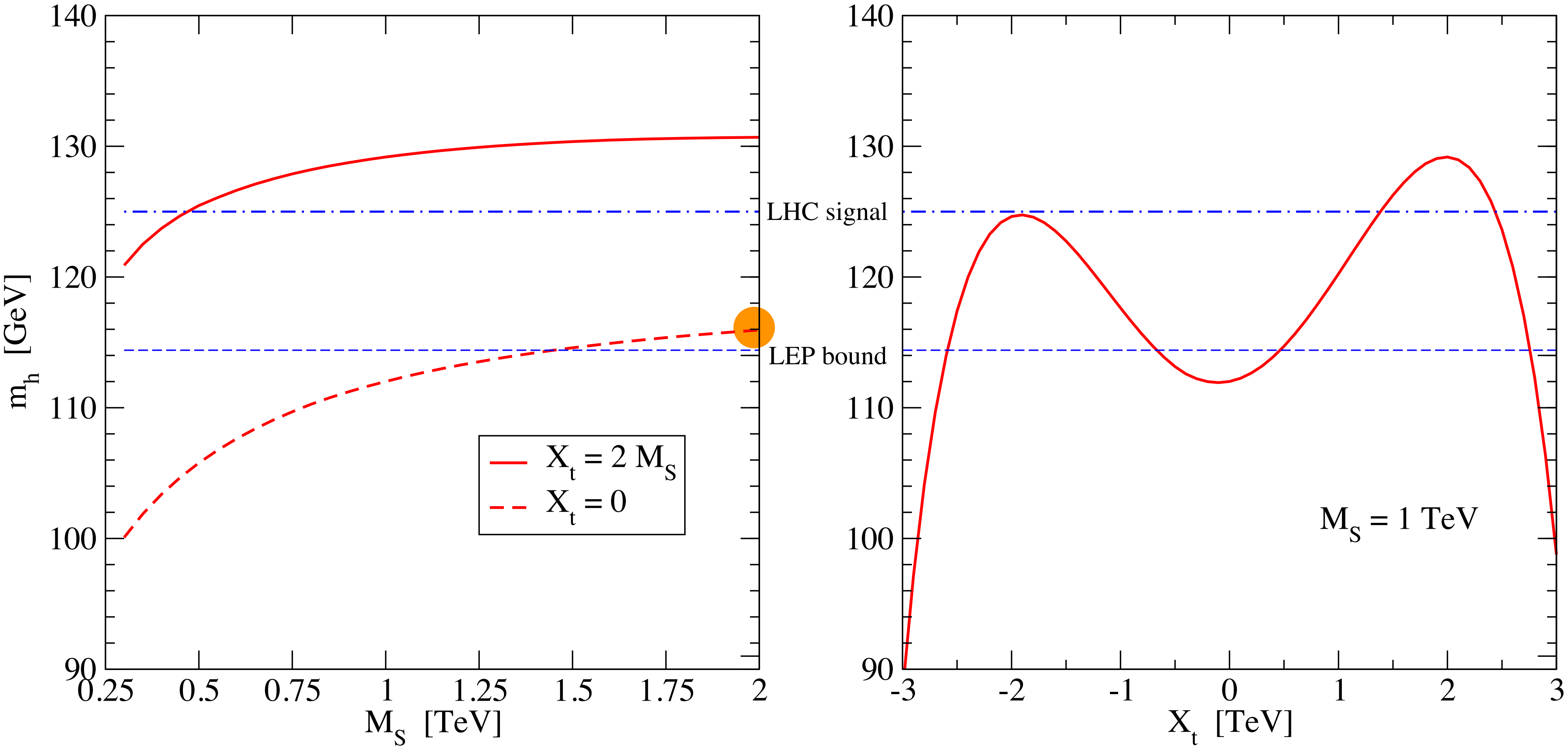

no-mixing scenario: M_s = 2 TeV, X_t = 0 TeV

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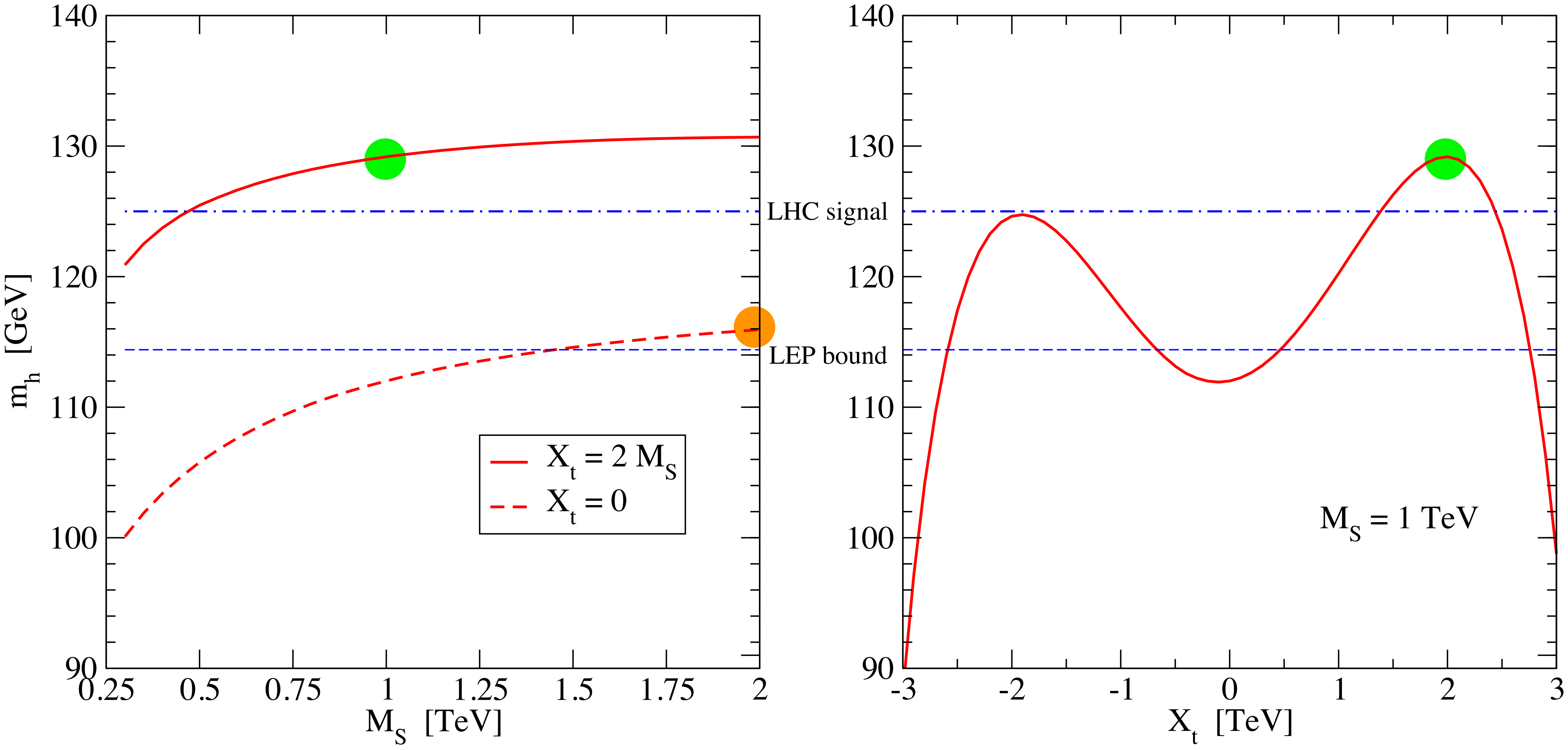

no-mixing scenario: $M_s =$ 2 TeV, $X_t = 0$ TeV

m_h^{max} scenario: $M_s =$ 1 TeV, $X_t = 2$ TeV

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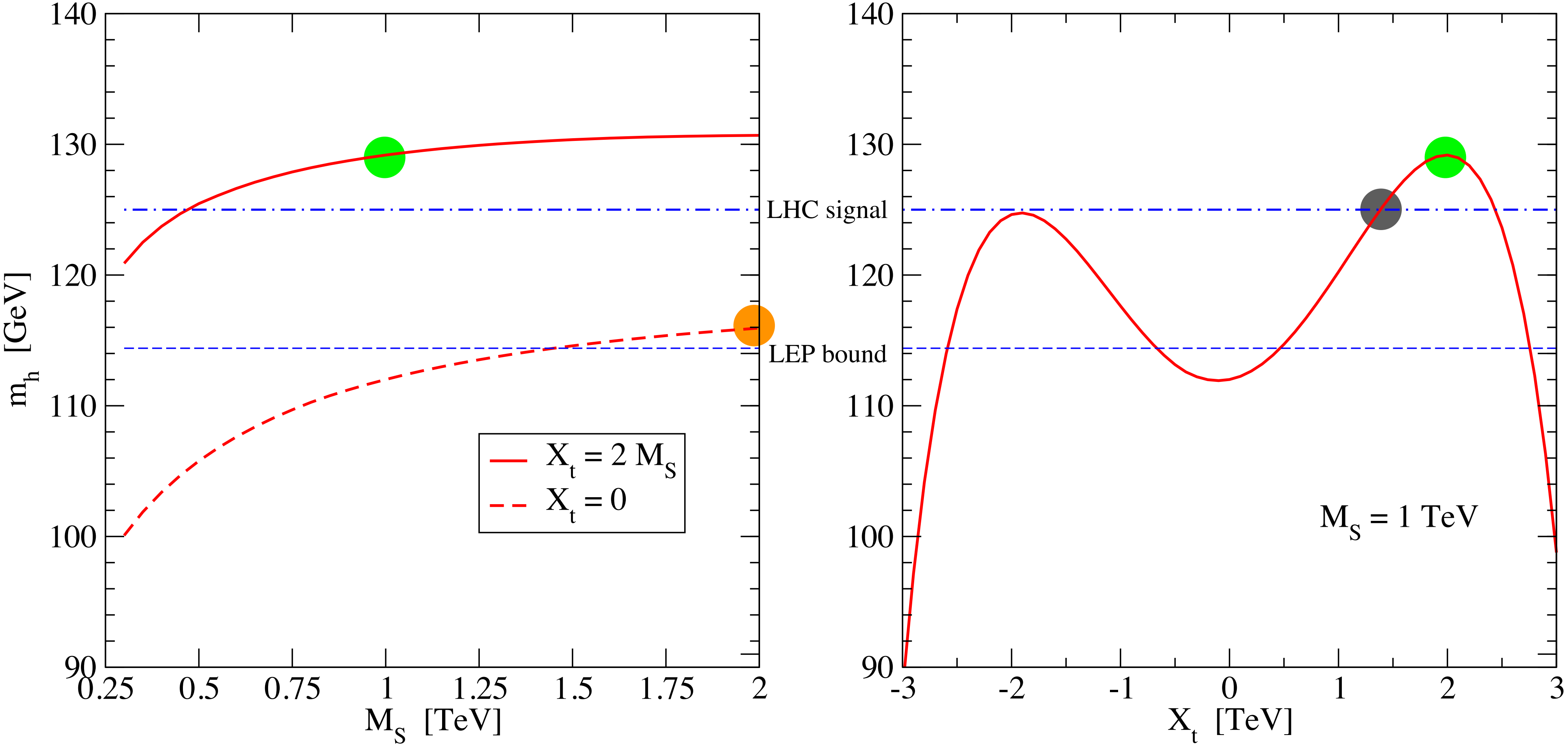
(plots produced with FeynHiggs)



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m_h^{max} scenario: $M_s =$ 1 TeV, $X_t = 2$ TeV

modified m_h^{max} scenario: $M_s =$ 1 TeV, $X_t = 1.3$ TeV

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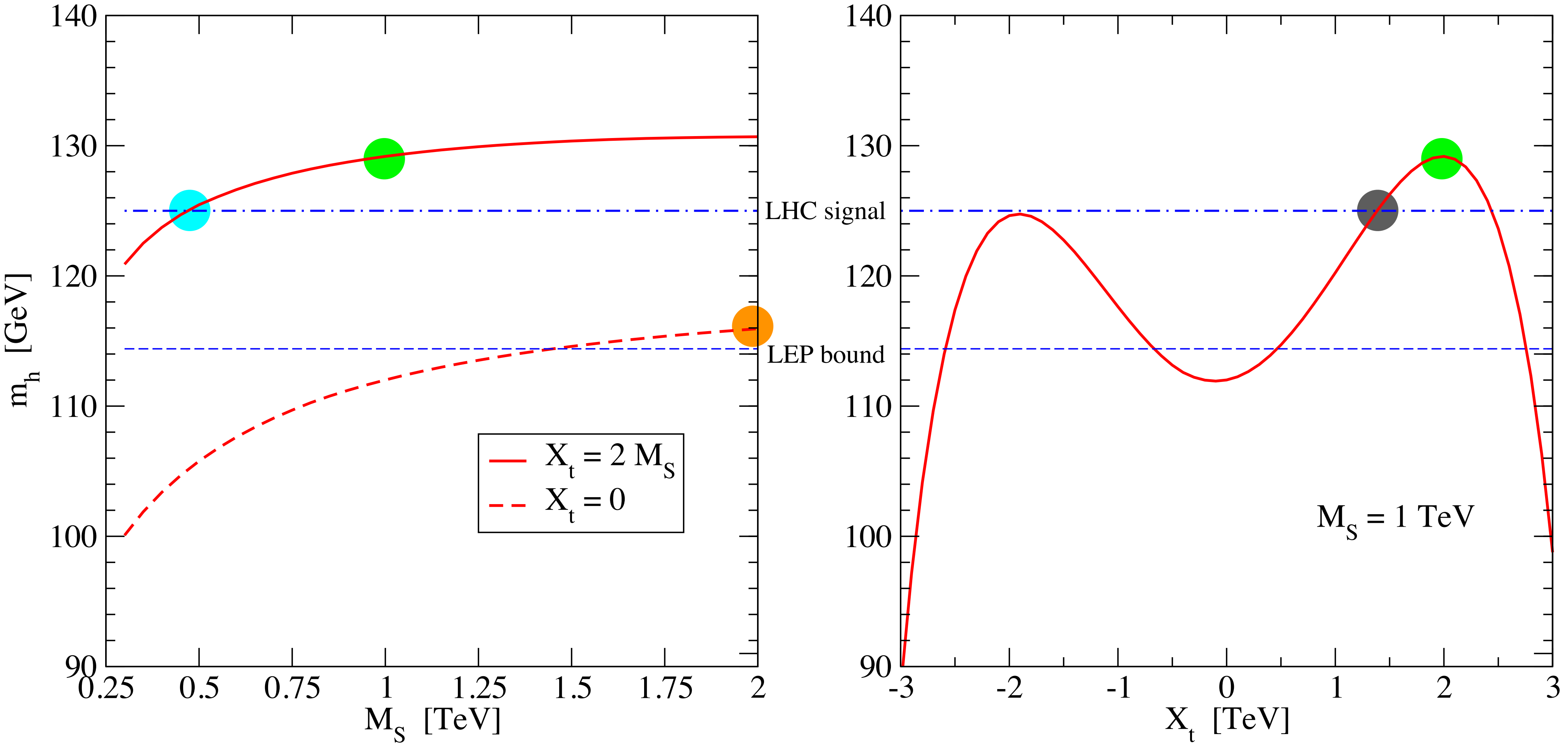

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modified m_h^{max} scenario: $M_s =$ 1 TeV, $X_t = 1.3$ TeV

light-stop scenario: $M_s \approx 500$ GeV, $X_t \approx 1$ TeV $(m_{\tilde{t}_1} \approx 320\ \text{GeV},\ m_{\tilde{t}_2} \approx 670\ \text{GeV})$

Uncertainty in the MSSM prediction for the light Higgs mass

Public codes for the MSSM mass spectrum (e.g. `FeynHiggs, SuSpect, SoftSusy, SPheno`) currently include full 1-loop plus leading 2-loop top/stop and bottom/sbottom corrections (2-loop part by Heinemeyer *et al.* 98-07; P.S. *et al.* 01-04)

The estimated *theoretical* uncertainty is $\Delta^{th}\, m_h \approx 3$ GeV (especially at large stop mixing!!!)

A nearly-full 2-loop calculation including EW (Martin 02-04) and even the leading 3-loop terms (Martin 07; Harlander *et al.* 08-10) are now available. Uncertainty should go down to ≤ 1 GeV

Still largish w.r.t. the expected *experimental* accuracy at LHC: $\Delta^{exp}\, m_h \approx 100$ MeV (with 30 fb^{-1})

We must also consider the *parametric* uncertainty stemming from the experimental uncertainty of the SM parameters entering the corrections (especially m_t)

More work to do!!! However - if squarks are found - a precise determination of m_h will allow us to constrain parameters that the LHC can measure only poorly (e.g., X_t)

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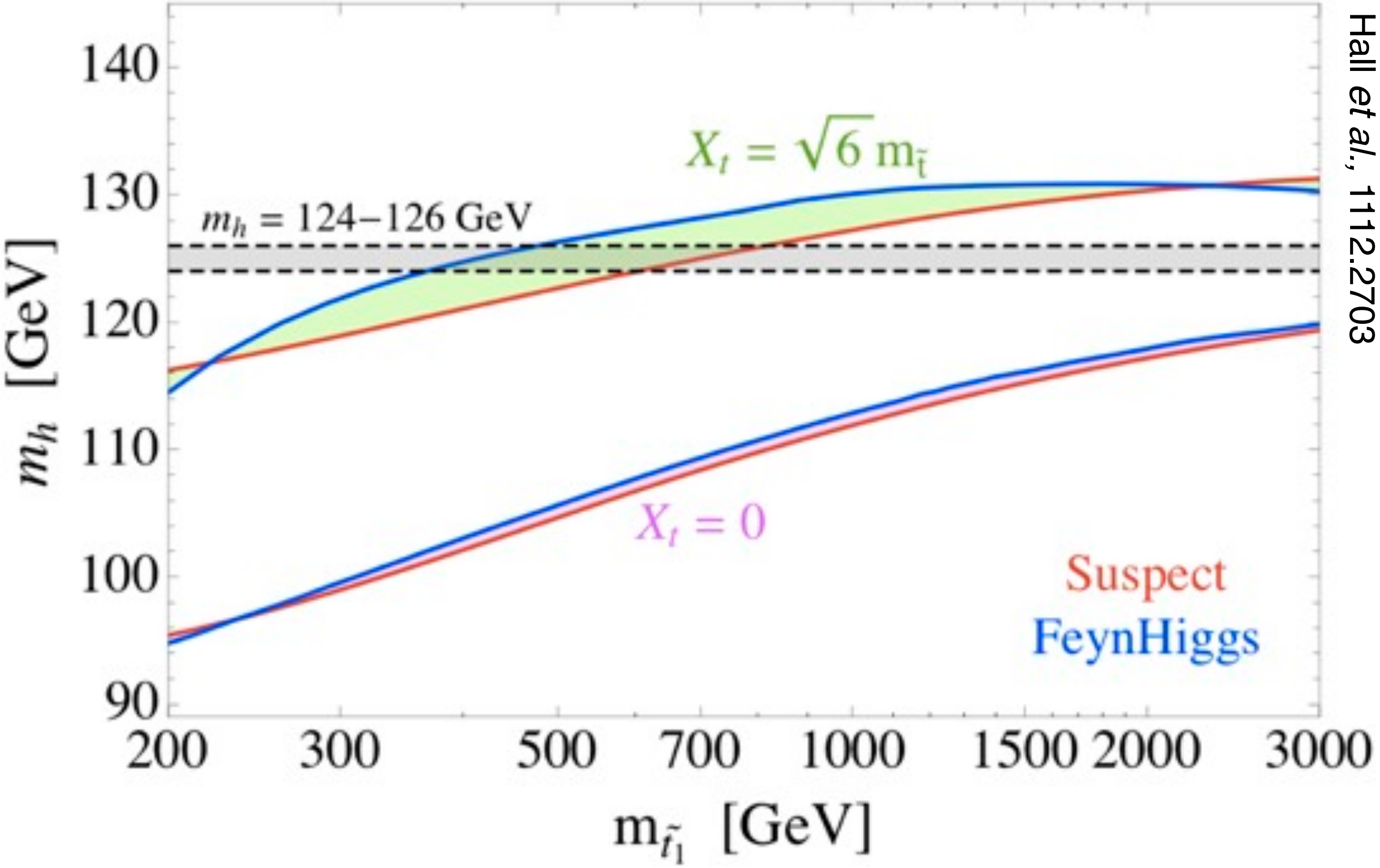

Hall *et al.*, 1112.2703

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