Theory SUSY Higgs

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Higgs Hunting 2011

Discussions on

Tevatron and LHC results

July 28-30, 2011, Orsay, France

Outline

The MSSM Higgs Sector

MSSM Higgs sector – supersymmetry & anomaly free theory $\Rightarrow$ 2 complex Higgs doublets

$\overset{\text{EWSB}}{\rightarrow}$ neutral, CP-even h, H | neutral, CP-odd A | charged H^+, H^-

Higgs masses

$$M_h \lesssim 140 \text{ GeV}$$
$$M_{A,H,H^\pm} \sim \mathcal{O}(v)...1 \text{ TeV}$$

Ellis et al;Okada et al;Haber,Hempfling;
Hoang et al;Carena et al;Heinemeyer et al;
Zhang et al;Brignole et al;Kant et al;...

Modified couplings with respect to the SM:

$\tan\beta \uparrow \Rightarrow g_{\Phi uu} \downarrow$

$g_{\Phi dd} \uparrow$

$g^{MSSM}_{\Phi VV} \lesssim g^{SM}_{\Phi VV}$

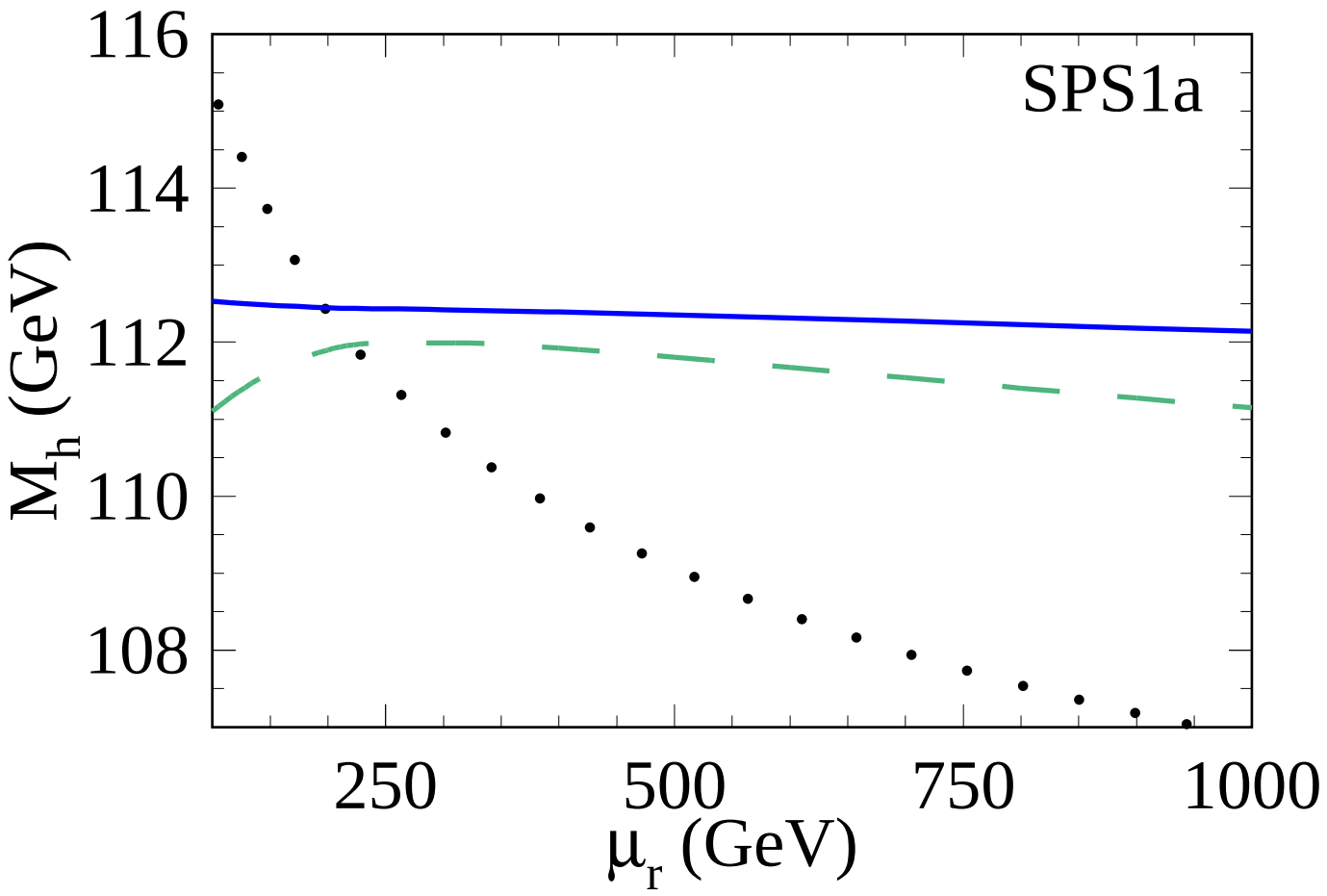
Direct search at LEP: $e^+e^- \rightarrow Z + h/H, A + h/H, \nu_e\bar{\nu}_e + h/H$

$M_{h,H} \gtrsim 92.6$ GeV, $M_A \gtrsim 93.4$ GeV, $M_{H^\pm} \gtrsim 78.6$ GeV,

$0.6 < \tan\beta < 2.5$ excluded ($m_t = 174.3$ GeV)

Light MSSM Higgs mass at three-loop order

Kant,Harlander,Mihaila,Steinhauser '10

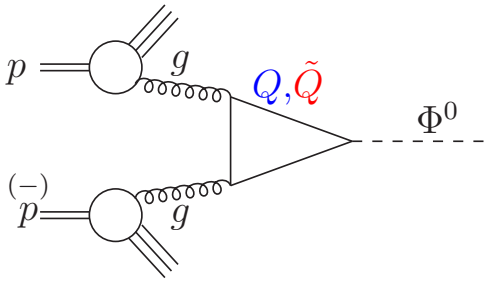


$\Delta M_h \approx 200$ MeV (1 GeV) for $m_{1/2} = 100$ GeV (1 TeV)

Higgs boson production in the MSSM

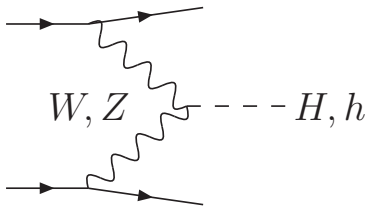
- **Gluon Fusion**

  $pp \to gg \to h, H, A$



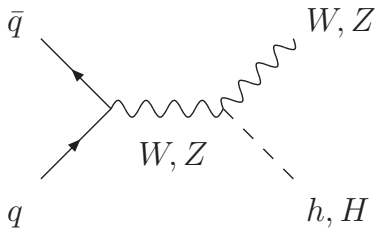
- **W/Z Fusion**

  $pp \to qq \to qq + WW/ZZ \to qq + h, H$



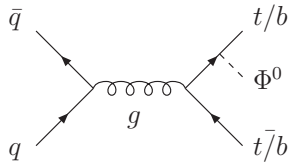
- **Higgs-strahlung**

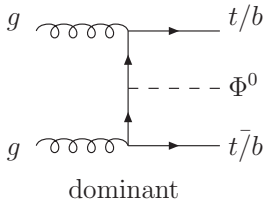
  $pp \to W^*/Z^* \to W/Z + h, H$



- **Associated Production**

  $pp \to t\bar{t}/b\bar{b} + h, H, A$





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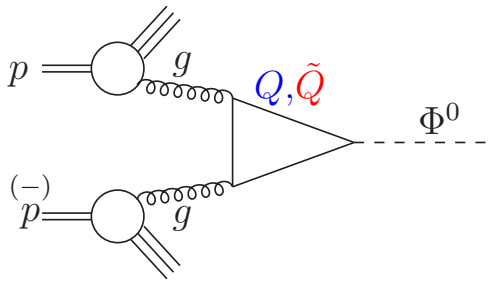

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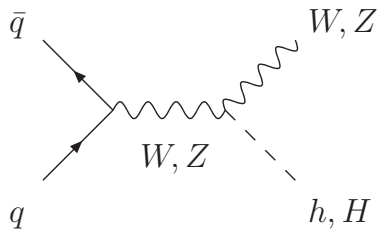


- **LHC**

$gg \to \phi$ dominant for $\tan\beta \lesssim 10$

$gg \to \phi b\bar{b}$ dominant for $\tan\beta \gtrsim 10$

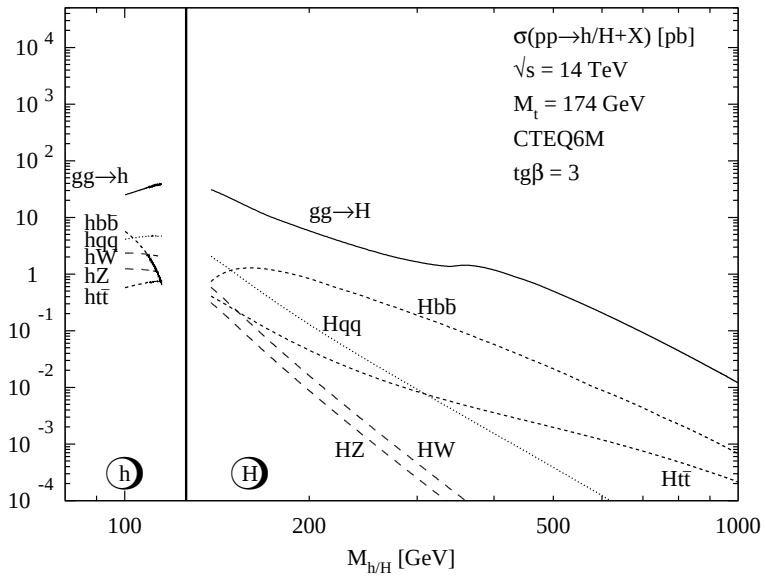
- **Tevatron**

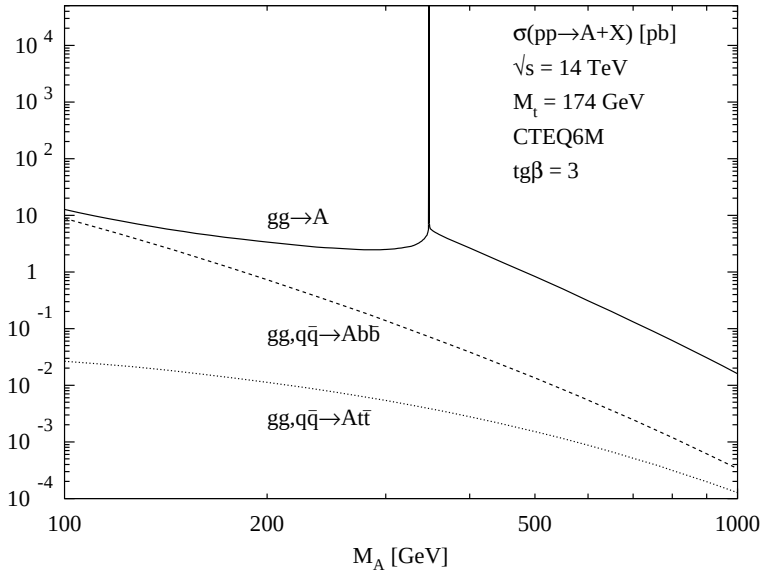
$gg \to \phi$ dominant, for large $\tan\beta$: $\phi b\bar{b}$

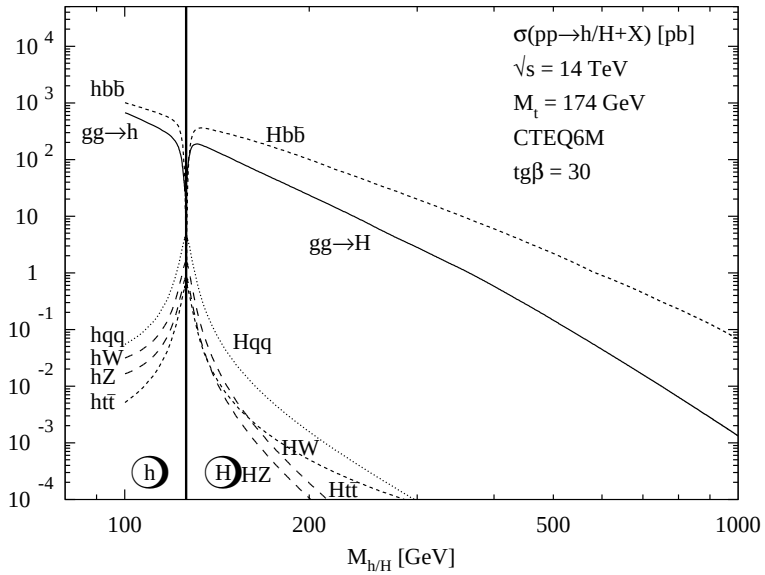
$q\bar{q}' \to \phi W$ most important

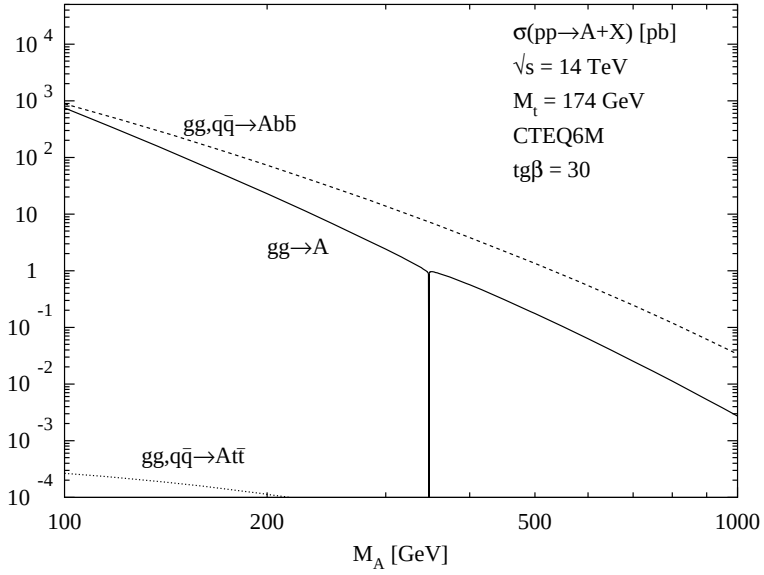
MSSM Higgs Boson Production at the LHC

Spira



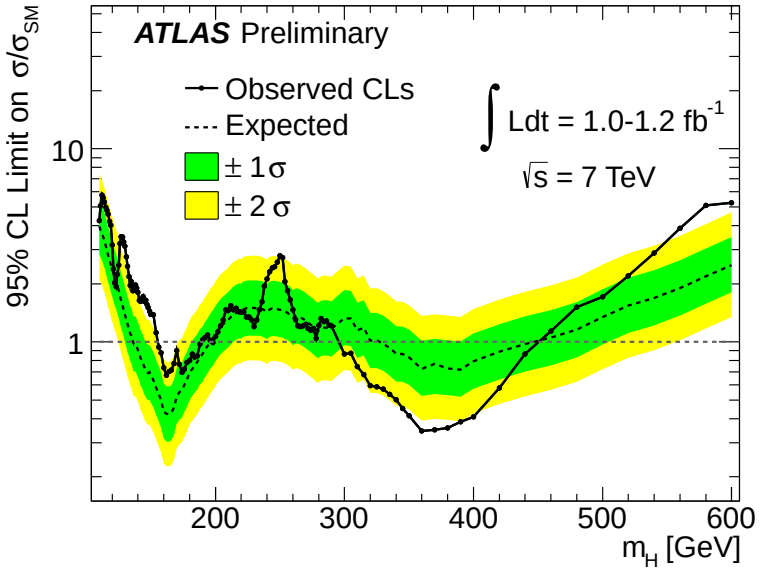




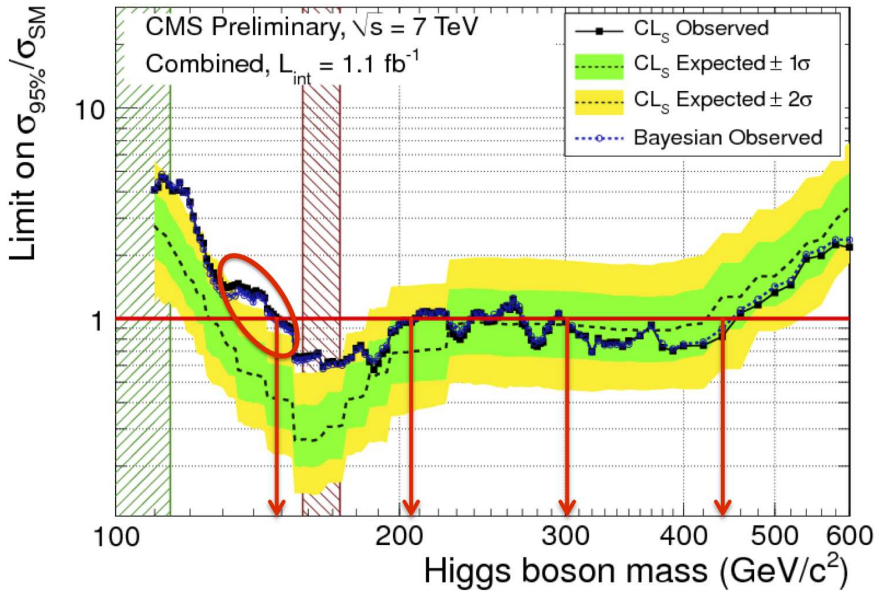


Combined Search Limits

ATLAS collaboration



CMS collaboration

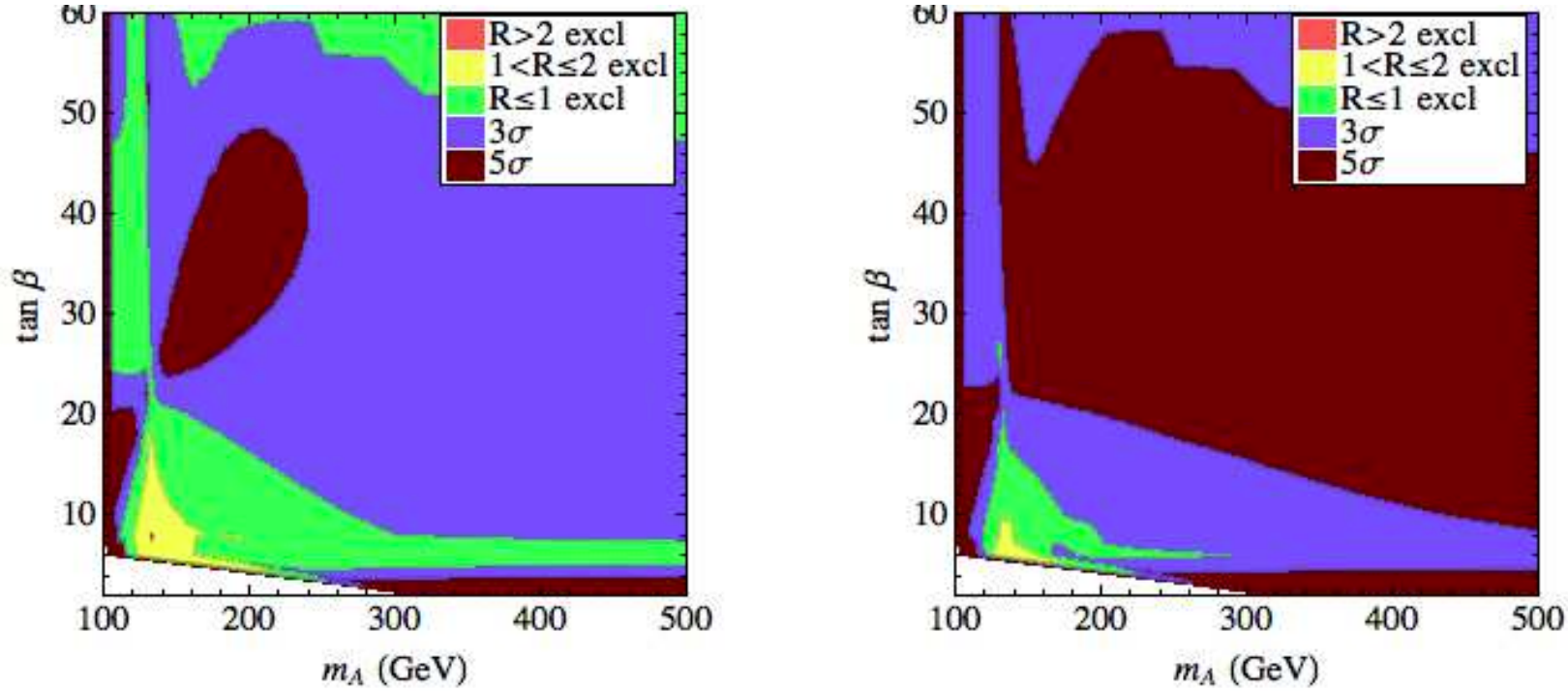


ATLAS exclusion: $155 < M_H < 190$ and $295 < M_H < 450$ GeV

CMS exclusion: $149 < M_H < 206$ and $300 < M_H < 440$ GeV & 3 short segments in between

The 7 TeV LHC Reach for MSSM Higgs Bosons

Carena,Draper,Liu,Wagner '11



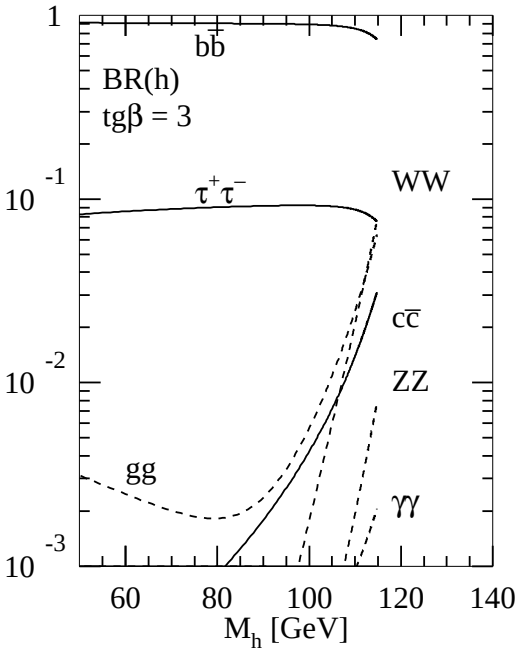
Several scenarios investigated

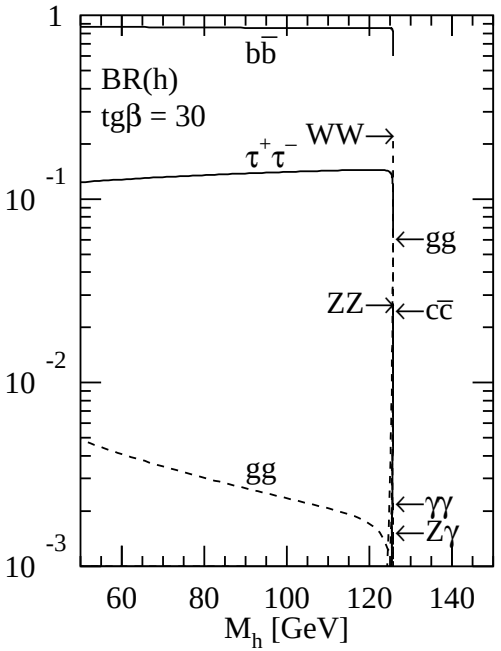
Here small α_{eff} scenario: $BR(h \to \gamma\gamma)$ enhanced at low M_A and large $\tan\beta$

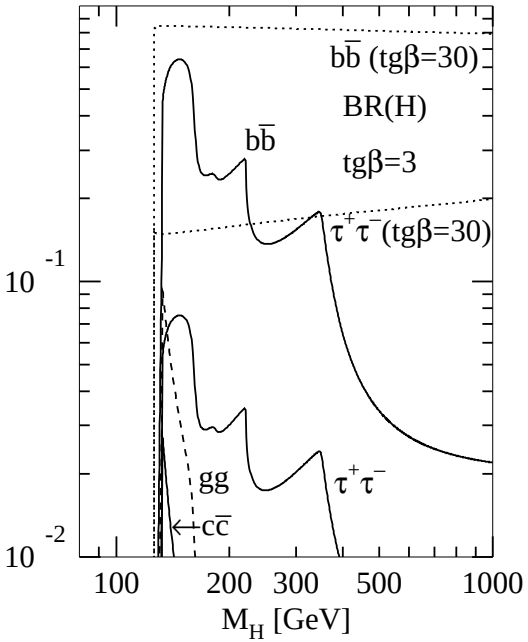
Decays

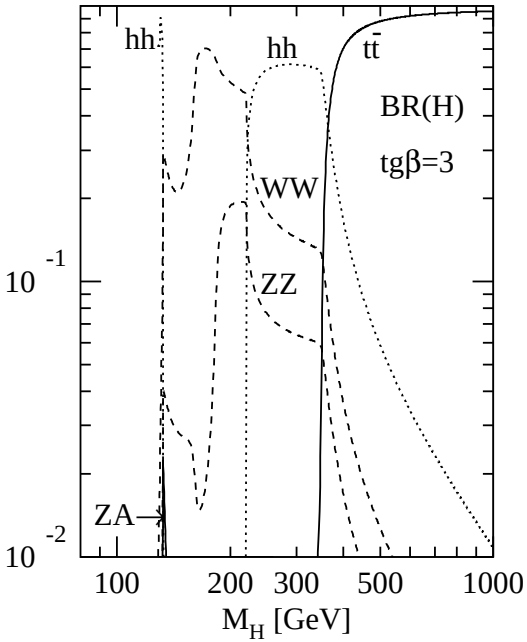
MSSM Branching Ratios

HDECAY









Branching Ratios

Created with HDECAY Djouadi,Kalinowski,MMM,Spira

PROPHECY4F Bredenstein,Denner,Dittmaier,Mück,Weber

⋆ HDECAY - upgrade '11

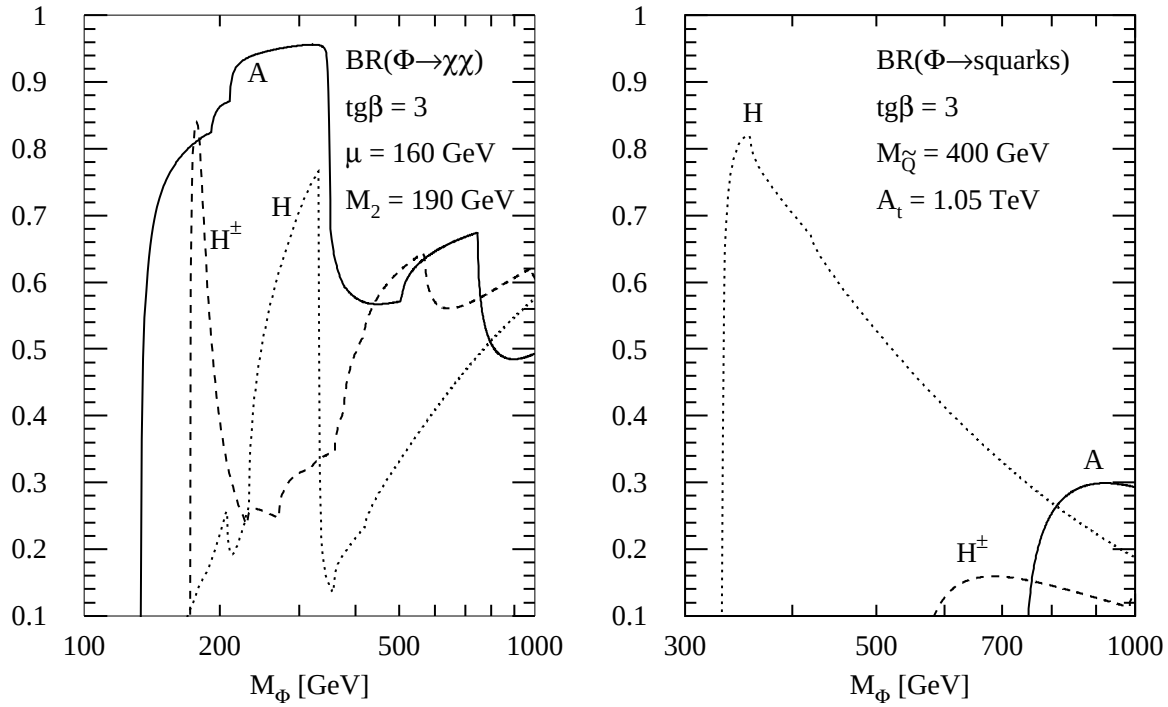
- SM 4th generation
- dominant EW corrs to $H \to WW, ZZ$ in fermiophobic and 4th generation SM
- 4-loop QCD to $H \to gg$ Baikov,Chetyrkin
- 3-loop QCD to $A \to gg$ Bardeen,Chetyrkin,Kniehl,Steinhauser
- NNLO running of α_s

⋆ PROPHECY4F

- $H \to WW/ZZ \to 4f$ complete NLO QCD and EW corrections w/ all interferences and leading 2-loop heavy Higgs corrections

SUSY Decays

- **New decay modes in SUSY particles: $\phi \to \tilde{\chi}\tilde{\chi}, \tilde{q}\bar{\tilde{q}}$**



HDECAY

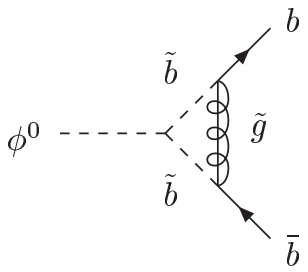
∗ important if kinematically possible ($\tilde{q}$ 3rd generation)

∗ very large SUSY-QCD corrections to $\phi \to \tilde{q}\bar{\tilde{q}} \rightsquigarrow$ needs investigation Bartl eal; Arhrib eal; Eberl eal

∗ consistent treatment of squark masses and couplings to Higgs bosons at NLO
$\rightsquigarrow \Delta_{\text{th}} \sim 5 - 10\%$ Accomando eal '11

$\mathcal{SUSY}$ $\mathcal{D}$ecays - Further developments

- **Large SUSY-QCD corrections to $\phi^0 \to b\bar{b}$**



$+\ldots \qquad \sim \frac{\alpha_s}{\pi} \frac{m_{\tilde{g}} \mu \tan\beta}{m^2_{\tilde{b}}}$

Hall eal; Carena eal; Nierste eal; Guasch eal; ...

$\Rightarrow$ resummed Yukawa couplings

Carena, Garcia, Nierste, Wagner; Eberl eal; Guasch, Häfliger, Spira

$*$ NNLO to effective bottom Yukawa couplings: Δ_{th} at per cent level

Noth,Spira '08; Mihaila, Reißer '10

- **Full 1-loop corrections to $h_a \to h_b h_c$, $h_a \to f\bar{f}$ in complex MSSM**

Williams,Rzehak Weiglein '11

[tools for complex MSSM: FeynHiggs Hahn eal, CPsuperH Lee eal]

- **HFOLD:** Fortran package for MSSM Higgs 2-body decays and BRs at full one-loop level

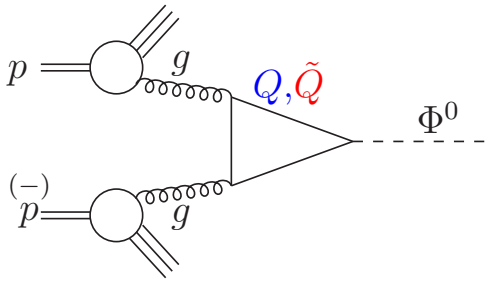
Frisch,Eberl,Hlucha '10

Production

$\mathcal{H}$iggs Boson Production in gluon fusion

(i) Dominant: Gluon Fusion $pp \to gg \to H^{SM}$ / h, H, A (small & moderate $\tan\beta$)

Georgi et al; Gamberini et al



QCD corrections to top & bottom loops

- ▷ NLO (SM, MSSM): increase σ by $\sim$ 10...100% [moderate for large $\tan\beta \leftarrow b$-loop] — Spira,Djouadi,Graudenz,Zerwas Dawson;Kauffman,Schaffer
- ▷ SM; tg$\beta \lesssim 5$: limit $M_\Phi \ll m_t$ - approximation $\sim$ 20-30% — Krämer,Laenen,Spira
- ▷ NNLO @ $M_\Phi \ll m_t \Rightarrow$ further increase by 20-30% — Harlander,Kilgore Anastasiou,Melnikov Ravindran,Smith,van Neerven
- ▷ Estimate of NNNLO effects @ $M_\Phi \ll m_t \rightsquigarrow$ scale stabilisation — Moch,Vogt Ravindran

  scale dependence: $\Delta \lesssim 10 - 15\%$
- ▷ NNLL resummation: $+ \sim 10\%$ — Catani,de Florian,Grazzini,Nason Ahrens,Neubert,Becher,Yang

$\mathcal{H}$iggs Boson Production in gluon fusion

Corrections to top & bottom loops

- ▷ NNLO mass effects (t loops) for $M_H \lesssim 300$ GeV $\Rightarrow \mathcal{O}(0.5\%)$ — Harlander,Ozeren;Pak,Rogal,Steinhauser; Marzani et al.
- ▷ NLO electroweak corrections $\sim -4\% - 6\%$ (SM) — Aglietti et al.;Degrassi,Maltoni; Actis et al
- ▷ mixed QCD and EW corrections — Anastasiou,Boughezal,Petriello

NLO corrections to squark loops

- ▷ in the heavy mass limit — Dawson,Djouadi,Spira
- ▷ full SUSY-QCD corrections in heavy mass limit — Harlander,Steinhauser;Harlander,Hofmann; Degrassi,Slavich '11
- ▷ bottom/sbottom contributions asymptotic expansion in $\tilde{M} \gg m_b, M_\phi$ — Degrassi,Slavich '11; Harlander,Hofmann,Mantler '11

$m_{\tilde{Q}} \lesssim 400$ GeV:

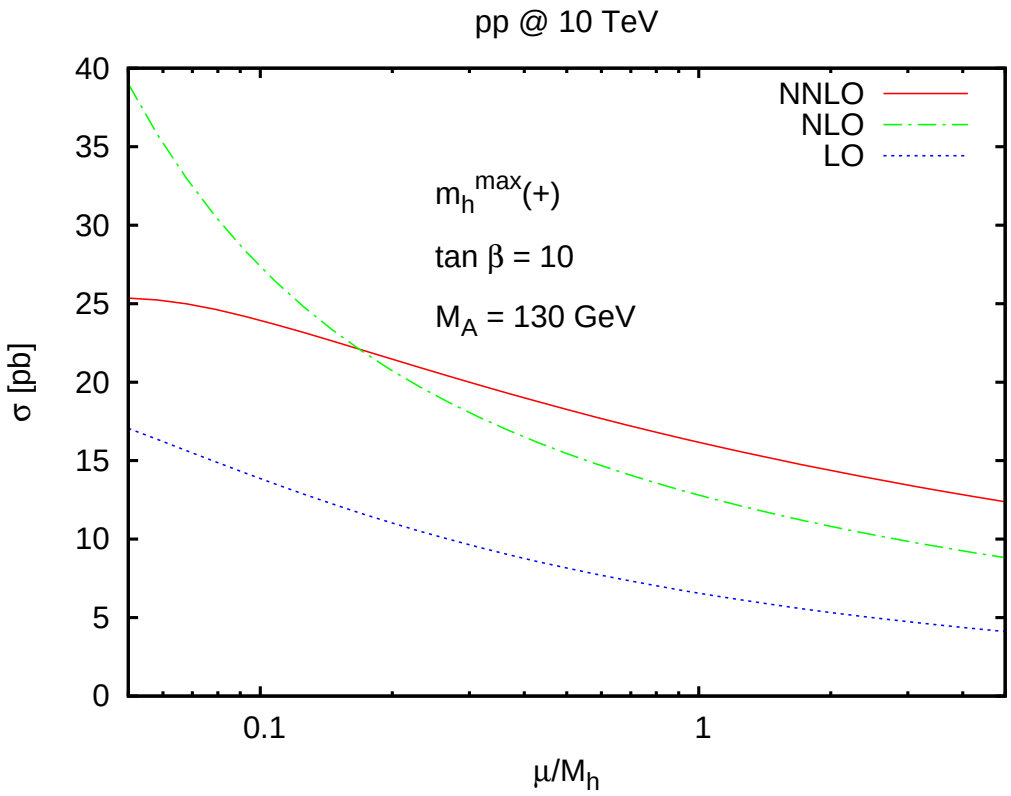
- ▷ NLO squark mass effects $\sim$ 15% — MMM,Spira;Anastasiou,Beerli,Bucherer, Daleo,Kunszt;Aglietti,Bonciani,Degrassi,Vicini
- ▷ full NLO SUSY QCD calculation — Anastasiou,Beerli,Daleo; MMM,Rzehak,Spira

NNLO SUSY-QCD corrections from $t/\tilde{t}$ sector — Pak,Steinhauser,Zerf '10

MSSM Higgs production in gluon fusion

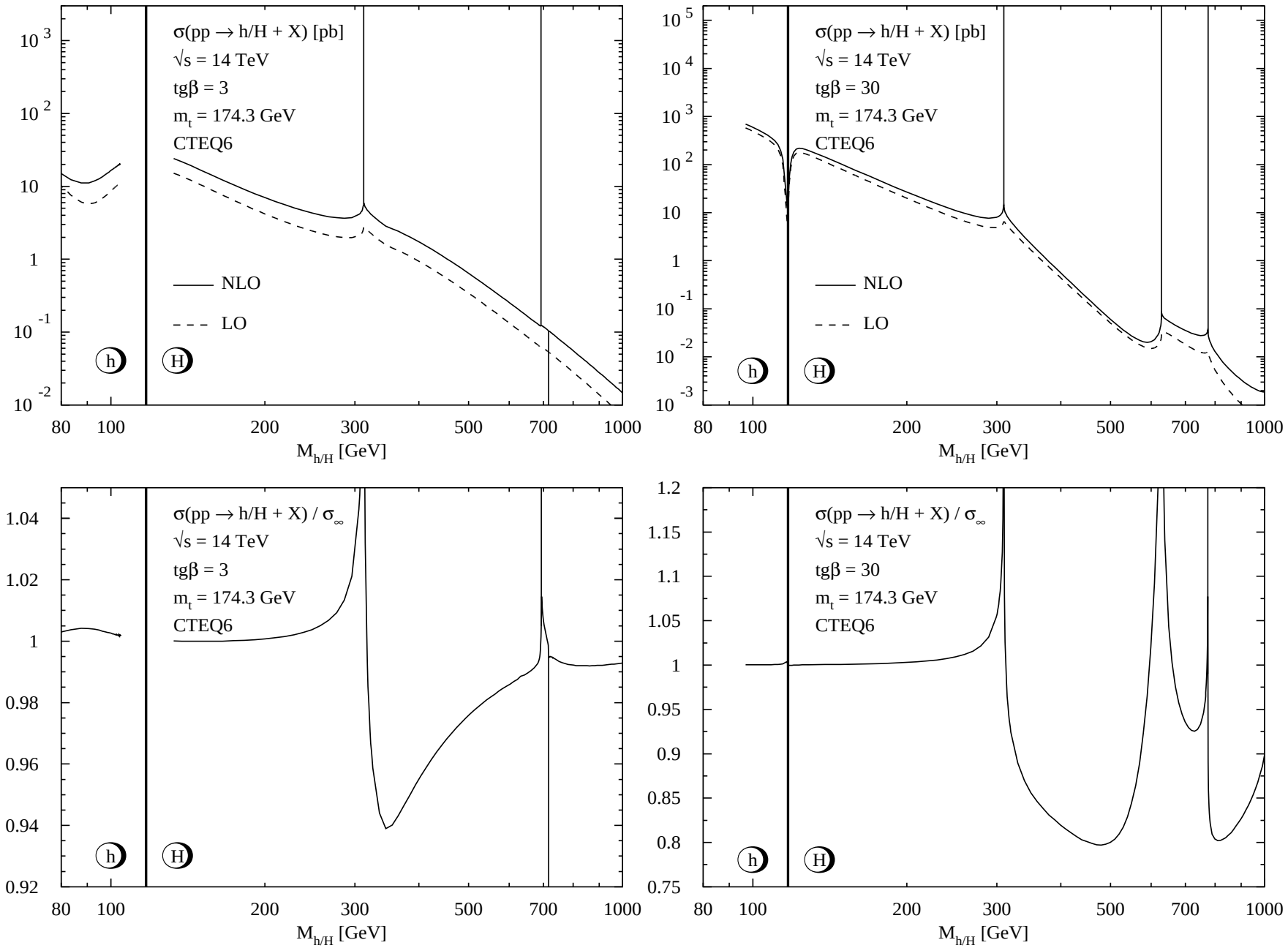
$$\sigma^{MSSM} = \sigma^{MSSM}_{NLO} + (g^h_t)^2 \left[(1+\delta_{EW})\sigma^{SM,t}_{NNLO} - \sigma^{SM,t}_{NLO}\right]$$

Harlander,Hofmann,Mantler '11



Mhmax: $\tan\beta = 10$, $M_{SUSY} = 1$ TeV, $\mu = 200$ GeV, $M_2 = 200$ GeV, $M_3 = 800$ GeV, $X_t = 2$ TeV
$m_{\tilde{t}_1} = 830$ GeV, $m_{\tilde{t}_2} = 1170$ GeV, $m_{\tilde{b}_1} \approx m_{\tilde{b}_2} \approx 1$ TeV, $m_{\tilde{g}} = 800$ GeV

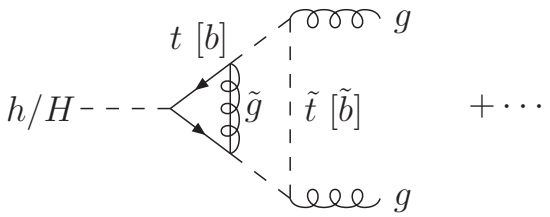
Pure QCD corrections to squark loops



Genuine SUSY-QCD corrections

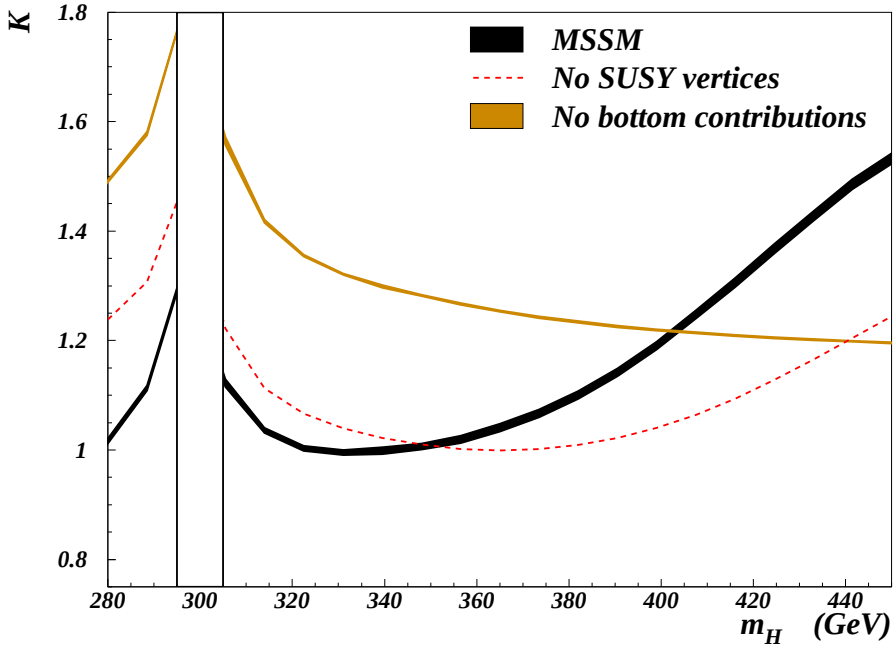
- **Limit heavy SUSY masses** $\rightarrow \mathcal{O}(10\ \%)$

Harlander,Steinhauser,Hofmann



Anastasiou,Beerli,Daleo
MMM,Rzehak,Spira

Anastasiou,Beerli,Daleo

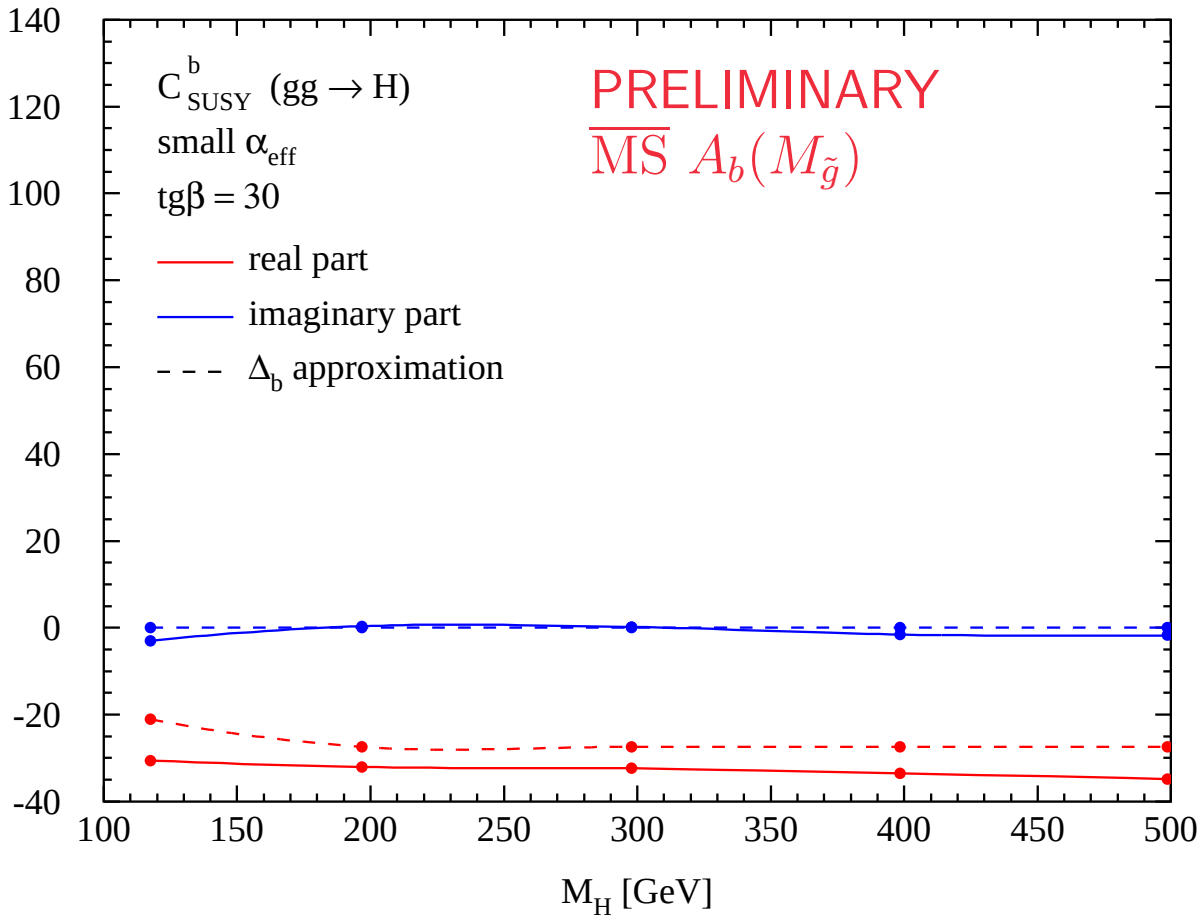


$\tan\beta = 20$, $\mu = 300$ GeV, $\alpha = 3°$, $\theta_t = \theta_b = 40°$, $m_{\tilde{g}} = 500$ GeV,
$m_{\tilde{t}_1} = 150$ GeV, $m_{\tilde{t}_2} = 350$ GeV, $m_{\tilde{b}_1} = 350$ GeV, $m_{\tilde{b}_2} = 370$ GeV

Genuine SUSY-QCD corrections

$$\sigma(pp \to \phi) = \sigma_0^{\phi} \tau_\phi \frac{d\mathcal{L}^{gg}}{d\tau_\phi}$$

$$\sigma^{h/H} = \frac{G_F \alpha_s^2}{288\sqrt{2}\pi} \left| \sum_Q g_Q^{h/H} A_Q^{h/H} \left[1 + C_{SUSY}^{Q} \frac{\alpha_s}{\pi} \right] + \sum_Q g_{\tilde{Q}}^{h/H} A_{\tilde{Q}}^{h/H}(\tau_{\tilde{Q}}) \right|^2$$



MMM, Rzehak, Spira

Further developments

- **Update of** `HIGLU: Version 3.01` Spira '11
  - NNLO QCD corrections and mixed EW/QCD corrections (fully factorized)
  - NNLO evolution of α_s
  - 4th generation SM4 with NNLO QCD (g_B, g_T, m_B, m_T)
  - inferface with LHAPDF library
- **Program** `iHixs` Anastasiou,Bühler,Herzog,Lazopoulos '11
  - gluon fusion & bottom quark fusion up to NNLO, mixed QCD/EW corrections, finite Γ_H effects
  - SM and modified w/ anomalous Yukawa couplings & EW interactions (4th generation, ...)
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  - inferface with LHAPDF library
- **Gluon fusion with four generations** Anastasiou et al '11
  - NLO QCD w/ full quark mass dependence, NNLO QCD in HQET, 3-loop EW/QCD corrections

    Cxn increased by factor 9 compared to SM Georgi eal; Anastasiou eal '11; Ruan,Zhang '11

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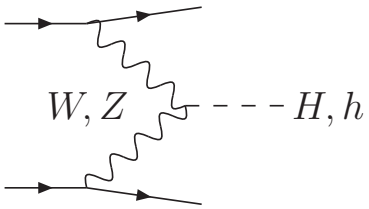
- **MadLoop** Hirschi et al. '11
  - complete automation of 1-loop QCD corrections
  - example $t\bar{t}H$ production

$\mathcal{H}$iggs Boson Production in W/Z boson fusion

(ii) W/Z boson fusion: $pp \to qq \to qq + WW/ZZ \to qq + H^{SM}$ / h, H



Cahn, Dawson
Hikasa
Altarelli, Mele, Pitolli

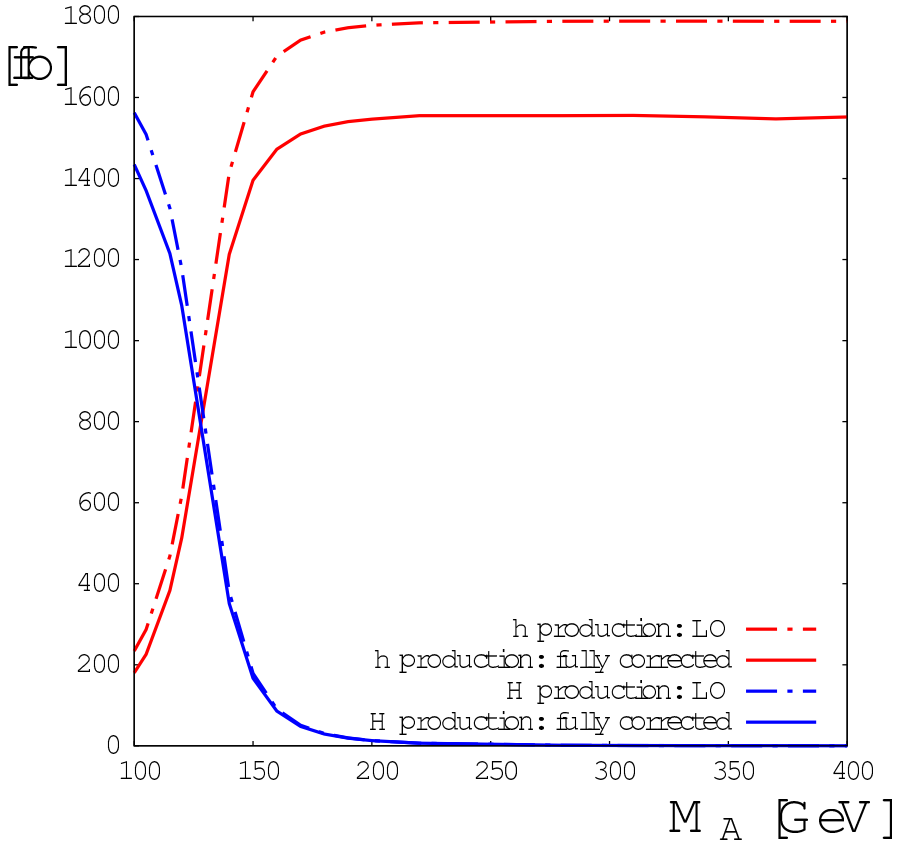
- ▷ **NLO QCD corrections to total rate (SM/MSSM)** ~ 5 to 10% — Han, Valencia, Willenbrock
  distributions (SM/MSSM) ~ 20 % — Figy, Oleari, Zeppenfeld; Berger, Campbell
- ▷ **SUSY QCD corrections small** — Djouadi, Spira
- ▷ **SUSY EW+QCD corrections small** — Hollik, Plehn, Rauch, Rzehak; Figy, Palmer, Weiglein '10
- ▷ **Full EW & QCD corrections** $\sim 5\%$ — Ciccolini, Denner, Dittmaier — HAWK — $(\Delta^{\text{theor}} \sim 5\ \%)$
- ▷ **One-loop interference effects in H+jj** — Andersen, Binoth, Heinrich, Smillie; Bredenstein, Hagiwara, Jäger
  between gg fusion and WBF at $\mathcal{O}(\alpha^2\alpha_s^3)$ — below percent level
- ▷ **NNLO QCD effects** $\mathcal{O}(\alpha^3\alpha_s^2)$ — $\Delta_{th} \sim 2\%$ — Harlander, Vollinga, Weber; Bolzoni, Maltoni, Moch, Zaro '10

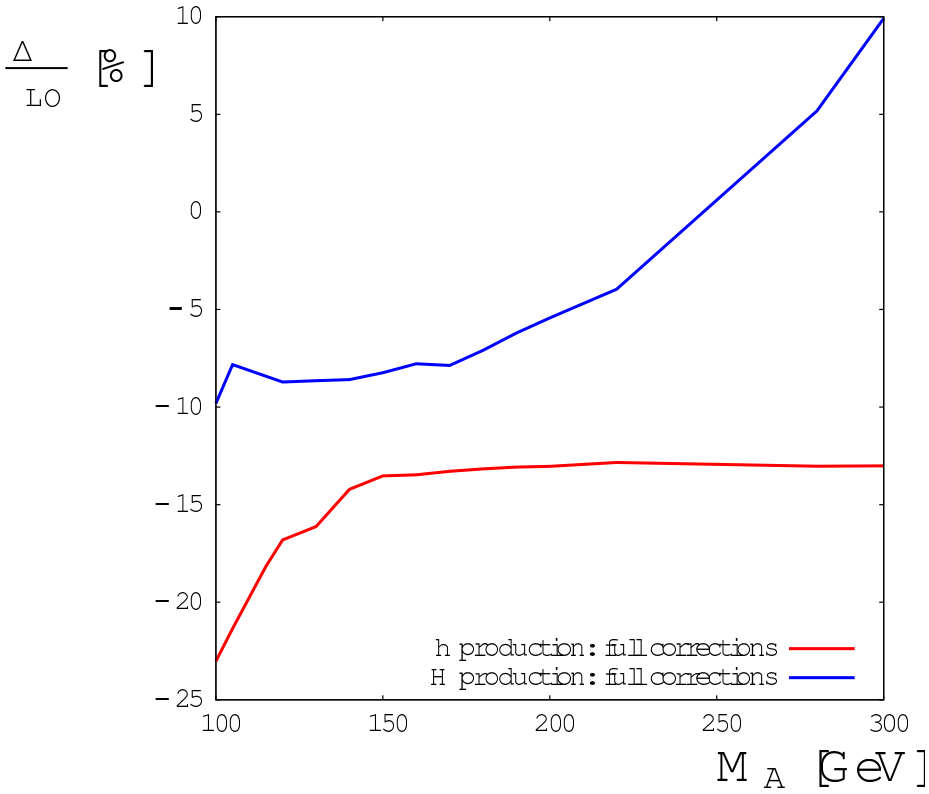
W/Z boson fusion in the SM and MSSM

SM: Full 1-loop

Figy,Palmer,Weiglein '10

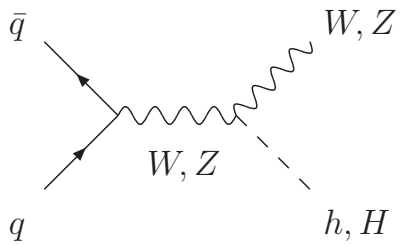
MSSM: dominant SUSY 1-loop combined w/ full 1-loop SM type corrections; complex phases





$\mathcal{H}$iggs-strahlung

(iii) $pp \to q\bar{q} \to Z^*/W^* \to Z/W + H^{SM}/\ h, H$



Glashow et al.
Kunszt et al.

Contribution to $\Phi \to \gamma\gamma$ discovery contour

- **NLO QCD corrections (SM/MSSM)** $\sim +30\%$ (Drell-Yan) — Han,Willenbrock

  NNLO QCD corrections (SM/MSSM) $\sim +5$-10% — Harlander,Kilgore; Hamberg,Van Neerven,Matsuura; Brein,Djouadi,Harlander

  $\Delta_{\text{theor}} \sim 5\ \%$

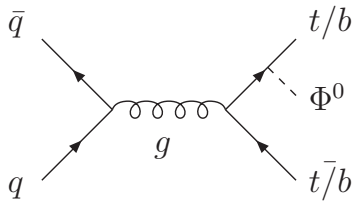
- **SUSY QCD corrections** $\lesssim$ few per cent — Djouadi,Spira

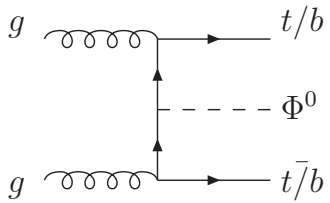
- **Full EW corrections (SM)** ~ -5-10% — Ciccolini,Dittmaier,Krämer

- **WH: fully exclusive at NNLO QCD** — Ferrera,Grazzini,Tramontano '11

Associated production with a $t\bar{t}$ pair

(iv) Higgs $t\bar{t}$ production: $pp \to q\bar{q}/gg \to t\bar{t} + H^{SM}/\, h(H, A)$





dominant

Kunszt;Gunion;
Marciano,Paige

Significant role: $M_H^{SM} \lesssim 150$ GeV; light scalar MSSM Higgs

- **NLO QCD corrections (SM,MSSM):** $\sim +20$ %
  $\Delta^{\text{theor}} \sim 15$ %

  Beenakker et al.;
  Dawson et al.

- **SUSY QCD corrections:** $\pm(10-30)$ %

  Peng et al.
  Dittmaier,Häfliger,Krämer,Spira,Walser

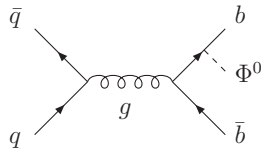
- **NLO bkg** $t\bar{t}b\bar{b}$, $t\bar{t}jj^*$

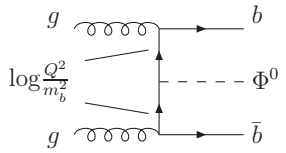
  Bredenstein,Denner,Dittmaier,Pozzorini;
  Bevilacqua,Czakon,Papadopoulos,Pittau,Worek
  *Bevilacqua et al. `HELAC-NLO`

Associated production with a $b\bar{b}$ pair

(v) Higgs $b\bar{b}$ production: dominant MSSM Higgs production mechanism for $\tan\beta \gtrsim 7$
measurement of $\tan\beta$

- Four-flavour scheme 4FS: LO cxn $gg \to b\bar{b}\Phi^0$





dominant

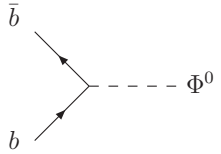
NLO with 0,1,2 high-transverse momentum b jets

Dittmaier,Krämer,Spira;
Dawson,Jackson,Reina,Wackeroth

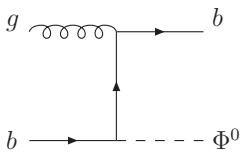
exact $g \to b\bar{b}$ splitting & mass/off-shell effects

large logs from phase space integration $\rightsquigarrow$ absorbed in bottom PDF $\Rightarrow$

- Five-flavour scheme 5FS: LO cxn $b\bar{b} \to \Phi^0$



NNLO



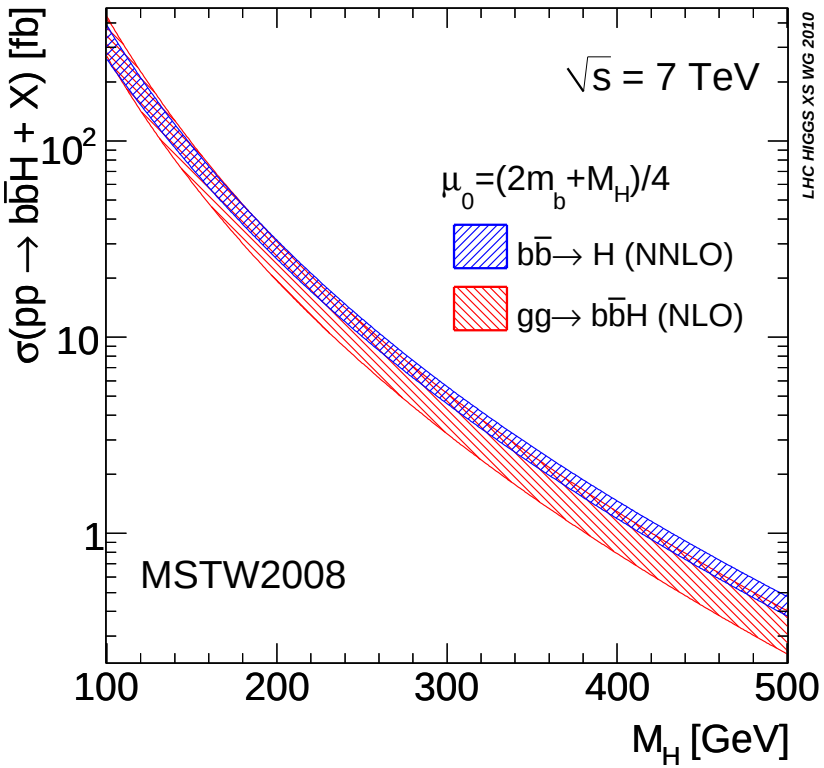
NLO

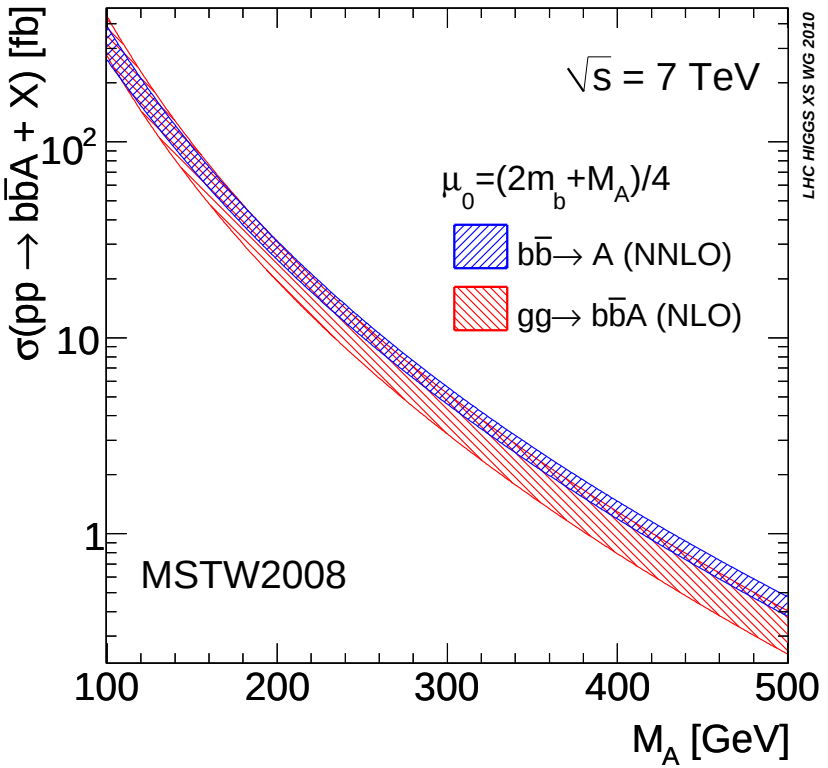
Dicus,Willenbrock
Stelzer et al.;Balazs et al.
Campbell et al.
Harlander,Kilgore
Kidonakis

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

Associated production with a $b\bar{b}$ pair

LHC Higgs XS WG





blue bands: combined scale and 68% CL PDF+α_s uncertainties of the 5FS

red bands: scale uncertainties of the 4FS

The Santander Matching

* **Difference 4FS $\leftrightarrow$ 5FS:** logarithmic

* **Weight:** 5FS 100% weight for $\frac{M_H}{m_b} \to \infty$

  4FS 100% weight for 'small' logarithms: $\ln(M_H/m_b) = 2$ (arbitrariness)

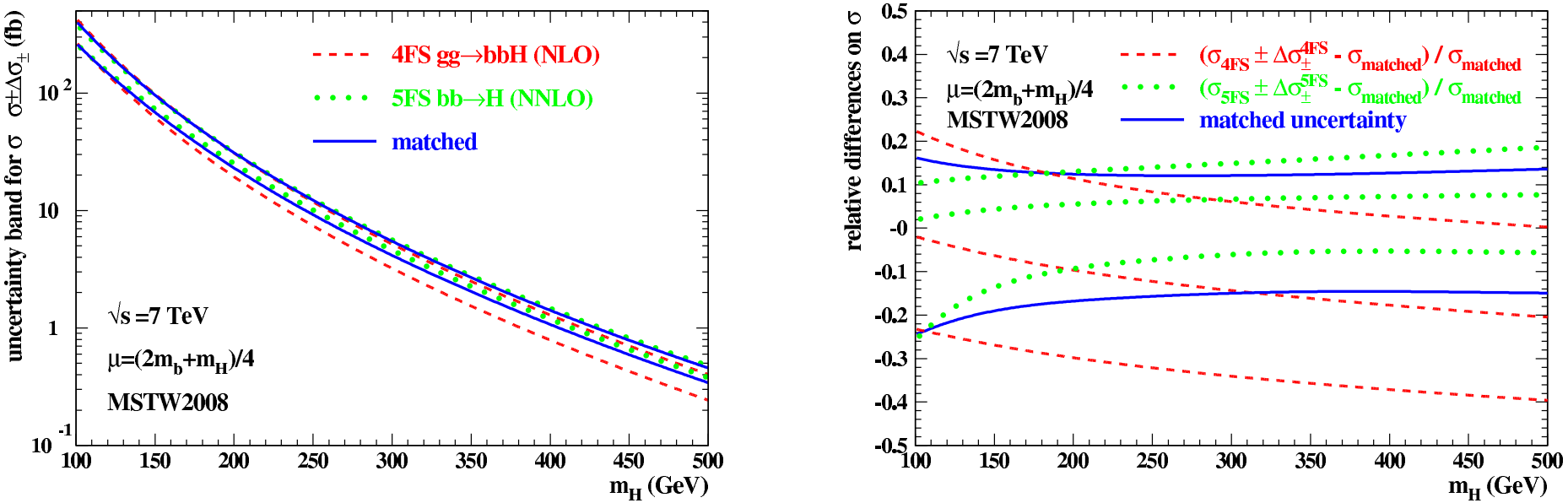
$$\sigma^{\text{matched}} = \frac{\sigma^{\text{4FS}} + w\sigma^{\text{5FS}}}{1+w}$$

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

$\Rightarrow$ 4FS and 5FS have same weight at $M_H = 100$ GeV.

The Santander Matching

Harlander,Krämer,Schumacher



(a) (b)

Figure 2: (a) Theory uncertainty bands for the total inclusive cross section in the 4FS (red, dashed), the 5FS (green, dotted), and for the matched cross section (blue, solid). (b) Uncertainty bands and central values, relative to the central value of the matched result (same line coding as panel (a)).

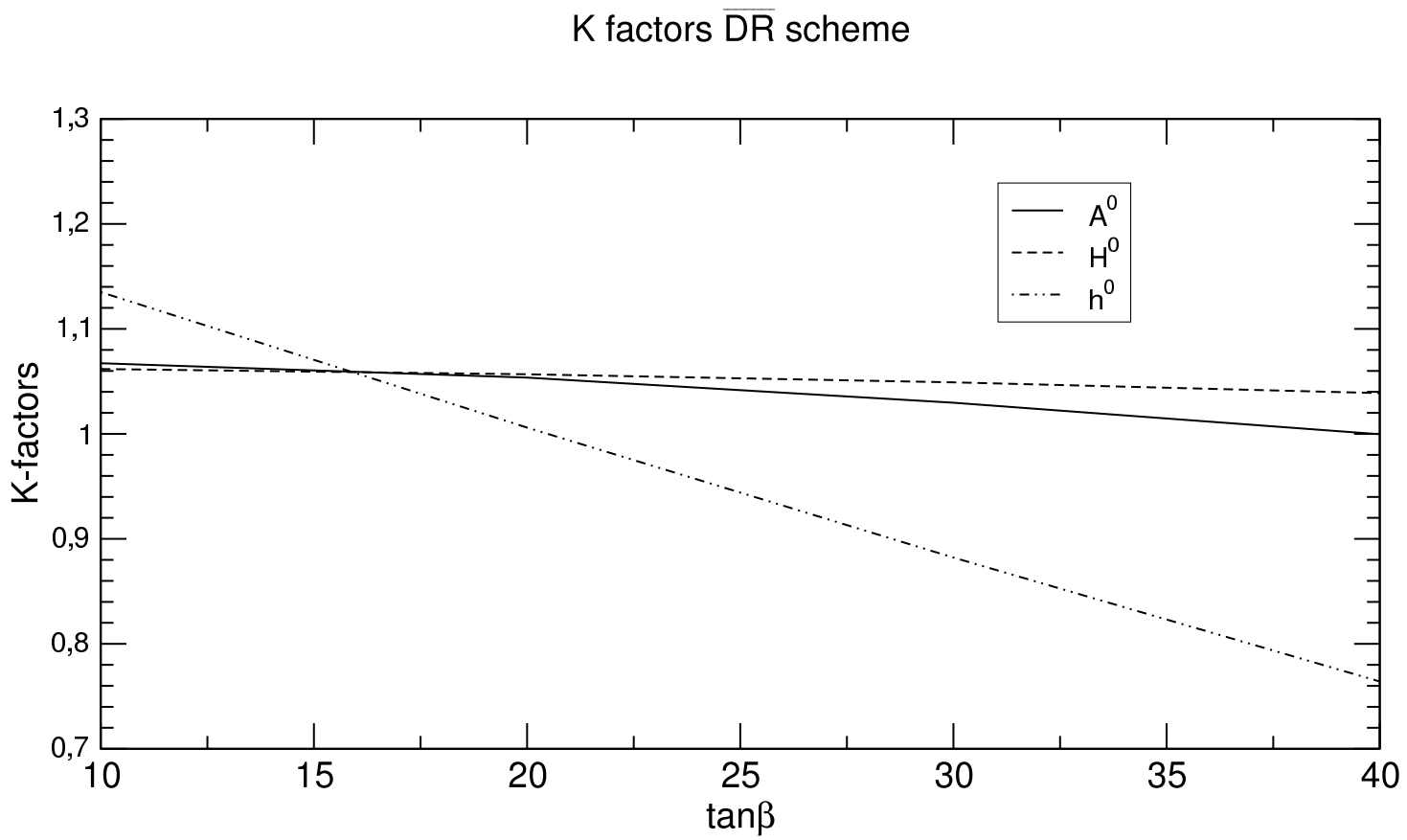
Associated production with a $b\bar{b}$ pair

- **Further corrections:**

◦ EW and QCD corrections to $b\bar{b} \to \Phi^0$:	few % ($\sim \Delta_b$)	Dittmaier,Krämer, Mück,Schlüter
◦ dominant t contr. to "NNLO" $b\bar{b}h$:	few % $M_H \lesssim 120$ GeV several 10 % above	Boudjema, Ninh
◦ SUSY QCD to $gg \to b\bar{b}h$		Gao et al.; Hollik,Rauch
◦ SUSY QCD to $b\bar{b} \to \Phi^0, bg \to b\Phi^0$:	few % ($\sim \Delta_b$)	Dawson, Jackson
◦ EW to $bg \to bH^{\text{SM}}$		Dawson, Jaiswal '10
◦ Complete EW to $bg \to b\Phi^0$		Beccaria, et al. '10

EW $\mathcal{C}$orrections to $bg \to b\Phi^0$

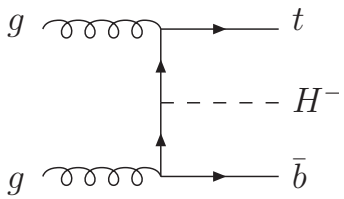
Beccaria,Dovier,Macorini,Mirabella,Panizzi,Renard,Verzegnassi '10



Charged Higgs Production

(vi) Dominant: $pp \to q\bar{q}, gg \to t\bar{b}H^- + X$ (4FS), $bg \to H^- t$ (5FS)

- Four-flavour scheme 4FS: LO cxn $pp \to q\bar{q}, gg \to t\bar{b}H^-$



Bawa eal;
Borzumati eal;
Belyaev eal

NLO QCD & SUSY QCD corrections

Peng et al.
Dittmaier et al.

scale dependence reduced: $\Delta \lesssim 25$ %

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

- Five-flavour scheme 5FS: LO cxn $gb \to H^- t$

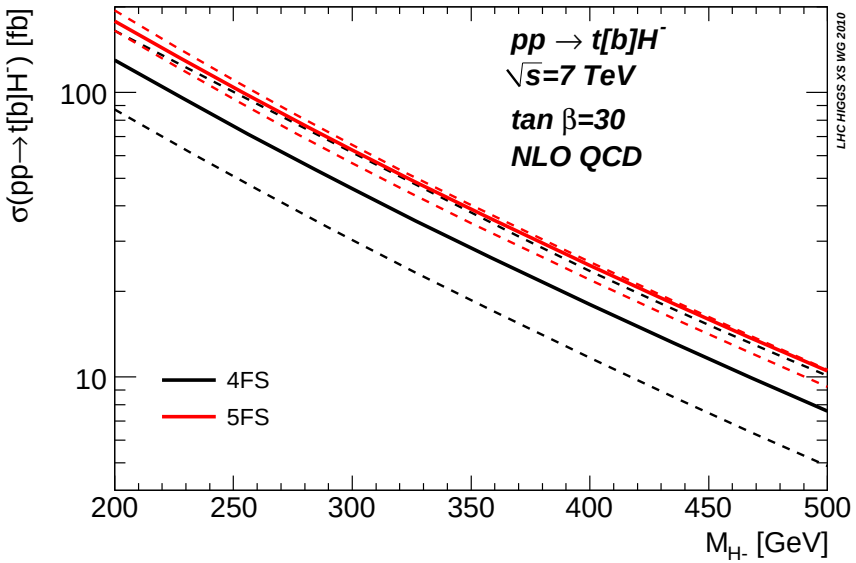
NLO SUSY QCD corrs.: significant

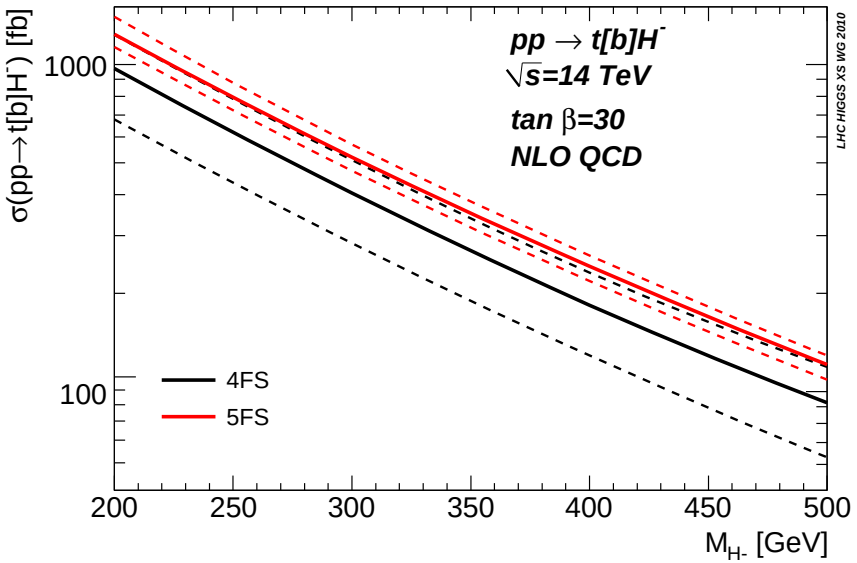
Zhu; Plehn; Berger eal;
Gao et al.;Kidonakis

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

Charged Higgs Production

LHC Higgs XS WG





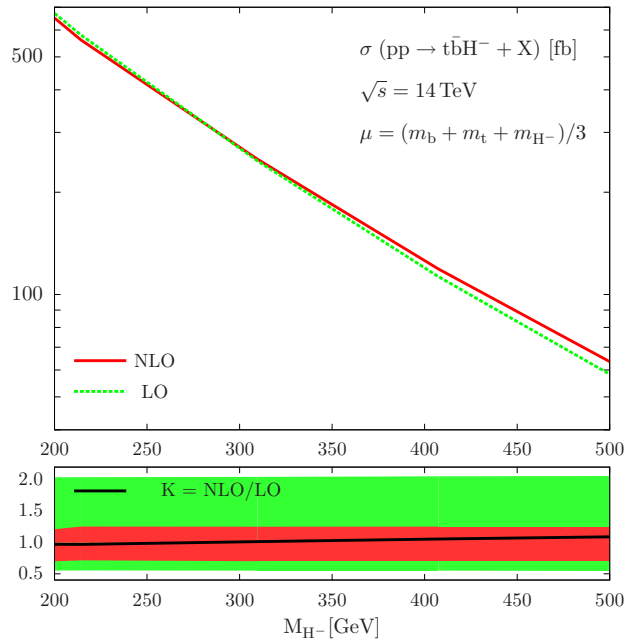
error bands: $\mu_0/3 \leq \mu_R, \mu_F \leq 3\mu_0$

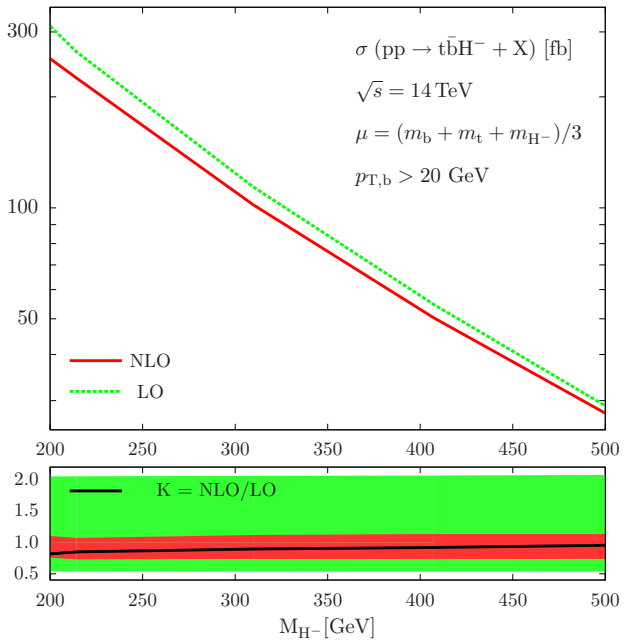
5FS: $\mu_0 = (m_t + M_{H^-})/4$

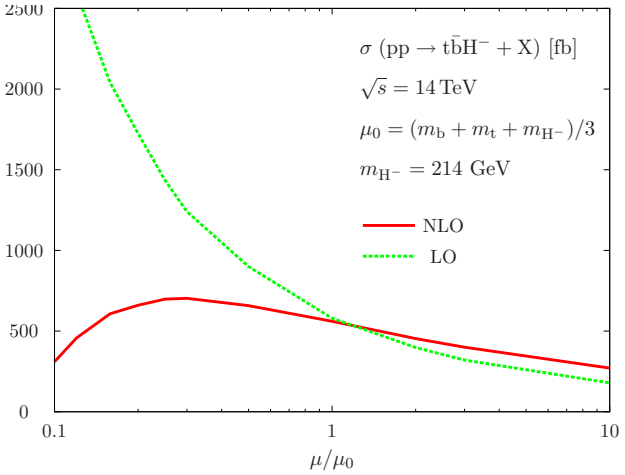
4FS: $\mu_0 = (m_t + m_b + M_{H^-})/3$

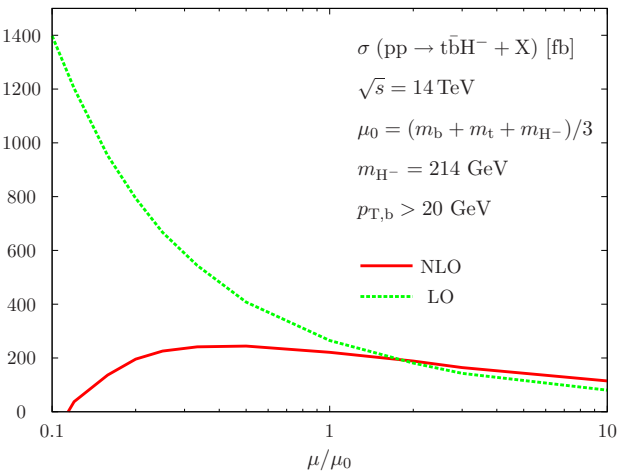
Charged Higgs Production

Dittmaier,Krämer,Spira,Walser









$\mathcal{C}$harged Higgs Production

- **Further corrections:**
  - SUSY EW to $gb \to tH^-$ — Jin et al.
  - Leading SUSY corrections to $H^+\bar{t}b$ — Belyaev et al
  - Complete NLO MSSM EW corrections to $bg \to tH^-$ can be sizeable — Beccaria et al.

The NMSSM Higgs Sector

- **Next-to-Minimal Supersymmetric Extension of the SM: NMSSM**

  Fayet; Kaul eal; Barbieri eal; Dine eal; Nilles eal; Frere eal; Derendinger eal; Ellis eal;
  Drees; Ellwanger eal; Savoy; Elliott eal; Gunion eal; Franke eal; Maniatis; Djouadi eal; Mahmoudi eal; ...

- **The μ-problem of the MSSM:** Higgsino mass parameter $\mu \leftrightarrow$ soft SUSY breaking masses?
- **Solution in the NMSSM:** μ from VEV of scalar component of additional chiral superfield $\hat{S}$:

$$\mu = \lambda \langle S \rangle$$

- **Superpotential:**

  $W_{NMSSM} = W_{MSSM} - \epsilon_{ab} \lambda \hat{S} \hat{H}_d^a \hat{H}_u^b + \frac{1}{3} \kappa \hat{S}^3 \leftarrow$ breaks Peccei-Quinn symmetry to avoid axion

- **Soft SUSY breaking potential:**

$$V_{soft} = V_{MSSM} + m_S^2 |S|^2 + (-\epsilon_{ab} \lambda A_\lambda S H_d^a H_u^b + \frac{1}{3} \kappa A_\kappa S^3 + h.c.)$$

- **New parameters:** $\lambda, \kappa, A_\lambda, A_\kappa, v_S$

- **Enlarged Higgs and neutralino sector:**

7 Higgs bosons:	$H_1, H_2, H_3, A_1, A_2, H^+, H^-$
5 neutralinos:	$\tilde{\chi}_i^0$ $(i = 1, ..., 5)$

NMSSM Higgs Phenomenology

- **Tree-level lightest Higgs mass** increased above M_Z value due to new coupling λ

  $\rightsquigarrow$ smaller higher-order corrections necessary

- **Higher-order corrections to Higgs masses**

  - ⋆ leading 1-loop in effective potential approach — Ellwanger; Elliott eal; Pandita
  - ⋆ LL 1-loop $\tilde{\chi}_i^0, \tilde{\chi}_i^\pm$ and scalar contributions — Ellwanger, Hugonie
  - ⋆ These and LL $\mathcal{O}(\alpha_t\alpha_s), \mathcal{O}(\alpha_t^2)$ corrections implemented in `NMHDECAY` — Ellwanger eal
  - ⋆ Full 1-loop corrections and 2-loop $\mathcal{O}(\alpha_t\alpha_s + \alpha_b\alpha_s)$ — Degrassi,Slavich
  - ⋆ 1-loop NMSSM masses with CP-violation — Ham eal

- **Higgs with SM-like couplings but main decays in lighter (pseudo)scalars**

  refinement of Tevatron, LHC Higgs search strategies — Ellwanger eal; Moretti eal; Stelzer eal; Cheung eal; Carena eal; Forshaw eal; Forshaw eal; Djouadi eal

- **LEP excess at $M_H \sim 100$ GeV** — Dermisek,Gunion

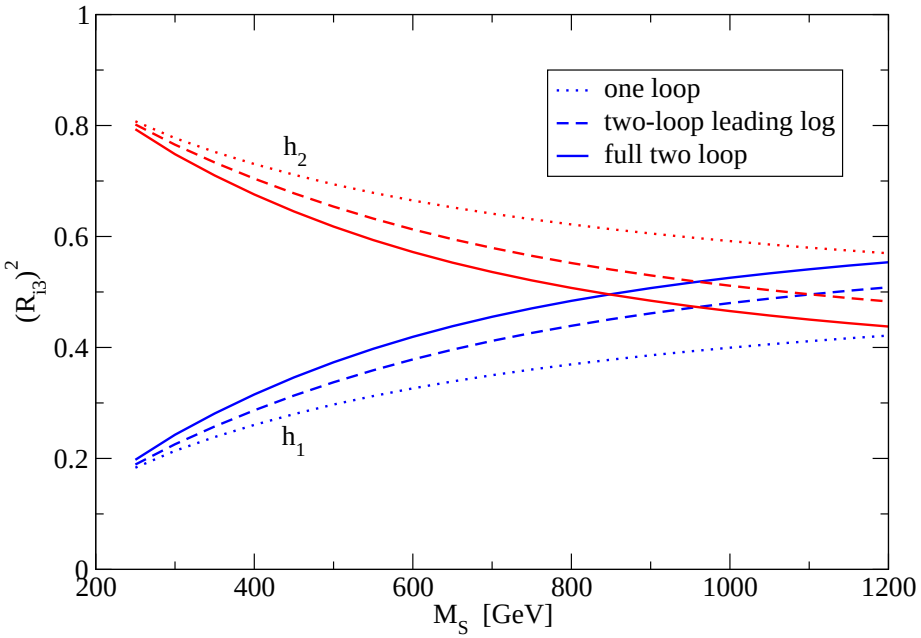
  - light Higgs $M_{H_1} \sim \mathcal{O}(100)$ GeV
  - BR$(H_1 \to b\bar{b}) \sim (0.1 - 0.2)\times$ BR$(H \to b\bar{b})_{\text{SM}}$, BR$(H_1 \to ZZ)$ SM-like
  - $H_1 \to A_1 A_1$ with $M_{A_1} < 2m_B \rightsquigarrow A_1 \to \tau^+\tau^-$, jets $\rightsquigarrow$ escape LEP limits

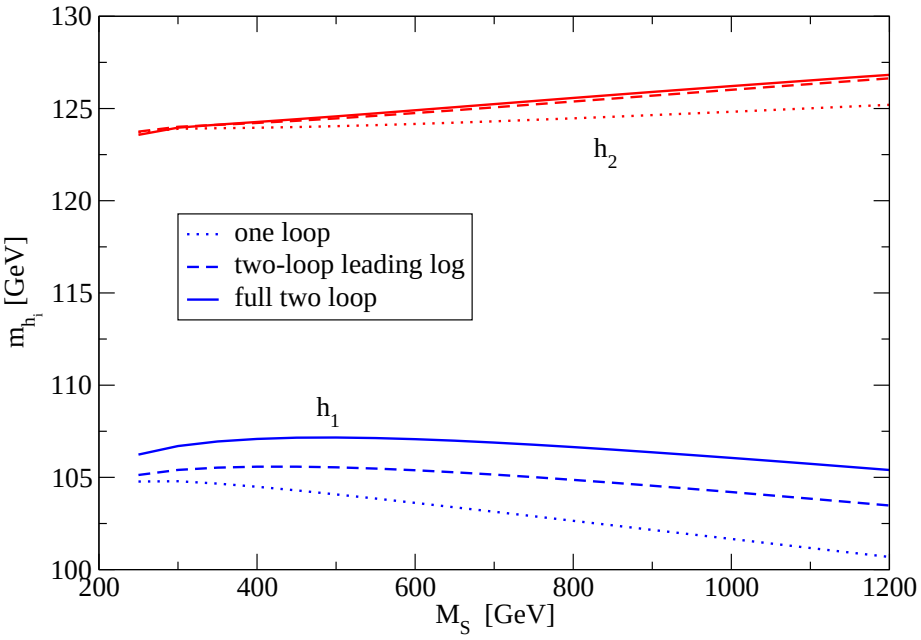
NMSSM Activities

* New constraints on A_1 and related NMSSM ideal Higgs scenarios — Dermisek,Gunion '10
* Enhanced di-photon Higgs signal in the NMSSM — Ellwanger '10
* Light Higgs bosons in phenomenological NMSSM — Mahmoudi eal '10
* NMSSM Higgs scenarios for partially universal GUT conditions — Gunion eal '11
* Reduced $BR(H \to AA \to 4\tau)$ from $A - \eta_b$ mixing — Domingo,Ellwanger '11
* Astrophysical limits on light NMSSM neutralinos — Albornoz Vasquez eal '11
* Naturalness & fine tuning in the NMSSM: implications of early LHC results — Ellwanger eal '11
* Many more publications on NMSSM phenomenology

Higher Order Corrections to NMSSM Higgs Masses

Degrassi,Slavich





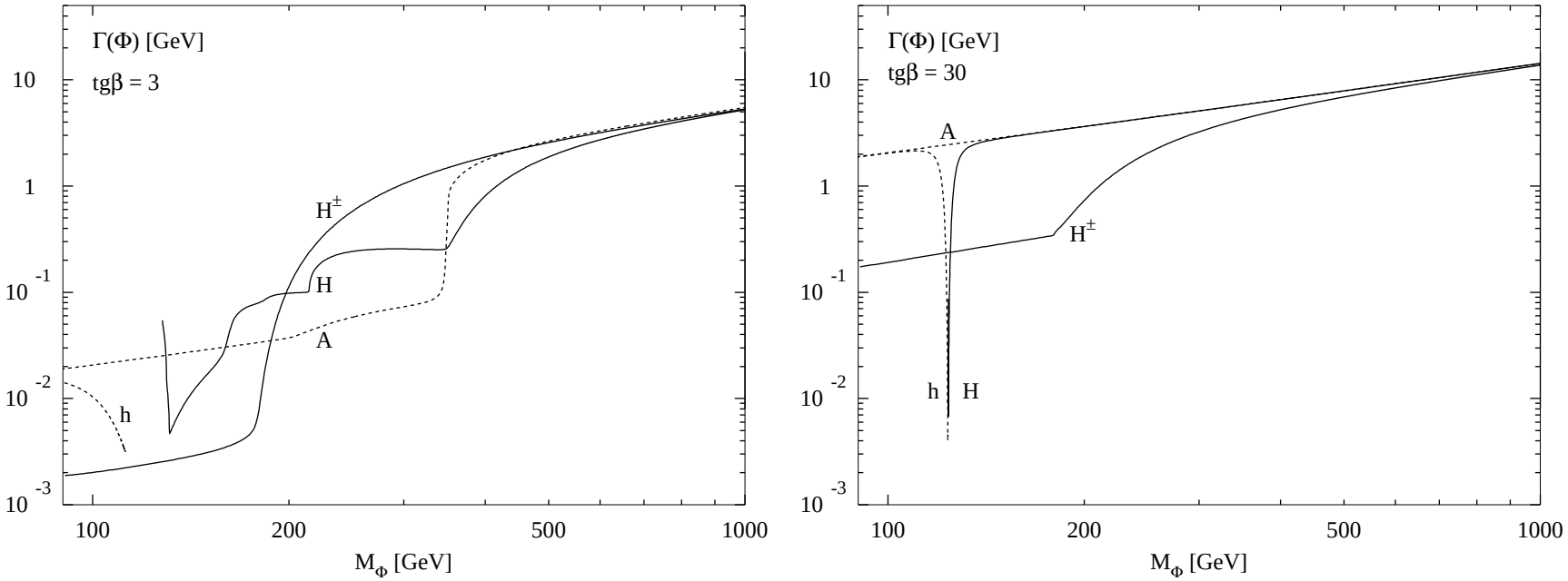
Summary

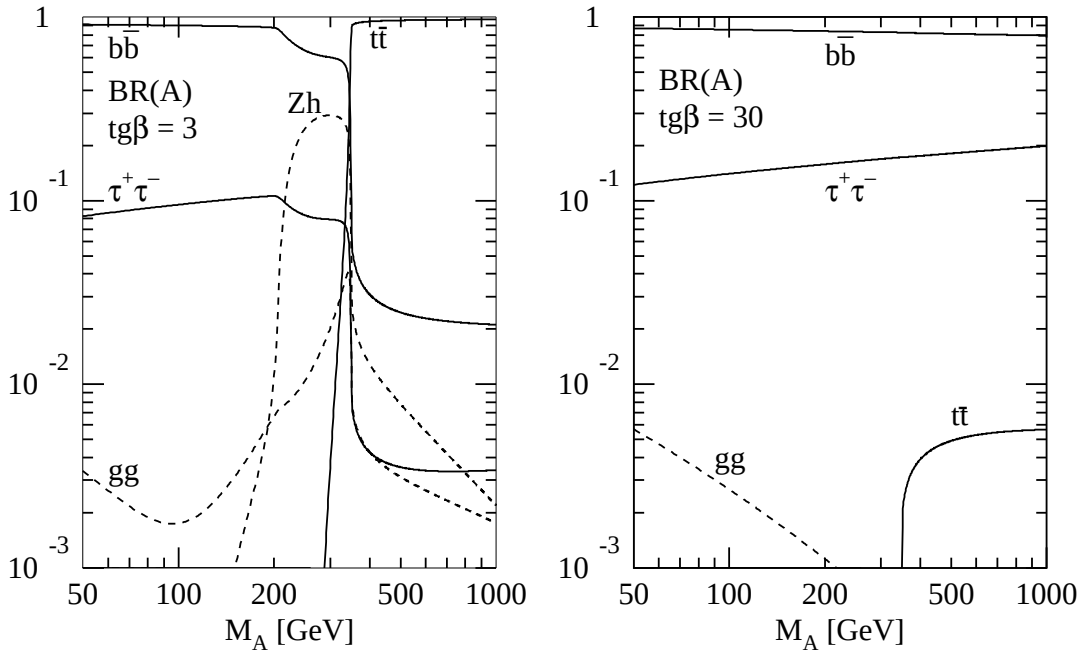
⋆ **Higgs discovery**	one of the major LHC goals
⋆ **Discovery prospects at LHC**	SM Higgs boson, at least one MSSM Higgs boson (light h)
⋆ **Higher order corrections**	most (SUSY-)QCD and EW corrections are known remaining theoretical uncertainties: $\sim 100\% \to \lesssim 15\%$
⋆ **LHC Higgs XS WG:**	provide best theory predictions for Higgs cxns and BRs
⋆ **New Physics extensions**	Example: NMSSM interesting new phenomenology

Backup

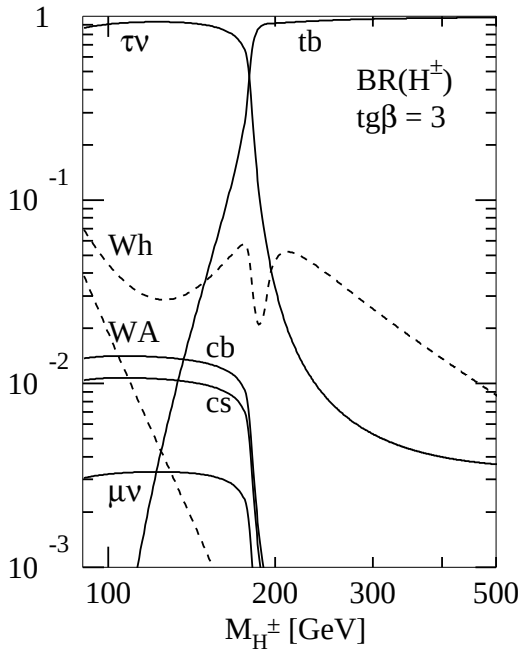
MSSM Total Widths

HDECAY




bb
tt
BR(A)
tgβ = 3
Zh
τ+τ−
gg
1
10 -1
10 -2
10 -3
50 100 200 500 1000
M_A [GeV]

bb
BR(A)
tgβ = 30
τ+τ−
tt
gg
1
10 -1
10 -2
10 -3
50 100 200 500 1000
M_A [GeV]


τν
tb
BR(H±)
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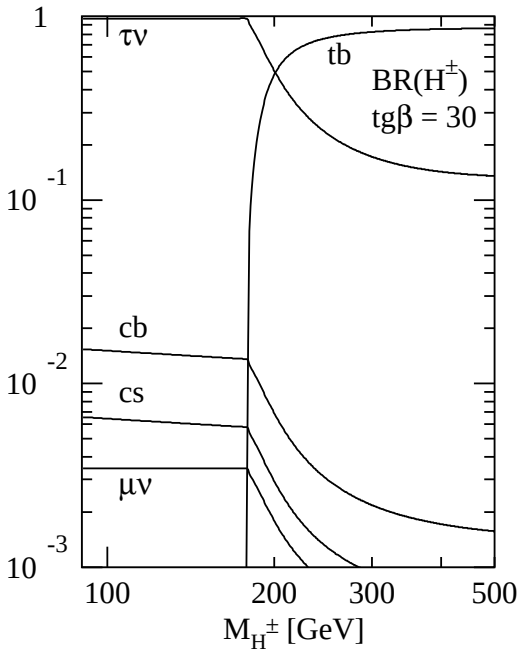
100 200 300 500
M_H± [GeV]


τν
tb
BR(H±)
tgβ = 30
cb
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1
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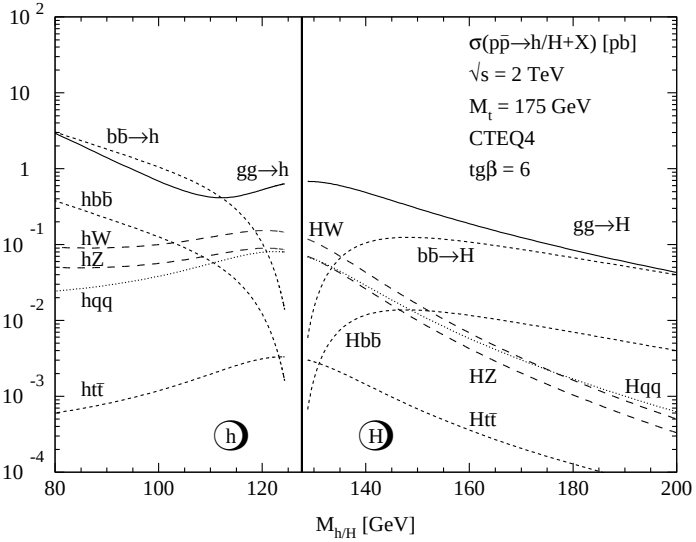
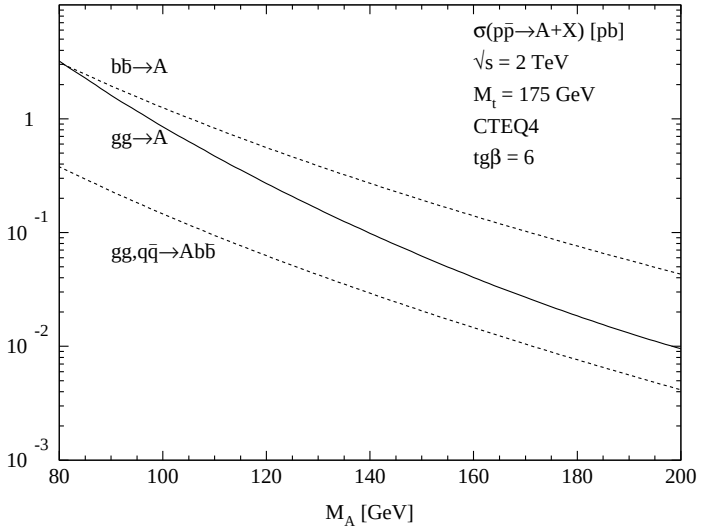
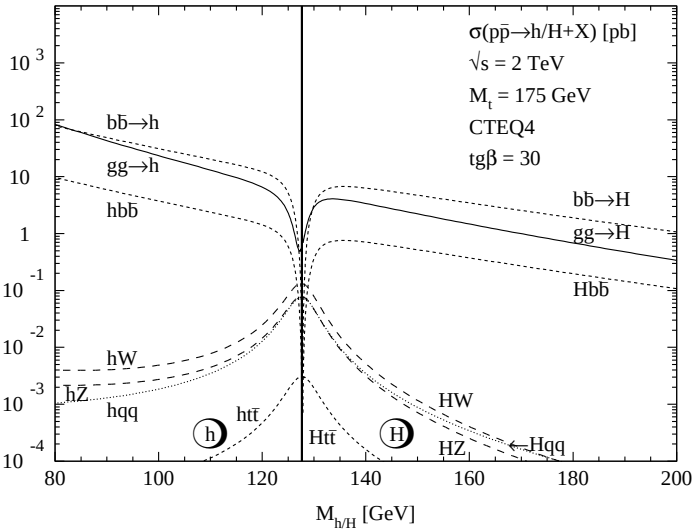
10 -3
100 200 300 500
M_H± [GeV]

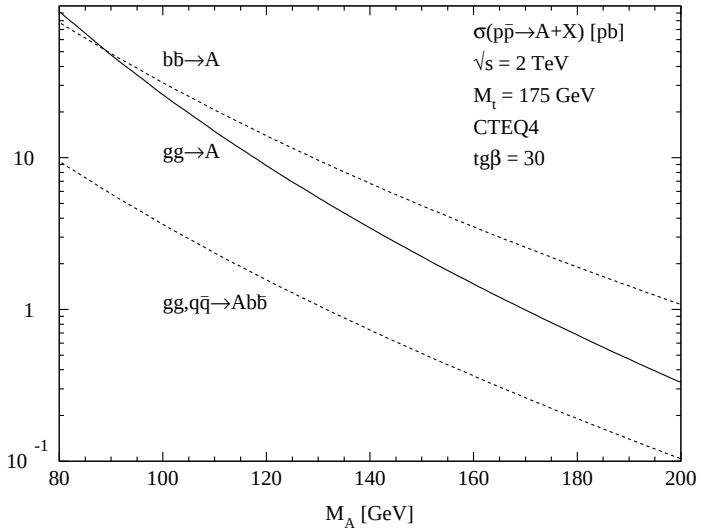
MSSM Higgs Boson Production at the Tevatron

Spira



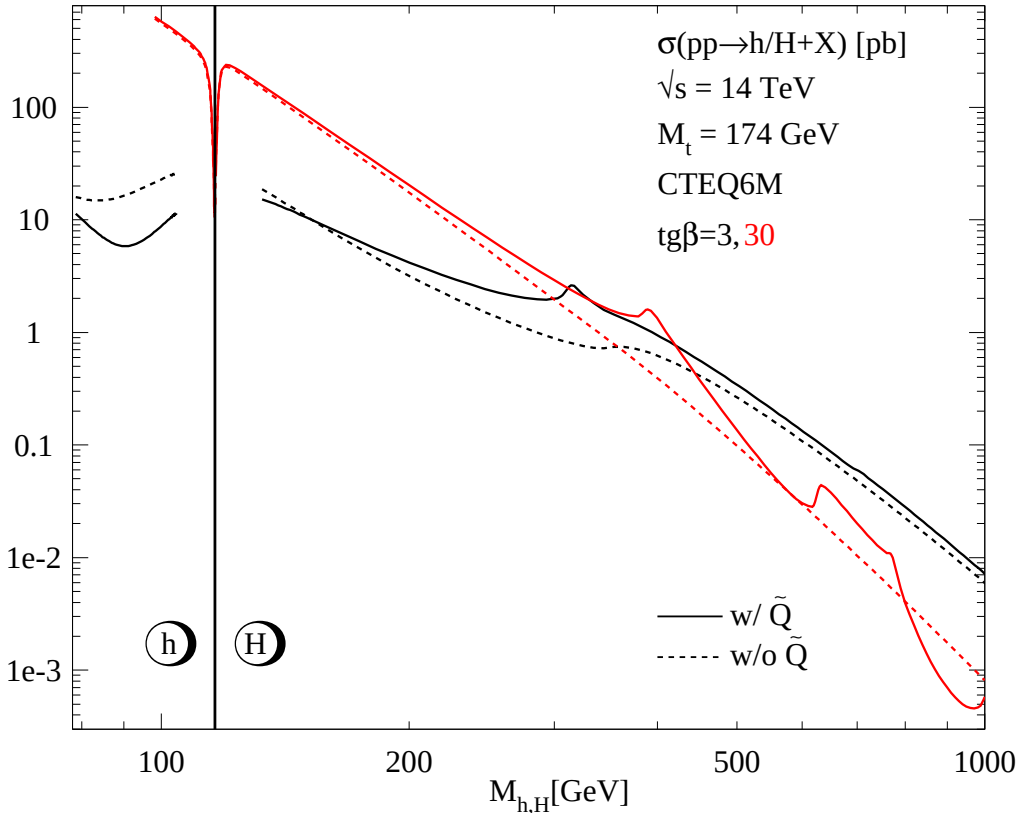






The $\mathcal{LO}$ Cross Section w/ and w/o Squarks

MMM,Spira



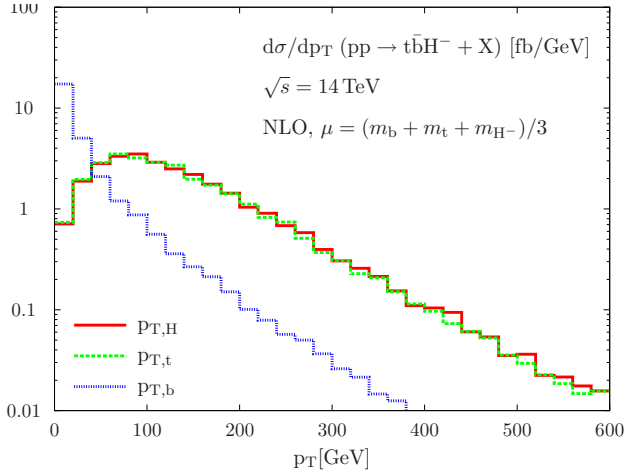
Gluophobic Higgs scenario:

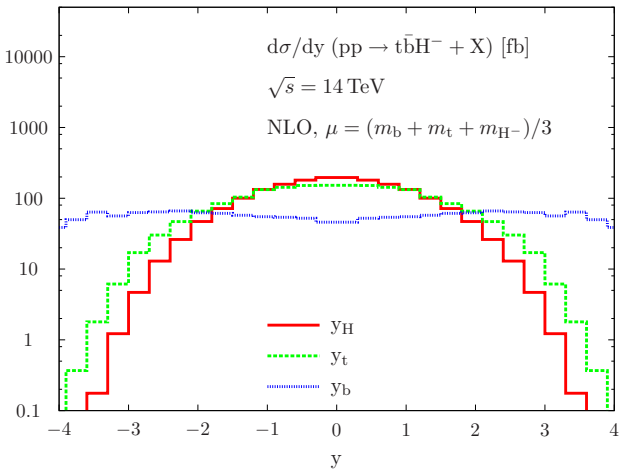
$\tan\beta = 3 : m_{\tilde{t}_1} = 156$ GeV, $m_{\tilde{t}_2} = 516$ GeV, $m_{\tilde{b}_1} = 346$ GeV, $m_{\tilde{b}_2} = 358$ GeV

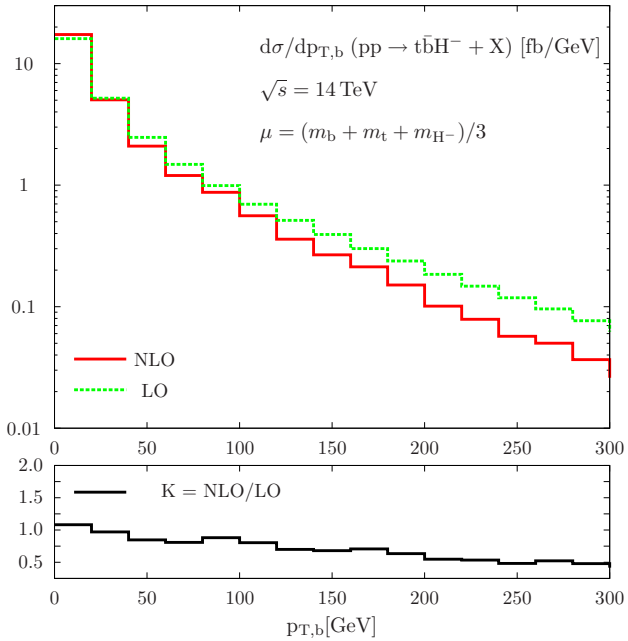
$\tan\beta = 30 : m_{\tilde{t}_1} = 195$ GeV, $m_{\tilde{t}_2} = 502$ GeV, $m_{\tilde{b}_1} = 315$ GeV, $m_{\tilde{b}_2} = 387$ GeV

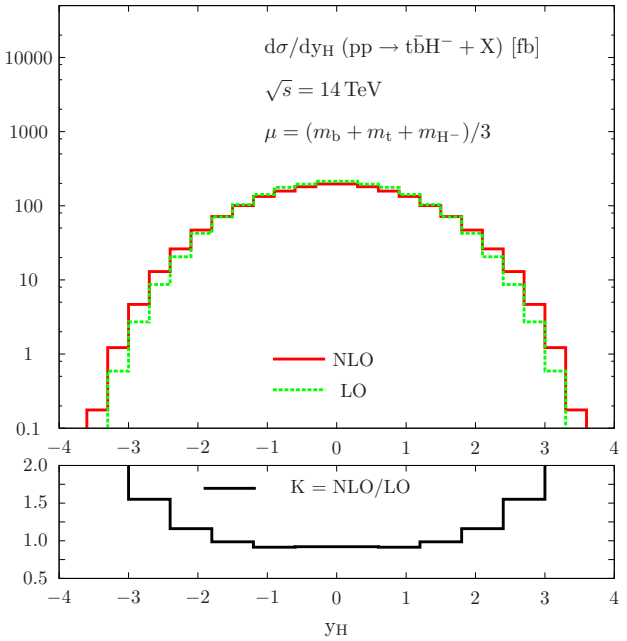
Charged Higgs Production

Dittmaier,Krämer,Spira,Walser







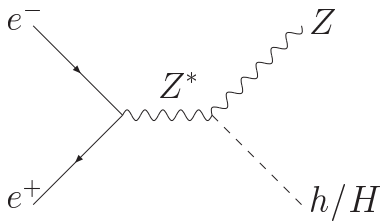


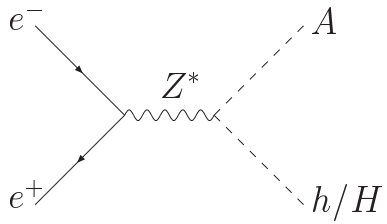
LHC Higgs Cross Section Working Group

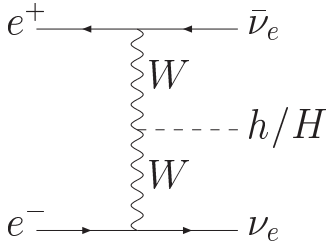
- *"Handbook of LHC Higgs cross sections: 1. Inclusive observables."* arXiv:1101.0593
- provide best theory prediction for Higgs cross sections and branching ratios (SM and MSSM)
- provide theoretical uncertainties on these quantities
- give precise common inputs
- inclusive cross sections (effects of cuts on cxns and K factors $\rightarrow$ future publication)
- https://twiki.cern.ch/twiki/bin/view/LHCPhysics/Cross Sections

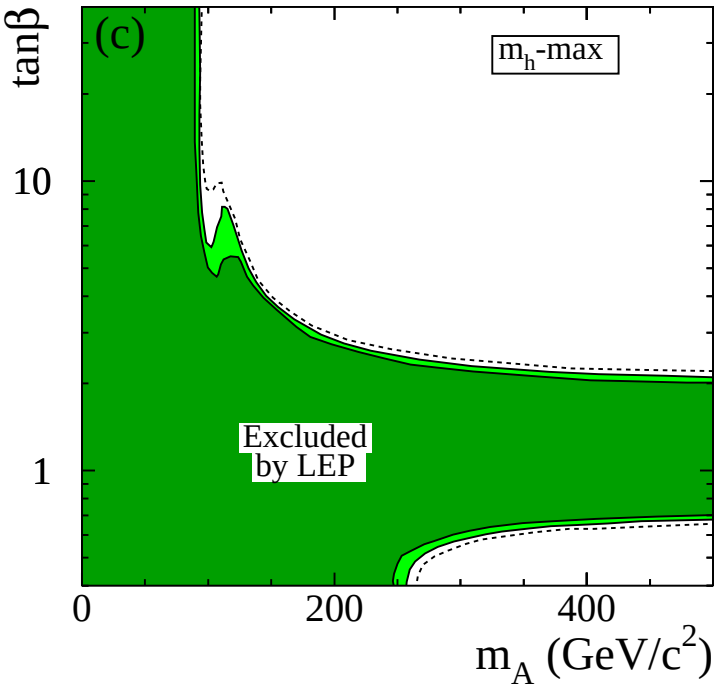
MSSM Higgs Mass Limits

▷ Direct Search at LEP $e^+e^- \to Z + h/H,\ A + h/H,\ \nu_e\bar{\nu}_e + h/H$









$M_{h/H} \gtrsim 92.6$ GeV

$M_A \gtrsim 93.4$ GeV

$M_{H^\pm} > 78.6$ GeV

$0.6 < \tan\beta < 2.5$ excluded

(only in this scenario, $m_t = 174.3$ GeV!)