$W^{\mp}H^{\pm}$ production and CP asymmetry at the LHC

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Outline

- Introduction: the complex MSSM and $H^{\pm}$ production
- $pp \to W^{\mp}H^{\pm}$: $b\bar{b}$ annihilation and gg fusion
- Bottom-Higgs couplings in the cMSSM
- Neutral-Higgs-mixing propagators
- $b\bar{b} \to W^{\mp}H^{\pm}$: improved-Born approximations
- NLO calculations (non-universal QCD, SUSY-QCD, EW corrections)
- Renormalization: OS-$\overline{\text{DR}}$ scheme (EW)
- Numerical results
- Conclusions

The MSSM

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$$\begin{aligned}\mathcal{L}_{soft} = &-\frac{1}{2}(M_3\tilde{g}\tilde{g} + M_2\tilde{W}\tilde{W} + M_1\tilde{B}\tilde{B} + \text{c.c.}) \\ &- m_F^2\tilde{F}^*\tilde{F} - m_f^2\tilde{f}_R^*\tilde{f}_R - m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - (bH_uH_d + \text{c.c.}) \\ &- (A_u Y_u \tilde{u}_R^* \tilde{Q} H_u + A_d Y_d \tilde{d}_R^* \tilde{Q} H_d + A_e Y_e \tilde{e}_R^* \tilde{L} H_d + \text{c.c.})\end{aligned}$$

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& - (A_u Y_u \tilde{u}_R^* \tilde{Q} H_u + A_d Y_d \tilde{d}_R^* \tilde{Q} H_d + A_e Y_e \tilde{e}_R^* \tilde{L} H_d + \text{c.c.})
\end{aligned}$$

- real MSSM (rMSSM or MSSM): all parameters are real.
- complex MSSM (cMSSM): M_3, M_1, A_t, A_b, A_τ and μ are complex (M_2 and b can be made real by redefining the fields; $Y_f = 0$ for the first two generations; $\mathcal{L}$ must be real.).

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- have impact on the masses, couplings, decay rates and cross sections, ...
- induce CP mixing in the Higgs sector through radiative corrections: neutral Higgses h_1, h_2, h_3 with both CP even and odd properties.
- induce CP violation (CPV) effects in many processes, *e.g.* charged Higgs production.
- Constraints from electron EDM: [Pospelov, Ritz '05]

$$|d_e| < 1.7 \times 10^{-27} \text{e cm},$$
$$d_e^{SUSY} \propto (m_e \sin\phi_\mu \tan\beta)/M_{SUSY}^2.$$

$\rightsquigarrow \phi_\mu \approx 0$ for $M_{SUSY} = \mathcal{O}(\text{TeV})$.

Charged Higgs boson production at the LHC

- Direct production:
  - $gb(g\bar{b}) \to tH^-(\bar{t}H^+)$: $\delta_{CP} \neq 0$, large cross section
  - $gg, b\bar{b} \to W^\pm H^\mp$: large δ_{CP}
    (loop-induced gg, CPV $\approx$ CP invariance)!!!
  - $gg, q\bar{q} \to t\bar{b}H^-(\bar{t}bH^+)$: $\delta_{CP} \neq 0$
  - $gg, q\bar{q} \to H^+H^-$: $\delta_{CP} = 0$
- Indirect production ($m_t > M_{H^\pm} + m_b$):
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- Finding $H^\pm$ at the LHC would be a clear signal of new physics.
- Measuring δ_{CP} can help constrain the phases.

$pp \to W^{\mp}H^{\pm}$: what has been done?

There are many studies on this channel in the rMSSM:

- $gg \to W^{\mp}H^{\pm}$: loop induced (no renormalization)
  [Barrientos Bendezu and Kniehl; Brein, Hollik and Kanemura]
- $b\bar{b} \to W^{\mp}H^{\pm}$: calculated at NLO
  - SM-QCD corrections [Hollik and Zhu; Gao, C.S. Li and Z. Li]
  - SUSY-QCD corrections [Zhao, C.S. Li and Z. Li; Rauch]
  - Yukawa corrections [Yang, C.S. Li, Jin and Zhu]
  - Full EW corrections: missing

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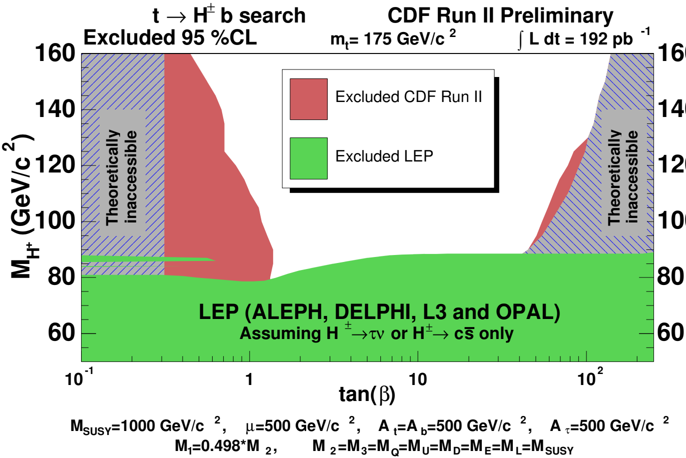
In this talk:

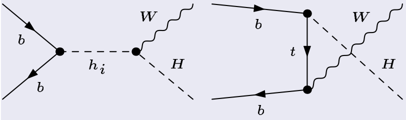
- We extend all those calculations to the cMSSM, including the full EW corrections.
- Use effective bottom-Higgs couplings and neutral Higgs-mixing propagators.
- The CP asymmetry is also studied.

Charged Higgs search



The tree-level relation: $M_{H^\pm}^2 = M_A^2 + M_W^2$.

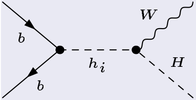
$b\bar{b} \to W^{\mp}H^{\pm}$

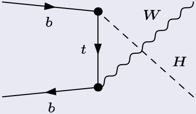


- $\lambda_{b\bar{b}h(H)} \propto \frac{m_b}{\cos\beta}$
- $\lambda_{b\bar{b}A} \propto m_b \tan\beta$
- $\lambda_{b\bar{t}H^+} \propto \frac{m_t}{\tan\beta} P_L + m_b \tan\beta P_R$

$W^{\mp}H^{\pm}$ production at the LHC

$b\bar{b} \rightarrow W^{\mp}H^{\pm}$





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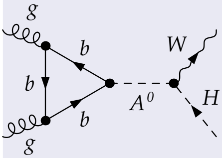
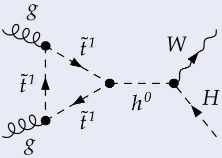
$gg \rightarrow W^{\mp}H^{\pm}$

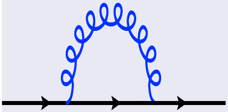




- h_i(h/H/A) propagators: $\frac{i}{p^2 - m_{h_i}^2}$, $m_{h_i} = ?$
- h-mixing effect is important!

Bottom-Higgs couplings

Running m_b (QCD):



$$m_b^{\rm OS} \to m_b^{\overline{\rm DR}}(\mu_R) = m_b\left[1 - \frac{\alpha_s}{\pi}\left(\frac{5}{3} - \ln\frac{m_b^2}{\mu_R^2}\right)\right]$$

- $\Delta_{\rm QCD} \notin \ln(m_b^2)$
- Input parameter: $m_b^{\overline{\rm MS}}(m_b^{\overline{\rm MS}}) \to m_b^{\overline{\rm MS}}(\mu_R) \to m_b^{\overline{\rm DR}}(\mu_R)$
- $\overline{\rm DR}$ scheme: $\delta m_b^{\overline{\rm DR}} = -m_b\frac{C_F\alpha_s}{4\pi}3C_{UV}$

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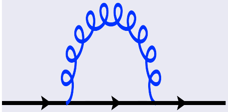

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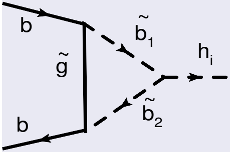
Dominant SUSY corrections, Δm_b:



$$\Delta m_b^{SQCD} = \frac{2\alpha_s(Q)}{3\pi} M_3^* \mu^* \tan\beta \; I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, m_{\tilde{g}}^2)$$

$$I(a,b,c) = \frac{ab\ln\frac{a}{b} + bc\ln\frac{b}{c} + ca\ln\frac{c}{a}}{(a-b)(b-c)(a-c)}, \; Q \sim m_{\tilde{g}}$$

[Carena, Garcia, Nierste, Wagner ’99; ...]

Bottom-Higgs couplings: more corrections

- Including dominant EW corrections

$$\boxed{\Delta m_b = \Delta m_b^{SQCD} + \Delta m_b^{SEW}}$$

$$\Delta m_b^{SEW} = \frac{\alpha_t}{4\pi} A_t^* \mu^* \tan\beta \; I(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, |\mu|^2) + \ldots, \; \alpha_t = h_t^2/(4\pi)$$

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- Sub-leading SUSY-QCD corrections:

$$\Delta_1 = -\frac{2\alpha_s(Q)}{3\pi} M_3^* A_b I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, m_{\tilde{g}}^2),$$

$$\Delta_b = \frac{\Delta m_b}{1+\Delta_1},$$ [Carena *et al.* '02; Guasch, Häfliger, Spira '03]

Bottom-Higgs couplings: more corrections

- Including dominant EW corrections

$$\boxed{\Delta m_b = \Delta m_b^{SQCD} + \Delta m_b^{SEW}}$$

$$\Delta m_b^{SEW} = \frac{\alpha_t}{4\pi} A_t^* \mu^* \tan\beta\ I(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, |\mu|^2) + \ldots,\ \alpha_t = h_t^2/(4\pi)$$

- Sub-leading SUSY-QCD corrections:

$$\Delta_1 = -\frac{2\alpha_s(Q)}{3\pi} M_3^* A_b I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, m^2_{\tilde{g}}),$$

$$\Delta_b = \frac{\Delta m_b}{1+\Delta_1},$$ [Carena *et al.* '02; Guasch, Häfliger, Spira '03]

- Important phases:
  $M_j = |M_j| e^{i\phi_j}$ $(j = 1, 3)$; $A_f = |A_f| e^{i\phi_f}$ $(f = t, b, \tau)$; $\phi_\mu = 0$.
- Remark: Δ_b is complex and depends on ϕ_1, ϕ_3 ϕ_t, ϕ_b.

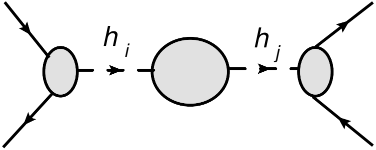
Bottom-Higgs couplings: resummation

Effective bottom-Higgs couplings (low-energy limit $M_Z \ll M_{SUSY}$), [Carena *et al.* '99 & '02; Guasch, Häfliger, Spira '03]:

$$\begin{aligned}
\bar{\lambda}_{b\bar{b}h} &= \frac{iem_b^{\overline{\rm DR}}}{2s_W M_W}\frac{\sin\alpha}{\cos\beta}\left(\Delta_b^1 P_L + \Delta_b^{1*} P_R\right),\\
\bar{\lambda}_{b\bar{b}H} &= \frac{-iem_b^{\overline{\rm DR}}}{2s_W M_W}\frac{\cos\alpha}{\cos\beta}(\Delta_b^2 P_L + \Delta_b^{2*} P_R),\\
\bar{\lambda}_{b\bar{b}A} &= \frac{em_b^{\overline{\rm DR}}}{2s_W M_W}\tan\beta(\Delta_b^3 P_L - \Delta_b^{3*} P_R),\\
\bar{\lambda}_{b\bar{t}H^+} &= \frac{ie}{\sqrt{2}s_W M_W}\left(\frac{m_t}{\tan\beta}P_L + m_b^{\overline{\rm DR}}\tan\beta\Delta_b^{3*} P_R\right),\\
\Delta_b^1 &= \frac{1-\Delta_b/(\tan\beta\tan\alpha)}{1+\Delta_b},\\
\Delta_b^2 &= \frac{1+\Delta_b\tan\alpha/\tan\beta}{1+\Delta_b},\\
\Delta_b^3 &= \frac{1-\Delta_b/(\tan\beta)^2}{1+\Delta_b}.
\end{aligned}$$

Remarks: Δ_b is resummed. m_t is the pole mass.

Neutral-Higgs-mixing propagator matrix



$$\mathcal{A}(p^2) = \sum_{ij} \Gamma_i \, \Delta_{ij}(p^2) \, \Gamma_j, \quad i = h, H, A$$

$$\Delta(p^2) = i[p^2 - \mathbf{M}(p^2)]^{-1},$$

$$\mathbf{M}(p^2) = \begin{pmatrix} m_h^2 - \hat{\Sigma}_{hh}(p^2) & -\hat{\Sigma}_{hH}(p^2) & -\hat{\Sigma}_{hA}(p^2) \\ -\hat{\Sigma}_{hH}(p^2) & m_H^2 - \hat{\Sigma}_{HH}(p^2) & -\hat{\Sigma}_{HA}(p^2) \\ -\hat{\Sigma}_{hA}(p^2) & -\hat{\Sigma}_{HA}(p^2) & m_A^2 - \hat{\Sigma}_{AA}(p^2) \end{pmatrix}.$$

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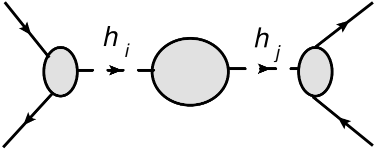

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\end{aligned}
$$

- The effect of $\text{Im}\,\hat{\Sigma}_{ij}(p^2)$ is important (especially for gg).
- The 1-loop Higgs-mixing effects are resummed.
- NLO EW: diagrams with $h/H/A$ mixing are discarded to avoid double counting.

$b\bar{b} \to W^{\mp}H^{\pm}$: 3 approximations

LO:

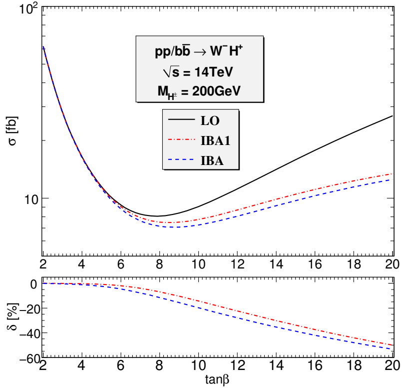
- tree-level b-Higgs couplings with $m_b = m_b^{\overline{\mathrm{DR}}}(\mu_R)$.

IBA1:

- effective b-Higgs couplings ($m_b^{\overline{\mathrm{DR}}}(\mu_R)$ and Δ_b resummation).

IBA:

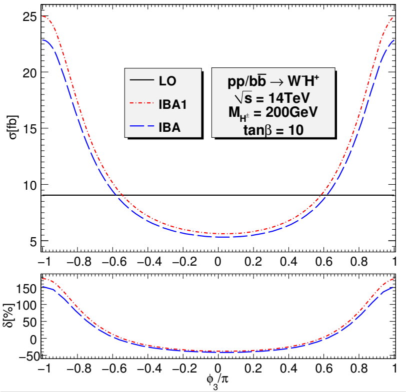
- effective b-Higgs couplings.
- use Higgs-mixing propagator matrix.

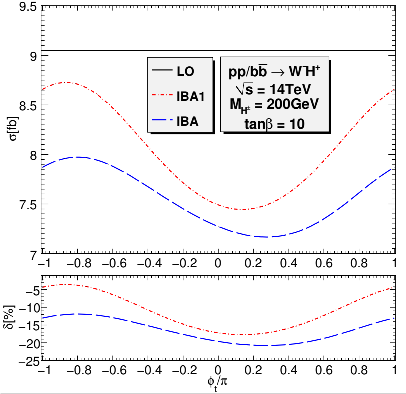


adapted CPX benchmark scenario:

$$|\mu| = 2\text{ TeV}, |M_2| = 200\text{ GeV}, |M_3| = 1\text{ TeV}, |M_1| = 5/3\tan^2\theta_W|M_2|,$$
$$|A_t| = |A_b| = |A_\tau| = 900\text{ GeV}, A_f = 0 \text{ for } f \neq t, b, \tau,$$
$$M_{\tilde{Q}} = M_{\tilde{D}} = M_{\tilde{U}} = M_{\tilde{L}} = M_{\tilde{E}} = M_{\text{SUSY}} = 500\text{ GeV},$$
$$\phi_t = \phi_b = \phi_\tau = \phi_3 = \phi_1 = \frac{\pi}{2}, \phi_\mu = \phi_2 = 0 \rightsquigarrow \text{Re}\,\Delta_b = 0, \delta = \mathcal{O}(\Delta_b^2).$$

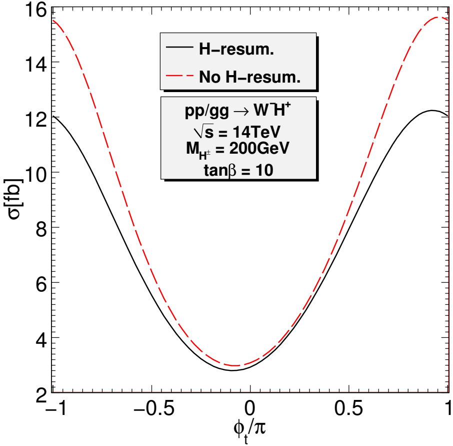
$b\bar{b} \to W^{\mp}H^{\pm}$: IBAs vs. LO (phase dependence)





- LO: no phase dependence.
- IBAs: depend strongly on ϕ_3 (SUSY-QCD effect) and ϕ_t (EW).
- Δ_b effect: large (150% for $\phi_3 = \pm\pi$).
- Higgs-mixing effect: small ($< 10\%$).

$gg \to W^{\mp}H^{\pm}$: Higgs mixing effects

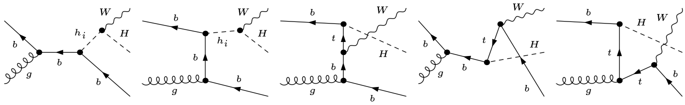


- Cross section depends strongly on ϕ_t.
- Higgs-mixing effect: can be large (20% at $\phi_t = \pm\pi$).

Non-universal NLO corrections

$b\bar{b} \to W^{\mp}H^{\pm}$: NLO QCD

- Virtual corrections: use $\overline{\text{DR}}$ scheme.
- Real corrections:



- IR divergences: use phase space slicing and *dipole subtraction* methods.

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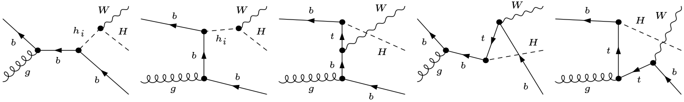

- IR divergences: use phase space slicing and *dipole subtraction* methods.
- Intermediate top quark can be on-shell (OS) and decay into $\bar{b}W^-$ and bH^+ (if $m_t > M_{H^\pm} + m_b$).
- This OS contribution is primarily a $\bar{t}H^+$ (tW^-) production and therefore should be discarded in a gauge invariant way. [Beenakker, Hopker, Spira, Zerwas '97; Tait '99; ...]

$b\bar{b} \to W^{\mp}H^{\pm}$: subtracting OS-$t$ contribution

- $\frac{i}{q^2 - m_t^2} \longrightarrow \frac{i}{q^2 - m_t^2 + i m_t \Gamma_t}$
- The OS part to be subtracted:

$$\left.\frac{d\sigma^{\bar{b}g\to W^- H^+ \bar{b}}}{dM_{bW}^2}\right|_{OS}^{\text{sub}} = \sigma^{\bar{b}g\to H^+\bar{t}} \frac{m_t\Gamma_t \mathrm{Br}(\bar{t} \to \bar{b}W^-)}{\pi[(M_{bW}^2 - m_t^2)^2 + m_t^2\Gamma_t^2]}.$$

- $\sigma_{\text{reg}}^{\bar{b}g\to W^- H^+ \bar{b}} = \lim_{\Gamma_t\to 0} \sigma_{\text{reg}}^{\bar{b}g\to W^- H^+ \bar{b}}(\Gamma_t)$

$b\bar{b} \to W^{\mp}H^{\pm}$: subtracting OS-$t$ contribution

- $\frac{i}{q^2 - m_t^2} \longrightarrow \frac{i}{q^2 - m_t^2 + i m_t \Gamma_t}$
- The OS part to be subtracted:

$$\frac{d\sigma^{\bar{b}g \to W^- H^+ \bar{b}}}{dM_{bW}^2}\Bigg|_{OS}^{\text{sub}} = \sigma^{\bar{b}g \to H^+ \bar{t}} \frac{m_t \Gamma_t \mathrm{Br}(\bar{t} \to \bar{b} W^-)}{\pi[(M_{bW}^2 - m_t^2)^2 + m_t^2 \Gamma_t^2]}.$$

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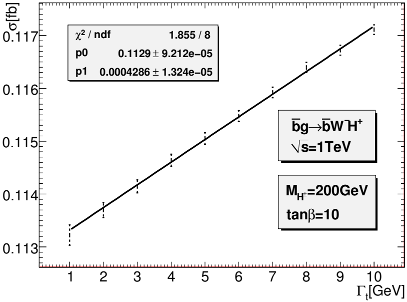

$b\bar{b} \to W^{\mp}H^{\pm}$: EW corrections

Missing piece (even for the rMSSM).
One of the main reasons is renormalization
(tree-level MSSM in `FeynArts`, one-loop rMSSM in `SloopS` Baro, Boudjema, Semenov '08 & '09).

Renormalization with CPV: Higgs sector

$$\mathcal{H}_u = \begin{pmatrix} H_{21} \\ H_{22} \end{pmatrix} = e^{i\xi} \begin{pmatrix} \phi_2^+ \\ v_2 + \frac{1}{\sqrt{2}}(\phi_2 + i\chi_2) \end{pmatrix},$$

$$\mathcal{H}_d = \begin{pmatrix} H_{11} \\ H_{12} \end{pmatrix} = \begin{pmatrix} v_1 + \frac{1}{\sqrt{2}}(\phi_1 - i\chi_1) \\ -\phi_1^- \end{pmatrix}, \quad \tan\beta = \frac{v_2}{v_1},$$

$$V_H = m_1^2 H_{1i}^* H_{1i} + m_2^2 H_{2i}^* H_{2i} - \epsilon^{ij}[m_{12}^2 H_{1i} H_{2j} + (m_{12}^2)^* H_{1i}^* H_{2j}^*]$$
$$+ \frac{1}{8}(g_1^2 + g_2^2)(H_{1i}^* H_{1i} - H_{2i}^* H_{2i})^2 + \frac{1}{2} g_2^2 |H_{1i}^* H_{2i}|^2.$$

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Tree level:

- $(h, H; A, G) = U_n(\alpha; \beta_n)(\phi_1, \phi_2; \chi_1, \chi_2)$; $(H^\pm, G^\pm) = U_c(\beta_c)(\phi_1^\pm, \phi_2^\pm)$
- $\xi = 0$ (CP conserving); $\beta_n = \beta_c = \beta$.

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One loop:

- CPV occurs: $(h_1, h_2, h_3) = U(h, H, A)$.
- Independent parameters: M_Z, M_W, e, $M_{H^\pm}$, $\tan\beta$, T_h, T_H, T_A (for the rMSSM: choose M_A and $T_A = \delta T_A = 0$)
- The mixing angles α, β_n and β_c are not renormalized.

OS-$\overline{\text{DR}}$ scheme

Frank, Hahn, Heinemeyer, Hollik, Rzehak, Weiglein, hep-ph/0611326

- Gauge sector (e, M_Z, M_W): normal OS scheme.
- Tadpoles: $\hat{T}_{h,H,A} = 0$.

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- Field renormalization: $\overline{\text{DR}}$ scheme

$$\mathcal{H}_u \to (1 + \frac{1}{2}\delta Z_{\mathcal{H}_u})\mathcal{H}_u,\ \mathcal{H}_d \to (1 + \frac{1}{2}\delta Z_{\mathcal{H}_d})\mathcal{H}_d,$$

$$\delta Z_{\mathcal{H}_u} = -\left[\mathrm{Re}\,\Sigma'_{hh}(m_h^2)|_{\alpha=0}\right]^{\text{div}},\ \delta Z_{\mathcal{H}_d} = -\left[\mathrm{Re}\,\Sigma'_{HH}(m_H^2)|_{\alpha=0}\right]^{\text{div}}$$

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- $\tan\beta$ renormalization: $\overline{\text{DR}}$ scheme

$$\tan\beta \to \tan\beta(1 + \delta\tan\beta),$$

$$\delta\tan\beta \equiv (\delta\tan\beta)^{\text{div}} = (\delta Z_{\mathcal{H}_u} - \delta Z_{\mathcal{H}_d})/2.$$

$b\bar{b} \to W^{\mp}H^{\pm}$: renormalization (subtle points)

Fermion-Fermion (OS scheme):

δm_q is real, BUT $\delta Z^q_{L,R}$ are complex if CPV is present. We have 4 eqs (the pole and unit-residue conditions and their hermitian conjugation) to solve for 5 real variables. The squared amplitude is invariant under $\psi = \psi_L + \psi_R \to e^{i\phi}\psi$. This freedom gives a constraint on $Z^q_{L,R}$.

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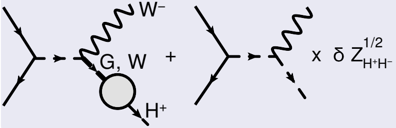
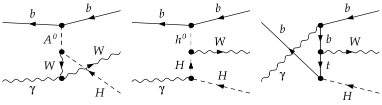
Corrections to external Higgs leg ($\overline{\text{DR}}$ scheme):

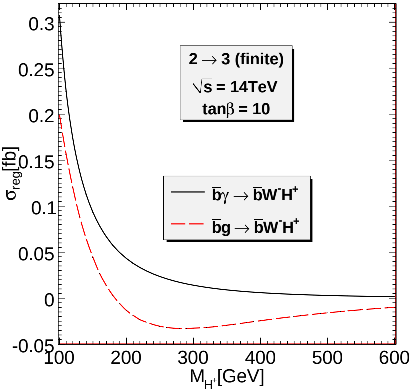


$$\delta Z^{1/2}_{H^- H^+} = -\frac{1}{2} \operatorname{Re} \frac{\partial}{\partial p^2} \hat{\Sigma}_{H^- H^+}(p^2)\Big|_{p^2 = M^2_{H^\pm}}$$

Photonic real corrections

Similar to QCD corrections, photon-radiation and photon-induced processes should be included ($\propto \alpha\gamma(x) \approx 0?$).





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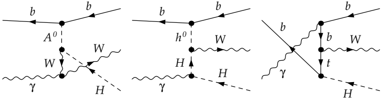

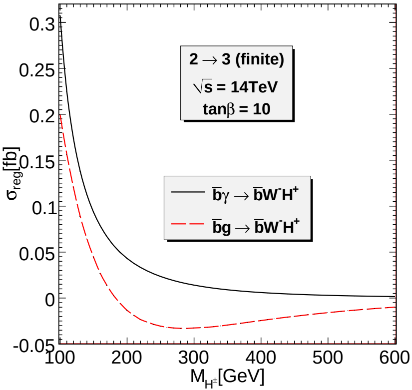

- Collinear singularity $\ln(m_b^2)$ are subtracted.
- $|\sigma(\bar{b}\gamma)| > |\sigma(\bar{b}g)|$ for $M_{H^\pm} < 200$ GeV.
- EW splittings $\gamma \to H^+H^-, W^+W^-$ induce large corrections at high energies ($M_{H^\pm}/Q \to 0$).

Hadronic cross section

$$\sigma^{pp}_{NLO} = \sum_{i,j} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 [F^p_i(x_1, \mu_F) F^p_j(x_2, \mu_F) \hat{\sigma}^{ij}_{NLO}(\mu_R) + (1 \leftrightarrow 2)]$$

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- Input: MRST2004qed PDFs. This means that $\delta q(x,\mu_F^2)$ is calculated by using $\overline{\text{MS}}$ scheme for QCD and $\texttt{DIS}$ scheme for EW corrections.

CP-violating asymmetry

$$\delta_{pp}^{\mathrm{CP}} = \frac{\sigma(pp \to W^- H^+) - \sigma(pp \to W^+ H^-)}{\sigma(pp \to W^- H^+) + \sigma(pp \to W^+ H^-)}.$$

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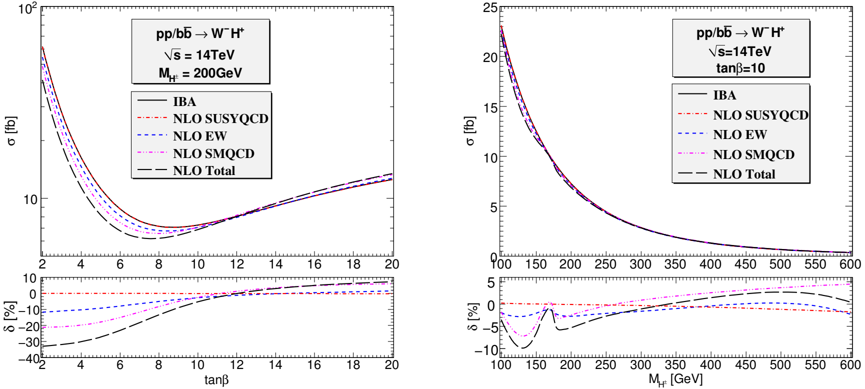
- Necessary conditions for $\delta_{pp}^{\mathrm{CP}} \neq 0$: both weak phase (from complex couplings) and strong phase (from loop integrals) must exist.
- $b\bar{b} \to W^\mp H^\pm$: LO is CP conserving. NLO corrections induce small CPV effects.
- Loop-induced gg fusion ($\sigma_{gg} \approx \sigma_{b\bar{b}}^{LO}$): generates large CP asymmetry.

Calculations and Checks

- Use `FeynArts` and `FormCalc-6.0` to generate the amplitude expressions.
- Implement the necessary counter terms in `FeynArts`.
- 2 independent calculations.
- check *QCD* gauge invariance for *gg* fusion ($p_{1\mu}A^{\mu\nu} = 0$).
- $b\bar{b} \to W^{\mp}H^{\pm}$ for rMSSM: virtual EW corrections agree with `SloopS`, SUSY-QCD agrees with Rauch.

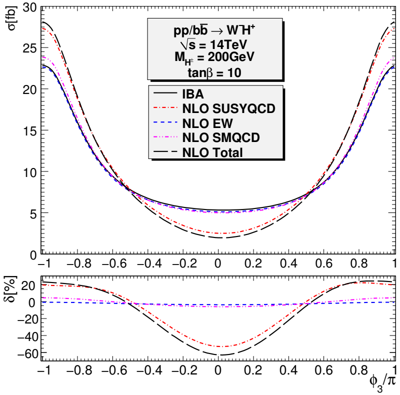
Numerical results

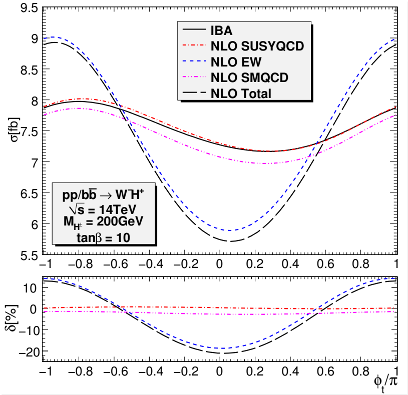
$b\bar{b} \to W^{\mp}H^{\pm}$: full NLO results ($\tan\beta$ and $M_{H^\pm}$)



Interesting structure at $M_{H^\pm} \approx m_t$: the OS top quark effect cannot be completely subtracted.

$b\bar{b} \to W^{\mp}H^{\pm}$: full NLO results (phases)





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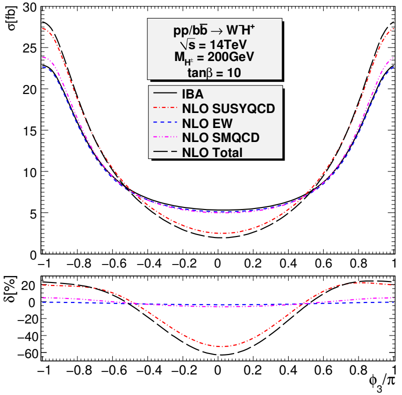
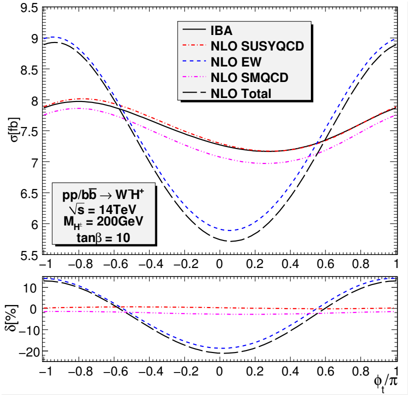
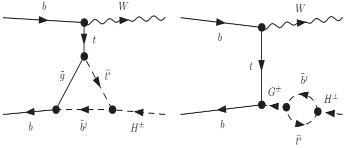




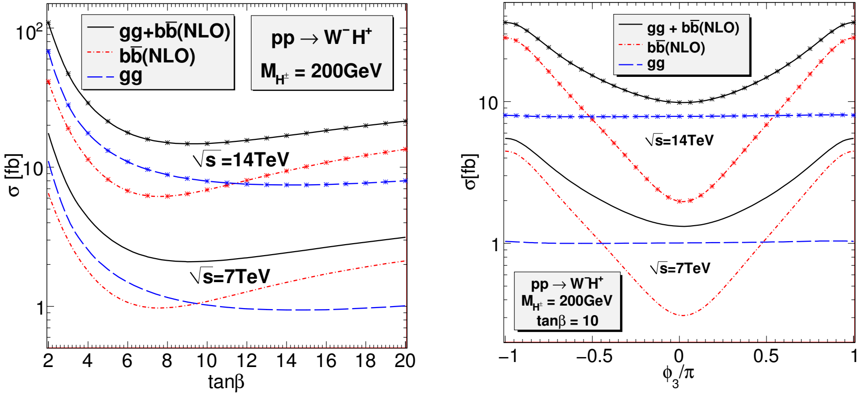


Sub-leading SUSY-QCD: $\tilde{\Delta}_t \propto \frac{2\alpha_s}{3\pi} M_3^* \mu^* \tan\beta$,

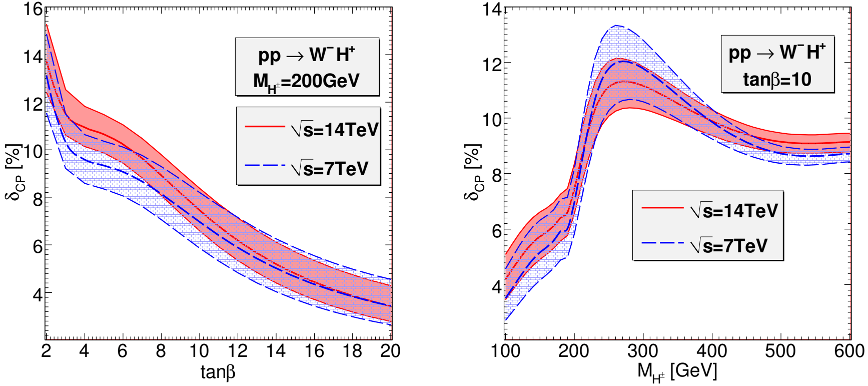
$\tilde{\lambda}_{b\bar{t}H^+} \propto \left(\frac{m_t}{\tan\beta}(1-\tilde{\Delta}_t)P_L + m_b^{\overline{\text{DR}}}\tan\beta\Delta_b^{3*}P_R\right)$

Sub-leading EW: $\propto A_t\mu\alpha_t/(4\pi)$

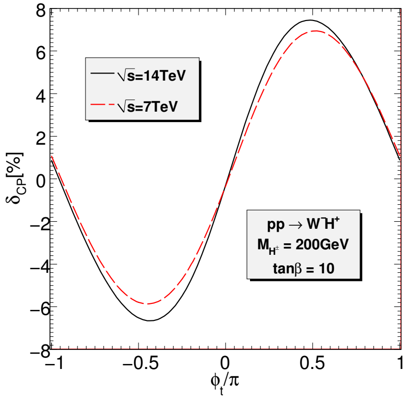
$pp \to W^{\mp}H^{\pm}$: total results

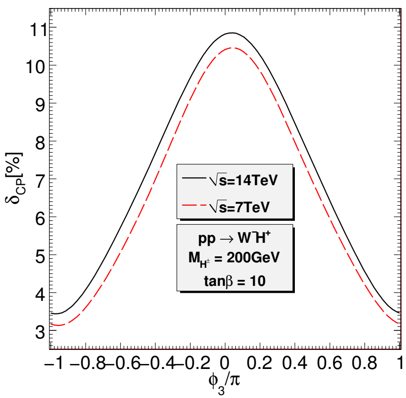


$pp \to W^{\mp}H^{\pm}$: CP asymmetry ($\tan\beta$ and $M_{H^\pm}$)

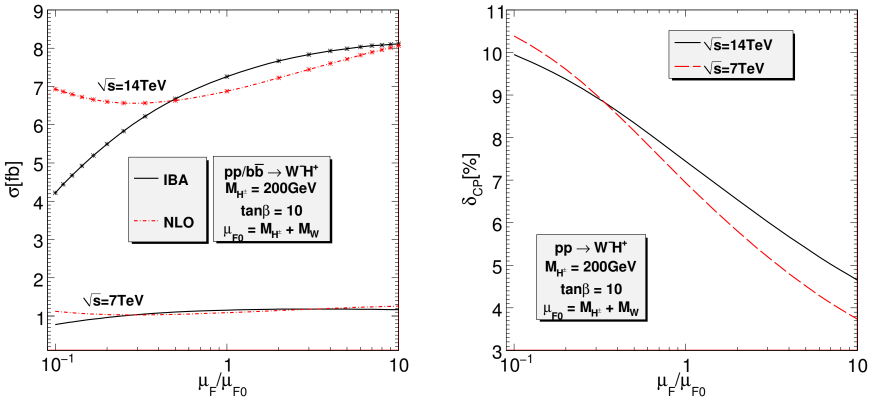


$pp \to W^{\mp}H^{\pm}$: CP asymmetry (ϕ_t and ϕ_3)





Scale dependence



δ_{CP} is dominantly generated by the loop-induced *gg* fusion, which has large scale dependence. (2-loop calculation is needed).

Conclusions

- We have made a complete NLO study of $pp \to W^{\mp}H^{\pm}$ production rates and CP asymmetry at the LHC in the MSSM with complex parameters.
- Large CP asymmetry generated by the *gg* fusion.
- We use the effective bottom-Higgs couplings (Δ_b resummation) and neutral-Higgs-mixing propagators.
- Results depend strongly on $\tan\beta$, $M_{H^\pm}$, ϕ_t and ϕ_3.
- For details: see *arXiv:1011.4820*.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