Charged Higgs bosons phenomenology in the MSSM and 2HDM with CP violation

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Morocco Map


SPAIN
Mediterranean Sea
Strait of Gibraltar
Tangier
Ceuta (Spain)
Asilah
Larache
Tétouan
Melilla (Spain)
Nador
Berkane
Ksar el Kebir
ER RIF
MOROCCO
Oujda
Kenitra
Salé
Taza
RABAT
Meknès
Fès
Guercif
Mohammedia
Sebou
Sefrou
Casablanca
Ben Slimane
Moulouya
Azrou
North Atlantic Ocean
El Jadida
Settat
Oued Zem
ATLAS MTS.
Khouribga
Khenifra
Bou Arfa
Safi
Oum er Rbia
Kasba Tadla
Beni Mellal
Figuig
Demnat
Er Rachidia
Essaouira
Marrakech
Erfoud
Rissani
Jebel Toubkal
Ouarzazate
Tazzarine
Tazenakht
Agadir
Zagora
Tiznit
ATLAS MTS.
Tata
Canary Is. (Spain)
Sidi Ifni
Akka
Guelmim
Bou Izakarn
Tan-Tan
Assa
SAHARA
Tarfaya
ALGERIA
Amot
WESTERN SAHARA
(Claimed by Morocco)
MAURITANIA

This talk

I. Charged Higgs Phenomenology

II. $H^\pm \to W^\pm(Z,\gamma)$ in MSSM and 2HDM

III. MSSM with CP violating phases

IV. CP violation in $H^\pm \to W^\pm(Z,\gamma)$

V. Conclusions

Based on

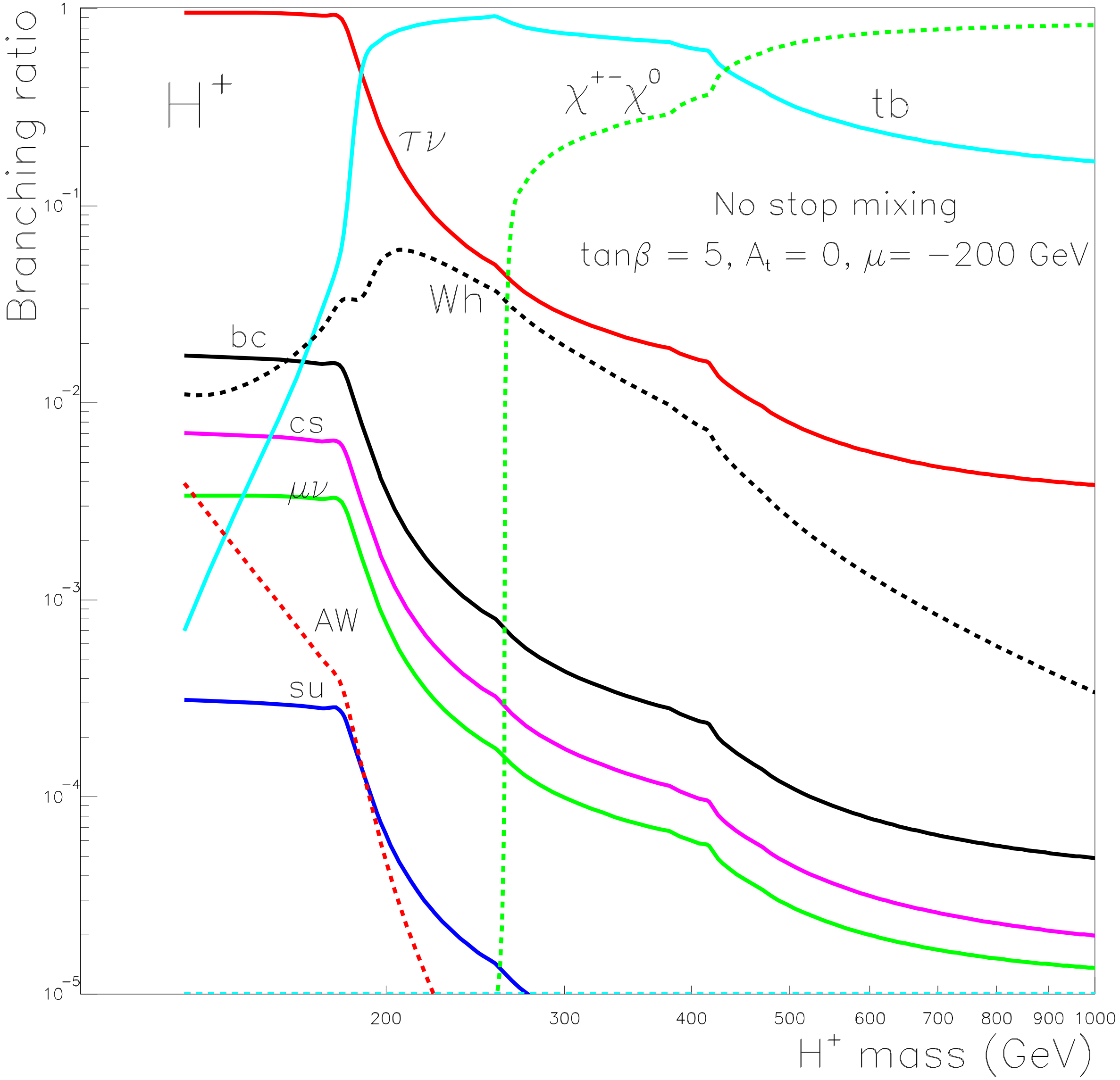
A. Arbrib, R. Benbrik and M. Chabab Phys. Lett. **B644** (2007) 248-255

A. Arhrib, R. Benbrik and M. Chabab J. Phys.G : Nucl. Part. Phys. **34** (2007) 1-22

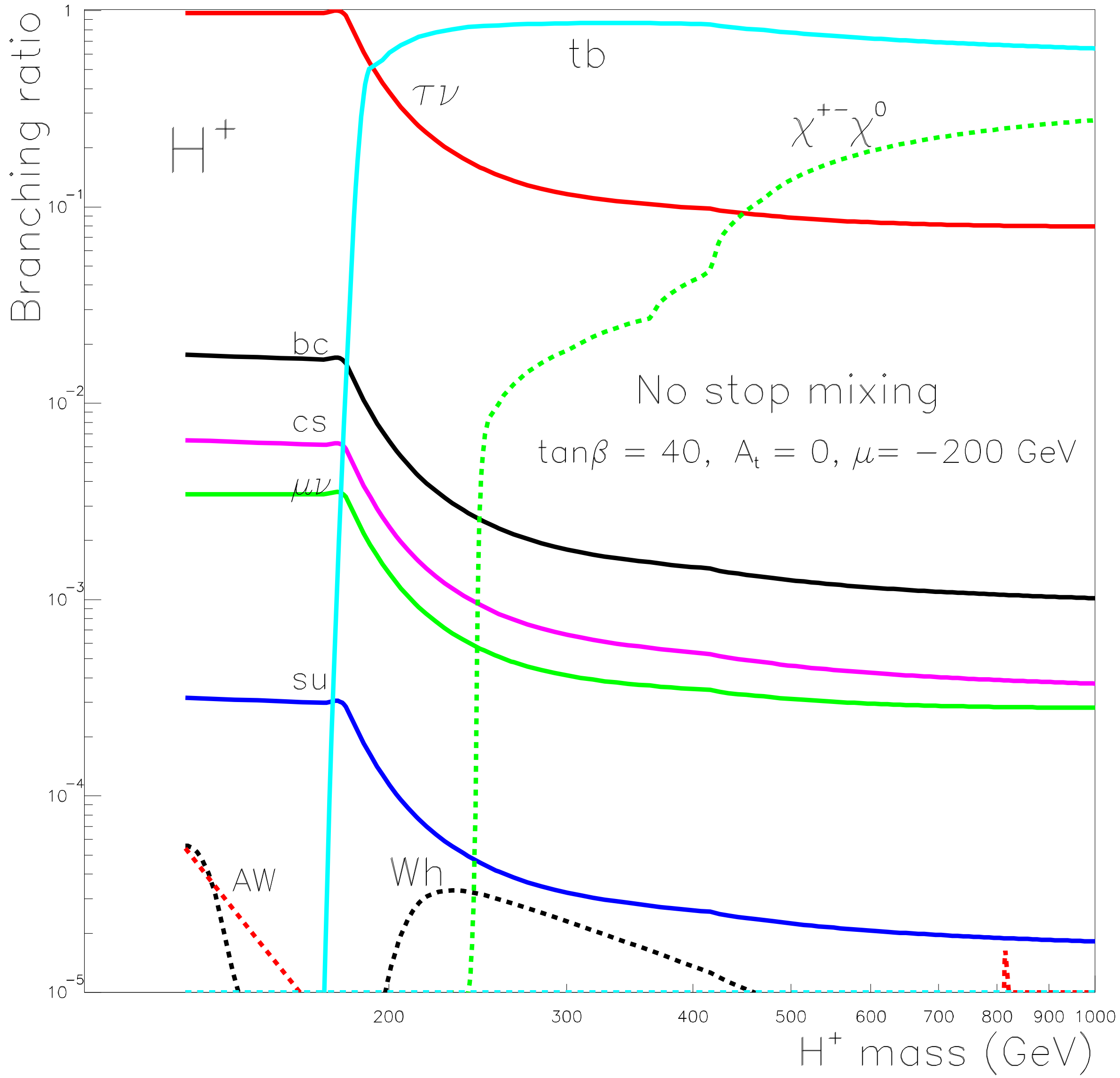
I. Charged Higgs phenomenology

- The Standard Model (SM) of electroweak interactions is very successful in explaining all experimental data available till now.
- The problematic scalar sector of the SM can be enlagred and some extensions such as the Minimal Supersymmetric Standard Model (MSSM) and the two Higgs Doublet Model (2HDM) are intensively studied.
- Both in the MSSM and 2HDM, the electroweak symmetry breaking is generated by 2 Higgs doublets Φ_u and Φ_d with opposite hypercharge to give masses to the up and down type quarks and leptons.
- After Electroweak Symmetry breaking: 5 physical Higgs scalars:
  two CP-even : h^0, H^0, (h^0light, H^0 heavy)
  two charged Higgs : $H^\pm$, one CP-odd : A^0
- The charged Higgs $H^\pm$, because of its electrical charge is differents from the other SM, its discovery would be a clear evidence of physics beyond the SM.

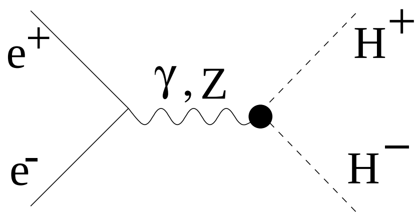
$H^{\pm}$ Branching ratio

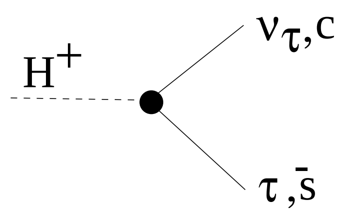


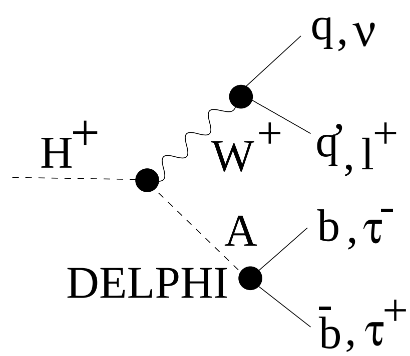
$H^{\pm}$ Branching ratio



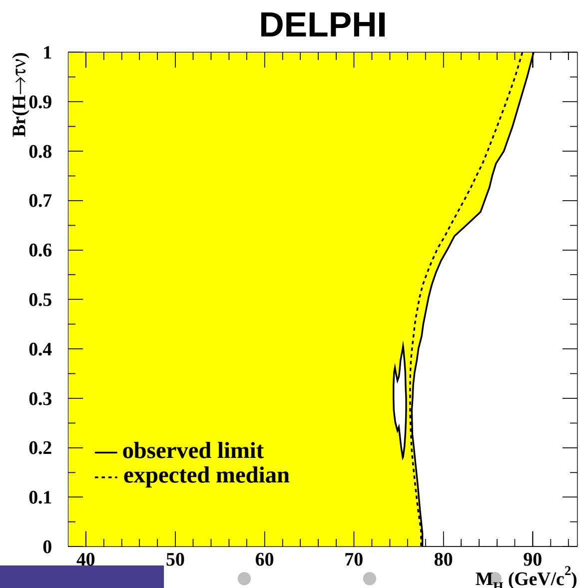
Experimental search @ LEP [hep-ex/0404012]





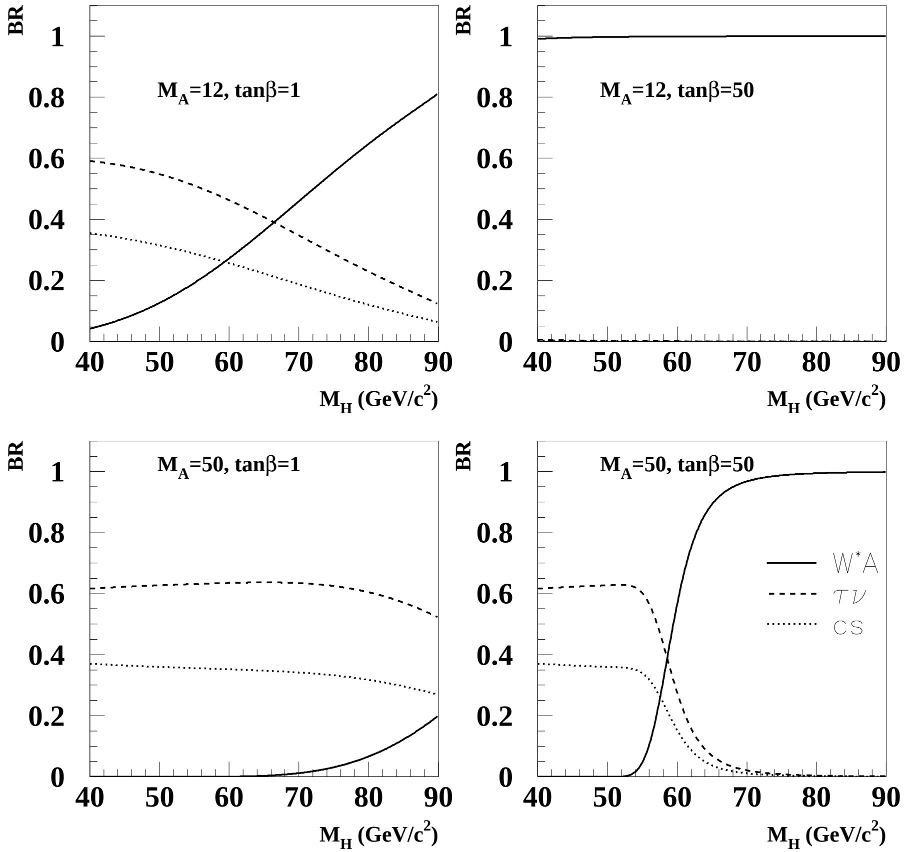


- If Br($H^{\pm} \to \tau\nu_{\tau}$)+ BR($H^{\pm} \to cs$)=1., $M_{H^{\pm}} > 78$ GeV:



Experimental search @ LEP [hep-ex/0404012]

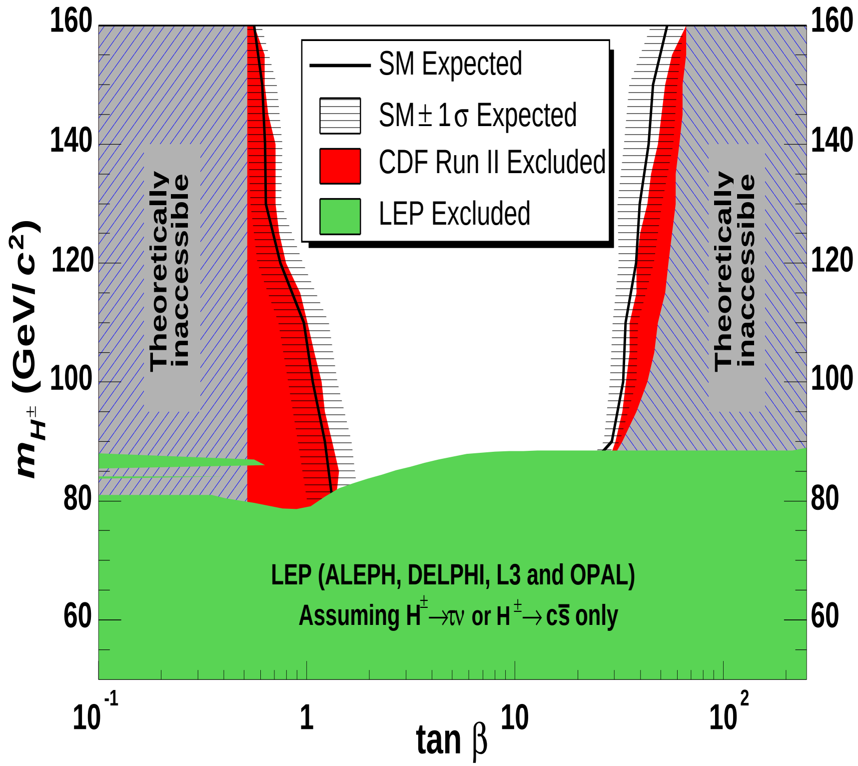
- If $\mathrm{Br}(H^{\pm} \to W^{\pm *} A) = 1$, possible in 2HDM-I,: $m_{H^{\pm}} > 76.7\mathrm{GeV}$ for 2HDM-I and $m_{H^{\pm}} > 74.4\mathrm{GeV}$ for 2HDM-II [DELPHI: EPJC34'04]



Exp. search @ TeVatron, $m_{H^\pm} < m_t$

• Production is through $p\bar{p} \to t\bar{t}$ followed by $t \to bH^+$.

• Light $H^\pm$ decay: $H^\pm \to \tau\nu$ for $\tan\beta > 1$ and $H^\pm \to \{c\bar{s}, t^\star \bar{b}\}$ for $\tan\beta < 1$ and also $H^\pm \to W^\pm h^0, W^\pm A^0$ [hep-ex/0510065]



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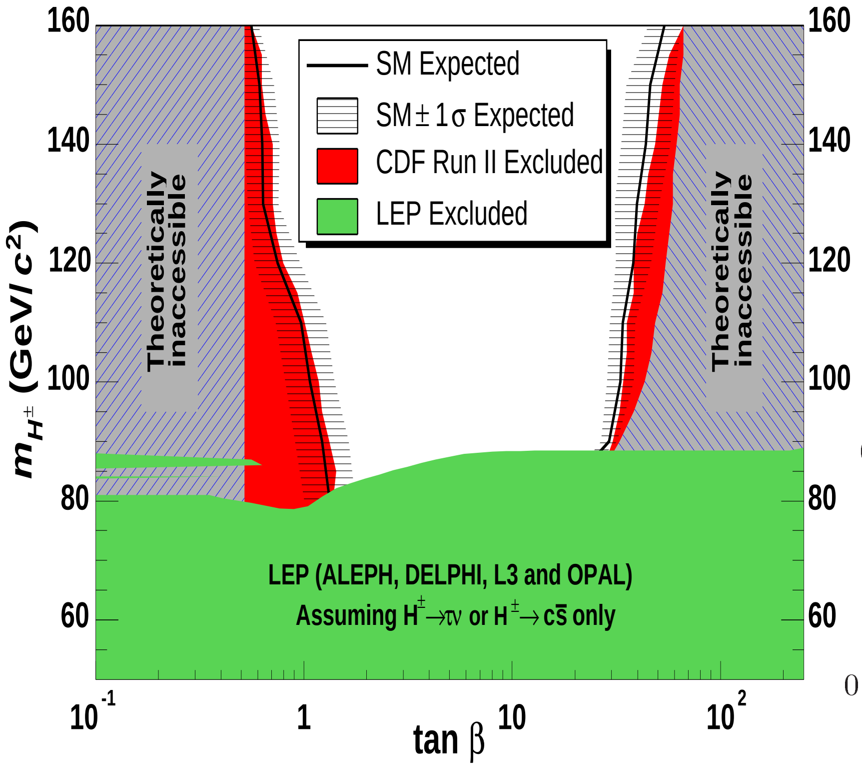
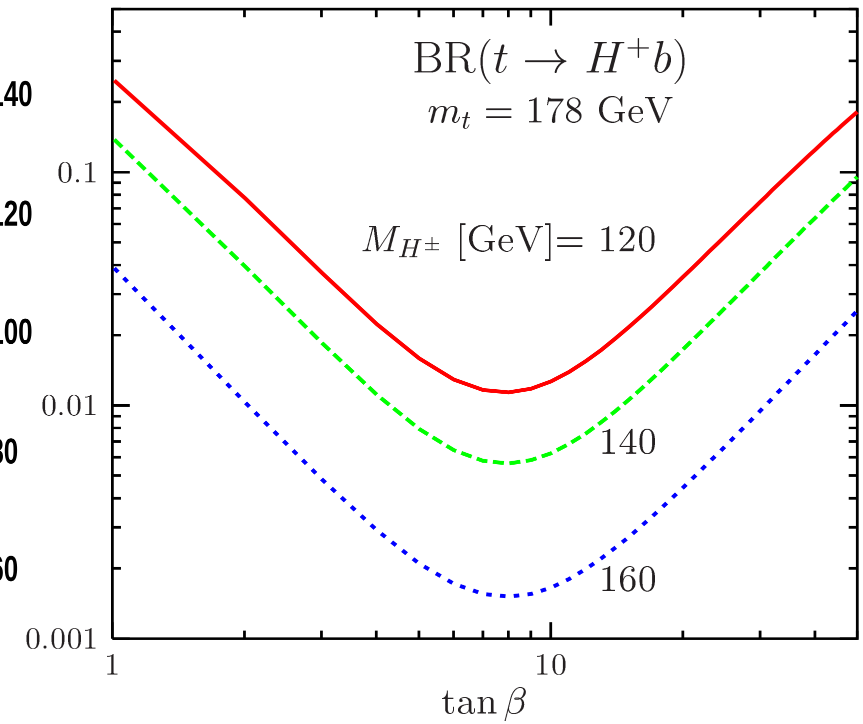


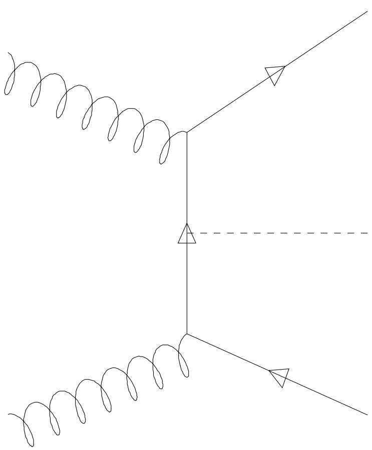


Exp. search @ LHC, $m_{H^\pm} > m_t$

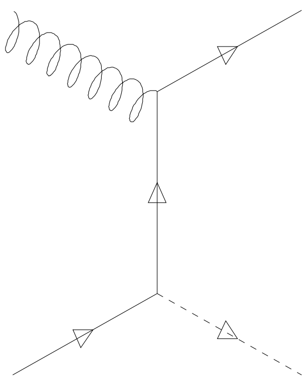
• At LHC with much larger $t\bar{t}$ production rate, one can extend the search to $m_{H^\pm} > 140$ GeV for all $\tan\beta$.

• At LHC for $m_{H^\pm} > m_t$, the main production mechanisms are: $gb \to tH^-$ and $gg \to tbH^-$, ($\sigma \approx$ 10pb for $m_{H^\pm} = 180$ GeV and large $\tan\beta$).

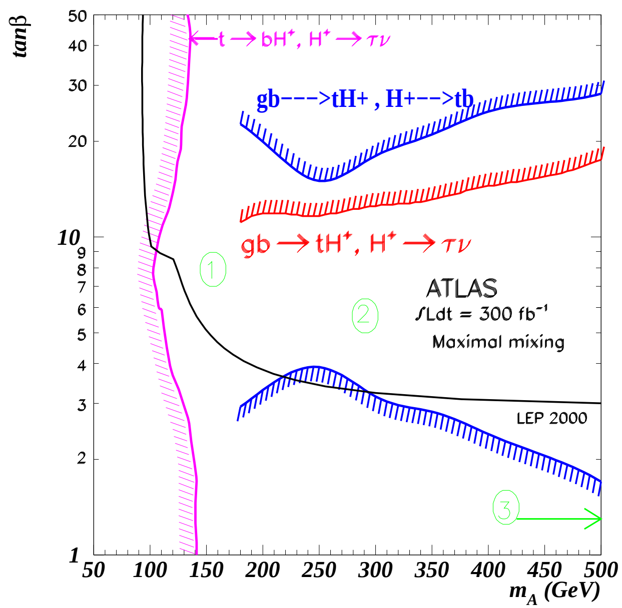
Discovery channel are $H^\pm \to \tau\nu$ for large $\tan\beta$ and $H^\pm \to t\bar{b}$.



$gg \to tH^+b$



$gb \to tH^+$



II. $H^\pm \to W^\pm V$ in MSSM and 2HDM

- In 2HDM and MSSM at tree level:

  $H^\pm W^\pm \gamma = 0$ because of electroweak gauge invariance $U(1)_{\rm em}$

  $H^\pm W^\pm Z = 0$ is due to the isospin symmetry

- In Higgs Triplet Model, $H^\pm W^\pm Z$ exist at tree level.
- $H^\pm \to W^\pm(Z,\gamma)$ are than rare processes, expected to be small, but loop or/and threshold effects can give a substantial effect.
- Also, any experimental deviation from the results within such a models should bring some information on the new physics.
- $H^\pm \to W^\pm(Z,\gamma)$ have a very clear signature and might emerge easily at future colliders.

  In SM: $H \to ZZ \to 4$leptons is considered to be the golden mode for Higgs discovery. The mode $H^\pm \to W^\pm Z \to 3$ leptons.

Previous works

- J.F. Gunion et al (1988), $H^\pm \to W^\pm\gamma$, Unitary gauge, no L-R mixing.
- A. Mendez et al (1991) $H^\pm \to W^\pm Z$ Unitary gauge, no L-R mixing.
- H. E. Haber et al (1991) Unitary gauge, Decoupling limit of heavy quarks (4th generation), heavy squarks, no Left-Right mixing
- S. Raychaudhuri and A. Raychaudhuri (1992,1994), $H^\pm \to W^\pm\gamma$, 'tHooft-Feynman gauge, MSSM bosonic loop, no scalar fermions.
- S. Kanemura (2000), $H^\pm \to W^\pm Z$ 'tHooft-Feynman gauge, 2HDM bosonic loop, no unitarity/vacuum stability constraints
- M. A. Perez et al, $H^\pm \to W^\pm\gamma$ in a nonlinear R_ξ-gauge 2HDM
- A.Arhrib et al, hep-ph/0607182, $H^\pm \to W^\pm(Z,\gamma)$ LR mixing, $b \to s\gamma$, unitarity/vacuum stability constraints, 'tHooft-Feynman gauge.
- A. Arhrib, R. Benbrik, W. T. Chang, W.-Y. Keung and T. C. Yuan, CP violation in $H^\pm \to W^\pm(Z,\gamma)$ work in progress.

At one-loop amplitude

The amplitude $\mathcal{M}$ for a scalar decaying to two gauges bosons V_1 and V_2 can be written as

$$\mathcal{M} = \frac{g^3 \varepsilon^{\mu}_{V_1} \varepsilon^{\nu}_{V_2}}{16\pi^2 m_W} \mathcal{M}_{\mu\nu}$$

• According to Lorenz invariance, the one loop amplitude

$$\mathcal{M}_{\mu\nu}(H^{\pm} \to W^{\pm}_{\mu} V_{\nu}) = (-\mathcal{F}_1 p_1.p_2 g_{\mu\nu} + \mathcal{F}_2 p_{1\mu} p_{2\nu} + i\mathcal{F}_3 \epsilon_{\mu\nu\rho\sigma} p_1^{\rho} p_2^{\sigma})\epsilon^{\mu *}\epsilon^{\nu *}$$

For $H^{\pm} \to W^{\pm}\gamma$, $U(1)_{em}$ imply $\mathcal{F}_1 = \mathcal{F}_2$.

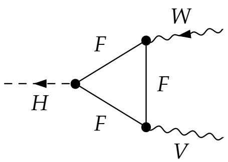
• In terms of an effective Lagrangian, from gauge invariance:

$$\mathcal{L}_{eff} = g_1 \underbrace{H^{\pm} W^{\mp}_{\mu} V^{\mu}}_{dim3} + g_2 \underbrace{H^{\pm} F^{\mu\nu}_{V} F_{W\,\mu\nu}}_{dim5} + i g_3 \underbrace{\epsilon_{\mu\nu\rho\sigma} H^{\pm} F^{\mu\nu}_{V} F^{W\,\rho\sigma}}_{dim5} + h.c$$

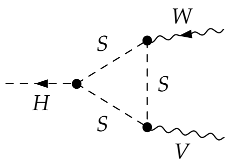
One conclude that $g_{2,3} = g(r)/M \quad \text{and} \quad g_1 = M g(r)$

M is a heavy scale in MSSM, $g(r)$ a dimensionless function and r is a ratio of internal masses of the model under study.

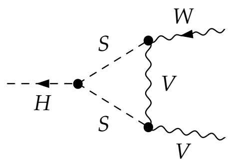
Vertex



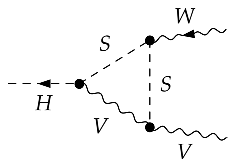
T1 G1 N1



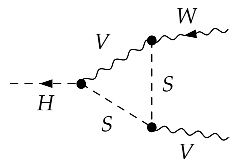
T1 G2 N2



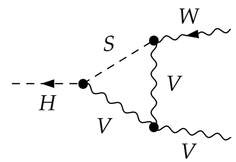
T1 G3 N3



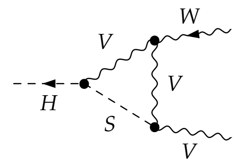
T1 G4 N4



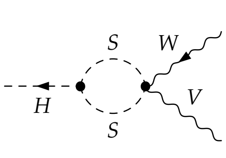
T1 G5 N5



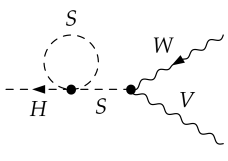
T1 G6 N6



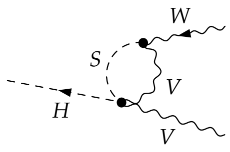
T1 G7 N7



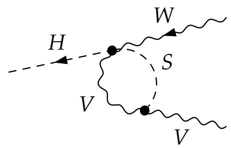
T2 G1 N8



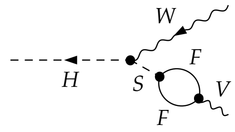
T3 G1 N9



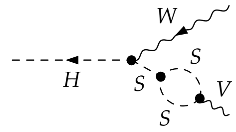
T4 G1 N10



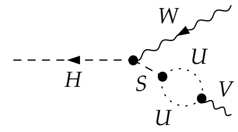
T5 G1 N11



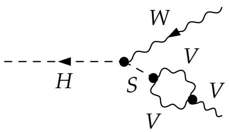
T6 G1 N12



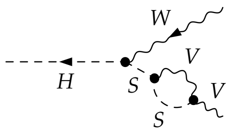
T6 G2 N13



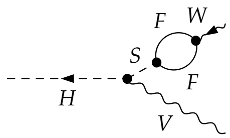
T6 G3 N14



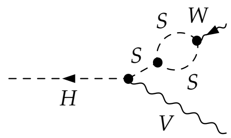
T6 G4 N15



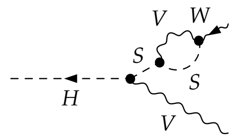
T6 G5 N16



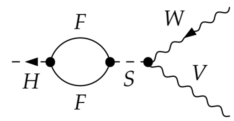
T7 G1 N17



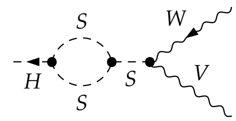
T7 G2 N18



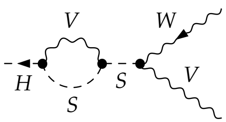
T7 G3 N19



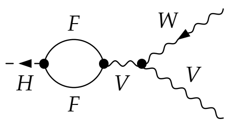
T8 G1 N20



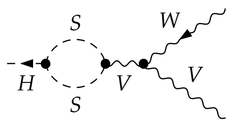
T8 G2 N21



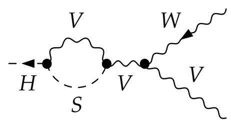
T8 G3 N22



T8 G4 N23

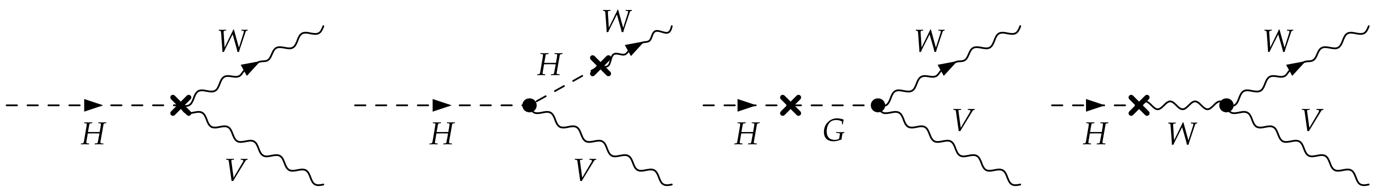


T8 G5 N24



T8 G6 N25

Counter-terms



On-shell Renormalization

For the Higgs sector, in this scheme, the Higgs field and vacuum expectation values are renormalized as follows:

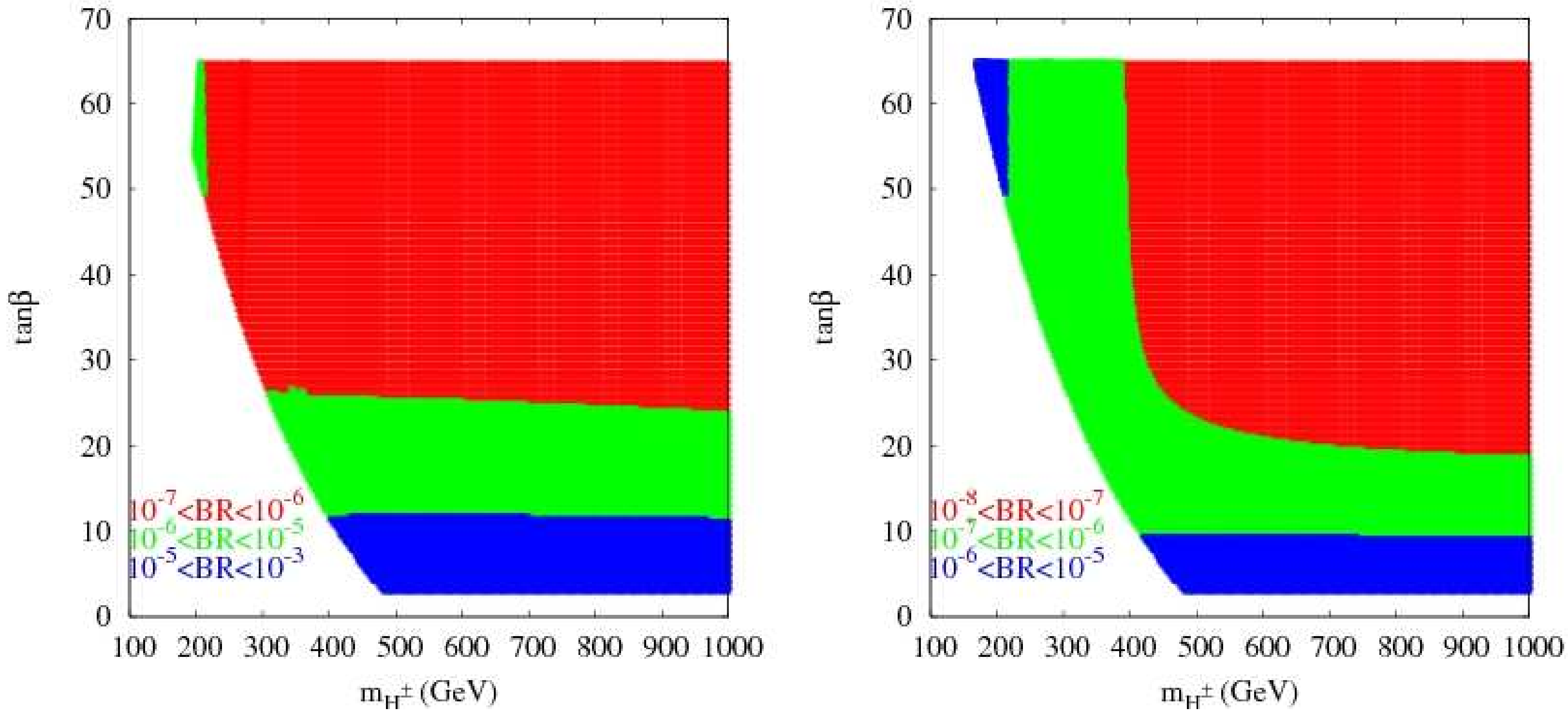
$$\Phi_i \longrightarrow (Z_{\Phi_i})^{1/2}\Phi_i$$
$$v_i \longrightarrow (Z_{\Phi_i})^{1/2}(v_i - \delta v_i)\,.$$

With these substitutions followed by $Z_i = 1 + \delta Z_i$ we obtain all the counter-terms relevant for our process [Dabelstein'94]:

$$\begin{aligned}
\delta[W_\nu^\pm H^\mp] &= k^\mu \Delta \\
\delta[A_\nu W_\mu^\pm H^\mp] &= -ieg_{\mu\nu}\Delta \\
\delta[Z_\nu W_\mu^\pm H^\mp] &= -ieg_{\mu\nu}\frac{s_W}{c_W}\Delta
\end{aligned}$$

In the on-shell scheme, we use the renormalization conditions to determines the terme Δ to be $\Delta = Re(\sum_{HW}(m^2_{H^\pm}))$

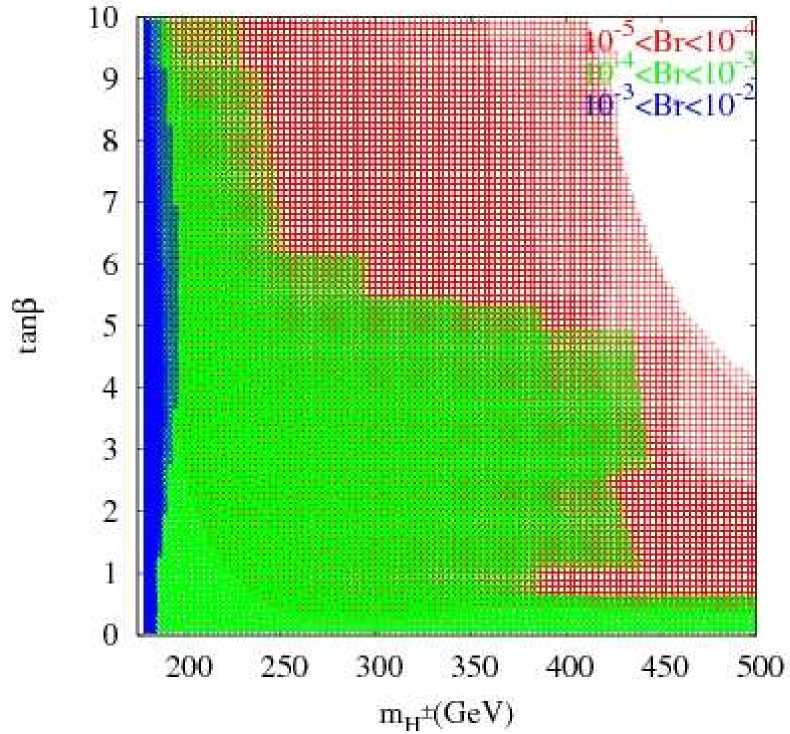
Numerics -MSSM-

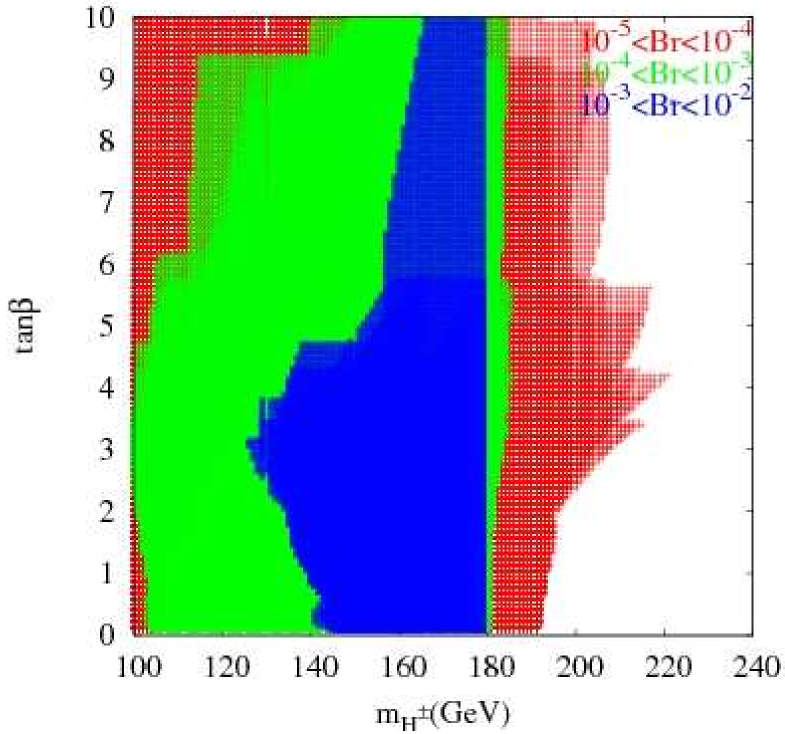


Scatter plots for branching ratios of $H^{\pm} \to W^{\pm} Z$ (left) and $H^{\pm} \to W^{\pm}\gamma$ (right)

$M_{SUSY} = 1$ TeV, $M_2 = 175$ GeV, $A_{t,b,\tau} = M_{SUSY}$ and $\mu = -1$ TeV

Numerics -2HDM type II-





Scatter plots branching ratios of $H^\pm \to W^\pm Z$ (left) and $H^\pm \to W^\pm \gamma$ (right) in type-II 2HDM. For $100GeV < m_{h^0} < 130GeV$, $150GeV < m_{H^0} < 350GeV$, $100GeV < m_{A^0,H^\pm} < 500GeV$, $-1 < \sin\alpha < 1$, $0.1 < \tan\beta < 10$ and $\lambda_5 = 0$

III. MSSM with CP violating phases

- In MSSM with, complex μ, M_i and/or A_f, the Higgs sector, even with CP-conserving tree level scalar potential, has loop induced CP violation (both explicit and spontaneous CPV) [A.Pilaftsis'98].
- In MSSM, Spontaneous CPV, leads to light CP-odd $m_A < 40$ GeV is ruled out by LEP experiments, [A.Pomarol'92,A.Haba'97]
- 2HDM have both explicit and spontaneous CPV [G. Branco etal'85]
- This induced CP violation imply scalar-pseudo scalar mixing with mass eigenstates H_1, H_2 and H_3 which are mixed states of CP.
- The size of CPV in the off diagonal terms Δ_{13}, Δ_{23} may be estimated as:

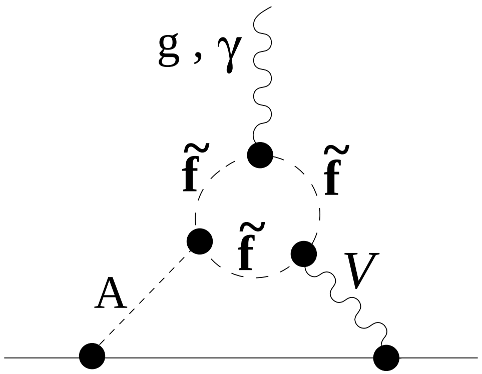
$$\Delta_{13} \simeq \mathcal{O}\left(\frac{m_t^4}{v^2}\frac{|\mu||A_t|}{32\pi^2 M_S^2}\right)\sin\phi_{CP}\{1, \frac{|A_t|^2}{M_S^2}, \frac{|\mu|^2}{\tan\beta M_S^2}, \frac{|\mu||A_t|}{M_S^2}\}$$

$\phi_{CP} = \mathrm{Arg}(\mu) + \mathrm{Arg}(A_{t,b})$, M_S is stop mass average

III. MSSM with CP violating phases

- Those large CP violating phases can give contributions to the EDM which exceed the experimental upper bound.
- The EDMs can be suppressed in SUSY models with:[S. Abel et al NPB'01]

1. Heavy SUSY scalars ($m_{sfermions} = 10TeV$)
2. The cancellation mechanisme.
3. Non universal term ($A_u = A_d = A_c = A_s = 0$, $A_b = A_t = A_\tau = A_0$, Arg(μ)<10^{-2})



IV. CP violation in $H^\pm \to W^\pm(Z,\gamma)$

$\mathcal{M}_{\mu\nu} = (-\mathcal{F}_1 p_1.p_2 g_{\mu\nu} + \mathcal{F}_2 p_{1\mu} p_{2\nu} + i\mathcal{F}_3 \epsilon_{\mu\nu\rho\sigma} p_1^\rho p_2^\sigma)\epsilon^{\mu *}\epsilon^{\nu *}$

The helecity amplitudes are:

$$|\mathcal{M}_{LL}|^2 \propto |(-r_W - r_Z)^2 \mathcal{F}_1 - \lambda(1, r_W, r_Z)\frac{\mathcal{F}_2}{2}|^2$$

$$|\mathcal{M}_{TT}|^2 \propto (1 - r_W - r_Z)^2 |\mathcal{F}_1|^2 + \lambda(1, r_W, r_Z)|\mathcal{F}_3|^2$$

The decay width is $\Gamma(H^\pm \to W^\pm Z) = m_{H^\pm}\frac{\sqrt{\lambda}}{16\pi}(|\mathcal{M}_{LL}|^2 + |\mathcal{M}_{RR}|^2)$

Under CP, the helecity states transform as:

$$\mathcal{M}(W^+V, ++) \longleftrightarrow \mathcal{M}(W^+V, --)$$

$$\mathcal{M}(W^+V, --) \longleftrightarrow \mathcal{M}(W^+V, ++)$$

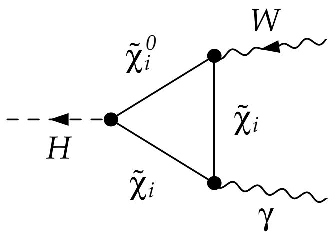
$$\mathcal{M}(W^+Z, 00) \longleftrightarrow \mathcal{M}(W^+Z, 00)$$

We will look only to the following CP asymmetry

$$\delta_{CP}^V = \frac{\Gamma(H^+ \to W^+ V) - \Gamma(H^- \to W^- V)}{\Gamma(H^+ \to W^+ V) + \Gamma(H^- \to W^- V)}$$

IV. CP violation in $H^\pm \to W^\pm(Z,\gamma)$

$$\delta^\gamma_{CP} = \frac{|\mathcal{F}_1|^2 - |\mathcal{F}_1^*|^2 + |\mathcal{F}_3|^2 - |\mathcal{F}_3^*|^2}{|\mathcal{F}_1|^2 + |\mathcal{F}_1^*|^2 + |\mathcal{F}_3|^2 + |\mathcal{F}_3^*|^2}$$



$$\mathcal{F}_1 = \frac{eg}{16\pi^2}\frac{1}{m^2_{H^\pm}}\sum_{i=1}^{4}\sum_{m=1}^{2}\left(a_{im1}I_{im1} + a_{im2}I_{im2}\right)$$

$$\mathcal{F}_3 = \frac{eg}{16\pi^2}\frac{1}{m^2_{H^\pm}}\sum_{i=1}^{4}\sum_{m=1}^{2}\left(b_{im1}J_{im1} + b_{im2}J_{im2}\right)$$

$$\delta^\gamma_{CP} \propto \sum_{i,j,\alpha,\beta,m,n1}\left[\mathrm{Im}(a_{im\alpha}a^*_{jn\beta})\mathrm{Im}(I_{im\alpha}I^*_{jn\beta}) + \mathrm{Im}(b_{im\alpha}b^*_{jn\beta})\mathrm{Im}(J_{im\alpha}J^*_{jn\beta})\right]$$

IV. CP violation in $H^\pm \to W^\pm(Z,\gamma)$

- $I_{im\alpha}$,$J_{jm\alpha}$ are the Feynman loops integrals defined by

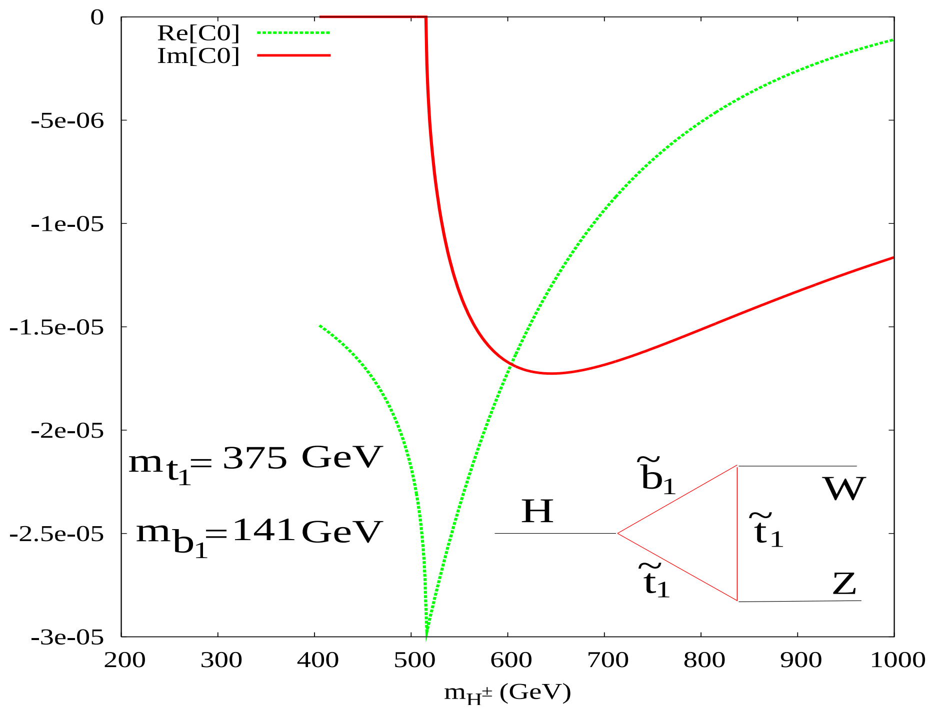
$$\left[I_{im1}, I_{im2}, J_{im1}, J_{im2}\right] = \int_0^1 dx \int_0^x \frac{\left[y(1-2x), 1-3y+2xy, y, 1-y\right]}{\varepsilon_i y + \varepsilon_m(1-y) - y(1-x) - \varepsilon_w y(x-y)}$$

with :

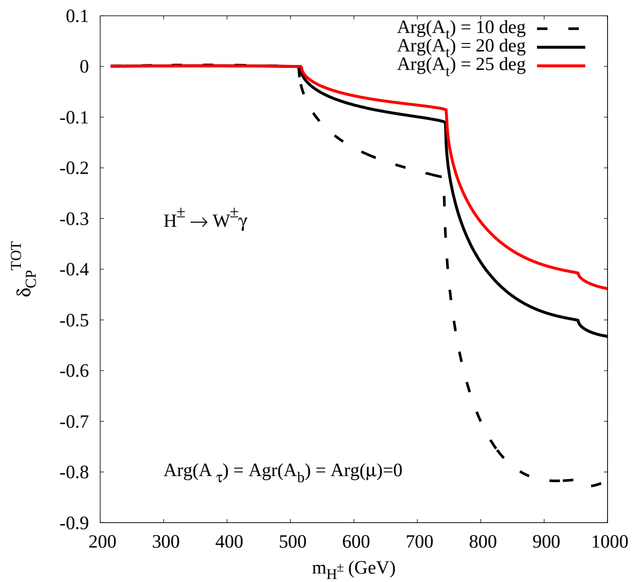
$$\varepsilon_i = \frac{m^2_{\tilde{\chi}^0_i}}{m^2_{H^\pm}}, \qquad \varepsilon_m = \frac{m^2_{\tilde{\chi}^\pm_m}}{m^2_{H^\pm}},$$

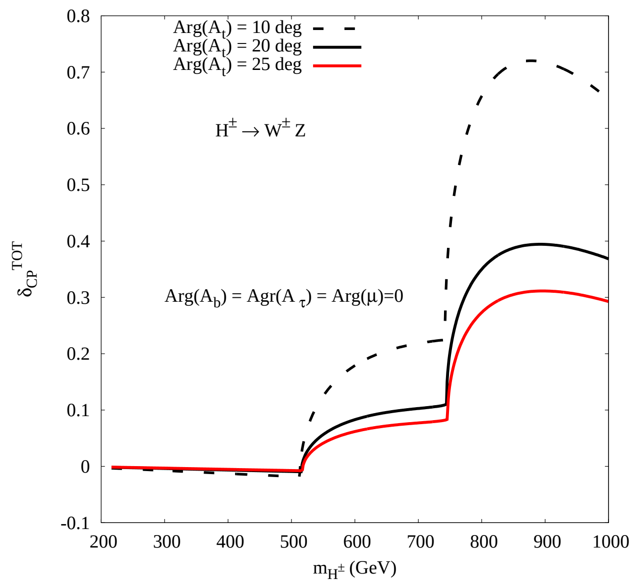
- Besides CP violating phases in the SUSY couplings, absorptive parts developed in the Feynman integrals I and J are necessary in order to produce nonzero for the δ^γ_{CP}.

Absorptive part



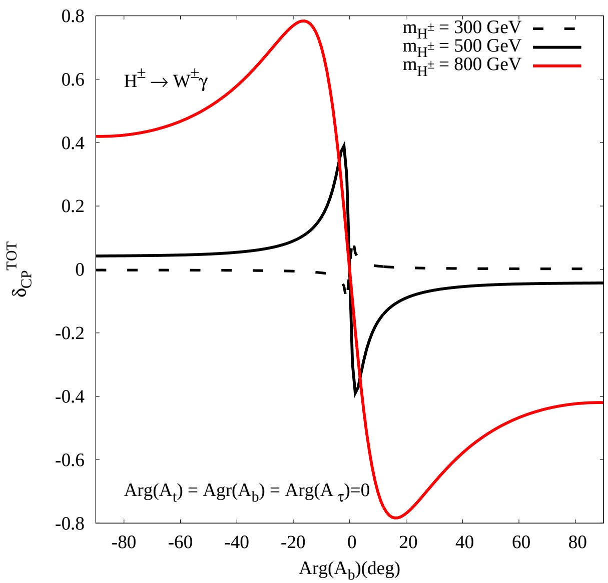
Preliminary results

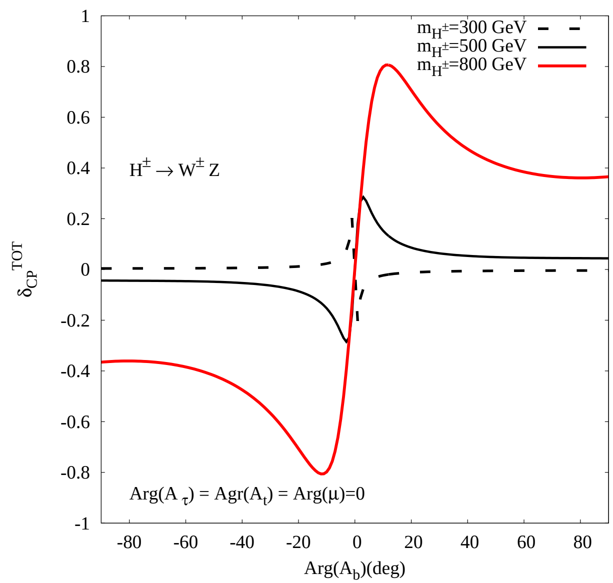




Total δ_{CP} in the $H^\pm \to W^\pm\gamma$ (left) and $H^\pm \to W^\pm Z$ (right) as of function of $m_{H^\pm}$in the MSSM model, with the parameters, $M_{SUSY} = 500$ GeV, $M_2 = 175$ GeV, $\tan\beta = 16$, $A_t = A_b = A_{tau} = -\mu$, $\mu = -1.4$TeV, for differents values of Arg(A_t)

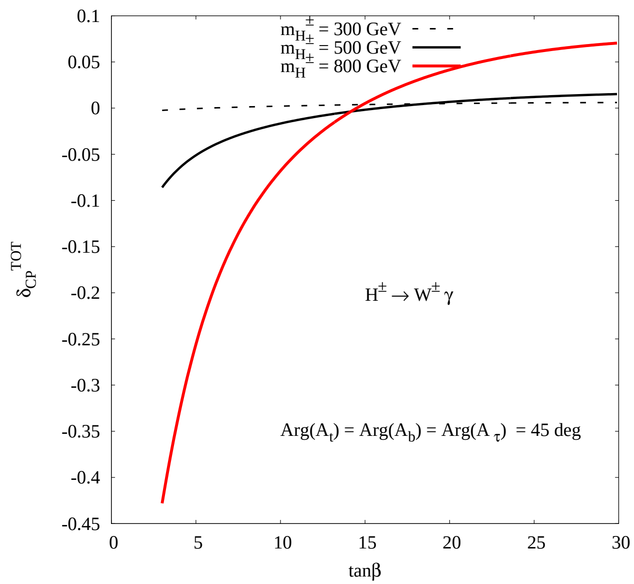
Preliminary results

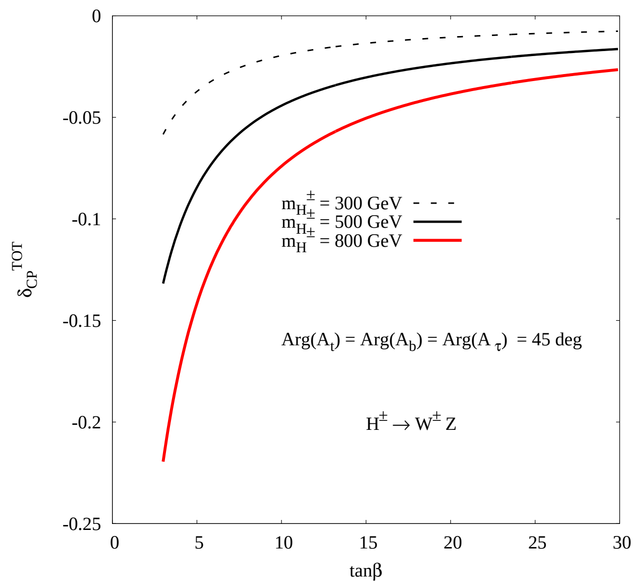




Total δ_{CP} in the $H^{\pm} \rightarrow W^{\pm}\gamma$ (left) and $H^{\pm} \rightarrow W^{\pm}Z$ (right) as of function of Arg(A_b), in the MSSM model, with the parameters, $M_{SUSY} = 500$ GeV, $M_2 = 175$ GeV,$\tan\beta = 20$, $A_t = A_b = A_{tau} = -\mu$, $\mu = -1.4$TeV for differents values of $m_{H^\pm}$

Preliminary results





Total δ_{CP} in the $H^\pm \to W^\pm\gamma$ (left) and $H^\pm \to W^\pm Z$ (right) as of function of $\tan\beta$ in the MSSM model, with the parameters, $M_{SUSY} = 500$ GeV, $M_2 = 175$ GeV, $\mu = -500$ GeV, $A_t = A_b = A_{tau} = -\mu$, for differents values of $m_H^\pm$.

V. Conclusions

- In the MSSM $Br(H^{\pm} \to W^{\pm}Z) \approx 10^{-3}$ can be obtained, light squarks with large $A_{t,b}$ can give substantial enhancement.
- Difficult to measure at the LHC , ILC
- May be measured at Super-LHC with $1000 fb^{-1}$
- In the 2HDM $10^{-4} < Br(H^{\pm} \to W^{\pm}(Z,\gamma)) < 10^{-2}$ is possible.
  $H^{\pm} \to W^{\pm}(Z,\gamma)$ may emerge at LHC.
  $\sigma(pp \to H^{+}\bar{t}b) \approx 10^{4}$ fb near threshold $m_{H^{\pm}} \approx 180$ GeV
- To get CPV in $H^{\pm} \to W^{\pm}V$, we need both MSSM CP violating phases and absorptive parts.
- In case where μ is real, one can get large CP asymmetry from the CP phases of A_t, A_b and A_τ