

HEP activities in Tangier

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Faculté des Sciences et Techniques Tangier, Morocco
HEP workshop in Morocco, Tangier 27-28 October'2017



Outlines

- Our team
- Research activities
- Projects
- Conclusions

Our team:

- A.A
- Dr. A. Jueid and J. Elfalaki (PhD student)

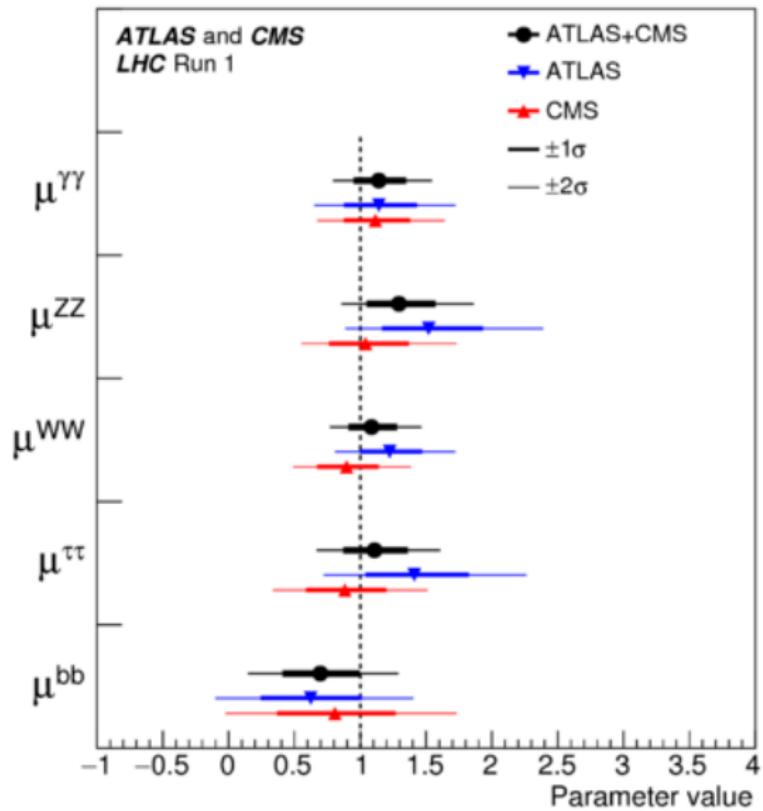


- H. Abouabid (new PhD student)



Our research activities:

ATLAS and CMS results

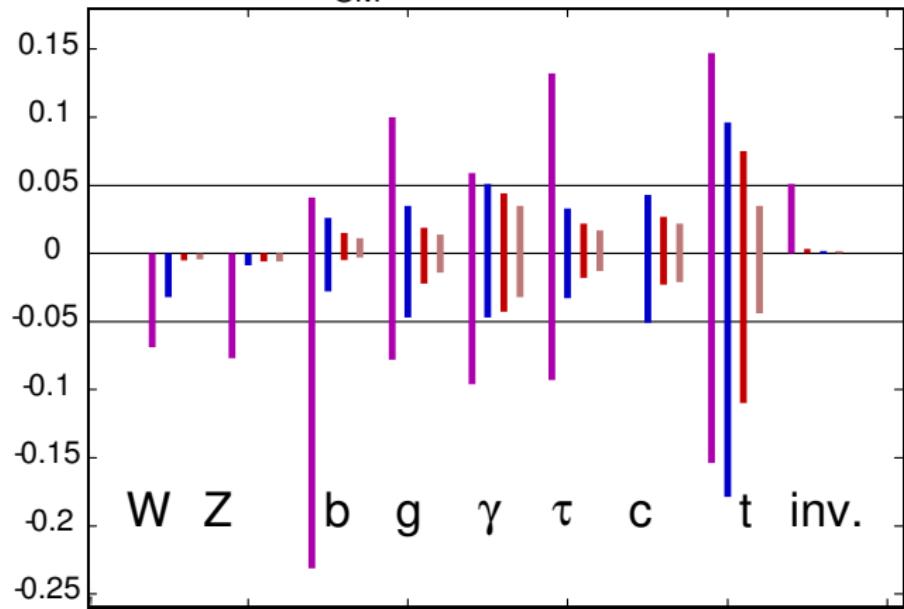


Our research activities:

LHC/ILC complementarity

$$g(hAA)/g(hAA)|_{SM} - 1$$

LHC/ILC1/ILC/ILCTeV



1. Radiative corrections in the SM and beyond

- Computation of observables at 1-loop level: $h \rightarrow f\bar{f}$; $h \rightarrow VV$; γW^+W^- , ZW^+W^- ; $e^+e^- \rightarrow H^+H^-$; $pp \rightarrow hh$; triple Higgs coupling hhh .
- Renormalization of wave functions and independent parameters
- Very complicated calculation, too many Feynman diagrams
- www.FeynArts.de , www.FormCalc.de
- Model file for FeynArts: 2 Higgs doublet model with/without CP violation
- Model file for FeynArts: Higgs triplet Model (type II seesaw)

2. Perturbative unitarity and boundedness from below for the scalar potential

- Many BSM models, involve Higgs with high representation:
more doublet, more singlet, doublet and triplet...
- Several CP-even Higgs, CP-odd, charged Higgs, doubly charged Higgs...
- Detail study of several scalar Potential:
 - i) type II seesaw Model.
 - ii) 2 Higgs doublet Model and inert Higgs model,
 - iii) 2 Higgs doublet and singlet fields.
 - iv) Georgi-Machacek model.

Extended Higgs sector: EWPT

mass terms:

$$\sum_i (D_\mu \Phi_i)^+ (D_\mu \Phi_i) \quad , \quad D_\mu = \partial_\mu + ig \vec{T}_a \vec{W}^a_\mu + ig' \frac{Y}{2} B_\mu$$

$$m_W^2 = \sum_i g^2 \frac{v_i^2}{2} (I_i(I_i + 1) - \frac{Y_i^2}{4}) \quad , \quad m_Z^2 = \frac{g^2}{4c_W^2} \sum_i v_i^2 Y_i^2$$

$$\rho = \frac{m_W^2}{c_W^2 m_Z^2} = \frac{\sum_i v_i^2 (I_i(I_i + 1) - \frac{Y_i^2}{4})}{\sum_i v_i^2 \frac{Y_i^2}{2}} \approx 1.00037 \pm 0.00023$$

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1. Doublets ($I_i=1/2$, $Y_i=\pm 1$): tree ok but “rad. corrections”
2. $4I_i(I_i + 1) = 3Y_i^2$: $I = 3$ and $Y = 4$, rather complicated

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2. $4I_i(I_i + 1) = 3Y_i^2$: $I = 3$ and $Y = 4$, rather complicated
3. Triplet representation: tune the triplet vev. In type-II see-saw:
 $v_\Delta < 5 - 8$ GeV

2HDM:

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \phi_1^0 + ia_1) \end{pmatrix}; \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \phi_2^0 + ia_2) \end{pmatrix}.$$

The most general potential for 2HDM:

$$\begin{aligned} V(\Phi_1, \Phi_2) &= m_1^2 \Phi_1^\dagger \Phi_1 + m_2^2 \Phi_2^\dagger \Phi_2 + (\textcolor{green}{m_{12}^2} \Phi_1^\dagger \Phi_2 + \text{h.c.}) \\ &+ \frac{1}{2} \lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2} \lambda_2 (\Phi_2^\dagger \Phi_2)^2 \\ &+ \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\ &+ \frac{1}{2} [\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + (\textcolor{red}{\lambda_6} \Phi_1^\dagger \Phi_1 + \textcolor{red}{\lambda_7} \Phi_2^\dagger \Phi_2) \Phi_1^\dagger \Phi_2 + \text{h.c.}], \end{aligned}$$

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- \mathbb{Z}_2 : $\Phi_i \rightarrow -\Phi_i \Leftrightarrow \lambda_{6,7} = 0$
- No explicit CP violation: $Im(m_{12}^2 \lambda_{5,6,7}) = 0$

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \phi_1^0 + ia_1) \end{pmatrix}; \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \phi_2^0 + ia_2) \end{pmatrix}.$$

$$-\mathcal{L}_Y = \sum_{a=1,2} \left[\bar{Q}_L Y_d^a \Phi_a d_R + \bar{Q}_L Y_u^a \tilde{\Phi}_a u_R + \bar{L}_L Y_\ell^a \Phi_a \ell_R + \text{h.c.} \right],$$

leads to FCNCs at tree level.

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leads to FCNCs at tree level.

- Classification of 2HDMs satisfying the Glashow-Weinberg condition which guarantees the absence of tree-level FCNC.

| | |
|--------------|-------------------------------|
| Type-I | $Y_{u,d}^1 = 0, Y_\ell^1 = 0$ |
| Type-II | $Y_u^1 = Y_{d,\ell}^2 = 0$ |
| Type-III (X) | $Y_{u,d}^1 = Y_\ell^2 = 0$ |
| Type-IV (Y) | $Y_{u,\ell}^1 = Y_d^2 = 0$ |

The Yukawa Lagrangian:

$$\begin{aligned}
 -\mathcal{L}_{Yuk} = & \sum_{\psi=u,d,l} \left(\frac{m_\psi}{v} \kappa_\psi^h \bar{\psi} \psi h^0 + \frac{m_\psi}{v} \kappa_\psi^H \bar{\psi} \psi H^0 - i \frac{m_\psi}{v} \kappa_\psi^A \bar{\psi} \gamma_5 \psi A^0 \right) + \\
 & \left(\frac{V_{ud}}{\sqrt{2}v} \bar{u} (m_u \kappa_u^A P_L + m_d \kappa_d^A P_R) d H^+ + \frac{m_l \kappa_l^A}{\sqrt{2}v} \bar{\nu}_L l_R H^+ + H.c. \right)
 \end{aligned}$$

| | κ_u^h | κ_d^h | κ_l^h | κ_u^A | κ_d^A | κ_l^A |
|----------|--------------------|---------------------|---------------------|--------------|--------------|--------------|
| Type-I | c_α/s_β | c_α/s_β | c_α/s_β | $\cot\beta$ | $-\cot\beta$ | $-\cot\beta$ |
| Type-II | c_α/s_β | $-s_\alpha/c_\beta$ | $-s_\alpha/c_\beta$ | $\cot\beta$ | $\tan\beta$ | $\tan\beta$ |
| Type-III | c_α/s_β | c_α/s_β | $-s_\alpha/c_\beta$ | $\cot\beta$ | $-\cot\beta$ | $\tan\beta$ |
| Type-IV | c_α/s_β | $-s_\alpha/c_\beta$ | c_α/s_β | $\cot\beta$ | $\tan\beta$ | $-\cot\beta$ |

Decoupling limit: $\beta - \alpha = \pi/2$; $c_\alpha = s_\beta$, $s_\alpha = -c_\beta$

- Couplings:

$$hVV \propto \sin_{\beta-\alpha}, \quad HVV \propto \cos_{\beta-\alpha}, \quad AVV = 0$$

$$hH^\pm W^\mp \propto \cos_{\beta-\alpha}, \quad HH^\pm W^\mp \propto \sin_{\beta-\alpha}, \quad AH^\pm W^\mp \propto \frac{g}{2}$$

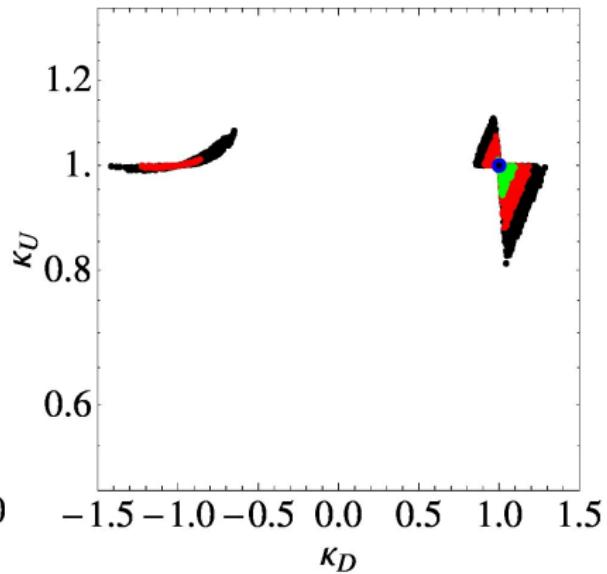
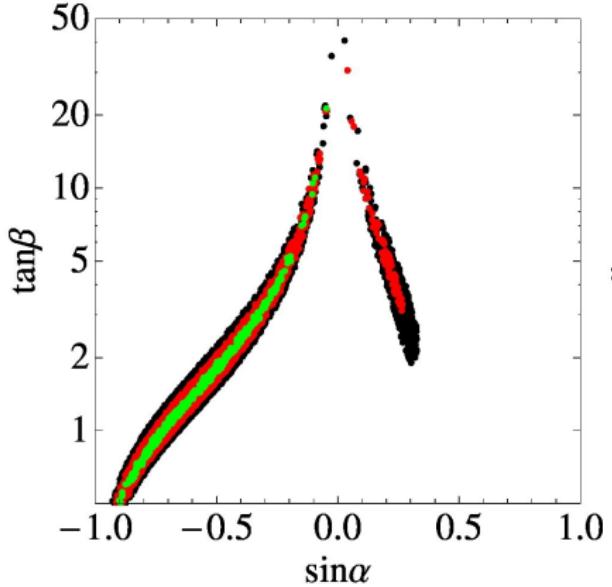
$$H^\pm W^\mp \gamma = 0 \text{ (e.m inv)}, \quad H^\pm W^\mp Z = 0 \text{ but loop mediated}$$

- 2 alignment limits:

- $h=125$ GeV SM-like: $\sin_{\beta-\alpha} = 1$ (Decoupling limit)
- $h < H=125$ GeV SM-like: $\cos_{\beta-\alpha} = 1$:
non-detected decays: $Br(H \rightarrow h^0 h^0, A^0 A^0) < 20 - 30\%$

profile of 2HDM-II with Flavor conservation

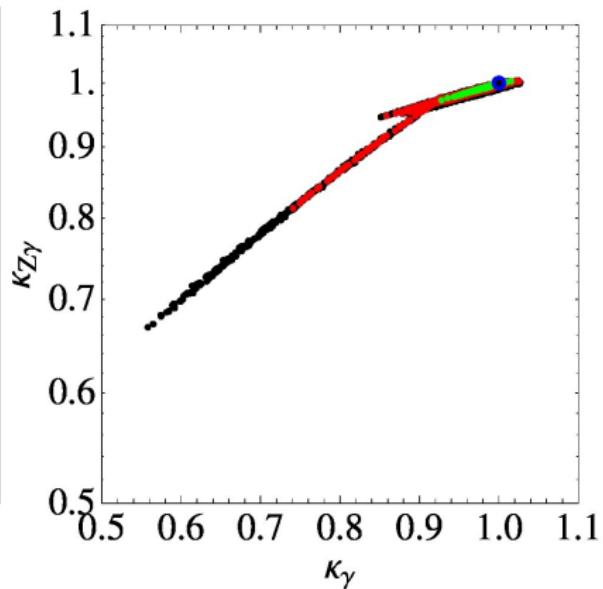
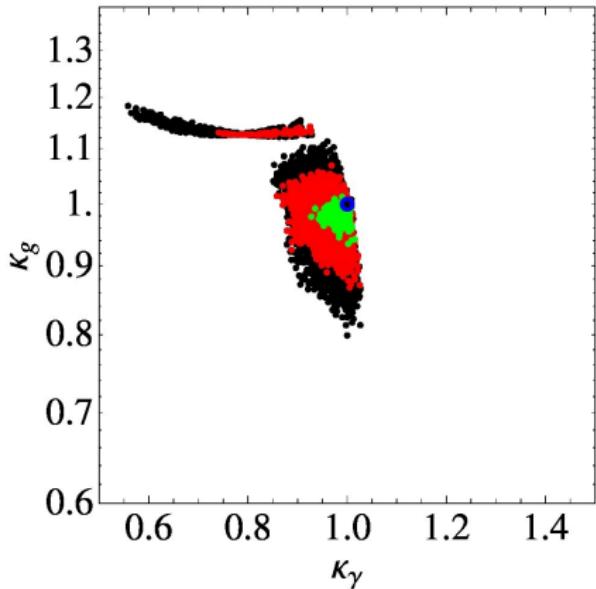
χ^2 fit: 99.7% CL (black), 95.5% CL (red) and 68% CL (green)



[A.A, R. Benbrik , C.-H Chen EPJC'16]

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Charged Higgs decays

fermionic decays

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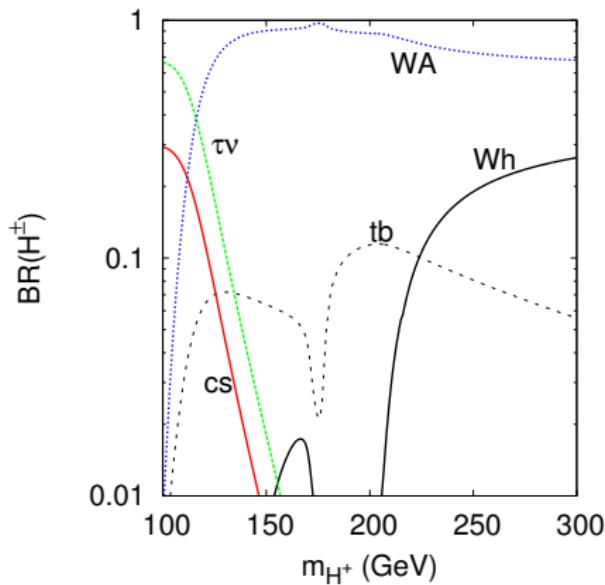
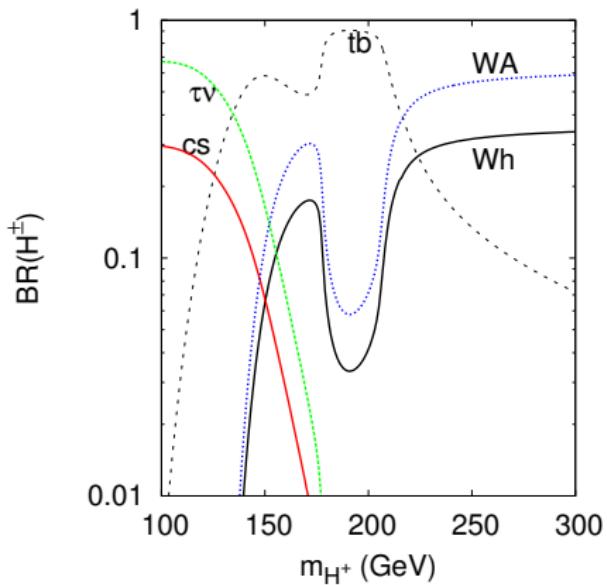
bosonic decays

- $H^\pm \rightarrow W^\pm \phi^0$, $\phi^0 = h^0, A^0, H^0$
- $H^\pm \rightarrow W^\pm \gamma, Z$: small loop mediated

A.A, R. Benbrik, W.T. Chang and T.C.Yuan, IJMP2007

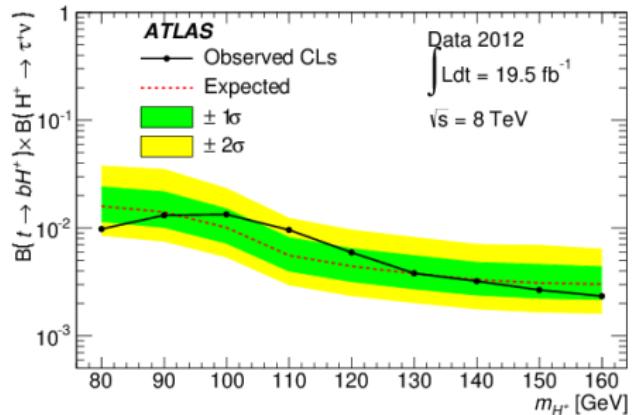
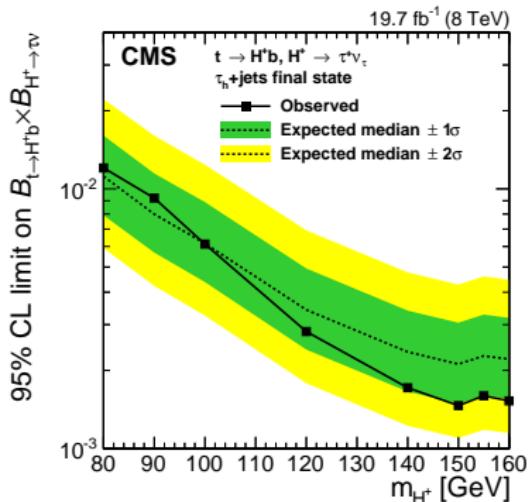
- $H^\pm \rightarrow W^\pm Z$ exists at tree level in triplet models.
(production through WZ fusion)

H^\pm decays: $\tan \beta = 4.5$, $m_H = 300$ GeV, (left) $m_A = 125$ GeV (right) $m_A = 90$ GeV: 2HDM-I



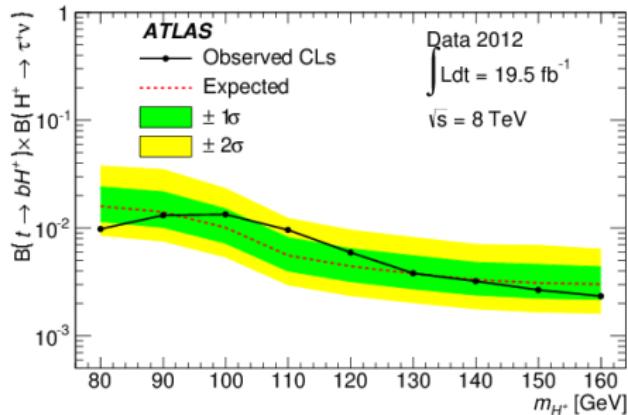
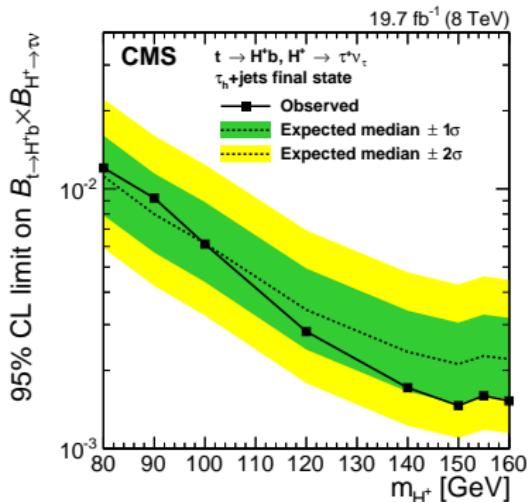
A.A, R. Benbrik and S. Moretti, EPJC'17

- ATLAS and CMS Limit on H^\pm : low mass



ATLAS and CMS Limits from $H^\pm \rightarrow c\bar{s}$ are weaker.

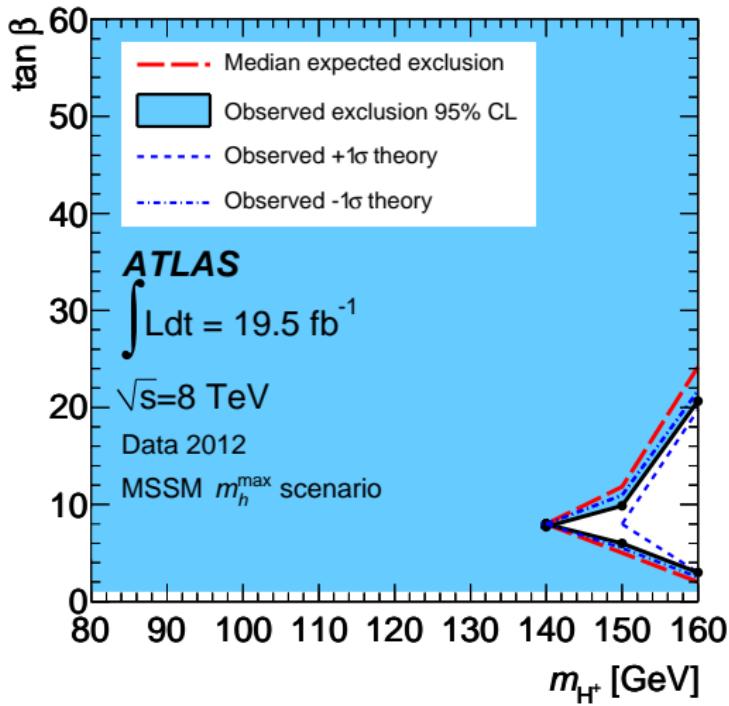
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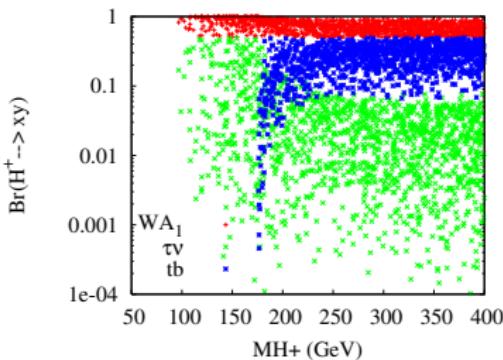
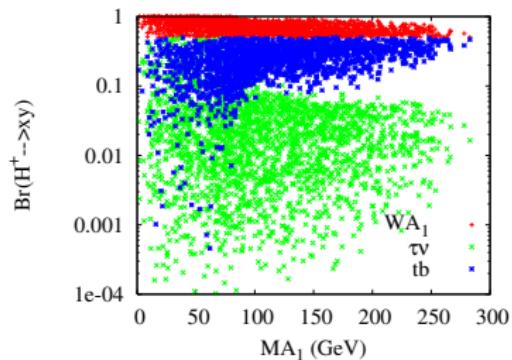
$$Br(t \rightarrow bH^+) = \frac{\Gamma(t \rightarrow bH^+)}{\Gamma(t \rightarrow bH^+) + \Gamma(t \rightarrow bW)} : \text{ depends only on } (\tan \beta, m_{H^\pm})$$

Implication for MSSM



Bosonic decay $H^\pm \rightarrow W^\pm + \text{Scalar}$ in the Next-MSSM

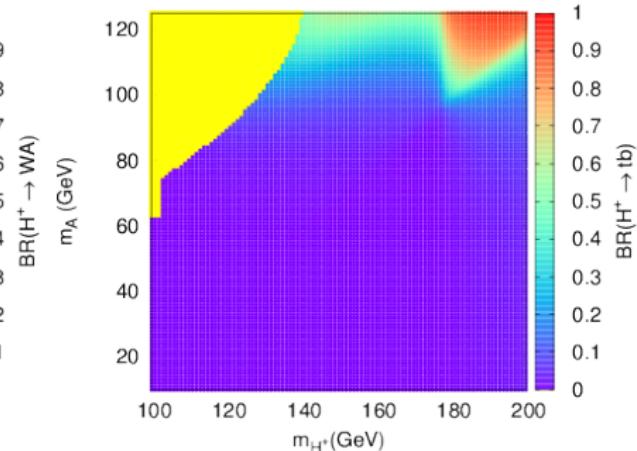
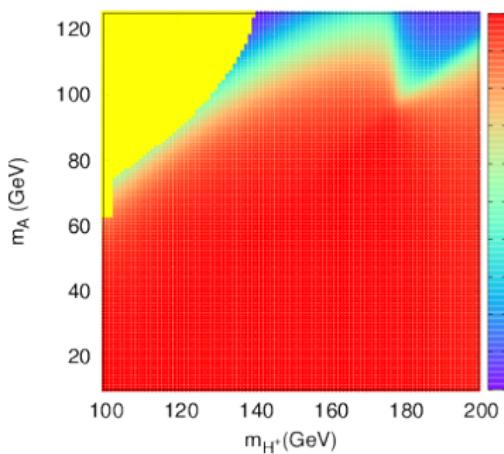
Next-MSSM: $H^\pm W^\mp A_1 \propto \cos \theta_A$: θ_A is the doublet-singlet mixing.



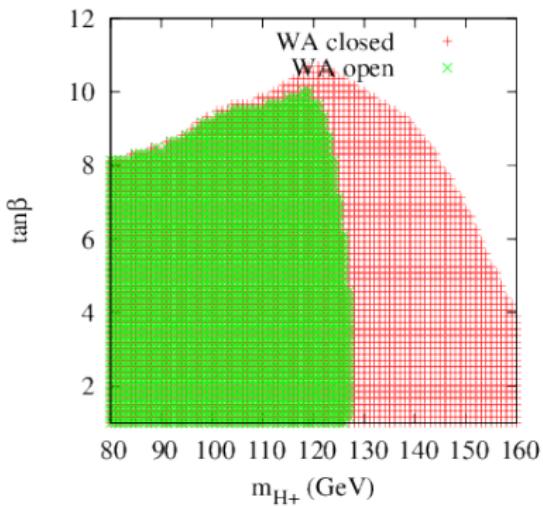
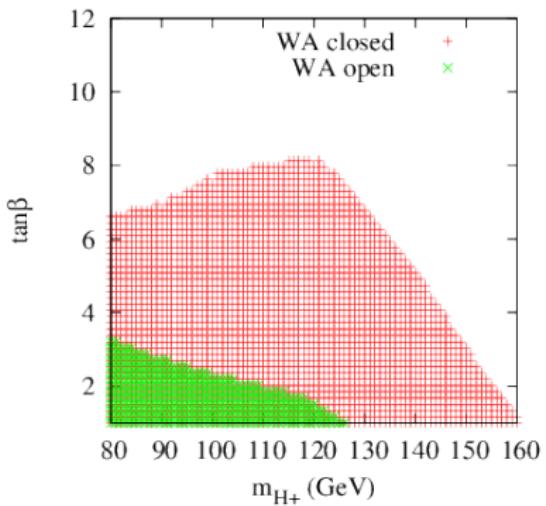
A. Akeroyd, A.A and Q.S. Yan EPJC'07

Bosonic decay $H^\pm \rightarrow W^\pm + \text{Scalar}$ in 2HDM type I

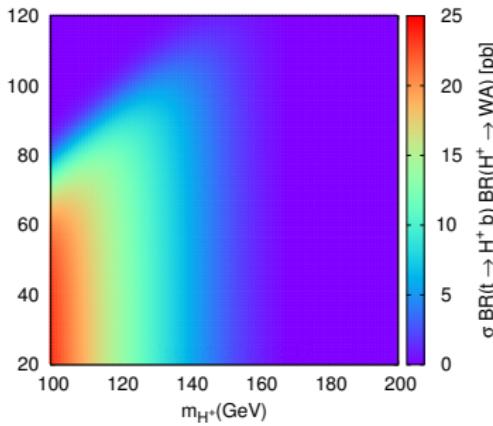
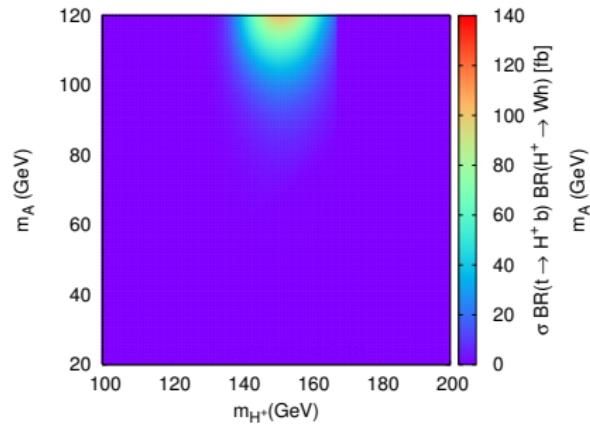
Very light A^0 : $\tan\beta = 5$, $m_H = 300$ GeV, $\sin(\beta - \alpha) = 1$:



Implication for 2HDM: (left) 2HDM-I, (right) 2HDM-III, WA open for $m_A = 40$ GeV

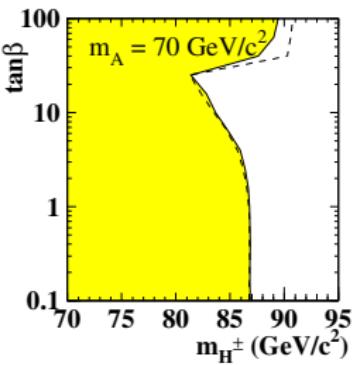
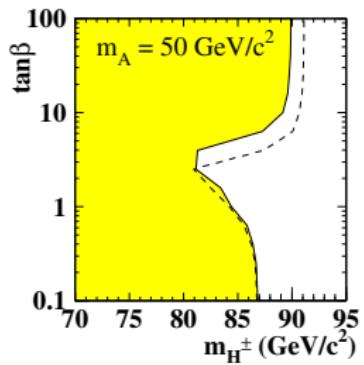
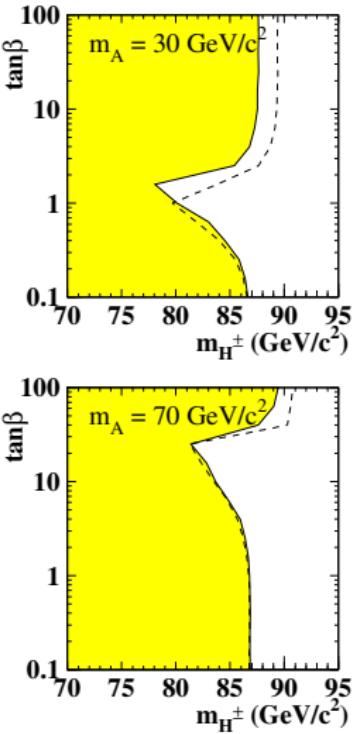
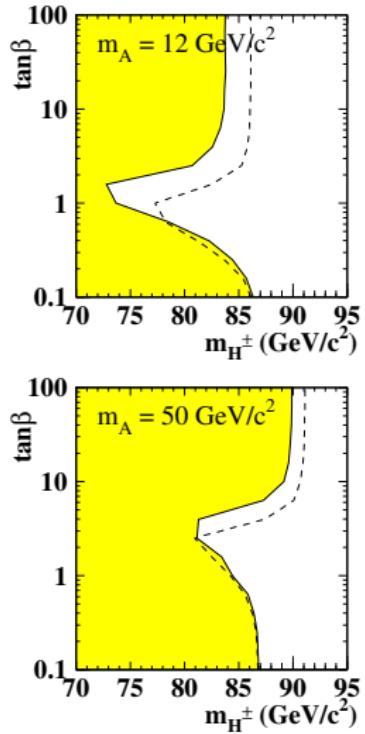


Cross sections



Search for $H^\pm \rightarrow W^\pm A^0$ at LEP-II

LEP 183-209 GeV

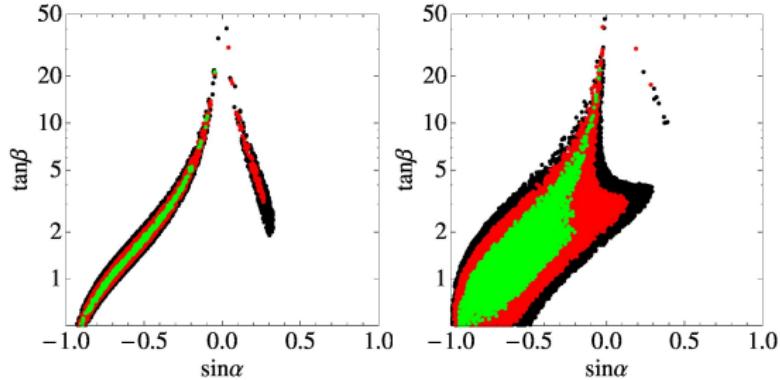


4. Top quark physics

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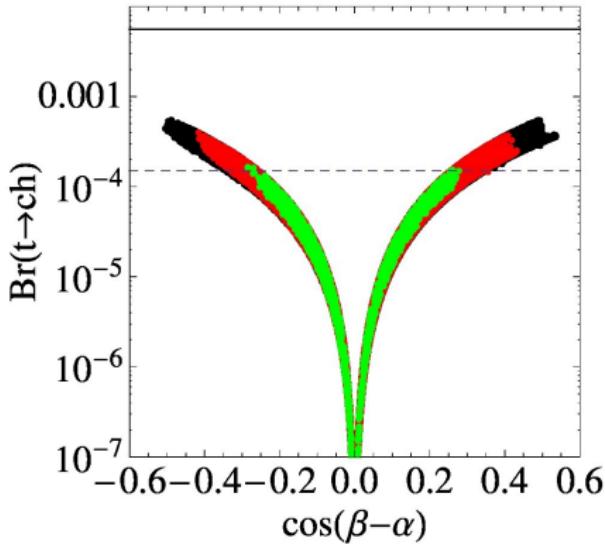
- Rare decays of top quark and FCNC decays of the Higgs in models with extra fermions.
- Profile of 2HDM without Flavor conservation (Higgs FCNC) χ^2 fit: 99.7% CL (black), 95.5% CL (red) and 68% CL (green)



[A.A, R. Benbrik, et al EPJC'16]

4. Top quark physics

- In 2HDM with Flavor violation we have $t \rightarrow ch$ at tree level?
 χ^2 fit: 99.7% CL (black), 95.5% CL (red) and 68% CL (green)



Solid line: LHC actual limit, dash line LHC with 3000 fb^{-1} .

4. Top quark physics: (see Adil Talk)



$$\begin{aligned}\mathcal{M}(t \rightarrow bW^+) = & \frac{-e}{\sqrt{2} \sin \theta_W} \bar{u}_b(p_b) ((V_L P_L + V_R P_R) \gamma^\mu \\ & + \frac{i \sigma^{\mu\nu} q_\nu}{M_W} (g_L P_L + g_R P_R)) u_t(p_t) \epsilon_\mu^*(q)\end{aligned}$$

- Constraints from $b \rightarrow s\gamma$ because of m_t/m_b factor

$$\begin{aligned}-0.15 \leq \text{Re}(g_R) \leq 0.57 \quad , \quad -7 \times 10^{-4} \leq V_R \leq 2.5 \times 10^{-3} \\ -1.3 \times 10^{-3} \leq g_L \leq 4 \times 10^{-4}\end{aligned}$$

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- Tevatron has reported 95% CL limit on anomalous couplings,
 $|V_R|^2 < 0.30$, $|g_L|^2 < 0.05$ and $|g_R|^2 < 0.12$
- A global fit from data on single top production and W helicity fractions gives:

$$\begin{aligned}-0.142 \leq g_R \leq 0.023 \quad , \quad -0.081 \leq g_L \leq 0.049, \\ 0.902 \leq V_L \leq 1.081 \text{ and } -0.112 \leq V_R \leq 0.162\end{aligned}$$

4. Top quark physics

- Study of tbW anomalous couplings in the 2 Higgs doublet model
- In model independent way, we propose new observables to probe the anomalous tbW coupling g_R (see Adil's Talk)

5. Triple Higgs coupling $hh\bar{h}$

- In order to establish the Higgs mechanism for EWSB we need to measure not only $H-f-f$ and $H-V-V$ but also the **self-coupling hhh and $hh\bar{h}h$ in order to reconstruct the scalar potential.**
- The measurement of the triple couplings, if precise enough, can help distinguishing between various extensions of the SM.

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- The measurement of the triple couplings, if precise enough, can help distinguishing between various extensions of the SM.
- At LHC: $pp \rightarrow gg \rightarrow h^* \rightarrow hh$: High luminosity option
- At ILC: $e^+e^- \rightarrow Zh^* \rightarrow Zh\bar{h}$ or
 $e^+e^- \rightarrow W^*W^* \rightarrow h^*\nu\bar{\nu} \rightarrow hh\nu\bar{\nu}$: High luminosity option

- In the 2HDM, and inert Higgs model: hhh receives large 1-loop corrections from Heavy particles.
A.A, R. Benbrik, J. Elfalaki, A Jueid, JHEP'14
A. Ahriche, A. Arhrib and S. Nasri, PLB 743, 279 (2015)
- both $pp \rightarrow h^*, H^* \rightarrow hh$ at LHC and $e^+e^- \rightarrow Zh$ can have significant enhancement with respect to SM.

Projects

- H2020: Non minimal Higgs:
EU: England, Portugal, Sweeden, France
non EU: Morocco, Egypt, Canada, Japan, USA
- "Projet dans les domaines prioritaires de la recherche scientifique et du développement technologique":
PPR/2015/6. Moroccan Ministry of Higher Education and Scientific Research MESRSFC and CNRST.
- Join collaboration programs between Tangier-Lisboa,
Tangier-Montpellier since 2004
- Involved in charged Higgs working group