COMPOSITENESS
vs
SUPERSYMMETRY

(2HDMs tell the story)

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INTRODUCTION

Mainly motivated by the hierarchy problem we consider

SUSY   **COMPOSITENESS**

Their phenomenology is very rich and interesting:
altered SM-like Higgs couplings, extended scalar sector, new resonances

we consider a Composite 2HDM and the MSSM as
minimal realisations of EWSB based on a 2HDM structure

Composite 2HDM (C2HDM) is simple natural alternative to SUSY (MSSM)

What do we know about the
- MSSM?   it provides 2 Higgs doublets and ... *you already know everything*
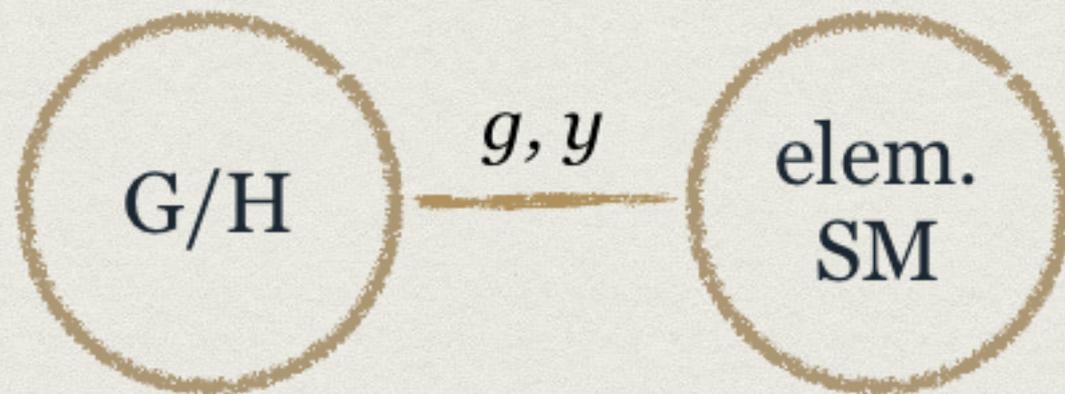- C2HDM?   it provides 2 Higgs doublets and ... *I am going to tell you something*

C2HDM VS MSSM

	Supersymmetry (Weak dynamics)	**Compositeness** (Strong dynamics)
Nature of Higgs	Elementary scalar Φ	Bound state $\langle\underline{\psi}\psi\rangle \sim \Phi$
Quadratic div.	Chiral symmetry	No elementary Higgs
Light Higgs	$m_h \sim m_Z$	Pseudo Nambu-Goldstone (pNGBs)
Higgs structure	2HDM (aka MSSM) required for $m_{u,d}$	2HDM depending on a global symmetry

Can you distinguish the two paradigms by looking at 2HDM dynamics?
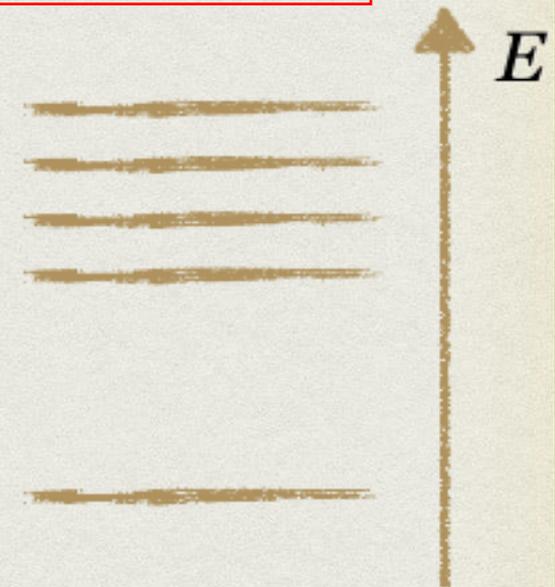
Compositeness, nothing new?

Two sites structure:
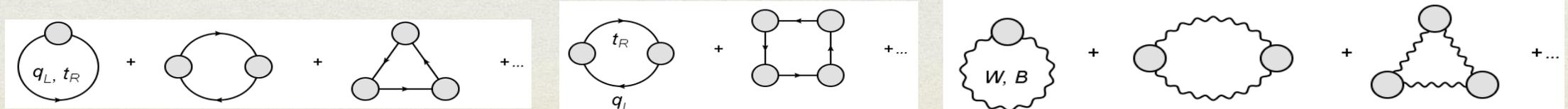

We borrow this idea from QCD: ie,

Nature has already realised this mechanism

The coset delivers a set of states at a common mass scale: m^*

A large separation between new fermions/vector states and Higgses can be achieved if we identify these with pNGBs: $m_{\rm h}$

Partial compositeness: *composite/elementary mixing (g,y) connect two sites, eventually generating a one-loop effective scalar potential a la Coleman-Weinberg (which we calculate for the first time for the 2HDM case)*
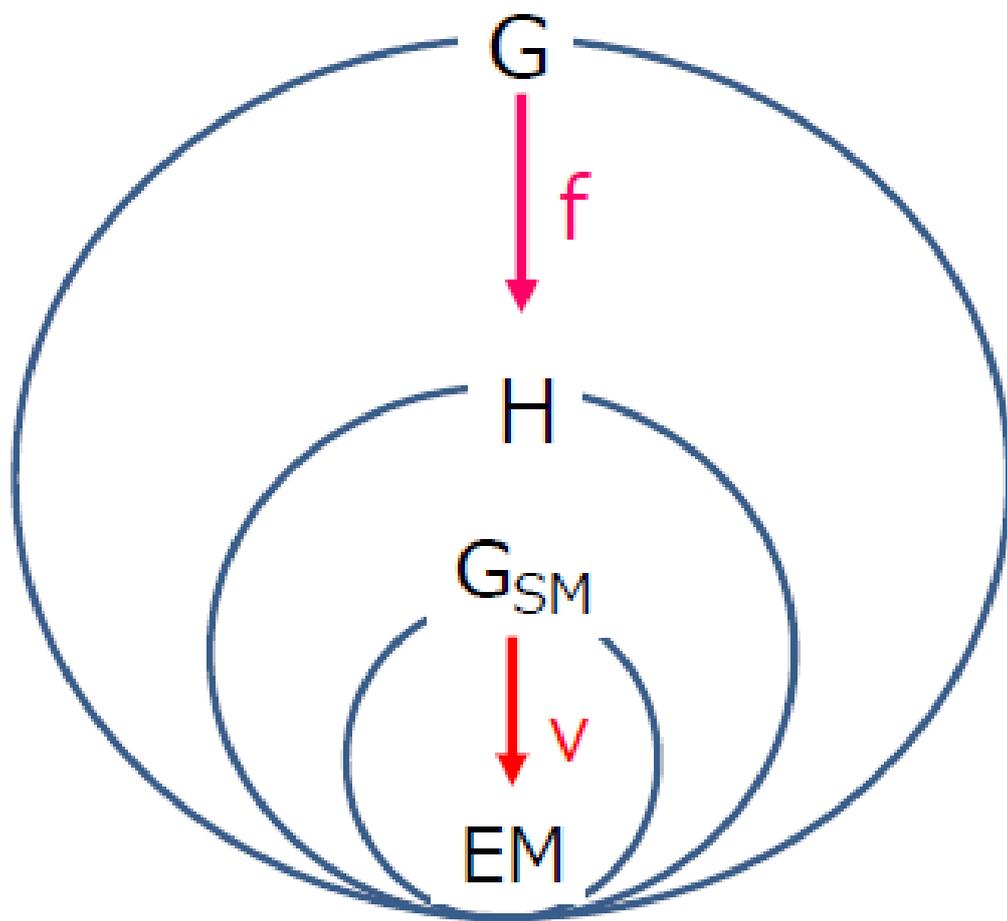
In essence:

	Pion Physics	**Composite pNGB Higgs**
Fundamental Theory	QCD	QCD-like theory
Spontaneous sym. breaking	$SU(2)_L \times SU(2)_R \to SU(2)_V$	$G \to H$ (spontaneous at compositeness scale f)
pNGB modes	$(\pi^0, \pi^\pm) \sim 135$ MeV	$h \sim 125$ GeV
Other resonances	$\rho \sim 770$ MeV, $\cdots$	New spin 1 and ½ states $\sim$ Multi-TeV

- Need to choose the correct G->H (spontaneous) breaking to have required NGBs
- Need to break H (explicitly, so pNGBs) via g (gauge) and y (Yukawa) mixings to generate effective (ie, one-loop) scalar potential for EWSB
- Gauge contribution significant but positive, look closely at Yukawa (negative)

Basic rules for a Composite Higgs Model with NGBs

☐ Suppose there is a global symmetry G at scale above f (~TeV) which is spontaneously broken down into a subgroup H

☐ The structure of the Higgs sector is determined by the coset G/H

☐ H should contain the custodial $SO(4) \simeq SU(2)_L \times SU(2)_R$ symmetry

☐ The number of NGBs (dimG-dimH) must be 4 or larger

G

f

H

G_{SM}

v

EM

Model construction
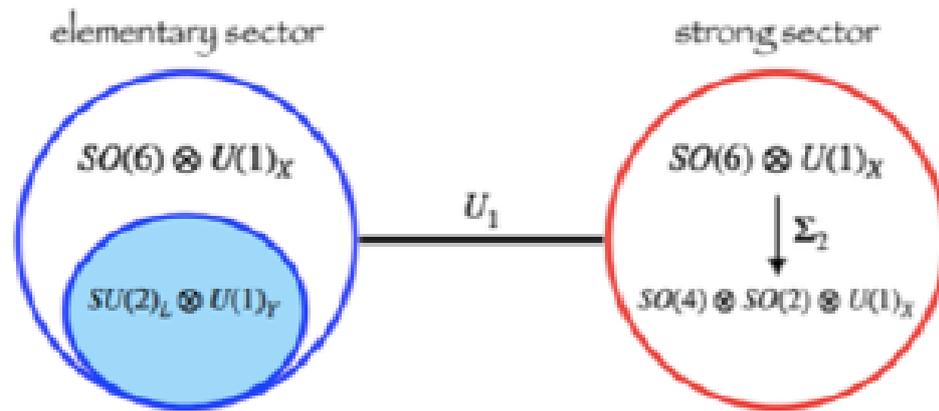
- **G/H**   **SO(6)/SO(4) x SO(2)**

  - *the coset delivers 8 NGBs (2 complex Higgs doublets)*

  - *new spin 1/2 and 1 resonances too*

G	H	N_G	NGBs rep.$[H] = $ rep.$[\mathrm{SU}(2) \times \mathrm{SU}(2)]$
$\mathrm{SO}(5)$	$\mathrm{SO}(4)$	4	$\mathbf{4} = (\mathbf{2}, \mathbf{2})$
$\mathrm{SO}(6)$	$\mathrm{SO}(5)$	5	$\mathbf{5} = (\mathbf{1}, \mathbf{1}) + (\mathbf{2}, \mathbf{2})$
$\mathrm{SO}(6)$	$\mathrm{SO}(4) \times \mathrm{SO}(2)$	8	$\mathbf{4}_{+2} + \overline{\mathbf{4}}_{-2} = 2 \times (\mathbf{2}, \mathbf{2})$
$\mathrm{SO}(7)$	$\mathrm{SO}(6)$	6	$\mathbf{6} = 2 \times (\mathbf{1}, \mathbf{1}) + (\mathbf{2}, \mathbf{2})$
$\mathrm{SO}(7)$	G_2	7	$\mathbf{7} = (\mathbf{1}, \mathbf{3}) + (\mathbf{2}, \mathbf{2})$
$\mathrm{SO}(7)$	$\mathrm{SO}(5) \times \mathrm{SO}(2)$	10	$\mathbf{10}_0 = (\mathbf{3}, \mathbf{1}) + (\mathbf{1}, \mathbf{3}) + (\mathbf{2}, \mathbf{2})$
$\mathrm{SO}(7)$	$[\mathrm{SO}(3)]^3$	12	$(\mathbf{2}, \mathbf{2}, \mathbf{3}) = 3 \times (\mathbf{2}, \mathbf{2})$
$\mathrm{Sp}(6)$	$\mathrm{Sp}(4) \times \mathrm{SU}(2)$	8	$(\mathbf{4}, \mathbf{2}) = 2 \times (\mathbf{2}, \mathbf{2}), (\mathbf{2}, \mathbf{2}) + 2 \times (\mathbf{2}, \mathbf{1})$
$\mathrm{SU}(5)$	$\mathrm{SU}(4) \times \mathrm{U}(1)$	8	$\mathbf{4}_{-5} + \overline{\mathbf{4}}_{+5} = 2 \times (\mathbf{2}, \mathbf{2})$
$\mathrm{SU}(5)$	$\mathrm{SO}(5)$	14	$\mathbf{14} = (\mathbf{3}, \mathbf{3}) + (\mathbf{2}, \mathbf{2}) + (\mathbf{1}, \mathbf{1})$

Mrazek et al., 2011

A Concrete Composite 2-Higgs Doublet Model

DC, Delle Rose, Moretti, Yagyu '18

elementary sector

$SO(6) \otimes U(1)_X$

$SU(2)_L \otimes U(1)_Y$

strong sector

$SO(6) \otimes U(1)_X$

$\Big\downarrow \Sigma_2$

$SO(4) \otimes SO(2) \otimes U(1)_X$

U_1

☑ The construction of the effective theory follows the same steps of the minimal 4DCHM (two-site model)

☑ The Lagrangian of the GBs + gauge sector is: (non-linear σ-models + resonances)

$$\mathcal{L}^{\text{gauge}}_{\text{C2HDM}} = \frac{f_1^2}{4}\text{Tr}|D_\mu U_1|^2 + \frac{f_2^2}{4}\text{Tr}|D_\mu \Sigma_2|^2 - \frac{1}{4g_\rho^2}(\rho^A)_{\mu\nu}(\rho^A)^{\mu\nu} - \frac{1}{4g_{\rho X}^2}(\rho^X)_{\mu\nu}(\rho^X)^{\mu\nu}$$

A, X=elementary gauge fields

$$- \frac{1}{4g_A^2}(A^A)_{\mu\nu}(A^A)^{\mu\nu} - \frac{1}{4g_X^2}X_{\mu\nu}X^{\mu\nu},$$

ρ^A, ρ^X=composite gauge fields

$U_i = \exp i\frac{f}{f_i^2}\Pi$

$\Sigma_2 = U_2\Sigma_0 U_2^T$

$\Sigma_0 = -i/\sqrt{2}(\delta_I^5\delta_J^6 - \delta_J^5\delta_I^6)$

$I, J = 1, .., 6$

GB matrix

$$U = \exp\left(i\frac{\Pi}{f}\right) \qquad \Pi \equiv \sqrt{2}h_\alpha^{\mathring{a}}T_\alpha^{\mathring{a}} = -i\begin{pmatrix} 0_{4\times4} & h_1^{\mathring{a}} & h_2^{\mathring{a}} \\ -h_1^{\mathring{a}} & 0 & 0 \\ -h_2^{\mathring{a}} & 0 & 0 \end{pmatrix} \qquad \Phi_\alpha \equiv \frac{1}{\sqrt{2}}\begin{pmatrix} h_\alpha^2 + ih_\alpha^1 \\ h_\alpha^4 - ih_\alpha^3 \end{pmatrix}$$

$=U_1 U_2$

8 broken SO(6) generators

$\alpha = 1, 2 \quad \mathring{a} = 1, .., 4$

$h^4{}_\alpha = h_\alpha + v_\alpha$

$v^2 \equiv v_1^2 + v_2^2$

$f^{-2} = f_1^{-2} + f_2^{-2}$

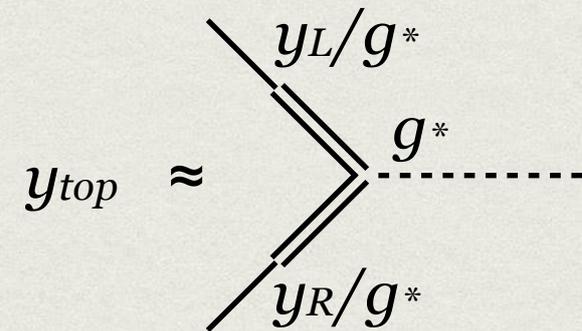☑ gauge boson masses generated by the VEVs of the fourth components of the Higgs fields

$$m_W^2 = \frac{g^2}{4}f^2\sin^2\frac{v}{f}$$

v_{SM}^2

Partial compositeness (y)

Linear interactions between composite and elementary (top) operators

$$\mathcal{L}_{\text{int}} = g J_\mu W^\mu$$

$$\mathcal{L}_{\text{int}} = y_L \, q_L \, \mathcal{O}_L + y_R \, t_R \, \mathcal{O}_R$$

$$y_{top} \approx \quad \begin{array}{c} y_L/g_* \\ g_* \\ y_R/g_* \end{array}$$

In our scenario with G/H = SO(6)/SO(4)xSO(2) and fermions in the **6** of SO(6):

$$
\begin{aligned}
\mathcal{L}_{\text{mix}} + \mathcal{L}_{\text{strong}} \quad = \quad & \Delta_L^I \bar{q}_L^{\mathbf{6}} \Psi_R^I + \Delta_R^I \bar{t}_R^{\mathbf{6}} \Psi_L^I \\
+ \quad & \bar{\Psi}^I i \slashed{D} \Psi^I - \bar{\Psi}_L^I M_\Psi^{IJ} \Psi_R^J - \bar{\Psi}_L^I \left(Y_1^{IJ} \Sigma + Y_2^{IJ} \Sigma^2 \right) \Psi_R^J
\end{aligned}
$$

GBs

$$\Sigma = U_1 \Sigma_2 U_1^T$$

All the parameters real → CP invariant scenario

- *Mixings, masses & Yukawas of heavy tops*
- *At least 2 heavy (I,J=1,2) top resonances are needed for UV finiteness*
- *Heavy resonances in the **6** of SO(6) delivers 4 top partners, 1 bottom partner and 1 exotic fermion with Q = 5/3*

Custodial symmetry

The predicted leading order correction to the T parameter arises from the non-linearity of the GB Lagrangian. In the SO(6)/SO(4)xSO(2) model is

$$\hat{T} \propto 16 \times \frac{v^2}{f^2} \times \frac{\text{Im}[\langle H_1 \rangle^{\dagger} \langle H_2 \rangle]^2}{(|\langle H_1 \rangle|^2 + |\langle H_2 \rangle|^2)^2}$$
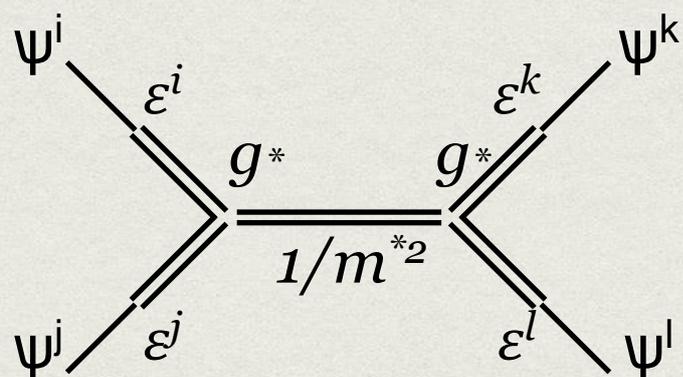
no freedom in the coefficient,
fixed by the coset

possible solutions:

- CP (which we assume)

- C_2: $H_1 \rightarrow H_1$, $H_2 \rightarrow -H_2$ forbidding H_2 to acquire a vev (see later)

FCNCs

FCNCs mediated by the heavy resonances

$$\sim \epsilon_L^i \epsilon_R^j \epsilon_L^k \epsilon_R^l \left(\frac{g^*}{m^*} \right)^2 a^{ijkl}, \quad a^{ijkl} \sim O(1)$$

for example, for $\Delta S = 2$, $\quad \sim \dfrac{1}{m^{*2}} \dfrac{m_d}{v} \dfrac{m_s}{v}$

- *does not require an excessive and unnatural tuning of the parameters*

Issues with Higgs-mediated FCNCs

FCNCs can be removed by

- assuming C_2 in the strong sector and in the mixings (ie, $Y_1 = 0$):

  inert C2HDM (not considered here)

- broken C_2 in the strong sector requires (flavour) *alignment* $Y_1^{IJ} \propto Y_2^{IJ}$ propagating to each type of fermions in the low energy Lagrangian

$$Y_u^{ij} Q^i u^j \left(a_{1u} H_1 + a_{2u} H_2\right) + Y_d^{ij} Q^i d^j \left(a_{1d} H_1 + a_{2d} H_2\right) + Y_e^{ij} L^i e^j \left(a_{1e} H_1 + a_{2e} H_2\right) + h.c.$$

(the ratios a_1/a_2 are predicted by the strong dynamics)

The scalar potential

The entire __effective__ potential is fixed by the parameters of the strong sector and the scalar spectrum is entirely predicted by the strong dynamics

Note: integrate out heavy composite resonances (both fermionic & bosonic)

Question is then, what does compositeness-driven EWSB *predicts*?

The potential up to the fourth order in the Higgs fields:

$$V = m_1^2 H_1^\dagger H_1 + m_2^2 H_2^\dagger H_2 - \left[m_3^2 H_1^\dagger H_2 + \text{h.c.} \right]$$

$$+ \frac{\lambda_1}{2}(H_1^\dagger H_1)^2 + \frac{\lambda_2}{2}(H_2^\dagger H_2)^2 + \lambda_3(H_1^\dagger H_1)(H_2^\dagger H_2) + \lambda_4(H_1^\dagger H_2)(H_2^\dagger H_1)$$

$$+ \frac{\lambda_5}{2}(H_1^\dagger H_2)^2 + \lambda_6(H_1^\dagger H_1)(H_1^\dagger H_2) + \lambda_7(H_2^\dagger H_2)(H_1^\dagger H_2) + \text{h.c.}$$

$y_{L,R}$

$y_{L,R}$

Light (SM-like) Higgs (ie, no inverted mass hierarchy):

without any tuning, the minimum of the potential is $v \sim f$

$$m_\Pi^2 \sim \frac{g^{*2}}{16\pi^2} y^2 f^2$$

while, in the tuned direction,

$$m_h^2 \sim \frac{g^{*2}}{16\pi^2} y^2 v^2$$

$$m_h^2 \sim \frac{N_c}{16\pi^2} g_\rho^2 \, m_t^2$$

(after reproducing top mass)

Heavy Higgs masses: $\quad M^2 \equiv \frac{m_3^2}{s_\beta c_\beta} \sim \frac{1}{16\pi^2} Y_1 Y_2 \sim \frac{f^2}{16\pi^2}$
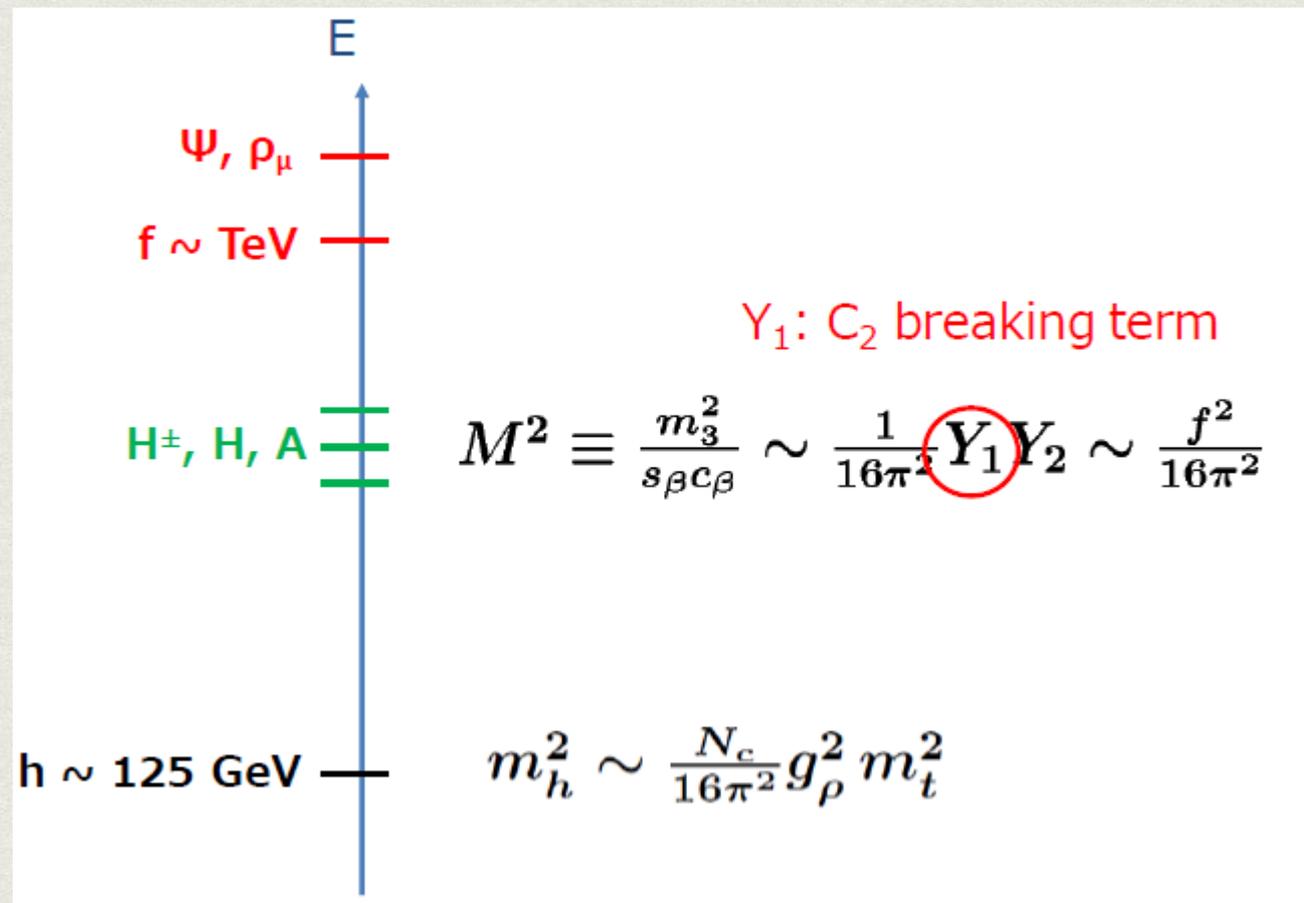
Any C$_2$ breaking in the strong sector induces (all real, following CP conservation in strong sector):

$$m_3^2 \neq 0, \lambda_6 \neq 0, \lambda_7 \neq 0$$

$$\lambda_6 = \lambda_7 = \frac{5}{3}\frac{m_3^2}{f^2}$$

it is not possible to realise a C2HDM scenario with a softly broken Z$_2$

To recap:

$$M^2 \equiv \frac{m_3^2}{s_\beta c_\beta} \sim \frac{1}{16\pi^2} Y_1 Y_2 \sim \frac{f^2}{16\pi^2}$$

Y_1: C_2 breaking term

$$m_h^2 \sim \frac{N_c}{16\pi^2} g_\rho^2 m_t^2$$
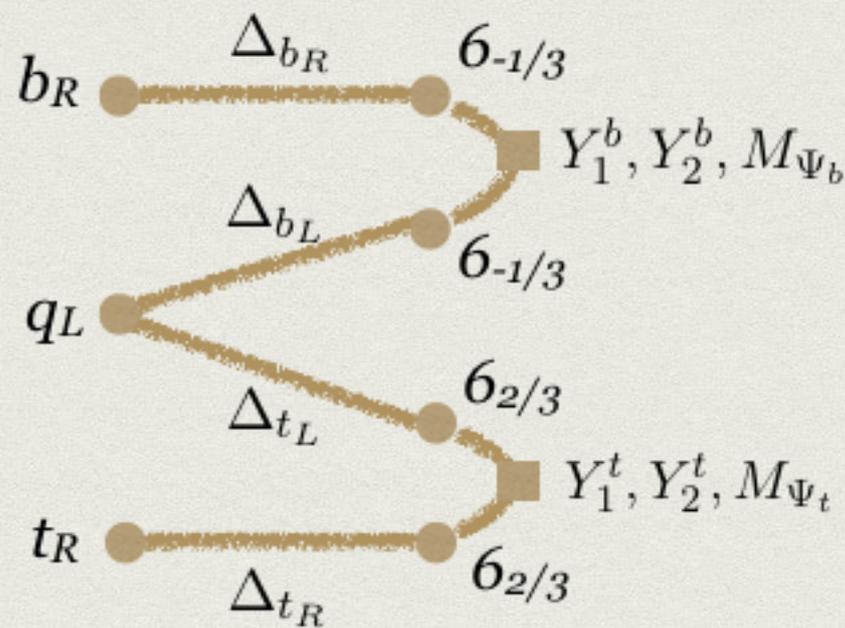
★ For $m_h \sim 125$ GeV , we need $g_\rho \sim 5$.

★ $f \rightarrow \infty$: All extra Higgses are decoupled
→ (elementary) SM limit.

★ To get M≠0, we need C_2 breaking
(Yukawa alignment is required →A2HDM). (see Penuelas' talk)

Sampling the parameter space (now include b)

C2HDM: we adopt the L-R structure based on the 2-site models which represents the minimal choice for a calculable effective potential *(De Curtis et al., 2012)*

m_i^2 (i=1,..,3) and λ_j (j=1,...,7) are determined by the parameters of the strong sector

$$f, \quad Y_1^{12}, \quad Y_2^{12}, \quad \Delta_L^1, \quad \Delta_R^2, \quad M_\Psi^{11}, \quad M_\Psi^{22}, \quad M_\Psi^{12}, \quad g_\rho$$

Yukawas   linear mixings   heavy fermion mass parameters

$$X = f,\ Y_1,\ Y_2,\ M_\Psi,\ \Delta_L,\ \Delta_R$$

$$600\,\text{GeV} < f < 3000\,\text{GeV} \qquad |X| < 10f$$

$$m_W^2 = \frac{1}{4}\frac{g_W^2 g_\rho^2}{g_W^2 + g_\rho^2} f^2 \sin^2 \frac{v}{f} \qquad \begin{array}{l} v^2 = v_1^2 + v_2^2 \\ \tan\beta = v_2/v_1 \end{array}$$

g^2 $V_{sm}^2 \sim (246\,\text{GeV})^2$

$$m_t = \frac{v}{\sqrt{2}} \frac{\Delta_L \Delta_R}{m_\Psi^2} \frac{Y_1 s_\beta + Y_2 c_\beta}{f}$$

Y_t

$$120\,\text{GeV} < m_h < 130\,\text{GeV}$$
$$165\,\text{GeV} < m_t < 175\,\text{GeV}$$

MSSM: we use **FeynHiggs 2.14.1** and LHCHXSWG-2015-002 prescriptions:

- 2loop + NNLL resummation $2 < \tan\beta < 45, \quad 200\,\text{GeV} < m_A < 1600\,\text{GeV}$

- soft SUSY breaking = M$_{\text{SUSY}}$ $1\,\text{TeV} < M_{\text{SUSY}} < 100\,\text{TeV} \qquad |X_t| < 3M_{\text{SUSY}}$

Present bounds on the CHM parameters

• **Higgs coupling measurements**
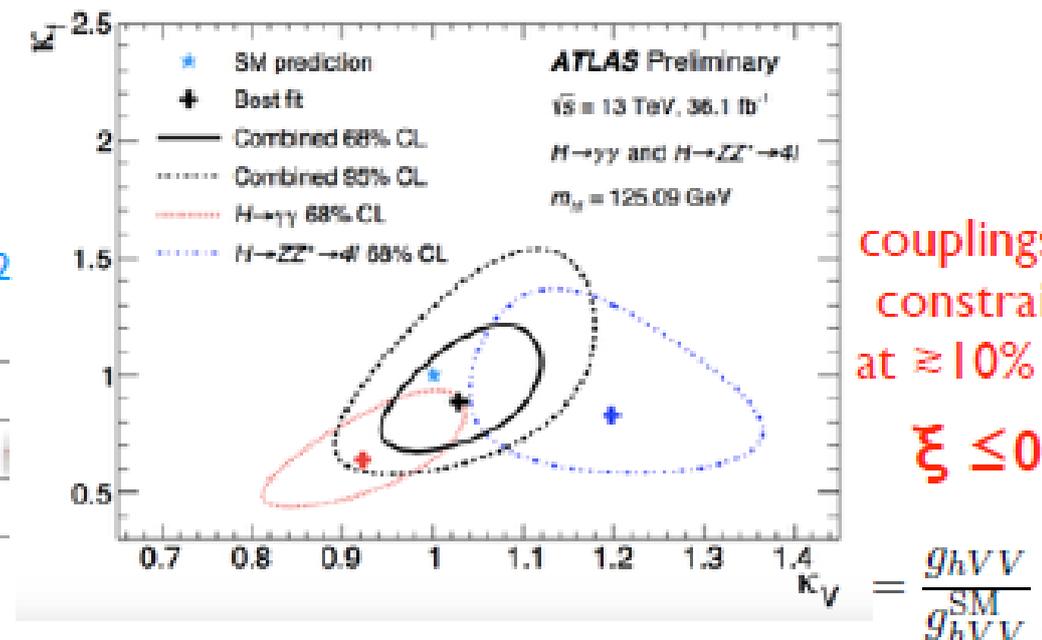
For SO(5)/SO(4):

$$g_{HVV} = g_{HVV}^{SM}\sqrt{1-\xi}; \quad g_{Hff} = g_{Hff}^{SM}\frac{(1-2\xi)}{\sqrt{1-\xi}} \qquad \xi = v^2/f^2$$

CMS Projection for precision of Higgs coupling measurement

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ
300	[5,7]	[4,6]	[4,6]	[6,8]	[10,13]	[14,15]	[6,8]
3000	[2,5]	[2,5]	[2,4]	[3,5]	[4,7]	[7,10]	[2,5]

In our analysis: f ≥ 600 GeV (ξ ≤ 0.17)

couplings still constrained at ≳10% level

ξ ≤0.2

$$\kappa_V = \frac{g_{hVV}}{g_{hVV}^{SM}}$$

• **Direct searches of heavy spin-1 resonances**

Search for new vector resonances decaying in di-bosons in 36.7 fb^{-1} data at $\sqrt{s}$ = 13 TeV recorded with ATLAS (1708.04445) adapted to our composite 2HDM parameters

In our analysis: m_ρ ≥ 2.5 TeV as function of g_ρ →

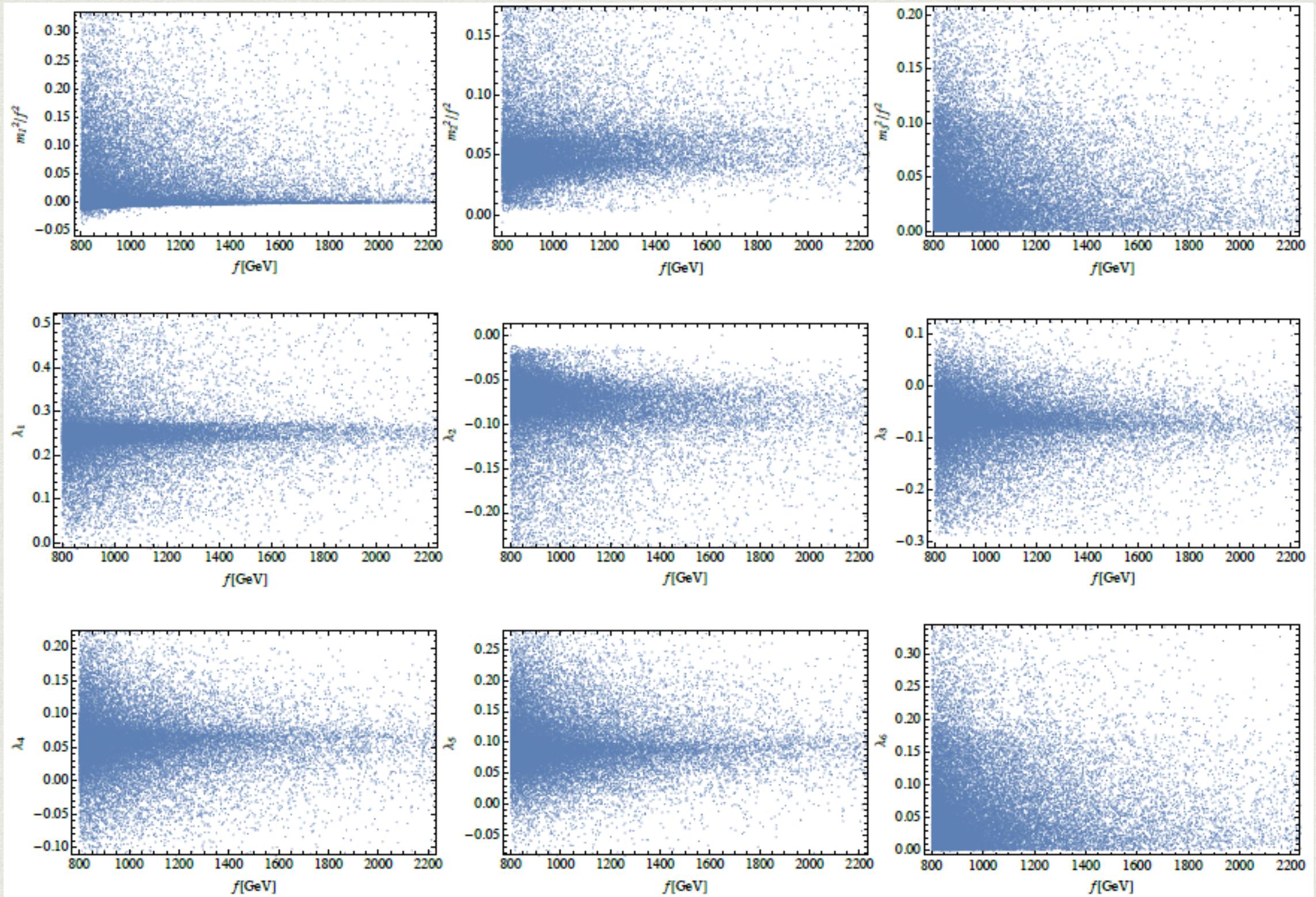Very conservative: narrow width approximation, BR=50% OK with bounds from EWPTs

• **Direct searches for partners of the 3rd generation quarks**

Lower mass bounds depend on the BR assumption: m_T(Wb=50%) > 1-1.2 TeV

Scalars decays relax bounds (Panizzi's talk) In our analysis: m_T ≥ 1 TeV

The entire effective potential is fixed by the parameters of the strong sector

Checked all theoretical constraints (vacuum stability, triviality, unitarity)

Yukawa sector $\xi \equiv v_{\text{SM}}^2/f^2$

$$-\mathcal{L}_{\text{Yukawa}} = \sum_{f=u,d,l} \frac{m_f}{v_{\text{SM}}} \bar{f} \left[\xi_h^f \, h + \xi_H^f \, H - 2iI_f \xi_A^f \, A\gamma^5 \right] f$$

$$+ \frac{\sqrt{2}}{v_{\text{SM}}} \left[V_{ud} \, \bar{u} \left(-\xi_A^u m_u P_L + \xi_A^d m_d P_R \right) d H^+ + \xi_A^l \, m_l \bar{\nu} P_R l \, H^+ \right] + \text{h.c.},$$

where $I_f = 1/2(-1/2)$ for $f = u\,(d,l)$ and the ξ^f coefficients are

$$\xi_h^f = (1 + c_f^h \, \xi) \cos\theta + (\zeta_f + c_f^H \, \xi) \sin\theta\,, \quad \xi_H^f = -(1 + c_f^h \, \xi) \sin\theta + (\zeta_f + c_f^H \, \xi) \cos\theta\,,$$

$$\xi_A^f = \zeta_f + \xi \left[-\frac{\tan\beta}{2} \frac{1 + \bar{\zeta}_t^2}{(1 + \bar{\zeta}_f \tan\beta)^2}, \right]$$

with

$$c_f^h = -\frac{1}{2} \frac{3 + \bar{\zeta}_f \tan\beta}{1 + \bar{\zeta}_f \tan\beta}\,, \quad c_f^H = \frac{1}{2} \frac{\bar{\zeta}_f (1 + \tan^2\beta)}{(1 + \bar{\zeta}_f \tan\beta)^2}\,,$$

$$\zeta_f = \frac{\bar{\zeta}_f - \tan\beta}{1 + \bar{\zeta}_f \tan\beta}\,, \qquad \bar{\zeta}_f = -\frac{Y_1^f}{Y_2^f}\,.$$

The parameter θ denotes the mixing between the physical components of the two CP-even states while ζ_f represents the normalised coupling to the fermion f of the CP-even scalar that does not acquire a VEV in the Higgs basis. Since θ is predicted to be small, ζ_f controls the interactions of the Higgs states $H, A, H^\pm$ at the zeroth order in ξ.

Higgs Boson Masses

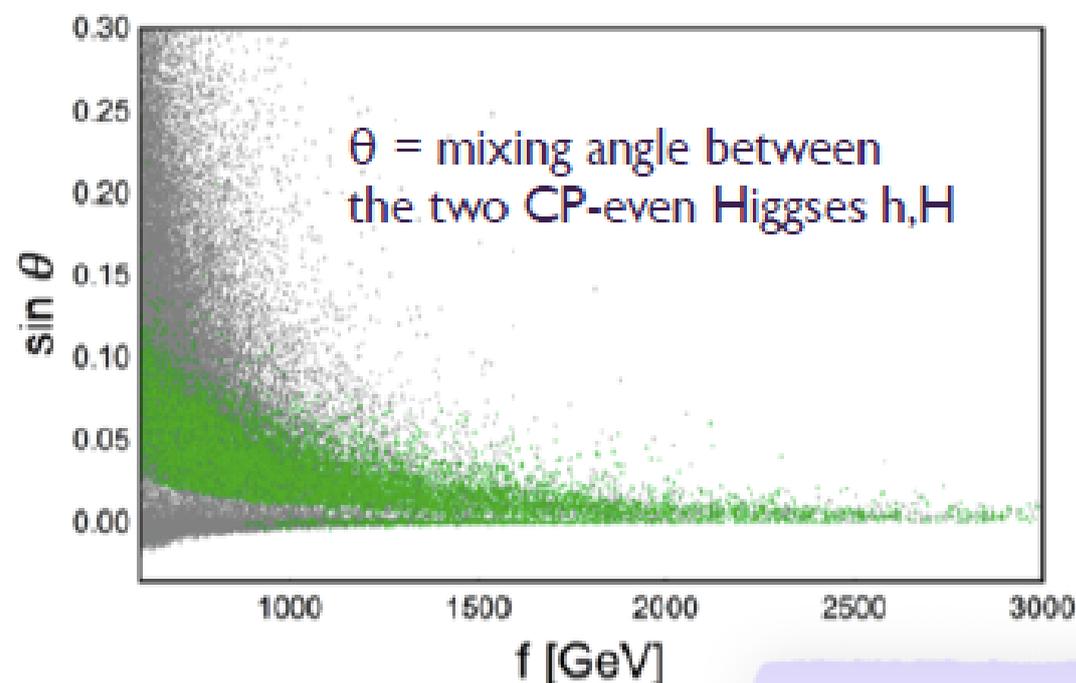Same physical Higgs states as in the E2HDM: h, H, A, H$^{\pm}$

SM-like Higgs

- They are identified in the Higgs basis after a rotation by an angle β: only one doublet provides a VEV and contains the GBs of W,Z

$$\tan\beta = v_2/v_1$$

- CP-even states:

$$m_h^2 = c_\theta^2 \mathcal{M}_{11}^2 + s_\theta^2 \mathcal{M}_{22}^2 + s_{2\theta}\mathcal{M}_{12}^2$$
$$m_H^2 = s_\theta^2 \mathcal{M}_{11}^2 + c_\theta^2 \mathcal{M}_{22}^2 - s_{2\theta}\mathcal{M}_{12}^2$$

$$\tan 2\theta = 2\frac{\mathcal{M}_{12}^2}{\mathcal{M}_{11}^2 - \mathcal{M}_{22}^2}$$

The tadpole conditions involve only $\mathcal{M}_{11}$ and $\mathcal{M}_{12}$ while $\mathcal{M}_{22}$ is ~ unconstrained thus

$m_h \sim \mathcal{M}_{11} \sim v$ $m_H \sim \mathcal{M}_{22} \sim f$ and θ is predicted to be small: $\mathcal{O}(\xi)$ for large f

θ = mixing angle between the two CP-even Higgses h,H

sin θ

f [GeV]

- **CP-odd & charged Higgses**

$m_A = \mathcal{M}_{22} + \mathcal{O}(v)$ ~ f

$m_{H^{\pm}} = \mathcal{M}_{22} + \mathcal{O}(v)$ ~ f

f → ∞   SM limit

H, A, H$^{\pm}$ decouple and h → h^{SM}

green points satisfy the bounds from direct and indirect Higgs searches

tested against HiggsBounds and HiggsSignals

smaller density of points at large f

- tan β (usual vev ratio) predicted by the strong sector

- m_h and m_{top} require tan β ~ O(1)

- larger tuning at large f

- values of tan β in the C2HDM and MSSM cannot be directly compared
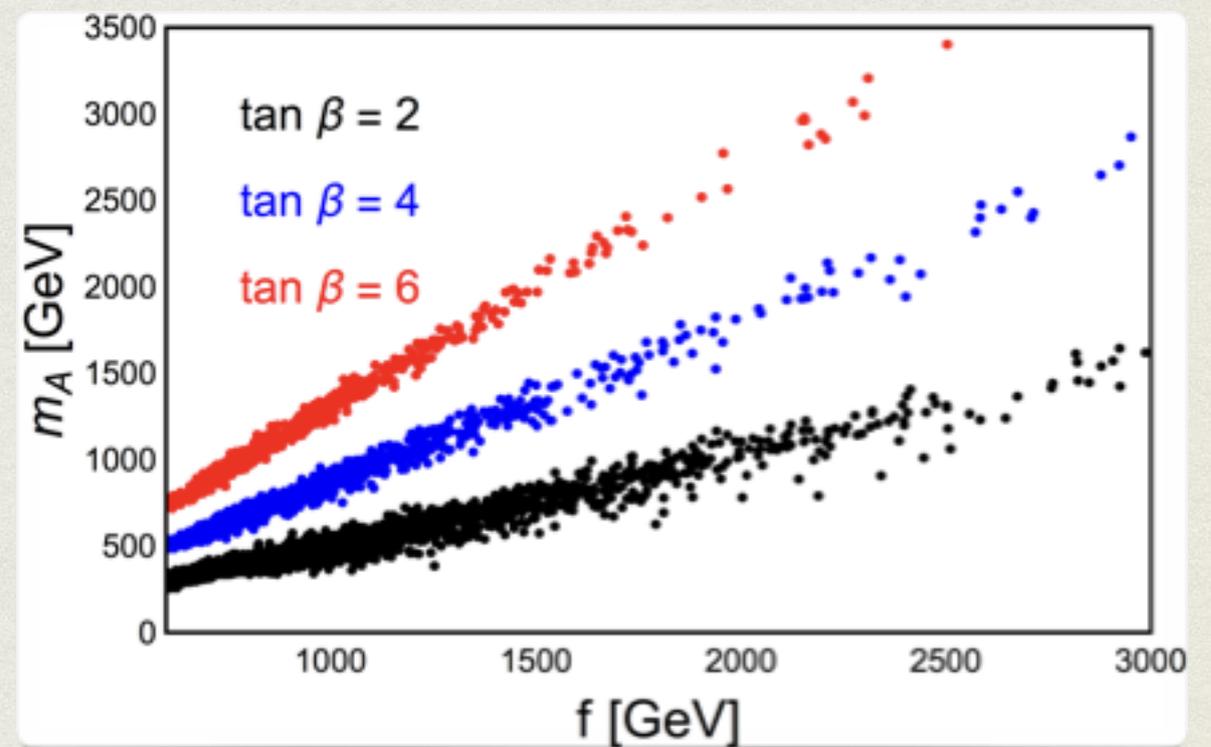
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- m_H, m_A, m_{H+} grow with f (and tan β)

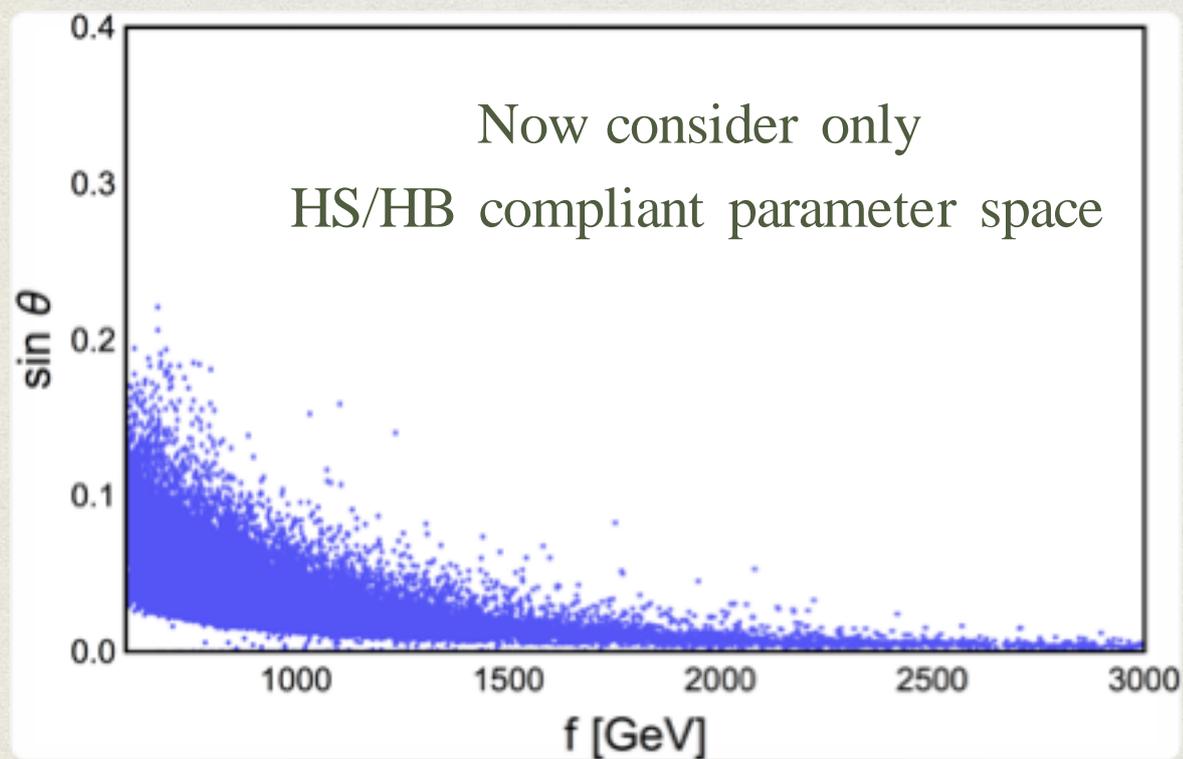$$\mathcal{M}^2 = \begin{pmatrix} \Lambda_1 v^2 & \Lambda_6 v^2 \\ \Lambda_6 v^2 & \mathcal{M}_{22}^2 \end{pmatrix}$$

fixed by minimisation of V

unconstrained

$\mathcal{M}_{22} \sim f$

$$T_1 \sim c_\beta(m_1^2 - M^2 s_\beta^2 + \lambda_i v^2)$$

$$T_2 \sim s_\beta(m_2^2 - M^2 c_\beta^2 + \lambda_i' v^2)$$

(tadpole conditions: some fine-tuning required)

tan β = 2
tan β = 4
tan β = 6

Now consider only
HS/HB compliant parameter space

Mixing between the CP-even states h, H:

$$\tan 2\theta = -2\frac{\Lambda_6 v^2}{\mathcal{M}_{22}^2 - \Lambda_1 v^2} \sim c\frac{v^2}{f^2}$$

SM-like h requires large f while

very non-SM-like h requires small f

Comment: tanβ is basis-dependent. In the E2HDM it is uniquely identified if the Z_2 properties are specified ex. Type-I or Type-II
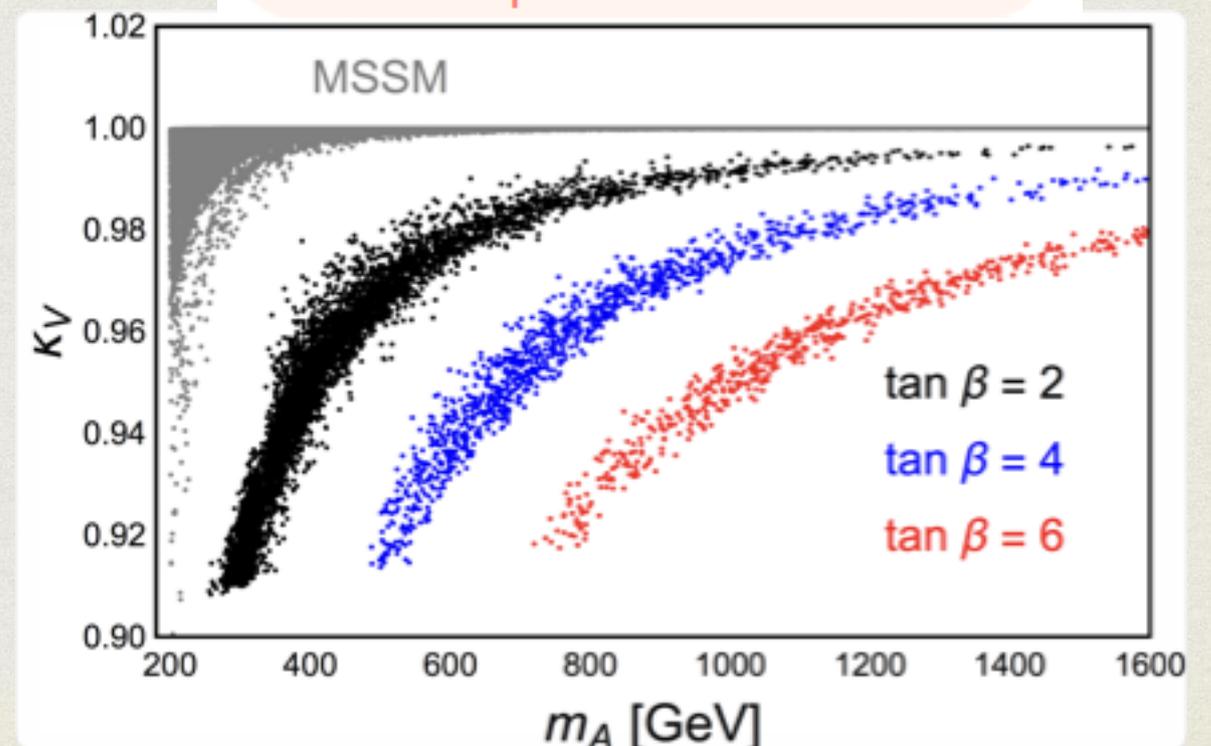
A comparison of the two scenarios for fixed tanβ values is not correct

The SM-like Higgs h coupling to W,Z

$$\kappa_V = \left(1 - \frac{\xi}{2}\right)\cos\theta, \quad \xi \equiv \frac{v_{\mathrm{SM}}^2}{f^2}$$

the alignment limit is approached more slowly in the C2HDM than in MSSM

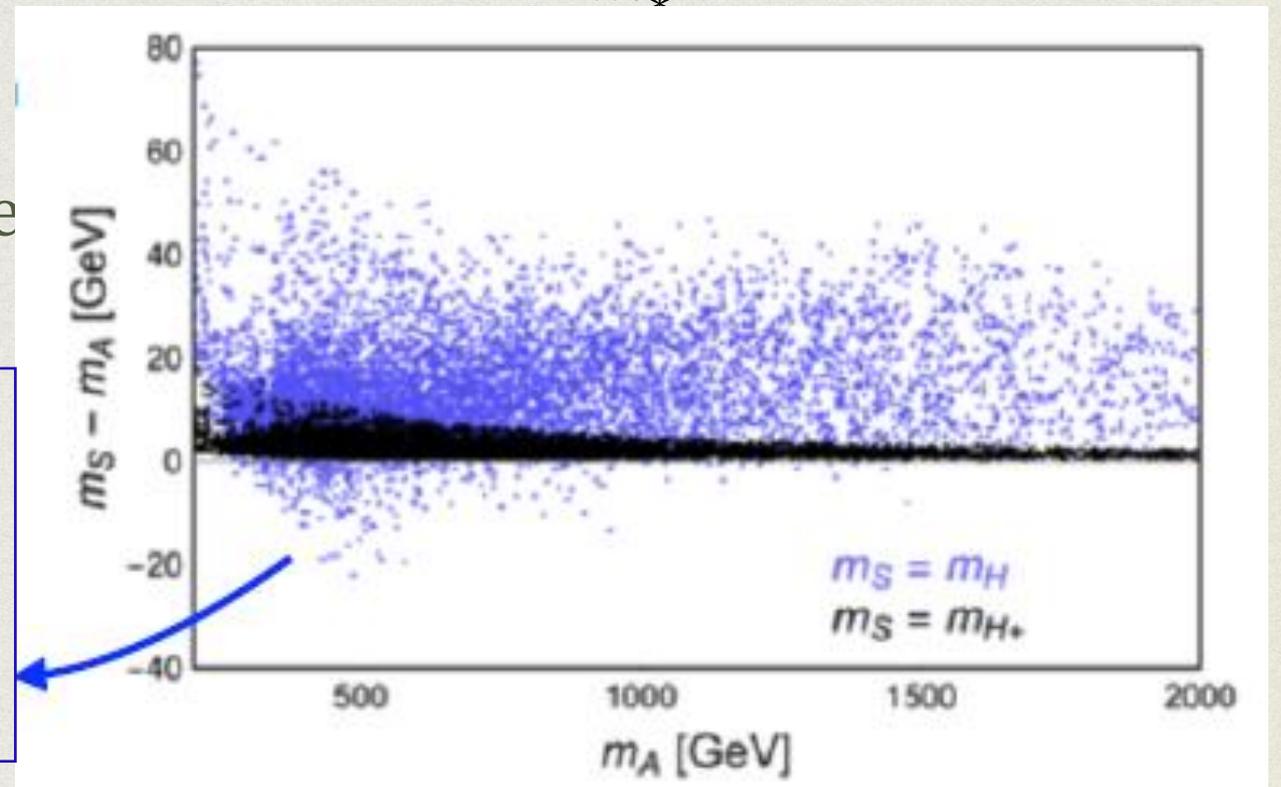*a relevant deviation is present even for no mixing*

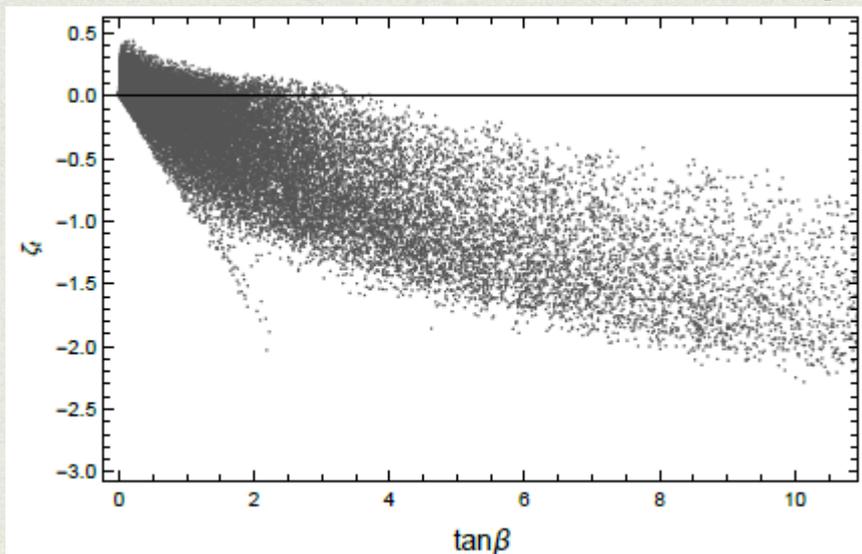# Can heavy Higgs mass spectra reveal C2HDM from MSSM?

- m_{H+} and m_A : very close in both scenarios (high degeneracy): very sharp prediction in the C2HDM, $\quad m^2_{H^\pm} - m^2_A \simeq \dfrac{\Delta^4_L}{m^4_\star} v^2$

- m_H and m_A: larger mass splitting prediction in the C2HDM than in the MSSM (max 15 GeV)

- $H \to A\, Z^*$ can be a channel discriminating the two scenarios
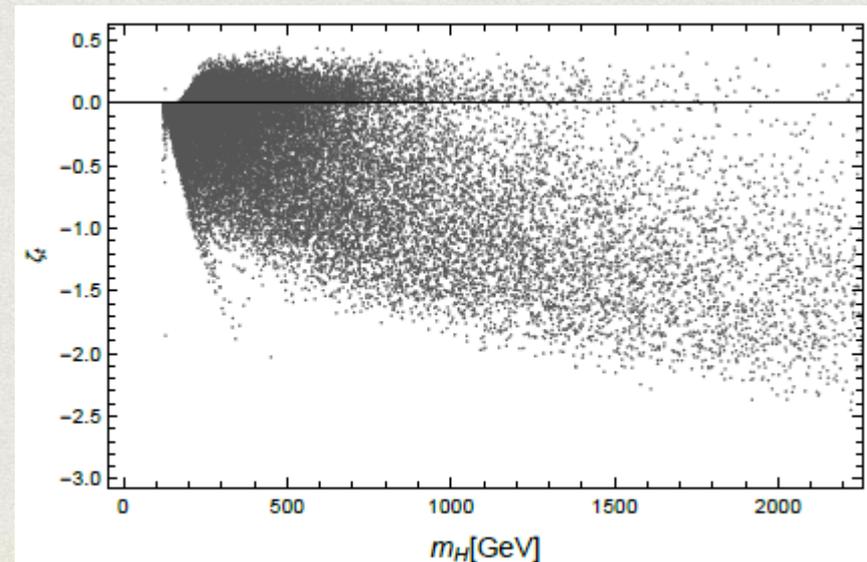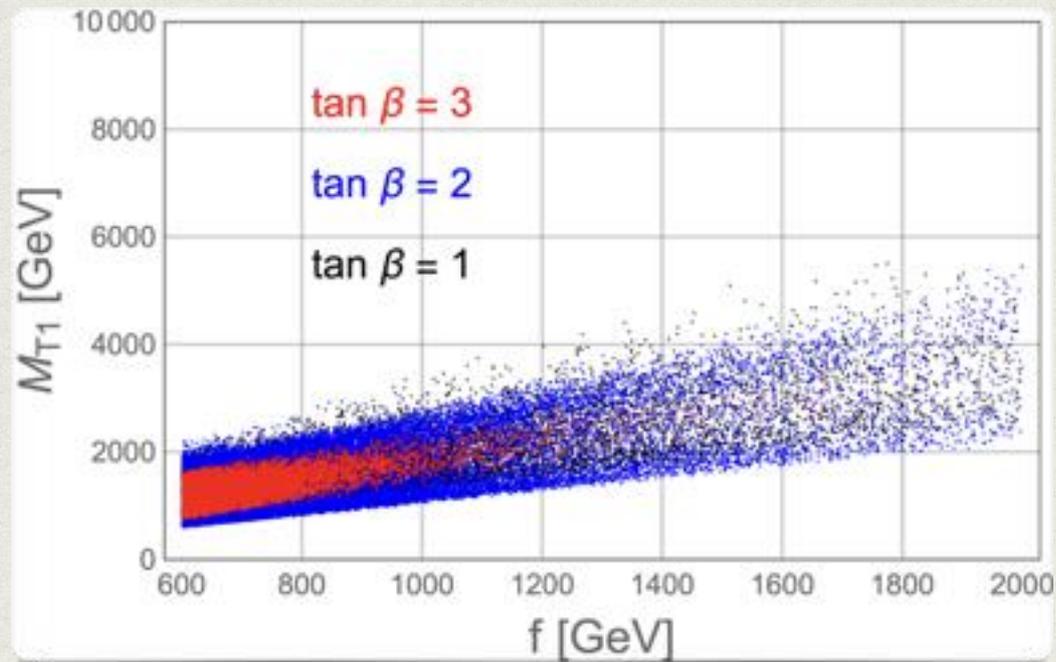- $A \to H\, Z^*$ could also be useful

Can correlate to Yukawas, tan β:

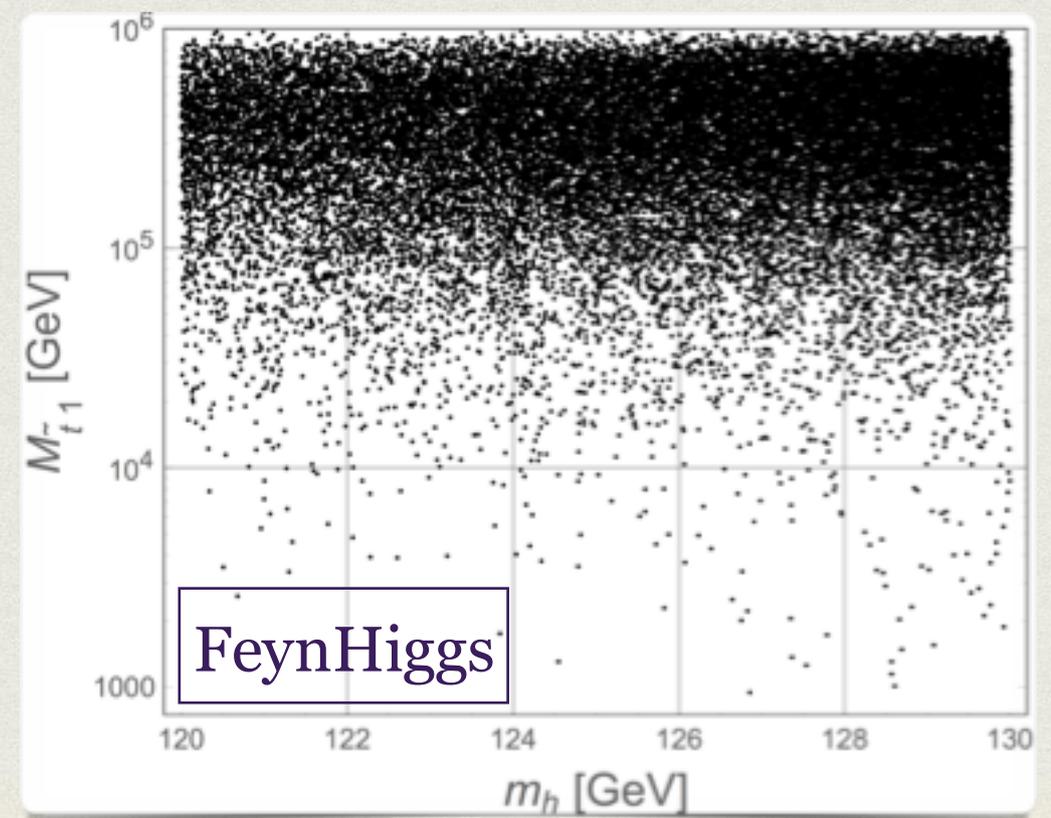correlation between ζ_t and $\tan\beta$ for all values of $f > 700$ GeV
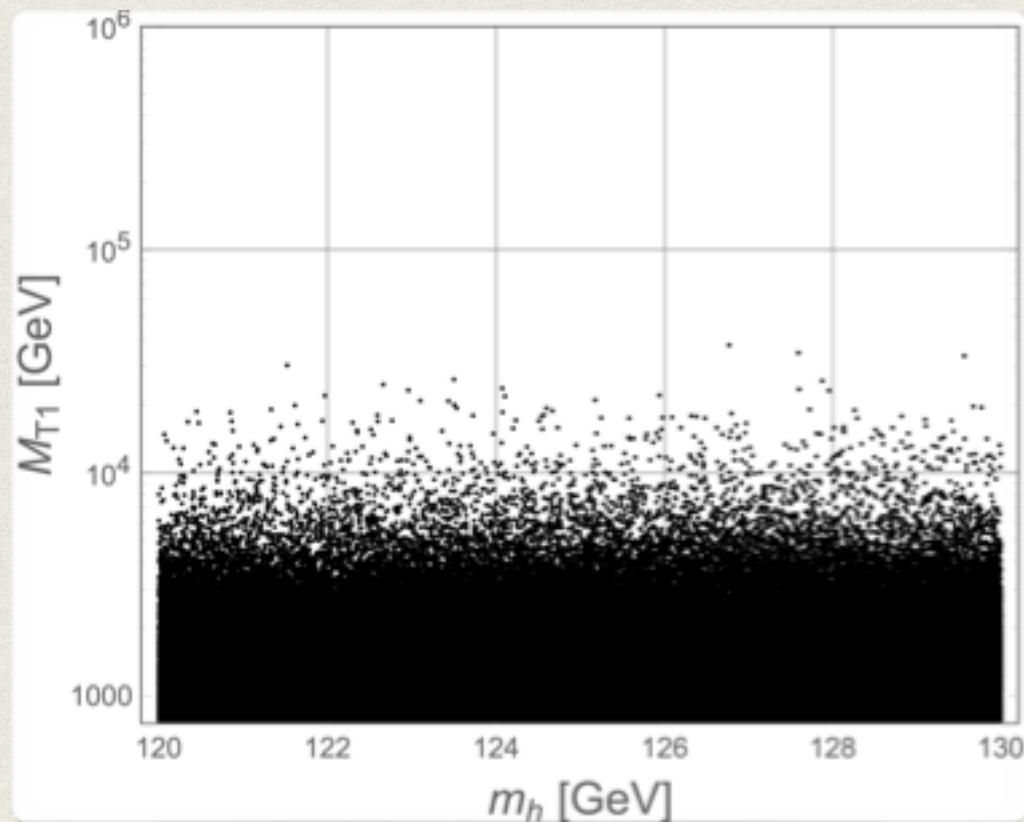
m_H:

correlation between ζ_t and the mass of the heavy CP-even boson

C2HDM: lightest top partner T_1

Reproducing the observed value of m_h requires a fermionic top partner in the C2HDM significantly lighter than the scalar one in the MSSM

MSSM: lightest stop $\tilde{t}_1$

CONCLUSIONS AND PERSPECTIVES

- A C2HDM is the simplest natural 2HDM alternative to its SUSY version (MSSM) in the context of CHMs

- We considered the $SO(6)/SO(4)xSO(2)$ scenario with a broken C_2 which realises a (Aligned) C2HDM

- Several existing observables can be used to discriminate between C2HDM and MSSM: k_V (delayed decoupling), heavy Higgses' inter-decay patterns, (lightest) top partner spectrum.

- Complete phenomenological study of the C2HDM in progress (fine tuning, new specific observables, …)

- Other interesting scenarios: exact C_2, broken CP, etc.