ANALYSIS OF THE HIGGS POTENTIALS FOR TWO DOUBLETS AND A SINGLET

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Based on work in Collaboration with F. Domingo. in

Phys. Rev. **D86** *115024*
arXiv:1209.6235 [hep-ph]

A CLEAR EVIDENCE OF NEW PHYSICS

A HIGGS-LIKE BOSON DISCOVERED WITH $M_H \simeq 125$ GEV

ATLAS mass meas. (combined) :

$$M_H = 125.5 \pm 0.2 \pm 0.6 \text{ GeV}$$

CMS mass meas. (combined) :

$$M_H = 125.7 \pm 0.3 \pm 0.3 \text{ GeV}$$

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- Signal strength compatible with SM within exp. precision.
- Is it SM or BSM ?$\longrightarrow$ accurate measurements of its properties crucial.

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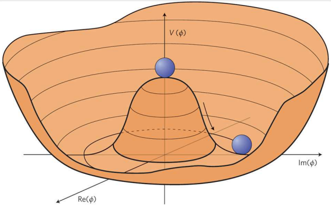
NEW ERA OF PRECISION MEASUREMENTS HAS STARTED

WHAT IS THE FORM OF THE HIGGS POTENTIAL ?

Once Higgs discovered $\longrightarrow$ measure its couplings to matter/gauge bosons and reconstruct the potential.



In the $\mathcal{SM}$, minimal implementation of the Higgs mechanism:

$$V(\Phi^\dagger \Phi) = \lambda \left(\Phi^\dagger \Phi - \frac{v^2}{2} \right)^2 \text{ with } \Phi = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}(v + H) \end{pmatrix} e^{i\omega^j \frac{\tau^j}{2v}}$$

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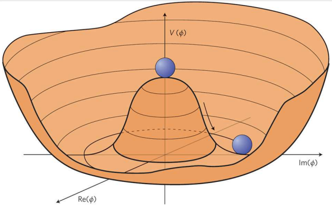

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Higgs sector essentially undetermined $\rightarrow$ no reason to stick to minimality if something can be gained with extended Higgs sectors

In many BSM models more Higgs fields are introduced : 2HDMs, $\mathcal{GUT}$ models, $\mathcal{SUSY}$ extensions of the $\mathcal{SM}$...

At least 2 Higgs doublet H_u, H_d in a type II 2HDM fashion.

MSSM

- 5 Physical Higgs states+ 2 mix angles
- $M_H^{TL} \lesssim M_Z$
- Large Rad. Cor. lift the mass ⇒ conflict with naturalness and fine-tuning required

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Singlet-extensions of the Higgs sector

- Additionnal Higgs singlet S $\rightarrow W \supset \lambda \hat{S}\hat{H}_u\hat{H}_d$
- More Physical Higgs bosons (NMSSM (6), UMSSM(5))+5 mix angles
- $m_H^{2\,TL} \leq M_Z^2 \cos^2\beta + \lambda^2 v^2 \sin^2 2\beta$
- Doublet-singlet mixing → 125 GeV SM-like Higgs boson possible at TL
- Less fine-tuning, solves "μ problem" ...

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Singlet-extended Higgs sector common to NMSSM, UMSSM, E_6MSSM, λ-SUSY, SUSY/compositeness Hybrids ("Fat Higgs Models"...)

TWO HIGGS DOUBLET + ONE SINGLET HIGGS POTENTIAL (2HDM+S)

- The most general 2HDM+S potential invariant under $SU(2)_L \times U(1)_Y$ restricted to renormalizable terms is given by:

$$\mathcal{V}^S = m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 - \left({m_{12}}^2 H_u \cdot H_d + h.c. \right) + \frac{\lambda_1}{2} |H_u|^4 + \frac{\lambda_2}{2} |H_d|^4 + \lambda_3 |H_u|^2 |H_d|^2 + \lambda_4 |H_u \cdot H_d|^2 + \left[\frac{\lambda_5}{2} (H_u \cdot H_d)^2 + (\lambda_6 |H_u|^2 + \lambda_7 |H_d|^2) H_u \cdot H_d + h.c. \right]$$

with

$$H_d = \begin{pmatrix} v_d + (h_d^0 + i a_d^0)/\sqrt{2} \\ H_d^- \end{pmatrix}, \quad H_u = \begin{pmatrix} H_u^+ \\ v_u + (h_u^0 + i a_u^0)/\sqrt{2} \end{pmatrix}, \quad S = s + (h_s^0 + i a_s^0)/\sqrt{2}$$

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- $10\ \mathbb{R} + 19\ \mathbb{C}$(in general) : 28 + 1 superfluous (e.g λ_T) parameters
- $m_S^2, m_{H_u}^2, m_{H_d}^2 \Longleftrightarrow v_u, v_d, s$ through the minimization conditions
- We consider only $\mathbb{R}$ parameters from now on to avoid CP violation.

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$\mathcal{SUSY}$ Higgs potential arises from F-terms, D-terms and $\mathcal{SUSY}$-breaking terms.

$$\begin{aligned}
\mathcal{V}^S = {} & m_{H_u}^2|H_u|^2 + m_{H_d}^2|H_d|^2 - \left(m_{12}{}^2 H_u\cdot H_d + h.c.\right) + \frac{\lambda_1}{2}|H_u|^4 + \frac{\lambda_2}{2}|H_d|^4 + \lambda_3|H_u|^2|H_d|^2 \\
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\end{aligned}$$

Imposing symmetries at the Classical Level

$$\mathcal{V}^S = m_{H_u}^2|H_u|^2 + m_{H_d}^2|H_d|^2 + \frac{\lambda_1}{2}|H_u|^4 + \frac{\lambda_2}{2}|H_d|^4 + \lambda_3|H_u|^2|H_d|^2$$
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NMSSM

- $\mathbb{Z}_3$ symmetry

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$$+ m_S^2|S|^2 + \quad + \left[\lambda_T S \quad + h.c.\right]$$

$$+ \left[A_{ud} S H_u\cdot H_d \quad + h.c.\right]$$

$$+ \lambda_P^u|S|^2|H_u|^2 + \lambda_P^d|S|^2|H_d|^2$$

nMSSM

- $\mathbb{Z}_5^R, \mathbb{Z}_7^R$ symmetry

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$$+ m_S^2 |S|^2 + \kappa^2 |S|^4$$

$$+ \left[A_{ud} S H_u \cdot H_d + h.c. \right]$$

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UMSSM

- $U(1)'$ symmetry

At the Radiative Level

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- $\mathbb{Z}_3$ symmetry

- Observation : Higgs self-couplings and spectrum are not *independent* $\longrightarrow$ measurement of the Higgs masses + mix. angles already constrain (even partially) the form of the Higgs potential
- Spectrum + mix. angles : 12 inputs to determine the $\lambda_i's$ (6 masses, 5 mixing angles + vev v) out of 29 parameters.
- Remaining parameters accessed through double Higgs or triple Higgs cross section measurements.
- This task would most comprehensibly be done at LCs.
- The reconstruction would give insights about the SUSY-breaking mechanism since $\mathcal{L}_{\text{soft}}$ contributes to EWSB

RECONSTRUCTION OF NMSSM HIGGS POTENTIAL I

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- To extract meaningful information, beyond LO, from the Higgs spectrum only, what is the form of the potential which captures the bulk of the corrections ?
- To identify those we computed the Coleman-Weinberg one-loop effective potential for all the sectors
- We confirm that only the parameters already present at LO get log-enhanced.

$$W_{NMSSM} = W_{MSSM}|_{\mu=0} + \lambda \hat{S}\hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3}\hat{S}^3$$

$$-\mathcal{L}_{\rm soft} = m_{H_u}^2|H_u|^2 + m_{H_d}^2|H_d|^2 + m_S^2|S|^2 + (\lambda A_\lambda H_u \cdot H_d S + \frac{1}{3}\kappa A_\kappa S^3 + h.c)$$

$$\begin{aligned}\mathcal{V}^S_{\mathbb{Z}_3} &= m_{H_u}^2|H_u|^2 + m_{H_d}^2|H_d|^2 + \frac{\lambda_1}{2}|H_d|^4 + \frac{\lambda_2}{2}|H_u|^4 + \lambda_3|H_u|^2|H_d|^2 + \lambda_4|H_u \cdot H_d|^2 \\ &+ m_S^2|S|^2 + \kappa^2|S|^4 + \left[\frac{A_S}{3}S^3 + h.c.\right] \\ &+ \lambda_P^u|S|^2|H_u|^2 + \lambda_P^d|S|^2|H_d|^2 + \left[A_{ud}SH_u \cdot H_d + \lambda_P^M S^{*\,2}H_u \cdot H_d + h.c.\right]\end{aligned}$$

The tree-level conditions resulting from the NMSSM read:

$$\lambda_1^0 = \frac{g^2+g'^2}{4} = \lambda_2^0 \quad ; \lambda_3^0 = \frac{g^2-g'^2}{4} \quad ; \lambda_4^0 = \lambda^2 - \frac{g^2}{2} \quad ; \lambda_P^{u\,0} = \lambda^2 = \lambda_P^{d\,0} \;;$$

$$\lambda_P^{M\,0} = \lambda\kappa \quad ; A_S^0 = \kappa A_\kappa \quad ; A_{ud}^0 = \lambda A_\lambda \quad ; \kappa^{0\,2} = \kappa^2$$

Potential now limited to 13 parameters

How can we absorb the effects of the corrected Higgs masses into a redefinition of the λ_i parameters beyond LO such that $\boxed{\lambda_i = \lambda_i^0 + \Delta\lambda_i}$?

For a type II model, we have :

$$
\begin{aligned}
h_i^0 t_L t_R^c &= -\frac{Y_t}{\sqrt{2}} S_{i2} \\
h_i^0 b_L b_R^c &= \frac{Y_b}{\sqrt{2}} S_{i1} \\
h_i^0 \tau_L \tau_R^c &= \frac{Y_\tau}{\sqrt{2}} S_{i1} \\
a_i^0 t_L t_R^c &= -i \frac{Y_t}{\sqrt{2}} c_\beta P'_{i1} \\
a_i^0 b_L b_R^c &= i \frac{Y_b}{\sqrt{2}} s_\beta P'_{i1} \\
a_i^0 \tau_L \tau_R^c &= i \frac{Y_\tau}{\sqrt{2}} s_\beta P'_{i1} \\
H^+ b_L t_R^c &= Y_t c_\beta \\
H^- t_L b_R^c &= -Y_b s_\beta \\
H^- \nu_{\tau L} \tau_R^c &= -Y_\tau s_\beta
\end{aligned}
$$

where,

$$
Y_t = \frac{m_t}{v s_\beta}, \quad Y_b = \frac{m_b}{v c_\beta}, \quad Y_\tau = \frac{m_\tau}{v c_\beta}
$$

- From the Higgs mass matrices we get a set of equations $f(\lambda_i, t_\beta, v, m_i, S_{ij}, P'_{ij}) = 0$

	$\text{diag}(m^2_{h^0_1}, m^2_{h^0_2}, m^2_{h^0_3}) = S\mathcal{M}^2_S S^{-1}$	: 6
$+$	$\text{diag}(m^2_{a^0_1}, m^2_{a^0_2}) = P'\mathcal{M}^2_{P'} P'^{-1}$	: 3
$+$	$m^2_{H^\pm}$	: 1
$+$	v, t_β	: 2
	# Conditions	12

- The restricted potential has 13 parameters $\rightarrow$ 1 d.o.f remaining
- We parametrize it as the singlet vev $s = \mu/\lambda$
- It could be measured from the higgsino masses in the gaugino sector.

- Higgs spectrum and mixing elements S_{ij}, P'_{ij} are taken from `NMSSMTools`

- Procedure similar to what has already been achieved in the MSSM
  Boudjema,Semenov '02

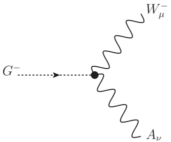
$$
\begin{cases}
\Delta\lambda_1 = \frac{1}{2v^2}\left[\frac{m^2_{h^0_i} S^2_{i1}}{\cos^2\beta} - m^2_{a^0_i} P'^2_{i1}\tan^2\beta - M_Z^2\right] \\
\Delta\lambda_2 = \frac{1}{2v^2}\left[\frac{m^2_{h^0_i} S^2_{i2}}{\sin^2\beta} - \frac{m^2_{a^0_i} P'^2_{i1}}{\tan^2\beta} - M_Z^2\right] \\
\Delta\lambda_3 = \frac{1}{2v^2}\left[2m^2_{H\pm} + \frac{2m^2_{h^0_i} S_{i1} S_{i2}}{\sin 2\beta} - m^2_{a^0_i} P'^2_{i1} - 2M_W^2 + M_Z^2\right] \\
\Delta\lambda_4 = \frac{1}{v^2}\left[m^2_{a^0_i} P'^2_{i1} - m^2_{H\pm} + M_W^2 - \lambda^2 v^2\right] \\
\Delta A_{ud} = \frac{1}{3}\left[\frac{\sin 2\beta}{s} m^2_{a^0_i} P'^2_{i1} + \frac{1}{v} m^2_{a^0_i} P'_{i1} P'_{i2}\right] - \lambda A_\lambda \\
\Delta\lambda_P^M = \frac{1}{3s}\left[\frac{\sin 2\beta}{2s} m^2_{a^0_i} P'^2_{i1} - \frac{1}{v} m^2_{a^0_i} P'_{i1} P'_{i2}\right] - \lambda\kappa \\
\Delta A_S = \frac{1}{3s}\left[\frac{v^2\sin^2 2\beta}{2s^2} m^2_{a^0_i} P'^2_{i1} - m^2_{a^0_i} P'^2_{i2} - \frac{v\sin 2\beta}{2s} m^2_{a^0_i} P'_{i1} P'_{i2}\right] - \kappa A_\kappa \\
\Delta\kappa^2 = \frac{1}{4s^2}\left[m_{h^0_i}{}^2 S^2_{i3} + \frac{1}{3} m^2_{a^0_i} P'^2_{i2} - \frac{v^2\sin^2 2\beta}{3s^2} m^2_{a^0_i} P'^2_{i1}\right] - \kappa^2 \\
\Delta\lambda_P^u = \frac{m^2_{h^0_i} S_{i2} S_{i3}}{2sv\sin\beta} + \frac{1}{3s\tan\beta}\left[\frac{\sin 2\beta}{s} m^2_{a^0_i} P'^2_{i1} - \frac{1}{2v} m^2_{a^0_i} P'_{i1} P'_{i2}\right] - \lambda^2 \\
\Delta\lambda_P^d = \frac{m^2_{h^0_i} S_{i1} S_{i3}}{2sv\cos\beta} + \frac{\tan\beta}{3s}\left[\frac{\sin 2\beta}{s} m^2_{a^0_i} P'^2_{i1} - \frac{1}{2v} m^2_{a^0_i} P'_{i1} P'_{i2}\right] - \lambda^2
\end{cases}
$$

- In the MSSM the bulk of the Rad. Cor. in Higgs-to-Higgs couplings can be absorbed by rewriting them in terms of the *corrected* Higgs masses.
  Brignole,Zwirner '93;Hollik, Peñaranda '02;Dobado *et.al* '02
- We assume this is still true in the NMSSM
- We take the Higgs spectrum and mix. angles from `NMSSMTools`
  Ellwanger,Gunion,Hugonie
- The procedure enables us to incorporate the leading corrections in the Higgs sector and to use the corrected Higgs masses in the calculation in a GI way
- The modified couplings were implemented in `NMSSMTools` and `SloopS` (Boudjema,Baro,G.C,Drieu La-Rochelle,Semenov) through `LanHEP`(Semenov)

GAUGE INVARIANCE AND $H \to \gamma\gamma$

Non-Linear gauge fixing for the NMSSM
G.C, Semenov '11

$$\begin{aligned}\mathcal{L}_{GF} \quad = \quad & -\frac{1}{\xi_W}|(\partial_\mu - ie\tilde{\alpha}A_\mu - igc_w\tilde{\beta}Z_\mu)W^{\mu\,+} \\ & +i\xi_W\frac{g}{2}(v + \tilde{\delta}_1 h_1^0 + \tilde{\delta}_2 h_2^0 + \tilde{\delta}_3 h_3^0 + i(\tilde{\kappa}G^0 + \tilde{\rho}_1 a_1^0 + \tilde{\rho}_2 a_2^0))G^+\,|^2 \\ & -\frac{1}{2\xi_Z}(\partial_\mu Z^\mu + \xi_Z\frac{g}{2c_w}(v + \tilde{\epsilon}_1 h_1^0 + \tilde{\epsilon}_2 h_2^0 + \tilde{\epsilon}_3 h_3^0)G^0)^2 \\ & -\frac{1}{2\xi_A}(\partial_\mu A^\mu)^2\end{aligned}$$



$eM_W(1 + \tilde{\alpha}g_{\mu\nu})$

$\texttt{SloopS} = \texttt{LanHEP} \xrightarrow{FR} \texttt{FormCalc}$

- Higgs masses computed à la Degrassi-Slavich (Degrassi,Slavich '10) using full 1-L + 2-L $\mathcal{O}(\alpha_t\alpha_s + \alpha_b\alpha_s)$ in the effective potential approach
- Pole mass corrections can be taken into account or not

$$\begin{aligned}
g_{h_i^0 H^+ H^-} &= \frac{\lambda_1 v s_\beta s_{2\beta} S_{i1}}{\sqrt{2}} + \frac{\lambda_2 v c_\beta s_{2\beta} S_{i2}}{\sqrt{2}} + \sqrt{2}\lambda_3 v [c_\beta^3 S_{i1} + s_\beta^3 S_{i2}] - \frac{\lambda_4 v s_{2\beta}}{\sqrt{2}} [s_\beta S_{i1} + c_\beta S_{i2}] \\
&+ \frac{s_{2\beta}}{\sqrt{2}} \left[A_{ud} + 4\lambda_P^M s)\right] S_{i3} + \sqrt{2}\left[\left(\lambda_P^d s\right) s_\beta^2 + (\lambda_P^u s)\ c_\beta^2\right] S_{i3} \\
g_{h_i^0 G^+ G^-} &= \sqrt{2}\Bigg[\left(\lambda_1 v c_\beta^3 + (\lambda_3 + \lambda_4) v c_\beta s_\beta^2\right) S_{i1} + \left(\lambda_2 v s_\beta^3 + (\lambda_3 + \lambda_4) v c_\beta^2 s_\beta\right) S_{i2} \\
&+ \left((\lambda_P^d c_\beta^2 + \lambda_P^u s_\beta^2) s - (A_{ud} + 2\lambda_P^M s) c_\beta s_\beta\right) S_{i3}\Bigg]
\end{aligned}$$

- The masses and mixing matrices should be computed as the same level of accuracy to preserve GI.
- EPA : Pole masses for kin. + $\overline{\mathrm{DR}}$ mix. matrices.($\Longleftrightarrow \lambda_i^{\overline{\mathrm{DR}}}$)
- PhA : λ_i from pole masses $\to$ force mass/mix. matrices to be *physical* ones

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$$
\begin{aligned}
g_{h_i^0 H^+ H^-} &= \frac{1}{v\sqrt{2}} \left\{ m_{h_i^0}^2 \left(\frac{\sin\beta^2}{\cos\beta} S_{i1} + \frac{\cos\beta^2}{\sin\beta} S_{i2} \right) + 2m_{H^\pm}^2 (\cos\beta S_{i1} + \sin\beta S_{i2}) \right. \\
&\left. - \frac{2m_{a_j^0}^2 P'_{j1} P'_{j2} S_{i3}}{3\sin 2\beta} - m_{a_j^0}^2 {P'_{j1}}^2 \left(\frac{S_{i1}}{\cos\beta} + \frac{S_{i2}}{\sin\beta} - \frac{4}{3}\frac{v}{s} S_{i3} \right) \right\} \\
g_{h_i^0 G^+ G^-} &= \frac{1}{v\sqrt{2}} \left\{ (m_{h_i^0}^2 (\cos\beta S_{i1} + \sin\beta S_{i2}) + 2M_W^2 \tilde{\delta}_i \right\}
\end{aligned}
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- Two benchmark points from King, Mühlleitner, Nevzorov '12 : NMP2 and NMP5

Mass [GeV]	NMP2		NMP5	
	no pole	pole	no pole	pole
$m_{h_1^0}$	129.4	126.5	96.1	95.6
$m_{h_2^0}$	133.1	132.4	128.9	126.5

NMP2		
$\Gamma(h_1^0 \to \gamma\gamma)$	$\tilde{\alpha} = \tilde{\delta}_1 = 0$	$\tilde{\alpha} = \tilde{\delta}_1 = 10$
SloopS (EPA)	$1.138108952362.\,10^{-5}$	$4.490893854783.\,10^{-5}$
SloopS (PhA)	$1.125710969262.\,10^{-5}$	$1.125710969261.\,10^{-5}$
NMSSMTools_3.2.0	$1.12699441.\,10^{-5}$	
NMSSMTools*	$1.12737737.\,10^{-5}$	
NMP5		
$\Gamma(h_2^0 \to \gamma\gamma)$	$\tilde{\alpha} = \tilde{\delta}_2 = 0$	$\tilde{\alpha} = \tilde{\delta}_2 = 10$
SloopS (EPA)	$1.053756232511.\,10^{-5}$	$3.628709516521.\,10^{-5}$
SloopS(PhA)	$1.044860481657.\,10^{-5}$	$1.044860481613.\,10^{-5}$
NMSSMTools_3.2.0	$1.04342526.\,10^{-5}$	
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- Gauge dep. part $\propto \tilde{\alpha}(M^{2\,kin.}_{h_i^0} - M^{2\,coup.}_{h_i^0})$
- In other gauges the gauge dep. would appear at HO (ex: $\tilde{\alpha} = -1$)

- Similar procedure to parametrize the rad. cor. to the Higgs masses and couplings for the computation of $\Omega_\chi h^2$ in the NMSSM with a rad. Higgs potential (Bélanger, Boudjema,Hugonie, Pukhov, Semenov '05)

$$\begin{aligned}\mathcal{V}_{\rm rad} &= \Delta\lambda_1|H_d|^2 + \Delta\lambda_2|H_u|^2 + \Delta\lambda_3|H_u|^2|H_d|^2 + \Delta\lambda_4|H_u\cdot H_d|^2 + \frac{\lambda_5}{2}\left[(H_u\cdot H_d)^2 + h.c\right] \\ &+ \Delta\lambda_P^u|S|^2|H_u|^2 + \Delta\lambda_P^d|S|^2|H_d|^2 + \left[\tilde{\lambda}_P^M S^2(H_u\cdot H_d) + \frac{\tilde{\kappa}_S^2}{4}S^4 + h.c\right] + \frac{\Delta\kappa^2}{2}|S|^4\end{aligned}$$

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Different choices in the radiative potential result in $\neq$ Higgs-to-Higgs couplings

- Using the **standard** `micrOMEGAs`
- Point in NMSSM parameter space giving $\Omega_\chi h^2 = 0.103$ and $m_{h_2^0} = 126.4$ GeV, passing all `NMSSMTools` constraints
- Main channel (72%) $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to a_1^0 a_1^0$ through h_2^0 resonance. Remaining contributions are annhilations into $f\bar{f}$

- Had we used our potential, only the coupling $h_2^0 a_1^0 a_1^0$ is modified

$$\frac{\sigma^S(\tilde{\chi}_1^0\tilde{\chi}_1^0 \to a_1^0 a_1^0)}{\sigma^M(\tilde{\chi}_1^0\tilde{\chi}_1^0 \to a_1^0 a_1^0)} \sim \frac{\Gamma^S(h_2^0 \to a_1^0 a_1^0)}{\Gamma^M(h_2^0 \to a_1^0 a_1^0)} \sim 1.2$$

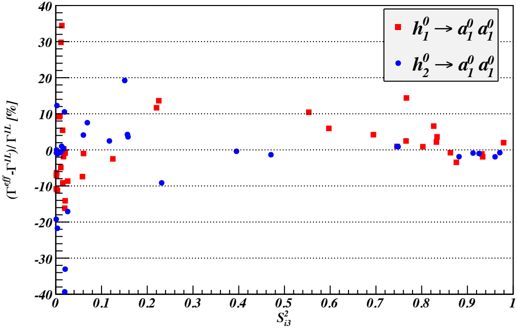
- $$\frac{\Omega_\chi^M h^2}{\Omega_\chi^S h^2} \simeq \frac{\sigma_{\mathrm{tot}}^S}{\sigma_{\mathrm{tot}}^M} \simeq 1.144 \Longrightarrow \Omega_\chi^S h^2 = 0.090$$

The point would actually lie outside the cosmologically interesting region

COMPARING THE EFFECTIVE AGAINST THE FULL 1-LOOP (PRELIMINARY)

FULL 1L result taken from Nhung et. al 13'

Corrected Higgs boson masses computed from Ender et. al 12':
full 1L $+\mathcal{O}(\alpha_s\alpha_t + \alpha_s\alpha_b)$(Degrassi,Slavich 10')



CONCLUSIONS

- Analysis of the most general renormalizable Higgs potential with 2 doublet and 1 singlet setup
- If experiments point to such a 2HDM+S Higgs sector :
  - 12 param. can be reconstructed from the Higgs spectrum and mix. angles
  - Remaining would be determined from exhaustive measurement of Higgs self-couplings at LCs
  - Parameters related to the singlet sector would be very difficult to access if reduced couplings to $\mathcal{SM}$ particles
- Reconstruction could give insight about, on top of EWSB, the mechanism of SUSY-breaking
- CW method enabled us to restrict the potential to an accuracy at the LL level
- Parameter reconstruction from a spectrum generator permits to encode the bulk of the rad. cor. in the Higgs sector in a GI way to perform "improved LO" calculations
- If a *restricted* potential is used, choice of the form not arbitrary and can lead to significant numerical differences
- Impact on DM phenomenology

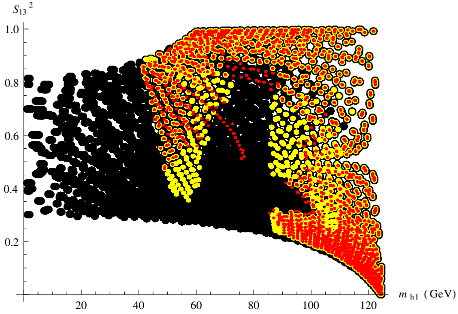
LPSC Grenoble

BACKUP

IMPACT ON THE NMSSM PARAMETER SPACE

We considered a region of the NMSSM parameter space in an approximate PQ limit ($\kappa/\lambda \ll 1$) where we have

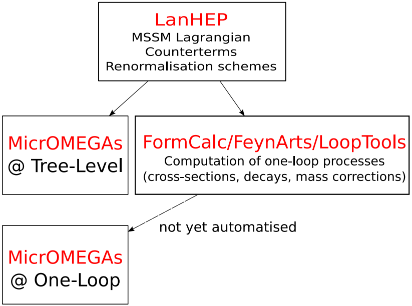
- light CP-even Higgs
- sizeable singlet-doublet mixing $S_{13}^2 \sim 0 - 100\%$
- light CP-odd Higgs with $m_{a_1^0} < 10.5\,\text{GeV} \to h_1^0 \to 2a_1^0$ open



We imposed limits from LEP B/Υ-physics, TeVatron and early LHC data, as implemented in `NMSSMTools`

$t_\beta = 5$	$\lambda = 0.5$	$\kappa = 0.05$
$M_1 = 200$	$M_2 = 400$	$M_3 = 1200$
$m_{\tilde{f}} = 1200$	$A_{\tilde{f}} = 1200$	$\lvert A_\kappa \rvert < 30$
$\mu_{eff} \in [100; 900]$		$M_A \in [0; 4000]$

AUTOMATIC TOOL FOR ONE-LOOP CALCULATIONS: SLOOPS



SLOOPS

A code for calculation of loops diagrams in the MSSM with application to colliders, astrophysics and cosmology.

- Evaluation of one-loop diagrams including a complete and coherent renormalisation of each sector of the MSSM with an OS scheme.
- Modularity between different renormalisation schemes.
- Non-linear gauge fixing.
- Checks: results UV,IR finite and gauge independent.

Karlsruher Institut für Technologie