Predictive 2HDM as a low energy Effective Theory

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In preparation
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Pragmatic point of view

- Motivation for collider searches.
- Plethora of non-standard particles from several 'BSM' physics scenarios.

We know

What to look for?

Important question

Where to look for ??

Simple Scalar Extension : Type-II 2HDM

Features :

- Introduce second Higgs doublet.
- Electroweak ρ parameter remains unity at tree level.
- Minimal Supersymmetric model based on Type-II two-Higgs structure.
- Five physical scalars : $(m_h, m_H, m_A, m_{H^\pm})$.
- LHC data compels to stay in the close vicinity of the *alignment limit*, and the SM-like Higgs can be recovered $m_h = 125$ GeV.
- Flavor constraints $(b \to s\gamma)$ puts bound on m_{H^+} for Type II model.

Aim:

- 2HDM as an low energy model arising from some fundamental UV theory.
- Predict the possibility of finding 2HDM scalar states at the accessible energy range.

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- Predict the possibility of finding 2HDM scalar states at the accessible energy range.

Parameter Counting :

Potential :

- Notation-I :

$$V = m_{11}^2\phi_1^\dagger\phi_1 + m_{22}^2\phi_2^\dagger\phi_2 - \left(m_{12}^2\phi_1^\dagger\phi_2 + \text{h.c.}\right) + \frac{\lambda_1}{2}\left(\phi_1^\dagger\phi_1\right)^2 + \frac{\lambda_2}{2}\left(\phi_2^\dagger\phi_2\right)^2$$
$$+\lambda_3\left(\phi_1^\dagger\phi_1\right)\left(\phi_2^\dagger\phi_2\right) + \lambda_4\left(\phi_1^\dagger\phi_2\right)\left(\phi_2^\dagger\phi_1\right) + \left\{\frac{\lambda_5}{2}\left(\phi_1^\dagger\phi_2\right)^2 + \text{h.c.}\right\}$$

- Eight free parameters $\Rightarrow$ 5 λ's and three bilinears, or, $m_h, m_H, m_A, m_+, \tan\beta, v, \cos(\beta-\alpha), m_{12}^2$.
- Fix λ's at High scale (Λ_S) $\rightarrow$ Determine the three bilinears from known v, m_h and $\cos(\beta-\alpha)\sim 0$.
- **MSSM** can be a good example. [Lee & Wagner '2015, Bagnaschi et. al '2016].

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Effective Theory of High scale SUSY

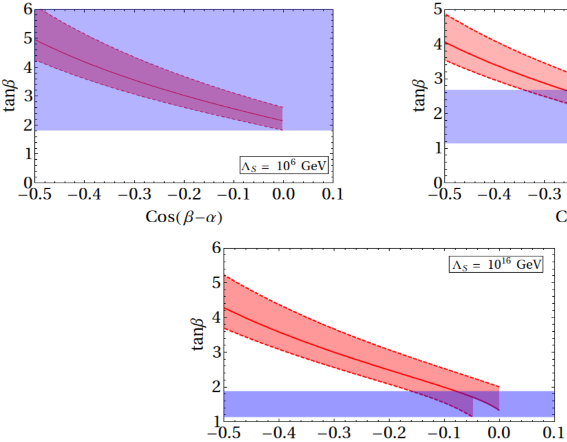
- The Higgs sector of MSSM is Type-II 2HDM.
- Higgs quartic couplings, at tree level, are simple functions of gauge couplings.
- Matching condition at High scale (Λ_S) ::

$$\begin{aligned}
\lambda_! &= \lambda_2 = \frac{1}{4}(g^2 + g'^2)\,, \\
\lambda_3 &= \frac{1}{4}(g^2 - g'^2)\,, \\
\lambda_4 &= -\frac{g^2}{2}\,, \\
\lambda_5 &= 0\,.
\end{aligned}$$

- RG running below (Λ_S) follows 2HDM RGEs.
- Run the RGEs at two-loop.
- Inputs $\rightarrow \tan\beta, \Lambda_S$.
- Outputs $\rightarrow \cos(\beta - \alpha), m_+, m_H, m_A$.
- Look for data driven region near $\cos(\beta - \alpha) \sim 0$.

Results: 2-Loop RGE

- 2-Loop running is essential in the close proximity of unit $\tan\beta$ to make robust predictions on the non-standard spectrum.
- The shaded blue region corresponds to absolute stable vacuum of the potential.
- The current or projected value of $\cos(\beta - \alpha)$ will narrow down the region of all the scalar masses and $\tan\beta$.



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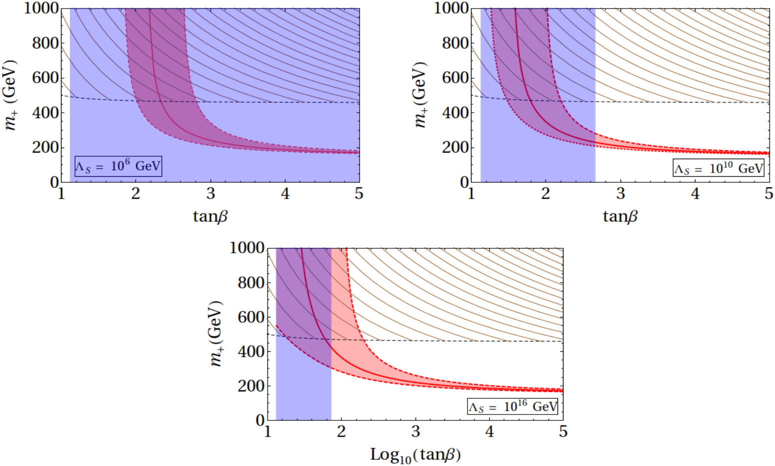
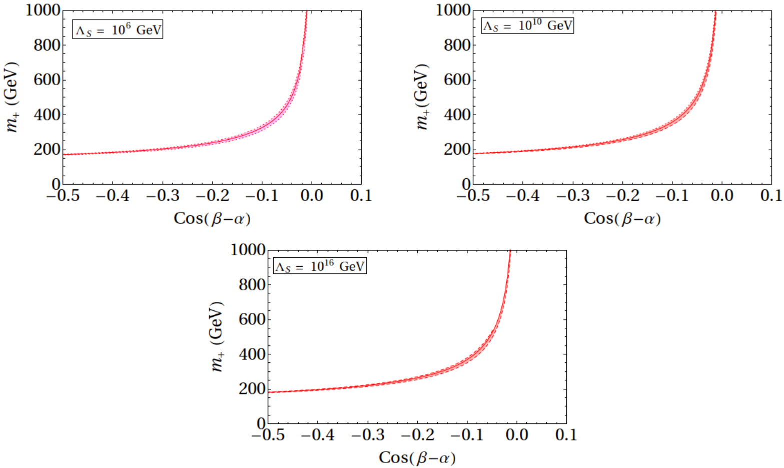


- Dashed region denotes the constraints on charged Higgs mass from $b \to s\gamma$.
- It brings an independent upper bound on $\tan\beta$.

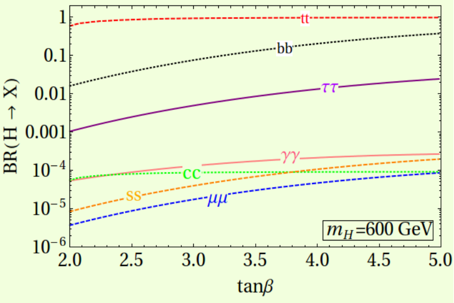
Results : 2-Loop RGE



- The m_+ and $\cos(\beta - \alpha)$ is strongly correlated despite of input uncertainties.
- The bounds on one can thus be translated to the other.

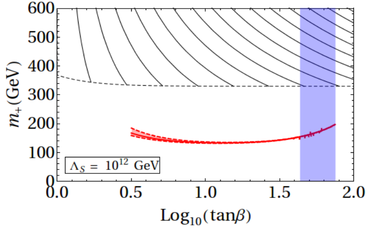
Phenomenological Implications

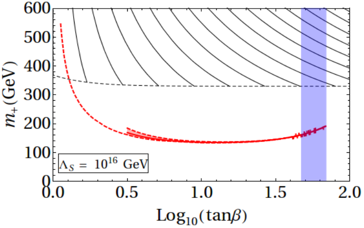
- Branching ratios of different decay channels mainly depend on $\tan\beta$.
- Observation of extra scalars can be tested.
- An example plot is shown for the Heavier CP-even state $m_H = 600$ GeV.



Non-supersymmetric toy scenario

- A non-supersymmetric origin is considered.
- At high scale, all the quartic couplings vanishes ($\lambda_i = 0, i = 1, 5$)
- The absolute stability favours large $\tan\beta \sim 50$.
- This particular scenario is, however, disfavored from experimental data.





Conclusion

- We have considered a general framework for fixing the 2HDM parameter space.
- We assume that the low energy effective 2HDM is embedded in a large theoretical framework at UV.
- The quartic couplings are unambiguously determined at High scale.
- MSSM is a well motivated scenario.
- Even if superpartners are super-heavy, the ancestral symmetry leaves it imprints on low scale observables.
- The crucial observation is the definitive prediction of nonstandard scalar masses in the accessible scale even if the ever increasing precision of Higgs result deviates from exact alignment limit.
- Our methodology is quite general, can be applied to a wide catagory of UV scenarios.


Thank you