Avoiding Death By Vacuum Decay

Constraints in the MSSM

Wolfgang Gregor Hollik

DESY Theory

February 2nd 2016 | DESY Fellow Meeting

The end is nigh...

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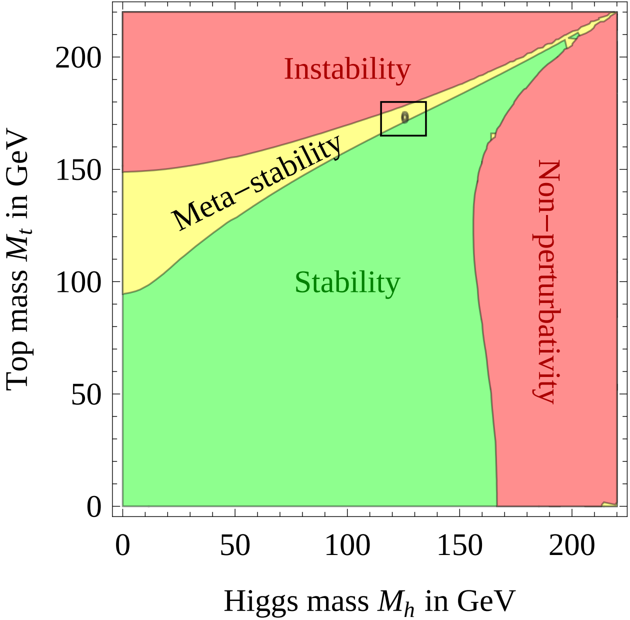
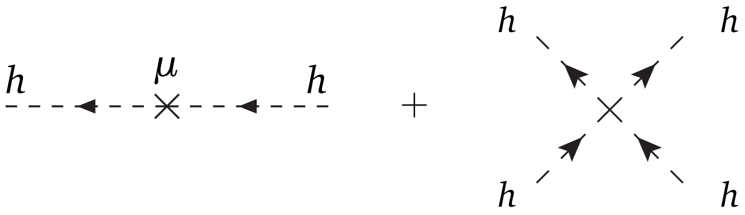
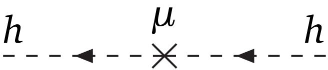


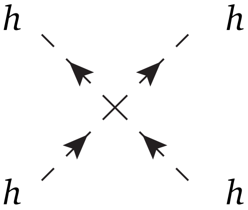
[Degrassi et al. 2012]



$$V(h) = -\frac{1}{2}\,\mu^2\,h^2 \quad + \quad \frac{1}{4}\,\lambda\,h^4$$

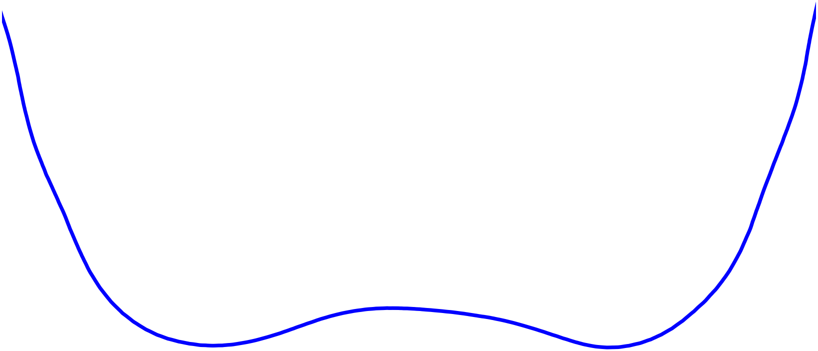


$+$



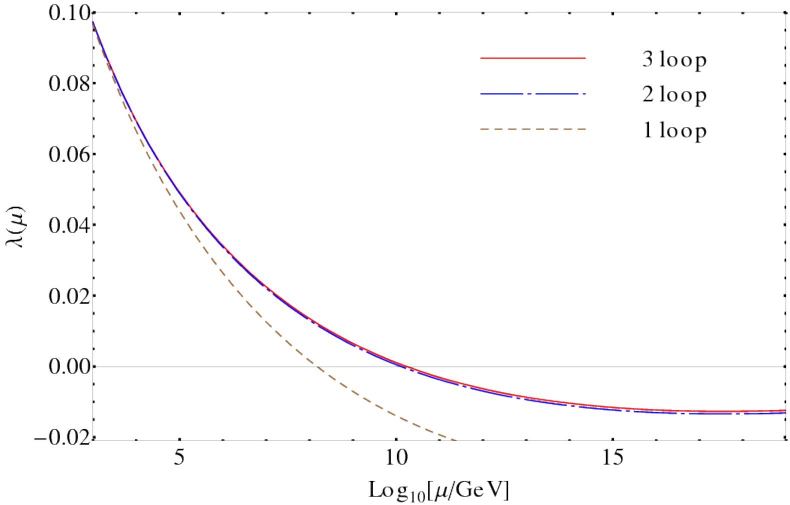
$$V(h) = -\frac{1}{2}\,\mu^2\,h^2 \quad + \quad \frac{1}{4}\,\lambda\,h^4$$

$$\mu^2 > 0, \qquad \lambda > 0$$



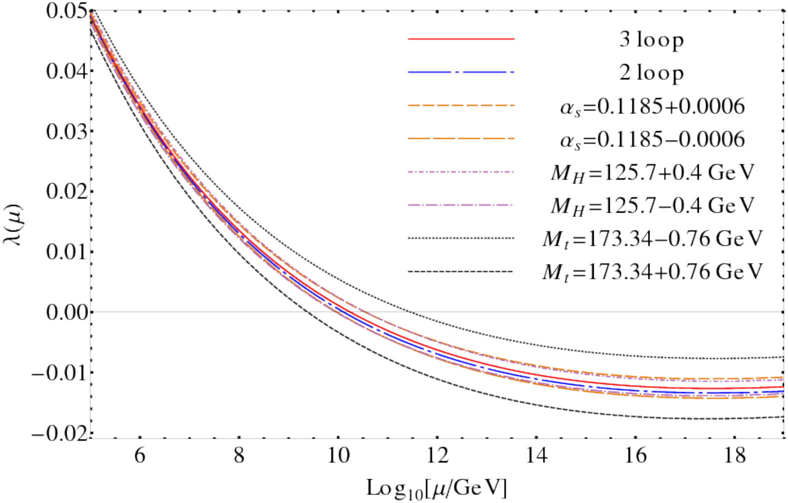
bounded from below @ tree-level

Let it run!



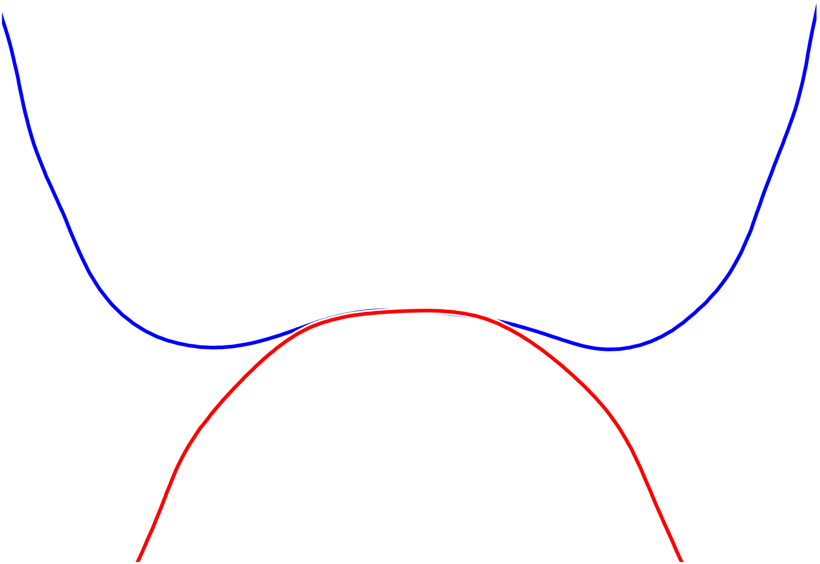
[Zoller 2014]

Let it run!

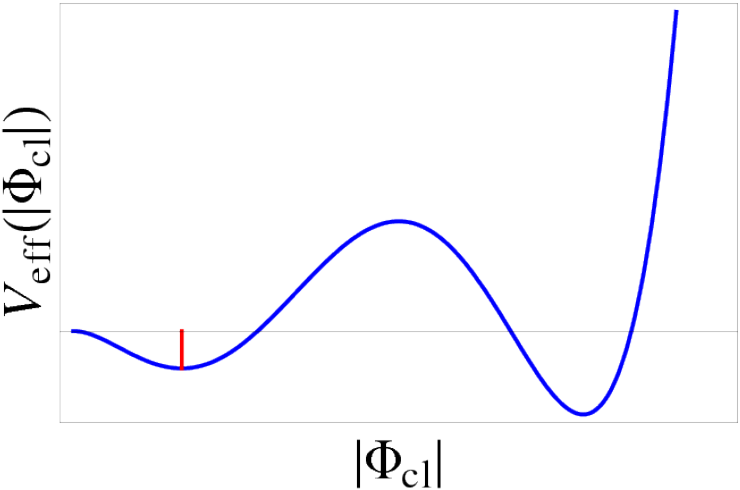


[Zoller 2014]

Unbounded from Below!?

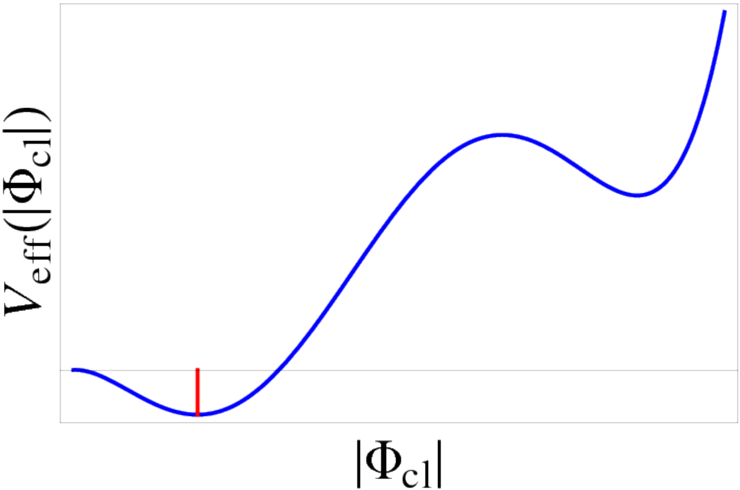


New Minimum around GUT…Planck scale



[Courtesy of Max Zoller]

New Minimum around GUT...Planck scale



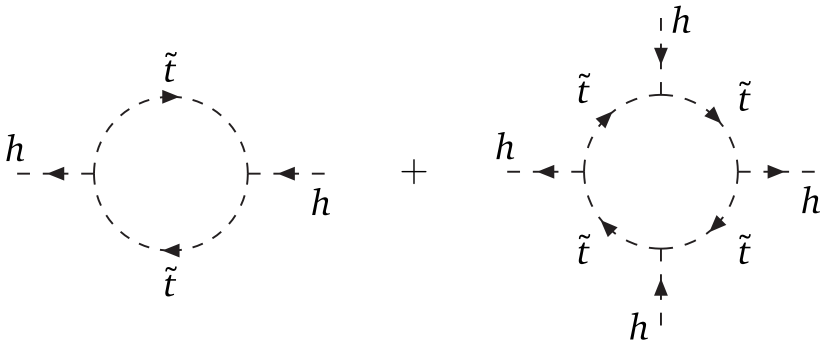
[Courtesy of Max Zoller]

+ **stabilizes Higgs potential**

- $+$ **stabilizes Higgs potential**
- $-$ **changes everything**

+ stabilizes Higgs potential

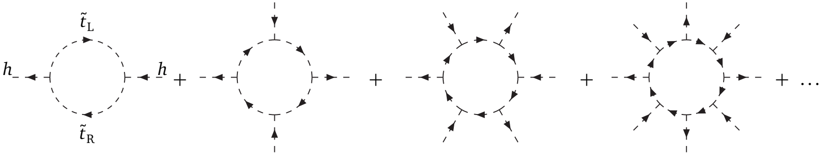
− changes everything

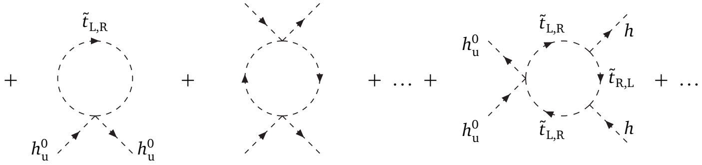


$\lambda_{\text{tree}} \sim g_1^2 + g_2^2 \rightarrow$
$\lambda_i(\tan\beta, \mu, M_1, M_2, \tilde{m}_Q^2, \tilde{m}_u^2, \tilde{m}_d^2, \tilde{m}_L^2, \tilde{m}_e^2, A_{\mathsf{u}}, A_{\mathsf{d}}, A_{\mathsf{e}})$.

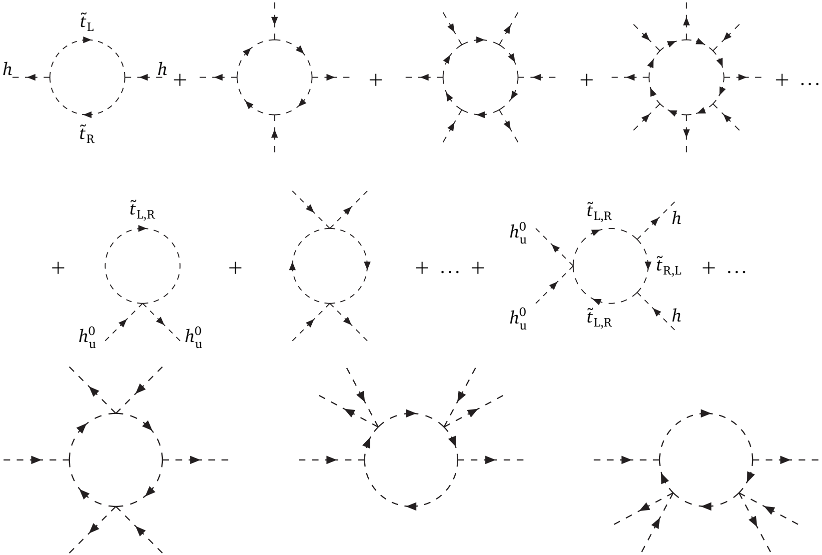
[Gorbahn, Jäger, Nierste, Trine 2011]

One-loop effective Higgs potential (in the MSSM)

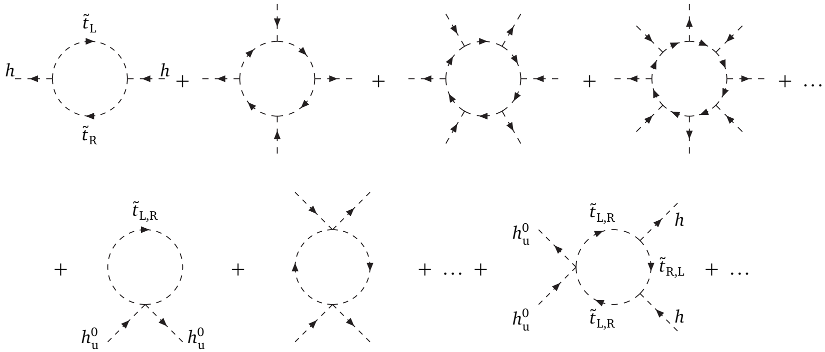




One-loop effective Higgs potential (in the MSSM)

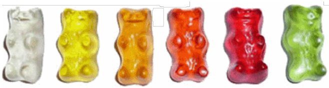


[Details, see arXiv:1505.07764]



gummi bear factor

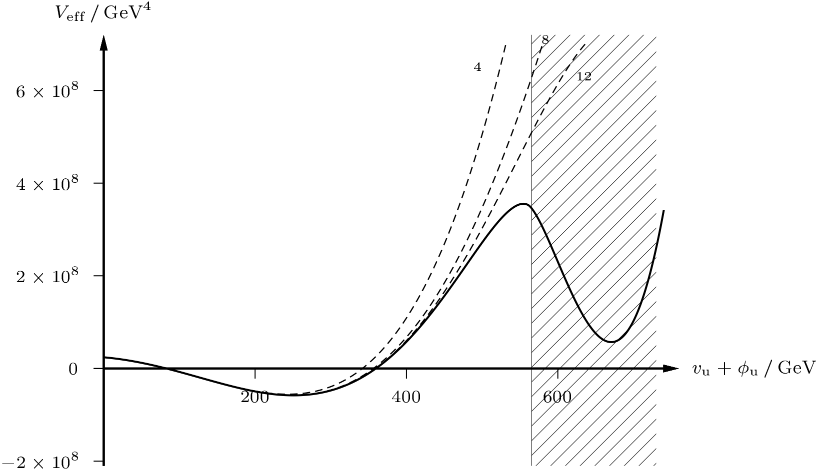
$$\frac{(2n+k-1)!}{k!(2n-1)!}$$



www.idn.uni-bremen.de/biologiedidaktik

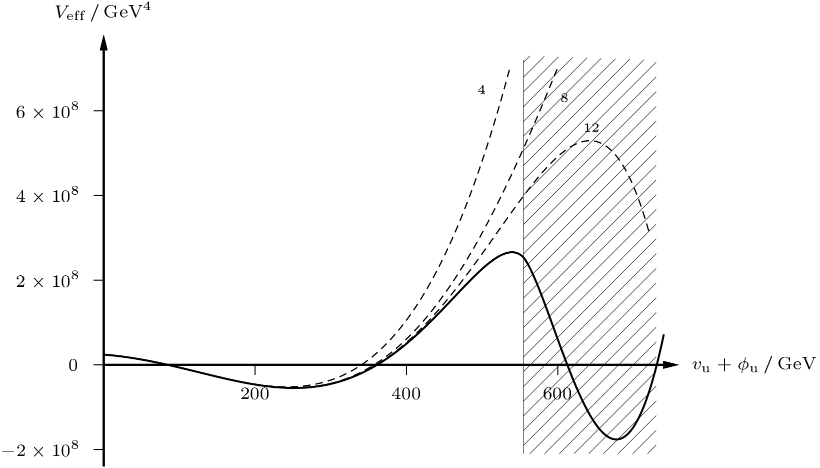
[Details, see arXiv:1505.07764]

[Bobrowski, Chalons, WGH, Nierste 2014]



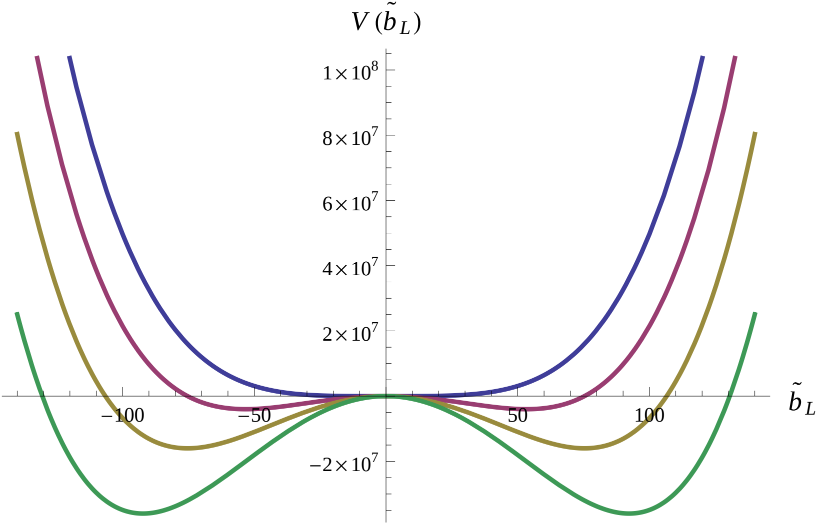
(Details omitted.)

[Bobrowski, Chalons, WGH, Nierste 2014]



(Details omitted.)

Scalar potential with $\langle \tilde{b} \rangle \neq 0$.



The breaking of electric and color charge...

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...is not desired.

. . . is not desired.

Why?

...is not desired.

Why?

- “our” vacuum neutral

. . . is not desired.

Why?

- "our" vacuum neutral

Problems

- MSSM scalar potential contains charged and colored directions
- exact minimization non-trivial
- tunneling from false to true vacua?

Better try to avoid. . .

- global CCB minima
- instable configurations

Generically difficult: e.g. Higgs-sbottom potential

$$
\begin{aligned}
V(h_u^0, h_d^0, \tilde{b}_L, \tilde{b}_R) = {} & (m_{H_u}^2 + |\mu|^2)|h_u^0|^2 + (m_{H_d}^2 + |\mu|^2)|h_d^0|^2 - 2B_\mu h_d^0 h_u^0 \\
& + \tilde{b}_L^*(\tilde{m}_Q^2 + |Y_b h_d^0|^2)\tilde{b}_L + \tilde{b}_R^*(\tilde{m}_b^2 + |Y_b h_d^0|^2)\tilde{b}_R \\
& - \left[\tilde{b}_L^*(\mu^* Y_b {h_u^0}^* - A_b h_d^0)\tilde{b}_R + \text{h.c.}\right] + |Y_b|^2|\tilde{b}_L|^2|\tilde{b}_R|^2 \\
& + \frac{g_1^2}{8}\left(|h_u^0|^2 - |h_d^0|^2 + \frac{1}{3}|\tilde{b}_L|^2 + \frac{2}{3}|\tilde{b}_R|^2\right)^2 \\
& + \frac{g_2^2}{8}\left(|h_u^0|^2 - |h_d^0|^2 + |\tilde{b}_L|^2\right)^2 \\
& + \frac{g_3^2}{6}\left(|\tilde{b}_L|^2 - |\tilde{b}_R|^2\right)^2
\end{aligned}
$$

Generically difficult: e.g. Higgs-sbottom potential

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\begin{aligned}
V(h_u^0, h_d^0, \tilde{b}_L, \tilde{b}_R) = &(m_{H_u}^2 + |\mu|^2)|h_u^0|^2 + (m_{H_d}^2 + |\mu|^2)|h_d^0|^2 - 2B_\mu h_d^0 h_u^0 \\
&+ \tilde{b}_L^*(\tilde{m}_Q^2 + |Y_b h_d^0|^2)\tilde{b}_L + \tilde{b}_R^*(\tilde{m}_b^2 + |Y_b h_d^0|^2)\tilde{b}_R \\
&- \left[\tilde{b}_L^*(\mu^* Y_b h_u^{0\,*} - A_b h_d^0)\tilde{b}_R + \text{h.c.}\right] + |Y_b|^2|\tilde{b}_L|^2|\tilde{b}_R|^2 \\
&+ \frac{g_1^2}{8}\left(|h_u^0|^2 - |h_d^0|^2 + \frac{1}{3}|\tilde{b}_L|^2 + \frac{2}{3}|\tilde{b}_R|^2\right)^2 \\
&+ \frac{g_2^2}{8}\left(|h_u^0|^2 - |h_d^0|^2 + |\tilde{b}_L|^2\right)^2 \\
&+ \frac{g_3^2}{6}\left(|\tilde{b}_L|^2 - |\tilde{b}_R|^2\right)^2
\end{aligned}
$$

Approach: choose distinct direction in field space, i.e. $\tilde{b}_L = \tilde{b}_R = \tilde{b}$ and $|h_d^0|^2 = |h_u^0|^2 + |\tilde{b}|^2$ or $h_d^0 = 0$, $h_u^0 = \tilde{b}$

- choose appropriate direction $\hookrightarrow$ one-field problem

$$V_\phi^{\text{tree}} = \bar{m}^2\phi^2 - A\phi^3 + \lambda\phi^4$$

- condition for non-trivial (i.e. $\langle\phi\rangle \neq 0$) vacuum *not* being global or degenerate with $V(0)$:

$$\bar{m}^2 > A^2/(4\lambda).$$

Keep us from charge and color breaking...

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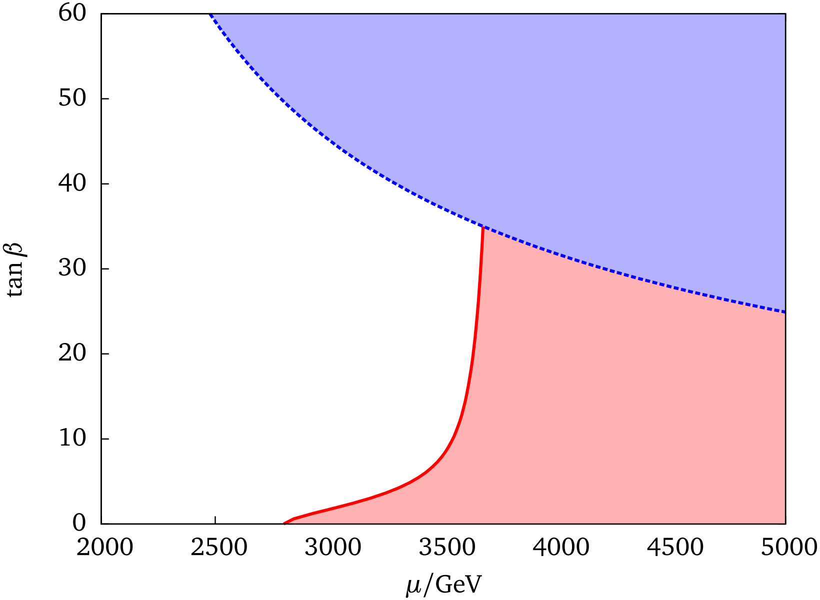
$$\bar{m}^2 > A^2/(4\lambda).$$

$h_u^0 = \tilde{b}$, $h_d^0 = 0$

$$m_{H_u}^2 + \mu^2 + \tilde{m}_Q^2 + \tilde{m}_b^2 > \frac{(\mu Y_b)^2}{Y_b^2 + (g_1^2 + g_2^2)/2}$$

$|h_d^0|^2 = |h_u^0|^2 + |\tilde{b}|^2$, $\tilde{b} = \alpha h_u^0$

$$m_{11}^2(1+\alpha^2) + m_{22}^2 \pm 2m_{12}^2\sqrt{1+\alpha^2} + \alpha^2(\tilde{m}_Q^2 + \tilde{m}_b^2) > \frac{4\mu^2\alpha^2}{2+3\alpha^2}$$



60
50
40
30
20
10
0
2000
2500
3000
3500
4000
4500
5000
$\tan\beta$
μ/GeV


Conclusions

- constraints from vacuum stability
- no charge and color breaking
- complementary to direct searches
- new bounds complement existing ones like

$$|A_\mathrm{t}|^2 \leq 3\left(\tilde{m}_Q^2 + \tilde{m}_t^2 + m_{H_\mathrm{u}}^2 + |\mu|^2\right)$$

[Frére, Jones, Raby '83; Gunion, Haber, Sher '88]

References

- Wolfgang Gregor Hollik: *"Charge and color breaking constraints in the Minimal Supersymmetric Standard Model associated with the bottom Yukawa coupling"* Physics Letters B **752** (2016) 7 – 12
- Markus Bobrowski, Guillaume Chalons, Wolfgang G. Hollik, Ulrich Nierste: *"Vacuum stability of the effective Higgs potential in the Minimal Supersymmetric Standard Model"* Physical Review D **90**, 035025 (2014)