Sfermion VEVs in the CMSSM

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in collaboration with
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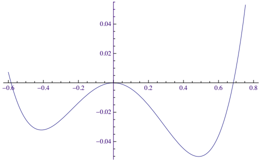
Julius-Maximilians-Universität Würzburg

BSM parallel session,
Helmholtz Terascale Alliance 7th Annual Workshop,
Karlsruhe, December 3rd, 2013

Even tree-level potentials for single scalars have in general multiple minima:



QFT potentials typically have multiple minima

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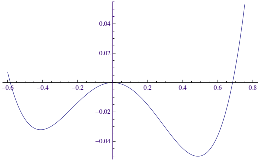
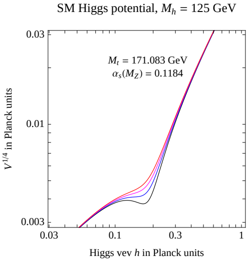
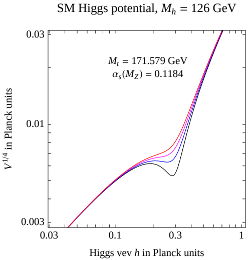


Top loops create extra minima for high Higgs field values in SM:





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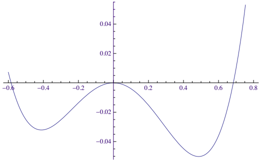
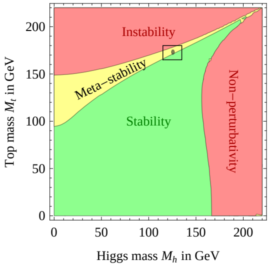


SM is probably metastable!



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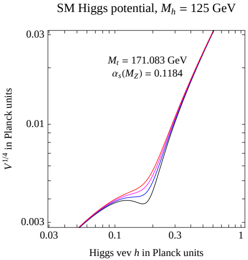
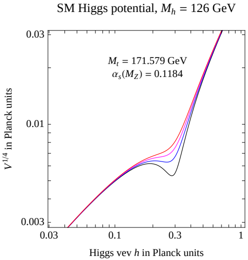
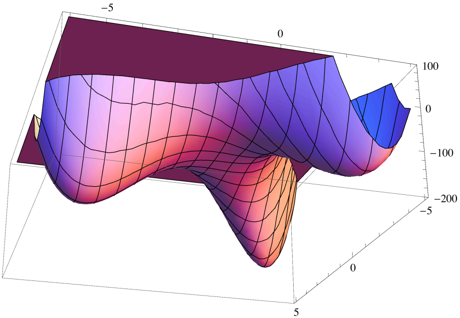




Figs. 2, 3, 4: Degrassi *et al.*, JHEP 1208 (2012)

More scalars ⇒ more minima in general

Multiple scalars in general yield many vacua:



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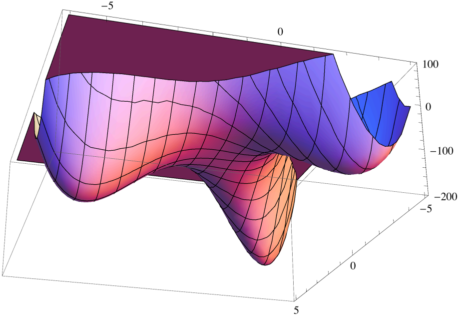

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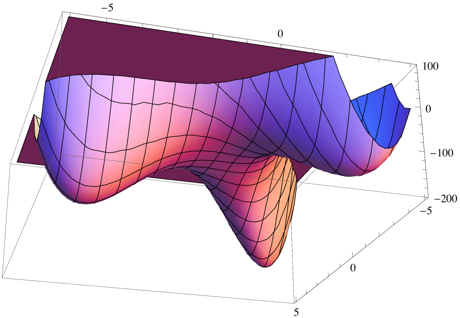

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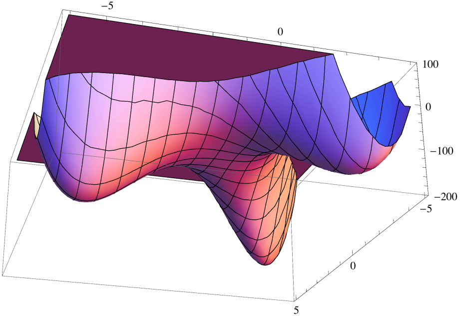
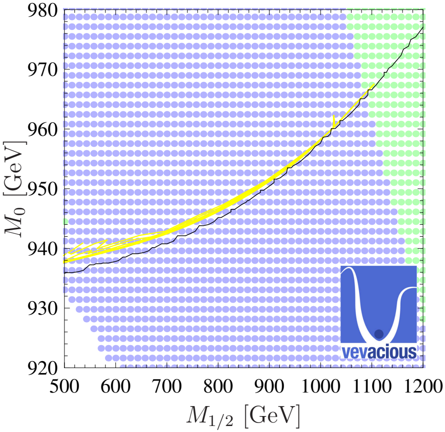


Finding the global minimum is not trivial!

- Charge- and/or color-breaking (CCB) minima (VEVs for charged or colored scalars [SUSY: scalar partners for τ, t, ...])?
- Desired VEV combination may not be global minimum (even non-CCB if there are enough VEVs required)

CCB restricts $\tilde{\tau}$ co-annihilation

$A_0 = +3$ TeV, $\tan\beta = 40$, $\mu > 0$
(Camargo-Molina, BO'L, Porod, Staub, `arXiv:1309.7212`)



blue: metastable ($\tau_{\text{tunnel}} > 3$ Gy); green: stable
yellow region: correct relic density; black: $m_{\tilde{\tau}_1} = m_{\tilde{\chi}^0_1}$

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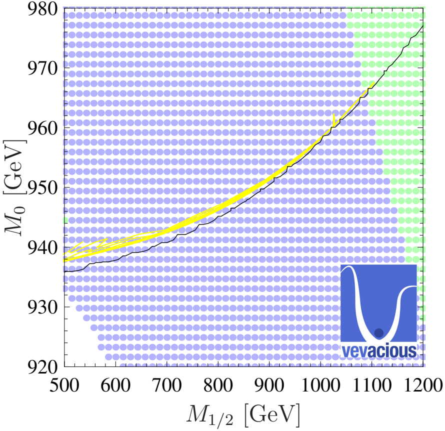

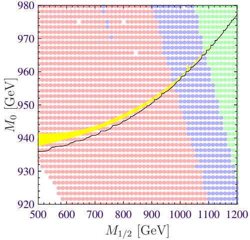

(Red $\tau_{\text{tunnel}} < 3$ Gy if misinterpreting `CosmoTransitions` $T \neq 0$K action as $T = 0$K action...)

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CCB restricts $\tilde{t}$ co-annihilation

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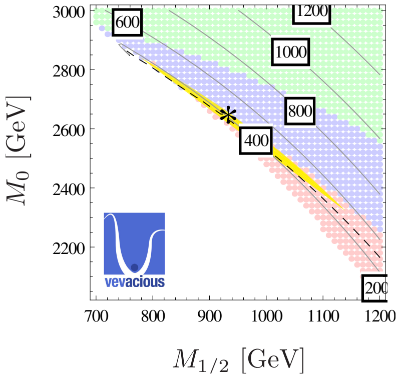
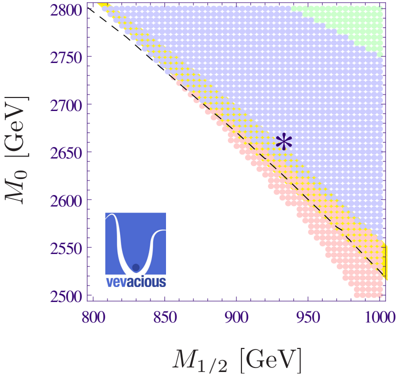
$A_0 = -6.444$ TeV, $\tan\beta = 8.52$, $\mu < 0$
$m_{\tilde{t}_1}$ (GeV) contours (`arXiv:1309.7212`)

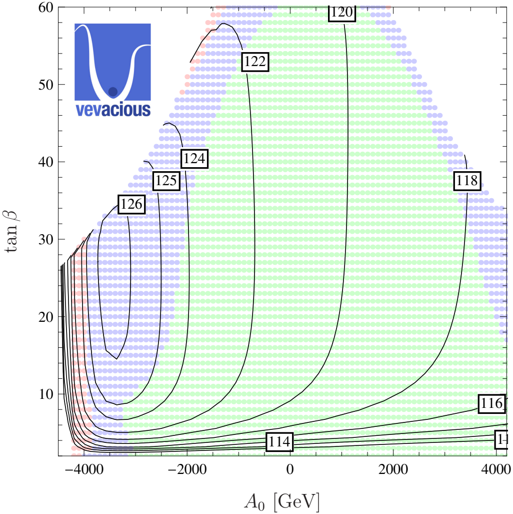




red/blue: metastable ($\tau_{\text{tunnel}} < / > 3$ Gy); green: stable
yellow region: correct relic density; dashed black for $m_{\tilde{\tau}_1} = m_{\tilde{\chi}_1^0}$

CCB restricts region with correct m_h

$M_0 = M_{1/2} = 1$ TeV, $\mu > 0$; m_h (GeV) contours
colors as before (1309.7212)



$$V^{\text{tree}}(H_d = v_d/\sqrt{2}, H_u = v_u/\sqrt{2}, \tilde{\tau}_L = v_{\tilde{\tau}_L}/\sqrt{2}, \tilde{\tau}_R = v_{\tilde{\tau}_R}/\sqrt{2})$$
$$= \frac{1}{32}\left(g_1^2(v_d^2 - v_u^2 + v_{\tilde{\tau}_L}^2 - 2v_{\tilde{\tau}_R}^2)^2 + g_2^2(v_d^2 - v_u^2 - v_{\tilde{\tau}_L}^2)^2\right) - B_\mu v_d v_u$$
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Some conditions in the literature have often been (mis-)used:

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Analytic conditions

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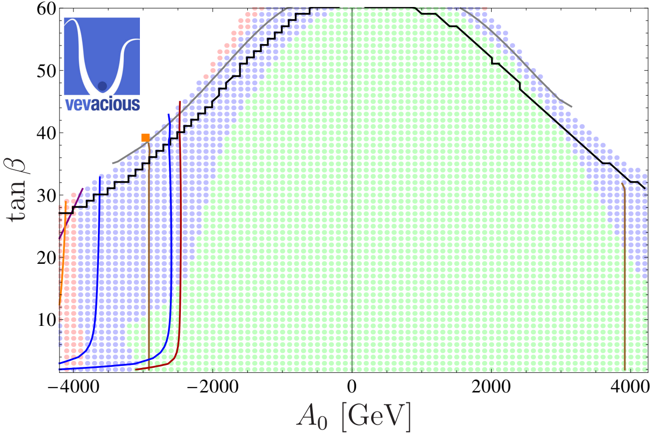
- $|(Y_\tau v_u \mu)/(\sqrt{2} m_\tau)| < 56.9\sqrt{m_{\tilde{\tau}_L} m_{\tilde{\tau}_R}} + 57.1(m_{\tilde{\tau}_L} + 1.03 m_{\tilde{\tau}_R}) - 1.28 \times 10^4\text{GeV} + \frac{1.67\times 10^6\text{GeV}^2}{m_{\tilde{\tau}_L} + m_{\tilde{\tau}_R}} - 6.41 \times 10^6\text{GeV}^3\left(\frac{1}{m_{\tilde{\tau}_L}^2} + \frac{0.983}{m_{\tilde{\tau}_R}^2}\right)$ ["numeric"]

("GUT": Ellwanger, Rausch de Traubenberg, Savoy, Nucl. Phys. B**492**
"A_τ", "A_t": Alvarez-Gaumé, Polchinski, Wise, Nucl. Phys. B**221**;
"numeric": Kitahara, Yoshinaga, arXiv:1303.0461, JHEP)

Analytic conditions do not always do well

$M_{1/2} = 1000$ GeV, $m_0 = 1000$ GeV, $\mu > 0$ (1309.7212)



Brown: "GUT"; Purple: "A_τ"; Orange: "A_t"
Grey: "numeric"; Dark red: "A_t" with small $v_{\tilde{b}}$
Bright blue: "A_t" for $\tan\beta \to \infty$ (range); Black: $m_{\tilde{\tau}_1} = m_{\tilde{\chi}^0_1}$

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Fast enough for scans! MSSM with additional non-zero VEVs for $\tilde{\tau}_L, \tilde{\tau}_R, \tilde{t}_L, \tilde{t}_R$: global minimum found within 5s on my laptop. (Tunneling time calculation varies: less than a second, up to 10 minutes.)

Download Vevacious! http://vevacious.hepforge.org/

Vevacious is a new, publicly-available code, that:

- takes a model file (automatically generated by SARAH)
- takes an SLHA file
- prepares and runs homotopy continuation code (HOM4PS2) to find *all* tree-level extrema
- prepares and runs gradient minimization code (PyMinuit) to account for loop corrections
- calculates tunneling time to undesired minima if found (CosmoTransitions)

Fast enough for scans! MSSM with additional non-zero VEVs for $\tilde{\tau}_L, \tilde{\tau}_R, \tilde{t}_L, \tilde{t}_R$: global minimum found within 5s on my laptop. (Tunneling time calculation varies: less than a second, up to 10 minutes.)

http://vevacious.hepforge.org/

Minimizing potentials not trivial:

vevacious

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Thank you for your attention!

Backup slides

CCB, $\tilde{t}$ mass, and thumb rules

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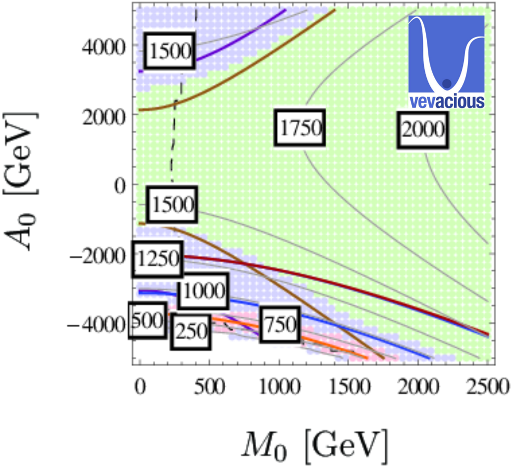
$M_{1/2} = 1$ TeV, $\tan\beta = 10$, $\mu > 0$; $m_{\tilde{t}_1}$ (GeV) contours (1309.7212)



Brown: “GUT”; Purple: “A_τ”; Orange: “A_t”; Dashed black: $m_{\tilde{\tau}_1} = m_{\tilde{\chi}^0_1}$

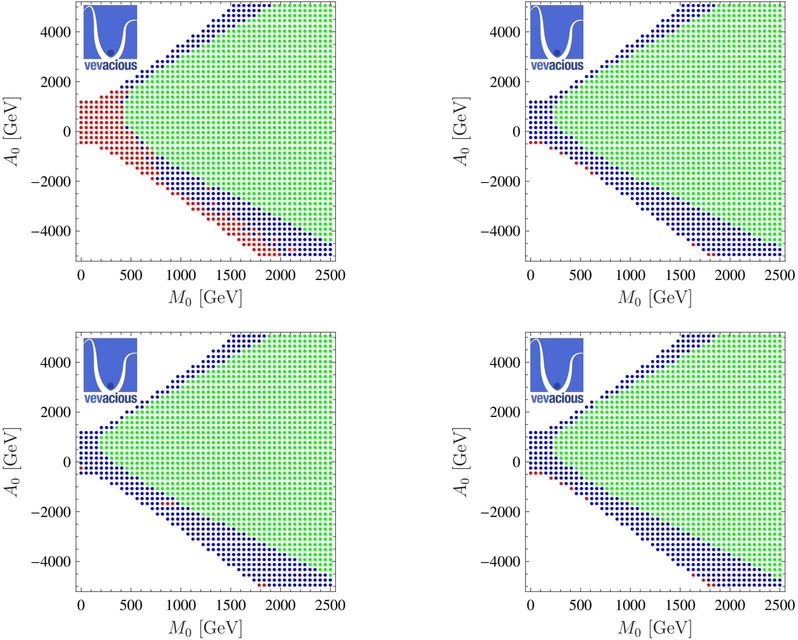
Dark red: “A_t” with small $v_{\tilde{b}}$ (Casas, Lleyda, Munoz, Nucl. Phys. B**471**)

Bright blue: “A_t” for $\tan\beta \to \infty$ (range) (Le Mouël, Phys. Rev. D**64**)

Tunneling times

- $\Gamma/$ volume $= Ae^{-B/\hbar}(1 + \mathcal{O}(\hbar))$
- A is solitonic solution, should be $\sim$ energy scale of potential
- $B \sim$ ([surface tension]/[energy density difference])^3 for small energy density differences ("thin wall" bubbles)
- B very strongly dependent on energy barrier for large depth differences ("thick wall" bubbles)

Scale and loop order dependence: halving Q



Scale and loop order dependence: doubling Q