Baryogenesis in the MSSM

P. John, *Susy98*, Oxford July 1998

$$\frac{n_B - n_{\bar{B}}}{s} \approx 3 \cdot 10^{-10}$$

Sakharov('67):

1. B violating processes (chiral anomalies, t'Hooft '76)

2. C- , CP- violating processes (L-R-asymmetry, CKM)

3. system must deviate from the thermodynamical equilibrium (phase transition of first order)

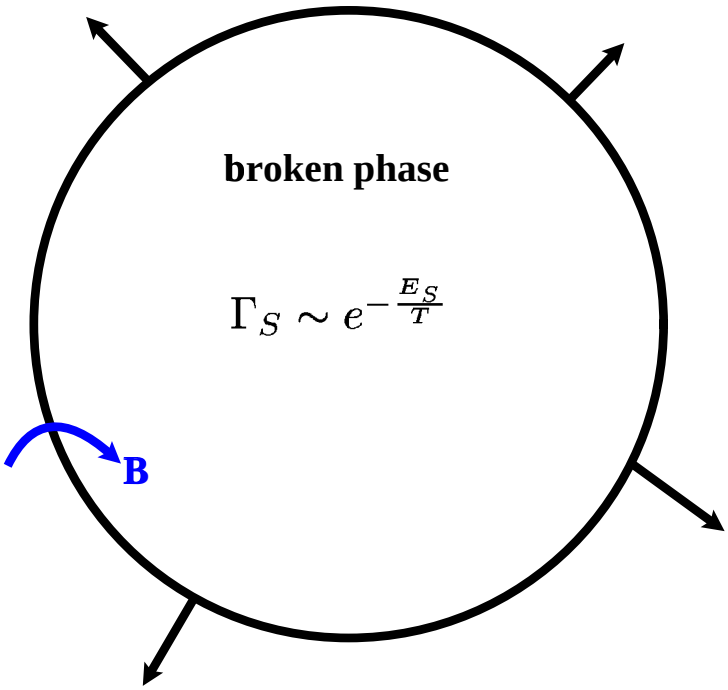
$\Rightarrow$ Electroweak phase transition !?

B Asymmetry via Sphalerons

symmetric phase

hot sphalerons

$$\Gamma_S^{hot} \sim T^4$$



Γ_S small at T_c

$$\frac{E(T_c)}{T_c} \sim \frac{m_W(T_c)}{T_c} \sim \frac{v(T_c)}{T_c} \rightarrow \text{large}$$

$$\boxed{\frac{v(T_c)}{T_c} > 1}$$

Standard Model (SM):

baryogenesis at $\frac{v(T_c)}{T_c} \gtrsim 1$

Effective 3d field theory: Integrate out all heavy degrees of freedom. e.g. SM:

$$L_3 = \frac{1}{4}F_{ij}^a F_{ij}^a + (D_i^w H)^+ (D_i^w H) + m_3^2 H^+ H + \lambda_3 (H^+ H)^2$$

Leads to value $x = \frac{\lambda_3}{g_3^2} \approx \frac{1}{8}\frac{m_H^2}{m_W^2} + C\frac{m_{top}^2}{m_W^2}$ ($C \sim 0.01$)

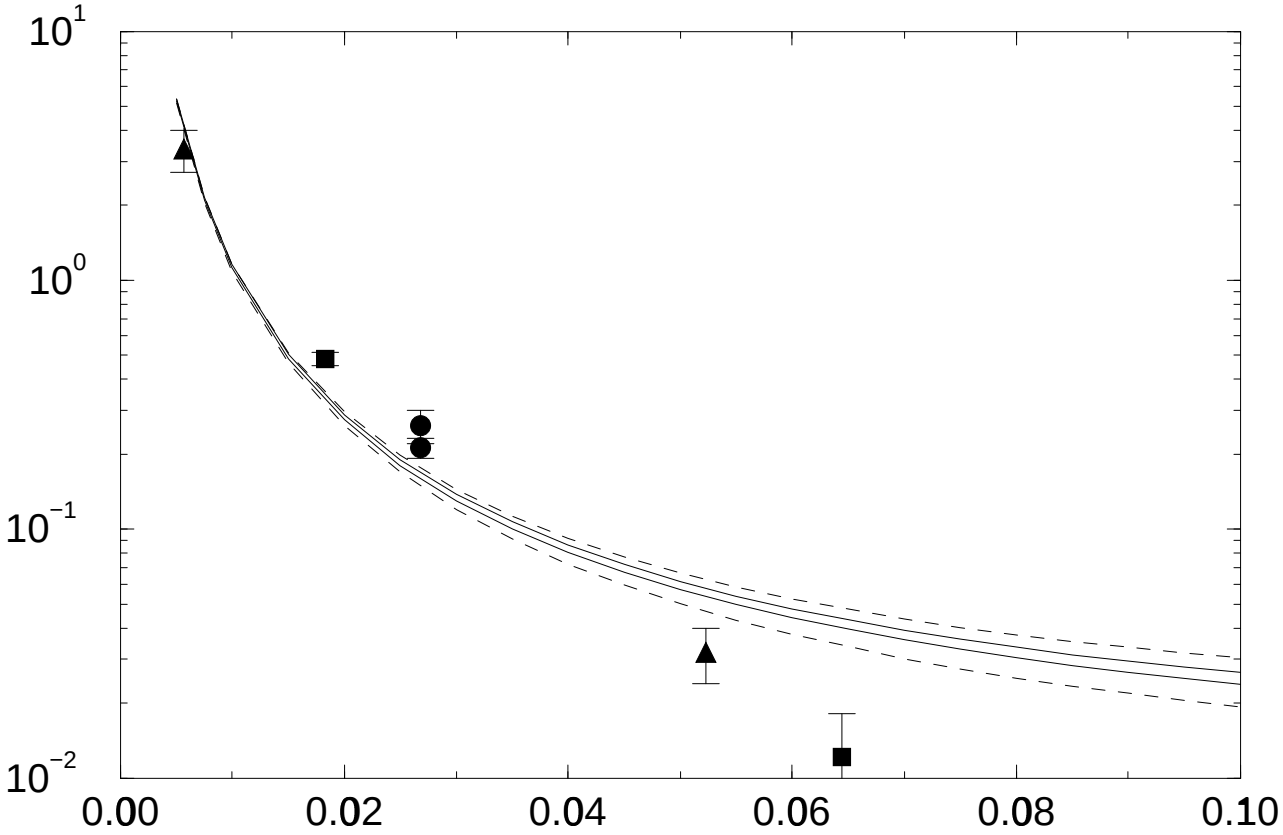
$x \gtrsim 0.11$	phase transition disappears; crossover
$x \lesssim 0.11$	lattice calculations predict a first order phase transition
$x \gtrsim 0.05$	deviations from lattice data increase, especially for surface tension σ
$x \lesssim 0.04$	($\frac{v(T_c)}{T_c} \gtrsim 1$) phase transition strong enough for baryogenesis

But: x too large for $m_{top} \approx 175 GeV$

$\Rightarrow$ SM cannot generate baryonasymmetry !

(does not depend on Higgs mass!)

surface tension σ [1]



■ [Kajantie, Laine, Rummukainen, Shaposhnikov, NPB 466('96)189]

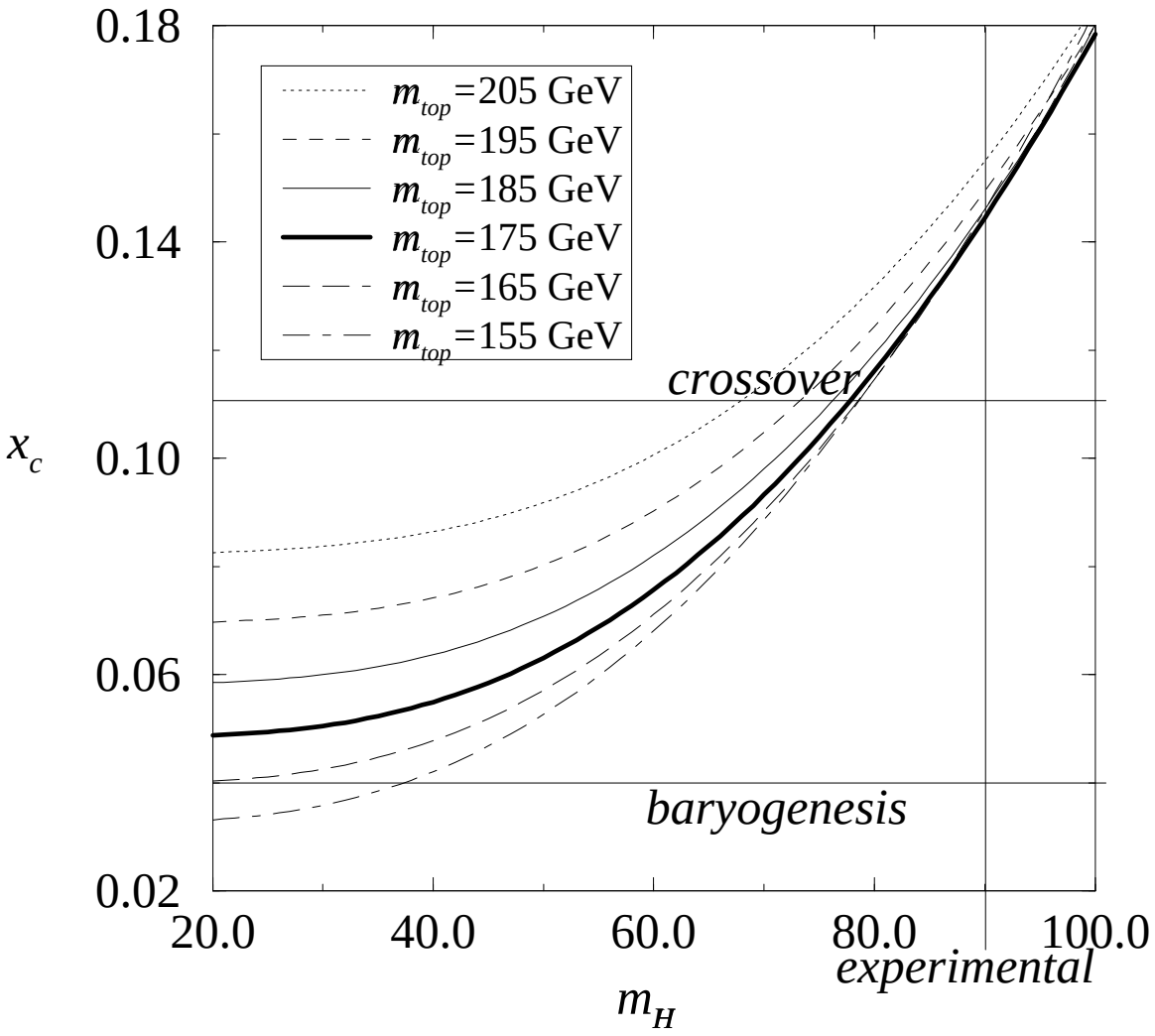
▲ [Fodor, Hein, Jansen, Jaster, Montvay, Csikor, PLB 334 ('94)405]

● [Csikor, Fodor, Hein, Heitger, PLB 357('95)156]

[1] [Krifpganz, Laser, Schmidt, Z. f. Phys.]

strength of phase transition in the SM

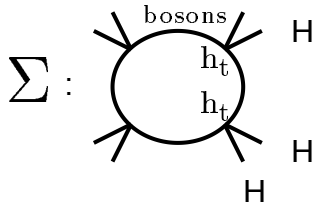
[Kajantie et al., NPB 466('96)189]



variants of the SM

$V_{eff} = DT^2\Phi^2 + ET\Phi^3 + \lambda_T\Phi^4$ (4-dimensional)

enlarge E to enlarge strength of phase transition



[parameters: $\tan\beta, h_t, m_A, m_H$, related]

MSSM

If one of the both Higgses is heavy and all Susy-partners are heavy too:

$\rightarrow$ same effective theory as the SM with different 4d-3d relations

$$m^2_{\tilde{t}_R} = m^2_U + m^2_{top}$$

$m_U \approx 50 - 150GeV \Rightarrow m_H \approx 70 - 75GeV$

[Laine]

$\rightarrow$ light stop enlarges the phase transition,

opens the window for baryogenesis

$m_U^2 = 0$ or even negative $m_U^2 < 0$? [Espinosa]

[Carena, Quiros, Wagner]

$\rightarrow$ new field U in 3d effective Lagrangian with mass

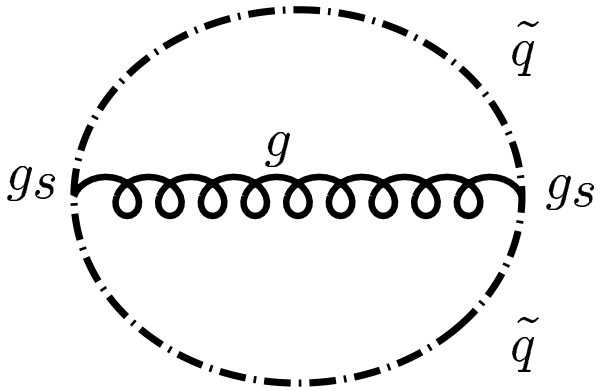
$$m_{U_3}^2 = m_U^2 + (\cdots)T^2 + log\text{-terms}$$

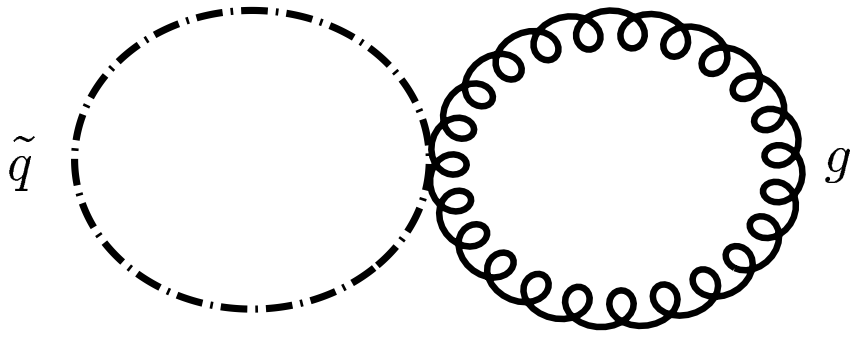
$$\begin{aligned} L_3 \;=\; & \frac{1}{4}F_{ij}^a F_{ij}^a + \frac{1}{4}G_{ij}^a G_{ij}^a \\ & + (D_i^w H)^+ (D_i^w H) + m_3^2 H^+ H + \lambda_3 (H^+ H)^2 \\ & + (D_i^s U)^+ (D_i^s U) + m_{U_3}^2 U^+ U + \lambda_{U_3} (U^+ U)^2 \\ & + \gamma_3 (H^+ H)(U^+ U) \end{aligned}$$

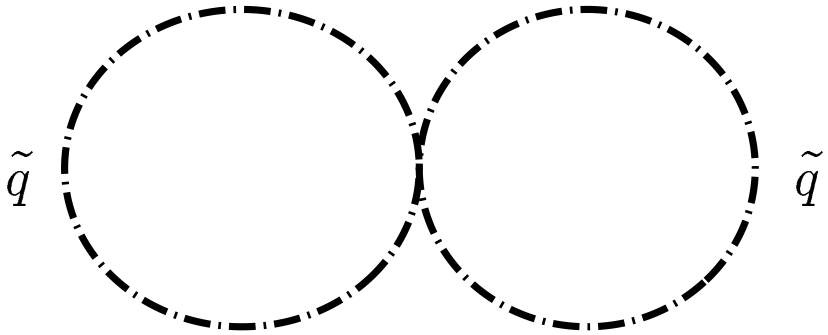
[Laine]

- 2-loop perturbation theory
  $\rightarrow$ strong coupling constant g_s in effective potential
- phase transition becomes much stronger for $m_U^2 < 0$
- in a special parameter space there is a 2-step phase transition with a broken colour vacuum

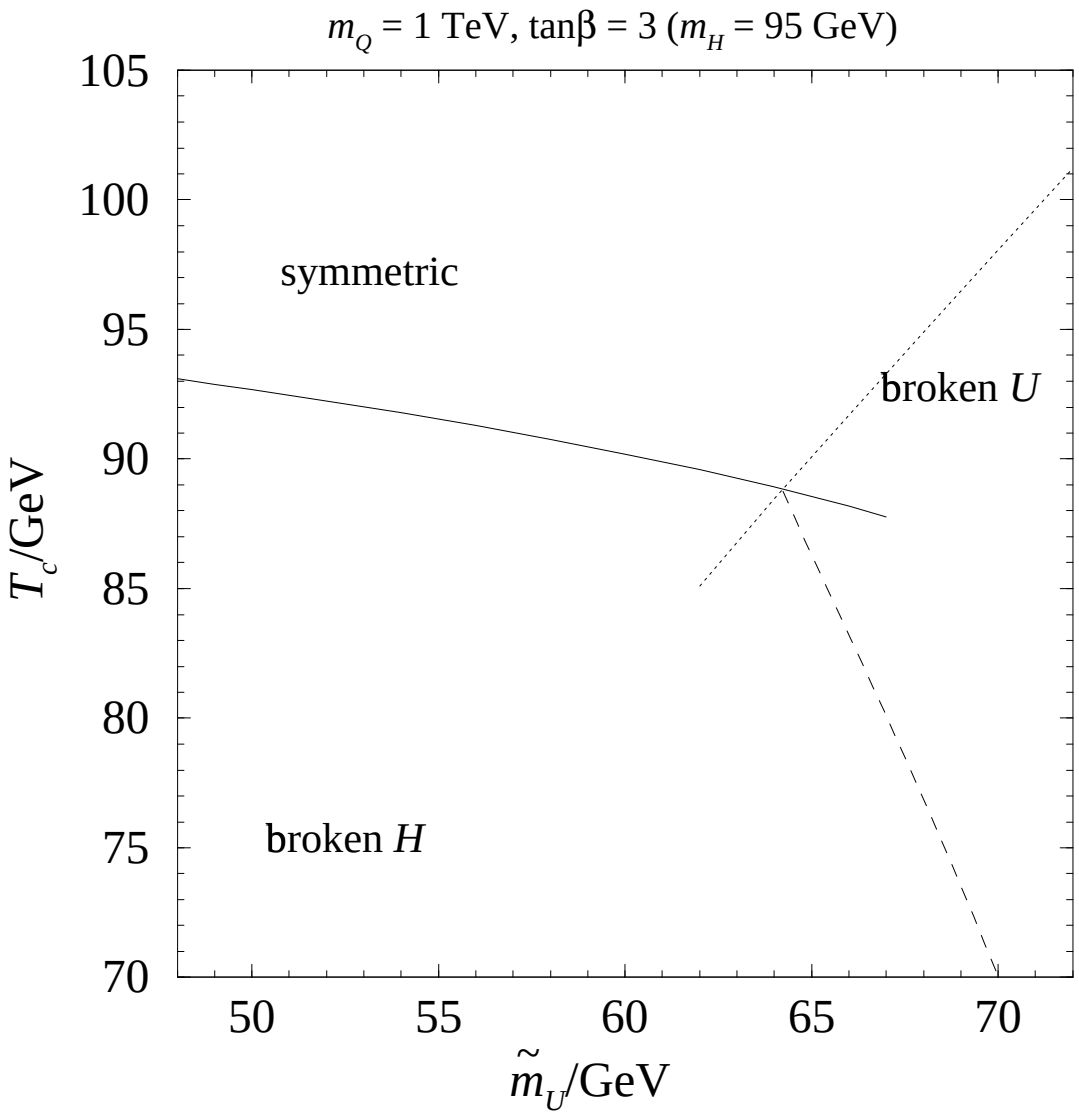
typical 2-loop diagrams







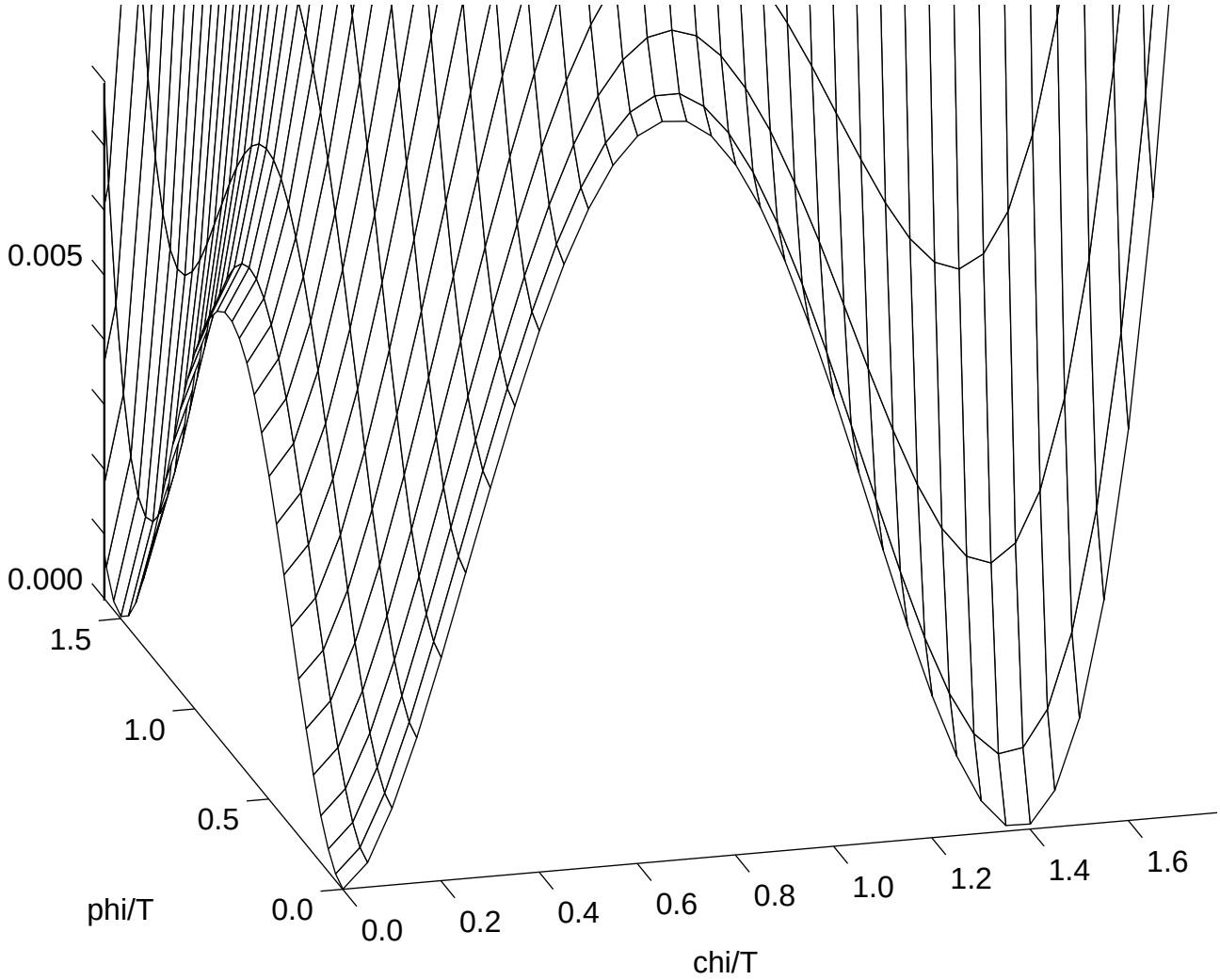
phase diagram of the MSSM



Effective potential at the critical Temperature

$T_{c,\chi} = T_{c,\phi}$, (tripel point)

$\tan\beta = 5, m_H = 92GeV, m_{\tilde{t}_R} = 158GeV$



Results and Confirmations

Predictions: $m_{\tilde{t}_R} \approx 155 - 165 GeV$

(2-step transition) $m_H \approx 90 - 105 GeV$

[Bödeker, John, Laine, Schmidt, NPB 497('97)387]

Oct '97 Confirmation by perturbation theory

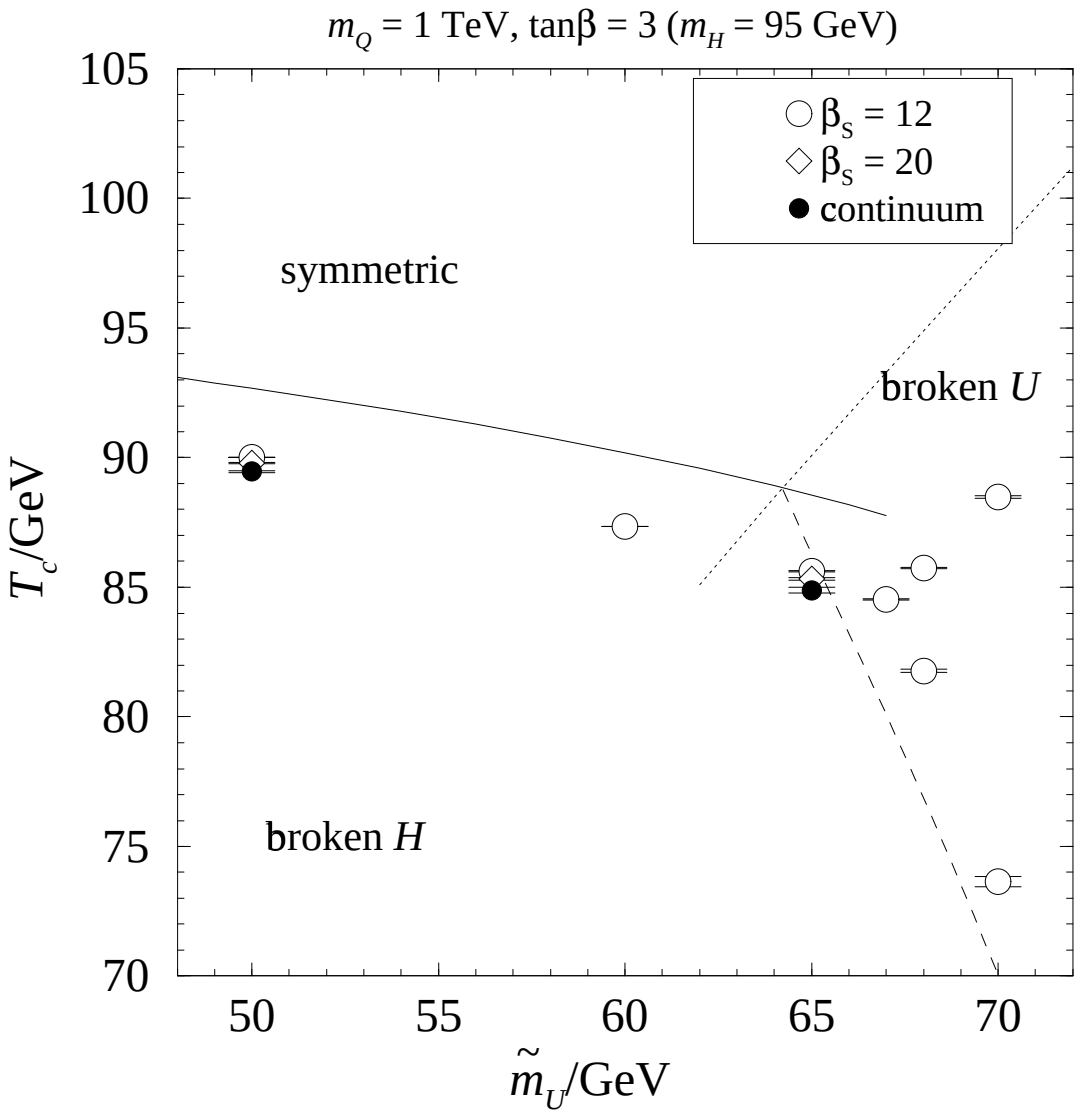
[Carena, Quiros, Wagner, NPB 524(1998)3, 4d]
[Losada, hep-ph 9806519, 3d]

Jan '98 Confirmation by lattice calculations
(2-step phase transition as well as surface tension)

[Laine, Rummukainen, hep-ph 9804019]

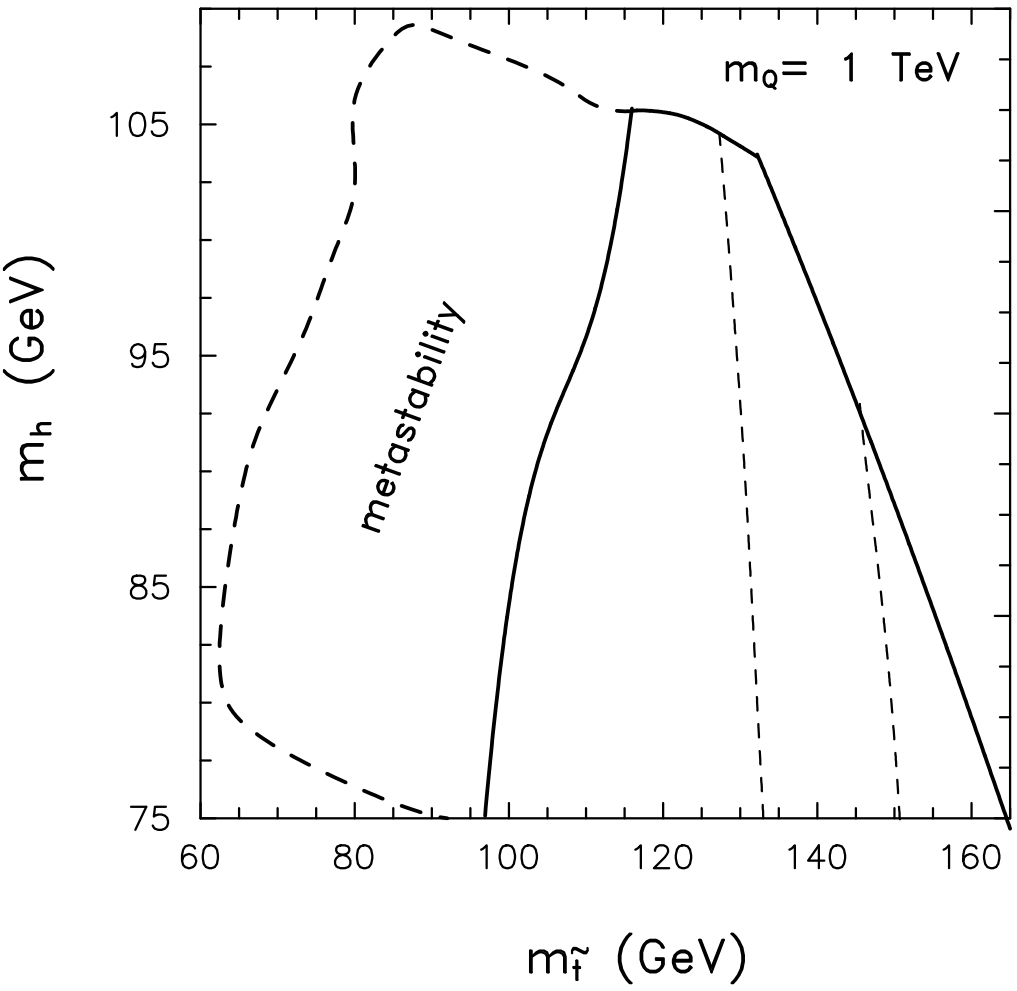
Phase diagram of the MSSM on the lattice

[Laine, Rummukainen, hep-lat/9804019]



4-dimensional confirmation

[Carena, Quiros, Wagner, NPB524 (1998)3]



Surface tension in 3 and 4 dimensions

[Laine, Rummukainen, hep-lat/9804019]