# SUPERSYMMETRIC SO(10) GUT
# WITH LIGHT SPARTICLE SPECTRUM

**Bethe Forum 10.11.2011**

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## Supersymmetric SO(10) GUT with light sparticle spectrum

- Introduction and motivation
- Yukawa unification in SO(10) with negative $\mu$
- Soft SUSY-breaking terms in SO(10) models
- Interplay between BR($b \longrightarrow s\gamma$) and $(g-2)_\mu$
- LSP relic abundance
- Numerical results
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  - recent constraints from LHC

Based on:
M. Badziak M.O. and S. Pokorski, JHEP 1108 (2011) 147

# Introduction and motivation

Already presented by S. Raby

# Yukawa unification in SO(10) with negative $\mu$

The unification of the top, bottom and tau Yukawa couplings at $M_{\rm GUT}$ leads to the tree level bottom mass much bigger than the observed mass

Finite loop correction must be negative and big enough

$$\left(\frac{\delta m_b}{m_b}\right) \approx \frac{g_3^2}{12\pi^2}\mu m_{\tilde{g}} \tan\beta\, I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, m_{\tilde{g}}^2) + \frac{h_t^2}{32\pi^2}\mu A_t \tan\beta\, I(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2)$$

For $\mu > 0$

- the first (sbottom) contribution has “wrong” sign so should be small
  $\Rightarrow$ heavy SUSY spectrum
- the second (stop) contribution must compensate the first one
  $\Rightarrow$ $A_t$ must be negative and large

Talk by S. Raby

Raby et al; Baer et al

For $\mu < 0$

- the sbottom contribution has “correct” sign
  $\Rightarrow$ soft squark masses may be relatively small
  $\Rightarrow$ $A_t$ much less restricted

Gluino-sbottom correction to the bottom mass:

$$\left(\frac{\delta m_b}{m_b}\right)^{\tilde{g}\tilde{b}} \approx \mathcal{O}(0.5)\frac{\mu}{m_{\tilde{g}}} \min\left(1, \left(\frac{m_{\tilde{g}}}{m_{\tilde{b}}}\right)^2\right)$$

Neglecting the chargino-stop correction one gets

$$|\mu| \lesssim 0.4 m_{\tilde{g}} \approx M_3 \qquad\qquad \text{if} \quad m_{\tilde{g}} \geqslant m_{\tilde{b}}$$

There is a problem when $\mu < 0$

The Standard Model prediction for the anomalous muon magnetic moment is more than $3\sigma$ below the experimental result

$$a_\mu^{\mathrm{SM}} = (11659180.2 \pm 4.9) \times 10^{-10}$$

$$a_\mu^{\mathrm{exp}} = (11659208.9 \pm 6.3) \times 10^{-10}$$

$$\delta a_\mu \equiv a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (28.7 \pm 8.0) \times 10^{-10}$$

The leading $\tan\beta$ enhanced part of the chargino-sneutrino contribution

$$a_\mu^{\chi^\pm} \approx \frac{g_2 h_\mu m_\mu}{24\pi^2} \sum_a \frac{m_{\chi_a^\pm}}{m^2_{\tilde{\nu}_\mu}} U_{a2} V_{a1} F_2^C \left( \frac{m^2_{\chi_a^\pm}}{m^2_{\tilde{\nu}_\mu}} \right)$$

may be approximated as:

$$a_\mu^{\chi^\pm} \approx \frac{1}{32\pi^2} \frac{m_\mu^2}{M^2_{\rm SUSY}} g_2^2 \,\mathrm{sgn}(\mu M_2) \tan\beta$$

Neutralino-smuon contribution in the same approximation:

$$a_\mu^{\chi^0} \approx \frac{1}{192\pi^2} \frac{m_\mu^2}{M^2_{\rm SUSY}} \left[ g_1^2 \,\mathrm{sgn}(\mu M_1) - g_2^2 \,\mathrm{sgn}(\mu M_2) \right] \tan\beta$$

$a_\mu^{\chi^0}$ could dominate only if $m_{\tilde{\nu}_\mu} \gg m_{\tilde{\mu}}$ which is impossible because SO(10) soft SUSY-breaking terms $\Rightarrow m_{\tilde{\nu}_\mu} \approx m_{\tilde{\mu}_L} < m_{\tilde{\mu}_R}$

Usually $a_\mu^{\rm SUSY}$ is dominated by the chargino-sneutrino contribution

$$a_\mu^{\chi^\pm} \approx \frac{g_2 h_\mu m_\mu}{24\pi^2} \sum_a \frac{m_{\chi_a^+}}{m^2_{\tilde{\nu}_\mu}} U_{a2} V_{a1} F_2^C \left( \frac{m^2_{\chi_a^+}}{m^2_{\tilde{\nu}_\mu}} \right)$$

which has the same sign as the product $\mu M_2$

For phenomenologically acceptable models

$$(\mu < 0) \quad \Rightarrow \quad (M_2 < 0)$$

Non-universal gaugino masses are necessary

Gogoladze, Khalid, Raza, Shafi, 2010

# Soft SUSY-breaking terms in SO(10)models

Radiative Electroweak Symmetry Breaking (REWSB)

Condition $m_{H_1}^2 - m_{H_2}^2 > M_Z^2$ must be fulfilled at the weak scale

For universal initial conditions at the GUT scale

- the RGEs give positive (negative) contribution to $m_{H_1}^2 - m_{H_2}^2$ proportional to $M_{1/2}^2$ ($m_0^2$)
- $M_{1/2}^2$ must be large
- for large $\tan\beta$ and heavy stop:
  value of $M_{1/2}^2$ is strongly correlated with $\mu^2$ (with $\mu^2 > M_{1/2}^2$)
- $\Rightarrow$ too large (positive or negative) correction to the bottom mass

Carena, M.O., Pokorski, Wagner, 1994

Non-universalities of soft scalar masses considered in SO(10)

Matalliotakis, Nilles, 1994; Polonsky, Pomarol, 1994; M.O., Pokorski, 1995

## Soft scalar masses in SO(10) models

All sfermions belong to 16-dim representations
Higgses belong to one 10-dim representation

$m_{16}^2$ and $m_{10}^2$ may be different at the GUT scale
(initial conditions + RGE running between $M_{\rm Pl}$ and $M_{\rm GUT}$)

Rank of SO(10) is bigger than rank of the SM gauge symmetry group
$\Rightarrow$ $D$-terms may be generated when SO(10) is broken

Kawamura, Murayama, Yamaguchi 1994

$$\begin{aligned} m_{H_1}^2 &= m_{10}^2 + 2D \\ m_{H_2}^2 &= m_{10}^2 - 2D \\ m_{Q,U,E}^2 &= m_{16}^2 + D \\ m_{D,L}^2 &= m_{16}^2 - 3D \end{aligned}$$

Positive $D$ term helps to achieve correct REWSB

not "just-so" = "SO(10)+HS"
not "DR3" = "SO(10) + DT + RHN + 3GS"    Baer, Kraml, Sekman, 2009

# Soft gaugino masses in SO(10) models

Gaugino masses generated by VEVs of $\boldsymbol{F}$-terms

$$\frac{\langle \boldsymbol{F}^{ab} \rangle}{M_{\text{Planck}}} \boldsymbol{\lambda}^a \boldsymbol{\lambda}^b + \text{c.c.}$$

- $\langle \boldsymbol{F}^{ab} \rangle$ must transform as the singlet of the SM gauge group
- $\boldsymbol{F}^{ab}$ must belong to the symmetric part of the product $45 \times 45$
- $\boldsymbol{F}^{ab}$ may transform non-trivially under SO(10)

$$(\mathbf{45} \times \mathbf{45})_S = \mathbf{1} + \mathbf{54} + \mathbf{210} + \mathbf{770}$$

Anderson et al 1996; Martin 2009

54-dimensional representation is very interesting leading to opposite signs of $M_2$ and $M_3$:

$$M_3 : M_2 : M_1 = 2 : -3 : -1$$

## $(g-2)_\mu$ vs $\mathrm{BR}(b \to s\gamma)$

- $(g-2)_\mu$:
  SM prediction is more than $3\sigma$ smaller than the experimental result
  $\Rightarrow$ light SUSY spectrum needed for substantial (positive) SUSY contribution

- $\mathrm{BR}(b \to s\gamma)$:
  SM prediction is in $1\sigma$ agreement with the experimental result
  Charged Higgs contribution increases the SM result
  $\Rightarrow$ usually heavy SUSY spectrum required to suppress additional SUSY contributions

How to disentangle SUSY (chargino) contributions to $(g-2)_\mu$ and $b \to s\gamma$?

One needs a more careful analysis of the (sign and magnitude of) SUSY contribution to $b \to s\gamma$

Dominant chargino contribution to $b \longrightarrow s\gamma$ for large $\tan\beta$:

$$C_{7,8}^{\chi^+} = \frac{1}{\cos\beta} \sum_{a=1,2} \left\{ s_{\tilde{t}} c_{\tilde{t}} \frac{U_{a2} V_{a2} m_t}{2 \sin\beta m_{\chi_a^+}} \left[ F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_1}^2}{m_{\chi_a^+}^2} \right) - F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_2}^2}{m_{\chi_a^+}^2} \right) \right] \right.$$

$$\left. + \frac{U_{a2} V_{a1} M_W}{\sqrt{2} m_{\chi_a^+}} \left[ F_{7,8}^{(3)} \left( \frac{m_{\tilde{q}}^2}{m_{\chi_a^+}^2} \right) - c_{\tilde{t}}^2 F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_1}^2}{m_{\chi_a^+}^2} \right) - s_{\tilde{t}}^2 F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_2}^2}{m_{\chi_a^+}^2} \right) \right] \right\}$$

Degrassi Gambino Giudice 2000

$s_{\tilde{t}}$ ($c_{\tilde{t}}$) – sine (cosine) of the stop mixing angle

$V_{a1}$ – gaugino component of $a$-th chargino

Dominant chargino contribution to $b \longrightarrow s\gamma$ for large $\tan\beta$:

$$C_{7,8}^{\chi^+} = \frac{1}{\cos\beta} \sum_{a=1,2} \left\{ s_{\tilde{t}} c_{\tilde{t}} \frac{U_{a2} V_{a2} m_t}{2 \sin\beta m_{\chi_a^+}} \left[ F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_1}^2}{m_{\chi_a^+}^2} \right) - F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_2}^2}{m_{\chi_a^+}^2} \right) \right] \right.$$
$$\left. + \frac{U_{a2} V_{a1} M_W}{\sqrt{2} m_{\chi_a^+}} \left[ F_{7,8}^{(3)} \left( \frac{m_{\tilde{q}}^2}{m_{\chi_a^+}^2} \right) - c_{\tilde{t}}^2 F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_1}^2}{m_{\chi_a^+}^2} \right) - s_{\tilde{t}}^2 F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_2}^2}{m_{\chi_a^+}^2} \right) \right] \right\}$$

Degrassi Gambino Giudice 2000

Signs (relative to the SM and $H^+$ contributions) are the same as:
$\text{sgn}(\mu A_t)$ for the stop-mixing part;
$\text{sgn}(-\mu M_2)$ for the "gaugino" part.

$A_t$ is often negative due to RGEs and the stop-mixing part has "wrong" (positive) sign when $\mu < 0$

gaugino part has always "correct" (negative) sign when $\mu, M_2 < 0$

Dominant chargino contribution to $b \to s\gamma$ for large $\tan\beta$:

$$C_{7,8}^{\chi^+} = \frac{1}{\cos\beta} \sum_{a=1,2} \left\{ s_{\tilde{t}} c_{\tilde{t}} \frac{U_{a2} V_{a2} m_t}{2 \sin\beta m_{\chi_a^+}} \left[ F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_1}^2}{m_{\chi_a^+}^2} \right) - F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_2}^2}{m_{\chi_a^+}^2} \right) \right] \right.$$
$$\left. + \frac{U_{a2} V_{a1} M_W}{\sqrt{2} m_{\chi_a^+}} \left[ F_{7,8}^{(3)} \left( \frac{m_{\tilde{q}}^2}{m_{\chi_a^+}^2} \right) - c_{\tilde{t}}^2 F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_1}^2}{m_{\chi_a^+}^2} \right) - s_{\tilde{t}}^2 F_{7,8}^{(3)} \left( \frac{m_{\tilde{t}_2}^2}{m_{\chi_a^+}^2} \right) \right] \right\}$$

Degrassi Gambino Giudice 2000

BR($b \to s\gamma$) prefers:

- substantial gaugino component of the lighter chargino $V_{11}$ ($M_2^2 \lesssim \mu^2$)
- big splitting between stops and 1st/2nd generation squarks
- positive or small $A_t$ (stop mixing)
  (no large negative $A_t$ needed for $\delta m_b$ if $\mu < 0$)

All above conditions are typically easier to satisfy if $M_{1/2} \ll m_{16}$

- Squark splitting
  For $M_{1/2} \ll m_{16}$ the RGEs for $m_Q$ and $m_U$ are dominated by terms proportional to the Yukawa couplings
  $\Rightarrow$ maximal mass splitting between stops and other up-type squarks
- Small $A_t$
  Since RGE running usually results in $A_t \sim \mathcal{O}(-M_{1/2})$ the hierarchy $M_{1/2} \ll m_{16}$ naturally suppresses the stop mixing angle.
- $M_2^2 \lesssim \mu^2$ (substantial gaugino component of the lighter chargino)
  Argument specific for models with top-bottom-tau Yukawa unification
  Requirement of not too large gluino-sbottom correction to $m_b$ gives:

$$|\mu/M_2| \sim 2|\mu/m_{\tilde{g}}| \lesssim 0.8 \max\left(1, \left(\frac{m_{\tilde{b}}}{m_{\tilde{g}}}\right)^2\right)$$

  $\Rightarrow$ the lighter chargino is dominated by the higgsino component unless the gluino is substantially lighter than the heavier sbottom and this is possible only if $M_{1/2} \ll m_{16}$.

# Neutralino relic abundance

In our model the lightest neutralino is bino-dominated

GUT initial conditions + RGE running

$\Rightarrow$ $|M_1| : |M_2| : |M_3| \approx 1 : 6 : 12$ at the weak scale

$\Rightarrow$ wino cannot be the LSP

Requirement of Yukawa unification sets the (conservative) constraint (at the weak scale):

$$1.2 \lesssim \left|\frac{\mu}{M_1}\right| \lesssim 5$$

$\Rightarrow$ the higgsinos are heavier than the bino but sometimes only slightly

LSP is bino-like but possibly with non-negligible higgsino admixture

# Numerical analysis

Parameters: $m_{16}$, $m_{10}$, $D$, $M_{1/2}$, $A_0$, $\tan\beta$

Initial values at the GUT scale:

$$
\begin{aligned}
m_{H_1}^2 &= m_{10}^2 + 2D \\
m_{H_2}^2 &= m_{10}^2 - 2D \\
m_{Q,U,E}^2 &= m_{16}^2 + D \\
m_{D,L}^2 &= m_{16}^2 - 3D
\end{aligned}
$$

$$
\begin{aligned}
M_3 &= M_{1/2} \\
M_2 &= -\tfrac{3}{2} M_{1/2} \\
M_1 &= -\tfrac{1}{2} M_{1/2}
\end{aligned}
$$

$$
\begin{aligned}
A_i &= A_0 \\
\mathrm{sgn}(\mu) &= -1
\end{aligned}
$$

Experimental constraints:

$12.7 \cdot 10^{-10} < \delta a_\mu^{SUSY} < 44.7 \cdot 10^{-10} \quad (2\sigma)$

$2.89 \cdot 10^{-4} < \mathrm{BR}(b \to s\gamma) < 4.21 \cdot 10^{-4} \quad (2\sigma)$

$\mathrm{BR}(B_s \to \mu^+\mu^-) < 5.8 \cdot 10^{-8}$

$\Omega_{\mathrm{DM}} h^2 < 0.13 \quad (3\sigma)$

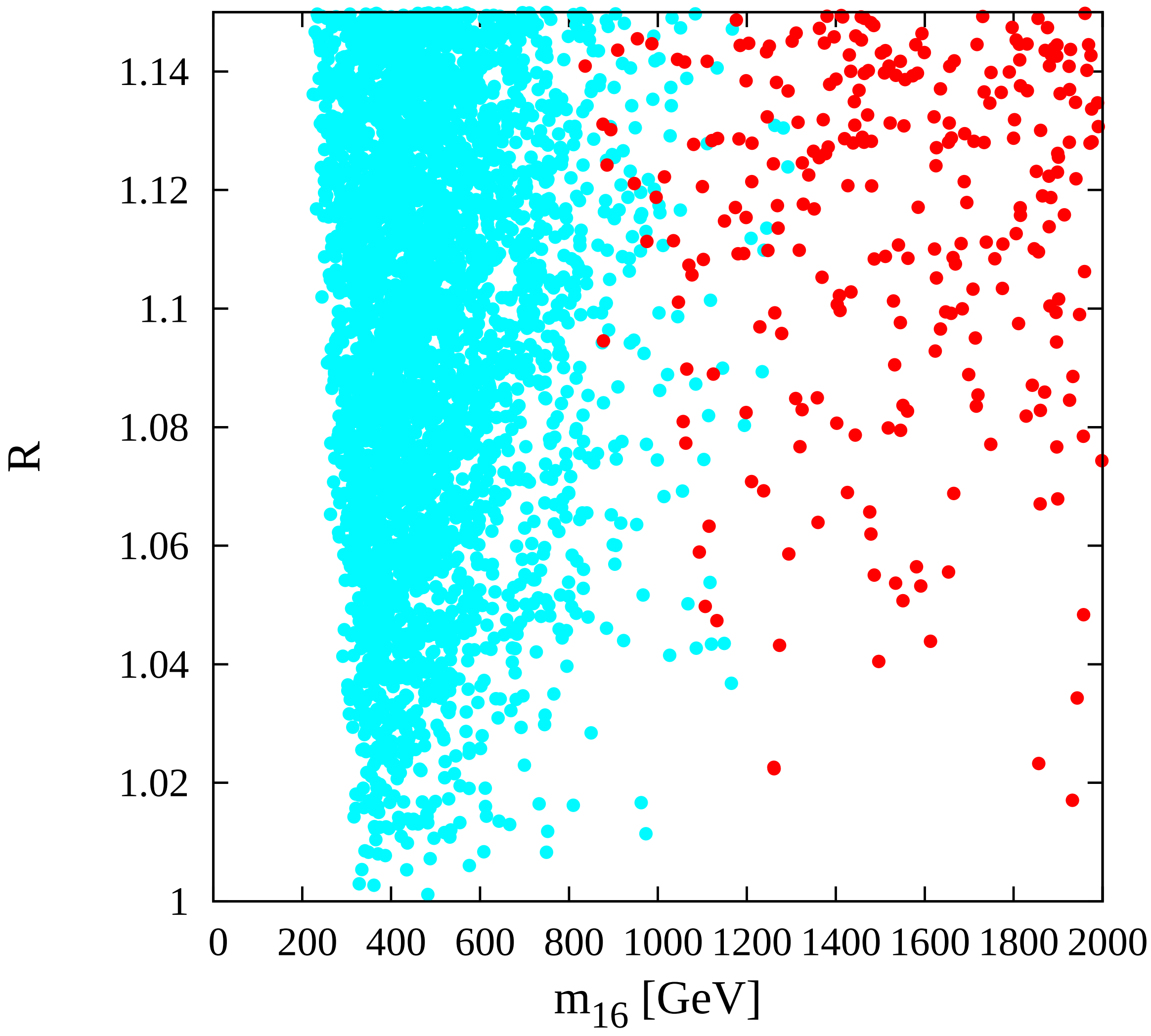
$m_{h^0} > 111.4\,\mathrm{GeV} \quad (114\mathrm{GeV})$

limits on SUSY particles masses, neutral LSP

Numerical codes:

SOFTSUSY, MICROMEGAS

Results of initial (wide) scan $\quad$ R= $\max(h_t, h_b, h_\tau)/\min(h_t, h_b, h_\tau)$




• $(g-2)_\mu$ within $2\sigma$

BR$(b \to s\gamma)$ outside $2\sigma$

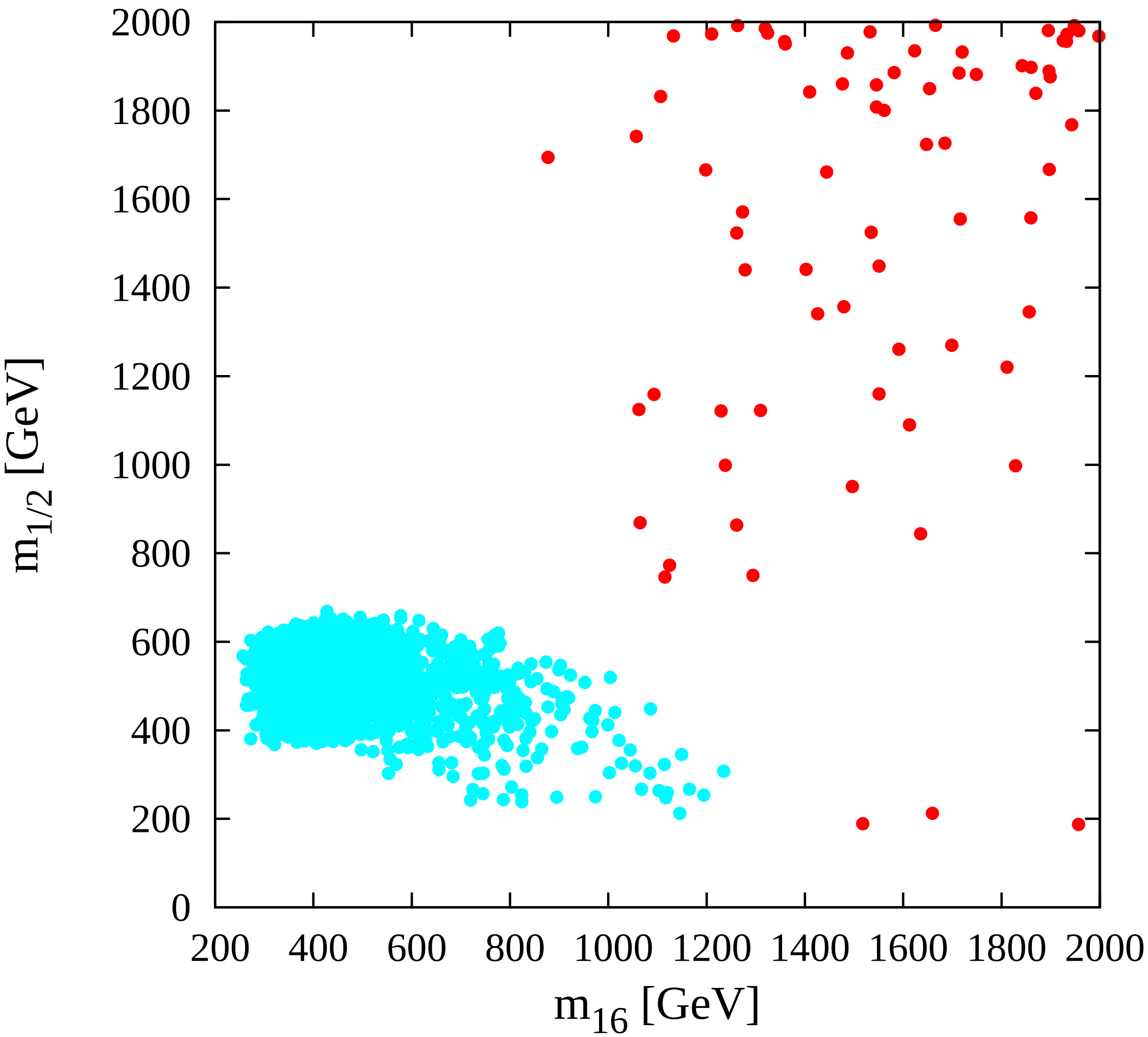
• BR$(b \to s\gamma)$ within $2\sigma$

$(g-2)_\mu$ outside $2\sigma$

Light sparticle spectrum → many points with reasonable values of $(g-2)_\mu$

BR$(b \to s\gamma)$ requires much more than just heavy sparticle spectrum

Results of initial (wide) scan

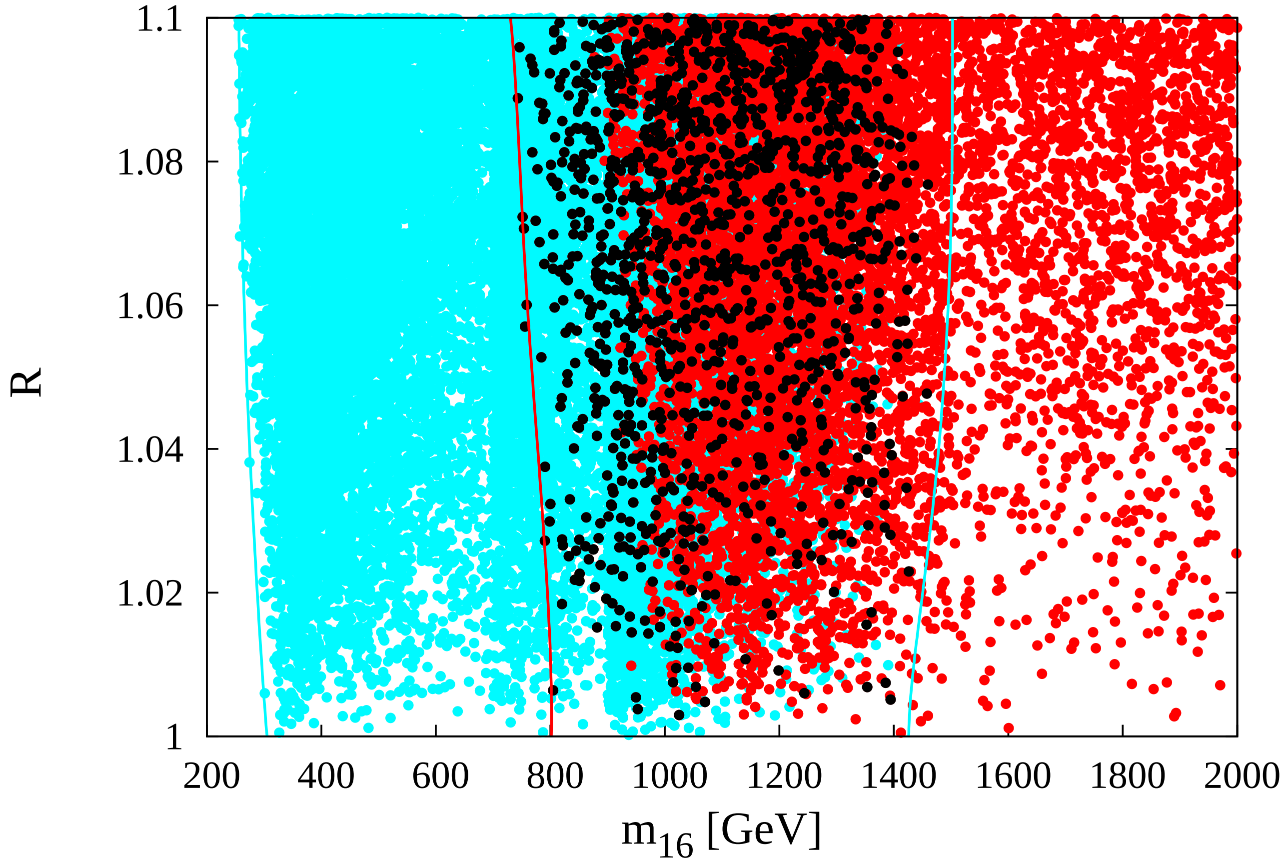



• $(g-2)_\mu$ within $2\sigma$
BR$(b \to s\gamma)$ outside $2\sigma$

• BR$(b \to s\gamma)$ within $2\sigma$
$(g-2)_\mu$ outside $2\sigma$

From now on $R \leq 1.1$

Two interesting regions: with and without hierarchy $m_{16} \gg M_{1/2}$



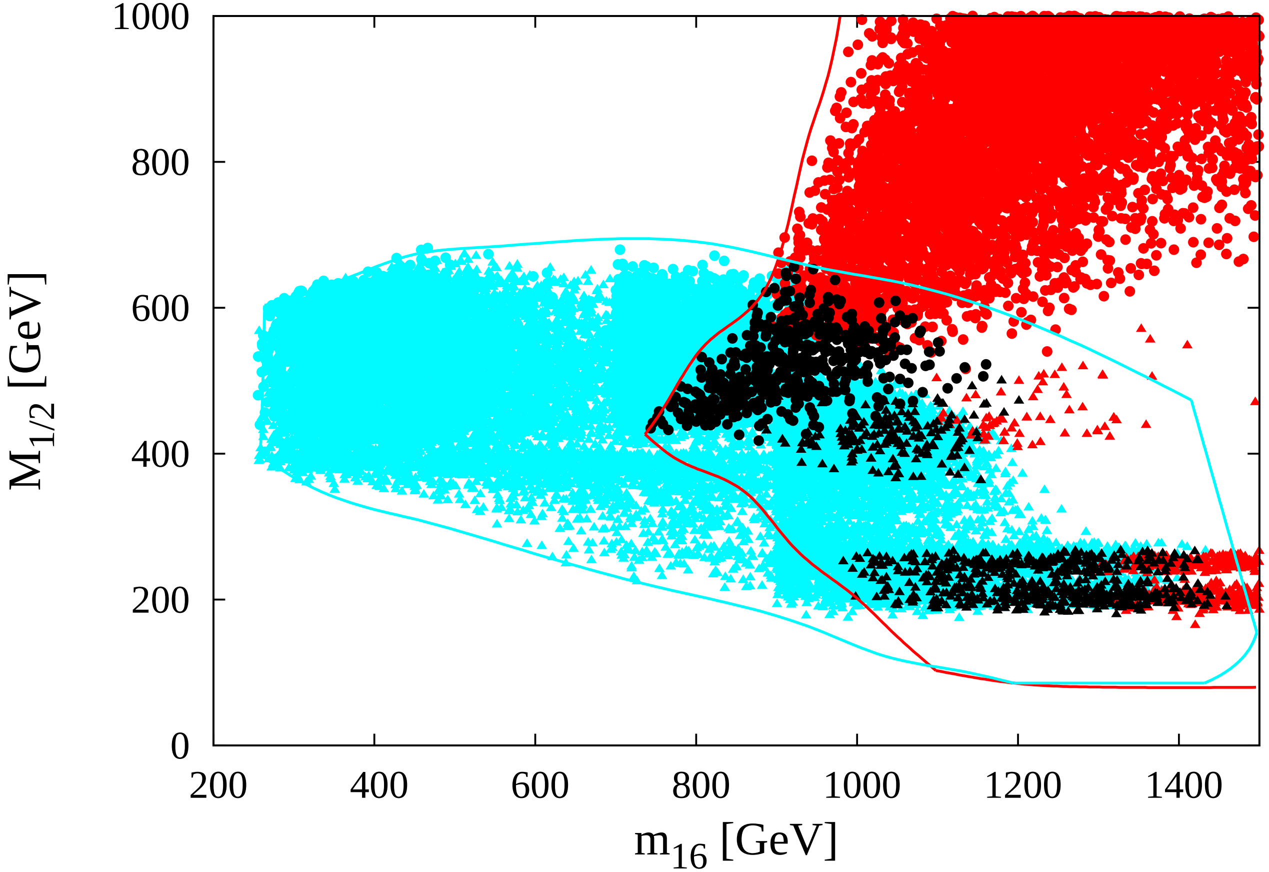

• $(g-2)_\mu$ within $2\sigma$

• $\mathrm{BR}(b \to s\gamma)$ within $2\sigma$

• $\mathrm{BR}(b \to s\gamma)$ and $(g-2)_\mu$ within $2\sigma$

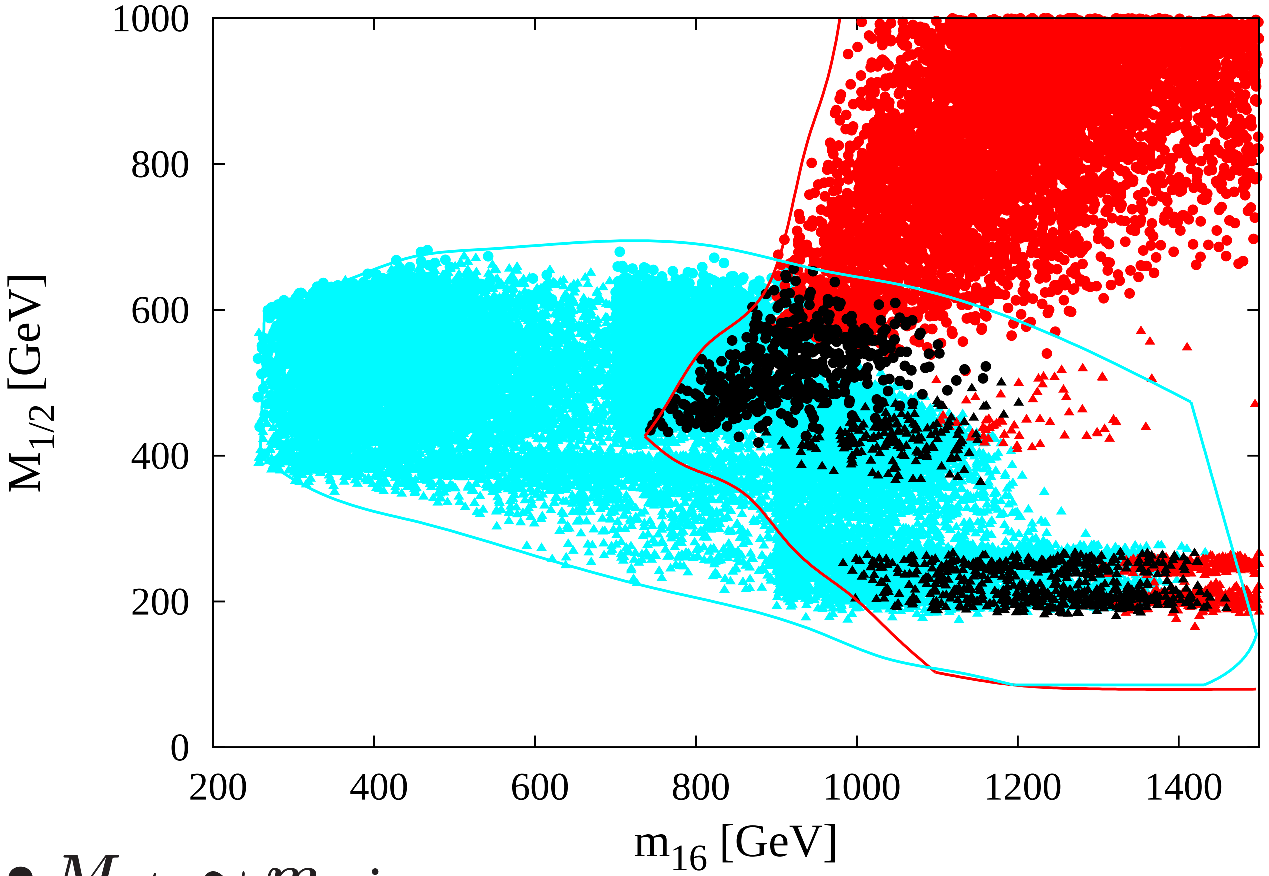
contours: arbitrary $\Omega_{\mathrm{DM}}$

- Perfect t-b-$\tau$ Yukawa unification possible for $m_{16} \gtrsim 300$ GeV
- $(g-2)_\mu$ within $2\sigma$ possible for $250 \text{ GeV} \lesssim m_{16} \lesssim 1500$ GeV
- $\mathrm{BR}(b \to s\gamma)$ within $2\sigma$ possible for $m_{16} \gtrsim 700$ GeV
- All 3 conditions: $800 \text{ GeV} \lesssim m_{16} \lesssim 1400$ GeV



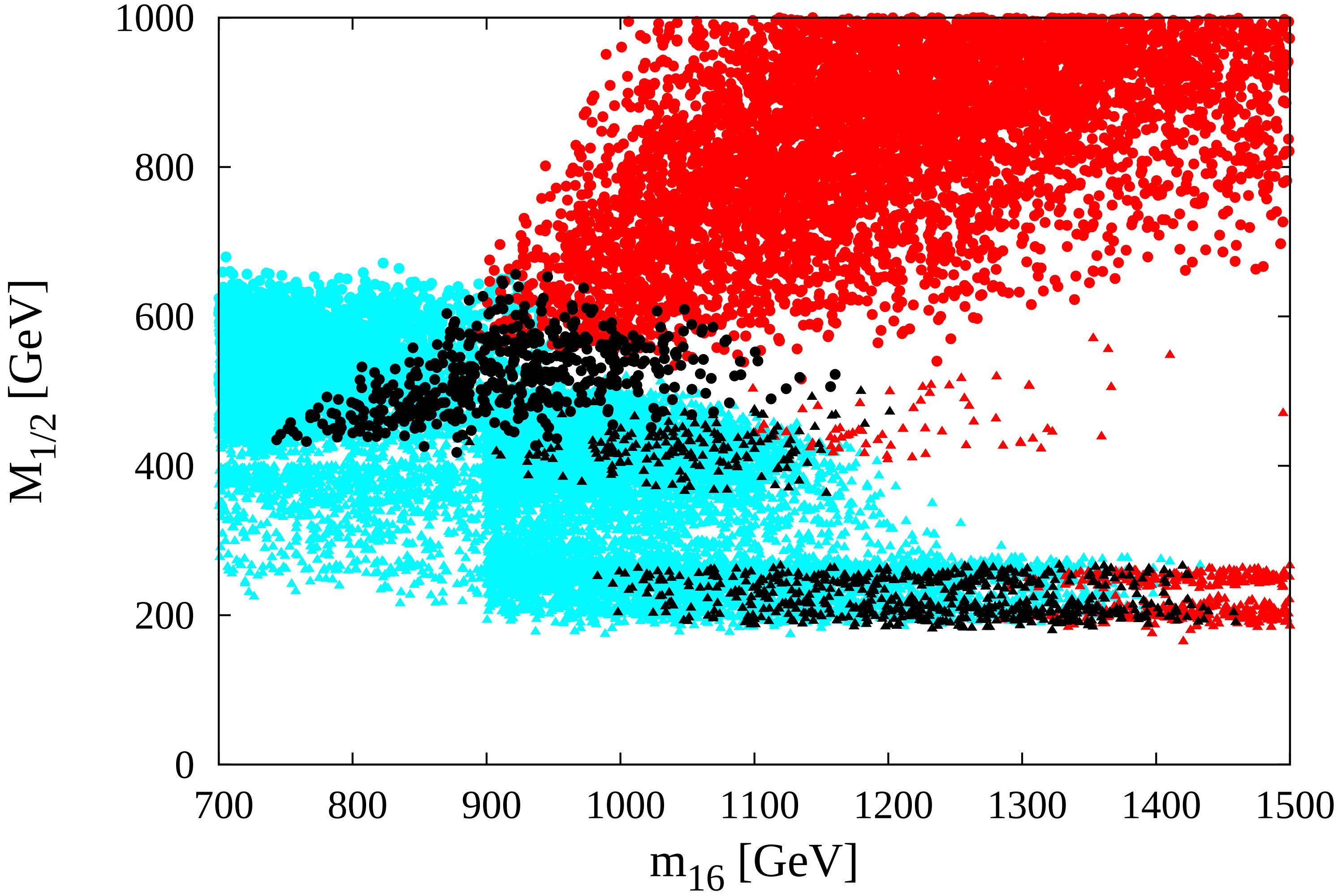

Tension between $b \longrightarrow s\gamma$ and $\Omega_{\mathrm{DM}}h^2$, especially for big $m_{16}$

- $b \longrightarrow s\gamma$ prefers big values of $|\mu|/M_2$
  gaugino component of the lighter chargino
- $\Omega_{\mathrm{DM}}h^2$ prefers small values of $|\mu|/M_1$
  higgsino component of LSP

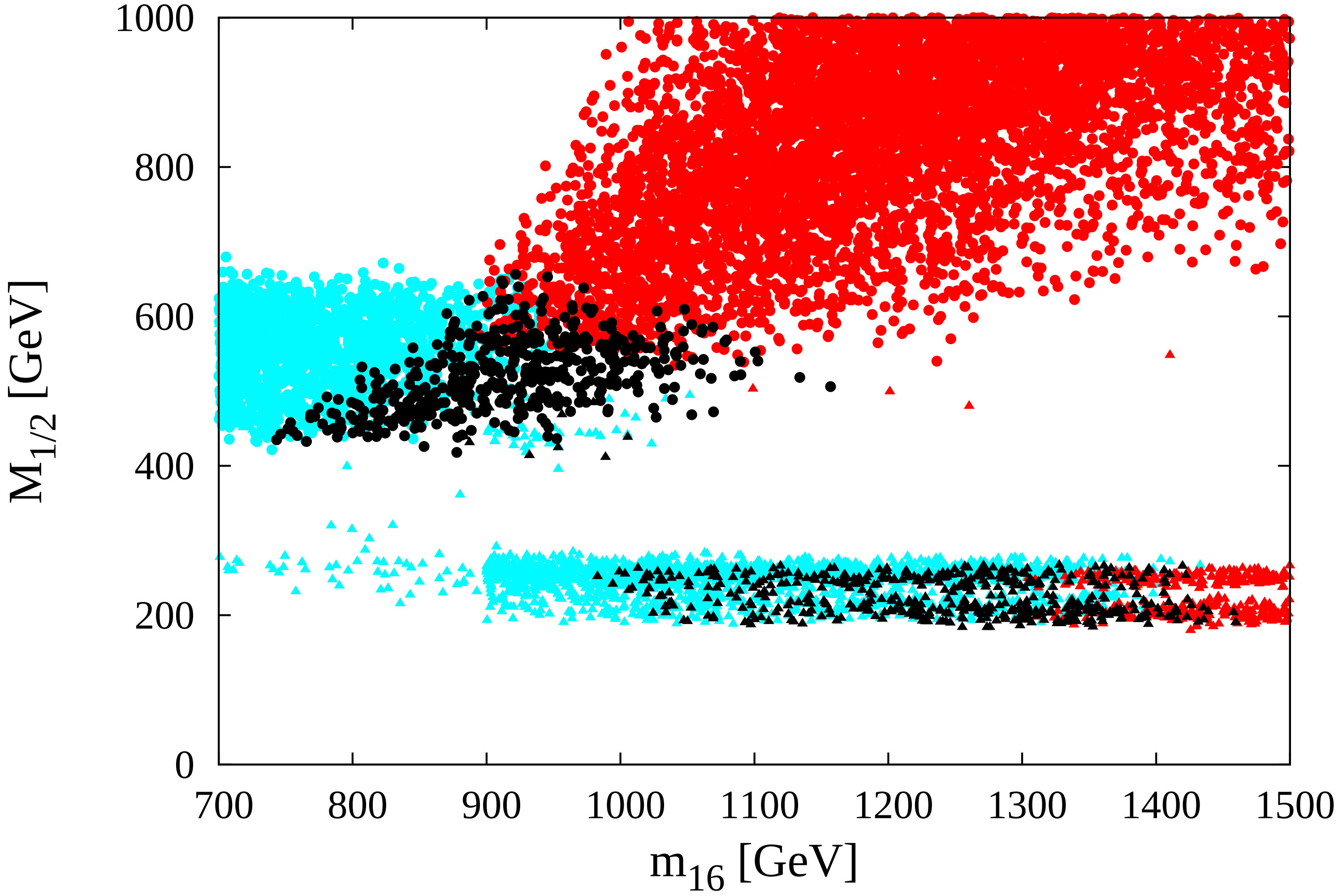



- $M_{1/2} \sim m_{16}$:
  co-annihilation with stau necessary to give small enough $\Omega h^2$
- $M_{1/2} \lesssim m_{16}$:
  annihilation via light $A^0$ (LHC?)
- $M_{1/2} \ll m_{16}$:
  light bino LSP (with a few % higgsino admixture)
  annihilate effectively via $h$ or $Z$ resonance

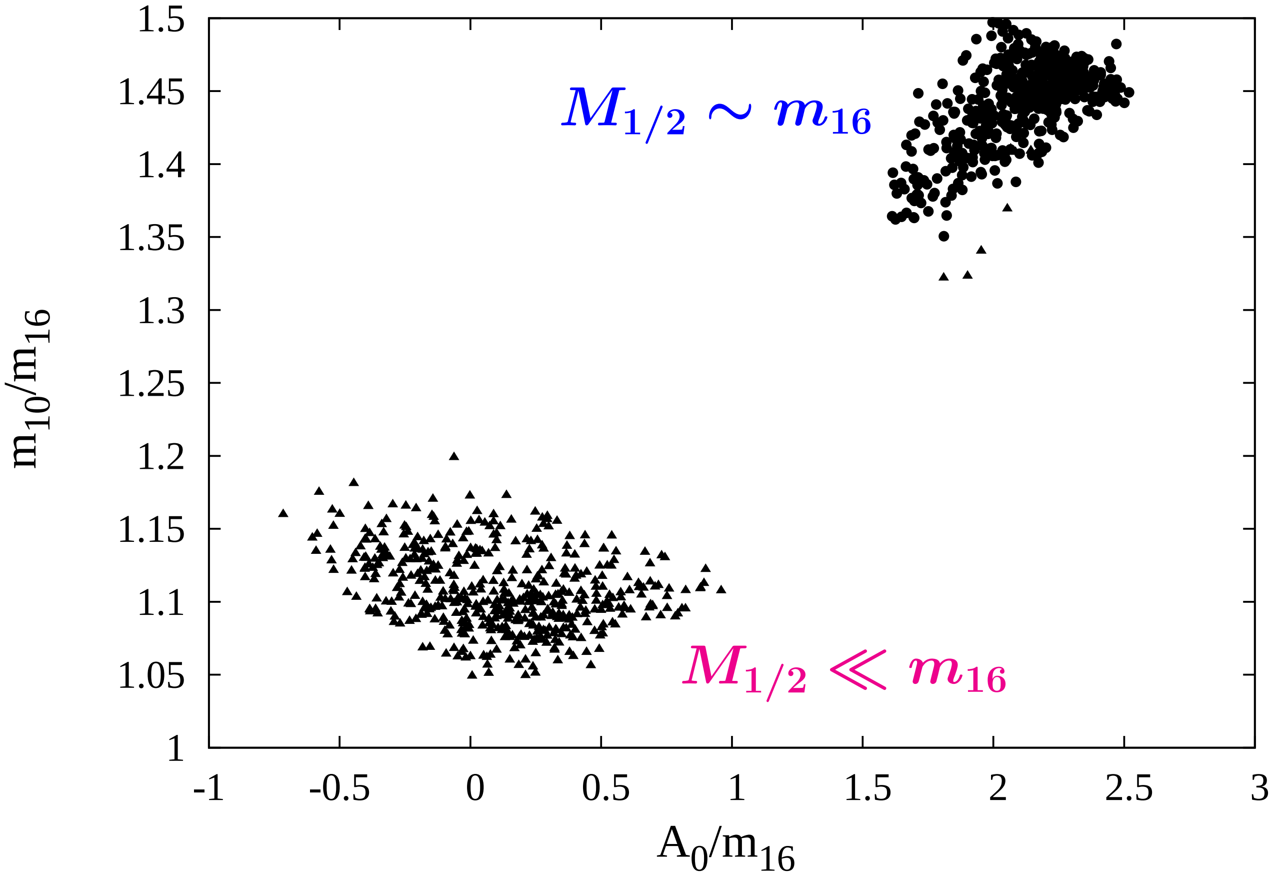
before August 30th 2011



after August 30th 2011

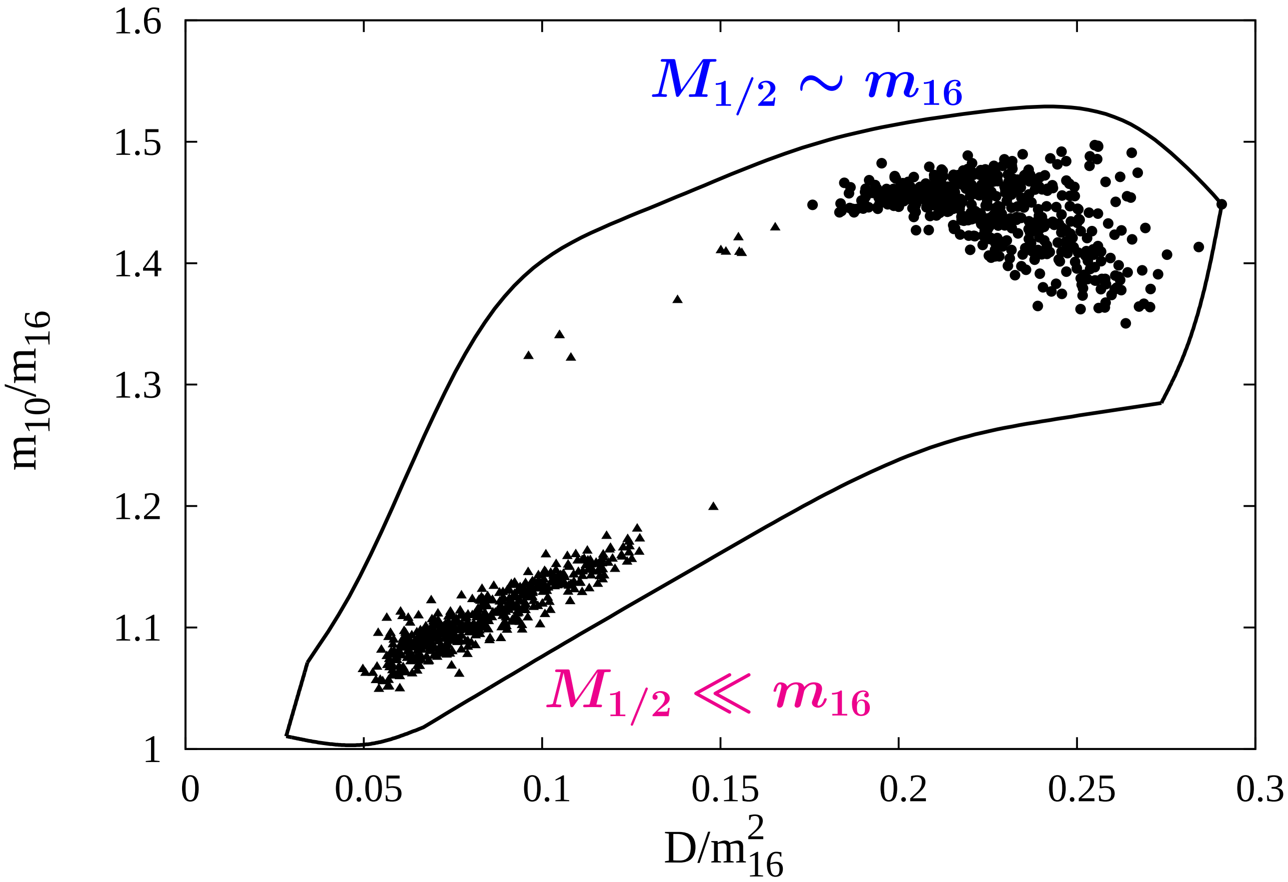



CMS PAS HIG-11-020




- $M_{1/2} \ll m_{16}$:
  the lighter chargino has big gaugino component so its contribution to BR($b \longrightarrow s\gamma$) may be negative even for negative $A_t$ (small $A_0$)

- $M_{1/2} \sim m_{16}$:
  $b \longrightarrow s\gamma$ requires positive $A_t$
  $\Rightarrow$ $A_0$ must be large (but not too large)

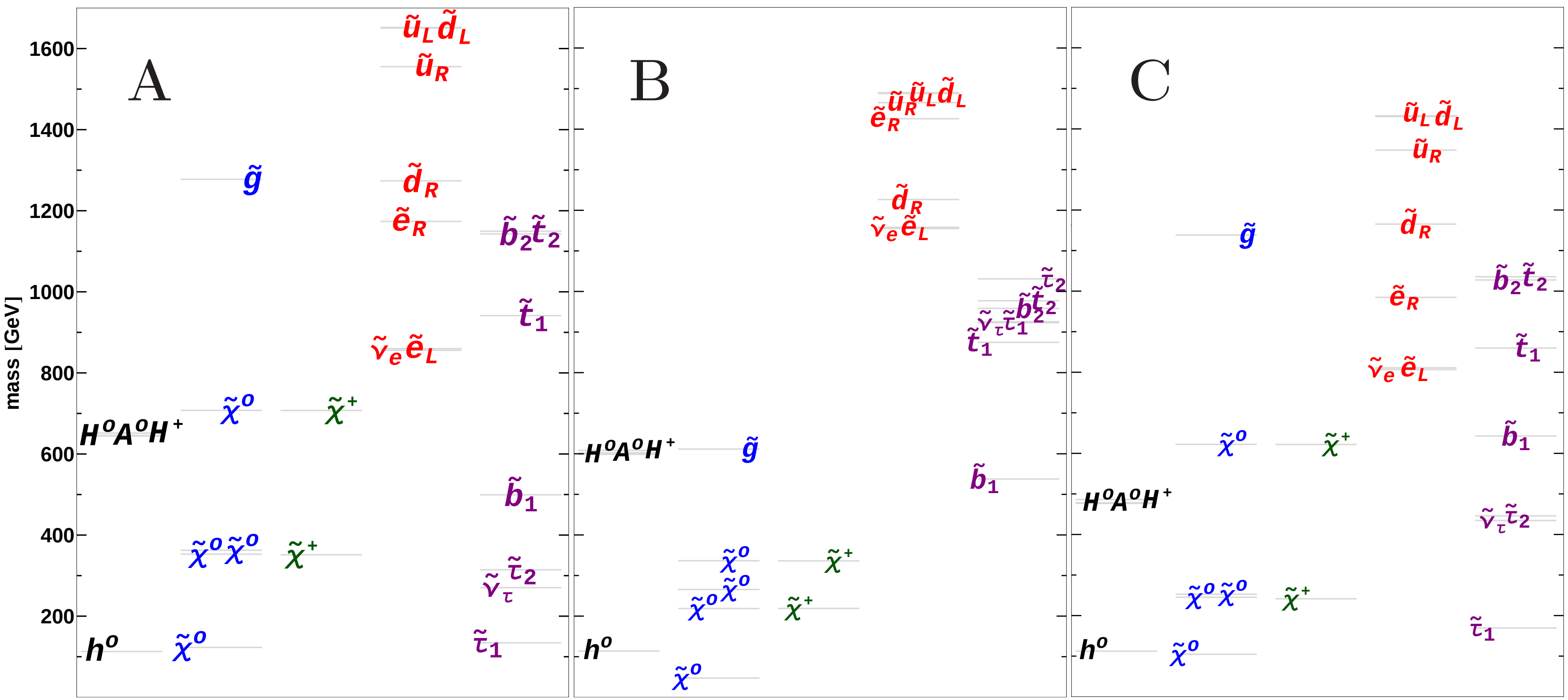



Condition of proper EWSB implies

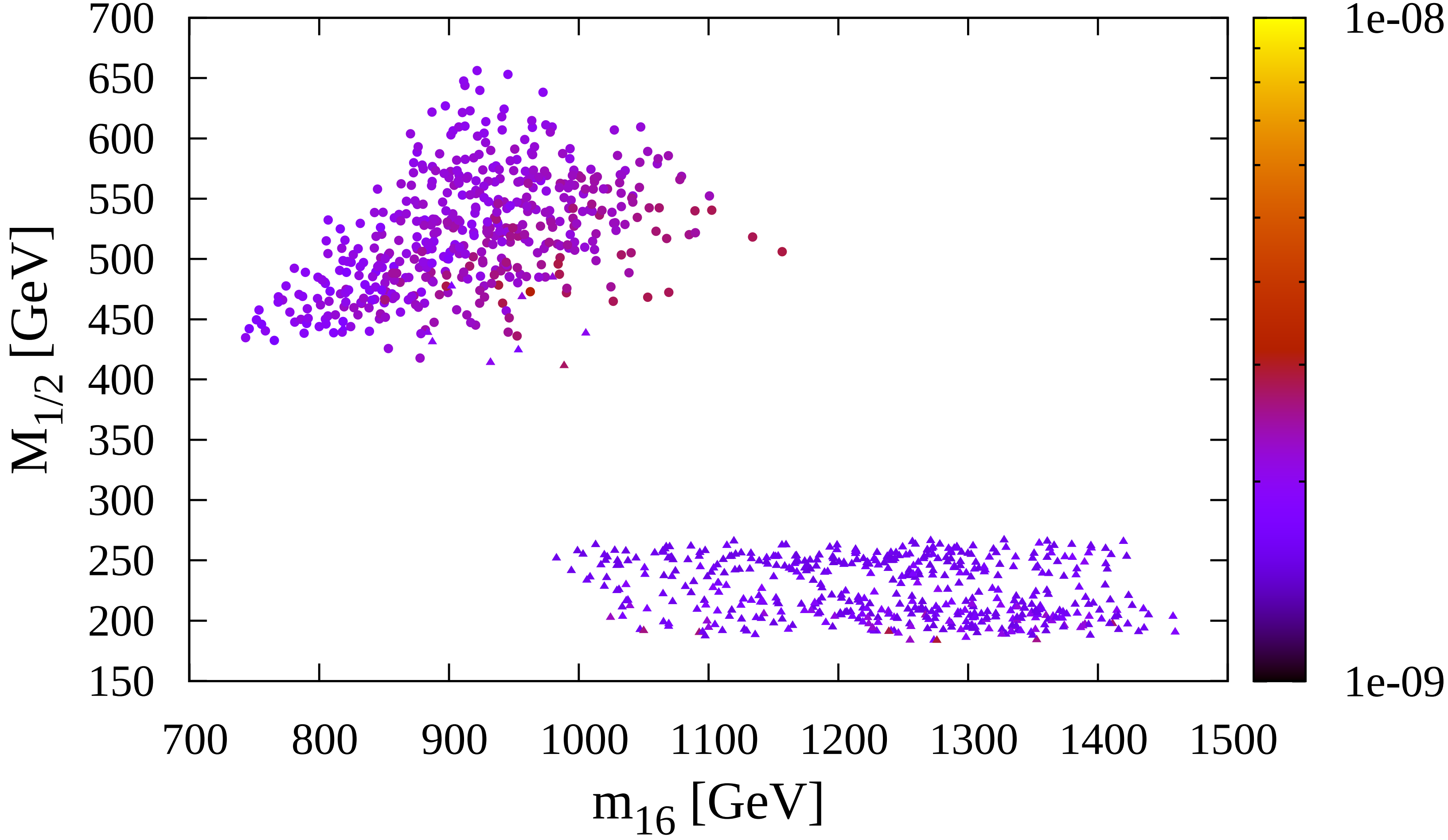
$$\frac{\mu^2}{M_{1/2}^2} \approx \left[1.2 + 0.65\frac{m_{16}^2}{M_{1/2}^2}\left(0.97 - \frac{m_{10}^2}{m_{16}^2} + 2.9\frac{D}{m_{16}^2} + 0.15\frac{A_0^2}{m_{16}^2} - 0.3\frac{M_{1/2}A_0}{m_{16}^2}\right)\right]$$

Yukawa unification requires $|\mu| < M_{1/2}$ and $D > 0 \;\Rightarrow\; m_{10}^2/m_{16}^2 > 1$

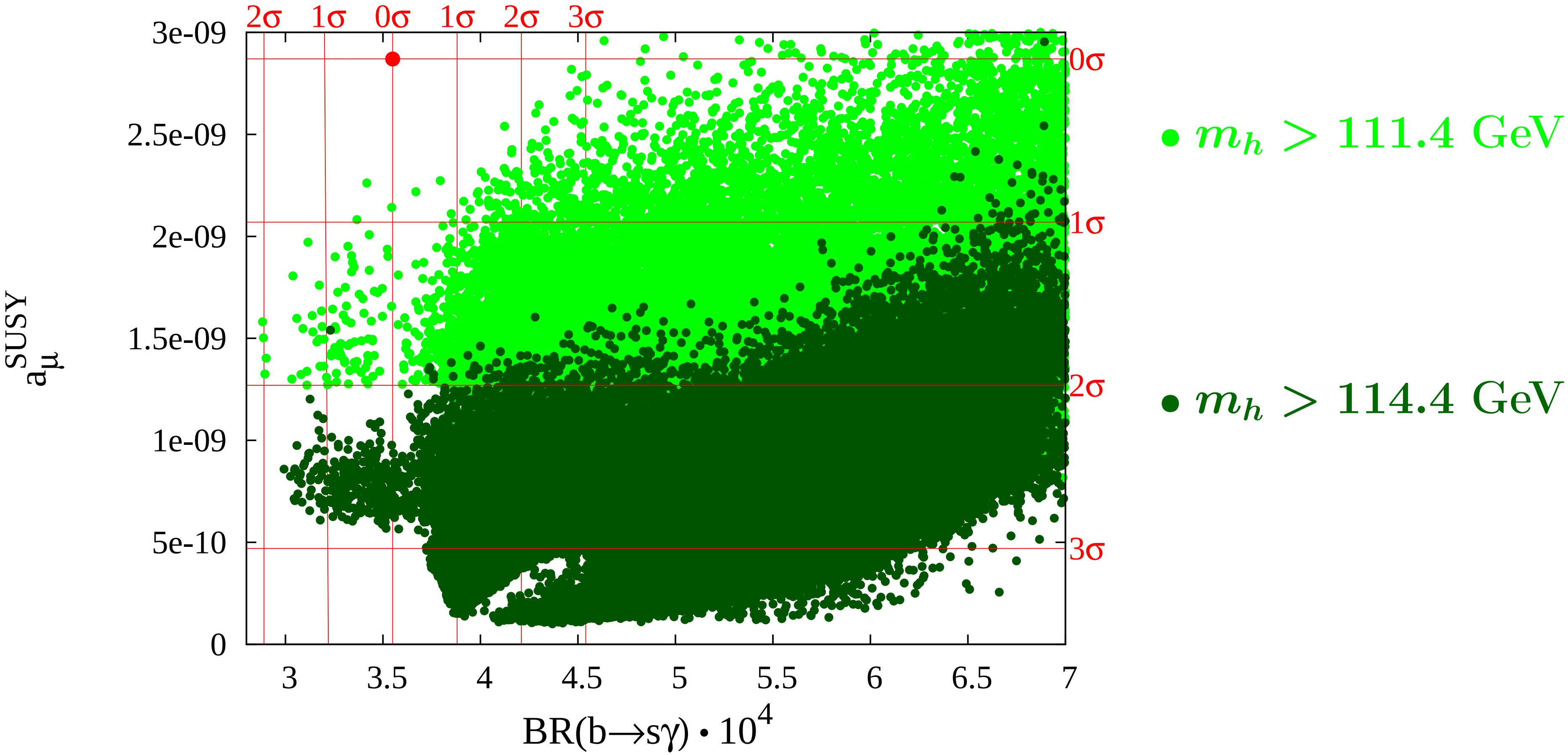
SO(10) RGEs give $m_{10}^2 > m_{16}^2$ for universal soft scalar masses at $M_{\rm Pl}$




| | $m_{16}$ | $M_{1/2}$ | $\frac{m_{10}}{m_{16}}$ | $\frac{D}{m_{16}^2}$ | $\frac{A_0}{m_{16}}$ | $\tan\beta$ | $a_\mu^{SUSY}$ | BR$(b \to s\gamma)$ | $\Omega_{\rm DM}h^2$ | $R$ |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 1054 | 542.5 | 1.454 | 0.1907 | 2.312 | 45.78 | $13.2 \cdot 10^{-10}$ | $3.83 \cdot 10^{-4}$ | 0.095 | 1.007 |
| B | 1352 | 224.2 | 1.125 | 0.0921 | −0.357 | 48.47 | $14.2 \cdot 10^{-10}$ | $4.11 \cdot 10^{-4}$ | 0.111 | 1.016 |
| C | 902 | 477.5 | 1.410 | 0.1501 | 1.465 | 47.89 | $17.1 \cdot 10^{-10}$ | $4.16 \cdot 10^{-4}$ | 0.123 | 1.077 |

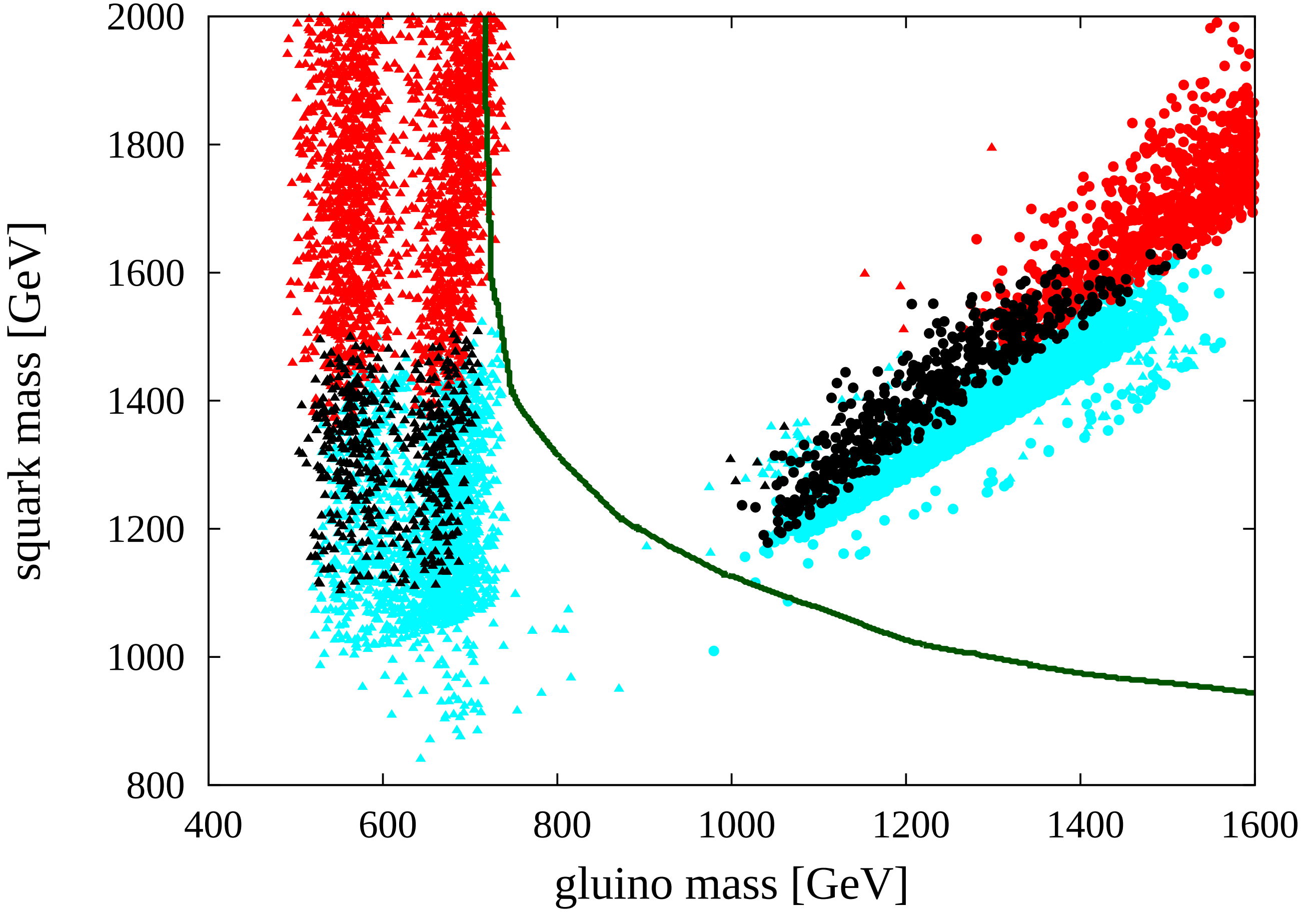



No problems with BR($\boldsymbol{B_s} \rightarrow \boldsymbol{\mu}^+\boldsymbol{\mu}^-$)




Squarks are relatively light $\quad\Rightarrow\quad$ the lightest Higgs is light

Green curve:
exclusion limit from ATLAS for a simplified model (talk by D. Tovey)




Are gluinos with mass below 700 GeV excluded in our model?
Dedicated analysis of the LHC data is necessary

# SUMMARY (1)

- Yukawa $t - b - \tau$ unification more natural when $\mu < 0$
- Non-universal soft gaugino and scalar masses at $M_{\rm GUT}$ are necessary
  - conditions $\mu M_3 < 0$ and $M_2 M_3 < 0$ are crucial
- Appropriate pattern of non-universalities easily accommodated in SO(10):
  - $m_{10}^2$–$m_{16}^2$ splitting and $D$ terms
  - gaugino masses from $F$ term transforming as 54-dim. rep.
- Tension between $(g-2)_\mu$ and BR($b \longrightarrow s\gamma$) may be relaxed
  - gaugino part of the chargino contribution to $b \longrightarrow s\gamma$ is important

- Other models with opposite signs of $M_3$ and $M_2$ also may accommodate acceptable values of $(g-2)_\mu$ and BR($b \longrightarrow s\gamma$) but may predict different SUSY spectrum - especially LSP

# SUMMARY (2)

- Two regions give acceptable relic abundance of LSP
  - A: $M_{1/2} \sim m_{16}$: co-annihilation with stau
  - B: $M_{1/2} \ll m_{16}$: resonance ($h$ or $Z$) annihilation
- Spectrum
  - Relatively light sparticles: all masses well below 2 TeV
  - gluino: A: ∼1000–1600 GeV; B: ∼500–700 GeV.
  - 1st/2nd generation squarks:
    A: ∼1000–1800 GeV; B: ∼900–1600 GeV.
  - stop: A: ∼800–1200 GeV; B: ∼700–900 GeV.
  - sbottom (R) typically much lighter then other squarks
  - LSP (bino-dominated): A: ∼100–200 GeV; B: ∼40–60 GeV.
  - the lightest sfermion: A: stau; B: sbottom.
  - Higgs mass close to the LEP bound
- Dedicated analysis necessary to compare with the LHC data

Backup

Higgs masses **A**

Mh = 112.77

MHH = 644.47

MH3 = 645.57

MHc = 651.50

Masses of odd sector Particles:

| | | |
|---|---|---|
| o1 : MNE1 = 122.9 | l1 : MSl1 = 134.2 | nl : MSnl = 270.3 |
| l2 : MSl2 = 314.4 | 1+ : MC1 = 351.4 | o2 : MNE2 = 352.9 |
| o3 : MNE3 = 362.7 | b1 : MSb1 = 499.4 | 2+ : MC2 = 707.4 |
| o4 : MNE4 = 707.6 | nm : MSnm = 854.5 | ne : MSne = 855.9 |
| mL : MSmL = 858.3 | eL : MSeL = 859.9 | t1 : MSt1 = 941.4 |
| b2 : MSb2 = 1142.8 | t2 : MSt2 = 1149.5 | mR : MSmR = 1171.6 |
| eR : MSeR = 1173.6 | sR : MSsR = 1273.5 | dR : MSdR = 1273.7 |
| g : MSG = 1277.5 | cR : MScR = 1555.4 | uR : MSuR = 1555.4 |
| cL : MScL = 1650.3 | uL : MSuL = 1650.4 | sL : MSsL = 1652.1 |
| dL : MSdL = 1652.2 | | |

o1 = 0.988*bino -0.008*wino -0.143*higgsino1 +0.052*higgsino2

Higgs masses B

Mh = 113.82

MHH = 598.64

MH3 = 602.46

MHc = 608.42

Masses of odd sector Particles:

| | | |
|---|---|---|
| o1 : MNE1 = 47.3 | o2 : MNE2 = 218.7 | 1+ : MC1 = 218.9 |
| o3 : MNE3 = 265.6 | 2+ : MC2 = 336.1 | o4 : MNE4 = 336.5 |
| b1 : MSb1 = 538.0 | g : MSG = 611.6 | t1 : MSt1 = 874.5 |
| nl : MSnl = 923.1 | l1 : MSl1 = 925.5 | b2 : MSb2 = 958.4 |
| t2 : MSt2 = 977.1 | l2 : MSl2 = 1031.0 | nm : MSnm = 1154.4 |
| ne : MSne = 1155.1 | mL : MSmL = 1157.2 | eL : MSeL = 1158.1 |
| sR : MSsR = 1226.4 | dR : MSdR = 1226.5 | mR : MSmR = 1424.6 |
| eR : MSeR = 1425.7 | cR : MScR = 1465.3 | uR : MSuR = 1465.3 |
| cL : MScL = 1487.8 | uL : MSuL = 1487.8 | sL : MSsL = 1489.8 |
| dL : MSdL = 1489.9 | | |

o1 = 0.983*bino -0.013*wino -0.180*higgsino1 +0.037*higgsino2