Anomaly mediated SUSY breaking scenarios in the light of cosmology and in the dark matter

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Based on: *arXiv:1103.3244 [hep-ph]* :
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Supervisors : Alexandre ARBEY and Aldo DEANDREA

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Outline

Supersymmetry

- SUSY motivation in particle physics : unification of gauge couplings, solution of the hierarchy problem, description of gravity, **candidates for cold dark matter (WIMP)**.
- A priori particles and their superpartners have the same mass which is a direct consequence of the supersymmetry algebra. As this mass degeneracy is not observed, **SUSY must be broken**.
- In supersymmetric theories, SM particles are lighter than their superpartners $\rightarrow$ break SUSY in a hidden sector and mediate the breaking to the MSSM sector.
- Orbifold GUTs provide a natural possibility for mediated SUSY breaking, using one orbifold fixed point (brane) to locate the MSSM, a different one to break supersymmetry and using a bulk field to mediate the breaking.

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Flavour observables

- Direct searches at LEP, B-factories, Tevatron and LHC.

$$2.16 \times 10^{-4} < \mathrm{BR}(B \to X_s \gamma) < 4.93 \times 10^{-4} \ .$$

$$\mathrm{BR}(B_s \to \mu^+ \mu^-) < 4.7 \times 10^{-8} \ .$$

$$\begin{aligned}
0.56 < & \quad \frac{\mathrm{BR}(B \to \tau\nu)}{\mathrm{BR}_{SM}(B \to \tau\nu)} & < 2.70 \ , \\
4.7 \times 10^{-2} < & \quad \mathrm{BR}(D_s \to \tau\nu) & < 6.1 \times 10^{-2} \ , \\
0.151 < & \quad \frac{\mathrm{BR}(B \to D^0 \tau\nu)}{\mathrm{BR}(B \to D^0 e\nu)} & < 0.681 \ , \\
0.982 < & \quad \mathrm{R}_{\ell 23}(K \to \mu\nu) & < 1.018 \ .
\end{aligned}$$

- These observables receive large enhancements from SUSY contributions.

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Cosmological observables

- WMAP limits on the relic density constraints :

$$0.088 < \Omega_{DM} h^2 < 0.123 \ .$$

- In the standard cosmology the dominant component before BBN is radiation, however energy density and entropy content can be modified (with no consequences on the cosmological observations).
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Minimal AMSB

- Predictive framework for SUSY breaking in which the **breaking of scale invariance** mediates between hidden and visible sectors, and the sparticles acquire their masses due to this mediation.
- mAMSB has very attractive properties, since the soft SUSY breaking terms are calculated in terms of one single parameter, namely the gravitino mass $m_{3/2}$.
- AMSB scenarios suffer from the problem that slepton squared masses are found to be negative, leading to tachyonic states.
- A solution to this problem is to consider that the scalar particles acquire a universal mass m_0 at the GUT scale, which when added to the AMSB soft SUSY breaking terms, makes them positive.

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parameter space

- mAMSB model relies on only four parameters :

$$m_0, m_{3/2}, \tan\beta, \mathrm{sgn}(\mu)\ .$$

- We generate mass spectra and couplings using Isajet 7.80. The calculation of flavour observables and the computation of the relic density are performed with SuperIso Relic v3.0.
- We disregard the case of negative $\mathrm{sgn}(\mu)$ since it is disfavoured by the muon anomalous magnetic moment constraint, and we scan over the intervals $m_0 \in [0, 2000]$ GeV, $m_{3/2} \in [0, 100]$ TeV and $\tan\beta \in [0, 60]$.

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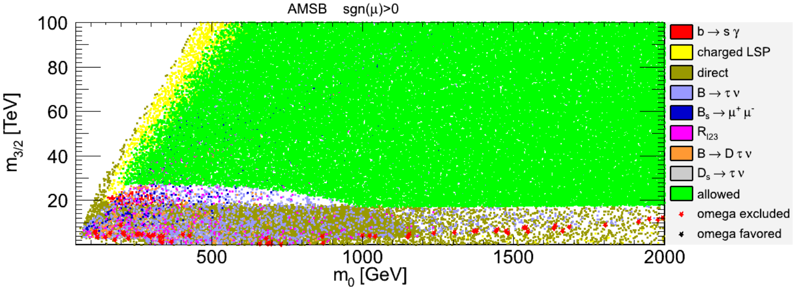
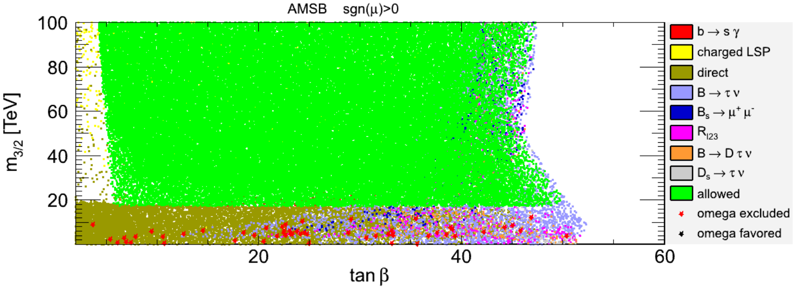
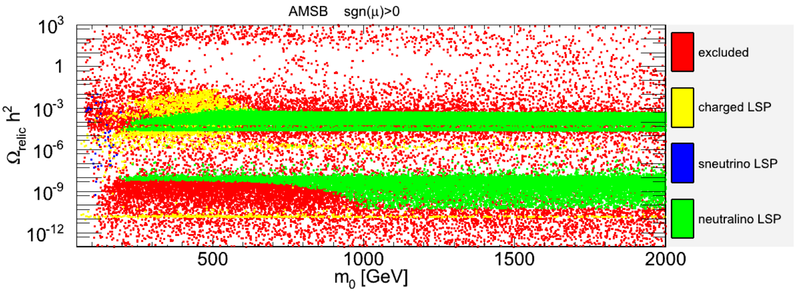
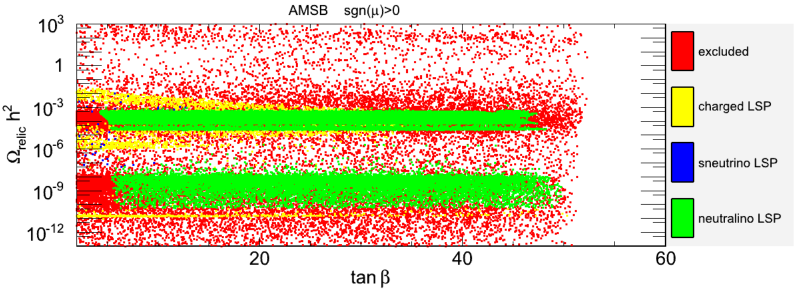




Results 2 mAMSB





HCAMSB

- Possibility to **solve the negative slepton squared masses** of the original AMSB scenario.
- Additional contribution to the gaugino mass M_1 is generated, which increase the weak scale slepton masses beyond tachyonic values, solving the generic AMSB problem .
- The HCAMSB scenario has four parameters :

$$\alpha = \frac{\tilde{M}_1}{m_{3/2}}, m_{3/2}, \tan\beta, \text{sgn}(\mu) \; .$$

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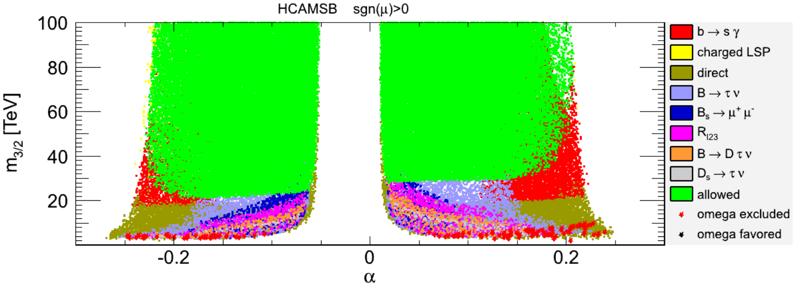

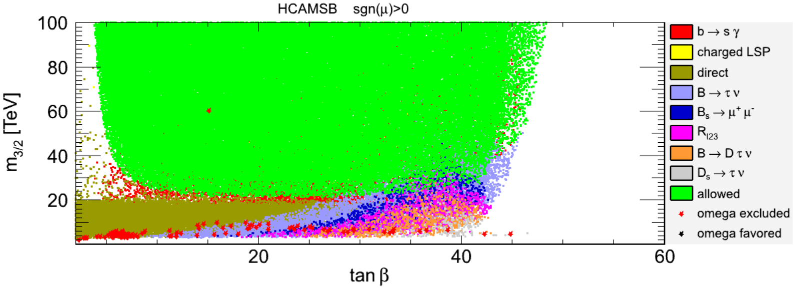

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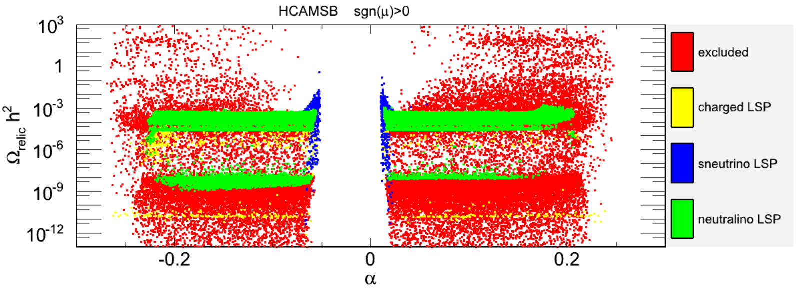

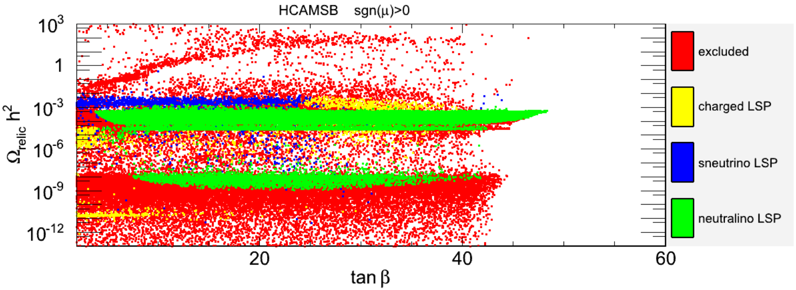

MMAMSB

- Provides viable dark matter candidates, in addition to solving the negative slepton mass problem naturally.
- The soft SUSY breaking terms receive comparable contributions from both **anomaly** and **modulus**, resulting in positive slepton masses.
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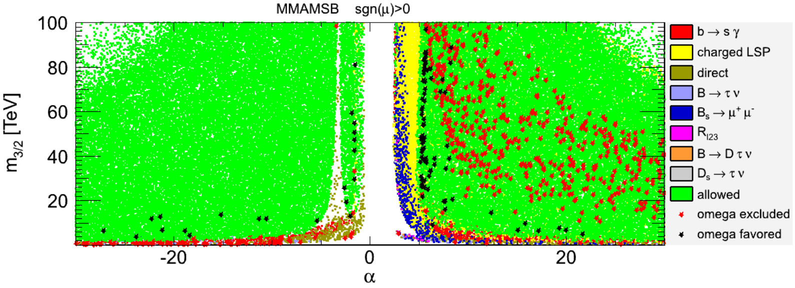

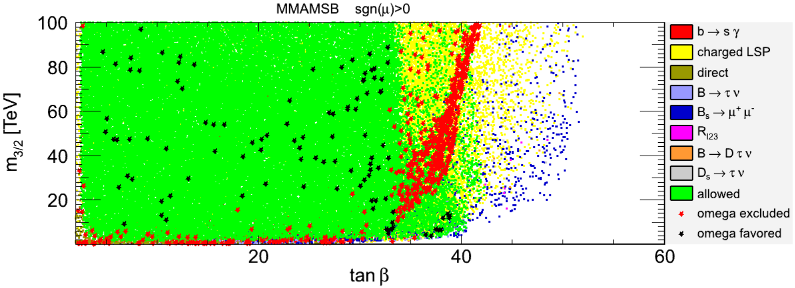

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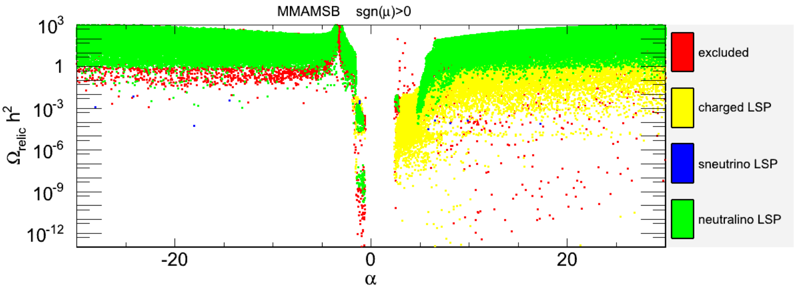

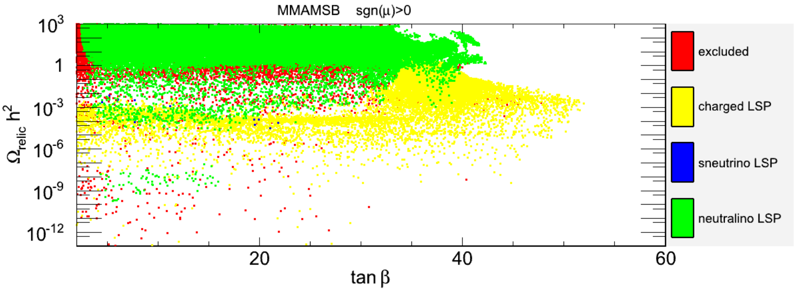

Benchmark points

- We reinterpret the previous results by considering four different alternatives to the cosmological standard scenario.
- We choose points which have $\mu > 0$ and are **in agreement with all the flavour and direct search constraints** but would be excluded by WMAP constraints based on the standard cosmology.

Point	Model	$\Omega_{DM} h^2$	m_0 (GeV)	α	$m_{3/2}$ (TeV)	$\tan\beta$	M_A(GeV
A	mAMSB	3.33×10^{-4}	1000	n/a	80	30	1060.5
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C	HCAMSB	3.24×10^{-4}	n/a	0.1	80	10	1931.3
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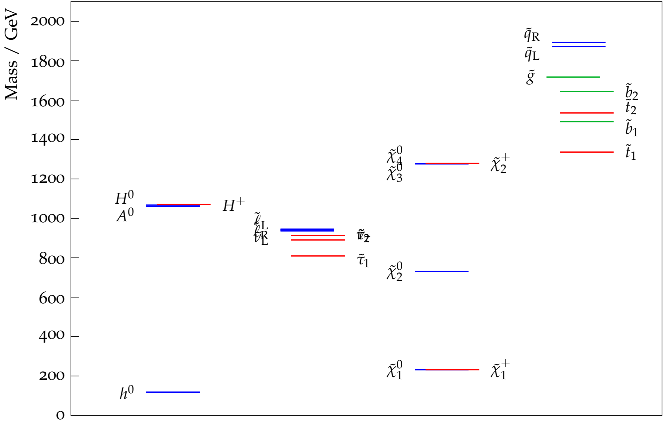
Mass Spectra



Point A

- Allowed region favours points in which the lightest chargino and neutralino are very close in mass and not so heavy.

Modified Equations

- The density number of supersymmetric particles is determined by the Boltzmann equation :

$$\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle (n^2 - n_{eq}^2) \ ,$$

- In the standard cosmology, the dominant component before BBN is considered to be radiation. This assumption is however relaxed in **alternative cosmology**.
- The Friedmann equation and the entropy evolution can be written as :

$$H^2 = \frac{8\pi G}{3}(\rho_{rad} + \rho_D) \ ,$$
$$\frac{ds}{dt} = -3Hs + \Sigma_D \ ,$$

- ρ_D : modified evolution of the total density of the Universe, beyond radiation density ρ_{rad}.
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Alternative Cosmology Scenarios

- Quintessence field before BBN was dominating the expansion of the Universe.

$$\rho_D(T) = \kappa_\rho \rho_{rad}(T_{BBN}) \left(\frac{T}{T_{BBN}} \right)^6 ,$$

where κ_ρ is the proportion of quintessence to radiation at the BBN temperature ($\sim$1 MeV).

- Late Decaying Inflaton :

$$\rho_D(T) = \kappa_\rho \rho_{rad}(T_{BBN}) \left(\frac{T}{T_{BBN}} \right)^8 .$$

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$$s_D(T) = \kappa_s s_{rad}(T_{BBN}) \left(\frac{T}{T_{BBN}} \right)^3 ,$$

κ_s : ratio of effective dark entropy density over radiation entropy density at BBN time.

- The corresponding entropy production is related to s_D by the relation

$$\Sigma_D = \sqrt{\frac{4\pi^3 G}{5}} \sqrt{1+\tilde{\rho}_D} T^2 \left[\sqrt{g_{eff}} s_D - \frac{1}{3} \frac{h_{eff}}{g_*^{1/2}} T \frac{ds_D}{dT} \right] ,$$

- Late Reheating : the entropy production evolves like

$$\Sigma_D(T) = \kappa_\Sigma \Sigma_{rad}(T_{BBN}) \left(\frac{T_{BBN}}{T} \right)$$

for $T > 1$ MeV $\rightarrow$ this entropy production stops at the time of BBN.

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$$s_D(T) = 3\sqrt{\frac{5}{4\pi^3 G}} h_{eff} T^3 \int_0^T dT' \frac{g_*^{1/2} \Sigma_D(T')}{\sqrt{1+\frac{\rho_D}{\rho_{rad}} h_{eff}^2 T'^6}} .$$

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Big-Bang Nucleosynthesis constraints

- The different scenarios do not have an impact on the cosmological observations, but they can modify the abundance of the elements.
- Conservative constraints :

$$0.240 < Y_p < 0.258\ , \qquad 1.2 \times 10^{-5} < {}^2H/H < 5.3 \times 10^{-5}\ ,$$
$$0.57 < {}^3H/{}^2H < 1.52\ , \qquad {}^7Li/H > 0.85 \times 10^{-10}\ , \qquad {}^6Li/{}^7Li < 0.66\ ,$$

  for the helium abundance Y_p and the primordial ${}^2H/H$, ${}^3H/{}^2H$, ${}^7Li/H$ and ${}^6Li/{}^7Li$ ratios.
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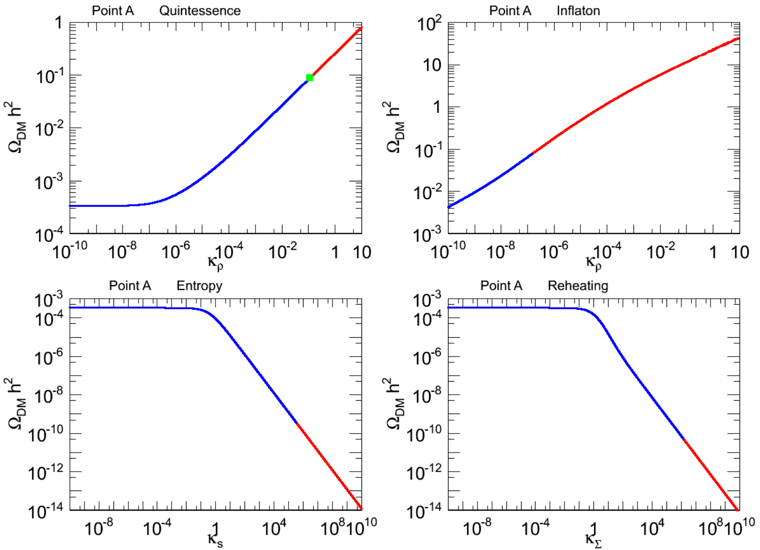
  for the helium abundance Y_p and the primordial ${}^2H/H$, ${}^3H/{}^2H$, ${}^7Li/H$ and ${}^6Li/{}^7Li$ ratios.
- We use the code AlterBBN integrated into SuperIso Relic to compute the abundance of the elements in these scenarios.

Relic density in function of the cosmological model parameters



Generalised relic density constraints

- The relic density constraints can be very strongly relaxed.
- We can increase or decrease any relic density with non-standard cosmological scenarios in agreement with the current cosmological data.
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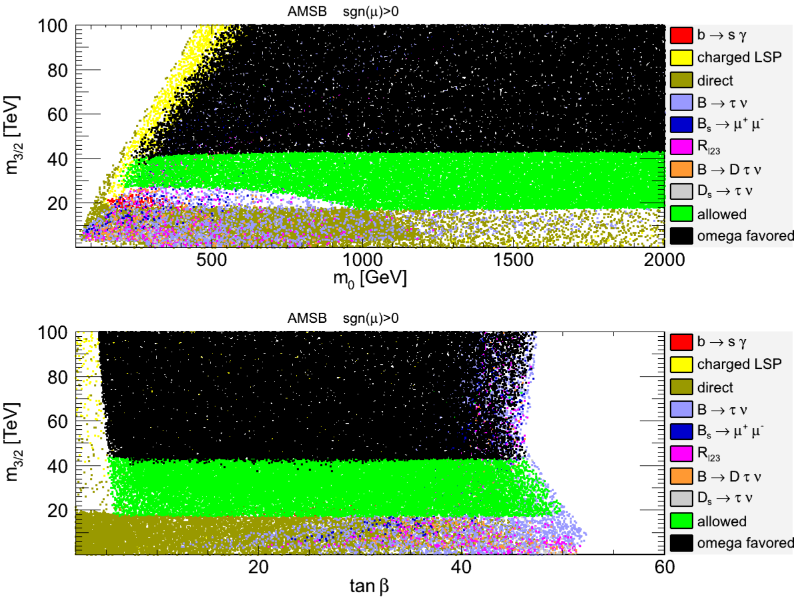
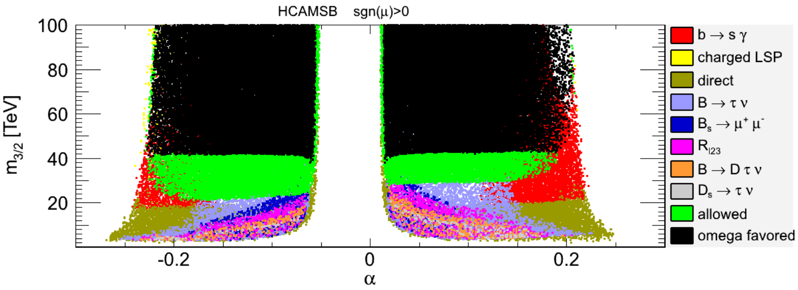
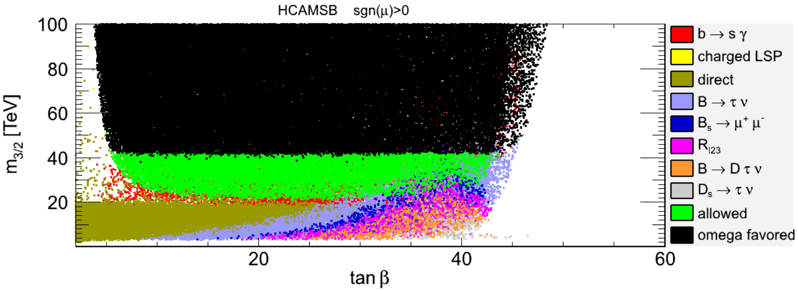
mAMSB in alternative cosmology

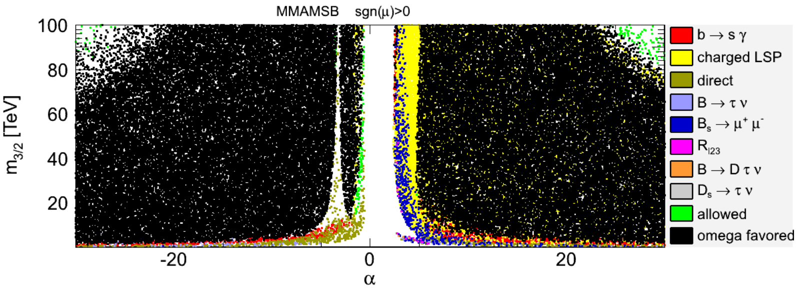


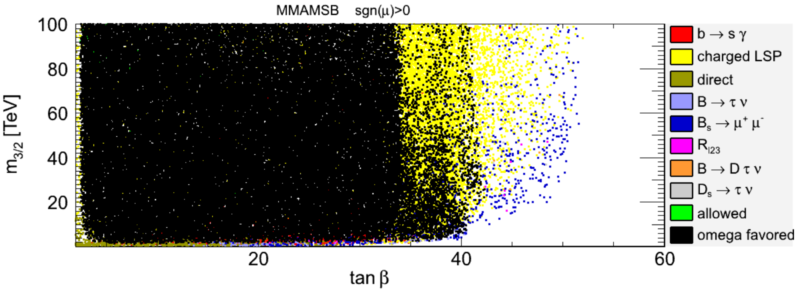
HCAMSB in alternative cosmology





MMAMSB with revised relic density interval





Results

- It is clear that the allowed regions are therefore much larger than with the initial relic density interval.
- Even with the very large interval for relic density, its constraint still excludes large part of the parameter spaces.
- In the mAMSB and HCAMSB scenarios, the relic density constraints clearly exclude the region $m_{3/2} \lesssim 40$ TeV.
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Decay modes for mAMSB (point A)

- $m_{\tilde{\chi}_1^0} = 231.76$ GeV and $m_{\tilde{\chi}_1^+} = 231.93$ GeV so that the mass splitting is only 170 MeV.
- Open decay modes for the $\tilde{\chi}_1^+$ are $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 l\nu$, where

$$\begin{aligned} \mathrm{BR}(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \mu^+ \nu_\mu) &\simeq 1.87 \times 10^{-2} \\ \mathrm{BR}(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 e^+ \nu_e) &\simeq 1.87 \times 10^{-2} \\ \mathrm{BR}(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \pi^+ \to \tilde{\chi}_1^0 e^+ \nu_e) &\simeq 0.96 \,, \end{aligned}$$

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$$\begin{aligned} \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^\pm W^\mp) &\simeq 0.75 \\ \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h^0) &\simeq 0.19 \\ \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-) &\simeq 5.5 \times 10^{-3} \,, \end{aligned}$$

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Conclusion

- We have considered in details the constraints (LEP, B-factories, Tevatron, LHC and WMAP) on different possible realisations of superconformal anomaly mediation breaking mechanisms in supersymmetry.
- We have discussed the standard cosmological approach and also alternative cosmological scenarios which do not change the cosmological observations but which can affect strongly the constraints on the parameter space of these supersymmetric models based on the relic abundance of dark matter.
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