New constraints on supersymmetric models from B physics

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Stockholm University – 22 November 2007

Outline

Introduction

New physics appears as a necessity:

- cosmological problems: dark matter, dark energy
- hierarchy problem in the Standard Model
- unification of interactions

The hope is that LHC will find something new!

- New Physics!

Many theoretical models beyond the SM, within reach of the LHC, already exist in the market.

Introduction

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- It would be an evidence for new physics!

- The question is: what kind of new physics?!?

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- Supersymmetry (SUSY) is the best motivated and studied candidate for physics beyond the Standard Model.
- It is based on a symmetry between fermions and bosons: $Q|fermion\rangle = |boson\rangle$ and $Q|boson\rangle = |fermion\rangle$
- Extension of the usual space time coordinates by anti-commuting Grassmanian coordinates
- SUSY operators: $Q_\alpha = \frac{\partial}{\partial\theta^\alpha} - i\sigma^\mu_{\alpha\dot{\beta}}\bar{\theta}^{\dot{\beta}}\partial_\mu$, $\bar{Q}_{\dot{\beta}} = -\frac{\partial}{\partial\bar{\theta}^{\dot{\beta}}} + i\theta^\alpha\sigma^\mu_{\alpha\dot{\beta}}\partial_\mu$
- Algebra: $\{Q_\alpha, \bar{Q}_{\dot{\beta}}\} = 2\sigma^\mu_{\alpha\dot{\beta}}P_\mu$, $[Q_\alpha, P_\mu] = [\bar{Q}_{\dot{\beta}}, P_\mu] = 0$

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Supersymmetry

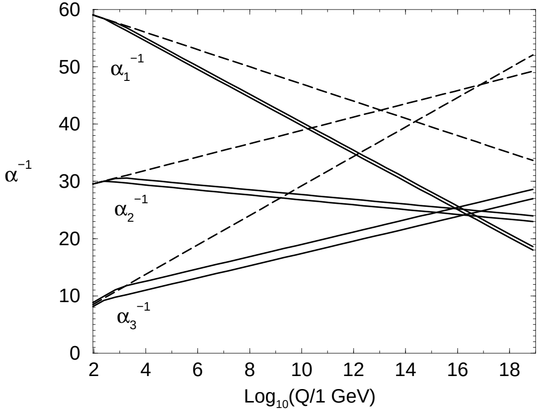
Motivation of SUSY in Particle Physics

- Unification of gauge couplings
- Unification with gravity
- Solution of the hierarchy problem
- Candidate for Dark Matter
- Elegant...

Supersymmetry

Unification of couplings

Embed the SM group into a larger simple Group.



Supersymmetry

Hierarchy

Two problems in the SM:

- How to arrange for the m_H to be many orders smaller than other fundamental mass scales, such as the Planck scale
- How to avoid corrections δm_H^2 which are much larger than m_H^2 itself

Supersymmetric solution: boson and fermion loop diagrams have opposite signs. If there are equal numbers of fermions and bosons, and if they have equal masses and couplings, the quadratic divergences cancel.

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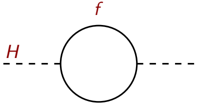
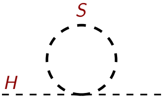
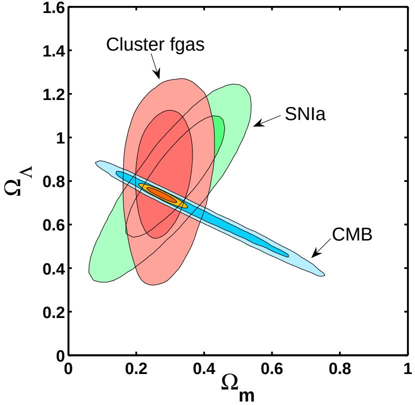




$\looparrowright$ $\delta m_H^2 \leq m_H^2$ provided $|m_f^2 - m_S^2| \leq 1\,TeV^2$

Supersymmetry

Dark Matter



Allen *et al.*, arXiv:0706.0033

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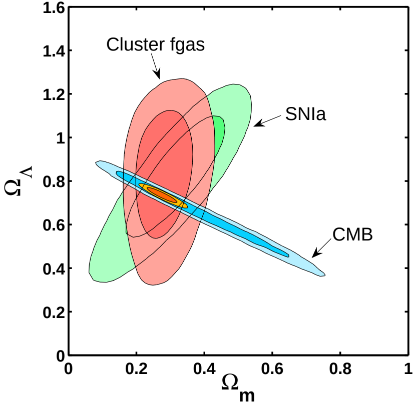

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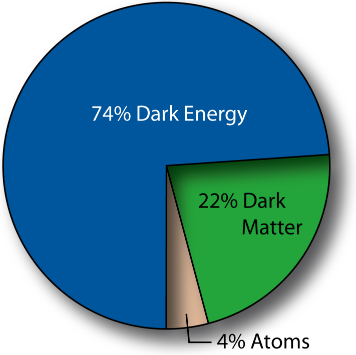

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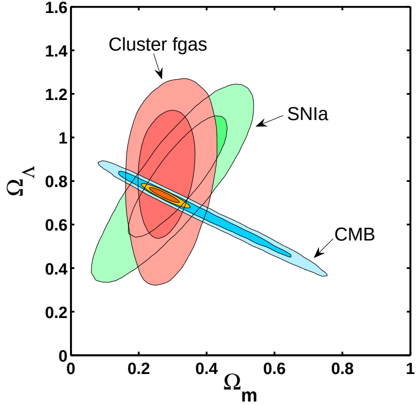

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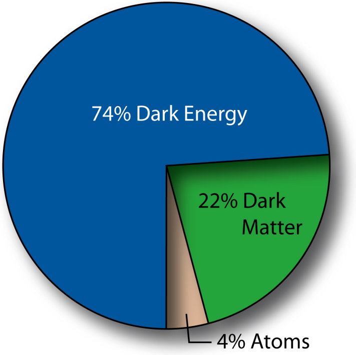

Need for a non-SM weakly interacting massive particle!

Minimal Supersymmetric Model (MSSM)

SM particle	spin	Superpartner	spin
quarks	1/2	squarks	0
leptons	1/2	sleptons	0
gauge bosons	1	gauginos	1/2
Higgs bosons	0	higgsinos	1/2

gauginos + higgsinos mix to 2 charginos + 4 neutralinos

2 Higgs doublets $\rightarrow$ 5 physical Higgs bosons:

- neutral states: scalar h, H; pseudoscalar A
- charged states: H^+, H^-

Supersymmetry

- If SUSY were an exact symmetry, the SM particles and their supersymmetric partners would have the same masses.
- As this is not the case,
- To keep δm_H^2 under control, the superparticles should have masses of about 1 TeV or less.
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Spontaneous SUSY breaking

- Terms in the Lagrangian that break SUSY softly, without introducing quadratic divergencies are:
  - gaugino masses $M_\lambda \, \lambda^a \lambda^a$
  - scalar mass terms $m^2 \, \phi^* \phi$
  - bilinear and trilinear couplings $B\phi^2 + A\phi^3$
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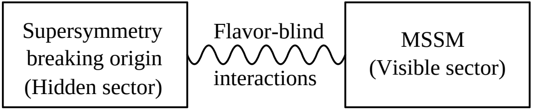

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- Spontaneous symmetry breaking, analogous to the SM Higgs mechanism.
- Fortunately, how SUSY is broken is irrelevant for phenomenology
- This is the mediation mechanism and the associated scale of SUSY breaking which is important

Gravity mediated SUSY breaking (SUGRA)

The hidden sector communicates with the MSSM through gravitational interactions.

- m_0: universal scalar mass at GUT scale,
- $m_{1/2}$: universal gaugino mass at GUT scale,
- A_0: trilinear soft breaking parameter at GUT scale,
- $\tan\beta$: ratio of the two Higgs vacuum expectation values,
- $sign(\mu)$: sign of Higgsino mass term.

Gauge mediated SUSY breaking (GMSB)

SUSY breaking in the hidden sector is mediated to the observable sector through gauge interactions.
$\rightarrowtail$ need to introduce some new chiral supermultiplets, called messengers

- Λ: scale of the SUSY breaking,
- M_{mess}: messenger mass scale ($> \Lambda$),
- N_5: equivalent number of $5 + \bar{5}$ messenger fields,
- $\tan\beta$: ratio of the two Higgs vacuum expectation values,
- $sign(\mu)$: sign of Higgsino mass term.

Anomaly mediated SUSY breaking (AMSB)

The hidden sector SUSY breaking is mediated to our world only through the auxiliary component of the supergravity multiplet.

- m_0: universal scalar mass at GUT scale,
- $m_{3/2}$: gravitino mass at GUT scale,
- $\tan\beta$: ratio of the two Higgs vacuum expectation values,
- $sign(\mu)$: sign of Higgsino mass term.

R parity

If R parity is conserved

- SUSY particles can only be produced in pairs
- Sparticles always decay to an odd number of sparticles
- the lightest SUSY particle (LSP) is stable
- any SUSY decay chain ends in the LSP, which is a dark matter candidates

Constraining the parameters

The most used constraints:

- Collider limits
- Electroweak precision tests
- Cosmological constraints, in particular from WMAP and the relic density
- The anomalous magnetic moment of the muon $(g-2)_\mu$

$$\Delta a_\mu \equiv a_\mu^{SUSY} \equiv a_\mu^{exp} - a_\mu^{SM} = (26 \pm 16) \times 10^{-10}$$

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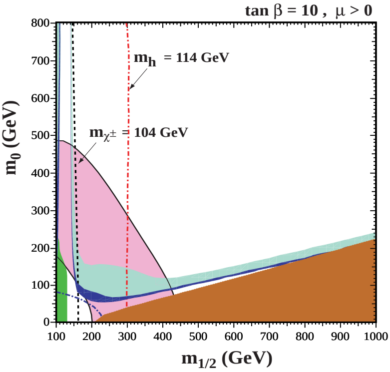

Ellis *et al.*, Phys. Lett. B565, 176 (2003)

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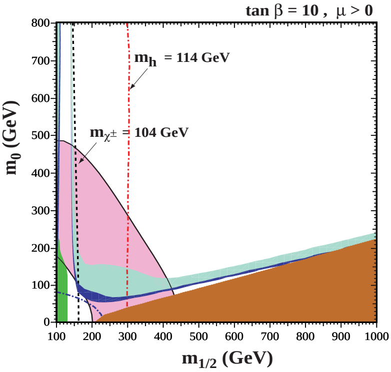

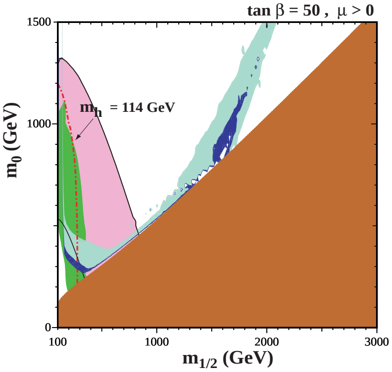

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Constraints from B Physics

- $b \longrightarrow s\gamma$ transition: very sensitive to new physics
  - forbidden at the tree level in SM and can only be induced via loop diagrams,
  - SM contributions are vanishingly small,
- branching ratios have been extensively used to constrain SUSY parameter space
- Study another observable: isospin asymmetry
  - already measured by BELLE and BABAR
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Effective Hamiltonian

The idea of $B \longrightarrow X_s\gamma$ decay begins with introducing an effective Hamiltonian:

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{8} C_i(\mu) O_i(\mu)$$

$$\begin{cases} O_1 = (\bar{s}_L \gamma_\mu T^a c_L)(\bar{c}_L \gamma^\mu T^a b_L) \qquad O_2 = (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L) \\ \\ O_3 = (\bar{s}_L \gamma_\mu b_L) \sum_q (\bar{q}\gamma^\mu q) \qquad O_4 = (\bar{s}_L \gamma_\mu T^a b_L) \sum_q (\bar{q}\gamma^\mu T^a q) \\ O_5 = (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} b_L) \sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q) \\ O_6 = (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a b_L) \sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q) \\ \\ O_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu} \qquad O_8 = \frac{g}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu} \end{cases}$$

Wilson Coefficients

$$C_i^{eff}(\mu) = C_i^{(0)eff}(\mu) + \frac{\alpha_s(\mu)}{4\pi} C_i^{(1)eff}(\mu) + \cdots$$

The effective coefficients evolve according to their RGE:

$$\mu \frac{d}{d\mu} C_i^{eff}(\mu) = C_j^{eff}(\mu) \gamma_{ji}^{eff}(\mu)$$

driven by the anomalous dimension matrix $\hat{\gamma}^{eff}(\mu)$:

$$\hat{\gamma}^{eff}(\mu) = \frac{\alpha_s(\mu)}{4\pi} \hat{\gamma}^{(0)eff} + \frac{\alpha_s^2(\mu)}{(4\pi)^2} \hat{\gamma}^{(1)eff} + \cdots$$

Isospin Asymmetry

$$\Delta_{0-} \equiv \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

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$$b_q = \frac{12\pi^2 f_B\, Q_q}{m_b\, T_1^{B\to K^*} a_7^c} \left(\frac{f_{K^*}^{\perp}}{m_b} K_1 + \frac{f_{K^*} m_{K^*}}{6\lambda_B m_B} K_2 \right)$$

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$$a_7^c = C_7 + \frac{\alpha_s(\mu) C_F}{4\pi} \Big(C_1(\mu) G_1(s_p) + C_8(\mu) G_8 \Big) + \frac{\alpha_s(\mu_h) C_F}{4\pi} \Big(C_1(\mu_h) H_1(s_p) + C_8(\mu_h) H_8 \Big)$$

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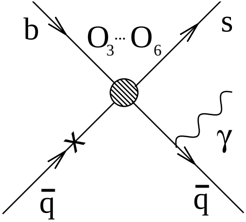
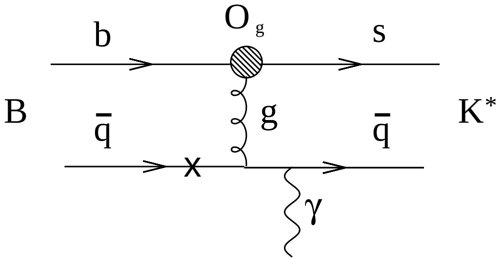
In the Standard Model: $\Delta_{0-} \simeq 8\%$

Kagan and Neubert, Phys. Lett. B 539, 227 (2002)
Bosch and Buchalla, Nucl. Phys. B 621, 459 (2002)

Contribution to Isospin Asymmetry



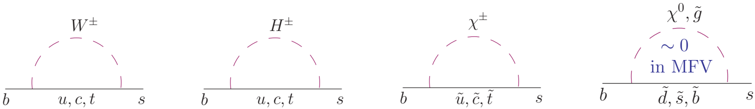
QCD penguin operators



Electro- and chromo-magnetic operators

Supersymmetric contributions

MSSM with minimal flavor violation (MFV)
$\hookrightarrow$ no more flavor/CP violation than in SM



Calculation of the coefficients at $\mu = M_W$:

$$C_i(\mu) = C_i^{W^\pm}(\mu) + C_i^{H^\pm}(\mu) + C_i^{\chi^\pm}(\mu)$$

Gómez et al. Phys. Rev. D74, 015015 (2006)
Degrassi et al. JHEP 12, 009 (2000)
Ciuchini et al. Nucl. Phys. B 534, 3 (1998)
Ciuchini et al. Nucl. Phys. B 527, 21 (1998)

SuperIso v1.0

A public C–program for calculating isospin asymmetry of $B \to K^*\gamma$ in supersymmetry.

- calculation of isospin asymmetry and inclusive branching ratio,
- automatic calculation in mSUGRA, AMSB and GMSB scenarios,
- compatible with the SUSY Les Houches Accord Format,
- modular program, with a well-defined structure.

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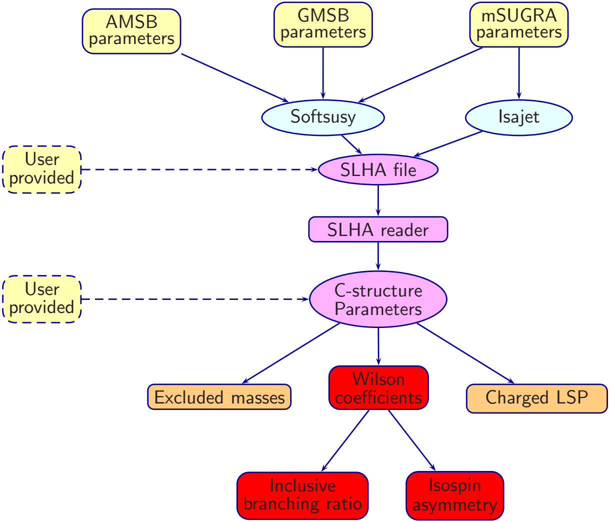


SuperIso v1.0

Can be downloaded from:

http://www3.tsl.uu.se/∼nazila/superiso/

Manual:

F. Mahmoudi, arXiv:0710.2067 to appear in Comp. Phys. Comm.

For more information:

Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

F. Mahmoudi, arXiv:0710.4501, to appear in JHEP

Experimental data

BABAR

$$\Delta_{0-} = -0.006 \pm 0.058(stat) \pm 0.009(syst) \pm 0.024(R^{+/0})$$

Aubert et al. (BABAR Collaboration) Phys. Rev. D72 (2005)

BELLE

$$\Delta_{0+} = +0.012 \pm 0.044(stat) \pm 0.026(syst)$$

Nakao et al. (BELLE Collaboration) Phys. Rev. D69 (2004)

$$\boxed{\text{Allowed Region: } -0.018 < \Delta_{0-} < 0.093}$$

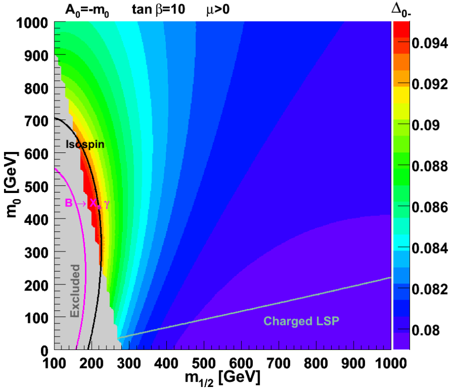
Experimental limits

Lower bounds on sparticle masses in GeV:

Particle	h^0	χ_1^0	$\tilde{l}_R$	$\tilde{\nu}_{e,\mu}$	$\chi_1^\pm$	$\tilde{t}_1$	$\tilde{g}$	$\tilde{b}_1$	$\tilde{\tau}_1$	$\tilde{q}_R$
Lower bound	111	46	88	43.7	67.7	92.6	195	89	81.9	250

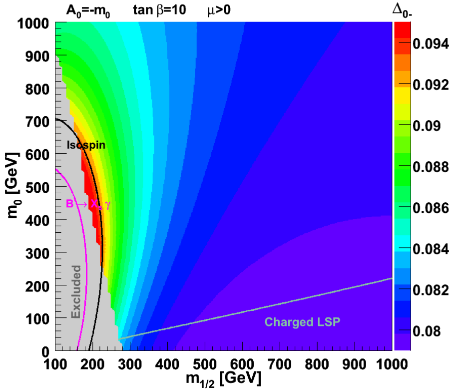
Yao et al. J. Phys. G33 (2006)

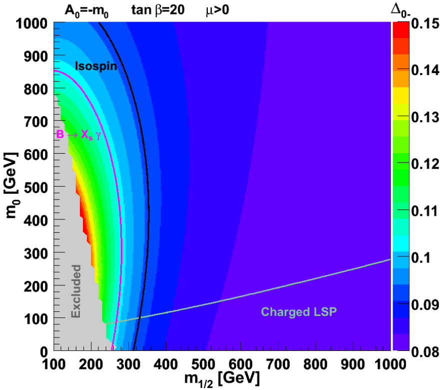
Results: mSUGRA



Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

Results: mSUGRA





Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

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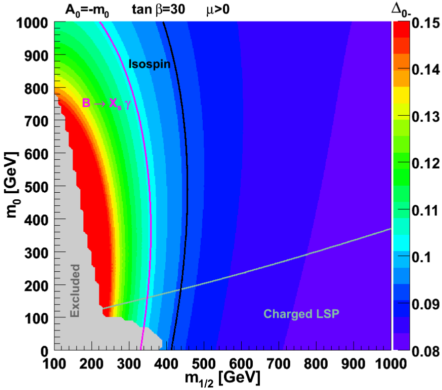

Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

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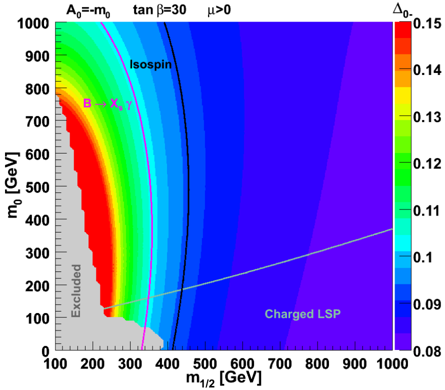
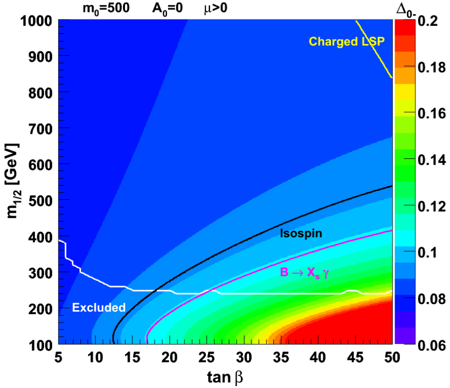


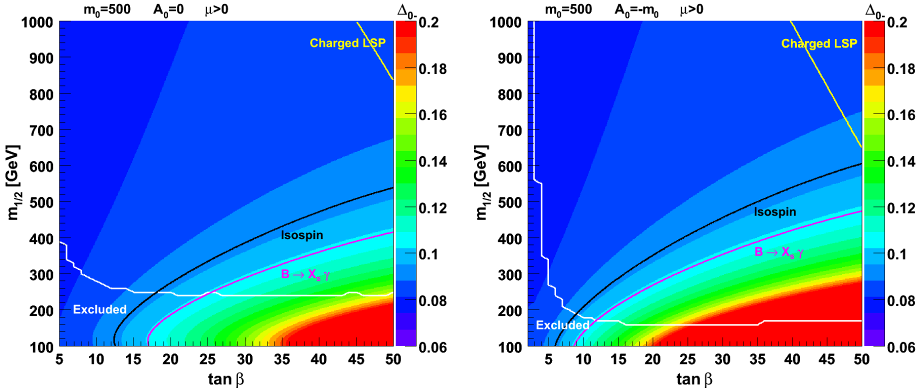
Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

Results: mSUGRA



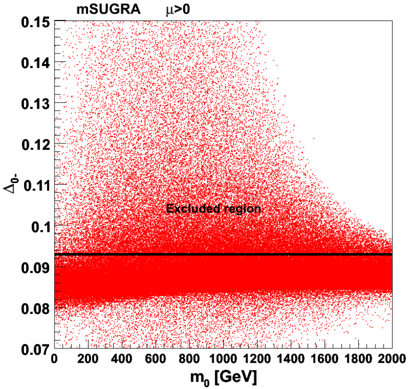
Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

Results: mSUGRA



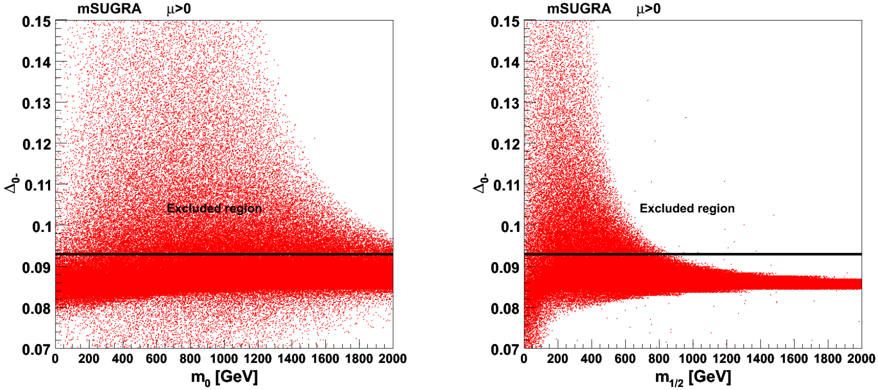
Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

Results: mSUGRA



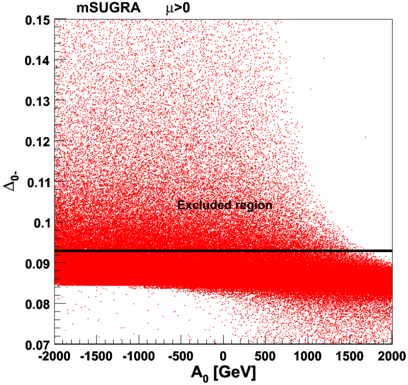
F. Mahmoudi, arXiv:0710.4501

Results: mSUGRA



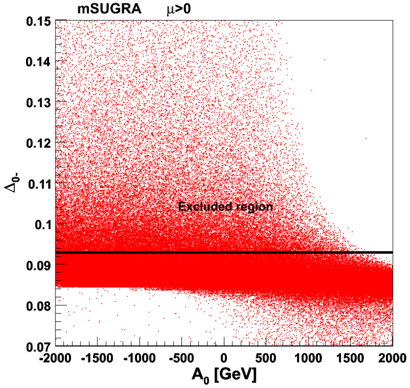
F. Mahmoudi, arXiv:0710.4501

Results: mSUGRA



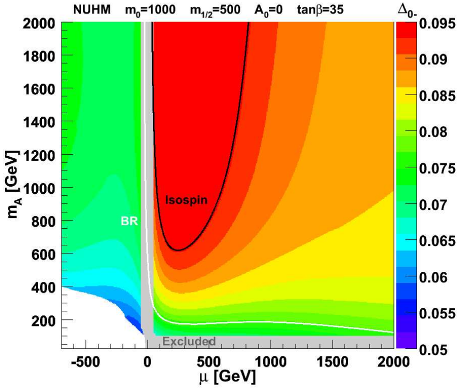
F. Mahmoudi, arXiv:0710.4501

Results: mSUGRA



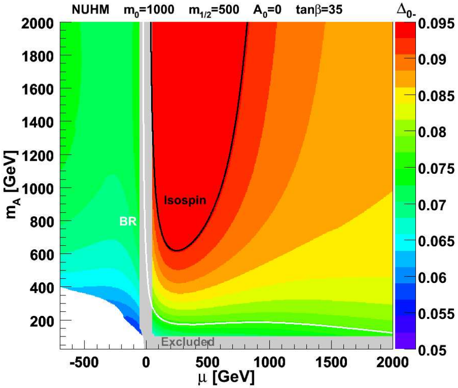
F. Mahmoudi, arXiv:0710.4501

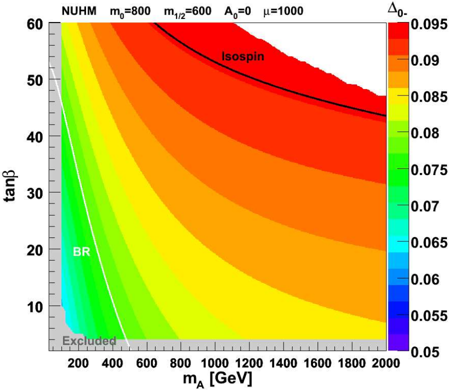
Results: NUHM



F. Mahmoudi, arXiv:0710.4501

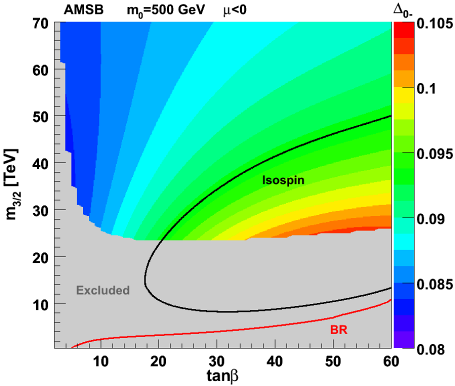
Results: NUHM





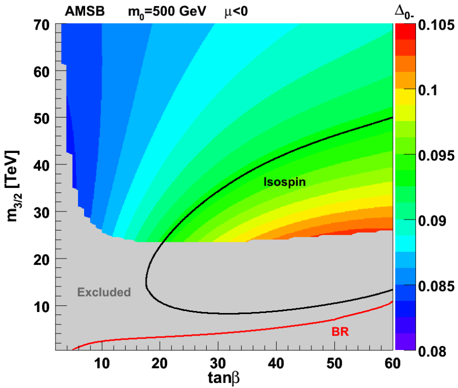
F. Mahmoudi, arXiv:0710.4501

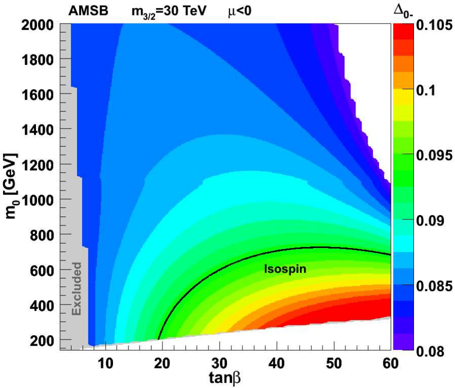
Results: AMSB



F. Mahmoudi, arXiv:0710.4501

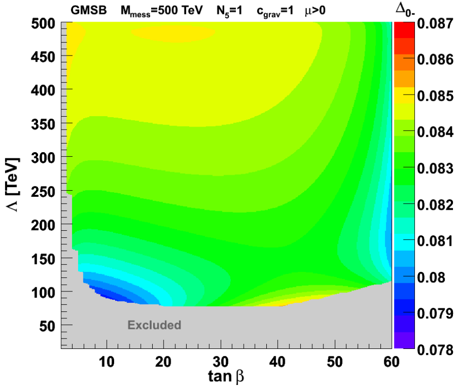
Results: AMSB





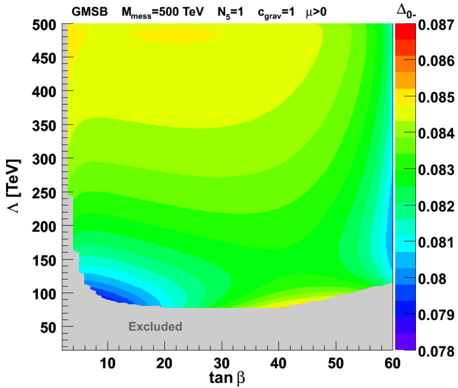
F. Mahmoudi, arXiv:0710.4501

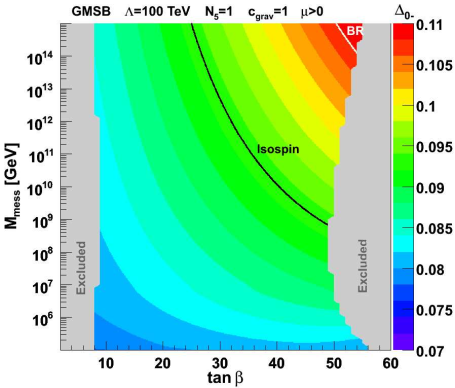
Results: GMSB



F. Mahmoudi, arXiv:0710.4501

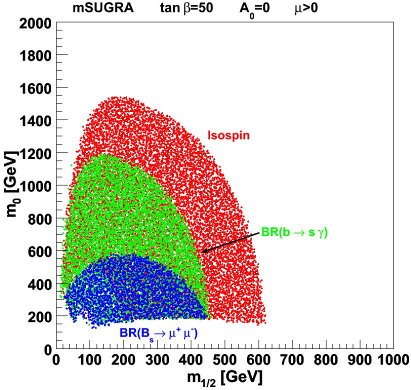
Results: GMSB





F. Mahmoudi, arXiv:0710.4501

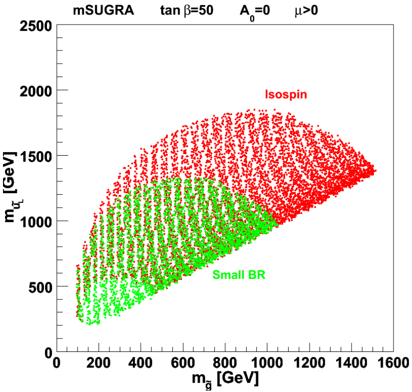
Results



$$\mathcal{B}(B_s \to \mu^+\mu^-) < 0.93 \times 10^{-7}$$

Results:

mSUGRA

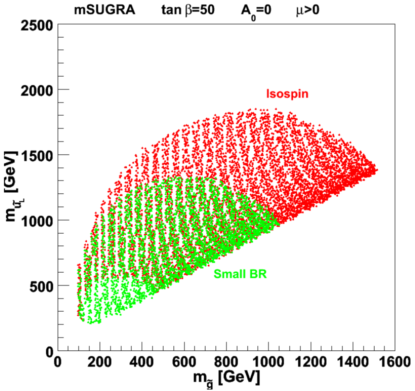


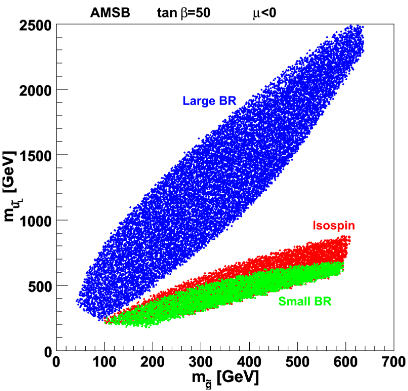
F. Mahmoudi, arXiv:0710.4501

Results:

mSUGRA

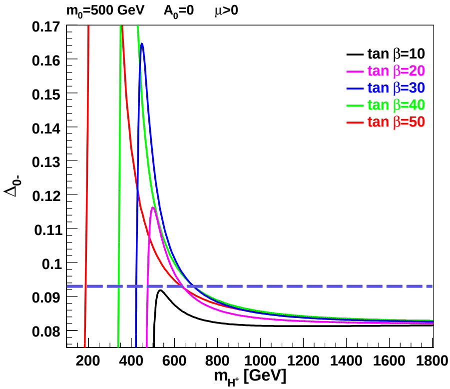
AMSB





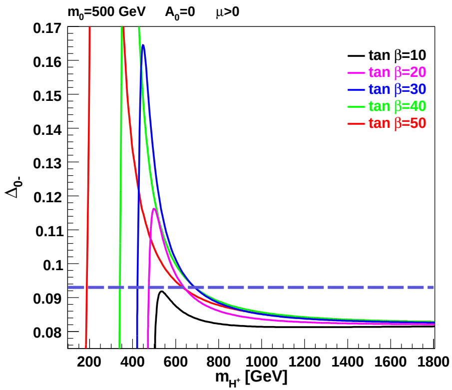
F. Mahmoudi, arXiv:0710.4501

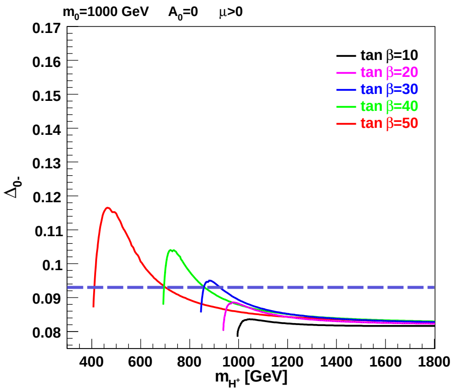
Results: mSUGRA



F. Mahmoudi, arXiv:0710.4501

Results: mSUGRA





F. Mahmoudi, arXiv:0710.4501

Conclusion

- We can obtain new constraints (new contours) using the Isospin asymmetry
- Very tight constraints on the studied parameter spaces, complementary or even more restrictive than the inclusive branching ratio
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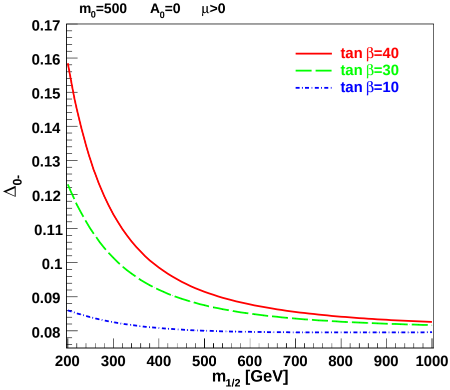
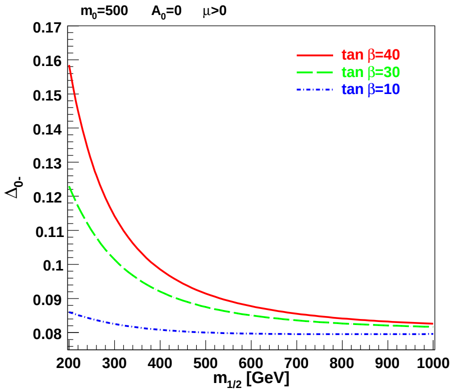
Backup

Results: mSUGRA



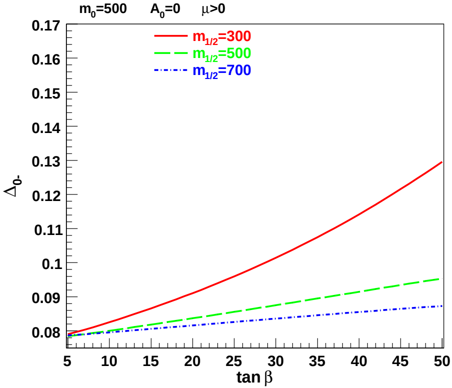
Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

Results: mSUGRA



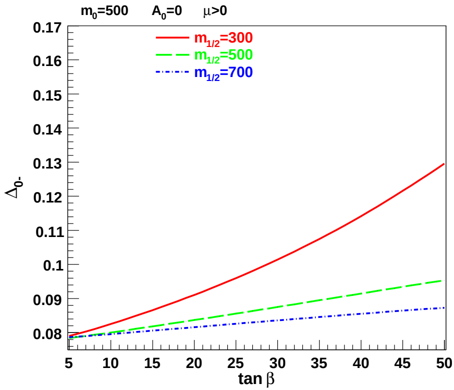
Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

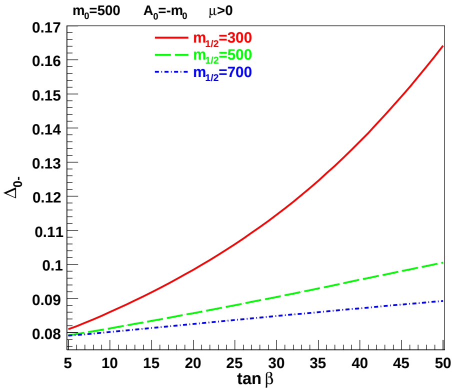
Results: mSUGRA



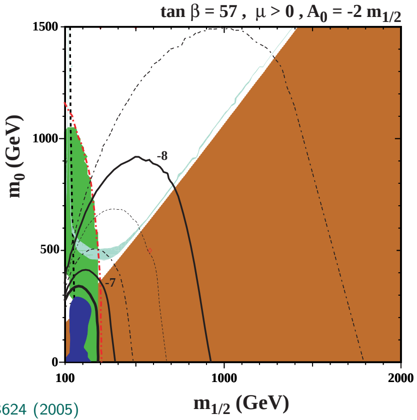
Ahmady & Mahmoudi, Phys. Rev. D75 (2007)

Results: mSUGRA





Ahmady & Mahmoudi, Phys. Rev. D75 (2007)



Ellis, Olive & Spanos, Phys.Lett. B624 (2005)

$$2.33 \times 10^{-4} < \mathcal{B}(b \to s\gamma) < 4.15 \times 10^{-4}$$