Quarks and Leptons as Nambu-Goldstone Fermions

(Based on arXiv:1004.4164 w/ M. Nojiri, M. Sudano and T. T. Yanagida)

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Fermilab Theory Seminar
July 15, 2010

Outline

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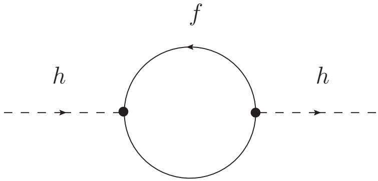
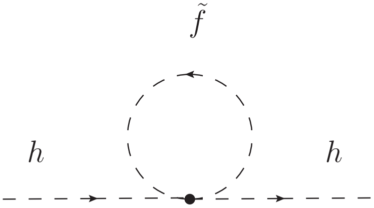
Controlling the Higgs





Enhanced gauge unification

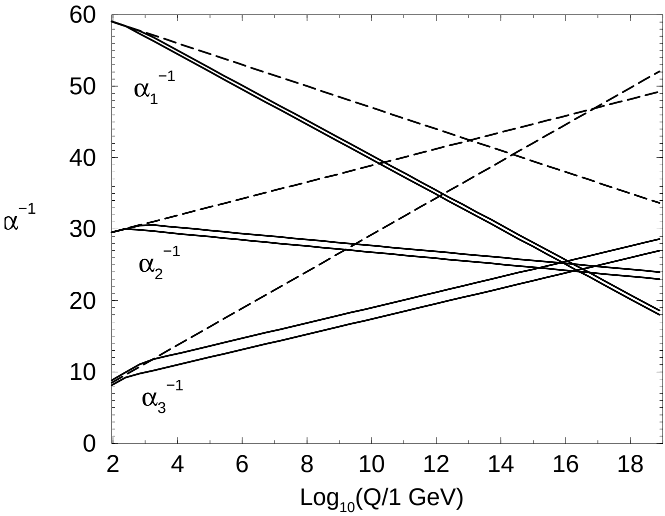
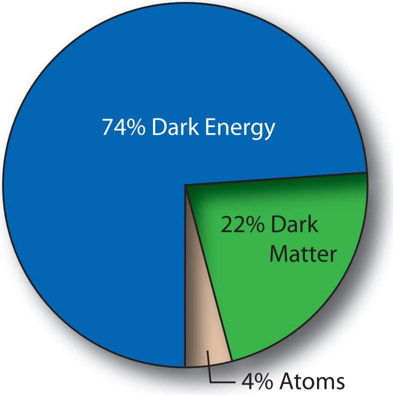
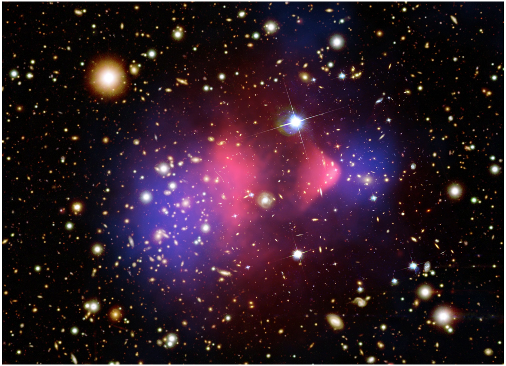


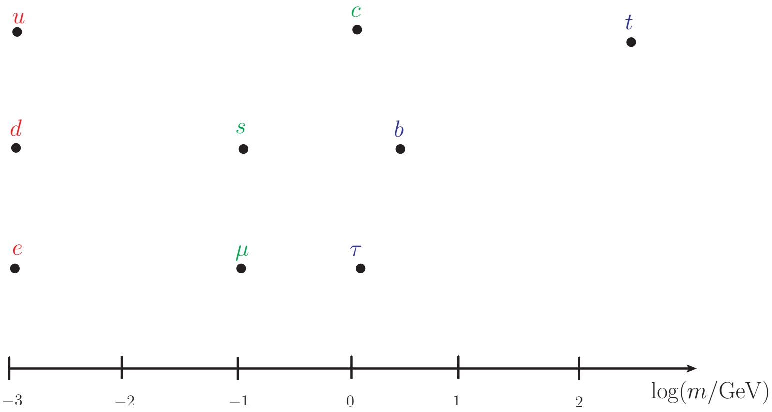
Figure: From S. P. Martin, arXiv:9709356

Neutral LSP as dark matter





Hierarchy of Yukawa couplings?



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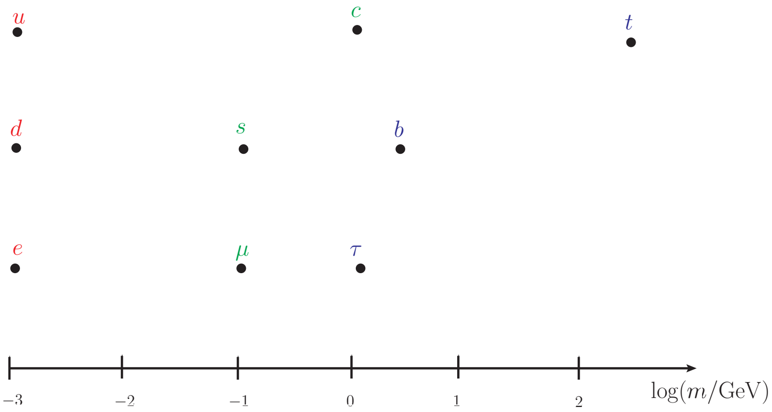

Ad-hoc $\Rightarrow$ dynamical origin of mass?

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But is it a viable strategy?

Formulation of SUSY nonlinear σ model

Under global symmetry breaking $G \to H$,

$$\mathcal{L}_{NGB}^{NL} = -\left(\partial^\mu \pi_i\right) g^{ij}\left(\pi/f_\pi\right)\left(\partial_\mu \pi_j\right)$$

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"Quasi"-NGBs n_{QNGB} minimal if G/H is Kähler!

The Kähler potential

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Then for scalars:

$$\mathcal{L}_{SUSY}^{NL} = -\partial^\mu \phi^{*i}\left[\frac{\partial^2 K\left(\phi^*, \phi\right)}{\partial\phi^{*i}\partial\phi^j}\right]\partial_\mu \phi^j$$

such that

$$\frac{\partial g_{ij}}{\partial\phi^{*k}} = \frac{\partial g_{kj}}{\partial\phi^{*i}}\,,\ \frac{\partial g_{ij}}{\partial\phi^k} = \frac{\partial g_{ik}}{\partial\phi^j}$$

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- $\Rightarrow$ 1st and 2nd generation sleptons/squarks too heavy
- Bagger and Witten, Phys. Lett. B **118**, 103 (1982)

Outline

An example manifold

- SUSY $U(6)/[U(4) \times SU(2)]$ nonlinear sigma model
- $(4 \times 2 + 1)$ NG chiral multiplets, ϕ_i^a and φ, where $a = 1, \ldots, 4$ and $i = 1, 2$

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- φ is the novino.
- All d.o.f. in ϕ_i^a and one real boson in φ are NG bosons; the remaining is the QNGB.

An example manifold (cont'd)

- Arrange fields into matrix

$$\Psi = \begin{pmatrix} e^{\kappa\varphi/v}\mathbf{1}_2 \\ \phi_i^a/v \end{pmatrix},$$

which has 12 components Ψ_i^α, $\alpha = 1, \ldots, 6$.

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- $U(6)$ nonlinearly realized by ϕ_i^a, φ

Supergravity and SUSY breaking

- Couple to supergravity:

$$\mathcal{L} = 3 \int d^2\theta d^2\bar{\theta}\mathcal{E}\exp\left(\frac{1}{3}K(\phi_i^a, \varphi, \phi_a^{\dagger i}, \varphi^\dagger)\right)$$

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- Introduce hidden SUSY breaking sector:

$$K = K(\phi_i^a, \varphi, \phi_a^{\dagger i}, \varphi^\dagger) + Z^\dagger Z + \ldots.$$

- NG bosons remain massless, but QNGB in φ gets mass $\mathcal{O}(m_{3/2})$.

Right-handed leptons and 2nd generation

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- Include 2nd generation with $(U(10)/[U(8)\times SU(2)])^2$ containing multiplets

$$\begin{aligned}(\phi_i^a)_L &= \begin{pmatrix} u_L^\xi & \nu_{eL} & c_L^\xi & \nu_{\mu L} \\ d_L^\xi & e_L^- & s_L^\xi & \mu_L^- \end{pmatrix} \sim (\mathbf{8},\mathbf{2}) \\ (\phi_i^a)_R &= \begin{pmatrix} u_R^\xi & \nu_{eR} & c_R^\xi & \nu_{\mu R} \\ d_R^\xi & e_R^- & s_R^\xi & \mu_R^- \end{pmatrix} \sim (\mathbf{8},\mathbf{2})\ .\end{aligned}$$

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LHC phenomenology does not depend on details of model!

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Parameter scan with DarkSUSY

- Scan mSUGRA models over $M_{H_u} \sim M_{H_d} \sim \mathcal{O}(m_{3/2})$ in the subspace

$$m_{1/2} = 300 \text{ GeV}, \quad \tan\beta = 10, \quad \mu > 0, \quad \text{A}_0 = 0$$

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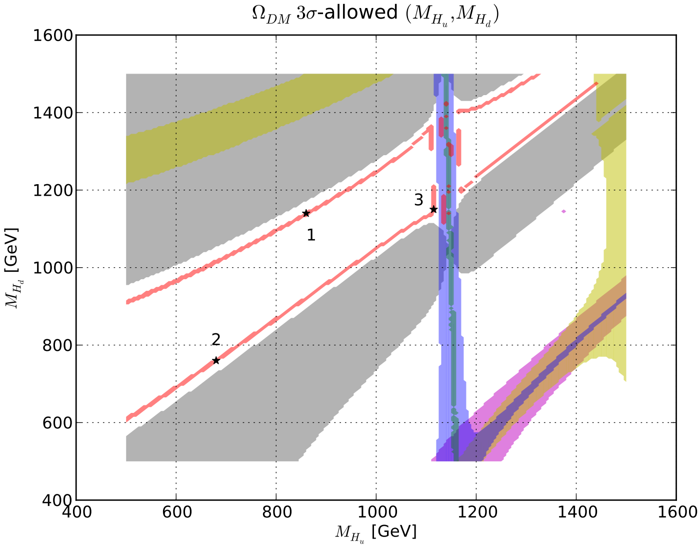
- At small m_0, $m_{1/2} \simeq 300$ GeV favored my muon $g-2$
- $\tilde{\tau}$ no longer favored co-annihilation partner or LSP
- Choose conventional mSUGRA point ("CP") for comparison:

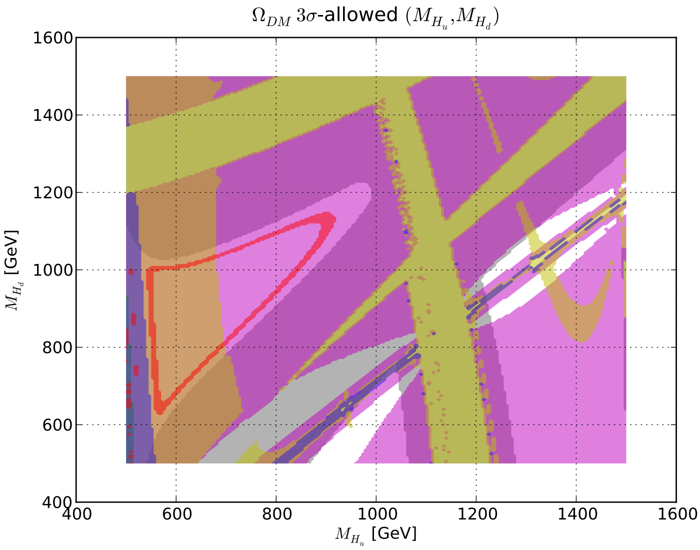
$$m_0 = 75 \text{ GeV}, \quad \mathrm{m}_{1/2} = 300 \text{ GeV}$$

$$\tan\beta = 10, \quad \mu > 0, \quad A_0 = -200 \text{ GeV}$$

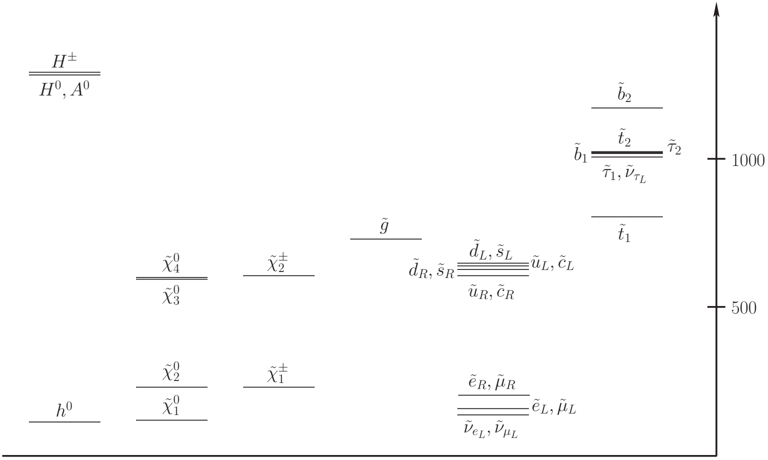
Scan results with benchmark points



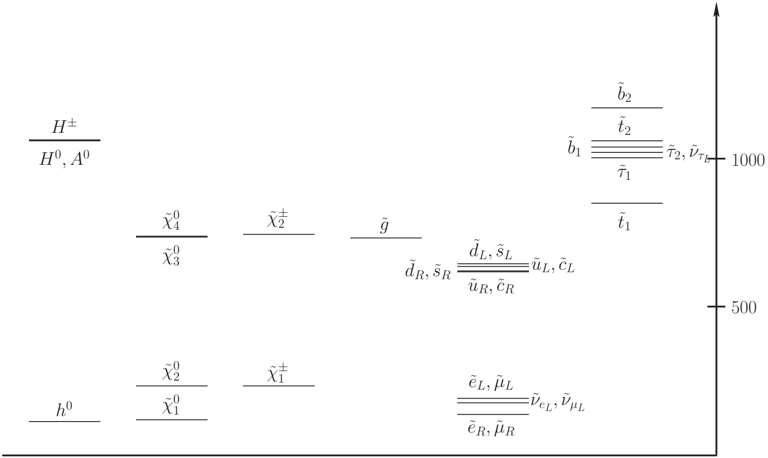
Scan results with $m_0 = 0$ for 3rd generation



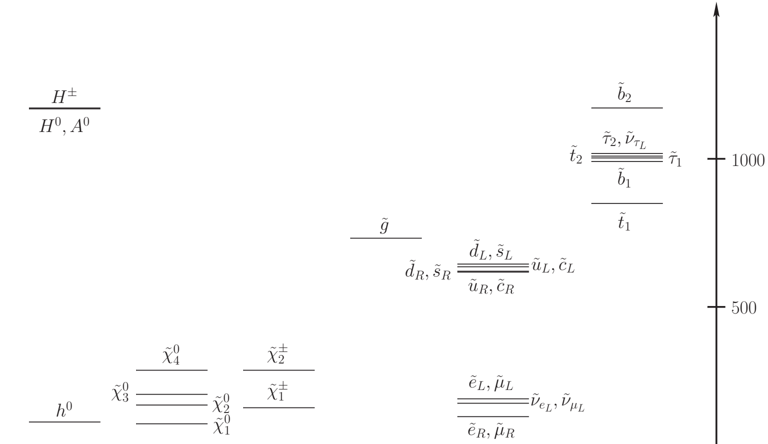
Benchmark Point 1



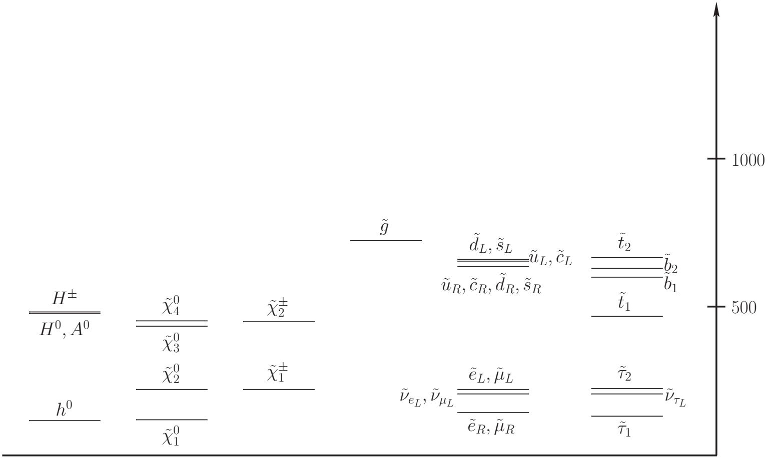
Benchmark Point 2



Benchmark Point 3



Conventional Point



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- SOFTSUSY for spectrum calculation
- ISAJET+HERWIG+ACERDET for event generation
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- 10^5 signal events at 14 TeV for inclusive squark production
- Production cross section is $\gtrsim 15\ \mathrm{pb} \Rightarrow 7\ \mathrm{fb}^{-1}$
- Standard SFOS subtraction of chargino events from DFOS
- τ- and *b*-jet tagging efficiency at 80%

Discriminator: multiplicities

Multiplicities:

- number of b-jets n_b with $p_T > 50\ \mathrm{GeV}$
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Model point	% $n_b \geq 1$	% $n_\tau \geq 1$	% $n_l \geq 2$
BP 1	2.29	0.04	15.80
BP 2	2.22	0.02	15.84
BP 3	3.17	2.284	28.97
CP	31.70	16.94	4.10

Discriminators: mass differences and charge asymmetry

- Mass determination and charge asymmetry from endpoint analysis of

$$(\tilde{g} \to)\ \tilde{q}j \to \tilde{\chi}_2^0 jj \to \tilde{l}^{\pm} jj l^{\mp} \to jj l^{\pm} l^{\mp} + \not{E}_T$$

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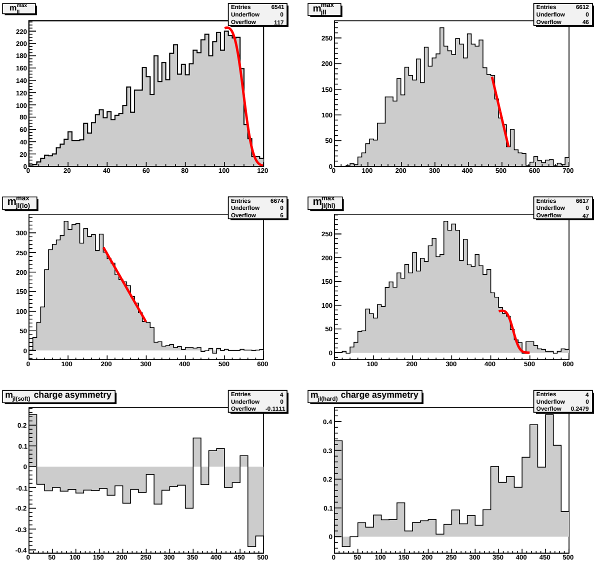
Benchmark points can be distinguished from normal mSUGRA points!

Sample endpoint fitting (BP 1)



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Why E_7?

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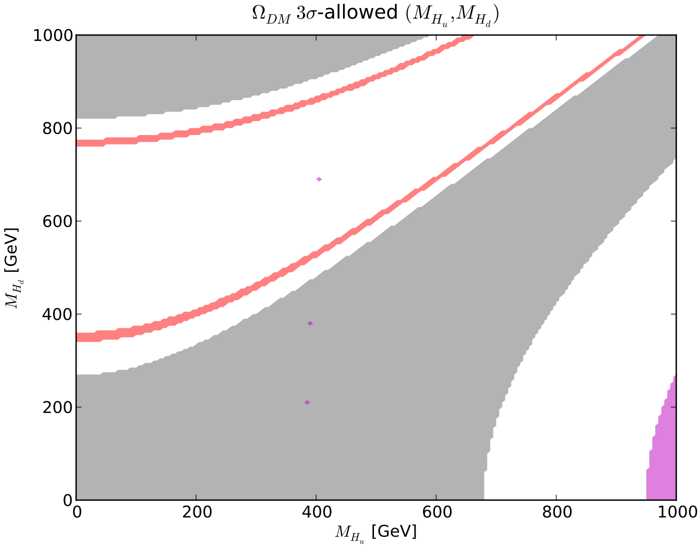
- E_6 too small, E_8 gives real representation

Heavy 5^*, Heavy 10



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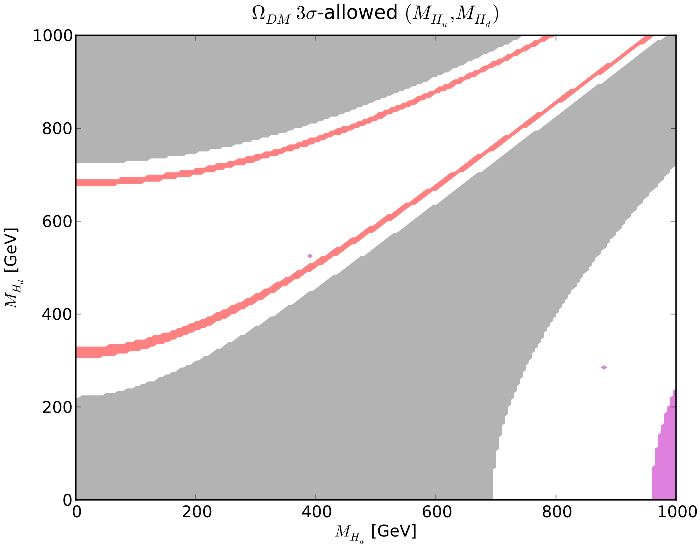

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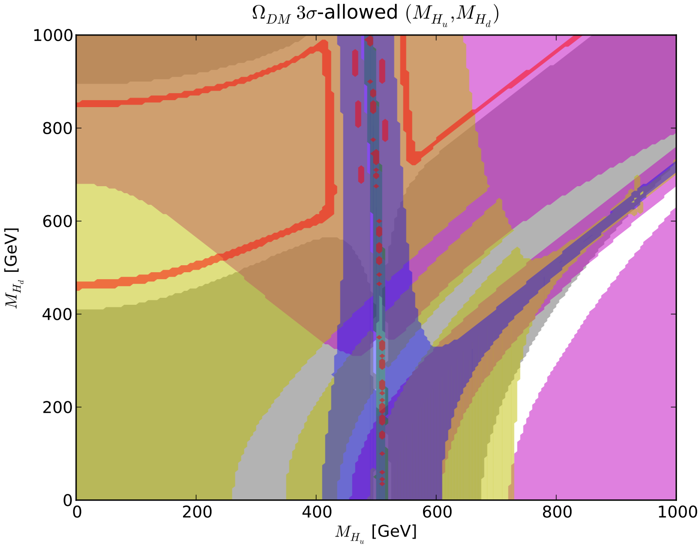

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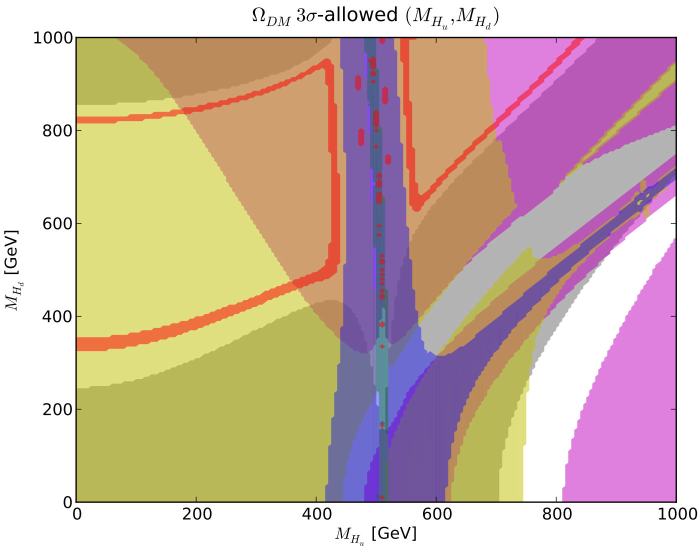

Outline

Other constraints

Dark matter

- BP 1 and BP 2 annihilations helicity-suppressed
- Mostly bino — suppressed gauge final states and direct detection cross-section
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FCNCs

- First "transition parameter" δ_{12} suppressed by λ^5 — near upper bound
- $s \to b$ suppressed only by λ_d^2 — contributes to $B_s - \bar{B}_s$ mixing?
- See Gabrielli, Masiero, Silvestrini, Phys. Lett. B **374**, 80 (1996)

Conclusions

Positive aspects

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Looks interesting!