Dark Matter Phenomenology of sub-GUT SUSY Breaking

Pearl Sandick

University of Minnesota

Ellis, Olive & PS, Phys. Lett. B **642** (2006) 389
Ellis, Olive & PS, arXiv:0704.3446

Why we like SUSY

- Solves the Naturalness Problem
- Gauge coupling unification (GUTs)
- Predicts a light Higgs boson

R-Parity conservation →

What We Do

- SUSY must be broken, so introduce soft SUSY-breaking parameters and assume high (GUT) scale values for them
- Evolve parameters down to weak scale using RGEs of low energy effective theory (MSSM)
- CMSSM: GUT-scale universality of soft breaking parameters

  Some other scale?

  – 5 inputs: m_0, $m_{1/2}$, A_0, $\tan(\beta)$, $\mathrm{sign}(\mu)$

GUT-less CMSSM

- Assume unification of soft SUSY-breaking parameters at some $M_{in} < M_{GUT}$
  - Constraints from colliders and cosmology:

$m_h > 114$ GeV	LEP
$m_{\chi^\pm} > 104$ GeV	LEP
$BR(b \to s\,\gamma)$	HFAG
$BR(B_s \to \mu^+\mu^-)$	CDF
$(g_\mu - 2)/2$	g-2 collab.

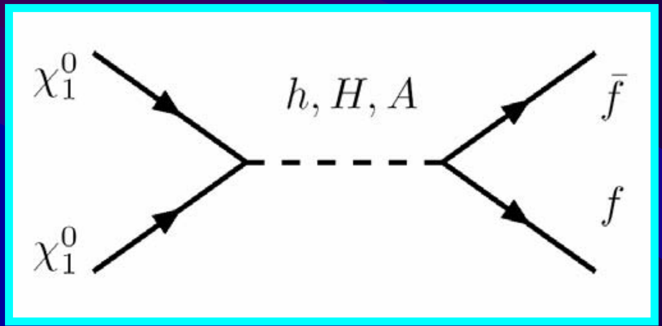
$$0.09 \leq \Omega_\chi h^2 \leq 0.12$$

SUSY Dark Matter

- Solve Boltzmann rate equation:

$$\frac{dn_\chi}{dt} = -3Hn_\chi - \langle \sigma v_{rel} \rangle \left[n_\chi^2 - (n_\chi^{eq})^2 \right]$$

- Special Situations:
  - s - channel poles
    - 2 $m_\chi \approx m_A$
  - thresholds
    - 2 $m_\chi \approx$ final state mass
  - Coannihilations
    - $m_\chi \approx m_{\text{other sparticle}}$



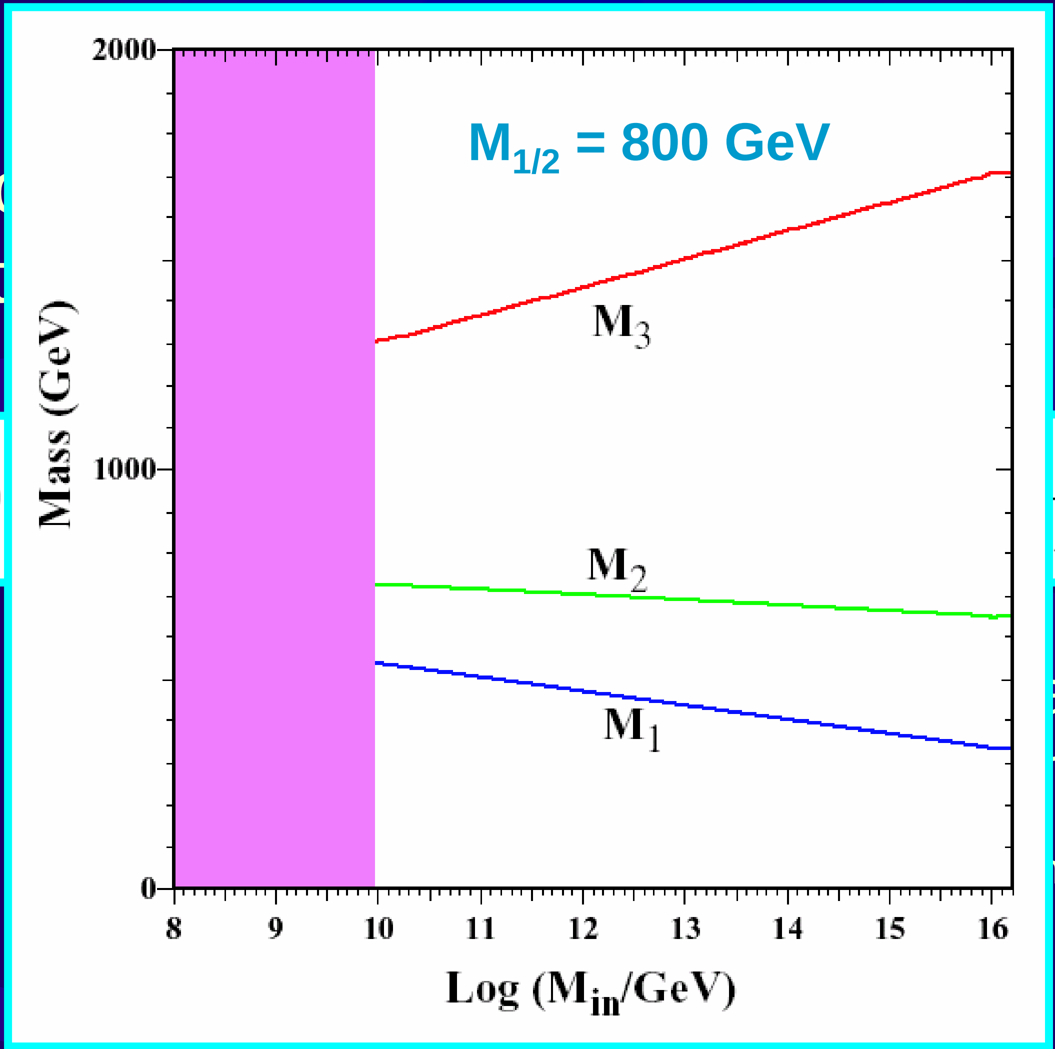
Evolution of the Soft Mass Parameters

- First l[...]
  evolut[...]

  Gaugi[...]

$M_a(Q)$ ... $\frac{(Q)}{M_{in})} m_{1/2}$

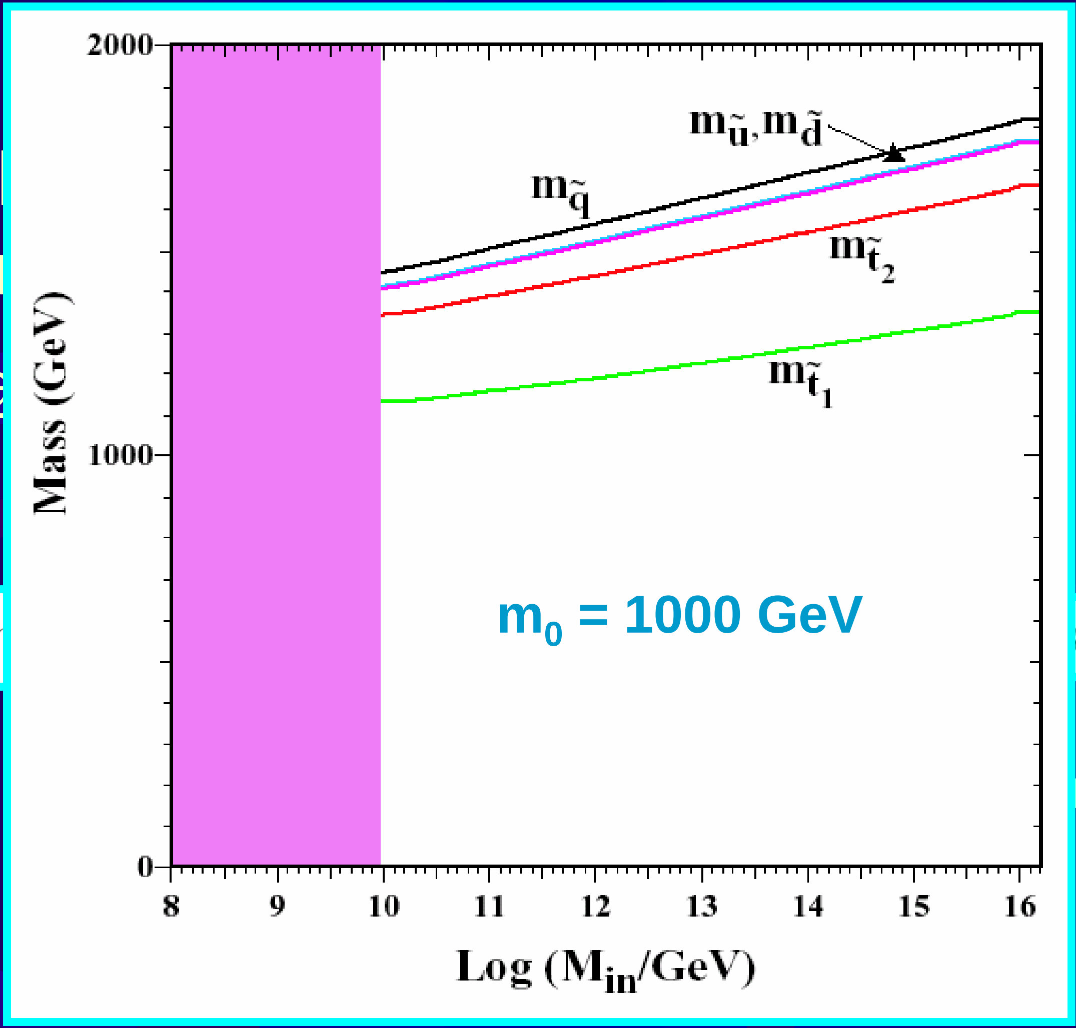
[...]al to
[...]no
[...], is



Evolution of the Soft Mass Parameters

- First l
  evolu

  Scala



m ... $M_{in} \to Q$

cale

.

Evolution of the Soft Mass Parameters

- Higgs mass parameter, μ (tree level):

$$\mu^2 = \frac{m_1^2 - m_2^2 \tan^2\beta}{\tan^2\beta - 1} - \frac{M_Z^2}{2}$$

As $M_{in} \rightarrow$ low scale Q, expect low scale scalar masses to be closer to m_0.

μ^2 becomes generically smaller as M_{in} is lowered.

Mass Evolution with M_{in}

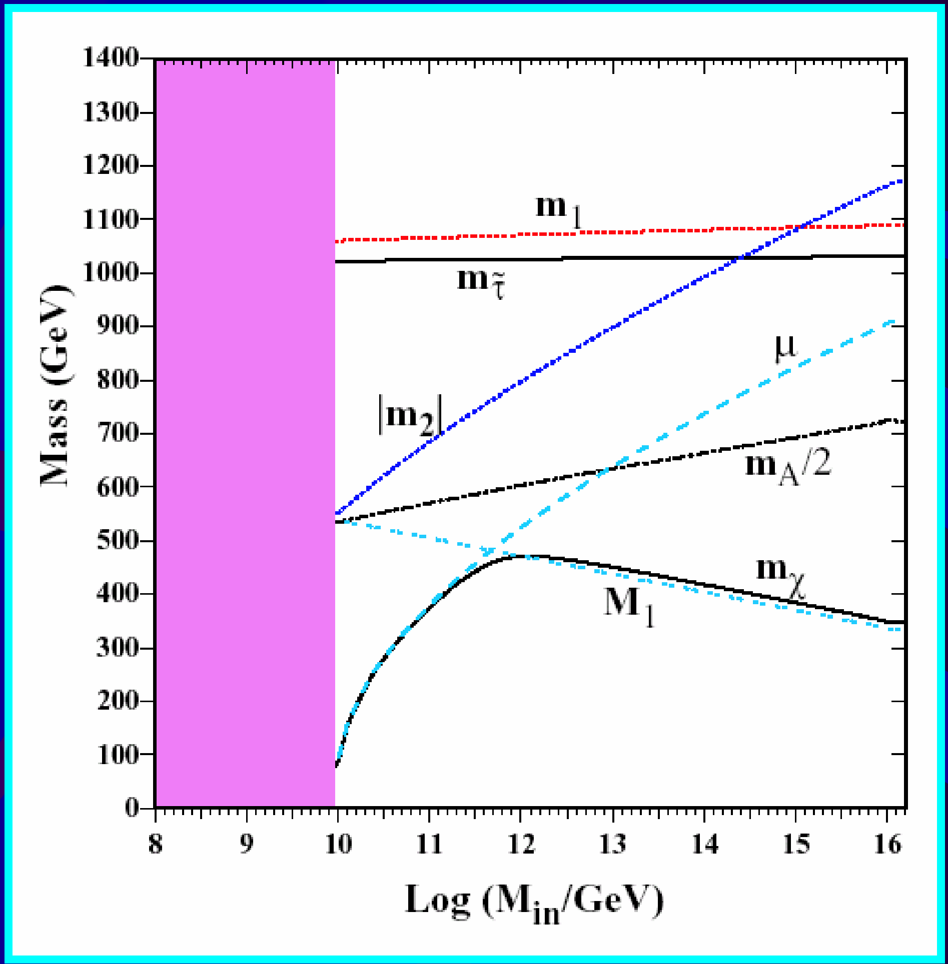
$m_{1/2}$ = 800 GeV

m_0= 1000 GeV

A_0 = 0

tan(β) = 10

μ > 0



How do we expect the constraints to evolve?

- m_A decreases logarithmically with M_{in}
  - BR($b \rightarrow s\,\gamma$) and BR($B_s \rightarrow \mu^+\mu^{--}$) at large tan($\beta$) have important contributions from heavy Higgs exchange. These constraints will become more important as M_{in} is lowered.
- μ decreases as M_{in} is lowered.
  - Expect that the unphysical region where $\mu^2 < 0$ encroaches farther into the plane.
  - When the LSP is bino-like, its mass *increases* as M_{in} is lowered, so the forbidden stau LSP region encroaches into the plane. When the LSP becomes Higgsino-like, it's mass *decreases* as M_{in} is lowered, so the stau LSP boundary falls back down.

Neutralinos and Charginos

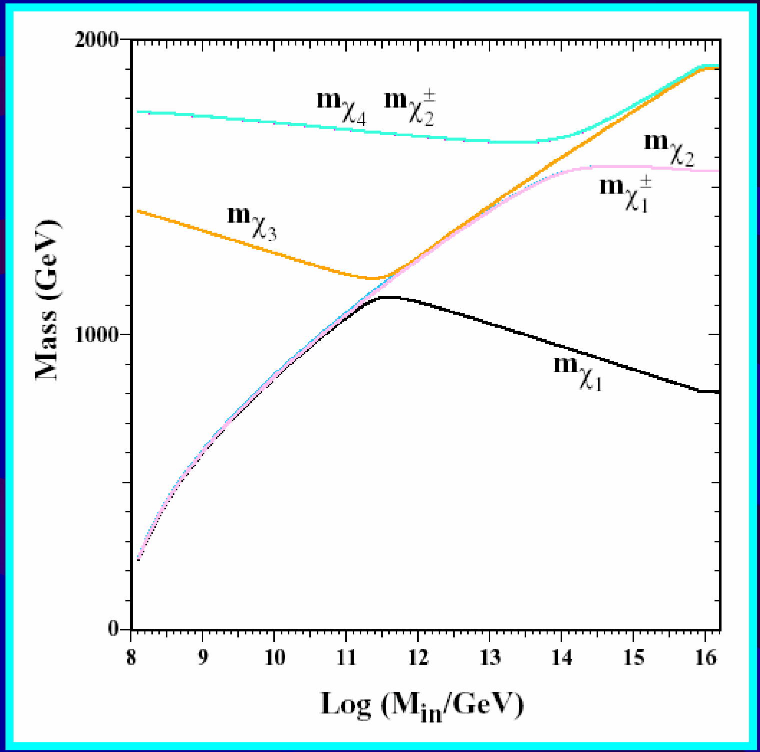
$m_{1/2}$ = 1800 GeV

m_0= 1000 GeV

A_0 = 0

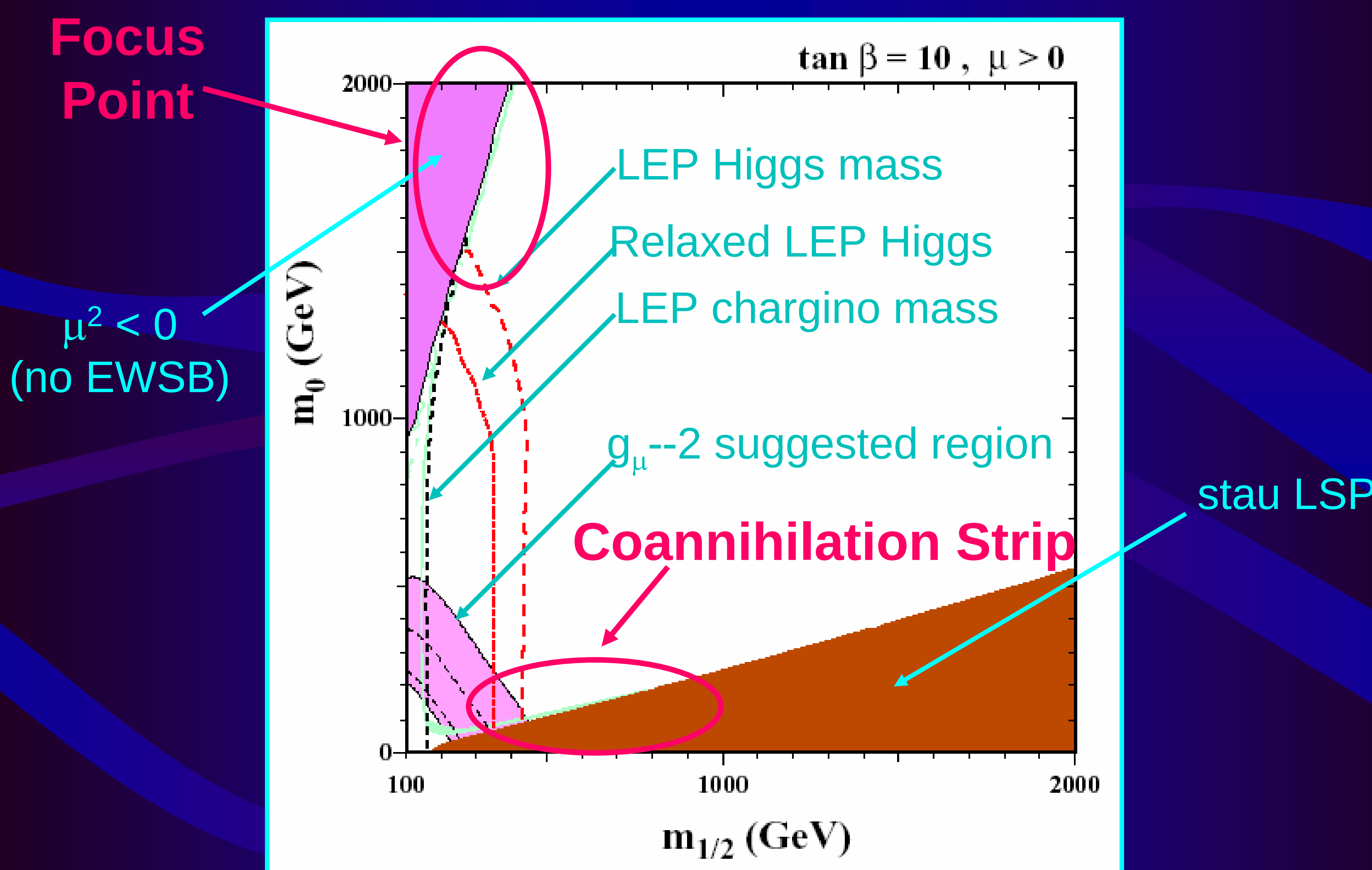
tan(β) = 10

μ > 0

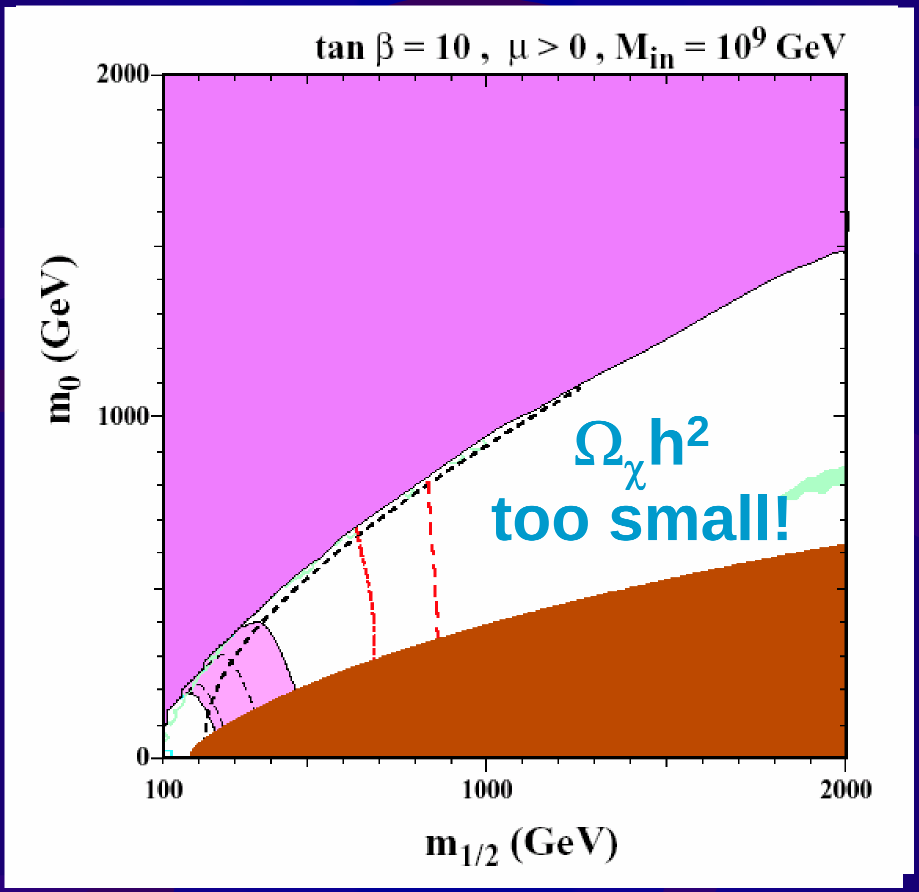


Must properly include coannihilations involving all three lightest neutralinos!

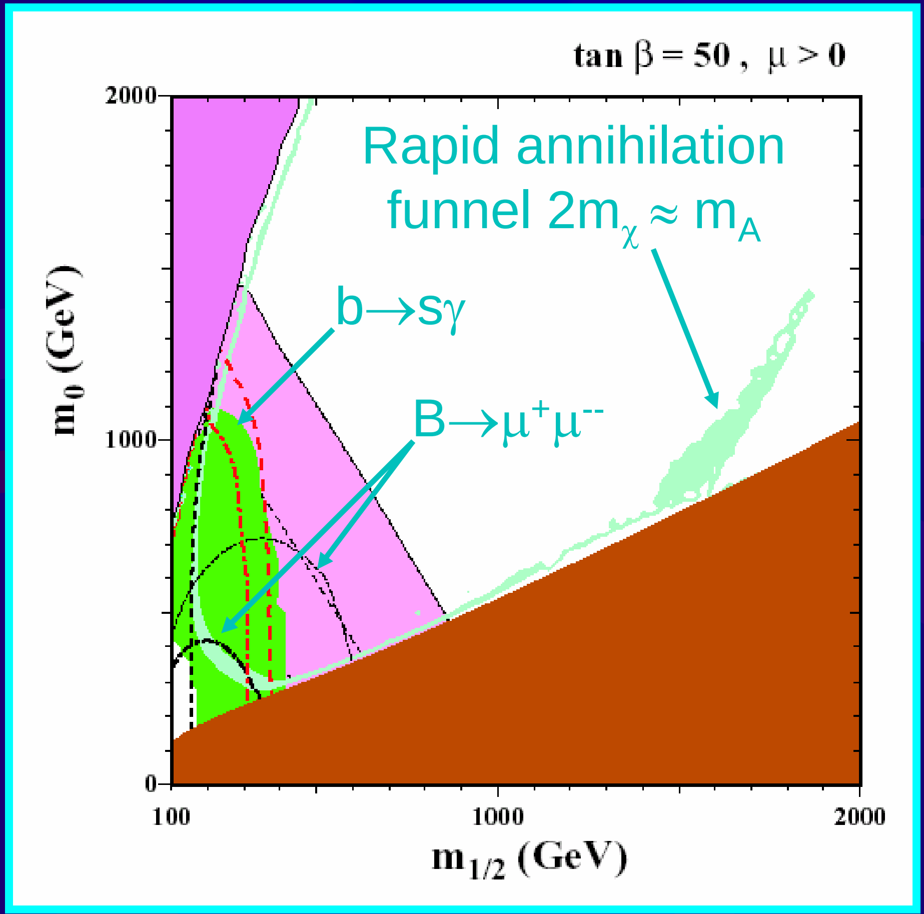
Standard CMSSM



Lowering M_{in} - $\tan(\beta) = 10$

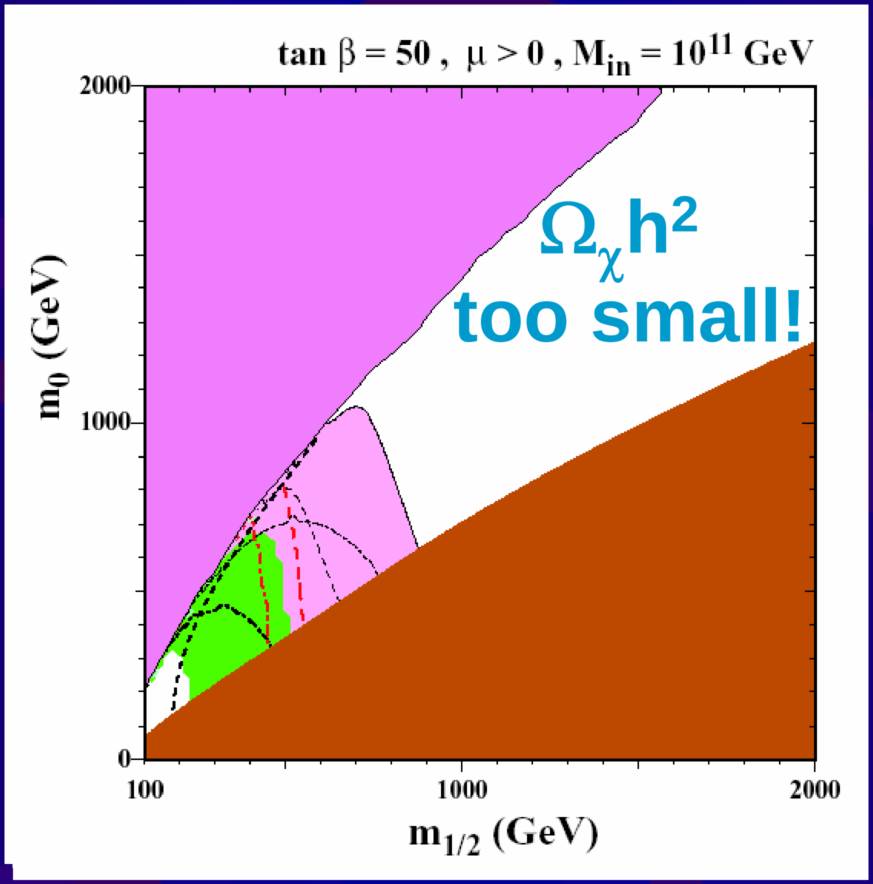


Large tan(β)



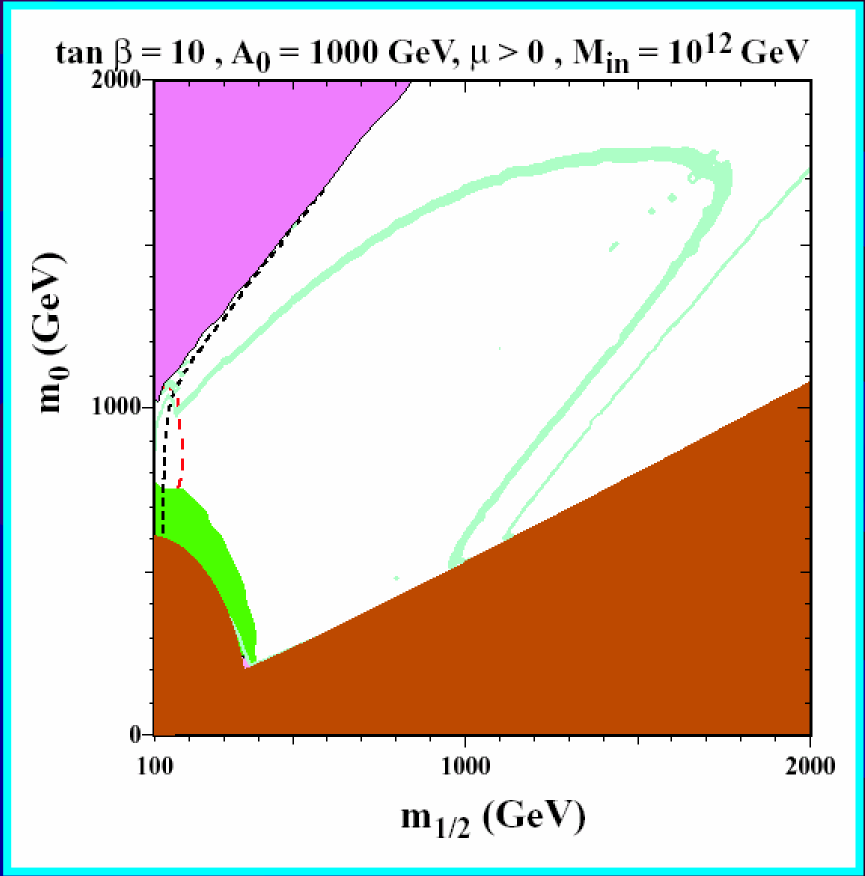
tan β = 50 , μ > 0
2000
1000
0
100
1000
2000
m0 (GeV)
m1/2 (GeV)
Rapid annihilation
funnel 2mχ ≈ mA
b→sγ
B→μ+μ--

Lowering M_{in} - $\tan(\beta) = 50$

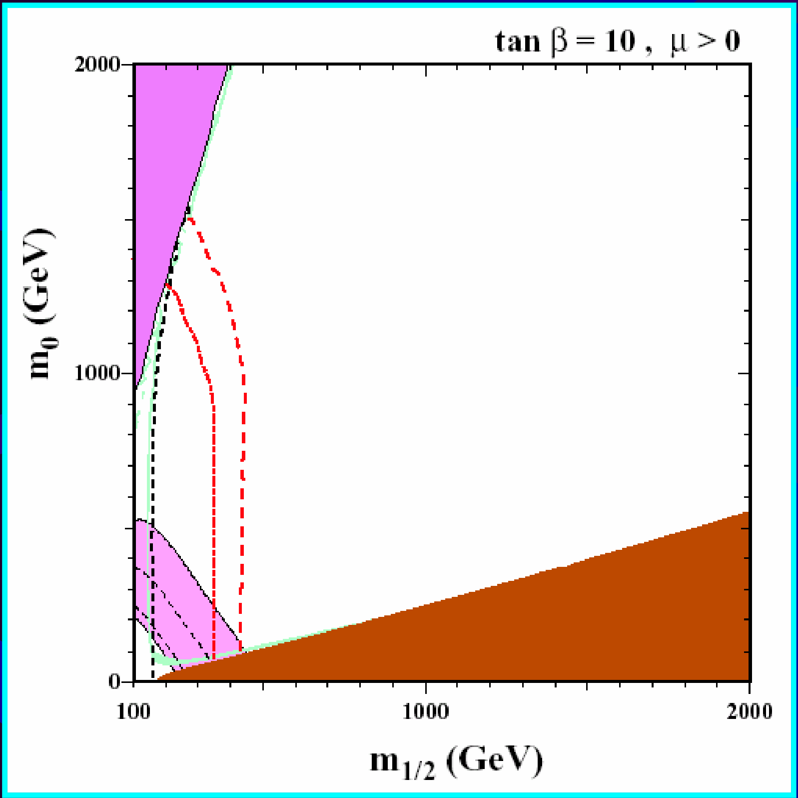


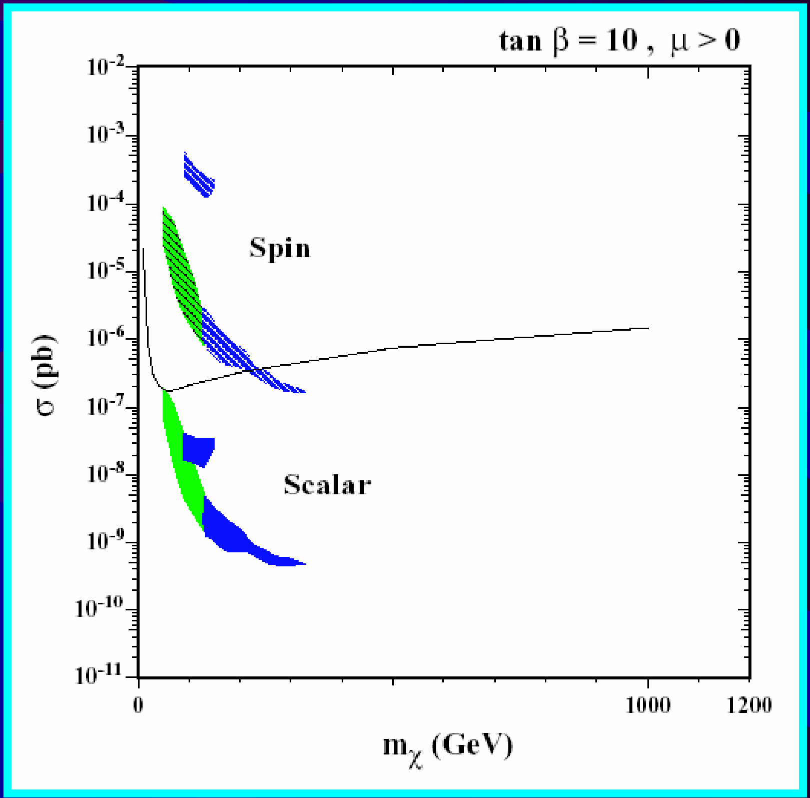
$A_0 \neq 0$

- $A_0 > 0 \Rightarrow$ larger weak-scale trilinear couplings, A_i
- Large loop corrections to μ depend on A_i, so μ is generically larger over the plane than when $A_0 = 0$.
- Also see stop-LSP excluded region



Direct Detection: Neutralino-Nucleon Cross Sections





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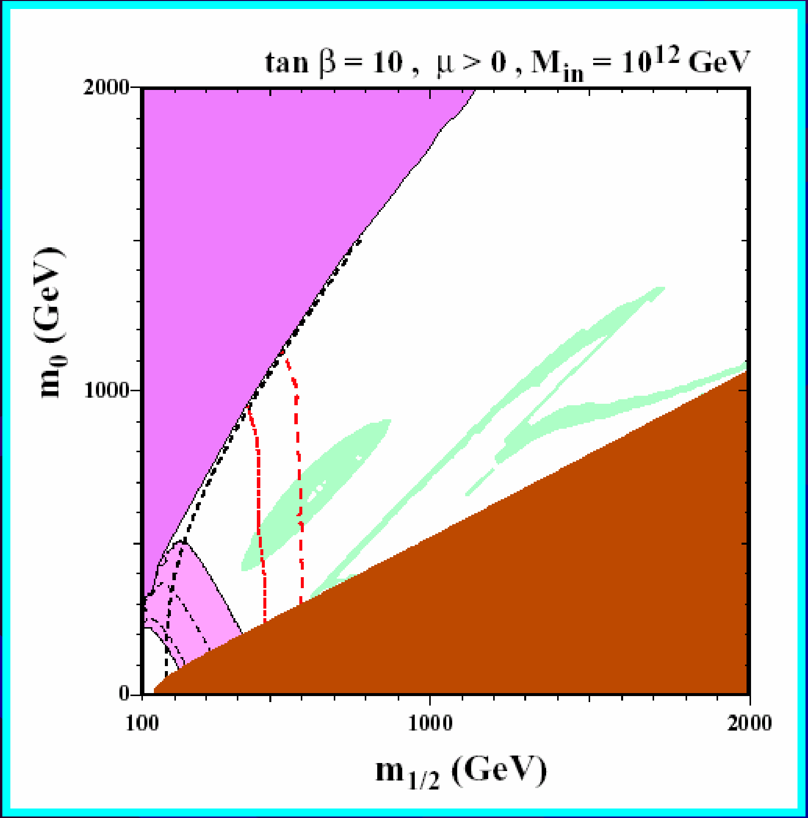
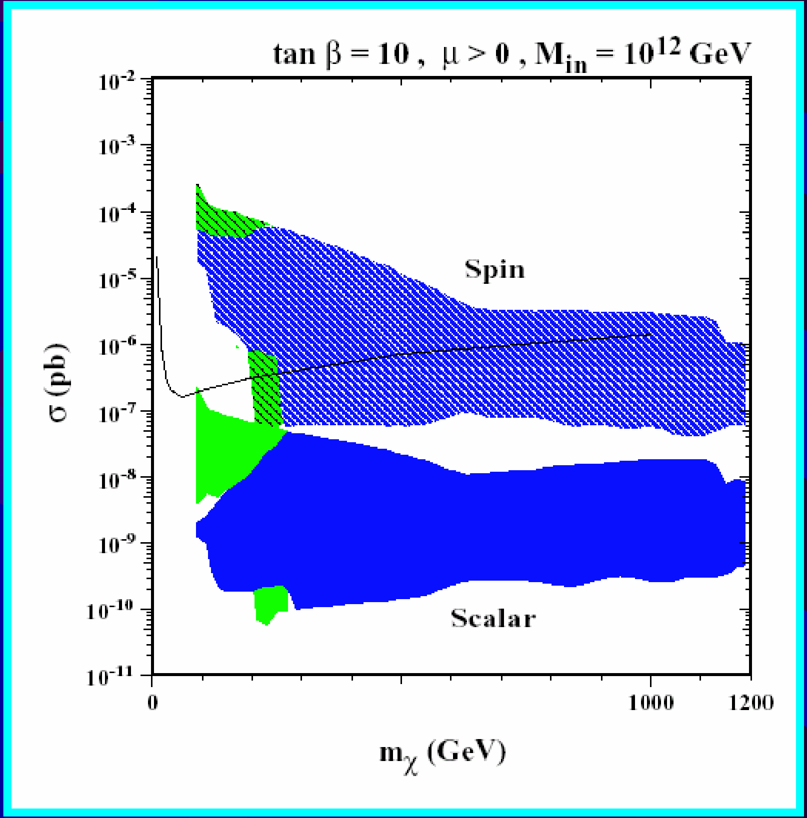
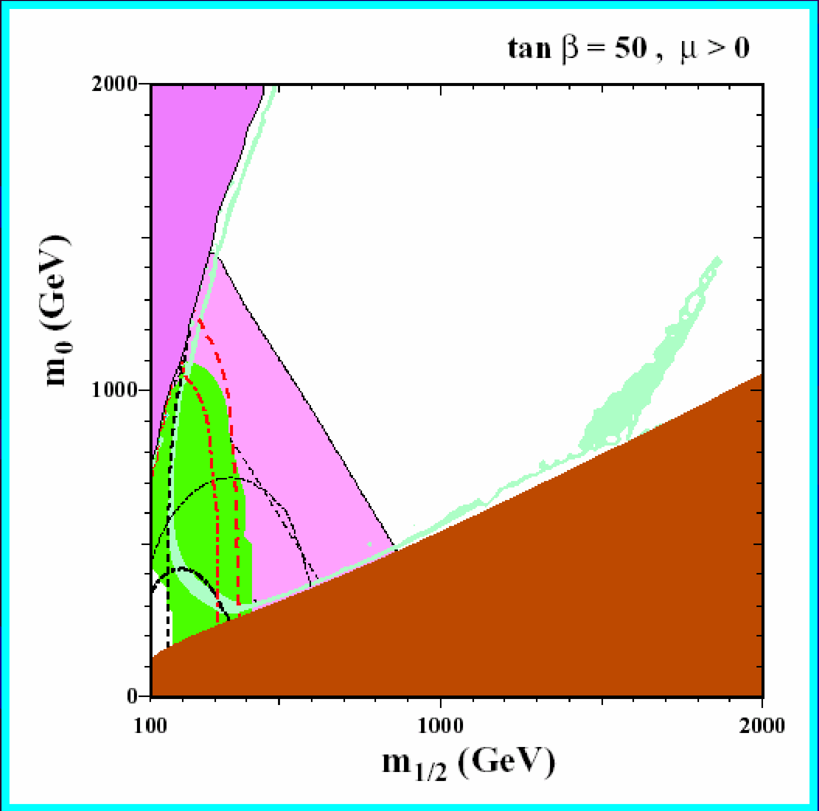


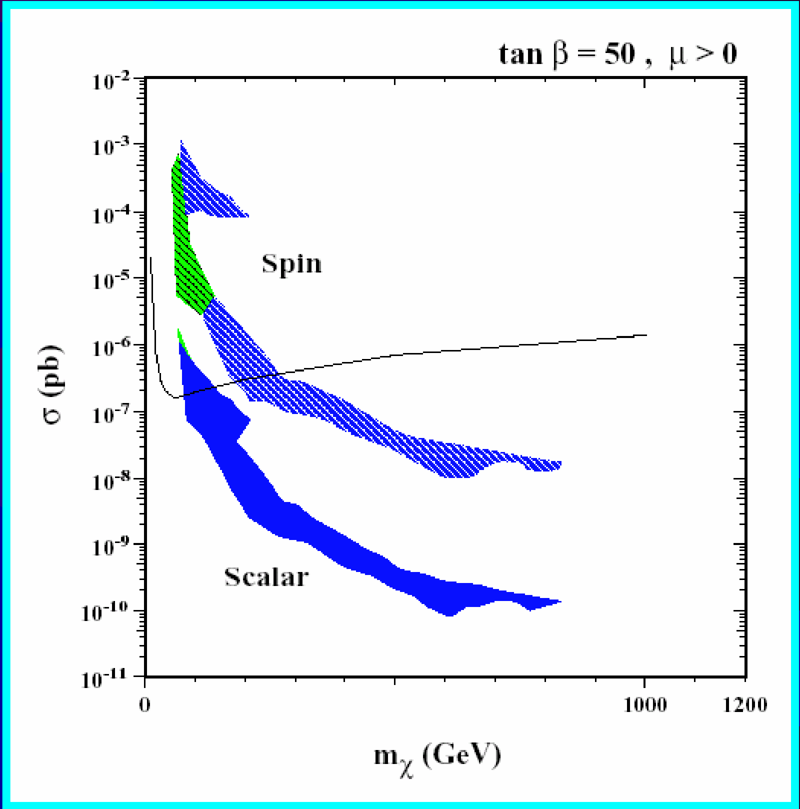


Conclusions

- Intermediate scale unification results in:
  - Rapid annihilation funnel even at low tan(β)
  - Merging of funnel and focus point
- Below some critical M_{in} (dependent on tan(β) and other factors), all of nearly all of the ($m_{1/2}$, m_0) plane is disfavored because the relic density of neutralinos is too low to fully account for the relic density of cold dark matter.

Neutralino-Nucleon Cross Sections





Neutralino-Nucleon Cross Sections