Supersymmetry, Dark Matter and Collider Physics

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OUTLINE

- ⋆ Gravity-mediated SUSY breaking
- ⋆ Constraints
- ⋆ SUSY search at Tevatron
- ⋆ SUSY search at LHC
- ⋆ Some non-standard scenarios
  - – Normal scalar mass hierarchy
  - – Split generations in Yukawa unified models
- ⋆ What will Tevatron teach us about LHC physics
- ⋆ Collaborators: Balazs, Belyaev, Krupovnickas, Tata

Gravity-mediated SUSY breaking models

Construction

- ⋆ Lagrangian for local SUSY gauge theories (Cremmer et al., 1983)
- ⋆ gauge symmetry: $SU(3)_C \times SU(2)_L \times U(1)_Y$
- ⋆ SM field content: fields $\Rightarrow$ superfields
  - – augment by additional Higgs doublet
- ⋆ Introduce hidden sector: arena for SUSY breaking
- ⋆ $m(sparticles) \sim m_{3/2} \sim TeV$

Gravity mediated SUSY breaking:

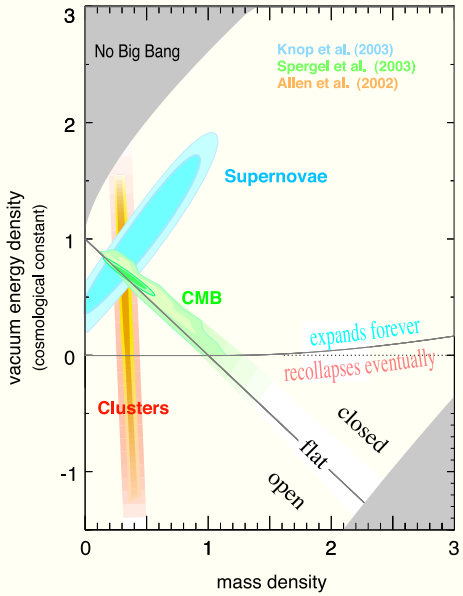
- ⋆ Advantages:
  - only 4 spacetime dimensions needed
  - minimal messenger sector (gravity)
  - good CDM candidate
- ⋆ Disadvantages:
  - arbitrary soft SUSY breaking terms
    - ∗ FCNCs
    - ∗ possible CP violation
- ⋆ mSUGRA model:
- ⋆ universal scalar, gaugino masses, A-terms
- ⋆ $m_0,\ m_{1/2}, A_0,\ \tan\beta,\ sign(\mu)$

Constraints on mSUGRA model

- ⋆ LEP2:
  - $m_h > 114.4$ GeV
  - $m_{\widetilde{W}_1} > 103.5$ GeV
- ⋆ $BF(b \to s\gamma)$
  - $BF(b \to s\gamma) = (3.25 \pm 0.54) \times 10^{-4}$
- ⋆ $a_\mu = (g-2)_\mu/2$
  - $\Delta a_\mu = (31.7 \pm 9.5) \times 10^{-10}$ Hagiwara et al. e^+e^-
- ⋆ WMAP: $\Omega_{CDM}h^2 = 0.1126 \pm 0.0090$

Relic density constraint

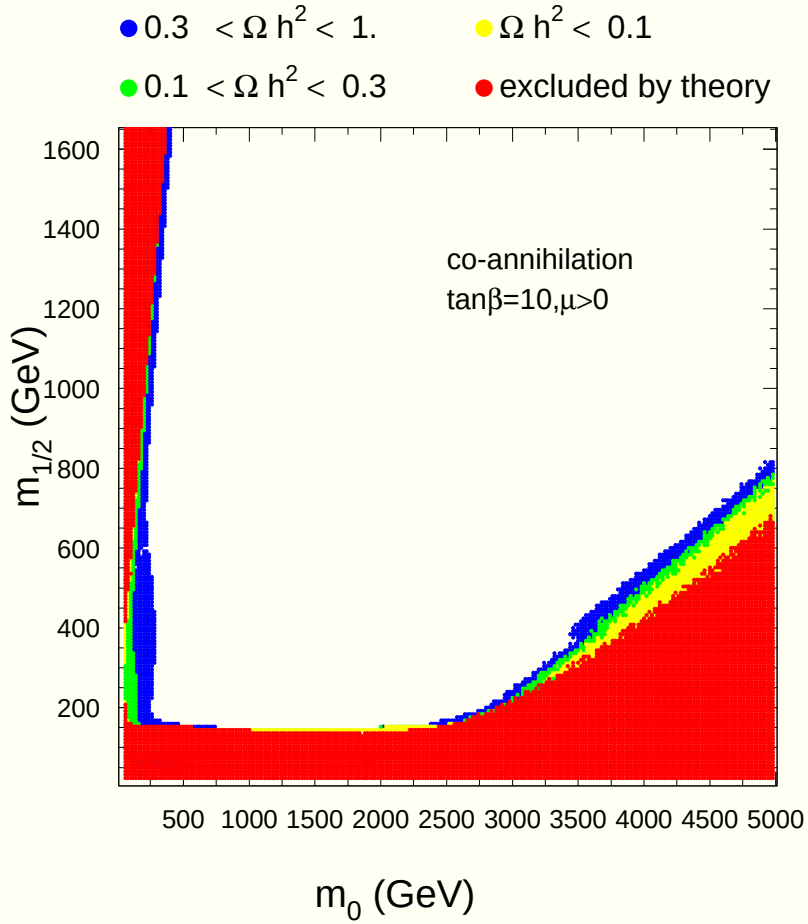
- baryons $\sim 5\%$
- neutrinos $< 1\%$
- CDM $\sim 25\%$
- DE $\sim 70\%$

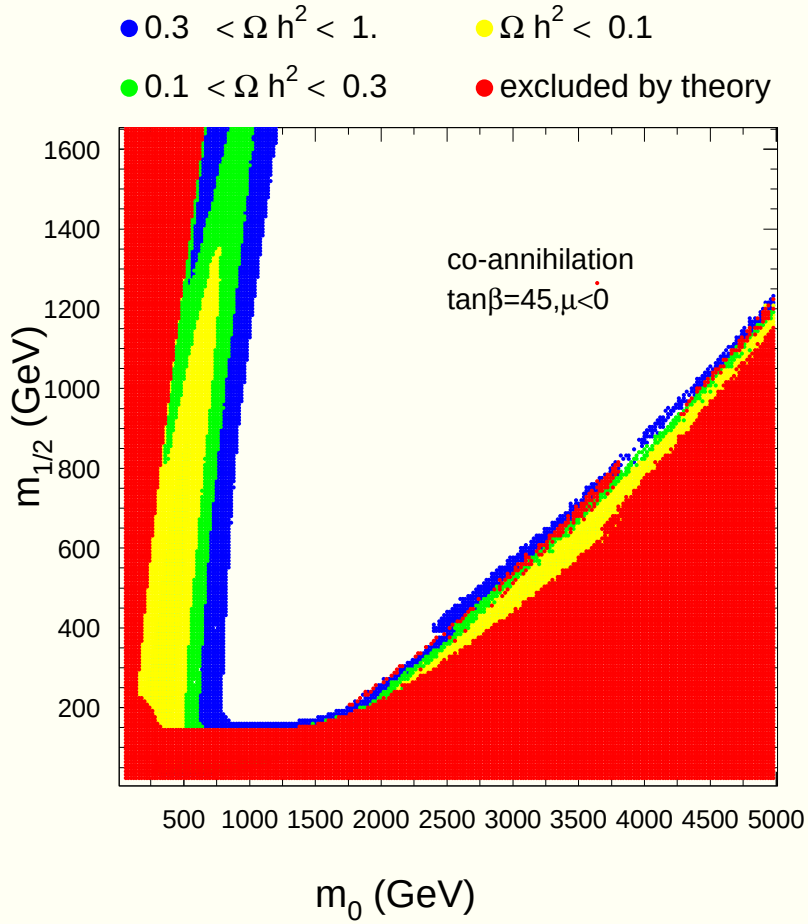


Calculating the relic abundance of neutralinos

- ⋆ At very high T, neutralinos in thermal equilibrium with cosmic soup
- ⋆ As universe expands and cools, expansion rate exceeds interaction rate (freeze-out)
- ⋆ number density is governed by Boltzmann eq. for FRW universe
  - $dn/dt = -3Hn - \langle \sigma v_{rel} \rangle (n^2 - n_0^2)$
  - depends critically on thermally averaged annihilation cross section times velocity
- ⋆ 1722 annihilation/co-annihilation reactions; 7618 Feynman diagrams
  - use CompHEP automatic Feynman diagrams calculation
- ⋆ IsaRed program (HB, A. Belyaev , C. Balazs)

Relic density of neutralinos in mSUGRA model

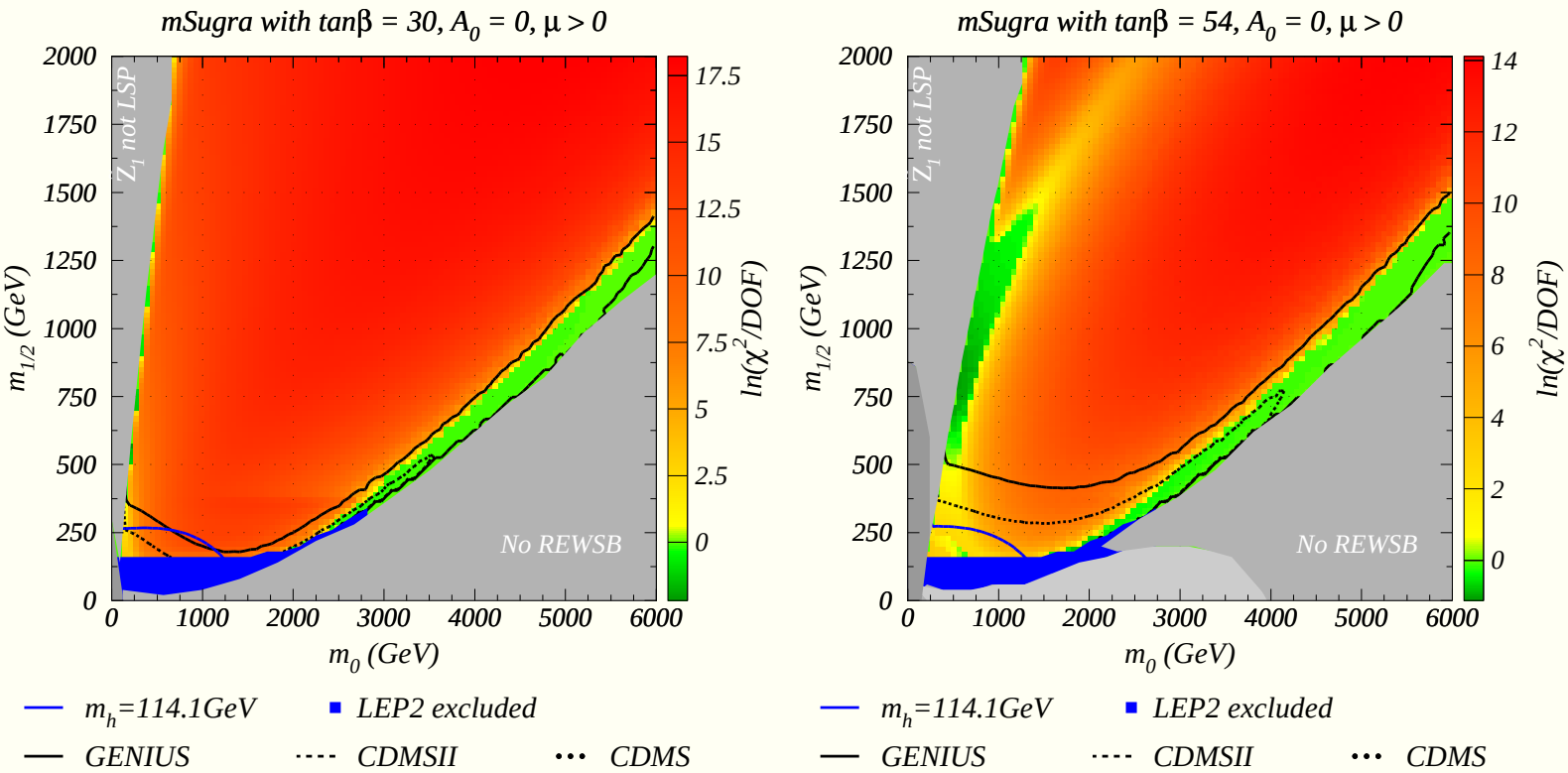




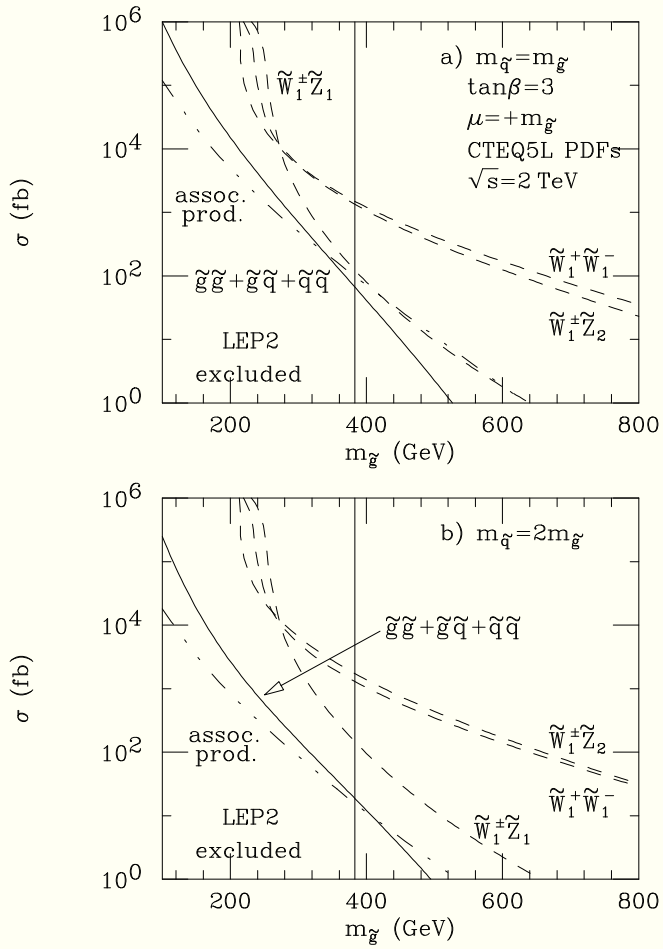
Named regions of p-space

- ⋆ bulk region: low m_0, $m_{1/2}$
- ⋆ stau co-ann.: low m_0
- ⋆ HB/FP: large m_0
- ⋆ A-funnel: large $\tan\beta$
- ⋆ h or Z annihilation corridor
- ⋆ stop co-annihilation: particular A_0 values
  - – motivated by EW baryogenesis (Balazs, Carena, Wagner)

Regions of low (green) and high (red) χ^2



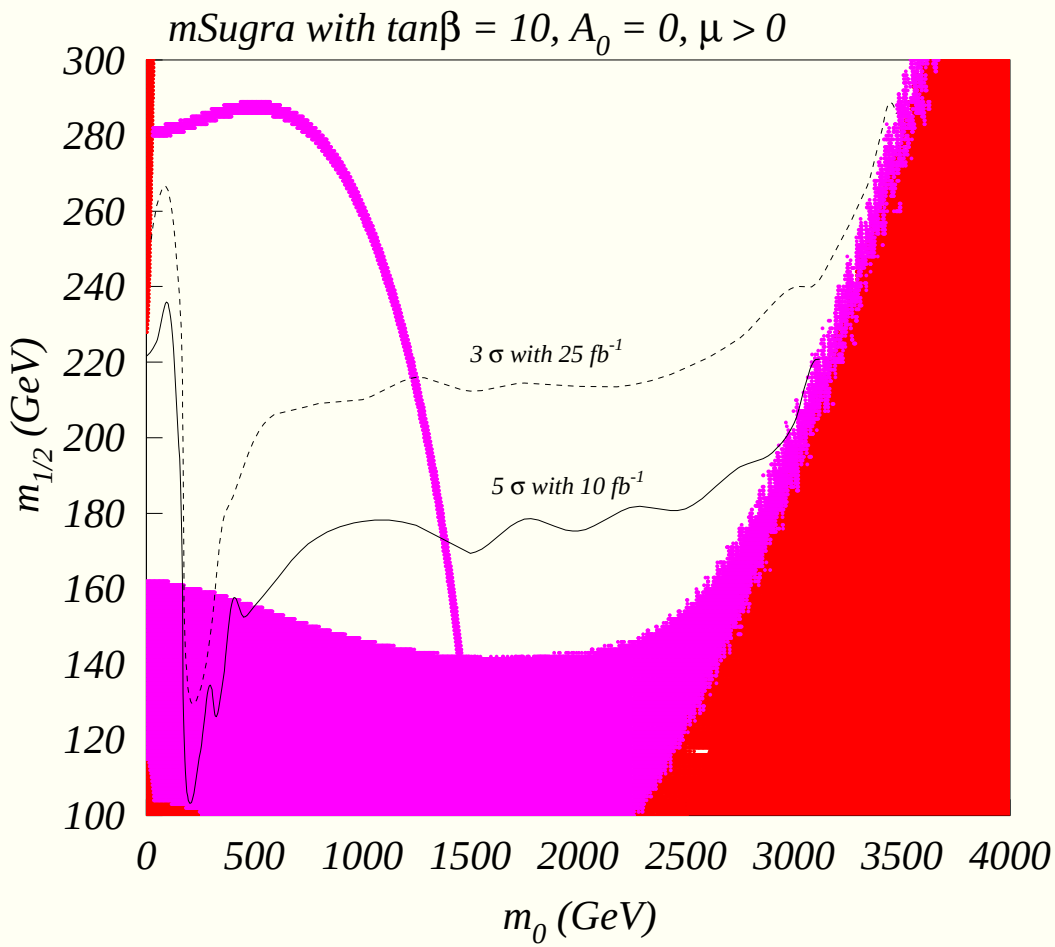
Production of sparticles at Tevatron



Search for SUSY at Tevatron collider

- ★ $\not{E}_T+$ jets signal from $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{q}$ production
  - largely pre-empted by LEP2 $m_{\widetilde{W}_1} > 103.5$ GeV bound
  - gaugino mass unif'n $\Rightarrow m_{\tilde{g}} \gtrsim 360$ GeV
- ★ 1ℓ, 2ℓ signals:
  - large BG from W, Z, WW, $t\bar{t}$
- ★ $p\bar{p} \to \widetilde{W}_1\widetilde{Z}_2 X \to 3\ell + \not{E}_T + X$
  - good rate if $BF(\widetilde{Z}_2 \to \widetilde{Z}_1\ell\bar{\ell})$ not suppressed
  - BG from WZ, $W^*\gamma^*$, W^*Z^*

Reach of Fermilab Tevatron: $p\bar{p} \to \widetilde{W}_1 \widetilde{Z}_2 \to 3\ell + \not{E}_T + X$



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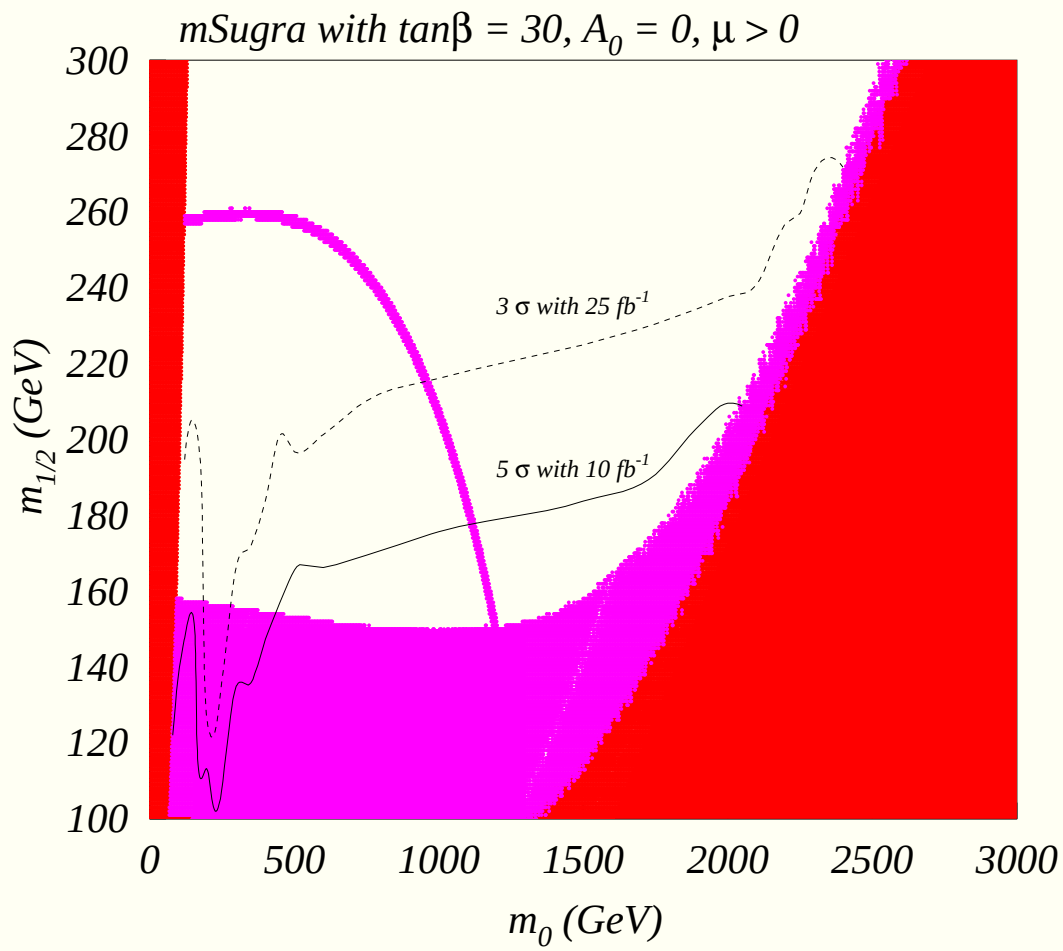
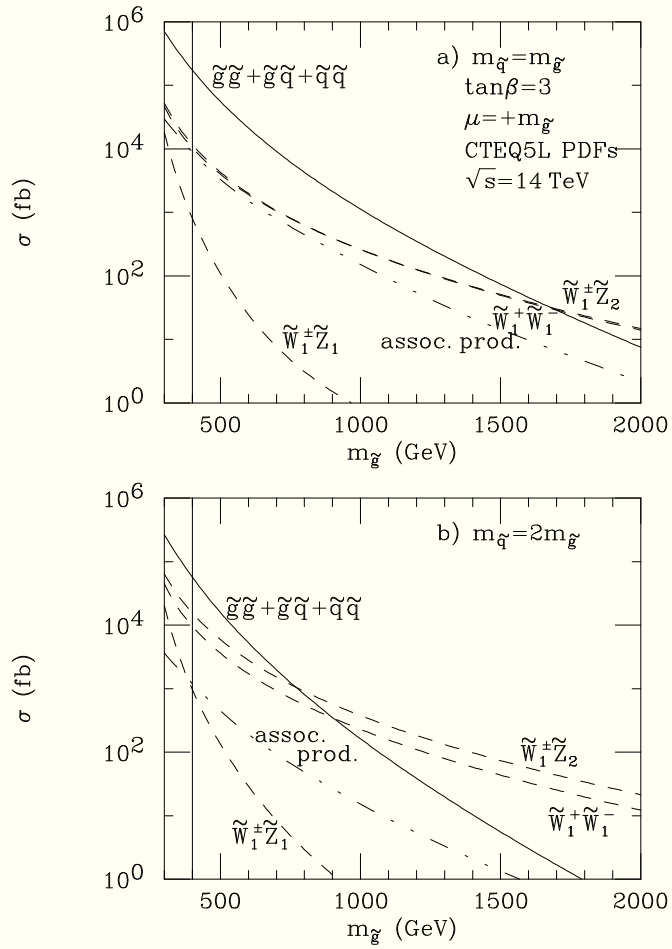


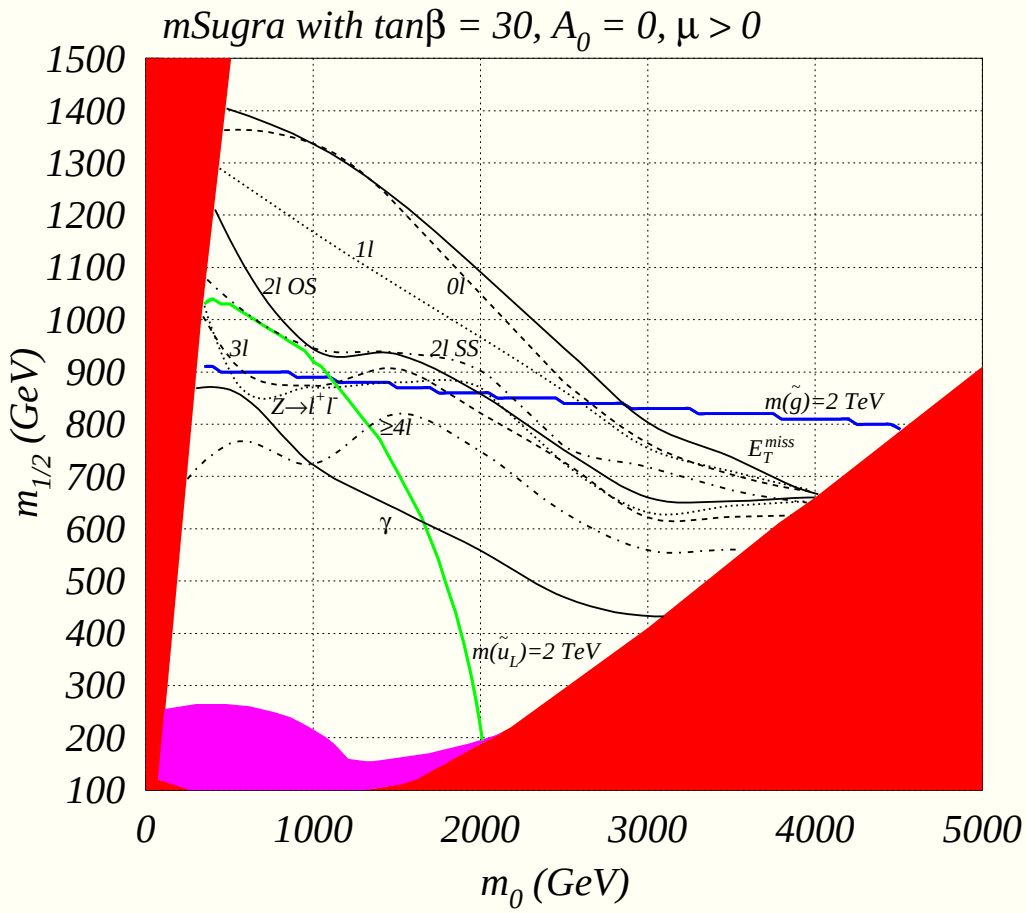
Production of sparticles at LHC



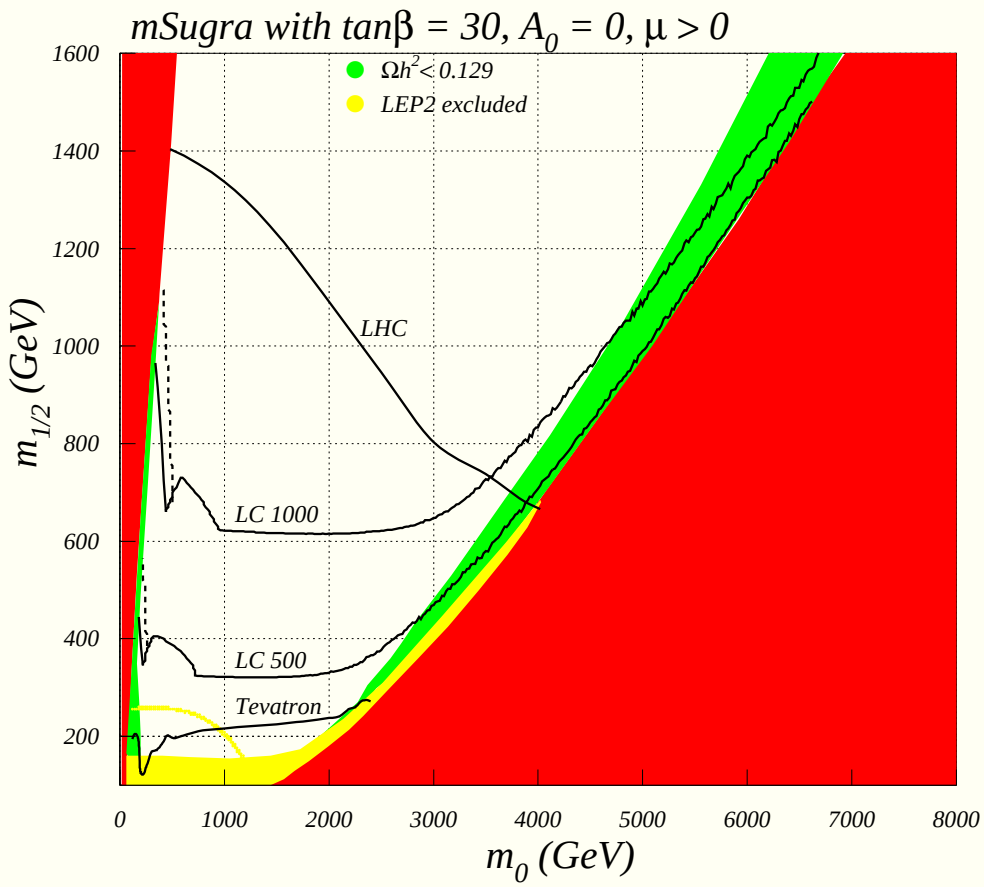
Search for SUSY at CERN LHC

- ★ $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, $\tilde{q}\tilde{q}$ production dominant for $m \lesssim 1$ TeV
- ★ lengthy cascade decays possible
  - $\not{E}_T+$ jets
  - $1\ell+\not{E}_T+$ jets
  - $OS\ 2\ell+\not{E}_T+$ jets
  - $SS2\ell+\not{E}_T+$ jets
  - $3\ell+\not{E}_T+$ jets
- ★ BG: $t\bar{t}$, $b\bar{b}$, WW, $4t$, $\cdots$

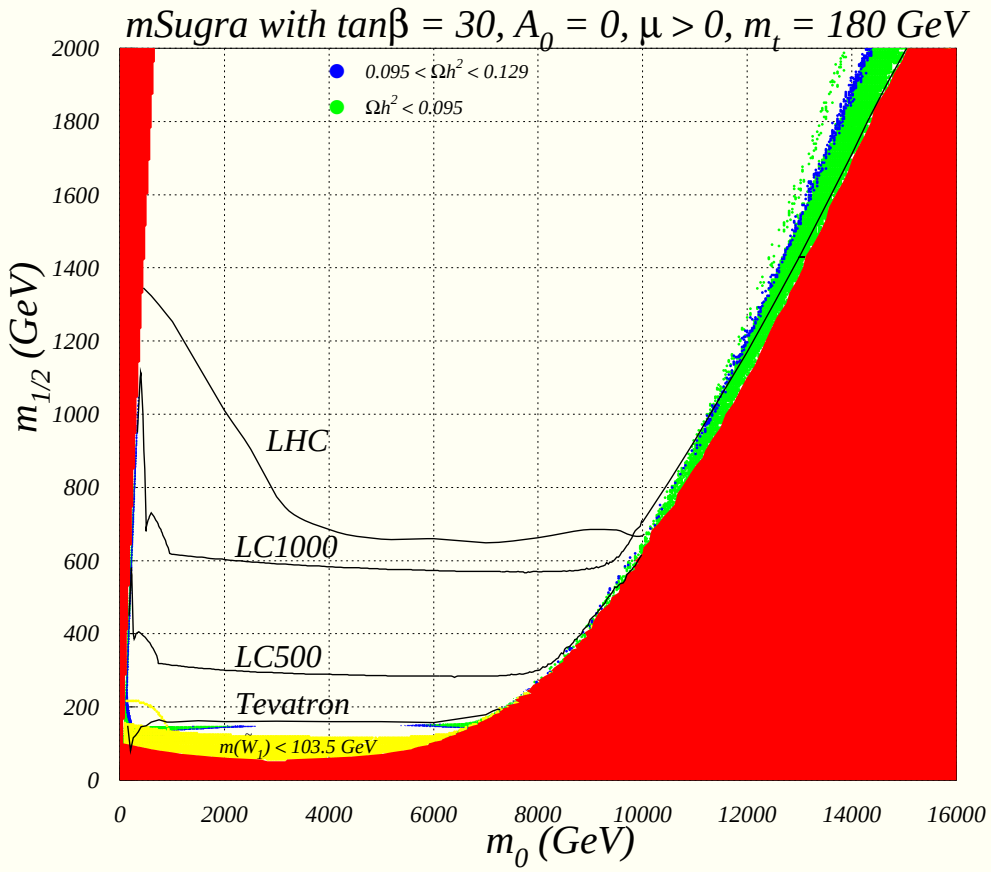
Reach of CERN LHC



Sparticle reach of all colliders with relic density



Sparticle reach of all colliders with $m_t = 180$ GeV



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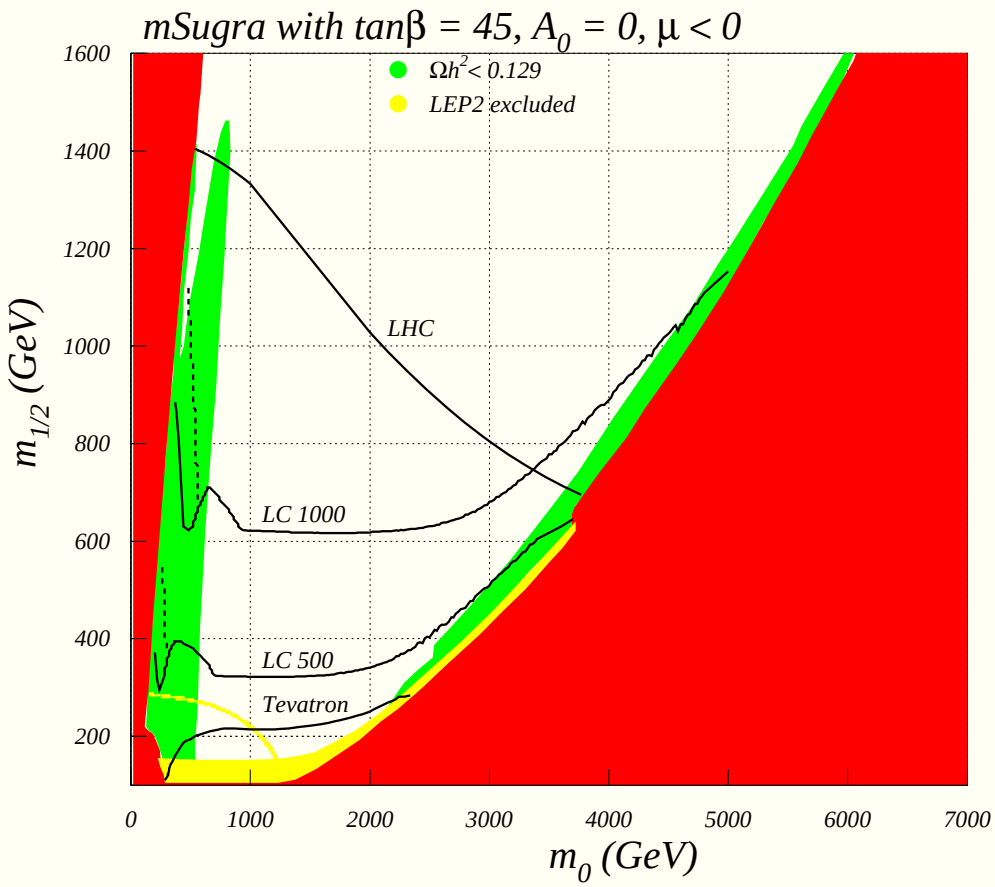

Some beyond mSUGRA scenarios:

- ⋆ Normal scalar mass hierarchy
  - Motivation: match $BF(b \to s\gamma)$, $(g-2)_\mu$, $\Omega_{CDM}h^2$ simultaneously
  - Split generations: $m_0(1) \simeq m_0(2) \ll m_0(3)$
  - Allowed by FCNCs
  - Observable 3ℓ rates at Tevatron
- ⋆ Split generations in Yukawa unified models
  - Motivation: match $\Omega_{CDM}h^2$ to WMAP; maintain $t-b-\tau$ unification
  - $m_{16}(1) \simeq m_{16}(2) \ll m_{16}(3)$ with Higgs splitting
  - gives $m_{\tilde{u}_R} \simeq m_{tc_R} \sim 90-120$ GeV so $\not{E}_T$+jets at Tevatron

What can Tevatron teach us about LHC physics?

- ⋆ Is h, Z ann. corridor responsible for $\Omega_{CDM}h^2$?
- ⋆ Is SUSY EW baryogenesis true? $m_{\tilde{t}_1} < m_t$, $m_h \lesssim 120$ GeV
- ⋆ Probe bulk region for low $\tan\beta$
- ⋆ Understand various QCD, EW backgrounds for LHC searches
- ⋆ Precision m_t: implications for BGs, location of HB/FP, Yukawa coupling unification
- ⋆ Test non-standard gravity-mediated SUSY models