Indirect, Direct and Collider Detection of SUSY Dark Matter

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Outline

- ⋆ WMAP allowed regions of p-space
- ⋆ Detection at colliders
  - Fermilab Tevatron
  - CERN LHC
  - $\sqrt{s} = 500$ or 1000 GeV linear e^+e^- collider
- ⋆ Direct DM detection
- ⋆ Indirect detection
  - $\widetilde{Z}_1\widetilde{Z}_1 \to f\bar{f},\ WW, \cdots \to \nu_\mu \to \mu$
  - detection of γs, e^+s and $\bar{p}$s

Wide variety of data *not* described by the SM

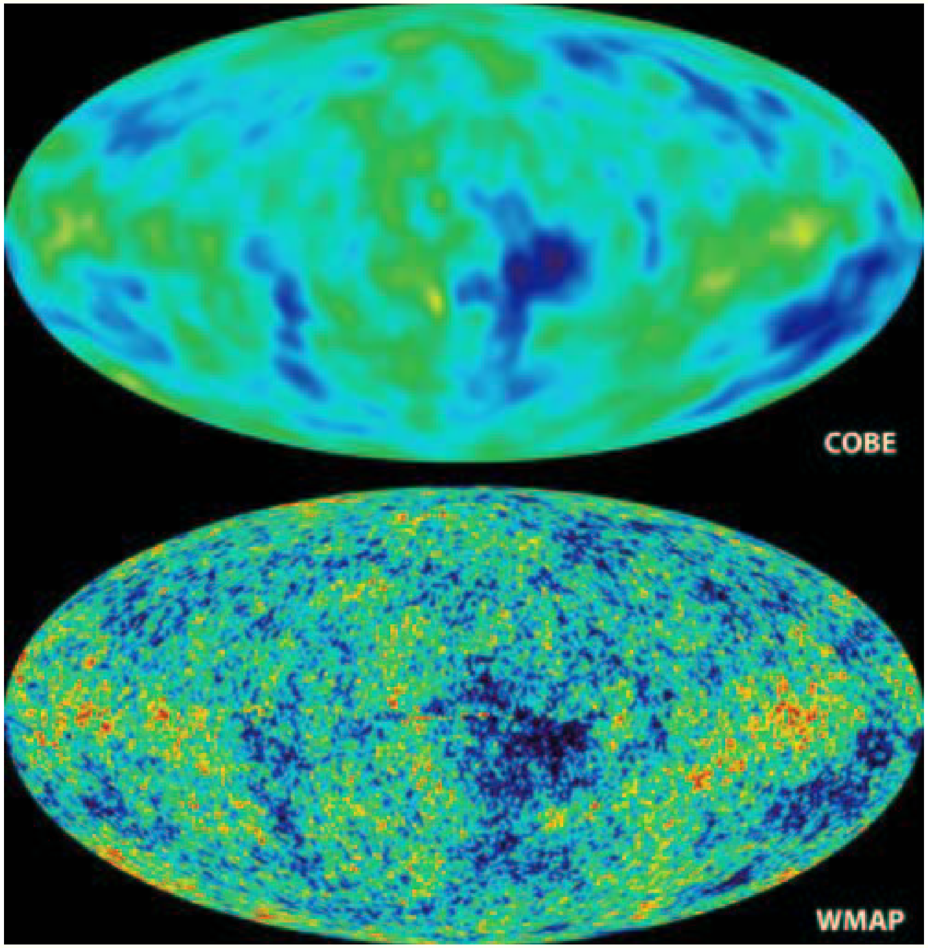
- neutrino masses and mixing
- baryogenesis $\eta \sim 10^{-10}$ (matter anti-matter asymmetry)
- cold dark matter
- dark energy

⋆ Note astro/cosmological origin of all discrepancies!

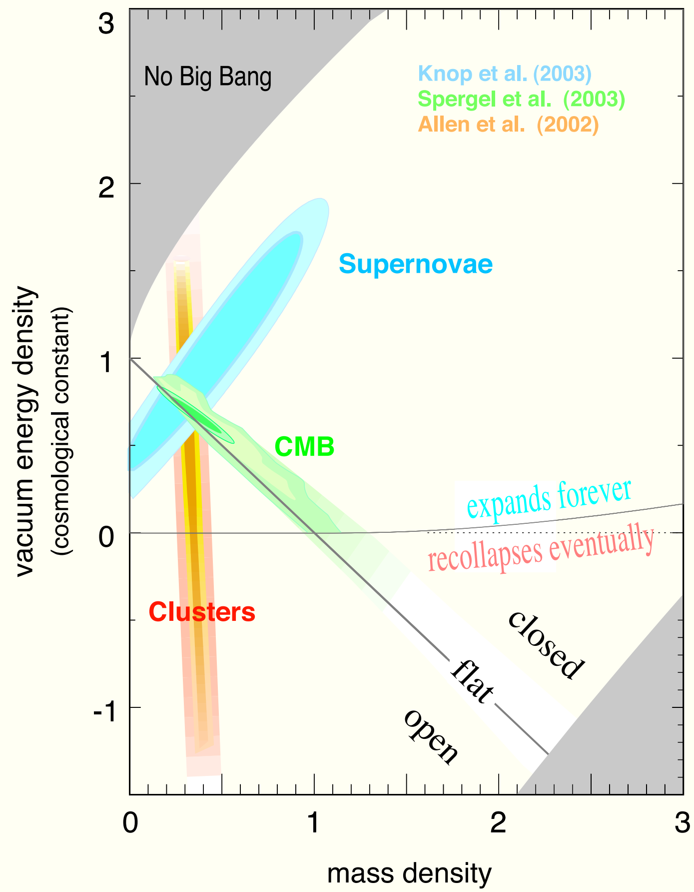
Evidence for dark matter in the universe

- ⋆ binding of galactic clusters (Zwicky, 1930s)
- ⋆ galactic rotation curves
- ⋆ large scale structure formation
- ⋆ gravitational lensing
- ⋆ inflation $\Rightarrow \Omega = \rho/\rho_c = 1$
- ⋆ anisotropy in cosmic microwave background (WMAP)
- ⋆ surveys of distant galaxies via supernovae (DE)
- ⋆ Big Bang nucleosynthesis
  - $\Omega_\Lambda \simeq 0.7$
  - $\Omega_{CDM} \simeq 0.25$
  - $\Omega_{baryons} \simeq 0.045$ (dark baryons ~ 0.040)
  - $\Omega_\nu \simeq 0.005$

Cosmic μ-wave background anisotropies (COBE to WMAP)



Dark matter versus dark energy

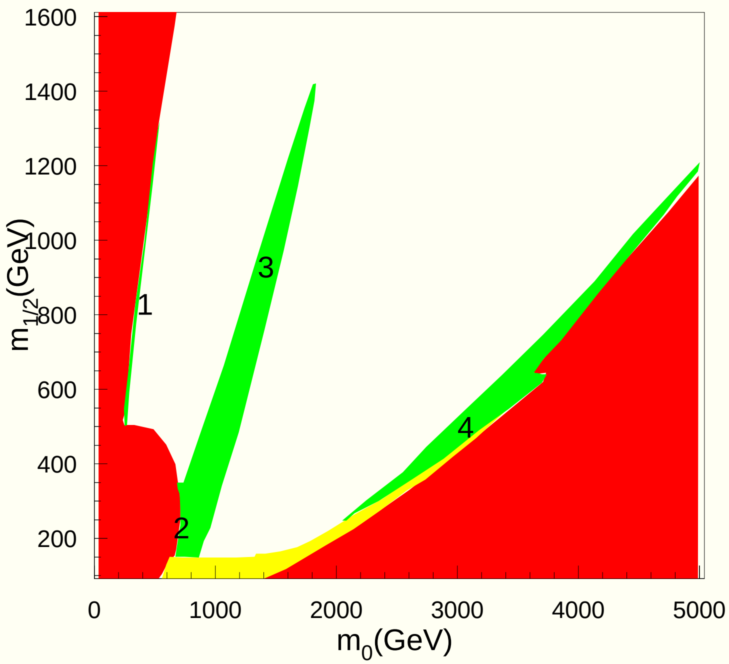


Neutralino relic density

HB, C. Balazs and A. Belyaev

- Must solve Boltzmann eq'n for neutralino number density in FRW universe
- Central part of calculation: evaluate thermally averaged neutralino-neutralino annihilation cross section times velocity
- Previously, HB, Brhlik used fully relativistic formulation by Gondolo/Gelmini to obtain proper relic density in vicinity of s-channel annihilation poles; h, Z, A and H
- Importance of co-annihilation stressed by Griest (chargino-neutralino), Ellis, Olive, Falk (neutralino-stau)
- Thus, we have recalculated relic density using Edsjo/Gondolo relativistic thermal averaging which has been generalized to include co-annihilations
- 1722 annihilation/coannihilation subprocesses including 7618 Feynman diagrams evaluated using CompHEP (similar program Micromegas)

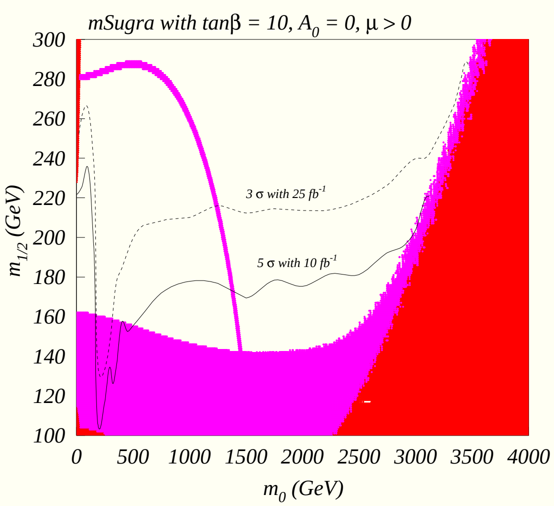
Relic density results

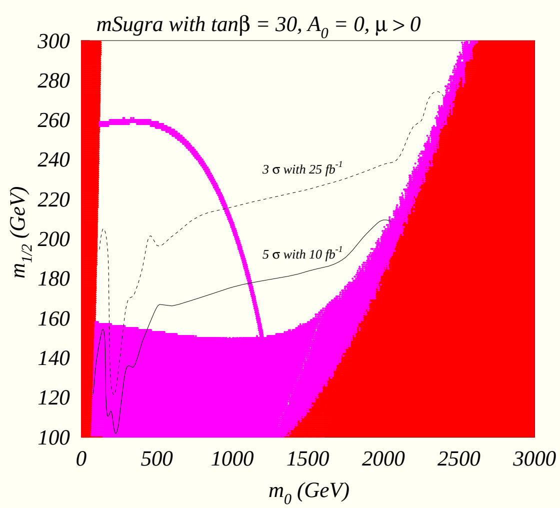


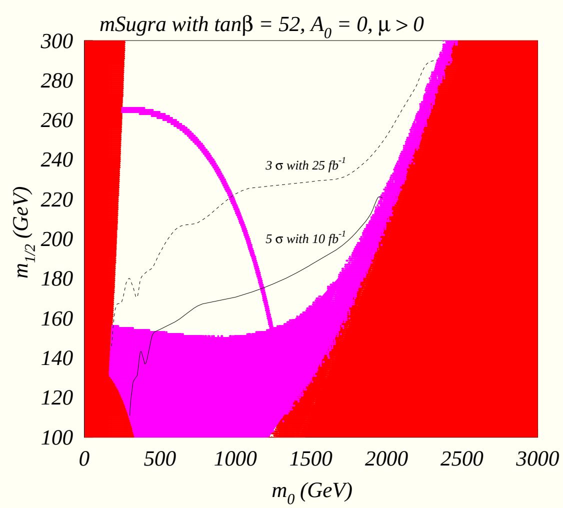
- low relic density in 1. stau CA, 2. bulk, 3. A funnel and 4. Higgsino (HB/FP) region

Prospects for mSUGRA at Tevatron

- for mSUGRA, best reach usually in clean trilepton channel
- $p\bar{p} \to \widetilde{W}_1 \widetilde{Z}_2 X \to 3\ell + \not{E}_T + X$
- reach mapped out using Barger/Kao soft cuts at SUSY/Higgs workshop to $m_0 = 1$ TeV: Barger/Kao, HB, Drees, Paige, Quintana, Tata; Matchev/Pierce
- extend reach to large m_0: HB, Krupovnickas, Tata

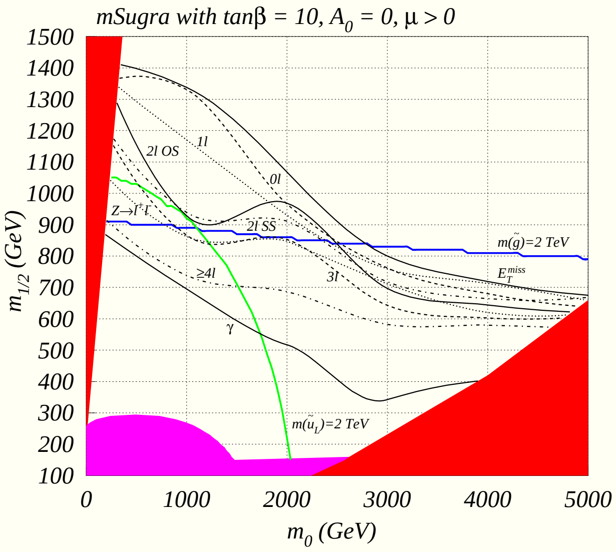


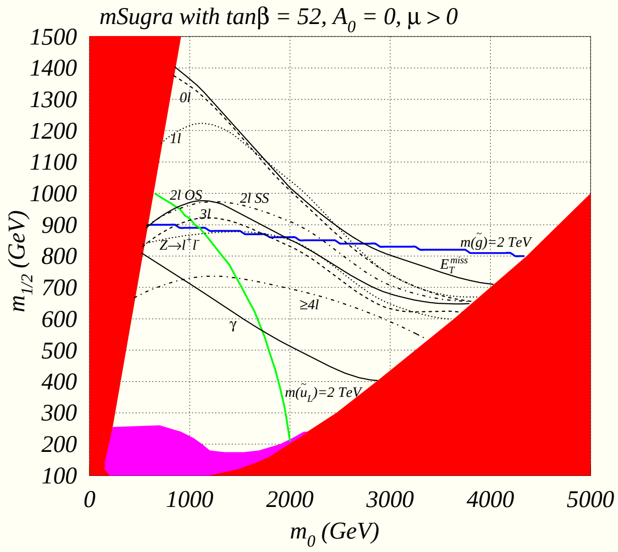




Prospects for mSUGRA at CERN LHC

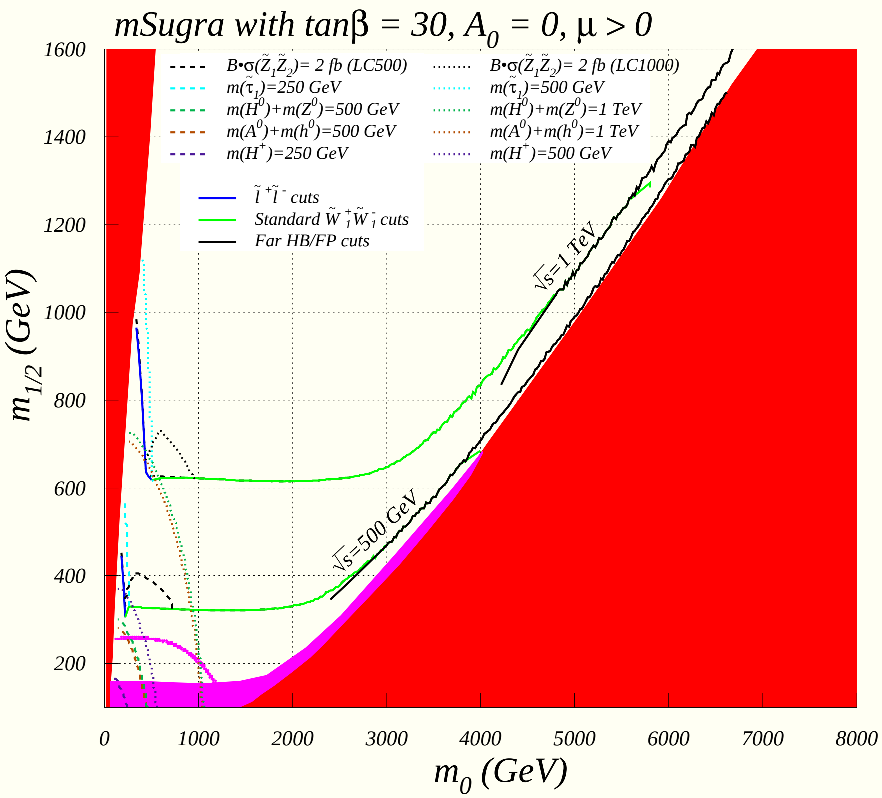
- for mSUGRA, good reach in a variety of channels
- updated analysis for 100 fb^{-1}; HB, Balazs, Belyaev, Krupovnickas,
- include photon channel, "Z" channel
- reach to $m_{\tilde{g}} \sim 1.8\ (3)$ TeV for high (low) m_0



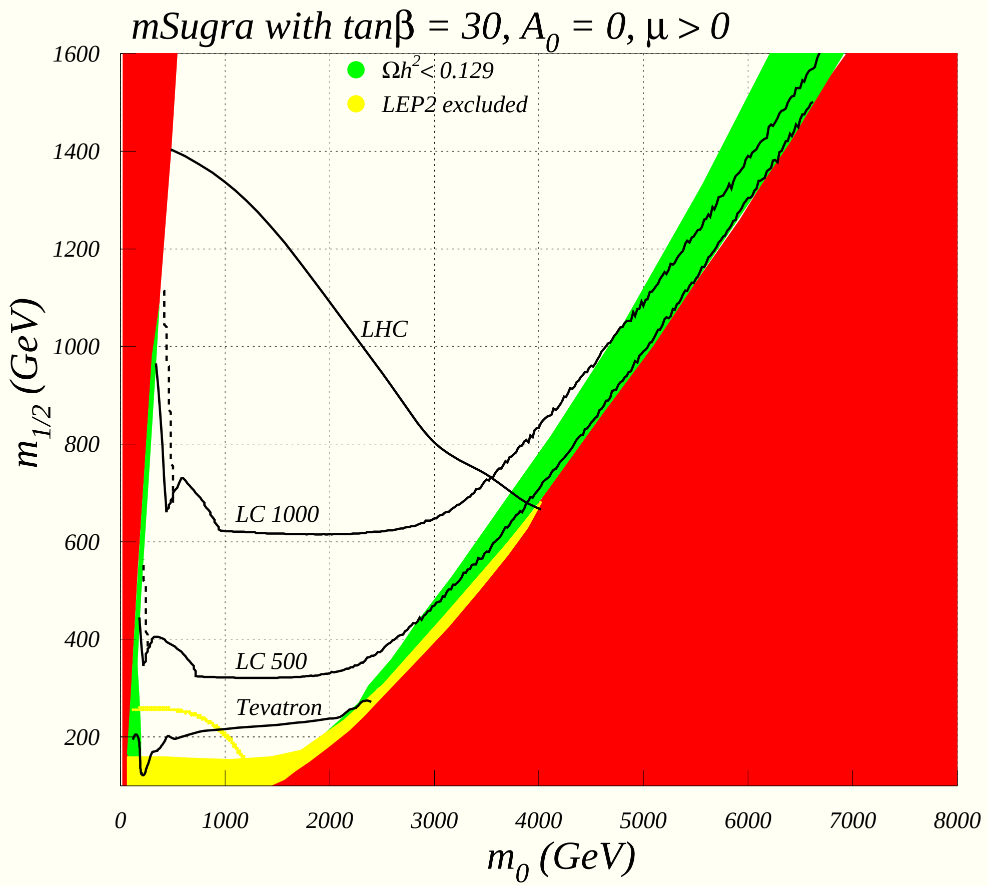


Compare against reach of linear e^+e^- collider

- LC reach for $\sqrt{s} = 500$ GeV, 30 fb^{-1}
- conventional cuts for sleptons/charginos
- specialized cuts needed in far HB/FP region



Sparticle reach of all colliders and relic density



- (HB, Belyaev, Krupovnickas, Tata)

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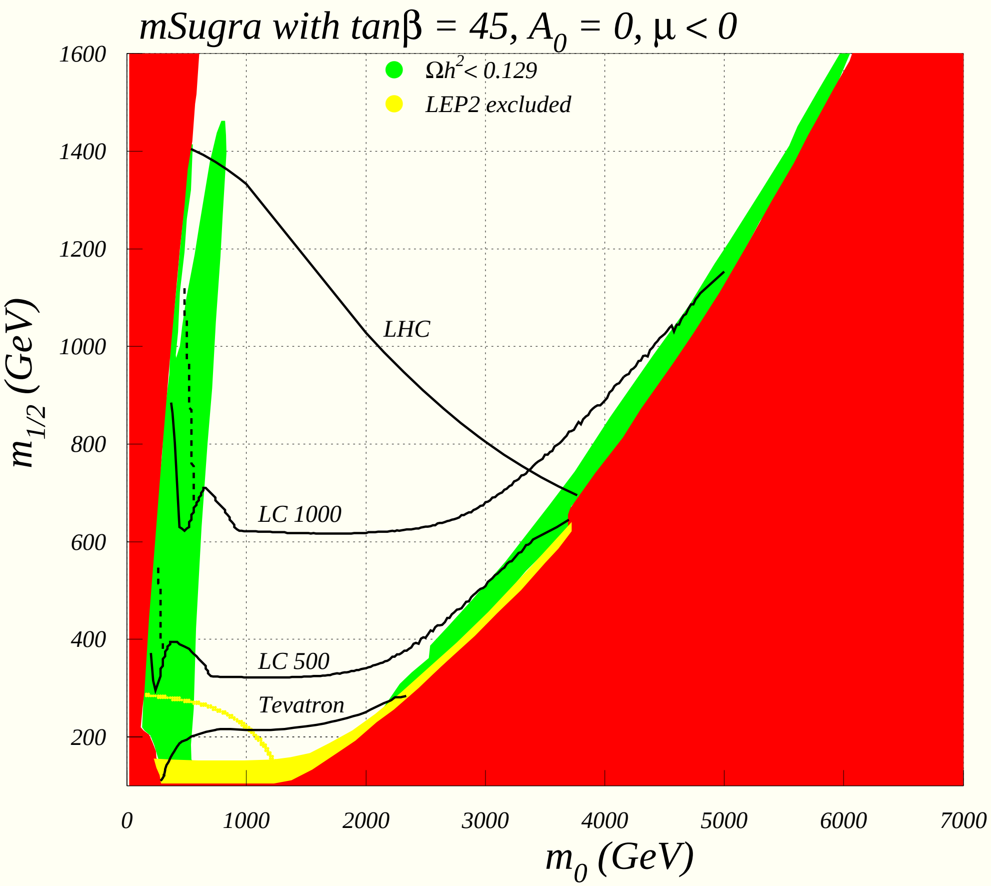

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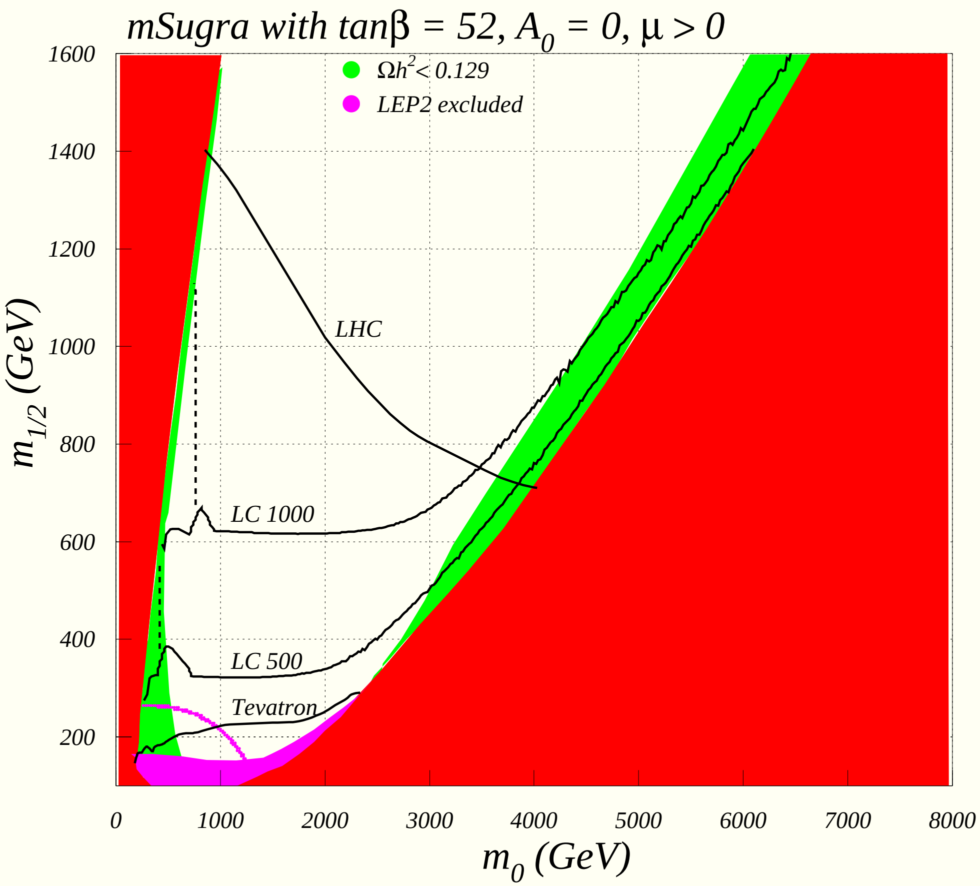
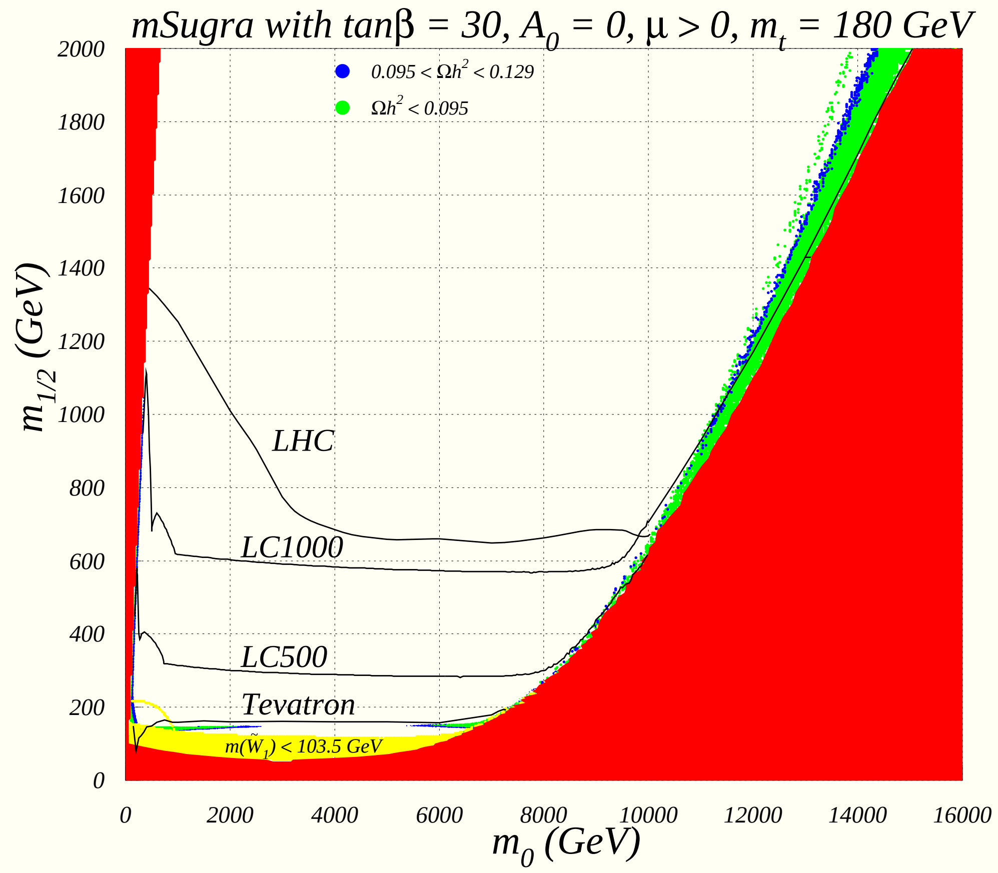


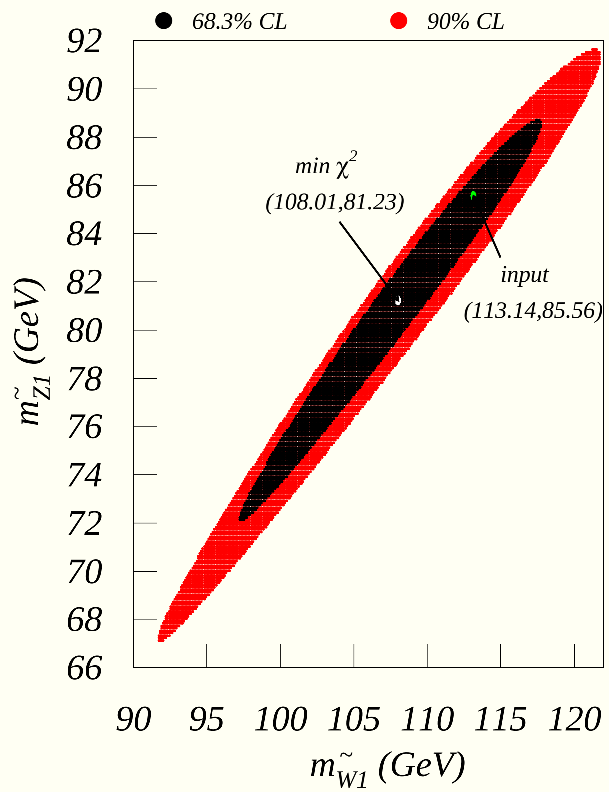
- (HB, Belyaev, Krupovnickas, Tata)

Sparticle reach if $m_t = 180$ GeV



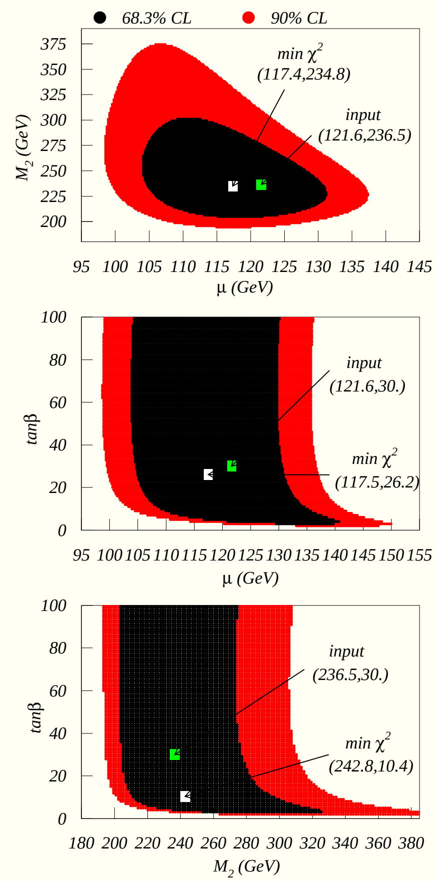
- (HB, Krupovnickas, Tata)

Measure sparticle masses in HB/FP region



- measure $m_{\widetilde{Z}_1}$ and $m_{\widetilde{W}_1}$ via $\widetilde{W}_1 \to q\bar{q}'\widetilde{Z}_1$

Determination of SUSY parameters in HB/FP



- determine μ and M_2 from $\sigma(\widetilde{W}_1^+\widetilde{W}_1^-)$, $m_{\widetilde{W}_1}$ and $m_{\widetilde{Z}_1}$

Direct and indirect detection of SUSY DM

⋆ Direct search via neutralino-nucleon scattering

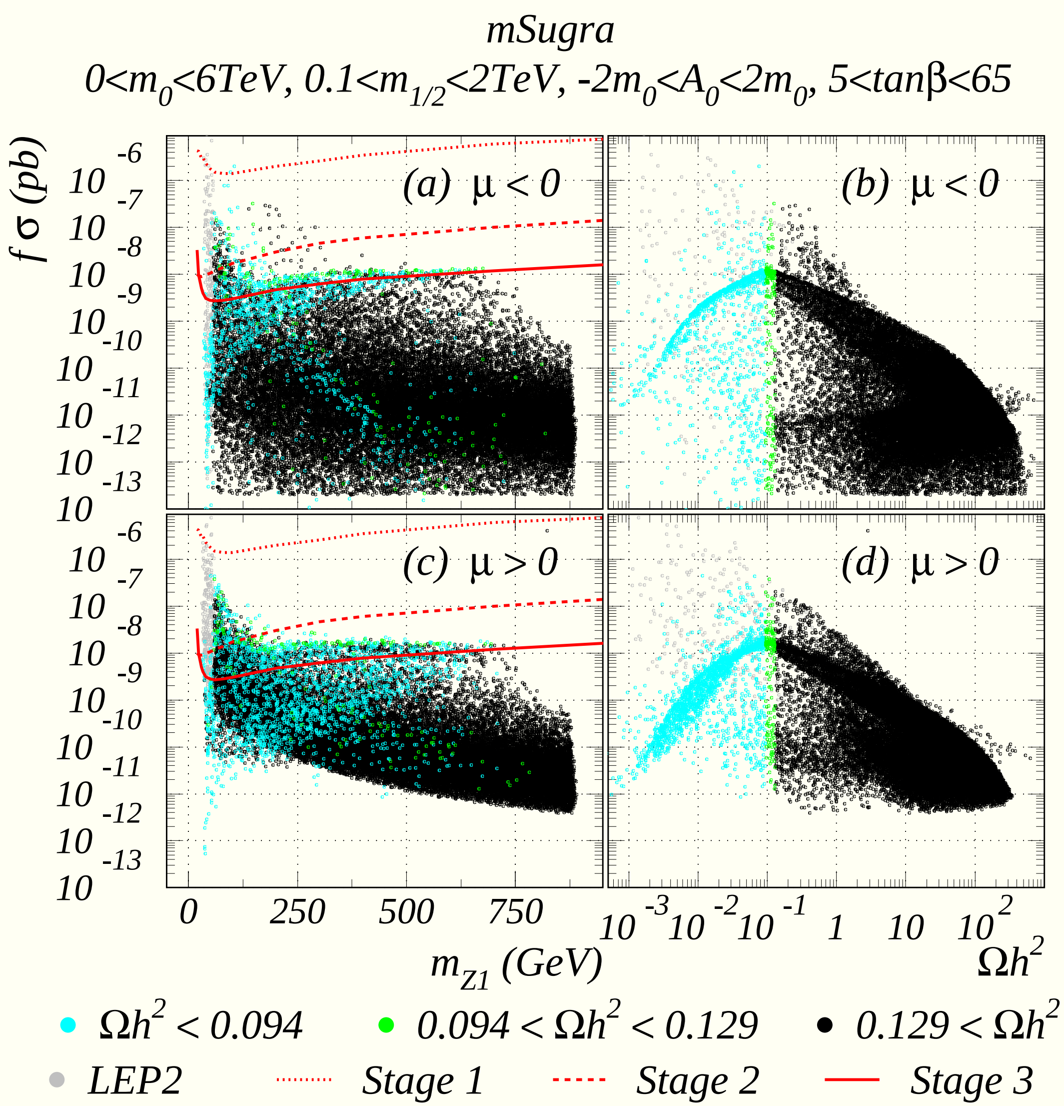
⋆ Indirect search for SUSY DM:

- $\tilde{Z}_1\tilde{Z}_1 \to b\bar{b}, etc.$ in core of sun (or earth): $\Rightarrow \nu_\mu \to \mu$ in ν telescopes
  - Amanda, Icecube, Antares
- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to \gamma$ in galactic core or halo
- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to e^+$ in galactic halo
- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to \bar{p}$ in galactic halo

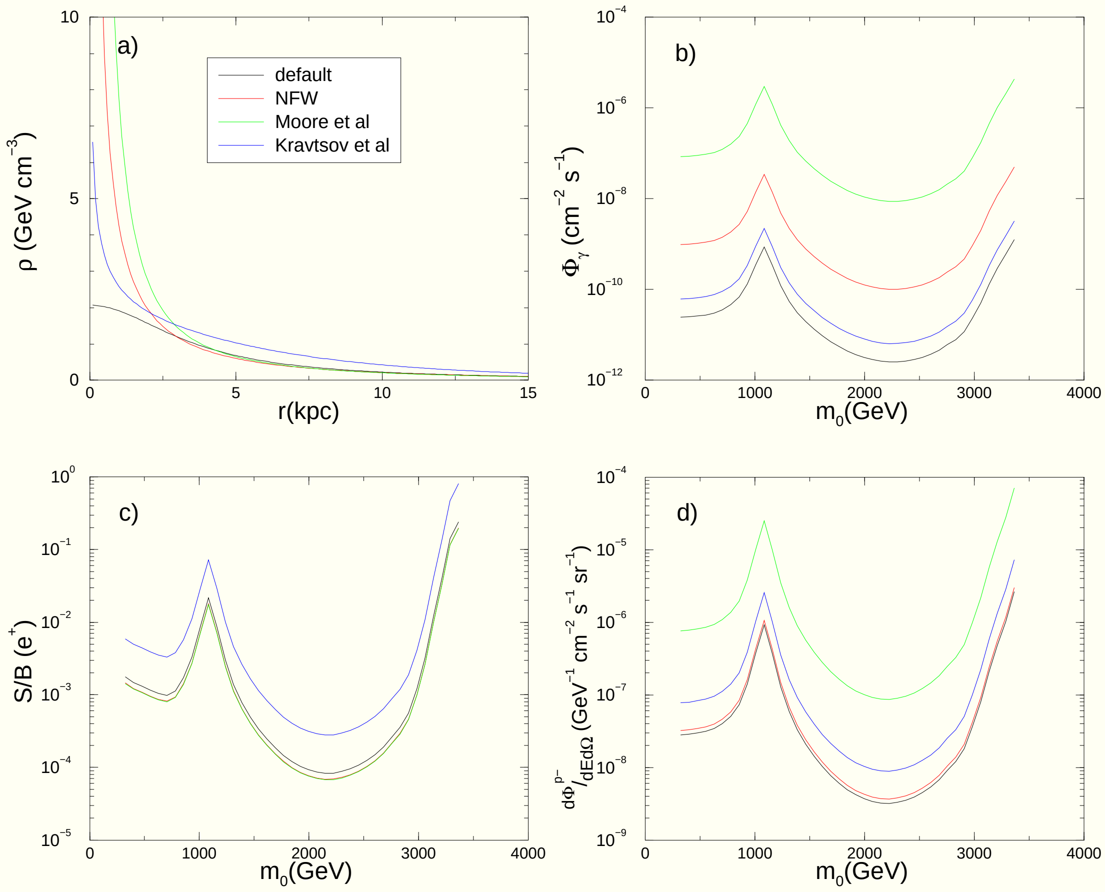
Direct detection of SUSY DM

scan over mSUGRA space :

- Stage 1: CDMS1, Edelweiss, Zeplin1
- Stage 2: CDMS2, CRESST2, Zeplin2, Edelweiss2
- Stage 3: Genius, Zeplin4, Xenon, WARP

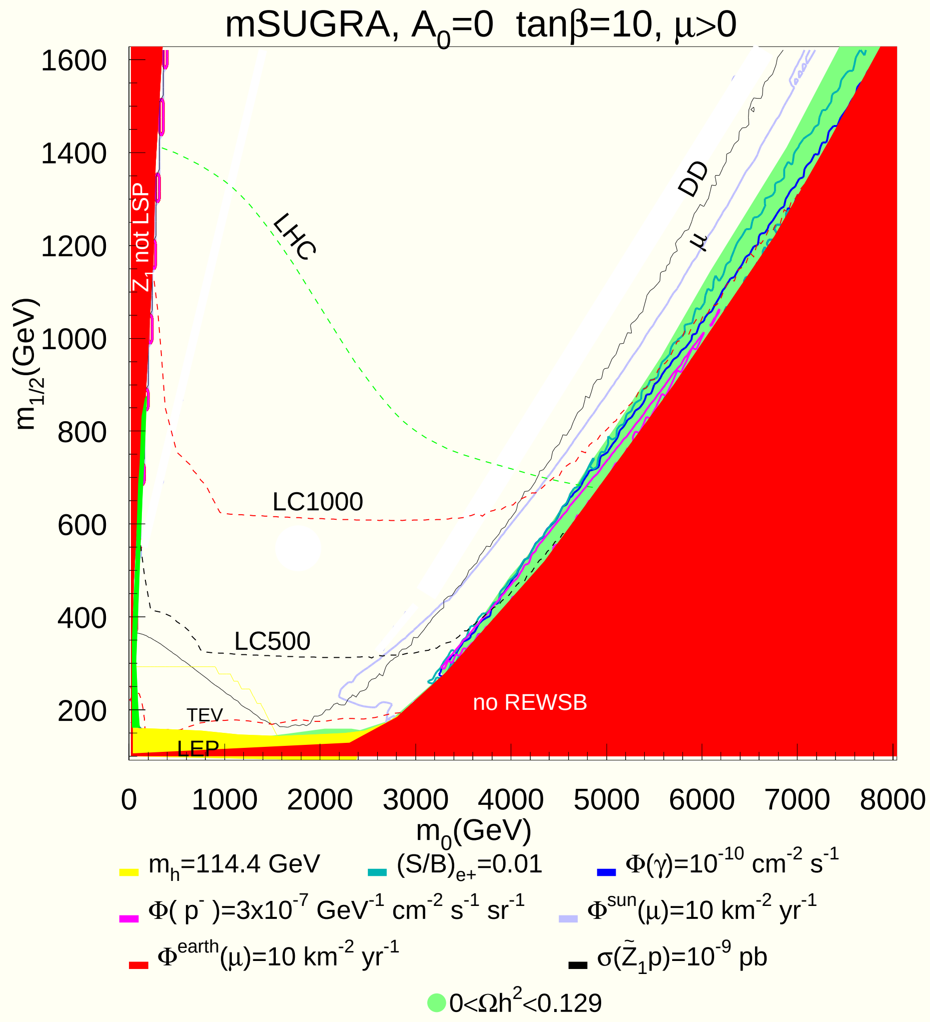

mSugra
0<m0<6TeV, 0.1<m1/2<2TeV, -2m0<A0<2m0, 5<tanβ<65
f σ (pb)
(a) μ < 0
(b) μ < 0
(c) μ > 0
(d) μ > 0
mZ1 (GeV)
Ωh2
Ωh2 < 0.094
0.094 < Ωh2 < 0.129
0.129 < Ωh2
LEP2
Stage 1
Stage 2
Stage 3

Rates for γs, e^+s, $\bar{p}$s



- HB, Belyaev, Krupovnickas and O' Farrill

Sparticle reach for direct and indirect detection of DM



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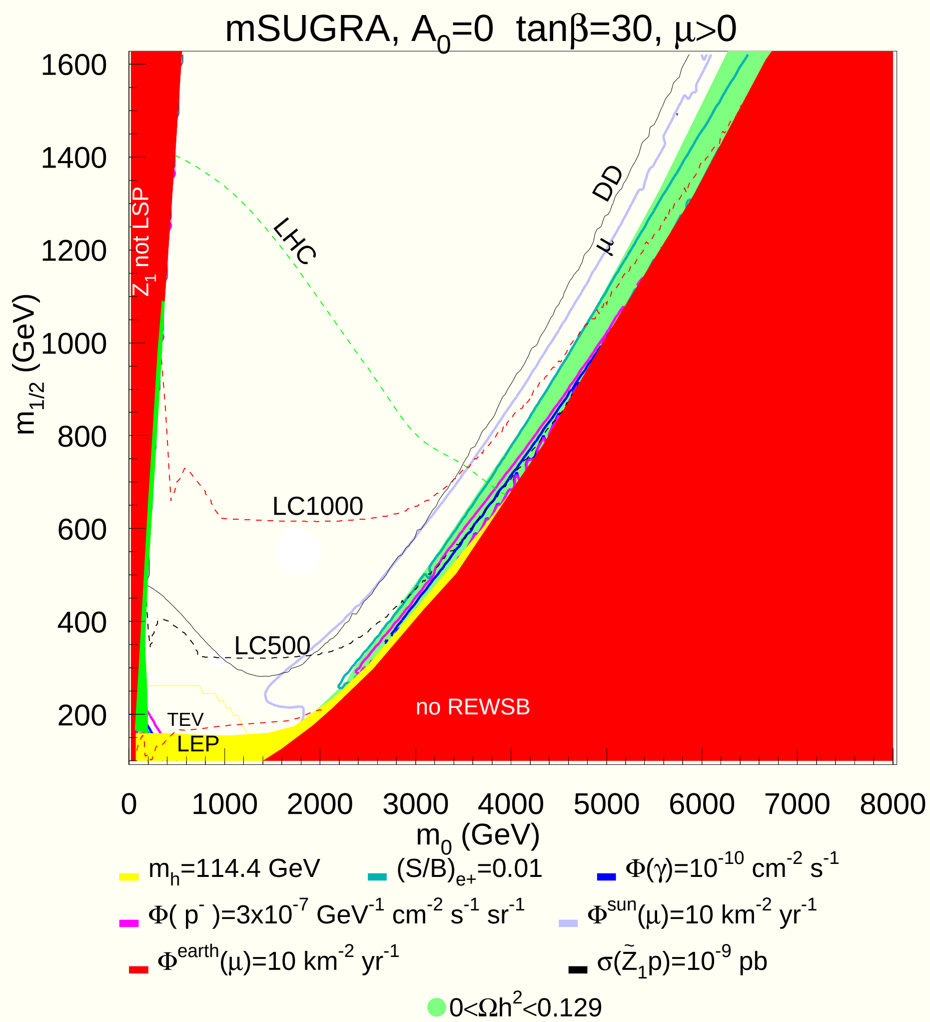

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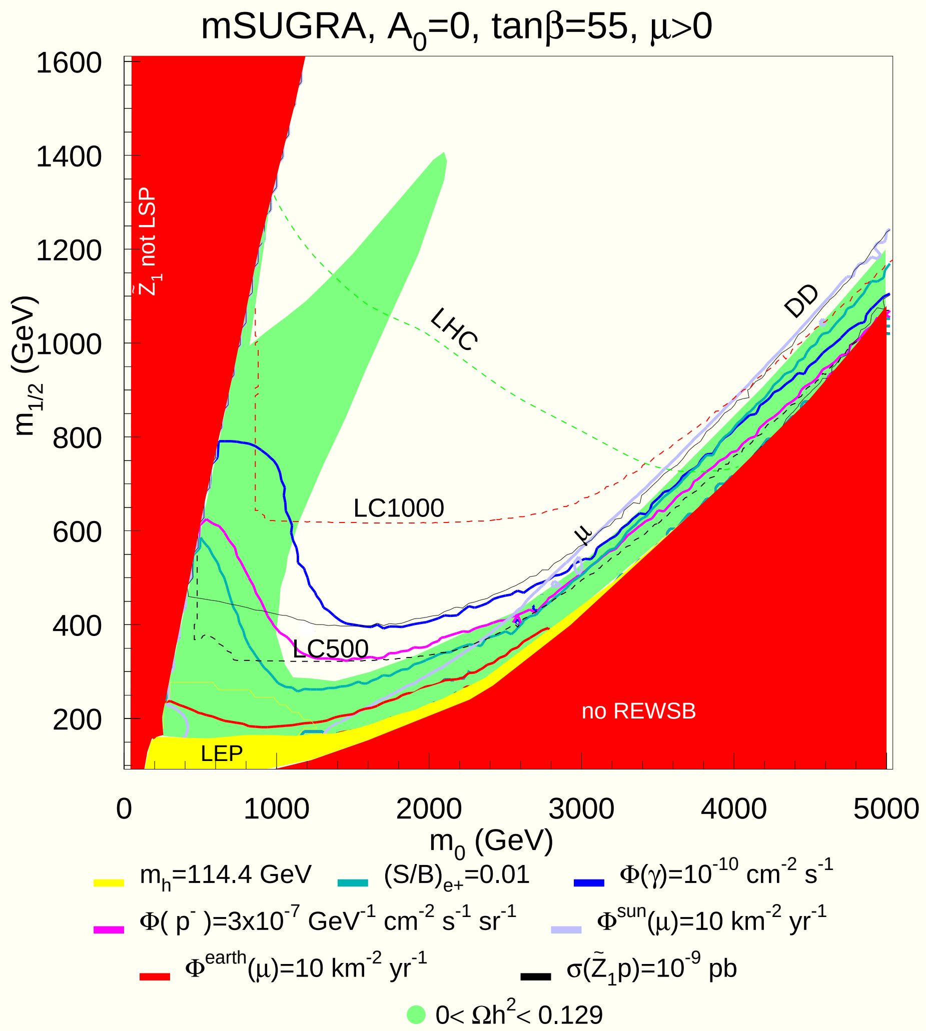

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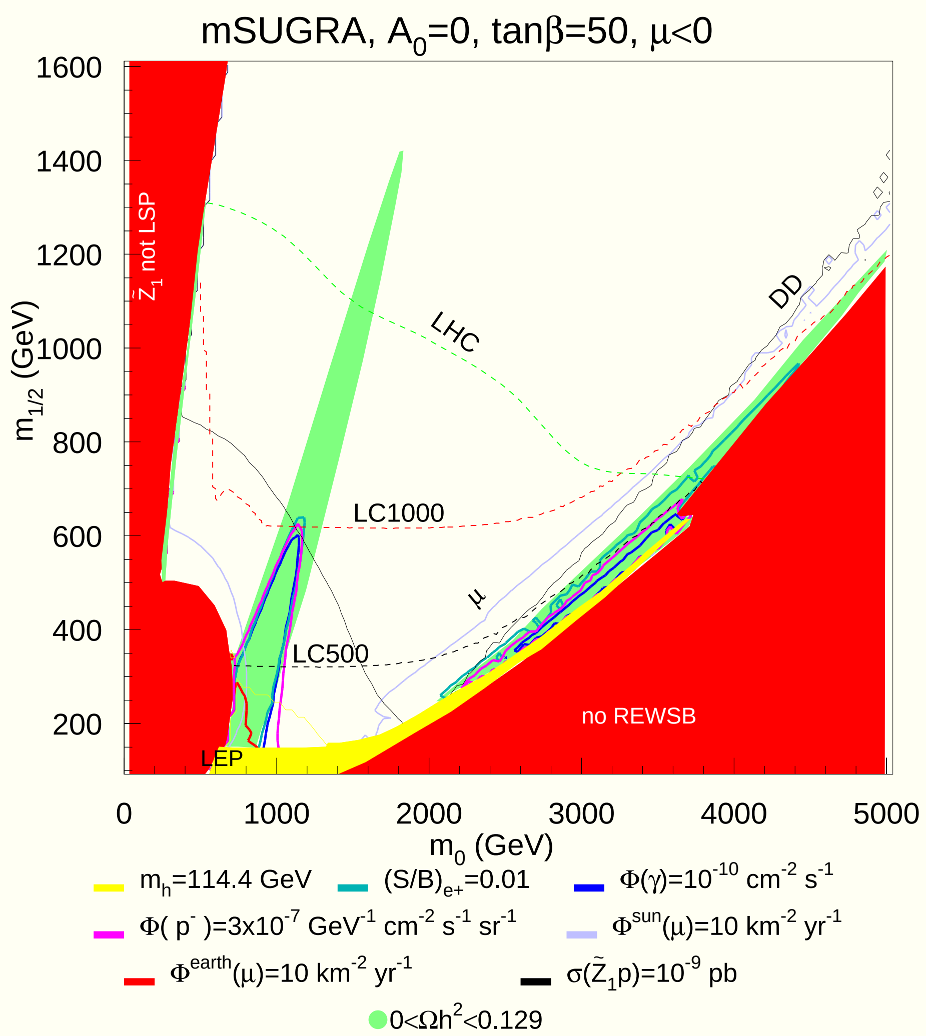

Conclusions

- ⋆ WMAP greatly restricts parameter space of SUGRA models
  - bulk region
  - stau co-annihilation
  - HB/FP region: mixed higgsino/bino LSP
  - A annihilation funnel
- ⋆ Tevatron enhanced reach in HB/FP region
- ⋆ LHC reach to $m_{\tilde{g}} \sim 3$ TeV (1.8 TeV) for $m_{\tilde{q}} \sim m_{\tilde{g}}$ ($m_{\tilde{q}} \gg m_{\tilde{g}}$)
- ⋆ LC reach outlined; surpasses LHC reach in HB/FP region!
- ⋆ Stage 3 direct DM detectors can explore *all* HB/FP region
- ⋆ IceCube ν telescope can rule in/out HB/FP region!
- ⋆ γs, e^+s and $\bar{p}$s seeable in HB/FP and also in A-annihilation funnel