Direct, Indirect and Collider Detection of SUSY Dark Matter

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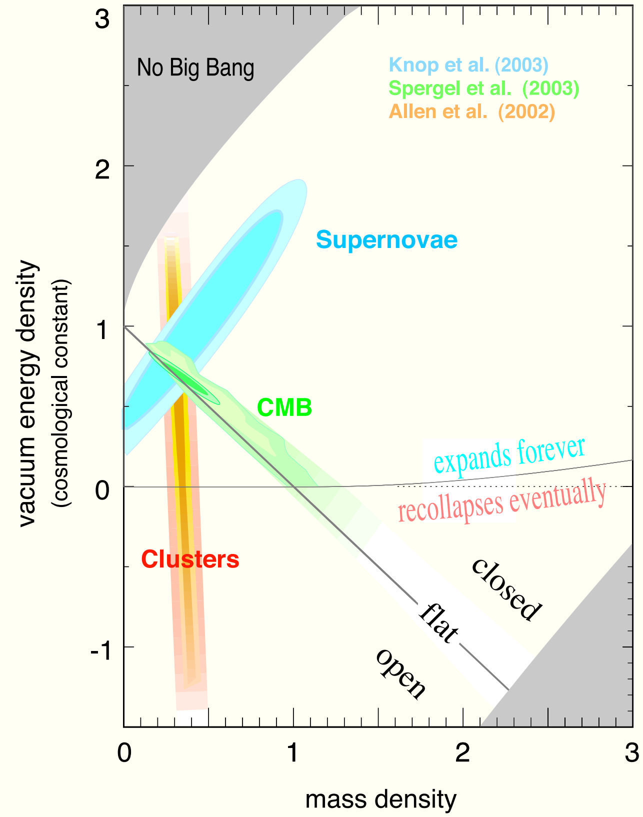
Outline

- ⋆ WMAP preferred regions of mSUGRA model
- ⋆ Prospects for *direct* DM detection
- ⋆ Prospects for *indirect* DM detection
- ⋆ Prospects for DM detection at *colliders*
- ⋆ Models with scalar mass non-universality
- ⋆ Models with gaugino mass non-universality

Dark matter/energy in universe:



★ ⇒ tight constraint on models with CDM: $\Omega_{CDM}h^2 = 0.113 \pm 0.009$

Models of SUSY breaking

- ⋆ Postulate SUSY breaking in hidden sector (HS)
- ⋆ Communicate SUSY breaking from HS to visible sector (VS)?
  - gravity mediation: supergravity (SUGRA) and local SUSY: minimal messenger sector: $m_{3/2} \sim$ TeV: LSP=bino/higgsino/wino/gravitino?
  - gauge mediation (GMSB): introduce messenger sector fields as intermediary between HS and VS: $m_{3/2} \ll$ TeV: LSP=gravitino
  - anomaly mediation (AMSB): $m_{3/2} >$ TeV: LSP=wino
- ⋆ role of extra dimensions? compactification? sequestered sector and AMSB; gaugino mediation; GUTs; $\cdots$
- ⋆ CDM most natural in SUGRA where $m_{\tilde{G}} \sim$ TeV

Gravity-mediated SUSY breaking models

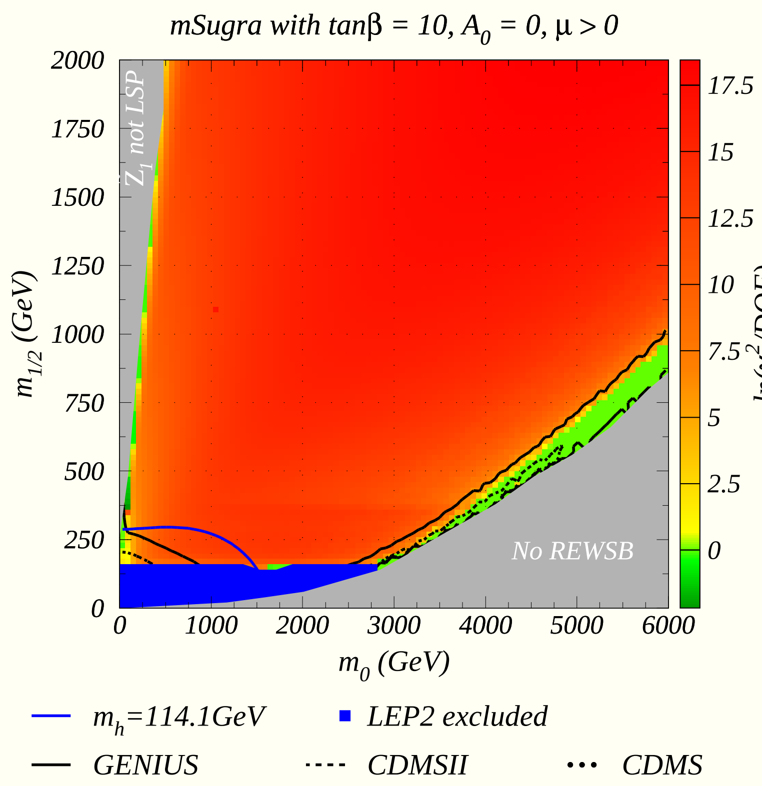
- ⋆ $m_{3/2} \sim M_s^2/M_{Pl} \sim 10^3$ GeV for $M_s \sim 10^{11}$ GeV
- ⋆ theory below $Q \sim M_{GUT}$ usually assumed to be MSSM
- ⋆ Soft SUSY breaking boundary conditions usually stipulated at $Q = M_{GUT}$
- ⋆ lots of possibilities depending on SUSY breaking/ GUTs/ compactification $\cdots$ (all unknown physics)
- ⋆ minimal choice: single scalar mass m_0, gaugino mass $m_{1/2}$, trilinear term A_0, bilinear term B
- ⋆ evolve couplings/soft terms to M_{weak} via RG evolution
- ⋆ EWSB radiatively due to large m_t
- ⋆ parameter space: $m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)$
- ⋆ this is simplest choice and a baseline model, but **many** other possibilities depending on high scale physics

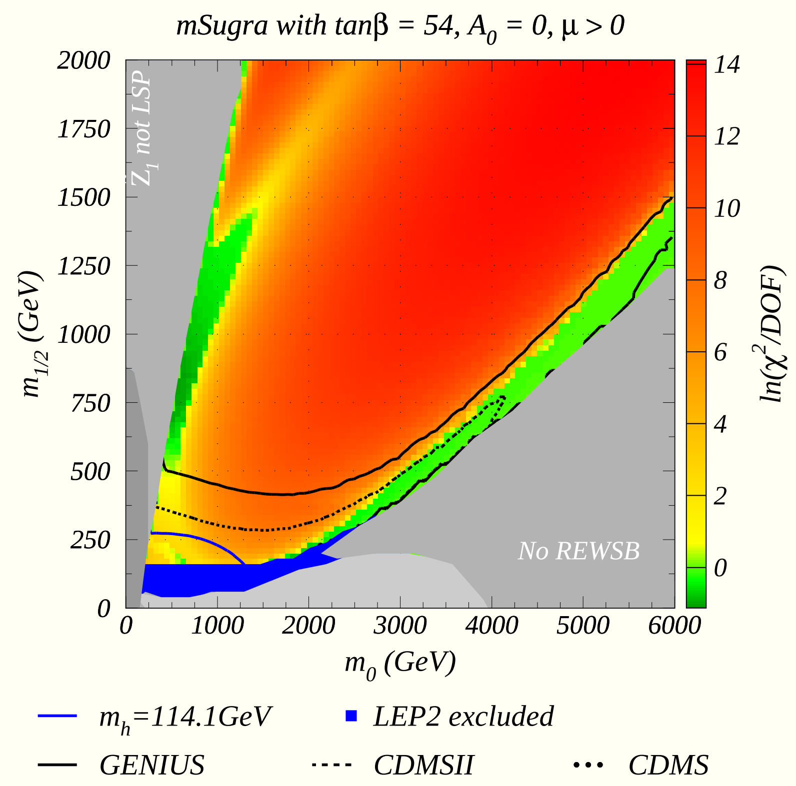
- non-universal scalar masses
- non-universal gaugino masses
- FC soft SUSY breaking terms
- large CP violating phases
- additional fields beyond MSSM below M_{GUT}?
- $\cdots$

From Ωh^2, $BF(b \to s\gamma)$, Δa_μ, compute χ^2

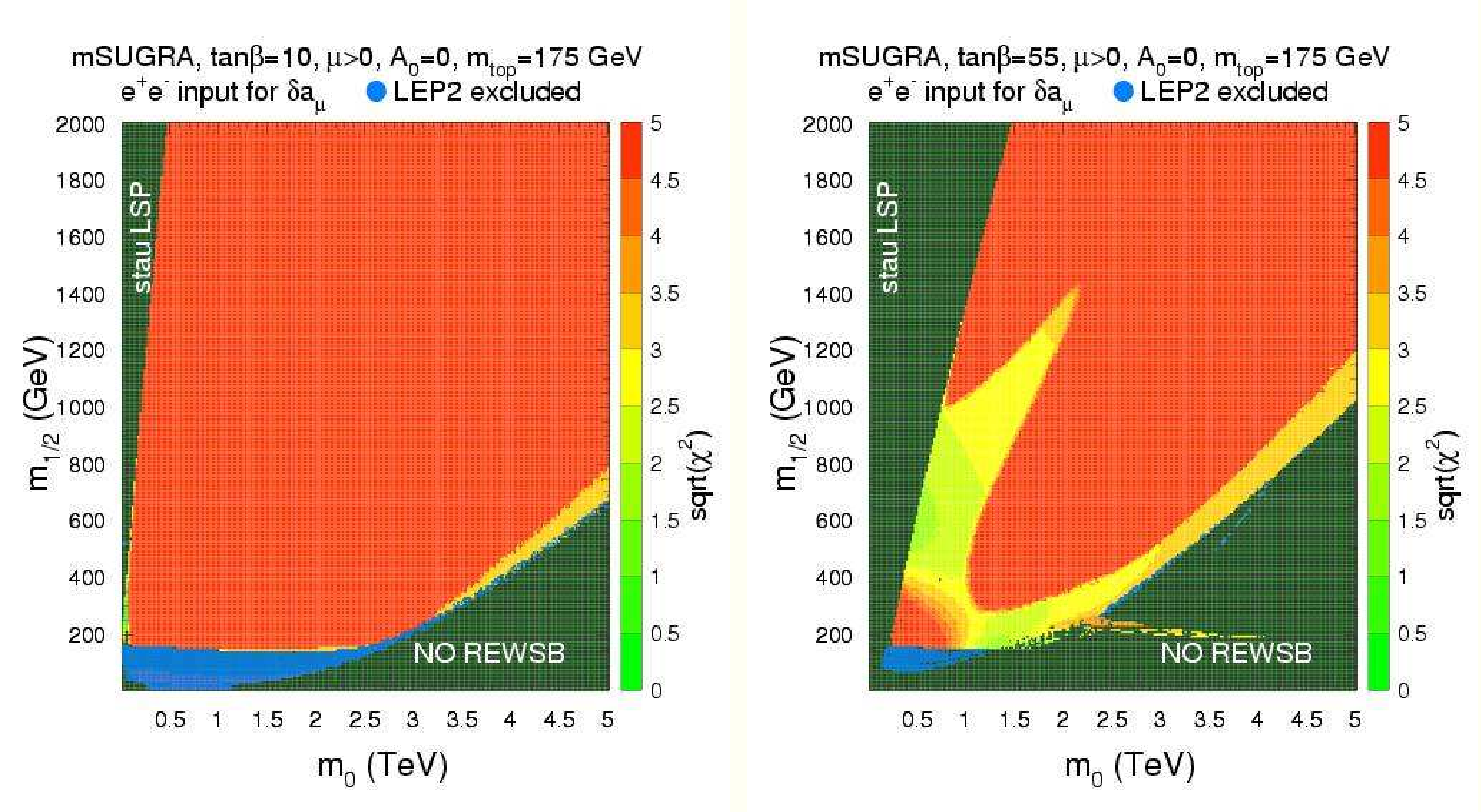
- calculate χ^2, plot in mSUGRA parameter space: (HB, Balazs)
- allowed regions
  - stau co-annihilation (Ellis, Falk, Olive; Arnowitt, Dutta, Santoso)
  - HB/FP (Chan, Chattopadyay, Nath; Feng, Matchev, Moroi; HB, Brhlik)
  - A-annihilation funnel (Drees, Nojiri; HB, Brhlik)
  - "bulk" region at low m_0, $m_{1/2}$ disfavored (LEP2, $b \to s\gamma$, $(g-2)_\mu$)
  - light Higgs h corridor at low $m_{1/2}$ (Arnowitt, Nath)
  - other co-annihilations *e.g.* $\widetilde{Z}_1 \tilde{t}_1$, etc.
- See also Ellis, Olive, Santoso and Spanos; Lahanas, Mavromatos, Nanopoulos; Chattopadhyay, Corsetti, Nath; Roskowski, Ruiz de Austri, Nihei; Bottino, Donato, Fornengo, Scopel; Drees, Djouadi, Kneur; Bednyakov, Klapdor-Kleingrothaus and Kovalenko; Accomando, Arnowitt, Dutta, Santoso; Edsjo, Gondolo, Schelke, Ulio; Gomez, Vergados; Corsetti, Nath; $\cdots$

Results of χ^2 fit using τ data for a_μ:





Results of χ^2 fit using e^+e^- data for a_μ :



Direct search for relic neutralinos

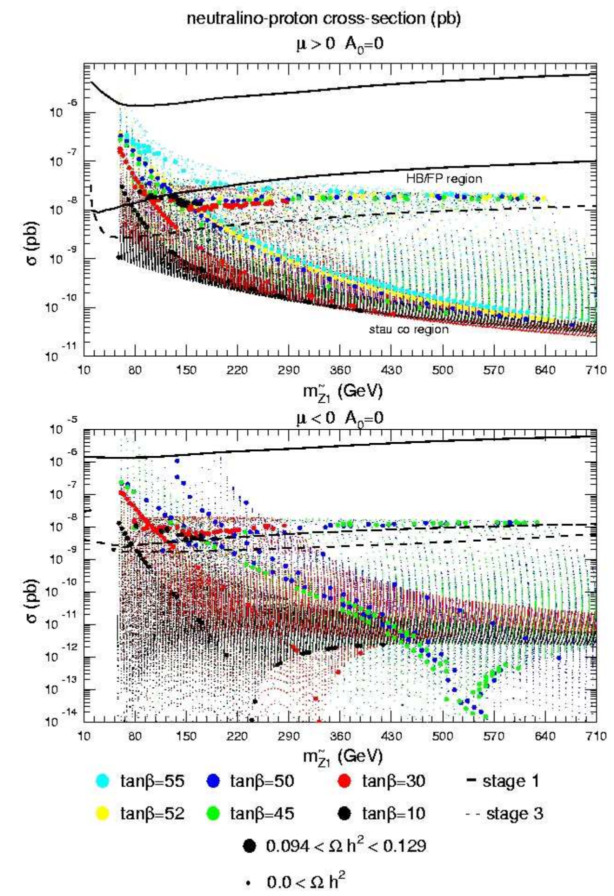
⋆ Search for $\widetilde{Z}_1 - nucleon$ scattering in underground cryogenic detectors

- Stage 2 detectors: CDMS2, CRESST2, Edelweiss2, Zeplin2,$\cdots$
- Stage 2 reach to $\sim 10^{-8}$ pb
- Stage 3 detectors: Genius, Xenon, Zeplin4, WARP, $\cdots$
- Stage 3 reach to $\sim 10^{-9} - 10^{-10}$ pb
- for an overview, see $e.g.$ HB, C. Balazs, A. Belyaev and O'Farrill; JCAP**09**, 007 (2003).

⋆ σ_{SI} large if

- $m_{\tilde{q}}$ is small
- mixed higgsino DM (as in HB/FP region)

$\sigma_{SI}(\widetilde{Z}_1 p)$ *vs.* $m_{\widetilde{Z}_1}$ in mSUGRA



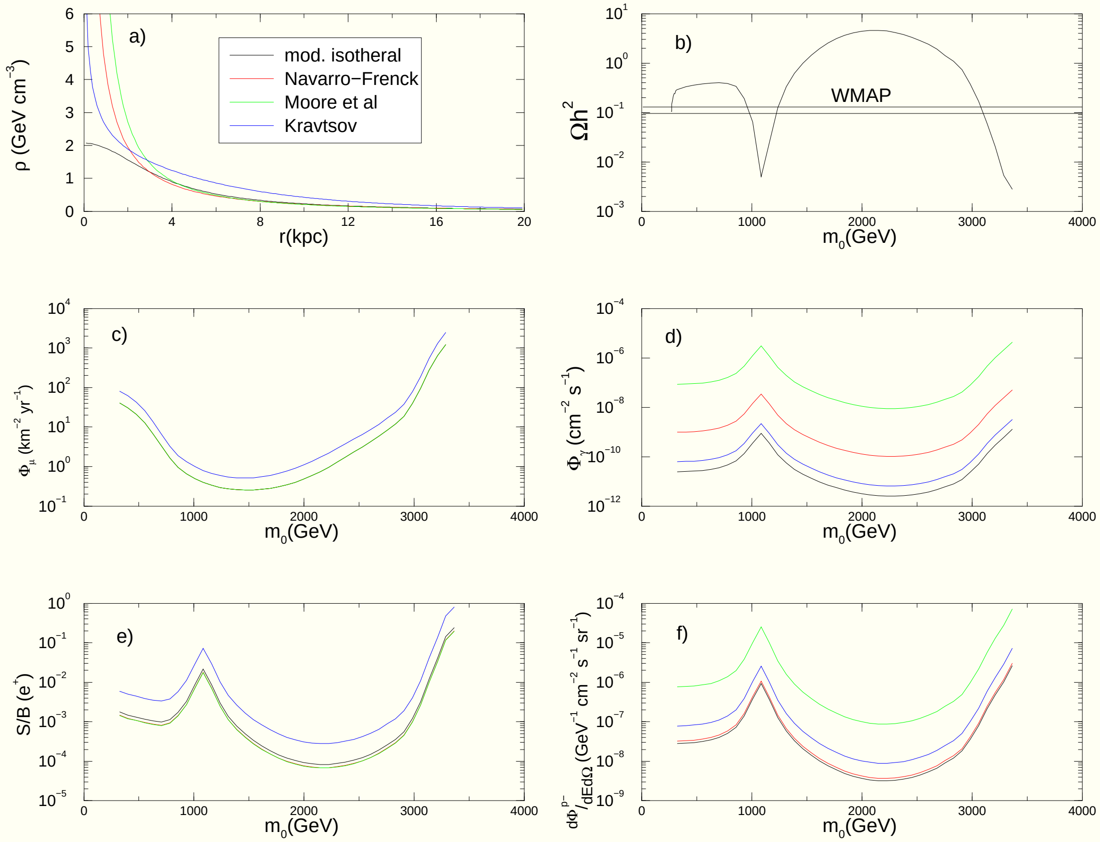
Indirect detection of SUSY DM

⋆ 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
  - ∗ rate $\Gamma_A \sim \frac{1}{2}C\tanh^2(\sqrt{CA}t_\odot)$
  - ∗ C =capture rate; $A =$ ann. rate times velocity
- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to \gamma$ 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

⋆ To estimate indirect rates, we use DarkSUSY (Gondolo *et al.*) Isajet interface

Rates for μs, γs, e^+s, $\bar{p}$s

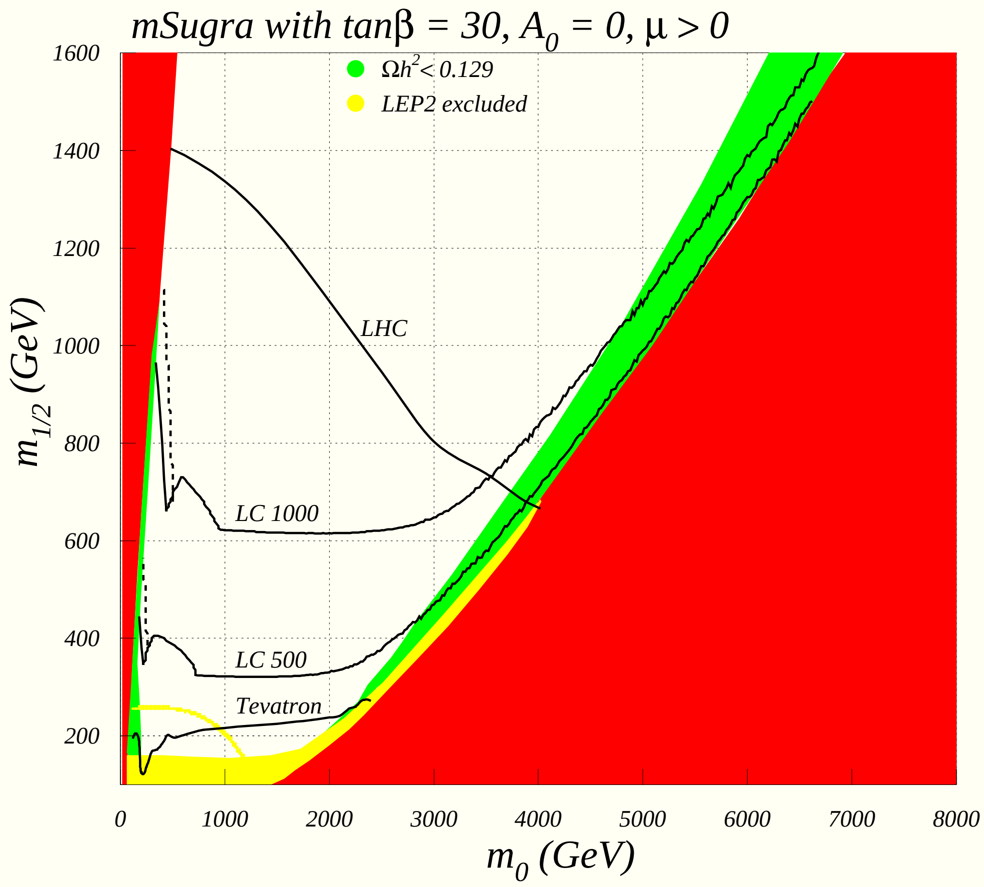


- slice of mSUGRA vs. m_0 where $m_{1/2} = 550$ GeV, $\tan\beta = 50$, $\mu < 0$
- HB, Belyaev, Krupovnickas and O' Farrill, JCAP**0408**, 005 (2004)

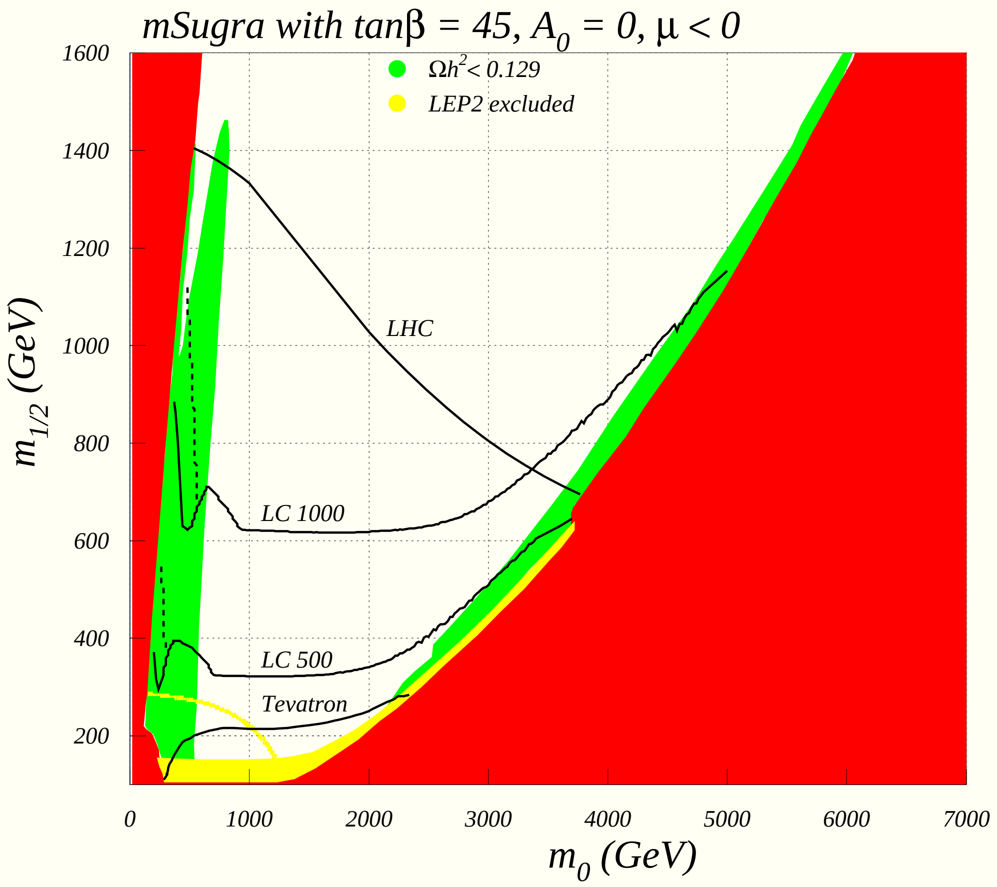
Search for SUSY DM at collider experiments

- ⋆ Fermilab Tevatron: $p\bar{p}$ collider; $\sqrt{s} = 2$ TeV; $2 - 10$ fb^{-1}; currently running
  - HB, Krupovnickas and Tata; JHEP**0307**, 020 (2003).
- ⋆ CERN LHC: pp collider; $\sqrt{s} = 14$ TeV; 100-300 fb^{-1}; start-up, 2007?
  - HB, C. Balazs, A. Belyaev, Krupovnickas and Tata; JHEP**0306**, 054 (2003).
- ⋆ linear e^+e^- collider: $\sqrt{s} = 0.5 - 1$ TeV; 100-300 fb^{-1};pending, 2015-2020?
  - HB, A. Belyaev, Krupovnickas and Tata; JHEP**0402**, 007 (2004) and JHEP**0406**, 061 (2004)

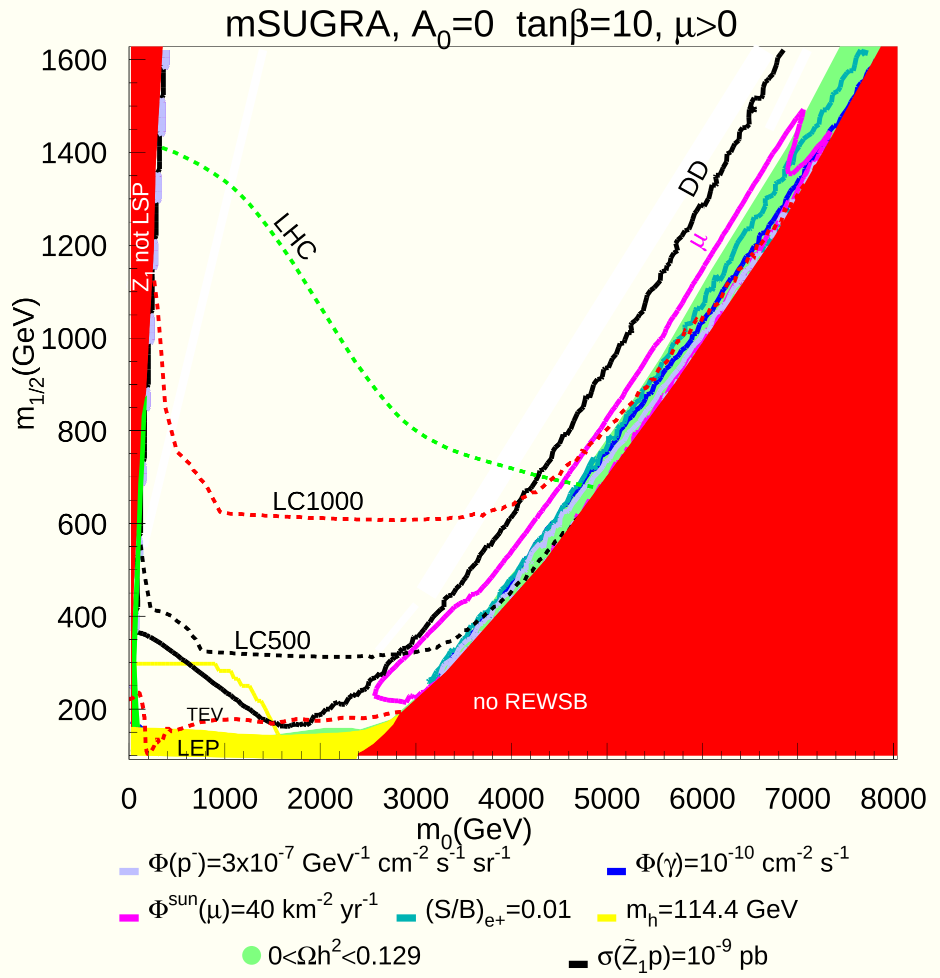
Sparticle reach of all colliders with relic density



Sparticle reach of all colliders and relic density



Sparticle reach for direct and indirect detection of DM



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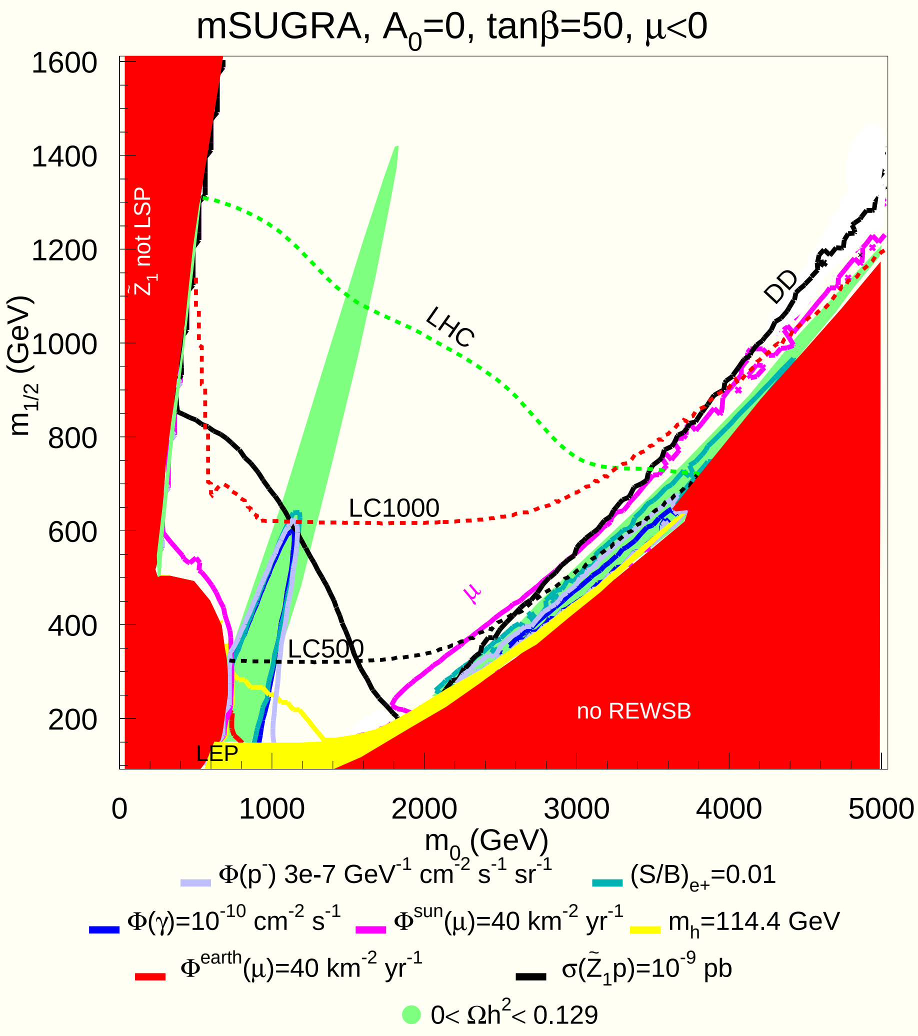

Scalar mass non-universality

- ⋆ Simplest case: non-universal Higgs masses
- ⋆ Inspired by SUSY GUTs where Higgs lie in diff. multiplets than matter
- ⋆ One extra param.: $m_\phi^2 \equiv m_{H_u}^2 = m_{H_d}^2$
  - $m_\phi^2 < 0$: $\Rightarrow$ A-funnel for any $\tan\beta$!
  - $m_\phi^2 >> m_0$: HB/FP for any m_0 choice!
- ⋆ Two parameter case
  - add $m_{H_u}^2,\ m_{H_d}^2 \leftrightarrow \mu,\ m_A$
  - can dial to A-funnel, HB/FP region
  - light $\tilde{u}_R,\ \tilde{c}_R$ case due to S term in RGEs
- ⋆ HB, Belyaev, Mustafayev, Profumo, Tata: hep-ph/0504001

Gaugino mass non-universality

- ⋆ $M_1 \neq M_2$ at GUT scale
- ⋆ For $M_1 \sim M_2$ at M_{weak}, get mixed wino DM
  - – enhanced direct/indirect detection rates
  - – spoiler modes of $\widetilde{Z}_2$ decay always closed due to small $\widetilde{Z}_2 - \widetilde{Z}_1$ mass gap
  - – HB, Mustafayev, Park, Profumo: hep-ph/0505227
- ⋆ For $M_1 \sim -M_2$ case:
- ⋆ Bino-wino co-annihilation scenario
  - • LSP is pure bino
  - • $\Omega_{\widetilde{Z}_1} h^2$ reduced via bino-wino co-annihilation
  - • Low rates for direct/indirect DM detection
  - • special photonic collider signatures: $\widetilde{Z}_2 \to \widetilde{Z}_1 \gamma$

Conclusions

- ⋆ WMAP etc. constraints ⇒ only special allowed regions of SUGRA models
  - bulk: almost excluded, but light sparticles
  - HB/FP: DD, ID, LHC?, ILC
  - A-funnel: ID, LHC, ILC?
  - Stau co-annihilation: LHC, ILC
- ⋆ non-universal Higgs masses: HB/FP, A-funnel, light $\tilde{u}_R$
- ⋆ non-universal gaugino masses
  - mixed wino DM
  - bino-wino co-annihilation
- ⋆ LHC turn-on in just 2 years!
- ⋆ array of direct/indirect CDM search experiments!
- ⋆ move forward on international linear e^+e^- collider (ILC)!