Relic density in SUGRA models

- Relic density in mSUGRA models
- Uncertainties from SUSY spectrum
- Implications for LHC
- Non universal models
- Remarks on direct detection

Introduction

- Supersymmetric models with R parity conservation have a good darkmatter candidate: neutralino LSP
- The WMAP precise measurement of the relic density strongly constrains supersymmetric models :

$.094 < \Omega h^2 < .129$ (2 sigma)

PLANCK is expecting to reach a precision of 2-3% (~2007)

- In mSUGRA one must appeal to very specific mechanisms to reach agreement with WMAP. The main reason

The LSP is mostly bino

- A bino LSP annihilates into fermion pairs through
  - t-channel exchange of right-handed slepton
- The coupling is U(1) strength → annihilation cross section for neutralino pairs is not efficient enough → too much relic density

  →Need rather fine adjustment of parameters to meet WMAP
- Is this generic of all MSSM models? (here consider only neutralino LSP)

Relic density

The number density n of a given particle is described by the Boltzmann equation

$$\frac{dn}{dt} = -3Hn - <\sigma v> \left[n^2 - n_{eq}^2\right] \qquad (4)$$

$<\sigma v>$: thermally averaged annihilation cross-section

v :relative velocity

- **Computation of thermally averaged cross section**

$$<\sigma v> = \frac{\sum_{i,j} g_i g_j \int_{(m_i+m_j)^2} ds \sqrt{s} K_1(\sqrt{s}/T) p_{ij}^2 \sigma_{ij}(s)}{2T(\sum_i g_i m_i^2 K_2(m_i/T))^2}$$

- **Suppression factor** $\exp^{-\Delta M/T_f}$ $\quad (T_f \approx M_{LSP}/25)$
- **Input parameters :** ***Susy Les Houches Accord***
  - ***Pole masses, mixing matrices …***
  - ***These parameters are taken from SUSY spectrum calculator code***
    - ***Suspect, Isasugra, Softsusy, SPheno***

Public codes for relic density calculation

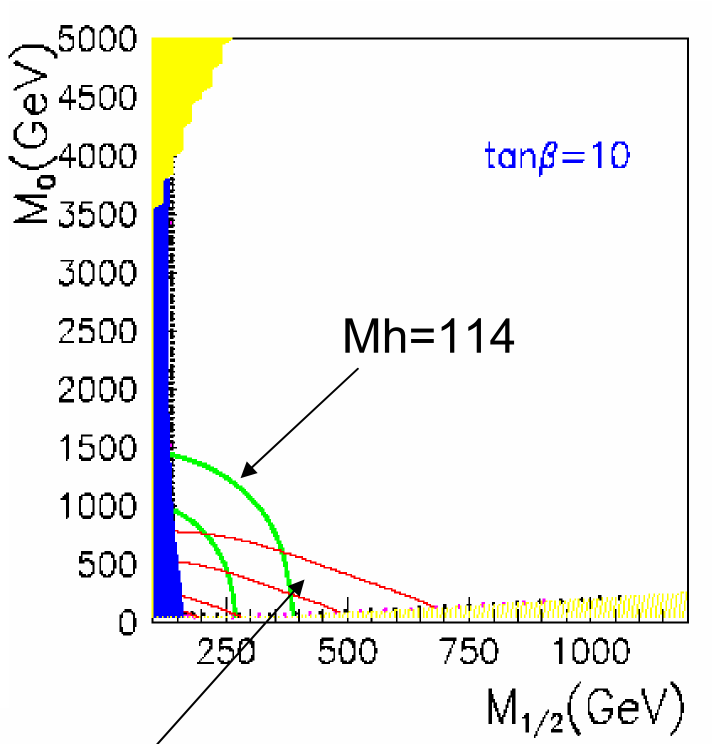
- **DarkSUSY4.0 (2004) Gondolo, Edsjo et al.**
  - **Relic density, direct/indirect detection,**
  - **Includes gaugino+slepton coannihilations**
  - **Isajet**

- **micrOMEGAs1.3 (2004) GB, Boudjema, Pukhov, Semenov**
  - **Includes all coannihilation channels and complete tree-level matrix elements for all processes**
  - **Loop corrected sparticle masses and mixings (taken from SUSY spectrum calculator codes interfaced via Susy Les Houches Accord)**
  - **General MSSM model, mSUGRA, non-universal SUGRA**
  - **Loop corrected Higgs masses and widths, including QCD and SUSY QCD corrections (ΔMb)**
  - **NLO corrections to b->s gamma**
  - **Other constraints: g-2, Δρ, Bs->μ μ**
  - **Also provides parton level cross sections (2->2) and decay widths (1->2) for any process in MSSM**
  - **wwwlapp.in2p3.fr/lapth/micromegas**

mSUGRA

- **Coannihilation with stau**
  - **Main channel:** $\tilde{\chi}_1^0\tilde{\tau} \to \tau\gamma$; $\tilde{\tau}\tilde{\tau} \to \tau\tau.$
  - **Efficient enough only if ΔM(NLSP-LSP)~ 10 GeV**
- **Annihilation near Higgs resonance**
  - **Light Higgs**
    - **Needs precise adjustment of masses : 2M(LSP) =Mh**

Mt=175 GeV



Other constraints

$$2.25 < Br(b \to s\gamma) \times 10^4 < 4.43$$

$$2.5 < \delta a_\mu \times 10^{10} < 54.4$$

$$Br(B_s \to \mu^+\mu^-) < 2 \times 10^{-7}$$

micrOMEGAs+SoftSUSY

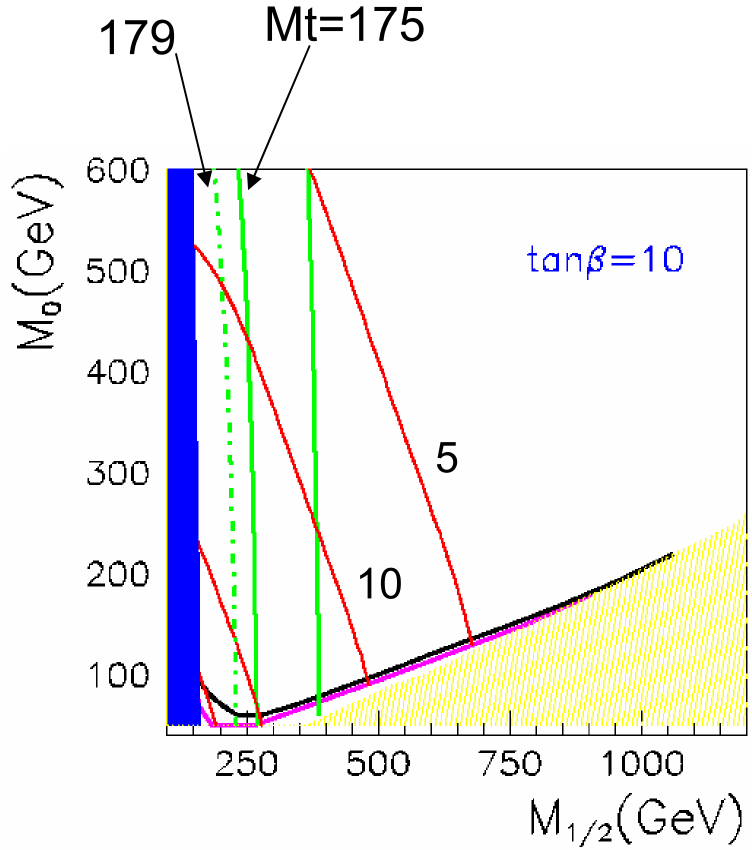
(expected Tevatron)

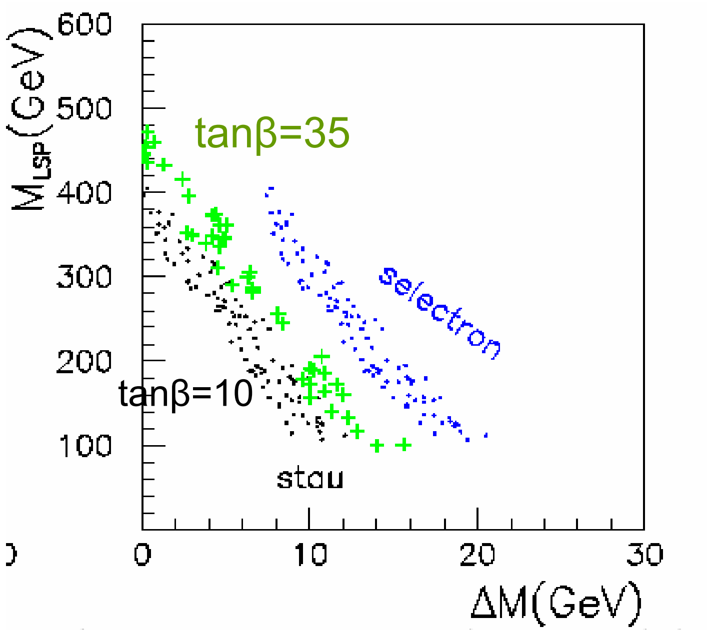
mSUGRA

- **Bulk has disappeared**
- **Coannihilation with stau**
  - **Main channel:**

$$\tilde{\chi}_1^0\tilde{\tau} \to \tau\gamma ; \quad \tilde{\tau}\tilde{\tau} \to \tau\tau.$$

  - **Efficient enough only if ΔM(NLSP-LSP)~ 1-15 GeV**





M(LSP)~M(stau) < 450 GeV
Squarks < 2TeV
Gluino< 2.3 TeV

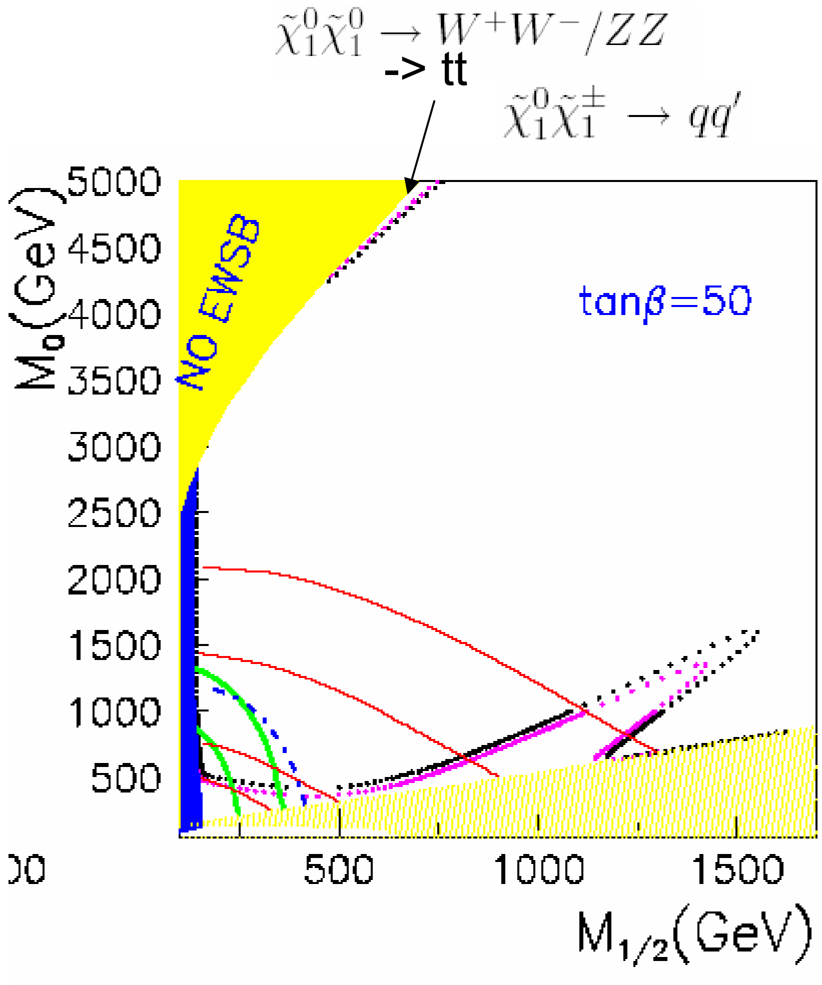
mSUGRA at large tanβ

- **Heavy Higgs resonance (funnel)**
  - **Heavy Higgs enhanced coupling to b quarks**
  - **Large width**
  - **Acceptable relic density if**
    - **$M(LSP)-M_A/2 \sim \Gamma_A$**
  - **Important contribution of diagram with Higgs exchange possible far from resonance if M(LSP)<200GeV**
  - **Constraint from b->sγ important**
- **Focus point: increasing the Higgsino component of neutralinos**

- μ is small, $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^+$ are light

  Efficient annihilation/coannihilation into gauge bosons

  Typically degenerate gauginos lead to $\Omega h^2 < .094$



Focus point region and Mt

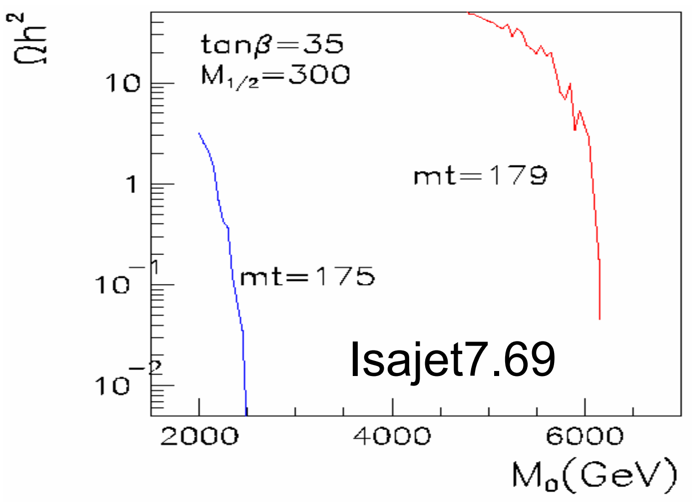
- **Strong dependence on the top quark mass**

Running of $m^2_{H_2}$ very sensitive to top Yukawa

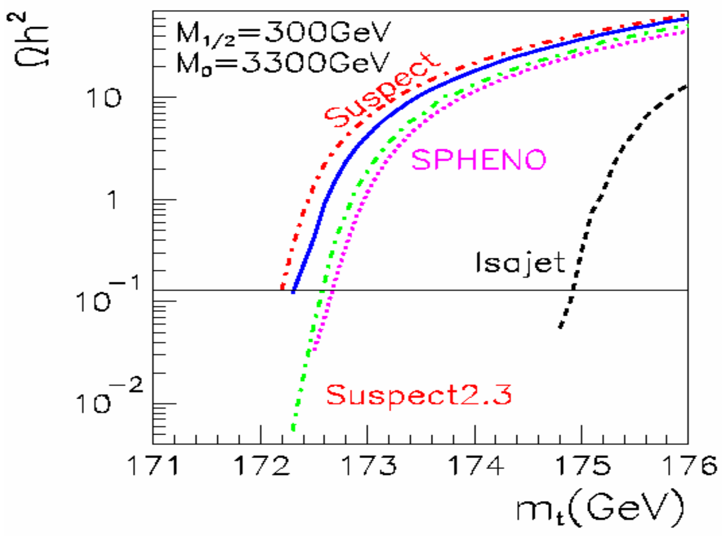
$$\frac{m^2_{H_2}}{dt} \approx \frac{3}{8\pi^2} h_t (m^2_{\tilde{Q}} + m^2_{\tilde{U}} + m^2_{H_2} + A^2_t)$$

μ parameter also sensitive to top Yukawa

$$\mu^2 = \frac{\overline{m}^2_{H_1} - \overline{m}^2_{H_2} \tan^2\beta}{\tan^2\beta - 1} - \frac{1}{2} M^2_Z$$



- **Increasing Mt pushes focus point towards heavier M_0**
- **Even with ΔMt=1 GeV, prediction for Ω can vary by more than one order of magnitude**
- **Dependence on the code used for evaluation of supersymmetric spectrum: critical parameter is μ**



Allanach et al., Les Houches

Focus point region and Mt

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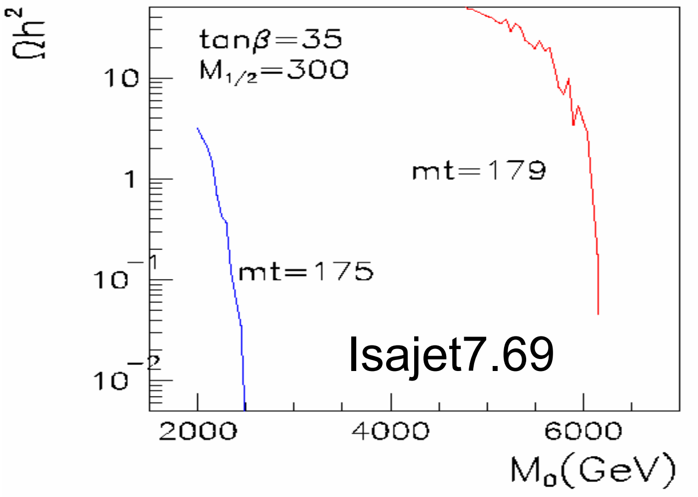

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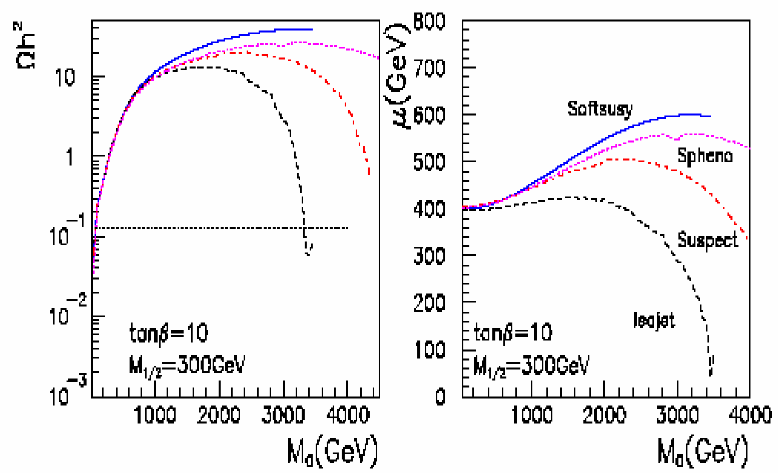
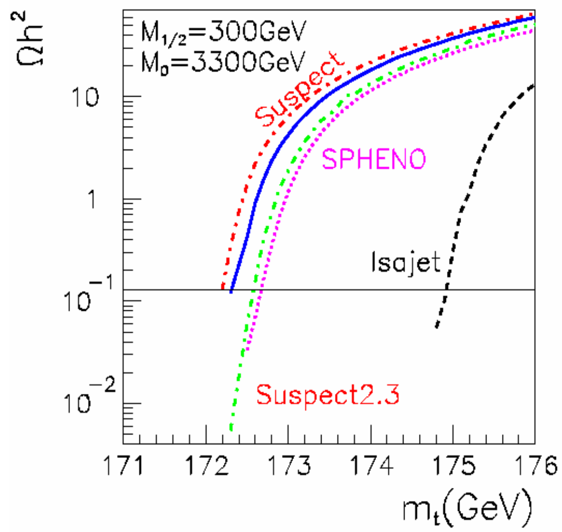
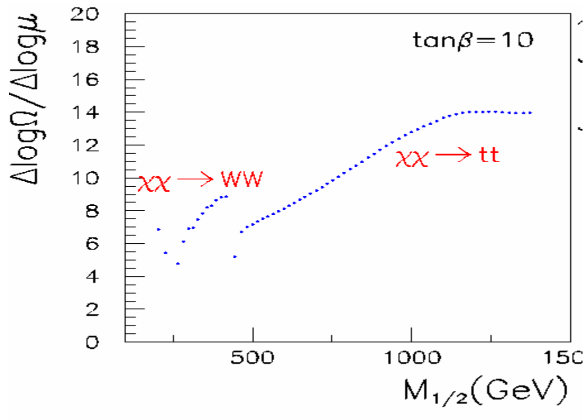


Allanach et al., Les Houches

Relic density and MSSM parameters

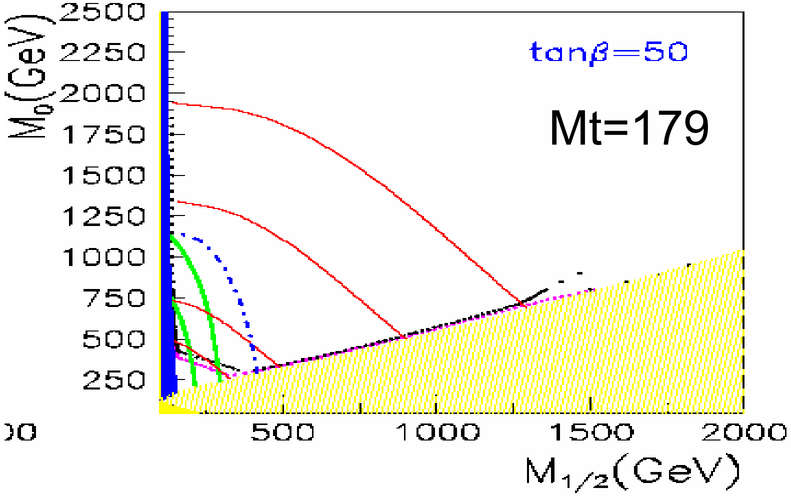
- **Even with ΔMt=1 GeV, prediction for Ω can vary by more than one order of magnitude**
- **In terms of MSSM parameters rather than mSUGRA prediction for Ωh^2 more stable**
- **What is the precision needed on the MSSM parameters to have accurate prediction for the relic density in WMAP favoured regions → test of the cosmological model**
  - **Work within ALC-cosmo group**
- **In focus point need to know μ to 1% for ΔΩ~10%**

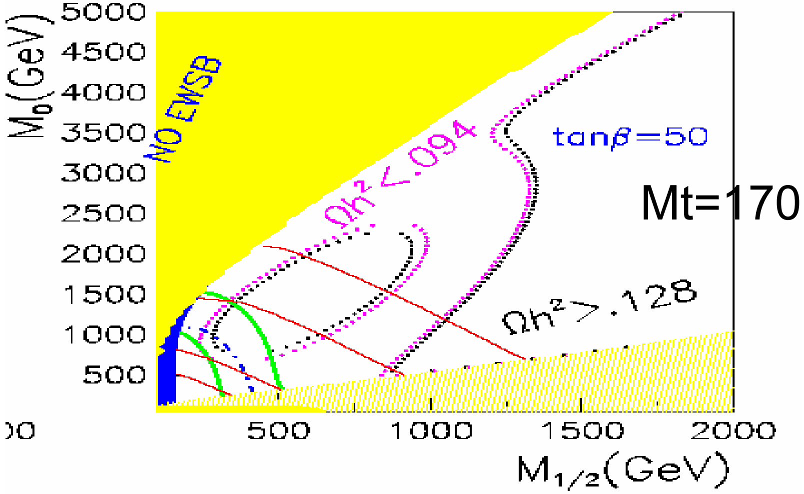




Impact of top quark mass

- Increasing Mt also increases heavy Higgs mass: the Higgs funnel almost disappears for Mt=179GeV
- Lighter top → heavy Higgs mass and μ decrease
  - more Higgs funnel and merges with focus point
  - Focus point for intermediate tanβ
- Large uncertainty in the relic density prediction is largely due to uncertainty in spectrum calculation.





Softsusy1.8.3

Higgs funnel and mb(mb)

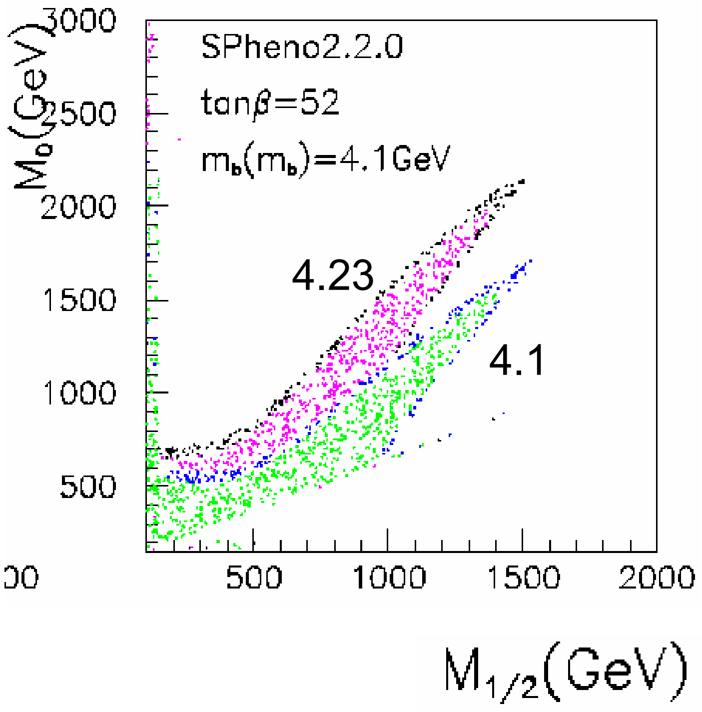
Position of the Higgs funnel also depends on mb(mb)

Running of $m^2_{H_1}$ sensitive to bottom Yukawa (large at high $\tan\beta$)

$$\frac{m^2_{H_1}}{dt} \approx \frac{3}{8\pi^2} h_b (m^2_{\tilde{Q}} + m^2_{\tilde{D}} + m^2_{H_1} + A^2_b)$$

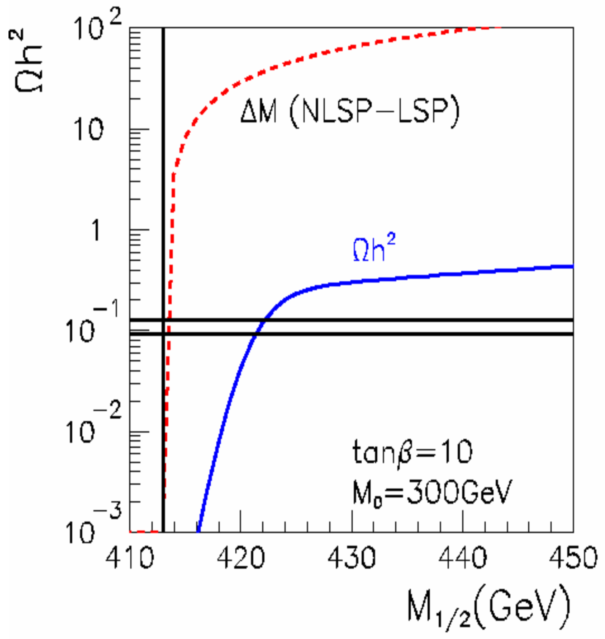
Pseudoscalar mass then also sensitive to bottom Yukawa

$$M^2_A = \frac{1}{\cos 2\beta}(\overline{m}^2_{H_2} - \overline{m}^2_{H_1}) + \frac{s^2_\beta t_1}{v_1} + \frac{c^2_\beta t_2}{v_2} - M^2_Z$$



mSUGRA : A_0

A0= -1700 GeV



- **New possibility: the stop can be NLSP**
  - **Large mixing needed**
- **Coannihilation with stop**

$$\tilde{\chi}_1^0 \tilde{t}_1 \rightarrow tg, W^+\bar{b}$$

  - **ΔM~30-50GeV**
- **Constraints from precision measurements + direct limits also change with A0, stop NLSP only consistent with b->sγ and Mh for large negative mixing**

Reach of LHC in mSUGRA

- **Low M0**

  $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$ and $\tilde{g}\tilde{g}$:

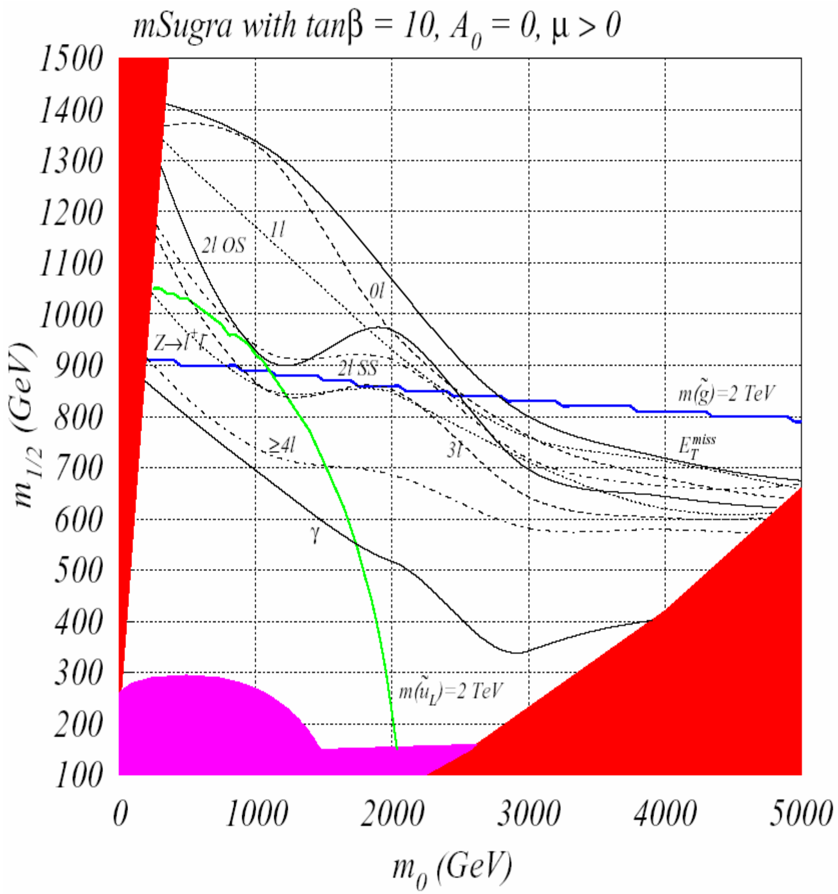
  – **Leptons in decay chains**
- **As M0 increases**

  $\tilde{g} \to \tilde{q}_R$ $\tilde{q}_R \to q\widetilde{Z}_1$

  – **Missing Et**
- **Eventually**

  $\tilde{g} \to \tilde{t}_1 t$

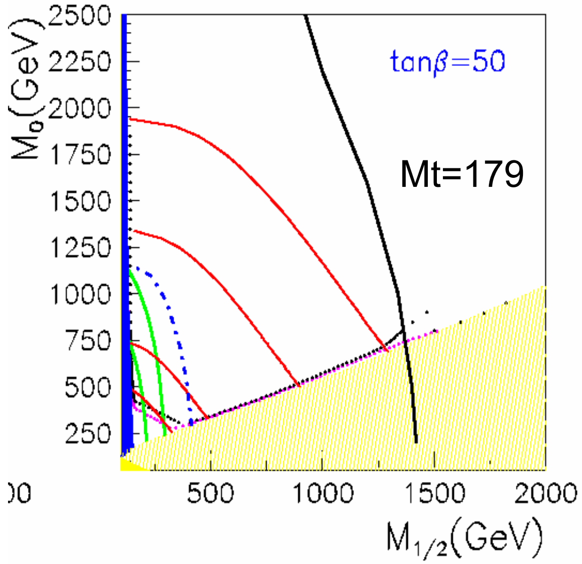
Only 3-body decays of gluinos
Reach ~ gluino 1.8TeV

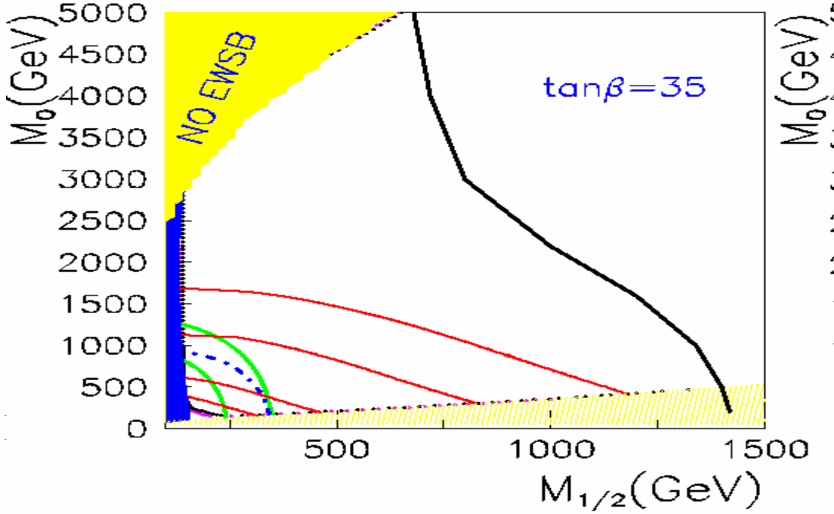


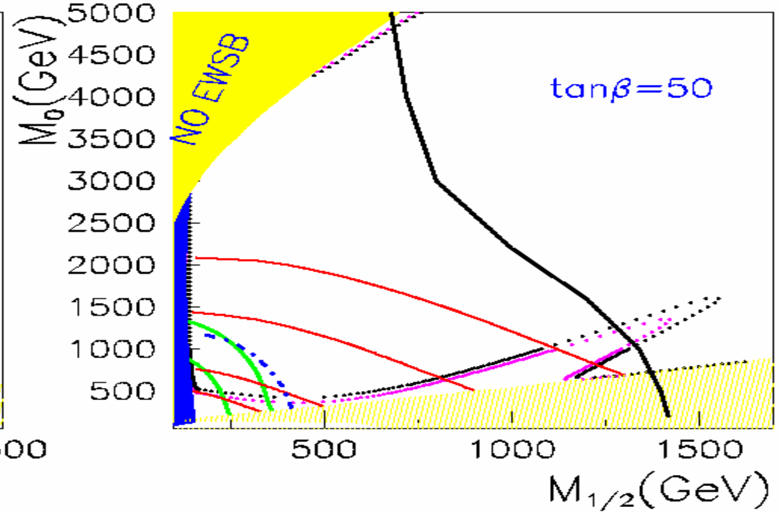
Baer et al., hep-ph/0304303

Implications for LHC

- **Coannihilation region:**
  - **squarks/gluinos are accessible at LHC except part of large tanβ**
- **Focus point region: heavy sfermions/light gauginos**
  - **Where this occurs in mSUGRA depends on the value of Mt, heavy top pushes towards large m0**
  - **Hard for LHC, only gluino accessible no squarks**
- **Models where MA =2M(LSP)**
  - **Models with very heavy Higgs and neutralinos are acceptable: whole spectrum could be heavy, possible only large tanβ**







Beyond mSUGRA

- Changing the nature of LSP has strong influence on predictions for the relic density: any model where LSP has significant Higgsino and/or wino component will have more efficient annihilation channels as well as coannihilation channels with charginos/neutralinos

- Changing the relation between neutralino mass and Higgs mass → annihilation through heavy Higgs can take place more easily

- Introducing some non universality in gaugino masses at GUT scale influences both heavy Higgs spectrum and wino/Higgsino component of LSP.
  - Heterotic orbifolds models: dilaton-dominated or moduli dominated
    - Binetruy et al hep-ph/0308047
  - AMSB …
- Alternatively one could modify universality condition on Higgsino masses

  also affects μ and MA
- In all models coannihilation with sleptons or other sfermions remain possible in specific regions of parameter space (need $\Delta M \sim 1$-10GeV for sleptons, can afford larger for squarks)

Non universal gaugino masses

- **Recall μ, M1,M2 determine the nature of the neutralino LSP**
  - **μ << M1,M2 → Higgsino**
  - **M1<<M2, μ → bino**
  - **M2< M1, μ → wino**
- **Approximate solution to RGE**

$$\mu^2 \approx -0.5M_Z^2 + 0.06M_0^2 + 2.6M'^2_3 - 0.2M'^2_2 +$$

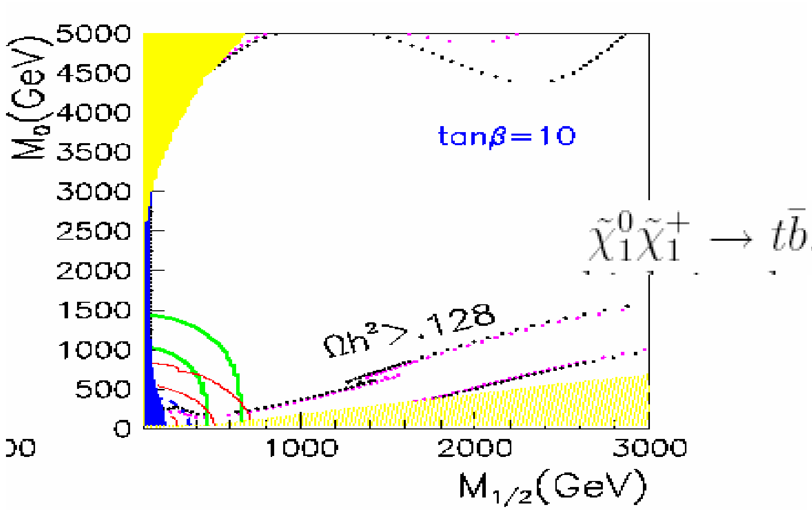
  - **If M3< M2 → partial cancellation → μ smaller**

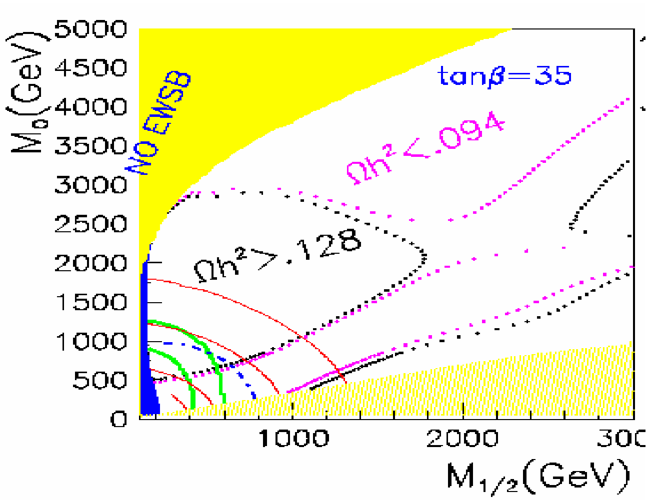
$$M_A^2 = -M_Z^2 + 1.08M_0^2 + 2.6M'^2_3 + 0.28M'^2_2 + 0.22M'_2M'_3$$

  - **If M3< M2 → MA decrease, can find 2M(LSP) ~MA even for small tanβ**

Relaxing universality: $M_3<M_2=M_1$

- **Heavy Higgs pole appears at small tanβ**
- **Find focus point region -> LSP more Higgsino**
- **Squarks and gluinos are lighter than in mSUGRA for a given M1/2**
  - **Gluino 3TeV ~ M1/2~2.8TeV**
  - **Focus point: M1/2~1.4TeV**
  - **Heavy SUSY spectrum is acceptable from relic density point of view**
- **In Higgs funnel: MA~2M(LSP)**
  - **No SUSY decay mode for the heavy Higgs**

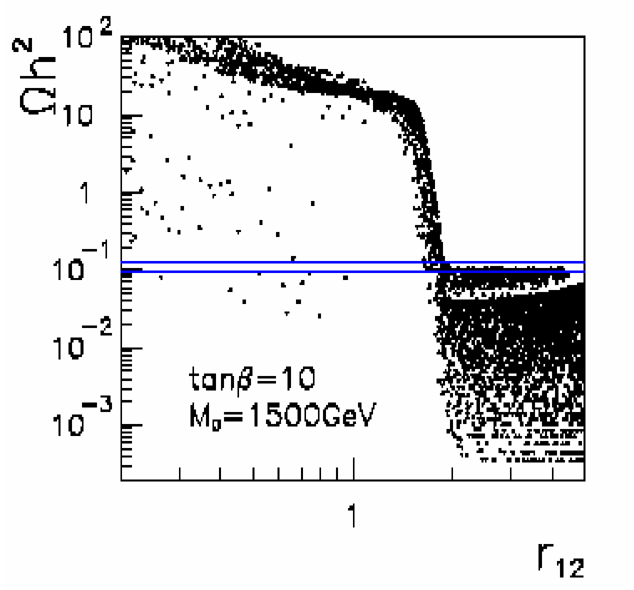




Relaxing universality :the wino LSP

- **M1>M2 at GUT scale : increasing the wino content of the LSP makes for more efficient annihilation → relic density constraint is easily satisfied**
- **Preferred channels:**
  - $\tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\chi}_1^0\tilde{\chi}_2^0, \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow$ **WW**

    $\tilde{\chi}_1^0\tilde{\chi}_1^+ \rightarrow q\bar{q}, ZW$

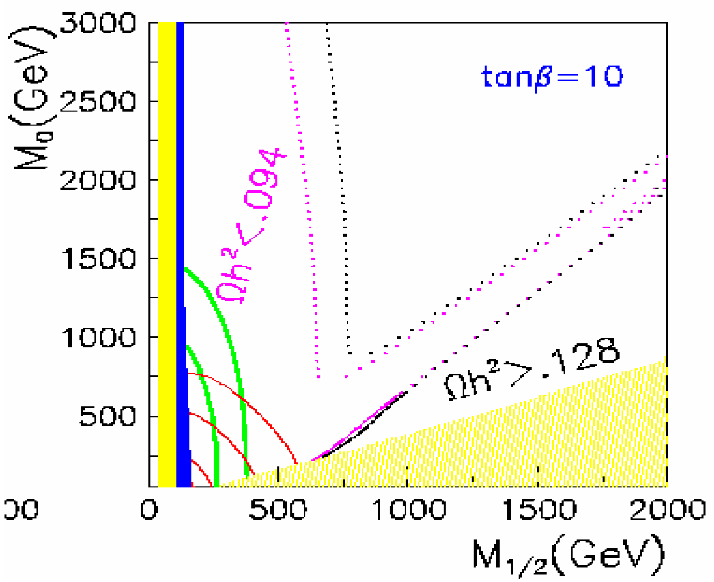


GB, Boudjema, Cottrant, Pukhov, Semenov

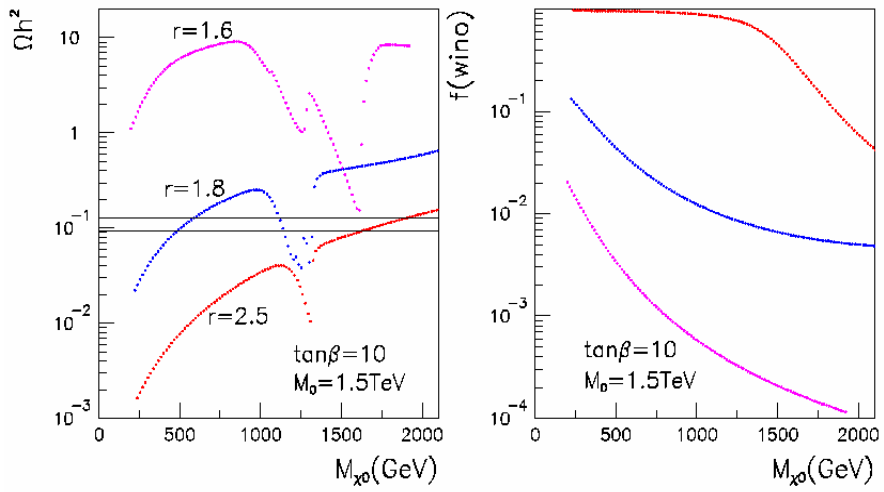
- **M1~1.8M2 at GUT scale →M1~M2 at weak scale**
  - **LSP is mixed wino/bino**

The nature of the LSP

- M1~1.8M2 at GUT scale
  - M1~M2 at weak scale
  - Wino LSP
  - Heavy Higgs annihilation
    - →tt,bb
    - Charged Higgs resonance
    - M(LSP)~600GeV



- M1>>M2 : not enough dark matter unless neutralinos are very heavy >1.5TeV
  - Whole SUSY spectrum heavy



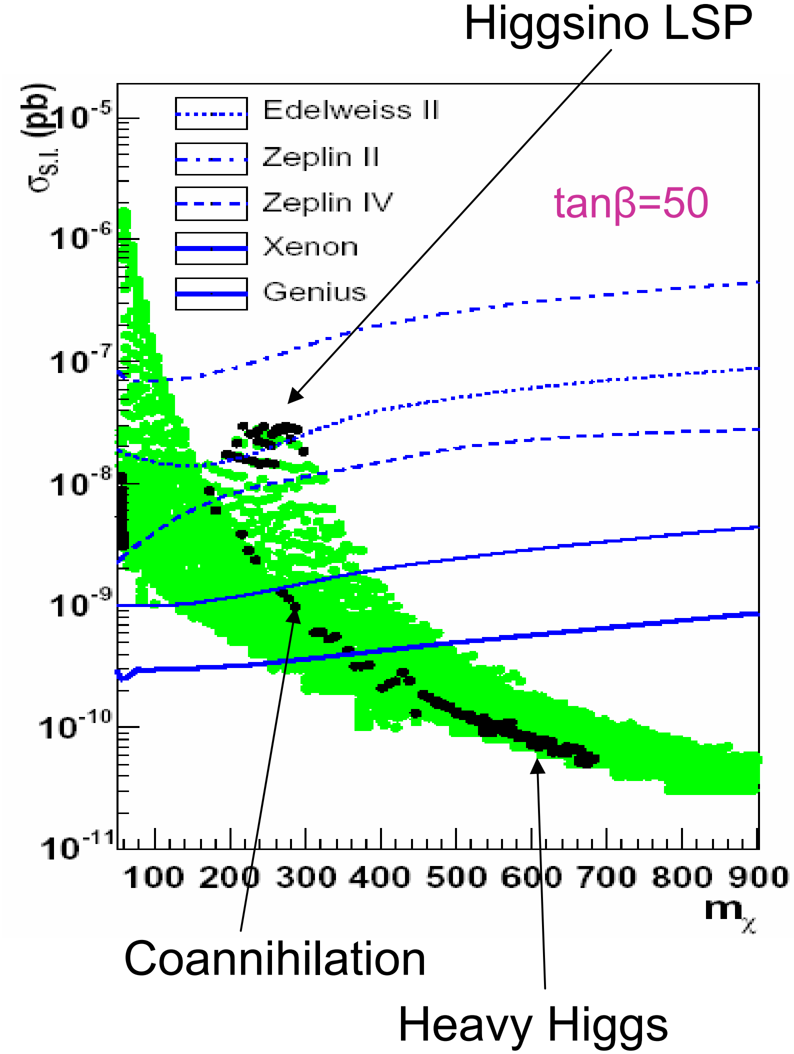
Direct detection

- **Many experiments under way, improvements planned → ton scale**
- **Spin independent cross section proceeds through Higgs exchange, squark exchange**
  - **LSP coupling to Higgs large for mixed gaugino/Higgsino LSP**
    - **mSUGRA-> focus point**
  - **Squark contribution large at low M_0**

  Constraints from mh, b->sγ

- **Coannihilation region not favourable for direct detection unless M(LSP)<400GeV**

- **Current detectors are not sensitive enough to probe mSUGRA but focus point will be accessible in near future**

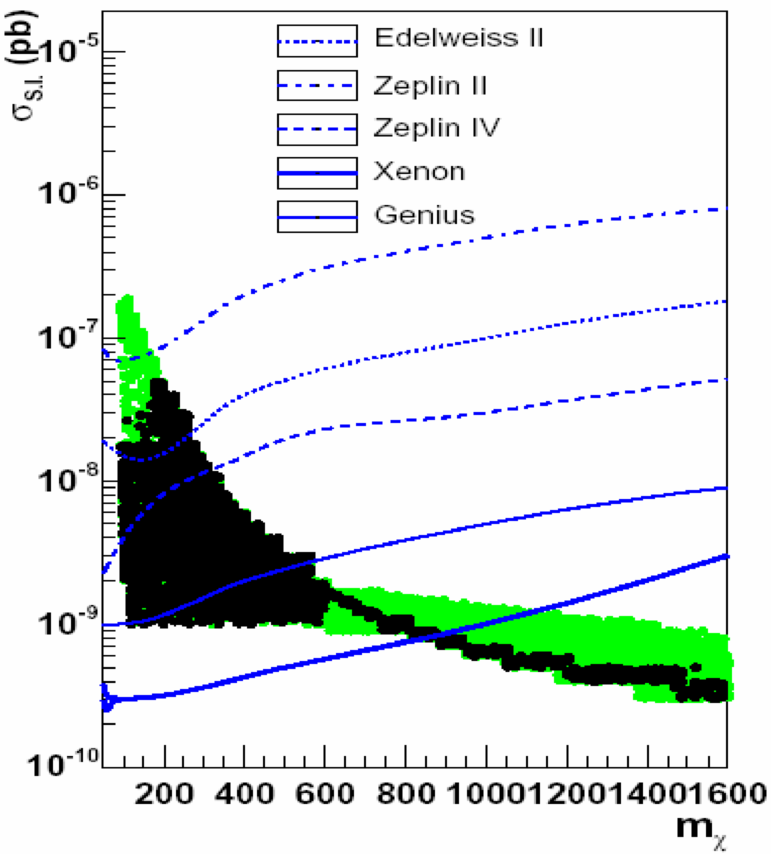


GB, Boudjema, Cottrant, Pukhov

Direct detection in nonuniversal models

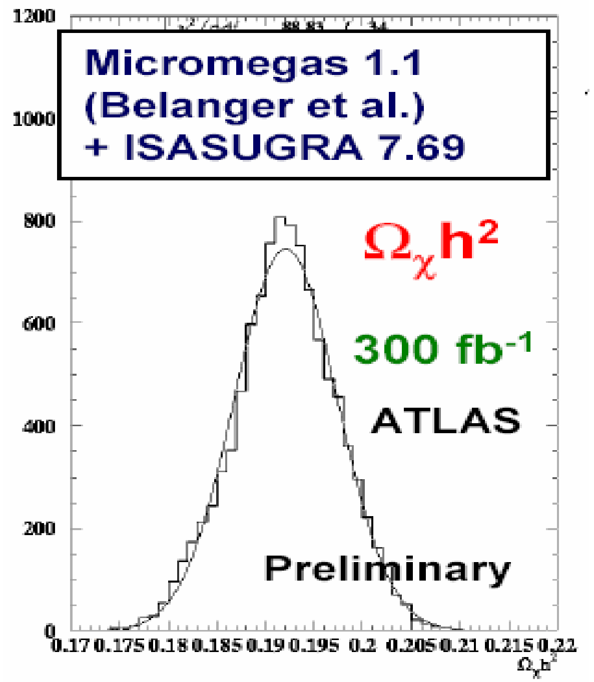
- Same mechanism that makes for effficient annihilation and good relic density also gives large direct detection cross sections except coannihilation and resonance annihilation
- Models with wino LSP (M1>M2) can have enhanced coupling to Higgs
  - Higgs coupling to neutralinos requires mixed Higgsino/gaugino state
- Heavy Higgs annihilation region: beyond reach of ton-scale detectors

$\Omega h^2 < .129$



Determination of parameters and relic density

- **Within mSUGRA SPS1A: precision on mSUGRA parameters at the LHC lead to 2-3% uncertainty in Ωh^2**
- **In WMAP favoured region need more precision since parameters rather fine tuned:**
  - **Coannihilation**
  - **Large tanβ: Higgs mass**
  - **Focus/Higgsino: μ**



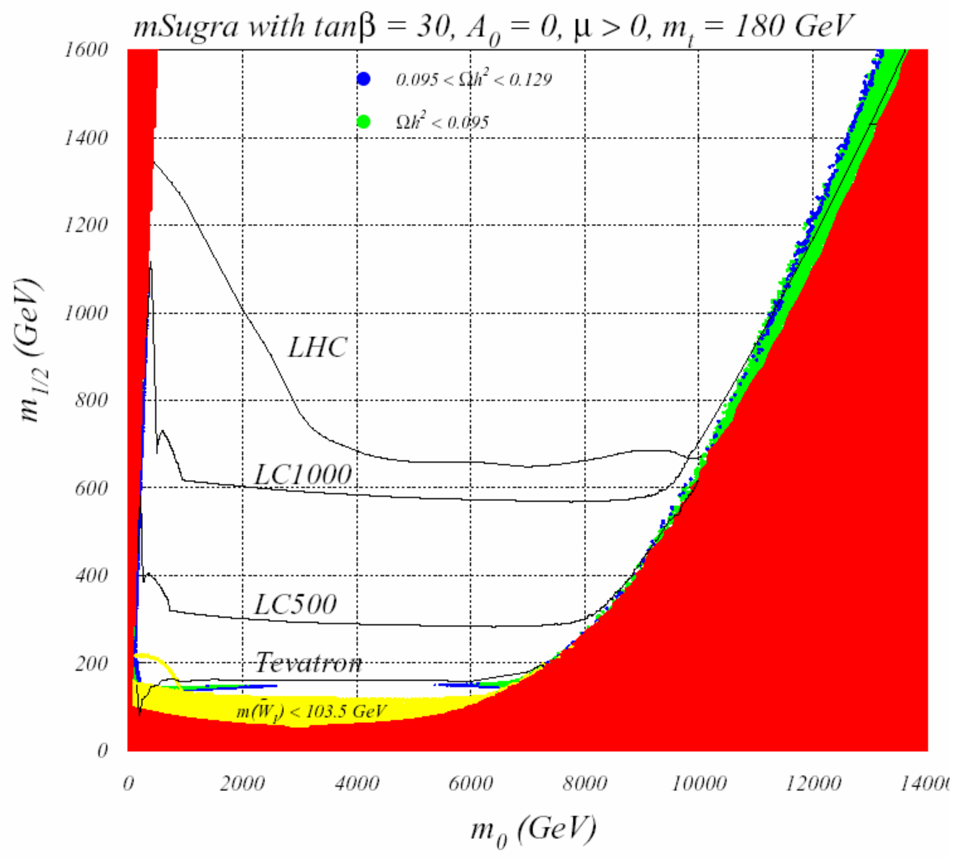
Tovey, Polesello

Conclusions

- In mSUGRA can only satisfy relic density constraint in specific region of parameter space because the LSP is bino
  - Coannihilation (stau and also stop)
  - Focus point : Higgsino
  - Higgs exchange

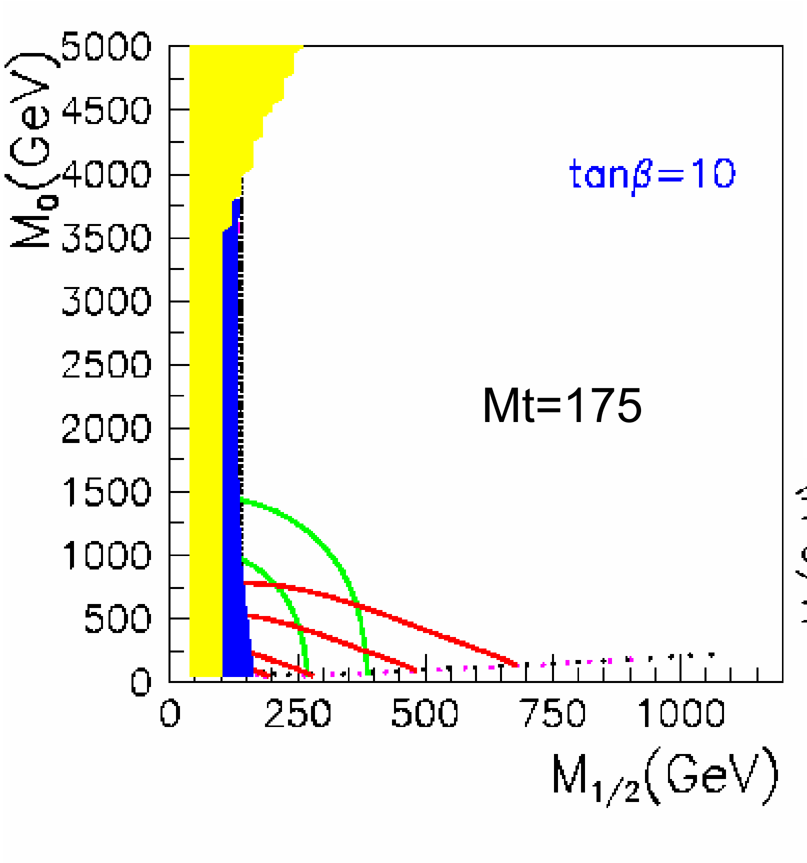
- Position of focus point/Higgs depends on standard model parameters : Mt, Mb . Higgsino LSP interesting scenario from dark matter point of view
- Higgsino LSP scenario can be associated with heavy sqaurks: only gluino may be accessible at LHC, complementarity with direct detection
- Heavy Higgs funnel (large tanβ) : difficult to discover SUSY
- Models where LSP is not pure bino satisfy more easily relic density constraint   : implications for searches at LHC?
- Using measurements from LHC what can we learn on cosmology?

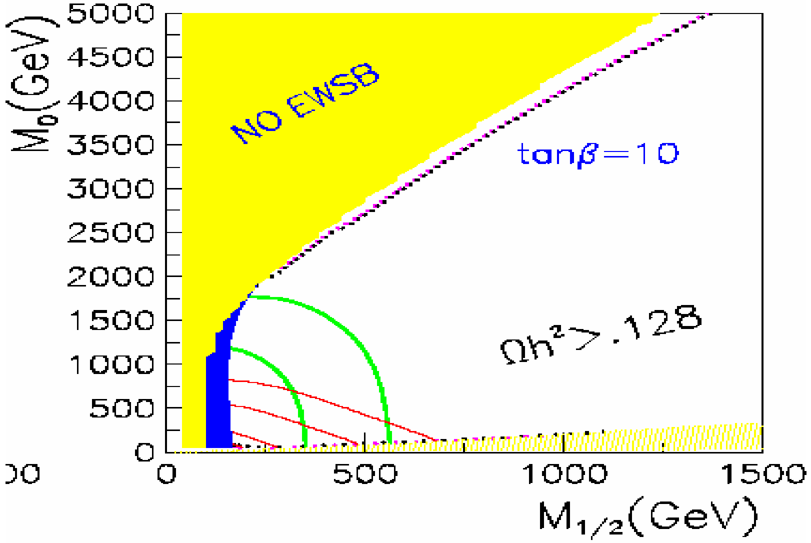
mSUGRA : complementarity



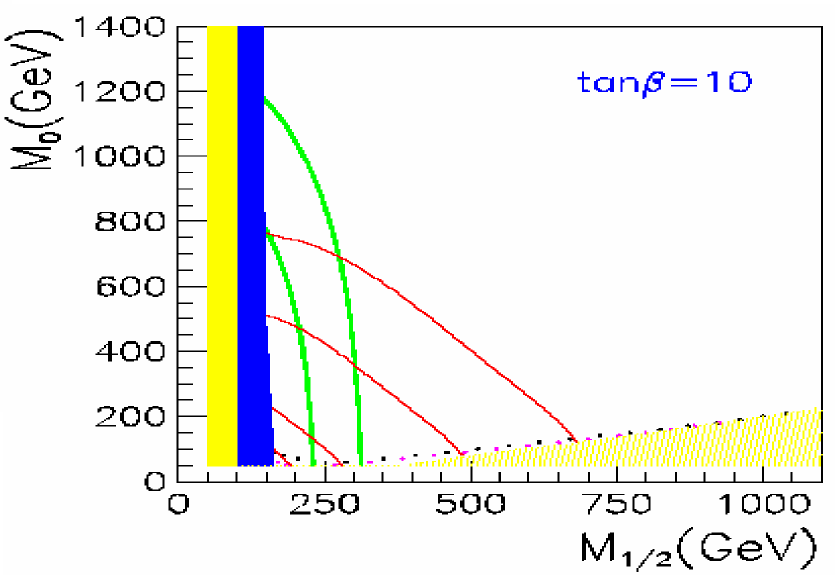
mSUGRA

micrOSoft
micrOMEGAs1.3+SoftSusy1.8





Mt=170



Mt=179