Neutralino Dark Matter and the Linear Collider

H. Baer, A. Belyaev, T. Krupovnickas (FSU)
and X. Tata (Hawaii)

OUTLINE

- mSUGRA model
- Constraints on mSUGRA
  - LEP2
  - relic density: WMAP
  - $b \to s\gamma$
  - $(g-2)_\mu$
  - χ^2 determination; favored regions of parameter space
- prospects for mSUGRA at a linear e^+e^- collider
- compare LC reach to that of Tevatron and LHC
- parameter determination in the HB/FP region
- non-universal SUGRA model
- favored regions of NU SUGRA parameter space
- prospects for colliders: light 1st/2nd gen. sleptons
- conclusions

Constructing the mSUGRA model

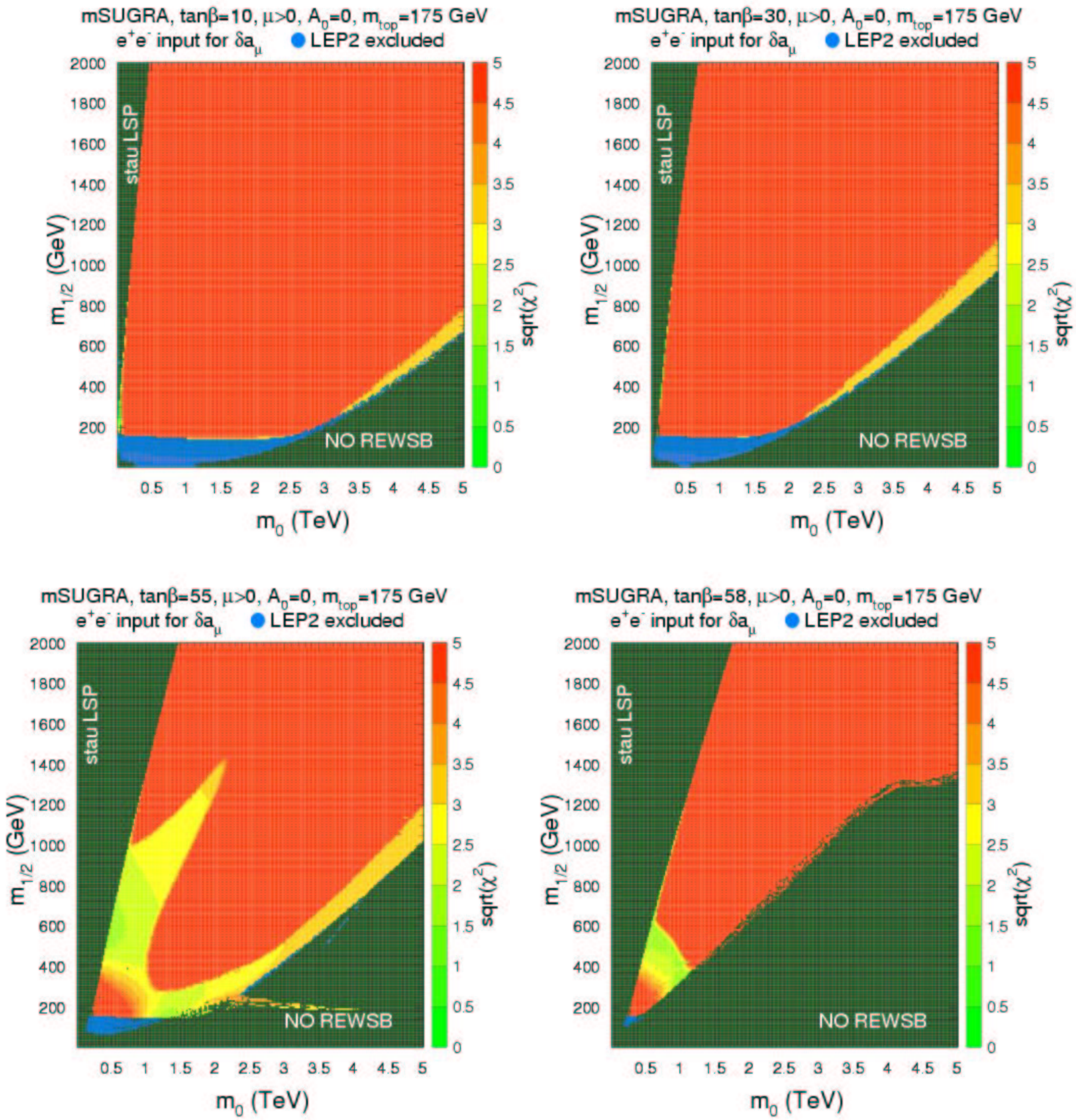
- Begin with Lagrangian of locally supersymmetric gauge theory
- Specify matter and Higgs superfields of MSSM
- Specify SM gauge symmetry
- Specify Kahler function $G = K + \log |f|^2$:
  - superpotential $f = f_{MSSM} + f_{hidden}$
  - flat Kahler metric: $K = \Sigma_i \hat{S}_i^\dagger \hat{S}_i + \hat{h}^\dagger \hat{h}$
- Specify simple gauge kinetic function: $f_{AB} = \delta_{AB} f(\hat{h})$
- Arrange for SUSY breaking in hidden sector
- Calculate supergravity induced soft SUSY breaking terms
- Limit as $M_{Pl} \to \infty$ with $m_{3/2}$ fixed: global SUSY renormalizable gauge theory with TeV scale soft breaking terms valid at high scale $e.g.\ M_{GUT}$
- weak scale model constructed via RGE evolution; EW symmetry broken radiatively
- mSUGRA model parameter space
  - $m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)$

Chamseddine, Arnowitt and Nath; Barbieri, Ferrara and Savoy; Hall, Lykken and Weinberg; $\cdots$

Constraints on mSUGRA model

- Generate SUSY spectrum in mSUGRA parameter space
  - Calculate $\Omega_{\widetilde{Z}_1}h^2$ HB, Balazs, Belyaev
    - use Gondolo, Gelmini , Edsjo +CompHEP: Isared program
    - WMAP: $\Omega_{CDM}h^2 = 0.1126 \pm 0.0090$
  - calculate $BF(b \to s\gamma)$ HB, Brhlik, Castano, Tata
    - $BF(b \to s\gamma) = (3.25 \pm 0.54) \times 10^{-4}$ (incl. 12% theory)
  - calculate SUSY contribution to $(g-2)_\mu$ HB, Balazs Ferrandis, Tata
    - $\Delta a_\mu = (31.7 \pm 9.5) \times 10^{-10}$ (Hagiwara *et al.* e^+e^-; new E821 results)
- from these three, calculate χ^2, plot in mSUGRA parameter space HB, Balazs
  - see also Ellis, Olive, Santoso and Spanos
- allowed DM regions
  - stau co-annihilation (Ellis et al.)
  - HB/FP (Chan, Chattopadyay, Nath; Feng, Matchev, Moroi)
  - A-annihilation funnel (Drees, Nojiri; HB, Brhlik)
  - "bulk" region at low m_0, $m_{1/2}$ disfavored (LEP2, $b \to s\gamma$, $(g-2)_\mu$)

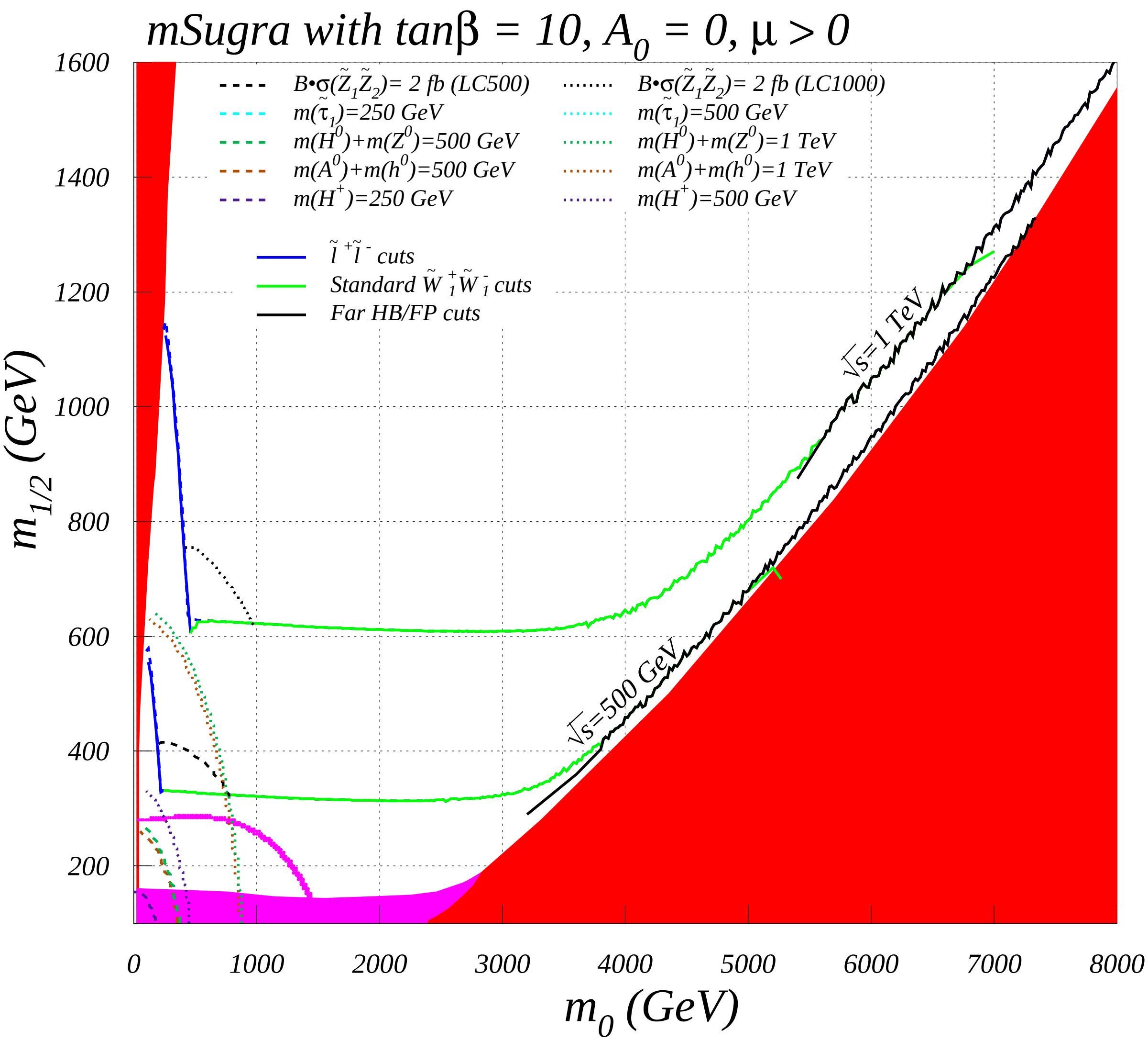
χ^2 for $\mu > 0$:



- green: low χ^2/dof
- yellow: medium χ^2/dof
- red: high χ^2/dof

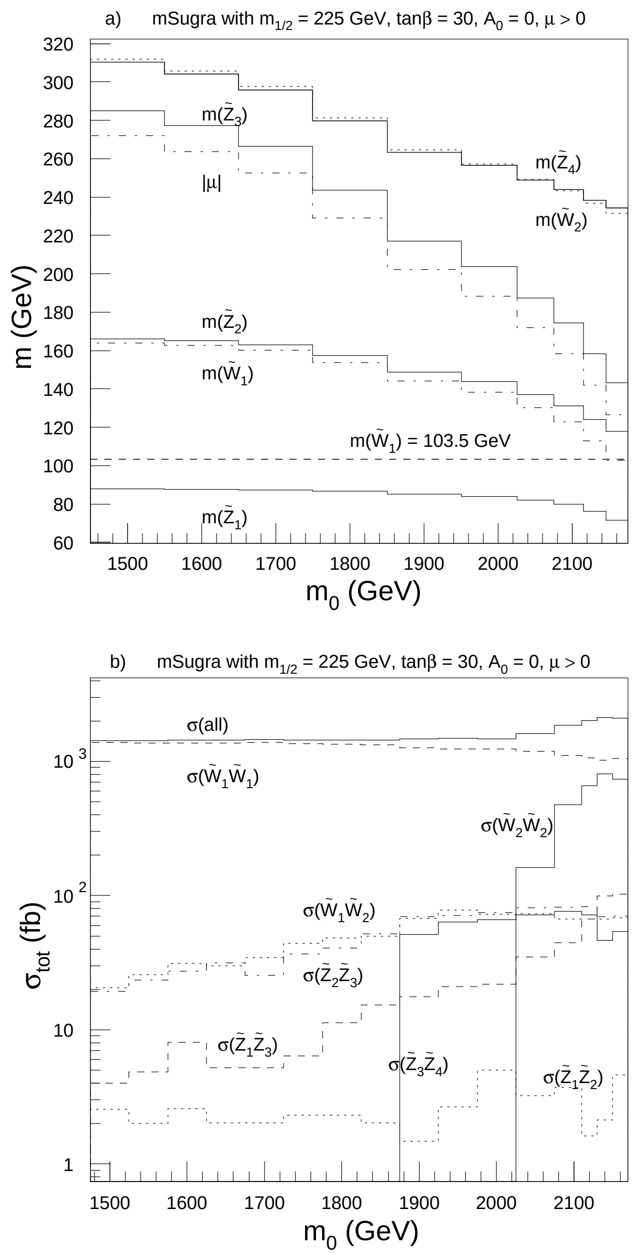
Reach of linear e^+e^- collider :

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



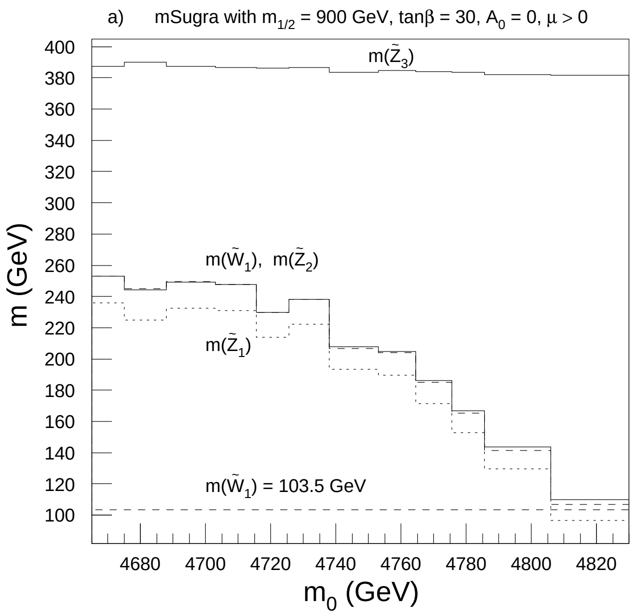
Sparticle masses/ cross sections in the HB/FP region:

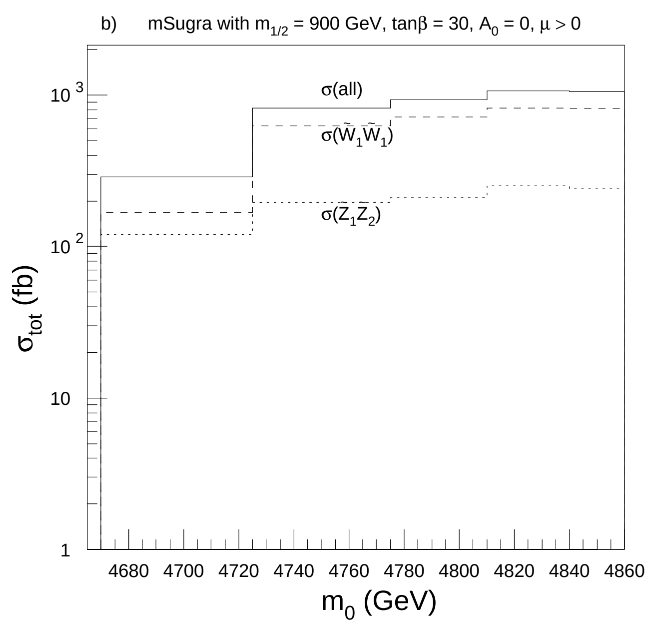
- In HB/FP, $\mu \rightarrow 0$
- $m_{1/2} = 225$ GeV



Sparticle masses/ cross sections in the HB/FP region:

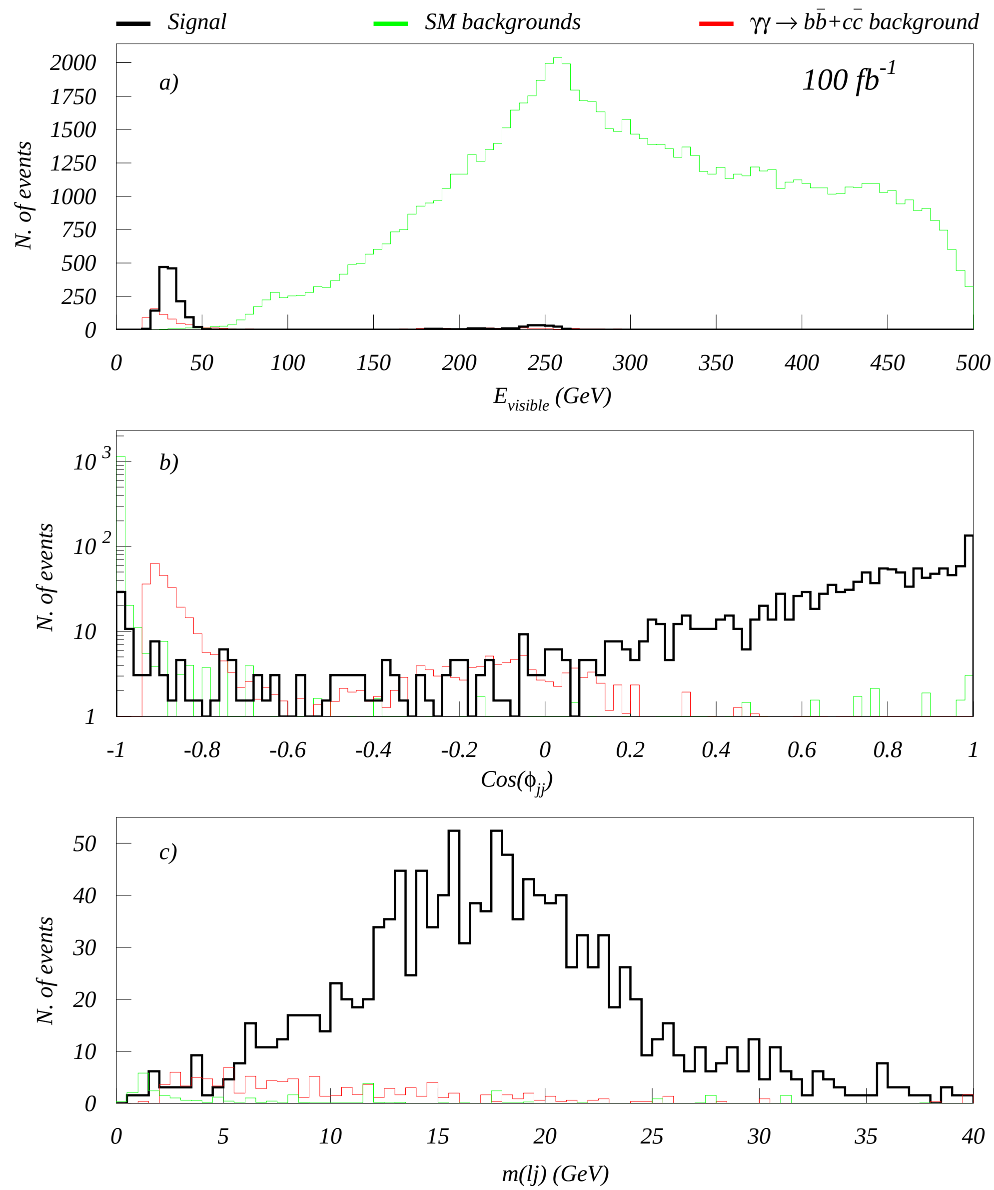
- $m_{1/2} = 900$ GeV





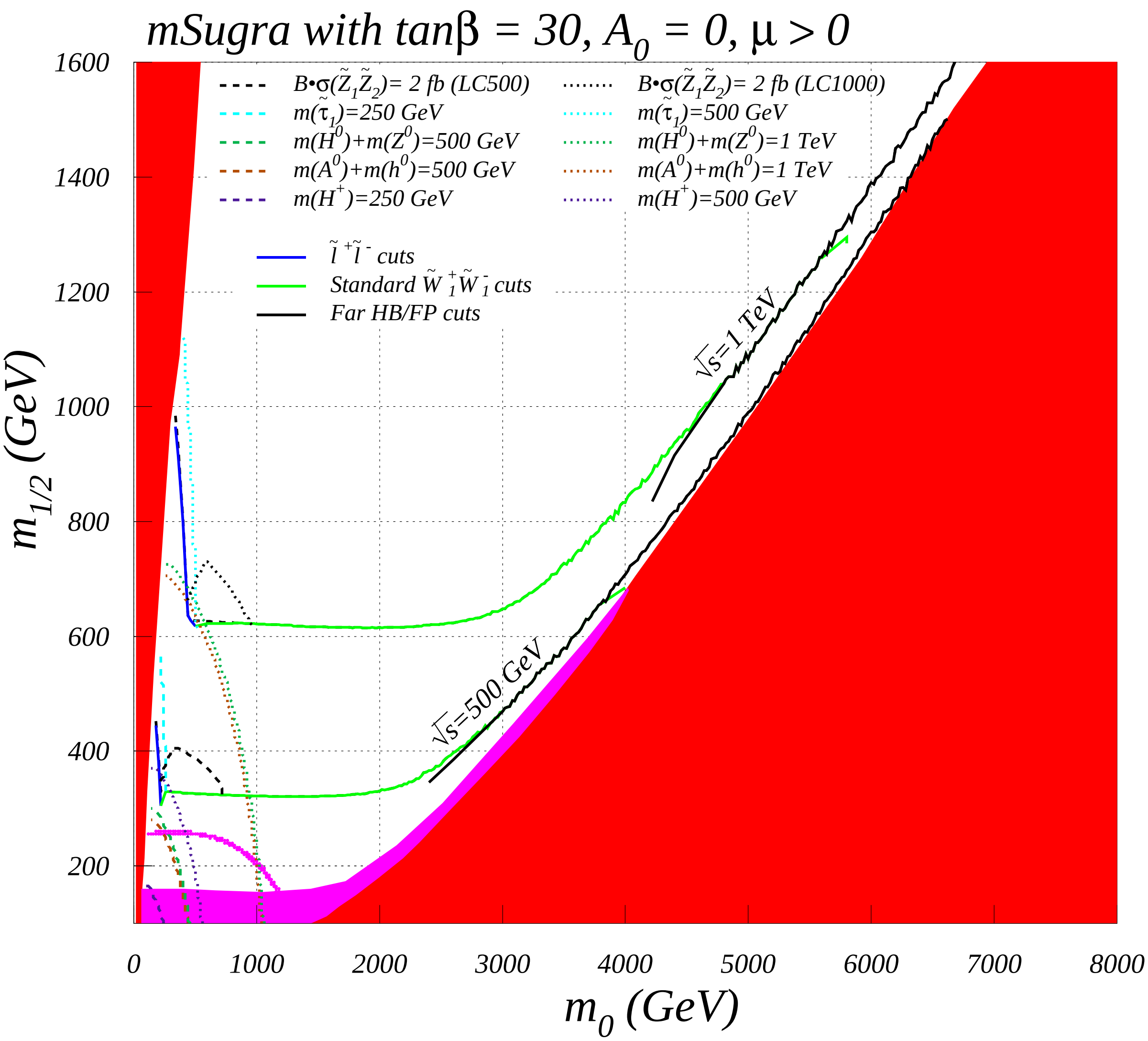
Distributions for case study in HB/FP region

- In HB/FP, $\mu \to 0$



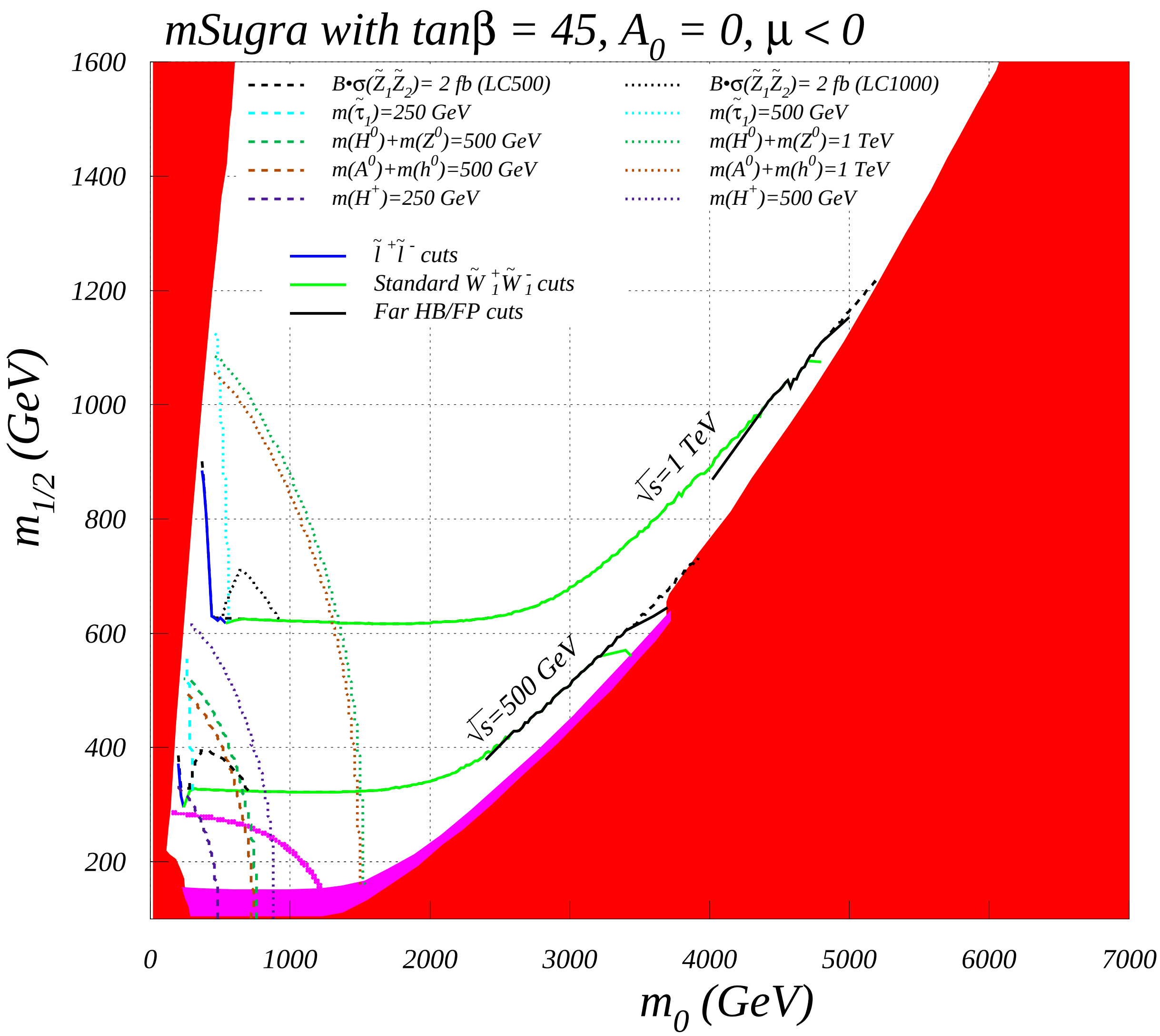
Reach of linear e^+e^- collider:

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



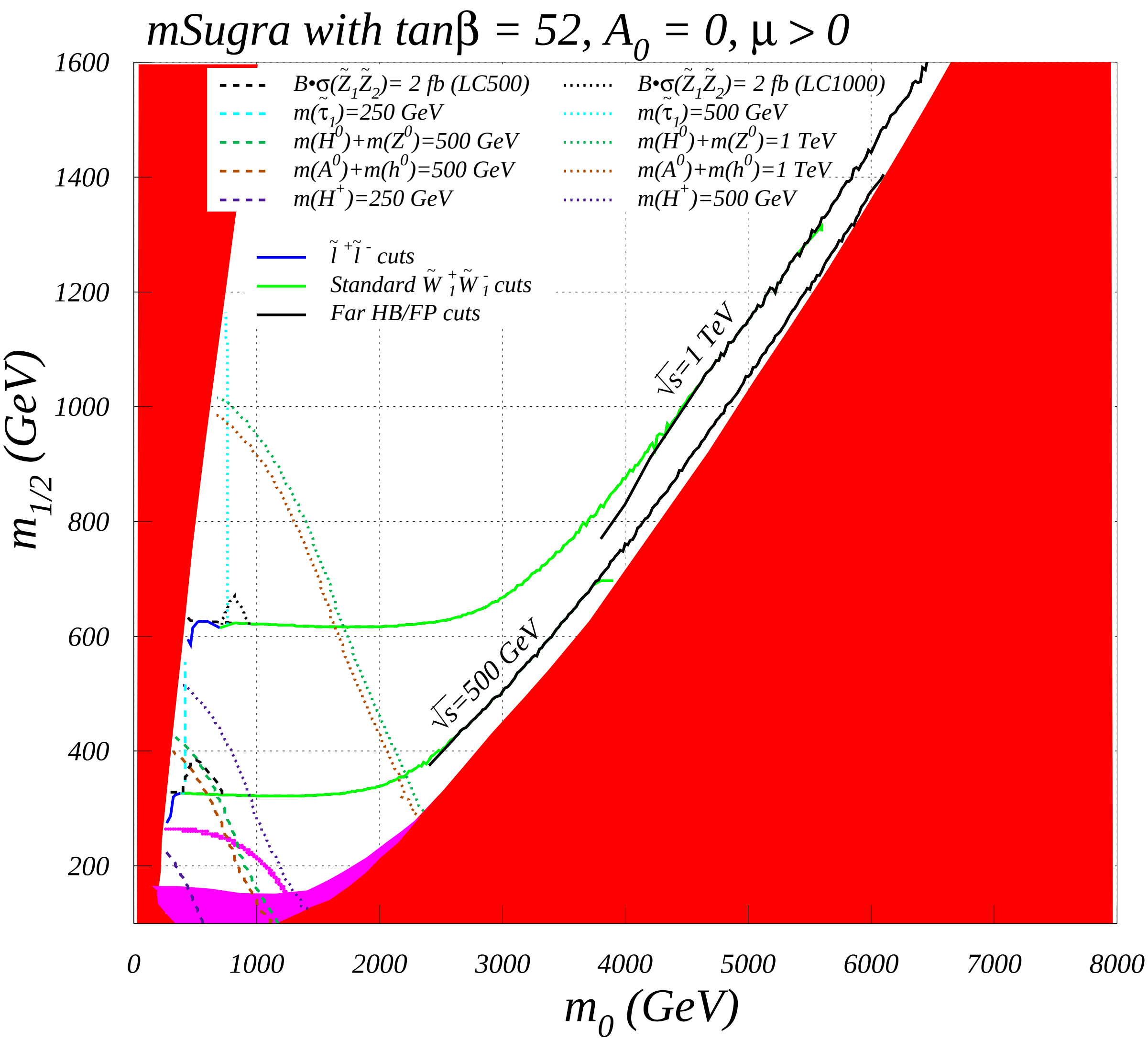
Reach of linear e^+e^- collider:

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



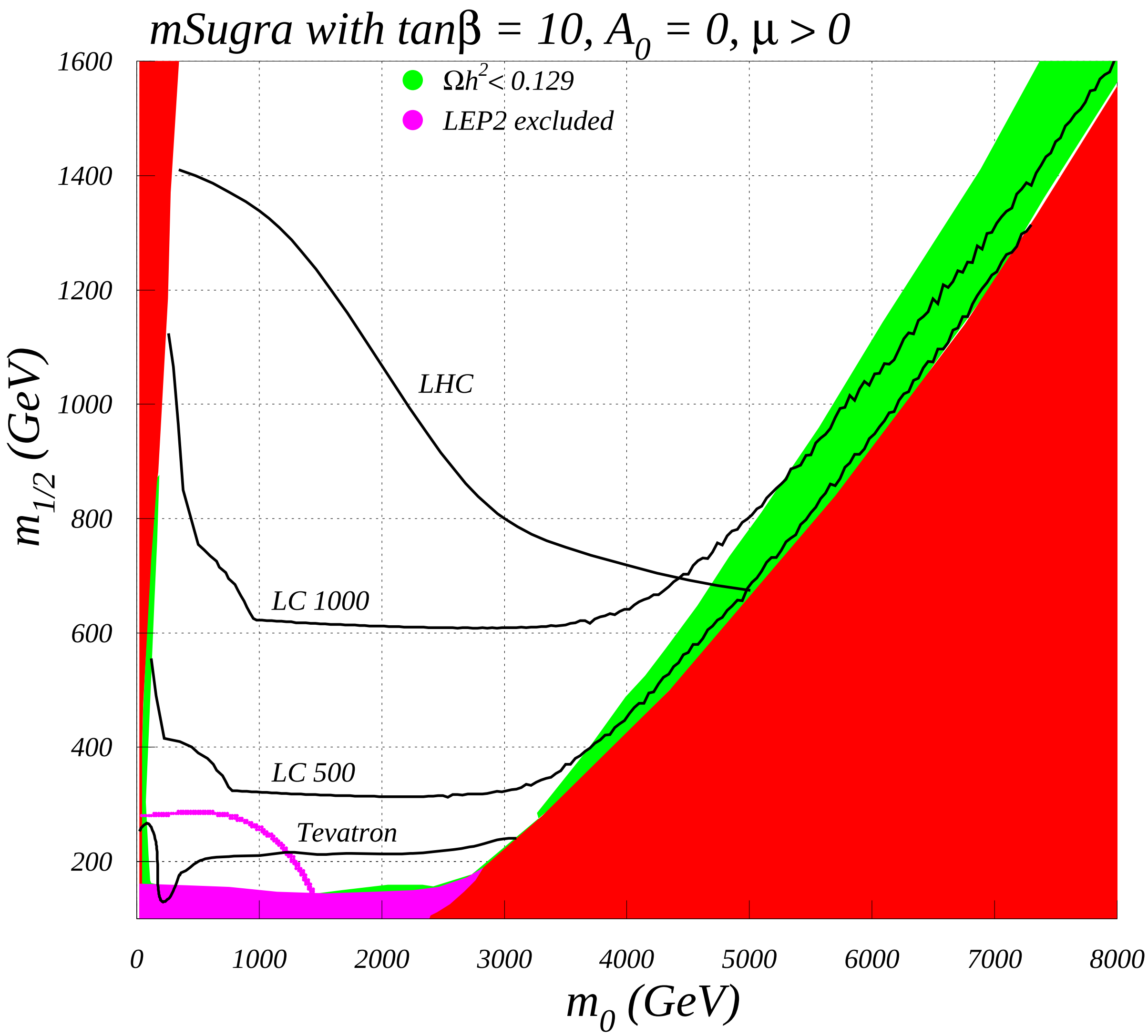
Reach of linear e^+e^- collider:

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



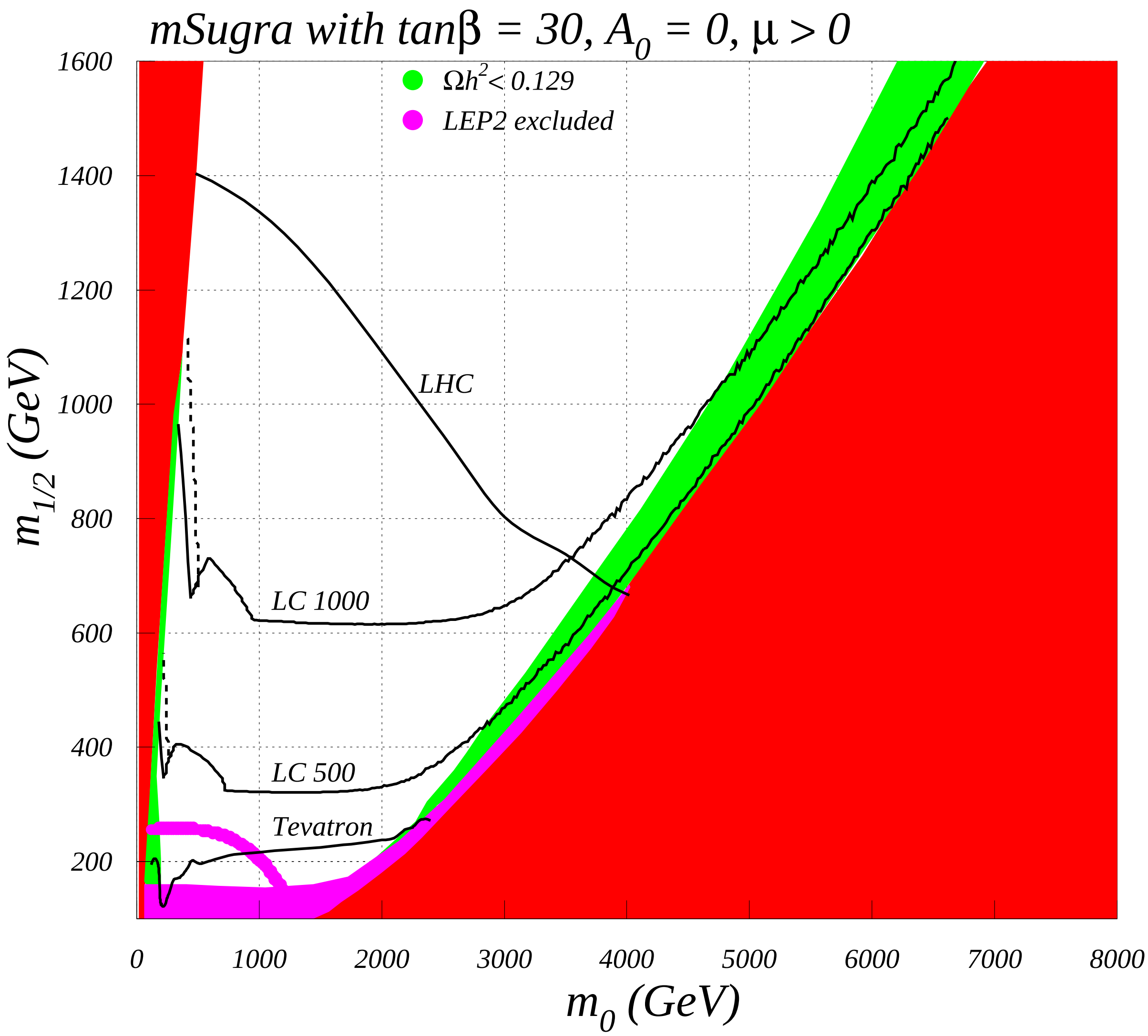
Compare all colliders with WMAP allowed region:

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



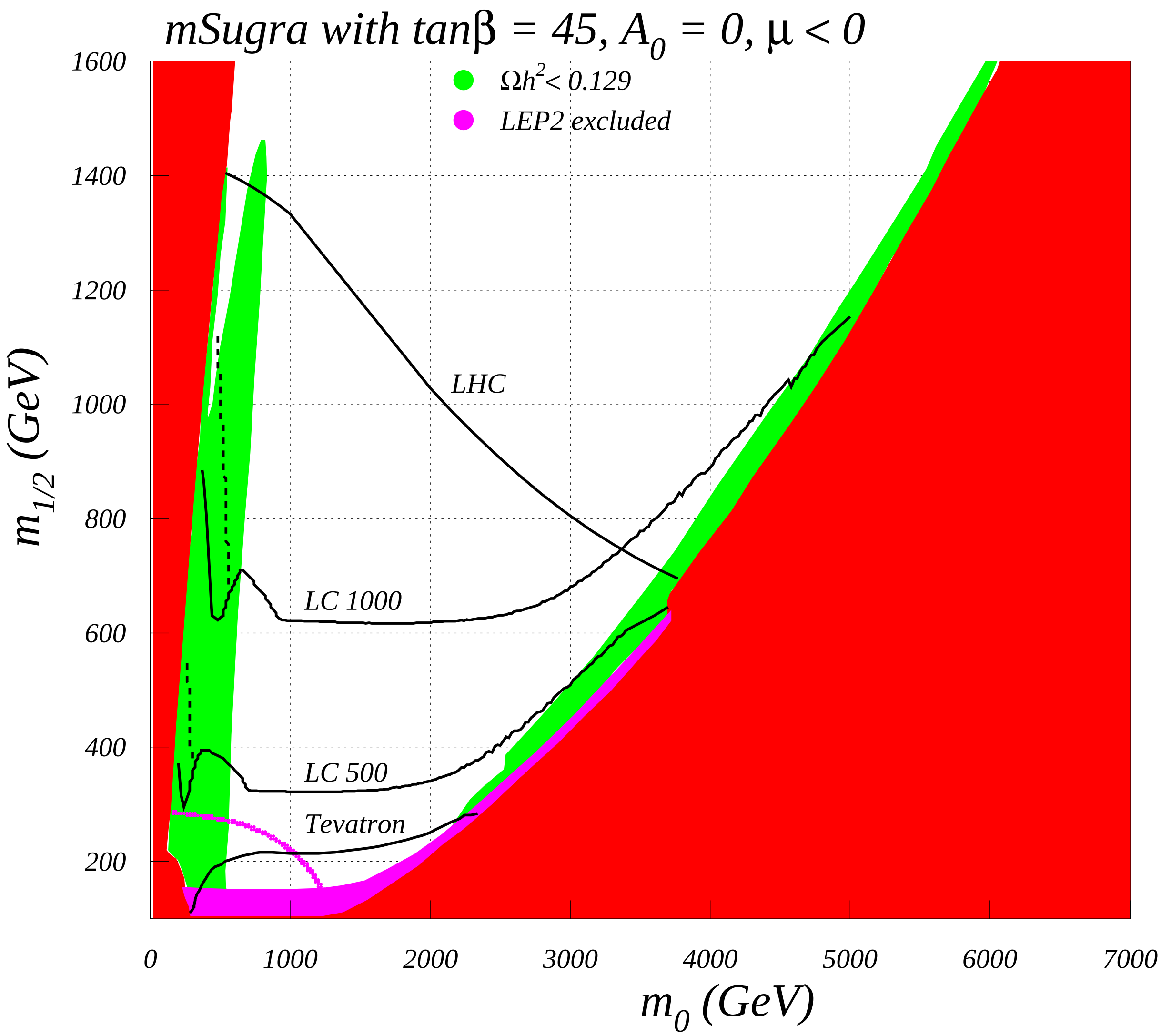
Compare all colliders with WMAP allowed region:

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



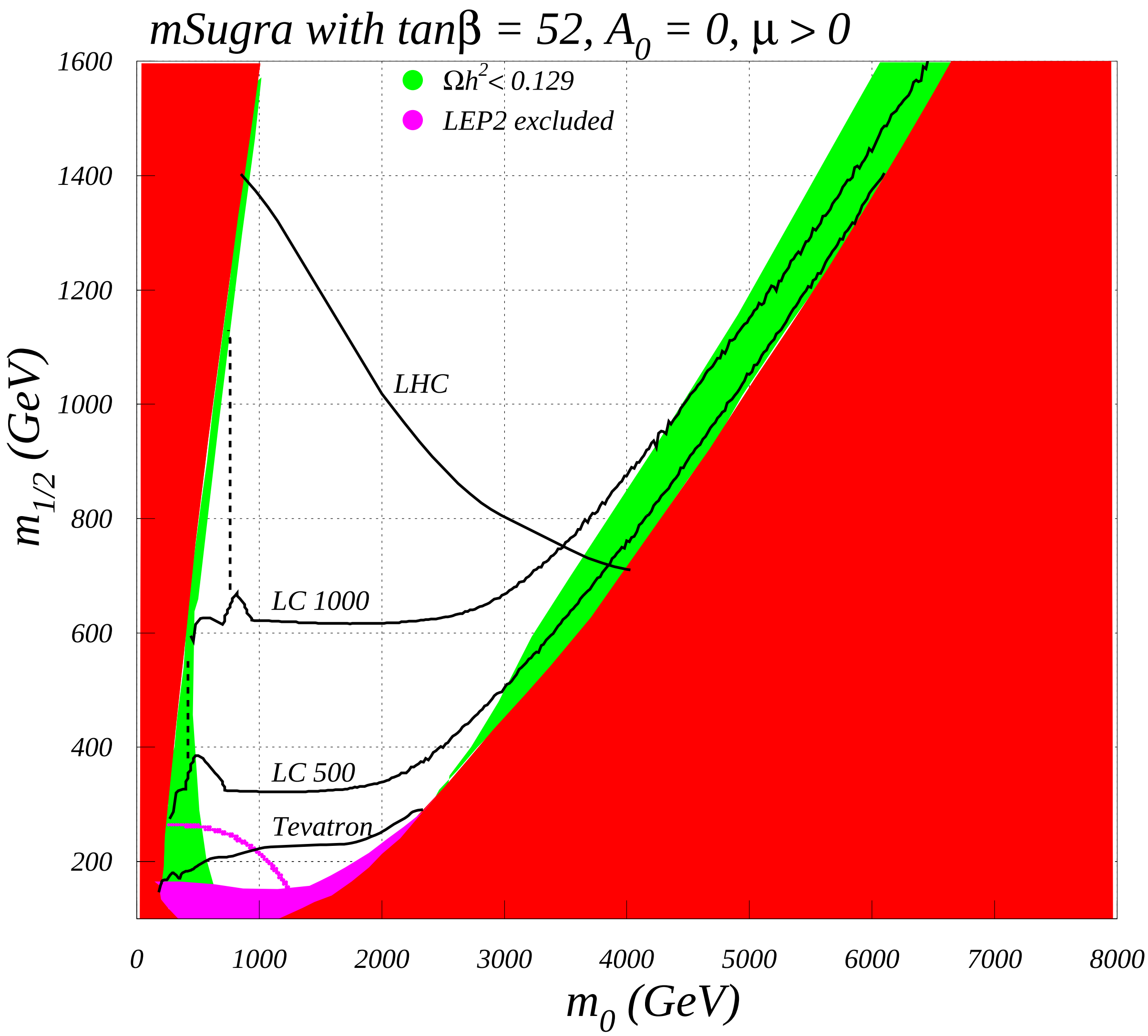
Compare all colliders with WMAP allowed region:

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



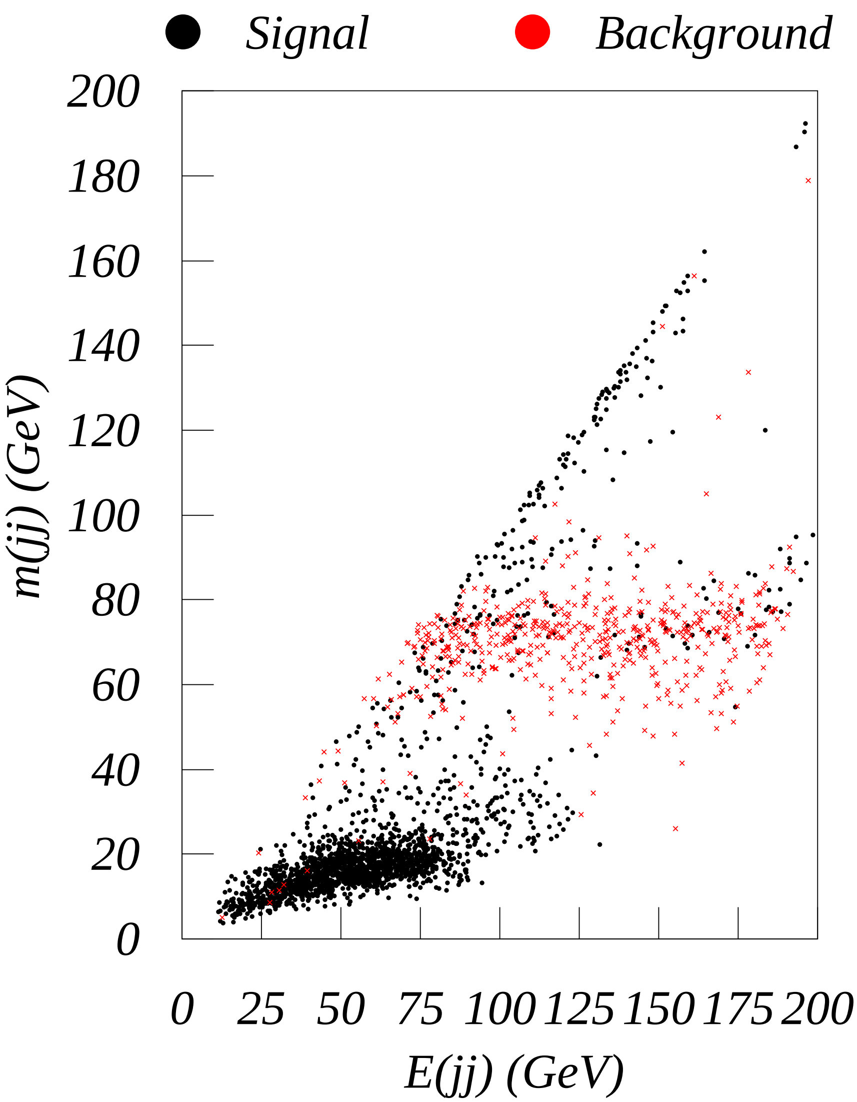
Compare all colliders with WMAP allowed region:

- LC reach for $\sqrt{s} = 0.5$ and 1 TeV, 100 fb^{-1}



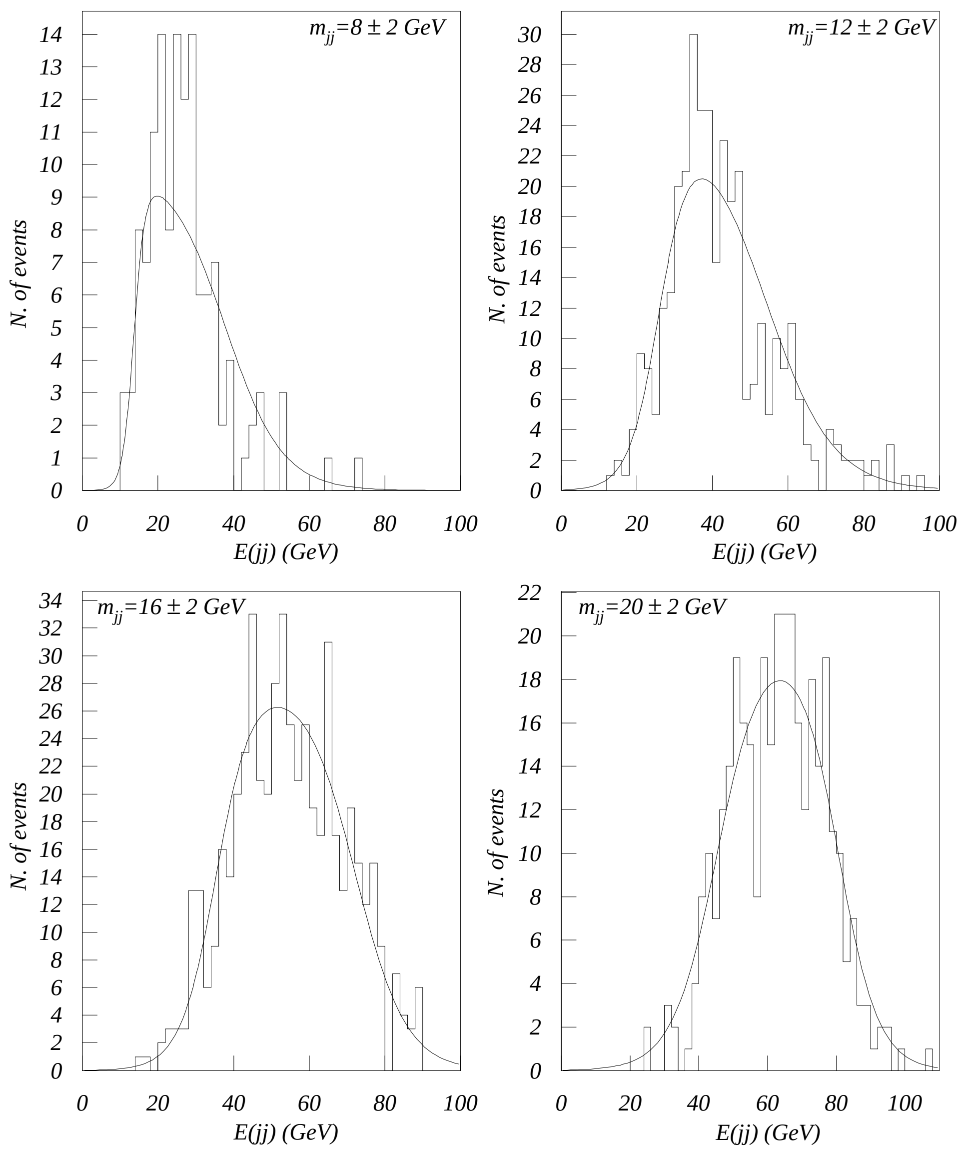
Determination of fundamental parameters:

- $m(jj)$ $vs.$ $E(jj)$



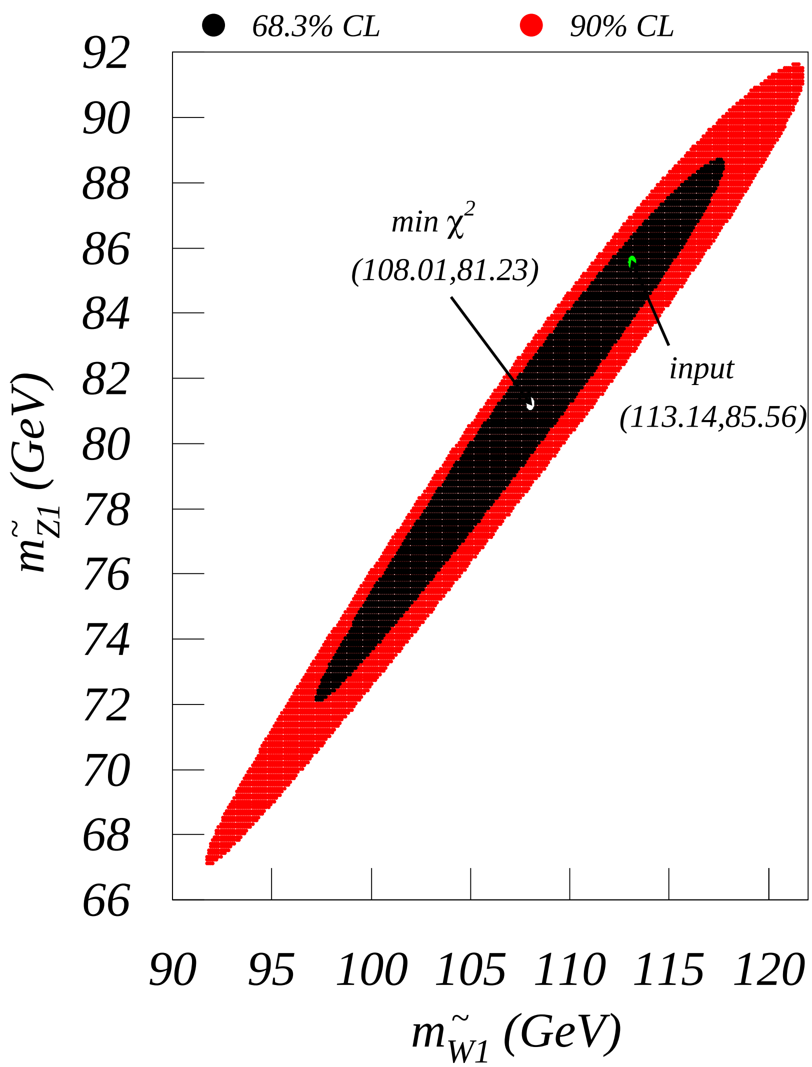
Determination of fundamental parameters:

- $E(jj)$ bins



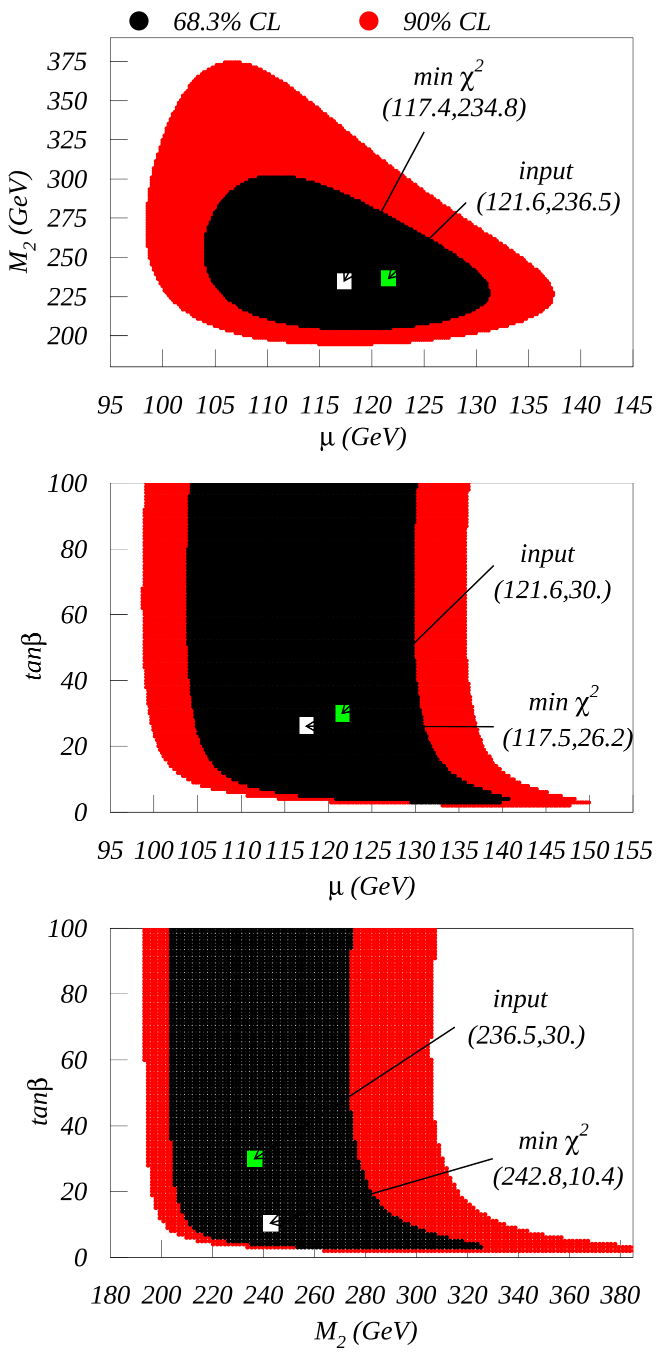
Determination of fundamental parameters:

- $m_{\widetilde{Z}_1}$ $vs.$ $m_{\widetilde{W}_1}$



Determination of fundamental parameters:

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



Motivation for non-universal SUGRA model

- In general SUGRA models, Kähler metric *not* flat
- Even if it is a tree level, universality destroyed by rad. corrections

Motivation from experiment

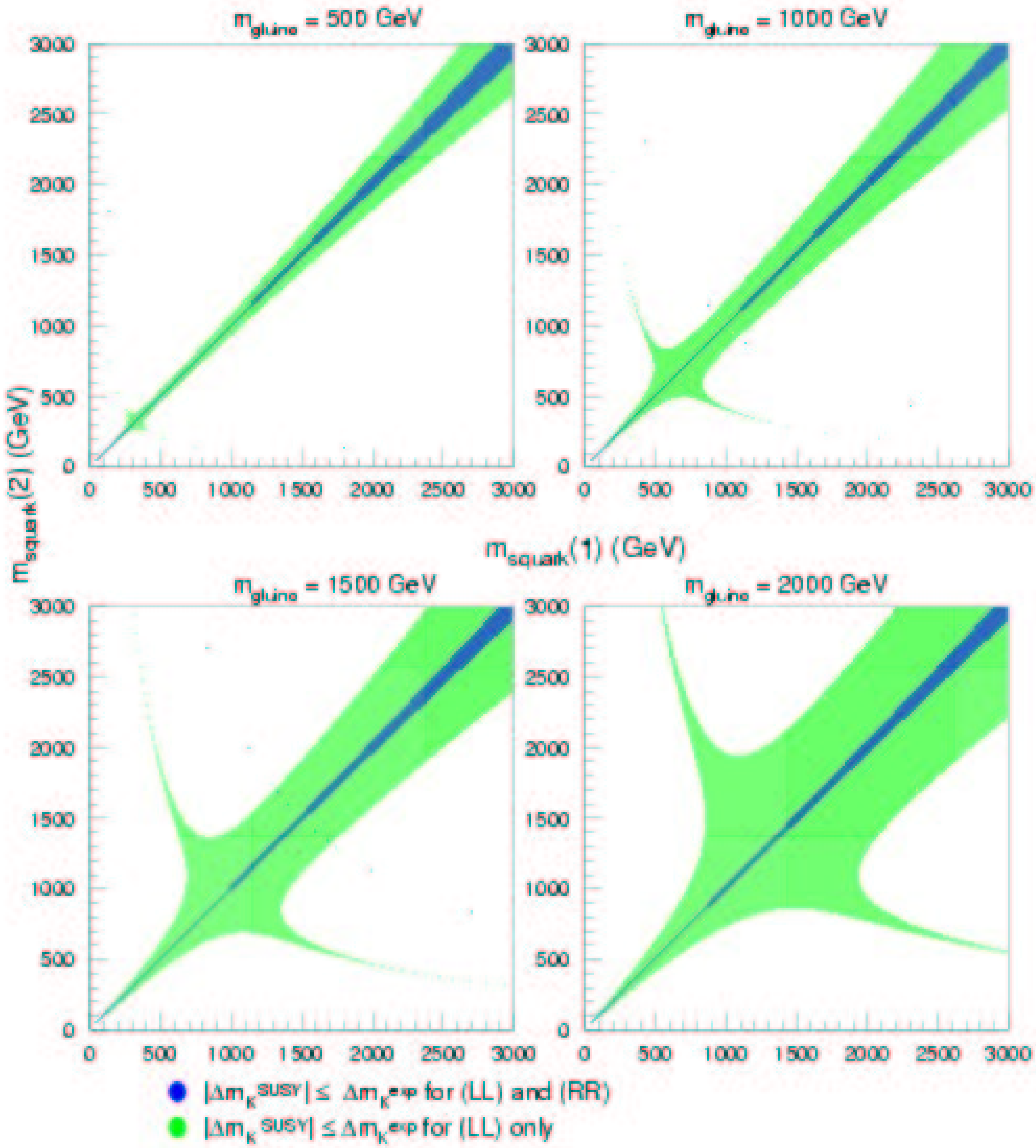
- $BF(b \to s\gamma)$ prefers $m_{\tilde{t}_1} \gtrsim 1$ TeV
- $(g-2)_\mu$ prefers relatively light 2nd ge. sleptons
- must all be consistent with WMAP $\Omega_{\widetilde{Z}_1} h^2$

Enlarge parameter space:

- $m_0(1),\ m_0(3),\ m_H,\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)$
- we take $m_0(1) \simeq m_0(2)$ to satisfy FCNC constraints
- take $m_H \simeq m_0(3)$ (gives best fit)
- (model realized in Allanach et al. model with twisted moduli sector)

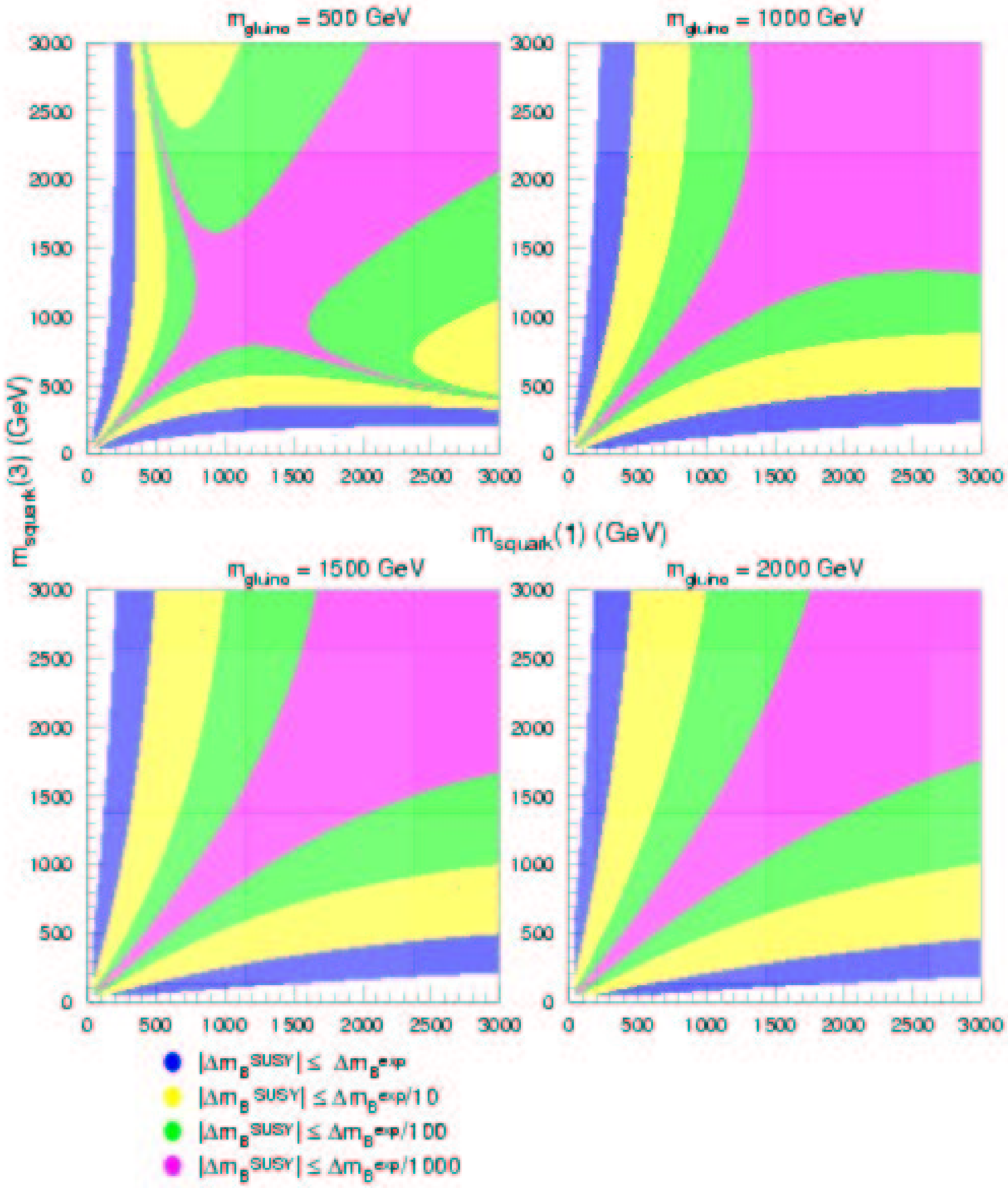
Constraint from Δm_K:

- prefer $m_{\tilde{q}}(1) \simeq m_{\tilde{q}}(2)$



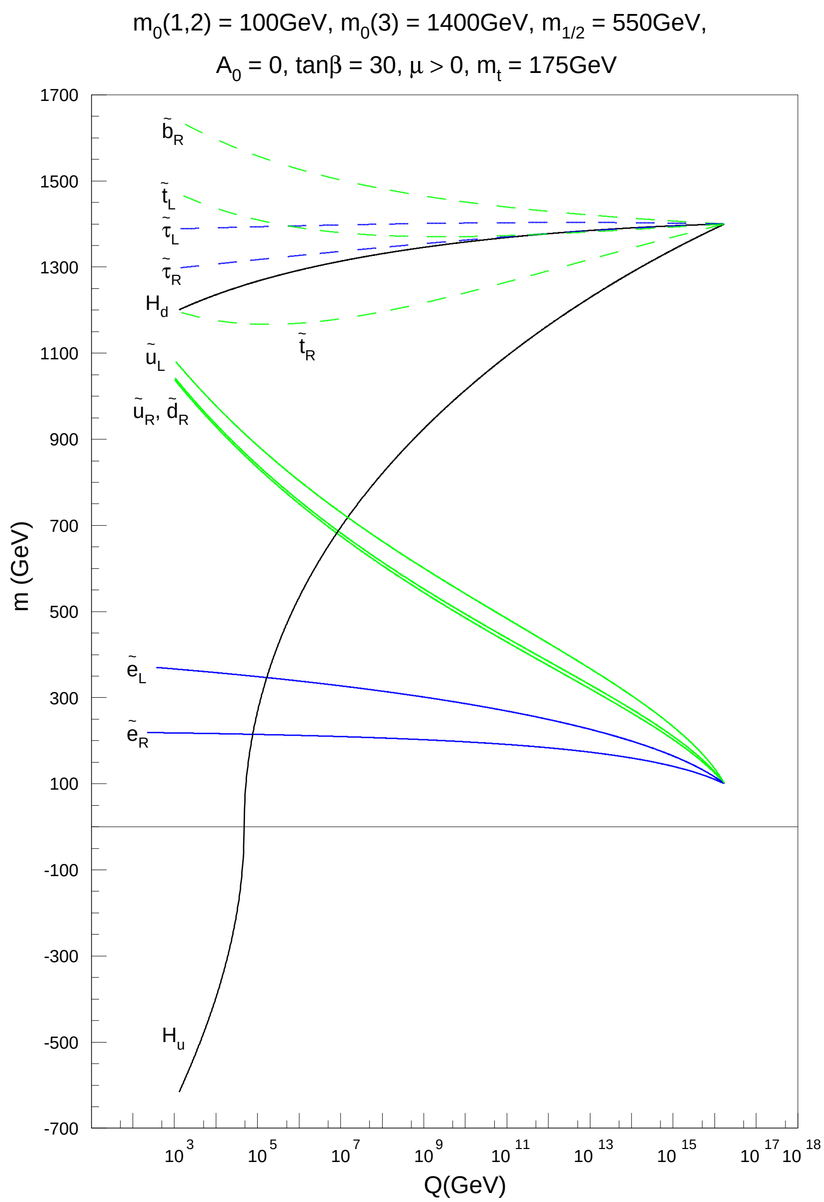
Constraint from Δm_B:

- allow $m_{\tilde{q}}(1) \simeq m_{\tilde{q}}(2) \neq m_{\tilde{q}}(3)$

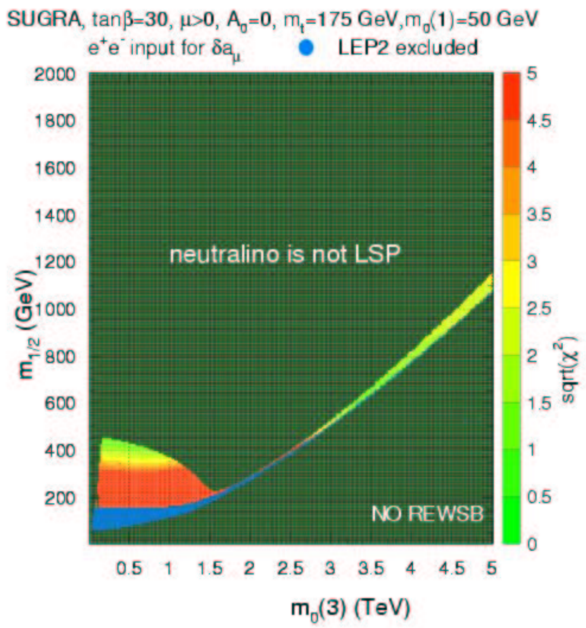


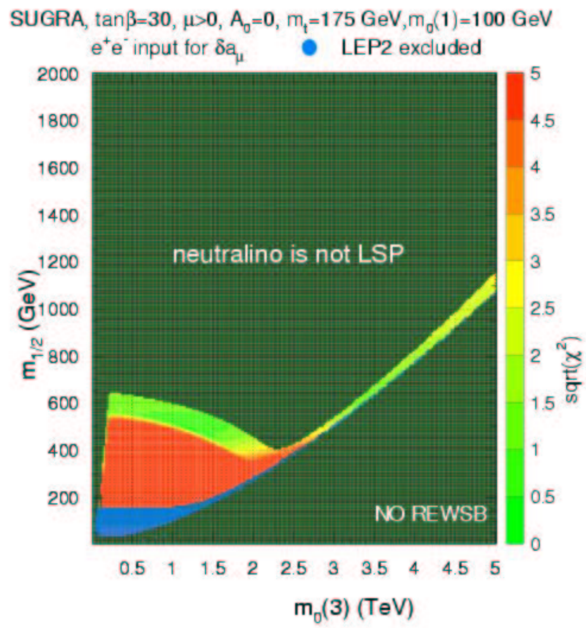
Soft term evolution:

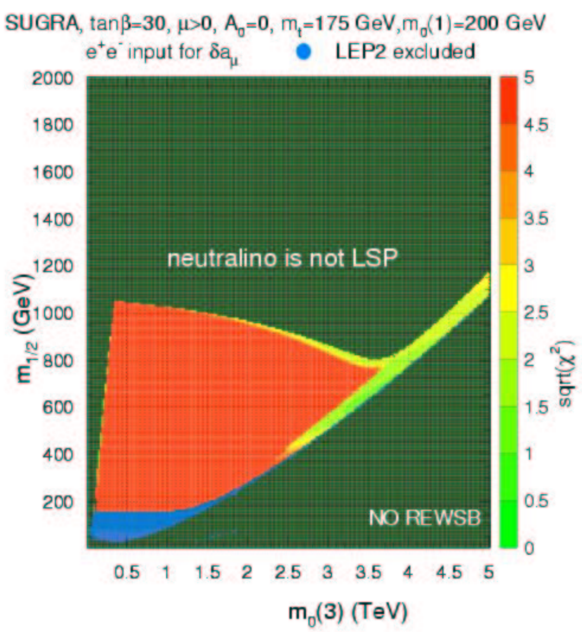
- gives $m_{\tilde{q}}(1) \simeq m_{\tilde{q}}(3)$
- also $m_{\tilde{e}} \simeq m_{\tilde{\mu}} \ll m_{\tilde{\tau}}$



χ^2 for NU SUGRA :







- green: low χ^2/dof
- yellow: medium χ^2/dof
- red: high χ^2/dof

parameter	value (GeV)
M_2	351.1
M_1	184.2
μ	516.9
$m_{\tilde{g}}$	1067.7
$m_{\tilde{u}_L}$	939.8
$m_{\tilde{u}_R}$	910.0
$m_{\tilde{d}_L}$	943.5
$m_{\tilde{d}_R}$	907.1
$m_{\tilde{t}_1}$	1175.1
$m_{\tilde{t}_2}$	1477.5
$m_{\tilde{b}_1}$	1460.0
$m_{\tilde{b}_2}$	1637.1
$m_{\tilde{e}_L}$	319.3
$m_{\tilde{e}_R}$	188.2
$m_{\tilde{\nu}_e}$	295.1
$m_{\tilde{\tau}_1}$	1386.1
$m_{\tilde{\tau}_2}$	1475.4
$m_{\tilde{\nu}_\tau}$	1468.5
$m_{\widetilde{W}_1}$	348.2
$m_{\widetilde{W}_2}$	542.4
$m_{\widetilde{Z}_1}$	179.4
$m_{\widetilde{Z}_2}$	347.2
m_A	1379.3
m_h	118.4
$\Omega_{\widetilde{Z}_1}h^2$	0.115
$BF(b \to s\gamma)$	3.52×10^{-4}
Δa_μ	35.1×10^{-10}

Masses and parameters in GeV units for $m_0(3),\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu) =$ 1500 GeV, 450 GeV, 0, 30, $+1$ in the NMH SUGRA model. We also take $m_H = m_0(3)$ and $m_0(1) = 100$ GeV. The spectrum is obtained using ISAJET v7.69.

Conclusions

- Constraints on mSUGRA (esp. WMAP)
  - "bulk" region dis-favored
  - stau co-annihilation strip
  - HB/FP region at large m_0
  - A-annihilation funnel
- reach of 0.5-1 TeV LC
  - see stau co-ann. region for $\tan\beta \lesssim 30$
  - see HB/FP region *beyond* LHC capability!
  - see part of A-annihilation funnel (LHC can see $\sim$ all)
- determination of μ, M_2 possible in (lower) HB/FP region
- non-universal SUGRA motivated by $BF(b \to s\gamma)$, $(g-2)_\mu$
- generically gives light sleptons; accessible to LC!