Long-lived Charginos in the MSSM Focus-point Region

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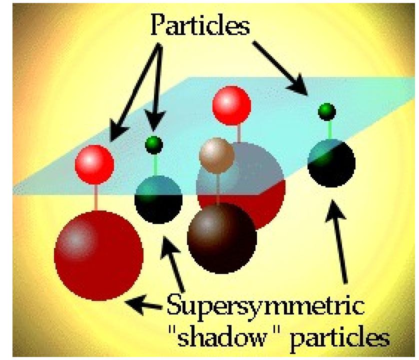
Long-lived Charginos in the MSSM Focus-point Region

- The MSSM
- Available Regions of mSUGRA Parameters Space
- Long-lived Charginos
- Phenomenology of light chargino scenario
- Conclusions

The MSSM



- Supersymmetric generalization of the SM based on fundamental symmetries.
- Two Higgs multiplets are required.
- The field content of this self-consistent theory, contain a super-partners for each SM matter field.
- Provides dark matter candidates and proposes an evidence of the existence of degenerate states (Long-lived sparticles).
- LEP2 puts limits on masses of super-partners, so; the light higgs boson is >114 GeV.
- Soft SUSY breaking in the MSSM involve four scenarios, one of them is the gravity mediation or mSUGRA..

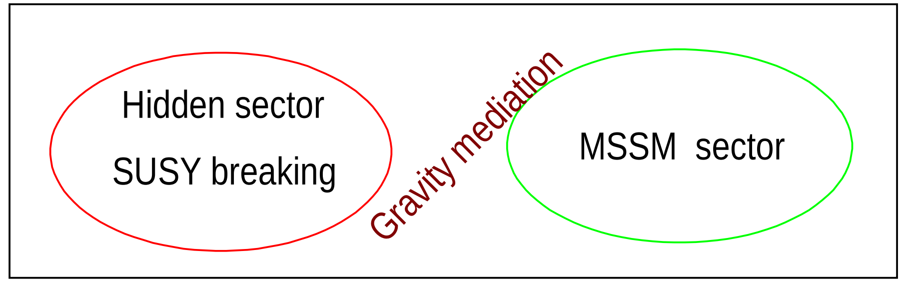
Particle	**Super-partner**
e,ν,u,d	$\tilde{e},\tilde{\nu},\tilde{u},\tilde{d}$
	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^{\pm},$
γ,W,Z,h	$\tilde{\chi}_1^0 \cdots \tilde{\chi}_4^0$

$$m_{\tilde{l}} > 100\ {}^{\mathrm{GeV}}\!/_{\mathrm{c}^2}$$

$$m_{\tilde{\chi}_1^0} > 43\ {}^{\mathrm{GeV}}\!/_{\mathrm{c}^2},\ m_{\tilde{\chi}_1^{\pm}} > 104\ {}^{\mathrm{GeV}}\!/_{\mathrm{c}^2}$$

$$m_{\tilde{g}\,\tilde{q}} > 195(300)\ {}^{\mathrm{GeV}}\!/_{\mathrm{c}^2}$$

The MSSM



- SUSY is not a exact symmetry of the nature,it must be broken.
- Supersymmetry is broken in the hidden sector by soft breaking terms of dimension < 4 and communicate with visible sector by gravity mediation.
- Universality hypothesis is postulated.
- The effective low energy theory resulting contain explicity soft breaking terms

$$L^{SUSY}_{SOFT} = -\frac{1}{M_P} F_X \sum_a \frac{1}{2} f_a \lambda^\alpha \lambda^\alpha + c.c. \leftarrow M_a \lambda^\alpha \lambda^\alpha$$

gaugino mass terms

$$-\frac{1}{M_P^2} F_X^* F_X K'^I_J \phi^{*J} \phi_I \leftarrow m^2 \phi^* \phi$$

2

*scalar **(mass)**^{2} **terms***

$$-\frac{1}{M_P^2} F_X \left(\frac{1}{6} y'^{ijk} \phi_i \phi_j \phi_k + \frac{1}{2} \mu'^{ij} \phi_i \phi_j\right) + c.c. \leftarrow A\phi^3 + B\phi^2$$

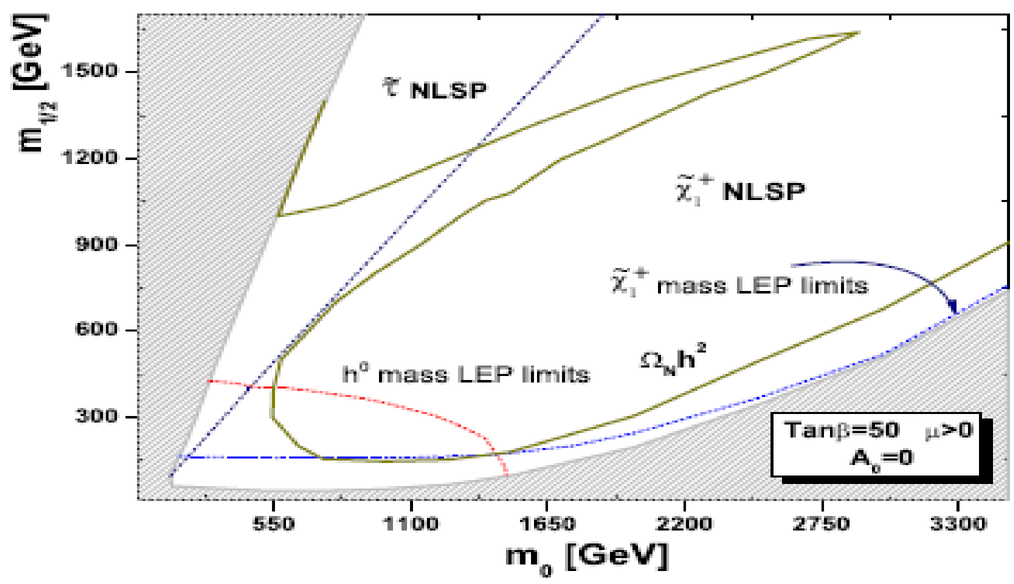
bilinear and trilinear couplings

Available Regions of mSUGRA Parameters Space

- Now, we only get a set of 4+1 free parameters space.

  [m_0, $m_{1/2}$, A_0, sign(μ), tan(β)]

- The role of A_0, μ , tan(β) is related to other parameters.
- So, we have only two fundamental parameters (m_0, $m_{1/2}$).
- Fixing, A_0, sign(μ) , tan(β) and varying (m_0, $m_{1/2}$), we can get regions in mSUGRA parameters space in where all experimental constraint are fulfilled.
- Available regions
  - bulk region
  - co-annihilations regions
  - funnel region
  - focus point region



Long-lived Charginos

- In mSUGRA model, the R-parity conserving neutralino becomes the LSP. In this case the NLSP is chargino.
- The chargino mass matrix reads

$$M^{(c)} = \begin{pmatrix} M_2 & \sqrt{2}M_W \sin\beta \\ \sqrt{2}M_W \cos\beta & \mu \end{pmatrix}$$

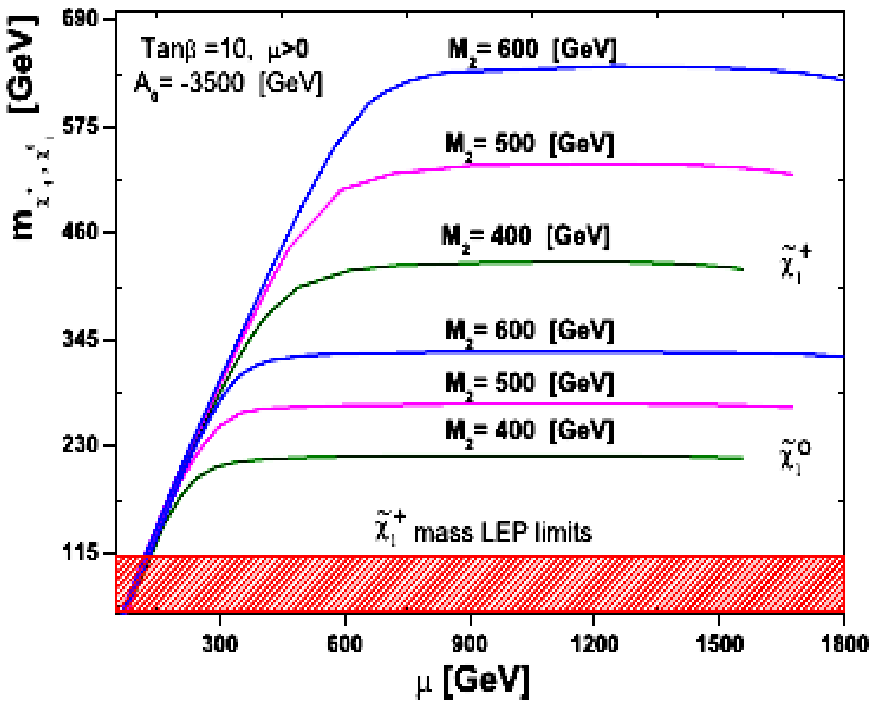
- The masses of the two physical states is obtained by diagonalization

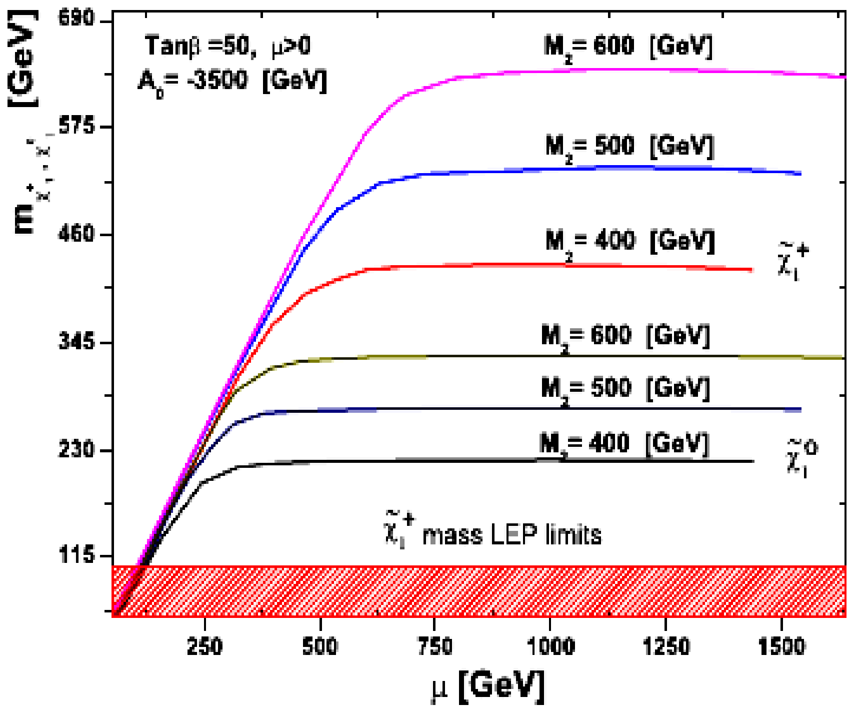
$$\begin{aligned} M_{1,2}^2 &= \frac{1}{2}\Big[M_2^2 + \mu^2 + 2M_W^2 \\ &\mp \sqrt{(M_2^2 - \mu^2)^2 + 4M_W^4\cos^2 2\beta + 4M_W^2(M_2^2 + \mu^2 + 2M_2\mu\sin 2\beta)}\Big] \end{aligned}$$

- Radiative corrections are known in the leading order, and typically they are of the order of a few percent.

Long-lived Charginos

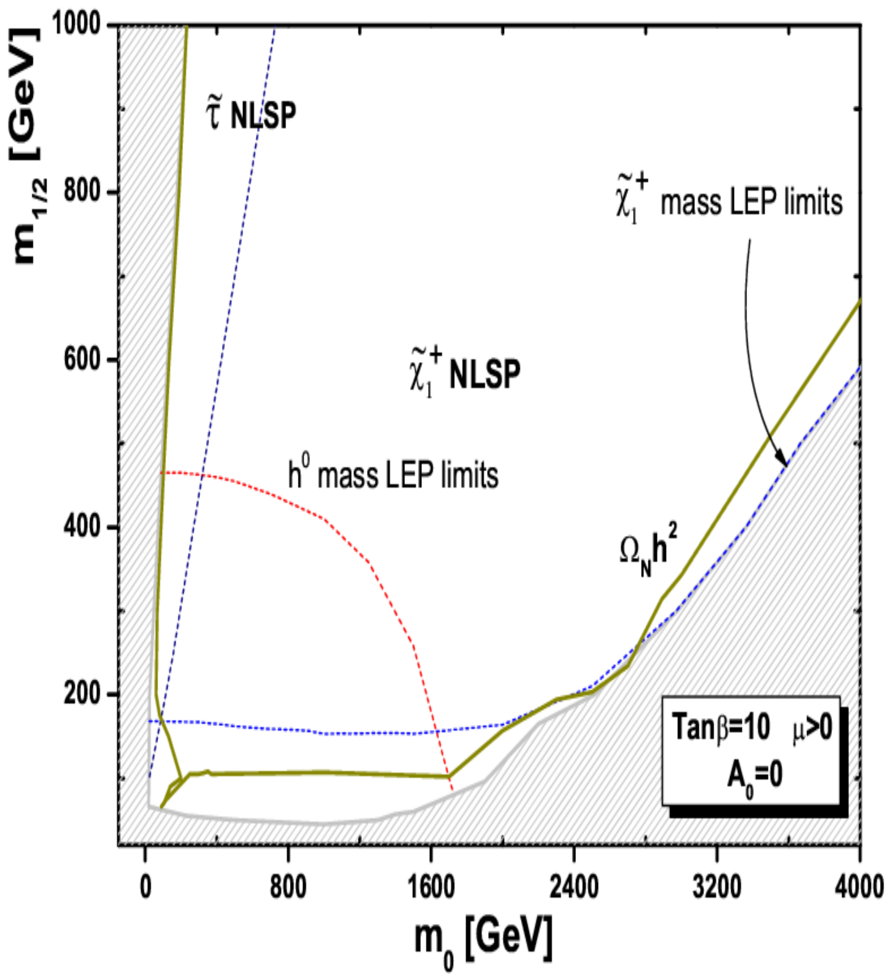
- In case when μ is small (less than M_Z), which takes place near the border line of radiative EWSB, the lightest chargino χ^{+}_{1} and two lightest neutralinos ($\chi^{0}_{1,2}$) are almost degenerate and have a mass of the order of μ.





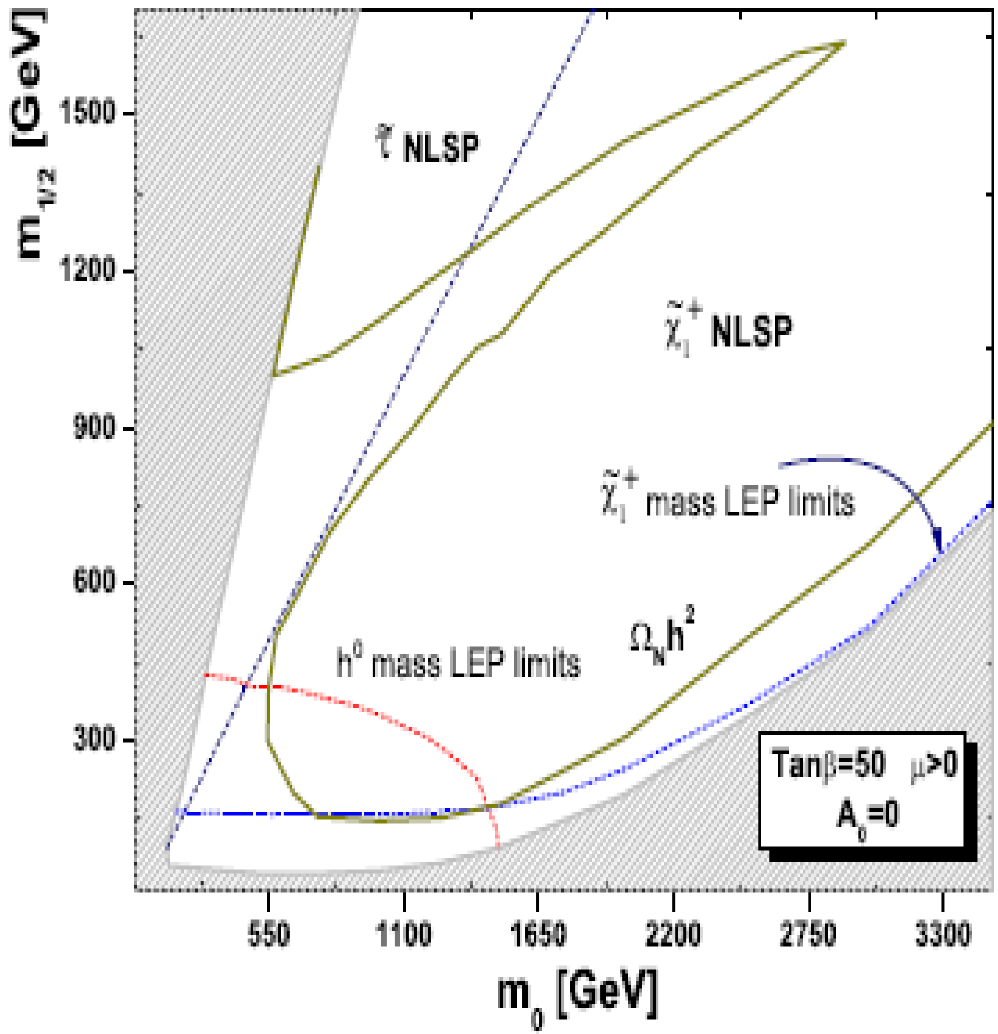
Long-lived Charginos

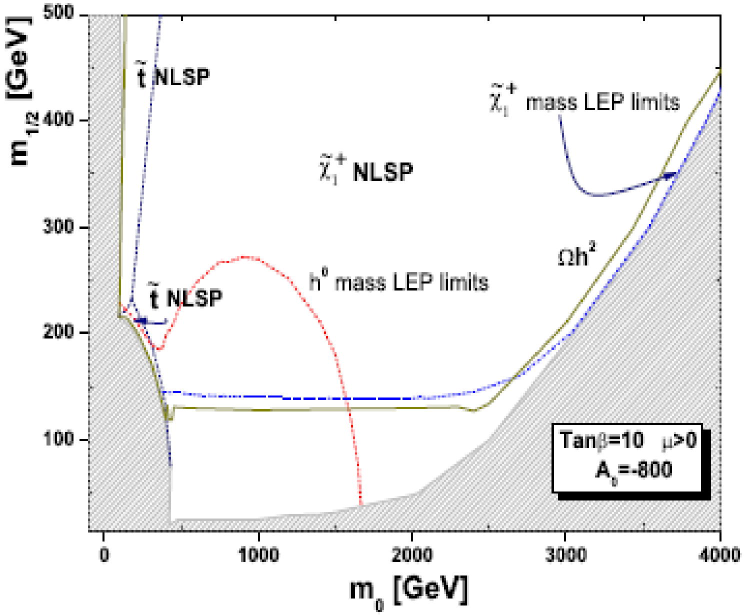
- The degeneracy takes place for any choice of the other parameters since tree level formulae weakly depend on them and corrections are small.
- However, since the value of μ is not arbitrary but taken from the EWSB requirement, one has to find the region where it is small. The region is known as a focus-point region



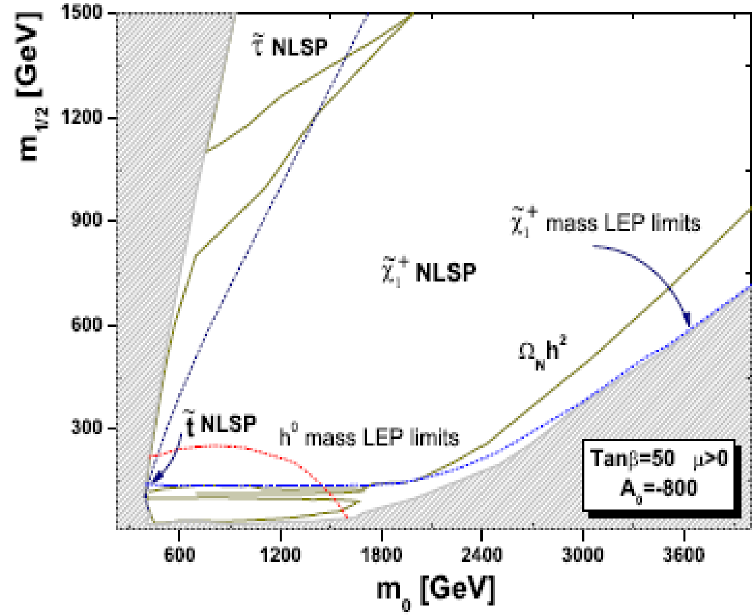
Long-lived Charginos

- Typically $m_{1/2} << m_0$.
- All constraint are satisfied in this region.
- In the case of almost degenerate NLSPs and LSP, when calculating the relic density one has to take into account co-annihilation of charginos $\chi^{\pm}$ and neutralinos χ^0
- For small values of A_0 the DM line does not go along the EWSB border but deviates from it, thus not allowing the small values of μ.

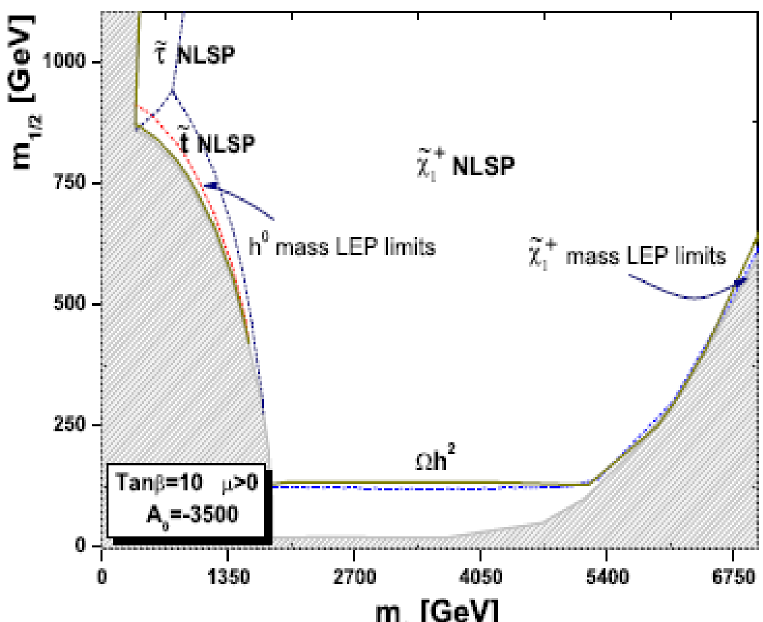




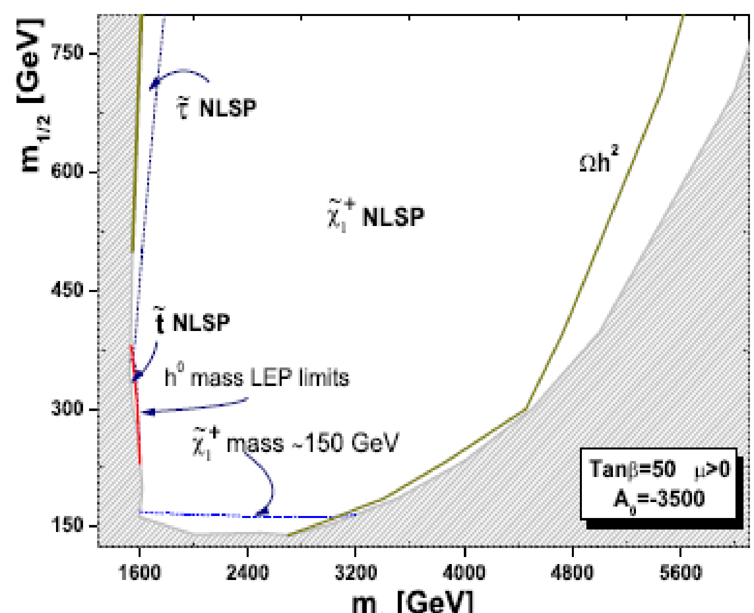
m_{1/2} [GeV]
m_0 [GeV]
t̃ NLSP
χ̃₁⁺ mass LEP limits
χ̃₁⁺ NLSP
Ωh²
h⁰ mass LEP limits
t̃ NLSP
Tanβ=10 μ>0
A_0=-800



m_{1/2} [GeV]
m_0 [GeV]
τ̃ NLSP
χ̃₁⁺ mass LEP limits
χ̃₁⁺ NLSP
Ω_N h²
t̃ NLSP
h⁰ mass LEP limits
Tanβ=50 μ>0
A_0=-800



m_{1/2} [GeV]
m_0 [GeV]
τ̃ NLSP
t̃ NLSP
χ̃₁⁺ NLSP
h⁰ mass LEP limits
χ̃₁⁺ mass LEP limits
Ωh²
Tanβ=10 μ>0
A_0=-3500



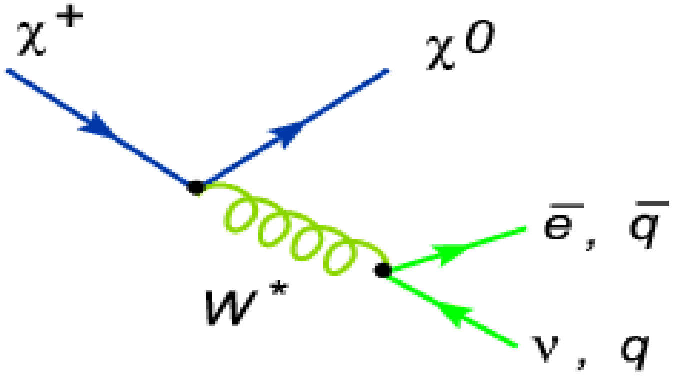
m_{1/2} [GeV]
m_0 [GeV]
τ̃ NLSP
Ωh²
χ̃₁⁺ NLSP
t̃ NLSP
h⁰ mass LEP limits
χ̃₁⁺ mass ~150 GeV
Tanβ=50 μ>0
A_0=-3500

Long-lived Charginos

- For large negative A_0, these lines almost coincide. Changing $\tan\beta$ one can reach smaller values of m_0 and $m_{1/2}$, thus allowing the other particles to be lighter without changing the chargino mass.
- It should be mentioned that the region near the EWSB border line is very sensitive to the SM parameters; a minor shift in α_s or m_t and m_b leads to noticeable change of spectrum
- Notice that though the region of small μ looks very fine-tuned and indeed is very sensitive to all input parameters, still in the whole four dimensional parameter space (assuming universality) it swaps up a wide area and can be easily reached
- The accuracy of fine-tuning defines the accuracy of degeneracy of the masses and, hence, the life time of the NLSP

Phenomenology of light chargino scenario

- Whence the parameters are chosen in such a way that one has mass degeneracy between the lightest chargino and the lightest neutralino one has a long-lived NLSP.
- The main decay process are



- The branching ratio for quarks final states is 74% and for leptons final states is 26%.

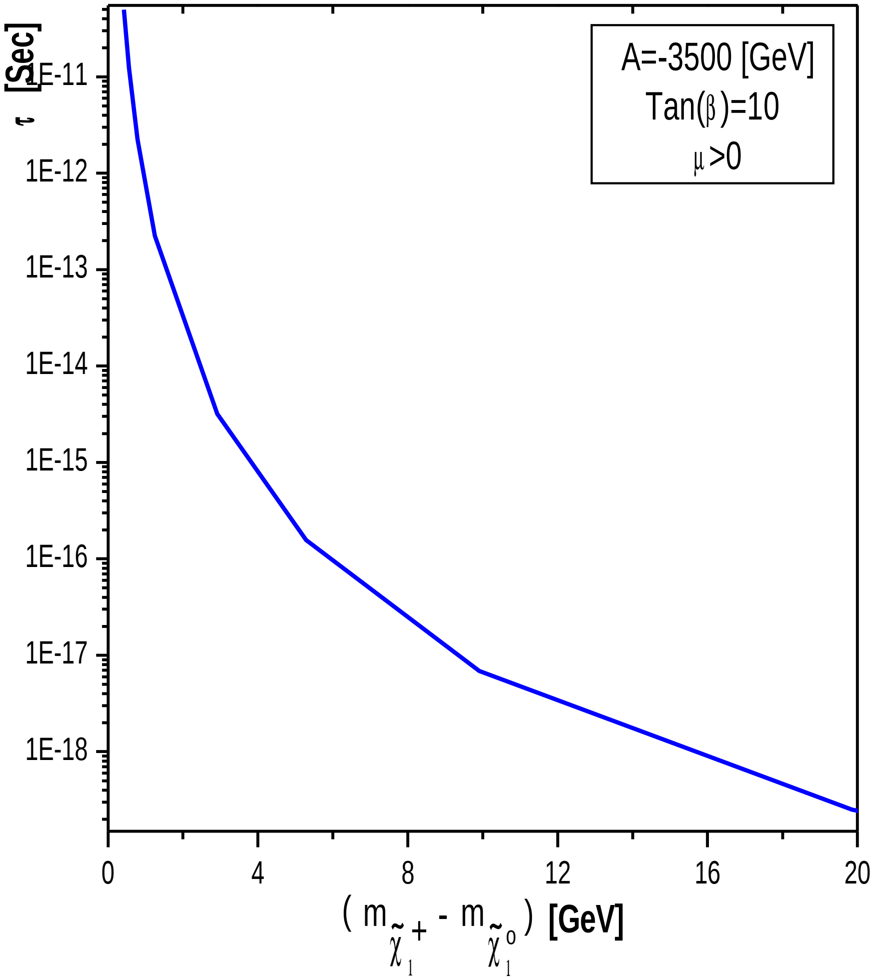
Lifetime of chargino

- Chargino lifetimes for different values of A_0, and tan().
- Large degeneracy correspond to $\tilde{\chi}_1^+ \to W^+ \tilde{\chi}_1^\circ$ mode

$$\tilde{\chi}_1^+ \to qq\, \tilde{\chi}_1^\circ$$

- The biggest lifetime corresponds to $\tilde{\chi}_1^+ \to l\, \nu_l\, \tilde{\chi}_1^\circ$

And decay



Lifetime of chargino

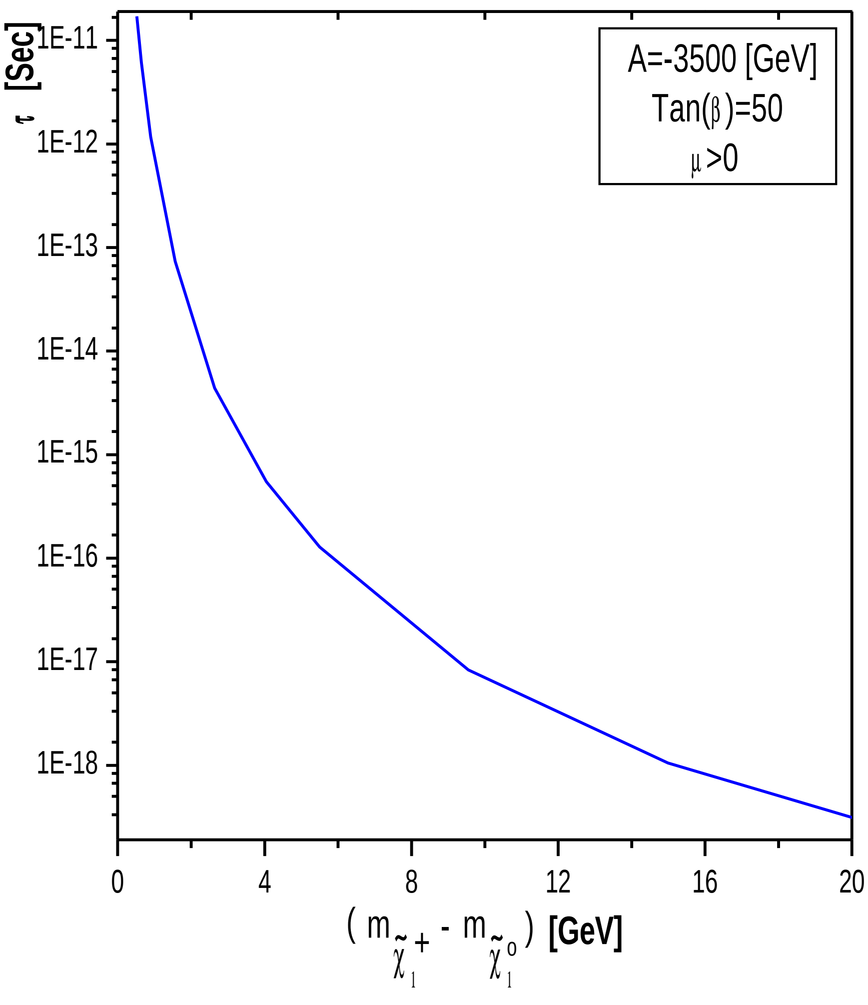
- The lifetime crucially depends on the mass difference between

  the chargino and neutralino

- one can see that the lifetime falls down rapidly from the EWSB line.

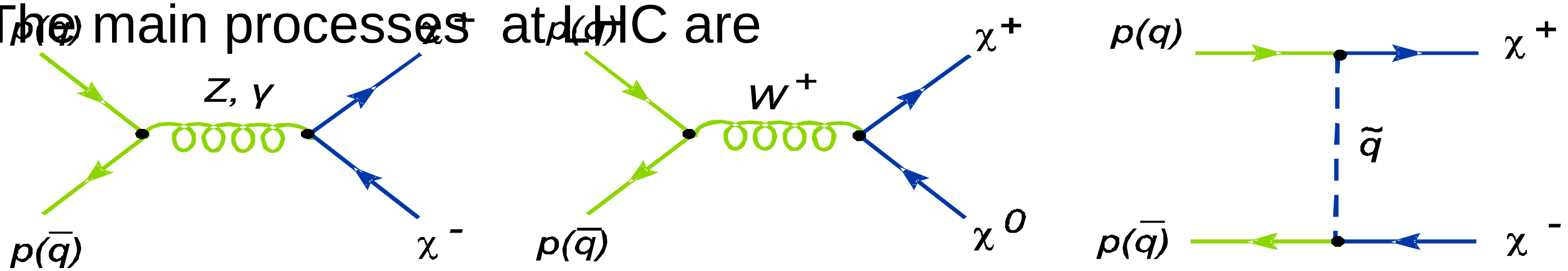
- to get a life-time around of 10^{-9} seconds in order to have a free pass of the order of cm one needs the degeneracy of

  less than 1 GeV.



Production of Long-Lived charginos at LHC

- Long-lived charginos can be produce at LHC
- The main processes at LHC are



- Since three states are almost degenerate one has also co-production which has to be taken into account. This refers also to the annihilation process that defines the amount of the Dark matter.
- To calculate the production rate one has to know the spectrum of the light states and the mixings in chargino-neutralino sector..
- Here, the NLSP chargino and the LSP neutralinos are almost pure higgsinos. This property defines the preferences in the interaction pattern.

Production of Long-Lived charginos at LHC

- We choose several benchmark points in mSUGRA parameter space and calculated the cross section numerically.

mSUGRA	$\tan\beta = 30$		
Benchmark Scenarios	m_0	$m_{1/2}$	A_0
a	3000	510	0
b	3500	507	-800
c	4000	489	-1500
d	5000	540	-2500
e	6000	585	-3500

- on average the cross-sections reach a few tenth of pb and vary with the factor of two with the change of A_0, and tan(□) .

Production of Long-Lived charginos at LHC

Process	a	b	c	d	e
	$pp \to \widetilde{\chi}_1^+ \widetilde{\chi}_1^-$				
$\overline{u}u \to \widetilde{\chi}_1^+ \widetilde{\chi}_1^-$	0.72	0.66	0.40	0.20	0.16
$\overline{d}d \to \widetilde{\chi}_1^+ \widetilde{\chi}_1^-$	0.30	0.30	0.16	0.08	0.07
$\sigma_{p_1}(Pb)$	1.02	0.96	0.56	0.28	0.23
	$pp \to \widetilde{\chi}_1^+ \widetilde{\chi}_1^0$				
$u\overline{d} \to \widetilde{\chi}_1^+ \widetilde{\chi}_1^0$	1.24	1.18	0.66	0.32	0.26
$\sigma_{p_2}(Pb)$	1.24	1.18	0.66	0.32	0.26
	$pp \to \widetilde{\chi}_1^+ \widetilde{\chi}_2^0$				
$u\overline{d} \to \widetilde{\chi}_1^+ \widetilde{\chi}_2^0$	0.88	0.82	0.50	0.26	0.22
$\sigma_{p_3}(Pb)$	0.88	0.84	0.50	0.26	0.22

Conclusions

- In mSUGRA, i,e, the MSSM with supergravity inspired breaking terms, it is possible to get long-lived chargino which might be produced at LHC.
- The cross section mostly depends on the masses and mixing and in the chosen region.
- The light chargino NLSP scenarios require large negative values of the trilinear SUSY breaking parameters A_0.
- Long-lived charginos might produce secondary vertex.
- In other scenarios, such as the gauge mediated susy breaking GMSB the situation is different due to the fact that lifetime of the NLSP is typically much larger.