Joint LHC-ILC Studies: Electroweakino Scan

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Contents

- Introduction
- LHC & LEP limits
- Simulation Tools
- Analysis strategy: LHC and ILC
- Results
- Summary and outlook

◉ Gauginos and Higgsinos
- Neutral ones: Bino, Wino, $\tilde{H}_u^0$, $\tilde{H}_d^0$
- charged ones: Winos, $\tilde{H}_u^+$, $\tilde{H}_d^-$

◉ Parameters: M_1, M_2, μ, $\tan\beta$

→

Electroweakinos

◉ Neutralinos and charginos

Introduction

Motivation and theoretical background:

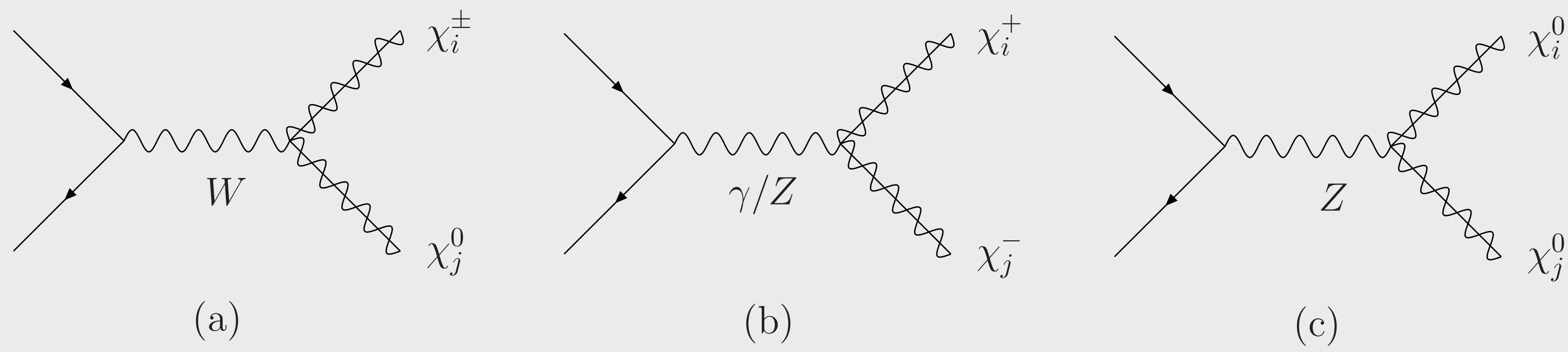
See previous talk by Shufang Su!

Goal: To explore the **LHC/ILC** reach in the MSSM electroweak sector with a comprehensive **scan in M_1, M_2 and mu.** Study prospects of **discovery/exclusion** reach of both LHC/ILC for electroweakino direct production.

Assumptions in the scan:

- Decouple the squark and slepton sectors
- Impose Higgs mass constraint
- Enforce LEP limits
- Avoid small mass splittings (n.b. loop-corrections)
- Explore properties related to on-shell and off-shell decays via **W/Z/h bosons**

Electroweakino Direct Production



For LHC:

$$p\overline{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\, X,\ \tilde{\chi}_1^{+}\tilde{\chi}_1^{-}\, X,\ \ldots$$

For ILC:

$$e^+e^- \to \tilde{\chi}_1^{+}\tilde{\chi}_1^{-},\ \tilde{\chi}_2^{+}\tilde{\chi}_2^{-},\ \tilde{\chi}_1^{0}\tilde{\chi}_2^{0},\ \ldots$$

Decays:

$$\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0$$

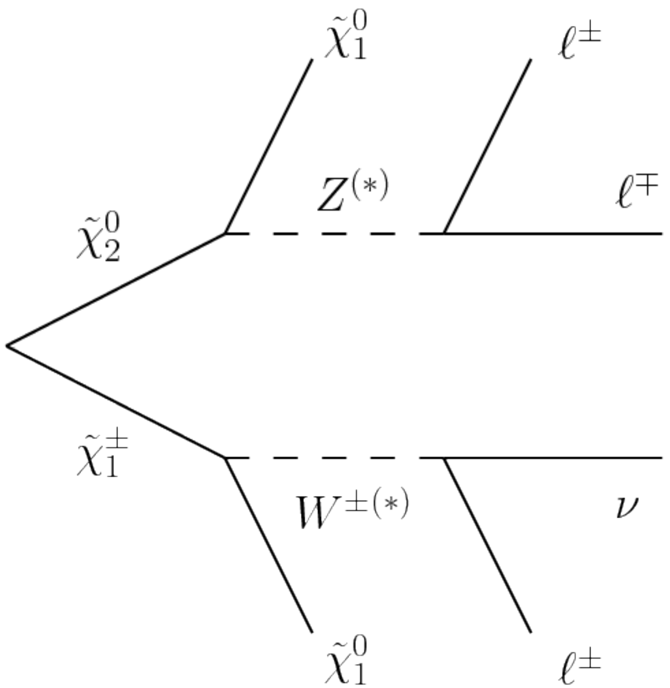
$$\tilde{\chi}_2^{0} \to (Z/h)\tilde{\chi}_1^0$$

$$\ldots$$

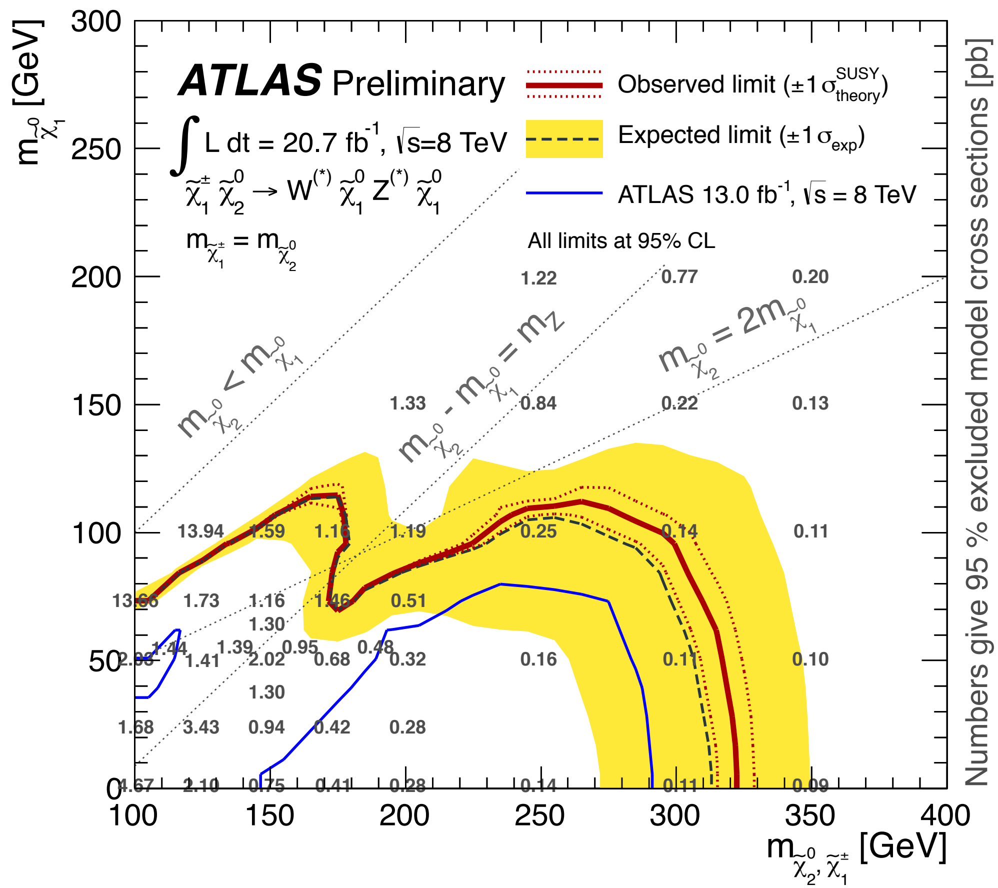
Higgs!

LHC limits

Simplified model:
$\tilde{\chi}_1^0$ is bino, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ are wino and degenerate



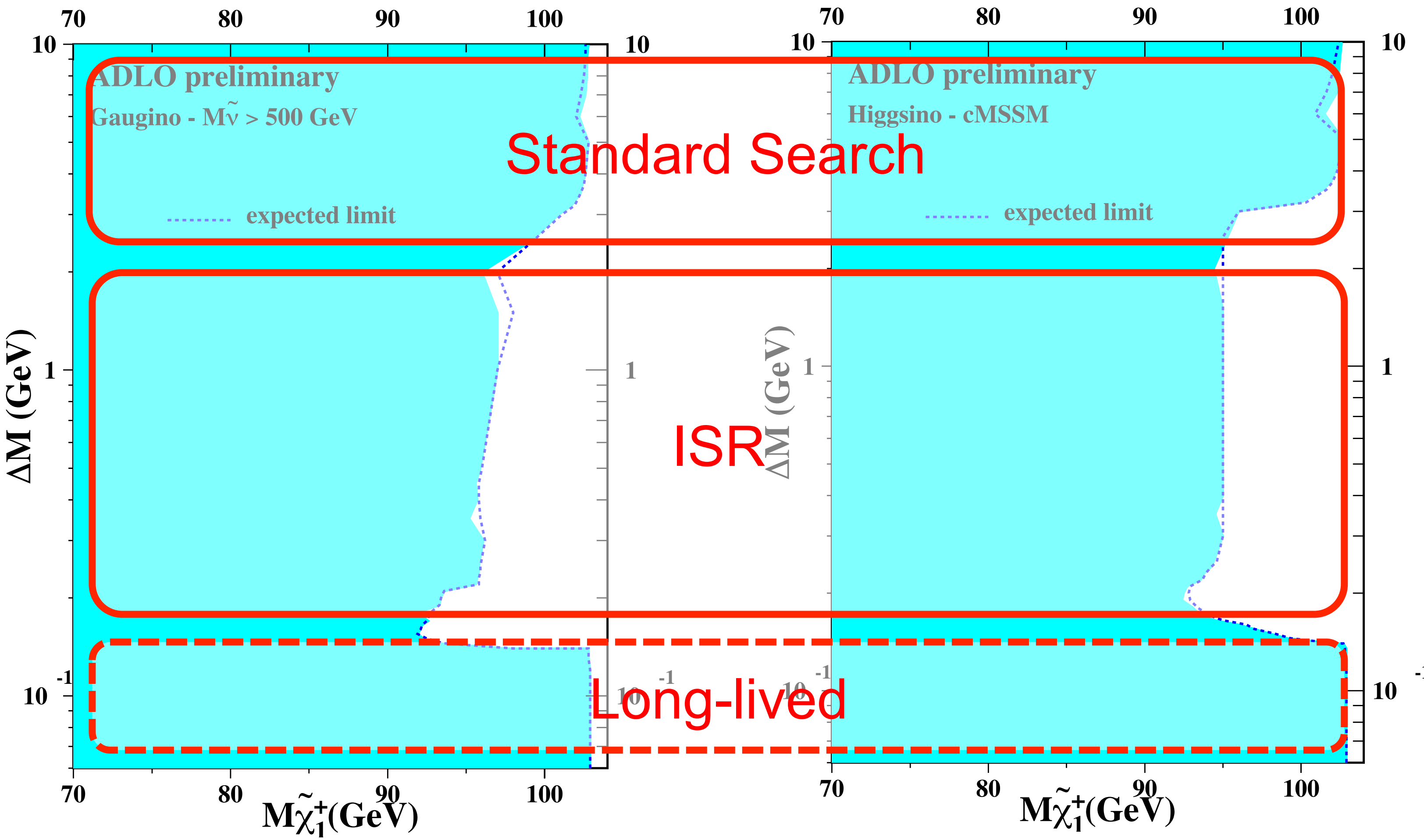
3 leptons + MET



ATLAS-CONF-2013-035

<u>100% BR into W/Z assumed</u>

LEP limits



Gaugino **Higgsino**

Simulation Tools

For LHC:

Delphes fast simulation – See plenary talk by Sanjay Padhi!

For ILC:

Simulation à Grande Vitesse (SGV): Covariant matrix machine

- Event generation & simulation on-the-fly
- Particle flow calorimetry treatment

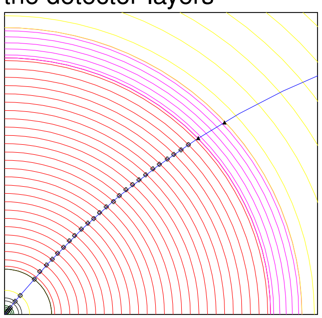
M. Berggren, ECFA LC2013

SGV | Tracker simulation

SGV: How tracking works

SGV is a machine to calculate covariance matrices

Follow track-helix through the detector-layers



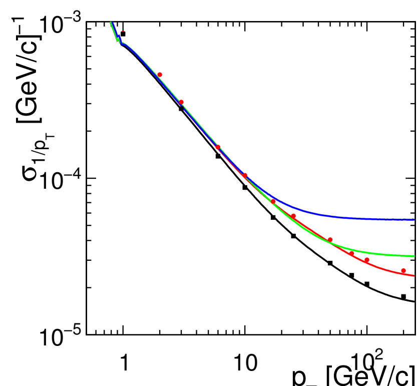
(Fringe benefit of stepping: EM-interactions in detector layers simulated)

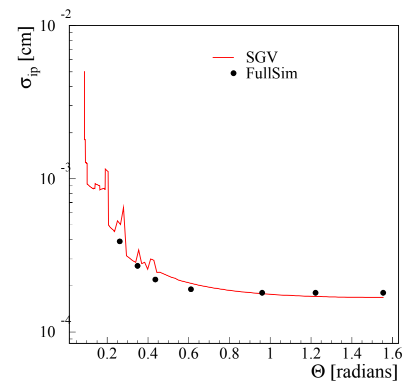
- Calculate cov. mat. at perigee, including material, measurement errors and extrapolation.
- Smear perigee parameters (Choleski decomposition: takes all correlations into account)
- Helix *parameters* exactly calculated, *errors* with one approximation: helix moved to (0,0,0) for this.
- Other stuff:
  - Plug-ins for particle identification, track-finding efficiencies,...
  - Information on hits accessible to analysis.

Mikael Berggren (DESY-HH) | SGV | ECFA LC, May 2013 | 4 / 12

SGV | Tracker simulation

SGV and FullSim: P_T and D_0 resolution





Lines: SGV, dots: Mokka+Marlin

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Energy and Luminosity

LHC:

- $\sqrt{s}$ = 14 TeV
- Integrated Luminosity = (t.b.d)

ILC:

- $\sqrt{s}$ = 500 GeV
- Integrated Luminosity = 500 fb^{-1}
- Beam polarization P(e+,e-) = (+0.3,-0.8)

Scan parameters

Common parameter ranges are used in the scan.

	M1	M2	mu
Bino LSP	100 GeV **(LSP)**	140-980 GeV in 40 GeV steps	150-1000 GeV in 50 GeV steps
Wino LSP	150-1000 GeV in 50 GeV steps	100 GeV **(LSP)**	140-980 GeV in 40 GeV steps
Higgsino LSP	150-1000 GeV in 50 GeV steps	140-980 GeV in 40 GeV steps	100 GeV **(LSP)**

Search strategy

Assume prompt electroweakino decays.

For LHC:

- Trigger on visible decay products
- Explore final states: WW, WZ, $\mathbf{Wh}$, ZZ, Zh, hh
  - e.g. Wh channel: 1 lepton + jets + MET

For ILC:

- For mass differences >= 30 GeV:
  - **4 jets + missing 4-momentum**
- For small mass differences:
  - **ISR photon + few soft particles**

LHC: *Wh* channel (1)

Reconstruct ***Wh*** with ***W→lν*** and ***h→bb***

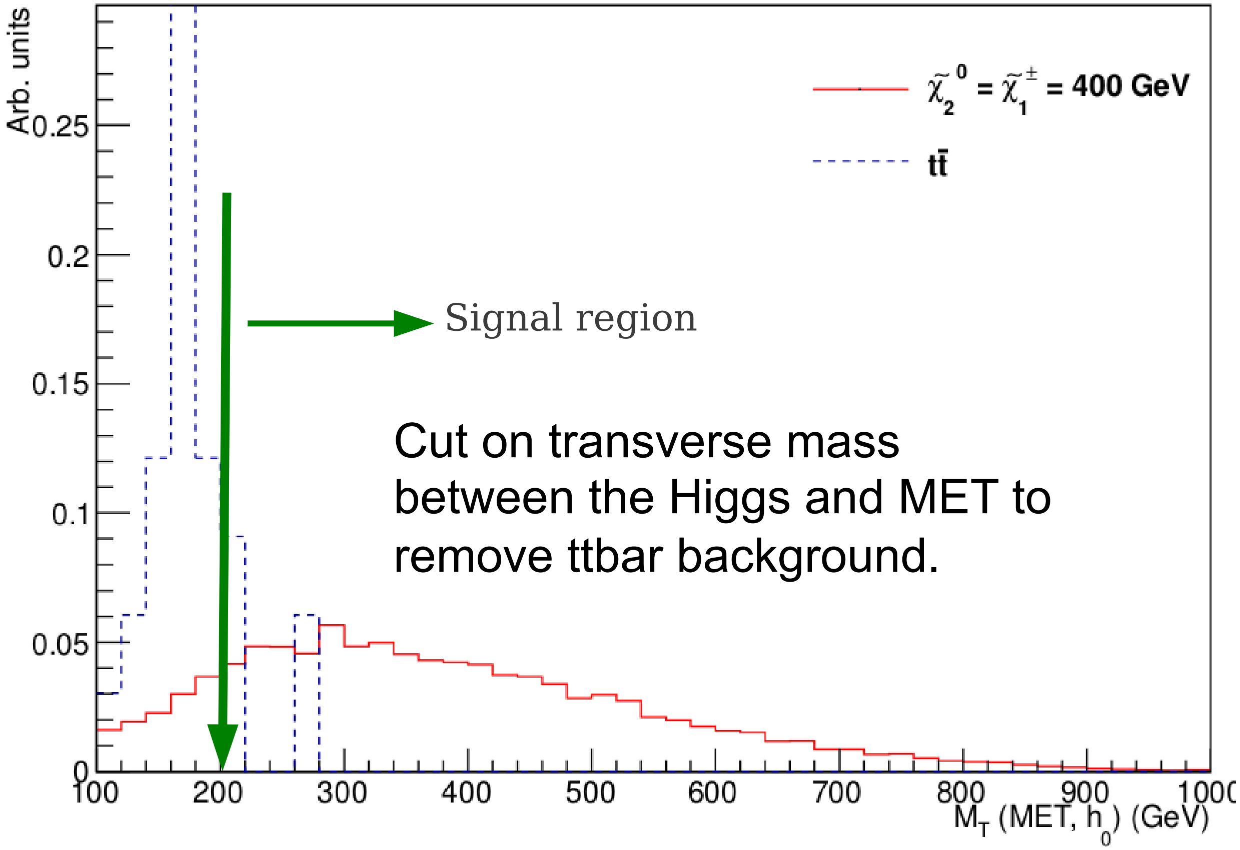
◉ Wh channel: 1l+jets + MET

- Isolated e(μ), Pt > 30(20) GeV, |eta| < 2.5
- Veto any additional e/μ with Pt > 10 GeV, |eta| < 2.5
- Veto any Taus or isolated Tracks
- 2 Jets Pt > 30 GeV, |eta| < 2.5
- Veto 3rd Jet with Pt > 20 GeV
- 2 bjets with Pt > 30 GeV, |eta| < 2.5
- 2 bjets in one hemi-sphere ←
- Invariant mass of two bjets 100 < M_{bb} (GeV) < 140
- MT (MET and the Higgs) > 200 GeV
- MET > 50 GeV

Signal regions:

(MT, MET) > (200, 50), (600, 50), (200, 100), (600,100) GeV

LHC: *Wh* channel (2)

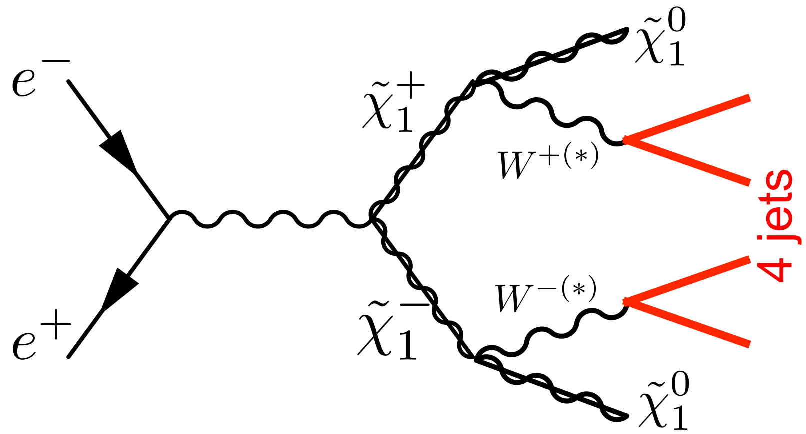


Sensitivity to large electroweakino masses

- Expected lower limit ~250 GeV for **LHC14, 10 fb^{-1}**

Result of **other channels** will be combined (*work in progress…*)

ILC: 4 jets + missing 4-momentum



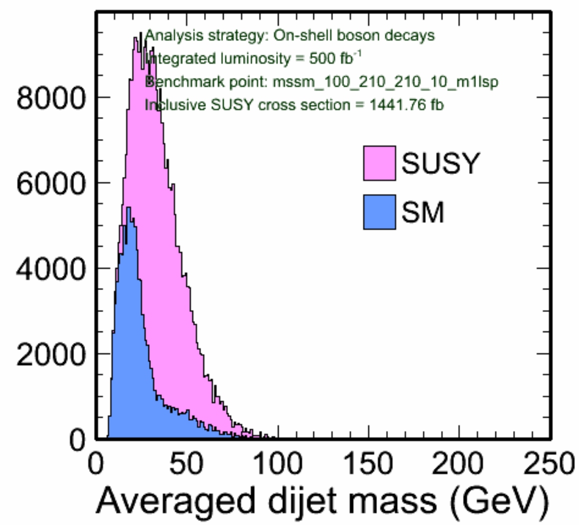
General strategy:
Reconstruct the hadronic decay of the chargino: **4 jets + missing 4-momentum** signature.

Choose jet combination most consistent with the same dijet mass.

Event selection based on:

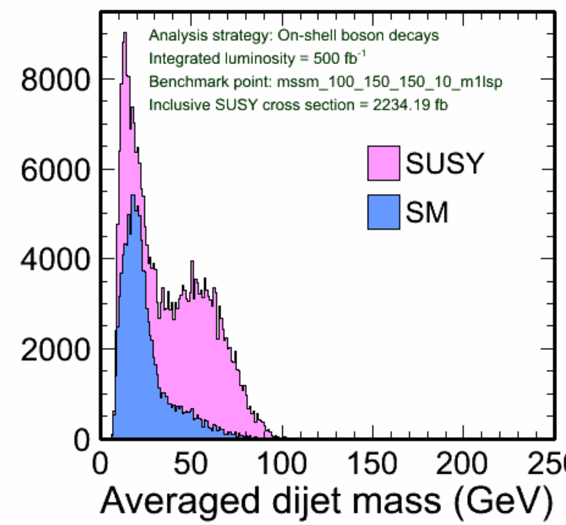
- Number of particles
- Large missing energy
- Missing momentum ***not*** along the beam pipe
- Require minimum jet energy
- Jet finder transition values

Inclusive SUSY signal is well reconstructed for mass differences > 25 GeV.



$$M_{\tilde{\chi}_1^0} = 90.9 \text{ GeV}$$

$$M_{\tilde{\chi}_1^\pm} = 165.9 \text{ GeV}$$

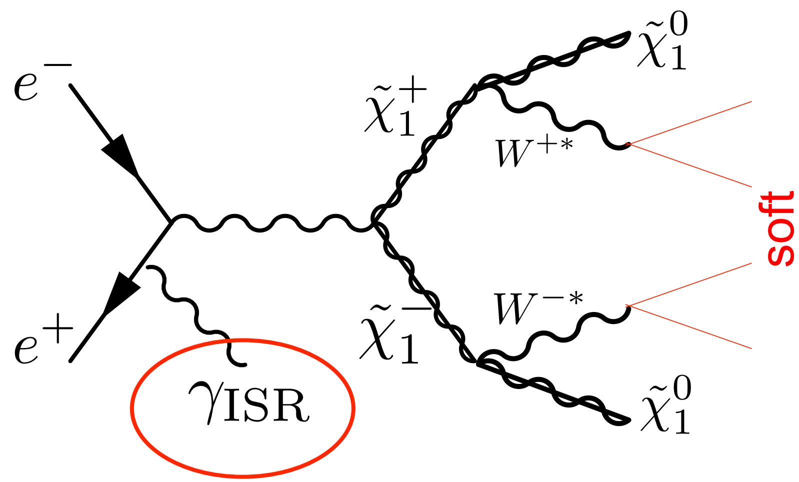


$$M_{\tilde{\chi}_1^0} = 77.8 \text{ GeV}$$

$$M_{\tilde{\chi}_1^\pm} = 105.5 \text{ GeV}$$

$$M_{\tilde{\chi}_2^\pm} = 226.5 \text{ GeV}$$

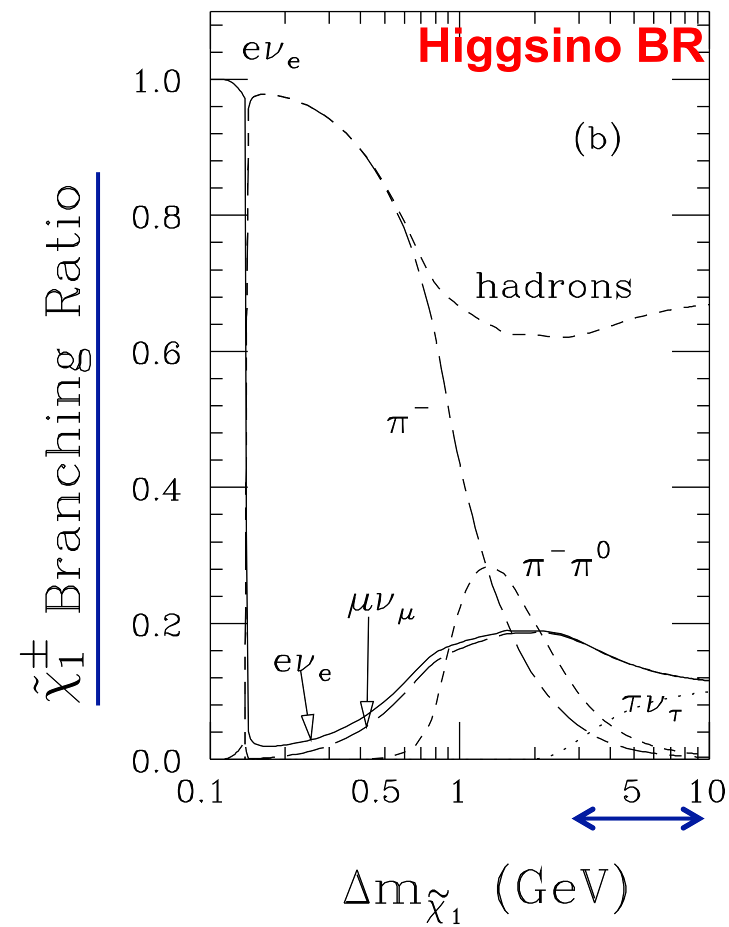
ILC: ISR photon + soft particles



The **ISR tag** is critical in reducing γγ backgrounds by kicking the **hard forward electrons** into detector acceptance.

For the soft particles:
Choose "semileptonic" signature:
lepton on one side + pions on the other side.

(*Analysis in progress…*)

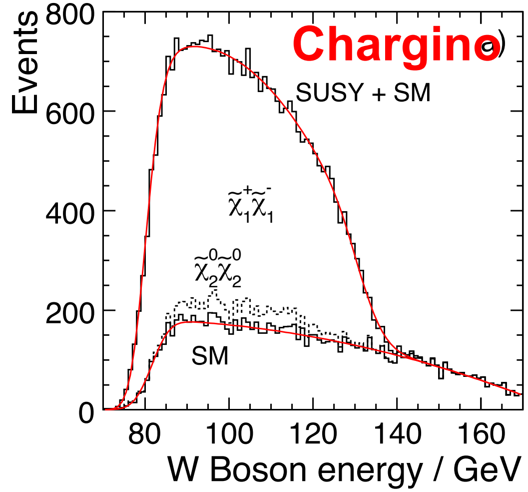


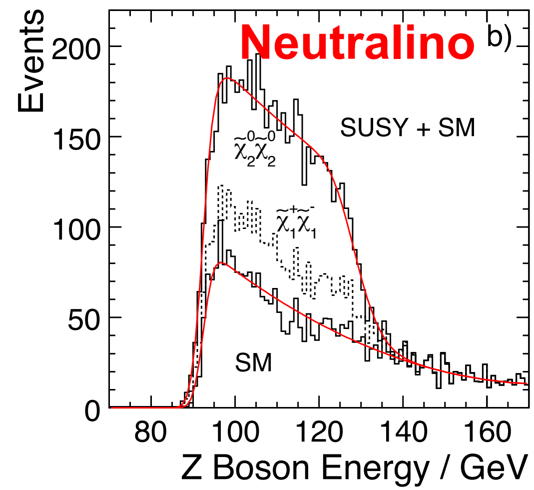
Chen, Drees, Gunion
[arXiv:hep-ph/9902309]

ILC: Mass resolutions

4 jets + missing 4-mom.

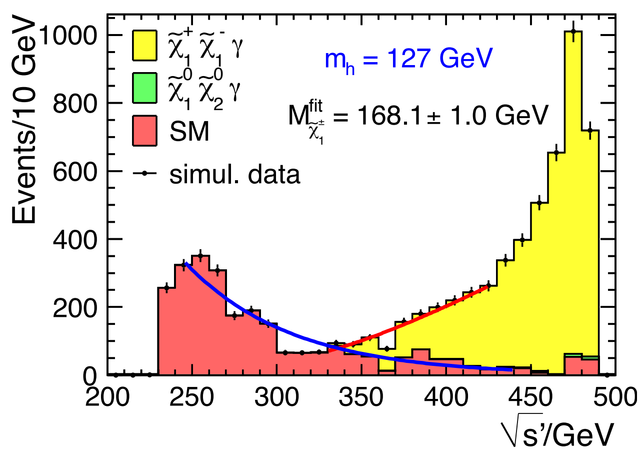
List, Suehara [arXiv:0906.5508]

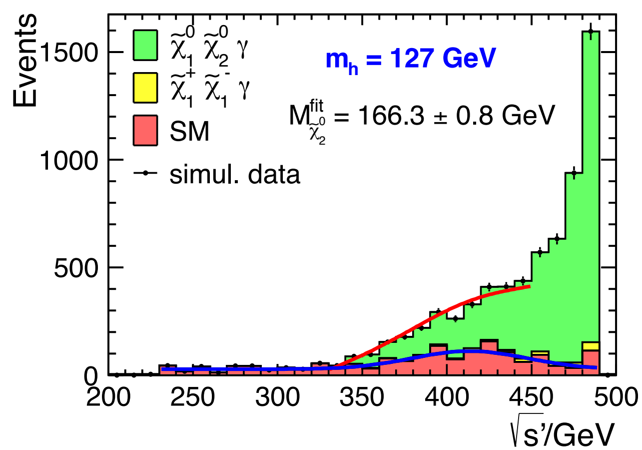




ISR + soft particles

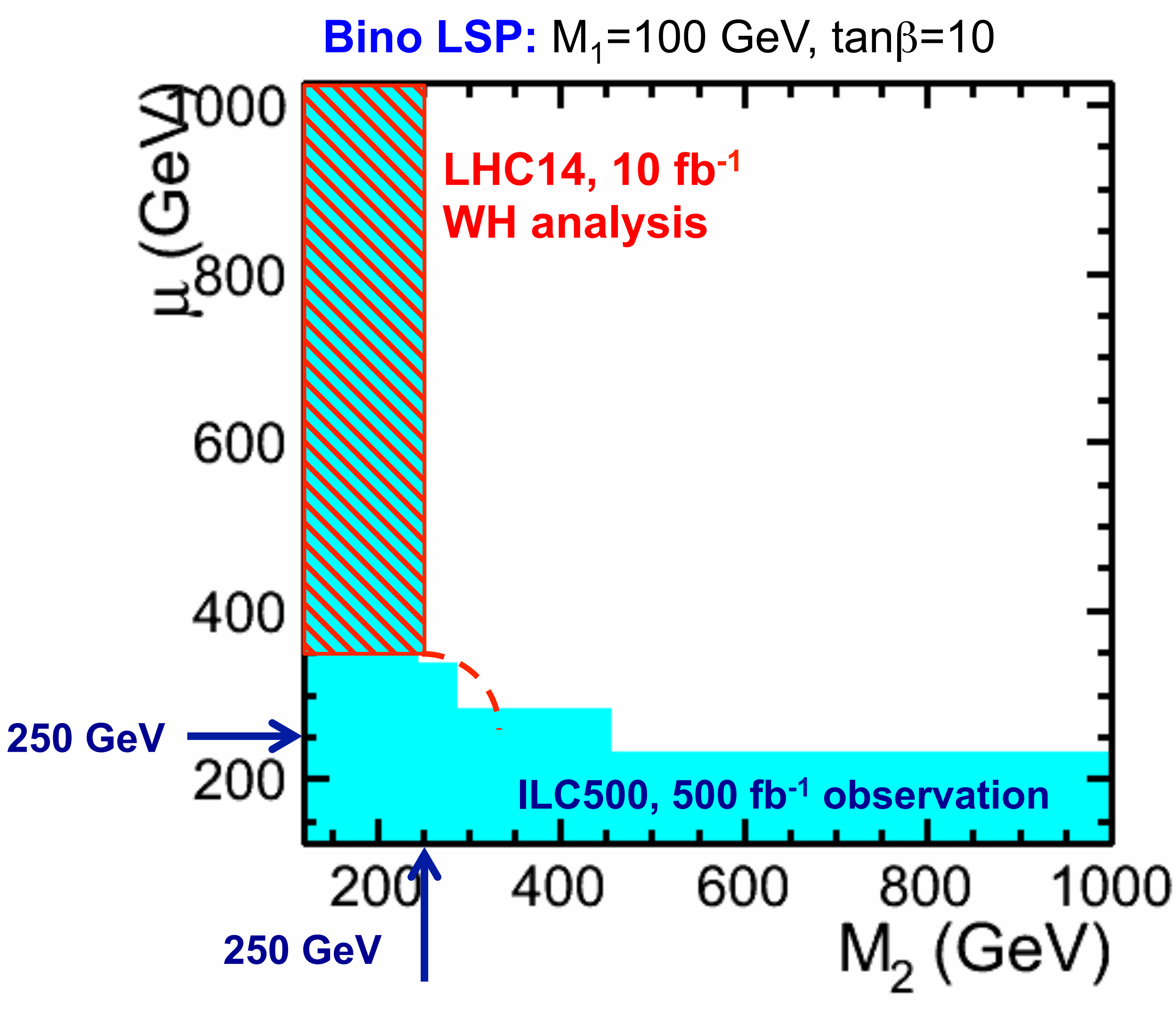
Berggren, Brümmer, List, Moortgat-Pick, Robens, Rolbiecki, Sert [To appear]





→ Typical mass resolutions O(1)%

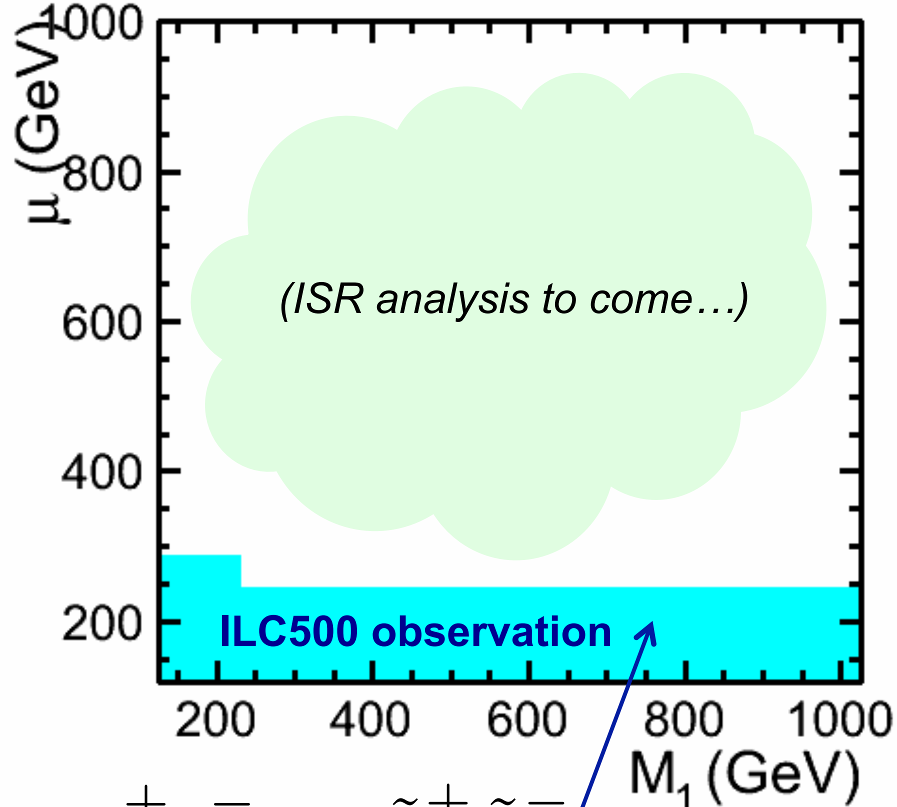
Results (1)



ILC: Need NLSP in kinematic range, limits up to half the CM energy.
LHC: reach will be extended by

Results (2)

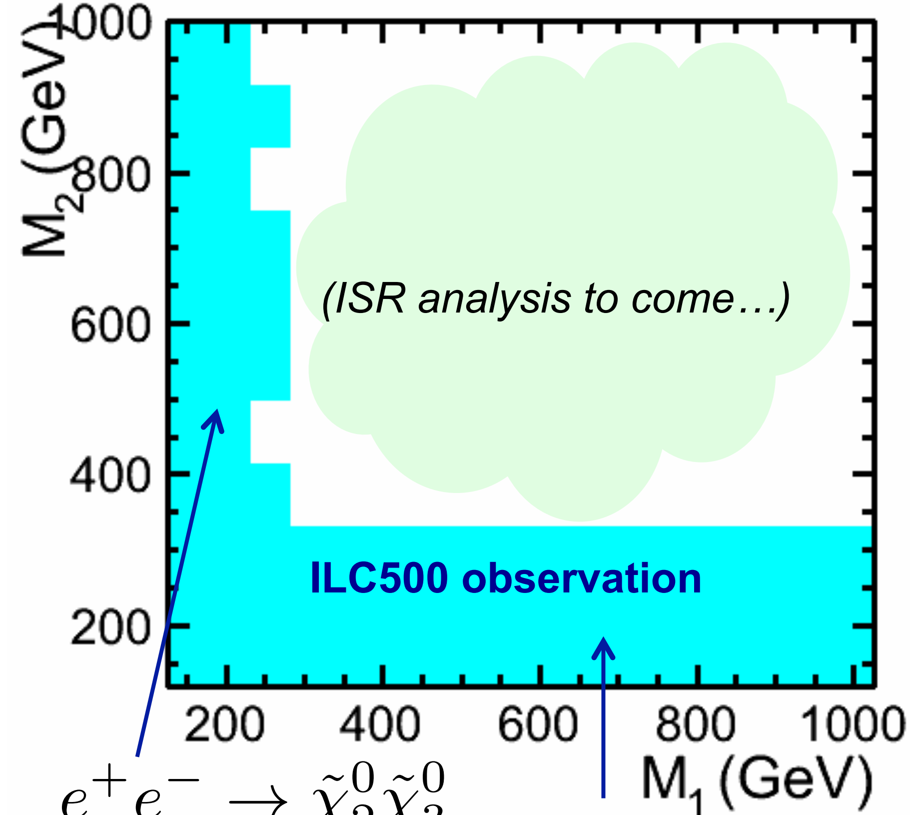
Wino LSP: M_2=100 GeV, tanβ=10



$$e^+e^- \rightarrow \tilde{\chi}_2^+\tilde{\chi}_2^-$$

LSP and NLSP are nearly degenerate for large mu.

Higgsino LSP, mu=100 GeV, tanβ=10



$$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_3^0$$

$$e^+e^- \rightarrow \tilde{\chi}_1^\pm\tilde{\chi}_2^\mp$$

LSP and NLSP are nearly degenerate for large M_1 & M_2

ISR analysis should be sensitive for both cases.

Summary and outlook

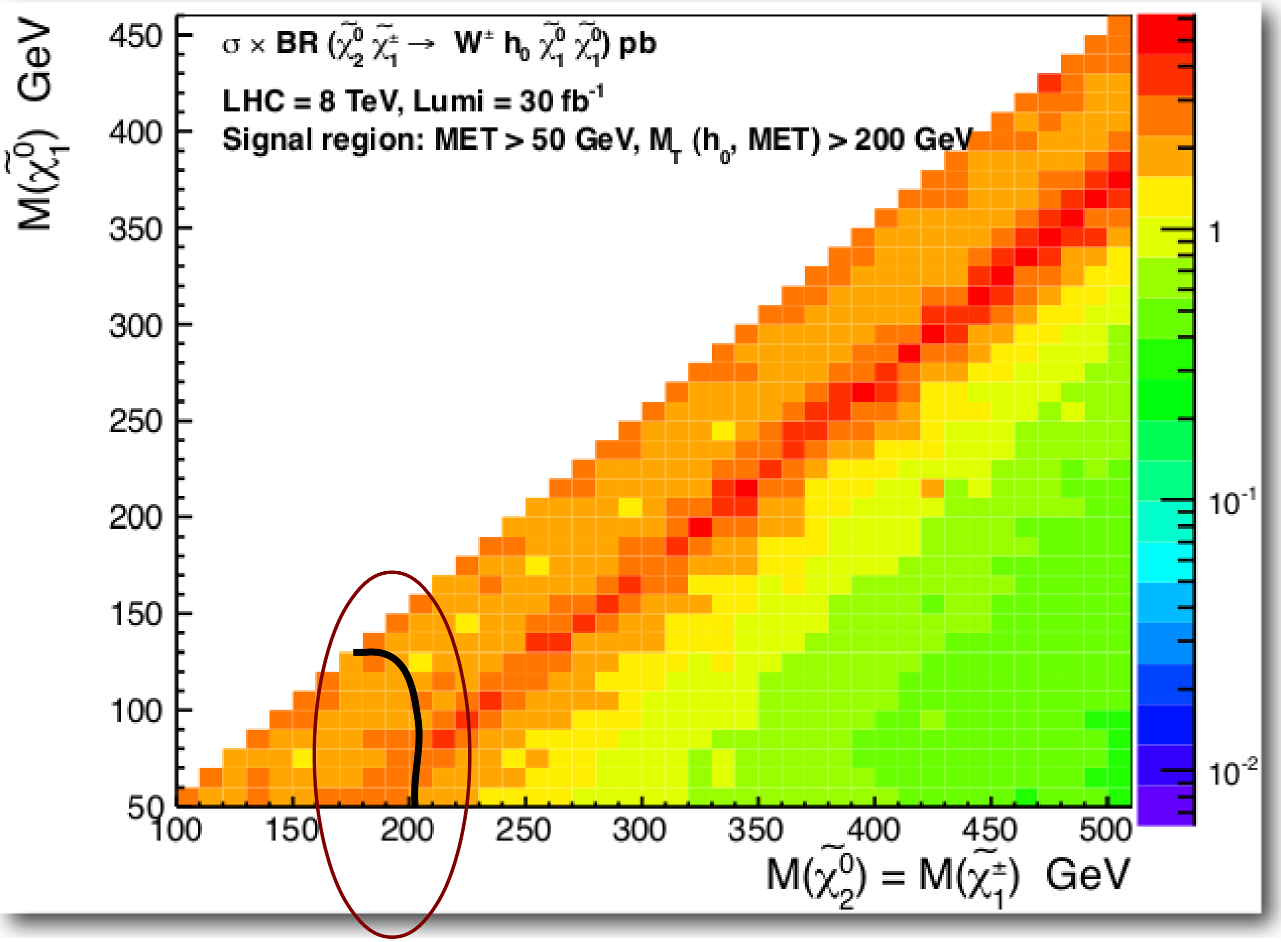
- **Naturalness** arguments call for the investigation of a **light electroweak sector** in the MSSM.
- Parameter scans are being performed for all cases: **Bino LSP, Wino LSP, Higgsino LSP.**
- The **complementary of the LHC/ILC** is expected to be demonstrated.

- **Whitepaper** to be submitted to the Snowmass process!!

Extra Slides

Possible LHC searches with Higgs in the final state

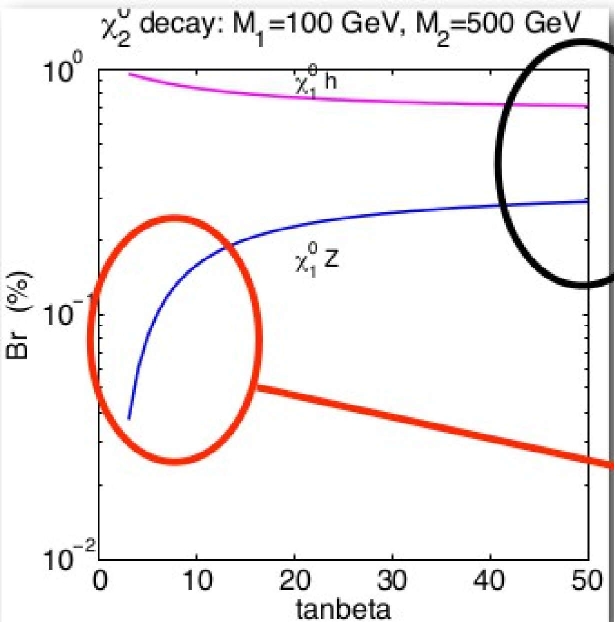
Wh: 1l+jets + MET **95% C.L. upper limit on signal cross section**



With background only hypothesis, one can be sensitive to ~ 200 GeV in mass

tanbeta dependency

- decay occur via mixing through Higgsino
- $M_2 >> M_1$, $\chi_2^0 \rightarrow \chi_1^0 Z$ dominated by the decay via Z_L (goldstone mode G^0)
- h, G^0 as mixture of H_u^0 and H_d^0



$$\Gamma(\chi_2^0 \to \chi_1^0 h) \propto \left(2s_{2\beta} + \frac{M_2}{\mu}\right)^2 \left[(M_2 + M_1)^2 - m_h^2\right],$$

$$\Gamma(\chi_2^0 \to \chi_1^0 Z) \propto \left(c_{2\beta}\frac{M_2}{\mu}\right)^2 \left[(M_2 - M_1)^2 - m_Z^2\right].$$

large tan β ; $[(M_2+M_1)^2 - m_h^2] \,/\, [(M_2-M_1)^2 - m_h^2]$

small tan β , Z channel relatively suppressed

Light Electroweakinos

$$m_Z^2 = -2\left(m_{H_u}^2 + |\mu|^2\right) + \mathcal{O}(\cot^2\beta)$$

Higgsino mass μ should be around O(100) GeV to avoid fine-tuning.

Possibly with small mass splitting.

→ Motivates search for light electroweakinos. Will consider in particular models where all other SUSY particles are heavy.