Experimental overview: Direct Electrowino Productions

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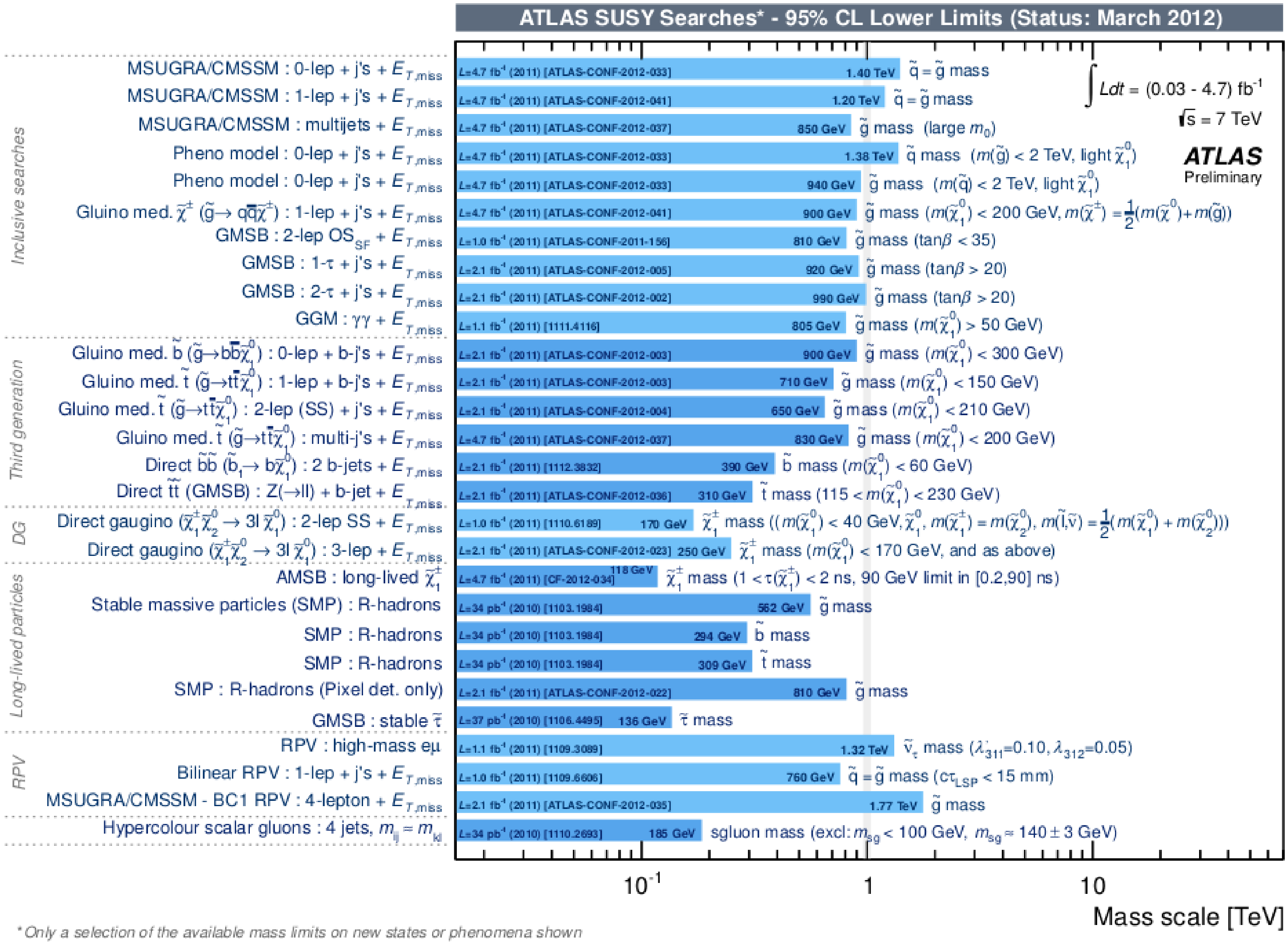
Outline

- Introduction
- Experimental constraints from LEP
- Experimental constraints from Tevatron
- Direct electrowino production at the LHC
- Search results (so far) from the LHC experiments
  - ATLAS results
  - CMS results
- Next steps in the weakly produced SUSY sector
- Summary and conclusion

Many thanks to members from ATLAS & CMS collaborations as well as Shufang Su and Tao Han

ATLAS results (CMS similar)



Both ATLAS and CMS experiments have excluded SUSY colored production up to the TeV scale (with assumptions, not including direct stops/sbottoms productions)

Introduction

The absence of spectacular events with large hadronic activities and MET implies

- New colored (excluding 3rd gen) SUSY particles may not have been copiously produced.

In anticipation of heavier colored SUSY partners:

- Search for SUSY sector from direct electroweak production (EWinos) are important

Natural electroweak symmetry breaking, on the other hand predicts that

higgsinos, stops, and the gluino should not be too far above the weak scale.

EW sector (+stops/sbottoms) might be the only accessible particles @ LHC

For details on third generation studies see talks by – R. Cavanaugh & T. Golling

It is important to note:

- Direct production of electroweak SUSY particles at the LHC will have low rates
- Dark matter consideration favors nearly degenerate charginos and neutralinos
    - See Arkani-Hamed et. al (hep-ph/0601041), Baer et. al (hep-ph/0611387)
    - Identification at the LHC will be challenging

Experimental constraints from LEP

Chargino ($\tilde{\chi}_i^{\pm}; i = 1,2$) and Neutralino ($\tilde{\chi}_i^0; i = 1-4$) productions at LEP:

$$e^+e^- \to \tilde{\chi}^+\tilde{\chi}^- \to W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

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

Neutralino pairs via s-channel Z or t-channel with slepton exchange

Using mSUGRA or CMSSM framework

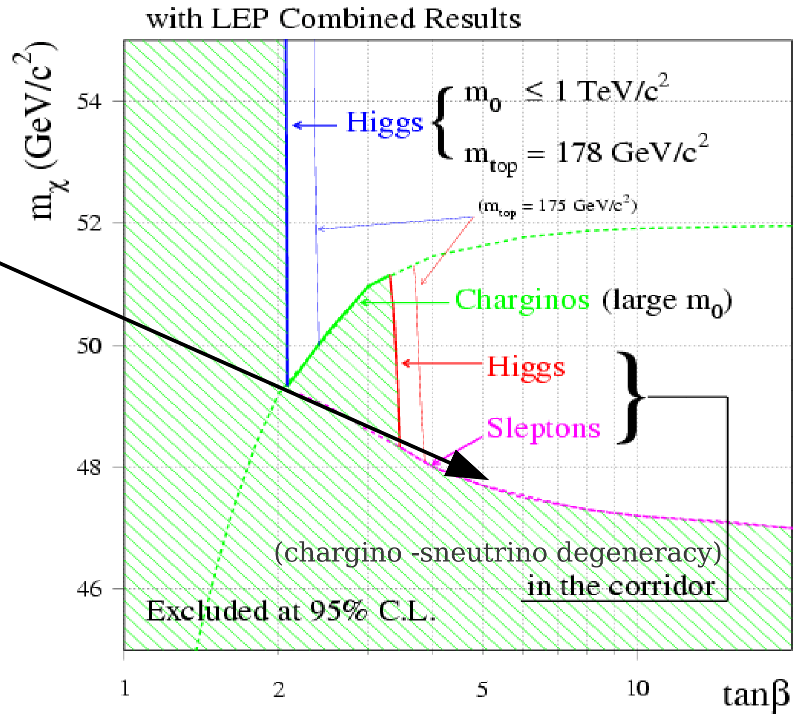
(assuming mixing in stau sector is small)

LSP mass below 47/50 GeV is excluded

However several assumptions are involved:

- mSUGRA / CMSSM
- gaugino mass unification
- tanβ < 3.3 limits at large M_0 (+higgs, chargino)

  (M0 - common sfermion mass at GUT)
- tanβ > 3.3 the limit is using small M_0

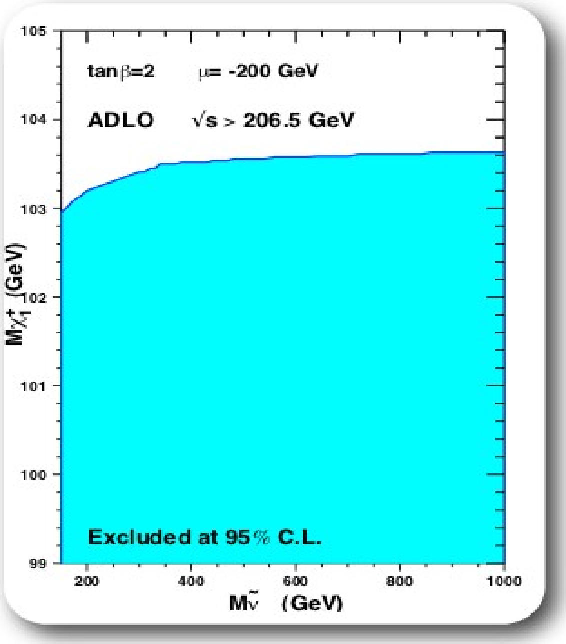


No mass limit in general outside these assumptions

Experimental constraints from LEP

Charginos via: s-channel γ/Z or t-channel with sneutrino exchange

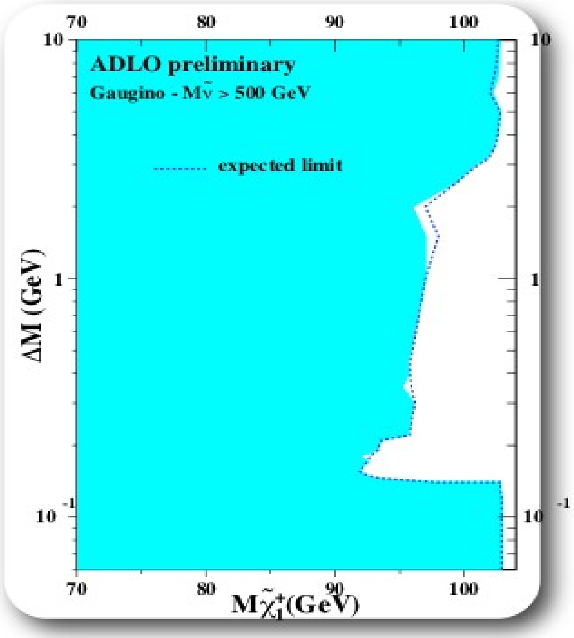
canonical case



$m\chi_1^{\pm}$ > 103.5 GeV for m_{snue} > 300 GeV

LEPSUSYWG/01-03.1

degenerate case



$m\chi_1^{\pm}$ > 91.9 /92.4 GeV

LEPSUSYWG/02-04.1

Unification of gaugino masses at GUT scale is assumed.

- M1 = (5/3)tan^2(theta_W) M2 ~ 0.5 M2

Canonical case:

- With M(sneutrino) > 300 GeV

Degenerate case:

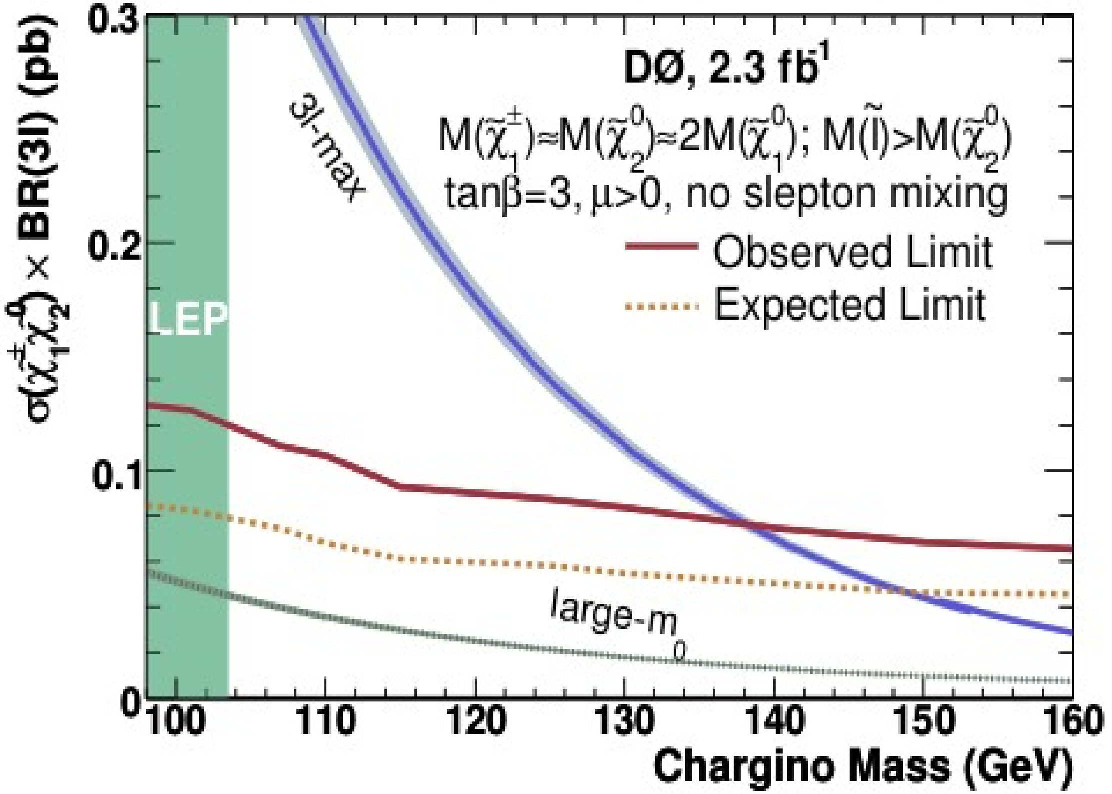
- M1 and M2 nearly degenerate
- Large M0 (m(snu) ~500 GeV)

<u>In general Charginos up to ~ 100 GeV in mass are excluded by the LEP experiments</u>

Experimental constraints from Tevatron

D0 Collaboration: $p\bar{p} \rightarrow \tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$

D0 Collab. Phys. Lett. B680, 34 (2009)



Three leptons + MET signature

- e, μ, and τ

4 Channels (eel, μμl, eμτl, μτl)

Dominant bkg: WZ, ZZ in MET tails

Within the context of MSUGRA

Assuming:

$$m_{\tilde{\chi}_1^{\pm}} \sim m_{\tilde{\chi}_2^0} \sim 2m_{\tilde{\chi}_1^0}$$

- and neglecting the slepton mixing

- sleptons and sneutrinos heavier than lightest charginos and next lightest neutralino

In the limit of heavy sleptons (large m0 scenario):

- the slepton mass is just above mass of $\tilde{\chi}_2^0$, leptonic BR is maximized (3l max case)

Chargino mass < 138 GeV is excluded by this study

Experimental constraints from Tevatron

CDF Collaboration: $p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$

CDF Note: 10636

Three leptons + MET signature

Several SRs in the plane - MET & M_{ll}

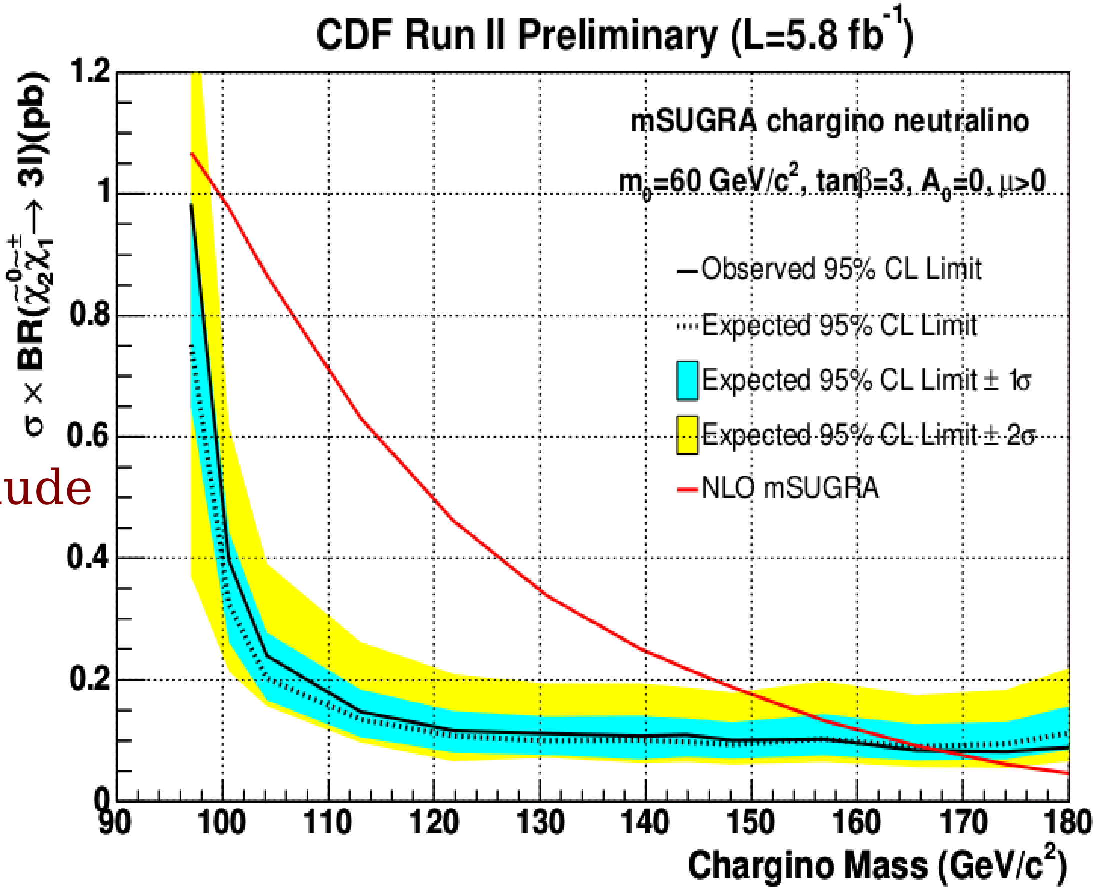
Modes:

- eel, μμl ; l = e, μ, τ (or single track)
- Expanded the acceptance & also include low p_T leptons ~ 5 GeV threshold.

Major backgrounds:

- WZ, ZZ, dileptons + fakes

Within the context of MSUGRA



Exclude at 95% CL $\sigma(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(lll)$ above 0.1 fb

Chargino mass below 168 GeV is excluded by this study

Direct electrowino production at the LHC

Let us look at MSSM Electroweak sector with:

- No assumption of gaugino mass unification
- No sfermion mass unification
- In fact decouple sfermions
- Decouple (?) mSUGRA

- 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, $\tan\beta$

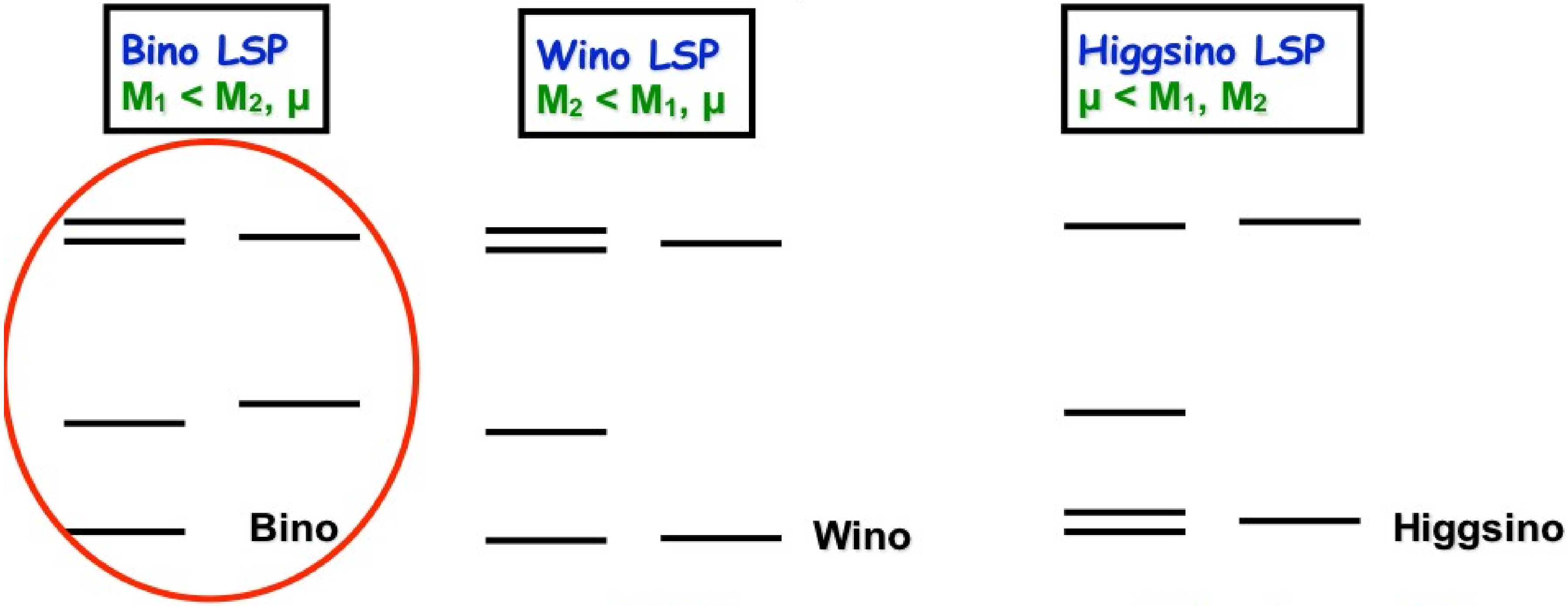
⇒

- Neutralinos and charginos

Similarly for the sleptons:

- Sleptons: slL, slR, three generations
  - No flavor mixing
  - No LR mixing for the 1st, 2nd generations
    ⇒ seL, seR, smuL, smuR, stau1, stau2
- Parameters: MslL2, MslR2, (LR for stau? universality?)

Decouple sleptons from the study (Most conservative case)



e.g.: sugra, CMSSM, gaugino mass unification,... canonical case

e.g.: AMSB,...

Chen et. al., hep-ph/9512230
Moroi et. al., hep-ph/9904250
Gherghetta et. al., hep-ph/9904378
Bear et. al., hep-ph/0007073
Moroi et. al., ArXiv: 0802.3725

e.g.:"Higgsino-world",...

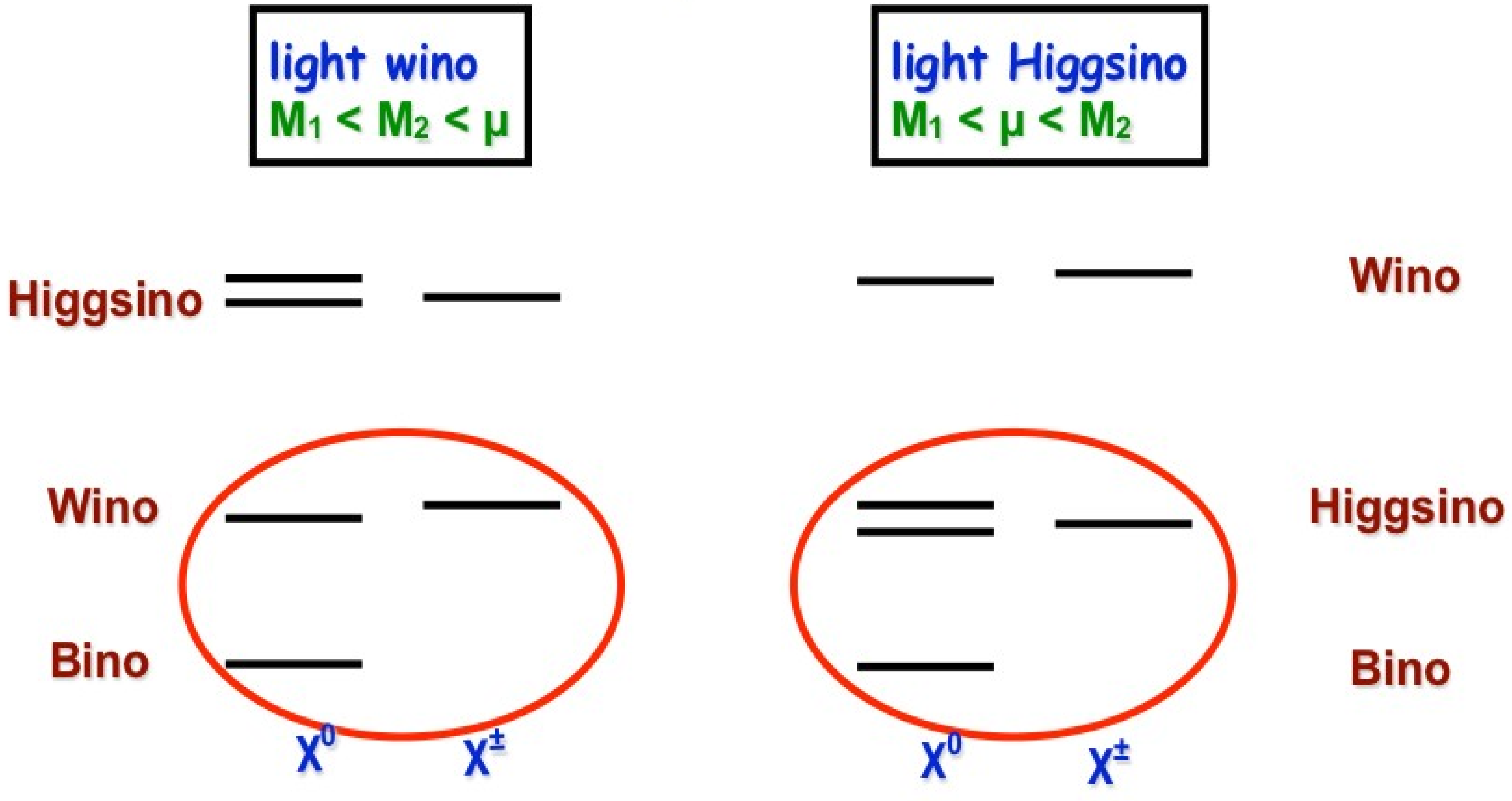
Baer, Barger and Huang, ArXiv: 1107.5581

Remaining parameters: M1, M2 and μ

Higgsino masses depend on μ

Direct electrowino production with bino LSP

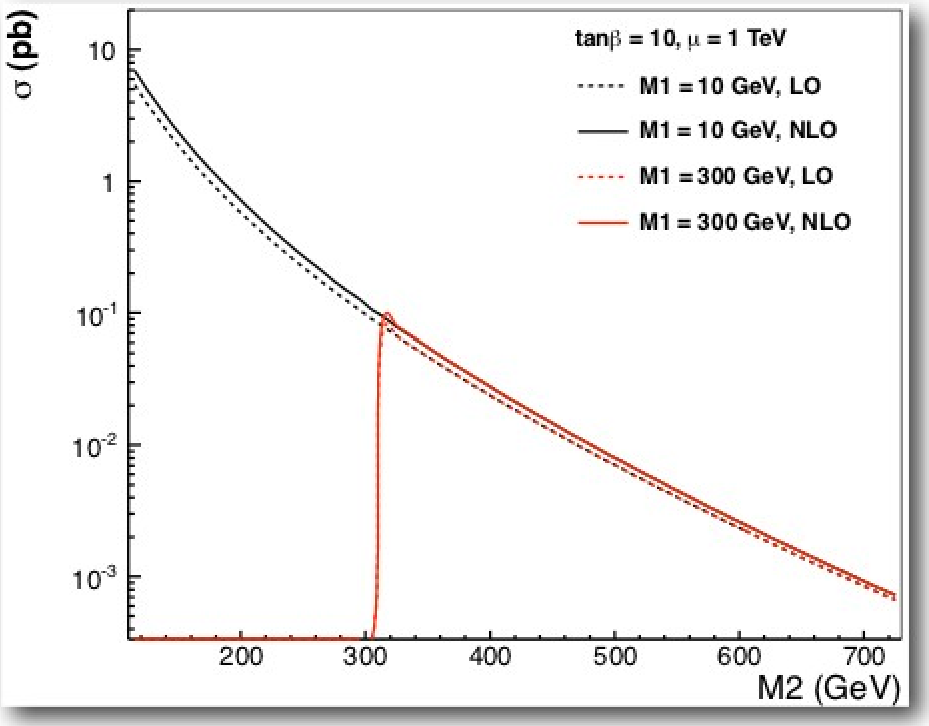
With Bino LSP - $\tilde{\chi}_1^0$

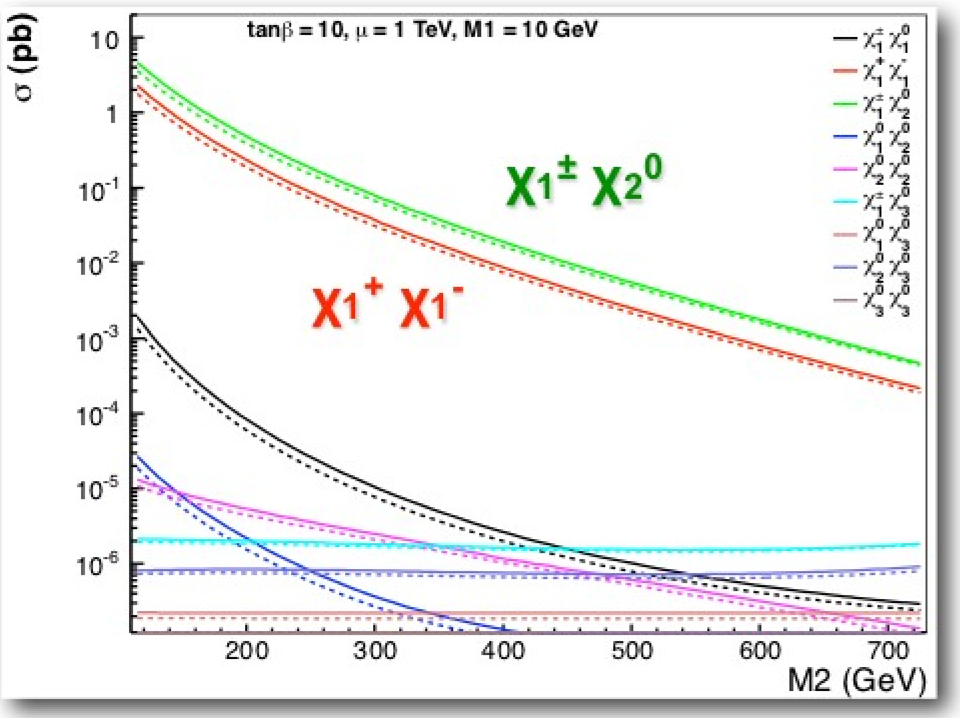


Consider only the light wino sector for the time being ...

Direct electrowino production with bino LSP

light wino $M_1 < M_2 < \mu$





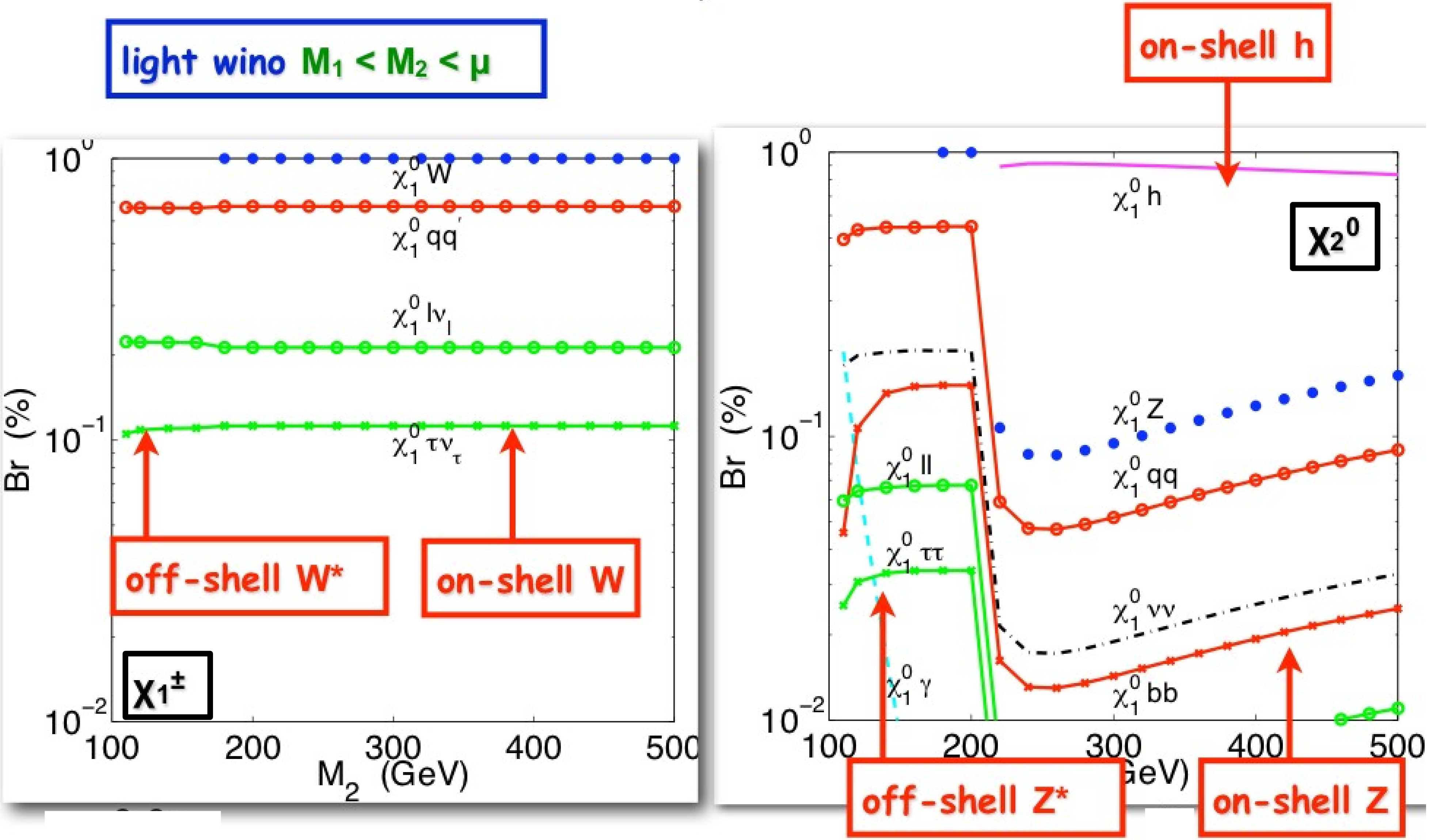
- cross section has little dependence on M_1

The dominant cross sections are from $\tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_1^\pm \tilde{\chi}_2^0$

The NLO corrections are ~10% level

Chargino decays (decoupled sleptons)

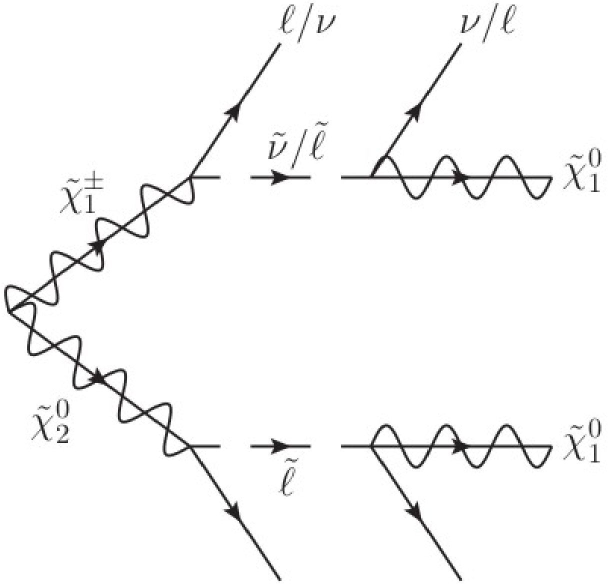
T. Han, S. Padhi, S. Su (To be sumitted)



Similar observation in case of light Higgino case (not shown)

Search for $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ using three leptons + MET (2.06 fb^{-1})– ATLAS, arXiv:1204.5638

$\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ decays via sleptons



Electrons/Muons: p_T > 10 GeV

Leading electron (muon) > 25 (20) GeV

- Mainly due to the trigger

At least on SFOS pair with m_{ll} > 20 GeV

Two orthogonal Signal regions.

SR1 : a) Z-veto b) Veto events with b-jets

SR2 : a) Z-enriched, require Z, b) No specific veto for bjets

Dominant background:

- Dibosons: WZ and ZZ (Use MC)
- Rare decays: ttbar + V (Use MC)
- Fakes from heavy flavor decays or jet fakes (Use Fake rate method)
- Electrons from photon conversion (Use control sample to estimate this)

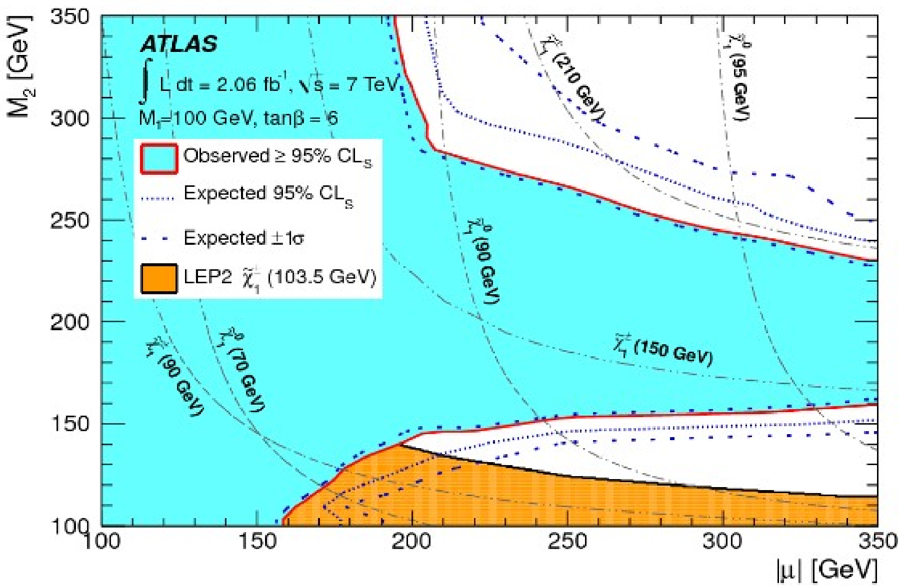
Search results from the LHC experiments - ATLAS

Model-independent $A \times \epsilon \times \sigma$ limit

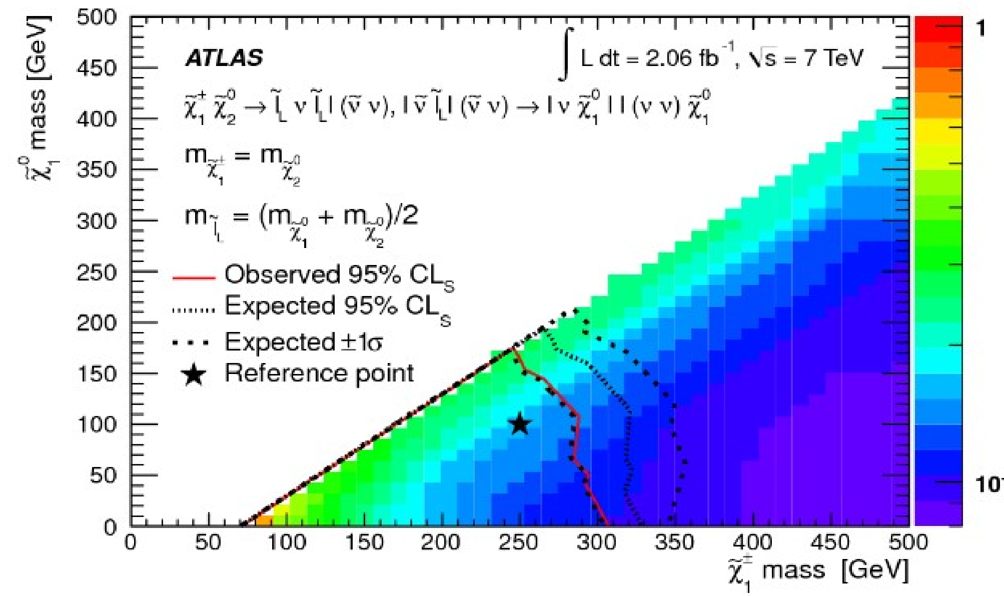
SR	95% CL_s limit expected [fb]	95% CL_s limit observed [fb]
SR1 (Z-veto)	7.1	9.9
SR2 (Z-rich)	14.1	23.8

See: A. Canepa talk

Limit in pMSSM



Limit in $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ simplified models



Impressive early results – Leptonic BF gain due to sleptons in the intermediate cascade

Hard to constrain charginos/neutralinos without decoupling sleptons

Search results from the LHC experiments - CMS

Search for new physics using multileptons and MET (4.98 fb^{-1}) - CMS SUS-11-013

- See details in S. Somalwar's Talk

Event selection:

- 3 and ≥ 4 lepton combination with e, μ and τ's
- Use single and dilepton triggers with p_T = 20, 10, 8 GeV
- Remove low mass resonances m_{ll} > 12 GeV
- Use MET Vs H_T or S_T (MET + H_T + Lepton p_Ts)
- Invariant mass cut m_{ll} : With Z veto and Z enriched regions

Tau selection:

- Isolated tracks
- HPS algorithm with π^0's

Major backgrounds:

- Dibosons from WZ and ZZ and top related bkgs (Use MC)
- Top related bkg – Use fake rates for heavy flavor decays

Other bkg:

- Z+Jets, WW, W+Jets, QCD – Use fake rate method
- Z + Asymmetric photon conversion – Estimate using dilepton + photon samples

Search results from the LHC experiments - CMS

Several signal regions based on With/Without Z, H_T, MET and lepton multiplicities

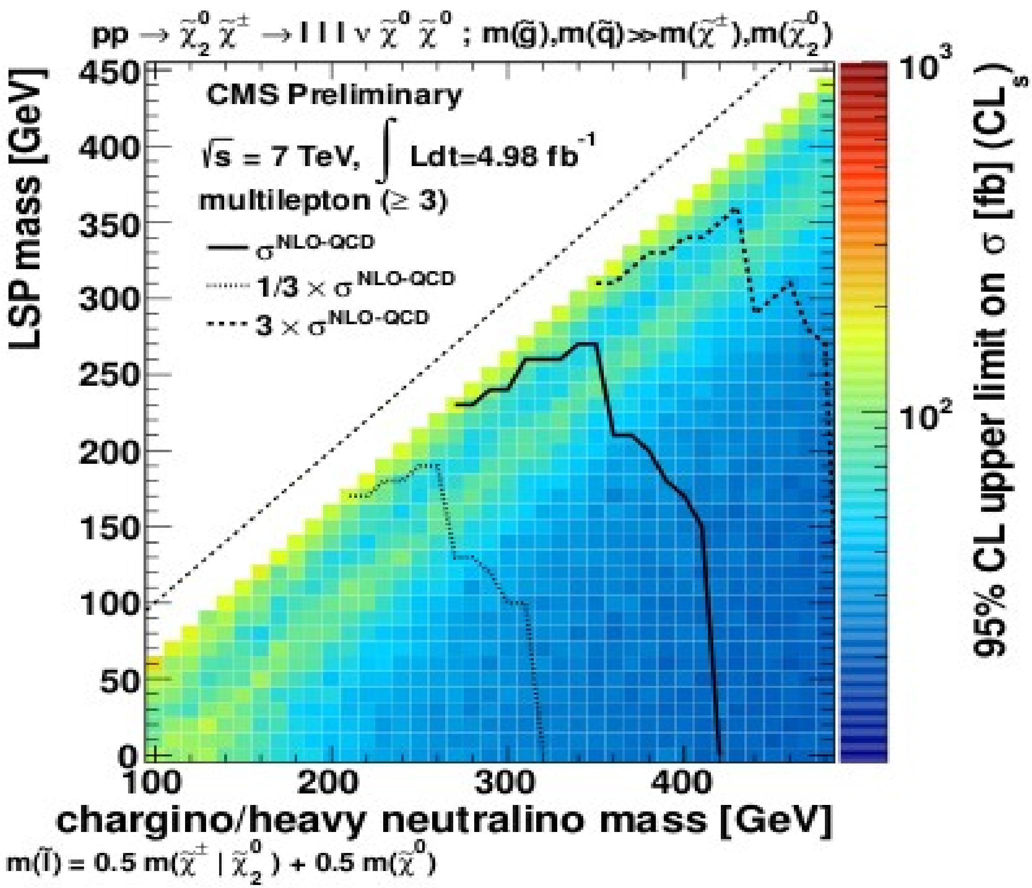
4 lepton mode

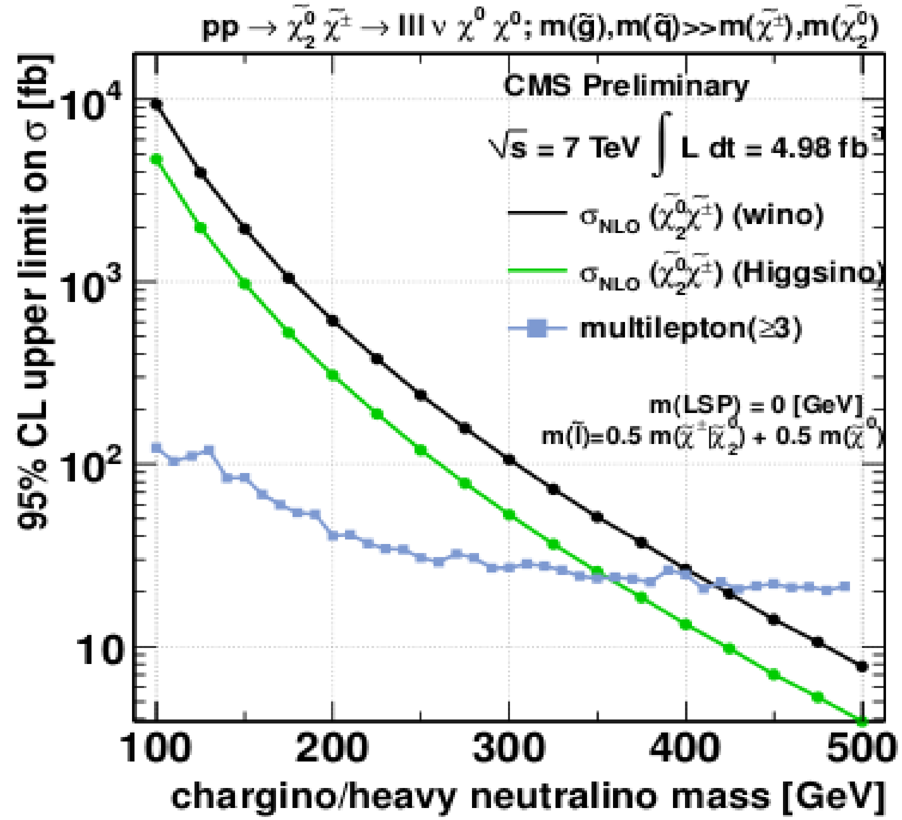
Selection			4(e/μ)		3(e/μ)+T		2(e/μ)+2T	
MET?	HT?	Z?	SM	Obs	SM	Obs	SM	Obs
MET>50	HT>200	NoZ	0.017 ± 0.005	0	0.08 ± 0.06	0	0.6 ± 0.6	0
MET>50	HT>200	Z	0.20 ± 0.04	0	0.25 ± 0.11	0	0.7 ± 1.0	0
MET>50	HT<200	NoZ	0.19 ± 0.07	1	0.56 ± 0.16	3	1.4 ± 0.6	1
MET>50	HT<200	Z	0.74 ± 0.20	1	2.2 ± 0.6	4	1.1 ± 0.7	0
MET<50	HT>200	noZ	0.006 ± 0.001	0	0.13 ± 0.08	0	0.25 ± 0.07	0
MET<50	HT>200	Z	0.78 ± 0.31	1	0.52 ± 0.20	0	1.13 ± 0.42	0
MET<50	HT<200	NoZ	2.4 ± 1.0	1	3.7 ± 1.2	5	10.5 ± 3.2	17
MET<50	HT<200	Z	35 ± 14	33	16.1 ± 4.9	20	42 ± 16	62
SUM	4-body		39 ± 15	37	23.6 ± 5.1	32	58 ± 16	80

3 lepton mode

Selection			3(e/μ)		2(e/μ)+T		1(e/μ)+2T	
MET?	HT?	Z?	SM	Obs	SM	Obs	SM	Obs
MET>50	HT>200	n/a	1.5 ± 0.5	2	30.3 ± 9.6	33	13.5 ± 2.6	15
MET>50	HT<200	n/a	6.5 ± 2.3	7	140 ± 37	159	106 ± 16	82
MET<50	HT>200	n/a	1.2 ± 0.7	1	16.5 ± 4.5	16	31.9 ± 4.8	18
MET<50	HT<200	n/a	11.6 ± 3.6	14	354 ± 55	446	1025 ± 171	1006
MET>50	HT>200	noZ	4.8 ± 1.3	8	31.0 ± 9.5	16	--	--
MET>50	HT>200	Z	17.8 ± 6.0	20	24.0 ± 4.9	13	--	--
MET>50	HT<200	noZ	25.9 ± 7.3	30	106 ± 27	114	--	--
MET<50	HT>200	noZ	4.4 ± 1.5	11	51.8 ± 6.2	45	--	--
MET>50	HT<200	Z	126 ± 47	141	115 ± 16	107	--	--
MET<50	HT>200	Z	18.4 ± 4.5	15	244 ± 24	166	--	--
MET<50	HT<200	noZ	142 ± 36	123	2906 ± 412	3721	--	--
MET<50	HT<200	Z	749 ± 181	657	15516 ± 2421	17857	--	--
SUM	3-body		1109 ± 191	1029	19533 ± 2457	22693	1177 ± 172	1121

Search results from the LHC experiments - CMS



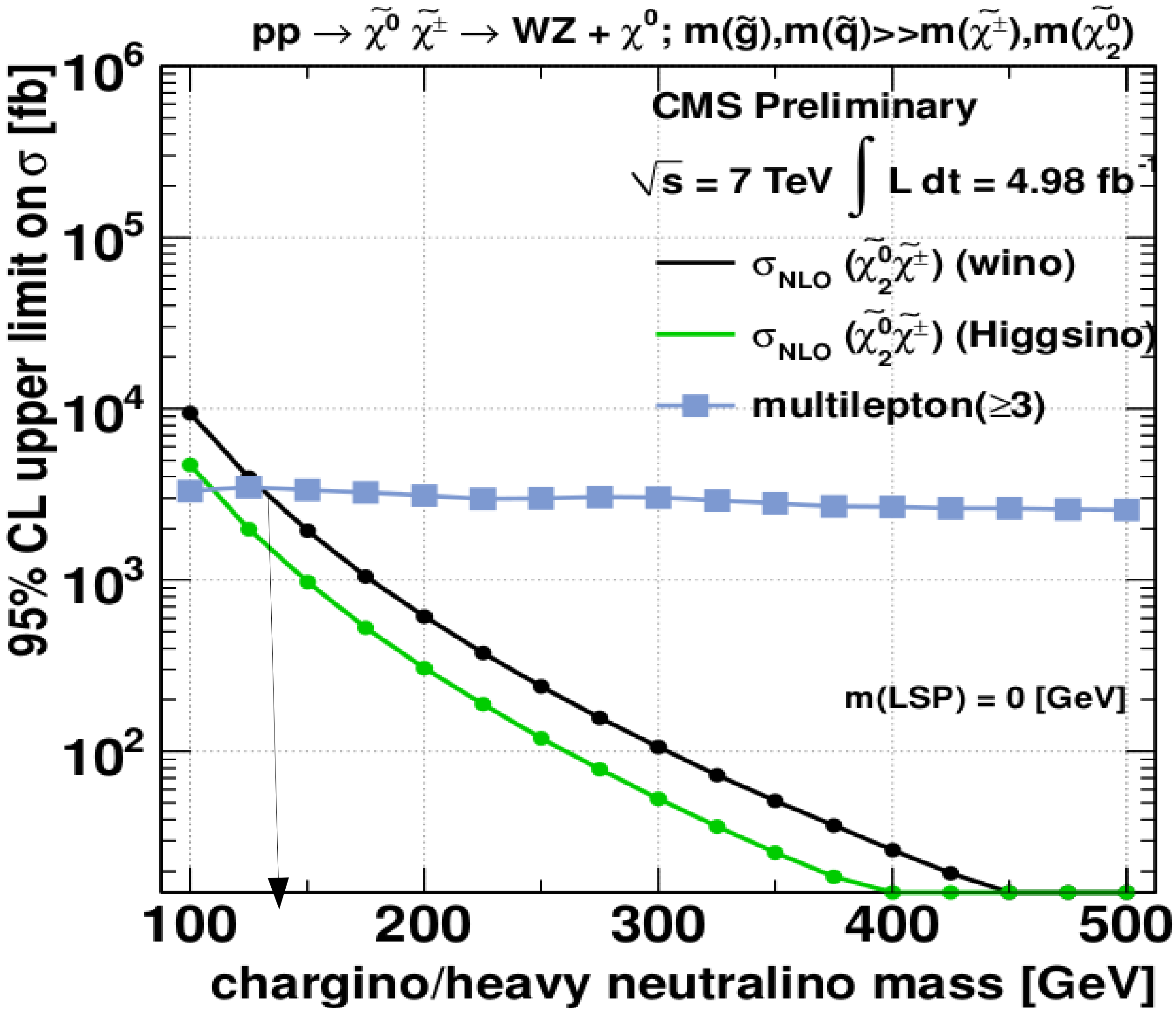


Impressive results:

- Similar to ATLAS with larger coverage and with sleptons in the intermediate state

Hard to constrain charginos/heavy neutralinos without decoupling sleptons

Search results from the LHC experiments - CMS



CMS SUS-11-016

In the slepton decouple limit:

Exclusion bounds from LHC with charginos/heavy neutralinos up to ~ 140 GeV

Search results from the LHC experiments

The remaining dominant contribution in EWKino (light Wino) sector is from: $\tilde{\chi}^+\tilde{\chi}^-$

None of the LHC experiments have bounds in this mode

- Re-interpretation/exclusion by M. Lisanti & N. Weiner (arXiv:1112.483)
- Use H → WW (and H → ZZ) results from ATLAS and CMS
- Simplified topology

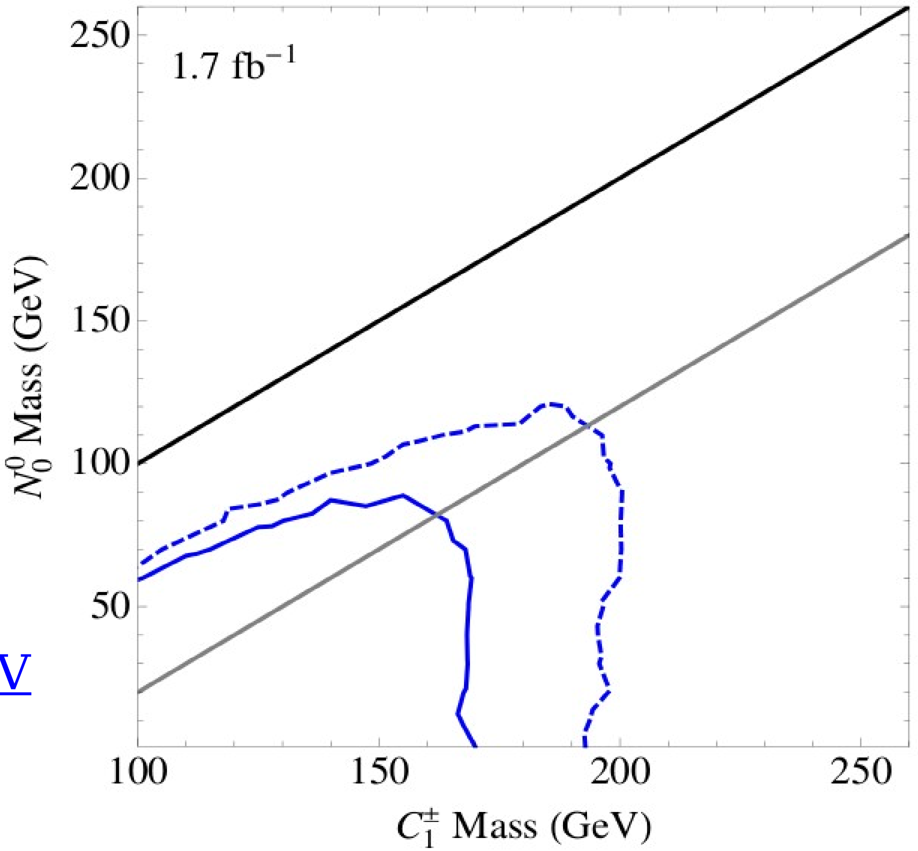
Dashed and solid lines indicate

- 1 and 2σ sensitivity

The sensitivity is defined as:

$$N_{\text{signal}} \geq 2 \times \sqrt{B_{\text{stat}}^2 + B_{\text{sys}}^2}.$$

Charginos are most likely above ~200 GeV based on this study



Next steps in the weakly produced SUSY sector

Experimental Search for direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ in OS leptons with Jet veto

- Similar to SM H → WW study

$\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$ - Search using Same Sign dileptons with Jet veto

Combination of 3 leptons + SS dileptons (+jet veto) should give largest sensitivity

Predominant decays of higgsinos are currently unexplored

- This has significant value from naturalness arguments

Investigation of h_0 ~ 125 GeV in weakly produced SUSY sector

Slepton pair productions at the LHC

-See also: “Slepton Discovery in Electroweak Cascade Decay”, arXiv:1111.2615

....

Summary and Outlook

SUSY Electrowino sector provides tremendous opportunity for NP

- in absence of spectacular MET and H_T events at the LHC

Naturalness requirement suggests Higgsinos to be light

Current limits on gauginos are relatively weak

With increase in luminosity along with 8 TeV collisions

- things might get interesting with the EWKino sector

Backup slides

TABLE I. Expected numbers of events from SM backgrounds (Bkg.) and observed numbers of events in data, for 2.06 fb^{-1}, in control regions VR1 and VR2, and in signal regions SR1 and SR2. Both statistical and systematic uncertainties are included.

Selection	VR1	VR2	SR1	SR2
$t\bar{t}W^{(*)}/Z^{(*)}$	1.4±1.1	0.7±0.6	0.4±0.3	2.7±2.1
$ZZ^{(*)}$	6.7±1.5	0.03±0.04	0.7±0.2	3.4±0.8
$WZ^{(*)}$	61±11	0.4±0.2	11±2	58±11
Reducible Bkg.	56±35	14±9	14±4	7.5±3.9
Total Bkg.	125±37	15±9	26±5	72±12
Data	122	12	32	95