LHC Studies on the Electroweak Sector of MSSM

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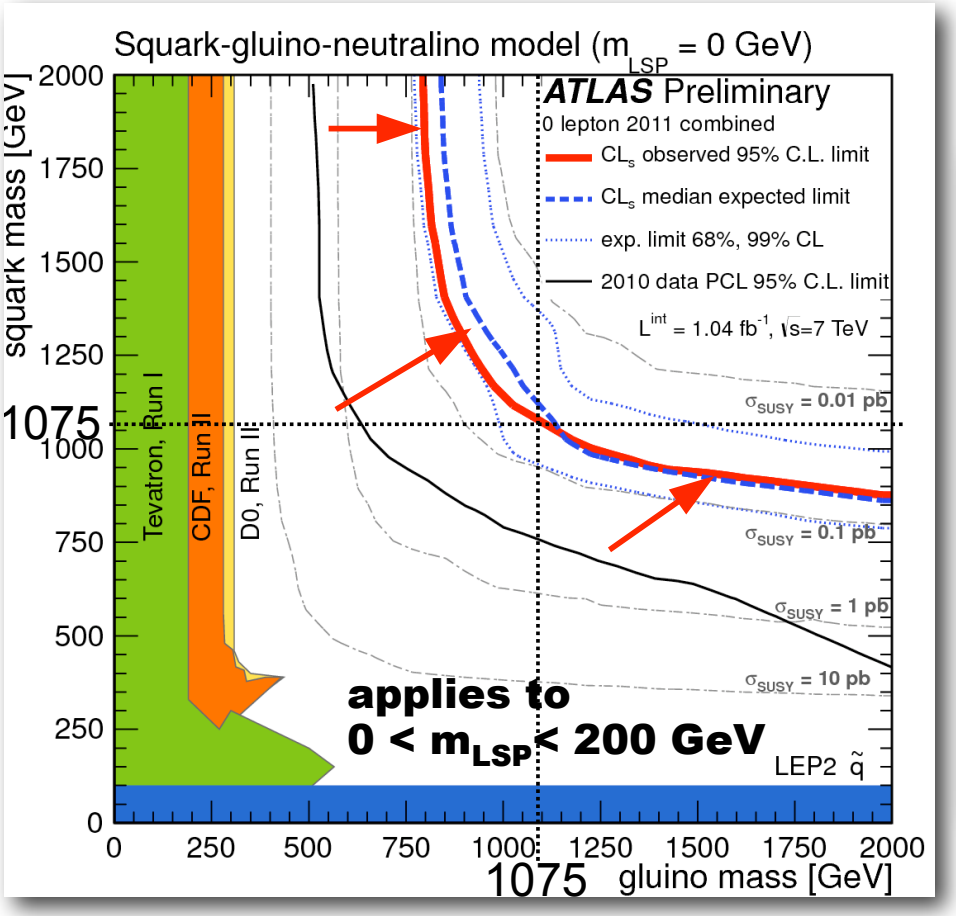
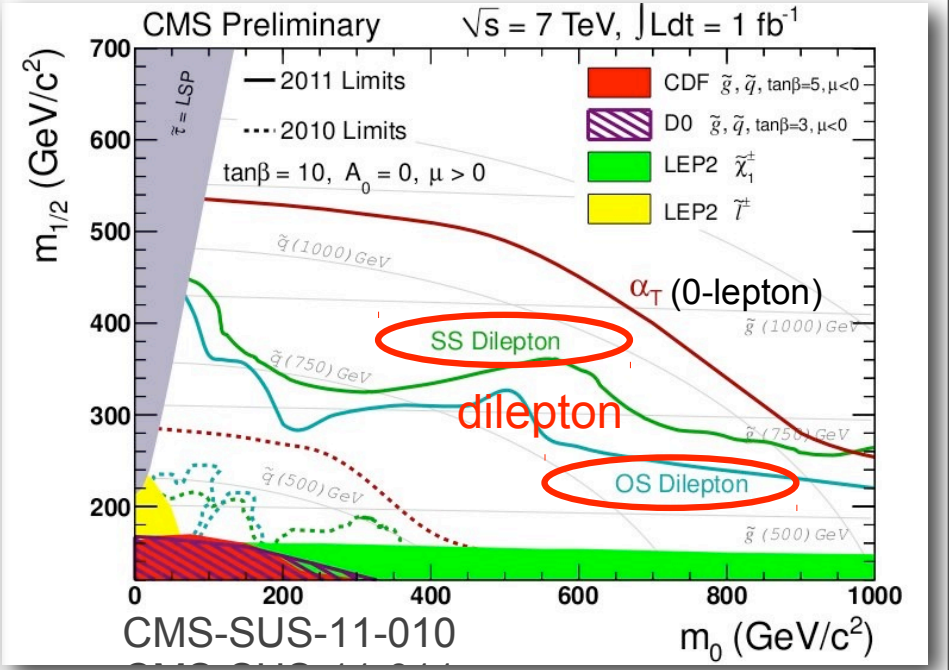
In collaboration with
J. Eckel, W. Shepherd, arXiv: 1109.xxxx;
T. Han, S. Padhi, arXiv: 1109.xxxx;

Outline

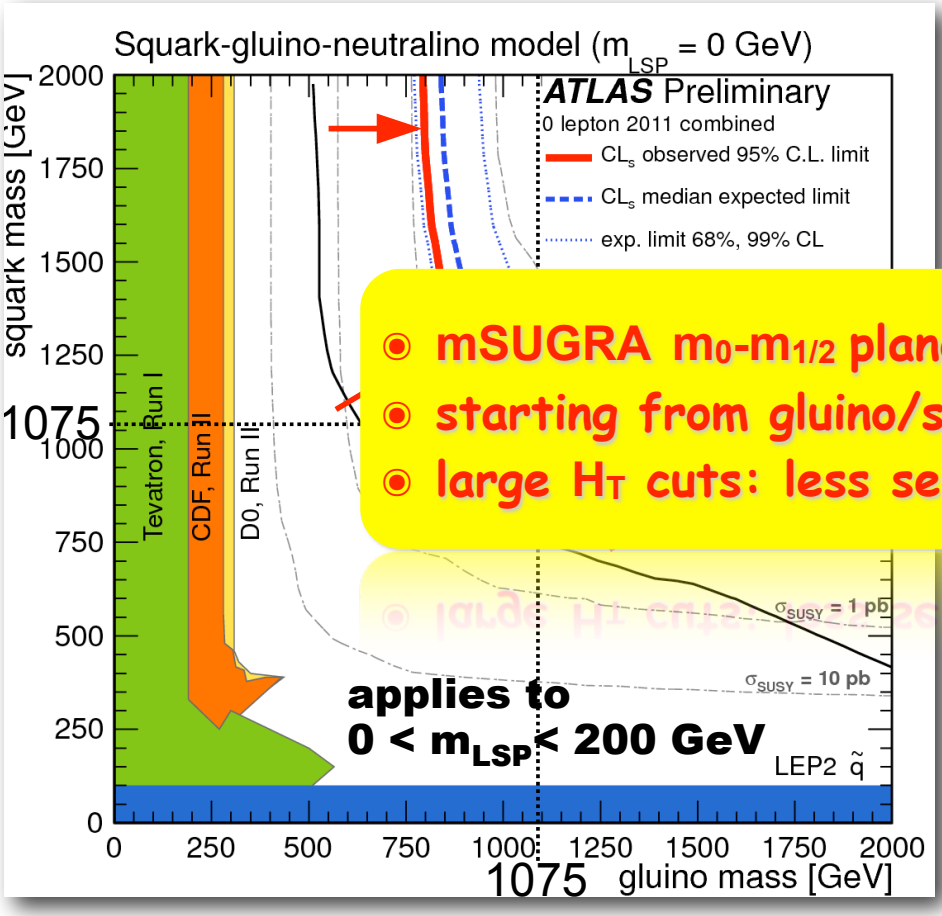
- Limitation of current LHC SUSY searches
- Current exp search limits on MSSM EW sector
- MSSM electroweak sector
- Neutralinos/Charginos: production and decay
- Two analyses:
  - Gauginos and Higgsinos (in slepton decoupling limit)
  - Sleptons via gaugino decays
- Conclusion

Current LHC SUSY searches: limitations

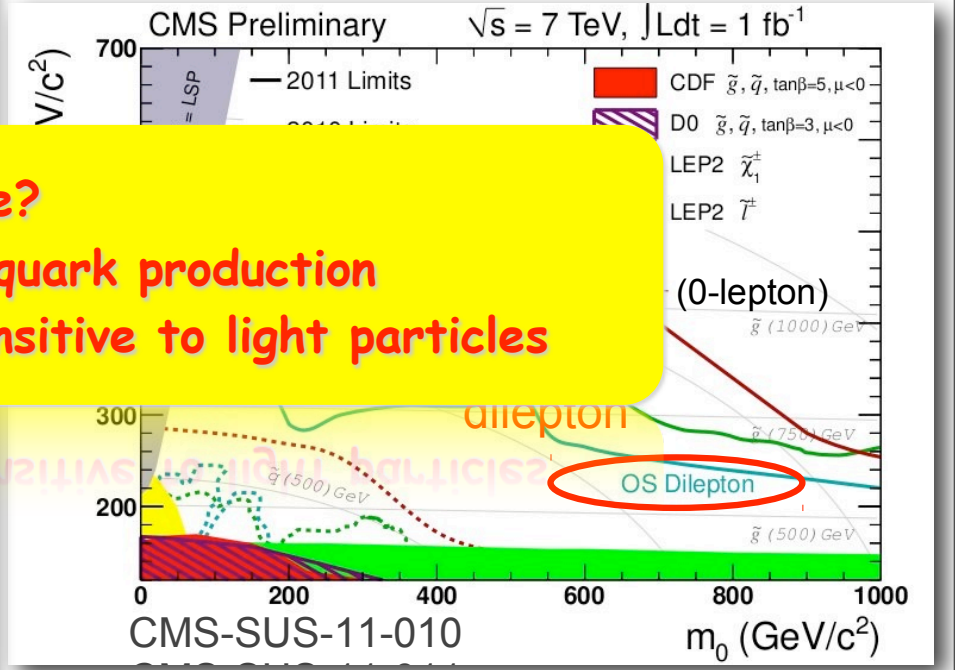




Current LHC SUSY searches: limitations

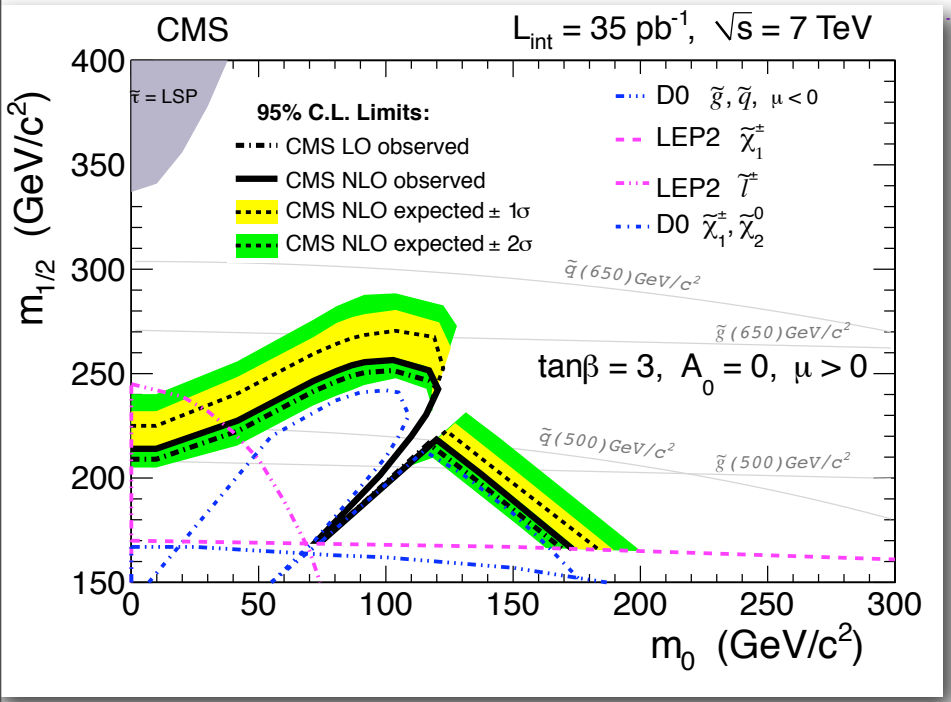


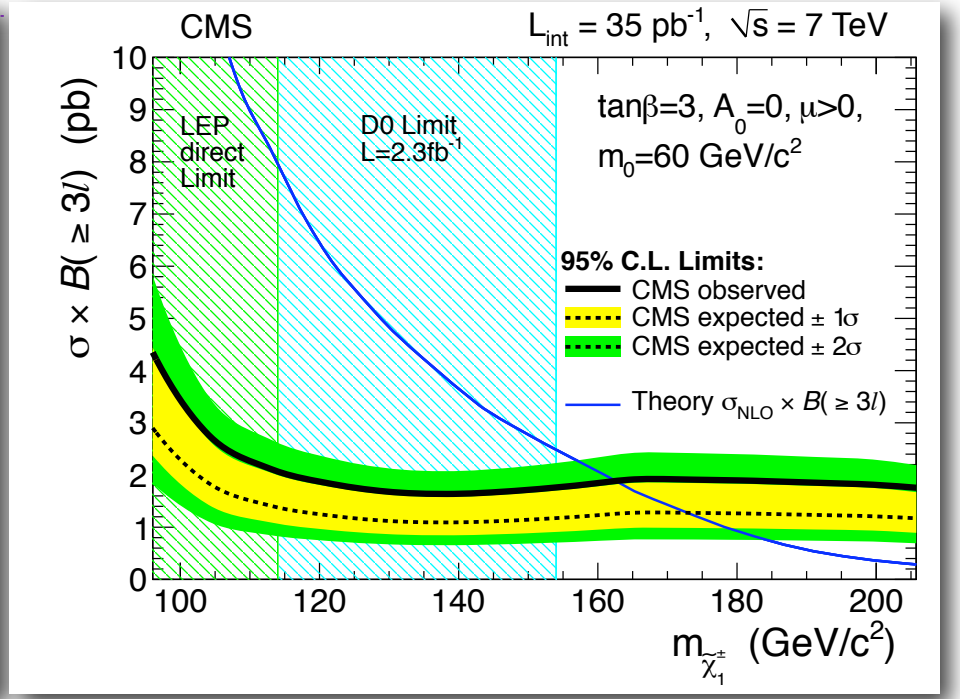
applies to
$0 < m_{LSP} < 200$ GeV



- mSUGRA m_0-$m_{1/2}$ plane?
- starting from gluino/squark production
- large H_T cuts: less sensitive to light particles

LHC vs. Tevatron

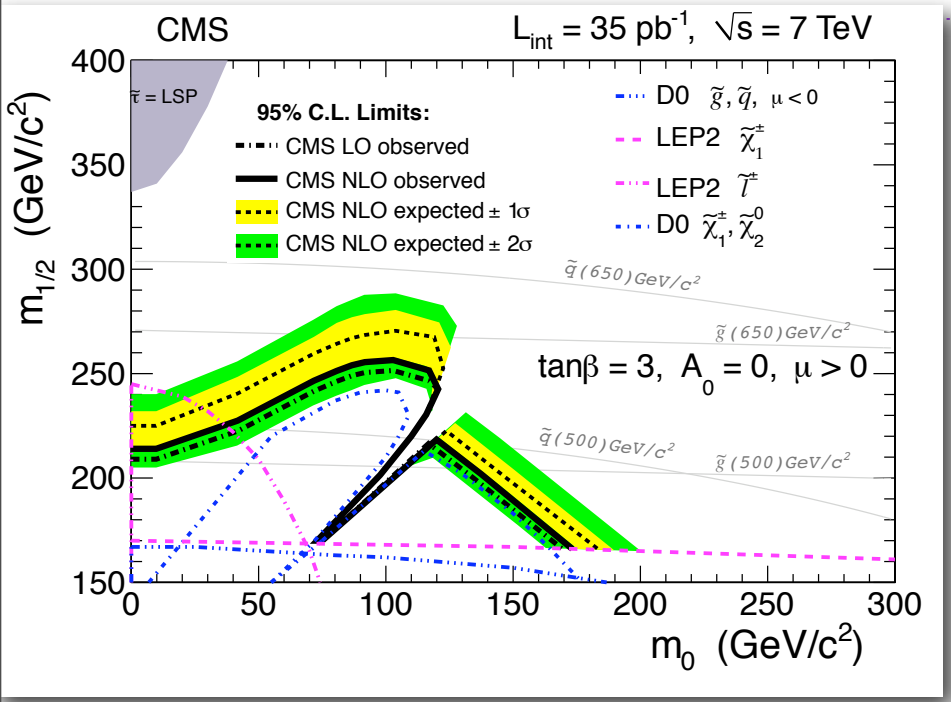


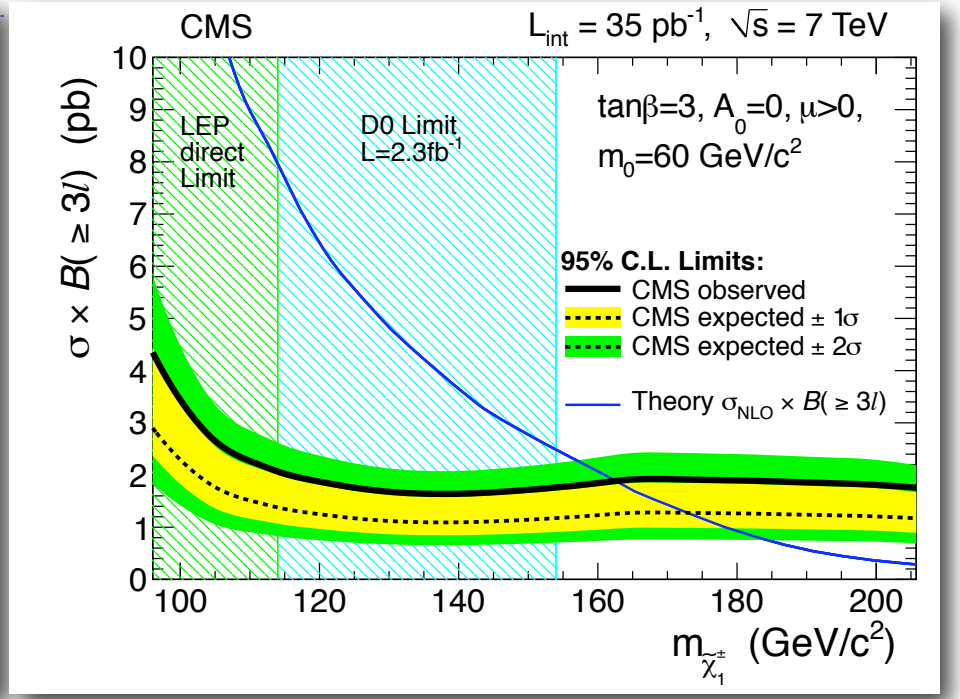


RunII: EW $\chi_1^{\pm}\chi_2^0$ production
LHC: gluino/squark pair production

not a direct limit on $m_{\chi_1^{\pm}}$
derived from mgluino

LHC vs. Tevatron





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- colored particles are heavy?
- gaugino masses do not unify?

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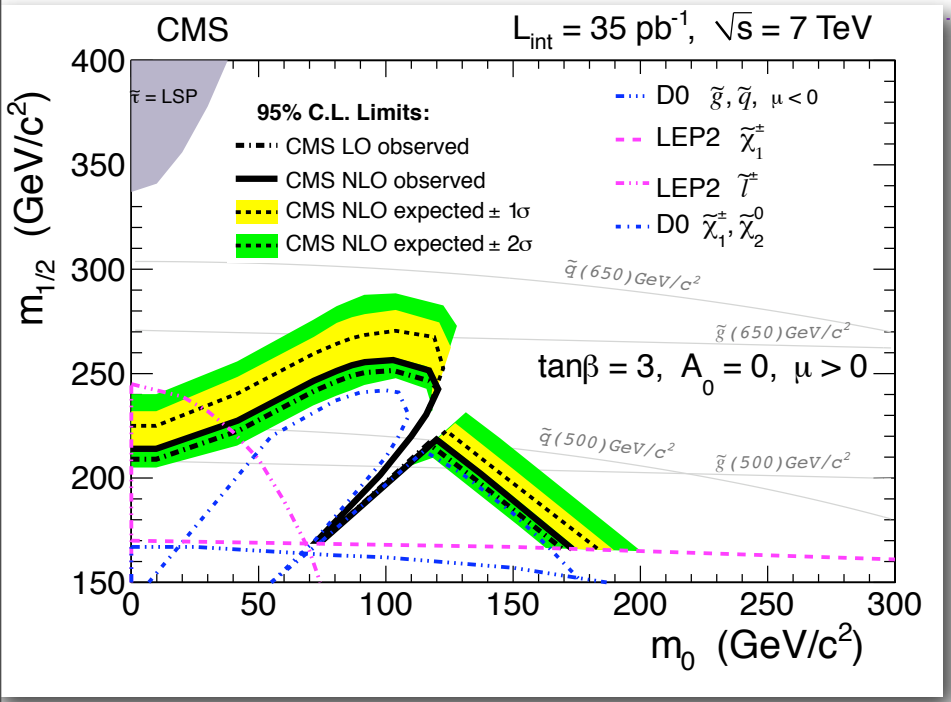

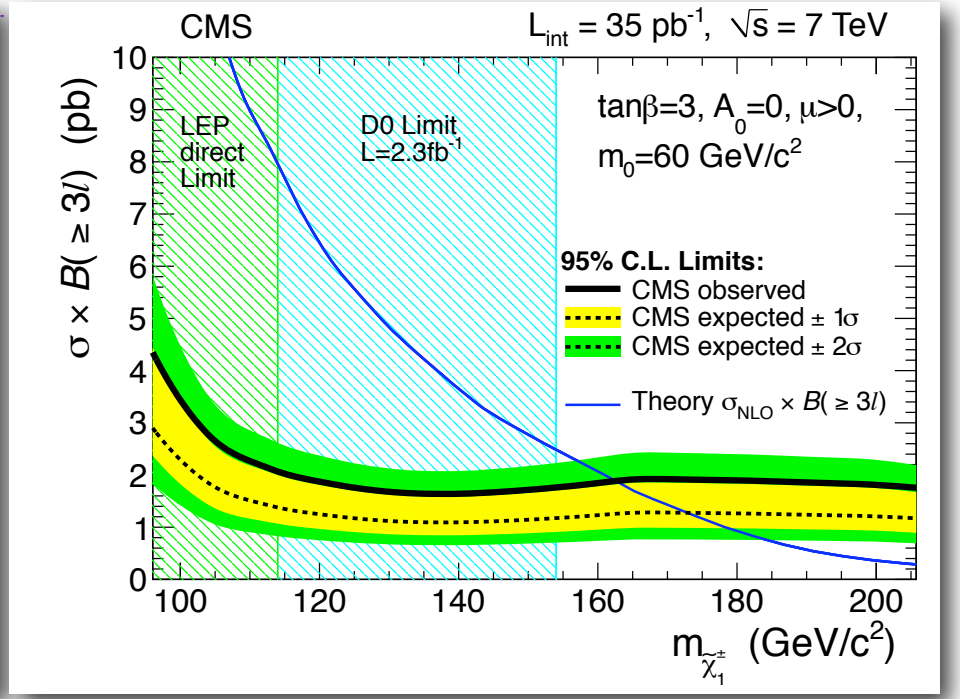

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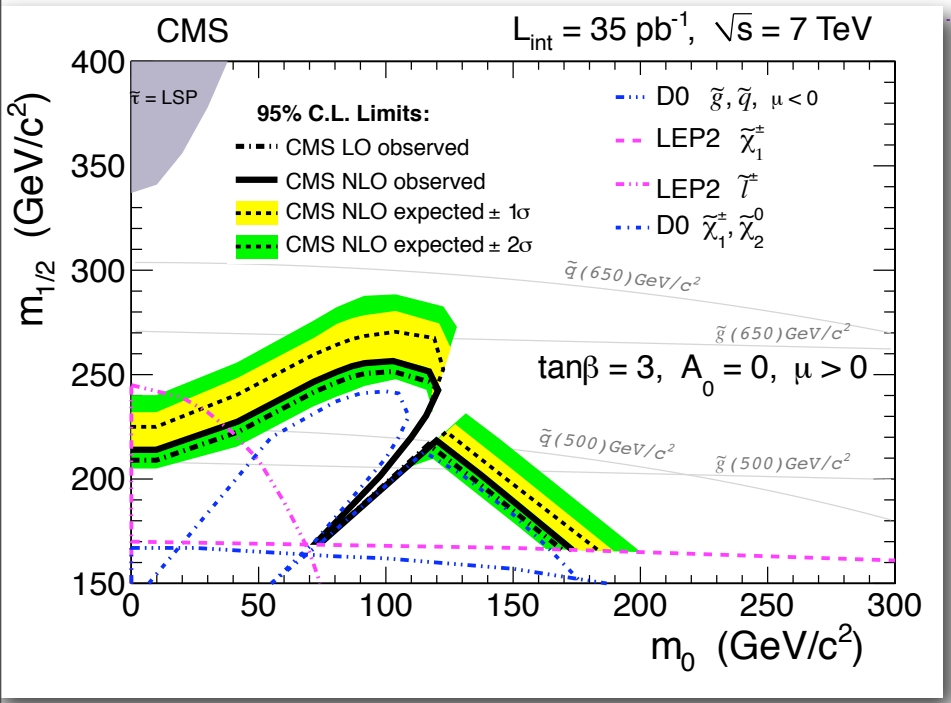
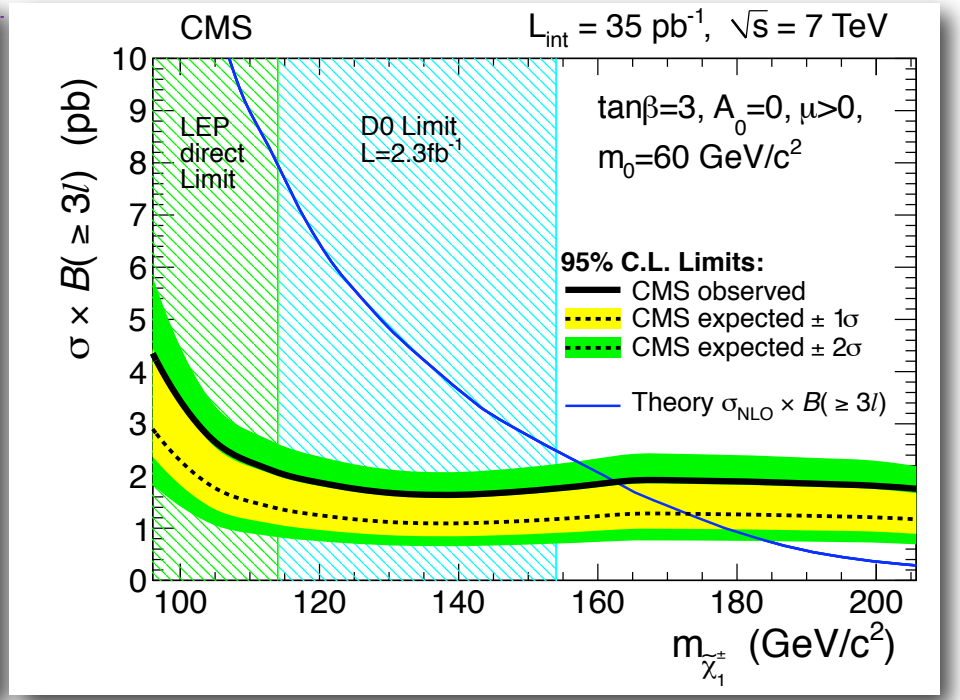
not a direct limit on $m_{\chi_1^{\pm}}$ derived from mgluino

- **not mSUGRA?** — **very likely**
- **colored particles are heavy?**
- **gaugino masses do not unify?**

LHC vs. Tevatron





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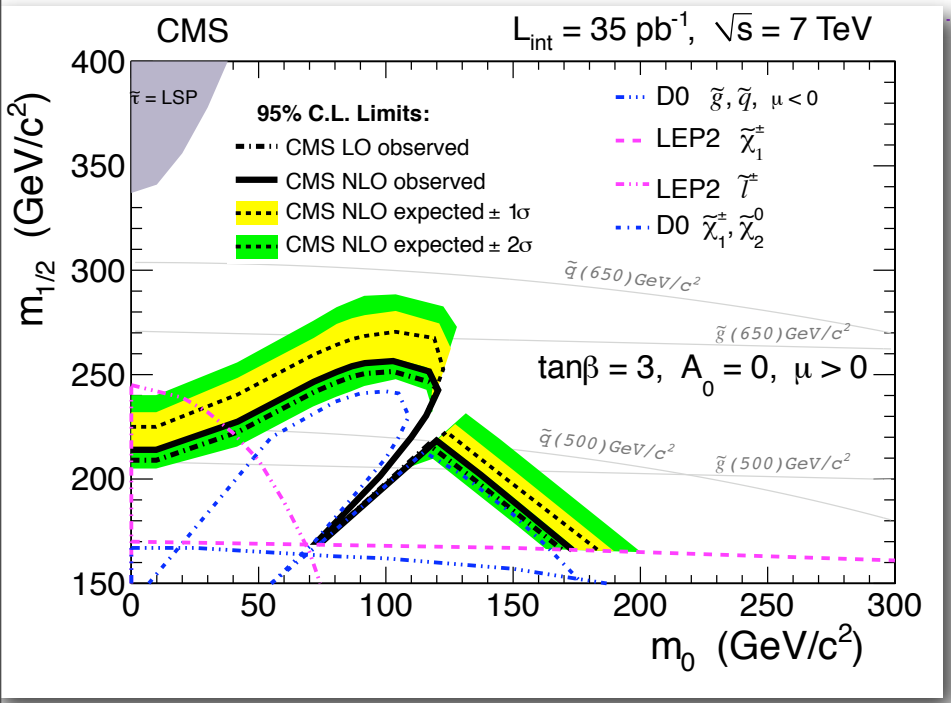

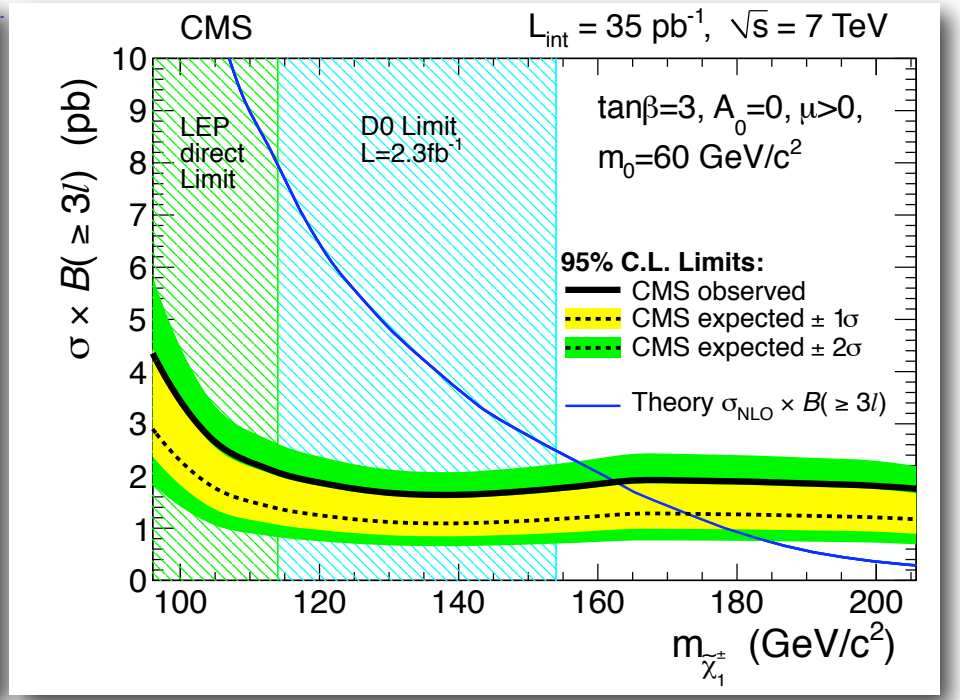

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not a direct limit on $m_{\chi_1^{\pm}}$ derived from mgluino

- not mSUGRA? — very likely
- colored particles are heavy? — likely
- gaugino masses do not unify? — likely

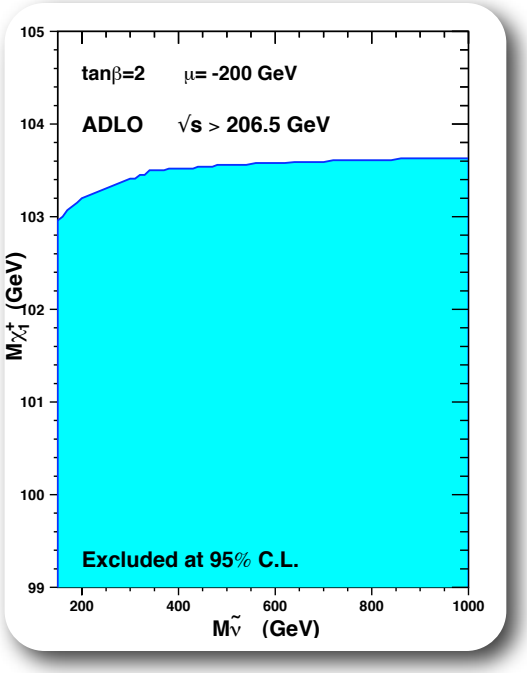
Motivation

Exploring LHC reach for the electroweak sector of MSSM
gauginos, Higgsinos and sleptons.

- DM connection
  - neutralinos: DM candidate
  - sleptons: relevant for DM annihilation process
- Superpartners of gauge bosons, Higgses, and leptons
  - suffer from small electroweak production
  - more work needs to be done regarding collider searches
  - current SUSY search strategy is not sensitive to lighter EW interacting particles (large H_T cuts reduce the signal efficiency)
- Colored superparticle might be very heavy
  - no indication from current LHC search
  - EW sector (+stop/sbottoms) might be the only particles accessible at the LHC
- Connection to Lepton Collider

Current limits: neutralino/chargino

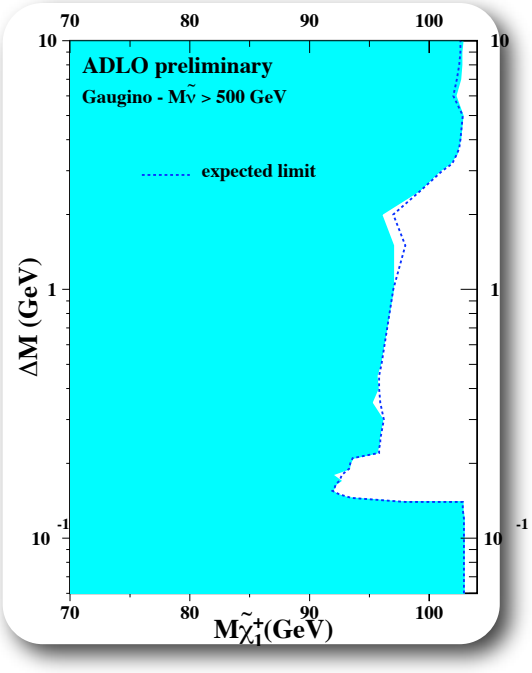
canonical case



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

LEPSUSYWG/01-03.1

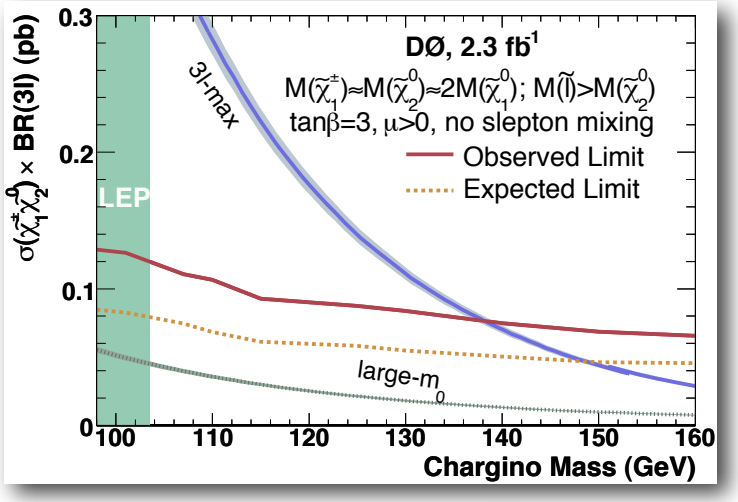
degenerate case



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

LEPSUSYWG/02-04.1

trilepton+MET from $\chi_1^\pm$ χ_2^0



$m_{\chi_1^\pm} > 138$ GeV (mSUGRA tanβ=3, A_0=0)

CDF Note 10636
D0: arXiv:0901.0646

$m_{\chi_1^0} > 47/50$ GeV (CMSSM, mSUGRA)

No mass limit in general

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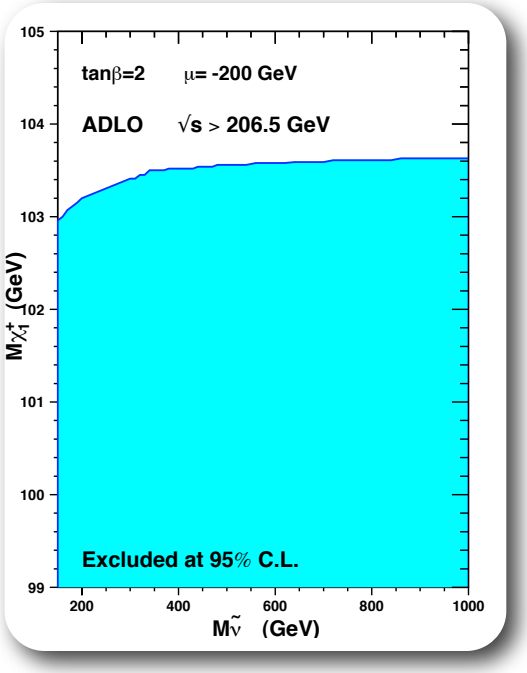
Current limits: neutralino/chargino

canonical case



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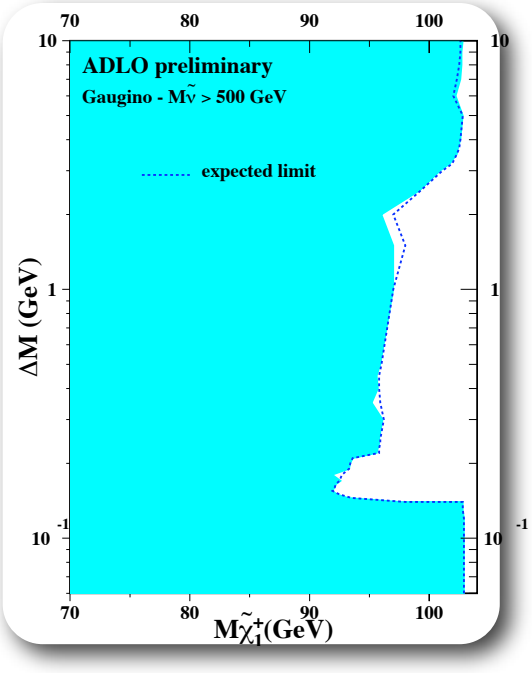

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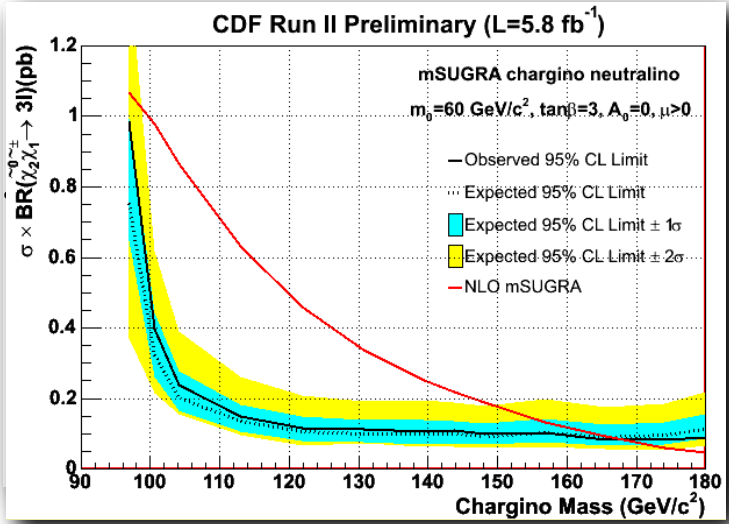


$m_{\chi_1^\pm} > 167$ GeV (mSUGRA tanβ=3, A_0=0)

CDF Note 10636
D0: arXiv:0901.0646

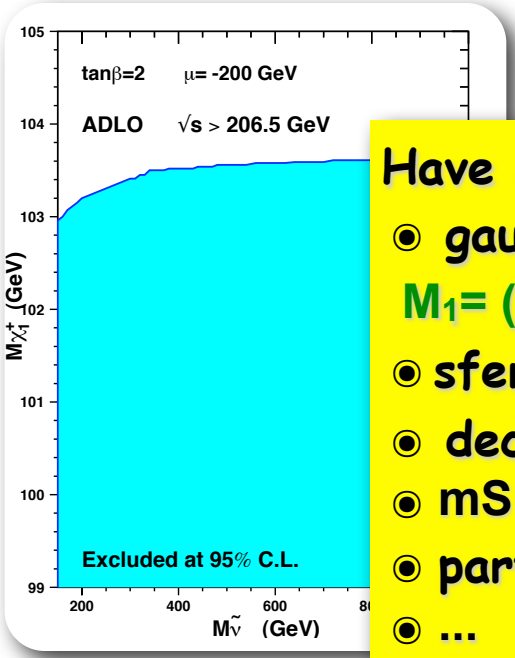
$m_{\chi_1^0} > 47/50$ GeV (CMSSM, mSUGRA)

No mass limit in general

S. Su

Current limits: neutralino/chargino

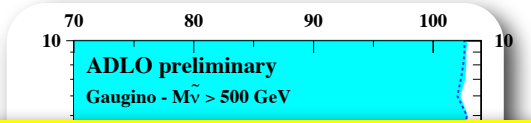
canonical case



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

LEPSUSYWG/01-03.1

degenerate case



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

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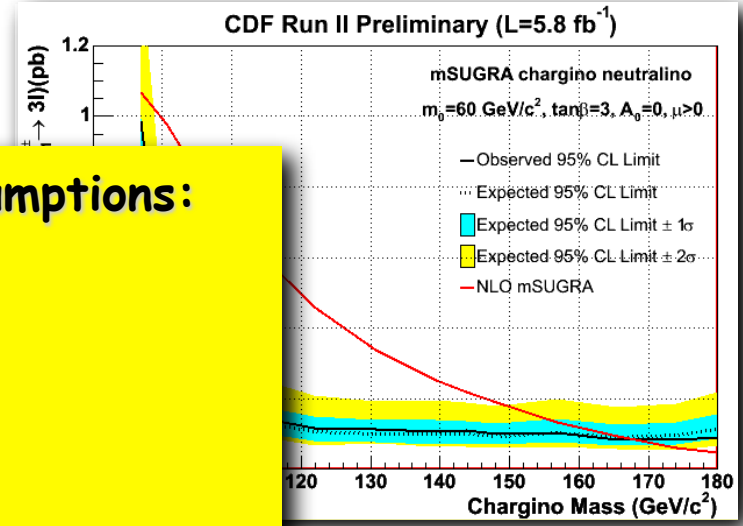

67 GeV
A tanβ=3, A_0=0)

CDF Note 10636
D0: arXiv:0901.0646

$m_{\chi_1^0} > 47/50$ GeV
(CMSSM, mSUGRA)
No mass limit in general

Have at least one of these assumptions:

- gaugino mass unification:
  $M_1 = (5/3)\tan^2\theta_W M_2 = 1/2\, M_2$
- sfermion mass unification
- decouple sfermions
- mSUGRA
- particular benchmark point
- ...

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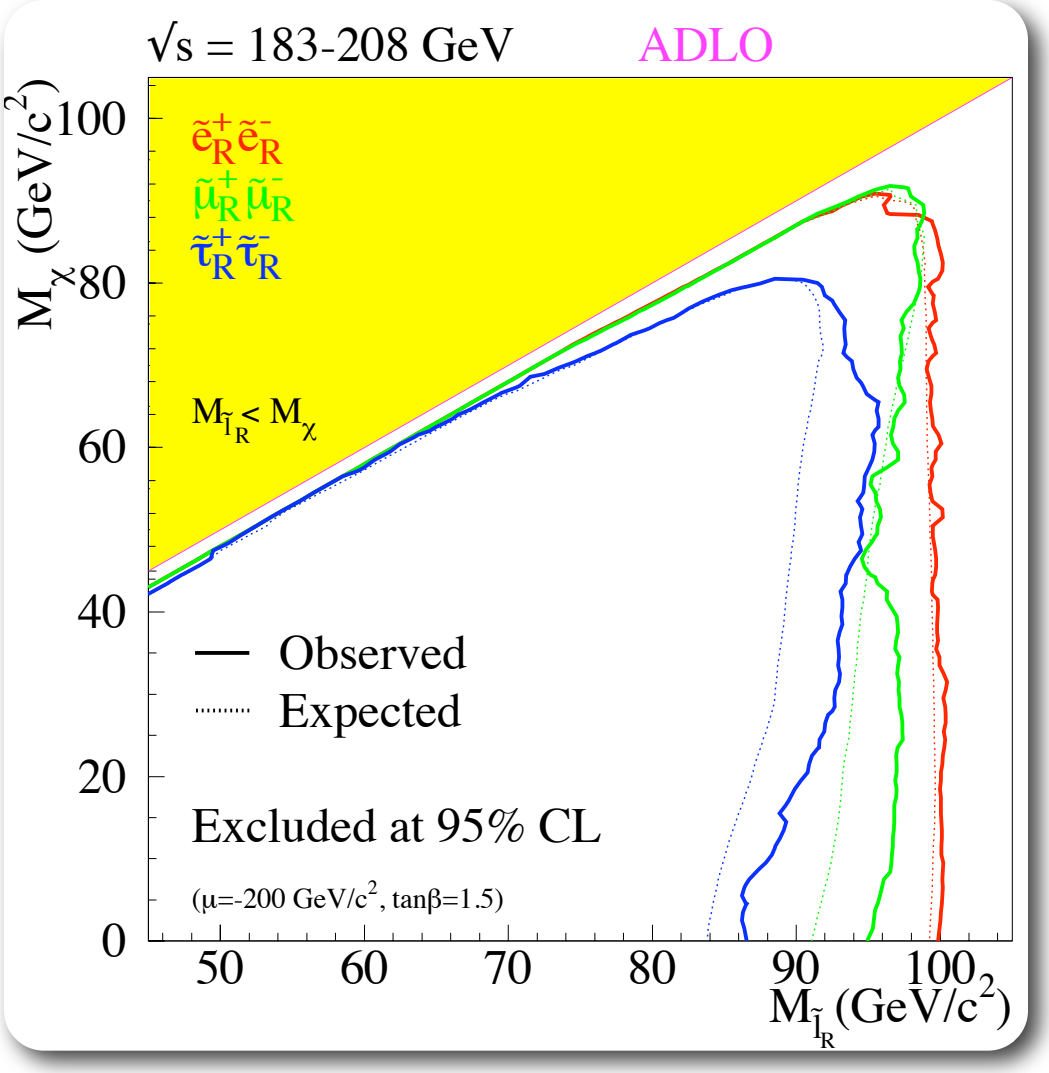
Current limits: slepton @ LEP

m_{se} > 99.6 GeV, m_{smu} > 94.9 GeV, m_{stau} > 85.9 (85.0) GeV

LEPSUSYWG/04-01.1



MSSM Electroweak sector

- 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, $\tan\beta$

- 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?)

Neutralinos

- **Neutralinos**

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_{\tilde{N}} = \begin{pmatrix} M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\ 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\ -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\ s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0 \end{pmatrix},$$

M_1	Bino
M_2	Wino
$\lvert\mu\rvert$	Higgsino
$\lvert\mu\rvert$	Higgsino

$$\begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \\ \chi_4^0 \end{pmatrix} = \begin{pmatrix} 1 & \mathcal{O}(\frac{m_Z}{M}\frac{m_Z}{M'}) & \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}\frac{m_Z}{M'}) & 1 & \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \tilde{B} \\ \tilde{W}^0 \\ \tilde{H}_d^0 \\ \tilde{H}_u^0 \end{pmatrix}$$

Charginos

- **Charginos**

$$\psi^{\pm} = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

$$M_{\tilde{C}} = \begin{pmatrix} 0_{2\times2} & X_{2\times2}^T \\ X_{2\times2} & 0_{2\times2} \end{pmatrix}, \quad \text{with} \quad X_{2\times2} = \begin{pmatrix} M_2 & \sqrt{2}s_\beta m_W \\ \sqrt{2}c_\beta m_W & \mu \end{pmatrix}$$

M_2 Wino

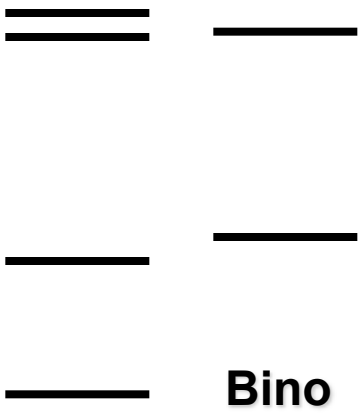
$|\mu|$ Higgsino

$$\begin{pmatrix} \chi_1^+ \\ \chi_2^+ \end{pmatrix} = \begin{pmatrix} 1 & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}) & 1 \end{pmatrix} \begin{pmatrix} \tilde{W}^+ \\ \tilde{H}_u^+ \end{pmatrix}$$

$$\begin{pmatrix} \chi_1^- \\ \chi_2^- \end{pmatrix} = \begin{pmatrix} 1 & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}) & 1 \end{pmatrix} \begin{pmatrix} \tilde{W}^- \\ \tilde{H}_d^- \end{pmatrix}$$

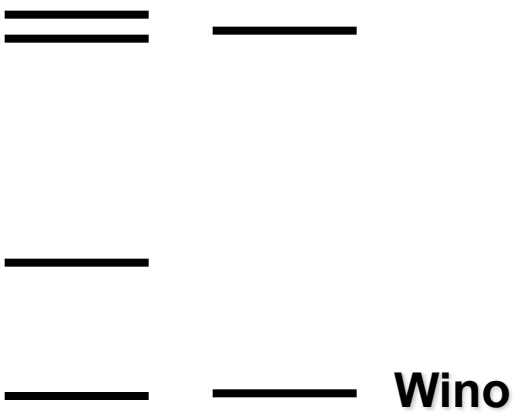
Order of M_1, M_2 and μ

Bino LSP
$M_1 < M_2, \mu$



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

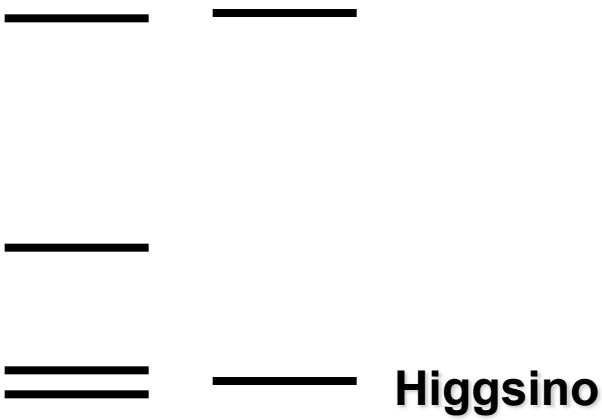
Wino LSP
$M_2 < M_1, \mu$



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

Higgsino LSP
$\mu < M_1, M_2$



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

Baer, Barger and Huang,
ArXiv: 1107.5581

Order of M_1, M_2 and μ

Bino LSP
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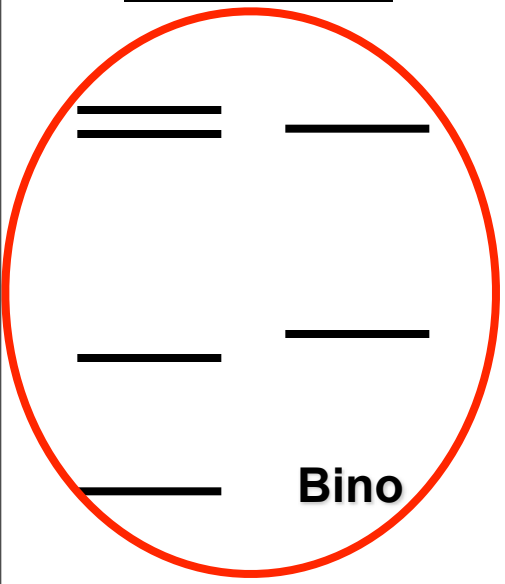

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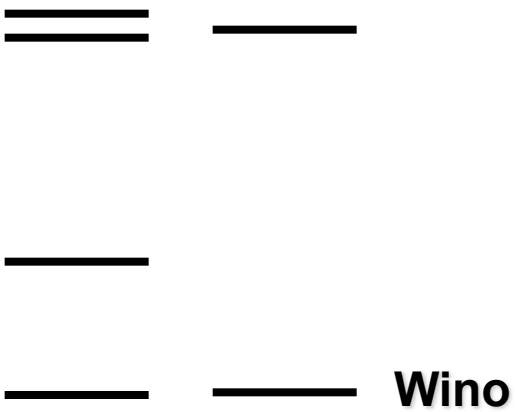

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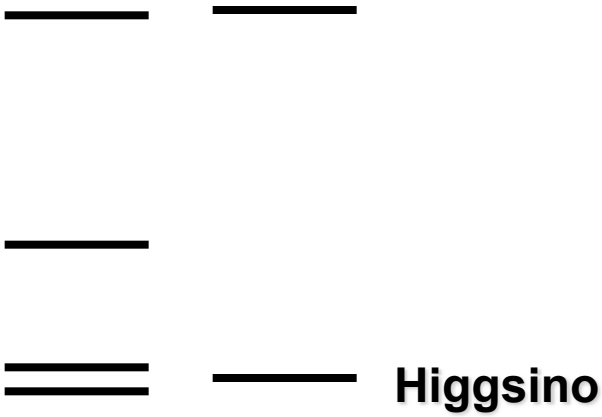

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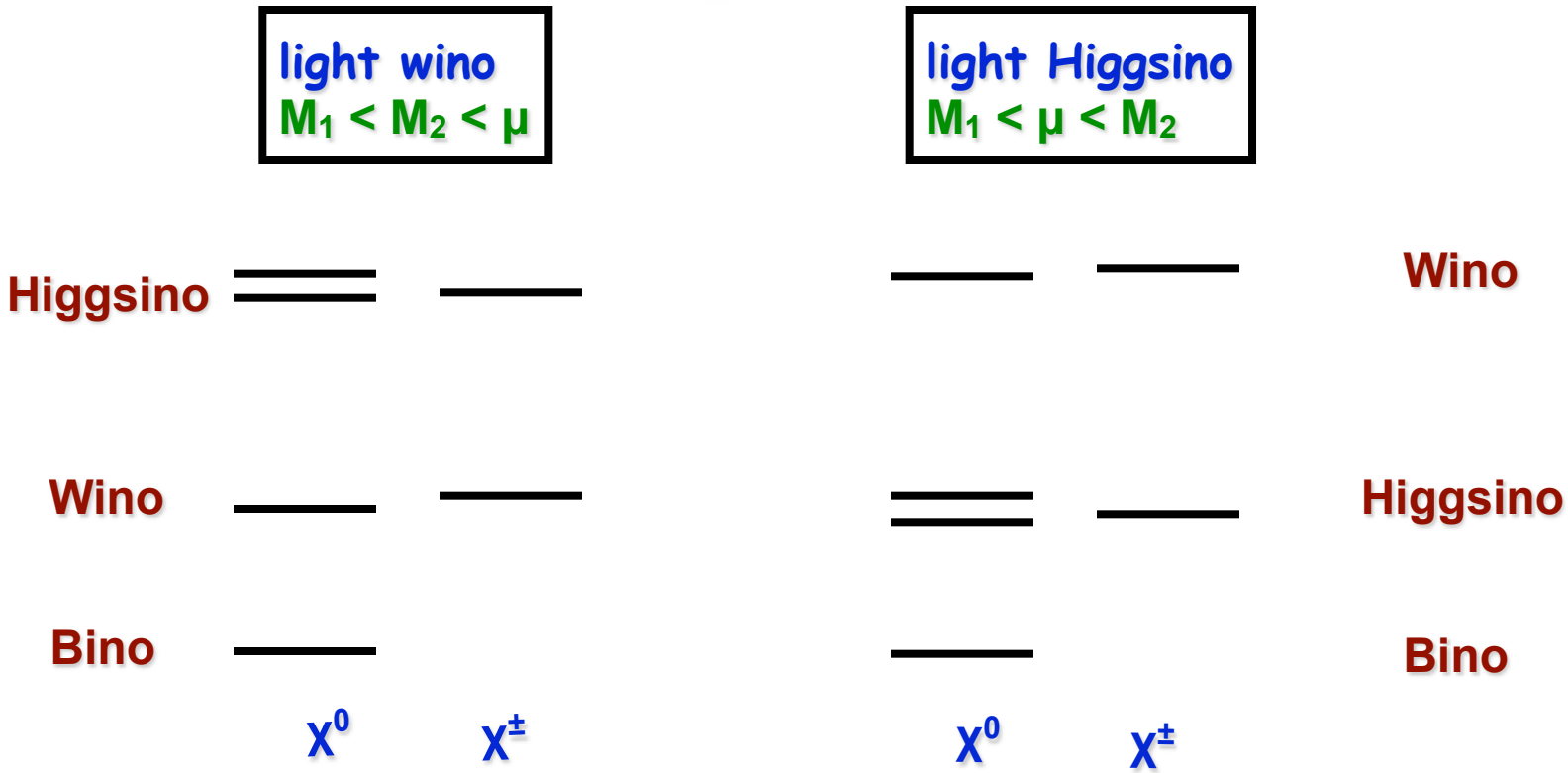
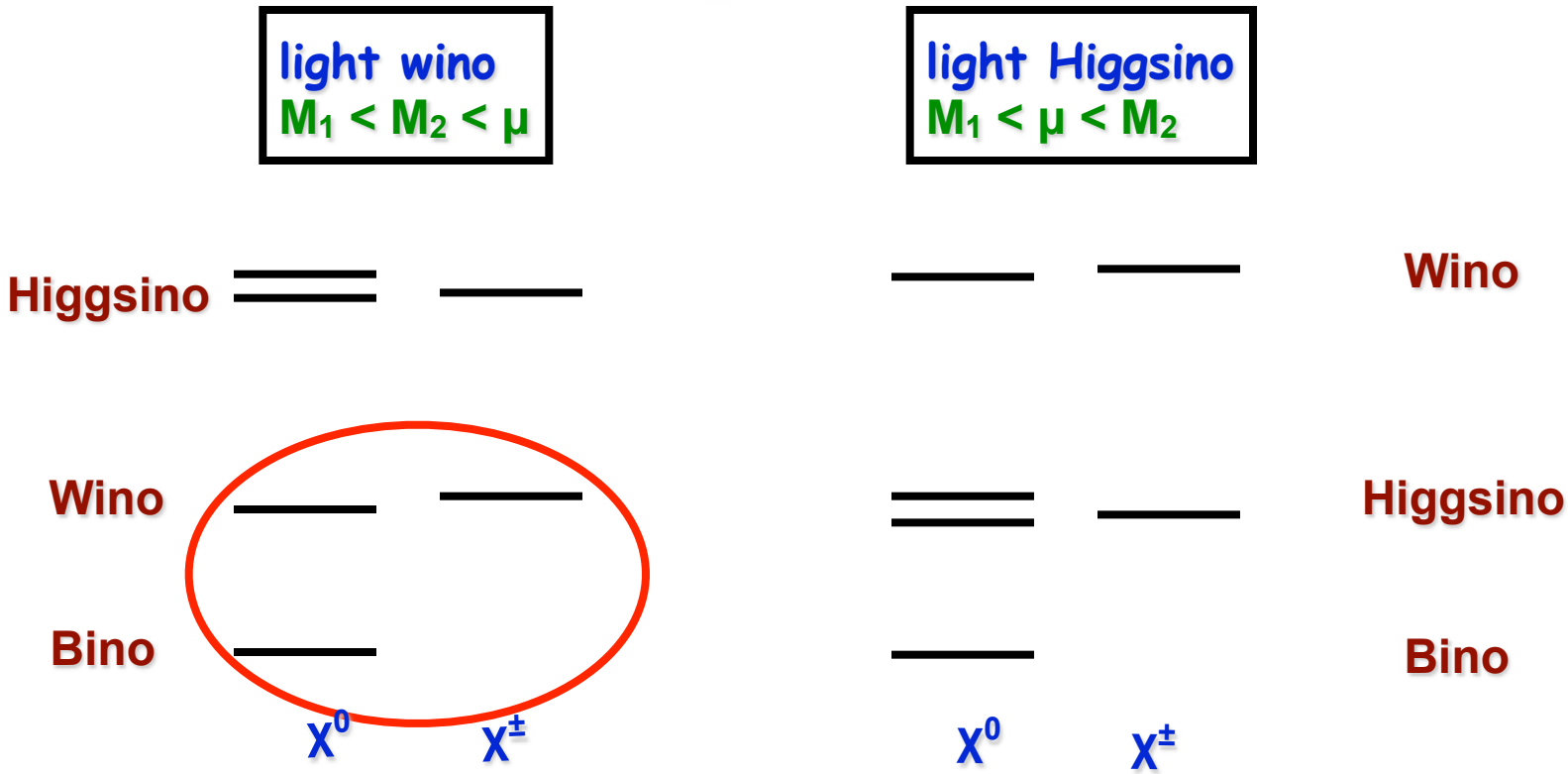
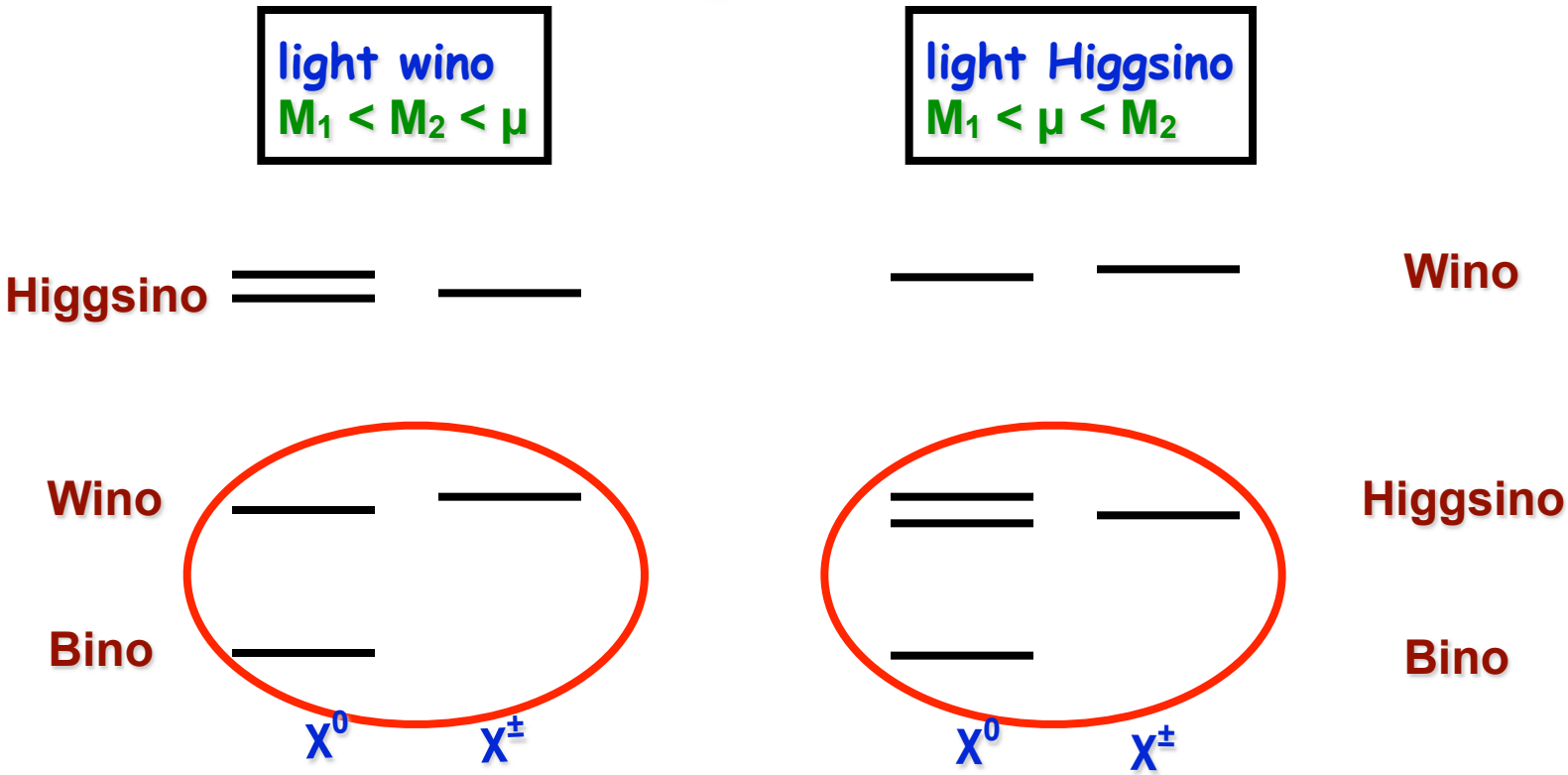
Bino LSP case



Bino LSP case

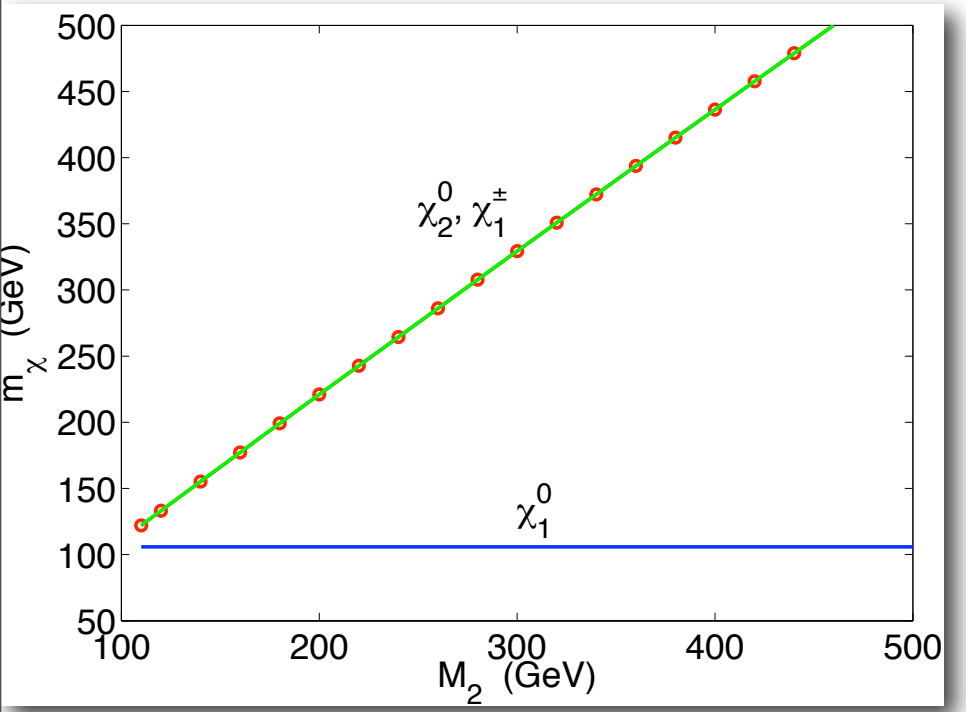


Bino LSP case

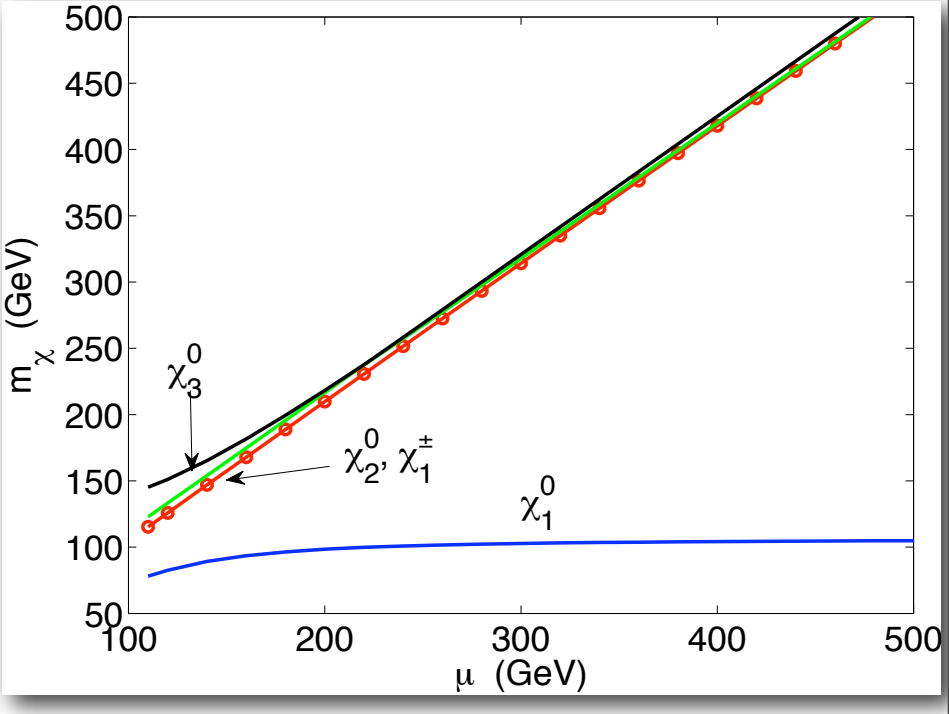


Masses

light wino $M_1 < M_2 < \mu$



light Higgsino $M_1 < \mu < M_2$

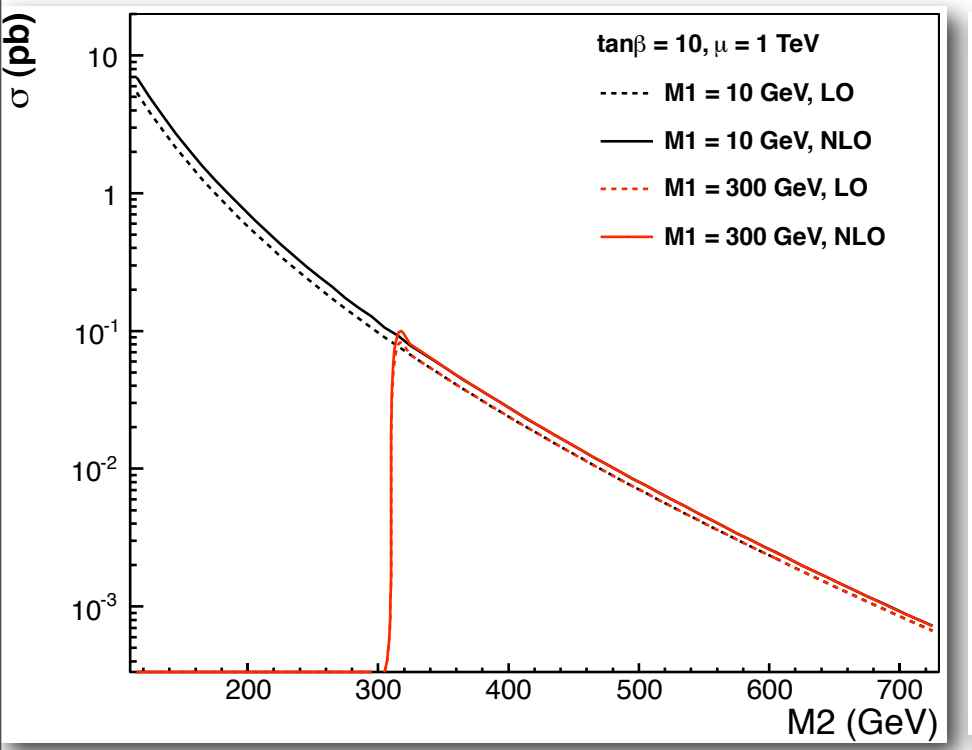


Neutralino and Chargino mixing

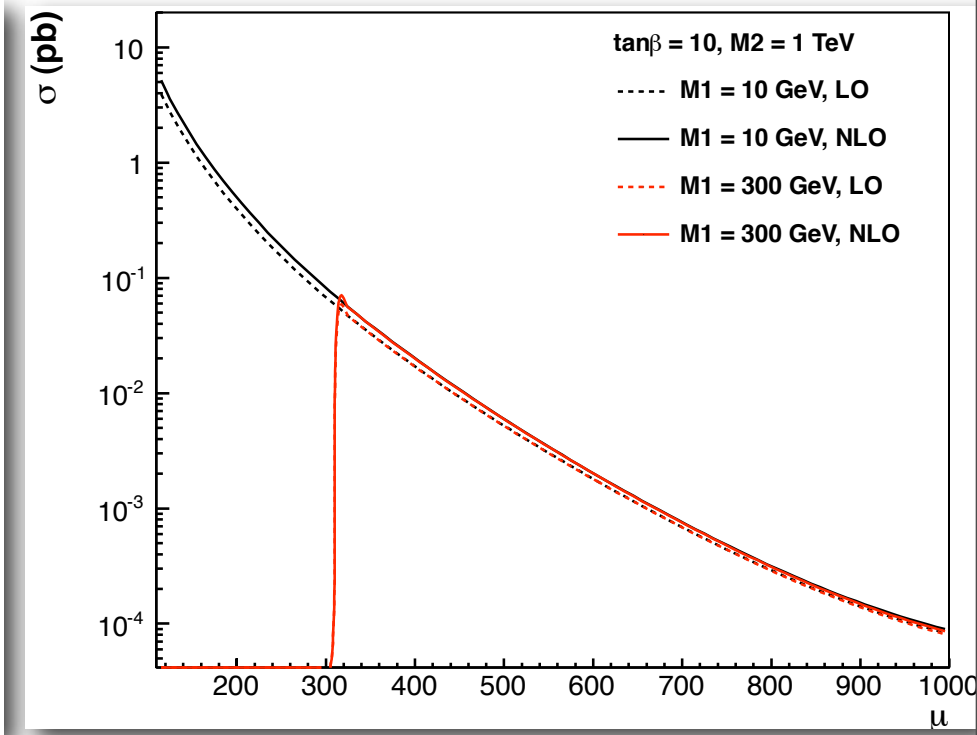
	Neutralinos	Charginos
light wino	$\chi_1^0 \sim \tilde{B} + \mathcal{O}(\frac{m_Z}{\mu})(\frac{m_Z}{M_2})\tilde{W}^0 + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_d^0 + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_u^0$ $\chi_2^0 \sim \mathcal{O}(\frac{m_Z}{\mu})(\frac{m_Z}{M_2})\tilde{B} + \tilde{W}^0 + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_d^0 + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_u^0$	$\chi_1^+ \sim \tilde{W}^+ + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_u^+$ $\chi_1^- \sim \tilde{W}^- + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_d^-$
light Higgsino	$\chi_1^0 \sim \tilde{B} + \mathcal{O}(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})\tilde{W}^0 + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_d^0 + \mathcal{O}(\frac{m_Z}{\mu})\tilde{H}_u^0$ $\chi_2^0 \sim \mathcal{O}(\frac{m_Z}{\mu})\tilde{B} + \mathcal{O}(\frac{m_Z}{M_2})\tilde{W}^0 + \frac{1}{\sqrt{2}}\tilde{H}_d^0 - \frac{1}{\sqrt{2}}\tilde{H}_u^0$ $\chi_3^0 \sim \mathcal{O}(\frac{m_Z}{\mu})\tilde{B} + \mathcal{O}(\frac{m_Z}{M_2})\tilde{W}^0 + \frac{1}{\sqrt{2}}\tilde{H}_d^0 + \frac{1}{\sqrt{2}}\tilde{H}_u^0$	$\chi_1^+ \sim \mathcal{O}(\frac{m_Z}{M_2})\tilde{W}^+ + \tilde{H}_u^+$ $\chi_1^- \sim \mathcal{O}(\frac{m_Z}{M_2})\tilde{W}^- + \tilde{H}_d^-$

Productions: Neutralinos and Charginos

light wino $M_1 < M_2 < \mu$



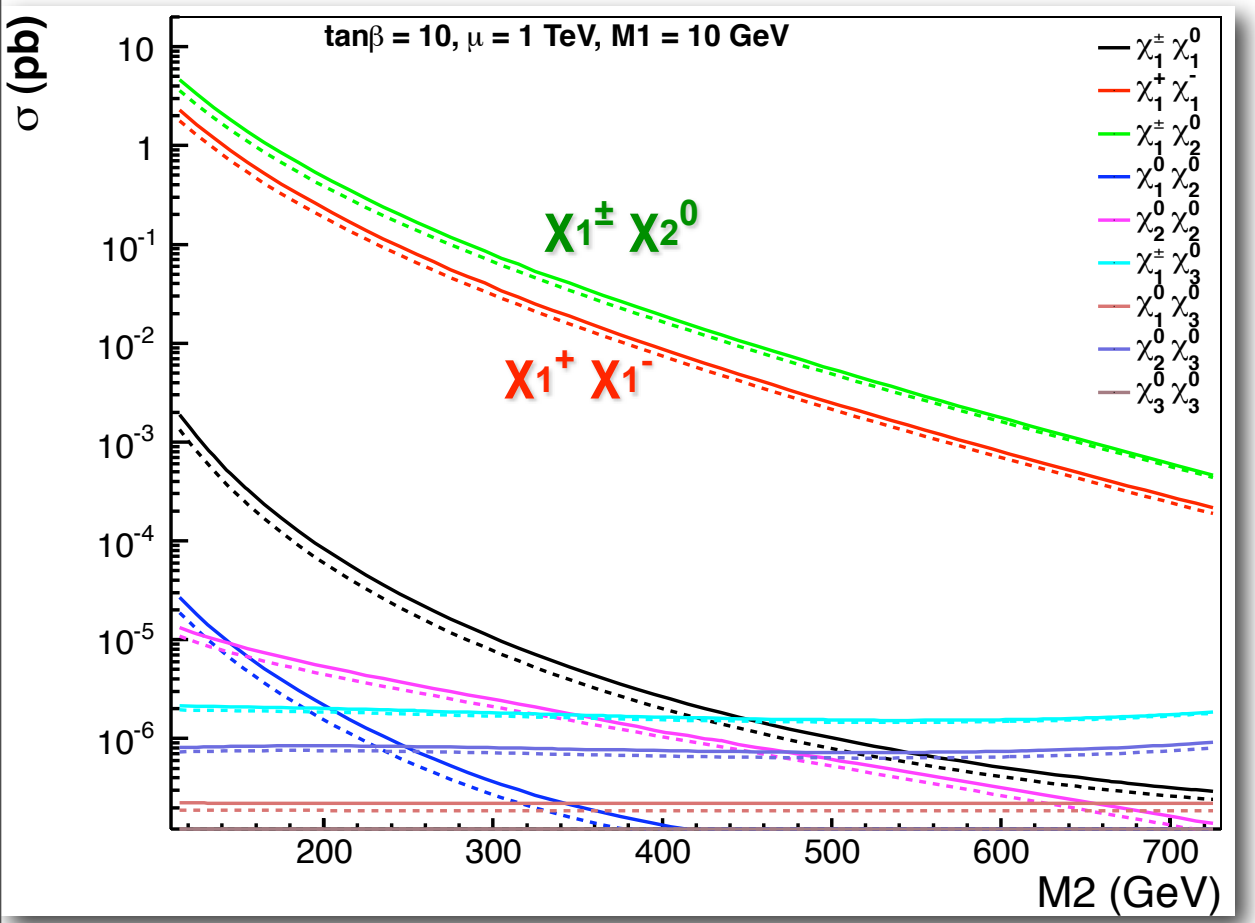
light Higgsino $M_1 < \mu < M_2$



- cross section has little dependence on M_1

Productions: contribution of subprocesses

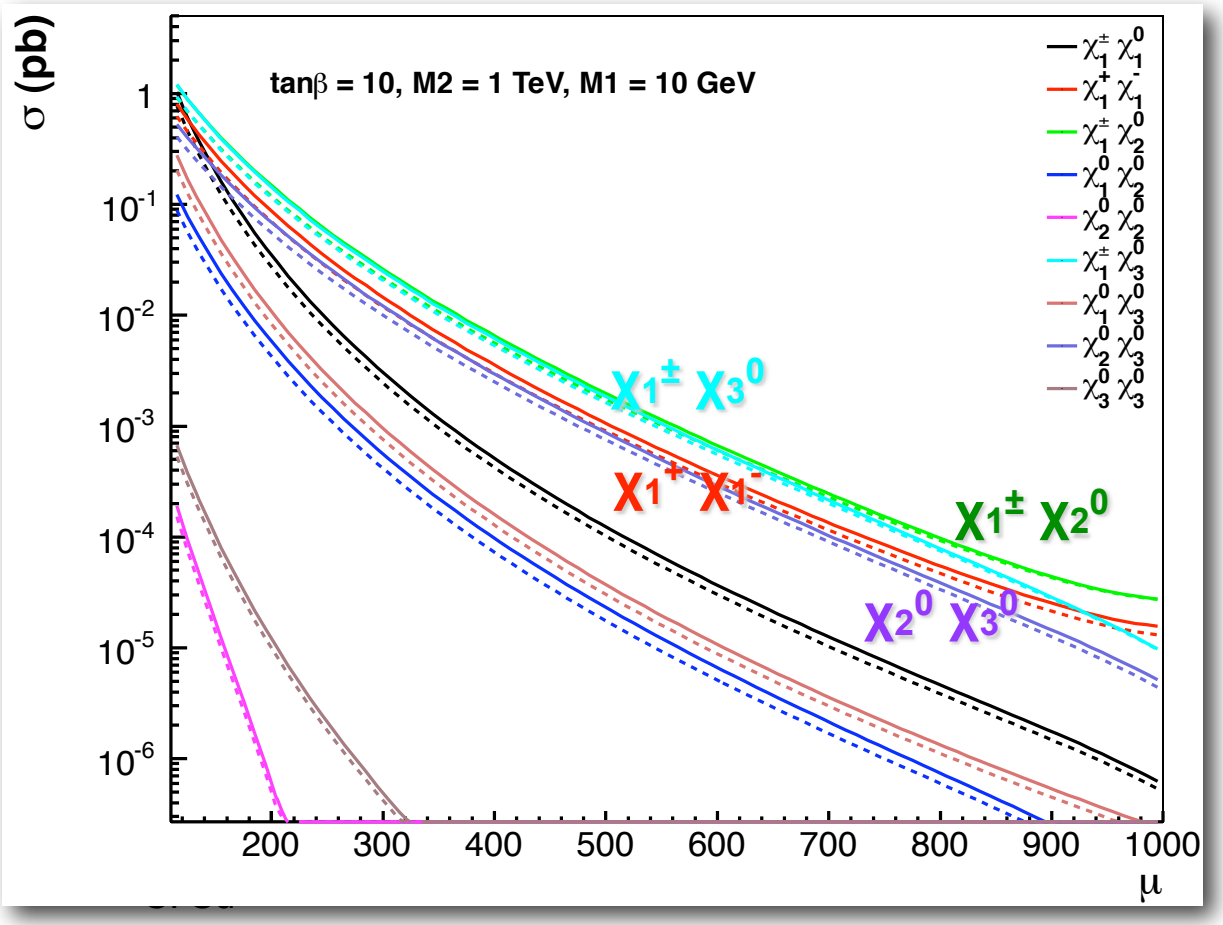
light wino $M_1 < M_2 < \mu$



	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^0\chi_1^0$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})^2$
$\chi_1^\pm\chi_1^0$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi_1^\pm\chi_1^\mp$	1	1
$\chi_1^0\chi_2^0$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_1^\pm\chi_2^0$	1	1
$\chi_2^0\chi_2^0$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{M_2})^2$
$\chi_1^\pm\chi_3^0$		1
$\chi_1^0\chi_3^0$		$(\frac{m_Z}{\mu})$
$\chi_2^0\chi_3^0$		1
$\chi_3^0\chi_3^0$		$(\frac{m_Z}{M_2})^2$

Productions: contribution of subprocesses

light Higgsino $M_1 < \mu < M_2$



	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^0\chi_1^0$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})^2$
$\chi_1^\pm\chi_1^0$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi_1^\pm\chi_1^\mp$	1	1
$\chi_1^0\chi_2^0$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_1^\pm\chi_2^0$	1	1
$\chi_2^0\chi_2^0$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{M_2})^2$
$\chi_1^\pm\chi_3^0$		1
$\chi_1^0\chi_3^0$		$(\frac{m_Z}{\mu})$
$\chi_2^0\chi_3^0$		1
$\chi_3^0\chi_3^0$		$(\frac{m_Z}{M_2})^2$

Neutralino/Chargino decays

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1

Neutralino/Chargino decays

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1

on-shell decay to h dominate over on-shell Z, slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1

on-shell decay to h dominate over on-shell Z, slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$

on-shell decay to h dominate over on-shell Z, slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

decay to on-shell slL, snuL dominant once it is open.

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$

on-shell decay to h dominate over on-shell Z, slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

decay to on-shell sIL, snuL dominant once it is open.

off-shell sIL/snuL dominate over off-shell Z/W

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$

on-shell decay to h dominate over on-shell Z, slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

decay to on-shell slL, snuL dominant once it is open.

off-shell slL/snuL dominate over off-shell Z/W

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$

on-shell decay to h dominate over on-shell Z, slepton

on-shell/off-shell decay via Z/W dominate over slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

decay to on-shell slL, snuL dominant once it is open.

off-shell slL/snuL dominate over off-shell Z/W

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$
$\chi_2^0 \to \ell\tilde{\ell}_R$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$

on-shell decay to h dominate over on-shell Z, slepton

on-shell/off-shell decay via Z/W dominate over slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

slR does not affect $m_{\chi_1^\pm}$ decay, except stau via LR mixing

decay to on-shell slL, snuL dominant once it is open.

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$
$\chi_2^0 \to \ell\tilde{\ell}_R$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$

on-shell decay to h dominate over on-shell Z, slepton

off-shell slL/snuL dominate over off-shell Z/W

on-shell/off-shell decay via Z/W dominate over slepton

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

slR does not affect $m_{\chi_1^\pm}$ decay, except stau via LR mixing

decay to on-shell slL, snuL dominant once it is open.

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$
$\chi_2^0 \to \ell\tilde{\ell}_R$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$

on-shell decay to h dominate over on-shell Z, slepton

off-shell slL/snuL dominate over off-shell Z/W

on-shell/off-shell decay via Z/W dominate over slepton

slR important as the only on-shell decay

Neutralino/Chargino decays

on-shell decay to h dominate over on-shell Z

$\chi_1^\pm$ decay 100% via on/off-shell W when no light slepton

slR does not affect $m_{\chi_1^\pm}$ decay, except stau via LR mixing

decay to on-shell slL, snuL dominant once it is open.

	light Wino $M_2 < \mu$	light Higgsino $\mu < M_2$
$\chi_1^\pm \to \chi_1^0 W^\pm$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$
$\chi^\pm \to \ell\tilde{\nu}_\ell, \tilde{\ell}\nu_\ell$	1	$(\frac{m_Z}{M_2})$
$\chi_2^0 \to \chi_1^0 Z$	$(\frac{m_Z}{\mu})^2$	$(\frac{m_Z}{\mu})$
$\chi_2^0 \to \chi_1^0 h$	$(\frac{m_Z}{\mu})$	1
$\chi_2^0 \to \ell\tilde{\ell}_L, \nu_\ell\tilde{\nu}_\ell$	1	$(\frac{m_Z}{\mu}), (\frac{m_Z}{M_2})$
$\chi_2^0 \to \ell\tilde{\ell}_R$	$(\frac{m_Z}{M_2})(\frac{m_Z}{\mu})$	$(\frac{m_Z}{\mu})$

on-shell decay to h dominate over on-shell Z, slepton

off-shell slL/snuL dominate over off-shell Z/W

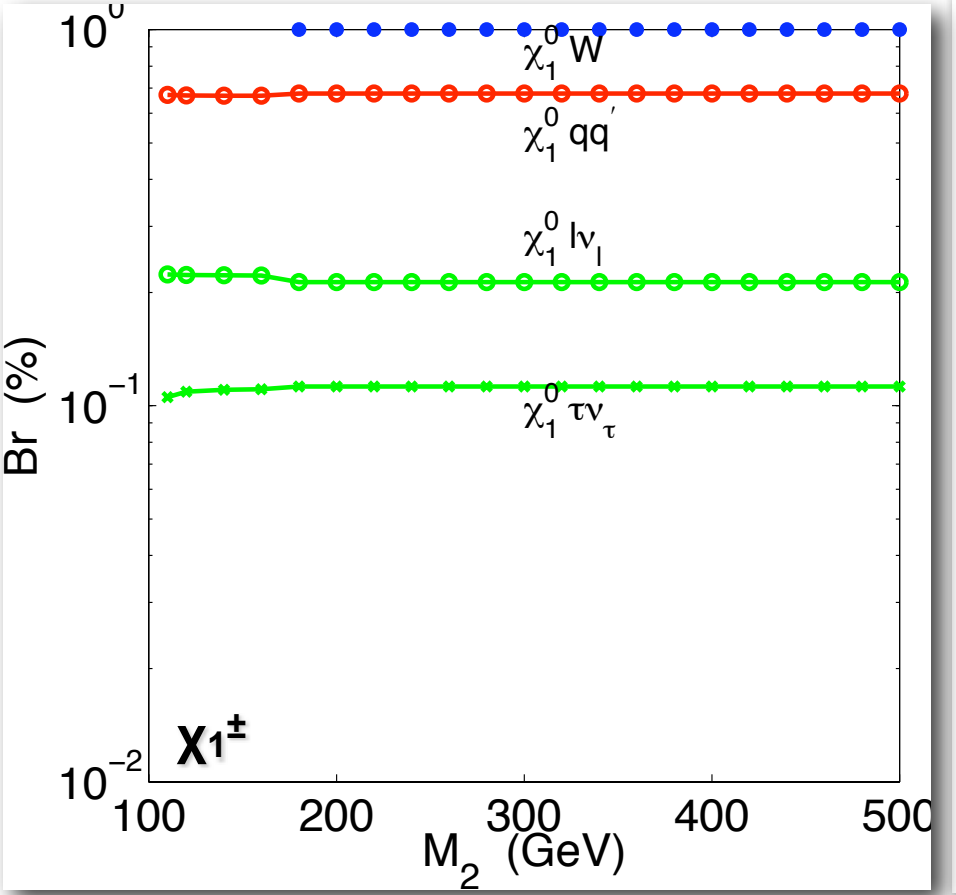
on-shell/off-shell decay via Z/W dominate over slepton

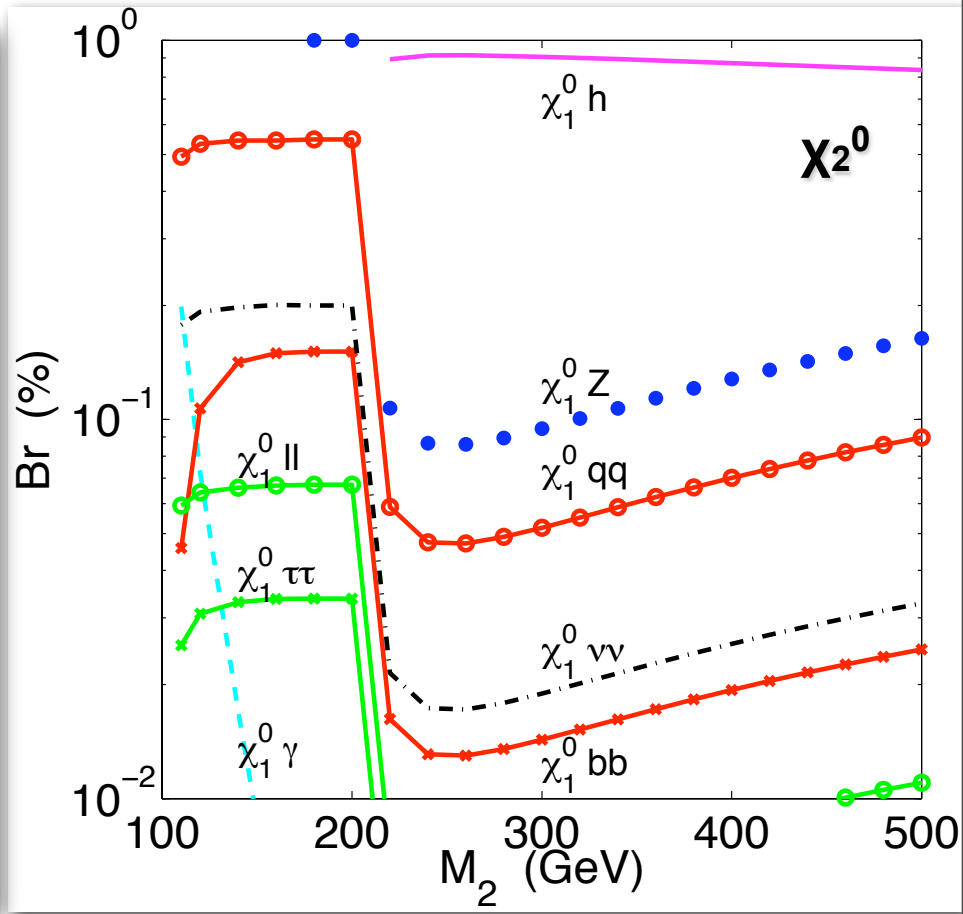
slR important as the only on-shell decay

slepton important as the only on-shell decay

$\chi_1^\pm$ decay with decoupled slepton

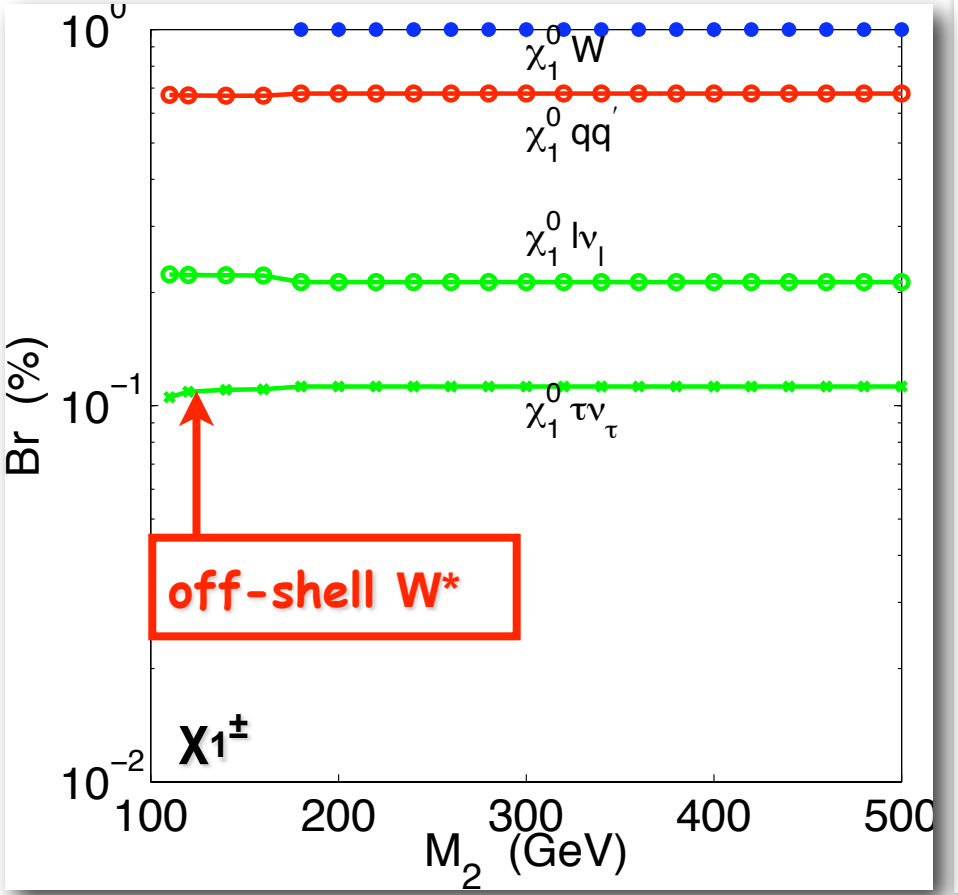
light wino $M_1 < M_2 < \mu$

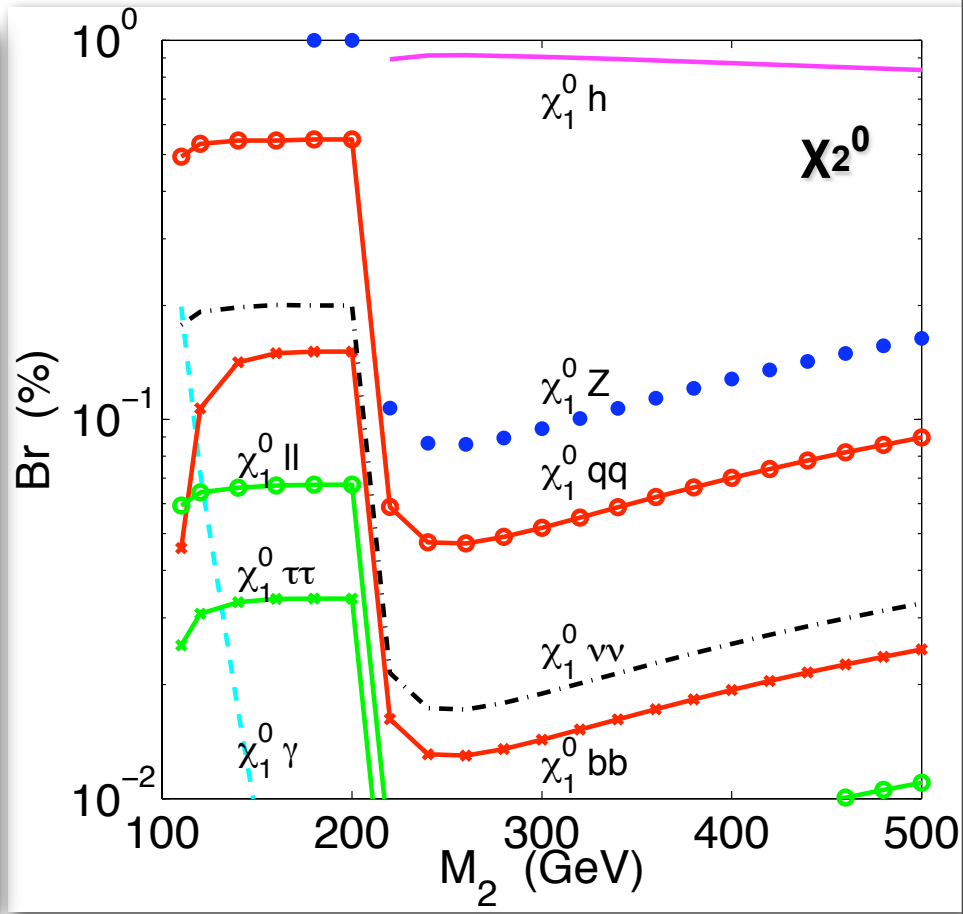




$\chi_1^\pm$ decay with decoupled slepton

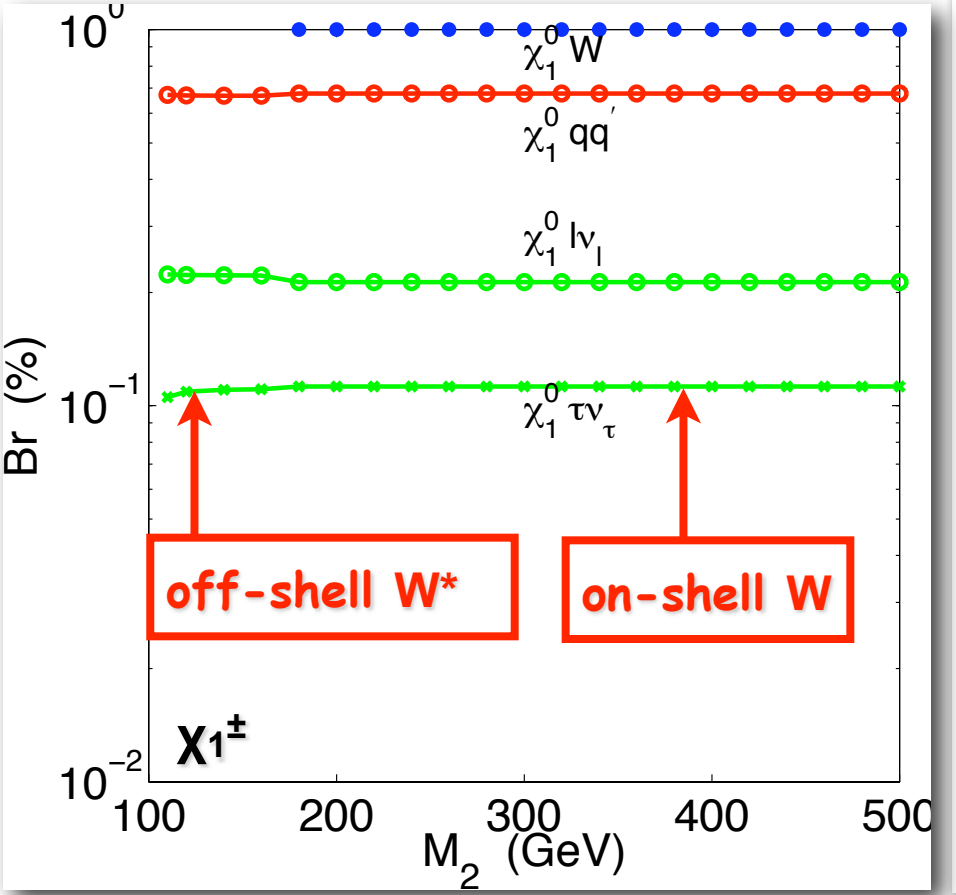
light wino $M_1 < M_2 < \mu$

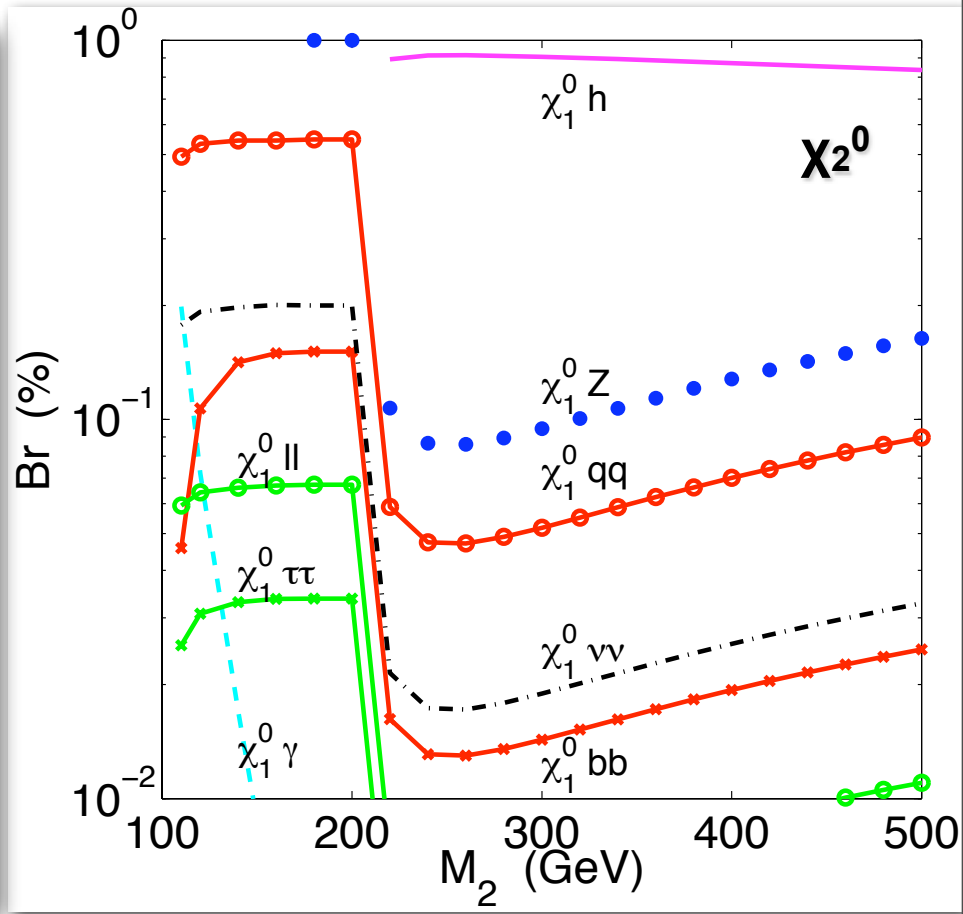




$\chi_1^\pm$ decay with decoupled slepton

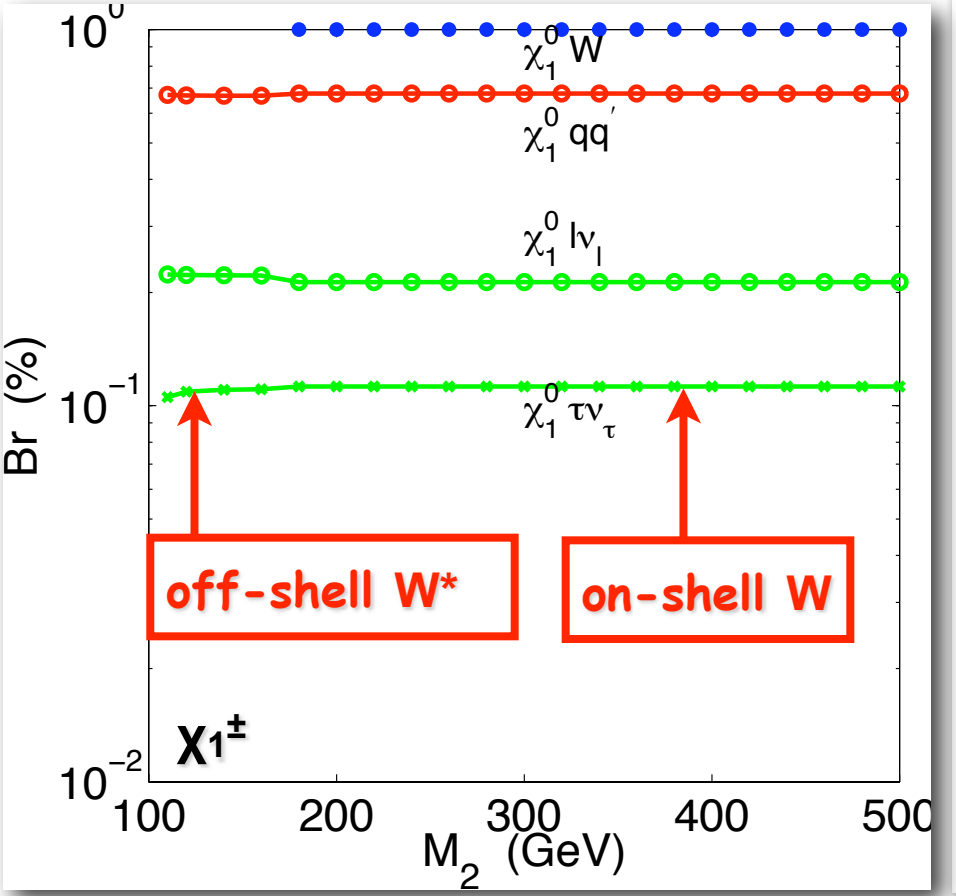
light wino $M_1 < M_2 < \mu$

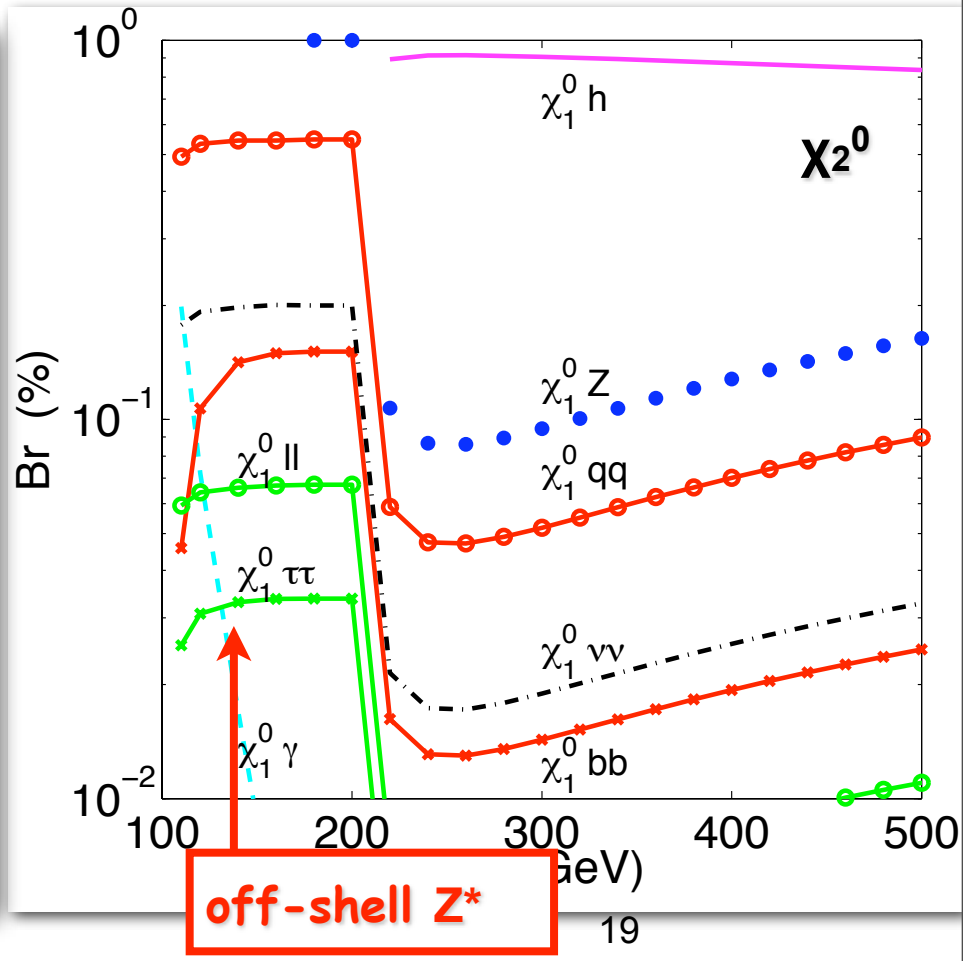




$\chi_1^\pm$ decay with decoupled slepton

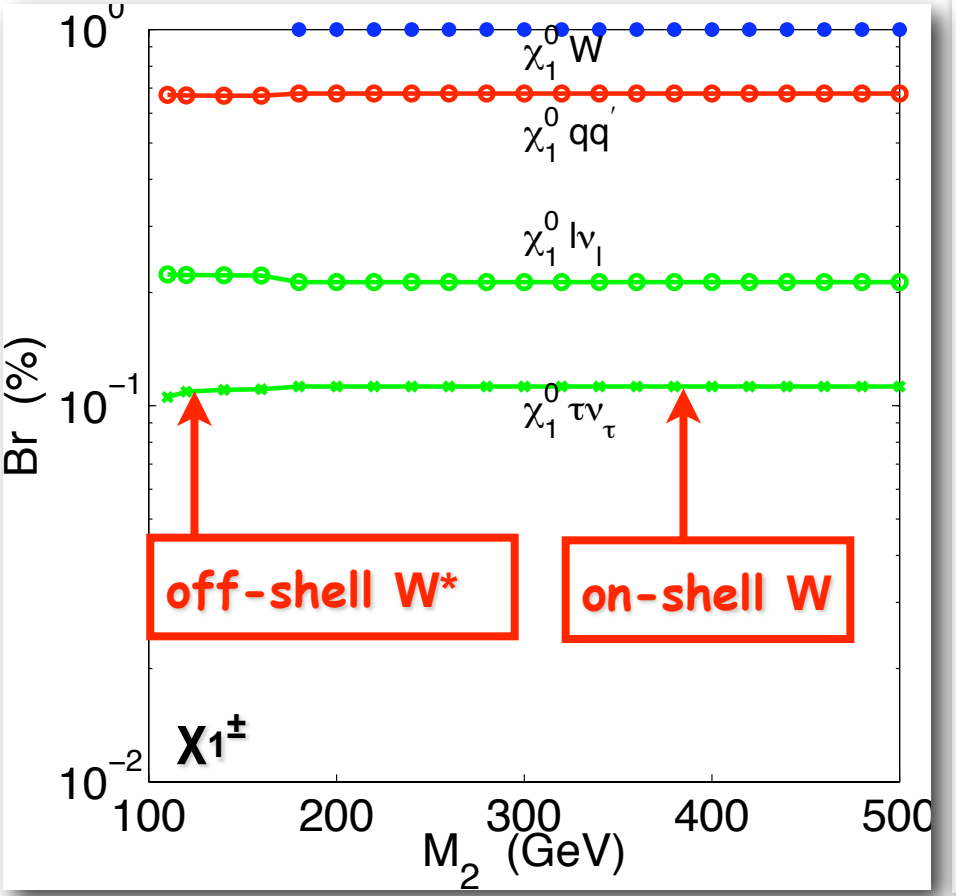
light wino $M_1 < M_2 < \mu$

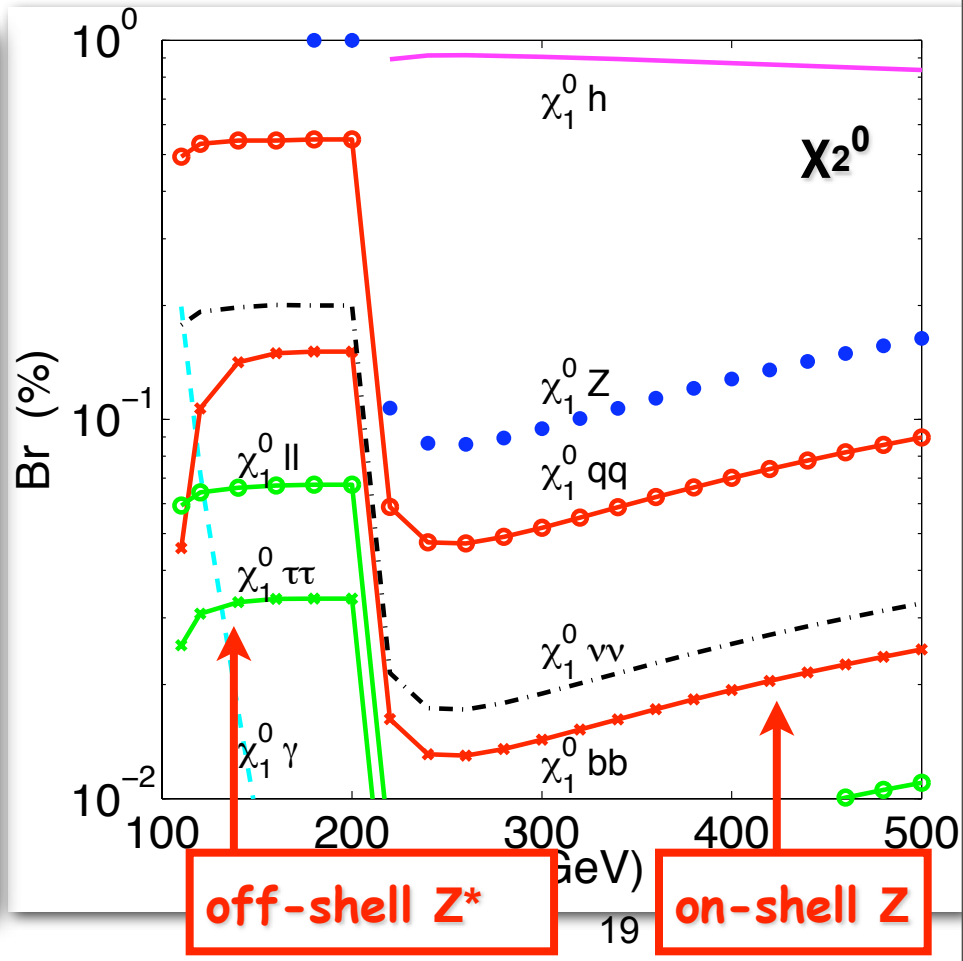




$\chi_1^\pm$ decay with decoupled slepton

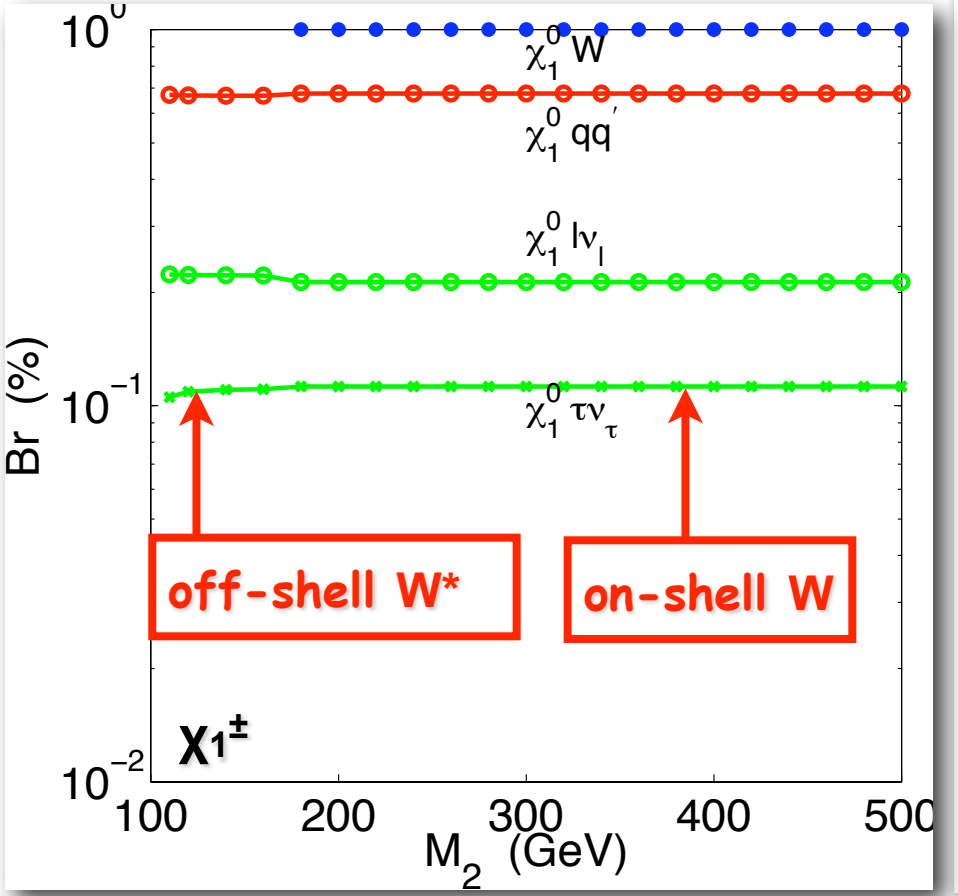
light wino $M_1 < M_2 < \mu$

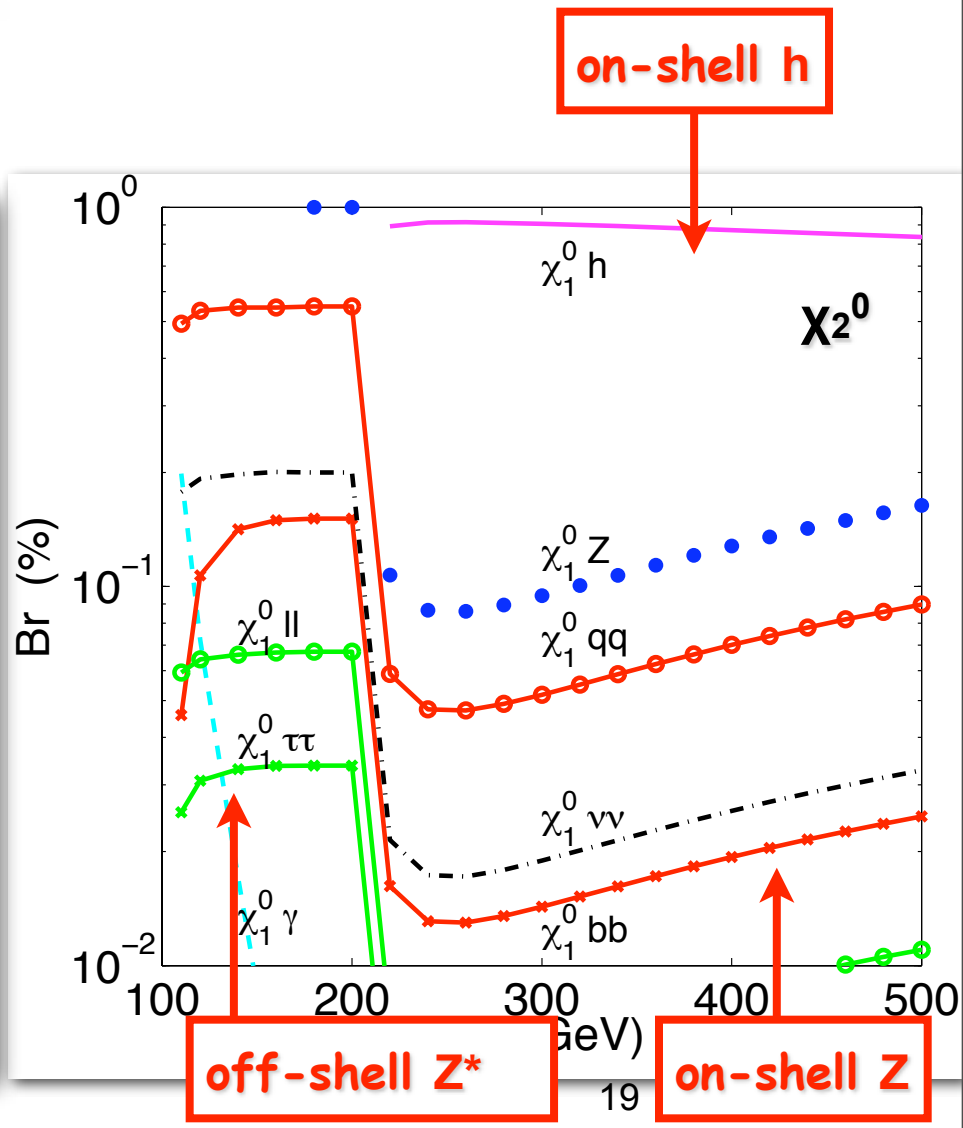




$\chi_1^\pm$ decay with decoupled slepton

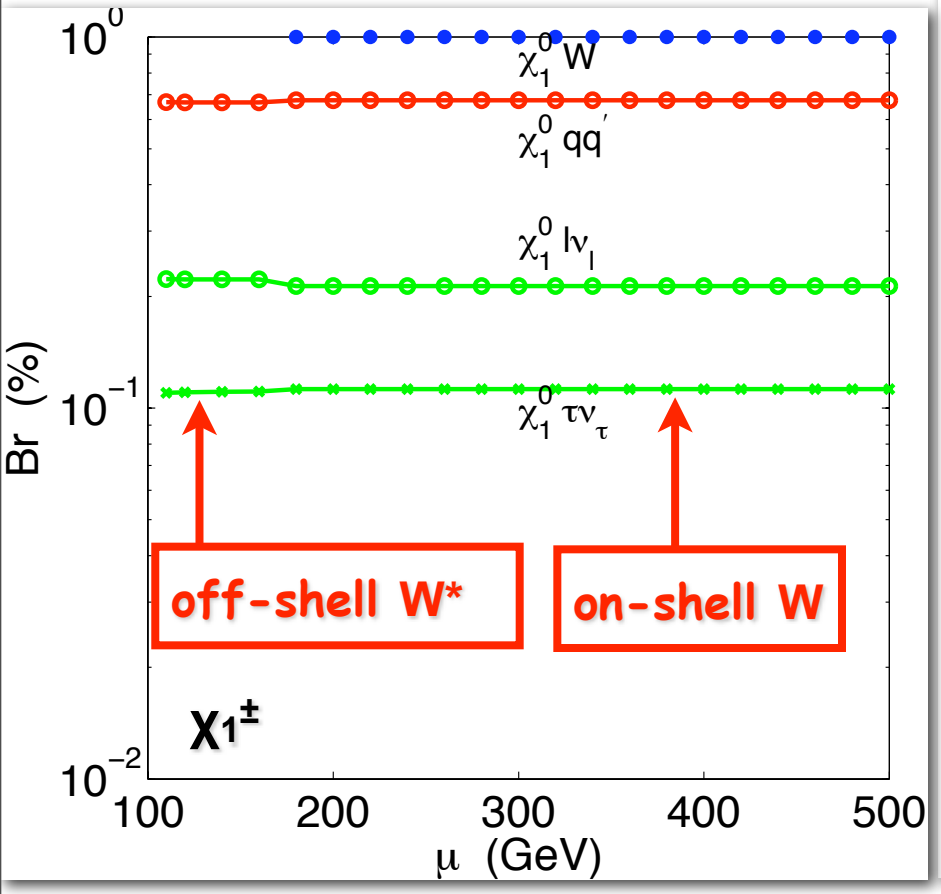
light wino $M_1 < M_2 < \mu$

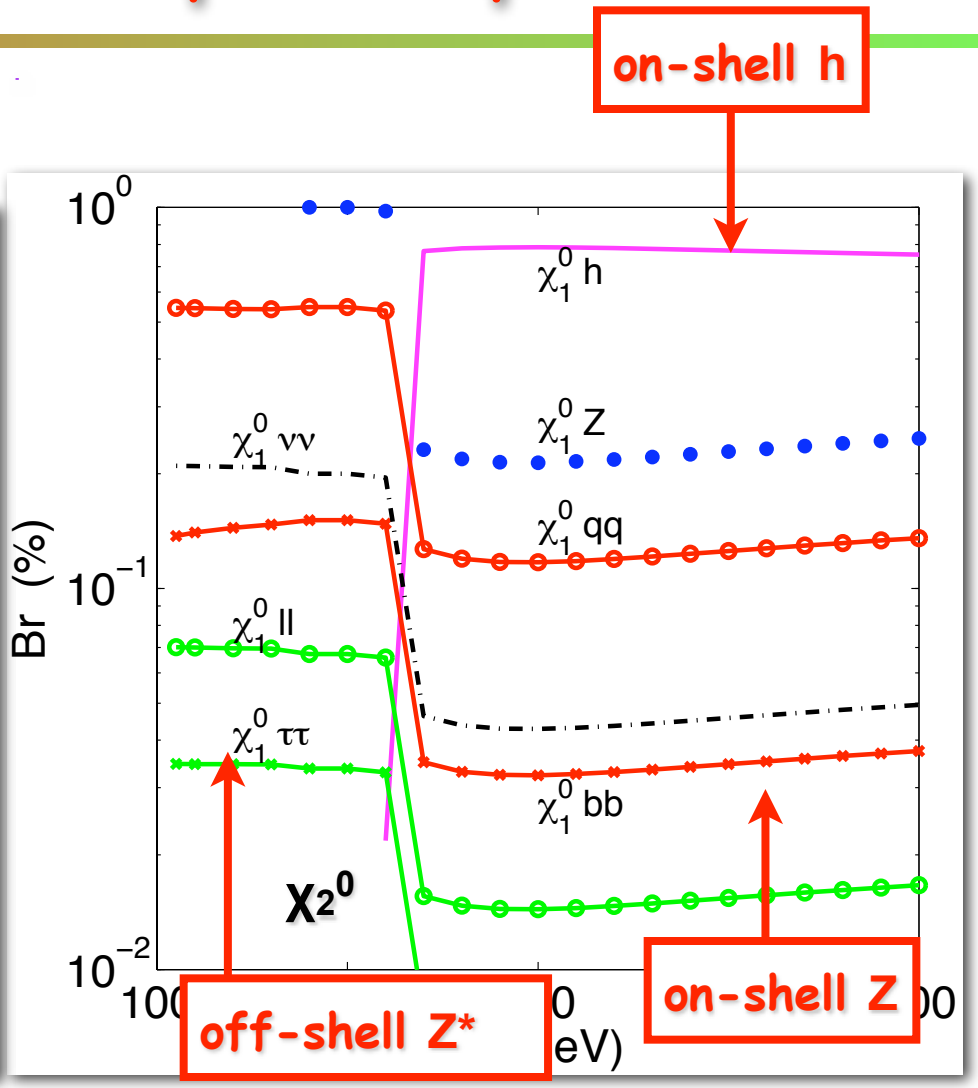




χ_2^0 decay with decoupled slepton

light Higgsino $M_1 < \mu < M_2$





- χ_3^0 decay similar to χ_2^0, except opening of decay to $\chi_1^\pm$, χ_2^0 for small μ

LHC searches

Collider signatures
- jets + MET
- 1l + jets + MET
- OS2l + jets + MET
- SS2l + jets + MET: include trilepton

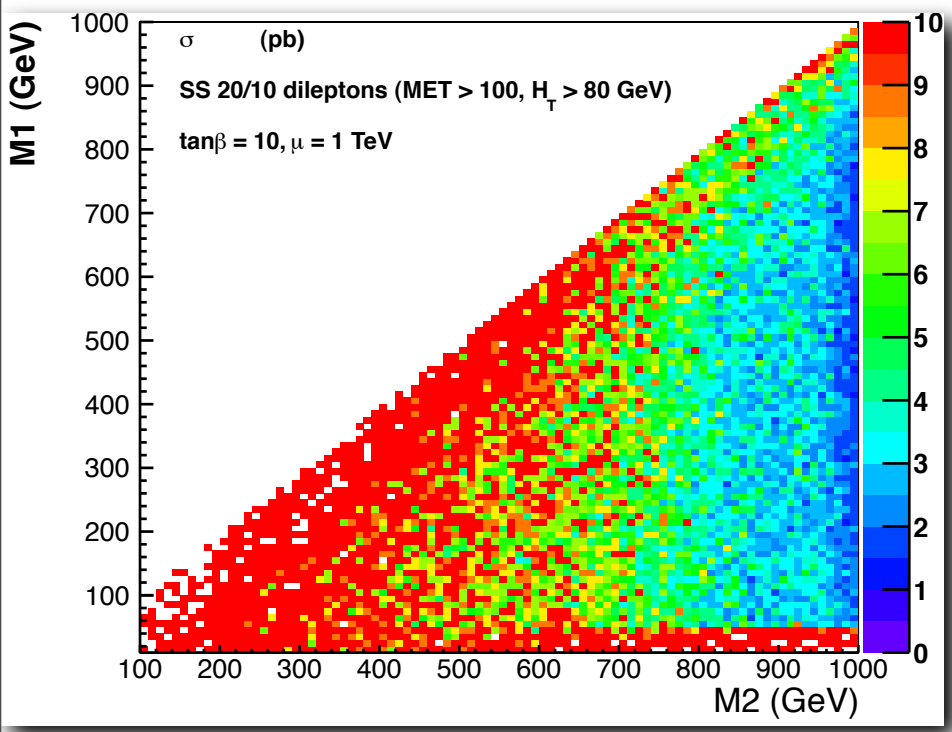
Validation of Monte-Carlo: compare with CMS analyses for Luminosity up to 1 fb^{-1}
LM1, event field from CMS single lepton study: 8.7 ± 0.1
Our simulation: 8.77

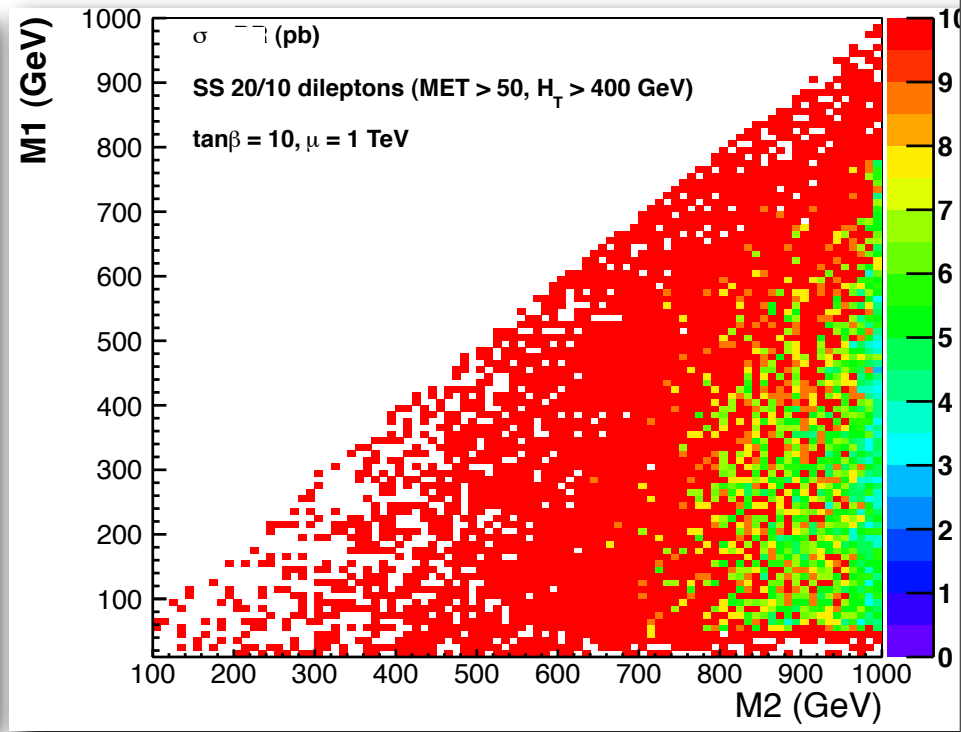
- Upper limit at 95% CL on event yield using existing CMS searches

	L		observed	BG	95%CL
jets + MET	1.1 fb^{-1}	8 channels	...	...	...
1l + jets + MET	36 pb^{-1}		29	27 ± 7.0	24
OS2l + jets + MET	0.98 fb^{-1}	high MET	8	4.2 ± 1.3	10
		high HT	4	5.1 ± 1.7	5.3
SS2l + jets + MET	0.98 fb^{-1}	7 channels	...	...	...

95% CL upper limit on cross sections

SS2l+jets + MET

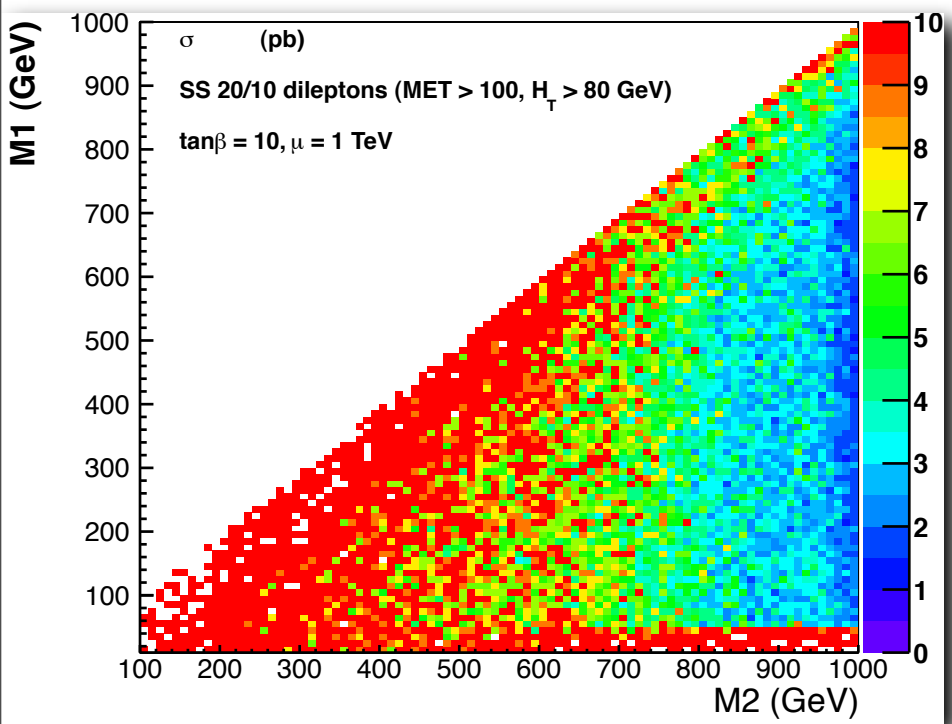


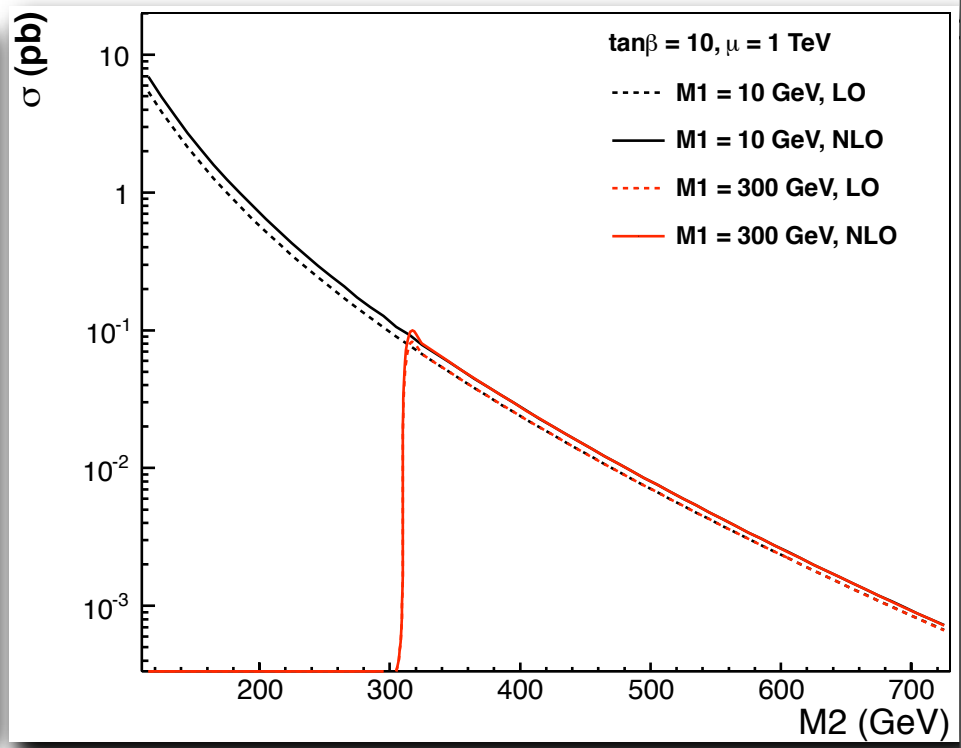


- low H_T cut has better reach!
- probably best exclusion channel among four searches

95% CL upper limit on cross sections

SS2l+jets + MET





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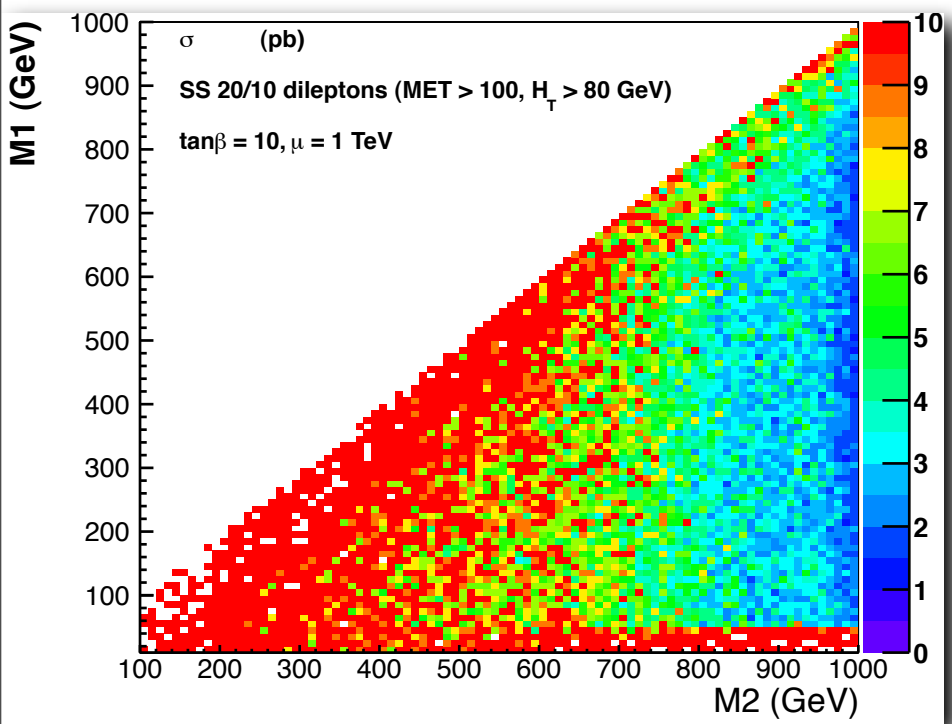
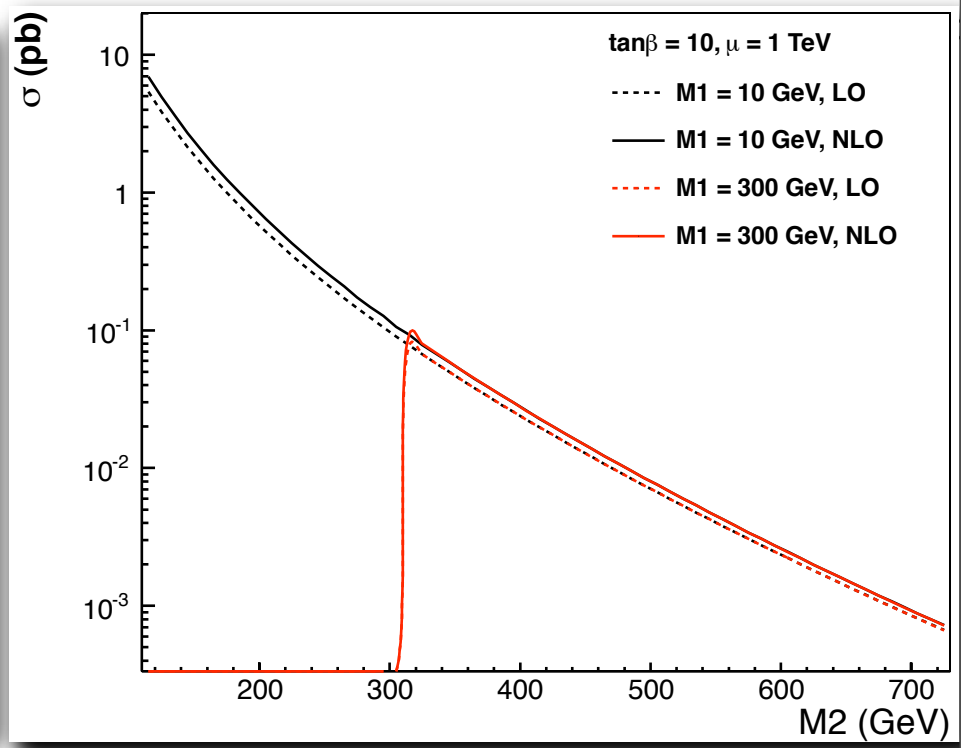
95% CL upper limit on cross sections

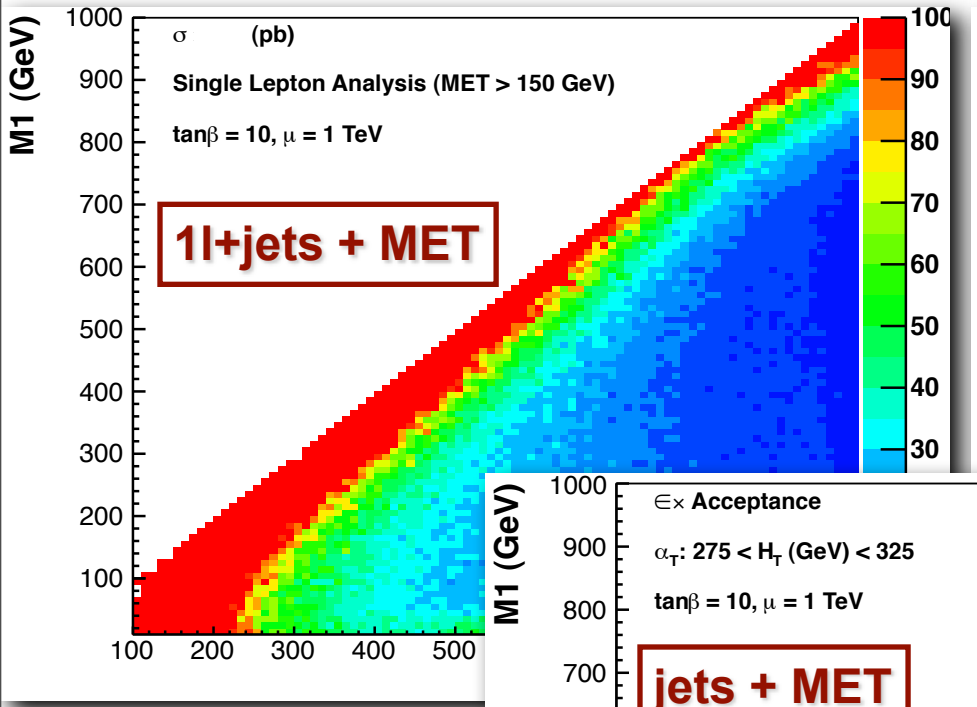
SS2l+jets + MET

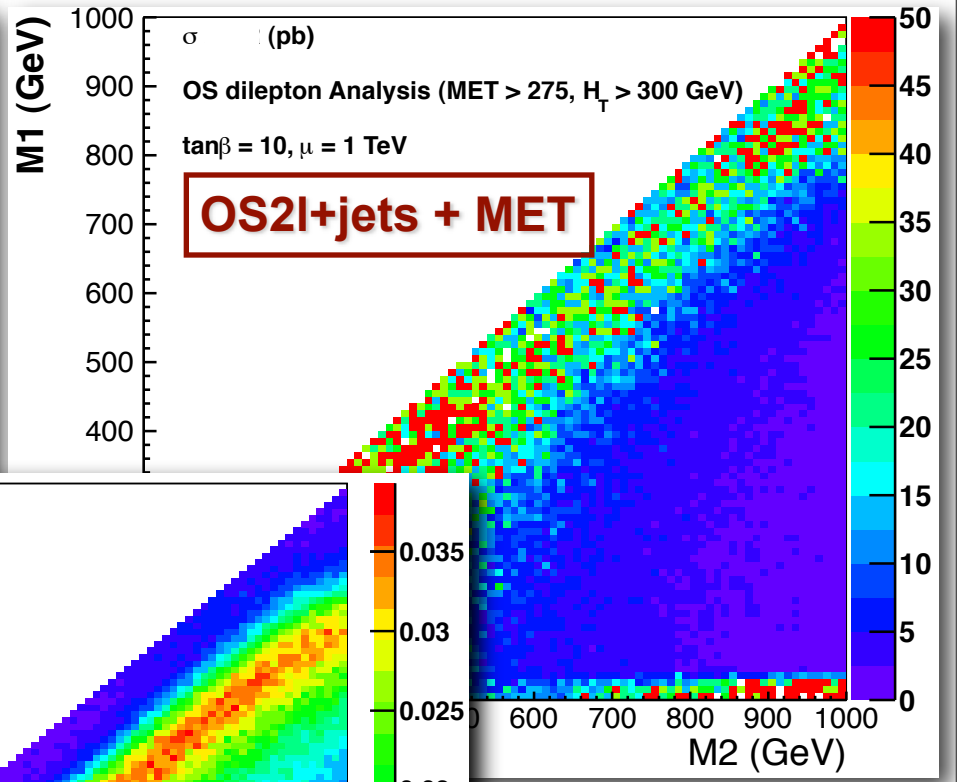


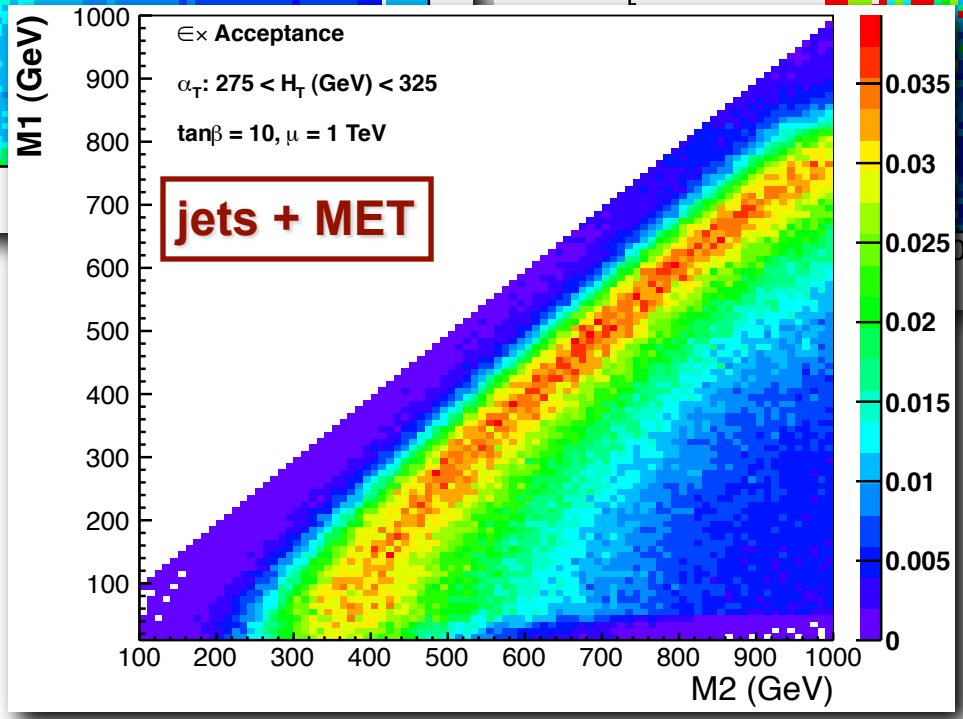


- low H_T cut has better reach!
- probably best exclusion channel among four searches
- 0.98 fb^{-1} has no reach
- with more data (even just 10fb^{-1}), should have some reach in M_1-M_2 plane.

95% CL upper limit on cross sections

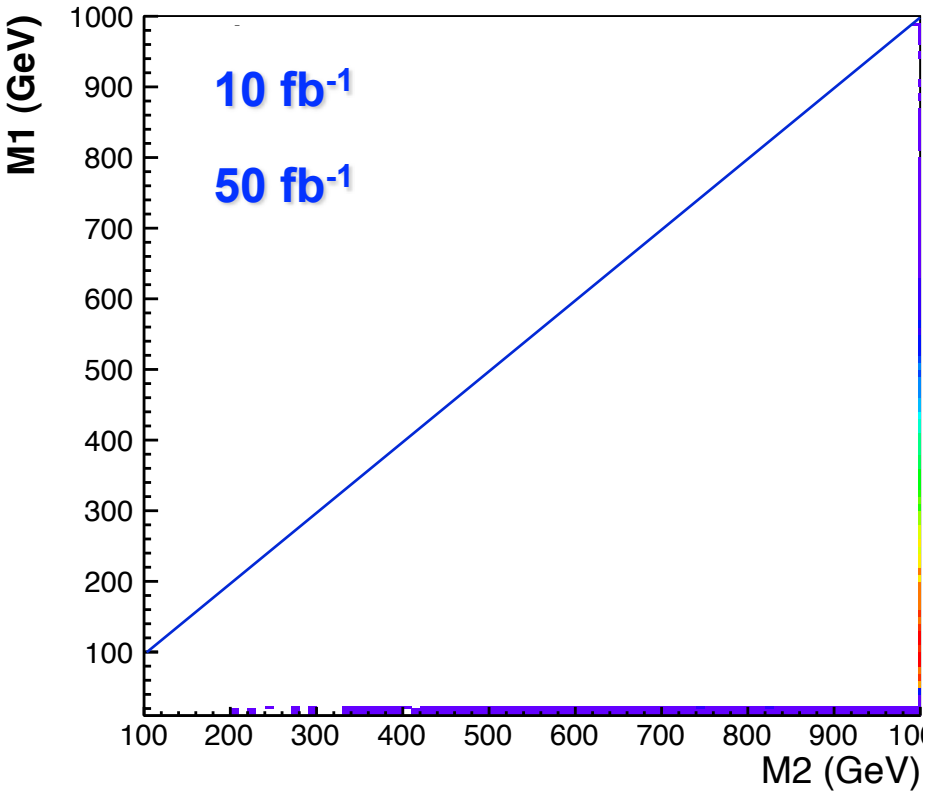


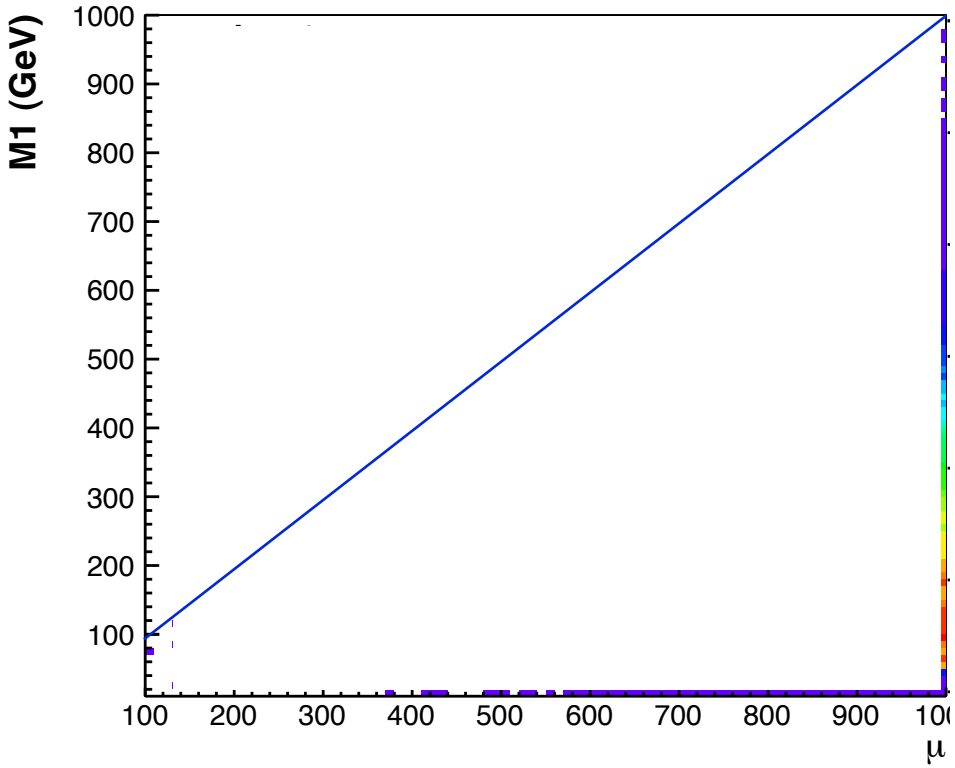




Reach in M1-M2 and M1-mu plane

- with optimized cuts ...





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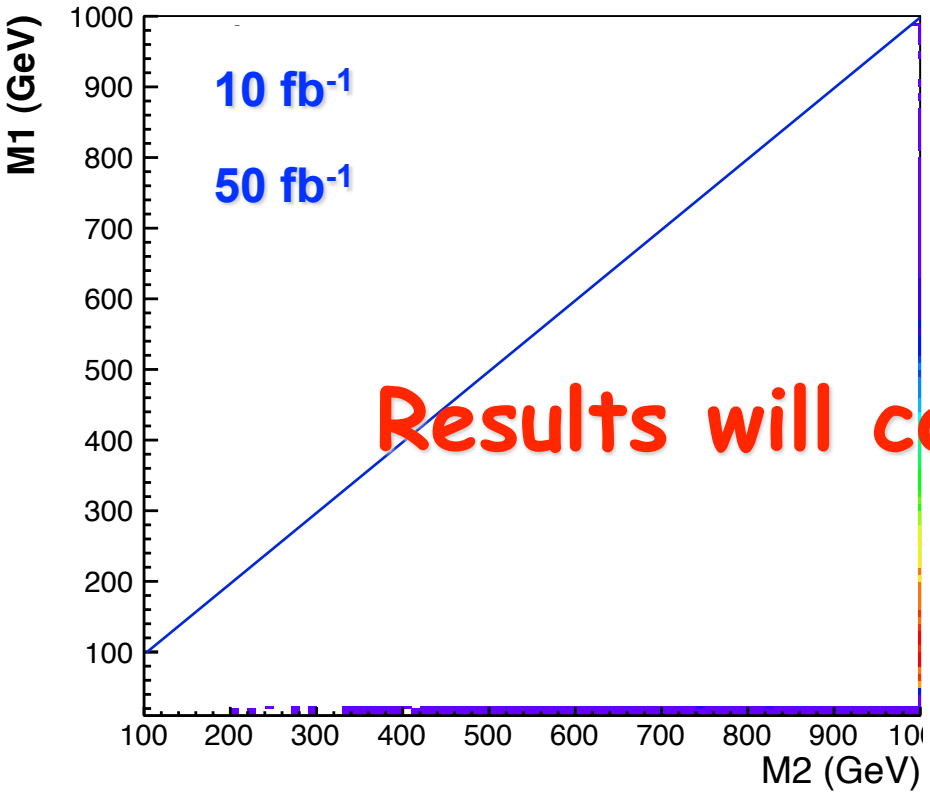
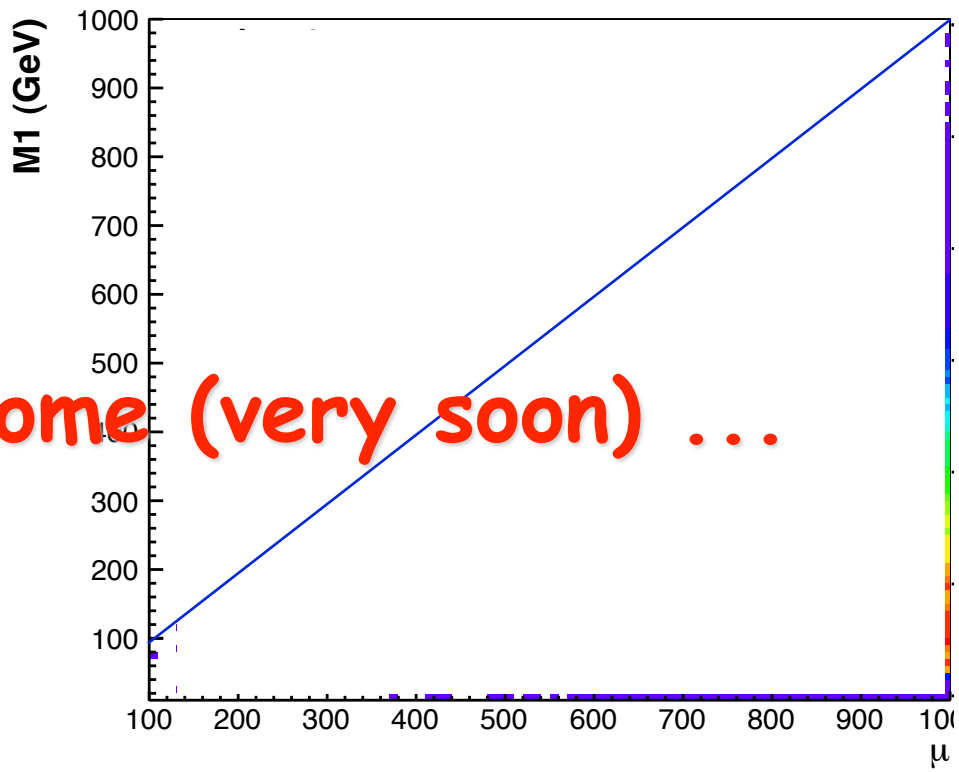
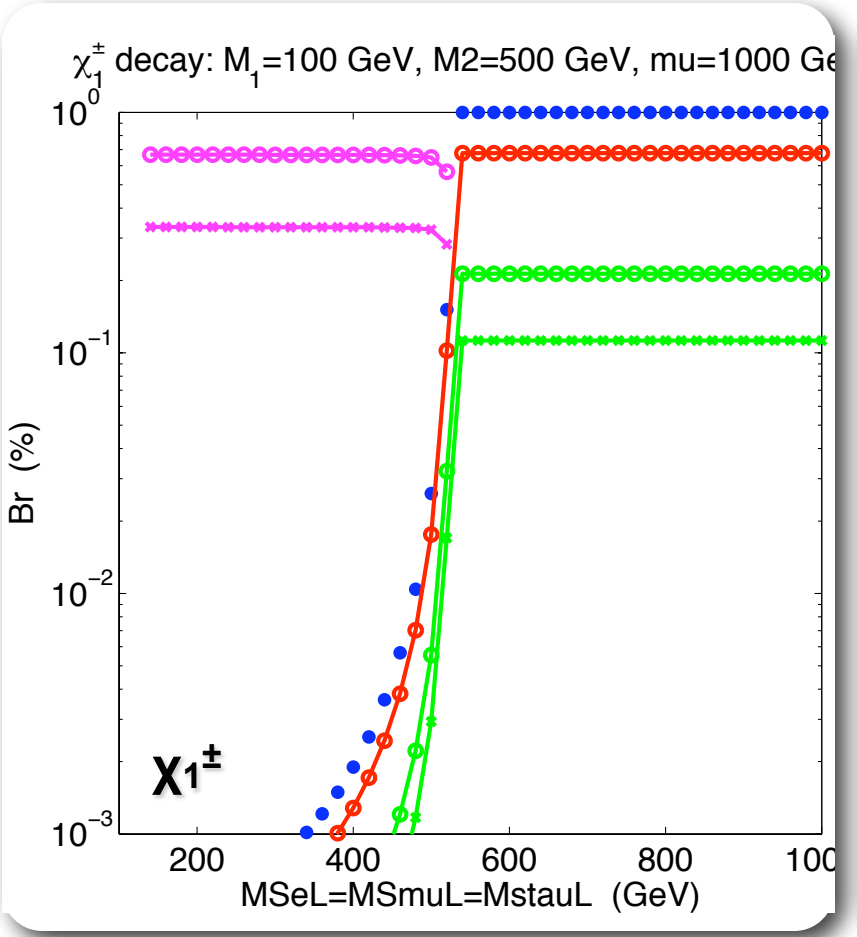




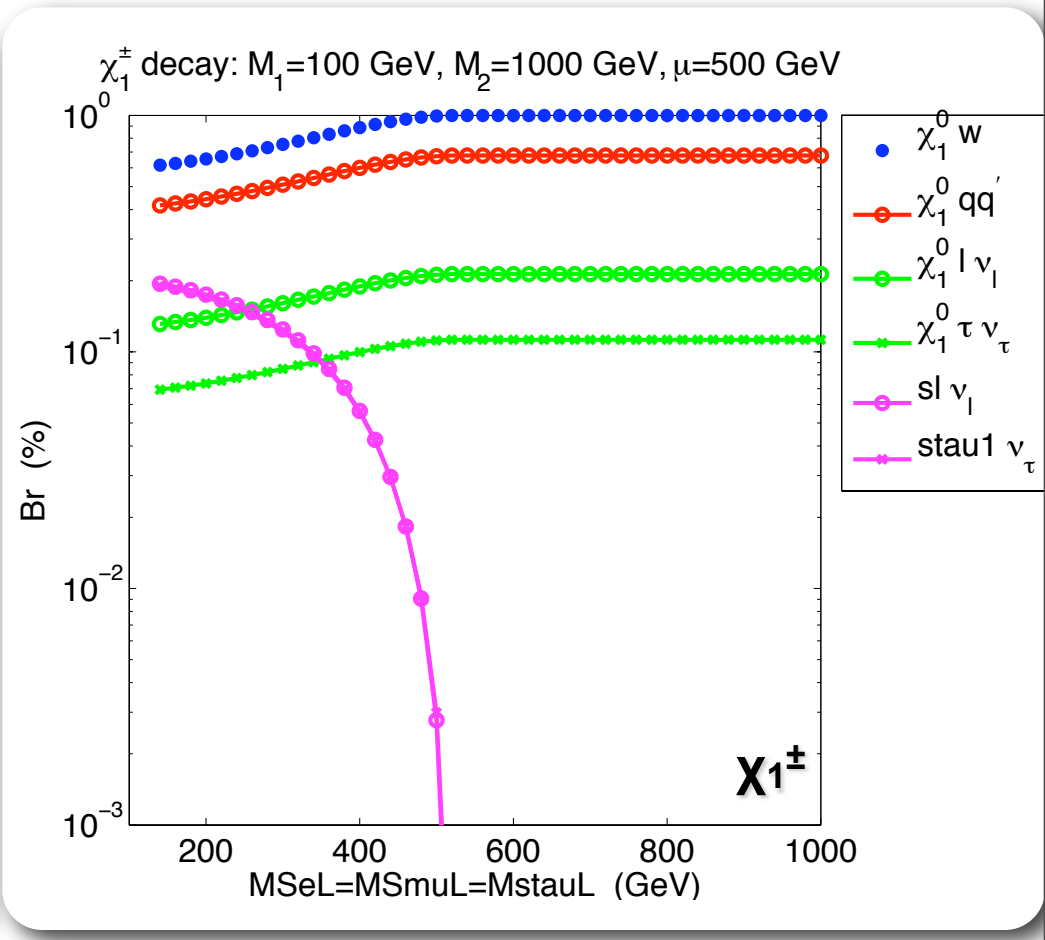
Results will come (very soon) ...

$\chi_1^\pm$ decay: light left-slepton

light wino $M_1 < M_2 < \mu$



light Higgsino $M_1 < \mu < M_2$



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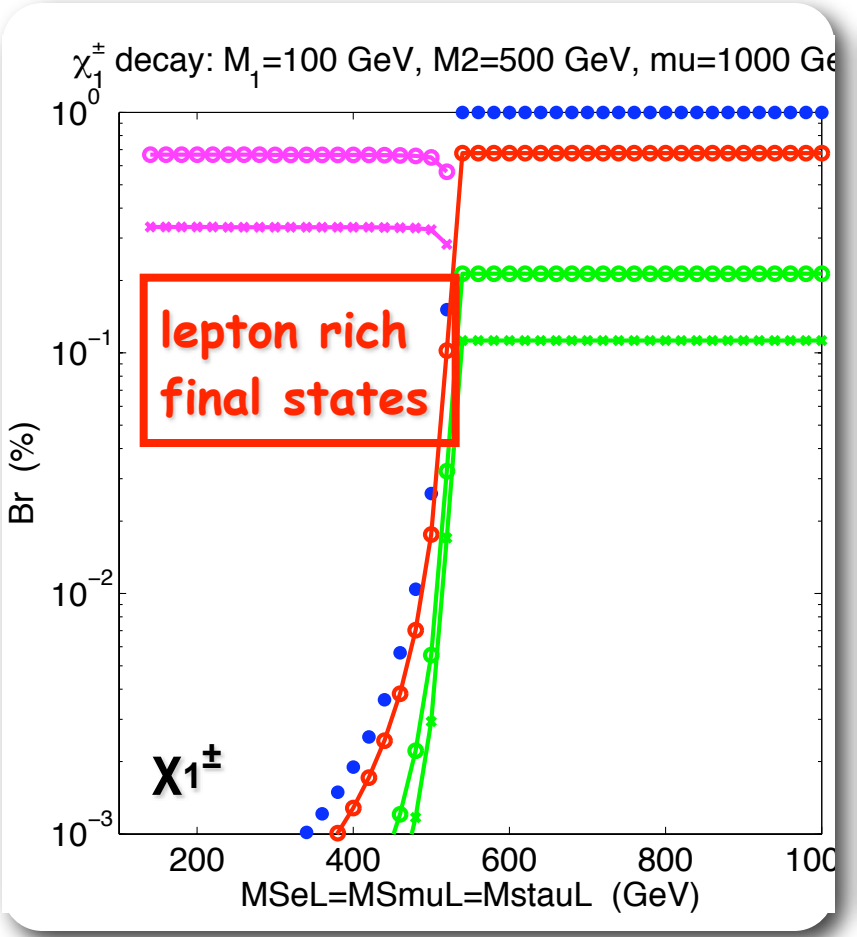
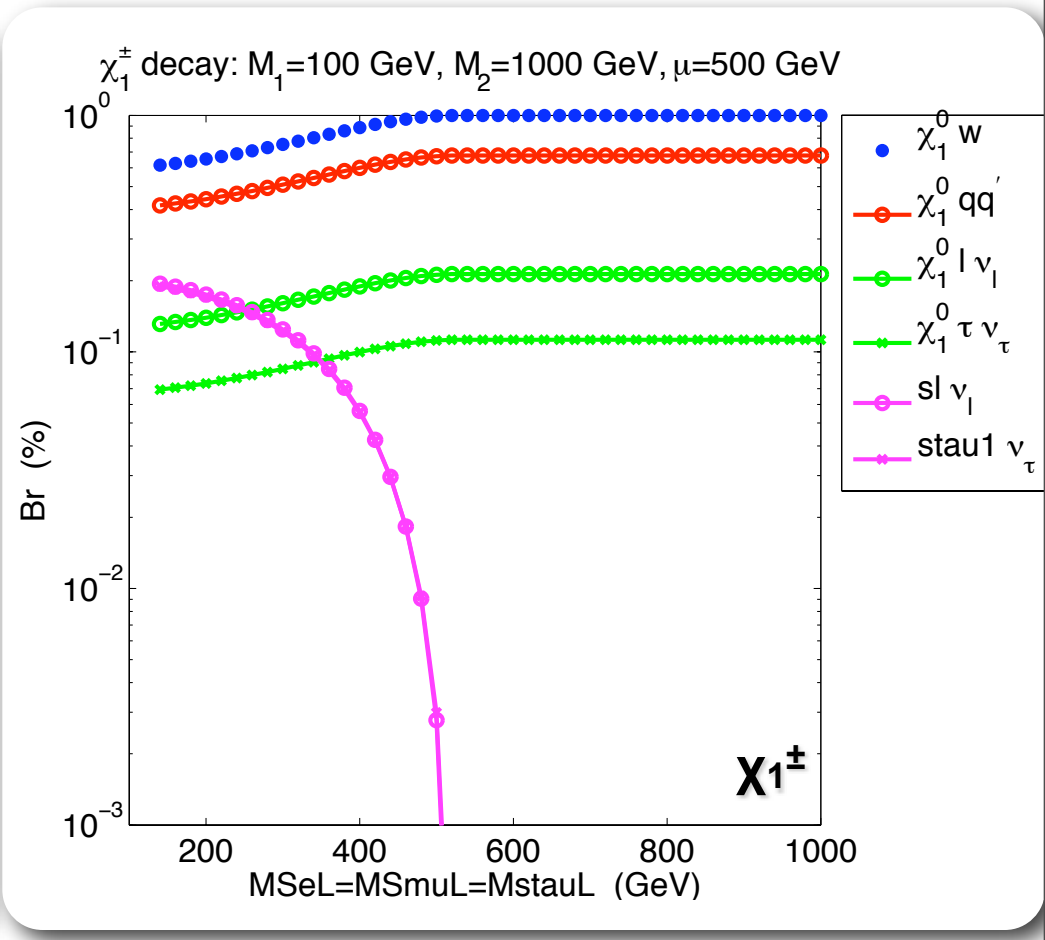
light wino $M_1 < M_2 < \mu$



light Higgsino $M_1 < \mu < M_2$



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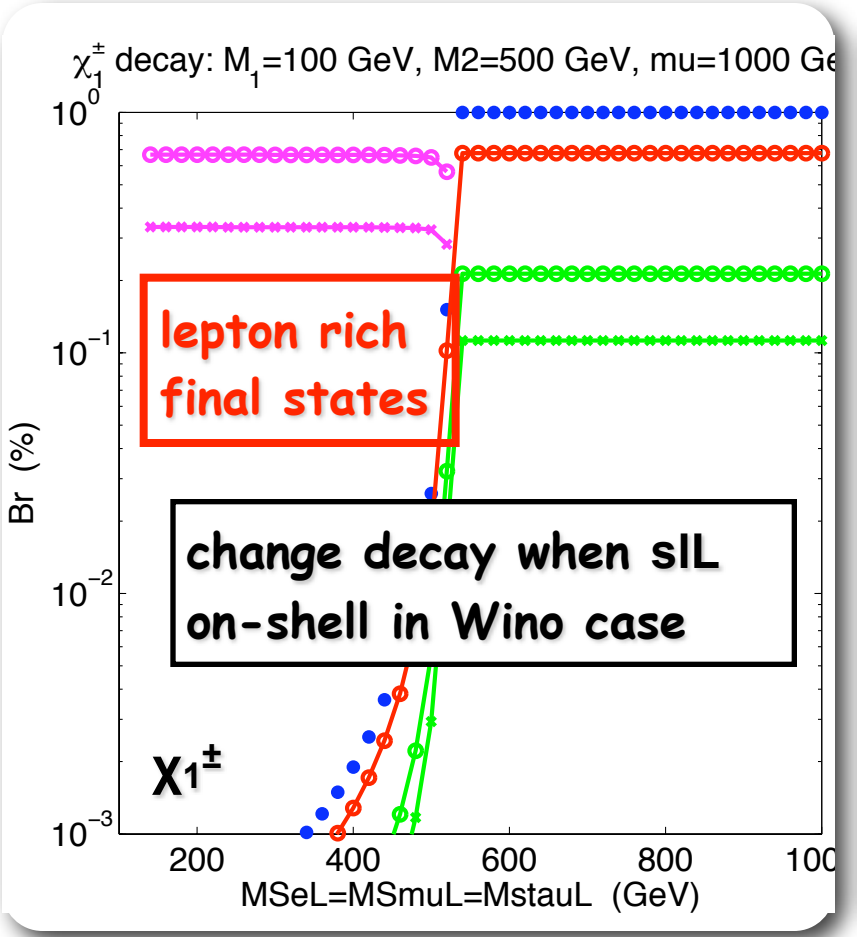

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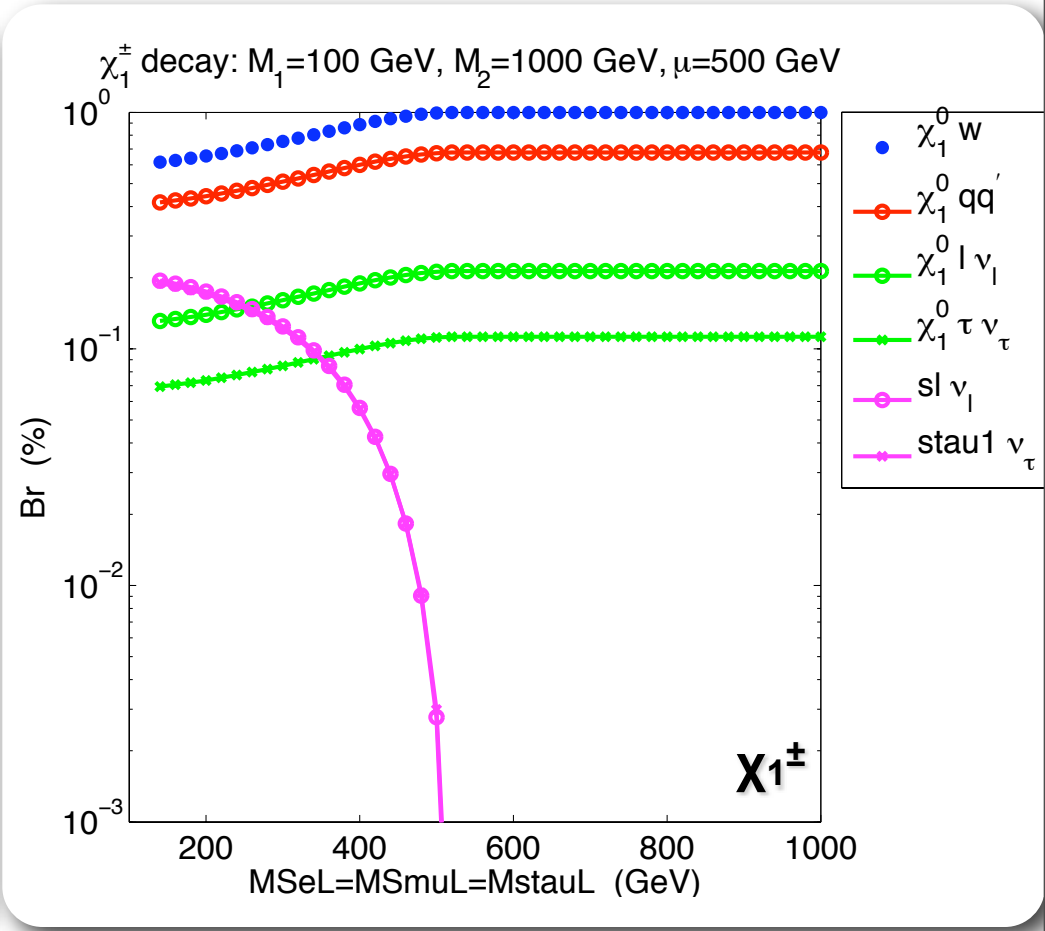

$\chi_1^\pm$ decay: light left-slepton

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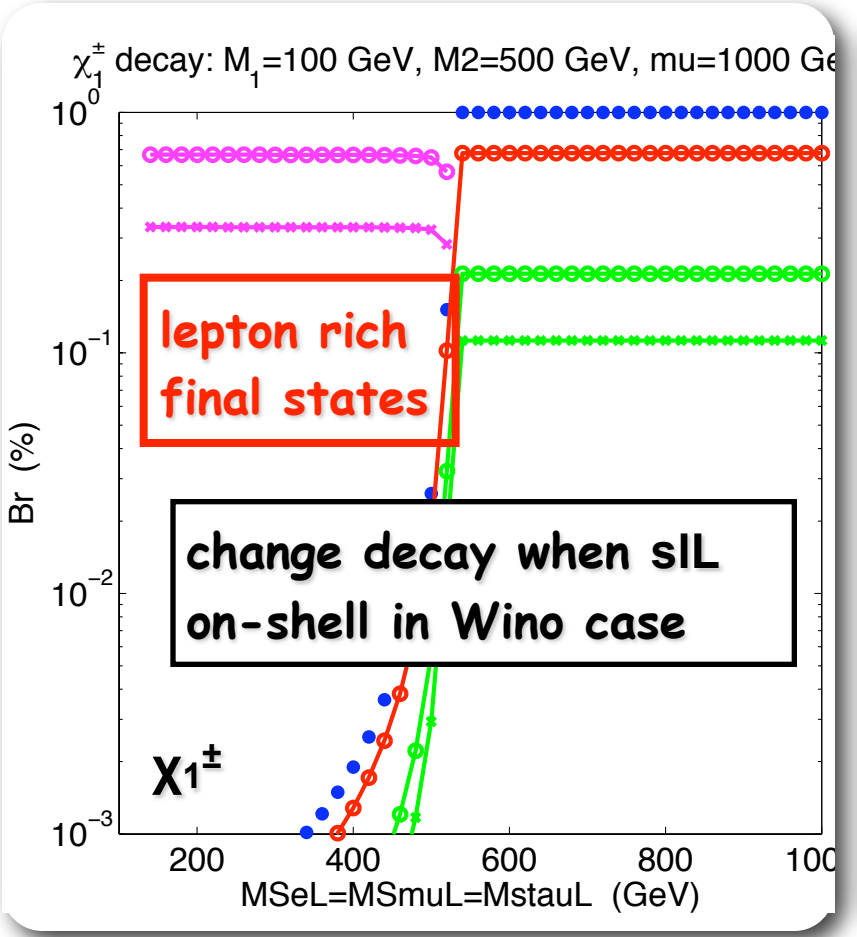

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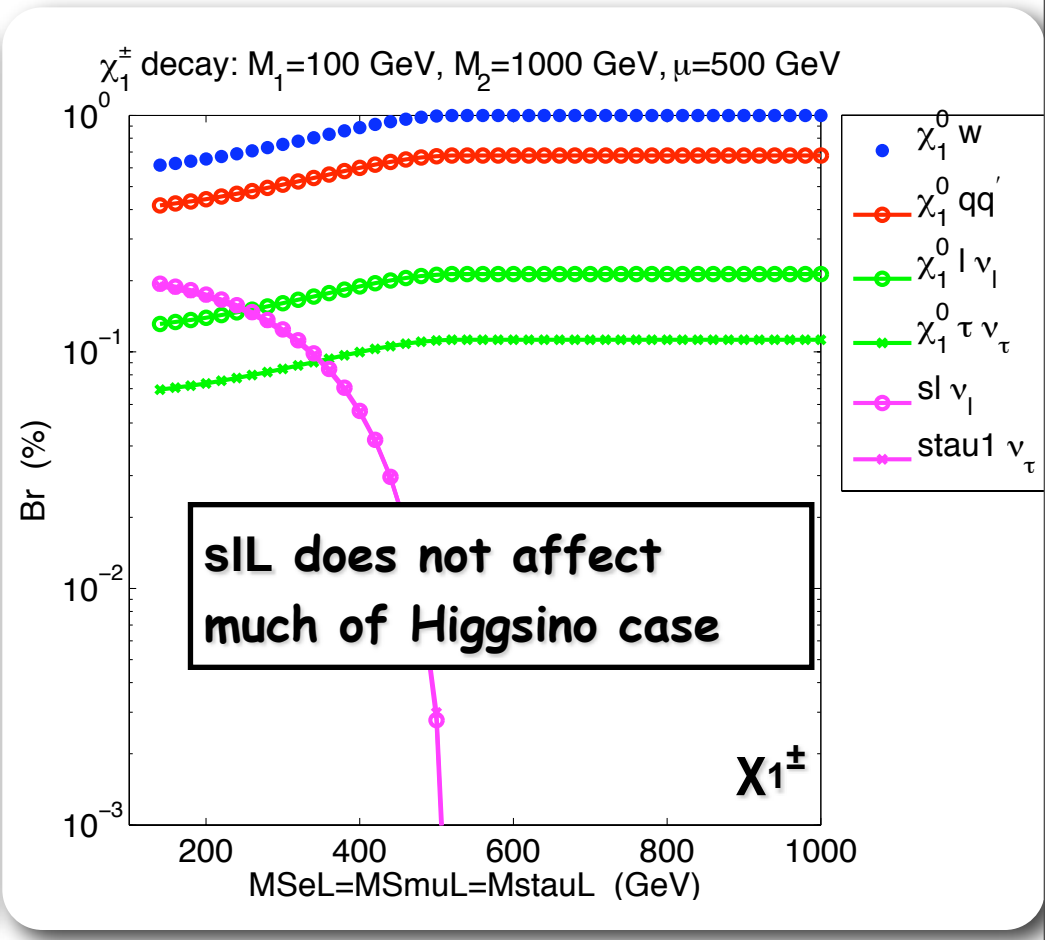
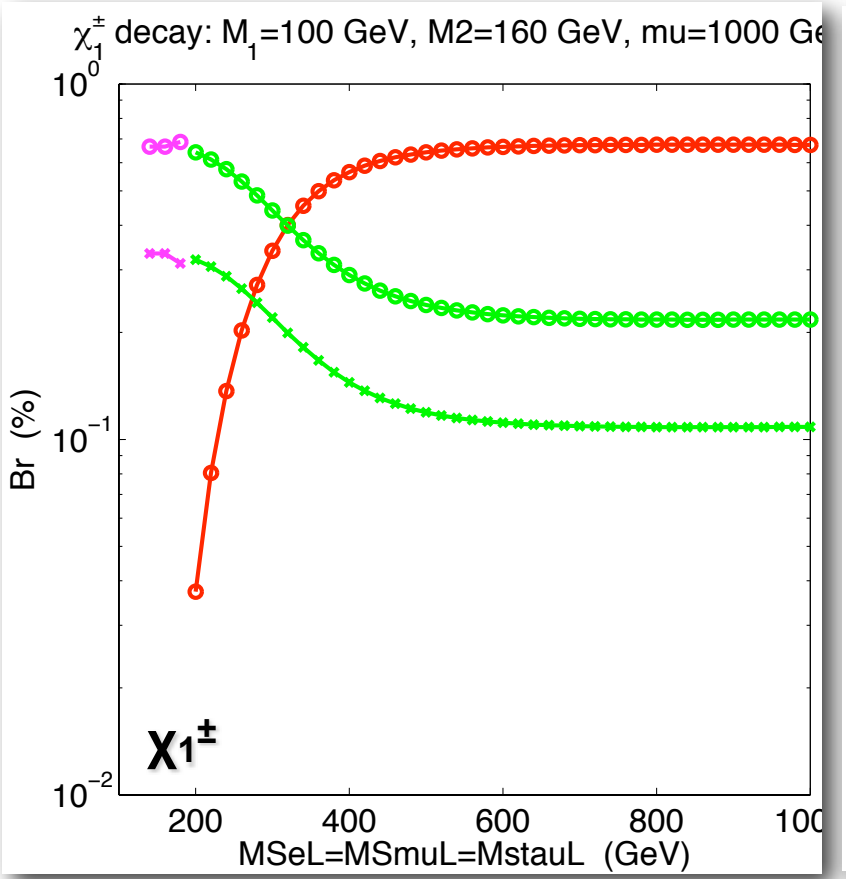
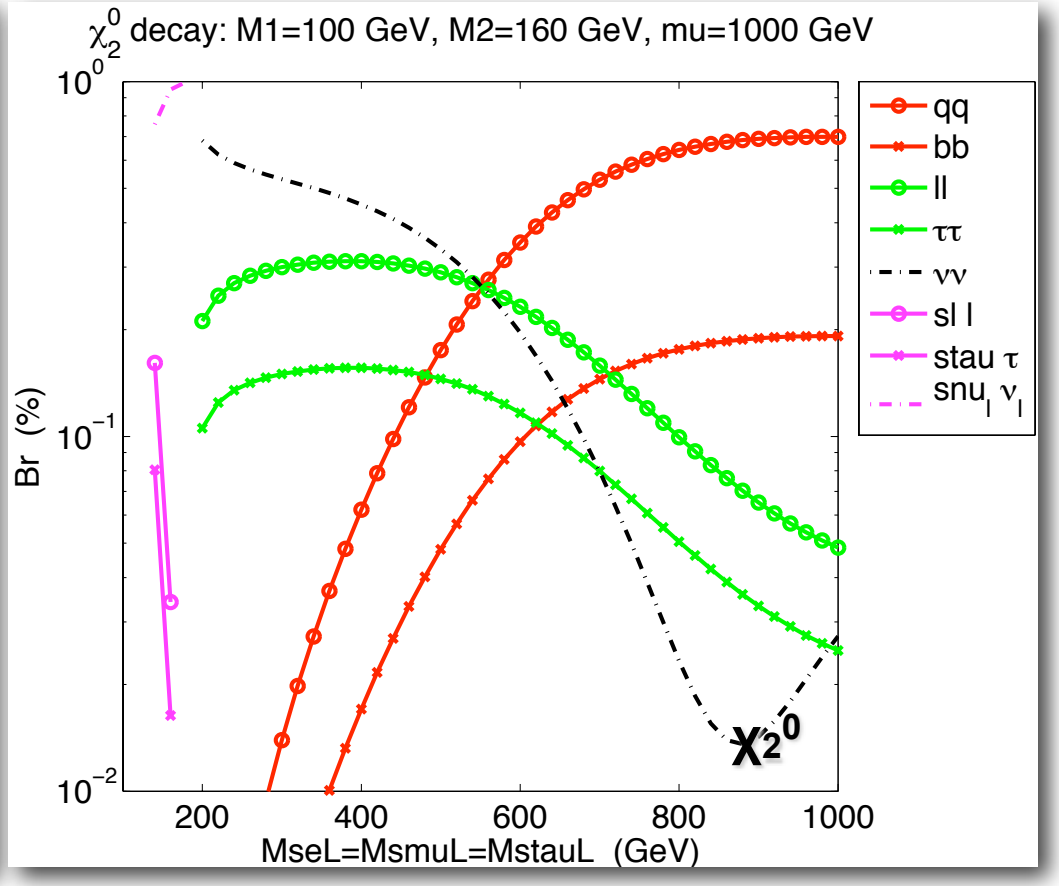


$\chi^{0,\pm}$ decay: off-shell effects of slL

light wino $M_1 < M_2 < \mu$





$\chi^{0,\pm}$ decay: off-shell effects of slL

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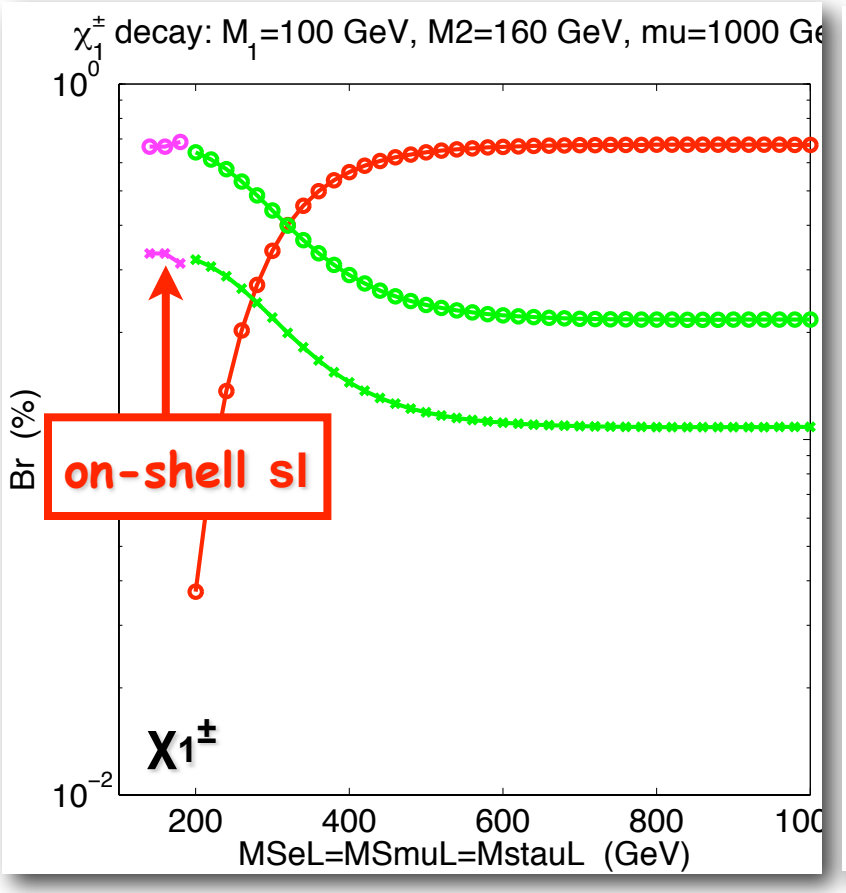

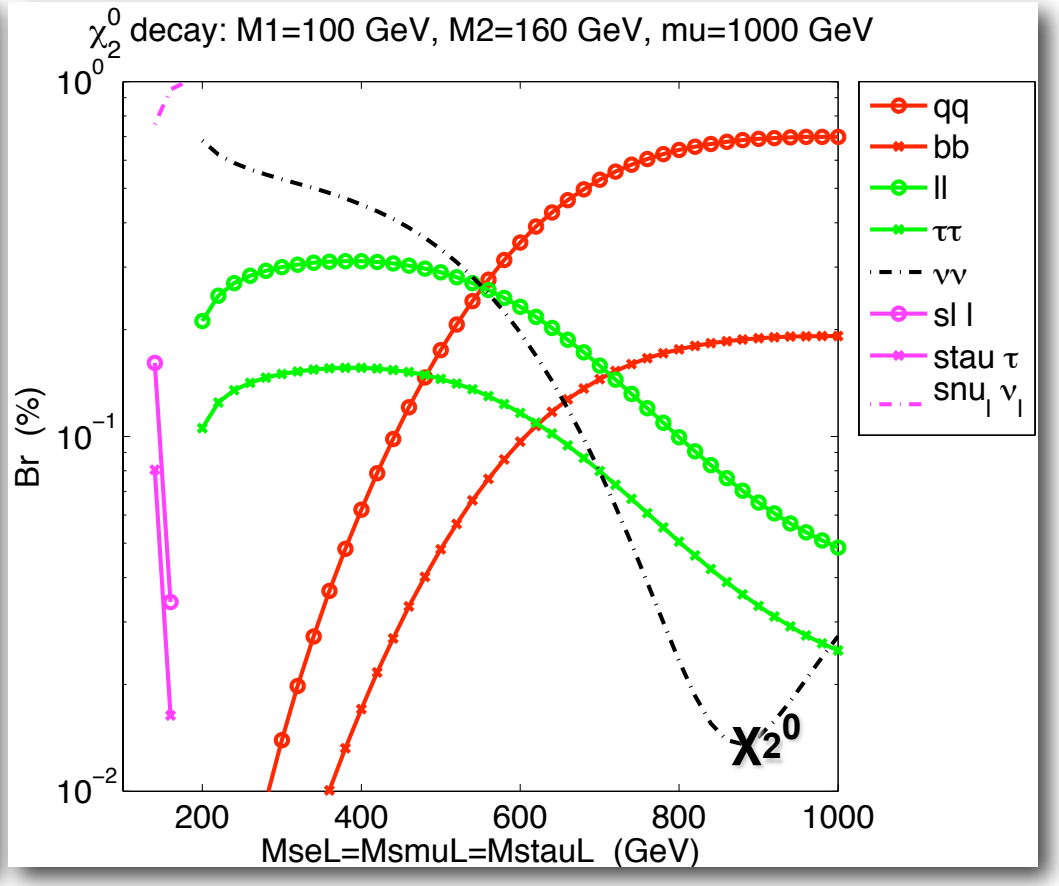

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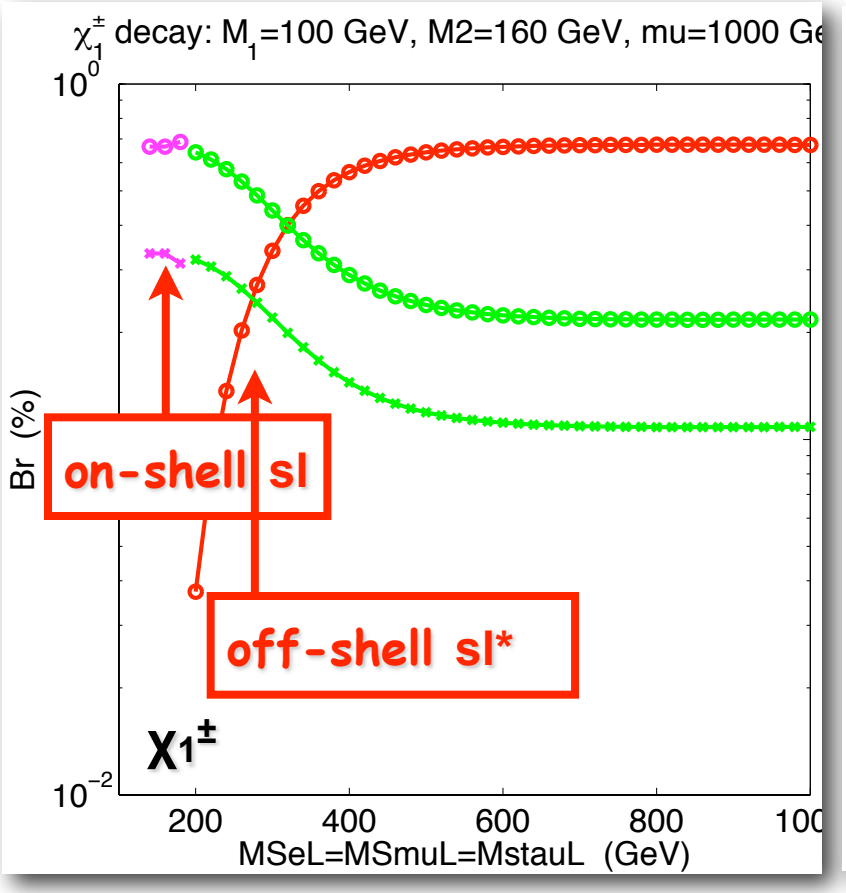

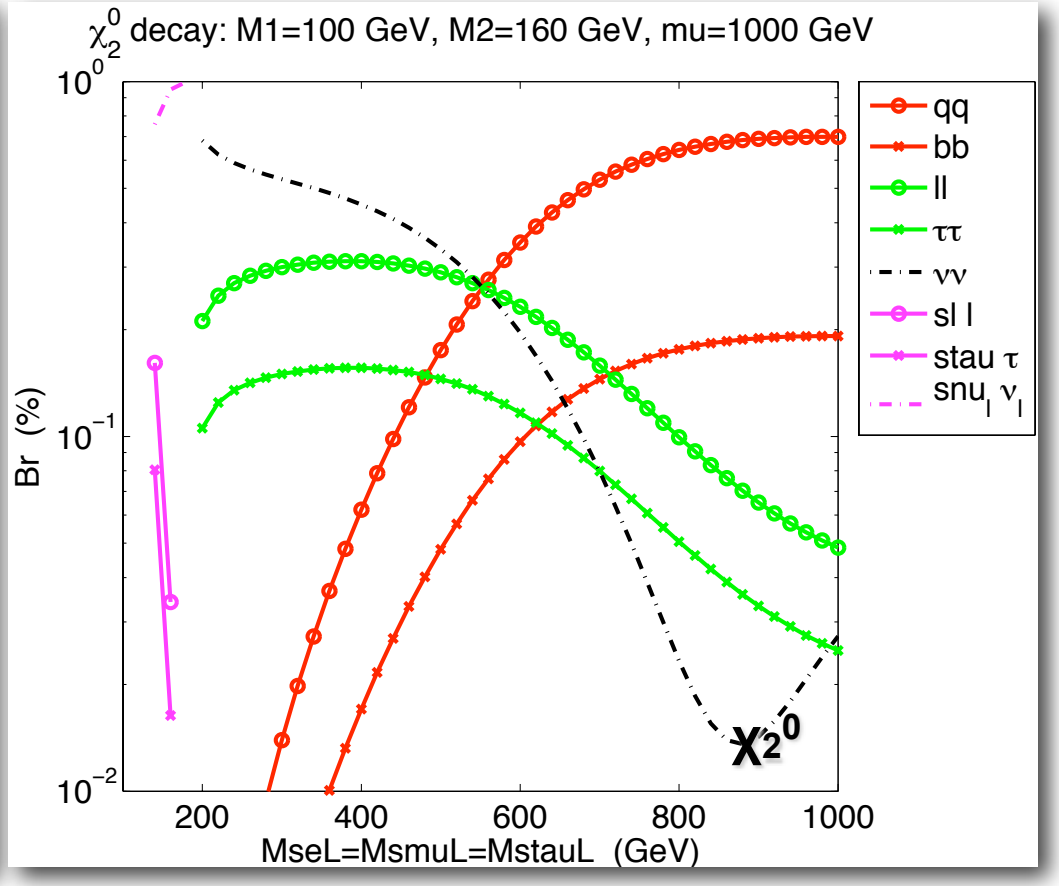

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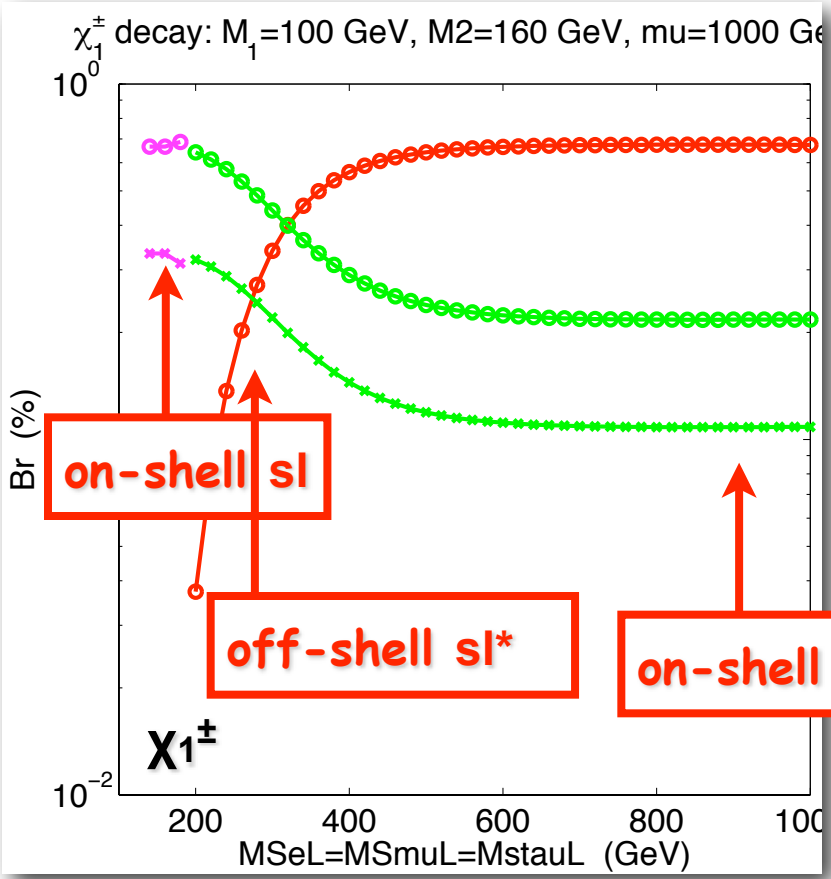

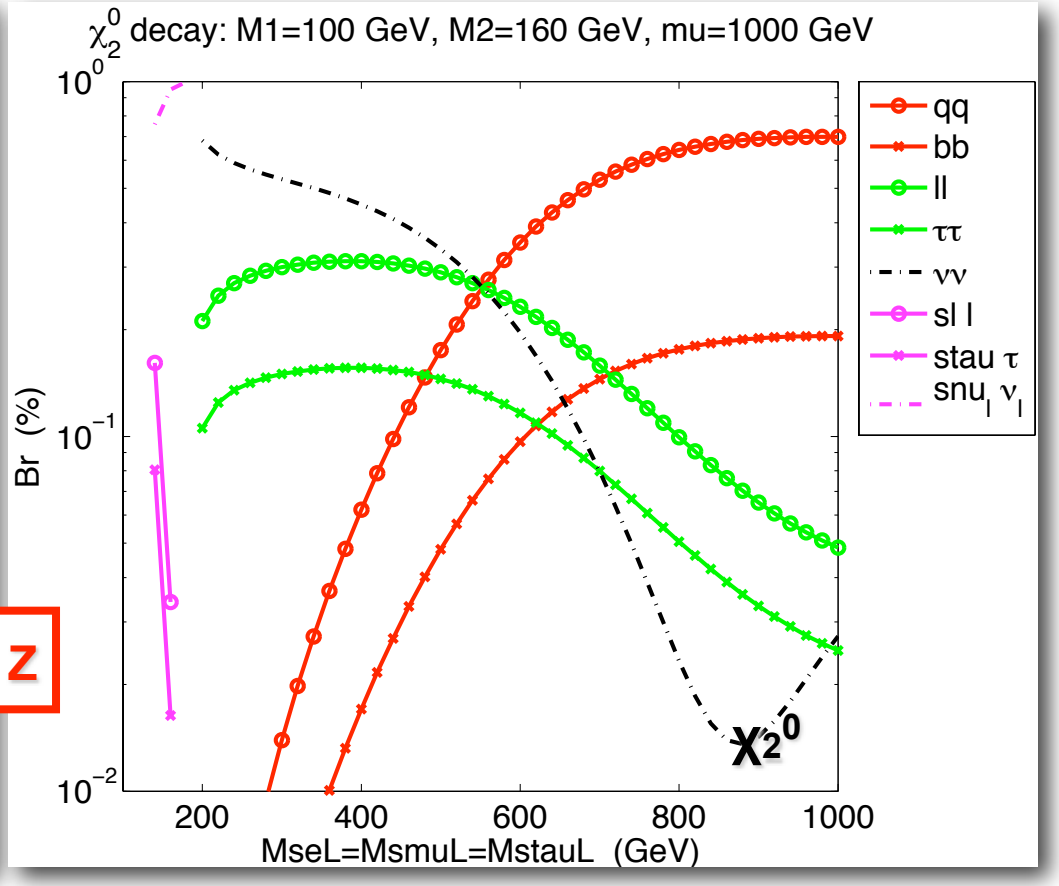

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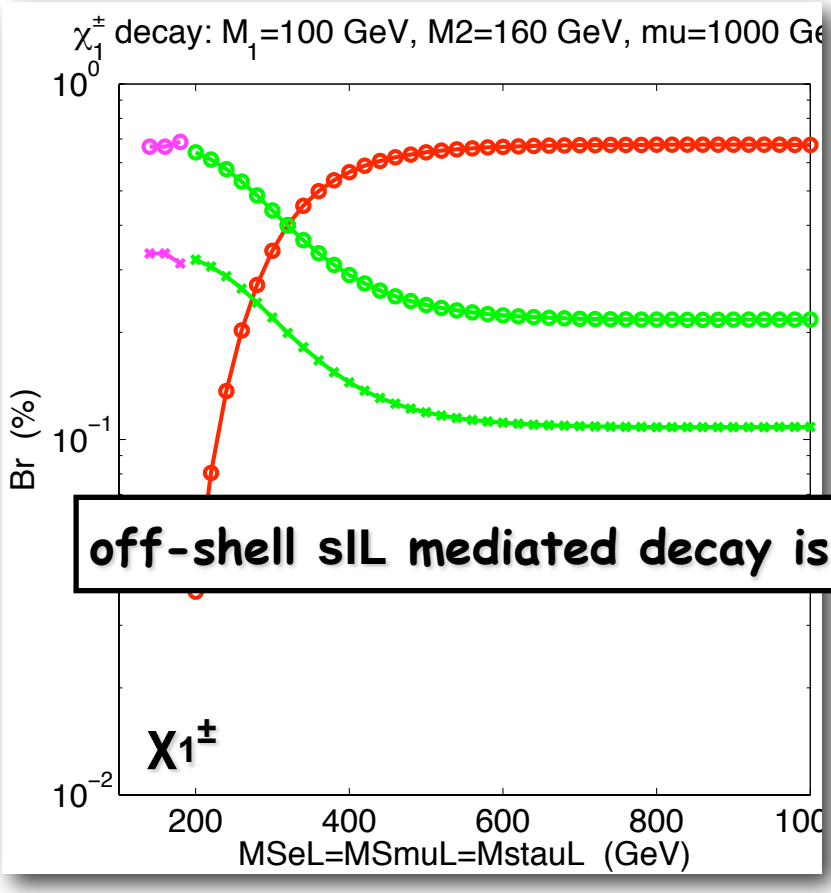
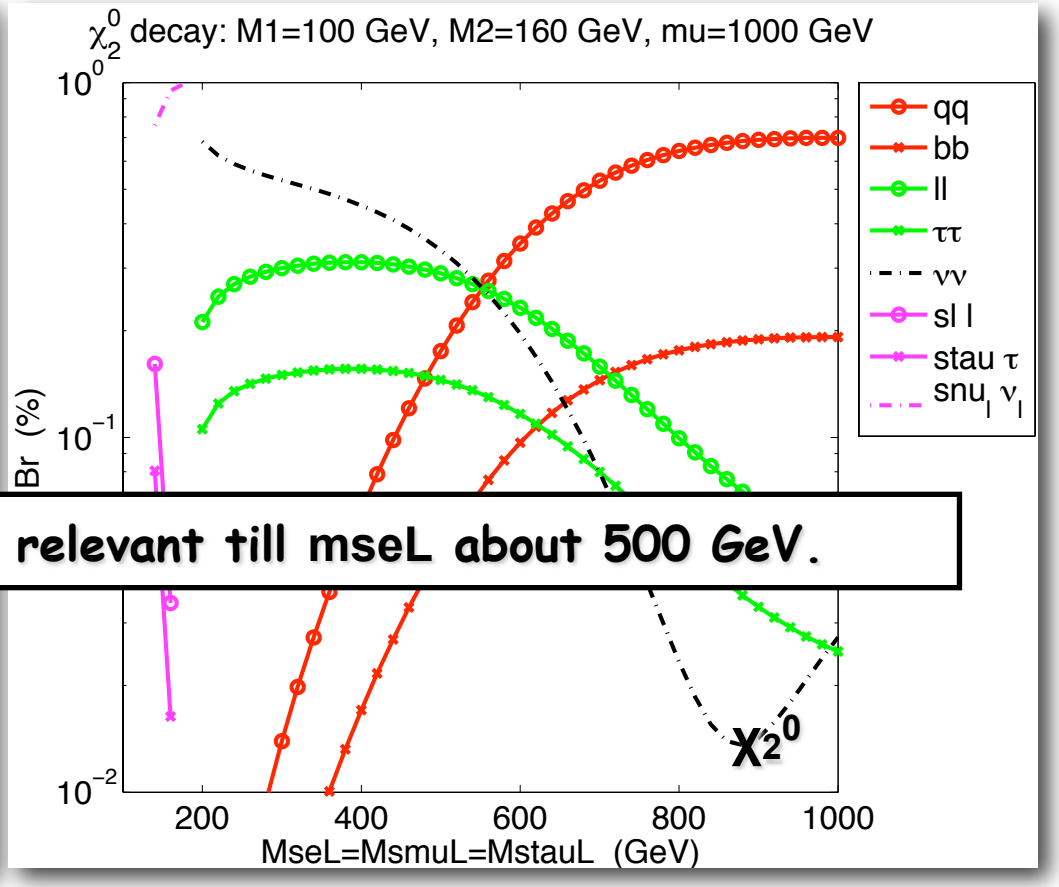
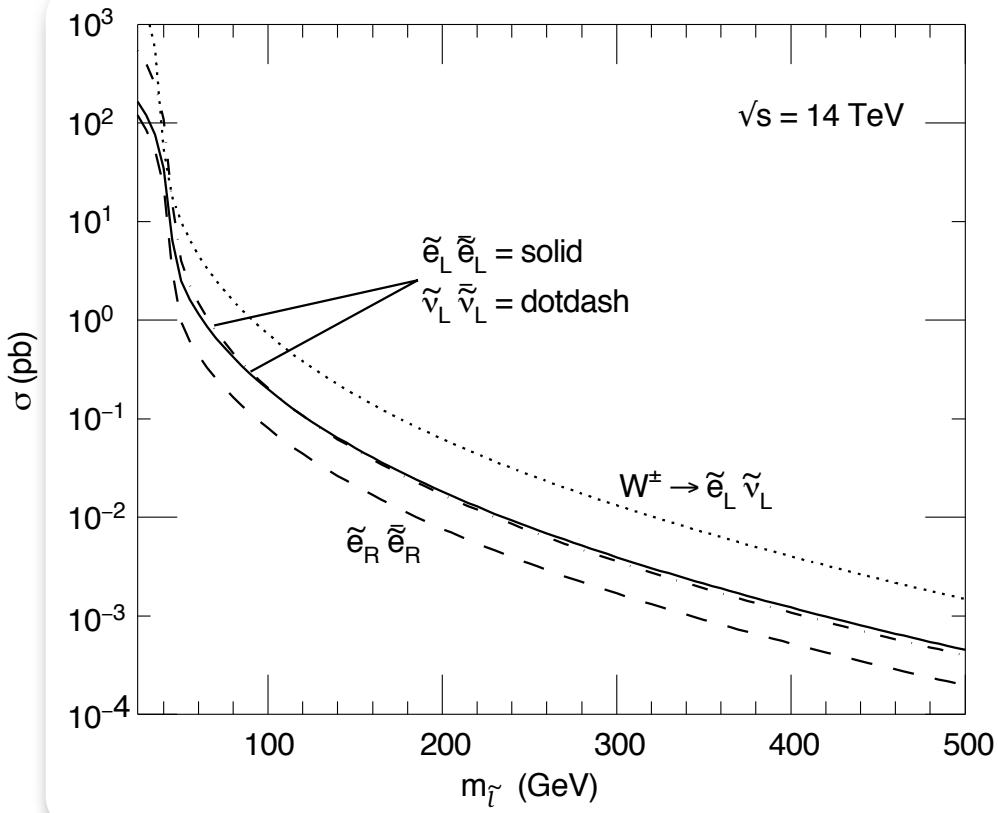




off-shell slL mediated decay is relevant till mseL about 500 GeV.

Slepton studies

- **Drell-Yan production cross section small**

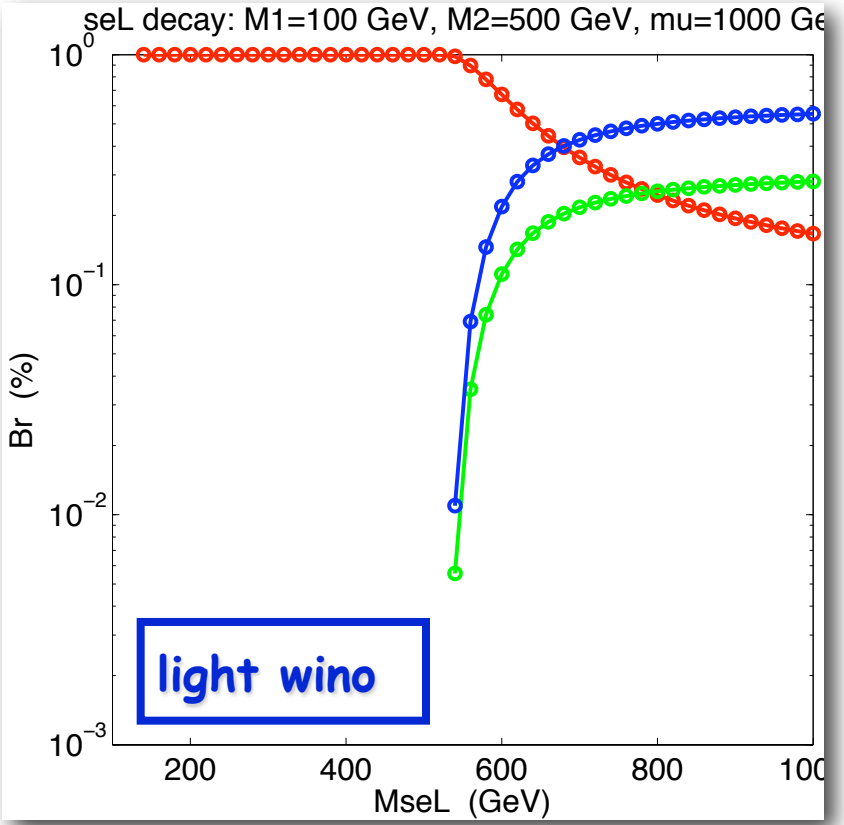


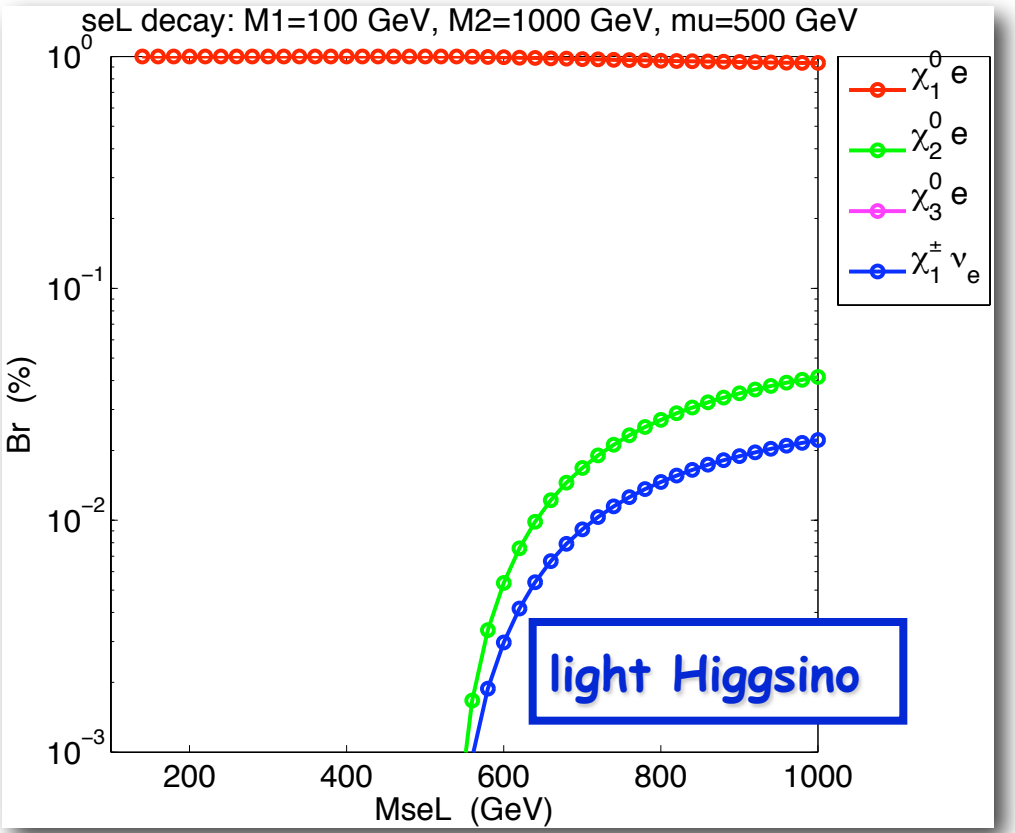
H.Baer, C.h.Chen, F.Paige, X.Tata,hep-ph/9311248, hep-ph/9512383

Slepton decay

- **direct decay:**
  - sIL, sIR → l χ_1^0
  - snuL → ν χ_1^0
  - MET, 1l+MET, 2l+MET signal

- **cascade decay:**
  - light wino case, MseL > M_2
  - sIL, sIR → l χ_2^0, ν $\chi_1^\pm$
  - snuL → ν χ_2^0, l $\chi_1^\pm$
  - complicated signature





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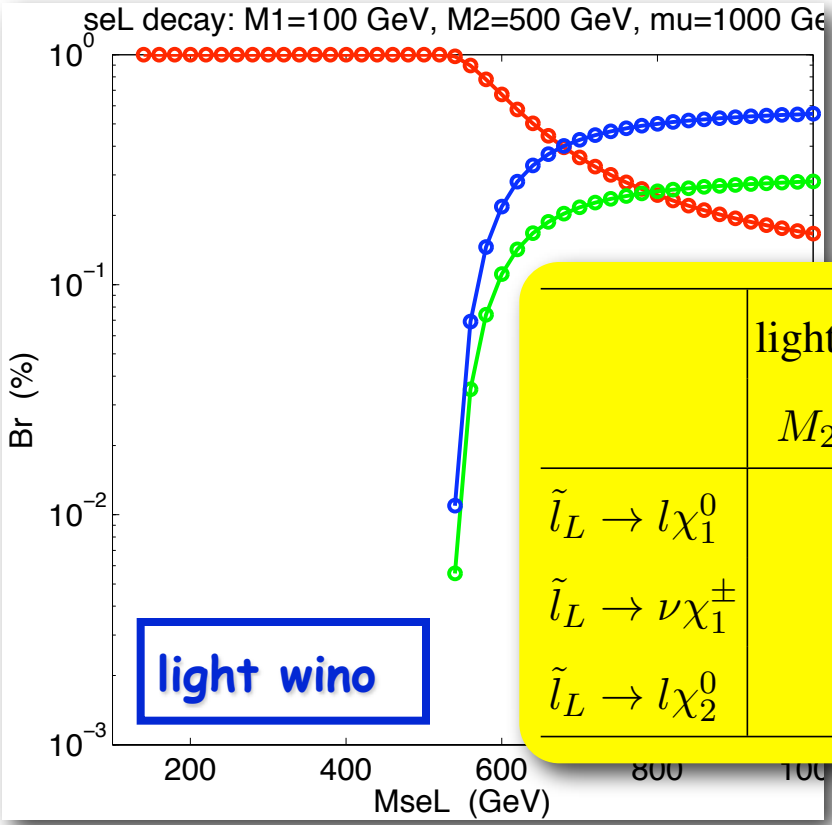
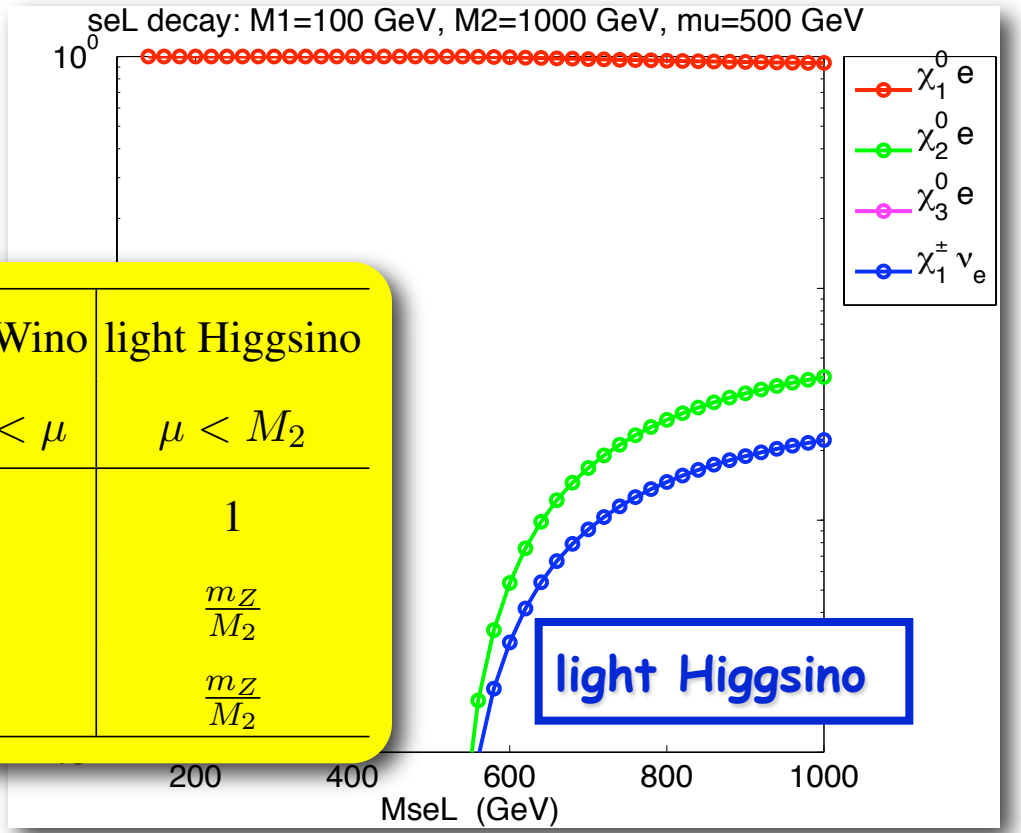


	light Wino	light Higgsino
	$M_2 < \mu$	$\mu < M_2$
$\tilde{l}_L \to l\chi_1^0$	1	1
$\tilde{l}_L \to \nu\chi_1^\pm$	1	$\frac{m_Z}{M_2}$
$\tilde{l}_L \to l\chi_2^0$	1	$\frac{m_Z}{M_2}$



Slepton studies via DY production

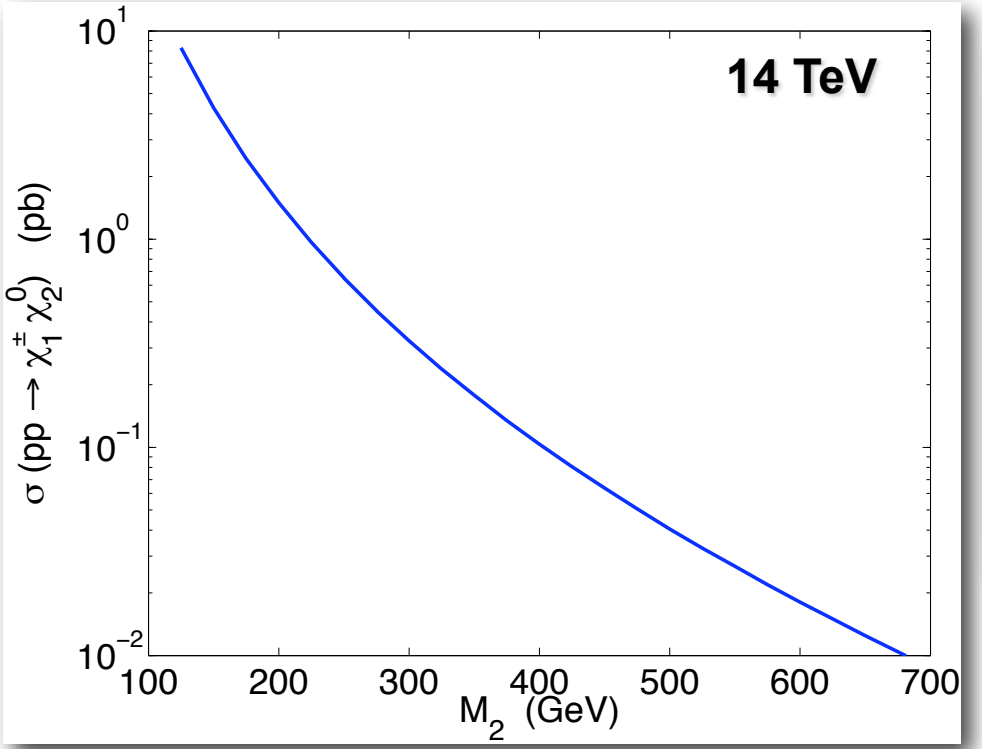
- SM BG large: W, WW, WZ , ttbar, etc.
- usually done in mSUGRA framework
- Limited reach: L=30 fb-1, 200 GeV for slR, 300 GeV for slL

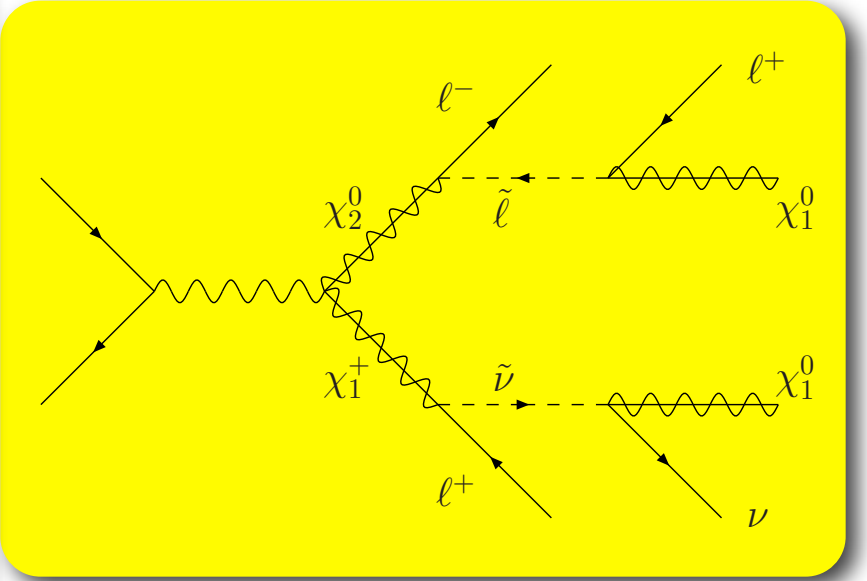
Y.M.Andreev, S.I.Bityukov, N.V.Krasnikov, hep-ph/0402229;
H.Baer, C.h.Chen, F.Paige, X.Tata,hep-ph/9311248, hep-ph/9512383

Slepton from Neutralino/Chargino decay

For MseL < M2, light Wino case

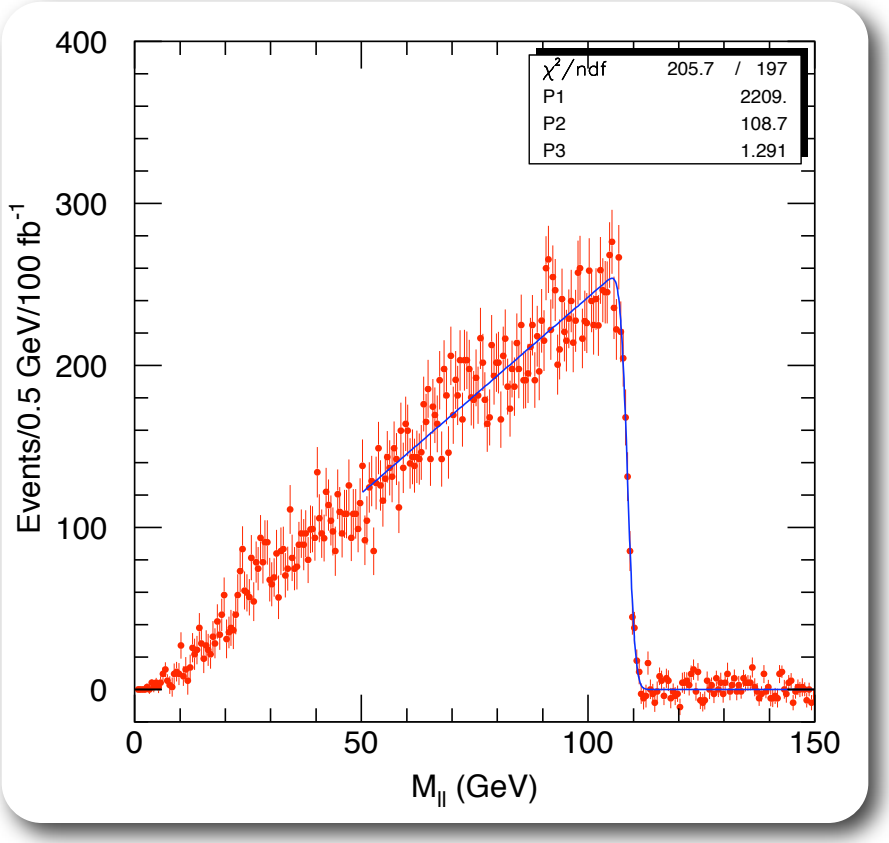
- **larger cross sections**

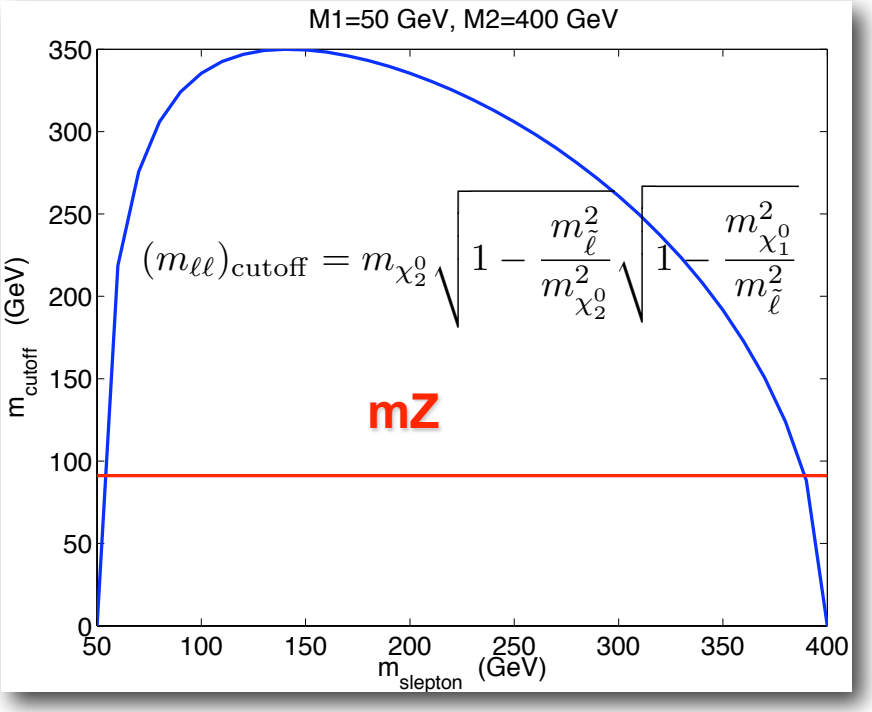




Slepton from Neutralino/Chargino decay

- large branching ratios
- trilepton + MET signal, less SM BG

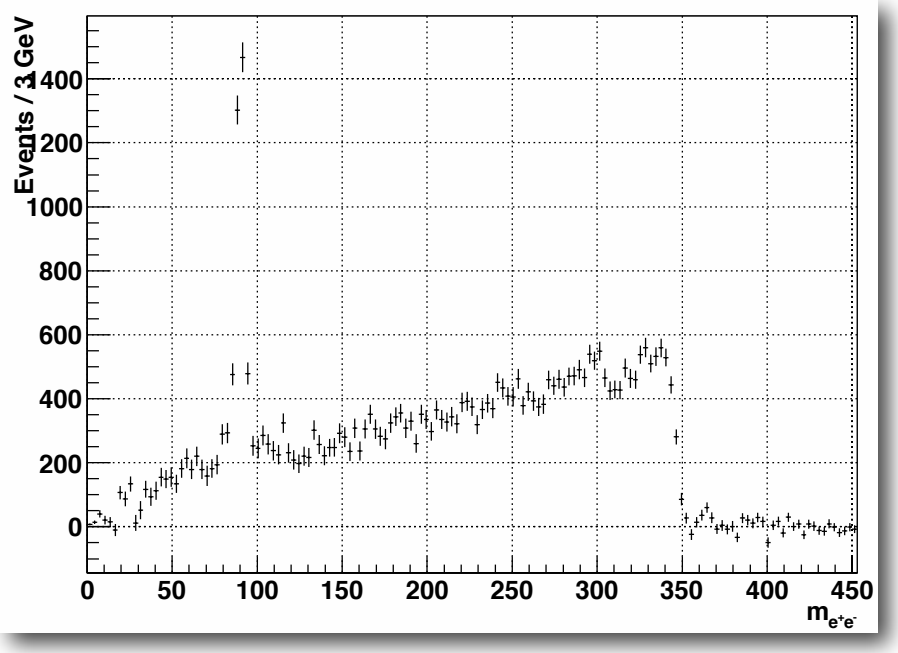




- distinctive triangle shape for mll
  - obvious-to-eye spectral shape
    How to use it to enhance our signal significance?
  - enhanced by only plotting the signal
    How about BG?

Bachacou, Hinchliffe, and Paige, hep-ph/9907518

Do We See the triangle?



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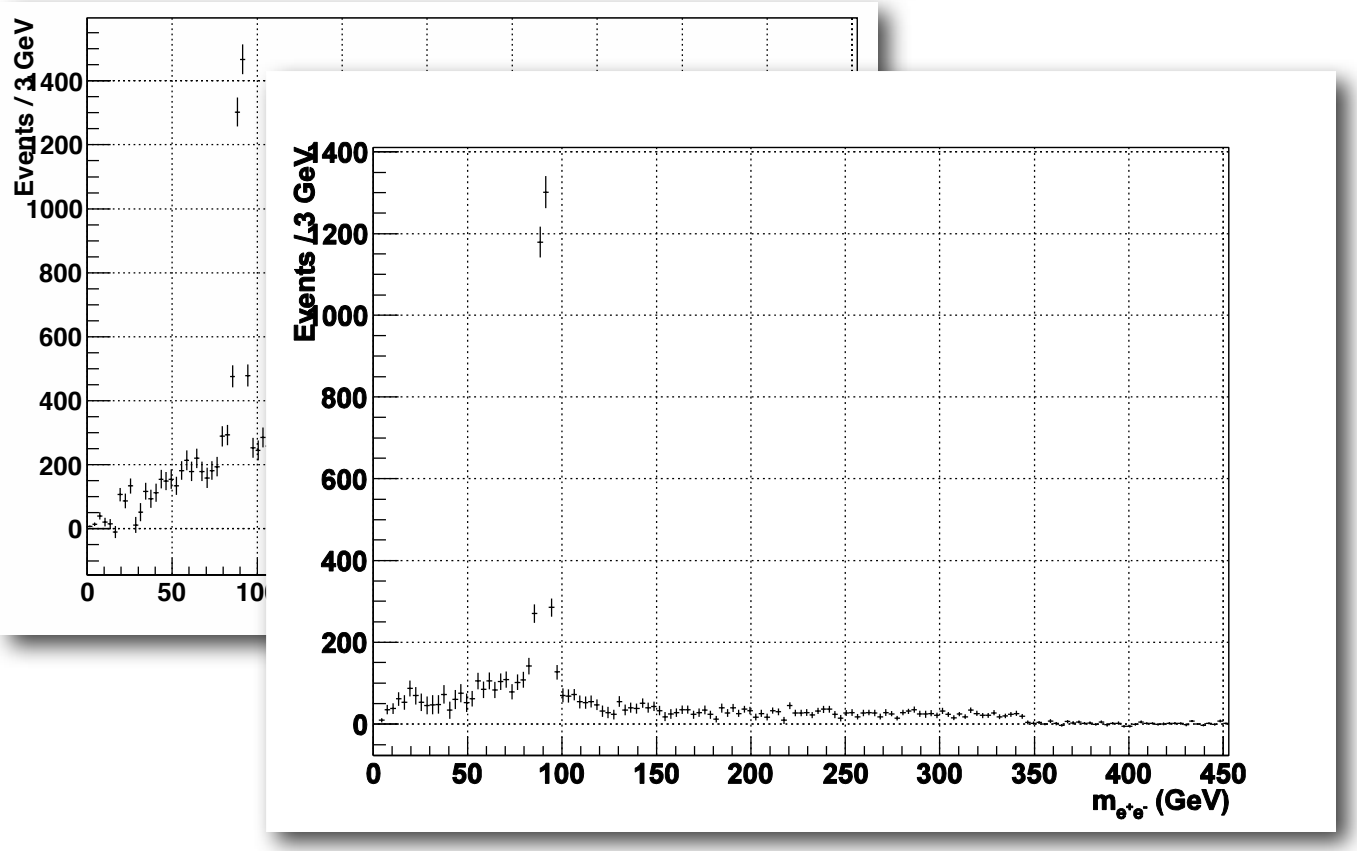

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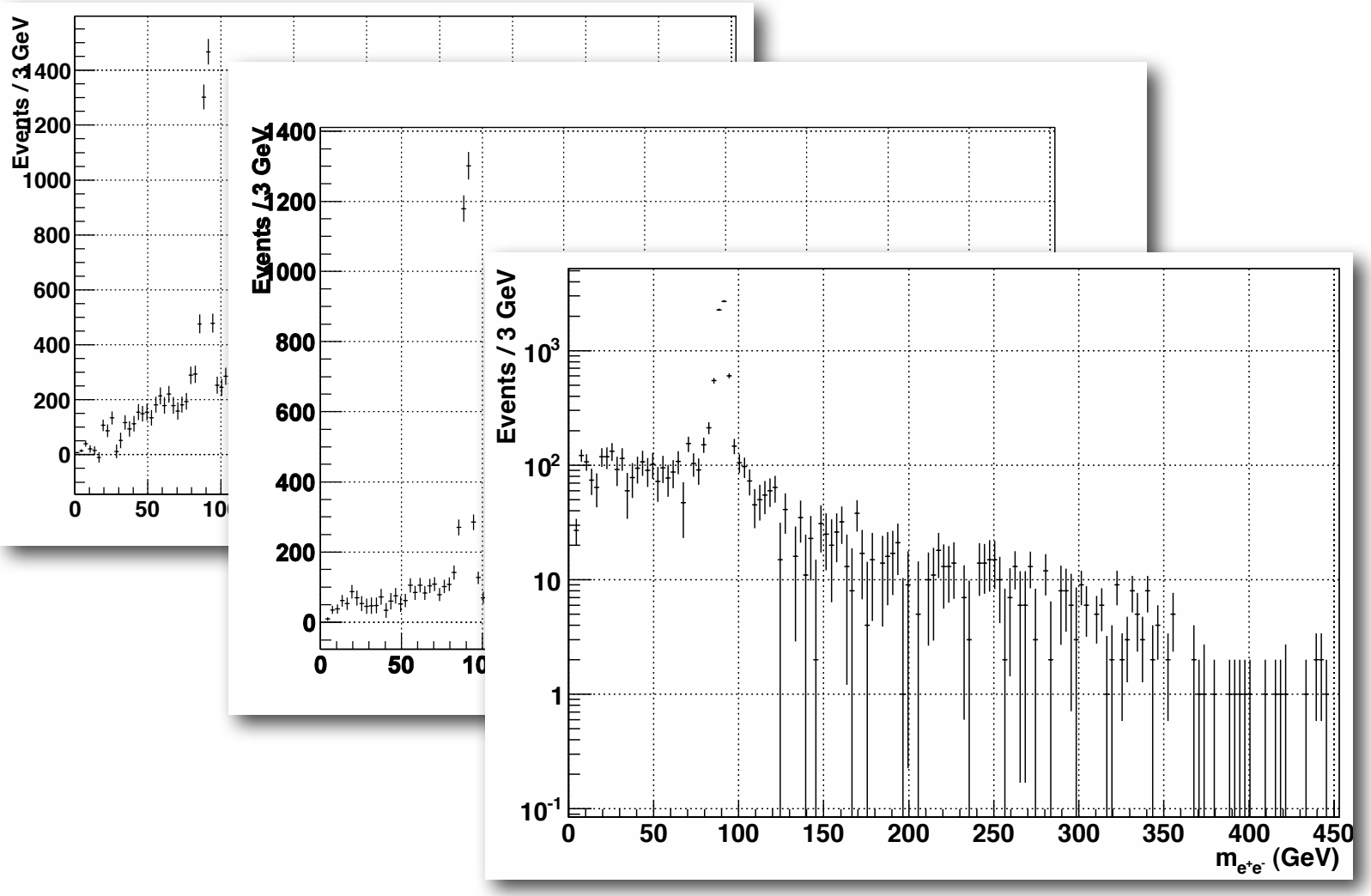

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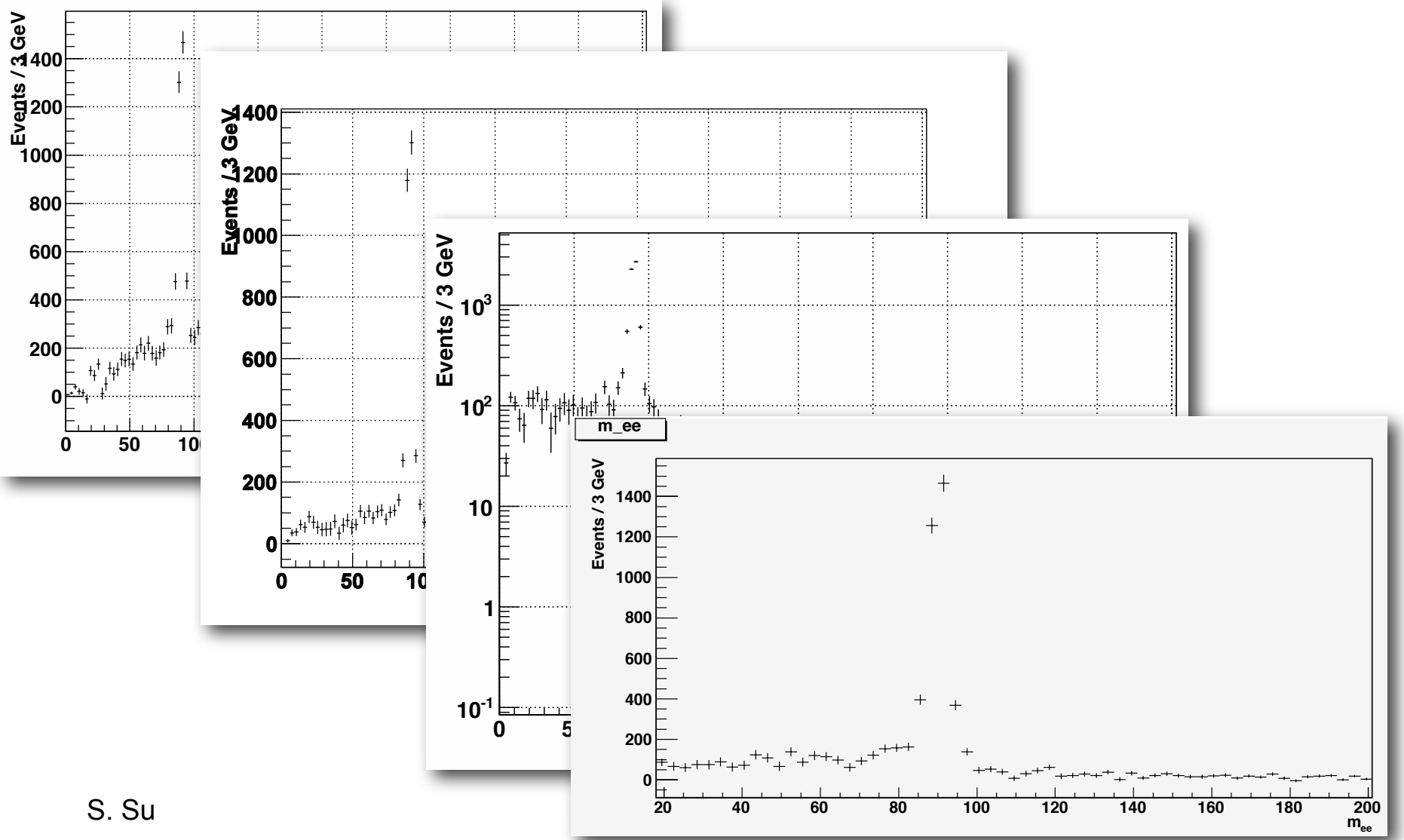


S. Su

Signal and background

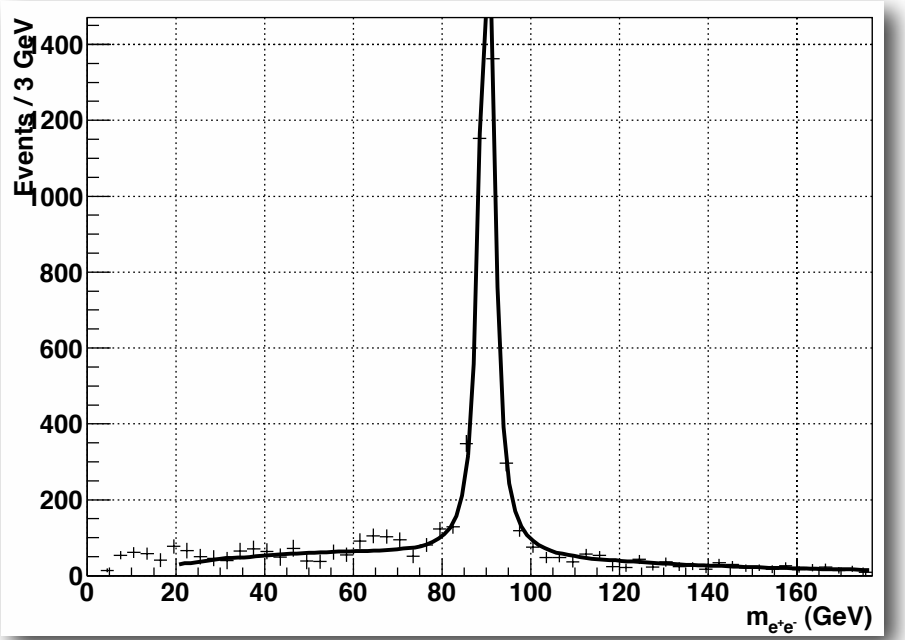
Signature: trilepton + MET

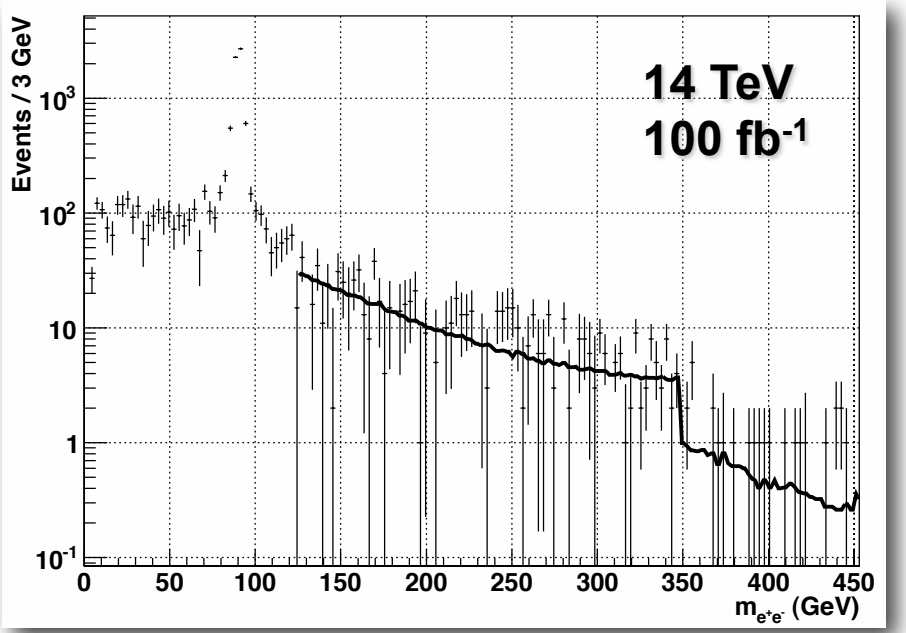
- Signal: MSSM $\chi_1^{\pm}\chi_2^0$ production, for a given (M1, M2, MseL) $\Rightarrow$ m_{cut}

- Dominant SM backgrounds:
  - WZ (anything containing Z)
  - ttbar+fake (from b), measurable from data, data driven method to understand the BG better

- Dominant SUSY backgrounds: $\chi_1^{\pm}\chi_2^0 \rightarrow WZ\chi_1^0\chi_1^0$,
  - containing a Z would be included
  - Br into W/Z small if dominantly decay into sleptons

Fitting

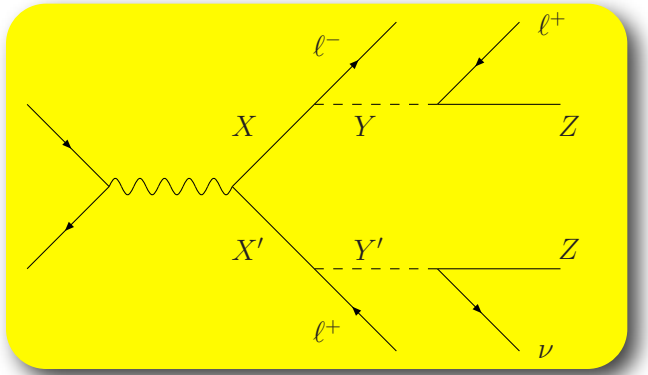


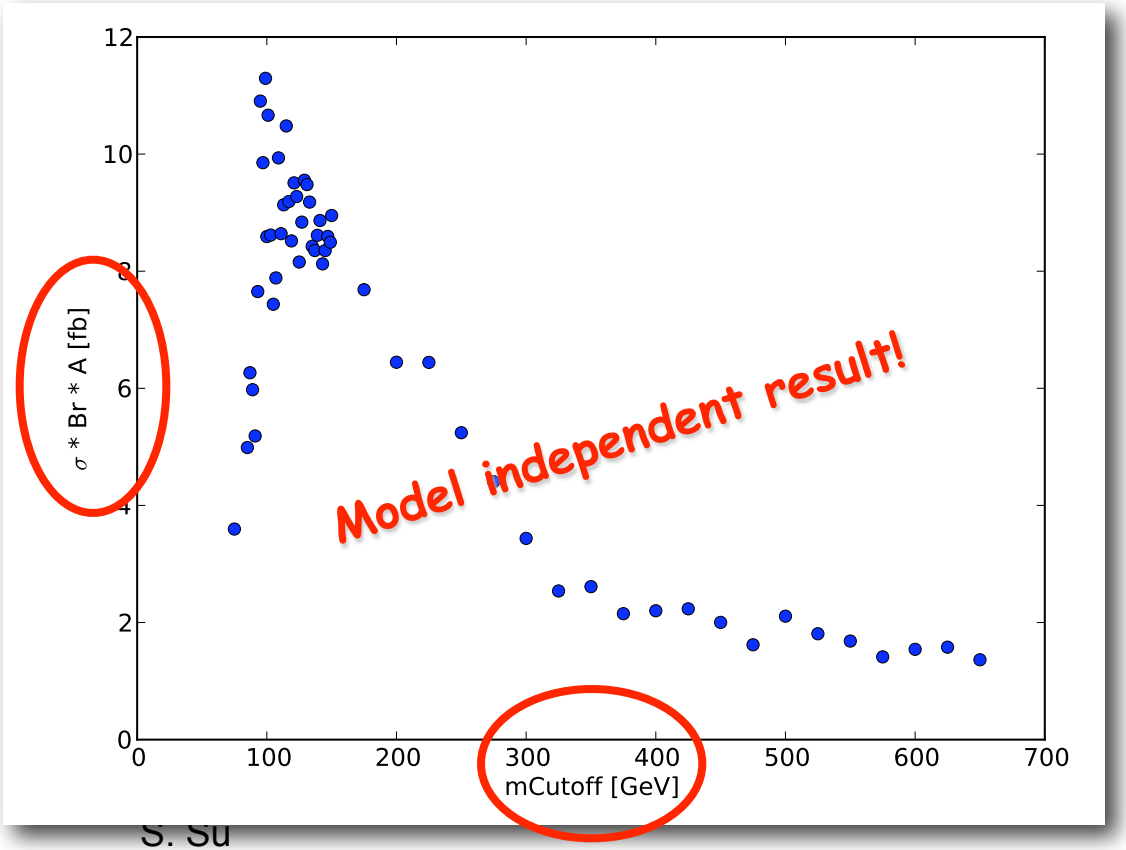


- **Z peak**
  - amplitude
  - peak position
  - width
- **ttbar+fake**
  - fake rate
- **Signal triangle**
  - signal counts
  - mll cutoff
  - gaussian smearing

Cross section reach

- given m_{cut}, marginalizing over other fitting parameters
  ⇒ Nsig required for 5 sigma ⇒ required sigma*Br*Acc





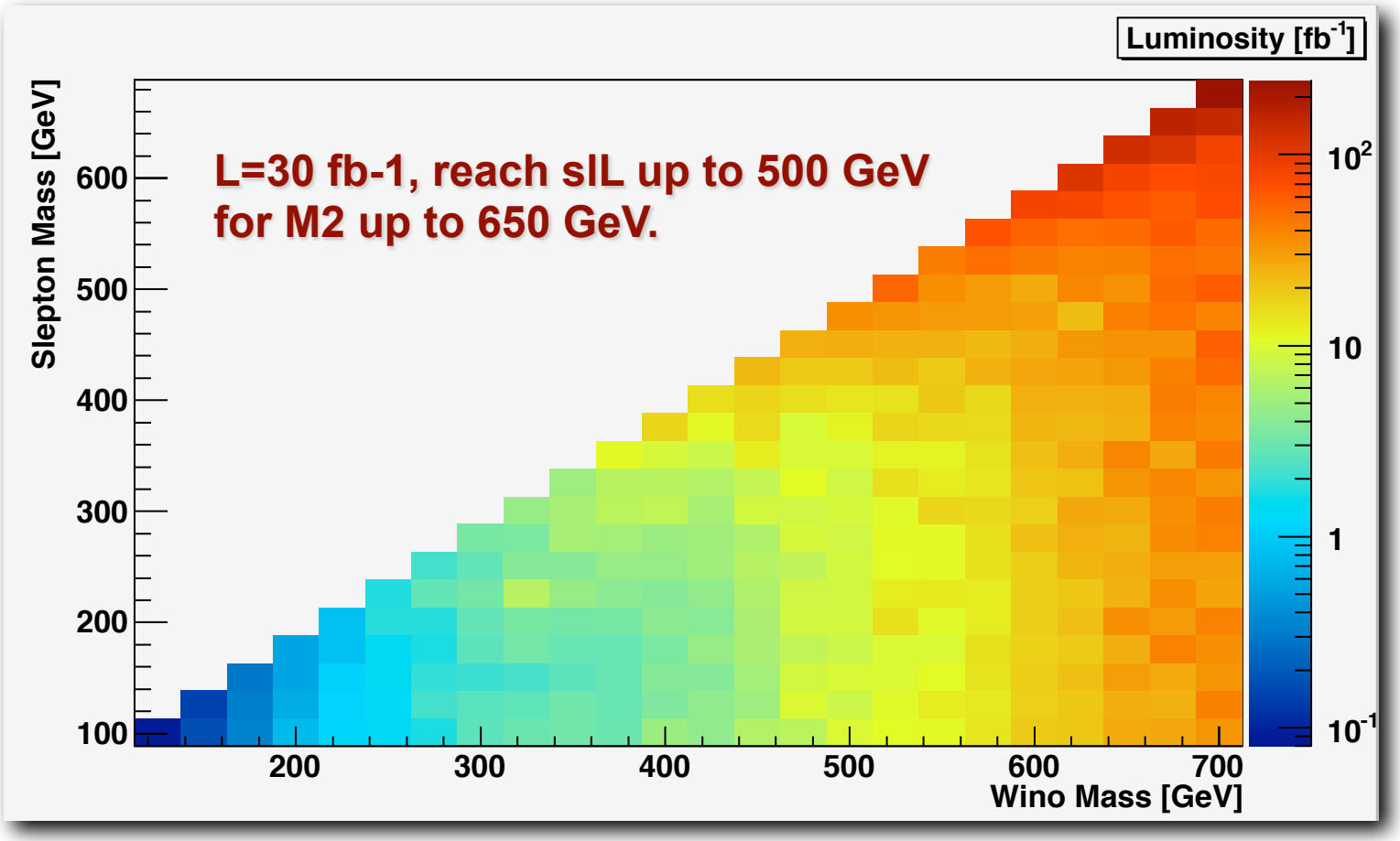
- Can be applied to other model with similar topology
- background fitting: any process give a Z peak
- results only sensitive to m_{cut}

- given model
  - mX, mY, mZ ⇒ mcut
  - sigma*Br*Acc

S. Su

MSSM Slepton: 14 TeV Reach

- Apply to MSSM case, slepton from $\chi_1^{\pm}\chi_2^0$ decay



Conclusions

- LHC has great reach for colored particles, but more studies needed to explore LHC potential for EW particles.
- Current LHC search already set strong bounds (TeV) on the mass of colored object, however, the search strategy is not optimized for EW particles.
- Existing study on EW particles make simple assumptions, e.g., mSUGRA or gaugino mass unification relation
- MSSM EW sector: neutralinos, charginos and sleptons with general parametrization

Conclusions

- Neutralinos/charginos: light wino and light Higgsino cases
  - decay pattern depends on the slepton masses
- LHC reach of neutralinos/charginos with decoupled slepton
  - M1-M2, M1-μ
- light slepton: slepton via neutralino/chargino decay
  - utilize the triangle shape in mll distribution
  - model independent approach: results can be applied to other models, and various mass spectrum
  - MSSM: 14 TeV with 30 fb^{-1}, M_2 up to 650 GeV, MseL up to 500 GeV

Regions to be explored

- neutralino/chargino reach for slepton heavier than $\chi_2^0/\chi_1^\pm$, but accessible through off-shell slepton decay
  lepton rich final state, but no triangle feature
- slepton DY, direct decay, for non-SUGRA spectrum
- slepton DY with cascade decay
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Stay tuned ...