Overview on theoretical aspects related to Higgs assisted SUSY electroweak sector

Shufang Su • U. of Arizona

In collaboration with M.Berggren, T. Han, Jenny List, Sanjay Padhi, Tomohiko Tanabe

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Exploring LHC/ILC reach for the electroweak sector of MSSM

gauginos, Higgsinos with the help of the Higgs boson

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Exploring LHC/ILC reach for the electroweak sector of MSSM
gauginos, Higgsinos with the help of the Higgs boson

Comprehensive scan in M_1, M_2 and mu and study both LHC/ILC prospects of discovery/exclusion reach for neutralinos/charginos.

Sanjay Padhi, Tomohiko Tanabe

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Tomohiko Tanabe: Joint LHC-ILC Studies-Electroweakino Scan

In collaboration with M.Berggren, T. Han, Jenny List, Sanjay Padhi, Tomohiko Tanabe

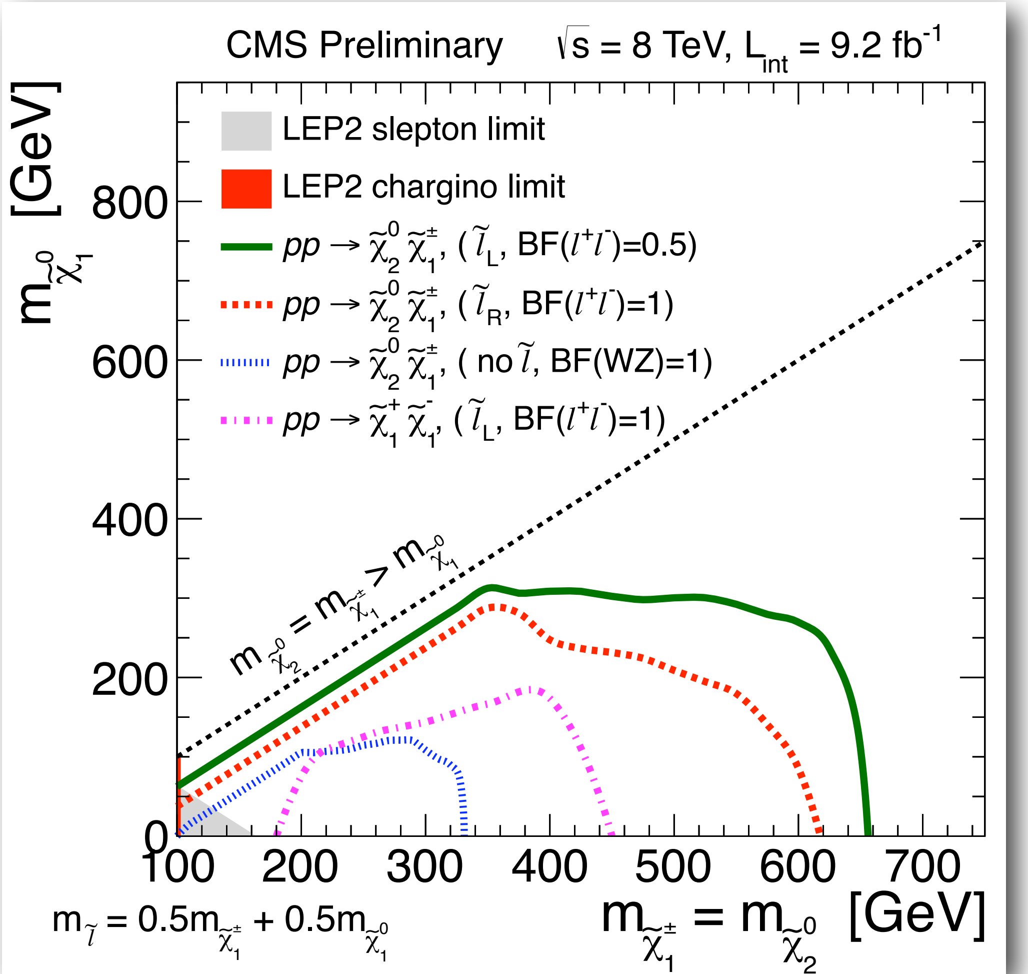
Motivation

- Higgs connection
  - natural SUSY: light gauginos and Higgsinos
- DM connection
  - neutralinos: DM candidate
- Colored superparticle might be very heavy
  - no indication from current LHC search: m_{sq}, m_{gluino} > 1 TeV
  - EW sector (+stop/sbottoms) might be the only particles accessible at the LHC
- Neutralinos and Charginos
  - suffer from small electroweak production
  - current search mostly focused on slepton assisted channels
  - current reach of neutralino/chargino w/o slepton: limited
- Connection to Lepton Collider

CMS limits

dilepton/trilepton + MET

CMS PAS SUS-12-022



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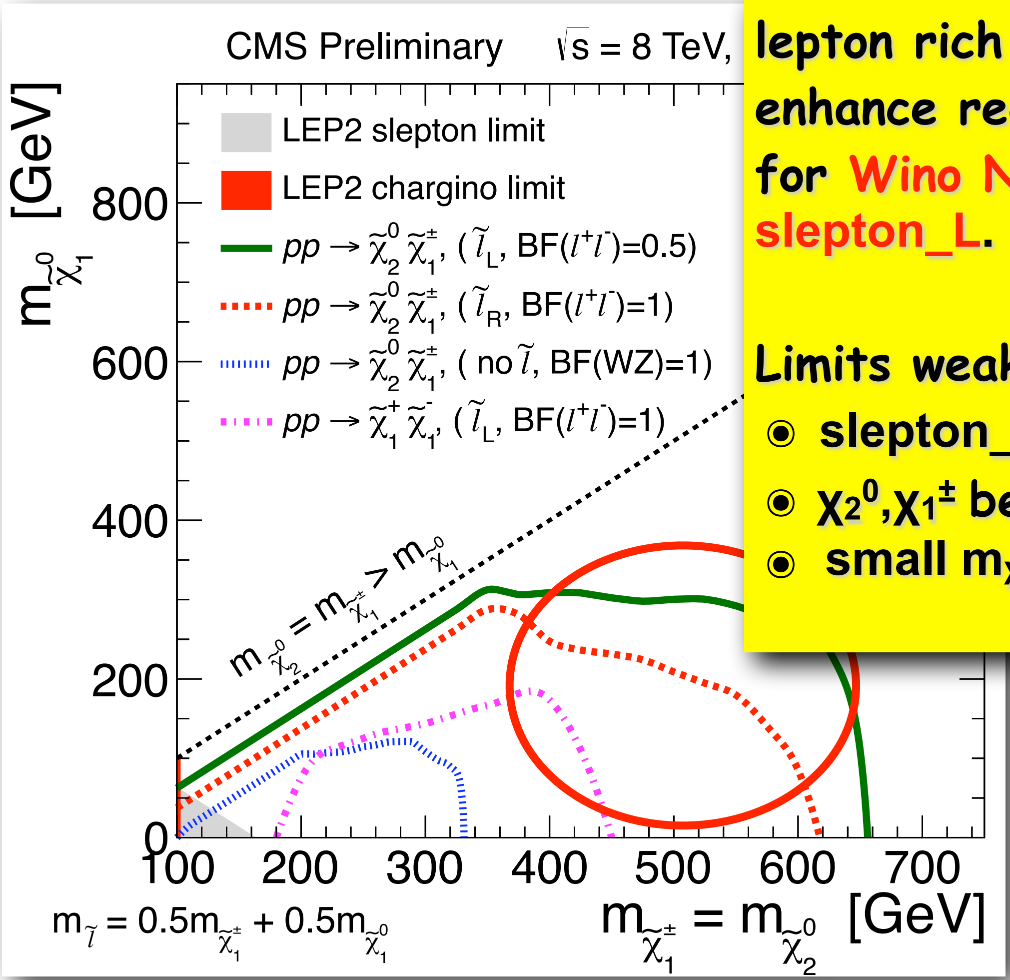

lepton rich final states to enhance reach: only works for Wino NLSP with light slepton_L.

Limits weaker for

- **slepton_L heavy**
- **$\chi_2^0, \chi_1^\pm$ being Higgsinos**
- **small $m_{\chi_1^\pm} - m_{\chi_1^0}$**

CMS limits

dilepton/trilepton + MET

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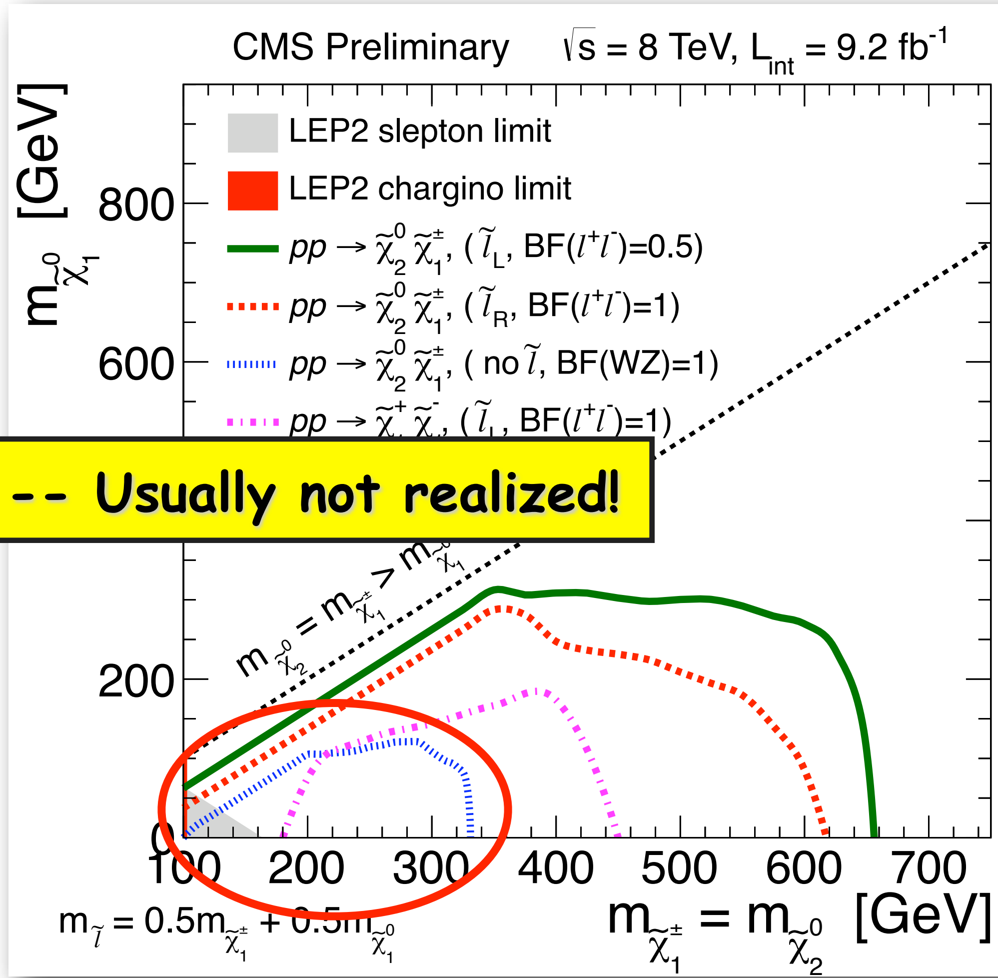
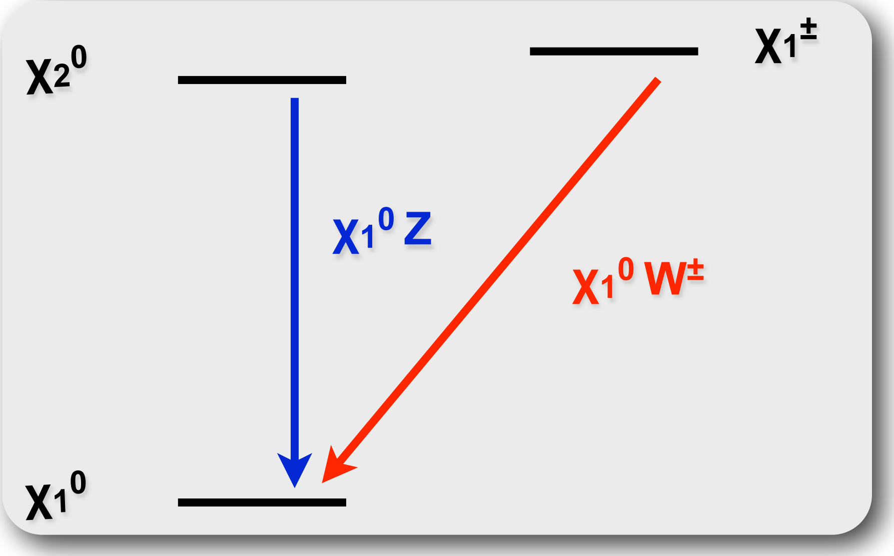


100% WZ Br -- Usually not realized!

Decay of heavy neutralino and chargino



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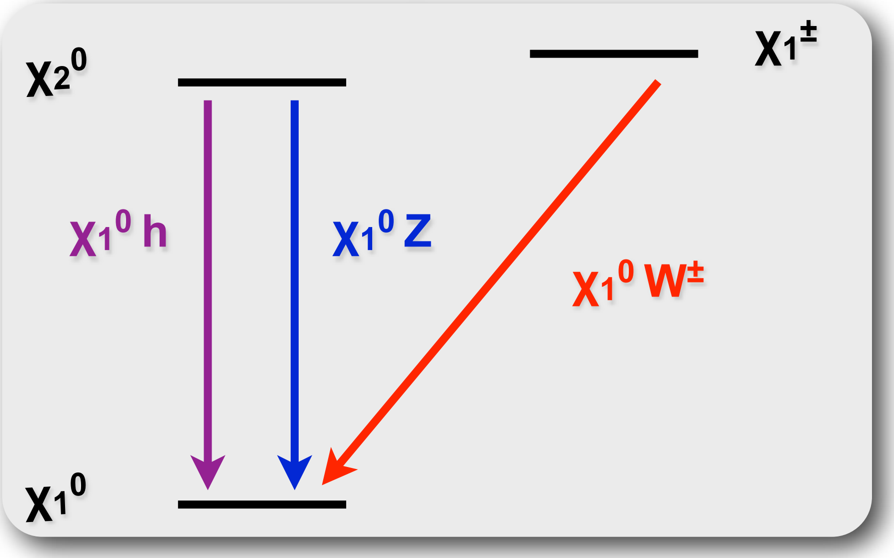

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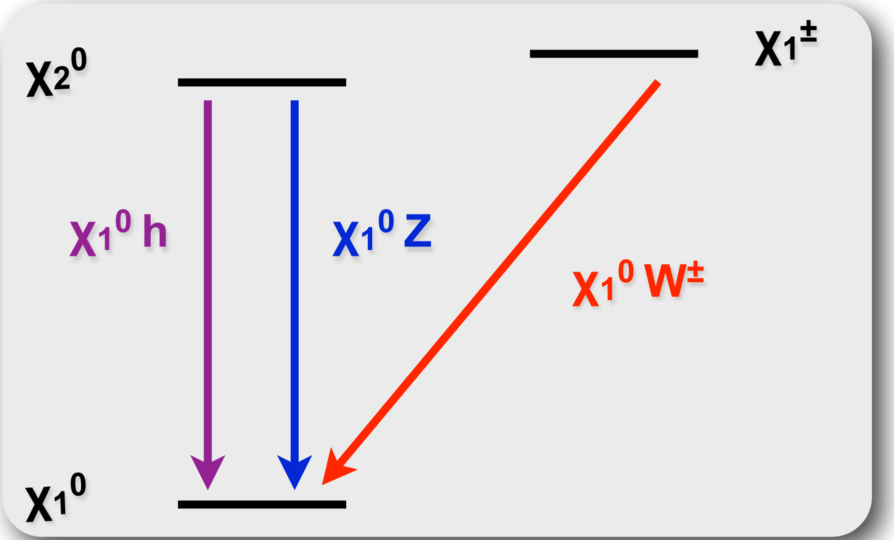

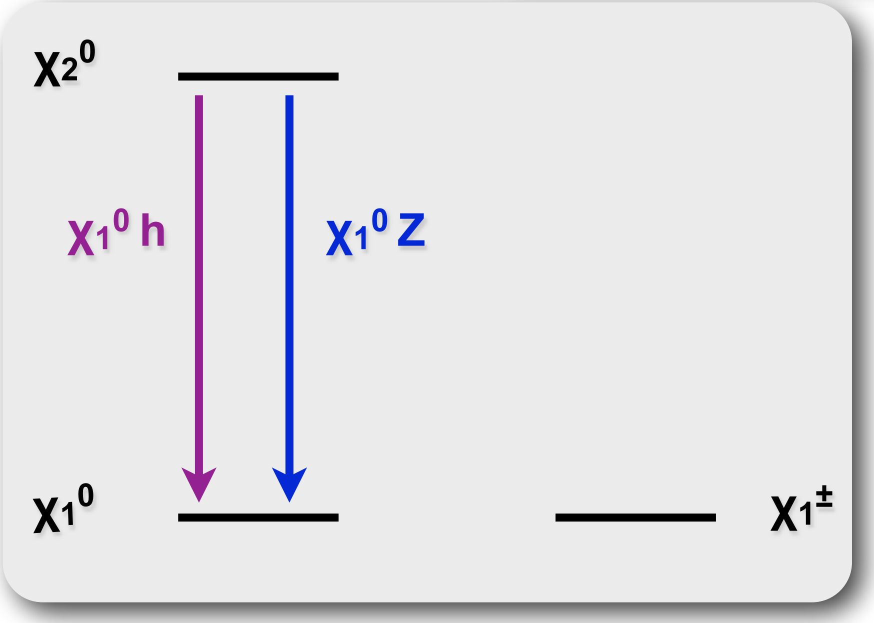

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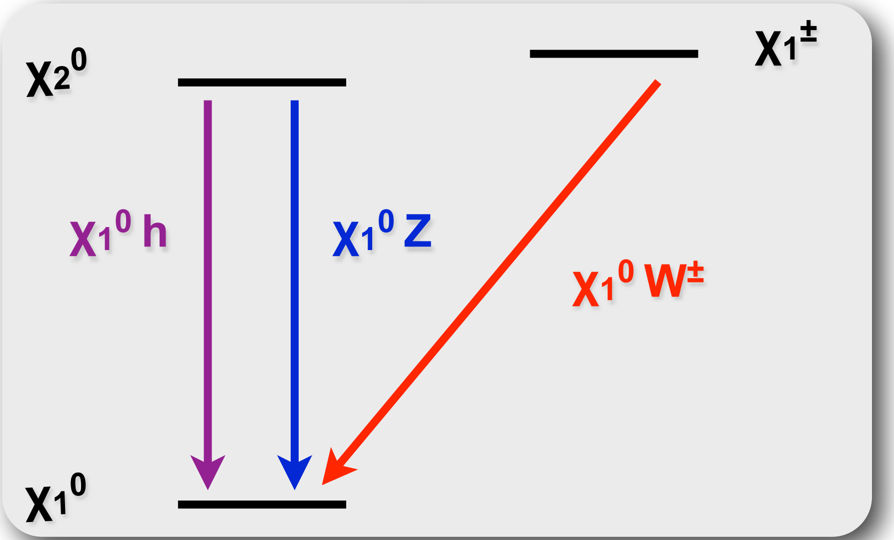

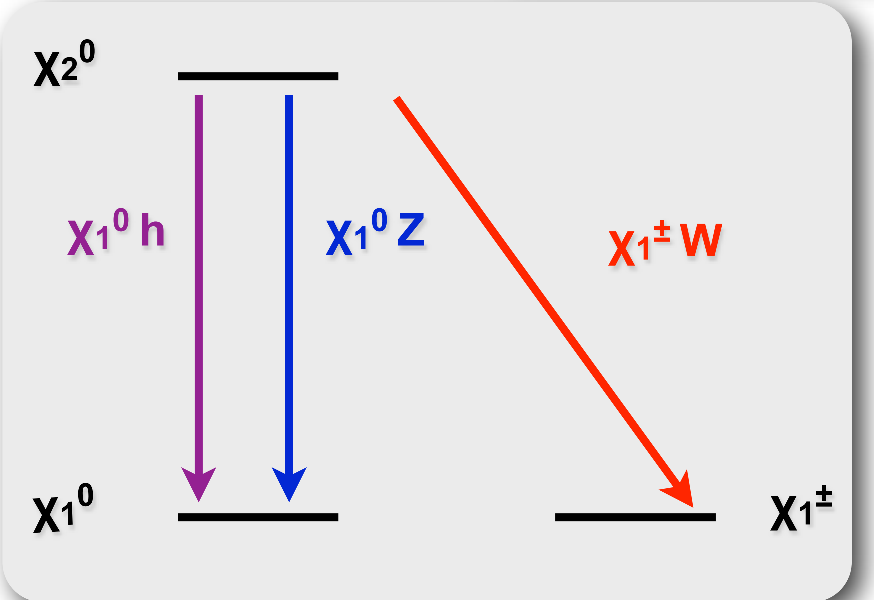

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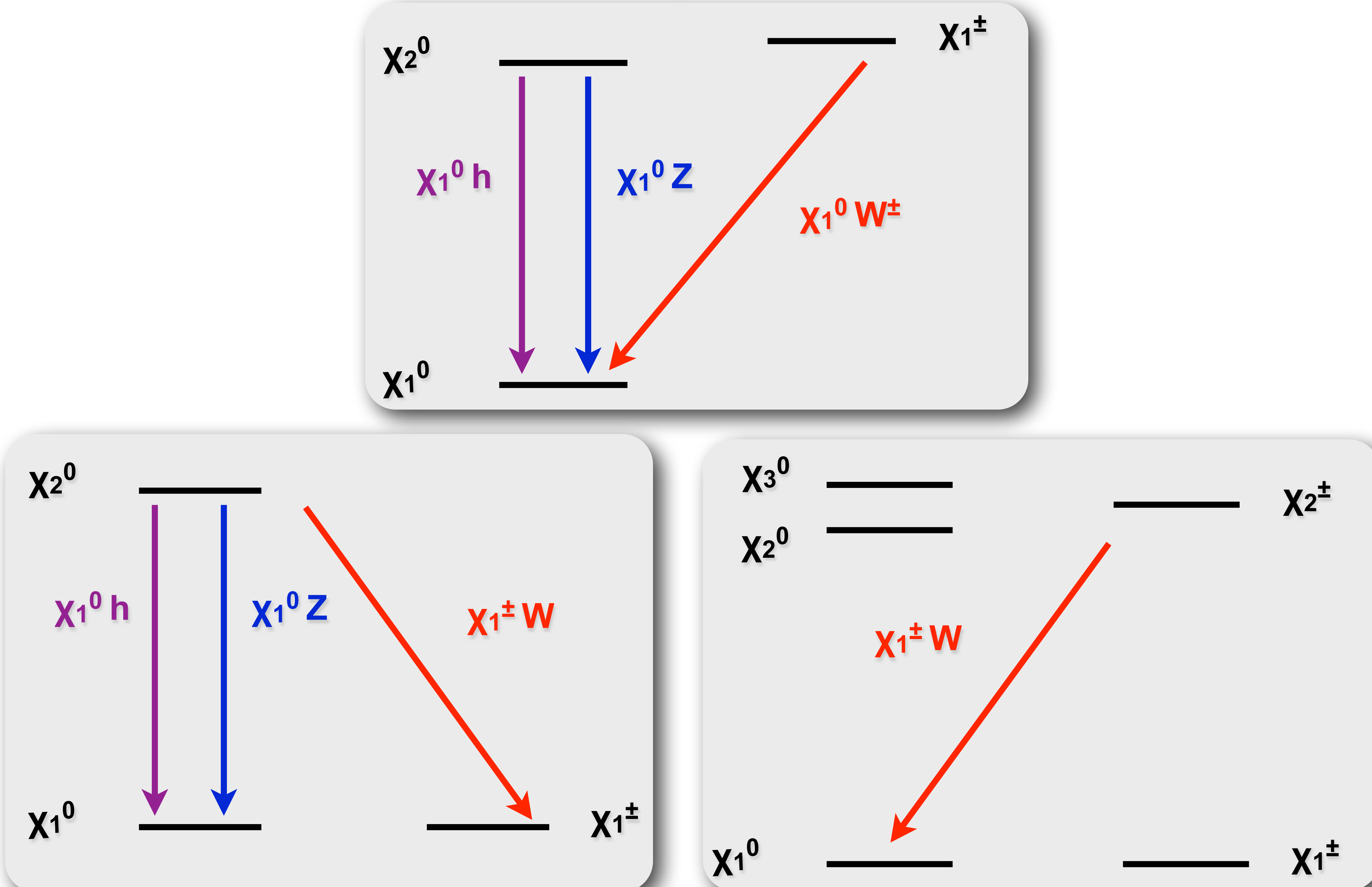

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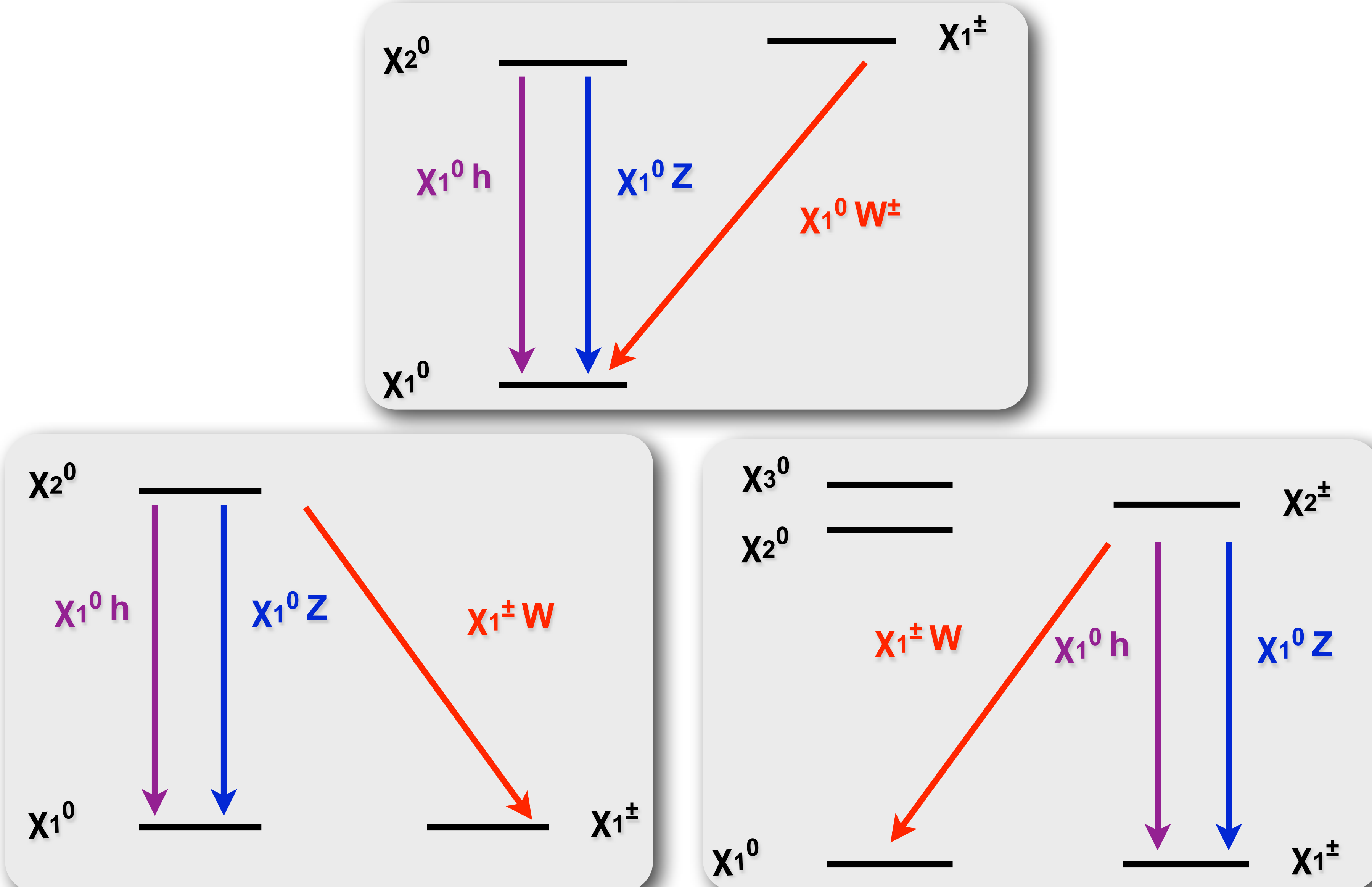

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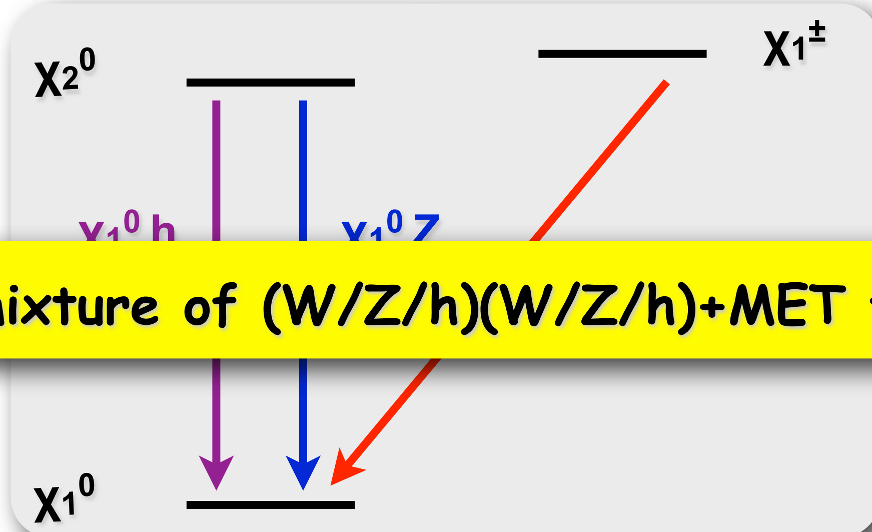
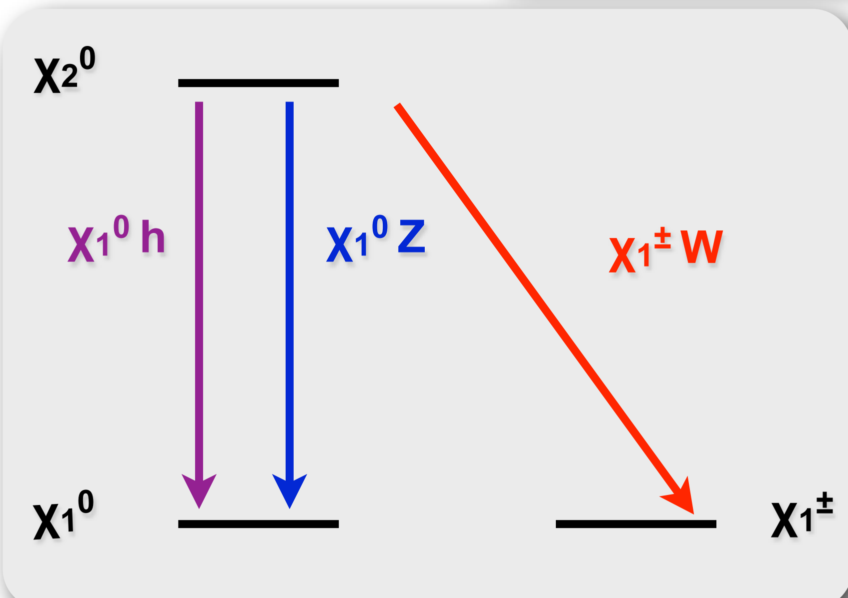
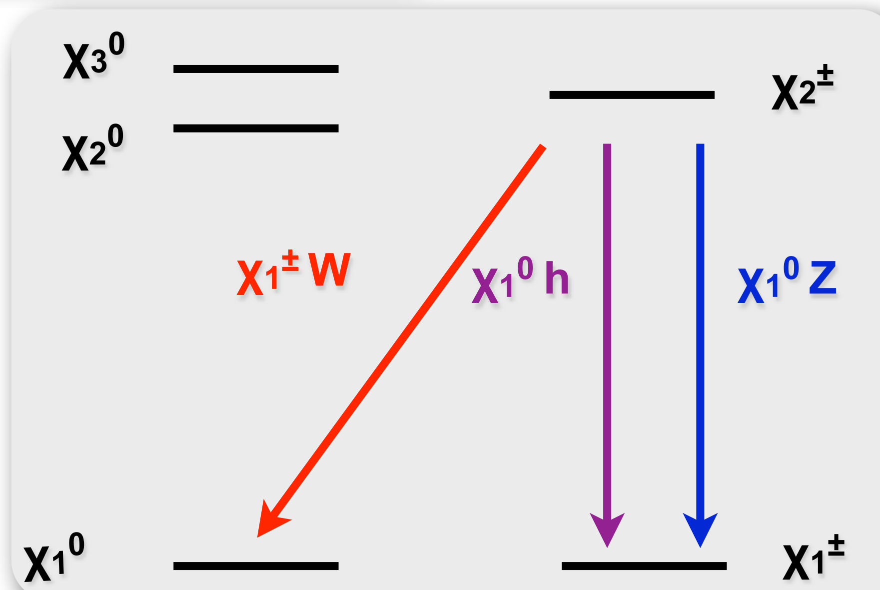


A rich mixture of (W/Z/h)(W/Z/h)+MET final states!





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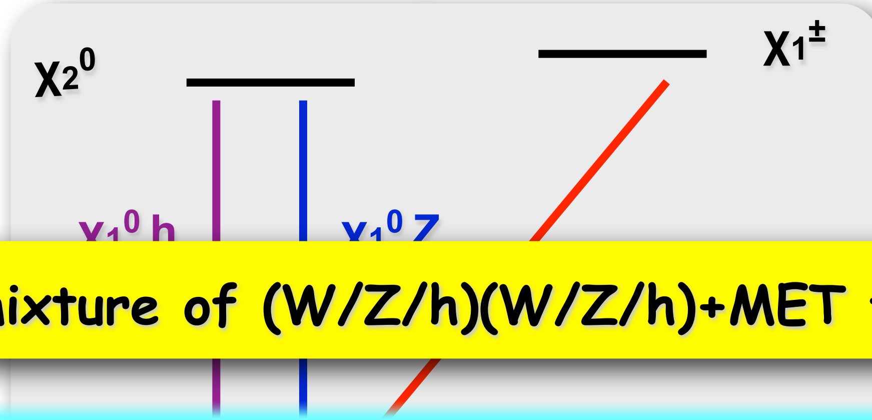
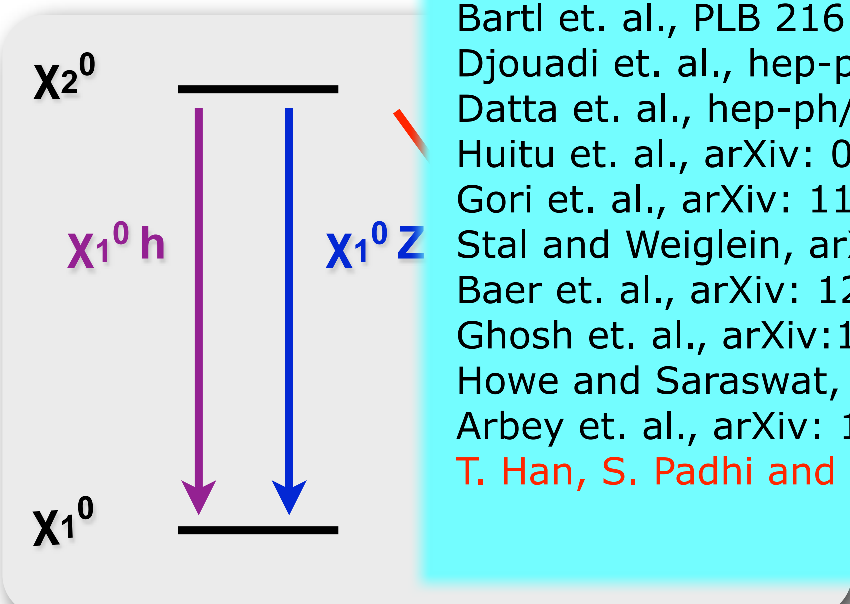
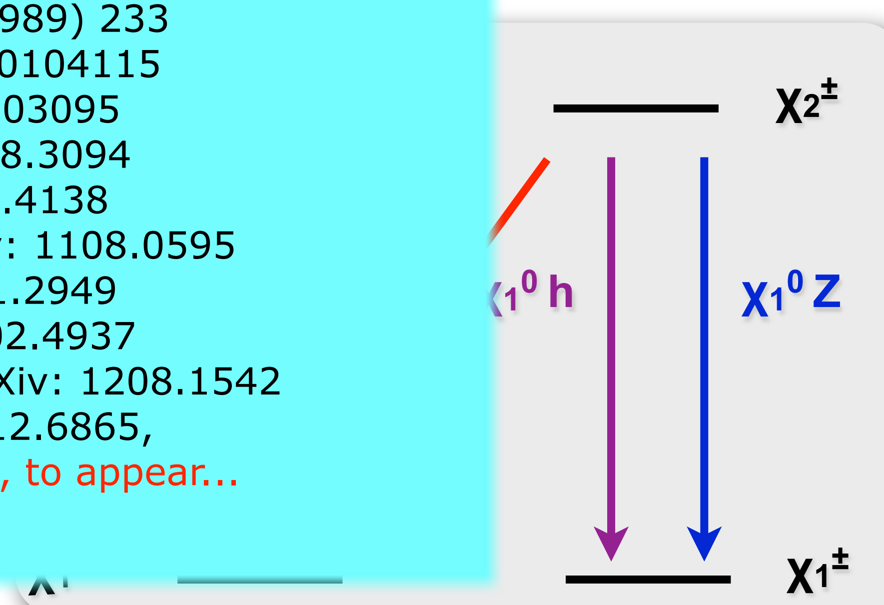


A rich mixture of (W/Z/h)(W/Z/h)+MET final states!

Gunion et. al., Int. J. Mod. Phys. A2 (1987) 1145
Gunion and Haber, PRD 37 (1988) 2515
Bartl et. al., PLB 216 (1989) 233
Djouadi et. al., hep-ph/0104115
Datta et. al., hep-ph/0303095
Huitu et. al., arXiv: 0808.3094
Gori et. al., arXiv: 1103.4138
Stal and Weiglein, arXiv: 1108.0595
Baer et. al., arXiv: 1201.2949
Ghosh et. al., arXiv:1202.4937
Howe and Saraswat, arXiv: 1208.1542
Arbey et. al., arXiv: 1212.6865,
T. Han, S. Padhi and SS, to appear...





MSSM EW-ino sector 101

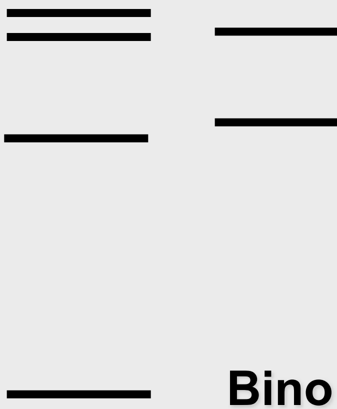
- Gauginos and Higgsinos
  - Neutral ones: Bino, Wino, $\tilde{H}_u^0$, $\tilde{H}_d^0$
  - charged ones: Winos, $\tilde{H}_u^+$, $\tilde{H}_d^-$
- Parameters: M_1, M_2, μ, $\tan\beta$

→

- Neutralinos and charginos

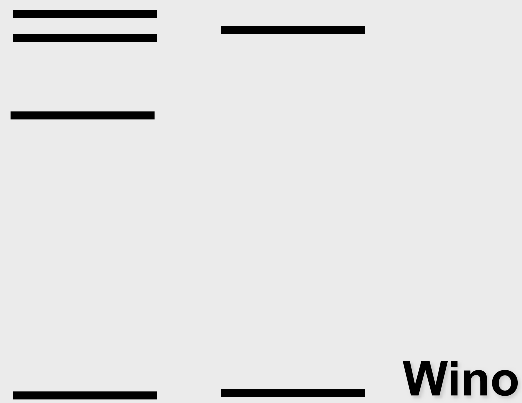
Order of M_1, M_2 and μ

Bino LSP
$M_1 < M_2, \mu$



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

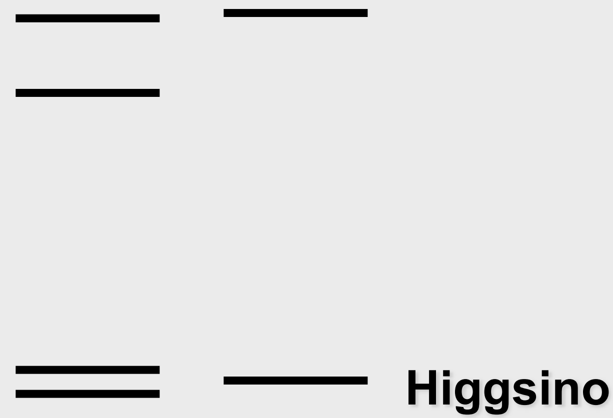
Wino LSP
$M_2 < M_1, \mu$



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

Six cases

LSP(s): usual LSP+degenerate states
NLSP(s): 2nd set low-lying (degenerate) states

Case AI: Bino LSP-Wino NLSP $M_1 < M_2 < \mu$
Case AII: Bino LSP-Higgsino NLSP $M_1 < \mu < M_2$

Case BI: Wino LSP-Bino NLSP $M_2 < M_1 < \mu$
Case BII: Wino LSP-Higgsino NLSP $M_2 < \mu < M_1$

Case CI: Higgsino LSP-Bino NLSP $\mu < M_1 < M_2$
Case CII: Higgsino LSP-Wino NLSP $\mu < M_2 < M_1$

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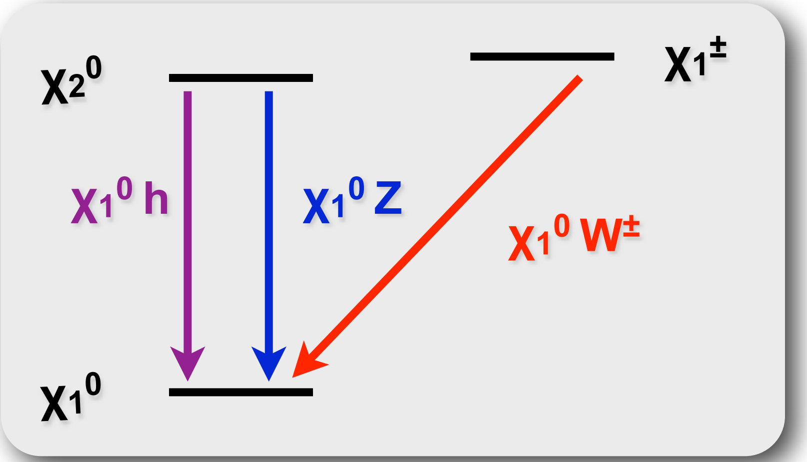
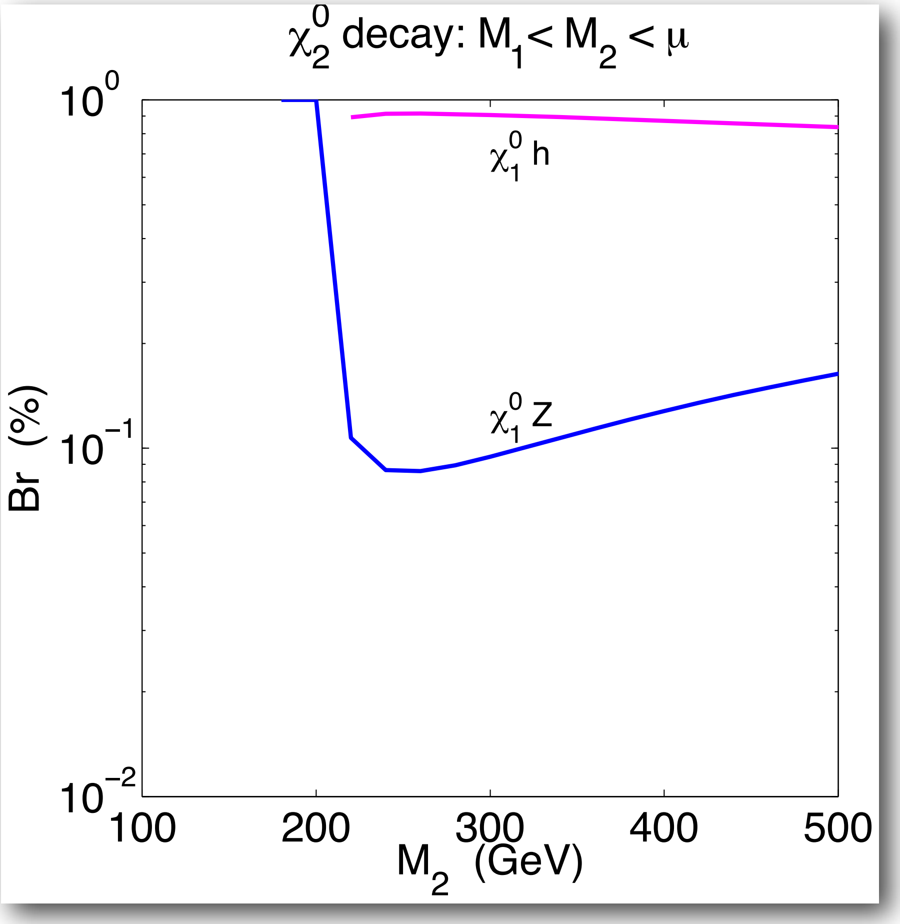
Case CII: Higgsino LSP-Wino NLSP $\mu < M_2 < M_1$

Small NLSP production at LHC: unobservable
nearly degenerate LSP pair productions at ILC: Unique opportunity!

Case AI: Bino LSP - Wino NLSP





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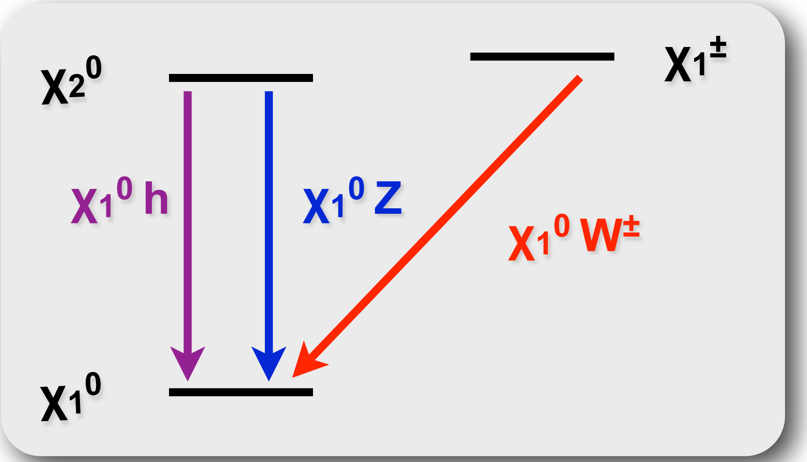
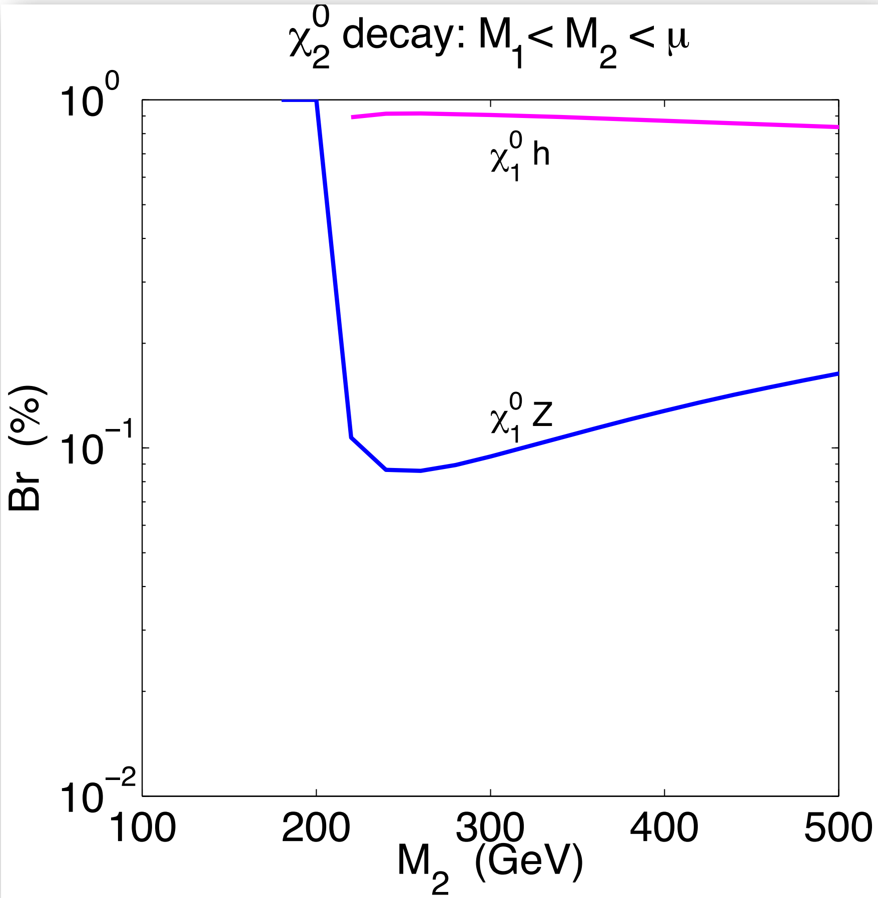
Case AI: Bino LSP - Wino NLSP



$\chi_1^\pm$ decay 100% via on/off-shell W



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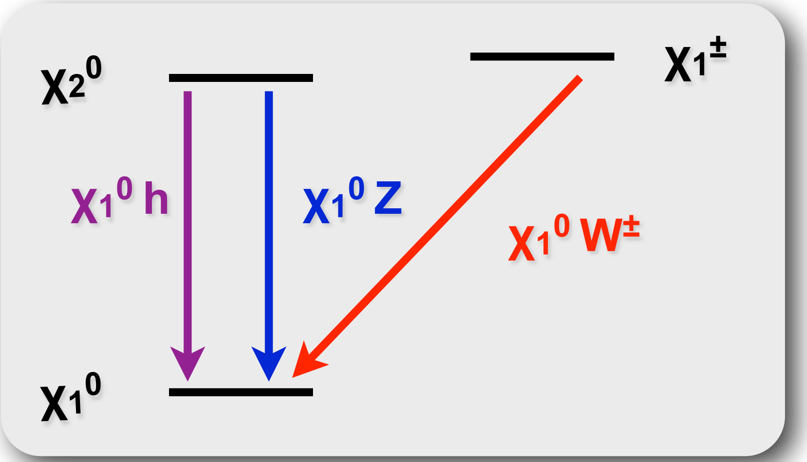
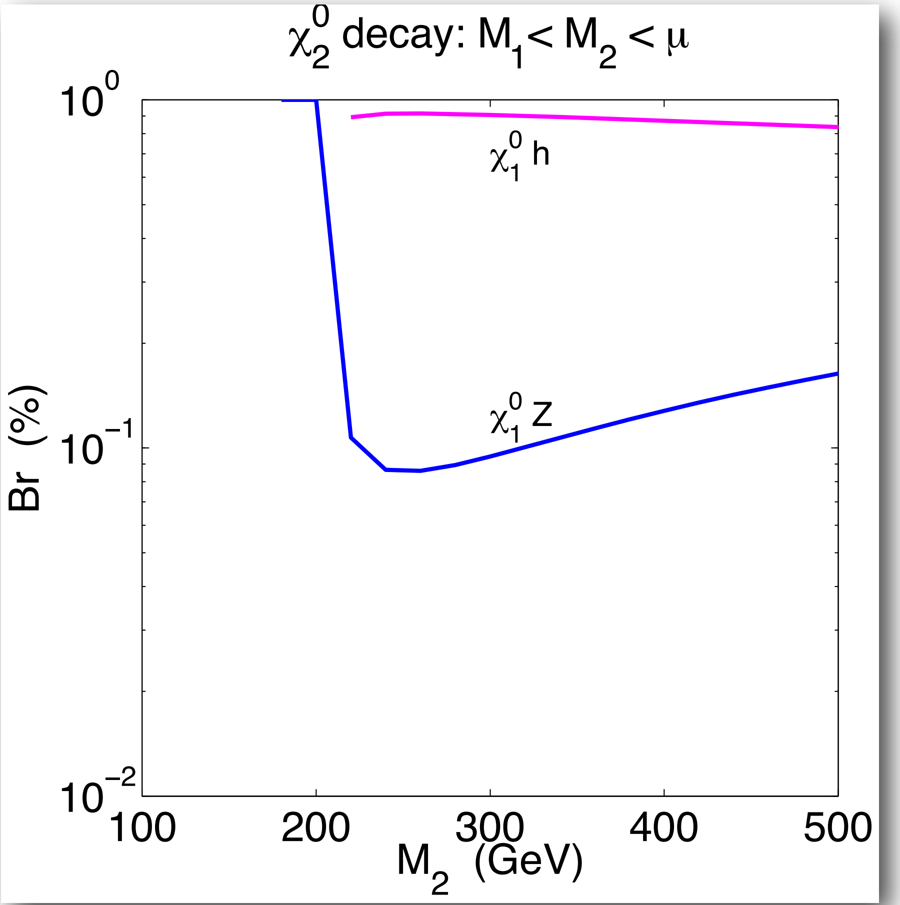


$\chi_1^\pm$ decay 100% via on/off-shell W

- below h threshold, decay via on/off-shell Z
- χ_2^0 on-shell decay to h dominate over on-shell Z for $\mu > 0$
- χ_2^0 decay to h and Z flipped for $\mu < 0$



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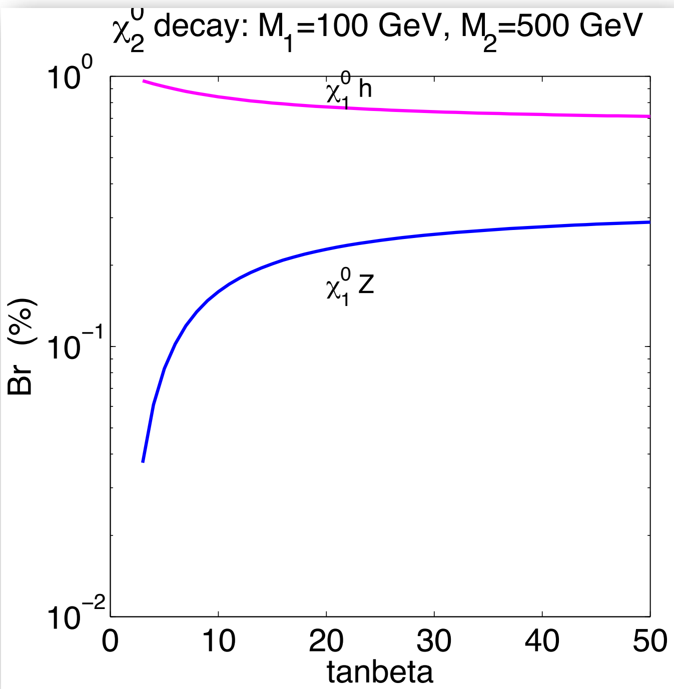
Case AI: Bino LSP - Wino NLSP

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

$$h = -\sqrt{2} \quad (s_\beta \,\mathrm{Re}(H_u^0) + c_\beta \,\mathrm{Re}(H_d^0)),$$
$$G^0 = \sqrt{2} \quad (s_\beta \,\mathrm{Im}(H_u^0) - c_\beta \,\mathrm{Im}(H_d^0)).$$



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

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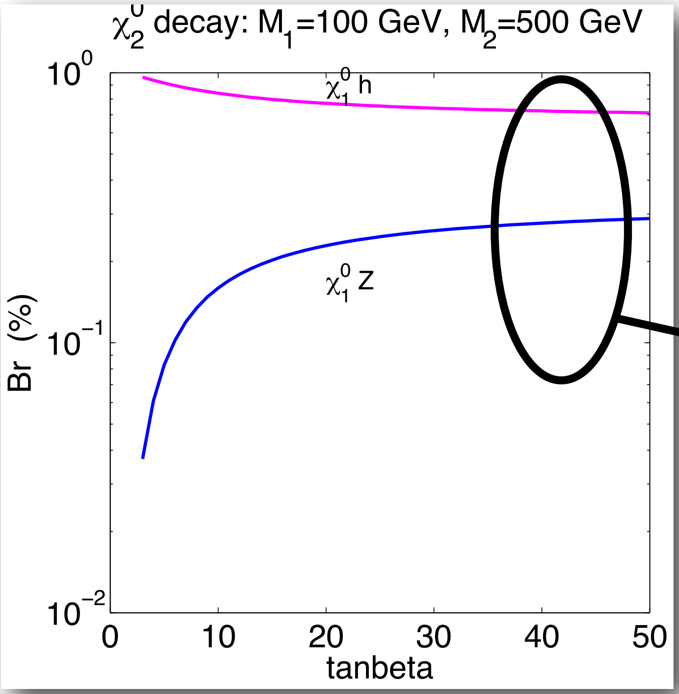

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large tanβ, $\left[(M_2 + M_1)^2 - m_h^2\right] / \left[(M_2 - M_1)^2 - m_h^2\right]$

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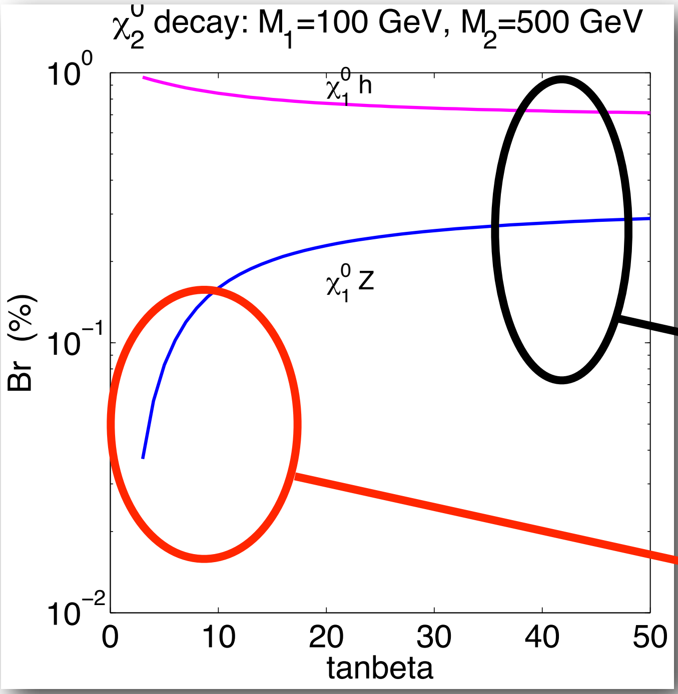

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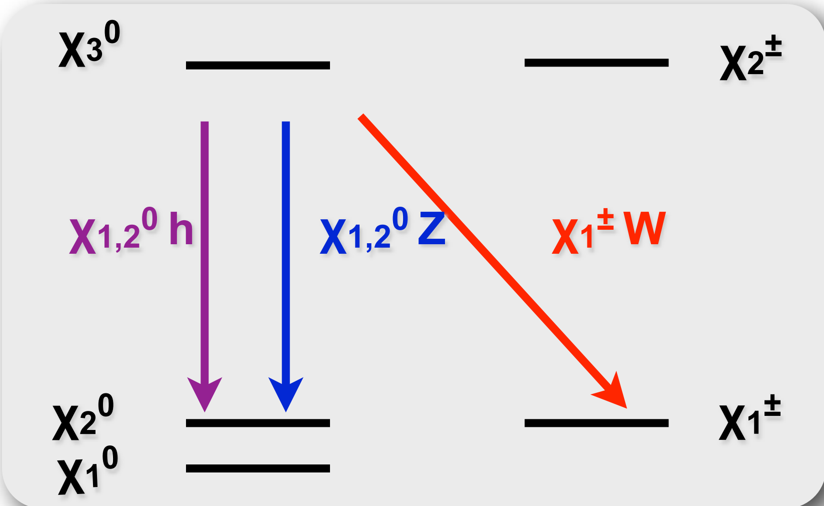
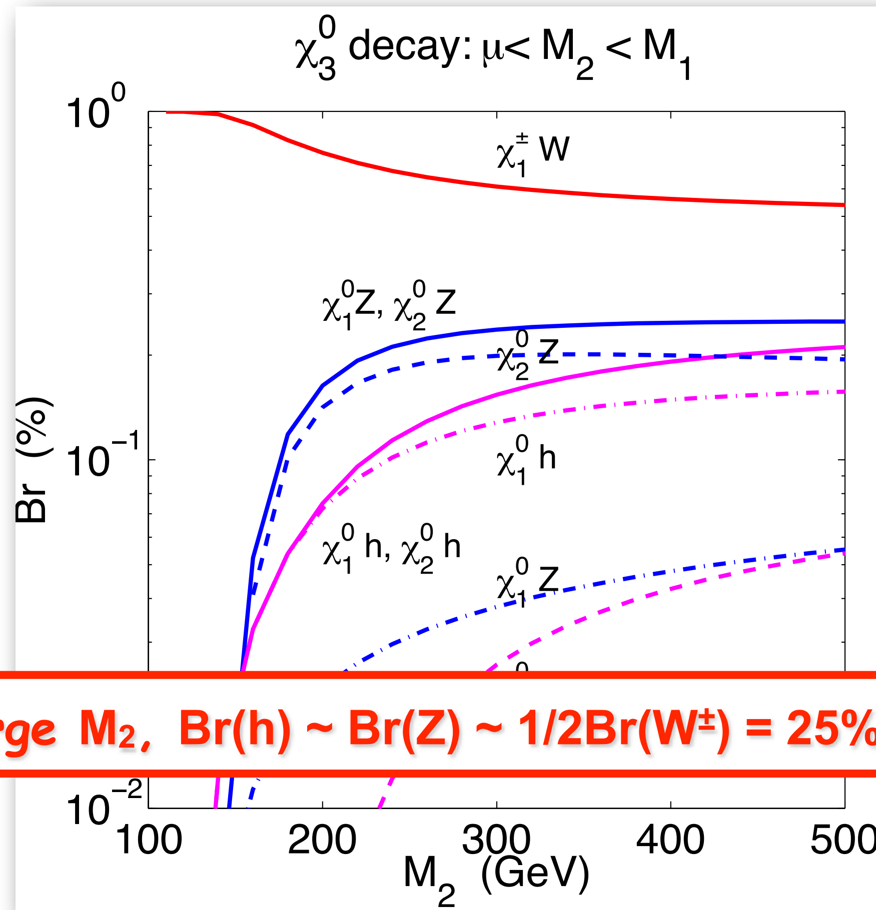
large tanβ, $\left[(M_2+M_1)^2 - m_h^2\right] / \left[(M_2-M_1)^2 - m_h^2\right]$

small tanβ, Z channel relatively suppressed

Case CII: Higgsino LSP- Wino NLSP

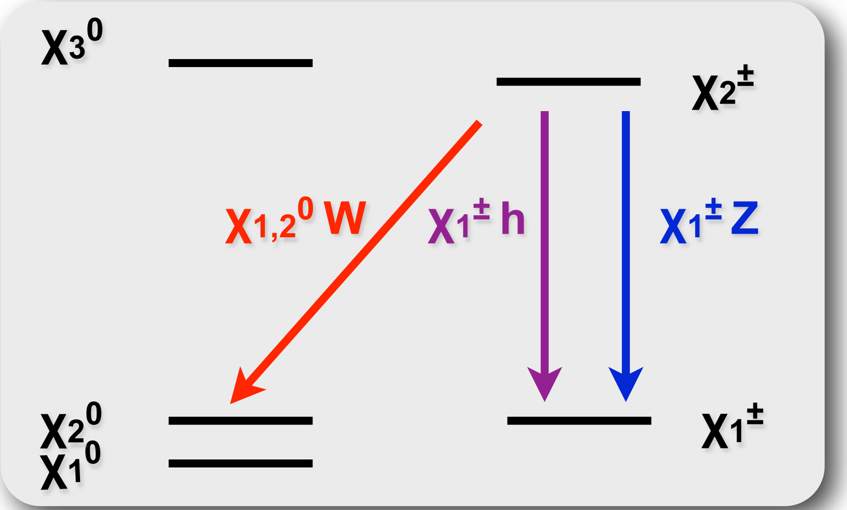


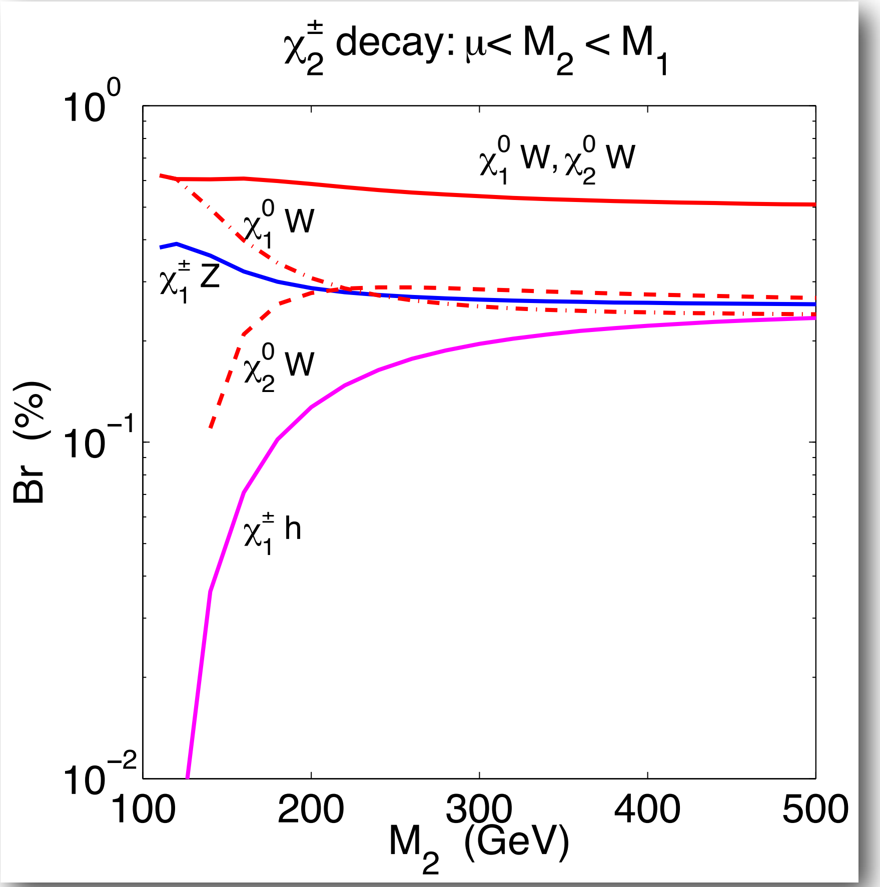
$$\Gamma_{\chi_1^+ W^-} = \Gamma_{\chi_1^- W^+}$$
$$\approx \Gamma_{\chi_1^0 Z} + \Gamma_{\chi_1^0 h} \approx \Gamma_{\chi_2^0 Z} + \Gamma_{\chi_2^0 h}$$
$$\approx \Gamma_{\chi_1^0 h} + \Gamma_{\chi_2^0 h} \approx \Gamma_{\chi_1^0 Z} + \Gamma_{\chi_2^0 Z}.$$



large M_2, Br(h) ~ Br(Z) ~ 1/2Br($W^{\pm}$) = 25%

Case CII: Higgsino LSP- Wino NLSP

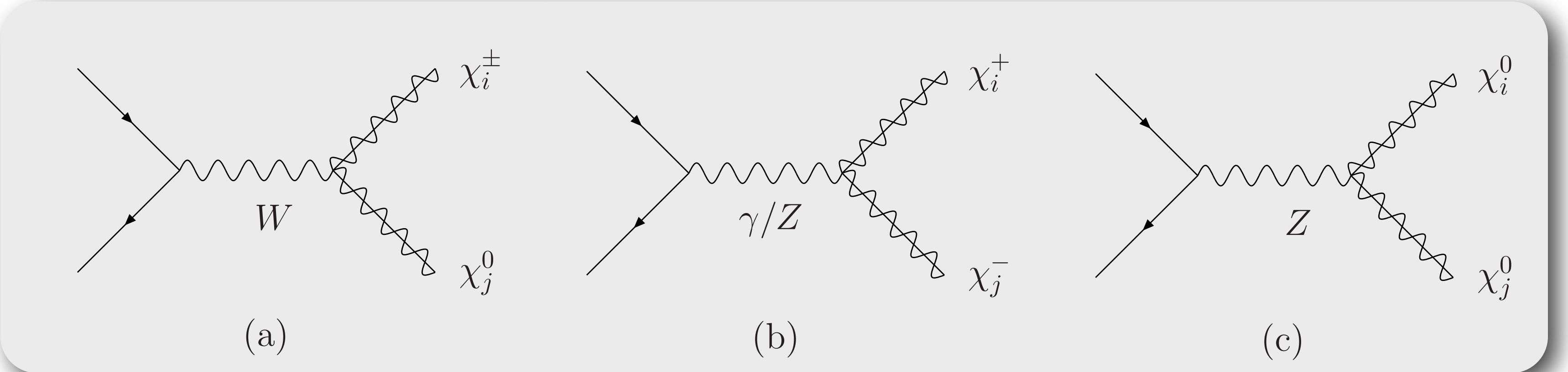




$$\Gamma_{\chi_1^0 W} : \Gamma_{\chi_2^0 W} : \Gamma_{\chi_1^\pm Z} : \Gamma_{\chi_1^\pm h} \approx 1:1:1:1$$

large M_2, Br(h) ~ Br(Z) ~ 1/2Br($W^\pm$) = 25%

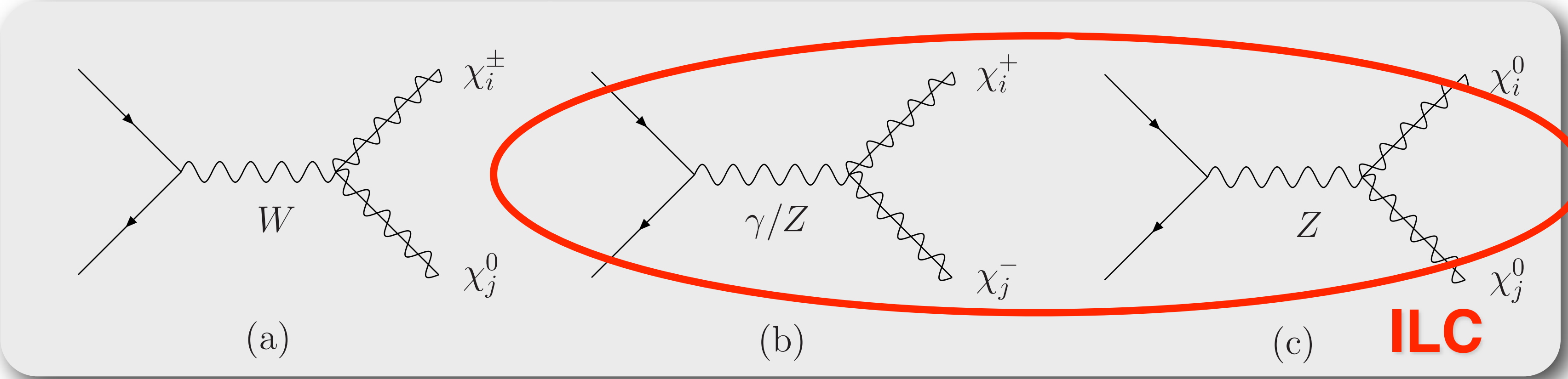
Productions



Dominant production:

- Wino pair production: cha-cha, cha-neu
- Higgsino pair production: cha-cha, cha-neu, neu-neu

Productions



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- **Wino pair production: cha-cha, cha-neu**
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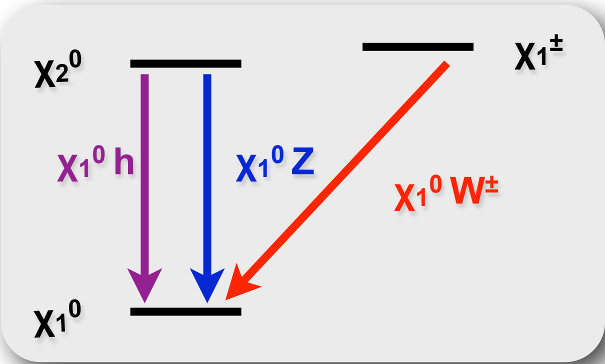
Productions: Bino LSP - Wino NLSP



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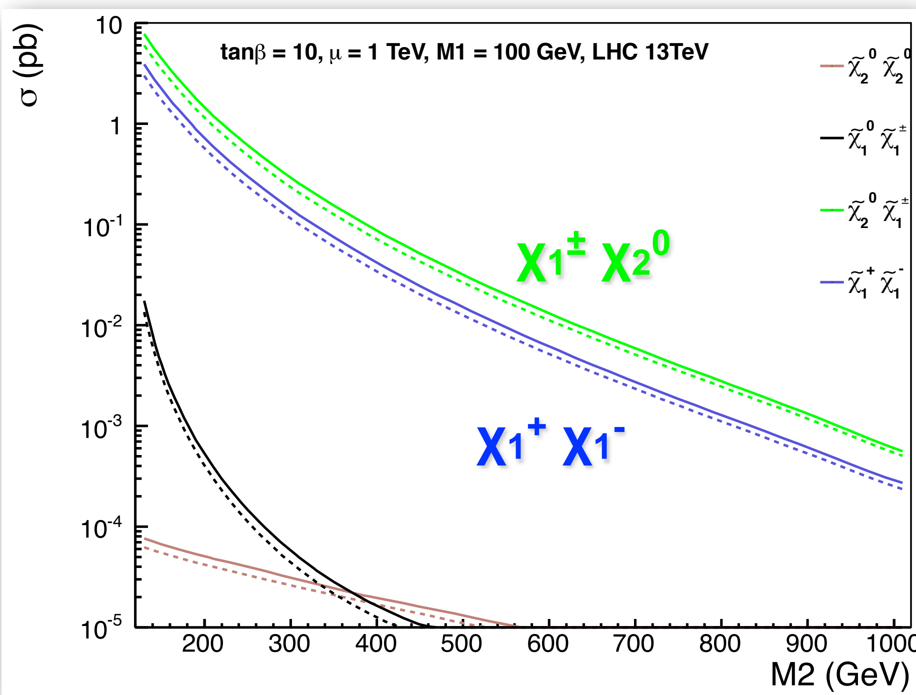
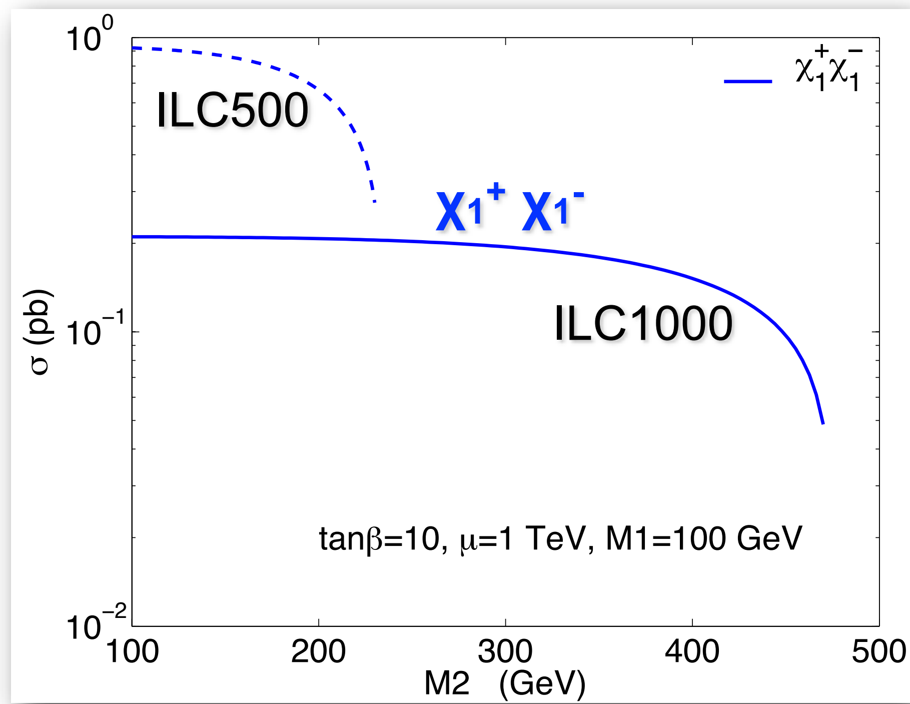
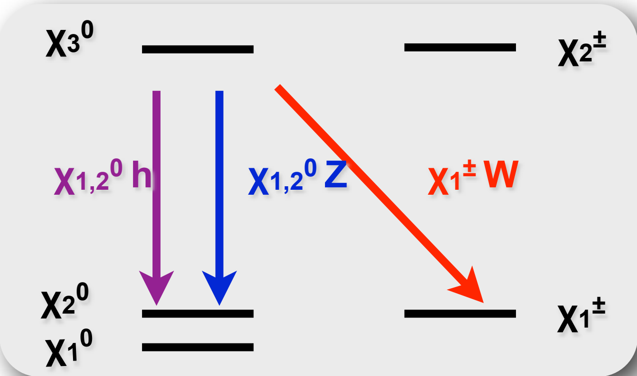
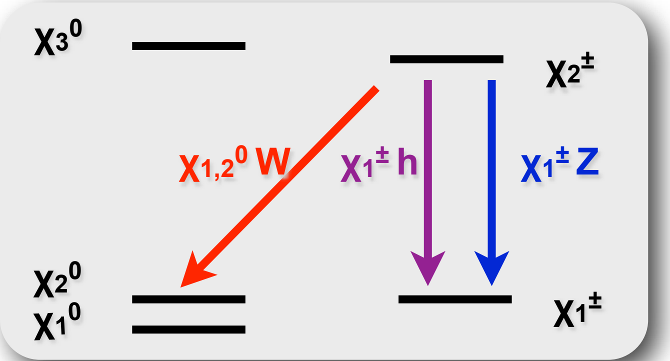


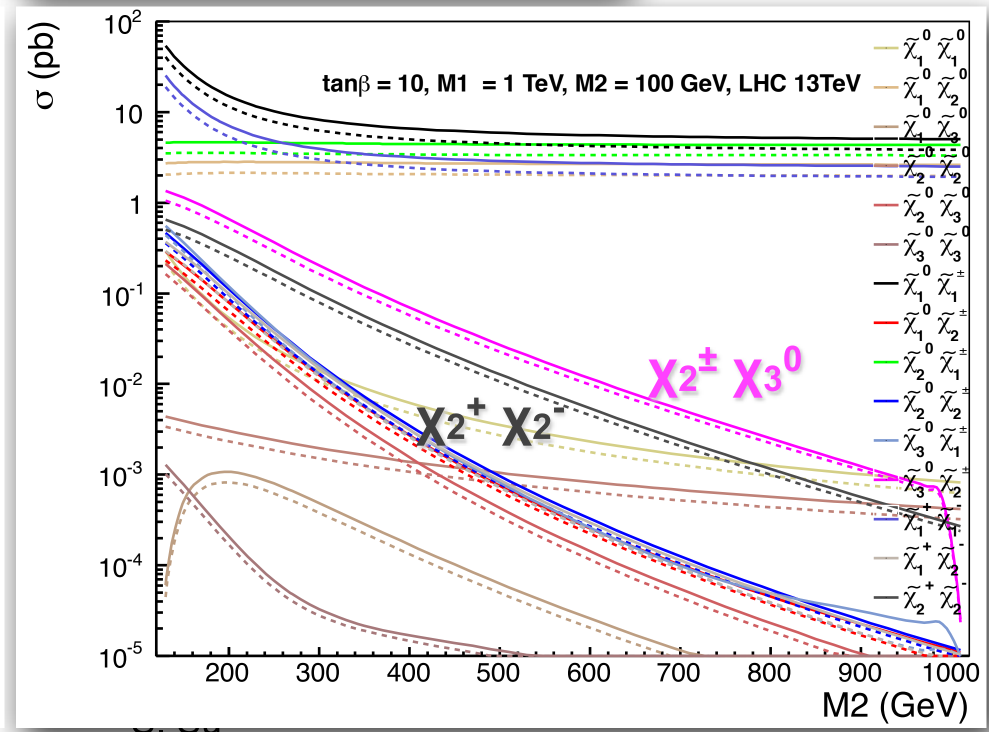


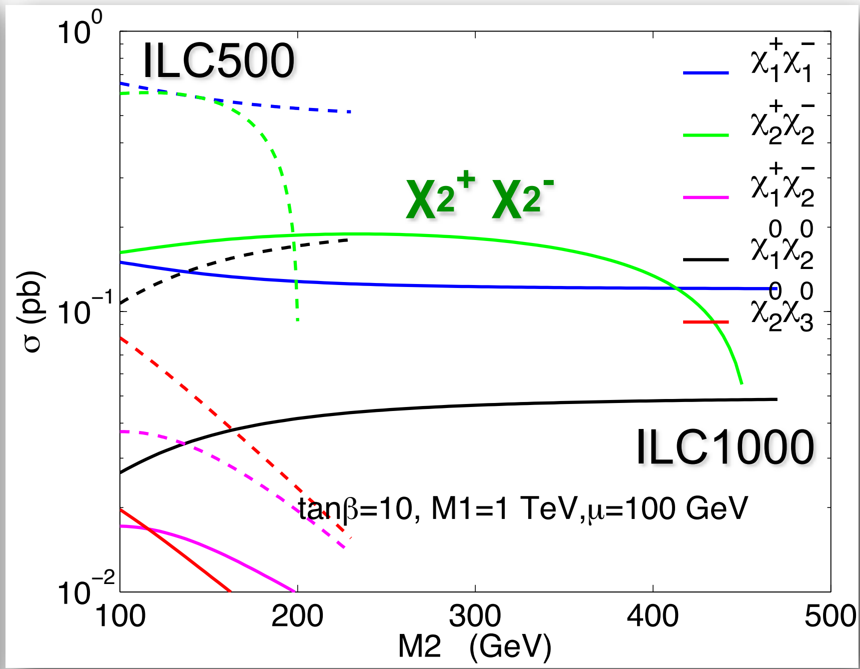
Productions: Higgsino LSP - Wino NLSP



Case CII: $\mu < M_2 < M_1$







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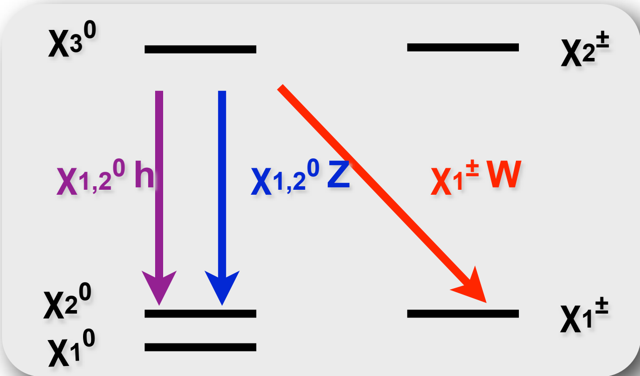
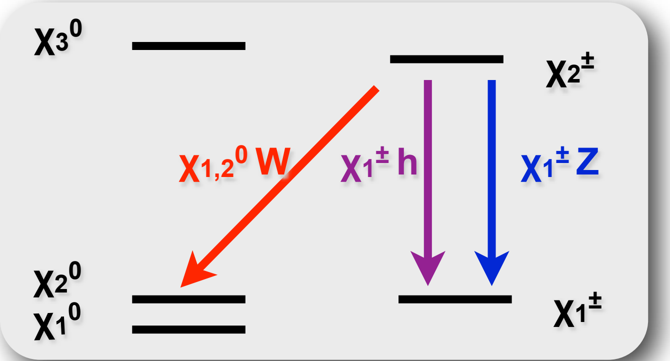
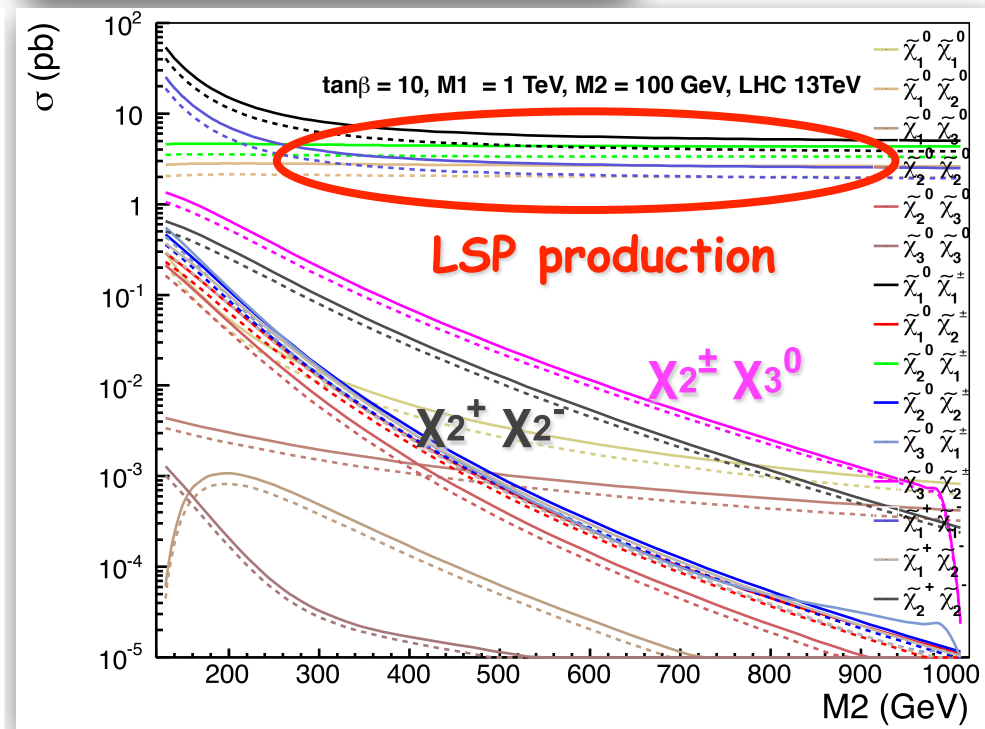
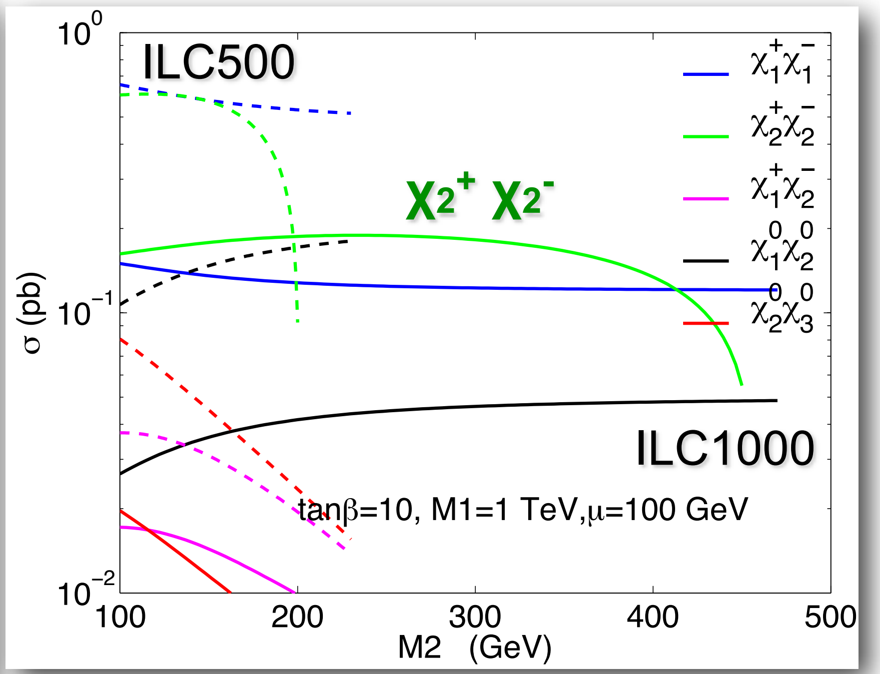


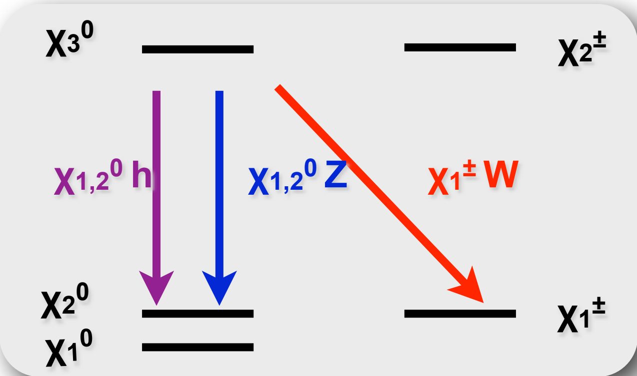
Case CII: $\mu < M_2 < M_1$



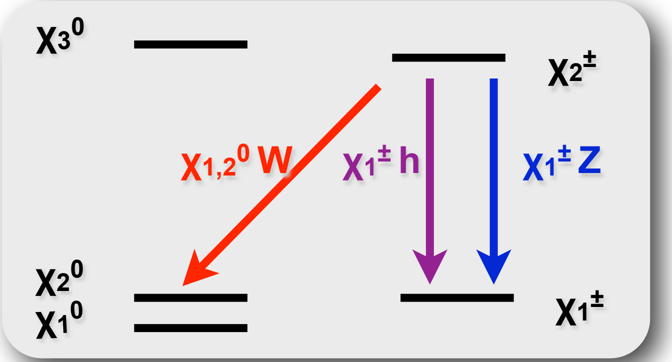


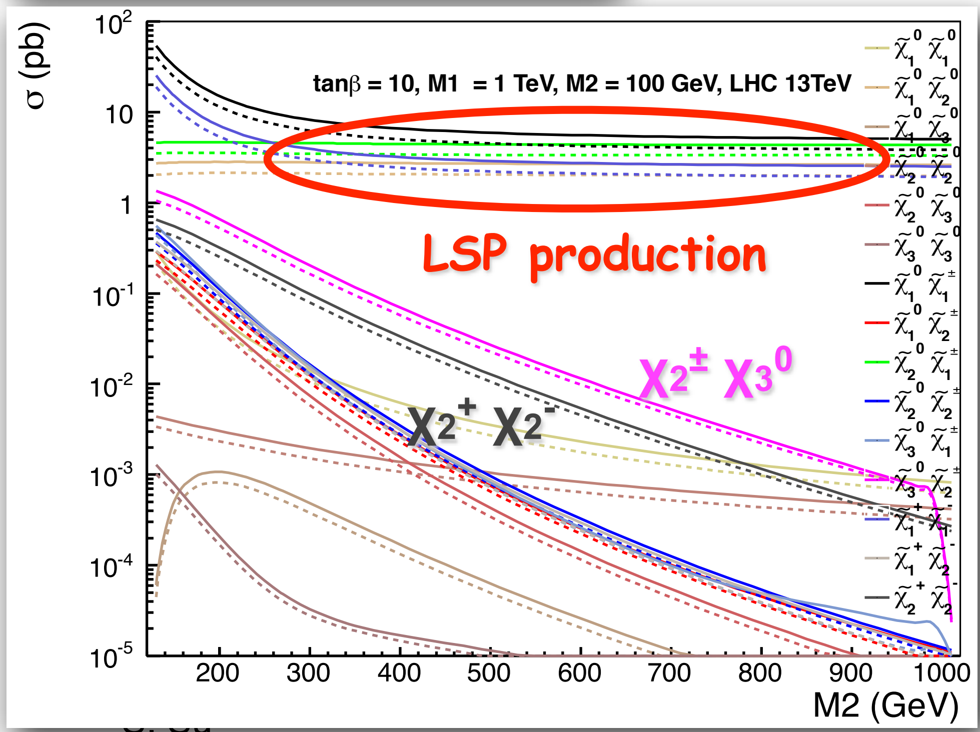


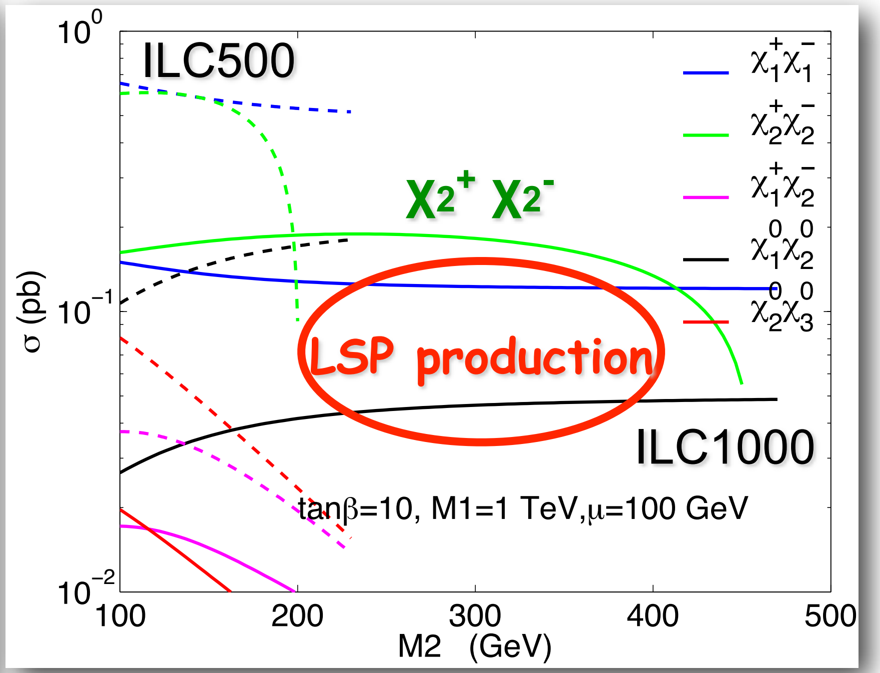
Productions: Higgsino LSP - Wino NLSP



Case CII: $\mu < M_2 < M_1$







Summary

$$\sigma_{XY}^{\rm tot} = \sum_{i,j} \sigma(\chi_i \chi_j) \times Br(\chi_i \chi_j \to XY),$$

$$XY = W^+W^-,\ W^\pm W^\pm,\ WZ,\ Wh,\ Zh,\ ZZ,\ \text{and}\ hh$$

- Br(WZ) < 100%, sometime highly suppressed
- Wh complementary to WZ channel: new discovery potential
- Zh could also be important
- hh usually is small

Summary

$$\sigma_{XY}^{\rm tot} = \sum_{i,j} \sigma(\chi_i\chi_j) \times Br(\chi_i\chi_j \to XY),$$

	NLSPs and Decay Br's		Production	Total Branching Fractions (%)						
				W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
Case AI	$\chi_1^\pm \to \chi_1^0 W^\pm$	100%	$\chi_1^\pm \chi_2^0$			16	84			
	$\chi_2^0 \to \chi_1^0 h$	84%(96–70%)	$\chi_1^+ \chi_1^-$	100						
Case AII	$\chi_1^\pm \to \chi_1^0 W^\pm$	100%	$\chi_1^\pm \chi_2^0$			25	75			
	$\chi_2^0 \to \chi_1^0 h$	75%(90–70%)	$\chi_1^\pm \chi_3^0$			78	22			
	$\chi_3^0 \to \chi_1^0 Z$	78%(90–70%)	$\chi_1^+ \chi_1^-$	100						
			$\chi_2^0 \chi_3^0$					64	20	16

Summary

$$\sigma_{XY}^{\rm tot} = \sum_{i,j} \sigma(\chi_i\chi_j) \times Br(\chi_i\chi_j \to XY),$$

current WZ+MET limit weakened

	NLSPs and Decay Br's		Production	Total Branching Fractions (%)						
				W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
Case AI	$\chi_1^\pm \to \chi_1^0 W^\pm$	100%	$\chi_1^\pm\chi_2^0$			16	84			
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			$\chi_2^0\chi_3^0$					64	20	16

Summary

$$\sigma^{\rm tot}_{XY} = \sum_{i,j} \sigma(\chi_i\chi_j) \times Br(\chi_i\chi_j \to XY),$$

new discovery potential

	NLSPs and Decay Br's		Production	Total Branching Fractions (%)						
				W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
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			$\chi_2^0 \chi_3^0$					64	20	16

Wh comparable to WZ channel

Summary

$$\sigma^{\rm tot}_{XY} = \sum_{i,j} \sigma(\chi_i\chi_j) \times Br(\chi_i\chi_j \to XY),$$

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			$\chi_2^0 \chi_3^0$					64	20	16

Wh comparable to WZ channel

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	NLSPs and Decay Br's		Production	Total Branching Fractions (%)						
				W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
Case BI	$\chi_2^0 \to \chi_1^\pm W^\mp, \chi_1^0 h, \chi_1^0 Z,$	68%, 27%(xx), 5%(xx),	production suppressed.							
Case BII	$\chi_2^\pm \to \chi_1^0 W^\pm$	35%	$\chi_2^\pm \chi_2^0$	12	12	33	23	10	9	2
	$\chi_2^\pm \to \chi_1^\pm Z$	35%	$\chi_2^\pm \chi_3^0$	12	12	27	29	11	3	7
	$\chi_2^\pm \to \chi_1^\pm h$	30%	$\chi_2^+ \chi_2^-$	12		25	21	21	12	9
	$\chi_2^0 \to \chi_1^\pm W^\mp$	67%	$\chi_2^0 \chi_3^0$	23	23	23	21	7	2	2
	$\chi_2^0 \to \chi_1^0 Z$	26%(30–24%)								
	$\chi_3^0 \to \chi_1^\pm W^\mp$	68%								
	$\chi_3^0 \to \chi_1^0 h$	24%(30–23%)								

S. Su

Wh comparable to WZ channel

Summary

$$\sigma_{XY}^{\mathrm{tot}} = \sum_{i,j} \sigma(\chi_i \chi_j) \times Br(\chi_i \chi_j \to XY),$$

	NLSPs and Decay Br's		Production	Total Branching Fractions (%)						
				W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
Case BI	**ILC, ISR analyses for Wino LSP pair**									
Case BII	$\chi_2^\pm \to \chi_1^0 W^\pm$	35%	$\chi_2^\pm \chi_2^0$	12	12	33	23	10	9	2
	$\chi_2^\pm \to \chi_1^\pm Z$	35%	$\chi_2^\pm \chi_3^0$	12	12	27	29	11	3	7
	$\chi_2^\pm \to \chi_1^\pm h$	30%	$\chi_2^+ \chi_2^-$	12		25	21	21	12	9
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	$\chi_3^0 \to \chi_1^0 h$	24%(30–23%)								

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$$\sigma^{\text{tot}}_{XY} = \sum_{i,j} \sigma(\chi_i\chi_j) \times Br(\chi_i\chi_j \to XY),$$

	NLSPs and Decay Br's		Production	Total Branching Fractions (%)						
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	$\chi_2^\pm \to \chi_1^\pm h$	30%	$\chi_2^+ \chi_2^-$	12		25	21	21	12	9
	$\chi_2^0 \to \chi_1^\pm W^\mp$	67%	$\chi_2^0 \chi_3^0$	23	23	23	21	7	2	2
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	$\chi_2^\pm \to \chi_1^\pm h$	30%	$\chi_2^+ \chi_2^-$	12		25	21	21	12	9
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	$\chi_2^0 \to \chi_1^0 Z$	26%(30–24%)								
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Summary

$$\sigma_{XY}^{\rm tot} = \sum_{i,j} \sigma(\chi_i\chi_j) \times Br(\chi_i\chi_j \to XY),$$

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	NLSPs and Decay Br's	Production	Total Branching Fractions (%)						
			W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
Case CI	$\chi_3^0 \to \chi_1^\pm W^\mp, \chi_{1,2}^0 Z, \chi_{1,2}^0 h$, 52%, 26%, 22%, production suppressed.								
Case CII	$\chi_2^\pm \to \chi_{1,2}^0 W^\pm$ 51 %	$\chi_2^\pm \chi_3^0$	14	14	26	24	11	6	5
	$\chi_2^\pm \to \chi_1^\pm Z$ 26 %	$\chi_2^+ \chi_2^-$	26		27	23	12	7	5
	$\chi_2^\pm \to \chi_1^\pm h$ 23 %								
	$\chi_3^0 \to \chi_1^\pm W^\mp$ 54 %								
	$\chi_3^0 \to \chi_{1,2}^0 Z$ 24 %								
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Wh comparable to WZ channel

Summary

$$\sigma_{XY}^{\rm tot} = \sum_{i,j} \sigma(\chi_i \chi_j) \times Br(\chi_i \chi_j \to XY),$$

	NLSPs and Decay Br's	Production	Total Branching Fractions (%)						
			W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
Case CI	**ILC, $\chi_{1,2}^0 \chi_3^0$ pair or ISR analyses for Higgsino LSP pair**								
Case CII	$\chi_2^\pm \to \chi_{1,2}^0 W^\pm$ 51 %	$\chi_2^\pm \chi_3^0$	14	14	26	24	11	6	5
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Wh comparable to WZ channel

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	NLSPs and Decay Br's	Production	Total Branching Fractions (%)						
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Case CI	ILC, $X_{1,2}^0 X_3^0$ pair or ISR analyses for Higgsino LSP pair								
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Wh comparable to WZ channel

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Wh comparable to WZ channel

LHC/ILC searches

Channel	Signal (LHC)	Signal (ILC)
W^+W^-	OS2L + MET	hadronic (4j), semileptonic, leptonic final states +MT
$W^\pm W^\pm$	SS2L + MET	
WZ	3L + MET	
Wh	1L + bb + MET	
Zh	OS2l +bb + MET	
LSP pair		ISR photon + soft

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W^+W^-	OS2L + MET	hadronic (4j), semileptonic, leptonic final states +MT
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Wh and Zh channels comparable/complementary to WW, WZ channels!

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Wh and Zh channels comparable/complementary to WW, WZ channels!

Tomohiko Tanabe: Joint LHC-ILC Studies-Electroweakino Scan