Search for Electroweak Production of Gauginos and Sleptons at CMS

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for the CMS Collaboration

Overview of Analyses

SUS Code	Title	Data Sample
SUS-13-006	Search for electroweak production of charginos, neutralinos, and sleptons using **leptonic final states** in pp collisions at 8 TeV	19.5 fb^{-1} 8 TeV
SUS-13-017	Search for electroweak production of charginos and neutralinos in **final states with a Higgs boson** in pp collisions at 8 TeV	19.5 fb^{-1} 8 TeV

NEW

BRAND NEW

All results available via CMS SUSY summary twiki:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

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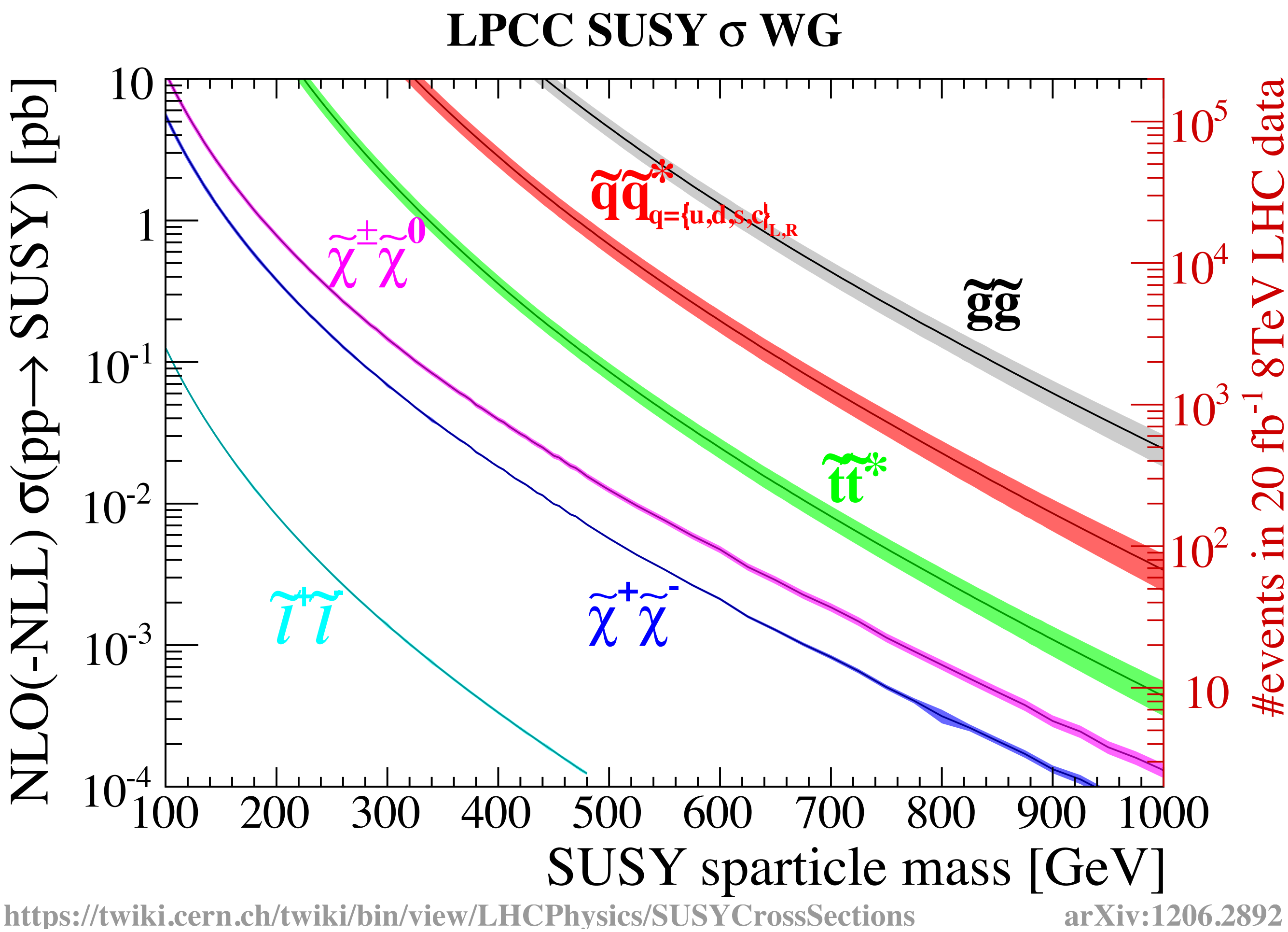
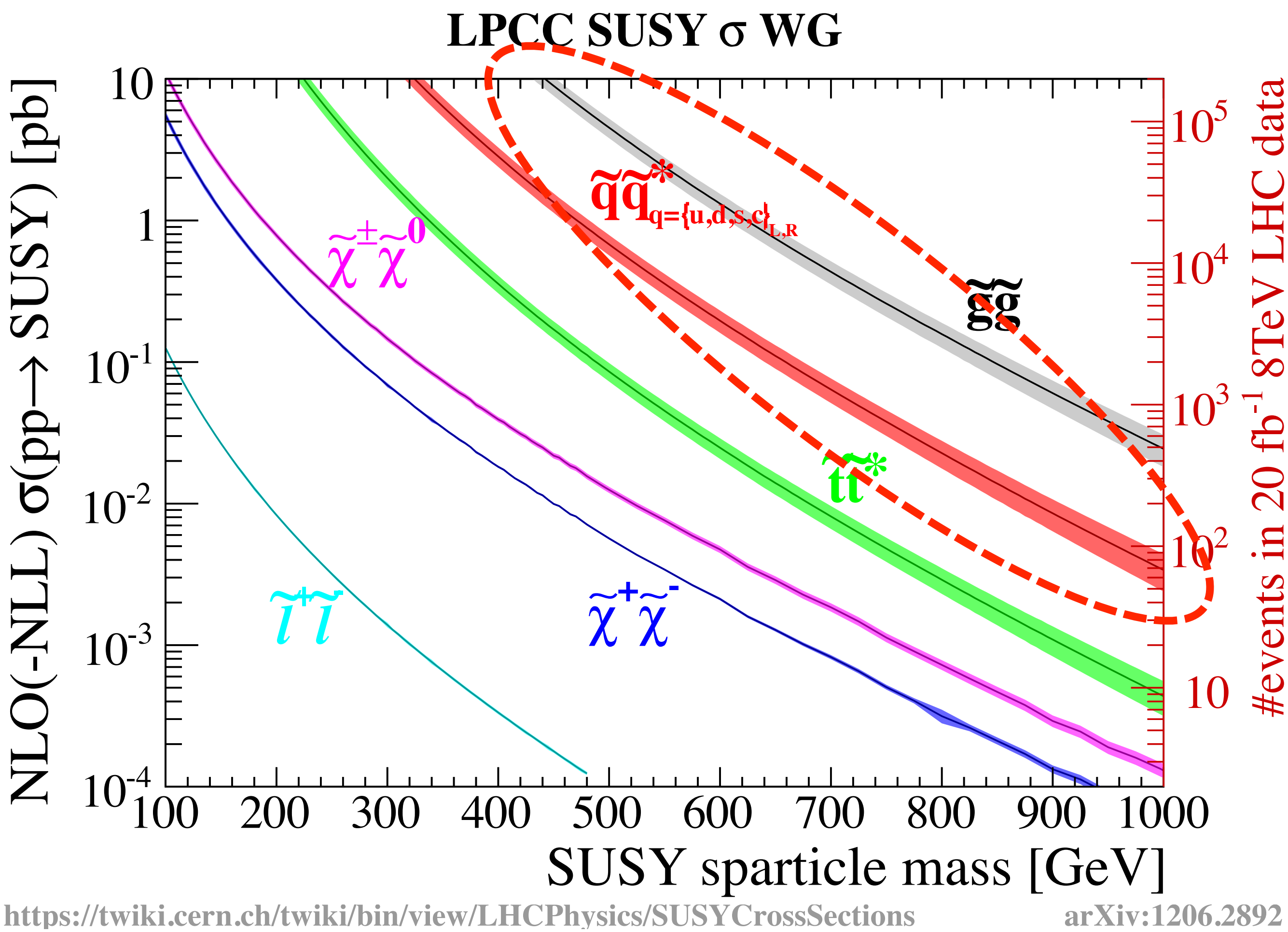
- **Introduction & Motivation**
- SUS-13-006: Searches in Leptonic Final States
- SUS-13-017: Searches with Higgs Bosons

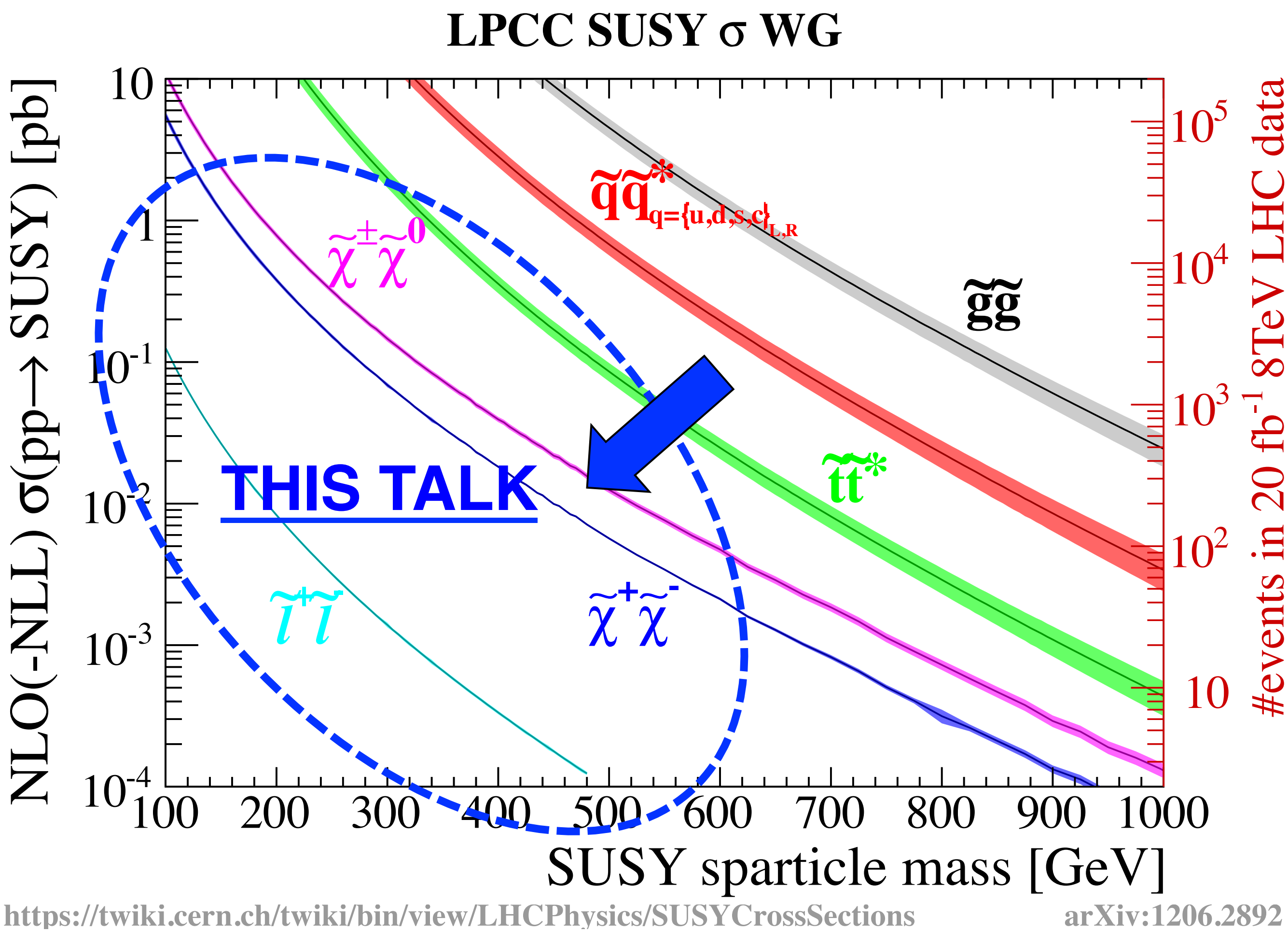
Intro/Motivation



Intro/Motivation



- "Strong SUSY" → large σ, jets, E_T^{miss}, (leptons)



- **"Electroweak SUSY" → small σ, lepton(s) + E_T^{miss}**

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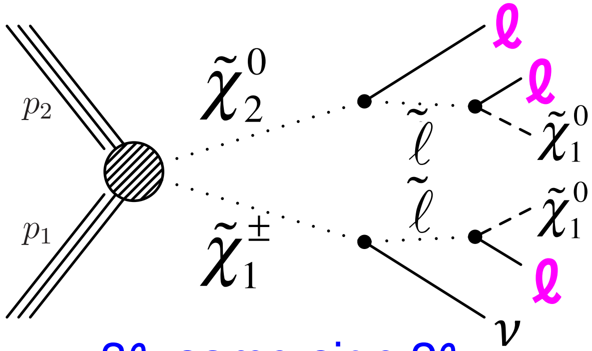
Models & Signatures

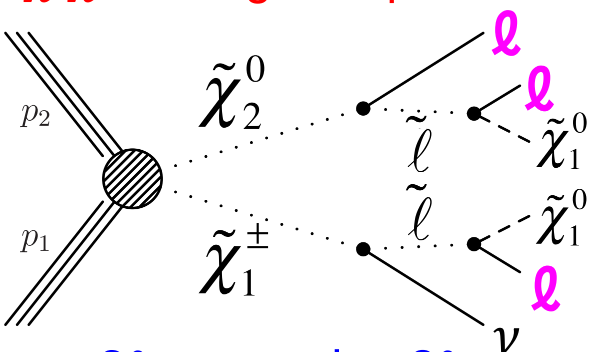
$\chi^{\pm}\chi^{0}$ with light sleptons



3ℓ, same-sign 2ℓ

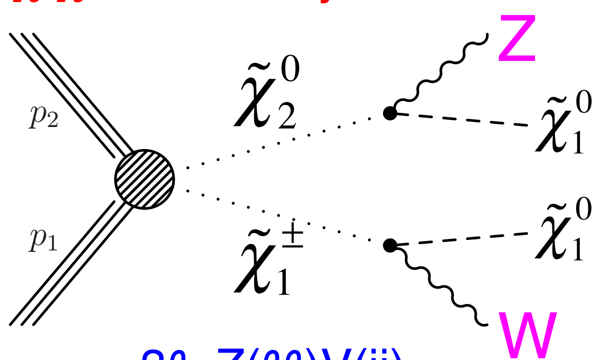
Models & Signatures

$\chi^{\pm}\chi^{0}$ with light sleptons



3ℓ, same-sign 2ℓ

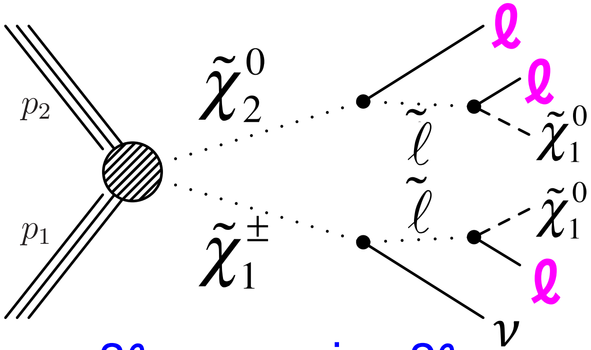
$\chi^{\pm}\chi^{0}$ with decays to W/Z



3ℓ, Z(ℓℓ)V(jj)

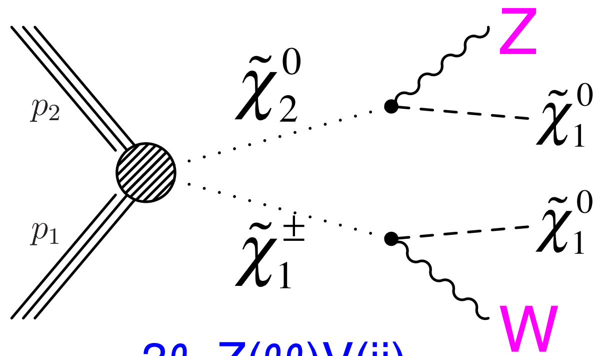
Models & Signatures

$\chi^{\pm}\chi^{0}$ with light sleptons



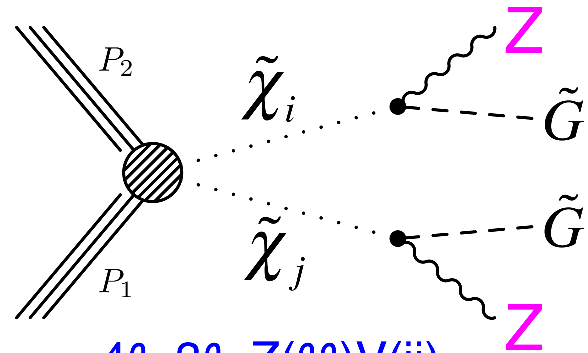
3ℓ, same-sign 2ℓ

$\chi^{\pm}\chi^{0}$ with decays to W/Z



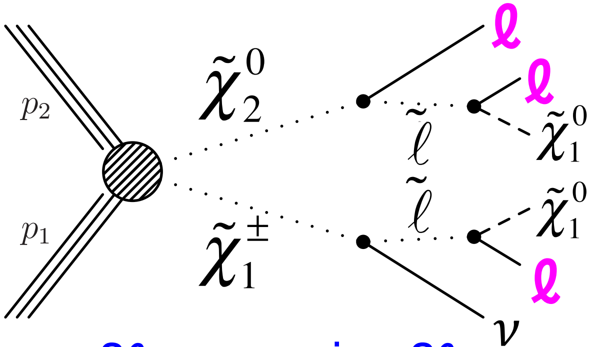
3ℓ, Z(ℓℓ)V(jj)

GMSB higgsino ZZ+MET



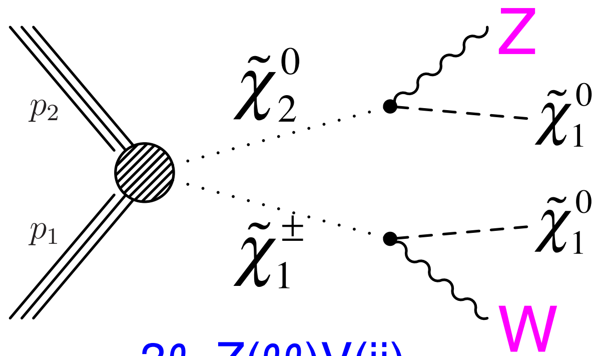
4ℓ, 3ℓ, Z(ℓℓ)V(jj)

$\chi^{\pm}\chi^{0}$ with light sleptons



3ℓ, same-sign 2ℓ

$\chi^{\pm}\chi^{0}$ with decays to W/Z



3ℓ, Z(ℓℓ)V(jj)

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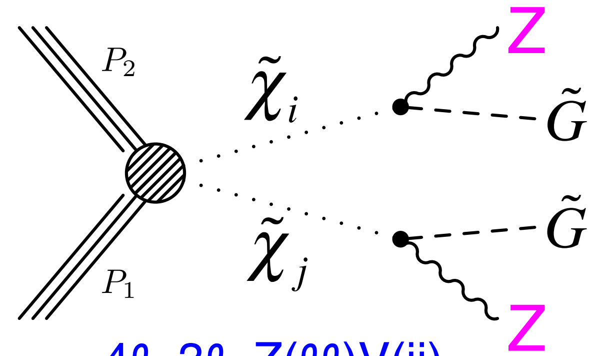
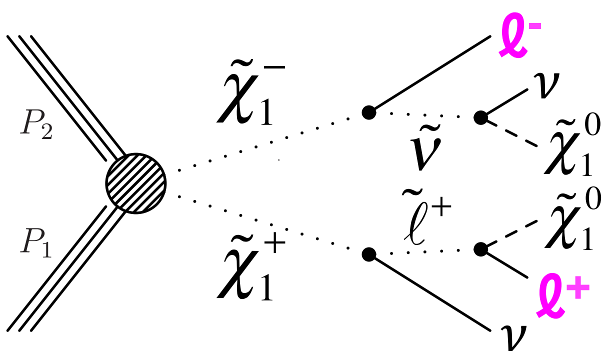


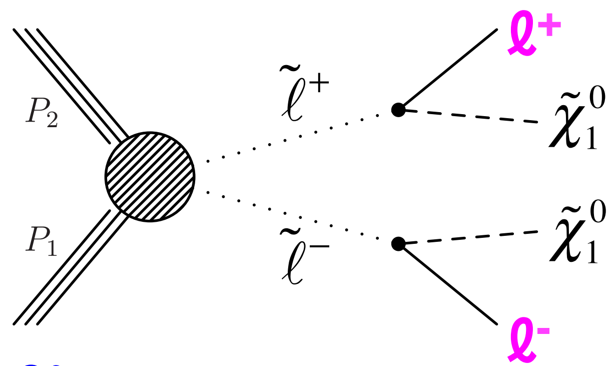
4ℓ, 3ℓ, Z(ℓℓ)V(jj)

$\chi^{+}\chi^{-}$ with light sleptons



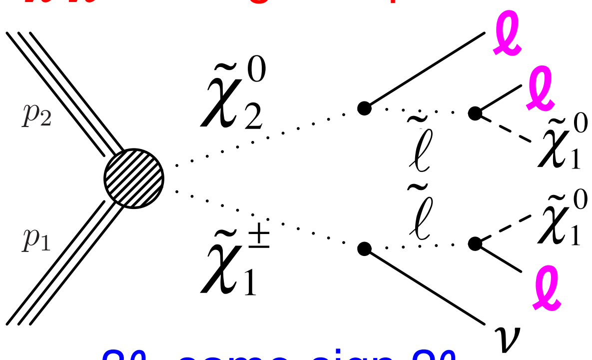
opposite-sign 2ℓ

direct slepton production



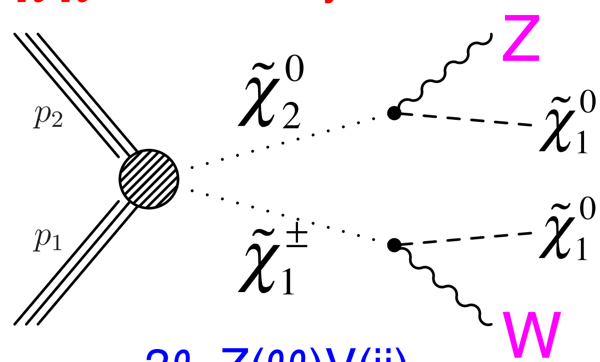
Models & Signatures

$\chi^{\pm}\chi^{0}$ with light sleptons



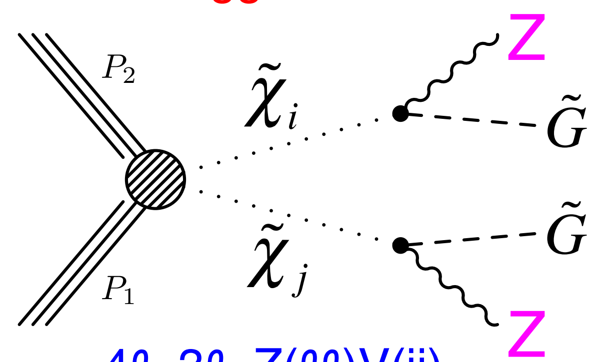
3ℓ, same-sign 2ℓ

$\chi^{\pm}\chi^{0}$ with decays to W/Z



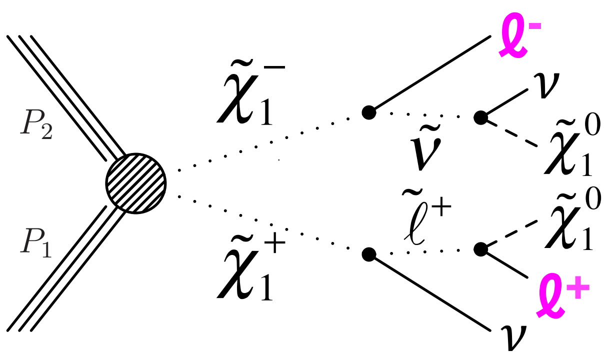
3ℓ, Z(ℓℓ)V(jj)

GMSB higgsino ZZ+MET



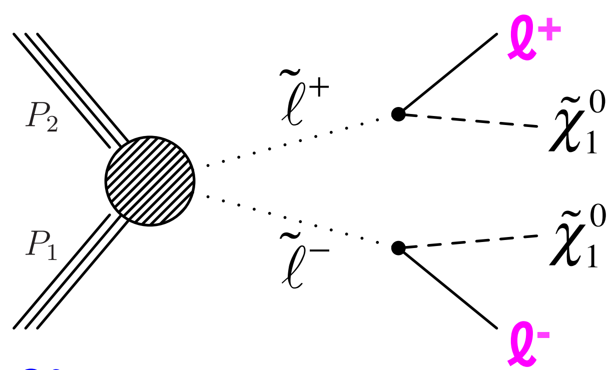
4ℓ, 3ℓ, Z(ℓℓ)V(jj)

$\chi^{+}\chi^{-}$ with light sleptons



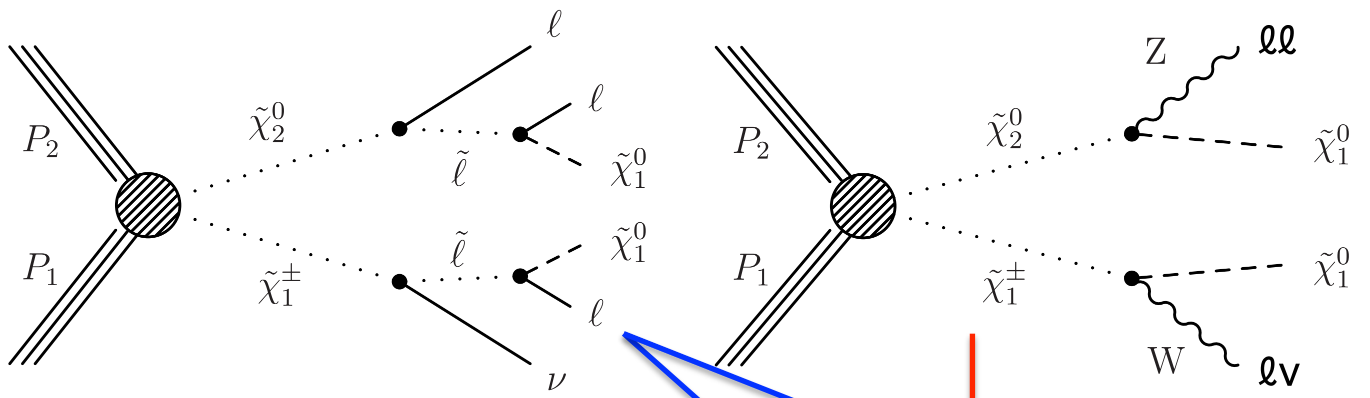
opposite-sign 2ℓ

direct slepton production

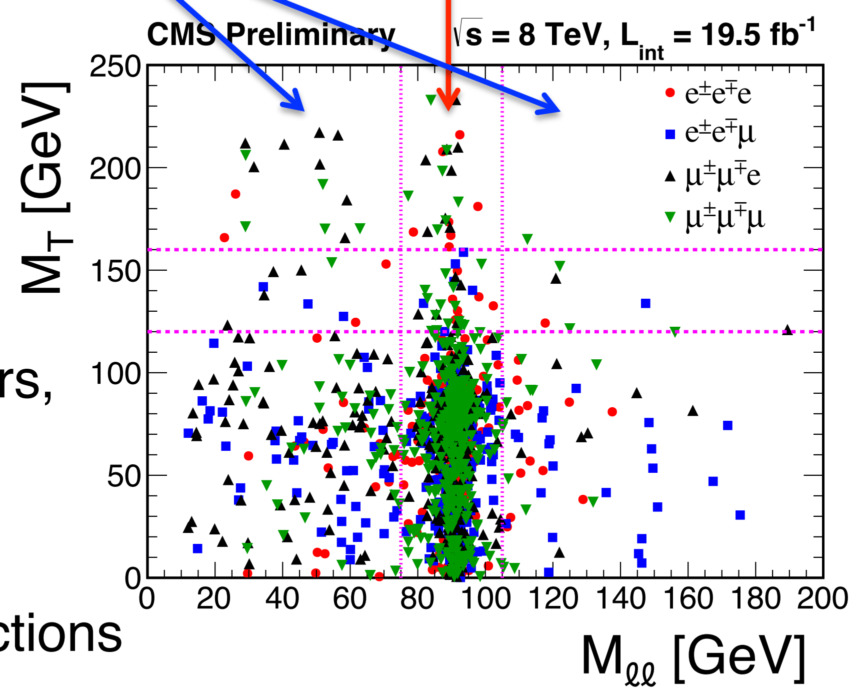


- **Broad array of searches targeting variety of final states**
- Analyses are exclusive → combined to improve sensitivity

3ℓ: Overview

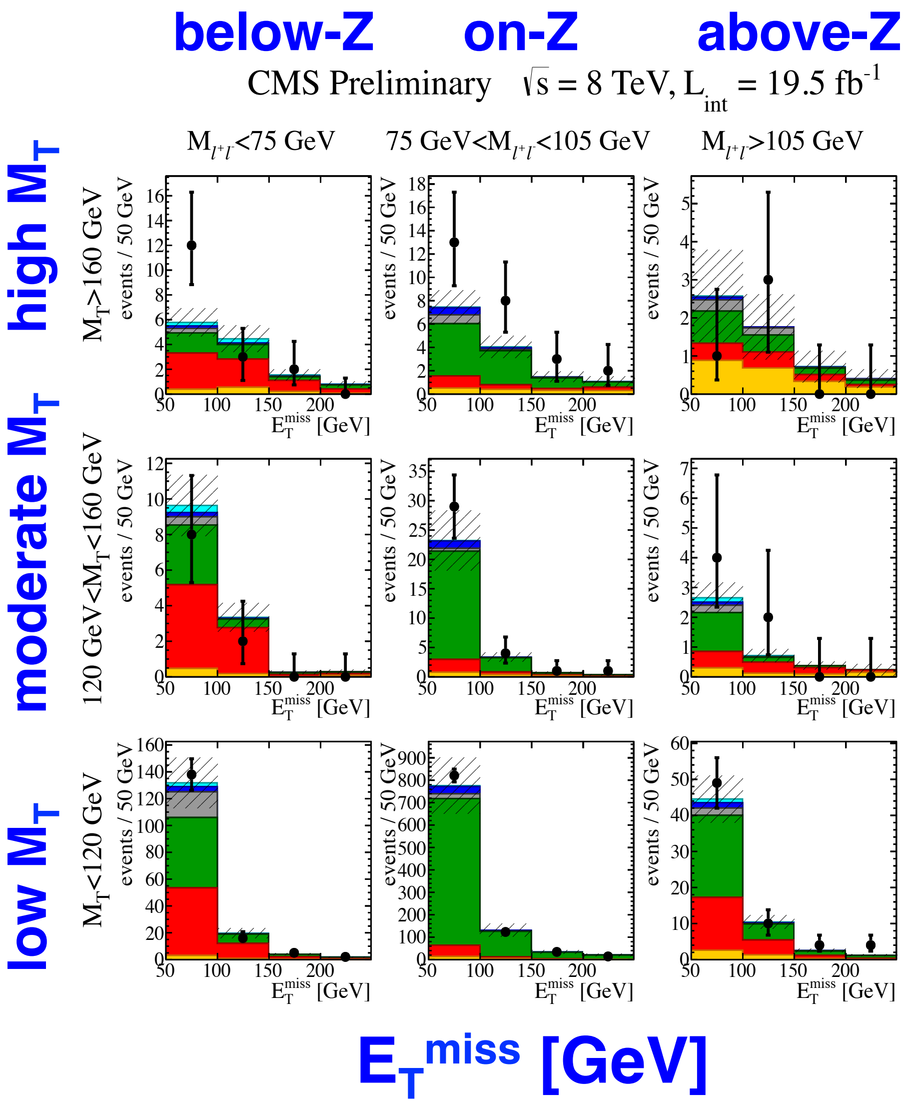


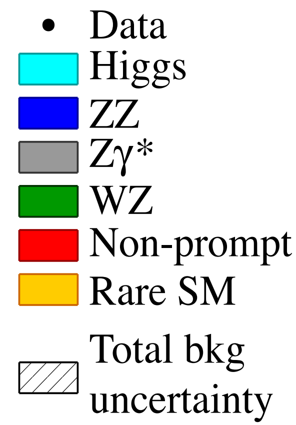
- **Event selection**
  - Exactly 3 leptons, up to 1 τ_{had}
  - MET > 50 GeV → suppress Z+jets
  - b-veto → suppress ttbar
  - Classify events based on lepton flavors, $M_{\ell\ell}$, $M_T(\ell,\mathrm{MET})$, MET



- **Dominant backgrounds:**
  - WZ: MC with data-driven E_T^{miss} corrections
  - tt+fake: data-driven fake rate methods

3ℓ: Results





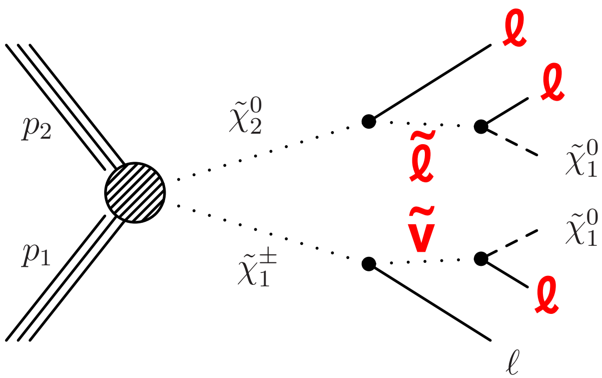
- Lepton flavor categories:
  - **3ℓ, OSSF pair (shown)**
  - 3ℓ, no OSSF pair
  - SS 2ℓ + τ_{had}
  - OS eμ + τ_{had}

  backup

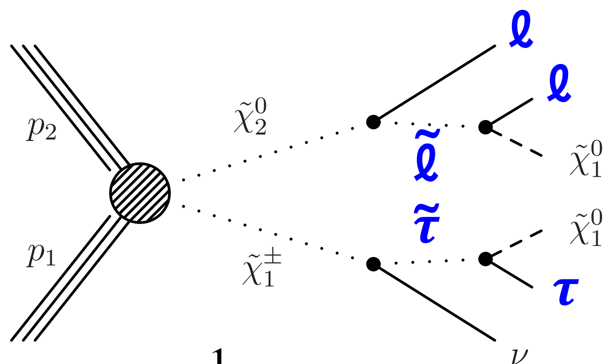
- **Data consistent with bkg over range of kinematical regions, lepton categories**

$\chi^{\pm}\chi^{0}$ Models with Light Sleptons

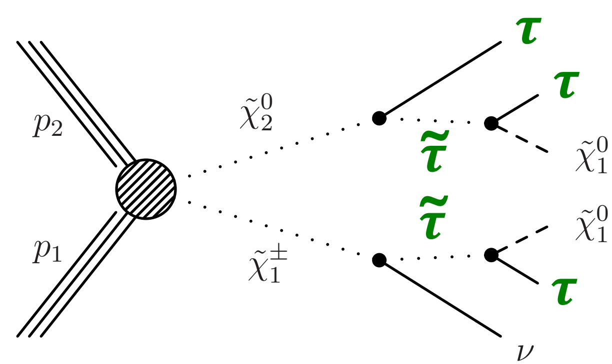
“flavor-democratic” (3ℓ)
light ($\tilde{\ell}_L, \tilde{\nu}_L$)



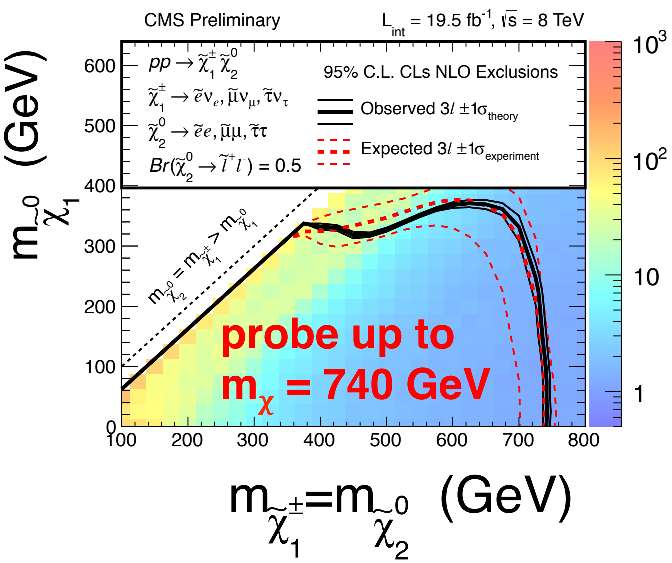
“tau-enriched” (2ℓ+τ)
light $\tilde{\ell}_R$, small tan β

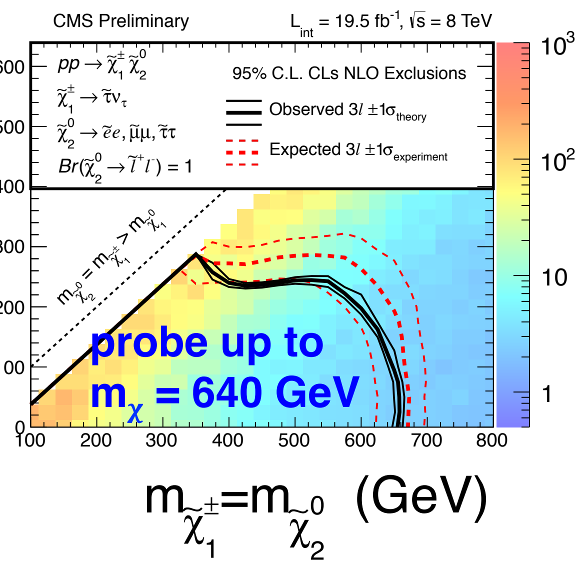


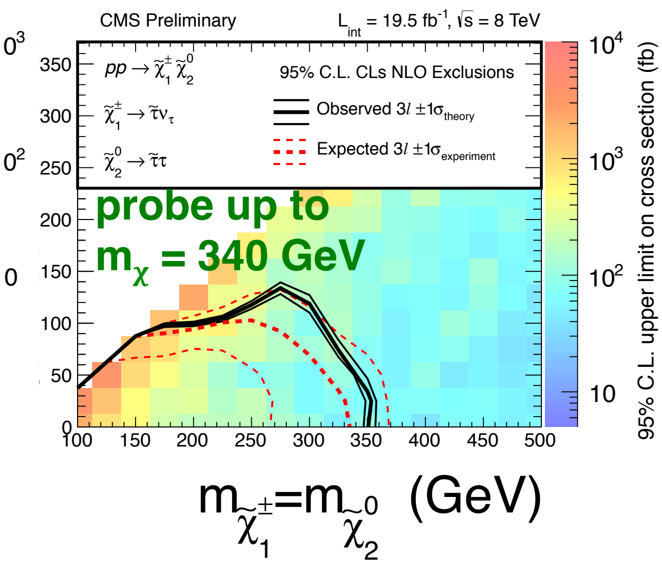
“tau-dominated” (3τ)
light $\tilde{\ell}_R$, high tan β



$$m_{\ell} = \frac{1}{2}(m_{\tilde{\chi}_1^\pm} + m_{\tilde{\chi}_1^0})$$

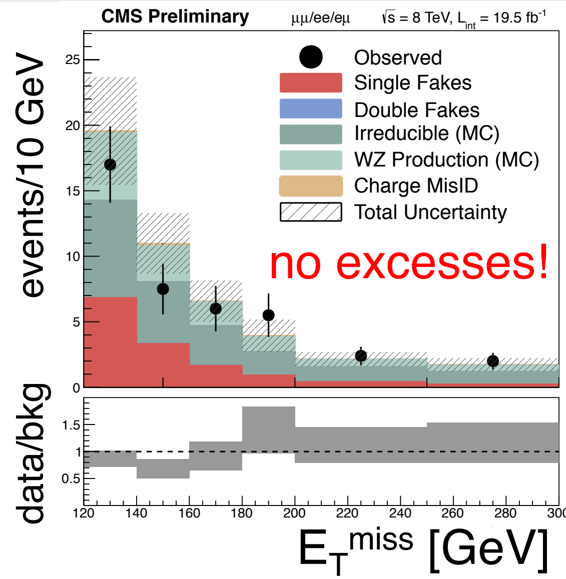


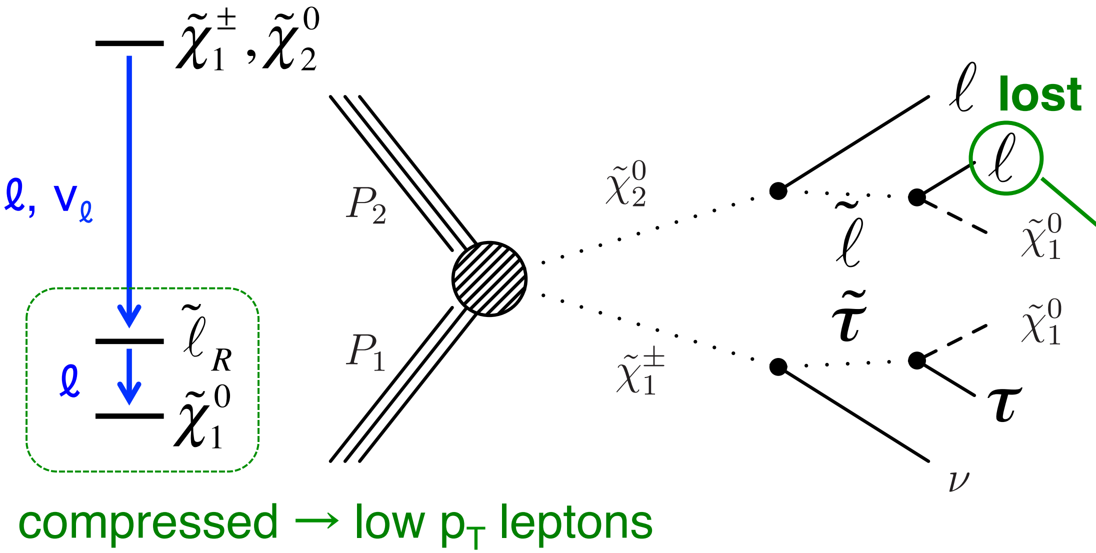


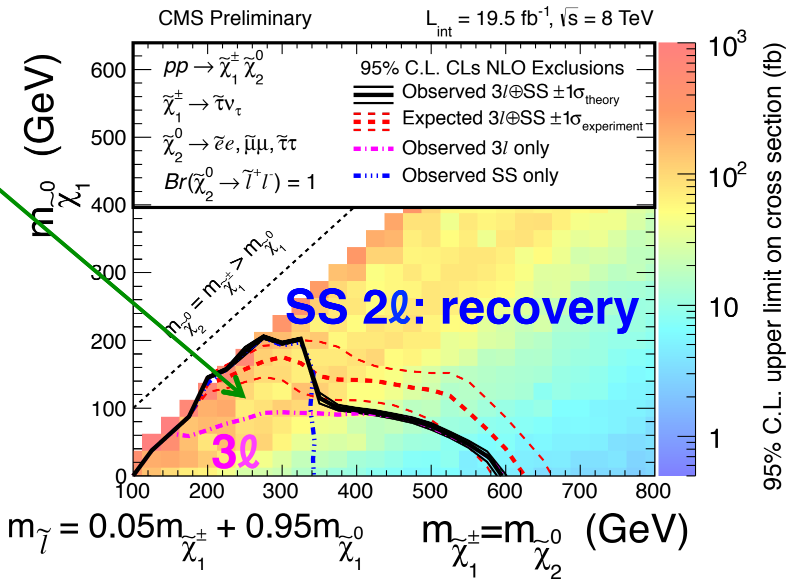


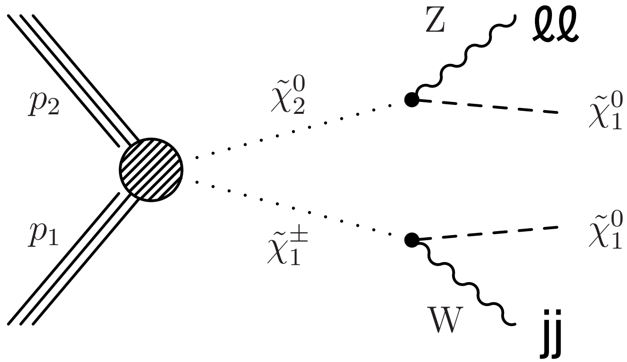
SS 2ℓ channel

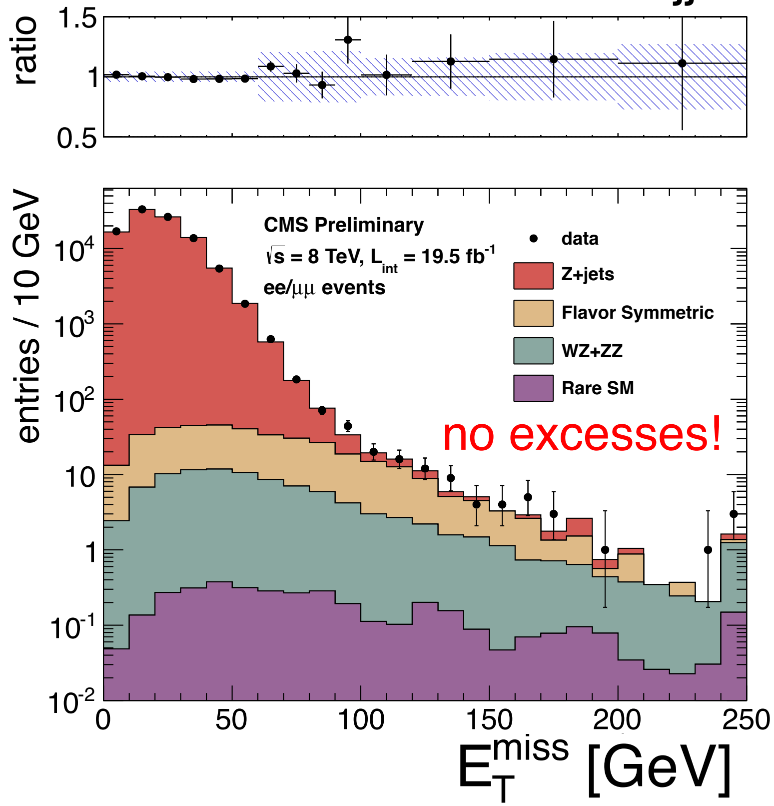
- **Event Selection**
  - Exactly 2 high p_T SS e/μ leptons
  - 2 exclusive signal regions
    - E_T^{miss} 120-200 GeV, $N_{jets} \leq 2$, $N_{b\text{-}jets} = 0$
    - $E_T^{miss} > 200$ GeV





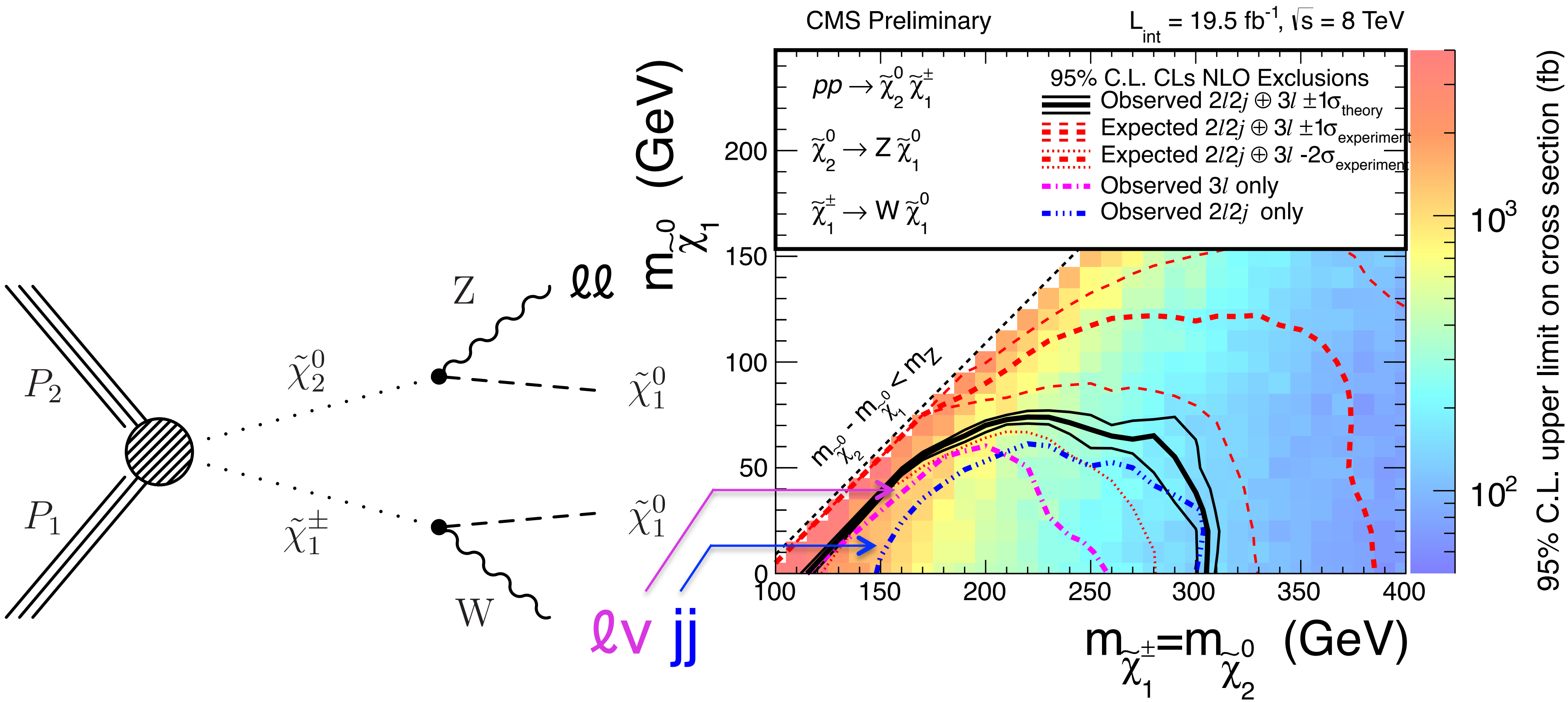






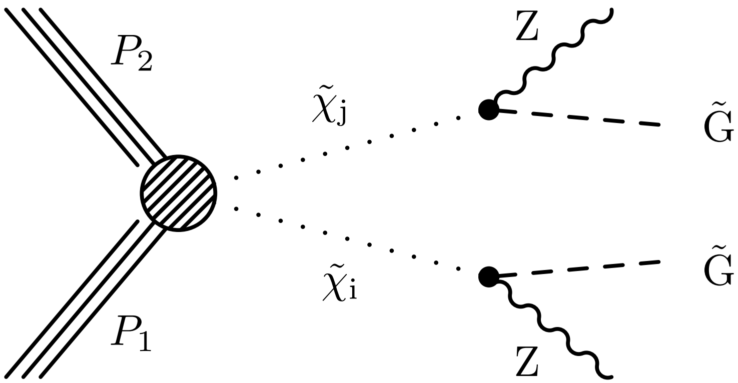
- **Event Selection**
  - Z→ee/μμ candidate
  - ≥2 jets with $M_{jj} \sim M_W/M_Z$
  - b-veto → suppress tt
- **Dominant backgrounds**
  - **Z+jets: model fake E_T^{miss} with γ+jets data control sample**
  - tt: from eμ data control sample
- **Results**
  - Data well-described over ~4 orders of magnitude → no excesses

$\chi^{\pm}\chi^{0} \rightarrow WZ+E_T^{miss}$ Interpretation



- Results based on **Z(ℓℓ)W(jj)** and **3ℓ** searches
  - Complementarity: improvement from combination

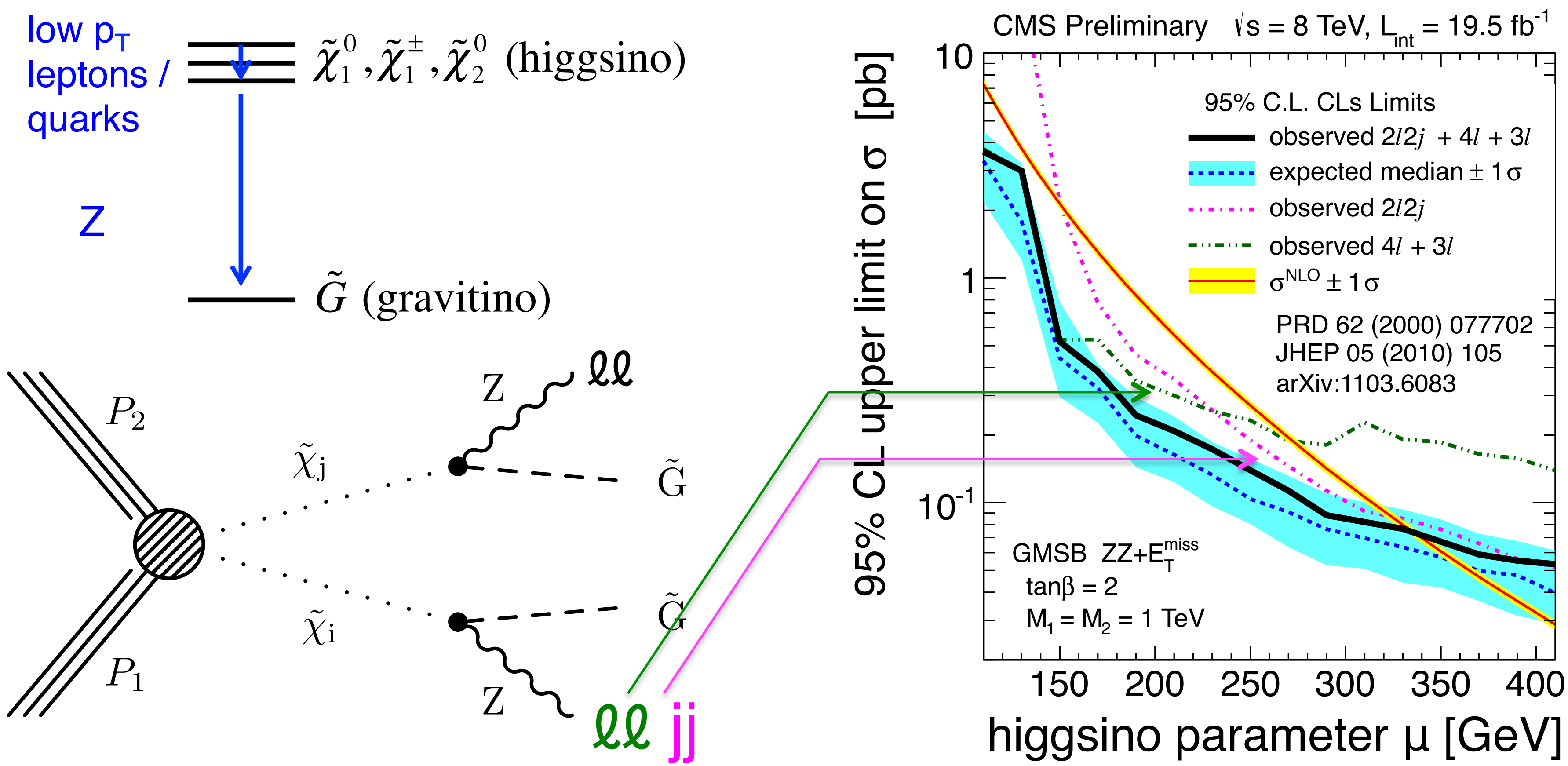
4ℓ Channel



E_T^{miss} (GeV)	Observed	Total Bkg
1 OSSF, 0 τ		
0–30	1	2.3 ± 0.6
30–50	3	1.2 ± 0.3
50–100	2	1.5 ± 0.4
> 100	2	0.8 ± 0.3
1 OSSF, 1 τ		
0–30	33	25 ± 12
30–50	11	11 ± 3.1
50–100	9	9.3 ± 1.9
> 100	2	2.9 ± 0.6
2 OSSF, 0 τ		
0–30	142	149 ± 46
30–50	25	28 ± 11
50–100	4	4.5 ± 2.7
> 100	1	0.8 ± 0.3

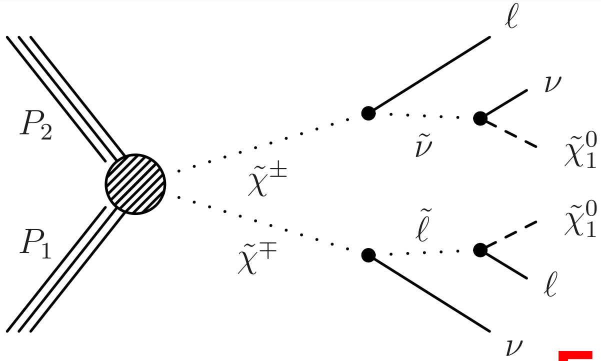
- **Event Selection**
  - 4ℓ, up to 1 τ_{had}
  - Classify events by #OSSF pairs, 0 vs. 1 τ_{had}, E_T^{miss}
- **Dominant backgrounds:**
  - ZZ: from MC, with data-driven MET corrections
- **Results**
  - Data agrees with SM background

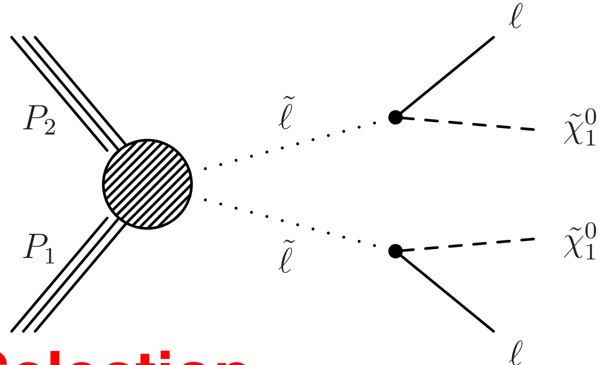
GMSB higgsino ZZ+E_T^{miss} Interpretation

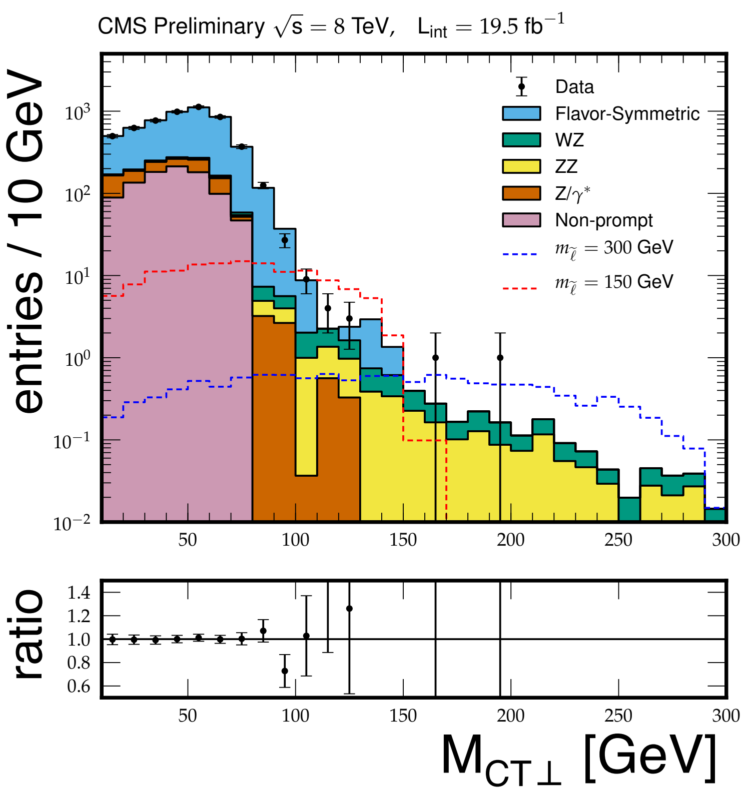


- Results based on **Z(ℓℓ)V(jj)** , **3ℓ+4ℓ**, and combination
  - Combine complementary channels → **exclude μ 110-330 GeV**
- **Probe μ in interesting range for Higgs naturalness**

OS dilepton channel



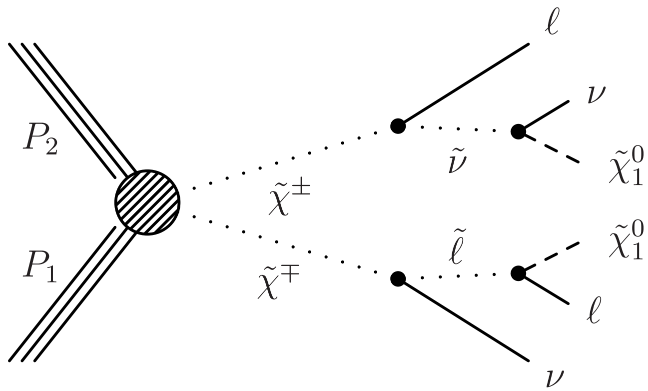


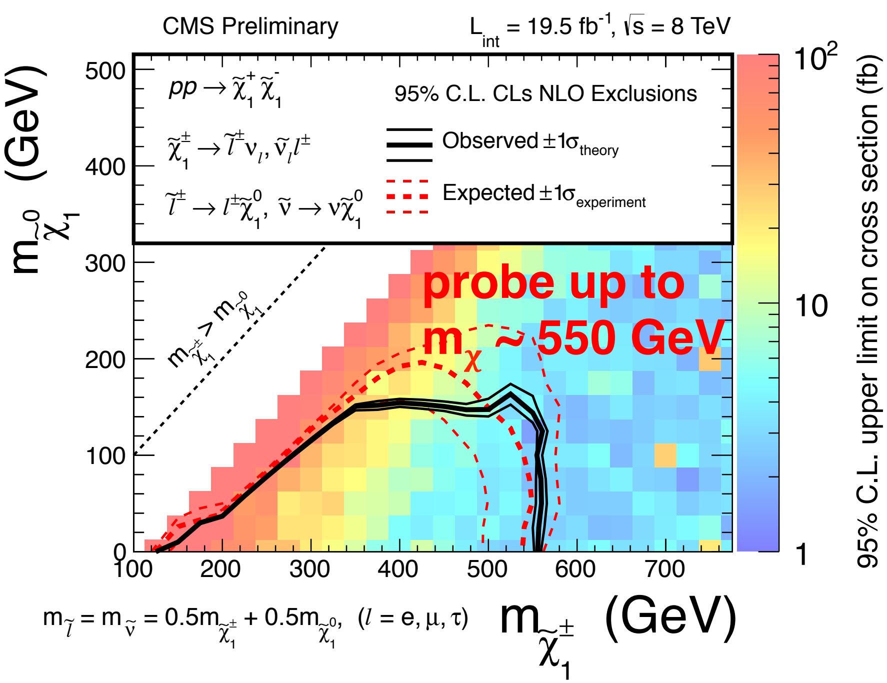


- **Event Selection**
  - 2 high p_T OS e/μ leptons with Z-veto
  - b-veto, moderate MET
- **Strategy**
  - Search for excess at high "$M_{CT\perp}$": $M_{CT\perp} < M_W$ for $WW \rightarrow 2\ell 2\nu$ processes
  - Fit $M_{CT\perp}$ with templates extracted from data control samples and MC
- **Results**
  - Observed $M_{CT\perp}$ agrees with prediction

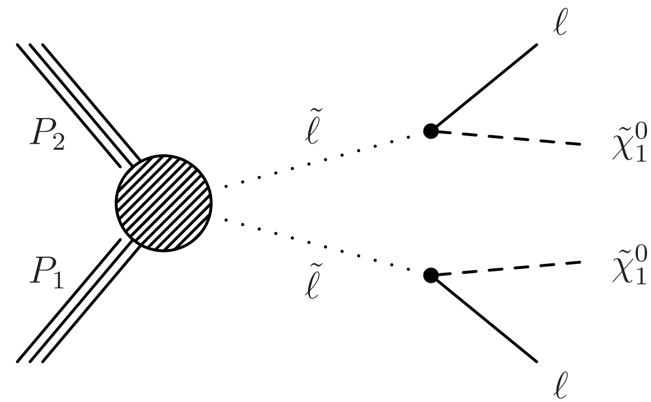
Chargino-Pairs and Slepton-Pairs

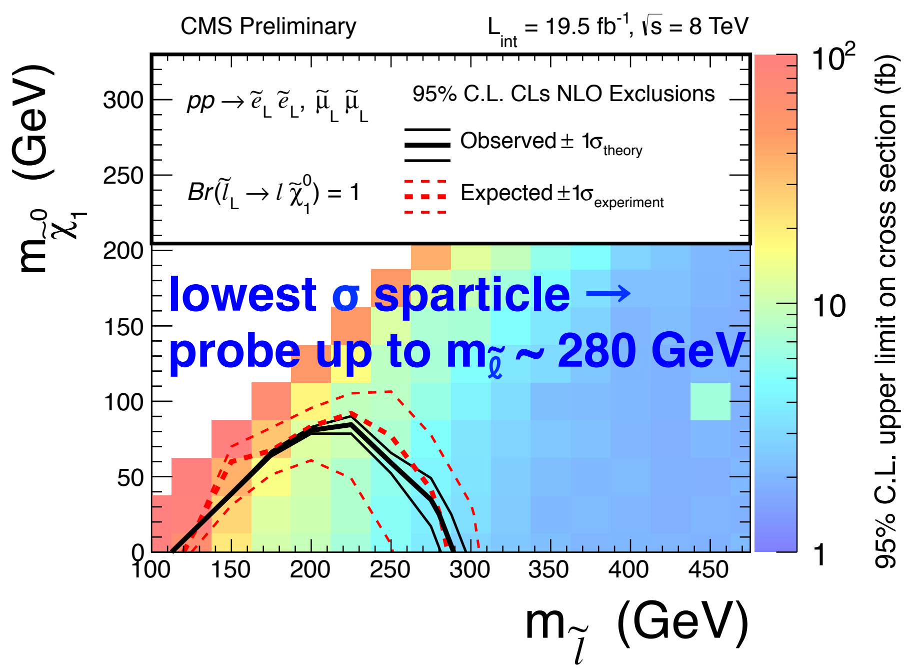
Use ee+μμ and eμ lepton pairs





Use ee+μμ lepton pairs only





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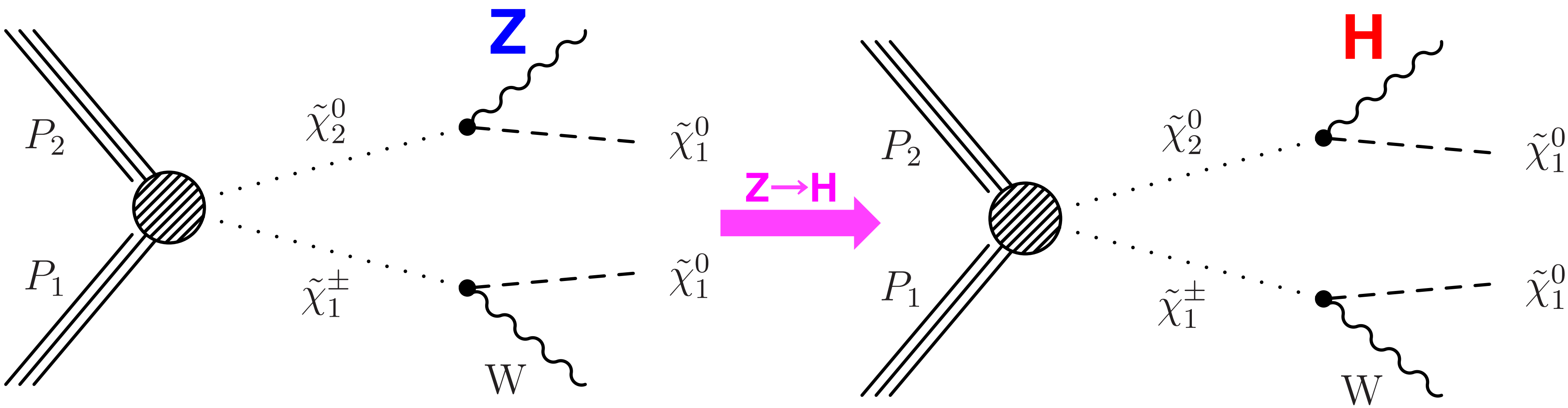
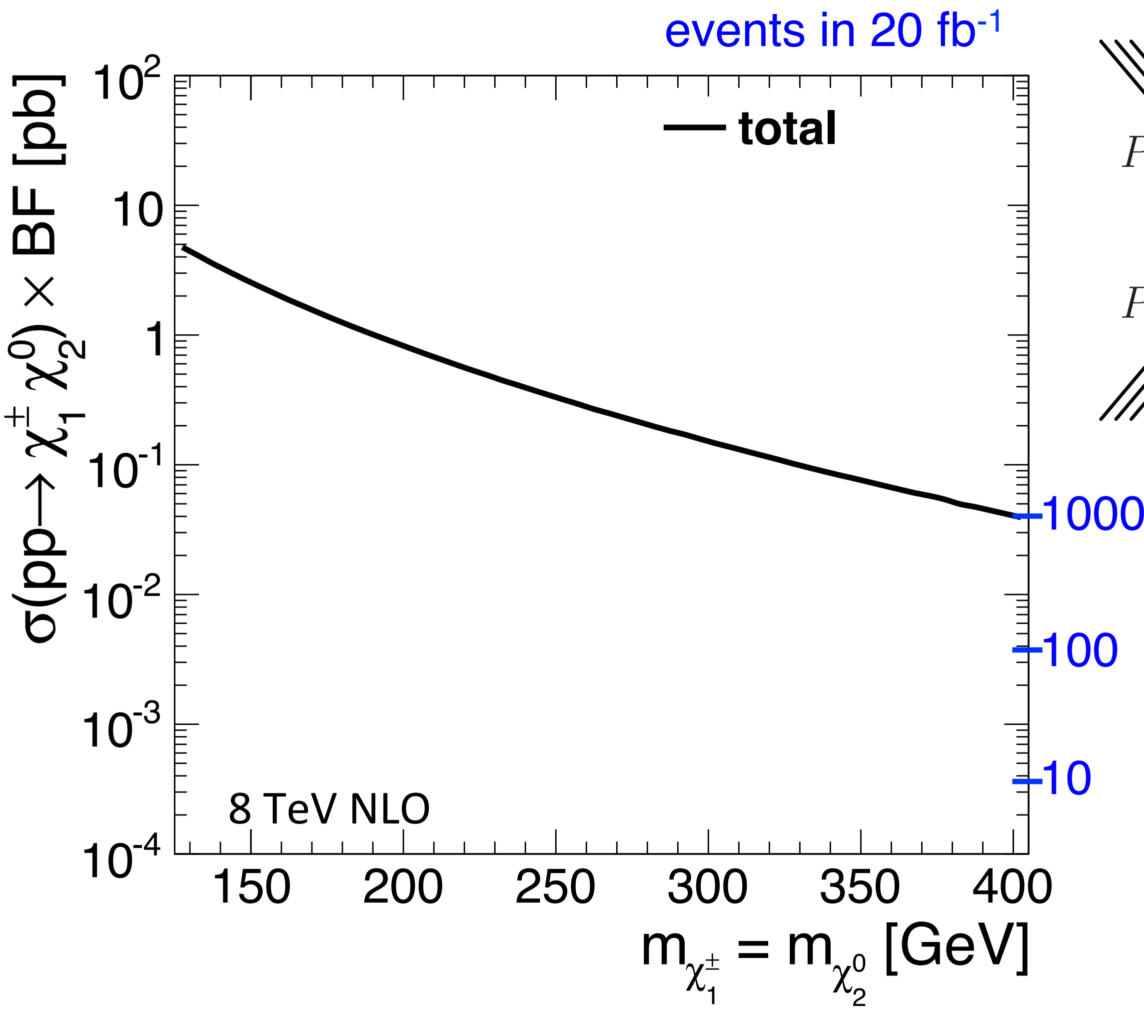
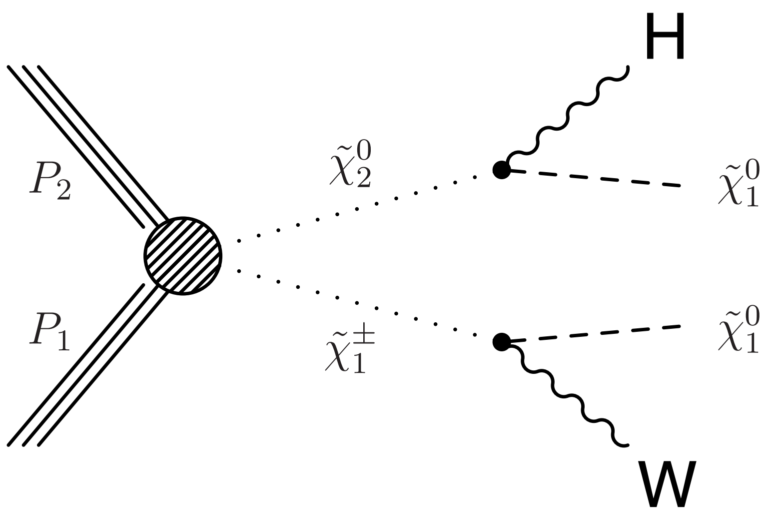
$WZ+E_T^{miss}$ **$WH+E_T^{miss}$**



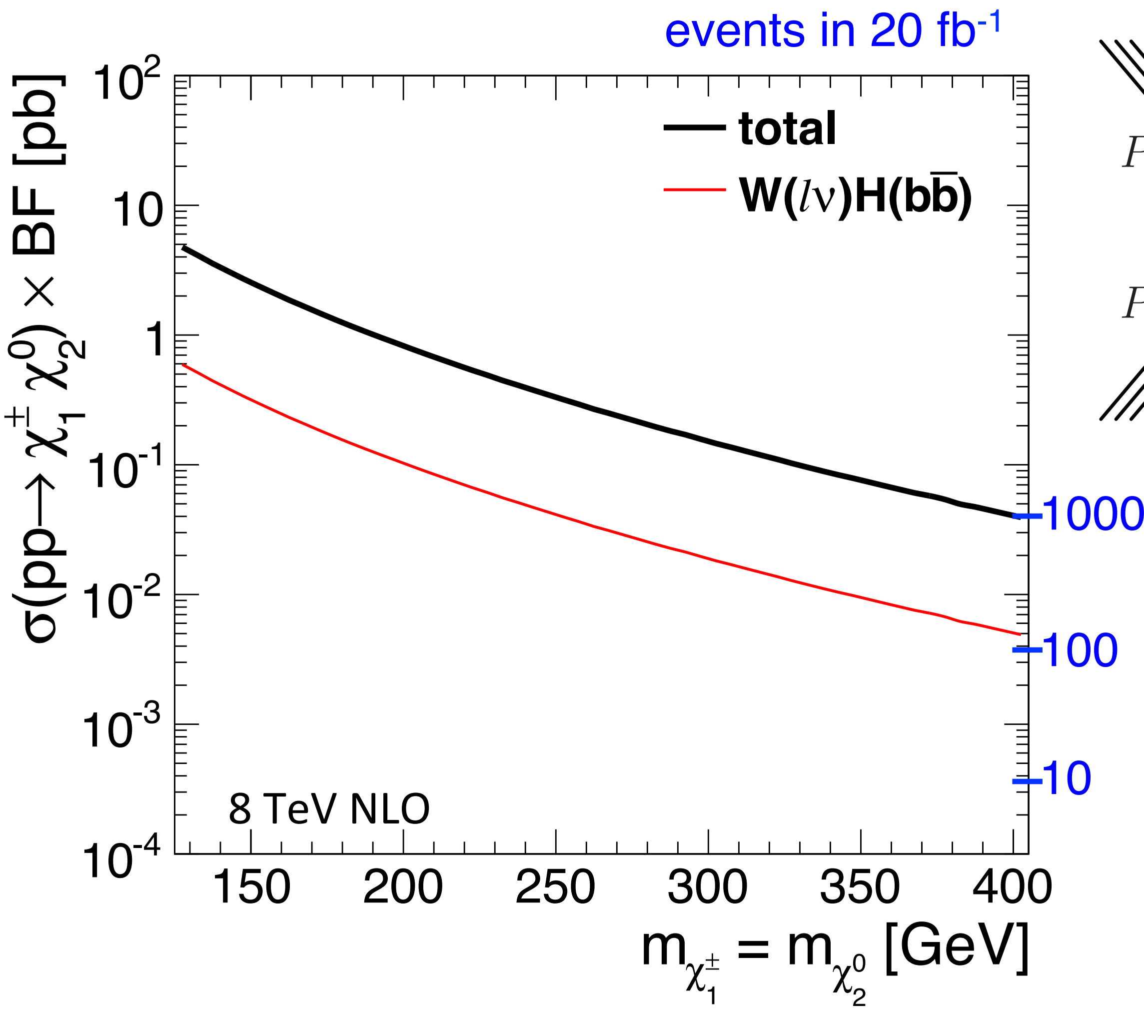
- New / unexplored final state: $WH+E_T^{miss}$
- Novel effort: **"Higgs-tagging"** in SUSY searches

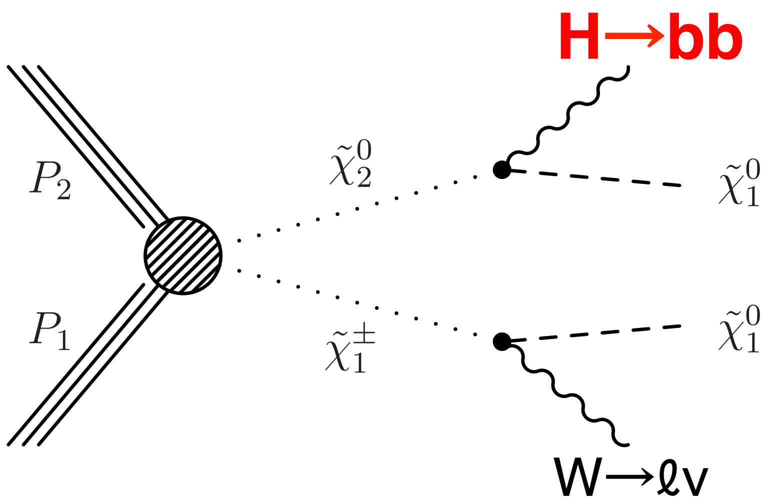
$\chi^{\pm}\chi^{0} \rightarrow WH+E_T^{miss}$ Signatures





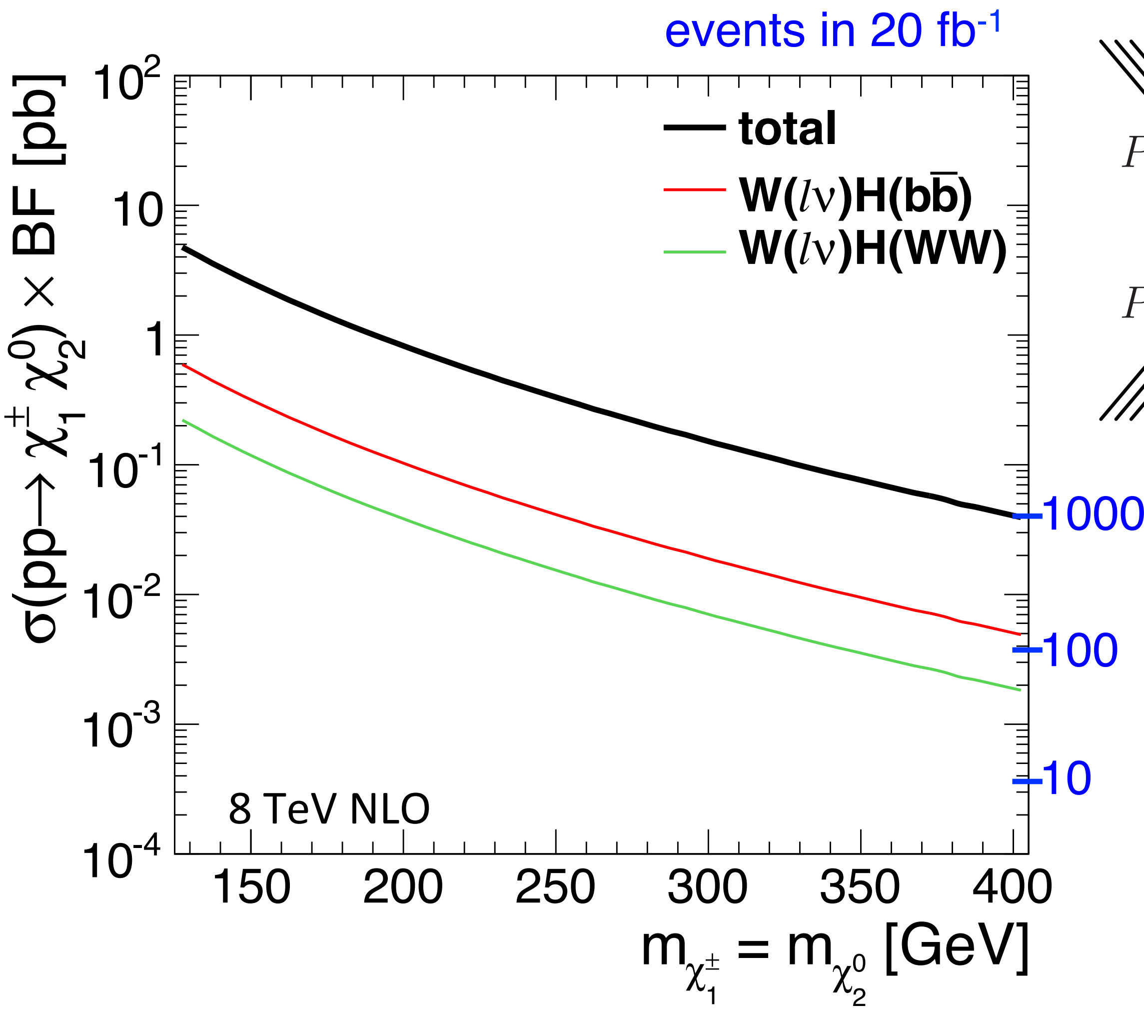
$\chi^{\pm}\chi^{0} \rightarrow WH+E_T^{miss}$ Signatures



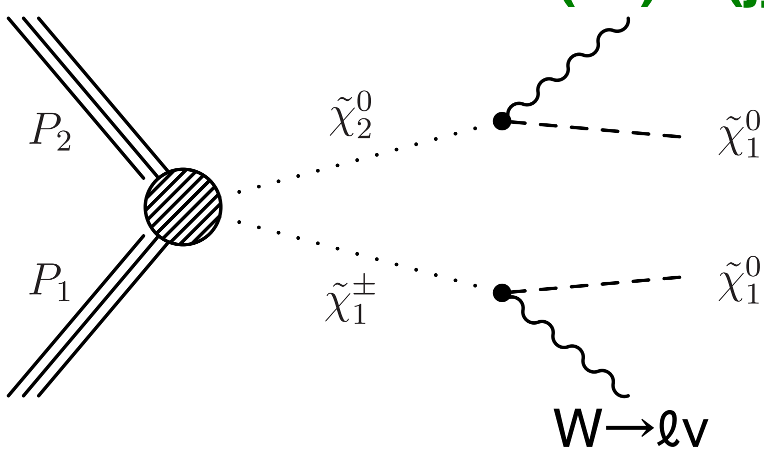


- 1ℓ NEW

$\chi^{\pm}\chi^{0} \rightarrow WH+E_T^{miss}$ Signatures

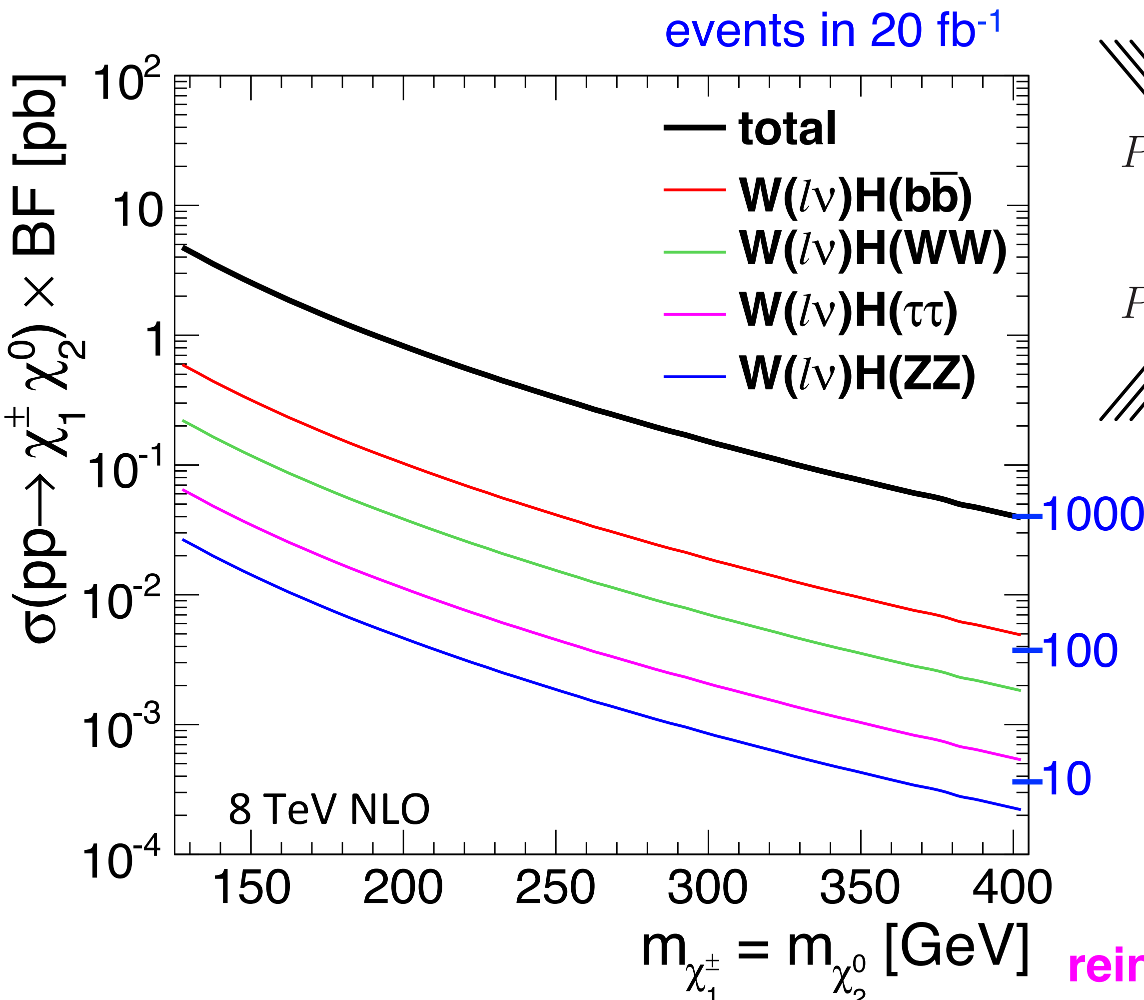


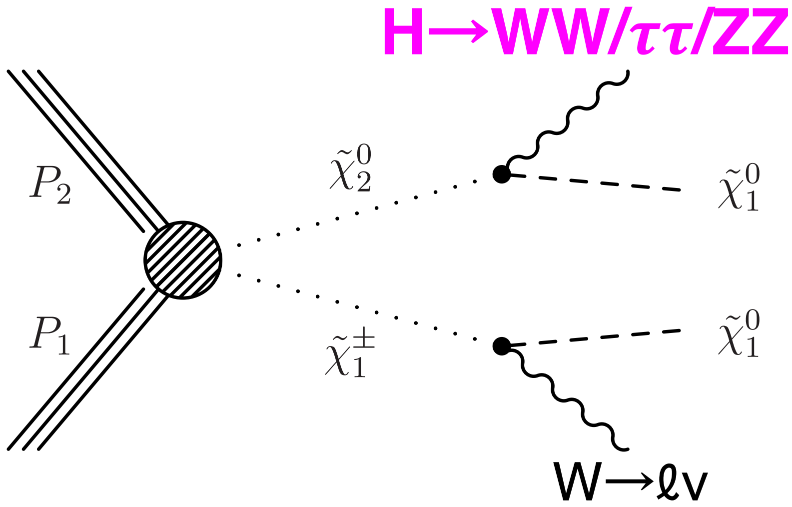
H→W(ℓν)W(jj)



- 1ℓ
- SS 2ℓ NEW

$\chi^{\pm}\chi^{0} \rightarrow WH+E_T^{miss}$ Signatures





- 1ℓ
- SS 2ℓ
- ≥3ℓ

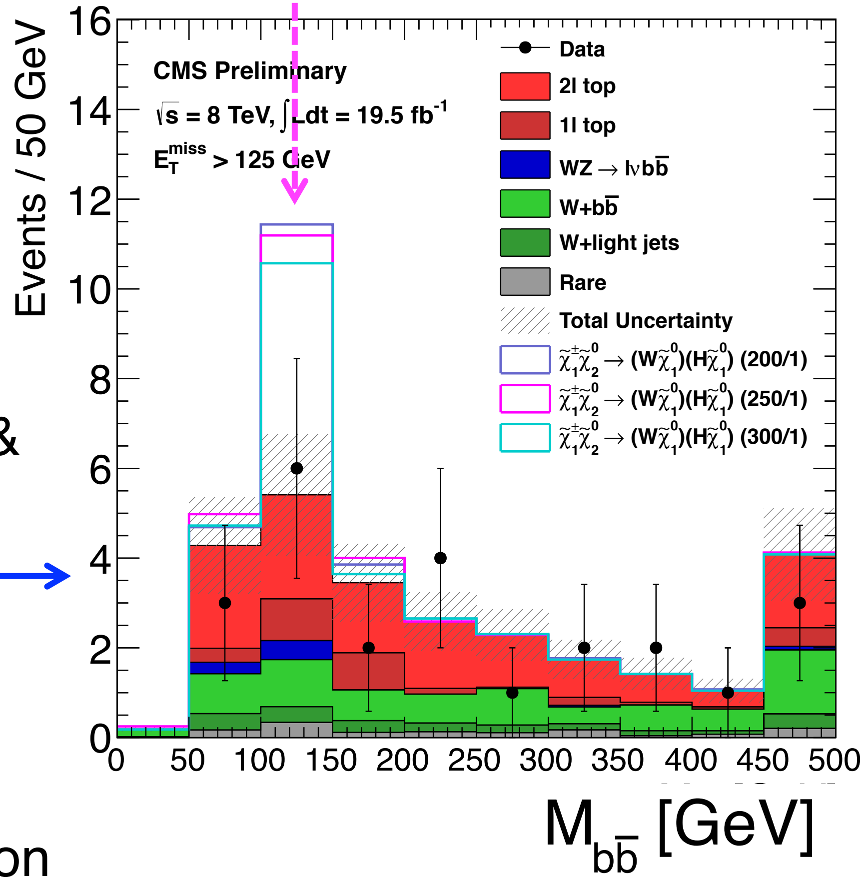
exclusive: combine to improve sensitivity

reinterpretation of SUS-13-002 inclusive multilepton SUSY search

$\chi^{\pm}\chi^{0} \rightarrow W(\ell\nu)H(bb)+E_T^{miss}$

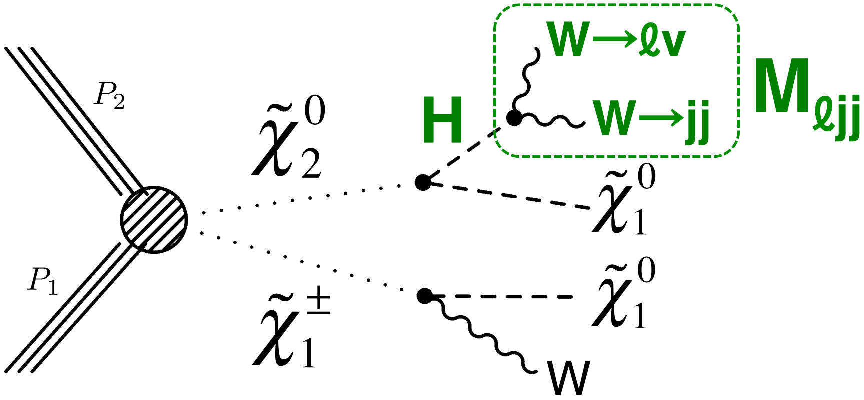
- **Event selection**
  - Exactly 1 high p_T e/μ
  - Exactly 2 jets, both b-tagged
  - Moderate E_T^{miss}
- **Strategy**
  - Suppress SM backgrounds with E_T^{miss} and related quantities
  - Background from MC, corrections & uncertainties from data
  - **Search for peak in M_{bb}**
- **Results**
  - No evidence for a peak in M_{bb}
  - Data agrees with bkg in signal region

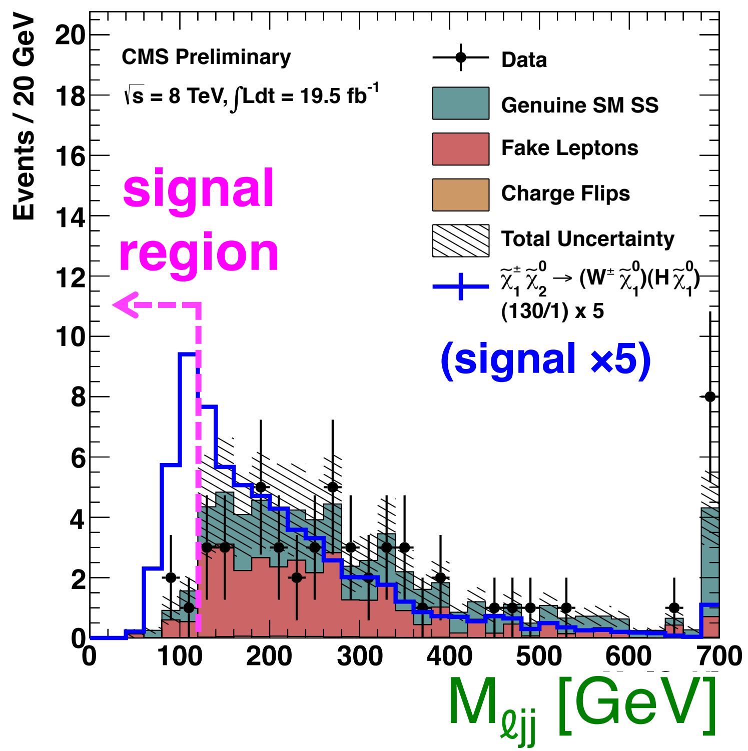
signal bin



$\chi^{\pm}\chi^{0} \rightarrow W(\ell\nu)H(WW)+E_T^{miss}$ with SS 2ℓ

- **Event selection**
  - Exactly 2 SS e/μ leptons
  - 2 or 3 jets, b-veto
  - Moderate E_T^{miss}
- **Strategy**
  - Suppress SM backgrounds with E_T^{miss} and related quantities
  - Data-driven fake lepton estimate, prompt SS 2ℓ bkg from MC
  - **Search for bump in $M_{\ell jj} \sim M_H$**
- **Results**
  - No evidence for a bump in $M_{\ell jj}$
  - Good agreement in signal region



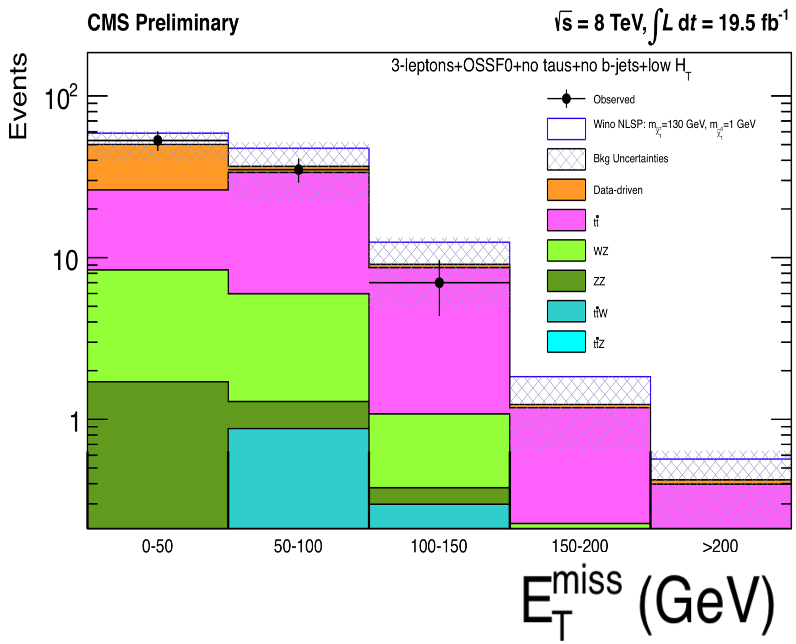


$\chi^{\pm}\chi^{0} \rightarrow WH+E_T^{miss}$ with Multileptons

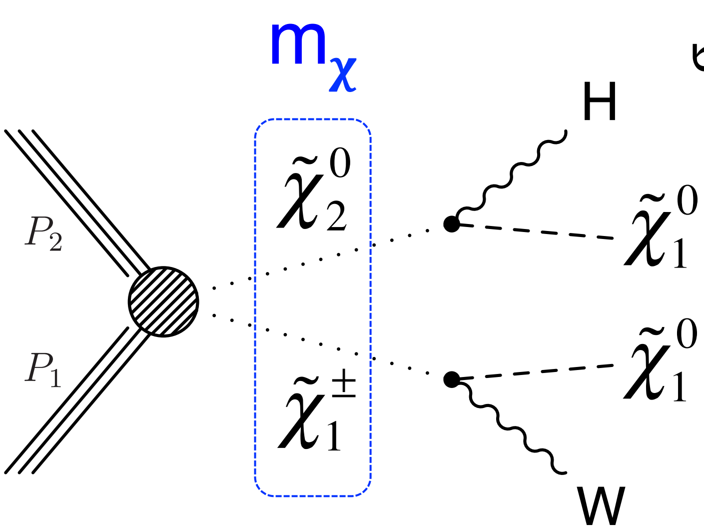
reinterpretation of SUS-13-002: inclusive multileptons (see talk: A. Gozzelino)

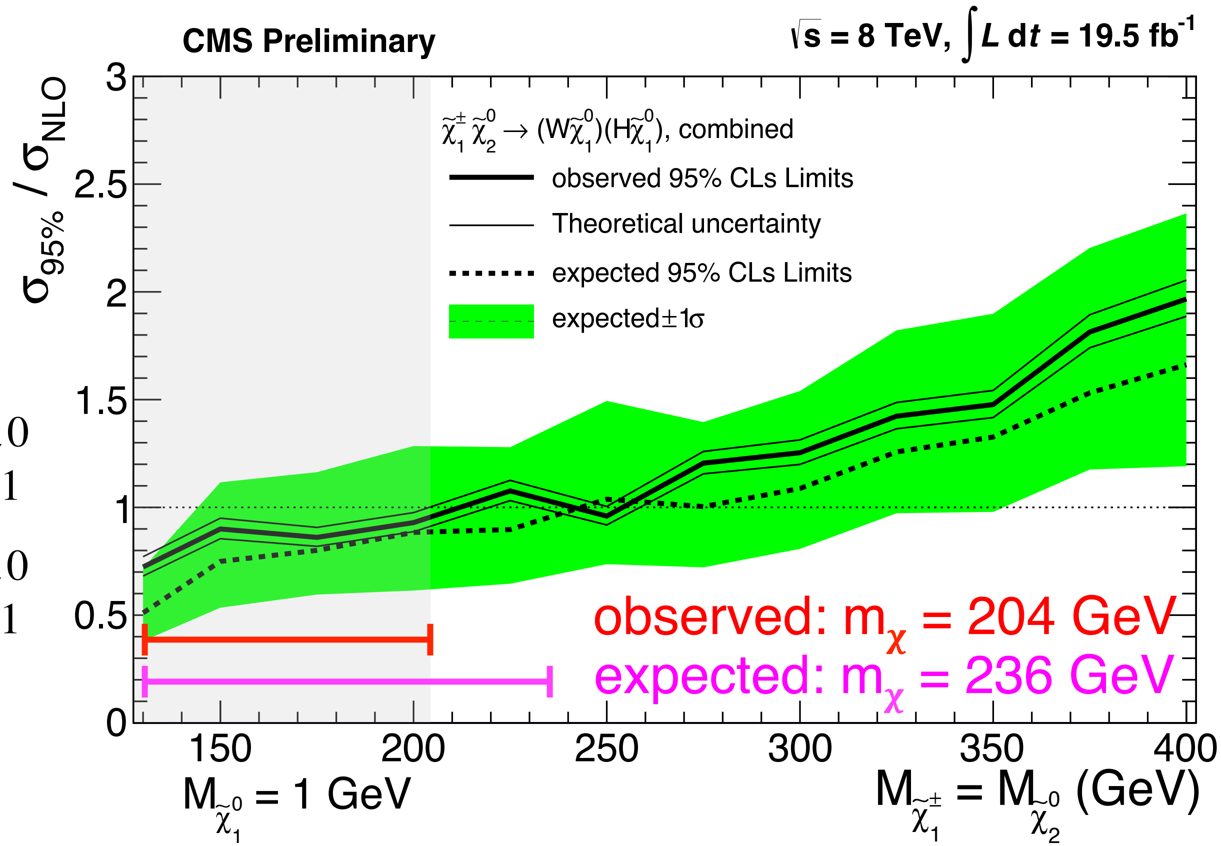
- **Event selection**
  - $\geq$3 leptons, $\leq$1 τ_{had}
  - Classify events based on number/flavor of leptons, #b-jets, E_T^{miss}, H_T
- **Strategy**
  - Extract limits from signal regions with exactly 3ℓ, 0 b-jets, low H_T

3ℓ, 0τ_{had}, no OSSF pair, 0 b-jets, low H_T



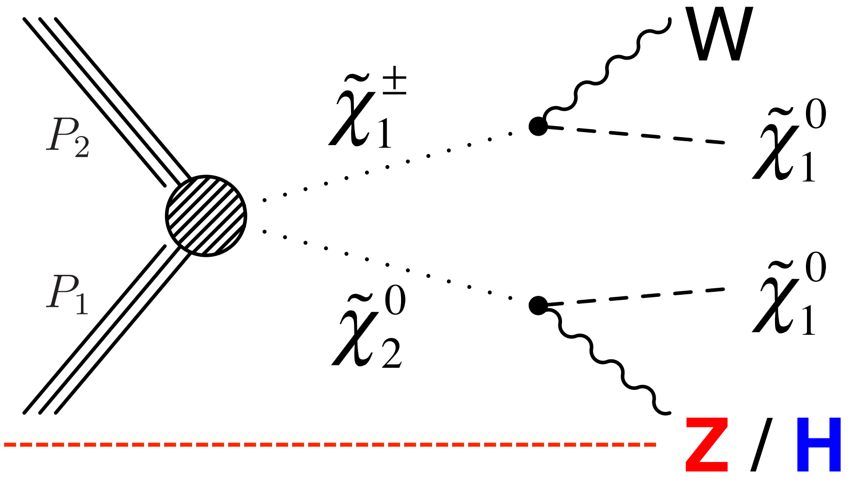
WH+E_T^{miss} Interpretation

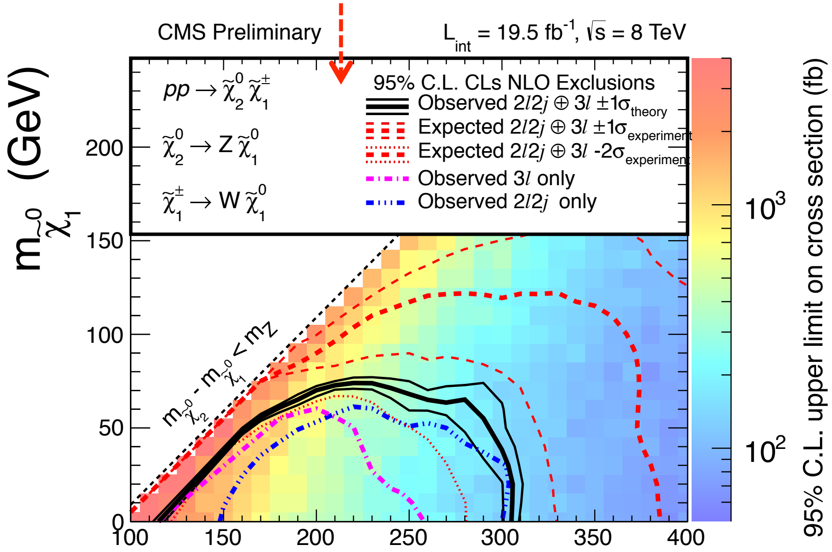




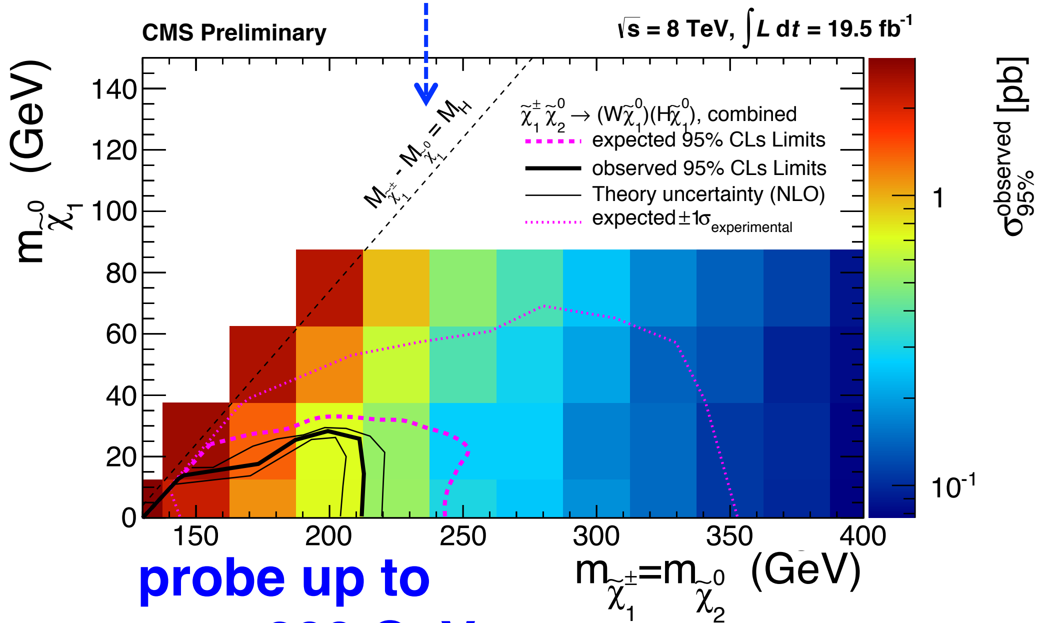
- 1ℓ best at large m_χ, SS 2ℓ and ≥3ℓ contribute at low m_χ (backup)
- **Combine 3 channels → probe up to m_χ ~ 204 GeV**
- Large improvement in 14 TeV data expected (see talk F. Golf)

$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + \mathbf{Z} / \mathbf{H}$



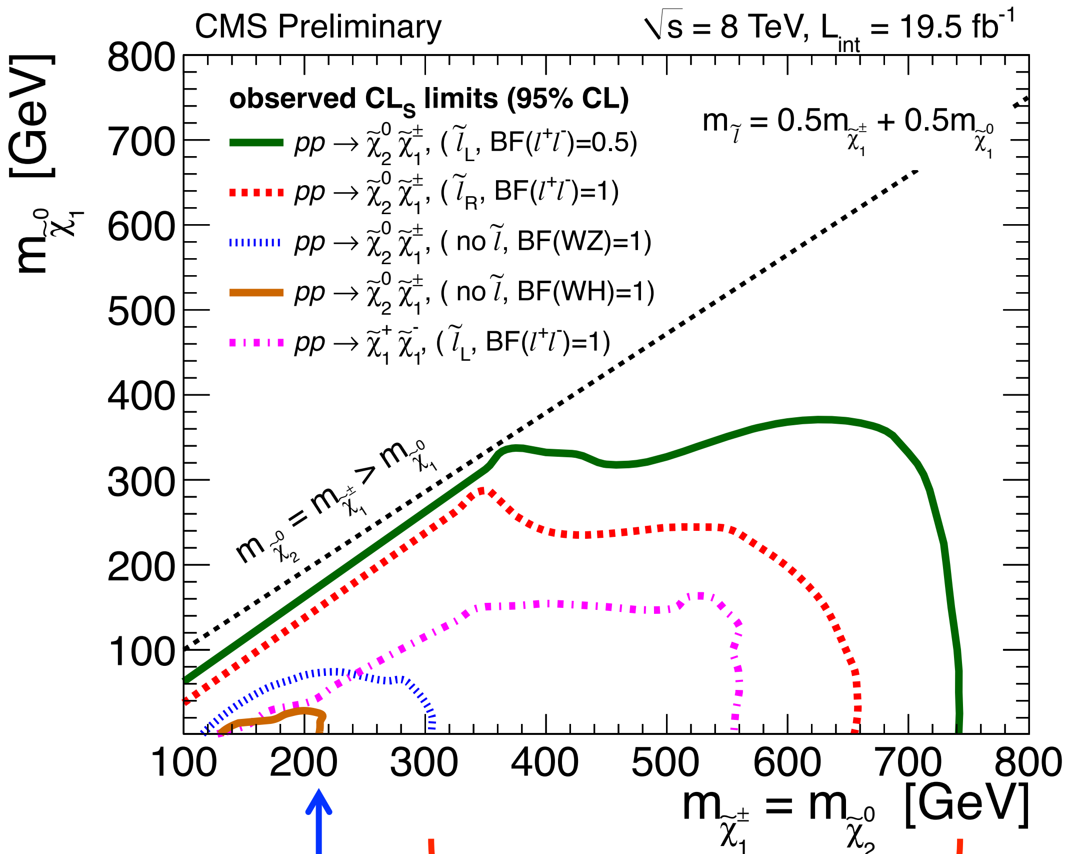


probe up to m_χ ~ 300 GeV



probe up to m_χ ~ 200 GeV

Conclusions



SUS-13-017: decays to Higgs

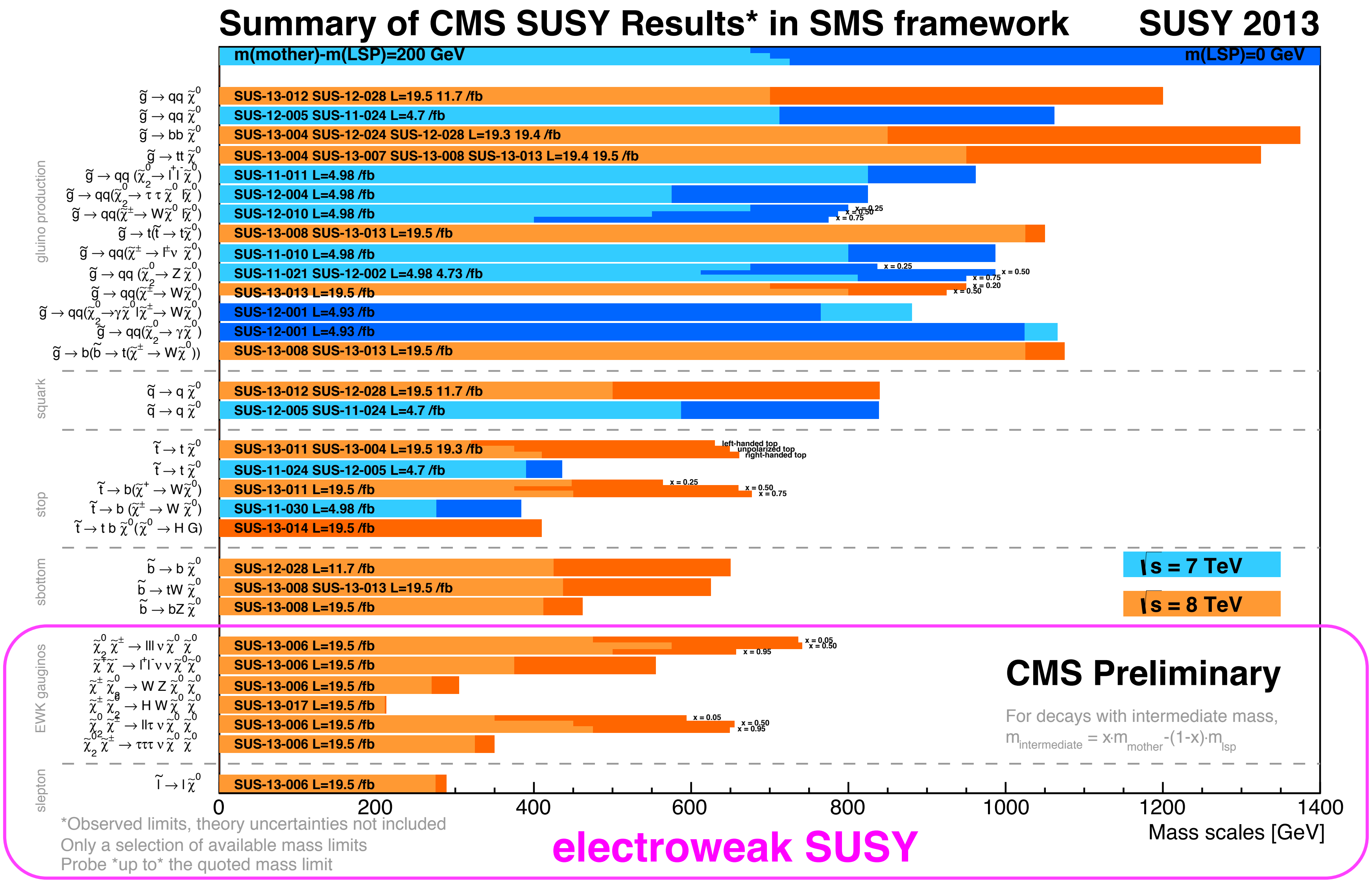
- **Probe gauginos up to m_χ ~ 200 GeV**

SUS-13-006: leptonic final states

- **Probe gauginos up to m_χ ~ 300-740 GeV**
- **Probe sleptons up to m_χ ~ 280 GeV**

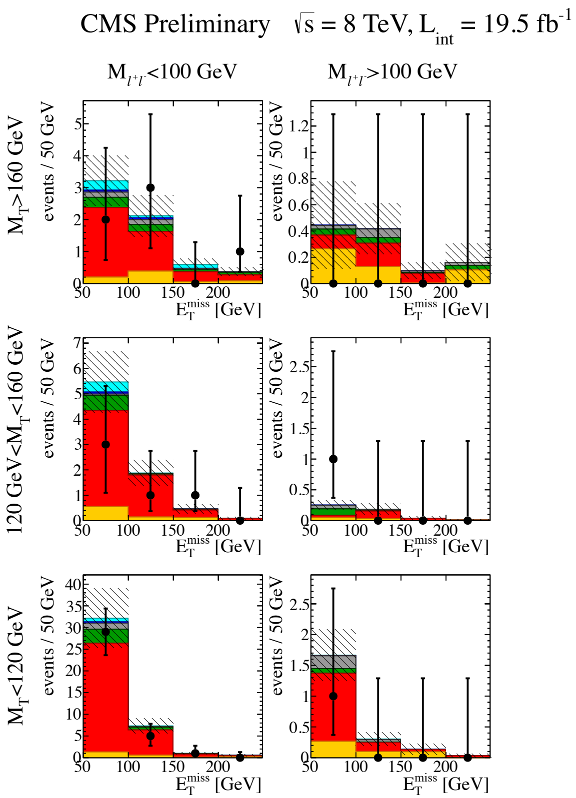
Additional Material

CMS SUSY Results

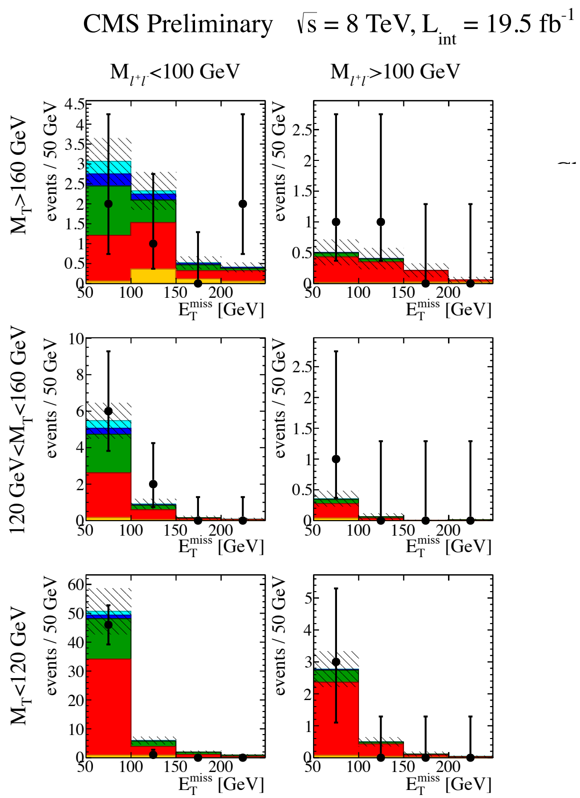


3ℓ Results

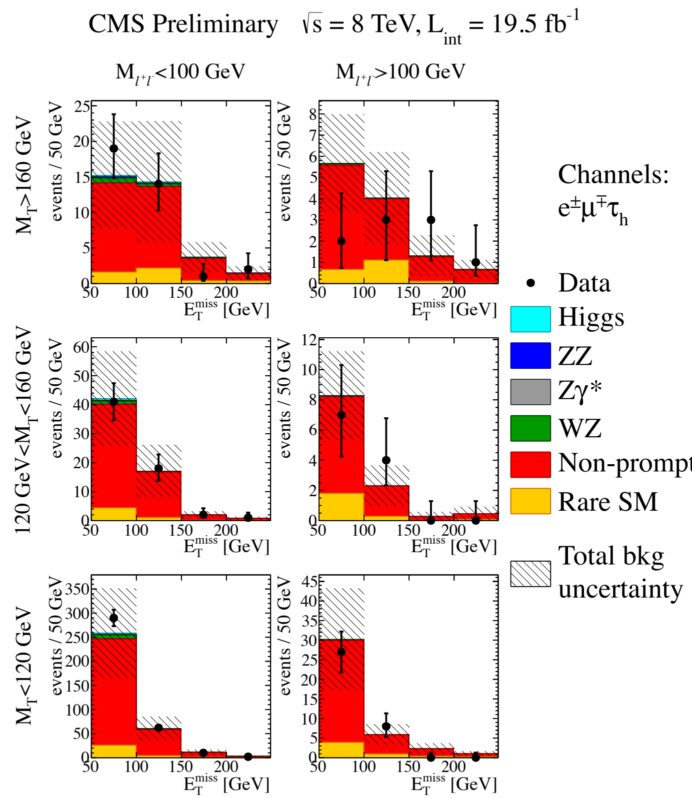
3ℓ, no OSSF pair



same-sign 2ℓ + τ_{had}

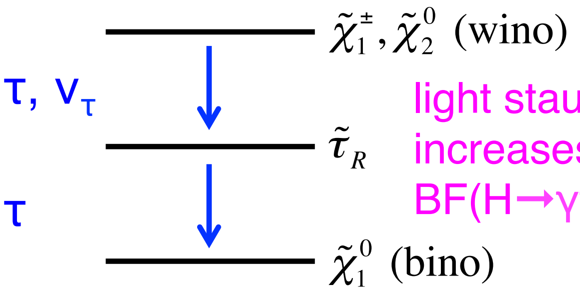


opposite-sign eμ + τ_{had}

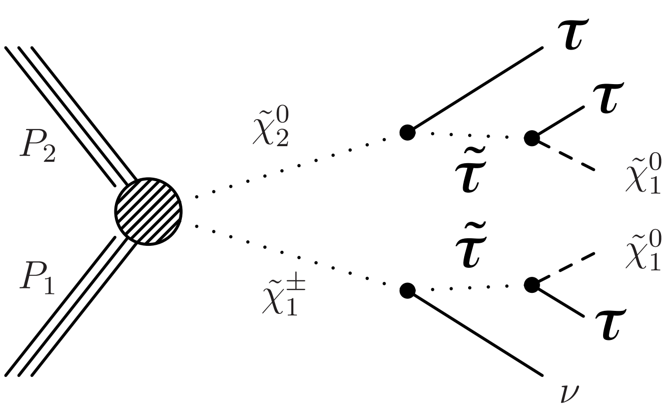


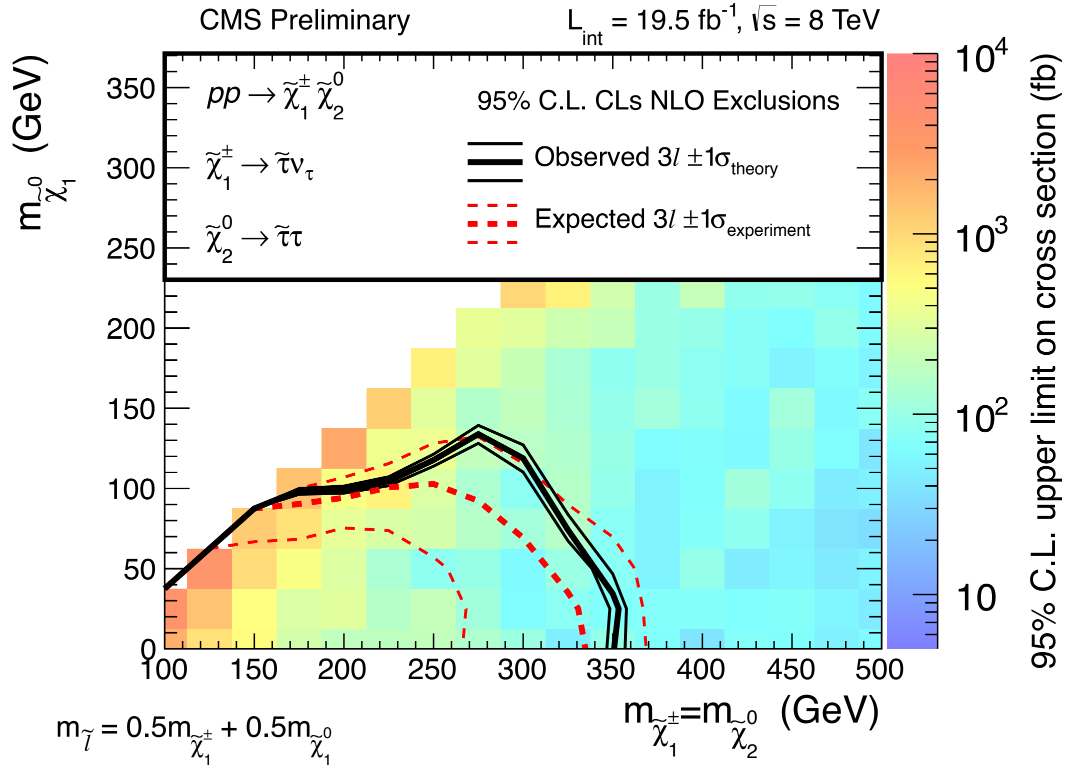
$\chi^{\pm}\chi^0 \rightarrow 3\tau$ Interpretation

[1] Carena, Gori, Shah, Wagner, Wang
arXiv:1205.5842 [hep-ph]



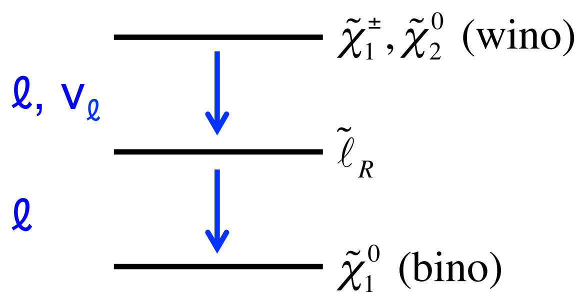
light stau increases BF(H→γγ) [1]

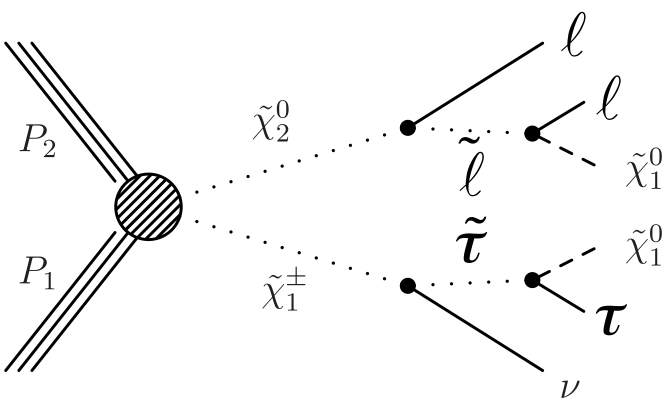


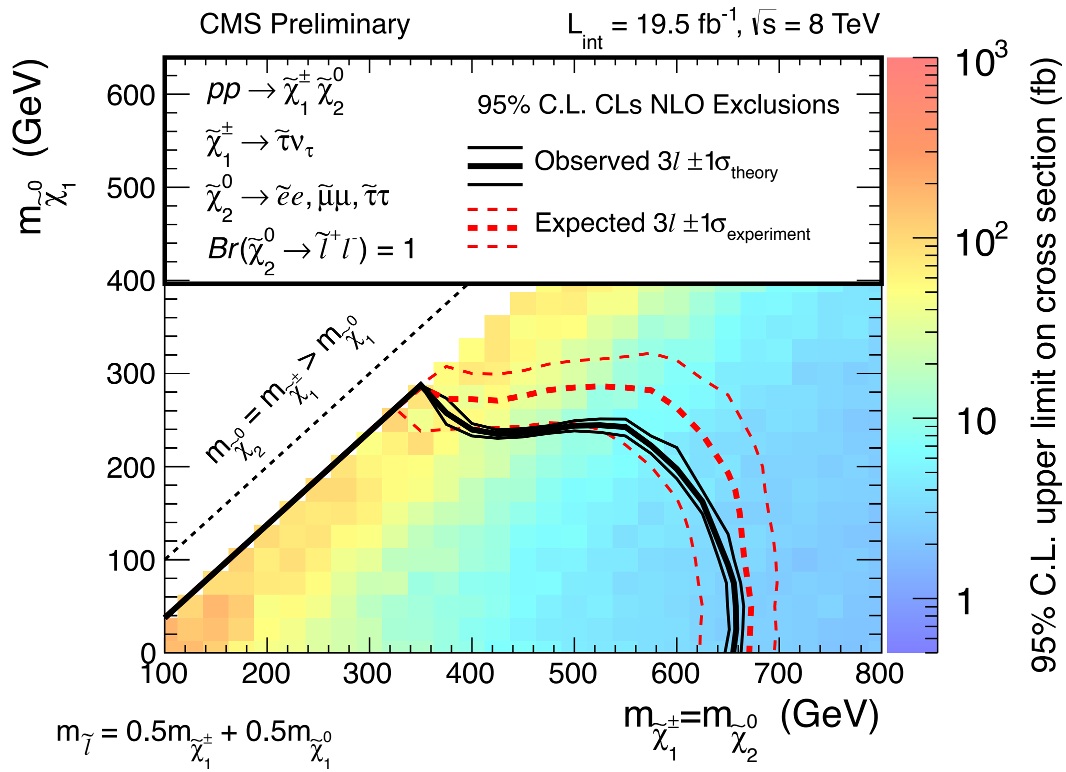


- Assume light right-handed sleptons leading to **3τ signature**
  - χ^+ couples to ℓ_R through higgsino component: $\chi^{\pm} \rightarrow \tau\nu$
  - **For high tan β**, χ^0 couples to ℓ_R through higgsino component: $\chi^0 \rightarrow \tau\tau$
- **Results from 3ℓ analysis probe m_χ up to ~340 GeV**

$\chi^{\pm}\chi^0 \rightarrow 2\ell+\tau$ Interpretation

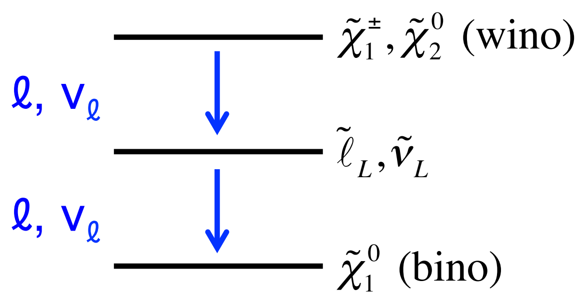


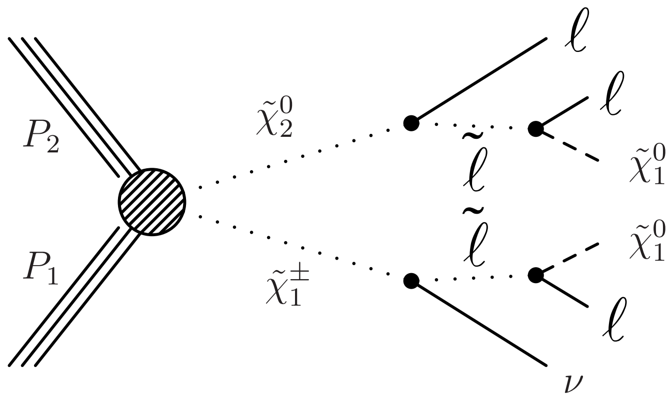


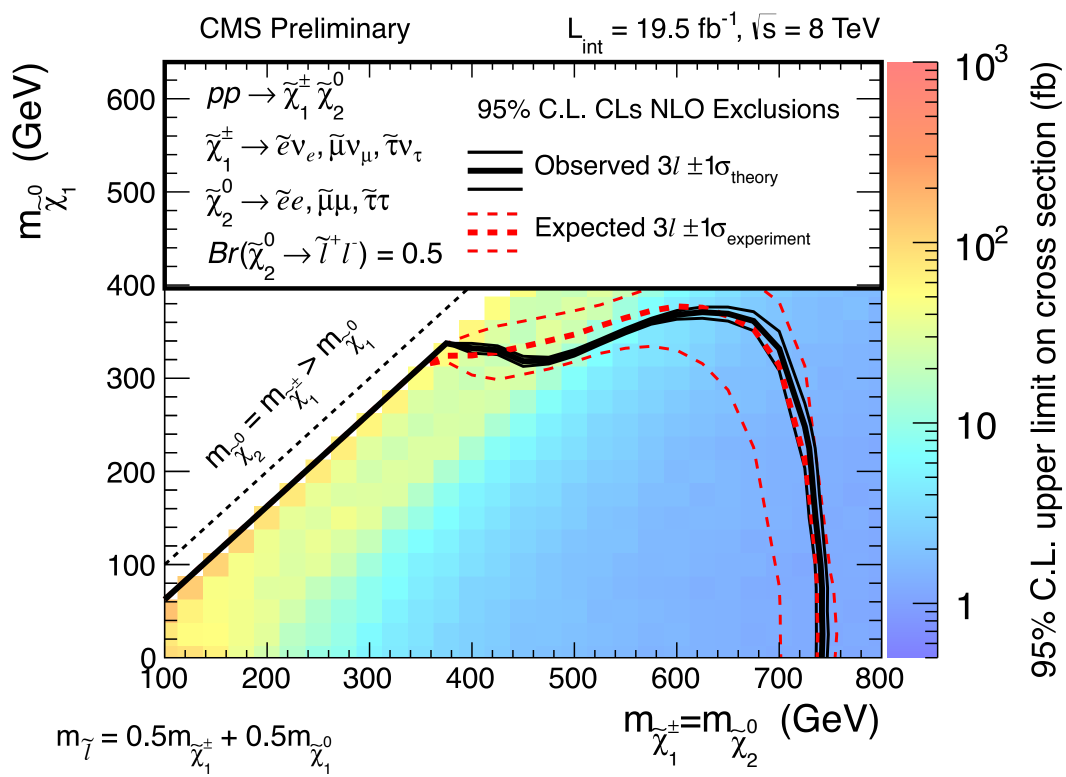


- Assume light right-handed sleptons leading to **$2\ell+\tau$ signature**
  - χ^+ couples to ℓ_R through higgsino component: **$\chi^{\pm} \rightarrow \tau\nu$**
  - **For low tan β**, χ^0 couples to ℓ_R through bino component: **$\chi^0 \rightarrow \ell\ell$**
- **Results from 3ℓ analysis probe m_χ up to ~640 GeV**

$\chi^{\pm}\chi^{0} \rightarrow 3\ell$ Interpretation

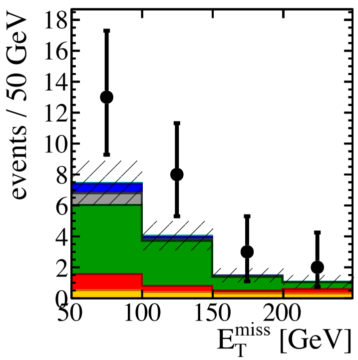




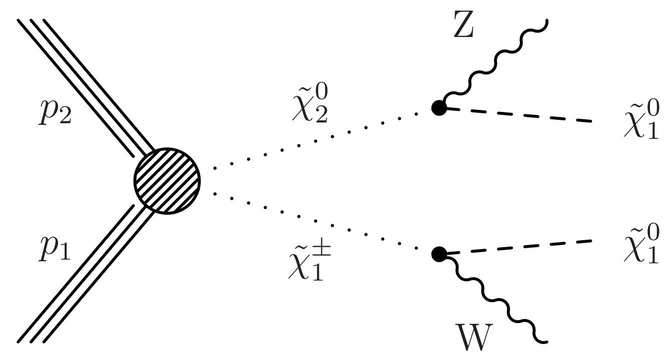


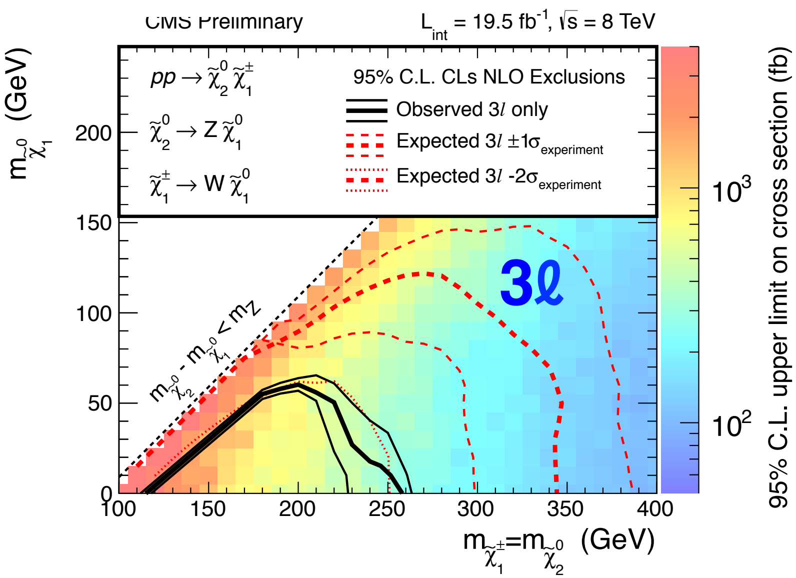
- Assume light left-handed sleptons/sneutrinos: **3ℓ signature**
  - Both χ^+ and χ^0 couple equally to e, μ, τ
  - 50% branching fraction penalty for $\tilde{\chi}_2^0 \rightarrow \tilde{\nu}\nu \rightarrow \tilde{\chi}_1^0 \nu\nu$
- **Results from 3ℓ analysis probe m_χ up to ~740 GeV**

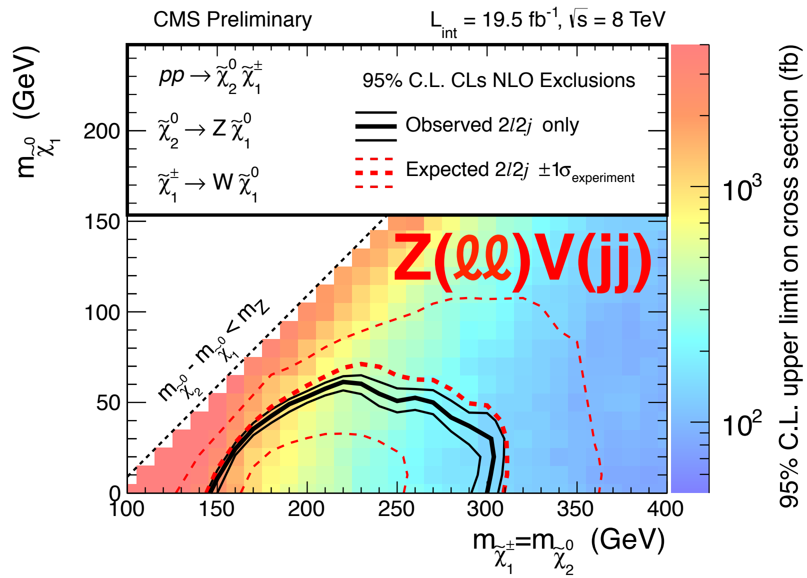
$\chi^{\pm}\chi^{0} \rightarrow$ WZ+MET: 3ℓ vs. Z(ℓℓ)V(jj)



3ℓ, no τ_{had}, on-Z, high M_T





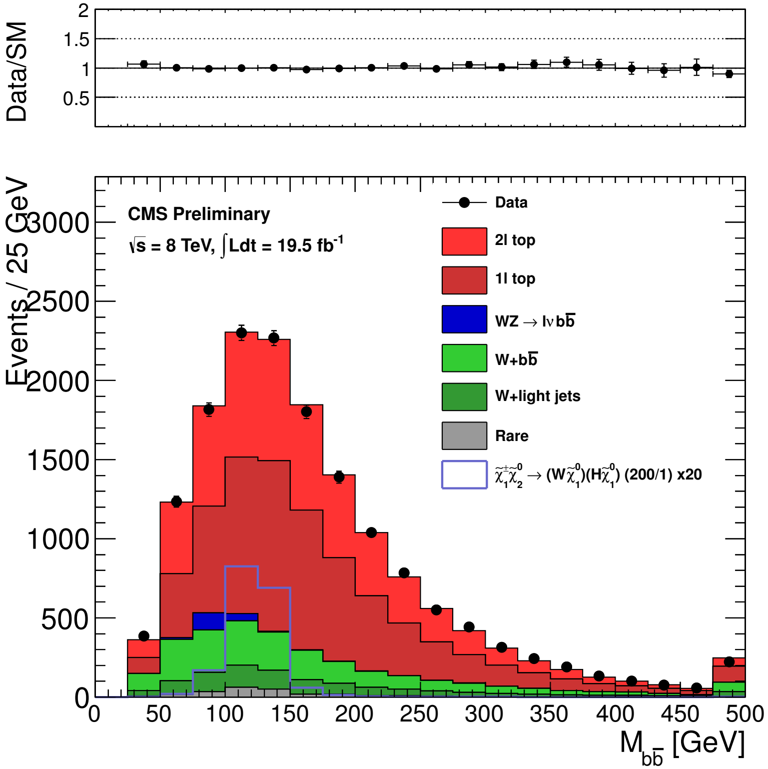


- ~2σ deviation between 3ℓ observed vs. expected
- Good agreement in Z(ℓℓ)V(jj) channel

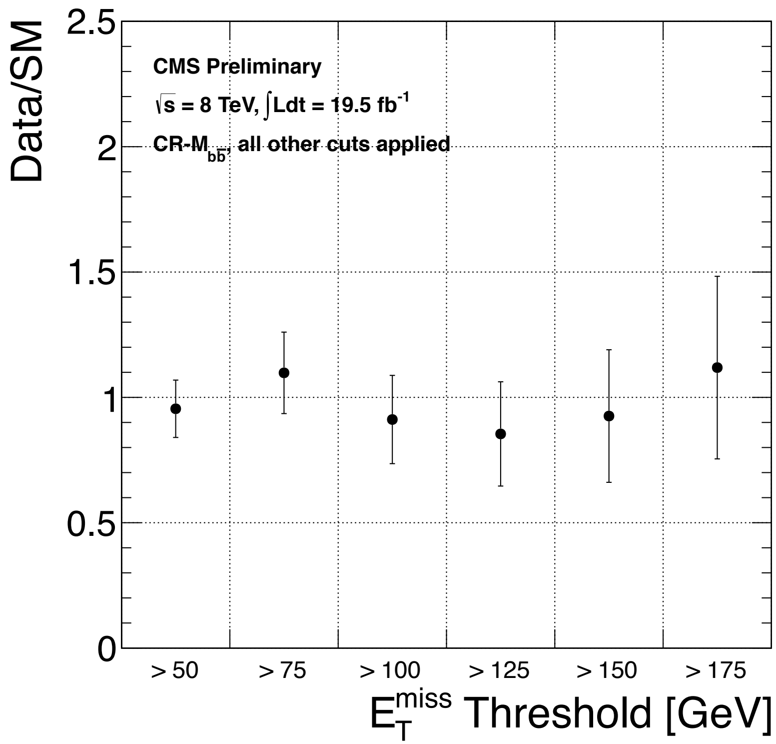
$\chi^{\pm}\chi^{0} \rightarrow W(\ell\nu)H(bb)+E_T^{miss}$

Preselection

exactly 1ℓ, 2 jets (both b-tagged), $E_T^{miss} > 50$ GeV



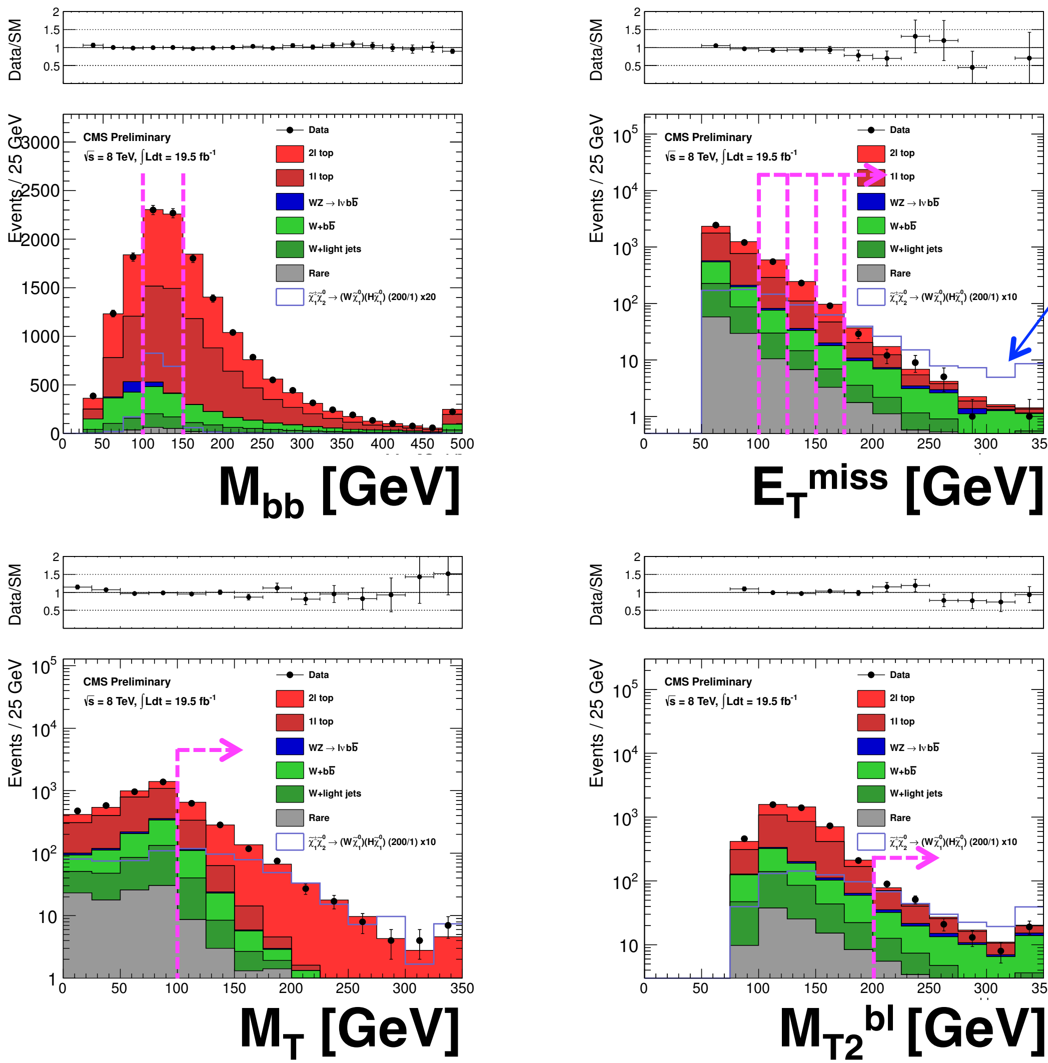
Signal region with M_{bb} mass window requirement inverted



- The M_{bb} shape is well-reproduced in preselection region
- Good agreement in signal region outside the M_{bb} mass window

$\chi^{\pm}\chi^{0} \rightarrow W(\ell\nu)H(bb)+E_T^{miss}$

Preselection: exactly 1ℓ, 2 jets (both b-tagged), $E_T^{miss} > 50$ GeV



example
signal model
scaled by ×10

Bai et. al.
JHEP 1207 (2012) 110

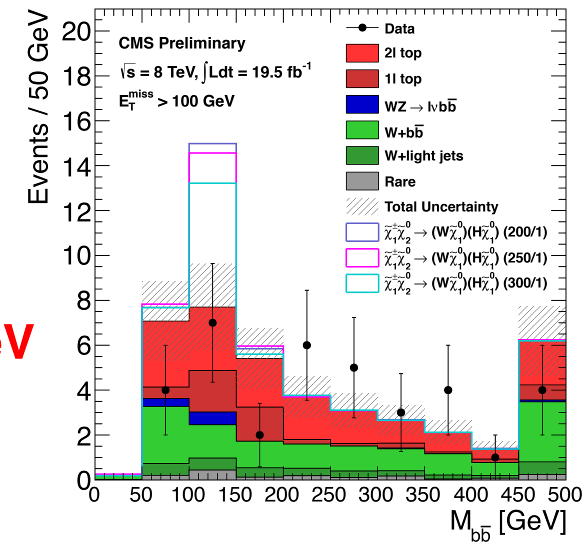
$\chi^{\pm}\chi^{0} \rightarrow W(\ell\nu)H(bb)+E_T^{miss}$

Sample	$E_T^{miss} > 100$ GeV	$E_T^{miss} > 125$ GeV	$E_T^{miss} > 150$ GeV	$E_T^{miss} > 175$ GeV
Dilepton top	2.8 ± 1.2	2.3 ± 1.0	1.7 ± 0.7	1.2 ± 0.5
Single lepton top	1.8 ± 1.1	0.9 ± 0.6	0.5 ± 0.3	0.2 ± 0.2
$WZ \rightarrow \ell\nu b\bar{b}$	0.6 ± 0.2	0.4 ± 0.2	0.3 ± 0.1	0.3 ± 0.1
$W + b\bar{b}$	1.5 ± 0.9	1.0 ± 0.7	0.9 ± 0.6	0.2 ± 0.3
W+light jets	0.5 ± 0.2	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Rare	0.4 ± 0.2	0.3 ± 0.2	0.3 ± 0.2	0.2 ± 0.1
Total SM	7.7 ± 1.9	5.4 ± 1.3	3.8 ± 1.0	2.3 ± 0.6
Data	7	6	3	3
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (130/1)	9.0 ± 1.2	7.5 ± 1.0	6.0 ± 0.8	4.5 ± 0.6
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (150/1)	7.3 ± 1.0	6.2 ± 0.9	5.0 ± 0.7	3.6 ± 0.5
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (200/1)	7.3 ± 1.0	6.0 ± 0.8	4.9 ± 0.7	3.6 ± 0.5
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (300/1)	5.5 ± 0.7	5.2 ± 0.7	4.6 ± 0.6	4.1 ± 0.6
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (400/1)	3.4 ± 0.4	3.3 ± 0.4	3.0 ± 0.4	2.7 ± 0.4

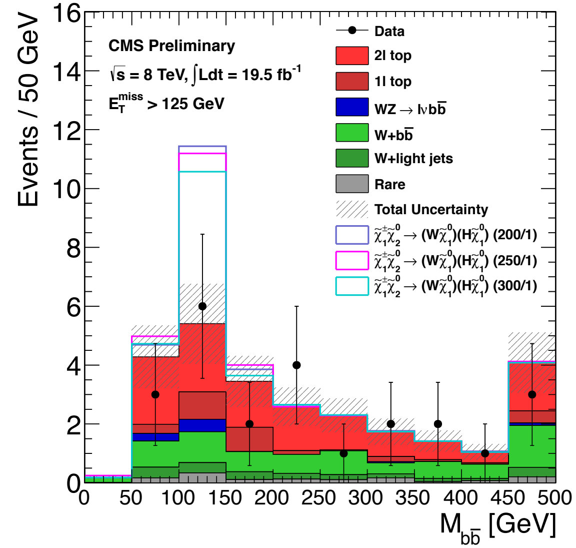
- Sliding E_T^{miss} cut: >100, 125, 150, 175 GeV
- Good agreement in all regions

$\chi^{\pm}\chi^{0} \rightarrow W(\ell\nu)H(bb)+E_T^{miss}$

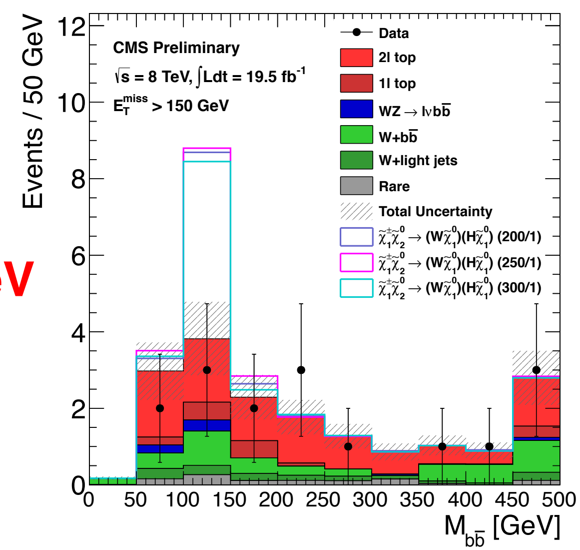
E_T^{miss} > 100 GeV



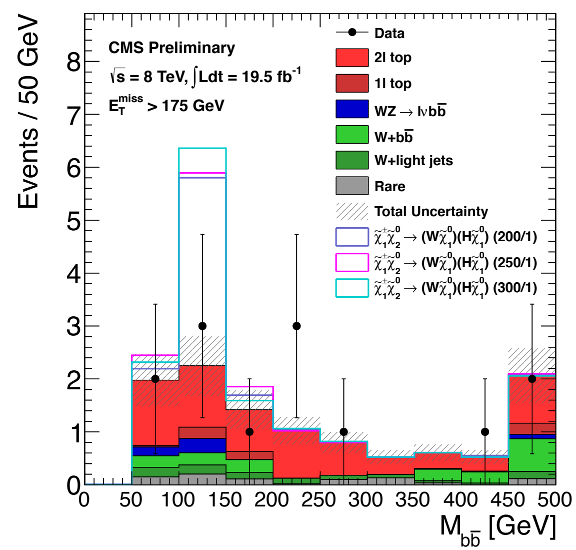
E_T^{miss} > 125 GeV



E_T^{miss} > 150 GeV



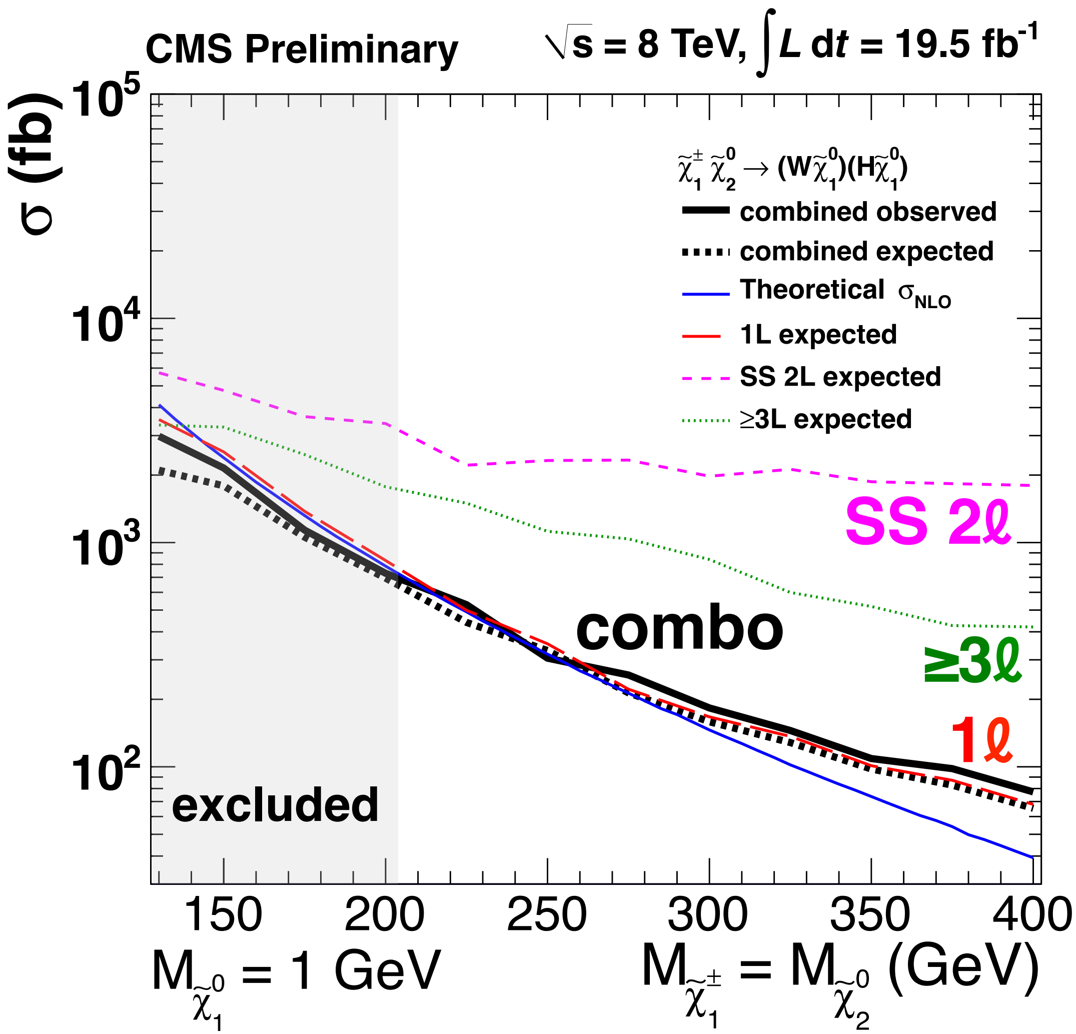
E_T^{miss} > 175 GeV

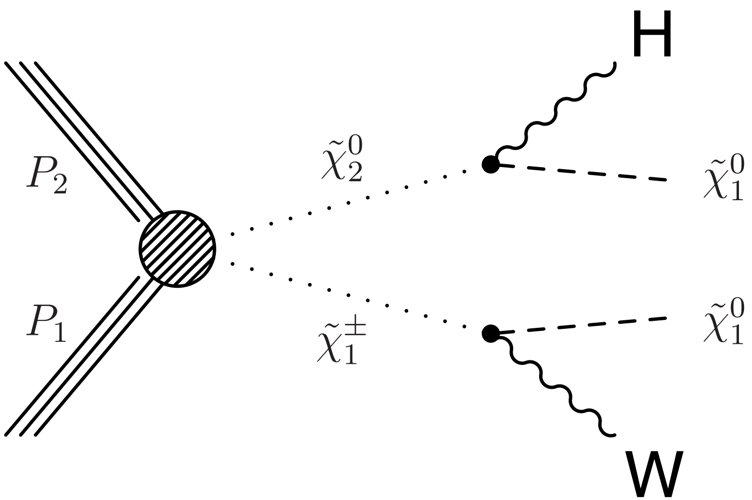


SS 2ℓ Results

Sample	ee	$\mu\mu$	$e\mu$	Total
Fakes	0.3 ± 0.3	0.2 ± 0.2	0.8 ± 0.5	1.3 ± 0.8
Charge Flips	< 0.01	< 0.01	< 0.03	< 0.03
Genuine SM SS	0.4 ± 0.4	0.4 ± 0.4	0.8 ± 0.6	1.6 ± 0.9
Total SM	0.7 ± 0.5	0.6 ± 0.5	1.6 ± 0.7	2.9 ± 1.2
Data	1	1	1	3
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (130/1)	0.8 ± 0.1	1.0 ± 0.1	1.9 ± 0.3	3.6 ± 0.5
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (150/1)	0.5 ± 0.1	0.6 ± 0.1	1.4 ± 0.2	2.5 ± 0.3
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (200/1)	0.20 ± 0.03	0.4 ± 0.1	0.6 ± 0.1	1.2 ± 0.2
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (300/1)	0.07 ± 0.01	0.12 ± 0.02	0.19 ± 0.03	0.4 ± 0.1
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(H\tilde{\chi}_1^0)$ (400/1)	0.02 ± 0.00	0.03 ± 0.00	0.06 ± 0.01	0.11 ± 0.02

Interpretation

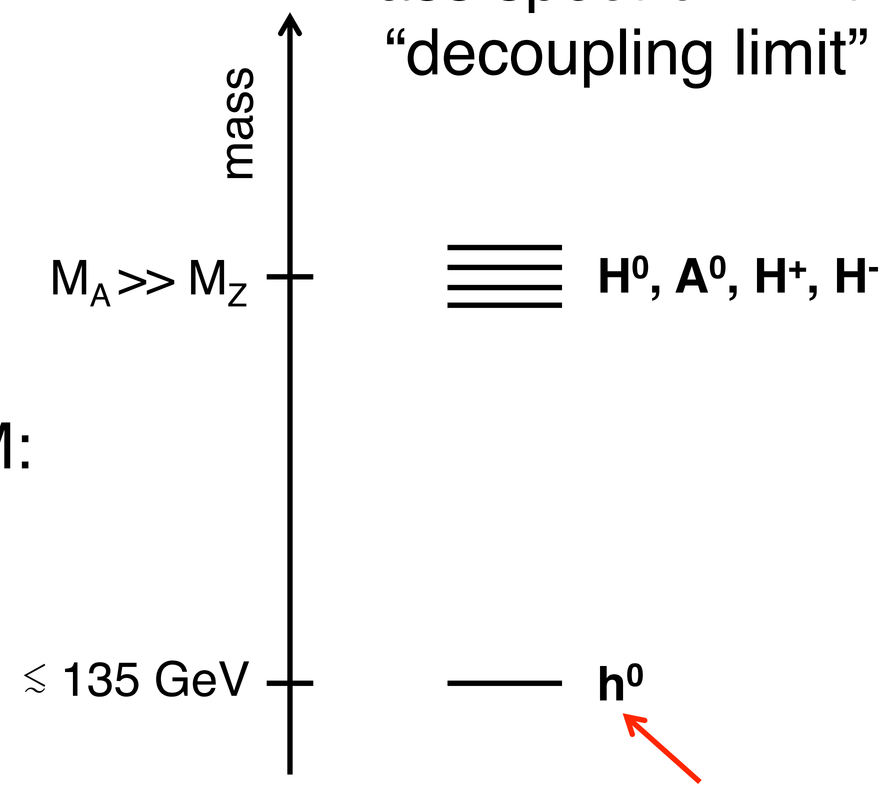




- Probe up to ~200 GeV
- Large sensitivity improvement in 14 TeV data expected

MSSM Higgs Bosons [1]

mass spectrum in the
“decoupling limit”

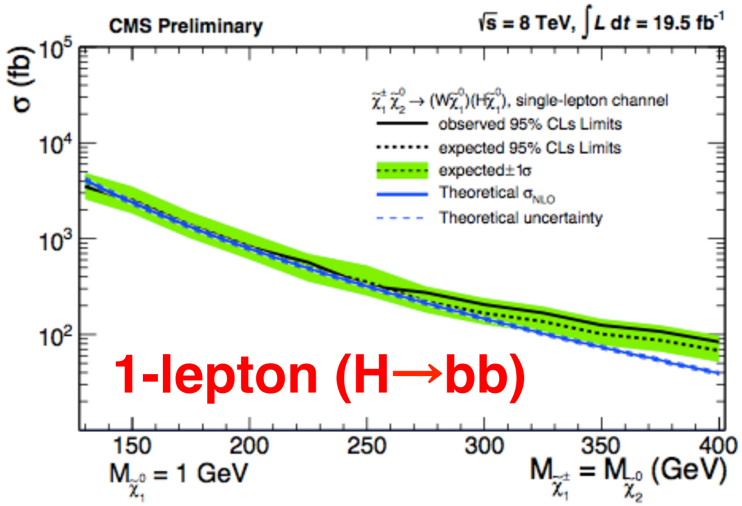


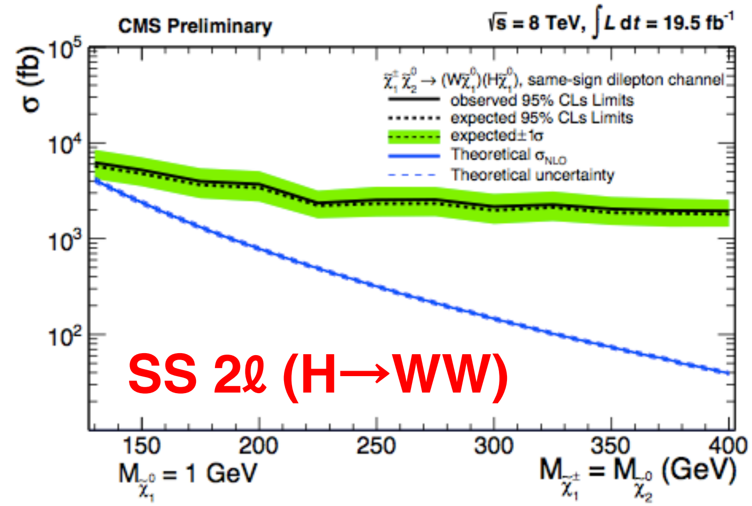
physical Higgs bosons in MSSM:
h^0, H^0, A^0, H^+, H^-

can be “SM-like”

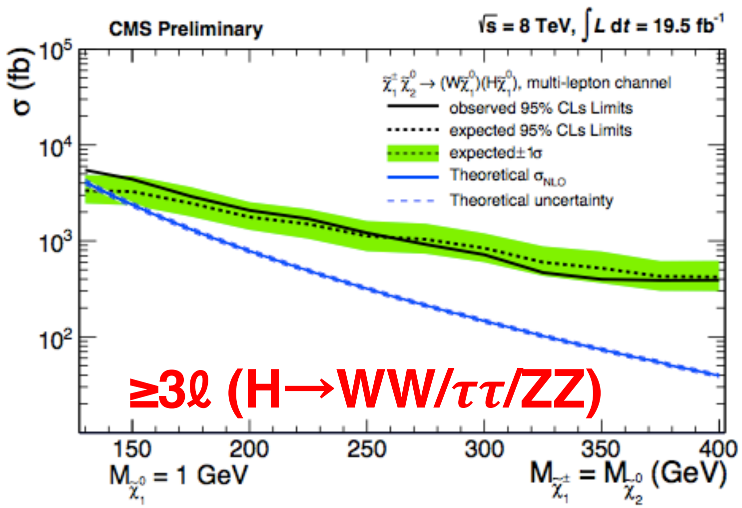
- [1] Ch. 8 of Martin’s SUSY primer http://arxiv.org/abs/hepph/9709356 and references therein

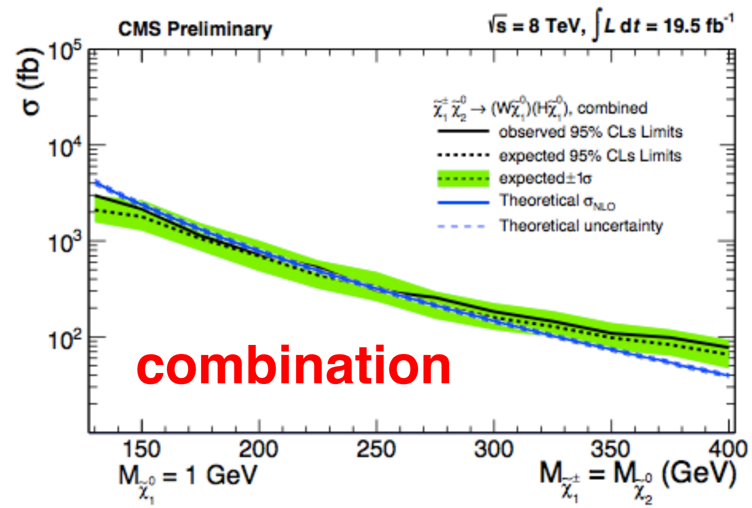
WH+E_T^{miss} Individual Limits



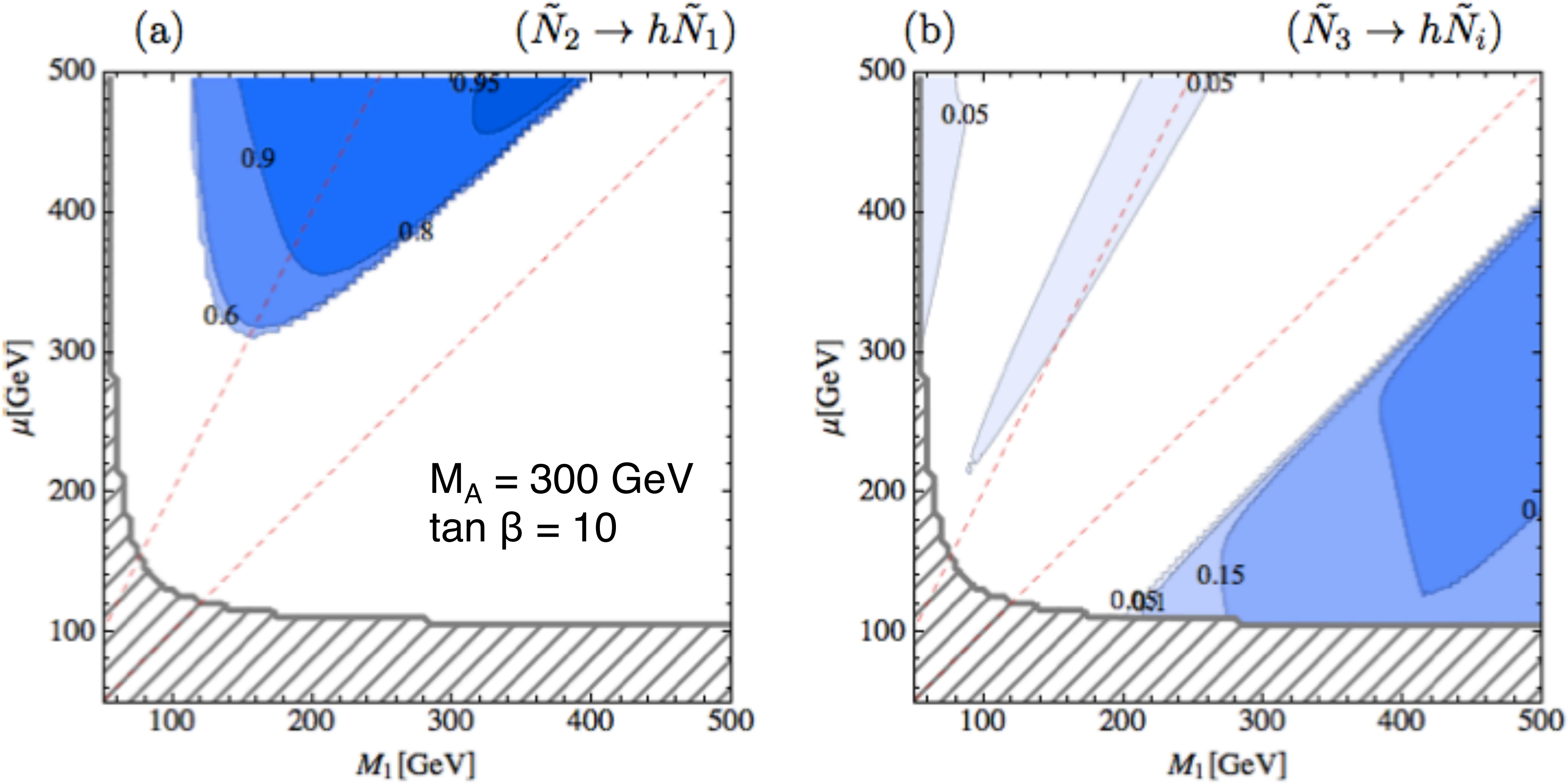


(a) (b)



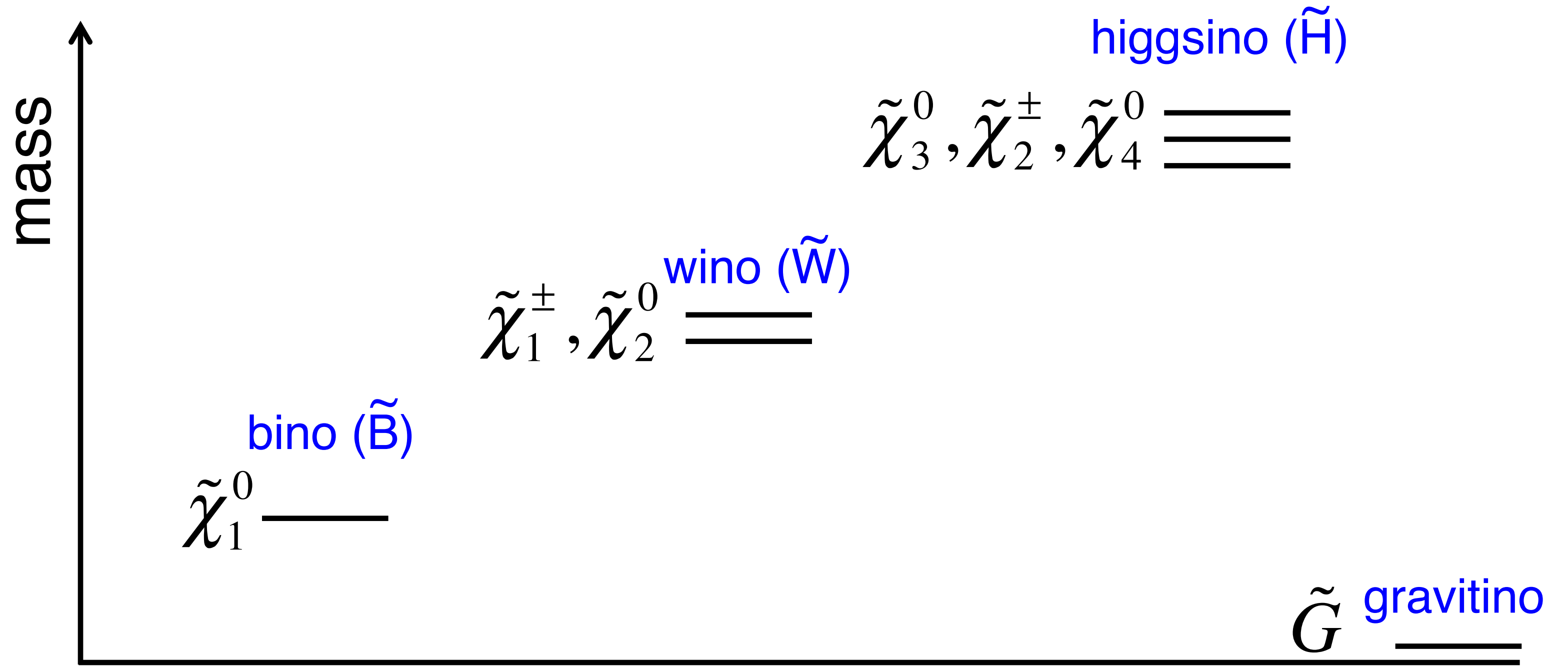


Neutralino Decays to Z vs. h



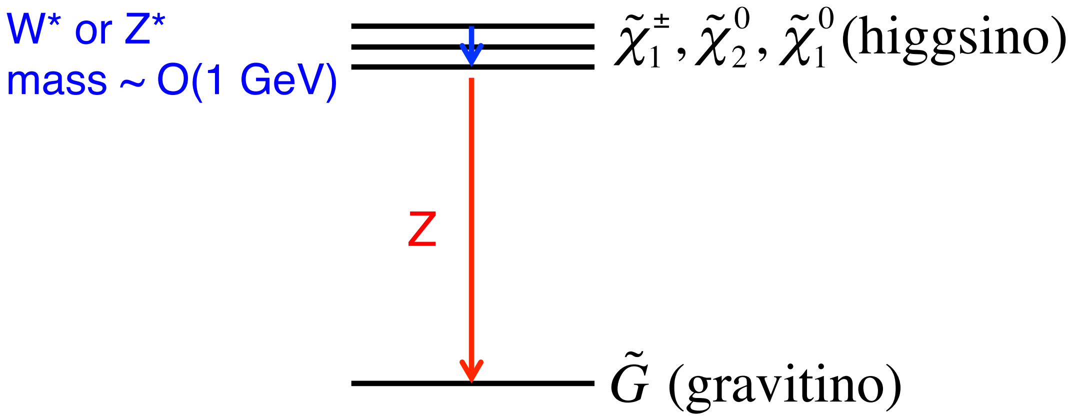
Gori, Schwaller, Wagner
arXiv:1103.4138

EWK SUSY Mass Spectrum



GMSB Higgsino ZZ+E_T^{miss} Model

Matchev, Thomas, Phys. Rev. D 62 (2000) 077702
Meade, Reece, Shih, JHEP 05 (2010) 105
Ruderman, Shih arXiv:1103.6083



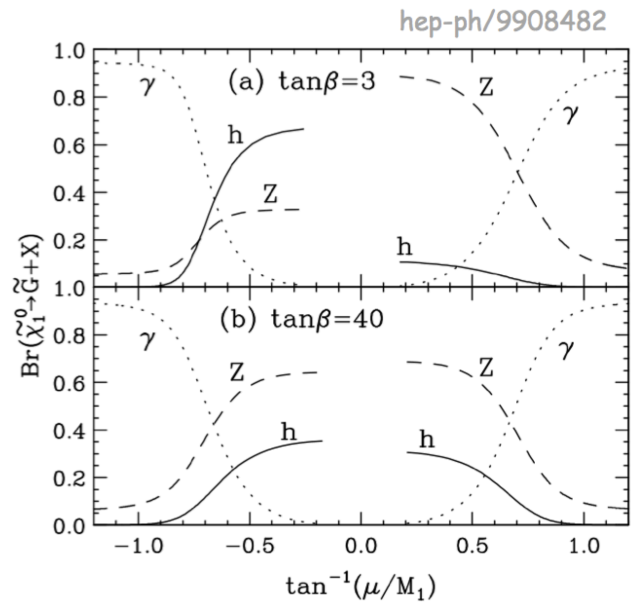
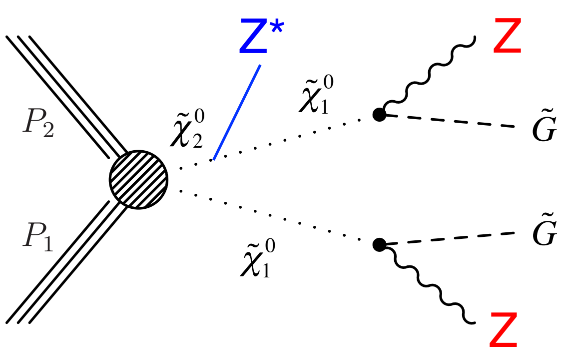
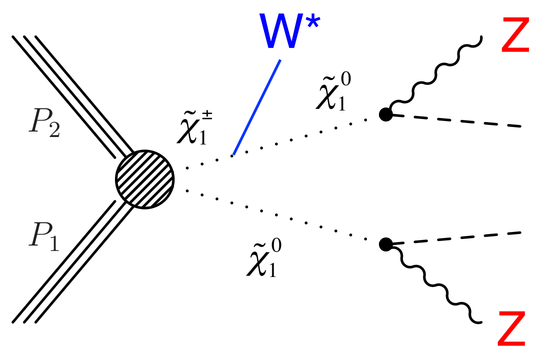


Figure 1: Branching ratios of the lightest neutralino $\mathrm{Br}(\tilde{\chi}_1^0 \to \tilde{G} + \gamma, h, Z)$ as a function of the neutralino mixing angle $\tan^{-1}(\mu/M_1)$, for a fixed mass $M_{\tilde{\chi}_1^0} = 160$ GeV and $m_h = 105$ GeV for (a) $\tan\beta = 3$ and (b) $\tan\beta = 40$.

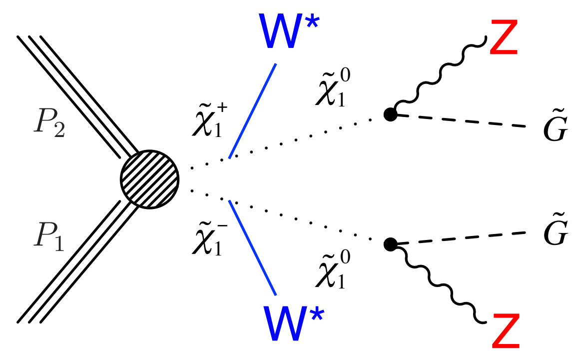
neutralino-neutralino



chargino-neutralino



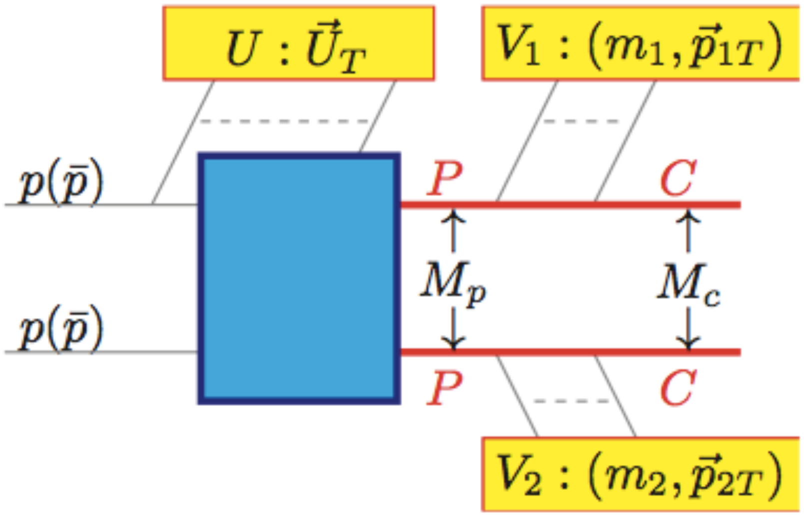
chargino-chargino



The $M_{CT\perp}$ Variable

L. Shchutska EPS2013

- **Konstantin Matchev and Myeonghun Park:**
  - Phys. Rev. Lett. 107, 061801 (2011) (hep-ph:0910.1584)



- for P→VC, where V - a visible particle:

$$M^2_{\mathrm{CT}} = m^2(\mathrm{V}_1) + m^2(\mathrm{V}_2)$$
$$+2\left[E_{\mathrm{T}}(\mathrm{V}_1)E_{\mathrm{T}}(\mathrm{V}_2) + \boldsymbol{p}_{\mathrm{T}}(\mathrm{V}_1)\cdot\boldsymbol{p}_{\mathrm{T}}(\mathrm{V}_2)\right]$$

- an endpoint:

$$M^{\max}_{\mathrm{CT}} = \frac{m^2(P)-m^2(C)}{m(P)}$$

- if PP are not at rest, use E_{T} and p_{T} components normal to $\vec{U}_{\mathrm{T}}$:

$$\vec{U}_{\mathrm{T}} = -\vec{E}^{\mathrm{miss}}_{\mathrm{T}} - \vec{p}_{\mathrm{T}}(\mathrm{V}_1) - \vec{p}_{\mathrm{T}}(\mathrm{V}_2)$$