

Search for electroweak production of charginos and neutralinos

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on behalf of the CMS collaboration

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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



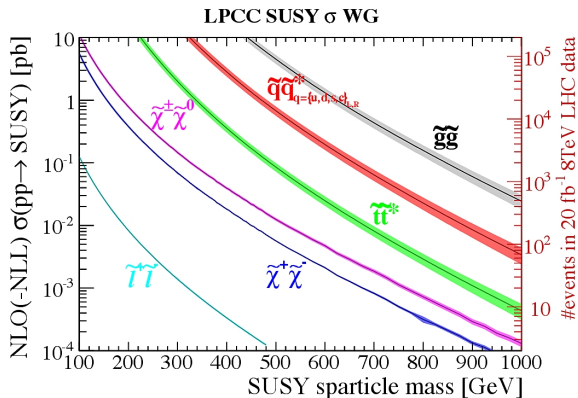
All results available via CMS SUSY summary twiki:

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS>

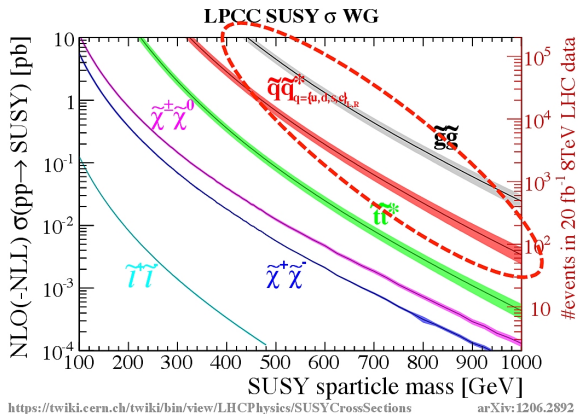
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- **Introduction & Motivation**
- SUS-13-006: Searches in Leptonic Final States
- SUS-13-017: Searches with Higgs Bosons

Intro/Motivation

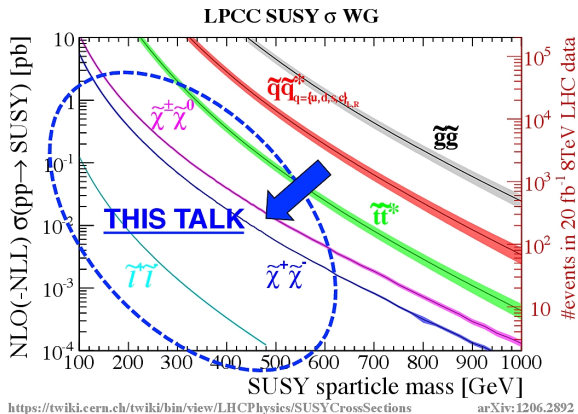


Intro/Motivation



- “Strong SUSY” \rightarrow large σ , jets, E_T^{miss} , (leptons)

Intro/Motivation

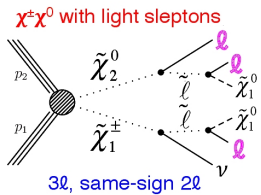


- “Electroweak SUSY” \rightarrow small σ , lepton(s) + E_T^{miss}

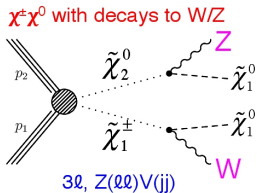
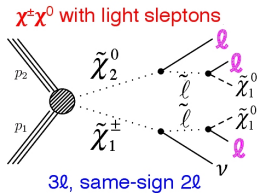
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- **SUS-13-006: Searches in Leptonic Final States**
- SUS-13-017: Searches with Higgs Bosons

Models & Signatures

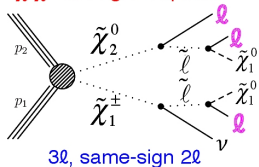


Models & Signatures

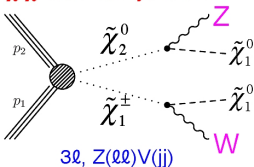


Models & Signatures

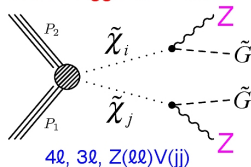
$\chi^\pm \chi^0$ with light sleptons



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

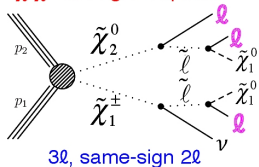


GMSB higgsino ZZ+MET

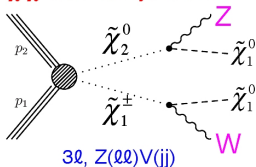


Models & Signatures

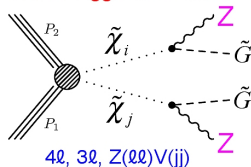
$\chi^\pm \chi^0$ with light sleptons



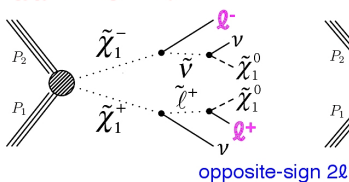
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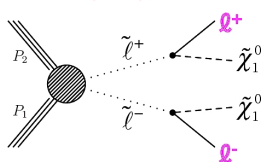
GMSB higgsino ZZ+MET



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

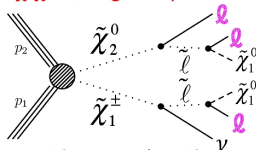


direct slepton production

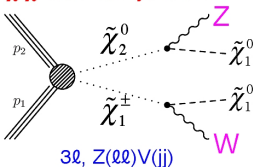


Models & Signatures

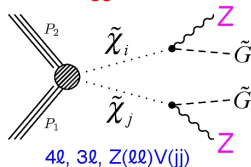
$\chi^\pm \chi^0$ with light sleptons



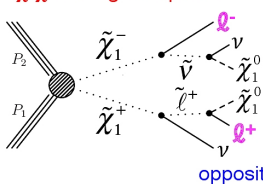
$\chi^\pm \chi^0$ with decays to W/Z



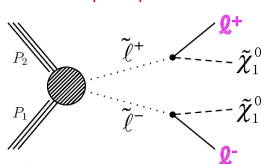
GMSB higgsino ZZ+MET



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

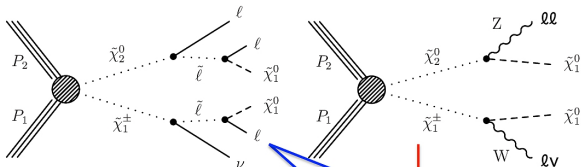


direct slepton production



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

3I : Overview

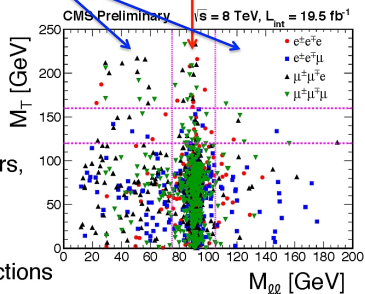


Event selection

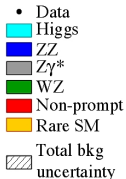
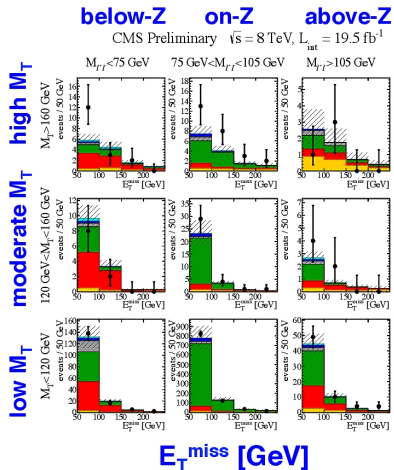
- Exactly 3 leptons, up to 1 τ_{had}
- MET > 50 GeV \rightarrow suppress Z+jets
- b-veto \rightarrow suppress $t\bar{t}$
- Classify events based on lepton flavors, $M_{\ell\ell}$, $M_T(\ell, \text{MET})$, MET

Dominant backgrounds:

- WZ: MC with data-driven E_T^{miss} corrections
- $t\bar{t}$ +fake: data-driven fake rate methods



3I : Results



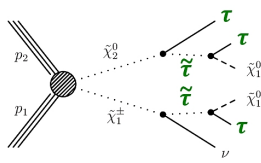
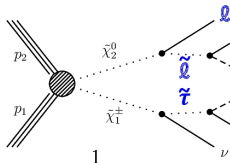
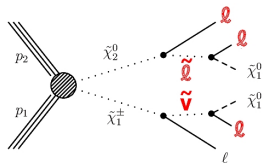
- Lepton flavor categories:
 - **3 ℓ , OSSF pair (shown)**
 - 3 ℓ , no OSSF pair
 - SS 2 ℓ + τ_{had}
 - OS $e\mu$ + τ_{had}
- } backup
- **Data consistent with bkg over range of kinematical regions, lepton categories**

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

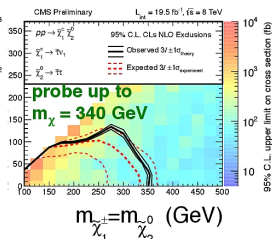
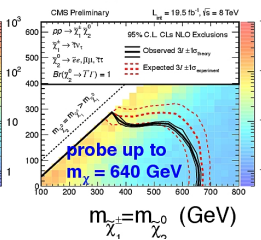
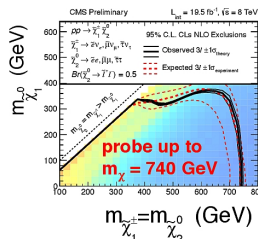
“flavor-democratic” (3ℓ)
light ($\tilde{\ell}_L, \tilde{\nu}_L$)

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

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



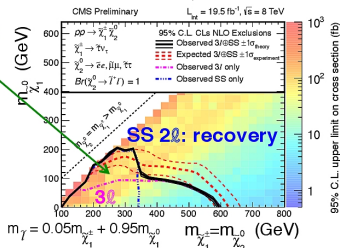
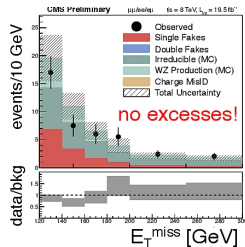
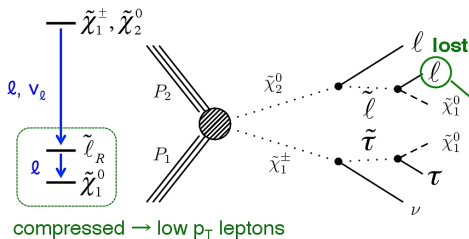
$$m_\ell = \frac{1}{2}(m_{\tilde{\chi}_1^\pm} + m_{\tilde{\chi}_1^0})$$



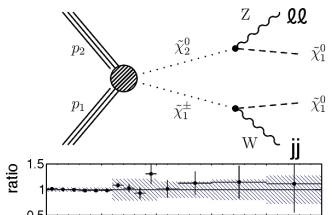
SS 2l channel

• Event Selection

- Exactly 2 high p_T SS e/μ leptons
- 2 exclusive signal regions
 - $E_{T, \text{miss}} \in [120, 200]$ GeV, $N_{\text{jets}} \leq 2$, $N_{\text{b-jets}} = 0$
 - $E_{T, \text{miss}} > 200$ GeV



Z(ll)V(jj) channel



• Event Selection

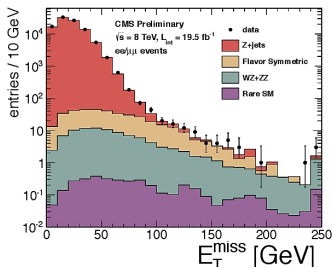
- Z \rightarrow e \bar{e} / $\mu\bar{\mu}$ candidate
- ≥ 2 jets with $M_{jj} \sim M_W/M_Z$
- b-veto \rightarrow suppress tt

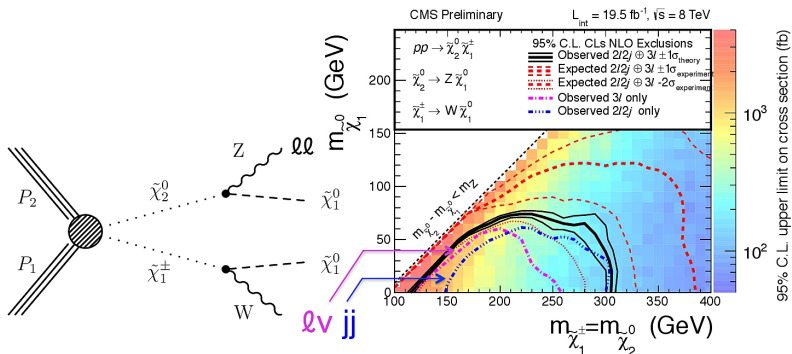
• Dominant backgrounds

- Z+jets: model fake E_T^{miss} with γ +jets data control sample
- tt: from e μ data control sample

• Results

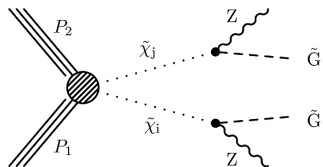
- Data well-described over ~ 4 orders of magnitude \rightarrow no excesses



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


- Results based on **Z($\ell\ell$)W(jj)** and **3 ℓ** 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

- 4 l , up to 1 τ_{had}
- Classify events by #OSSF pairs, 0 vs. 1 τ_{had} , E_T^{miss}

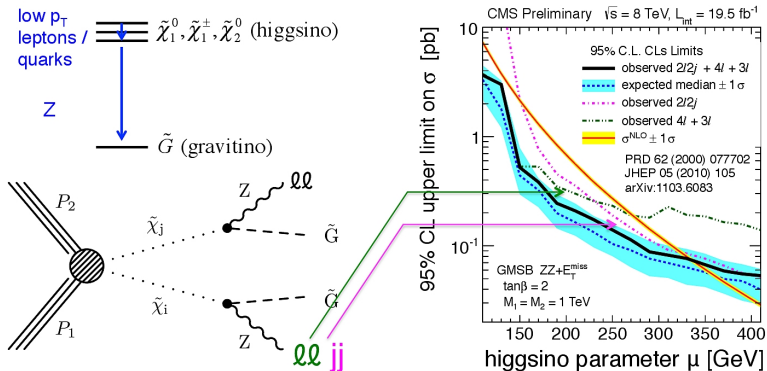
• Dominant backgrounds:

- ZZ: from MC, with data-driven MET corrections

• Results

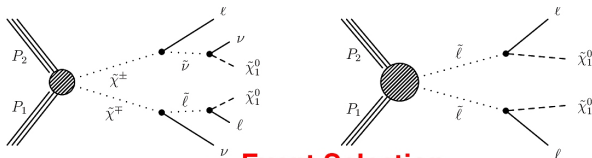
- Data agrees with SM background

GMSB higgsino $ZZ + E_T^{miss}$ Interpretation



- Results based on $Z(\ell\ell)V(jj)$, $3\ell+4\ell$, and combination
 - Combination of complementary channels \rightarrow exclude μ 110-330 GeV
- **Probe μ in interesting range for Higgs naturalness**

OS dilepton channel



• Event Selection

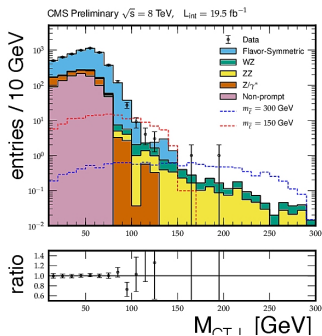
- 2 high p_T OS e/μ leptons with Z-veto
- b-veto, moderate MET

• 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

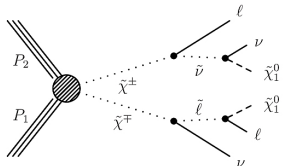
• Results

- Observed $M_{CT\perp}$ agrees with prediction



Chargino-Pairs and Slepton-Pairs

Use $ee+\mu\mu$ and $e\mu$ lepton pairs



Use $ee+\mu\mu$ lepton pairs only

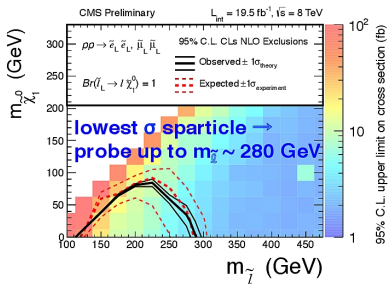
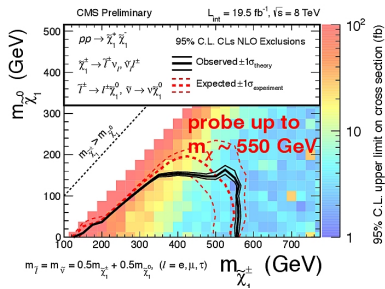
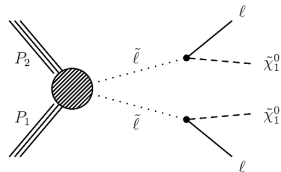
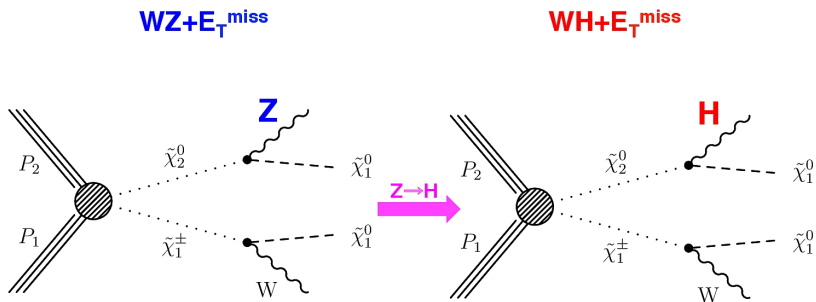


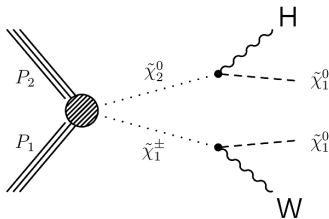
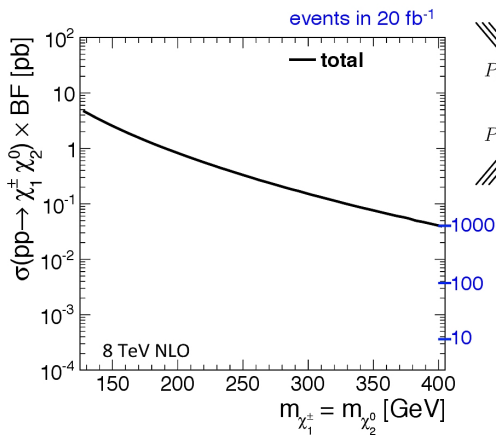
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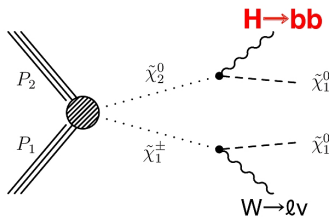
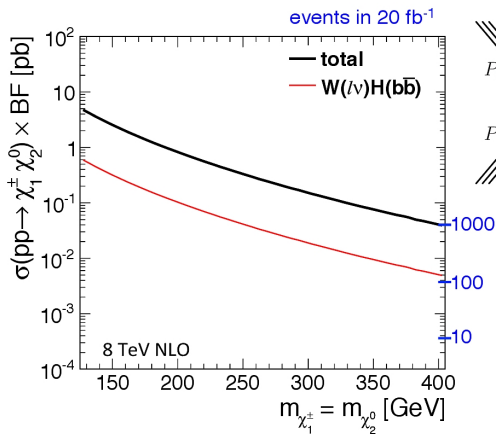
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- **SUS-13-017: Searches with Higgs Bosons**

WH + E_T^{miss} signature

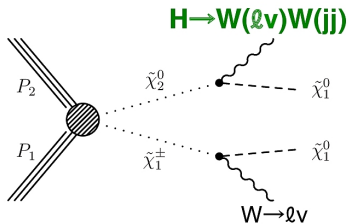
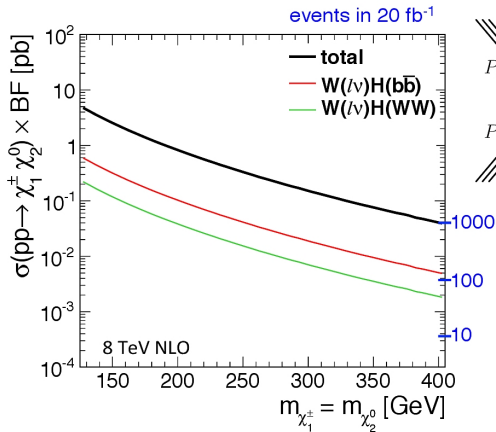


- New / unexplored final state: $WH + E_T^{miss}$
- Novel effort: “**Higgs-tagging**” in SUSY searches

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


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


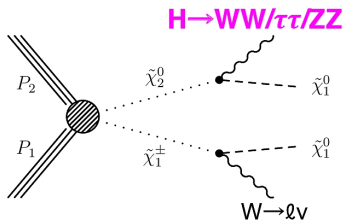
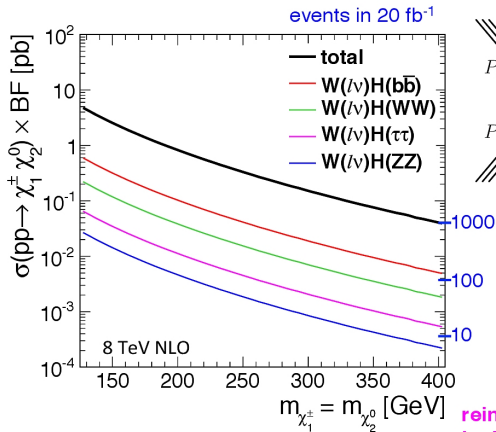
• 1 ℓ **NEW**

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


- 1 ℓ

- SS 2 ℓ



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


- 1 ℓ
 - SS 2 ℓ
 - $\geq 3\ell$
- exclusive:**
combine to
improve
sensitivity

reinterpretation of SUS-13-002
inclusive multilepton SUSY search

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

• Event selection

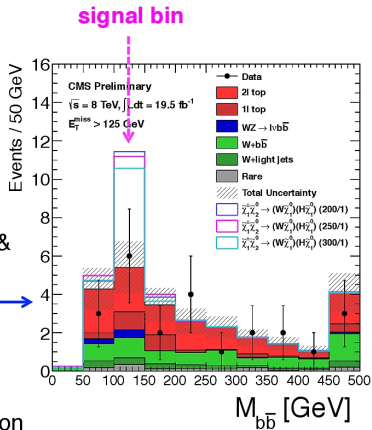
- Exactly 1 high p_T e/μ
- Exactly 2 jets, both b-tagged
- Moderate E_T^{miss}

• 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



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

• Event selection

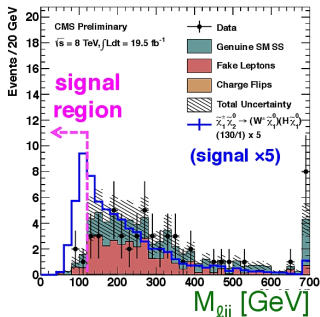
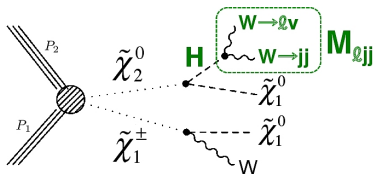
- Exactly 2 SS e/ μ leptons
- 2 or 3 jets, b-veto
- Moderate E_T^{miss}

• 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 $M_{\ell j j} \sim M_H$

• Results

- No evidence for a bump in $M_{\ell j j}$
- Good agreement in signal region



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

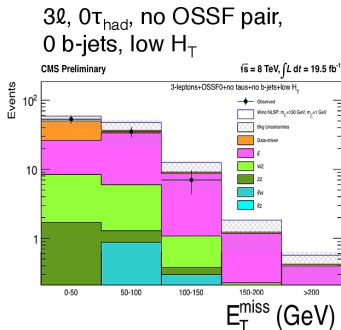
reinterpretation of SUS-13-002: inclusive multileptons

• Event selection

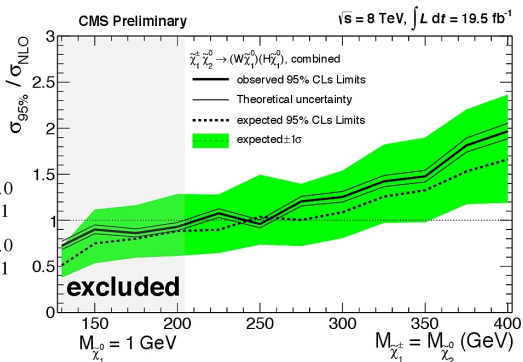
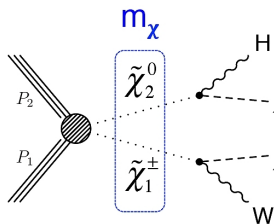
- ≥ 3 leptons, $\leq 1 \tau_{had}$
- Classify events based on number/flavor of leptons, #b-jets, E_T^{miss} , H_T

• Strategy

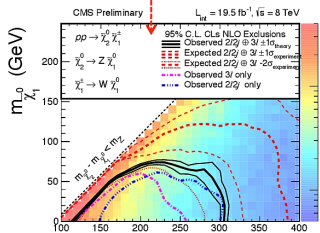
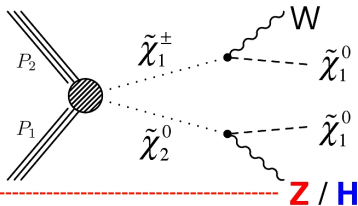
- Extract limits from signal regions with exactly 3ℓ , 0 b-jets, low H_T



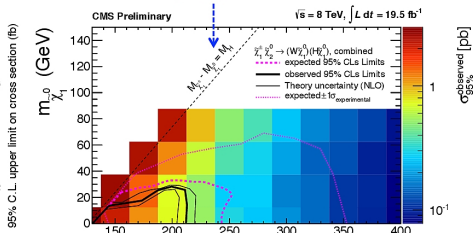
Interpretation



- 1 ℓ best at large m_x , SS 2 ℓ and $\geq 3\ell$ contribute at low m_x (backup)
- **Combine 3 channels \rightarrow probe to $m_x \sim 200 \text{ GeV}$**
- Large improvement in 14 TeV data expected

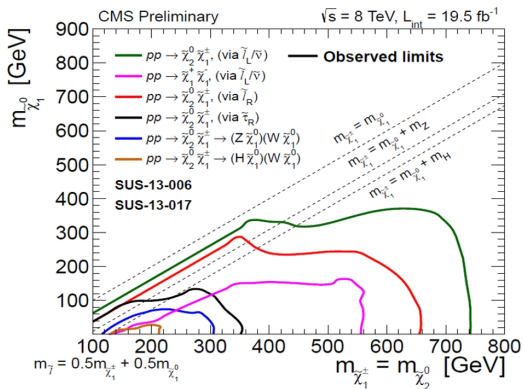
χ_2^0 to $\chi_1^0 + Z/H$


probe up to $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^\pm}$ (GeV)
 $m_{\tilde{\nu}} \sim 300 \text{ GeV}$



probe up to $m_{\tilde{\nu}} \sim 200 \text{ GeV}$

Conclusions



SUS-13-006: decays to Higgs

- probe up to $m_{\tilde{\chi}} \sim 200 \text{ GeV}$

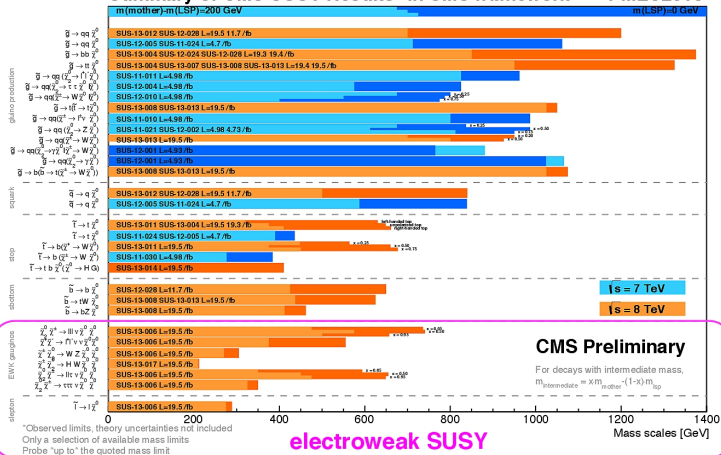
SUS-13-017: leptonic final states

- probe gauginos up to $m_{\tilde{\chi}} \sim 300\text{-}740 \text{ GeV}$
- probe sleptons up to $m_{\tilde{\chi}} \sim 280 \text{ GeV}$

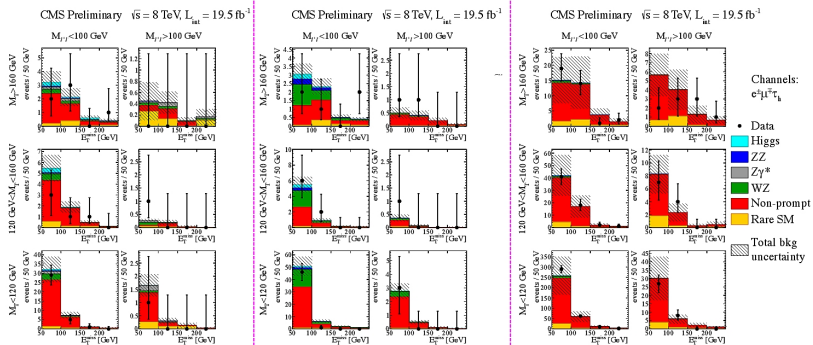
END

CMS SUSY Results

Summary of CMS SUSY Results* in SMS framework PMLC2013

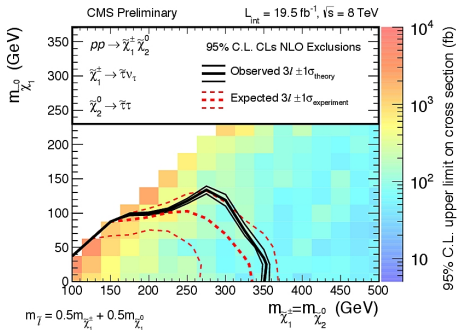
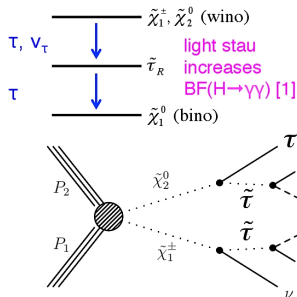


3l Results

3 l , no OSSF pairsame-sign 2 l + τ_{had} opposite-sign $e\mu$ + τ_{had} 

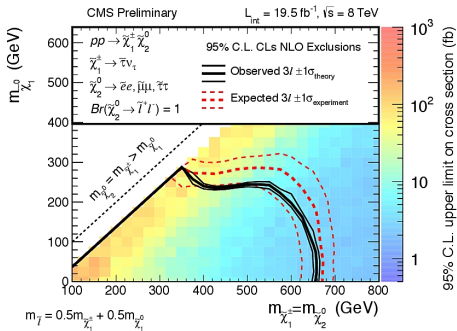
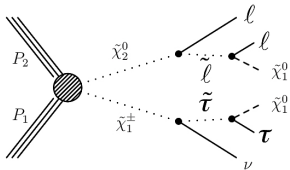
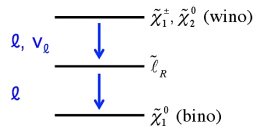
$\chi^\pm \chi^0 \rightarrow 3\tau$ Interpretation

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



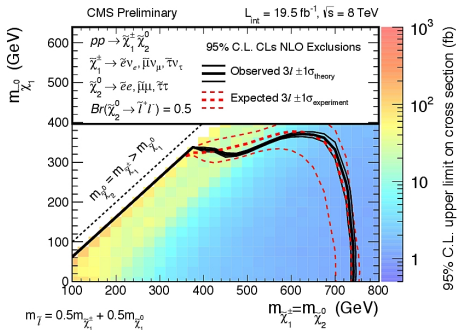
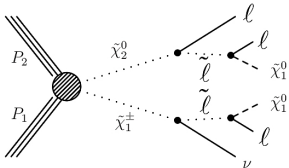
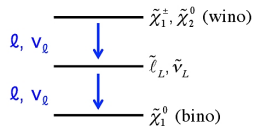
- Assume light right-handed sleptons leading to **3 τ signature**
 - χ^+ couples to ℓ_R through higgsino component: $\chi^\pm \rightarrow \tau\nu$
 - For high $\tan\beta$, χ^0 couples to ℓ_R through higgsino component: $\chi^0 \rightarrow \tau\tau$
- **Results from 3 ℓ analysis probe m_ν up to ~ 340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

$\chi^\pm \chi^0 \rightarrow 2l + \tau$ Interpretation

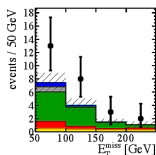


- Assume light right-handed sleptons leading to **$2l + \tau$ signature**
 - χ^+ couples to ℓ_R through higgsino component: $\chi^\pm \rightarrow \tau \nu$
 - For low $\tan \beta$, χ^0 couples to ℓ_R through bino component: $\chi^0 \rightarrow \ell \ell$
- Results from $3l$ analysis probe m_ν up to ~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

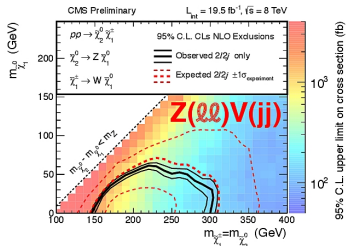
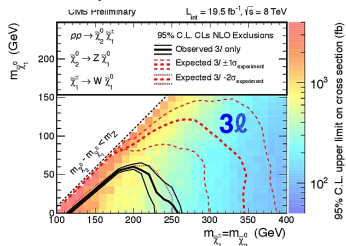
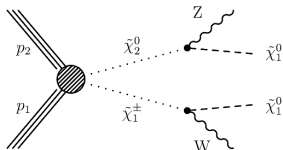
$\chi^\pm \chi^0 \rightarrow 3l$ Interpretation



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

$$\chi^\pm \chi^0 \rightarrow WZ + MET \text{ vs. } Z(\ell\ell)V(jj)$$


3ℓ , no τ_{had} , on-Z, high M_T

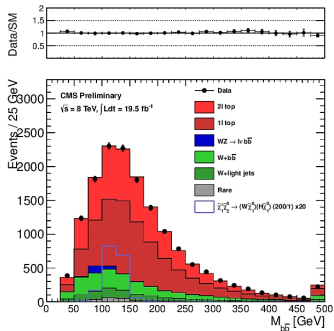


- $\sim 2\sigma$ deviation between 3ℓ observed vs. expected
- Good agreement in $Z(\ell\ell)V(jj)$ channel

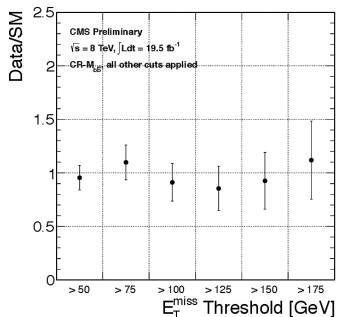
$$\chi^\pm \chi^0 \rightarrow W(l\nu)H(bb) + MET$$

Preselection

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



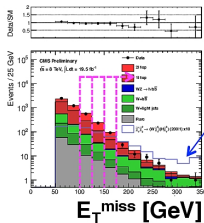
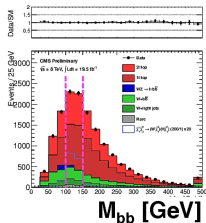
Signal region with M_{bb} mass
 window requirement inverted



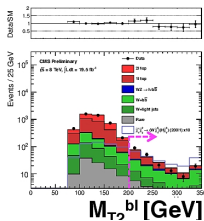
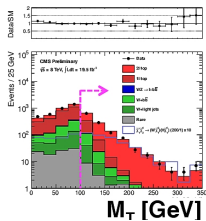
- The M_{bb} shape is well-reproduced in preselection region
- Good agreement in signal region outside the M_{bb} mass window

$$\chi^\pm \chi^0 \rightarrow W(l\nu)H(bb) + MET$$

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



example
signal model
scaled by $\times 10$



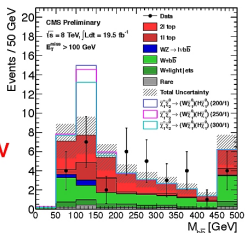
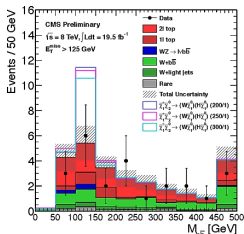
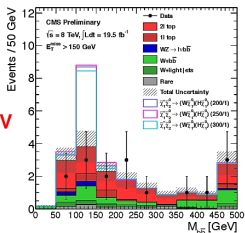
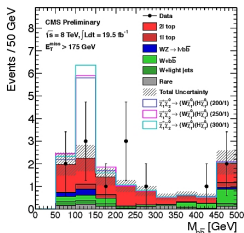
Bai et. al.
JHEP 1207 (2012) 110

$$\chi^\pm \chi^0 \rightarrow W(l\nu)H(bb) + MET$$

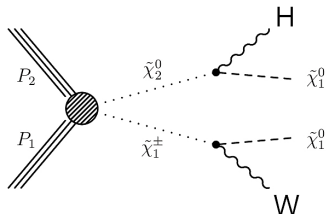
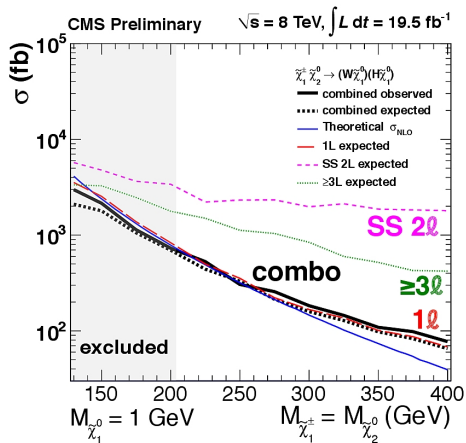
Sample	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 125 \text{ GeV}$	$E_T^{\text{miss}} > 150 \text{ GeV}$	$E_T^{\text{miss}} > 175 \text{ GeV}$
Dilepton top	2.8 ± 1.2	2.3 ± 1.0	1.7 ± 0.7	1.2 ± 0.5
Single lepton top	1.8 ± 1.1	0.9 ± 0.6	0.5 ± 0.3	0.2 ± 0.2
$WZ \rightarrow l\nu b\bar{b}$	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

$$\chi^\pm \chi^0 \rightarrow W(l\nu)H(bb) + MET$$

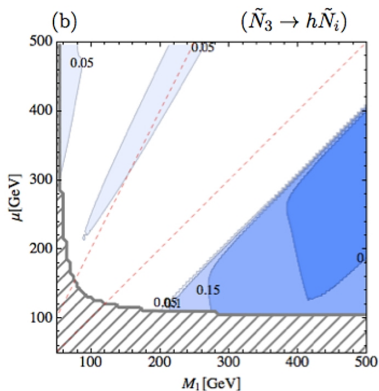
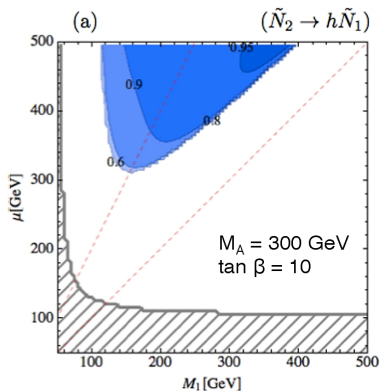
 $E_T^{\text{miss}} > 100 \text{ GeV}$

 $E_T^{\text{miss}} > 125 \text{ GeV}$

 $E_T^{\text{miss}} > 150 \text{ GeV}$

 $E_T^{\text{miss}} > 175 \text{ GeV}$


Interpretation



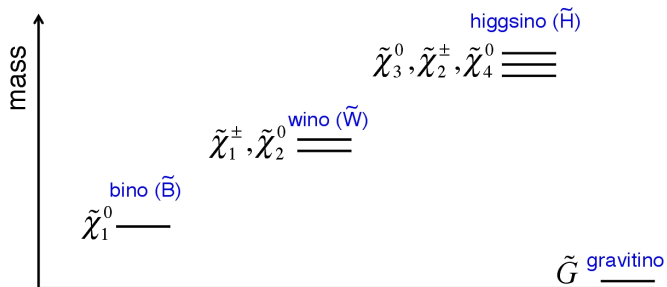
- Probe up to $\sim 200 \text{ GeV}$
- Large sensitivity improvement in 14 TeV data expected

Neutralino decay to Z vs. H



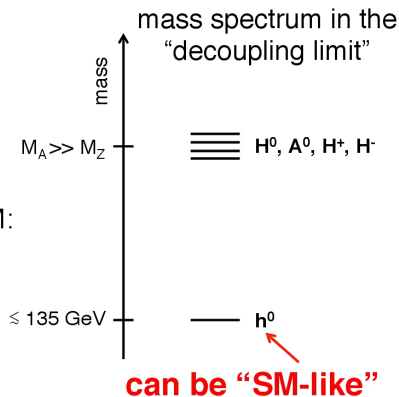
Gori, Schwaller, Wagner
arXiv:1103.4138

EWK SUSY mass spectrum



MSSM Higgs Bosons¹

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



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

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

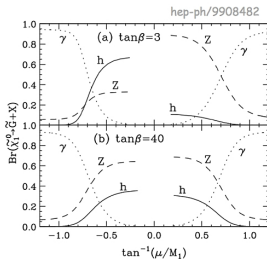
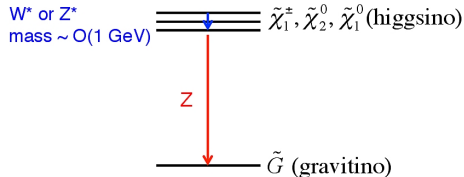
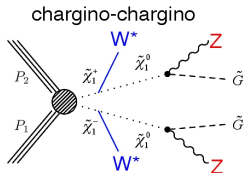
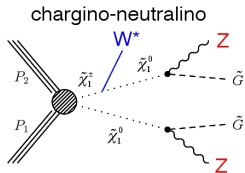
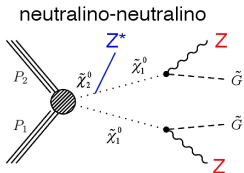


Figure 1: Branching ratios of the lightest neutralino $\text{Br}(\tilde{\chi}_1^0 \rightarrow \tilde{G} + \gamma, h, Z)$ as a function of the neutralino mixing angle $\tan^{-1}(\mu/M_1)$, for a fixed mass $M_{\tilde{\chi}_1^0} = 160 \text{ GeV}$ and $m_h = 105 \text{ GeV}$ for (a) $\tan\beta = 3$ and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



The $M_{CT\perp}$ Variable

- Konstantin Matchev and Myeonghun Park:

- Phys. Rev. Lett. 107, 061801 (2011) (hep-ph:0910.1584)

- for $P \rightarrow VC$, where V - a visible particle:

$$M_{CT}^2 = m^2(V_1) + m^2(V_2)$$

$$+2[E_T(V_1)E_T(V_2) + \mathbf{p}_T(V_1) \cdot \mathbf{p}_T(V_2)]$$

- an endpoint:

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

- if PP are not at rest, use E_T and p_T components normal to \vec{U}_T :

$$\vec{U}_T = -\vec{E}_T^{\text{miss}} - \vec{p}_T(V_1) - \vec{p}_T(V_2)$$

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EPS2013**

