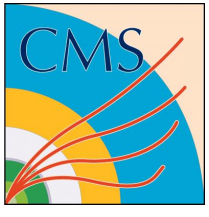
Search for Supersymmetry in States with four W Bosons and multiple B-Quarks at CMS.

Niklas Pietsch on behalf of the CMS collaboration

UHH / DESY

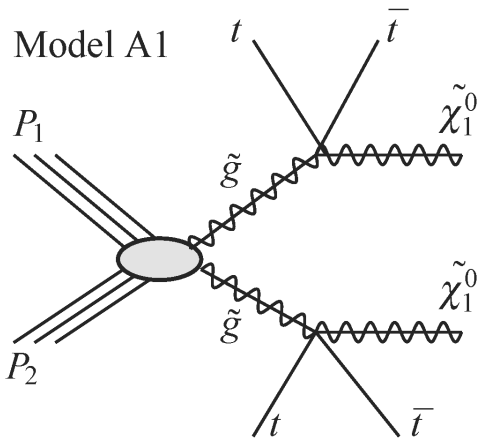
Phenomenology Symposium, Pittsburgh, 6^{th} May 2013

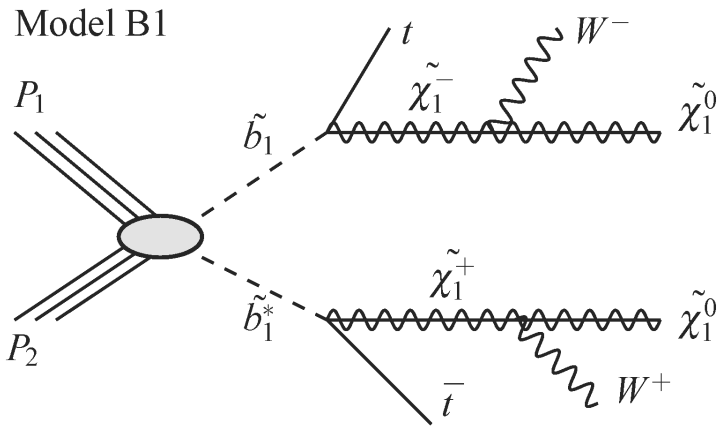


Introduction

- In order for SUSY to be "natural", stop and sbottom quark must not be too heavy $\longrightarrow$ Search for
  - Direct stop pair production ($\rightarrow$ see talk by A. Graziani)
  - Direct sbottom pair production
  - Gluino induced production: $\tilde{g} \rightarrow t\tilde{t}^{*}$, $\tilde{g} \rightarrow b\tilde{b}^{*}$

$\longrightarrow$ May give rise to events with four W bosons and multiple b-quarks





Introduction

- Motivates to search in a variety of final-states classified by the number of leptons originating from the decay of the four W bosons
- In this talk: Focus on leptonic searches
  - Single lepton searches PAS-SUS-13-007
  - Same-sign dilepton search JHEP03(2013)037
  - Search with 3 and more leptons PAS-SUS-12-026
- Not discussed here: All hadronic searches
  - in $\not{E}_T$, H_T, $N_{\text{b-jets}}$ PAS-SUS-12-024
  - in H_T, $N_{\text{b-jets}}$ using α_T arXiv:1303.2985
    ($\rightarrow$ see talk by S. Hewamanage)

Outline

> Single Lepton Searches

> Same-Sign Dilepton Search

> Search with three and more Leptons

> Summary

Single Lepton Searches

Baseline event selection

- **1 isolated muon or electron** with $p_T > 20\,\text{GeV}$ and $|\eta| < 2.4$ (2.5)
- Veto on events with 2^{nd} (looser) lepton
- $\geq$ **6 ak5 jets** with $p_T > 40\,\text{GeV}$ and $|\eta| < 2.4$
- $\geq$ **2 or** $\geq$ **3 b-jets** (identified with a combined secondary-vertex track-based algorithm)
- $\mathbf{H_T > 500\,GeV}$ (scalar sum of the jets p_T)

$\longrightarrow$ Main SM background contains one $W \to l\,\bar{\nu}_l$

$\longrightarrow$ Searches performed in

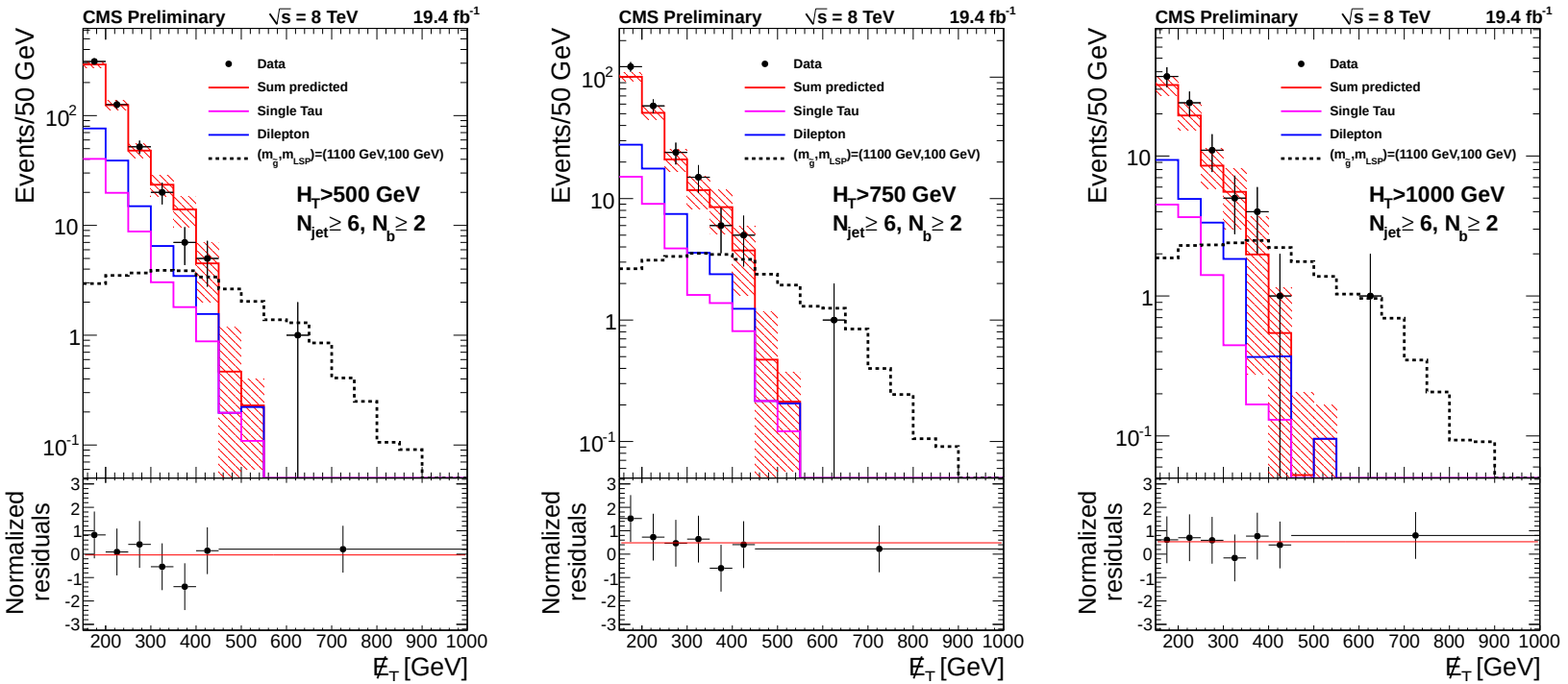
- $\not{E}_T$ and H_T using the Lepton Spectrum Method
- $S_T^{\text{lep}} \equiv \sqrt{p_{T_W}^2 + M_{T_W}^2}$ using the Delta Phi Method

$\longrightarrow$ Complementary as methods examine different kinematic variables

Lepton Spectrum Method

> Uses similarity of lepton and neutrino p_T in $W \to l\,\bar{\nu}_l$ to estimate $\not{E}_T$ distribution from p_T spectrum

PAS-SUS-13-007



Measured and predicted $\not{E}_T$ distribution in different H_T bins.

$\longrightarrow$ No excess in $\mathcal{L} = 19.4\,\text{fb}^{-1}$ observed

Delta Phi Method

PAS-SUS-13-007

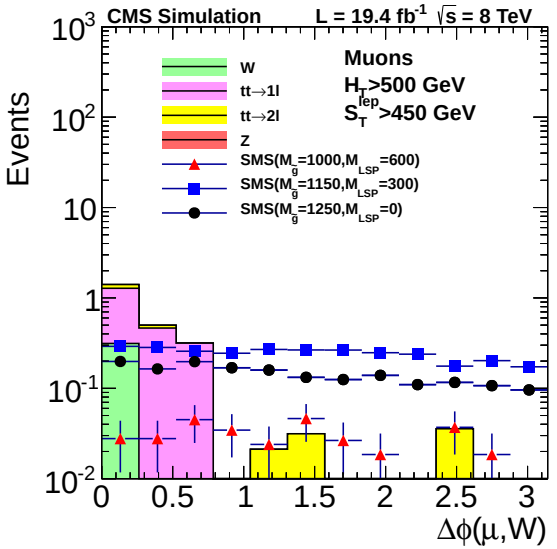
- At large values of $S_T^{\text{lep}} \equiv \sqrt{p_{T_W}^2 + M_{T_W}^2}$ leptonically decaying W in SM events largly boosted $\longrightarrow \Delta\Phi(W, l)$ is small
- Distribtion of $\Delta\Phi(W, l)$ for signal events flat

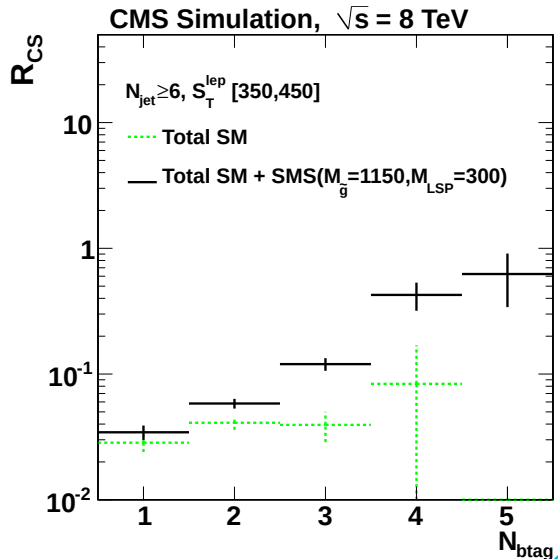
$\longrightarrow$ Define signal region by $\Delta\Phi(W, l) > 1$

Background Estimation

- Ratio R_{CL} of events with $\Delta\Phi(W, l) > 1$ and $\Delta\Phi(W, l) < 1$ and $N_{\text{b-jets}}$ almost uncorrelated

$\longrightarrow$ Use factorization ansatz to predict background in signal region from control regions in data





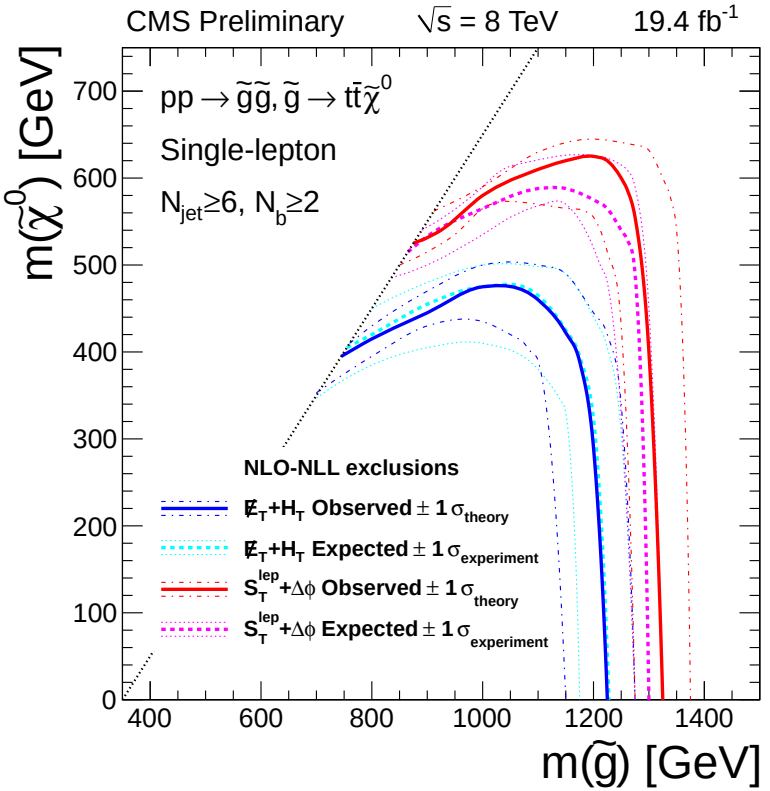
Delta Phi Method / Interpretation

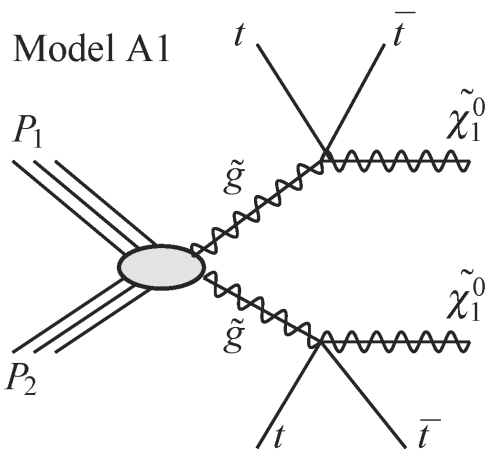
Event yields for $N_{\text{btags}} = 2$ and $N_{\text{btags}} \geqq 3$

		S_T^{lep} [GeV]	control reg. data	prediction	observation
N_b=2	Muons	[250,350]	141	$6.00 \pm 2.40\ (2.23)$	9
		[350,450]	24	$1.37 \pm 1.19\ (1.12)$	2
		>450	9	$0.0 \pm 0.66\ (0.66)$	0
	Electr.	[250,350]	112	$3.83 \pm 1.84\ (1.75)$	9
		[350,450]	28	$2.74 \pm 2.02\ (1.86)$	2
		>450	9	$0.0 \pm 0.42\ (0.42)$	0
$N_b \geq 3$	Muons	[250,350]	28	$1.92 \pm 0.95\ (0.84)$	0
		[350,450]	13	$0.57 \pm 0.58\ (0.52)$	0
		>450	2	$0.0 \pm 0.22\ (0.22)$	0
	Electr.	[250,350]	45	$1.89 \pm 1.03\ (0.94)$	4
		[350,450]	7	$0.85 \pm 0.80\ (0.70)$	0
		>450	0	$0.0 \pm 0.08\ (0.08)$	0

$\longrightarrow$ No excess in $\mathcal{L} = 19.4\,\text{fb}^{-1}$ observed

PAS-SUS-13-007





- Blue: Lepton Spectrum Method
- Red: Delta Phi Method

Outline

Same-Sign Dilepton Search

Baseline event selection

- **Two isolated same-sign leptons** (μ or e) with $m_{ll} > 8\,\text{GeV}$
- Veto on events with 3^{rd} (looser) lepton that contain a same-flavor opposite-sign pair with
  - $m_{ll} < 12\,\text{GeV}$ or
  - $76\,\text{GeV} < m_{ll} < 106\,\text{GeV}$
- $\geq$ **2 b-jets**

Signal regions

- Defined by different N_{Jets}, $\not{E}_T$, and H_T requirements

$\longrightarrow$ Background estimation

1. Fake and non-prompt leptons:
   - Predicted by tight-to-loose-method
   - uncertainty of $\sim 50\%$
2. Charge flips:
   - Estimated from opposite-sign ee or $e\mu$ control sample
   - uncertainty of $\sim 20\%$
3. Rare processes (mostly $t\bar{t}W$, $t\bar{t}Z$):
   - Predicted from simulated events
   - uncertainty of $\sim 50\%$

Same-Sign Dilepton Search

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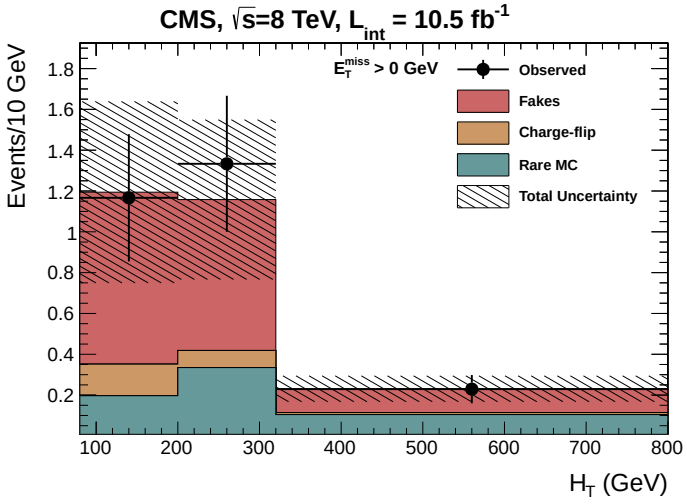
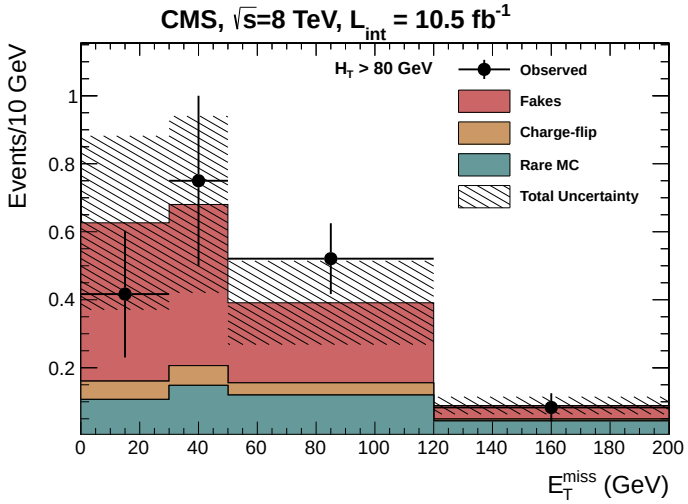
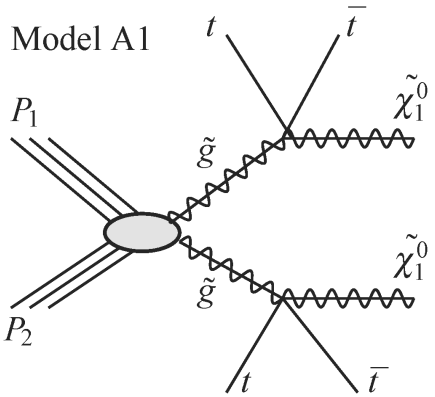


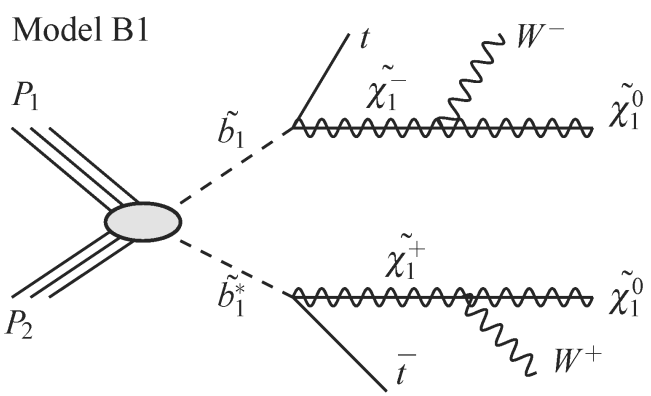


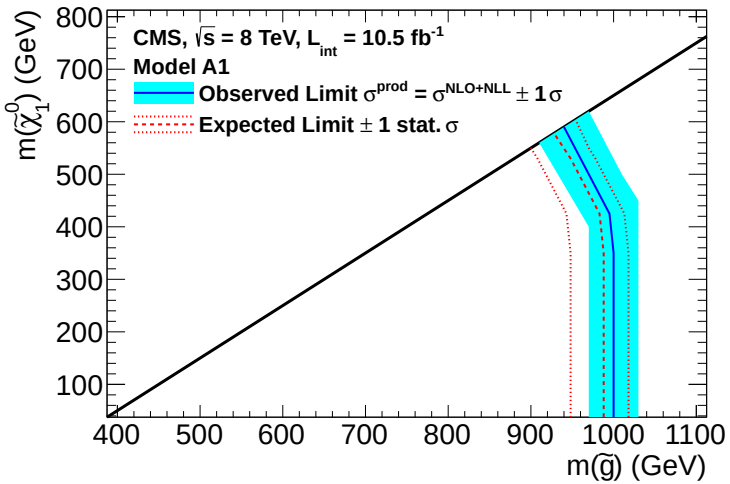
	SR0	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8
No. of jets	≥ 2	≥ 2	≥ 2	≥ 4	≥ 4	≥ 4	≥ 4	≥ 3	≥ 4
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
E_T^{miss}	> 0 GeV	> 30 GeV	> 30 GeV	> 120 GeV	> 50 GeV	> 50 GeV	> 120 GeV	> 50 GeV	> 0 GeV
H_T	> 80 GeV	> 80 GeV	> 80 GeV	> 200 GeV	> 200 GeV	> 320 GeV	> 320 GeV	> 200 GeV	> 320 GeV
Fake BG	25 ± 13	19 ± 10	9.6 ± 5.0	0.99 ± 0.69	4.5 ± 2.9	2.9 ± 1.7	0.7 ± 0.5	0.71 ± 0.47	4.4 ± 2.6
Charge-flip BG	3.4 ± 0.7	2.7 ± 0.5	1.4 ± 0.3	0.04 ± 0.01	0.21 ± 0.05	0.14 ± 0.03	0.04 ± 0.01	0.03 ± 0.01	0.21 ± 0.05
Rare SM BG	11.8 ± 5.9	10.5 ± 5.3	6.7 ± 3.4	1.2 ± 0.7	3.4 ± 1.8	2.7 ± 1.5	1.0 ± 0.6	0.44 ± 0.39	3.5 ± 1.9
Total BG	$\mathbf{40 \pm 14}$	$\mathbf{32 \pm 11}$	$\mathbf{17.7 \pm 6.1}$	$\mathbf{2.2 \pm 1.0}$	$\mathbf{8.1 \pm 3.4}$	$\mathbf{5.7 \pm 2.4}$	$\mathbf{1.7 \pm 0.7}$	$\mathbf{1.2 \pm 0.6}$	$\mathbf{8.1 \pm 3.3}$
Event yield	**43**	**38**	**14**	**1**	**10**	**7**	**1**	**1**	**9**
N_{ul} (13% unc.)	27.2	26.0	9.9	3.6	10.8	8.6	3.6	3.7	9.6
N_{ul} (20% unc.)	28.2	27.2	10.2	3.6	11.2	8.9	3.7	3.8	9.9
N_{ul} (30% unc.)	30.4	29.6	10.7	3.8	12.0	9.6	3.9	4.0	10.5

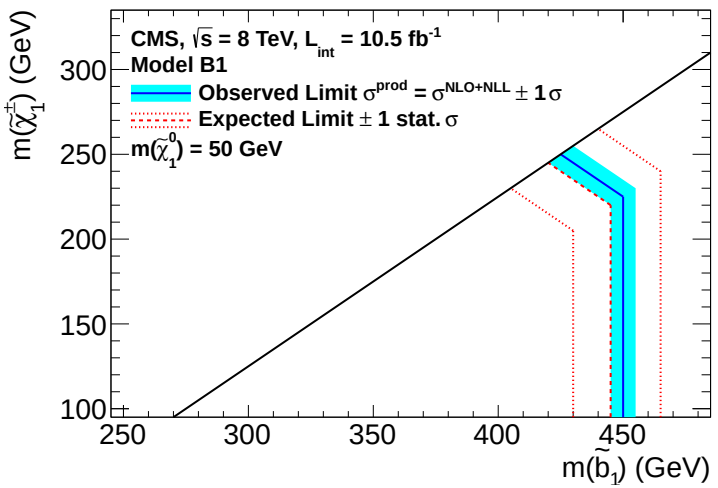
$\longrightarrow$ No excess in $\mathcal{L} = 10.5\,\text{fb}^{-1}$ observed

Same-Sign Dilepton Search









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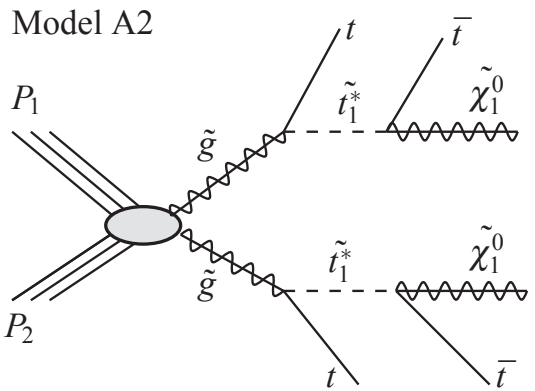
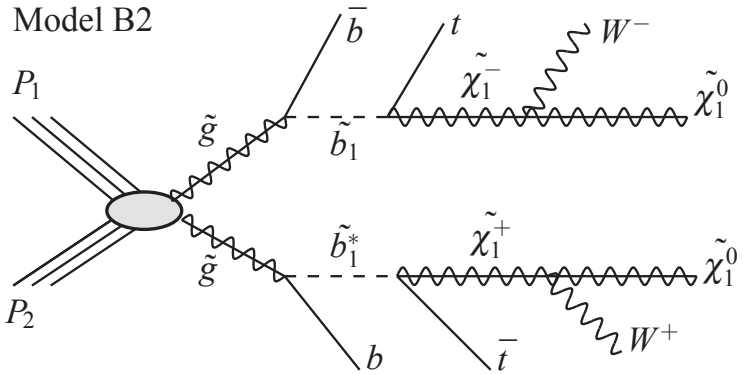
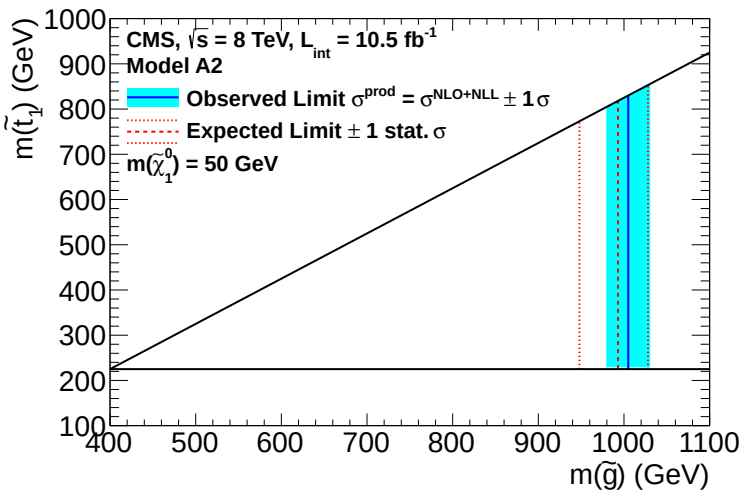
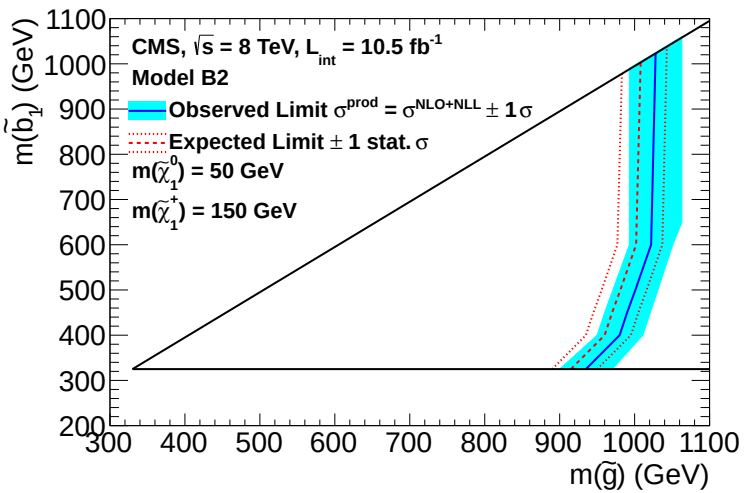
Same-Sign Dilepton Search









$\longrightarrow$ For $m_{\chi_1^0} = 50\,\text{GeV}$ and $m_{\chi_1^0} = 250\,\text{GeV}$
(backup) limit independent of $m_{\tilde{t}_1}$
within considered ranges

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Outline

Search with three and more Leptons

Baseline event selection

- **2 leptons (μ or e) with $p_T > 20$ and $p_T > 10\,\text{GeV}$**
- **1 μ or e with $p_T > 10\,\text{GeV}$ or 1 hadronically decaying τ_h with $p_T > 20\,\text{GeV}$ and $|\eta| < 2.3$**
- Veto on events with more than 1 τ_h

Signal regions

- Defined by different
  - Numbers of leptons, b-jets, taus
  - Numbers of OSSF pairs
  - Z mass constraints
  - $\not{E}_T$ and H_T requirements

$\longrightarrow$ Background estimation

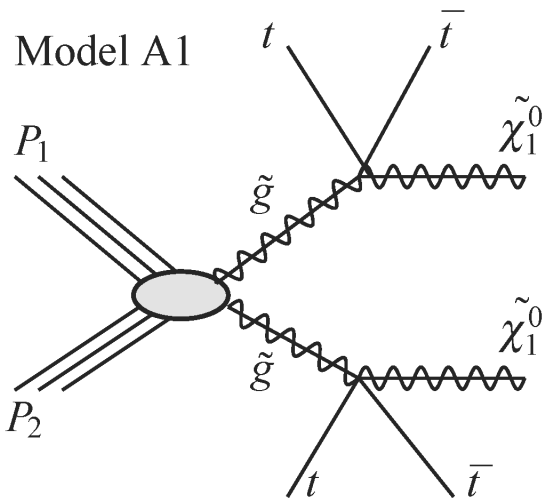
1. Fake and non-prompt leptons:
   - Z+Jets and WW+Jets estimated from data
   - $t\bar{t}$+Jets predicted from simulated events validated in control regions
2. Asymmetric photon conversion:
   - $l^+l^-\gamma$
   - Estimated from data
3. Rare processes:
   - WZ, ZZ, $t\bar{t}W$, $t\bar{t}Z$
   - Predicted from simulated events

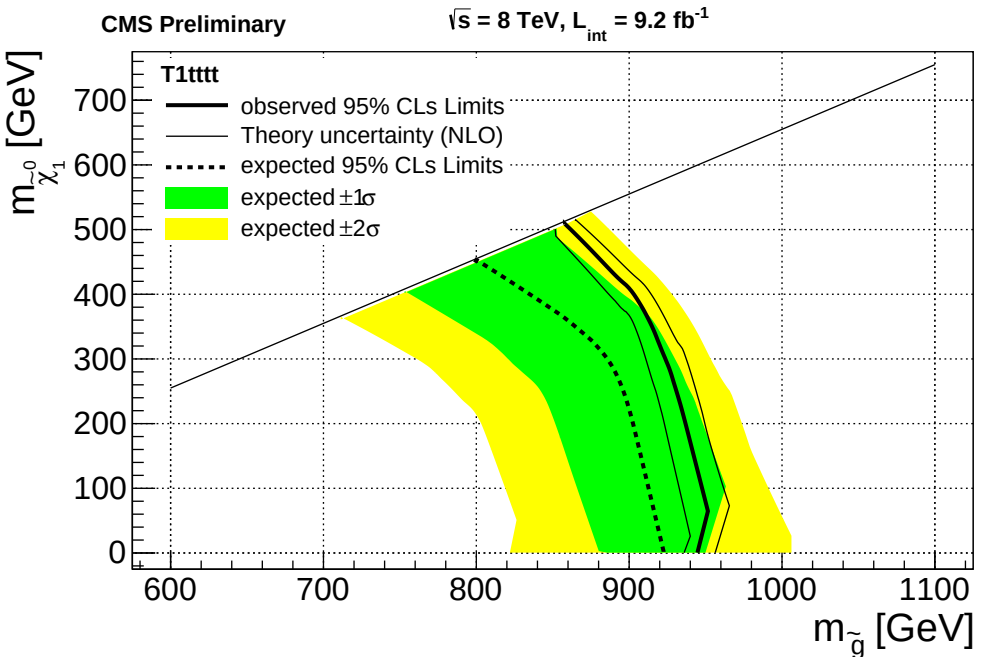
Search with three and more Leptons

PAS-SUS-12-026

Selection		MET	N(τ)=0, NbJet=0 obs	N(τ)=0, NbJet=0 expect	N(τ)=1, NbJet=0 obs	N(τ)=1, NbJet=0 expect	N(τ)=0, NbJet$\geq$1 obs	N(τ)=0, NbJet$\geq$1 expect	N(τ)=1, NbJet$\geq$1 obs	N(τ)=1, NbJet$\geq$1 expect
3 Lepton Results $H_T > 200$										
OSSF0	NA	$(100, \infty)$	1	1.9 ± 1.2	15	7.7 ± 3.6	1	2.9 ± 1.5	27	21 ± 11
OSSF0	NA	$(50, 100)$	1	1.4 ± 0.8	13	17 ± 7.4	1	4.2 ± 1.7	41	37 ± 19
OSSF0	NA	$(0, 50)$	2	1 ± 0.8	13	10 ± 3.4	0	1.9 ± 0.8	32	21 ± 11
OSSF1	above-Z	$(100, \infty)$	2	2.2 ± 0.9	2	4 ± 2.4	3	2.8 ± 1.3	11	6.8 ± 3.7
OSSF1	below-Z	$(100, \infty)$	2	3.5 ± 0.8	8	7.6 ± 3.4	3	3.4 ± 1.6	12	8.3 ± 4.3
OSSF1	on-Z	$(100, \infty)$	17	30 ± 5.3	4	7.9 ± 2.2	5	6.3 ± 1.9	8	5.4 ± 2.8
OSSF1	above-Z	$(50, 100)$	1	1.9 ± 0.49	10	3.7 ± 2.3	4	3.1 ± 1.2	17	12 ± 6.6
OSSF1	below-Z	$(50, 100)$	4	4.5 ± 0.9	11	6.4 ± 2.4	3	5 ± 2.1	9	9.4 ± 5.3
OSSF1	on-Z	$(50, 100)$	39	38 ± 6.2	34	26 ± 5.4	10	9.6 ± 2.7	12	9.5 ± 3.9
OSSF1	above-Z	$(0, 50)$	3	3.2 ± 0.42	19	18 ± 4.5	0	2.7 ± 0.8	6	9.9 ± 4.6
OSSF1	below-Z	$(0, 50)$	9	11 ± 1.2	57	43 ± 10	2	4.7 ± 1.4	11	13 ± 5.3
OSSF1	on-Z	$(0, 50)$	58	63 ± 8.7	256	271 ± 66	12	14 ± 2.6	39	34 ± 7.9

$\longrightarrow$ No excess in $9.2\,\text{fb}^{-1}$ observed





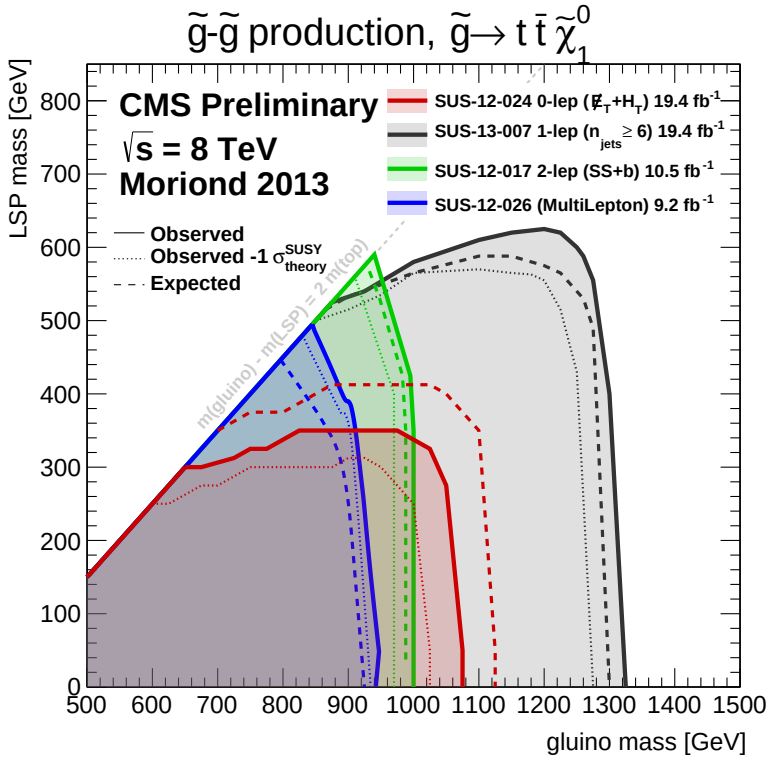
Outline

Summary

- Searches in states with 4 W and multiple b-quarks at CMS using up to $20\,\text{fb}^{-1}$ at $\sqrt{s} = 8\,\text{TeV}$ have been presented
  - Single lepton PAS-SUS-13-007
  - Same-sign dilepton JHEP03(2013)037
  - $\geqq 3$ leptons PAS-SUS-12-026
- No excess has been observed

$\longrightarrow$ Limits set in different simplifed models

- Not discussed here: All hadronic searches
  - in $\not{E}_T$, H_T, $N_{\text{b-jets}}$ PAS-SUS-12-024
  - in H_T, $N_{\text{b-jets}}$ using α_T arXiv:1303.2985



95% CLs limits for $\tilde{g}\tilde{g} \to t\bar{t}t\bar{t}\chi_1^0\chi_1^0$

More information about object and event selection efficiencies at CMS physics results page https:twiki.cern.chtwikibinviewCMSPublicPhysicsResultsSUS

Backup - Single Lepton Searches

PAS-SUS-13-007

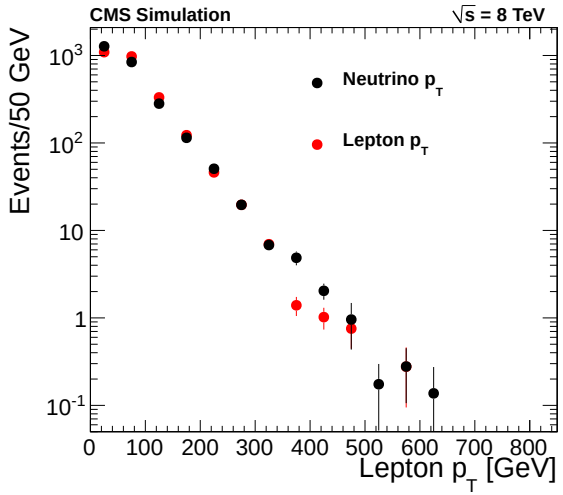
⟶ Use similarity of lepton and neutrino p_T in $W \to l\,\bar{\nu}_l$ to estimate $\not\!\!E_T$ distribution:

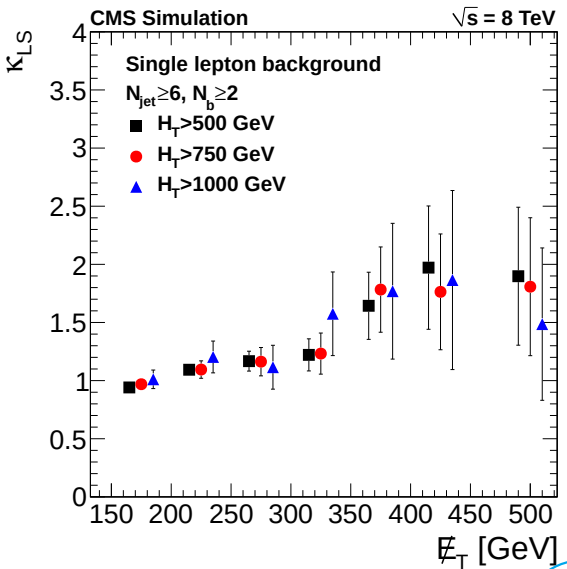
1. Measure lepton p_T spectrum
2. Smear spectrum using $\not\!\!E_T$ resolution template[2] obtained from multijet data sample
3. Apply scale factor[3] κ_{LS} calculated in MC to account for effect of W polarization in $t\bar{t}$ decays

> Other relevant backgrounds

> > $\tau \to l\nu_\tau\bar{\nu}_l$: Emulated in single (μ, e) and dilepton $(\mu\mu, ee, \mu e)$ control samples

> > Dilepton events with lost leptons predicted from similar control sample

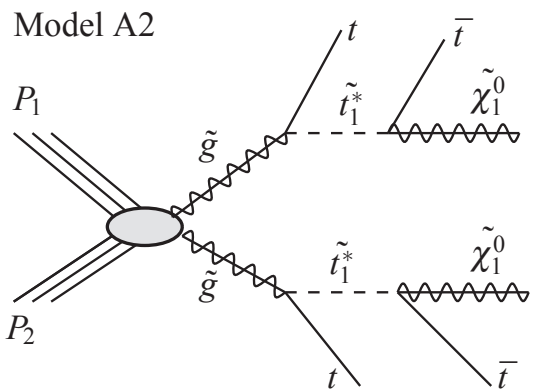


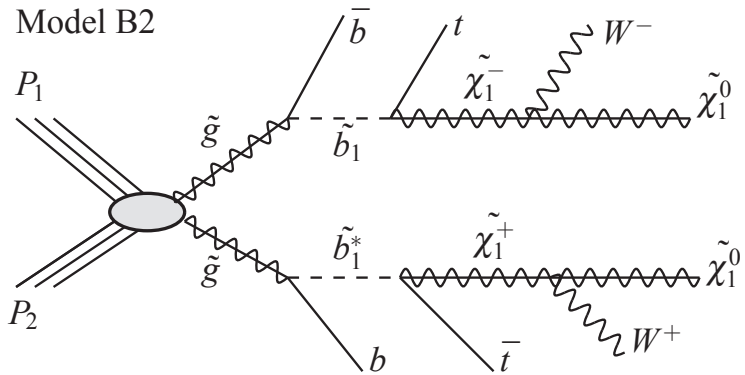


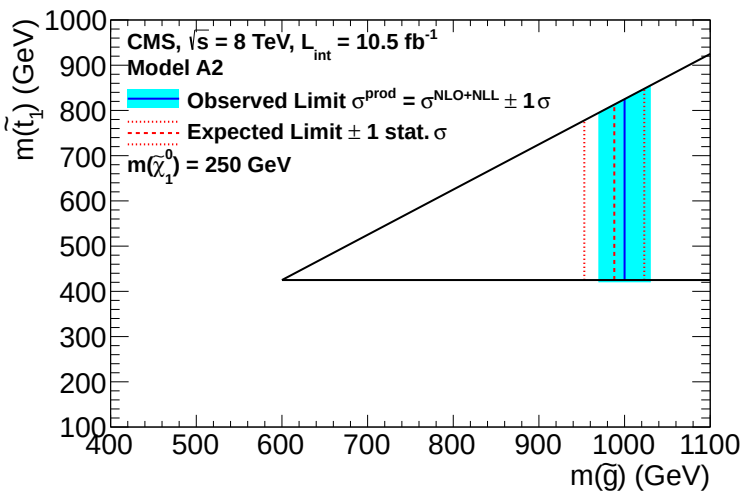
[2] binned in H_T and jet multiplicity

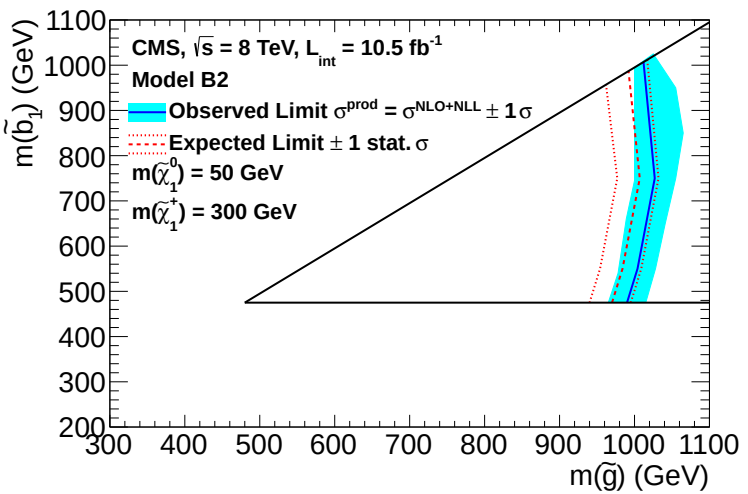
[3] binned in $\not\!\!E_T$

Backup - Same-Sign Dilepton Search









JHEP03(2013)037