Search for supersymmetry in events with one lepton, multiple jets and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV

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on behalf of the CMS Collaboration

Motivation

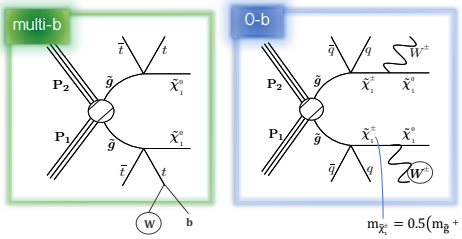
Supersymmetry (SUSY) is a promising extension of the Standard Model (SM) of Particle Physics; the addition of SUSY partners to the SM particles can lead to the suppression of quadratically divergent loop corrections to the mass squared of the Higgs boson, while in SUSY models with R-parity conservation the Lightest SUSY Particle (LSP) can provide a Dark Matter candidate.

Basic Information

CMS PAS SUS-16-042
cds.cern.ch/record/2257294

- SUSY search in **one lepton, multiple jets & missing p_T** final state events
- **35.9 fb^{-1}** of p – p collision data at **13 TeV**, recorded in 2016 by CMS

Signal (SUSY) signatures [$\tilde{g}$ pair production]



⇒ Main Background (SM) processes

- $t\bar{t}$ [semileptonic – through one W]
- W + jets [leptonic]

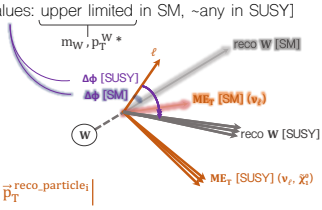
Major discriminating variable

- $\Delta\phi(\vec{p}_T^{\,\ell}, \vec{p}_T^{\,\text{reco W}})$

* $\Delta\varphi_{\text{cut}}$ depends on L_T, ϵ (0.5,1)

Control Region (CR) – low Δφ | Search Region (SR) – high Δφ

[values: upper limited in SM, ~any in SUSY]



Analysis binning

- #jets
- #b-jets
- $L_T \equiv p_T^\ell + ME_T$ *
- $H_T \equiv \sum_i p_T^{\text{jet}_i}$

where $ME_T \equiv |\vec{p}_T^{\,\text{miss}}| \equiv |-\sum_i \vec{p}_T^{\,\text{reco_particle}_i}|$

multi-b 39 bins

n_{jet}	n_b	L_T [GeV]	H_T [GeV]	ΔΦ [rad]
[6,8]	=1; =2	[250,450]	[500,1000] [1000,1500] > 1500	1.0
		[450,600]	[500,1000] [1000,1500] > 1500	0.75
		[600,750]	[500,1000] [1000,1500] > 1500	0.5
		> 750	> 500	0.5
	≥ 3	[250,450]	[500,1000] [1000,1500] > 1500	1.0
		[450,600]	[500,1000] [1000,1500] > 1500	0.75
		> 600	> 500	0.5
≥ 9	=1; =2; ≥ 3	[250,450]	[500,1500] > 1500	1.0
		> 450	[500,1500] > 1500	0.75

0-b 28 bins

n_{jet}	n_b	L_T [GeV]	H_T [GeV]	ΔΦ [rad]
5	0	[250,350]	[500,750] > 750	1.0
		[350,450]	[500,750] > 750	1.0
		[450,650]	[500,750] [750,1250] > 1250	0.75
		> 650	[500,750] [750,1250] > 1250	0.5
[6,7]	0	[250,350]	[500,1000] > 1000	1.0
		[350,450]	[500,1000] > 1000	1.0
		[450,650]	[500,750] [750,1250] > 1250	0.75
		> 650	[500,750] [750,1250] > 1250	0.5
≥ 8	0	[250,350]	[500,1000] > 1000	1.0
		[350,450]	[500,1000] > 1000	1.0
		[450,650]	[500,1250] > 1250	0.75
		> 650	[500,1250] > 1250	0.5

Search regions and minimum Δφ requirements

Trigger Suite & Efficiency

(cross) triggers used:
e, μ : $p_T > 15$ GeV [loosely isolated], jets : $H_T > 350(400)$ GeV

$ME_T > 100$ GeV, 110 GeV, 120 GeV
e : $p_T > 27$ GeV [isolated], $> 105(115)$ GeV, > 50 GeV
μ : $p_T > 24$ GeV [isolated], > 50 GeV

Efficiency: e channel: (98±1)% , μ channel: ≈100%

>Absolute (relat.) isolation: $I^{\ell}_{\text{abs (rel)}} = \left(\frac{1}{p_T^{\ell}}\right) \sum_i p_T^{\text{part}_i : \Delta R(\text{part}_i, \ell) < a}$

Event selection

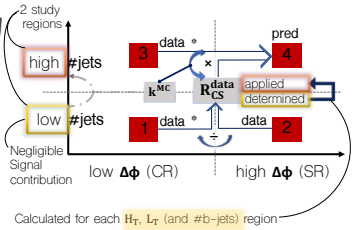
- Single e/μ with $p_T > 25$ GeV, $|\eta| < 2.4$
- Jets with $p_T > 30$ GeV, $|\eta| < 2.4$ [b-tagger: CSVv2]
- #jets ≥ 6 (5), for #b-jets ≥ 1 (=0) in multi-b (0-b) analysis
- $H_T > 500$ GeV
- $L_T > 250$ GeV

An event is accepted if all above conditions are satisfied and none of the ones below (needed to suppress still dominant $t\bar{t} \longrightarrow 2\ell$ background, while not reducing much signal in SR):

- Additional e/μ (looser) with $p_T > 10$ GeV ('veto leptons')
- Hadronic (leptonic) isolated high-p_T tracks with $I_{\text{rel}} < 0.1(0.2)$ for $a = 0.3$ ('iso track veto') and $M_{T2} < 60\ (80)$ GeV, where:

$$M_{T2}(\vec{p}_T^{\,\ell}, \vec{p}_T^{\,t}, \vec{p}_T^{\,\text{miss}}) = \min_{\vec{p}_{T1}+\vec{p}_{T2}=\vec{p}_T^{\,\text{miss}}} \max\{M_{T2}(\vec{p}_T^{\,\ell}, \vec{p}_{T1}), M_{T2}(\vec{p}_T^{\,t}, \vec{p}_{T2})\}$$

Background estimation

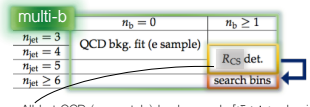


Calculated for each H_T, L_T (and #b-jets) region

* Subtract 'QCD' (multi-jet) [10–15% (negligible) in region 1(4)]

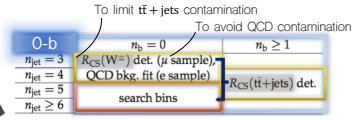
As #b-jets increases, relative contribution from: $t\bar{t}$ + jets increases, W + jets decreases.

Multi-b bins with #b-jets=1 (>1), #jets∈{4,5}:
$t\bar{t}$ + jets: ~80% , W + jets: ~15–20%
($t\bar{t}$ + jets: dominant) ⇒ one R_{CS} in multi-b



All but QCD (separately) backgrounds [$t\bar{t}$ + jets dominates]

0-b bins: $t\bar{t}$ + jets , W + jets: ~equal contribution,
2 low #jets regions ({3,4},{4,5}) ⇒ 2 R_{CS} in 0-b



Rare backgrounds taken from MC, QCD calculated separately

Systematic Uncertainties

Can affect simulation, and therefore k^{MC} (R_{CS}^{MC} / R_{CS}^{MC}) values*

Affecting ...the estimates of the SM processes **Background**

Source	multi-b: Uncertainty for multi-b [%]	0-b: Uncertainty for zero-b [%]
Dilepton control sample	0.9–7.0	0.3–18
JES	0.3–18	0.7–26
Tagging of b-jets	0.1–3.0	0.7–3.0
σ(W+jets)	0.3–9.3	0.3–10
$\sigma(t\bar{t})$	0.1–7.5	0.7–13
$\sigma(t\bar{t}V)$	0.2–20	0.1–3.8
W polarization	0.1–3.3	0.7–13.8
nISR reweighting	0.5–7.0	0.2–11
Pileup	0.4–7.1	0.1–19.6
Statistical uncertainty in MC events	5–30	5.2–35.9

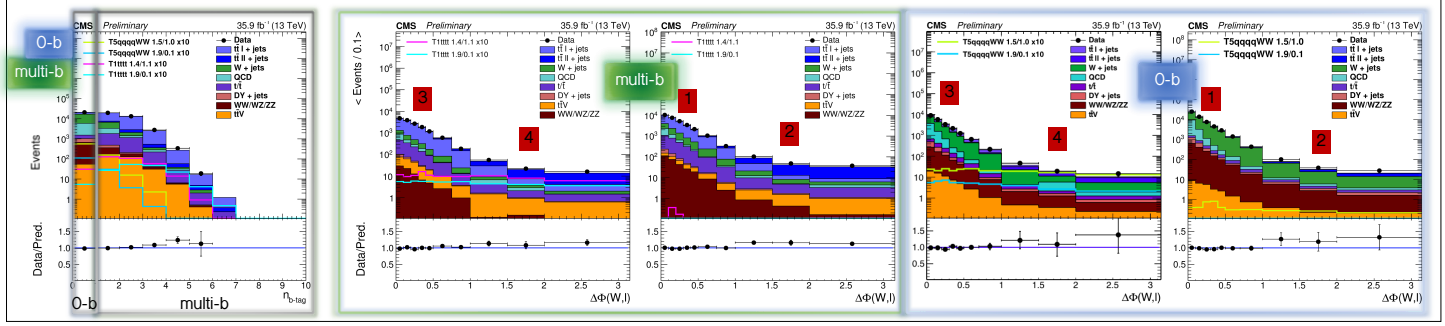
- Main SU arises from the extrapolation of R_{CS}: low #jets → high #jets (calculation → application)
- 1ℓ $t\bar{t}$ + jets : dominant in CR / 2ℓ $t\bar{t}$ + jets : dominant in SR
  * (a good description of the above ratio as a function of #jets is important)

...the expected **Signal** yields
[typical values, similar for multi-b, 0-b)]

Source	Uncertainty [%]
Trigger	2
Pileup	10
Lepton efficiency	2
Isolated track veto	4
Luminosity	2.6
ISR	2–25
Tagging of b-jets (heavy flavors)	1–6
Tagging of b-jets (light flavors)	1–4
JES	3–40
Factorization/renormalization scale	1–3
E_T^{miss}	2–20

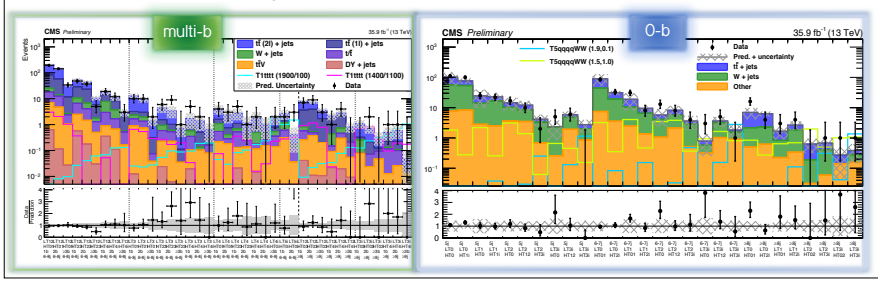
...both

Distributions



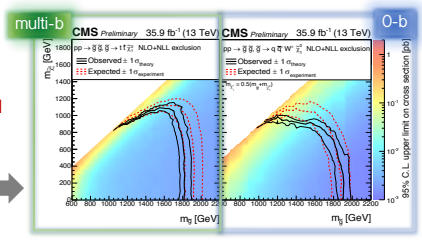
Results

Background estimates & data observed



⇒ No significant excess observed

Exclusion limits



In multi-b (0-b) model: $m_{\tilde{g}} \leq 1.8\ (1.9)$ TeV excluded for $m_{\tilde{\chi}_1^0} \leq 0.8\ (0.3)$ TeV
$m_{\tilde{\chi}_1^0} \leq 1.1\ (0.95)$ TeV excluded for $m_{\tilde{g}} \leq 1.7\ (1.2)$ TeV

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