Searches for supersymmetry in final states with photons in CMS

Pheno 2018

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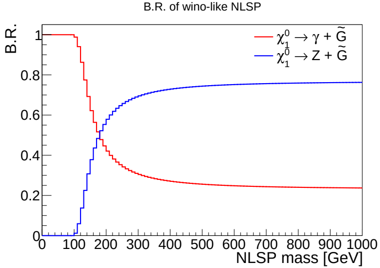
Photon final states in Supersymmetry

One possible scenario: Gauge-mediated supersymmetry breaking

Gauge-mediated SUSY breaking

- virtually massless (stable) $\tilde{G}$ as LSP
- $\tilde{\chi}_1^0$ as NLSP
- NLSP is Bino-like: high probability for $\tilde{\chi}_1^0 \rightarrow \tilde{G} + \gamma$



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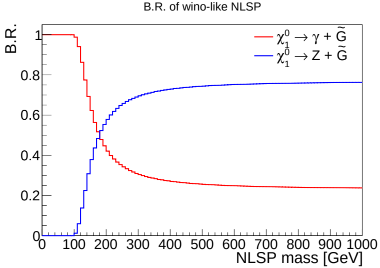
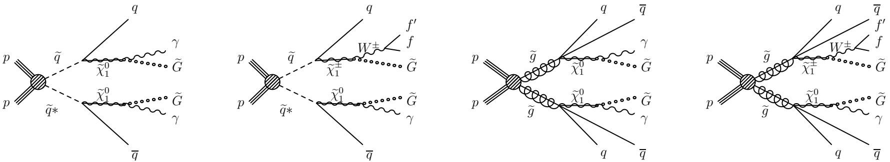


Public results with photons at 13 TeV

CADI-label	Signature	Journal	Data set	
SUS-15-012	$\gamma\gamma$	Phys. Lett. B 769 (2017) 391	2015	
SUS-16-012	$\mathrm{H} \rightarrow \gamma\gamma$ + Razor	PAS	2015	
SUS-16-023	$\gamma + S_T^\gamma$	PAS	2015	
SUS-16-045	$\mathrm{H} \rightarrow \gamma\gamma$ + Razor	Phys. Lett. B 779 (2018) 166	2016	
SUS-16-046	$\gamma + S_T^\gamma$	**Phys. Lett. B 780 (2018) 118**	**2016**	(2)
SUS-16-047	$\gamma + H_T^\gamma$	**JHEP 12 (2017) 142**	**2016**	(1)

Focus on strong production, high-p_T jets



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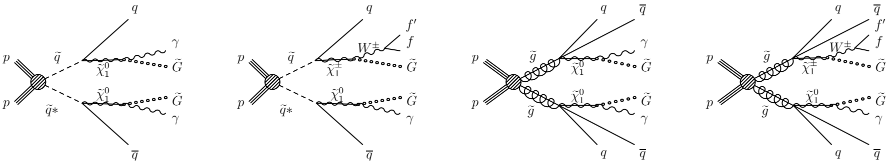
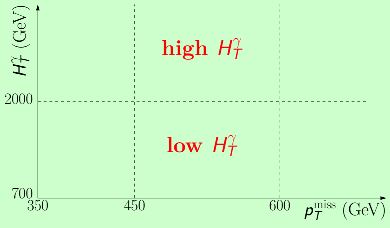


Event Selection

- $\geq 1\gamma$, $p_T^\gamma > 100$ GeV, $|\eta| < 1.4$
- $p_T^{\text{miss}} > 350$ GeV
- $H_T^\gamma > 700$ GeV
- $|\Delta\phi(p_T^{\text{miss}}, \gamma)| > 0.3$

$$H_T^\gamma = p_T^\gamma + \sum_{\text{jets}} p_T$$

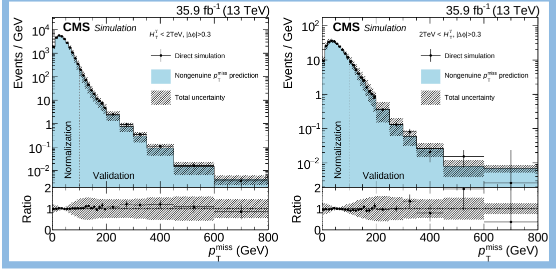
Signal regions



SUS-16-047 ($\gamma + H_T^\gamma$): Backgrounds

γ+jets

- multijet events are similar, $\sigma_E(\gamma) << \sigma_E(\text{jet})$
- Select multijet events with $p_T^{\text{miss}} < 100\,\text{GeV}$
- Rescale p_T^{miss} of multijet events so their spectrum matches with γ+jet spectrum (χ^2 fit)
- Scale factor 0.9 (0.84) for high (low) H_T^γ
- Systematic uncertainty from deviation from unity



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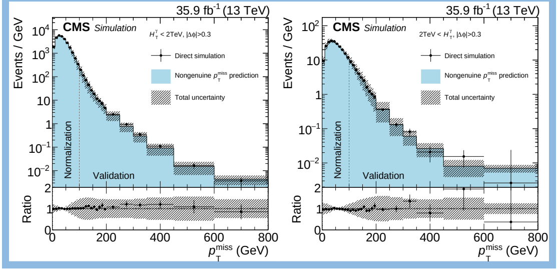

$e \to \gamma$

- Tag-and-probe method
- $f_{e\to\gamma} = 2.7\,\%$
- 30 % systematic uncertainty

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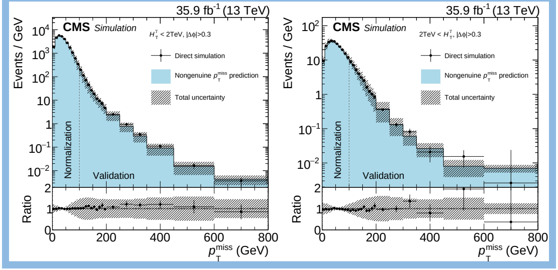

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γW, γZ, $\gamma t\bar{t}$

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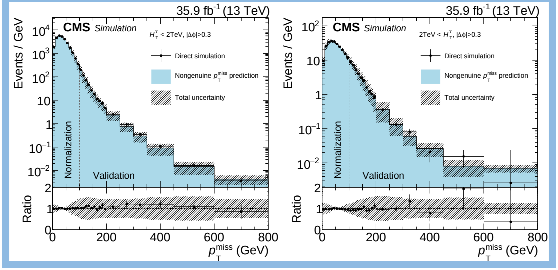

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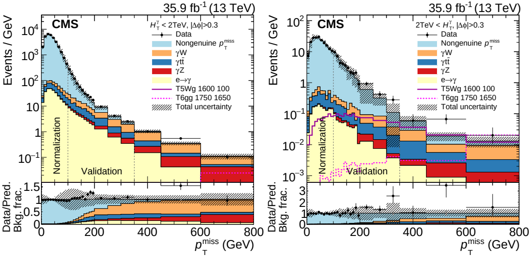
$\gamma\mathrm{W}$, $\gamma\mathrm{Z}$, $\gamma\mathrm{t}\bar{\mathrm{t}}$

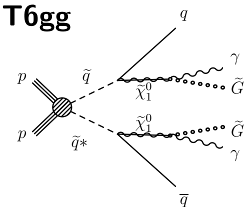
- Estimated from simulation

Probe full prediction in two exclusive validation regions:

- $1.4 < |\eta_\gamma| < 2.4$
- $100 < p_T^{\text{miss}} < 350\,\text{GeV}$

SUS-16-047 ($\gamma + H_T^\gamma$): Results+Interpretation

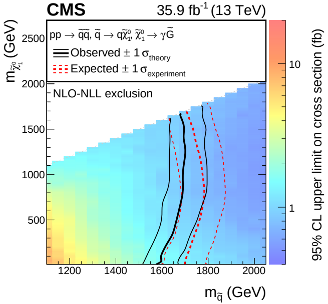


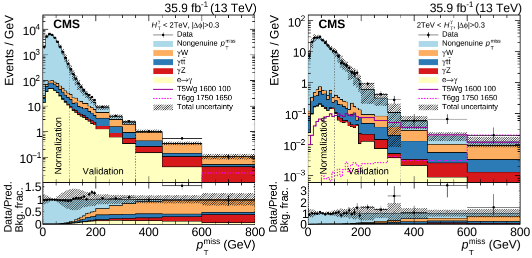


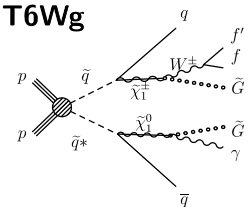
- Deviations in medium p_T^{miss} bins
- Not compatible with new physics models
- 1.9 and 2.7 σ significance
- Considered fluctuations, set limits

Limits:

- T6gg: up to $m_{\tilde{q}} > 1650\,\text{GeV}$







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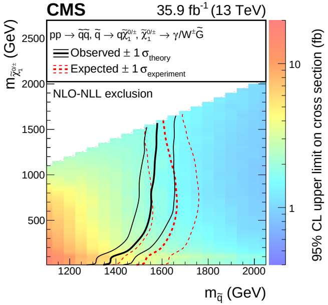

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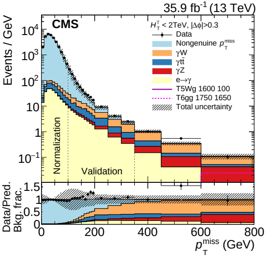
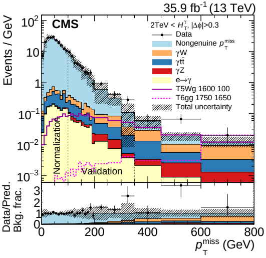
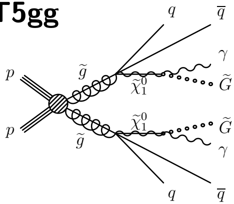




T5gg



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Limits:

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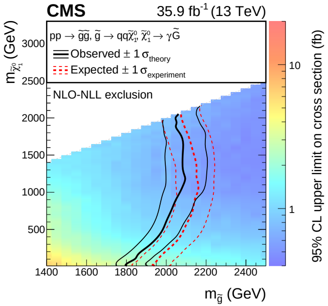
- T5gg: up to $m_{\tilde{\text{g}}} > 2000\,\text{GeV}$



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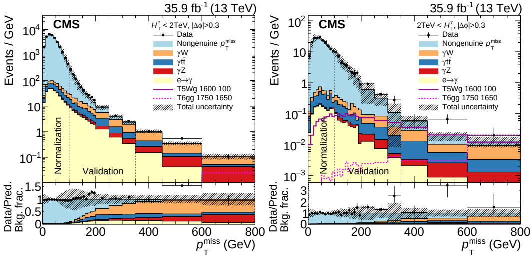

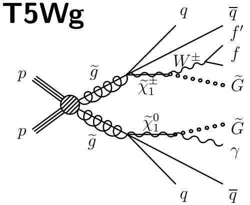

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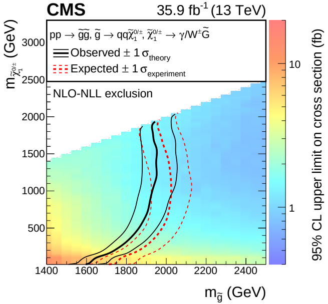
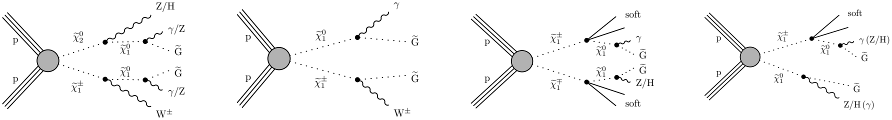


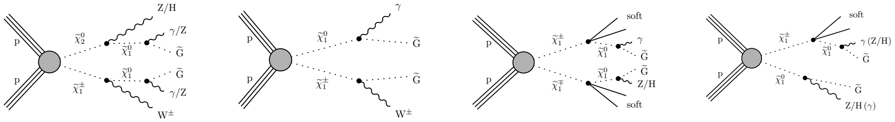
Very inclusive search, no requirement on leptons, jets, H_T



Also sensitive for strong production (as for previous analysis) in compressed scenarios

SUS-16-046 ($\gamma + S_T^\gamma$)

Very inclusive search, no requirement on leptons, jets, H_T



Also sensitive for strong production (as for previous analysis) in compressed scenarios

Event selection

- $\geq 1\gamma$, $p_T^\gamma > 180$ GeV
- $\Delta R(\gamma, \text{nearest jet}) > 0.5$
- If $p_T^{\text{jet}} > 100$ GeV: $\Delta\phi(\text{jet}, p_T^{\text{miss}}) > 0.3$

Control region

$p_T^{\text{miss}} > 100$ GeV, $M_T(\gamma, p_T^{\text{miss}}) > 100$ GeV
Veto SR

$S_T^\gamma = \sum_{\gamma_i} p_{T,i} + p_T^{\text{miss}}$

Signal regions

- $p_T^{\text{miss}} > 300$ GeV
- $M_T(\gamma, p_T^{\text{miss}}) > 300$ GeV
- $S_T^\gamma > 600$ GeV

counting experiment in 4 bins of S_T^γ

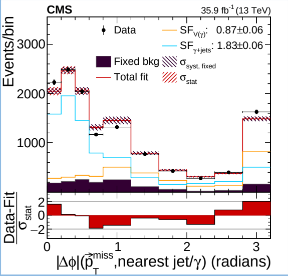
Validation region

Signal region, but $S_T^\gamma < 600$ GeV

SUS-16-046 ($\gamma + S_T^{\gamma}$): Backgrounds

γ+jets and Vγ

- Simultaneous fit of MC to data in control region
- χ^2 fit on template variable $\Delta\phi(p_T^{\text{miss}}$, nearest jet or $\gamma)$
- Other backgrounds and total scale fixed
- Additional uncertainties on shape



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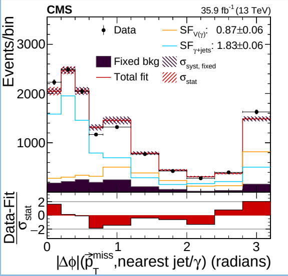

$e \rightarrow \gamma$

- tag-and-probe method
- $f_{e\rightarrow\gamma} = 2.7\,\%$
- $50\,\%$ uncertainty

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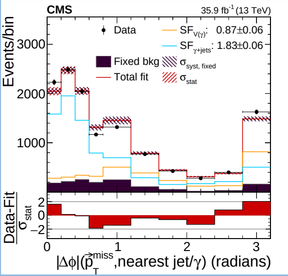

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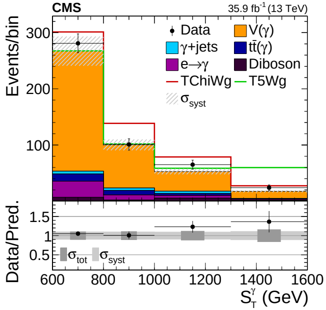
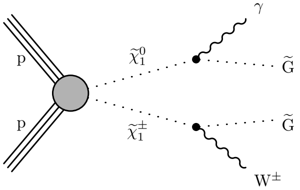
$t\bar{t}\gamma$

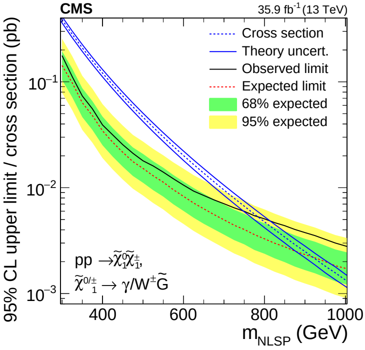
- Simulation without further scaling

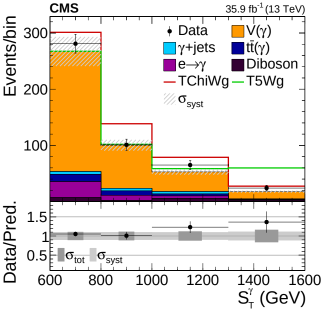
SUS-16-046 ($\gamma + S_T^\gamma$): Results and Interpretation

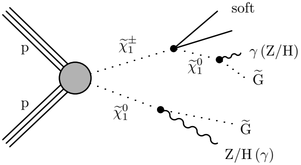




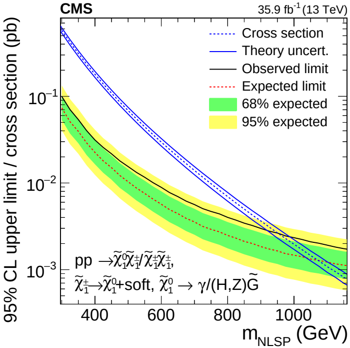
TChiWg

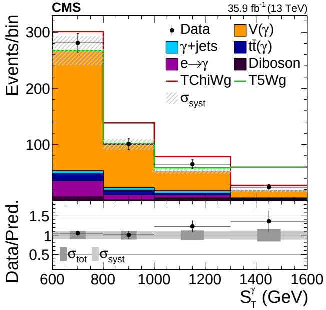


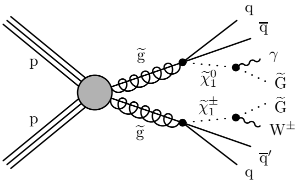

CMS
35.9 fb-1 (13 TeV)
Events/bin
Data
V(γ)
γ+jets
tt̄(γ)
e→γ
Diboson
TChiWg
T5Wg
σsyst
Data/Pred.
σtot
σsyst
600
800
1000
1200
1400
1600
S_T^γ (GeV)


p
p
soft
γ (Z/H)
G̃
G̃
Z/H (γ)

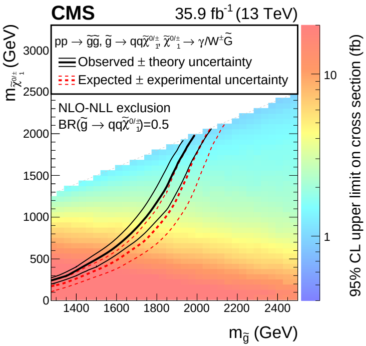
TChiNg


CMS
35.9 fb-1 (13 TeV)
95% CL upper limit / cross section (pb)
Cross section
Theory uncert.
Observed limit
Expected limit
68% expected
95% expected
m_NLSP (GeV)





T5Wg



Limits on more models (General gauge mediation+strong production)

Summary and outlook

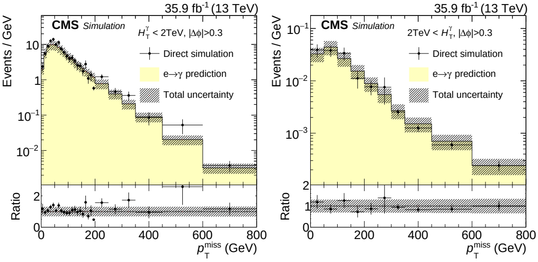
- Presented two searches for SUSY in final states with photons
- Signals motivated by gauge mediated SUSY breaking
- $\gamma + H_T^\gamma$: Focus on strong production
- $\gamma + S_T^\gamma$: Inclusive search, sensitive also to EWK production

What's next?

- Search for SUSY in $\ell\gamma$ final states with 2016 data set approved
- Search for SUSY in $\gamma\gamma$ final states with 2016 data set seeking approval for summer conferences
- Combination of SUSY photon searches for different GMSB models expected for summer conferences

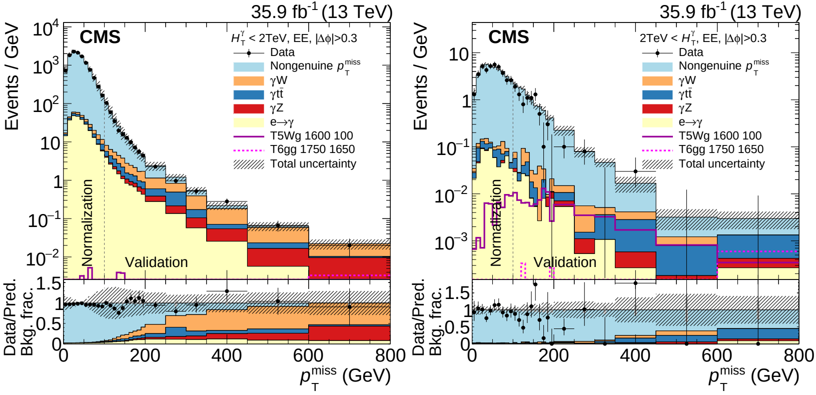
BACKUP

$\gamma + H_T^\gamma$: $\mathrm{e} \to \gamma$



- Photon CR: Photon candidate has pixel seeds
- Sample dominated by $Z \to \mathrm{ee}$ events
- For higher p_T^{miss} values, dominated by W production
- Uncertainty accounts for differences in misreconstruction at high $p_T^{miss}$and H_T^γ values

$\gamma + H_T^\gamma$: Validation



$\gamma + H_T^\gamma$: Systematic uncertainties

Source	Relative uncertainty (%) background	signal
Nongenuine p_T^{miss}	14–250	
$e \to \gamma$	30	
Integrated luminosity	2.5	2.5
Photon scale factors	2	2
Trigger	4	4
PDFs	5–10	
Renormalization/factorization scales	16–27	0–1
Jet energy scale and resolution	2–20	1–6
Pileup	0.2–6	0.2–10
ISR		0–10
Fast simulation p_T^{miss} modelling		0.5–6

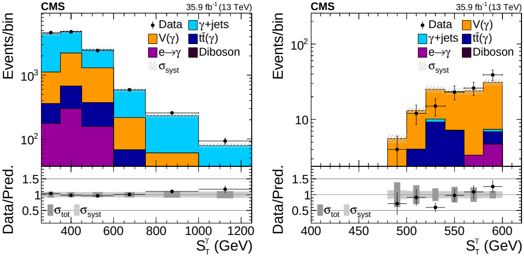
Table 2. Systematic uncertainties for background determined from control samples in data (first two rows) and simulation (all other rows). If two values are given, the first one is for simulated SM backgrounds, while the latter is for simulated signal. The PDF and scale uncertainties for the signal simulation affect the shape only, as the uncertainty in the rate is already considered in the overall cross section uncertainty [35].

$\gamma + H_T^\gamma$: Results

H_T^γ (GeV)	<2000			>2000		
p_T^{miss} (GeV)	(350, 450)	(450, 600)	>600	(350, 450)	(450, 600)	>600
Nongenuine p_T^{miss}	$9.6\,^{+\,11.1}_{-\,9.6}$	$2.2\,^{+\,5.5}_{-\,2.2}$	< 0.1	2.83 ± 2.51	1.31 ± 0.74	$0.73\,^{+\,0.86}_{-\,0.73}$
γW	51.3 ± 9.7	29.1 ± 5.5	11.6 ± 2.5	1.58 ± 0.58	0.70 ± 0.37	1.23 ± 0.43
$\gamma t\bar{t}$	17.1 ± 5.4	5.6 ± 2.6	1.9 ± 0.4	0.97 ± 0.38	0.45 ± 0.29	0.40 ± 0.22
γZ	11.5 ± 2.4	9.7 ± 1.8	7.1 ± 1.4	0.12 ± 0.07	0.25 ± 0.11	0.21 ± 0.10
$e \to \gamma$	15.1 ± 4.6	6.3 ± 1.9	1.4 ± 0.5	0.21 ± 0.10	0.13 ± 0.07	0.05 ± 0.04
Total bkg.	104.6 ± 16.5	53.0 ± 8.6	22.0 ± 3.0	5.72 ± 2.60	2.84 ± 0.89	2.62 ± 0.99
Data	103	82	21	6	10	4
T5Wg 1600 100	0.4 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	3.66 ± 0.40	3.09 ± 0.40	2.41 ± 0.32
T6gg 1750 1650	0.5 ± 0.1	0.8 ± 0.1	4.9 ± 0.4	0.31 ± 0.04	0.46 ± 0.07	4.12 ± 0.32

Table 1. Observed data compared to the background prediction and the expected signal yields for two signal scenarios. The expectations are given for the T5Wg signal scenario with a gluino mass of 1600 GeV and a gaugino mass of 100 GeV and the T6gg signal scenario with a squark mass of 1750 GeV and a neutralino mass of 1650 GeV. The quadratic sum of statistical and systematical uncertainties is given. Only experimental uncertainties for the signal model are stated.

$\gamma + S_T^\gamma$: Fit+Validation



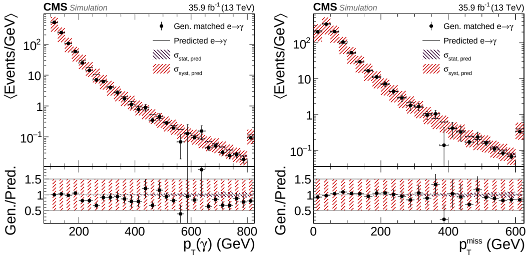
left: control region, right: validation region

Scale factors:

$V\gamma < 1$ because of electroweak corrections for high $\gamma - p_T$

$\gamma +$ jets > 1 because no k-factor applied and QCD corrections

Signal contamination: Light gauginos because similarity to $V\gamma$



Similar to other analysis, study also nonresonant background in $e\mu$

Dependency in η_γ, p_T^γ and other variables leads to uncertainty

$\gamma + S_T^{\gamma}$: Systematic uncertainties

Table 2
Systematic uncertainties in the background prediction in percent.

	V(γ)	γ + jets	e $\rightarrow \gamma$	$t\bar{t}(\gamma)$	Diboson
Fit uncert. of statistical origin	6.9	3.3	–	–	–
Scale uncertainty in shape	3.8–9.0	2.8–7.1	–	–	–
PDF uncertainty in shape	1.6–3.8	1.9–8.2	–	–	–
JES uncertainty in shape	5.0–5.9	0.9–32	–	–	–
Tag-and-probe fit	–	–	50	–	–
Cross section, PDF, scales	–	–	–	30	30
Integrated luminosity	–	–	–	2.5	2.5
Photon eff. scale factor	–	–	–	2.0	2.0
Trigger efficiency	–	–	–	0.4	0.4

Table 3
Systematic uncertainties in the signal predictions in percent.

Source	Signal scenario	
	EWK	Strong production
Statistical MC precision per signal region	1–28	2–50
Fast simulation uncertainty in p_T^{miss}	<0.1–5	<0.1–25
Scale uncertainty in shape	<0.1–1.8	<0.1–1.2
Integrated luminosity	2.5	2.5
Trigger efficiency	0.4	0.4
Photon scale factor	2.0	2.0
Pileup	<0.1–0.4	<0.1–2.1
ISR reweighting	0.6–3.0	–

$\gamma + S_T^\gamma$: Results

Table 4
Background and data yields, as well as the statistical and systematic uncertainties for the separate signal region bins. For the total background uncertainty the uncertainties of the individual background components are summed quadratically.

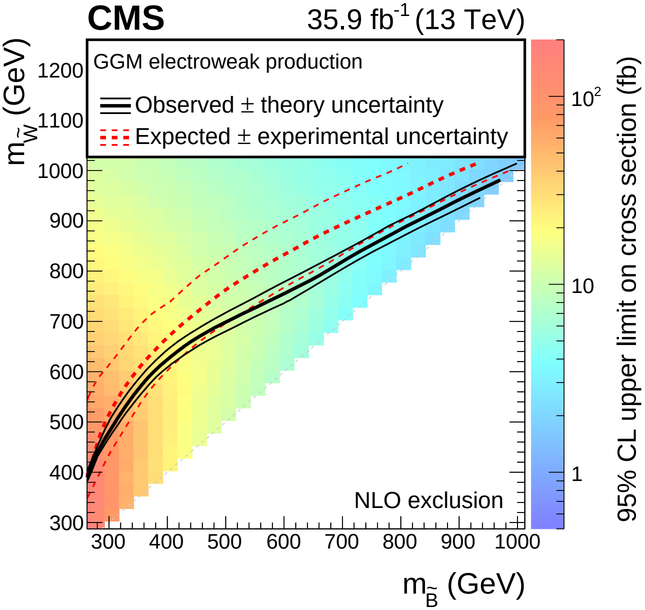
S_T^γ: 600–800 GeV	Yield	σ_{stat}	σ_{syst}
V(γ)	213	4.4	21.3
γ + jets	5	1.1	0.5
$t\bar{t}(\gamma)$	13	5.7	3.9
$e \to \gamma$	29	0.9	14.2
Diboson	7	2.8	2.1
Total	267	7.9	26.0
Data	281		

S_T^γ: 800–1000 GeV	Yield	σ_{stat}	σ_{syst}
V(γ)	76.8	1.9	8.1
γ + jets	4.4	1.2	0.4
$t\bar{t}(\gamma)$	8.0	3.8	2.4
$e \to \gamma$	9.2	0.5	4.6
Diboson	1.9	1.7	0.6
Total	100.2	4.7	9.7
Data	101		

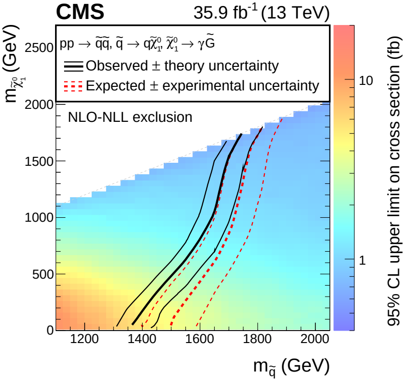
S_T^γ: 1000–1300 GeV	Yield	σ_{stat}	σ_{syst}
V(γ)	35.0	1.3	3.9
γ + jets	4.2	1.3	0.4
$t\bar{t}(\gamma)$	3.5	0.9	1.1
$e \to \gamma$	4.7	0.4	2.3
Diboson	5.4	3.0	1.6
Total	52.8	3.6	5.0
Data	65		

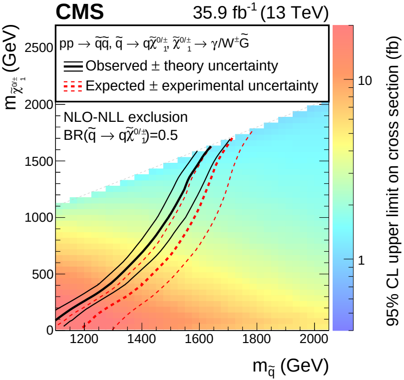
S_T^γ: >1300 GeV	Yield	σ_{stat}	σ_{syst}
V(γ)	12.6	0.7	1.6
γ + jets	1.1	0.5	0.4
$t\bar{t}(\gamma)$	0.7	0.5	0.2
$e \to \gamma$	1.5	0.2	0.8
Diboson	1.7	1.7	0.5
Total	17.6	2.0	1.9
Data	24		

$\gamma + S_T^{\gamma}$: GGM



$\gamma + S_T^\gamma$: T6gg/T6Wg





$\gamma + S_T^\gamma$: T5gg/T5Wg