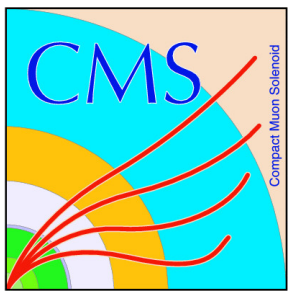
Search for supersymmetry in events with photons and missing transverse momentum

Johannes Schulz
on behalf of the CMS collaboration

RWTH Aachen University

July 5, 2016
SUSY 2016 Conference, Melbourne



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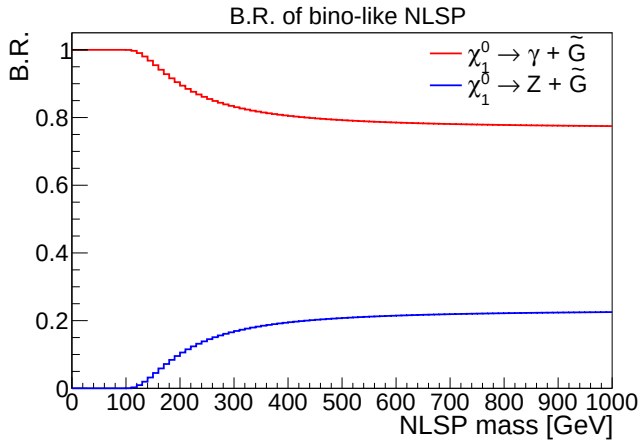
Motivation and Overview

$\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$ final states well motivated in **Gauge Mediated Supersymmetry breaking** (GMSB) SUSY scenarios

- Gravitino $\widetilde{G}$ (essentially massless) is LSP
- $\widetilde{\chi}_1^0$ is NLSP and promptly decaying
- Esp. **bino** NLSPs decay with high probability to $\gamma+\widetilde{G}$
- **R-Parity conservation** $\rightarrow$ stable LSPs lead to $E_{\mathrm{T}}^{\mathrm{miss}}$
- If strong production $\rightarrow$ high jet activity



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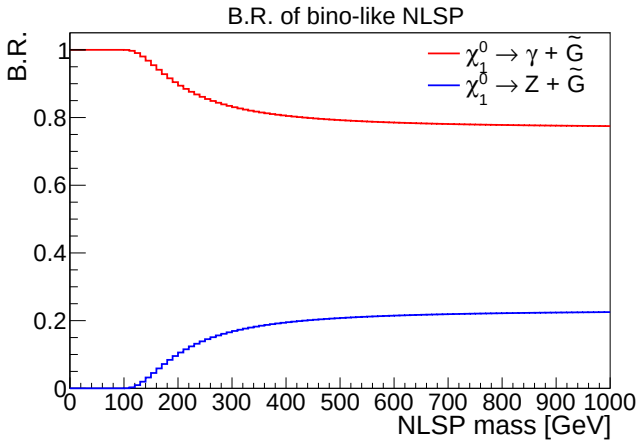

Public photon results:

Reference	Title	Journal (Date)
SUS-15-012	**Search for supersymmetry in events with photons and missing transverse energy**	**PAS** (***April 2016***)
SUS-14-016	**Search for supersymmetry in electroweak production with photons and large missing transverse energy in pp collisions at $\sqrt{s} = 8$ TeV**	**PLB 759 (2016)** (***28 February 2016***)
SUS-14-017	Search for SUSY with Higgs in the diphoton final state using the razor variables	PAS (*August 2015*)
SUS-14-013	Search for supersymmetry in events with a photon, a lepton, and missing transverse momentum in pp collisions at $\sqrt{s} = 8$ TeV	PLB 757 (2016) 6 (*5 August 2015*)
SUS-14-004	Search for supersymmetry with photons in pp collisions at $\sqrt{s} = 8$ TeV	PRD 92 (2015) 072006 (*10 July 2015*)
SUS-14-009	Search for stealth supersymmetry in events with jets, either photons or leptons, and low missing transverse momentum in pp collisions at 8 TeV	PLB 743 (2015) 503 (*26 November 2014*)

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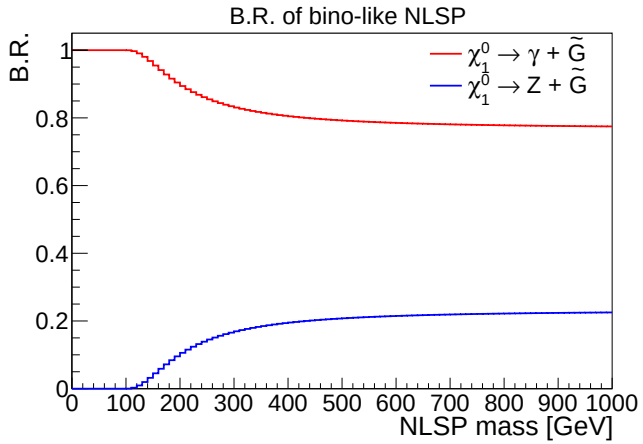
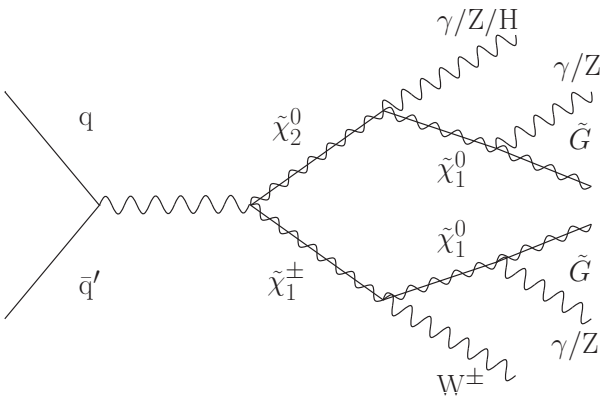


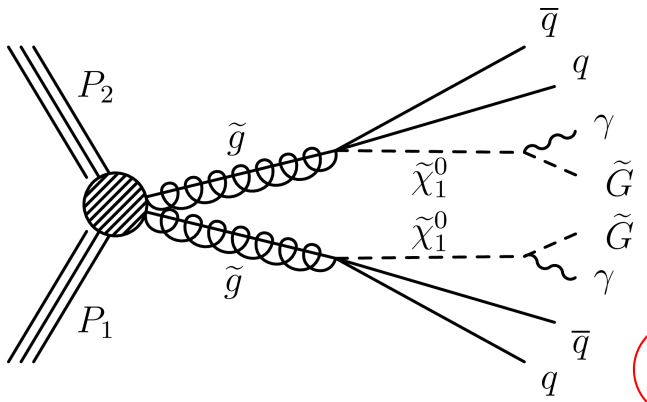
Single Photon (CMS-SUS-14-016)



1

electroweak production
$\geq 1\ \gamma + E_{\mathrm{T}}^{\mathrm{miss}}$
8 TeV

Diphoton (CMS-PAS-SUS-15-012)



2

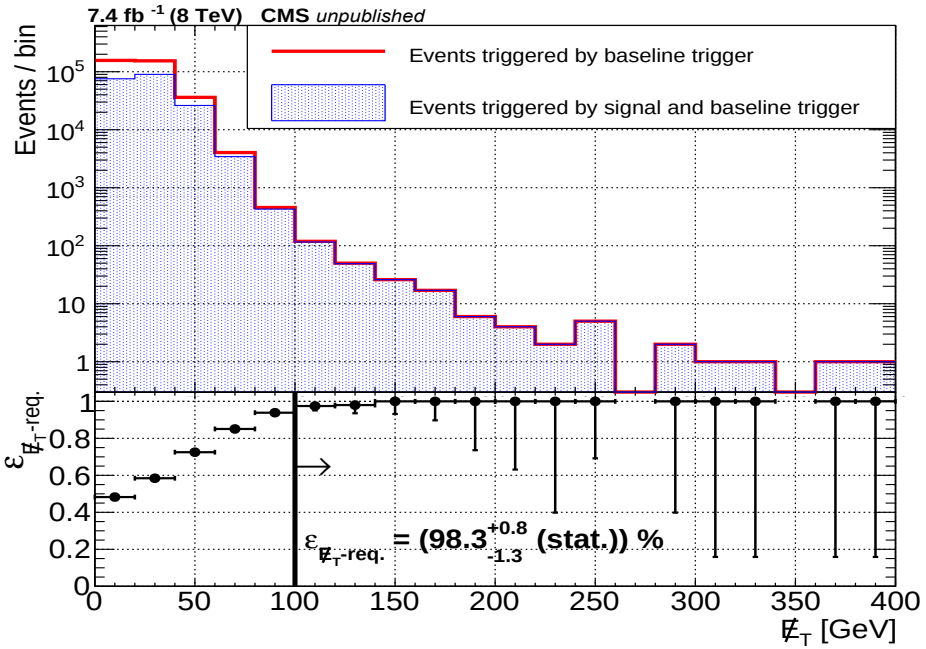
strong production
$\geq 2\ \gamma + E_{\mathrm{T}}^{\mathrm{miss}}$
13 TeV

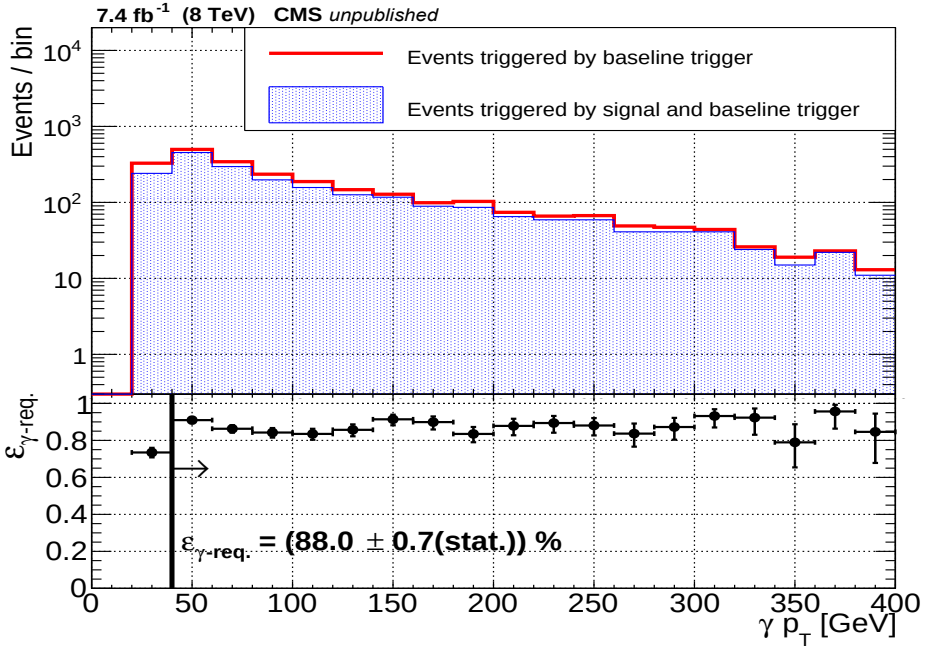
Single Photon ∼ "Parked Data"

"Parked Data":

- significantly lower trigger thresholds, reconstructed after data taking in 2012
- $\int \mathcal{L}\, dt = 7.4\ \text{fb}^{-1}$, $\sqrt{s} = 8$ TeV
- **Signal** trigger: isolated γ with $p_T > 30$ GeV + $E_T^{miss} > 25$ GeV
- Baseline triggers: isolated γ with $p_T > 30$ GeV, $E_T^{miss} > 100$ GeV
- $\varepsilon_{trigger} = \varepsilon_{E_T^{miss}\text{-req.}} \cdot \varepsilon_{\gamma\text{-req.}} = (86.5^{+1.0}_{-1.3}(stat.))$ %

→ Higher sensitivity to **electroweak production** and **small mass differences** of the lightest gauginos





Single Photon $\sim$ Selection

- **Preselection:**
  - $\geq 1\ \gamma$ with $p_T > 40$ GeV
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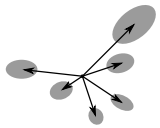
  - $E_T^{miss,signif} > 80$

E_T^{miss} significance:



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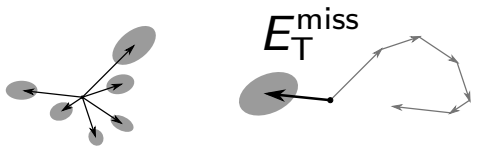

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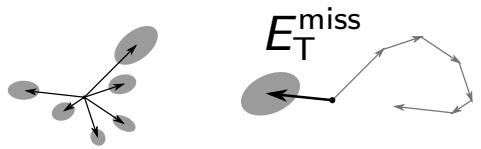

low $E_T^{miss,signif}$ high $E_T^{miss,signif}$

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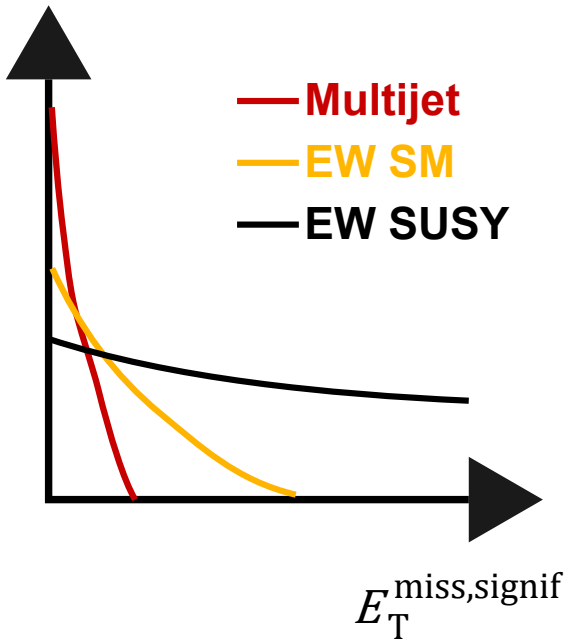

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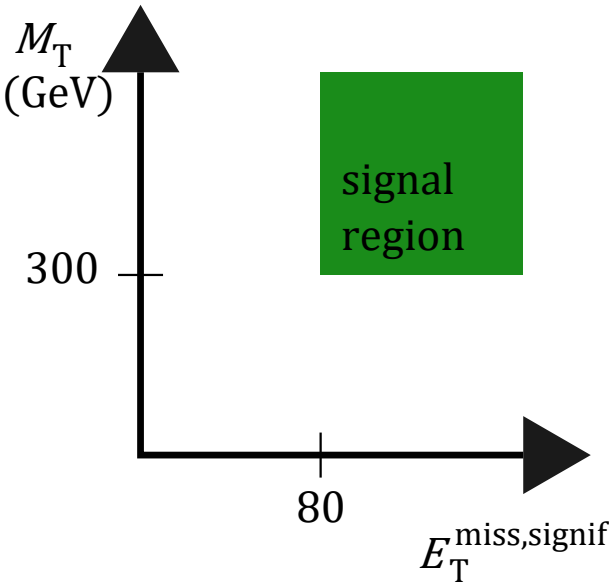
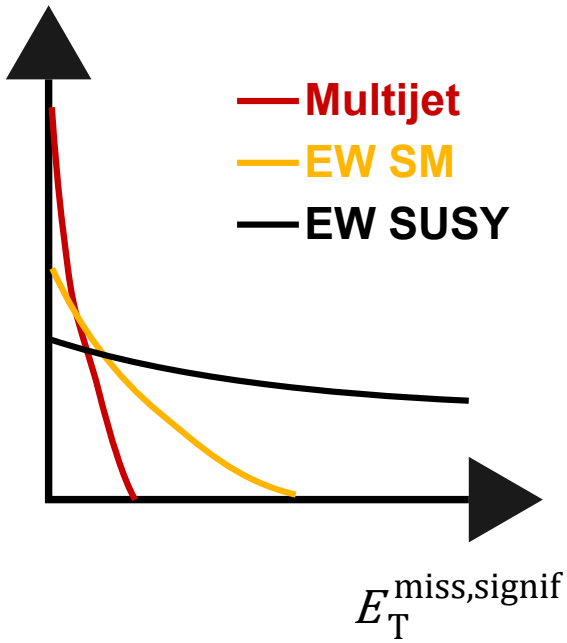
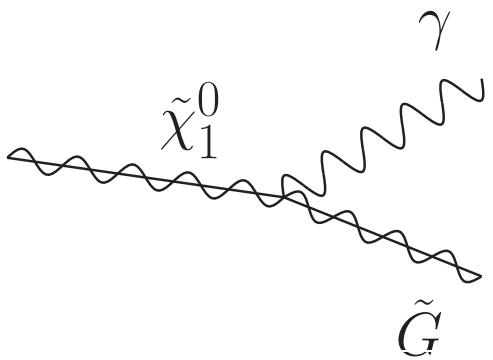
  - $M_T(1st\ \gamma, E_T^{miss}) > 300$ GeV







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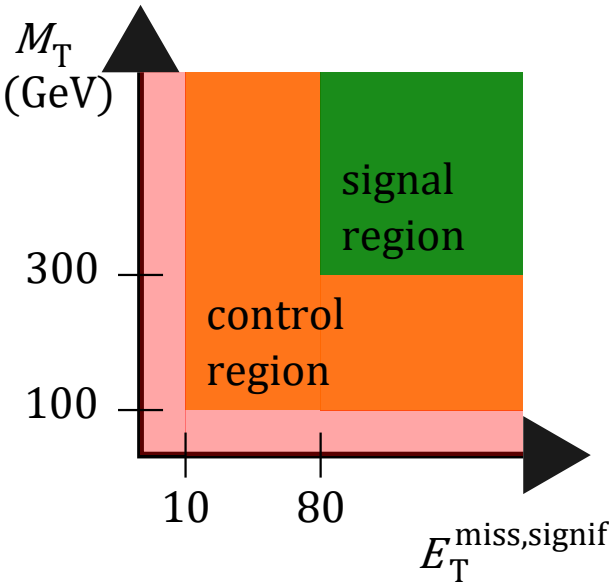
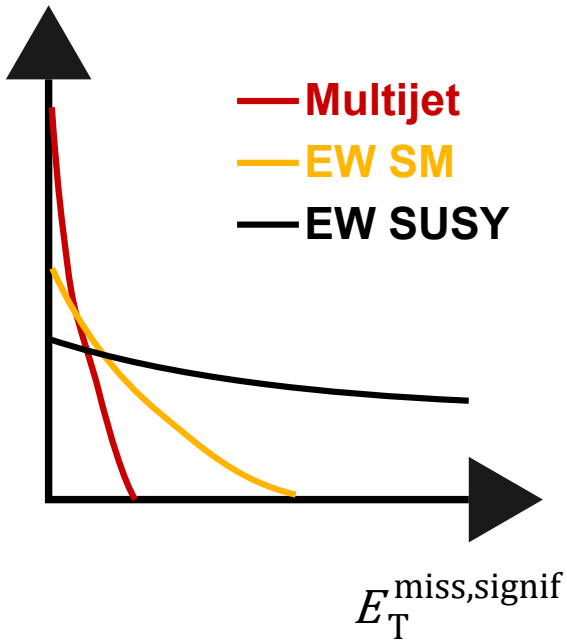
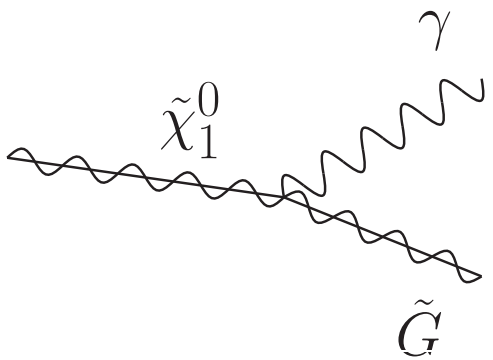






Single Photon ∼ Background prediction

MC normalization in control region for Vγ and γ+jets:

Main backgrounds:

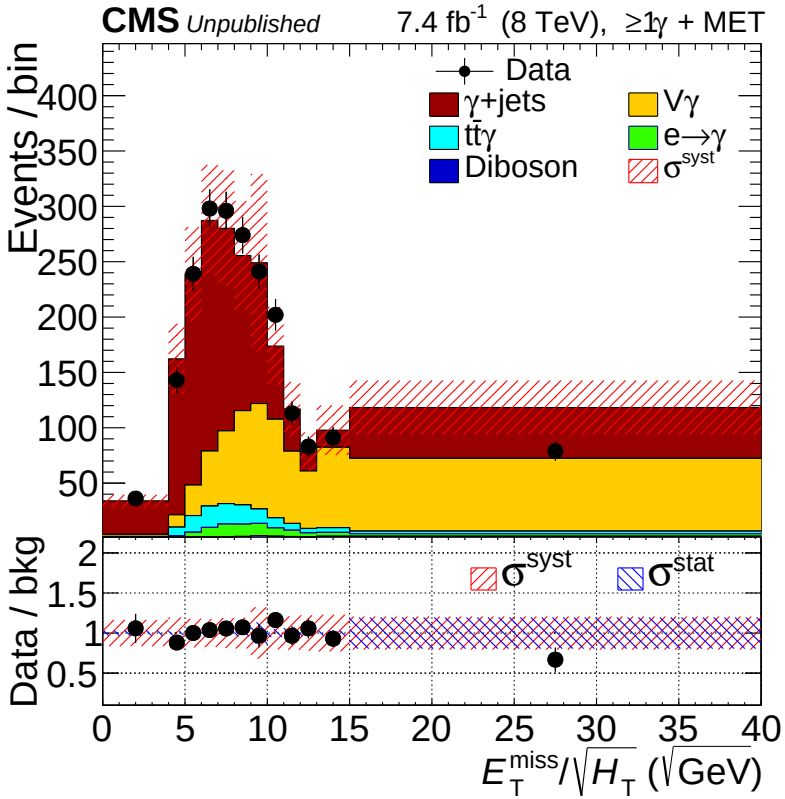
- Vγ ($W\gamma + Z\gamma$) LO MadGraph + NLO correction
- γ+jets LO MadGraph

Estimation method:

- $E_T^{miss}/\sqrt{H_T}$ separates the shapes of Vγ and γ+jets
- Fix other backgrounds
- Fix total scale
- Vary scales of Vγ and γ+jets and do χ^2-test

Resulting scale factors:

- Vγ: 0.94 ± 0.23 (dominant uncert.)
- γ+jets: 2.20 ± 0.31



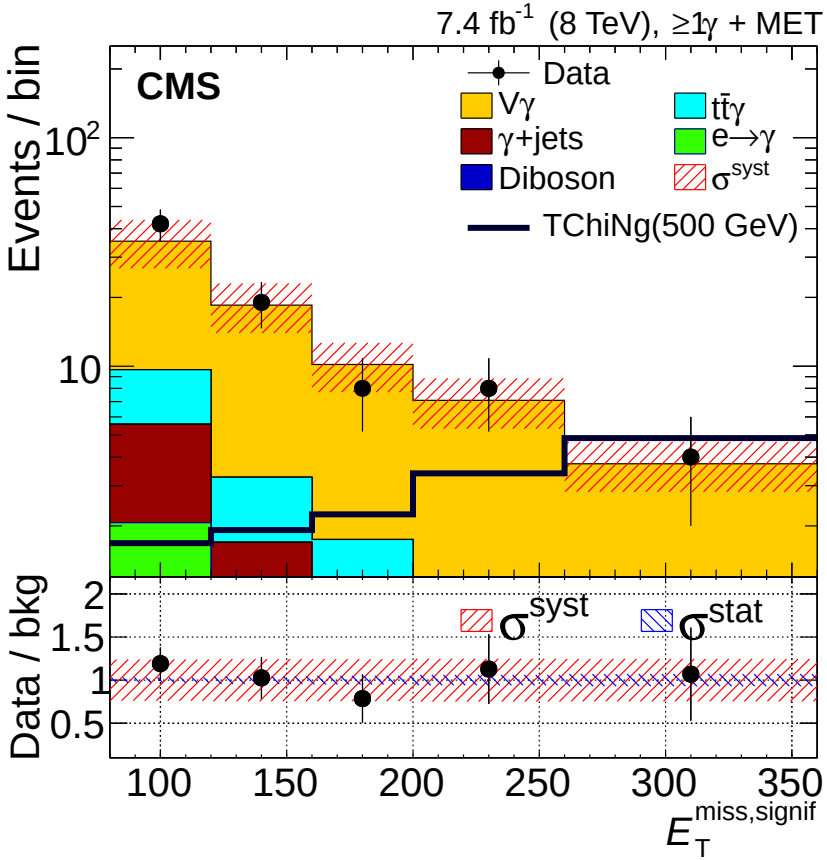
Subdominant backgrounds:

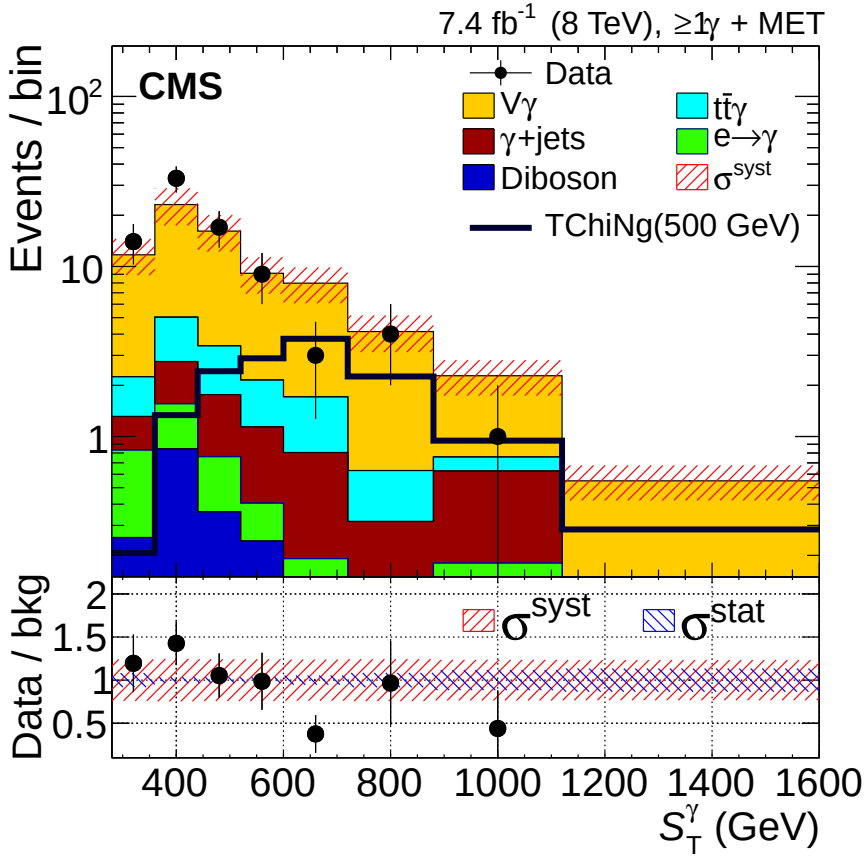
- e → γ fakes: data driven (11% uncert.) scaling e control sample by fake probability
- $t\bar{t}\gamma$, Diboson (WW, WZ, ZZ): MC simulation (26-50% uncert.)

Single Photon ∼ Results

PLB 759 (2016), arXiv:1602.08772

$$S_T^\gamma = \sum_i p_T(\gamma_i) + E_T^{miss}$$

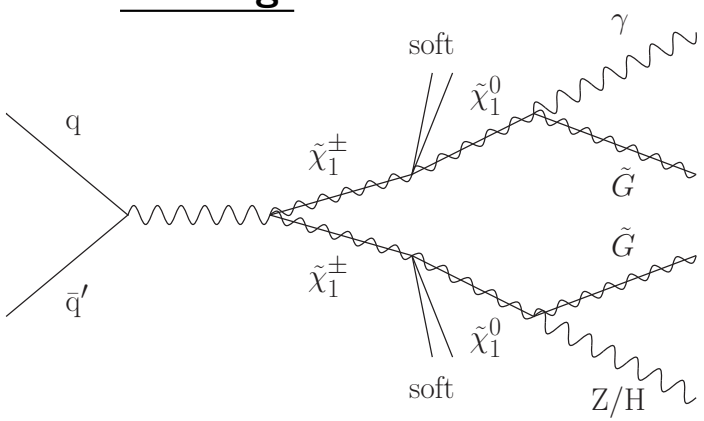


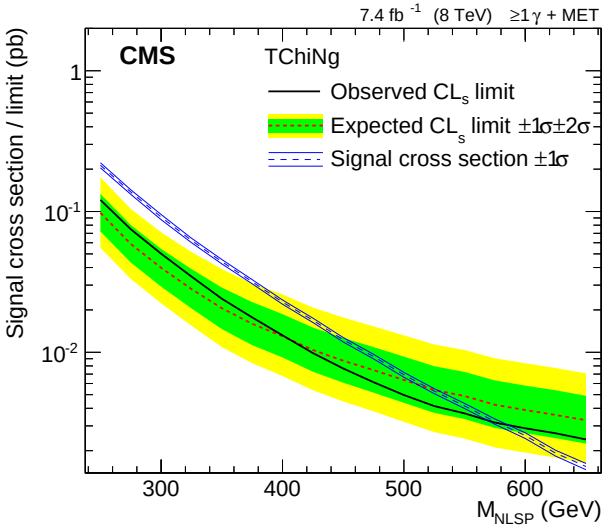


$E_T^{miss,signif}$	> 200	< 200	> 200	< 200
S_T^γ (GeV)	> 600	> 600	< 600	< 600
Background	5.3 ± 1.2	9.7 ± 1.8	5.8 ± 1.3	54.3 ± 10.6
Data	4	4	8	65

Single Photon ∼ Interpretation (SMS)

TChiNg:





- $M_{NLSP} < 570$ GeV excluded
- First limit in this scenario

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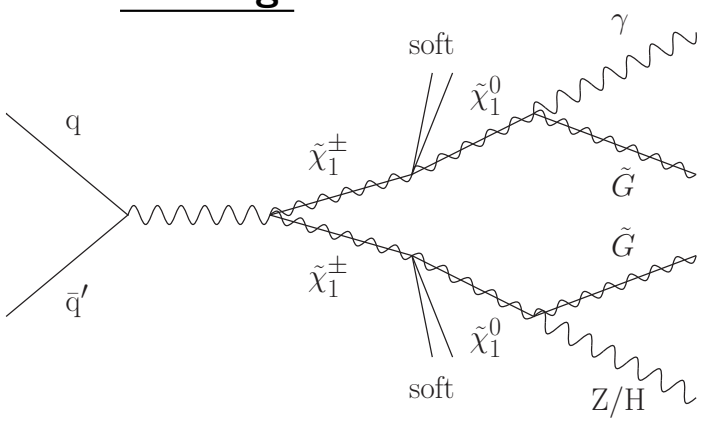

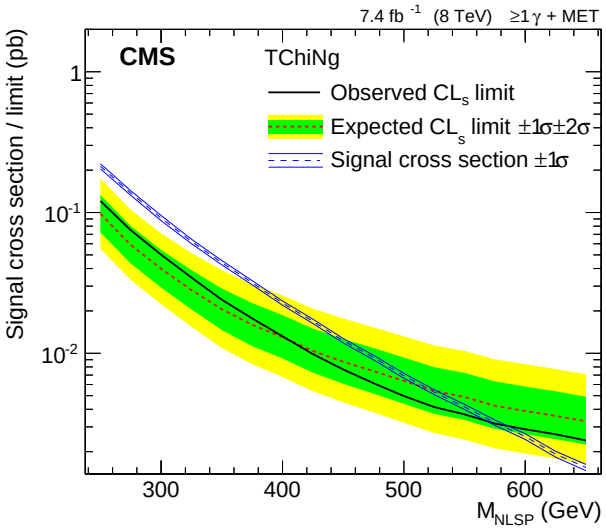

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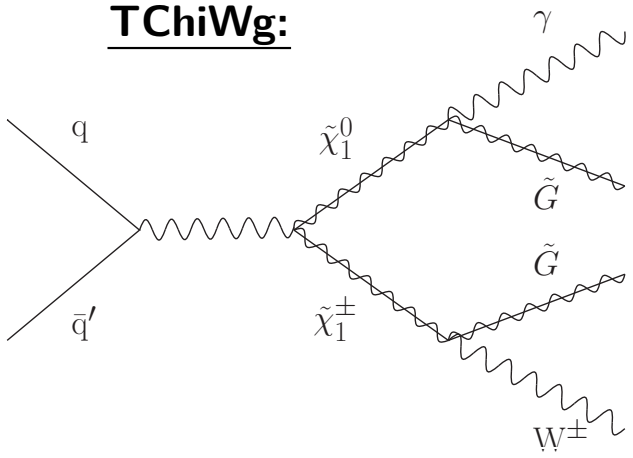
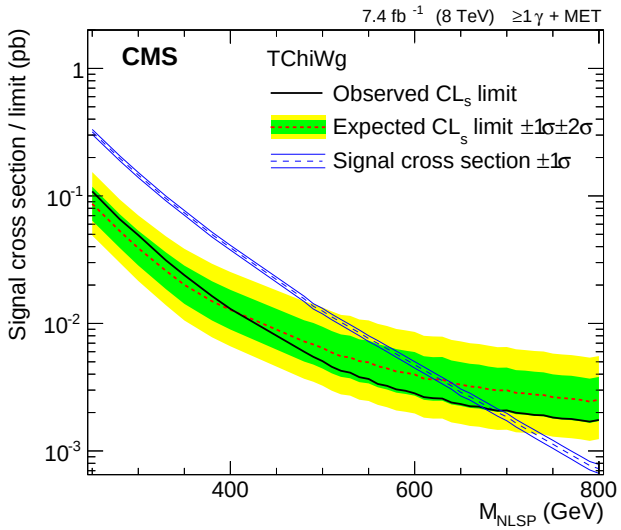
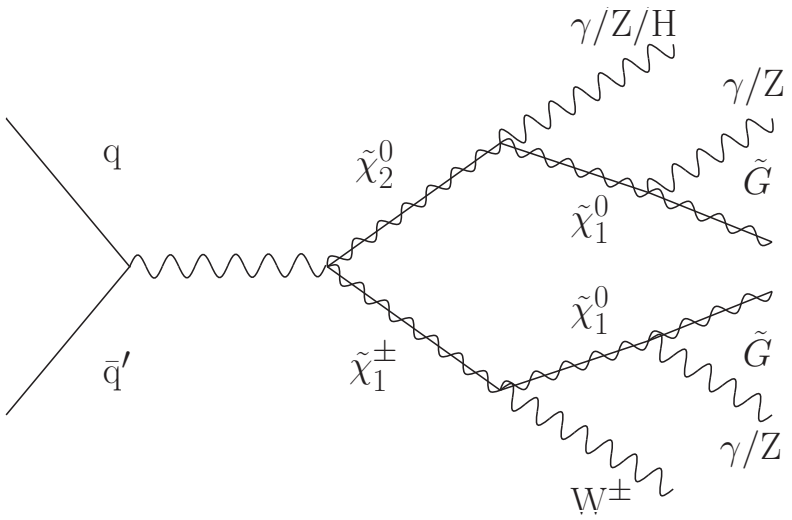
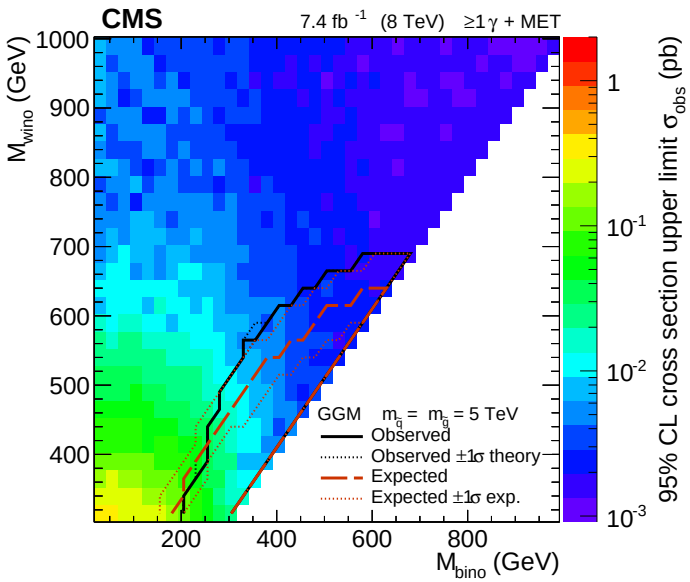




- $M_{NLSP} < 680$ GeV excluded
- Improving on other 8 TeV results by 140 GeV

Single Photon ∼ Interpretation (GGM)





- $M_{wino} \mathrel{\hat{=}} M_{\chi_2^0}$, $M_{\chi_1^\pm}$ and $M_{bino} \mathrel{\hat{=}} M_{\chi_1^0}$
- Analysis sensitive to electroweak production with mass splittings of M_{wino} and M_{bino} up to 200 GeV

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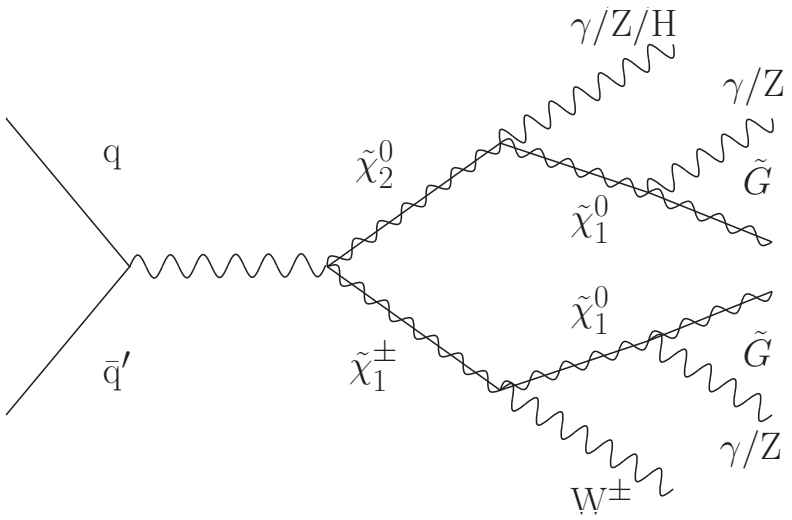

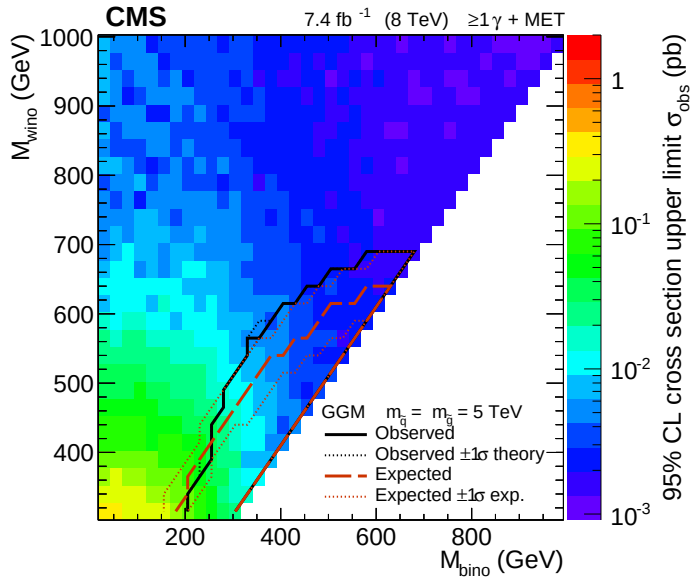

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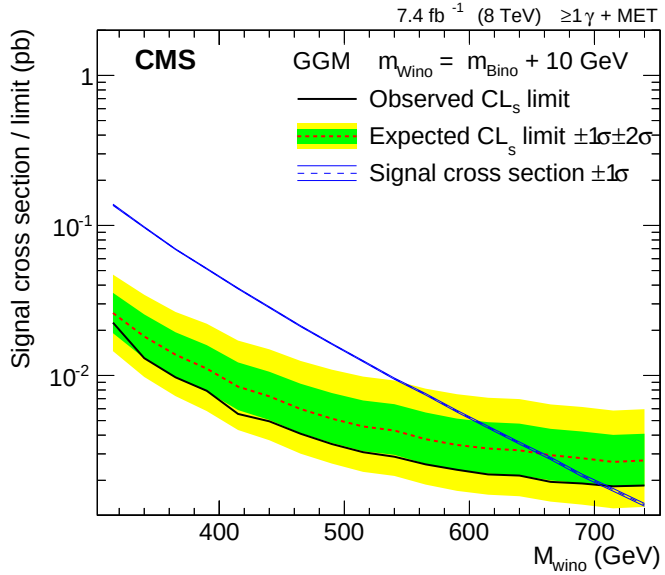
- Analysis sensitive to electroweak production with mass splittings of M_{wino} and M_{bino} up to 200 GeV
- Wino masses below approximately 710 GeV are excluded if $M_{wino} = M_{bino} + 10$ GeV
- Improvement of 220 GeV



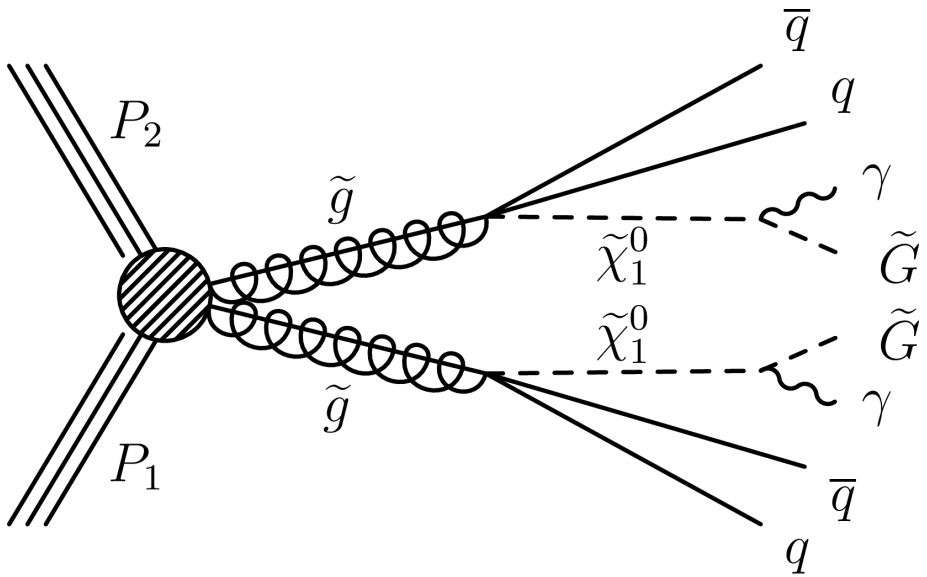
CMS-PAS-SUS-15-012

Diphoton analysis

Diphoton ∼ Overview

Data set:

- $\int \mathcal{L}\ \mathrm{dt} = 2.3\ \mathrm{fb}^{-1}$, $\sqrt{s} = 13$ TeV
- **Signal** trigger: 2 isolated γ with p_{T} $(\gamma_1, \gamma_2) > 30, 18$ GeV + $\mathrm{M}_{\gamma\gamma} > 95$ GeV
- $\varepsilon_{\text{trigger}} \cdot \varepsilon_{\text{photon ID}} = 93.4 \pm 2.5$ %



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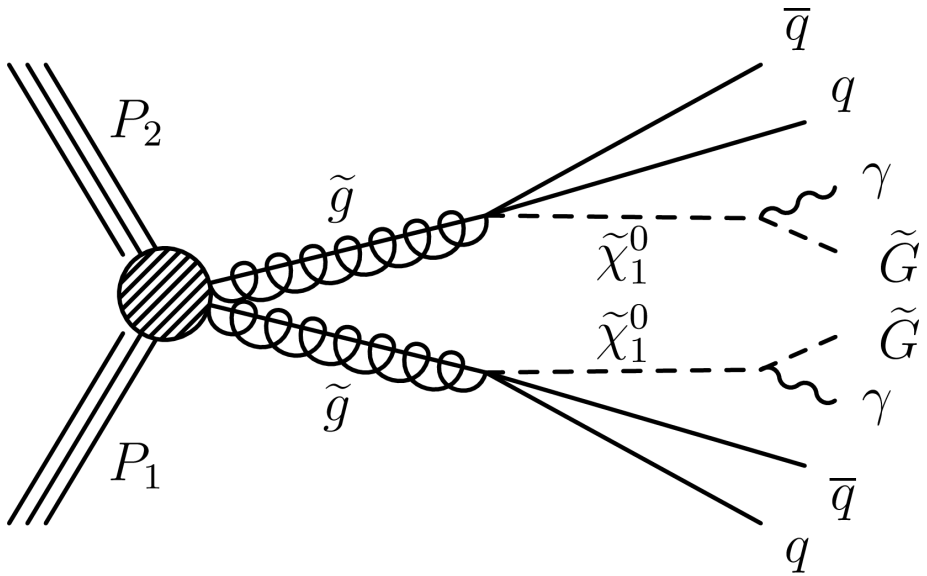
Signal selection:

- 2 isolated γ with $p_\mathrm{T}\ (\gamma_1, \gamma_2) > 40$ GeV and $|\ \eta(\gamma_1, \gamma_2)\ | < 1.44$
- $\mathrm{M}_{\gamma\gamma} > 105$ GeV
- $E_\mathrm{T}^{\mathrm{miss}} > 100$ GeV



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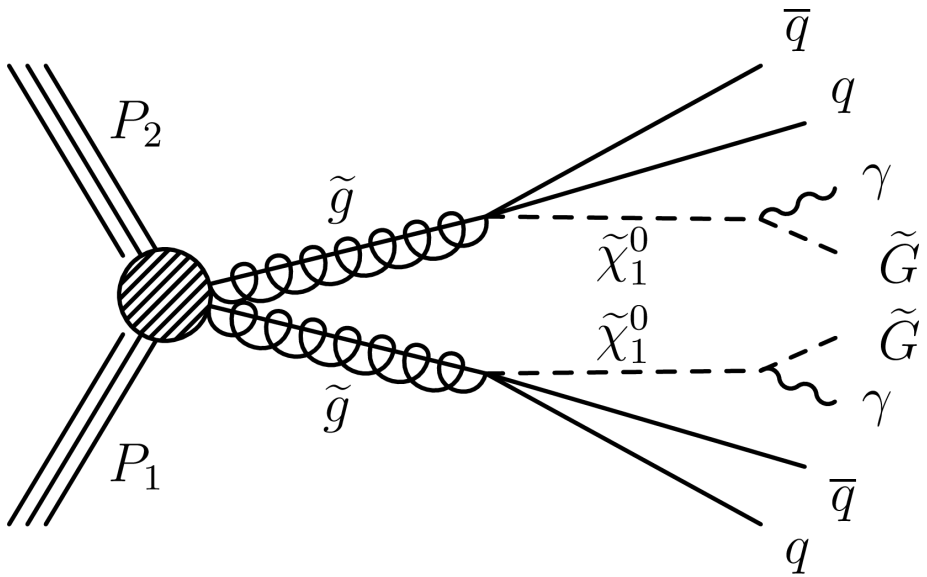
Search region:

- 4 exclusive bins in $E_\mathrm{T}^{\mathrm{miss}}$:
  - (100 - 110) GeV
  - (110 - 120) GeV
  - (120 - 140) GeV
  - (140 - ∞) GeV



Diphoton $\sim$ Strategy

fully data driven background estimation in $\gamma\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$ signal selection

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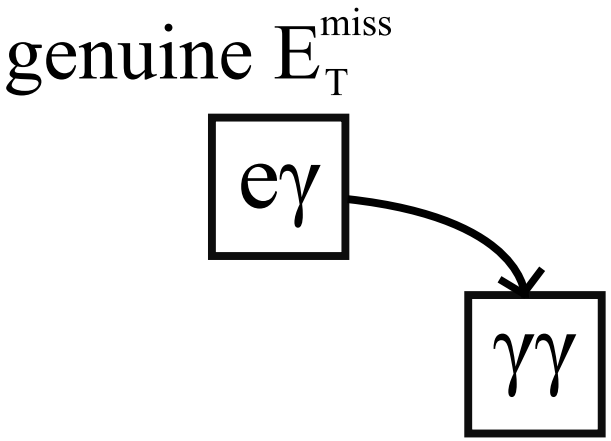
Genuine E_T^{miss} contribution:

- from W$\gamma \rightarrow e\nu\gamma$, where e is misidentified as γ
- Misidentification rate $f_{e\rightarrow\gamma} = 0.021 \pm 0.002$ measured with tag&probe method on Z→ee resonance
- eγ control sample scaled by factor $f_{e\rightarrow\gamma}/(1 - f_{e\rightarrow\gamma})$ to predict electroweak contribution



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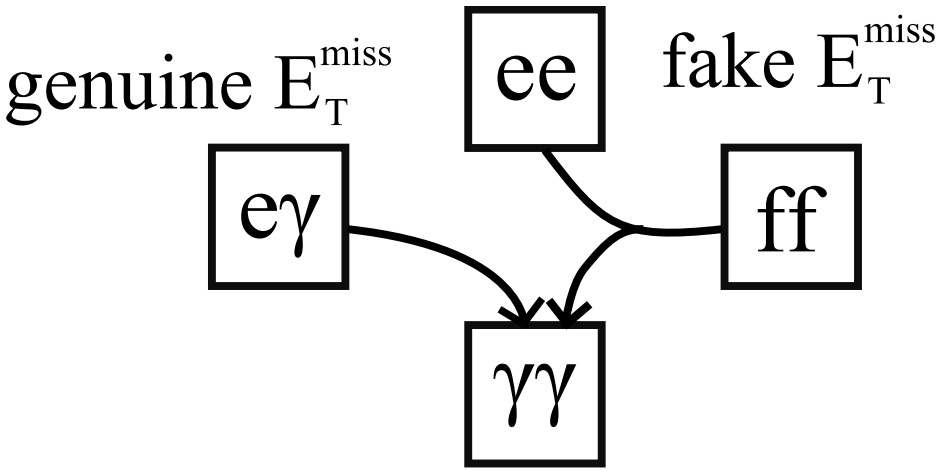
Fake E_T^{miss} contribution:

- from QCD processes with mismeasured jets
- **define fake γ-like objects (f)** with same γ ID, except for loosened ECAL cluster shape **or** charged hadron isolation criterion
- use ee and ff control sample to predict QCD contribution to $\gamma\gamma$ signal sample



Diphoton ∼ Strategy

fully data driven background estimation in $\gamma\gamma + E_T^{miss}$ signal selection

Genuine E_T^{miss} contribution:

- from W$\gamma \rightarrow e\nu\gamma$, where e is misidentified as γ
- Misidentification rate $f_{e\rightarrow\gamma} = 0.021 \pm 0.002$ measured with tag&probe method on Z→ee resonance
- eγ control sample scaled by factor $f_{e\rightarrow\gamma}/(1 - f_{e\rightarrow\gamma})$ to predict electroweak contribution

Fake E_T^{miss} contribution:

- from QCD processes with mismeasured jets
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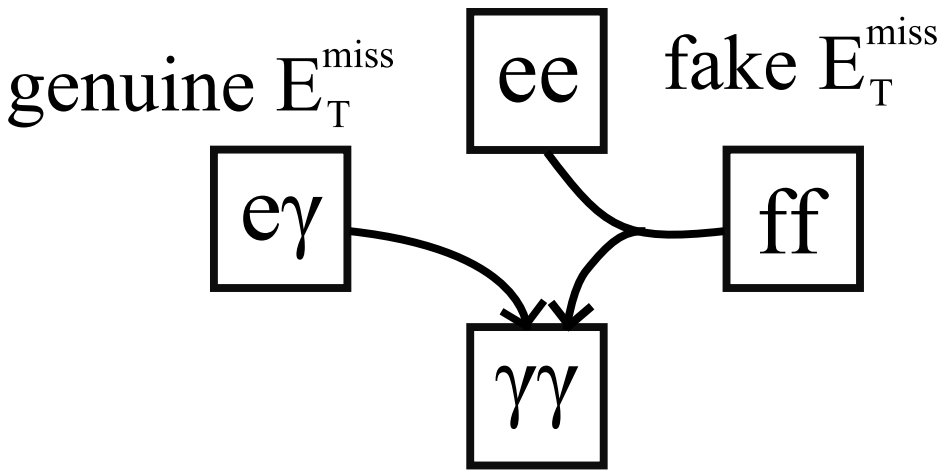
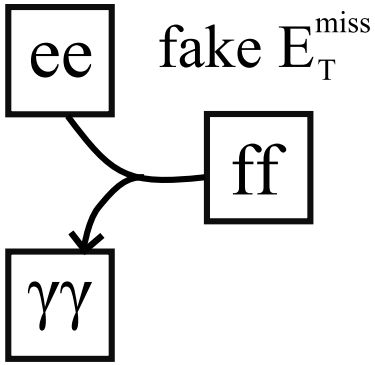


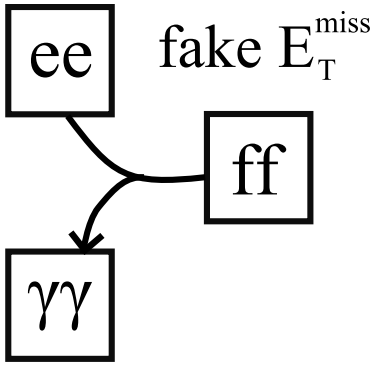
Diphoton $\sim$ QCD background



QCD contribution:

- Environment of ee and ff control and $\gamma\gamma$ signal event samples have different hadronic activity

Diphoton ∼ QCD background



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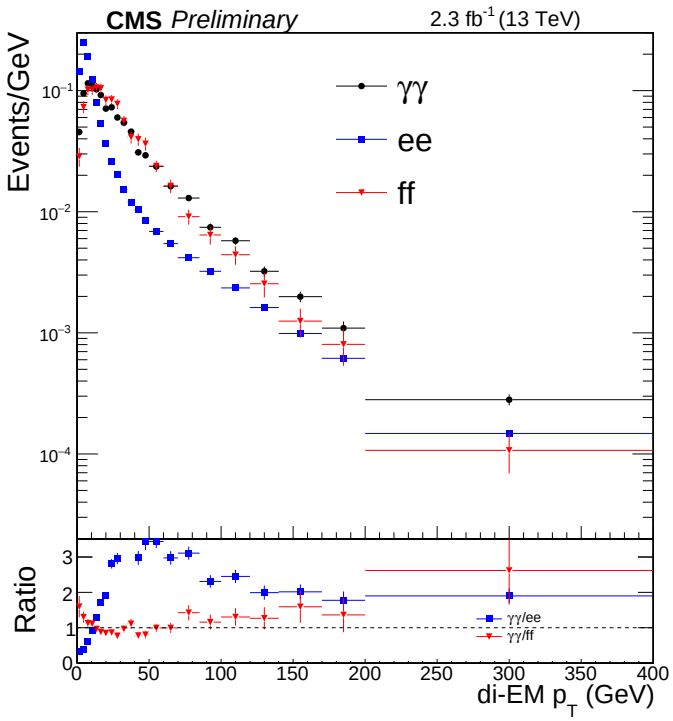
- Environment of ee and ff control and $\gamma\gamma$ signal event samples have different hadronic activity
- As a measure, the di-EM p_T is defined as

$$\text{di-EM } p_T = |\vec{p_T}(EM_1) + \vec{p_T}(EM_2)|$$

- To account for this difference, the ee and ff control samples are reweighted by the ratio of the di-EM p_T distribution with respect to $\gamma\gamma$



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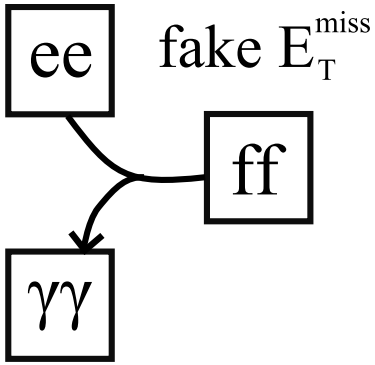

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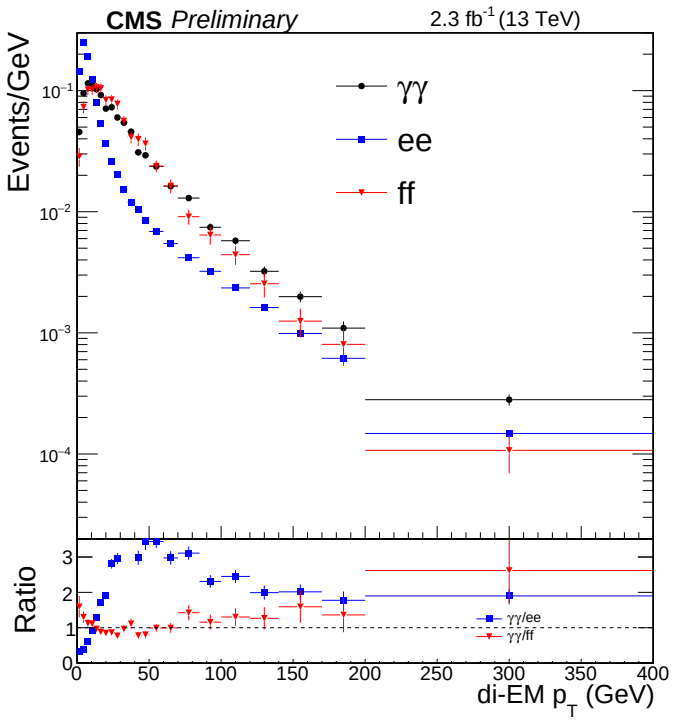
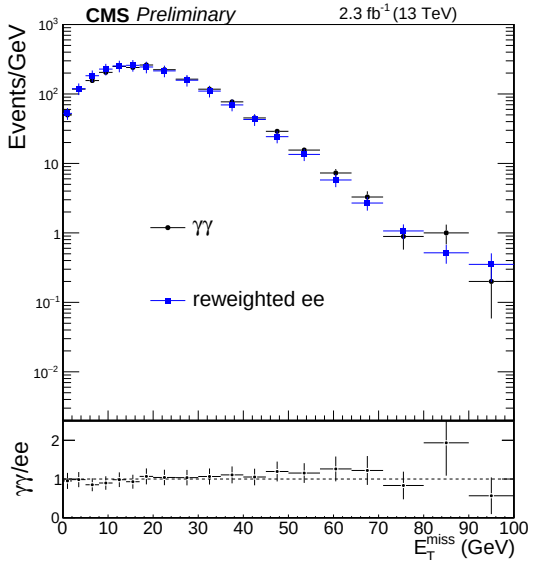
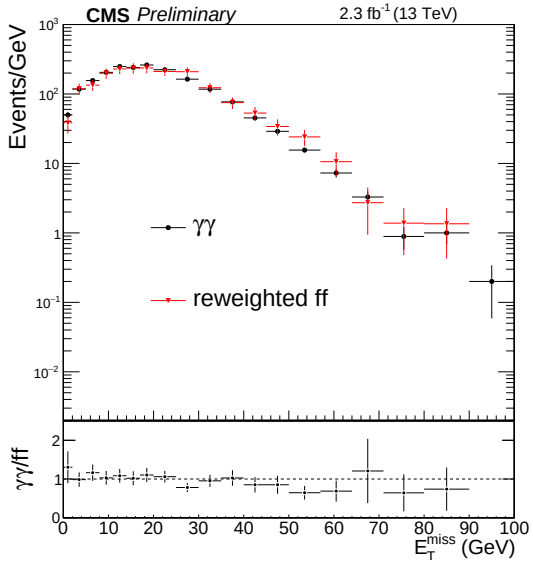
- ee and ff control samples normalized to $\gamma\gamma$ sample in E_T^{miss}<50 GeV region
- Primary QCD estimate determined by ee control sample, ff sample serves as cross check → difference in E_T^{miss} prediction taken as systematic uncertainty



Diphoton ∼ QCD background

- $\gamma\gamma$ $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution compared to
  - reweighted ee (left)
  - reweighted ff (right)





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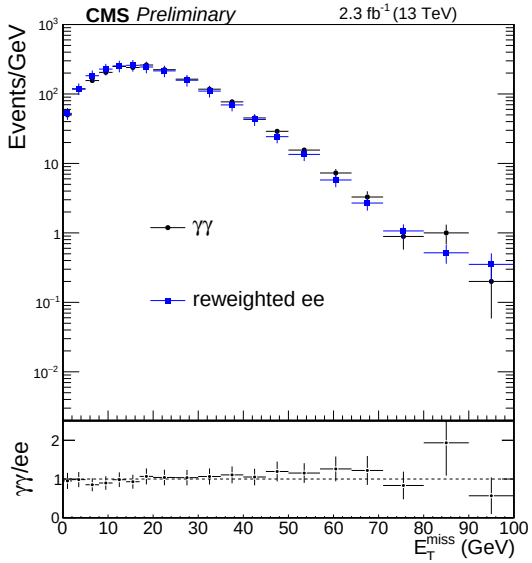
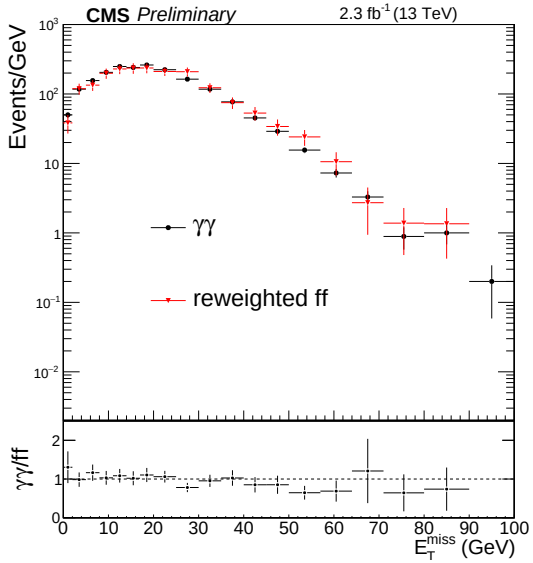




- **Systematic uncertainties:**
  - **di-EM p_{T} reweighting (15-39 %)**

→ propagation of different reweightings using toy di-EM p_{T} ratio distributions allowed to vary by 1 σ_{stat} of events in each bin of ee control sample

  - dependency on **jet multiplicity (15-34 %)**

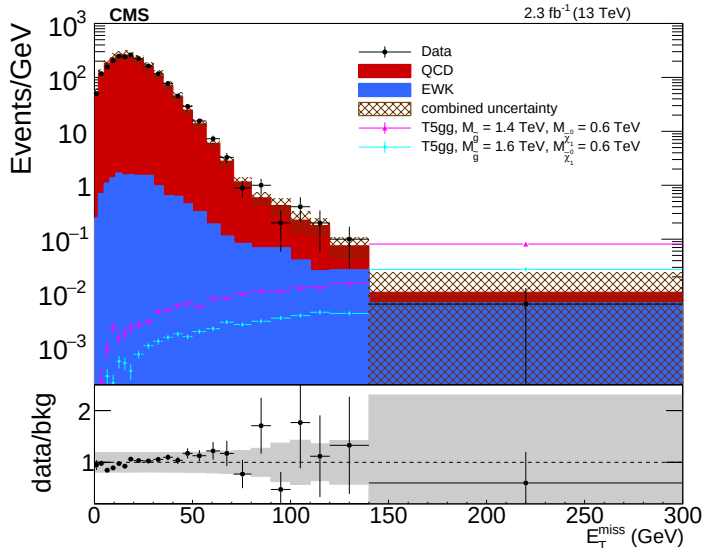
→ direct difference between di-EM p_{T} + jet multiplicity reweighting and di-EM p_{T} reweighting only

  - $E_{\mathrm{T}}^{\mathrm{miss}}$ **shape difference** between ee and ff control sample **(12-150%)**

→ fitting $E_{\mathrm{T}}^{\mathrm{miss}}$ tail of ee and ff sample with the function $(E_{\mathrm{T}}^{\mathrm{miss}})^{p_0} e^{p_1 (E_{\mathrm{T}}^{\mathrm{miss}})^{p_2}}$. Systematic uncertainty taken from fractional difference between the fitted functions

Diphoton ∼ Results

expected: 7.2 ± 2.5, observed: 9



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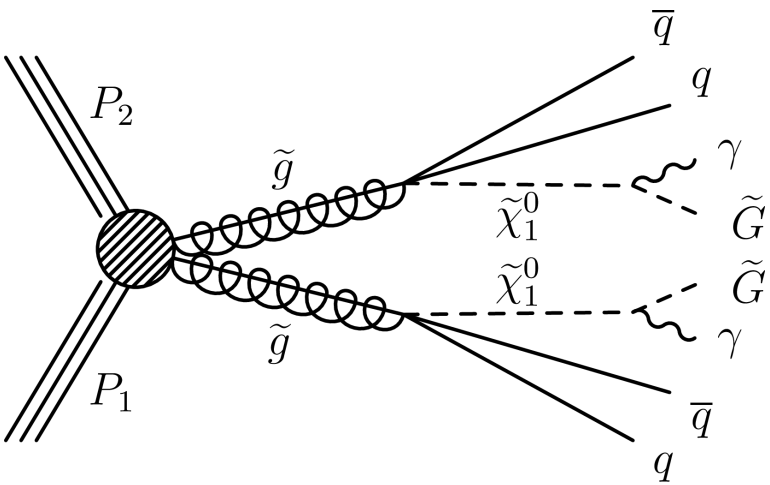
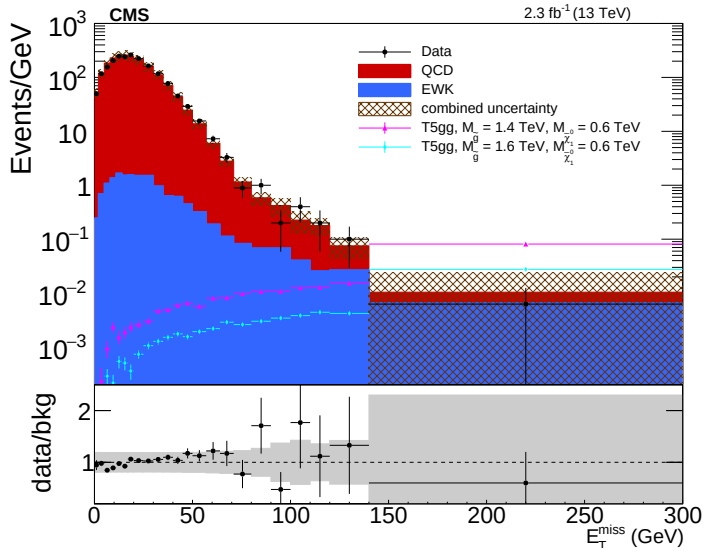
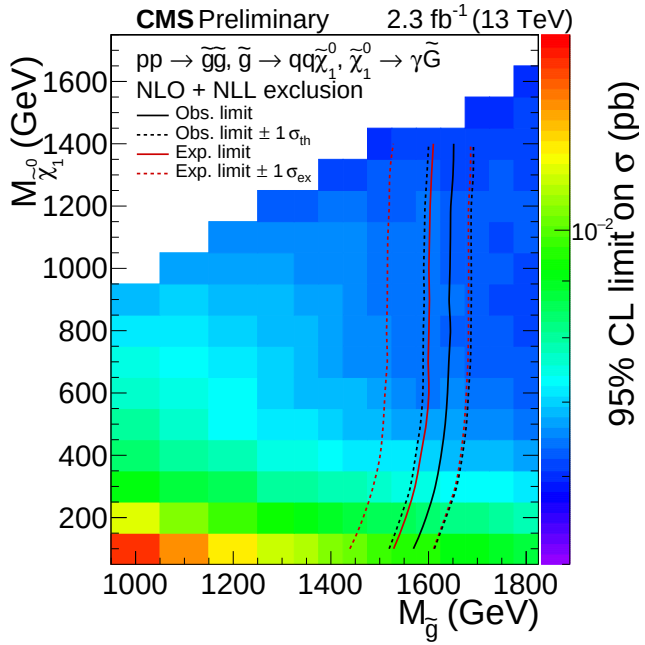
- T5gg exclusion at 95% CL:
  - nearly independent from $M_{\tilde{\chi}_1^0}$
  - $M_{\tilde{g}} \lesssim 1600$ GeV
  - improving on previous 8 TeV searches by approx. 300 GeV







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  - many CMS exclusion limits for both strong and electroweak production
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    - **TChiNg**: $M_{NLSP} < 570$ GeV, **TChiWg**: $M_{NLSP} < 680$ GeV
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Thank you for your attention!

BACKUP

Single Photon ∼ Systematic Uncertainties

Systematic uncertainties:

Source	Sample	Rel. uncertainty (on total BG)
$V\gamma$ normalization	$V\gamma$	24 % (19 %)
γjets normalization	γjets	14 % (1 %)
Tag&Probe fit	$e \to \gamma$	11 % (0.3 %)
Cross-section measurement	$t\bar{t}\gamma$	26 % (3 %)
MC simulation	diboson	50 % (1 %)
MC simulation	multijet	100 % (0 %)
PDF uncertainty on acceptance	signal	$<$0.1–11 %
PDF and scale uncertainty	signal	4–8 %
Luminosity	diboson, multijet, and signal	2.6 %
Trigger efficiency	diboson, multijet, and signal	1.2 %
Jet energy scale	diboson, multijet, and signal	1–2 %

Single Photon $\sim$ Results

Event yields:

	$E_{\mathrm{T}}^{\mathrm{miss}}$ sig.$>$ 200, $S_{\mathrm{T}}^{\gamma} > 600$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ sig. $<$ 200, $S_{\mathrm{T}}^{\gamma} > 600$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ sig. $<$ 200, $S_{\mathrm{T}}^{\gamma} < 600$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ sig. $>$ 200, $S_{\mathrm{T}}^{\gamma} < 600$ GeV
$V\gamma$	4.7 ± 1.2	7.0 ± 1.8	42.3 ± 10.4	5.0 ± 1.3
γjets	0.1 ± 0.1	1.3 ± 0.3	3.4 ± 0.7	$0.0 \pm < 0.1$
$\mathrm{t\bar{t}}\gamma$	0.3 ± 0.1	1.1 ± 0.3	5.5 ± 1.5	0.4 ± 0.1
Diboson	0.1 ± 0.1	0.2 ± 0.1	1.5 ± 0.8	0.2 ± 0.1
$e \rightarrow \gamma$	$0.1 \pm < 0.1$	$0.1 \pm < 0.1$	1.6 ± 0.2	0.2 ± 0.1
Multijet	0.0	0.0	0.0	0.0
Background	5.3 ± 1.2	9.7 ± 1.8	54.3 ± 10.6	5.8 ± 1.3
Data	4	4	65	8
Signal	6.9 ± 0.2	1.7 ± 0.1	1.1 ± 0.1	$0.7 \pm < 0.1$
Acceptance [%]	26.5 ± 0.9	6.7 ± 0.3	4.2 ± 0.2	2.6 ± 0.2

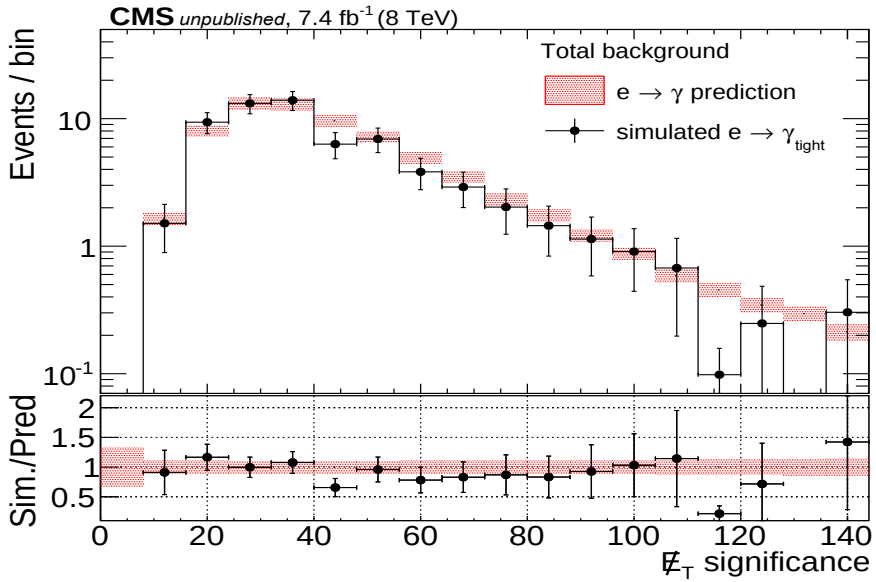
Single Photon $\sim$ Subdominant Backgrounds

Datadriven e $\rightarrow$ γ fakes:

- Rerun analysis with same photon definition, but $N_{Pixelseed} > 0$ (γ_{pixel})
- Scale distributions with factor $f_{e\rightarrow\gamma}$ / (1 - $f_{e\rightarrow\gamma}$)
- MC: using MC truth info, Data: tag&probe on Z-resonance (Ref.: CMS AN-13-240, Yutaro et al.)
- Simulation: $f^{sim}_{e\rightarrow\gamma} = (0.95 \pm 0.05\ (stat.) \pm 0.09\ (sample))$ %
- Data: $f^{data}_{e\rightarrow\gamma} = (1.48 \pm 0.10\ (measurem.) \pm 0.13\ (sample))$ %
- Closure: generated electron criterion: $\Delta R(gen.\ e, \gamma_{tight}) < 0.1$

From Simulation:

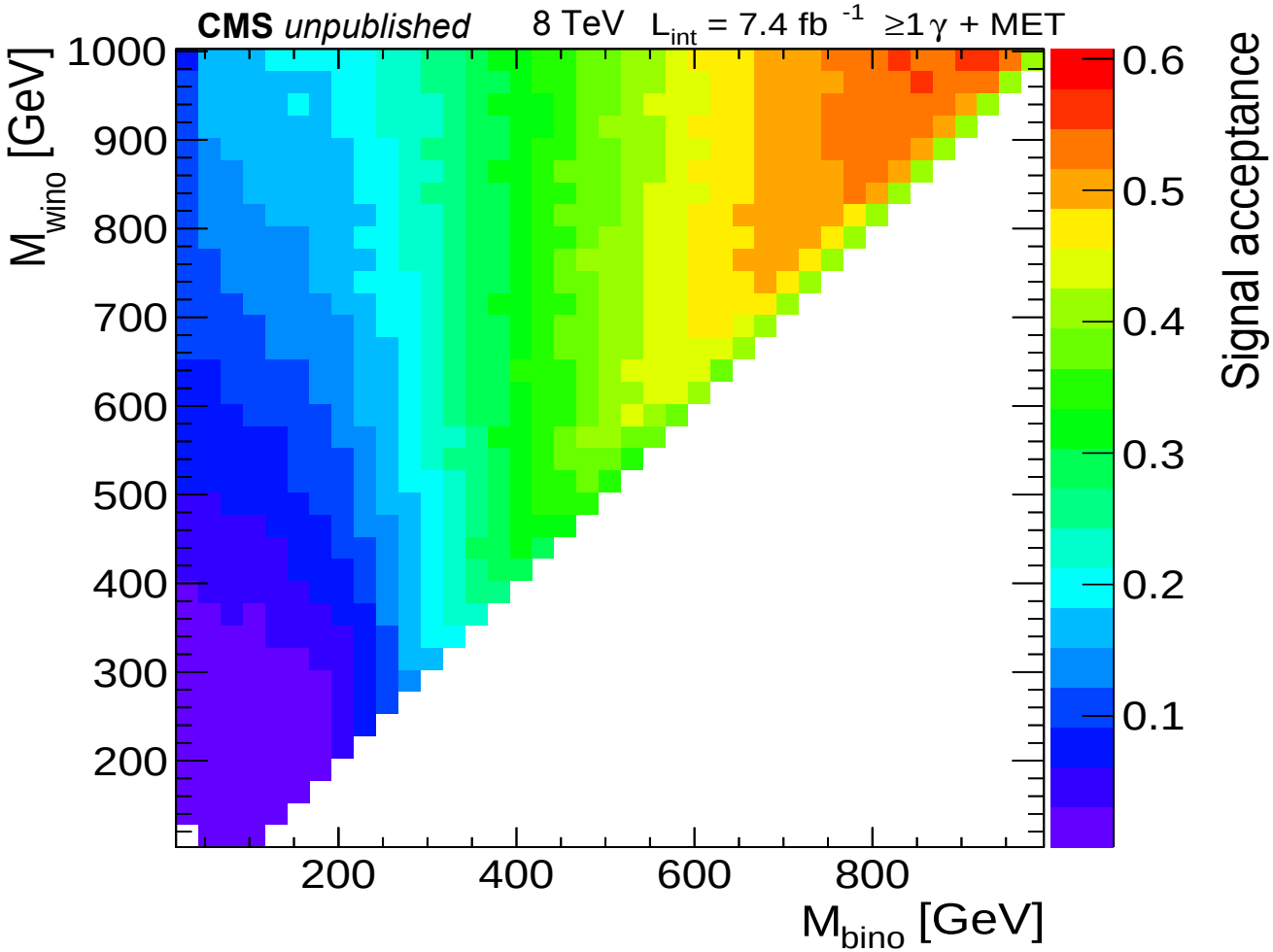
- $t\bar{t}\gamma$
- Diboson (WW, WZ, ZZ)
- QCD (negligible)



Single Photon ∼ Cutflow Table

Cut	TChiNg_500		TChiWg_650		GGM_640_630	
	N_{signal}	ε	N_{signal}	ε	N_{signal}	ε
generated	51.0	1.0	21.2	1.0	29.9	1.0
$\not{E}_T$ filters	50.98	1.0	21.16	1.0	29.86	1.0
$\not{E}_T > 100$ GeV	46.1	0.90	19.9	0.94	27.6	0.93
$\geq 1\gamma_{\text{tight}}$ ($p_T > 40$ GeV)	28.5	0.56	12.9	0.61	17.7	0.59
$r9(\gamma_{\text{tight}}) > 0.9$, $\mid \eta(\gamma_{\text{tight}}) \mid < 1.44$	26.7	0.52	12.3	0.58	17.0	0.57
$\Delta R(1^{st}\gamma$, nearest jet$) > 0.5$	26.1	0.51	12.1	0.57	16.6	0.56
$H_T > 100$ GeV	21.8	0.43	10.4	0.49	14.3	0.48
control + signal region	21.4	0.42	10.2	0.48	14.1	0.47
signal region	16.3	0.32	8.7	0.41	12.0	0.40

Single Photon ∼ GGM Acceptance



Diphoton $\sim$ ee and ff reweighting