Search for SUSY in events with a photon, a lepton, and p_T^{miss} using full Run2 data

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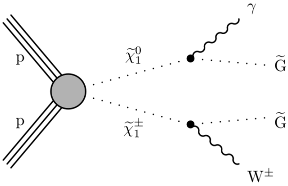
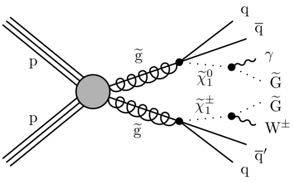
Introduction

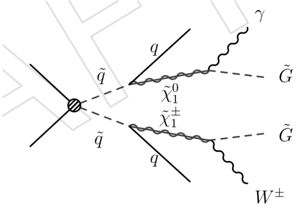
- In Gauge-Mediated Supersymmetry Breaking (GMSB) scenario, gravitino ($\tilde{G}$) is taken to be massless LSP, neutralino ($\tilde{\chi}^0$) and chargino ($\tilde{\chi}^{\pm}$) are taken to be co-NLSPs with equal masses.
- Assuming R-parity conservation, $\tilde{\chi}_1^0\tilde{\chi}_1^{\pm}$ are pair produced.
- $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$ and $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{G} \rightarrow \ell^{\pm}\nu\tilde{G}$
  $\gamma + \ell + p_T^{miss}$ is a typical signature of $\tilde{\chi}_1^0\tilde{\chi}_1^{\pm}$ pair production.



TChiWG



T5WG



T6WG

Triggers for event selection

- $e\gamma$ signal region data come from diphoton triggers (electrons can be photon candidates at the trigger level).
- $\mu\gamma$ signal region data come from the muon-gamma cross trigger.

Object definition

Photon

- $p_T > 35$GeV, $|\eta| < 1.4442$
- passes HLT selection
- R9 > 0.5
- cut-based loose ID
- pixel seed veto
- no μ or *e* within $\triangle R < 0.3$

H_T

- $H_T = \sum p_T^{jet}$
- AK4 PF jet with $p_T > 30$ GeV, $|\eta| < 2.5$, $\triangle R$ (jet, ℓ or γ) > 0.4

Electron

- $p_T > 25$ GeV, $|\eta| < 2.5$
- passes HLT selection
- R9 > 0.5 (0.8) for EB (EE)
- cut-based medium ID
- mini-Isolation < 0.1

Muon

- $p_T > 25$ GeV, $|\eta| < 2.4$
- passes HLT selection
- cut-based medium ID
- mini-Isolation < 0.2
- $|d_0| < 0.05, |d_z| < 0.1$

Event selection

Selections :

- $= 1\ \gamma, \geq 1\ \mathrm{e}/\mu$
- At least one good vertex
- Passes MET filters
- $\triangle$R $(\ell, \gamma) >$ 0.8
- For $e\gamma$ channel: $\mathrm{M}_{e\gamma} - \mathrm{M}_{\mathrm{Z}} >$ 10 GeV

Control region (CR) : $\mathrm{p}_{\mathrm{T}}^{\mathrm{miss}} <$ 70 GeV

Validation region : $\mathrm{M}_{\mathrm{T}}(\ell, \mathrm{p}_{\mathrm{T}}^{\mathrm{miss}}) <$ 100 GeV

Signal region (SR) :

- $\mathrm{p}_{\mathrm{T}}^{\mathrm{miss}} >$ 120 GeV
- $\mathrm{M}_{\mathrm{T}}(\ell, \mathrm{p}_{\mathrm{T}}^{\mathrm{miss}}) >$ 100 GeV, $\mathrm{M}_{\mathrm{T}} = \sqrt{2\mathrm{p}_{\mathrm{T}}^{\ell}\mathrm{p}_{\mathrm{T}}^{\mathrm{miss}}(1 - \cos\triangle\phi(\ell, \mathrm{p}_{\mathrm{T}}^{\mathrm{miss}}))}$
- Binned in $\mathrm{p}_{\mathrm{T}}^{\mathrm{miss}} \times \mathrm{H}_{\mathrm{T}} \times \gamma_{\mathrm{p}_{\mathrm{T}}}$:
  $\mathrm{p}_{\mathrm{T}}^{\mathrm{miss}}$: [120-200, 200-400, $>$ 400], H_{T} : [0-100, 100-400, $>$ 400]
  $\gamma_{\mathrm{p}_{\mathrm{T}}}$: [35-200, $>$ 200]

Background estimation overview

- $W(Z) + \gamma$
  - ▷ main background
  - ▷ true photon, lepton and p_T^{miss}
  - ▷ take shape from simulation and derive the normalization in control region
- Mis-identified objects :
  - ▷ fake γ from e
    estimate the fake rate with $Z \rightarrow ee$ tag and probe method
  - ▷ fake γ from jet
    estimated using jet-enriched control samples
  - ▷ fake lepton from jet
    take shape from control samples and derive the normalization in control region together with $W(Z) + \gamma$
- Rare processes :
  $t\bar{t}\gamma$, $WW\gamma$, $WZ\gamma$ taken from simulation

Mis-identified γ from e

Electrons with no track seeds are misidentified as photons. Arises from Drell-Yan di-electron productions, $\mathrm{t\bar{t}}$ and WW events with *ee* and $e\mu$.

- Electron faking as γ contribution is estimated by applying **"fake rate"** to **"proxy sample"** as an event weight.
- **Proxy sample :** $e\gamma/\mu\gamma$ events with γ having pixel seed and matches to an electron with $\triangle R < 0.02$
- **Fake rate (R) :** probability of *e* misidentified as γ

$$R = \frac{N_{e\gamma}}{N_{ee}}$$

  estimated using Z$\rightarrow$ ee tag-and-probe method.
- Measure the dependence of fake rate on p_T, $|\eta|$ and N_{vtx}

$$f\ (p_T, N_{vtx}, \eta) = N \cdot (A \cdot p_T + B)^n \cdot (D + E \cdot N_{vtx}) \cdot f(\eta)$$

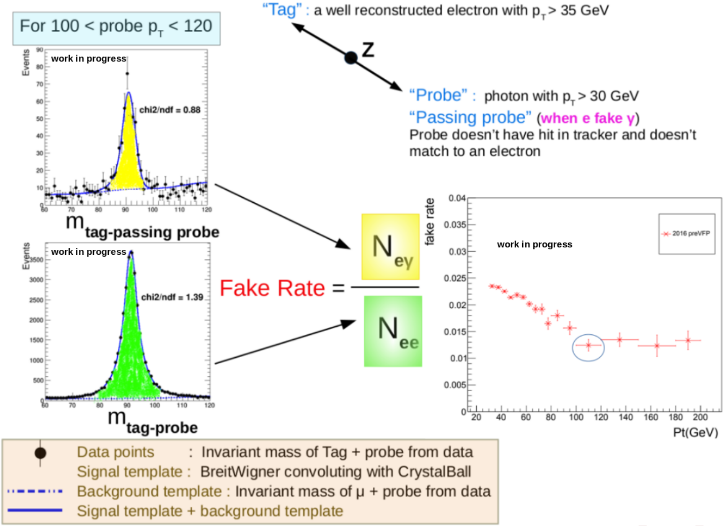
Z→ee tag-and-probe method

Tag and probe in control region ($p_T^{miss} < 70$ GeV)

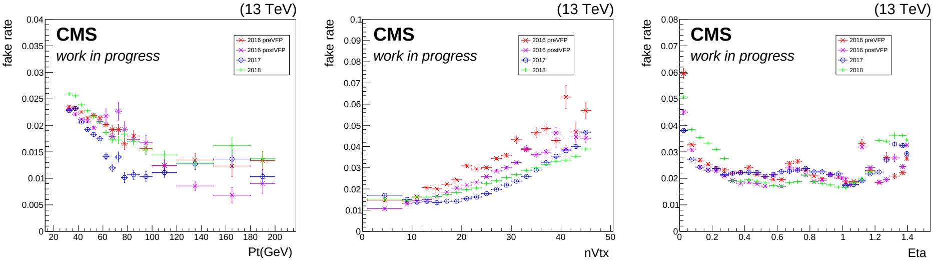
- **Fitting target**
  - ▷ dataset : SingleElectron, trigger : HLT_Ele*_WPTight_Gsf
  - ▷ Tag : electron with $p_T > 35$ GeV, $|\eta| < 2.1$
    match HLT object, medium WP, mini-Isolation < 0.1
  - ▷ Probe : photon with $p_T > 30$ GeV, loose WP
- **Signal template (Breit-wigner convoluting with crystal ball function)**
- **Background template (μ + probe)** utilizing lepton flavor symmetry
  - ▷ W($\rightarrow e\nu$)+γ and Z($\rightarrow$ ee)+γ for the numerator
    di-electron decay of $t\bar{t}$ for the denominator
  - ▷ dataset : SingleMuon, trigger : HLT_IsoMu*
  - ▷ Tag : muon with $p_T > 35$ GeV, $|\eta| < 2.1$
    medium WP, mini-Isolation < 0.2, $|d_0| < 0.05$, $|d_z| < 0.1$
  - ▷ Probe : photon with $p_T > 30$ GeV, loose WP, $\triangle(\mu,\gamma) > 0.3$
- Passing probe (photon candidate) :
  probe doesn't match to an electron with $\triangle R < 0.03$

  and doesn't have pixel seed

- Tag-probe (passing probe) invariant mass from data is fitted with signal and background template to calculate N_{ee} ($N_{e\gamma}$).
- Normalization and parameters of the signal shapes are determined from the fit.
- N_{ee} and $N_{e\gamma}$ values are given by the integrals of signal shapes between 80 GeV and 101 GeV in the corresponding sample.



Fitting plots : 2016-preVFP 2016-postVFP 2017 2018



$$\mathsf{f}\,(p_T, N_{vtx}, \eta) = N \cdot (A \cdot p_T + B)^n \cdot (D + E \cdot N_{vtx}) \cdot \mathsf{f}\,(\eta)$$

Mis-identified γ from jet

It happens when jet energy is mostly carried by a π^0 or η which decays into two nearly collinear photons.

- Jet faking as γ contribution is estimated by applying **"fake rate"** to **"proxy sample"** as an event weight.
- **Proxy sample :** $\ell\gamma$ events from data with γ failing either $\sigma_{i\eta i\eta}$ or $\mathrm{I_{h^\pm}}$ cuts. i.e. $\sigma_{i\eta i\eta} > 0.0106$ or $1.694 < \mathrm{I_{h^\pm}} < 15$ GeV
- **Fake rate (R) :**
  probability of jet being misidentified as γ, estimated in $\mathrm{p_T^{miss}} < 70$ GeV CR.

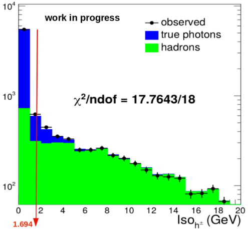
$$\mathrm{R} = \frac{\mathrm{N_{fake}}}{\mathrm{N_{proxy}}} = \frac{\mathrm{f_{had}} \times (\text{Number of signal } \gamma\text{s} - \text{Number of e fake } \gamma\text{s})^{\text{CR}}_{\text{data}}}{(\text{Number of jet proxies})^{\text{CR}}_{\text{data}}}$$

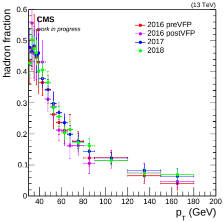
  Hadron fractions ($\mathrm{f_{had}}$) are estimated from template fits to $\mathrm{I_{h^\pm}}$
  $\mathrm{N_{proxy}}$: $\ell\gamma$ events from data with γ failing either $\sigma_{i\eta i\eta}$ or $\mathrm{I_{h^\pm}}$ cuts.
- Parameterize the $\mathrm{p_T}$ dependence of the fake rate using analytical functions.

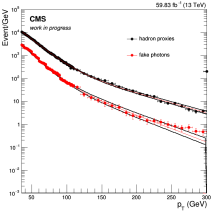
$$\mathrm{R} = \frac{\mathrm{N_{fake}}}{\mathrm{N_{proxy}}} = \frac{C1 \cdot e^{\lambda_1 p_T} + C2 \cdot e^{\lambda_2 p_T}}{C3 \cdot e^{\lambda_3 p_T} + C4 \cdot e^{\lambda_4 p_T}}$$

Hadron fractions ($\mathrm{f_{had}}$) are estimated from template fits to $\mathrm{I_{h^\pm}}$

- **Fitting target**: signal photons from data, $\sigma_{i\eta i\eta} < 0.0106$
- Pure photon template: signal photons from GJet MC, $\sigma_{i\eta i\eta} < 0.0106$ with photon truth-matching to a generator level prompt photon.
- Hadron template: sideband photons from data, $0.0106 < \sigma_{i\eta i\eta} < 0.014$







$$\mathrm{f_{had}} = \frac{\text{Integral of hadronic template in } 0 < I_{h^\pm} < 1.694}{\text{Integral of observed photons in } 0 < I_{h^\pm} < 1.694}, \quad \mathrm{R} = \frac{\mathrm{N_{fake}}}{\mathrm{N_{proxy}}}$$

Mis-identified lepton from jet

All leptons that do not originate from a W/Z are considered as fakes. Fake muons mostly come from heavy flavor quarks, while fake electrons predominantly come from light flavor jets.

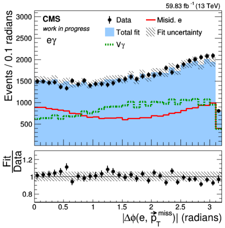
- Jet fake lepton estimate = **Scale factor** × **Lepton proxy sample**
- **Lepton proxy-sample :** one candidate γ, one fake lepton proxy.

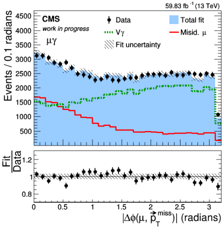
  e proxy :
  - dominantly light-flavoured jets
  - fail $\sigma_{i\eta i\eta}$, $\triangle\eta_{i\eta}$, $\triangle\phi_{i\eta}$ cuts or $0.1 <$ mini-iso < 0.4

  μ **proxy :**
  - dominantly heavy-flavor decay muons b$\rightarrow$ c/u $+ \ell + \bar{\nu}$
  - $0.2 <$ mini-iso < 0.4
- **Scale factor** is obtained from template fitting on $\triangle\phi(\ell, \mathrm{p}_{\mathrm{T}}^{\mathrm{miss}})$

Fake leptons and $V\gamma$ (true lepton) scale factors

- For the fake lepton background, p_T^{miss} is typically caused by mismeasured object whereas W/Z $+\gamma$ events contain genuine p_T^{miss}.
  The W/Z $+\gamma$ and fake lepton have different $\triangle\phi$ (ℓ, p_T^{miss}) shapes.
- The **scale factors** for W/Z $+ \gamma$ and fake lepton backgrounds are determined from a template fit to the $\triangle\phi$ (ℓ, p_T^{miss}) distribution in the control region ($40 < p_T^{miss} < 70$ GeV).
  - ▷ Fit target : $N^{data}_{\ell\gamma} - N^{prediction}_{e\ fake\ \gamma} - N^{prediction}_{jet\ fake\ \gamma} - N^{MC}_{rare\ bkgs}$
  - ▷ Template 1 : misidentified lepton proxy samples
    Template 2 : mixture of $W\gamma$ and $Z\gamma$ MC samples.

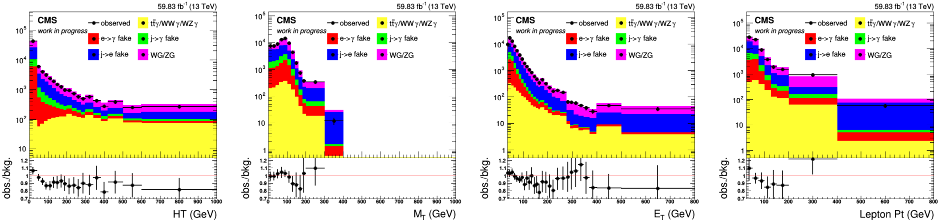




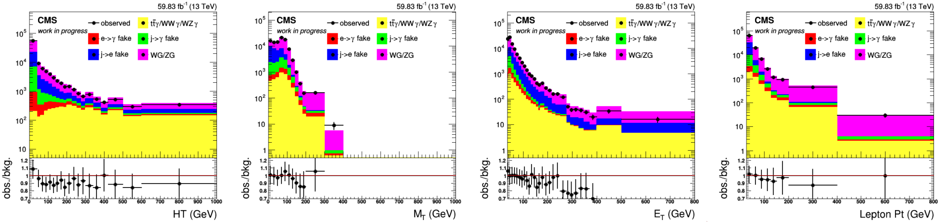
Control region (40 GeV $< p_T^{miss} <$ 70 GeV)

$e\gamma$ channel

2018



$\mu\gamma$ channel



Summary and future plan

- We have looked at each SM background estimation.
- We need to look more closely to understand weird fake rate values in some cases. We also have to understand some of the discrepancies between data and estimated SM backgrounds in the control region.
- The analysis work is ongoing and we are expecting to finish it soon.

Additional materials

$V\gamma$ backgrounds

Take the shape from simulation:

- **$W\gamma$ samples :**
  WGToLNuG_TuneCP5_13TeV-madgraphMLM-pythia8
  WGJets_MonoPhoton_PtG-130_TuneCP5_13TeV-madgraph-pythia8
  WGJets_MonoPhoton_PtG-40to130_TuneCP5_13TeV-madgraph-pythia8
- **$Z\gamma$ samples :**
  ZGToLLG_01J_5f_TuneCP5_13TeV-amcatnloFXFX-pythia8

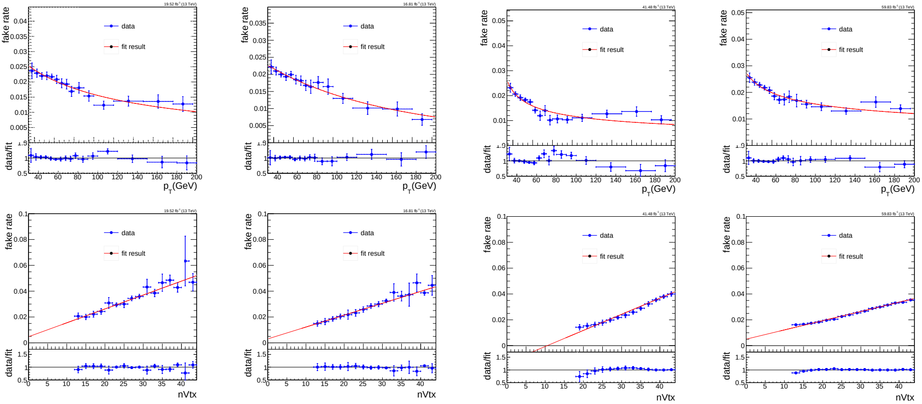
Rare backgrounds

$t\bar{t}\gamma$, $WW\gamma$, $WZ\gamma$

Backgrounds are taken directly from simulation.

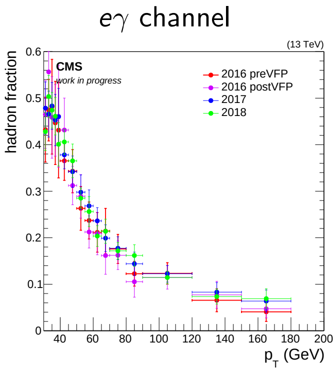
- TTGJets_TuneCP5_13TeV-amcatnloFXFX-madspin-pythia8
- TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8
- WWG_TuneCP5_13TeV-amcatnlo-pythia8
- WZG_TuneCP5_13TeV-amcatnlo-pythia8

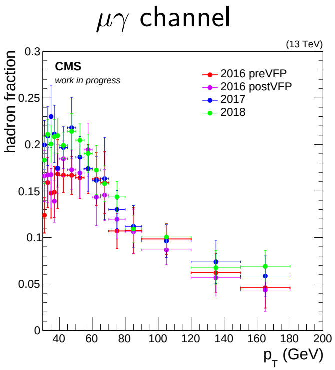
$$\mathsf{f}\ (p_T, N_{vtx}, \eta) = N \cdot (A \cdot p_T + B)^n \cdot (D + E \cdot N_{vtx}) \cdot \mathsf{f}\ (\eta)$$



2016-preVFP 2016-postVFP 2017 2018

Hadron fractions (f_{had})

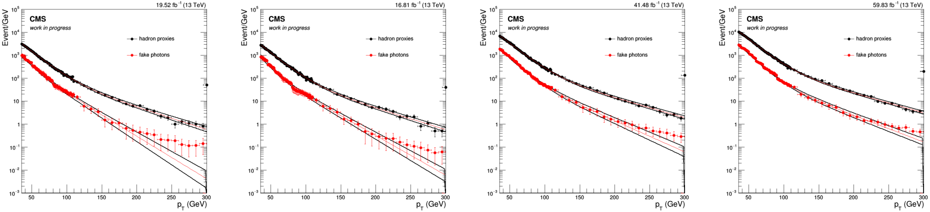




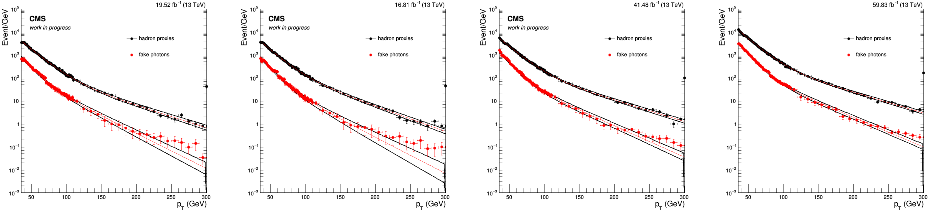
Fitting plots in $e\gamma$ channel : 2016-preVFP 2016-postVFP 2017 2018

Fitting plots in $\mu\gamma$ channel : 2016-preVFP 2016-postVFP 2017 2018

$e\gamma$ channel



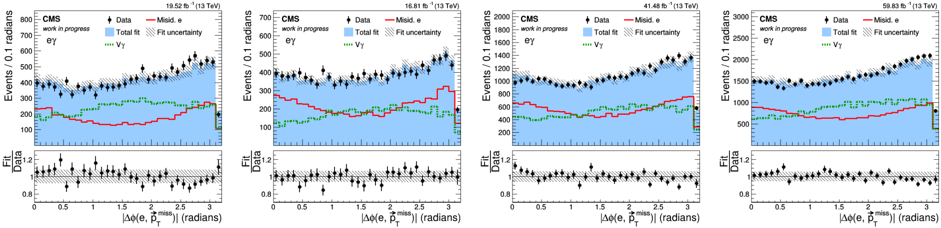
$\mu\gamma$ channel



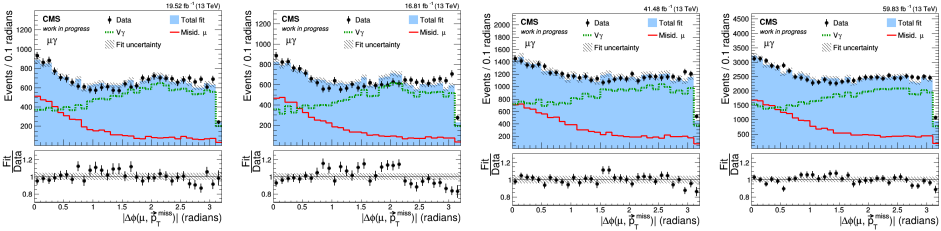
$$\text{Fake rate, } R = \frac{N_{\text{fake}}}{N_{\text{proxy}}}$$

Template fitting on $\Delta\phi\,(\ell, p_T^{miss})$

$e\gamma$ channel



$\mu\gamma$ channel



- Scale factors obtained from template fitting on $\triangle\phi(\ell, p_T^{miss})$
- Fake fraction = coeff of fake lepton pdf (Template 1) used in fitting
- Fake lep scale = $\dfrac{\text{Fake fraction} \times \text{Total events in Fit target}}{\text{Integral of fake lepton sample (Template 1)}}$
- Vgamma scale = $\dfrac{\text{(1-Fake fraction)} \times \text{Total events in Fit target}}{\text{Integral of W}\gamma\text{ and Z}\gamma\text{ MC sample (Template 2)}}$

eγ channel

	2016-preVFP	2016-postVFP	2017	2018
Vgamma scale	1.95	1.7	1.83	2.0
Fake lep scale	0.39	0.52	0.41	0.37

μγ channel

	2016-preVFP	2016-postVFP	2017	2018
Vgamma scale	1.72	1.77	1.63	1.49
Fake lep scale	0.88	0.97	0.88	0.94