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CMS Draft Analysis Note

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2024/11/16
Archive Hash: a9d646e-D
Archive Date: 2024/09/14

Search for new physics in dileptonically decaying top quark pairs produced with a photon in proton-proton collisions at sqrt(s) = 13 TeV using effective field theory in Run II

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Abstract

We present a search for new physics using the framework of effective field thoery (EFT) in events containing a pair of top quarks and a photon, where the both top quark decay via the leptonic channels (e and μ). The Run 2 data set is used, consisting of 137 fb^{-1} of data collected by the CMS experiment. Private EFT simulation samples are genearted using the dim6top model for 11 Wilson coefficeints affecting the $\mathrm{t\bar{t}}\gamma$ process: c_{Qq}^{11}, c_{Qq}^{31}, c_{Qq}^{18}, c_{Qq}^{38}, c_{tq}^{1}, c_{tq}^{8}, $c_{\varphi Q}^{-}$, $c_{\varphi \mathrm{t}}$, $c_{\mathrm{t}G}$, c_{tW}, and c_{tZ}. All 11 coefficients are fit both simultenously and individually.

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PDFTitle:	Search for new physics in top quark pair production with a a photon in proton-proton collisions at sqrt“(s“) = 13 TeV using effective field theory in Run II
PDFSubject:	CMS
PDFKeywords:	CMS, physics, top, EFT

Please also verify that the abstract does not use any user defined symbols

1 Introduction

The standard model effective field theory (SMEFT) provides a robust framework for describing physics beyond the SM, specifically when the on-shell effects are beyond the reach of the LHC, and the heavy mass propagators may be integrated out. The SMEFT model respects the observed symmetries of the SM, and cast new physics in terms of combinations of SM fields. A general SMEFT Lagrangian may be parameterized as perturbative expansion, where the SM is the lowest order term:

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d,i} \frac{c_i^d}{\Lambda^{d-4}} \mathcal{O}_i^d, \tag{1}$$

where $\mathcal{L}_{\text{SM}}$ is the SM Lagrangian, c^d are the Wilson coefficients (WCs) of dimension d controlling the strength of the EFT effects, Λ is the energy scale (set to 1 TeV for sample generation), suppressed by increasing powers of $d-4$, and $\mathcal{O}$d are the SM fields of dimension d. Additionally, we choose to respect the lepton flavor (LF) and baryon number (BN) symmetries observed in nature. In SMEFT, all odd-numbered dimensions violate LF and/or BN, so the lowest order this analysis is sensitive to is dimension six. We use the dim6top model [1] to generate events involving $\mathrm{t\bar{t}}$ pairs with exactly one photon.

2 Data and MC samples

2.1 Data samples

The analysis uses the full Run 2 dataset collected by the CMS collaboration, with all events marked in the Golden JSON file 1. The triggers for each year are listed in Tables 2, 3, and 4.

Year	Golden JSON	Int. Lumi (fb^{-1})
2016	Cert_271036-284044_13TeV_Legacy2016_Collisions16_JSON	36.33
2017	Cert_294927-306462_13TeV_UL2017_Collisions17_GoldenJSON	41.48
2018	Cert_314472-325175_13TeV_Legacy2018_Collisions18_JSON	59.83

Table 1: JSON files with certified luminosity blocks used for each data-taking year.

2.2 MC signal samples

Signal samples are generated at the matrix-element (ME) level at leading order (LO) using the MADGRAPH event generator with the dim6top UFO model [2] to model the EFT effects. Events are generated with up to one extra parton at the ME level. The decay of the top quarks, additional jets, and ME parton showering and hadronization are modeled using the PYTHIA generator [3]. The 11 WCs in Table 5 are found to change the $\mathrm{t\bar{t}}\gamma$ cross section by any measurable amount with the absolute value of the WC below 100.

TODO: update with $\mathrm{t\bar{t}}\gamma$ samples

2.3 MC background samples

All background samples are generated only at the SM. The $\mathrm{t\bar{t}}$, single-t, $\mathrm{Z}\gamma$, and di-vector boson samples are generated at next-to-leading order (NLO) using POWHEG [4–9] at the ME level. The Drell-Yan (DY) samples are generated at LO using MADGRAPH. All samples use PYTHIA to model the parton shower and hadronization steps.

2016 Triggers
SingleMuon
IsoMu24
IsoTkMu24
IsoMu22_eta2p1
IsoTkMu22_eta2p1
IsoMu22
IsoTkMu22
IsoMu27
SingleElectron
Ele27_WPTight_Gsf
Ele25_eta2p1_WPTight_Gsf
Ele27_eta2p1_WPLoose_Gsf
DoubleMuon
Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ
Mu17_TrkIsoVVL_Mu8_TrkIsoVVL
Mu17_TrkIsoVVL_TkMu8_TrkIsoVVL
Mu17_TrkIsoVVL_TkMu8_TrkIsoVVL_DZ
TripleMu_12_10_5
DoubleEG
Ele23_Ele12_CaloIdL_TrackIdL_IsoVL
Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ
Ele16_Ele12_Ele8_CaloIdL_TrackIdL
MuonEG
Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL
Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ
Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ
Mu8_DiEle12_CaloIdL_TrackIdL
Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL
Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ
Mu23_TrkIsoVVL_Ele8_CaloIdL_TrackIdL_IsoVL
Mu23_TrkIsoVVL_Ele8_CaloIdL_TrackIdL_IsoVL_DZ
DiMu9_Ele9_CaloIdL_TrackIdL

Table 2: Triggers used to record the 2016 data for this analysis.

A noticeable discrepancy is observed in the CR enriched in $Z\gamma$. There are two causes for this. The first is the photon isolation cone (R0gamma) which is set to 0.05. This results in a large number of soft and collinear photons produced near jets. These soft and collinear photons can lead to divergences in the cross section computation, resulting in an incorrect normalization for $Z\gamma$. The second is a clear shape in the jet multiplicity. The $Z\gamma$ is generated at NLO, so the zero and one parton events are computed in POWHEG. All higher jet multiplicities are modeled purely in PYTHIA, which is know to not match the data as well. To correct both issues, we include a $Z\gamma$ CR in the final fit which is fully correlated with the $Z\gamma$ in the SR. This allows us to correct for the data-MC disagreement in an orthongonal channel, and account for correlations among systematic uncertainties when applying said corrections.

TODO: add missing samples that are being skimmed

2017 Triggers
SingleMuon
IsoMu24
IsoMu27
SingleElectron
Ele32_WPTight_Gsf
Ele35_WPTight_Gsf
DoubleMuon
Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ
Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass3p8
TripleMu_12_10_5
DoubleEG
Ele23_Ele12_CaloIdL_TrackIdL_IsoVL
Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ
Ele16_Ele12_Ele8_CaloIdL_TrackIdL
MuonEG
Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL
Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ
Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ
Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ
Mu8_DiEle12_CaloIdL_TrackIdL
Mu8_DiEle12_CaloIdL_TrackIdL_DZ
DiMu9_Ele9_CaloIdL_TrackIdL_DZ

Table 3: Triggers used to record the 2017 data for this analysis.

2.4 Overlap removal

Following the approach taken in [10], we apply an overlap removal between $\mathrm{t\bar{t}}\gamma$ and $\mathrm{t\bar{t}}$ samples. The radiation of a high p_{T} photon is also possible in $\mathrm{t\bar{t}}$, and this results in an overlapping phase space between the two samples. An overlap removal procedure is applied on $\mathrm{t\bar{t}}$ at generator level that vetoes events from the sample with photons that have $p_{\mathrm{T}} > 10\,\mathrm{GeV}$, $|\eta| < 5$, and are isolated from other particles (except for other photons and neutrinos) with $p_{\mathrm{T}} > 5\,\mathrm{GeV}$ within $\Delta R < 0.1$ cone. Furthermore, the photons are required to have non-hadronic particles in their parentage history. In the case of $\mathrm{t\bar{t}}\gamma$, if there are events with no such photons, then such events are vetoed from the sample. A similar overlap removal procedure is also applied between $\mathrm{Z}\gamma$ and DY, where the kinematic requirements on the photons are changed to be $p_{\mathrm{T}} > 15\,\mathrm{GeV}$, $|\eta| < 2.6$, and isolation cone of $\Delta R < 0.05$. Events with the photons meeting the criteria are vetoed from DY, and conversely, events with no such photons are discarded from $\mathrm{Z}\gamma$.

3 Object selection

4 Event selection

The analysis targets events enriched in $\mathrm{t\bar{t}}\gamma$. To achieve this, we require exactly two oppositely charged final-state leptons, with a (sub)leading p_{T} of 25(15) GeV. The two leptons can be either same-flavored (ee,$\mu\mu$) or opposite-flavored (eμ). We also require that the two leptons have a minimum invariant mass $m(\ell\ell)$ of 20 GeV, which suppresses all event contributions from multijet QCD processes. Furthermore, in the same-flavored channel, two other selection criteria are

2018 Triggers
SingleMuon
IsoMu24
IsoMu27
EGamma
Ele32_WPTight_Gsf
Ele35_WPTight_Gsf
Ele23_Ele12_CaloIdL_TrackIdL_IsoVL
Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ
Ele16_Ele12_Ele8_CaloIdL_TrackIdL
DoubleMuon
Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ
Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass3p8
TripleMu_12_10_5
MuonEG
Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL
Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ
Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ
Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ
Mu8_DiEle12_CaloIdL_TrackIdL
Mu8_DiEle12_CaloIdL_TrackIdL_DZ
DiMu9_Ele9_CaloIdL_TrackIdL_DZ

Table 4: Triggers used to record the 2018 data for this analysis.

Operator category	WCs	WC variable names
Two heavy quarks	$c_{\varphi Q}^{-}$, $c_{\varphi t}$, c_{tW}, c_{tZ}, c_{tG}	cpQM, cpt, ctW, ctZ, ctG
Two light quarks two heavy quarks	c_{Qq}^{31}, c_{Qq}^{38}, c_{Qq}^{11}, c_{Qq}^{18}, c_{tq}^{1}, c_{tq}^{8}	cQq13, cQq83, cQq11, cQq81, ctq1, ctq8

Table 5: List of WCs included in this analysis. The definitions of the WCs and the definitions of the corresponding operators can be found in Table 1 of Ref. [2]. Note that in order to allow MADGRAPH5_aMC@NLO to properly handle the emission of gluons from the vertices involving the c_{tG} WC, an extra factor of the strong coupling is applied to the c_{tG} coefficients.

imposed. First, we demand that the events have $m(\ell\ell)$ outside of 15 GeV of Z mass in order to reject DY contribution. Second, the events must have $m(\ell\ell\gamma)$ outside of 15 GeV of Z mass, which aids in suppression of $Z\gamma$ contribution in the signal region. We require exactly one photon with $p_T > 20\,\text{GeV}$, which helps remove the $t\bar{t}$ background where PYTHIA generated a soft photon in the shower step. The photon must pass the medium cutBased ID. We also require at least one jet, and at least one b-tagged jets. Jets are tagged as originated from a b quark using the DEEPJET algorithm [11, 12]. We use the fixed working-point tagger with the medium ID, and the "mujets" scale factors. Table 11 gives a breakdown of the event selection. Each event weight is parameterized by

$$w(c_i) = s_0 + \sum_{j}^{N} s_{1j} \frac{c_j}{\Lambda^2} + \sum_{j}^{N} s_{2j} \frac{c_j^2}{\Lambda^4} + \sum_{j \neq k}^{N} s_{3jk} \frac{c_j}{\Lambda^2} \frac{c_k}{\Lambda^2}, \tag{2}$$

where s_0, s_1, s_2, and s_3 are the structure contents for the SM, SM-EFT interference, pure EFT, and EFT interference terms respectively.

Process	Xsec (pb)	Events	Location
$t\bar{t}H$	0.2151	8.0M	/store/user/kmohrman/FullProduction/FullR2/UL16/Round1/Batch1/naodOnly_step/v2/nAOD_step_ttHJet_all22WCsStartPtCheckdim6TopMay20GST_run0
$t\bar{t}l\nu$	0.2353	9.1M	/store/user/kmohrman/FullProduction/FullR2/UL16/Round1/Batch1/naodOnly_step/v2/nAOD_step_ttlnuJet_all22WCsStartPtCheckdim6TopMay20GST_run0
$t\bar{t}\ell\bar{\ell}$	0.281	8.1M	/store/user/kmohrman/FullProduction/FullR2/UL16/Round1/Batch1/naodOnly_step/v2/nAOD_step_ttllNuNuJetNoHiggs_all22WCsStartPtCheckdim6TopMay20GST_run0
$tl\bar{l}q$	0.0758	7.5M	/store/user/kmohrman/FullProduction/FullR2/UL16/Round1/Batch1/naodOnly_step/v2/nAOD_step_tllq4fNoSchanWNoHiggs0p_all22WCsStartPtCheckV2dim6TopMay20GST_run0
tHq	0.07096	7.5M	/store/user/kmohrman/FullProduction/FullR2/UL16/Round1/Batch1/naodOnly_step/v2/nAOD_step_tHq4f_all22WCsStartPtCheckdim6TopMay20GST_run0
$t\bar{t}t\bar{t}$	0.0120	7.5M	/store/user/kmohrman/FullProduction/FullR2/UL16/Round1/Batch1/naodOnly_step/v2/nAOD_step_tttt_FourtopsMay3v1_run0
$t\bar{t}\gamma$	2.2471	15M (update)	/store/user/apiccine/FullProduction/FullR2/UL16/Round1/Batch1/nAOD_step/v1patch_GCRC/nAOD_step_ttgamma_0001_run0

Table 6: Privately produced UL16 signal samples used in this analysis, located at the Notre Dame T3.

UL16APV Background Samples	Xsec (pb)
/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	87.31
/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	364.351
/TTZToLL_M-1to10_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.082
/TWZToLL_thad_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Whad_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	0.0015
/WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	12.178
/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-[v1,ext1-v1]/NANOAODSIM	0.2086
/WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-[v1,ext1-v1]/NANOAODSIM	0.1651
/WLLJJ_WToLNu_EWK_TuneCP5_13TeV_madgraph-madspin-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	5.2843
/WZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-[v1,ext1-v1]/NANOAODSIM	0.05565
/ZZTo4L_TuneCP5_13TeV_powheg_pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	1.256
/GluGluToContinToZZTo2e2mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2nu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v3/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2mu2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo4e_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	0.00159
/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-[v1,ext1-v1]/NANOAODSIM	0.01398
/ZGToLLG_01J_5f_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	55.78
/ZZ_TuneCP5_13TeV-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	16.52
/WZ_TuneCP5_13TeV-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	47.13
/WW_TuneCP5_13TeV-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	116.1
/TTZZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	0.001573
/TTWZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	0.002919
/TTWW_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	0.0115
/WGToLNuG_01J_5f_PDFWeights_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	191
/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	18610.0
/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	6025.2
/ST_s-channel_4f_leptonDecays_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	3.68
/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	136.02
/ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	80.95
/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	35.85
/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	35.85
/TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	831.76
/WJetsToLNu_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	61526.7

Table 7: List of UL16APV background samples used in this analysis (CMSSW_10_6_26). In the first section of the table are listed the samples of the processes for which we use the simulation to extract the final yields and shapes, in the second section the samples of the processes we will estimate from data. The "TTJets*" sample was used to verify the $t\bar{t}\gamma$ overlap removal.

5 Background estimation

5.1 Zgamma background

- $Z\gamma$ forms the most important prompt photon background contribution to the SR
- How do we create a $Z\gamma$ enriched region in the analysis?
- Talk about njet shape not being well modeled for $Z\gamma$ in this CR
- We then follow the approach taken by Top-23-002 where we feed this CR to the final fitting
- Several kinematic distributions relevant to this CR

5.2 Non-prompt photon background

Once we apply the event selection outlined in 4, we still have nonprompt photon background, mostly coming from $t\bar{t}$ events. However, the nonprompt photons can originate from various sources and can contain real photons. Therefore, it is important to understand the differences between a prompt and a nonprompt photon. The nonprompt photon categorization is done using a generator level matching procedure. The procedure takes a reconstructed photon and matches it to the nearest generator particle with p_T within 50% of the photon. In case no such

UL16 Background Samples	Xsec (pb)
/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	87.31
/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	364.351
/TTZToLL_M-1to10_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.082
/TWZToLL_thad_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Whad_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.0015
/WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	12.178
/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-[v1,ext1-v1]/NANOAODSIM	0.2086
/WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-[v1,ext1-v1]/NANOAODSIM	0.1651
/WLLJJ_WToLNu_EWK_TuneCP5_13TeV_madgraph-madspin-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM	5.2843
/WZTo3LNu_mllmin4p0_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2	5.2843
/WLLJJ_WToLNu_EWK_TuneCP5_13TeV_madgraph-madspin-pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM	0.2353
/WZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-[v1,ext1-v1]/NANOAODSIM	0.05565
/ZZTo4L_TuneCP5_13TeV_powheg_pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	1.256
/GluGluToContinToZZTo2e2mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2nu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.00319
/GluGluToContinToZZTo2mu2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.00319
/GluGluToContinToZZTo4e_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.00159
/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-[v1,ext1-v1]/NANOAODSIM	0.01398
/ZGToLLG_01J_5f_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	55.78
/ZZ_TuneCP5_13TeV-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	16.52
/WZ_TuneCP5_13TeV-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	47.13
/WW_TuneCP5_13TeV-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	116.1
/TTZZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.001573
/TTWZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.002919
/TTWW_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	0.0115
/WGToLNuG_01J_5f_PDFWeights_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	191
/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	18610.0
/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	6025.2
/ST_s-channel_4f_leptonDecays_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM	3.68
/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	136.02
/ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	80.95
/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM	35.85
/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM	35.85
/TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	831.76
/WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	61526.7

Table 8: List of UL16 background samples used in this analysis (CMSSW_10_6_26). In the first section of the table are listed the samples of the processes for which we use the simulation to extract the final yields and shapes, in the second section the samples of the processes we will estimate from data. The "TTJets*" sample was used to verify the $t\bar{t}\gamma$ overlap removal.

particle is found within a cone of radius of 0.3 around the photon, the matching fails. If the photon is matched to a gen-level lepton, quark, or a boson, it is labeled as a genuine/real photon. Else, it is nonprompt photon.

Owing to the application of overlap removal between and $t\bar{t}$ samples as described in 2.4, ideally, all the events left in $t\bar{t}$ should contribute to nonprompt photon categories, making $t\bar{t}$ the biggest nonprompt contributor in our analysis. However, DY and single-top processes could also contribute.

We rely on data-driven methods for non-prompt photon background estimation because simulations struggle to model these backgrounds accurately. Non-prompt photons, which often arise from misidentified jets or electrons, involve complex processes and detector effects that MC simulations fail to fully capture. Furthermore, we also need to generate a lot of simulations for a better estimation of non-prompt photon backgrounds. Using data, on the contrary, allows us to account for these experimental nuances directly, providing a more reliable background estimate with better statistical uncertainty than what simulations can achieve.

We use ABCD method for this estimation, similar to the approach taken by [10]. As shown in figure [PUT FIGURE REF HERE], we define four orthogonal regions. Region A is the signal region of the analysis, and along with region B, they form the application region (AR) of the method. Regions C and D are the measurement regions (MRs). These four regions are distinguished by using two photon observables that have good discriminating power between genuine and nonprompt photons. They are: i) PF charged hadron isolation (I_{ch}) and ii) $\sigma_{i\eta}$. The I_{ch} variable is a measure of the isolation of the photon from charged hadrons in a cone around the photon direction. The non-prompt photons have bigger values of I_{ch} since they are often

UL17 Background Samples	Xsec (pb)
/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	87.31
/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	364.351
/TTZToLL_M-1to10_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.082
/TWZToLL_thad_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Whad_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.0015
/WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	12.178
/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-[v1,ext1-v2]/NANOAODSIM	0.2086
/WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.1651
/WZTo3LNu_mllmin4p0_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	5.2843
/WLLJJ_WToLNu_EWK_TuneCP5_13TeV_madgraph-madspin-pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM	0.2353
/WZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-[v1,ext1-v2]/NANOAODSIM	0.05565
/ZZTo4L_TuneCP5_13TeV_powheg_pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	1.256
/GluGluToContinToZZTo2e2mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2nu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2mu2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo4e_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	0.00159
/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.01398
/ZGToLLG_01J_5f_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	55.78
/ZZ_TuneCP5_13TeV-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	16.52
/WZ_TuneCP5_13TeV-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	47.13
/WW_TuneCP5_13TeV-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	116.1
/TTZZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.001573
/TTWZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.002919
/TTWW_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.0115
/WGToLNuG_01J_5f_PDFWeights_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	191
/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	18610.0
/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	6025.2
/ST_s-channel_4f_leptonDecays_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	3.68
/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	136.02
/ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	80.95
/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	35.85
/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM	35.85
/TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	831.76
/WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	61526.7

Table 9: List of UL17 background samples used in this analysis (CMSSW_10_6_26). In the first section of the table are listed the samples of the processes for which we use the simulation to extract the final yields and shapes, in the second section the samples of the processes we will estimate from data. The "TTJets*" sample was used to verify the $t\bar{t}\gamma$ overlap removal.

accompanied by nearby charged hadrons. Similarly, the $\sigma_{i\eta}$ variable represents the width of the photon shower in the ECAL. Lower values of $\sigma_{i\eta}$ are highly characteristic of prompt photons. It is also important to mention that these two variables make up the cutBased ID for photons, so an easy way to visualize the ABCD diagram would be that the photons entering region A are at least medium cutBased ID and for region B and the MRs, we relax the cuts on these two observables. As can be seen from the schematic, the selection criteria for the AR and MR are as follows:

Any criteria that are not listed here are exactly the same as that of the signal region (region A). In order to populate events in these four regions, we first define a photon collection that is at least medium cutbased with the $\sigma_{i\eta}$ and I_{ch} components relaxed. This collection is called fakeable photon collection. The fakeable photon collection has I_{ch} of (0,1.141) $\cup$ (4.0,15) and $\sigma_{i\eta}$ of (0,0.01015) $\cup$ (0.012,0.022). All other cuts are same as that of signal region photons. The gaps along the two axes reduce the contamination of genuine photons in non-signal regions without having a significant impact on the statistics in these regions.

5.3 Other backgrounds

6 Statistical methods

We perform statistical inference to find the maximum likelihood estimate for all 11 WCs using the combine tool [13]. Each bin is treated as an independent Poisson measurement, where the mean value is given by the sum of all weights (Eq. 2) in a given bin. A profiled likelihood fit is performed using two scenarios: scanning over a single WC while treating the other 10

UL18 Background Samples	Xsec (pb)
/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	87.31
/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	364.351
/TTZToLL_M-1to10_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	0.082
/TWZToLL_thad_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Whad_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	0.003004
/TWZToLL_tlept_Wlept_5f_DR_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	0.0015
/WWTo2L2NuWWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	12.178
/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	0.2086
/WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	0.1651
/WZTo3LNu_mllmin4p0_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	5.2843
/WLLJJ_WToLNu_EWK_TuneCP5_13TeV_madgraph-madspin-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.2353
/WZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-[v1,ext1-v2]/NANOAODSIM	0.05565
/ZZTo4L_TuneCP5_13TeV_powheg_pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	1.256
/GluGluToContinToZZTo2e2mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2nu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2e2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo2mu2tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.00319
/GluGluToContinToZZTo4e_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4mu_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.00159
/GluGluToContinToZZTo4tau_TuneCP5_13TeV-mcfm701-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	0.00159
/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	0.01398
/ZGToLLG_01J_5f_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	55.78
/ZZ_TuneCP5_13TeV-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	16.52
/WZ_TuneCP5_13TeV-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	47.13
/WW_TuneCP5_13TeV-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	116.1
/TTZZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.001573
/TTWZ_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.002919
/TTWW_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	0.0115
/WGToLNuG_01J_5f_PDFWeights_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	191
/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	18610.0
/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	6025.2
/ST_s-channel_4f_leptonDecays_TuneCP5_13TeV-amcatnlo-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	3.68
/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	136.02
/ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	80.95
/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	35.85
/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	35.85
/TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	831.76
/WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	61526.7

Table 10: List of UL18 background samples used in this analysis (CMSSW_10_6_26). In the first section of the table are listed the samples of the processes for which we use the simulation to extract the final yields and shapes, in the second section the samples of the processes we will estimate from data. The "TTJets*" sample was used to verify the $t\bar{t}\gamma$ overlap removal.

Selection	Signal region
N_{leptons}	2 tight
Lepton charge	$\ell^{\pm}\ell^{\mp}$
Lepton flavor	e and μ
$\ell_0(\ell_1)$ p_{T}	25 (15) GeV
$m(\ell\ell)$	> 20 GeV
$\lvert m(\ell\ell) - m(\mathrm{Z})\rvert$ SF	> 15 GeV
$\lvert m(\ell\ell\gamma) - m(\mathrm{Z})\rvert$ SF	> 15 GeV
N_{γ}	1 medium
N_{jets}	≥ 1
$N_{\mathrm{b-jets}}$ (DEEPJET)	≥ 1

Table 11: Signal region event selection

Measurement Region	**Application Region**
$4.0 < I_{ch} < 15$	$I_{ch} < 1.141$
$N_{bjet} \geq 0$	$N_{bjet} > 1$
$N_j \geq 1(0)$ for SF(OF)	$N_j \geq 1$ (both flavors)

Table 12: Selection criteria for the ABCD regions

WCs as additional, unconstrained nuisance parameters (NPs); or scanning over a single WC and fixing the other 10 to their SM value of 0. All NPs are profiled in both cases. While Wilks' theorem cannot guarantee proper coverage when EFT effects are parametrized with quadratic polynomials [14], we still use the standard 68, 95, and 99.7% levels defined as when twice the negative log-likelihood crosses 1, 4, and 9 respectively.

7 Systematic uncertainties

A number of experimental and theoretical systematic uncertainties are considered in the analysis. Unless otherwise stated, each term is correlated among all processes and years. Terms labeled as "rate" only affect the total normalization, and are constrained with a ln N prior. Terms labeled as "rate + shape" affect both the total normalization and the shape of the fitted distribution. These terms are provided as up/down templates in combine, and is constrained by a Gaussian prior.

TODO: add all the standard systs.

Photon identification and efficiency: Rate + shape. The SFs for photon ID and efficiency (provided by the EGM POG) are shifted up/down by their total uncertainty to define the $\pm1\sigma$ templates.

Pixel veto: Rate + shape. An additional map for the pixel seed veto is provided by the EGM POG based on the photon $|\eta|$ and $R9$ energy crystal cluster. This map is shifted up/down by the total uncertainty.

Conversion-safe electron veto: Rate + shape. An additional map for the conversion-safe electron veto is provided by the EGM POG. The $\pm1\sigma$ uncertainty is estimated by shifting the map up/down by the total uncertainty.

8 Results

9 Summary

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