Inclusive & differential ttγ measurement in the dilepton channel

Experimental joker talk

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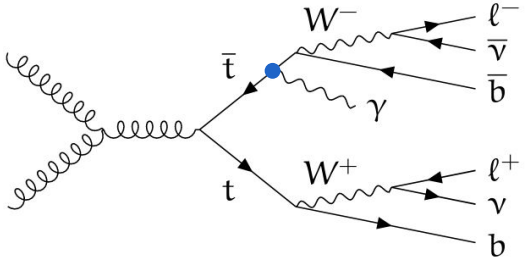
for the CMS collaboration

14th International Workshop on Top Quark Physics

Introduction

Goal and motivation:

- Inclusive & differential measurements using 138 fb^{-1} of CMS data in 2 lepton channel
- Probe t-γ coupling → constrain SMEFT operators that could modify it
- Combination of EFT result with l+jets measurement

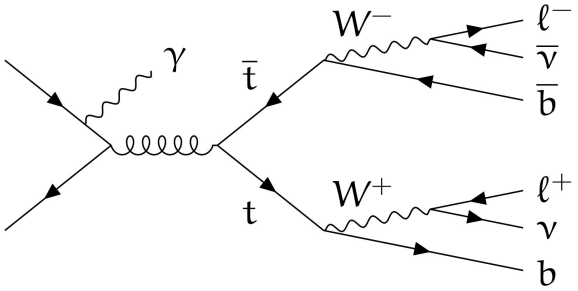


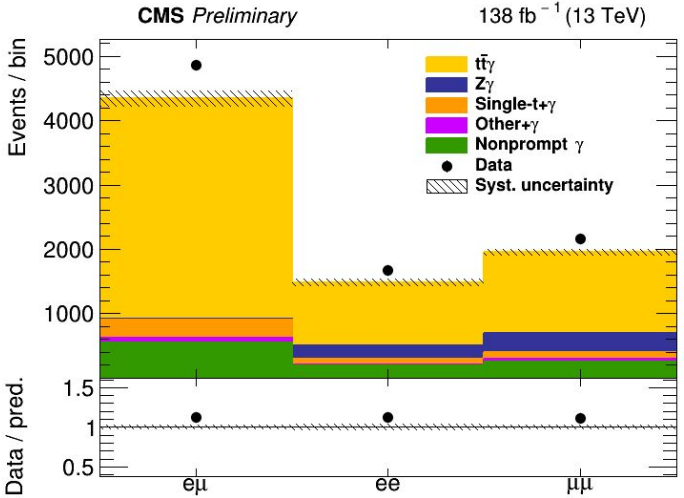
Signal simulation:

- simulated as p p → 2l 2b 2v + γ at leading order
- photon can originate anywhere, no cuts targeting photons from top quarks
- overlap with ttbar removed using generator information

Photon categories:

- prompt γ: gen-match to photon from leptons / quarks / bosons
- nonprompt γ: all others / photons from mesons, faked by jets or from pileup





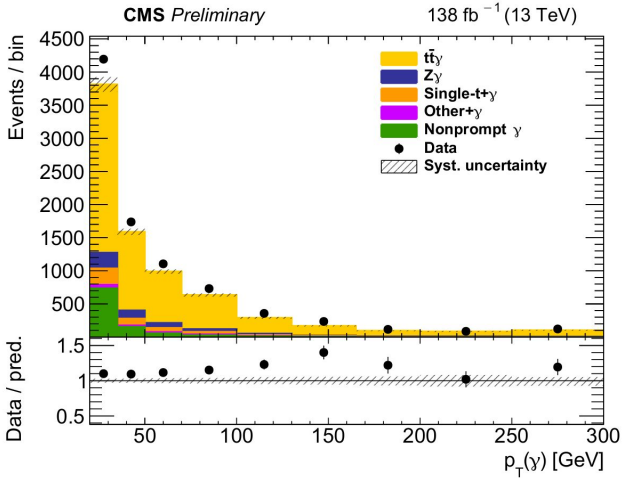
Background modeling & signal selection

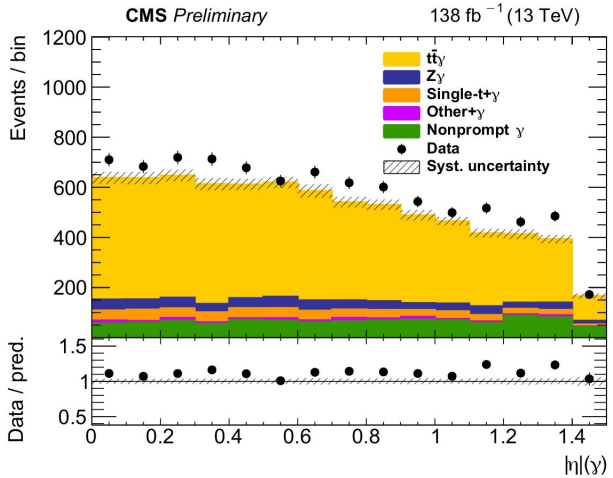
Backgrounds:

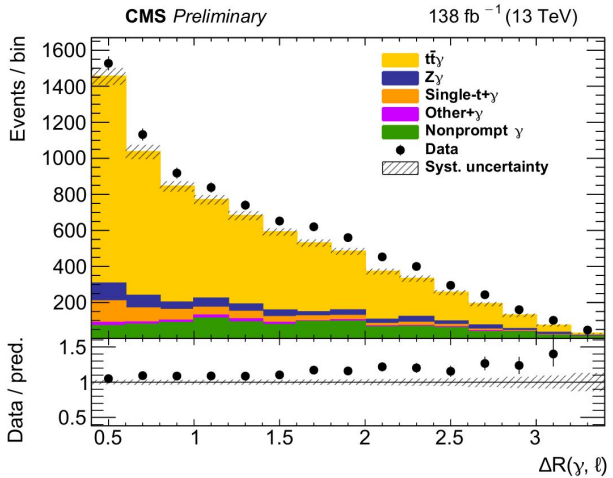
- **$Z\gamma$:** predicted using simulation, mismodeling corrected using control region
- **Single-t+γ & Other+γ:** predicted using simulation
- **nonprompt γ** (any process) : **estimated from data,** closure test performed in simulation

Signal selection:

- two isolated, OS leptons p_T>25/15 GeV $|\eta|$<2.4 m(ll) > 20 GeV $|m(ll) - m_Z|$ > 15 GeV
- one isolated photon p_T>20 GeV $|\eta|$<1.4442 $\Delta R(\ell,\gamma)$>0.4 $|m(ll\gamma) - m_Z|$ > 15 GeV
- at least one b-tagged jet p_T>30 GeV $|\eta|$<2.4 $\Delta R(j,\gamma)$>0.1, $\Delta R(j,\ell)$>0.4

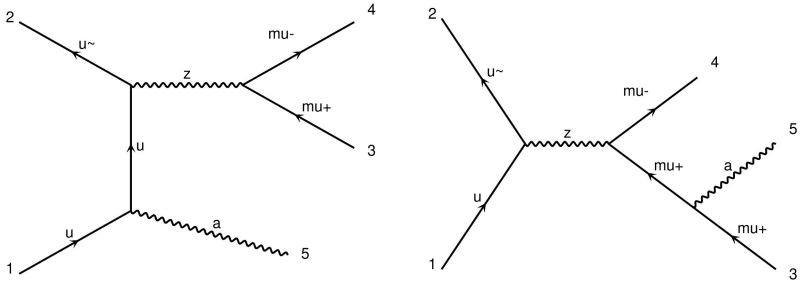


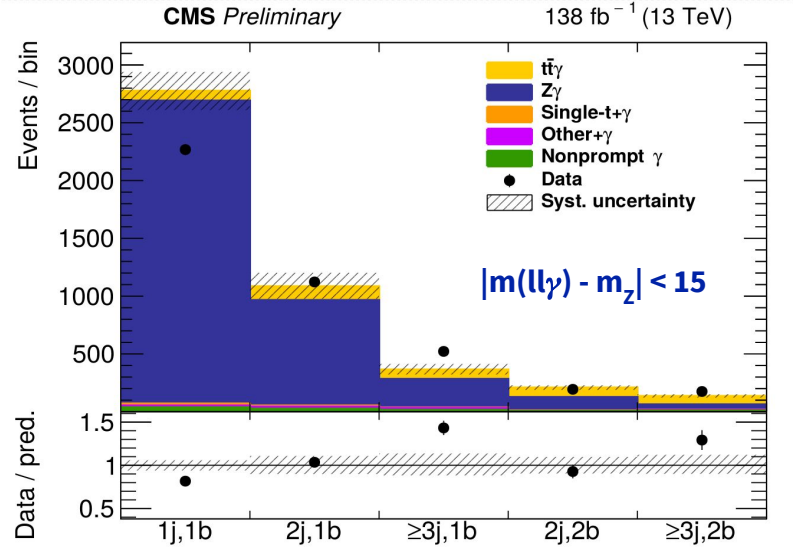


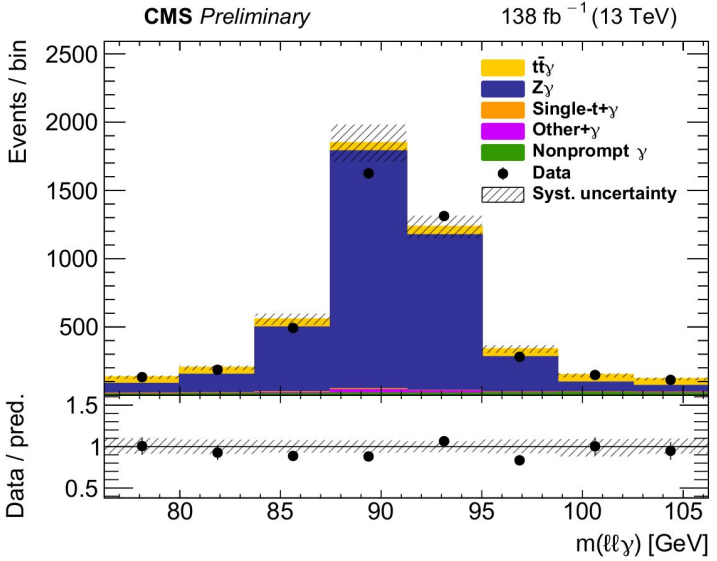


Zγ correction

- Control region: invert signal region cut on $|m(ll\gamma) - m_Z|$
- Mismodeling of N_j, N_b distribution, other distributions OK
- Other distributions look reasonable
- Correction factors per N_j, N_b bin, for same flavour channels
- Consider uncertainties for
  - statistics of correction factors
  - presence of signal in the CR
  - differences in production channel: ISR vs FSR photons





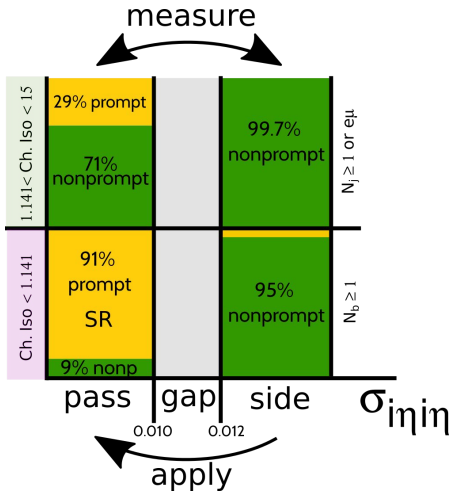


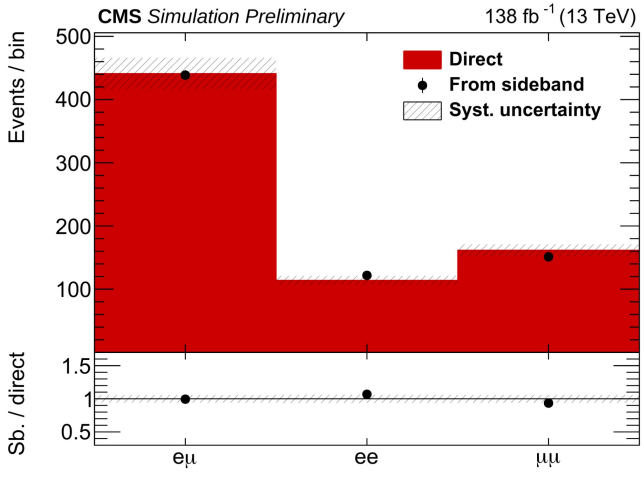
Nonprompt γ prediction

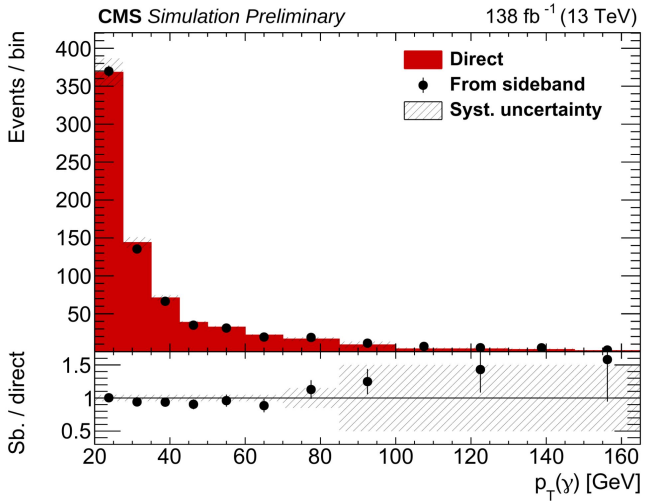
Relax cuts on $\sigma_{\eta\eta}$ and Charged Isolation cuts in photon ID, then:

- measure # passing $\sigma_{\eta\eta}$ / # falling into sideband in events failing Charged Isolation cut
- apply to events passing Charged Isolation cut → estimate of nonprompt γ yield in signal region
- prompt γ contributions subtracted before measuring / applying the ratios
- Zγ corrections applied in all regions

- Closure tests performed in simulation → systematic uncertainties assigned based on level of closure







Systematic uncertainties

Main uncertainties:

- Luminosity: includes new & improved 2016 lumi measurement
- Photon selection: because of course
- Factorization & normalization scale:

  pre-fit envelope over 6 variations with

  μ_R & μ_F varied up/down separately & together
- Electron selection efficiency

  ~ relatively small thanks to MVA-based lepton ID @ Very Loose WP
- Final state radiation

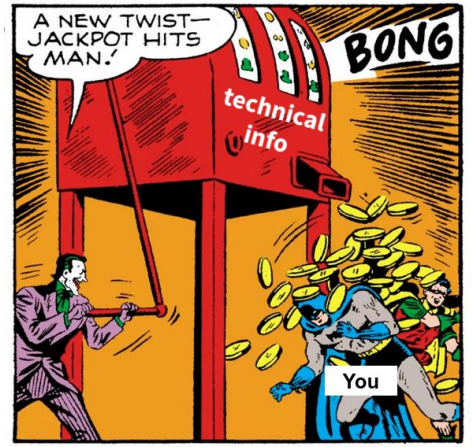
	Source	Correlation	Uncertainty [%] Prefit range	Postfit
Experimental	Integrated luminosity	∼	1.3–3.2	1.7
	Pileup	✓	0.1–1.4	0.6
	Trigger efficiency	×	0.6–1.7	0.6
	Electron selection efficiency	∼	1.0–1.3	1.1
	Muon selection efficiency	∼	0.3–0.5	0.5
	Photon selection efficiency	∼	0.4–3.7	0.9
	Jet energy scale	∼	0.1–1.3	0.5
	Jet energy resolution	✓	0.0–0.6	<0.1
	b tagging efficiency	∼	0.9–1.4	1.1
	L1 prefiring	✓	0.0–0.8	0.3
Theoretical	Choice in μ_R and μ_F	✓	0.3–3.5	1.5
	PDF choice	✓	0.3–4.5	0.2
	PS modelling: ISR & FSR scale	✓	0.3–3.5	1.2
	PS modelling: colour reconnection	✓	0.0–8.4	0.2
	PS modelling: b fragmentation	✓	0.0–2.2	0.6
	Underlying event tune	✓	0.5	0.5
Background	$Z\gamma$ correction & normalization	✓	0.0–0.2	<0.1
	$t\gamma$ normalization	✓	0.0–0.9	0.8
	other+γ normalization	✓	0.3–1.0	0.8
	Nonprompt γ normalization	✓	0.0–1.8	0.9
	MC statistics	×	1.5–7.6	0.9
	Total systematic uncertainty			3.6
	Statistical uncertainty			1.4
	Total uncertainty			3.9

Fiducial region definition

Defined at the **particle level**

- stable particles "Status 1 particles"
- isolated = no stable particle (except neutrinos) with p_T > 5 GeV within ΔR = 0.1
- leptons dressed using photons found within ΔR < 0.1
- jets clustered using anti-k_T algorithm (R = 0.4)
- b-quark jets identified using ghost-matching procedure

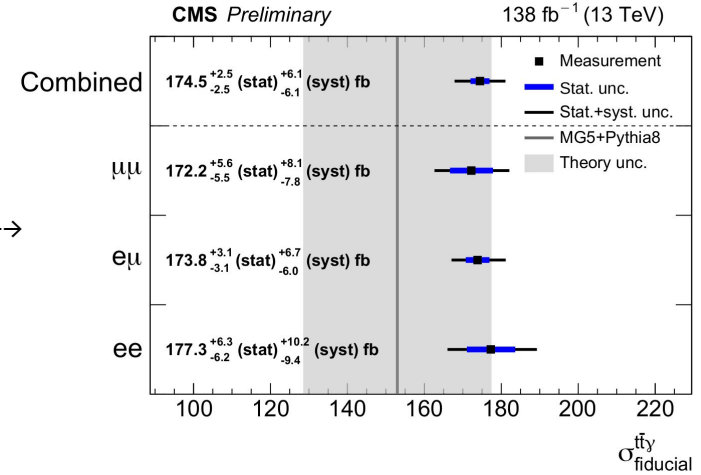
- aligns with reco-level signal selection
- no Z-mass window requirements on m(ll) & m(llγ) distributions

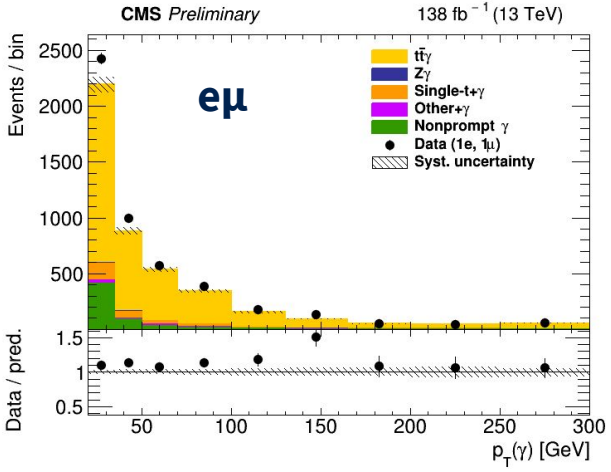


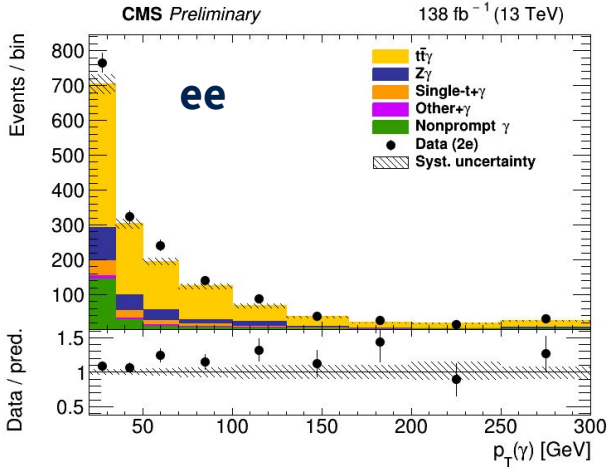
Leptons	Photons	Jets	b jets	Events
$p_T > 25(15)$ GeV	$p_T > 20$ GeV	$p_T > 30$ GeV	$p_T > 30$ GeV	$N_l = 2$
$\|\eta\| < 2.4$	$\|\eta\| < 1.4442$	$\|\eta\| < 2.4$	$\|\eta\| < 2.4$	$N_\gamma = 1$
	$\Delta R(\gamma, l) > 0.4$	$\Delta R(jet, l) > 0.4$	$\Delta R(jet, l) > 0.4$	$N_b \geq 1$
	isolated	$\Delta R(jet, \gamma) > 0.1$	$\Delta R(jet, \gamma) > 0.1$	$m(\ell\ell) > 20$ GeV
			matched to b hadron	

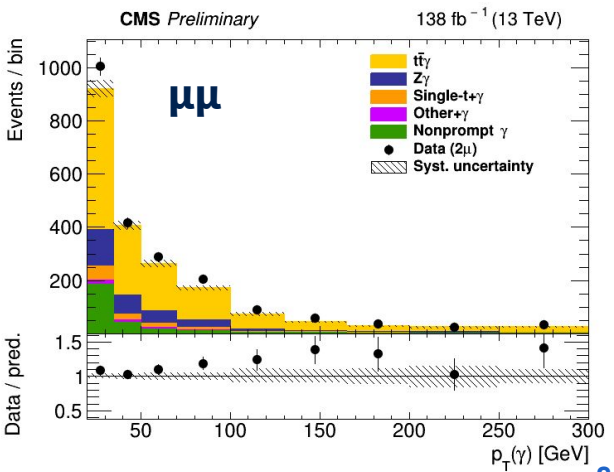
Inclusive cross section measurement

- fit to $p_T(\gamma)$ distributions, per channel, per year
- **< 4% total uncertainty**, thanks to high signal purity
- results **compatible between channels**, within theory uncertainties -->
- fiducial region definition similar to reco-level signal selection



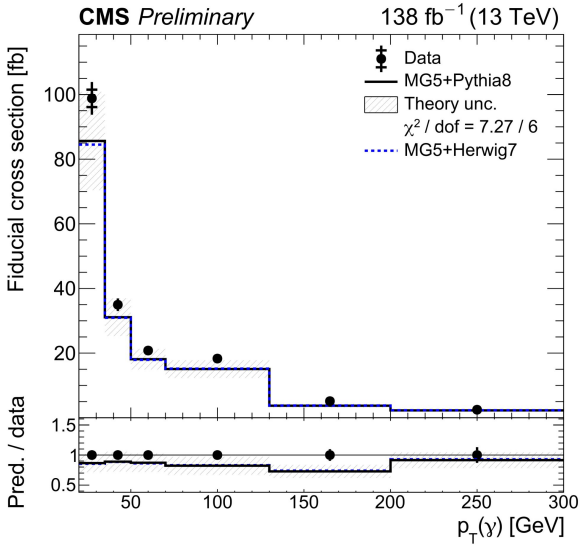


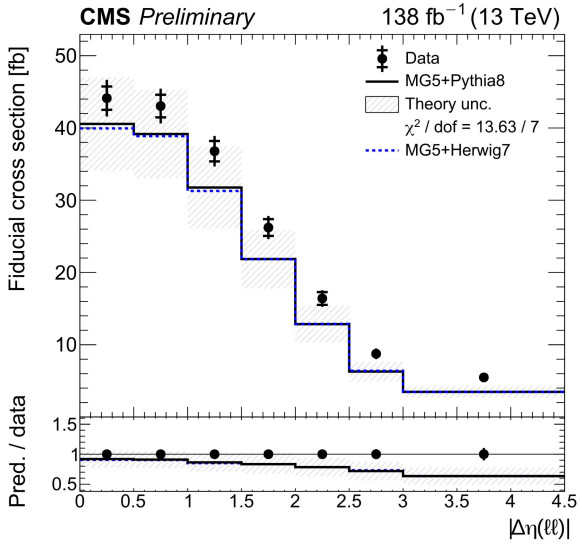


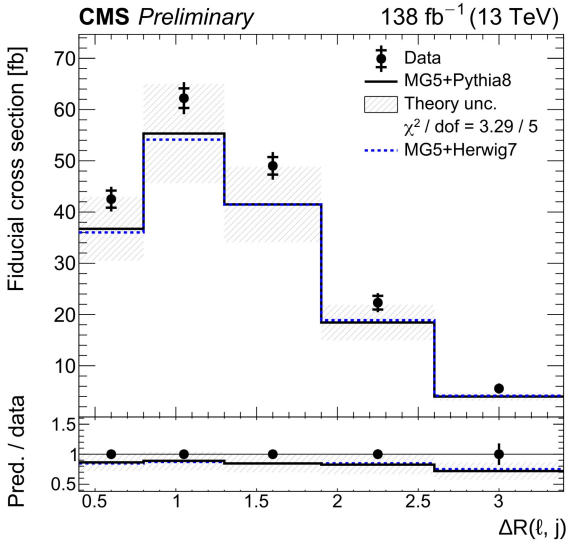


Differential cross section measurement

- **Particle level** distributions obtained by **unregularized** unfolding using TUnfold
- Including photon, lepton, and jet kinematics & angles between objects, 12 distributions in total
- Compared to MadGraph5MC@NLO + Pythia8 / herwig7 predictions
- Provide both **normalized & non-normalized** results

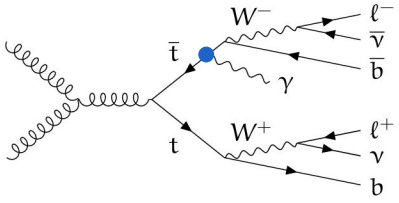






SMEFT interpretation

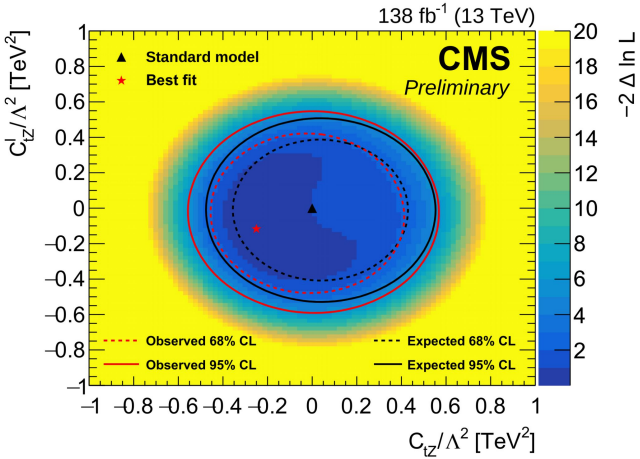
- SMEFT operators introduce / modify couplings ~ **t-γ**
- Measurements can constrain wilson coefficients ~ **c_{tZ} & c^{I}_{tZ}**
- Suppressed by Λ scale → effect in high energy tails ~ **high pt(γ)**

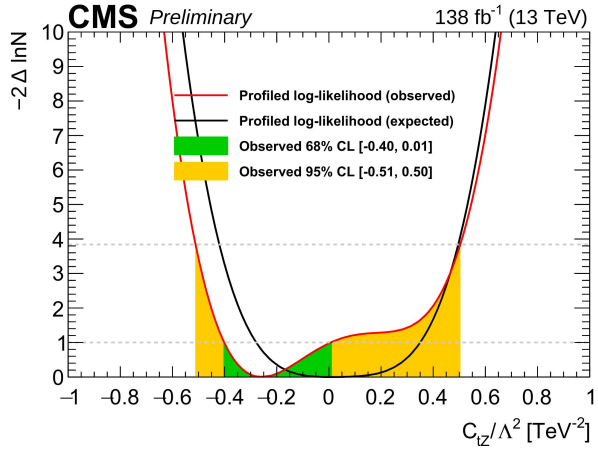


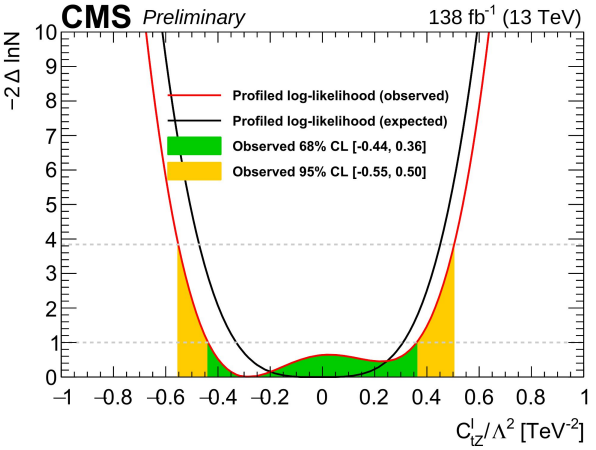
- Operator effects modeled using gen-level reweighting
- Best fit within 1σ of standard model prediction

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_{j}^{N_{d8}} \frac{b_j}{\Lambda^4} \mathcal{O}_j^{(8)} + \dots ,$$

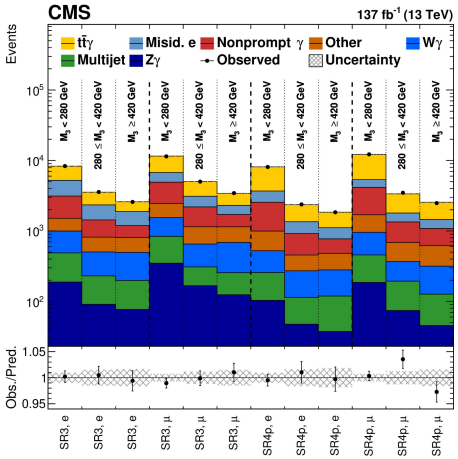
dimension 6 operators

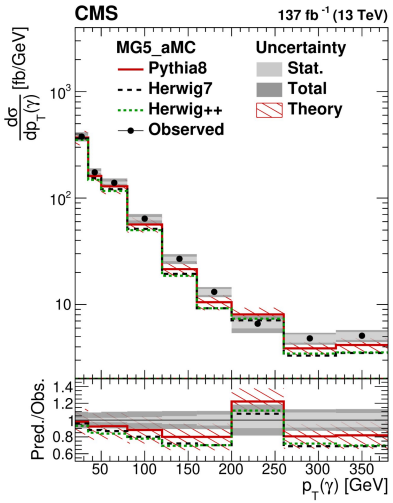






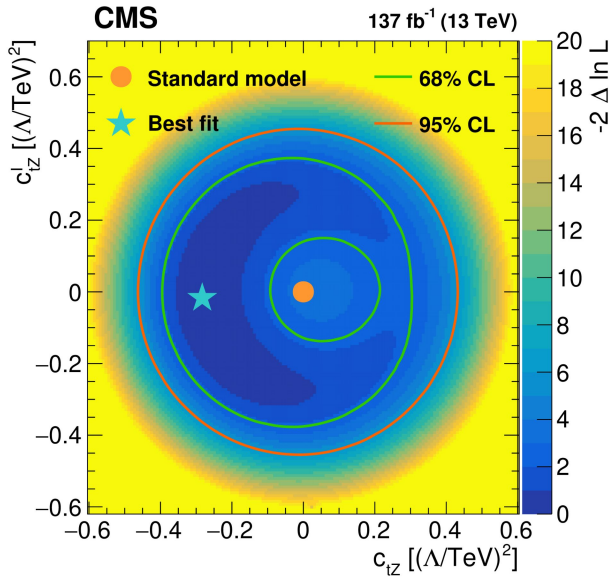
$t\bar{t}\gamma$ in the l+jets channel (arxiv:2107.01508):





- 1 lepton, 1 photon, ≥3 jets, ≥1 b-tagged jet
- control regions for misidentified electrons and for Wγ & Zγ
- nonprompt γ, misidentified electrons , and multijet backgrounds from data
- binning per channel & jet multiplicity for final fit

$\sigma_{\text{fid (particle level)}} = 800 \pm 7\ (\text{stat}) \pm 46\ (\text{syst})$ fb

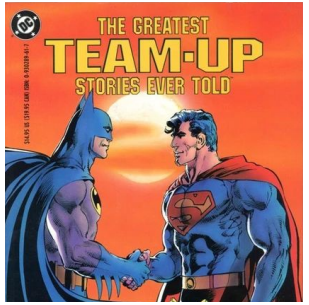


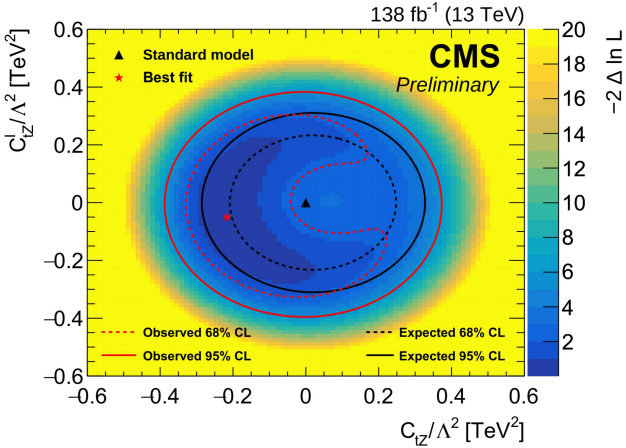
SMEFT results

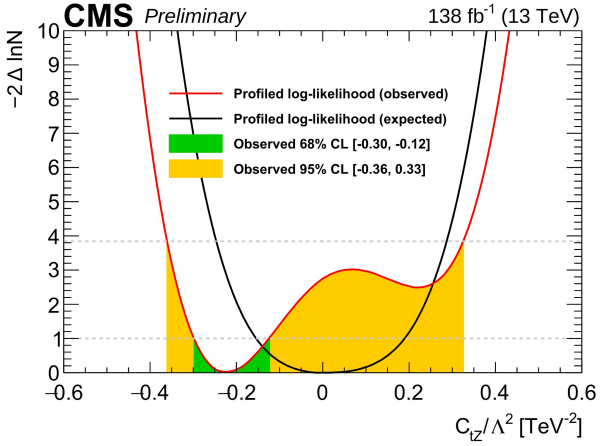
	Wilson coefficient		68% CL interval $(\Lambda/\text{TeV})^2$	95% CL interval $(\Lambda/\text{TeV})^2$
Expected	c_{tZ}	$c_{tZ}^I = 0$	$[-0.19, 0.21]$	$[-0.29, 0.32]$
		profiled	$[-0.19, 0.21]$	$[-0.29, 0.32]$
	c_{tZ}^I	$c_{tZ} = 0$	$[-0.20, 0.20]$	$[-0.30, 0.31]$
		profiled	$[-0.20, 0.20]$	$[-0.30, 0.31]$
Observed	c_{tZ}	$c_{tZ}^I = 0$	$[-0.35, -0.16]$	$[-0.42, 0.38]$
		profiled	$[-0.35, 0.07]$	$[-0.42, 0.39]$
	c_{tZ}^I	$c_{tZ} = 0$	$[-0.35, -0.16], [0.17, 0.35]$	$[-0.42, 0.42]$
		profiled	$[-0.32, 0.31]$	$[-0.41, 0.41]$

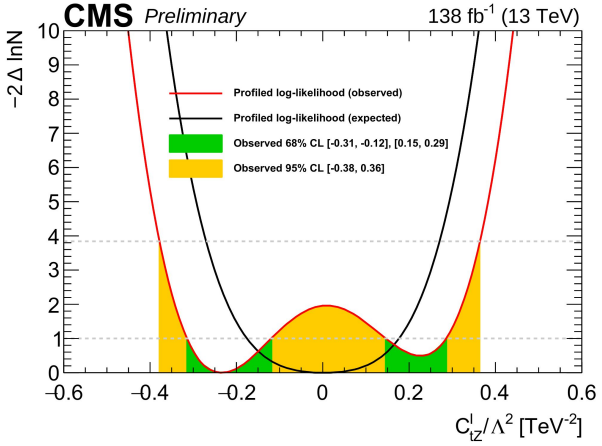
SMEFT: combination with l+jets (TOP-18-010)

- Complimentary analysis:
  - larger branching ratio → better statistics (most notably at high $p_T(\gamma)$) → drives EFT sensitivity
  - larger backgrounds → larger systematic uncertainties → better inclusive precision in 2l measurement
- Same basic framework → straightforward combination
- Limited overlap:
  - l+jets in 2l selection negligible
  - 2l events in l+jets selection 5% at most
- Results:
  - ~25% improvement w.r.t. l+jets only
  - same minimum ~ same leading order signal samples









Summary

- Inclusive measurement of ttγ in the dilepton channel by CMS at 13 TeV
  σ_{fid} = 174.4 ± 2.5 (stat) ± 6.1 (syst) fb = highest precision to date
- Particle-level differential results including **photon, lepton, and jet kinematics**
- EFT interpretation delivering **tight constraints on c_{tZ} & c_{tZI}** wilson coefficients ↙
- Combination of EFT results with l+jets measurement ↘

2l result

	Wilson coefficient		68% CL interval $(\Lambda/TeV)^2$	95% CL interval $(\Lambda/TeV)^2$
Expected	c_{tZ}	$c_{tZ}^{[I]}=0$	$[-0.28, 0.36]$	$[-0.42, 0.50]$
		profiled	$[-0.36, 0.44]$	$[-0.49, 0.56]$
	$c_{tZ}^{[I]}$	$c_{tZ}=0$	$[-0.33, 0.31]$	$[-0.48, 0.46]$
		profiled	$[-0.42, 0.40]$	$[-0.54, 0.51]$
Observed	c_{tZ}	$c_{tZ}^{[I]}=0$	$[-0.41, 0.01]$	$[-0.51, 0.51]$
		profiled	$[-0.47, 0.42]$	$[-0.57, 0.58]$
	$c_{tZ}^{[I]}$	$c_{tZ}=0$	$[-0.44, 0.37]$	$[-0.55, 0.51]$
		profiled	$[-0.49, 0.43]$	$[-0.60, 0.55]$

combination l+jets & 2l

	Wilson coefficient		68% CL interval $(\Lambda/TeV)^2$	95% CL interval $(\Lambda/)^2$
Expected	c_{tZ}	$c_{tZ}^{[I]}=0$	$[-0.16, 0.19]$	$[-0.25, 0.29]$
		profiled	$[-0.22, 0.26]$	$[-0.29, 0.33]$
	$c_{tZ}^{[I]}$	$c_{tZ}=0$	$[-0.18, 0.18]$	$[-0.27, 0.27]$
		profiled	$[-0.24, 0.24]$	$[-0.32, 0.32]$
Observed	c_{tZ}	$c_{tZ}^{[I]}=0$	$[-0.30, -0.12]$	$[-0.37, 0.33]$
		profiled	$[-0.34, 0.23]$	$[-0.40, 0.38]$
	$c_{tZ}^{[I]}$	$c_{tZ}=0$	$[-0.32, -0.11], [0.15, 0.29]$	$[-0.38, 0.37]$
		profiled	$[-0.33, 0.31]$	$[-0.40, 0.39]$