Top quark associated production (tt+W/Z/tt/γ) at CMS

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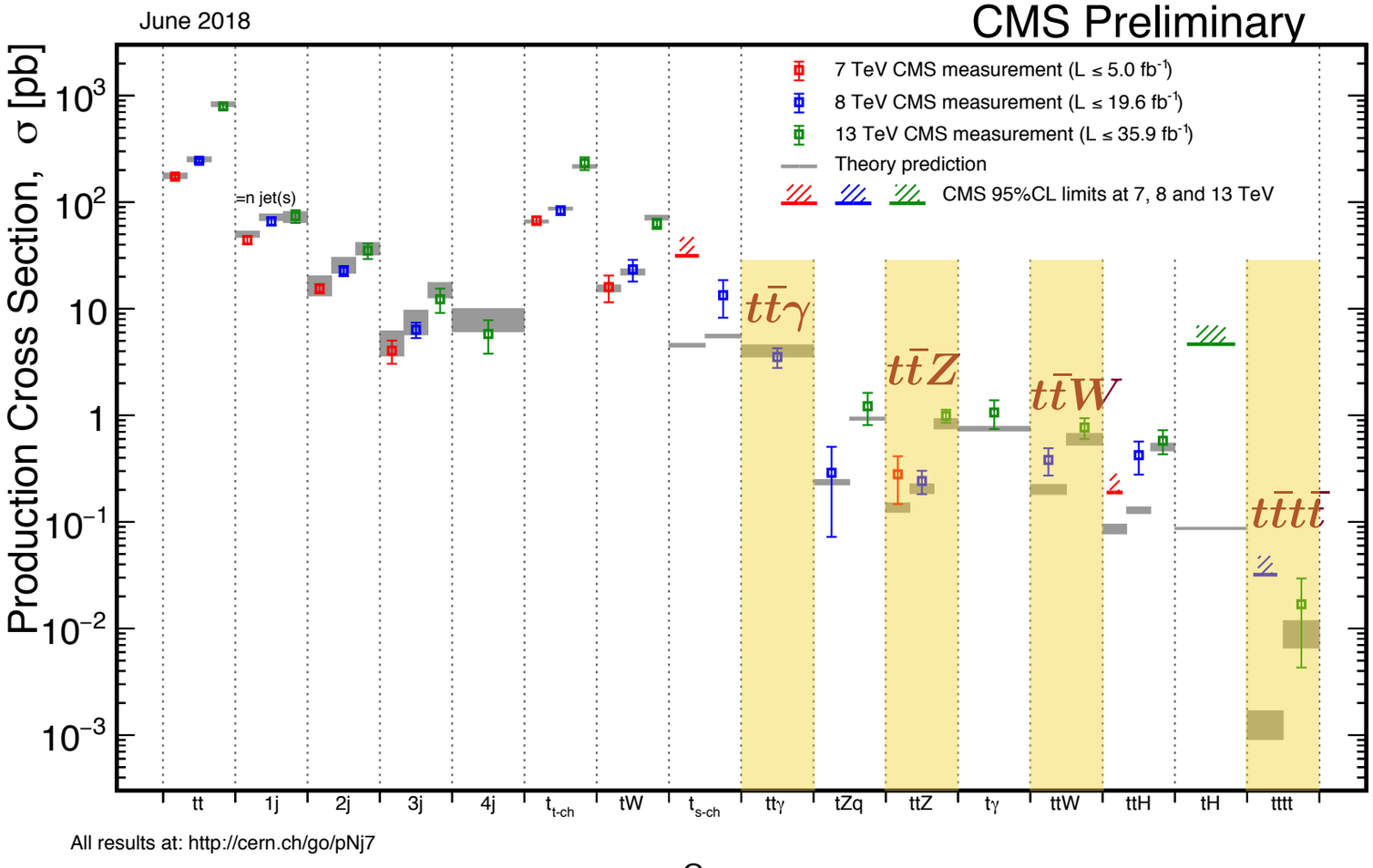
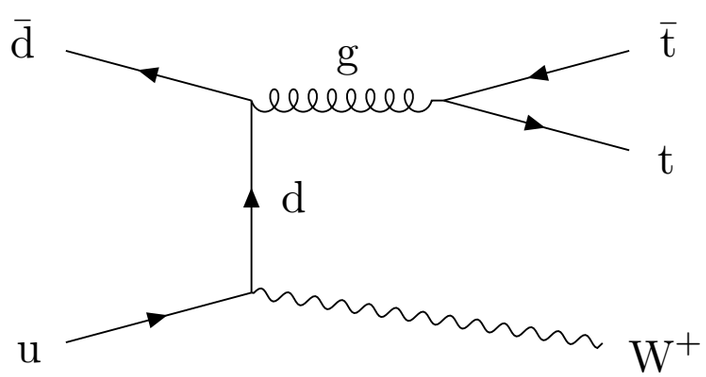
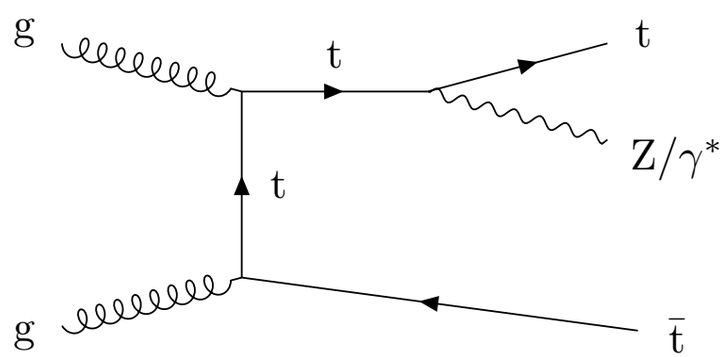
Associated Production

- Precision measurement of associated top quark pair production provides
  - Check the SM predictions in rare production channels
  - Direct test of top couplings
  - Window to new physics
  - Important background for BSM or rare SM searches



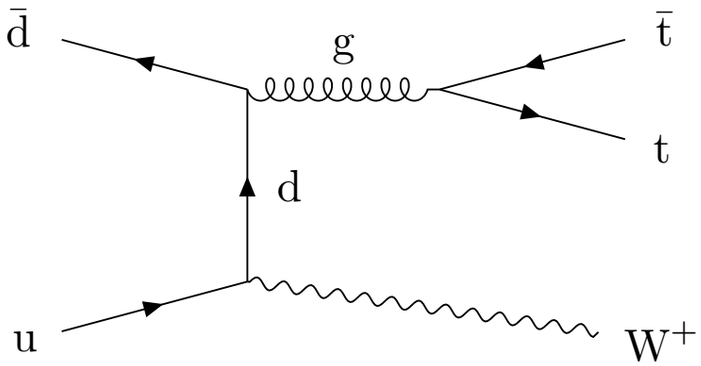
ttW & ttZ





$t\bar{t}W$ & $t\bar{t}Z$

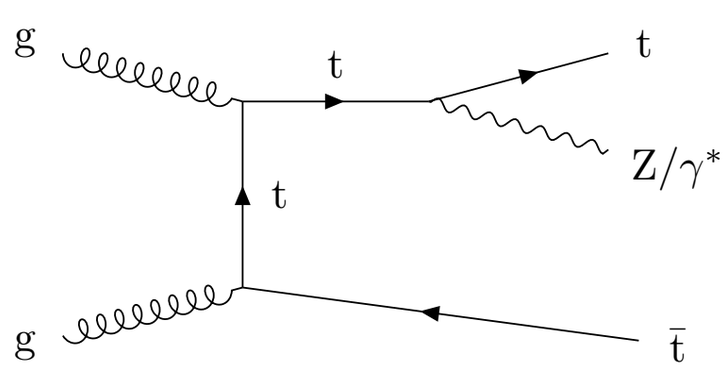
- Measurement of the ttW and ttZ production cross sections at 13 TeV
- Performed using 2016 dataset (35.9 fb^{-1})



$t\bar{t}W$

$\sigma_{\text{th.}}^{t\bar{t}W} = 0.61 \pm 0.08 \text{ pb}$

- Measured in the same-sign (SS) dilepton final state



$t\bar{t}Z$

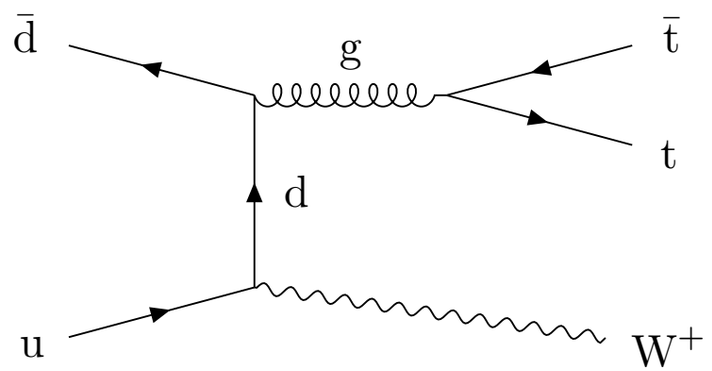
$\sigma_{\text{th.}}^{t\bar{t}Z} = 0.84 \pm 0.10 \text{ pb}$

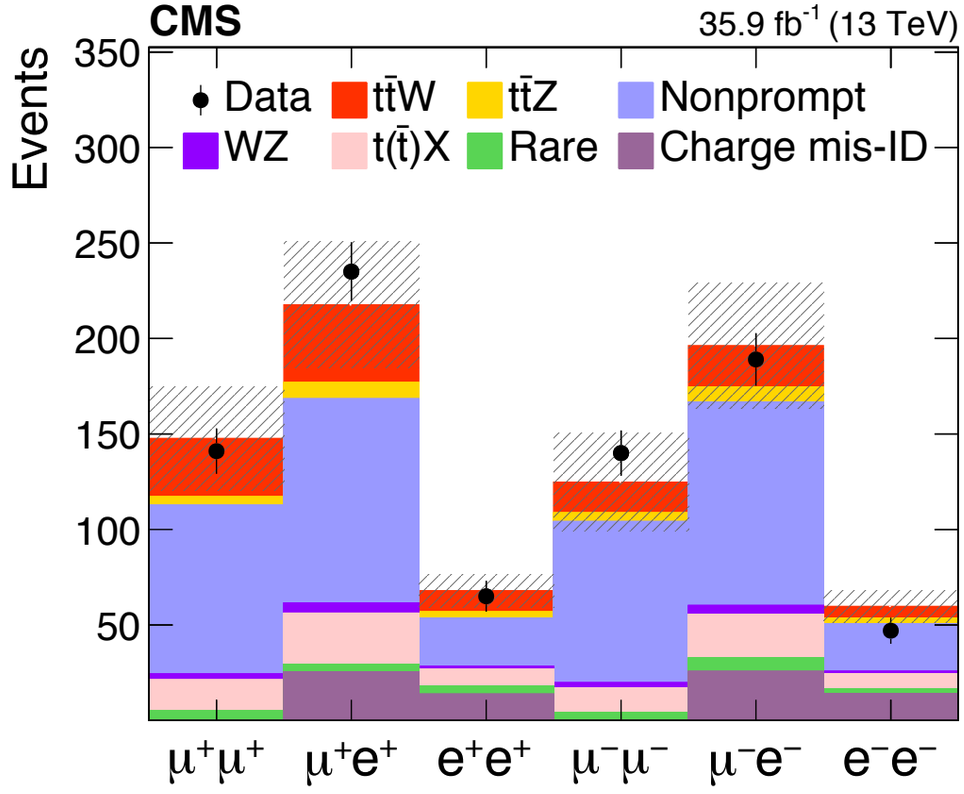
- Measured in 3 & 4 lepton final states, containing opposite sign same flavor (OSSF) pair

arXiv:1711.02547
JHEP 08 (2018) 011

$t\bar{t}W$ Analysis

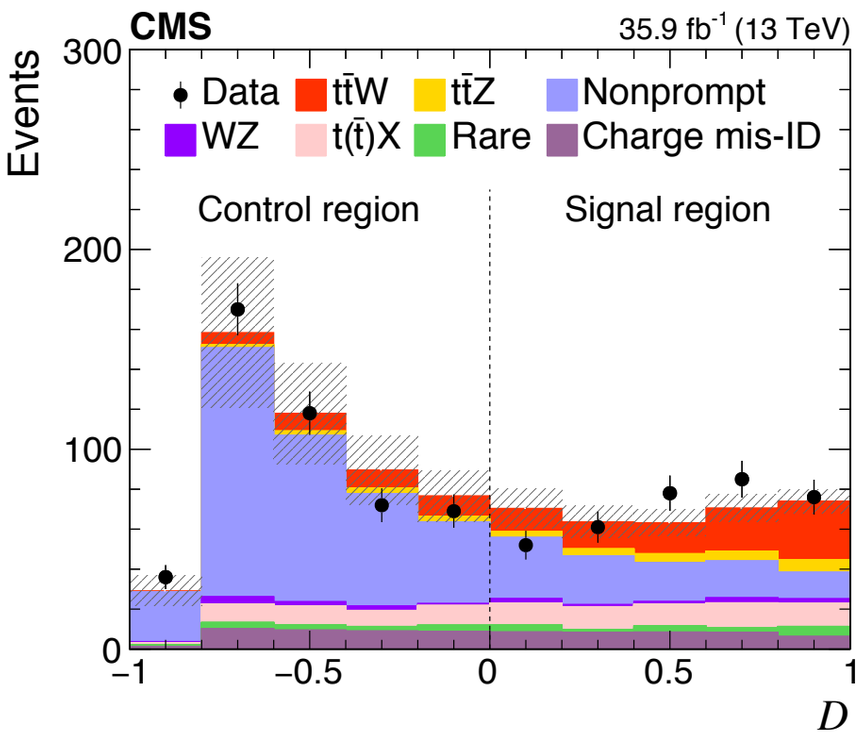
- Analysis selects same-sign dilepton events
  - Exactly 2 leptons (e or μ) with same sign
  - At least 2 jets and 1 b-tag
  - Reject events with $m_{\ell\ell} < 12$ GeV or dielectron events with $|m_{\ell\ell}-m_Z| < 15$ GeV
  - $p_T^{miss} > 30$ GeV
- Backgrounds:
  - Nonprompt leptons: estimated from loose selection sideband (tight-to-loose ratio)
  - Misidentified charge
  - t(t)+X (ttH, tZq, tWZ, tWq, …)
  - Rare (WW, ZZ, Wγ, Zγ, triboson)





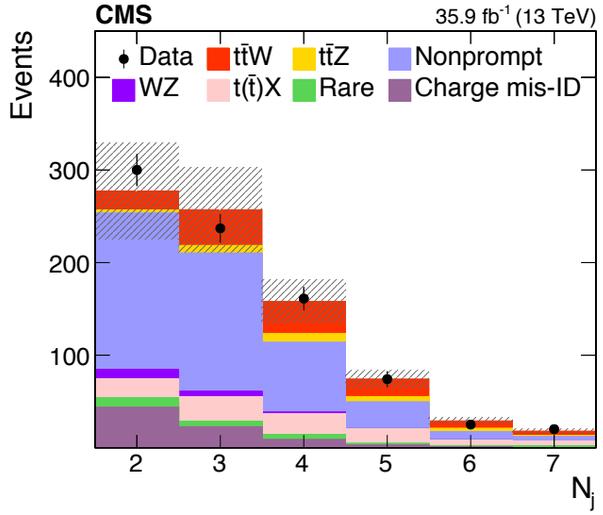
$t\bar{t}W$ Analysis

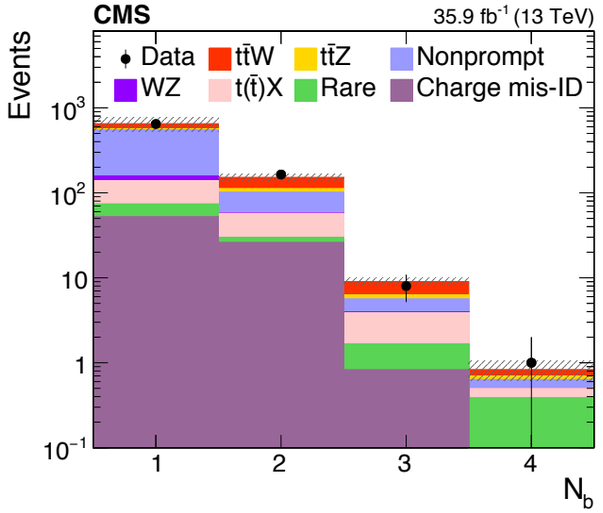
- Boosted Decision Tree classifier used to discriminate signal from non-prompt background
  - Using jet/b-jet multiplicities, and lepton/jet kinematics
- BDT discriminant (D) used to separate signal region (D>0) and control region (D<0)

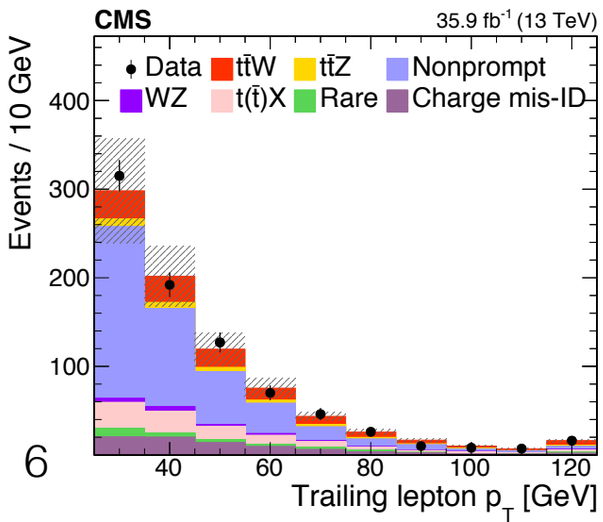


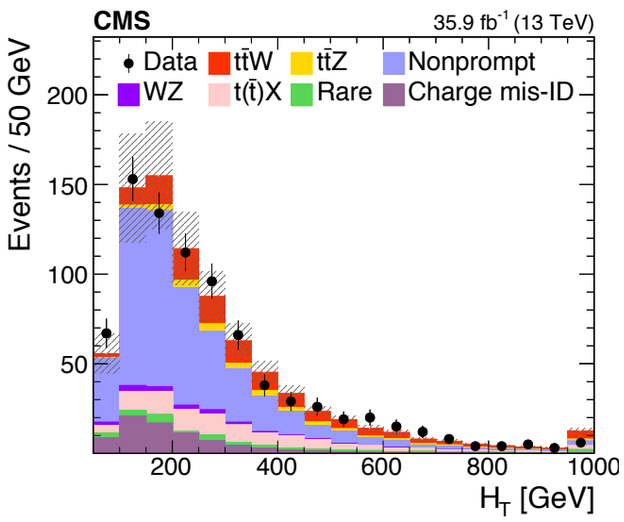
BDT input variables

- N_{j}
- N_{b}
- p_{T} leading lepton
- p_{T} trailing lepton
- M_{T} leading lepton
- H_{T}: scalar sum of p_{T} of jets
- $p_{\mathrm{T}}^{\mathrm{miss}}$
- p_{T} leading and second leading jets
- ΔR between trailing lepton and nearest jet



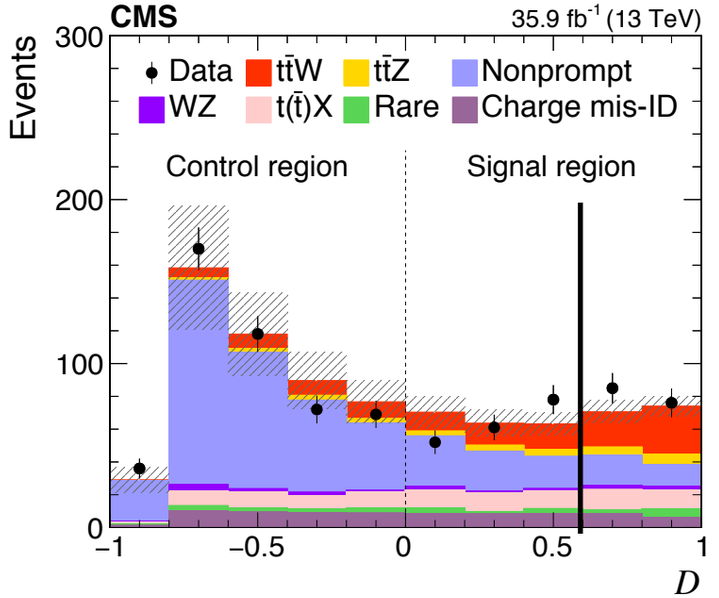


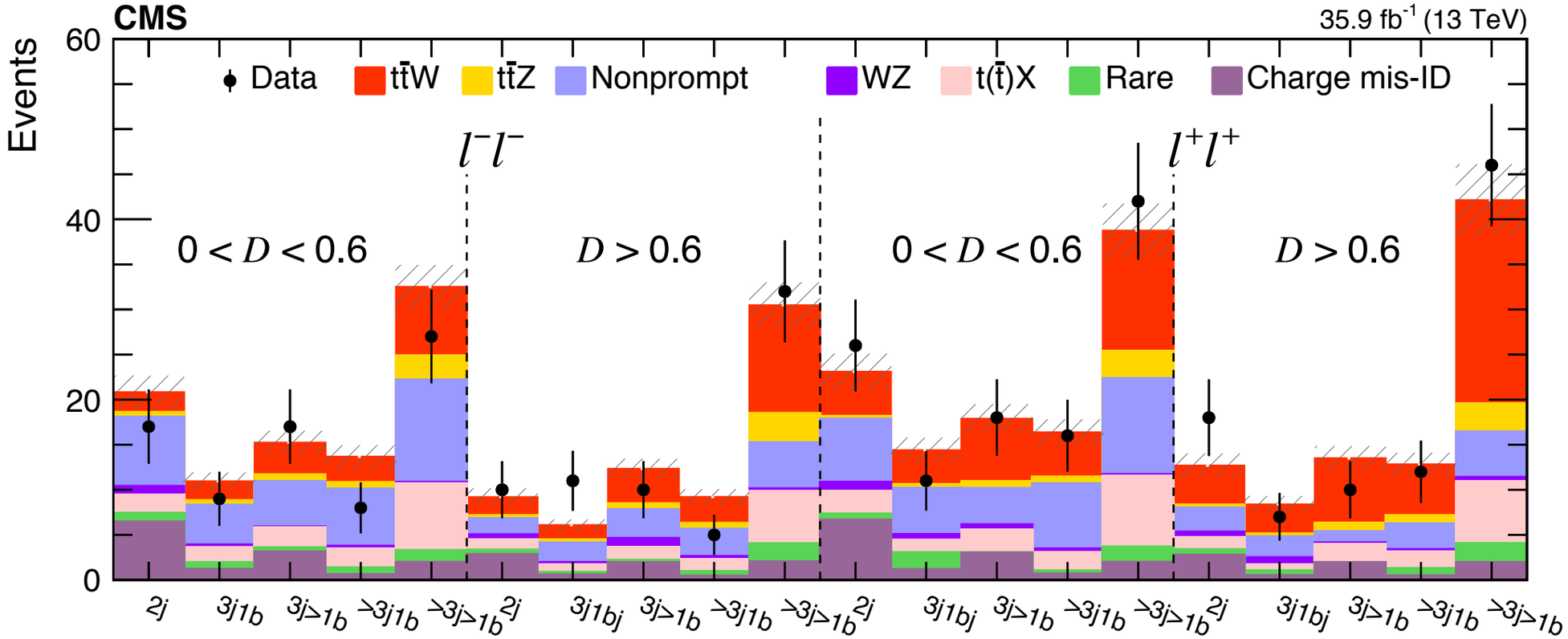




$t\bar{t}W$ Analysis Regions

- Signal region split up to define 20 exclusive signal regions
  - Split $\ell^+\ell^+$ from $\ell^-\ell^-$ to take advantage of difference between ttW^+ and ttW^-
  - Split in 0<D<0.6 and D>0.6
  - Define exclusive jet/b-jet multiplicity bins
    - =2j, =3j=1b, =3j>1b, >3j=1b, >3j>1b



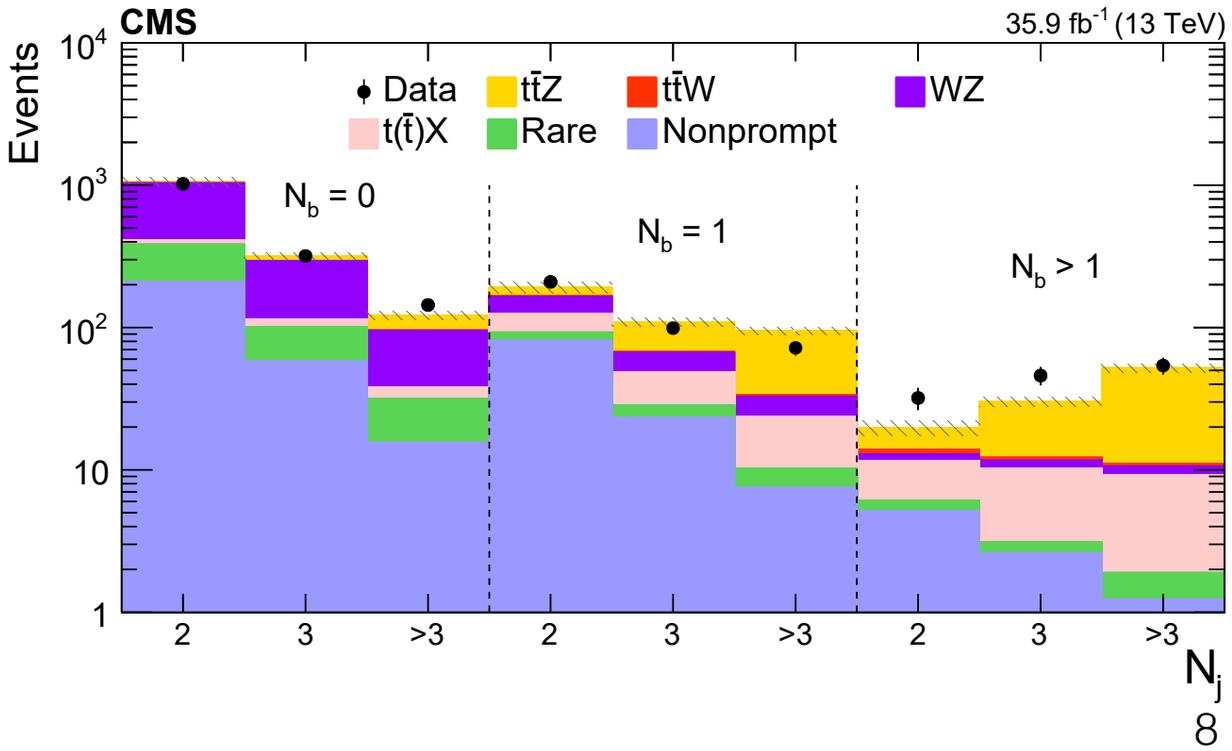


$t\bar{t}Z$ Analysis Regions

- Event selection for both three-lepton and four-lepton final states

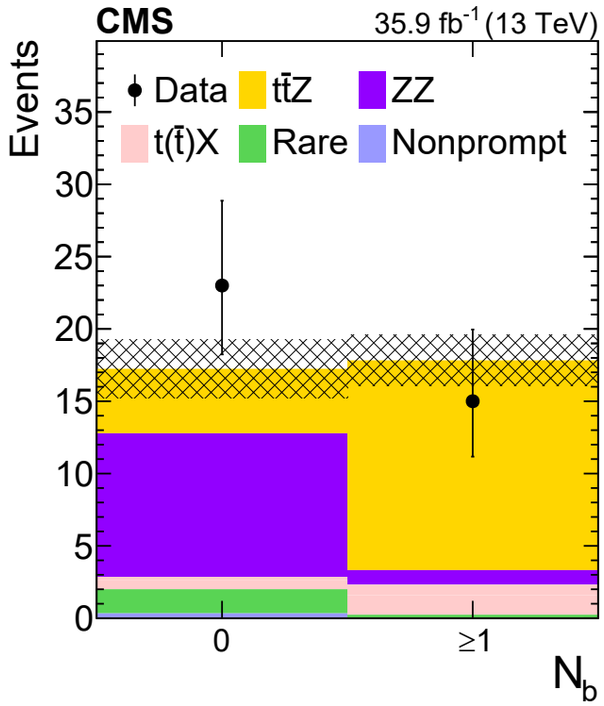
Three-leptons

- Exactly three leptons (μμμ,μμe,μee,eee)
- One opposite sign/ same flavor (OSSF) pair with $|m_{\ell\ell}-m_Z| < 10$ GeV
- Form 9 exclusive bins
  - N_j=2,3,>3
  - N_b=0,1,>1



Four-leptons

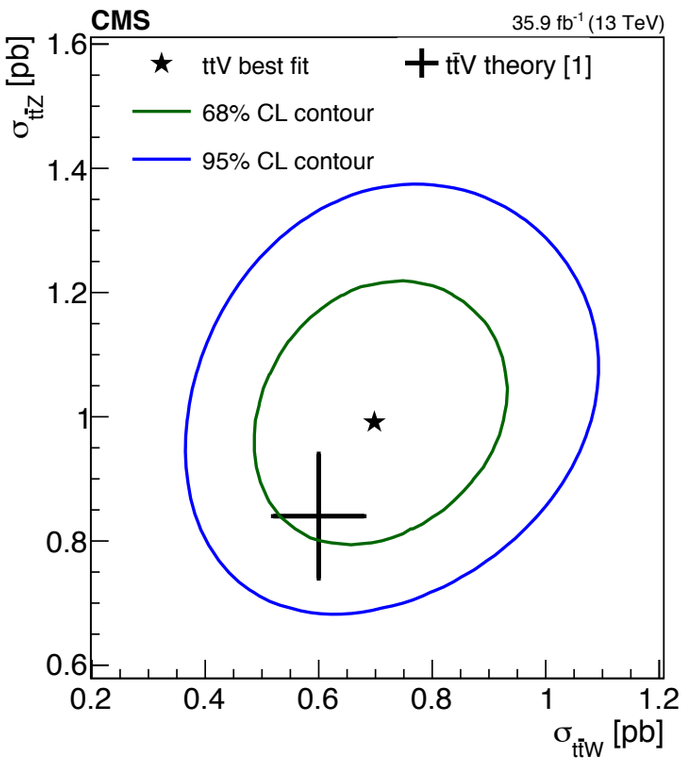
- Exactly four leptons, 2 ℓ^+, 2 ℓ^-
- One OSSF pair with $|m_{\ell\ell}-m_Z| < 20$ GeV
  - Veto μμμμ, μμee, or eeee events with second pair in mass peak
- Require ≥2 jets, split in 0b & ≥1b



$t\bar{t}W$ & $t\bar{t}Z$ Results

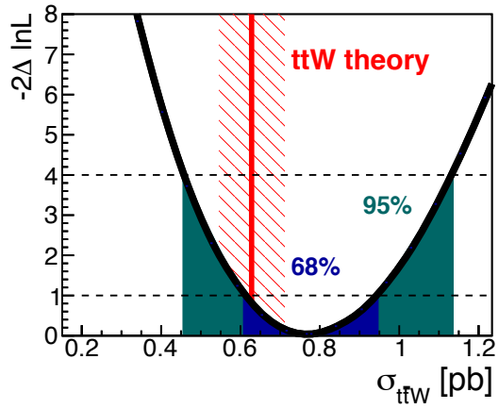
- Likelihood function defined based on event yields in combination of same sign dilepton, 3-lepton, and 4-lepton categories.
- Fit to extract both the ttW and ttZ cross sections

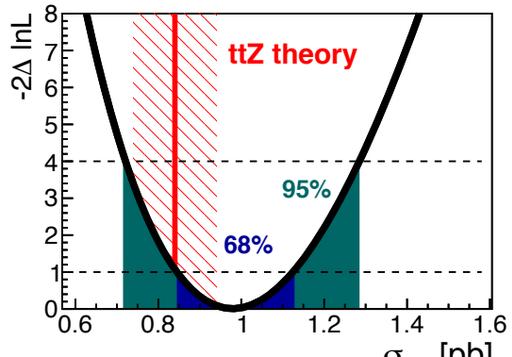
$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}W}) = 0.77^{+0.12}_{-0.11}(\mathrm{stat})^{+0.13}_{-0.12}(\mathrm{syst})\ \mathrm{pb}$$
$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}W^{+}}) = 0.58 \pm 0.09(\mathrm{stat})^{+0.09}_{-0.08}(\mathrm{syst})\ \mathrm{pb}$$
$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}W^{-}}) = 0.19 \pm 0.07(\mathrm{stat}) \pm 0.06(\mathrm{syst})\ \mathrm{pb}$$
$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}Z}) = 0.99^{+0.09}_{-0.08}(\mathrm{stat})^{+0.12}_{-0.10}(\mathrm{syst})\ \mathrm{pb}$$



- Systematics uncertainties from lepton identification, trigger efficiencies, non prompt background, b-tagging have largest effects on cross sections

Channel	Expected significance	Observed significance
SS dilepton $\ell^{-}\ell^{-}$ ($\mathrm{t\bar{t}W^{-}}$)	2.4	2.3
SS dilepton $\ell^{+}\ell^{+}$($\mathrm{t\bar{t}W^{+}}$)	4.2	5.5
SS dilepton $\ell^{\pm}\ell^{\pm}$ ($\mathrm{t\bar{t}W^{\pm}}$)	4.5	5.3
Three-lepton ($\mathrm{t\bar{t}Z}$)	>5.0	>5.0
Four-lepton ($\mathrm{t\bar{t}Z}$)	4.7	4.5
Three- and four-lepton combined ($\mathrm{t\bar{t}Z}$)	>5.0	>5.0





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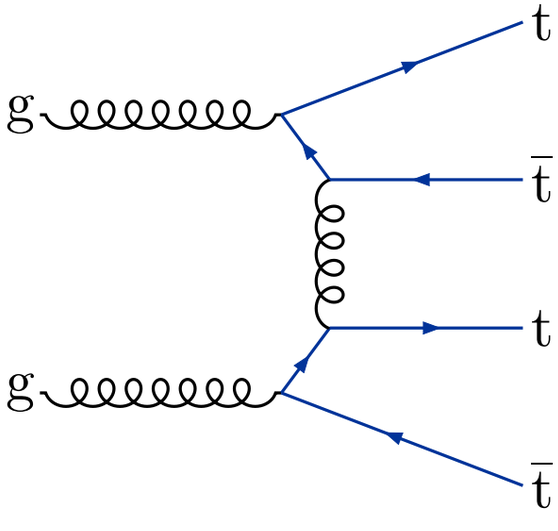
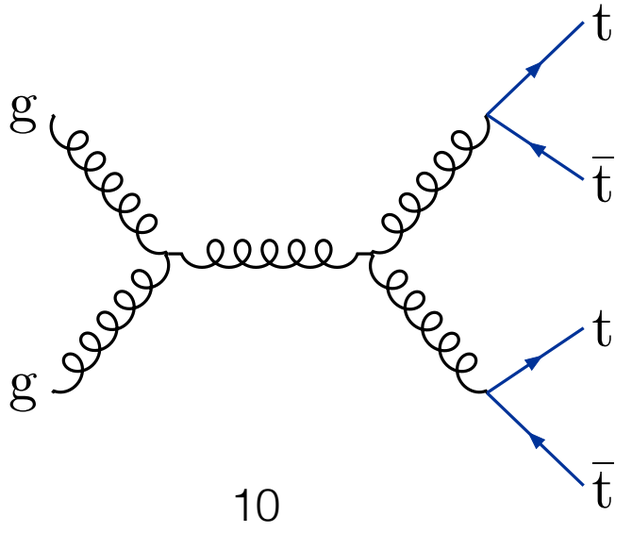
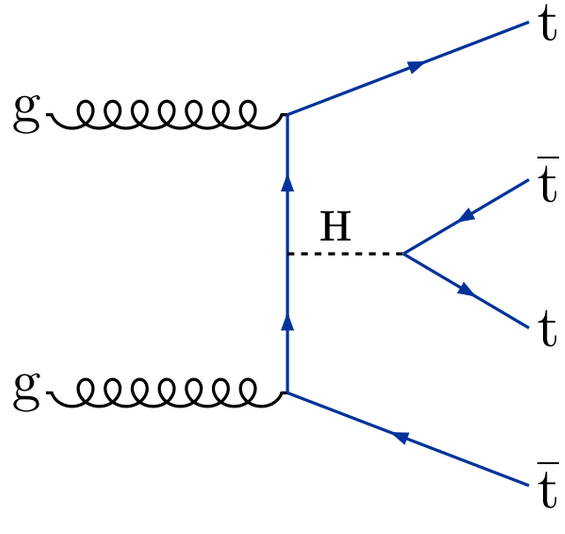
$tttt$

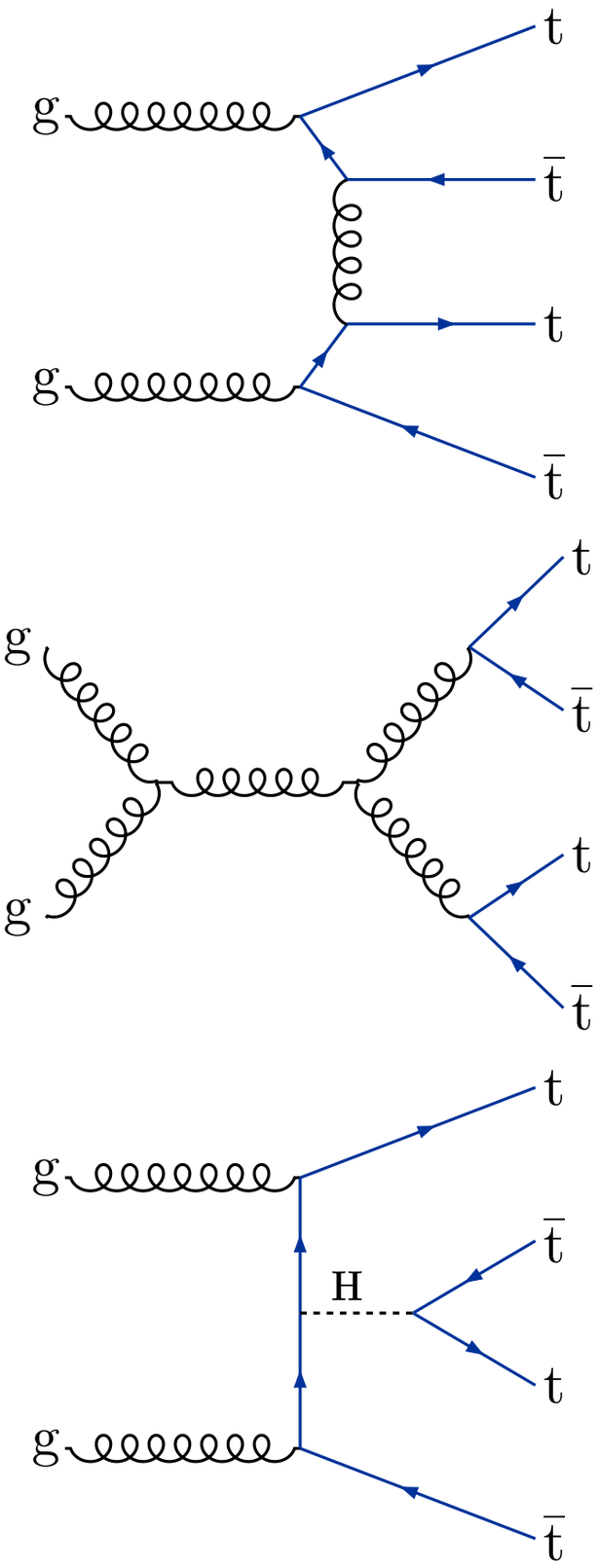






$t\bar{t}t\bar{t}$ Analysis

- Search for SM 4-top production
  - $\sigma(pp \to t\bar{t}t\bar{t}) = 9.2^{+2.9}_{-2.4}$ fb at NLO
  - Small in SM, but enhanced in many BSM theories
- Measured in same-sign dilepton and 3+ lepton final states
- Selection requires ≥2 jets, ≥2 b-jets, H_T>300 GeV, and p_T^{miss} > 50 GeV
- Define signal regions based on lepton, jet, and b-jet multiplicities



N_ℓ	N_b	N_{jets}	Region
2	2	≤5	CRW
		6	SR1
		7	SR2
		≥8	SR3
	3	5, 6	SR4
		≥7	SR5
	≥4	≥5	SR6
≥3	2	≥5	SR7
	≥3	≥4	SR8
Inverted Z veto			CRZ

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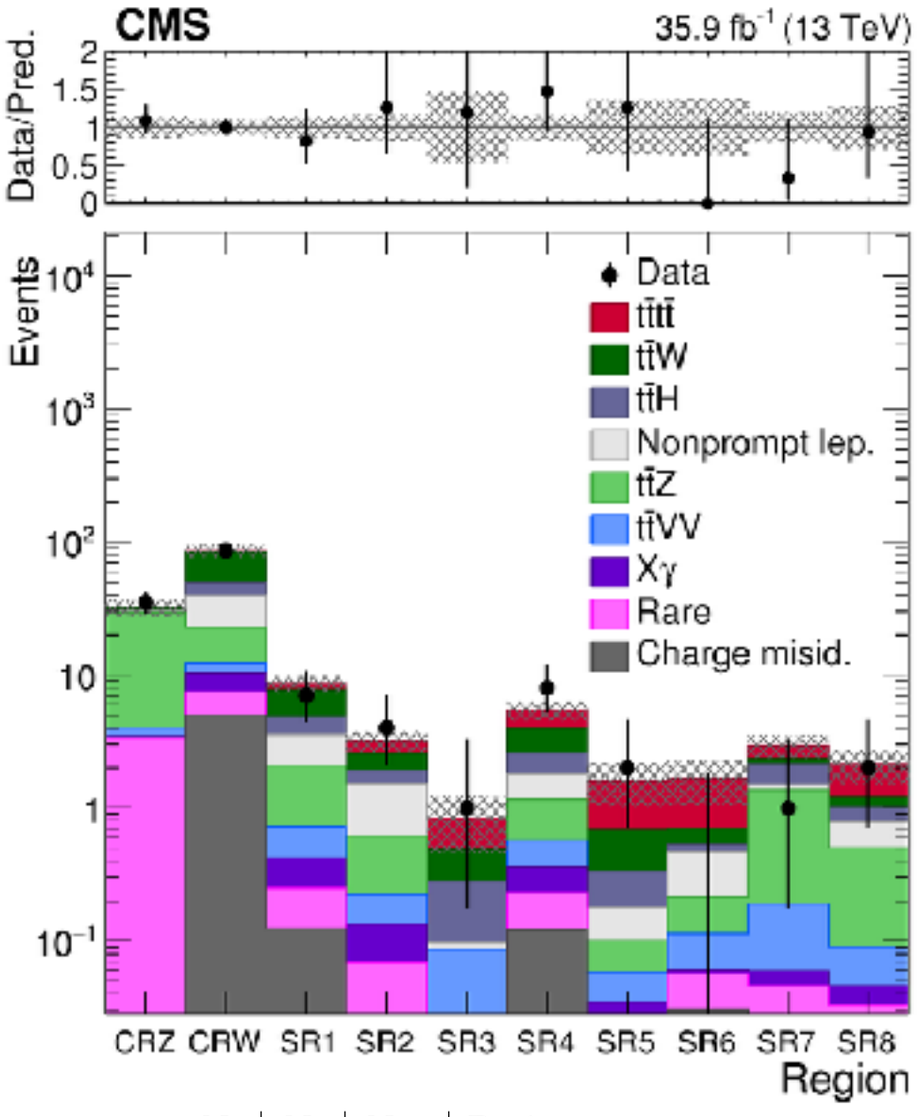
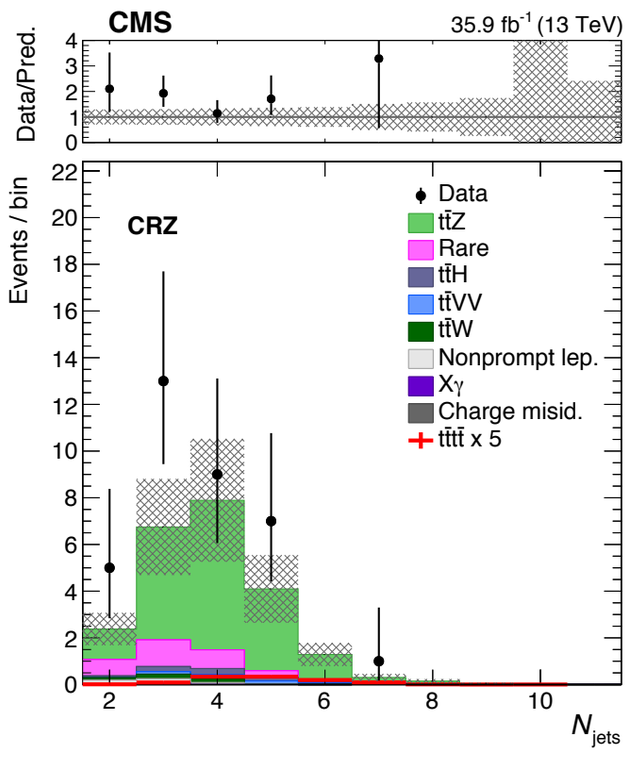
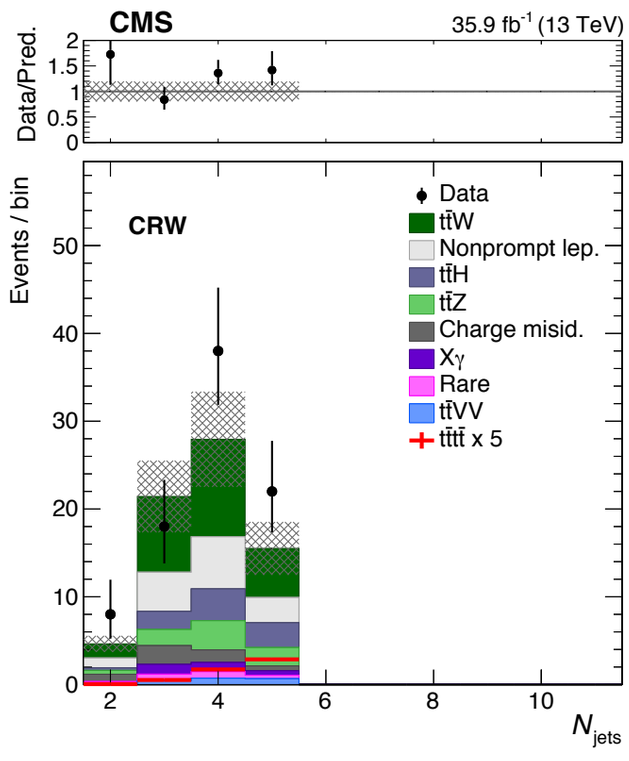
Eur. Phys. J. C 78 (2018) 140

$t\bar{t}t\bar{t}$ Analysis

- Backgrounds come from two main categories
- Rare top multilepton processes (ttW, ttZ, ttH, …):
  - Estimated with simulation, and verified in control regions (CRW, CRZ)
- Non prompt leptons events:
  - Estimated in each region with “tight-to-loose” method







N_ℓ	N_b	N_{jets}	Region
2	2	≤ 5	CRW
		6	SR1
		7	SR2
		≥ 8	SR3
	3	5, 6	SR4
		≥ 7	SR5
	≥ 4	≥ 5	SR6
≥ 3	2	≥ 5	SR7
	≥ 3	≥ 4	SR8
Inverted Z veto			CRZ

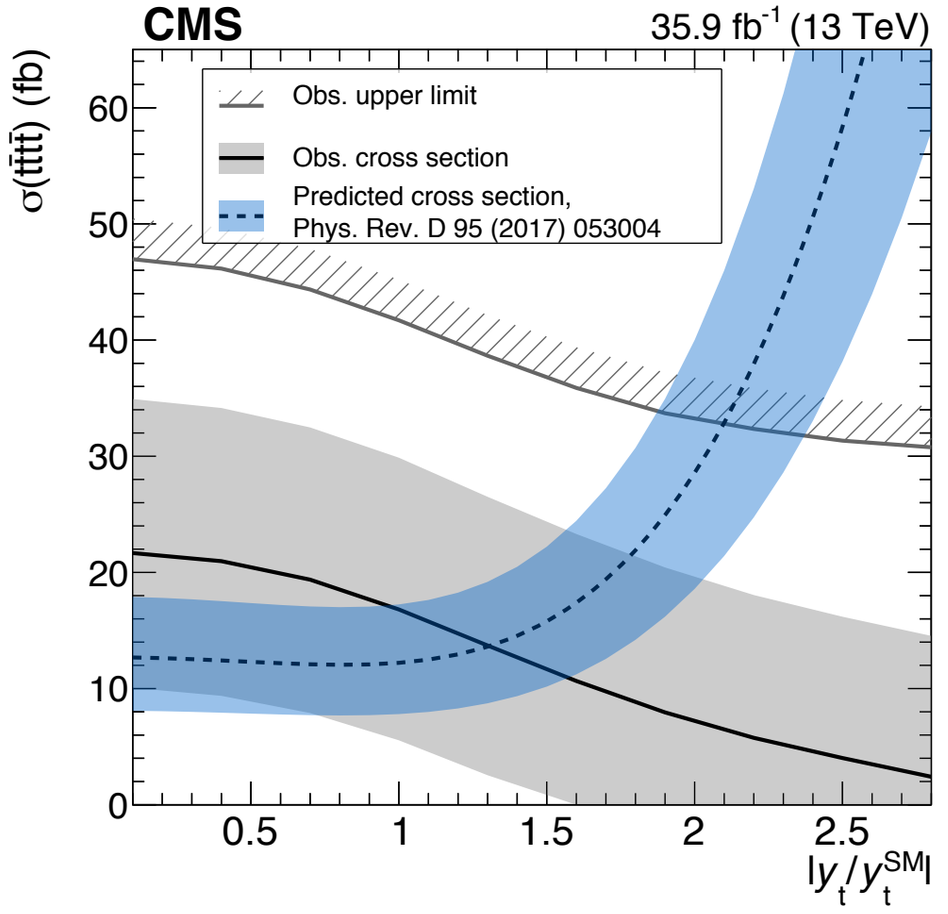
$t\bar{t}t\bar{t}$ Analysis

- Likelihood function defined for event yields in 2 CR's and 8 SR's, fit to extract tttt signal yield

$$\sigma^{\text{meas.}}(\text{pp} \to \text{t}\bar{\text{t}}\text{t}\bar{\text{t}}) = 16.9^{+13.8}_{-11.4}\ \text{fb}$$
$$\sigma^{\text{th.}}(\text{pp} \to \text{t}\bar{\text{t}}\text{t}\bar{\text{t}}) = 9.2^{+2.9}_{-2.4}\ \text{fb}$$

- 95% CL upper limit of 41.7 fb
- Observed significance of 1.6σ (expected 1.0σ)
- Yukawa coupling limit at 95% of $|y_\text{t}/y_\text{t}^\text{SM}| < 2.1$

	SM background	$t\bar{t}t\bar{t}$	Total	Observed
CRZ	31.7 ± 4.6	0.4 ± 0.3	32.1 ± 4.6	35
CRW	83.7 ± 8.8	1.9 ± 1.2	85.6 ± 8.6	86
SR1	7.7 ± 1.2	0.9 ± 0.6	8.6 ± 1.2	7
SR2	2.6 ± 0.5	0.6 ± 0.4	3.2 ± 0.6	4
SR3	0.5 ± 0.3	0.4 ± 0.2	0.8 ± 0.4	1
SR4	4.0 ± 0.7	1.4 ± 0.9	5.4 ± 0.9	8
SR5	0.7 ± 0.2	0.9 ± 0.6	1.6 ± 0.6	2
SR6	0.7 ± 0.2	1.0 ± 0.6	1.7 ± 0.6	0
SR7	2.3 ± 0.5	0.6 ± 0.4	2.9 ± 0.6	1
SR8	1.2 ± 0.3	0.9 ± 0.6	2.1 ± 0.6	2



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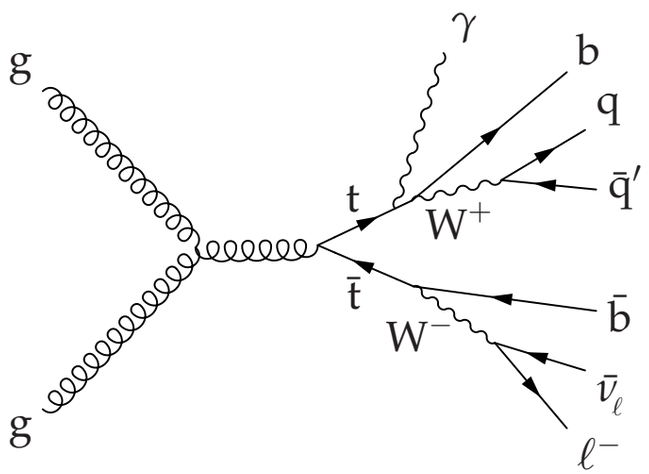
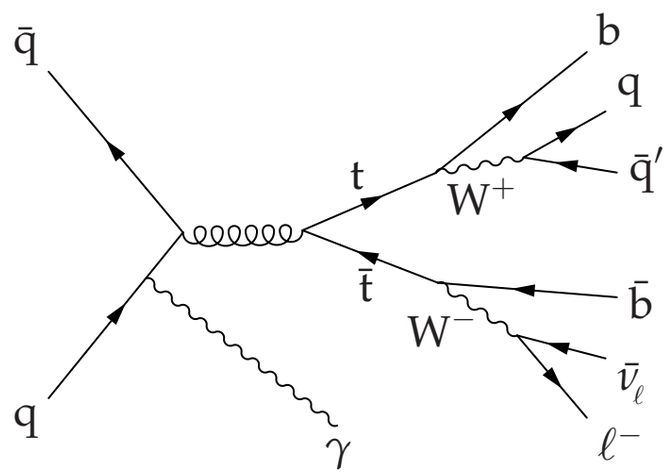
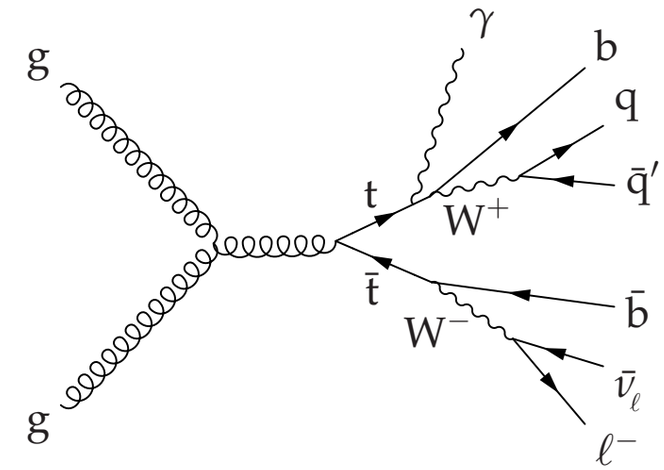
$t\bar{t}\gamma$

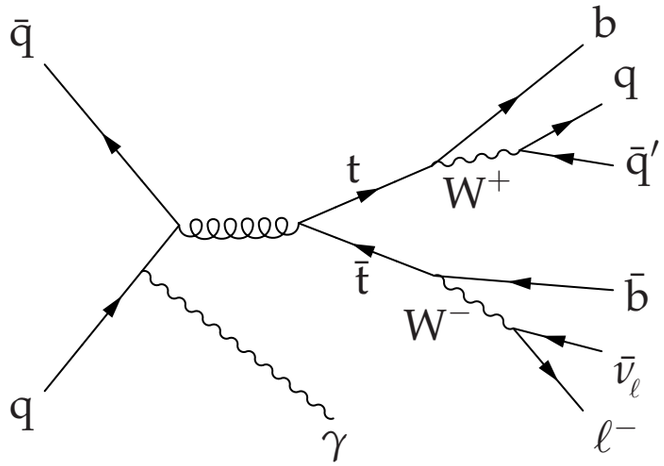


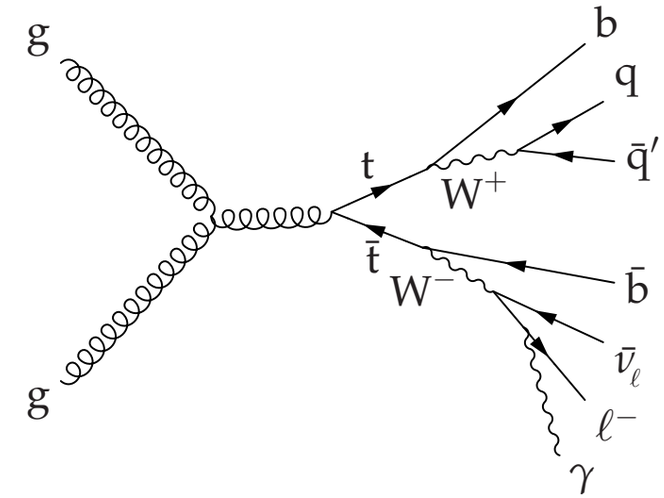


$t\bar{t}\gamma$ Analysis

- Analysis with 8 TeV data collected in 2012
- Measured in the lepton+jets (e or μ) final state
- Select events with leptons+jets signature with reconstructed photon
  - Exactly one isolated lepton, ≥3 jets, ≥1 b-tag, p_T^{miss}>25 GeV
  - At least one isolated photon, p_T>25 GeV
- Backgrounds come mainly from two categories:
  - Top pair events with a fake photon
  - Non-top events (W/Z+γ) with a real photon







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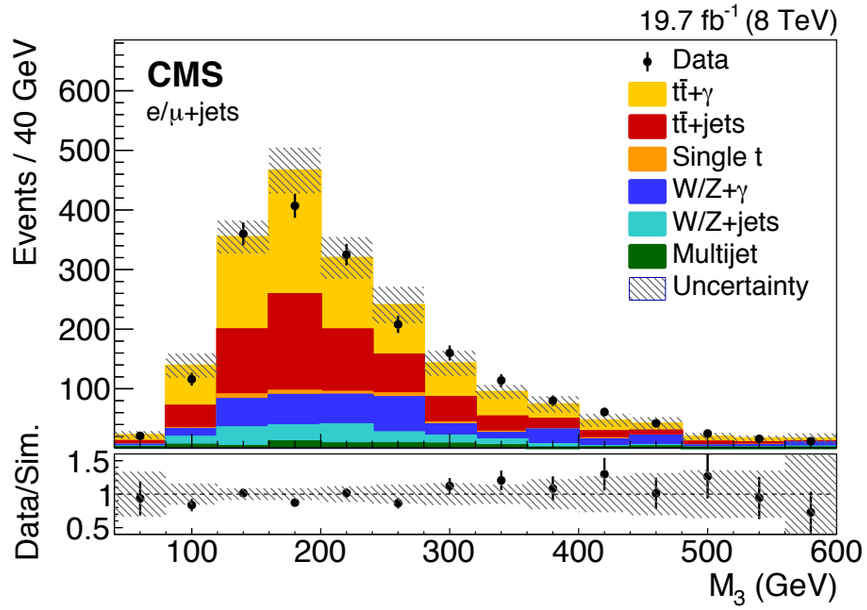
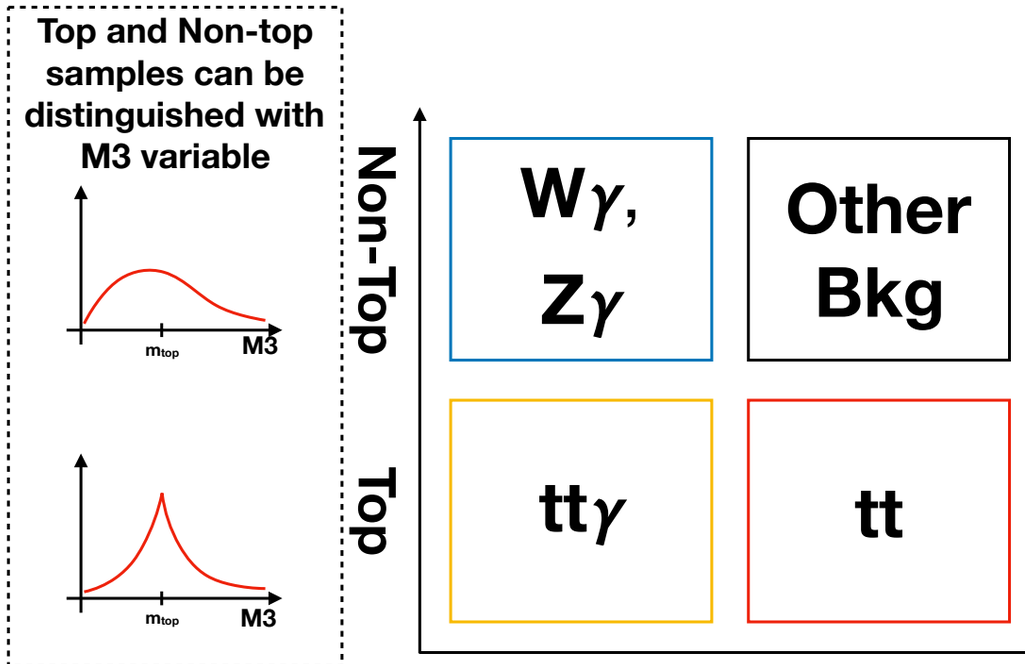
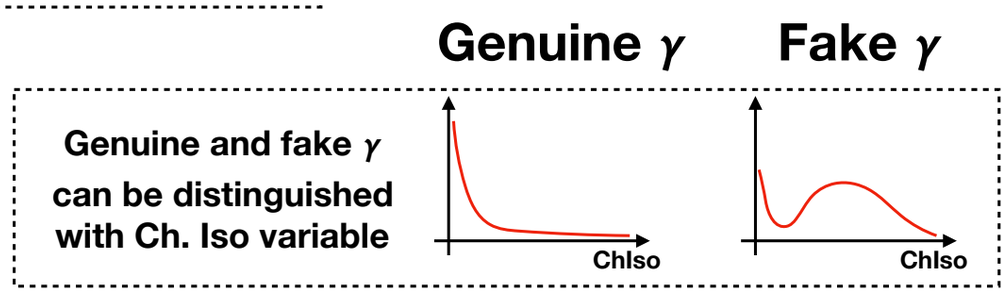
arXiv:1706.08128

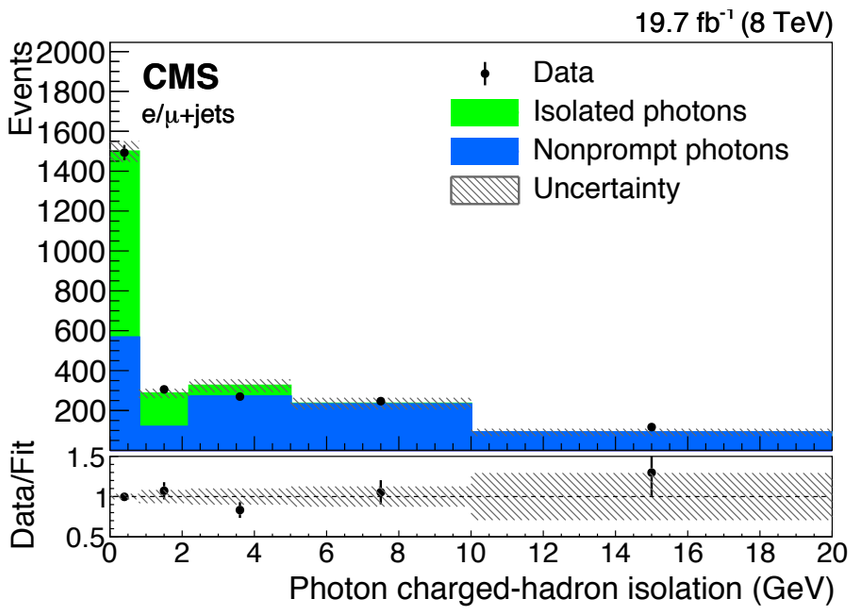
$t\bar{t}\gamma$ Analysis





- Strategy used is to:
  - Fit M_3 distribution to distinguish top from non-top events (measuring top purity)
  - Fit photon isolation to distinguish genuine and fake photons (measuring photon purity)





$t\bar{t}\gamma$ Results

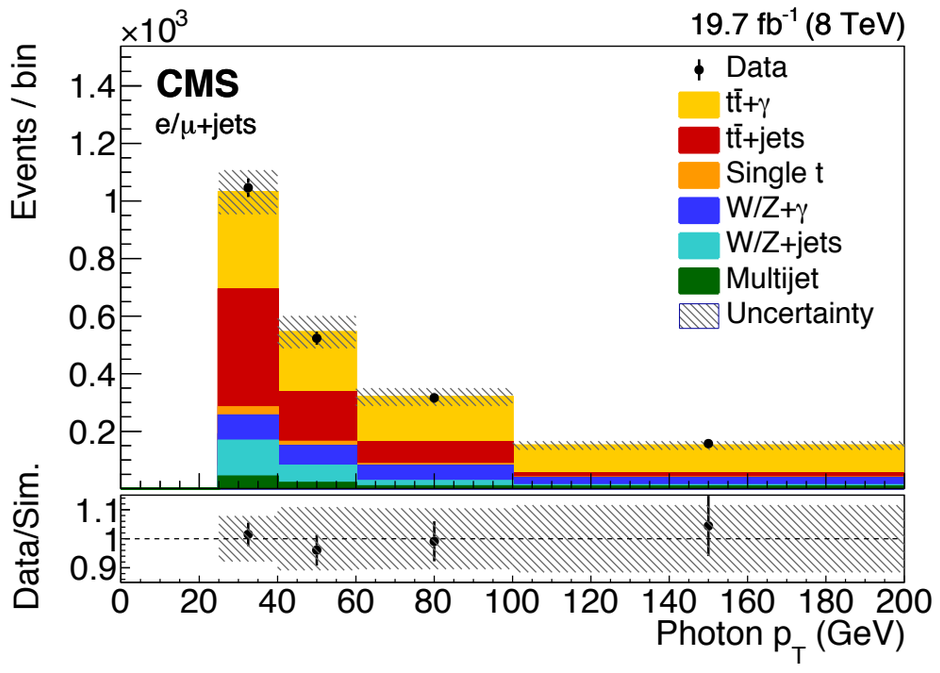
- Combine measurements of photon purity, top quark purity, and total event yield in likelihood to extract number of $t\bar{t}\gamma$ events

$$\chi^2 = \frac{(\pi_\gamma^{\text{data}} - \pi_\gamma^{\text{MC}})^2}{\sigma^2_{\pi_\gamma}} + \frac{(\pi_{t\bar{t}}^{\text{data}} - \pi_{t\bar{t}}^{\text{MC}})^2}{\sigma^2_{\pi_{t\bar{t}}}} + \frac{(N^{\text{data}} - N^{\text{MC}})^2}{\sigma^2_N}$$

$$N_{t\bar{t}\gamma} = 338 \pm 53\ (\text{stat})\ \text{in}\ e + \text{jets}$$
$$N_{t\bar{t}\gamma} = 442 \pm 69\ (\text{stat})\ \text{in}\ \mu + \text{jets}$$

- Measure ratio to $t\bar{t}$ (R), extract cross section by multiplying ratio by measured top pair cross section
- Largest uncertainty is statistical (associated with fit method and emphasis on data-driven estimates), followed by uncertainties on top mass and jet energy scale

Category	R	$\sigma^{\text{fid}}_{t\bar{t}+\gamma}$ (fb)	$\sigma_{t\bar{t}+\gamma}\,\mathcal{B}$ (fb)
e+jets	$(5.7 \pm 1.8) \times 10^{-4}$	138 ± 45	582 ± 187
μ+jets	$(4.7 \pm 1.3) \times 10^{-4}$	115 ± 32	453 ± 124
Combination	$(5.2 \pm 1.1) \times 10^{-4}$	127 ± 27	515 ± 108
Theory	—	—	$592 \pm 71\ (\text{scales}) \pm 30\ (\text{PDFs})$



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Summary & Outlook

- Results of many CMS measurements of top quark associated production presented
- Measurements agree with theory predictions

Process	σ	(stat)	(syst)
$t\bar{t}W$	0.77 pb	15%	17%
$t\bar{t}Z$	0.99 pb	9%	12%
$t\bar{t}t\bar{t}$	16.9 fb	81%	
$t\bar{t}\gamma \times \mathcal{BR}$	515 fb	23%	

- Further improvements to measurements in the pipeline:
  - tt+W & tt+Z : improvements to the lepton identification reduce nonprompt backgrounds and systematics
  - tttt : Larger datasets to improve statistical uncertainty
  - tt+γ : More data (13 TeV measurement) and improvements to analysis technique to push down statistical and systematic uncertainties

Backup Slides

ttW/ttZ Supporting Material

$t\bar{t}W$ Selection

- SS dilepton, p_T > 25 GeV
- ≥2 jets, ≥1 b-tag
  - p_T > 30 GeV

BDT Variables

- N_{j}
- N_{b}
- H_{T}: scalar sum of p_{T} of jets
- $p_{\mathrm{T}}^{\mathrm{miss}}$
- p_{T} leading lepton
- p_{T} trailing lepton
- M_{T} leading lepton
- p_{T} leading and second leading jets
- ΔR between trailing lepton and nearest jet

$t\bar{t}W$ Event Yields

SS Dilepton D > 0

		N_j	N_b	Background	$t\bar{t}W$	$t\bar{t}Z$	Total	Observed
$\ell^-\ell^-$	$0 < D < 0.6$	2	>0	18.1 ± 1.8	2.2 ± 0.4	0.5 ± 0.1	20.8 ± 1.9	17
		3	1	8.3 ± 0.9	2.1 ± 0.4	0.5 ± 0.1	10.9 ± 0.9	9
			>1	10.9 ± 1.1	3.5 ± 0.6	0.8 ± 0.1	15.2 ± 1.3	17
		>3	1	10.1 ± 1.1	2.8 ± 0.5	0.7 ± 0.2	13.7 ± 1.3	8
			>1	22.2 ± 2.0	7.6 ± 1.2	2.7 ± 0.4	32.5 ± 2.4	27
	$D > 0.6$	2	>0	6.8 ± 0.9	2.0 ± 0.3	0.4 ± 0.1	9.2 ± 0.9	10
		3	1	4.1 ± 0.6	1.6 ± 0.3	0.3 ± 0.1	6.1 ± 0.6	11
			>1	7.8 ± 0.9	3.8 ± 0.6	0.7 ± 0.1	12.3 ± 1.1	10
		>3	1	5.6 ± 0.7	2.9 ± 0.5	0.7 ± 0.2	9.2 ± 0.9	5
			>1	15.3 ± 1.5	12.0 ± 1.9	3.2 ± 0.5	30.5 ± 2.5	32
$\ell^+\ell^+$	$0 < D < 0.6$	2	>0	17.9 ± 1.8	4.9 ± 0.8	0.3 ± 0.1	23.1 ± 2.0	26
		3	1	10.2 ± 1.3	3.7 ± 0.6	0.4 ± 0.1	14.4 ± 1.4	11
			>1	10.2 ± 1.2	6.9 ± 1.1	0.8 ± 0.2	17.9 ± 1.6	18
		>3	1	10.7 ± 1.2	4.9 ± 0.8	0.8 ± 0.2	16.4 ± 1.4	16
			>1	22.4 ± 2.0	13.3 ± 2.2	3.0 ± 0.5	38.7 ± 3.0	42
	$D > 0.6$	2	>0	8.0 ± 1.1	4.3 ± 0.7	0.4 ± 0.1	12.7 ± 1.3	18
		3	1	4.8 ± 0.7	3.2 ± 0.5	0.3 ± 0.1	8.4 ± 0.9	7
			>1	5.4 ± 0.7	7.1 ± 1.2	1.0 ± 0.2	13.5 ± 1.4	10
		>3	1	6.3 ± 0.8	5.6 ± 0.9	0.9 ± 0.2	12.8 ± 1.2	12
			>1	16.5 ± 1.5	22.5 ± 3.7	3.1 ± 0.5	42.1 ± 4.0	46

SS Dilepton D < 0

Process	$N_j = 2$	$N_j = 3$	$N_j > 3$
Nonprompt	136.5 ± 13.9	110.3 ± 11.3	57.3 ± 6.1
Total background	192.1 ± 15.6	137.7 ± 11.7	74.0 ± 6.4
$t\bar{t}W$	13.1 ± 0.3	17.6 ± 0.3	13.8 ± 0.3
$t\bar{t}Z$	1.6 ± 0.4	3.1 ± 0.7	4.4 ± 1.0
Total	206.8 ± 15.7	158.4 ± 11.8	92.3 ± 6.5
Observed	229	144	92

$t\bar{t}Z$ Event Yields

Three-lepton

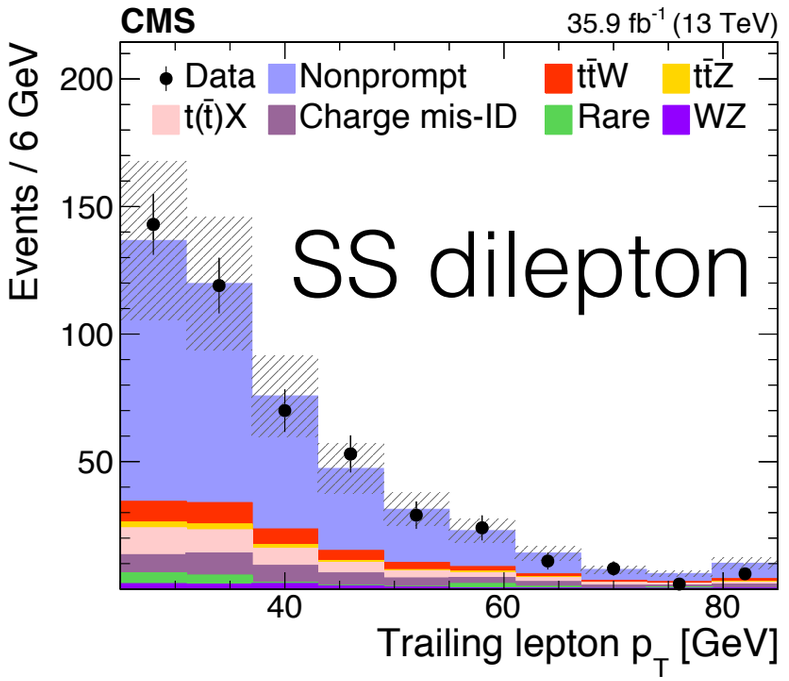
N_b	N_j	Background	$t\bar{t}W$	$t\bar{t}Z$	Total	Observed
0	2	1032.8 ± 77.1	0.9 ± 0.1	18.2 ± 3.2	1051.9 ± 77.2	1022
	3	293.5 ± 21.4	0.4 ± 0.1	22.3 ± 3.9	316.3 ± 21.8	318
	>3	95.4 ± 7.4	0.3 ± 0.1	26.1 ± 4.6	121.8 ± 8.7	144
1	2	164.6 ± 17.8	1.9 ± 0.3	24.3 ± 4.3	190.7 ± 18.3	209
	3	66.6 ± 6.7	0.9 ± 0.2	41.2 ± 7.2	108.7 ± 9.8	99
	>3	32.8 ± 3.3	0.8 ± 0.1	61.3 ± 10.8	94.9 ± 11.3	72
>1	2	12.9 ± 2.4	1.0 ± 0.2	5.9 ± 1.0	19.8 ± 2.6	32
	3	11.6 ± 1.7	0.6 ± 0.1	17.9 ± 3.2	30.1 ± 3.6	46
	>3	10.6 ± 1.6	0.4 ± 0.1	41.0 ± 7.2	52.0 ± 7.4	54

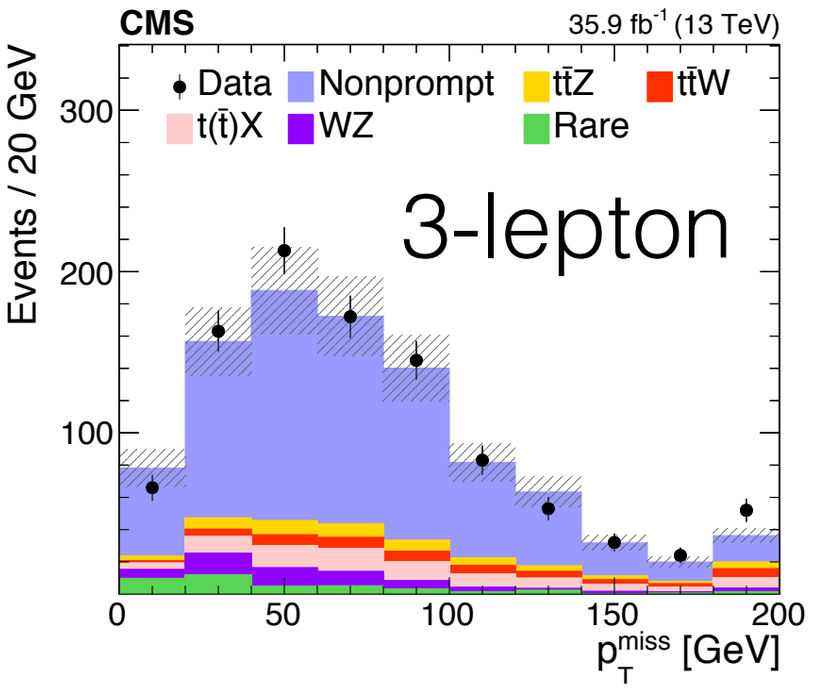
Four-lepton

Process	$N_b = 0$	$N_b > 0$
Total background	12.8 ± 2.0	3.3 ± 0.3
$t\bar{t}Z$	4.5 ± 0.6	14.5 ± 1.8
Total	17.2 ± 2.0	17.8 ± 1.8
Observed	23	15

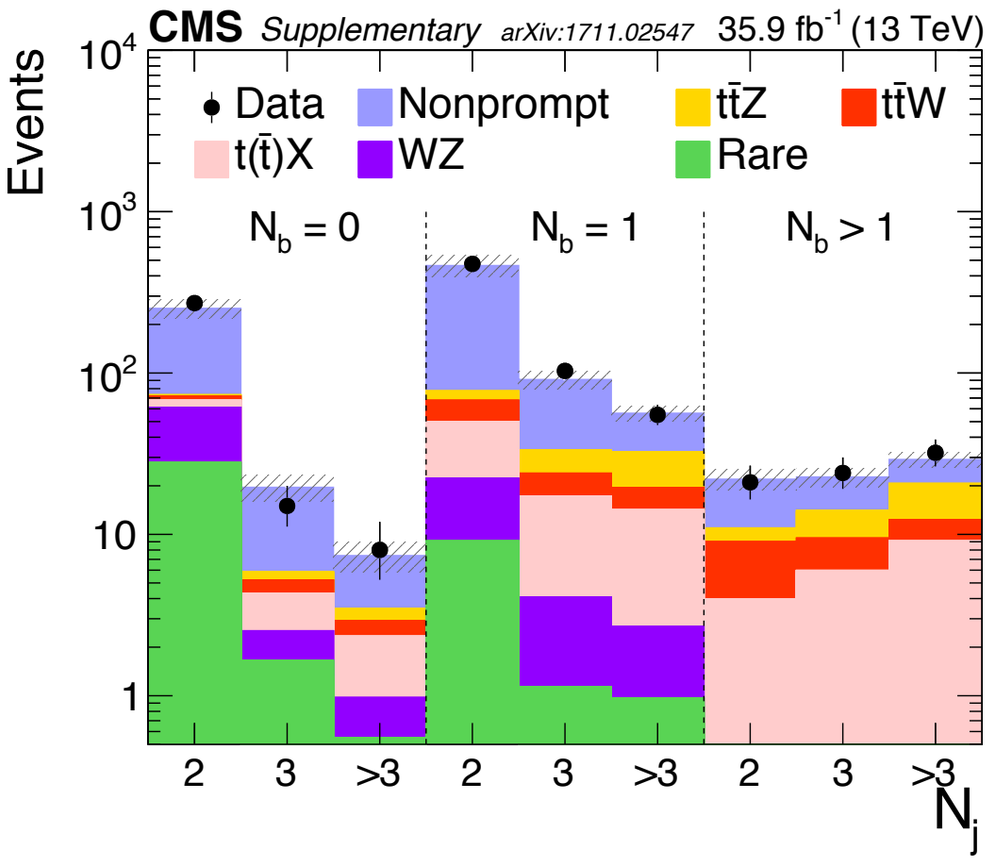
Nonprompt Lepton Background

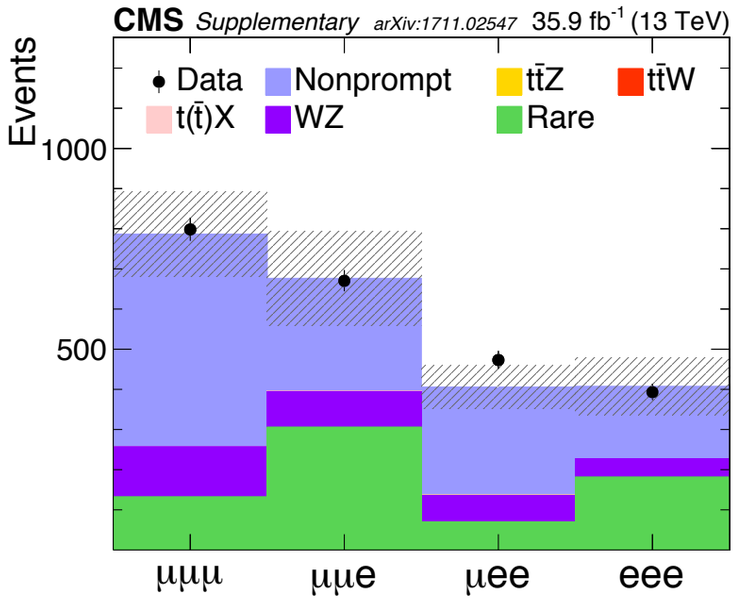
- Measure tight-to-loose lepton ratio (probabililty lepton passing loose selection passes tight selection)
  - Measured in non prompt lepton enriched control region: 1 loosely isolated lepton and ≥1 jet
  - Parameterized as a function of lepton p_T and η
- Define sideband regions, same as signal regions, but where one lepton passes only loose criteria
  - Tight-to-loose ratio used to extrapolate from application region to signal regions
- Verified in MC, and non prompt enriched control regions:
  - BDT < 0 in SS dilepton
  - In 3 lepton, control region defined by either absence of an OSSF lepton pair, or with OSSF having $|m_{\ell\ell}-m_Z| > 10$ GeV and with at least one b jet present.

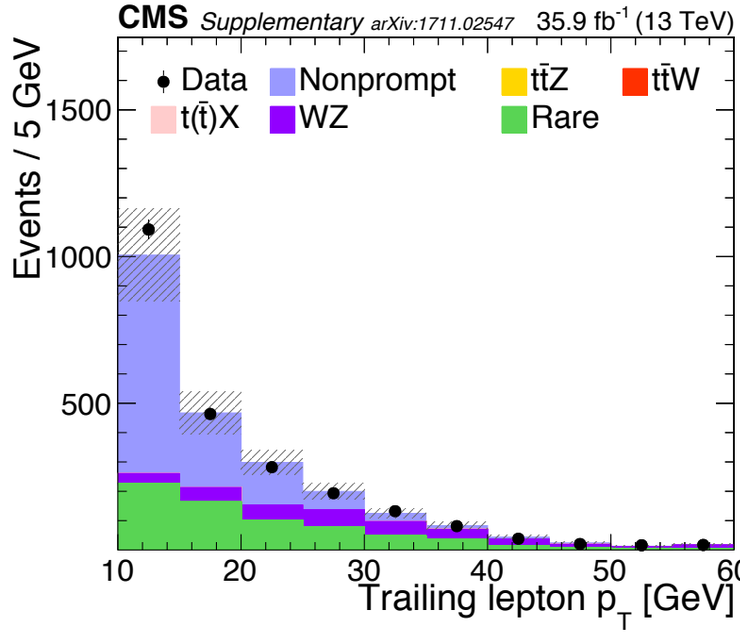


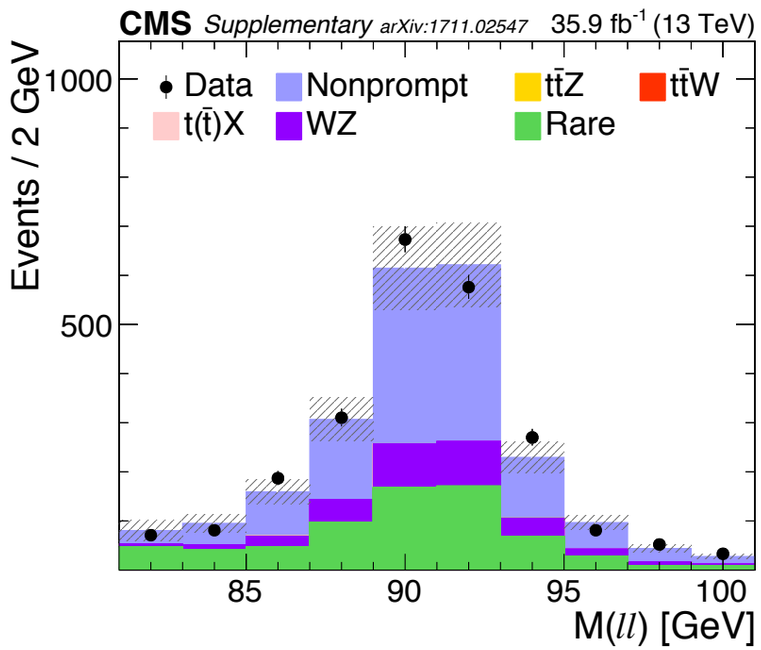


Nonprompt background





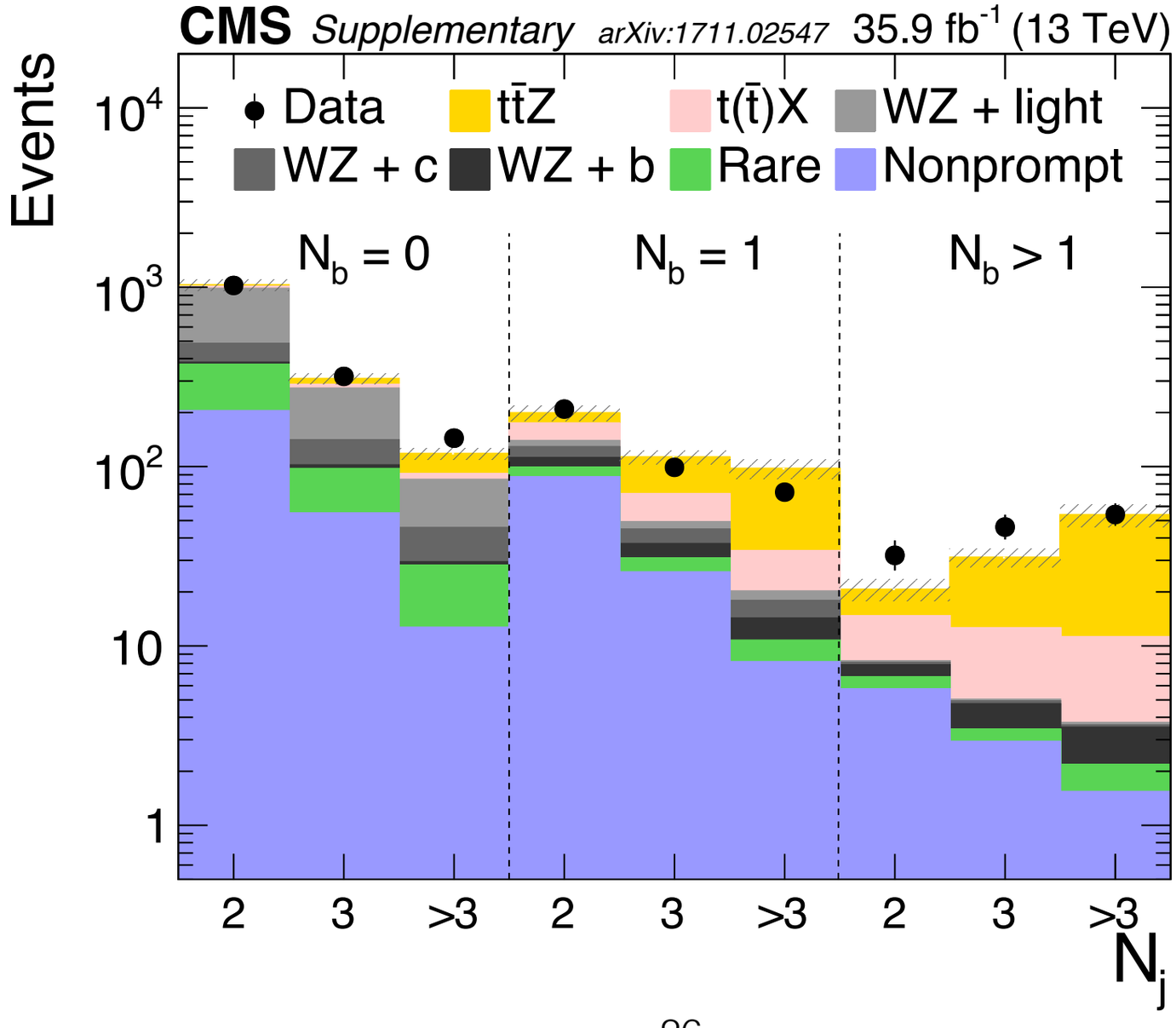




Jet/b-jet categories in non prompt control region for trilepton channel

Trilepton Jet Categories

Trilepton jet categories with WZ background split by heavy flavor content



Systematics

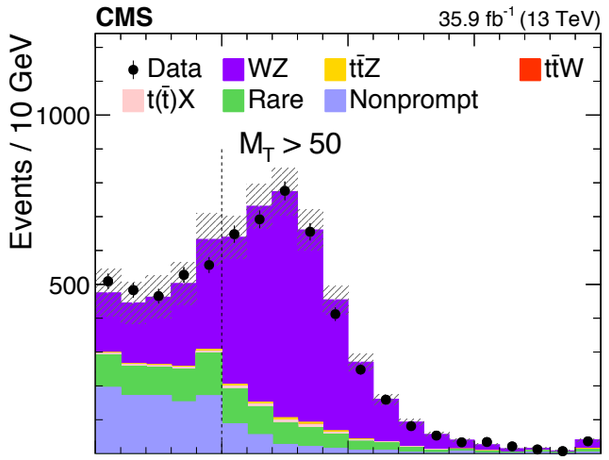
Source	Uncertainty from each source (%)	Impact on the measured $t\bar{t}W$ cross section (%)	Impact on the measured $t\bar{t}Z$ cross section (%)
Integrated luminosity	2.5	4	3
Jet energy scale and resolution	2–5	3	3
Trigger	2–4	4–5	5
B tagging	1–5	2–5	4–5
PU modeling	1	1	1
Lepton ID efficiency	2–7	3	6–7
Choice in μ_R and μ_F	1	<1	1
PDF	1	<1	1
Nonprompt background	30	4	<2
WZ cross section	10–20	<1	2
ZZ cross section	20	—	1
Charge misidentification	20	3	—
Rare SM background	50	2	2
$t(\bar{t})X$ background	10–15	4	3
Stat. unc. in nonprompt background	5–50	4	2
Stat. unc. in rare SM backgrounds	20–100	1	<1
Total systematic uncertainty	—	14	12

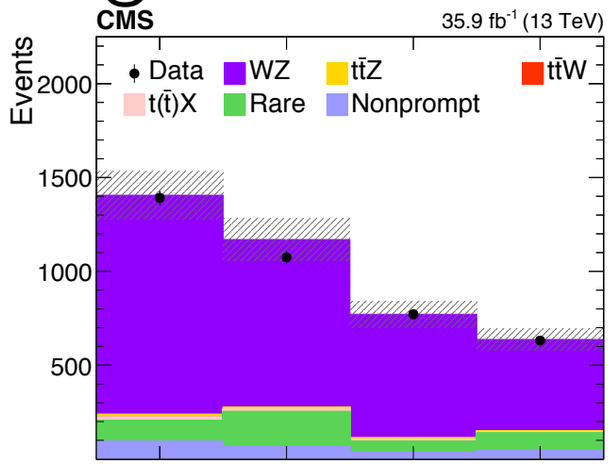
Background Estimates

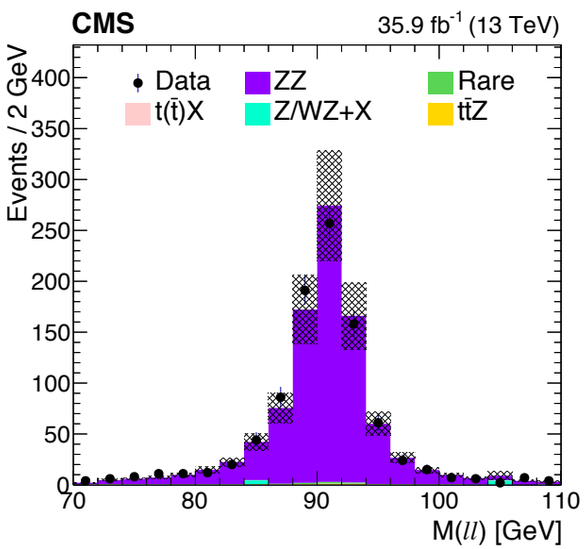
- Charge misidentification of electrons: Estimated by looking at events ee and eμ events in opposite charge data, reweighted by electron-charge misidentification probability derived from simulation

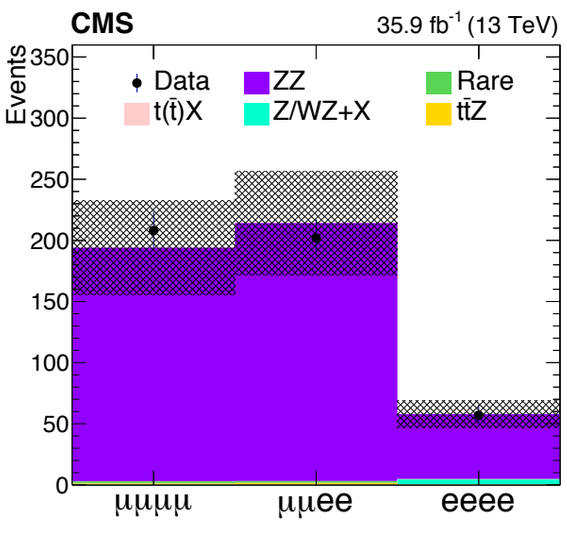
- WZ/ZZ : Taken from simulation, verified in dedicated control regions

WZ control region:









ttGamma Supporting Material

tt+gamma Event Yields

Sample	Genuine photon	Misid. electron	Nonprompt photon	Total
$t\bar{t}+\gamma$	312 ± 17	0.2 ± 0.1	8.5 ± 0.9	321 ± 17
$t\bar{t}$+jets	—	22 ± 3	215 ± 13	237 ± 14
W+γ	75 ± 25	—	—	75 ± 25
W+jets	—	—	60 ± 15	60 ± 15
Z+γ	14 ± 5	1.3 ± 1.1	$0.5^{+0.7}_{-0.5}$	16 ± 5
Z+jets	—	43 ± 28	11 ± 6	54 ± 30
Single t	11 ± 3	2.0 ± 1.3	16 ± 4	29 ± 7
QCD multijet	—	—	31 ± 18	31 ± 18
Total	412 ± 31	69 ± 29	342 ± 28	823 ± 52
Data	—	—	—	935

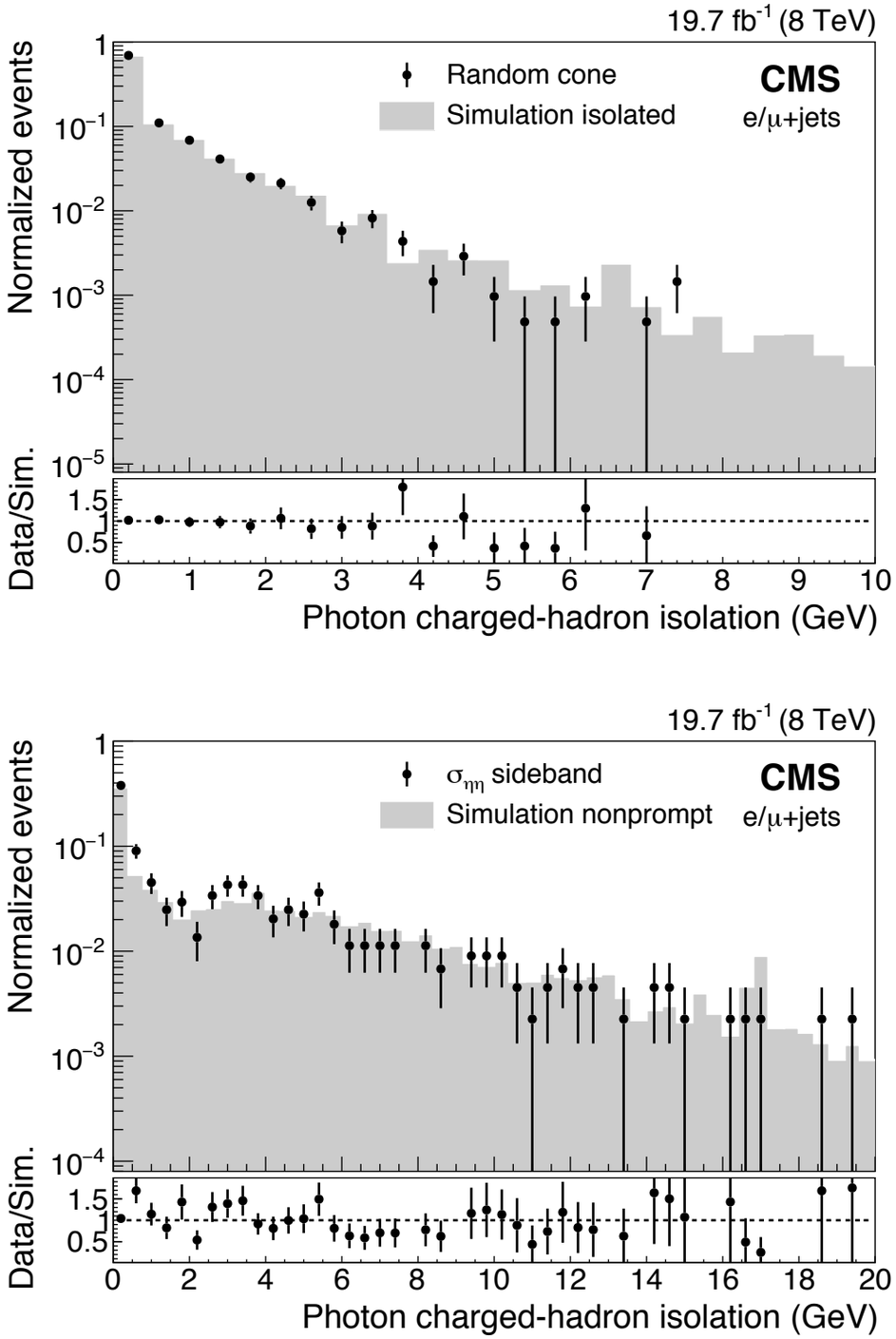
Sample	Genuine photon	Misid. electron	Nonprompt photon	Total
$t\bar{t}+\gamma$	407 ± 23	0.4 ± 0.3	11 ± 1	418 ± 24
$t\bar{t}$+jets	—	31 ± 5	291 ± 16	322 ± 17
W+γ	140 ± 41	—	9.0 ± 6.7	149 ± 45
W+jets	—	—	57 ± 14	57 ± 14
Z+γ	21 ± 7	—	1.4 ± 0.9	23 ± 7
Z+jets	—	—	9.6 ± 5.8	10 ± 6
Single t	12 ± 3	1.5 ± 1.3	25 ± 13	38 ± 14
QCD multijet	—	—	36 ± 20	36 ± 20
Total	580 ± 48	33 ± 5	440 ± 33	1053 ± 61
Data	—	—	—	1136

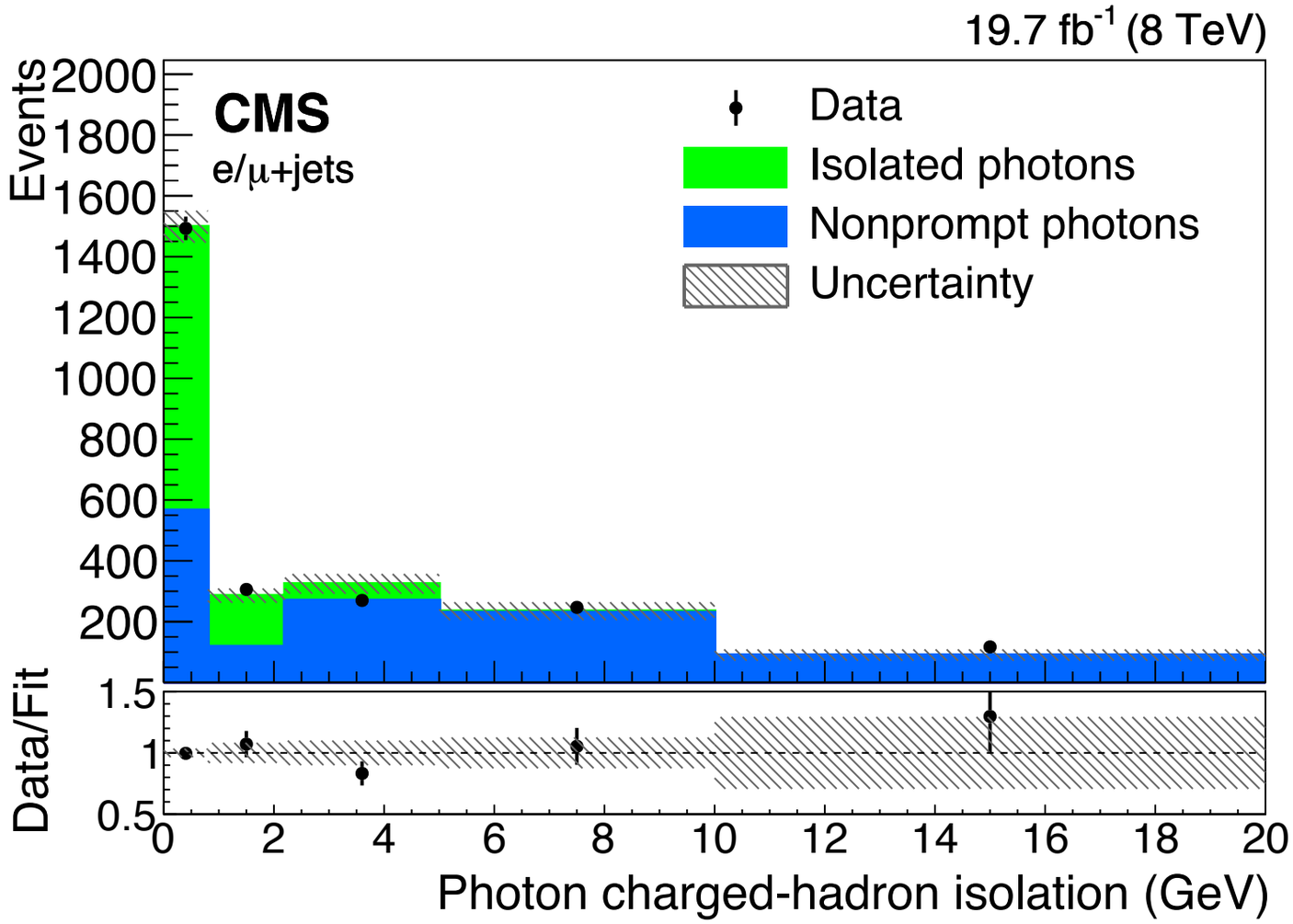
tt+gamma Uncertainties

- Largest contribution is statistical (likelihood fit uncertainty)
- Followed by modeling uncertainties:
- Top mass
- Q2 scale
- Jet energy scale corrections

Source	Uncertainty (%)
Statistical likelihood fit	15.5
Top quark mass	7.9
JES	6.9
Fact. and renorm. scale	6.7
ME/PS matching threshold	3.9
Photon energy scale	2.4
JER	2.3
Multijet estimate	2.0
Electron misid. rate	1.3
Z+jets scale factor	0.8
Pileup	0.6
Background normalization	0.6
Top quark p_{T} reweighting	0.4
b tagging scale factor	0.3
Muon efficiency	0.3
Electron efficiency	0.1
PDFs	0.1
Muon energy scale	0.1
Electron energy scale	0.1
Total	20.7

tt+gamma





- Fit to photon charged-hadron isolation to extract photon purity (percent of photons coming from genuine sources)
- Data driven templates of isolated (genuine) photons and non-prompt (fake)

Four top Supporting Material

Systematics

Source	Uncertainty (%)
Integrated luminosity	2.5
Pileup	0–6
Trigger efficiency	2
Lepton selection	4–10
Jet energy scale	1–15
Jet energy resolution	1–5
b tagging	1–15
Size of simulated sample	1–10
Scale and PDF variations	10–15
ISR/FSR (signal)	5–15
$t\bar{t}H$ (normalization)	50
Rare, $X\gamma$, $t\bar{t}VV$ (norm.)	50
$t\bar{t}Z$, $t\bar{t}W$ (normalization)	40
Charge misidentification	20
Nonprompt leptons	30–60

W/Z control regions

- Comparison of data to prediction in ttW and ttZ control regions
- CRW:
  - 2 leptons, 2-5 jets, =2 b-tags
- CRZ:
  - 3 leptons, ≥2 jets, ≥2 b-tags, OSSF pair with $|m_{\ell\ell}-m_Z| < 15$ GeV