Measurement of the cross section of $t\bar{t}W$ at CMS

15th International Workshop on Top-Quark Physics (TOP2022)

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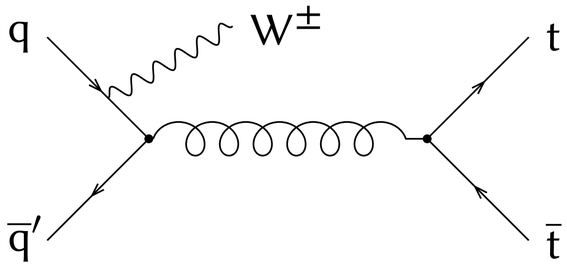
on behalf of the CMS Collaboration

CMS-TOP-21-011
arXiv:2208.06485

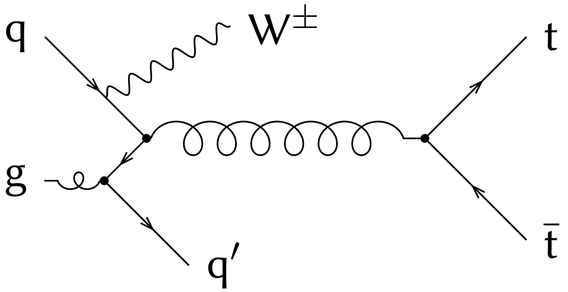
Introduction

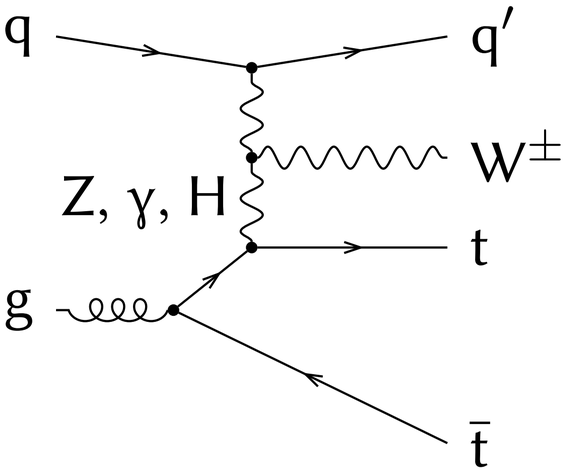
- The associated W can only be radiated off an initial-state quark via $q\bar{q}$ at LO, gq at NLO and gg at NNLO
- Sizeable difference between $t\bar{t}W^+$ and $t\bar{t}W^-$ production rate
- Foundation for charge asymmetry and differential measurements
- Large corrections from the EW production diagrams at NLO
- Cross section measured at the LHC are higher than theoretical prediction → more investigation
- Dominant irreducible background to several LHC searches (eg. $t\bar{t}H$ and $t\bar{t}t\bar{t}$)

$t\bar{t}W$ (LO)



$t\bar{t}W$ (NLO)

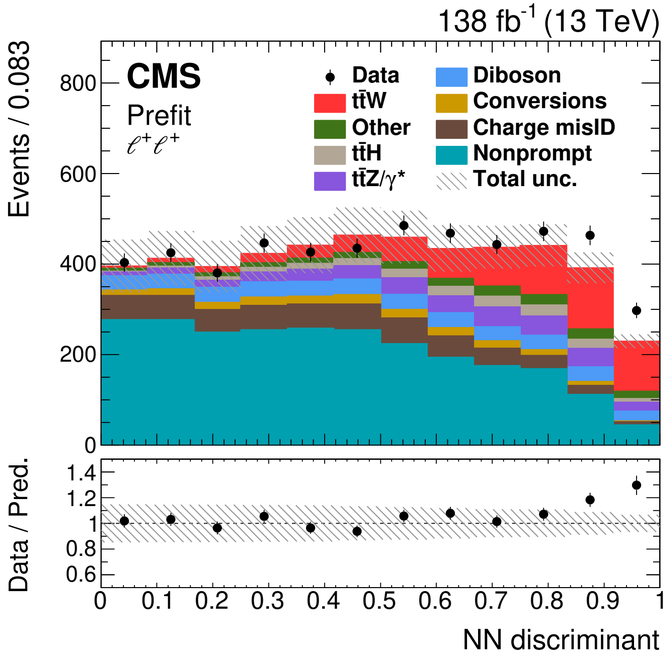


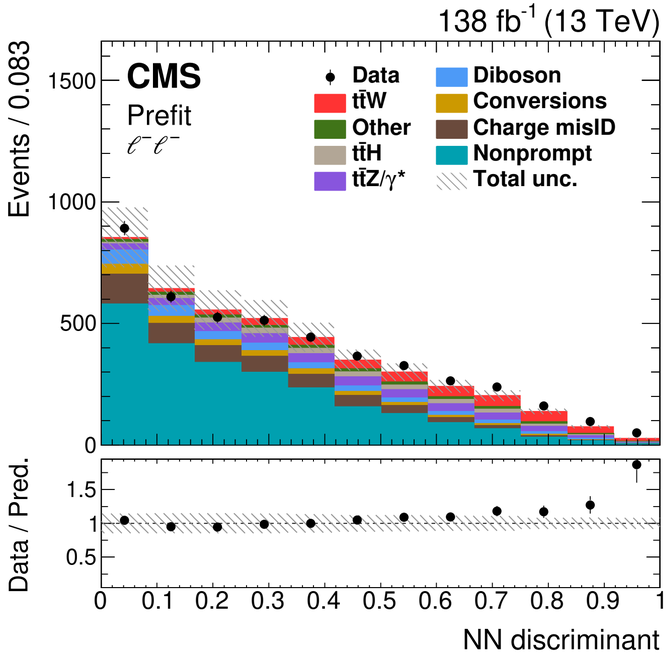


Analysis strategy

Same sign dilepton

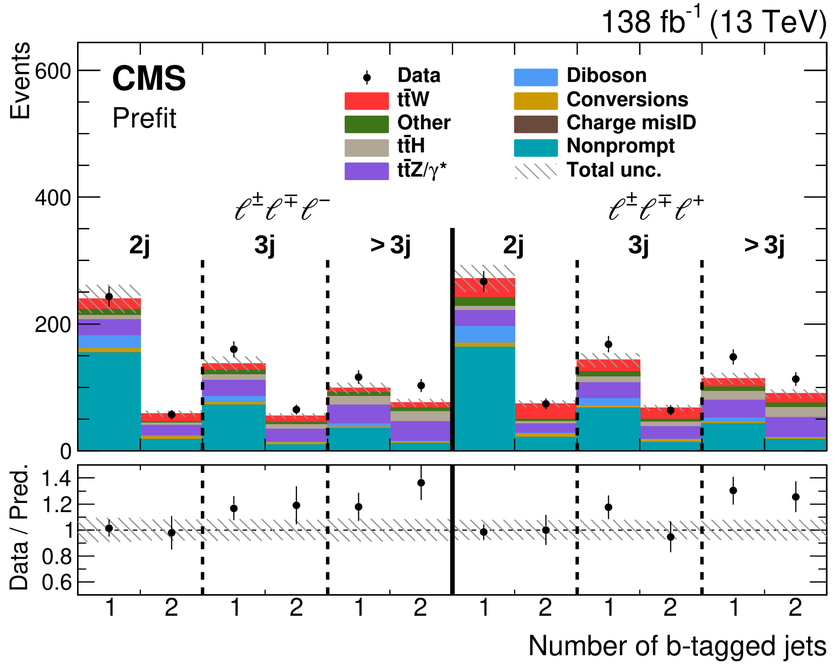
- Exactly 2 leptons (electron or muon) with same charge
- $\geq$ 2 jets
- $\geq$ 1 medium (~82% eff.) bjet or $\geq$ 2 loose (~91% eff.) bjets
- Categorisation: Charge and flavour of leptons
- Neural network with 4 classes: $t\bar{t}W$, $t\bar{t}H/Z$, $t\bar{t}\gamma$ and nonprompt





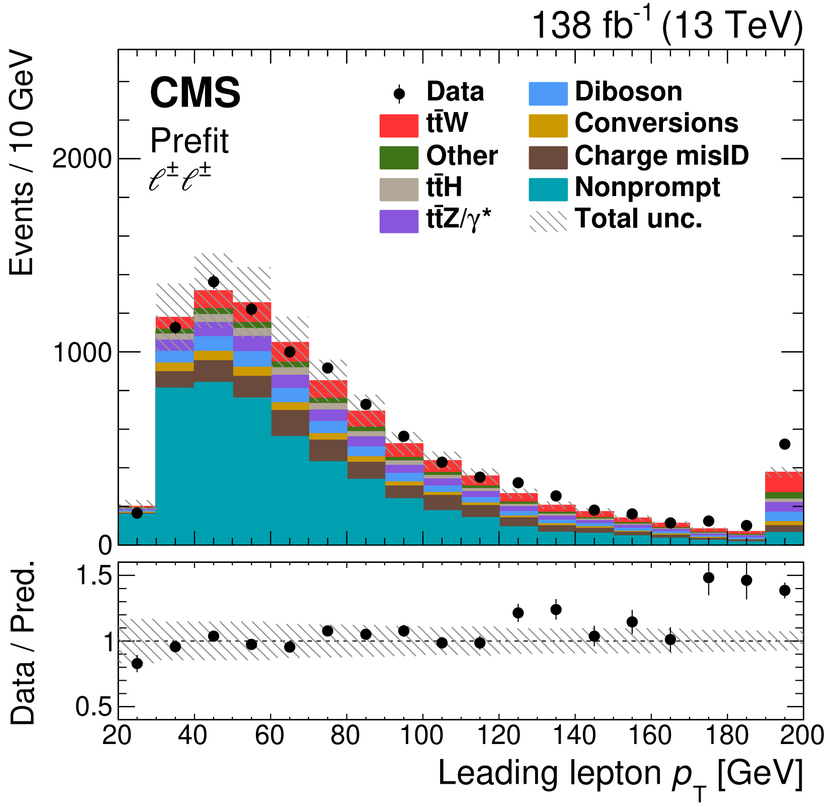
Trilepton

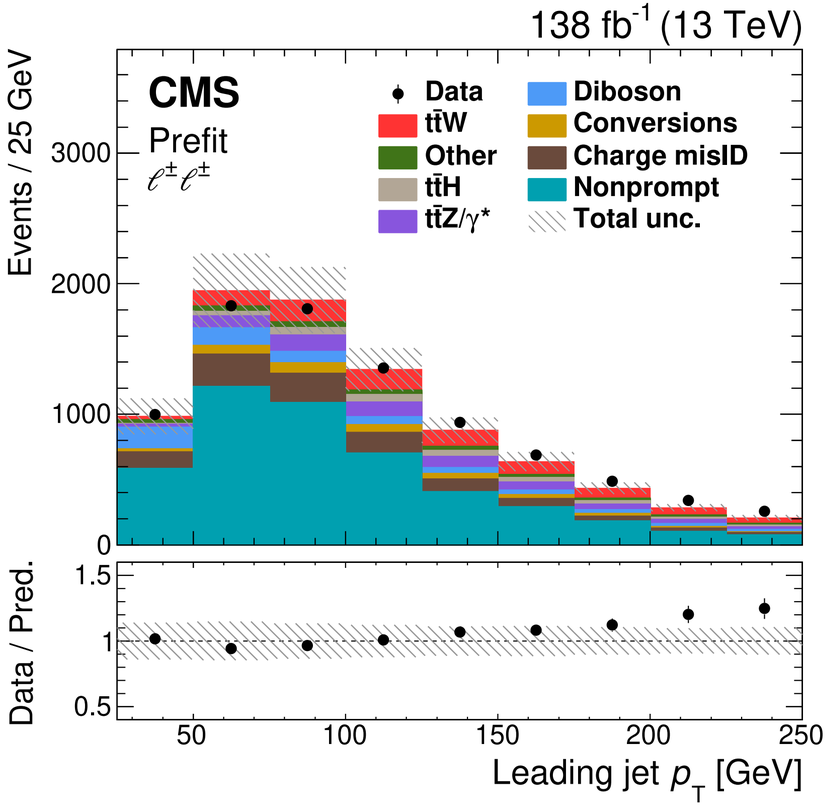
- Exactly 3 leptons (electron or muon)
- $\geq$ 2 jets
- $\geq$ 1 medium (~82% eff.) b jet
- Categorisation: Charge of leptons, numbers of jets and bjets
- m(3ℓ) is used as a discriminant

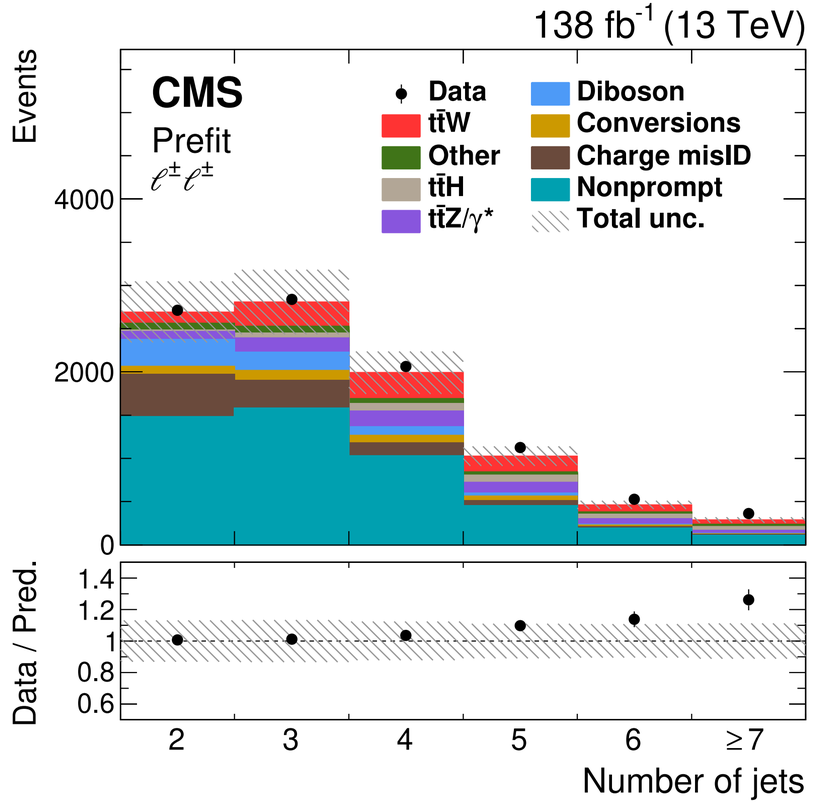


Main backgrounds: Nonprompt lepton, charge misID (2SSL only), $t\bar{t}H$, $t\bar{t}Z/\gamma*$ and diboson.

Analysis strategy



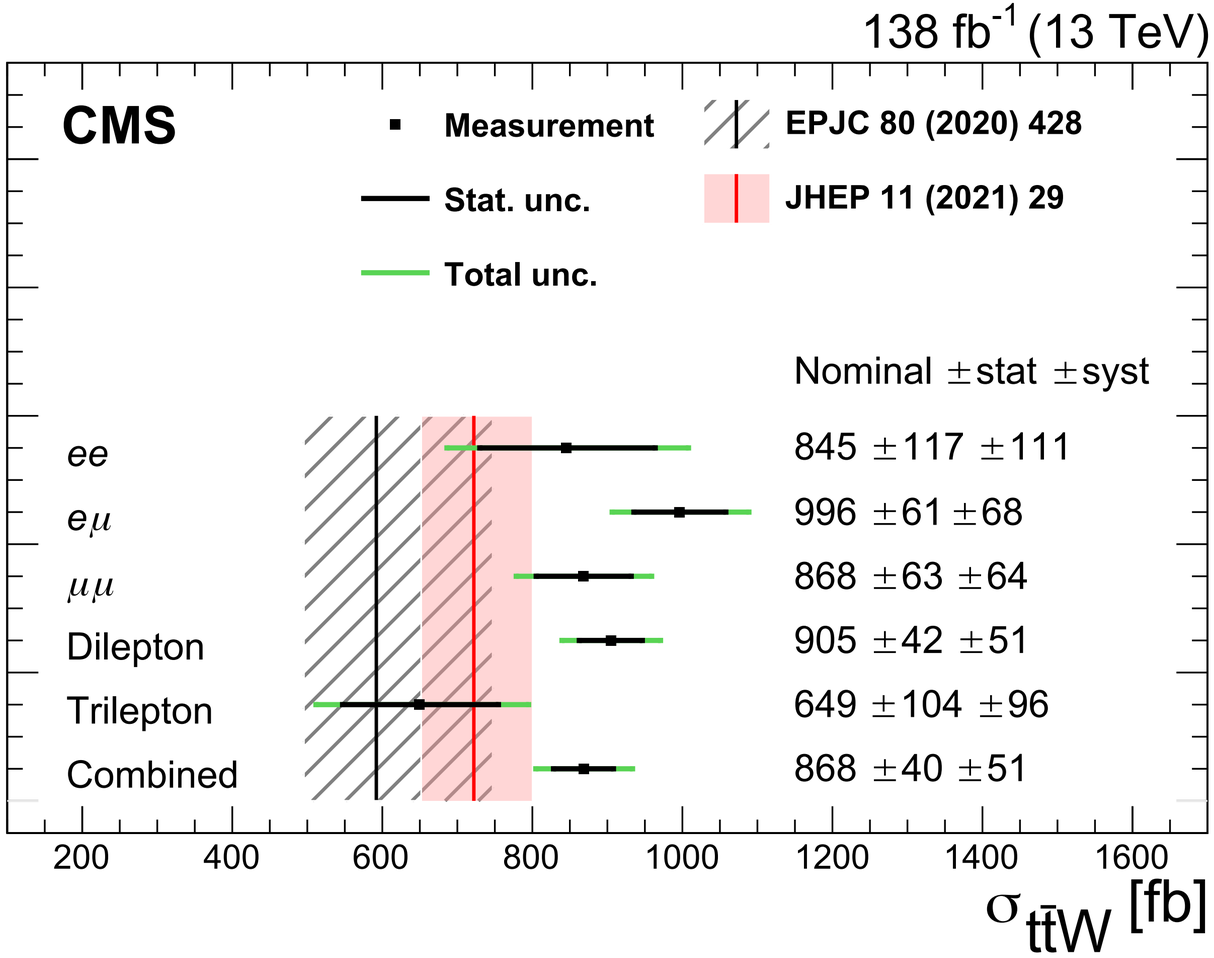




Good agreement between observed and predicted events in important NN input variables

Result

- Binned profile likelihood fit to NN (in 2SSL) and $m(3\ell)$ (in 3ℓ) distributions (simultaneously)



Inclusive cross section of $t\bar{t}W$

Observed:

$868 \pm 40\ (\text{stat}) \pm 51\ (\text{syst})$ fb

Theoretical:

NLO+NNLL: 592^{+155}_{-97} fb [1]

NLO+FxFx: 722^{+71}_{-78} fb [2]

[1] EPJC 80 (202) 428, A. Kuleszaa et al.
[2] JHEP 11 (2021) 029, R. Frederix, I. Tsinikos

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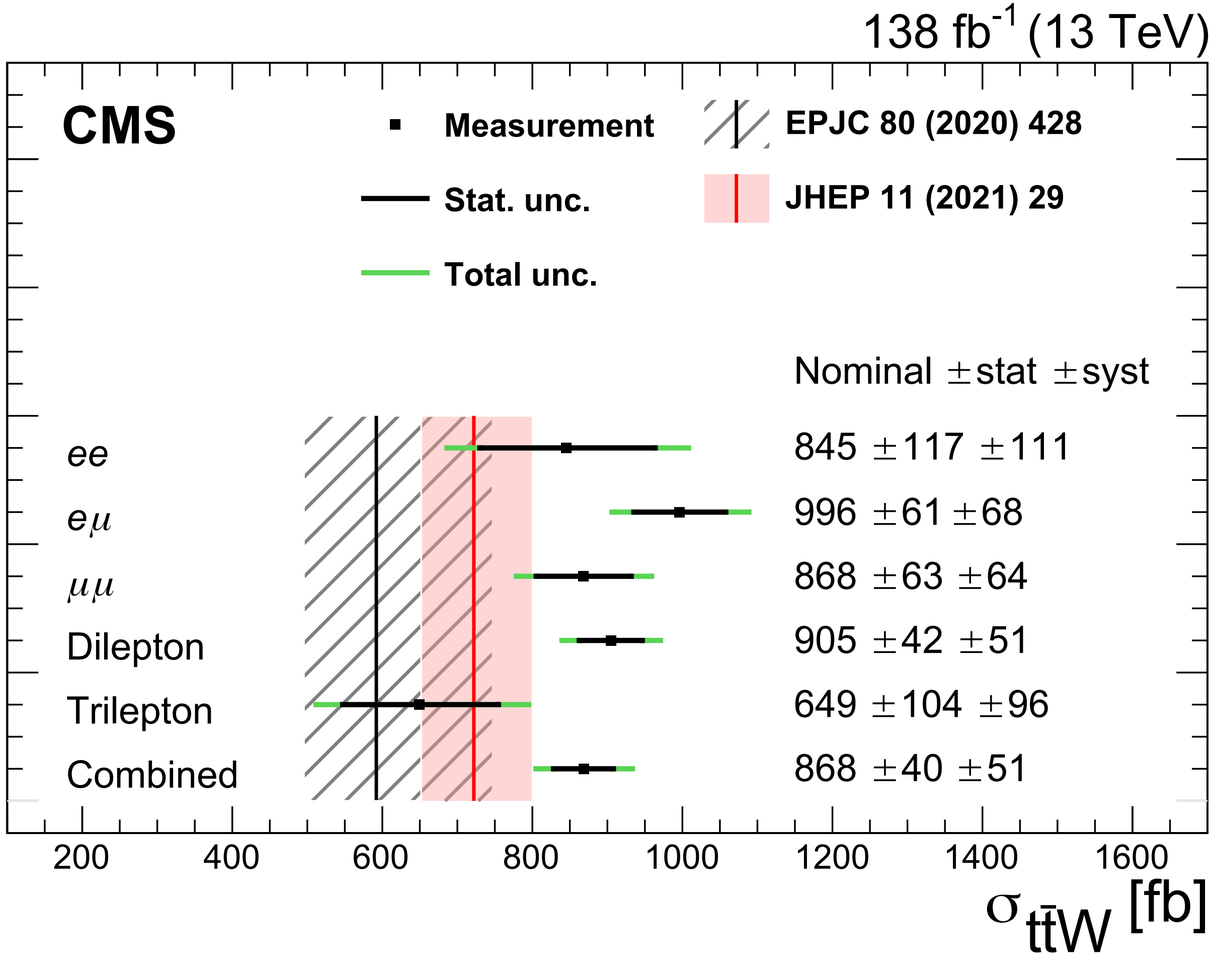

The most precise result up to date

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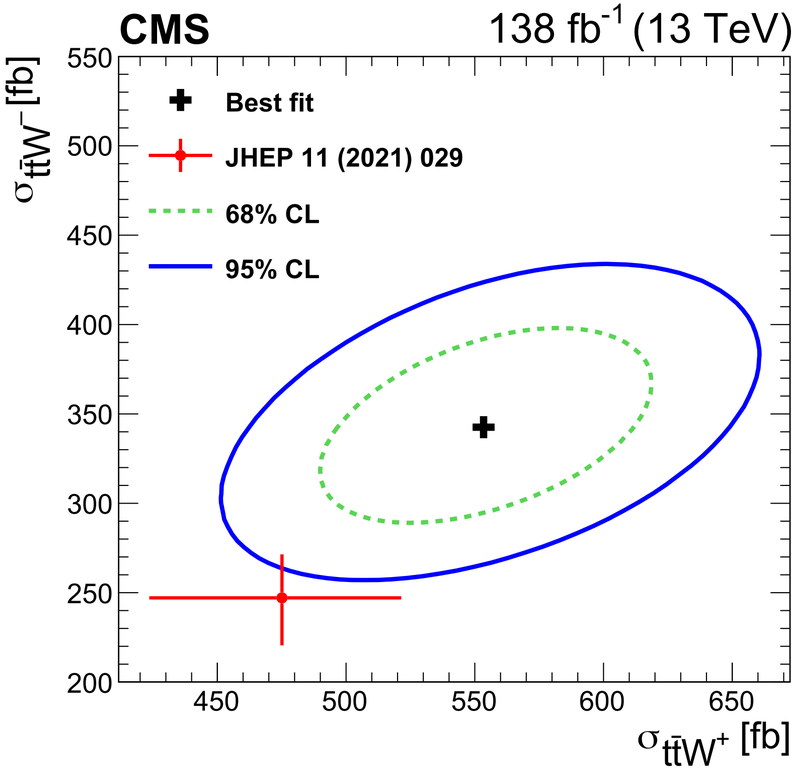
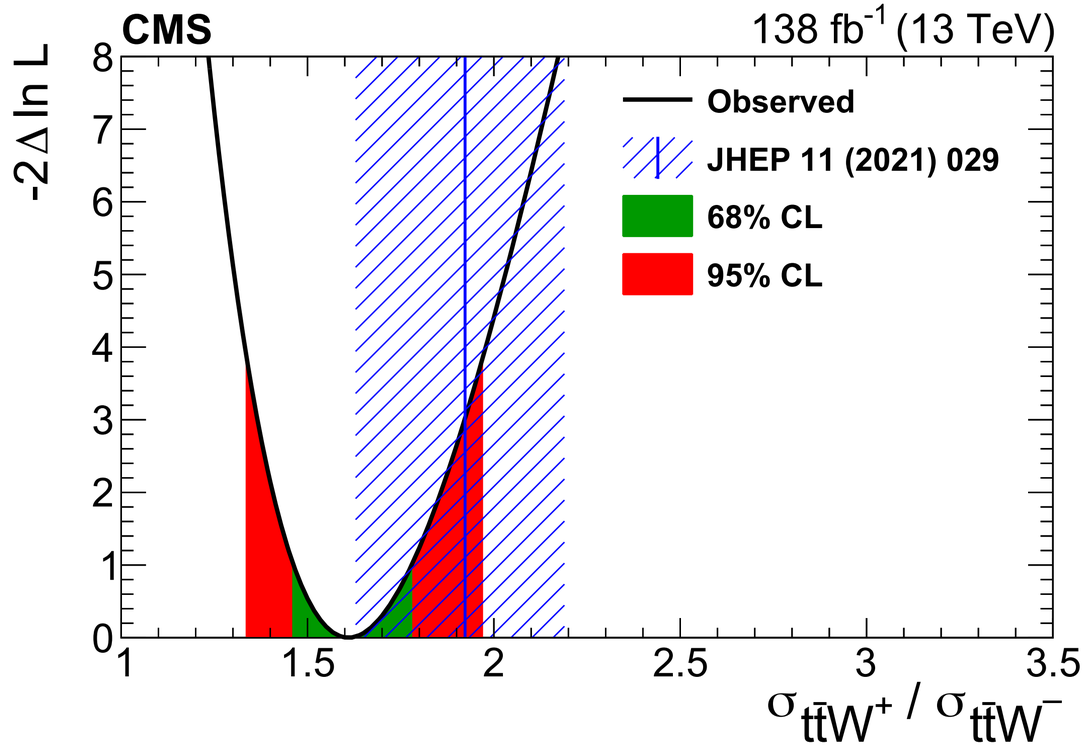
Result

Observable	Measurement	SM prediction NLO + NNLL [1,3]	SM prediction NLO + FxFx [2]
$\sigma_{t\bar{t}W}$	$868 \pm 40\,(\text{stat}) \pm 51\,(\text{syst})$ fb	$592\,^{+155}_{-97}$ fb	$722\,^{+71}_{-78}$ fb
$\sigma_{t\bar{t}W+}$	$553 \pm 30\,(\text{stat}) \pm 30\,(\text{syst})$ fb	$384\,^{+53}_{-33}$ fb	$475\,^{+46}_{-52}$ fb
$\sigma_{t\bar{t}W-}$	$343 \pm 26\,(\text{stat}) \pm 25\,(\text{syst})$ fb	$198\,^{+26}_{-17}$ fb	$247\,^{+24}_{-27}$ fb
$\sigma_{t\bar{t}W+}/\sigma_{t\bar{t}W-}$	$1.61 \pm 0.15\,(\text{stat})\,^{+0.07}_{-0.05}\,(\text{syst})$	$1.94\,^{+0.37}_{-0.24}$	$1.92\,^{+0.27}_{-0.29}$

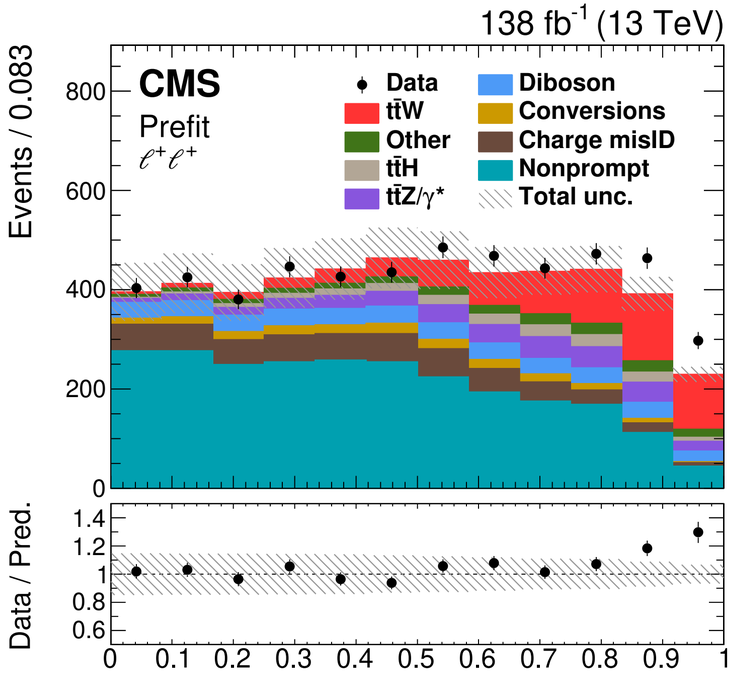


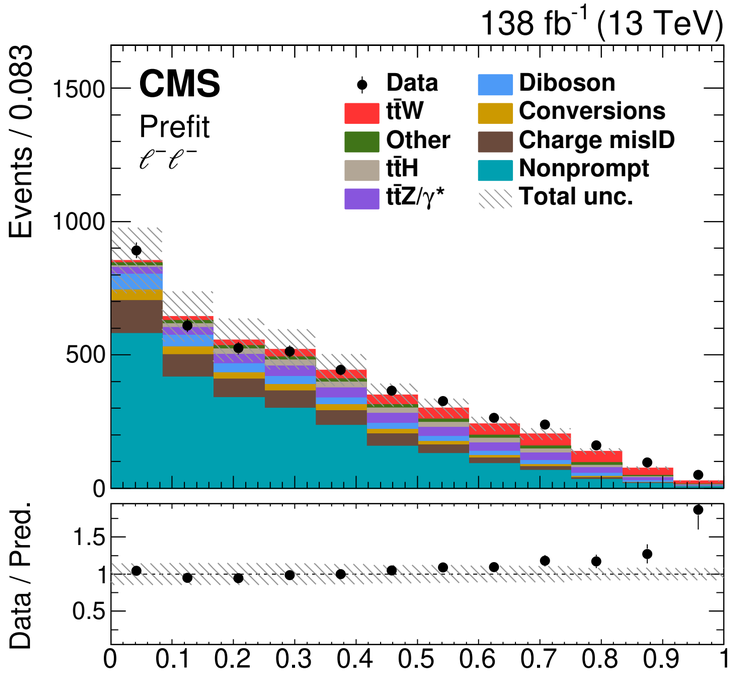


[1] EPJC 80 (202) 428, A. Kuleszaa et al.
[2] JHEP 11 (2021) 029, R. Frederix, I. Tsinikos
[3] JHEP 08 (2019) 039, A. Broggio et al.

Observe agreement with theory within 2 standard deviations

Backup


138 fb-1 (13 TeV)
CMS
Prefit
ℓ+ℓ+
Data
tt̄W
Other
tt̄H
tt̄Z/γ*
Diboson
Conversions
Charge misID
Nonprompt
Total unc.
Events / 0.083
Data / Pred.


138 fb-1 (13 TeV)
CMS
Prefit
ℓ−ℓ−
Data
tt̄W
Other
tt̄H
tt̄Z/γ*
Diboson
Conversions
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Nonprompt
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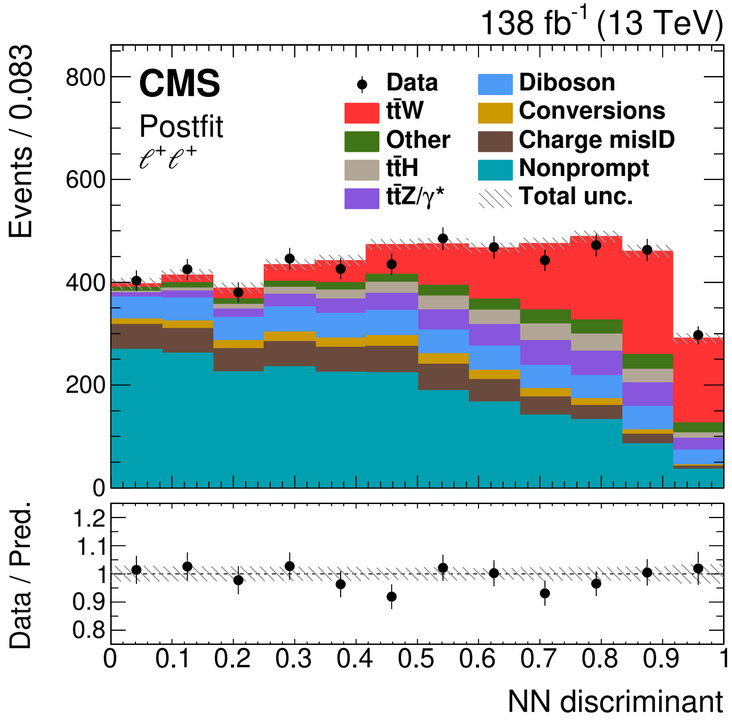
138 fb-1 (13 TeV)
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Data
tt̄W
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Conversions
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Nonprompt
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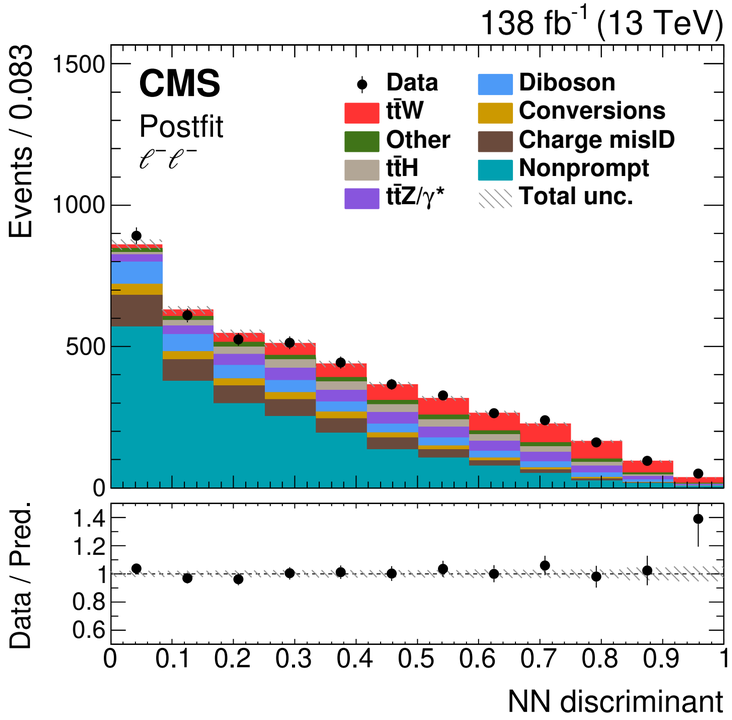
Events / 0.083
Data / Pred.
NN discriminant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Data
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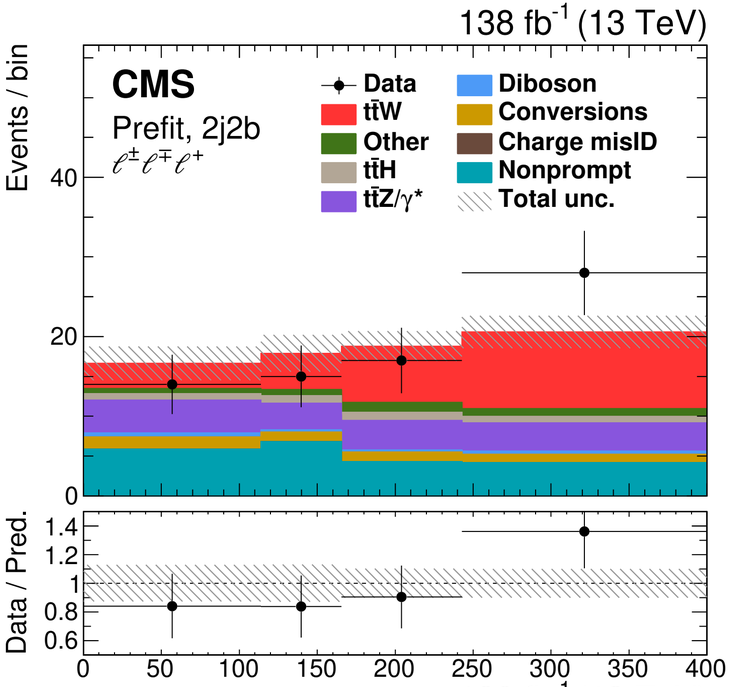
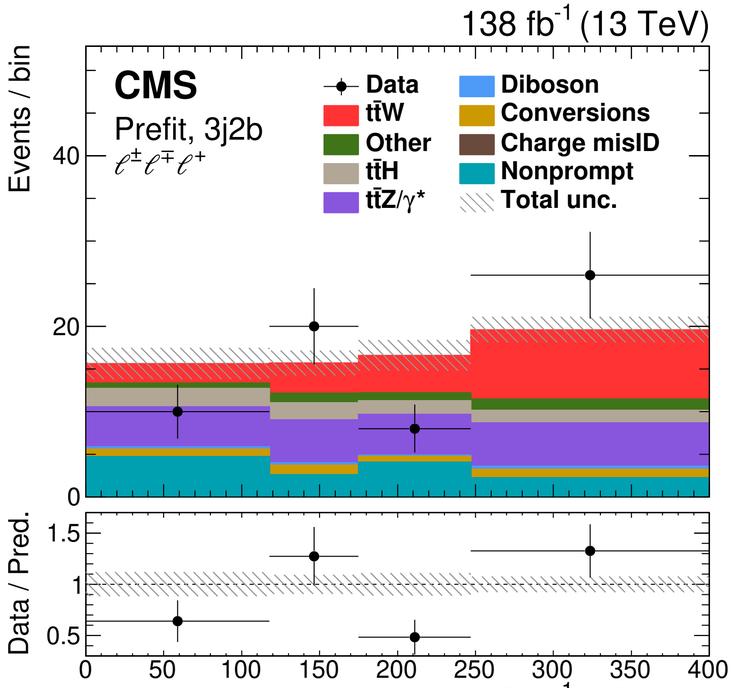

138 fb^{-1} (13 TeV)
CMS
Prefit, 2j2b
$\ell^{\pm}\ell^{\mp}\ell^{+}$
Data
$t\bar{t}W$
Other
$t\bar{t}H$
$t\bar{t}Z/\gamma^{*}$
Diboson
Conversions
Charge misID
Nonprompt
Total unc.
Events / bin
Data / Pred.


138 fb^{-1} (13 TeV)
CMS
Prefit, 3j2b
$\ell^{\pm}\ell^{\mp}\ell^{+}$
Data
$t\bar{t}W$
Other
$t\bar{t}H$
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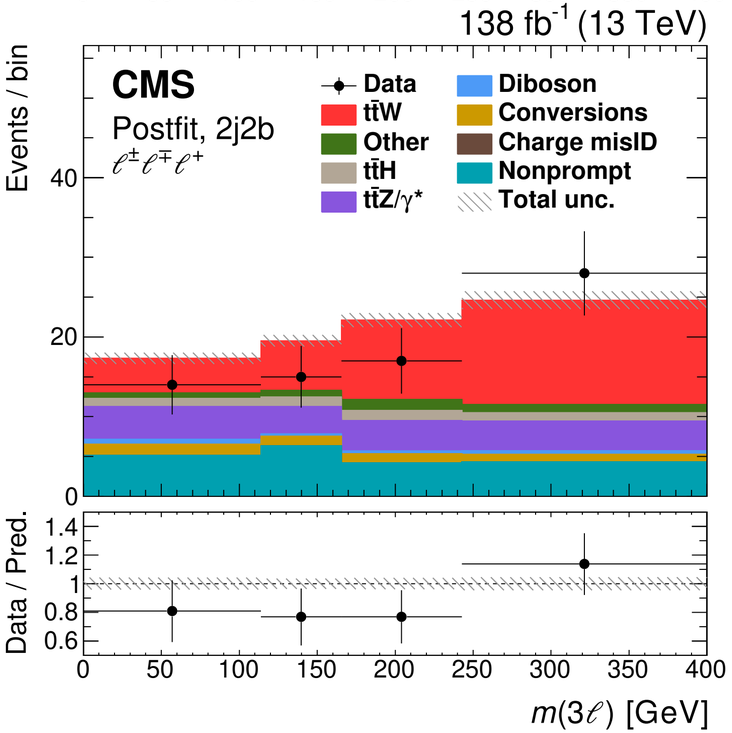
Diboson
Conversions
Charge misID
Nonprompt
Total unc.
Events / bin
Data / Pred.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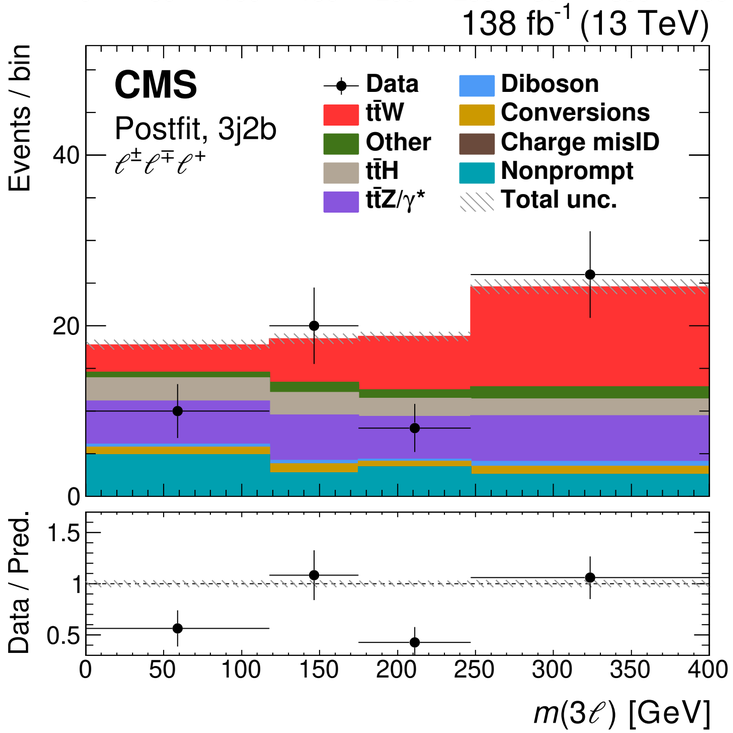
$m(3\ell)$ [GeV]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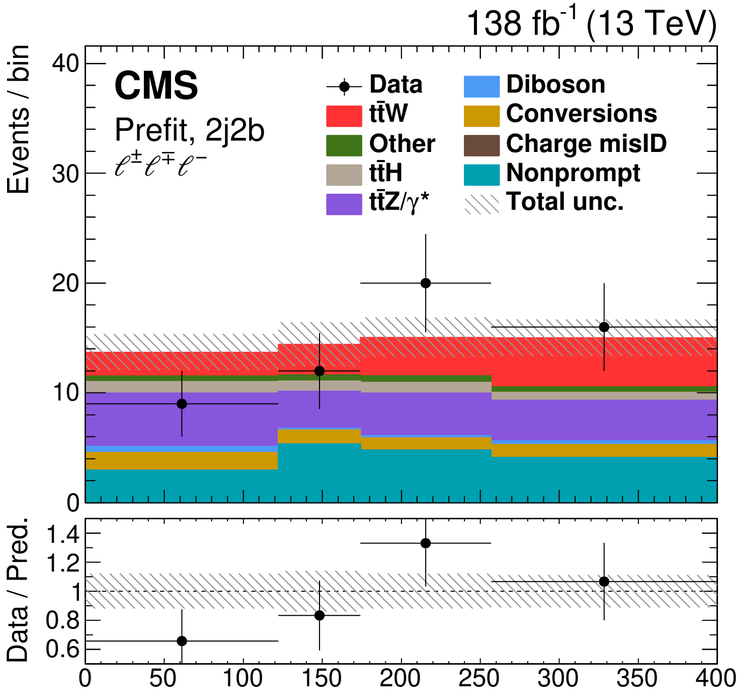
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CMS
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$\ell^{\pm}\ell^{\mp}\ell^{-}$
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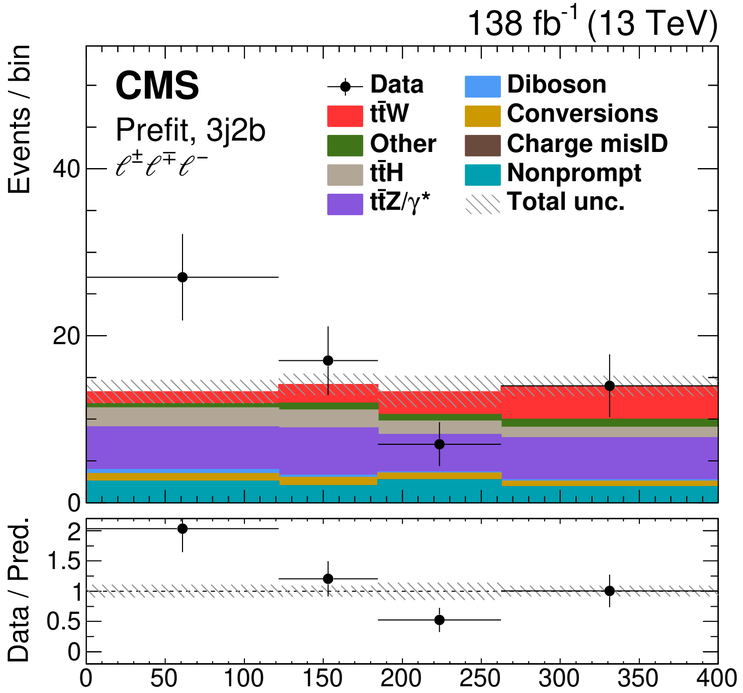
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CMS
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$\ell^{\pm}\ell^{\mp}\ell^{-}$
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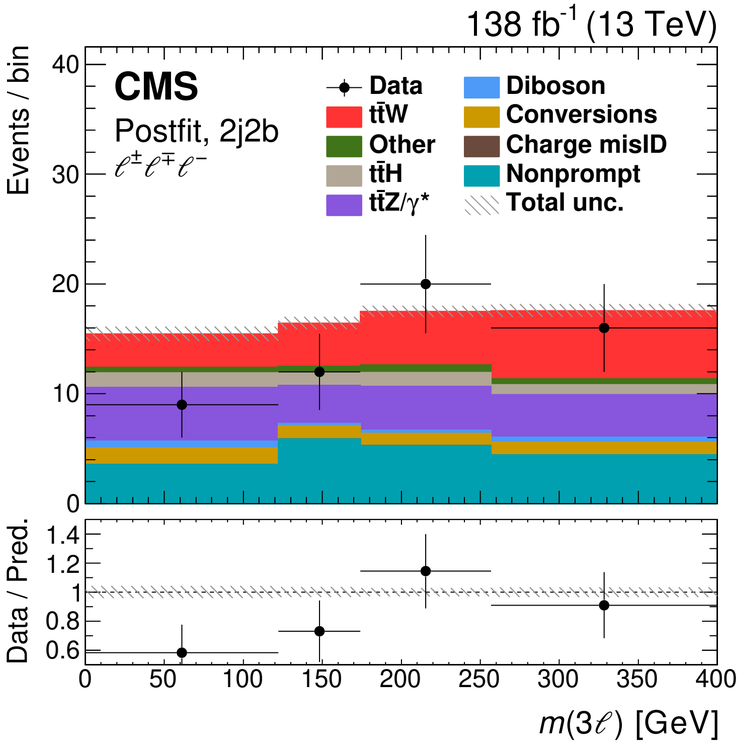
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CMS
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$\ell^{\pm}\ell^{\mp}\ell^{-}$
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tt̄W
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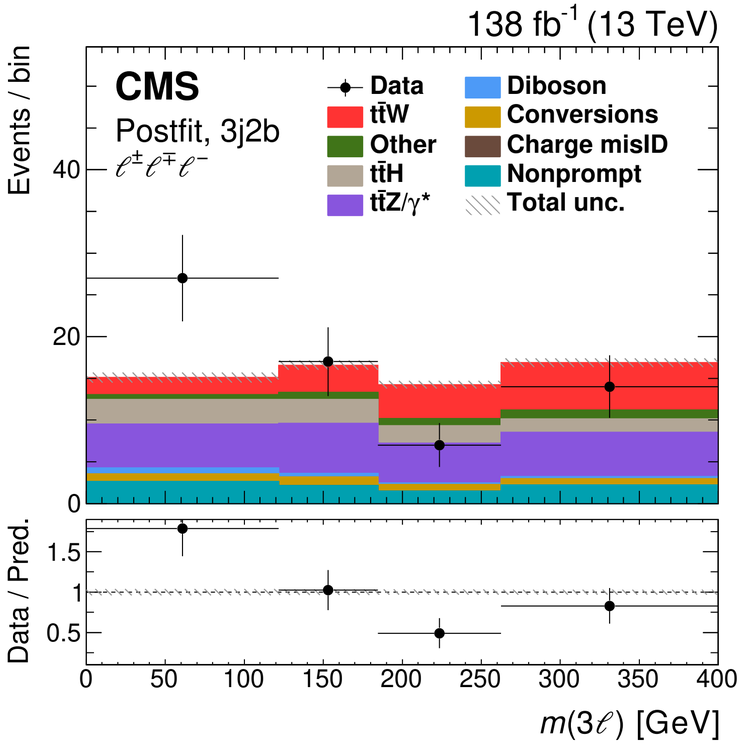
$m(3\ell)$ [GeV]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Data
tt̄W
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tt̄Z/γ*
Diboson
Conversions
Charge misID
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Total unc.
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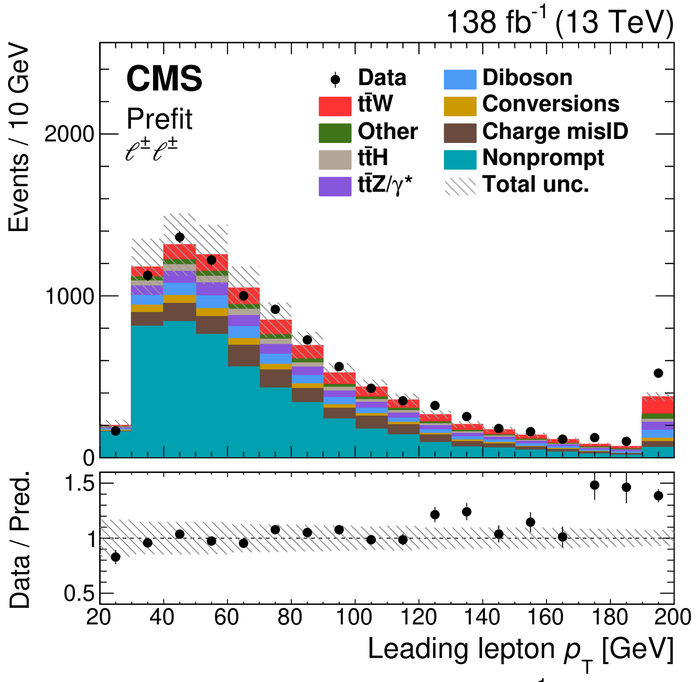
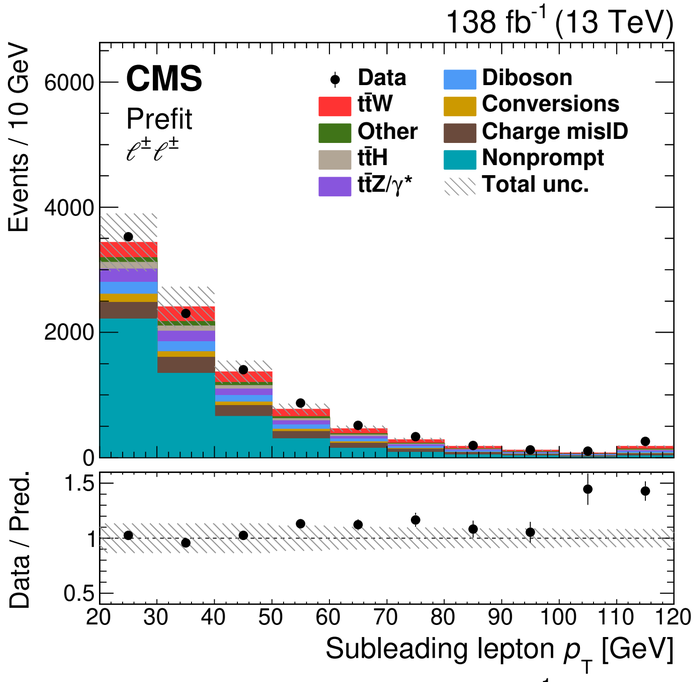
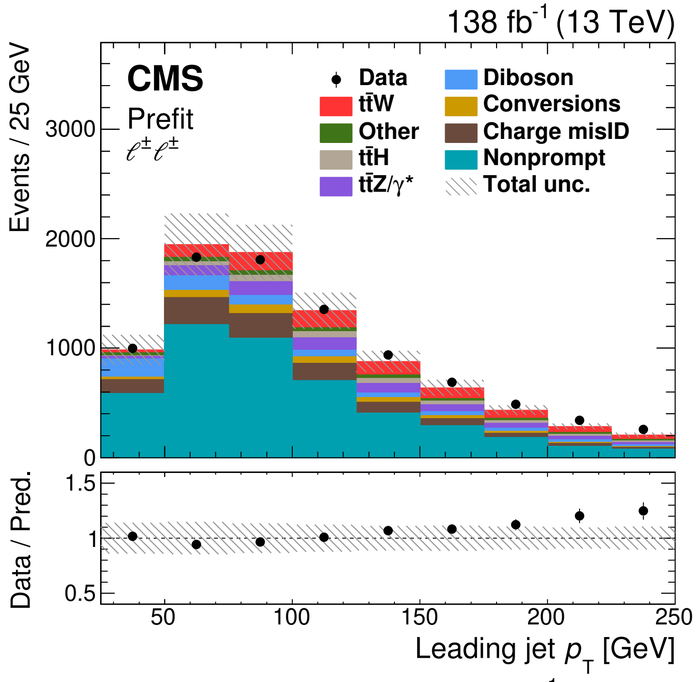
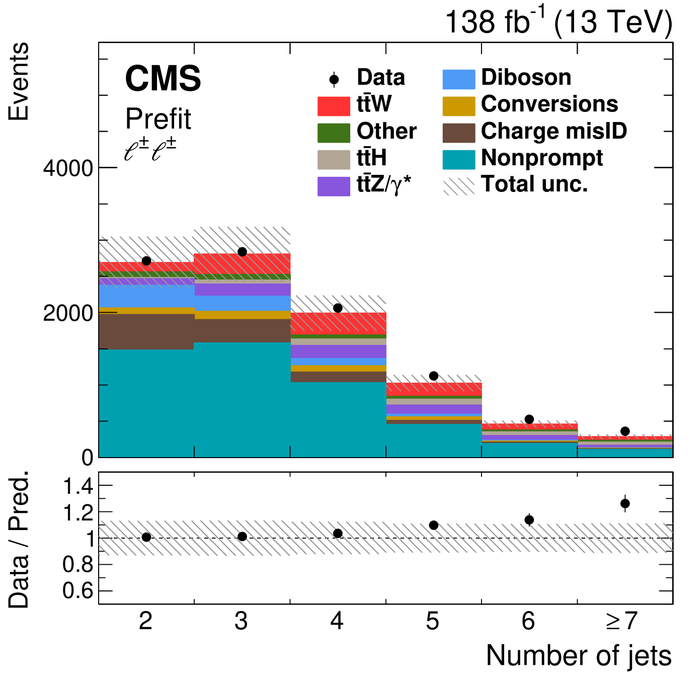
$m(3\ell)$ [GeV]

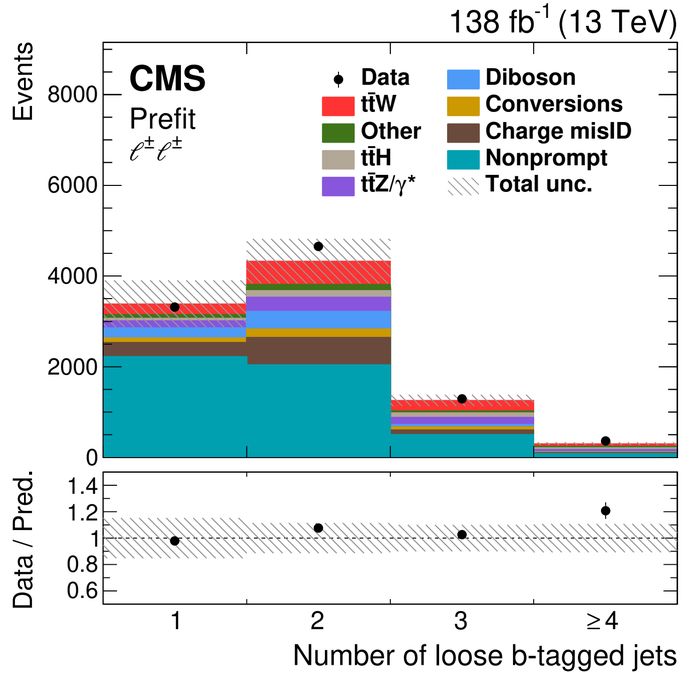
2SSL kinematics observables

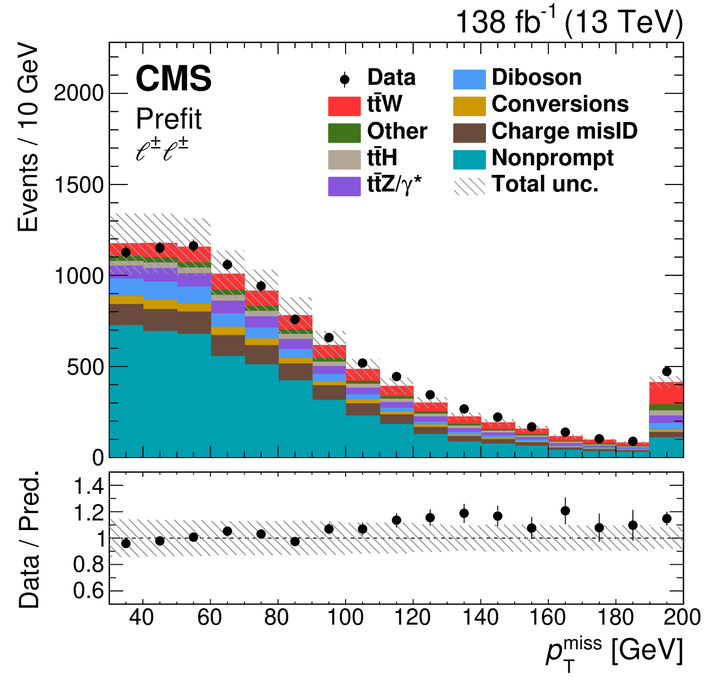




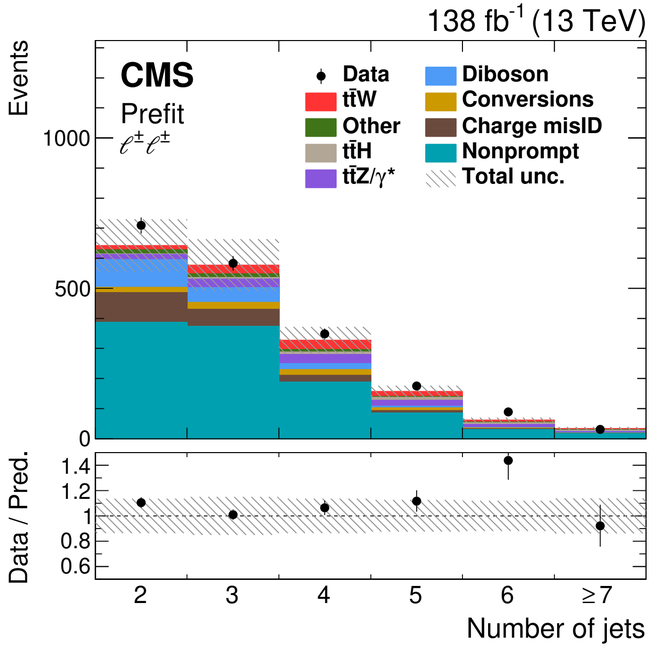


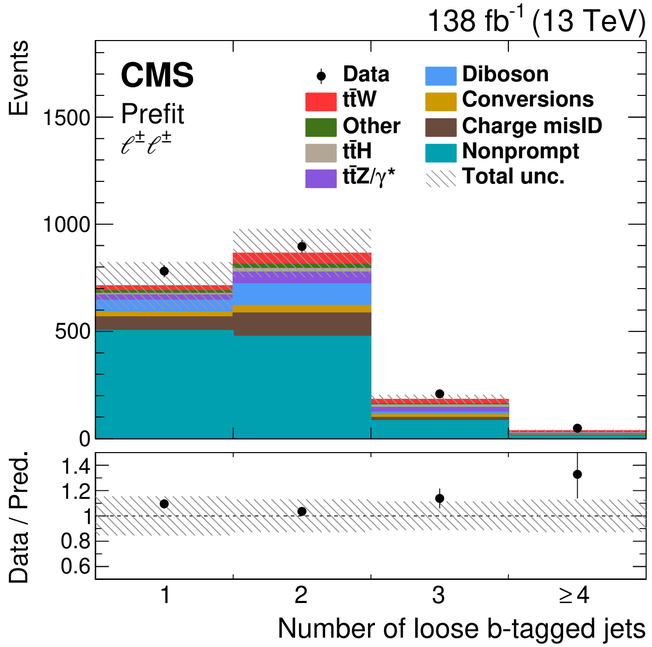


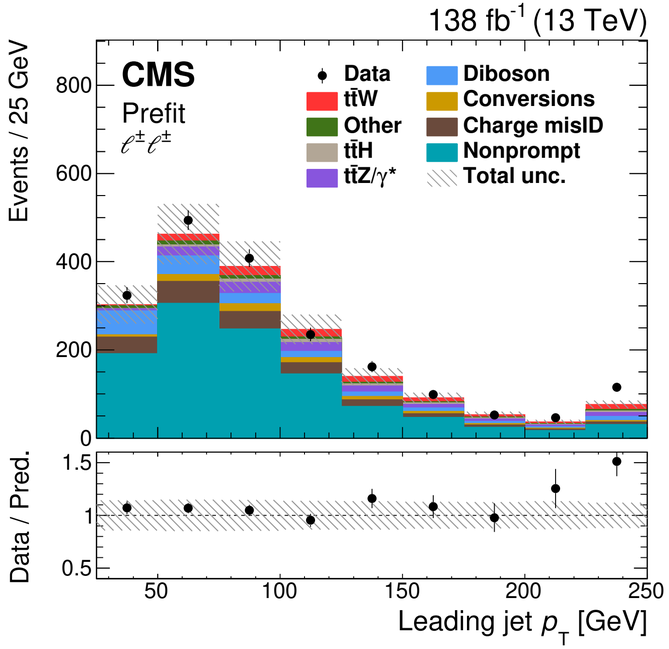


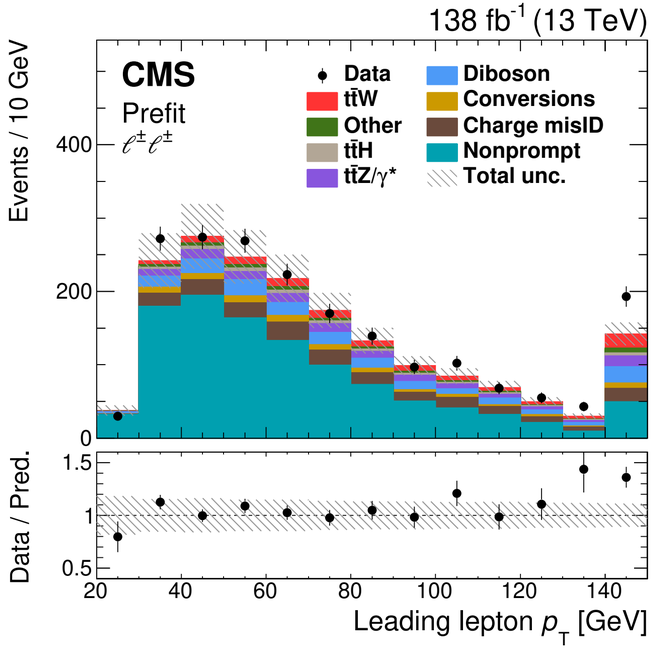


2SSL validation regions (inverted p_T^{miss} cut)

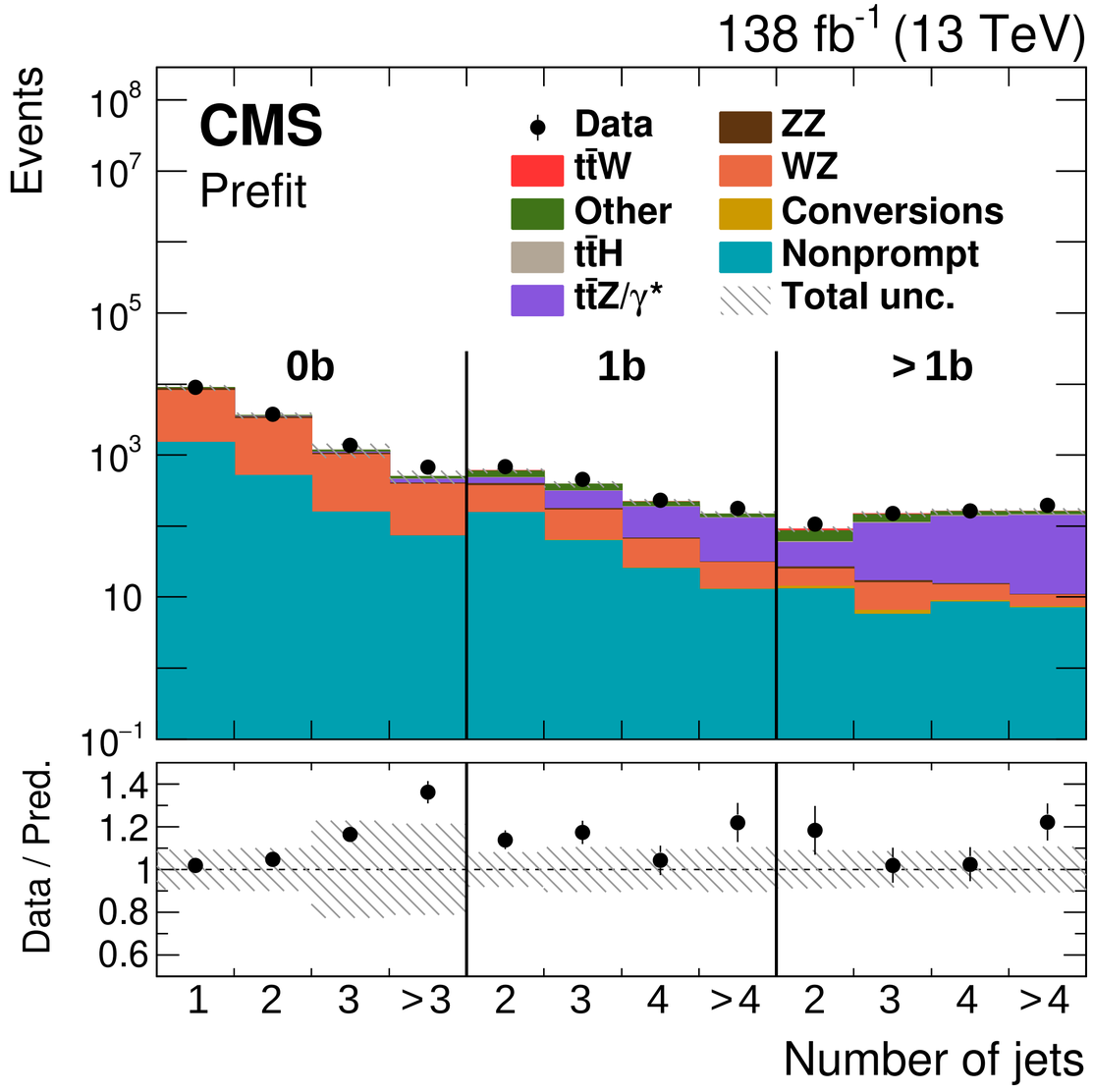




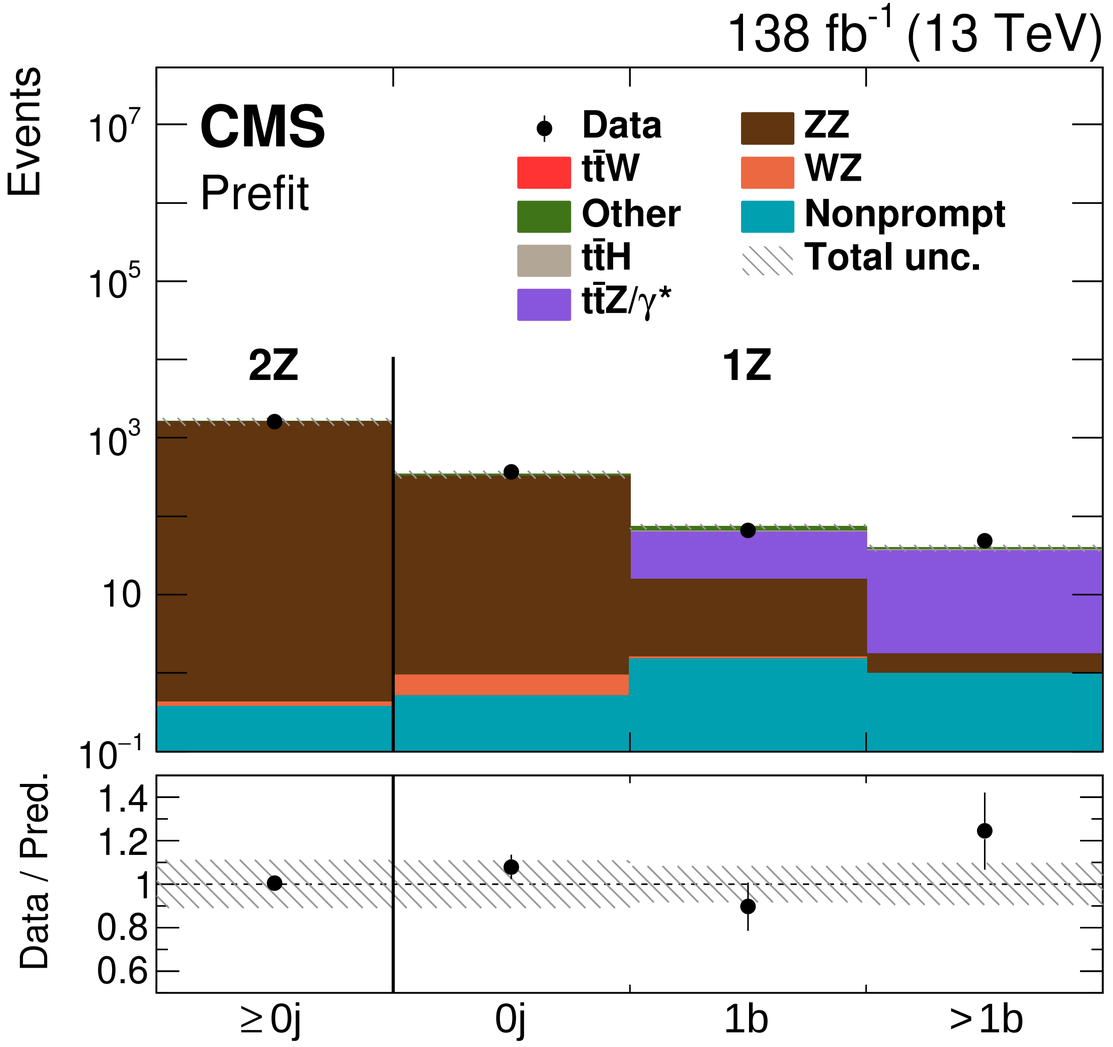




3l control regions



4l control regions



Uncertainties

Source	Uncertainty [%]
Experimental uncertainties	
Integrated luminosity	1.9
b tagging efficiency	1.6
Trigger efficiency	1.2
Pileup reweighting	1.0
L1 inefficiency	0.7
Jet energy scale	0.6
Jet energy resolution	0.4
Lepton selection efficiency	0.4
Background uncertainties	
$t\bar{t}H$ normalization	2.6
Charge misidentification	1.6
Nonprompt leptons	1.3
VVV normalization	1.2
$t\bar{t}VV$ normalization	1.2
Conversions normalization	0.7
$t\bar{t}\gamma$ normalization	0.6
ZZ normalization	0.6
Other normalizations	0.5
$t\bar{t}Z$ normalization	0.3
WZ normalization	0.2
tZq normalization	0.2
tHq normalization	0.2

Source	Uncertainty [%]
Modeling uncertainties	
$t\bar{t}W$ scale	1.8
$t\bar{t}W$ color reconnection	1.0
ISR & FSR scale for $t\bar{t}W$	0.8
$t\bar{t}\gamma$ scale	0.4
VVV scale	0.3
$t\bar{t}H$ scale	0.2
Conversions	0.2
Simulation statistical uncertainty	1.8
Total systematic uncertainty	5.8