Search for tZq production in the dilepton final state using CMS nanoAOD run 2 samples

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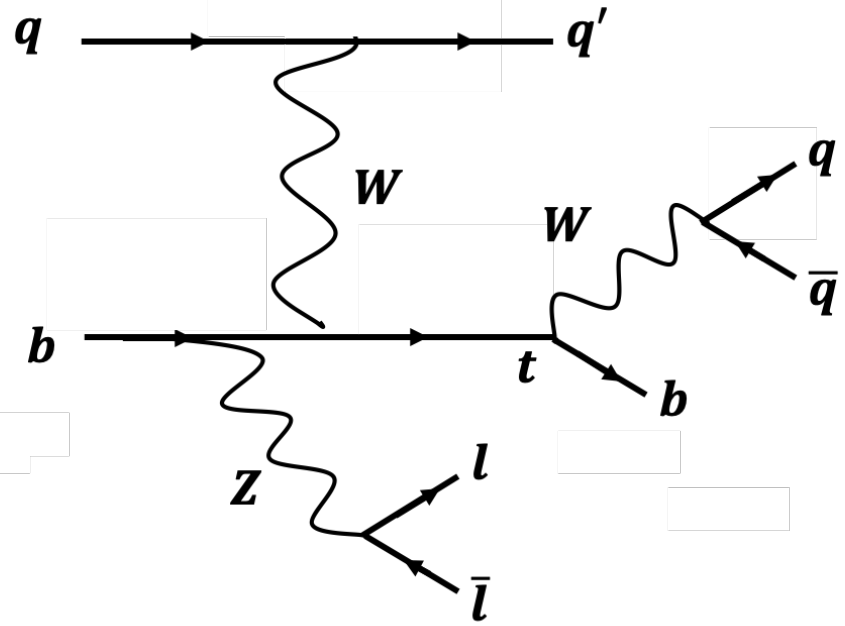
tZq production in the dilepton final state

- Shape-based analysis

- Motivations:
  - Rare process predicted by the SM
  - **Top quark does not hadronise ⇒ spin info passed onto decay particles**
  - Sensitive to the tZ and WWZ couplings
  - tZq forms an irreducible background to the tZ-FCNC process



Methodology

Events with bad luminosities were filtered using the golden json file

- The golden json file provides the run numbers and luminosity ranges of good lumisections:
  - 2016: Cert_271036-284044_13TeV_PromptReco_Collisions16_JSON.txt
  - 2017: Cert_294927-306462_13TeV_PromptReco_Collisions17_JSON.txt
  - 2018: in AFS, copy file across to where you want it
    (path: */afs/cern.ch/cms/CAF/CMSCOMM/COMM_DQM/certification/Collisions18/13TeV/ PromptReco/ Cert_314472-325175_13TeV_PromptReco_Collisions18_JSON.txt*)

- PdmV twiki:
  - 2016: https://twiki.cern.ch/twiki/bin/viewauth/CMS/PdmV2016Analysis
  - 2017: https://twiki.cern.ch/twiki/bin/viewauth/CMS/PdmV2017Analysis
  - 2018: https://twiki.cern.ch/twiki/bin/viewauth/CMS/PdmV2018Analysis

- Twiki link is here

Event cleaning removes events affected by known anomalies

- Primary vertex filter (Flag_goodVertices)
- Beam halo filter (Flag_globalSuperTightHalo2016Filter)
- HBHE noise filter **(**Flag_HBHENoiseFilter**)**
- HBHEIso noise filter (Flag_HBHENoiseIsoFilter)
- ECAL trigger primitive filter (Flag_EcalDeadCellTriggerPrimitiveFilter)
- Bad PF muon filter (Flag_BadPFMuonFilter)
- Bad charged hadron filter (Flag_BadChargedCandidateFilter)
- Flag_ecalBadCalibFilter
- Flag_eeBadScFilter

Twiki page outlining the differences between years is here.

Signal Region: Event Selection using CMS nanoAOD samples for 2016 ($35.88\ fb^{-1}$)

- Lepton selection (ee and $\mu\mu$ channels):
  - Exactly two. Opposite sign and same flavour.
  - Leading (subleading) **electrons**: $p_T > 35\ (15)$ GeV, $|\eta| < 2.4$
  - Leading (subleading) **muons**: $p_T > 26\ (20)$ GeV , $|\eta| < 2.4$

- Jet selection:
  - Anti-K_T jets with **ΔR = 0.4**.
  - Jets: $|\eta| < 4.7, p_T > 30$ GeV.

- B-tagged jets: $|\eta| < 2.4$. 1-2 b-jets using CSVv2 at the **medium working point**.

- W boson candidate reconstruction:
  - A pair of quark jets (excluding the leading b jet) with a reconstructed mass **closest to the W mass**.
  - Mass window cut of **20 GeV** is applied.

- Top quark reconstruction:
  - From the W boson and the leading b jet with an invariant mass **closest to that of the top quark mass**.

Signal Region: Event Selection using CMS nanoAOD samples for 2017 ($41.53\ fb^{-1}$) and 2018 ($59.69 fb^{-1}$)

- Same as 2016, except for changed cuts shown in red:

- Lepton selection (ee and $\mu\mu$ channels):
  - Exactly two. Opposite sign and same flavour.
  - Leading (subleading) **electrons**: $p_T > 38\ (15)$ GeV, $|\eta| < 2.4 \rightarrow p_T > 38\ (15)$ GeV, $|\eta| < 2.5$
  - Leading (subleading) **muons**: $p_T > 29\ (20)$ GeV , $|\eta| < 2.4 \rightarrow p_T > 29\ (20)$ GeV , $|\eta| < 2.5$

- B-tagged jets: $|\eta| < 2.4 \rightarrow |\eta| < 2.5$.

Increased p_T cuts due to **increased single lepton trigger thresholds** from 2016 to 2017.

Increased $|\eta|$ cut due to **increased tracker acceptance**.

Control Regions

- $t\bar{t}$
    - Lepton selection changed: exactly one tight electron and one tight muon are required with $p_T > 25$ GeV. No additional loose leptons.
- Z+jets
    - W boson mass requirement is inverted (no pair of jets may have an invariant mass within 20 GeV of the nominal W boson mass, excluding the leading b jet). The event must have less than 50 GeV of missing transverse energy.

Experimental blinding is carried out to apply a side-band region to data and MC. This prevents unintentionally-biased choices.

Based on $HH \rightarrow b\bar{b}b\bar{b}$ analyses [1, 2]

$$\chi^2 = \left(\frac{m_W^{rec} - m_W}{\sigma_W}\right)^2 + \left(\frac{m_{top}^{rec} - m_{top}}{\sigma_T}\right)^2 \Longrightarrow$$

Side band region:
Signal region:

Where:

m_W^{rec} = nominal W mass

m_W = reconstructed W boson mass

m_{top}^{rec} = nominal top mass

m_{top} = reconstructed top boson mass

σ_W = resolution of the reconstructed W boson mass

σ_T = resolution of the reconstructed top quark mass

Experimental blinding (continued)

- In the equation on the previous slide, the m_W^{rec}, m_T^{rec}, σ_W and σ_T values are calculated from Gaussian fits that have been applied to the **W and top mass** distributions.

- The m_W and m_T values are 80.385 GeV and 173.3 GeV, respectively.

Experimental blinding (continued)

- Using MC events as input to the equation, the χ^2 is calculated for each event.

- The χ^2 range was defined so that it contained all events where the reconstructed W mass was within 5σ of the known W mass. The range also contains 68% of the simulated signal events.

- A value of 68% was chosen because anything higher would leave **too few background events** to properly model backgrounds with confidence.

- Data events were filtered with this χ^2 range. For unblinding, this filter was removed.

Non prompt lepton (NPL) estimation

$$N_{data}^{OS_{nonprompt}} = \left(N_{data}^{SS} - N_{real+mis-ID}^{SS}\right) \cdot \underbrace{\frac{N_{MC}^{OS_{nonprompt}}}{N_{MC}^{SS_{nonprompt}}}}_{\text{Used for normalisation}}$$

where:

N_{data}^{SS} = number of same sign events observed in data

$N_{real+mis-ID}^{SS}$ = expected number of real same sign events and events with charge misidentification

$N_{MC}^{OS_{nonprompt}}$ = number of opposite-sign NPLs in simulation

$N_{MC}^{SS_{nonprompt}}$ = number of same-sign NPLs in simulation

Simulation corrections are applied to match MC with data.

- Normalisation factor
- Lepton Efficiency
    - Lepton identification, isolation, reconstruction and trigger efficiencies
- Lepton Energy Corrections
    - Electron regression, electron energy scale and electron smearing
    - Rochester corrections
- Jet Energy Corrections
    - Jet smearing
    - L1 pile up (already included in nanoAOD)
    - L2 relative and L3 absolute (already included in nanoAOD)
    - L2L3 residual (already included in nanoAOD)
- Pileup modelling
- b tagging efficiency
- Top quark p_T reweighting
- Miscalibrated Tracker APV Chips (2016 only)

Simulation corrections – Normalisation Factor ($\boldsymbol{w}$

$$w = \frac{\mathcal{L}\sigma}{N}$$

$\mathcal{L}$ = integrated luminosity, σ = cross section, N = number of simulated events

- The $\mathcal{L}$ is calculated using the brilcalc tool

Simulation corrections – Lepton Efficiencies

- The muon identification (ID), isolation (ISO) and reconstruction efficiency scale factors are provided by CMS: Twiki page for 2016, Twiki page for 2017, Twiki page for 2018
  - ROOT files for 2016
    - MuonID_EfficienciesAndSF_BCDEF.root
    - MuonID_EfficienciesAndSF_GH.root
    - MuonISO_EfficienciesAndSF_BCDEF.root
    - MuonISO_EfficienciesAndSF_GH.root
  - ROOT files for 2017
    - Muon_RunBCDEF_SF_ID.root
    - Muon_RunBCDEF_SF_ID_syst.root
    - Muon_RunBCDEF_SF_ISO.root
    - Muon_RunBCDEF_SF_ISO_syst.root
  - ROOT files for 2018:
    - RunABCD_SF_ID.root
    - RunABCD_SF_ISO.root

Simulation Corrections – Lepton efficiency (continued)

- A trigger scale factor is calculated for each channel (ee, $\mu\mu$ and $e\mu$) using the cross-trigger method (from ???).
- MET samples were chosen for the cross trigger, since they are weakly correlated to tZq events.

$$\varepsilon_{MC\ (DATA)} = \frac{Number\ of\ MC\ (data)\ events\ that\ pass\ the\ MET\ triggers, lepton\ triggers\ and\ the\ event\ selection}{Number\ of\ MC\ (Data)\ events\ that\ pass\ the\ lepton\ triggers\ and\ event\ selection\ only}$$

$$SF_{Trig} = \frac{\varepsilon_{DATA}}{\varepsilon_{MC}}$$

Simulation Corrections – Lepton Energy Corrections

- Electron regression, energy scale and smearing corrections
  - Link to EGammaPOG Twiki page
  - File 1 for 2016
  - File 2 for 2016
  - File 1 for 2017
  - File 2 for 2017
  - File 3 for 2017
  - File 1 for 2018
  - File 2 for 2018

The files for **2018** were downloaded from this Twiki page.

- Rochester corrections
  - The roccor.Run2.v3.tgz package was used for run 2
  - Link to Twiki page

Simulation Corrections – Jet Energy Corrections

- Already applied in nanoAOD

- L1 pile up
- L2 relative and L3 absolute
- L2L3 residual

Simulation correction – Jet Energy Smearing

- The hybrid method was used to apply the correction factor to the four momentum of the reconstructed jet. If 2 is true, 1 is used. Else, 3 is used.

1. $c_{JER} = 1 + (s_{JER} + 1)\frac{p_T - p_T^{ptcl}}{p_T}$

2. $\Delta R = R_{cone}/2$ and $|p_T - p_T^{ptcl}| < 3\sigma_{JER} p_T$

3. $c_{JER} = 1 + N(0, s_{JER})\sqrt{\max(s_{JER}^2 - 1{,}0)}$

Where:

c_{JER} = correction factor
s_{JER} = data-to-simulation core resolution factor
σ_{JER} = transverse momentum resolution
p_T = jet transverse momentum

p_T^{ptcl} = the p_T of a generator-level jet

$N(0, s_{JER})$ = random number sampled from a normal distribution, with a mean of zero and variance of σ^2

$\max(s_{JER}^2 - 1{,}0)$ = the largest value out of $s_{JER}^2 - 1$ or 0

Simulation correction – Jet Energy Smearing (continued)

- s_{JER} and σ_{JER} are read from text files.

- Text files provided by CMS:
  - σ_{JER} for 2016
  - σ_{JER} for 2017
  - σ_{JER} for 2018
  - s_{JER} for 2016
  - s_{JER} for 2017
  - s_{JER} for 2018

Explanations of the format of the s_{JER} and σ_{JER} text files are given on slides 21 and 22.

Simulation correction – Jet Energy Smearing (continued)

- For σ_{JER} , use the p_T resolution text file e.g. for 2017 (Fall17_V3_MC_PtResolution_AK4PFchs.txt):

```
{2    JetEta    Rho    1    JetPt    sqrt([0]*abs([0])/(x*x)+[1]*[1]*pow(x,[3])+[2]*[2])    Resolution}
-4.7    -3.2       0     6.37     6     15     3000     -29.87     29.84     0.1045     -1.995
-4.7    -3.2    6.37     12.4     6     15     3000      -23.2     23.09     0.1051     -1.987
-4.7    -3.2    12.4    18.42     6     15     3000      4.337    0.2253    0.06986    -0.4215
```

- **Columns 1 and 2** = Min and max η values (Jet_eta).
- **Columns 3 and 4** = Min and max ρ values (fixedGridRhoFastjetAll).
- **Column 5** = Just to say there are 6 more columns after this one (this column is not used).
- **Columns 6 and 7** = Min and max p_T values (Jet_pt).
- **Columns 8, 9, 10 and 11** = Values you substitute into [0], [1], [2] and [3] in the equation, respectively, (where x is the input p_T)

Simulation correction – Jet Energy Smearing (continued)

- For s_{JER} use the SF file e.g. for 2017 (Fall17_V3_MC_SF_AK4PFchs.txt)

```
{1 JetEta 0 None ScaleFactor}
-5.191 -3.139 3 1.1542 1.0019 1.3066
-3.139 -2.964  3 1.2696 1.1607 1.3785
-2.964 -2.853 3 2.2923 1.9180 2.6665
```

- **Columns 1 and 2** = Min and max η values.
- **Columns 3** = to tell you there are three more columns after this one (not used).
- **Column 4** = central SF value.
- **Column 5** = SF down (column 4 – column 5 = lower uncertainty)
- **Column 6** = SF up (column 6 – column 4 = upper uncertainty)

Simulation Correction – Pile Up Modelling

- The number of primary vertices (root branch name = *PV_npvs*) in MC was reweighted.

- ROOT files containing the reweighted values have been created:
  - Link to the ROOT file for [2016]
  - Link to the ROOT file for [2017]
  - Link to the ROOT file for [2018]

Simulation Correction – Pile up Modelling (cont.)

E.g. To make the MC PU distribution for 2018:

- The python file used by CMS for 2018 MC generation: https://github.com/cms-sw/cmssw/blob/master/SimGeneral/MixingModule/python/mix_2018_25ns_JuneProjectionFull18_PoissonOOTPU_cfi.py

- The pt bins from the above script were pasted into this script: https://github.com/brunel-physics/tZq_analysis/blob/run_2/scripts/createPileUpMC2017.C

Simulation Correction – Pile up Modelling (cont.)

- These instructions were followed to produce the pile up profiles for data: https://twiki.cern.ch/twiki/bin/viewauth/CMS/PileupJSONFileforData

- Linux command used (in CMSSW):
  - *pileupCalc.py -i Cert_314472-325175_13TeV_PromptReco_Collisions18_JSON.txt --inputLumiJSON pileup_latest.txt --calcMode true --minBiasXsec 69200 --maxPileupBin 100 --numPileupBins 100 MyDataPileupHistogram2018.root*

Simulation Correction – b Tagging Efficiency

- The b-tagging event weight, $\boldsymbol{\omega}$, is calculated using method 1a in this twiki:

$$P(MC) = \prod_{i\,=\,tagged} \varepsilon_i \prod_{j=\,not\ tagged} (1-\varepsilon_j)$$

$$P(DATA) = \prod_{i\,=\,tagged} SF_i\varepsilon_i \prod_{j=\,not\ tagged} (1-SF_j\varepsilon_j)$$

$$\boldsymbol{\omega} = \frac{P(DATA)}{P(MC)}$$

ε = the B-tagging efficiency that *you* calculate (explained on the next two slides).

SF = the *CMS-calculated* b-tagging scale factor (explained on slide 21).

Tagged = a b-tagged jet (b).

Not tagged = up quark, down quark, strange quark, charm quark (c) or a gluon (g). The first three are collectively known as “light quarks” (l).

$$\varepsilon_i = \varepsilon_b$$
$$\varepsilon_j = \varepsilon_l \times \varepsilon_c \times \varepsilon_g$$

Simulation Correction – b Tagging Efficiency (continued)

For b-tagged jets:

$$\varepsilon = \frac{number\ of\ bjets\ in\ MC\ correctly\ identified\ by\ CSVv2}{number\ of\ bjets\ in\ MC}$$

- <u>Numerator</u> = This is a 2D histogram. Find the number of events with tight jets that have GenPart_pdgId == 5 && Jet_btagCSVV2 > 0.8838 && abs(bjet η) < 2.4. Plot a 2D histogram of the **p_T versus $\boldsymbol{\eta}$** for these events.

- <u>Denominator</u> = same as numerator but without Jet_btagCSVV2 > 0.8838.

Simulation Correction – b Tagging Efficiency (continued)

For non bjets:

$$\varepsilon = \frac{number\ of\ non\ bjets\ in\ MC\ correctly\ identified\ by\ CSVv2}{number\ of\ non\ bjets\ in\ MC}$$

In the numerator,
GenPart Requirement is:

- GenPart_pdgId > 0 && GenPart_pdgId < 4 (light jets)
- GenPart_pdgId == 4 (charm)
- GenPart_pdgId == 21 (gluons)

See page 2 of this link for these values.

- Numerator = This is a 2D histogram. Number of events with tight jets that have GenPart Requirement && Jet_btagCSVV2 > 0.8838 && abs(bjet η) < 2.4. Plot a 2D histogram of the **p_T versus $\boldsymbol{\eta}$** for these events.

- Denominator = same as numerator but without Jet_btagCSVV2 > 0.8838.

Simulation Correction – b Tagging Efficiency (continued)

Twiki page that explains the csv file format is here

- The SF has already been calculated by CMS:
  - .csv file for 2017 (CSVv2_94XSF_V2_B_F.csv) can be downloaded here
  - Information for all years is here

- General CSV file format (explained on the next slide):

```
0, comb, central, 1, -2.5, 2.5, 20, 1000, 0, 1, "0.986369+(-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))"
0, comb, central, 0, -2.5, 2.5, 20, 1000, 0, 1, "0.986369+(-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))"
0, comb, down, 1, -2.5, 2.5, 20, 30, 0, 1, "0.986369+((-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))-0.088046833872795105)"
0, comb, down, 1, -2.5, 2.5, 30, 50, 0, 1, "0.986369+((-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))-0.031759314239025116)"
```

Simulation Correction – b Tagging Efficiency (continued)

```
0, comb, central, 1, -2.5, 2.5, 20, 1000, 0, 1, "0.986369+(-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))"
0, comb, central, 0, -2.5, 2.5, 20, 1000, 0, 1, "0.986369+(-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))"
0, comb, down, 1, -2.5, 2.5, 20, 30, 0, 1, "0.986369+((-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))-0.088046833872795105)"
0, comb, down, 1, -2.5, 2.5, 30, 50, 0, 1, "0.986369+((-(4.21155e-05*(log(x+19)*(log(x+18)*(3-(-(6.02128*log(x+18))))))))-0.031759314239025116)"
```

- Column 1 = CSVv2 operating point
- Column 2 = Measurement type
- Column 3 = Systematic type
- Column 4 = Jet flavour
- Columns 5 and 6 = Min and max η values
- Columns 7 and 8 = Min and max p_T values
- Columns 9 and 10 = CSVv2 discriminant value

Compare input values with the values in columns 1-10 and return the answer that the equation in column 11 gives if the conditions are met (where x is the transverse momentum).

More info on this twiki.

Simulation Corrections – Top p_T Reweighting

- The top p_T in Standard Model $t\bar{t}$ MC events is reweighted using the factor ω:

$$\omega = \sqrt{SF(t)SF(\bar{t})} \text{ where } SF(p_T) = e^{-0.0615-0.0005\cdot p_T}$$

GenPart_pdgId == 6 for top quarks and **-6** for antitop quarks.

GenPart_statusFlags == 13 (isLastCopy).

- Link to the twiki page is here
- CMS-TOP-12-028

Simulation Corrections – Miscalibrated Tracker APV Chips (2016 only)

Shape uncertainties

- Jet energy corrections (already in nanoAOD)
- Jet smearing
- Missing transverse energy (MET)
- PU reweighting
  - vary the expected minimum bias cross section in simulation by ±4.6%
- b tagging SFs
  - vary the SF values by ±1σ
- PDFs
- Perturbative and non-perturbative factorisation and normalisation scales
- Matching threshold energy

Shape uncertainties – Jet Smearing

- The up and down uncertainties applied to the SF are provided by CMS

- E.g. in **Fall17_V3_MC_SF_AK4PFchs.txt**:

```
-5.191 -3.139 3 1.1542 1.0019 1.3066
-3.139 -2.964  3 1.2696 1.1607 1.3785
-2.964 -2.853 3 2.2923 1.9180 2.6665
-2.853 -2.500 3 1.9909 1.4225 2.5593
-2.500 -2.322 3 1.4085 1.2066 1.6105
```

Column 4 = nominal value

Column 5 = down

Column 6 = up

Shape uncertainties – MET

- MET: https://twiki.cern.ch/twiki/bin/view/CMS/MissingETUncertaintyPrescription#PF_MET

Shape uncertainties – Pile up reweighting

- The cross section for the MC PU profile was varied by $\pm 4.6\%$

- E.g. Linux commands used (in CMSSW) to obtain the MC PU profiles for the up and down uncertainties for 2018:
  - **Linux command used for the up uncertainty:** *pileupCalc.py -i Cert_314472-325175_13TeV_PromptReco_Collisions18_JSON.txt --inputLumiJSON pileup_latest.txt --calcMode true --minBiasXsec 72383.2 --maxPileupBin 100 --numPileupBins 100 MyDataPileupHistogramScaleUp2018.root*
  - **Linux command used for the down uncertainty:** *pileupCalc.py -i Cert_314472-325175_13TeV_PromptReco_Collisions18_JSON.txt --inputLumiJSON pileup_latest.txt --calcMode true --minBiasXsec 66016.8 --maxPileupBin 100 --numPileupBins 100 MyDataPileupHistogramScaleDown2018.root*

Shape uncertainties – btagging scale factors

- Provided by CMS in the csv file (**CSVv2_94XSF_V2_B_F.csv** for run 2)

```
0, comb, down, 0, -2.5, 2.5,
0, comb, down, 0, -2.5, 2.5,
0, comb, down, 0, -2.5, 2.5,
0, comb, up, 1, -2.5, 2.5,
0, comb, up, 1, -2.5, 2.5,
0, comb, up, 1, -2.5, 2.5,
```

The method is the same as for obtaining the equation to calculate the nominal scale factor, except **column 3** must be equal to **up or down**.

Shape uncertainties – PDFs

- The branch LHEPdfWeight was used

- Single top tW sample: https://arxiv.org/abs/1410.8849
- All other samples: https://arxiv.org/abs/1510.03865

Shape uncertainties – Perturbative factorisation and normalisation scales

- Alpha min and alpha max?

Shape uncertainties – Non-perturbative factorisation and normalisation scales

- In 2016, **additional samples** are provided that contain the weights

- In 2017 and 2018, **weights are stored in the nanoAOD samples** for: tZq (signal), $\bar{t}W$, single top s-channel, single top t-channel top, single top t-channel anti-top, $t\bar{t}\gamma$, $t\bar{t}$ (to hadronic) and $t\bar{t}$ (to semileptonic).

- In these samples for 2017 and 2018, the branch **PSWeight** was used:
  - PSWeight.at(0) = isr down
  - PSWeight.at(1) = fsr down
  - PSWeight.at(2) = isr up
  - PSWeight.at(3) = fsr up

Shape uncertainties – Matching threshold energy

POWHEG V2 matching threshold energy = $\frac{hdamp^2}{hdamp^2 + {p_T}^2}$

(where $hdamp$ has been tuned to $1.58 \times m_{top}$)

- Samples for the hdamp up and hdamp down variations have been provided by CMS for 2016, 2017 and 2018.

With the exception of lepton efficiency scale factor uncertainties, rate uncertainties are implemented using the combine tool

- **Integrated luminosity**
  - Estimated to be 2.5% in 2016 [4], 2.3% in 2017 [5] and 2.5% in 2018 [6].
- **Cross section normalization**
  - A value of 30% was used in the trilepton search [7.], but a value of 10% was used for this dilepton analysis
- **Non prompt lepton background estimate**
  - A 30% normalisation uncertainty value was applied based on other analyses with similar background contributions.

- **Lepton efficiencies** are provided by CMS (combine tool not used to implement them). The lepton efficiency scale factors were varied by $\pm 1\sigma$

Multivariate analysis

- Through the tact tool, a Boosted Decision Tree (BDT) was used to separate signal-like and background-like events.

The Higgs Combine Tool was used to implement the rate uncertainties and carry out the signal extraction

Results

Results: Signal Region – Cutflow

Results: Z+jets Control Region – Cutflow

Results: $\boldsymbol{t\bar{t}}$ Control Region – Cutflow

Results: Signal Region – Event Yields

Results: Z+jets Control Region – Event Yields

Results: $t\bar{t}$ Control Region – Event Yields

Results: Signal Region – Event Yields (NPL)

Results: Z+jets Control Region – Event Yields (NPL)

Results: $t\bar{t}$ Control Region – Event Yields (NPL)

Results: Signal Region – Event Yield Distributions

Results: Z+jets Control Region – Event Yield Distributions

Results: $t\bar{t}$ Control Region – Event Yield Distributions

Conclusions

References

[1] M. Aaboud et al. “Search for pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state using proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector”. arXiv: 1606.04782 [hep-ex].

[2] V. Khachatryan et al. “Search for resonant pair production of Higgs bosons decaying to two bottom quark–antiquark pairs in proton–proton collisions at 8 TeV”. arXiv: 1503.04114 [hep-ex].

[3] https://arxiv.org/abs/1607.03663

[4] http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/LUM-17-001/index.html

[5] http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/LUM-17-004/index.html

[6] http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/LUM-18-002/index.html

[7] https://arxiv.org/abs/1712.02825

Back up

Samples 2016 (1)

Process	Sample(s)
tZq (signal)	/tZq_ll_4f_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM
Z+jets (aMCatNLO)	/DYJetsToLL_M-50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM /DYJetsToLL_M-10to50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /DYJetsToLL_M-10to50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM
ZPlusJets (Madgraph)	/DYJetsToLL_M-50_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /DYJetsToLL_M-50_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM /DYJetsToLL_M-10to50_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM

Process	Sample(s)
Z+jets (pT-binned)	/DYJetsToLL_Zpt-0To50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv6-Nano25Oct2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /DYJetsToLL_Pt-50To100_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /DYJetsToLL_Pt-50To100_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext3-v1/NANOAODSIM /DYJetsToLL_Pt-100To250_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /DYJetsToLL_Pt-100To250_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /DYJetsToLL_Pt-100To250_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM /DYJetsToLL_Pt-100To250_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext5-v1/NANOAODSIM /DYJetsToLL_Pt-250To400_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /DYJetsToLL_Pt-250To400_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /DYJetsToLL_Pt-250To400_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM /DYJetsToLL_Pt-250To400_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext5-v1/NANOAODSIM

Process	Sample(s)
Z+jets (pT-binned)	/DYJetsToLL_Pt-400To650_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /DYJetsToLL_Pt-400To650_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /DYJetsToLL_Pt-400To650_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM /DYJetsToLL_Pt-650ToInf_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /DYJetsToLL_Pt-650ToInf_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /DYJetsToLL_Pt-650ToInf_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM

Process	Sample(s)
Single top	t-channel top: /ST_t-channel_top_4f_inclusiveDecays_13TeV-powhegV2-madspin-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM t-channel top scale up: /ST_t-channel_top_4f_scaleup_inclusiveDecays_13TeV-powhegV2-madspin-pythia8/RunIISummer16NanoAODv6-PUMoriond17_Nano25Oct2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM t channel top scale down: /ST_t-channel_top_4f_scaledown_inclusiveDecays_13TeV-powhegV2-madspin-pythia8/RunIISummer16NanoAODv3-PUMoriond17_94X_mcRun2_asymptotic_v3-v1/NANOAODSIM t-channel antitop scale up: /ST_t-channel_antitop_4f_scaleup_inclusiveDecays_13TeV-powhegV2-madspin-pythia8/RunIISummer16NanoAODv6-PUMoriond17_Nano25Oct2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM t-channel antitop scale down: /ST_t-channel_antitop_4f_scaledown_inclusiveDecays_13TeV-powhegV2-madspin-pythia8/RunIISummer16NanoAODv6-PUMoriond17_Nano25Oct2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM t-channel antitop: /ST_t-channel_antitop_4f_inclusiveDecays_13TeV-powhegV2-madspin-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM s-channel: /ST_s-channel_4f_InclusiveDecays_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM

Samples 2016 (2)

Process	Sample(s)
Single top	tW: /ST_tW_top_5f_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM tW scale up: /ST_tW_top_5f_scaleup_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM tW scale down: /ST_tW_top_5f_scaledown_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM tW_tbar: /ST_tW_antitop_5f_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM tW_tbar_ScaleUp: /ST_tW_antitop_5f_scaleup_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM tW_tbar_ScaleDown: /ST_tW_antitop_5f_scaledown_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM

Samples 2016 (3)

Process	Sample(s)
Single top	tZq (hadronic Z, leptonic W): tHq: /THQ_Hincl_13TeV-madgraph-pythia8_TuneCUETP8M1/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM tWZ tLL: /ST_tWll_5f_LO_13TeV-MadGraph-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM
VVV	WWW to 4F: /WWW_4F_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM WWZTo4F: /WWZ_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM WZZ: /WZZ_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM ZZZ: /ZZZ_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM

Samples 2016 (4)

Process	Sample(s)
VV	ZZTo4L: /ZZTo4L_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM ZZTo2L2Nu: /ZZTo2L2Nu_13TeV_powheg_pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM ZZTo2L2Q: /ZZTo2L2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM WWTo2L2Nu: /WWTo2L2Nu_13TeV-powheg/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM WZTo1L1Nu2Q: /WZTo1L1Nu2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM WWToLNuQQ: /WWToLNuQQ_13TeV-powheg/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /WWToLNuQQ_13TeV-powheg/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM WZTo3LNu: /WZJToLLLNu_TuneCUETP8M1_13TeV-amcnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM WZTo2L2Q: /WZTo2L2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM WZTo1L1Nu2Q: /WZTo1L1Nu2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM

Samples 2016 (5)

Process	Sample(s)
ttbar	ttbar_madgraph: /TTJets_DiLept_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /TTJets_DiLept_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM TTToHadronic: not used ttbar_aMCatNLO: /TTJets_TuneCUETP8M2T4_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM ttbar 2l2nu: /TTTo2L2Nu_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM TTToSemileptonic: not used

Samples 2016 (6)

Process	Sample(s)
ttbar	TT_hdampUP: /TT_hdampUP_TuneCUETP8M2T4_13TeV-powheg-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM TT_hdampUP_ext: /TT_hdampUP_TuneCUETP8M2T4_13TeV-powheg-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM TT_hdampDOWN: /TT_hdampDOWN_TuneCUETP8M2T4_13TeV-powheg-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM TT_hdampDOWN_ext: /TT_hdampDOWN_TuneCUETP8M2T4_13TeV-powheg-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM ST_tchannel_top_hdampup: ST_tchannel_top_hdampdown: ST_tchannel_top_ScaleUp: ST_tchannel_top_ScaleDown:

Samples 2016 (7)

Process	Sample(s)
ttbar	TT_isr_UP: /TT_TuneCUETP8M2T4_13TeV-powheg-isrup-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM TT_isr_DOWN: /TT_TuneCUETP8M2T4_13TeV-powheg-isrdown-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM TT_isr_DOWN_ext: /TT_TuneCUETP8M2T4_13TeV-powheg-isrdown-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM TT_fsr_UP: /TT_TuneCUETP8M2T4_13TeV-powheg-fsrup-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM TT_fsr_UP_ext: /TT_TuneCUETP8M2T4_13TeV-powheg-fsrup-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM TT_fsr_DOWN: /TT_TuneCUETP8M2T4_13TeV-powheg-fsrdown-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM TT_fsr_DOWN_ext: /TT_TuneCUETP8M2T4_13TeV-powheg-fsrdown-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM

Samples 2016 (7)

Process	Samples(s)
ttbarV	ttgamma: not used TTZToQQ: /TTZToQQ_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM TTZToLL: /TTZToLLNuNu_M-10_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /TTZToLLNuNu_M-10_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM /TTZToLLNuNu_M-10_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext3-v1/NANOAODSIM TTZToLLNuNu: /TTZToLLNuNu_M-10_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /TTZToLLNuNu_M-10_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM /TTZToLLNuNu_M-10_TuneCUETP8M1_13TeV-amcatnlo-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext3-v1/NANOAODSIM ttWJetsToLNu: /TTWJetsToLNu_TuneCUETP8M1_13TeV-amcatnloFXFX-madspin-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext1-v1/NANOAODSIM /TTWJetsToLNu_TuneCUETP8M1_13TeV-amcatnloFXFX-madspin-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM ttWJetsToQQ: /TTWJetsToQQ_TuneCUETP8M1_13TeV-amcatnloFXFX-madspin-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM ttHTobb: /ttHTobb_M125_TuneCUETP8M2_ttHtranche3_13TeV-powheg-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM ttHToNonbb: /ttHToNonbb_M125_TuneCUETP8M2_ttHtranche3_13TeV-powheg-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM

Samples 2016 (7)

Process	Sample(s)
W+jets	W Jets To L Nu: /WJetsToLNu_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7-v1/NANOAODSIM /WJetsToLNu_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIISummer16NanoAODv5-PUMoriond17_Nano1June2019_102X_mcRun2_asymptotic_v7_ext2-v1/NANOAODSIM
Data	Double Muon: Double electron: /DoubleEG/Run2016B-22Aug2018_ver2-v1/NANOAOD /DoubleEG/Run2016C-Nano25Oct2019-v1/NANOAOD /DoubleEG/Run2016D-Nano25Oct2019-v1/NANOAOD /DoubleEG/Run2016E-Nano25Oct2019-v1/NANOAOD /DoubleEG/Run2016F-Nano25Oct2019-v1/NANOAOD /DoubleEG/Run2016G-Nano25Oct2019-v1/NANOAOD /DoubleEG/Run2016H-Nano25Oct2019-v1/NANOAOD

Samples 2017 (1)

Process	Sample(s)
tZq (signal)	/tZq_ll_4f_ckm_NLO_TuneCP5_PSweights_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv4-PU2017_12Apr2018_Nano14Dec2018_new_pmx_102X_mc2017_realistic_v6-v1/NANOAODSIM
Z+jets	/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM /DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7_ext1-v1/NANOAODSIM /DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM
Single top	t-channel top: /ST_t-channel_top_4f_InclusiveDecays_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM t-channel antitop: /ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM s-channel: /ST_s-channel_4f_leptonDecays_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM tW: /ST_tW_top_5f_inclusiveDecays_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM

Samples 2017 (2)

Process	Sample(s)
Single top	tbarW: /ST_tW_antitop_5f_inclusiveDecays_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM tZq (hadronic Z, leptonic W): /tZq_W_lept_Z_hadron_4f_ckm_NLO_13TeV_amcatnlo_pythia8/RunIIFall17NanoAODv5- PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM tHq: /THQ_4f_Hincl_13TeV_madgraph_pythia8/RunIIFall17NanoAODv5- PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM tWZ tLL:/ ST_tWll_5f_LO_TuneCP5_PSweights_13TeV-madgraph-pythia8/RunIIFall17NanoAODv5- PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7_ext1-v1/NANOAODSIM
VVV	WWW to 4F: /WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5- PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM WWZTo4F: /WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5- PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM WZZ: /WZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5- PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM ZZZ:/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5- PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM

Samples 2017 (3)

Process	Sample(s)
VV	ZZTo4L: /ZZTo4L_13TeV_powheg_pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM ZZTo2L2Nu: /ZZTo2L2Nu_13TeV_powheg_pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM ZZTo2L2Q: /ZZTo2L2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM WWTo2L2Nu: /WWTo2L2Nu_NNPDF31_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7_ext1-v1/NANOAODSIM WWTo1L1Nu2Q: /WWTo1L1Nu2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM WWToLNuQQ: /WWToLNuQQ_NNPDF31_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7_ext1-v1/NANOAODSIM WWlnuQQ: /WWToLNuQQ_NNPDF31_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7_ext1-v1/NANOAODSIM WZTo3LNu: /WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM WZTo2L2Q: /WZTo2L2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM WZTo1L1Nu2Q: /WZTo1L1Nu2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM

Samples 2017 (4)

Process	Sample(s)
ttbar	ttbar_madgraph: /TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM TTToHadronic: /TTToHadronic_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM ttbar_aMCatNLO: /TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM ttbar 2l2nu /TTTo2L2Nu_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM TTToSemileptonic:/TTToSemiLeptonic_TuneCP5_PSweights_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM

Samples 2017 (5)

Process	Samples(s)
ttbarV	ttgamma: /TTGamma_Dilept_TuneCP5_PSweights_13TeV_madgraph_pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM TTZToQQ: /TTZToQQ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM TTZToQQ_ext: /TTZToQQ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7_ext1-v1/NANOAODSIM TTZToLL: /TTZToLL_M-1to10_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM TTZToLLNuNu: /TTZToLLNuNu_M-10_TuneCP5_13TeV-amcatnlo-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM ttWJetsToLNu: /TTWJetsToLNu_TuneCP5_PSweights_13TeV-amcatnloFXFX-madspin-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM ttWJetsToQQ: /TTWJetsToQQ_TuneCP5_13TeV-amcatnloFXFX-madspin-pythia8/RunIIFall17NanoAODv PU2017_12Apr2018_Nano1June2019_102X_mc2017_realistic_v7-v1/NANOAODSIM ttHTobb: /ttHTobb_M125_TuneCP5_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM ttHToNonbb: /ttHToNonbb_M125_TuneCP5_13TeV-powheg-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM

Samples 2017 (6)

Process	Sample(s)
W+jets	W Jets To L Nu:/WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIFall17NanoAODv5-PU2017_12Apr2018_Nano1June2019_new_pmx_102X_mc2017_realistic_v7-v1/NANOAODSIM
Data	Double Muon: /DoubleMuon/Run2017B-Nano14Dec2018-v1/NANOAOD /DoubleMuon/Run2017C-Nano14Dec2018-v1/NANOAOD /DoubleMuon/Run2017D-Nano14Dec2018-v1/NANOAOD /DoubleMuon/Run2017E-Nano14Dec2018-v1/NANOAOD /DoubleMuon/Run2017F-Nano14Dec2018-v1/NANOAOD Double electron: /DoubleEG/Run2017B-Nano14Dec2018-v1/NANOAOD /DoubleEG/Run2017C-Nano14Dec2018-v1/NANOAOD /DoubleEG/Run2017D-Nano14Dec2018-v1/NANOAOD /DoubleEG/Run2017E-Nano14Dec2018-v1/NANOAOD /DoubleEG/Run2017F-Nano14Dec2018-v1/NANOAOD

Samples 2018 (1)

Process	Sample(s)
tZq (signal)	/tZq_ll_4f_ckm_NLO_TuneCP5_13TeV-madgraph-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM
Z+jets (M50)	/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM /DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext2-v1/NANOAODSIM
Z+jets (M10to50)	/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM /DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM
Single top	t-channel top: /ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM t-channel antitop: /ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM s-channel: /ST_s-channel_4f_leptonDecays_TuneCP5_13TeV-madgraph-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM tW: /ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM

Samples 2018 (2)

Process	Sample(s)
Single top	tbarW: /ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM tZq (hadronic Z, leptonic W): /tZq_Zhad_Wlept_4f_ckm_NLO_TuneCP5_PSweights_13TeV-amcatnlo-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM tHq: /THQ_4f_Hincl_13TeV_madgraph_pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM tWZ tLL: /ST_tWll_5f_LO_TuneCP5_PSweights_13TeV-madgraph-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM
VVV	WWW to 4F: /WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM WWZTo4F: /WWZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM WZZ: /WZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM ZZZ: /ZZZ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM

Samples 2018 (3)

Process	Sample(s)
VV	ZZTo4L: /ZZTo4L_TuneCP5_13TeV_powheg_pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext2-v1/NANOAODSIM ZZTo2L2Nu: /ZZTo2L2Nu_TuneCP5_13TeV_powheg_pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM /ZZTo2L2Nu_TuneCP5_13TeV_powheg_pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext2-v1/NANOAODSIM ZZTo2L2Q: /ZZTo2L2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM WWTo2L2Nu: /WWTo2L2Nu_NNPDF31_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM WWTo1L1Nu2Q: /WWToLNuQQ_NNPDF31_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAOD Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM WWToLNuQQ: Not in 2018 WZTo3LNu: /WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM /WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM WZTo2L2Q: /WZTo2L2Q_13TeV_amcatnloFXFX_madspin_pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM WZTo1L1Nu2Q:

Samples 2018 (4)

Process	Sample(s)
ttbar	ttbar_madgraph: /TTJets_DiLept_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM TTToHadronic: /TTToHadronic_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM ttbar_aMCatNLO: /TTJets_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM ttbar 2l2nu: /TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM TTToSemileptonic: /TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM

Samples 2018 (5)

Process	Samples(s)
ttbarV	ttgamma: /TTGamma_Dilept_TuneCP5_13TeV-madgraph-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM /TTGamma_Dilept_TuneCP5_13TeV_madgraph_pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM TTZToQQ: /TTZToQQ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM TTZToQQ_ext: /TTZToQQ_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19_ext1-v1/NANOAODSIM TTZToLL: TTZToLLNuNu: ttWJetsToLNu: ttWJetsToQQ: ttHTobb: /ttHTobb_M125_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM ttHToNonbb: /ttHToNonbb_M125_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM

Samples 2018 (6)

Process	Sample(s)
W+jets	W Jets To L Nu: /WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIAutumn18NanoAODv5-Nano1June2019_102X_upgrade2018_realistic_v19-v1/NANOAODSIM
Data	Double Muon: Double electron:

Samples for trigger SF calculations (2016)

Process	Sample(s)
ttbar	
MET	

Samples for trigger SF calculations (2017)

Process	Sample(s)
ttbar	
MET	

Samples for trigger SF calculations (2018)

Process	Sample(s)
ttbar	
MET	

Results – Normalisation Factors 2016 (1)

Sample	Number of simulated events	Cross section	Normalisation factor
tZq	13656784	0.0758	0.000199163
Z+jets (M 50 aMCatNLO)	120777245	5941.0	1.76507
Z+jets (M10To50 aMCatNLO)	67942840	18810.0	9.93422
Z+jets (M10To50 ext aMCatNLO)	40154170	18810.0	16.8092
Z+jets (M50 Madgraph)	49748967	4963.0	3.57972
Z+jets (M50 Madgraph ext)	96531428	4963.0	1.84486
Z+jets (M10To50 Madgraph)	35114961	16270.0	16.6259

Results – Normalisation Factors 2016 (2)

Sample	Number of simulated events	Cross section	Normalisation factor
Z+jets (pt binned, 0-50)	37458375	5352.57924	5.12747
Z+jets (pt binned, 50-100)	21847075	363.81428	59755.1
Z+jets (pt binned, 50-100 ext)	108670239	363.81428	0.120132
Z+jets (pt binned, 100-250)	2046961	84.014804	1.47277
Z+jets (pt binned, 100-250 ext1)	2805972	84.014804	1.07439
Z+jets (pt binned, 100-250 ext2)	2991815	84.014804	1.00765
Z+jets (pt binned, 100-250 ext5)	76440229	84.014804	0.0394387

Results – Normalisation Factors 2016 (2)

Sample	Number of simulated events	Cross section	Normalisation factor
Z+jets (pt-binned, 250-400)	423976	3.228256512	0.273222
Z+jets (pt-binned, 250-400 ext1)	590806	3.228256512	0.19607
Z+jets (pt-binned, 250-400 ext2)	594317	3.228256512	0.194912
Z+jets (pt-binned, 250-400 ext5)	19567800	3.228256512	0.00591991
Z+jets (pt-binned, 400To650)	432056	0.436041144	0.036214
Z+jets (pt-binned, 400To650_ext1)	589842	0.436041144	0.0265265
Z+jets (pt-binned, 400To650_ext2)	604038	0.436041144	0.0259031

Results – Normalisation Factors 2016 (3)

Sample	Number of simulated events	Cross section	Normalisation factor
Z+jets (pt-binned, 600ToInf)	430691	0.040981055	0.00341433
Z+jets (pt-binned, 600ToInf ext1)	599665	0.040981055	0.00245224
Z+jets (pt-binned, 600ToInf ext2)	597526	0.040981055	0.00246102
ttbar (inc)	76857480	730.6	
ttbar (madgraph)	6068369	56.86	0.33622
ttbar (madgraph ext)	24767666	56.86	0.0823779

Results – Normalisation Factors 2016 (4)

Sample	Number of simulated events	Cross section	Normalisation factor
ttbar (TT to hadronic)	Not used	Not used	Not used
ttbar (TT to semileptonic)	Not used	Not used	Not used
ttbar (aMCatNLO)	43768838	722.8	0.592573
Single top (t-channel, top)	67105876	136.02	0.0727329
Single top (t-channel, top, scale up)	5992440	136.02	0.814494
Single top (t-channel, top, scale down)	64352832	136.02	0.0758445
Single top (t-channel, antitop)	38811017	80.95	0.0748429
Single top (t-channel, antitop, scale up)	3970546	80.95	0.731569
Single top (t-channel, antitop, scale down)	37359247	80.95	0.731569
Single top (s-channel)	2989199	10.12	0.121483

Results – Normalisation Factors 2016 (5)

Sample	Number of simulated events	Cross section	Normalisation factor
ttbar (hdamp up)	29833668	730.6	0.878743
ttbar (hdamp up ext)	28855428	730.6	0.908533
ttbar (hdamp down)	29047858	730.7	0.902638
ttbar (hdamp down ext)	29229088	730.7	0.897042
Single top (tchannel, top, hdampup)			
Single top (tchannel, top, hdampdown)			

Results – Normalisation Factors 2016 (6)

Sample	Number of simulated events	Cross section	Normalisation factor
ttbar (TT_isr_UP)	58977100	730.6	0.444513
ttbar (TT_isr_DOWN)	28409782	730.6	0.922785
ttbar (TT_isr_DOWN_ext)	29915551	730.6	0.876337
ttbar (TT_fsr_UP)	29632372	730.6	0.884712
ttbar (TT_fsr_UP_ext)	29501065	730.6	0.88865
ttbar (TT_fsr_DOWN)	29571600	730.6	0.88653
ttbar (TT_fsr_DOWN_ext)	29571600	730.6	0.88653

Results – Normalisation Factors 2016 (7)

Sample	Number of simulated events	Cross section	Normalisation factor
Single top (tW)	6952830	38.09	0.196579
Single top (tW, scale up)	997880	38.09	1.36969
Single top (tW, scale down)	993640	38.09	1.37553
Single top (t bar W)	6933094	38.06	0.196984
Single top (t bar W, scale up)	1000000	38.06	1.36571
Single top (t bar W, scale down)	999068	38.06	1.36698
Single top (tHq)	3495799	0.2609	0.00267804
Single top (tZq, W lept Z had)	Not used	Not used	Not used
Single top (tWZ tWLL)	50000	0.01104	0.00792297
Diboson (ZZ to 2L2Nu)	8931750	0.5644	0.00226746
Diboson (ZZ to 2L2Nu ext)	Doesn’t exist	Doesn’t exist	Doesn’t exist
Diboson (ZZ to 2L2Q)	15462693	3.222	0.00747703

Results – Normalisation Factors 2016 (8)

Sample	Number of simulated events	Cross section	Normalisation factor
Diboson (ZZ to 4L)	10711278	1.204	0.00403342
Diboson (WW1nuqq)	Not used	Not used	Not used
Diboson (WZ to 2L2Q)	26517272	5.606	0.007586
Diboson (WZ to 3LNu)	1959179	4.688	0.0858622
Diboson (WZ to 1L1Nu2Q)	24311445	10.73	0.0158372
Diboson (WW to 2L2Nu)	1999000	10.48	0.188121

Results – Normalisation Factors 2016 (9)

Sample	Number of simulated events	Cross section	Normalisation factor
Diboson (WW to LNuQQ)	1999200	43.53	0.781306
Diboson (WW to LNuQQ ext)	6655400	43.53	0.234695
Diboson (WG to LNuG)	Not used	Not used	Not used
Diboson (ZG to LLG)	Not used	Not used	Not used
Triboson (WWW to 4F)	240000	0.2086	0.0311883
Triboson (WWZ to 4F)	250000	0.1651	0.0236971
Triboson (WZZ)	246800	0.05565	0.00809112
Triboson (ZZZ)	249237	0.01398	0.00201272

Results – Normalisation Factors 2016 (10)

Sample	Number of simulated events	Cross section	Normalisation factor
W+jets	22533326	60430.0	96.2312
W+jets (ext)	237263153	60430.0	9.13926
ttbarV (ttW jets to LNu)	2160168	0.2001	0.0033239
ttbarV (ttW jets to LNu ext)	3120397	0.2001	0.00230105
ttbarV (ttW jets to QQ)	833298	0.405	0.0174399
ttbarV (ttZ to LL)	1992438	0.2529	0.00455463
ttbarV (ttZ to LL ext2)	5837781	0.2529	0.0015545
ttbarV (ttZ to LL ext3)	5934228	0.2529	0.00152923
ttbarV (ttZ to QQ)	749400	0.5297	
ttbarV (ttgamma)	Not used	Not used	Not used
ttbarV (ttH to bb)	3872944	0.5638	0.00522363
ttbarV (ttH to nonbb)	3981250	0.5638	0.00508153

Results – Normalisation Factors 2017 (1)

Sample	Number of simulated events	Cross section	Normalisation factor
tZq	13276146	0.07358	0.000230159
Z+jets (M 50)	27529915	6529.0	9.84879
Z+jets (M50 ext)	182104014	6529.0	1.48891
Z+jets (M10To50)	316134	15810	2076.83
ttbar (2l2nu)	69098644	88.29	0.0530619
ttbar (madgraph)	6094476	56.86	0.120653

Results – Normalisation Factors 2017 (2)

Sample	Number of simulated events	Cross section	Normalisation factor
ttbar (TT to hadronic)	130091218	377.96	0.137907
ttbar (TT to semileptonic)	110014744	365.34	0.194558
ttbar (aMCatNLO)	154280331	722.8	0.387446
Single top (t-channel, top)	122630600	136.02	0.000464558
Single top (t-channel, antitop)	63620800	80.95	0.0460622
Single top (s-channel)	9883805	3.74	0.0528395

Results – Normalisation Factors 2017 (3)

Sample	Number of simulated events	Cross section	Normalisation factor
Single top (tW)	7945242	34.91	0.0157141
Single top (t bar W)	7745276	34.97	0.182467
Single top (tHq)	3381548	0.3184	0.187499
Single top (tZq, W lept Z had)	1000000	0.1573	0.0039102
Single top (tWZ tWLL)	986000	0.01103	0.00653235
Diboson (ZZ to 2L2Nu)	8744768	0.5644	0.00268028
Diboson (ZZ to 2L2Q)	27611672	3.222	0.00484589

Results – Normalisation Factors 2017 (4)

Sample	Number of simulated events	Cross section	Normalisation factor
Diboson (ZZ to 4L)	6964071	1.256	0.00748975
Diboson (WW1nuqq)	8785360	45.99	
Diboson (WZ to 1L2Nu2Q)	4997672	45.68	0.379577
Diboson (WZ to 2L2Q)	27582164	5.606	0.00844045
Diboson (WZ to 3LNu)	10987679	5.052	0.0190941
Diboson (WW to 1L1Nu2Q)	4997672	45.68	0.379577
Diboson (WW to 2L2Nu)	2000000	11.08	0.230065

Results – Normalisation Factors 2017 (5)

Sample	Number of simulated events	Cross section	Normalisation factor
Diboson (WW to LNuQQ)	8785360	45.99	0.217393
Diboson (WG to LNuG)	6283083	405.27	2.67863
Diboson (ZG to LLG)	30490034	51.50	0.070144
Triboson (WWW to 4F)	232300	0.2086	0.0372912
Triboson (WWZ to 4F)	250000	0.1651	0.0274251
Triboson (WZZ)	250000	0.05565	0.00924413
Triboson (ZZZ)	250000	0.01398	0.00232225

Results – Normalisation Factors 2017 (6)

Sample	Number of simulated events	Cross section	Normalisation factor
W+jets	30008250	52940.0	73.2629
ttbarV (ttW jets to LNu)	4908905	0.2198	0.00185945
ttbarV (ttW jets to QQ)	811306	0.4316	0.0220921
ttbarV (ttgamma)	4642344	0.5804	0.00519196
ttbarV (ttZ to LL)	250000	0.05324	0.0088438
ttbarV (ttH to bb)	8000000	0.5269	0.00273514
ttbarV (ttH to nonbb)	7966779	0.5638	0.00293889

Results – Normalisation Factors 2017 (7)

Sample	Number of simulated events	Cross section	Normalisation factor
ttbarV (ttZ to LLNuNu)	7563490	0.2432	0.00133531
ttbarV (ttZ to QQ)	750000	0.5104	0.0282612
ttbarV (ttZ to QQ ext)	8940000	0.5104	0.00237091

Results – Normalisation Factors 2018 (1)

Sample	Number of simulated events	Cross section	Normalisation factor
tZq	13736000	0.07358	0.000319732
Z+jets (M 50)	997561	6529.0	390.656
Z+jets (M50 ext)	193094040	6529.0	2.0182
Z+jets (M10To50)	39392062	15810	23.9558
Z+jets (M10To50 ext)	46976952	15810	20.0879
ttbar (2l2nu)	64310000	88.29	0.0819445
ttbar (madgraph)	28701360	54.23	0.112778

Results – Normalisation Factors 2018 (2)

Sample	Number of simulated events	Cross section	Normalisation factor
ttbar (TT to hadronic)	133664000	377.96	0.168779
ttbar (TT to semileptonic)	101550000	365.34	0.214736
ttbar (aMCatNLO)	142155064	831.76	0.349239
Single top (t-channel, top)	154307600	136.02	0.0526141
Single top (t-channel, antitop)	79090800	80.95	0.0610911
Single top (s-channel)	19965000	3.74	0.0111812

Results – Normalisation Factors 2018 (3)

Sample	Number of simulated events	Cross section	Normalisation factor
Single top (tW)	9598000	34.91	0.217098
Single top (t bar W)	7623000	34.97	0.273815
Single top (tHq)	3375995	0.3184	0.00562935
Single top (tZq, W lept Z had)	4977000	0.1518	0.0018205
Single top (tWZ tWLL)	248600	0.01103	0.00264826
Diboson (ZZ to 2L2Nu)	8382600	0.5644	0.00401879
Diboson (ZZ to 2L2Nu ext)	48046000	0.5644	0.00070116
Diboson (ZZ to 2L2Q)	27900469	3.222	0.00689289

Results – Normalisation Factors 2018 (4)

Sample	Number of simulated events	Cross section	Normalisation factor
Diboson (ZZ to 4L)	99009000	1.256	0.000757185
Diboson (WZ to 1L2Nu2Q)	18901469	10.73	0.0118683
Diboson (WZ to 2L2Q)	28193648	5.606	0.0280525
Diboson (WZ to 3LNu)	10749269	5.052	0.0338837
Diboson (WZ to 3LNu ext)	11248318	5.502	0.0852367
Diboson (WW to 1L1Nu2Q)	19199100	45.68	0.142014
Diboson (WW to 2L2Nu)	7758900	11.08	3.96022

Results – Normalisation Factors 2018 (5)

Sample	Number of simulated events	Cross section	Normalisation factor
Diboson (WW to LNuQQ)	Not sample	No sample	No sample
Diboson (WG to LNuG)	6108186	405.27	0.220411
Diboson (ZG to LLG)	13946364	51.50	0.0518788
Triboson (WWW to 4F)	240000	0.2086	0.039418
Triboson (WWZ to 4F)	250000	0.1651	0.0132865
Triboson (WZZ)	250000	0.05565	0.00326613
Triboson (ZZZ)	250000	0.01398	44.4886

Results – Normalisation Factors 2018 (6)

Sample	Number of simulated events	Cross section	Normalisation factor
W+jets	71026861	52940.0	00.00261138
ttbarV (ttW jets to LNu)	4911941	0.2149	0.030841
ttbarV (ttW jets to QQ)	835296	0.4316	0.030841
ttbarV (ttZ to ll)	250000	0.05324	0.0127112
ttbarV (ttZ to QQ)	750000	0.5104	
ttbarV (ttZ to QQ ext)	8891000	0.5104	
ttbarV (ttgamma)	5968000	0.5804	0.00580478
ttbarV (ttgamma ext)	4940000	0.5804	0.00701274
ttbarV (ttH to bb)	9580000	0.5269	0.00328284
ttbarV (ttH to nonbb)	7525991	0.5638	0.00447145

More useful links

- NanoAOD twiki page is here
- Documentation for the description of nanoAOD branches can be found here.

- CMS Top Quark Group Twiki
- Top systematics twiki
- Top systematics twiki (Run 2)
- CMS Top Approval Procedure
- Info for each year (change the year in the URL for 2017 and 2018)
- Jet energy smearing twiki
- JECs:
  - Twiki page
  - Text files for 2016 and 2017
  - Recommended JECs and uncertainties for data and MC twiki
  - Link to the paper

Editing the analysis note (in lxplus)

- Example commands: https://twiki.cern.ch/twiki/pub/CMS/Internal/TdrProcessing/lxplus_git_example.txt

- When typing the commands given in the above text file, change “alverson” to your CERN username. Also change:

git clone --recursive https://:@gitlab.cern.ch:8443/tdr/papers/AN-18-280.git

to

*git clone --recursive https://:@gitlab.cern.ch:8443/tdr/**notes/AN-18-280**.git*

Editing the analysis note (in lxplus)

- Twiki page: https://twiki.cern.ch/twiki/bin/viewauth/CMS/Internal/TdrProcessing

Setting up a grid certificate

- Step 1: https://twiki.cern.ch/twiki/bin/viewauth/CMS/DQMGUIGridCertificate
- Step 2: https://cafiles.cern.ch/cafiles/certificates/Grid.aspx
- Step 3 (to double check): https://ca.cern.ch/ca/Help/?kbid=040110

EPR

- Rules: https://twiki.cern.ch/twiki/bin/view/Main/EprRulesExplained
- Manpower needs (tracker DPG): https://twiki.cern.ch/twiki/bin/viewauth/CMS/TrackerDPGManpowerNeeds