Top LHC France
23 May 2018

Measurement of the tZq cross section

Nicolas Tonon – IPHC

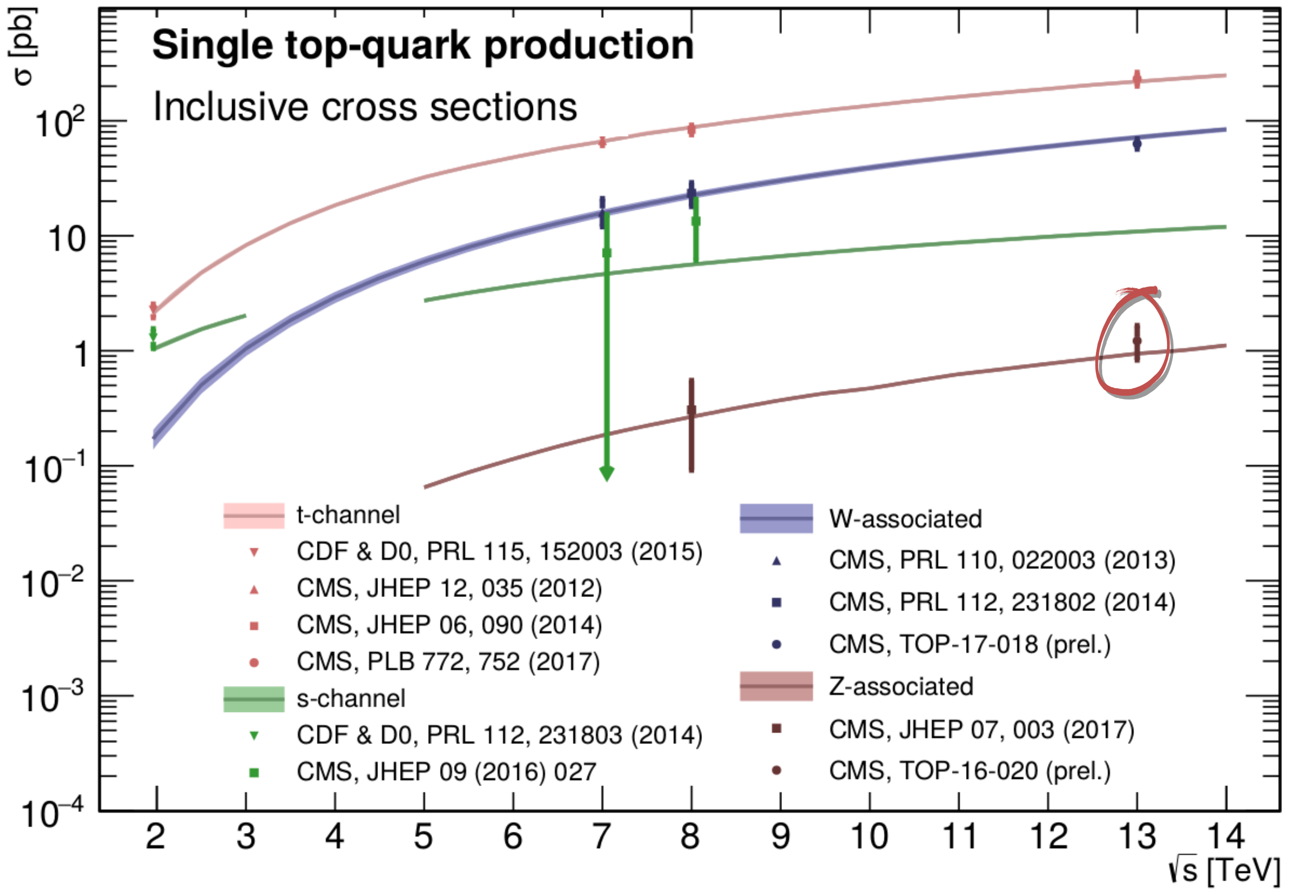
On behalf of CMS & ATLAS collaborations

Rare process

- Yet unobserved SM process involving single top quark

$$\sigma(t\ell^+\ell^- q) = 94.2^{+1.9}_{-1.8}\ (\text{scale}) \pm 2.5\,(\text{PDF})\ \text{fb}$$

ℓ : electrons, muons, taus
$m_{\ell^+\ell^-} > 30$ GeV
(CMS)

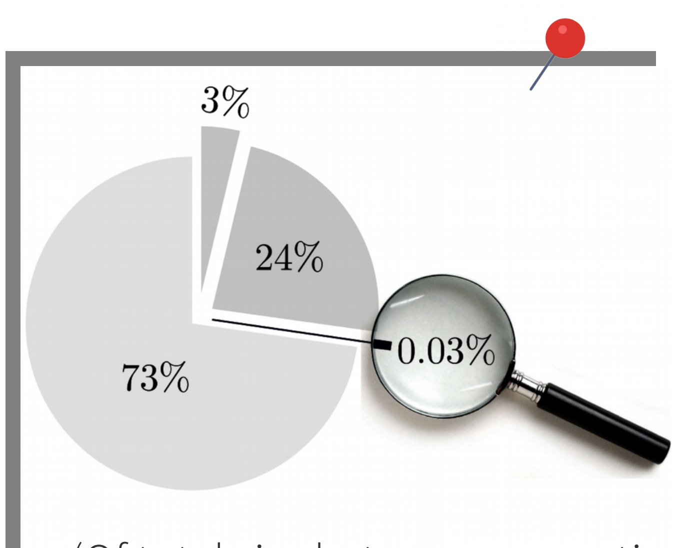


t-channel

tW channel

s-channel

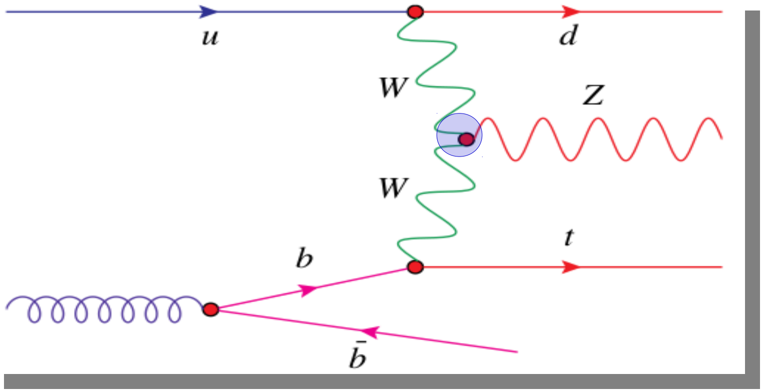
tZq

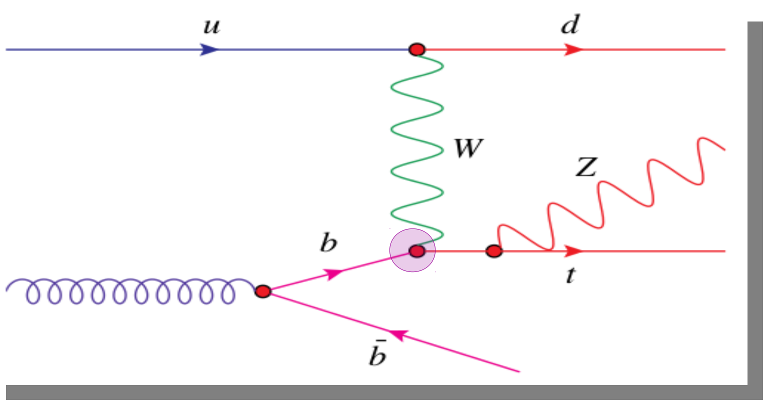


(Of total single-top cross-section)

Interesting process

- Background to $t\bar{t}H/V$, tHq, …
- Sensitive to tZ & WWZ couplings





Interesting process

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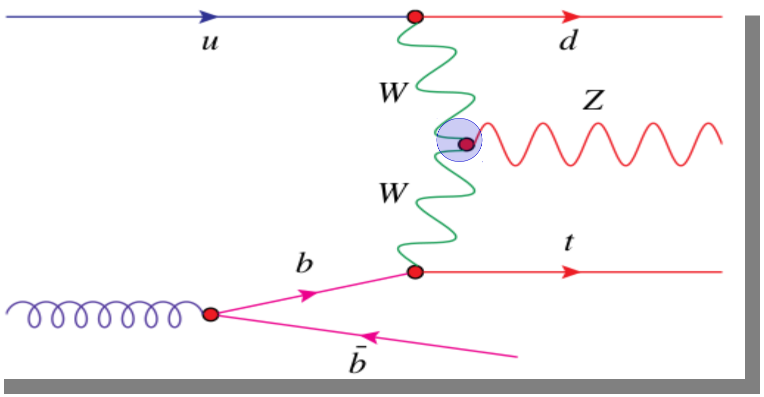
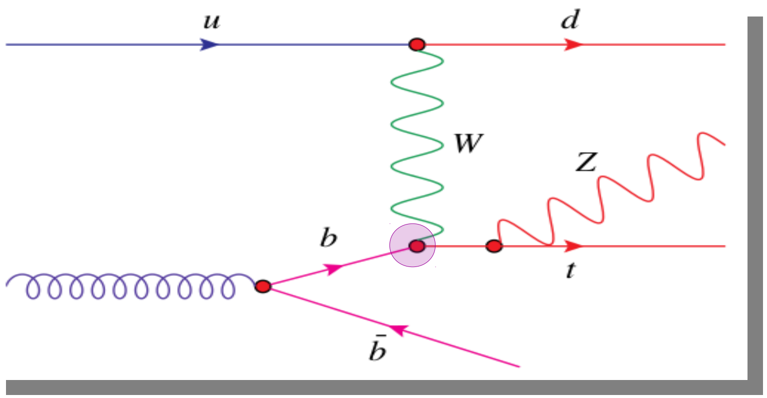
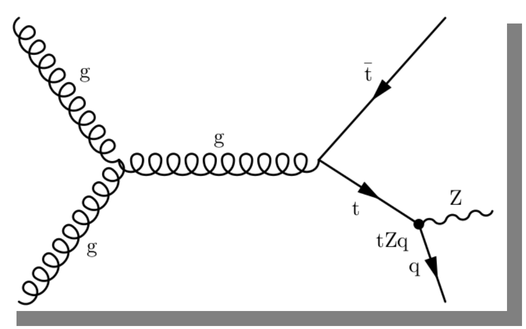


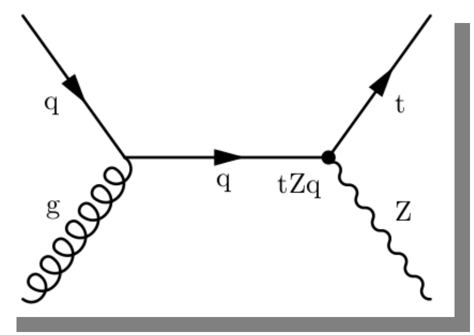


- Similar final state via FCNC interaction
- Highly suppressed within SM

  $[\ \mathcal{B}(t \to Xq) \approx 10^{-17} - 10^{-12}\ ]$

- Many BSM models predict FCNC enhancement [up to $\mathcal{B}(t \to Xq) \approx 10^{-3}$ [1]]





Key process to test SM & constrain new physics

State of the art

8 TeV : **2.4 σ** observed (**1.8 σ** expected)

arXiv:1702.01404

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Measurement of the associated production of a single top quark and a Z boson in pp collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration *

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Measurement of the production cross-section of a single top quark in association with a Z boson in proton–proton collisions at 13 TeV with the ATLAS detector

The ATLAS Collaboration *

CMS article (13 TeV)

P.L.B. - 04/2018

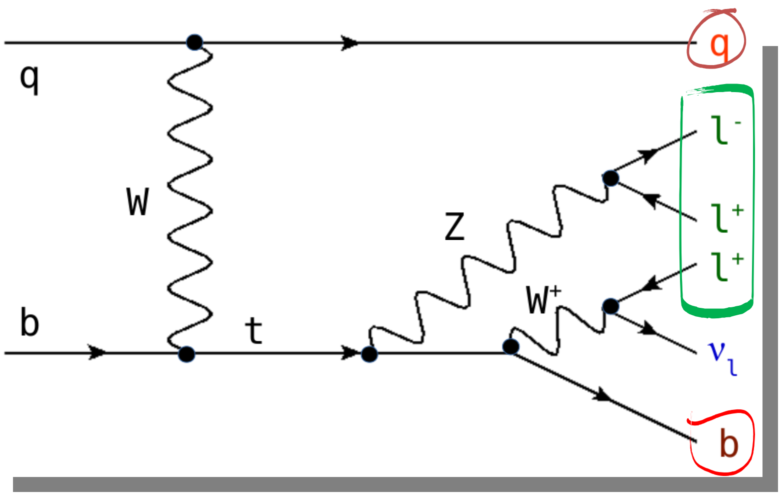
arXiv:1712.02825v2

ATLAS article (13 TeV)

P.L.B. - 05/2018

arXiv:1710.03659v2

Final state



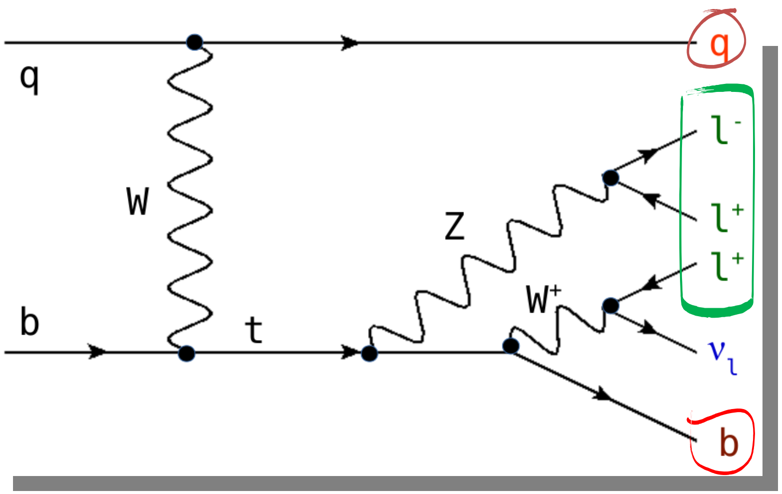
3 leptons

1 b-jet

1 forward light jet

MET

Final state



3 leptons

1 b-jet

1 forward light jet

MET

CMS

- Signal generated at **NLO** (4FS)
  - <u>Theory x-sec</u>

- 5FS

- Off-shell Z/γ* interference included

- m_{ll} > 30 GeV requirement

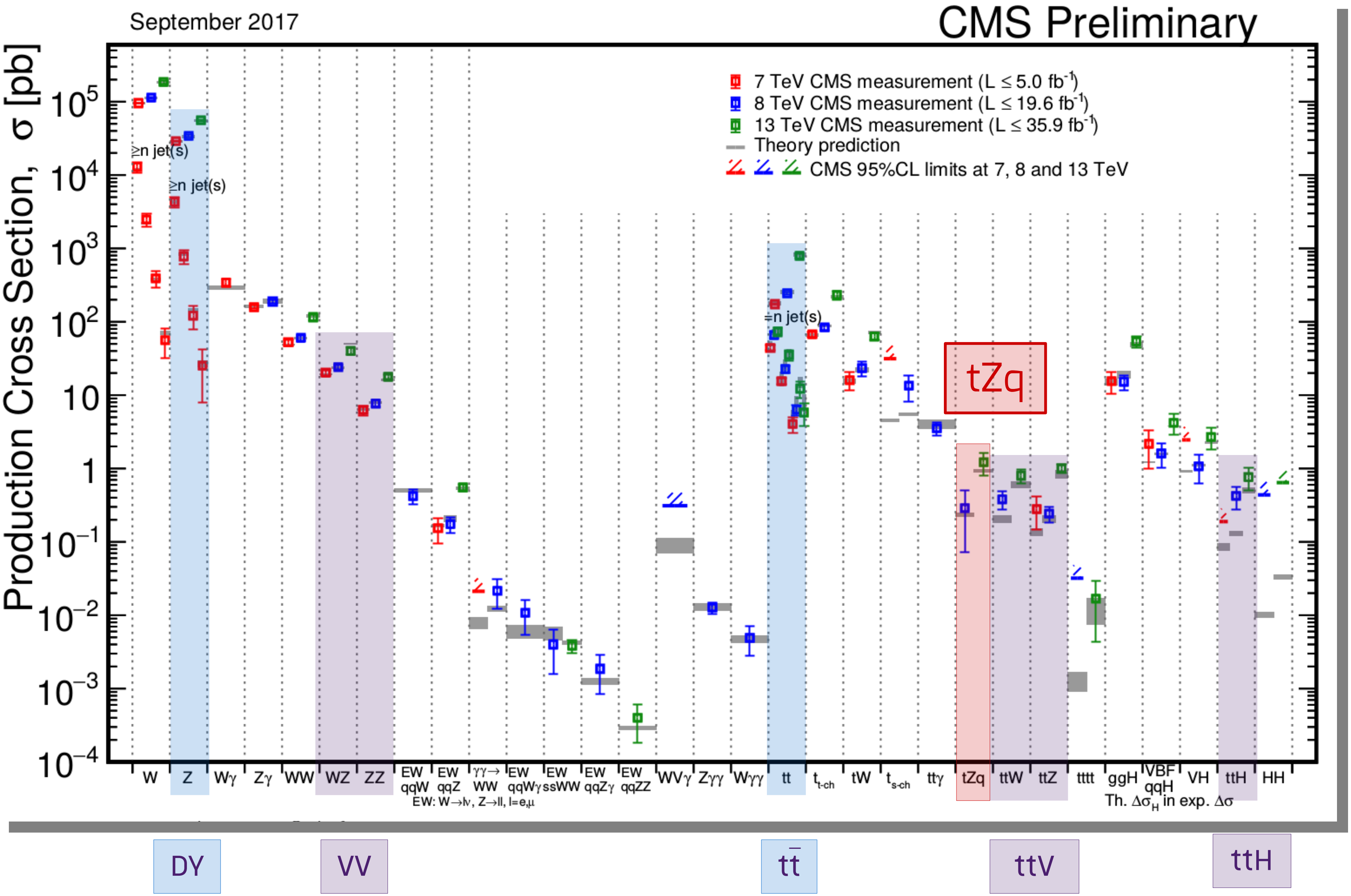
ATLAS

- Signal generated at **LO** (4FS), rescaled to NLO
  - <u>Theory x-sec</u>

- 4FS

- Z forced on-shell

Backgrounds



Background control is key to this analysis

Event selection

- p_T(lep) > 25 GeV
- $|m_{ll} - mZ| < 15$ GeV
- 2 or 3 jets, $p_T > 30$ GeV
- Btagging : 83 % WP, 10 % mistag

- p_T(lep) > **28/25/15** GeV
- $|m_{ll} - mZ| < 10$ GeV
- == 2 jets, $p_T > 30$ GeV
- Btagging : 77% WP, 1% mistag
- $m_T(W) > 20$ GeV

Event sel. & Regions - *ATLAS*

CMS:

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- m_T(W) > 20 GeV

- Validation regions → Check main bkgs modelling
- Control regions → Extract norm. of diboson & $t\bar{t}$ bkgs

SR	Diboson VR / CR	$t\bar{t}$ VR	$t\bar{t}$ CR
$\geq$1 OSSF pair	$\geq$1 OSSF pair	$\geq$1 OSSF pair	$\geq$1 OSDF pair
$\lvert m_{\ell\ell} - m_Z \rvert < 10$ GeV	$\lvert m_{\ell\ell} - m_Z \rvert < 10$ GeV	$\lvert m_{\ell\ell} - m_Z \rvert > 10$ GeV	No OSSF pair
2 jets, $\lvert\eta\rvert < 4.5$	1 jet, $\lvert\eta\rvert < 4.5$	2 jets, $\lvert\eta\rvert < 4.5$	2 jets, $\lvert\eta\rvert < 4.5$
1 b-jet, $\lvert\eta\rvert < 2.5$	–	1 b-jet, $\lvert\eta\rvert < 2.5$	1 b-jet, $\lvert\eta\rvert < 2.5$
–	VR/CR: $m_T(\ell_W, \nu) > 20/60$ GeV	–	–

Event sel. & Regions - *CMS*

- p_T(lep) > 25 GeV
- $|m_{ll} - mZ| < 15$ GeV
- **2 or 3 jets**, p_T > 30 GeV
- Btag : 83 % WP, **10 % mistag**

- p_T(lep) > **28/25/15** GeV
- $|m_{ll} - mZ| < 10$ GeV
- **== 2 jets**, p_T > 30 GeV
- Btag : 77% WP, **1% mistag**
- m_T(W) > 20 GeV

- Splitting by lepton flavours → 4 channels
- Define **3 different regions, all included in final fit** :

SR « 1bjet » :	2 or 3 jets	exactly 1 b-jet	↔ Signal-enriched
CR « 2bjet » :	at least 2 jets	at least 2 b-jets	↔ Mainly ttZ, some signal
CR « 0bjet » :	at least 1 jet	no b-jet	↔ Mainly WZ & DY (+non-prompt)

Non-prompt bkg. - *ATLAS*

Non-prompt lepton (NPL) ↔ not from W or Z decay (meson decay, mis-ID, …)

- Non-prompt backgrounds (DY, $t\bar{t}$) are the most challenging
  - Known to be poorly modeled by MC → Data-driven methods

- DY & $t\bar{t}$ are evaluated separately, to account for different behaviours of NPL
- $t\bar{t}$: shape from MC, single scale factor from $t\bar{t}$ CR
  - ~ No contamination from DY/SR events
  - Uncertainty estimated by deriving SFs using different m_{ll} mass windows, + stat.

$t\bar{t}$ CR
≥1 OSDF pair
No OSSF pair
2 jets, $\|\eta\| < 4.5$
1 b-jet, $\|\eta\| < 2.5$
–

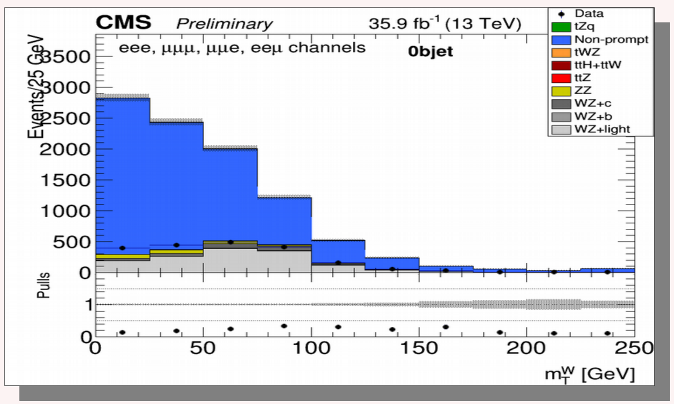
- DY : data events, scale factor from SR sideband with $m_T(W) < 20$ GeV
  - Separately for e / μ
  - ~ 50 % contamination from other bkgs, substracted
  - Uncertainty of 40 %

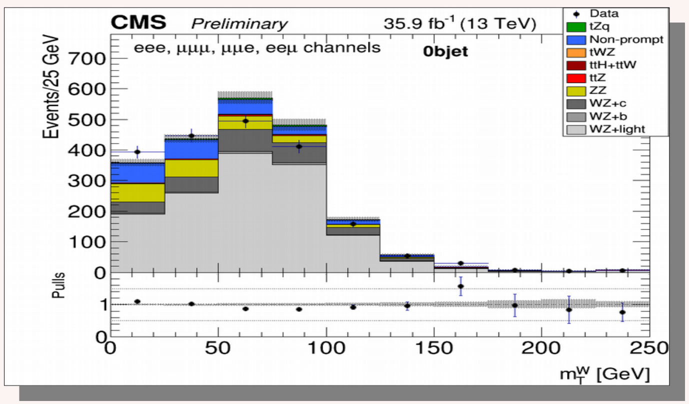
$$\frac{N_{data}(3iso)}{N_{data}(2iso, 1fail)}$$

Non-prompt bkg. - *CMS*

- **Single data-driven NPL sample** (correct relative proportions, by construction)
  - Inverted isolation & looser ID for 1 lepton among any of the 3

- « Out-of-the-box » normalisation is arbitrary





0bjet CR

→ **« Prefit » normalisation of non-prompt** bkg only, using $m_T(W)$ distribution in 0bjet control region

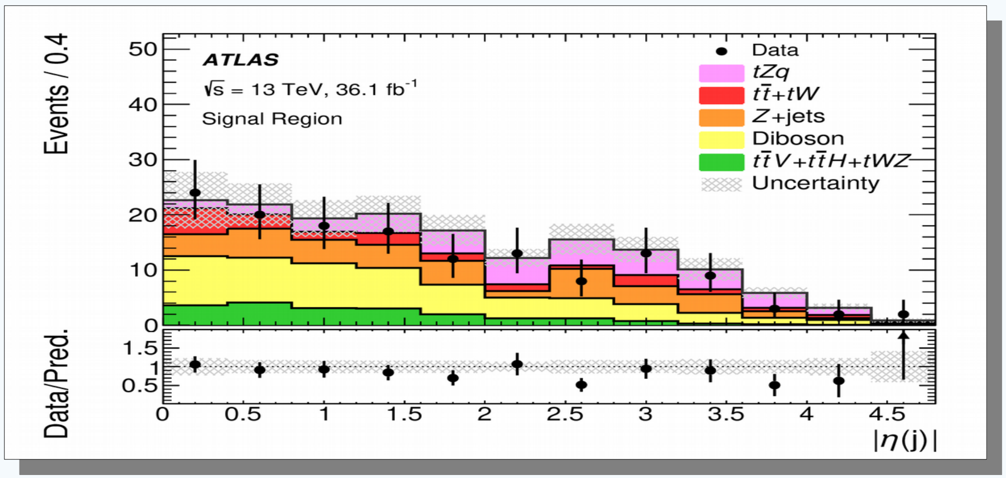
- NPL e/μ yields = independent **free parameters in the fit**
- **Shape uncertainty** accounted for, by varying iso requirement

MVA ATLAS : Neural Network

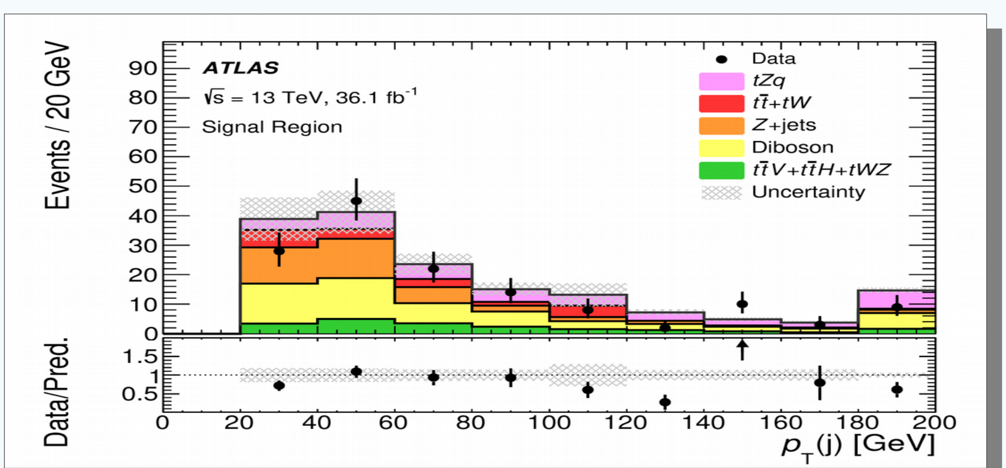
- Neural network trained with **all processes BUT $t\bar{t}$**

→ DY included !

η(fwd jet) - SR



p_T(fwd jet) - SR



- 10 input variables :
  - Kinematics
  - Reconstructed top/Z variables

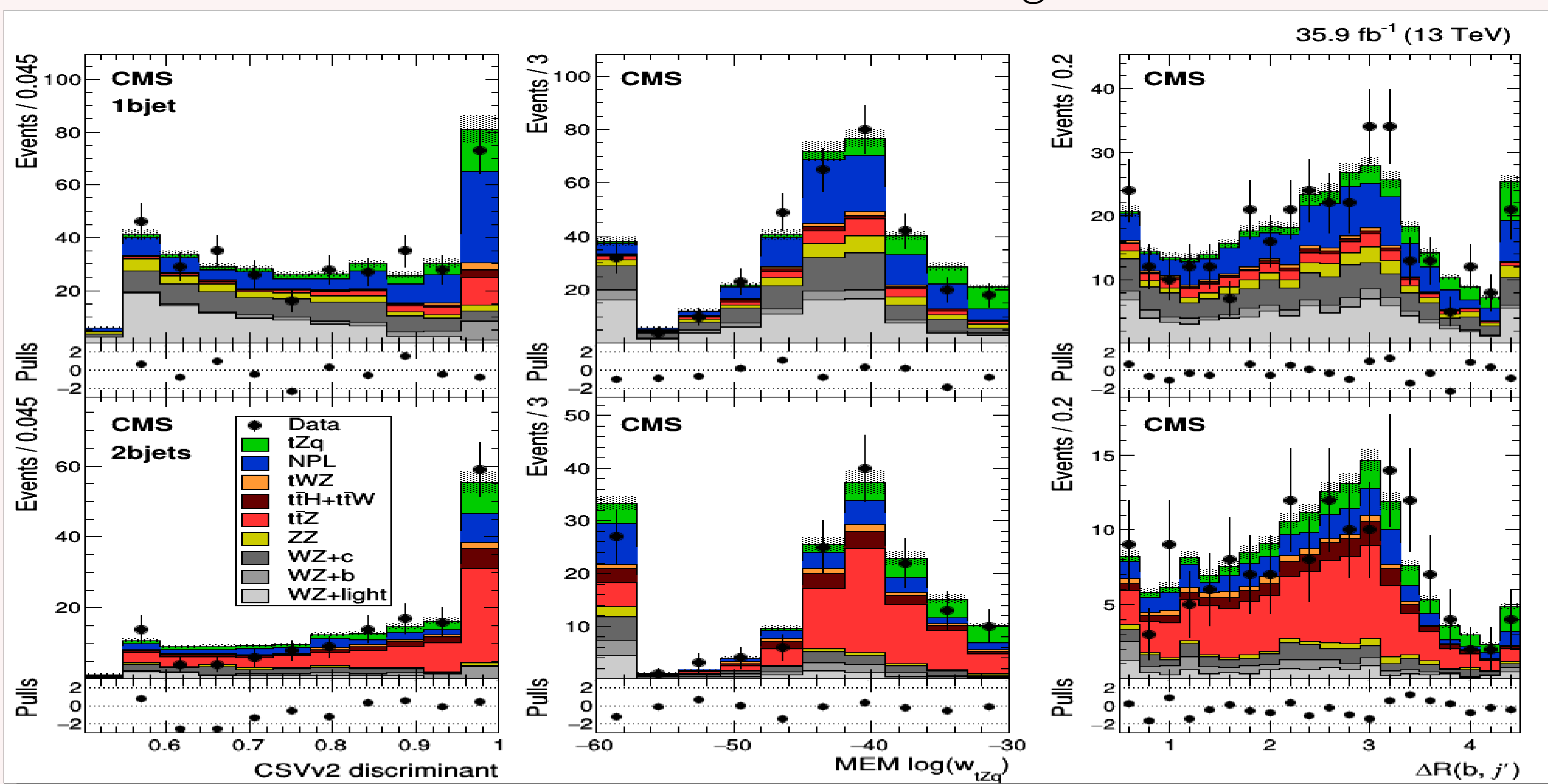
Variable	Definition
$\lvert\eta(\mathrm{j})\rvert$	Absolute value of untagged jet η
$p_{\mathrm{T}}(\mathrm{j})$	Untagged jet p_{T}
m_t	Reconstructed top-quark mass
$p_{\mathrm{T}}(\ell^W)$	p_{T} of the lepton from the W-boson decay
$\Delta R(\mathrm{j}, Z)$	ΔR between the untagged jet and the Z boson
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}})$	Transverse mass of W boson
$p_{\mathrm{T}}(t)$	Reconstructed top-quark p_{T}
$p_{\mathrm{T}}(b)$	Tagged jet p_{T}
$p_{\mathrm{T}}(Z)$	p_{T} of the reconstructed Z boson
$\lvert\eta(\ell^W)\rvert$	Absolute value of η of the lepton coming from the W-boson decay

MVA CMS : BDT + MEM (I)

- 1 BDT in SR ✚ 1 BDT in 2bjets CR
  - Trained against ttZ, WZ, ZZ backgrounds (**not enough MC statistics for NPL**)
- <u>Input variables</u> : lepton/jet kinematics, distances, top mass, btag discri.
- Postfit distributions of some of the most discriminating ones :

SR

2bjet CR



MVA CMS : BDT + MEM (2)

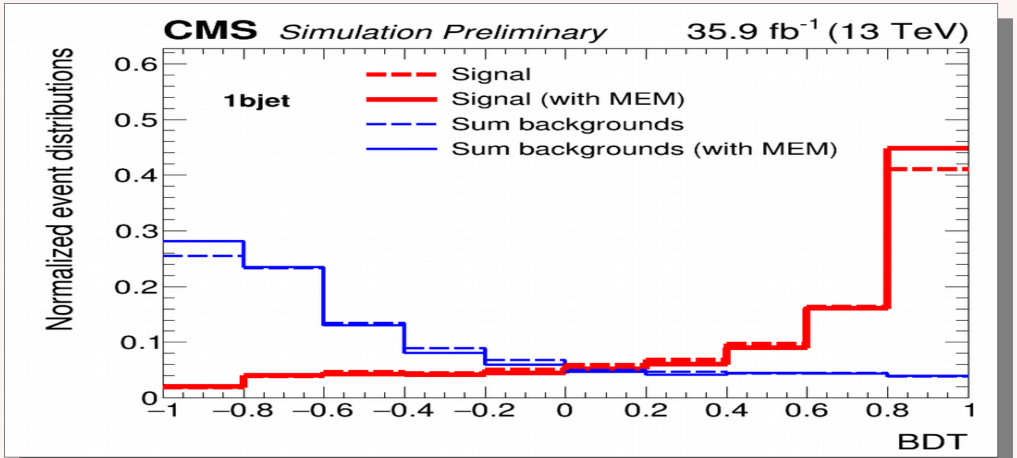
Principle : for each event, compute a probability related to a given hypothesis

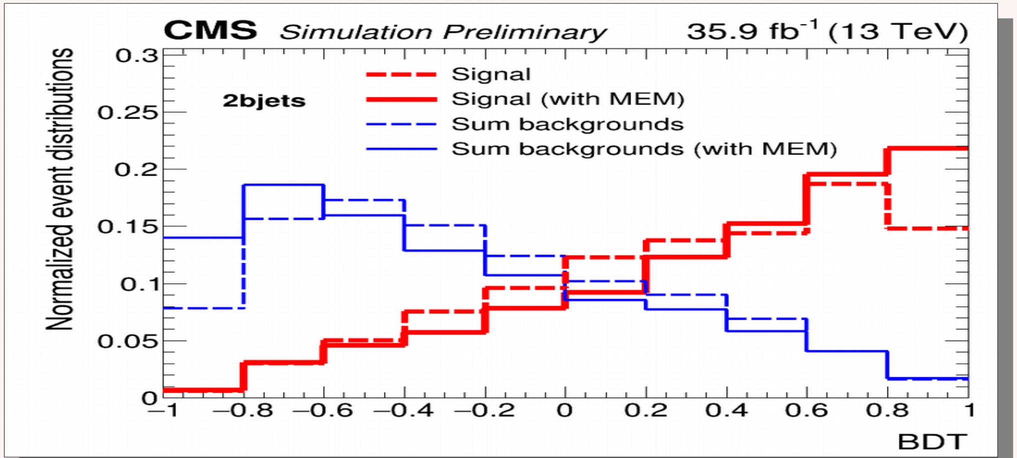
$$P(\boldsymbol{x}|\boldsymbol{\alpha}) = \frac{1}{\sigma_\alpha}\int \underbrace{d\Phi(\boldsymbol{y})dq_1dq_2}_{\text{Phase-space}}\overbrace{f_1(q_1)f_2(q_2)}^{\text{PDF}}\underbrace{|M_\alpha|^2}_{\text{Matrix element}}(\boldsymbol{y})\overbrace{W(\boldsymbol{x},\boldsymbol{y})}^{\text{Transfer func.}}$$

- Weights are computed for tZq, ttZ & WZ hypothesis

Include MEM variables into BDT training (4 in 1bjet SR & 2 in 2bjets CR)

— with MEM
- - - no MEM





Fitting procedure

ATLAS

- Fit output of Neural Network in SR

CMS

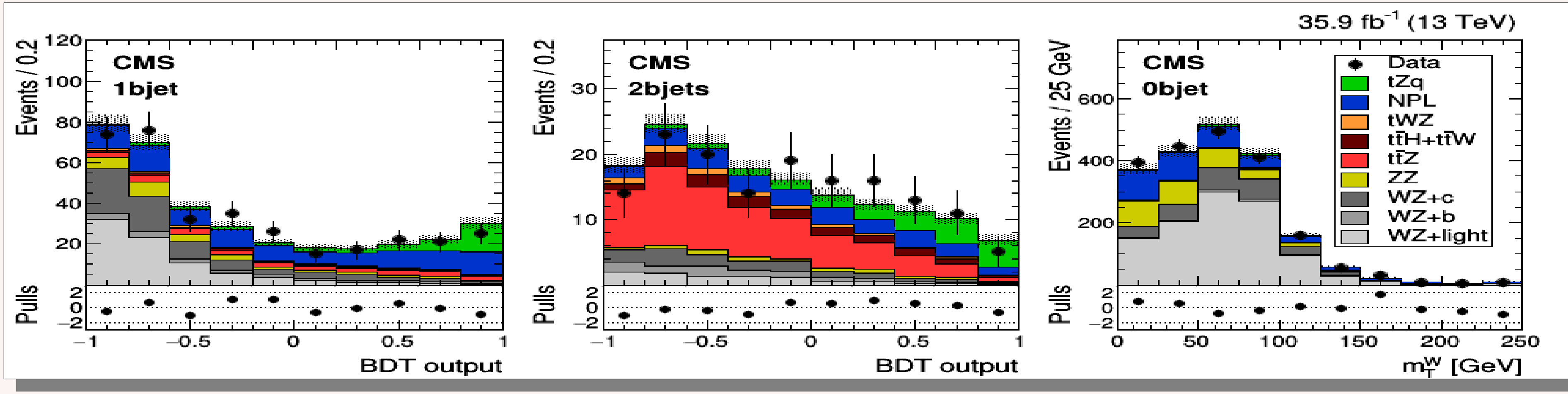
- σ_{tZq} extracted from simultaneous fit to [3 regions X 4 channels]
  - **BDT** in 1bjet SR
  - **BDT** in 2bjet CR
  - **$m_T(W)$** in 0bjet CR
- NPL rates as free parameters
- WZ+jets sample split according to jet flavour
  - b/c/light

  → Infer relative proportions from data

Results

- Significance : 3.7 σ observed (3.1 σ expected)

$$\mu = 1.31^{+0.35}_{-0.33}\,(\text{stat})^{+0.31}_{-0.25}\,(\text{syst})$$

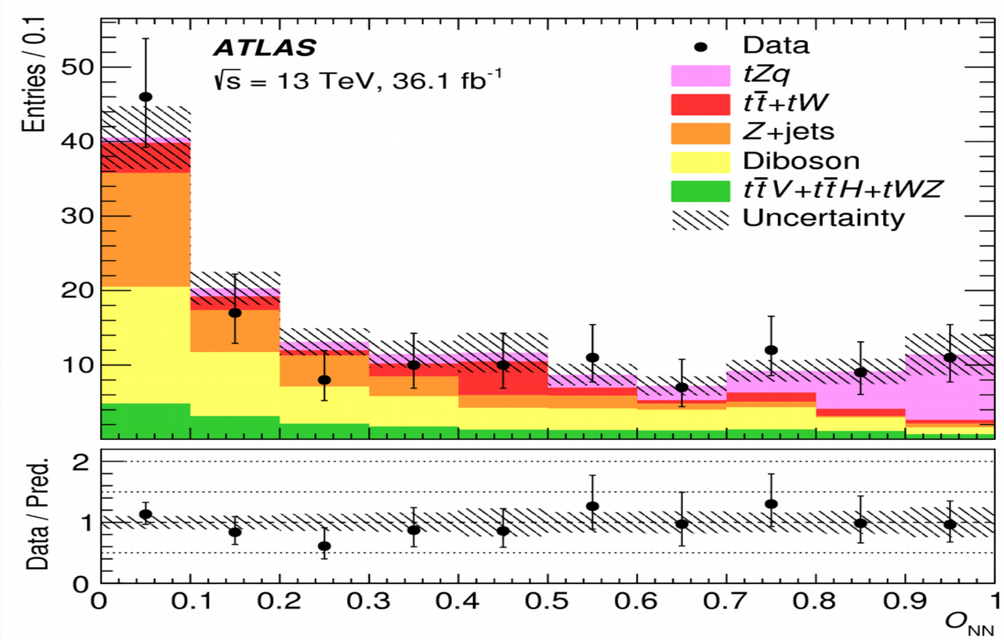


- Significance :

4.2 σ observed

(5.4 σ expected)

$$\mu = 0.75 \pm 0.21(\text{stat}) \pm 0.17(\text{syst}) \pm 0.05(\text{th})$$



Uncertainties

- Main systematics :
  - NPL backgrounds norm.
  - Scale dependance at PS level
  - Btagging efficiency
  - $t\bar{t}Z$ norm.

	Norm. uncert.
All bkgs	30 %
NPL	flat prior, constrained from fit

Source	Uncertainty [%]
tZq radiation	±10.8
Jets	±4.6
b-tagging	±2.9
MC statistics	±2.8
tZq PDF	±2.2
Luminosity	±2.1
Leptons	±2.1
$E_{\mathrm{T}}^{\mathrm{miss}}$	±0.3

Impact of systematics on signal yield

	Norm. uncert.
Diboson	30 %
DY & $t\bar{t}$	40 %
$t\bar{t}H/t\bar{t}V/tWZ$	13 %

Still **statistically-limited** for now

CL & outlook

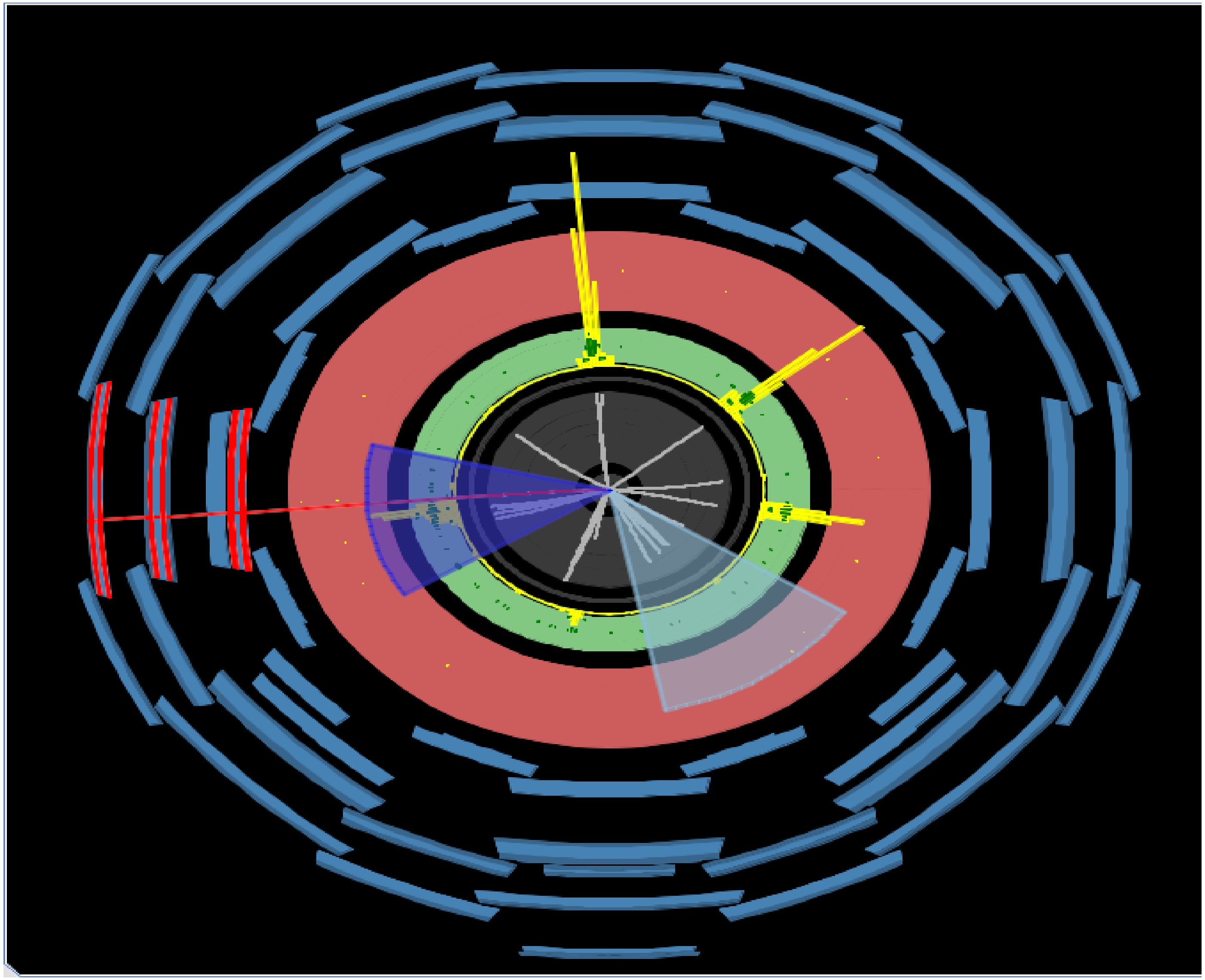
- Measurement of tZq cross-section provides interesting **test of SM**

- **Evidence** for this rare process found by both ATLAS (4.2 σ obs.) and CMS (3.7 σ obs.)
  - Compatible with SM prediction

- Main differences b/w analysis :
  - Signal modelisation
  - Non-prompt bkg estimation & treatment
  - Fitting strategy

- Uncertainty still dominated by statistics

- 2017 dataset + technical improvements (e.g. fake-rate method, lepton ID, etc.) likely to allow **discovery** !



3 ELECTRONS

B-JET

(+ fake μ ?)

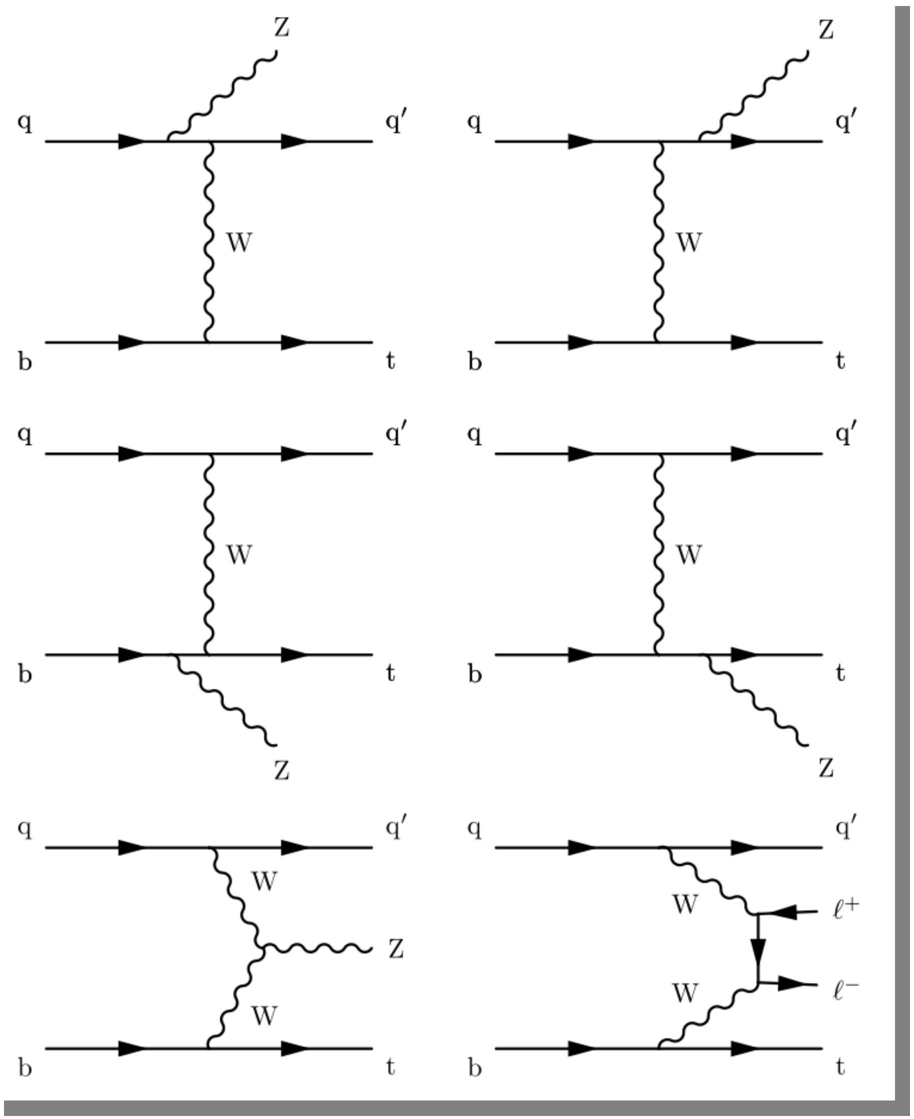
FWD JET

ATLAS event display of a tZq candidate

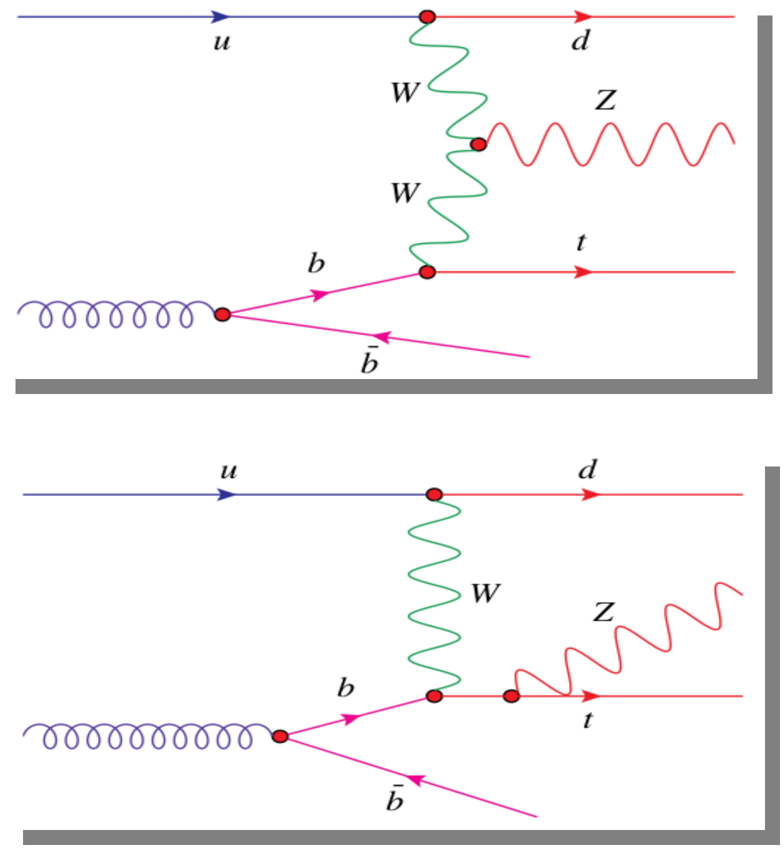
BACKUP

Feynman diagrams

5 FS



4 FS



Input variables

Description of the variables used in the BDTs. The symbol Y (N) in the third and fourth columns indicates that the variable was (was not) used in the 1bjet and 2bjets BDTs.

	Variable description	1bjet	2bjets
1	CSVv2 algorithm discriminant	Y	Y
2	ΔR separation between the jet identified as a b quark and the recoiling jet	Y	Y
3	η of the recoiling jet	Y	Y
4	p_T of the recoiling jet	Y	Y
5	η of the Z boson	Y	Y
6	Top quark mass	Y	Y
7	ΔR separation between the top quark decay lepton and the jet closest to it	Y	Y
8	Top quark decay lepton asymmetry	Y	Y
9	Azimuth angle separation between the top quark decay lepton and the Z boson	Y	Y
10	Azimuth angle separation between the top quark decay lepton and the b quark	Y	N
11	η of the top quark decay lepton	Y	N
12	η of the jet with highest p_T	Y	N
13	ΔR separation between the top quark decay lepton and the recoil jet	N	Y
14	ΔR separation between the Z boson and the top quark	N	Y
15	p_T of the Z boson	N	Y
16	Number of b tagged jets	N	Y
17	Logarithm of the MEM score associated to the most probable tZq kinematic configuration	Y	Y
18	Logarithm of the MEM score associated to the most probable $t\bar{t}Z$ kinematic configuration	N	Y
19	Log-likelihood ratio of the tZq hypothesis against the $t\bar{t}Z$ hypothesis	Y	N
20	Log-likelihood ratio of the tZq hypothesis against the $t\bar{t}Z$ hypothesis with $t\bar{t}Z$ and tZq weights rescaled such that their mean values are similar	Y	N
21	Log-likelihood ratio of the MEM weights for $t\bar{t}Z$ against $t\bar{t}Z+WZ$ hypothesis	Y	N

Variables used as input to the neural network, ordered by their separation power.

Variable	Definition
$\|\eta(j)\|$	Absolute value of untagged jet η
$p_T(j)$	Untagged jet p_T
m_t	Reconstructed top-quark mass
$p_T(\ell^W)$	p_T of the lepton from the W-boson decay
$\Delta R(j, Z)$	ΔR between the untagged jet and the Z boson
$m_T(\ell, E_T^{miss})$	Transverse mass of W boson
$p_T(t)$	Reconstructed top-quark p_T
$p_T(b)$	Tagged jet p_T
$p_T(Z)$	p_T of the reconstructed Z boson
$\|\eta(\ell^W)\|$	Absolute value of η of the lepton coming from the W-boson decay

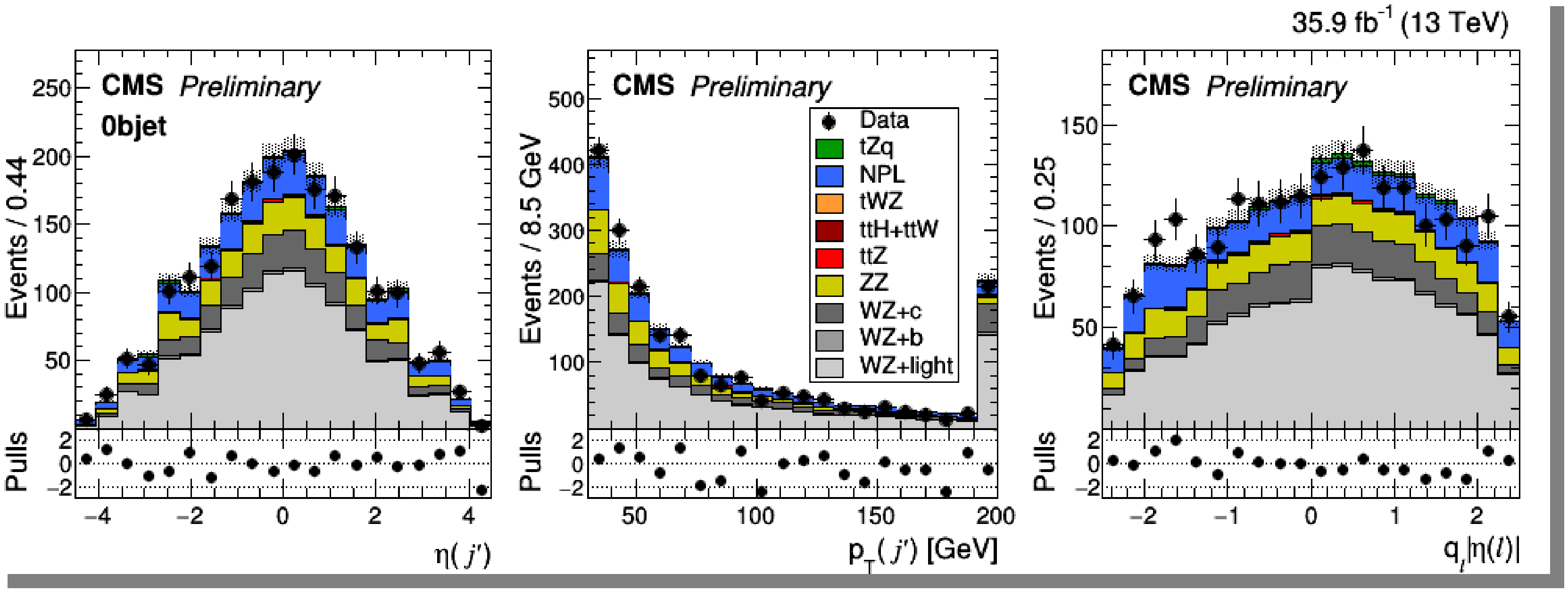
Postfit yields

Process	eee	eeμ	$\mu\mu$e	$\mu\mu\mu$	All channels	$\frac{N^{obs}}{N^{pred}}$
tZq	5.0±1.5	6.6±1.9	8.5±2.5	12.3±3.6	32.3±5.0	–
$t\bar{t}$Z	3.7±0.7	4.7±0.9	6.1±1.2	8.0±1.5	22.4±2.2	0.9±0.2
$t\bar{t}$W	0.3±0.1	0.3±0.1	0.7±0.2	0.6±0.2	1.9±0.3	1.0±0.2
Z Z	4.8±1.3	3.2±0.9	9.0±2.5	7.8±2.2	24.7±3.6	1.3±0.3
WZ+b	3.0±0.9	3.4±1.1	4.6±1.4	5.5±1.7	16.6±2.6	1.0±0.2
WZ+c	9.0±2.4	13.7±3.7	18.0±4.9	24.2±6.5	64.8±9.3	1.0±0.2
WZ+light	12.2±1.6	16.6±2.0	22.4±2.8	29.1±3.4	80.3±5.1	0.7±0.1
$t\bar{t}$H	0.6±0.2	0.9±0.3	1.0±0.3	1.5±0.4	4.0±0.6	1.0±0.2
tWZ	1.0±0.3	1.3±0.4	1.7±0.5	2.4±0.7	6.5±1.0	1.0±0.2
NPL: electrons	19.2±3.1	0.6±0.1	17.9±2.8	–	37.7±4.2	–
NPL: muons	–	7.2±2.3	31.1±9.9	15.3±4.9	53.6±11.3	–
Total	58.8±4.8	58.4±5.5	120.9±12.4	106.6±10.1	344.8±17.6	
Data	56	58	104	125	343	

Channel	Number of events	
	Asimov dataset	Data
tZq	35 ± 9	26 ± 8
$t\bar{t}$ +tW	28 ± 7	17 ± 7
$Z+$jets	37 ± 11	34 ± 11
Diboson	53 ± 13	48 ± 12
$t\bar{t}V+t\bar{t}H+tWZ$	20 ± 3	18 ± 3
Total	163 ± 12	143 ± 11

CMS - 0bjet CR, postfit variables

- 4 channels summed



ATLAS - Prefit plots

- Best training variables

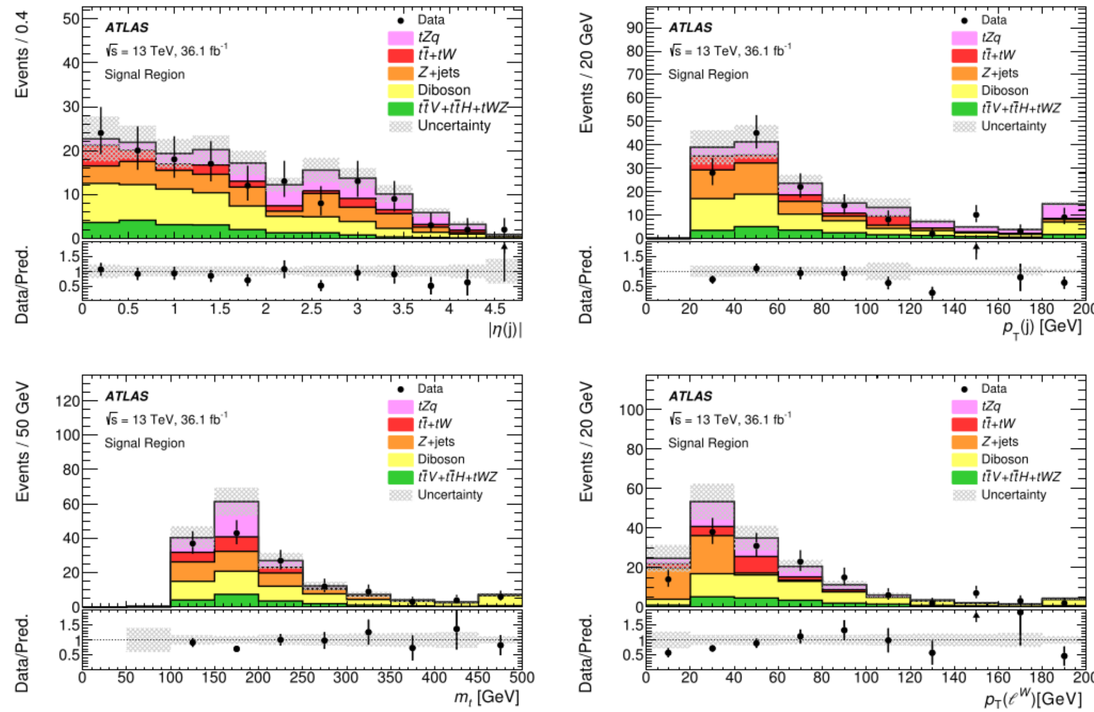


Fig. 2. Comparison of the data and the signal + background model for the neural-network training variables with the highest separation power. Signal and backgrounds are normalised to the expected number of events. The Z + jets background is estimated using a data-driven technique. The uncertainty band includes the statistical uncertainty and the uncertainties in the backgrounds derived in Section 6. The rightmost bin includes overflow events.

- Output of NN in Diboson (left) and tt (right) validation regions

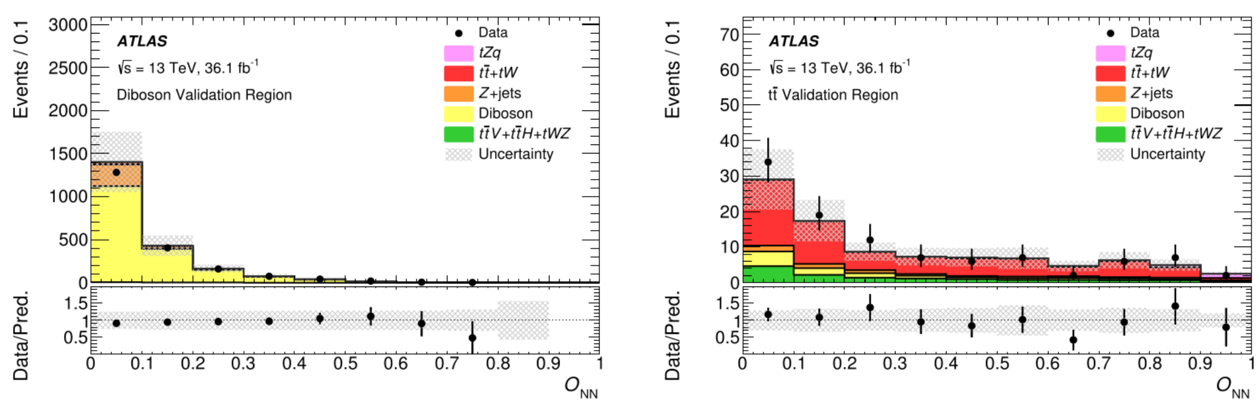


Fig. 3. Neural-network output distribution of the events in the diboson (left) and $t\bar{t}$ (right) validation regions. Signal and backgrounds are normalised to the expected number of events. The Z + jets background is estimated using a data-driven technique. The uncertainty band includes the statistical uncertainty and the uncertainties in the backgrounds derived in Section 6.

Simulations

- tZq : MG5_aMC@NLO, **NLO, 4FS, off-shell Z/γ* included**
- WZ, ttV : MG5_aMC@NLO, **NLO**, up to 1 additionnal jet
- ZZ : MG5_aMC@NLO, **NLO**
- ttH : POWHEG, NLO
- tWZ : Madgraph, LO
- All samples normalised to NLO cross-sections, except tWZ at LO
- PDF set : NNPDF3.0 (for all generators)
- Interfaced to PYTHIA8 for parton shower & hadronisation

- tZq : MG5_aMC@NLO, **LO, 4FS, on-shell Z only**
- PS & hadronisation : Pythia6, Perugia2012 param.
- PDF set : CTEQ6L1 LO PDF
- Diboson : Sherpa, **LO**, up to 3 additional partons, CT10 PDFs
- tt, tW : Powheg-box, processed w/ Pythia6, CT10 PDFs
- ttV, ttH, tWZ : MG5_aMC@NLO, processed with Pythia8, NNPDF2.3LO PDFs

- Multiple minimum bias events (Pythia8) added for each event to mimic presence of PU. Events reweighted so that distribution of number of PU interactions matched in data & MC
- Full detector simulations from GEANT4

MEM (I) - Formula

Matrix element method:

- Custom framework in C++
- Categories where 1 or 2 **jets are not reconstructed** are included: integrate over missing jet momenta

Integration: **VEGAS** in ROOT

Matrix element: **Madgraph** C++ standalone

MEM weight

$$w_{i,\alpha}(\Phi') = \frac{1}{\sigma_\alpha} \int d\Phi_\alpha \cdot \delta^4\Big(p_1^\mu + p_2^\mu - \sum_{k\geq 2} p_k^\mu\Big) \cdot \frac{f(x_1,\mu_F)f(x_2,\mu_F)}{x_1 x_2 s} \cdot \Big|\mathcal{M}_\alpha(p_k^\mu)\Big|^2 \cdot W(\Phi'|\Phi_\alpha)$$

Phase-space enforcing 4-momentum conservation: **analytic** (same as in Madweight)

Pdf: **LHAPDF** interface NNPDF2.3 LO

Transfert functions: Evaluated in MC

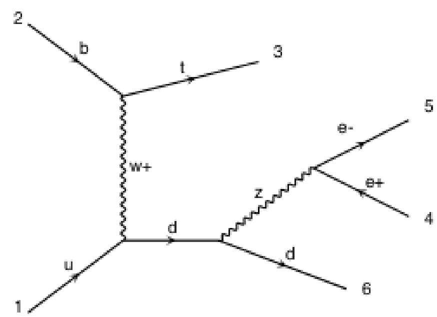
5

MEM (2) - Hypothesis

Hypothesis

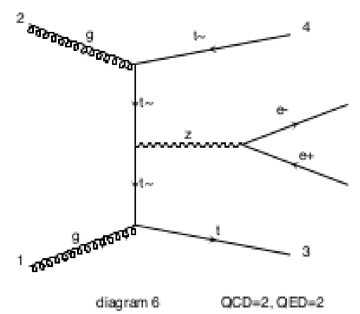
- Assume **narrow-width for top**
- Treat final-state b from top as massive
- Keep **full W and Z propagators** in the top ME: follows a Breit-Wigner
- Dilepton : Z and gamma* contributions included

TZQ hypothesis



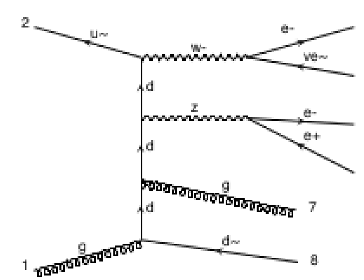
- sm_no_b_mass model in MG5: initial-state b is massless (5FS)
- Top leptonic decay

TTZ hypothesis



- Tops : leptonic and hadronic decay

WZ hypothesis



- 2 additional jets considered in the ME

Kin. fit

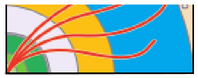
Look for the kinematic configuration having maximum probability:

Maximize

$$w_{i,\alpha}(\Phi') = \frac{1}{\sigma_\alpha} \int d\Phi_\alpha \cdot \delta^4\Big(p_1^\mu + p_2^\mu - \sum_{k\geq 2} p_k^\mu\Big) \cdot \frac{f(x_1,\mu_F) f(x_2,\mu_F)}{x_1 x_2 s} \cdot \left|\mathcal{M}_\alpha(p_k^\mu)\right|^2 \cdot W(\Phi'|\Phi_\alpha)$$

- The system is fully constrained, by construction: Lorentz momenta of any particles in the hypothesis could be computed
- We will **use solely the maximum of the function** integrated, i.e. the score of the kinematic fit (obtained with the **highest integrand value** tried by **VEGAS** among all iterations of the integration: does not add computing time)

MEM (3) - Phase space & Transfer func.



Phase space : use **parametrization from Madweight** paper

$$d\Phi_{top,had} \propto dE_b d\theta_b d\phi_b \cdot d\theta_{j1} d\phi_{j1} \cdot d\theta_{j2} d\phi_{j2} \cdot dm_W$$

$$d\Phi_{top,lep} \propto dE_b d\theta_b d\phi_b \cdot dE_l d\theta_l d\phi_l \cdot d\phi_\nu dm_W$$

$$d\Phi_Z \propto dE_{l1} d\theta_{l1} d\phi_{l1} \cdot dE_{l2} d\theta_{l2} d\phi_{l2}$$

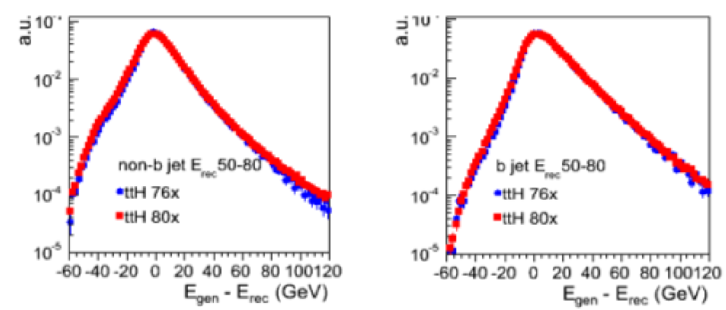
$$d\Phi_j \propto dE_j d\theta_j d\phi_j$$

b-jet/jet angles, and **lepton energy and angles** assumed to be **known**

Full integration on **neutrino variable**, assumed **unknown**

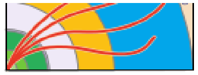
Transfer functions : Relating parton energies to reconstructed energies
- Integrate over jet and b-jet energy, **constrained** by a transfer function
- **Jets, b-jets Erec/Egen:** distributions in 3 eta bins x 6 Energy bins

use 76X MC
(very similar to 80X)



- **mET and mET Φ pdfs** : 2 mET bins and 3 mET sum bins

MEM (4) - Assignment to ME partons



Leptons:

- The three reconstructed leptons are assigned to the partonic leptons

B-quarks:

- Up to 2 jets with highest CSV are assigned to the partonic b-quarks

Non b-quarks: they are selected among the remaining jets

- **TZQ hypothesis**: Select the single jet with highest $|\eta|$
- **TTZ hypothesis**:
  - Select 2 jets with dijet mass closest to mW (hadronic top)
  - Reconstructed jets can be escaping detection (in tZq region): extend integration phase space to the missing jets
- **WZ hypothesis**: Select 2 jets with highest pT

Weight average over permutations

$$\begin{cases} w_\alpha = 10^{-300} & \text{if } \sum w_i = 0 \\ w_\alpha = \frac{1}{N_{w_i \neq 0}} \sum_{w_i \neq 0} w_i & \text{else} \end{cases}$$

Systematics - CMS

- Luminosity (2.5%, norm.)
- Trigger (1-2 %, norm.)
- Pile-up (+- 4.6 %, shape)
- Lepton selection (SFs +- 1σ, shape + norm.)
- Jet Energy Scale & Resolution (+- 1σ, shape + norm.)
- B-tagging (SFs +- 1σ, shape + norm.)
- Normalisations of MC backgrounds (30 %, norm.)
- NPL backgrounds shape uncertainties (variation of iso. Criterion)
-
  - **The scale and PDF uncertainties for simulated signal (tZq) and background processes.** These uncertainties affect the shape of the signal as well as the shape and normalisation of the simulated background samples, except for tWZ, for which only normalisation uncertainties from scale and PDF were considered.
    - The renormalisation and factorisation scales at the matrix element level are varied by factors of 1/2 and 2.
    - The renormalisation and factorisation scales at the parton shower level are varied by factors of 1/2 and 2; this uncertainty is only estimated for the signal sample.
    - The PDF uncertainties are estimated following the PDF4LHC recommendations, as the RMS of the results from 100 variations of the NNPDF.

  The dominant systematic uncertainties arise from the normalisation of the NPL background, the scale variations at the parton shower level, the b-tagging efficiency, and the normalisation of the $t\bar{t}Z$ background.

CMS - Triggers & Signal strength / channel

- Lowest p_T threshold for tri-lepton triggers : 16/12/8 GeV (electrons) & 12/10/5 GeV (muons)
- Lowest p_T thresholds for di-lepton triggers : 23/12 GeV (electrons) & 17/8 GeV (muons)
- p_T thresholds for single-lepton triggers : 32 GeV (electrons) & 24 GeV (muons)

→ ~ 100 % trigger efficiency

- Signal strength per channel :

- mmm : $1.22^{+0.75}_{-0.63}$ Best channel

- eee : $1.32^{+1.14}_{-0.99}$

- eem : $0.66^{+0.78}_{-0.63}$

- mme : $0.01^{+0.97}_{-0.01}$