ATLAS and CMS Run-1 $t\bar{t}V$ production measurement

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LHC TOP WG meeting
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Outline

- Introduction
- $t\bar{t}Z$ and $t\bar{t}W$ decay modes
- Analyses strategies
- Signal and background modelling
- Cross section measurement
- *Extra: Extended interpretation (CMS)*
- Combination plans
- Conclusions

Based on:

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Measurement of the $t\bar{t}W$ and $t\bar{t}Z$ production cross sections in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector

The ATLAS Collaboration

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2015-248
2015/10/06

submitted to: JHEP

CMS-TOP-14-021

arXiv:1510.01131 [hep-ex]

Observation of top quark pairs produced in association with a vector boson in pp collisions at $\sqrt{s} = 8$ TeV

The CMS Collaboration*

Introduction

- $t\bar{t}Z$: associated production of a top quark pair and a Z-boson
  - FSR processes would allow us to measure the weak isospin of the top
  - cross-section of $t\bar{t}Z$ production sensitive to anomalous t-Z couplings!

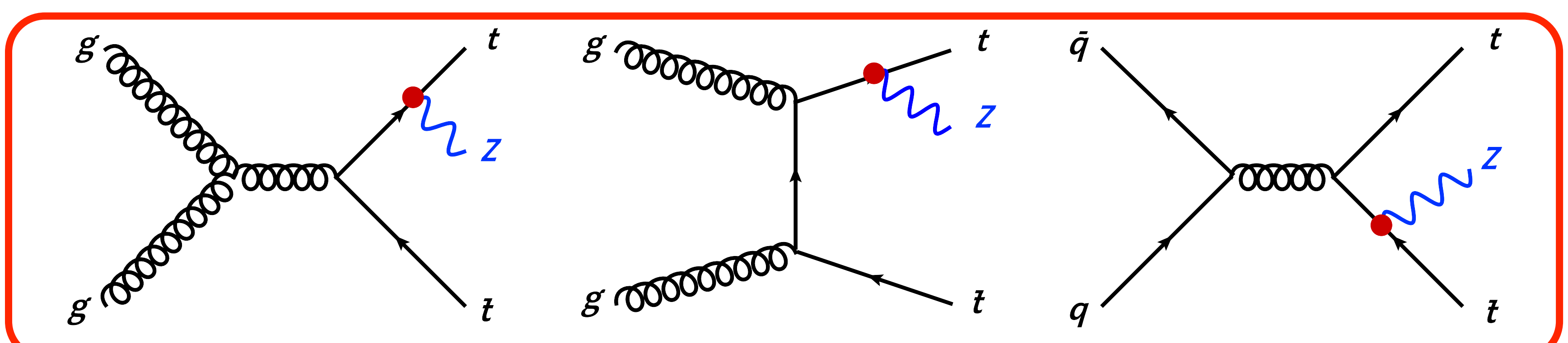
- $t\bar{t}W$: associated production of a top quark pair and a W^+ or W^- -boson
  - only ISR processes - similar to $t\bar{t}Z$ ISR

- Some new physics models enhance the $t\bar{t}W$ and $t\bar{t}Z$ cross sections **without** affecting Higgs or top production

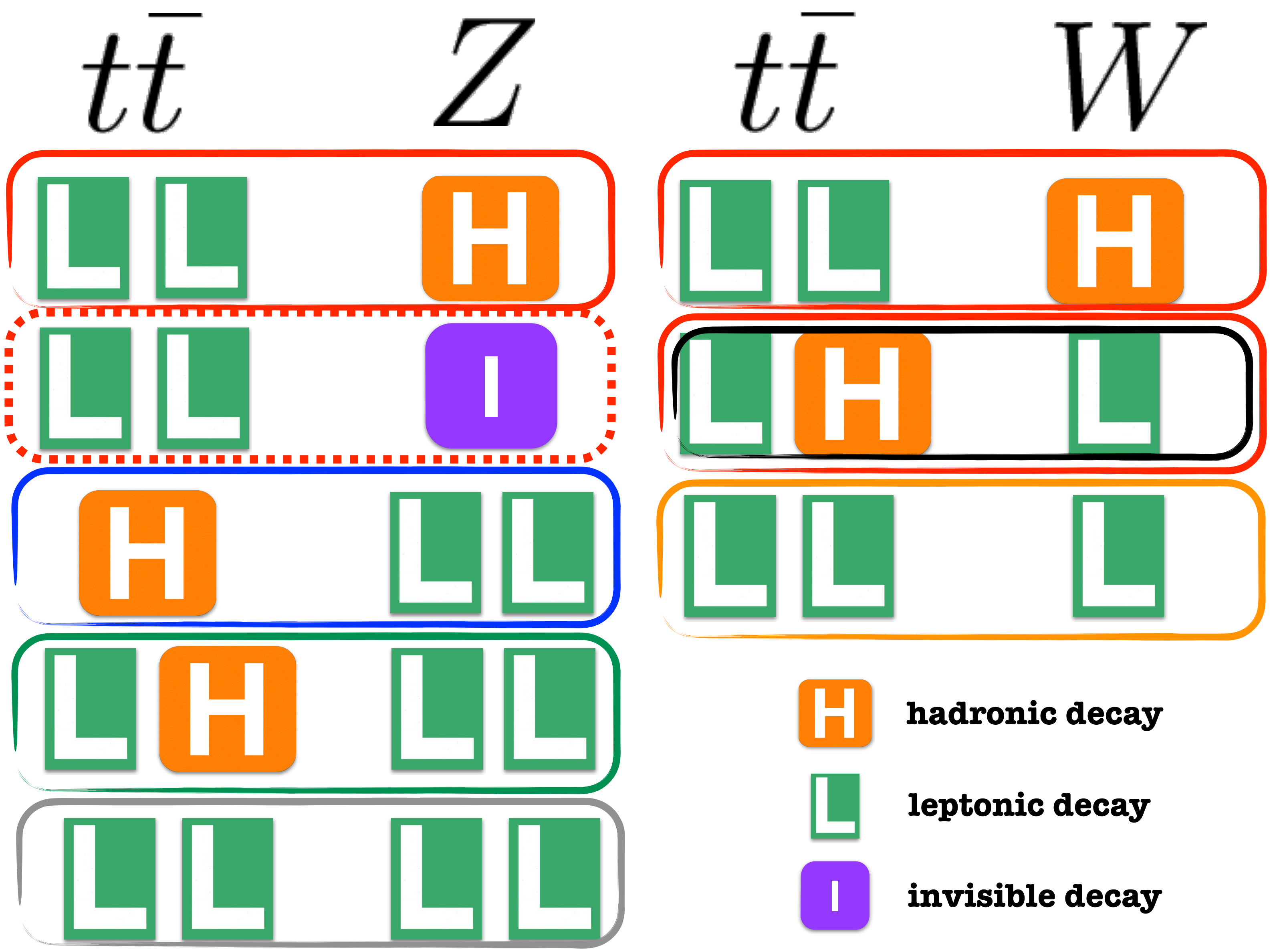
- $t\bar{t}Z$ and $t\bar{t}W$ are dominant (irreducible) backgrounds for $t\bar{t}H$ and many NP searches - **it is important to measure both processes**

ISR

FSR



$t\bar{t}$Z/W decay modes

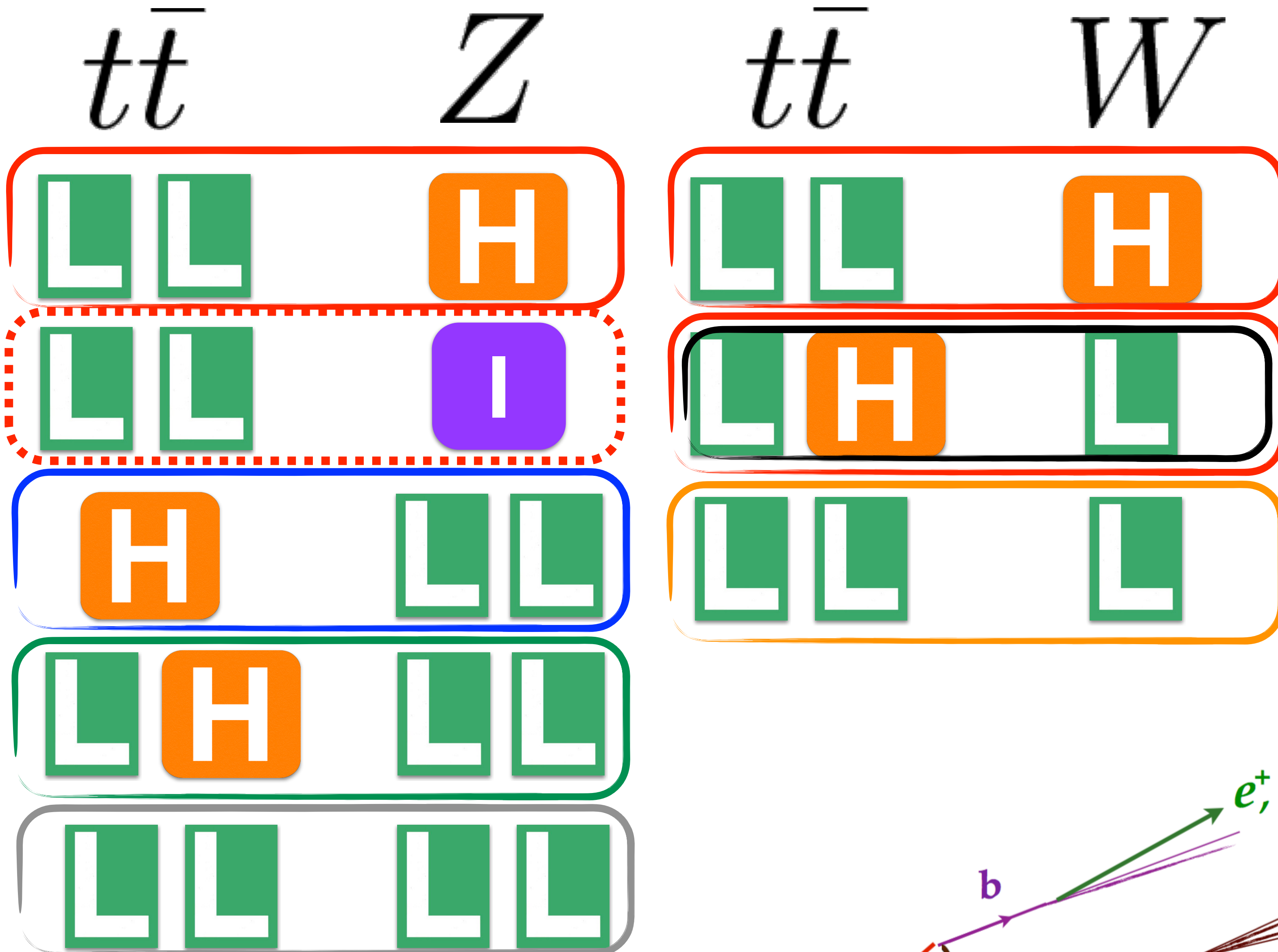


- 2ℓ-noZ-OS — largest BR, small S/B
- 2ℓ-Z-OS
- 2ℓ-SS — **most sensitive to $t\bar{t}$W**
- 3ℓ-Z — **most sensitive to $t\bar{t}$Z**
- 3ℓ-noZ
- 4ℓ — smallest BR, high purity

* All analysis channels included by both ATLAS and CMS experiment at 8 TeV with full Run-1 dataset (except 2ℓ-noZ-OS, only present in ATLAS)

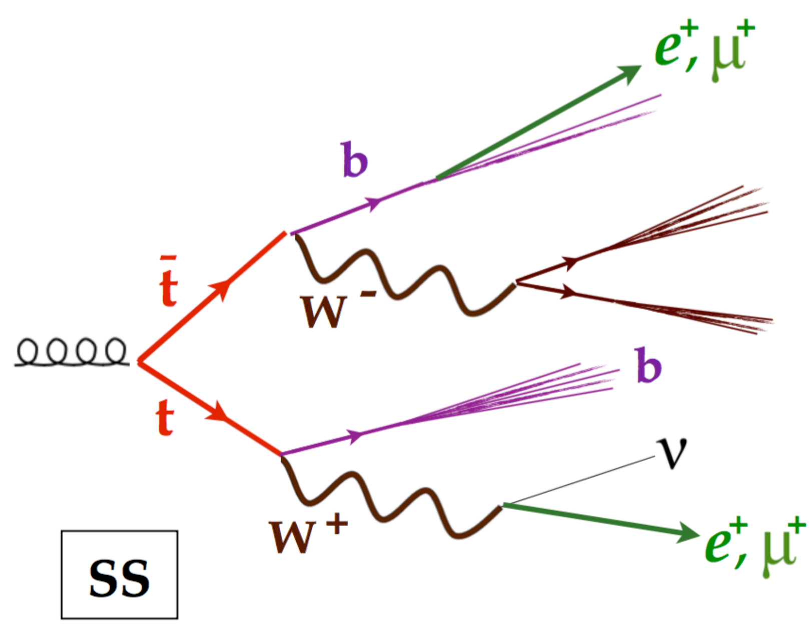
Z: $|m(\ell\ell) - m(Z)| < 10$ GeV
noZ: $|m(\ell\ell) - m(Z)| > 10$ GeV
OS: leptons with opposite sign charge
SS: leptons with same sign charge

$t\bar{t}Z/W$ decay modes: main backgrounds

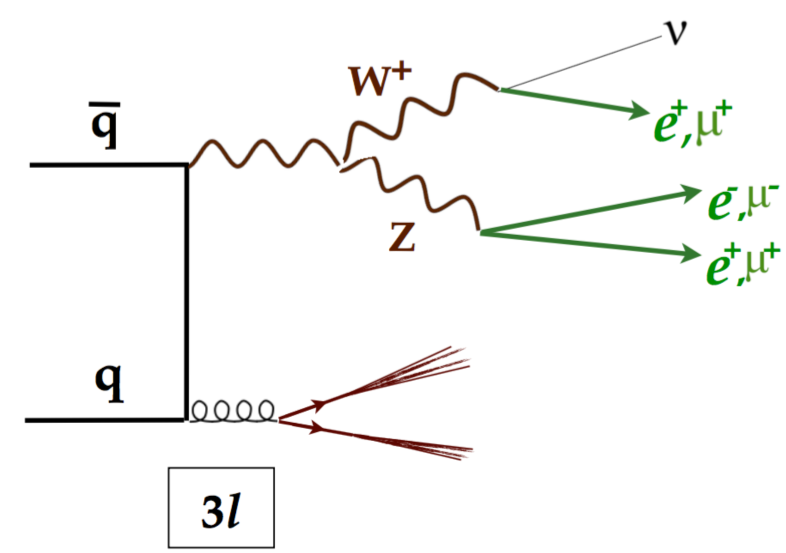


Main Background contributions

OS $t\bar{t}Z$&$t\bar{t}W$	$t\bar{t}$
OS $t\bar{t}Z$	Z+jets
SS $t\bar{t}W$	non-prompt ℓ, QMisID
3ℓ $t\bar{t}Z$	WZ(+HF)
3ℓ $t\bar{t}W$	non-prompt ℓ
4ℓ $t\bar{t}Z$	ZZ(+HF)



non-prompt ℓ (from $t\bar{t}$)



WZ(+HF)

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Analysis Channels (OS, SS and 3ℓ)

CMS

Channel	OS tt̄Z		SS tt̄W			3ℓ tt̄W		3ℓ tt̄Z	
Lepton flavor	ee/$\mu\mu$	eμ	ee	eμ	$\mu\mu$	Any		Any	
Lepton ID	2 loose		2 tight			SS tight		SS tight	
Lepton charge ID	≥0 pass		2 pass			SS pass		SS pass	
Z → $\ell\ell$ candidates	1		0			0		≥1	
Number of jets	5	≥6	3	≥4		1	≥2	3	≥4
Number of b tags	≥1 medium		≥2 loose or ≥1 medium						
Other			Z → ee veto						
Subchannels	4		6			2		2	

'**Loose**' retains ~90-99% prompt ℓ, rejects ~50% non-prompt ℓ

'**Tight**' retains ~80/90% prompt e/μ, rejects **~85/80%** non-prompt e/μ

CRs targeting tt̄+jets (OS tt̄Z)

Medium (Loose) CSV b-tagging WP: 70 (85)% b-eff, 20 (40)% c-mistag, 1 (10)% light mistag)

ATLAS

Channel	OS tt̄Z			OS tt̄Z&tt̄W			SS tt̄W			3ℓ tt̄W	3ℓ tt̄Z		
Lepton flavor	ee, μμ			Any			ee	eμ	μμ	Any	Any		
Lepton ID	2 'loose'			2 'loose'			2 'tight'			3 'loose'	3 'loose'		
Z→$\ell\ell$ candidates	1			0			0			0	1 (OS SF)		
Number of jets	3	4	≥5	3	4	≥5	2, 3	≥ 4		≥ 2	3	≥4	
Number of b tags	2			1, 2			≥ 2			≥ 2	0	1	2
ETmiss [GeV]							40-80	≥ 80					
Other							H_T > 240 GeV			not all same-sign			
Sub channels	1 + 2			1 + 2			1 (ee) + 8			1	1 + 3		

CRs targeting Z+jets (OS tt̄Z), tt̄ (OS tt̄Z&tt̄W), WZ (3ℓ tt̄Z), and ZZ (4ℓ tt̄Z)

Low/High Njets and Low/High ETmiss regions only in **eμ and μμ (SS tt̄W)**

MV1 b-tagging WP: same % as Medium CSV from CMS

✱ Dilepton triggers (CMS) vs Single lepton trigger (ATLAS): lepton pT of leading lepton (25 GeV ATLAS)

Analysis Channel (4ℓ)

ATLAS **CMS**

- Events selected with 2 pairs of OS leptons, at least 1 pair is same-flavour (SF)
  - **Z_1** = OSSF lepton pair with M_{inv} closest to m_Z
  - **Z_2** = the remaining pair

ATLAS

- Five signal regions defined according to the relative flavour of the Z_2 lepton pair: **SF** or **DF**

Region	Z_2 leptons	p_{T4}	p_{T34}	$\lvert m_{\ell\ell} - m_{Z_2}\rvert$	E_T^{miss}	N_{jets}	$N_{b\text{-jets}}$
4ℓ-DF-0b	$e^{\pm}\mu^{\mp}$	> 10 GeV	> 45 GeV	-	-	≥ 2	0
4ℓ-DF-1b	$e^{\pm}\mu^{\mp}$	> 7 GeV	> 35 GeV	-	-	-	1
4ℓ-DF-2b	$e^{\pm}\mu^{\mp}$	> 7 GeV	-	-	-	-	≥ 2
4ℓ-SF-1b	$e^{\pm}e^{\mp}, \mu^{\pm}\mu^{\mp}$	> 7 GeV	> 25 GeV	> 10 GeV < 10 GeV	> 40 GeV > 80 GeV	-	1
4ℓ-SF-2b	$e^{\pm}e^{\mp}, \mu^{\pm}\mu^{\mp}$	> 7 GeV	-	> 10 GeV < 10 GeV	- > 40 GeV	-	≥ 2

- Include 4ℓ-ZZ control region ($|m_{Z1,2} - m_Z| < 10$ GeV and $E_T^{miss} < 50$ GeV)

CMS

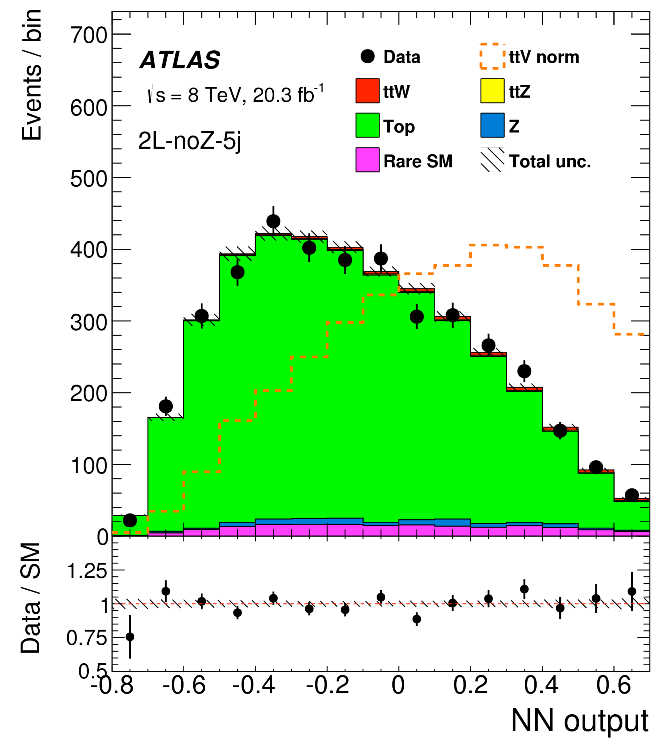
- Signal region if Z_2 is **DF** or if **SF** pair has a mass outside a Z-mass window of 10 GeV

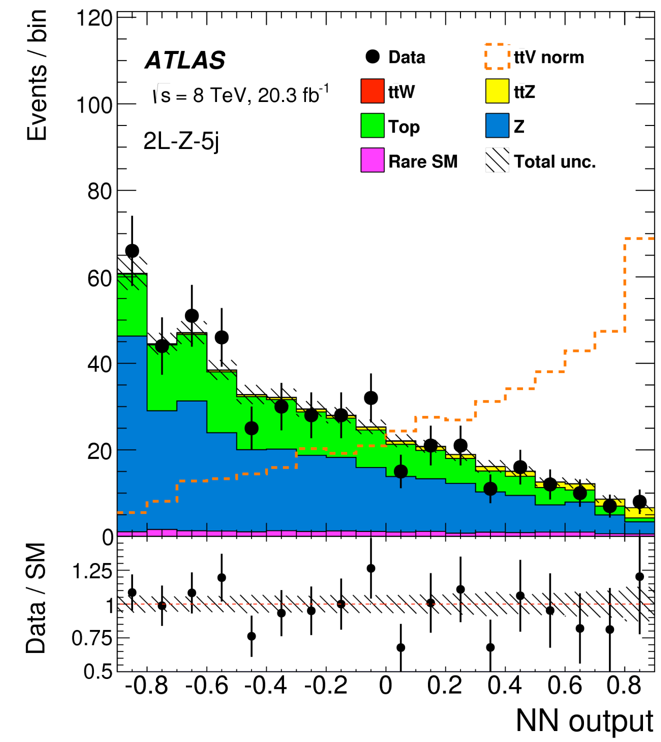
Channel	4ℓ $t\bar{t}Z$	
Lepton flavor	Any	
Lepton ID	4 loose	
Lepton charge ID	4 pass	
$Z \rightarrow \ell\ell$ candidates	2	1
Number of jets	≥ 1	
Number of b tags	≥ 1 loose	
Other	$H_T^{miss} > 30$ GeV	
Subchannels	2	

- ATLAS: all "counting" analyses, except OS $t\bar{t}Z$ and OS $t\bar{t}Z$&$t\bar{t}W$ channels, where a **neural network** (NN) is trained in each of the 3 signal regions

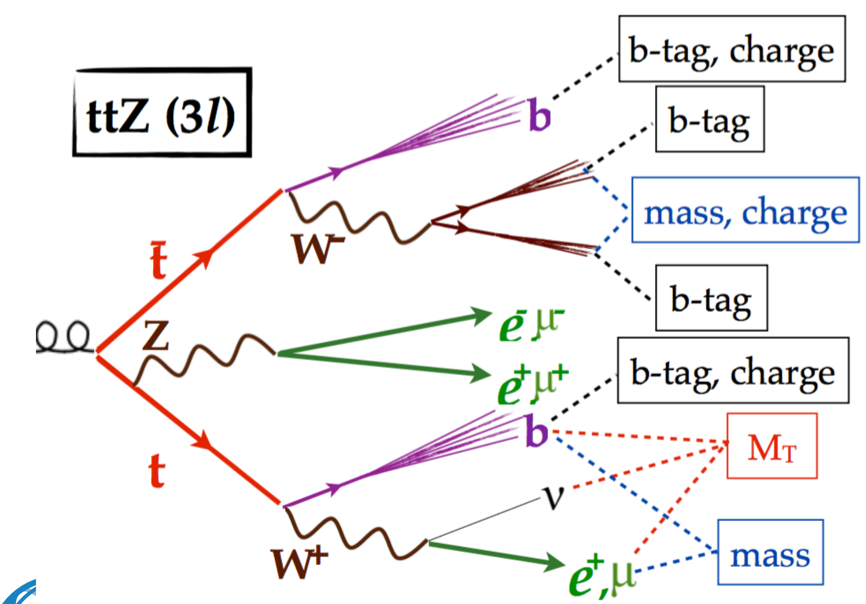
	1 b + 2 b (2ℓ-noZ)	2 b (2ℓ-Z)
3 j	normalisation	HT (jets)
4 j	NN	HT (jets)
≥ 5 j	NN	NN

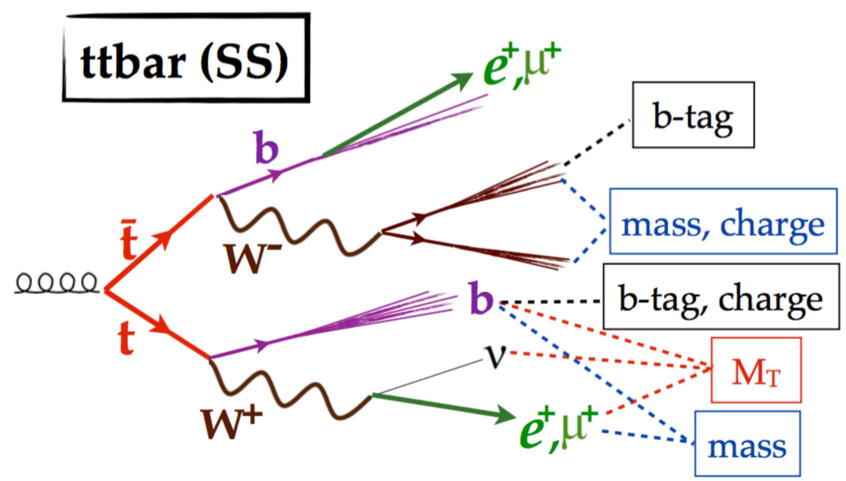
control region — **signal region**





- CMS: event reconstruction using Matching Linear Discriminant (MatchLD), as input to BDT (except 4ℓ)





- Leptons, jets, ETmiss from **$t\bar{t}$ decays** preserve information of parent particles
- Build variables from permutations

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Signal and background modelling

- **Signal**: modelled with Madgraph5+Pythia6
  - same tt̄Z NLO QCD calculation based on Powhel (arxiv 1208.2665)
    - **ATLAS** includes the off shell tt$\gamma^* \to \ell\ell$ production in the tt̄Z cross section = 215 fb
    - tt̄Z on shell = 206 fb
  - different tt̄W NLO QCD calculation:
    - **ATLAS** uses tt̄W sec = 232 fb, from MCFM (arxiv 1204.5678)
    - **CMS** uses sec = 203 fb from Powhel (arxiv 1208.2665)
    - Different scale choice: mt (MCFM) . vs . mt + mw/2 (Powhel)

- **Prompt background** (ℓ originating from W/Z decay): estimated with MC simulation
  - **CMS**: Madgraph5+Pythia6 for all processes, except tt̄H (Pythia)

ATLAS	Generator
Z+jets	Alpgen+Pythia6
tt̄, single top	PowHeg+Pythia6
WW, WZ, ZZ	Sherpa.1.4.1 (massive b/c)
tZq, WtZ(*), tt̄WW	Madgraph+Pythia6
tt̄H	PowHel+Pythia8

(*) WtZ not included in CMS

- Both ATLAS and CMS apply corrections on some of these background processes, e.g.: tt̄ (top pT)

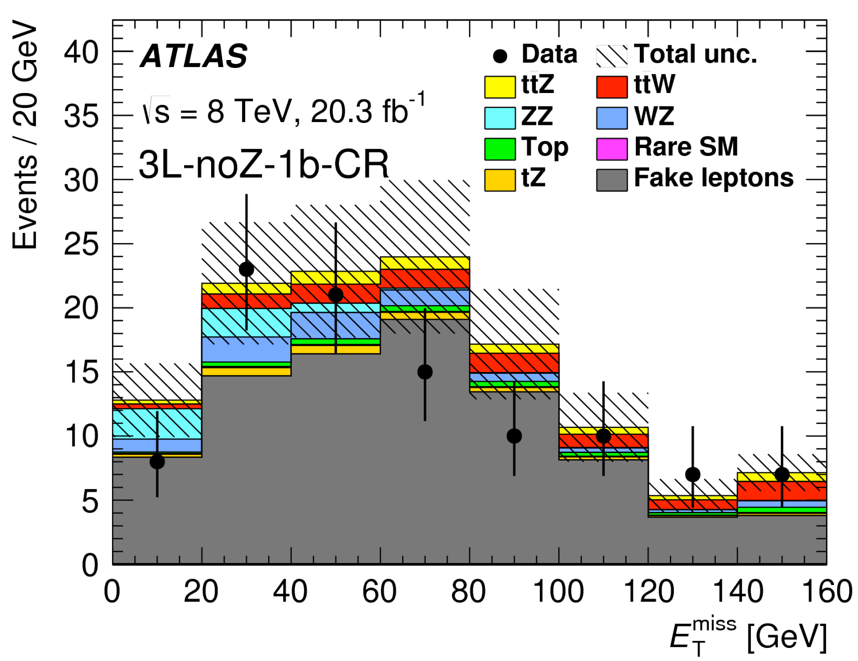
- CMS applies corrections to Z, WZ and ZZ + additional jets from data (ATLAS includes uncertainties)

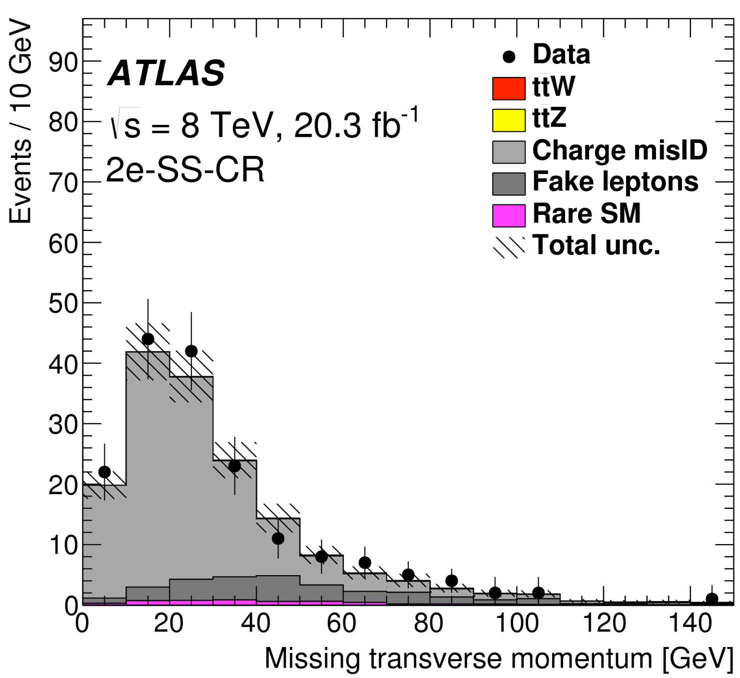
- Both apply uncertainty on extra heavy partons (Z+jets, WZ, ZZ)

Fakes and QMisID background processes

- **Non-prompt leptons**: semileptonic b-decay, jet fakes
  - main sources: $t\bar{t}$ in SS events, $t\bar{t}$ and Z in 3ℓ → estimated from data driven estimation
    - define control regions with looser lepton requirements
    - fake factors estimated from control/sideband regions as $f = N_{tight}/N_{loose}$, measured separately for e and μ, and binned in lepton pT
    - uncertainty ~ 40 (60) % for e (μ) in CMS and 20-25% in ATLAS
  - main sources: ($t\bar{t}$, Z, and WZ) in 4ℓ, and ($t\bar{t}$, W+jets and single top) in OS events → from MC simulation (+correction factor in 4ℓ)

- **Charge misidentification:** mostly affecting di-electron SS region
  - charge misID rates measured in data from control regions, parametrised in p_T and η (ATLAS) or only η of the electron (CMS)
  - weights from charge misID rates applied to OS data-driven background template
  - uncertainty 10-30%





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Cross section measurement

- Simultaneous binned profile likelihood fit

$$L(\mu,\theta) = L_{Pois}(\mu,\theta)\cdot\prod_p \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{\theta_p^2}{2}\right)$$

- **Parameters of interest**: signal strength $\mu_{t\bar{t}Z}$ and $\mu_{t\bar{t}W}$

$$\mu = \frac{\sigma_{t\bar{t}V}}{\sigma_{t\bar{t}V}^{SM}}$$

- **Systematic uncertainties** included in the fit as <u>nuisance parameters θ</u>
  - Need sufficiently flexible model of signal and background!
- **ATLAS**: Include CRs to constrain main background processes: tt̄, Z+jets, WZ, and ZZ
  - WZ and ZZ floating normalisation factors (μ_{WZ} and μ_{ZZ}) correlated across channels
- **CMS**: BDT helps separating background-like from signal-like regions → constrain of main background uncertainties

Systematic Uncertainties within each experiment

- **Correlate** jet/E_T^{miss}-related, lepton-related, b-tag calibration related NPs
- **Correlate** common background modelling NPs (tZ, tt̄H)
- **Correlate** signal modelling uncertainties
- Other background modelling uncertainties (QMisID, MisID/non-prompt, tt̄, Z+jets, WZ and ZZ shape uncertainties, and small background contributions) **uncorrelated** across channels

Results: signal strength and significance

CMS

individual measurements (1μ)

$t\bar{t}W$	Cross section (fb)		Signal strength (μ)		Significance (σ)	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
SS	203^{+88}_{-73}	414^{+135}_{-112}	$1.00^{+0.45}_{-0.36}$	$2.04^{+0.74}_{-0.61}$	3.4	4.9
3ℓ	203^{+215}_{-194}	210^{+225}_{-203}	$1.00^{+1.09}_{-0.96}$	$1.03^{+1.07}_{-0.99}$	1.0	1.0
SS + 3ℓ	203^{+84}_{-71}	382^{+117}_{-102}	$1.00^{+0.43}_{-0.35}$	$1.88^{+0.66}_{-0.56}$	3.5	4.8

$t\bar{t}Z$	Cross section (fb)		Signal strength (μ)		Significance (σ)	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
OS	206^{+142}_{-118}	257^{+158}_{-129}	$1.00^{+0.72}_{-0.57}$	$1.25^{+0.76}_{-0.62}$	1.8	2.1
3ℓ	206^{+79}_{-63}	257^{+85}_{-67}	$1.00^{+0.42}_{-0.32}$	$1.25^{+0.45}_{-0.36}$	4.6	5.1
4ℓ	206^{+153}_{-109}	228^{+150}_{-107}	$1.00^{+0.77}_{-0.53}$	$1.11^{+0.76}_{-0.52}$	2.7	3.4
OS + 3ℓ + 4ℓ	206^{+62}_{-52}	242^{+65}_{-55}	$1.00^{+0.34}_{-0.27}$	$1.18^{+0.35}_{-0.29}$	5.7	6.4

- **$t\bar{t}W$**: expected sensitivity comparable in ATLAS&CMS
- **$t\bar{t}Z$**: higher expected sensitivity in CMS
- slight excess in data in 2ℓSS channel ($t\bar{t}W$) in both ATLAS&CMS

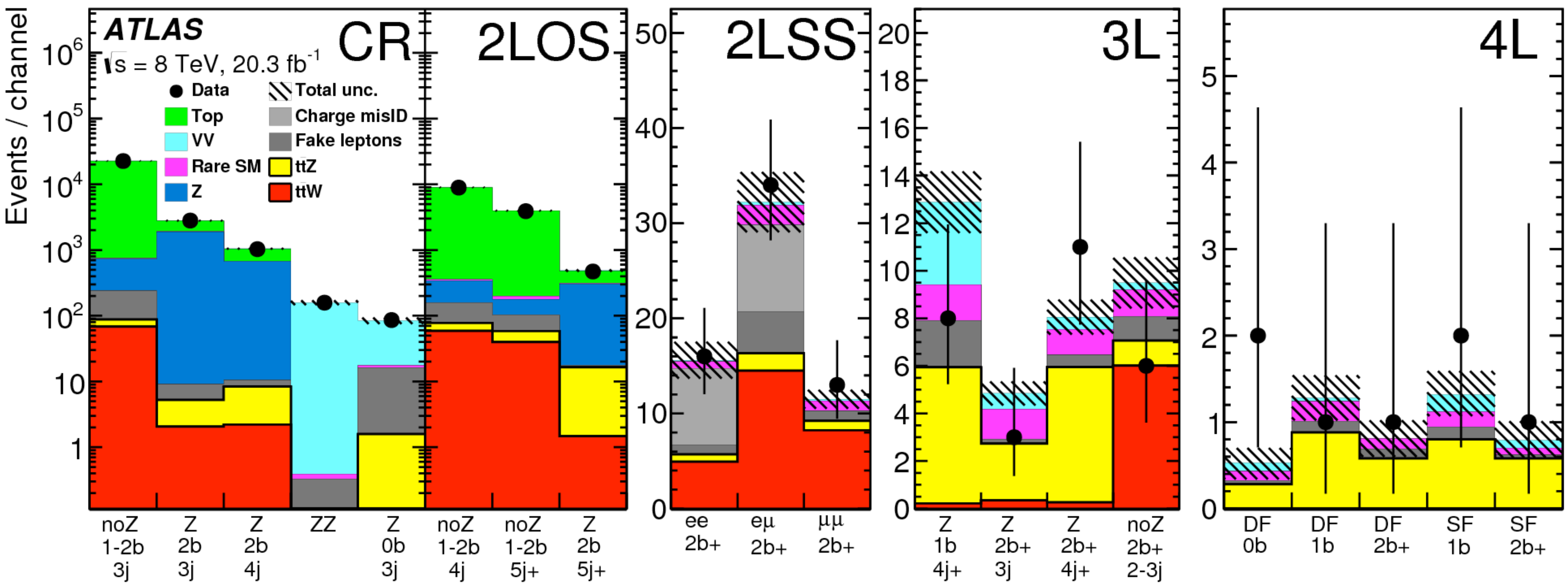
ATLAS

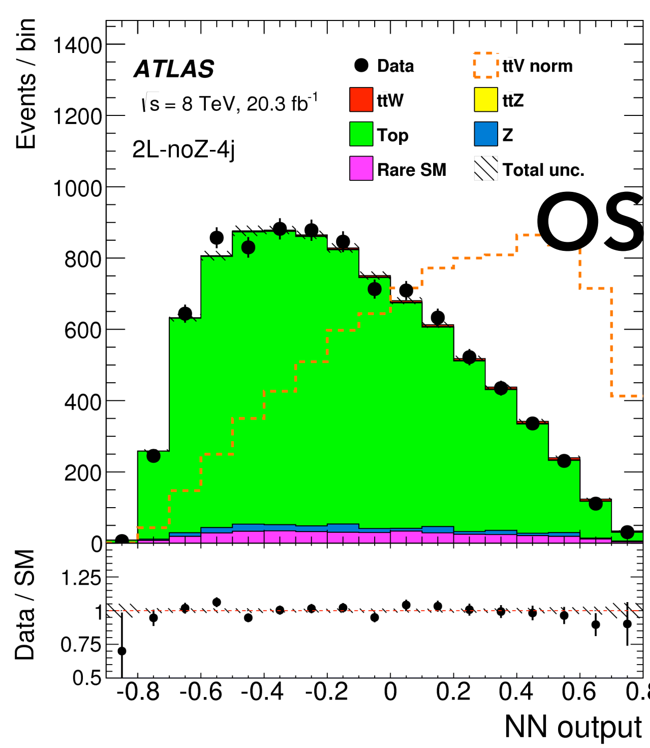
Channel	$t\bar{t}W$ significance		$t\bar{t}Z$ significance	
	Expected	Observed	Expected	Observed
2ℓOS	0.4	0.1	1.4	1.1
2ℓSS	2.8	5.0	-	-
3ℓ	1.4	1.0	3.7	3.3
4ℓ	-	-	2.0	2.4
Combined	3.2	5.0	4.5	4.2

individual measurements (1μ)

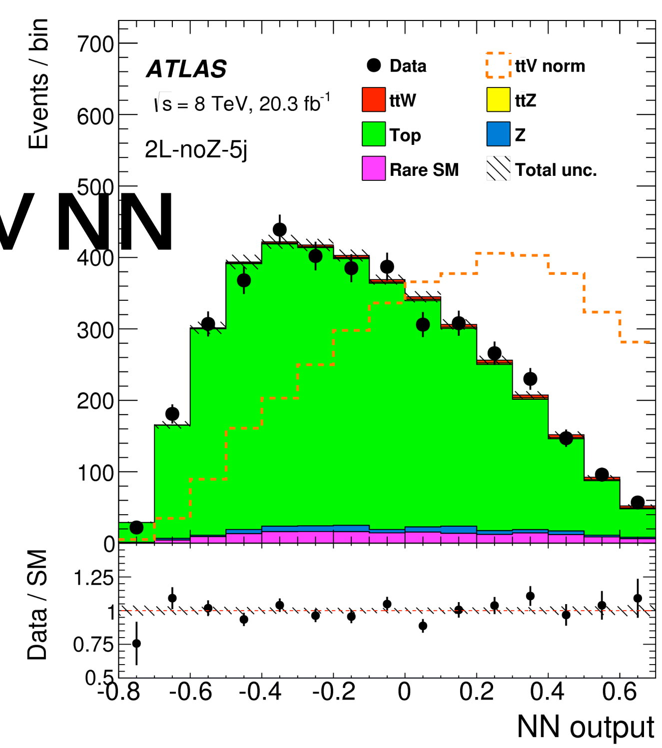
simultaneous measurement (2μ)

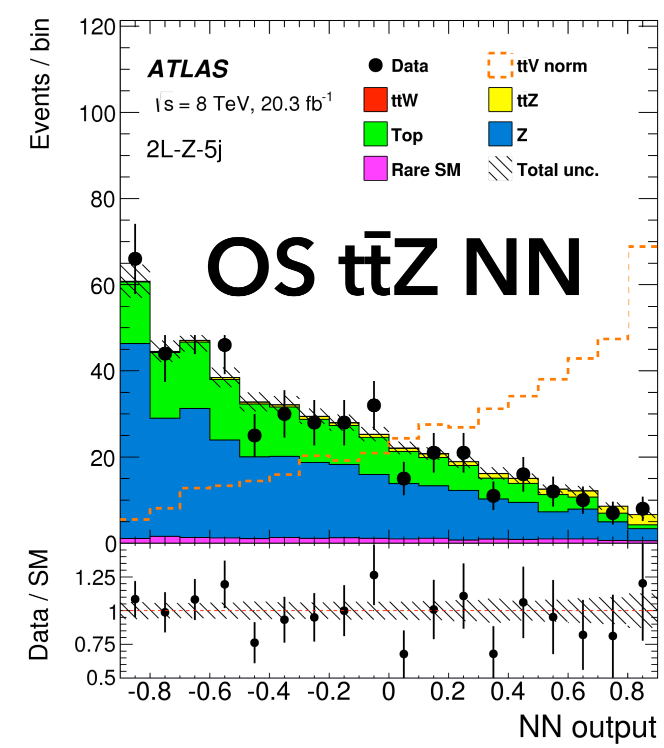
Post-fit yields and NN ATLAS





OS $t\bar{t}V$ NN

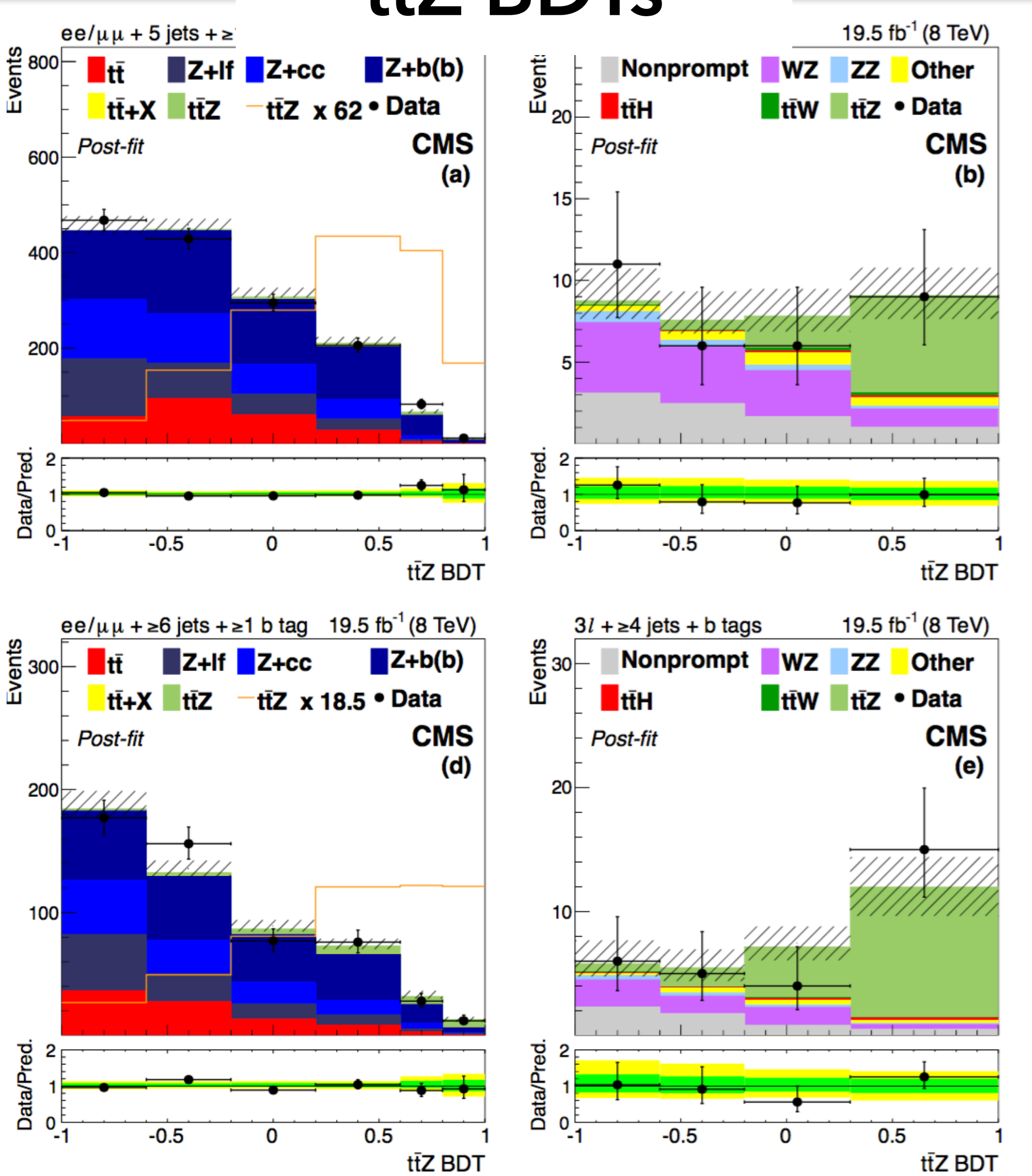




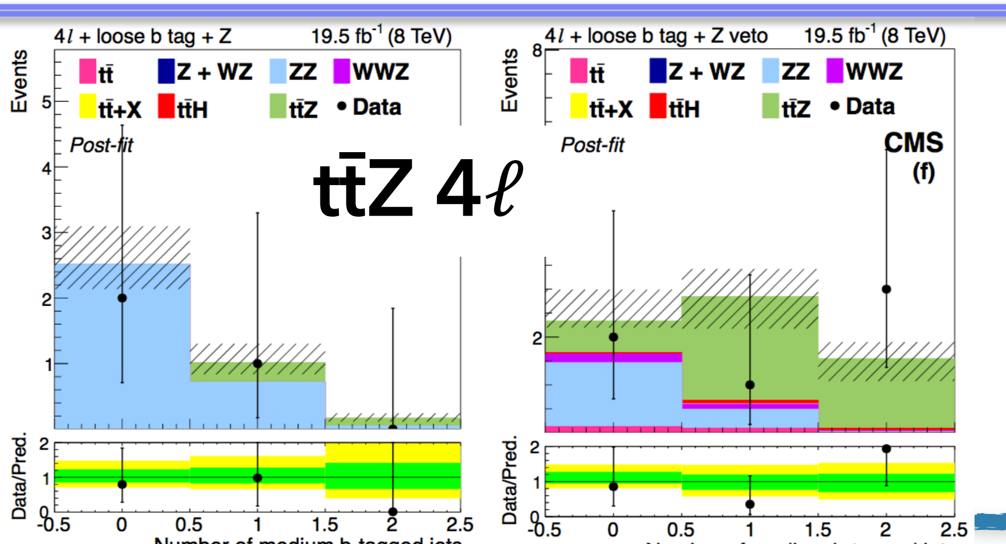
OS $t\bar{t}Z$ NN

Post-fit yields and BDTs CMS

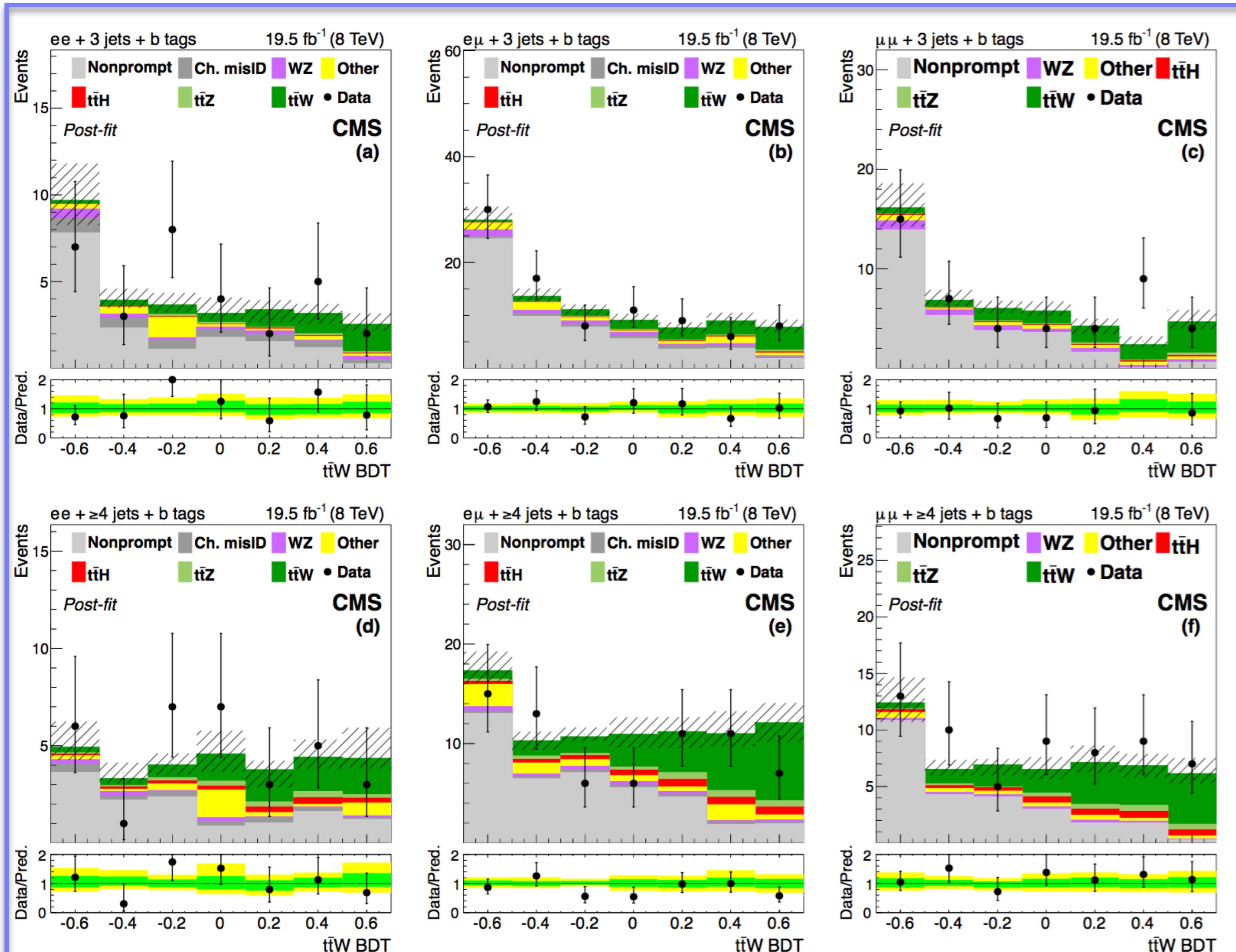
$t\bar{t}Z$ BDTs

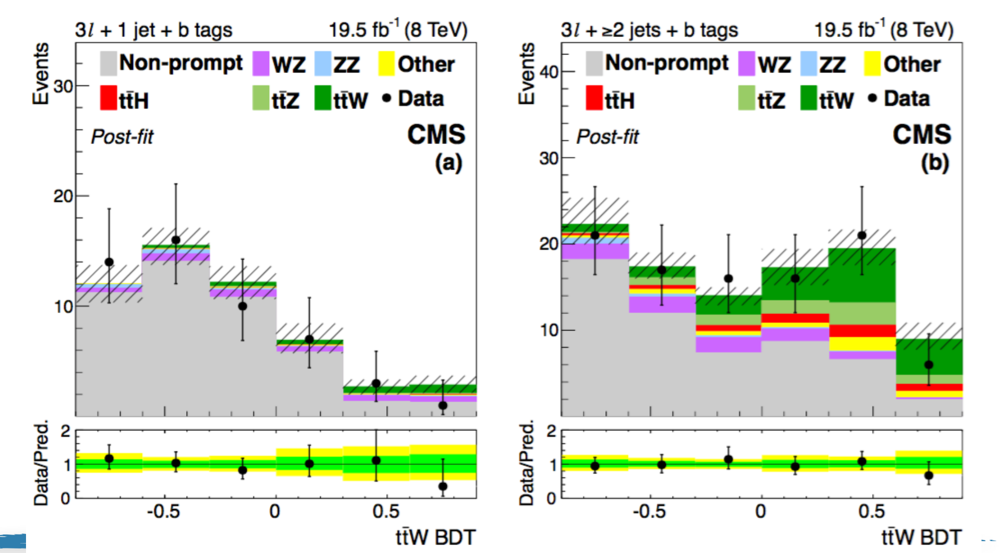


$t\bar{t}Z$ 4ℓ



$t\bar{t}W$ BDTs





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Results: impact systematic uncertainties

CMS

Systematic uncertainties removed	$t\bar{t}W$	$t\bar{t}Z$
Signal modeling	5.2%	7.1%
Nonprompt backgrounds	12.5%	0.5%
Inclusive prompt backgrounds	0.7%	2.6%
Prompt backgrounds with extra jets	0.2%	3.4%
Prompt backgrounds with extra heavy flavor jets	<0.1%	1.1%
b tagging efficiency	6.1%	7.3%
Jet energy scale	1.4%	<0.1%
Lepton ID and trigger efficiency	0.3%	0.5%
Integrated luminosity and pileup	0.7%	0.5%
Bin-by-bin statistical uncertainty in the prediction	4.4%	1.2%
All systematic uncertainties removed	31%	29%

ATLAS

Uncertainty	$\sigma_{t\bar{t}W}$	$\sigma_{t\bar{t}Z}$
Luminosity	3.2%	4.6%
Reconstructed objects	3.7%	7.4%
Backgrounds from simulation	5.8%	8.0%
Fake leptons and charge misID	7.5%	3.0%
Signal modelling	1.8%	4.5%
Total systematic	12%	13%
Statistical	+24% / −21%	+30% / −27%
Total	+27% / −24%	+33% / −29%

- Repeat $t\bar{t}Z$ and $t\bar{t}W$ fit (individually) fixing the corresponding set of nuisance parameters to 0 (expected in CMS, observed in ATLAS)
- CMS (Δi-Δj), ATLAS (subtract in quadrature)
  - similar stat and syst contribution to total uncertainty in CMS, stat dominating in ATLAS
- ATLAS 'Statistical' includes bin-by-bin MC statistical uncertainty
- Dominant systematic uncertainties:
  - **$t\bar{t}W$**: non-prompt ℓ (QmisID) background (ATLAS&CMS), b-tagging efficiency and signal modelling (CMS), background from simulation (ATLAS)
  - **$t\bar{t}Z$**: modelling background from simulation (ATLAS), b-tagging efficiency (CMS) and signal modelling (ATLAS&CMS)

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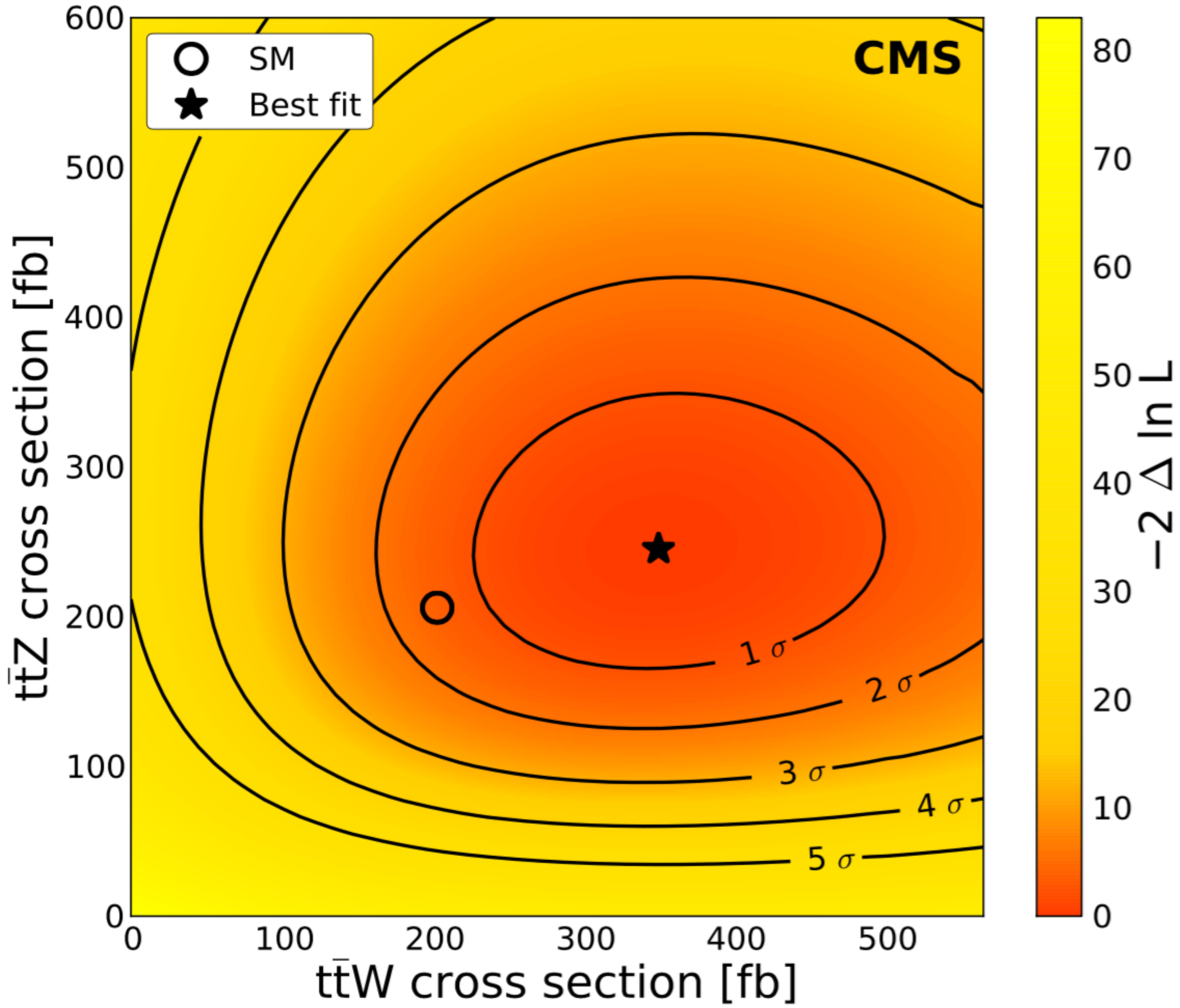
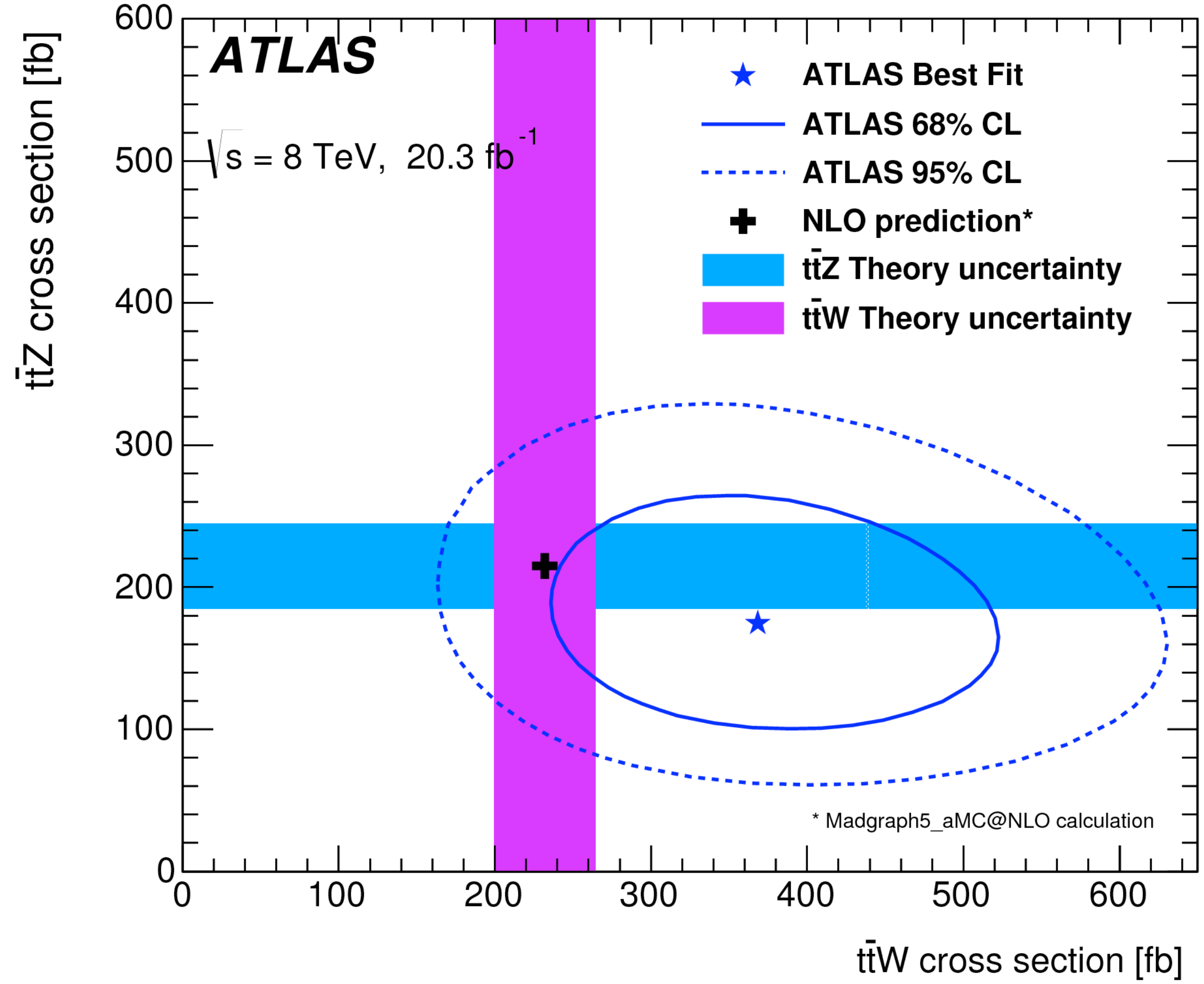
Simultaneous fit $t\bar{t}Z$ and $t\bar{t}W$





$$\sigma_{t\bar{t}W} = 350^{+150}_{-123}\ \text{fb}$$

$$\sigma_{t\bar{t}Z} = 245^{+104}_{-80}\ \text{fb}$$

$$\sigma_{t\bar{t}W} = 369^{+86}_{-79}\,(\text{stat.}) \pm 44\,(\text{syst.})\ \text{fb} = 369^{+100}_{-91}\ \text{fb}$$

$$\sigma_{t\bar{t}Z} = 176^{+52}_{-48}\,(\text{stat.}) \pm 24\,(\text{syst.})\ \text{fb} = 176^{+58}_{-52}\ \text{fb}.$$

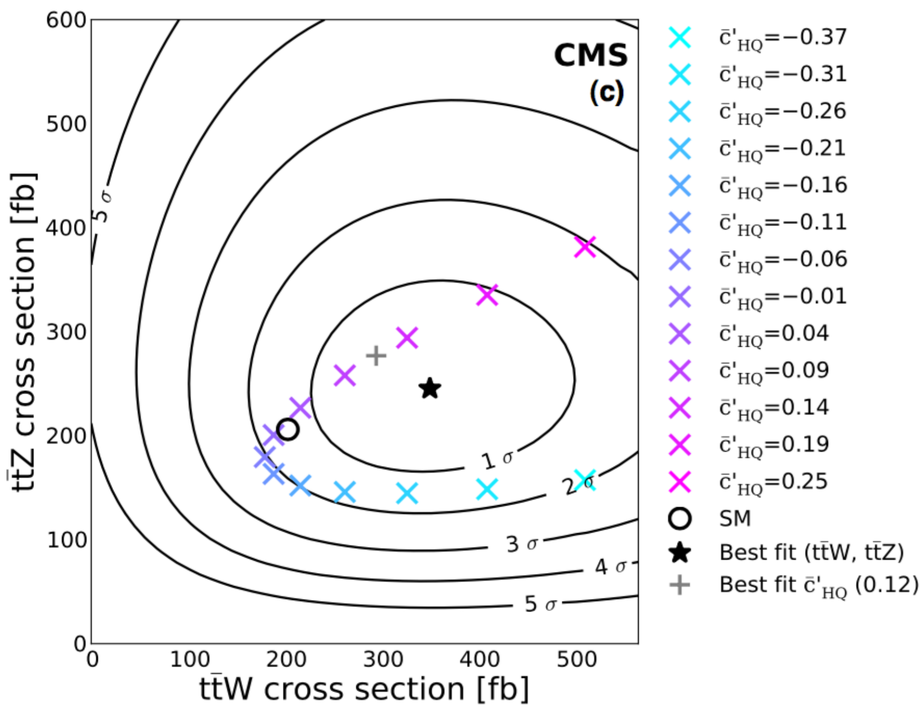
Extended interpretation (CMS)

Constraints on dimension six operators

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda}\mathcal{L}_1 + \frac{1}{\Lambda^2}\mathcal{L}_2 + \cdots$$
$$= \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda}\sum_i (c_i\mathcal{O}_i + \text{h.c.}) + \frac{1}{\Lambda^2}\sum_j (c_j\mathcal{O}_j + \text{h.c.}) + \cdots,$$

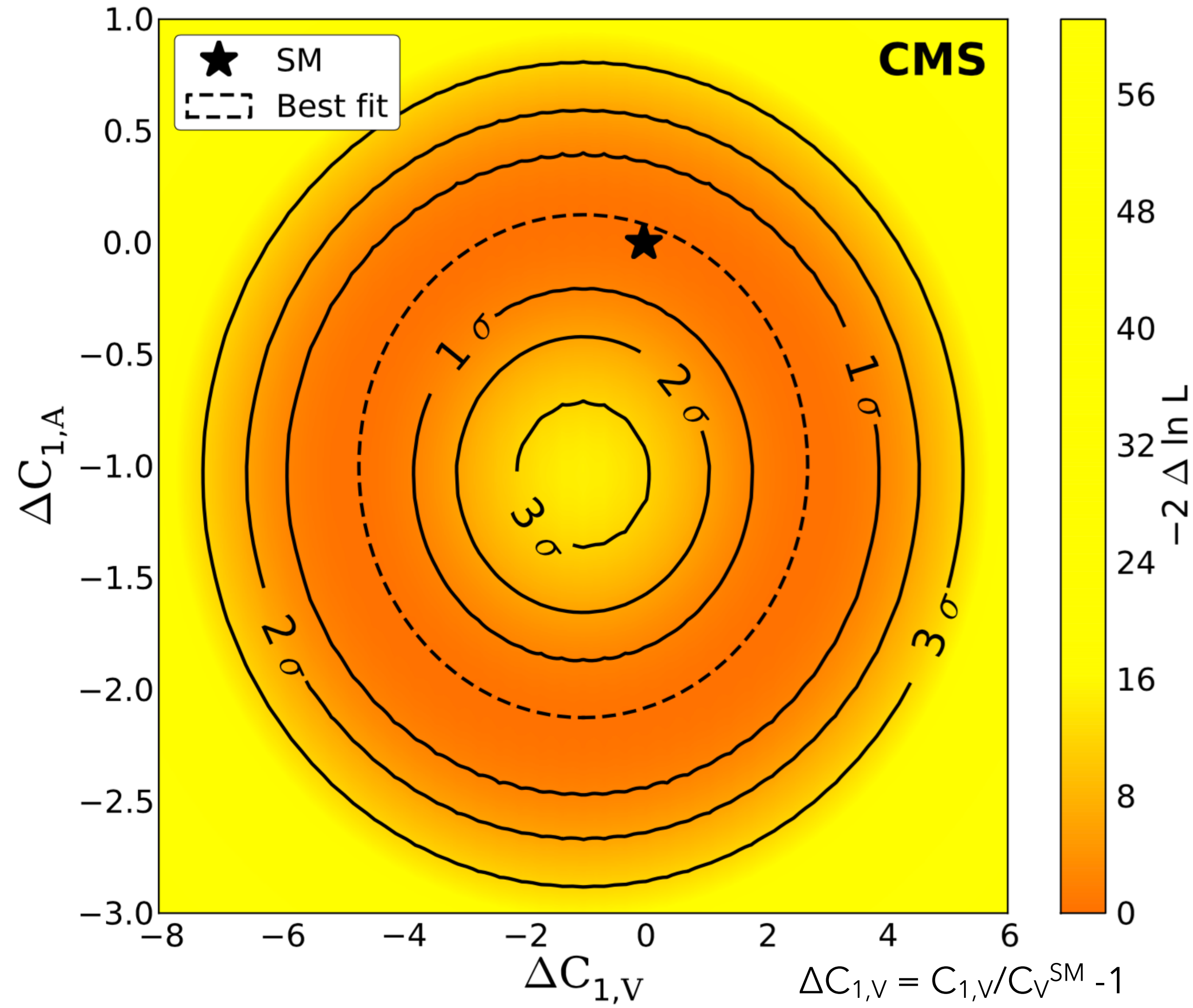
CMS $t\bar{t}Z$ and $t\bar{t}W$ cross section measurements place the best direct constraints certain dimension six operators to date

Operator	Best fit point(s)	1 standard deviation CL	2 standard deviation CL
$\bar{c}_{uB}$	−0.07 and 0.07	[−0.11, 0.11]	[−0.14, 0.14]
$\bar{c}_{3W}$	−0.28 and 0.28	[−0.36, −0.18] and [0.18, 0.36]	[−0.43, 0.43]
$\bar{c}'_{HQ}$	0.12	[−0.07, 0.18]	[−0.33, −0.24] and [−0.02, 0.23]
$\bar{c}_{Hu}$	−0.47 and 0.13	[−0.60, −0.23] and [−0.11, 0.26]	[−0.71, 0.37]
$\bar{c}_{HQ}$	−0.09 and 0.41	[−0.22, 0.08] and [0.24, 0.54]	[−0.31, 0.63]



Constraints on the axial and vector components of the tZ coupling

Interpret $t\bar{t}Z$ cross section measurement in terms of limits on $C_{1,V}$ and $C_{1,A}$



$\Delta C_{1,V} = C_{1,V}/C_V^{SM} - 1$

$$C_{1,V} = C_V^{\text{SM}} + \frac{1}{4\sin\theta_w\cos\theta_w}\frac{v^2}{\Lambda^2}\text{Re}[\bar{c}'_{HQ} - \bar{c}_{HQ} - \bar{c}_{Hu}],$$
$$C_{1,A} = C_A^{\text{SM}} - \frac{1}{4\sin\theta_w\cos\theta_w}\frac{v^2}{\Lambda^2}\text{Re}[\bar{c}'_{HQ} - \bar{c}_{HQ} + \bar{c}_{Hu}].$$

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Run1 $t\bar{t}V$ Combination

- Work ongoing towards **Run1 legacy $t\bar{t}V$ ATLAS+CMS combination**
  - Option to interpret results in terms of anomalous couplings (as done by CMS)
  - Contacts: Markus and Andrew
- One common fitting technique: **profile likelihood fit**
  - The **RooFit** toolkit extends the ROOT analysis environment by providing a language to describe data models
  - Fitting tools based on **RooStat** (project to provide advanced statistical techniques for the LHC collaborations, built on top of *RooFit*)
- One common data model format: **workspace**
  - Save data and an arbitrarily complicated model in a ROOT file (using *RooWorkspace* class)
  - Inputs to the fit
  - Allows the combination of $t\bar{t}V$ channels
- Previous experience from LHC Higgs Run1 coupling combination
  - similar setups, $t\bar{t}V$ NLO QCD cross section discussion

Run1 $t\bar{t}V$ Combination: status

Status:

- [x] Workspaces exchanged and tested by each experiment (since Oct 6th)
- [x] Decide correlation scheme (preliminary):
    - (Part of) luminosity, as in other cross-section combinations
    - Signal modelling (need to map variations)
    - Background modelling: $t\bar{t}H$ normalisation
        - Other backgrounds not clear (different phase space cuts)
- [ ] Study effect of correlation . vs . uncorrelation for the dominant systematics in case of doubt
- [ ] Need to agree on $t\bar{t}W$ NLO QCD calculation:
    - does not change the result, just different signal strength (not quoted in ATLAS)
- [ ] Run fit with both fitting frameworks, as a cross-check
- [ ] Combine each channel separately and run per-channel fits
- [ ] Interpret result in terms of anomalous couplings

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Conclusions

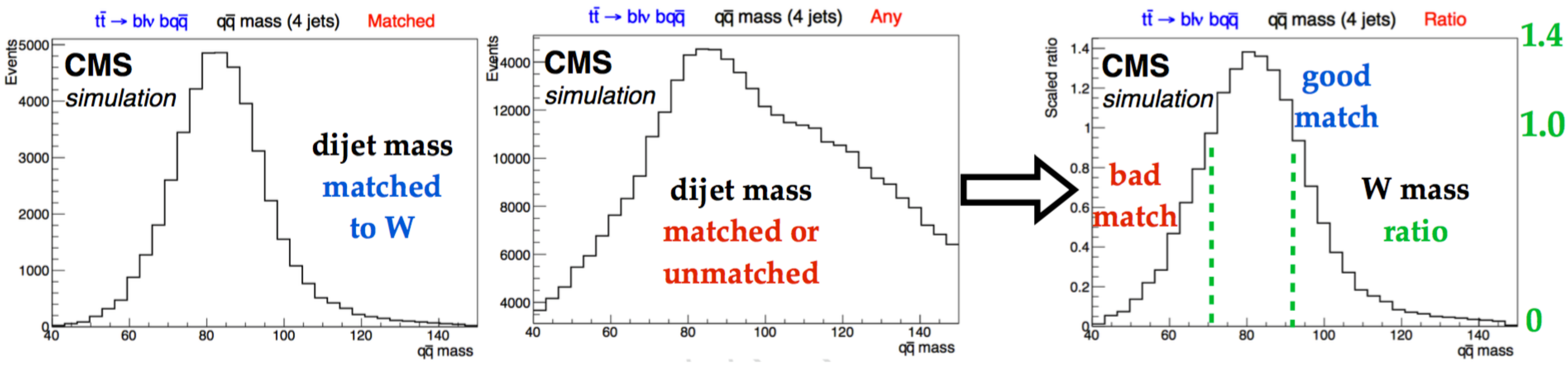
* Both ATLAS and CMS exploited the full Run1 dataset to perform competitive $t\bar{t}Z$ and $t\bar{t}W$ cross section measurements: new channels, new techniques, background modelling studies, etc.
  - **Observation** of both $t\bar{t}Z$ and $t\bar{t}W$ processes with ~20 fb^{-1} at 8 TeV (in one or the other experiment)

* Run1 ATLAS+CMS **combination** ongoing: already performing combination tests with individual channels with each combination+fitting framework

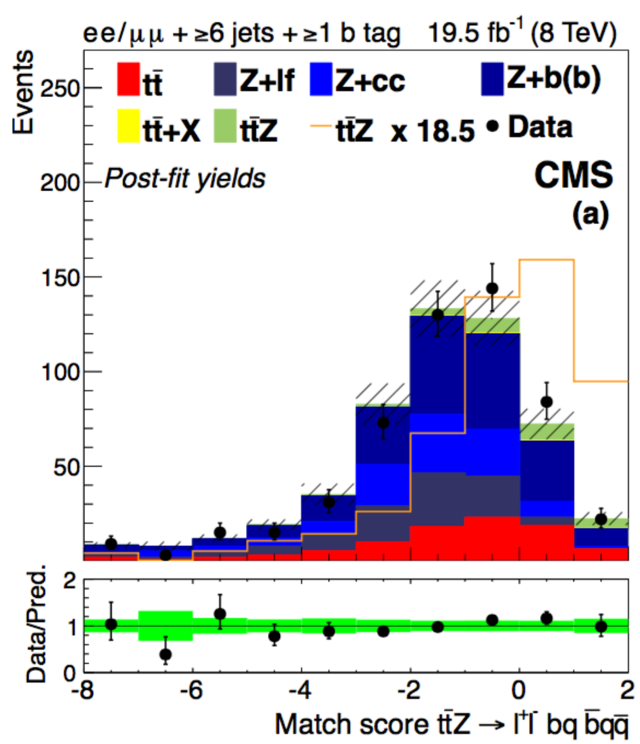
Additional material

Event reconstruction and BDT in CMS

- For each input variable to the discriminant, get ratio of value for the correct jet(s) to value for any jet(s)

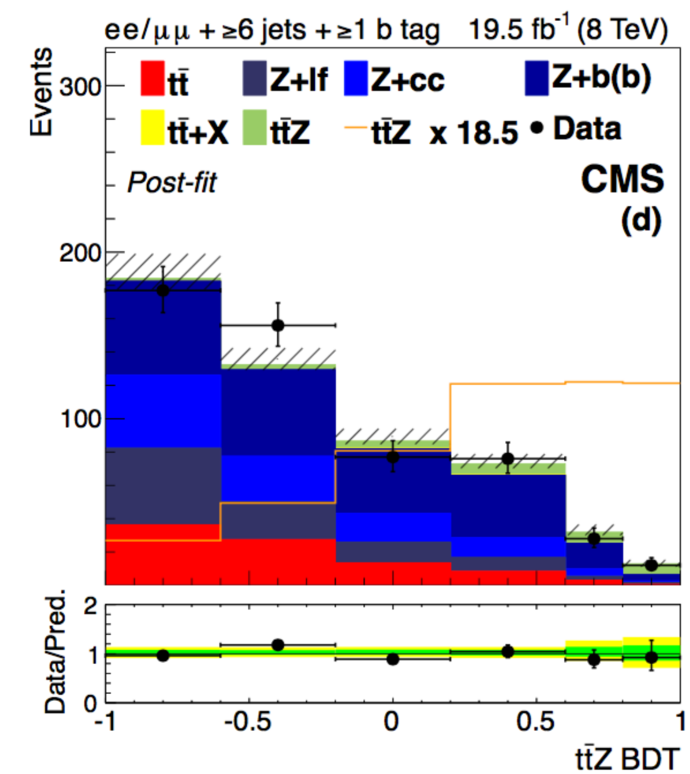


- Matching linear discriminant = product of each bin values from all the ratio histograms
- Permutation with the highest discriminant value = best reconstruction of the tt̄ system
- Reconstruction efficiencies: **75%** for events with 4j, **40%** for events with ≥5j



Match scores + event reconstruction variables + kinematic variables (lepton pT, jet CSV values,…)

input to train Boosted Decision Trees (BDTs) in each signal region



Lepton ID in CMS

Table 1: Summary of preselected, loose, tight, and charge ID lepton selection requirements.

Lepton selection criteria	Preselected		Loose		Tight		Charge ID	
Lepton flavor	e	μ	e	μ	e	μ	e	μ
p_T (GeV)	>10	>10	>10	>10	>10	>10		
$\|\eta\|$	<2.5	<2.4	<2.5	<2.4	<2.5	<2.4		
Relative isolation	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4		
Charged relative isolation			<0.15	<0.20	<0.05	<0.15		
Ratio of lepton p_T to jet p_T					>0.6	>0.6		
x-y distance to vertex (mm)	<5	<5	<5	<5	<5	<5		
z distance to vertex (mm)	<10	<10	<10	<10	<10	<10		
$\|IP\|$ (mm)					<0.15			
S_{IP}	<10	<10	<10	<4	<10	<4		
Inner tracker hits								>5
Missing inner tracker hits	<2		<2		<2		0	
Tracker charge − ECAL charge							0	
Electron conversion veto							Pass	

Event Yields CMS (after the fit)

OS $t\bar{t}Z$	$e^{\pm}e^{\mp}/\mu^{\pm}\mu^{\mp}$		$e^{\pm}\mu^{\mp}$	
Process	5 jets	≥6 jets	5 jets	≥6 jets
Z+lf jets	265 ± 57	93 ± 20	<0.1	<0.1
Z+$c\bar{c}$ jets	341 ± 74	106 ± 23	<0.1	<0.1
Z+b jet	236 ± 59	68 ± 18	<0.1	<0.1
Z+$b\bar{b}$ jets	378 ± 72	136 ± 25	<0.1	<0.1
$t\bar{t}$+lf jets	188 ± 19	58.4 ± 7.3	180 ± 16	57.8 ± 6.4
$t\bar{t}$+hf jets	57 ± 16	30.6 ± 8.3	52 ± 15	27.3 ± 7.3
tbZ/$t\bar{t}$WW	4.2 ± 1.8	1.8 ± 0.7	<0.1	<0.1
$t\bar{t}$H	1.4 ± 0.1	1.0 ± 0.2	1.0 ± 0.1	0.6 ± 0.1
Background	1470 ± 135	494 ± 45	233 ± 21	85.8 ± 9.7
$t\bar{t}$Z	24.0 ± 5.5	28.2 ± 6.8	1.3 ± 0.3	0.8 ± 0.2
$t\bar{t}$W	1.1 ± 0.2	0.5 ± 0.1	1.2 ± 0.2	0.8 ± 0.2
Expected	1495 ± 135	523 ± 45	236 ± 21	87.4 ± 9.7
Data	1493	526	251	78

SS $t\bar{t}$W	$e^{\pm}e^{\pm}$		$e^{\pm}\mu^{\pm}$		$\mu^{\pm}\mu^{\pm}$	
Process	3 jets	≥4 jets	3 jets	≥4 jets	3 jets	≥4 jets
Nonprompt	16.0 ± 3.7	12.9 ± 3.1	57.0 ± 5.4	40.5 ± 4.2	29.0 ± 4.7	26.0 ± 4.4
Charge-misidentified	3.3 ± 1.6	1.7 ± 0.8	2.9 ± 0.7	1.6 ± 0.4	—	—
WZ	1.6 ± 0.5	0.9 ± 0.3	4.5 ± 1.4	2.2 ± 0.8	3.1 ± 1.0	1.3 ± 0.5
ZZ	0.2 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.1
Multiboson	0.8 ± 0.3	0.5 ± 0.2	1.5 ± 0.5	1.2 ± 0.4	1.2 ± 0.5	1.1 ± 0.4
tbZ/$t\bar{t}$+X	1.4 ± 0.4	2.5 ± 1.3	4.1 ± 1.4	5.8 ± 2.2	0.9 ± 0.3	1.2 ± 0.4
$t\bar{t}$H	0.3 ± 0.1	1.4 ± 0.2	1.1 ± 0.1	4.0 ± 0.5	0.7 ± 0.1	3.0 ± 0.5
Background	23.7 ± 4.1	20.1 ± 3.5	71.4 ± 5.8	55.4 ± 4.9	35.1 ± 4.8	32.8 ± 4.5
$t\bar{t}$W	5.5 ± 1.4	8.1 ± 1.9	13.9 ± 3.7	25.2 ± 5.5	10.4 ± 2.8	17.7 ± 4.0
$t\bar{t}$Z	0.4 ± 0.1	1.3 ± 0.3	1.1 ± 0.2	3.0 ± 0.6	0.7 ± 0.1	2.1 ± 0.4
Expected	29.6 ± 4.4	29.4 ± 4.0	86.4 ± 6.9	83.6 ± 7.3	46.2 ± 5.6	52.6 ± 6.0
Data	31	32	89	69	47	61

	3ℓ $t\bar{t}$W		3ℓ $t\bar{t}$Z		4ℓ $t\bar{t}$Z	
Process	1 jet	≥2 jets	3 jets	≥4 jets	≥1 jet+Z	≥1 jet+Z-veto
Nonprompt	44.6 ± 5.3	54.8 ± 6.4	8.2 ± 2.8	5.4 ± 2.1	—	—
Nonprompt WZ/Z	—	—	—	—	<0.1	<0.1
Nonprompt $t\bar{t}$	—	—	—	—	<0.1	0.2 ± 0.2
WZ	3.2 ± 0.8	8.0 ± 1.7	11.7 ± 2.9	5.4 ± 1.6	—	—
ZZ	1.0 ± 0.2	1.5 ± 0.3	1.6 ± 0.4	0.9 ± 0.3	3.3 ± 0.5	1.8 ± 0.3
Multiboson	0.1 ± 0.1	0.4 ± 0.2	0.5 ± 0.2	0.5 ± 0.2	<0.1	0.3 ± 0.1
tbZ/$t\bar{t}$+X	0.4 ± 0.1	3.8 ± 1.1	1.6 ± 0.6	0.7 ± 0.3	<0.1	<0.1
$t\bar{t}$H	0.2 ± 0.1	4.7 ± 0.4	0.3 ± 0.1	0.4 ± 0.1	<0.1	0.2 ± 0.1
Background	49.5 ± 5.4	73.1 ± 6.7	23.9 ± 4.1	13.3 ± 2.7	3.3 ± 0.5	2.4 ± 0.4
$t\bar{t}$W	2.5 ± 0.8	18.8 ± 4.7	0.5 ± 0.1	0.2 ± 0.1	—	—
$t\bar{t}$Z	0.3 ± 0.1	7.5 ± 1.2	8.8 ± 1.9	16.9 ± 3.6	0.4 ± 0.1	4.3 ± 1.0
Expected	52.3 ± 5.4	99.4 ± 8.3	33.2 ± 4.5	30.4 ± 4.5	3.7 ± 0.5	6.7 ± 1.1
Data	51	97	32	30	3	6

Event Yields ATLAS (before the fit)

Region	$t + X$	Bosons	Fake leptons charge misID	Total expected background	$t\bar{t}W$	$t\bar{t}Z$	Data
2ℓ-noZ-3j*	20800 ± 2600	600 ± 200	160 ± 80	21600 ± 2700	42.0 ± 2.8	23.2 ± 1.5	22585
2ℓ-noZ-4j	8200 ± 1400	240 ± 90	80 ± 40	8600 ± 1400	36.6 ± 1.8	22.4 ± 1.1	8909
2ℓ-noZ-5j	3700 ± 850	100 ± 40	47 ± 23	3810 ± 870	24.9 ± 2.2	22.4 ± 2.0	3901
2ℓ-Z-3j*	800 ± 140	1960 ± 880	4.1 ± 2.1	2760 ± 890	1.24 ± 0.13	3.71 ± 0.38	2806
2ℓ-Z-4j*	330 ± 70	740 ± 390	2.2 ± 1.1	1100 ± 400	1.31 ± 0.11	7.21 ± 0.58	1031
2ℓ-Z-5j	170 ± 40	340 ± 200	1.4 ± 0.7	510 ± 210	0.89 ± 0.07	17.7 ± 1.4	471
$2e$-SS	0.66 ± 0.13	0.17 ± 0.10	8.9 ± 2.4	9.8 ± 2.6	2.97 ± 0.30	0.93 ± 0.23	16
$e\mu$-SS	1.9 ± 0.35	0.39 ± 0.28	14.1 ± 4.5	16.4 ± 5.1	8.67 ± 0.76	2.16 ± 0.51	34
2μ-SS	0.94 ± 0.17	0.25 ± 0.14	0.93 ± 0.55	2.12 ± 0.86	4.79 ± 0.40	1.12 ± 0.27	13
3ℓ-Z-0b3j*	1.11 ± 0.32	67 ± 16	15.2 ± 6.0	83 ± 15	0.05 ± 0.03	1.86 ± 0.47	86
3ℓ-Z-1b4j	1.58 ± 0.42	3.8 ± 1.3	2.4 ± 1.1	7.8 ± 1.6	0.14 ± 0.05	7.1 ± 1.6	8
3ℓ-Z-2b3j	1.29 ± 0.34	0.68 ± 0.33	0.19 ± 0.13	2.16 ± 0.42	0.21 ± 0.07	2.76 ± 0.69	3
3ℓ-Z-2b4j	1.00 ± 0.29	0.48 ± 0.24	0.42 ± 0.37	1.93 ± 0.49	0.14 ± 0.07	6.6 ± 1.6	11
3ℓ-noZ-2b	1.06 ± 0.25	0.27 ± 0.17	1.31 ± 0.90	2.7 ± 0.9	3.7 ± 0.9	1.23 ± 0.32	6
4ℓ-DF-0b	0.06 ± 0.01	0.11 ± 0.04	0.03 ± 0.17	0.21 ± 0.22	-	0.28 ± 0.01	2
4ℓ-DF-1b	0.22 ± 0.03	0.05 ± 0.03	0.13 ± 0.22	0.39 ± 0.27	-	1.05 ± 0.03	1
4ℓ-DF-2b	0.11 ± 0.02	<0.01	0.11 ± 0.19	0.22 ± 0.21	-	0.64 ± 0.02	1
4ℓ-ZZ*	0.01 ± 0.00	134.2 ± 1.2	0.27 ± 0.18	134.5 ± 1.3	-	0.07 ± 0.01	158
4ℓ-SF-1b	0.16 ± 0.02	0.29 ± 0.06	0.14 ± 0.19	0.61 ± 0.27	-	0.91 ± 0.02	2
4ℓ-SF-2b	0.08 ± 0.01	0.09 ± 0.03	0.04 ± 0.18	0.21 ± 0.23	-	0.64 ± 0.02	1

- Reminder:
  - ATLAS uses tt̄W sec = 231 fb, from MCFM (arxiv 1204.5678)
  - CMS uses sec = 203 fb from Powhel (arxiv 1208.2665)
- Started discussion with LHC Higgs XS WG convenors
- Different scale choice: mt (MCFM) . vs . mt + mw/2 (Powhel)
  - Both in the region where the NLO cross section mildly depends on the scale ("plateu region")
- Powhel uses parton shower NLO Monte Carlo, while MCFM is a fixed-order NLO Calculator (total cross section can still differ)
- **Final recommendation:** best choice for tt̄W would be Powhel (mt+mw/2) - it is in the region of least dependence and it is in line with other choices made for tt̄V
- ATLAS could change to Powhel tt̄W xsec, with x2/0.5 scale uncertainty.