Semileptonic WW/WZ decay in proton-proton collisions @7 TeV: cross section and anomaluos Triple Gauge Couplings measurements

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12 Aprile 2013

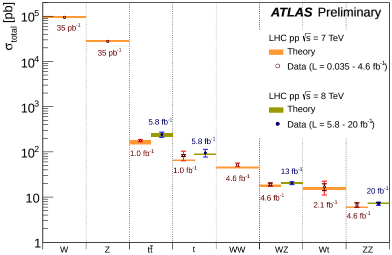
Cross section status

- diboson Physics at LHC
- semileptonic final state
- results with 2011 data
- systematics
- ongoing studies and improvements

Diboson Physics at LHC (I)

Studying diboson Physics at LHC is interesting in general:

- test electroweak couplings
- probe weak boson self-interactions
- background to new Physics searches
- diboson studies in ATLAS:



Investigated channels up to now:

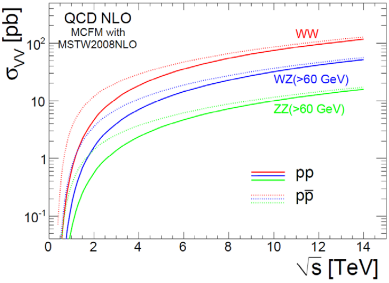
- $WW \rightarrow l\nu l\nu$
- $WZ \rightarrow l\nu ll$
- $ZZ \rightarrow ll\nu\nu$
- $ZZ \rightarrow llll$

- semileptonic final states: $WW/WZ \longrightarrow l\nu jj$ with $l = e,\ \mu$
- demonstrate that ATLAS can reconstruct low-p_T dijet resonances
- also interested in checking the CDF bump in the same channel

Diboson Physics at LHC (II)

Production rate estimates (all channels):

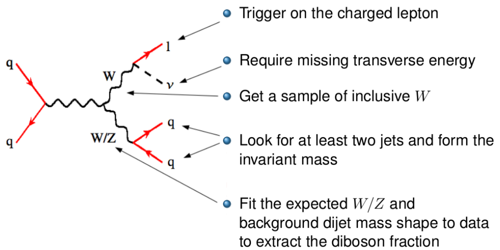
- diboson production rates at LHC are 3-5 larger than at Tevatron
- multijet and W + jets backgrounds are $\sim$ 10 time larger at LHC than at Tevatron
- more difficult at the LHC than at the Tevatron:
  - larger background rates
  - smaller S/B and $S/\sqrt{B}$
  - higher pile-up



SM production Xsec	Tevatron (1.96 TeV)	LHC (7 TeV)
WW	11.7 pb	47.04 pb
WZ	3.5 pb	18.57 pb

- semileptonic channel:
  - W+jets is dominant
  - $S/B < 1\%$ to begin with

Semileptonic final state



leptonic W

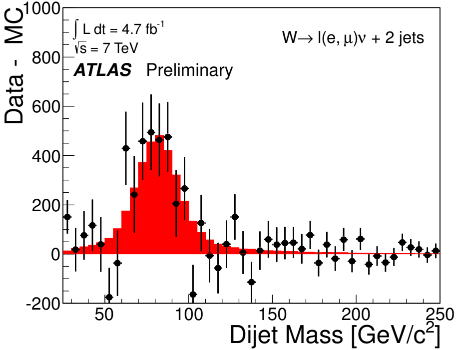
hadronic W/Z

The presence of two jets in the final state rises different problems with respect to purely leptonic final states:

- with low-p_T jets, large JES uncertainties
- main backgrounds:
  - W+jets (dominant)
  - $t\bar{t}$ and single-top
  - multijet
- analysis splitted in:
  - Preselection: common selection, cleaning cuts
  - Control Regions: check MC/data agreement
  - Selection: extraction of signal from the dijet mass spectrum

Results and current status

- measured diboson σ_{prod} at $\sqrt{s} = 7$ TeV using 2011 data ($\sim 4.7\ \mathrm{fb}^{-1}$):
  $\sigma(\mathrm{WW} + \mathrm{WZ}) = 72 \pm 9(\mathrm{stat.}) \pm 15(\mathrm{syst.}) \pm 13(\mathrm{MC\ stat.})$ pb
- Standard Model prediction at : $\sqrt{s} = 7$ TeV: 63.4 ± 2.6 pb
- boson mass compatible with the W/Z mass



Systematics

Source	$\Delta\sigma/\sigma\%$
Data Statistics	±12
MC Statistics	±18
W/Z+jets normalization	±11
W/Z jets shape variation	±5
Multijet shape and normalization	±5
Top normalization	±6
Top ISR/FSR	±1
Jet energy scale (all samples)	±12
Jet energy resolution (all samples)	±6
Lepton reconstruction (all samples)	±1
WW/WZ ISR/FSR	±2
JES uncertainty on WW/WZ normalization	±6
PDF (all samples)	±2
Luminosity	±3.9
Total systematics	±28

Note and further studies

Draft version 1.1

ATLAS NOTE

November 4, 2012

Evidence of the di-boson WW+WZ production in $\sqrt{s} = 7$ TeV proton-proton collisions with the ATLAS detector in the semileptonic decay channel

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The note is public, and has been already presented at conferences.
Editors: Chiara Roda, Dmitri Tsybychev, Viviana Cavaliere.
After interactions with the Editorial Board, we decided to improve the results focusing on four major points:

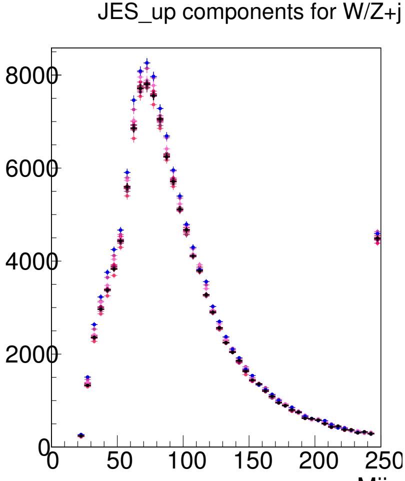
- bin-by-bin uncertainty
- JES uncertainty
- jet veto at 25 GeV instead of 20 GeV
- adding an aTGC limit study (more on this later)

bin-by-bin

- bin-by-bin error is related to finite statistics in MC
- AFII extended W+jets samples have been requested
- samples validated
- assuming all other systematics are unchanged, with new statistics the b-b-b error should drop from 18 % to 11 %; total systematics around 24 %; total systematics without bin-by-bin: $\sim$ 21 %.

JES breakdown (I)

The JES is composed of different uncorrelated components, but currently the systematics is evaluated shifting all components together.
The JES contribution could be better described splitting the various components in order to feed the fit with different templates:



JES breakdown (II)

Very preliminary result:

Muon W/Z+jets	Component	JES_up(%) Avg Unc	JES_up(%) Max Bin Unc.	JES_down(%) Avg Unc	JES_down(%) Max Bin Unc.
Mjj	All	5.4	13.4	-7.4	-12.4
	Insitu Comp. 1	0.7	4.2	-1.2	-8.9
	Insitu Comp. 2	-1.7	-9.6	1.2	4.8
	Insitu Comp. 3	0.4	4.9	-0.7	4.0
	Insitu Comp. 4	0.0	1.8	-0.1	-3.3
	Insitu Comp. 5	-0.2	-1.8	0.1	2.5
	Insitu Comp. 6	0.1	1.9	-0.1	-1.8
	Eta InterCalibration: Stat	0.2	-3.3	-0.4	-3.7
	Eta InterCalibration: Modelling	-0.1	-6.4	-0.8	7.5
	High pT jet	0.0	0.0	0.0	0.0
	Closure	0.0	0.0	0.0	0.0
	NPV Pile-up	-0.2	3.6	-0.1	6.6
	Mu Pile-up	-0.4	5.1	-0.2	3.5
	Close-by Jet	0.0	5.1	-0.2	-7.0
	Flavor Comp.	4.5	14.6	-5.7	-15.5
	Flavor Response	2.5	13.9	-3.2	-11.5
	b-jet	0.0	1.5	0.0	-1.1

This may help understanding which components are more critical.

Jet veto

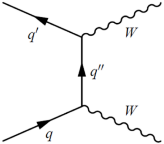
Currently the selection is such that events with jets with $p_T > 20$ GeV other than the diboson candidates are vetoed.
Want to shift the veto threshold to 25 GeV to be in a safer region with jets.

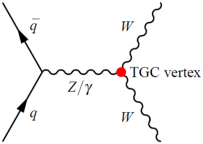
anomalous TGC

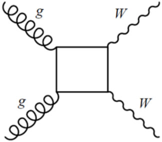
- Diboson production
- effective lagrangian overview
- adopted approch for aTGC limits

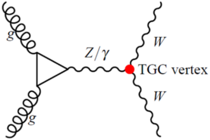
Diboson production diagrams

W^+W^-

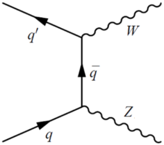


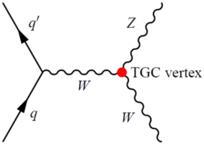






$W^\pm Z$





Effective lagrangian in SM

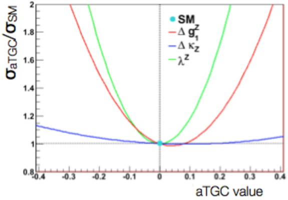
- the most general $WW\gamma, Z$ effective Lagrangian has 14 couplings
- C and P conserving terms plus QED gauge invariance $\rightarrow$ 5 couplings
- TGC values according to SM: $g_1^Z = 1$, $k_{\gamma,Z} = 1$, $\lambda_{\gamma,Z} = 0$

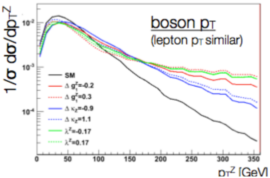
$$\begin{aligned} i\mathcal{L}_{eff}^{WWV} \quad = \quad & g_{WWV} \Big[g_1^V \left(W_{\mu\nu}^\dagger W^\mu - W^{\dagger\,\mu} W_{\mu\nu} \right) V^\nu + \kappa_V \, W_\mu^\dagger W_\nu V^{\mu\nu} \\ & + \frac{\lambda_V}{m_W^2} W_{\rho\mu}^\dagger W^\mu{}_\nu V^{\nu\rho} - g_4^V W_\mu^\dagger W_\nu (\partial^\mu V^\nu + \partial^\nu V^\mu) \\ & + i g_5^V \varepsilon_{\mu\nu\rho\sigma} \left((\partial^\rho W^{\dagger\,\mu}) W^\nu - W^{\dagger\,\mu} (\partial^\rho W^\nu) \right) V^\sigma \\ & + i\tilde{\kappa}_V W_\mu^\dagger W_\nu \tilde{V}^{\mu\nu} + i \frac{\tilde{\lambda}_V}{m_W^2} W_{\rho\mu}^\dagger W^\mu{}_\nu \tilde{V}^{\nu\rho} \Big] \, . \end{aligned}$$

$W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$; same for $V_{\mu\nu}$; $\tilde{V}_{\mu\nu} = (1/2)\epsilon_{\mu\nu\rho\sigma} V^{\rho\sigma}$
$g_{WW\gamma} = e$; $g_{WWZ} = e \cot\theta_W$

Effective lagrangian for aTGC

- g_1^Z, κ_Z, κ_γ, λ_Z and λ_γ are the terms entering the aTGC for the diboson (not neutral diboson)
- the idea is to set limits for the variations from the SM values for these parameters
- $p_T(Z)$, $p_T(W)$ and the cross section could change with aTGC

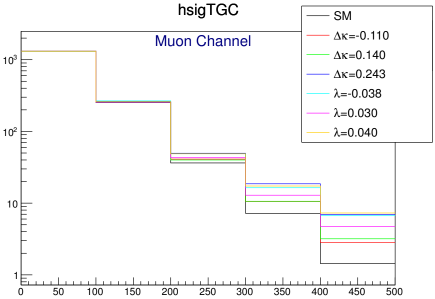




- NLO calculation increase the same regions: need to use an NLO MC generator; should move from Herwig to MC@NLO
- three possible scenarios:
  - LEP: $\Delta\kappa_\gamma = (\cot\theta_W)^2(\Delta g_1^Z - \Delta\kappa_Z)$, $\lambda_Z = \lambda_\gamma$ (3 parameters)
  - HISZ: $\Delta g_1^Z = \Delta\kappa_Z/(\cos^2\theta_W - \sin^2\theta_W)$, $\Delta\kappa_\gamma = 2\Delta\kappa_Z\cos^2\theta_W/(\cos^2\theta_W - \sin^2\theta_W)$ (2 parameters)
  - equal couplings: $\Delta\kappa_Z = \Delta\kappa_\lambda$, $\lambda_Z = \lambda_\gamma$ (2 parameters)

aTGC limits with LEP scheme

Different kinematic variables heve been tested; the most sensible one seems to be the $p_T(jj)$; this has been used to preliminarly study the aTGC:



Results with toys:

limits on aTGC's		
	λ	$\Delta\kappa_\gamma$
95% CL no bin-by-bin	[-0.035, 0.035]	[-0.189, 0.213]
95% CL with bin-by-bin	[-0.040,0.040]	[-0.219,0.242]

Comparison with CMS results

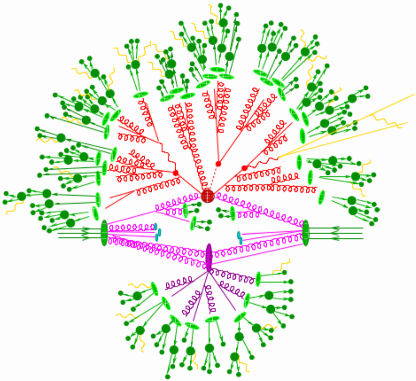
- CMS has already published a study on the semileptonic diboson channel: see here
- cross section result: $68.9 \pm 8.7\ (\mathrm{stat.}) \pm 9.7\ (\mathrm{syst.}) \pm 1.5\ (\mathrm{lum.})$
- our current result:
  $\sigma(\mathrm{WW} + \mathrm{WZ}) = 72 \pm 9(\mathrm{stat.}) \pm 15(\mathrm{syst.}) \pm 13(\mathrm{MC\ stat.})$
- aTCG limits:
  - $-0.038 < \lambda < 0.030$
  - $-0.11 < \Delta\kappa_\gamma < 0.14$
- our preliminary aTCG limits (LEP scheme):
  - $-0.040 < \lambda < 0.040$
  - $-0.219 < \Delta\kappa_\gamma < 0.242$
- not yet understood which scheme CMS adopted for aTGC
- for ATLAS, $p_T(jj)$ systematics is still missing

Back-up

MonteCarlo event generation

Monte Carlo event generators

- **Hard interaction**
  exact matrix elements $|\mathcal{M}|^2$
- **QCD bremsstrahlung**
  parton showers in the initial and final state
- **Multiple Interactions**
  beyond factorisation: modelling
- **Hadronisation**
  non perturbative QCD: modelling
- **Hadron Decays**
  phase space or effective theories



➔ **fully exclusive hadronic final states**

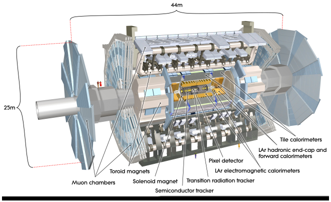
➔ **direct comparison with experimental data**

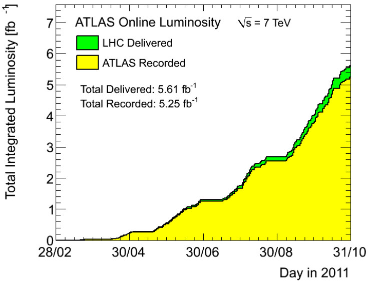
Herwig, Pythia, Sherpa

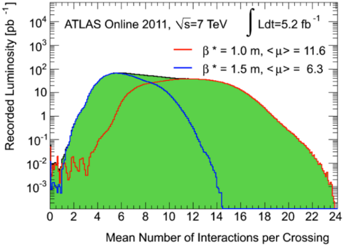
[Gleisberg et. al ’04, ’09]

The ATLAS detector and LHC conditions in 2011

ATLAS: a general purpose experiment







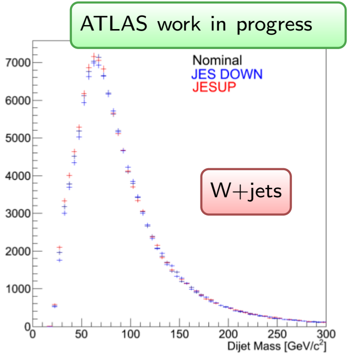
- collected good data in 2011: 4.7 fb^{-1}
- $\sqrt{s} = 7$ TeV
- luminosity: from 0.5 to $3.5 \cdot 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- important pile-up effects
- detector performances under control

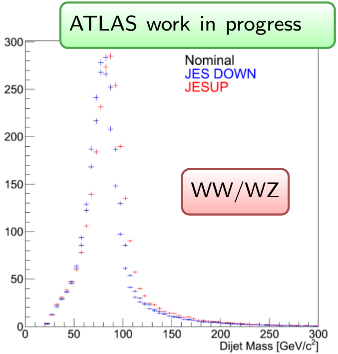
the presented analysis is over 2011 data

A word on systematics

Main systematics are:

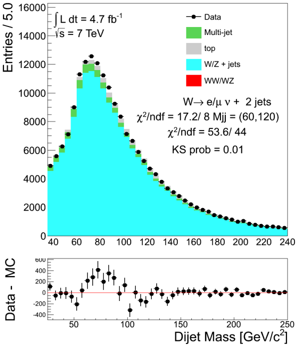
- Jet Energy measurement
- uncertainty in QCD shape and normalization
- W+jets shape and normalization

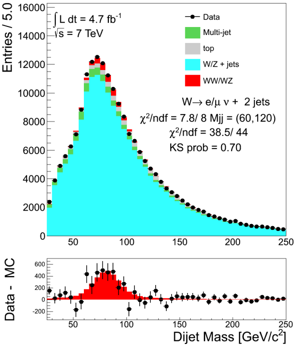




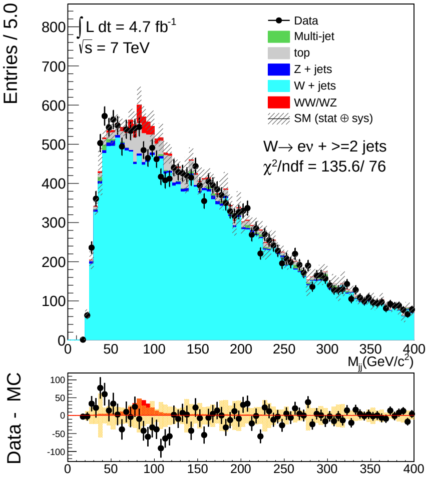
Check on results

- the semileptonic diboson signal analysis in ATLAS with 2011 data has been presented
- this channel is very challenging:
  - low S/B, low $S/\sqrt{B}$
  - backgrounds peak under signal
- the proposed selection have been studied to optimize S/B, $S/\sqrt{B}$
- measured diboson cross section at $\sqrt{s} = 7~\mathrm{TeV}$:
  $\sigma(\mathrm{WW} + \mathrm{WZ}) = 72 \pm 9(\mathrm{stat.}) \pm 15(\mathrm{syst.}) \pm 13(\mathrm{MC\ stat.})$



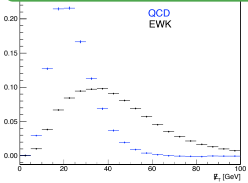


A different study has been tried to better separate the signal from the background:



Multijet data-driven estimate

ATLAS work in progress



- some multijet events enter the selection:
  - jets faking electrons
  - muons from a heavy flavour decay
- very difficult to model
- multijet contribution is extracted using a data-driven method
- Multijet shape: define a control data samples dominated by Multijet
  - invert transverse impact parameter cut in muon data
  - loose selection cuts in electron data
- Multijet normalization:
- $\not\!\!E_T$ has good discriminating power to separate multijet from EWK contributions
- fit the $\not\!\!E_T$ data distributions with MC to extract multijet normalization and W+jets, Z+jets scale factors

This procedure is repeated for each cut in the selection for which a plot is needed.

Preselection

Preselection cutflow:

- general event quality criteria
- request on primary vertex
- a single lepton candidate in the event
- lepton $p_T > 25$ GeV, central η, which fires the trigger
- $\not{E}_T > 30$ GeV
- $m_T > 40$ GeV
- jet cleaning criteria
- at least 2 jets with $|\eta| < 2.8$ and $p_T > 25$ GeV
- leading and subleading jets: W candidates
- $\Delta\phi(\not{E}_T, j_{lead}) > 0.8$ to reduce QCD

The Preselection is considered as a starting point for the other selections.

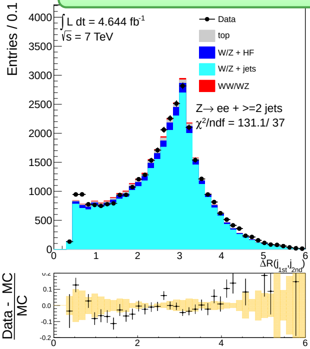
Control Regions

Control regions are built on top of the Preselection:

- Z+jets: remove second lepton veto, require opposite charge leptons
- $t\bar{t}$: at least 1 b-tagged jet, at least 2 non b-tagged jets

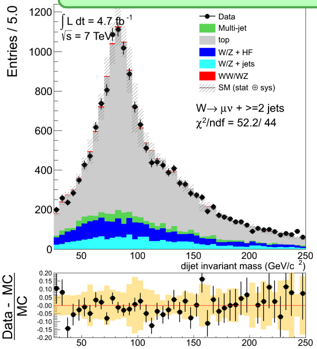
Z+jets Control Region

ATLAS work in progress



$t\bar{t}$ Control Region

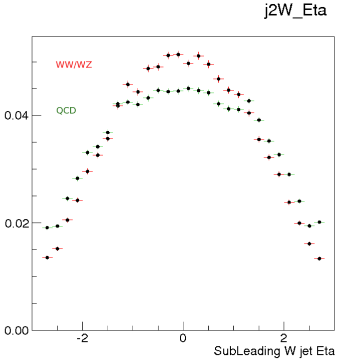
ATLAS work in progress

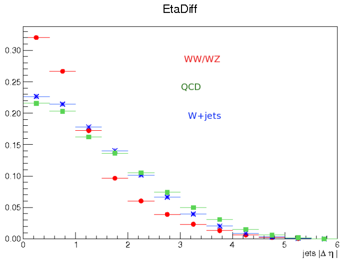


Nominal selection

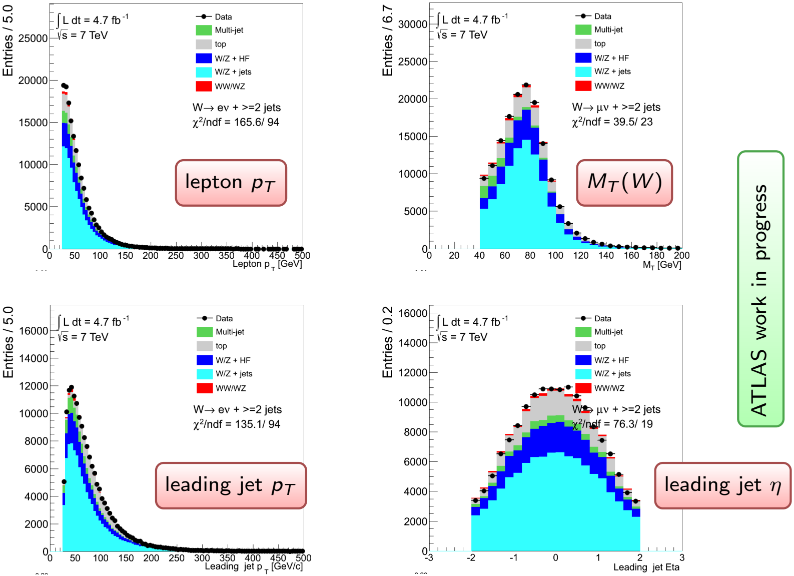
On top of the Preselection:

- exactly 2 jets in the event
- $|\eta_{jet}| < 2$: signal jets are more central; improve JES uncertainty
- leading jet $p_T > 30\ \mathrm{GeV}$
- $\Delta R(j_1, j_2) > 0.7$: Alpgen level cut
- $\Delta\eta(j_1, j_2) < 1.5$: improve S/B



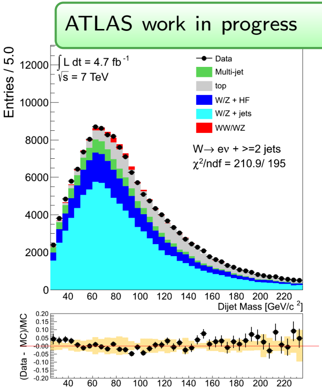


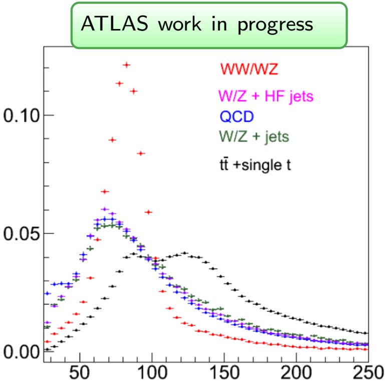
Nominal selection: Data/MC agreement



Nominal Selection: Dijet distributions

M_{jj} distribution and normalized templates:

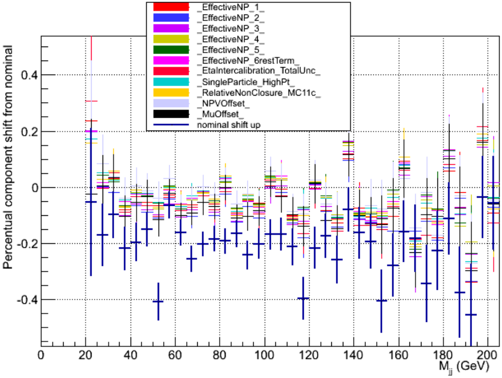




- selection efficiency: $\epsilon \sim 1.1\%$, S/B ratio: 2.6%
- templates are used for a fit method to extract WW/WZ σ
- binned maximum likelihood fit to M_{jj} distributions
- systematic uncertainties and background normalizations treated as nuisance parameters

JES components

- the JES uncertainty is made up of various contributions
- a different approach to reduce the JES uncertainty would be to vary the single components one by one
- for example, JES components up:



SM effective lagrangian (I)

$$
\begin{aligned}
i\mathcal{L}_{eff}^{WWV} \quad = \quad & g_{WWV}\Big[g_1^V\left(W_{\mu\nu}^{\dagger}W^{\mu} - W^{\dagger\,\mu}W_{\mu\nu}\right)V^{\nu} + \kappa_V\, W_{\mu}^{\dagger}W_{\nu}V^{\mu\nu} \\
& + \frac{\lambda_V}{m_W^2}\, W_{\rho\mu}^{\dagger}W^{\mu}{}_{\nu}V^{\nu\rho} - g_4^V\, W_{\mu}^{\dagger}W_{\nu}(\partial^{\mu}V^{\nu} + \partial^{\nu}V^{\mu}) \\
& + i g_5^V\, \varepsilon_{\mu\nu\rho\sigma}\left((\partial^{\rho}W^{\dagger\,\mu})W^{\nu} - W^{\dagger\,\mu}(\partial^{\rho}W^{\nu})\right)V^{\sigma} \\
& + i\tilde{\kappa}_V W_{\mu}^{\dagger}W_{\nu}\tilde{V}^{\mu\nu} + i\frac{\tilde{\lambda}_V}{m_W^2}\, W_{\rho\mu}^{\dagger}W^{\mu}{}_{\nu}\tilde{V}^{\nu\rho}\Big]\,.
\end{aligned}
$$

$W_{\mu\nu} = \partial_{\mu}W_{\nu} - \partial_{\nu}W_{\mu}$; same for $V_{\mu\nu}$; $\tilde{V}_{\mu\nu} = (1/2)\epsilon_{\mu\nu\rho\sigma}V^{\rho\sigma}$

$g_{WW\gamma} = e$; $g_{WWZ} = e\cot\theta_W$

SM effective lagrangian (II)

- In the SM:

$$g_1^Z = g_1^\gamma = \kappa_Z = \kappa_\gamma = 1,$$
$$\lambda_Z = \lambda_\gamma = g_4^V = g_5^Z = g_5^\gamma = \tilde{\kappa}_V = \tilde{\lambda}_V = 0$$

- g_1^V, κ_V and λ_V respect charge conjugation (C) and parity (P)
- g_4^V and g_5^V violate C invariance
- g_4^V, $\tilde{\kappa}_V$ and $\tilde{\lambda}_V$ violate CP invariance
- for on-shell photons: $g_1^\gamma = 1$ (electric charge of W), $g_4^\gamma = g_5^\gamma = 0$ (em gauge invariance)
- higher dimensional operators do not lead to a new Lorentz structure
- they can be taken into account by allowing the couplings g_1^V, κ_V etc. to be energy dependent so-called form factors

Effective lagrangian for aTGC

- aTGCs: those differing from the SM predictions
- g_1^V, κ_V and λ_V are those entering the aTGC
- aTGCs are taken into account introducing form factors which depends on $\sqrt{\hat{s}}$ and on a Λ cut-off
- this energy and scale dependence implies that:
  - increased contribution in cross section
  - larger effects in distributions with larger dependency on $\sqrt{s}$
- three possible scenarios:
  - LEP: $\Delta\kappa_\gamma = (\cos\theta_W/\sin\theta_W)^2(\Delta g_1^Z - \Delta\kappa_Z)$, $\lambda_Z = \lambda_\gamma$ (3 parameters)
  - HISZ: $\Delta g_1^Z = \Delta\kappa_Z/(\cos^2\theta_W - \sin^2\theta_W)$, $\Delta\kappa_\gamma = 2\Delta\kappa_Z \cos^2\theta_W/(\cos^2\theta_W - \sin^2\theta_W)$ (2 parameters)
  - equal couplings: $\Delta\kappa_Z = \Delta\kappa_\lambda$, $\lambda_Z = \lambda_\gamma$ (2 parameters)
- how to model MC?
  - NLO generators
  - MC reweighting