Measurement of the WW/WZ production cross section in the semileptonic channel in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

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Overview

- semileptonic WW/WZ cross section
- limits on anomalous TGC
- conclusions

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Measurement of the WW and WZ production cross section and limits on the anomalous triple gauge couplings in the semileptonic final state in 4.7 fb^{-1} of pp collisions with the ATLAS detector at $\sqrt{s} = 7$ TeV

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Abstract

A study of the WW/WZ production using 4.7±0.2 fb^{-1} sample of proton-proton collisions at $\sqrt{s} = 7$ TeV recorded with the ATLAS detector at the Large Hadron Collider in 2011 is presented. The diboson cross section is measured in the $WW/WZ \to l\nu jj$ decay channel where the lepton can be a muon or an electron. The cross section is measured with a sensitivity of 3.5σ and is found to be equal to $\sigma(WW + WZ) = 70 \pm 8$ (stat.) ± 18 (syst.) pb, in agreement with the Standard Model expectation $\sigma(WW + WZ) = 63.4 \pm 2.6$ pb. The reconstructed dijet transverse momentum distribution allows to set limits on anomalous contributions to the triple gauge coupling vertices.

ATL-COM-PHYS-2013-1516

Goal of the analysis

Measurement of the WW and WZ production cross section in the semileptonic final state in 4.7 fb^{-1} of pp collisions with the ATLAS detector at $\sqrt{s} = 7$ TeV and limits on anomalous trilinear gauge couplings

Goals of the analysis:

- cross section measurement: $\sigma\left(WW/WZ \longrightarrow l\nu jj\right)$, $l = e, \mu$
- anomalous Triple Gauge Coupling limits

Data taking conditions:

- $\sqrt{s} = 7$ TeV
- integrated luminosity: $L = 4.7\ \mathrm{fb}^{-1}$
- Standard Model predictions:
  - $\sigma = 63 \pm 2.6$ pb (MCFM)
  - aTGC: all paramethers equal to zero

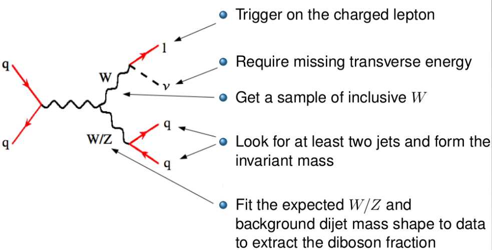
cross section measurement

- strategy for the cross section measurement results
- cross check of the measurement

Semileptonic diboson searches with ATLAS

The $WW/WZ \longrightarrow l\nu jj$ $l = e, \mu$ channel has not yet been measured by ATLAS:

- semileptonic final states have completely different research issues
- in this channel:
  - WW/WZ cross section increases by a factor of 4 wrt Tevatron
  - $W + 2$ jets increases by a factor ~ 20 wrt Tevatron
- challenging final state:
  - W+jets is dominant
  - $S/B < 1\%$



Semileptonic diboson issues

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 (QCD)
- W+jets peaks in the same region where the diboson peaks
- W from top under the signal
- still low statistics to make a boosted search

Selection optimized to move the background peak away from the signal peak have been tried, but they show a not optimal data/MC agreement and a lower sensitivity.
This will be tried for the 2012 analysis, since MC describes better W+jets.

Analysis selection

leptonic W

muon channel:

- trigger: lowest unprescaled μ
- only 1 muon with $p_T > 25$ GeV
- veto on second lepton
- track and calo isolation
- vertex pointing: $d_0/\sigma(d_0) < 3$

electron channel:

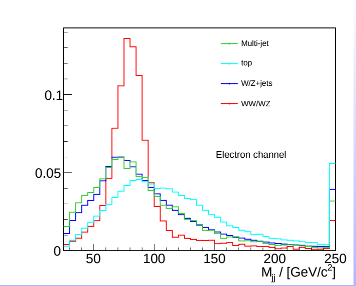
- trigger: lowest unprescaled e
- only 1 electron with $p_T > 25$ GeV
- veto on second lepton
- track and calo isolation
- vertex pointing: $d_0/\sigma(d_0) < 10$

- $\not{E}_T > 30$ GeV
- $M_T(W) > 40$ GeV

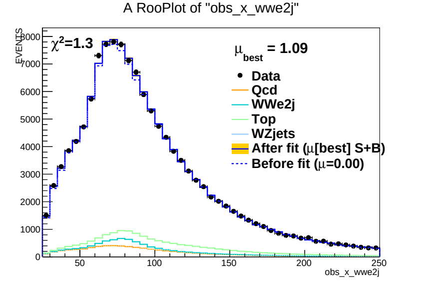
hadronic W/Z

- jet cleaning and overlap removal
- at least 2 good jets with $p_T > 30, 25$ GeV and $|\eta| < 2.8$
- $|JVF| > 0.75$ if $|\eta| < 2.5$
- $\Delta\phi(\not{E}_T, j_{lead}) > 0.8$: further reduction of multijet background
- $|\eta_{jet}| < 2$: increase S/B and select region with smaller JES uncertainty
- $\Delta R(j_1, j_2) > 0.7$: avoid mis-modeling due to a generator level cut
- $|\Delta\eta(j_1, j_2)| < 1.5$: improve S/B

M_{jj} distribution before fit



templates

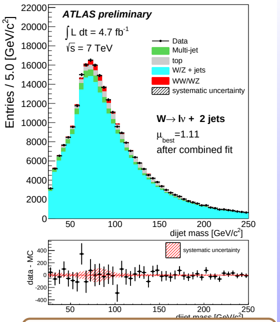


pre-fit results

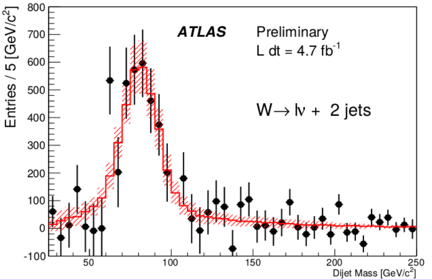
- maximum likelihood fit to the templates
- systematics included using shifted templates (nuisance parameters) in the fit or pseudo-experiments
- the fit returns $\mu = \frac{\sigma_{\rm obs}}{\sigma_{\rm SM}}$

Fit results

- combined e- and μ-channels



data/MC comparison

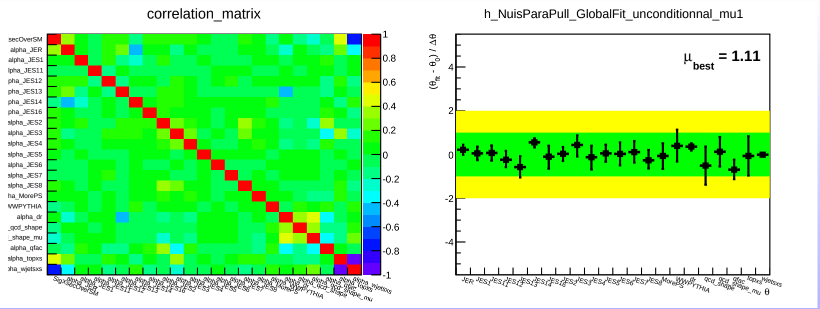


data-backgrounds

- SM expectation: $\sim 3 \cdot 10^5$ events
- analysis efficiency: $\sim 1\%$ $\longrightarrow$ expected ~ 3000 events
- SM prediction: $\sigma = 63 \pm 2.6$ pb
- our result: $\sigma = 70 \pm 8\,(\mathrm{stat.}) \pm 18\,(\mathrm{syst.})$ pb

Nuisance parameters after fit

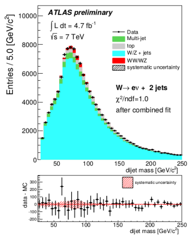
Shift of the nuisance parameters with respect to the nominal value. The high constraint on the W+jets cross section is understood.

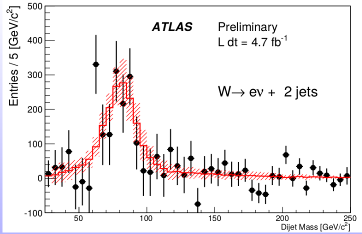


We verified that the constraints of the nuisance parameters are not due to the presence of signal in the fit.

Checks

separate fit in electron and muon channels:

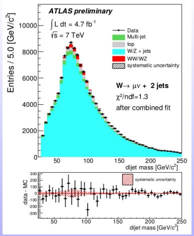


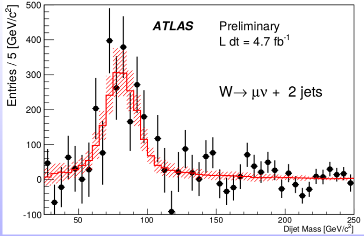


electron

data/MC comparison

data-backgrounds

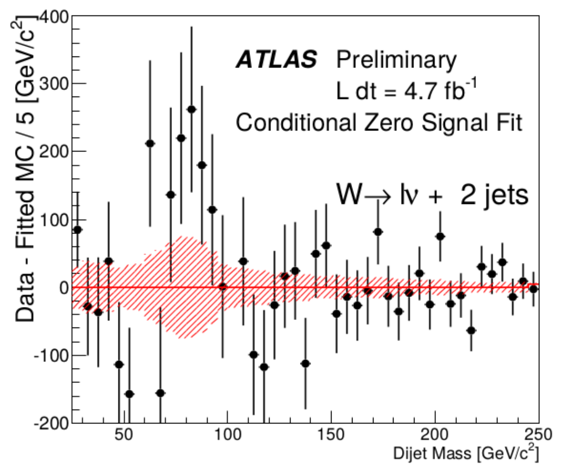




muon

Checks fitting with zero signal

Another check is fitting imposing zero signal, and look for discrepancies between the data and the fit result:



Cross section measurement

Result of binned maximum likelihood fit on m_{jj} templates:

- $\mu = 1.11 \pm 0.13\ (\mathrm{stat}) \pm 0.29\ (\mathrm{syst})$
- $\sigma_{\mathrm{NLO}} = 63.4 \pm 2.6$ pb
- $\sigma_{\mathrm{measured}} = 70 \pm 8\ (\mathrm{stat}) \pm 18\ (\mathrm{syst})$ pb
- completed break-down of systematics:

Source	$\Delta\sigma_{\mathrm{WW+WZ}}/\sigma_{\mathrm{WW+WZ}}(\%)$
Data Statistics	± 13
MC Statistics	± 12
$\mathrm{W/Z + jets}$ rate	± 14
$\mathrm{W/Z + jets}$ shape variation	± 3.5
Multijet shape and rate	± 6.0
Top rate	± 5.7
Top shape from ISR/FSR	± 0.9
Jet energy scale shape (all samples)	± 12
Jet energy resolution shape (all samples)	± 8.4
Lepton reconstruction (all samples)	± 1.0
WW/WZ Signal modelling	± 3.9
JES/JER uncertainty on *WW/WZ* rate	± 6.0
PDF (all samples)	± 1.0
Luminosity	± 1.8
Total systematics	± 26

anomalous TGC

- Diboson production
- adopted approch for aTGC limits

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: $g_1^Z = 1$, $k_{\gamma,Z} = 1$, $\lambda_{\gamma,Z} = 0$

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

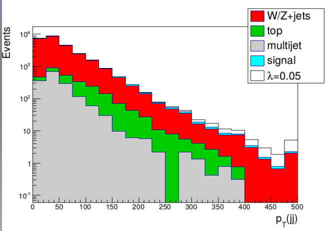
$W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$; same for $V_{\mu\nu}$; $\tilde{V}_{\mu\nu} = (1/2)\epsilon_{\mu\nu\rho\sigma}V^{\rho\sigma}$

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

All-neutral TGC are forbidden in the SM at tree-level.

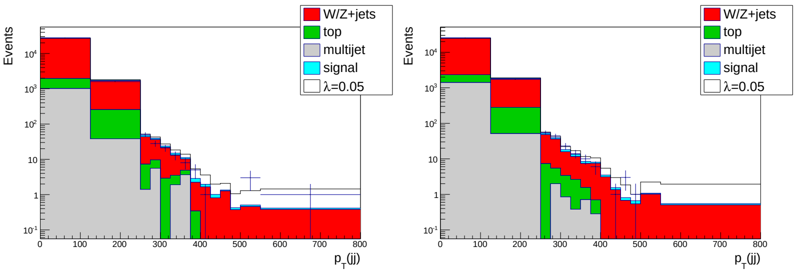
Effective lagrangian for aTGC

- g_1^Z, κ_Z, κ_γ, λ_Z and λ_γ are the terms entering the aTGC for the diboson (not neutral diboson)
- 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
- LEP scheme:
  - $\Delta\kappa_\gamma = (\cot\theta_W)^2(\Delta g_1^Z - \Delta\kappa_Z)$
  - $\lambda_Z = \lambda_\gamma$, $\Delta g_1^Z = 0$
  - 3 parameters

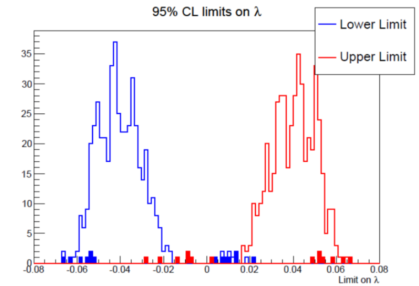
P_t^{jj} distributions

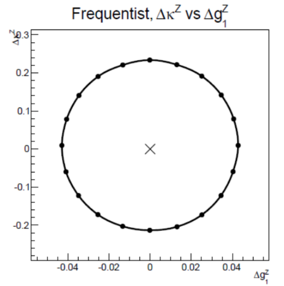


- data/MC comparison for p_T^{jj}
- muons left, electrons right
- effect of aTGC $\lambda = 0.05$ shown for comparison

1D, 2D limits

- calculate 1D and 2D limits for Δk_γ and λ
- expected limits on λ:





Comparison with CMS results

- CMS has already published a study on the semileptonic diboson channel: see here
- CMS X-section result: $68.9 \pm 8.7\,(\mathrm{stat.}) \pm 9.7\,(\mathrm{syst.}) \pm 1.5\,(\mathrm{lum.})$
- our current result: $\sigma(\mathrm{WW} + \mathrm{WZ}) = 70 \pm 8\,(\mathrm{stat.}) \pm 18\,(\mathrm{syst.})$ pb
- aTCG limits:
  - $-0.038 < \lambda < 0.030$
  - $-0.11 < \Delta\kappa_\gamma < 0.14$
- our preliminary aTCG limits (LEP scheme):
  - $-0.046 < \lambda < 0.046$
  - $-0.20 < \Delta\kappa_\gamma < 0.22$
- for ATLAS, $p_T(jj)$ systematics is still being finalized

Conclusions

- summary
- what's next

Summary

- 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, $S/\sqrt{B}$
- also the aTGC limits are set
- no deviations from the Standard Model predictions
- CONF note in CDS: ATL-COM-PHYS-2013-1516
- already implemented first round of comments
- Editorial Board components:
  - Marjorie Shapiro (chair)
  - Christian Schmitt
  - Gideon Bella
  - Jimmy Proudfoot
- working on a draft for the paper
- foreseen end of analysis: first half of 2014

Critical points

- need a very good data/MC agreement in order to use the template method
- good sensitivity VS good modeling: the signal is on top of the background
- MC statistics is an issue both for the cross section and the aTGC measurements
- JES, JER very critical
- analysis limited mainly by systematics and MC statistics

Next steps

The 7 TeV analysis is being finalized and it is going to be published; the 8 TeV analysis is starting; some ideas:

- since systematics limit the analysis, data-driven methods are welcome; or at least, extract more information from data
- Sherpa samples should improve data/Mc agreement for the W+jets
- need cuts to move the signal from the top of the background
- try boosted topology, eventually with fat-jets; should improve the limits on aTGC
- W+jet will be the main background as in 7 TeV analysis
- q/g tagging may be useful here

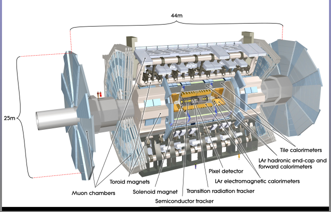
People which showed interest in Pisa:

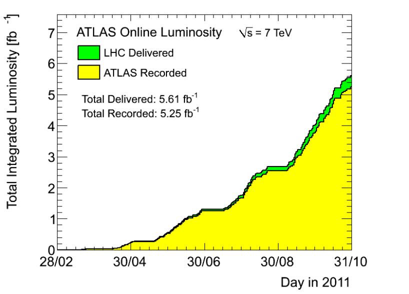
- Nino Del Prete, Margherita Spalla
- already experienced with a multiresolution analysis using 7 TeV data for SM and exotic searches in the diboson channel

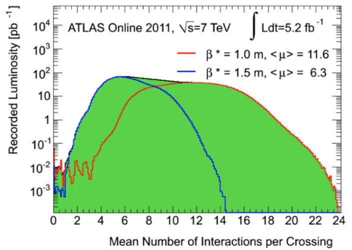
Back-up

The ATLAS detector and LHC conditions in 2011

ATLAS: a general purpose experiment







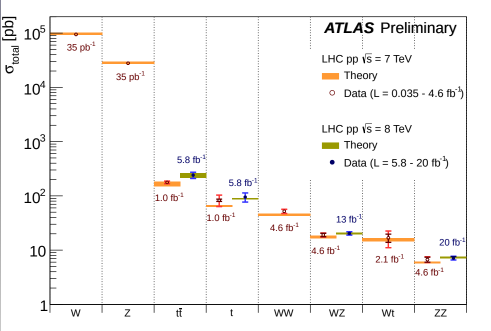
- collected good data in 2011: 4.7 fb^{-1}
- $\sqrt{s} = 7$ TeV
- luminosity: from 0.5 to 3.5 $\cdot\, 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- important pile-up effects
- detector performances under control

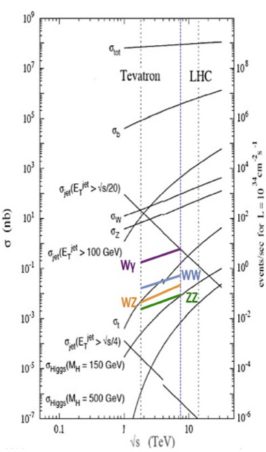
the presented analysis is over 2011 data

Diboson Physics at LHC (I)

Studying diboson Physics at LHC is interesting in general:

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

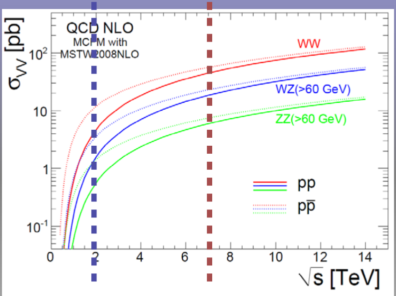




Diboson Physics at LHC (II)

Production rate estimates (all channels):

- diboson production rates at LHC are 3-5 larger than at Tevatron
- QCD 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

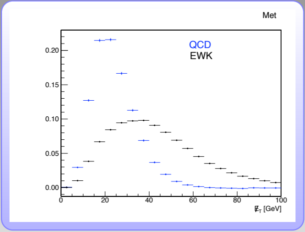


SM production Xsec	Tevatron (1.96 TeV)	LHC (7 TeV)
WW	12.4 pb	44.9 pb
WZ	3.7 pb	18.5 pb
ZZ	1.4 pb	6.0 pb

QCD data-driven estimate

QCD contribution is extracted using a data-driven method because it is very difficult to model the multijet background (jets faking a lepton)

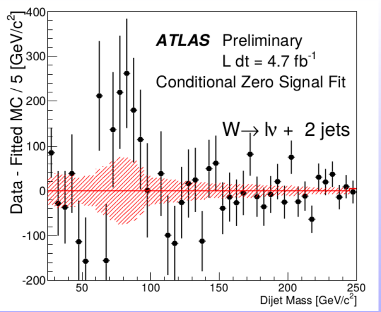
- shape is extracted from a QCD-enriched sample
  - invert quality requirements for electrons
  - invert pointing request for muons
  - orthogonal selection wrt the signal selection
- normalization is extracted fitting the $\not{E}_T$ for MC and data
  - technique used also in CDF
  - $\not{E}_T$ is the best variable which separate the W+jets contribution from the multijet

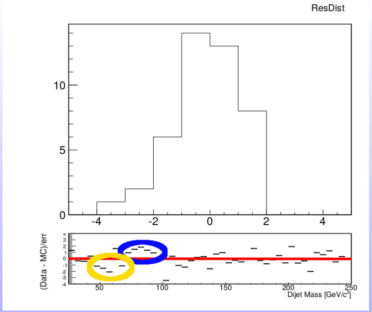


- boson + jet is left floating
- QCD and V+jets normalization are used for the fit
- tipical V+jets correction: less than 10 %

Checks fitting with zero signal

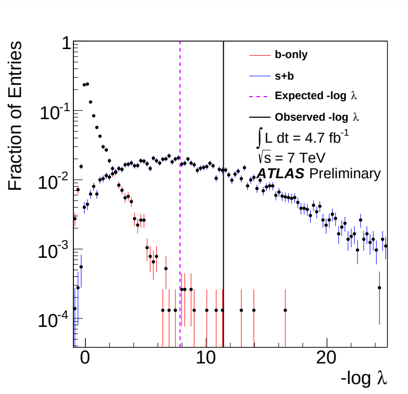
Another check is fitting imposing zero signal, and look for discrepancies between the data and the fit result:





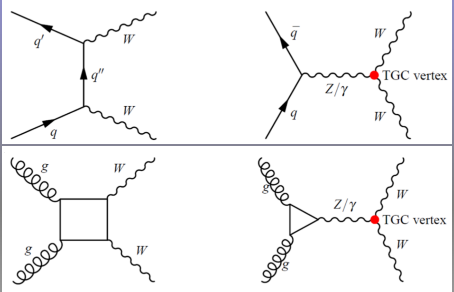
Sensitivity

- 10000 toys
- exp. sensitivity: 3.1 σ
- obs. sensitivity: 3.5 σ

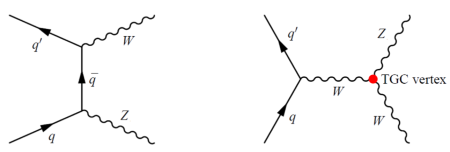


Diboson production diagrams

W^+W^-



$W^\pm Z$



2D limits

- calculate 2D limits with and without the high p_T samples