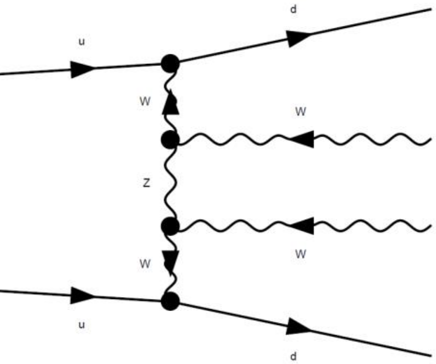
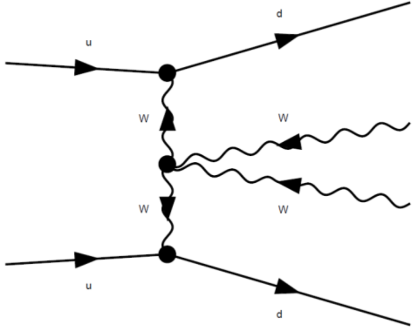
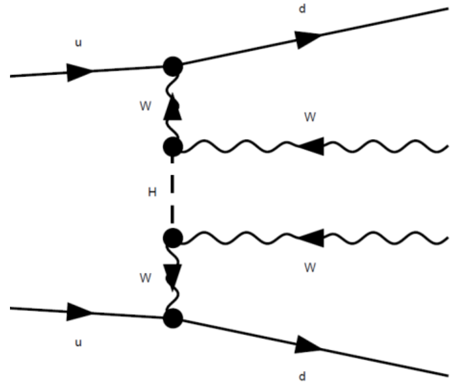
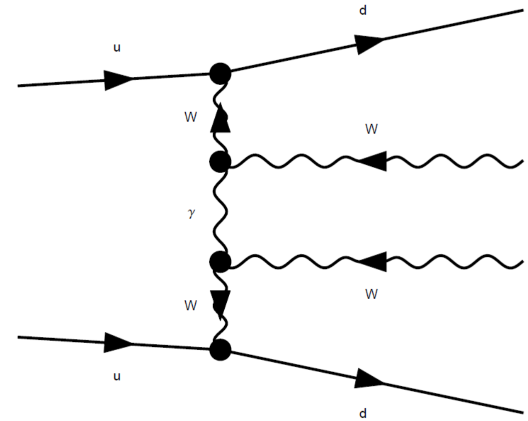
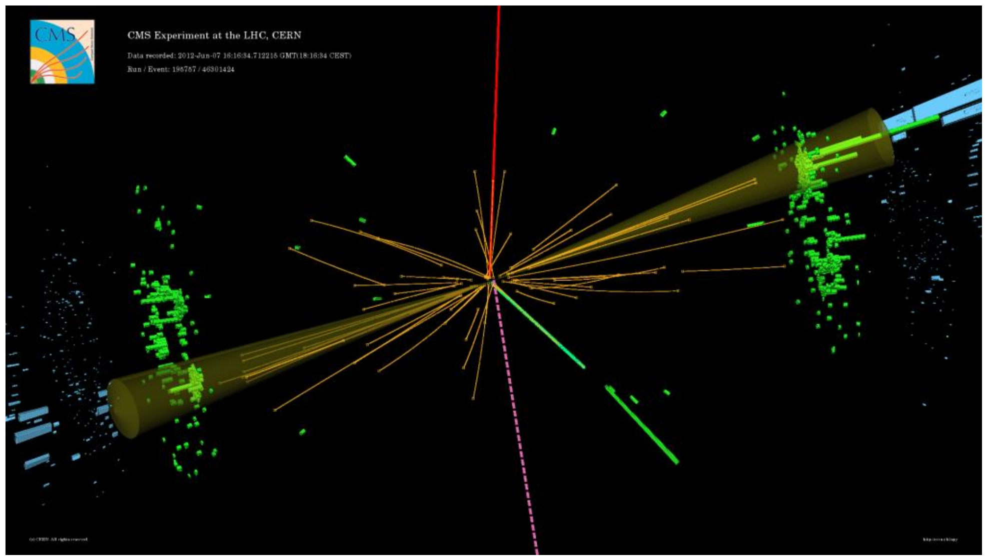










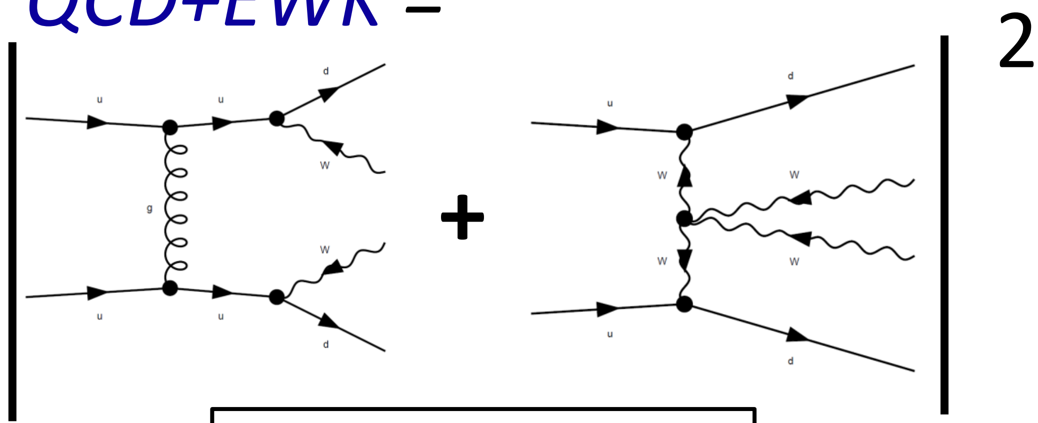
CMS $W^{\pm}W^{\pm}jj$ analysis

Introduction

- CMS performed a search for electroweak $W^{\pm}W^{\pm}jj$ on 19.4 fb^{-1} of 8 TeV data
- We will give an overview of the analysis and answer ATLAS questions
- CMS public results are here:
  - http://cds.cern.ch/record/1713393?ln=en
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP13015

Signal Definition

- *Define signal as QCD+EWK =*



Representative diagrams

<u>MadGraph notation</u>

QCD = *p p > w+ w+ p p QED=2 QCD=2, w+ > l+ vl*

EWK = *p p > w+ w+ p p QED=4 QCD=0, w+ > l+ vl*

QCD+EWK = p p > w+ w+ p p QED=4 QCD=2, w+ > l+ vl

- Interference between QCD and EWK is not negligible, around 10% effect, but sign of interference depends on QCD scale

Event Selection

- Exactly two same sign selected leptons and at least two selected jets
- $m_{jj} > 500$ GeV
- $|\Delta\eta_{jj}| > 2.5$

VBS topology

- $m_{ll} > 50$ GeV
- $|m_{ee} - m_Z| > 15$ GeV

Dilepton invariant mass

- No b-tagged jets

Top veto

- Reject events with:
  - full ID electron and a PF hadron candidate pair with $|m_Z - m_{ll}| < 10$ for $|\eta| > 2.5$
  - reconstructed lepton with d0<0.02, dz<0.1, $p_t > 10$ and isoLepton/$p_t < 0.1$
  - opposite-sign same-flavor reconstructed lepton pair with $|m_Z - m_{ll}| < 10$ and $p_t > 10$

Third lepton veto

- MET > 40 GeV

Neutrinos

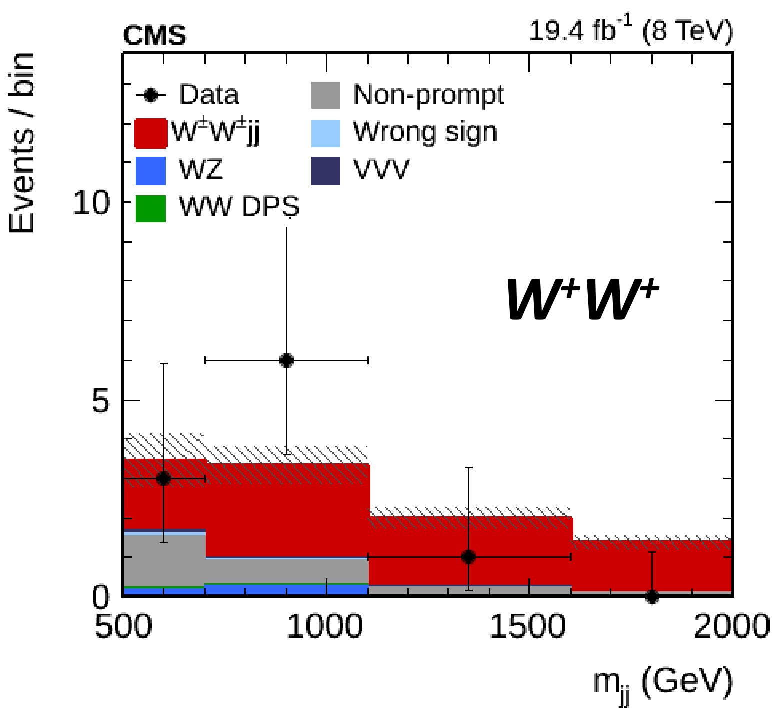
Backgrounds

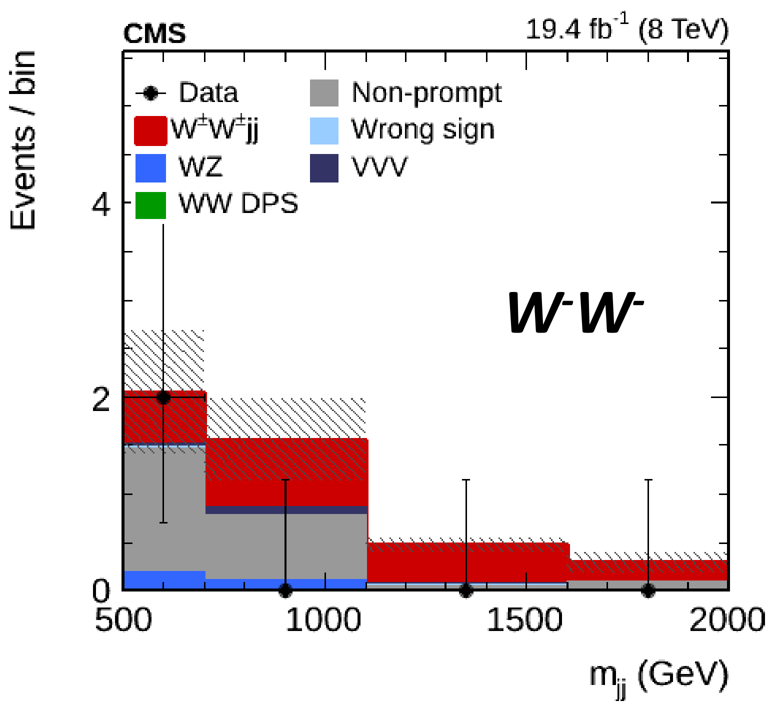
	Data	$W^{\pm}W^{\pm}jj$	Total bkg.	Non-prompt	WZ	VVV	Wrong sign	WW DPS
$W^{\pm}W^{\pm}$	12	8.8 ± 0.2	5.7 ± 0.8	4.2 ± 0.8	1.0 ± 0.1	0.3 ± 0.1	0.1 ± 0.08	0.1 ± 0.1
$W^{+}W^{+}$	10	7.0 ± 0.2	3.1 ± 0.6	2.1 ± 0.6	0.6 ± 0.1	0.2 ± 0.1	0.1 ± 0.08	0.1 ± 0.1
$W^{-}W^{-}$	2	1.8 ± 0.1	2.6 ± 0.6	2.1 ± 0.5	0.4 ± 0.1	0.1 ± 0.1	—	—

- Non-prompt
  - measure fake rate in data in dijet sample
  - apply to events with one passing and one failing lepton
- WZ
  - Use MadGraph WZjj sample, with data/MC scale factor from 3 lepton control region (0.75 ± 0.28)

Results

- Statistical analysis in 8 bins: 2 charge bins × 4 m_{jj} bins
  - Profile-likelihood approximation
  - Expected significance: 3.1 σ
  - Observed significance: 2.0 σ





Question from ATLAS 1

1) a) What is the motivation for a fiducial phase space with lower Lepton pT(10 GeV), Jet pT(20GeV), and lower M(j,j) (300GeV), when this does not correspond to your analysis selections Lepton pT(20 GeV), Jet pT(30GeV), and lower M(j,j) (500GeV).

We want to make sure that events that pass the analysis selection are dominated by events in the fiducial phase space i.e. we want to reduce as much as possible the events that migrate from outside the fiducial phase space to inside the signal region.

Question from ATLAS 2

2) ATLAS has more stringent veto lepton selection with pT>7 (6) GeV for electrons (muons), while CMS: uses pt>10 GeV, but ATLAS estimates a higher WZ background (~25%) than CMS (15%) . CMS employs a cut on mll>50 GeV, but in the ATLAS study this cut removes very little of the WZ background, see:

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2013-06/figaux_11.png

Why is the WZ background estimation so much lower for CMS?

In addition to vetoing loosely identified leptons, we also veto the following cases:

- **Events with a loosely isolated, reconstructed muon or electron.**
- **Events with a fully identified lepton and another opposite-charge, same-flavor, lepton-reconstructed lepton (without an isolation requirement), such that their invariant mass is compatible with a Z boson.**
- **Events with a fully identified lepton and an isolated hadron-reconstructed lepton, such that their invariant mass is compatible with a Z boson.**

Those additional requirements reduce by ~60% the WZ background with a tiny effect on the dilepton events. The mll cut is pretty much irrelevant after all, but it was actually applied to reduce the non-prompt lepton background at preselection level.

Question from ATLAS 3

3) Why is the event yield much smaller for CMS than for ATLAS (~9 vs ~15 ssWW events expected) ?

(Is it the top veto ? What's its efficiency ?)

There are several effects, although it's not totally clear to us either. The top-veto efficiency is about 80% for the signal (and about 20% for the top-quark background). We also think our lepton selection is tighter than the one applied in ATLAS which reduces the signal component, but also the non-prompt lepton background by a large amount.

Question from ATLAS 4

4) How is the WZ(+2j) background (signal) generated? Madgraph for both the WZ inclusive and WZ+2j process? Do you use k-factors to extrapolate to NLO in addition the the data control region for the xsection measurement / prediction?

It is generated using MadGraph and only the WZ+2j process is considered. No, we don't use k-factors.

4) a) How are the WZ QCD process and WZ+2j process electroweak generated? Do you use Madgraph to generate the LO WZ inclusive and LO WZ+2j electroweak process?

Both WZjj QCD and WZjj EWK are included in our WZjj sample and they are both considered as background.

4) b) Do you apply any QCD NLO corrections to correct for the MC event shape, in addition to determining the WZ background normalisation in the data control region?

No, we don't apply any NLO corrections to the WZ process.

Question from ATLAS 5

5) aQGC limits: What is CMS plan for the unitarization scheme?

CMS policy on the unitarization is the following:

- **We believe that experimental measurements are still valid even if limits overlap with unitarity violating coupling parameter space. It just means that we don't have enough sensitivity to say something non-trivial about the parameters.**
- **An attempt to modify an effective model leads to an ad-hoc model that is not well motivated from the first principles and instead of testing an effective model, we in fact test a specific model. That's why unitarization is not required in CMS analyses even if sensitivity is poor**
- **Authors are free to add unitarized models, but in practice it never happens simply due to lack of manpower. Given that a number of Standard Model measurement in CMS is still not published, we don't want to add extra requirements that may delay the process even more.**

Backup Slides

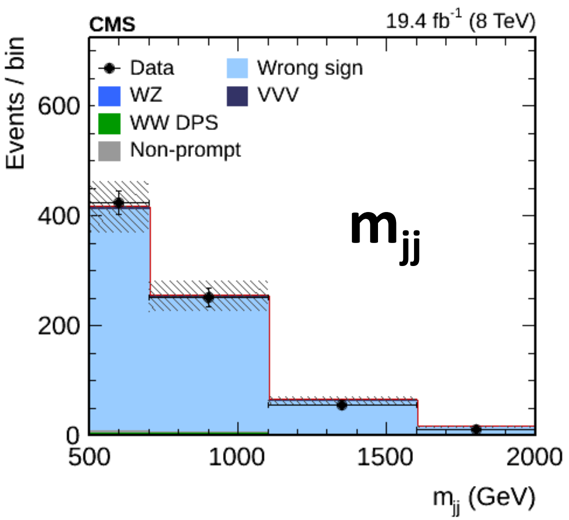
lepton+fake background estimation

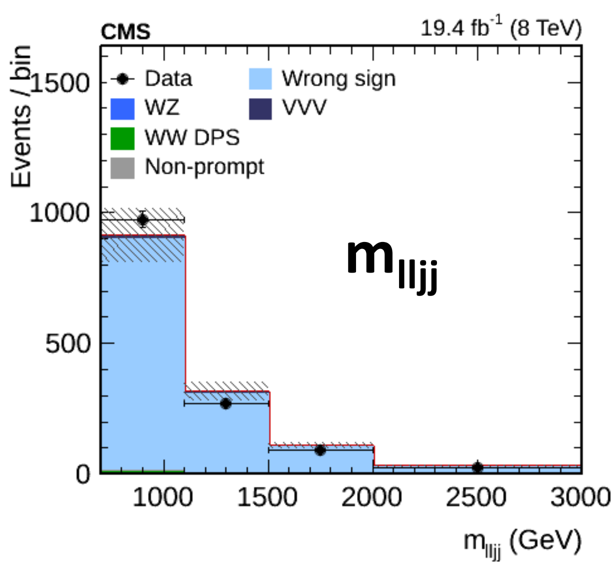
- use fake rate method
- measure FR in data in dijet sample
  - correct for flavor composition with data from 3l+1b+ MET
- apply to events with one passing and one failing lepton:

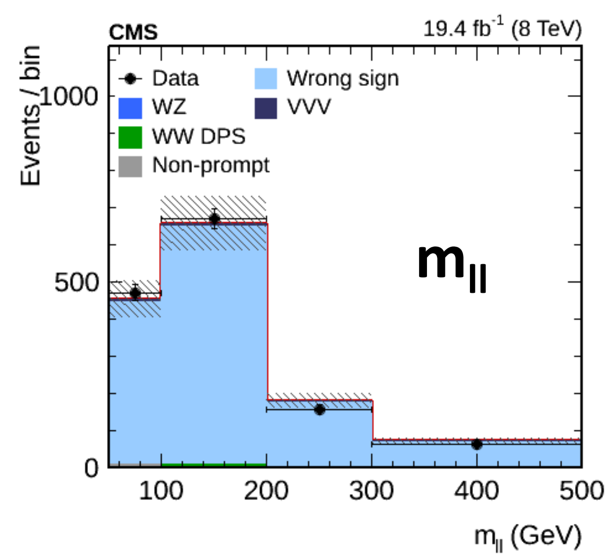
$$w_i = \frac{\epsilon_{\text{fake}}(p_{\text{Ti}}, \eta_i)}{1 - \epsilon_{\text{fake}}(p_{\text{Ti}}, \eta_i)}$$

b Tag Control Region

- require opposite sign instead of same sign leptons
- replace b veto with b tag in the selection
- use only opposite flavor leptons







Fiducial Cross Section Calculation Procedure

$$\sigma_{\text{measured}} = \mu_{\text{best fit}}\, \sigma_{\text{generator}}\, \epsilon_{\text{generator to fiducial}}$$

- $\mu_{\text{best fit}}$ is the best-fit signal strength
- $\sigma_{\text{generator}}$ is the xs computed by MadGraph
- $\epsilon_{\text{generator to fiducial}}$ is the efficiency to go from the generator level cuts to the fiducial cuts, computed by running over the LHE file

Fiducial Region Definition

- Fiducial region
  - $pT_l > 10$ GeV
  - $pT_j > 20$ GeV
  - $m_{jj} > 300$ GeV
  - $|\Delta\eta_{jj}| > 2.5$
  - $|\eta_l| < 2.5$
  - $|\eta_j| < 5.0$

Tradeoff between purity and efficiency, we choose high purity.

Note: denominators includes hadronic taus, while numerators doesn't

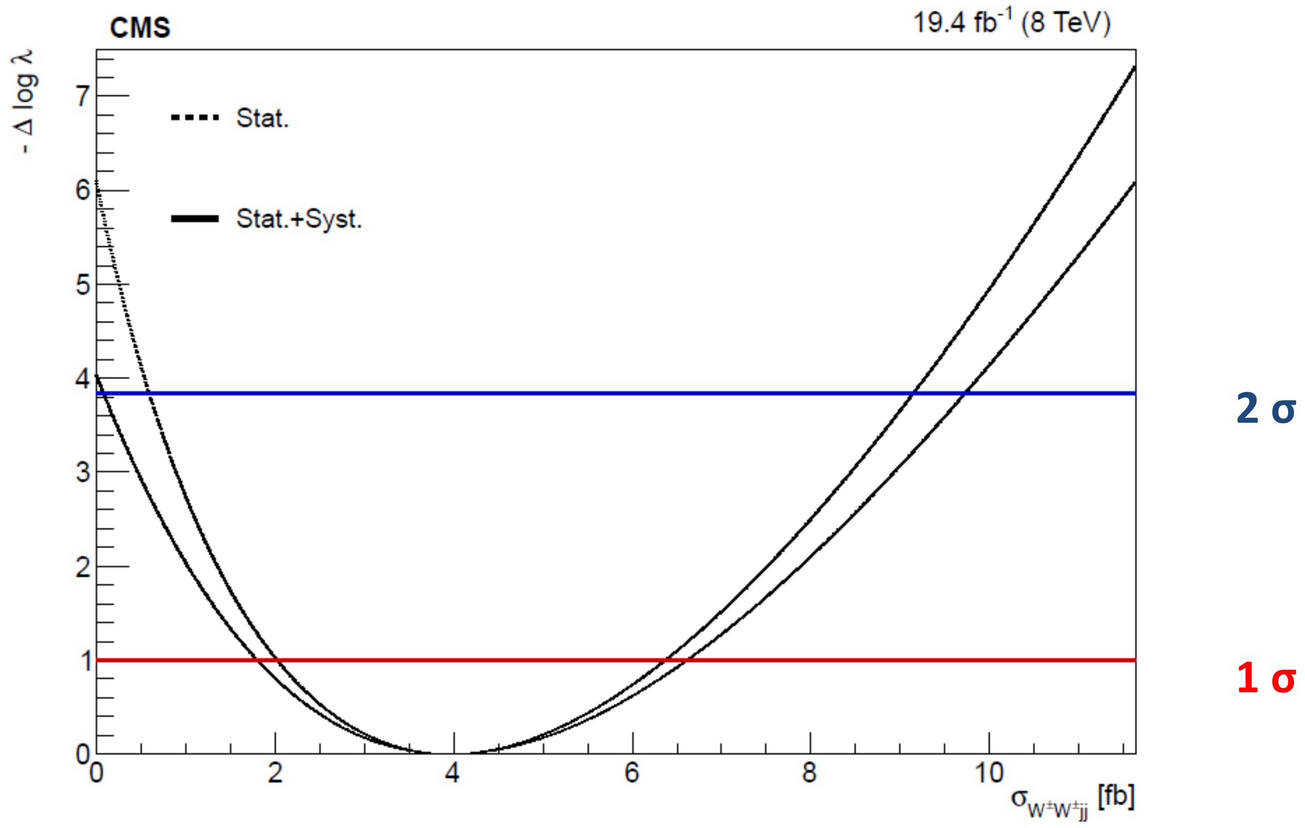
- $\frac{\text{\# of reconstructed selected events from fiducial region}}{\text{\# of generated events in fiducial region}} = 7.30\%$
- $\frac{\text{\# of reconstructed selected events}}{\text{\# of generated events in fiducial region}} = 7.35\%$

Alternative Fiducial Region

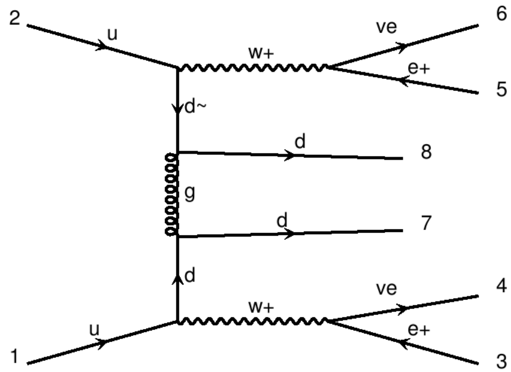
- $pT_l > 20$ GeV
- $pT_j > 30$ GeV
- $m_{jj} > 500$ GeV
- $|\Delta\eta_{jj}| > 2.5$
- $|\eta_l| < 2.5$
- $|\eta_j| < 5.0$
- $\frac{\#\text{ of reconstructed selected events from fiducial region}}{\#\text{ of generated events in fiducial region}} = 9.30\%$
- $\frac{\#\text{ of reconstructed selected events}}{\#\text{ of generated events in fiducial region}} = 9.80\%$

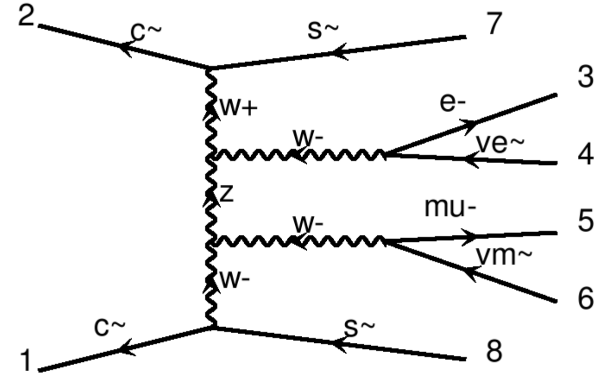
Fiducial Cross Section Result

- $\sigma_{\mathrm{fid}} = 4.0^{+2.4}_{-1.9}\,(\mathrm{stat.})^{+1.1}_{-1.0}\,(\mathrm{syst.})\;\mathrm{fb}$



$W^{\pm}W^{\pm}jj$ Sample



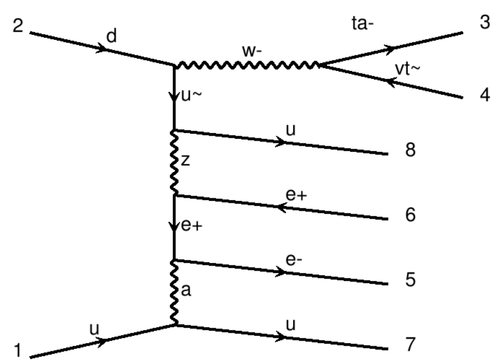


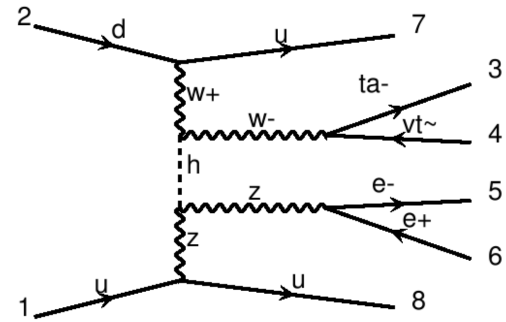
Means at most 4 QED or electroweak vertices and at most 2 QCD vertices before the W decays

l = electron, muon, tau

MadGraph syntax: p p > w+ w+ j j QED=4 QCD=2, w+ > l+ vl

WZjj Sample

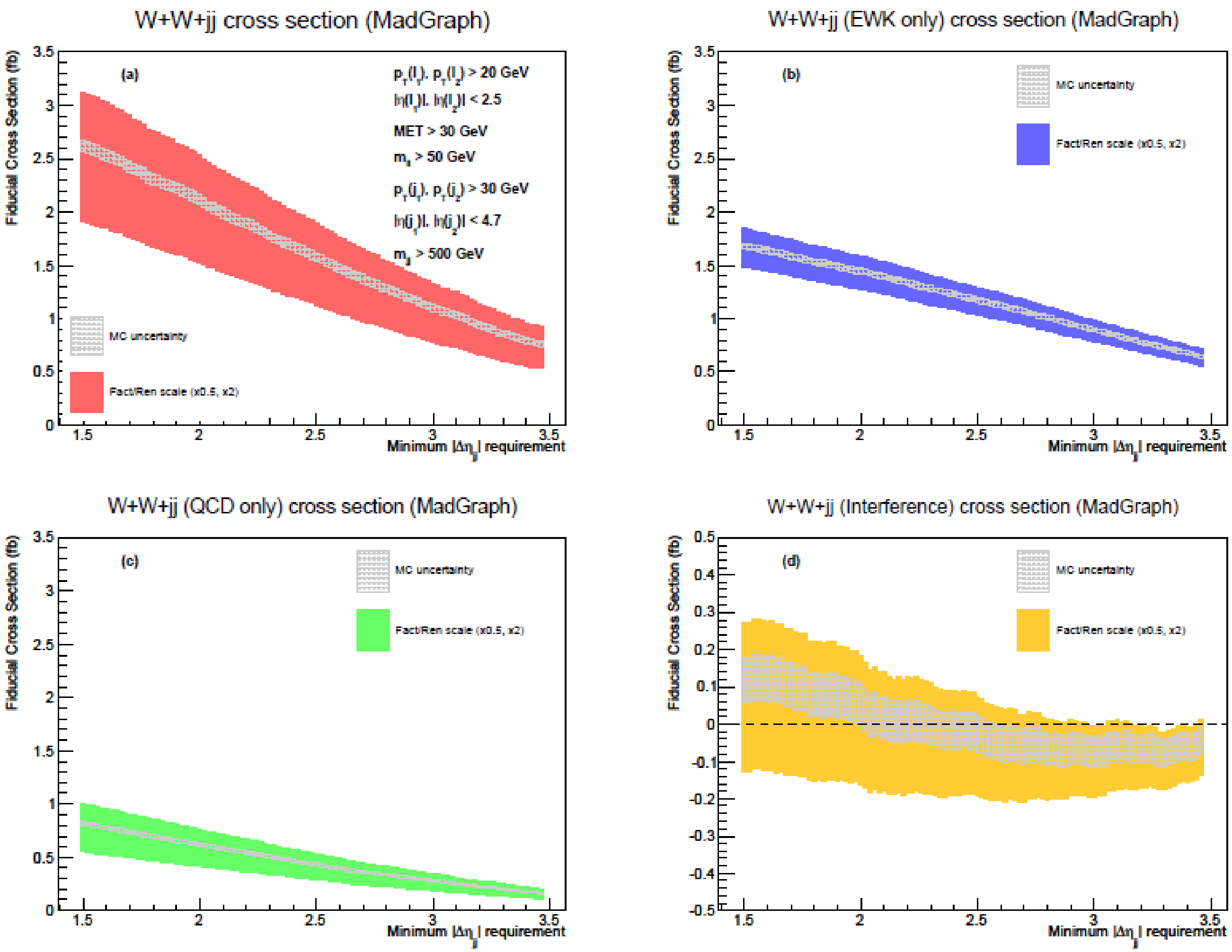




MadGraph syntax: p p > w- l- l+ j j QED=5 QCD=2, w- > l- vl~

Diagrams are just representative. There are actually 4080 diagrams for $W^{\pm}W^{\pm}jj$ and 52568 diagrams for WZjj.

Effect of QCD Scale on Interference



ATLAS-CMS comparisons

VBS Signal Region				
	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$	Total
$W^{\pm}W^{\pm}$jj Electroweak	2.55 ± 0.25	7.3 ± 0.6	4.0 ± 0.4	13.9 ± 1.2
$W^{\pm}W^{\pm}$jj Strong	0.25 ± 0.06	0.71 ± 0.14	0.38 ± 0.08	1.34 ± 0.26
$WZ/\gamma^{*}, ZZ, t\bar{t}+W/Z$	2.2 ± 0.5	4.2 ± 1.0	1.9 ± 0.5	8.2 ± 1.9
$W+\gamma$	0.7 ± 0.4	1.3 ± 0.7	–	2.0 ± 1.0
OS prompt leptons	1.39 ± 0.27	0.64 ± 0.24	–	2.0 ± 0.5
Other non-prompt	0.50 ± 0.26	1.5 ± 0.6	0.34 ± 0.19	2.3 ± 0.7
Total Predicted	7.6 ± 1.0	15.6 ± 2.0	6.6 ± 0.8	29.8 ± 3.5
Data	6	18	10	34

	Data	$W^{\pm}W^{\pm}jj$	Total bkg.	Non-prompt	WZ	VVV	Wrong sign	WW DPS
$W^{\pm}W^{\pm}$	12	8.8 ± 0.2	5.7 ± 0.8	4.2 ± 0.8	1.0 ± 0.1	0.3 ± 0.1	0.1 ± 0.08	0.1 ± 0.1
$W^{+}W^{+}$	10	7.0 ± 0.2	3.1 ± 0.6	2.1 ± 0.6	0.6 ± 0.1	0.2 ± 0.1	0.1 ± 0.08	0.1 ± 0.1
$W^{-}W^{-}$	2	1.8 ± 0.1	2.6 ± 0.6	2.1 ± 0.5	0.4 ± 0.1	0.1 ± 0.1	—	—

Systematic Uncertainties (in percent)

Source	Signal	WW DPS	WZ	Wrong sign	VVV	Non-prompt
Luminosity	2.6	2.6	-	2.6	2.6	-
Lepton efficiency	3.6	3.6	3.6	3.6	3.6	-
Momentum resolution	0.2	0.2	0.2	0.2	0.2	-
b-tagging	2.0	2.0	-	2.0	2.0	-
$E_{\mathrm{T}}^{\mathrm{miss}}$	1.0	1.0	1.0	1.0	1.0	-
JES	3.0	3.0	3.0	3.0	3.0	-
PDF	7.7	7.0	7.1	-	-	-
QCD scales EWK	5.0	-	-	-	-	-
QCD scales VVV	-	-	-	-	50.0	-
WZ normalization	-	-	37.0	-	-	-
Wrong sign normalization	-	-	-	10.0	-	-
Nom-prompt normalization	-	-	-	-	-	36.0
Statistical uncertainty	2.0	57.0	15.0	55.0	18.0	19.0

Limits on dimension 8 operator coefficients

- Units are TeV^{-4}

Operator coefficient	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity limit
$F_{S,0}/\Lambda^4$	-42	43	-38	40	0.016
$F_{S,1}/\Lambda^4$	-129	131	-118	120	0.050
$F_{M,0}/\Lambda^4$	-35	35	-33	32	80
$F_{M,1}/\Lambda^4$	-49	51	-44	47	205
$F_{M,6}/\Lambda^4$	-70	69	-65	63	160
$F_{M,7}/\Lambda^4$	-76	73	-70	66	105
$F_{T,0}/\Lambda^4$	-4.6	4.9	-4.2	4.6	0.027
$F_{T,1}/\Lambda^4$	-2.1	2.4	-1.9	2.2	0.022
$F_{T,2}/\Lambda^4$	-5.9	7.0	-5.2	6.4	0.08