Di-boson production measurements
with ATLAS detector
On behalf of the ATLAS Collaboration

Introduction

$W\gamma, Z\gamma$ cross section

$WZ, ZZ$ cross section

$WW+WZ$ semi-leptonic

$WW$ cross section

VBF/VBS
See talk N.L. Martinez

aTGC

Summary

$WZ \rightarrow 3l\nu$

Laurent Chevalier
CEA-Saclay, eps-hep 2015, Vienna 22-29 July
LHC measurements → Standard Model: almost perfect?

**Introduction**

- $W\gamma, Z\gamma$ cross section
- $WZ, ZZ$ cross section
- $WW+WZ$ semi-leptonic
- $WW$ cross section
- VBF/VBS
  - See talk
  - N.L. Martinez

**Summary**

14 orders of magnitude

**Figure**

- ATLAS Preliminary
  - Run 1 $\sqrt{s} = 7, 8$ TeV
  - $LHC pp \sqrt{s} = 7$ TeV
    - Theory
    - Observed $4.5 - 4.9$ fb$^{-1}$
  - $LHC pp \sqrt{s} = 8$ TeV
    - Theory
    - Observed $20.3$ fb$^{-1}$

- $\sigma$ [pb]
- $0.1 < p_T < 2$ TeV
- $0.3 < m_{jj} < 5$ TeV
- $n_j \geq 0$ 35 pb$^{-1}$
- $n_j \geq 1$
- $n_j \geq 2$
- $n_j \geq 3$
- $n_j \geq 4$
- $n_j \geq 5$
- $n_j \geq 6$
- $n_j \geq 7$
- $n_j \geq 8$
- Total $ggF H \rightarrow WW$
- $H \rightarrow WW$
- $H \rightarrow \gamma \gamma$
- $W + Z$ total
- $W + ZZ$ total
- $t\bar{t}W$ total
- $t\bar{t}Z$ total
- $Z\gamma$ total
- $W\gamma$ total
- $W^+W^-$ total
- $WW+ZZ$ total

→ Precise measurements
→ Anomalous coupling

LHC pp $\sqrt{s} = 7$ TeV
- Theory
- Observed 4.5 – 4.9 fb$^{-1}$

LHC pp $\sqrt{s} = 8$ TeV
- Theory
- Observed 20.3 fb$^{-1}$

Summary
**SM**

Non-Abelian structure of $SU(2)_L \times U(1)_Y$

allow TGC (charged only) & QGC (charged only)

**EFT**

$\Lambda$: scale of new physics

$O_i^{(d)}$: new operators of higher dimensions $(d)$

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_d \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} O_i^{(d)}$$

=> Modify differential and total cross sections
**Wγ & Zγ cross sections at 7 TeV**

**Wγ, Zγ cross section**

**Wγ/Zγ → ℓνγ, ℓℓγ, ννγ**
- high $E_T$ isolated photon
- high $p_T$ isolated lepton
- $\Delta R_{(\text{lepton, photon})} > 0.7$

**BKG**
- $W/Z$+jets
- $γ$+jets
- $W → eν$

**Remarks:**
- $Zγ$ fair agreement
- $Wγ$ measurement above NLO
- NNLO QCD corrections are needed (see next slide)
Introduction

**Wγ & Zγ cross sections at 7 TeV**

**NNLO QCD corrections are needed**

- **Wγ**: arXiv:1407.1618v1 [hep-ph]

**Graph**

- pp→lνγ+X, √s=7 TeV
- MSTW2008

**Legend**

- **ATLAS**
- **NLO**
- **NNLO**

**Summary**

- VBF/VBS
- See talk
- N.L. Martinez

**aTGC**
WZ & ZZ cross sections at 7 and 8 TeV

Introduction

Wγ,Zγ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS
See talk N.L. Martinez

aTGC

Summary

ZZ → 4l
• 4 high pT leptons
• bkg negligible

Run Number: 183602, Event Number: 282919
Date: 2011-06-18, 06:36:40 CET

• ATLAS-CONF-2014-033
• ATLAS-CONF-2013-020
• JHEP03(2013)128
WZ & ZZ cross sections at 7 and 8 TeV

**WZ → lνll**
- 3 high $p_T$ & isolated leptons
- $E_{T}^{miss} > 25$ GeV
- $66$ GeV $< M_{Z→ll} < 116$ GeV

**BKG**
- $Z$+jets ($\sim 15\%$): data driven
- ZZ ($\sim 5\%$): from MC
- Top ($\sim 4\%$): data driven
- $W/Z+\gamma$ ($\sim 3\%$): from MC

**ZZ → llll**
- 4 high $p_T$ leptons
- BKG negligible

**ZZ → lllν** (7 TeV only)
- Axial $E_{T}^{miss} > 80$ GeV

**BKG**
- WZ ($\sim 20\%$): from MC
- WW+Top ($\sim 16\%$): data driven

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**Introduction**

Wγ, Zγ cross section

WZ, ZZ cross section

WW+ZZ semi-leptonic

WW cross section

VBF/VBS

See talk N.L. Martinez

aTGC

Summary
**WW + WZ in semi-leptonic mode at 7 TeV**

**WW+WZ→lvjj**
- high $p_T$ isolated lepton
- $E_{miss}^\tau$ cuts

**BKG**
- $W/Z+\text{jets}$ (~89%) : data driven
- multi-jets ( ~5%) : data driven
- Top ( ~4%) : from MC

- **All contributions including TGC, observed with a 3.4 $\sigma$ confidence**
- **SM consistent**

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**Introduction**

$W\gamma, Z\gamma$ cross section

$WZ, ZZ$ cross section

**WW+WZ** semi-leptonic

**WW** cross section

VBF/VBS

See talk N.L. Martinez

**Summary**

- JHEP01(2015)049
- arXiv:1410.7238
**WW cross section at 8 TeV**

- **WW → lνlν**
  - 2 isolated high $p_T$ leptons (opp. charge)
  - $E_{miss}$
  - Hard jet veto (reject tt & single-top)

**Introduction**

*Wγ, Zγ cross section*

*WZ, ZZ cross section*

*WW + WZ semi-leptonic*

*WW cross section*

*VBF/VBS*

See talk N.L. Martinez

**Summary**

ATLAS-CONF-2014-033
**WW cross section at 8 TeV**

**WW→lνlν (in 0-jet bin)**
- 2 isolated high $p^T$ leptons (opp. charge)
- $E_{\text{miss}}^T$ (45, 45, 25 GeV: ee, eµ, µµ)
- hard jet veto (reject tt & single-top)

**BKG**
- Top (~15%)
- W+jets (~5%)
- Drell-Yan (~5%)

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**Summary**

- Whatever the pdf chosen
  - CT10, MSTW2008,...
- NNLO corrections: up to 10%
  - See arXiv:1408.5243
- Re-summation at large logs partially explain excess → arXiv:
  - 1407.4537, 1407.4481
  - 1507.02565v1

$\sim 2.1 \sigma$ higher than SM
**Introduction**

- **$W\gamma, Z\gamma$ cross section**
- **$WZ, ZZ$ cross section**
- **$WW+WZ$ semi-leptonic**
- **$WW$ cross section**

**Summary**

See talk N.L.Martinez

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**VBF/VBS**

- Run Number: 207490
- Event Number: 33152138
- Date: 2012-07-26, 05:16:35 CET

- **Muon**: blue
- **Cells**: Tile, EM, FCal, HEC

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**Topologies**

**VBF/VBS**

See talk N.L.Martinez

**ATLAS**

- Data 2012
- Syst. Uncertainty
- $WWjj$ Electroweak
- $WWjj$ Strong
- Prompt
- Conversions
- Other non-prompt

**8TeV**

$|\Delta y| > 2.4$

**Pseudo-Rapidity between the 2 jets**

**Topology: forward jets**

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PRL 113, 141803 (2014)
aTGC

Anomalous couplings:
- increase cross sections and modification of kinematic distributions
- Anomalous effect from beyond SM
- physics can be modelled (SM+higher dimension operators)
Summary of cross section

Di-boson in ATLAS:

- **$W\gamma, Z\gamma$ cross section at 7 TeV (4.6fb$^{-1}$, NNLO)**
  - $W\gamma \rightarrow l\nu\gamma$: $2.77 \pm 0.03$ (stat) $\pm 0.33$ (syst) $\pm 0.14$ (lumi)
  - $Z\gamma \rightarrow ll\gamma$: $1.31 \pm 0.02$ (stat) $\pm 0.11$ (syst) $\pm 0.05$ (lumi)

- **WZ cross-section**
  - 7 TeV: 4.6fb$^{-1}$ $19.0^{+1.4}_{-1.3}$ (stat) $\pm 0.9$ (syst) $\pm 0.4$ (lumi)
  - 8 TeV: 13.0fb$^{-1}$ $20.3^{+0.8}_{-0.7}$ (stat) $^{+1.2}_{-1.1}$ (syst) $^{+0.7}_{-0.6}$ (lumi)

- **ZZ cross-section**
  - 7 TeV: 4.6fb$^{-1}$ $6.7 \pm 0.7$ (stat) $^{+0.4}_{-0.3}$ (syst) $\pm 0.3$ (lumi)
  - 8 TeV: 20.3fb$^{-1}$ $7.1^{+0.5}_{-0.4}$ (stat) $\pm 0.3$ (syst) $\pm 0.2$ (lumi)

- **WW+WZ semi-leptonic**
  - 7 TeV: 4.6fb$^{-1}$ $68. \pm 7$ (stat) $\pm 19$ (syst)

- **WW cross-section**
  - 7 TeV: 4.6fb$^{-1}$ $51.9 \pm 2.0$ (stat) $\pm 3.9$ (syst) $\pm 2.0$ (lumi)
  - 8 TeV: 20.3fb$^{-1}$ $71.4 \pm 1.2$ (stat) $^{+5.0}_{-4.4}$ (syst) $^{+2.2}_{-2.1}$ (lumi)

- ~2.1 $\sigma$ higher than SM

- aTGC
  - No deviation

Introduction

W$\gamma$, Z$\gamma$ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS

See talk N.L. Martinez

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Summary

Including Higgs
Summary

- Run-1 allowed to explore di-boson production processes: **SM consistent**

- Most di-boson measurements are systematically limited.

- Tri-boson and VBS processes are accessible.

- Promising Run-2 analysis!
backup
Signature

- Leptons/photons
  - High-pT
  - Isolated
- Z Bosons
  - Invariant mass in windows around the Z pole
- W Bosons
  - Large Missing ET to account for the neutrino
  - Transverse mass selection

Background

Estimated with data driven methods
- V+jets
  - Genuine high-pt leptons from boson decay
  - Leptons from heavy flavour decays
  - Jets misidentified as leptons/photons
  - Particles outside the detector acceptance => Missing ET
- tt(bar) and single top
  - Prompt isolated leptons from W leptons
  - Large Missing ET
Number of data events

Number of background events

Luminosity

Branching Ratio

Efficiency corrections

Acceptance

\[ \sigma_{fid} = \frac{N_{data} - N_{bkg}}{C \cdot \int L dt} \]

\[ \sigma_{tot} = \frac{N_{data} - N_{bkg}}{A \cdot C \cdot BR \cdot \int L dt} \]

\[ A = \frac{N_{MC, gen}^{fid}}{N_{MC, gen}^{tot}} \]

\[ C = \frac{N_{\text{Selected}}^{Reco}}{N_{MC, gen}^{fid}} \]
Introduction

$W_\gamma, Z_\gamma$

cross section

$WZ, ZZ$

cross section

$WW + WZ$

semi-leptonic

$WW$

cross section

VBF/VBS

See talk

N.L. Martinez

 Summary

aTGC

$
\Delta g^Z_1 = \Delta \kappa_Z + \tan^2 \theta_W \Delta \kappa_\gamma$

$$
\begin{align*}
\mathcal{L}_{\text{eff}} &= \mathcal{L}_{\text{SM}} + \sum_d \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)} \\
\mathcal{L} &= ig_{WWV} \left( g^V_1 (W^\mu_\nu W^-_{\mu\nu} - W^+_{\mu\nu} W^-_{\mu\nu}) V^\nu + \kappa_V W^\mu_\nu W^-_{\mu\nu} V^\nu + \frac{\lambda_V}{M^2_W} W^\mu_\nu W^-_{\mu\nu} V^\nu \right) \\
&+ ig^V_4 W^+_{\mu\nu} V^-_{\nu\rho} (\partial^\rho V^\nu + \partial^\nu V^\rho) - ig^V_5 \epsilon^{\mu\nu\rho\sigma} (W^+_{\mu\nu \rho} W^-_{\rho\sigma} - \partial_\rho W^+_{\mu\nu} W^-_{\rho\sigma}) V^\nu \\
&+ \tilde{\kappa}_V W^+_{\mu\nu} \tilde{W}^\mu_{\nu\rho} + \frac{\tilde{\lambda}_V}{M^2_W} W^+_{\mu\nu} W^-_{\mu\nu} \tilde{V}^\nu_{\rho} \tilde{V}^\mu_{\rho} \right),
\end{align*}
$$

EFT

SM

aTGC

$\mathcal{L}_{\text{SM}}$

$W$

TGC

$Z \gamma$

$W$

$\Delta g^Z_1 = \Delta \kappa_Z + \tan^2 \theta_W \Delta \kappa_\gamma$

$g_1^Z = 1 + c_W \frac{m_Z^2}{2\Lambda^2}$

$\kappa_\gamma = 1 + (c_W + c_B) \frac{m_W^2}{2\Lambda^2}$

$\kappa_Z = 1 + (c_W - c_B \tan^2 \theta_W) \frac{m_W^2}{2\Lambda^2}$

$\lambda_\gamma = \lambda_Z = c_{WWW} \frac{3g^2 m_W^2}{2\Lambda^2}$

$g_4^V = g_5^V = 0$

$\tilde{\kappa}_\gamma = c_{WW} \frac{m_W^2}{2\Lambda^2}$

$\tilde{\kappa}_Z = -c_W \tan^2 \theta_W \frac{m_W^2}{2\Lambda^2}$

$\tilde{\lambda}_\gamma = \tilde{\lambda}_Z = c_{WWW} \frac{3g^2 m_W^2}{2\Lambda^2}$
**Wγ & Zγ cross sections at 7 TeV**

**Wγ / Zγ → lνγ, llγ, ννγ**
- Single lepton or photon triggers:
  - Electrons: 20-22 GeV
  - Muons: 18 GeV
  - Photons: 80 GeV
- |d0|/σd0 < 10(3) e(μ)
- |z0| < 1mm
- Calorimeter isolation in cone ΔR < 0.3 less than 6 GeV (e)
- pT isolation in cone ΔR < 0.3 less than 15% of the μ pT
- Wγ modelled with ALPGEN (CTEQ6L1)
- Zγ, ννγ modelled with Sherpa (CTEQ6.6M)

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### $W\gamma$ & $Z\gamma$ cross sections at 7 TeV

**pb (data)**

Di-boson in ATLAS:

- $W\gamma, Z\gamma$ cross section at 7 TeV (4.6fb⁻¹)
  - $W\gamma \rightarrow l\nu\gamma$: $2.77 \pm 0.03$ (stat) $\pm 0.33$ (syst) $\pm 0.14$ (lumi) $1.96 \pm 0.17$
  - $Z\gamma \rightarrow ll\gamma$: $1.31 \pm 0.02$ (stat) $\pm 0.11$ (syst) $\pm 0.05$ (lumi) $1.18 \pm 0.05$
  - $Z\gamma \rightarrow l\nu\nu$: $0.133 \pm 0.01$ (stat) $\pm 0.02$ (syst) $\pm 0.05$ (lumi) $0.156 \pm 0.012$

---

### Summary

**pb (theory)**
WZ & ZZ cross sections at 7 and 8 TeV

Introduction

$W\gamma, Z\gamma$ cross section

$WZ, ZZ$ cross section

$WW+WZ$ semi-leptonic

$WW$ cross section

VBF/VBS
See talk
N.L. Martinez

Summary

Backgrounds to ZZ$\rightarrow$ll$\nu\nu$:

- $WZ\rightarrow$llll: MC based, validated using trilepton control region
- $WW$/top/Z$\tau\tau$: real $E_T^{\text{miss}}$, data driven, flavor symmetry
- $Z$+jets: fake $E_T^{\text{miss}}$, estimated with $\gamma$+jets events
- $W$+jets/QCD: fake lepton, matrix method and fake-factor method
- Others: ZZ$\rightarrow$4l
WZ & ZZ cross sections at 7 and 8 TeV

### Electrons

**Central Electron Selection:**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>$\ell^+\ell^-\nu\bar{\nu}$ final state</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $e$: Type</td>
<td>author==1 or 3</td>
</tr>
<tr>
<td>2. $e$: Quality</td>
<td>(OQ AND 1446 == 0)</td>
</tr>
<tr>
<td>3. $e$: ID cut</td>
<td>Medium++</td>
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<tr>
<td>4. $e$: $\eta$</td>
<td>$</td>
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<tr>
<td>5. $e$: $E_T$</td>
<td>$E_T &gt; 25$ GeV</td>
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<tr>
<td>6. $e$: $z_0 \ast \sin(\theta)$</td>
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<td>7. $e$: $d_0$</td>
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<tr>
<td>8. $e$: Track isolation</td>
<td>$\Sigma p_T(\Delta R &lt; 0.2)/p_T &lt; 15%$</td>
</tr>
<tr>
<td>9. $e$: Calo isolation</td>
<td>$\Sigma E_T(\Delta R &lt; 0.2)/E_T &lt; 15%$</td>
</tr>
</tbody>
</table>
| 10. $e$: Overlap removal | a) Remove $e$ if $\Delta R < 0.1$ from $\mu$
   b) Remove lowest $E_T$ $e$ in $\Delta R < 0.1$ from another $e$ |

### Muons

**Standard Muons**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>$\ell^+\ell^-\nu\bar{\nu}$ final state</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $\mu$: type</td>
<td>Combined, “loose” STACO muons,</td>
</tr>
<tr>
<td>2. $\mu$: $p_T$ and $\eta$</td>
<td>$p_T &gt; 25$ GeV, $</td>
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<tr>
<td>3. $\mu$: ID hits</td>
<td>MCP recommendations</td>
</tr>
<tr>
<td>4. $\mu$: $z_0 \ast \sin(\theta)$</td>
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<tr>
<td>5. $\mu$: $d_0$</td>
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<tr>
<td>6. $\mu$: track iso</td>
<td>$\Sigma p_T(\Delta R &lt; 0.2)/p_T &lt; 15%$</td>
</tr>
<tr>
<td>7. $\mu$: calo iso</td>
<td>$\Sigma E_T(\Delta R &lt; 0.2)/E_T &lt; 15%$</td>
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</tbody>
</table>

### Jets

**AntiKT4LCTopo Jets**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>$\ell^+\ell^-\nu\bar{\nu}$ final state</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. jet: $p_T$ and $\eta$</td>
<td>$p_T &gt; 25$ GeV, $</td>
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<tr>
<td>2. jet: Bad Jets</td>
<td>Remove events with &quot;LooserBad&quot; jets</td>
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<tr>
<td>3. jet: JVF</td>
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<tr>
<td>4. jet: Overlap removal</td>
<td>Remove jets if overlapped with selected leptons, $\Delta R &lt; 0.3$</td>
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</table>

**MET:** RefFinal
WZ & ZZ cross sections at 7 and 8 TeV

Total phase-space: $66 < m_{Z1}, m_{Z2} < 116$ GeV

Fiducial phase-space:

- 2 pairs of opposite sign same flavor leptons
- $p_T^\ell > 7$ GeV
- $66 < m_Z < 116$ GeV
- $\Delta R(\ell, \ell) > 0.2$ (all leptons)
- $4\mu$: $|\eta_\mu| < 2.7$
- $2e2\mu$:
  - $|\eta_\mu| < 2.7$
  - $|\eta_e| < 2.5$ (both $e$), OR $|\eta_{e_1}| < 2.5$ and $|\eta_{e_2}| < 4.9$
- $4e$:
  - $|\eta_e| < 2.5$ (all $e$), OR $|\eta_e| < 2.5$ (3$e$) and $|\eta_{e_4}| < 4.9$
- 2 same-flavor opposite sign leptons
- $76$ GeV < $m_Z$ < 106 GeV
- $p_T^\ell > 25$ GeV
- Axial-$E_T^{\text{miss}} > 90$ GeV
- $\frac{|p_T^{V\bar{V}} - p_T^Z|}{p_T^Z} < 0.4$
- $|\eta_\ell| < 2.5$
- No jets with $p_T > 25$ GeV and $|\eta| < 4.5$ (remove jets with electrons $\Delta R = 0.3$)
- $\Delta R(\ell, \ell) > 0.3$
WW & WZ in semi-leptonic mode at 7 TeV

**WW/WZ→lνjj**
- Exactly one high-pT isolated lepton pT>25 GeV
- \(|d0 / σ(d0)| < 3\) (10) for muons (electrons)
- \(|z0| < 1\) mm
- ETmiss > 30 GeV, mT,W > 40 GeV
- Exactly two jets with pT > 25 GeV and |η| < 2.8 (pT > 30 GeV for the leading jet)
- Azimuthal angular separation between the leading jet pT and the Etmiss vectors must fulfil |Δφ(ETmiss,j1)| > 0.8
- |Δη(j1,j2)| < 1.5, ΔR(j1, j2) > 0.7 if pT of the dijet system is less than 250 GeV
- 25 < mjj < 250 GeV
**WW production at 8 TeV**

**WW→lνlν (in 0-jet bin)**

- Lowest order: \(W±W± + 2\)jets, there is no SM inclusive \(W±W±\)
- for EW+strong measurement ("inclusive signal phase space")
  - exactly 2 high \(p_T\) same-sign leptons with \(p_T > 25\) GeV in \(|\eta| < 2.5\)
  - \(m_{ll} > 20\) GeV, \(\Delta R_{ll} > 0.3\)
  - \(\geq 2\) jets with \(p_T > 30\) GeV, \(|\eta| < 4.5\)
  - ETmiss > 40 GeV (from W decays)
  - veto events containing b-jets
  - Z-veto in ee channel: \(|m_{ee} - m_Z| > 10\) GeV
  - \(m_{jj} > 500\) GeV
- for EW-only measurement ("VBS signal phase space")
  - additional cut on \(|\Delta Y_{jj}| > 2.4\)
**WW production at 8 TeV**

**WW→lνlν** (in 0-jet bin)
- 2 isolated high $p_T$ leptons (opp. charge)
- $E_{\text{miss}}$ (45,45,25 GeV: ee,e$\mu$,\mu$\mu$)
- hard jet veto (reject tt & single-top)
- Z veto (15,10 GeV: ee, \mu$\mu$)

**BKG**
- Top (~15%)
- W+jets (~5%)
- Drell-Yan (~5%)

**Summary**
- NNLO corrections: up to 10% (arXiv:1408.5243)
- re summation at large logs: partially explain excess (arXiv:1407.4537,1407.4481,1507.02565v1)
WW production at 7 & 8 TeV

CMS  \[ 60.1 \pm 0.9 \text{(stat.)} \pm 3.2 \text{(exp.)} \pm 3.1 \text{(th.)} \pm 1.6 \text{(lum.)} \text{ pb.} \]

ATLAS  \[ 71.4^{+1.2}_{-1.2} \text{(stat)} +^{5.0}_{-4.4} \text{(syst)} +^{2.2}_{-2.1} \text{(lumi)} \text{ pb} \]

ATLAS and CMS in agreement.

Theoretical predictions cited:
- 59.8 ± 1.2 pb (CMS)
- NNLO "qqbar+qq" (no H)
- 58.7 ± 2.9 pb (ATLAS)

NLO qqbar + LO gg + NNLO H
Vector Boson Scattering topology: **unitary issue**
Pair of same charge W with 2 jets
Quartic Gauge Vertex contribution
W in leptonic mode: \( W \rightarrow l\nu \) \((l=e,\mu)\)

**Phys. Rev. Lett. 113, 141803**
Transverse-momentum resummation for vector-boson pair production at NNLL+NNLO
Massimiliano Grazzini, Stefan Kallweit, Dirk Rathlev, Marius Wiesemann

$W^+W^- @ 8$ TeV

Veto efficiency vs. $p_T$ veto [GeV]

Ratio to NNLL vs. $p_T$ veto [GeV]