DiBoson Production Cross Section at Ecm=8 TeV
DiBoson Production

Test SM predictions, probe new phenomena/aTGCs, background to Higgs

![Graph showing DiBoson Production](image)
DiBoson Analyses Overview

- Leptonic W/Z decay channels allow signal extraction from large BG (ℓ = e or μ)
- SM BR(W→ ℓν) = 0.108, BR(Z→ ℓℓ) = 0.03366
- Experimental signature: isolated high p_T leptons, MET if ν present
- Common backgrounds: Top, V+jets/γ, other diboson processes
- Data driven methods used where possible

Today’s menu:

WW → ℓνℓν
WZ → ℓνℓℓ
ZZ → ℓℓℓℓ
ZZ → ℓℓνν
VZ → Vbb

Today’s specials:

W±W± jj → ℓνℓν jj
Z → 4ℓ
Main Preselection Cuts:
- $p_T(\ell) > 20$ GeV, 3rd $\ell$ veto $>10$ GeV
- No jets with $p_T > 30$ GeV, $|\eta| < 4.7$
- $MET_{rel} > 45/45/20$ GeV (ee, $\mu\mu$, $e\mu$)
- $|m_{\ell\ell}-m_Z| > 15$ GeV (ee, $\mu\mu$)
- $m_{\ell\ell} > 12$ GeV (ee, $\mu\mu$),
- $p_T(\ell\ell) > 45$ GeV

Major backgrounds: V+jets, Top, VV

Expected S/B: ~2.5
Main syst: jet veto efficiency

Measured total cross section:
- $\sigma_{WW} = 69.9\pm2.8$(stat)$\pm5.6$(syst)$\pm3.1$(lum) pb.
- SM: $\sigma_{WW}$ (NLO) = 57.3$^{+2.3}_{-1.6}$ pb
  (Higgs contribution @ $m_H$ 125 GeV: +4%)

[PLB 721 (2013) 190–211]
WZ → ℓνℓℓ

Preselection:
- Z: 2ℓ, p_T > 15 GeV,
- |m_{ℓℓ} - m_Z| < 10 GeV,
- W: 3rd ℓ, p_T > 20 GeV,
- MET > 25 GeV,
- m_T > 20 GeV

Major backgrounds: Z+j/γ, ZZ, Top

- Expected S/B: 3.0
- Main systs: reco acceptance, BG, lumi

Measured total cross section:
\[ \sigma_{WZ} = 20.3^{+0.8}_{-0.7} \text{ (stat)} ^{+1.2}_{-1.1} \text{ (syst)} ^{+0.7}_{-0.6} \text{ (lumi)} \text{ pb} \]
- SM: \( \sigma_{WZ} \) (NLO) = 20.3 ± 0.8 pb
- xsecs in common fid. vol. provided as well

WZ xsec vs. center-of-mass energy:
WZ → ℓνℓℓ (II) [CMS-PAS-SMP-12-006]

Measured total cross section (ratio):
- \( \sigma_{WZ} = 24.6 \pm 0.8 \text{(stat)} \pm 1.1 \text{(syst)} \pm 1.1 \text{(lumi)} \text{ pb} \)
- \( \text{SM: } \sigma_{WZ} \text{ (NLO)} = 21.9_{-0.9}^{+1.2} \text{ pb} \text{ [71 GeV < } m_Z < 111 \text{ GeV]} \)
- \( \left( \frac{\sigma_{W^+Z}}{\sigma_{W^-Z}} \right)_{8 \text{ TeV}} = 1.81 \pm 0.12 \text{ (stat.)} \pm 0.03 \text{ (syst.)} \)
- xsec ratio SM expectation: 1.724 ± 0.003
Preselection:
- four leptons with $p_T > 7$ GeV,
- trigger matched $\ell$-$p_T > 25$ GeV,
- $66 \text{ GeV} < m_{\ell\ell} < 116 \text{ GeV}$ (each pair)
- Expected S/B: $\sim 14$

Major backgrounds: $V + j/\gamma$, top, $VV$

Measured total cross section:
- $\sigma_{ZZ} = 7.1^{+0.5}_{-0.4}\text{ (stat)} \pm 0.3\text{ (syst)} \pm 0.2\text{ (lumi)} \text{ pb}$
- SM: $\sigma_{ZZ} \text{ (NLO)} = 7.2^{+0.3}_{-0.2} \text{ pb}$ (both $Z$’s in mass window)
- xsecs in common fid. vol. provided as well
Preselection:
• similar to ATLAS,
• $60 \text{ GeV} < m_{\ell\ell} < 120 \text{ GeV}$ (each pair)
• include $Z \rightarrow \tau\tau$ for 2nd $Z$ candidate:
  $20/30 \text{ GeV} < m_{\tau\tau} < 90 \text{ GeV}$ (e$\mu$/other)
• Expected S/B for $\ell\ell\tau\tau$ : $\sim 1$

Measured total cross section:
• $\sigma_{ZZ} = 7.7^{+0.5}_{-0.5}(\text{stat})^{+0.5}_{-0.4}(\text{syst}) \pm 0.4(\text{theo}) \pm 0.3(\text{lumi}) \text{ pb}$
• SM: $\sigma_{ZZ}$ (NLO) $= 7.7 \pm 0.6 \text{ pb}$ [Z’s in mass window]
• Anom. coupling limits using $m_{4\ell}$ dist:
  $-0.004 < f_{4}^{\gamma,Z} < 0.004$, $-0.005 < f_{5}^{\gamma,Z} < 0.005$

normalized differential fiducial xsec:
ZZ → ℓℓνν

**Main preselection cuts:**
- 2 same flavour leptons of $p_T > 20$ GeV
- $|m_{ℓℓ} - m_Z| < 7.5$ GeV, $p_T(ℓℓ) > 45$ GeV
- $0.4 < \text{MET}/p_T(ℓℓ) < 1.8$
- reduced MET > 65 GeV
- No (b-)jets w/ $p_T > (20)30$ GeV, $|\eta| < (2.4)5$

**Major backgrounds:** WZ, Z+j, WW, Top

- Expected S/B: \( \sim 0.7 \)
- Main systs: JES, BG shape/norm.

**Measured cross section:**
- $\sigma_{ZZ} = 6.8^{+0.8}_{-0.8} \text{(stat)}^{+1.8}_{-1.4} \text{(syst)} \pm 0.3 \text{(lumi)}$ pb [60 GeV < $m_Z$ < 120 GeV]
- SM: $\sigma_{ZZ} \text{(NLO)} = 7.9^{+0.4}_{-0.2}$ pb

**Use** $p_T(ℓℓ)$ **distribution to set stringent limits on anom couplings** $f_{4,5}^V$ (=0 in SM):

```
CMS Preliminary 2012, $\sqrt{s}=8$ TeV

<table>
<thead>
<tr>
<th>Entries</th>
<th>ZZ → 2ℓν</th>
<th>WZ → 3ℓv</th>
<th>Z → 2ℓ (data)</th>
<th>top, WW, W+jets (data)</th>
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<td>Expected limit</td>
<td>Expected ± 1σ</td>
<td>Expected ± 2σ</td>
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95% CL limit on $σ/σ_{SM+TGC}$

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<th>0.001</th>
<th>0.01</th>
<th>0.1</th>
<th>1</th>
<th>10</th>
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</thead>
</table>
```
VZ → Vbb

Basic Preselection:
- 2 b-jets (|η| < 2.5), m_{jj} < 250 GeV
- 0ℓ(Z → νν): MET > 100 GeV
- 1ℓ(W → ℓν): MET > 45 GeV
- 2ℓ(Z → ℓℓ): 75 GeV < m_{ℓℓ} < 105 GeV
- Fit of multivariate discriminant / m_{jj}

Measured total cross section:
- $\sigma_{ZZ} = 6.5 \pm 1.7\text{(stat)} \pm 1.0\text{(syst)} \pm 0.9\text{(theo)} \pm 0.2\text{(lumi)}$ pb
- $\sigma_{WZ} = 30.7 \pm 9.3\text{(stat)} \pm 7.1\text{(syst)} \pm 4.1\text{(theo)} \pm 1.0\text{(lumi)}$ pb
- SM (NLO, 60 GeV < m_Z < 120 GeV): $\sigma_{ZZ} = 7.7 \pm 0.4$ pb, $\sigma_{WZ} = 22.3 \pm 1.1$ pb
- Fiducial xsecs (p_T(V)>100 GeV) also provided

Major backgrounds: V+j, top, VH

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(CMS-PAS-SMP-13-011)
Vector Boson Scattering

- VV → VV provides insight into EWSB mechanism, access to quartic couplings:
  
  electroweak VVjj production includes:

  strong VVjj production includes:

- Experimental signature (W±W± example):
  - 1,2 = Central, high-pT charged leptons from V decays
  - 3,4 = Forward/backward tagging jets (large mjj and well separated in y)
**W^±W^±jj → ℓνℓνjj**

**Preselection:**
- exactly 2 same-charge ℓ (p_T > 25 GeV)
- ≥ 2 jets, p_T > 30 GeV
- MET > 40 GeV, no b-jets
- mjj > 500 GeV, |Δy_jj| > 2.4

**Main backgrounds:** prompt ℓ (WZ/γ*+j), conversion (Wγ+j), non-prompt

**Expected S/B:** 0.9

**Main syst:** WZ/γ*+j norm. theo. uncert., JES

**Measured EW fiducial cross section:**
- σ_{EW}^{W±W±jj} = 1.3 ± 0.4(stat) ± 0.2(syst) fb
- SM: σ_{EW}^{W±W±jj} (NLO) = 0.95 ± 0.06 fb
- 1st evidence (3.6 σ) for EW W^±W^±jj prod.
- Access to WWWWW vertex, derive

1st limits on anom. quartic couplings α_{4,5}:
Basic Preselection:
- four leptons with $p_T > 4/7$ GeV ($\mu$/e),
- leading $\ell$-$p_T$'s > 20, 15, 8/10 GeV,
- $m_{12} > 20$ GeV, $m_{34} > 5$ GeV
- $4e$, $4\mu$: $m_{\ell\ell} > 5$ GeV
- $80$ GeV < $m_{4\ell}$ < $100$ GeV
- Expected S/B: ~145

Backgrounds: VV, Z+j, top

Measured total cross section: $[m_{\ell\ell} > 5\text{GeV}, 80 < m_{4\ell} < 100\text{GeV}]$
- $\sigma_{Z \rightarrow 4\ell} = 107 \pm 9 \text{ (stat)} \pm 4 \text{ (syst)} \pm 3 \text{ (lumi)} \text{ fb}$
- SM (NLO, 8 TeV): $\sigma_{Z \rightarrow 4\ell} = 104.8 \pm 2.5 \text{ fb}$

Measured $Z \rightarrow 4\ell$ branching fraction (7&8 TeV):
- subtract expected non-resonant contribs,
- normalize to $Z \rightarrow \mu\mu$ in same dataset:
  $\Gamma_{Z \rightarrow 4\ell}/\Gamma_Z = (3.20 \pm 0.25 \text{ (stat)} \pm 0.13 \text{ (syst)}) \times 10^{-6}$
- SM expectation: $(3.33 \pm 0.01) \times 10^{-6}$
**Summary**

**VV cross sections:**
- Compatible with SM expectations
- Differential xsecs probe MC modelling

**aGCs:**
- Competitive limits obtained

**Plans:**
- 8 TeV publications in preparation for all VV
- Analyses for VBF/VBS/VVV are ramping up
- Working towards combination across channels (& experiments)
- Need for coherent NLO+PS MC for all analyses; NNLO QCD, NLO EW
- 13/14 TeV data will allow measurements of new rare processes, probe NP
dessert
$\mu^+\mu^+jj$ Candidate Event

\[ m_{jj} = 2800 \text{ GeV} \quad |\Delta y_{jj}| = 6.3 \]