The WW story

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Based on 1407.4481 with Patrick Meade and Mao Zeng
1407.xxxx with Patrick Meade and Prerit Jaiswal.
Importance of WW

• LHC Era of Electroweak precision measurements
• WW is large background to H->WW. Higgs Precision Analysis
• WW huge background to many BSM searches
The WW Cross Section

• WW decaying into opposite sign dilepton
• One of few channels with a Jet Veto
• Results available for ATLAS and CMS @ 7&8TeV
• Indirect Results also available as background to H->WW
• Both ATLAS and CMS routinely reported excess.
Experimental Results
Summary-CMS

CMS Preliminary

CMS measurements vs. NLO theory

<table>
<thead>
<tr>
<th>Process</th>
<th>Experimental Result</th>
<th>Theoretical Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma \gamma ) (NNLO th.)</td>
<td>1.04 ± 0.11 ± 0.09</td>
<td>5.0 fb(^{-1} )</td>
</tr>
<tr>
<td>( W\gamma )</td>
<td>1.16 ± 0.13 ± 0.06</td>
<td>5.0 fb(^{-1} )</td>
</tr>
<tr>
<td>( Z\gamma )</td>
<td>0.98 ± 0.05 ± 0.05</td>
<td>5.0 fb(^{-1} )</td>
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<tr>
<td>( WW+WZ )</td>
<td>1.05 ± 0.20 ± 0.03</td>
<td>4.9 fb(^{-1} )</td>
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<tr>
<td>( WW )</td>
<td>1.22 ± 0.12 ± 0.04</td>
<td>3.5 fb(^{-1} )</td>
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<tr>
<td>( WZ )</td>
<td>1.17 ± 0.10 ± 0.03</td>
<td>4.9 fb(^{-1} )</td>
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<tr>
<td>( WZ )</td>
<td>1.12 ± 0.08 ± 0.05</td>
<td>19.6 fb(^{-1} )</td>
</tr>
<tr>
<td>( ZZ )</td>
<td>0.99 ± 0.15 ± 0.06</td>
<td>4.9 fb(^{-1} )</td>
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<td>( ZZ )</td>
<td>1.00 ± 0.10 ± 0.08</td>
<td>19.6 fb(^{-1} )</td>
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</table>

Production Cross Section Ratio: \( \sigma_{\text{exp}} / \sigma_{\text{theo}} \)

All results at: http://cern.ch/go/pNj7
WW Excess in Differential Direction

Could Shape Be Important?
How is $WW$ measured?

$$n = \sigma_{fid} L + n_{BG}$$

$$\sigma_{fid} = \sigma_{total} \epsilon \cdot A \cdot Br$$

- $\epsilon, A$: efficiency and Acceptance.
- $A$ captures the cuts placed.
- Jet-veto of 30GeV placed to reduce top background.
- $\sigma_{fid}$ is unfolded with respect to $\epsilon$ and $A$ to get $\sigma_{total}$
Can shape affect reported cross section?

Full Phase-space. Both curves Normalized to unity.

Shape effect translates to different Fiducial cross-section.
Theoretical Advances

• Total normalization effect complete NNLO calculation

\[\text{NLO+gg}: 57.25 \text{pb} (\text{MCFM})\]
\[\text{NNLO}: 59.84 \text{pb} (\text{T. Gehrmann et al. 1408.5243})\]

• Understanding higher order QCD effects to \textit{shape}:
  \[p_T \text{ resummation and jet veto resummation}\]
Need for Resummation

- In fixed order perturbation theory,

\[ \hat{O} = \sum \alpha_s^n c_n + e_n \]

- valid only if \( c_n \) & \( e_n \) are well behaved

- often in problems involving two length scales,

\[ c_n \sim (\text{Log}^2(r))^n \]

- where \( r \) is the ratio of two scales.

- These large logs spoil perturbation theory

- Way forward: resumming these large logs
Jet veto vs pT resummation

- Jet veto resummation: \( \log[\text{pT(veto)}/\text{mWW}] \).
- \( pT \) resummation: \( \log[ pT / \text{mWW} ] \)
- Transverse momentum of WW strongly correlated with jet pt.
- Whereas pT resummation gets the pT observable of WW right, jet veto resummation will predict the 0-jet cross-section.
Jet veto resummation results
Jaiswal, Okui (1407.4537)

Figure 6: Same as Fig. 5 but with MC samples generated using MC@NLO interfaced with HERWIG6 for parton-showering.

Figure 7: Same as Fig. 5 but with MC samples generated using POWHEG interfaced with Pythia6 for parton-showering.

4.4 Comparison with Experimental Results

Even though both ATLAS and CMS experiments present their measurements as the inclusive \( p_\text{p}! W + W \) cross section, we have seen that the jet-veto efficiencies they use to extrapolate from the measured jet-veto cross sections to the quoted inclusive cross sections suffer from the large logarithms that are not properly resummed by the MC+PS generators. Since both what they actually measured and what we calculated from SCET are the jet-veto cross section, not the inclusive cross section, we first must undo the jet-veto efficiencies from the inclusive cross sections quoted by the ATLAS and CMS collaborations:

\[
\epsilon(p_{\text{veto}}) = \epsilon(WW) \epsilon(veto WW).
\]
pT resummation results

Figure 6: Plot of Resummation predicted and MC+shower predictions for $W + \bar{W}$ transverse momentum distributions at 8 TeV. The shaded region represents the scale $Q$ variation by a factor of 2 relative to the central scale choice $Q = m_W$ for the resummation prediction.

performed by the LHC experiments. An example of the cuts implemented by the ATLAS measurement at 7 TeV is reproduced below in Table 1. The cuts from CMS are quite similar, the jet veto as we will show turns out to be the most important effect, and CMS has a jet veto of 30 GeV compared to 25 GeV for ATLAS. We comment on this slight difference in Section 4, however, since CMS hasn't produced a plot of the $p_T$ of the $W + \bar{W}$ system similar to ATLAS, we adopt the ATLAS cuts when demonstrating the effect of using the $p_T$ resummed reweighted distributions. Pythia8 was used with default tuning and since all our results are shape dependent, the reweighting procedure should be performed again using our resummation-theory curves when using a non-default pythia8 tuning.

Exactly two oppositely-sign leptons, $p_T > 20$ GeV, $p_T$ leading $> 25$ GeV,$m_{ll} > 15$, $10$ GeV (ee, $\mu\mu$, $e\mu$) $|m_{ll} - m_Z| > 15$, $15$, $0$ GeV (ee, $\mu\mu$, $e\mu$) $E_{miss}$, $Rel > 45$, $45$, $25$ GeV (ee, $\mu\mu$, $e\mu$)

Table 1: ATLAS cut flow for 7 TeV analysis
Reweighting Procedure

- each event has a truth level $p_{TWW}$.
- calculate reweighting function to make MC $p_{TWW}$ shape agree with resummation shape.
- pass MC events through detector simulation.
- apply all cuts.
- Reweight with reweighting function.
- compare events passing cuts before and after resummation reweighting.
pT resummation results contd

To demonstrate the effects on differential distributions, we use the ATLAS cutflows and show the predictions of pT resummation for the 7 TeV ATLAS study [1] compared to the original MC@NLO+Herwig++ results used by ATLAS. In Figure 7, we plot the four distributions shown in [1]. As can be seen in Figure 7, pT reweighting can improve the differential distributions somewhat, but is not capable of explaining the full discrepancy using a central choice of scales.

pT resummation results contd
New CMS results

• full luminosity 8TeV, uses pT resummation reweighting.

Table 5: The $W^+W^-$ production cross section in fiducial regions defined by requiring zero jets at particle level with varying jet $p_T$ thresholds.

<table>
<thead>
<tr>
<th>$p_T^{jet}$ threshold (GeV)</th>
<th>$\sigma_{0jet}$ measured (pb)</th>
<th>$\sigma_{0jet}$ predicted (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>$36.2 \pm 0.6$ (stat.) $\pm 2.1$ (exp.) $\pm 1.1$ (th.) $\pm 0.9$ (lum.)</td>
<td>$36.7 \pm 0.1$ (stat.)</td>
</tr>
<tr>
<td>25</td>
<td>$40.8 \pm 0.7$ (stat.) $\pm 2.3$ (exp.) $\pm 1.3$ (th.) $\pm 1.1$ (lum.)</td>
<td>$40.9 \pm 0.1$ (stat.)</td>
</tr>
<tr>
<td>30</td>
<td>$44.0 \pm 0.7$ (stat.) $\pm 2.5$ (exp.) $\pm 1.4$ (th.) $\pm 1.1$ (lum.)</td>
<td>$43.9 \pm 0.1$ (stat.)</td>
</tr>
</tbody>
</table>

• CMS(old) : $69.9 \pm 7.0$ pb
• CMS(new) : $60.1 \pm 4.8$ pb
• NNLO theory: $59.8 \pm 1.3$ pb
• Old theory : $57.3 \pm 1.0$ pb
Analysis

- pT resummation easier to use: reweight MC events with respect to WW transverse momentum.
- Could pT resummation capture jet veto logs well?
- Jet veto resummation and pT resummation predict slightly different efficiencies
- Study needed to do an apples-to-apples comparison between the two resummation procedures.
Comparing jet-veto and pT resummation

• Reweight MC generated 0-jet bin with jet veto resummation prediction.
• Then compare JV-resummation reweighted pTWW prediction with pT resummation.

• Reweight MC generated events with pT resummation (described before)
• Compare reweighted efficiency with jet veto prediction
Aspects of study

• MPI effects affect jet but not pTWW.
• What about Hadronization effects?
• expect pTWW and jet-veto resummation to agree better for larger R.
Results MPI off vs on

The graph shows the comparison of MPI off and MPI on for different processes such as PowhegPythia and JV ressumation. The y-axis represents some metric (ε), and the x-axis shows pT(veto). The lines indicate trends for different processes and conditions, illustrating the impact of MPI on the results.
Results: R dependence

\[ R = 0.4 \]

\[ R = 1 \]
pT(WW) shape prediction
Conclusions

• JV and pT resummation consistent with each other
• Switching off MPI; agree better
• going to large R; agree better
• Yet Both cannot be done simultaneously
Outlook

• with knowledge of full NNLO matrix elements, we can take both pT and jet veto resummation to the next order, ie. NNLL+NNLO
• Joint Resummation
• Is it possible to decouple these effects and study them separately?
• NP effects
• Resummation scale.