PROCEEDINGS OF SCIENCE

The WW story

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Run 1 of the LHC reported routine excesses in WW measurements both at 7 and 8 TeV. However accounting for higher order QCD effects through p_T resummation can account for some of the differences between theory and experiment. A closely related approach; jet veto resummation has also had success explaining this excess. In this note, we analyse in detail and compare predictions from these two methods.

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1. Introduction

The ATLAS and CMS experiments at the LHC have been a phenomenal success probing physics at hitherto unreached energy scales. With the discovery of the Higgs, which provided the missing piece in the standard model jigsaw, the focus shifts to standard model precision measurements, Higgs precision and new physics searches. The W^+W^- channel is important in all these respects. It provides a test of the triple gauge boson coupling, and is used to place limits on anomalous TGCs. It is also a dominant background to $H \rightarrow W^+W^-$ in the fully leptonic decay channel. This particular Higgs decay channel doesnt possess the bump that ZZ and $\gamma\gamma$ do due to MET and hence it is very important to get the W^+W^- standard model background verified. Finally, its signature, two oppositely charged leptons +MET is also the signature of many new physics studies. The fully leptonic channel, $W^+W^- \rightarrow l\nu l\nu$ was measured by both experiments at 7[3, 4] and 8 TeV[5, 6]. The experimental results tabulated in Table 1 with the corresponding state of the art theory calculation circa 2014, show that although consistent within 3σ error bars, there is a 20% excess and ATLAS and CMS seem to agree with each other better than with theory. On close inspection, the excess is also concentrated at low WW transverse momentum. This excess is intriguing as it stands, alone, while all other diboson channels confirm standard model calculations.

Data	Experiment(pb)	Theory(pb)
ATLAS 7TeV	51.9 ± 4.8	44.7 ± 2
CMS 7TeV	52.4 ± 5.06	44.7 ± 2
ATLAS 8TeV	71.4 ± 5.28	57.3 ± 2
CMS 8TeV	69.9 ± 6.98	57.3 ± 2

Table 1: Experiment vs Theory circa 2014

Some of the proposals to explain the W^+W^- excess include involking supersymmetric particles viz. Charginos[7], Sleptons[8], Stops[9, 10, 11] and more exotic cases [12] . A common theme among these papers is SUSY particles mimicing the ll+MET signature hence enhancing the W^+W^- signal measurement. Interestingly, a few of these models preferentially populate the low pT bins to explain the shape mismatch as well. Higher order standard model calculations have also been subsequently accomplished. Calculation of the next order in perturbation theory (NNLO)[13] was completed and provides an increase in total cross section over the NLO value. Higher order QCD contributions to shape effects, which shall be the focus of this note, have been captured using resummation calculations.

To understand shape effects, it is important to mention jet veto which is unique to W^+W^- among the diboson measurements. Events that contain jets above 25(30) GeV are vetoed by ATLAS(CMS) in order to reduce top background. The measured fiducial 0-jet cross section is then unfolded with respect to the theoretically computed efficiency to report a total cross section. The introduction of a new energy scale(jet veto scale) introduces large logs ($Log[\frac{p_T(\text{veto})}{m_{WW}}$) which spoil perturbation theory. These logs are resummed to restore perturbation theory using Jet Veto resummation and hence said calculation provides a more reliable estimate of the fiducial cross section(albeit without detector simulation) compared to a MonteCarlo +Parton Shower that does resummation only at Leading Log. This procedure was carried out at the NNLL+LO accuracy[14] and the result was a higher theoretical cross section that could explain all the excess away.

The discrepancy in low p_T(ll+MET) regions, which is a place holder for the $p_T(WW)$ variable, prompted a transverse momentum resummation calculation that resums logs of $\frac{p_T(WW)}{mWW}$. This was also performed at NNLL+LO[1] and predicted a softer p_T spectrum that would explain some of the shape discrepancy. However it is important to note that resummation calculations explicitly add diagrams at all order and hence will not be able to provide complete final particle four momentum description of events that could then be sent thru detector simulation. As a work around, the resummed p_T shapes have been used to reweight MonteCarlo+Parton Shower event samples in Higgs(HqT)[15] and W mass measurements. This reweighted MC sample is then passed thru detector simulation. It is also important to note that at NLO, the jet recoils off of the diboson and hence $p_T(WW) = p_T$(leading jet). This equality gets diluted due to higher order emissions as well as jet clustering but the strong correlation between the two variables is retained. Hence $p_T(WW)$ reweighting, apart from correcting the p_T shape could also be used to estimate the jet veto cross section. This approach, along with the NNLO cross section calculation was used by CMS in its full luminosity analysis[16] and after reweighting, data agrees very well with the theoretical predicition, 60.1 $\pm$ 4.8pb as against the updated NNLO prediction of 59.8 $\pm$ 1.2 pb.

The success of the reweighting procedure, demands a tighter scrutiny of the two methods of resummation and elimination of any ambiguities or arbitrariness arising from theoretical assumptions. A naive comparison of the efficiency prediction from the two methods suggested a disagreement with the jet veto resummation calculation predicting a slightly larger efficiency. However on closer analysis, some of this discrepancy is due to different scale choices for the two studies as well as an overall normalization effect due to π^2 resummation employed in the jet veto calculation. In our new study, we take specific care to do both analysis with the same renormalization and factorization scales as well as keep the overall cross-section constant so as to study the shape effects only. We also propose a reweighting procedure using the differential leading jet p_T shape. We then analyse the effects of varying jet radius R and multi parton interactions (MPI) on the interplay between jet veto and transverse momentum resummation.

In Section 2 we briefly review results of the two resummation papers as well as describe reweighting procedures. We also talk about MPI effects and jet cone radius. Section 3 is devoted to results and a discussion.

2. Resummation procedures

2.1 Jet Veto Resummation

As explained in the introduction, the jet veto imposed on the WW events makes a jet veto resummation study necessary. For a discussion on the SCET formalism of the theory we refer the reader to [14]. The direct result from such a jet veto resummation study is

$$\varepsilon(p_T(\text{veto})) = \frac{\sigma(p_T(\text{veto}))}{\sigma_{\text{total}}} \tag{2.1}$$

This efficiency however cannot be directly used in measurements because it does not contain full event information and there is no way to fold in various detector effects. Towards this we propose a reweighting procedure very similar to transverse momentum resummation. We obtain the differential cross section $\frac{d\sigma}{dp_T j}$ where $p_T j$ is the leading jet's transverse momentum, by binning $\sigma(p_T(\text{veto})$ into very small p_T intervals. This is then used to reweight Monte Carlo events which can be passed thru detector simulation to get experimentally accessible event samples.

2.2 Transverse momentum Resummation

Transverse momentum resummation resums logs of the $p_T(WW)$ variable and hence accurately captures the low p_T region. In Figure 1 we plot how p_T resummation compares with various monte carlo event generators. We employ the same reweighting procedure as described in [1]. We can then compare the efficiencies obtained from said reweighted events with the direct prediction from jet veto resummation.

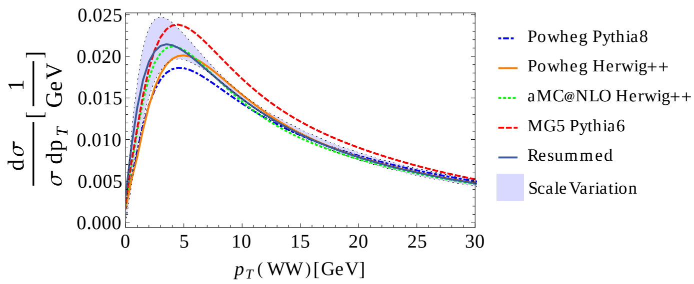


Figure 1: Plot of Resummation predicted and MC+shower predictions for W^+W^- transverse momentum distributions at 8 TeV. The shaded region represents the scale Q variation by a factor of 2 relative to the central scale choice $Q = m_W$ for the resummation prediction.

3. Results and Discussion

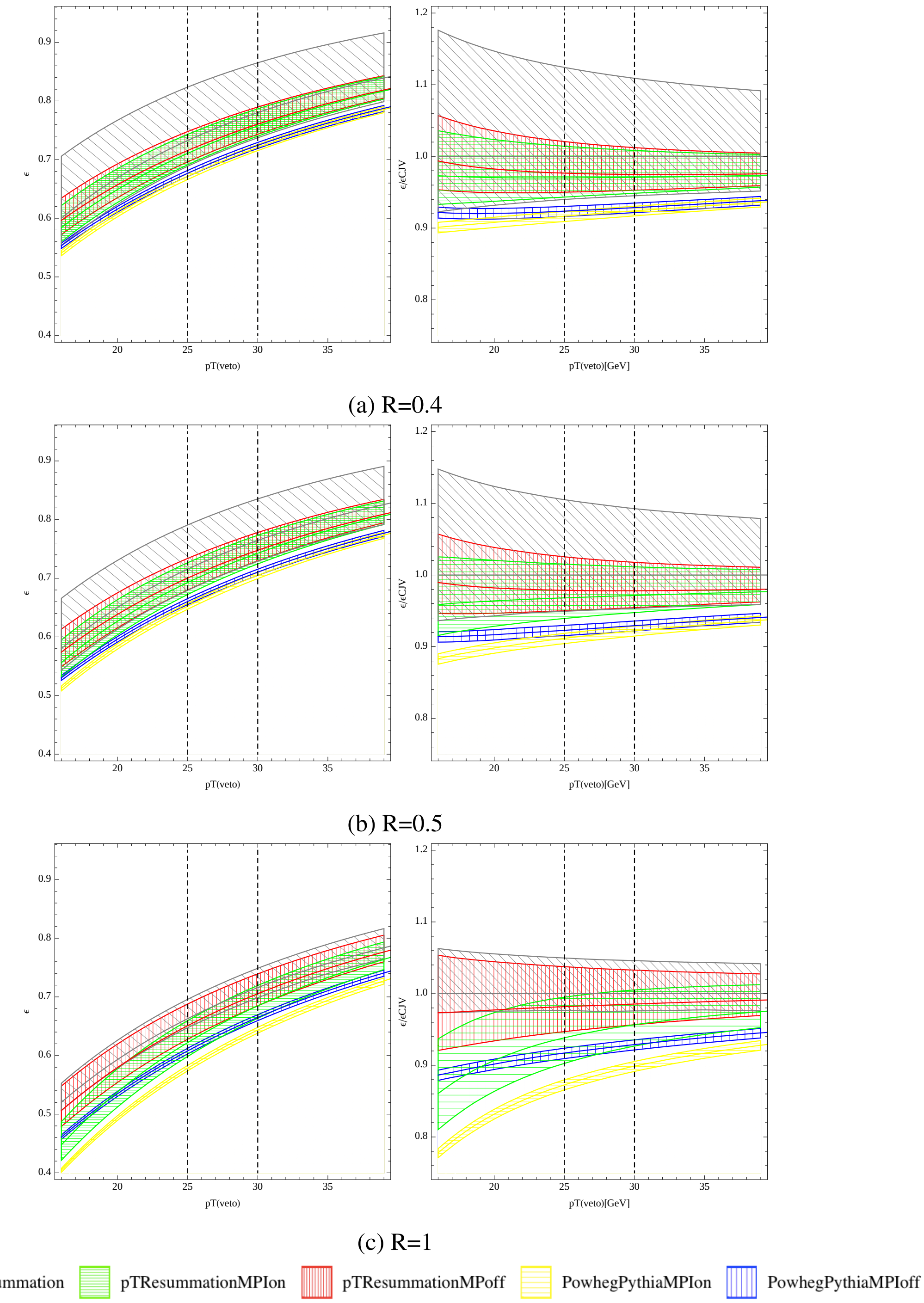
The Powheg+Pythia events reweighted using the two resummation scheme using the procedure described in the previous section, is then used to calculate efficiency.

3.1 MPI effects

While jet veto resummaton does not take into account Multi-parton interactions, the default Powheg+Pythia setting does. We observe that, while turning off MPI does not affect the $p_T(WW)$ shape, it does have an effect on jet-veto efficiency especially for large R. Thus the p_T reweighted sample can capture MPI effects based on whether the MPI switch was turned or off in the underlying Powheg-Pythia Sample.

3.2 Jet cone radius R

The jet-veto resummation calculation contains Log[R] terms and we expect better agreement between jet veto and p_T resummation when R is large. This is because, for larger R, a larger part of the jet activity is captured as a single jet and hence the correlation between the leading jet momentum and WW momentum is higher.



(a) R=0.4

(b) R=0.5

(c) R=1

Figure 2: comparison for efficiencies from jet veto resummation and p_T resummation for MPI off and on for R=0.4,0.5 and 1

3.3 Analysis and Conclusions

From the plots in Figure 2, we see that the p_T and jet veto resummation predictions for the jet veto are consistent within error bars. The agreement is particularly strong for R=1 for MPI off. Increasing R also increases the disagreement between MPI on and off.

To conclude, larger R makes the agreement between the two resummation calculations better albeit only when the MPI effects are off, but it is impossible to turn MPI off in an actual experiment. Transverse momentum resummation predictitions for efficiencies for R=0.4 and 0.5 agree within error bars with the corresponding predictions from jet veto resummation and hence we verify the correlation between jet and WW transverse momentum. Thus we recommend the continuing use of p_T resummation reweighting for the next LHC run as well. The error bars from scale uncertainties are very large and NNLL+NNLO resummation when completed will reduce this considerably. A joint resummation scheme that resums p_T and jet veto simultaneously might be useful to answer questions about scale choice and non-perturbative factors. In our forthcoming publication, we discuss effects on $p_T(WW)$ shapes, non-perturbative factors as well as a repeat of this analysis at higher center of mass energy, relevant to the next LHC run.

References

[1] P. Meade, H. Ramani and M. Zeng, Phys. Rev. D **90**, no. 11, 114006 (2014) [arXiv:1407.4481 [hep-ph]].

[2] arXiv:1508:XXXX Patrick Meade, Prerit Jaiswal and Harikrishnan Ramani

[3] G. Aad *et al.* [ATLAS Collaboration], "Measurement of W^+W^- production in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector and limits on anomalous WWZ and $W\gamma$ couplings," arXiv:1210.2979 [hep-ex].

[4] "Measurement of WW production rate" - CMS-PASSMP-12-005

[5] "Measurement of W^+W^- production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector", ATLAS-CONF-2014-033

[6] "Measurement of WW production rate" - CMS-PASSMP-12-013

[7] D. Curtin, P. Jaiswal and P. Meade, Phys. Rev. D **87**, no. 3, 031701 (2013) [arXiv:1206.6888 [hep-ph]].

[8] D. Curtin, P. Jaiswal, P. Meade and P. -J. Tien, JHEP **1308**, 068 (2013) [arXiv:1304.7011 [hep-ph]].

[9] K. Rolbiecki and K. Sakurai, JHEP **1309**, 004 (2013) [arXiv:1303.5696 [hep-ph]].

[10] D. Curtin, P. Meade and P. -J. Tien, arXiv:1406.0848 [hep-ph].

[11] J. S. Kim, K. Rolbiecki, K. Sakurai and J. Tattersall, arXiv:1406.0858 [hep-ph].

[12] P. Jaiswal, K. Kopp and T. Okui, Phys. Rev. D **87**, no. 11, 115017 (2013) [arXiv:1303.1181 [hep-ph]].

[13] T. Gehrmann, M. Grazzini, S. Kallweit, P. MaierhÃűfer, A. von Manteuffel, S. Pozzorini, D. Rathlev and L. Tancredi, Phys. Rev. Lett. **113**, no. 21, 212001 (2014) [arXiv:1408.5243 [hep-ph]].

[14] P. Jaiswal and T. Okui, Phys. Rev. D **90**, no. 7, 073009 (2014) [arXiv:1407.4537 [hep-ph]].

[15] D. de Florian, G. Ferrera, M. Grazzini and D. Tommasini, JHEP **1111**, 064 (2011) [arXiv:1109.2109 [hep-ph]].

[16] V. Khachatryan *et al.* [CMS Collaboration], arXiv:1507.03268 [hep-ex].