Measurements of SM VV' Production by ATLAS

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Introduction

- Diboson processes are important tests of the SM
- Also major backgrounds to new physics processes
- ATLAS measuring the VV' production cross sections in many channels
- Focus here on the decay channels with e, μ and ν in the final states

Current Measurements by ATLAS

- The ATLAS collaboration has measured the production cross sections at $\sqrt{s} = 7$ TeV of:
  - W^+W^- in the $\ell\nu_\ell\ell'\nu_{\ell'}$ channel with both 1.02 fb^{-1} (arXiv:1203.6232, accepted by PLB) and 4.7 fb^{-1} (ATLAS-CONF-2012-025)
  - $W^\pm Z$ in the $\ell\nu\ell'\ell'$ channel with 1.02 fb^{-1} (*Phys. Lett. B* **709** (2012) 341-357)
  - ZZ in the $\ell\ell\ell'\ell'$ channel with 1.02 fb^{-1} (*Phys.Rev.Lett.* **108** (2012) 041804) and 4.7 fb^{-1} (ATLAS-CONF-2012-026)
  - ZZ in the $\ell\ell\nu\bar{\nu}$ channel with 4.7 fb^{-1} (ATLAS-CONF-2012-027)

Current Measurements by ATLAS (ctd.)

- Measured both fiducial cross sections and extrapolated total cross sections as:

$$\sigma_{\text{total}} = \frac{\sigma_{\text{fiducial}}}{A_{VV'}}, \ \sigma_{\text{fiducial}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\mathcal{L} \times \mathcal{B}r \times C_{VV'}} \tag{1}$$

- Where $\mathcal{L}$ is the luminosity, $\mathcal{B}r$ is the branching fraction for VV' to decay to the measured channel, $C_{VV'}$ is a measurement efficiency correction factor and $A_{VV'}$ is the theoretical acceptance correction used to extrapolate from the fiducial phase space to the total phase space

Principles Employed in Constructing Fiducial Volumes: Leptons

- The fiducial volumes are all constructed using leptons dressed with all final state photons within a cone of $\Delta R < 0.1$
- Leptons are required to have the same minimum p_{T} as the reconstructed leptons used in the analysis
- Leptons are required to be within the η range of the muon spectrometer (viz. $|\eta| < 2.7$)
- If leptons are required to have tracks, they are required to be within the η range of the tracking detector acceptance (viz. $|\eta| < 2.5$)
- In some cases, leptons are further constrained based on calorimeter or trigger coverage

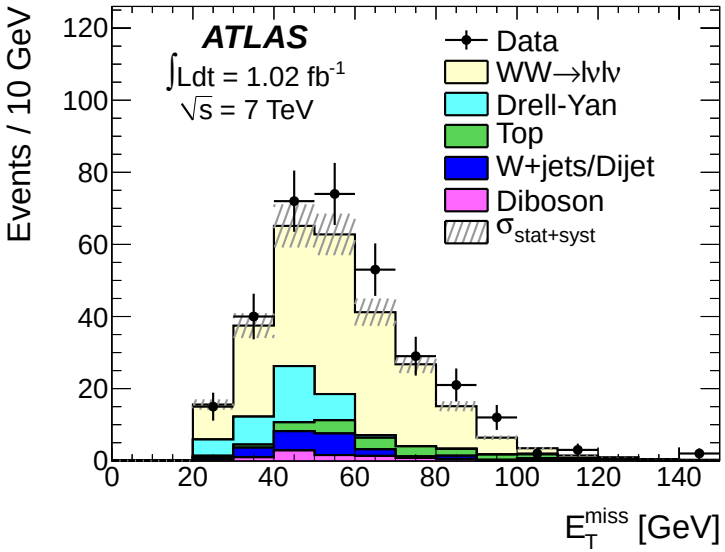
Principles Employed in Constructing Fiducial Volumes: Neutrinos, Jets and Vector Bosons

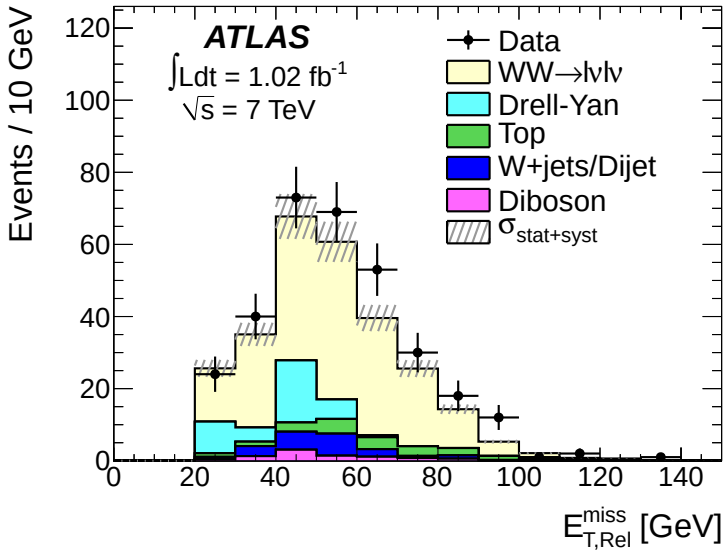
- Neutrinos:
  - Vector sum p_{T} constrained in the same way as the reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$
- Jets:
  - Jet vetos are defined in terms of jets constructed by applying the anti$-k_{\mathrm{T}}$ algorithm to stable particles after showering and hadronization
  - Jets are only taken when $\Delta R(\ell, j) > 0.3$, or in the W^+W^- case $\Delta R(e, j) > 0.3$
- Vector Bosons:
  - Use the same range for the invariant mass of Z, for both selection and veto, as the reconstructed Z candidates
  - Use the same range for the transverse mass of $W \to \ell\nu$ as the reconstructed W candidates

Fiducial Volume: $W^+W^- \to \ell\nu_\ell\ell'\nu_{\ell'}$

- p_T of leading lepton must be at least 25 GeV
- p_T of sub-leading lepton must be at least 20 GeV
- p_T of e in $e\mu$ channel must be at least 25 GeV
- Muons must have $|\eta| < 2.4$ (for trigger coverage)
- Electrons must have $|\eta| < 2.47$ (for calorimeter coverage), excluding the calorimeter transition region $1.37 < |\eta| < 1.52$
- Component of vector sum p_T of neutrinos perpendicular to vector sum p_T of leptons must be at least 55 GeV, 50 GeV or 25 GeV in the $\mu\mu$, ee and $e\mu$ channels respectively (see next slide)
- $m(\ell\ell) > 10(15)$ GeV in $e\mu$ (ee or $\mu\mu$) channels
- Z veto: $|m(\ell\ell) - m_{\mathrm{PDG}}(Z)| > 15$ GeV
- No jets with $p_T > 25$ GeV

Relative $E_{\mathrm{T}}^{\mathrm{miss}}$





- As stated on the previous slide, the W^+W^- fiducial volume uses the component of neutrino vector sum p_{T} perpendicular to $p_{\mathrm{T}}(\ell\ell)$
- This corresponds to the requirement on the relative $E_{\mathrm{T}}^{\mathrm{miss}}$ of reconstructed events
- The plot shows the reconstructed values of $E_{\mathrm{T}}^{\mathrm{miss}}$ (left) and relative $E_{\mathrm{T}}^{\mathrm{miss}}$ (right)

Fiducial Volume: $W^{\pm}Z \to \ell\nu\ell'\ell'$

- p_{T} of Z leptons must be at least 15 GeV
- p_{T} of W lepton must be at least 20 GeV
- All leptons must have $|\eta| < 2.5$
- p_{T} of neutrino must be at least 25 GeV
- Z decay products must have $|m(\ell\ell) - m_{\mathrm{PDG}}(Z)| < 10$ GeV
- W decay products must have transverse mass of at least 20 GeV

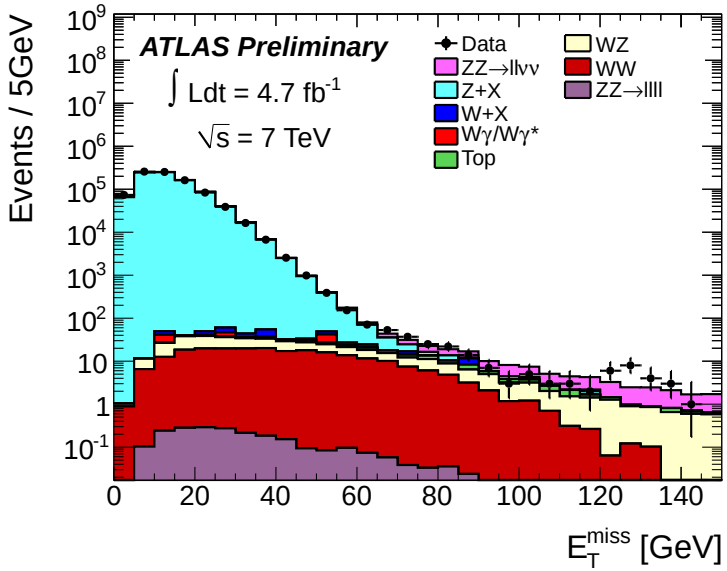
Fiducial Volume: $ZZ \to \ell\ell\ell'\ell'$

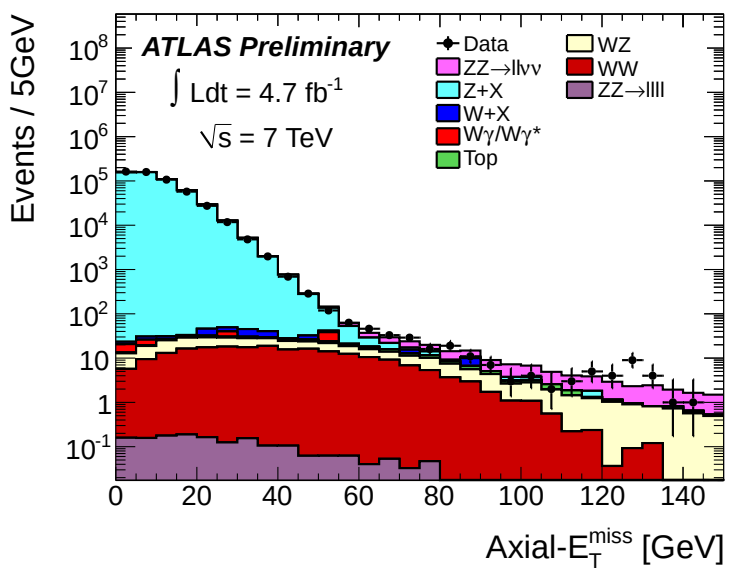
- p_{T} of all leptons must be at least 7 GeV
- All leptons must have $|\eta| < 2.7$
- Decay products of each Z must have 66 GeV $< m(\ell\ell) <$ 116 GeV

Fiducial Volume: $ZZ \to \ell\ell\nu\bar{\nu}$

- p_{T} of all leptons must be at least 20 GeV
- All leptons must have $|\eta| < 2.5$
- $Z \to \ell\ell$ decay products must have $|m(\ell\ell) - m_{\mathrm{PDG}}(Z)| < 15$ GeV
- No jets with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 4.5$
- Component of vector sum p_{T} of neutrinos antiparallel to vector sum p_{T} of leptons must be at least 80 GeV (see next slide)
- Difference between magnitudes of vector sum p_{T} of leptons and neutrinos must be less than 60% of the vector sum p_{T} of the leptons

Axial $E_{\mathrm{T}}^{\mathrm{miss}}$





- As stated on the previous slide, the $ZZ \to \ell\ell\nu\bar{\nu}$ fiducial volume uses the component of neutrino vector sum p_{T} anti-parallel to $p_{\mathrm{T}}(\ell\ell)$, since the ZZ are produced back-to-back
- This corresponds to the requirement on the axial $E_{\mathrm{T}}^{\mathrm{miss}}$ of reconstructed events
- The plot shows the reconstructed values of $E_{\mathrm{T}}^{\mathrm{miss}}$ (left) and axial $E_{\mathrm{T}}^{\mathrm{miss}}$ (right)

Principles Employed in Cross Section Extrapolation

- Fiducial cross sections are extrapolated to total phase space using acceptance factors ($A_{VV'}$) calculated using MCFM unless fiducial volume includes jet veto
- If fiducial volume includes jet veto, use MC@NLO+HERWIG instead
- The invariant mass of $Z \to \nu\nu$ is not constrained (since no Z/γ^* interference)
- The invariant mass of $Z \to \ell\ell$ in the extrapolated phase space is restricted to be in the range 66-116 GeV
- The $ZZ \to \ell\ell\ell'\ell'$ measurement uses zero-width approximation in the Monte Carlo calculation of C_{ZZ} used for the 1 fb^{-1} measurement. Moving to finite width in 4.7 fb^{-1} updates.

Extrapolated Cross Sections

- The W^+W^- production cross section is $53.4 \pm 2.1(\text{stat.}) \pm 4.5(\text{syst.}) \pm 2.1(\text{lumi.})$ pb
- The $W^{\pm}Z$ production cross section is $20.5^{+3.1}_{-2.8}(\text{stat.})^{+1.4}_{-1.3}(\text{syst.})^{+0.9}_{-0.8}(\text{lumi.})$ pb
- The ZZ production cross section measured in the $\ell\ell\ell'\ell'$ channel is $7.2^{+1.1}_{-0.9}(\text{stat.})^{+0.4}_{-0.3}(\text{syst.}) \pm 0.3(\text{lumi.})$ pb
- The ZZ production cross section measured in the $\ell\ell\nu\bar{\nu}$ channel is $5.4^{+1.3}_{-1.2}(\text{stat.})^{+1.4}_{-1.0}(\text{syst.}) \pm 0.2(\text{lumi.})$ pb
- All measurements agree with NLO SM predictions

Desired Additional Features in Monte Carlo

- Would like to pursue a consistent FullSim generator for all diboson production studies
- Currently using mix of Sherpa and MC@NLO for FullSim sample and mix of MCFM and MC@NLO for normalization
- Would like to have a NLO calculation of VV'+jets in addition to the inclusive calculation
- Currently only have NLO generators in the leptonic decay channels, would like generators that support hadronic decay channels as well

Backup

Theoretical W^+W^- Cross Section: ATLAS vs. CMS

- ATLAS and CMS differ in the theory prediction
- ATLAS calculates 45.1±2.8 pb and CMS uses the 47.0±2.0(scale) pb from the MCFM paper
- Difference is entirely a product of differing the input to MCFM:
  - PDF: MSTW8NN vs. CT10 changes $\sigma_{W^+W^-}$ by -2.7%
  - Scale: dynamic vs. fixed changes $\sigma_{W^+W^-}$ by -2.5%
  - EW Scheme: MCFM default vs. ATLAS[1] changes $\sigma_{W^+W^-}$ by +1.3%
  - Branching Fractions: 0.1075 (MCFM default) versus 0.108 (PDG) changes $\sigma_{W^+W^-}$ by -1%
- Overall difference within MCFM using ATLAS options compared to defaults is -4.6%

[1] from ATL-COM-PHYS-2010-695