WH production and its Heavy Boson Background

NLO Merging with SHERPA

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Outline

Trilepton Final States

- ATLAS and CMS both have analyses for the trilepton final state of WH production.
- Trilepton final states are a clean signal with a small background.
- The Higgs boson processes give a direct probe into the coupling of the Higgs boson to the vector bosons.
- Triboson processes are interesting for anomalous gauge couplings.
- The trilepton final states are also used in SUSY searches.

Signal Process

These analyses target the signal process $W^{\pm}H(W^{+}W^{-})$

Other trilepton final states with an on-shell Higgs boson are also considered as signal processes:

- $W^{\pm}H(\tau^{+}\tau^{-})$
- $W^{\pm}H(ZZ)$
- $ZH(W^{+}W^{-})$
- $ZH(\tau^{+}\tau^{-})$
- $ZH(ZZ)$

All signal processes are calculated with MEPS@NLO with 1 jet contribution at NLO.

Background Processes

Vetoes

- b jets - eliminate $t\bar{t}V$.
- Z veto - reduces Z boson background contributions.

Backgrounds considered:

1. $W^{\pm}Z$
2. $W^{\pm}W^{+}W^{-}$
3. $W^{+}W^{-}Z$
4. ZZ
5. $W^{\pm}ZZ$
6. ZZZ

- **MEPS@NLO** - 1 jet NLO
  - WZ
  - WWW
- **MENLOPS**
  - WWZ
  - ZZ
  - WZZ
  - ZZZ

Background Considerations

Higs contribution:

- We can consider either an on-shell Higgs boson or an off-shell Higgs boson.
- The off-shell Higgs boson can be considered as either signal or background.
- The process has large interferences with the on-shell WWW production.
- Here the off-shell contribution is included in the background.

1-jet merged WWW:

- $WWWj$ contribution at NLO contains $WWWbb$ configurations.
- This introduces a double counting with the $t\bar{t}V$ process.
- To eliminate this, the MC@NLO process does not include b quarks.

Setup

$$\sigma_{\text{NLO}} = \int \mathrm{d}\Phi_B (B(\Phi_B) + I(\Phi_B) + \tilde{V}(\Phi_B)) + \int \mathrm{d}\Phi_R (R(\Phi_R) - D(\Phi_R))$$

- This study used the SHERPA event generator and the following ME generators:
  - AMEGIC for Born (B) and integrated parts (I).
  - COMIX for real-subtraction parts (RD).
- OpenLoops is used for the virtual loops (V).
- The COLLIER library is used by OpenLoops.

Matching with MC@NLO

The MC@NLO method is implemented in SHERPA as S-MC@NLO.

$$\mathrm{d}\sigma^{\text{S-MC@NLO}} = \mathrm{d}\Phi_B \, \bar{B}_n(\Phi_B) \, \bar{F}_n(\mu_Q^2) + \mathrm{d}\Phi_R \, H_n(\Phi_R) \, F_{n+1}(\tilde{\mu}_Q^2)$$

$\bar{B}_n$ is the Born-like part of the NLO calculation, and is H_n is rest:

$$\begin{aligned} \bar{B}_n(\Phi_B) &= B_n(\Phi_B) + \tilde{V}_n(\Phi_B) + I_n(\Phi_B, \, \mu_Q^2) \, , \\ H_n(\Phi_R) &= R_n(\Phi_R) - D_n(\Phi_R) \, \Theta\left(\mu_Q^2 - t\right) \end{aligned}$$

And I_n is the integrated subtraction term given by:

$$I_n(\Phi_B, \, \mu_Q^2) = \int \mathrm{d}\Phi_1 \, D_n(\Phi_B, \Phi_1) \, \Theta\left(\mu_Q^2 - t\right)$$

and $\bar{F}_n$ and F_{n+1} are the generating functions for the parton shower, D_n are the subtraction terms, and t is the evolution variable.

NLO Merging

MENLOPS:

$$\begin{aligned}\mathrm{d}\sigma_n^{\mathrm{excl}} &= \mathrm{d}\Phi_n\ \bar{B}_n(\Phi_n)\,\bar{F}_n(\mu_Q^2\,; < Q_{\mathrm{cut}}) \\ &\quad + \mathrm{d}\Phi_{n+1}\,\Theta(Q_{\mathrm{cut}} - Q(\Phi_{n+1}))\,H_n(\Phi_{n+1})\,F_{n+1}(\mu_Q^2\,; < Q_{\mathrm{cut}})\end{aligned}$$

with LO higher order cross sections:

$$\begin{aligned}\mathrm{d}\sigma_{n+k} &= \mathrm{d}\Phi_{n+k}\,\Theta(Q(\Phi_{n+k}) - Q_{\mathrm{cut}})\ k_n(\Phi_{n+1}(\Phi_{n+k})) \\ &\quad B_{n+k}(\Phi_{n+k})\ F_{n+k}(\mu_Q^2\,; < Q_{\mathrm{cut}})\end{aligned}$$

k_n is the local K-factor. This method can be extended to higher order NLO matrix elements (MEPS@NLO):

$$\begin{aligned}\mathrm{d}\sigma_{n+k}^{\mathrm{excl}} &= \mathrm{d}\Phi_{n+k}\,\Theta(Q(\Phi_{n+k}) - Q_{\mathrm{cut}})\ \tilde{B}_{n+k}(\Phi_n + k)\,\bar{F}_{n+k}(\mu_Q^2\,; < Q_{\mathrm{cut}}) \\ &\quad + \mathrm{d}\Phi_{n+k+1}\,\Theta(Q(\Phi_{n+k}) - Q_{\mathrm{cut}})\,\Theta(Q_{\mathrm{cut}} - Q(\Phi_{n+k+1})) \\ &\quad \tilde{H}_{n+k}(\Phi_{n+k+1})\,F_{n+k+1}(\mu_Q^2\,; < Q_{\mathrm{cut}})\ ,\end{aligned}$$

ATLAS and CMS Analyses

ATLAS-CONF-2013-075, CMS-PAS-HIG-13-009

ATLAS

Veto all SFOS pairs

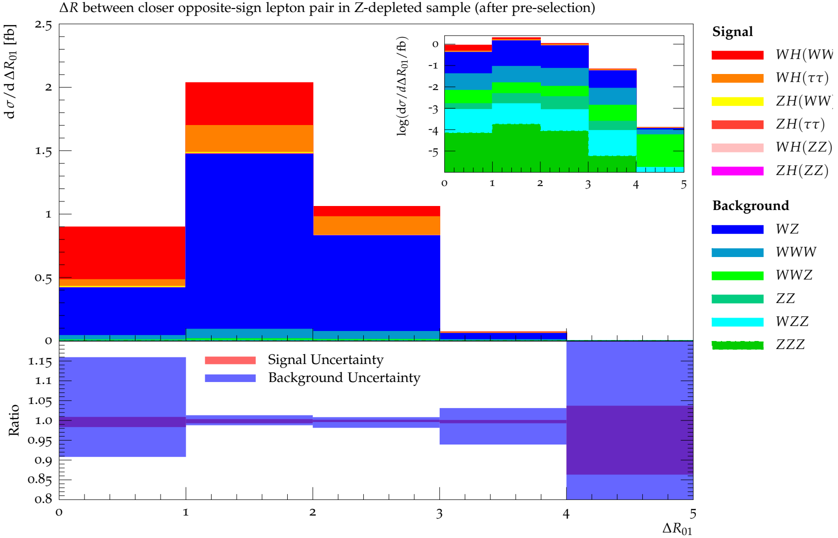
CMS

Veto SFOS pairs in a mass window $|m_{\text{SFOS}} - m_Z| < 25$ GeV

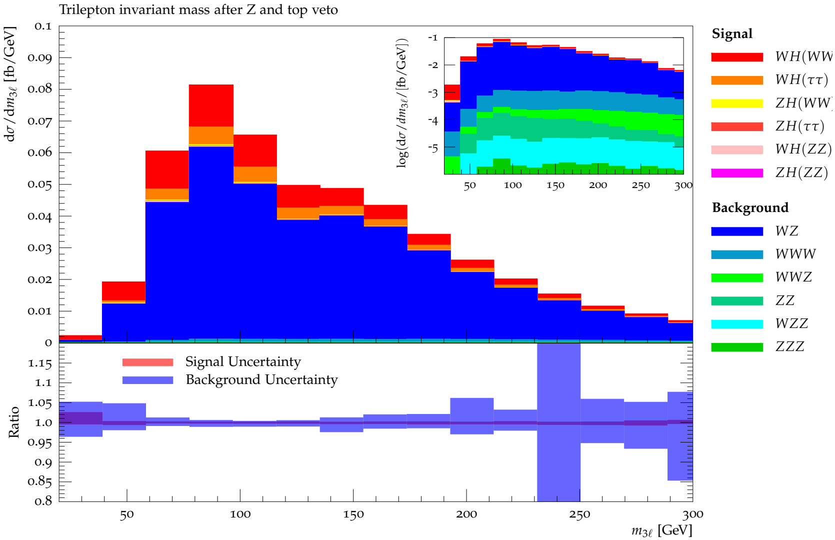
Samples

- The results are at hadron level.
- Scale uncertainties are evaluated at the parton level.
- Hadronisation and underlying event affect the lepton isolation.

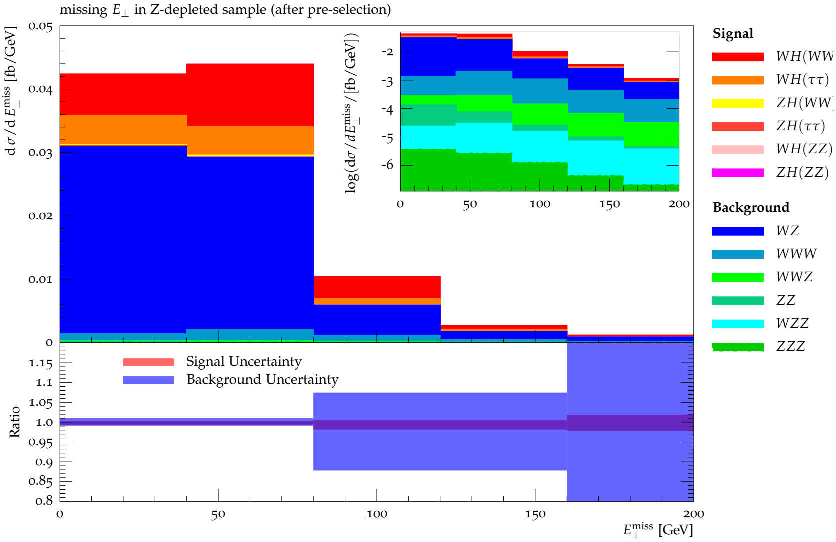
ΔR of Closer Opposite Sign Leptons with ATLAS Cuts



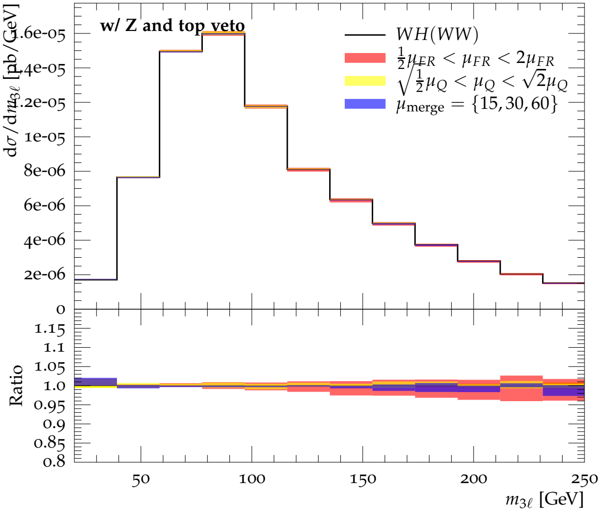
Trilepton Invariant Mass with CMS Cuts



$E_\perp^{\text{miss}}$ with ATLAS Cuts



Scale Uncertainties for Trilepton Invariant Mass



Conclusion and Outlook

- The trilepton final state is useful for many different studies:
  1. Triboson studies looking at anomalous gauge couplings.
  2. Triboson studies for Higgs boson couplings.
  3. SUSY searches.
- The signal and background for $W^{\pm}H(W^{+}W^{-})$ production with trilepton decays can be calculated at NLO with SHERPA+OpenLoops.
- The signal and dominant backgrounds have been calculated with 1 jet merged at NLO, up to the WWW contribution.