Prospects for New Physics Searches in the ssWW Channel for HL-LHC

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Introduction and Motivation

- With the most recent LHC 8 TeV proton-proton collision experimental data, we recently witnessed for the first time the production of electroweak same-sign WW boson scattering (ssWW-EW) and gave us our first insights into anomalous Quartic Gauge Coupling (aQGC) limits.
- This is exciting because it’s a SM process that produces Vector Boson Scattering (VBS), which violates unitarity at ~1 TeV
  - The Higgs may provide a mechanism to conserve unitarity at higher energies
  - Alternatively, there may be new physics to conserve unitarity for electroweak symmetry breaking.
We have chosen to study fully-leptonic decay channels since they don’t suffer from high top-antitop quark background.

Specifically, we pick the ssWW-EW process because it has the highest signal-to-background ratio.

\[ p p \rightarrow W^\pm W^\pm + j j \rightarrow l^\pm \nu l^\pm \nu + j j \]
VBS ssWW-EW

- Characteristic signature
  - Two forward “tagging jets”
    - $|\Delta \eta| \geq 2.5$ and $\eta_{j_1} \times \eta_{j_2} < 0$
    - Large invariant mass $M_{jj}$
  - More central same-sign lepton pair

→ allows for efficient reduction of SM backgrounds

- Two analysis regions for this study
  - The “inclusive analysis region” (a.k.a. looser cut) is defined as the region where the two jets have an invariant mass $m_{jj} \geq 500$ GeV to measure the fiducial cross section.
  - The “VBS analysis region” (a.k.a. pure signal) imposes an extra cut that the jets are well separated in rapidity ($|\Delta \eta| > 2.4$) to extract only the ssWW-EW signal.
In the generic form of the EFT Lagrangian only operators of even dimensions are desired if lepton and baryonic number are to be conserved.

While the dimension-6 operator does provide some aQGC processes in addition to aTGC, it doesn’t allow for many, for example neutral gauge boson processes.

The dimension-8 operator is the lowest order term solely for aQGC, our focus for new physics at the LHC.

\[
\mathcal{L}^\text{EFT} = \mathcal{L}^\text{SM} + \beta_1 \mathcal{L}'_0 + \sum_i \alpha_i \mathcal{L}_i + \frac{1}{\Lambda} \sum_i \alpha_i^{(5)} \mathcal{L}_i^{(5)} + \frac{1}{\Lambda^2} \sum_i \alpha_i^{(6)} \mathcal{L}_i^{(6)} + \frac{1}{\Lambda^4} \sum_i \alpha_i^{(8)} \mathcal{L}_i^{(8)} + \ldots
\]
- Dim-8:

\[
\sum_{j=0,1} \frac{f_{S,j}}{\Lambda^4} \mathcal{O}_{S,j} + \sum_{j=0,\ldots,9} \frac{f_{T,j}}{\Lambda^4} \mathcal{O}_{T,j} + \sum_{j=0,\ldots,7} \frac{f_{M,j}}{\Lambda^4} \mathcal{O}_{M,j}
\]

\[
\mathcal{O}_{S,0} = (D_\mu \Phi)^\dagger D_\nu \Phi \times (D_\mu \Phi)^\dagger D_\nu \Phi
\]

- Higgs Fields

\[
\mathcal{O}_{S,1} = (D_\mu \Phi)^\dagger D_\mu \Phi \times (D_\nu \Phi)^\dagger D_\nu \Phi
\]

\[
\mathcal{O}_{M,0} = \text{Tr} [W_{\mu \nu} W^{\mu \nu}] \times (D_\beta \Phi)^\dagger D_\beta \Phi
\]

\[
\mathcal{O}_{M,1} = \text{Tr} [W_{\mu \nu} W^{\mu \beta}] \times (D_\beta \Phi)^\dagger D_\mu \Phi
\]

\[
\mathcal{O}_{M,6} = (D_\mu \Phi)^\dagger W_{\beta \nu} W^{\beta \nu} D_\mu \Phi
\]

\[
\mathcal{O}_{M,7} = (D_\mu \Phi)^\dagger W_{\beta \nu} W^{\beta \mu} D_\nu \Phi
\]

- Gauge Boson Fields

\[
\mathcal{O}_{T,0} = \text{Tr} [W_{\mu \nu} W^{\mu \nu}] \times \text{Tr} [W_{\alpha \beta} W^{\alpha \beta}]
\]

\[
\mathcal{O}_{T,1} = \text{Tr} [W_{\alpha \nu} W^{\mu \beta}] \times \text{Tr} [W_{\mu \beta} W^{\alpha \nu}]
\]

- Higgs and Gauge Boson Fields

\[
\mathcal{O}_{T,2} = \text{Tr} [W_{\alpha \mu} W^{\mu \beta}] \times \text{Tr} [W_{\beta \nu} W^{\nu \alpha}]
\]
ssWW-EW VBS processes with quartic boson couplings

\[ \text{with } \begin{array}{c}
\text{X} = \text{X} + \text{X} + \text{X} + \text{X}
\end{array} \]

ssWW-EW processes that give same end result but are not VBS

ssWW-QCD background processes

- Some diagrams do not contribute to the final $l^\pm \nu l^\pm \nu$ state. The absence of QCD diagrams with initial gluon-gluon states improves the signal to background ratio.
Simulation Procedure

- We simulate VBS ssWW-EW at 14 TeV
- The new physics candidate signals and backgrounds are created by Madgraph through Monte Carlo simulations, and parton showered through Pythia8.
- The detector smearing is simulated using Delphes with both 0 pileup and the more realistic 80 pileup.
- The WZ (lllv final state) and the ssWW-QCD were the only samples generated. The rest were scaled accordingly by a factor of 1.71, the best estimate given the data from the 8 TeV results.
- Use Root for analysis cuts and extrapolate the yield of the HL-LHC at 3000 fb\(^{-1}\) using the following formula:

\[
Event\ Yield = \frac{Cross\ Section \times Luminosity \times Analysis\ Cuts}{Number\ of\ Events}
\]

- Look for a 5\(\sigma\) significance with a combination of the log likelihood ratio and the frequentist method.
### New Physics in FT10 vs 80 pu

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<th>Cross Section (fb)</th>
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<th>Event Yield (80 Pileup)</th>
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FT1 New Physics Significance

Significance Studies for New Physics (FT1) in the ssWWEW channel

- Significance calculated by log likelihood ratio / frequentist concatenation

8/7/2014
Mauricio Gonzalez-Aranda
FT (Gauge Field Only) New Physics

- FT1 is the shows more sensitivity to new physics by a factor 2
- Is it attainable?

![Significance Studies for New Physics in the ssWWEW channel](image)
SM Signal: 0 vs 80 pileup

- 14 TeV signal at 3000 fb$^{-1}$ luminosity
- Lower ratio of signal to background at 80 pileup
- Expect to see new physics in the last few bins
FT Signal at 0.2 TeV$^{-4}$ with 80 pu

FT1 $\sigma = 33.2$

FT0 $\sigma = 4.1$

FT2 $\sigma = 2.0$

New Physics
Conclusion

• **Summary**
  – There is promising potential to find New Physics in the ssWW-EW channel
    • High Signal to Noise Ratio
    • aQGC allows for the study of dimension-8 operators in the Lagrangian
  – FT1 is the most promising Gauge Field for new physics discovery.

• **Plans**
  – Continue to explore the Higgs Fields (FS0, FS1) and the Higgs and Gauge Fields (FM0, FM1, FM6, FM7)
  – Redo current work with new analysis cuts that are currently being developed.
Traveling Europe
Analysis Cuts

• **Leptons**
  - Exactly 2 same charge leptons
  - Transverse momentum $p_T > 25$ GeV
  - $|\eta| < 4.0$
  - Single lepton trigger
  - Third lepton veto

• **Jets**
  - At least 2 jets of high transverse momentum ($p_T > 30$ GeV)
  - $|\eta| < 4.5$

• **Other Cuts**
  - $m_{ll} > 20$ GeV
  - Lepton centrality $> 0.2$
  - $m_{jj} > 900$ GeV
  - $|\Delta\eta_{jj}| < 2.4$