Application of a novel Machine Learning approach for the search of heavy resonances with topological features at the LHC

SALAH-EDDINE DAHBI

School of Physics, University of the Witwatersrand, Johannesburg, South Africa.

High Energy Particle Physics workshop
(HEPP2020)
University of Venda

January 29-31, 2020
Outline

1. Problematic
2. Research and hypothesis
3. Experimental measurement
4. Data Analysis
   - Why novel Machine Learning approach?
   - Methodology
   - The difference between full supervision and weak supervision.
   - Results
   - Results

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**The Scientific Method**

- Ask a question or address a problem
- Research
- Hypothesis
- Analysis
- Experiment
- Conclusion (and win the science fair)
The Standard model of particle physics

- The Standard model of particle physics (SM) has been developed in 1967, to describe the elementary particles and their interactions.

- The SM explains about 5% of the energy
- The SM can not explain the full elementary particle phenomenology of the universe:
  
  The rotation of the galaxies indicates the exciting of D.M.

- Quadratic divergence of the Higgs mass.
- The nature of the neutrino mass.
- The Gravity is not included in the SM.
- Dark matter! Dark energy!
- ...
Beyond the Standard Model

- Many theories beyond the Standard Model (BSM) are introduced to explain the SM deficiencies.
- Among these theories, a simplified model predicting a heavy scalar of mass in the range of 250-280 GeV (H), which interacts strongly with the SM Higgs boson and an additional Higgs-like scalar singlet (S) has been introduced.
- This model might aid in the understanding of Dark Matter which makes about 27% of the Universe.

The simplified model seems to describe the discrepancies in different corners of the phase-space with large differences in cross-sections (See Bruce’s and Stefan’s talks).

<table>
<thead>
<tr>
<th>Selection</th>
<th>Best-fit $\beta^2_0$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS Run 1 SS $\ell\ell$ and $\ell\ell + b$-jets</td>
<td>6.51 ± 2.99</td>
<td>2.37σ</td>
</tr>
<tr>
<td>ATLAS Run 1 OS $e\mu + b$-jets</td>
<td>4.09 ± 1.37</td>
<td>2.99σ</td>
</tr>
<tr>
<td>CMS Run 2 SS $e\mu, \mu\mu$ and $\ell\ell + b$-jets</td>
<td>1.41 ± 0.80</td>
<td>1.75σ</td>
</tr>
<tr>
<td>CMS Run 2 OS $e\mu$</td>
<td>2.79 ± 0.52</td>
<td>5.45σ</td>
</tr>
<tr>
<td>CMS Run 2 $\ell\ell + E_T^{miss}$ (WZ)</td>
<td>9.70 ± 3.88</td>
<td>2.36σ</td>
</tr>
<tr>
<td>ATLAS Run 2 SS $\ell\ell$ and $\ell\ell + b$-jets</td>
<td>2.22 ± 1.19</td>
<td>2.01σ</td>
</tr>
<tr>
<td>ATLAS Run 2 OS $e\mu + b$-jets</td>
<td>5.42 ± 1.28</td>
<td>4.06σ</td>
</tr>
<tr>
<td>ATLAS Run 2 $\ell\ell + E_T^{miss}$ (WZ)</td>
<td>9.05 ± 3.35</td>
<td>2.52σ</td>
</tr>
<tr>
<td>Combination</td>
<td>2.92 ± 0.35</td>
<td>8.04σ</td>
</tr>
</tbody>
</table>
The Large Hadron Collider

- The Large Hadron Collider (LHC) is a 26.7 Km circular accelerator located at CERN.
- Beams of protons travel in opposite direction and collide at four points along the ring: ATLAS, ALICE, CMS and LHCb.

<table>
<thead>
<tr>
<th>LHC Beam parameter</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
<td>6.5</td>
<td>6.5</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Number of protons per bunch $N_b \times 10^{11}$</td>
<td>1.0</td>
<td>1.3</td>
<td>1.5</td>
<td>1.0</td>
<td>1.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Number of bunch per beam $n_b$</td>
<td>368</td>
<td>1380</td>
<td>1380</td>
<td>2244</td>
<td>2200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\int_0^T \mathcal{L} dt$</td>
<td>48.1 fb$^{-1}$</td>
<td>5.46 fb$^{-1}$</td>
<td>22.8 fb$^{-1}$</td>
<td>4.2 fb$^{-1}$</td>
<td>38.5 fb$^{-1}$</td>
<td>50.2 fb$^{-1}$</td>
<td>65 fb$^{-1}$</td>
</tr>
</tbody>
</table>
Why Machine learning?

- The power of artificial intelligence is so incredible and it will change virtually every aspect of our world in some very deep ways.
- Machine learning is a method of data analysis that automates analytical models.
- Using Deep Neural Networks (DNN) and computing power to find complex patterns in data.
- These neural networks learn how to do complex analyses.
- Their algorithms can be employed in the problem of classifying signal and background events with high precision.

“No problem can be solved from the same level of consciousness that created it.”

ALBERT EINSTEIN
Methodology

- Strategy: Combining weak-supervision and full-supervision learning in conjunction with Deep Neural Network algorithms.
- Evaluation of the strategy on the production of SM Higgs boson decaying to a pair of photons inclusively and in exclusive regions of phase space.
- After verifying the ability of the methodology to extract different Higgs signal mechanisms, a search for new phenomena in high-mass diphoton final states is setup for the LHC.
- Classifying events as Signal or Background:
  - Signal (Monte Carlo Period 15-17): $ggH$, $WH$, $ZH$, $VBFH$, $t\bar{t}H$.
  - Background (Monte Carlo 15-17): $\gamma\gamma$, $\gamma jet$, $V\gamma$, $V\gamma\gamma$. 
The difference between full supervision and weak supervision.

Full supervision
- Sampled 1: Background in Side Band:
  - $115 \text{ GeV} < m_{\gamma\gamma} < 120 \text{ GeV}$
  - $130 \text{ GeV} < m_{\gamma\gamma} < 135 \text{ GeV}$
- Sampled 2: Signal Mass window:
  - $120 \text{ GeV} < m_{\gamma\gamma} < 130 \text{ GeV}$

Weak supervision
- Sampled 1: Background Side Band:
  - $115 \text{ GeV} < m_{\gamma\gamma} < 120 \text{ GeV}$
  - $130 \text{ GeV} < m_{\gamma\gamma} < 135 \text{ GeV}$
- Sampled 2: Signal and backg. in the Mass window:
  - $120 \text{ GeV} < m_{\gamma\gamma} < 130 \text{ GeV}$
"Unless you are a student, you can't show any result which makes use of ATLAS samples. This restriction does apply to Post-Docs."
"Results can be discussed in the next talk".