The search for resonances with topological requirements with the $Z\gamma$ final state at the LHC

Joshua Choma, Salah-Eddine Dahbi, Gaogalalwe Mokgatitswane, Xifeng Ruan & Bruce Mellado

University of the Witwatersrand
School of Physics
The Institute for Collider Particle Physics

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Overview

Motivation

- Search for any resonances in the $X + \textit{objects} \to Z\gamma \to \ell\ell\gamma$, final states, using machine learning techniques
- We propose the use of deep neural networks based on full supervised learning to search for heavy resonances at the electroweak scale with topological requirements.
- This approach is complemented with semi-supervised learning and used to calculate the limit on the production of Higgs-like to $Z\gamma$ where the significance of the signal is maximum.

Machine Learning

- Machine learning is a subset of artificial intelligence that gives computers the ability to learn without being explicitly programmed
- Algorithms that can learn from and make predictions on data
    - Classification
    - Clustering
    - Regression
- Machine Learning plays important role from analysis to event reconstruction and identification in HEP

Types of Learning Techniques

- Supervised: Learning with a labelled training set
- Unsupervised: Discover patterns in unlabelled data
- Semi-Supervised: Semi-supervised learning is describes a task of learning a functional form from data that has both labelled and unlabelled instances

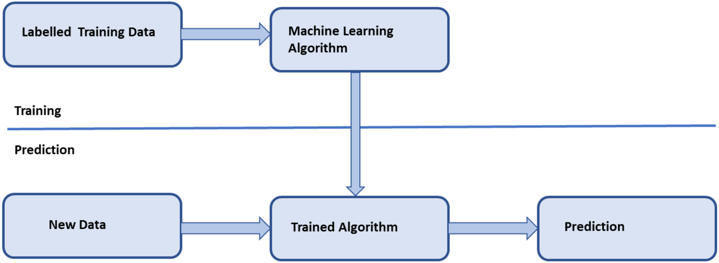
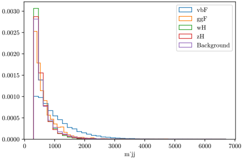
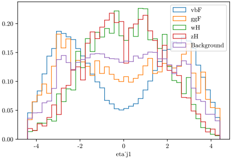


Figure: Illustration of supervised learning

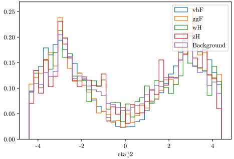
Kinematic Features



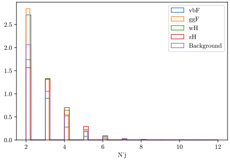
(a) m_jj



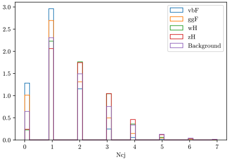
(b) eta_j1



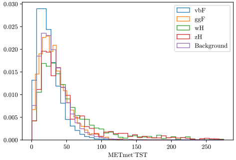
(c) eta_j2



(d) N_j

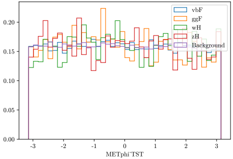


(e) N_cj

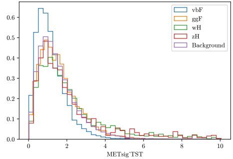


(f) METmet_TST

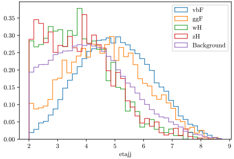
Kinematic Features



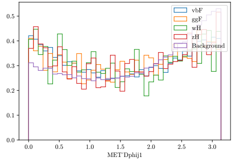
(g) METphi_TST



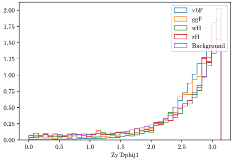
(h) METsig_TST



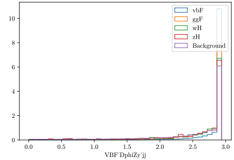
(i) etajj



(j) MET_Dphij1



(k) Zy_Dphij1



(l) VBF_DphiZy_jj

Event Selections and yields

- For each mass point we defined:
  - Mass window 6% of Center Mass
  - Sideband 12% of Center Mass
- Examples at $m_{Z\gamma}$ = 200 GeV:
  - Sideband $m_{Z\gamma}$: 182 - 194 & 206 - 218 GeV
  - Mass window $m_{Z\gamma}$: 194 - 206 GeV

Expected $Z\gamma$ backgrounds Yields:

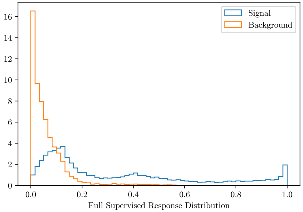
Events yield at different mass points

Center Mass (GeV)	Sideband	Signal Region
200	13175	6444
300	3949	1915
350	2515	1231
450	988	462
500	683	333
600	380	187
700	218	107
800	137	65
900	87	40

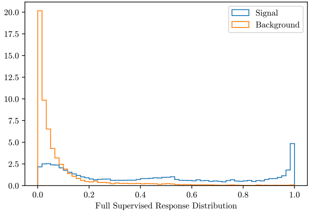
Pre-selection	SideBand	Signal Region	Signal Injection
Inclusive	13175	6444	160
$metsig > 2.5$	808	394	40
$Nj >= 2; 60 < mjj < 120$	839	414	40
$Nj >= 2; mjj > 300; dEtajj > 2$	498	245	30

Events yield for inclusive and for the considered phase-space at 200 GeV

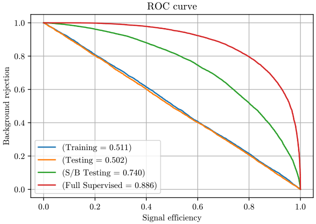
Response Distribution Plots & ROC Curves



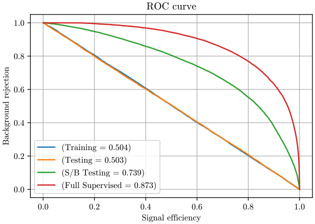
(m) VBF: 150 GeV



(n) VBF: 200 GeV

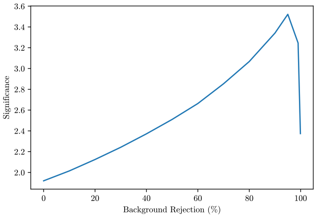


(o) VBF: 150 GeV

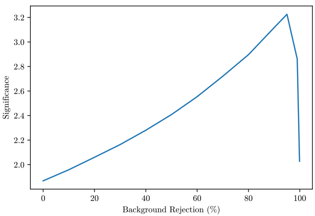


(p) VBF: 200 GeV

Maximum Significance



(q) VBF: 150 GeV

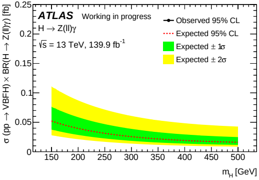


(r) VBF: 200 GeV

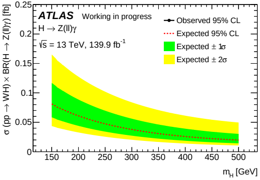
$$\text{significance} = \frac{S}{\sqrt{S+B}}$$

Mass point (GeV)	Inclusive	VBF	*metsig* > 2.5, wh	*metsig* > 2.5, zh	$Nj >= 2; 60 < mjj < 120$, wh	$Nj >= 2; 60 < mjj < 120$, zh
150	-	3.52	4.79	5.28	3.47	3.05
200	1.98	3.22	3.99	4.68	3.26	2.94
300	2.29	3.11	-	-	-	-
500	2.12	2.73	-	-	-	-

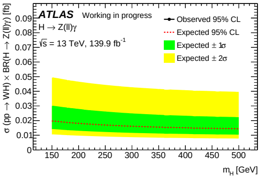
Limits Plots



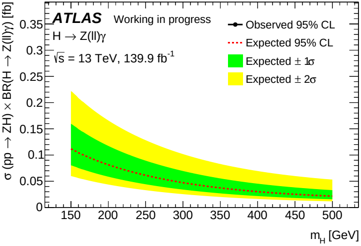
(s) VBF



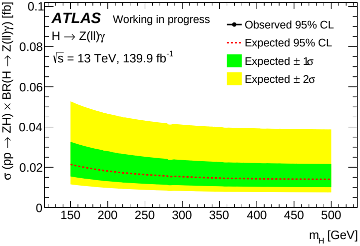
(t) $metsig > 2.5$, wh



(u) $metsig > 2.5$, zh



(v) $Nj >= 2; 60 < mjj < 120$, wh



(w) $Nj >= 2; 60 < mjj < 120$, zh

Conclusion

- Searching for any resonances in Data with full supervised learning in $Z\gamma$ final states in the predefined categories
- Calculating the limit on the production of Higgs-like to $Z\gamma$ where the significance of the signal is maximum
- The performance of the full supervision approach was compared to semi-supervised learning, with supervised learning giving better results
- Search for new phenomena in high-mass final states is setup for the LHC