Search for a heavy pseudo-scalar decaying into a Z boson and another heavy scalar boson leading to four lepton final states in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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Overview

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Motivation

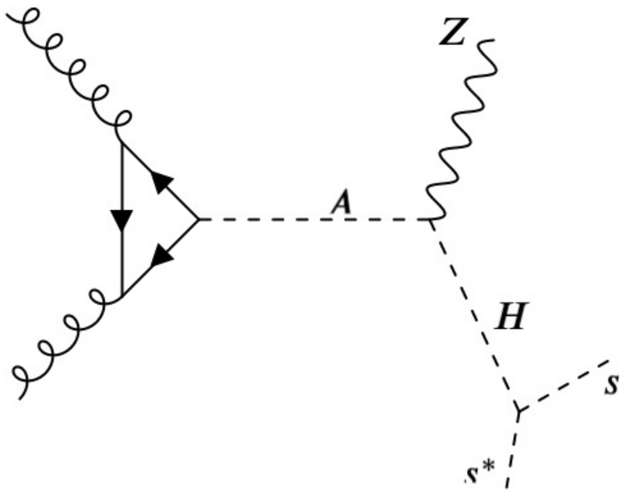
- Despite the success of the Standard Model (SM) in describing the interactions of elementary particles, there remain observations that suggest the existence of additional phenomena.
- In an effort uncover evidence of Beyond the Standard Model (BSM) physics, the ATLAS experiment recently conducted a model-independent study (CERN-EP-2021-063) in events involving three or four leptons.
- Additionally, in 2015 Wits introduced the scalars H and S (arXiv:1506.00612v2) via an effective model to explain several features in the LHC Run 1 data.
- This model suggests the production and decay modes of these scalars which could have significant signals at the LHC, which can be tested with newer and statistically more precise datasets.
- Recent research ($arXiv$: 1711.07874v3)at Wits has explained additional excesses in the Zh spectrum , as well as the production of three leptons and two b-tagged jets, by assuming $m_A \approx 600\ GeV$.
- The conclusions from these studies further reinforce the relevance of multi-lepton final states in the search for new bosons.

Introduction

- The simple extensions of the SM are the two-Higgs doublet models (2HDMs) so they require an additional Higgs-doublet in the model to fit the features in the data.
- As a result of this additional doublet, the scalar spectrum is populated with two CP-even ($h; H$), one CP-odd (A) and charged ($H^{\pm}$) scalar bosons.
- However, as pointed out in Refs. [arXiv:1606.01674v3 [hep-ph], arXiv:1709.09419v1 [hep-ph]], a 2HDM alone is not able to accommodate certain features of the data.
- The next point is to explore the production of A and its decay into $A \rightarrow ZH \rightarrow 4\ell$.
- The significance of rare multi-lepton final states was highlighted in Ref arXiv:1606.01674v3 [hep-ph]. These would include the production of four leptons from the production of four Ws, as well as the production of three same sign leptons from the production of six Ws.
- The LHC experiments have not reported on this signature to date, though due to low backgrounds one can expect an excellent signal to background ratio.

The simplified model

- The model described previously is a 2HDM with an additional real singlet ϕ_s , and it serves as the foundation for our formalism, and we call this model the 2HDM+S.
- Events were passed through a selection process after being generated and showered at 13 TeV. In the scenario considered here, the decay entails a four-lepton final state: $gg \rightarrow\ A\ \rightarrow ZH$.
- Heavy Higgs boson (H): $2m_h <\ m_H < 2m_t$, where m_t is the top-quark mass, and m_h is the SM Higgs boson.
- $m_h\ \approx$ 125 GeV and $Z\ \approx$ 90GeV
- Thereafter, $Z\ \rightarrow \ell\ell$ and SS decays to leptons via WW.



The representative Feynman diagram for the production mode of A and its subsequent decay to SS via gluon fusion (ggF) production mode.

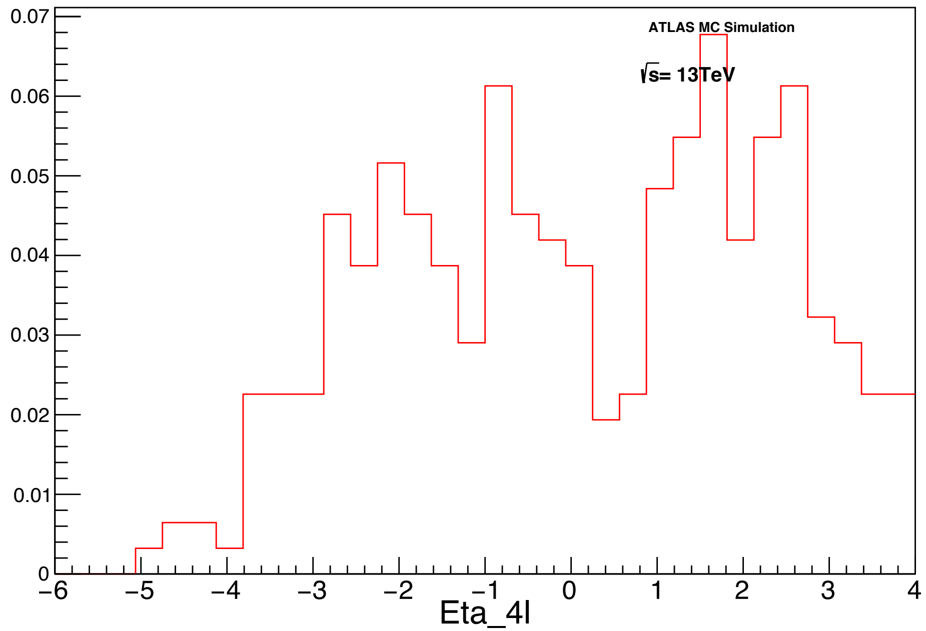
Event selection

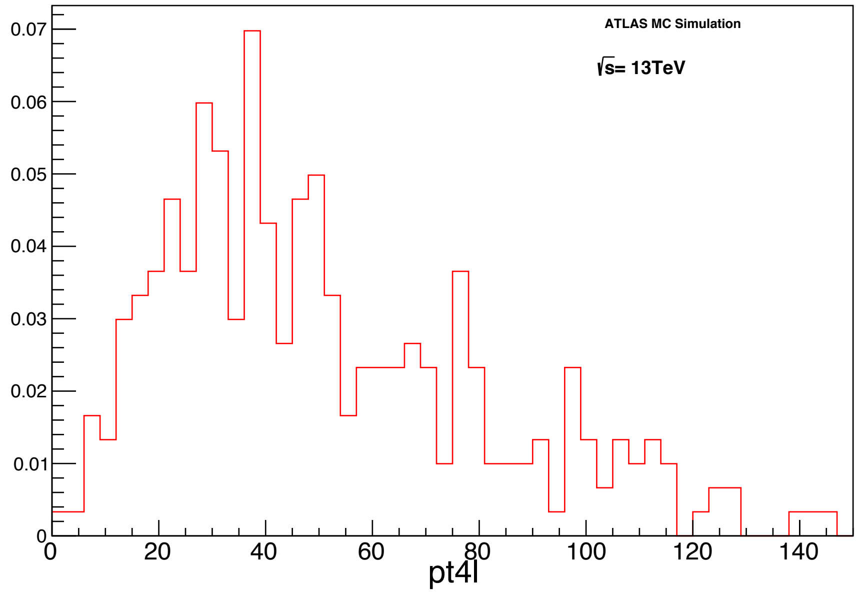
- Monte Carlo simulation samples are used to model the background and signal processes for this search.
- Dominant background: $qqZZ$.
- Events categorized depending on the SFOS lepton pairs:
  - Second category: $e\mu 2e/e\mu 2\mu$ → 1-SFOS pair:
- Highest p_T lepton in the quadruplet must satisfy p_T> 20 GeV.
- Second (third) lepton in p_T order must satisfy p_T> 15 (10) GeV.

Preselection	Require exactly four leptons with total charge equal zero
	Leptons require loose identification and isolation criteria
	$\|\eta^e\|$< 2.47, excluding 1.37<$\|\eta^e\|$< 1.52
	$\|\eta^\mu\|$< 2.5
	Event Trigger
	At least 1-lepton matched to triggering-lepton
	Each lepton must have $p_T^l > 10$ GeV
	Events with SFOS require $m_{ll} > 12$ GeV
Categories	1-SFOS

Results

Signal samples

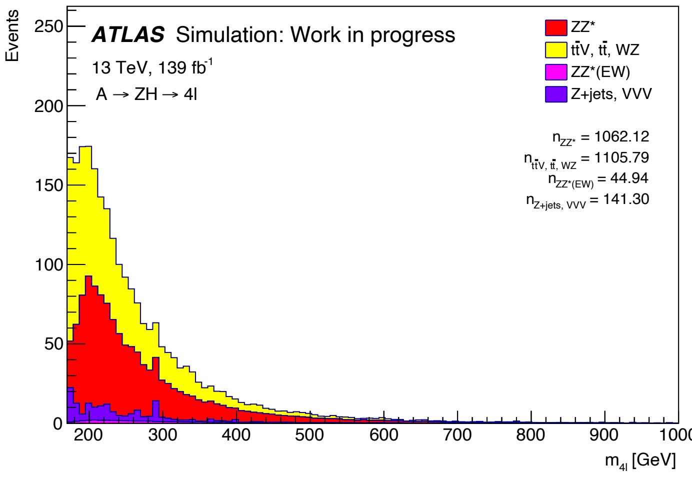


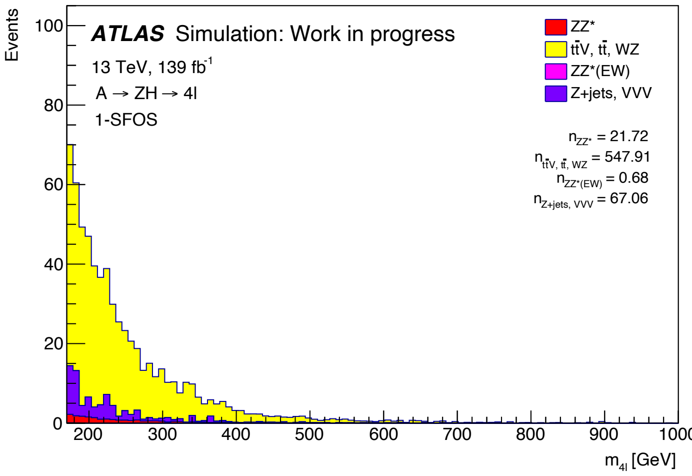


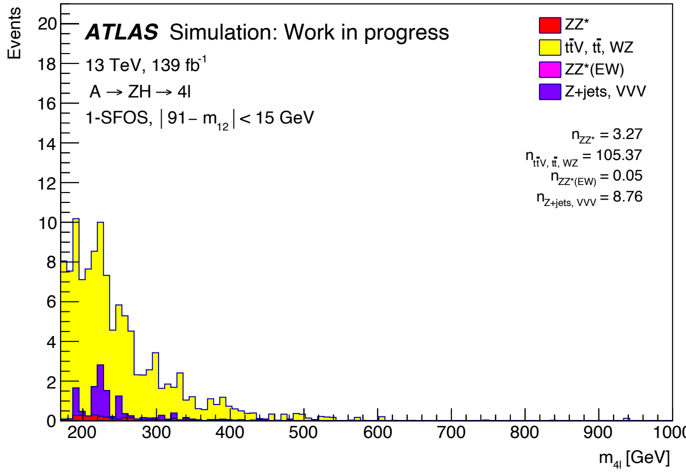
Background Cut flow Table

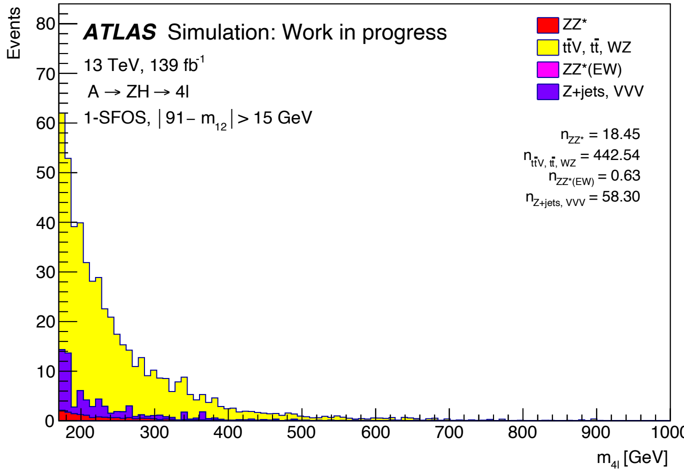
	$qqZZ$	ggZZ	$qqZZEW$	$Z + jets$	VVV	ttV	$t\bar{t}$	WZ	Total
4ℓ	1534.83	9.42	107.34	1007.44	10.97	79.10	2651.21	110.17	5510.50
1-SFOS	40.79	0.12	1.32	153.72	4.89	39.50	1312.53	53.14	1606.05
1-SFOS & $\|91 - m_Z\| < 15$	3.57	0.0048	0.059	7.98	0.83	6.68	134.82	6.35	160.31
1-SFOS & $\|91 - m_Z\| > 15$	37.21	0.12	1.26	145.73	4.06	32.82	1177.71	46.79	1445.73

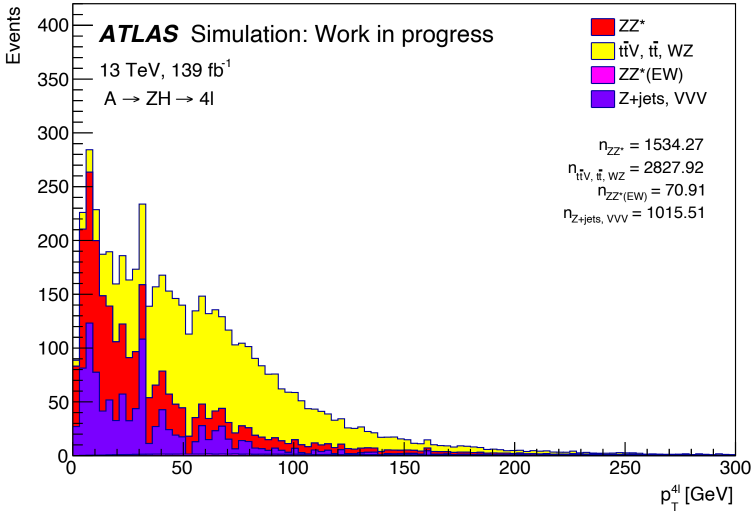
Background Samples

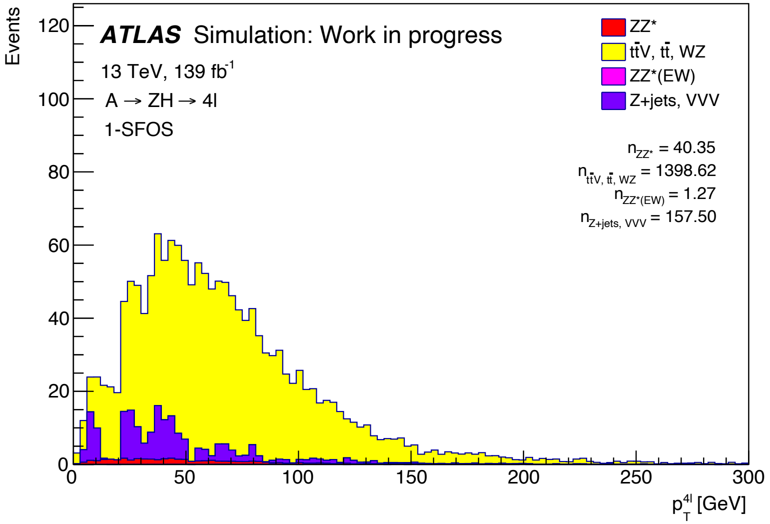


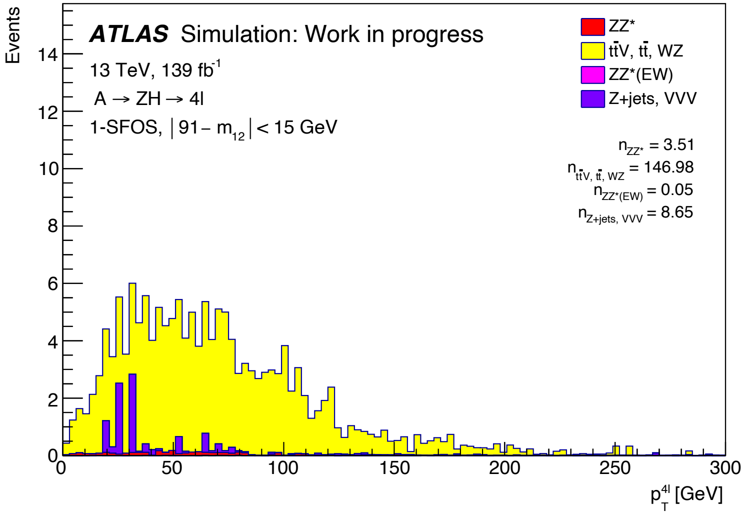


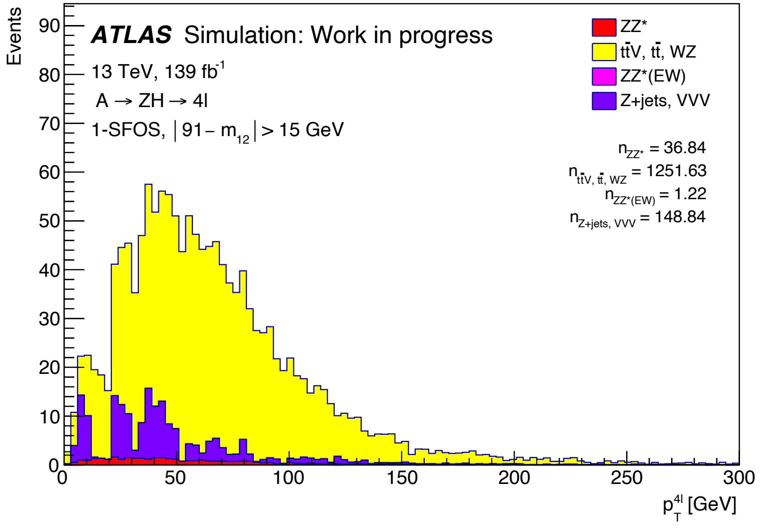





ATLAS Simulation: Work in progress
13 TeV, 139 fb-1
A → ZH → 4l
ZZ*
tt̄V, tt̄, WZ
ZZ*(EW)
Z+jets, VVV
nZZ* = 1534.27
ntt̄V, tt̄, WZ = 2827.92
nZZ*(EW) = 70.91
nZ+jets, VVV = 1015.51
Events
p4l T [GeV]


ATLAS Simulation: Work in progress
13 TeV, 139 fb-1
A → ZH → 4l
1-SFOS
ZZ*
tt̄V, tt̄, WZ
ZZ*(EW)
Z+jets, VVV
nZZ* = 40.35
ntt̄V, tt̄, WZ = 1398.62
nZZ*(EW) = 1.27
nZ+jets, VVV = 157.50
Events
p4l T [GeV]


ATLAS Simulation: Work in progress
13 TeV, 139 fb-1
A → ZH → 4l
1-SFOS, |91 − m12| < 15 GeV
ZZ*
tt̄V, tt̄, WZ
ZZ*(EW)
Z+jets, VVV
nZZ* = 3.51
ntt̄V, tt̄, WZ = 146.98
nZZ*(EW) = 0.05
nZ+jets, VVV = 8.65
Events
p4l T [GeV]


ATLAS Simulation: Work in progress
13 TeV, 139 fb-1
A → ZH → 4l
1-SFOS, |91 − m12| > 15 GeV
ZZ*
tt̄V, tt̄, WZ
ZZ*(EW)
Z+jets, VVV
nZZ* = 36.84
ntt̄V, tt̄, WZ = 1251.63
nZZ*(EW) = 1.22
nZ+jets, VVV = 148.84
Events
p4l T [GeV]

Conclusion

- We have introduced a search for a heavy pseudo-scalar decaying into a Z boson and another heavy scalar boson with the ATLAS detector in pp at $\sqrt{s}$ = 13 TeV.
- Monte Carlo simulation samples are used to model the background and signal processes for this search.
- The decay process analysed was the $gg \rightarrow A \rightarrow ZH$. The decay $A \rightarrow ZH$ leads to interesting final states, as pointed out earlier. For the sake of simplicity, here we considered the case where S decays to 2ℓ.
- No discrepancies noted on the background samples.
- Signal will be observed if one of the Z from A decays to 2ℓ.

Keep an eye out for the future $A \rightarrow ZH$ results using full ATLAS Run 2 data!