General searches for new phenomena with the ATLAS experiment

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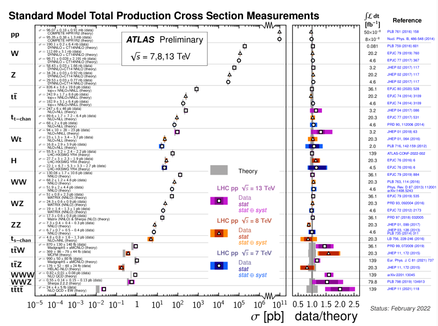
Introduction

The Standard Model (SM)

- A successful theory of fundamental particles and interactions
- Tested by many experiments like the LHC
- SM is not perfect:
    - Unification of the interactions?
    - No gravity
    - ...



ATL-PHYS-PUB-2022-009

Physics beyond the Standard Model (BSM) Searches

- No new physics has been found so far by model-specific searches
- Signals might be hidden in kinematic regimes and final states that have remained unexplored
- Motivate a model-independent analysis to search for BSM physics

General search

What is the general search

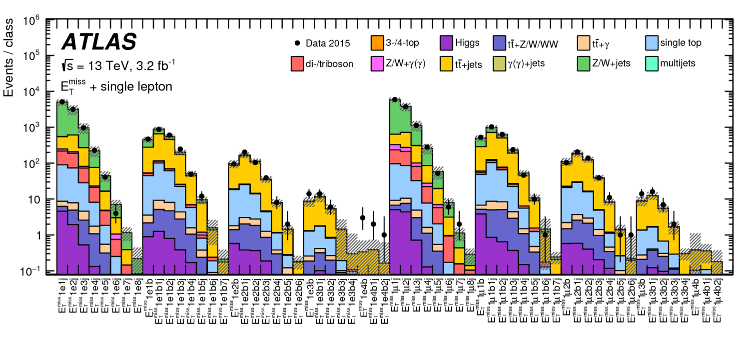
- It is generic: performed with multiple final states
- It is model-independent: minimal features of BSM physics are assumed

General searches at ATLAS

- Global general search: Eur. Phys. J. C 79, 120 (2019).
- A search for new resonances in multiple final states with a high transverse momentum Z boson ($Y \to Z + X$): arXiv:2209.15345
- Anomaly detection search for new resonances decaying into a Higgs boson and a generic new particle X in hadronic final states($Y \to H + X$): ATLAS-CONF-2022-045
- Search for new phenomena in three- or four-lepton events (Multi-lepton general search): Phys. Lett. B 824 (2022) 136832

Global general search

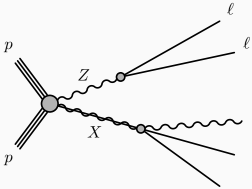
- Classify events according to the combinations of high p_T reconstructed objects (e, μ, γ, (b-)jets, E_T^{miss}) in the event
- Obtain the background from MC predictions
- Calculate the deviation between data and SM expectations in **686** classes
- **No significant deviations are found in the $3.2 fb^{-1}$ of dataset collected with ATLAS detector in 2015**

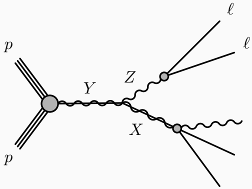


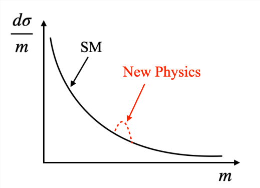
Eur. Phys. J. C 79, 120 (2019).

$Y \to Z + X$: Introduction

- A general search for new resonances in events with high p_T (> 100GeV) Z ($66 < m_Z < 116$GeV) (arXiv:2209.15345)
- Signal process: $pp \to Z(ee/\mu\mu) + X$, X: all possible final states
- Resonance can be induced by X or Y, use m_X and m_{ZX} as observables
- Define 6 exclusive event categories by the leading p_T object in X: Lead small-R jet, Lead b-jet, Lead large-R jet, Lead photon, Lead electron, and lead muon. Additionally, one inclusive category is defined
- Search for local excesses on m_X and m_{ZX} spectra in each category

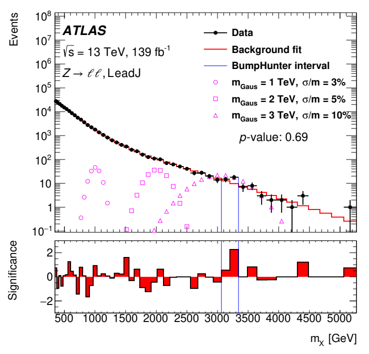


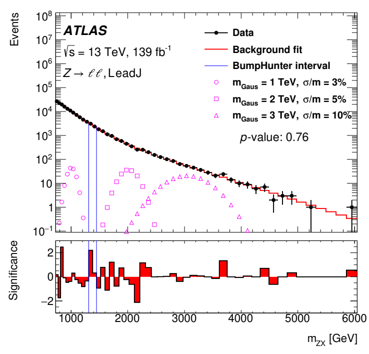




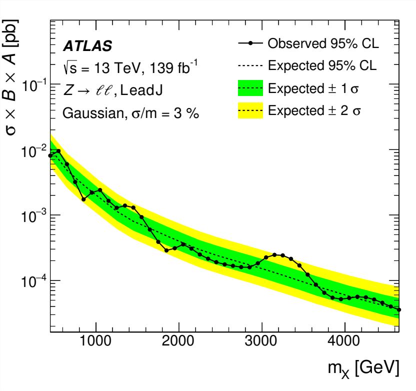
$Y \to Z + X$: Search strategy

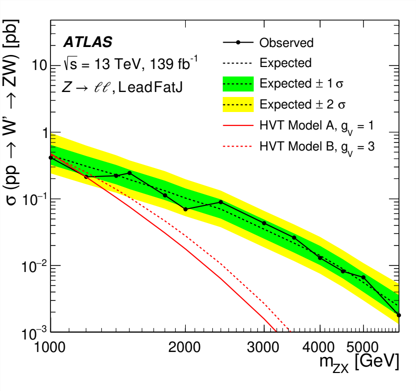
- The SM background is modelled by a fit to the m_X or m_{ZX} spectra with smooth functions
- BumpHunter(BH) algorithm is applied to the mass spectrum to search local excesses
- The largest excess has a BH p-value of 0.48 and 0.1 before and after excluding the initial BH interval
- **No significant excesses are observed in any of the mass spectra**





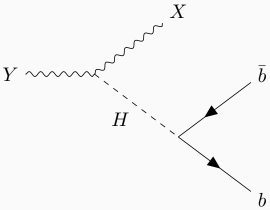
- Exclusion upper limits are derived at 95% CL for:
  - **Model-independent results:** Gaussian-shaped signals with relative width values of 3%, 5% and 10%
  - **Model-dependent results:** HVT signal ($W' \to ZW \to llqq$)

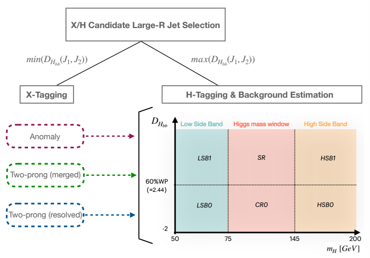




$Y \rightarrow H + X$: Introduction

- Search for a heavy resonance Y decaying to a SM Higgs ($b\bar{b}$) and a new particle X in a fully hadronic final state(ATLAS-CONF-2022-045).
- Higgs($b\bar{b}$) and $X(q\bar{q})$ are highly boosted, and each is reconstructed as a single large-R jet
- Tag the X in a signal model-agnostic way through the use of a per-jet anomaly score derived from a ML-based data-driven method





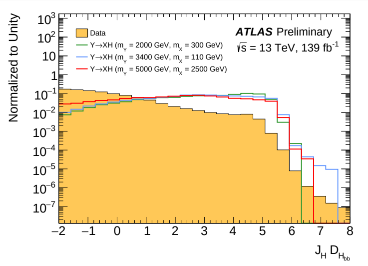
Analysis workflow

- Resolve the ambiguity between two large-R jets into X and H candidates using $D_{H_{bb}}$
- Separate events into three categories (**anomaly**, **two-prong merged** and **two-prong resolved**) according to D_2^{trk} (the energy correlator substructure variable) or anomaly score of the X candidate
- Define CRs(CR0, HSB0, HSB1), VRs(LSB0, LSB1) and SR according to the H candidate mass and $D_{H_{bb}}$ score

$Y \to H + X$: Selection

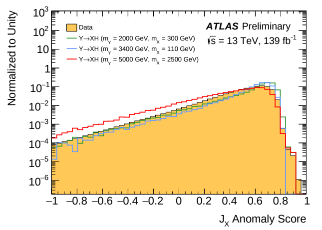
Higgs candidate tagging

- Discriminate Higgs jet from the two J in the events using the jet-level discriminant $D_{H_{bb}}$
- $D_{H_{bb}} = ln \frac{p_{Higgs}}{f_{top} \cdot p_{top} + (1 - f_{top}) \cdot p_{multijet}}$
- p_{Higgs}, p_{top} and $p_{multijet}$ are three NN classification scores
- f_{top} determines the weight of the top background shape
- A selection of $D_{H_{bb}} > 2.44$ defines a WP at 60% efficiency



Anomaly SR

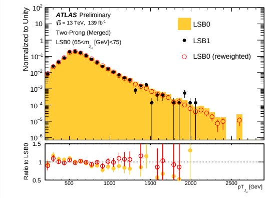
- Primary SR based on anomaly detection
- Select X particles based solely on their incompatibility with the expected SM background
- *Anomaly detection* is based on a fully unsupervised variational recurrent neural network (VRNN, arXiv:2105.09274)
- Anomaly Score (AS) of the X candidate > 0.5

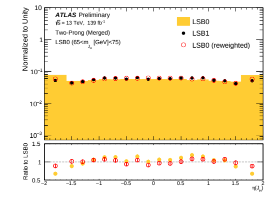


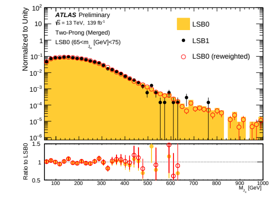
Two-prong SRs:

- Based on the reconstruction of X
- Previous results with $36.1 fb^{-1}$ data [Phys. Lett. B 779 (2018) 24]
- **Merged**: large-R jet with two-pronged substructure
- **Resolved**: two small-R jets

- Background dominated by high-p_T multijet events
- The background estimation is fully data-driven and derived from regions that are orthogonal to the SR
- Strategy: Derive weights using a DNN to reweight CR to SR and estimate the background[1]
- The background shapes are obtained from data in CR0
- Weights are derived from HSB0 and HSB1, validated using data in LSB0 and LSB1
- Good agreement is observed of the reweighted shapes to the true tagged data in all distributions



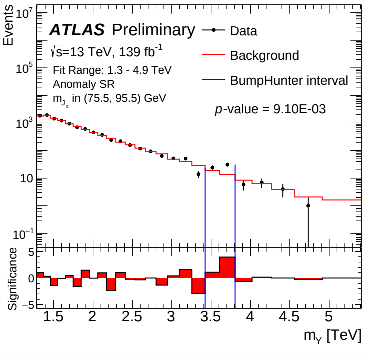


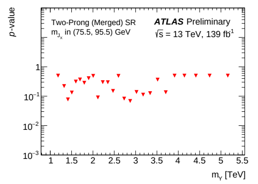


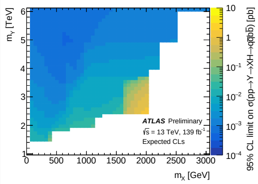
[1] U. Michelucci and F. Venturini, Estimating neural network's performance with bootstrap: A tutorial, Machine Learning and Knowledge Extraction 3 (2021) 357

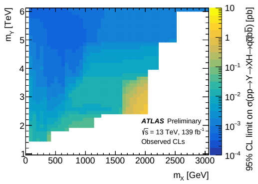
$Y \to H + X$: Results

- Results are derived by performing background-only fits and scanning with BumpHunter
- Considering all m_Y and m_X bins, the largest observed excess has a global significance of 1.47σ
- **No significant deviations of data are observed**
- Signal-plus-background fits are performed to determine the 95% CL upper limit on the cross-section of the $Y \to XH$ process
- It is the FIRST result from ATLAS that uses unsupervised machine learning!









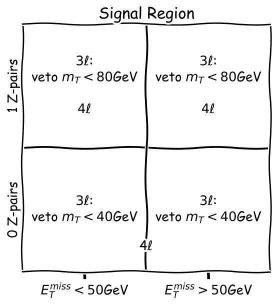
Multi-lepton general search: introduction

Overview

- Search the entirety of the three or four leptons (3ℓ and 4ℓ, $\ell = e, \mu$) data, except validation and control regions (Phys. Lett. B 824 (2022) 136832)

Signal Region (SR) Definition

- Separate 3/4 lepton phase space into **7** signal regions
- **Event split**: $E_T^{miss} > 50GeV$ and on-/off-Z lepton pair ($81 < m_{ll} < 101$GeV)
- Further split the SRs by the distribution of m_{inv} of all leptons



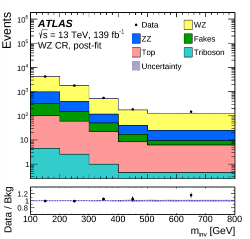
Control Region

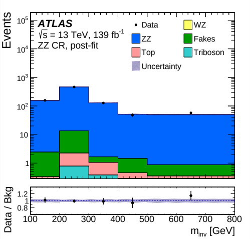
- 2 control regions are used to constrain the normalization factors of disboson (**WZ** and **ZZ**) background and check the fake performance
- CRs are universal for all signal regions

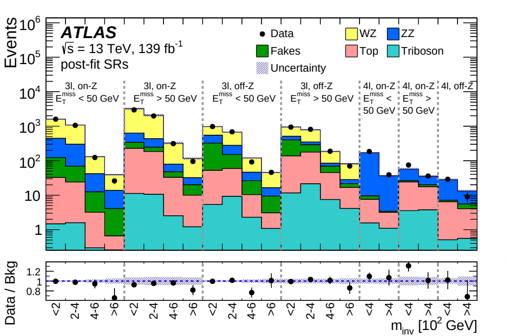
Multi-lepton general search: statistical analysis

Normalization factors

- The normalization factors of WZ and ZZ are obtained by fitting CRs simultaneously
- **WZ:** 0.98 ± 0.07
- **ZZ:** 1.05 ± 0.09



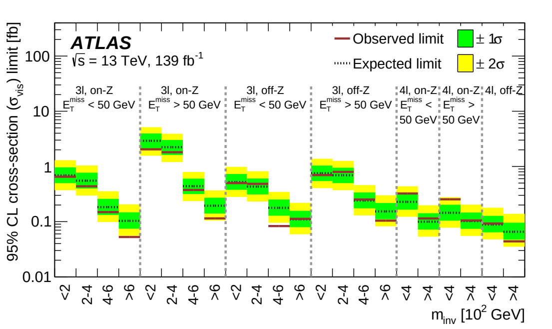




- All SRs with data and post-fit background yields
- For each SR, define the significance as: $Z = \hat{N}_S / \Delta\hat{N}_S$
  $\hat{N}_S$: the number of signal events
  $\Delta\hat{N}_S$: uncertainty from fitting
- **No significant excess is found in any of the SRs**

Multi-lepton general search: results

- Limits on the number of signal events are set for the visible cross-section σ_{vis}
- The results are also interpreted for two particular BSM models



Model	Mass [GeV]	Best single SR	m_{inv}	$A \times \epsilon$	σ^{95}_{exp} [fb]	σ^{95}_{obs} [fb]
Type-III Seesaw	400	3ℓ, Off-Z, $E_{\text{T}}^{\text{miss}} > 50$ GeV	> 600 GeV	0.0036	41^{+17}_{-11}	27
	700	3ℓ, Off-Z, $E_{\text{T}}^{\text{miss}} > 50$ GeV	> 600 GeV	0.012	12^{+5}_{-3}	8.8
$H^{\pm\pm}$	300	4ℓ, Off-Z	> 400 GeV	0.37	$0.18^{+0.08}_{-0.05}$	0.12
	500	4ℓ, Off-Z	> 400 GeV	0.40	$0.16^{+0.07}_{-0.05}$	0.11

Summary

- Model-independent general searches for BSM can help to explore the phase-space regions that remained uninvestigated
- It's not as sensitive as a dedicated analysis optimized for a specific BSM model, but it could help to identify the promising phase-space regions for the future dedicated study
- No significant excesses have been found in general searches covered by this talk
- More results are coming from Run 2 and Run 3 data!