Search for resonances produced in association with or decaying to a Z boson at large transverse moment in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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- Event Selection
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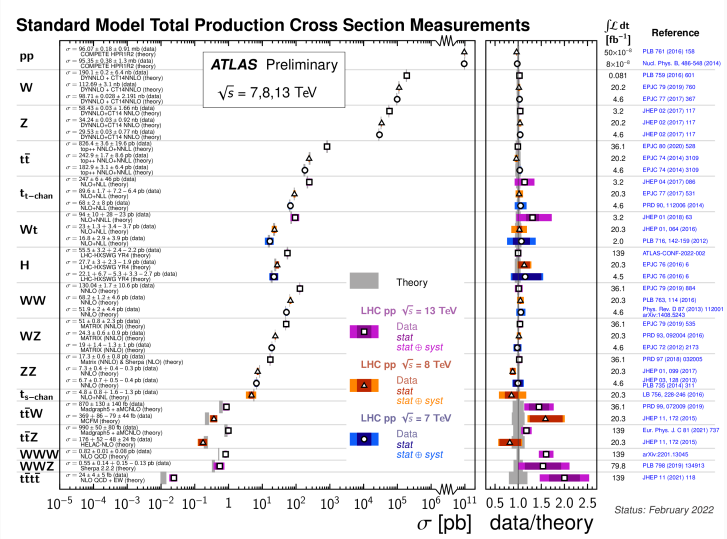
Introduction

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?
  - Extra dimensions?
  - ...



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Physics beyond the Standard Model (BSM) Searches

- Most of searches are optimized for a specific BSM model
- 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 model-independent searches!

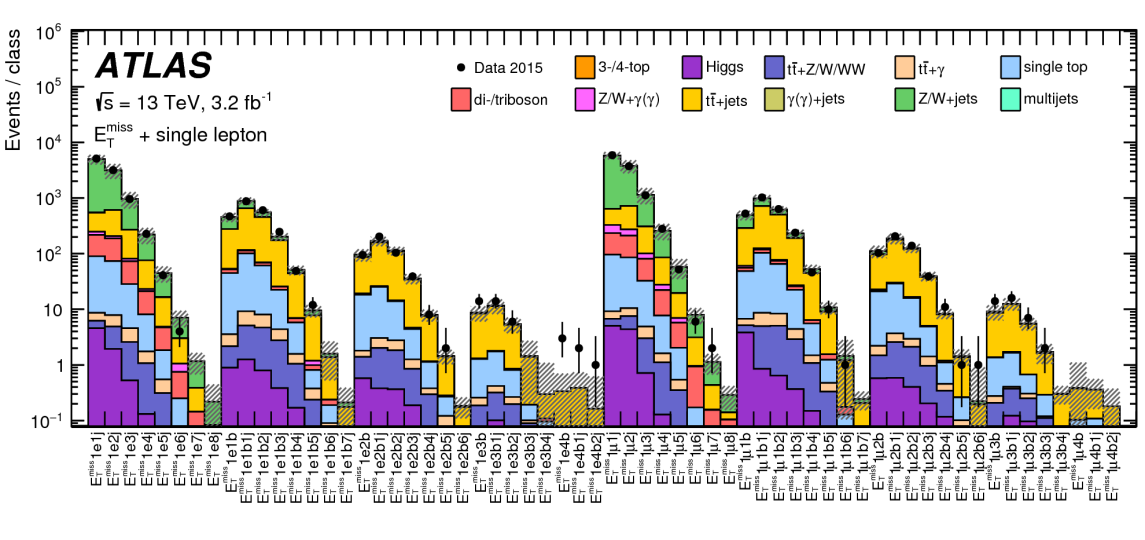
Introduction

What is the general search

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

An example of general searches

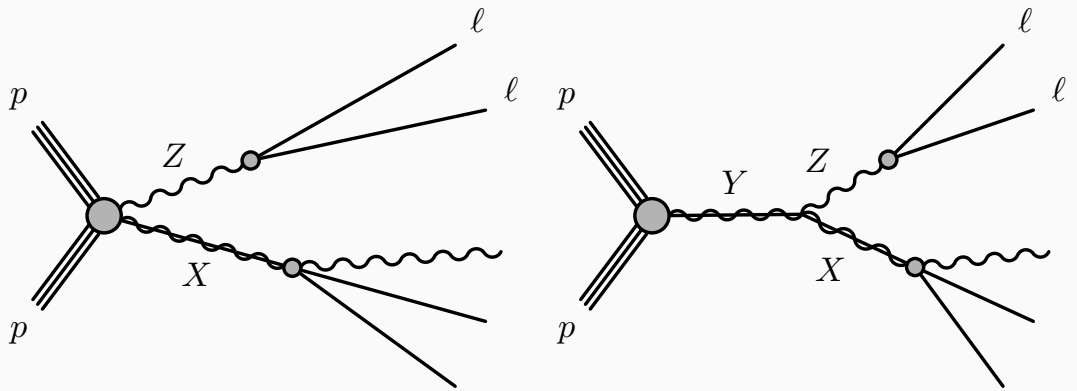
- Classify events according to the combinations of high p_T reconstructed objects (e, μ, γ, (b-)jets, E_T^{miss}) in the event
- Calculate the deviation between data and SM expectations in **686** classes

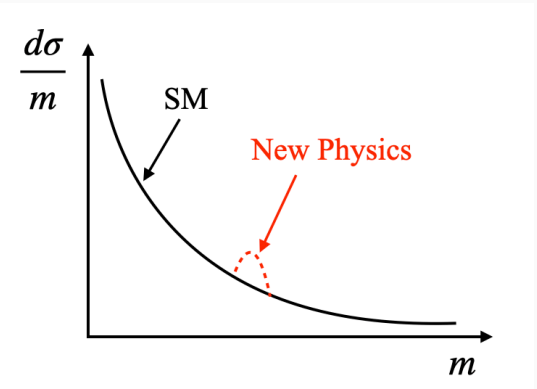


Eur. Phys. J. C 79, 120 (2019).

Introduction

- A general search for new resonances in events with high p_T (> 100GeV) Z ($66 < m_Z < 116$GeV) [arXiv:2209.15345]
- Data: $139 fb^{-1}$ collected by ATLAS in Run 2
- 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
- Search for local excesses on m_X and m_{ZX} spectra in each category





Analysis Strategy

Analysis strategy

- 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 the local excesses on m_X and m_{ZX} spectra in each category using *BumpHunter*

Signal region

- OS 2ℓ, $66 < m_{\ell\ell} < 116$GeV, $p_T^{\ell\ell} > 100$GeV

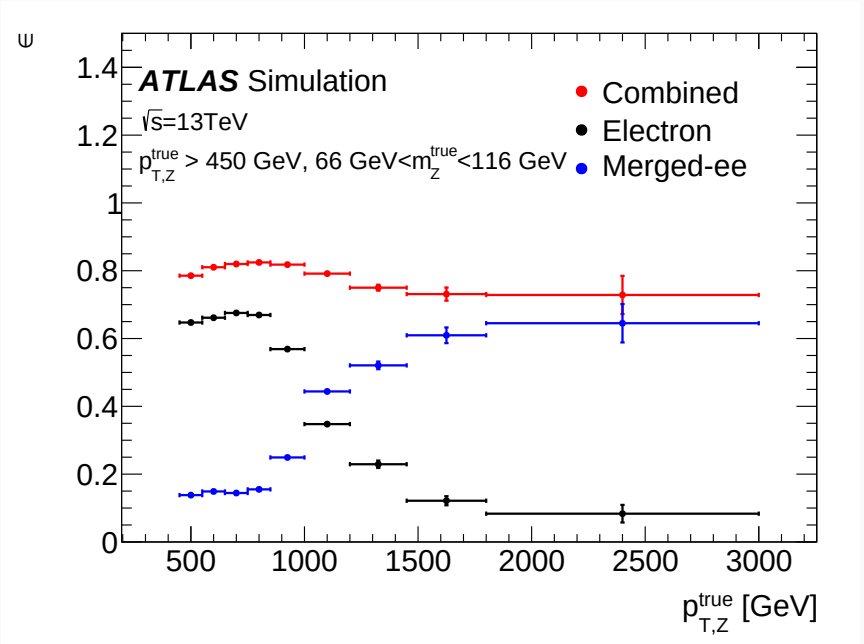
Event yields

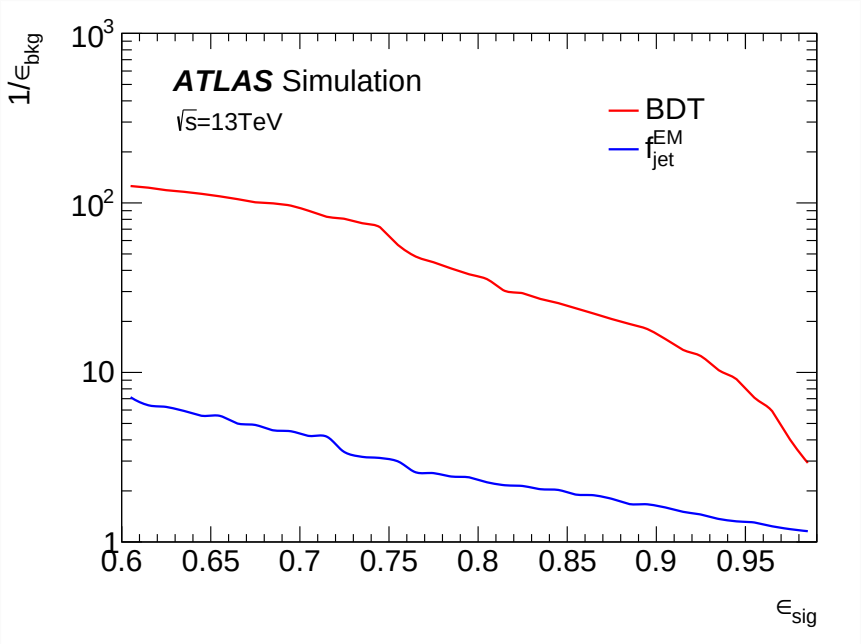
- Lead small-R jet, Lead b-jet, and Lead large-R jet dominate the event yields of data:

Category	LeadJ	LeadB	LeadFatJ	LeadP	LeadE	LeadM
e^+e^-	979 074	77 625	181 561	2 601	565	530
$\mu^+\mu^-$	1 307 187	99 927	228 986	3 418	790	766

Merged-ee identification

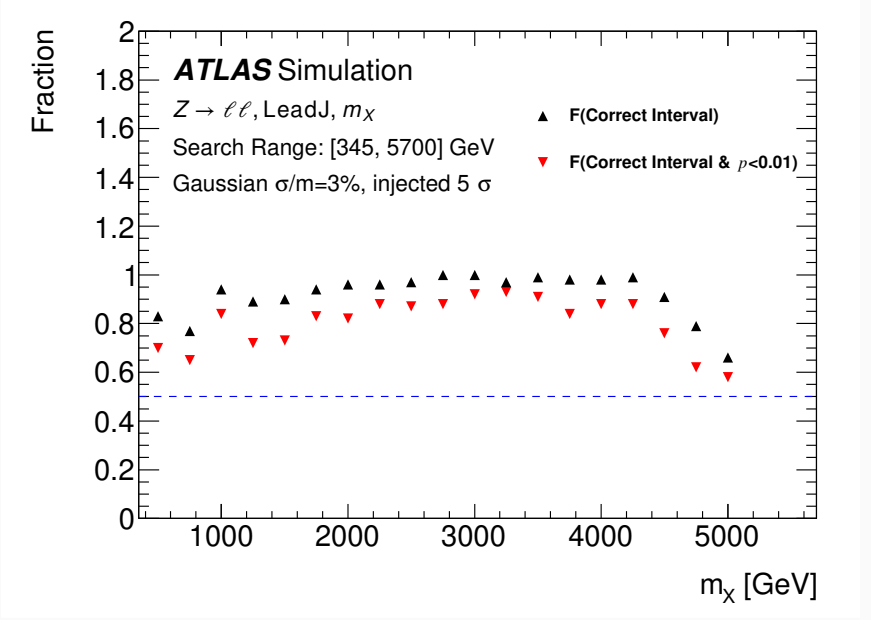
- When $Z(ee)$ boson is highly boosted, we can not reconstruct the Z boson using 2 good electrons
- We will try to reconstruct the Z boson from small-R jet with $p_T > 450$GeV instead when we **fail** to reconstruct it with 2 leptons (NO overlap)
- The merged-ee identification is based on BDT using jet properties as input variables
- Signal events: $Z(ee) + jets$, Background events: other SM background MC samples
- It increases the event yields in the high Z p_T region by several times

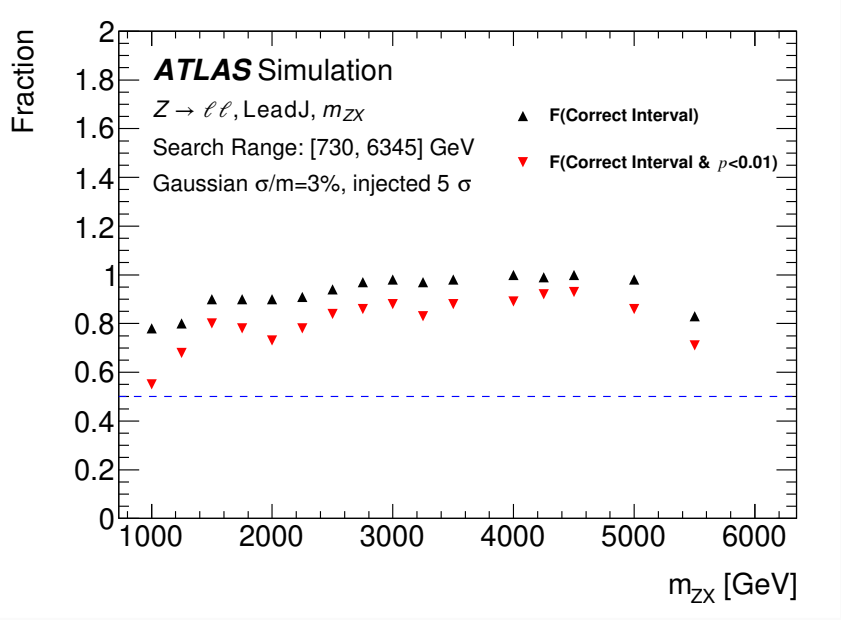




Background modelling and BumpHunter

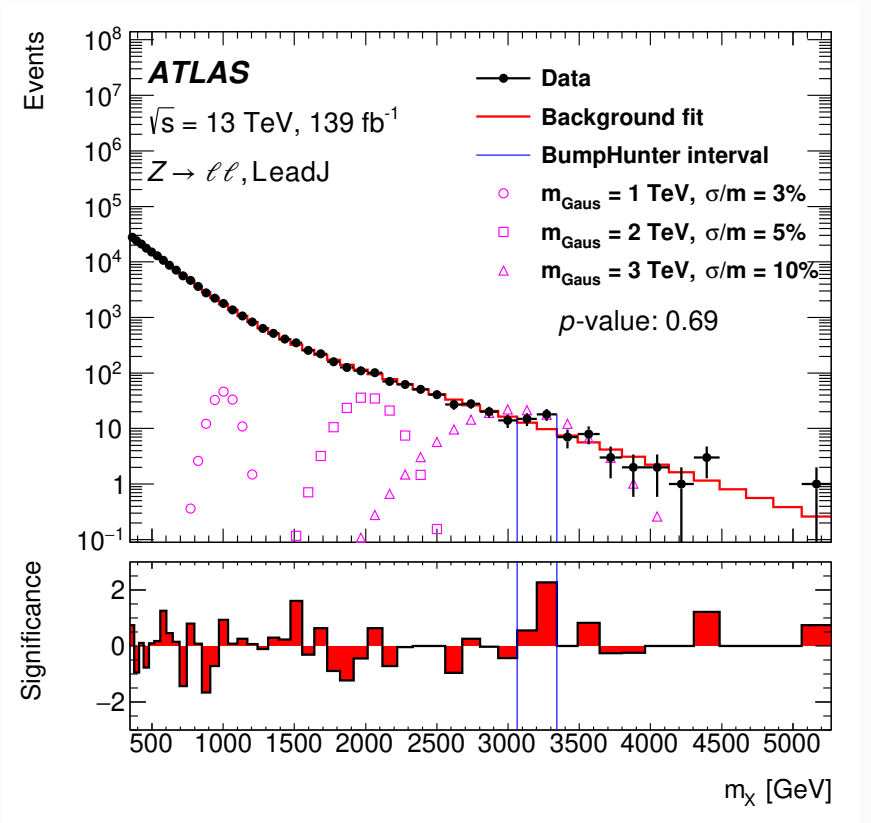
- The SM background is modelled by a fit to the binned m_X or m_{ZX} spectra with smooth functions in each categories
- BumpHunter(BH) algorithm is applied to the mass spectrum to search local excesses
- Using background derived by the background-only fit excluding the BH interval increases the significance
- Pseudo-experiments (PE) are generated to obtain a mass range to detect a signal
- Sensitive search range: the region with PE fraction above 50% (BH p–value< 0.01)

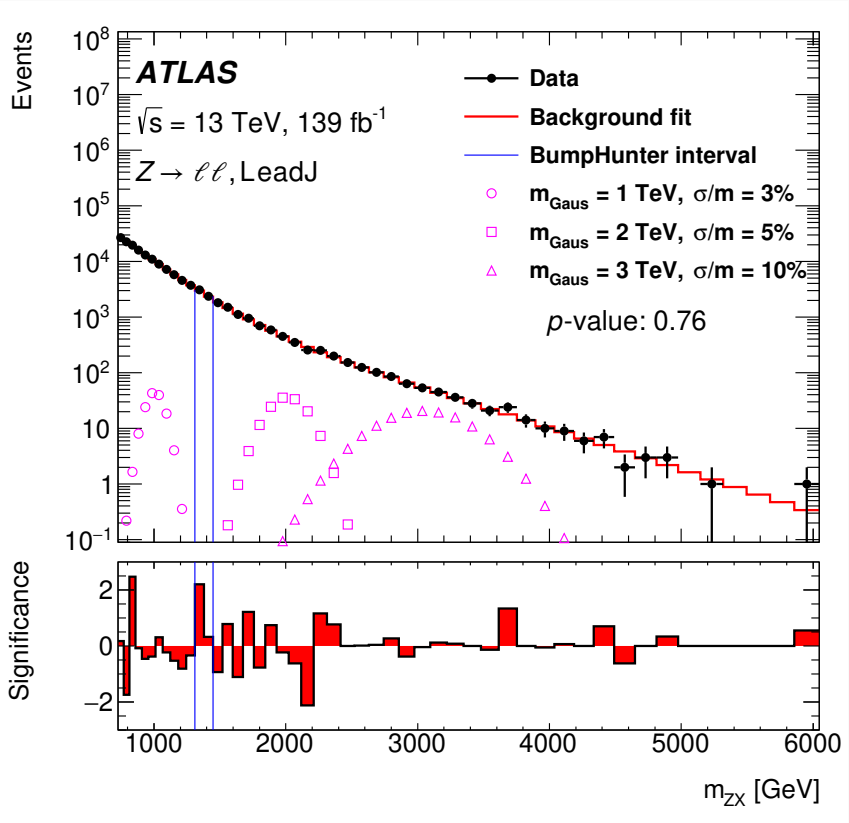




BumpHunter search results

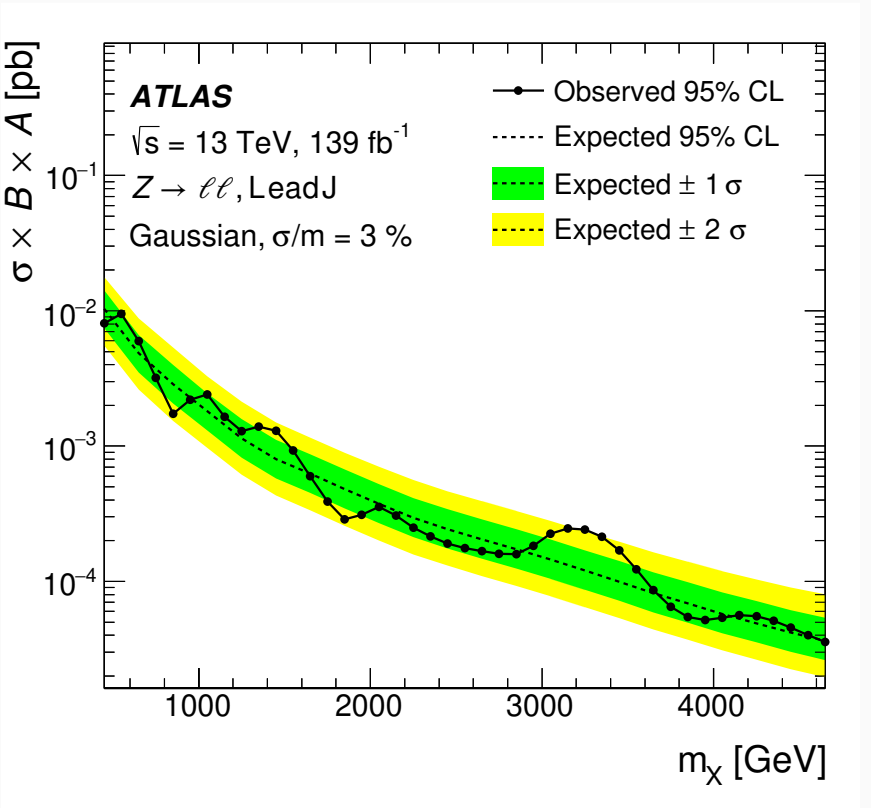
- The largest excess is at around 1.6TeV in the m_{ZX} spectrum of the leading large-R jet category with a BH p-value of 0.48 and 0.1 before and after excluding the initial BH interval, respectively
- **No significant excesses are observed in any of the mass spectra**

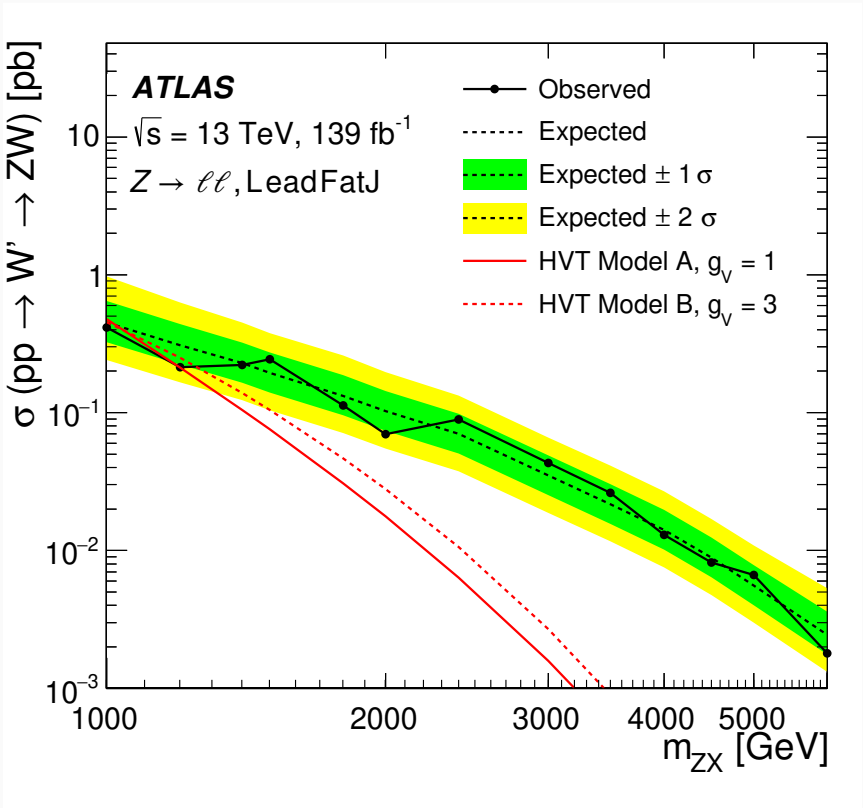




Results

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





Summary

- Model-independent general searches for BSM can help to explore the phase-space regions that remained uninvestigated
- The aim of the general search is not discovery, but probe a large number of phase spaces simultaneously and help to identify the sensitive phase-space regions for the future dedicated searches
- We perform a novel generic search for resonances associated with or decaying to high p_T Z boson using ATLAS full Run-2 data [arXiv:2209.15345]
- No significant excesses have been found in $Y \to Z + X$ general search
- More general search results are coming from Run 2 and Run 3 data!

Backup

Background modelling

- The SM background is modelled by a fit to the binned m_X or m_{ZX} spectra with 2 smooth functions in each categories:
-
$$f_1(x) = p_0 \left(\mathrm{e}^{-p_1 x} + p_2 \mathrm{e}^{-(p_1+p_3)x} + p_4 \mathrm{e}^{-(p_1+p_3+p_5)x} + \cdots \right) \quad (1)$$

  where $x = (\mathcal{M} - \mathcal{M}_{\mathrm{min}})/(\mathcal{M}_{\mathrm{max}} - \mathcal{M}_{\mathrm{min}})$ in Eq. (1), $\mathcal{M}_{\mathrm{min}}$ and $\mathcal{M}_{\mathrm{max}}$ are the lower and upper fit boundaries of the distribution
-
$$f_2(x) = p_0 (1-x)^{p_1} x^{p_2 + p_3 \ln x + p_4 \ln^2 x + \cdots} \quad (2)$$

  $x = \mathcal{M}/\sqrt{s}$ in Eq. (2)
- p_0 is a free normalisation factor and p_i are a number of other free parameters controlling the shape of a mass distribution