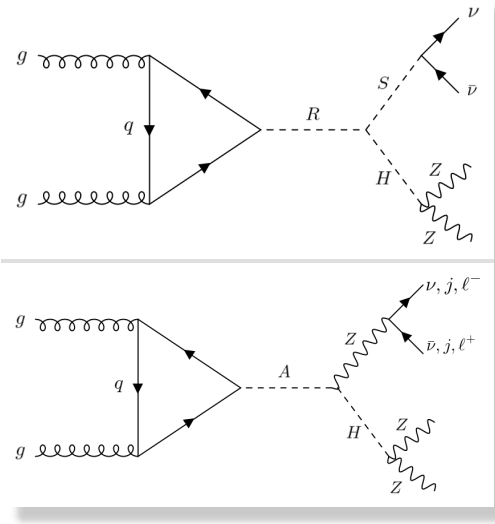
4ℓ+MET analysis: unblinded results

Abdualazem Fadol

February 20, 2023

Introduction

- In this analysis, we're searching for heavy resonances in final states
- with four leptons and missing transverse energy or jets.
- Interpret the data in terms of two models:
  - $R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$, [1]
  - $A \to ZH \to 4\ell + X$, [2,3]

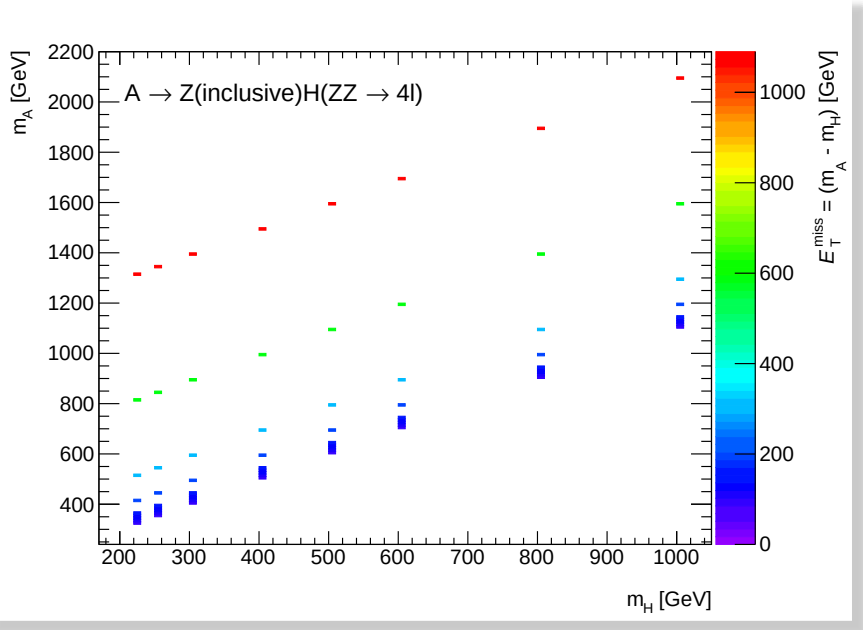


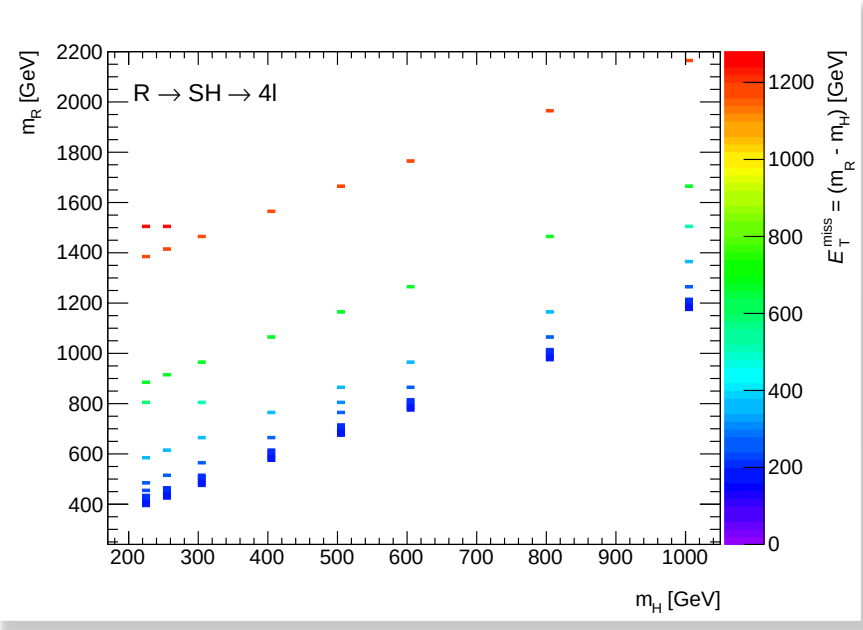
- We unblinded the Run-2 dataset with luminosity of 139 fb^{-1}.
- Expected and observed 2D limit on the $m_{A/R}$-m_H plane.

[1] JHEP 03 (2017) 094
[2] Phys.Rev.Lett.113
[3] Eur. Phys. J. C (2016)

Benchmark

- Data: Run-2 dataset (unblinded now)
- Signal samples:
  - $A \to ZH \to 4\ell + X$: $A \to Z(\to 2\ell)H(\to 2\ell + X)$ and $A \to Z(\to X)H(\to 4\ell)$
  - $R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$: The S decays to neutrinos, and its mass is fixed 160 GeV.





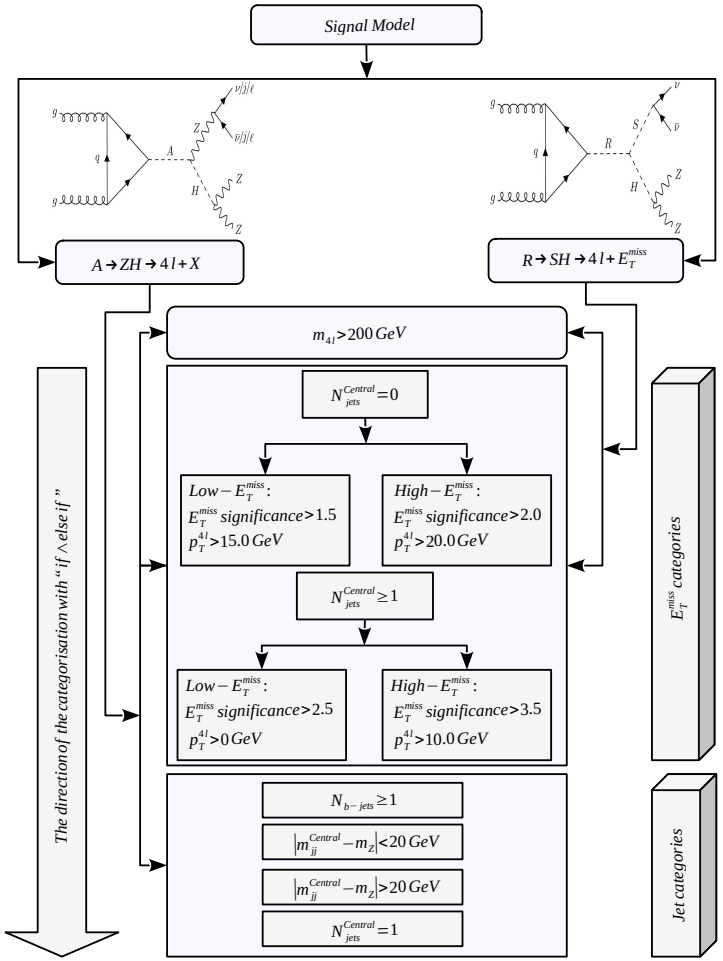
- **SM backgrounds:**
  - The dominant backgrounds are $q\bar{q} \to ZZ$ and $gg \to ZZ$— 85% & 11%.
  - Small contribution from VVV, $t\bar{t}V$, $t\bar{t}$, $Z + \mathrm{jets}$, WZ and $q\bar{q} \to ZZ(EW)$
  - The background shapes are taken from simulation for all SM backgrounds.
  - Fit range (bin, xmini, xmaxi) $\equiv (2000, 200, 1200)$

Event selection

- **Triggers:**
  - single-lepton
  - di-lepton
  - tri-lepton
- **Jets:**
  - using central jets
  - b-jets: 77% efficiency
- **4ℓ+MET specific selection to optimise:**
  - $R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$
  - $A \to ZH \to 4\ell + X$

Physics Objects	
Electrons	Loose Likelihood quality electrons with hit in innermost layer, $E_{\mathrm{T}} > 7$ GeV and $\lvert\eta\rvert < 2.47$ Interaction point constraint: $\lvert z_0 \cdot \sin\theta\rvert < 0.5$ mm (if ID track is available)
Muons	Loose identification with $p_{\mathrm{T}} > 5$ GeV and $\lvert\eta\rvert < 2.7$ Calo-tagged muons with $p_{\mathrm{T}} > 15$ GeV and $\lvert\eta\rvert < 0.1$, segment-tagged muons with $\lvert\eta\rvert < 0.1$ Stand-alone and silicon-associated forward restricted to the $2.5 < \lvert\eta\rvert < 2.7$ region Combined, stand-alone (with ID hits if available) and segment-tagged muons with $p_{\mathrm{T}} > 5$ GeV Interaction point constraint: $\lvert d_0\rvert < 1$ mm and $\lvert z_0 \cdot \sin\theta\rvert < 0.5$ mm (if ID track is available)
Jets	anti-k_T jets with *bad-loose* identification, $p_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 2.5$ (Central jets only)
Overlap removal	Jets within $\Delta R < 0.2$ of an electron or $\Delta R < 0.1$ of a muon are removed
Vertex	At least one collision vertex with at least two associated track
Primary vertex	Vertex with the largest p_{T}^2 sum
Event Selection	
Quadruplet Selection	- Require at least one quadruplet of leptons consisting of two pairs of same-flavour opposite-charge leptons fulfilling the following requirements: - p_{T} thresholds for three leading leptons in the quadruplet: 20, 15 and 10 GeV - Maximum one calo-tagged or stand-alone muon or silicon-associated forward per quadruplet - Leading di-lepton mass requirement: $50 < m_{Z_1} < 106$ GeV - Sub-leading di-lepton mass requirement: $m_{\mathrm{threshold}} < m_{Z_2} < 115$ GeV - $\Delta R(\ell, \ell') > 0.10$ for all leptons in the quadruplet - Remove quadruplet if alternative same-flavour opposite-charge di-lepton gives $m_{\ell\ell} < 5$ GeV - Keep all quadruplets passing the above selection
Isolation	- Contribution from the other leptons of the quadruplet is subtracted - FixedCutPFlowLoose WP for all leptons
Impact Parameter Significance	- Apply impact-parameter significance cut to all leptons of the quadruplet - For electrons: $d_0/\sigma_{d_0} < 5$ - For muons: $d_0/\sigma_{d_0} < 3$
Best Quadruplet	- If more than one quadruplet has been selected, choose the quadruplet with highest Higgs decay ME according to channel: 4μ, $2e2\mu$, $2\mu2e$ and $4e$
Vertex Selection	- Require a common vertex for the leptons: - χ^2/ndof < 6 for 4μ and χ^2/ndof < 9 for others decay channels

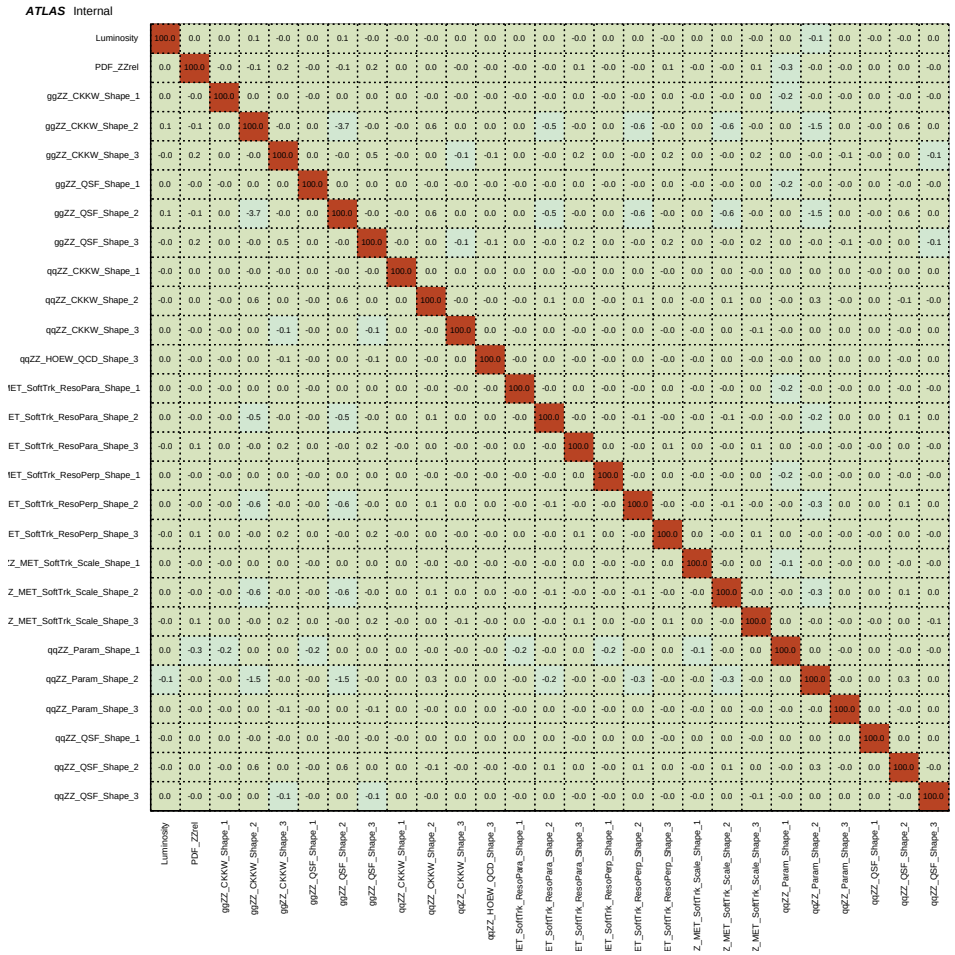
Specific selection depending on the model



The fit strategy

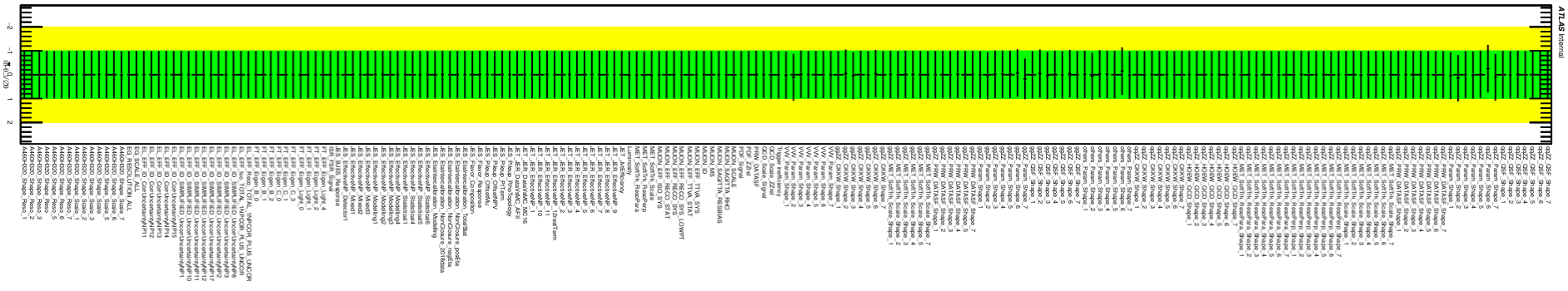
- We use the TRExFitter statistical tool to perform the fit.
- The fit is performed on the invariant mass of the four-lepton system;
- The fit range is between 200 and 1200 GeV with 0.5 GeV as a step for each bin.
- A binned maximum-likelihood fit is used to fit signal-plus-background Asimov data.
- For $A \to ZH \to 4\ell + X$: seven categories are fitted simultaneously.
- For $A \to ZH \to 4\ell + X$: three categories are fitted simultaneously.
- Float $q\bar{q} \to ZZ$ and $gg \to ZZ$ with a normalisation that depends on the category.
- The VVV and others backgrounds are fixed to the SM prediction.
- All nuisance parameters are floated during the fit.

Fit results
Correlation Matrix



☐ Correlation between nuisance parameters for the $(m_R, m_H) = (420, 250)$ GeV signal

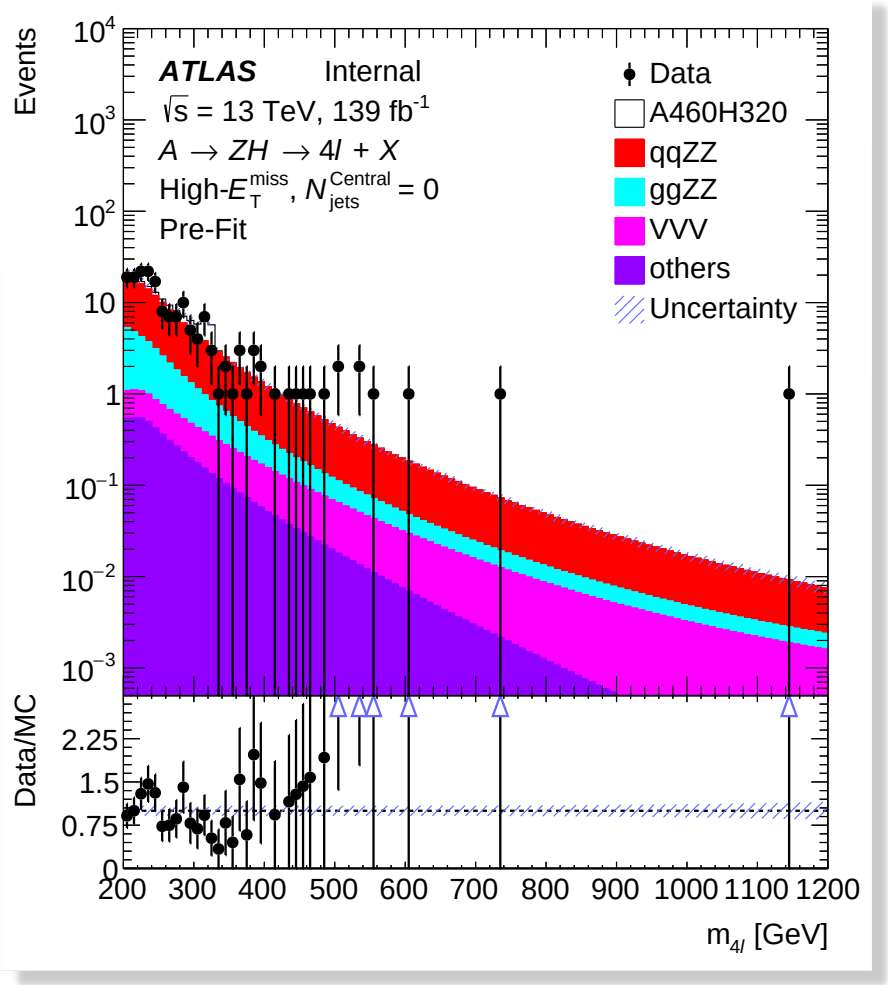
Fit results
Pull plot

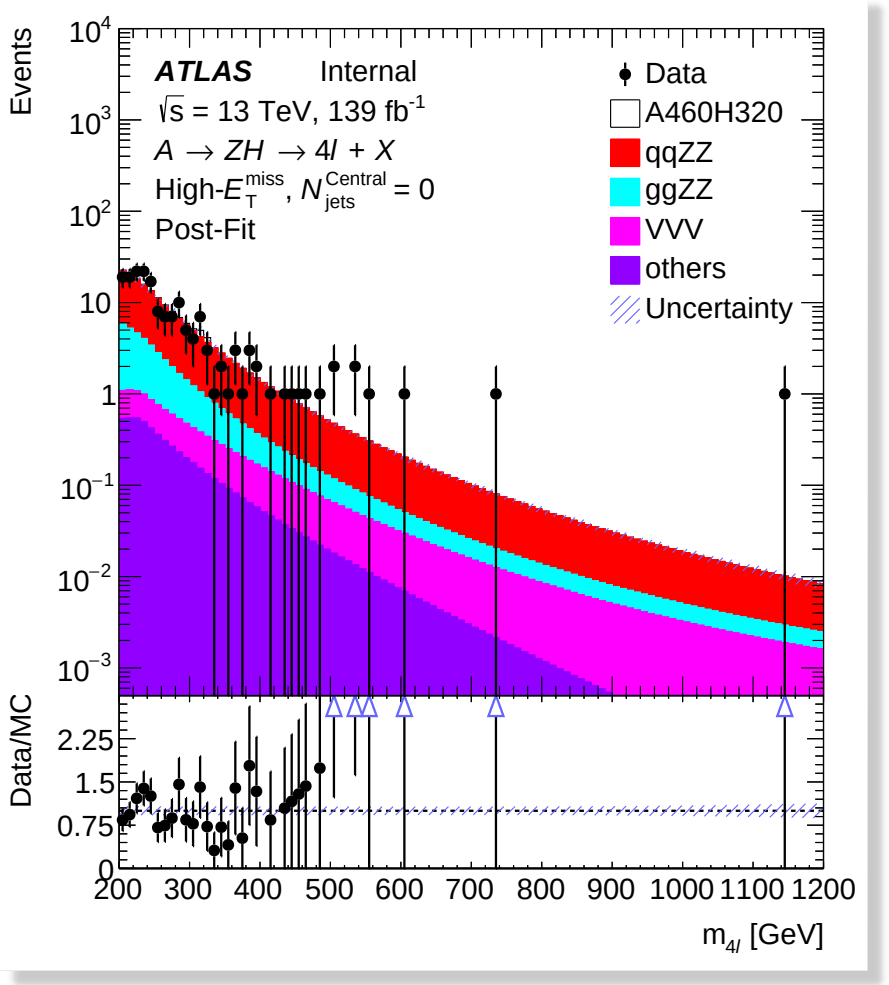


- Well constrained nuisance parameters within $\pm 1\sigma$ for the $(m_R, m_H) = (420, 250)$ GeV signal.

Fit results

Background+Signal fit for $A \to ZH \to 4\ell + X$

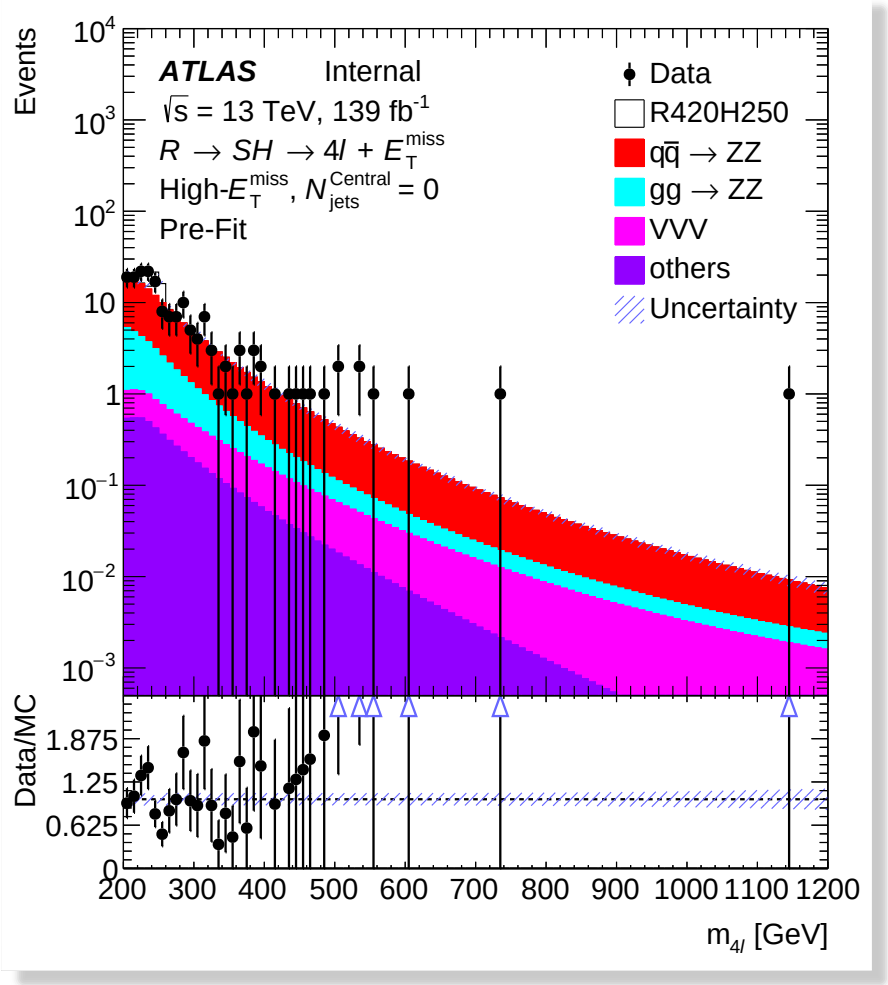


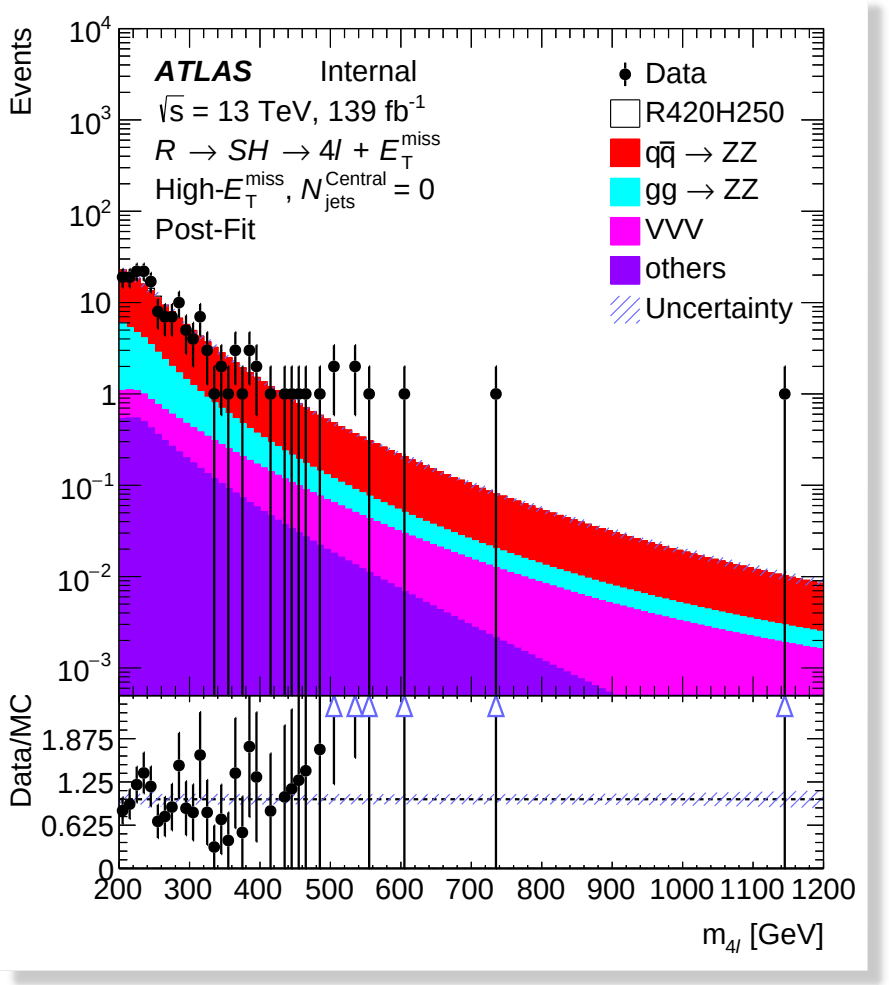


- Pre-fit (left) and post-fit (right)

Fit results

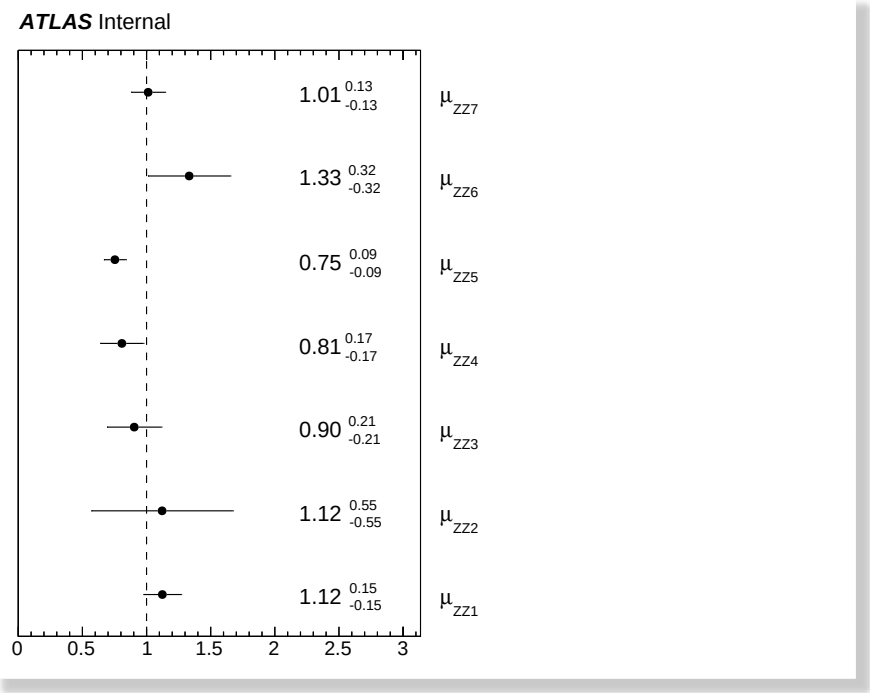
Background+Signal fit for $R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$



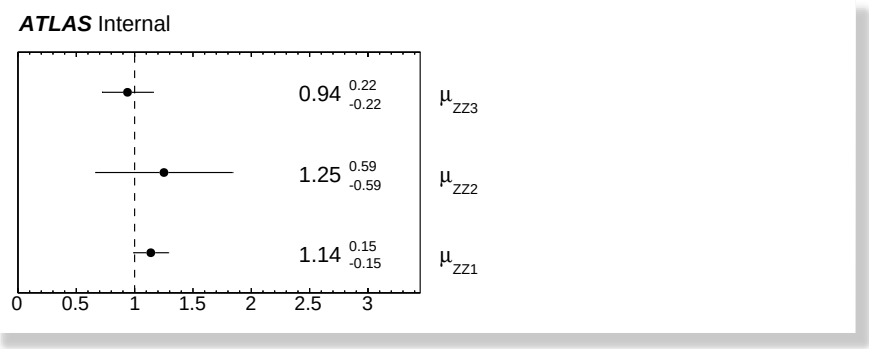


- Pre-fit (left) and post-fit (right)

Fit results
Background+Signal fit



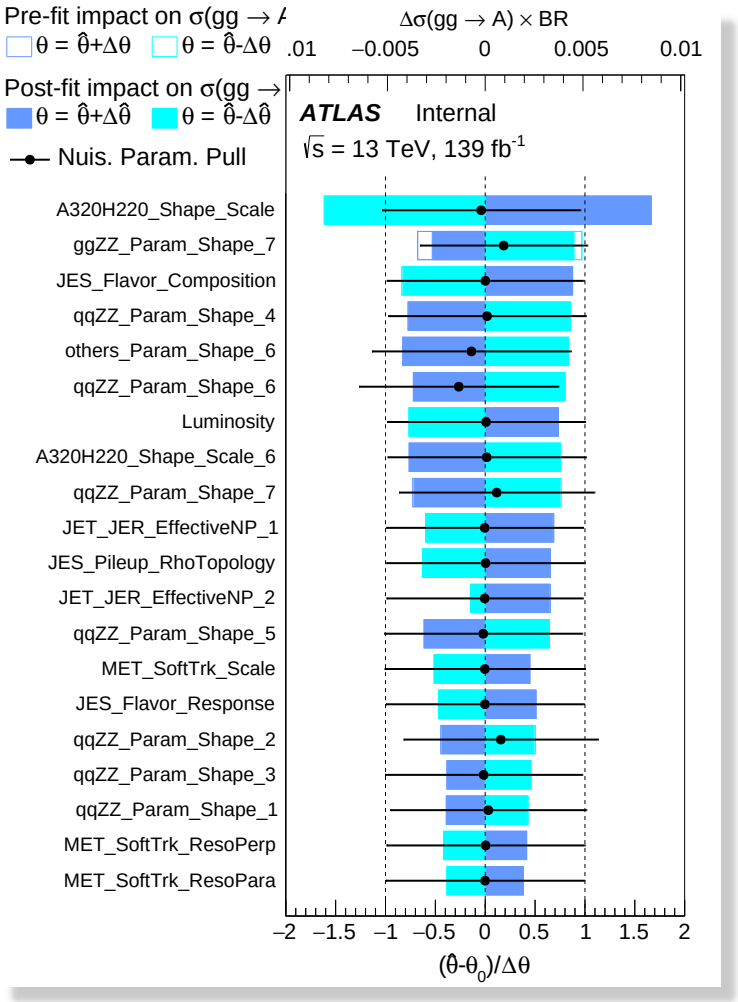
$A \to ZH \to 4\ell + X$: A460H320



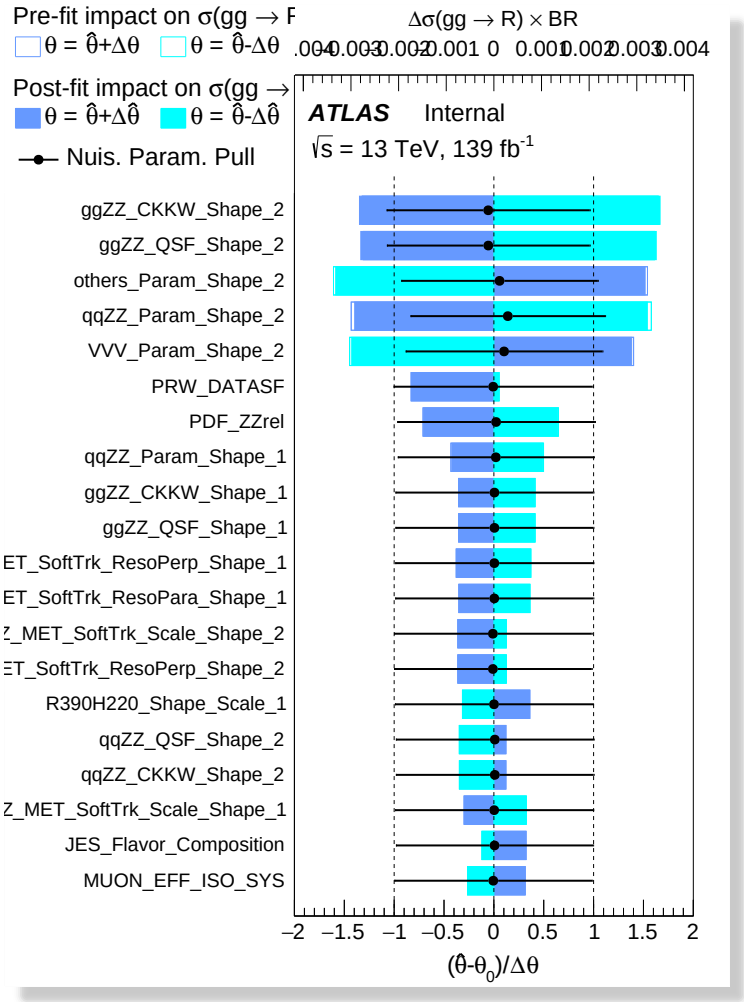
$R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$: R420H250

Fit results

The impact of NPs parameter on the POI



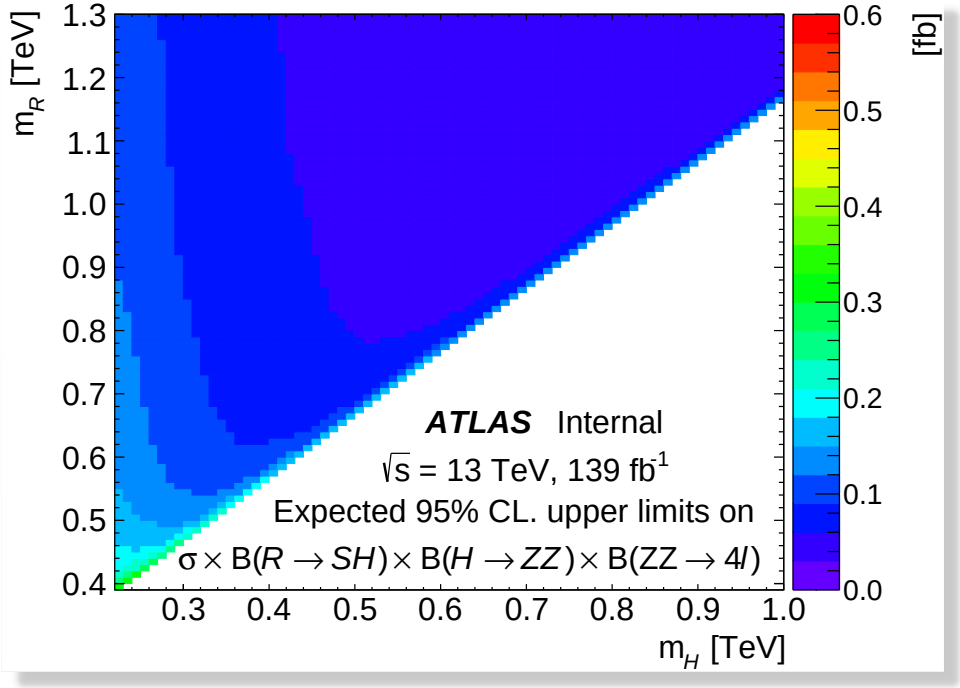
A320H220

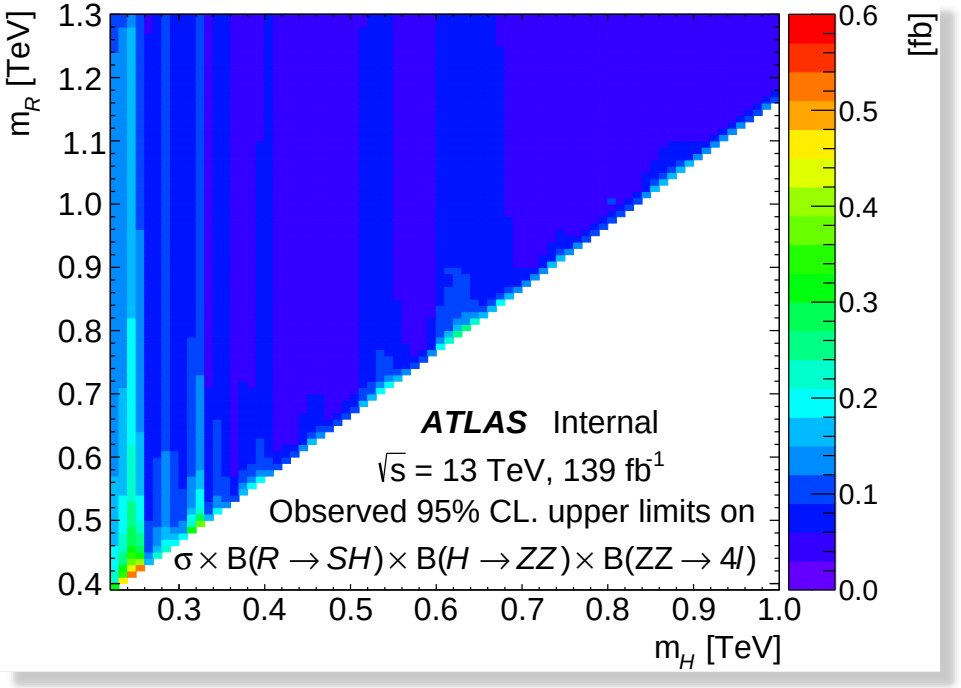


R390H220

Expected and observed upper limits

on the (m_H, m_R) plane for the $R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$ model

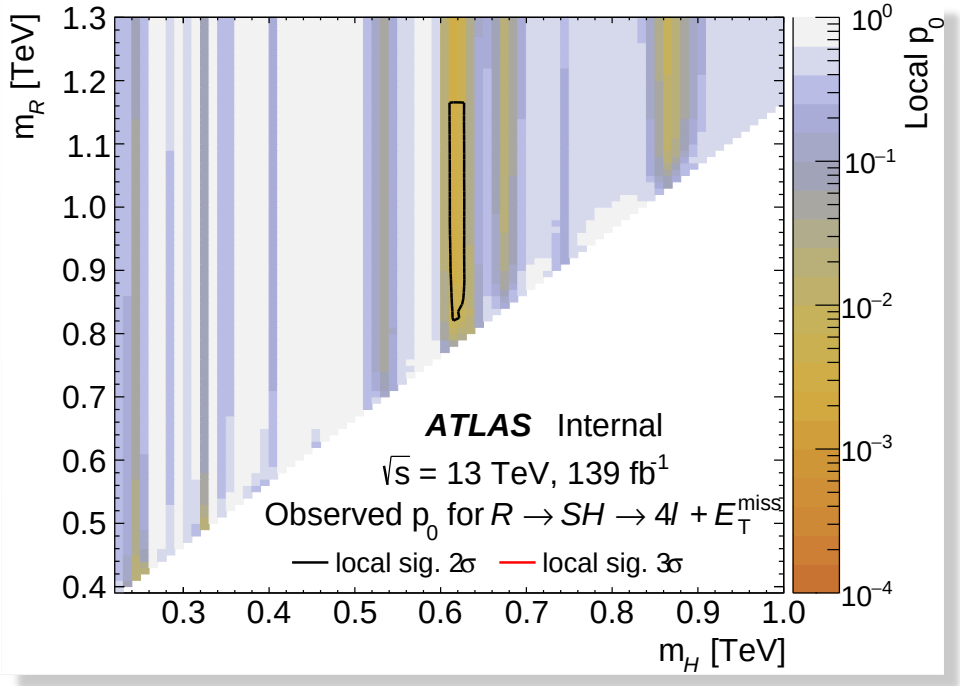


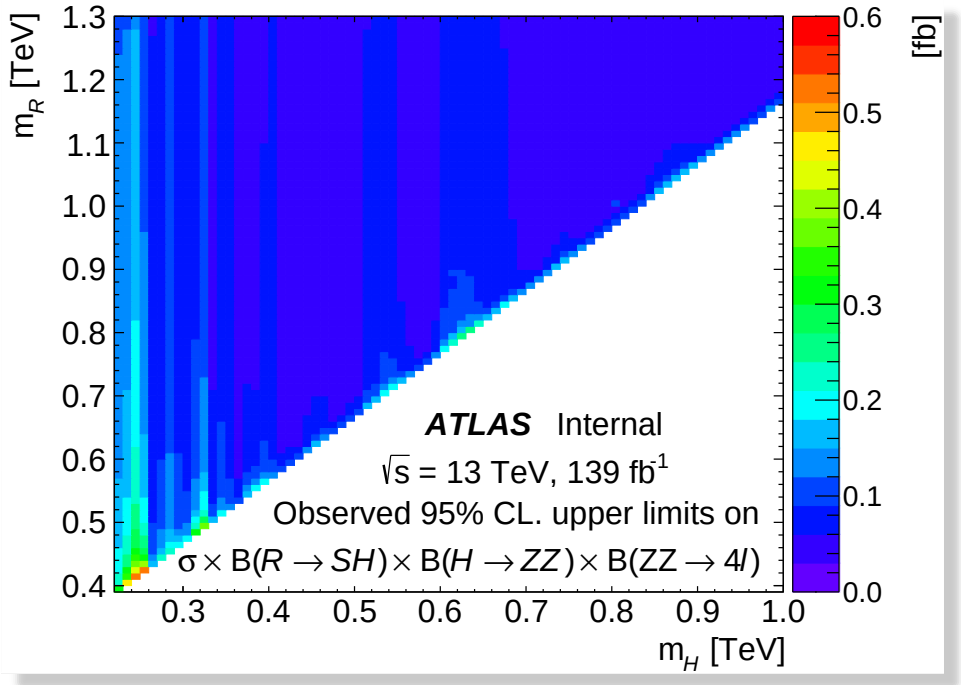


- Expected upper limits at 95% CL between [0.030 - 0.322] fb on (320, 1300) - (220, 1000) GeV.
- Expected upper limits at 95% CL between [0.027 - 0.532] fb on (320, 1300) - (220, 1000) GeV.

Observed local p values

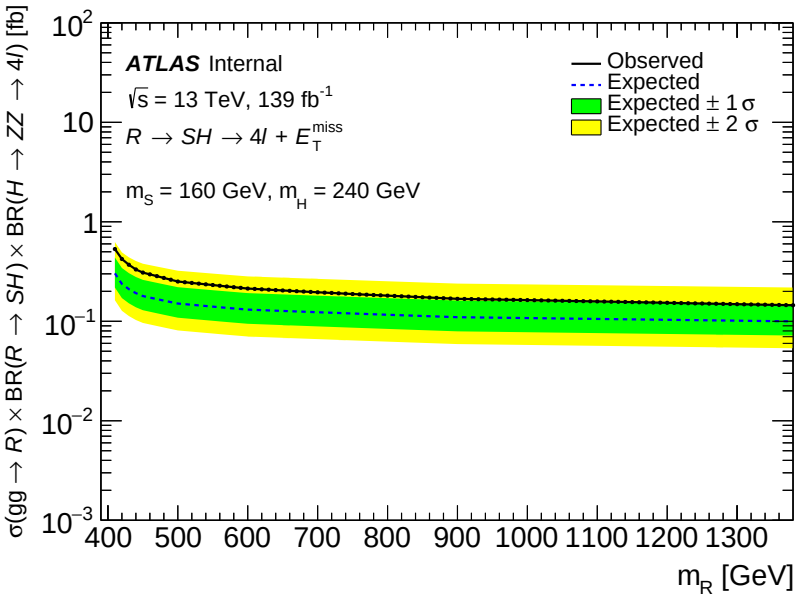
on the (m_H, m_R) plane for the $R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$ model

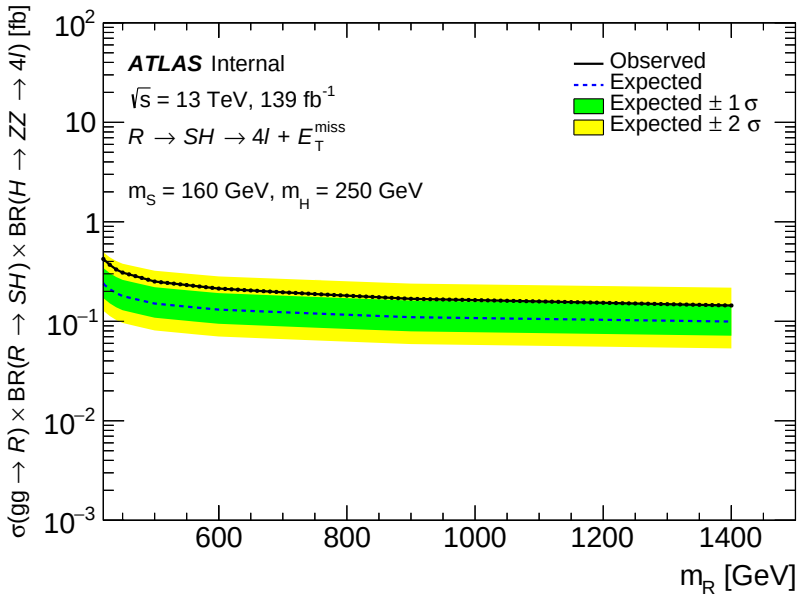




Expected and observed 1D upper limit

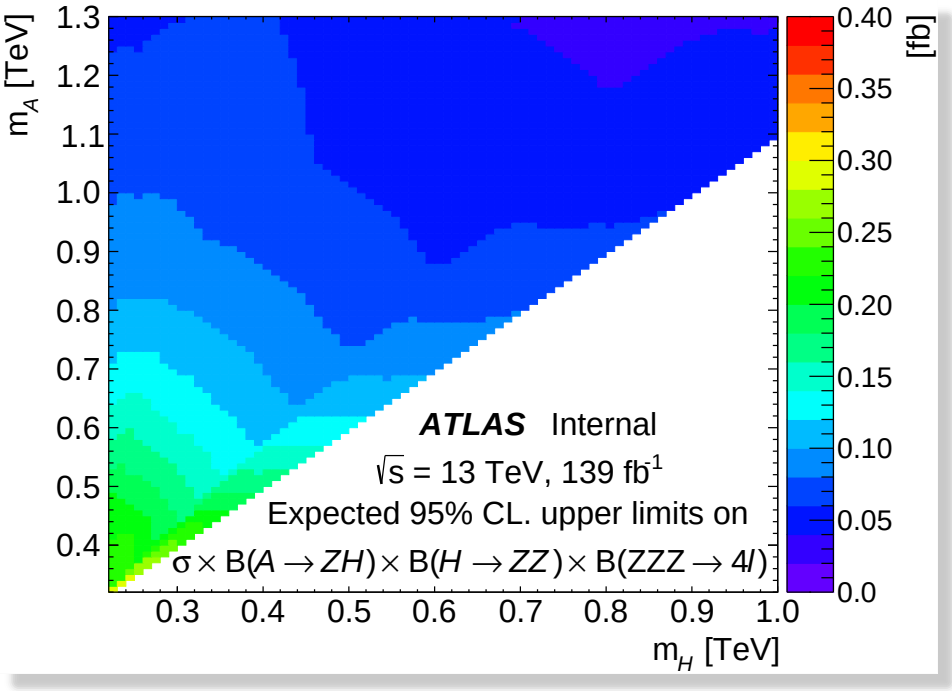
for the $R \to SH \to 4\ell + E_{\mathrm{T}}^{\mathrm{miss}}$ model

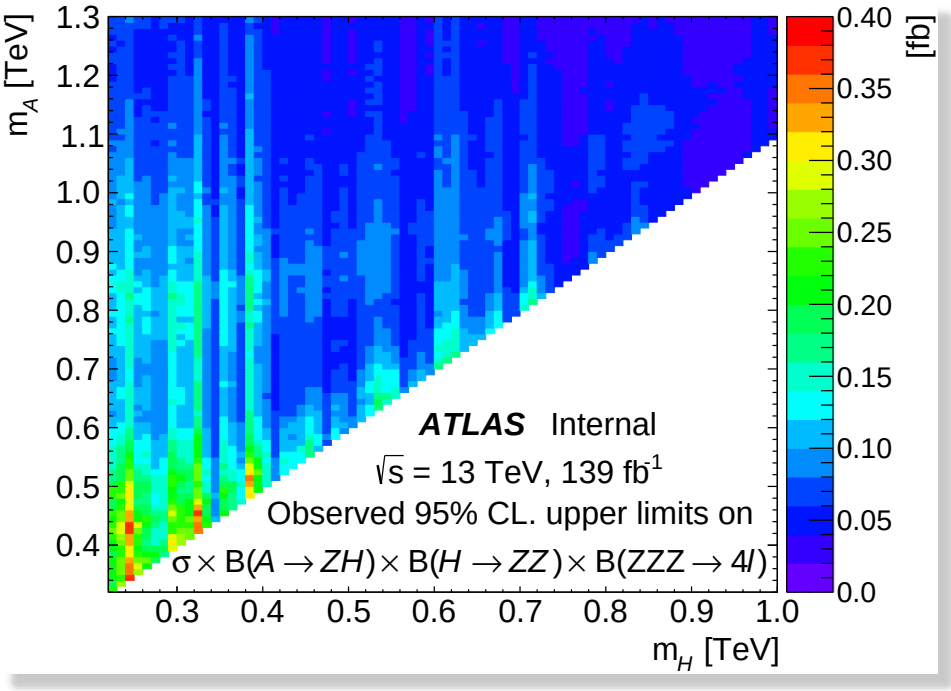




Expected and observed upper limits

on the (m_H, m_A) plane for the $A \to ZH \to 4\ell + X$ model

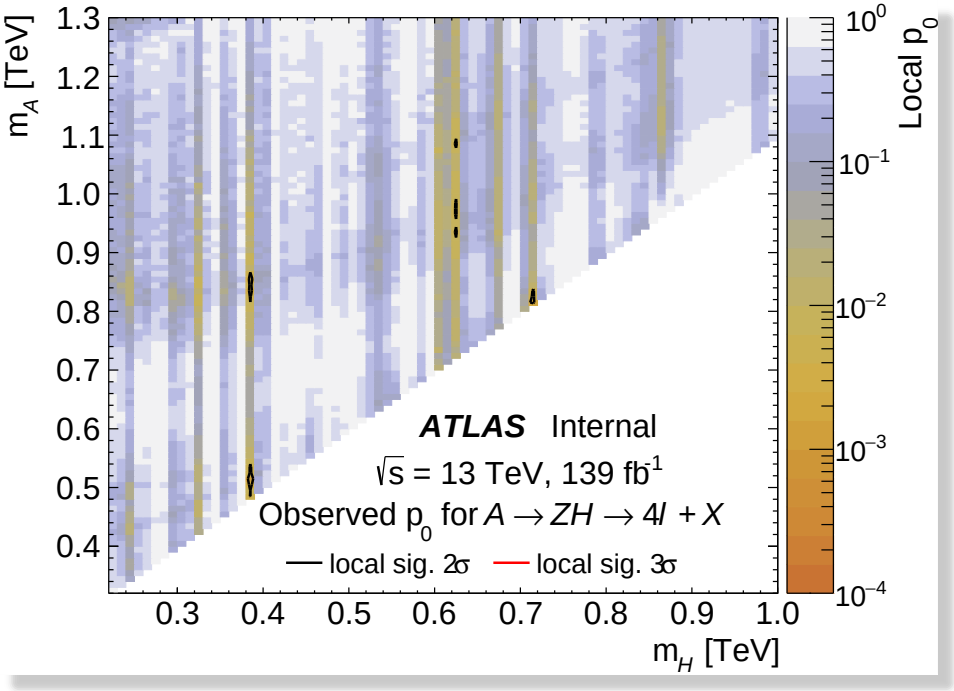


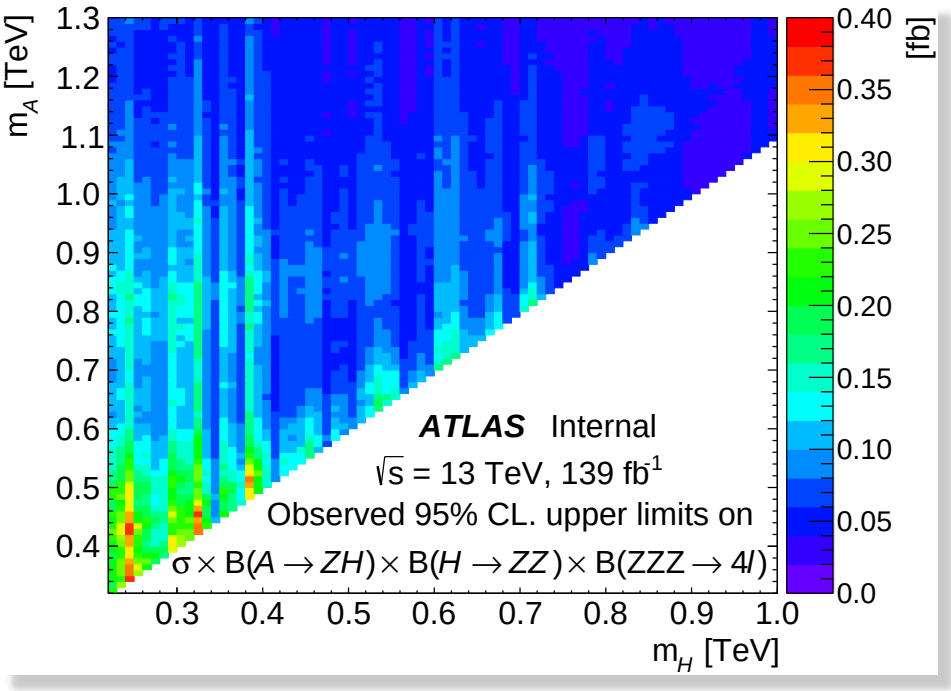


- Expected upper limits at 95% CL between [0.028 - 0.289] fb on (320, 1300) - (220, 1000) GeV.
- Observed upper limits at 95% CL between [0.023 - 0.378] fb on (320, 1300) - (220, 1000) GeV.

Observed local p values

on the (m_H, m_A) plane for the $A \to ZH \to 4\ell + X$ model

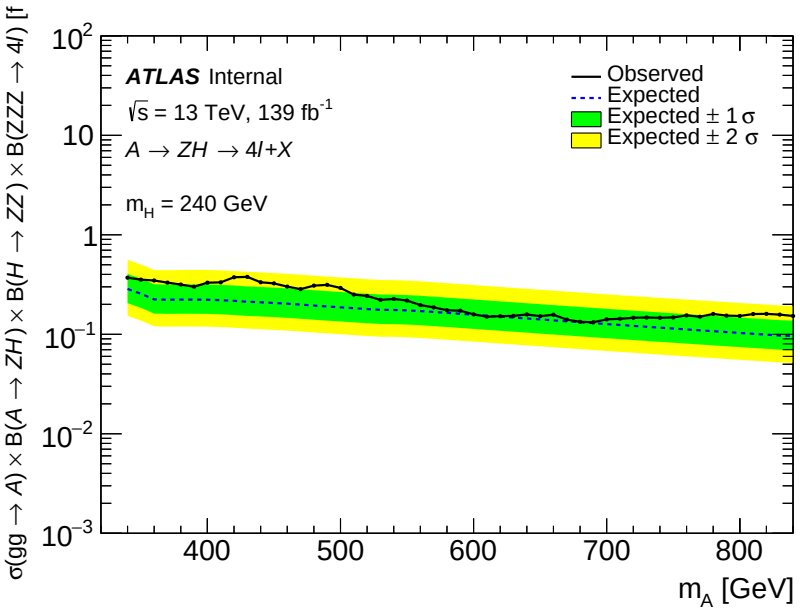


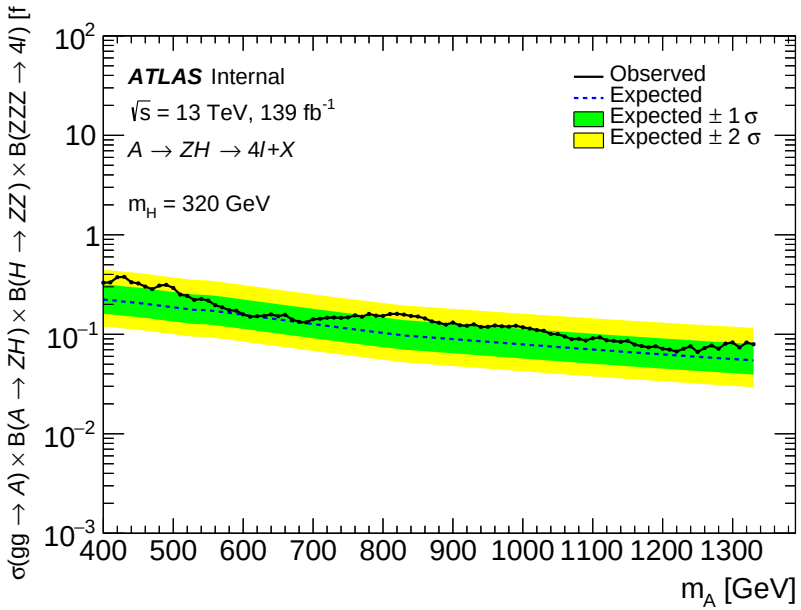


- The highest excess is observed around $(m_H, m_H) = (385, 515)$ GeV with local significance of 2.5σ
- $m_H = 385, 625$ and 715

Expected and observed 1D upper limit

for the $A \to ZH \to 4\ell + X$ model





Summary

- ☐ We showed the unblinded results for the 4ℓ+MET analysis.
- ☐ No significance deviation beyond the Standard Model background was observed.
- ☐ There are still a few jobs running for some mass points that will be added soon.

Additional slides
Cut-flow table

	$q\bar{q} \to ZZ$	$gg \to ZZ$	$q\bar{q} \to ZZ^*(EW)$	$t\bar{t}V$	VVV	$Z + jets$	WZ	$t\bar{t}$	Data	Expected
Preselection	2518.94±4.23	349.23±0.67	32.77±0.27	47.18±0.44	19.05±0.11	3.85±1.15	4.89±0.31	2.80±0.19	3296.00	2978.72±7.38
High-$E_{\mathrm{T}}^{\mathrm{miss}}$ & $N_{\mathrm{jets}}^{\mathrm{Central}} = 0$	115.24±1.15	27.74±0.19	0.48±0.03	2.07±0.08	7.48±0.06	0.58±0.07	1.73±0.19	0.64±0.08	177.00	155.96±1.86
Low-$E_{\mathrm{T}}^{\mathrm{miss}}$ & $N_{\mathrm{jets}}^{\mathrm{Central}} = 0$	177.34±1.04	34.58±0.18	0.49±0.03	0.19±0.03	0.79±0.02	0.33±0.03	0.45±0.08	0.06±0.02	258.00	214.23±1.42
High-$E_{\mathrm{T}}^{\mathrm{miss}}$ & $N_{\mathrm{jets}}^{\mathrm{Central}} \geq 1$	12.93±0.23	2.68±0.06	0.38±0.02	5.31±0.15	4.78±0.06	0.05±0.02	0.75±0.12	0.58±0.07	32.00	27.47±0.74
Low-$E_{\mathrm{T}}^{\mathrm{miss}}$ & $N_{\mathrm{jets}}^{\mathrm{Central}} \geq 1$	44.15±0.46	8.54±0.11	1.18±0.04	1.79±0.09	1.51±0.03	0.11±0.03	0.32±0.08	0.20±0.07	55.00	57.78±0.91
$N_{b-\mathrm{jets}} \geq 1$	60.68±0.49	6.79±0.10	1.80±0.06	34.94±0.38	0.50±0.02	0.12±0.03	0.14±0.05	0.95±0.13	135.00	105.91±1.26
$\lvert m_{jj}^{\mathrm{Central}} - m_Z \rvert < 20$	44.10±0.29	7.38±0.10	2.16±0.07	0.30±0.04	0.19±0.01	0.00±0.00	0.04±0.03	0.01±0.01	49.00	54.16±0.54
$\lvert m_{jj}^{\mathrm{Central}} - m_Z \rvert > 20$	196.51±0.60	27.79±0.19	15.09±0.16	1.35±0.09	1.09±0.02	0.80±0.73	0.31±0.08	0.08±0.02	197.00	243.01±1.89
$N_{\mathrm{jets}}^{\mathrm{Central}} \geq 1$	537.70±1.94	82.98±0.33	9.20±0.15	1.06±0.06	1.60±0.03	0.24±0.05	0.69±0.12	0.17±0.04	665.00	633.64±2.71