Search for invisible decays of the Higgs boson with the ATLAS detector

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for the ATLAS collaboration

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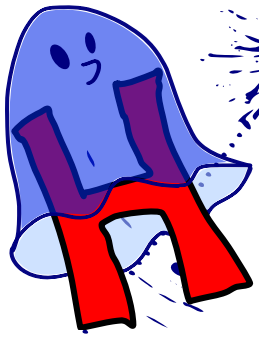
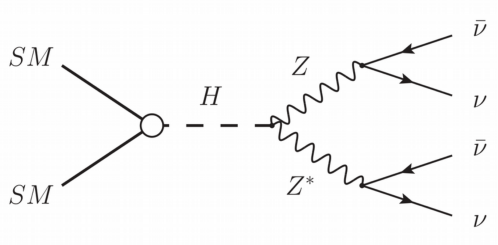


Introduction



SM $\mathcal{B}_{H\to\text{inv}} \approx 0.1\%$

The Higgs could Yukawa-couple to massive Dark Sector particles
(model with few parameters and UV complete)

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$\mathcal{B}_{H\to\text{inv}}$ could be significantly higher!

At collider experiments we need activity in the detector to trigger such events

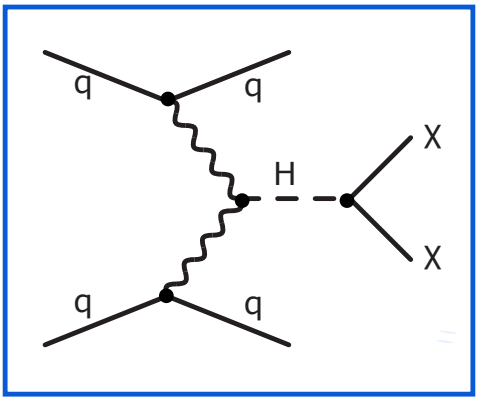
Common signature: visible particles recoiling against the invisible Higgs, producing a significant amount of missing transverse momentum ($E_{\text{T}}^{\text{miss}}$)

Production modes

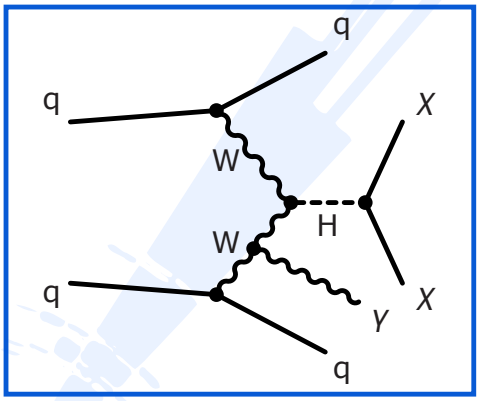
Different searches to target main production modes

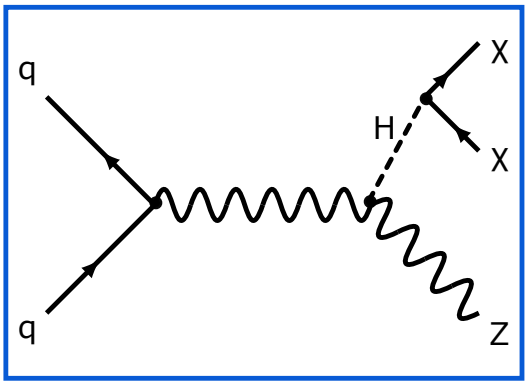
Main sensitivity comes from VBF+MET

VBF+MET

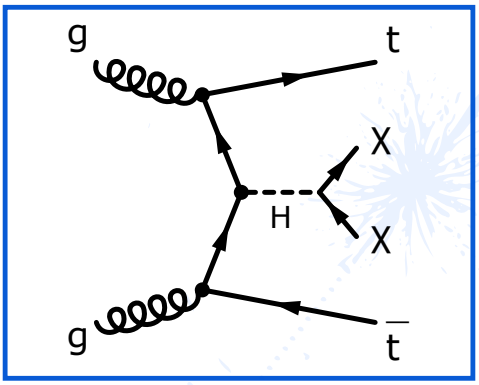


VBF+y+MET

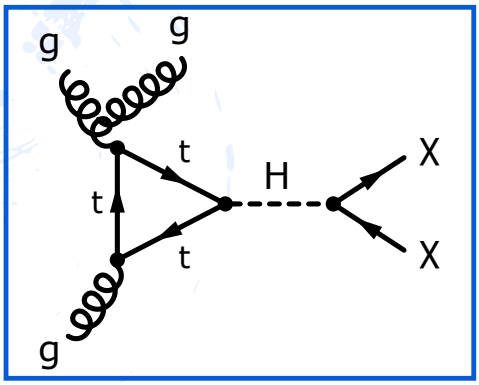




Z+MET



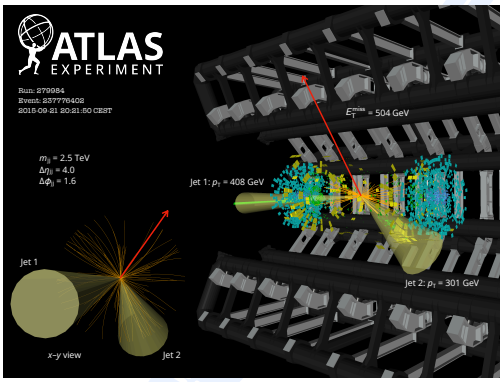
tt+MET



jet+MET

VBF+MET - arxiv:2202.07953

VBF topology: events selected with a pair of jets with large angular separation on the η plane and large invariant mass



Further selections:

- lepton/photon veto
- high $E_{\mathrm{T}}^{\mathrm{miss}}$
  - trigger constraint
  - reject QCD events
- upper cut on $\Delta(\phi)_{jj}$ to further reduce QCD

$\rightarrow$

Main backgrounds:

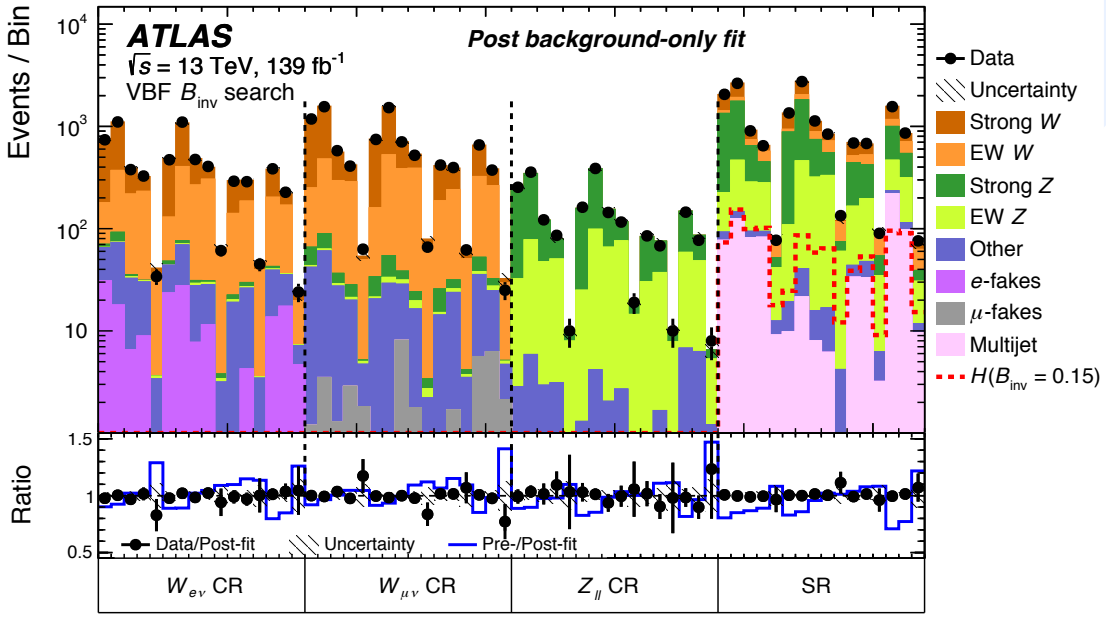
- $Z \rightarrow \nu\nu$ (both strong and electroweak production)
- $W \rightarrow \ell\nu$ with lost lepton

$\downarrow$

systematics strongly reduced exploiting 2ℓ and 1ℓ control regions and recent theoretical calculation (arXiv:2204.07652)

VBF+MET (2)

Signal and control regions split in 16 bins of $E_{\mathrm{T}}^{\mathrm{miss}}$, m_{jj} and $\Delta(\phi)_{jj}$ to maximise signal extraction



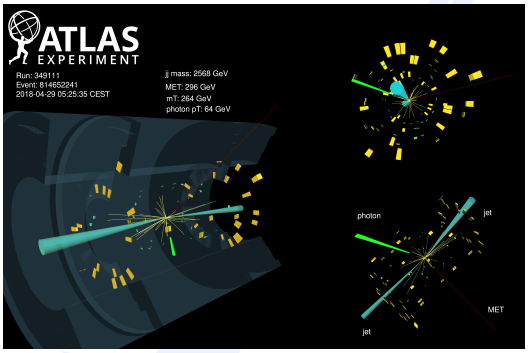
Assuming SM cross section, observed (expected) upper limit on $\mathcal{B}_{H\to\mathrm{inv}}$ of 0.145 (0.103) at 95% CL

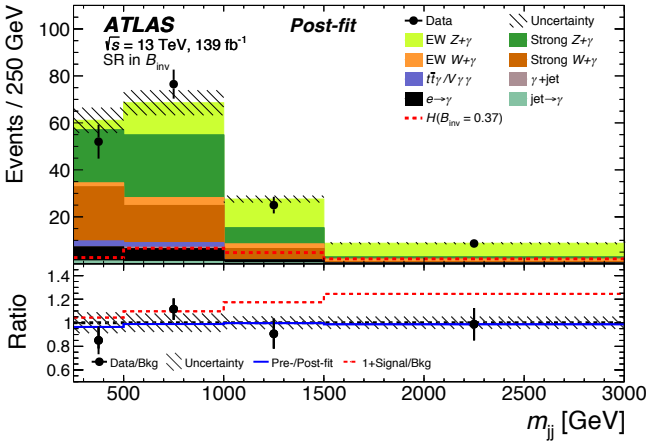
VBF+MET+γ - EPJC 82 (2022) 105

Similar VBF-like event selection,
+ requirement for one extra photon

↓

usually radiated from the scattering W within the large η gap between the two VBF jets





Final state dominated by EW $Z(\to \nu\nu)\gamma jj$ production

paper reports first observation of this process at the LHC!

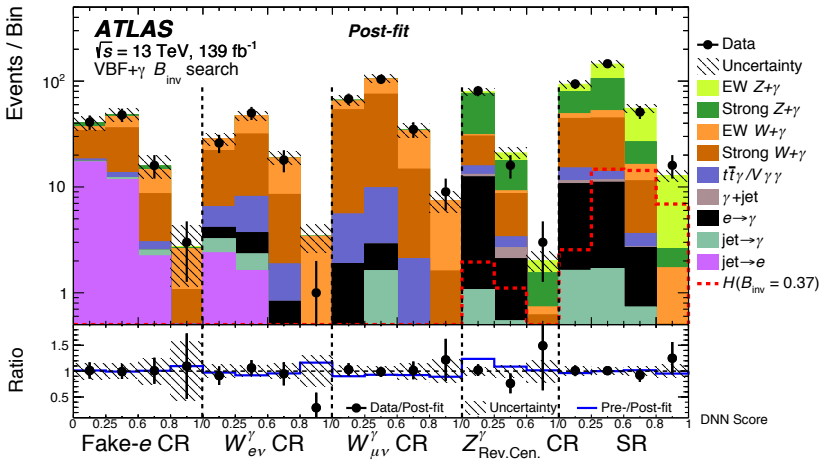
VBF+MET+γ (2)

DNNevent classification to improve sensitivity for $H \rightarrow$ inv signal

(dark photon interpretation also available, see backup)

Most important features

- leading jets kinematics and angular separation
- m_{jj}
- $E_{\mathrm{T}}^{\mathrm{miss}}$ (subtracting the γ)
- photon pseudorapidity



Assuming SM cross section, observed (expected) upper limit on $\mathcal{B}_{H\rightarrow\mathrm{inv}}$ of 0.37 (0.34) at 95% CL

Result limited by statistics $\rightarrow$ large room for improvement in Run 3

Z+MET - Phys.Lett.B 829 (2022) 137066

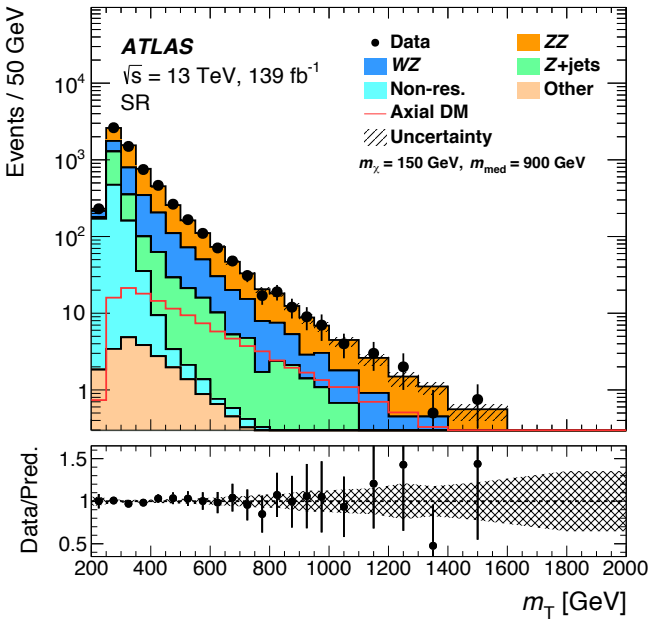
Events are required to have two oppositely-charged electrons or muons with $m_{\ell\ell}$ consistent with the Z mass

Further requirements:

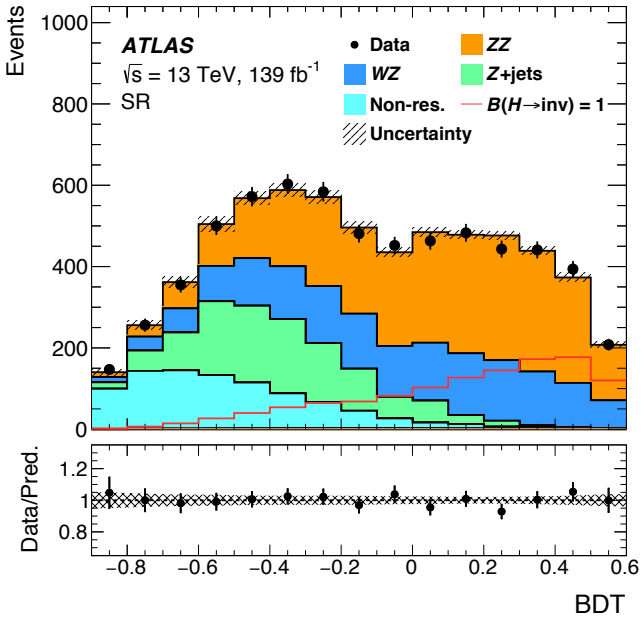
- $E_{\mathrm{T}}^{\mathrm{miss}} > 90$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 9
- small angular separation between the leptons

Main backgrounds (ZZ-WZ) constrained in dedicated control regions

Non-resonant background also estimated from data, using $e\mu$ events



Z+MET (2)



Sensitivity for $H \rightarrow$ inv enhanced using a BDT to improve the separation between signal and background.

Variables considered:

- $E_{\mathrm{T}}^{\mathrm{miss}}$ significance
- total hadronic activity
- kinematics of the leptonic system

BDT output distribution used in the profile likelihood fit

↓

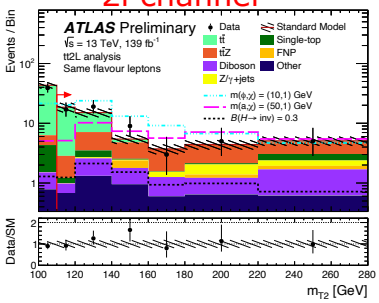
Assuming SM cross section, observed (expected) upper limit on $\mathcal{B}_{H\rightarrow \mathrm{inv}}$ of 0.19 (0.19) at 95% CL

$t\bar{t}$ +MET - ATLAS-CONF-2022-007

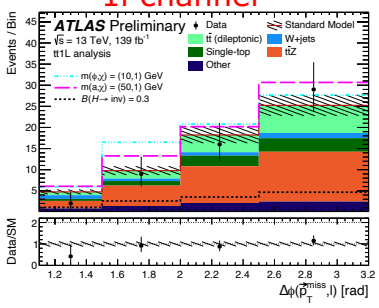
Combination searches for new physics in the $t\bar{t}$ $+E_{\mathrm{T}}^{\mathrm{miss}}$ final state

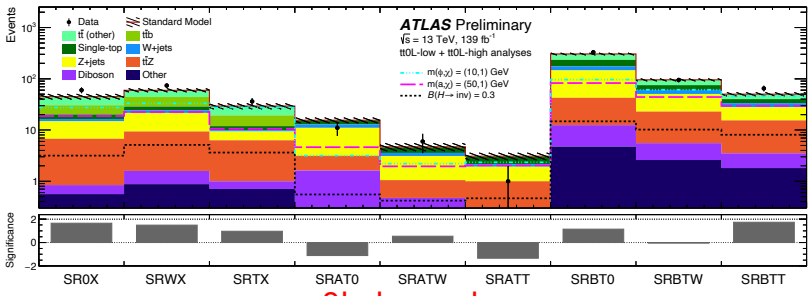
Different decay channels considered: 0, 1 and 2 leptons

2l channel



1l channel





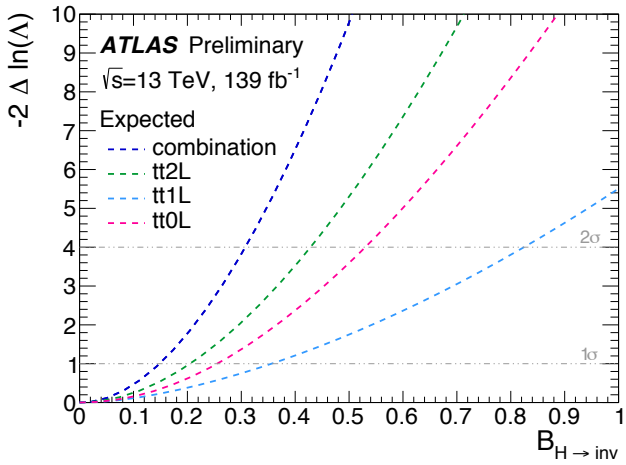
0l channel

Main backgrounds
$t\bar{t}$, ttZ and Z+jets

More than just combination!

- common ttZ estimation
- 0ℓ channel extended with a lower MET region thanks to b-jet triggers

$t\bar{t}$ +MET (2)



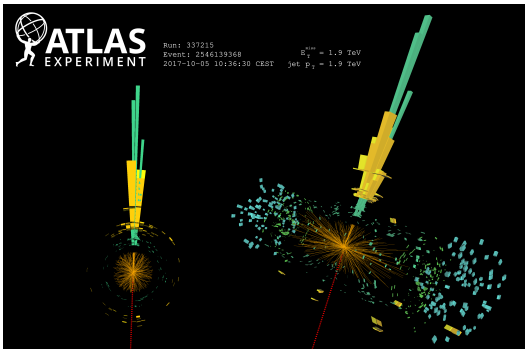
Analysis	Best fit $\mathcal{B}_{H\to\text{inv}}$	Observed upper limit	Expected upper limit
tt0L	$0.48^{+0.27}_{-0.27}$	0.95	$0.52^{+0.23}_{-0.16}$
tt1L	$-0.04^{+0.35}_{-0.29}$	0.74	$0.80^{+0.40}_{-0.26}$
tt2L	$-0.09^{+0.22}_{-0.20}$	0.39	$0.42^{+0.18}_{-0.12}$
$t\bar{t}H$ comb.	$0.08^{+0.16}_{-0.15}$	0.40	$0.30^{+0.13}_{-0.09}$

Expected upper limit on $\mathcal{B}_{H\to\text{inv}}$ improved by 30% with respect to the individual best channel (2ℓ)

Observed limit weakened by mild excess in the 0ℓ channel

NB all channels are stat limited $\rightarrow$ large room for improvement in Run 3

Jet+MET - Phys.Rev.D 103 (2021) 112006

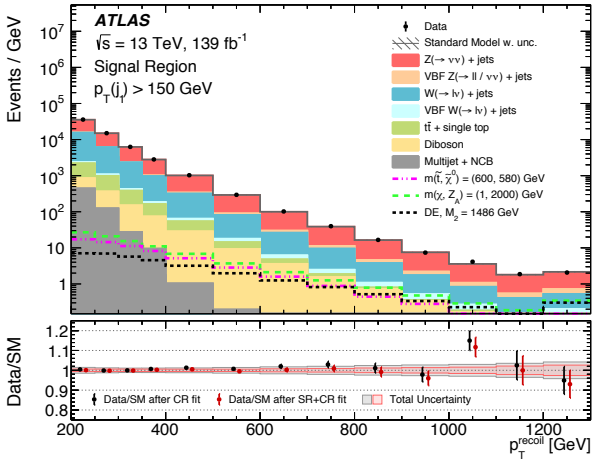


Events selected with ≥ 1 high p_{T} central jet and $E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV

Shape fit on p_{T} of the system recoiling against the initial state radiation jet

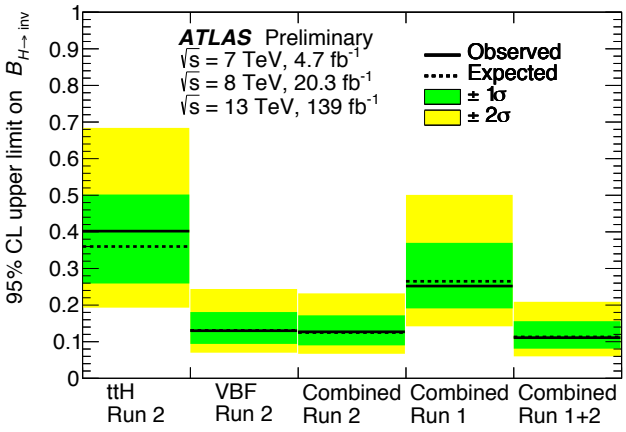
Simultaneous fit on signal (0ℓ) and control regions (1 or 2 ℓ) to constrain backgrounds

Assuming SM cross section, observed (expected) upper limit on $\mathcal{B}_{H\to\mathrm{inv}}$ of 0.34 (0.39) at 95% CL



Partial combination - ATLAS-CONF-2020-052

Release of partial combination of the VBF and ttMET (0 lepton and 2 leptons only) channels, together with Run 1 results.



Observed upper limit on $\mathcal{B}_{H\to\text{inv}}$ is 0.11 at 95%CL

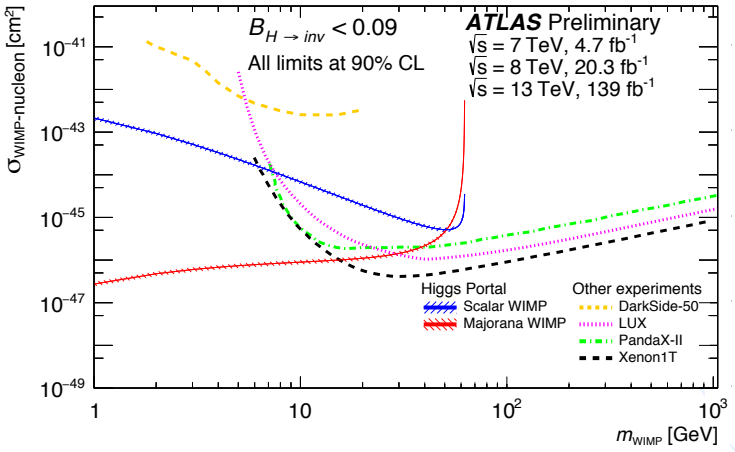
Limits driven by VBF Run 2 but production modes missing!
$\rightarrow$ large room for improvement

This illustrates the interest/feasibility of combinations

Comparison with Direct Detection experiments

Interpretation: spin-independent DM-nucleon elastic scattering cross section using Higgs invisible decay width

$\rightarrow$ complementarity with direct detection results



- $\mathcal{B}_{H\to \text{inv}}$ limit (at 90%CL) is converted to DM-nucleon cross-section limit
- ATLAS hashed lines due to uncertainty on Higgs-nucleon form factor

Conclusions

Invisible decay of the Higgs is a powerful tool to look for new physics

- many production channels investigated
  $\rightarrow$ even the more rare ones, each of them giving complementary sensitivity
- VBF channel driving the results
- current 95%CL limits to $\mathcal{B}_{H\rightarrow \text{inv}}$ approach 10%
- combinations expected to further improve our knowledge