Exotic Higgs Decay at ATLAS and CMS

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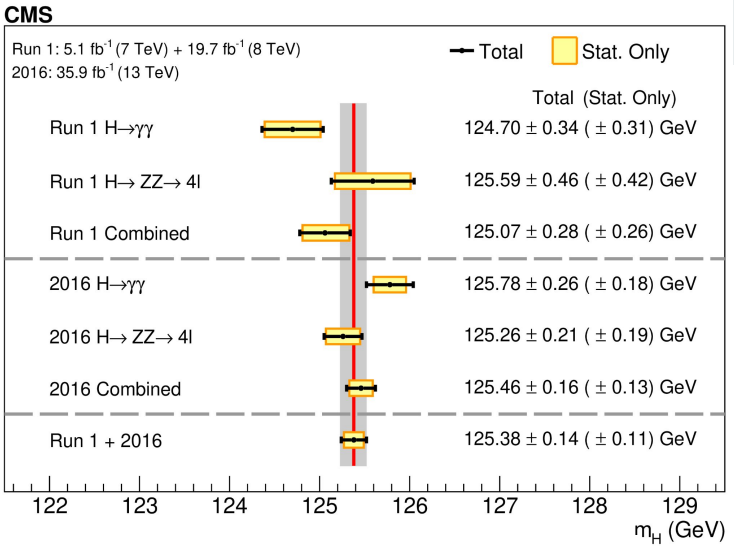
Brookhaven Forum 2021

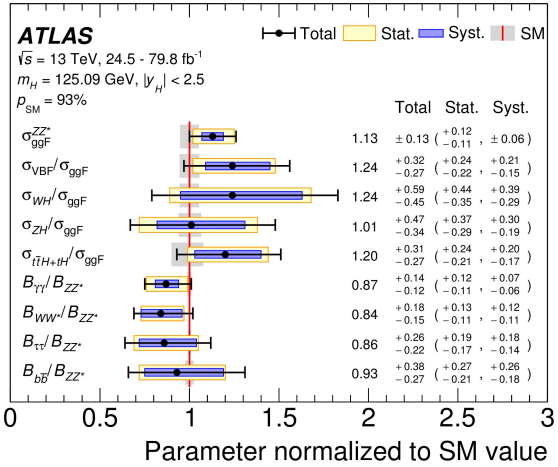
Introduction

- Does the Higgs boson behave as we expect?
  - Higgs Boson properties (cross section, mass, width,...)
  - Exotic Higgs sector
  - Higgs boson decay (SM or Exotic)

- Focus on selected set of latest results with exotic, prompt decays of the 125 GeV boson
  - H → aa → 4γ
  - H → invisible
  - H → invisible (VBF)
  - H → aa → bbμμ
  - ZH → bb + invisible
  - ZH → ll + invisible
  - H → 4l
  - H →lepton flavor violation

CMS ATLAS Both

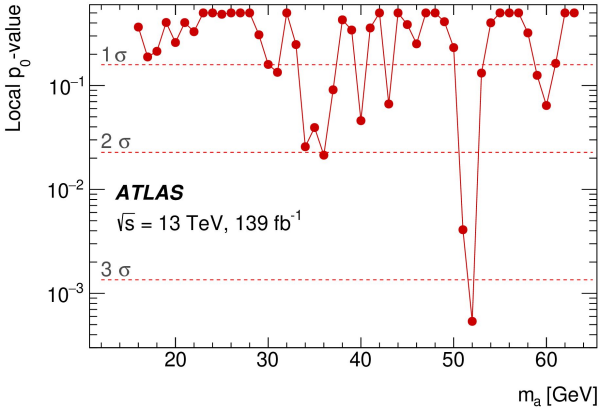


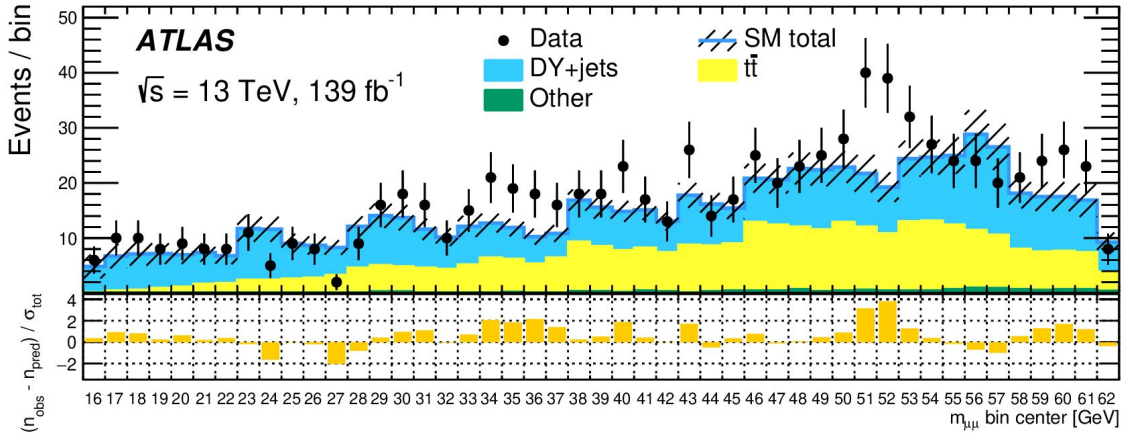


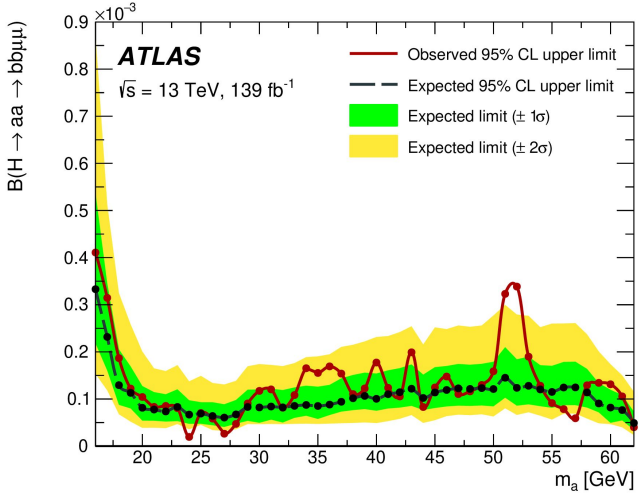
HDBS-2021-03

H → aa → bbμμ

- Good branching fraction from a → bb, clean signatures from a →μμ
- Boosted decision tree used to improve signal background discrimination for high m_a
- At m_a ~ 52 GeV, local (global) significance of 3.3σ (1.7σ)
- Kinematic likelihood (KL) fit to rescale b-jets such that $m_{bb} = m_{ll}$
- Corresponding CMS result at 35 fb^{-1}



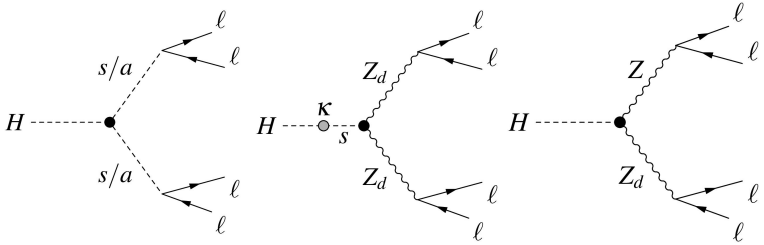


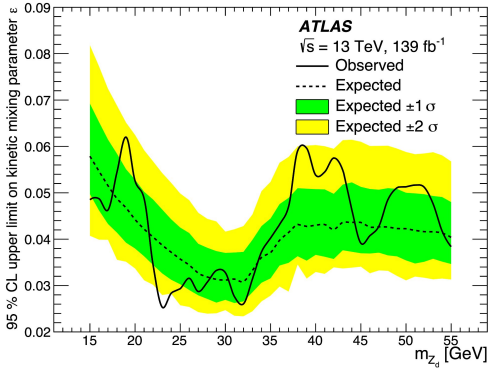


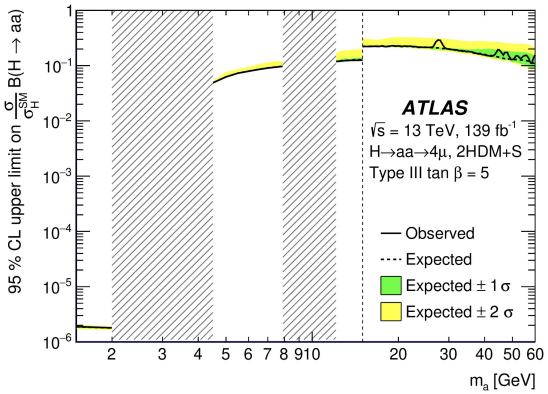
HDBS-2018-55 CMS-HIG-19-007

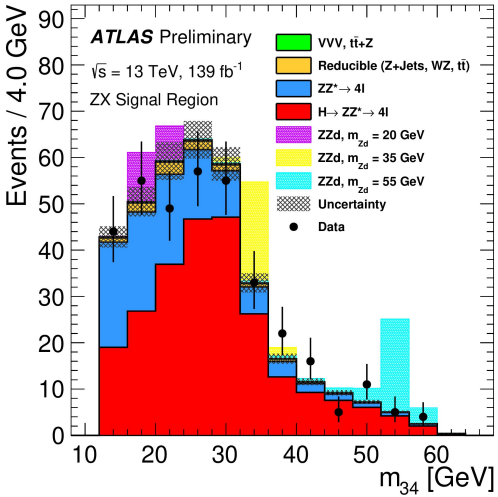
H → ZX/XX → 4l

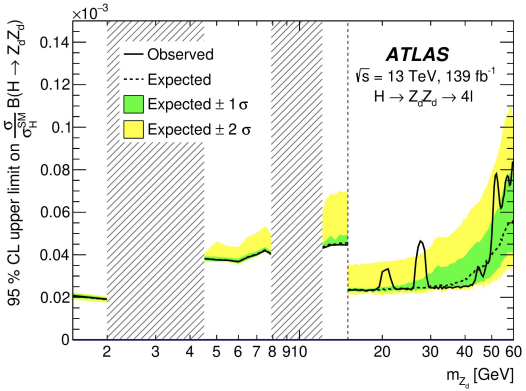
- Consider X as dark photon Z_d, dark Higgs s or pseudo-scalar a
- Different strategy for ZX and XX topology
- Report exclusion on cross section, branching fractions and dark photon model parameters
- Corresponding CMS result at 139 fb^{-1}





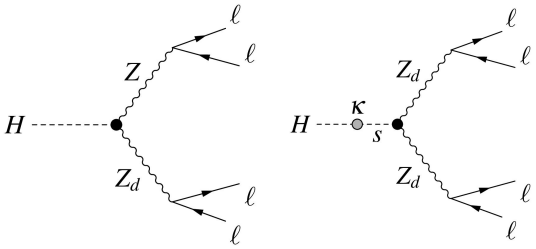


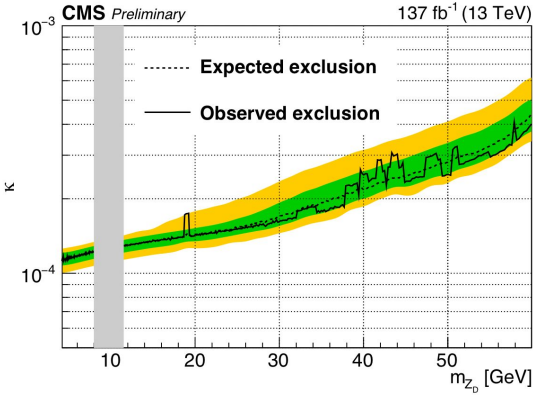


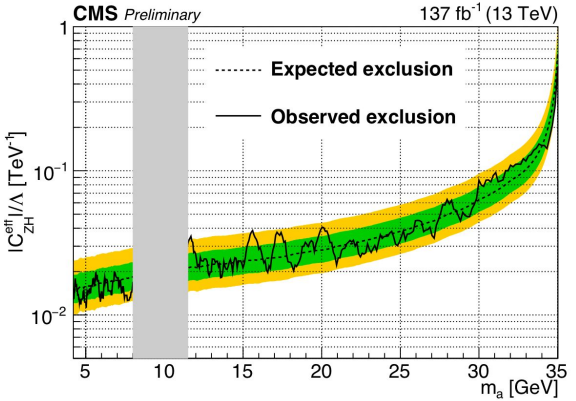


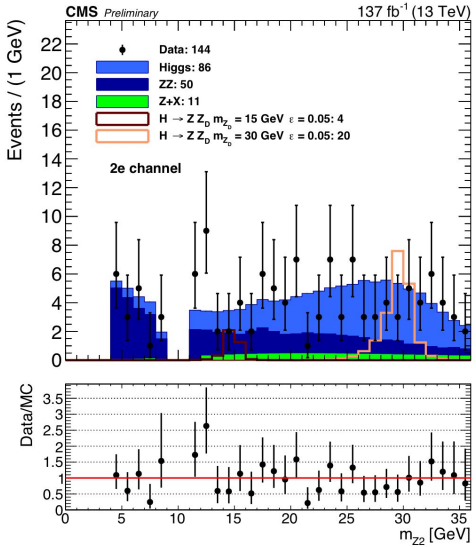
H → ZX/XX → 4l

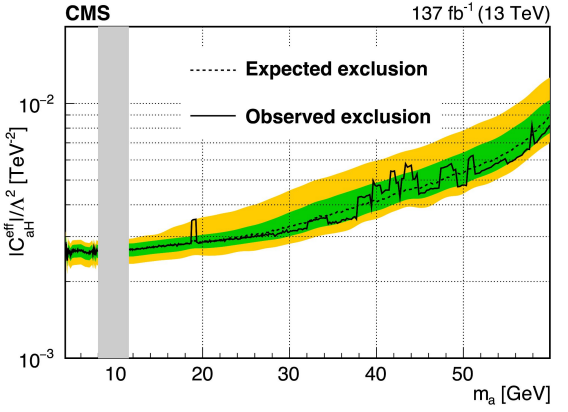
- CMS result consider dark photon and axion-like particle model
- Exclude specific model parameters such as dark Higgs coupling, Wilson coefficients







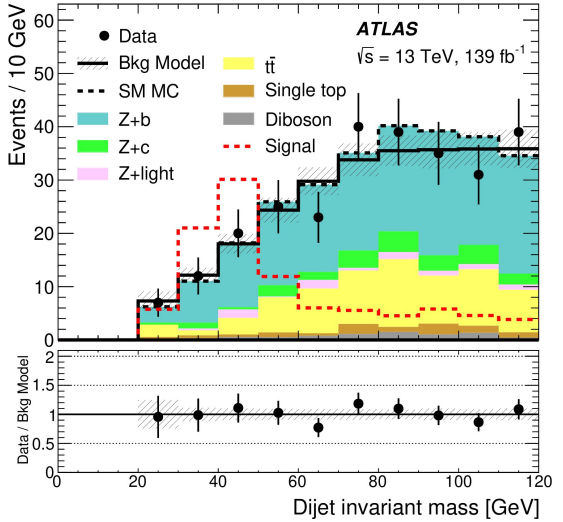




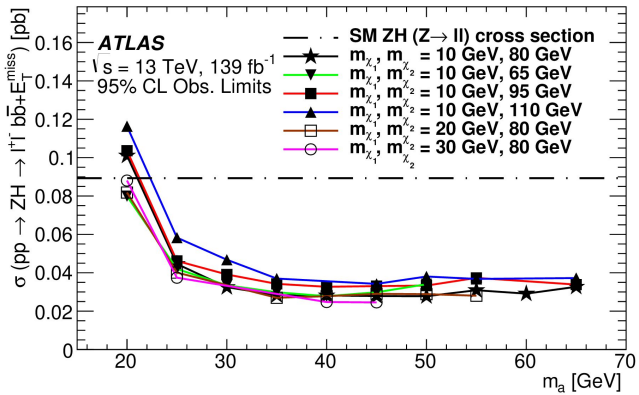
HDBS-2018-07

ZH → bb + invisible

- ZH production in an NMSSM scenario, H→ $\tilde{\chi}_{20}\tilde{\chi}_{10}$, with $\tilde{\chi}_{20}$ →a $\tilde{\chi}_{10}$
- Near the PQ symmetry limit of the NMSSM, this decay channel dominates over H→ aa
- Analysis strategy
  - Perform search in a → bb invariant mass distribution
  - Three-dimensional scan (a, $\tilde{\chi}_{20}$, $\tilde{\chi}_{10}$) mass

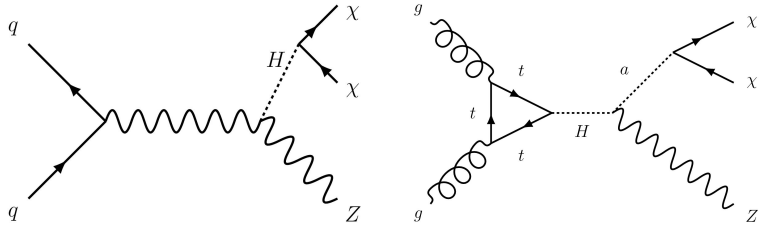


	SR	CRZ	CRTop	VRMET
Number of leptons			2	
Number of jets			≥ 2	
Number of b-tagged jets			≥ 1	
Dilepton p_{T} [GeV]			> 40	
p_{T} fraction			[0.8, 1.2]	
Dilepton mass [GeV]	[81, 101]	[81, 101]	[50, 81] or > 101	[81, 101]
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 100	[60, 100]	> 100	> 50
Dijet mass [GeV]	[20, 120]	[20, 120]	[20, 120]	> 150

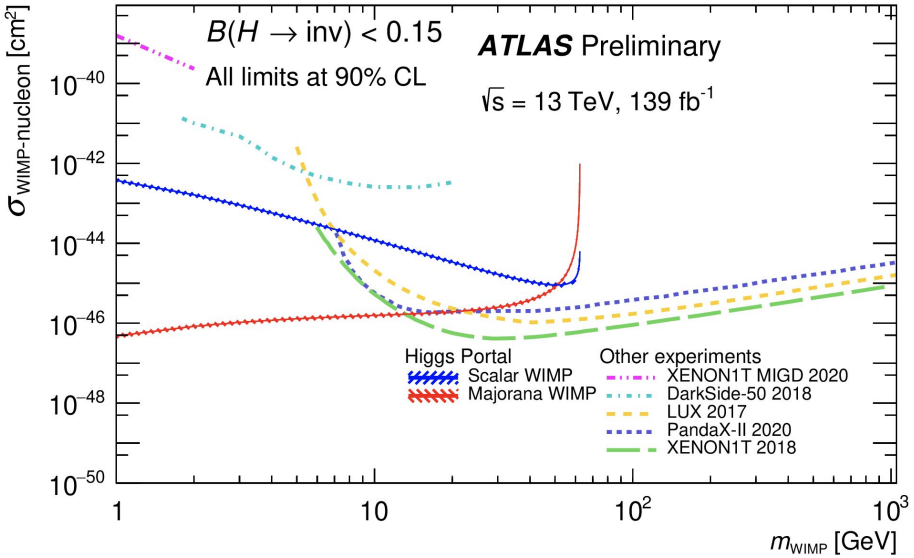


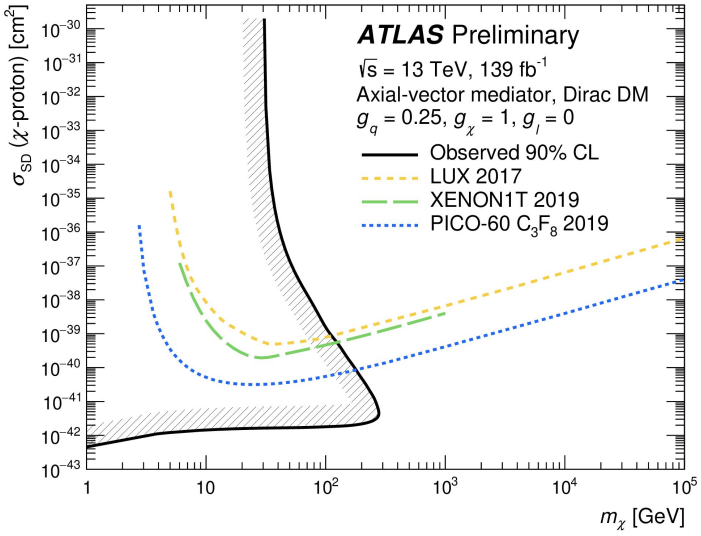
ATLAS-CONF-2021-029

ZH → ll + invisible



- Higgs decay to dark matter with associated Z boson production
- Exclusion limits on simplified dark matter, 2HDM+a models, and WIMP-nucleon cross section

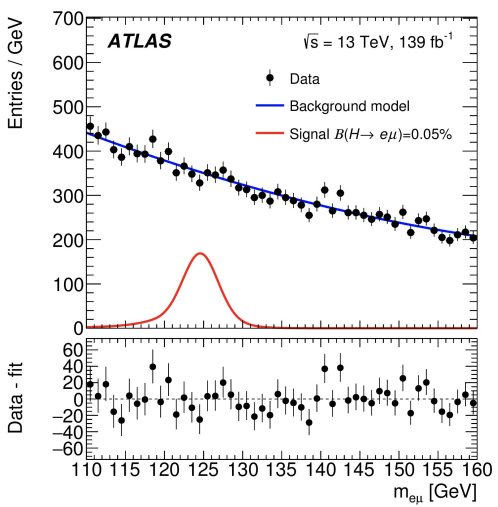


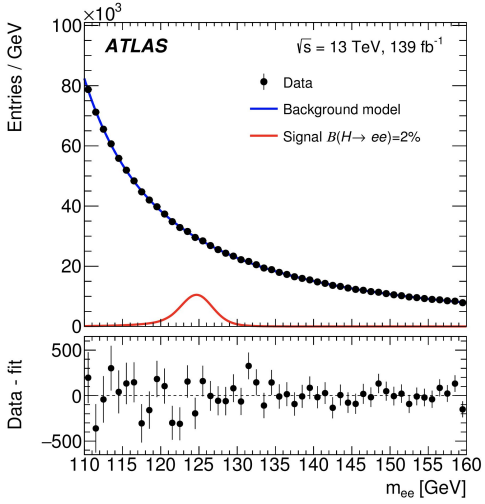


ATLAS-HIGG-2018-58 CMS-HIG-20-009

Lepton flavor violation

- $H \rightarrow ee$
  - Branching fraction still far below the sensitivity of the LHC experiment
  - Exclude branching fraction $B(H \rightarrow ee) \sim 10^{-4}$
- $H \rightarrow e\mu$
  - complements LFV constraints from $\mu \rightarrow e\gamma$ or electric dipole moment measurement of electron
  - Exclude branching fraction $B(H \rightarrow e\mu) \sim 10^{-5}$
- Analytic fits to dilepton invariant mass distributions
- Improvements by factors of about five and six on the previous best limits

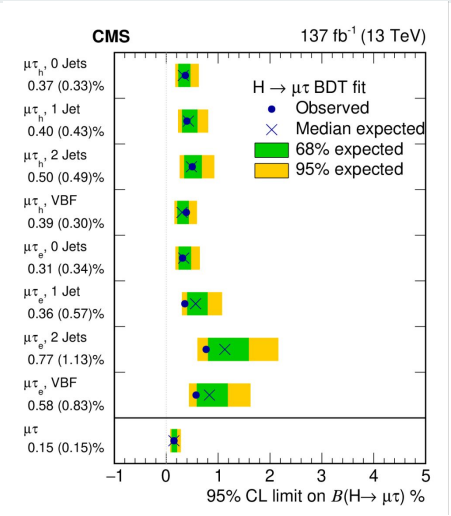


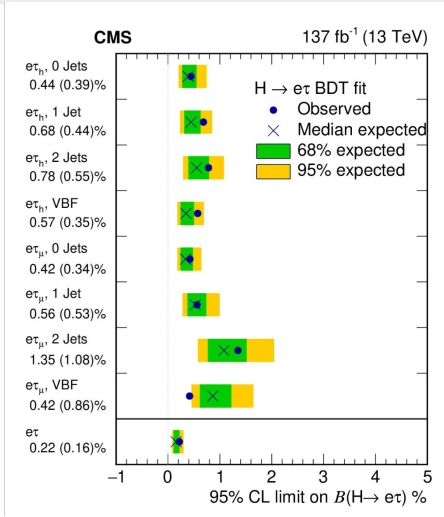


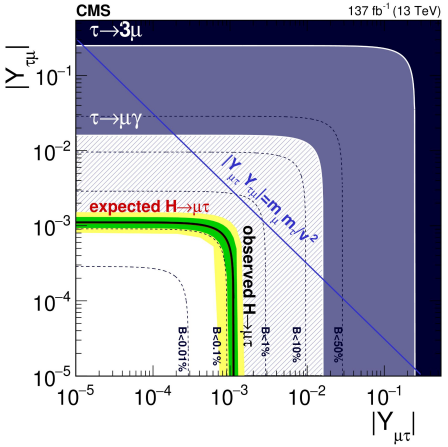
ATLAS-HIGG-2018-58 CMS-HIG-20-009

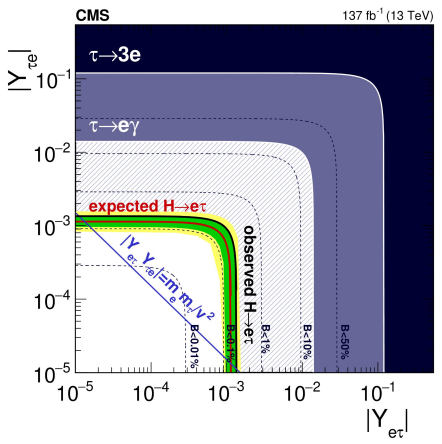
Lepton flavor violation

- Complements sensitivities provided by:
  - Search for rare τ decay
  - Measurement of electron and muon magnetic moment
- H → μτ
  - Exclude branching fraction B(H → μτ) ~ 0.15%
- H → eτ
  - Exclude branching fraction B(H → eτ) ~ 0.22%
- Boosted decision tree for signal and background discrimination
- Also reported limits on LFV Yukawa couplings





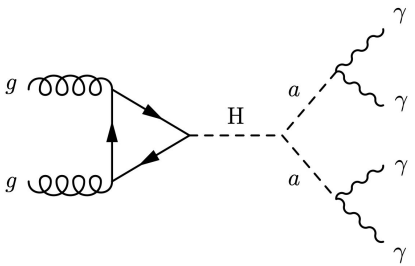


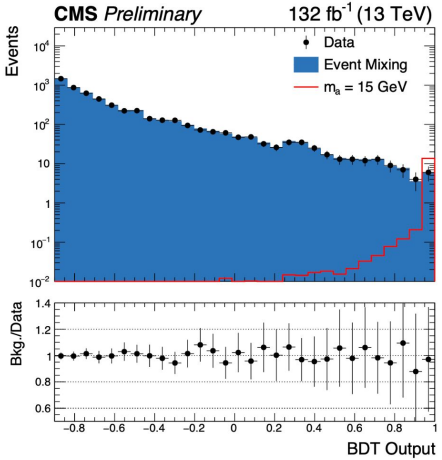


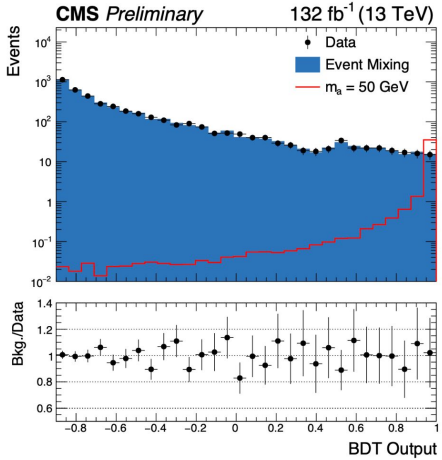
CMS-HIG-21-003

H →aa → 4γ

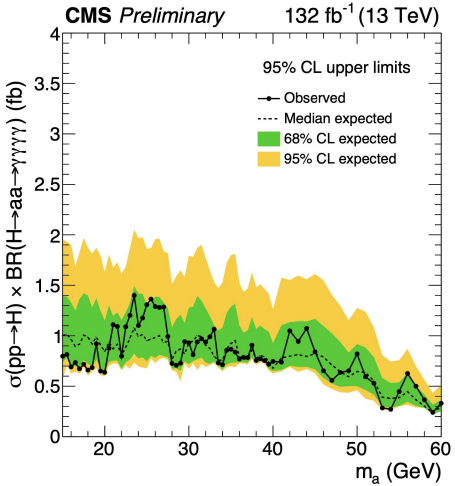
- Model independent analysis focus on final state with fully resolved photons
  - Full reconstructed photon separately
- Analysis strategy
  - Signature selection
    - $15 < m_a < 60$ GeV
    - $110 < m_{\gamma\gamma\gamma\gamma} < 180$ GeV
  - Data-driven background estimation
  - MVA classifier distinguish signal from γγγγ background
- Corresponding ATLAS results at Run 1







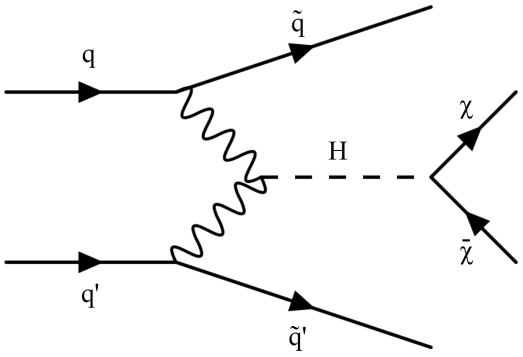
m_a	Min. BDT output value	Signal efficiency with respect to selection on BDT
15	0.883	0.884
20	0.891	0.867
25	0.876	0.857
30	0.897	0.840
35	0.931	0.815
40	0.945	0.780
45	0.952	0.801
50	0.958	0.805
55	0.976	0.773
60	0.987	0.714

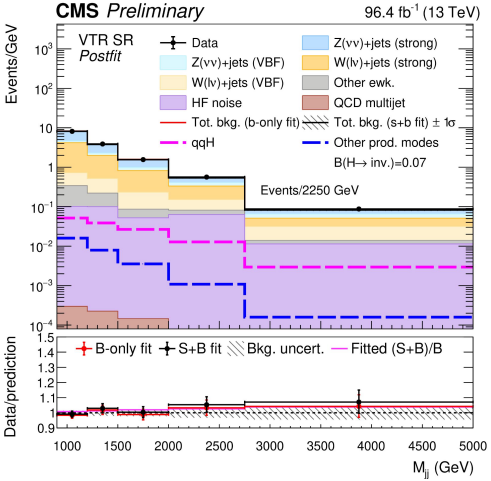


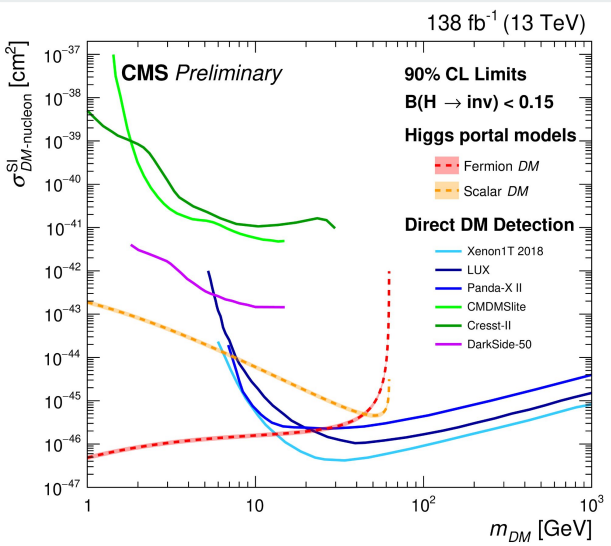
ATLAS-CONF-2020-052 ATLAS-CONF-2020-008 CMS-HIG-20-003

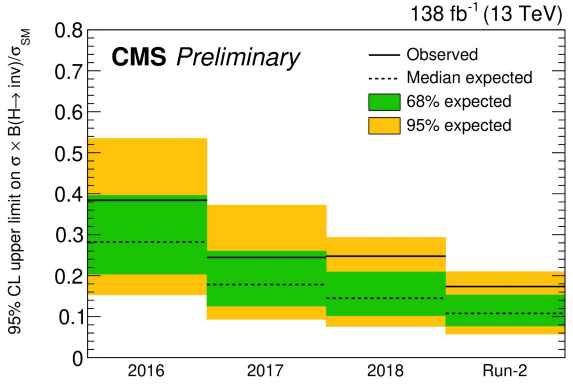
H → invisible (VBF)

- Various BSM models predicts much higher Br(H → inv) than SM (~0.1%)
- Higgs boson as a mediator for SM particles and dark matter
- High production cross section and distinctive signal topology
- Corresponding ATLAS result at 139 fb^{-1}





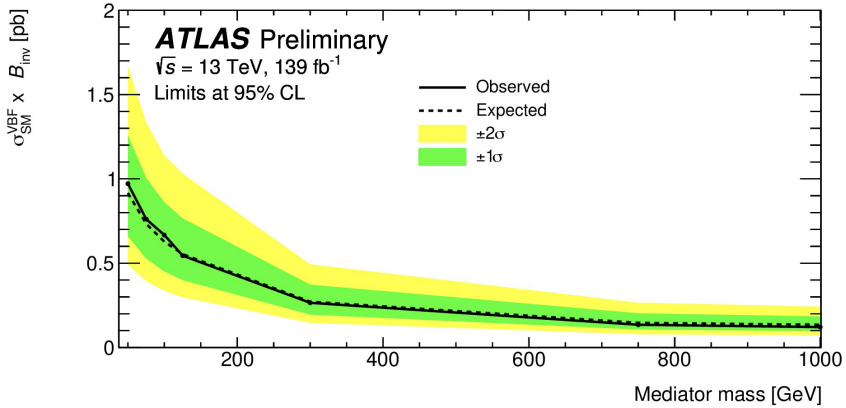


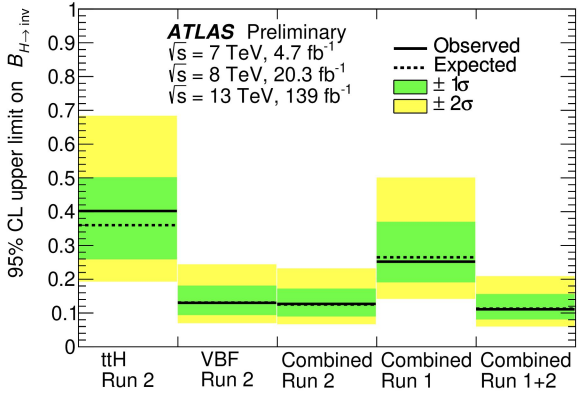


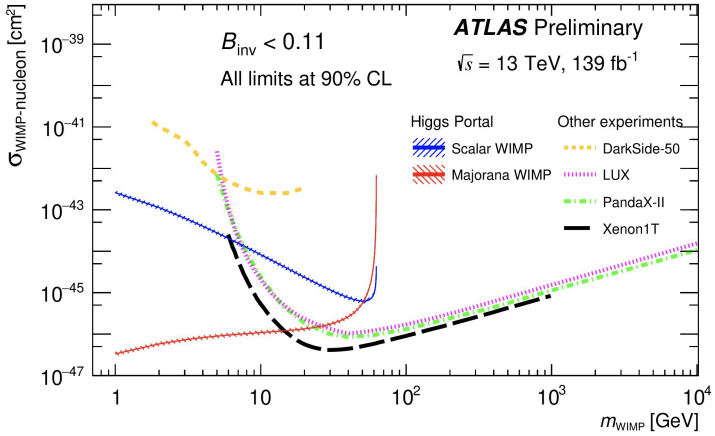
ATLAS-CONF-2020-052 ATLAS-CONF-2020-008 CMS-HIG-20-003

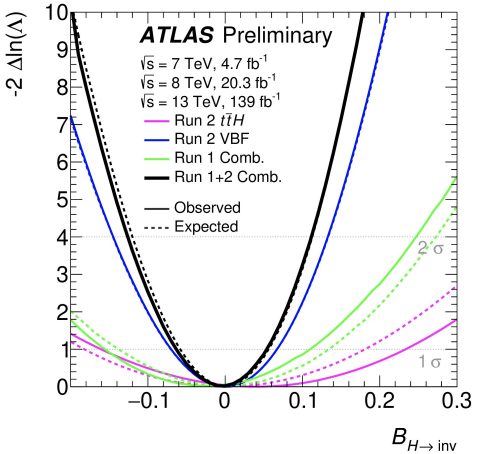
H → invisible

- Similar results from ATLAS includes combination and VBF channel
- Constrain invisible branching fraction < 0.11
- Results also interpreted as exclusion on dark matter models with Higgs as portal





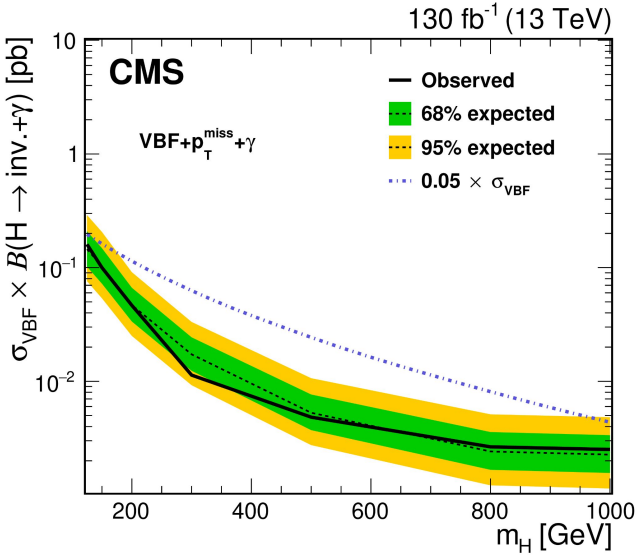


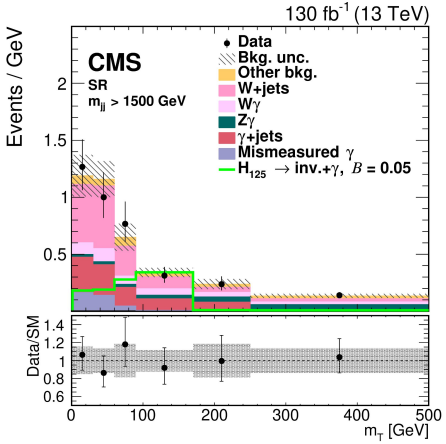


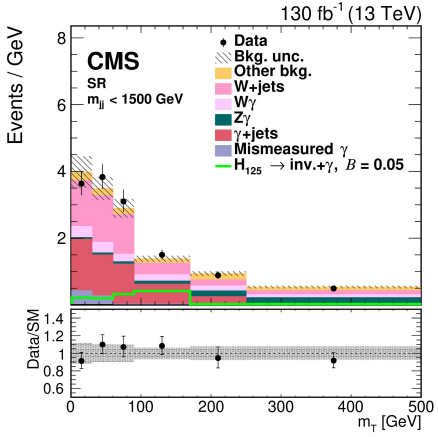
CMS-EXO-20-005

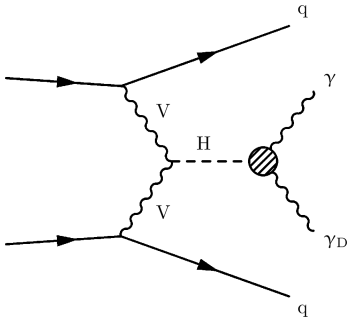
H → invisible + γ

- $H \rightarrow \gamma\gamma_D$ where γ_D is a massless dark photon
- $B(H \rightarrow inv + \gamma)$ could be as large as 5%
- A model-independent search for VBF production is performed for neutral Higgs bosons with masses between 125 and 1000 GeV, and plus ZH for H125
- Signal signature: two jets + γ + MET









Conclusion

- ATLAS and CMS has gained significant progress in understanding various properties of Higgs boson, such as its exotic decays
- The most stringent constraints on various channel generally come from full Run II datasets, thanks to:
  - Increased data statistics
  - Improved detector reconstruction
  - More advanced analysis methods
- Selected set of results in this talk:
  - $H \rightarrow aa \rightarrow 4\gamma$
  - $H \rightarrow$ invisible
  - $H \rightarrow$ invisible (VBF)
  - $H \rightarrow aa \rightarrow bb\mu\mu$
  - $ZH \rightarrow bb$ + invisible
  - $H \rightarrow 4l$
  - $H \rightarrow$lepton flavor violation
- More interesting results are coming out with full Run II data Stay tuned!
- In a longer term, we will achieve higher sensitivity with large data sets in Run III and beyond