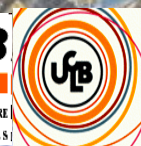# Searches for additional low-mass Higgs bosons at the LHC

Suzanne GASCON-SHOTKIN

IP2I Lyon (IN2P3-CNRS)/Université Claude Bernard Lyon 1

Cosmology, Astrophysics,Theory and

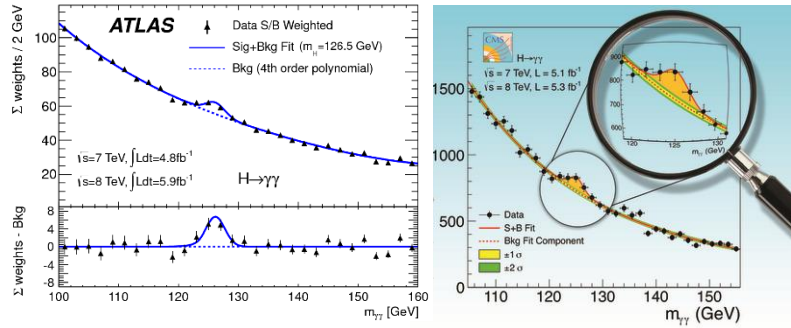Collider Higgs 22+2

May 1 , 2024 DIAS Dublin (IR)

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Motivations

- Why do we still look for others? And why should they be light?
- There is still 'room' left for exotic decays of H_{125} to non-SM particles
- Many BSM theories allow new light (pseudo-)scalars

- We found one Higgs boson in 2012….

This talk: Selection of most recent additional low-mass Higgs boson searches from ATLAS and CMS (*)

- Light (pseudo-) scalars a:
  - In association with Z from $H_{125} \rightarrow Za \rightarrow \ell\ell\gamma\gamma$ ALP
  - In pairs from H_{125} or $X \rightarrow aa$ or $\phi\phi \rightarrow \gamma\gamma\gamma\gamma$ dark SUSY
  - In pairs from $pp \rightarrow (H_{125}) \rightarrow aa \rightarrow \mu\mu\mu\mu$ vector portal, NMSSM
  - In pairs from VH_{125}, $H_{125} \rightarrow aa \rightarrow bbbb$ with 2DHM + S
- SM-like (or not) scalar H (or X) $\rightarrow \gamma\gamma$
- 'Dark' Higgs boson s from $Z'^* \rightarrow Z' + s \rightarrow \chi\chi + bb$
- Scalar and pseudoscalar h,A from $Z^* \rightarrow h/H$ $A \rightarrow \tau\tau\tau\tau$ (60-160 GeV)   Type X 2HDM
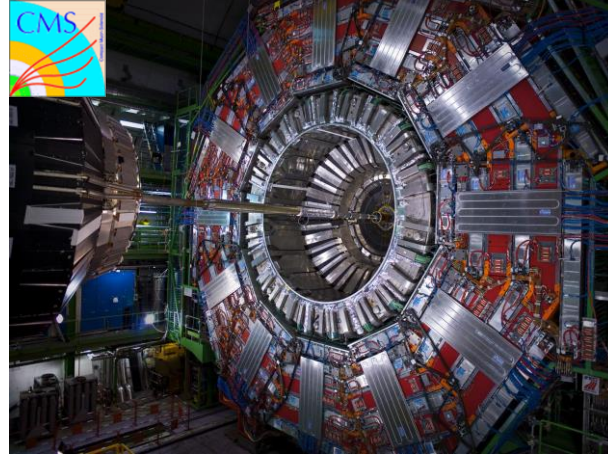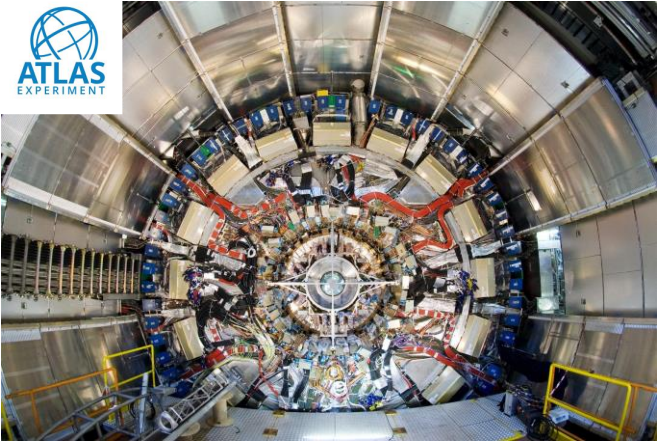- Conclusions and perspectives
- Acknowledgements

(*) Not covered:
- CMS Higgs + DM searches (see A.Calderon's talk on Thursday!)
- Additional low-mass Higgs bosons co-produced with H_{125} (see J. Schaarschmidt's talk on Thursday!)

Detectors and Methods

- Light (pseudo-) scalars a:
  - In association with Z from $H_{125} \rightarrow Za \rightarrow \ell\ell\gamma\gamma$ ← resolved and merged di-γ reconstruction → access lower m_a
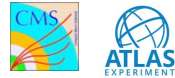 - In pairs from H_{125} or X → aa or $\phi\phi$ → $\gamma\gamma\gamma\gamma$: ← search for both prompt and long-lived decays
  - In pairs from pp → (H_{125}) → aa → $\mu\mu\mu\mu$:
  - In pairs from VH_{125}, H_{125} → aa → bbbb : ← Kinematic boosted decision trees (BDT)/ML
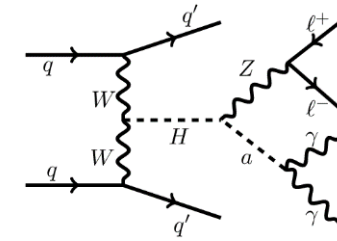- SM-like (or not) scalar H (or X) → $\gamma\gamma$
- 'Dark' Higgs boson s from Z'* → Z'+s → $\chi\chi$ + pb   Missing p_T trigger → lower m_s, resolved + merged di-b
- Scalar and pseudoscalar h,A from Z* → h/H A → $\tau\tau\tau\tau$ (60-160 GeV)
- Summary and Conclusion
- Acknowledgements

Light pseudoscalar a from $H_{125} \to Za \to \ell\ell\gamma\gamma$ (0.1-33 GeV) PLB 848 (2024) 138536

- Merged (resolved) di-γ categories for $m_a <$ (>)2 GeV, with $m_{\gamma\gamma}$ ($\Delta R(Z,\gamma)$) as discriminating variable
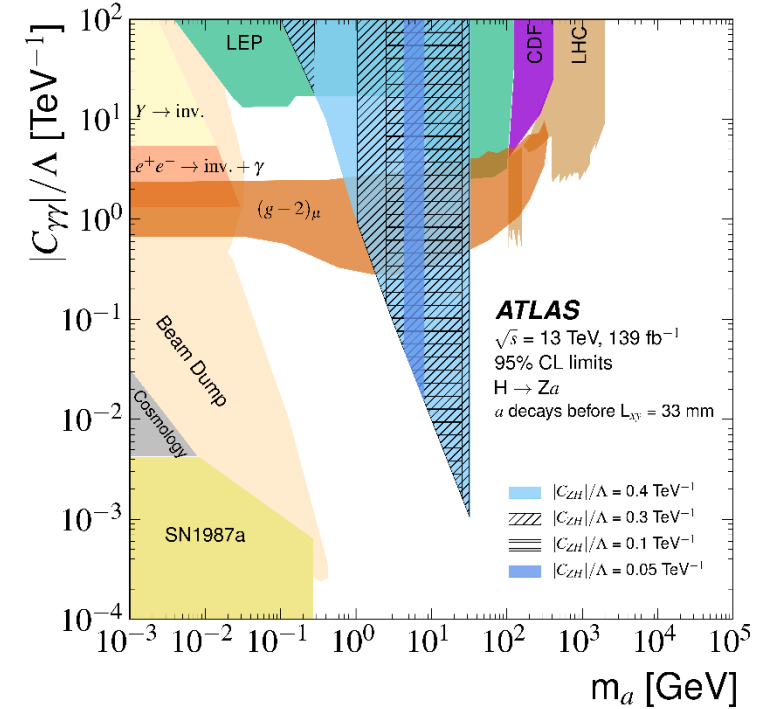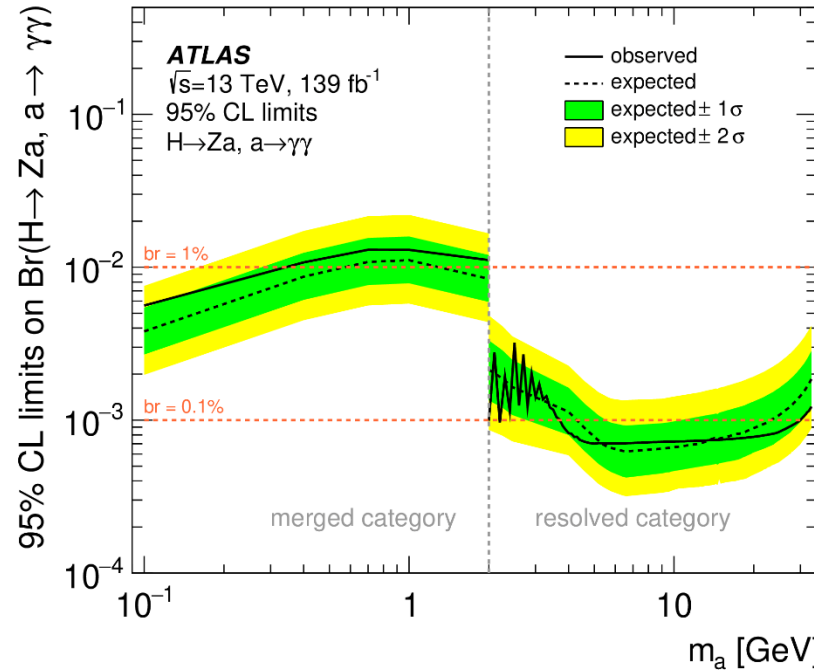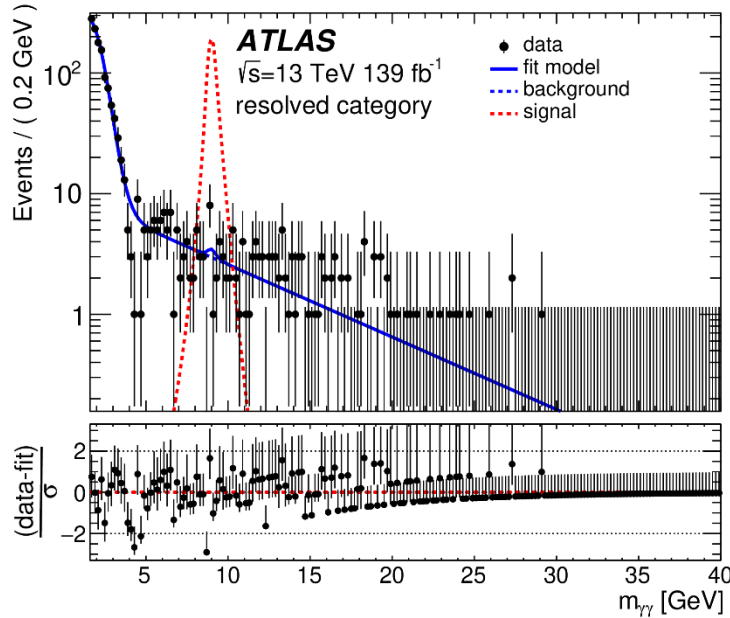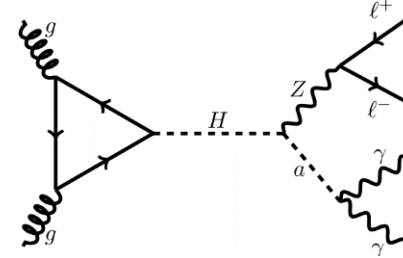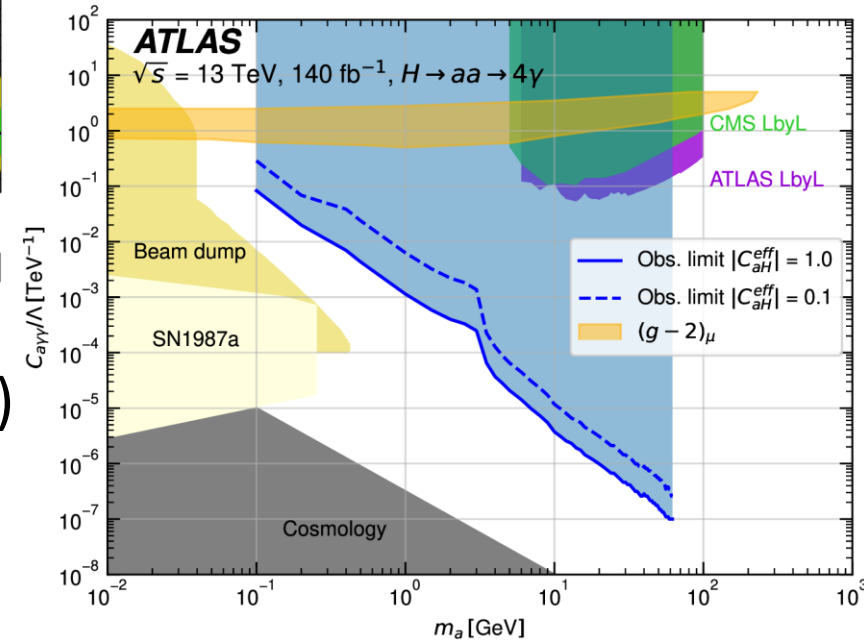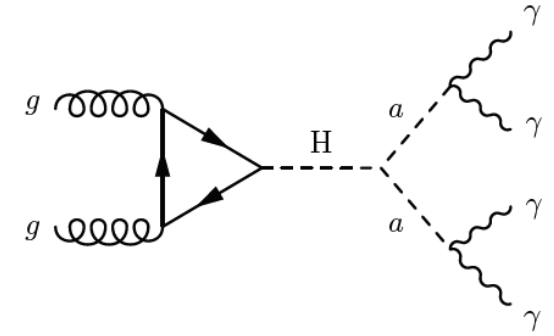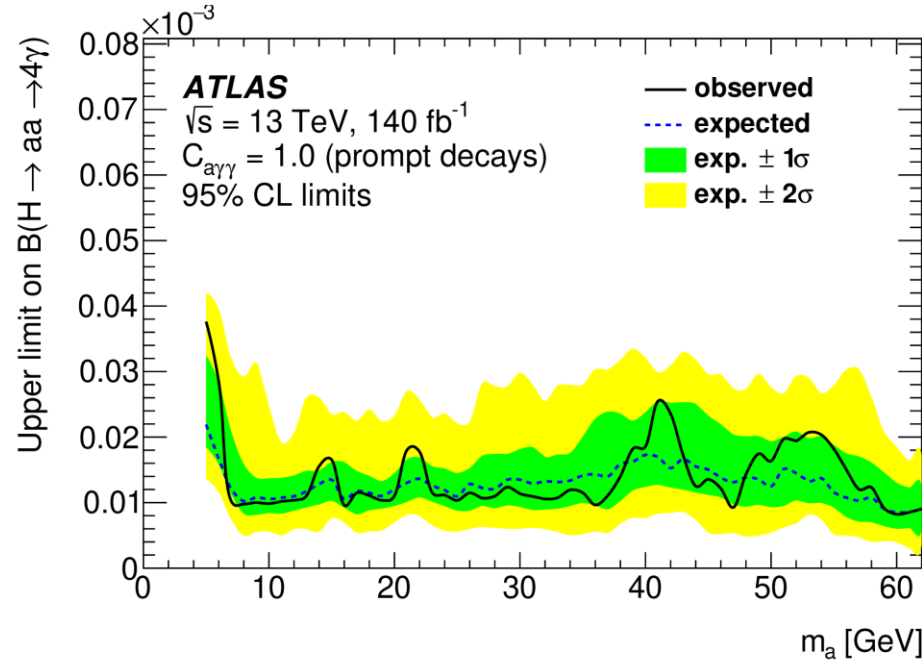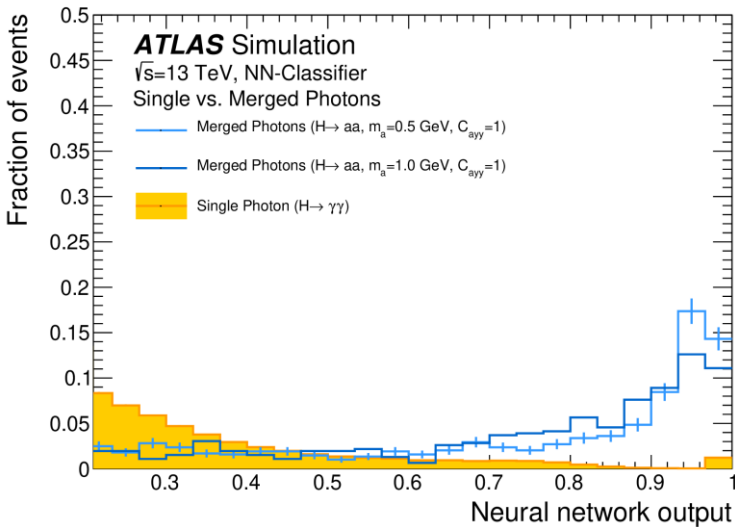

- Backgrounds from Z+γ and Z+jets processes

- 95% confidence level limits on B($H_{125} \to Za$, $a \to \gamma\gamma$) between 0.08-2%.

- ALP interpretation in $\{m_a, |C_{\gamma\gamma}|/\Lambda\}$ phase space, for several $|C_{ZH}|/\Lambda$ values, prompt decays only

- Corresponding CMS result: $<\sim 10^{-4}$ for 1<m_a<30 GeV PLB 852 (2024) 138582

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Light pseudoscalar pair from $H_{125} \to aa \to \gamma\gamma\gamma\gamma$ (0.1-62 GeV)

- Search for prompt or long-lived ALPs ($C_{a\gamma\gamma} >$ or <0.1)

- Prompt case: 95% confidence level limits on $B(H_{125} \to aa, a \to \gamma\gamma)$ between 2×10^{-5} to 3×10^{-2}.

- Long-lived case: between 2-6 x 10^{-5} for 10 GeV < m_a < 62 GeV, between 10^{-4} to 3×10^{-2} for 0.1 GeV < m_a < 10 GeV. Most stringent limits to-date.

- Neural network to distinguish single from merged photons ➔ categories

- ALP interpretation in $\{m_a, |C_{a\gamma\gamma}|/\Lambda\}$ phase space, for $|C^{eff}_{aH}| = \{1, 0.1\}$

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Light spin-0 boson pair from X→φφ→γγγγ (1.5-75 GeV)

- 0.3<m_X<3 TeV, 0.5<m_ϕ/m_X<2.5%→only merged diphotons
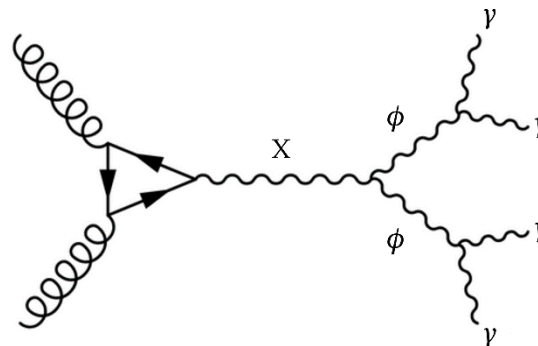
- Most sensitive search of its kind at the LHC.

- 2 convolutional NN to regress merged mass and classify with P{γγ, γ, hadron}:
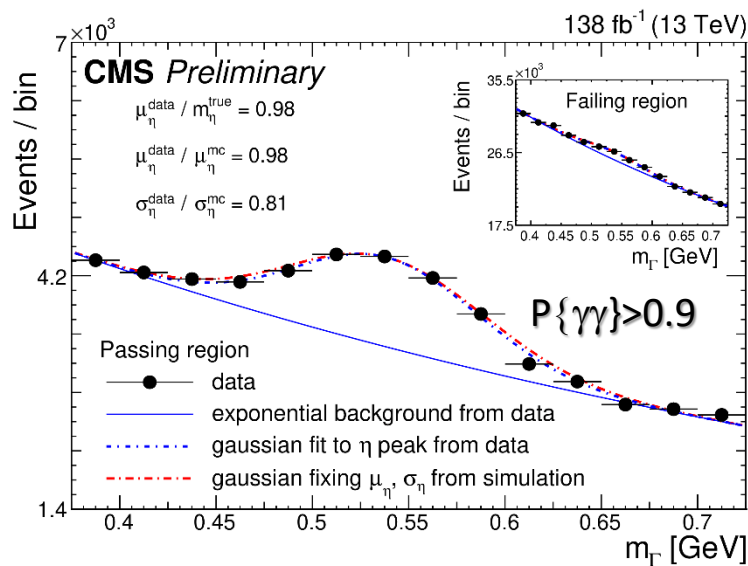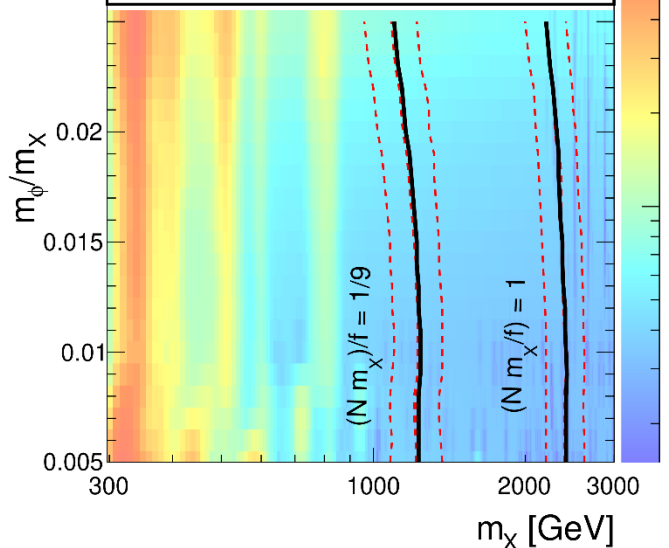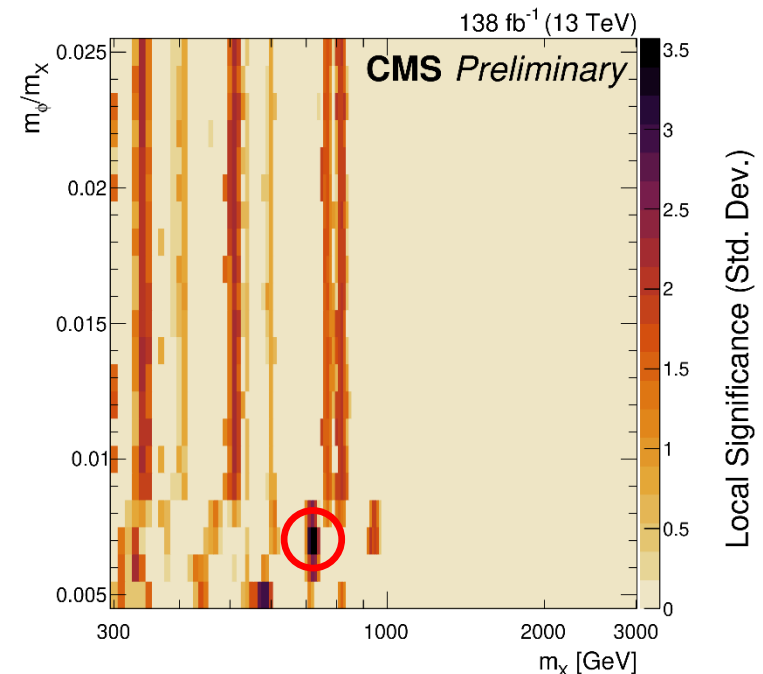
- Validation with boosted η→γγ

- 95% confidence level limits on σ, BR=100% : between 0.03 and 1.06 fb.

- Largest excess @ {m_X, m_ϕ}~{720,5.04} GeV, 3.57σ (1.07σ) local (global) significance

Light boson pair from pp($\to$H)$\to$aa$\to\mu\mu\mu\mu$ (0.21-60 GeV)

- Model-independent search....
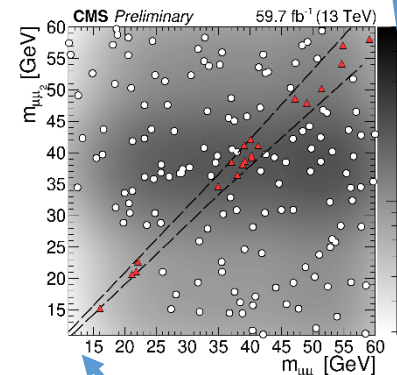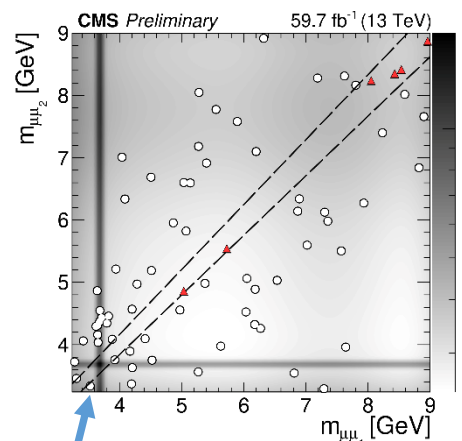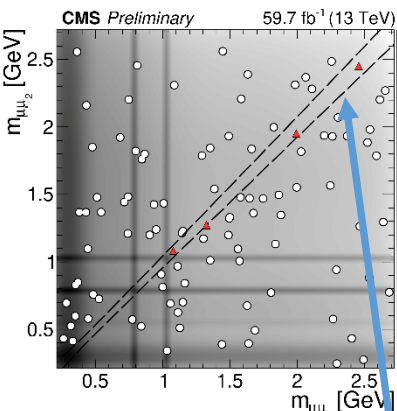
- Select 2 isolated di-μ pairs in regimes avoid J/ψ, Υ, enforce mass proximity:

$$|m_{\mu\mu_1} - m_{\mu\mu_2}| < W((m_{\mu\mu_1} + m_{\mu\mu_2})/2)$$

2017 + 2018

Add 2016 prior result for lowest masses
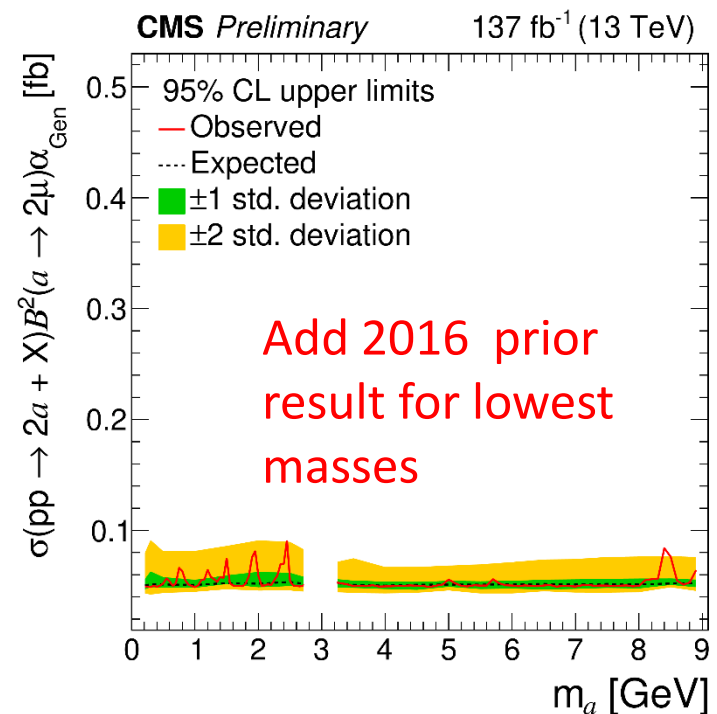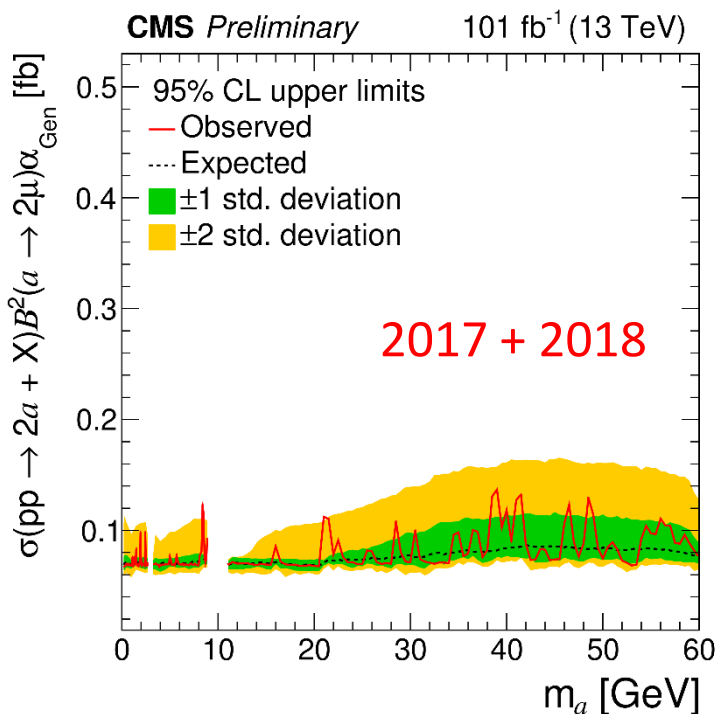
- 95% confidence level limits as a function of m_a on σ x B^2 X acceptance for pp$\to\mu\mu\mu\mu$: between 0.049 and 0.247 fb.
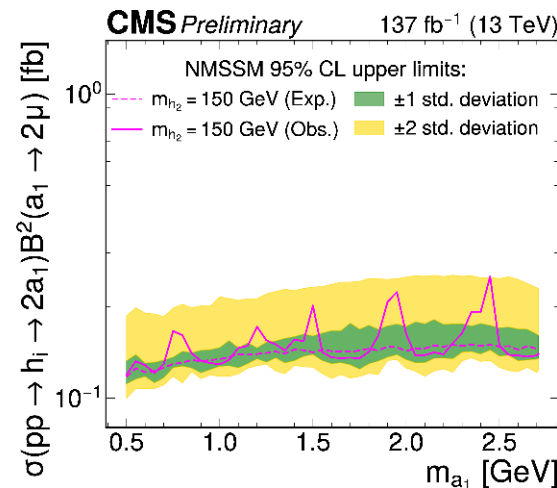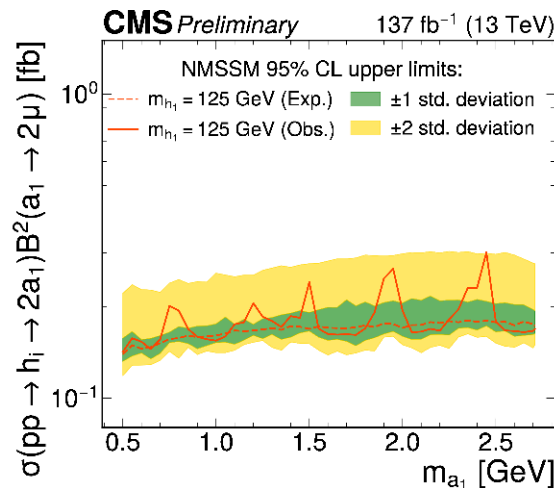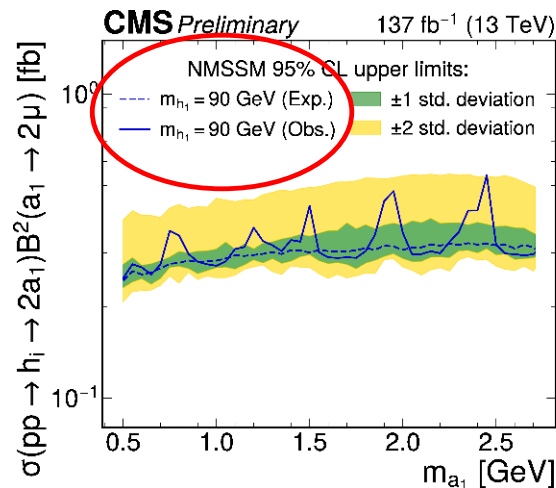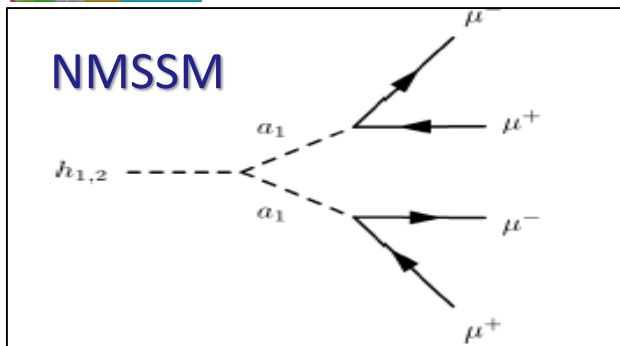
- Trigger without vertex constraint in 2018
  $\to$probe cτ < 100mm

Light boson pair from pp($\to$H)$\to$aa$\to\mu\mu\mu\mu$ (0.21-60 GeV)

- Interpretations…

NMSSM

Vector Portal: $Z_D \to S_D \overline{S_D} \to 4\mu$

DarkSusy
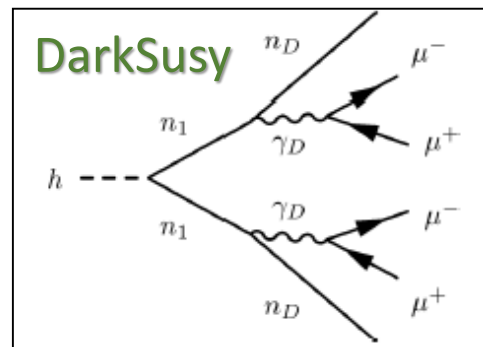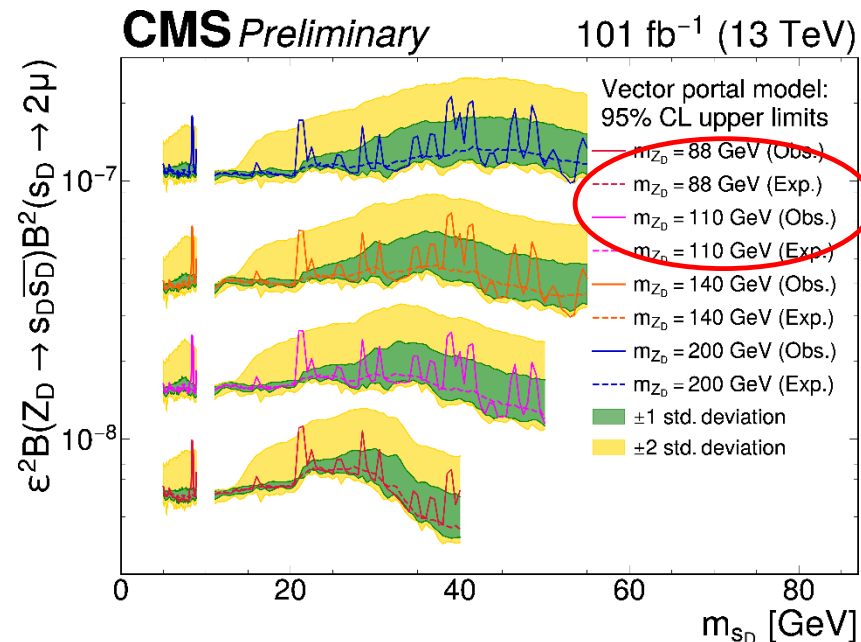
- Related ATLAS search: JHEP 03 (2022) 041
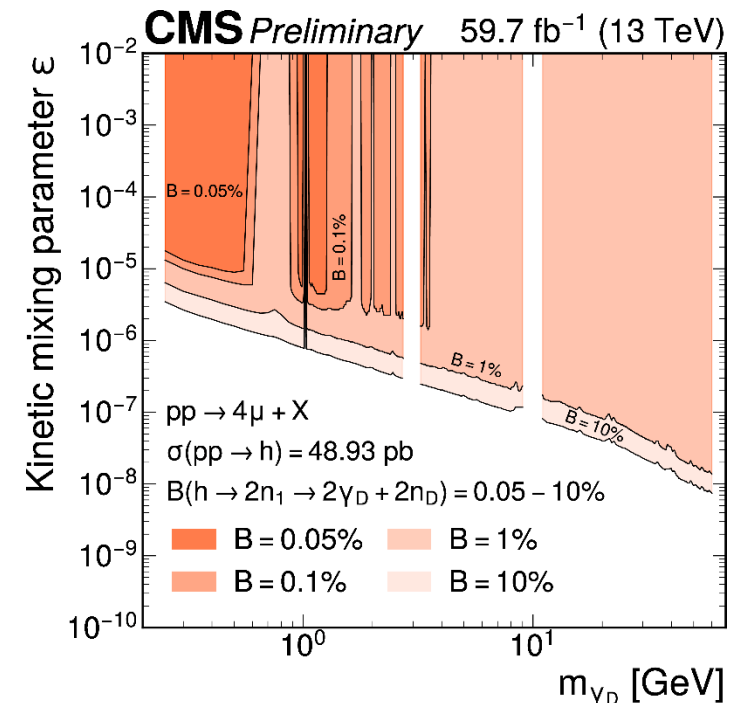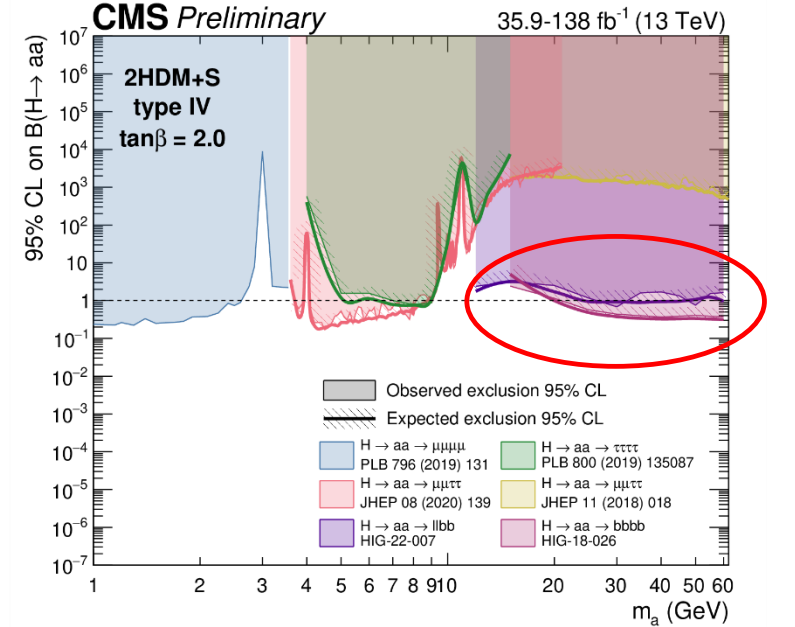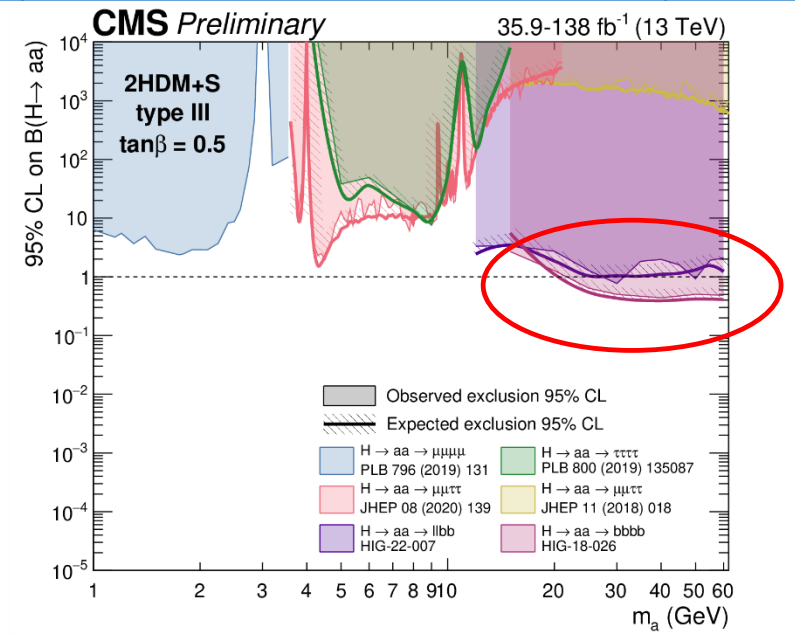
VH$_{125}$, H$_{125}$➔aa➔bbbb (15-60 GeV)

- 4b final state with 1-2 additional leptons from W or Z
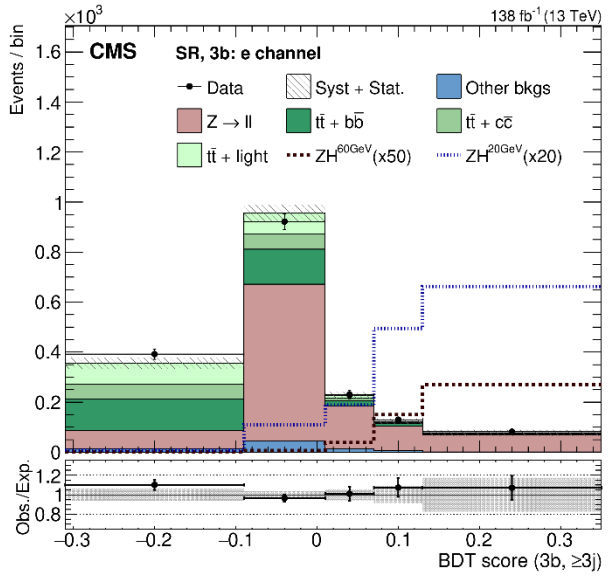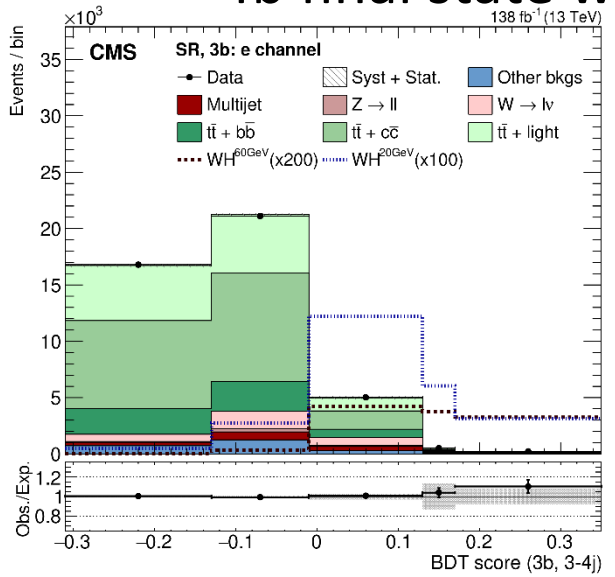
- N$_{bjet}$, N$_{jet}$ event categories with dedicated kinematic BDTs for W/ZH (discriminating variable)
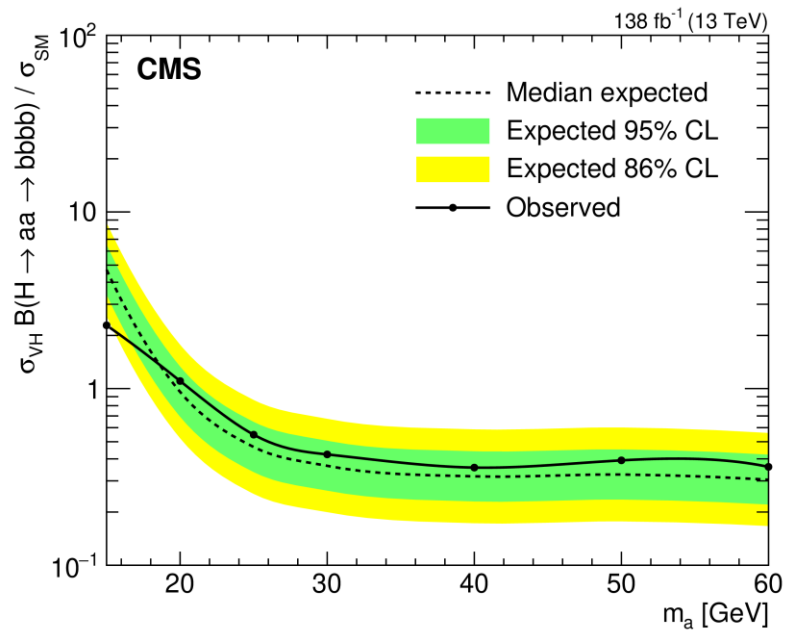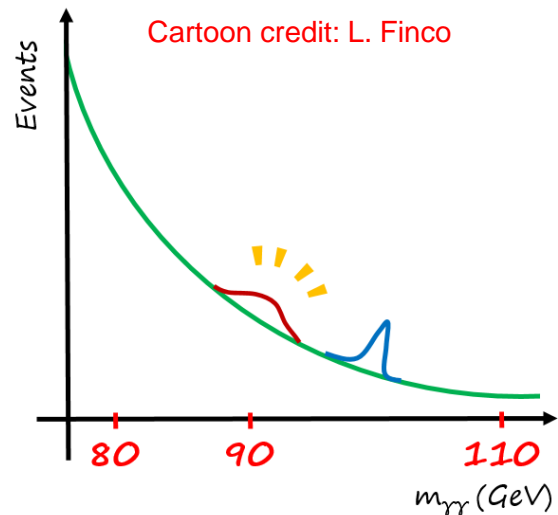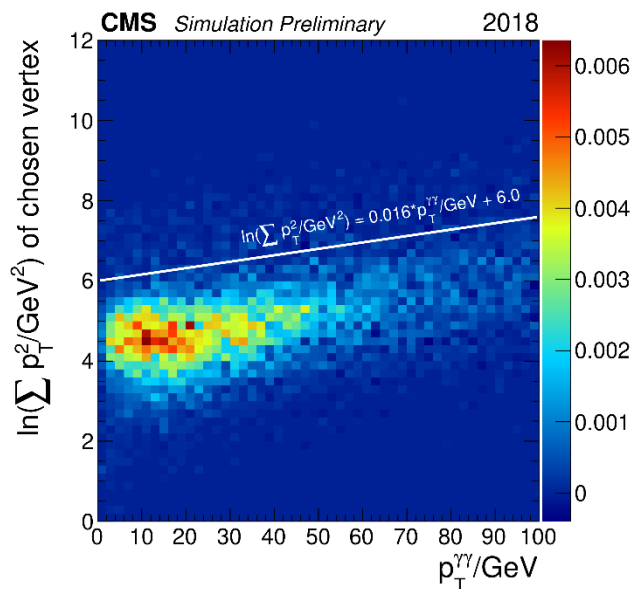
- 95% CL UL on σ$_{VH}$ X B/σ$_{SM}$: 1.1-0.36

- New exclusion in Types III + IV 2HDM + S phase space

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SM-like (or not) scalar H(X)→γγ (66 or 70 GeV<m_H<110 GeV)

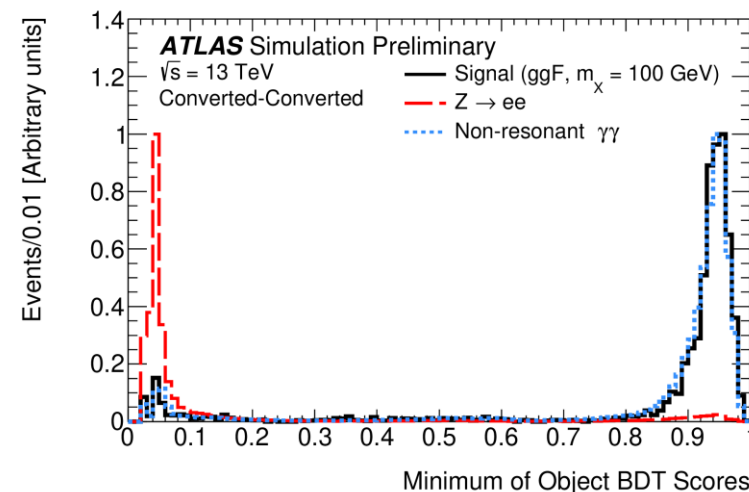Cartoon credit: L. Finco

- Biggest challenge: misidentified Z→ee pairs

- CMS: veto tracks late or missed by pixel detector, but spare boosted events
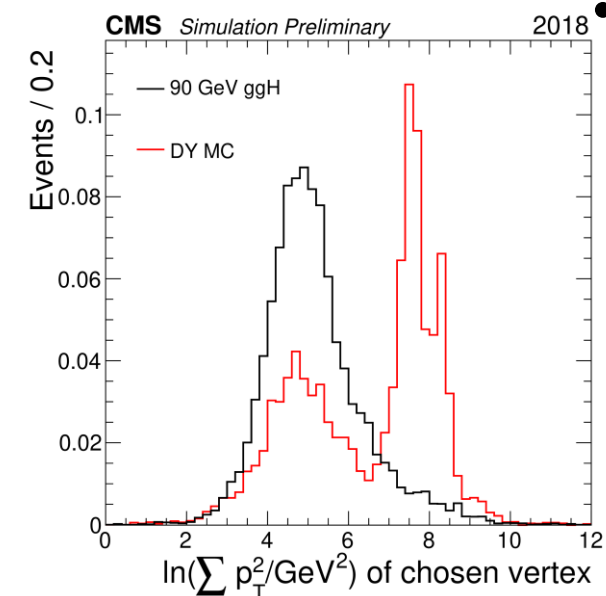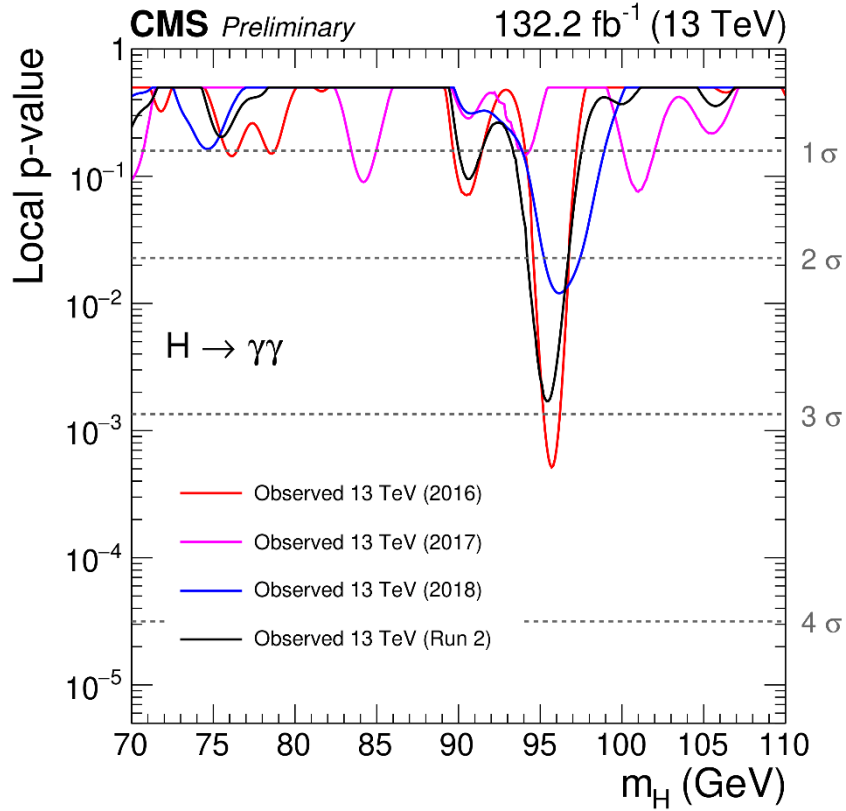
- ATLAS: kinematical object BDT w/conversion variables

- Model-dependent case: object BDT→ diphoton BDT

SM-like (or not) scalar H(X)→γγ (66 or 70 GeV<m_H<110 GeV)
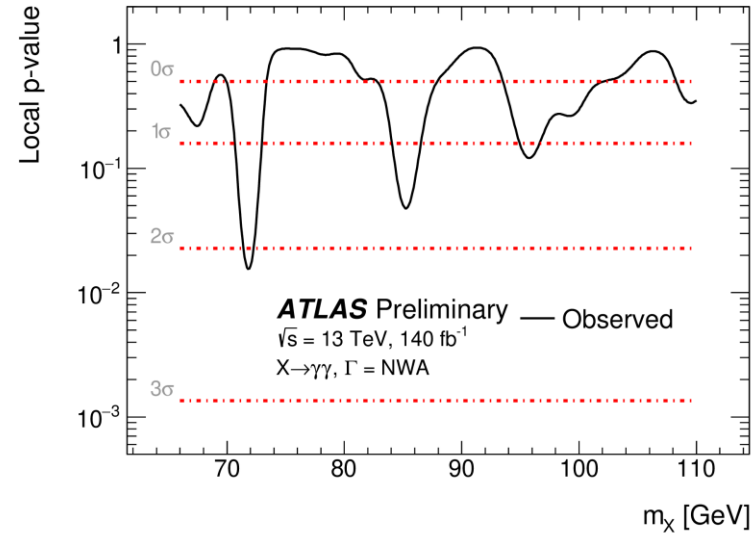
- **Model-independent:**
Mild excess: ~2.2σ local significance at $m_{\gamma\gamma}$=71.8 GeV

- **Model-dependent:**
Largest excess: ~1.7σ local significance at $m_{\gamma\gamma}$=95.4 GeV

- 95% CL UL on $\sigma_{\textbf{fid}}$ X B: 8-53 fb
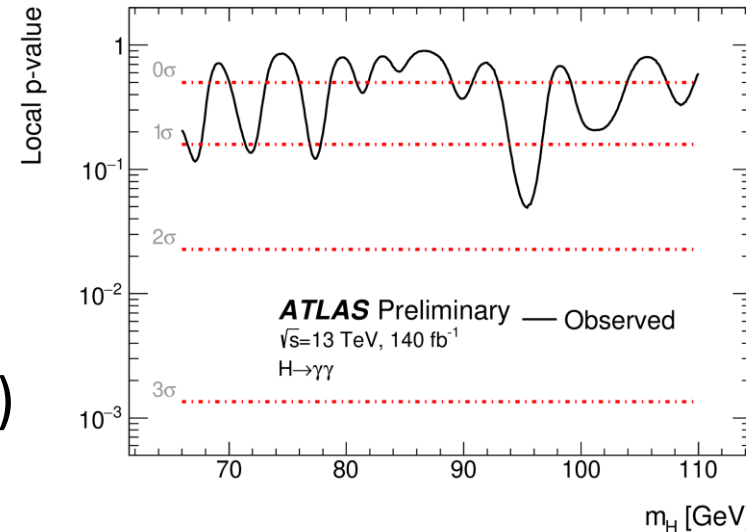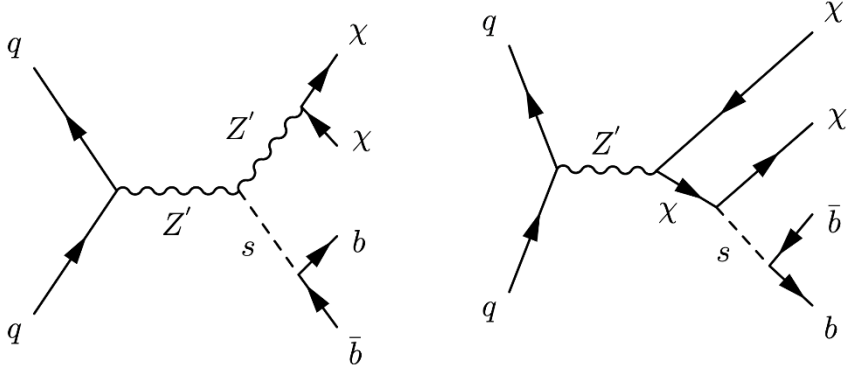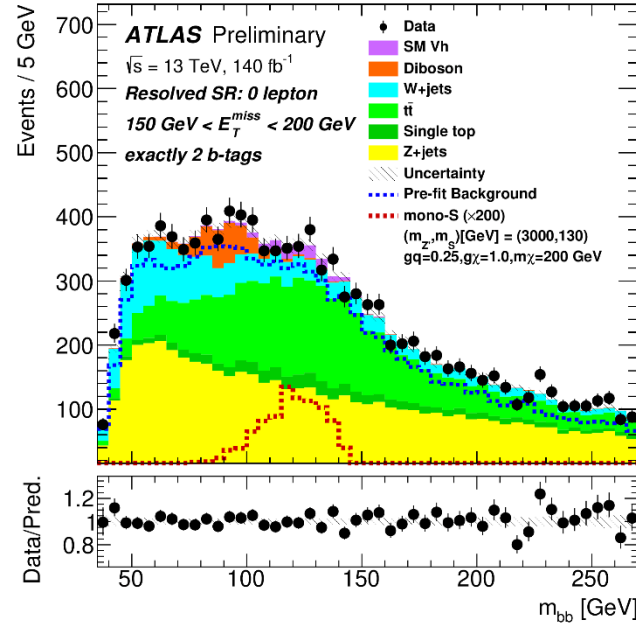
- Modest excess: ~2.9σ local (1.3σ global) significance at $m_{\gamma\gamma}$=95.4 GeV

- 95% CL UL on σ X B between 15-73 fb ⇔

- 95% CL UL on σ X B between 19-102 fb (model-dependent)

'Dark' Higgs s from Z'*→Z'+s→χχ + bb (30-150 GeV)

- Signature: merged or resolved bb system, m_{bb} binned in Et_{miss}

- Backgrounds from tt and V+jets

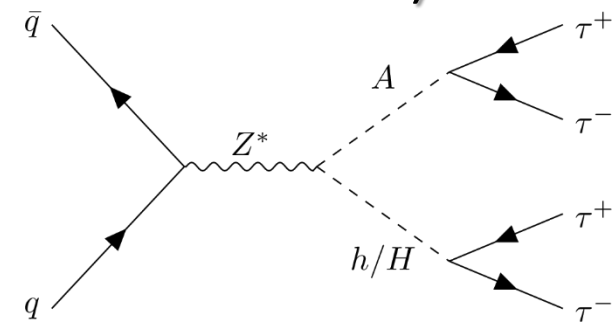- Access lower m_s with Et_{miss} trigger and dedicated merged-bjet (large R) tagger

- Exclusions in $\{m_s, m_{Z'}\}$ plane: Scenario 1: Z'-χ (DM) coupling fixed

- Scenario 2: Z'-χ coupling floats to match the relic density

- Largest deviations for m_s~60, 130 GeV
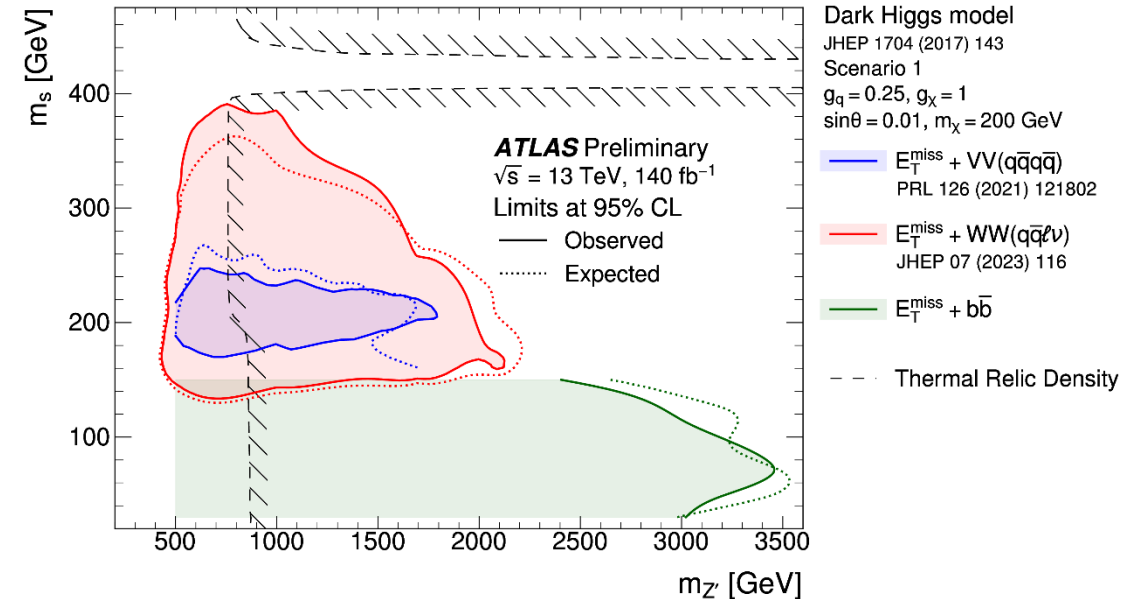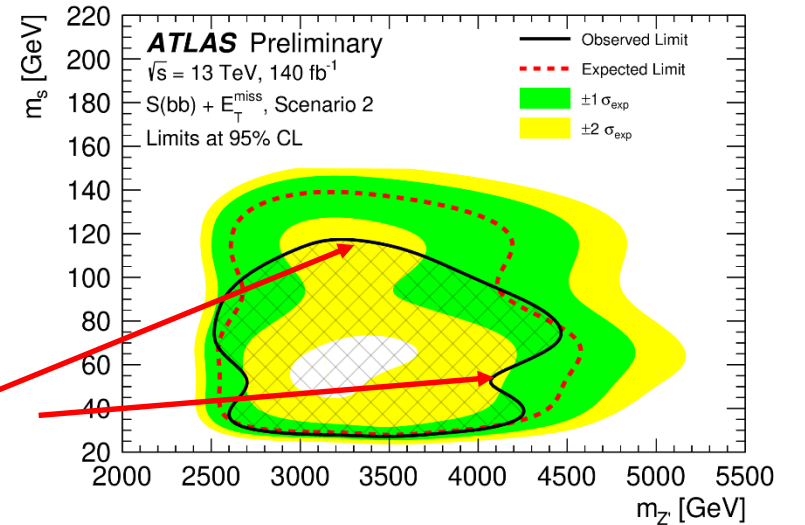
New h/H(φ), A from Z*→φ A→ττττ (100-300, 60-160 GeV)

CMS-PAS-SUS-23-007

- Categories with up to $4\tau_h$ + 1 with $3\tau_h$, some subdivision in OS/SS
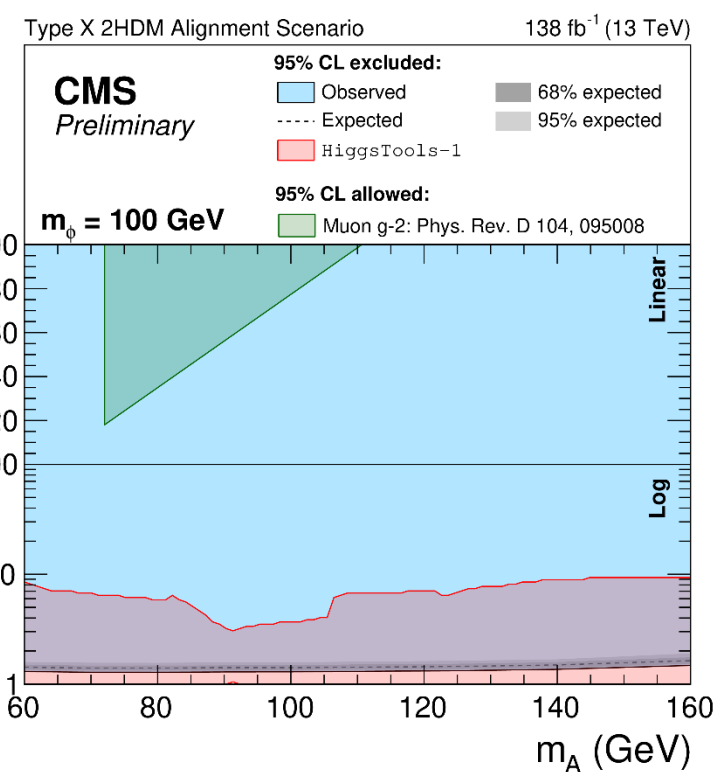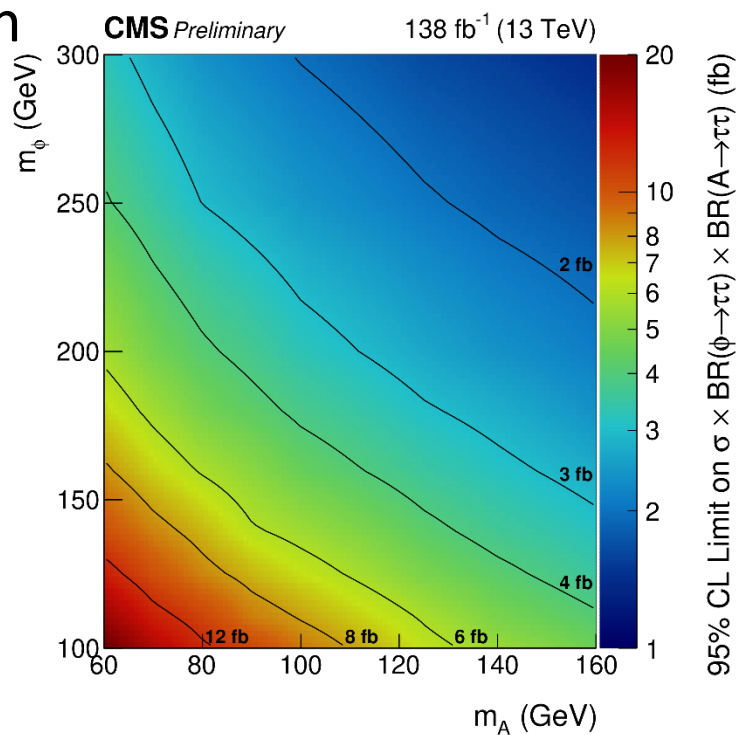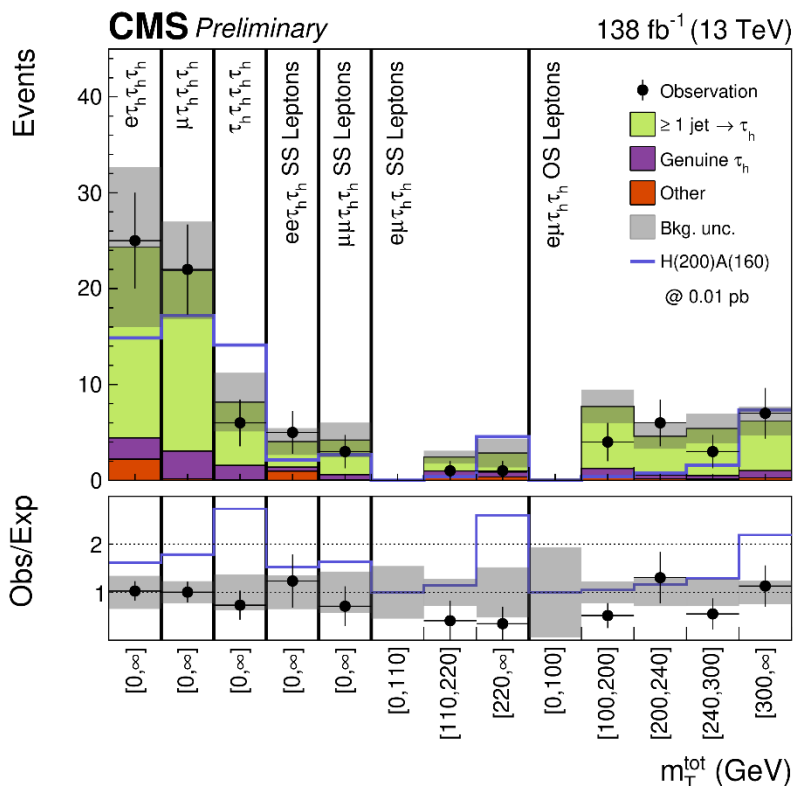
- 95% CL UL on σ X B² : from 1.4 fb at m_A, m_ϕ = {160, 300} GeV to 20 fb at {60, 100} GeV

- Discriminating variable: m_T^{tot}

$$m_T^{tot} = \sqrt{\sum_{i,j=1; i<j}^{N} m_T(\vec{p}_T^i, \vec{p}_T^j)^2},$$

- Muon g-2-allowed region in Type X ('lepton-specific') 2HDM excluded

Conclusions and Perspectives

- No evidence for the existence of extra Higgs bosons has been found so far by CMS and ATLAS.

- Only 1 result presented here not performed with Full LHC Run 2 data set

- Perspectives for Run 3 (2022-2025): Hope for ~250fb^{-1} ➔Double the discovery possibilities!

- HL-LHC: Starts ~2029, expect 3ab^{-1}

https://hilumilhc.web.cern.ch/content/hl-lhc-project Feb 2022

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Acknowledgements

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