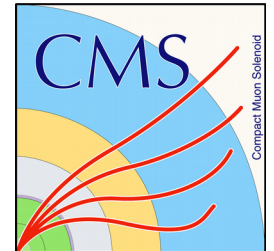


Searches for additional Higgs bosons at CMS

Gilson Correia Silva (DESY)
on behalf of the CMS collaboration



EPS-HEP Conference 2023
Hamburg, 22 August 2023

Many Beyond Standard Model (BSM) theories predict extended Higgs sectors with additional Higgs, e.g., Supersymmetry, Two-Higgs-Doublet models (2HDM) and variations, Three-Higgs-Doublet models (3HDM), ...

The simplest extension with two Higgs doublets predicts five Higgs bosons:

- two charged scalars: H^\pm
- two neutral scalars: H and h
- one neutral pseudoscalar: A

Sometimes the additional neutral (pseudo)scalar bosons are referred as ϕ .



It is crucial to have searches covering a broad mass range for additional Higgs bosons to maximize the sensitivity to different models.

Searches for additional Higgs bosons at masses above 60 GeV with the CMS experiment are presented in this talk.

Many searches for additional Higgs bosons were performed:

$A/H \rightarrow tt$: Eur. Phys. J. C 77 (2017) 578

$A/H \rightarrow bb$: JHEP 08 (2018) 113

$A/H \rightarrow \tau\tau$: JHEP 09 (2018)007

$A/H \rightarrow \mu\mu$: Phys. Lett. B 798 (2019)

$A \rightarrow Zh \rightarrow (ll, \nu\nu)bb$: Eur. Phys. J. C 79 (2019)

$H/A \rightarrow Z(ll)A/H(bb)$: JHEP 03 (2020) 055

$H \rightarrow WW$: JHEP 03 (2020) 034

$H \rightarrow AA \rightarrow 4\gamma$: Accepted for publication in Phys. Rev. Lett.

$X \rightarrow YH \rightarrow b\bar{b}b\bar{b}$: Phys. Lett. B 842 (2023) 137392

$H^\pm \rightarrow tb$: JHEP 2020:096 + JHEP 2020:126

$H^\pm \rightarrow \tau_h\nu$: JHEP 2019:142

$H^\pm \rightarrow cs, cb$: Phys. Rev. D 102, 072001 (2020)

$H^+ \rightarrow Wa$: Phys. Rev. Lett. 123, 131802 (2019)

$H^+ \rightarrow H(\tau\tau)W^+$: Accepted for publication in J. High Energy Phys.

This talk report on recent searches for additional Neutral Higgs bosons:

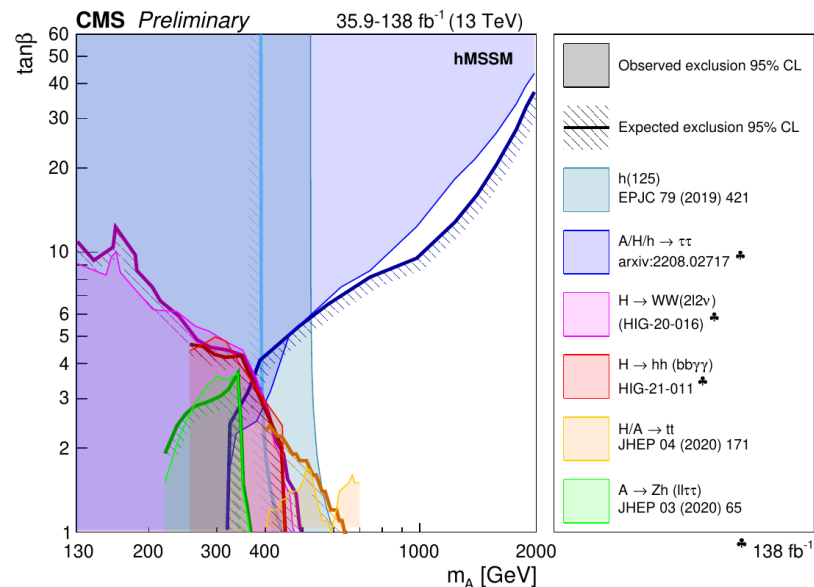
$\phi \rightarrow \tau\tau$: JHEP 07 (2023) 073

$H \rightarrow \gamma\gamma$: CMS-PAS-HIG-20-002

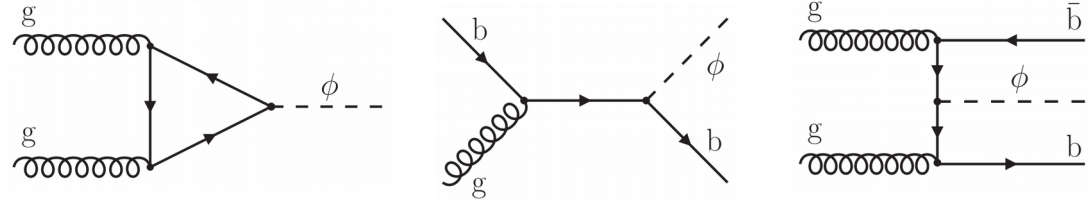
$H \rightarrow e\mu$: Submitted to Phys. Rev. D

$\phi \rightarrow ll$: CMS-PAS-EXO-21-018

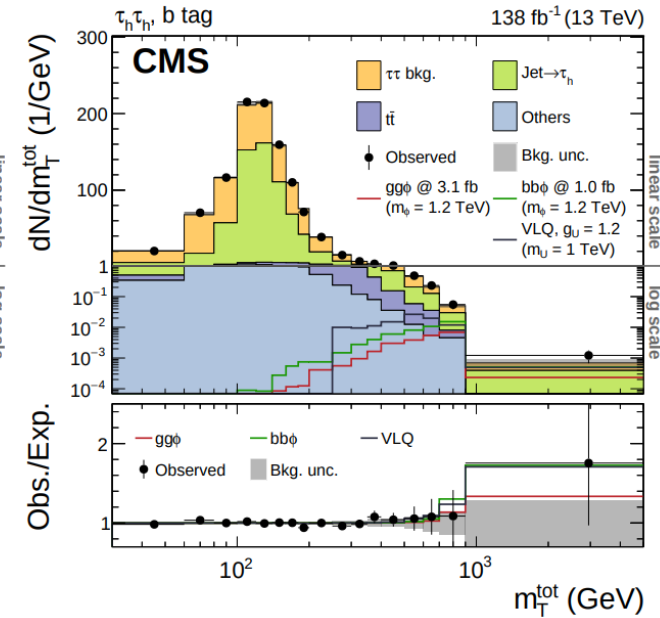
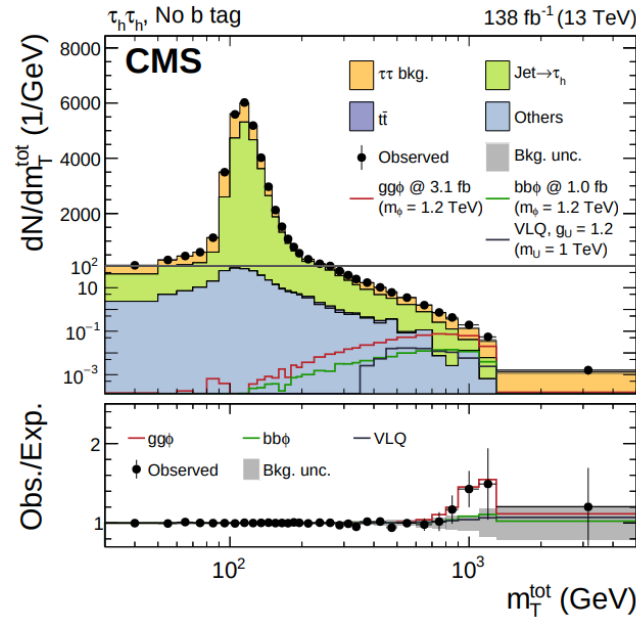
$H/A \rightarrow t\bar{q}$: CMS-PAS-TOP-22-010 **NEW**



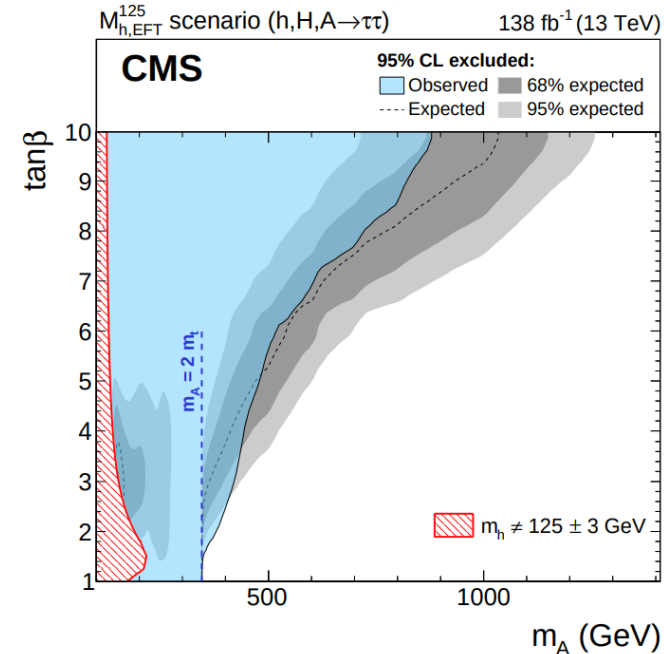
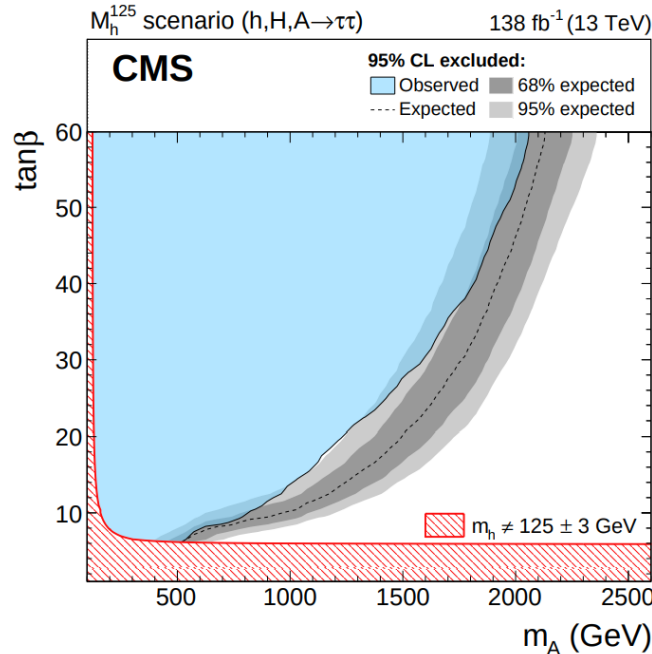
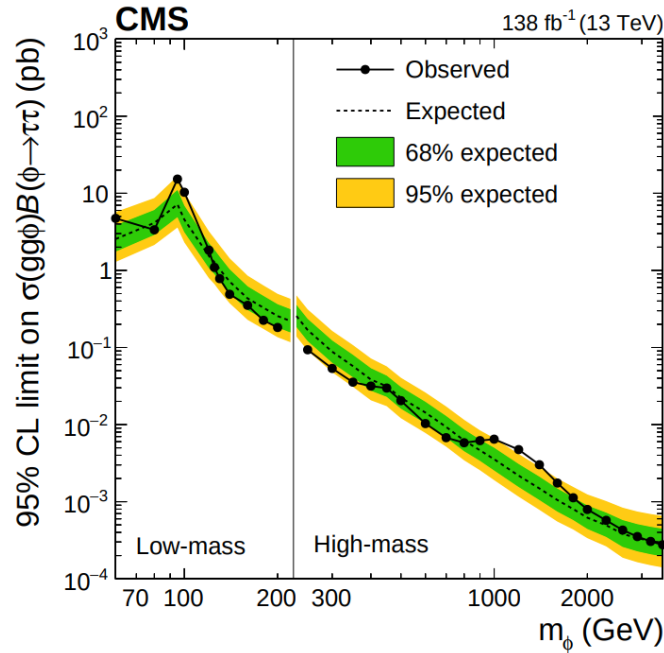
The $\tau\tau$ final state has a leading role in searches for additional heavy neutral Higgs bosons.



- Search performed in four $\tau\tau$ final states: $e\mu$, $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$.
- Main backgrounds:
 - Processes with two genuine τ leptons
 - Processes where jets are misidentified as τ_h
- Signal is extracted from distributions of $m_{\tau\tau}^{\text{tot}}$, $m_{\tau\tau}$, and y_l depending of the category.

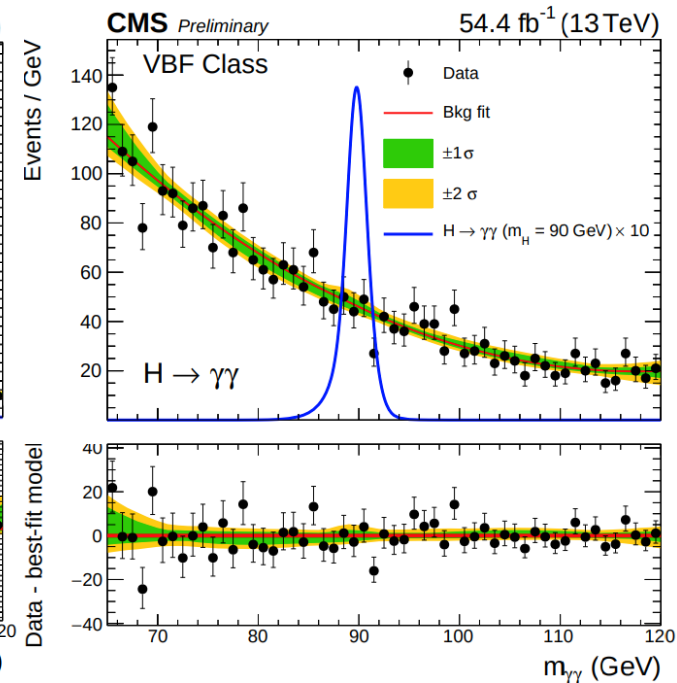
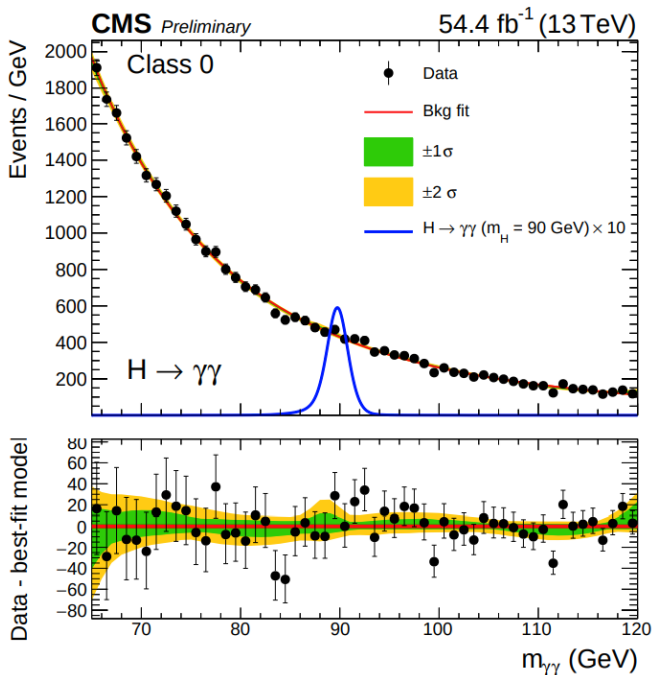


- Narrow spin-0 resonance: Two excesses for $gg\phi$ production with local p-values equivalent to about three standard deviations at $m_\phi = 0.1$ and 1.2 TeV.
- MSSM: Additional Higgs bosons with masses below 350 GeV are excluded at 95% CL for the $M_{h,EFT}^{125}$ benchmark.

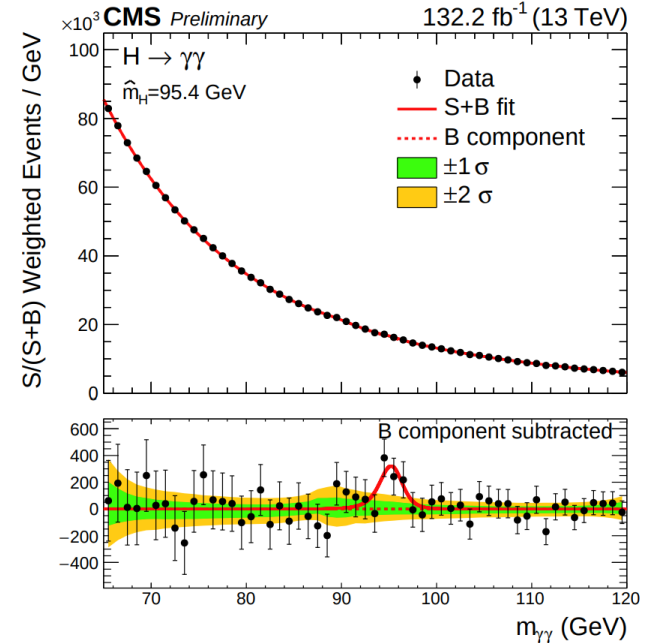
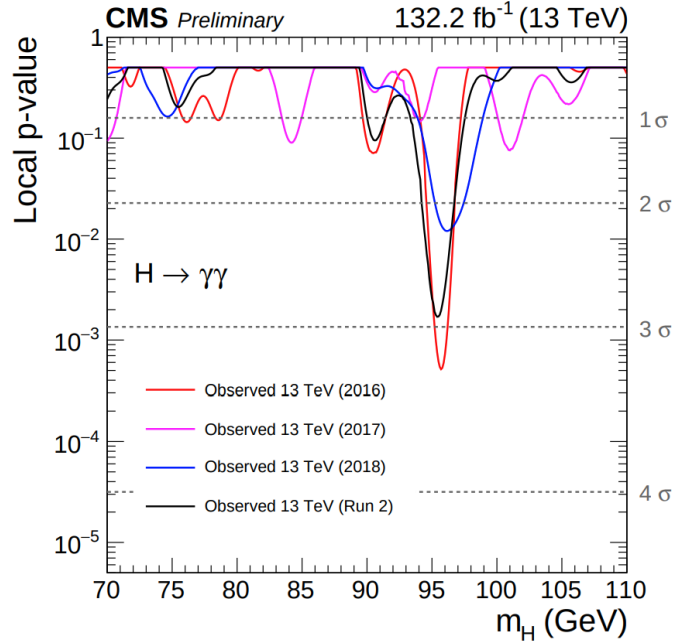
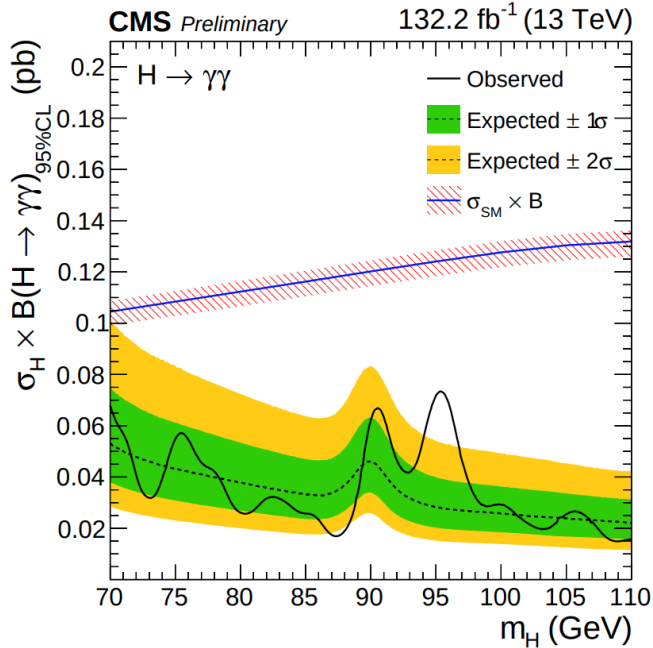


Check existence of additional “SM-like” Higgs boson with mass below 125 GeV.

- Multivariate analysis (MVA) techniques are used in photon identification and event classification.
- Signal is extracted from the background using a parametric fit to the $m_{\gamma\gamma}$ distribution.
- Dominant backgrounds:
 - direct diphoton production.
 - processes with jets misidentified as photons.

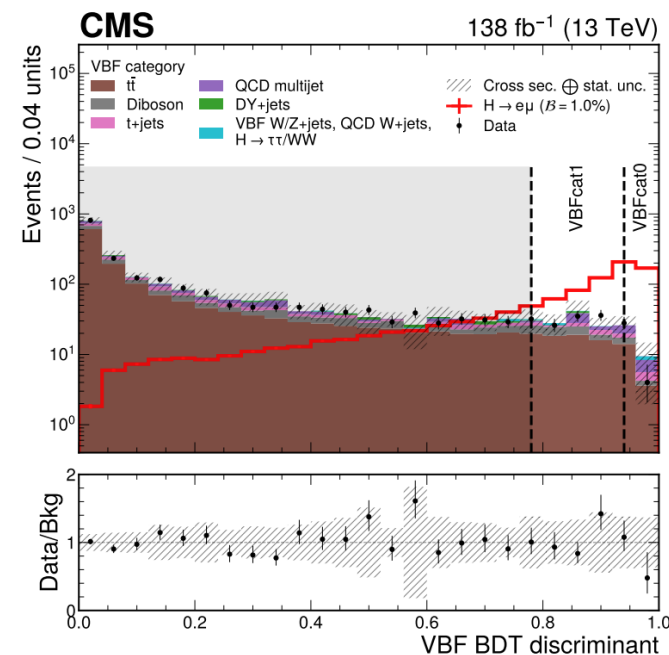
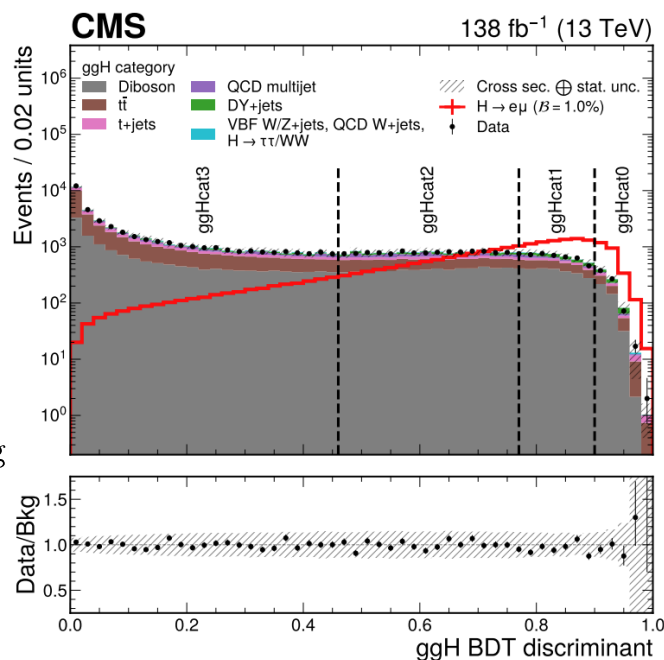


- For the combined data set, one excess with approximately 2.9 local (1.3 global) significance is observed for a mass hypothesis of 95.4 GeV.

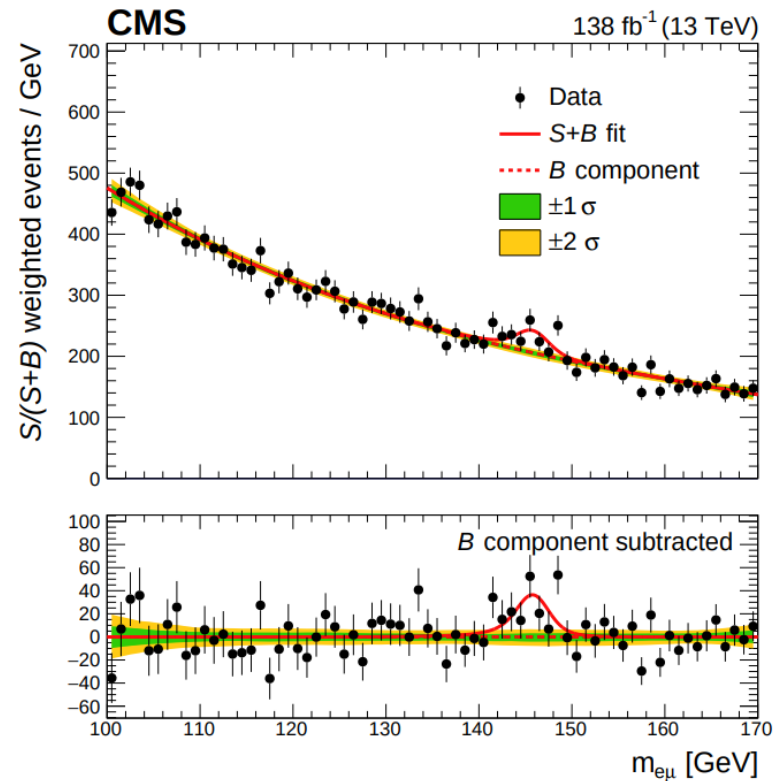
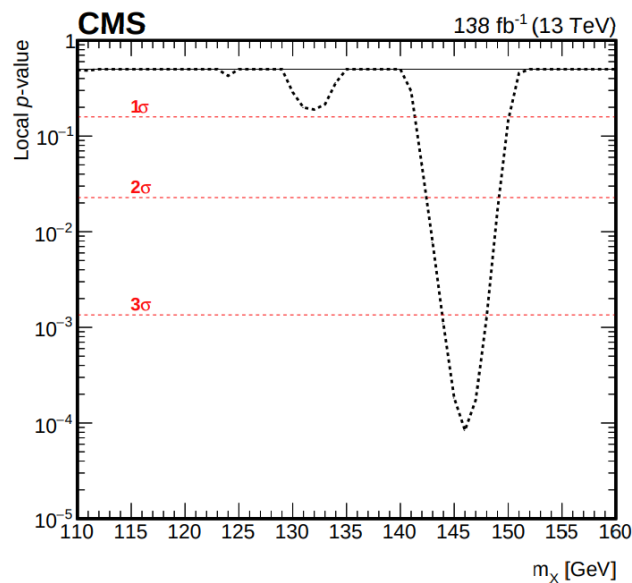
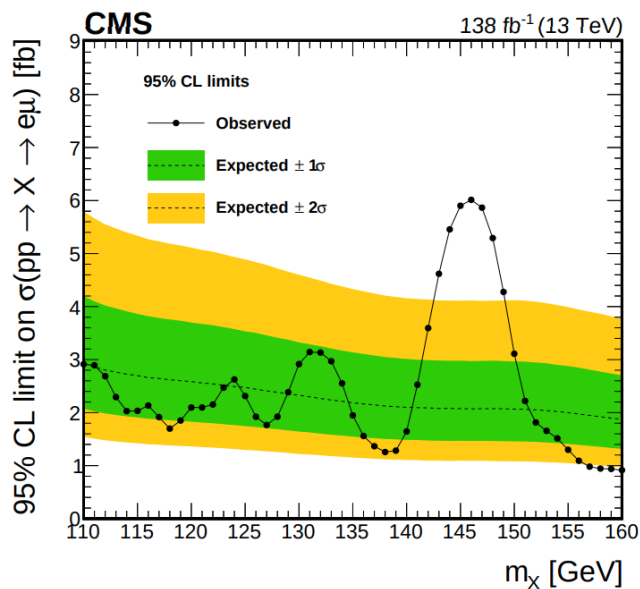


Additional Higgs bosons with a mass below $2m_W$ in the LFV decay channels is important to constrain the Type-III 2HDM model.

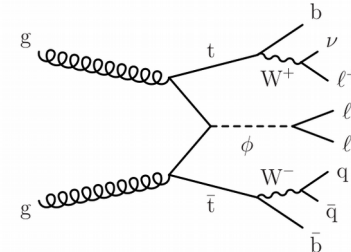
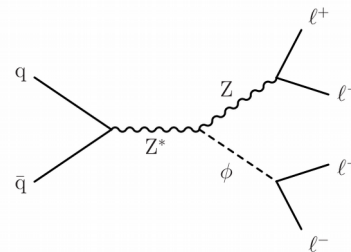
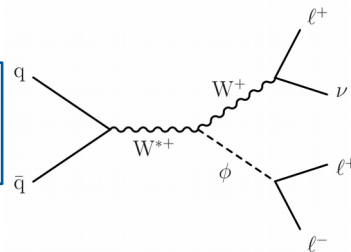
- Signal topology:
 - oppositely charged electron-muon pair.
 - possible additional jets (no bjets).
- Events are split into production modes, then into categories using the output of BDTs.
- Signal is extracted from the background using a parametric fit to the $m_{e\mu}$ distribution.



- SM Higgs boson: no excess of data above the background prediction has been observed. (More information in Federica Riti's talk.)
- Additional Higgs bosons: a peak local (global) combined significance of 3.8 (2.8) standard deviations is observed at $m_X \approx 146$ GeV.



First direct search for $(Z \setminus W \setminus t\bar{t})\phi$ that considers decays into all lepton flavors.

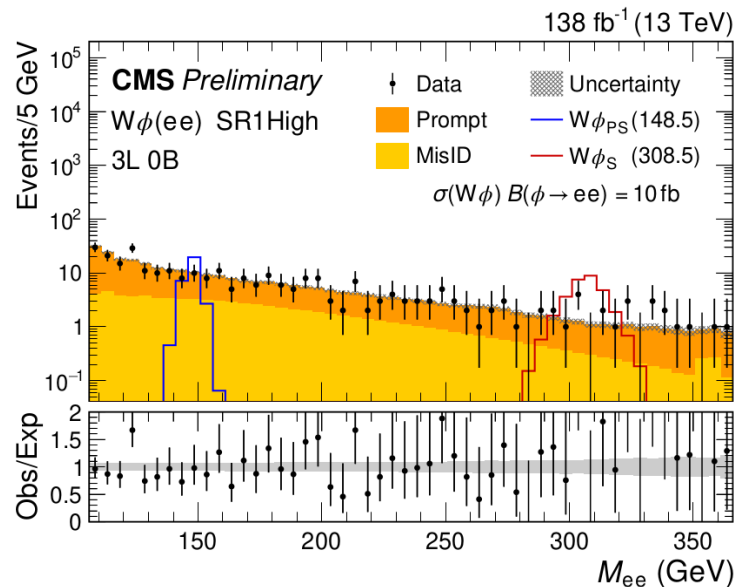
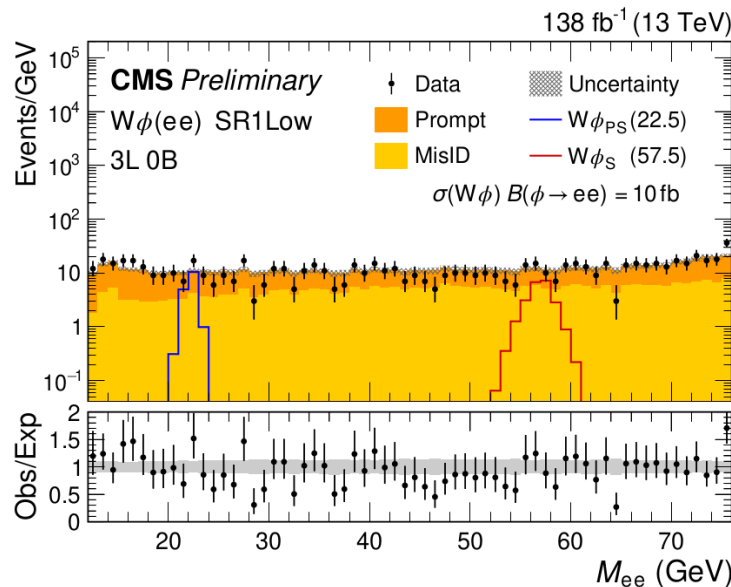


- 24 $X\phi$ signal scenarios for production mode, coupling, and decay are probed separately.

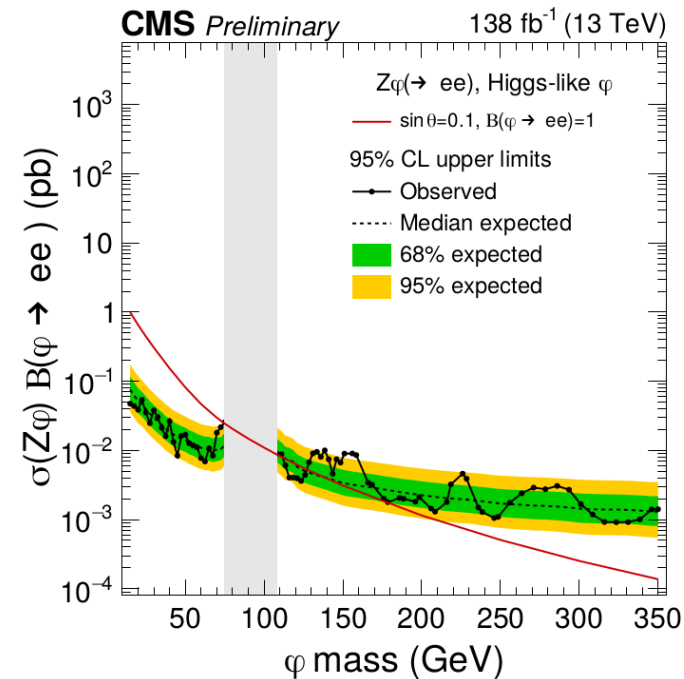
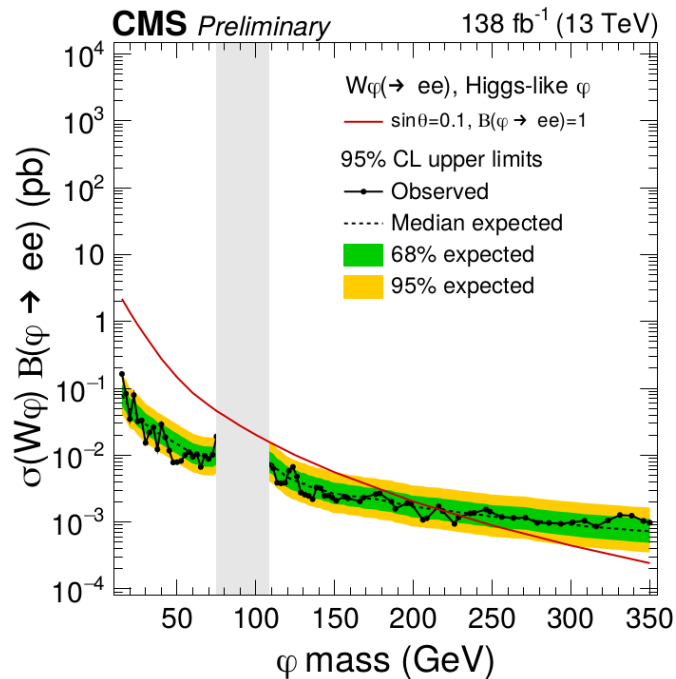
- Couplings:
 - Scalar (S)
 - Pseudoscalar (PS)
 - Higgs-like (H)

- SRs definition results in 37 observed dilepton mass spectra.

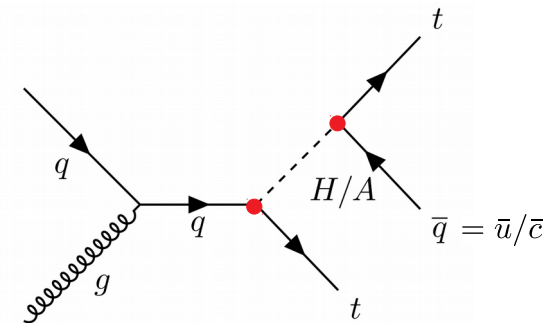
- Main Backgrounds:
 - Prompt $\rightarrow ZZ$ and WZ .
 - MisID $\rightarrow DY$ and $t\bar{t}$.



- It was observed no statistically significant deviation from the SM expectations in any of the probed mass distributions.
- The largest deviation is observed in the $Z\phi(\rightarrow ee)$ mass spectrum at 156 GeV, with an local (global) significance corresponding to 2.9 (1.4) standard deviations.



Possible explanations for the electroweak baryogenesis and muon anomalous magnetic moment in the g2HDM model with new Yukawa couplings.

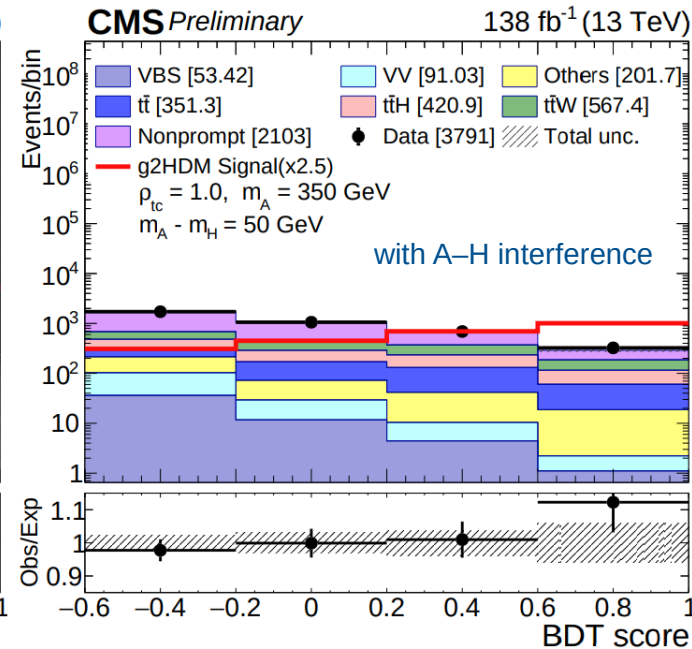
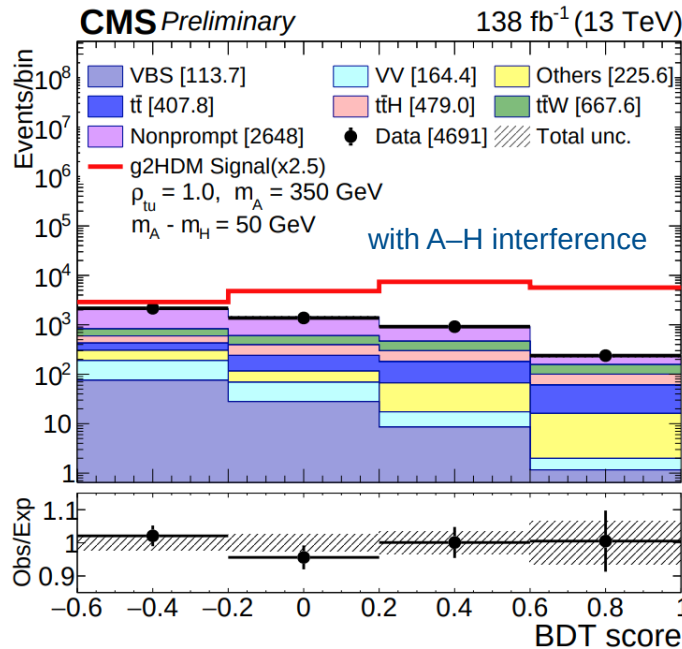


- Search for the existence of two new couplings: ρ_{tu} and ρ_{tc} .

- Signal topology:
 - two same-sign leptons
 - at least 3 jets: 2 b jets, and 1 u or c jet
 - missing transverse momentum

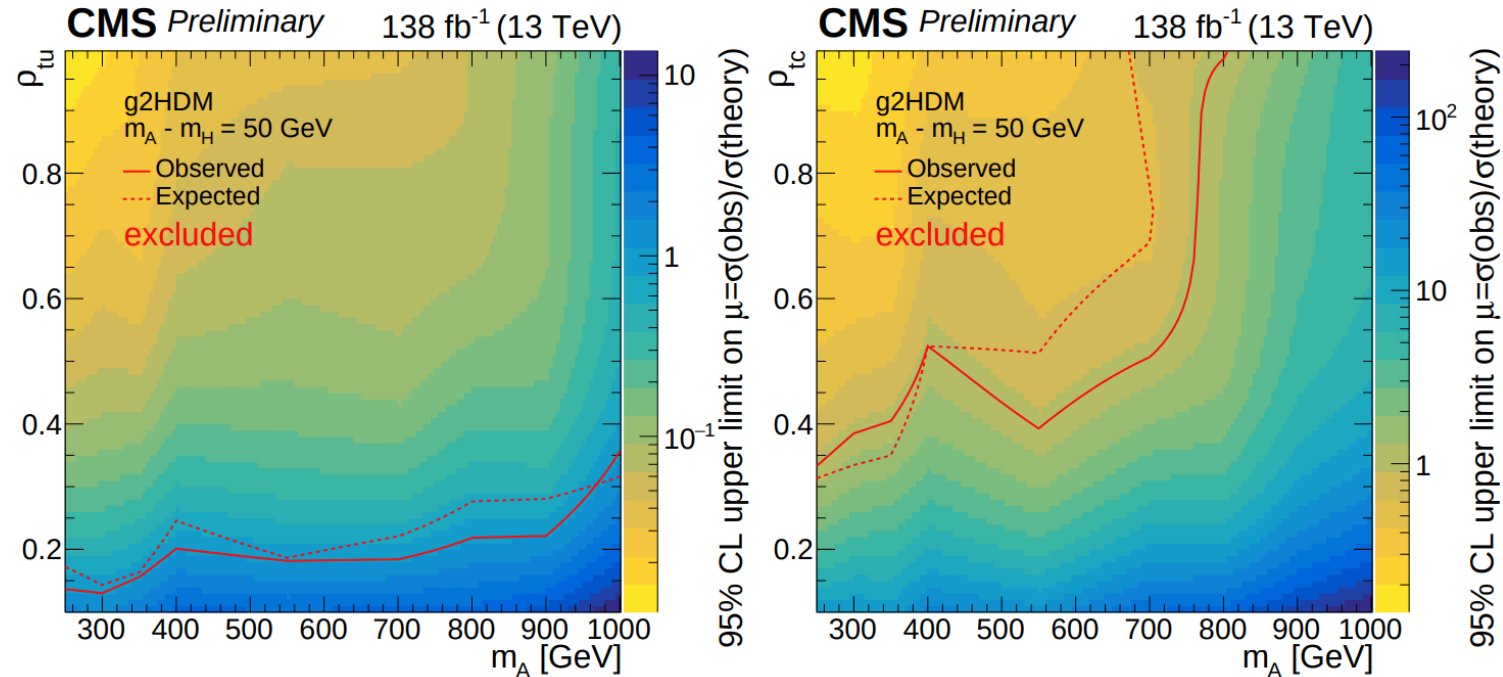
- The search is performed in three same-sign dilepton categories: $e \pm e \pm$, $\mu \pm \mu \pm$, and $e \pm \mu \pm$.

- A BDT discriminant is used to separate signal and background events.

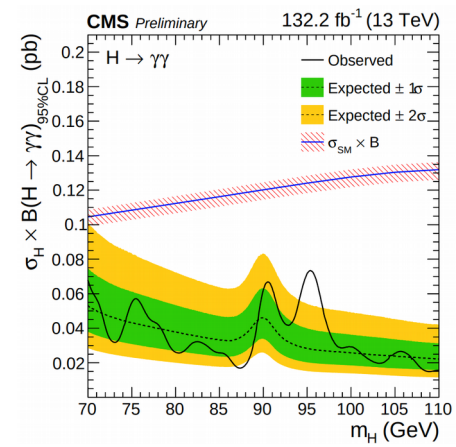
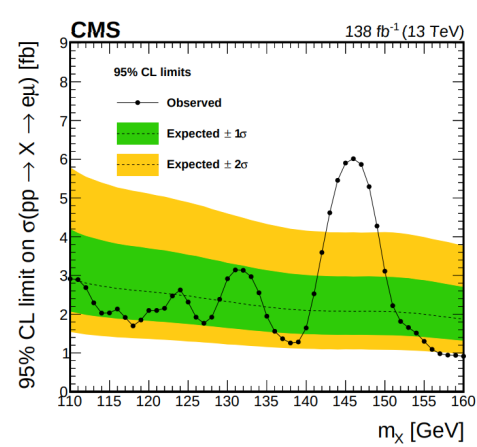
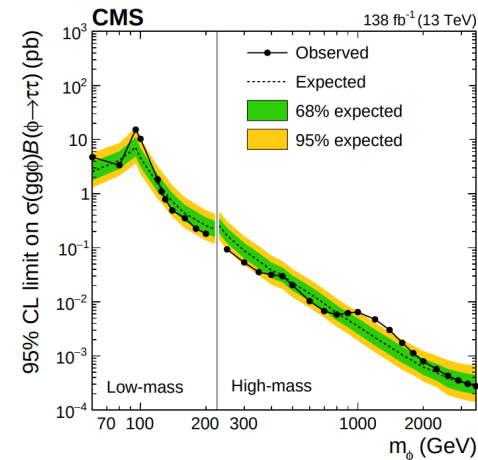


- No significant excess over the expected SM background is observed.

Observed 95% CL upper limit on the signal strength with A - H interference for the combination of all decay channels.



- It was presented new searches for additional Neutral Higgs bosons with Run 2 dataset, in a wide mass range.
- So far good agreement of measurements with predictions from Standard Model (SM) assumptions.
- Some excesses were observed but more data will be needed to clarify their nature.
- Searches for additional Higgs bosons above and below 125 GeV expected in Run 3.



THANKS FOR YOUR ATTENTION!