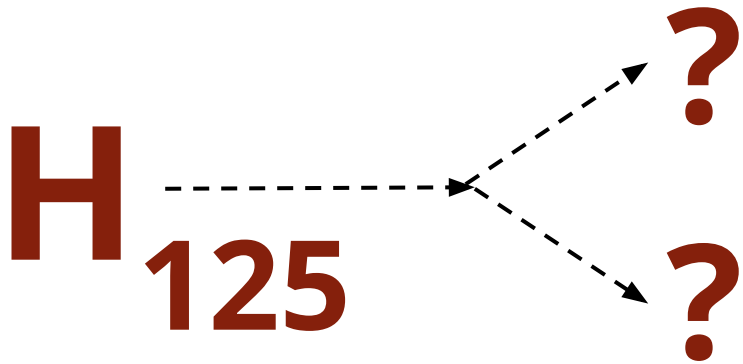
BSM and rare H_{125} decays at CMS



Maxime Gouzevitch on behalf of the CMS collaboration

13/09/2022

Introduction

1) Motivation for the searches
2) LFV decays
3) Decay to light pseudo-scalars: $H_{125} \rightarrow AA \rightarrow 4\gamma$
4) $H_{125} \rightarrow Z\gamma$

Not covered: $H_{125} \rightarrow ZJ/\psi$, $H_{125} \rightarrow$ long lived

1) Theoretical motivation for $H_{125} \longrightarrow$ BSM decays

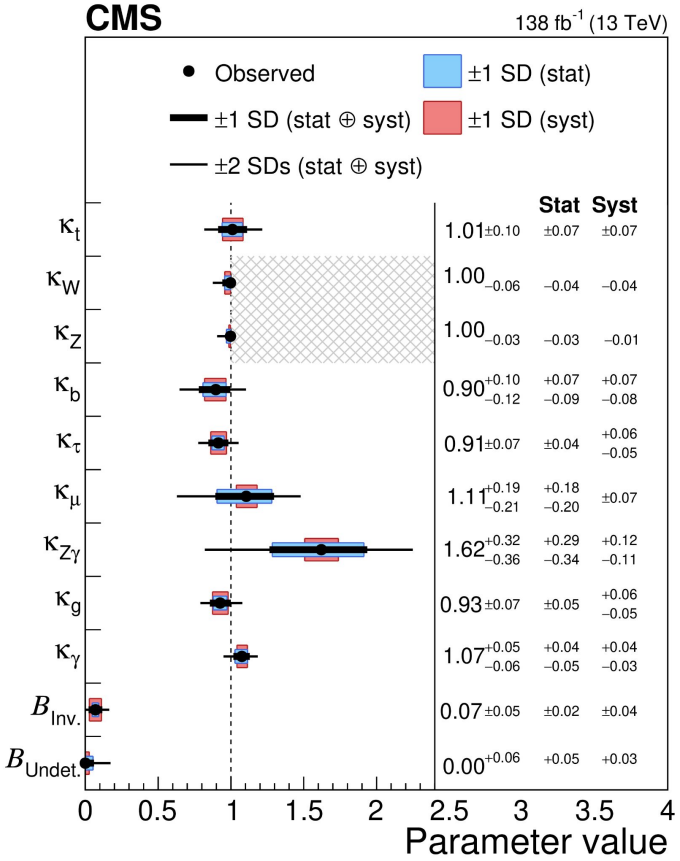
- Most of the extensions of the Higgs sector compatible with data predicts the existence of multiple scalars mixing together. Obtaining:
  - 1 boson "SM-like" denoted H_{125}:
    - Couplings to W, Z, t, b, μ are constrained by LHC measurements.
    - Couplings to B_{BSM} → this talk
  - Additional BSM Higgs bosons → Y. Wen talk.

1) Experimental motivation for $H_{125} \rightarrow$ BSM decays

- Assuming a constraint on k_Z and k_W it is possible to constraint

  B_{BSM}, B_{Inv} <~ 6% at 68% CL

- **B_{inv}** is constrained by looking on large ME_T events. Discussed in a separate talk.
- **B_{BSM}** is this talk.



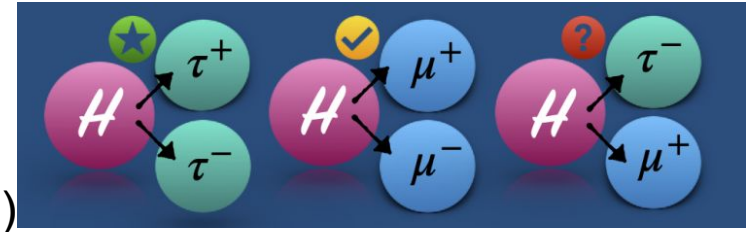
Nature 607 (2022) 60-68

2) LFV decays: basics

- There is no fundamental symmetry that would enforce LF conservation. For quarks there is a violation.
- General Framework: $$\mathcal{L}_Y = -m_i \bar{f}_L^i f_R^i - Y_{ij}(\bar{f}_L^i f_R^j)h + h.c. + \cdots$$
- SM lepton sector: $$Y_{ij} = (m_i/v)\delta_{ij}$$
- BSM: it is possible to have $$Y_{ij} \neq (m_i/v)\delta_{ij}$$

  For example in linear EFT with D6 operator $$Y_{ij} = \frac{m_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2}\hat{\lambda}_{ij}$$
- Most stringent experimental constraint $\sqrt{|Y_{\mu e}|^2 + |Y_{e\mu}|^2} < 3.6 \times 10^{-6}$ from $\mu \to e\gamma$ (see JHEP03(2013)026 for more details).
- $Y_{\mu\tau}$ and $Y_{e\tau}$ much less constrained.

2) Search for $H_{125} \rightarrow \tau\mu$ / τe



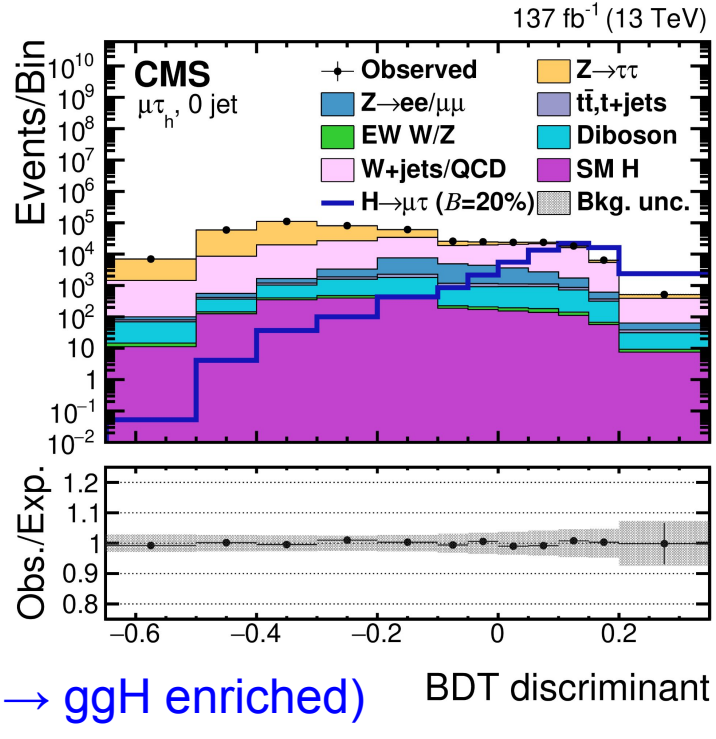
- $H_{125} \rightarrow e\tau/\mu\tau$ similar to $H \rightarrow \tau\tau$ search ($H \rightarrow \tau_e\tau/\tau_\mu\tau$)
- Same production processes: ggH and VBF H.
- Second decaying leptonically or hadronically τ_h

Differences:

- In average e/μ more prompt than τ_e/τ_μ
- Less MET and MET aligned with τ
- Assume Higgs boson mass to be 125.

- Main backgrounds:
  $Z \rightarrow \tau\tau$, t t, W + jets, $H_{125} \rightarrow \tau\tau$

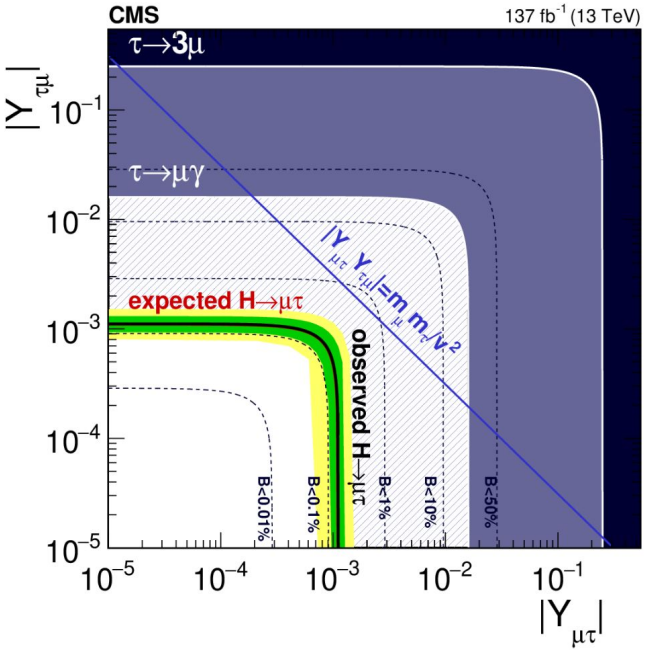
- Using BDT to separate S from B.
  Example: very sensitive channel

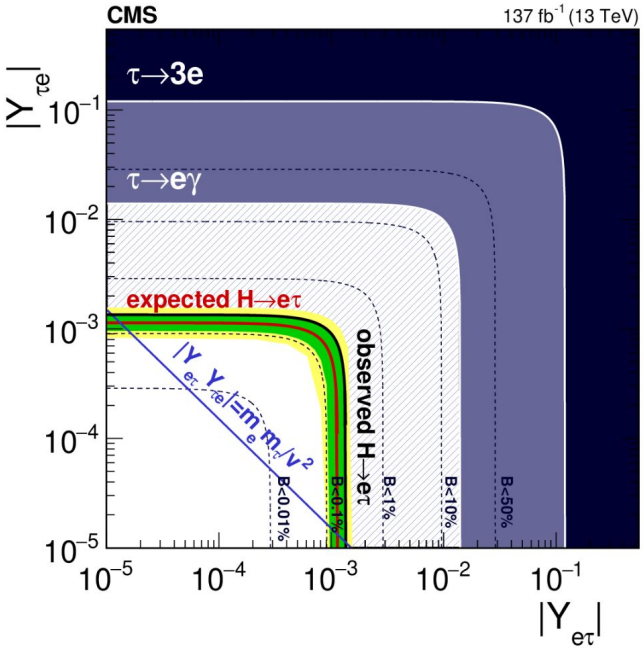


$\mu\tau_h$ (0 jets → ggH enriched)

PhysRevD.104.032013

2) LFV decays

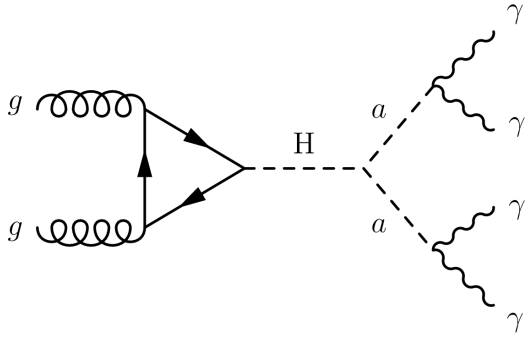




$$\mathcal{B}(H \to e\tau) < 0.22\%$$
$$\mathcal{B}(H \to \mu\tau) < 0.15\%$$

- Yukawa coupling constrained below typically 10^{-3}.
- This constraint is more stringent than indirect ones with τ→3μ/μγ.

3) H→AA → 4 γ



- A can be typically an axion-like particle (ALP) or a light pseudo-scalar boson.

- Interesting connections to cosmology: connected to universe formation, dark matter etc… Searched for in cosmic rays.

$0.1 < M_A < 1.2$ GeV

- Typically ALP, with forbidden decay to heavy fermions A → ff
- A boosted and γγ is part of the same super-cluster (ΔR ~ Moliere radius).

CMS-PAS-HIG-21-016

$1.2 < M_A < 15$ GeV

NO 4γ ANALYSIS but 2τ2μ can be used

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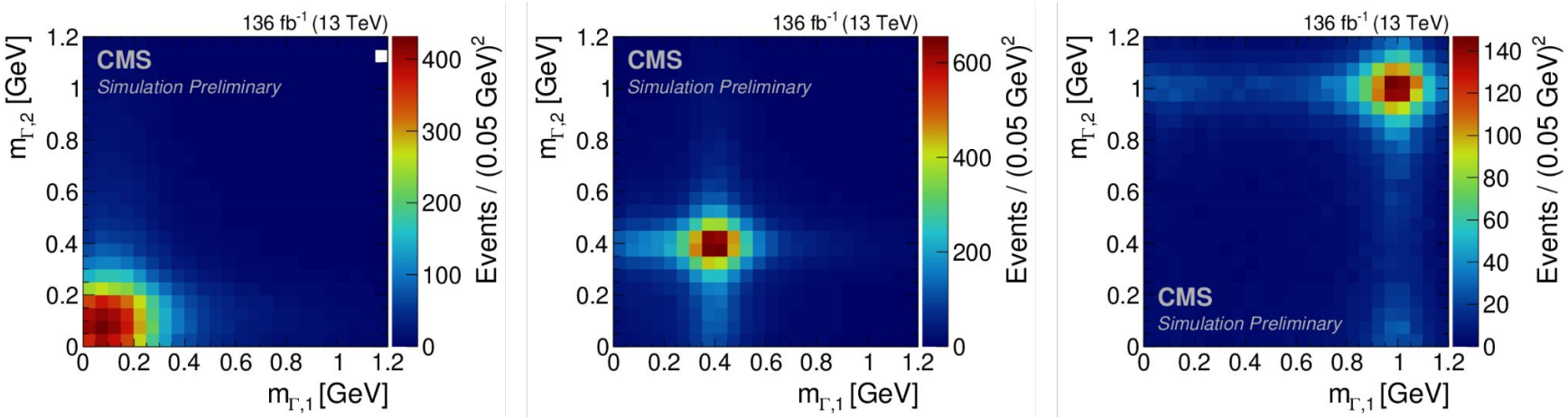
$15 < M_A < 60$ GeV

- Typically light fermiophobic boson
- 4 well resolved photons.

arXiv:2208.01469. Sub. to JHEP.

3) H→AA → 4 γ: boosted

CMS-PAS-HIG-21-016

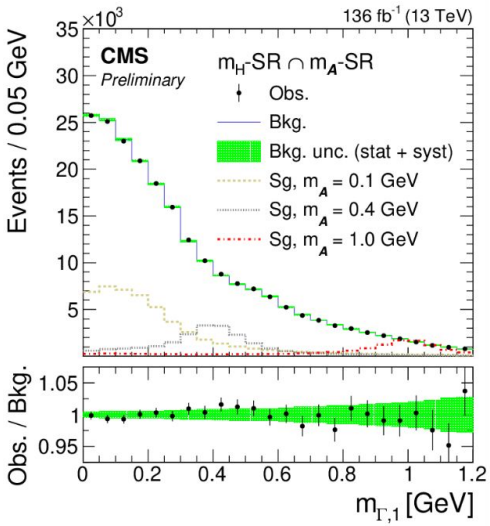


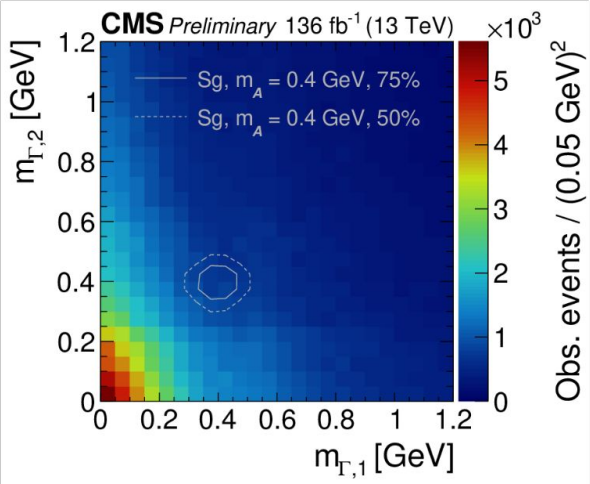
Γ ≡ A candidate

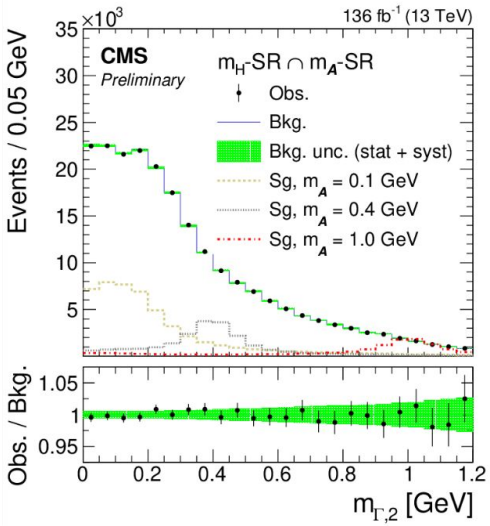
- Analysis and selections similar to H → γγ search. Except:
  → $M_{\gamma\gamma}$ constraint is used.
  → Only barrel photons used to reduce tracker material effects.
  → Cluster shape constraints are relaxed, isolation constraints increased to compensate.
  → Using DNN technique to reconstruct and measure the mass of merged photon system in CMS ECAL arXiv:2204.12313. Acc. by PRD..

3) H→AA → 4 γ: boosted

CMS-PAS-HIG-21-016





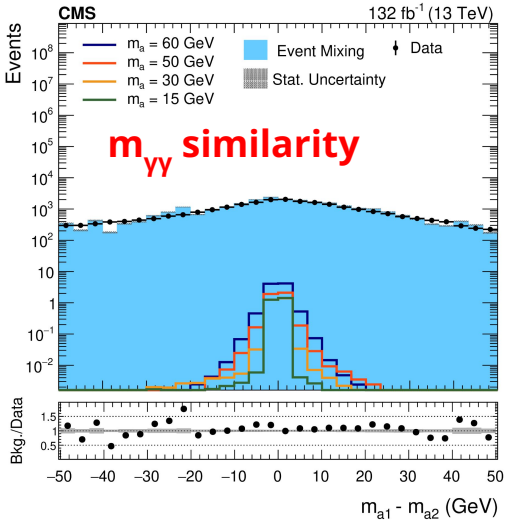


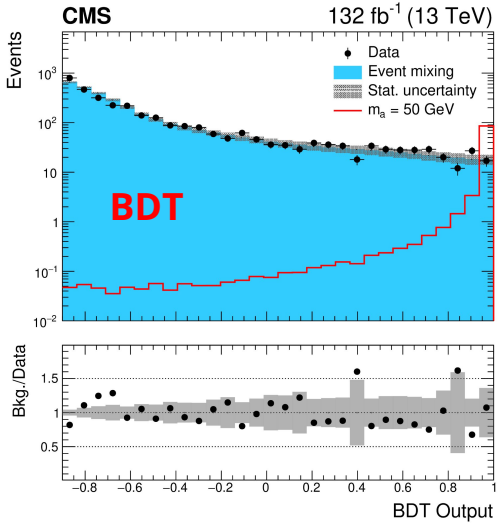
- Background: QCD production with prompt and "fake" photons from $\pi^0 \rightarrow \gamma\gamma$ decay.
- Using MC simulation for $H \rightarrow \gamma\gamma$ and data driven templates from $M_{\Gamma 1}$-$M_{\Gamma 2}$ side band for non-resonant background.
- No excess observed over background.

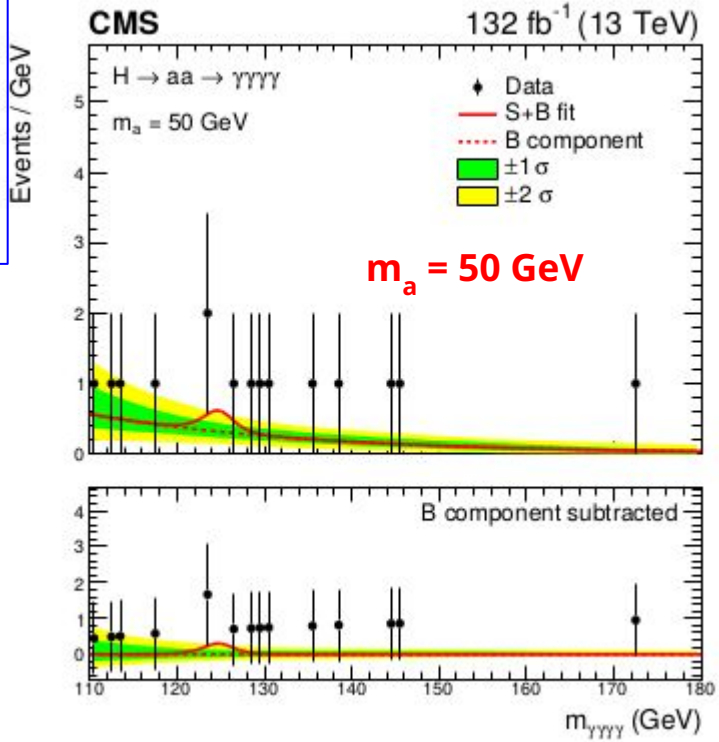
3) H→AA → 4 γ: resolved

arXiv:2208.01469. Sub. to JHEP.

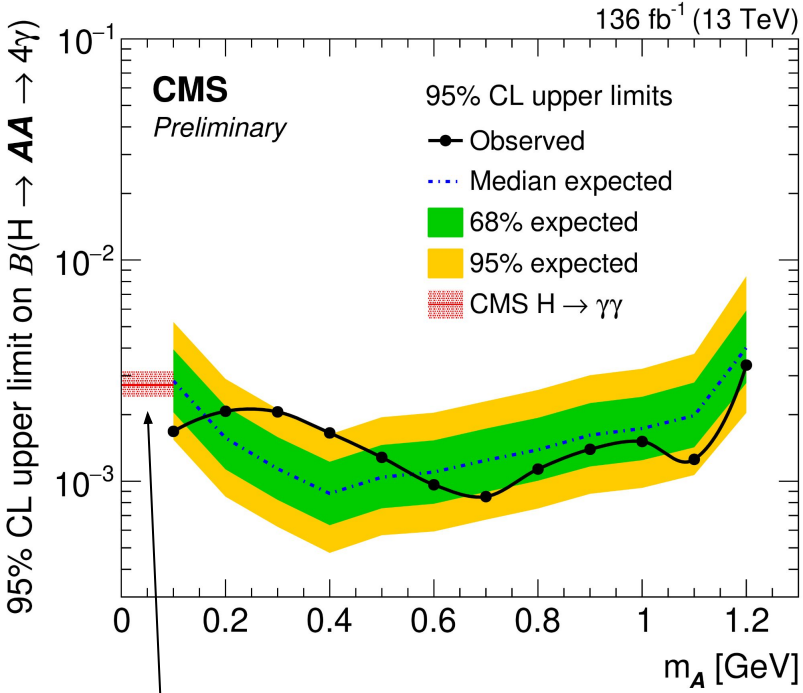
- Looking for excess over SM background in $m_{4\gamma}$ ~ 125 GeV using Bump Hunting technique.
- BDT built using photons id and kinematics. Looking for similarity of two paired $m_{2\gamma}$ mass.

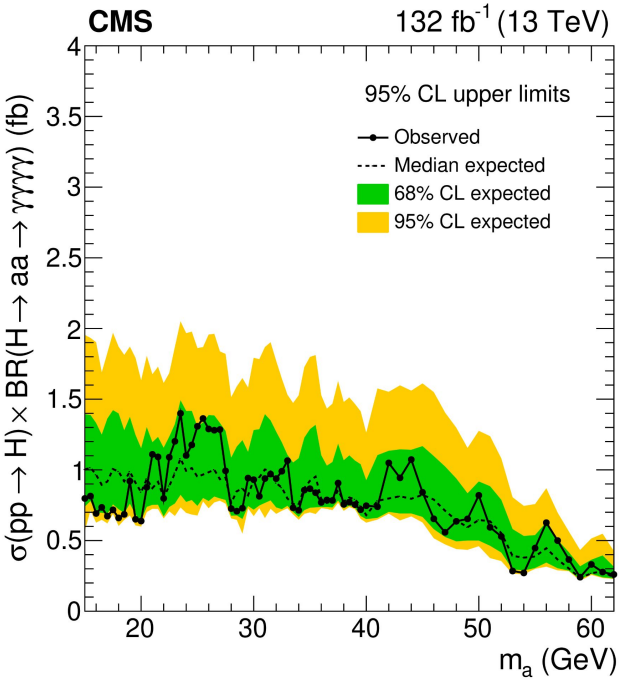






3) H→AA → 4 γ: constraints



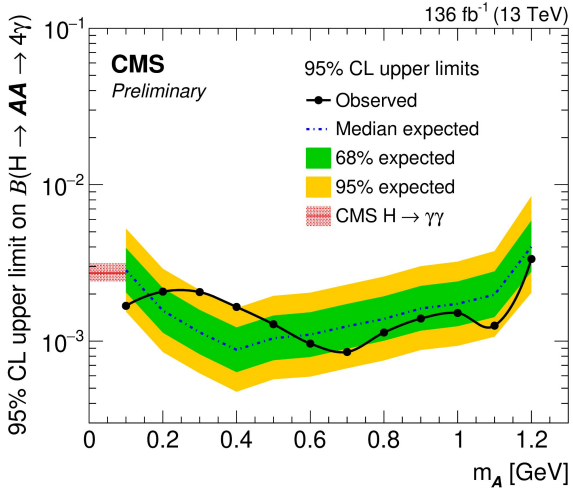


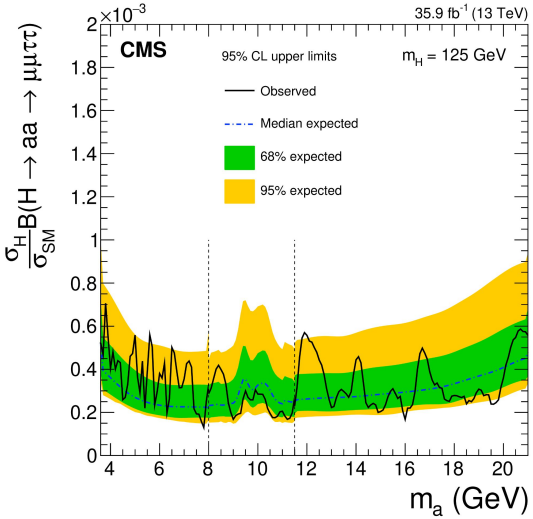
Degenerate with H → γγ signal

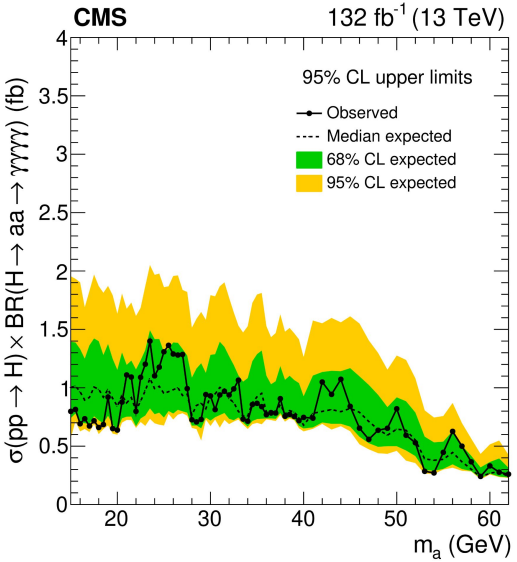
Stringent constraints comparable or much better to H →γγ

BR(H→aa) < 0.02%
(assuming σ_H = 48.6 pb)

3) H→AA → 4 γ: constraints







BR(H→aa) < 0.3%
(assuming σ_H = 48.6 pb)

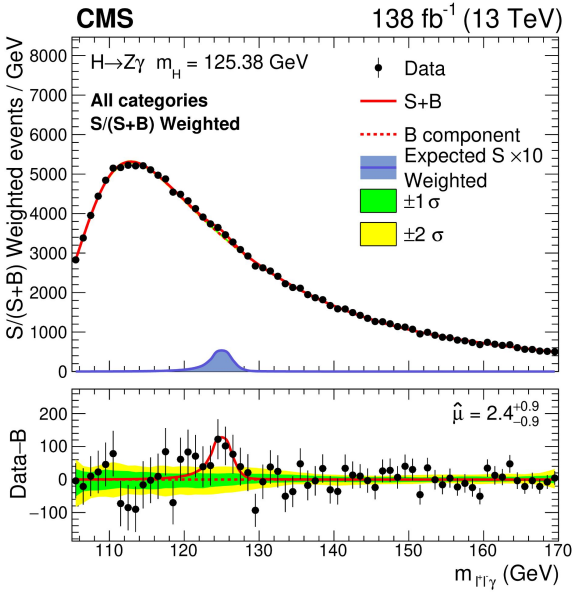
BR(H→ aa) < 0.05 %
covering the gap in $M_{4\gamma}$.

BR(H→aa) < 0.02%
(assuming σ_H = 48.6 pb)

4) Rare decay: $H_{125} \rightarrow Z\gamma$

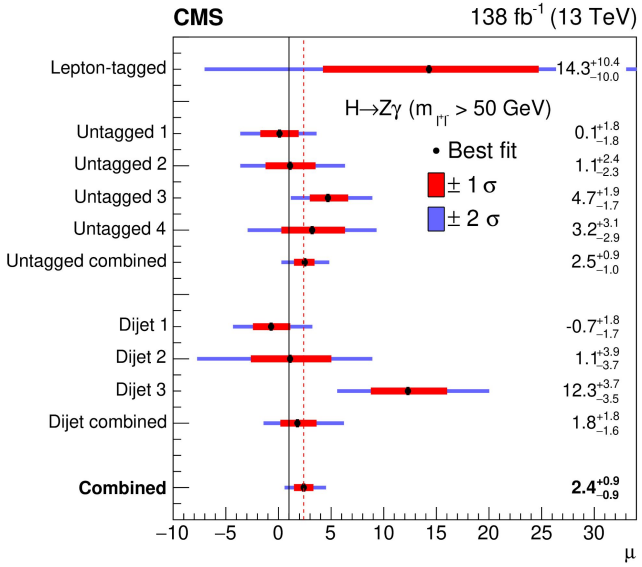
arXiv:2204.12945. Sub. to JHEP

- $Z \rightarrow ll$ final state considered
- Search performed like $H \rightarrow \gamma\gamma$ in $M_{ll\gamma}$ spectrum.
- A particular care to reconstruct well $Z \rightarrow ll$ mass using KinFit and FSR recovery.
- Events are selected using BDT classifier to fight $Z/\gamma^*+\gamma$ / Z/γ^*+jet / tt backgrounds.



Local significance of 2.7 σ observed

Above SM prediction but compatible at 1.5 σ.



Summary and Conclusion

- BSM decays of the H125 is an active domain of search for BSM physics in the EW sector.
- H_{125} LFV sector is particularly relevant to explore B physics anomalies. A constraint below 0.2% is set at 95 CL. This is more stringent than global constraint of B_{BSM} (< 6% at 68 CL).
- $H_{125} \rightarrow AA \rightarrow 4\gamma$ search is relevant for many models predicting ALP and BSM scalars. Constraints at 0.01% level down to 200 MeV!
- Hints for $H_{125} \rightarrow Z\gamma$ rare decay appeared on the horizon.

Danielle Monico, 2021

4) H→AA → 2μ 2τ: semi-boosted

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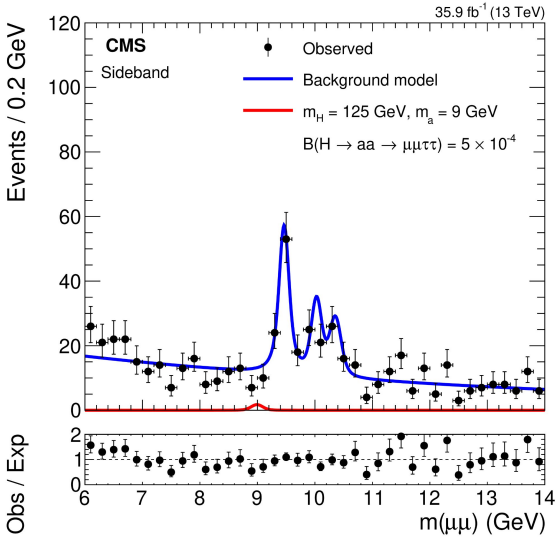
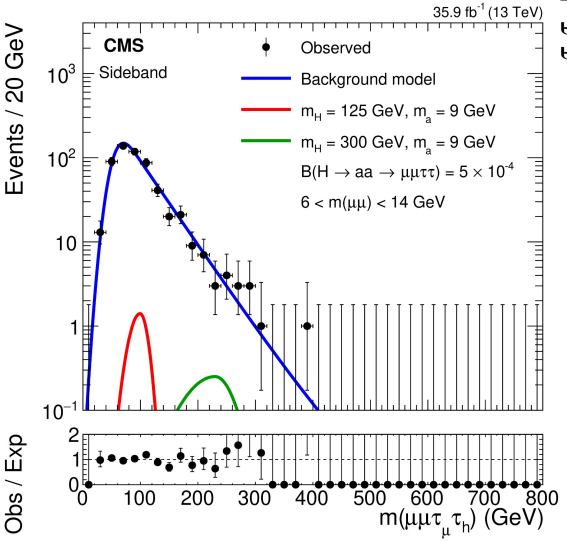
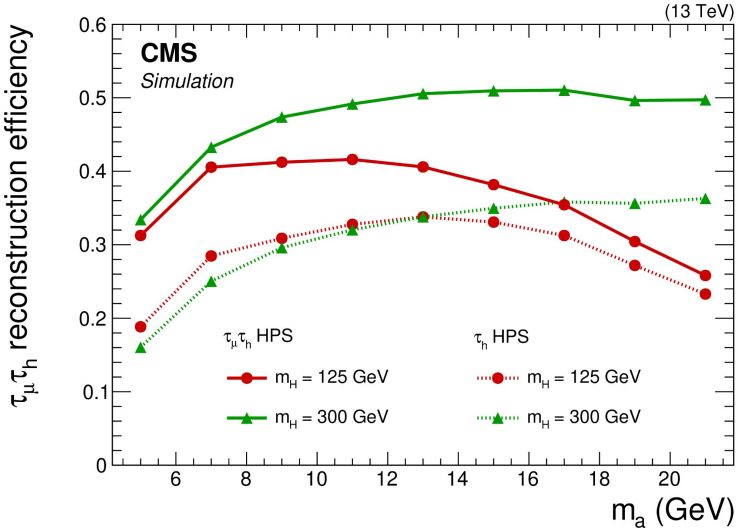
- Analysis channel: H → $\mu\mu\tau_\mu\tau_h$.
- A dedicated reconstructing algorithm allows to identify the boosted $\tau_\mu\tau_h$ final state.
- 2 D fit model using templates from side band:







4) H→AA → 2μ 2τ: resolved

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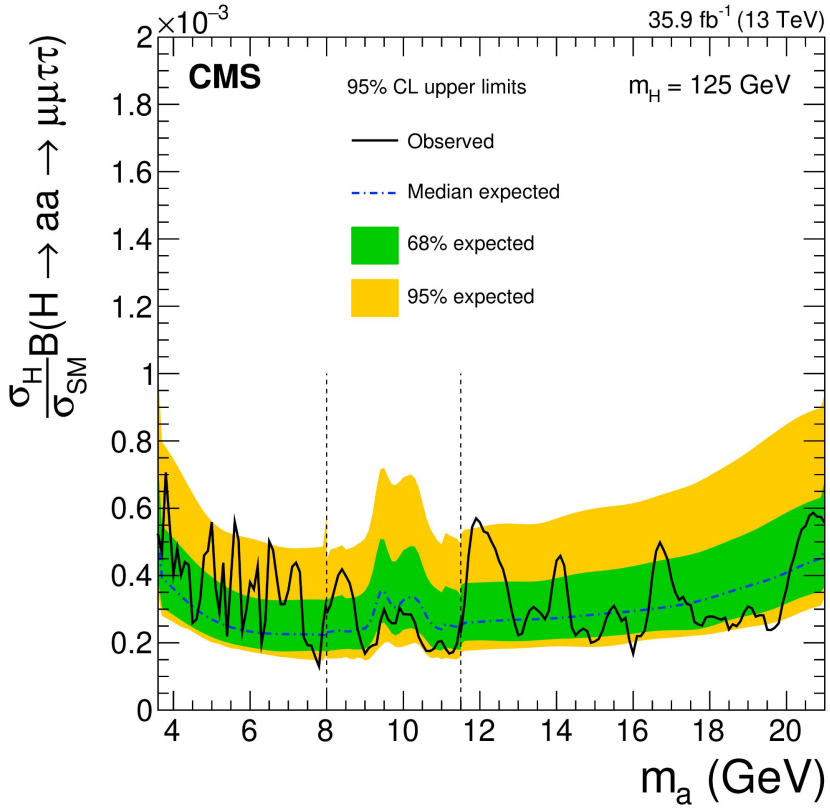

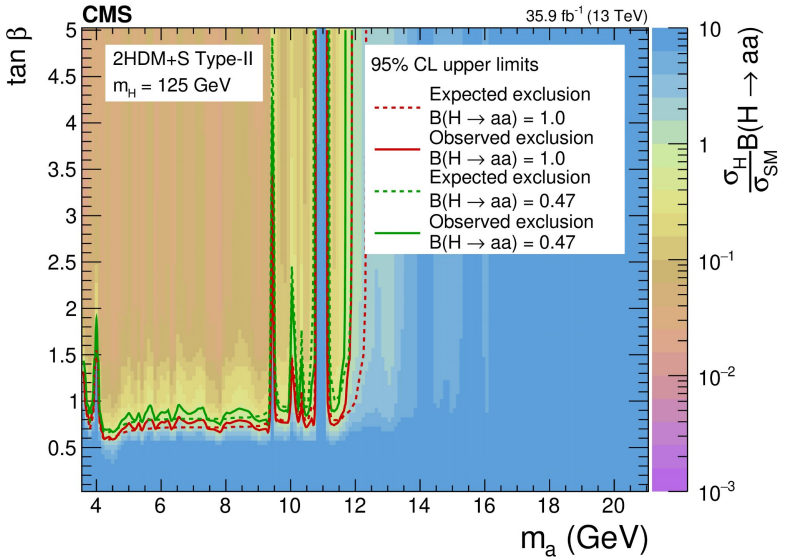

- BR(H→ aa) < 0.2-0.3 % covering the gap in $M_{4\gamma}$. Even if matching is model dependant.
- Example of reinterpretation in 2HDM.