



# 39<sup>th</sup> International Conference on High Energy Physics (ICHEP 2018)

4–11 July 2018, Seoul (Korea)



## Searches for Light Higgs Bosons at CMS

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(for the CMS collaboration)

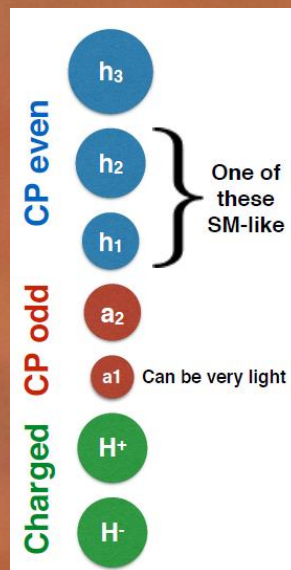


# Outline – LHC Run 2 Results

Light Higgs Searches @

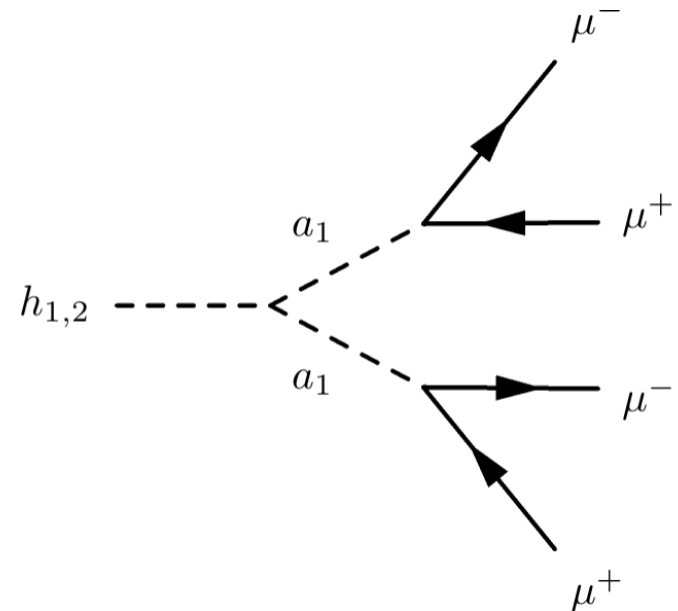


- $H(125) \rightarrow aa \rightarrow 4\mu$
- $H(125) \rightarrow aa \rightarrow 2\mu 2\tau$
- $H(125) \rightarrow aa \rightarrow 2b 2\tau$
- Light Scalar  $\rightarrow \gamma\gamma$

Next-to-MSSM  
(NMSSM)



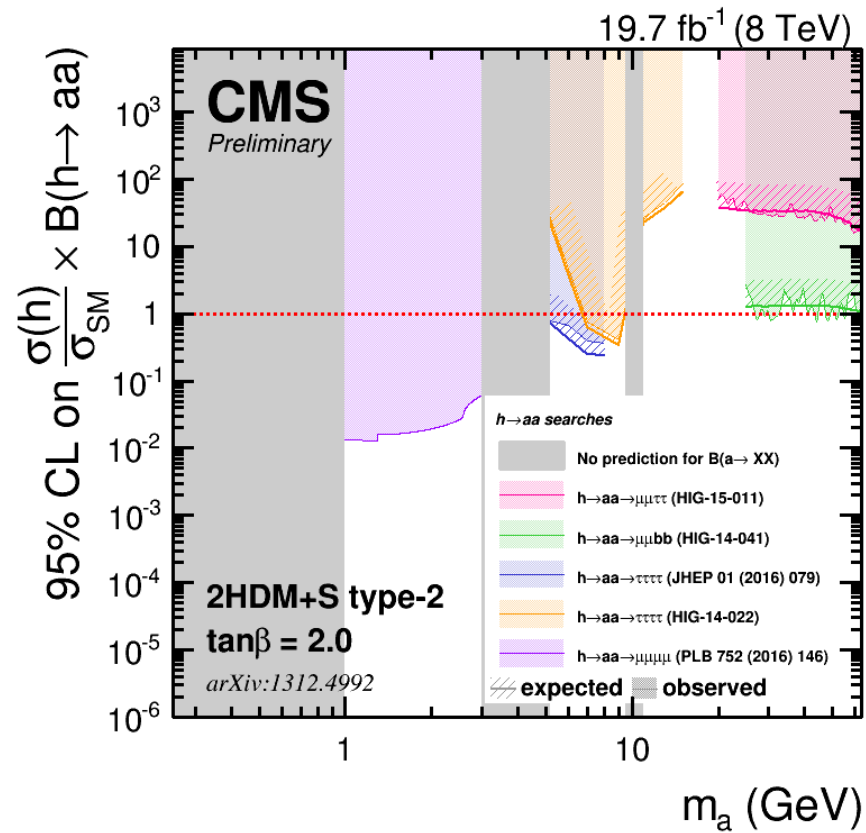
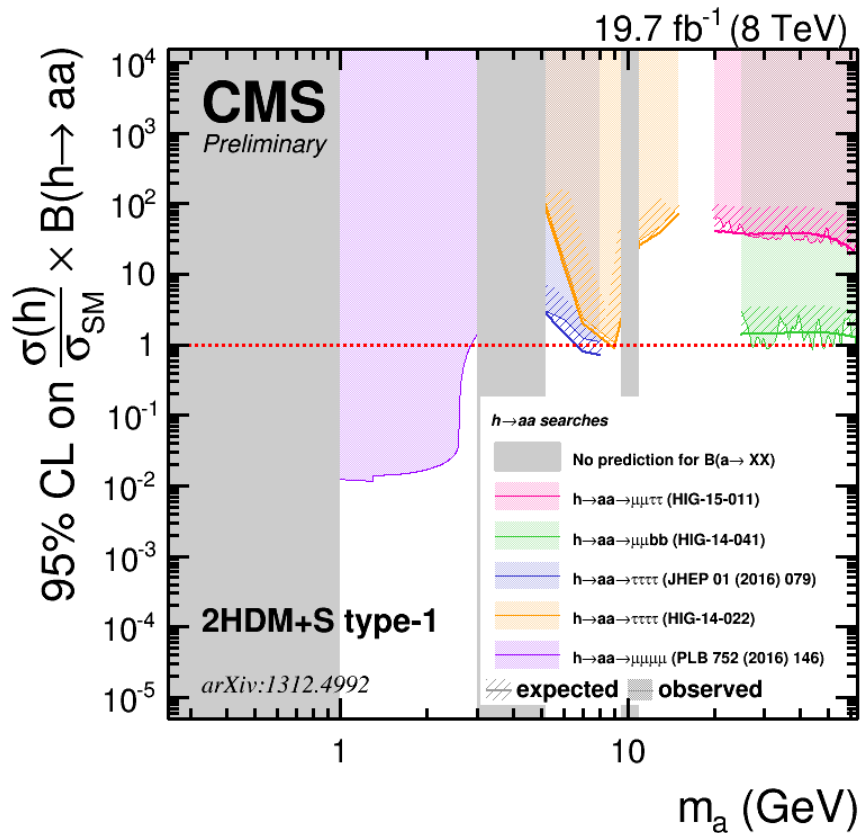
- General Two Higgs Doublet Model (**2HDM**)
  - 2 Higgs Doublets  $\longrightarrow$  5 Higgs bosons:  $h, H, A, H^\pm$
- Next-to-Minimal Supersymmetric Standard Model (**NMSSM**)
  - 2 Higgs Doublets + 1 singlet  $\longrightarrow$  7 Higgs bosons:  $h_1, h_2, h_3, a_1, a_2, H^\pm$
- The **Higgs boson at 125 GeV** can be identified as the **next-to-lightest scalar**, allowing to envisage a possible **lighter particle**



BR of “a” boson to SM particles depends on

- **mass of the “a” boson**
- **models (types of the 2HDM)**
- **model parameters ( $\tan\beta$ )**

<https://twiki.cern.ch/twiki/bin/viewauth/CMSPublic/SummaryResultsHIG>



✓ Searches performed in several final states

✓ No excess was found and results are interpreted in several 2HDM + S scenarios

$$H(125) \rightarrow aa \rightarrow 4\mu$$

**CMS PAS-HIG-16-035**

SM background dominated by:

### **bb production**

in which both b-quarks decay to a pair of muons via double semi-leptonic decay or resonances

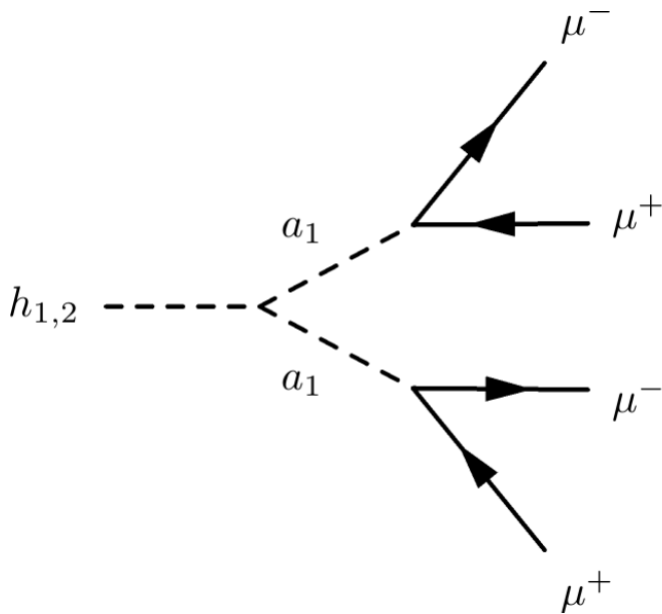
small contributions from:

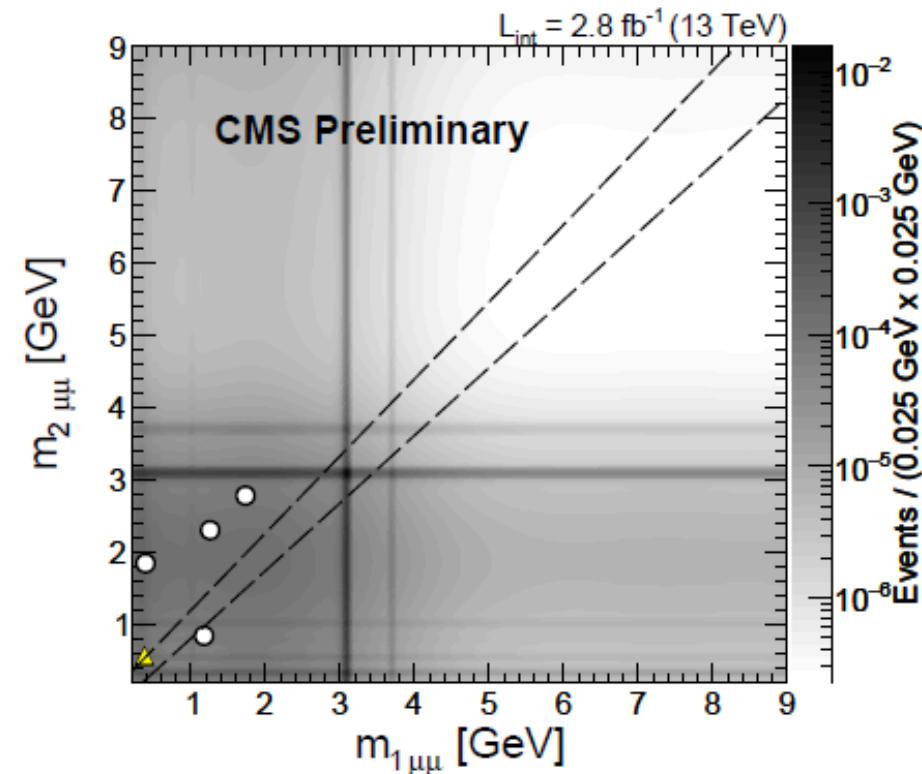
### **electroweak production of four muons**

such as  $qq \rightarrow ZZ \rightarrow 4\mu$  and  $qq \rightarrow Z \rightarrow 2\mu$ , the latter where a second Z is radiated and decays to a muon pair

### **direct $J/\psi$ pairs**

Irreducible background, two production mechanisms SPS and DPS. Estimated with a combination of data (control region) and MC simulation.





2D background template include all SM processes

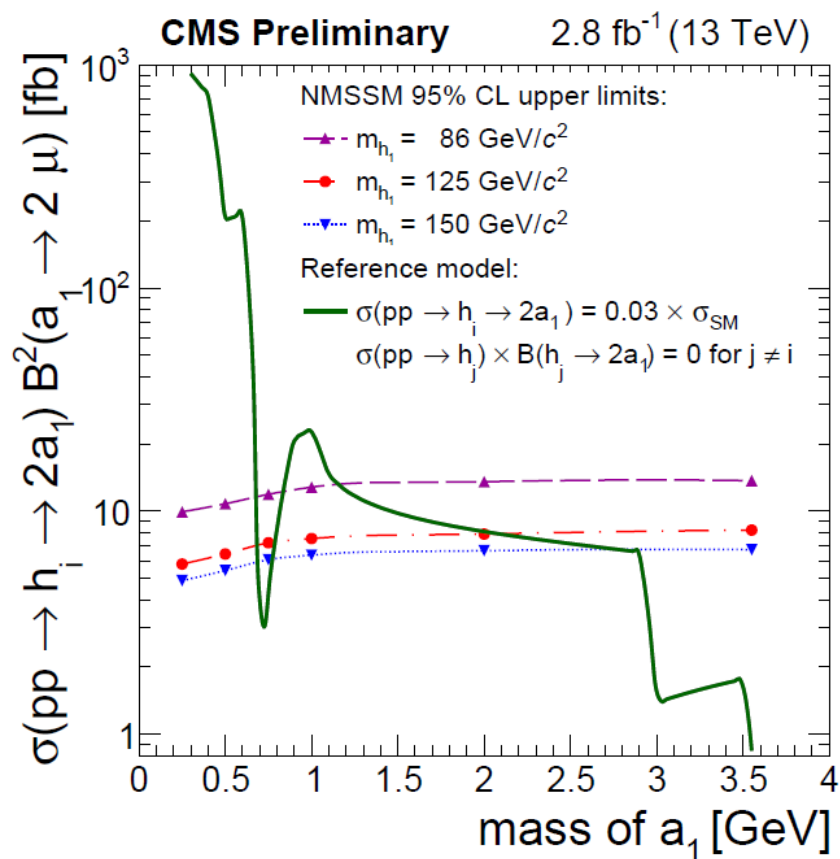
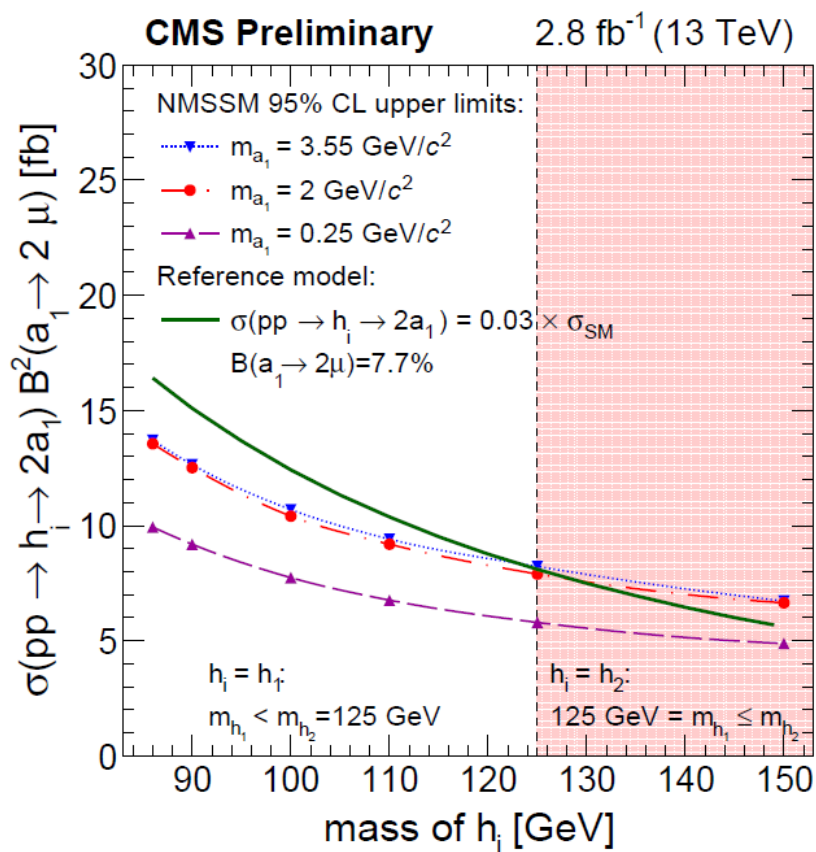
Points represent the data surviving all selection except the invariant mass cut

Triangle: observed event on the border of signal region, i.e. about  $5\sigma$  away from the exact diagonal

- 1 event is observed in signal region, with  $0.74 \pm 0.34$  stat.  $\pm 0.15$  syst. events expected from SM backgrounds
- Upper limit at 95% CL on cross section times branching fraction times acceptance obtained for light boson masses in range  $2m_\mu < m_a < 2m_\tau$   
Result compared in the **NMSSM** scenario



**CMS PAS-HIG-16-035**



$$H(125) \rightarrow aa \rightarrow 2\mu 2\tau$$

- 4 final states scenarios studied:

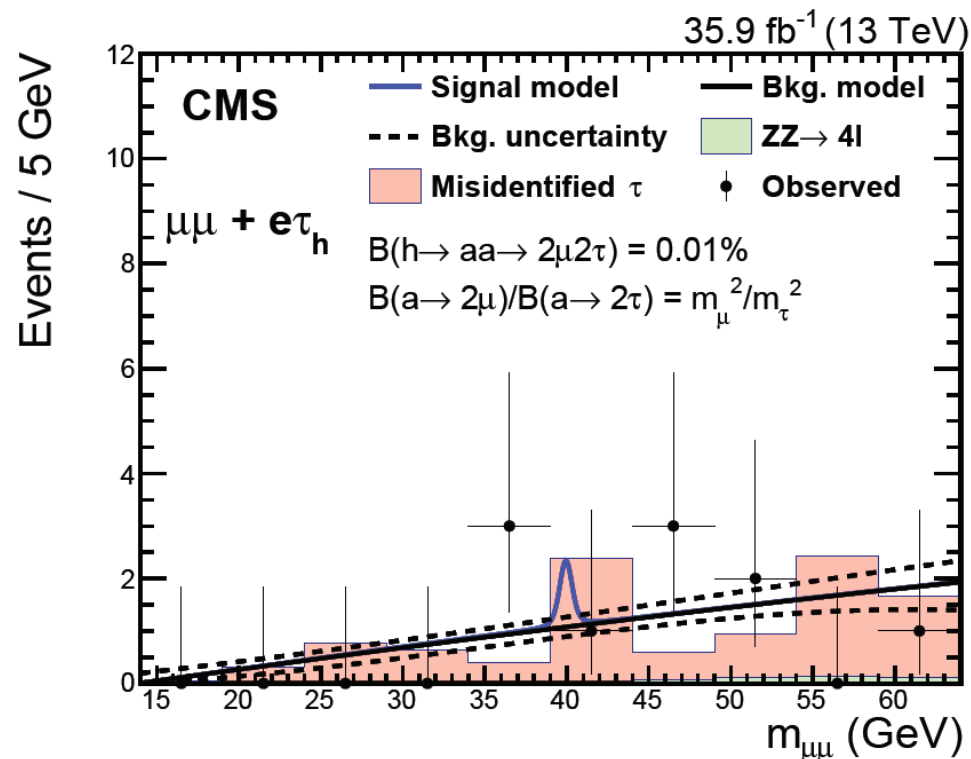
$\mu\mu \times (e\mu, e\tau_h, \mu\tau_h, \tau_h\tau_h)$

- target on **non-boosted  $\tau$  pairs**, and requires 4 well reconstructed and isolated leptons

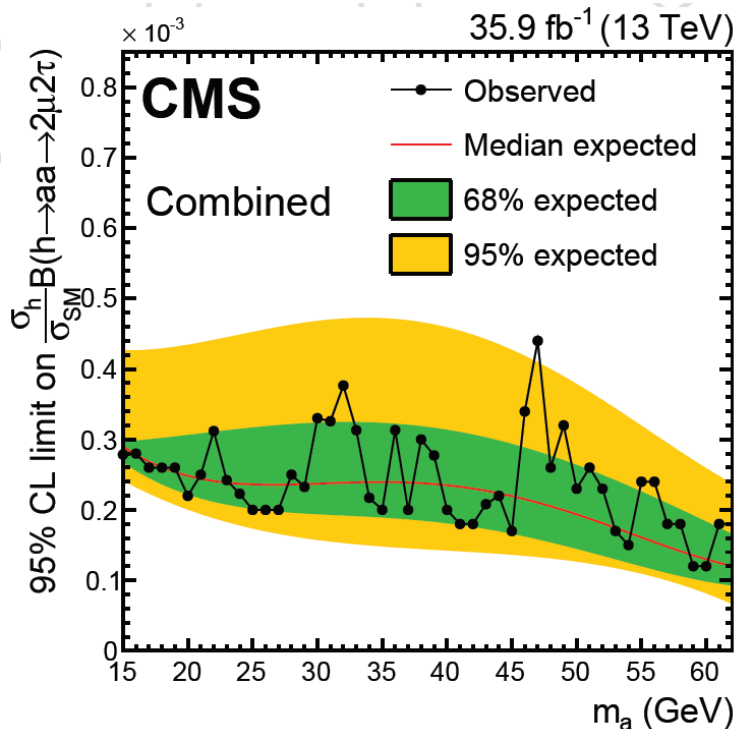
- main backgrounds (fake leptons or taus) estimated from data mostly **Z+jets** and **WZ+jets** events

- **shape** obtained from data in signal and ZZ background free control region with  $\tau_h$  candidates of same sign (SS),  $\tau_h$  isolation relaxed
- **yield** is estimated from data events that have one or two non-isolated  $\tau_h$

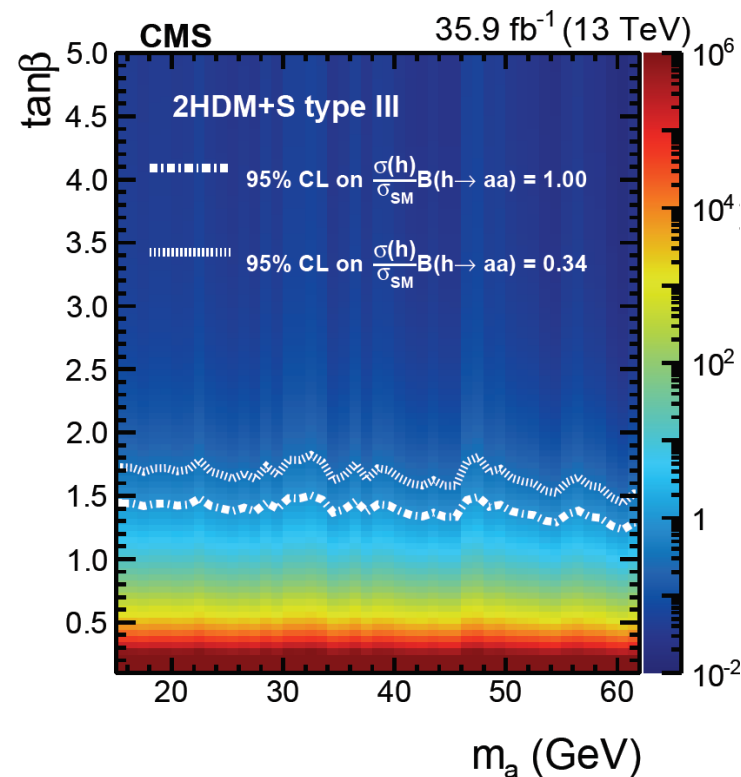
- final observable is **dimuon mass distribution**



**CMS-PAS-HIG-17-029**  
(accepted by JHEP)



most stringent limits are obtained in 2HDM+S type III at large  $\tan\beta$ , where couplings to leptons are enhanced



Maximum-likelihood fit to the **dimuon invariant mass** distribution is performed

No significant excess observed above expected backgrounds in  $m_{\mu\mu}$  range from **15** to **62.5 GeV**

Upper limits on  $BR(H \rightarrow aa \rightarrow 2\mu 2\tau)$  relative to SM Higgs production as low as  **$1.2 \times 10^{-4}$**  for  **$m_a = 60$  GeV**

$$H(125) \rightarrow aa \rightarrow 2b2\tau$$

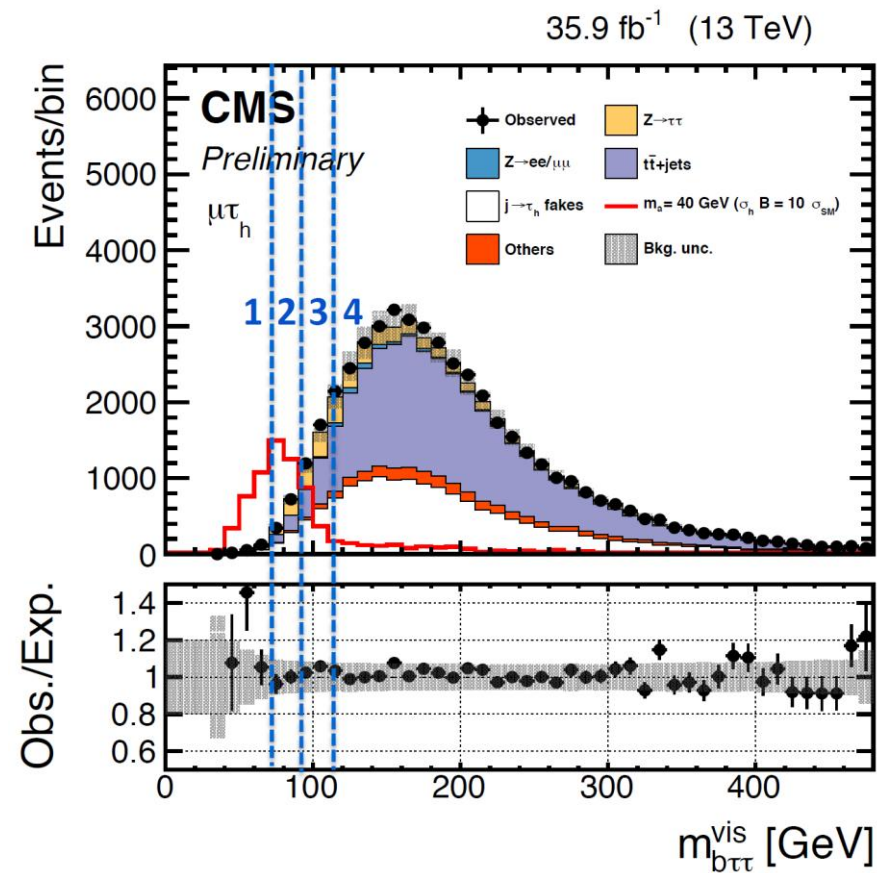


## CMS-PAS-HIG-17-024

3 tau pair final states investigated:  $e\tau_h$ ,  $\mu\tau_h$ ,  $e\mu$

- ❑  $T_h T_h$  discarded because of high trigger thresholds,  $ee$  and  $\mu\mu$  discarded because of low BR and large backgrounds
- ❑ At least **1 b-tagged jet** ( $p_T > 20$  GeV) in addition to the leptons:
- ❑ Most signal events only have one b-tagged jet because the generated b-jets are too soft

- Visible invariant mass of tau pair and b-jet less than 125 GeV as neutrinos in  $\tau$  decays and soft b-jets not reconstructed
- **4 categories based on  $m_{b\tau\tau}$**



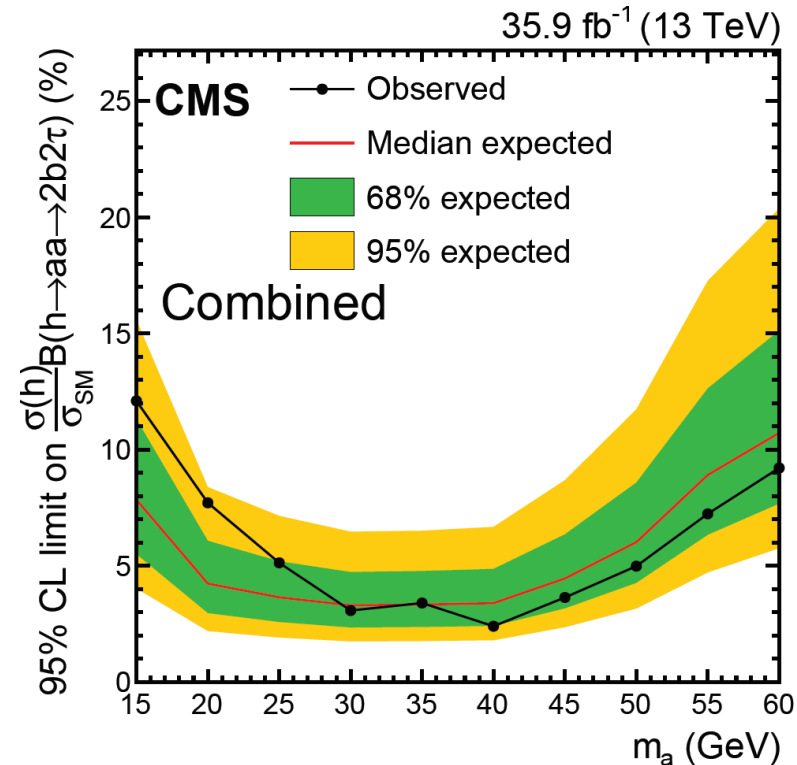
Low  $m_{b\tau\tau}$  categories with smaller background  
 Highest  $m_{b\tau\tau}$  category maximum background used  
 as control region

Thresholds on kinematic cuts depend on the final  
 state and category

Lowest  $m_{b\tau\tau}$  category is the most sensitive with  
 smallest background contribution

Results extracted by fits to di-tau visible mass  
 distributions (to peak below  $m_a$ )

Uncertainties include  $e/\mu$ ,  $\tau_h$  and b-jet identification,  
 $\tau_h$  energy scale,  $Z \rightarrow ll$  bkg, jet  $\rightarrow \tau_h$  fakes bkg and  
 top quark pair bkg (normalisation),  $Z \rightarrow \tau\tau$  shape



**CMS-PAS-HIG-17-024**  
(submitted to PLB)

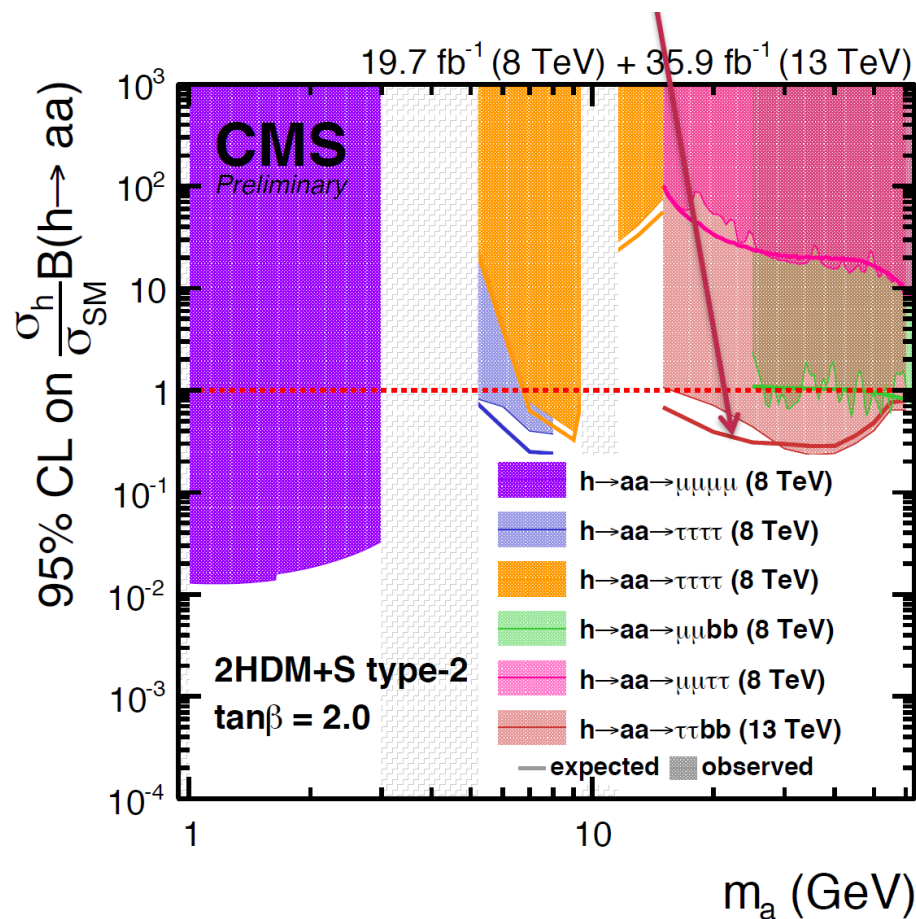
First time  $h \rightarrow aa \rightarrow 2b2\tau$  decays are probed:  
Large branching fraction (heavy b and  $\tau$  mass),  
and possible to trigger in ggF production

No significant excess of events observed

In the NMSSM,  $BR(h \rightarrow aa) > 23\%$  excluded  
at 95% CL for  $m_a \sim 35$  GeV  
 $\Rightarrow$  Most sensitive results so far at the LHC

Limits improved by several factors in the  
mass region  $25 \text{ GeV} < m_a < 62.5 \text{ GeV}$ ,  
and by more than an order of magnitude in  
 $15 \text{ GeV} < m_a < 25 \text{ GeV}$

**This result**



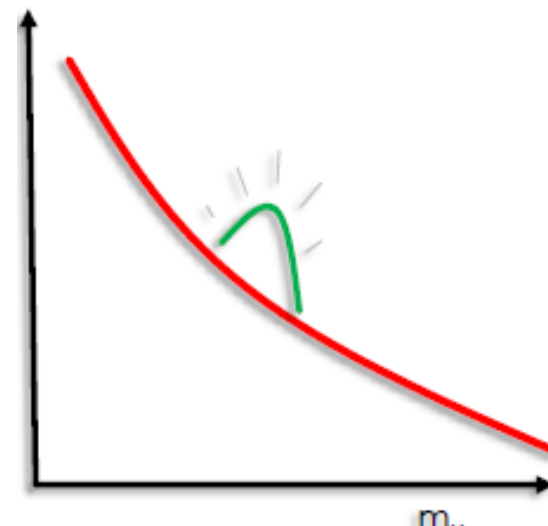
Light Scalar  $\rightarrow \gamma\gamma$

- Clean final state: **2 isolated photons**
- Large smoothly-decreasing background (continuum)
  - 1) Reducible (jet-jet and  $\gamma$ +jet with jet faking photon)
  - 2) Irreducible diphoton production
- Low-mass analysis specificity: Drell-Yan background, with electrons from the Z boson misidentified as photons
- Use of a stricter electron veto based on the pixel detector
- Include relic DY contribution in background model
- Mass resolution is crucial (calibrations, energy regression and vertex identification)
- Classification of diphoton events to gain in sensitivity

$$M_{\gamma\gamma} = \sqrt{(4 E_{\gamma_1} E_{\gamma_2} \sin^2 \frac{\theta}{2})}$$

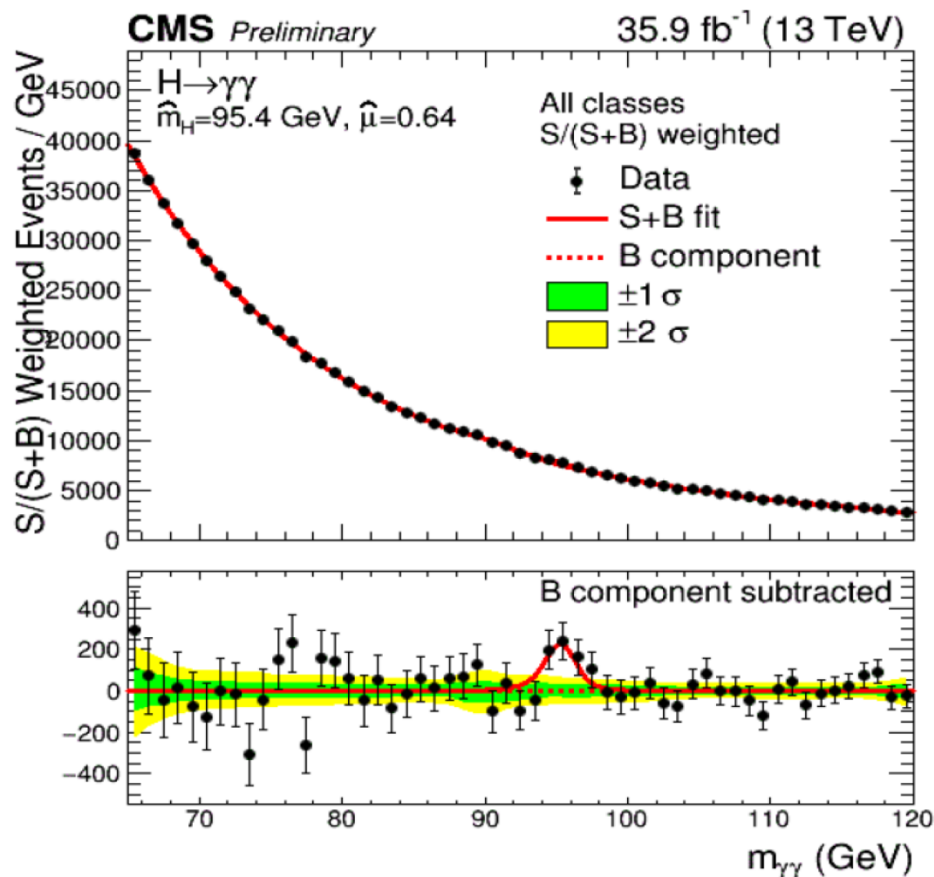
ECAL performance

Vertex Identification

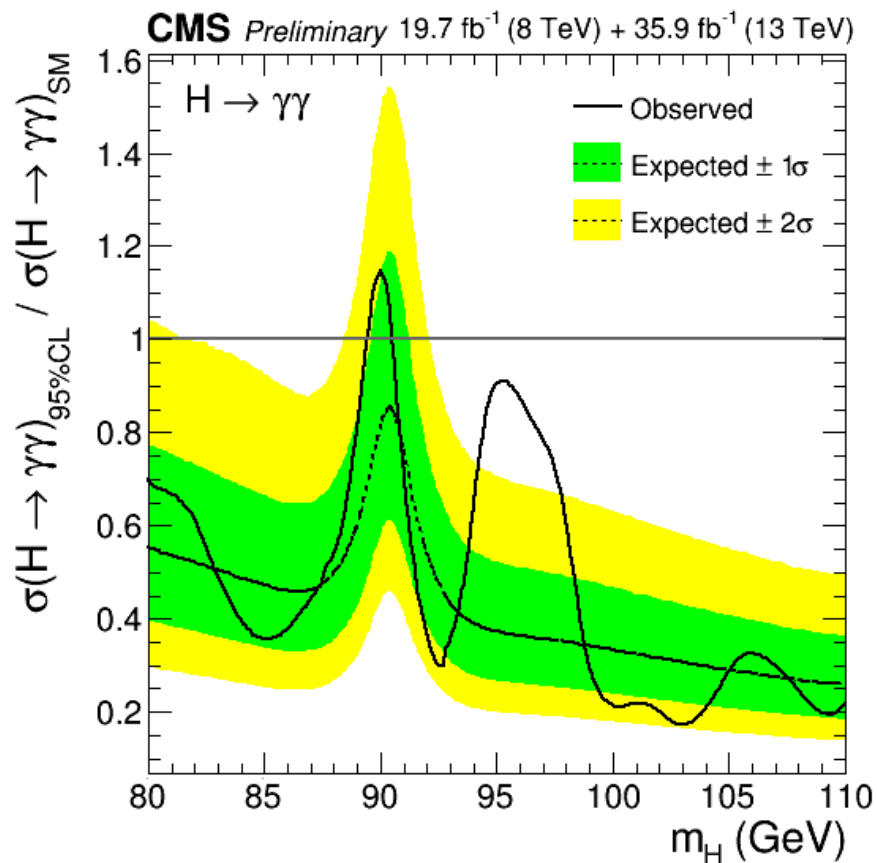




**CMS PAS HIG-17-013**



- ☐ Fits of S+B model over all event classes
- ☐ Each event weighted by the ratio  $S/(S+B)$  for its event class.
- ☐ Main systematic uncertainties:
  - Photon identification BDT distribution shape, largest unc. 14.6% (VBF, 13 TeV)
  - Per-photon energy resolution 13.7% (ggh, 8 TeV)
  - Due to QCD scale variations 7.5% (ggh, 8 TeV)
  - Trigger efficiency 5.5% (13 TeV)



- 8 TeV+13 TeV: minimum (maximum) limit on  $(\sigma \times \text{Br}) / (\sigma \times \text{Br})_{\text{SM}}$ : 0.17(1.15) at  $m=103.0$  (90.0) GeV
- Combined 8 TeV+13 TeV:  $\sigma \times \text{BR}$  limit normalized to SM expectation (production processes assumed in SM proportion)
- **There is an excess with respect to expected limits at  $m=95.3$  GeV**

**13 TeV:** Excess  $\sim 2.9 \sigma$  local ( $1.47\sigma$  global) significance at  $m=95.3$  GeV

**8TeV+13 TeV:** Excess  $\sim 2.8\sigma$  local ( **$1.3\sigma$  global**) significance

More data are required to ascertain the origin of this mild excess



✓ Observed Higgs boson at mass 125 GeV may be part of an **extended Higgs sector**

✓ Many BSM models predicting new scalar and pseudoscalar neutral Higgs bosons (2HDM, MSSM, NMSSM ...) have been explored at CMS

**No signs for BSM** in the Higgs boson sector yet...

✓ **No signs of light Higgs bosons yet;** but now exploration with **larger data sample at LHC Run-2**, other searches targeting the very low mass region is ongoing (results expected soon)

✓ Exciting times ahead of us with full LHC Run II data set