Search for $H \to a_1 a_1 \to \mu\mu bb$

Using 2016 CMS dataset

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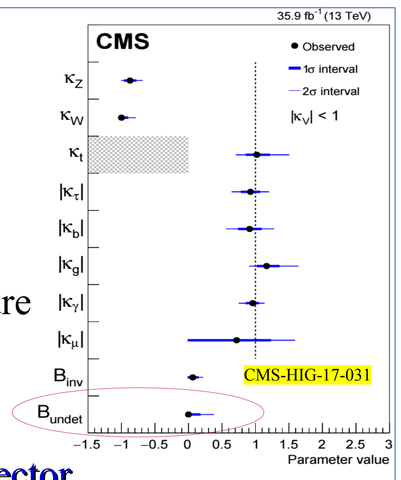
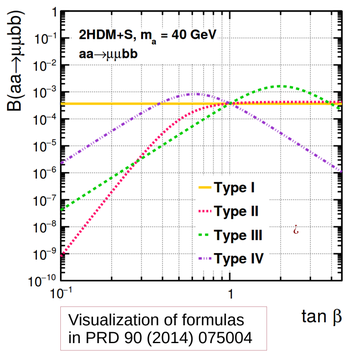
Open window for Higgs BSM Decays

- Combined CMS measurements of Higgs couplings at 13 TeV:
  $BR(h \to BSM) < 40\%$ (2σ)
- LHC Run I combination
  $BR(h \to BSM) < 34\%$
- Ultimate precision from indirect measurements in future LHC projections suggest
  $BR(h \to BSM) < O(5\% - 10\%)$



Exotic Higgs decays in models with extended Higgs sector

- Four different types of 2HDM are defined based on the coupling structure of SM fermions with the two Higgs doublets, Φ_1 and Φ_2
  - ➔FCNC is not allowed in these types
- After EWKSB, the 2HDM Higgs sector contains $H^{\pm}$, A (pseudoscalar), H^0 and h (scalar)
  - ➔h can be realized as h(125)
- The phenomenology of 2HDM can be enriched via adding a complex scalar singlet, $S_R + iS_I$
  - ➔Has no direct Yukawa coupling with SM
  - ➔Small mixing with h : the SM nature of h is preserved
  - ➔*s(a)* is a (pseudo)scalar mass eigenstate mostly composed of $S_R(S_I)$
- h boson can decay to fermions through *s(a)*



Visualization of formulas in PRD 90 (2014) 075004

The μμbb final state

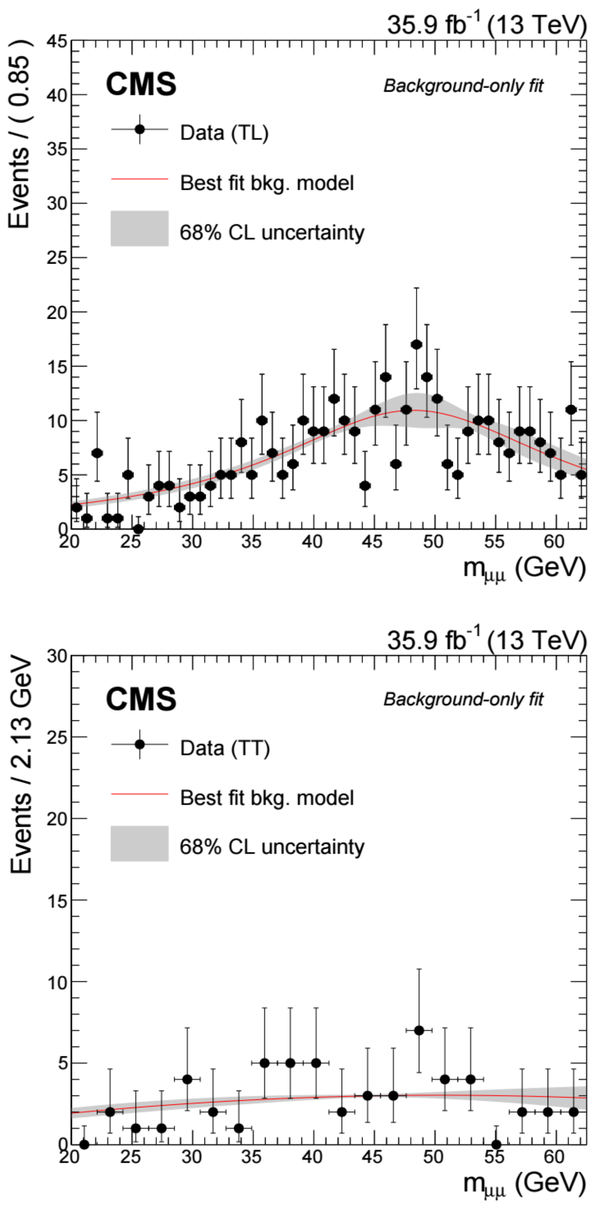
- $a \to \mu\mu$: a clear peak
- $a \to bb$: large BR in many parts of the parameter space
- Some regions accessible by a→bb only

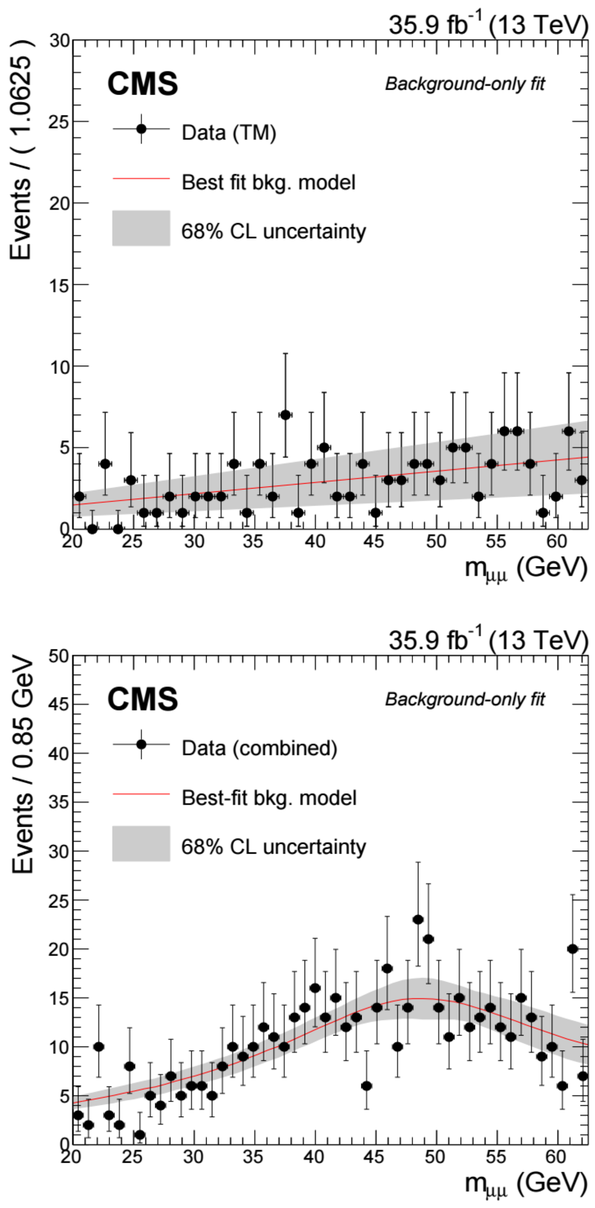
Signal shape

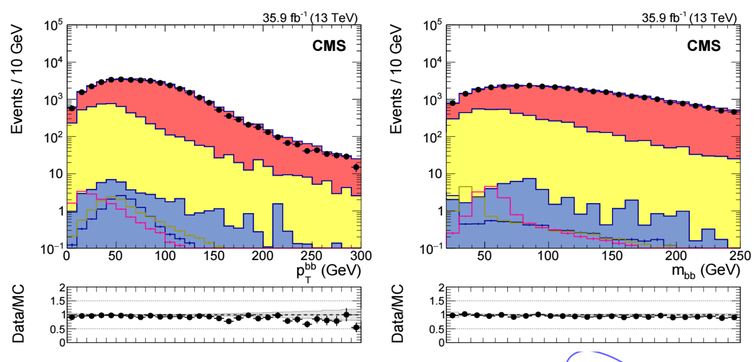
- ➔Modeled as Voigt Profile + Crystal Ball function
- ➔All parameters, except resolutions, are found independent of m_a
- ➔$\sigma_v = \sigma_{v,0} + \alpha m_{\mu\mu}$, $\sigma_{cb} = \sigma_{cb,0} + \beta m_{\mu\mu}$

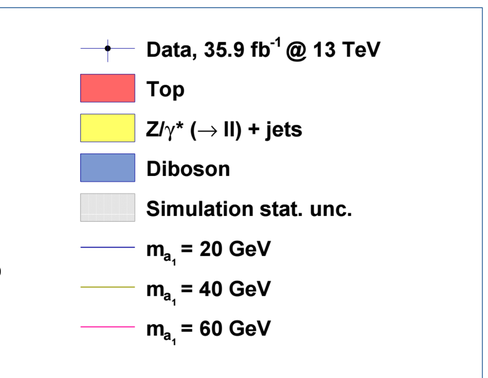
Background shape modeling

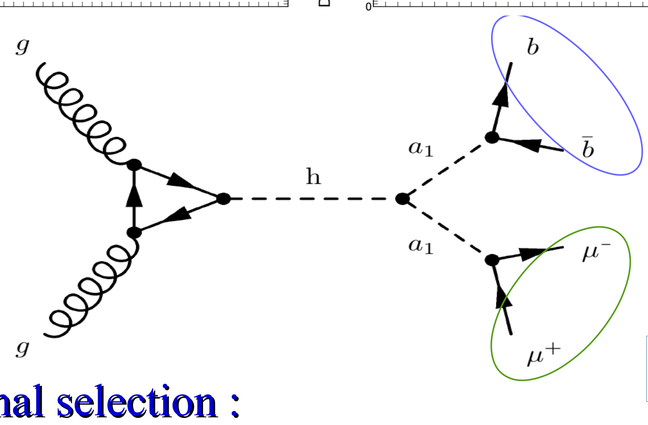
- ➔Fully data driven method
- ➔Background modeling and estimation with the envelope method
- ➔Different types of polynomials are checked on data in SR
- ➔F-test is used to determine the degree of selected polynomials







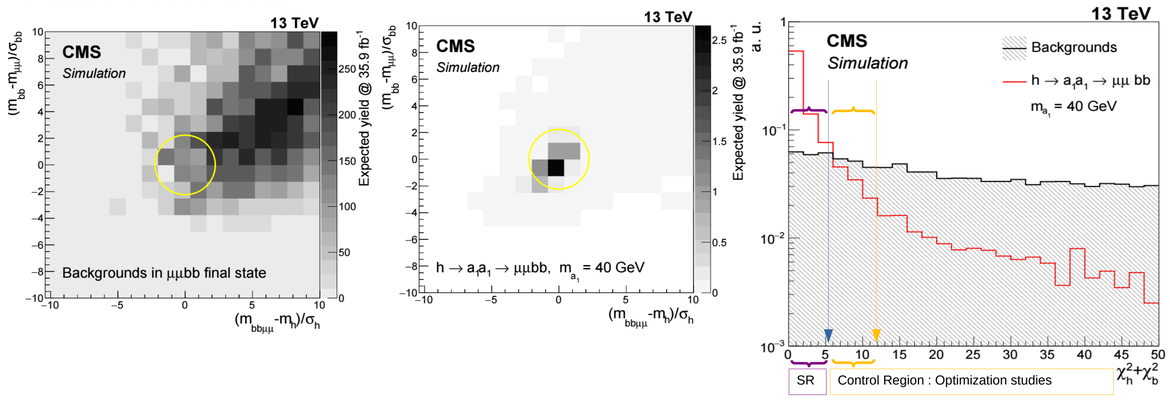




di-muon trigger
MET < 60 GeV
At least two jets :
Pt > 20/15 GeV
One loose/One tight b-tagged jet
2 Opposite sign Muons :
Pt > 20/9 GeV
15 GeV < $m_{\mu\mu}$ < 70 GeV

$$\chi_{bb} = \frac{(m_{bb} - m_{\mu\mu})}{\sigma_{bb}} \quad \text{and} \quad \chi_h = \frac{(m_{\mu\mu bb} - 125)}{\sigma_h}.$$

Final selection :



Categorization

- Based on the b-tagging of the loose b-tagged jet
- Tight-Tight, Tight-Medium & Tight-Loose

Process	$\mu^+\mu^-b\bar{b}$ selection	Final selection
Top ($t\bar{t}$, single top quark)	$33\,730 \pm 120$	198 ± 9
Drell–Yan	5237 ± 77	399 ± 21
Diboson	51 ± 4	1 ± 0.1
Total expected background	$39\,015 \pm 140$	598 ± 23
Data	36 360	610
Signal for $\sigma_h \mathcal{B} \approx 8$ fb		
$m_{a_1} = 20$ GeV	14.0 ± 0.1	6.0 ± 0.1
$m_{a_1} = 40$ GeV	14.8 ± 0.1	7.5 ± 0.1
$m_{a_1} = 60$ GeV	16.7 ± 0.1	10.1 ± 0.1

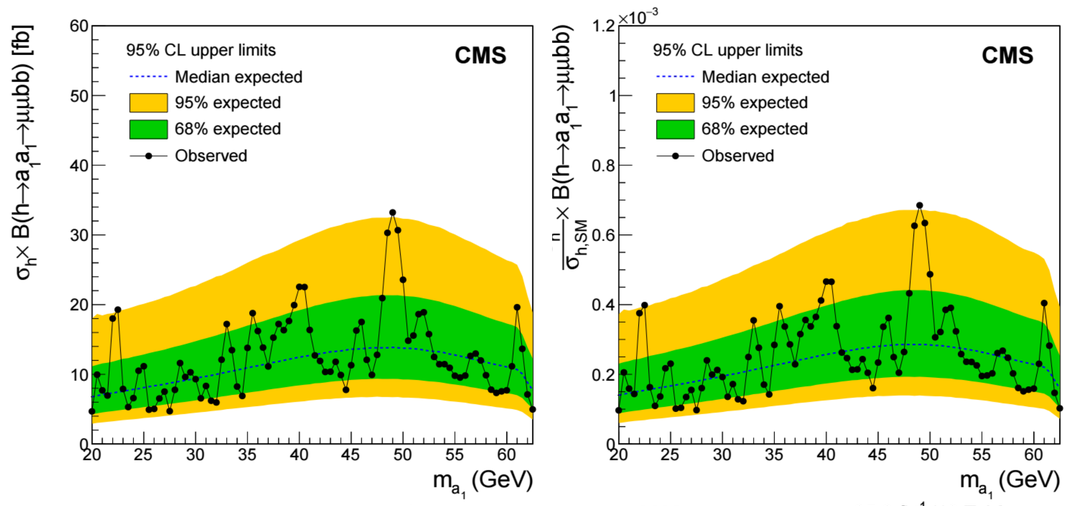
Systematics

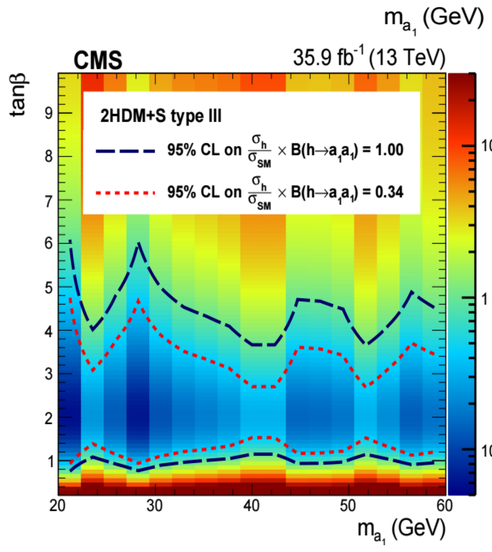
- ➔Background uncertainty: discrete profiling method
- ➔Uncertainties on signal acceptance and shape are considered
- ➔Dominant systematic uncertainty: b-tagging efficiency (~17% for m_a=40)

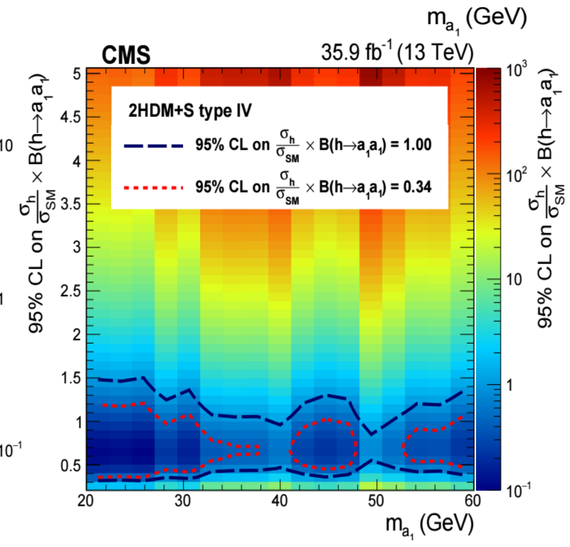
Results:

$$\sigma_h Br(h \to a_1 a_1 \to \mu^+\mu^- b\bar{b}) < (5\text{-}33)\ \text{fb}$$

$$\sigma_h Br(h \to a_1 a_1 \to \mu^+\mu^- b\bar{b})/\sigma_{h,SM} < (1\text{-}6) \times 10^{-4}$$







Contribution of $\mu^+\mu^-\tau^+\tau^-$ signal that is misidentified as $\mu^+\mu^- b\bar{b}$ is considered

More info

CMS-HIG-18-011
arXiv:1812.06359 [hep-ex]
Submitted to Phys. Lett. B