Search for the exotic decay of the Higgs boson in the h→ αα → bbττ channel

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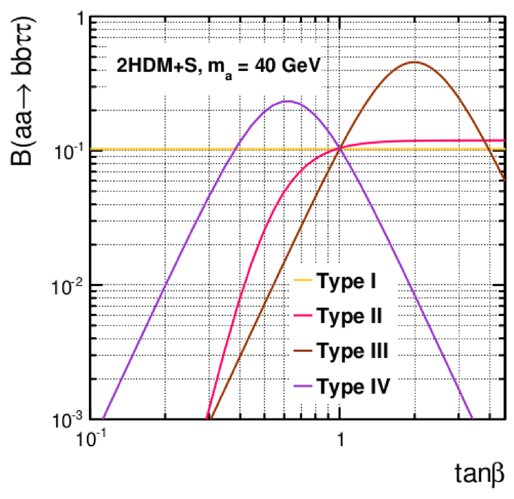
Introduction

- Indirect constraint by ATLAS and CMS on B(h→ BSM) < 34% at 95% CL [1]
  - Large room left for exotic Higgs decays: h→αα
- Many models include exotic decays of a SM-like Higgs boson like 2HDM+S
- The results are interpreted in the four types of 2HDM+S without FCNC at tree level [2]
- B(h→ SM particles) through BSM physics depends on type, m_α and tanβ
- The largest B(αα → 2b2τ)≈ 0.45 for type-III with tanβ=2.0



Baseline selection

Three di-tau final states are probe:

- **$e\tau_h$, $\mu\tau_h$, eμ**
- For each final state events pass a different trigger: single electron in **$e\tau_h$**, single muon or muon + tau in **$\mu\tau_h$** and electron + muon in **eμ**
- ***Table 1:*** *Baseline selection criteria on the objects selected in the various final states.*

	$\mu\tau_h$	$e\tau_h$	$e\mu$
$p_T(\tau_h)$	> 25 GeV	> 25 GeV	-
$p_T(\mu)$	> 20 GeV	-	> 24/10 GeV
$p_T(e)$	-	> 26 GeV	> 13/24 GeV
$p_T(b)$	> 20 GeV	> 20 GeV	> 20 GeV
$\|\eta(\tau_h)\|$	< 2.3	< 2.3	-
$\|\eta(\mu)\|$	< 2.1	-	< 2.4
$\|\eta(e)\|$	-	< 2.1	< 2.4
$\|\eta(b)\|$	< 2.4	< 2.4	< 2.4
Isolation (τ_h)	MVA	MVA	-
Isolation (μ)	< 0.15	-	< 0.15
Isolation (e)	-	< 0.10	< 0.10

Background Estimation

- In the eμ final state, the W + jets background is estimated from simulation.
- The QCD background is estimated from same-sign data. All same-sign processes are subtracted from same-sign data
- A correction is applied to extrapolate the normalization obtained in the same-sign region to the signal region.
- Single top, diboson and tt_{bar} processes estimated from simulation
- SM Higgs boson processes considered as backgrounds

Jet→τ_h fake background estimation

- Backgrounds with jets misidentified as a τ_h candidate are estimated from data using the fake rate method (consist mostly of W+jets and QCD multijets events)
- The probabilities for jets misidentified as a τ_h candidates, denoted f, are estimated from Z→μμ+jets events in data separately for each τ_h decay mode and parameterized with as a function of the τ_h p_T
- Events that pass all the selection criteria for the signal region, except that the τ_h candidate fails the isolation condition, are reweighted with a weight $f/(1-f)$ to estimate the contribution of events with jets in the signal region.

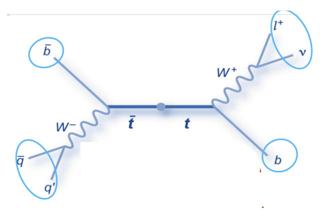
References

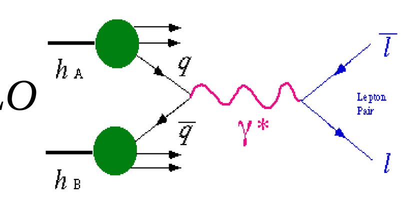
1. ATLAS and CMS Collaborations, "Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at √s = 7 and 8 TeV", JHEP 08 (2016) 045, doi:10.1007/JHEP08(2016)045, arXiv:1606.02266.
2. G. C. Branco et al., "Theory and phenomenology of two-Higgs-doublet models", Phys.Rep. 516 (2012) 1, doi:10.1016/j.physrep.2012.02.002, arXiv:1106.0034.
3. CMS PAS HIG-17-024, "Search for the exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state with two b quarks and two τ leptons"

MC Simulations

Background samples:

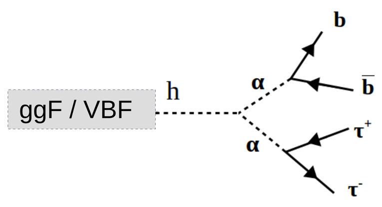
- *DY + jets, scaled to NLO cross section MADGRAPH (k-factor =1.16)*
- *W + jets, scaled to NLO cross section MADGRAPH (k-factor = 1.21)*
- *tt_{bar} and single top, scaled to NLO cross section, POWHEG*
- *Diboson WW, WZ, ZZ, VV, scaled to NLO cross section, AMC@NLO*
- *SM Higgs Decays, scaled to NLO cross section, POWHEG*





Signal samples:

- *gg→h→αα→bbττ 10 mass points (15 to 60 GeV)*
- *VBF and VH di-tau mass distribution set equal to ggF and rescaled*



Categorization

We have four categories based on the visible invariant mass of the di-tau lepton and the leading b-jet because the data and the signal have very different distributions

- The thresholds that define the categories depend on the final states and are shown with the vertical red lines in the figures 1 and 2 below
- First categories have very few backgrounds (1, 2)
- Intermediary categories contain low m_a signal (2, 3)
- High category is signal free and used to constrain the background (4)

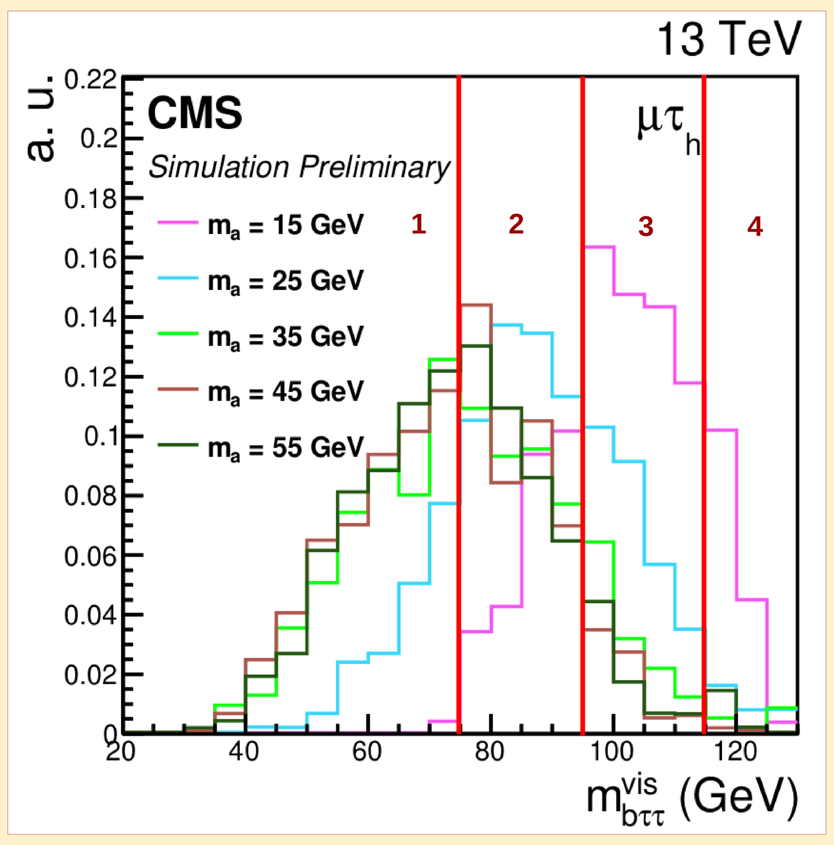


Figure 1: Visible invariant mass of the di-tau lepton and the leading b-jet distribution for different m_a hypothesis

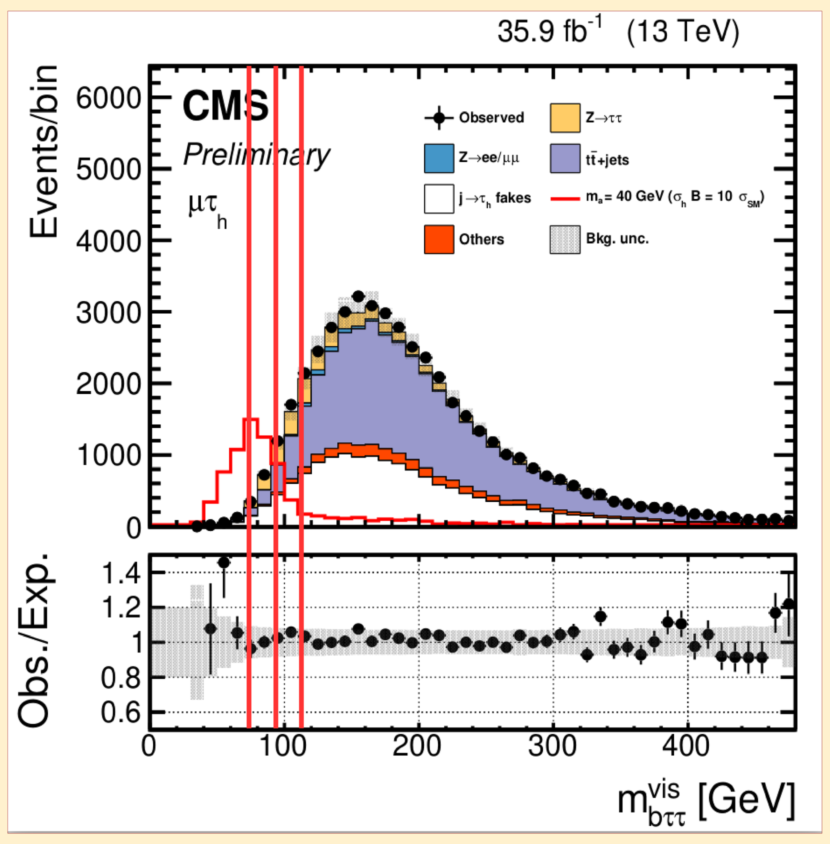


Figure 2: Visible invariant mass of the di-tau lepton and the leading b-jet distribution in the $\mu\tau_h$ final state

- The visible invariant mass of the tau candidates and of the leading b-jet is well below 125GeV for the signal because 1b jet missing and due to neutrinos in the tau decays
- Background lie at high invariant mass

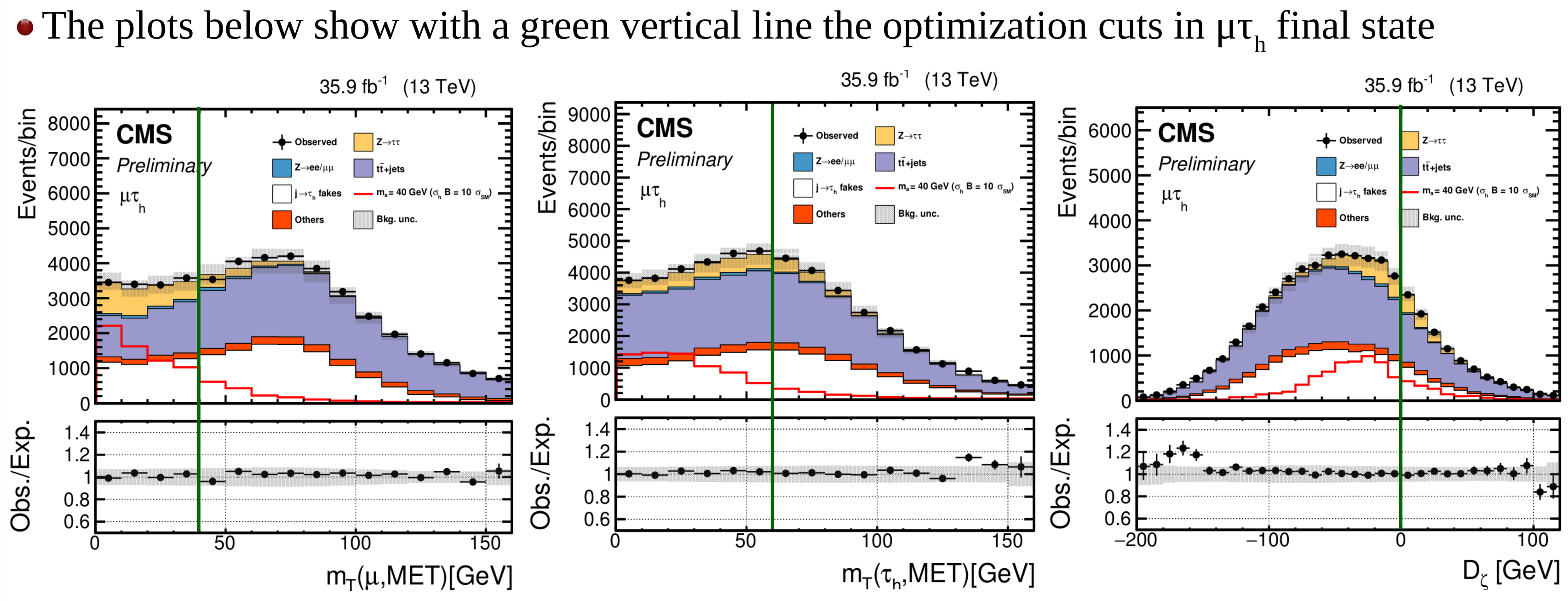
Selection Optimization

- Selection criteria are applied to optimize the expected limits on the signal cross section times the branching fraction
- They are based on the transverse mass of the missing p_T and the leptons, m_T , and on D_ζ *(Table 2)*

Cut	Category 1	Category 2	Category 3	Category 4
		$e\mu$		
$m_{e\mu b}$	< 65 GeV	∈ [65,80] GeV	∈ [80,95] GeV	> 95 GeV
$m_T(e, \vec{p}_T^{miss})$	< 40 GeV	< 40 GeV	< 40 GeV	< 40 GeV
$m_T(\mu, \vec{p}_T^{miss})$	< 40 GeV	< 40 GeV	< 40 GeV	< 40 GeV
D_ζ	> −30 GeV	> −30 GeV	> −30 GeV	> −30 GeV
		$e\tau_h$		
$m_{e\tau_h b}$	< 80 GeV	∈ [80,100] GeV	∈ [100,120] GeV	> 120 GeV
$m_T(e, \vec{p}_T^{miss})$	< 40 GeV	< 50 GeV	< 50 GeV	< 40 GeV
$m_T(\tau_h, \vec{p}_T^{miss})$	< 60 GeV	< 60 GeV	< 60 GeV	< 60 GeV
		$\mu\tau_h$		
$m_{\mu\tau_h b}$	< 75 GeV	∈ [75,95] GeV	∈ [95,115] GeV	> 115 GeV
$m_T(\mu, \vec{p}_T^{miss})$	< 40 GeV	< 50 GeV	< 50 GeV	< 40 GeV
$m_T(\tau_h, \vec{p}_T^{miss})$	< 60 GeV	< 60 GeV	< 60 GeV	< 60 GeV
D_ζ	-	< 0 GeV	-	-

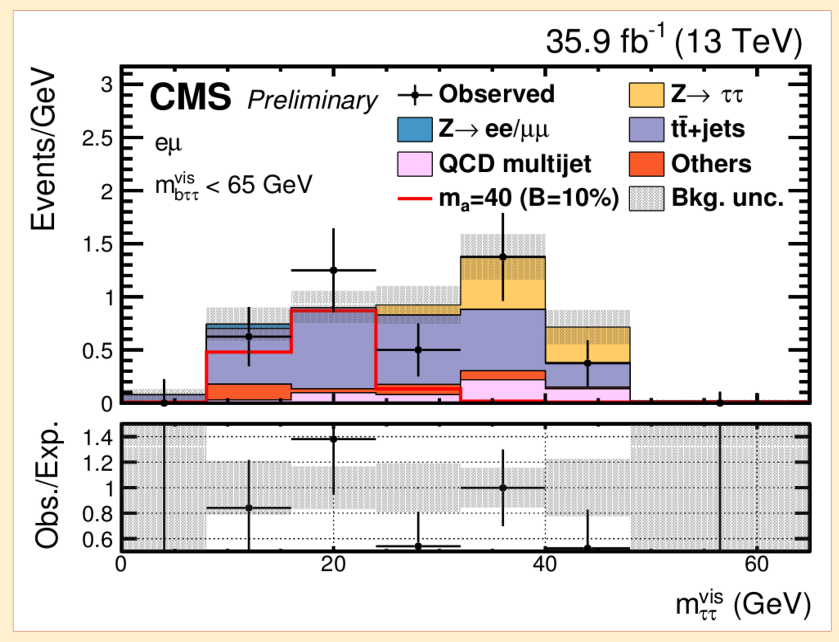
Table 2: *Optimized selection and categorization in the various final state*

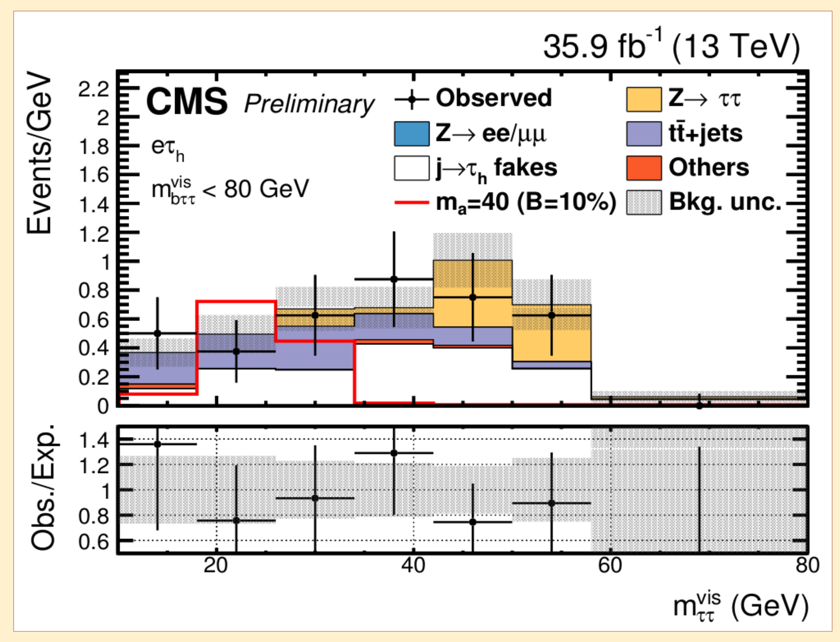
- The plots below show with a green vertical line the optimization cuts in $\mu\tau_h$ final state

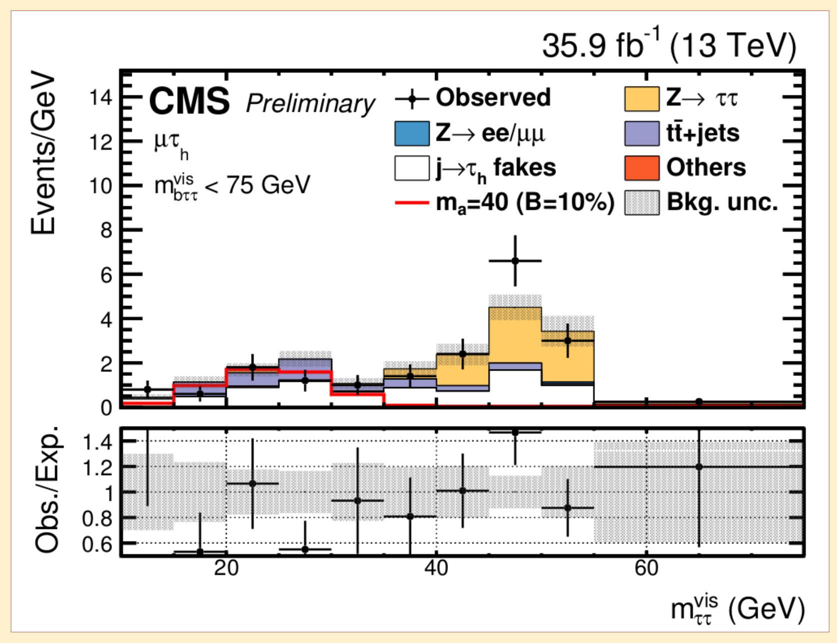


Results

The invariant $m_{\tau\tau}$ distributions in the different channels and categories

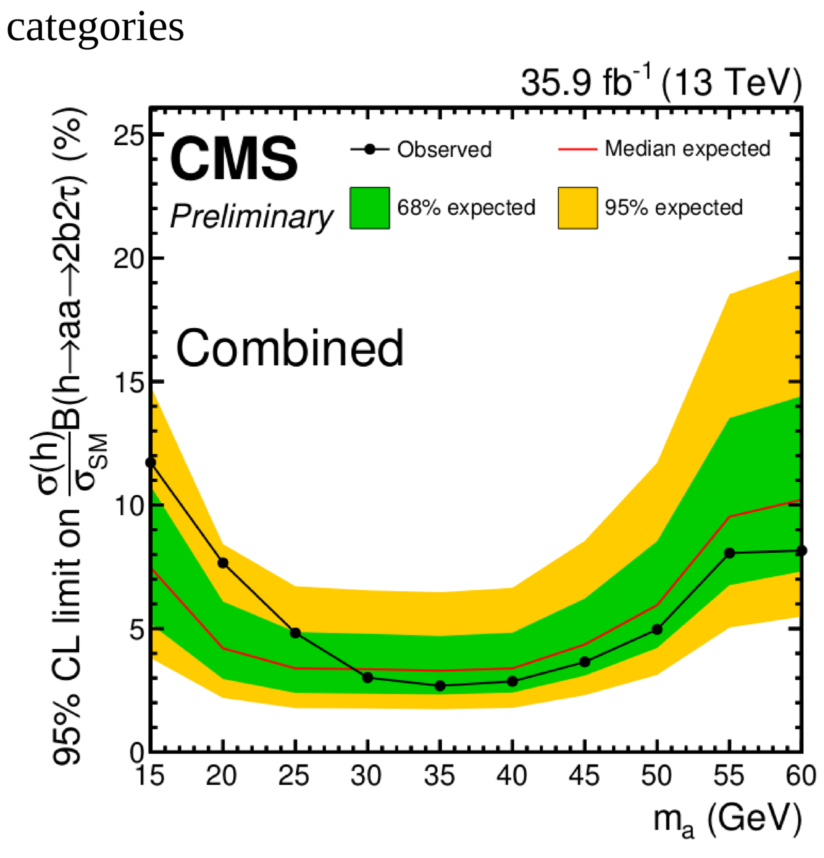




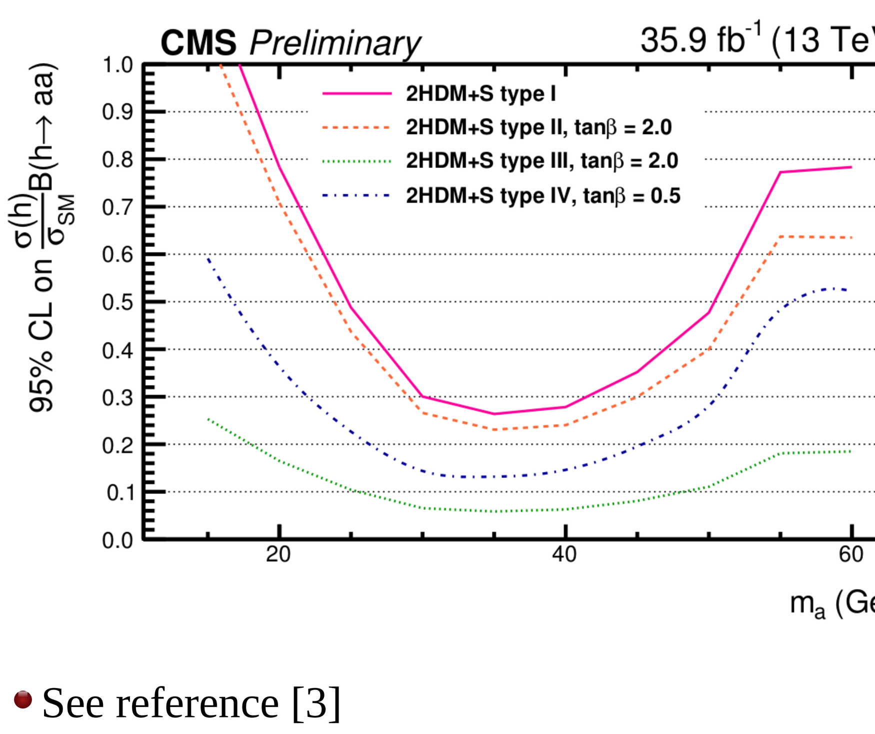


Conclusions

- Systematic uncertainties related to physics objects and related to background estimation are implemented
- Maximum likelihood fit based on the invariant di-tau mass distributions in different channels and categories



- Upper limits on B(h→αα) for the most favorable 2HDM+S scenarios **are between 6% -24%**



- See reference [3]