BSM Higgs boson searches at CMS

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Introduction

The discovery of a new boson compatible to the SM Higgs is just the start of the story:

- the detailed structure of the Higgs sector is still unclear
- the SM cannot be a final theory

Several searches for additional Higgs bosons have been carried out Beyond the SM (2HDM, MSSM, triplets, Dark SUSY) might hold the answer:

- Indirect searches: measurement of a possible deviation of the SM Higgs couplings (ttH, non-resonant Higgs pair production)
- Direct searches for BSM Higgs like particles:
  - Charged and further Neutral Higgs bosons
  - Resonant Higgs pair production
  - Diboson resonances (WW, ZZ, Zh) from Higgs decays
  - Light neutral Higgs

Outline

- Summary of results using the Run I data
    - Interpreted in the context of 2HDM
    - Interpreted in the context of the MSSM

- New results using Run II 13 TeV data:
    - Indirect searches
    - Direct searches

- Conclusions

2HiggsDoubletModel(2HDM)

Results of RunI have been summarized in the form of exclusion contours for 4 benchmark scenarios, that commonly have:

in addition to the SM Higgs scalar doublet, a second one, giving rise to five physical states:

- **2 CP-even h(light), H(heavy)**
- **1 CP-odd A**
- **2 charged H^+, H^-**

Ratio of vacuum expectation values of the Higgs doublets

Mixing angle

Soft Z_2-breaking mass parameter

7 free parameters: **masses of bosons, $\tan\beta$, $\cos(\alpha-\beta)$ and m_{12}**

Type-I:

Both the Higgs doublets couple to the fermions.

Type-II:

One Higgs doublet couples exclusively to Down-type fermions, an the other to the Up-type fermions.

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Ratio of vacuum expectation values of the Higgs doublets

2 free parameters: **mass of boson A , tanβ**

MSSM:

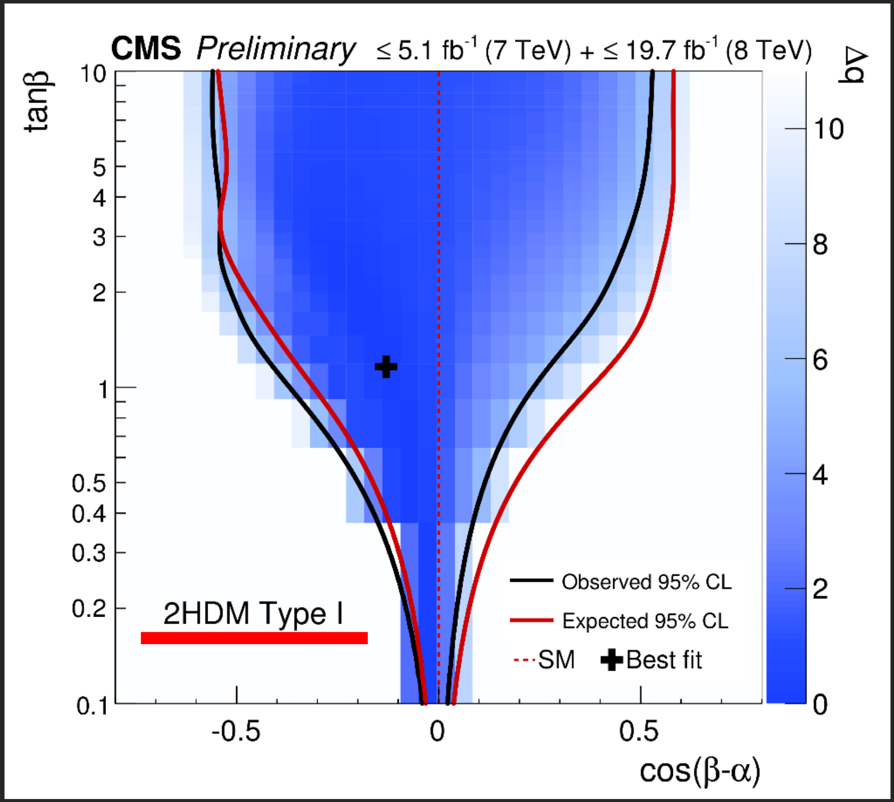
Is a kind of Type II model where the relations between the Higgs bosons and the mixing angle α are fixed.

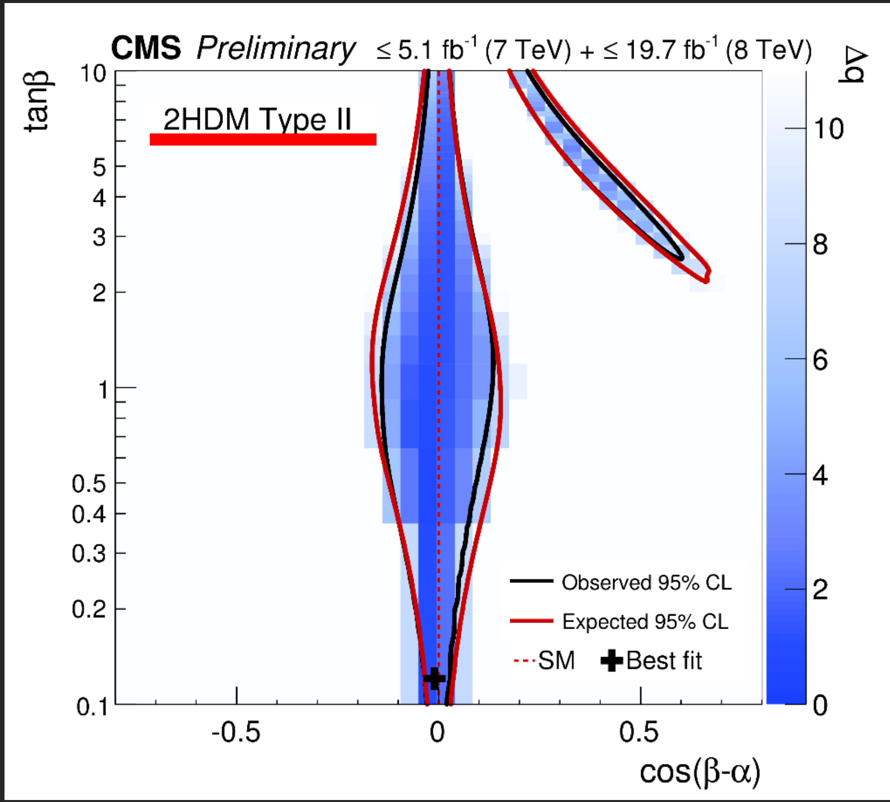
Run I Results:
19.7 fb^{-1} at 8 TeV

Summary of Run I

General constraints on 2HDM from indirect searches

obtained interpreting the observed Higgs boson as h boson



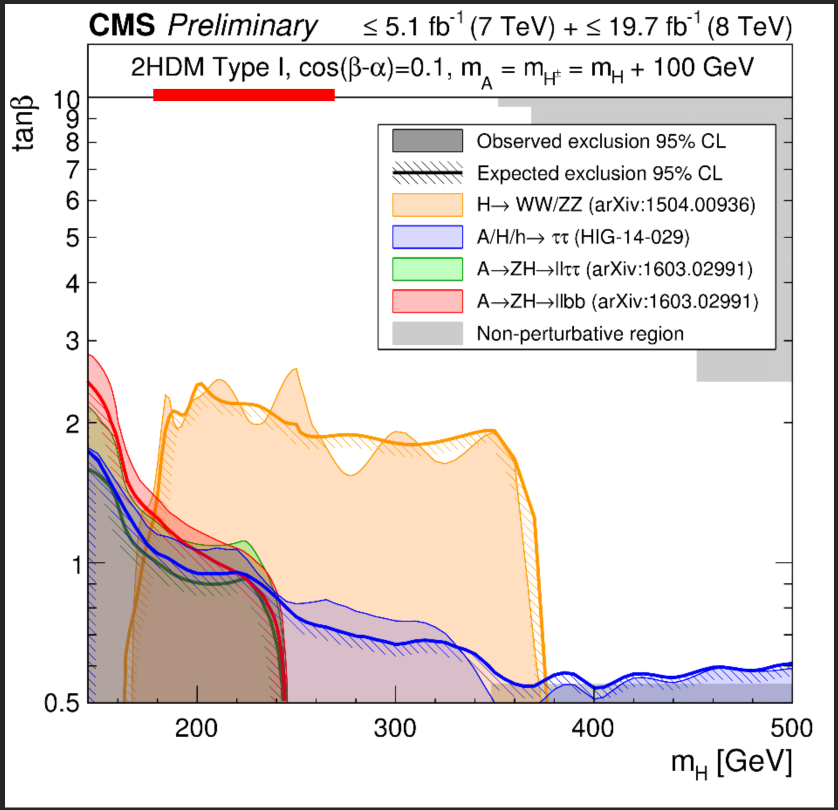


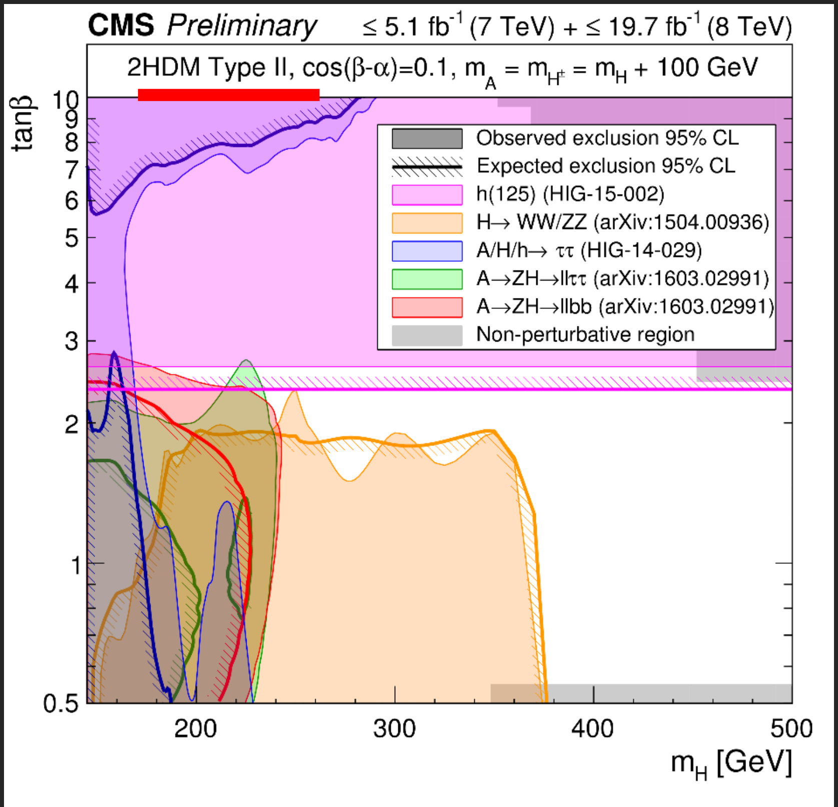
The measured Higgs coupling set strong constraints on cos(α-β)

Constraints on 2HDM from direct searches

Both scenarios have been chosen with:

- $\cos(\alpha-\beta) = 0.1$:
  - SM Higgs properties are manifested
  - masses of H and A are degenerate
- $m_A \leq m_{H+} = m_H + 100$ GeV:
  - to allow the A→ZH process





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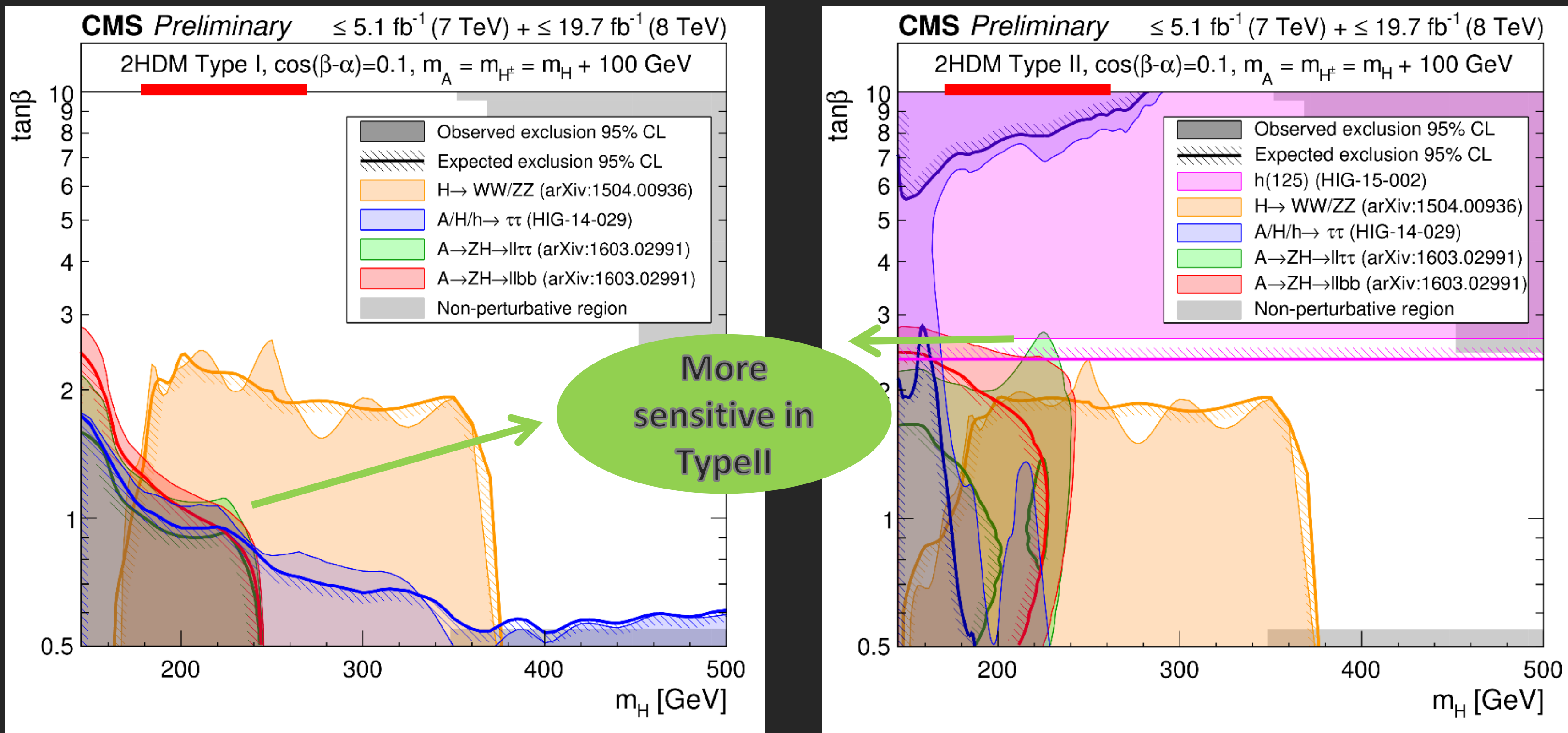

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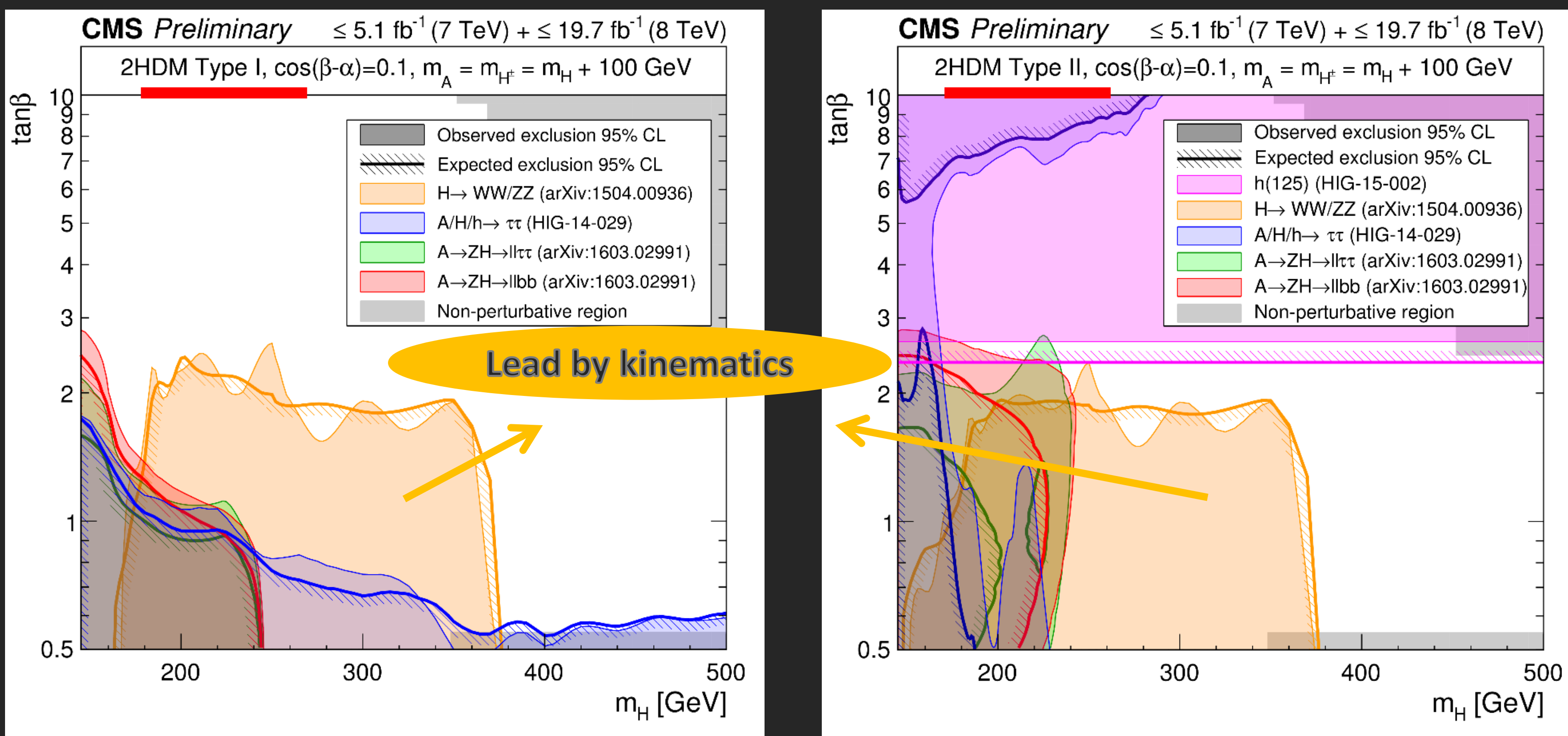

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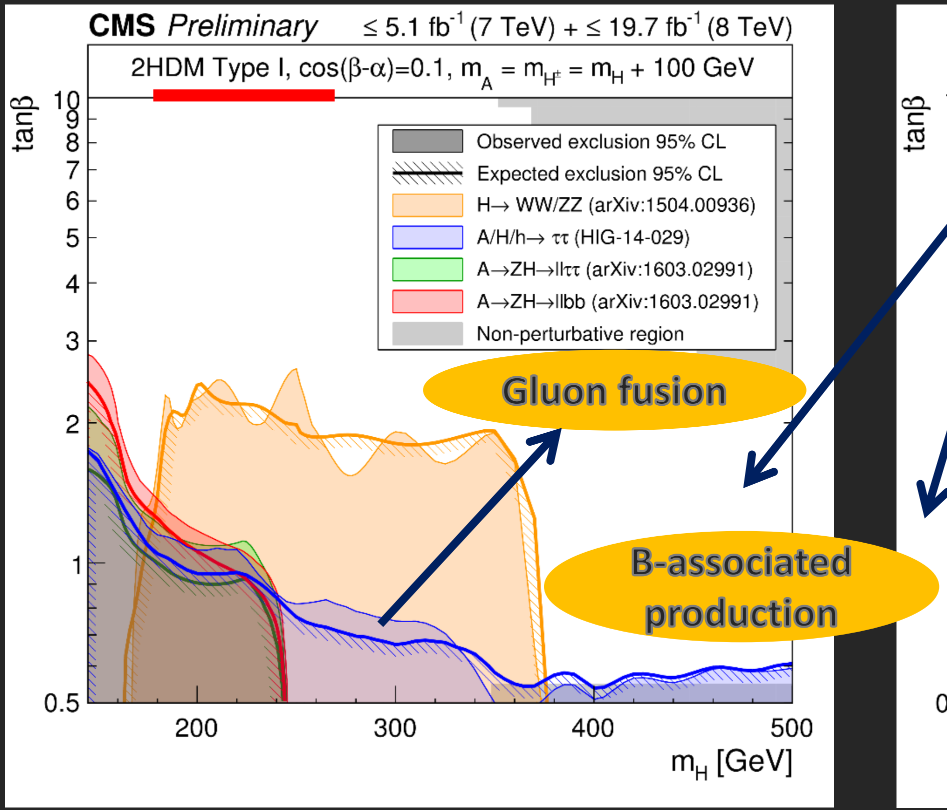
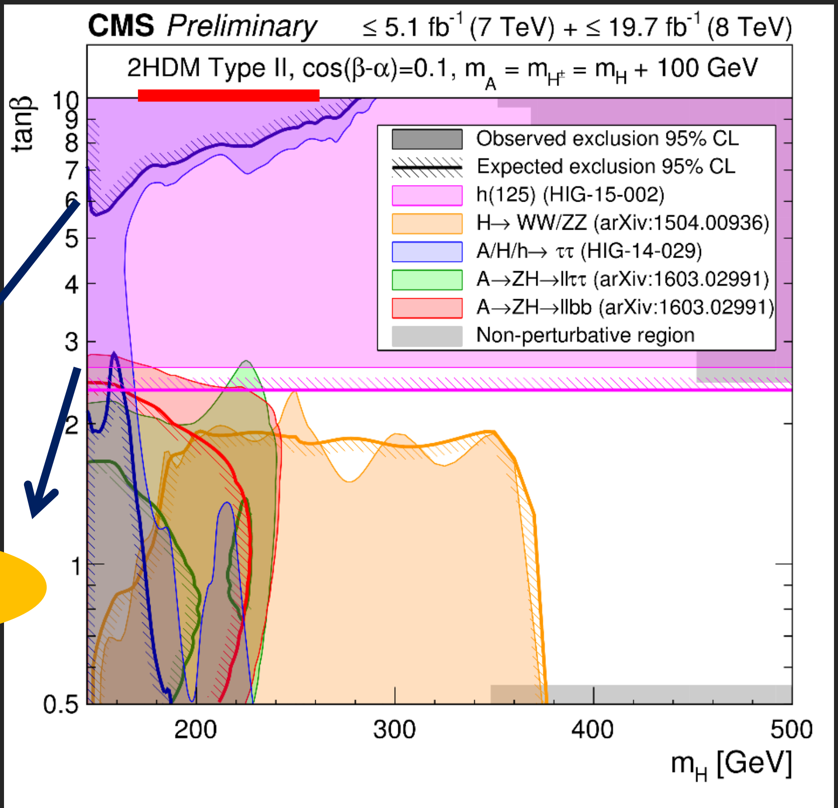


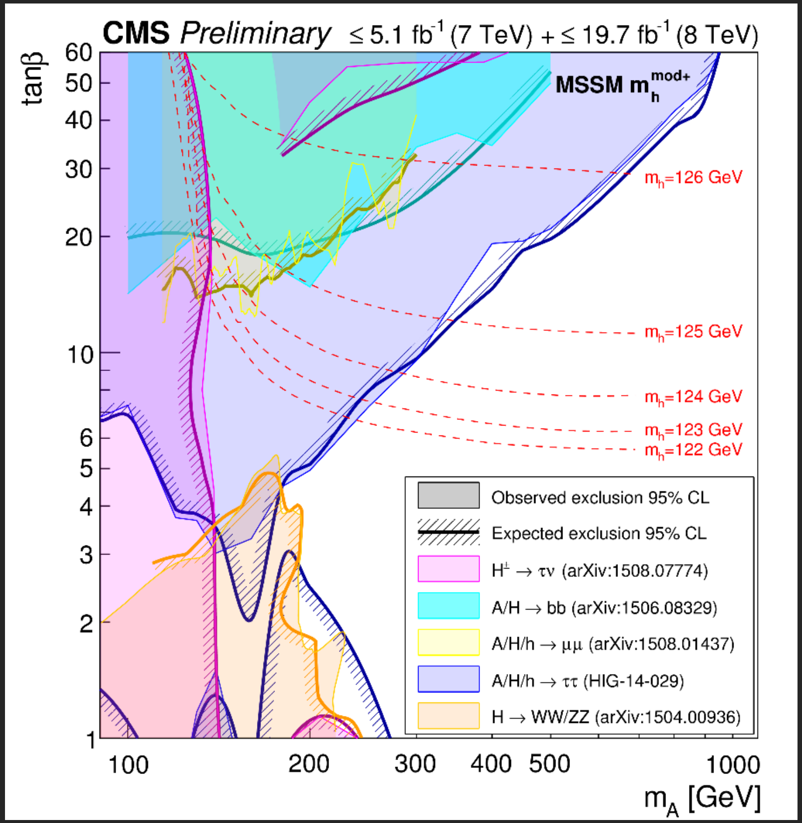


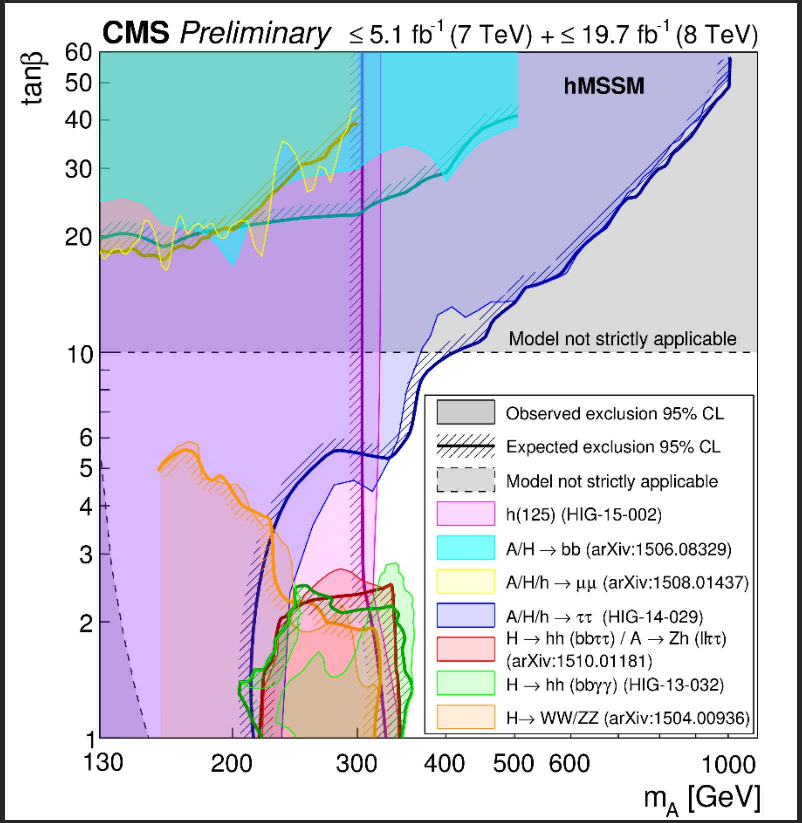
Summary of Run I

Constraints on MSSM from direct searches

m_h^{mod+} scenario: $m_h < 125 \pm 3$ GeV

hMSSM scenario: $m_h \equiv 125$ GeV
Strictly valid for $m_A > 130$ GeV, $\tan\beta < 10$
Approximatively valid up to $\tan\beta = 60$





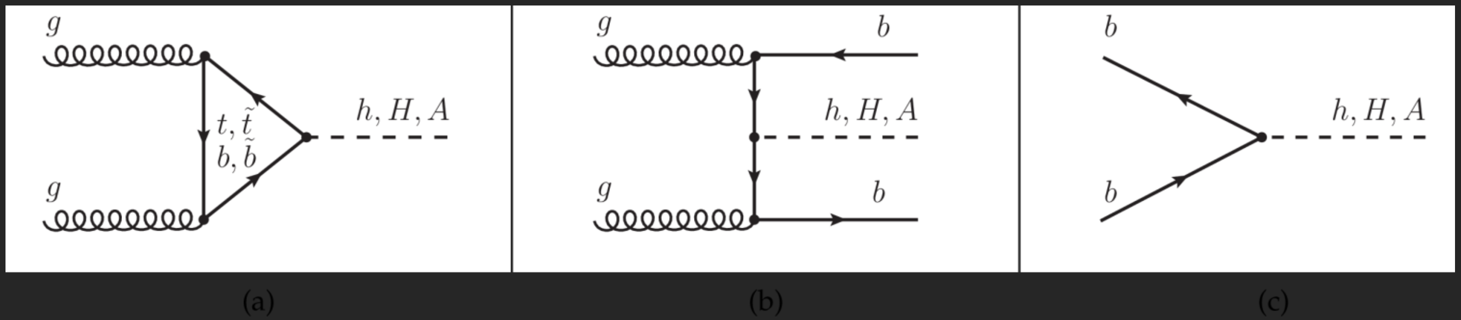
Run II Results:
12.9 fb^{-1} at 13 TeV

A/H/h to ττ

CMS-PAS-HIG-16-037

Best significance w.r.t. bb channel (highest BR but very challenging QCD background) and μμ channel (the cleanest signature but the lowest BR).

Production via gluon fusion and associated to b-quark



Dominant at small and medium tanβ

Enhanced at large tanβ due to stronger coupling between Higgs and down-type fermions

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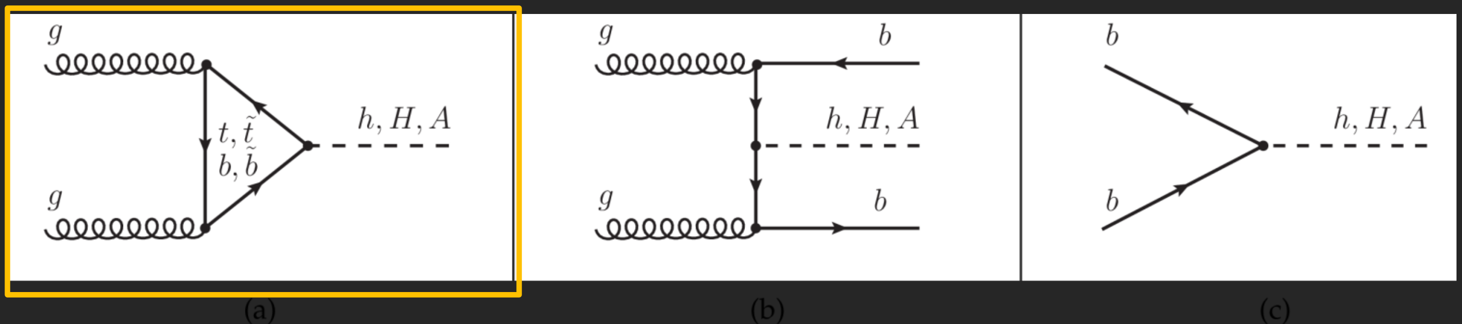

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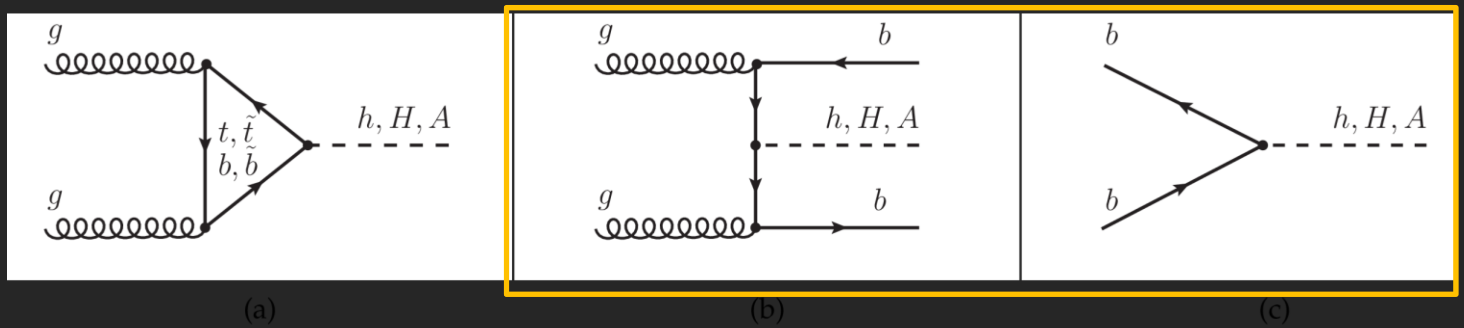

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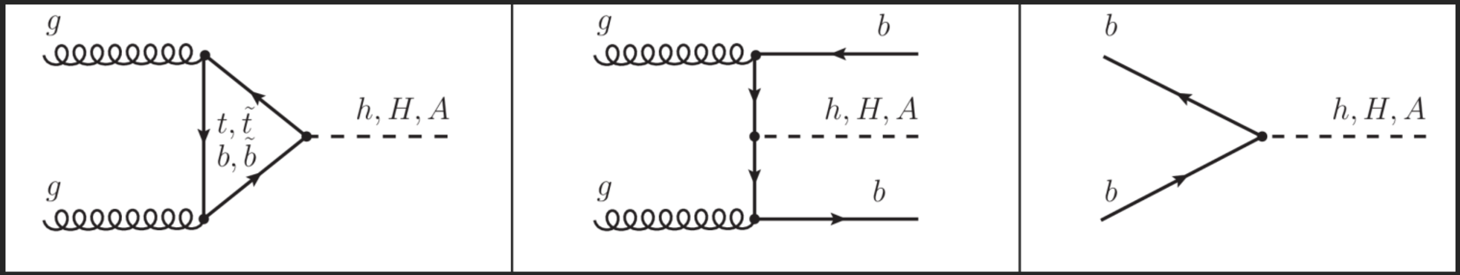


(a) (b) (c)

Dominant at small and medium tanβ

Enhanced at large tanβ due to stronger coupling between Higgs and down-type fermions

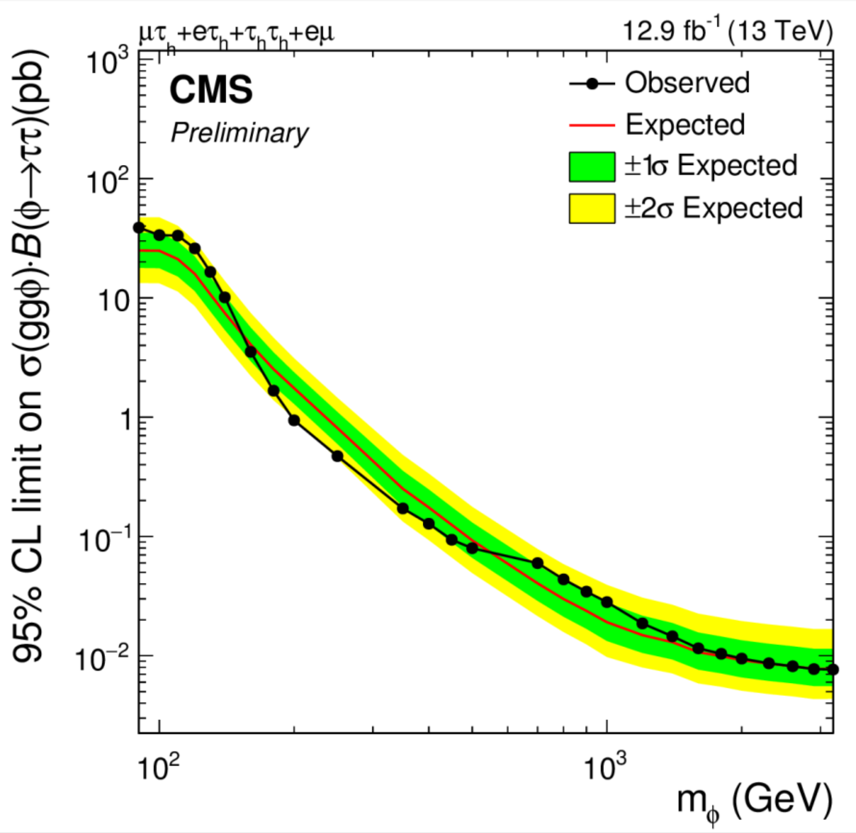
Categorization according to τ decays:

- **fully hadronic ($\tau_h\tau_h$)**
- **fully leptonic (eμ)**
- **semileptonic ($\tau_h\mu$ and $\tau_h e$)**

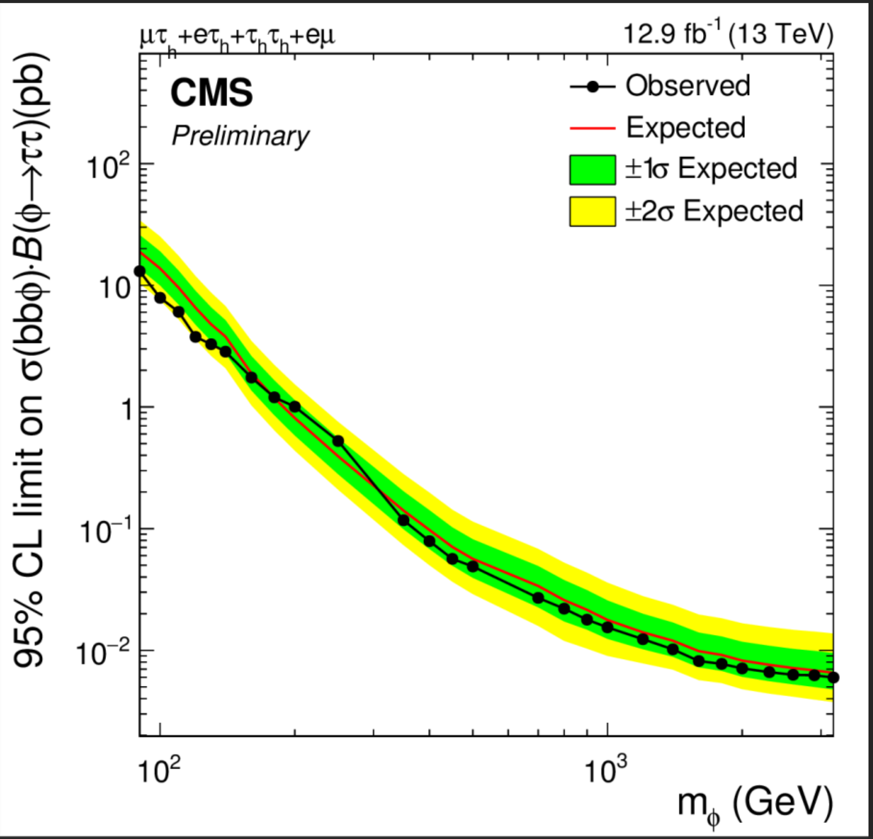
A/H/h to ττ

CMS-PAS-HIG-16-037

Limit on cross section X BR using the narrow-width approximation and no SM Higgs included as background



(a)



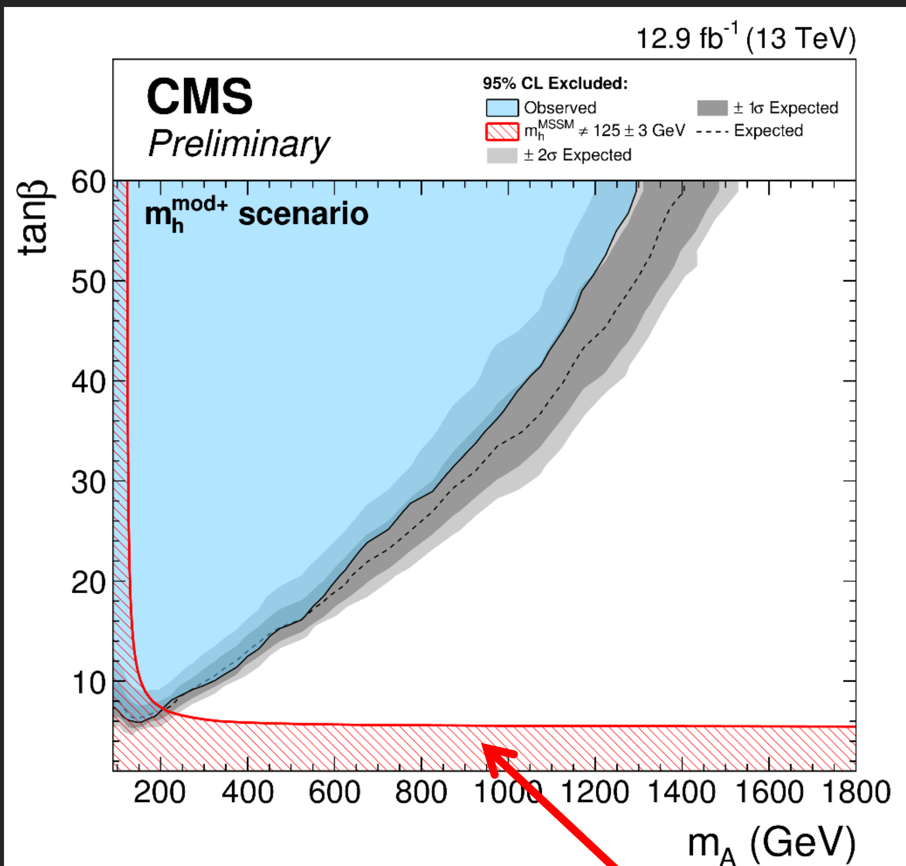
(b)

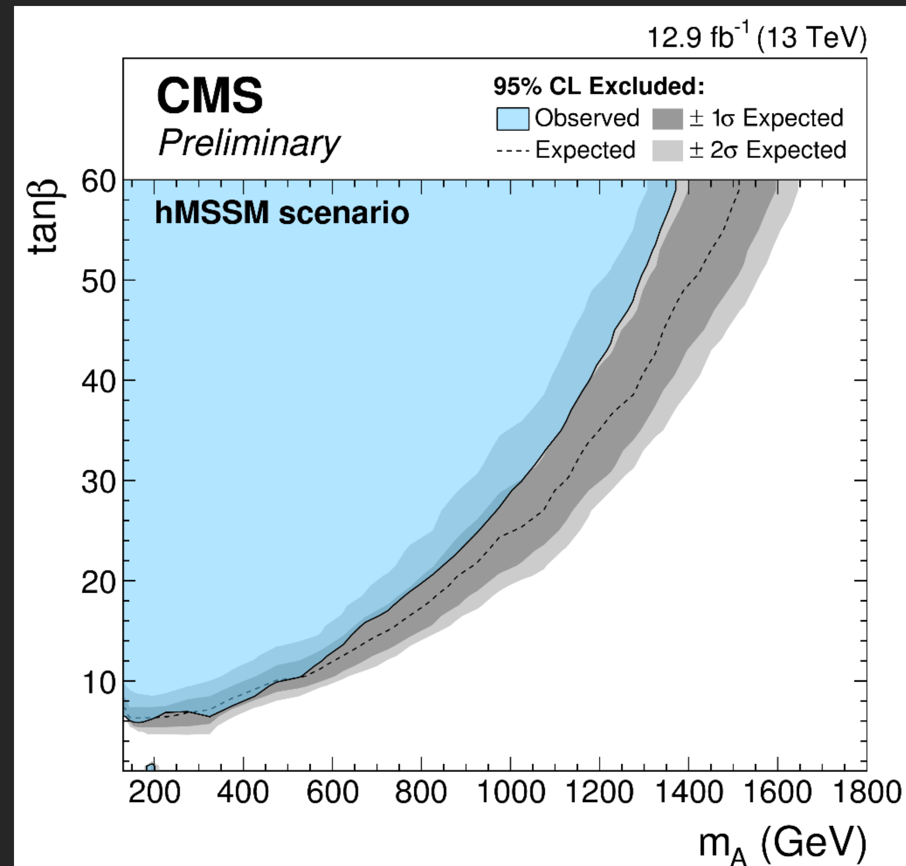
A/H/h to ττ

CMS-PAS-HIG-16-037

Exclusion limit for MSSM scenarios:

m_h^{mod+} hMSSM

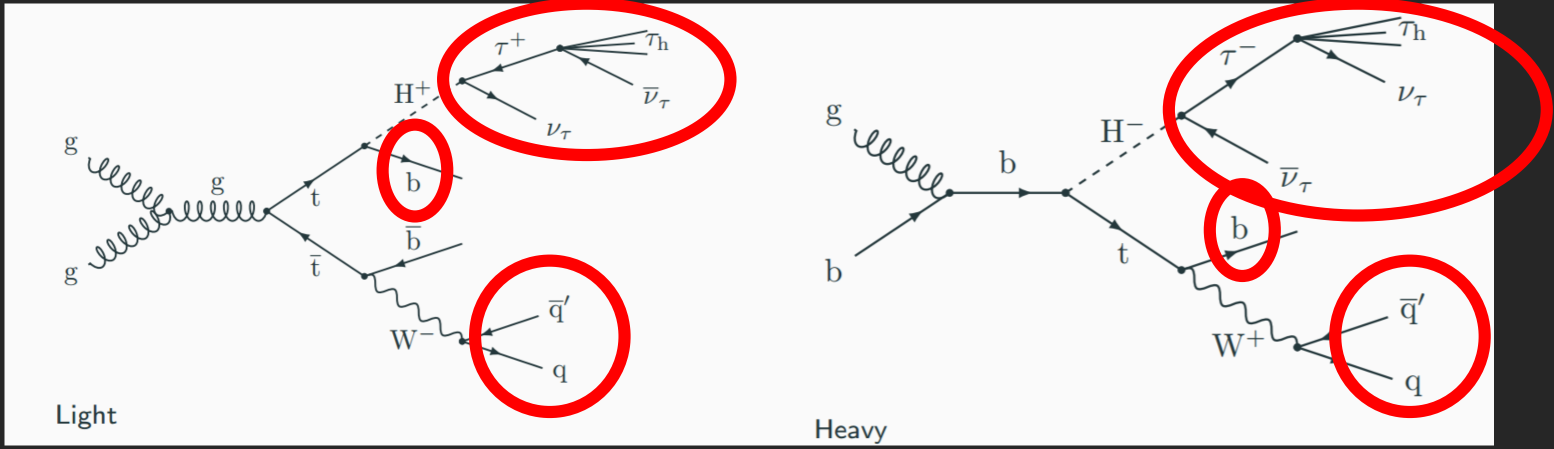




Excluded if h ≡ SM Higgs

Charged Higgs

CMS-PAS-HIG-16-031



Light-mass scenario
$m_H < m_t - m_b$ (≈160 GeV)

Heavy-mass scenario: kinematic acceptance $m_H > m_t$ (≈180 GeV)

- **BR(H→τν)** increases with tanβ
- fully hadronic τ decays have the advantage that all the neutrinos originate from H decay (transverse mass can be reconstructed)

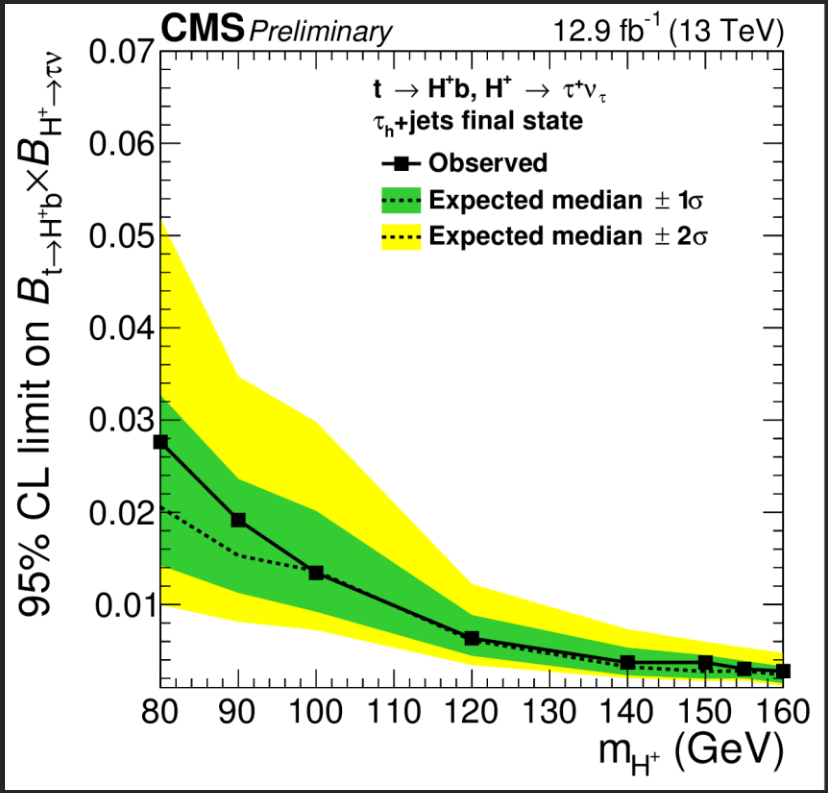
- Events are selected containing a τ, large missing energy and at least 3 jets
- Events with back-to-back configuration between τ and missing energy are rejected
- Main background comes from misidentified jets faking an hadronic τ

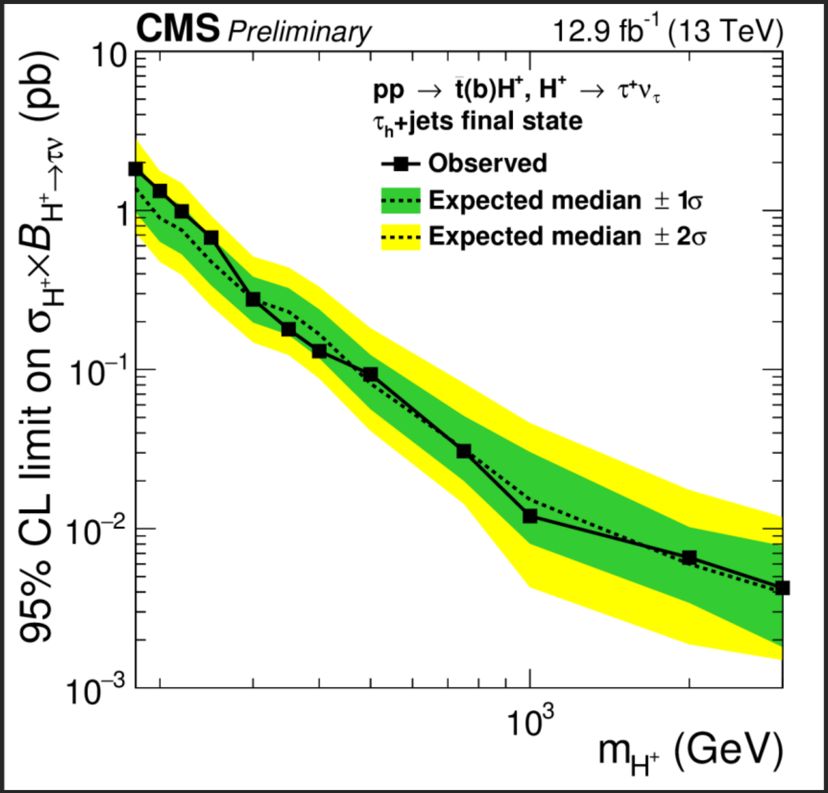
Charged Higgs

CMS-PAS-HIG-16-031

Model independent limits on:

$BR(t \to H^+ b) \times BR(H^+ \to \tau\nu)$ $\sigma(H^+) \times BR(H^+ \to \tau\nu)$

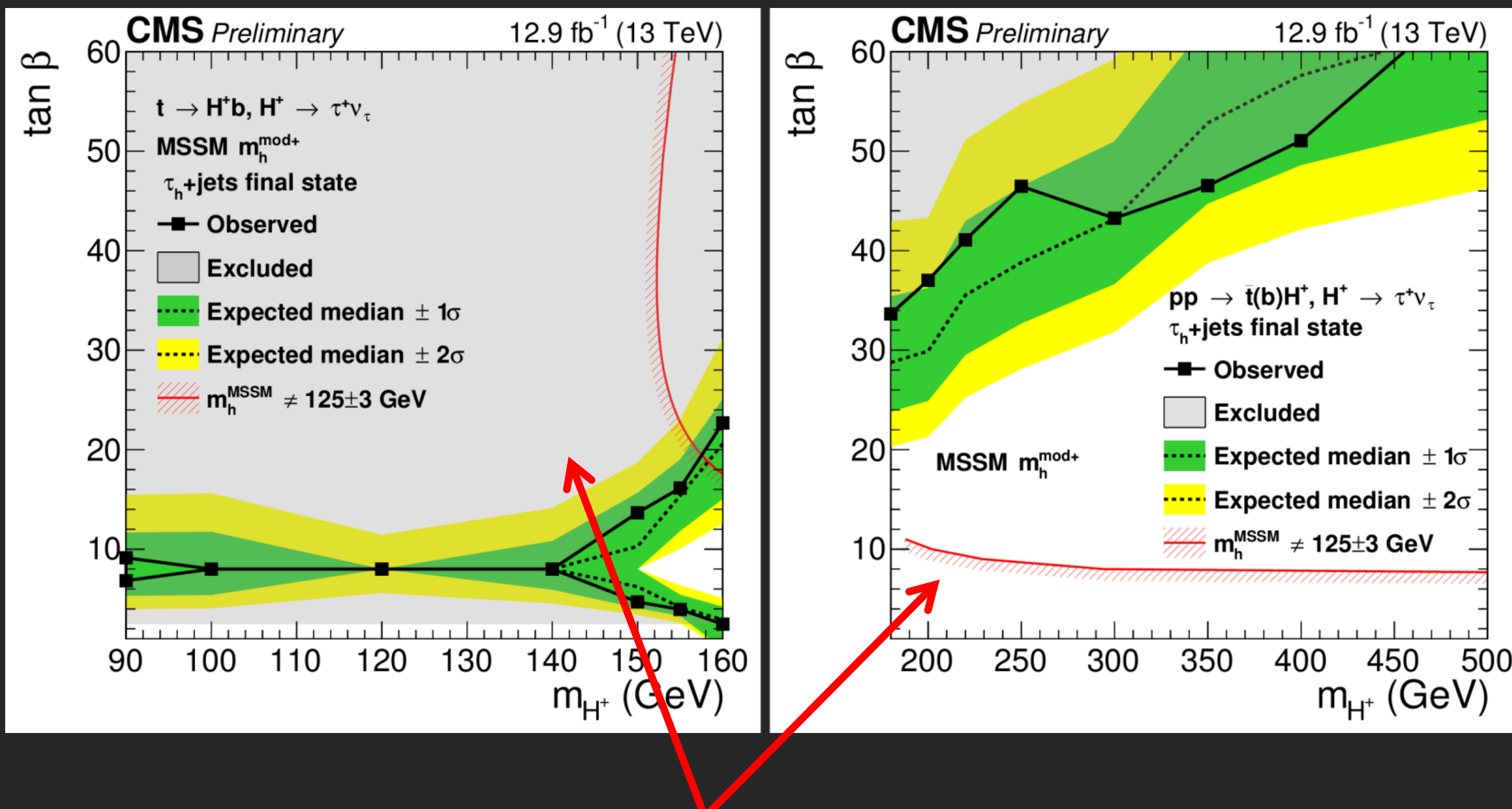




Charged Higgs

CMS-PAS-HIG-16-031

Exclusion limit for m_h^{mod+} scenario



Excluded if h ≡ SM Higgs

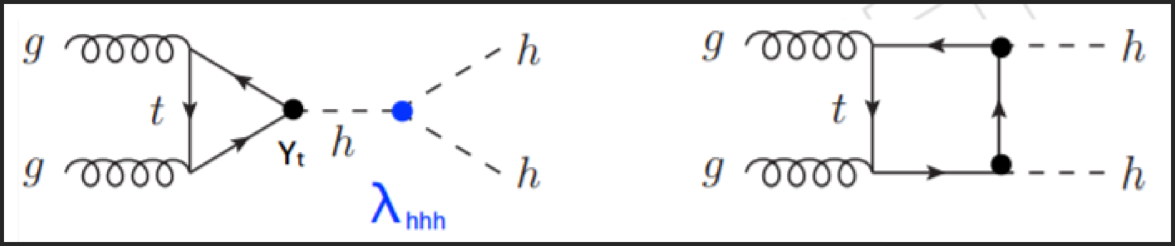
Non-resonant hh to bbττ

Higgs boson self-coupling can be measured in Higgs pair production processes: λ_{hhh}.

This is predicted by SM

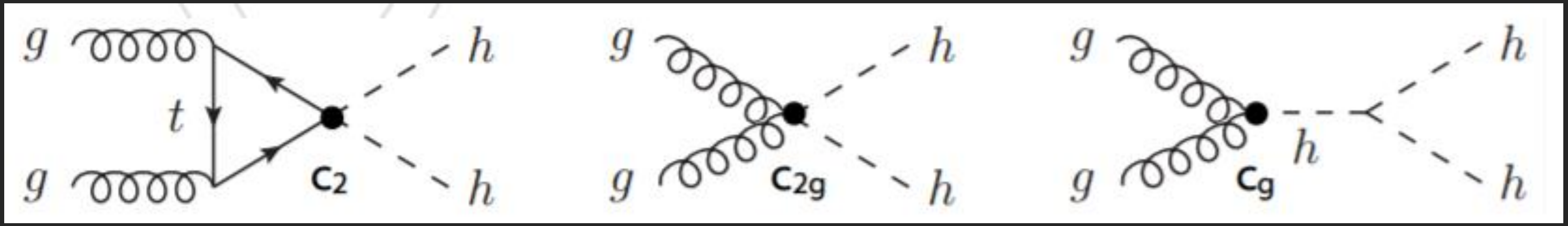
$$\lambda_{hhh} \equiv \lambda_{hhh}^{\mathrm{SM}} = \frac{m_h^2}{2v^2} \simeq 0.129.$$

Leading Order processes in SM



BSM processes enhance the cross-section:

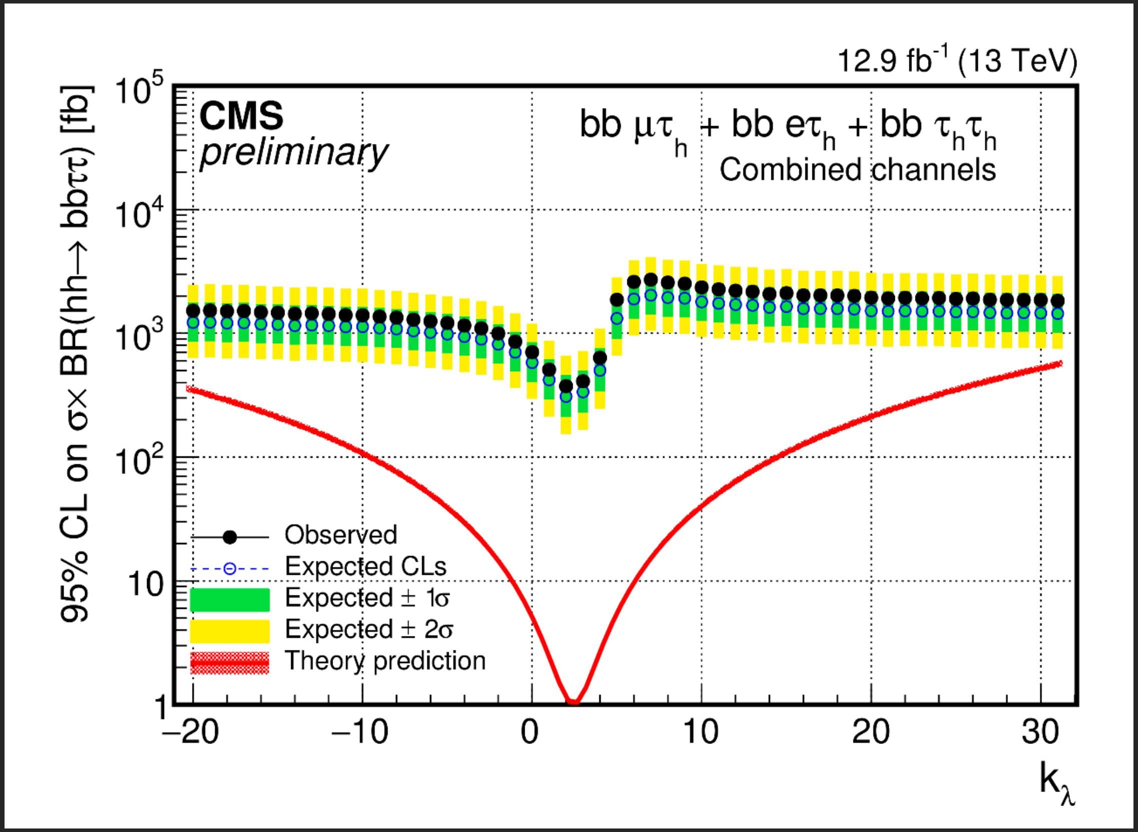
- **anomalous coupling to the heavy quarks**
- **new particles entering in the loop modification of the λ_{hhh}**



The sensitivity achieved in RunII does not allow to measure the SM λ_{hhh} ,but BSM models can be constrained.

Non-resonant hh to bbττ

bbττ channel is the best compromise between BR and background contamination



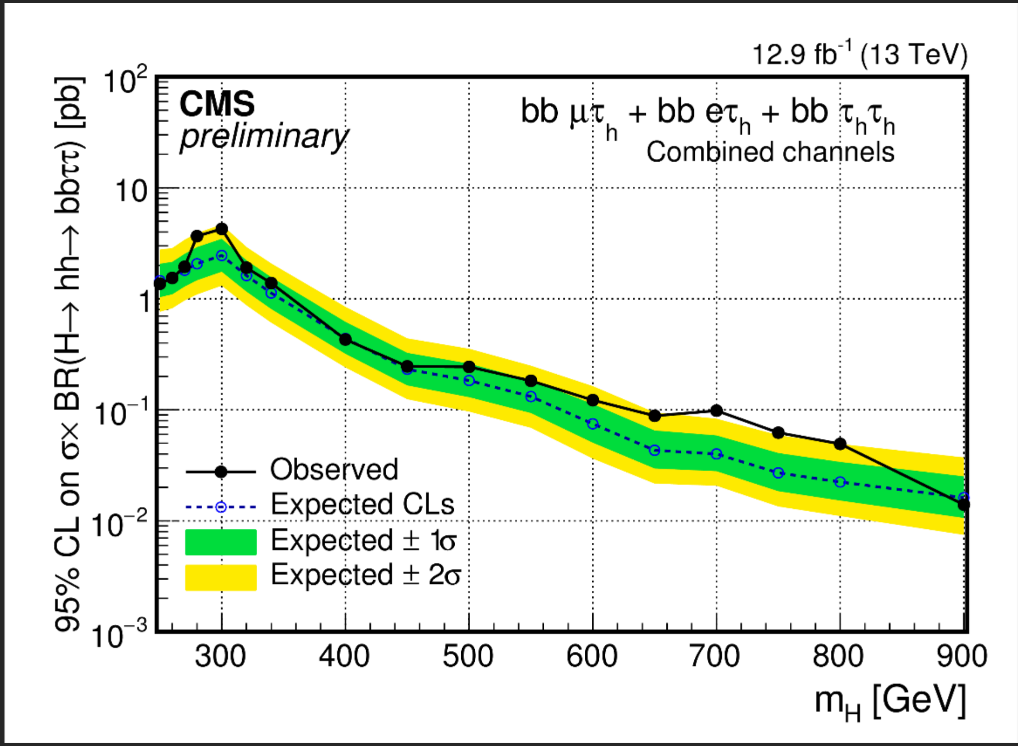
Limit is set assuming that only the trilinear coupling is modified and no other BSM effects are present

Resonant X→hh to bbττ

Model independent search for narrow resonance H decaying to 2 SM Higgs

Process predicted by some BSM extension of the Higgs sector

Significant BR (H→hh) below the threshold for the decay to top-quark pair
Promising channel in the low tanβ region (non observation of SUSY), where the A/H natural width is smaller than the experimental resolution.



Resonant X to ZZ

CMS-PAS-HIG-16-033
CMS-PAS-HIG-16-034

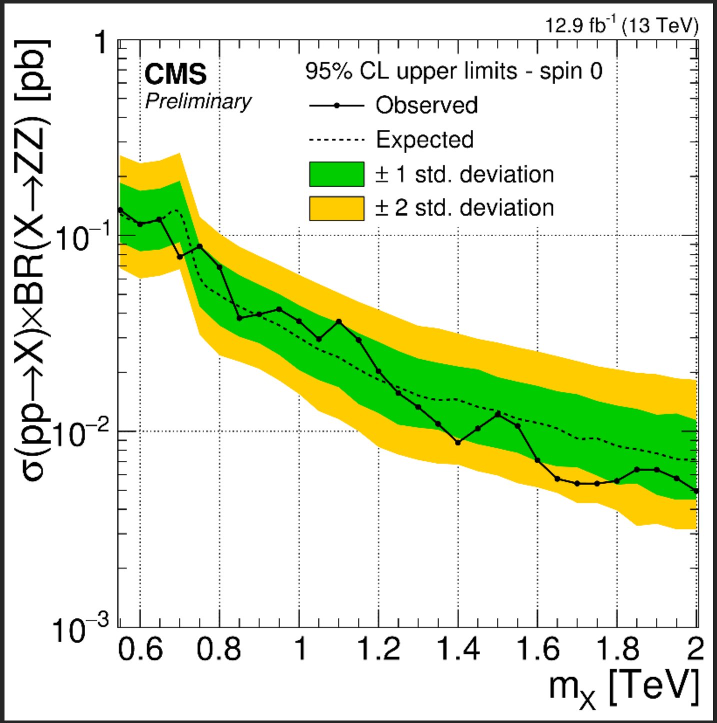
Model independent search for narrow resonance H decaying into 2 Z :

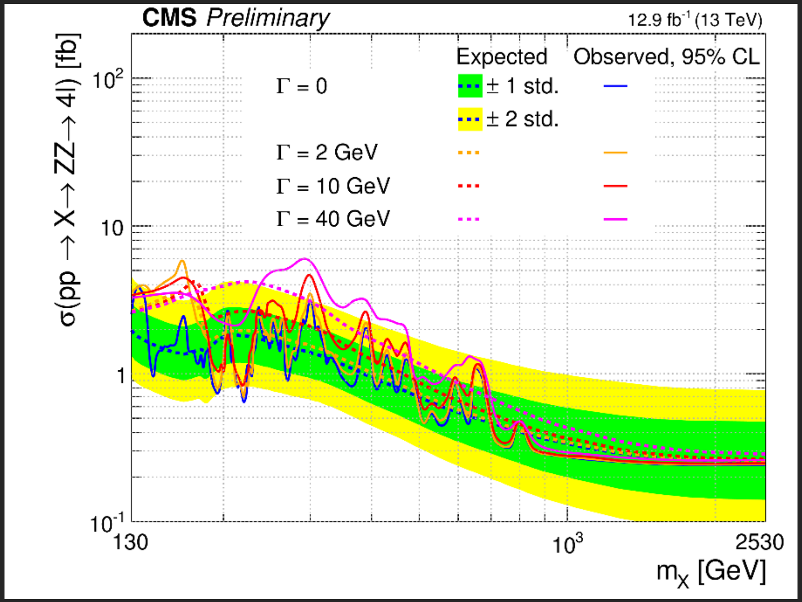
Semileptonic final state (2q2l) with electrons or muons and very high p_T jets:

- boosted topology (hadronisation of 2 quarks reconstructed as 1 jet)
- resolved topology (fit of reconstructed Z)
- main background from Z+jets events
- good sensitivity starting from high mass

Leptonic final state (4l) with electrons or muons:

- production by gluon fusion or Vector Boson Fusion (also VH is taken into account)
- Some values of width Γ up to Mx have been tested





Summary

- **BSM Higgs from RunI:**
  - Agreement between direct and indirect searches
  - Several limits on new physics have been set
  - Further than the 2HDM, a lot of searchers on exotic Higgs production and decay modes have been performed

- **Extensive program during RunII:**
  - No discovery, but several limits on new physics have been set
  - Stringent limits are coming using the full 2016 data (35 fb^{-1})
  - Much more is expected until the end of 2018

Back-up

Couplings in 2HDM

TypeI: small values of tanB produce large deviations of the couplings Ku=Kd. The same is true for coupling to the up-type fermions in TypeII(dominated by the constraints on the couplings higgs-top and higgs-tau).

Table 2: Modifications of the couplings of the h to *up*- (κ_u), *down*-type (κ_d) fermions and vector bosons (κ_V), with respect to the SM expectation, in 2HDM's model of *type*-I (second column) and II (third column) and for the *hMSSM* (fourth column). The coupling modifications for the *hMSSM* are completed by the expressions for s_u and s_d as given in Equation (4).

	2HDM		**hMSSM**
	type I	type II/MSSM	
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\frac{s_d+s_u\tan\beta}{\sqrt{1+\tan^2\beta}}$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$s_u\frac{\sqrt{1+\tan^2\beta}}{\tan\beta}$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$s_d\sqrt{1+\tan^2\beta}$

$$s_u = \frac{1}{\sqrt{1+\frac{(m_A^2+m_Z^2)^2\tan^2\beta}{(m_Z^2+m_A^2\tan^2\beta-m_h^2(1+\tan^2\beta))^2}}} \qquad s_d = s_u\cdot\frac{m_A^2+m_Z^2\tan\beta}{m_Z^2+m_A^2\tan^2\beta-m_h^2(1+\tan^2\beta)},$$

A/H/h to ττ

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