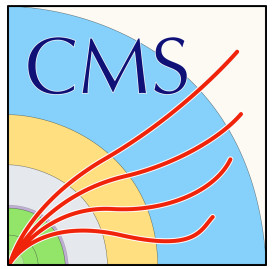
CMS results and prospects for new scalar searches

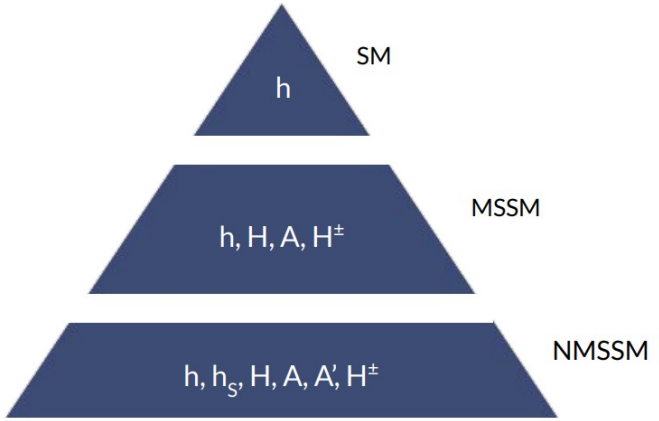
Agni Bethani for the CMS collaboration

25 May 2022



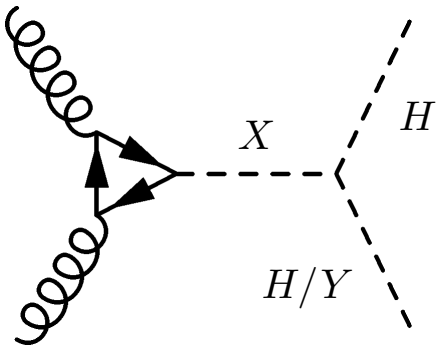
Extended scalar sector models

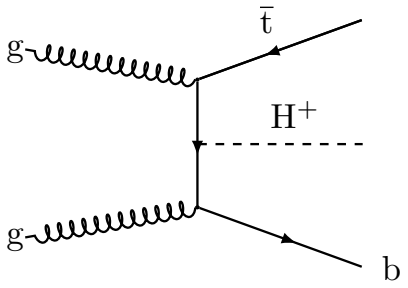
- The Higgs boson was discovered 10 years ago and is the latest addition to the Standard Model (SM) of particle physics.
- but we still have open physics questions! It only makes sense to explore the Higgs sector more.
- Many new-physics scenarios predict extended Higgs sectors, with one particle closely resembling the SM Higgs boson, and additional scalars.
- Benchmarks and model interpretations in CMS:
  - 2HDM
  - MSSM (various scenarios)
  - NMSSM
  - Randall–Sundrum model (spin 0 Radion)

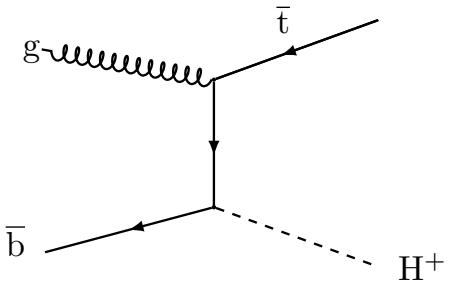


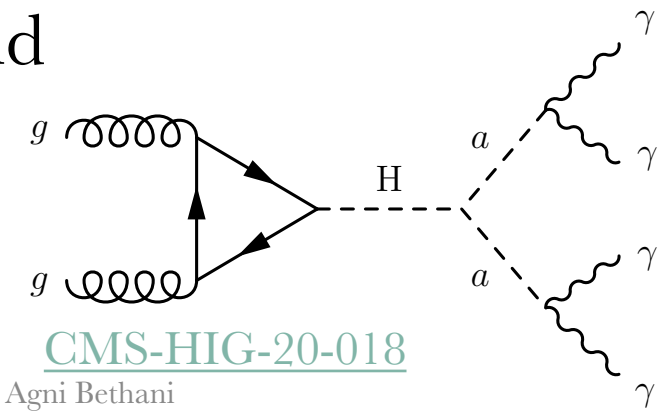
Types of searches in CMS

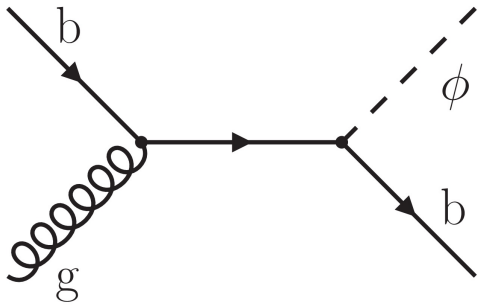
- Heavy scalar with SM-like decays
- X decays into HH or YH (or multi-Higgs)
- Charged Higgs
- Light Higgs bosons (<125 GeV)
- Today I will present a combination of recent (138 fb^{-1}) CMS results and prospect studies for HL-LHC.
  Not an exhaustive list!











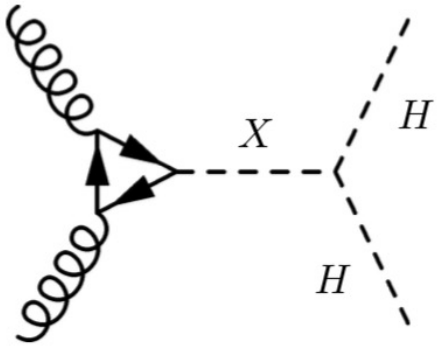
CMS-HIG-20-018

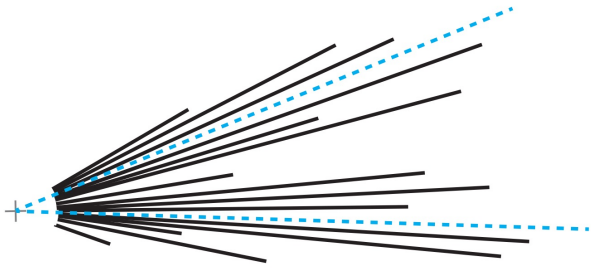
Current results

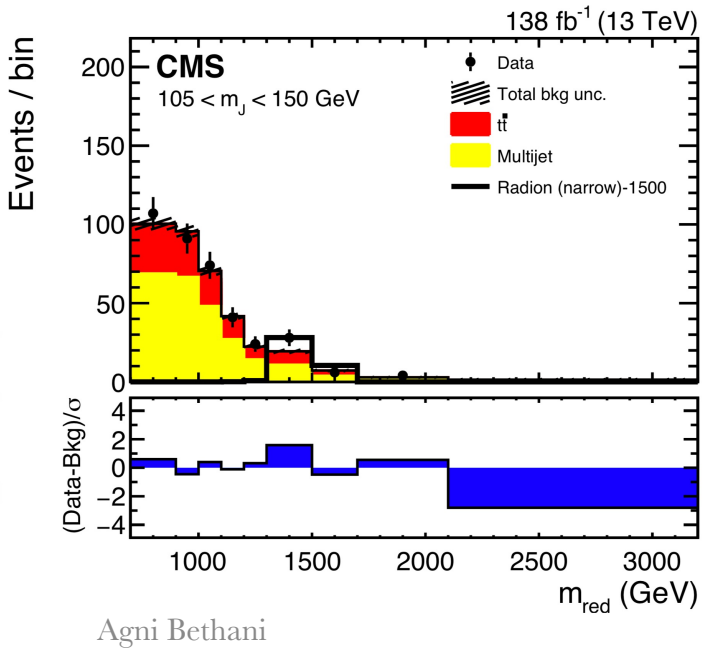
X->HH->bbbb (boosted and semi-boosted) B2G-20-004

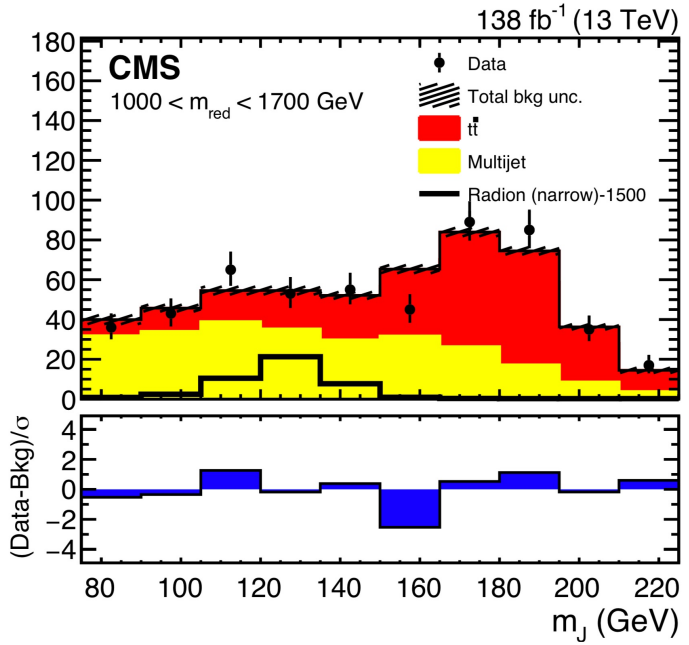
- Search for resonances
  1TeV<mx<3 TeV
  spin 0 (Radion) and spin 2 (Graviton)
- Large R jets identified by DeepAk8
- 3 event categories
  - 1 large R jet and 2 resolved jets
  - 2 large R jets both pass tight selection
  - 2 large R jets both pass loose selection
- QCD multijets background: datadriven
- Fit is performed on 2D m_{J1} vs m_{jjred}

$$m_{jjred} \equiv m_{JJ} - (m_{J1} - m_H) - (m_{J2} - m_H)$$

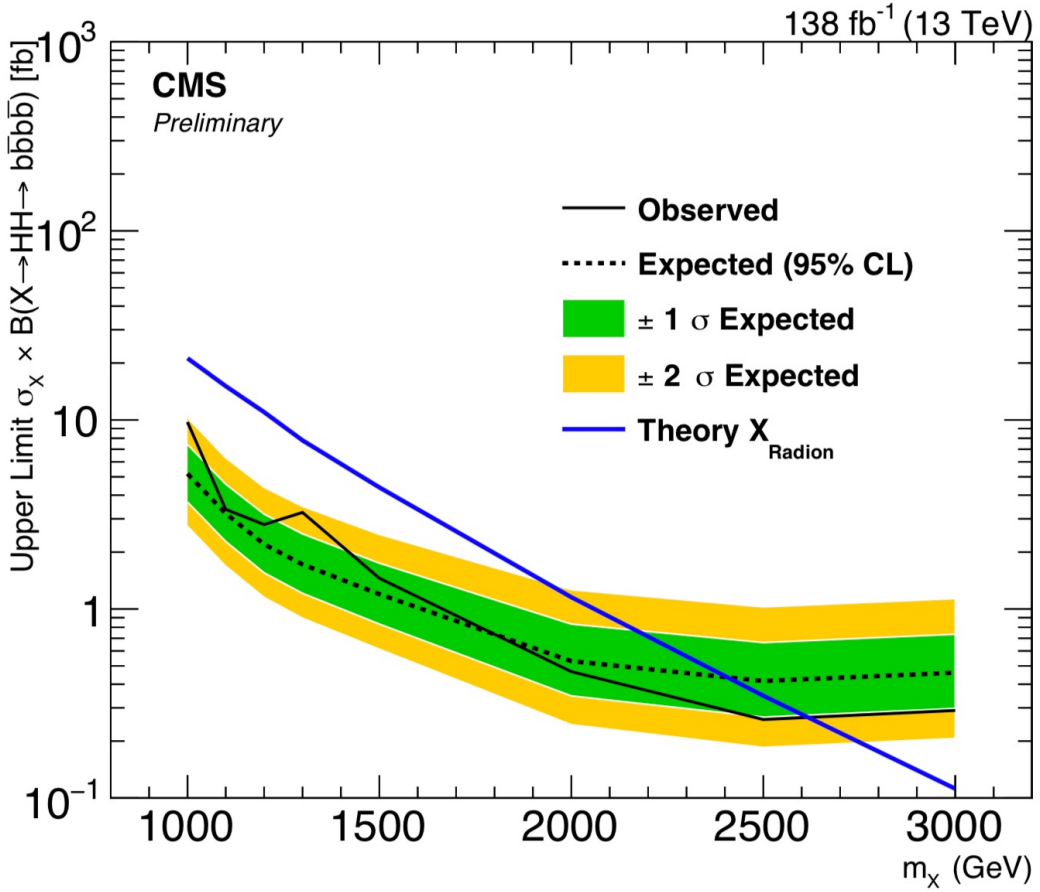






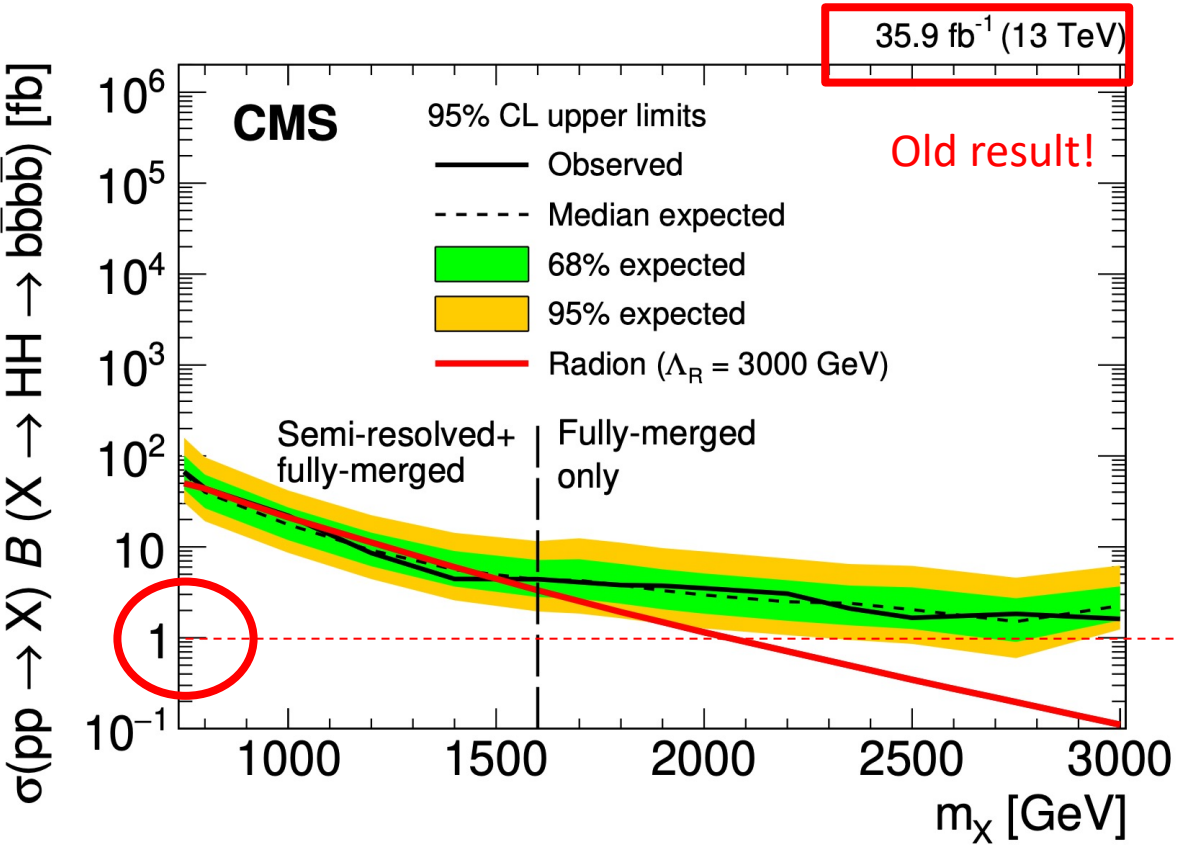


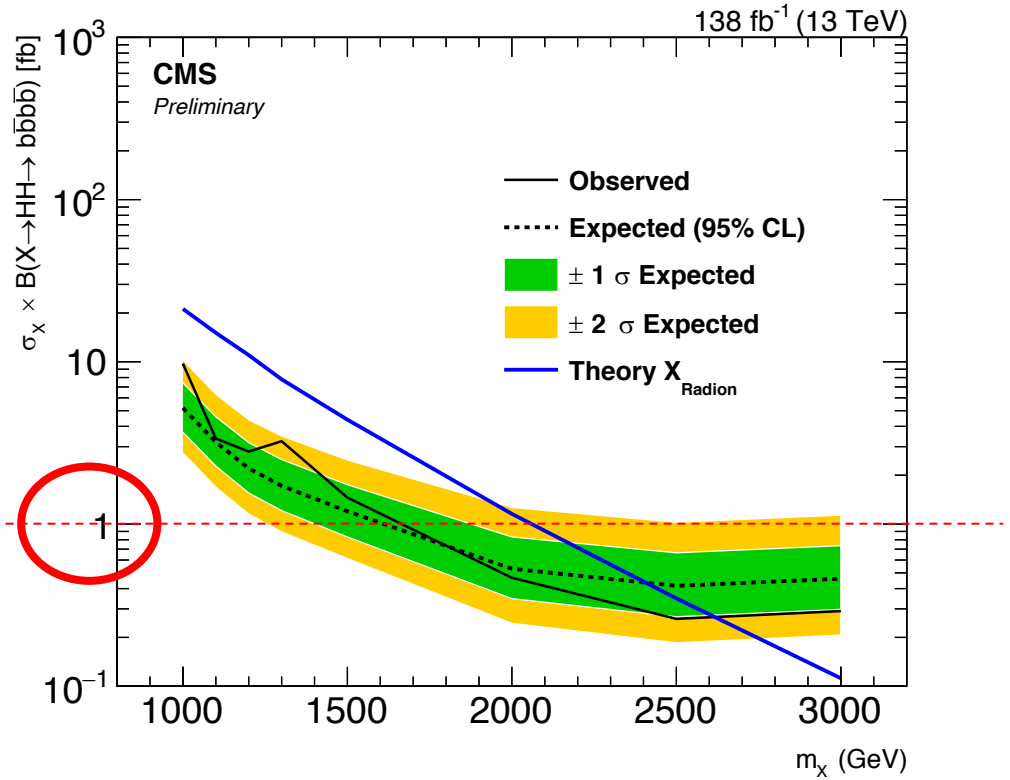
X->HH->bbbb (boosted and semi-boosted) B2G-20-004



X->HH->bbbb (boosted and semi-boosted)

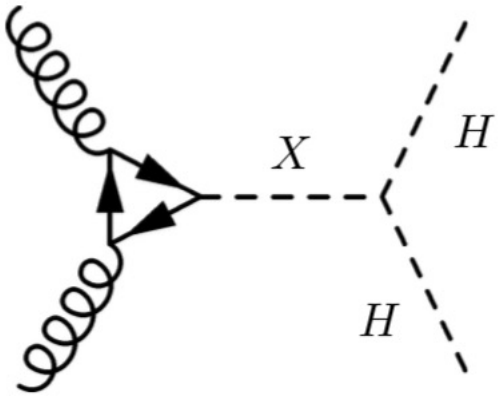
B2G-20-004

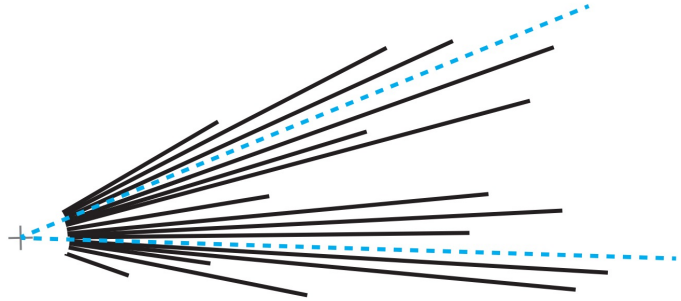




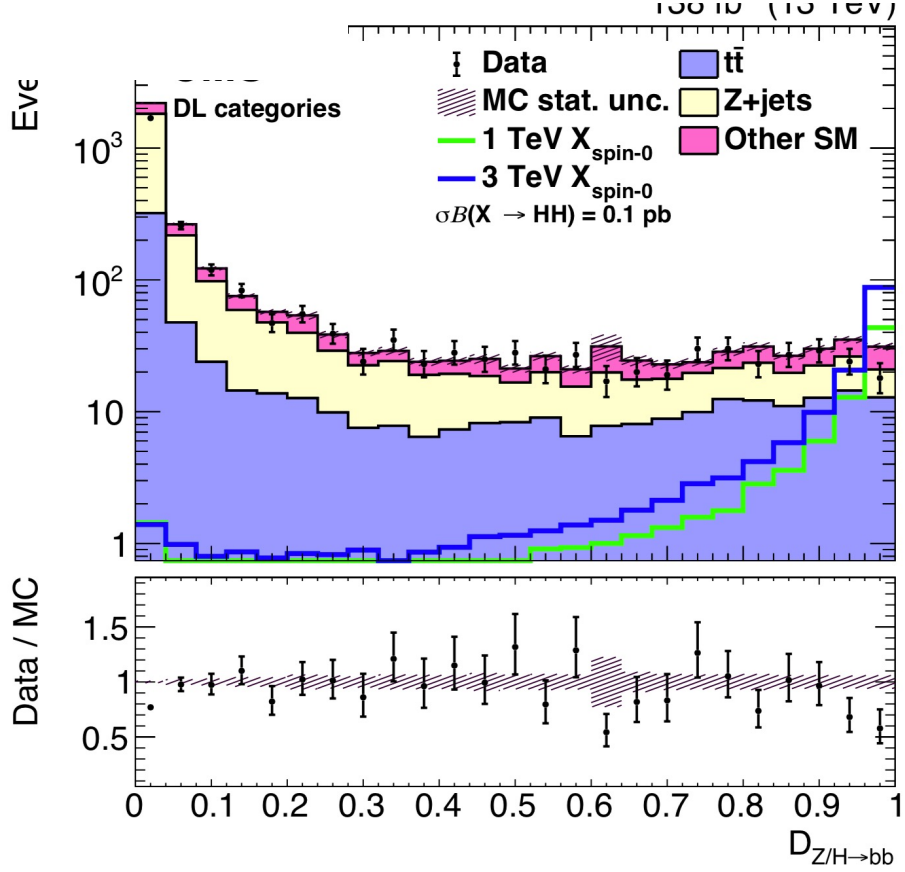
X->HH->bbWW

B2G-20-007

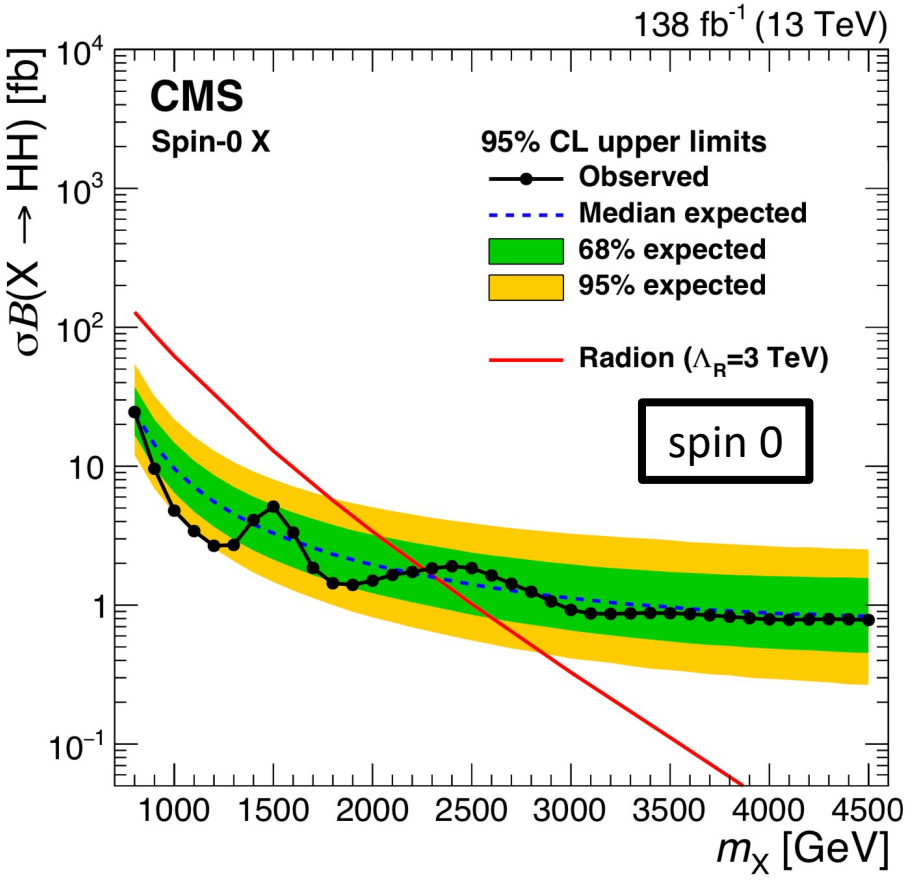




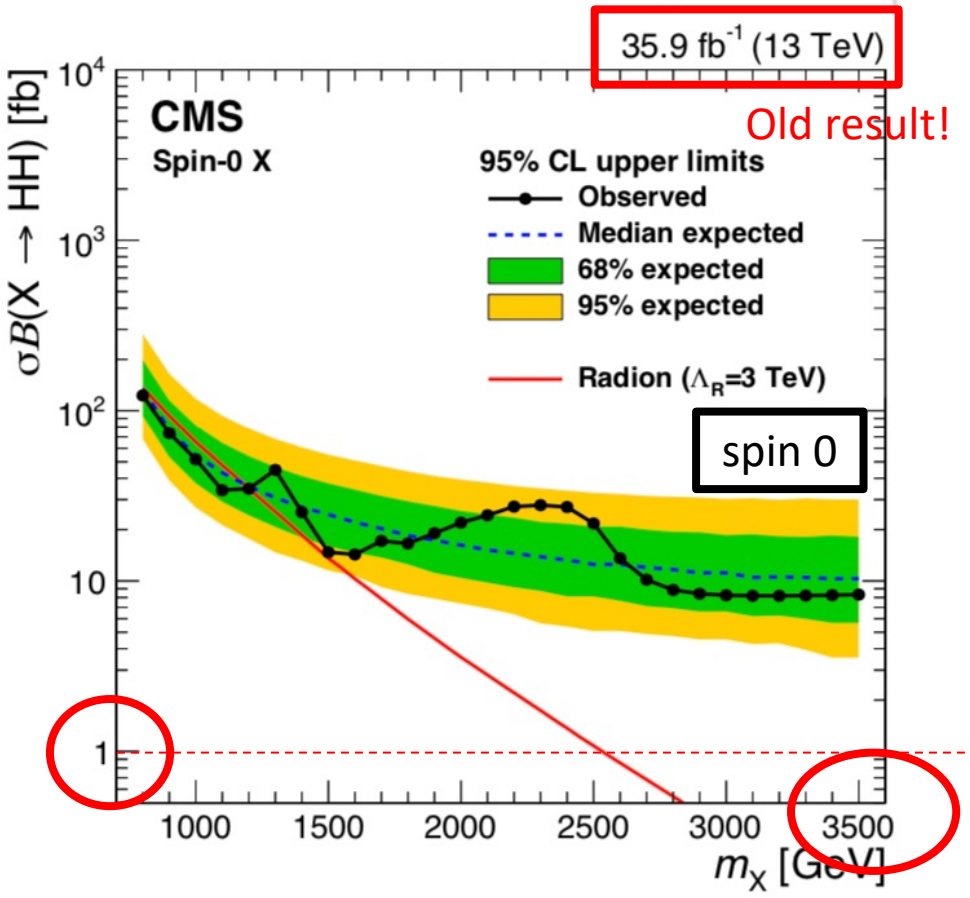
- Search for resonances
  800 GeV<mx<4.5 TeV
  spin 0 (Radion) and spin 2 (Graviton)
- H→bb
  - Large R jet indentified by H→bb tagger ($D_{Z/H\to bb}$)
- H→WW (or H→ττ)
  - Single-lepton (1l) channel
  - Dilepton (2l) channel
- 8 categories in 1l, 4 categories in 2l
  - according the lepton flavour and $D_{Z/H\to bb}$ and signal purity (1l)
- Simultaneous fit in 2D m_{bb}-m_{HH} plane



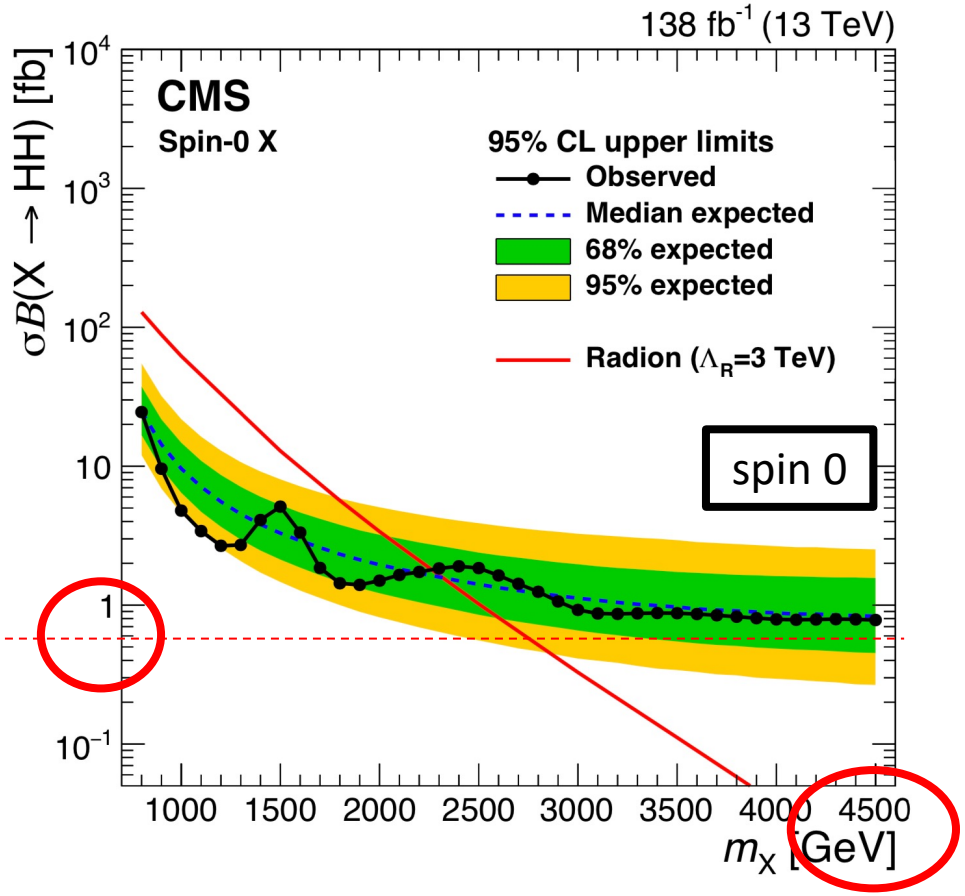
X->HH->bbWW


138 fb^{-1} (13 TeV)
CMS
Spin-0 X
95% CL upper limits
Observed
Median expected
68% expected
95% expected
Radion (Λ_R=3 TeV)
spin 0
$\sigma B(X \rightarrow HH)$ [fb]
10^4
10^3
10^2
10
1
10^{-1}
1000 1500 2000 2500 3000 3500 4000 4500
m_X [GeV]

X->HH->bbWW

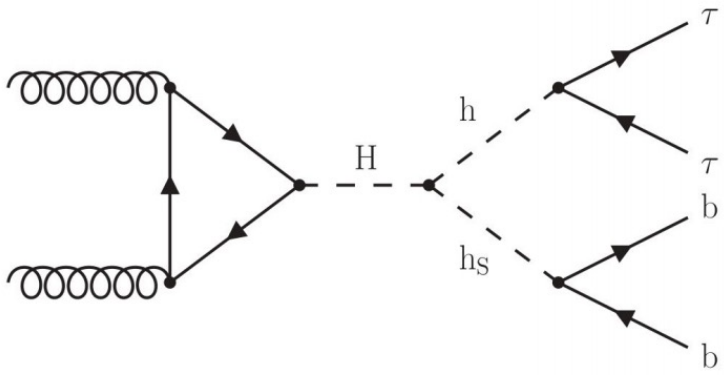


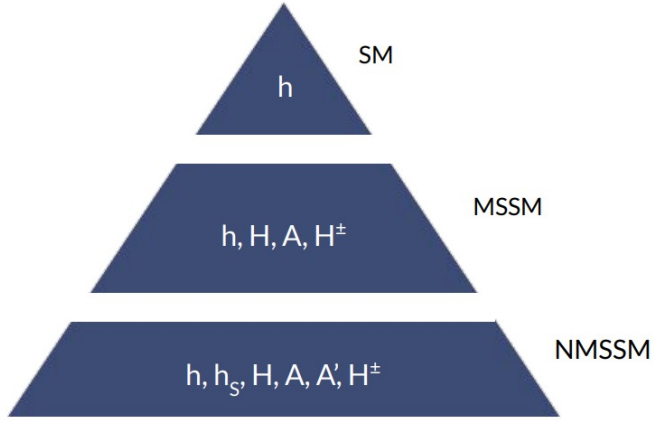
Old result!



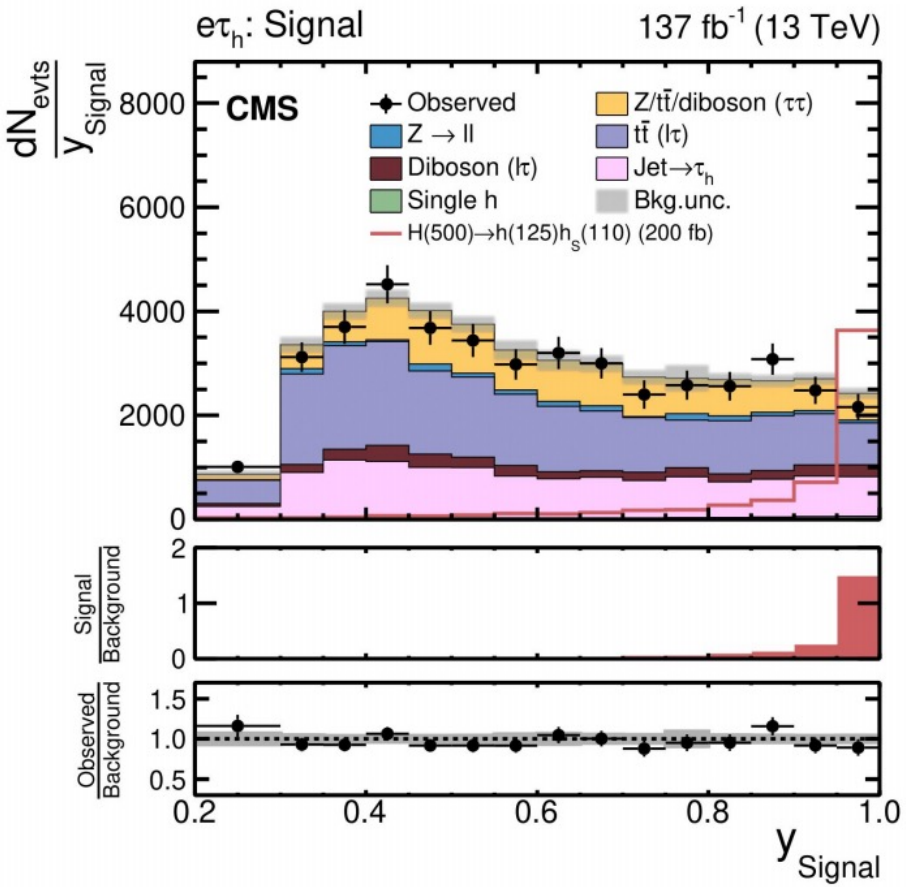
$H \rightarrow Y\,h \rightarrow bb\tau\tau$

HIG-20-014



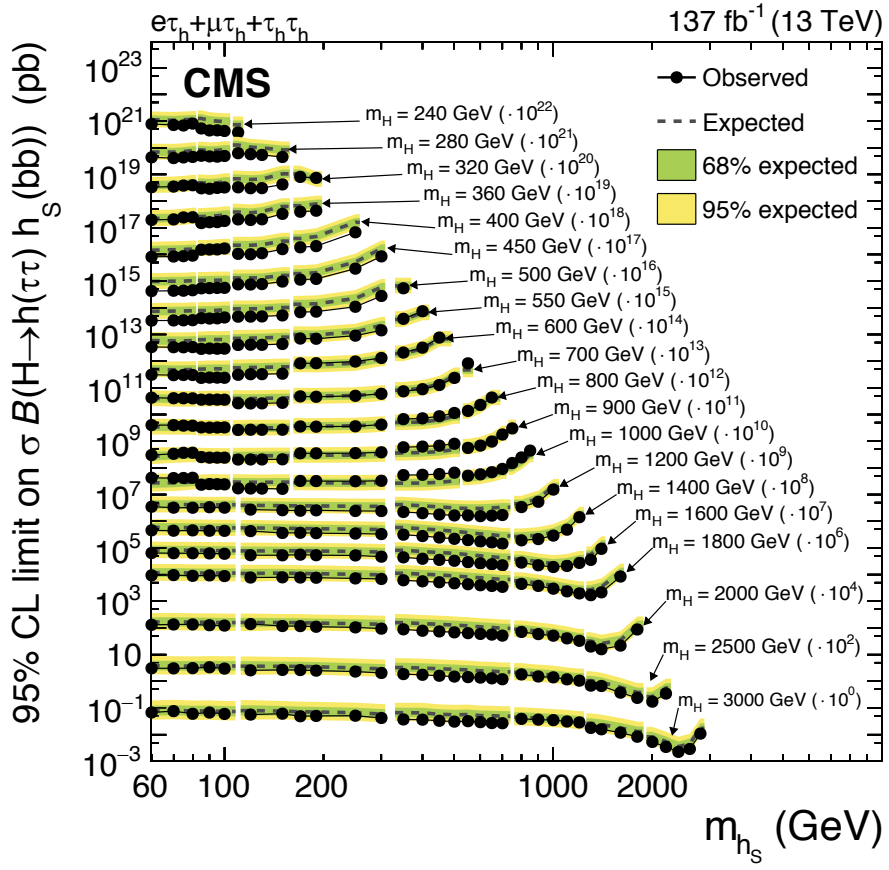


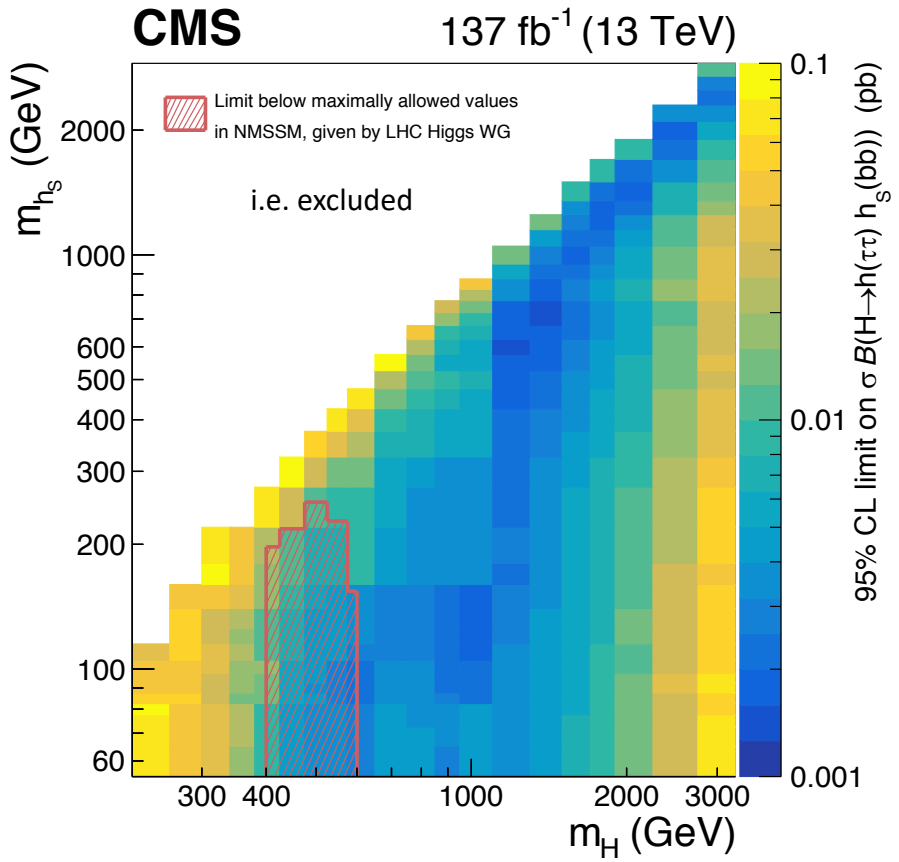
- $240<m_H<3000$ GeV
  $60<m_{hs}<2800$ GeV
- $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$
- multiclass DNN: returns probability-like score for each category, events get assigned to category with highest score.
  - 4 background categories and 1 for each signal
  - 68 trainings
- Maximum likelihood fit performed on the NN score



$H \rightarrow Y\ h \rightarrow bb\tau\tau$

HIG-20-014

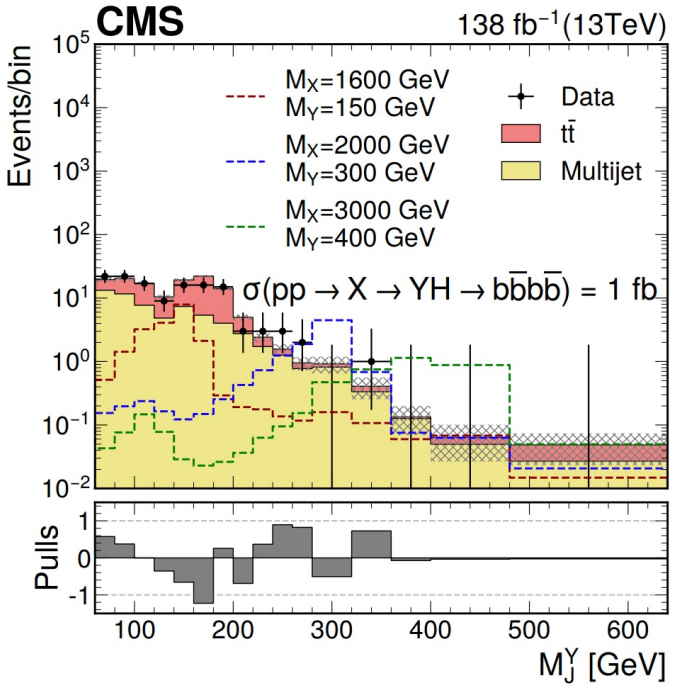


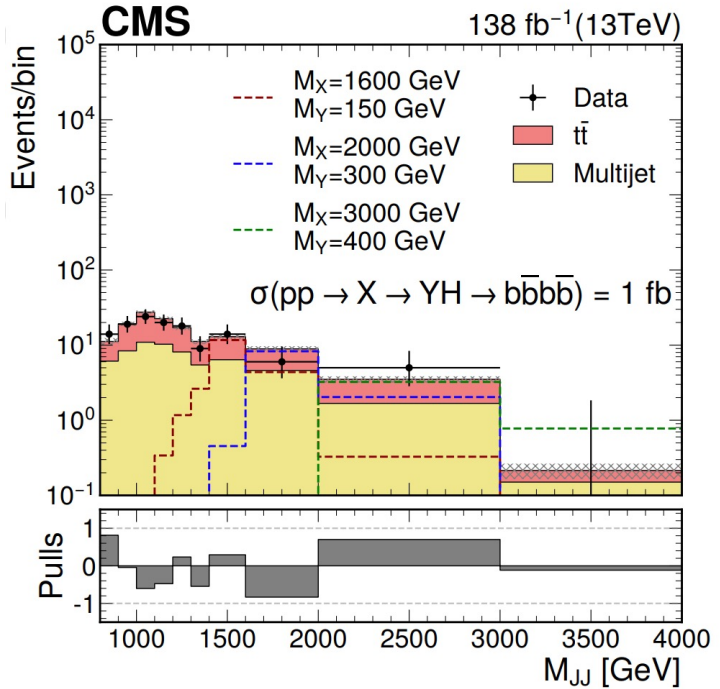


$H \rightarrow Y\ h \rightarrow bbbb$

CMS-PAS-B2G-21-003

- $900 < m_H < 4000$ GeV
  $60 < m_{hs} < 600$ GeV
- Boosted topology
- bb dentified using the ParticleNet algorithm
- ParticleNet scores of the H and Y jets are used to classify events into categories.
- Maximum likelihood fit performed on 2D distribution (M_{JJ},M_J^Y)
  - M_{JJ} invariant mass of the two leadingAK8 jets in the event
  - M_J^Y soft-drop mass of Y candidate





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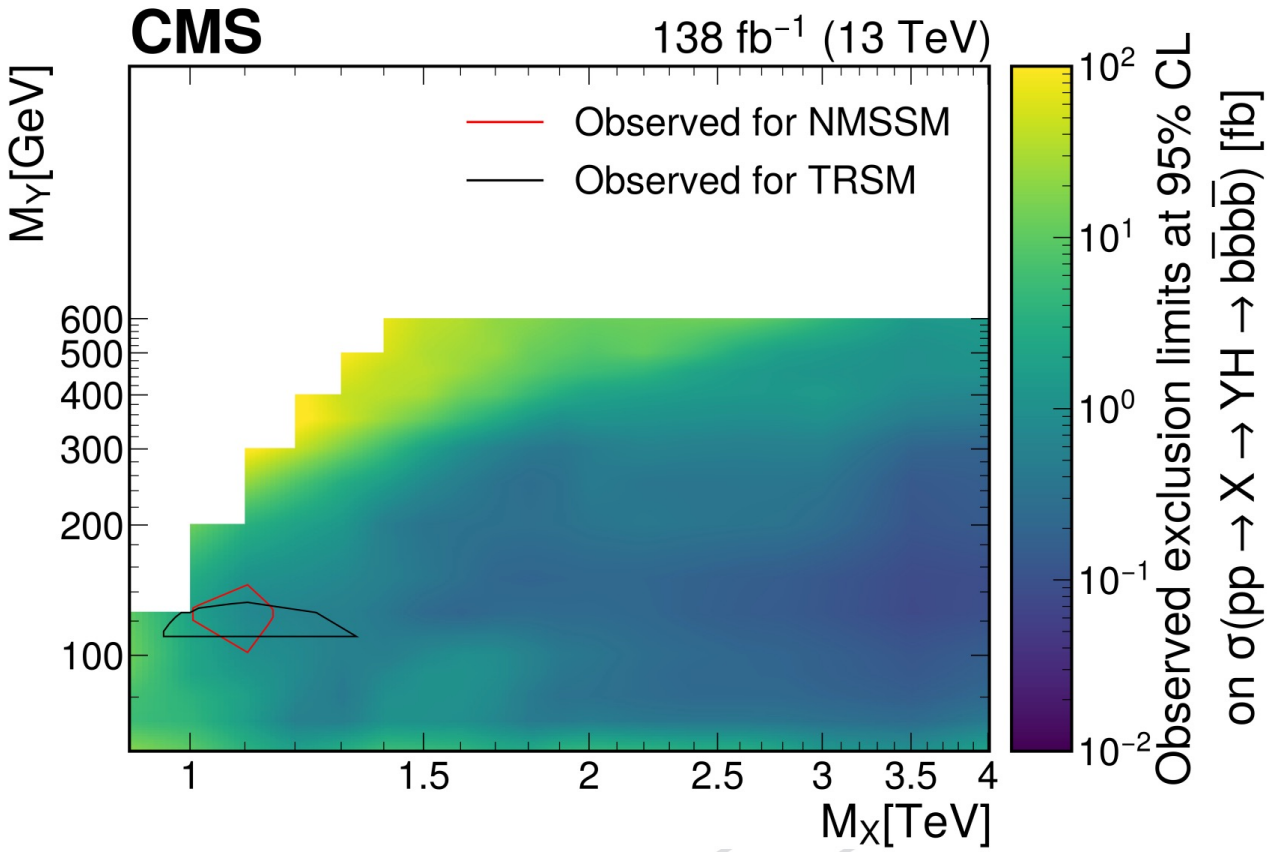
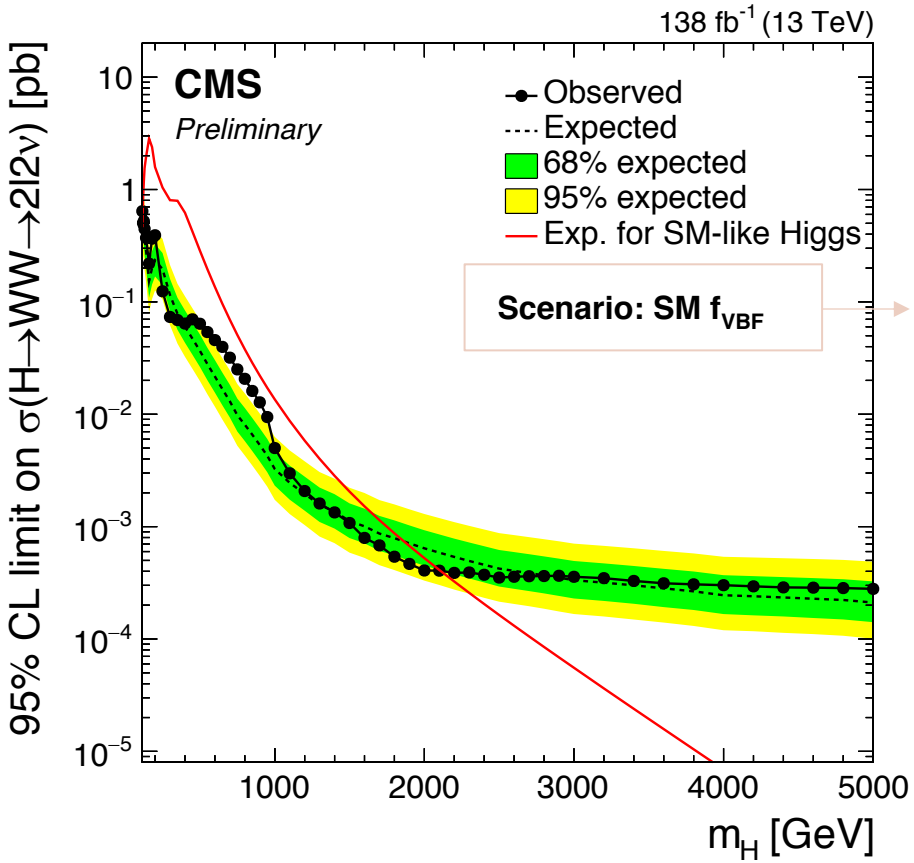


H->WW [CMS-PAS-HIG-20-016]

- Fully leptonic
- m_H 115 GeV-5 TeV
- ggF and VBF signal production processes are considered
- Different scenarios for the relative ggf and VBF cross-section investigated
- categories: “ggF”, “VBF” and “background”by a DNN.
- DNN to reconstruct m_H
  - score used for signal extraction

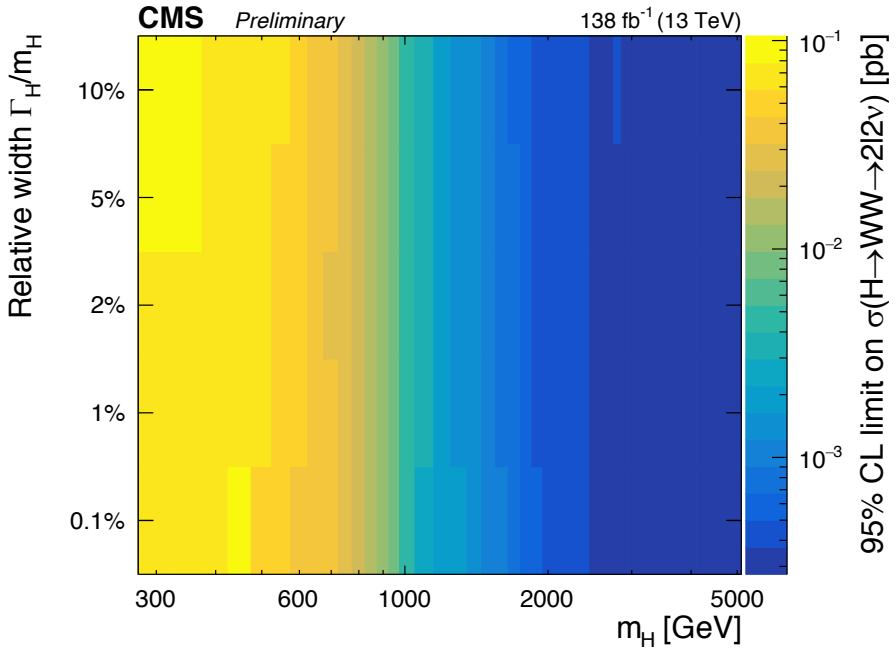


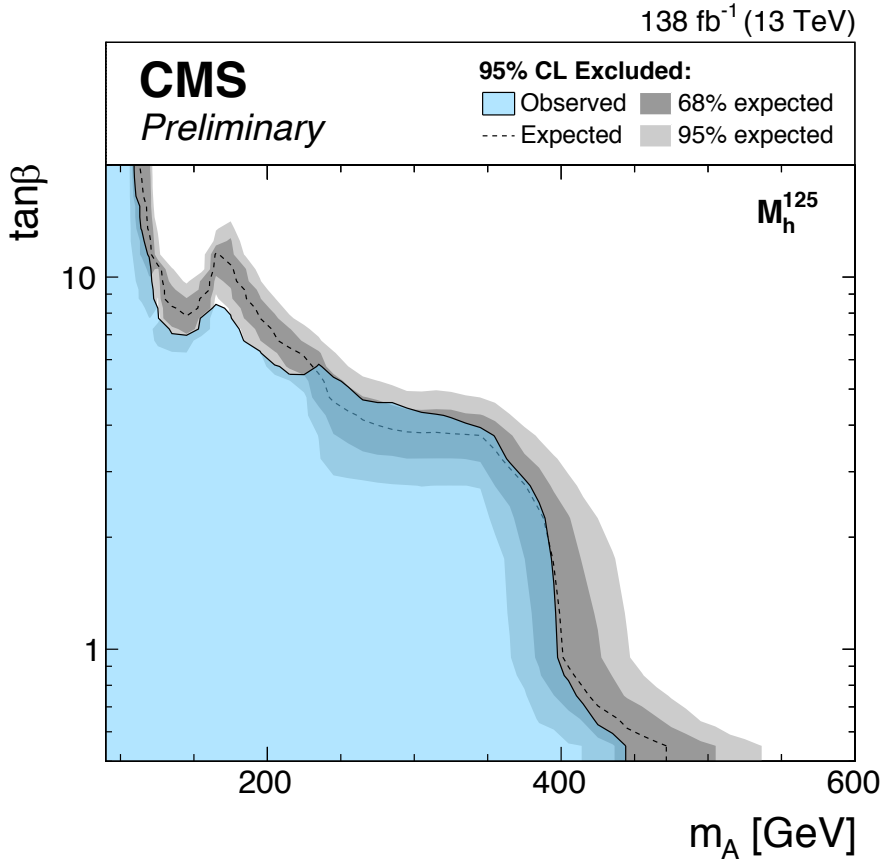
other scenarios:
- fVBF = 1
- fVBF = 0
- floating fVBF

H->WW

CMS-PAS-HIG-20-016

- Shown here for baseline MSSM.
- Many more presented in the publication

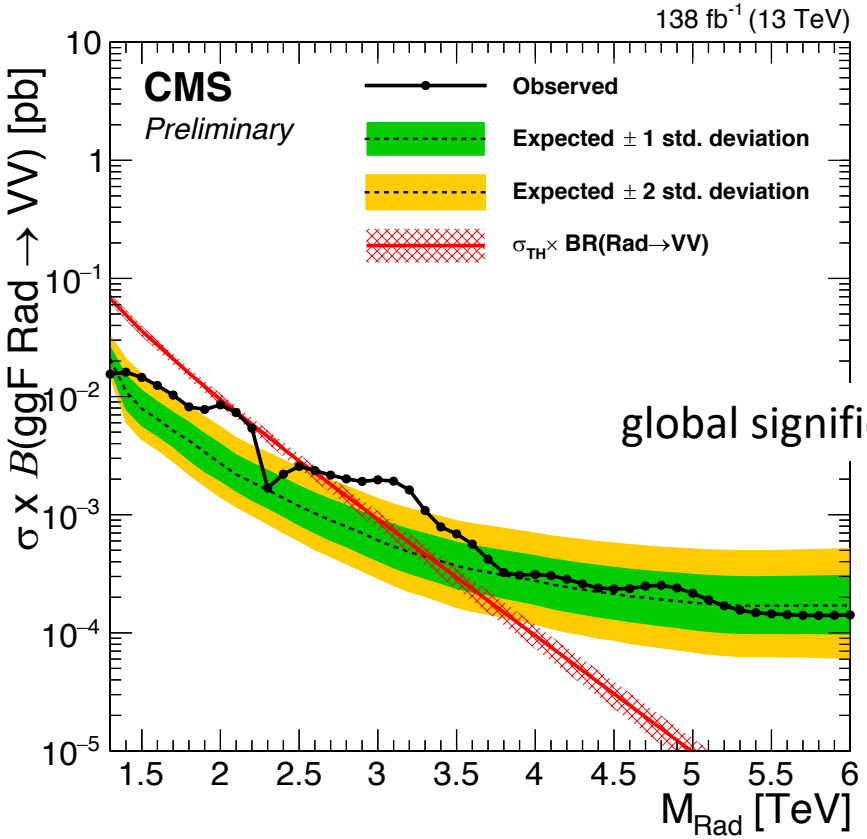




X->WW,WZ,ZZ,WH,ZH

B2G-20-009

- All-jets final state
- mX> 1.3 TeV
- boosted topology, large R jets
- Drell-Yan production, ggf or VBF
- DNN to distinguish jets from W, Z, and H decays from other jets.
- Events are categorized to optimise to VBF category
- a3D maximum likelihood fit (mjj , mj1 , mj2)

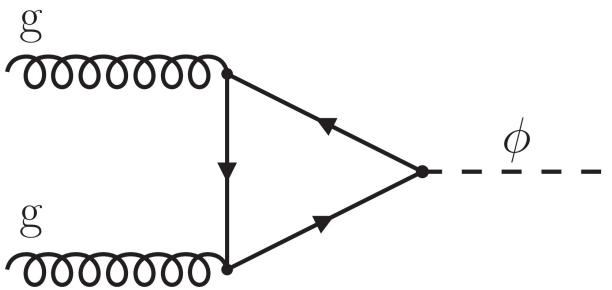


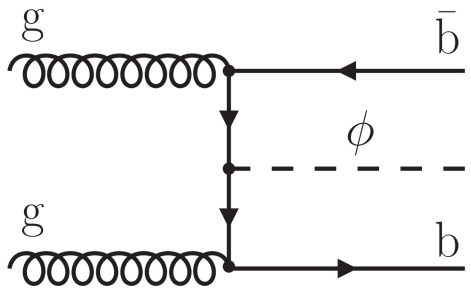
global significance 2.3σ

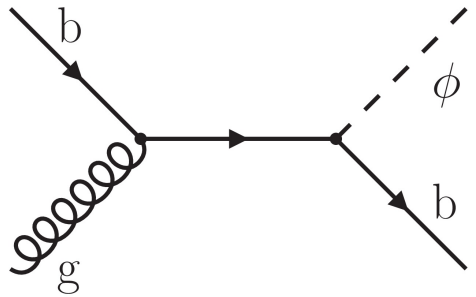
MSSM H/A->ττ

HIG-21-001

- ggϕ and in bbϕ
- 60 GeV to 3.5 TeV
- eμ, eτ_h , μτ_h , or τ_h τ_h
- Categories:
  - b-tag and no b-tag categories to identify bbϕ
  - in leptonic channels additional high/low mass categories
  - further categorization based on kinematic properties.
- Background estimation based of real or fake tau
  - real τ: embedding
  - fake τ: fake-factor method, SS-method

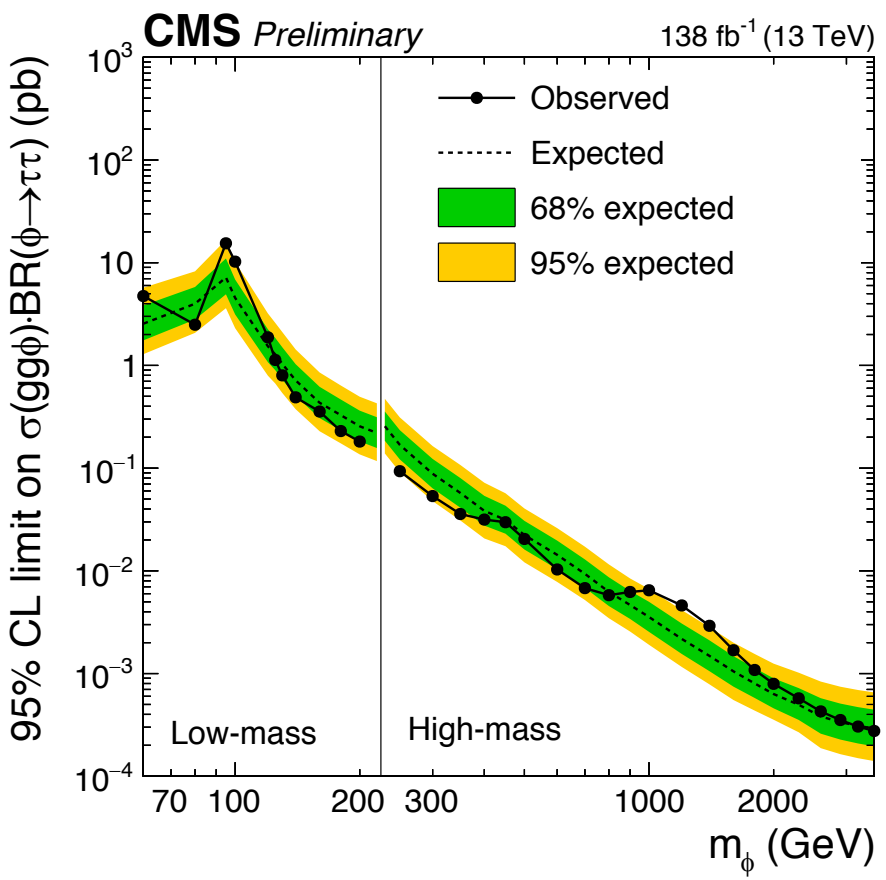


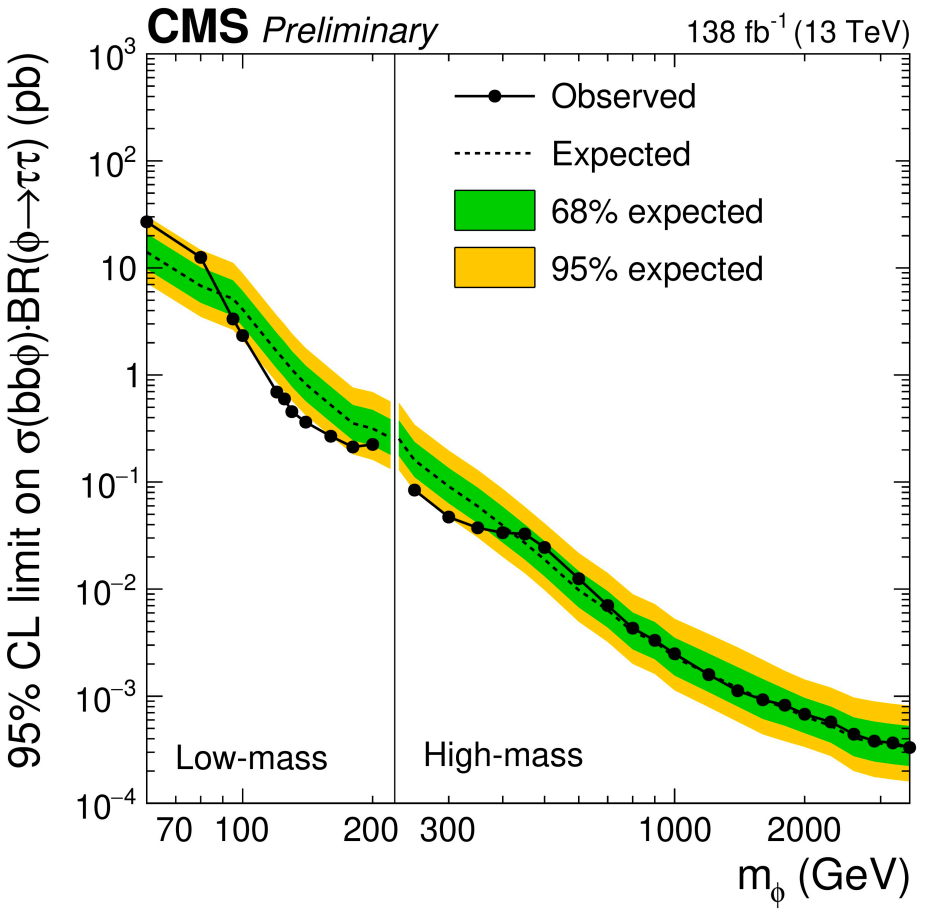




MSSM H/A->ττ

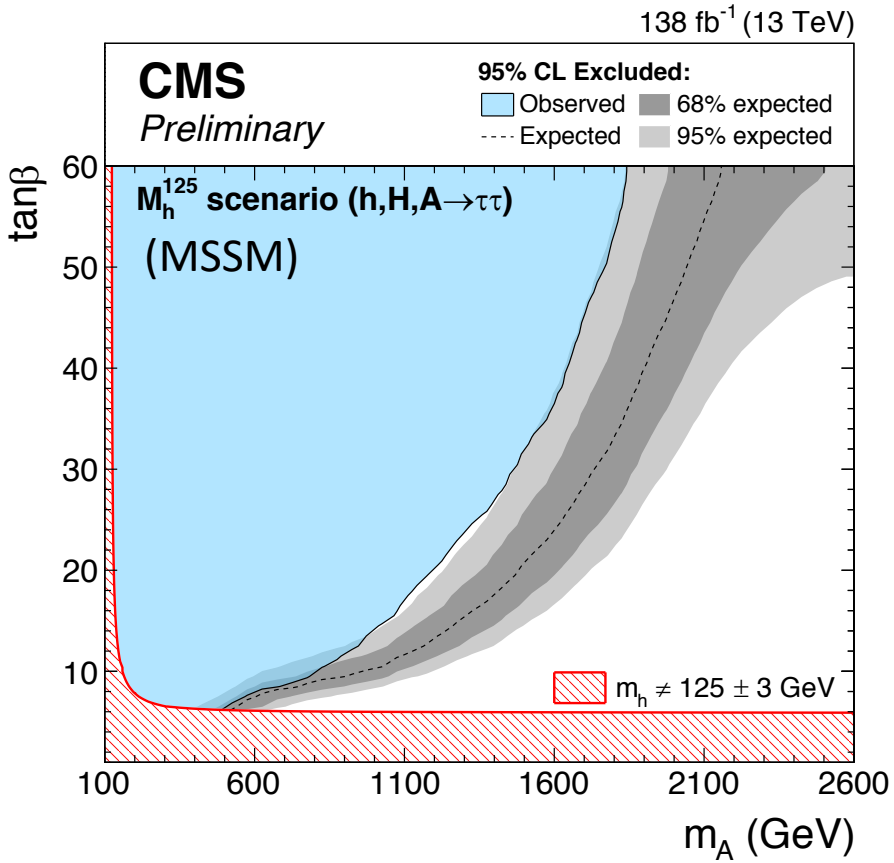
HIG-21-001

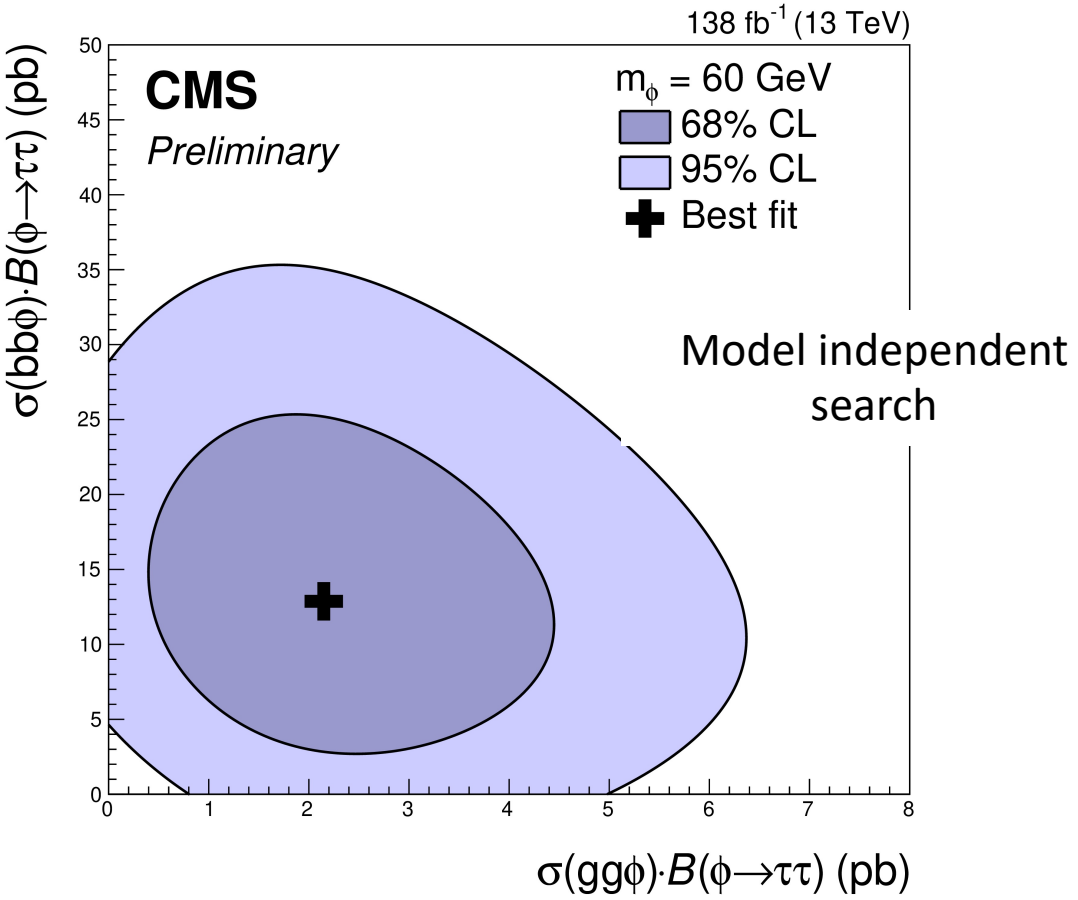




Local pp-values equivalent to about 3σ at 0.1 and 1.2 TeV.

MSSM H/A->ττ

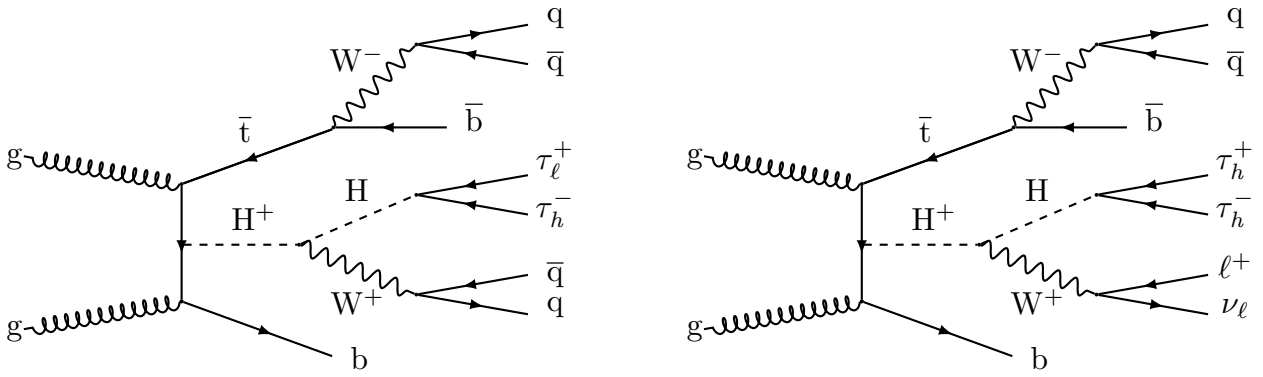




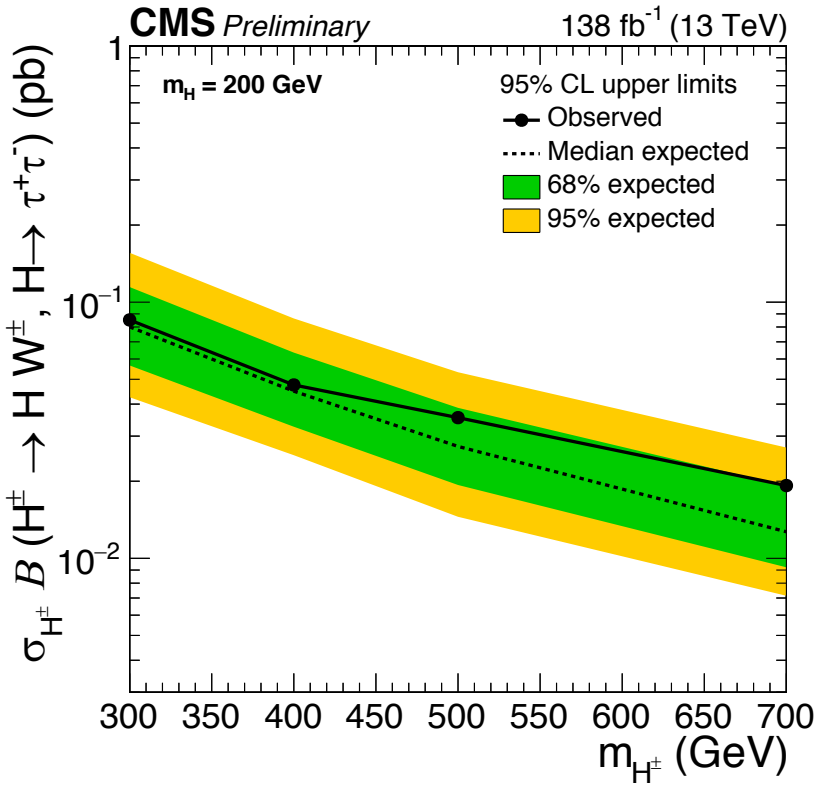
Model independent search

$H^{+/-} \rightarrow HW^{+/-}$

CMS-PAS-HIG-21-010



- H heavy neutral Higgs boson
- one isolated electron or muon and a pair of tau leptons with at least one decaying hadronically
- $e\tau_h\tau_h$, $\mu\tau_h\mu\tau_h$, $e\tau_h\tau_h\tau_h\tau_h$, and $\mu\tau_h\tau_h\mu\tau_h\tau_h$.
- BDT sig vs background
- Fit BDT shape



Prospects

HL-LHC


You are here
LHC / HL-LHC Plan
HiLumi
LARGE HADRON COLLIDER
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13 - 14 TeV
14 TeV
energy
splice consolidation
button collimators
R2E project
cryolimit
interaction
regions
Diodes Consolidation
LIU installation
Civil Eng. P1-P5
inner triplet
radiation limit
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
5 to 7.5 x nominal Lumi
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
30 fb-1
190 fb-1
350 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1
HL-LHC TECHNICAL EQUIPMENT:
DESIGN STUDY
PROTOTYPES
CONSTRUCTION
INSTALLATION & COMM.
PHYSICS
HL-LHC CIVIL ENGINEERING:
DEFINITION
EXCAVATION
BUILDINGS

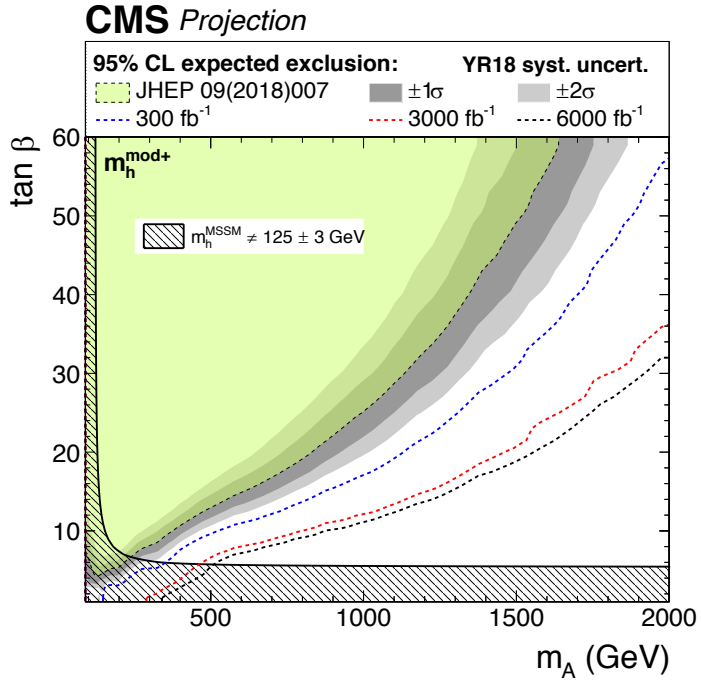
HL-LHC

- Searching for an extended Higgs sector (i.e. additional Higgs boson) at high and low masses, is an important part of the HL-LHC Higgs physics program.
- Benefit from increased sample size, detector improvements and reconstruction improvements.
- Potential to study unexplored production modes and decay processes.
- The mass reach for new heavy Higgs bosons can be pushed to a few TeV

CMS PAS FTR-18-017

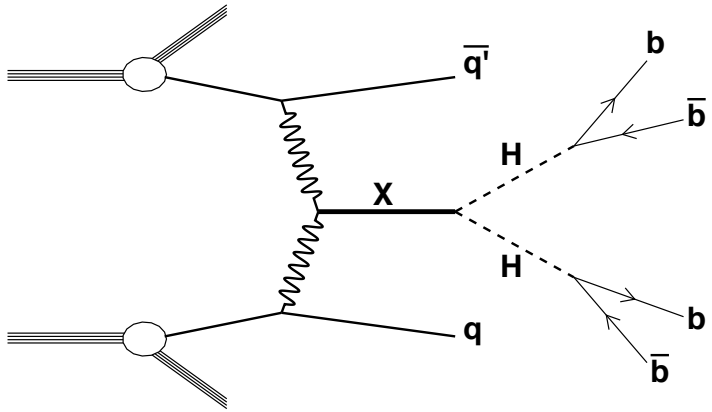
MSSM H/A->ττ (HL)

- heavy Higgs bosons decaying to ττ leptons
- projection from a 36fb^{-1} analysis
- mH>1 TeV, improvement about one order of magnitude @ 95% limits on cross-section the cross section.
- in MSSM expected possible exclusion of mH from 1.25 to 2 TeV for tanβ=36

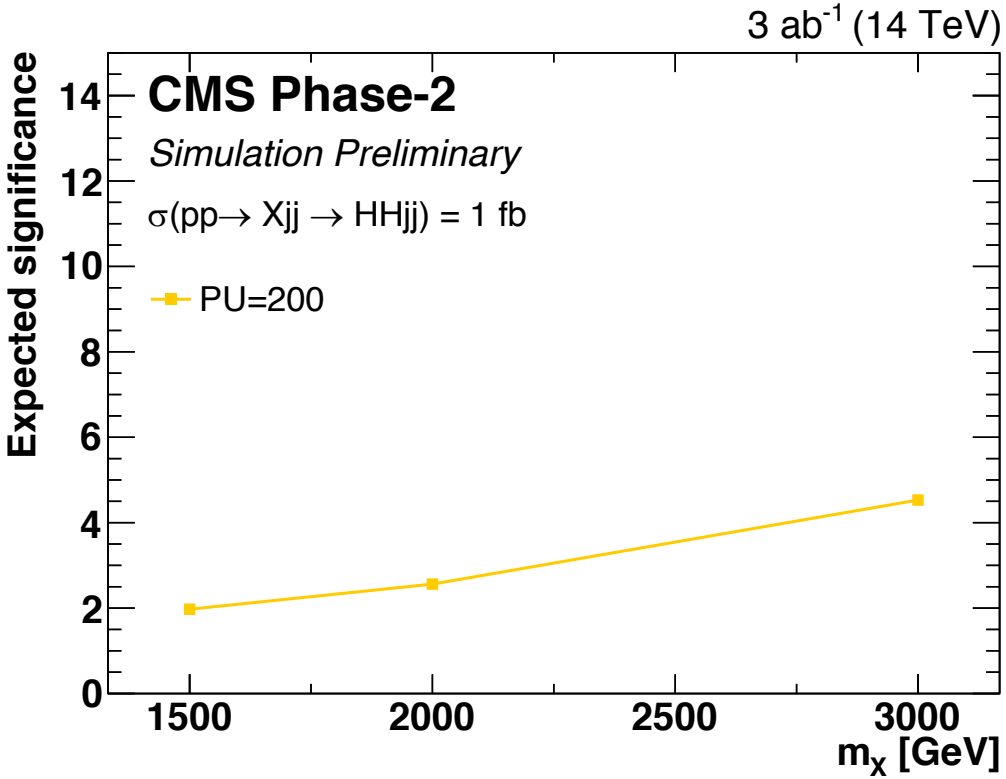


VBF X->HH->bbbb (HL)

CMS PAS FTR-18-003



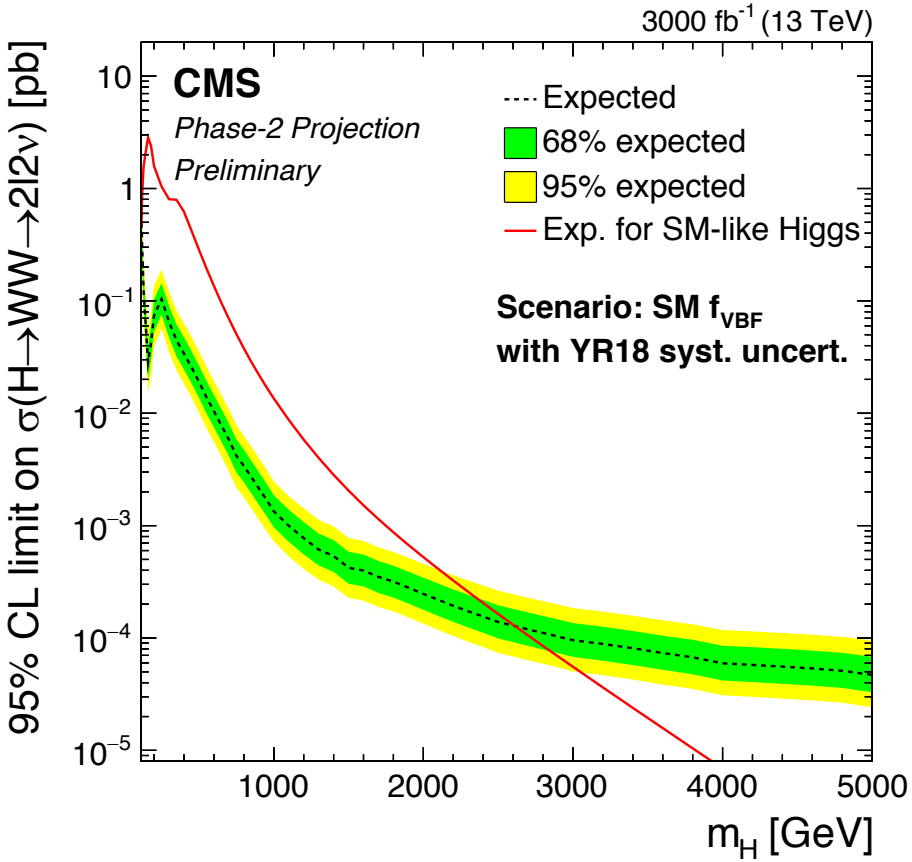
- 1500 and 3000 GeV
- Boosted topology, merged jets
- Spin-0 radion
- extrapolation of a 36 fb^{-1} analysis
- In the future better event reconstruction and identification techniques
  plus
  upgrades (Phase 2) CMS detector design, will help improve these projections even further.

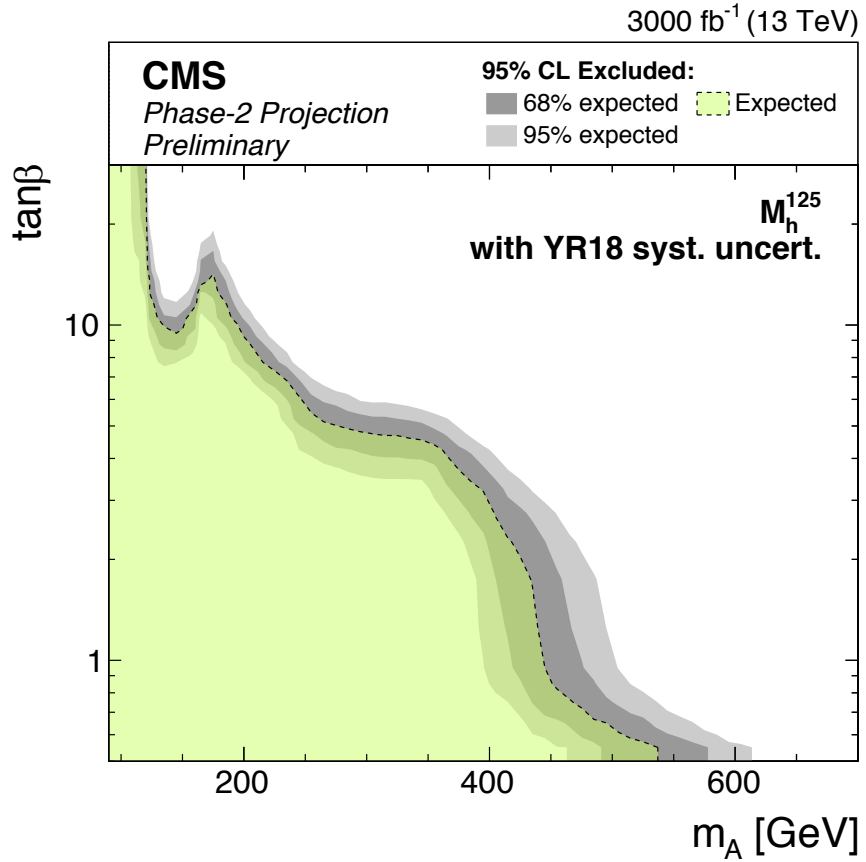


H->WW

CMS-PAS-HIG-20-016

- Fully leptonic
- ggF and VBF
- part of the same publication as presented earlier





Conclusions

- CMS has a rich program for searches of scalar particles
  - however still many final states, productions and different interpretations to do!
- Exploiting boosted topologies and machine learning
- Searches are performed in model independent way, varying parameters like mass and width, relative cross-sections
- Variety of benchmark models used in a variety interpretations
- HL-LHC will bring improvements
- Beyond HL: new colliders -> new energy frontier->new particles?

Backup

MSSM scenarios

- M^{125}_{h} (τ): With respect to the baseline scenario (M125 h), this scenario considers light staus.
- M^{125}_{h} (χ): With respect to the baseline scenario, this scenario considers light neutralinos and charginos.
- M^{125}_{h} (alignment): This scenario considers alignment without decoupling. The lighter scalar h is the SM Higgs boson.
- $M^{125}_{h,EFT}$: With respect to the baseline scenario, this scenario is designed specifically for the low tanβ region and is only defined up to tan β = 10. The SUSY mass scale is adjusted throughout the mA-tan β-plane to set the mass of the light CP-even Higgs boson h close to 125 GeV.
- $M^{125}_{h,EFT}$(χ): This scenario is like $M^{125}_{h,EFT}$, but assumes light neutralinos and charginos similar to M^{125}_{h} (χ) with respect to M^{125}_{h} .