Higgs and New Physics at CMS

P. Bortignon
University of Florida
on behalf of the CMS collaboration

The 26th International Workshop on Weak Interactions and Neutrinos
University of California
Irvine, June 19 – 24, 2017

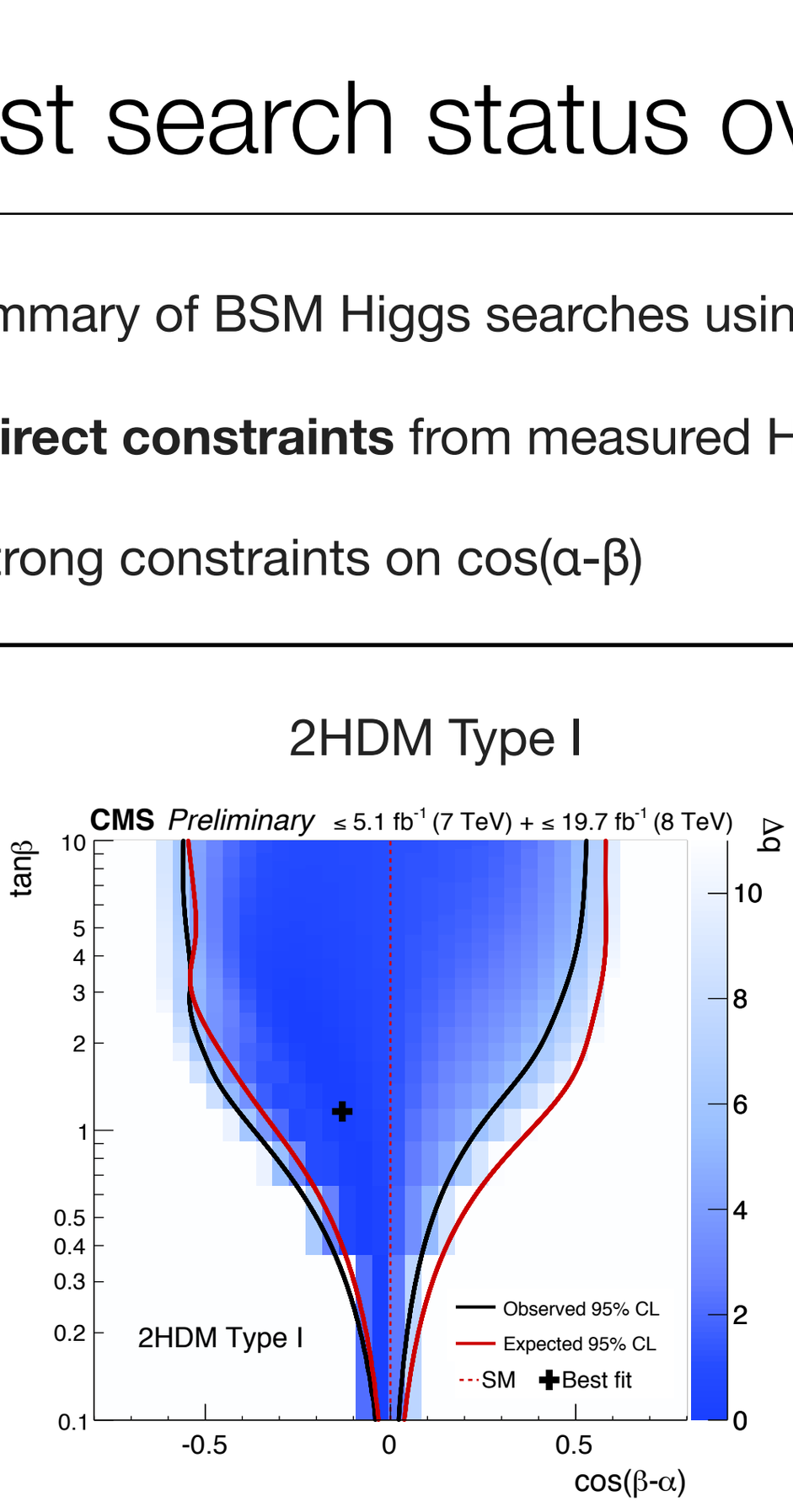
Introduction

- A Higgs boson consistent with the Standard Model has been observed
  - the detailed structure of the Higgs sector is still under investigation
  - the SM still is not a satisfying theory
- Beyond the Standard Model theories propose solution to SM limits
  - some extending the Higgs sector (2HDM, hMSSM, etc.)
  - some predicting massive particles that couple with the SM Higgs (Composite Higgs, Dark Matter, Extra dimensions, Graviton, etc)
  - the Higgs sector is a powerful tool for probing physics beyond the SM

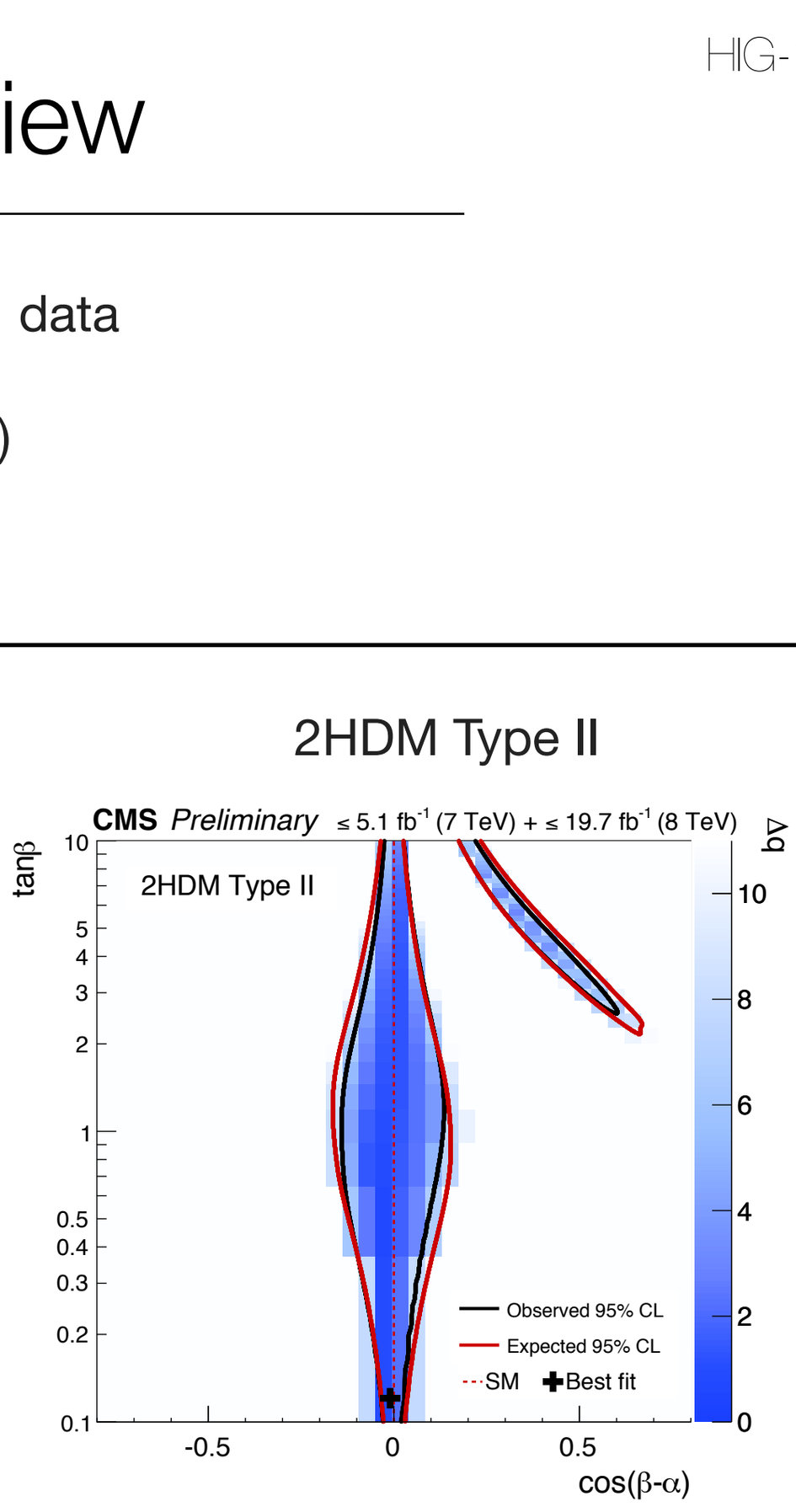
Past search status overview

- Summary of BSM Higgs searches using Run1 data
- **Indirect constraints** from measured Higgs (h)
  - strong constraints on cos(α-β)

2HDM Type I

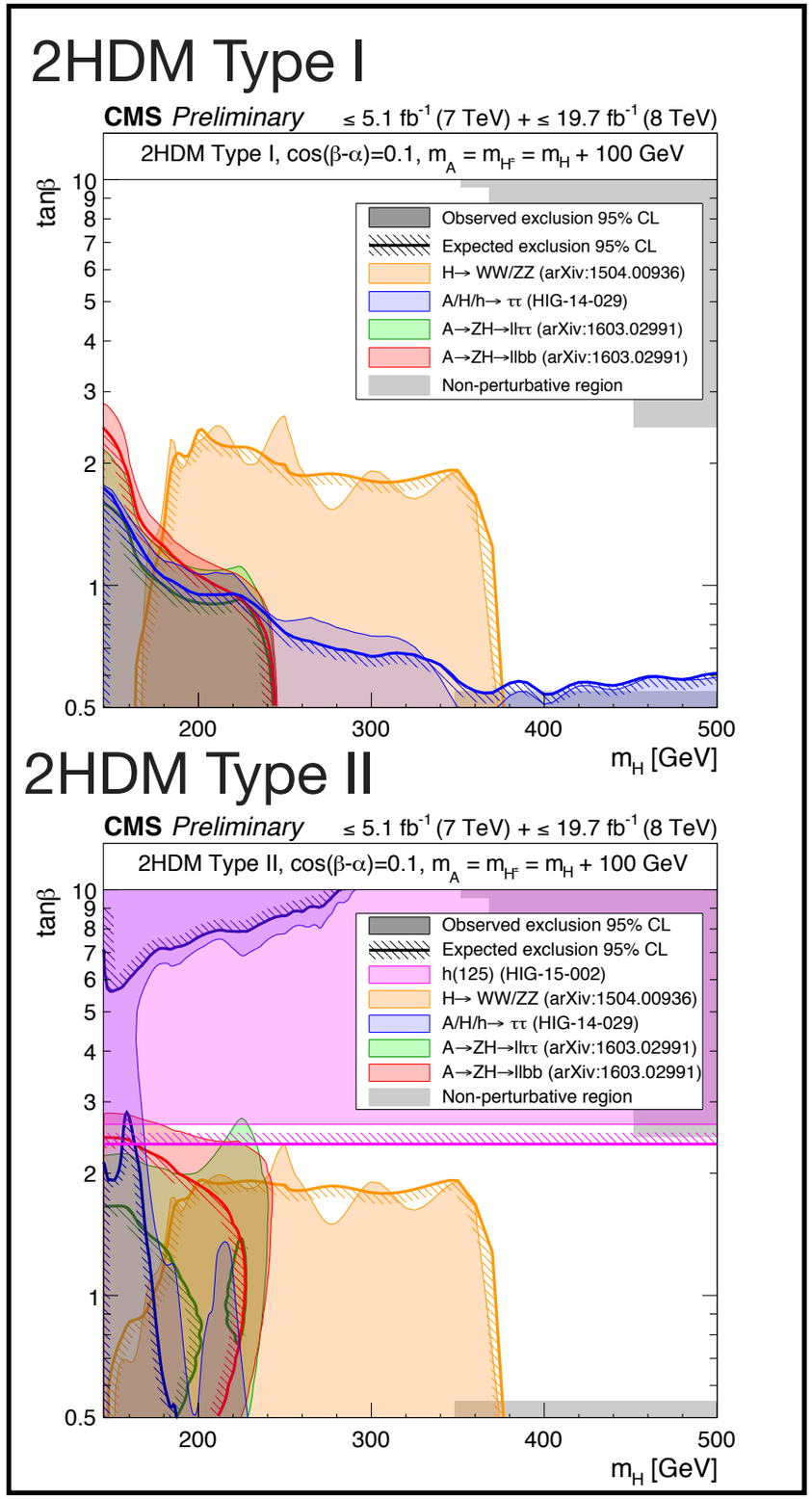


2HDM Type II



Past search status overview

- Summary of BSM Higgs searches using Run1 data
- Constrain from **direct heavy neutral A/H searches**
- cos(α-β) = 0.1
  - H0 interpreted as SM Higgs (h)
  - masses of H and A are degenerate
  - mA, $m_{H^+} = m_H + 100$ GeV
    - to allow the A⟶ZH process
- Analyses probe different part of the phase space
  - A/H/h → ττ channel most sensitive to all

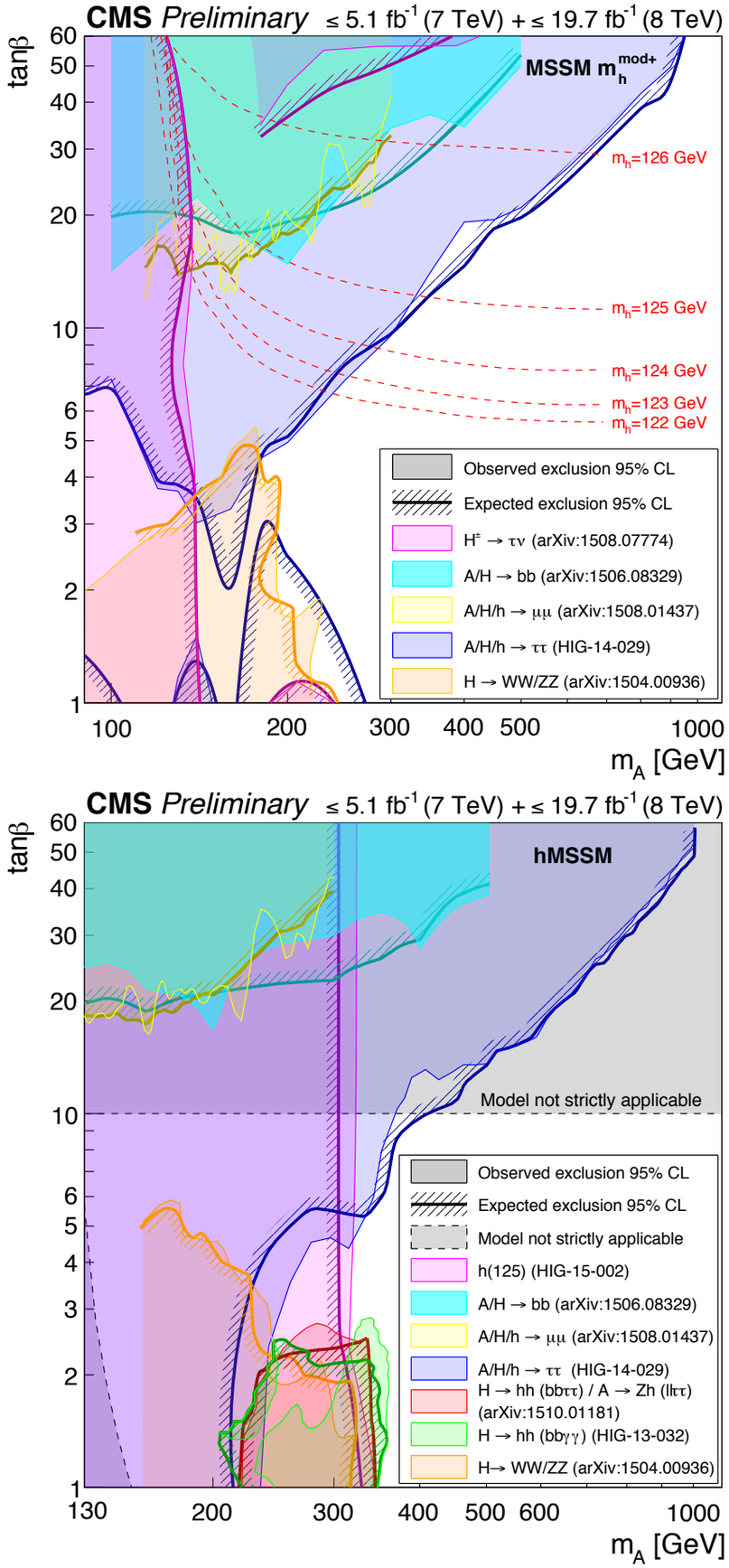


Past search status overview

- m_h^{mod+} scenario:MSSM compatible with m_h = 125GeV
- hMSSM scenario sets $m_h \equiv 125$ GeV

In summary

- 2HDM type-I
  - constrained cos(β – α) <0.5 driven by SM Higgs
  - m_H<380 GeV and tan β < 2 driven by direct X ⟶ VV
- 2HDM type-II
  - constrained cos(β – α) <0.2 by SM H (with small corridor around tan β >2) and direct X ⟶ VV
- m_h^{mod+}
  - m_A strongly constrained up to 300 GeV
- hMSSM
  - m_A excluded up to 300 GeV



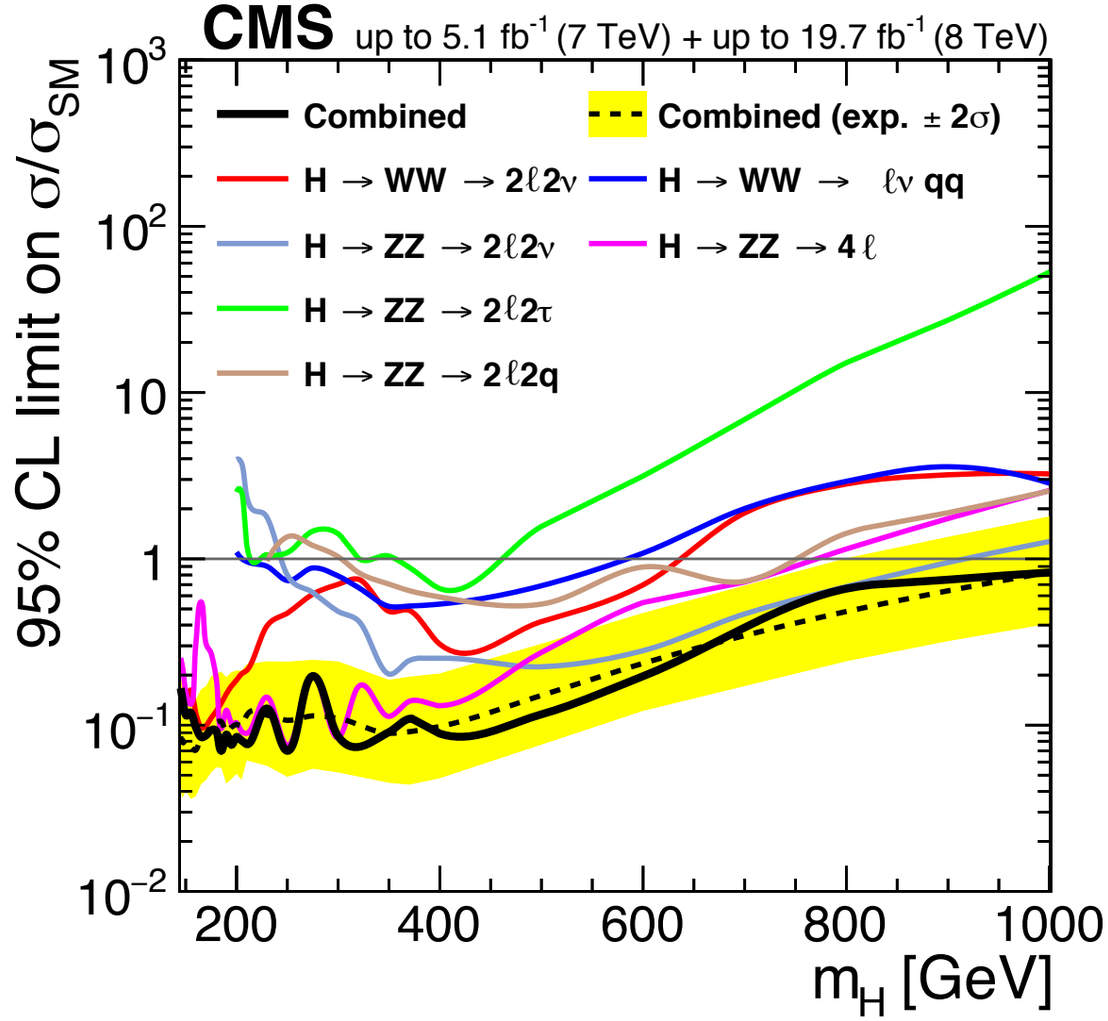
Outline

- This talk will cover recent results from CMS on BSM Higgs searches
  - neutral heavy Higgs, graviton
  - charged Higgs, higgs triplet model
  - vector-like quark $X_{5/3}$, T, Y, composite Higgs model (CHM)
- In the same working group there will be dedicated talks for CMS results on
  - Standard Model Higgs production
  - Standard Model Higgs properties
  - Double Higgs Searched
  - Anomalous H-VV coupling
  - Charged Lepton Flavour / Lepton Number violation searches

JHEP 10 (2015) 144

X ⟶ VV searches

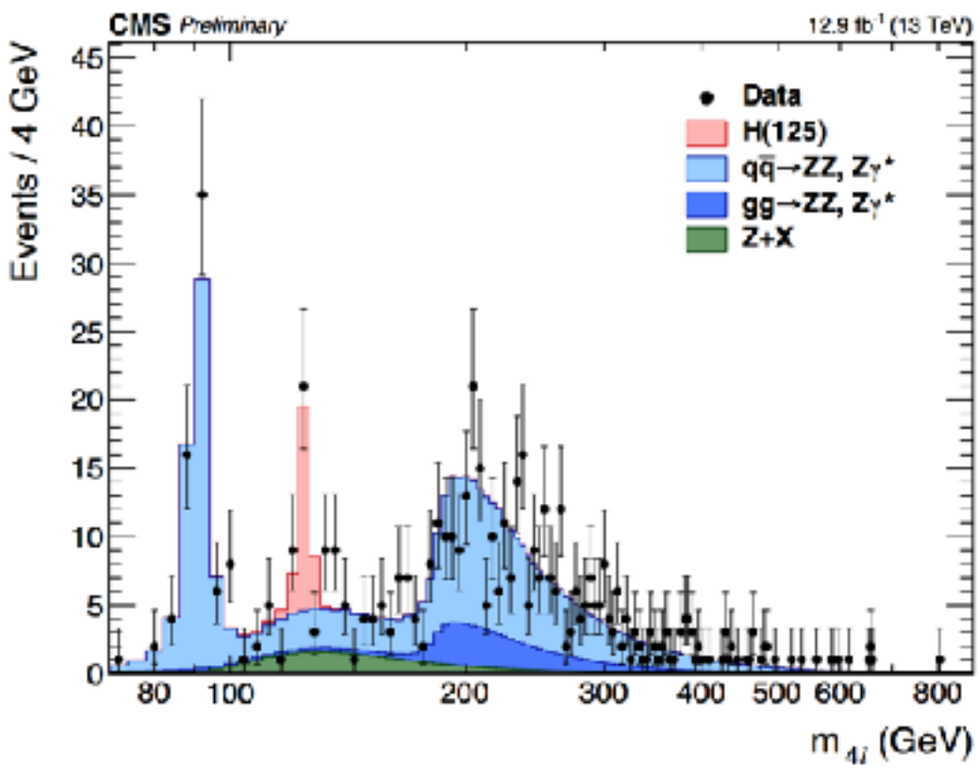
- New particles decaying to VV predicted by many BSM models
  - typical production are gg or VBF
  - spin 0, scalar, narrow or wide
- **Results form Run1** - all final states matter
  - X⟶ZZ
    - <500GeV: 4l
    - 500-600 GeV: 2l2v, 2l2q
    - >600GeV: 2l2q
  - X⟶WW
    - <500GeV: 2l2v
    - >500GeV: lvqq

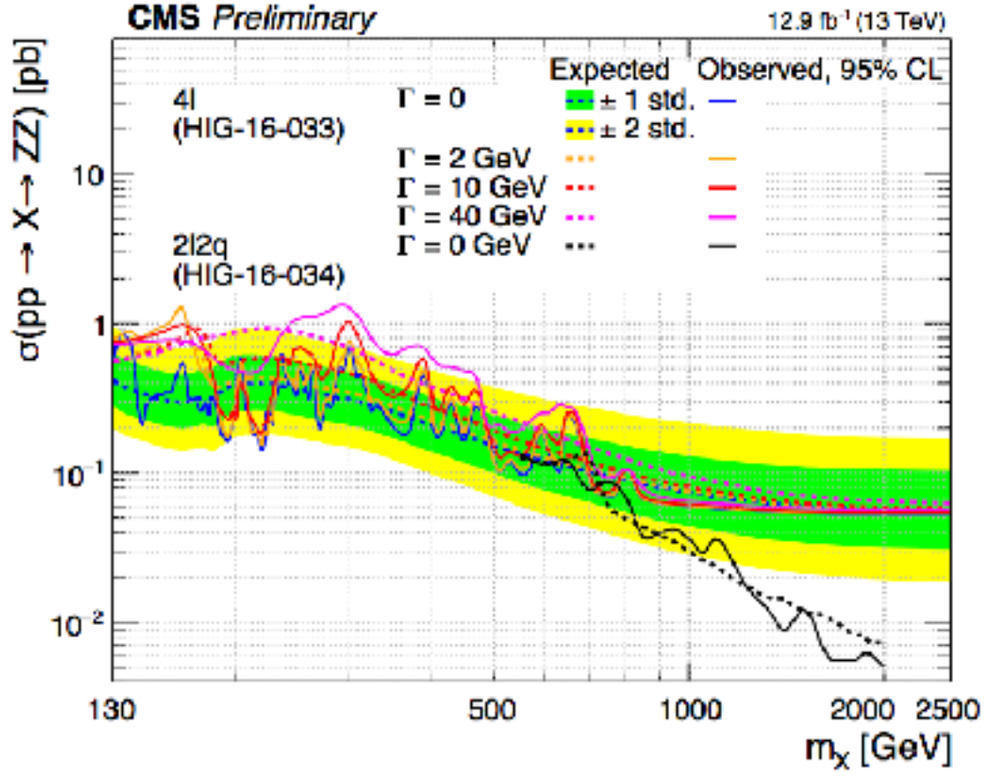


Heavy Higgs searches

X⟶ZZ (4l)

- 2 categories: gg and VBF (includes VH)
- m4l as observable
- parametrised signal shape in m_X and Γ_X
- High-mass region selection optimization
- No significant excess
- gg and VBF cross section limits for different values of Γ_X (0 to 40GeV)

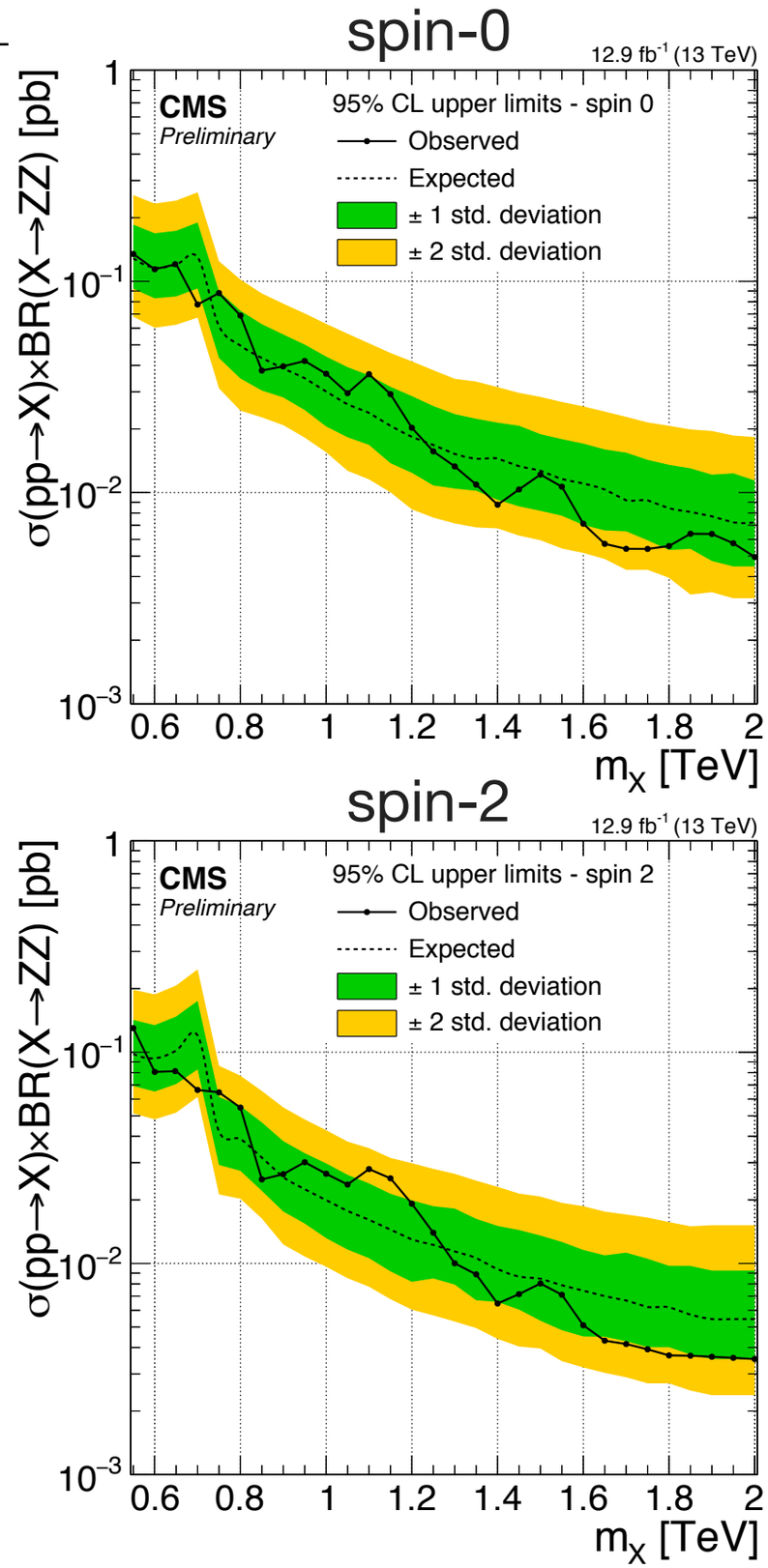




Heavy Higgs and Graviton searches

X⟶ZZ (2l2q)

- Categorisation
  - resolved/merged jets, btag/nob-tag, VBF/gg
- look only for narrow scalar (no interference)
  - spin0 (Higgs) - includes VBF
  - spin2 (bulk graviton) - only gg assumed
- matrix element based discriminants for
  - VBF and gg category
  - signal/Z+jet separation *DZjj*
- mZZ vs *DZjj* as observables for signal extraction



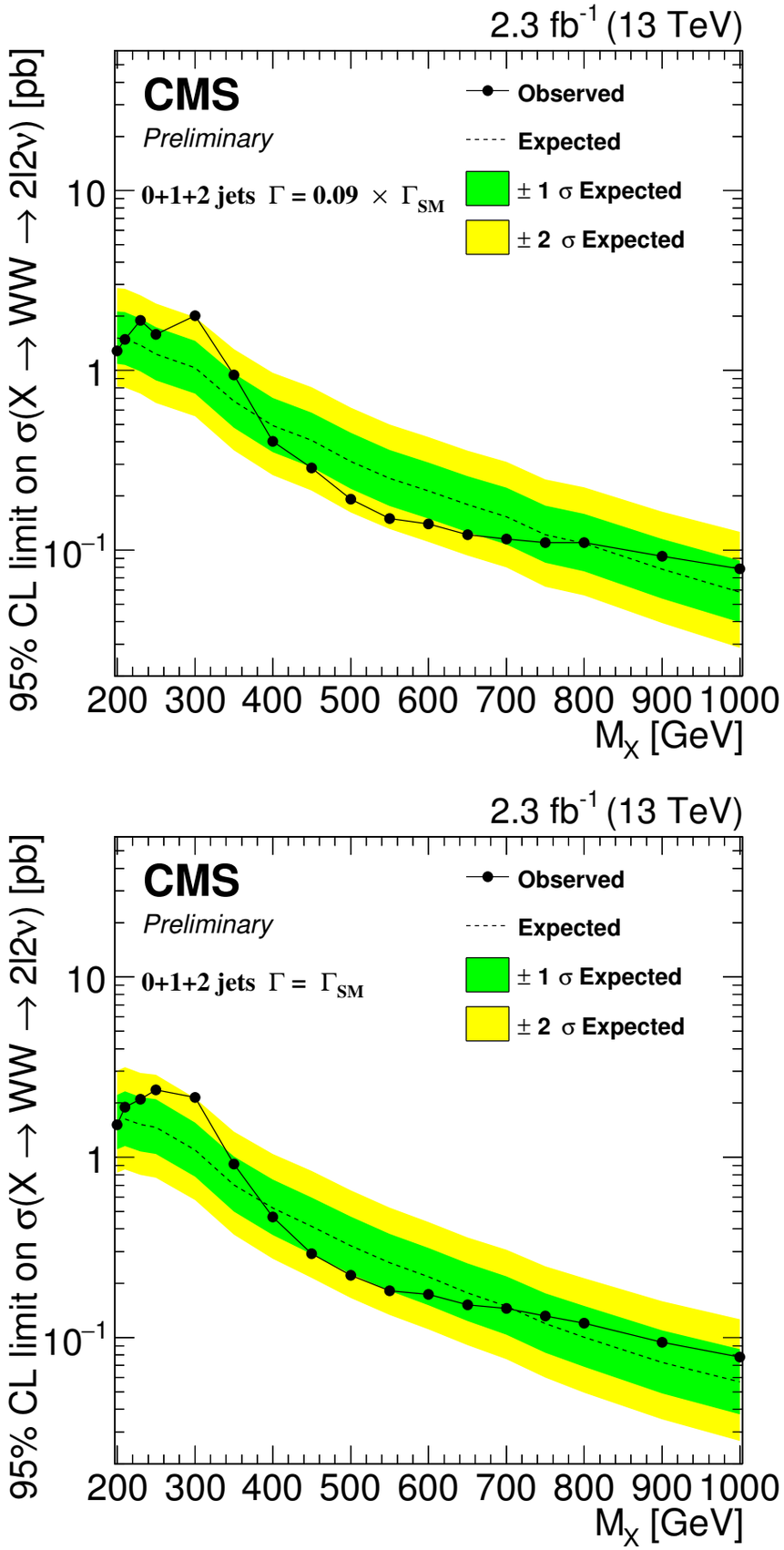
EW singlet searches

X: spin-0, EW singlet, mixing with SM H

- X⟶WW (2l2ν)
- eμ final state
- ggH (0-jets), 1 jet, VBF category
- VBF/gg ratio floated
- Interference properly modelled
- Modified m_T as observable

$$m_{\mathrm{T,i}} = \sqrt{(p_{ll} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{ll} + \vec{p}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

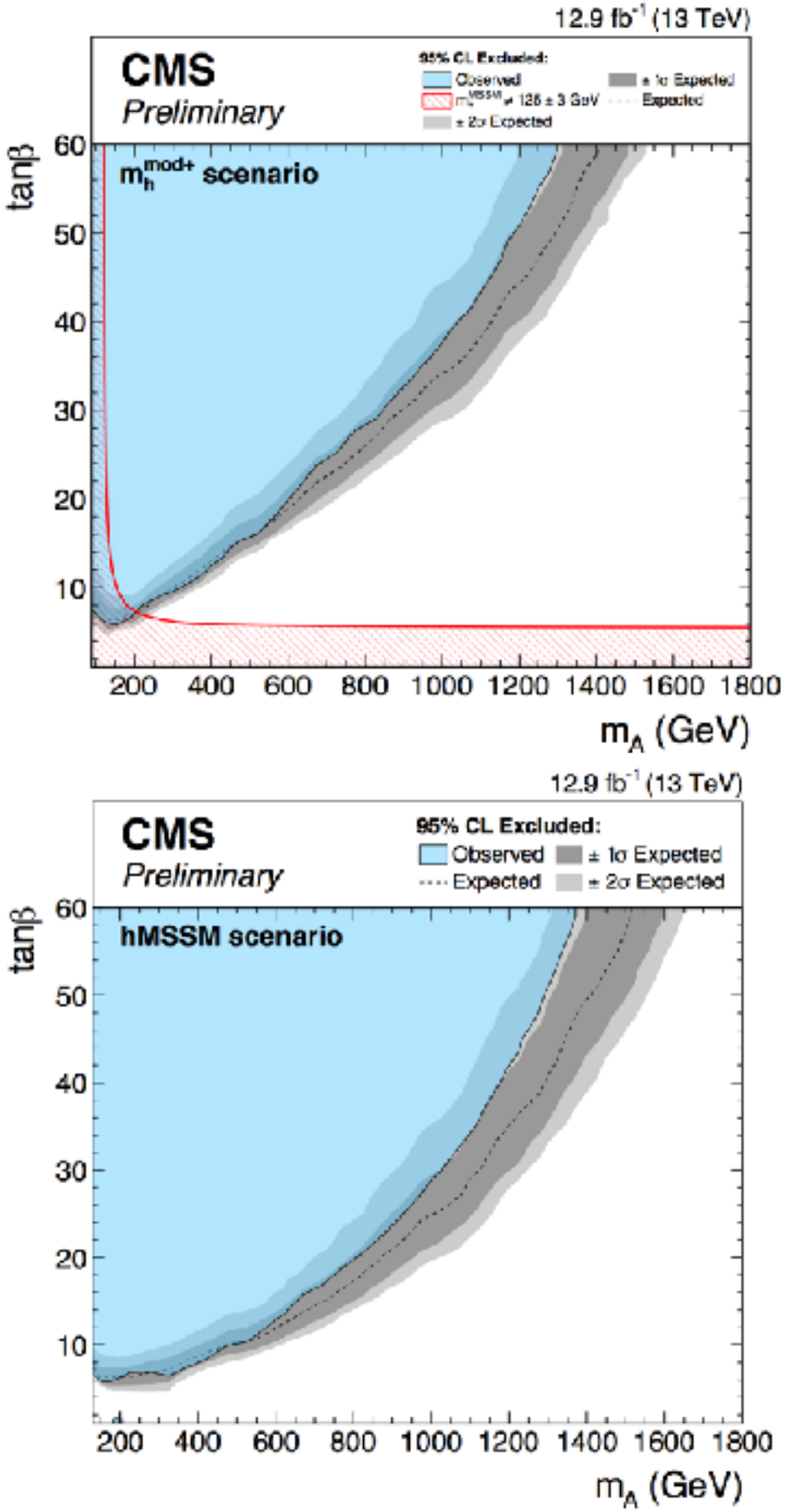
- Γ_X scan from 0.09x Γ_{SM} to 1x Γ_{SM}
- No significant excess
  - Limit set on production cross sections



Heavy Higgs searches

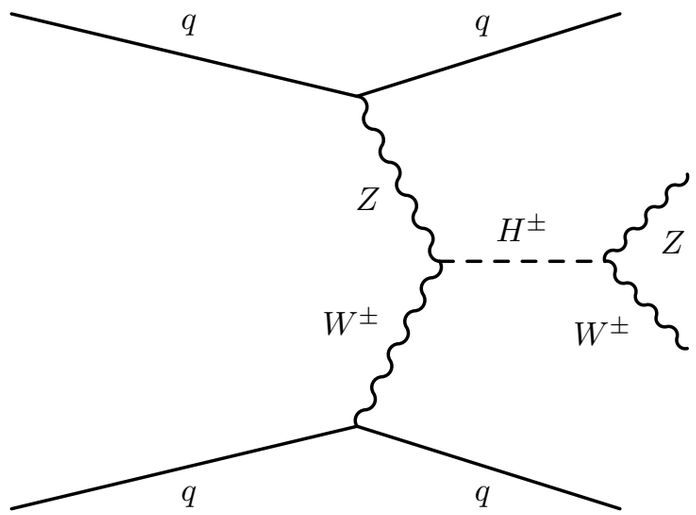
A,H,h ⟶ ττ

- 4 channels: eμ, eτh, μτh and τhτh
  - Well identified, isolated, separated, and opposite charged taus
- Additional kinematic channel cuts to reduce backgrounds
- Categorisation in b-tag, m_T
- No significant excess
  - mA-tanB parameters space limit for benchmark scenarios m_h^{mod+} and hMSSM



Higgs triplet model - Charged Higgs

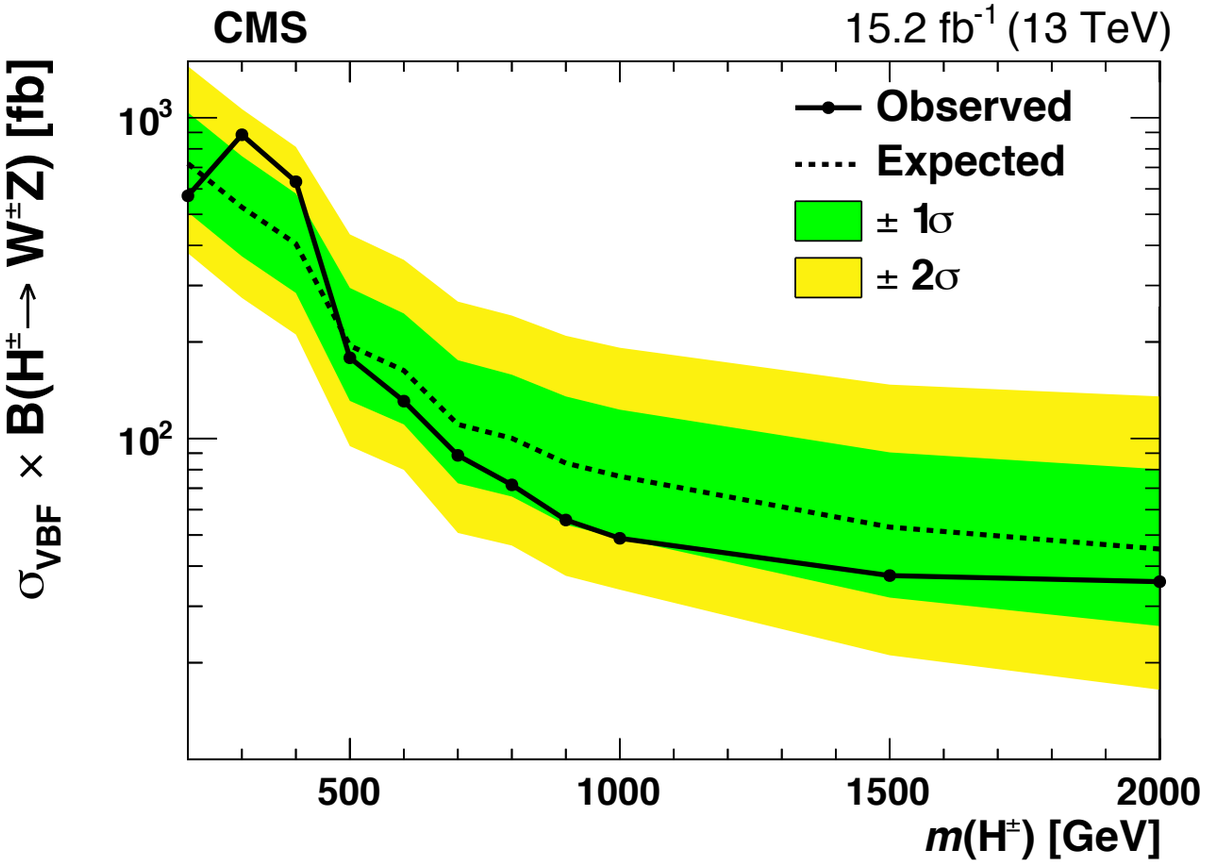
- Higgs triplet model (ex. Georgi Machaceck model) predicts fermiophobic charged Higgs boson
- VBF as production mode

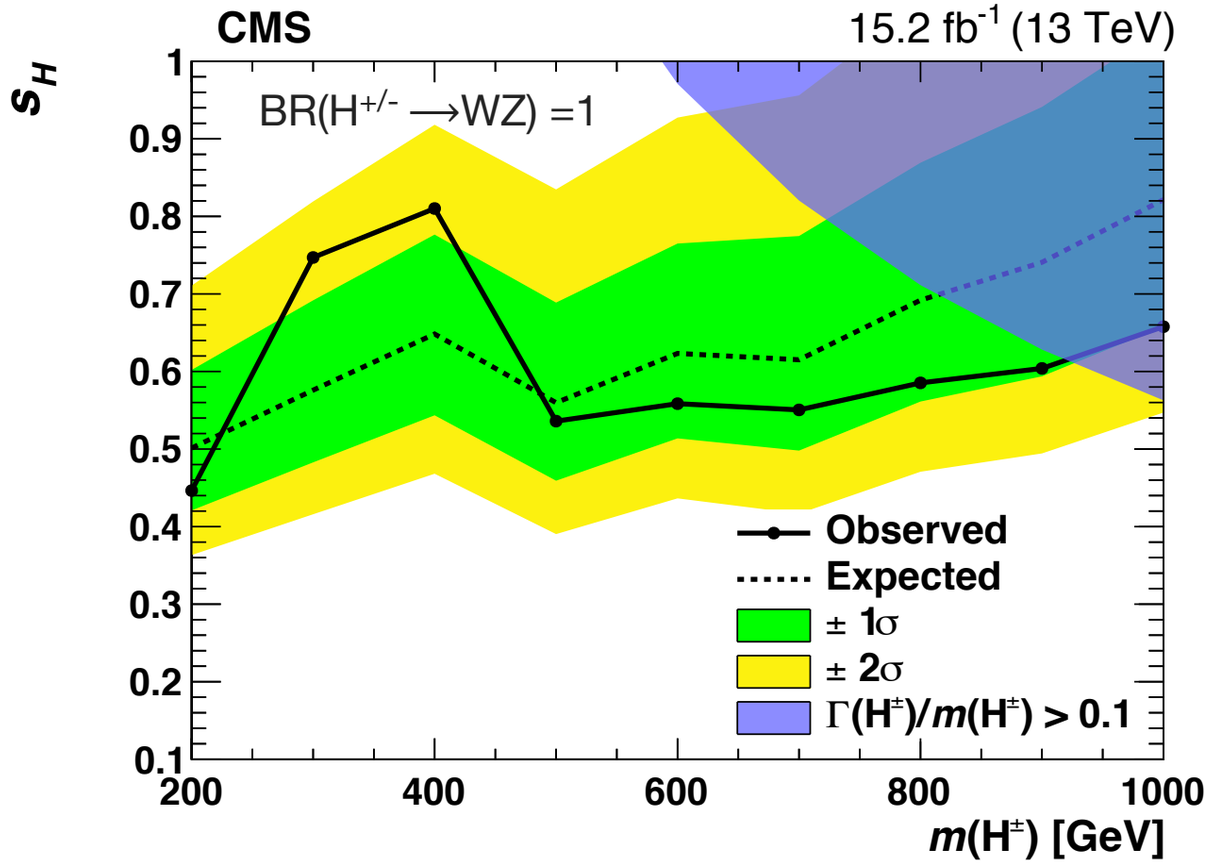


- Search performed using electron and muon decays of W and Z
- Event selection criteria
  - 2 jets with large pseudorapidity and mass to select VBF topology
  - 3 well identified and isolated leptons
  - Large transverse missing energy

Higgs triplet model - Charged Higgs

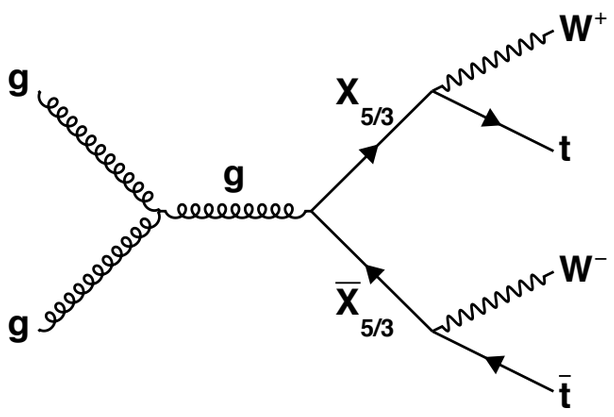
- Signal extraction fitting transverse mass of the WZ system
- Limits on cross section x BR setting are function of $m_{H+/-}$
- Result are interpreted in the Georgi-Machacek model setting limits on s_H-m_H plane

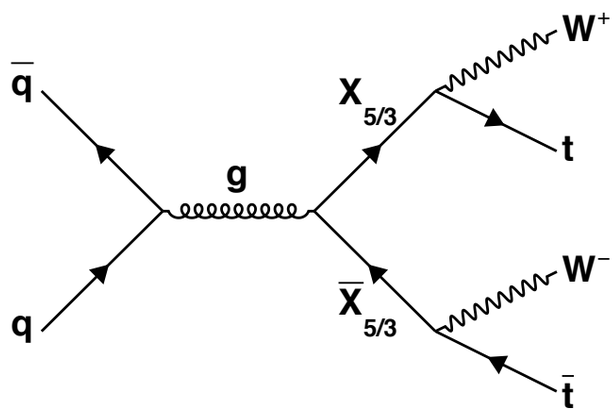




Composite Higgs, little Higgs, and other models

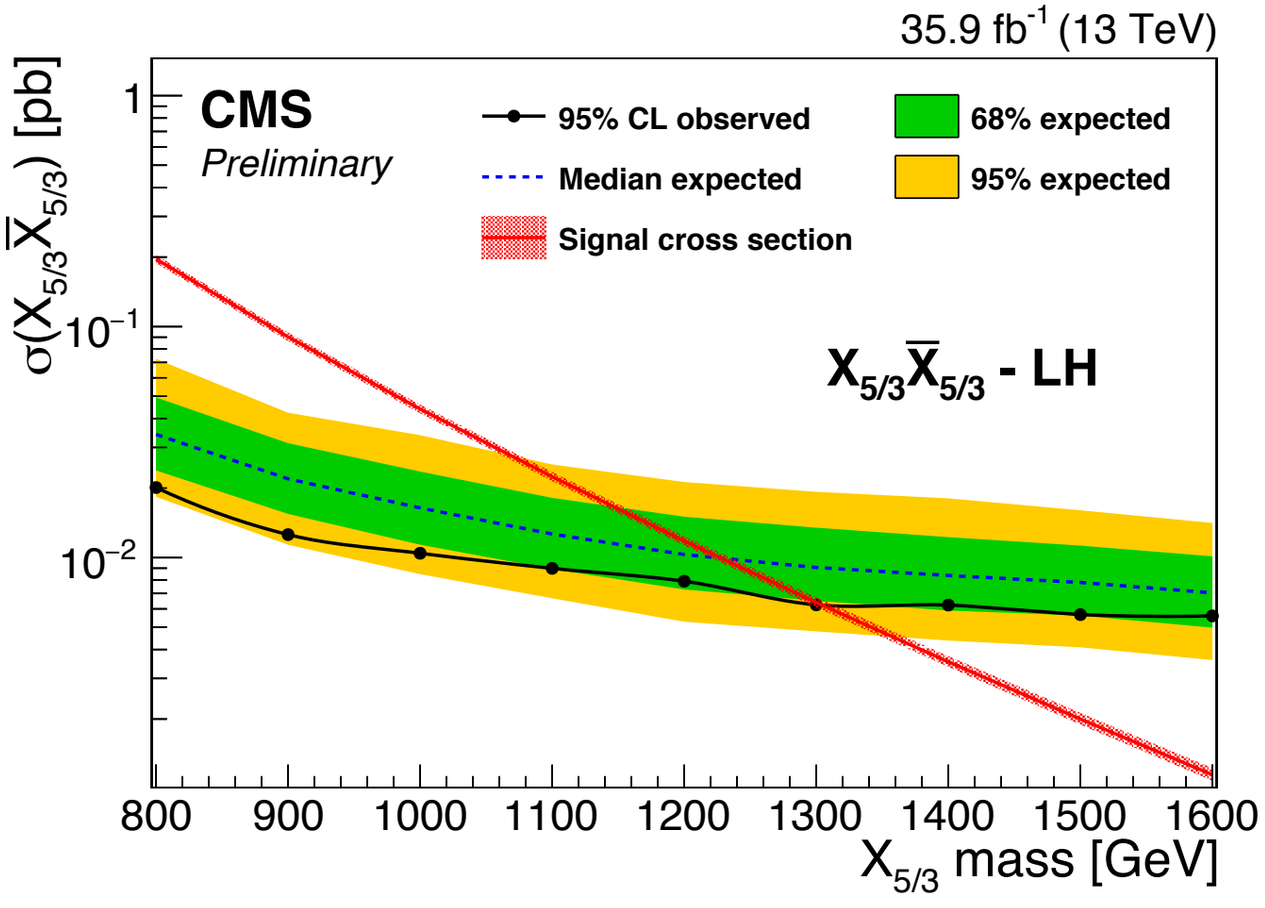
- Composite Higgs (CHM), little Higgs, Randall-Sundrum, and other models predict Vector-Like Quarks
  - Spin 1/2 fermions that couples as vectors: left and right-handed component transform in the same way under the SM symmetries
- Recently published CMS analyses investigate $X_{5/3}$ pair production
- $X_{5/3}$ is a heavy partner of the top quark with electric charge of 5/3
- They decay predominantly in tW: $X_{5/3}\,X_{5/3} \longrightarrow tWtW$
- Search performed for pure left (LH) or right-handed (RH) coupling to W
- Event selection
  - A single well identified lepton
  - Large missing energy
  - At least 4 energetic jets, at least one b-tagged
  - Categorisation based on lepton flavour, number of b, top, and W tagged jets

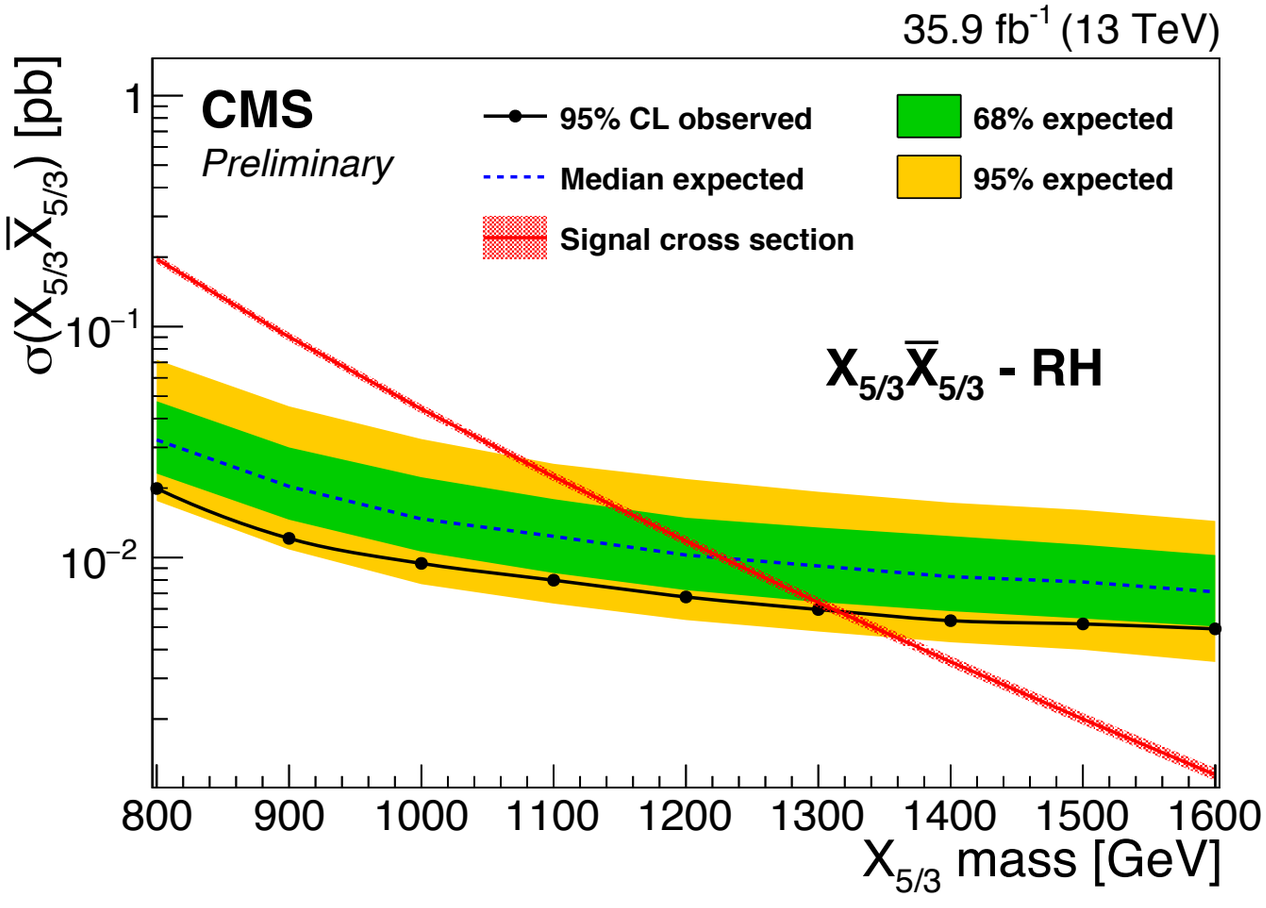




Composite Higgs, little Higgs, and other models

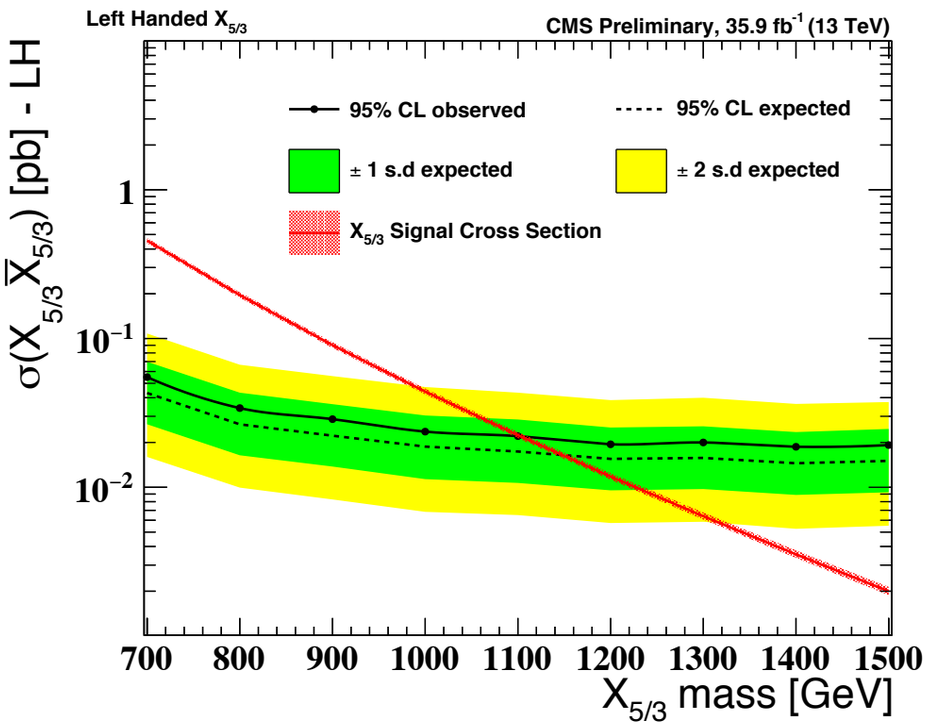
- Signal extraction
  - likelihood fit of invariant mass of lepton and b-tagged jet
  - no significant excess found
  - limit set on production cross section for LH and RH hypothesis

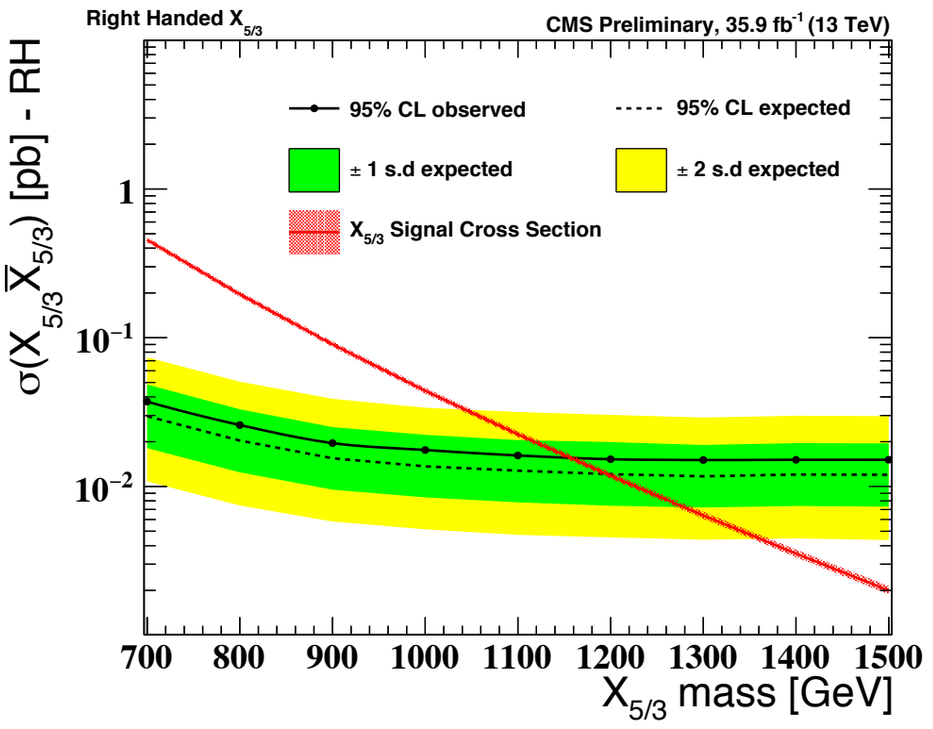




Composite Higgs, little Higgs, and other models

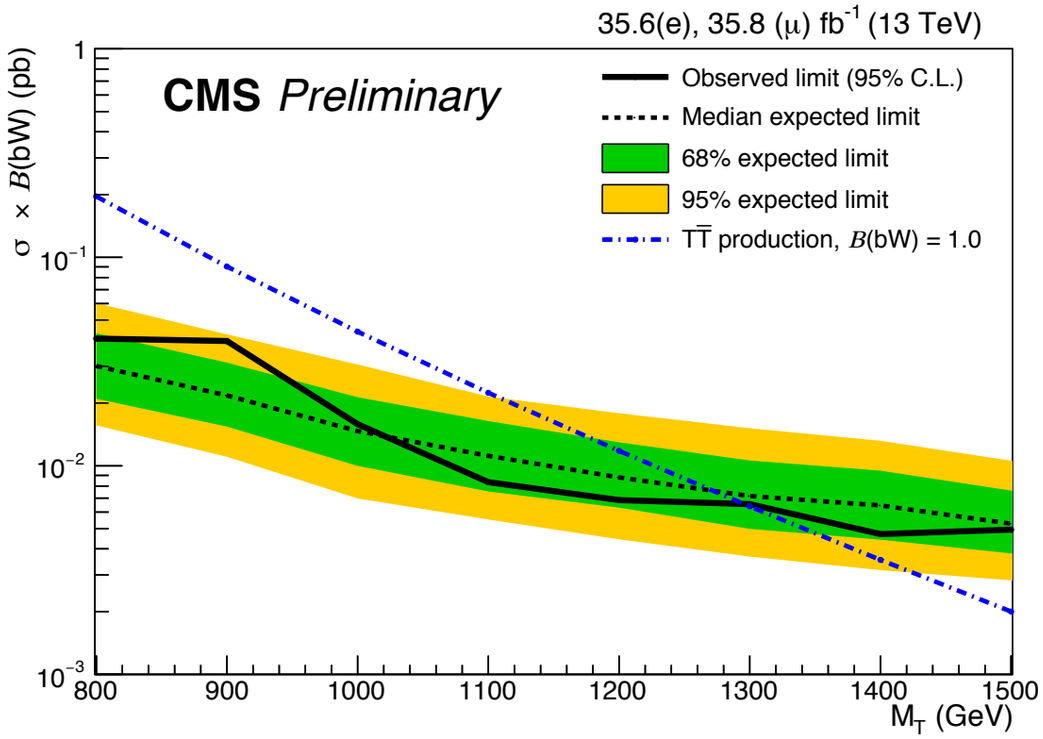
- $X_{5/3}\,X_{5/3} \longrightarrow tWtW$
- Same production mechanism as before but different final state
- Event selection
  - same sign dilepton (muon, electron)
  - Z mass verto and quarkonia veto
  - at least 2 energetic jets
- Signal extraction
  - Likelihood fit on H^{lep}_T transverse scalar p_T sum of leptons and jets
- Results
  - Exclusion limits are set on the production cross section of the LH and RH $X_{5/3}$





Composite Higgs, little Higgs, and other models

- VLQ T and Y-quark pair production
  - T and Y have predicted with electric charge of 2/3 and -4/3 respectively
  - T and Y decays assumed 100% to bW
  - complete final state bWbW ⟶ blvbqq
- Event selection
  - one lepton (muon or electron)
  - at least 4 jets (2 b-tagged)
  - large transverse missing energy
- Signal extraction
  - Fitting of M_{reco} (VLQ reconstructed mass) after constrained kinematic fit
- Results
  - Limits are set for strong pair production of T/Y VLQ

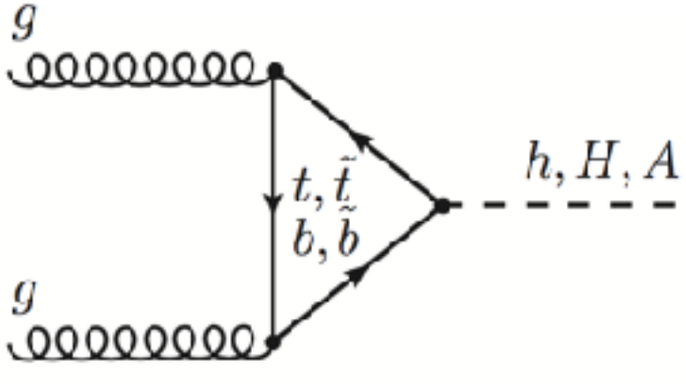


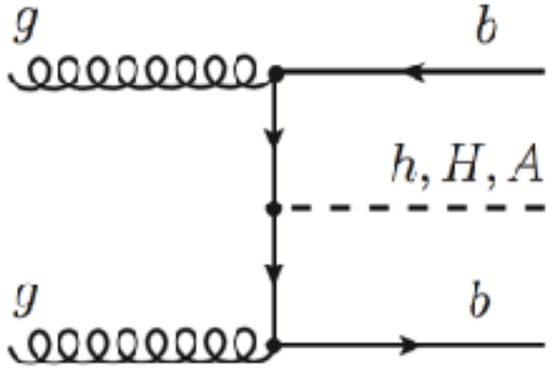
Summary

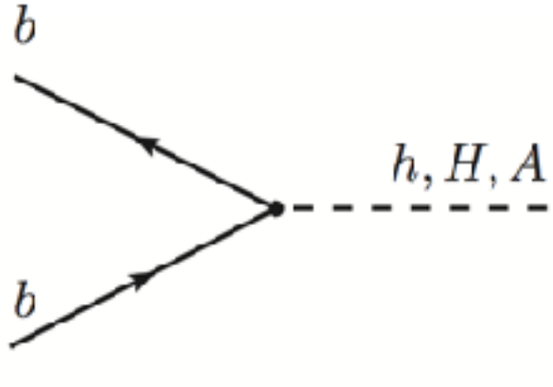
- Recent results from CMS BSM Higgs searches have been presented
- No significant excess has been found
- A set of limits on production cross section and parameter space of benchmark models have been set
- The search continues with 2017 LHC data!

backup

Heavy Higgs searches - MSSM







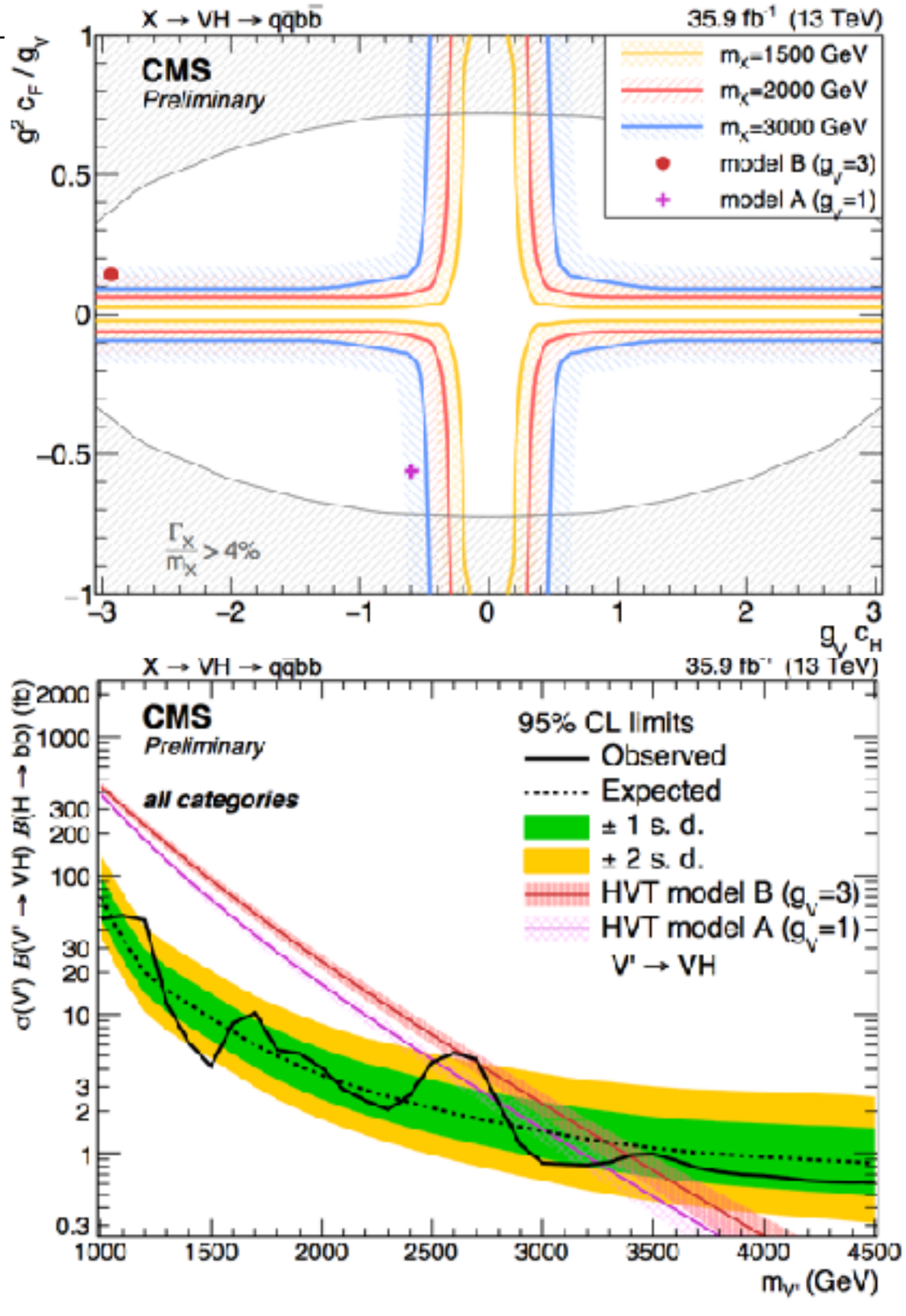
- The MSSM expressed in terms of two free parameters at tree level
  - m_A: mass of the pseudoscalar Higgs boson
  - tan β: the ratio of vacuum expectation values of the two doublets
- Main production method of A,H,h via gg and bb
- Coupling to down type fermions enhanced for large tanβ values (b, taus, etc.)
- m_h^{mod+} model
  - parameter choice made such that the majority of m_A-tanβ plane is consistent with a scalar Higgs at 125GeV
- hMSSM
  - the condition of m_h = 125 GeV is fixed across the whole plane and the radiative corrections adjusted accordingly.

Heavy Vector Triplet (HVT)

- Triplet of vector boson: V'=(Z',W')
  - model A: V' mostly decay in to fermions
  - model B: V' mostly decays in to boson

V'⟶VH (2q2b)

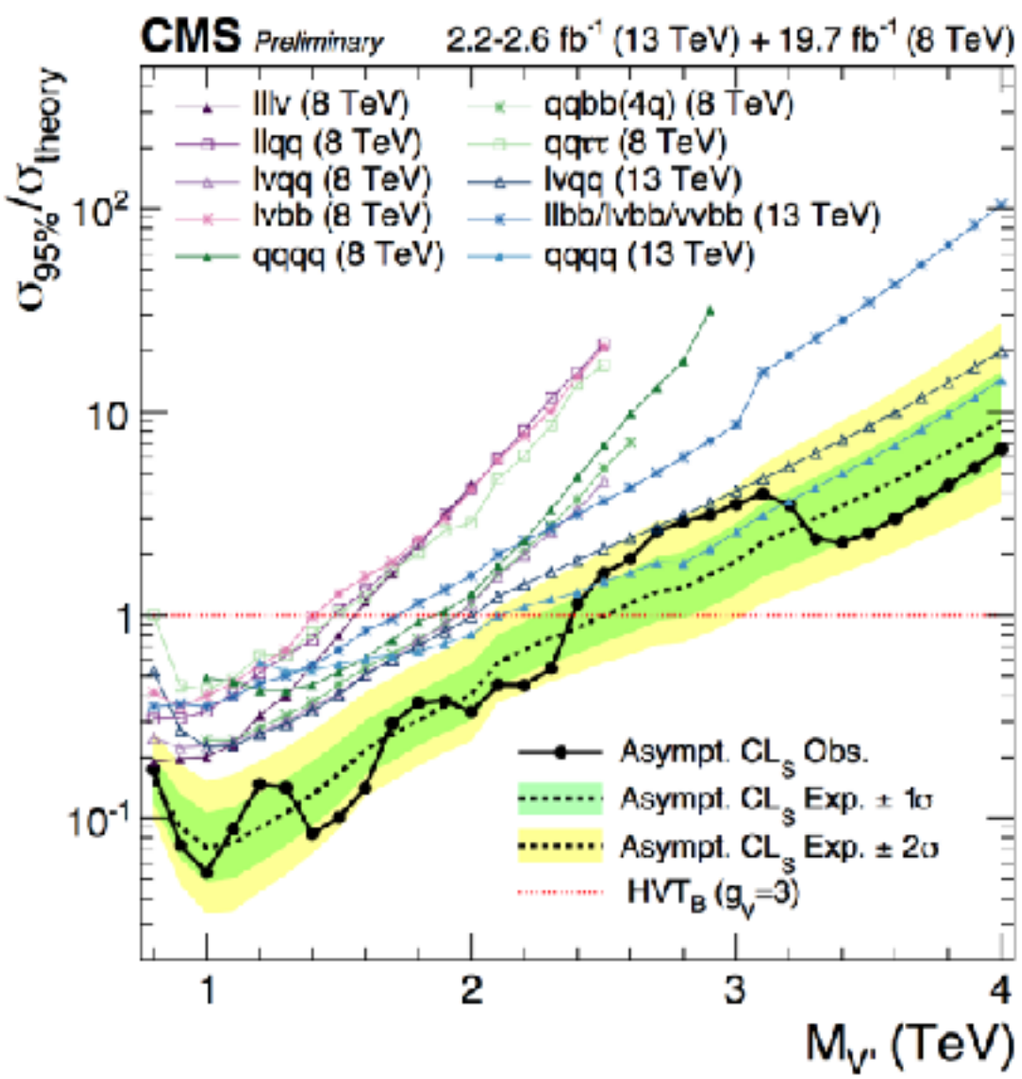
- 2 merged jets, 2 sub-jets btag
- signal extracted via parametric fit m_{VH}
- 3.5 sigma excess in W' from Atlas at ~3TeV
  - not confirmed by CMS
- Limit on cross section x BR
- Limit on parameter space in HVT models

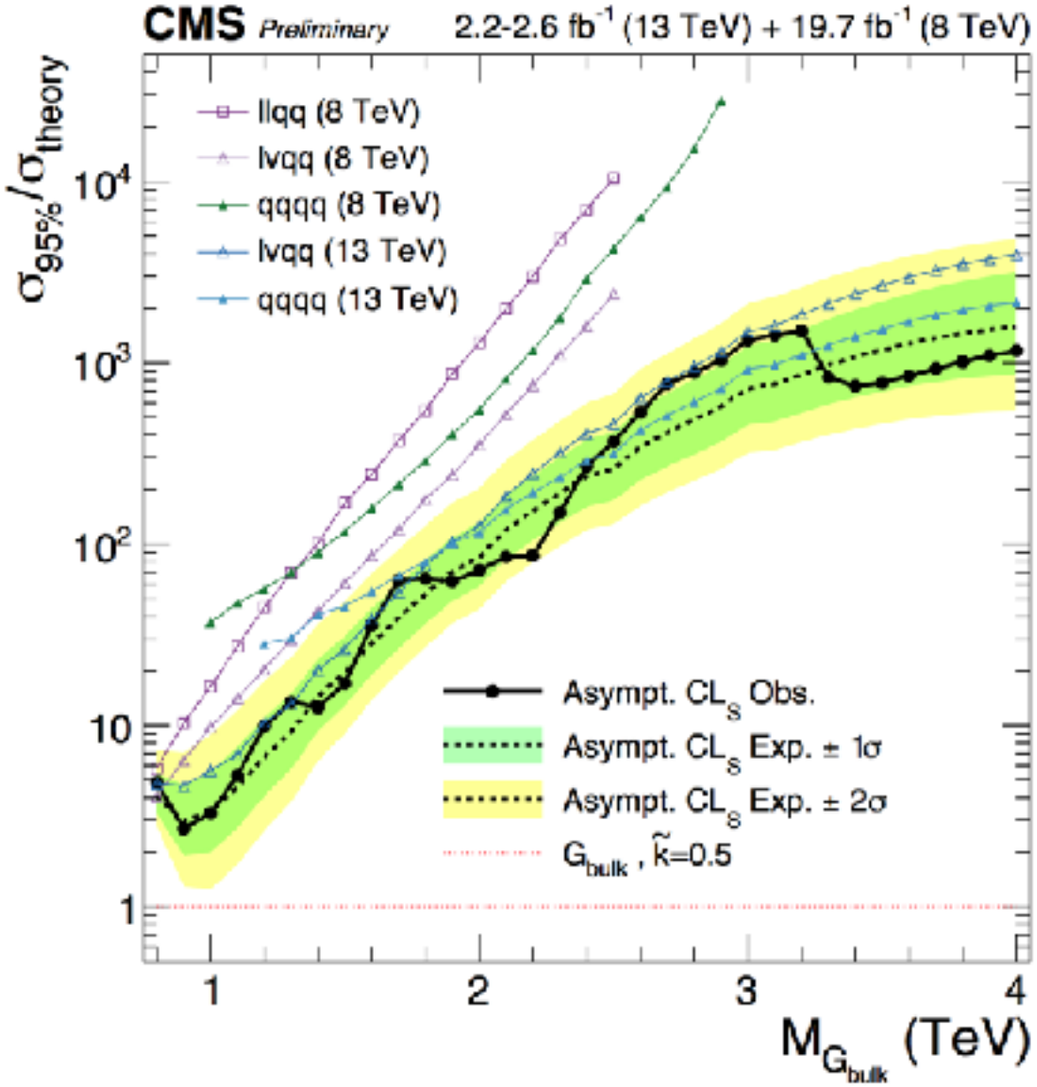


Heavy Vector Triplet and Graviton searches

X->VV,VH Run1 + Run2 Combination

- interpreted as HVT model B and bulk graviton





Heavy Higgs and Graviton searches

X⟶ZZ (2l2v)

- Modified transverse mass as discriminat for signal extraction
- Categorisation to probe ggH and VBF using number of jets
- Interpretation and exclusion limits for various EWK singlet models