Imperial College London

High mass neutral/MSSM Higgs searches from CMS

A. de Wit, on behalf of the CMS collaboration

15/06/2016

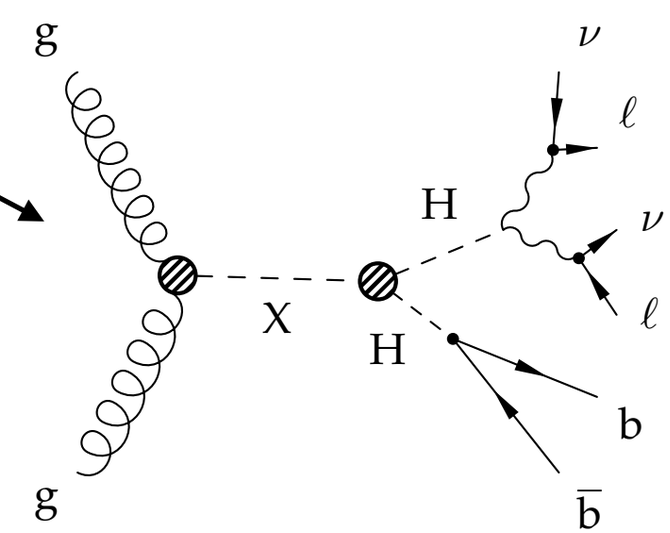
LHCP 2016, Lund

Outline

- Introduction
- Overview of results from Run I
  - Summary model interpretations
- Run II results with 2015 dataset
  - $H \to hh$
  - $H \to ZZ$
  - $H \to \tau\tau$
- Summary

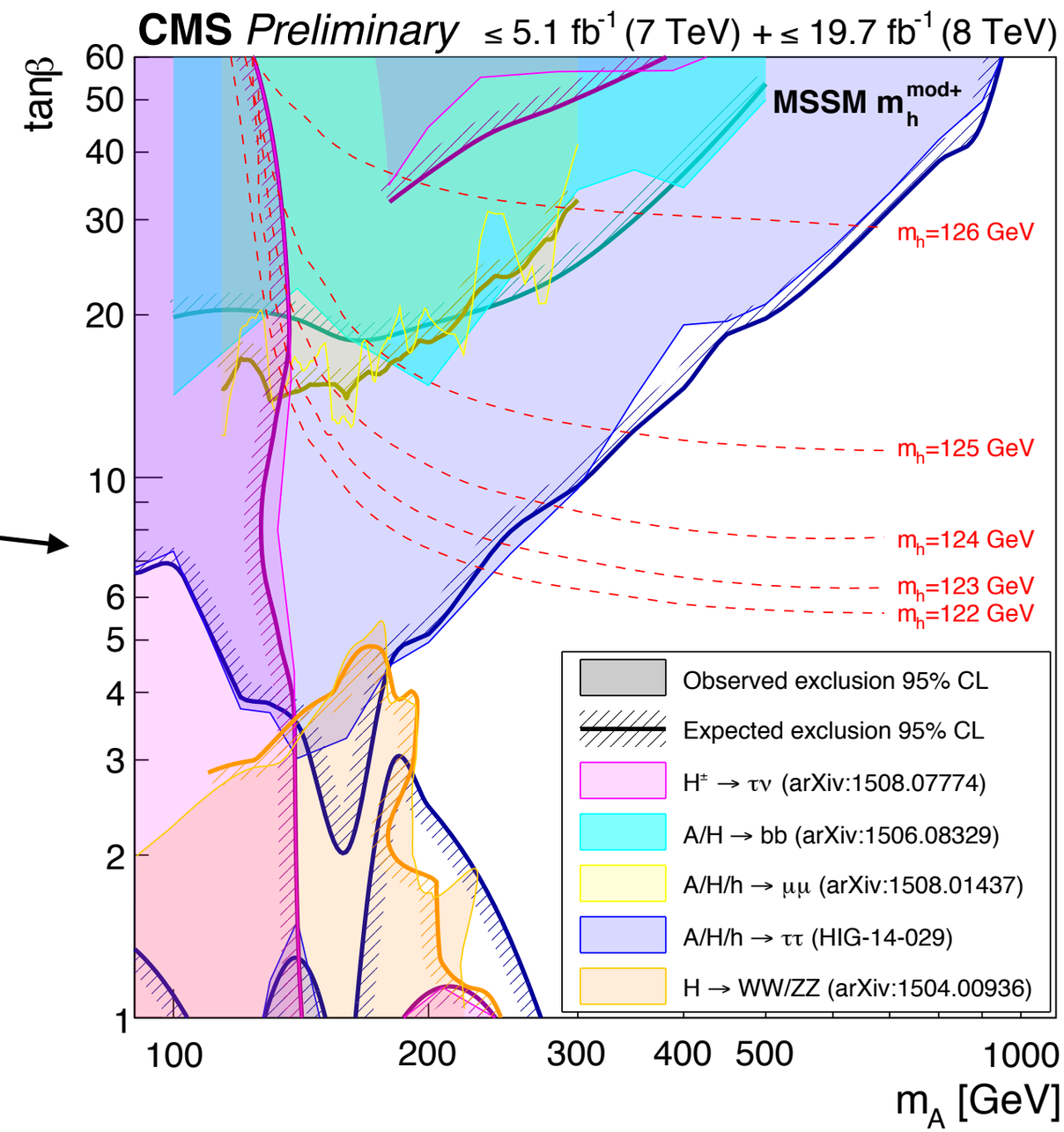
Introduction

- Discovery of SM-compatible m_H~125 GeV Higgs boson in 2012
  - **What else** can we find?
- BSM models with 2 Higgs doublets → 5 Higgs bosons :
  - MSSM
    - Two free parameters at tree level:
      - m_A, tanβ (ratio of VEVs of Higgs doublets)
    - Additional parameters entering in radiative corrections: fixed in benchmark scenarios
  - Generic 2HDM (e.g. type I, II)
    - MSSM: subset of type II 2HDMs
    - Parameters: masses of Higgs bosons, tanβ, mixing angle between Higgs doublets α
    - Couplings of SM-like H to up-type fermions
      - ~ cos α/sinβ in type I
      - ~ - sin α/cos β in type II
- Resonances decaying to 125 GeV Higgs
  - e.g. radion, graviton in models with warped extra dimensions



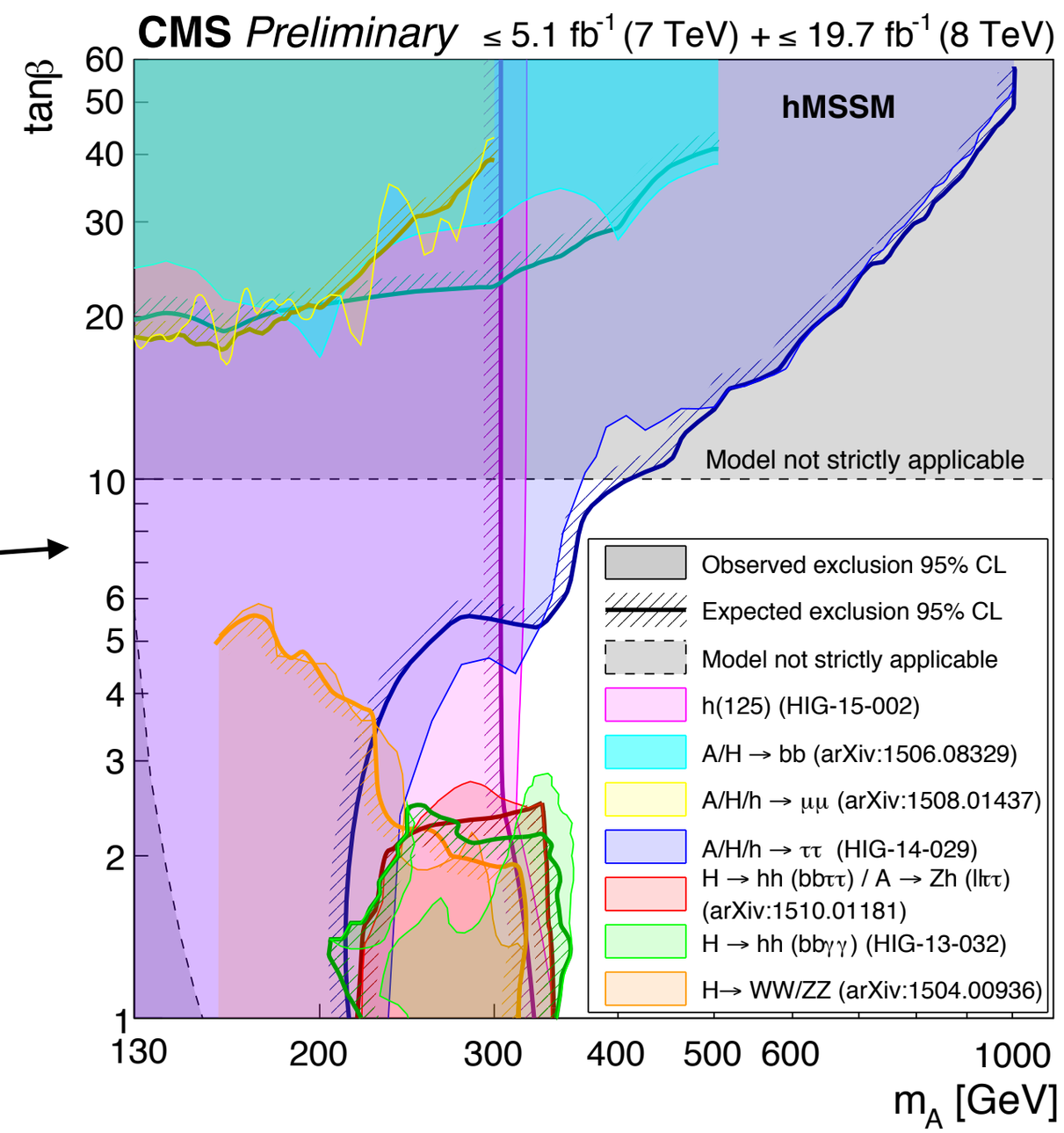
Run I BSM Higgs results

- Searches performed in many channels during Run I:
  - **H→bb**, **H→WW,H→ZZ, H→ττ**, **H→μμ**, H→hh, A→Zh, **H±→τν**,…
- Interpretations in **MSSM** - scan in m_A-tanβ plane of:
  - **m_h^{mod+}**
  - hMSSM
- Large part of high tanβ region excluded



Run I BSM Higgs results

- Searches performed in many channels during Run I:
  - **H→bb**, **H→WW,H→ZZ, H→ττ**, **H→μμ**, **H→hh**, **A→Zh**, **H±→τν**,…
- Interpretations in **MSSM** - scan in m_A-tanβ plane of:
  - m_h^{mod+}
  - **hMSSM**
- Sensitivity to H→hh, A→Zh at low tanβ

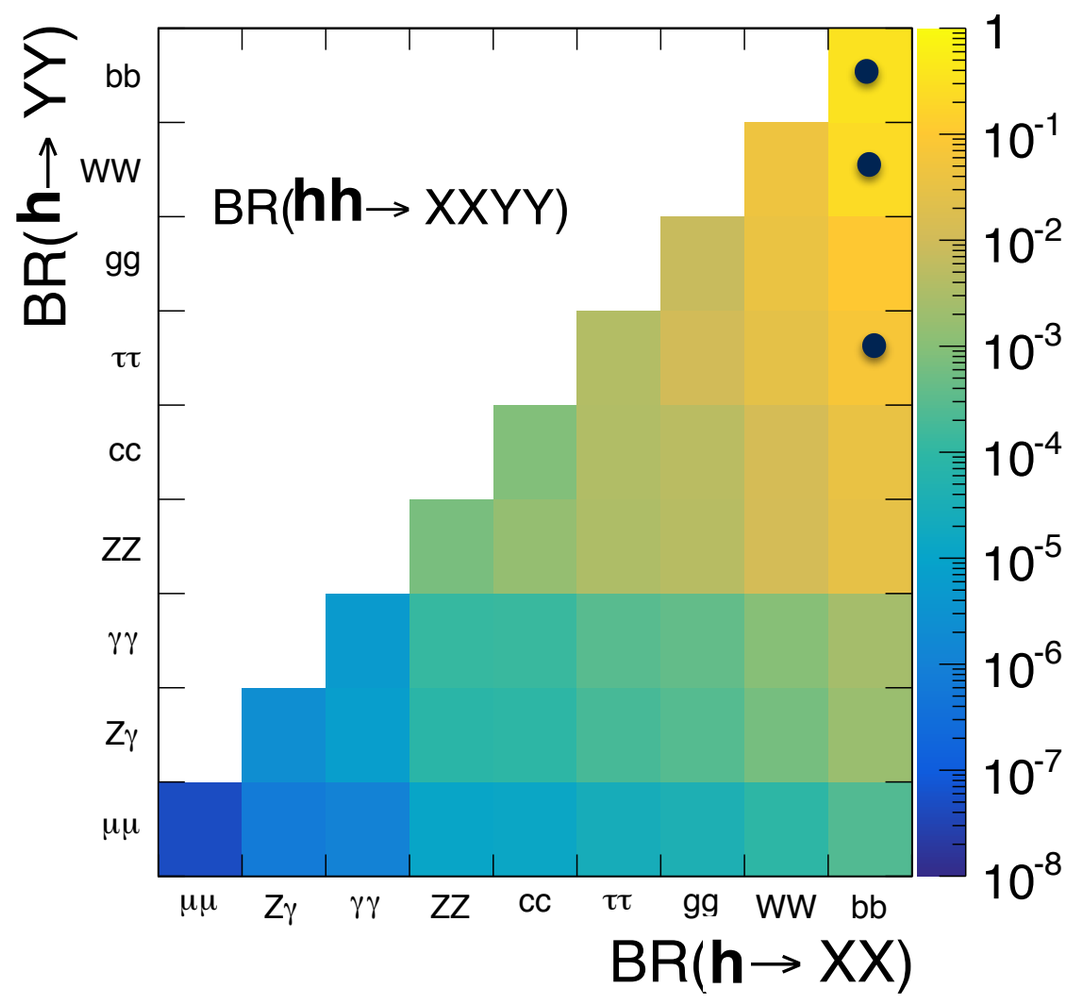


High mass Higgs searches in Run II

- Searches included in this talk:
  - $H \to hh$:
    - $H \to hh \to bbbb$ **HIG-16-002**
    - $H \to hh \to bbWW$ **HIG-16-011**
    - $H \to hh \to bb\tau\tau$ **HIG-16-013**
  - $H \to ZZ$ **HIG-15-004, HIG-16-001**
  - $H \to \tau\tau$ **HIG-16-006** **NEW**
- A lot of material to cover in 15 minutes, particular focus on new results presented for the first time today

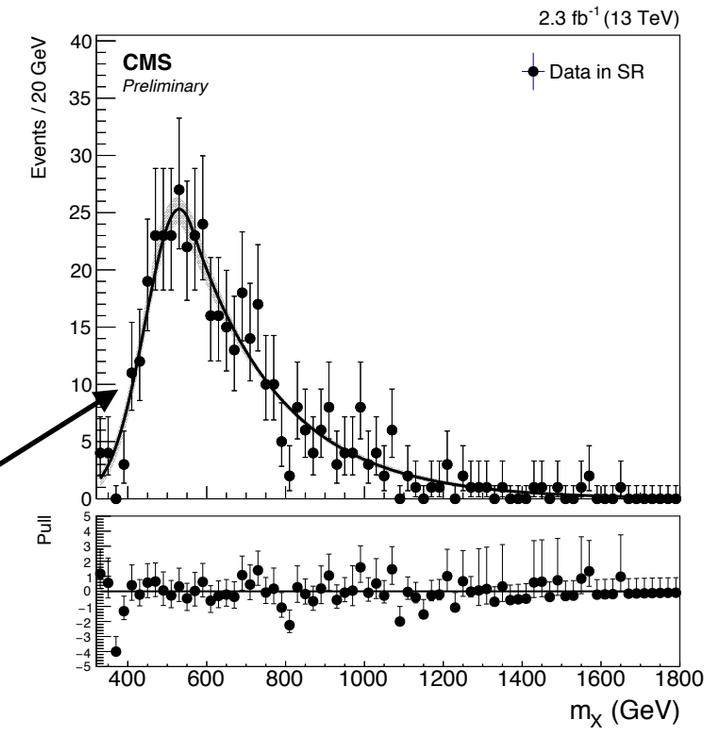
Resonant hh

- Common strategy for resonant hh searches:
  - Pick h(125) decays with large branching ratios or clean final states:
    - H→hh→**bb**bb
    - H→hh→**bb**WW
    - H→hh→**bb**ττ
  - Use information of 125 GeV Higgs:
    - Select h candidates with invariant mass compatible with 125 GeV
  - Reconstruct mass of resonance for signal extraction
  - In absence of signal:
    - Model independent upper limits on σxBR
    - Comparison with models

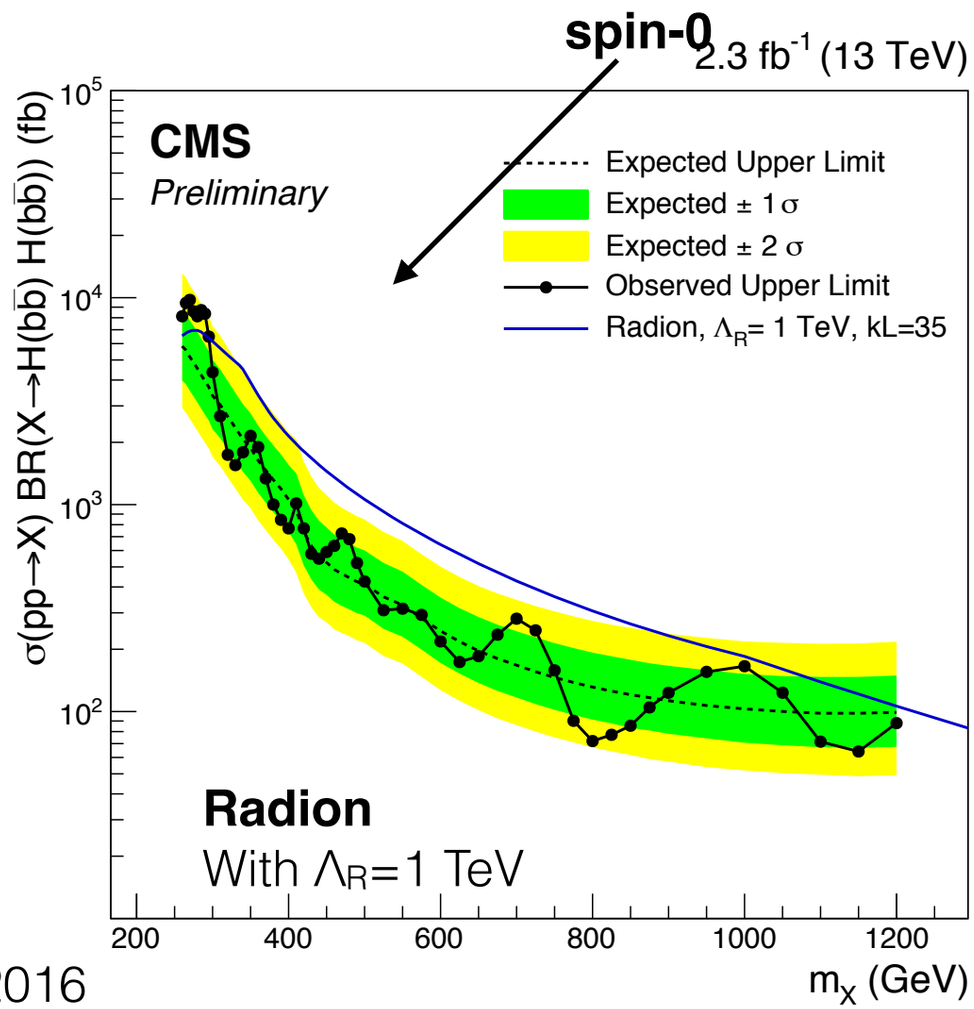


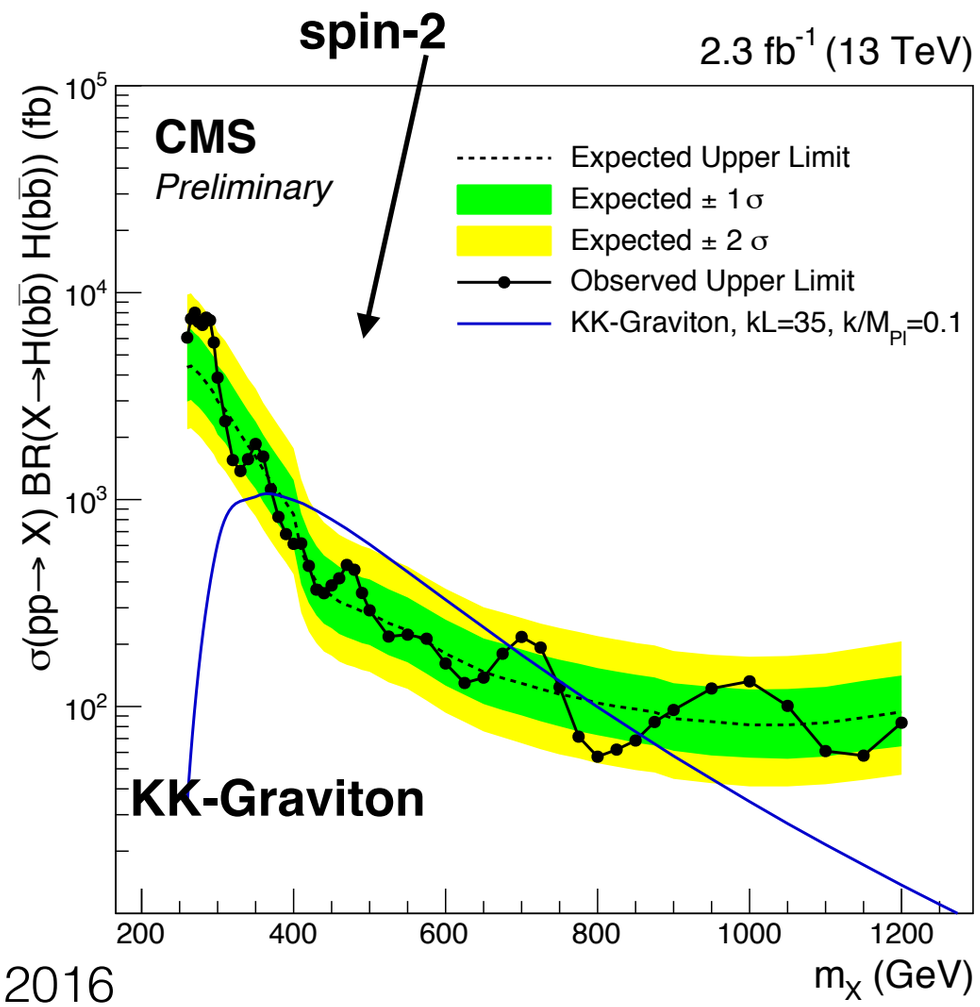
X→hh→bbbb

- Search for a **spin-0** or **spin-2** narrow width resonance X
- Select events with **4 b-tagged jets**
- Split mass region into low and medium mass region
  - 260-400 GeV: hh candidates chosen such that their invariant mass is close to 125 GeV
  - 400-1200 GeV: hh candidates chosen such that ΔR between jets is small
- Use kinematic fit to determine m_X
- Dominant background: QCD, shape estimated by fitting m_X distribution in sideband in data



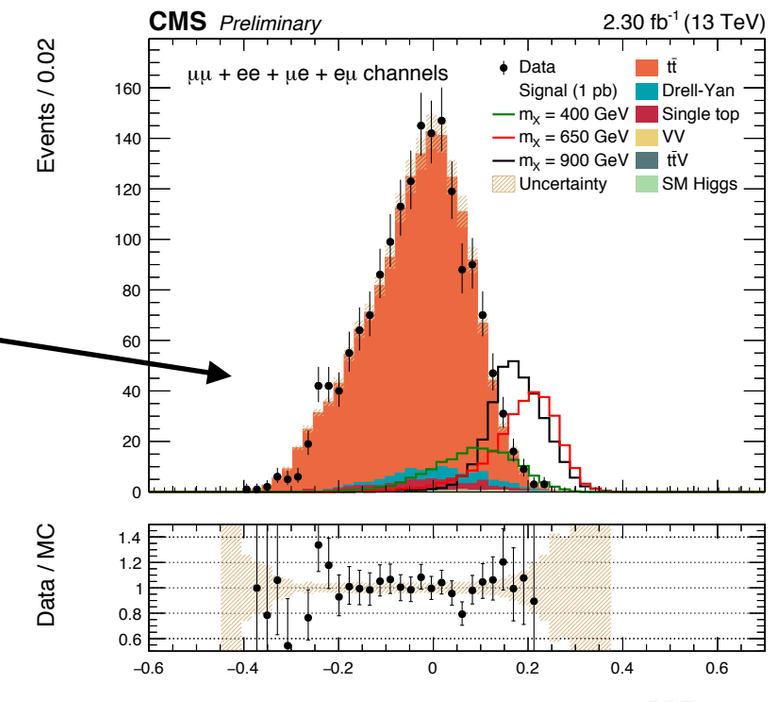
Model-independent upper limits on σ *BR

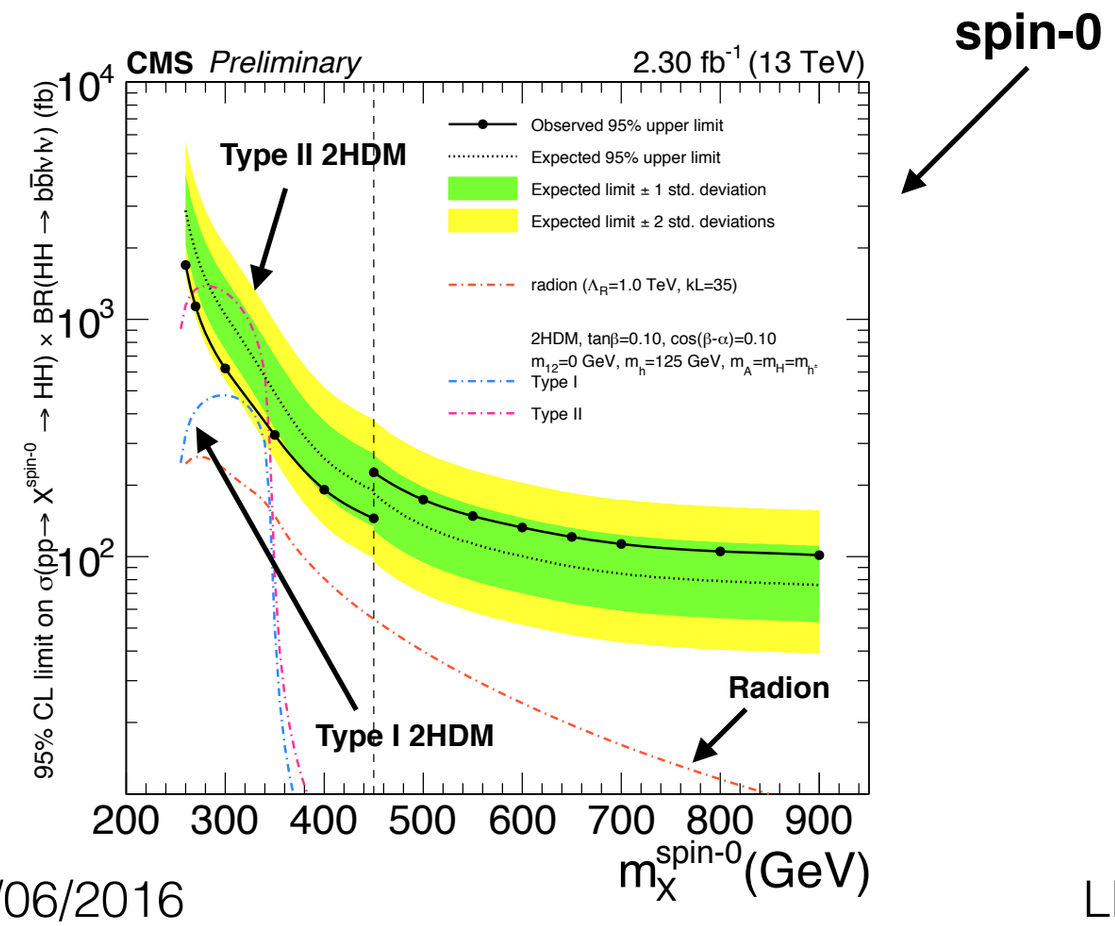


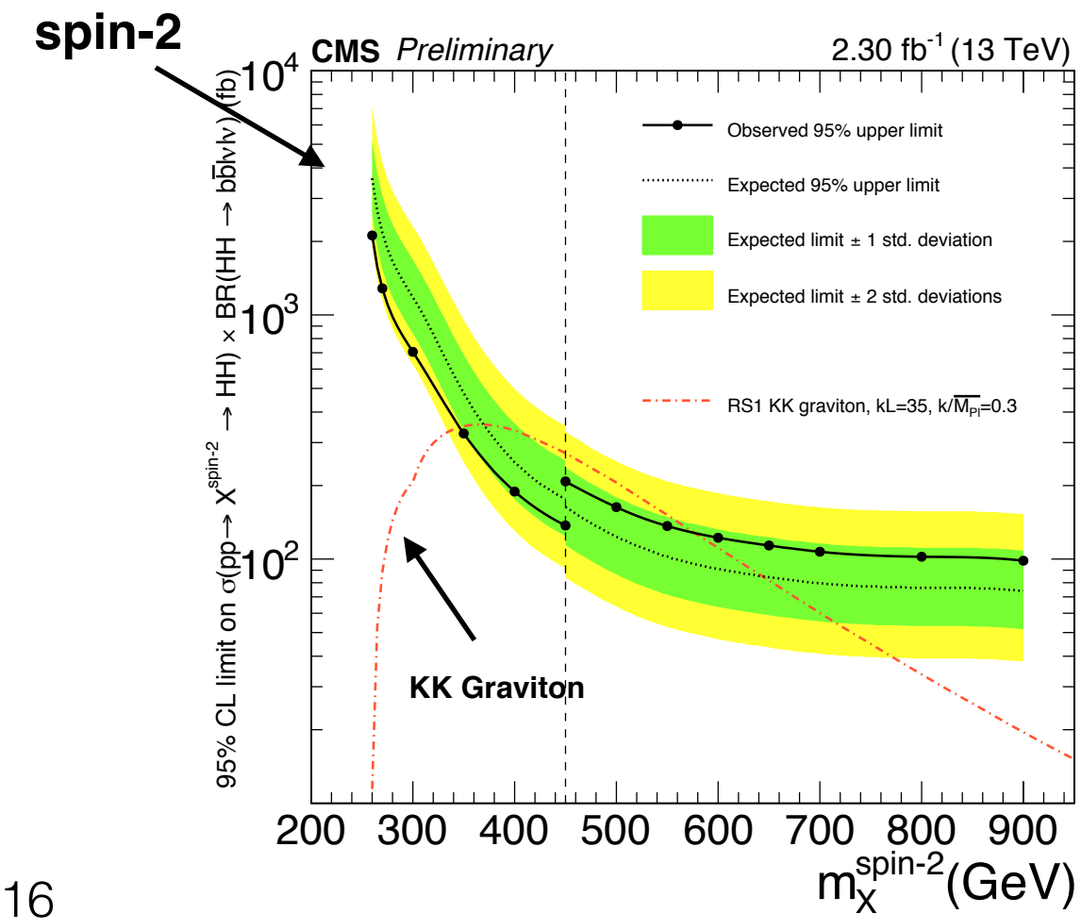


X→hh→bbW(lν)W(lν)

- Search for **spin-0 or spin-2** resonance X
- Select events with two oppositely charged e/μ and two b-tagged jets
- Use BDTs trained on kinematic variables to separate signal from dominant tt background:
  - for mass range 260<m_X<450 GeV: BDT trained on 400 GeV signal
  - for mass range 450<m_X<900 GeV: BDT trained on 650 GeV signal
- Define 4 categories for each BDT by splitting into low- and high BDT scores and applying m_{jj} cut around 125 GeV
- Upper limits on σ x BR, compared with radion, graviton, type I and type II 2HDM scenarios

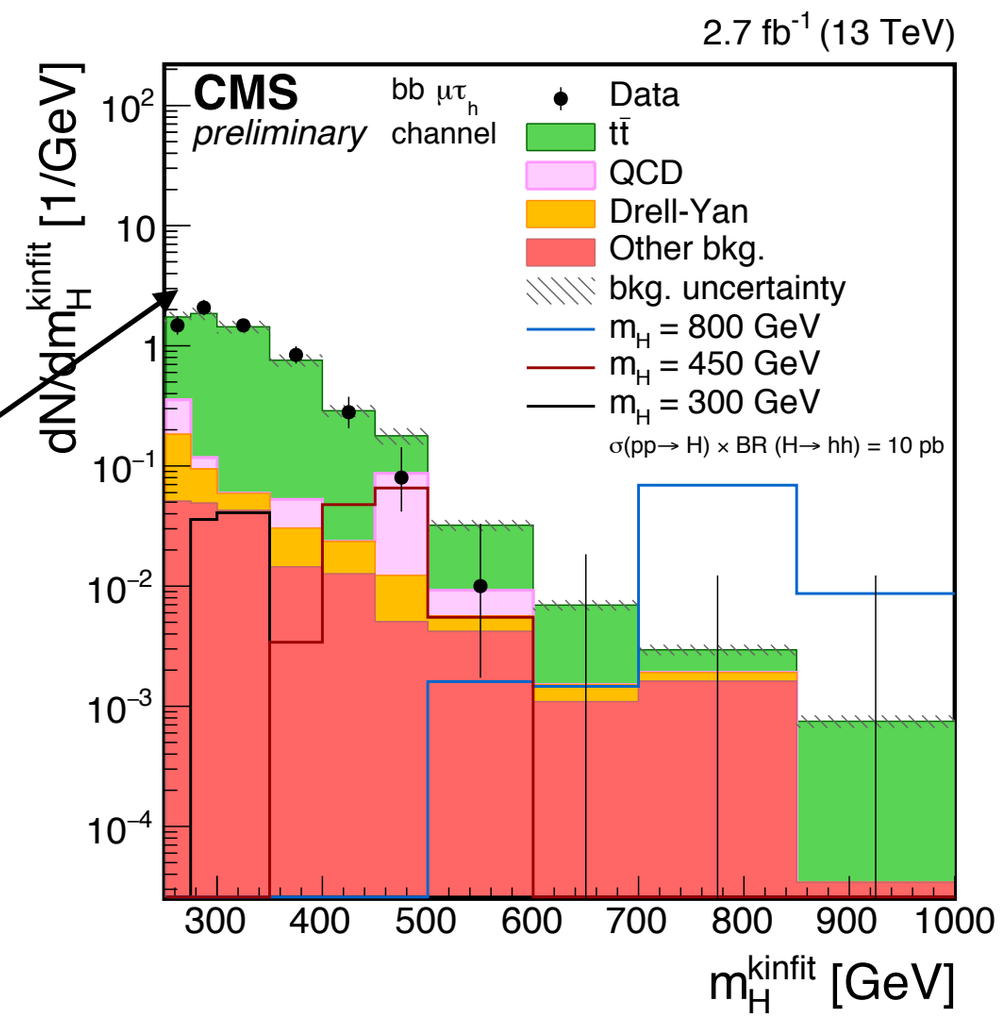


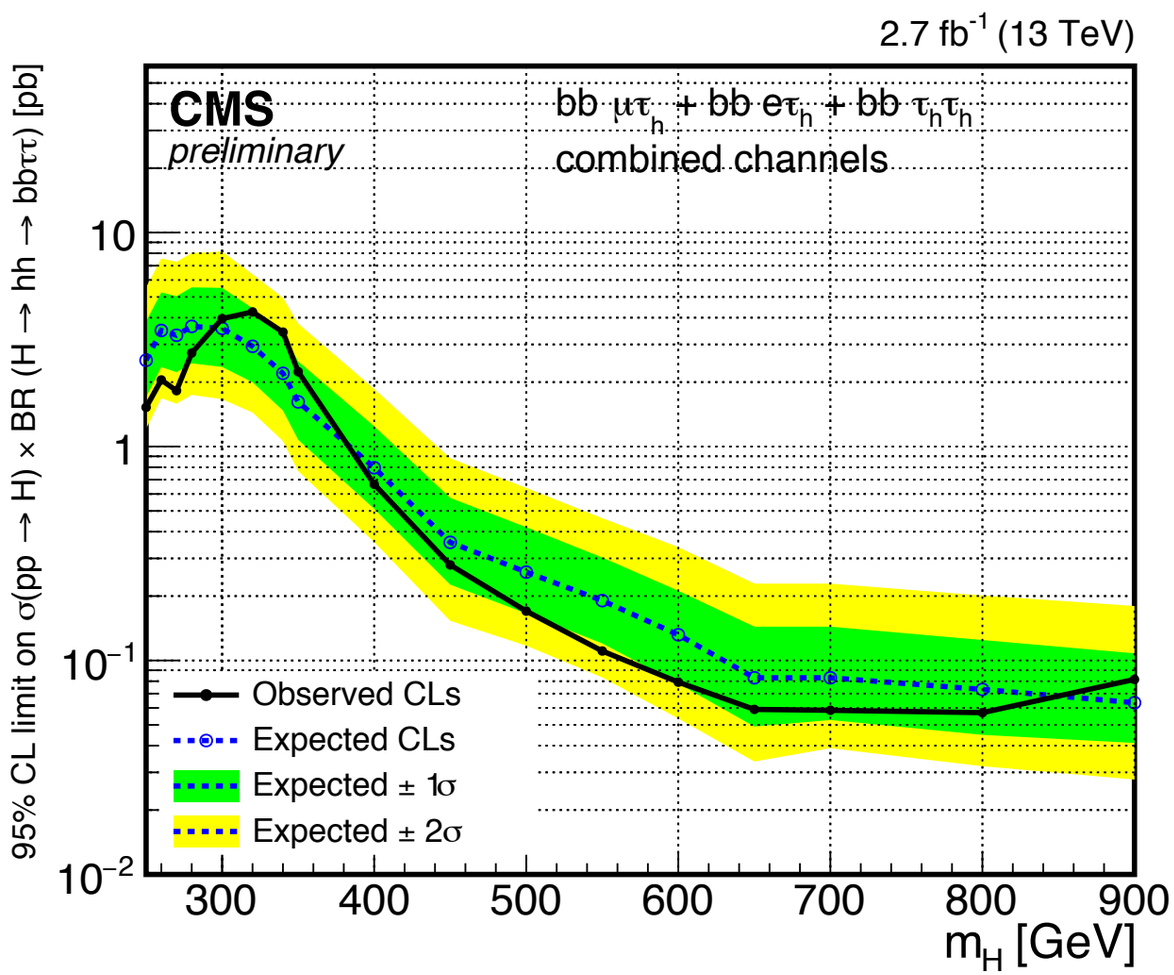




X→hh→bbττ

- Select events with two b-tagged jets + di-τ pair **$e\tau_h$, $\mu\tau_h$ or $\tau_h\tau_h$**, with **τ_h** a hadronically decaying τ
- Requirement on reconstructed di-τ invariant mass and bb invariant mass: **$80 < m_{\tau\tau}, m_{bb} < 160$ GeV**
- Reconstruct invariant mass of di-Higgs candidate pair using **kinematic fit** which assumes m_h=125 GeV



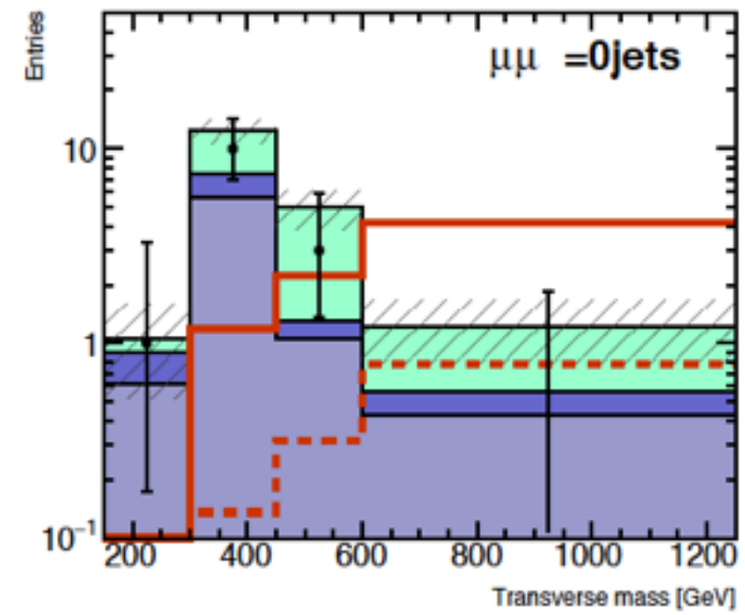


Upper limits on σ x BR
Ranging from **~0.1 pb** at high mass to **~4 pb** at low mass

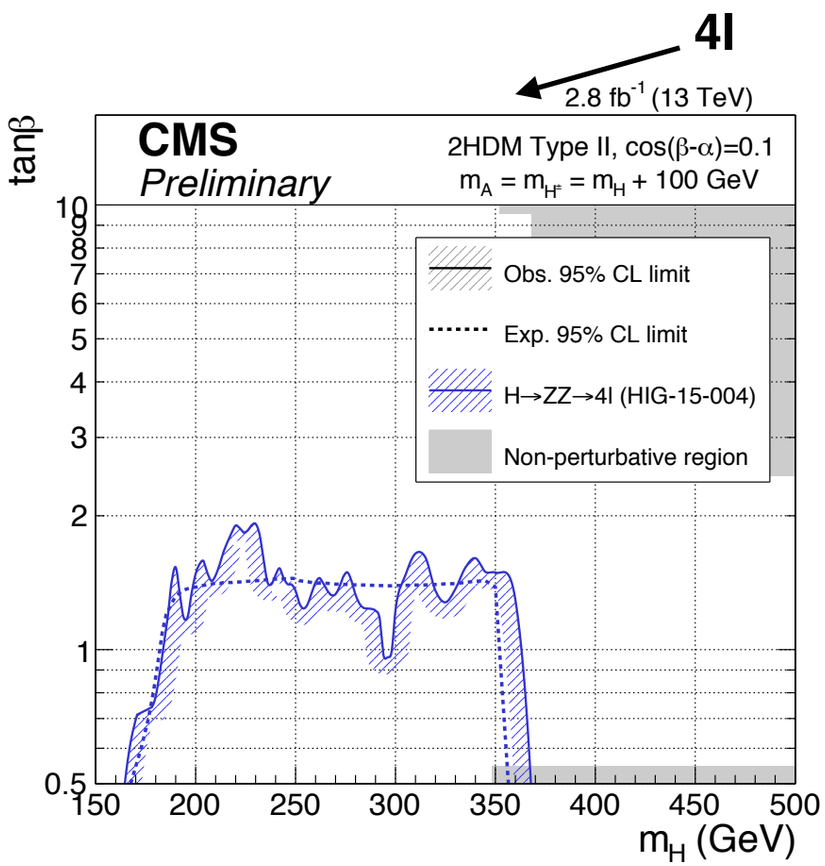
CMS-PAS-HIG-15-004
CMS-PAS-HIG-16-001

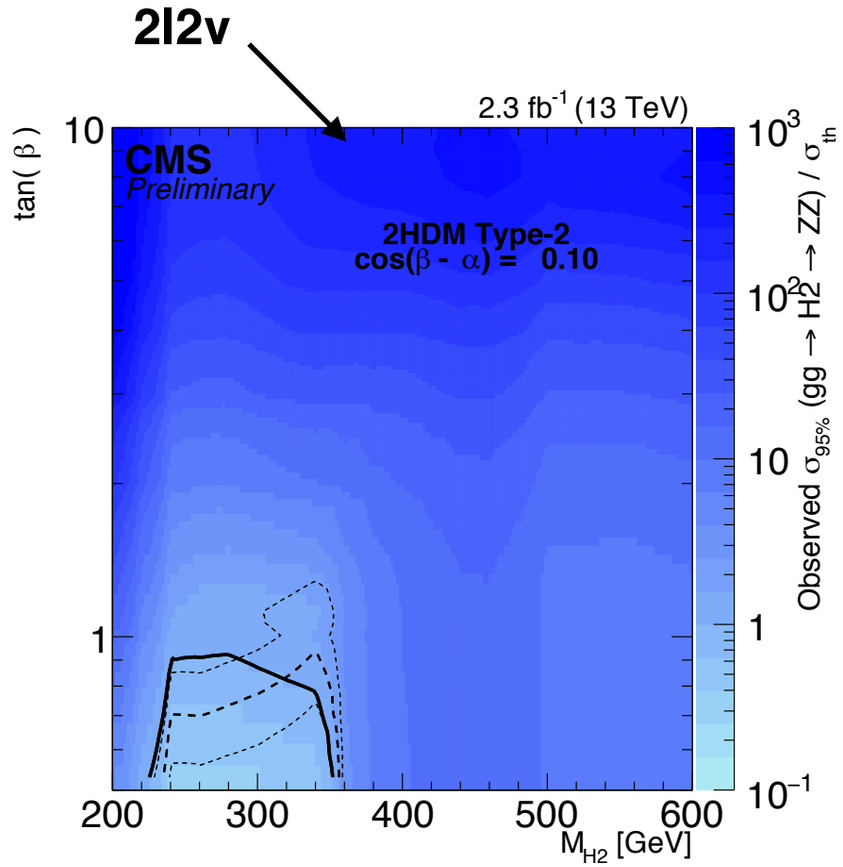
H→ZZ

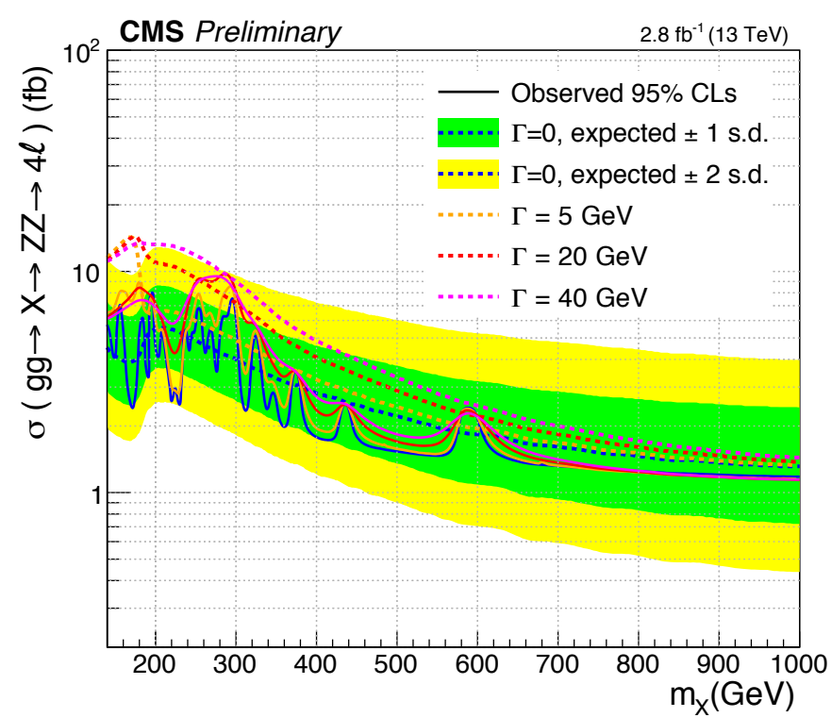
- Searches performed in two final states:
- H→ZZ →**2l2v**:
  - Require Z →ll candidate + large MET, use **transverse mass** for signal extraction
  - 3 categories to maximise sensitivity: **VBF, >= 1 jet , 0- jet**
- H→ZZ→**4l**:
  - Select Z→ll candidates, use 4-lepton invariant mass for signal extraction
  - Upper limits on σ x BR for **different resonance widths**



Interpretation in type II 2HDM





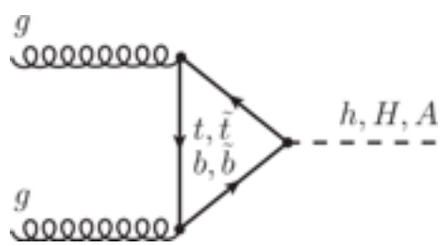


NEW CMS-PAS-HIG-16-006

H/A→ττ overview

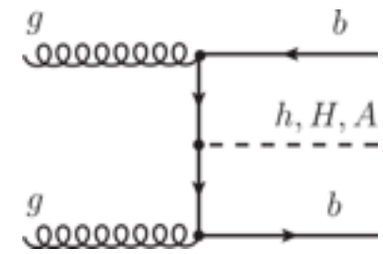
- Search for H/A→ττ , **masses up to 3.2 TeV** in 4 final states
  - **eτh, μτh, τhτh, eμ** τh = hadronically decaying τ
- Divide events into **two categories**:

no b-tag:
0 b-tagged jets

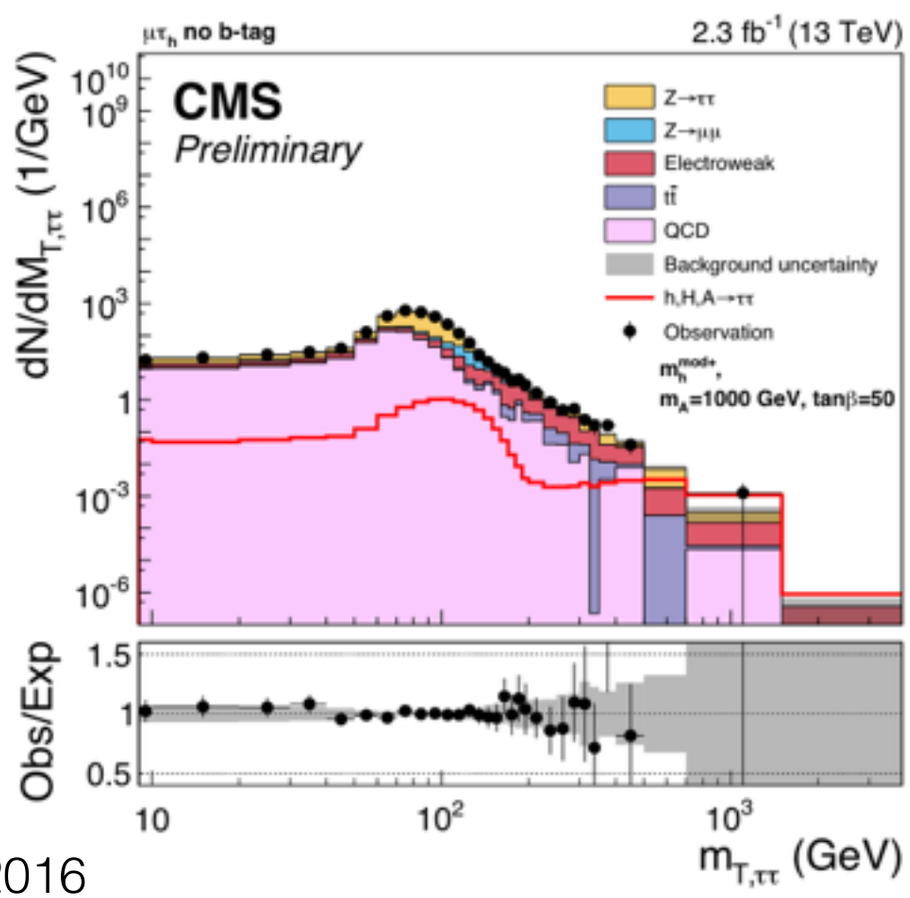


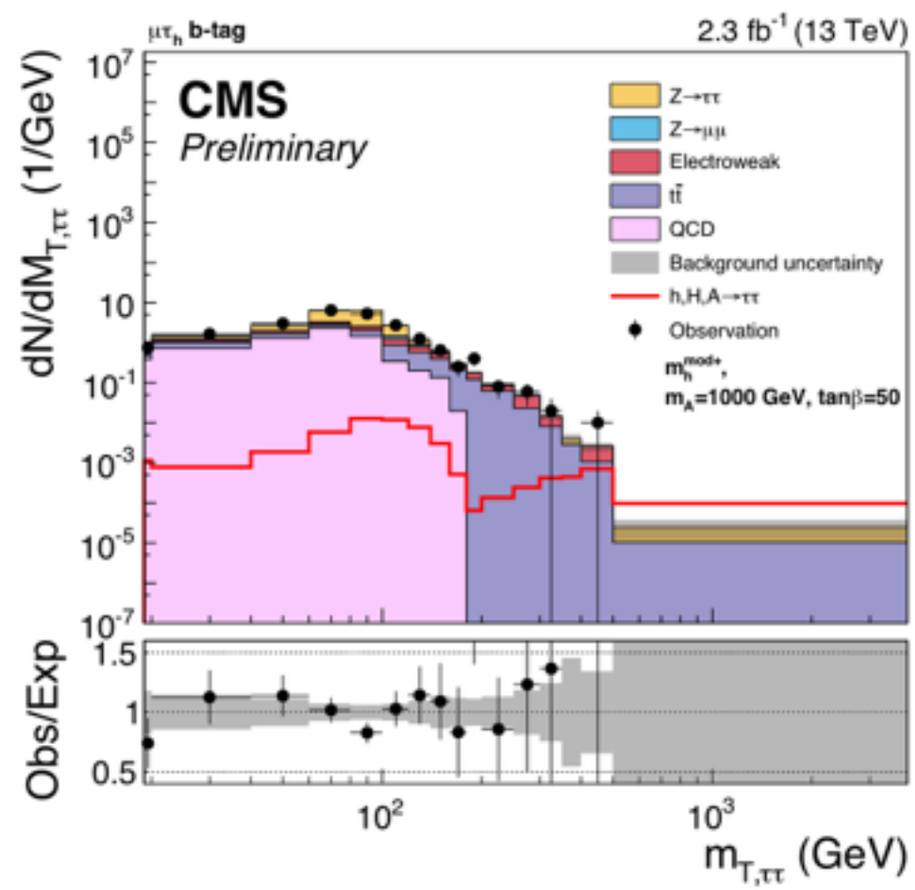
targets gg→h,H,A

b-tag:
≥1 b-tagged jet



targets gg→bbh,H,A

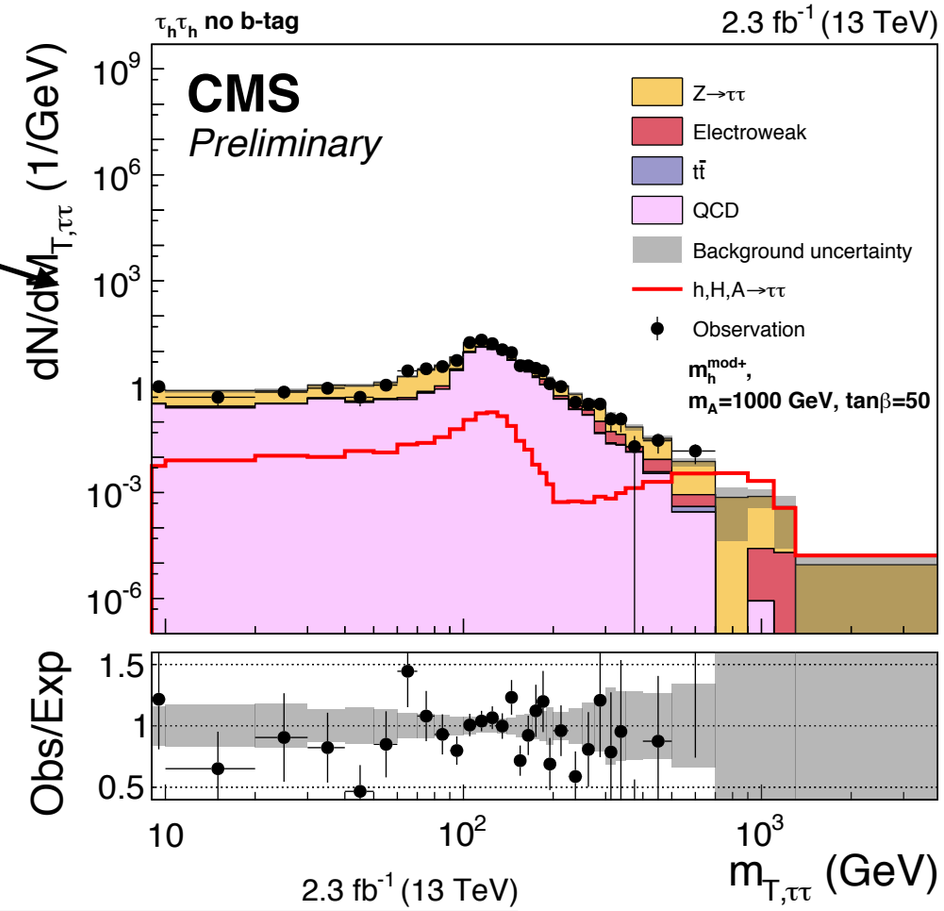


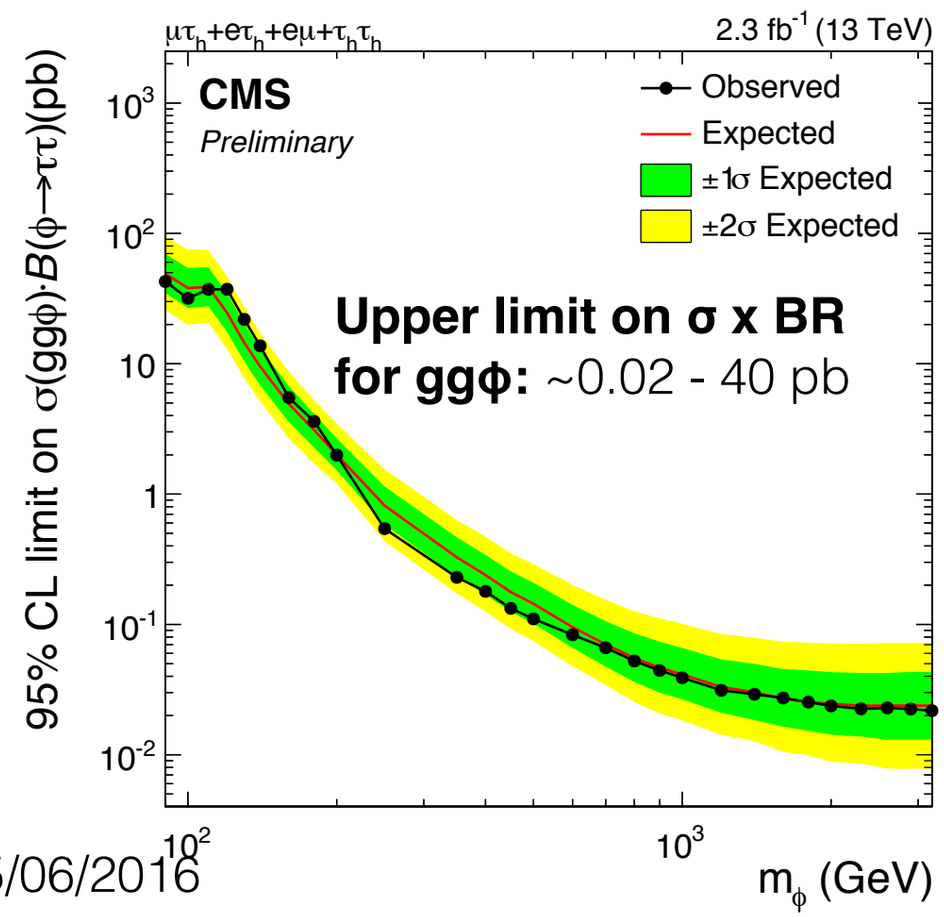


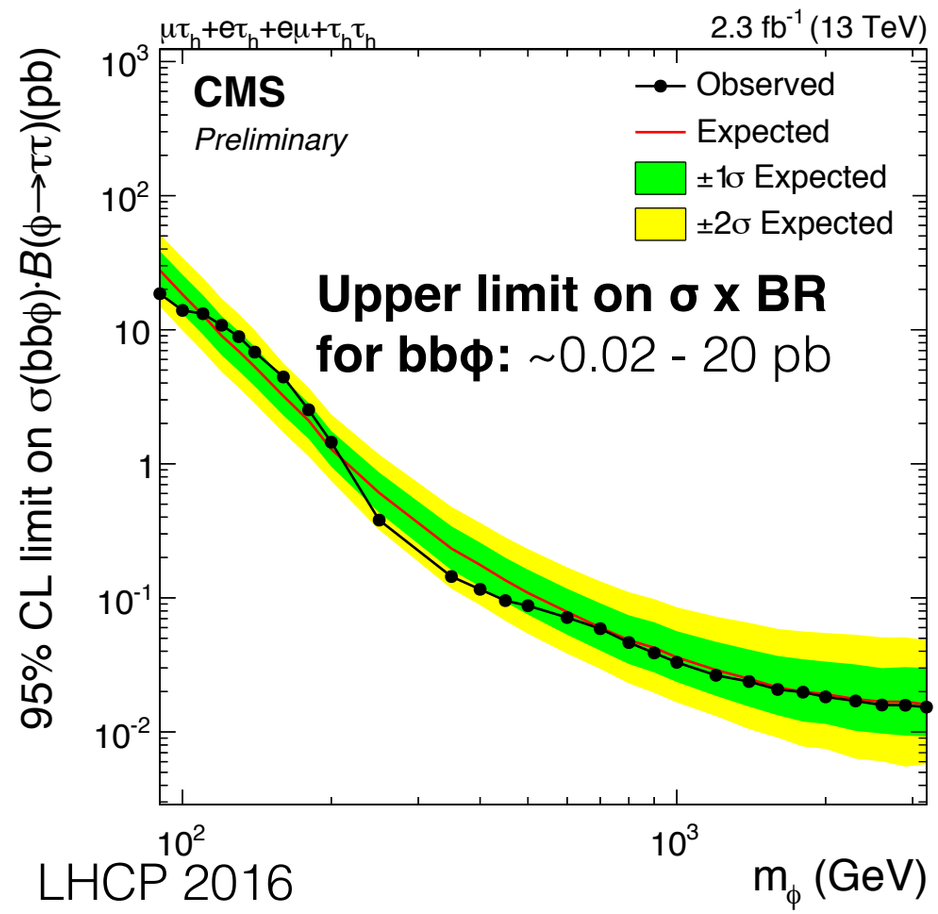
NEW CMS-PAS-HIG-16-006

H/A→ττ results

- Fit **reconstructed di-τ transverse mass** to set model-independent upper limits on σ x BR
- Scan m_A-tanβ plane in benchmark MSSM scenarios for model-dependent limits



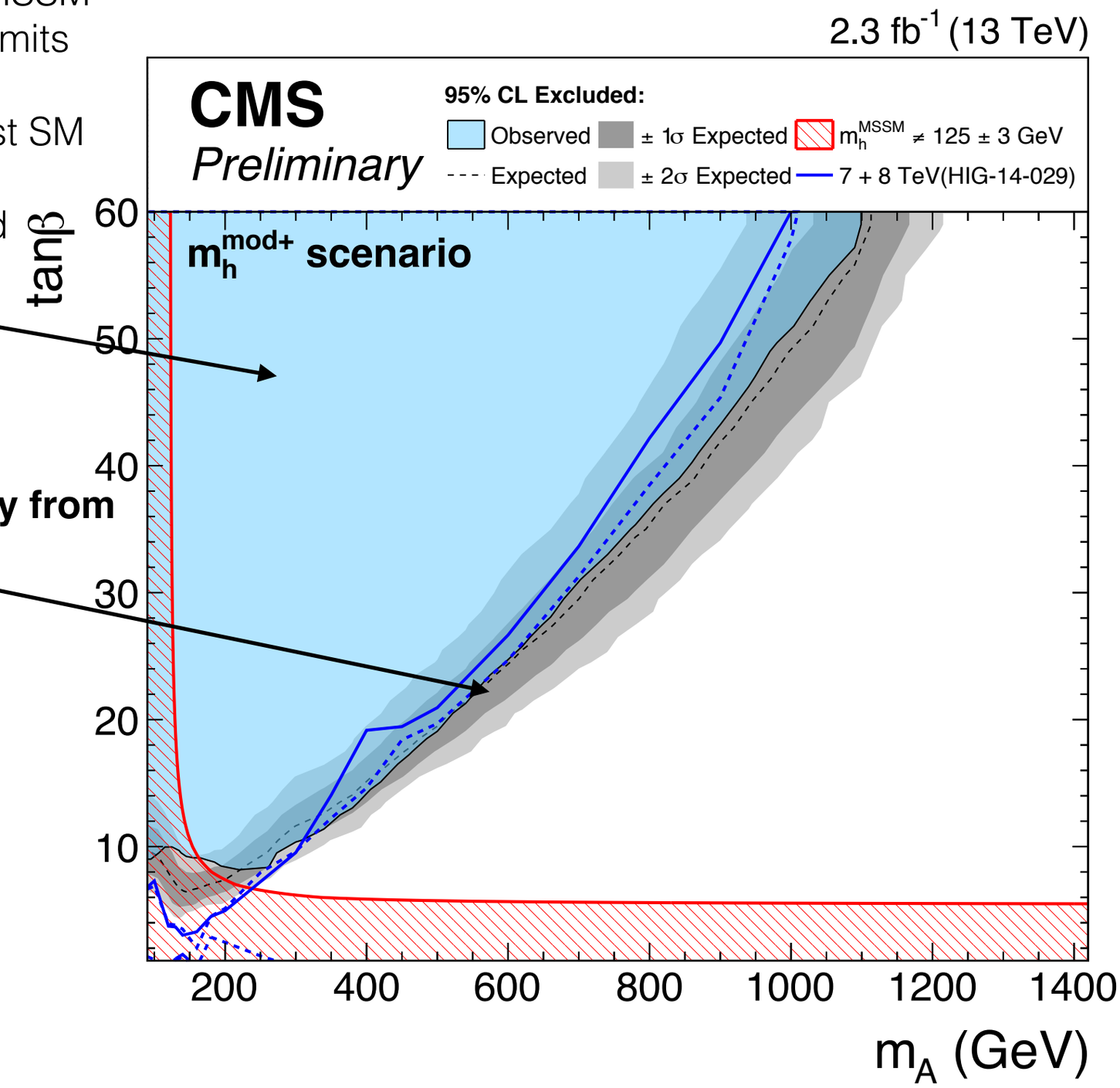


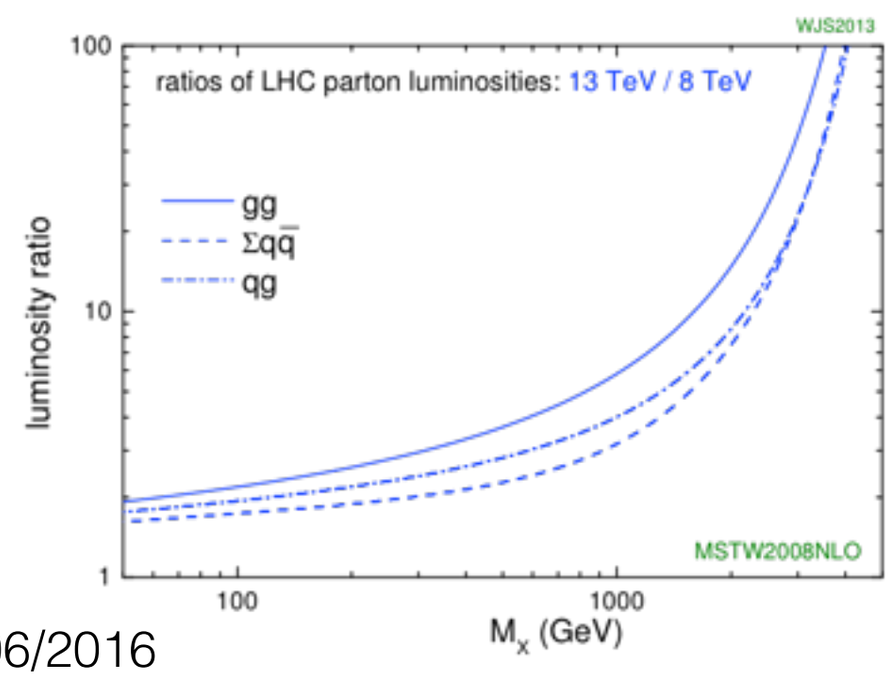


NEW CMS-PAS-HIG-16-006

H/A→ττ model interpretation

- Scan m_A-tanβ plane in benchmark MSSM scenarios to set model-dependent limits
  - For example in $\mathbf{m_h^{mod+}}$ scenario
- Test MSSM signal hypothesis against SM Higgs + bkg hypothesis
- **Light blue** shaded region: observed exclusion
- Dashed (solid) blue line: expected (observed) exclusion from 7+8 TeV H—> ττ analysis
  - **Surpassing expected sensitivity from Run I starting m_A ~ 600 GeV**





Summary

- During run I of the LHC, BSM Higgs boson searches were already performed with CMS in many decay channels
  - Can exclude large part of parameter space in benchmark MSSM model scenarios
- These searches continue at 13 TeV in run II
  - Searches for high mass resonances decaying to a pair of SM-like Higgs bosons
    - Final states of **bbbb, bbWW, bbττ** have been discussed
  - Direct resonance searches
    - Covered **H→ZZ** and **H→ττ**
  - **No excess above SM expectation has been found**
    - Upper limits on σ x BR are set
    - The H→ττ result has been interpreted in MSSM benchmark scenarios and **surpasses the limits set during run I at intermediate and high m_A**
- **New physics reach with 2015 dataset already - and more data coming in quickly to extend this even further**

Backup

MSSM scenarios

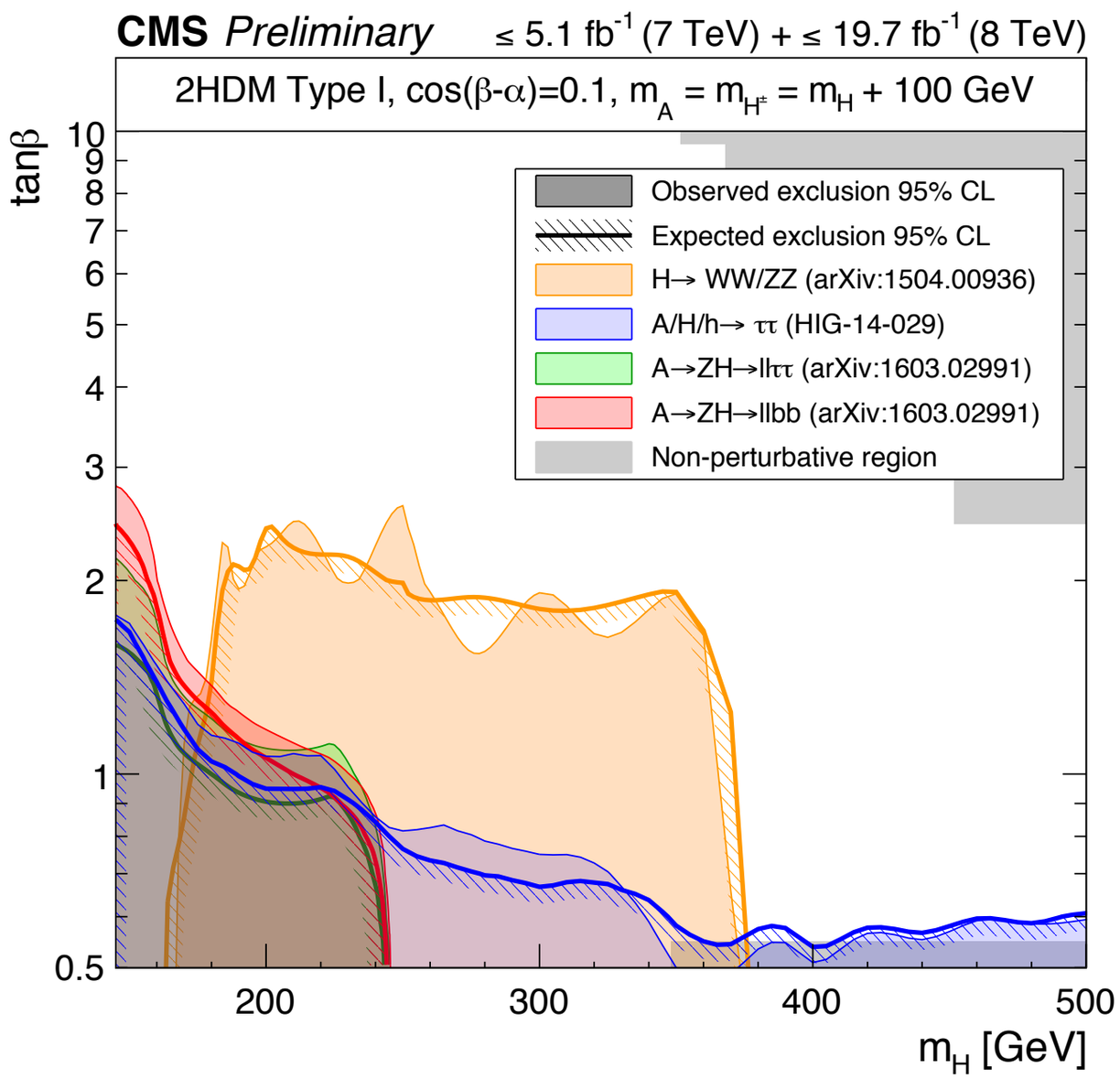
- m_h^{mod+} scenario:
  - Modified version of m_h^{max} scenario to incorporate 125 GeV higgs boson
  - m_h^{max} scenario:
    - Used in LEP Higgs searches
    - M_{SUSY} = 1 TeV
    - Stop mixing parameter $X_t = 2M_{SUSY}$
  - In m_h^{mod+} scenario: $X_t = 1.5\ M_{SUSY}$, other parameters remain the same:
    - μ = 200 GeV, $M_1=5/3\ M_2 \tan^2\theta_w$, M_2=200 GeV, $A_b=A_t=A_\tau$, m_{gl}=1.5TeV, m_{l3}=1TeV
- hMSSM scenario:
  - Effective MSSM model, trading precise knowledge of SM-like Higgs against unknown higher order corrections
  - Strictly valid for m_A>130 GeV and tanβ<10
    - Can be formulated for values up to tanβ 60 by omitting direct higher order SUSY corrections to down-type fermion couplings and corrections due to SUSY particles in loops

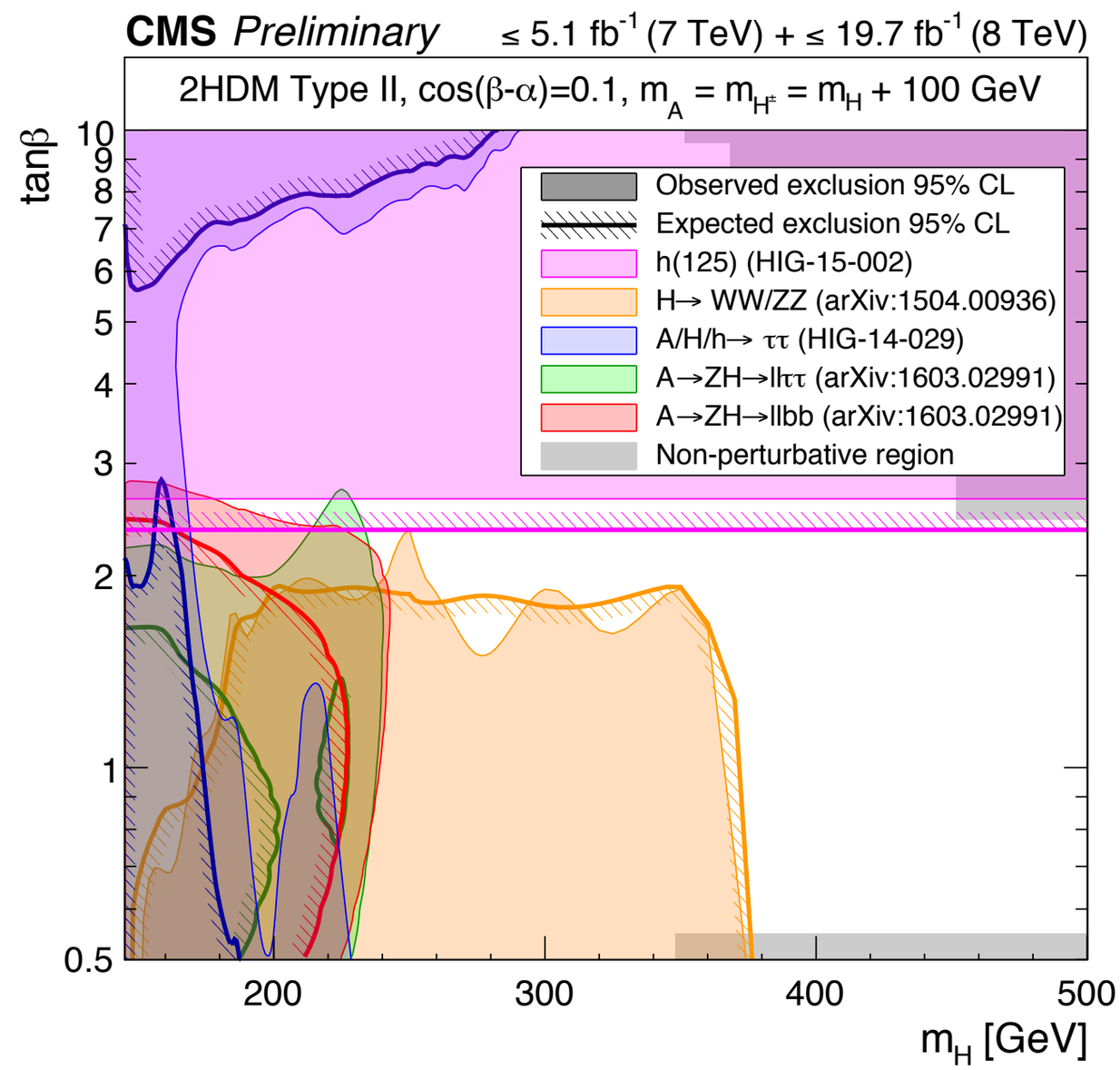
BSM Higgs searches in Run I

- **2HDM (type I and II)**
  - Scan in m_H - tanβ plane
  - m_h=125 GeV, m_A=m_{H+-}=m_H+100 GeV
  - cos(β-α) = 0.1

Run I BSM Higgs results

- Direct searches interpreted in 2HDM scenarios





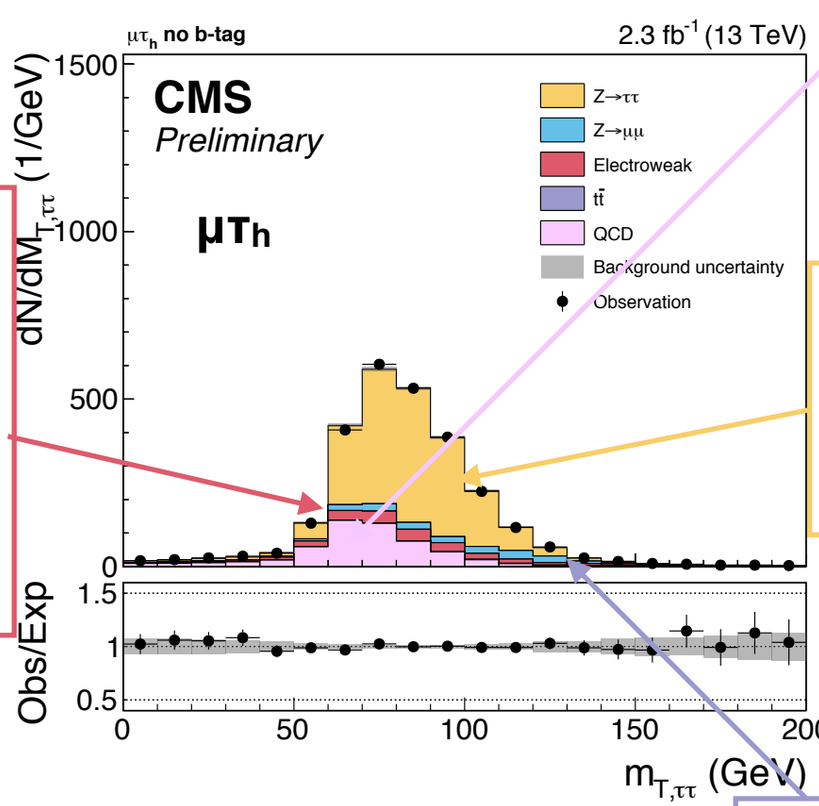
NEW CMS-PAS-HIG-16-006

H/A→ττ

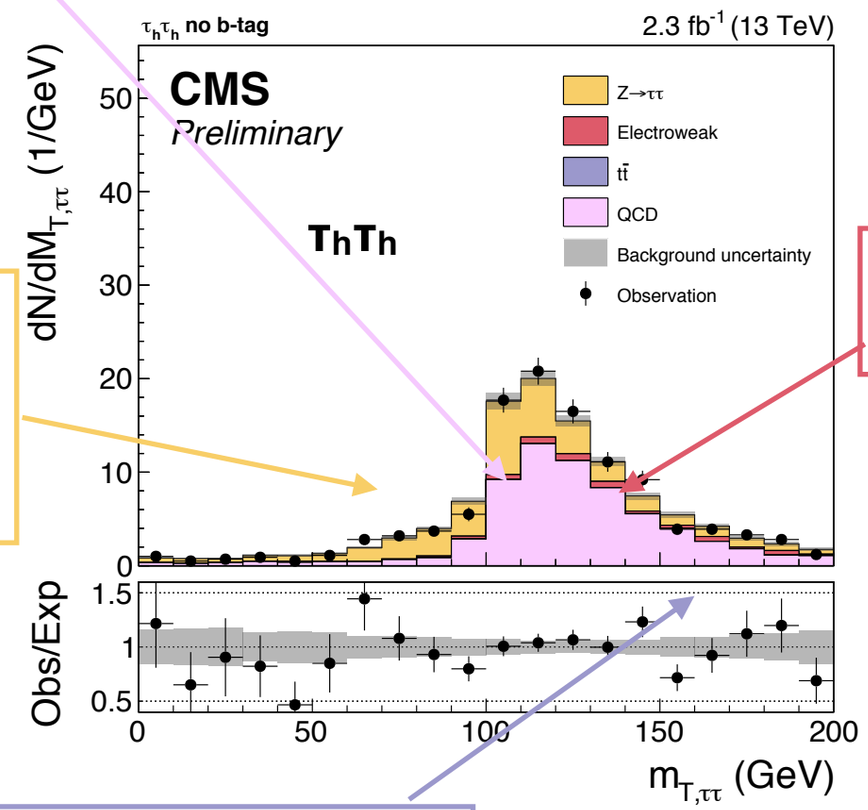
- **Dominant backgrounds** vary between the different channels

QCD
from sideband in data

W+Jets
Data—driven estimate (norm), shape from MC



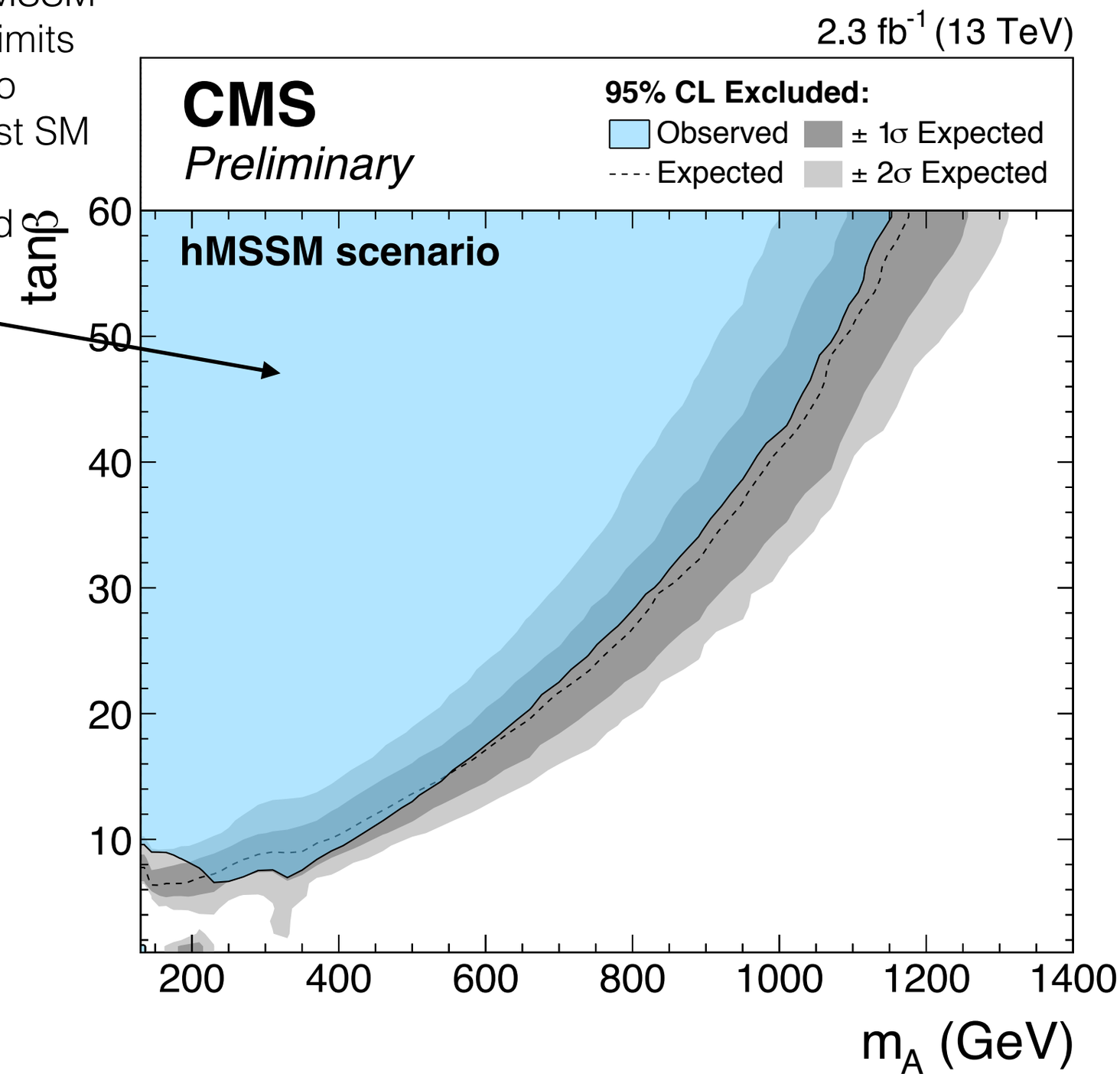
Z→ττ
From MC with data—driven correction



W+Jets
From MC

ttbar
From MC with data—driven correction

NEW CMS-PAS-HIG-16-006

H/A→ττ model interpretation

- Scan m_A-tanβ plane in benchmark MSSM scenarios to set model-dependent limits
  - For example in **hMSSM** scenario
- Test MSSM signal hypothesis against SM Higgs + bkg hypothesis
- **Light blue** shaded region: observed exclusion
- Note: model not strictly applicable for tanβ>10