Imperial College London

Searches for additional neutral Higgs bosons in the di-tau final state with the CMS experiment

D. Winterbottom
IOP Conference
University of Bristol
26/3/2016

d.winterbottom15@imperial.ac.uk

Overview

- Introduction
- Previous results from CMS
- Overview of analysis
  - Strategy
  - Categorisation
  - Background methods
- Results
  - Model independent limits
  - Model dependent limits
- Summary

d.winterbottom15@imperial.ac.uk

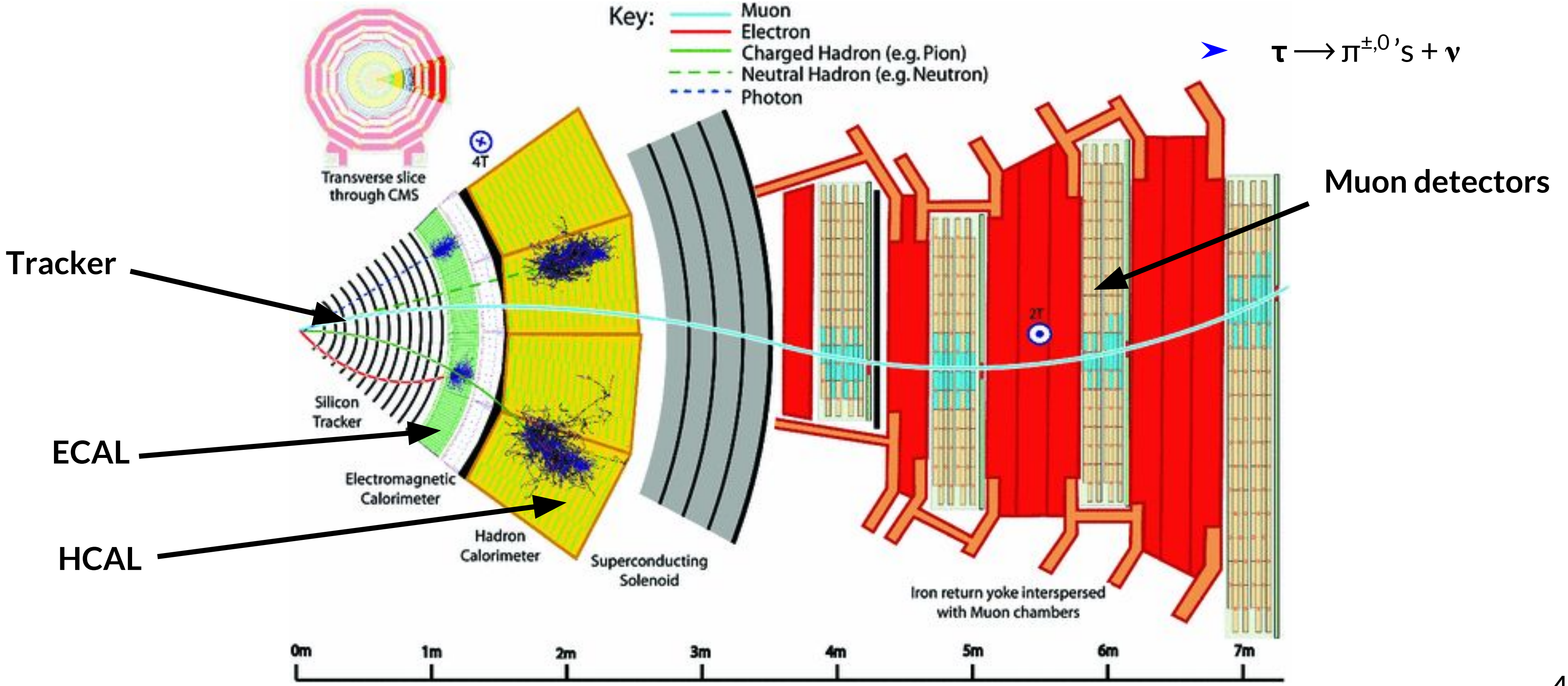
Introduction

- In 2012 CMS + ATLAS discovered SM-like Higgs boson
- SM Higgs sector has 1 higgs-doublet ⟶ 1 scalar Higgs boson
- Many BSM theories require additional Higgs doublets
- 2 higgs-doublet models (2HDM) ⟶ 2 scalar bosons (H, h) + 1 pseudoscalar (A) + 2 charged Higgs ($H^{\pm}$)
- MSSM Higgs sector is a type of 2HDM (type-2 2HDM)
- At tree-level is described by 2 parameters m_A and tanβ ($\tan\beta = v_u/v_d$)
- Dependencies on SUSY parameters enter at high orders ⟶ set these to values in representative benchmark scenarios

d.winterbottom15@imperial.ac.uk

The CMS Experiment

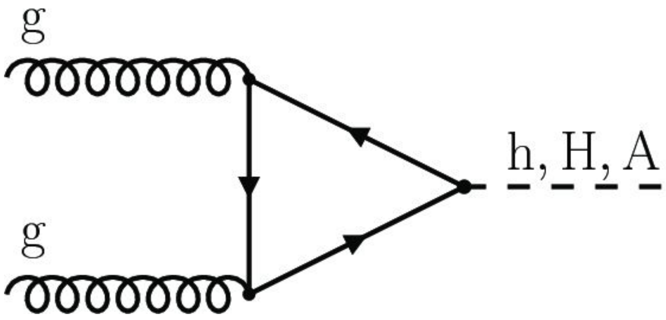
- $\tau \longrightarrow \mu + 2\nu$
- $\tau \longrightarrow e + 2\nu$
- $\tau \longrightarrow \pi^{\pm,0}$'s $+ \nu$



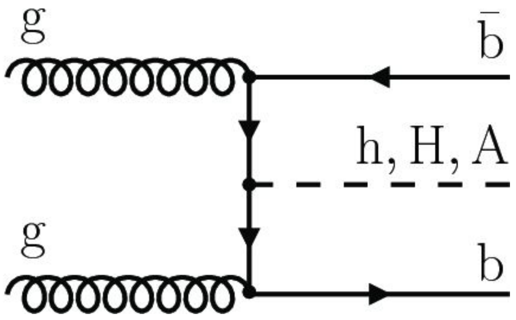
d.winterbottom15@imperial.ac.uk

Φ→ττ Motivation

- Focus on neutral bosons (φ = H, h, A) decaying into tau leptons
- Consider 2 production modes: b-associated (bbφ) and gluon-fusion (ggφ)
- At high tanβ branching ratio to down-type particles is enhanced:
  - H, h, A → ττ branching ratio is enhanced
  - bbφ cross-section is enhanced



ggφ



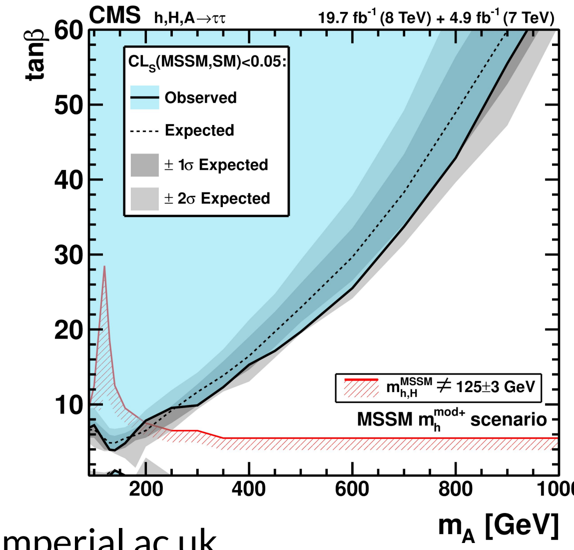
bbφ

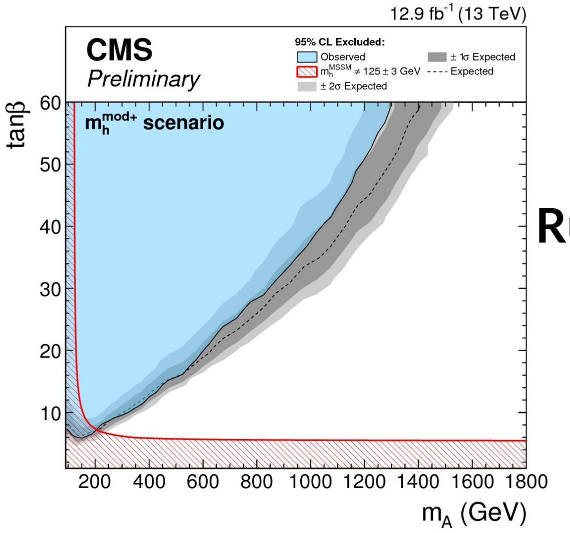
d.winterbottom15@imperial.ac.uk

Previous CMS Results

- Run 1 analysis set tight limits at low mass
- First Run 2 result on 12.9 fb^{-1} of 13 TeV data excluded significantly more at high mass

Full Run 1





Run 2 (12.9 fb^{-1})

d.winterbottom15@imperial.ac.uk

Analysis Overview

- Most recent analysis on full 2016 dataset
- 35.9 fb^{-1} of 13 TeV data
- I will present the results on this analysis on the preceding slides

d.winterbottom15@imperial.ac.uk

Analysis Strategy

- Taus unstable - decay close to primary vertex:
  - $\tau \longrightarrow \mu + 2\nu$
  - $\tau \longrightarrow e + 2\nu$
  - $\tau \longrightarrow \pi^{\pm,0}$'s $+ \nu$
- Reconstruct tau from decay products - muon (τ_μ), electron (τ_e) or hadrons (τ_h):
- Neutrinos give rise to missing transverse momentum, p_T^{miss}
- Split events into channels based on tau decays
- Use 4 most sensitive channels: $\tau_e\tau_\mu$, $\tau_e\tau_h$, $\tau_\mu\tau_h$, $\tau_h\tau_h$
- Discriminating variable is total-transverse-mass, m_T^{tot}:

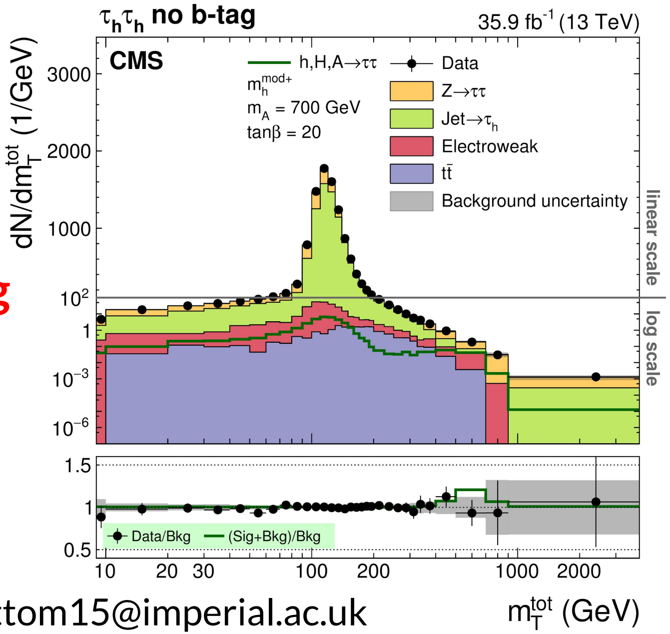
$$m_T^{tot} = \sqrt{m_T^2(p_T^{\tau_1}, p_T^{\tau_2}) + m_T^2(p_T^{\tau_1}, p_T^{miss}) + m_T^2(p_T^{\tau_2}, p_T^{miss})}$$

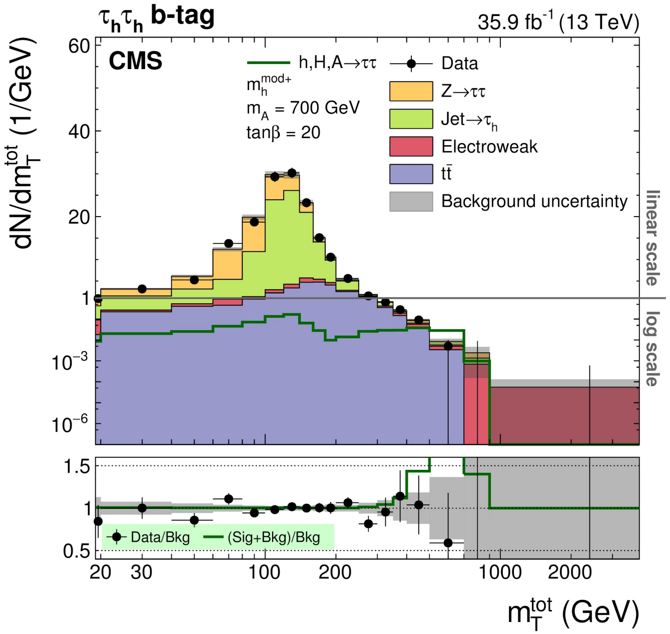
d.winterbottom15@imperial.ac.uk

Categorisation

- Split events into categories based on number of b-tagged jets:
  - ➤ no b-tag ⟶ targeting ggφ [no b-tagged jets]
  - ➤ b-tag ⟶ targeting bbφ [at least 1 b-tagged jet]

no b-tag





b-tag

d.winterbottom15@imperial.ac.uk

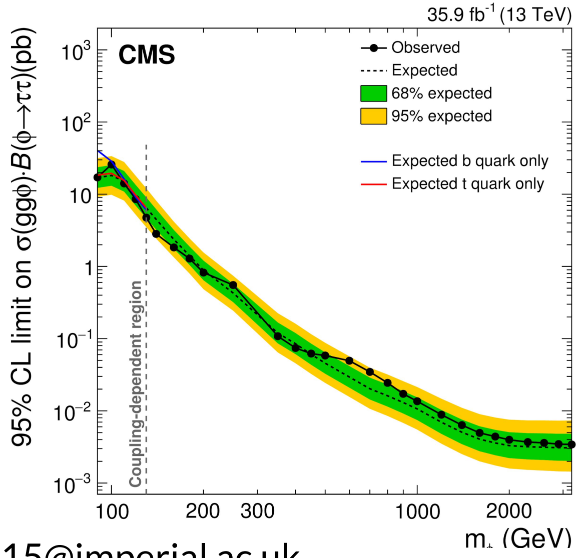
Background modelling

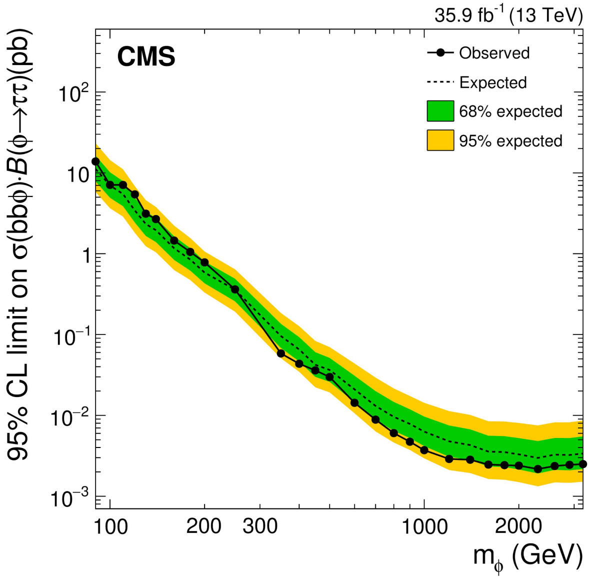
- $Z \to \tau\tau$:
  - Estimated from MC
  - $Z \to \mu\mu$ control-regions used to constrain normalization
- Jet$\to\tau_h$ fakes:
  - Includes all background with jets faking hadronic taus: QCD, W+jets, tt, ect.
  - Model using data-driven "fake-factor" method
  - Jet$\to\tau_h$ misidentification-rate of taus measured in control regions - apply to events in sideband region (sideband region = τ_h failing nominal ID/isolation cuts)
- tt:
  - Predominantly in b-tag category
  - Estimate from MC
  - Control-region used to constrain normalization and shape
- QCD ($\tau_e\tau_\mu$):
  - Estimated using same-sign data (invert requirement for e and μ to have opposite charge)
- Smaller backgrounds [di-boson, single top, $Z \to ll$, W ($\tau_e\tau_\mu$ channel)] estimated from MC

Results - Model Independent

- Most recent result on full 2016 data set - 35.9 fb^{-1} of 13 TeV data
- 4 channels ($\tau_e\tau_\mu + \tau_e\tau_h + \tau_\mu\tau_h + \tau_h\tau_h$) are combined
- No excess observed - limits set on cross-section*branching-ratio for ggφ and bbφ

ggφ





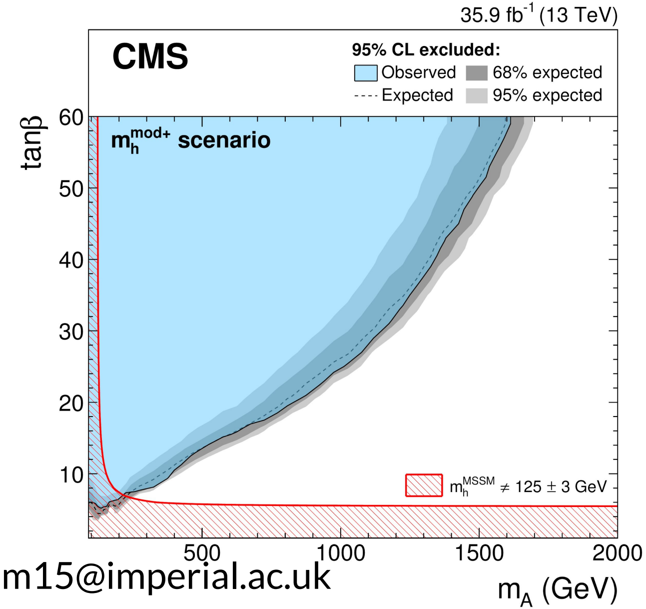
bbφ

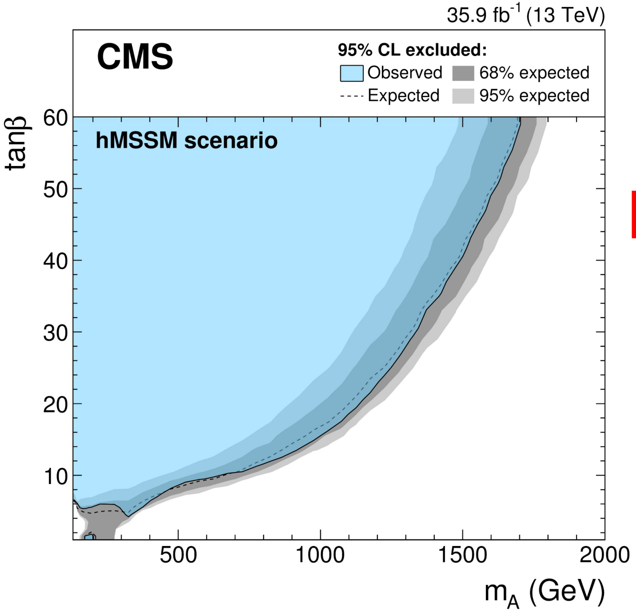
d.winterbottom15@imperial.ac.uk

Results - Model Dependent

- Model dependent limits set for 2 benchmark scenarios: m_h^{mod+} and hMSSM
- MSSM Higgs bosons up to $m_A \lesssim 250$ GeV is excluded for $\tan\beta > 6$
- Exclusion contour reaches 1.6 TeV for $\tan\beta = 60$

m_h^{mod+}





hMSSM

d.winterbottom15@imperial.ac.uk

Summary and Outlook

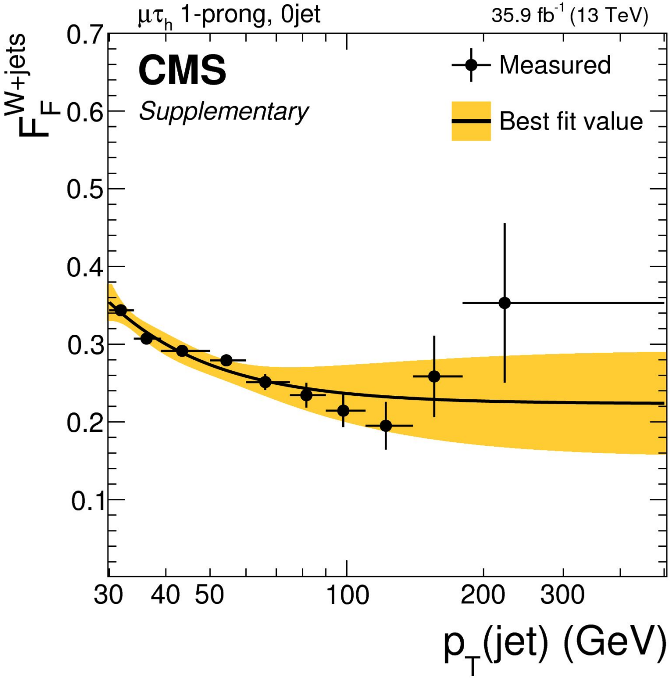
- A search for additional neutral Higgs bosons in the di-tau final state has been presented
- No excess observed - model independent/dependent limits set
- Next result planned for full Run 2 data set (≃100 fb^{-1})
- Increased luminosity expected to improve limits significantly (especially at high mass)
- Thanks for your attention!

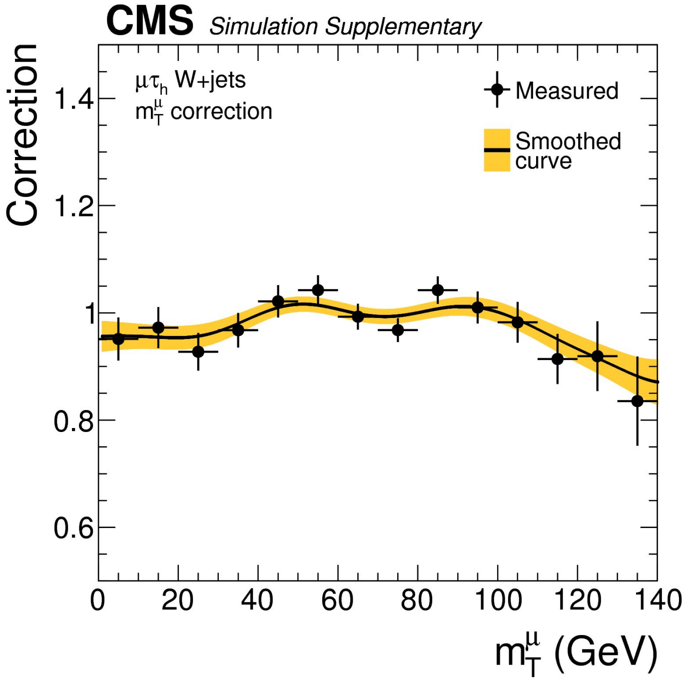
d.winterbottom15@imperial.ac.uk

Backup

Fake-Factor Method

1. Measure misidentification rate (fake-factor)
2. Derive corrections (due to extapolations)

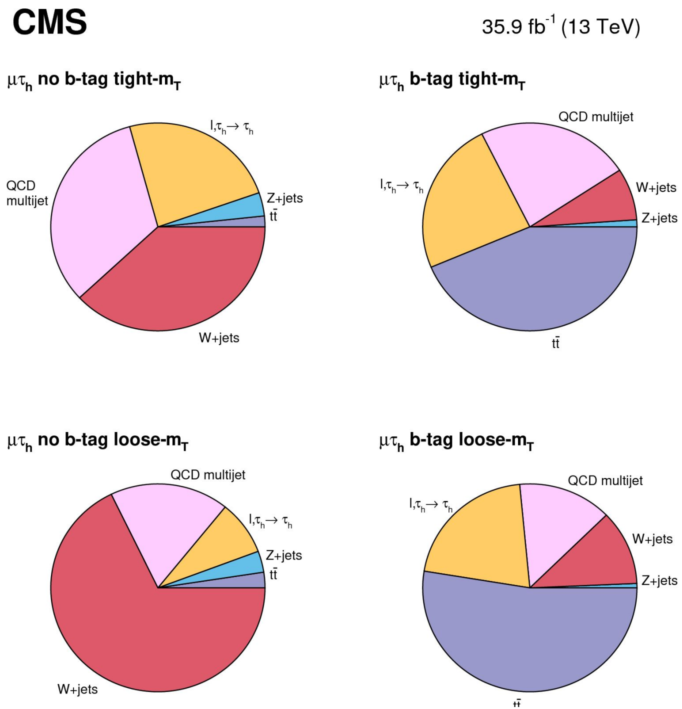




Fake-Factor Method

3. Repeat 1. and 2. for all processes

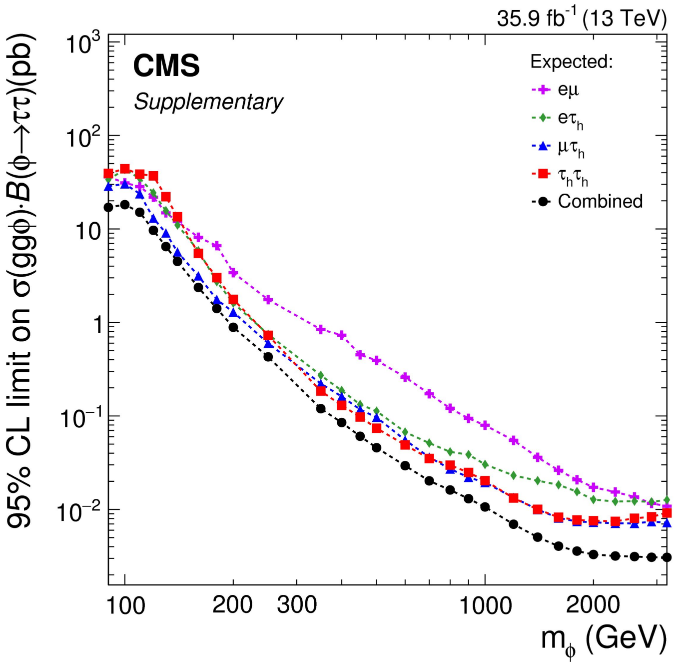
4. Apply weighted average of fake-factors in side-band region

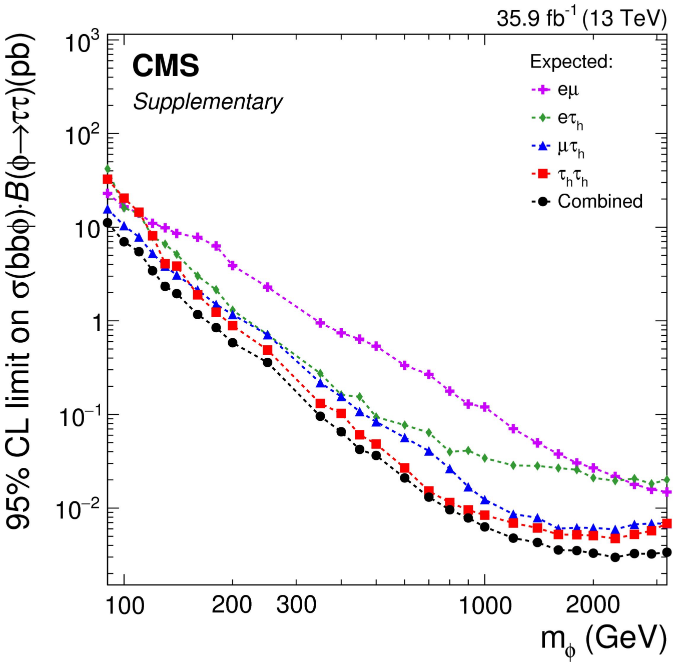


Limits Split by Channel

- Expected limits for ggφ and bbφ production for each channel compared to combination

ggφ





bbφ

MSSM Benchmark Scenarios

- MSSM benchmark scenarios are chosen to exhibit certain features of the MSSM phenomenology and to be consistent with the observation of the 125 GeV Higgs boson over large regions of the parameter space
- m_h^{mod+}:
  - ➢ SUSY parameters are fixed to sensible choices based on theoretical and experimental arguments
  - ➢ This scenario is consistent with the observation of the 125 GeV Higgs boson (exception is at low m_A / low $\tan\beta$)
  - ➢ Ref: https://arxiv.org/pdf/1302.7033.pdf
- hMSSM:
  - ➢ Interprets the 125 GeV Higgs boson boson as h
  - ➢ The uncertainties in the mass measurement are then used in turn to estimate the main radiative corrections to predict the masses and couplings of the remaining MSSM Higgs bosons
  - ➢ Ref: https://link.springer.com/article/10.1140%2Fepjc%2Fs10052-013-2650-0