Search for exotic decays of the Higgs boson at CMS

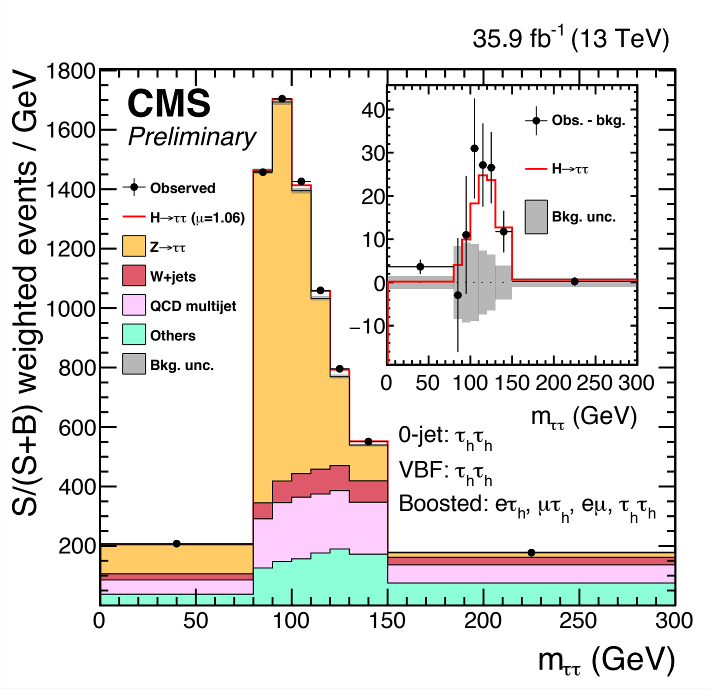
Cécile Caillol (University of Wisconsin-Madison), on behalf of the CMS Collaboration

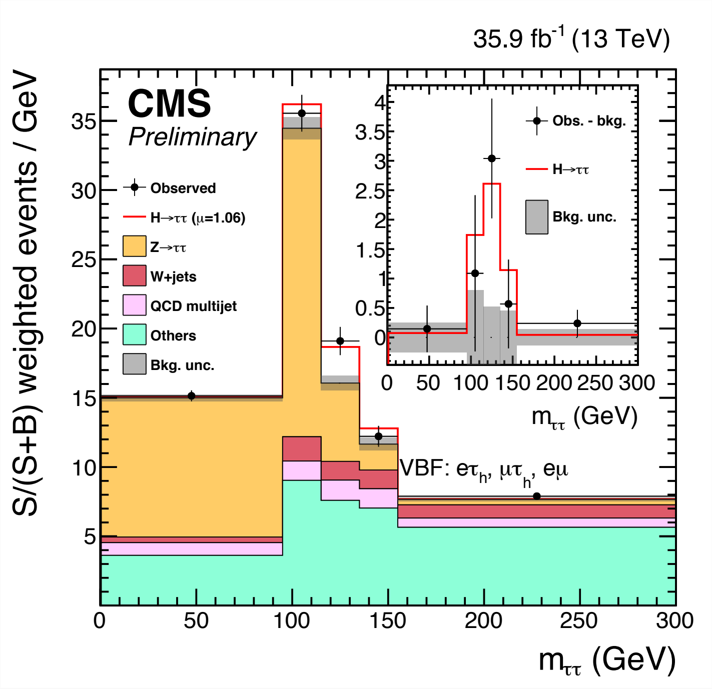
LHCP 2017, Shanghai

Why study exotic Higgs boson decays?

- Higgs boson observed in H→γγ, H→ZZ, … and H→ττ decays!

HIG-16-043





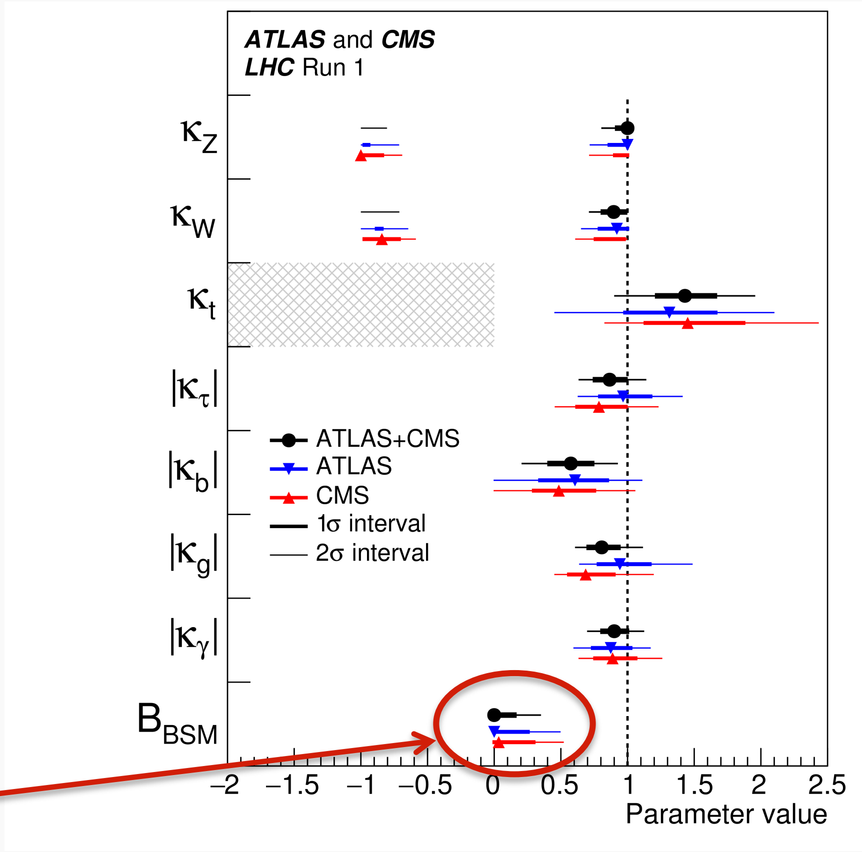
- All measurements so far are compatible with the SM expectations
- But does the Higgs boson also decay in ways not allowed in the SM?

Why study exotic Higgs boson decays?

JHEP 08 (2016) 045

- Possibilities to highlight BSM physics in the scalar sector:
  - Indirect evidence through observation of deviations in the couplings of the H boson (but precision limited and increasing slowly with additional data)
  - Direct evidence through observation of exotic decays of the Higgs boson

- Large room still viable for exotic Higgs boson decays (~20%)



Outline

- Search for Higgs boson decays to SM particles not allowed in the SM:
  - non-diagonal elements of the Yukawa coupling matrix → lepton flavor violating Higgs decays

SM values

$$Y = \begin{pmatrix} \boxed{Y_{ee}} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & \boxed{Y_{\mu\mu}} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & \boxed{Y_{\tau\tau}} \end{pmatrix}$$

- Search for Higgs boson decays to non-SM particles:
  - Invisible Higgs boson decays, with H produced via ggF, VBF, or VH (H→invisible)
  - Higgs boson decays to light pseudoscalars/scalars, decaying to SM particles (H→aa)

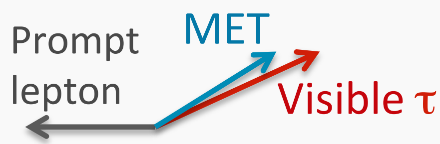
LFV H→μτ/eτ/eμ: Status at LHCP 2016

- 2.4σ excess for H→μτ from CMS in Run-1:
  - Best-fit branching fraction: 0.84 ± 0.38%
- Compatible with 1σ excess from ATLAS in Run-1
  - Best-fit branching fraction: 0.53 ± 0.51%
- Slight tensions with 1σ deficit from CMS with 2015 data (but large uncertainty because only 2.3 fb^{-1}):
  - Best-fit branching fraction: -0.76 ± 0.83%
- No excess in H→eτ and H→eμ searches
- **H→μτ ($\mu\tau_h$ and $\mu\tau_e$ final states) and H→eτ ($e\tau_h$ and $e\tau_\mu$ final states) analyses updated with full dataset collected by CMS in 2016 (see next slides)** *HIG-17-001*

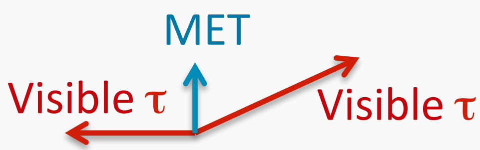
How to separate signal and backgrounds?

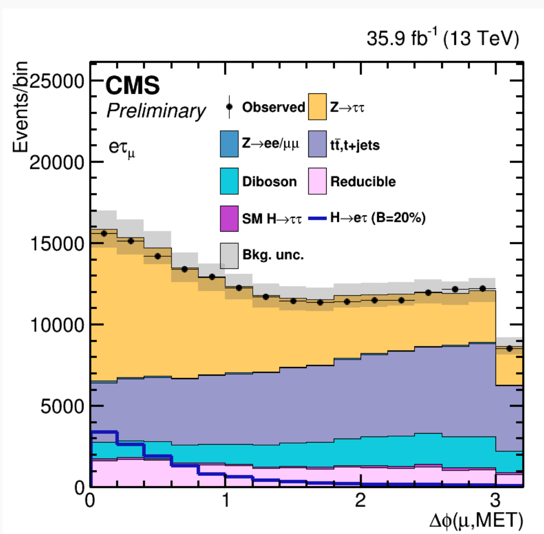
- The MET is close to aligned with the visible tau decay product

Signal event:

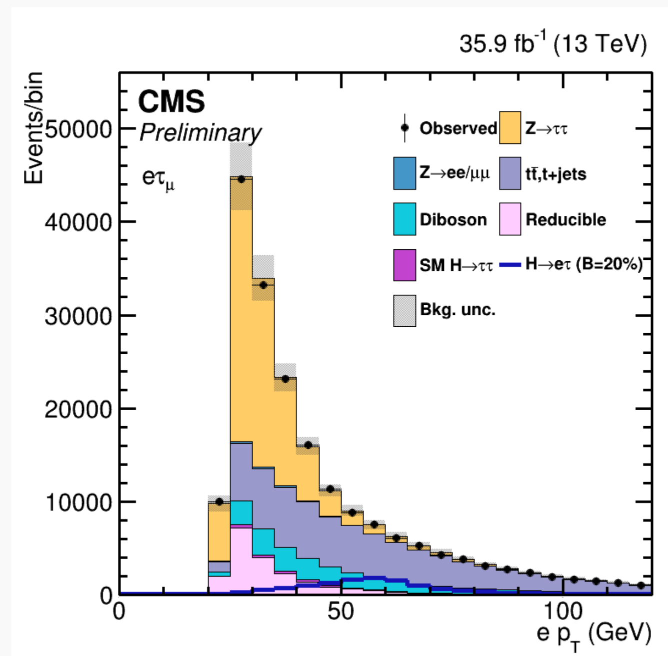


Z→ττ event:



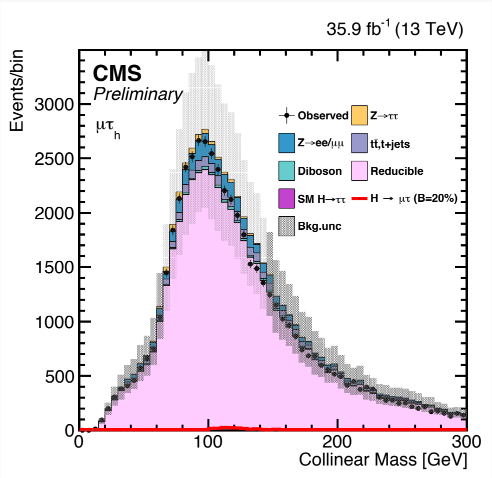


- The decay products have on average higher p_T than in Z→ττ events (where part of the energy is lost by neutrinos in both tau decays), and in events with misidentified leptons (jet→e/μ/τ_h rate decreases with p_T)

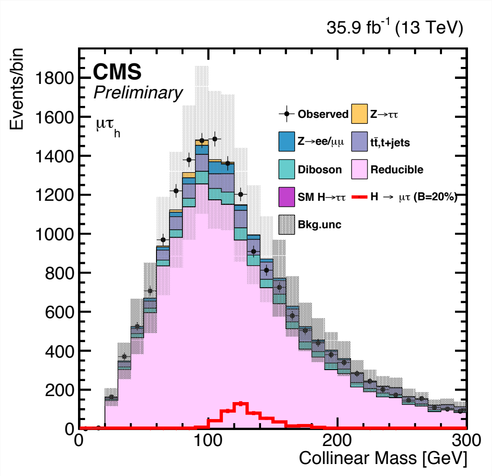


Background estimation

- The backgrounds are estimated from MC samples, except for:
  - Jet→e/μ/τ_h background in the eτ_h/μτ_h final states(mostly W+jets, and a bit of QCD multijet): observed events with anti-isolated τ_h reweighted with a misidentification rate depending on p_T, η, and reconstructed decay mode
  - QCD multijet in eμ final state: obtained from events with same-sign leptons (other MC processes subtracted from data), and reweighted by a scale factor that accounts for same-sign/opposite-sign differences



Validation in same-sign events

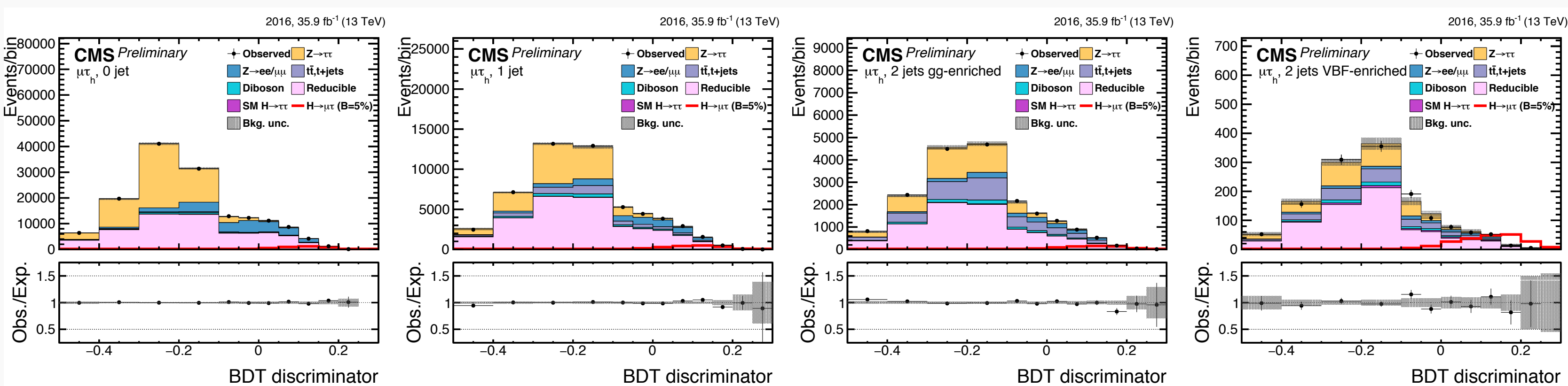


Validation in opposite-sign events with high m_T(μ,MET) and m_T(τ_h,MET)

Signal extraction

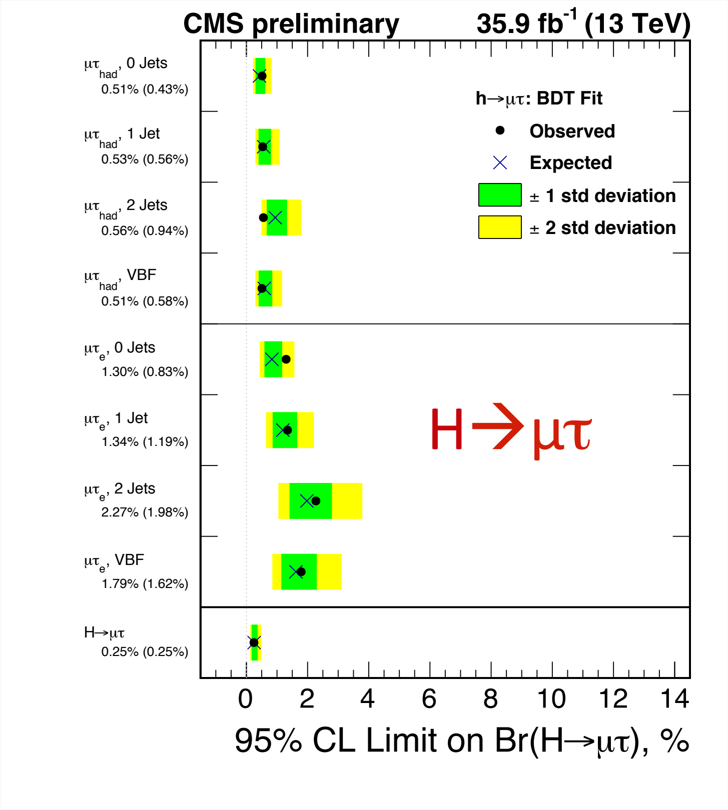
- Events divided into 4 categories to target different productions modes:
  - 0 jet: Targets gg→H events
  - 1 jet: Targets gg→H events produced in association with a jet
  - 2 jets, low m_{jj}: Targets gg→H events with additional jets
  - 2 jets, high m_{jj}: Targets qq→H events

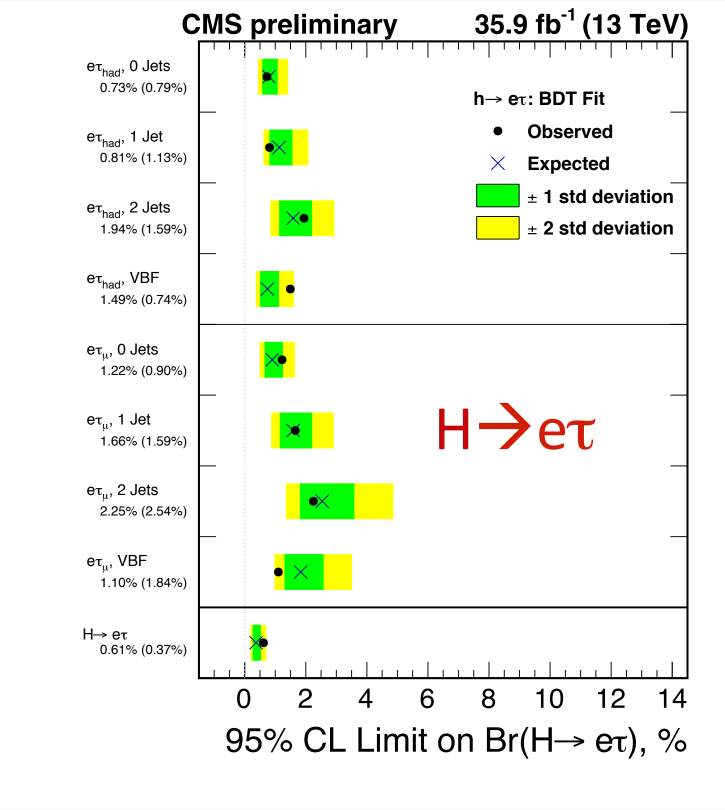
- BDT trained on the signal against a selection of background samples (reducible background for $e\tau_h$ and $\mu\tau_h$, ttbar and/or Z→ττ for $e\tau_\mu$ and $\mu\tau_e$)



- Cross-check using a cut-based approach with the collinear mass as observable → compatible results but less sensitivity

Results of H→μτ and H→eτ searches

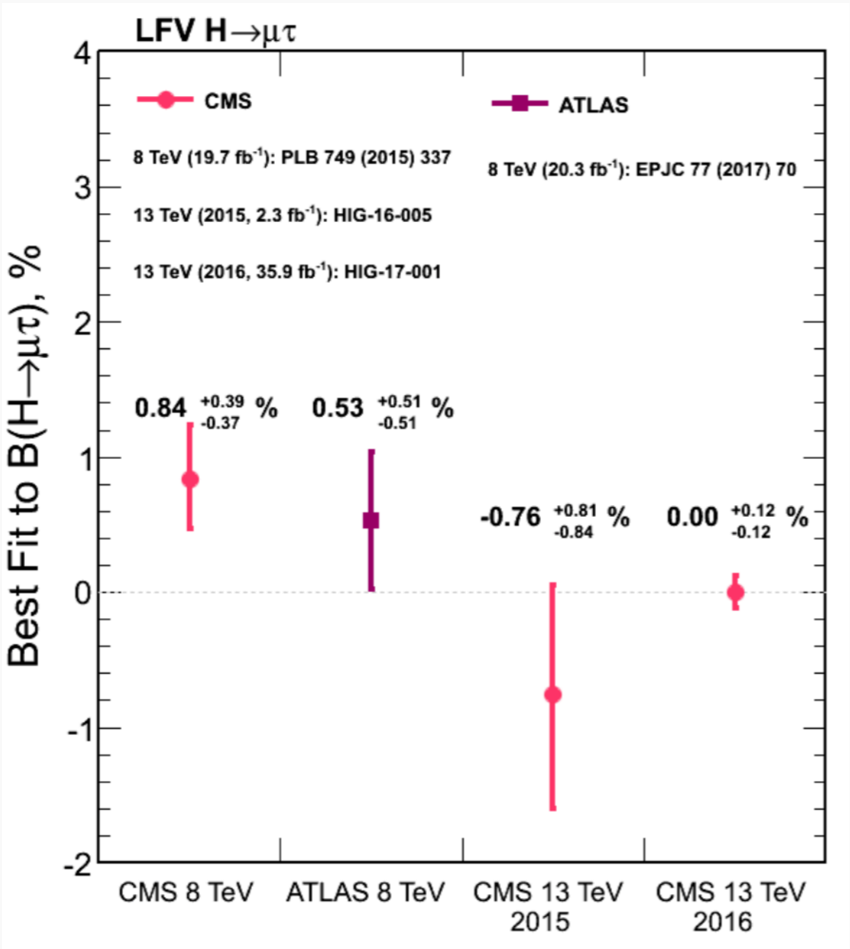


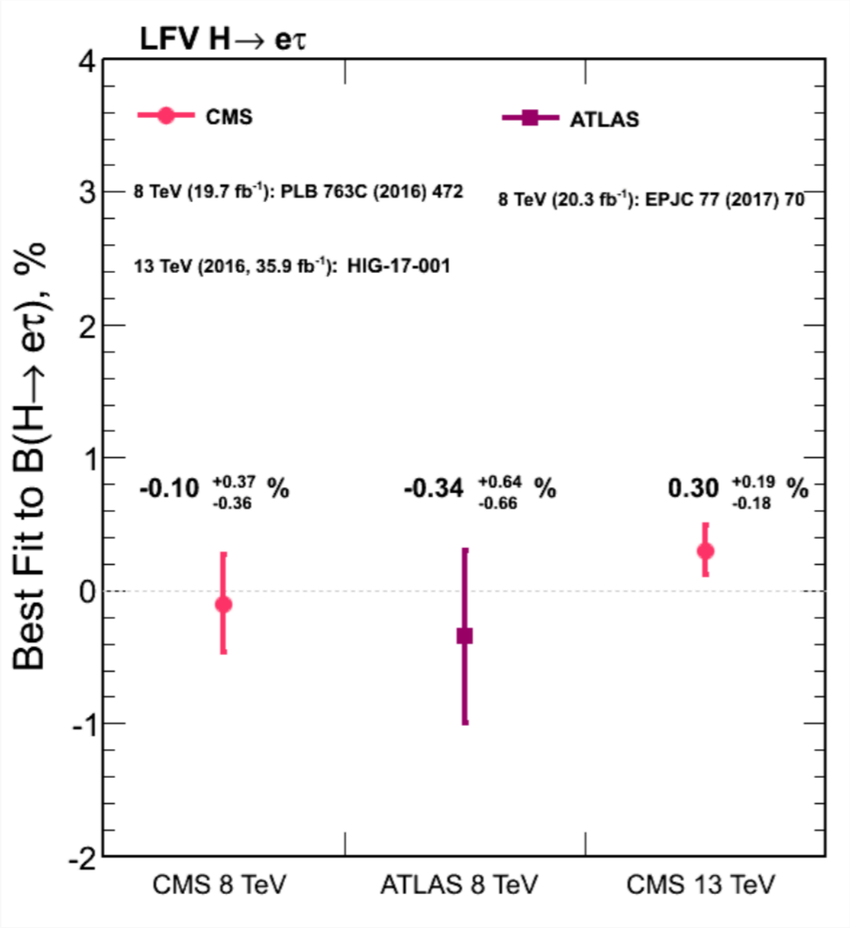


- No excess of data
- Best fit branching fraction: 0.00 ± 0.12%
- B(H→μτ) < 0.25% at 95% CL

- Slight excess of data (1.6 σ)
- Best-fit branching fraction: 0.30 ± 0.18%
- B(H→eτ) < 0.61% at 95% CL

Results of H→μτ and H→eτ searches





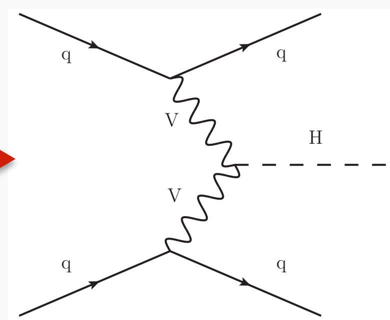
Search for invisible Higgs decays

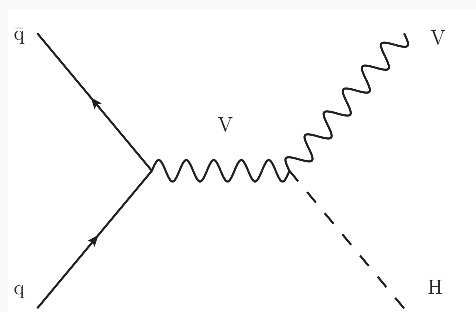
- Many models allow Higgs decays to invisible particles, including:
  - SUSY models with Higgs decays to a pair of LSP
  - Large extra dimension models with mixing of graviscalars with the Higgs boson
  -

JHEP 02 (2017) 135

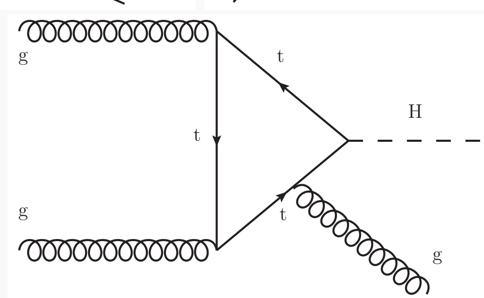
- Analyses target different Higgs boson production modes:

VBF production:
2 forward jets

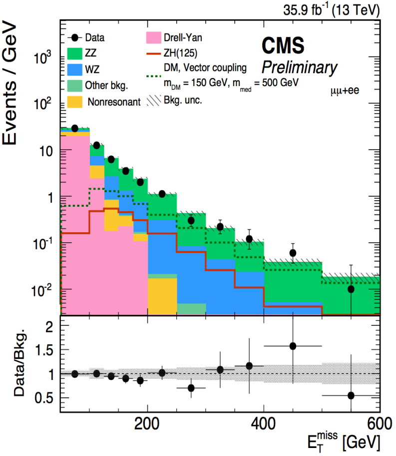


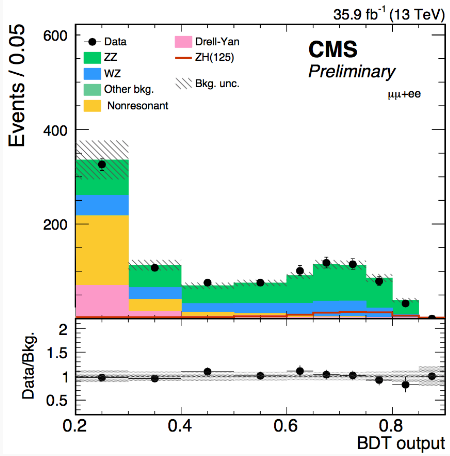


VH production with:
- Z→ee/μμ
- Z→bb
- W/Z→qq



ggH production in association with ISR





Z→ee/μμ:

- Di-lep mass compatible with Z boson mass
- Di-lep system recoiling against MET
- BDT-based analysis in 2016 data brings 10% additional sensitivity

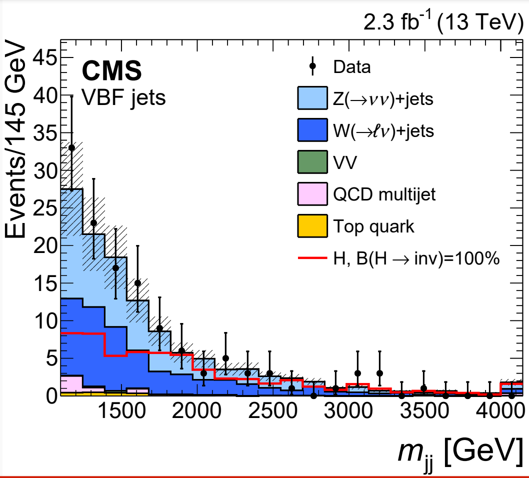
H→inv

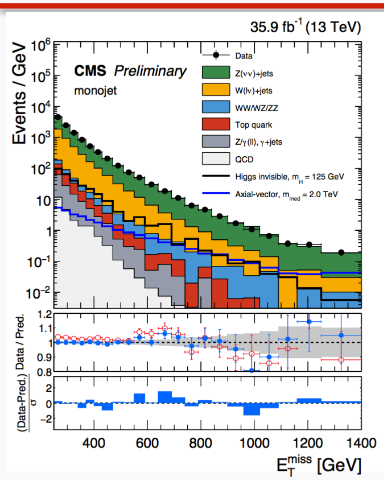
EXO-16-052

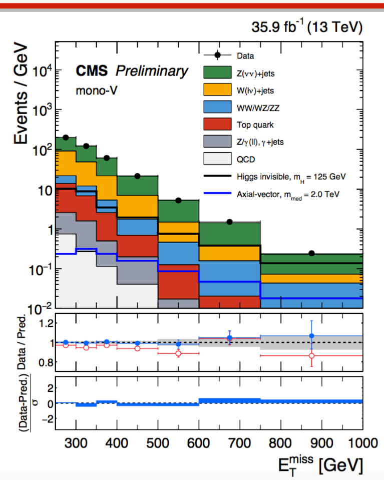
VBF analysis:

JHEP 02 (2017) 135

- Based on a trigger that requires two jets (p_T > 40 GeV in 2015) separated by a large $\Delta\eta$ (3.5) and with a large invariant mass (> 600 GeV in 2015)
- Control regions with one or more leptons included in the fit to constrain the yield of the major backgrounds
- Jets required to recoil against the MET to reduce QCD bkg







V(jj) and monojet analyses:

- Targets ggH with ISR, and VH with hadronic decays
- Simultaneous fit of MET distributions in signal and control regions

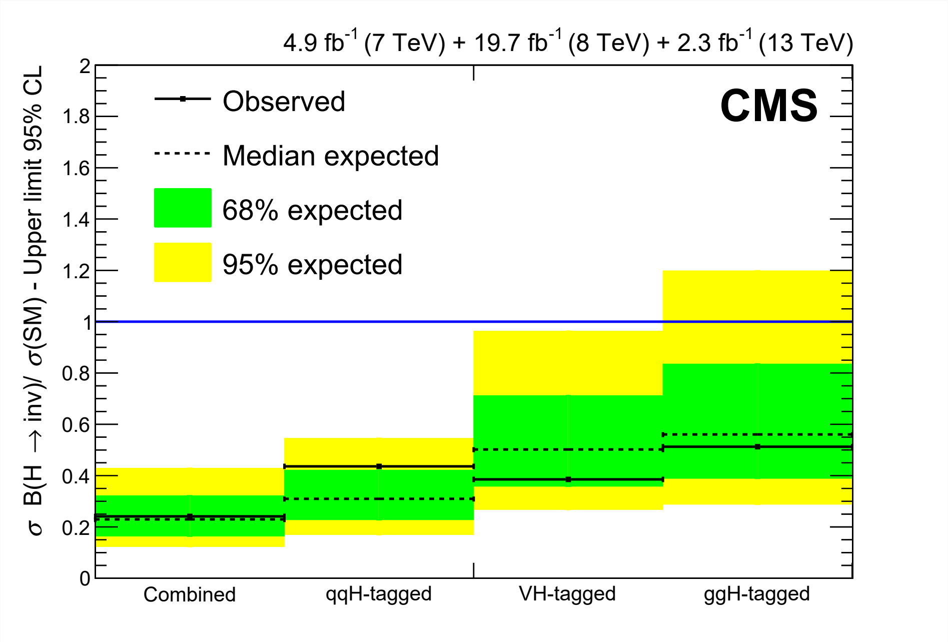
EXO-16-048

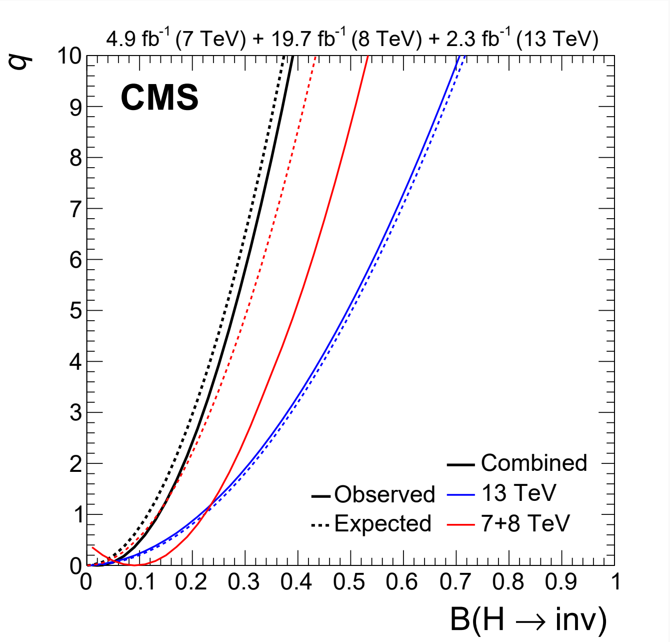
Results of invisible H boson searches

- Combination of 2011 (7 TeV), 2012 (8 TeV), and 2015 (13 TeV) results:
  – B(H→invisible) < 0.24/0.23 (obs./exp.) at 95% CL, where the largest sensitivity comes from the VBF analysis

- Z(ll)+ MET analysis updated with full 2016 dataset:
  – B(H→invisible) < 0.40/0.42 (obs./exp.)

- Monojet and V(jj) analyses updated with full 2016 dataset:
  – B(H→invisible) < 0.53/0.40 (obs./exp.)



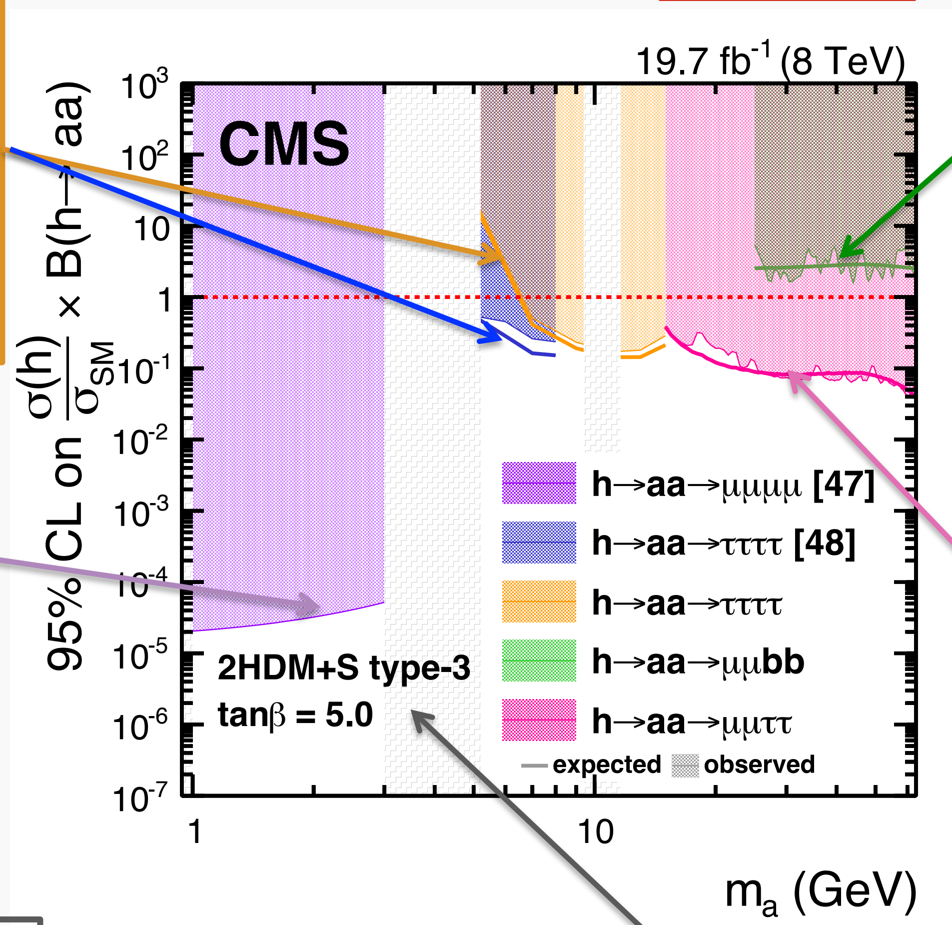


Overview of CMS H→aa searches

HIG-16-015

H→aa→4τ:
Dominant decay mode for $m_a < 2\, m_b$
Taus are collimated
→ need specific tau reconstruction techniques

H→aa→4μ:
Dominant decay mode for $m_a < 2\, m_\tau$



H→aa→2μ2b:
Benefits from large B(a→bb), and narrow dimuon resonance

H→aa→2μ2τ:
Benefits from narrow dimuon resonance and low level of backgrounds

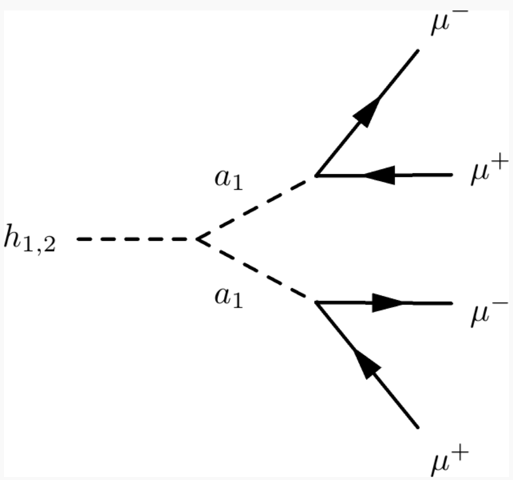
Below the red line, analyses are sensitive to B(h→aa) < 1

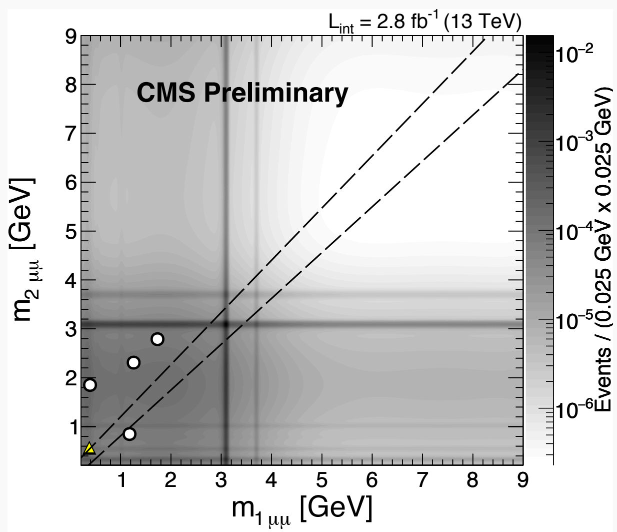
In 2HDM+S type-3 with high tan β, decays to leptons are enhanced over decays to quarks

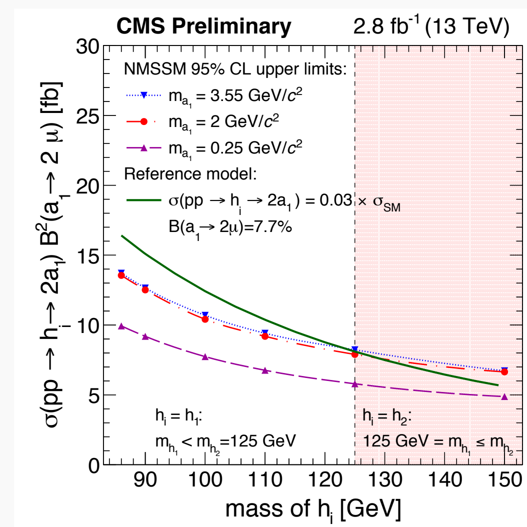
H→aa→4μ

HIG-16-035

- For $m_a < 2\,m_\tau$ (~3.5 GeV), a→2μ is by far the largest a boson decay mode
- The dimuon pairs are required to have approximately the same mass in the signal region
- Dominant backgrounds: direct bbbar and J/psi production
- One event observed in the signal region using 2.8 fb^{-1} of 2015 data, compatible with the background expectation: 0.74 ± 0.34 (stat.) ± 0.15 (syst.)







Conclusion

- Exotic decays of the Higgs boson would bring a direct evidence for the existence of BSM physics

- The 2.4σ excess in the $H \rightarrow \mu\tau$ channel is ruled out by 2016 data collected by CMS, and an upper observed limit on $B(H \rightarrow \mu\tau)$ of 0.25% is set

- No hint for new physics found when looking for $H \rightarrow aa$ and $H \rightarrow$invisible decays, but these analyses will soon be updated with the data collected in Run-2

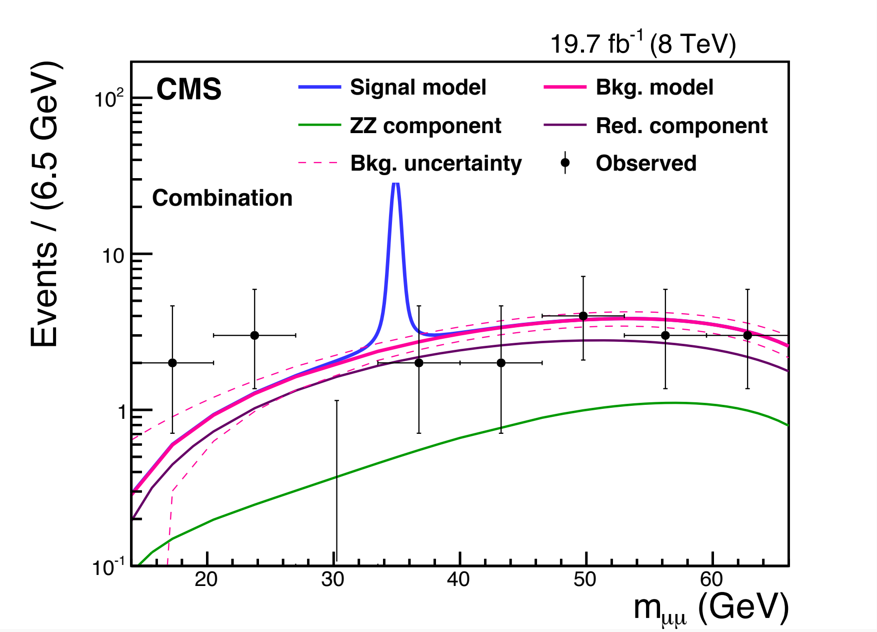
BACKUP

H→aa→μμττ and H→aa→μμbb

HIG-16-015

- For 20 < m_a < 62.5 GeV: decay products not collimated
- Search for a narrow dimuon resonance on top of a flat background (parametric fit)
- Main backgrounds estimated from data
- Latest results based on 20 fb^{-1} of data collected in Run-1
- No excess of data wrt SM predictions

H→aa→μμττ



H→aa→μμbb