Search for a heavy Higgs H decaying to two 125 GeV Higgs bosons h in the 2 τ leptons and 2 b-quarks final state at CMS

Maria Teresa Grippo[1,2]

on behalf of CMS collaboration

[1]University of Siena, [2]INFN Pisa

UNIVERSITÀ DI SIENA 1240

Outline

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- Analysis strategy
- Signal extraction
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- Results
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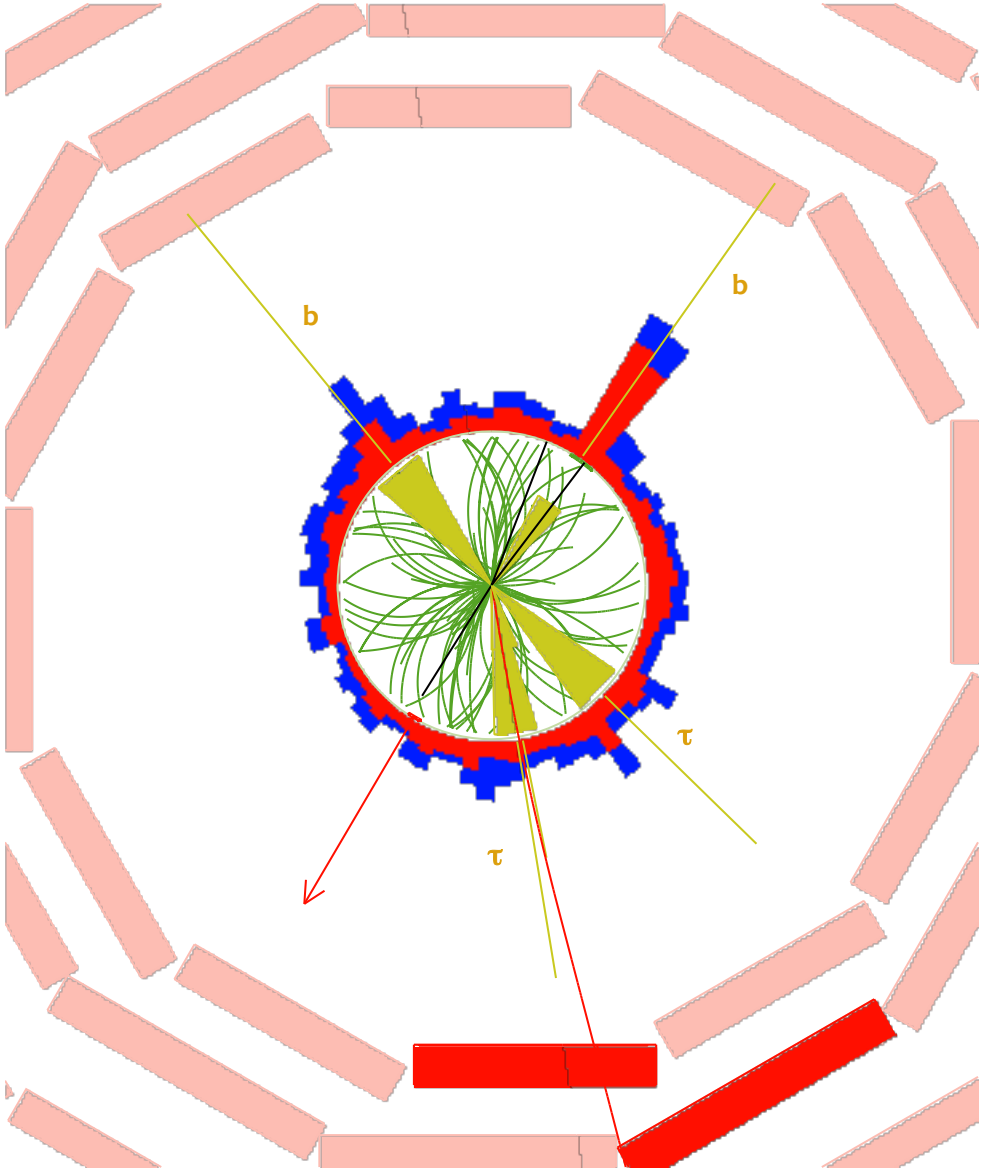
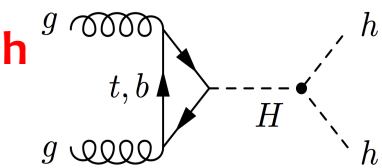


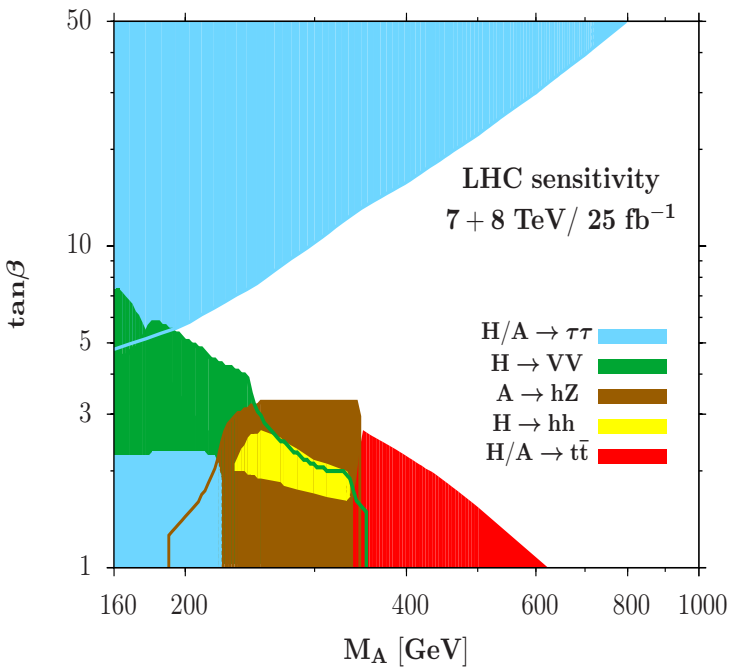
Physics Motivation

MSSM and 2HDM (Type II) models predict enhanced sensitivity for **H →hh** channel at *low tanβ* [*] in the range of M_H between 260 and 350 GeV. These regions were not excluded by previous searches.

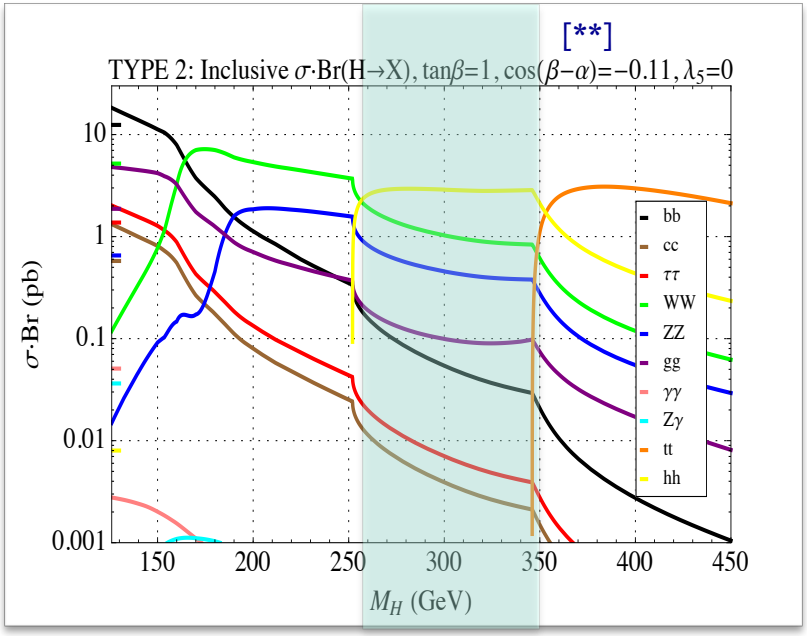


MSSM scenario

arXiv:1304.1787
doi:10.1007/JHEP10(2013)028



Example of 2HDM



arXiv:1305.2424

[*] tanβ = ratio of the vacuum expectation values of the two Higgs doublets
[**] α = the mixing of the two neutral CP-even Higgses

Analysis strategy résumé

- Search for **H → h (125 GeV) h (125 GeV) →bbττ**
  - To reconstruct the **h →ττ** candidate, the same methods of the search for the SM[1] and MSSM[2] Higgs boson decaying to a τ pair were used.
    The most sensitive final states are studied: **$e\tau_h$, $\mu\tau_h$** and **$\tau_h\tau_h$** (τ_h denotes a hadronic τ decay).
  - For **h →bb** required at least two b jet candidates in the event.
  - Used **M_H** distribution to extract the signal contribution
- Analyzed data collected in 2012 at 8 TeV from CMS, corresponding to an integrated luminosity of 19.7 fb^{-1}
- Results combined with the analysis **A → Zh→*ll*ττ** (CMS-HIG-14-034)

[1] doi:10.1007/JHEP05(2014)104 [2] doi:10.1007/JHEP10(2014)160

$h \to \tau\tau$ and $h \to bb$ reconstruction

$h \to \tau\tau$

$h \to l\tau_h$

- A well identified and isolated lepton e/μ with $|\eta| < 2.1$ and $p_T > 24/20$ GeV
- A well identified and isolated τ_h ($p_T > 20$ GeV and $|\eta|<2.3$)
- $m_T(\text{lepton}, p_T^{miss}) < 30$ GeV

$h \to \tau_h\tau_h$

- Two well identified and isolated τ_h ($p_T > 45$ GeV, $|\eta|<2.1$)

Required **opposite sign pair** and **no other leptons** in the event

$h \to bb$

b jet requirements

- $p_T > 20$ GeV and $|\eta| < 2.4$
- The combined secondary vertex discriminator (CSV[3]) is used to identify b jets

The two b jets with the **highest** CSV values are chosen to reconstruct the **$h \to bb$** candidate

[3] doi:10.1088/1748-0221/8/04/P04013

H→ hh Reconstruction and Signal Extraction

The events with at least two jets are classified in different categories:

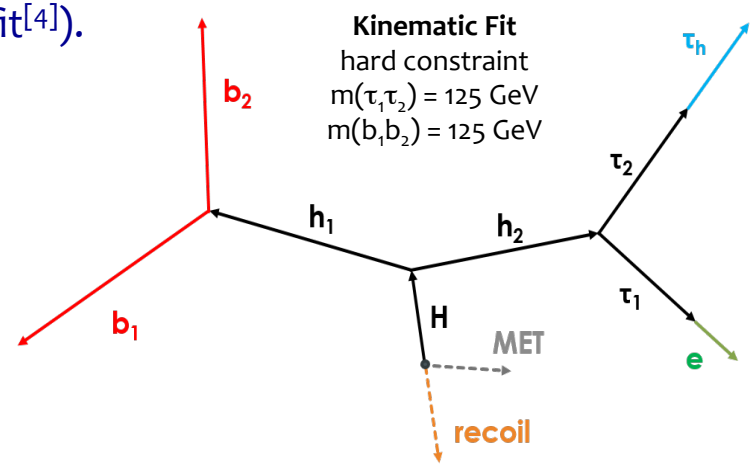
Event category	Number of well identified b jets	Comments
2jet-0tag	0	least sensitive category, background dominated ($Z\rightarrow \tau\tau$, W, QCD)
2jet-1tag	1	less than half of signal but still background dominated ($Z\rightarrow \tau\tau$, W, QCD and ttbar)
2jet-2tag	≥2	most sensitive category, less background present (mostly ttbar background)

$M_{\tau\tau}$ is reconstructed with a Likelihood based algorithm (SVfit[4]).

M_{bb} is the invariant mass of b jet pair.

Applied **mass window** cut: $90 < M_{\tau\tau} < 150$ GeV, $70 < M_{bb} < 150$ GeV

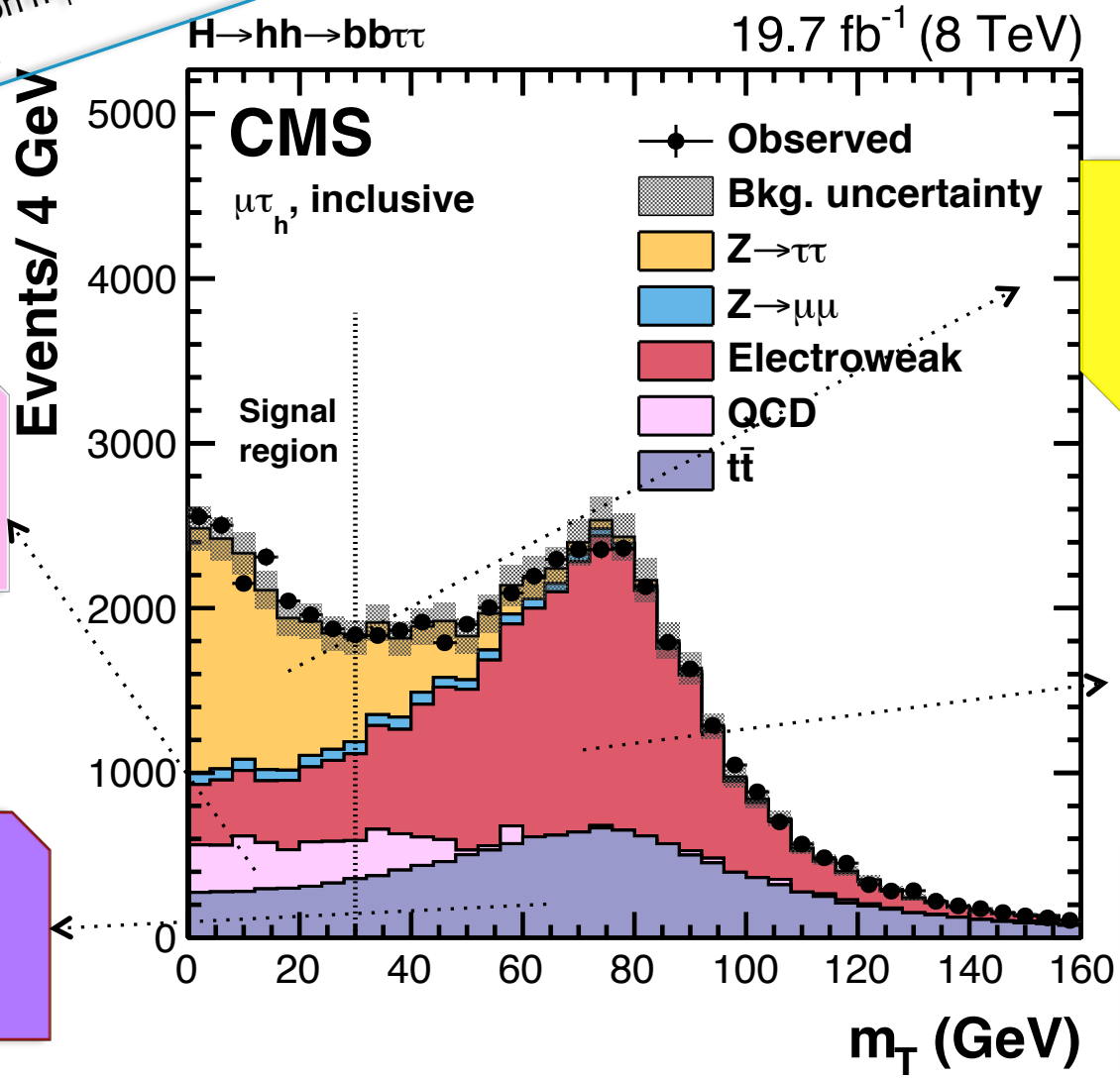
To further improve the reconstruction of M_H a kinematic fit is applied, constraining h bosons mass to be 125 GeV.



[4] doi:10.1088/1742-6596/513/2/022035

Example of background composition for $\mu\tau_h$ channel

Inclusive: before cut on m_T, $M_{\tau\tau}$, M_{bb} and no kin fit applied



QCD
Data driven method

Z→ ττ
Combined data driven and MC background modeling

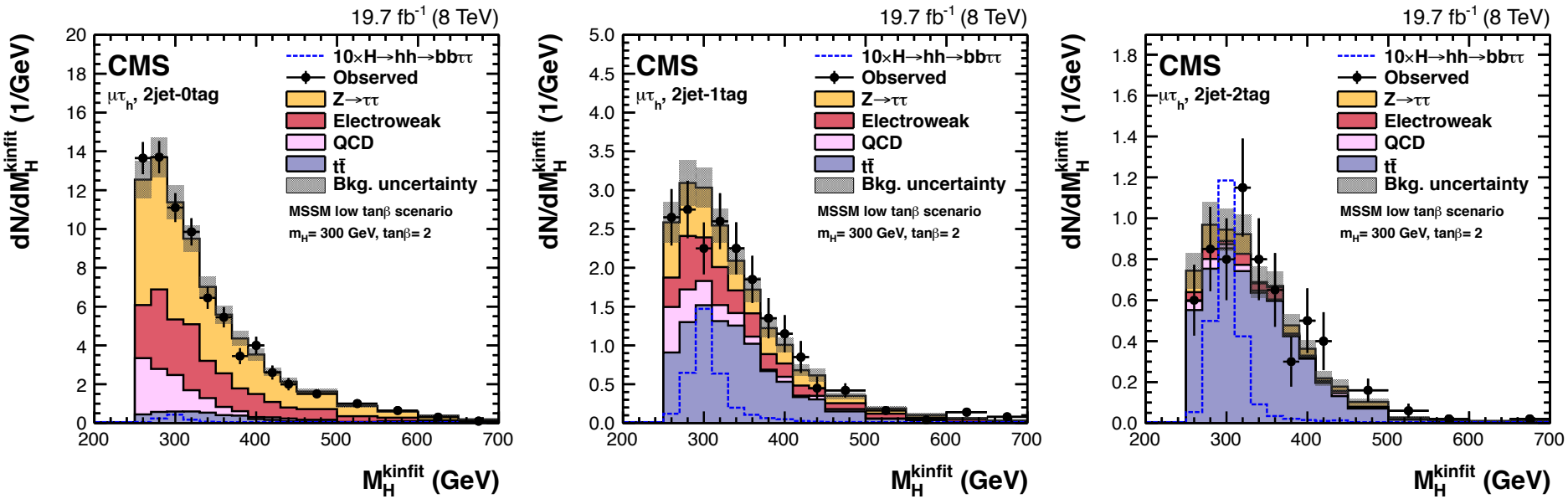
Wjets
Data driven method

ttbar
MC background modeling

Good agreement
between Data and background modeling

Signal extraction using M_H – $\mu\tau_h$ channel

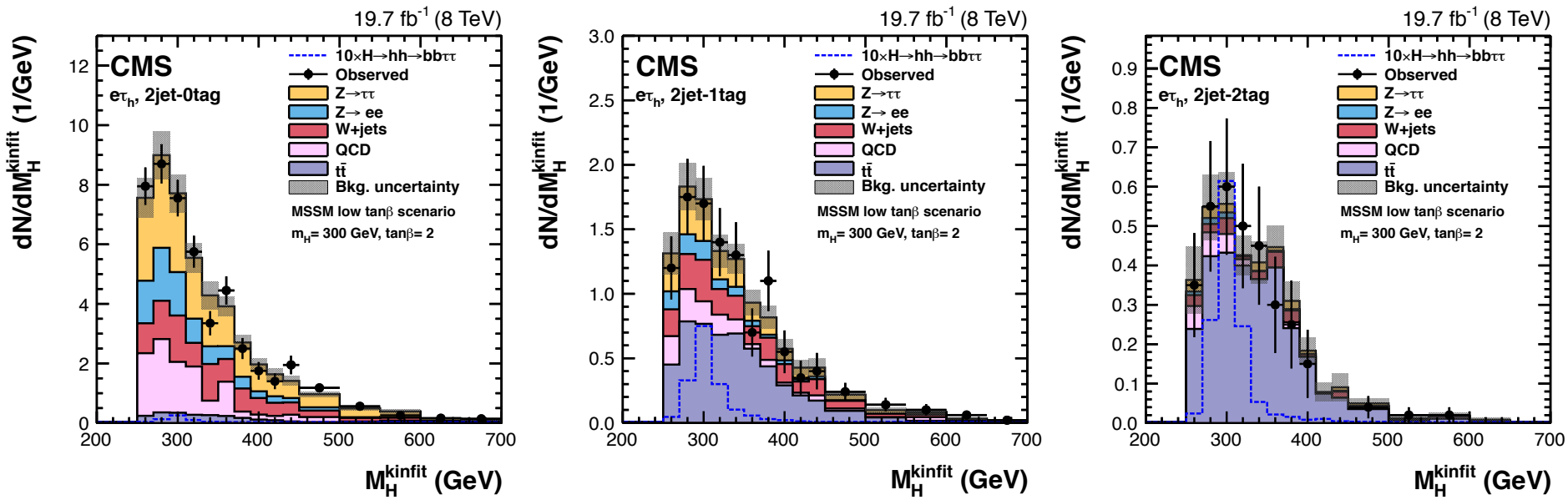
2jet-0tag **2jet-1tag** **2jet-2tag**



Example of the expected signal, scaled by a factor 10, for one of the MSSM scenarios (m_H = 300 GeV and tanβ=2).

Signal extraction using M_H – $e\tau_h$ channel

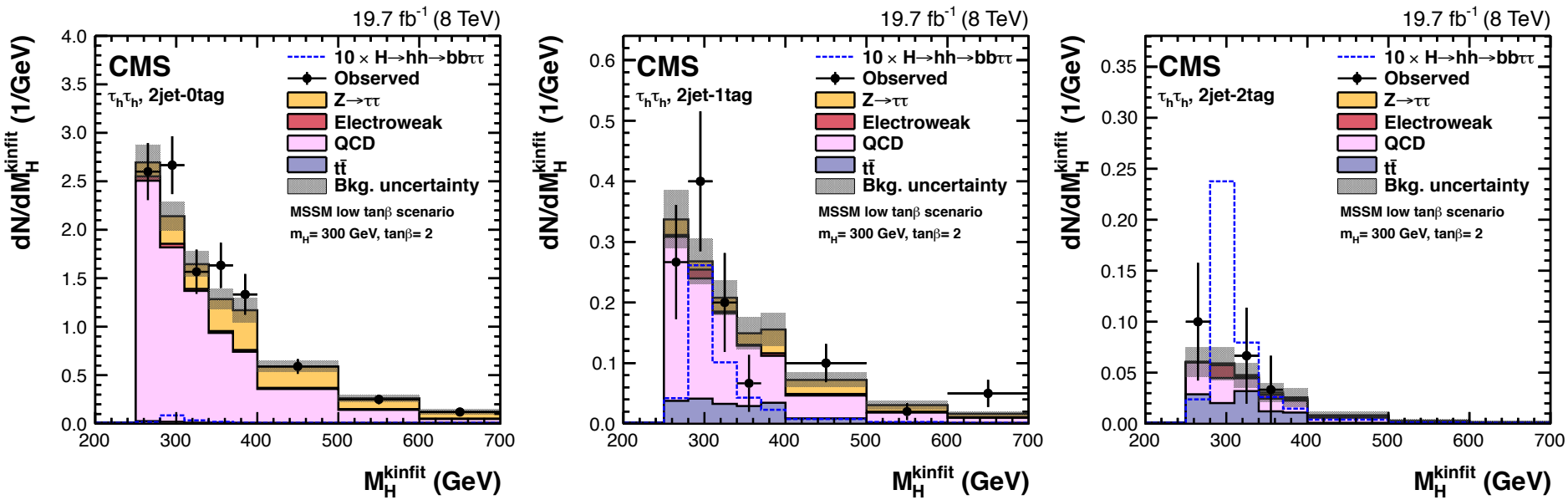
2jet-0tag **2jet-1tag** **2jet-2tag**



Example of the expected signal, scaled by a factor 10, for one of the MSSM scenarios (m_H = 300 GeV and tanβ=2).

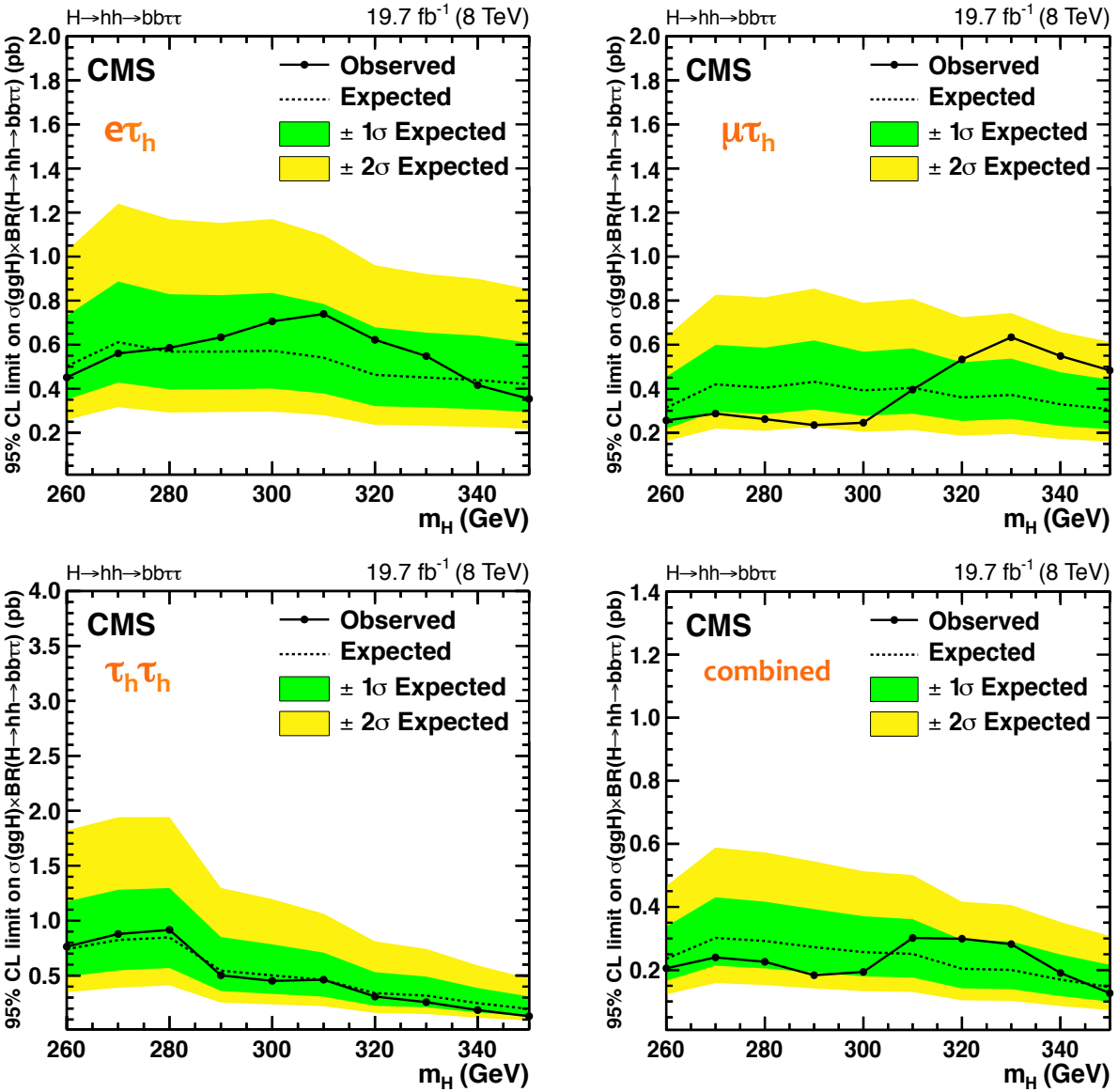
Signal extraction using $M_H - \tau_h\tau_h$ channel

2jet-0tag **2jet-1tag** **2jet-2tag**



Example of the expected signal, scaled by a factor 10, for one of the MSSM scenarios (m_H = 300 GeV and tanβ=2).
The binning used takes into account the lower statistics in this channel.

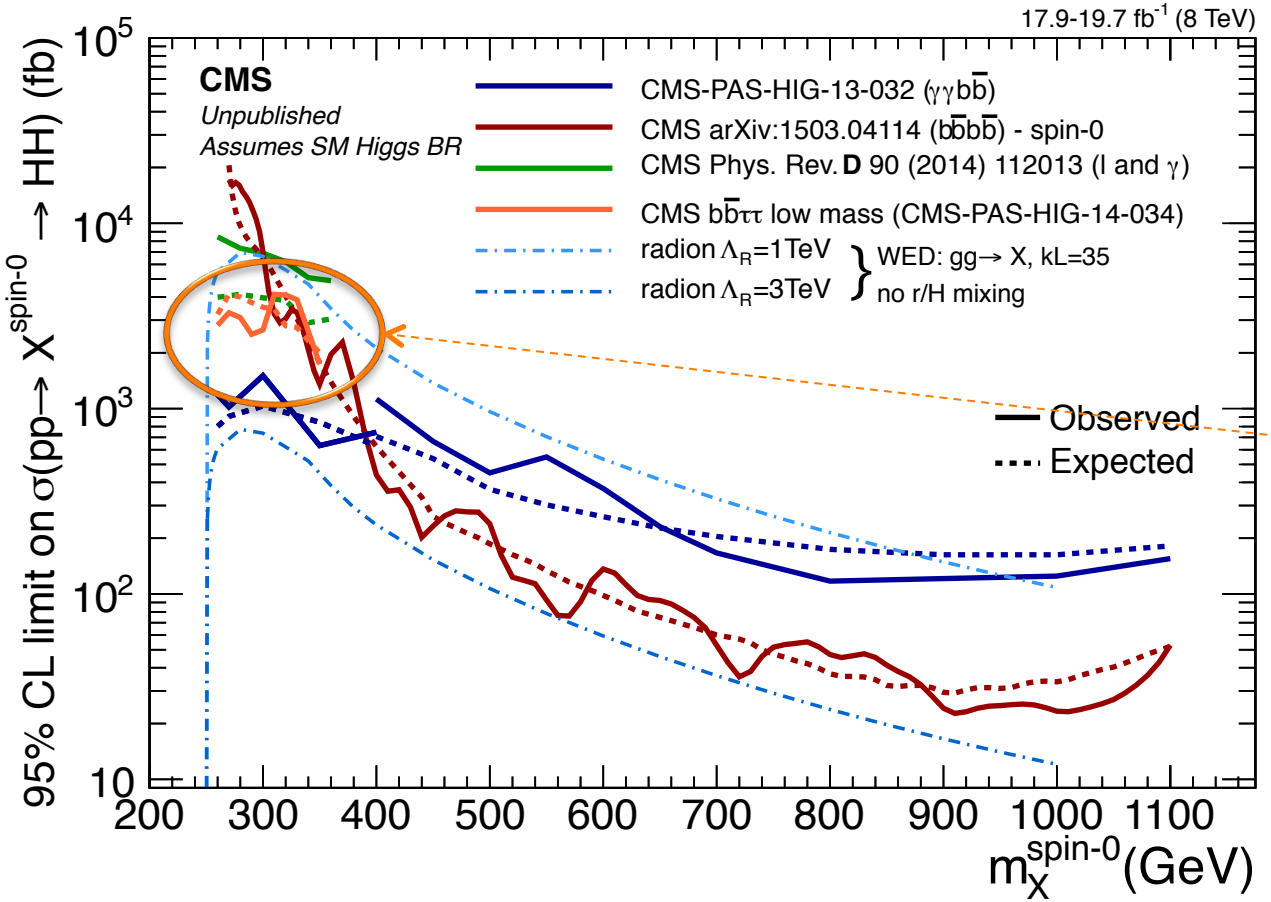
Results: Model Independent Limits



No evidence for the presence of a BSM signal.

The 95% CL exclusion limits on production cross-section times branching ratio have been set at ~ 0.3 pb.

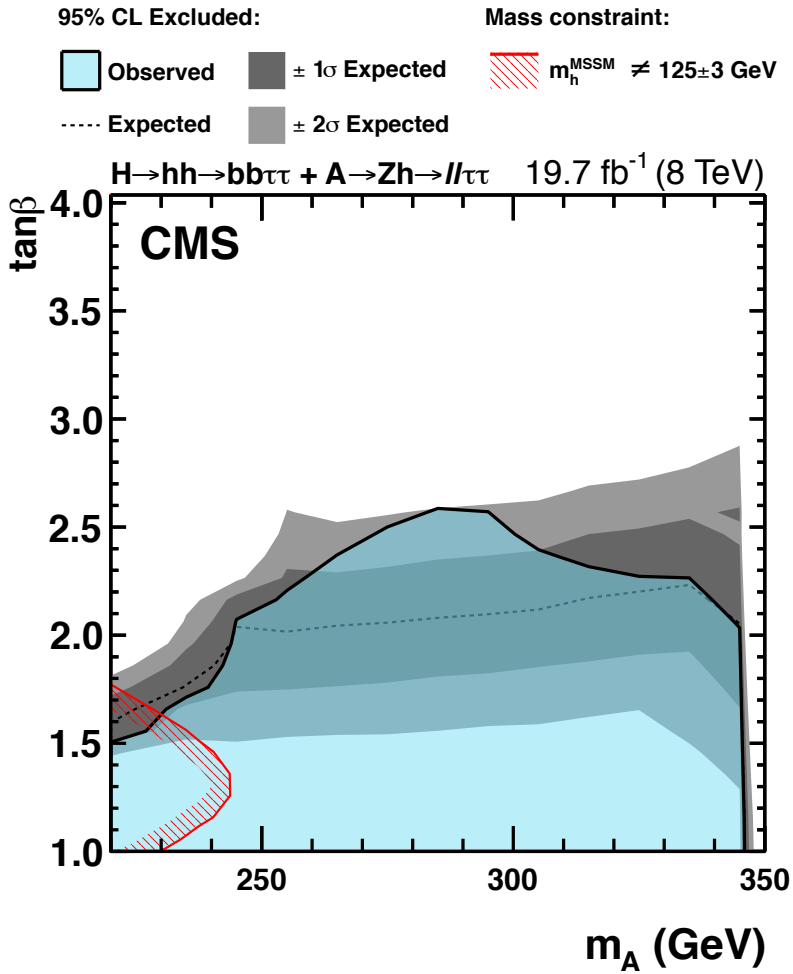
CMS Model independent limits X (spin 0) → hh



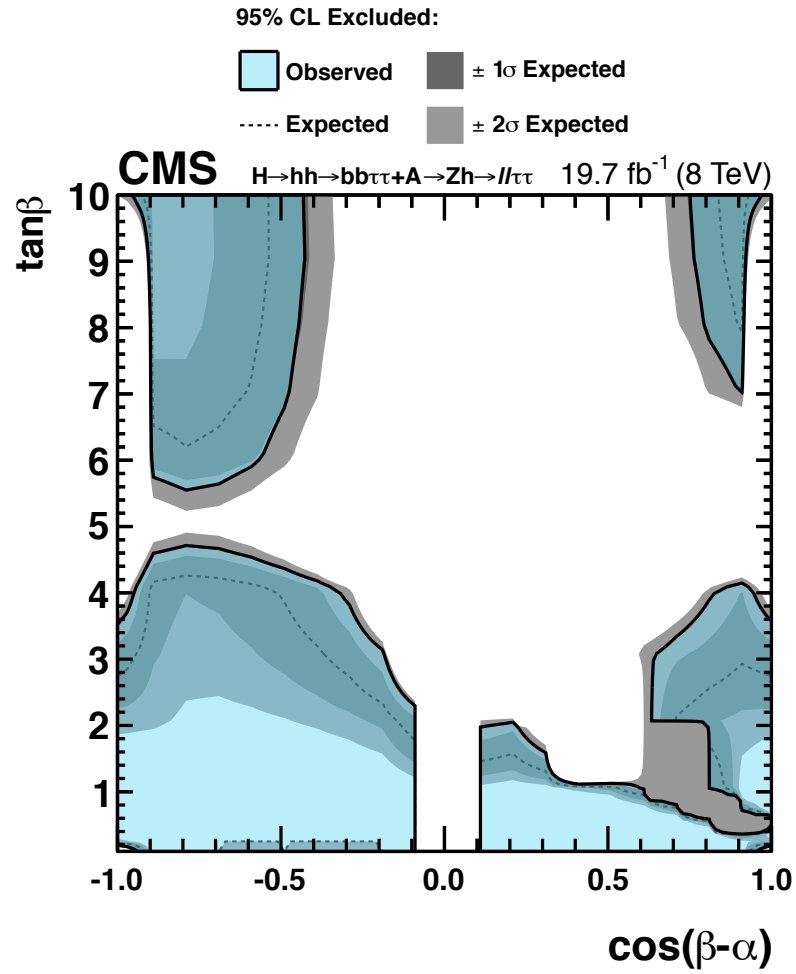
In the low mass region, $bb\tau\tau$ sensitivity is between bbbb and $\gamma\gamma bb$.

Combined model dependent limits H→ hh→bbττ + A → Zh→*ll*ττ

MSSM low $\tan_\beta$ scenario



2HDM type-II $m_A = m_H = 300$ GeV



Observed and expected limits in MSSM low tanβ scenario and 2HDM type-II model. The highlighted blue area is excluded at 95% CL.

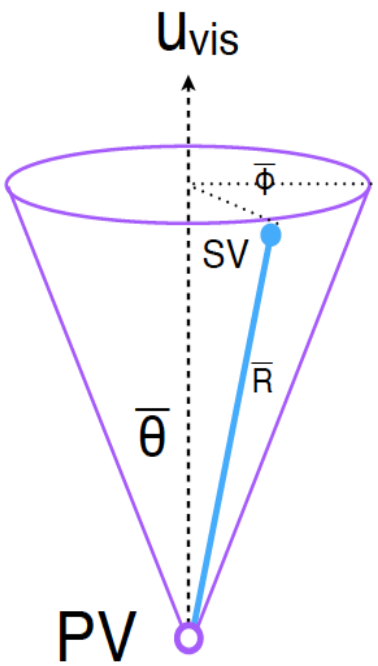
Summary

- The search for a heavy Higgs boson decaying to two 125 GeV Higgs bosons in the final state $bb\tau\tau$, using the data collected by CMS in 2012, has been presented.
- The data, corresponding to an integrated luminosity of 19.7 fb^{-1}, have shown no evidence for a BSM signal.
- The combined **$H \rightarrow hh \rightarrow bb\tau\tau + A \rightarrow Zh \rightarrow ll\tau\tau$** exclusion limits on the production cross-section times branching ratio have been interpreted in the MSSM low $\tan\beta$ and 2HDM type-II scenarios.

Additional materials

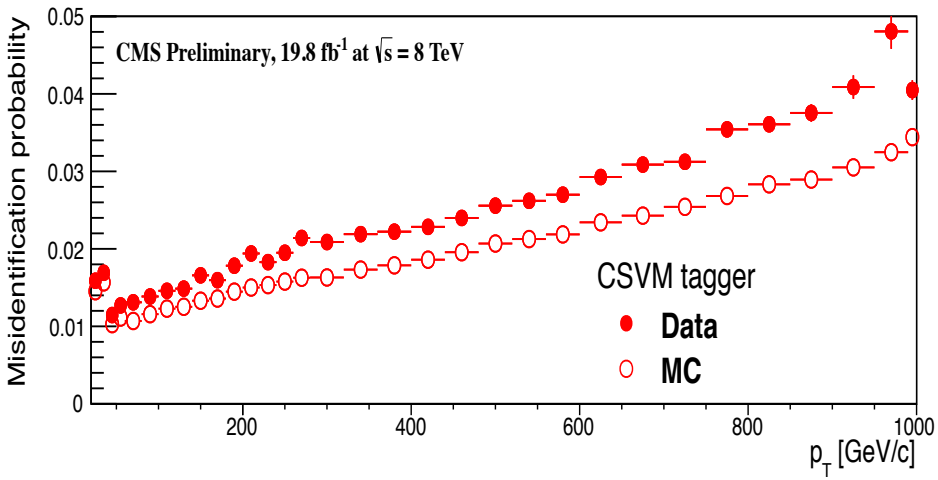
SVfit algorithm

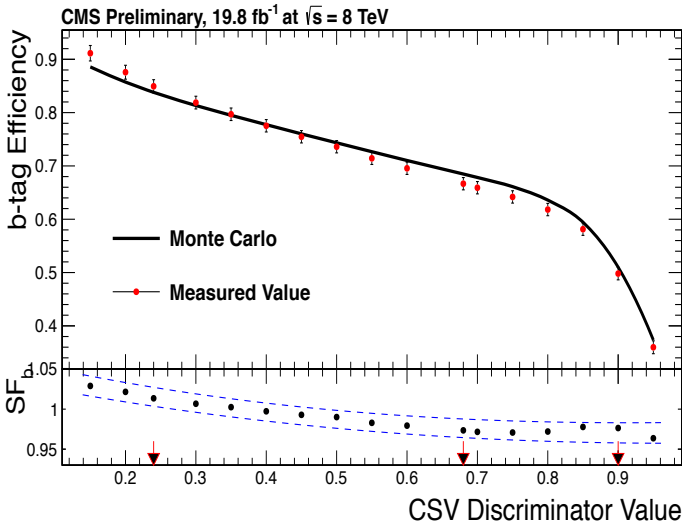
- SVfit is a likelihood based algorithm for the reconstruction of h boson decaying to τ leptons.
- The kinematics of τ decays can be parameterized by following variables:
  - θ – the angle between the boost direction of the τ lepton and the momentum of the visible decay products in the rest frame of the τ.
  - ϕ – the azimuthal angle of the τ in the CMS detector frame.
  - $m_{\nu\nu}$ – invariant mass of the invisible momentum system for leptonic τ decays
- The kinematics of the τ pair decays depends upon 4-6 parameters, which are constrained only by 2 observables from MET
- Using Dynamical Likelihood Methods, SVfit reconstruct kinematic quantities on an event-by-event basis.



CSV algorithm

- This sophisticated and complex tag exploits all known variables, which can distinguish b from non-b jets.
- Its goal is to provide optimal b tag performance, by combining information about impact parameter significance, the secondary vertex and jet kinematics. (Currently lepton information is not included).
- The variables are combined using a likelihood ratio technique to compute the b tag discriminator.





Systematic uncertainties

- **Normalization uncertainties:**
  - *ID/isolation and trigger efficiencies*
  - *Background Normalization:* used alternative methods and studied the difference in yield, but largely dominated by statistical uncertainties, due to limited statistics in data control region
  - *b tag uncertainties:* evaluated by shifting up and down in b tag scale factors and evaluating the overall change in yield in each category
  - *E_T^{miss} scale*
- **Shape uncertainties:**
  - *jet energy scale*
  - *τ energy scale*

Common Experimental Uncertainties	
Source	Uncertainty
Luminosity Measurements	2.6%
Electron ID and trigger	2–3%
Muon ID and trigger	2–3%
τ lepton ID and trigger	6–19%

$H \to hh$ **Experimental Uncertainties**		
Source	$\mu\tau_h$-$e\tau_h$	$\tau_h\tau_h$
E_T^{miss}	1–10%	–
b tagging efficiency	1–70[1]%	2–5%
b mistag rate	1–5%	2.5%
Z production	3.3%	3.3%
$Z \to \tau\tau$: category selection	5%	6–175[1]%
$Z \to \tau\tau$ due to $t\bar{t}$ embedded	–	5–49%
$t\bar{t}$	10%	10%
Diboson	15%	15%
QCD multijet	10–100%	10–40%
W+jets	10–100%	20%
$Z \to ee$: e misidentified as τ_h	20–40%	–
$Z \to \mu\mu$: μ misidentified as τ_h	30–60%	–
Z+jets: jet misidentified as τ_h	20–90%	–
$Z \to ll$: jet and l misidentification	–	30–67%