CERN-LHC Seminar
03/12/2013

Direct measurement of Higgs Boson Fermionic Properties at CMS

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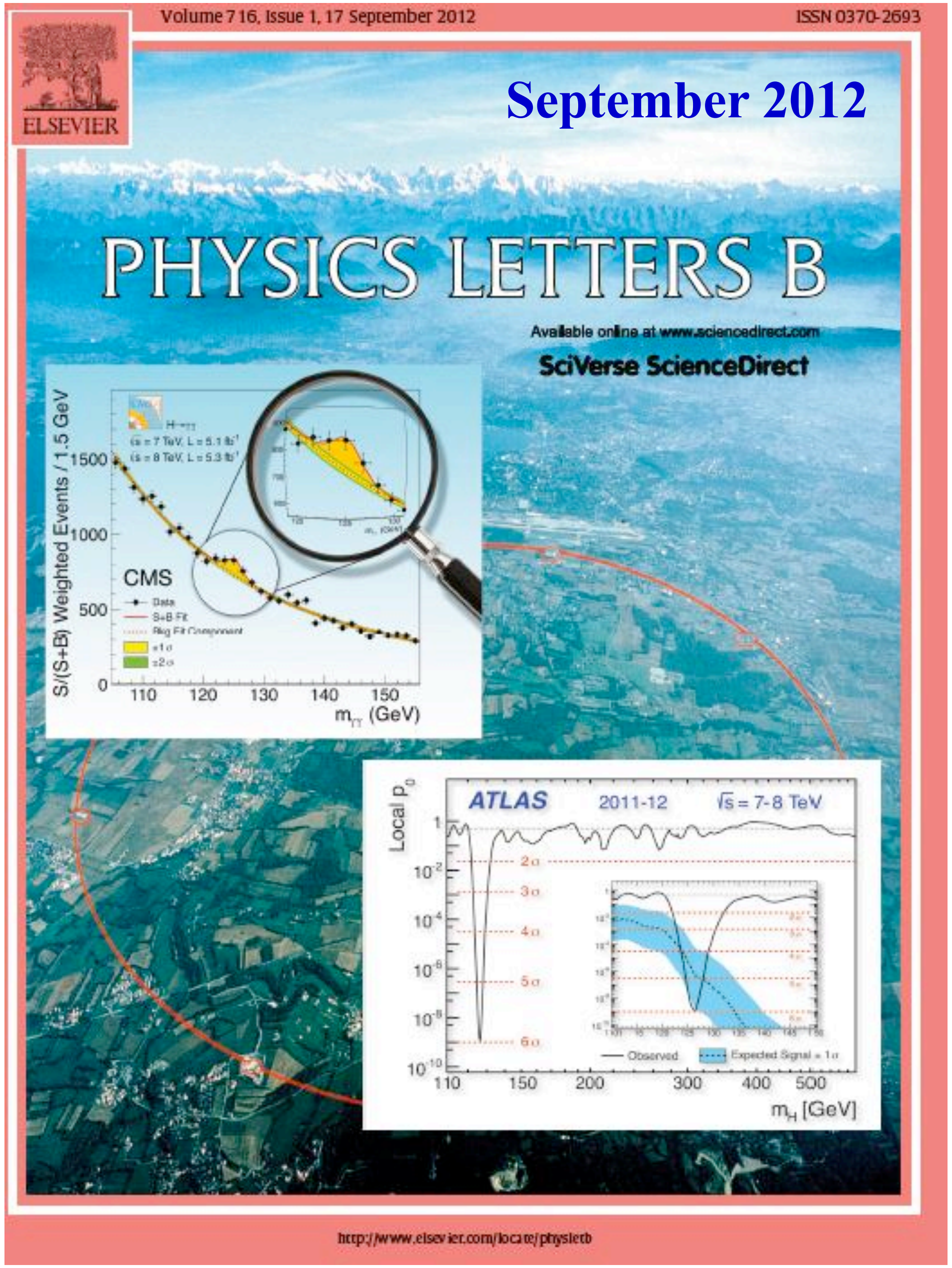
(on behalf of the CMS Collaboration)

Search for the Higgs @ the LHC

It's not that difficult!

Discovery of new boson Summer 2012!

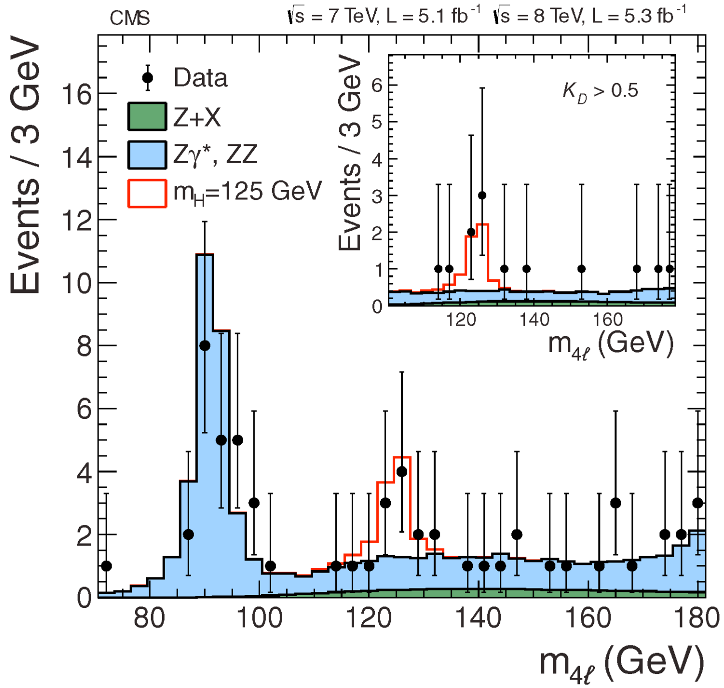


Observation new particle with mass of ~125.6 GeV by ATLAS & CMS

ATLAS: 5.1 σ

CMS: 5.0 σ

With just
5 fb^{-1} @ 7 TeV
6 fb^{-1} @ 8 TeV
of data!



$H \rightarrow ZZ \rightarrow 4l$

Is the new particle a Standard Model-like Higgs boson?

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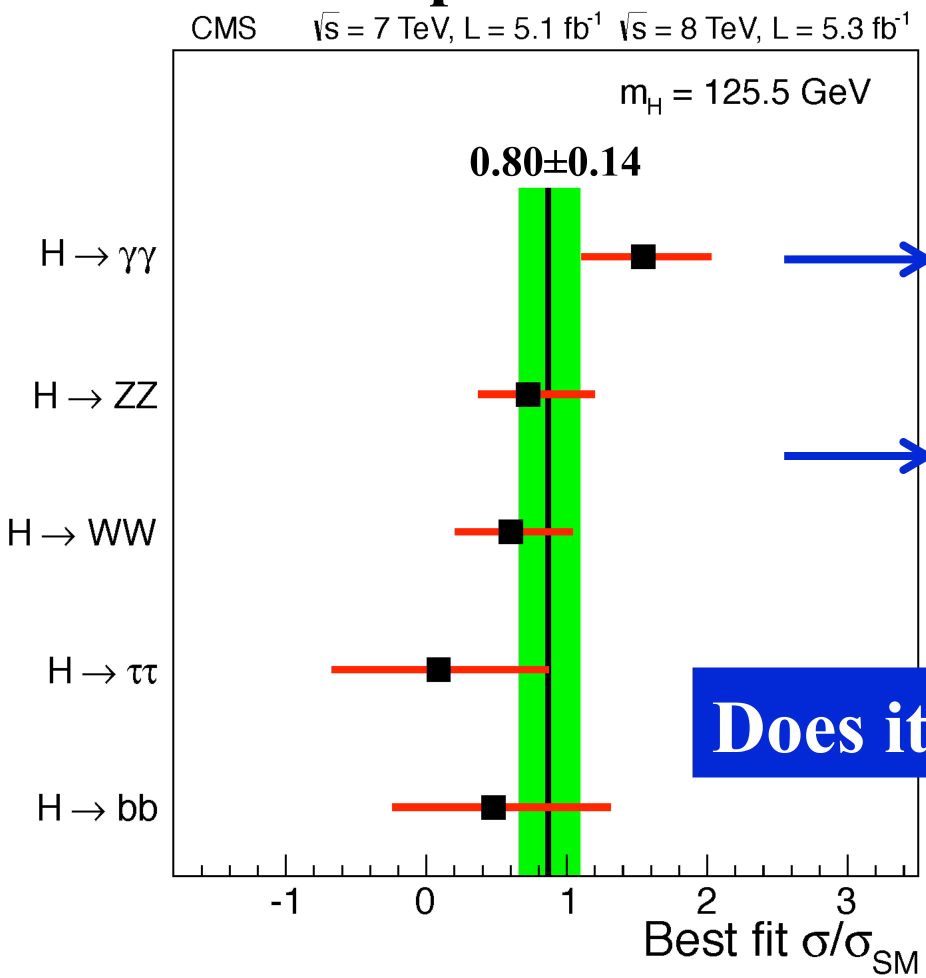
July 2012: best fit of signal strength $\mu=\sigma/\sigma_{SM}$ compared to expectation from SM Higgs boson



Compatible with SM expectation

Couples to γγ: new particle is a boson with spin different to 1

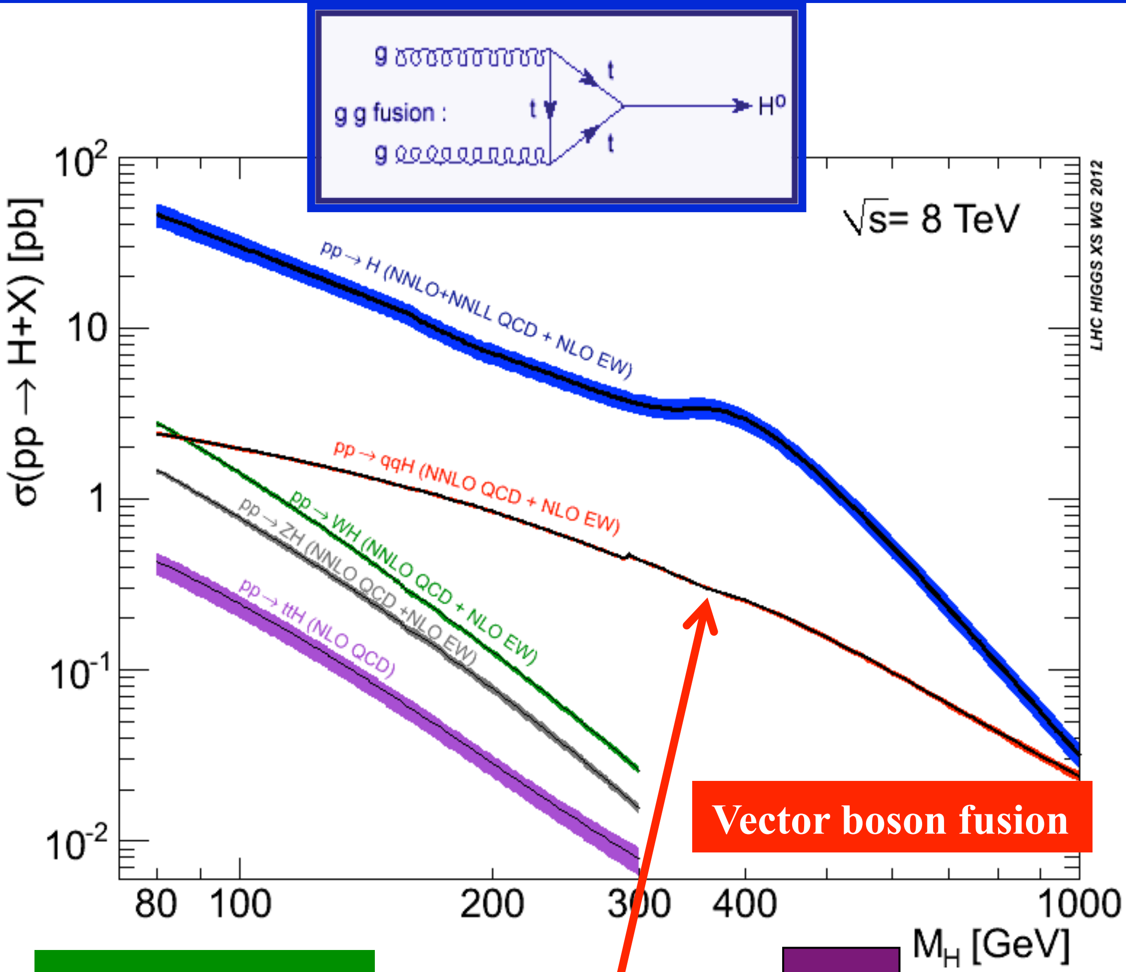
Couples to ZZ/WW: plays a role in electroweak symmetry breaking

Does it couple to "down-type" fermions?

➔ **Since then we added 15 fb^{-1} of 8 TeV data …**

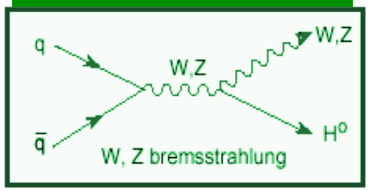
Standard Model Higgs Production @LHC

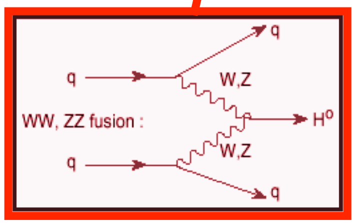
gluon-gluon fusion dominant production mechanism



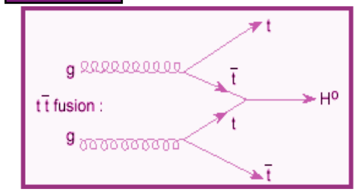
Vector boson fusion

Higgs Strahlung

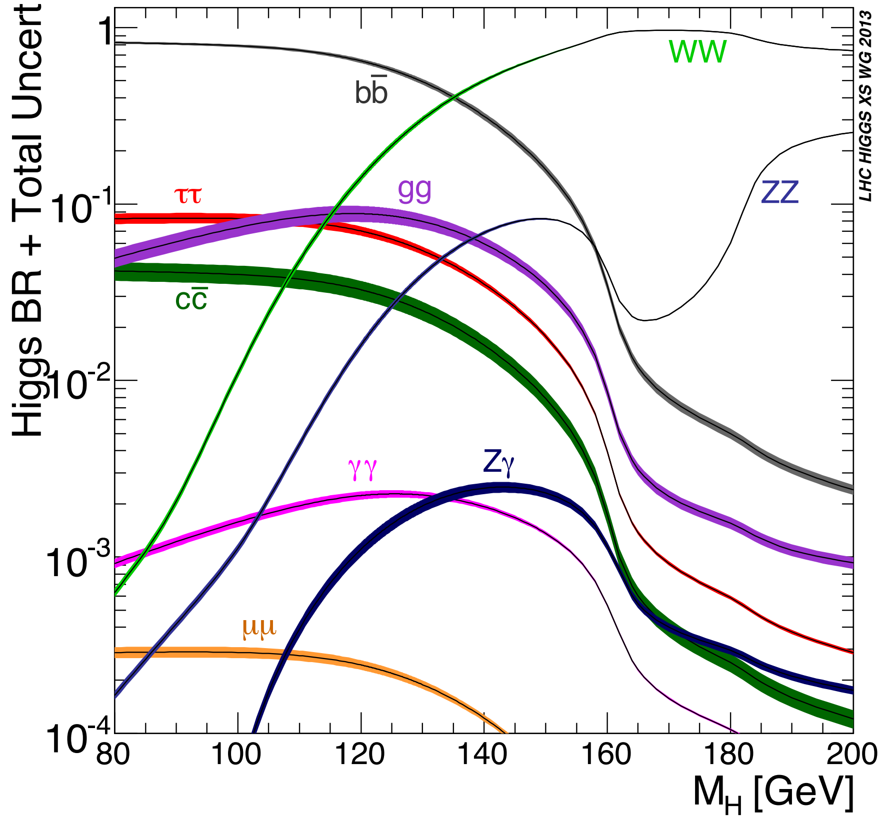




ttH



Branching Ratios



Fermionic decay modes studied:

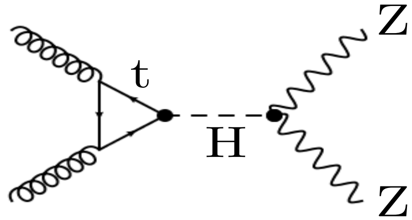
- bb
- ττ
- μμ, ee

ttH production search

Current Status of Higgs Searches

Imperial College London

- **Discovery of Higgs boson in γγ, ZZ*, WW* final states is established**
  → **indirect evidence for ttH coupling ("up-type" fermion coupling)**
- **The new discovered boson is "SM-like"**
  - ➢ **Signal strength compatible with μ=1**
  - ➢ **Observations compatible with $J^P=0^+$ hypothesis (other J^P hypothesis tested so far have been ruled out)**



Does it couple to fermions as expected from a SM Higgs boson?

Tevatron

H→bb: 2.8σ (observed) 1.5σ (expected)

CMS Preliminary (status Spring 2013)

H→bb: 2.2σ (observed) 2.1σ (expected)

H→ττ: 2.9σ (observed) 2.6σ (expected)

ATLAS Preliminary (Nov 2013)

H→μμ, bb: no significant excess yet

H→ττ: 4.1σ (observed) 3.2σ (expected)

Significance at m_H=125 GeV

Latest CMS Higgs fermionic searches will be presented next

Content

Most recent CMS Higgs fermionic searches will be presented

- **ttH(→γγ, bb, ττ, multi-leptons): new**
- **VH(→bb): published**
- **H→ττ: brand new!**
  - **VH(→bb)+H→ττ combination**
- **H→μμ & H→ee: new**
- **MSSM H→ττ: new**

ttH search

(search for direct evidence to top quark coupling)

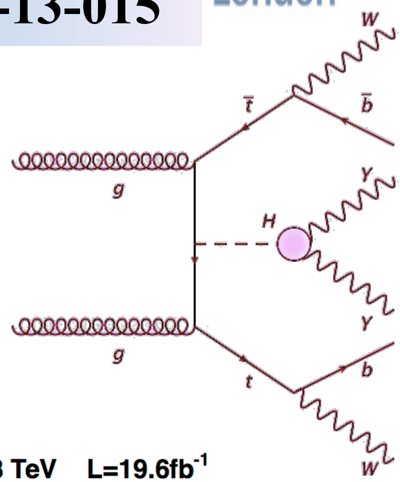
ttH, H→γγ

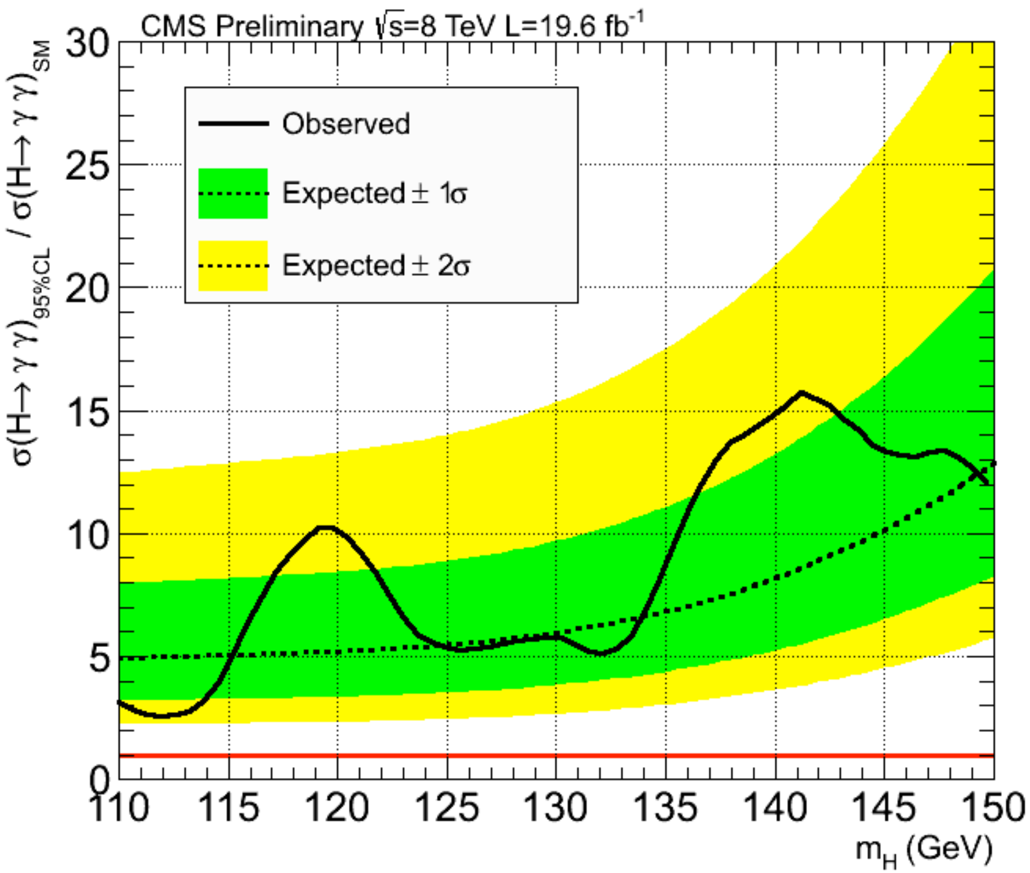
HIG-13-015

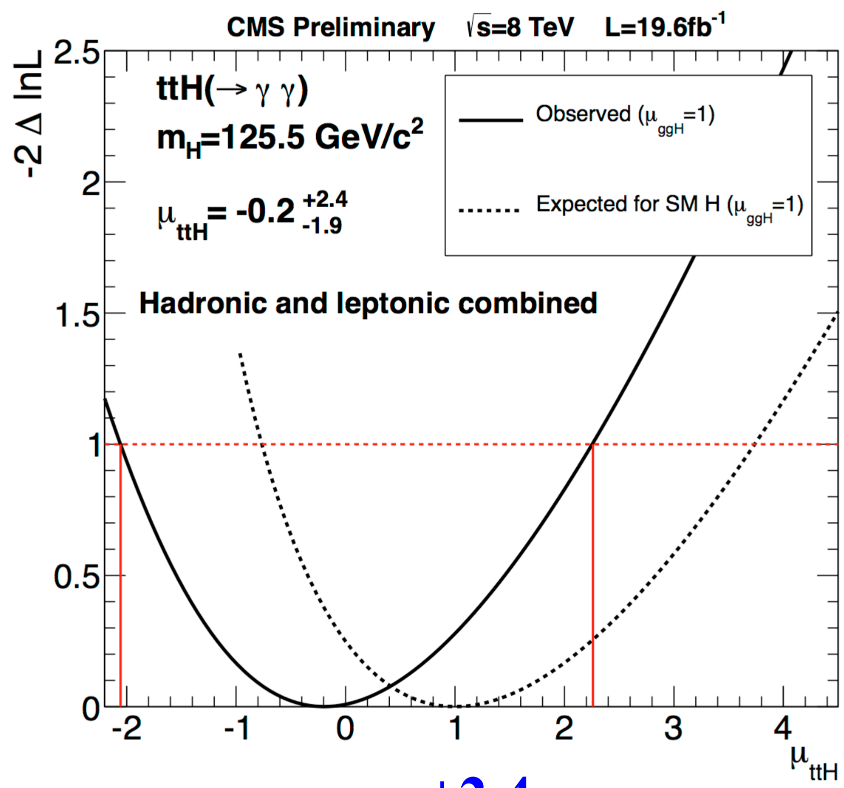
Select events with two photons, large number of jets and at least one b-tag

Search for mass peak in di-photon spectrum as standard H→γγ analysis

Two channels: fully hadronic and leptonic







$$\mu_{ttH} = -0.2^{+2.4}_{-1.9}$$

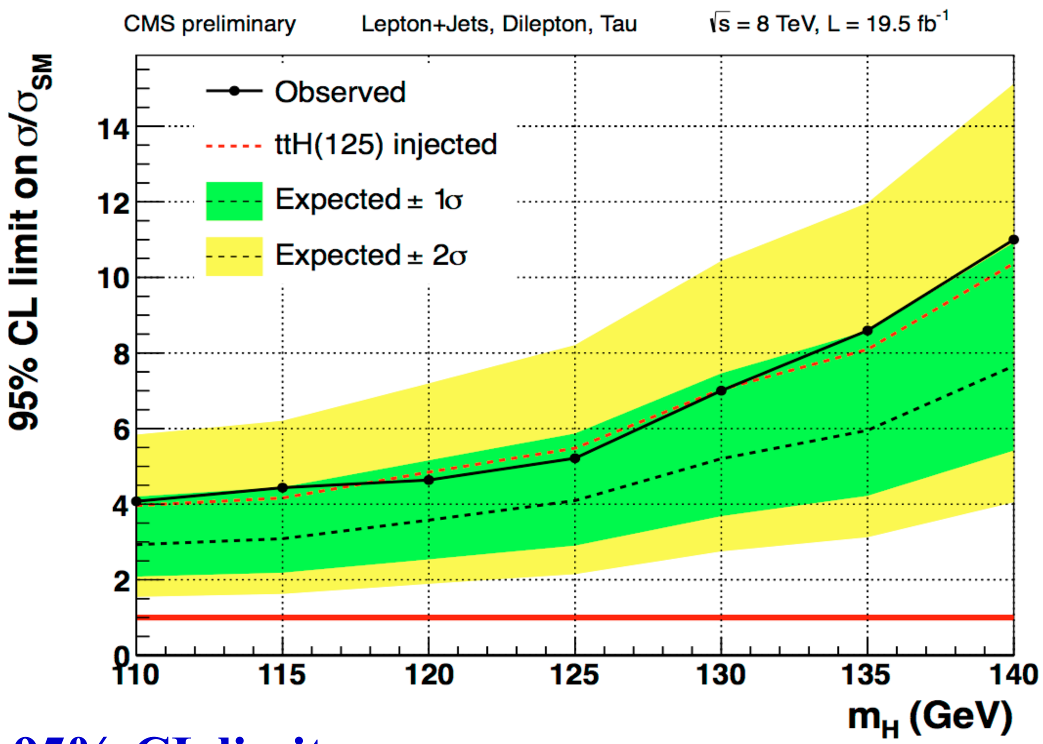
ttH, H→bb and H→ττ

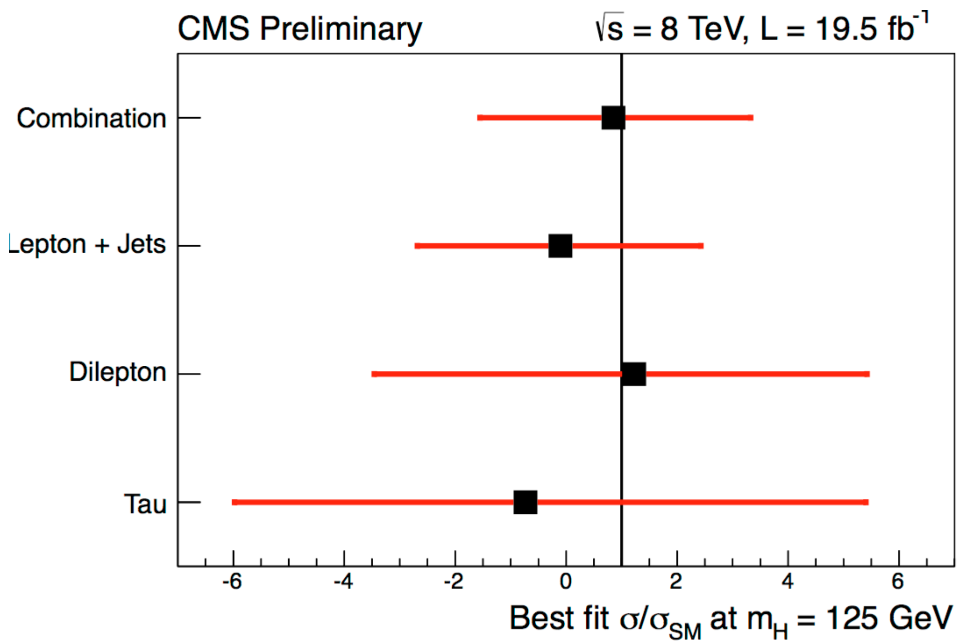
HIG-13-019

Semileptonic and dilepton tt decays with H→bb

- ttH→lνjjbb and ttH→lνlνbb
- H→ττ

Shape analysis using MVA with simultaneous fit of different jet and b-tag multiplicities



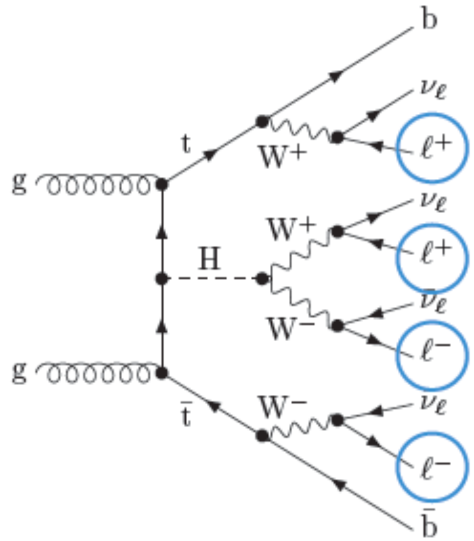


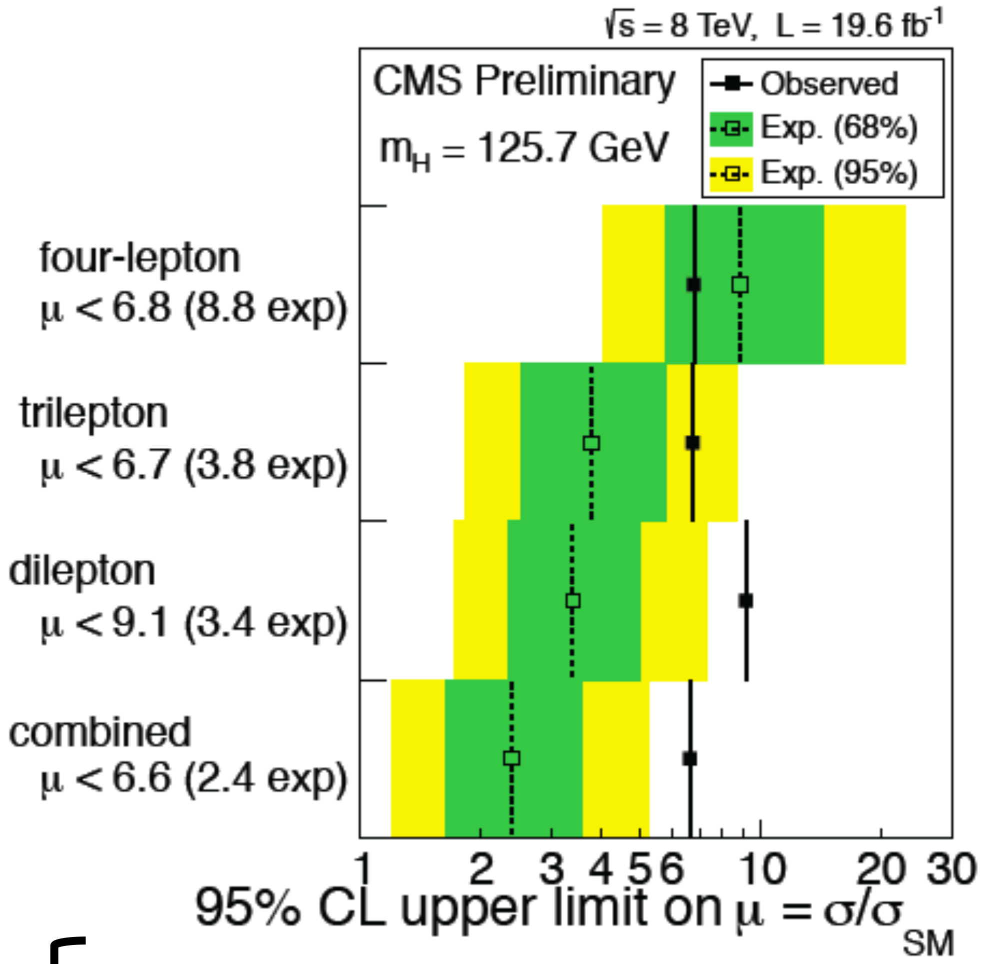
95% CL limit on μ at m_H = 125 GeV

Observed: 5.2 Expected: 4.1

ttH: multi-lepton search

Target ttH production in leptonic (e, μ) final states from $H \rightarrow \tau\tau$, ZZ^*, WW^*





4 leptons + b-jets (other than $H \rightarrow ZZ \rightarrow 4l$, no resonant $Z \rightarrow ll$)

3 leptons + b-jets (no resonant $Z \rightarrow ll$)

2 same-sign leptons (ee, eμ, μμ) + b-jets

Excess mainly comes from SS di-muon channel

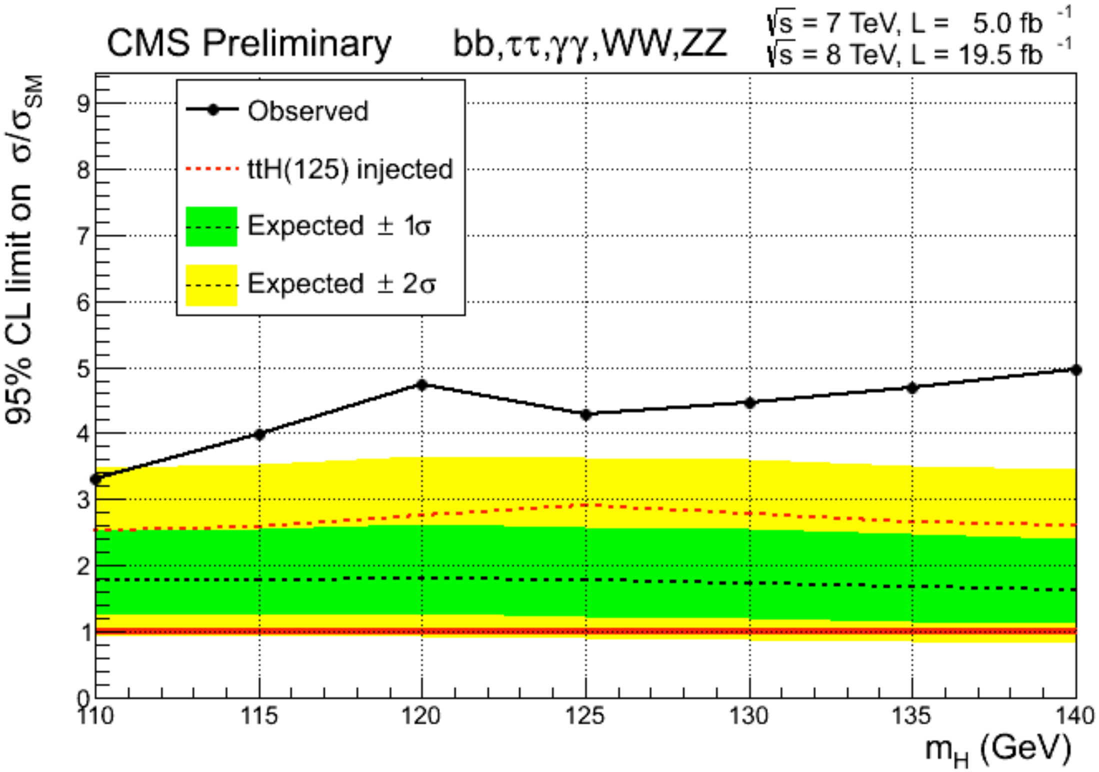
95% CL limit on μ at m_H= 125 GeV

- observed: **6.6**
- expected: **2.4** (in absence of ttH signal) / **3.5** (with SM ttH production)

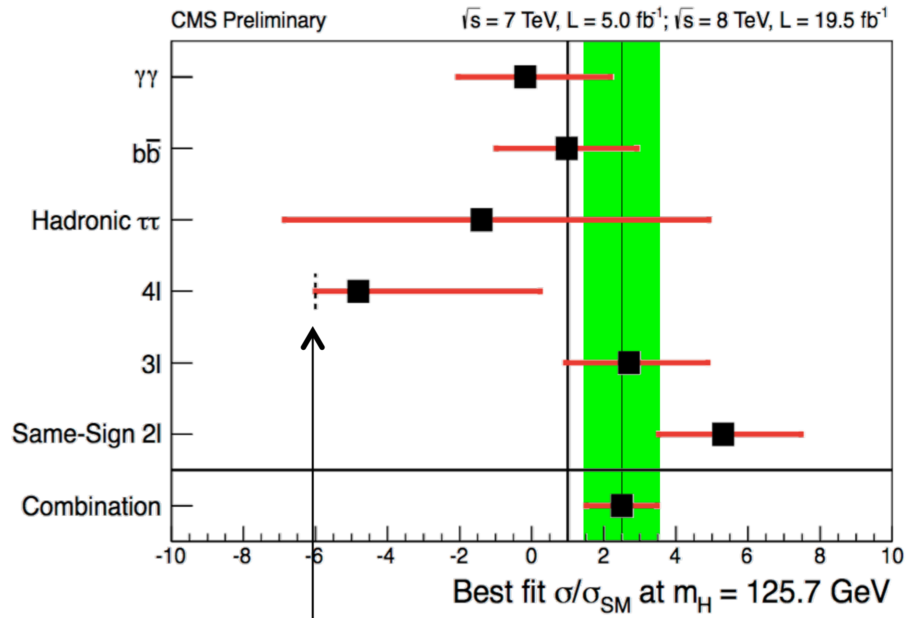
ttH search: combination

γγ, bb, ττ, multi-lepton channels combined

ttHCombinationTWiki



Best fit of signal strength



Expected signal-plus-background event yield must not be negative

95% CL limit on μ at m_H= 125 GeV

Observed limit: 4.3
Expected limit: 2.9

Direct hint of the Higgs coupling to top quarks

$$\mu = \frac{\sigma}{\sigma_{SM}} = 2.5^{+1.1}_{-1.0}$$

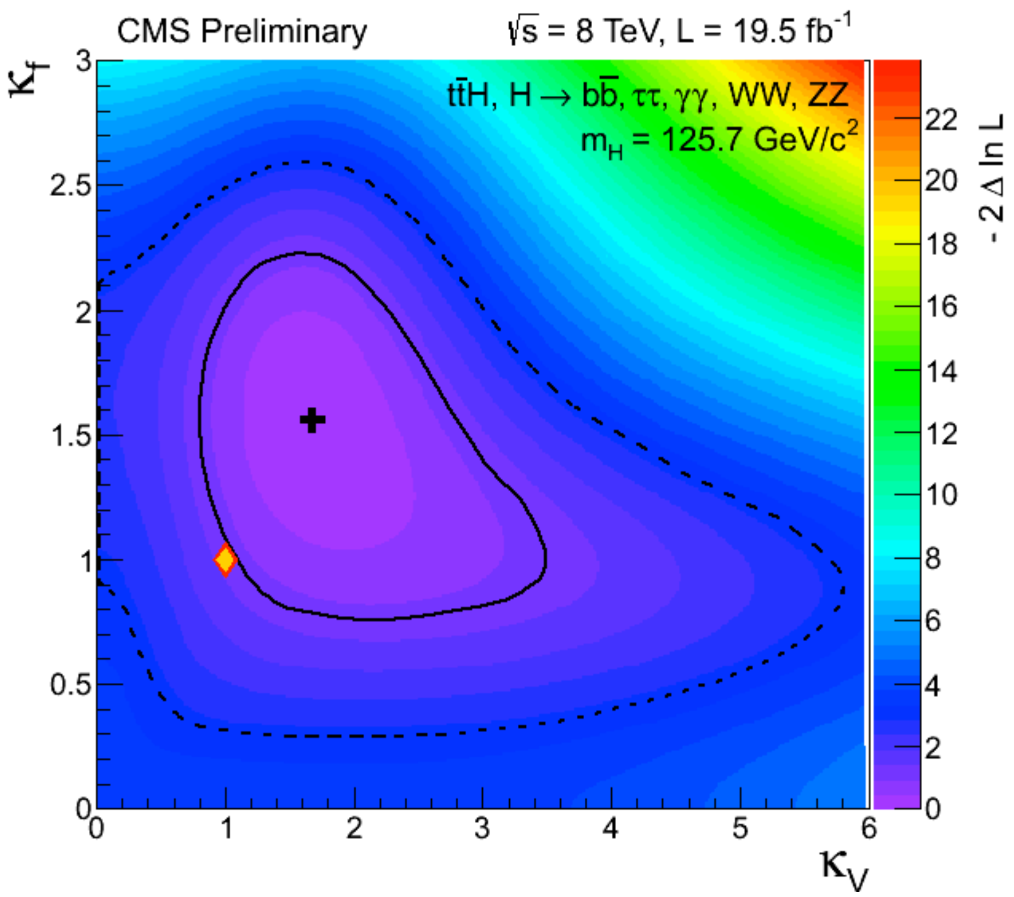
ttH: coupling ratios

Test modification of couplings compared to SM

ttHCombinationTWiki

Vector and fermion couplings grouped
all productions and decays are scaled
κ_V: $\kappa_W=\kappa_Z$ κ_F: $\kappa_t=\kappa_b=\kappa_\tau$

SM: $\kappa_V=\kappa_F=1$



Couplings ratios consistent with SM expectation

H→bb associated production

(access to "down-type" fermion couplings)

H→bb associated production

Largest Branching Ratio at low mass

Challenges:

Control of large SM background → study of Higgs associated production

B-tagging

Improve sensitivity:

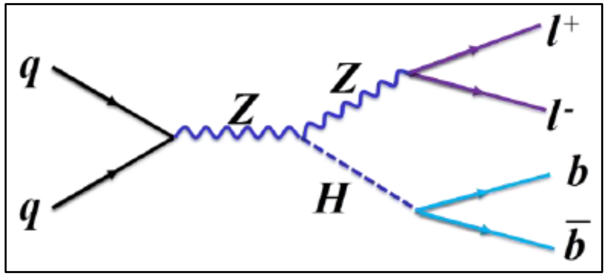
b-jet energy regression

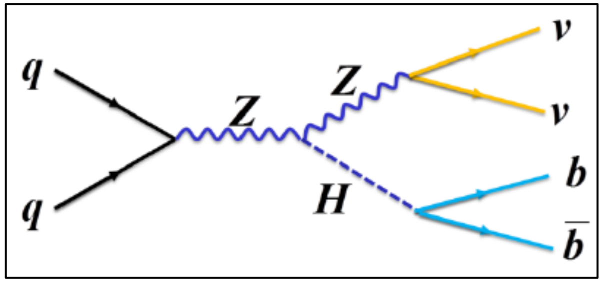
boosted analysis: different regions of $p_t(V)$

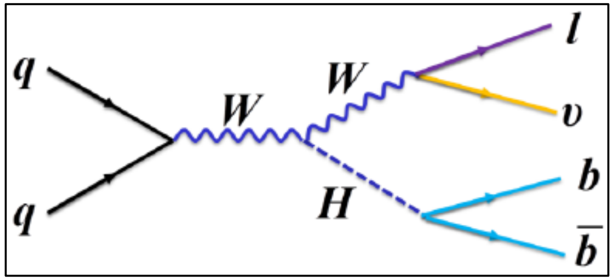
BDT shape analysis for signal extraction

6 topologies considered: Z(ll)H(bb), Z(νν) H(bb), W(lν) H(bb)

W(τν) included





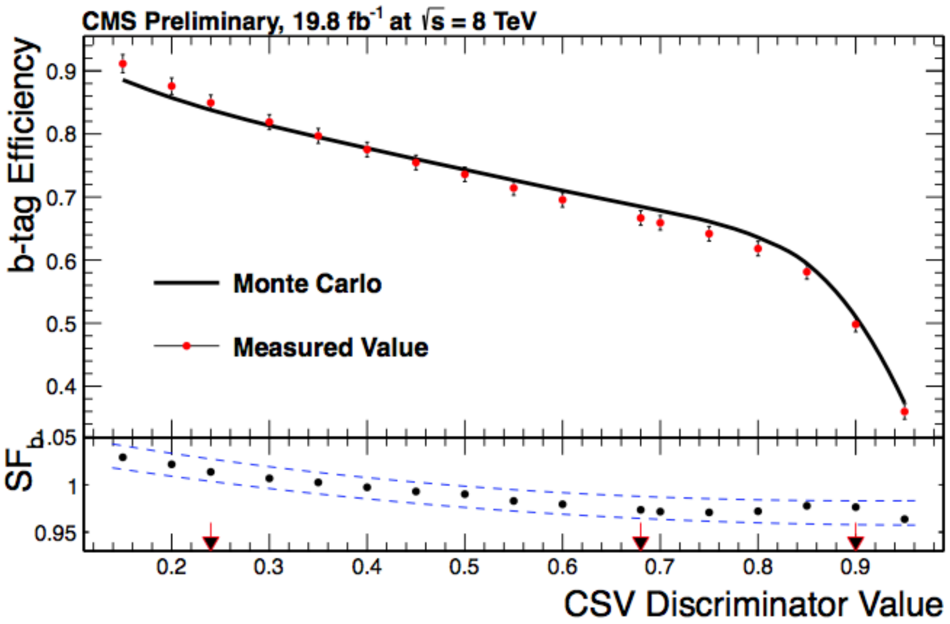


Main backgrounds: V+jets and ttbar

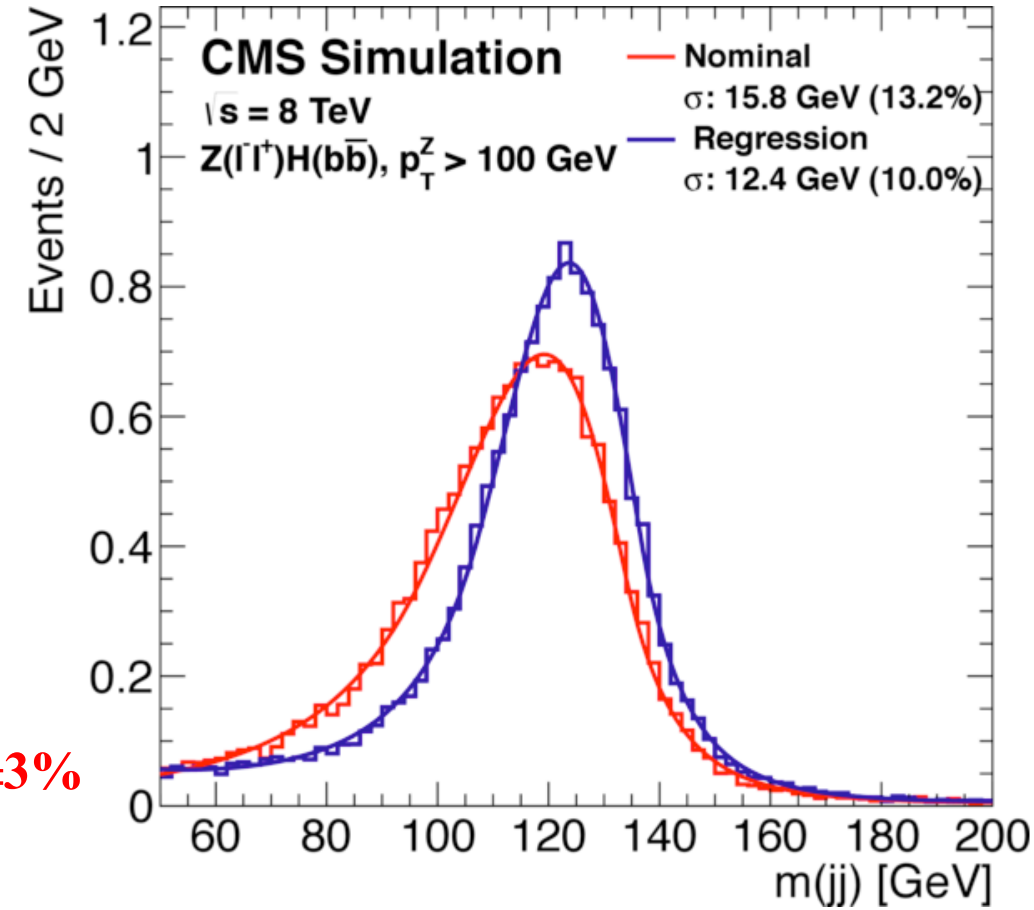
Normalization estimated from data in control regions

b-tagging & b-jet energy calibration

Combined Secondary Vertex discriminator
(track impact parameters and secondary vertices within jets information used)



±3%



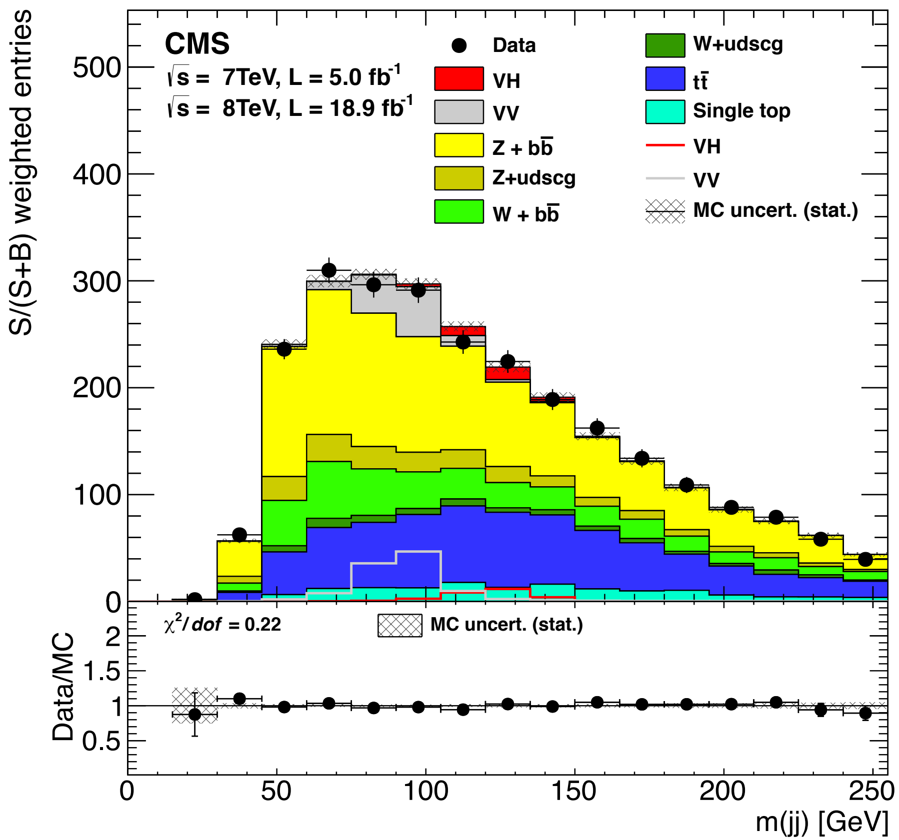
Tagging efficiency working points used
b-tag: 50-75 %
c-quark: 5-25%
Light quark & gluons: 0.15-3%

Measured in ttbar & multi-jet events

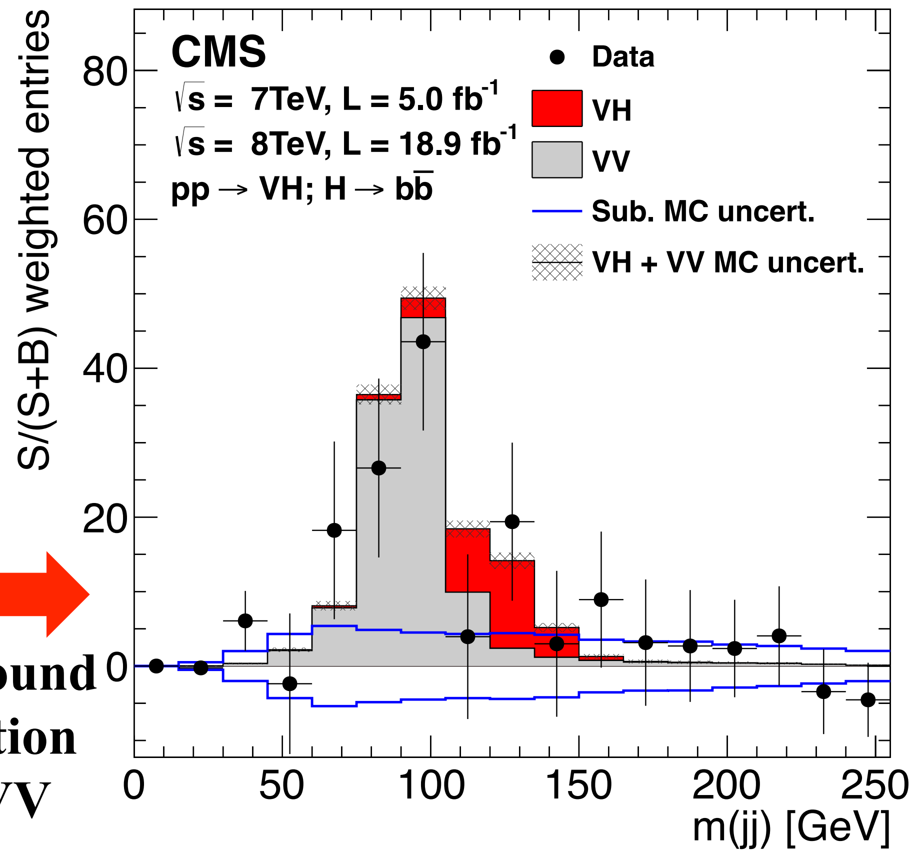
- **BDT regression** trained on VH signal using jet and soft-lepton variables
- **Improves** mass resolution by 15% and **sensitivity by 10-20%**
- Validated in data control regions (bbZ→ll, ttbar, single top, …)

H→bb associated production: di-jet mass cross check analysis

arXiv:1310.3687



Background subtraction except VV



Fit to the dijet invariant mass M_{jj} gives:

small excess consistent with the production of SM Higgs at 125 GeV

VZ, Z→bb measurement: μ_{VV}=1.09, significance > 6σ SMP-13-011

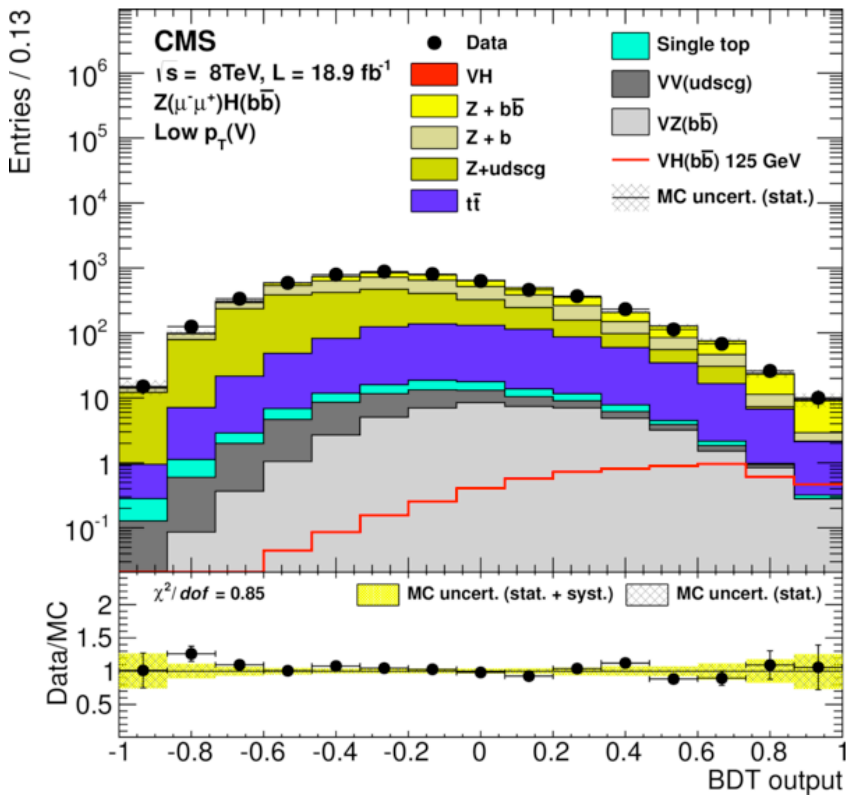
H→bb associated production

arXiv:1310.3687

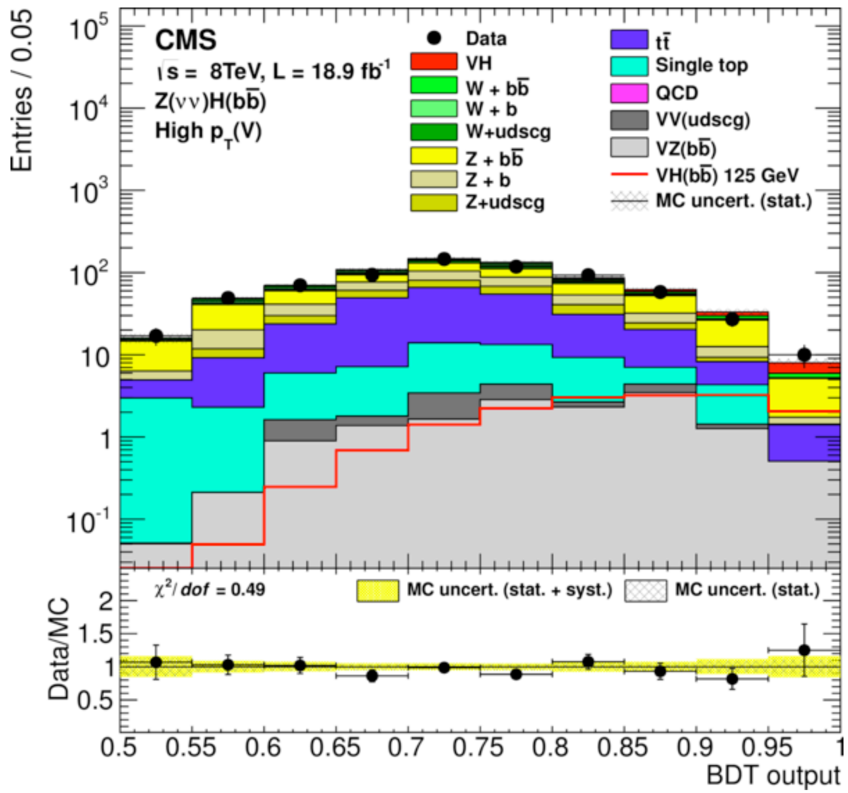
A fit to the BDT shape gives 20% improvement over cut-and-count

- Inputs include kinematics, b-tag information, angles
- Categorize in different $p_T(V)$ and b-tag categories
- BDT is studied in background control regions

Z(→μμ)H(→bb), low p_T(Z)

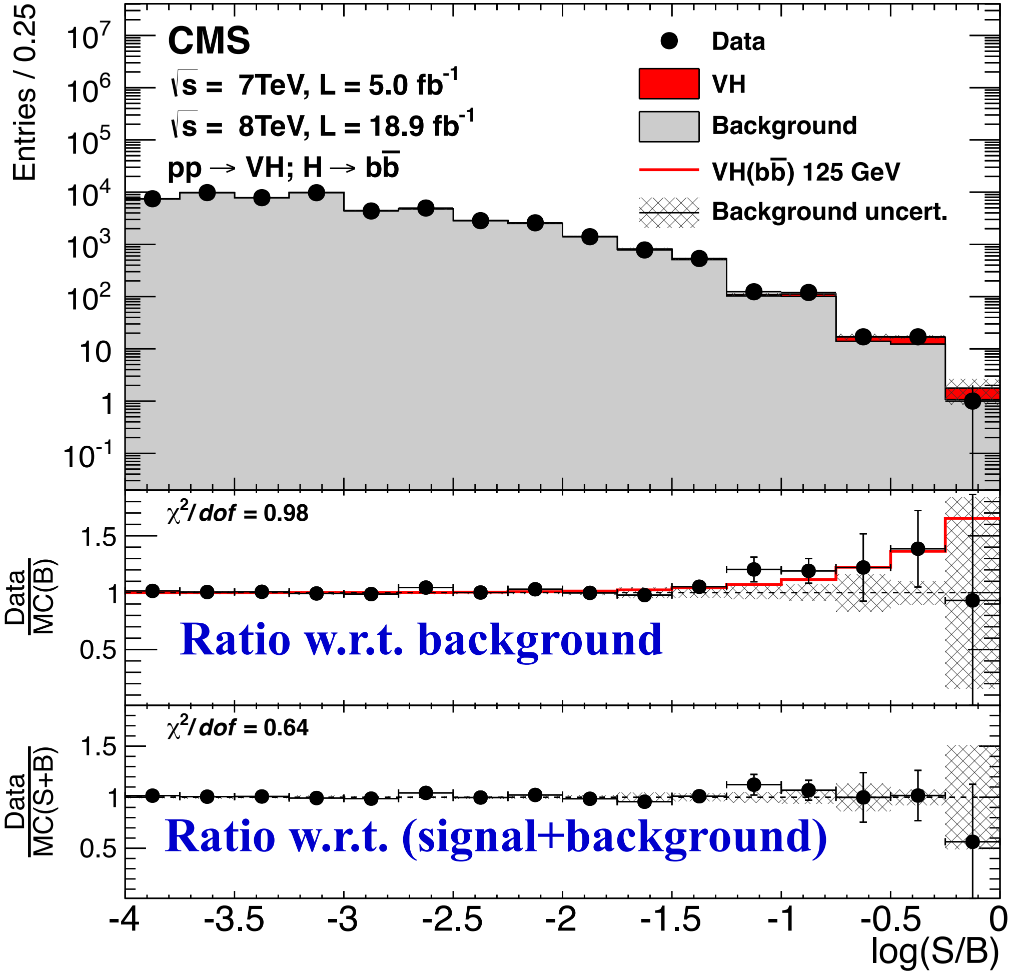


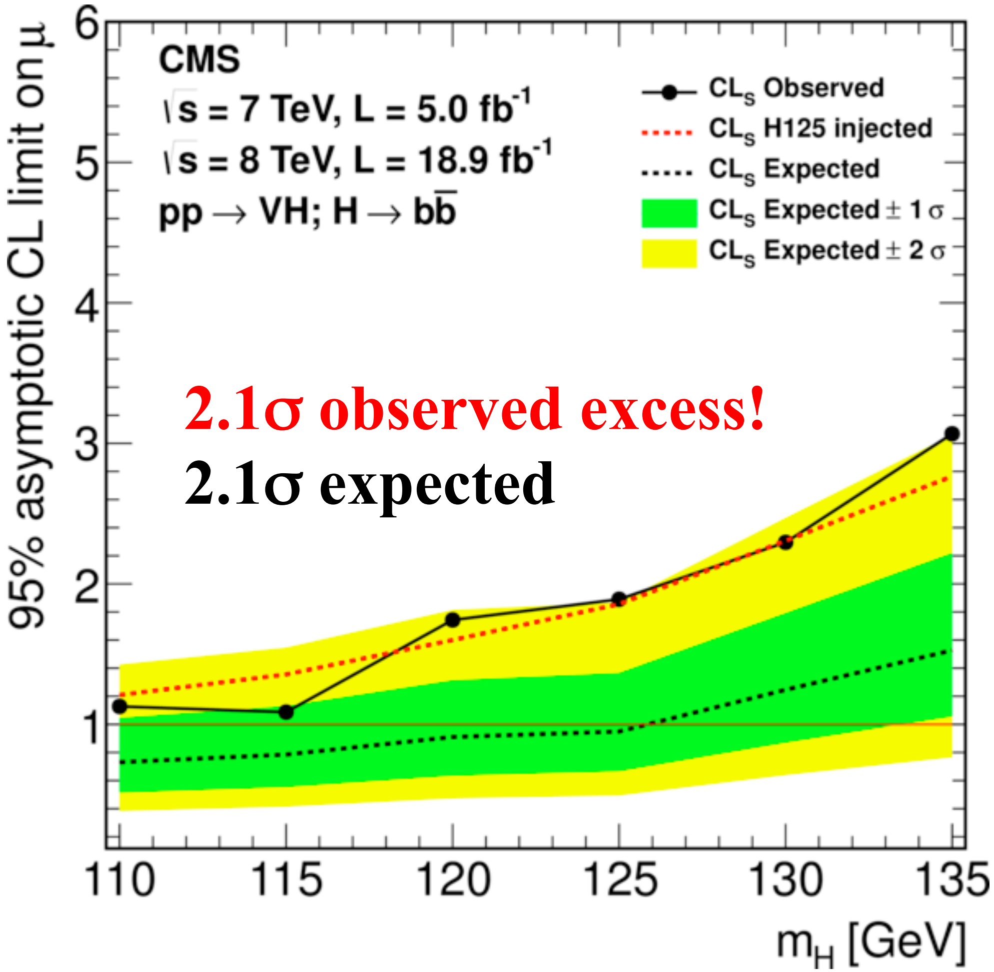
Z(→νν)H(→bb), high p_T(Z)



H→bb associated production

arXiv:1310.3687





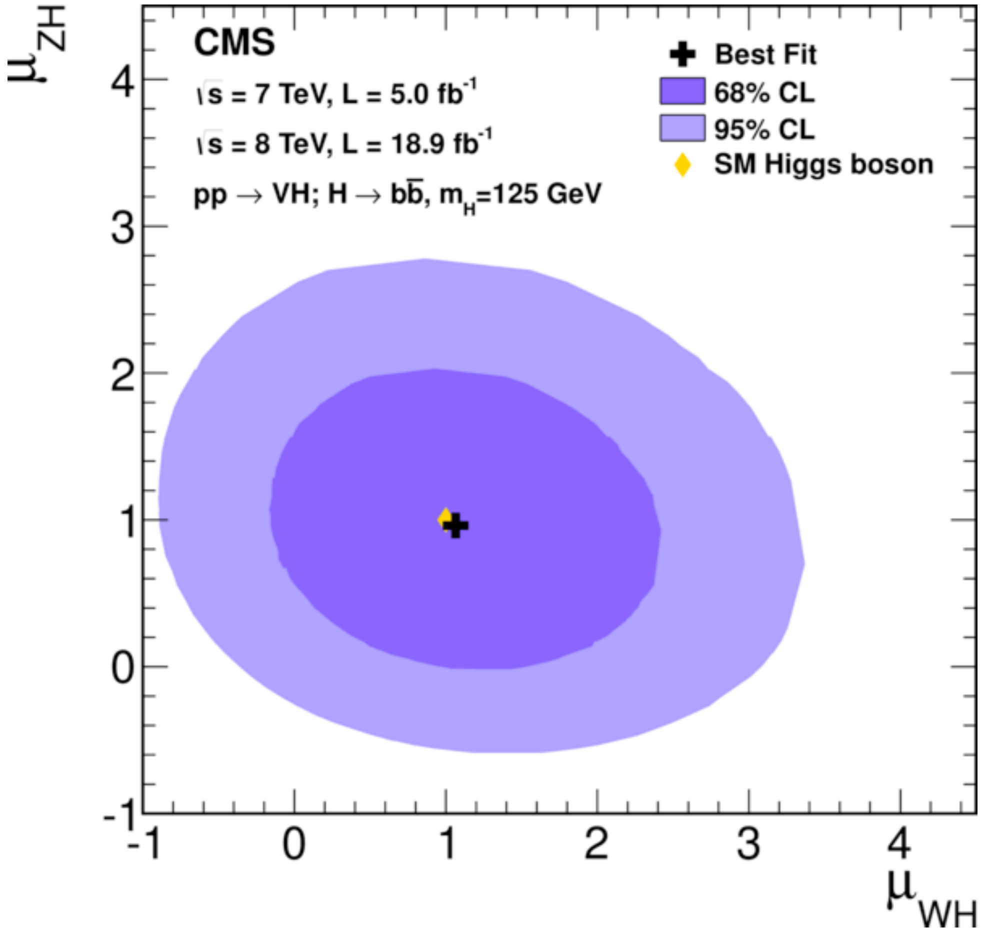
All channels combined

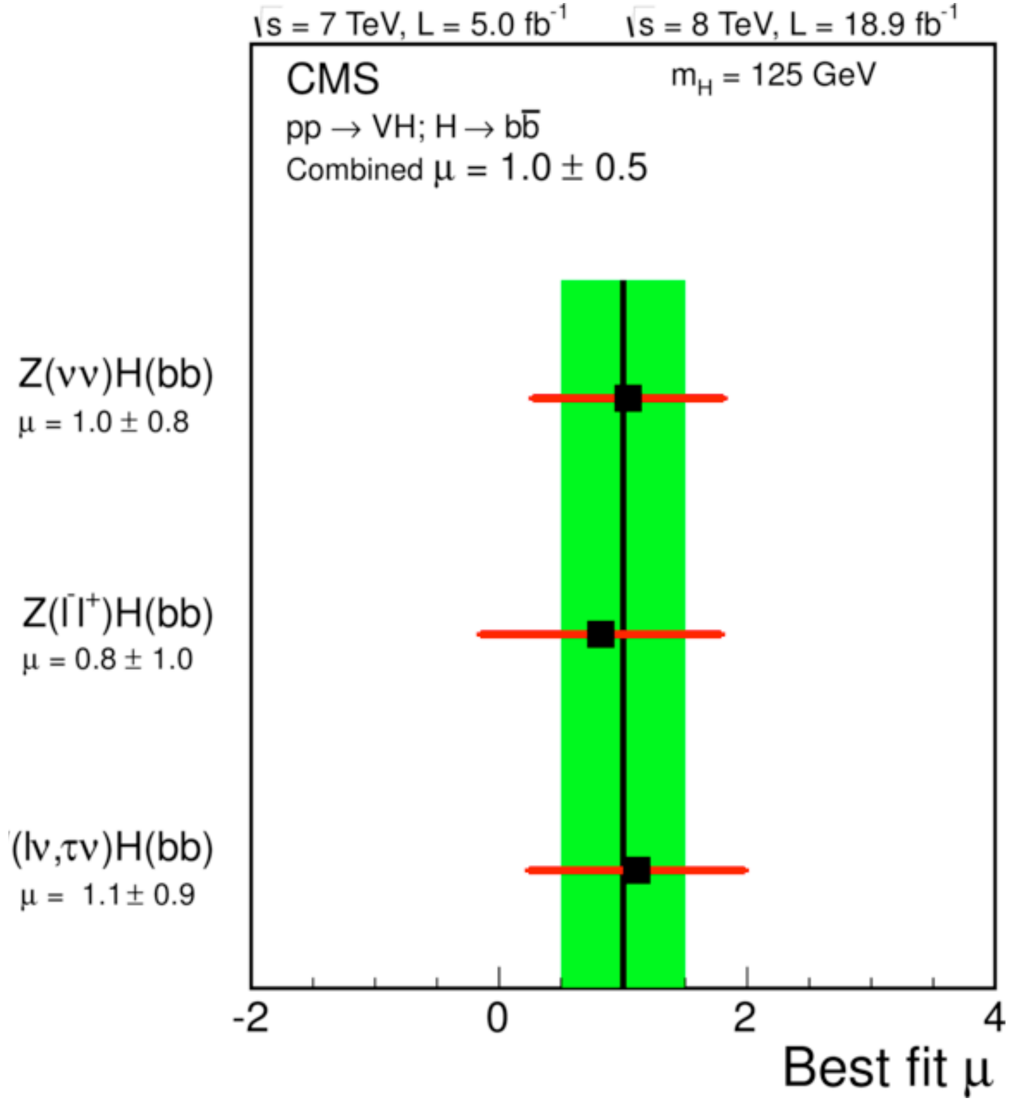
Events sorted in bins of similar S/B as given by the output of the BDT

Signal strength of excess: μ=1.0±0.5

H→bb associated production: signal strength

arXiv:1310.3687





Signal strength and couplings consistent with SM expectations

SM $H \to \tau\tau$ search

(access to "down-type" fermion couplings)

$H \rightarrow \tau\tau$

Significant Branching Ratio (~ 6%) at low mass

Challenges:

- **Reconstruction of different tau decay modes: Hadronic tau (τ_h) reconstruction**
- **Reconstruction of di-τ mass (presence of ν's)**

Improve sensitivity:

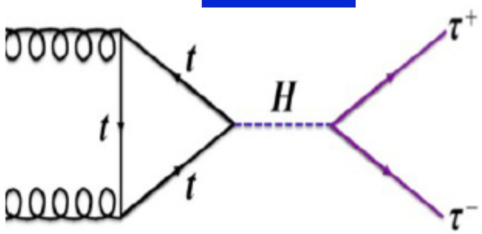
Different categories based on jet multiplicity and τ p_t

Optimized τ_{had}-isolation and $e,\mu \rightarrow \tau_{had}$ fake rejection

Event categories:

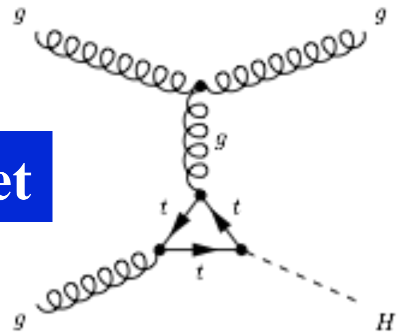
Background dominated

0-jet



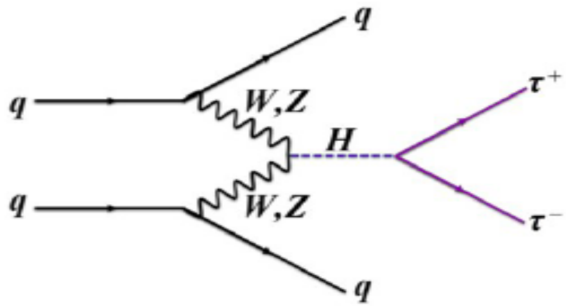
Enhanced gluon-fusion contribution

1-jet



Vector Boson Fusion (VBF)
(best S/B)

2-jet



0-jet category: **allows to control systematics uncertainties (nuisances in fit)**

Fit for Higgs signal is performed in all categories

$H\rightarrow\tau\tau$: Event categorization

Event categorization has been **re-optimized** since last iteration of the analysis

0-jet | **1-jet** | **2-jet**

$\mu\tau_h$

- $p_T(\tau_h) > 45$ GeV
  - 0-jet: high $p_T(\tau_h)$
  - 1-jet: high $p_T(\tau_h)$
  - 1-jet, $p_T^{\tau\tau} > 100$ GeV: high $p_T(\tau_h)$ boost
- baseline
  - 0-jet: low $p_T(\tau_h)$
  - 1-jet: low $p_T(\tau_h)$
- 2-jet, $m_{jj} > 500$ GeV, $|\Delta\eta_{jj}| > 3.5$: loose VBF tag
- 2-jet, $p_T^{\tau\tau} > 100$ GeV, $m_{jj} > 700$ GeV, $|\Delta\eta_{jj}| > 4.0$: tight VBF tag (2012 only)

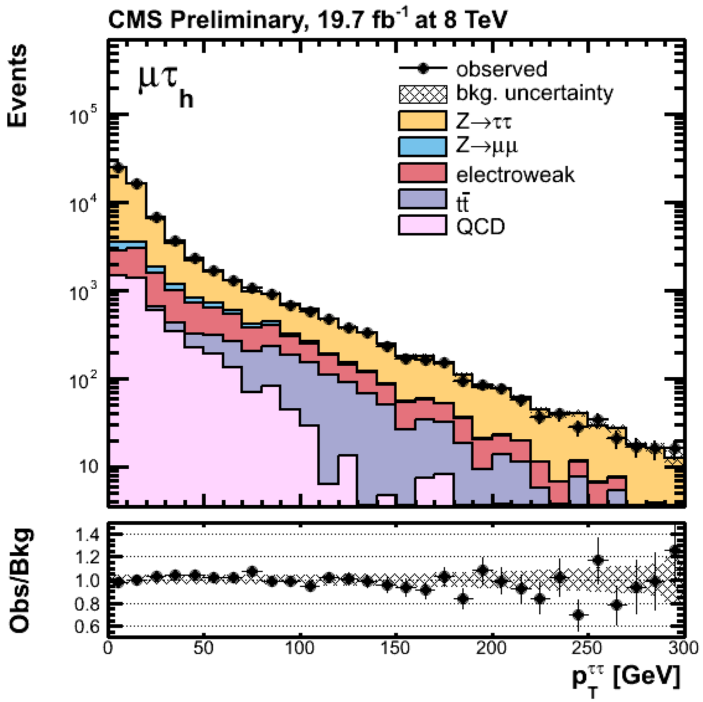
Introduced new high sensitivity categories:

- **1-jet: high $p_t(\tau_h)$ boost**
  $p_t(\tau_h) > 45$ GeV, $p_t^{\tau\tau} > 100$ GeV
- **2-jet: tight VBF tag**
  $M_{jj} > 700$ GeV, $|\Delta\eta_{jj}| > 4$, $p_t^{\tau\tau} > 100$ GeV

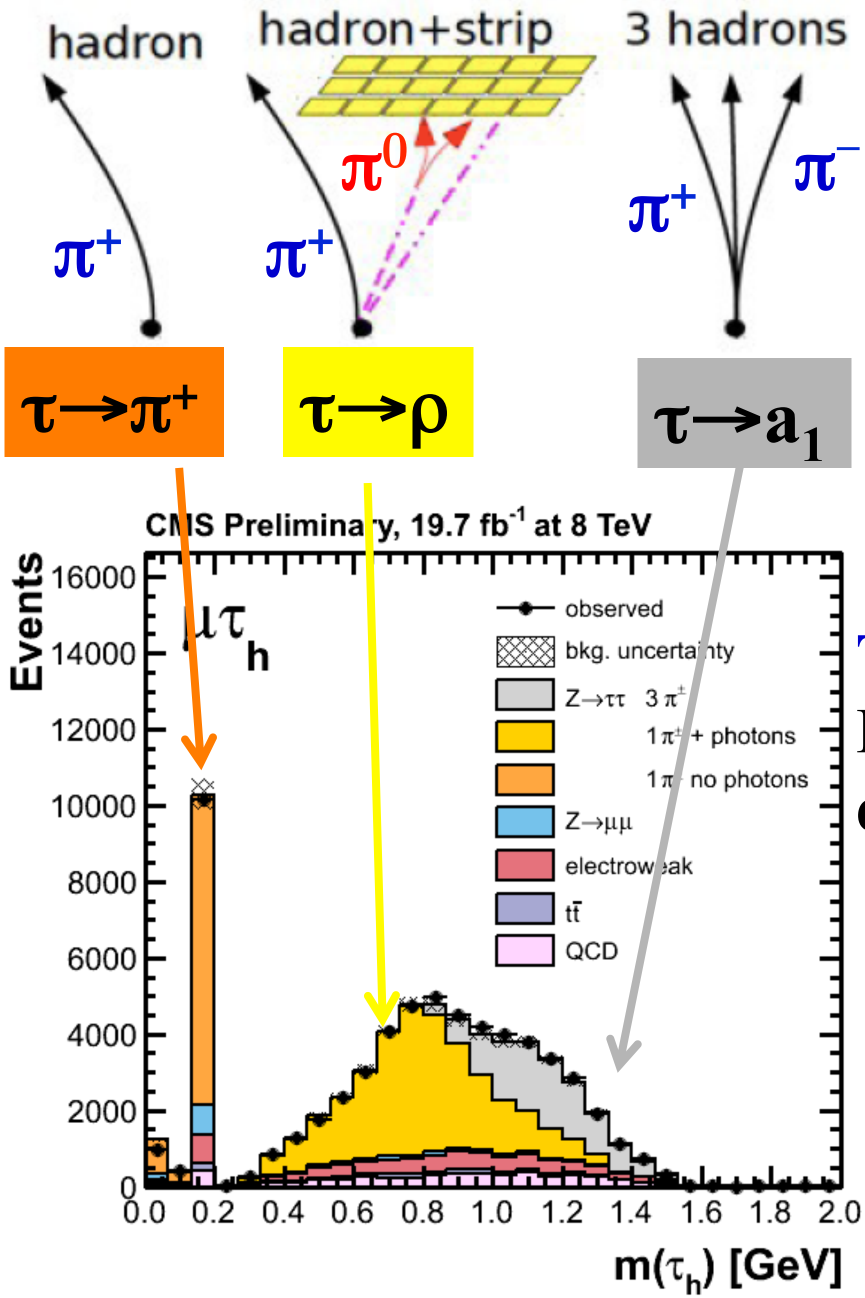
$$p_t^{\tau\tau} = |\vec{p}_t(L_1) + \vec{p}_t(L_2) + \vec{E}_T^{miss}|$$

L_1, L_2 : two final state leptons

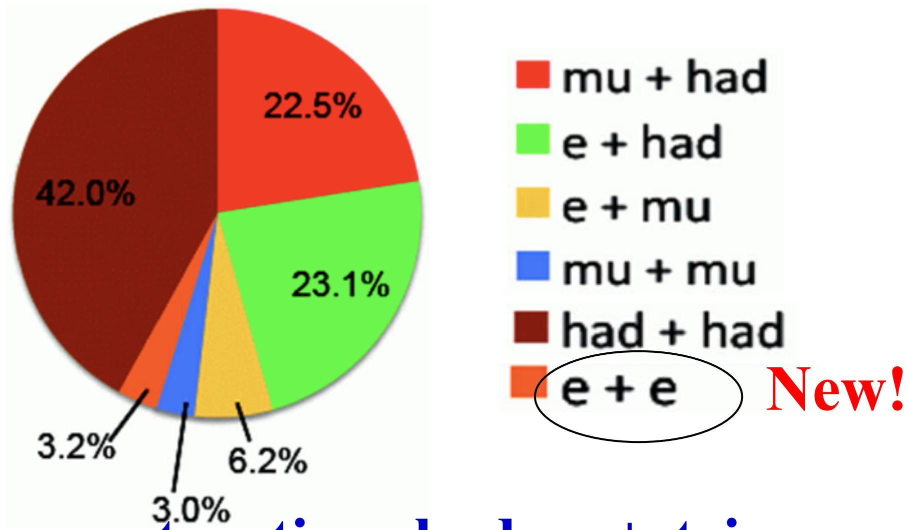
→ variable well controlled



H→ττ: di-τ final state reconstruction



All di-tau final states are studied now



Tau reconstruction: hadron+strip

Particle-flow based algorithm to reconstruct different hadronic tau decay modes

τ_h identification: efficiency ~ 60%
fake rate ~ 1%

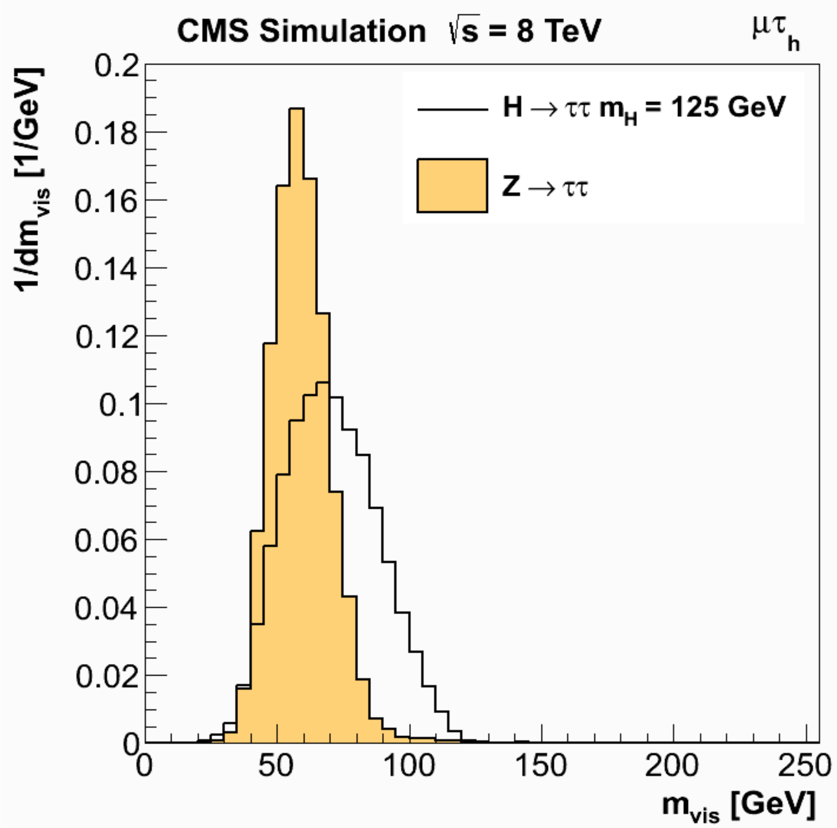
The τ_h mass distribution used to control the tau energy-scale within 3% & reconstruction of decay modes

H→ττ: mass reconstruction

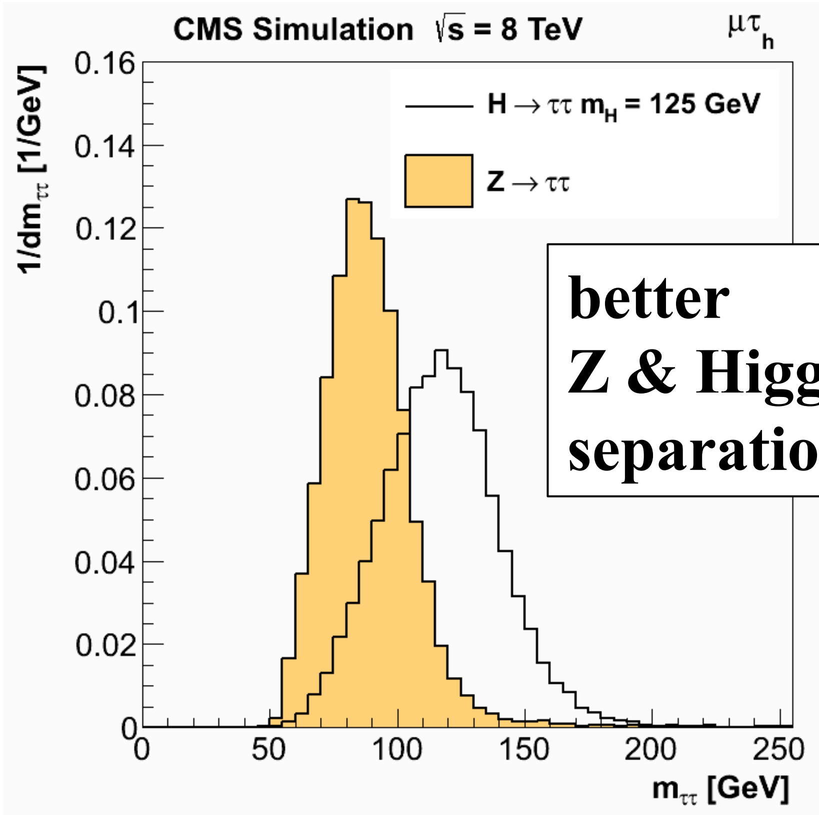
Di-tau mass estimation uses **visible decay products** & **missing E_T** in **a maximum likelihood fit**

The mass resolution is ~ 10-20% depending on channel/category

Visible mass



Full reconstructed mass

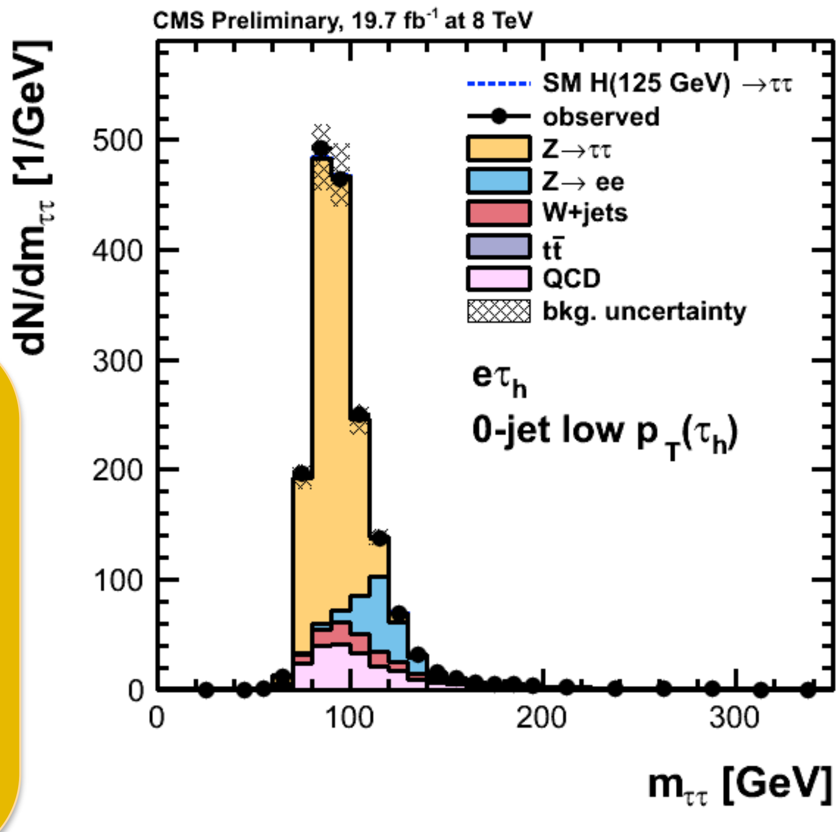


better Z & Higgs separation

H→ττ: background estimation

HIG-13-004

All normalizations are data-driven



Z→ττ:
embedded samples
No MET/JES scale uncertainties
Shape estimation and correction for selection efficiencies

W+jets:
- Normalization from high m_T control region
- Shape from MC

ttbar:
- Normalization from eμ b-tag control region
- Shape from MC

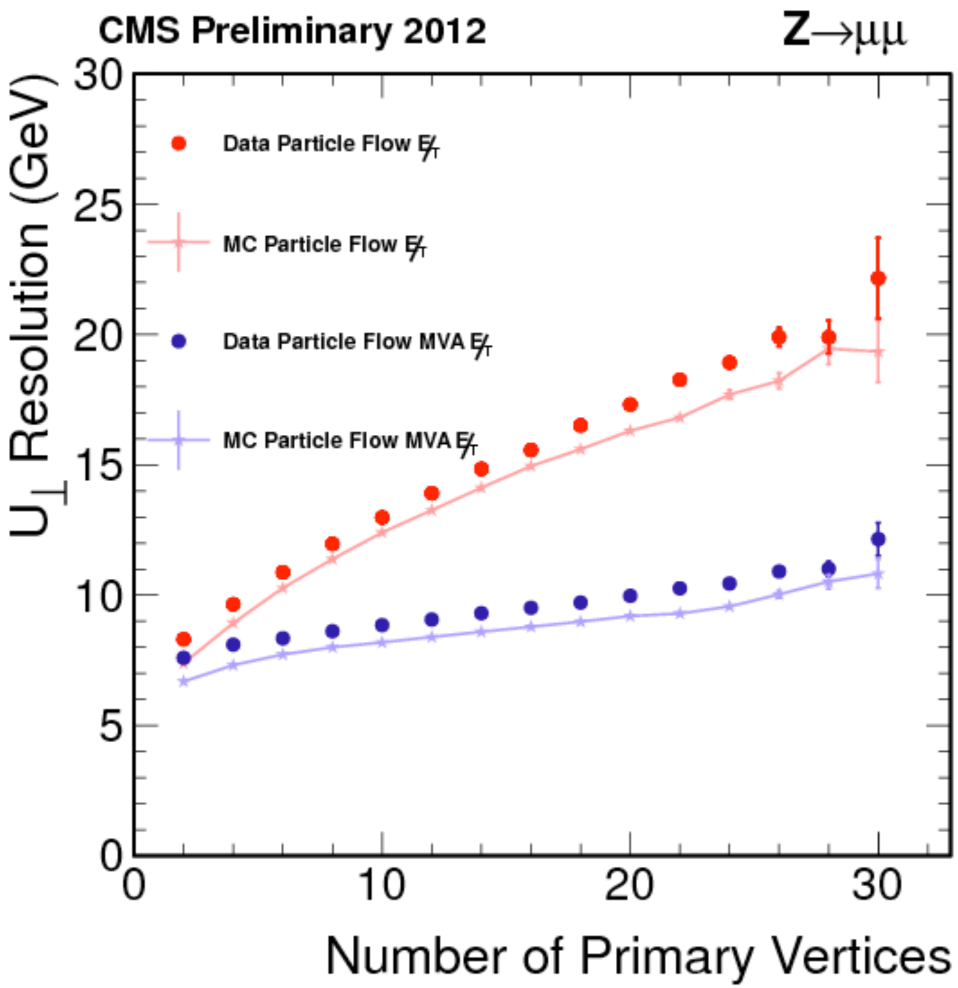
Z→ee/μμ
- Normalization scale factor from tag-and-probe in data
- Shape from MC

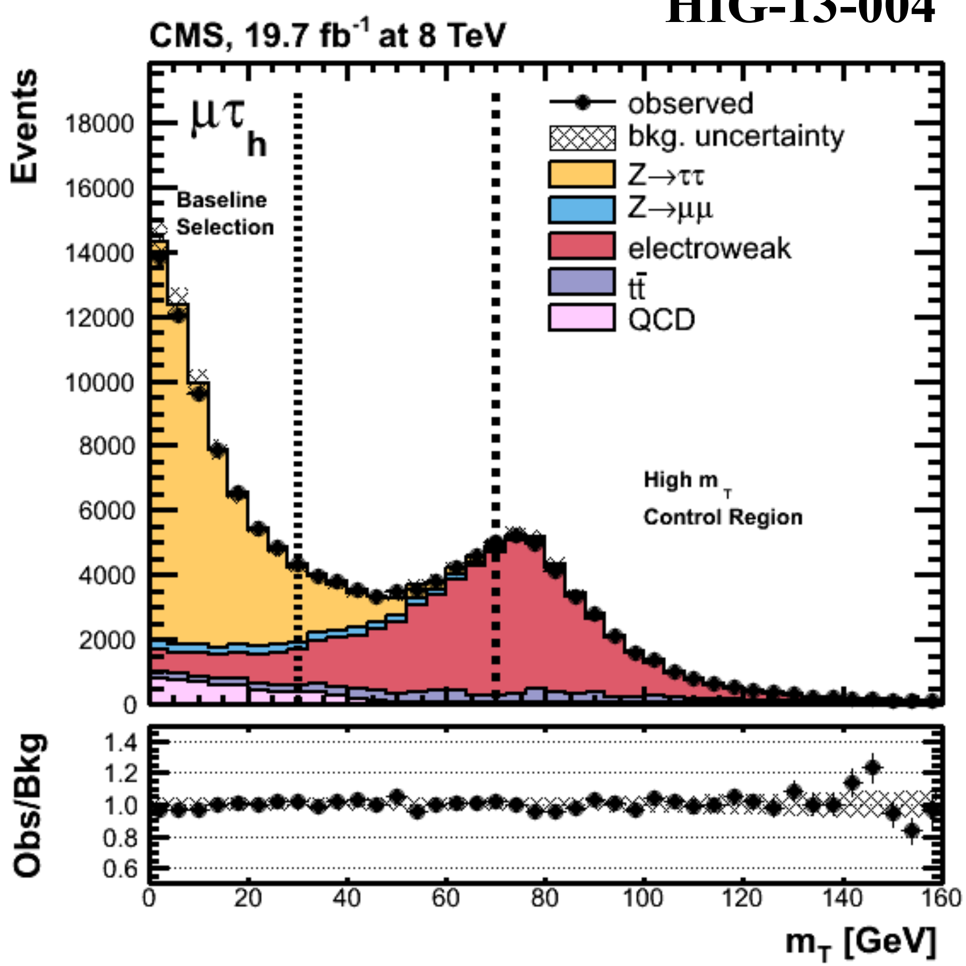
QCD:
- Normalization from ratio of same-sign(SS) to opposite-sign (OS) data events
- Shape from SS data events

H→ττ: control of W+jet background

HIG-13-004

Multivariate E_T^{miss} regression





E_T^{miss}: significant improvement in resolution and dependence on pileup

Crucial for H→ττ analysis: $m_{\tau\tau}$ reconstruction and separation of signal from W+jets background using $m_T(\mu,E_T^{miss})$ selections

H→ττ: systematic uncertainties

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Experimental uncertainties

Background estimation

Uncertainty	Affected samples	Change in acceptance
Tau energy scale	signal & sim. backgrounds	shape
Tau ID & trigger	signal & sim. backgrounds	8–19%
e misidentified as τ_h	$Z \to ee$	20–74%
μ misidentified as τ_h	$Z \to \mu\mu$	30%
Jet misidentified as τ_h	Z boson plus jets	20–80%
Electron ID & trigger	signal & sim. backgrounds	2–6%
Muon ID & trigger	signal & sim. backgrounds	2–4%
Electron energy scale	signal & sim. backgrounds	shape
Jet energy scale	signal & sim. backgrounds	0–20%
E_T^{miss} scale	signal & sim. backgrounds	1–12%
$\varepsilon_{b\text{-tag}}$ b jets	signal & sim. backgrounds	0–8%
$\varepsilon_{b\text{-tag}}$ light-flavoured jets	signal & sim. backgrounds	1–3%
Norm. Z production	Z	3%
$Z \to \tau\tau$ category	$Z \to \tau\tau$	2–14%
Norm. W+jets	W+jets	10–100%
Norm. $t\bar{t}$	$t\bar{t}$	8–35%
Norm. diboson	diboson	15–45%
Norm. QCD multijet	QCD multijet	6–70%
Shape QCD multijet	QCD multijet	shape
Luminosity 7 TeV (8 TeV)	signal & sim. backgrounds	2.2% (2.6%)

- **τ energy scale uncertainty:** changes **expected μ** value by **less than 4%**
  Ignoring τ energy scale uncertainty has an **effect of ~ 40% in the μ uncertainty**
- **0-jet category** allows to **constrain backgrounds** (eg. peaking Z→ee, Z→μμ)

H→ττ: Theoretical uncertainties

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Dominant systematic in the extraction of μ

Uncertainty	Affected samples	Change in acceptance
PDF (qq)	signal & sim. backgrounds	4%
PDF (gg)	signal & sim. backgrounds	10%
Scale variation	signal	3–41%
Underlying event & parton shower	signal	2–10%
Limited number of events	all	bin-by-bin

Uncertainty on signal acceptance in each category due to:

- **PDF:** take envelope of variation from CT10, MSTW and NNPDF sets
- **Scale μ_F and μ_R:** applied on total cross section and as a modified p_t spectrum
- **Parton shower modeling:** difference in acceptance between CMS (Z2*) and ATLAS (AUET2) tunes
- **p_T Matching:** vary Powheg threshold for the additional NLO jet
- **ggH MC Comparison:** compare default Powheg NLO to Madgraph, Powheg+MINLO and aMC@NLO

Re-weight Higgs p_T to NNLO Hres distribution in gluon-fusion samples

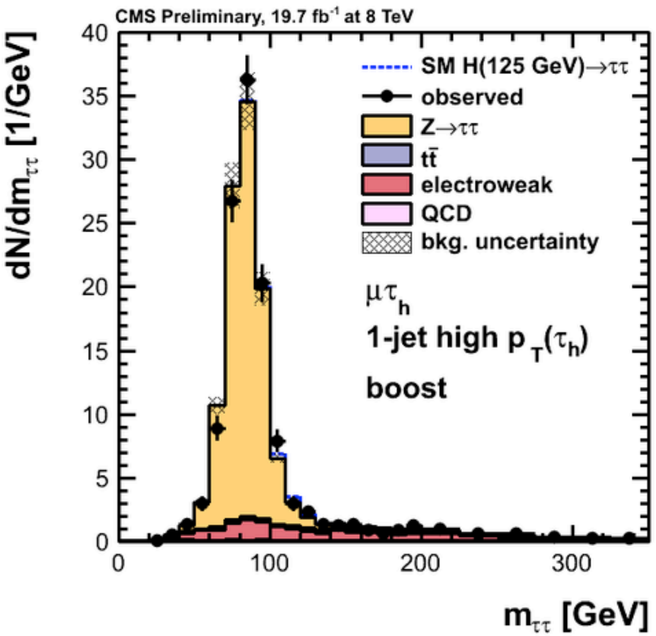
→ Uncertainty covered by shape systematic on signal templates

$H \rightarrow \tau\tau \rightarrow \mu\tau_h$

$\mu\tau_h$: most sensitive channel

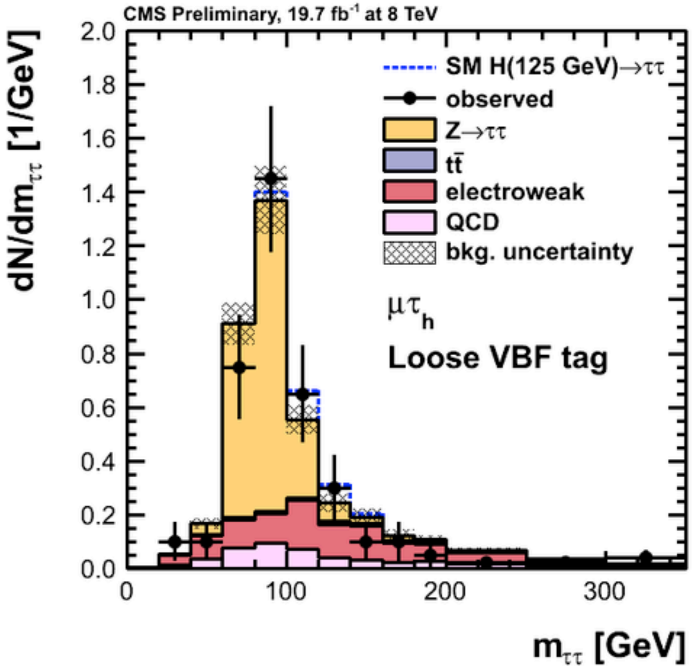
HIG-13-004

1-jet high $p_t(\tau_h)$ boost



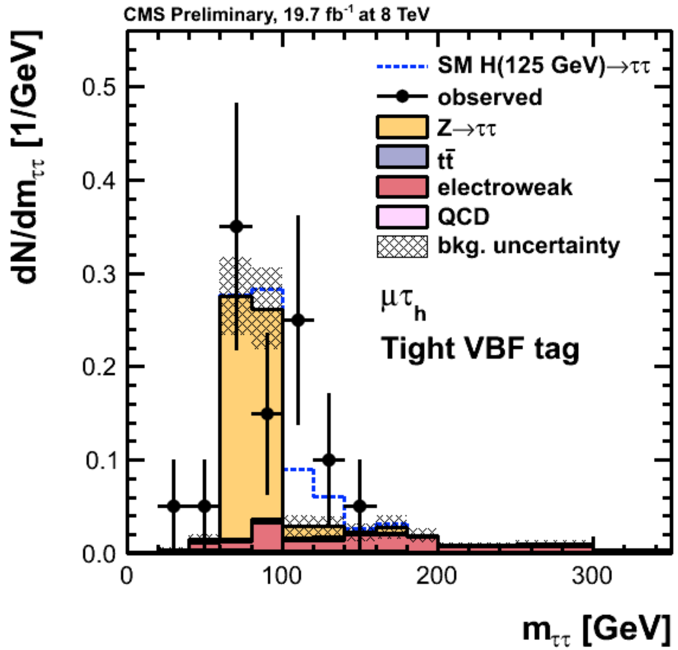
$p_t(\tau_h) > 45$ GeV
$p_t^{\tau\tau} > 100$ GeV

2-jet: loose VBF tag



$M_{jj} > 500$ GeV $|\Delta\eta_{jj}| > 3.5$

2-jet tight VBF tag

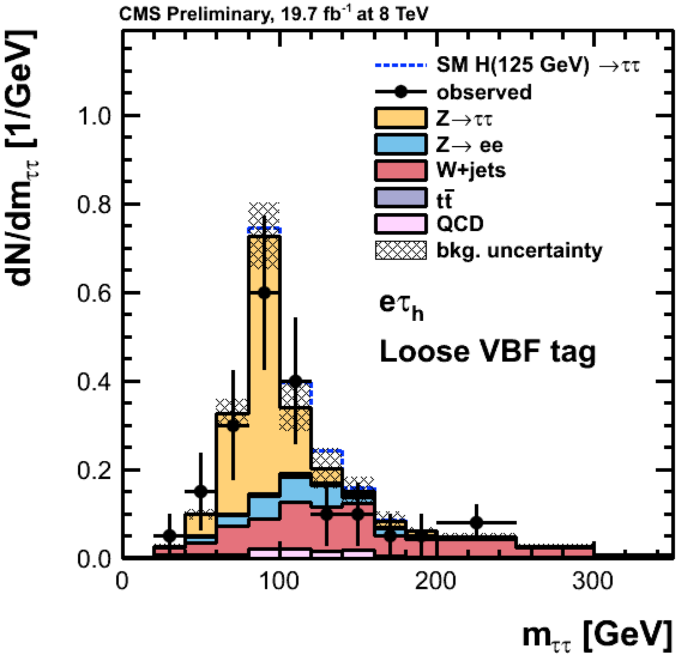


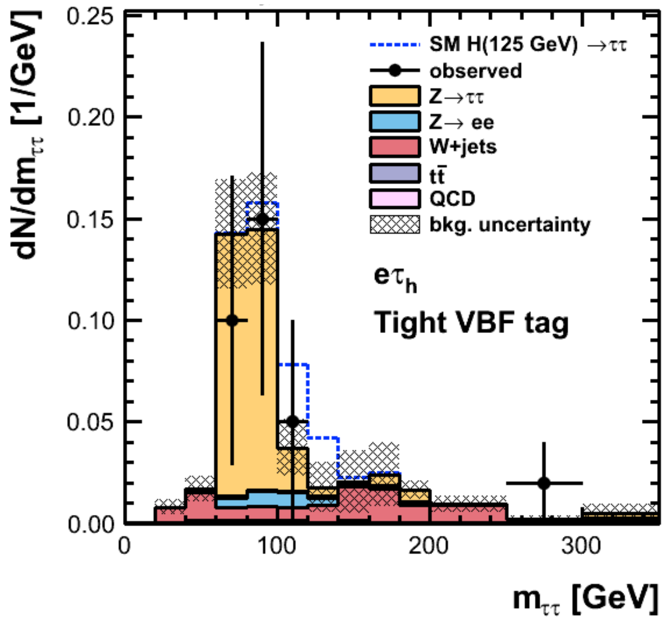
$M_{jj} > 700$ GeV, $|\Delta\eta_{jj}| > 4$
$p_t^{\tau\tau} > 100$ GeV

H→ττ: VBF tag

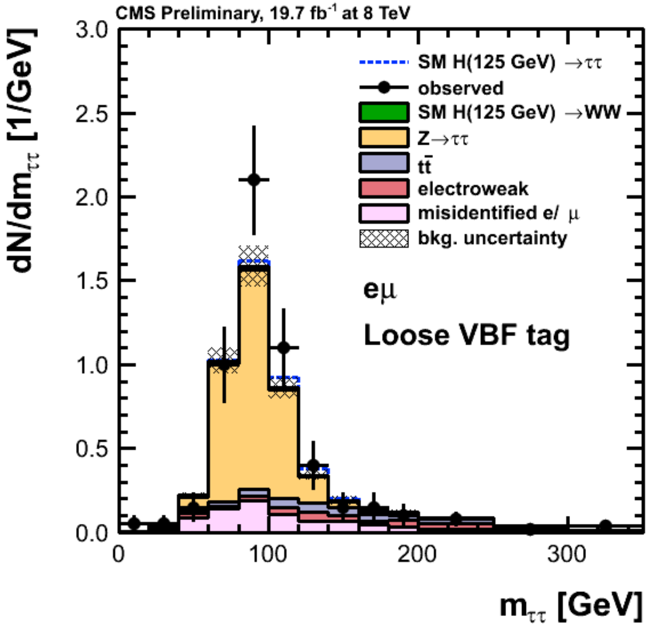
HIG-13-004

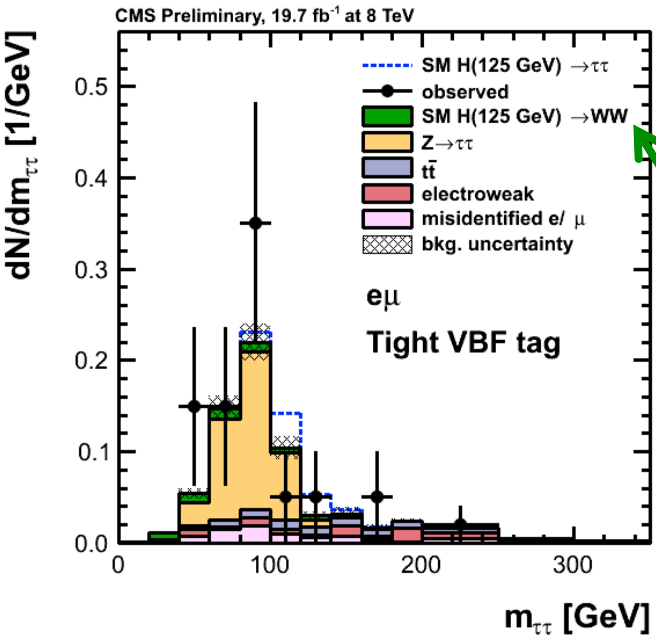
eτ



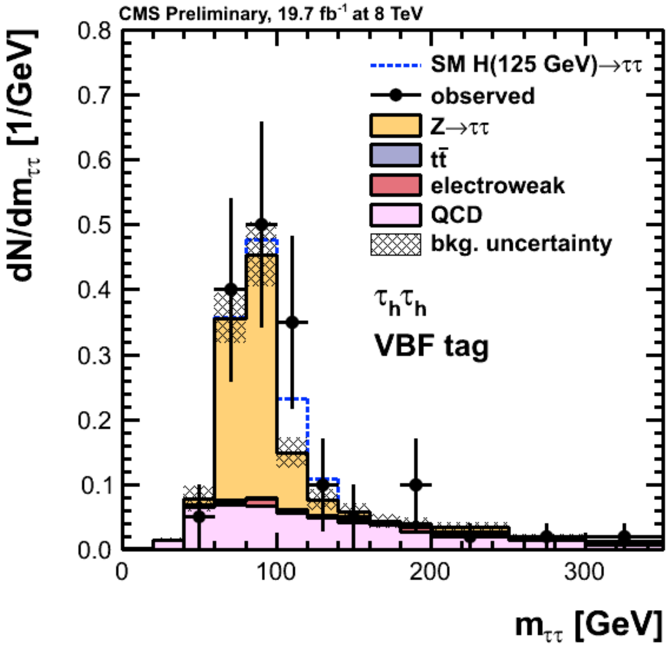


eμ





$\tau_h\tau_h$



$\tau_h\tau_h$: no tight-VBF

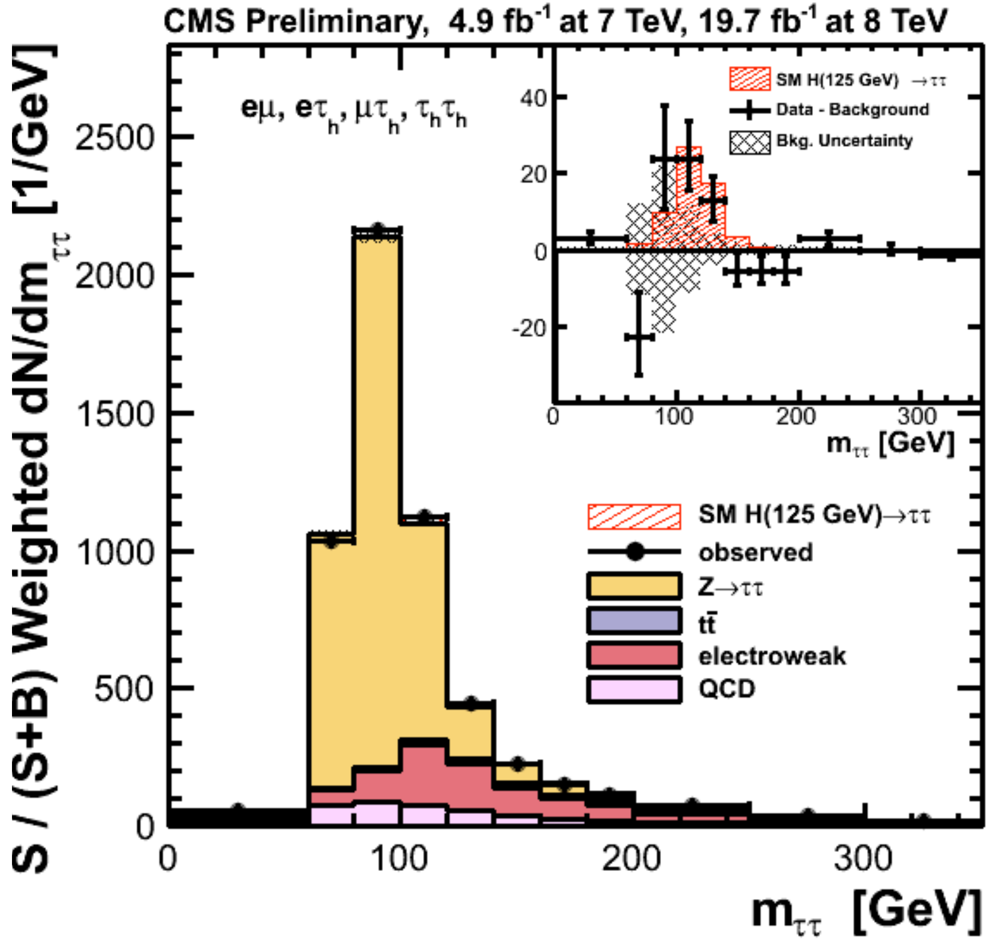
eμ:
H→WW contribution!

H→WW is treated as background to probe fermionic decay contribution

H→ττ: Combined Mass distribution

HIG-13-004

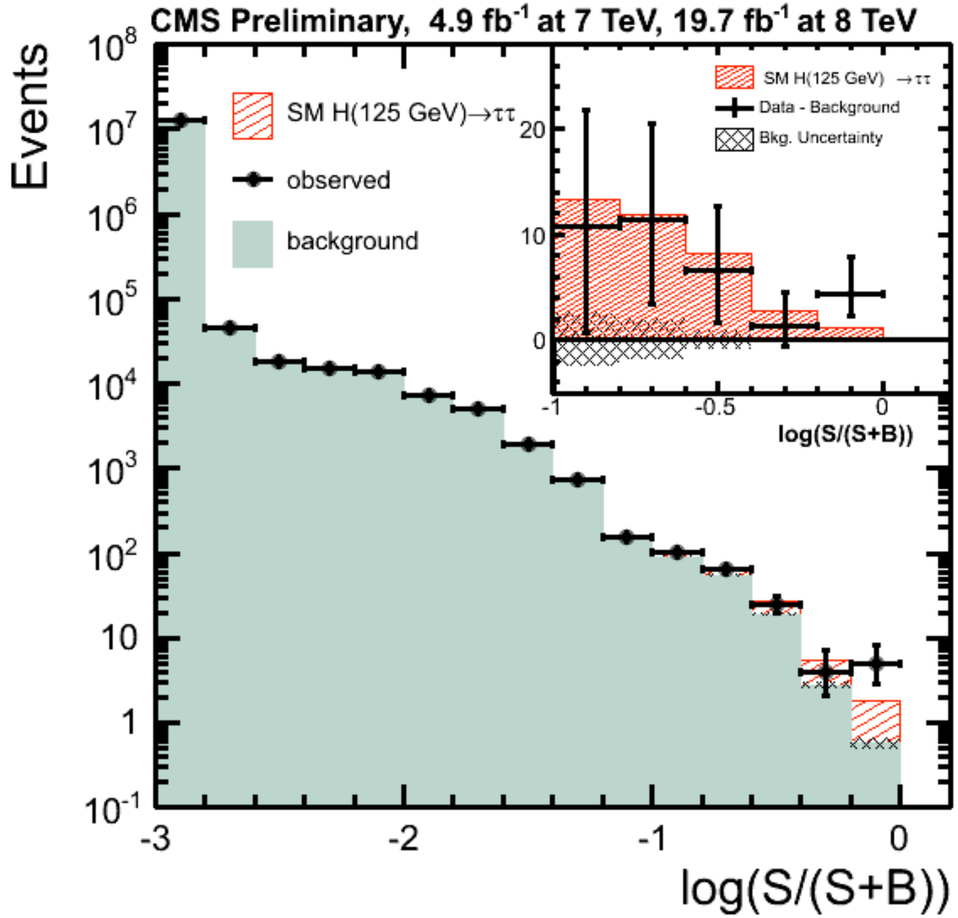
$e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$ only (ee, μμ use BDT)



Weighted by S/(S+B) using 68% region around the $m_{\tau\tau}$ peak

<u>All di-τ final states</u>:

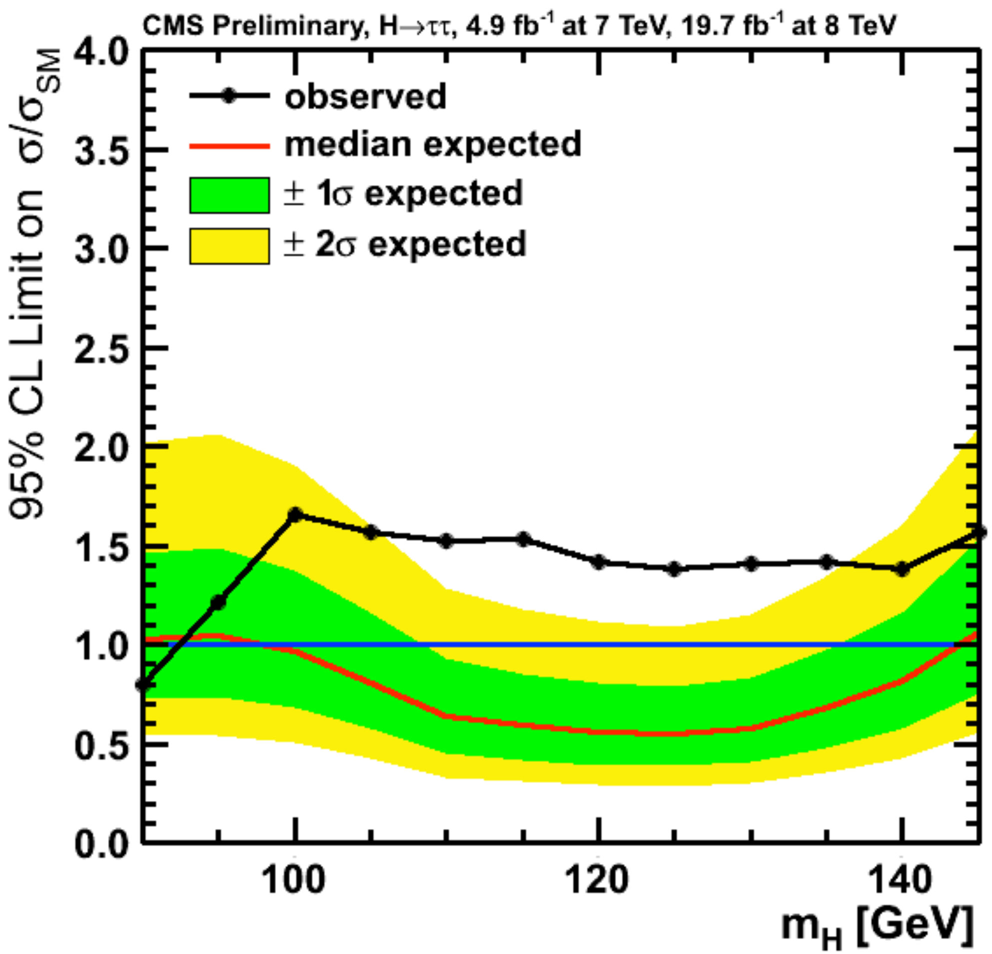
$e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$, ee, μμ

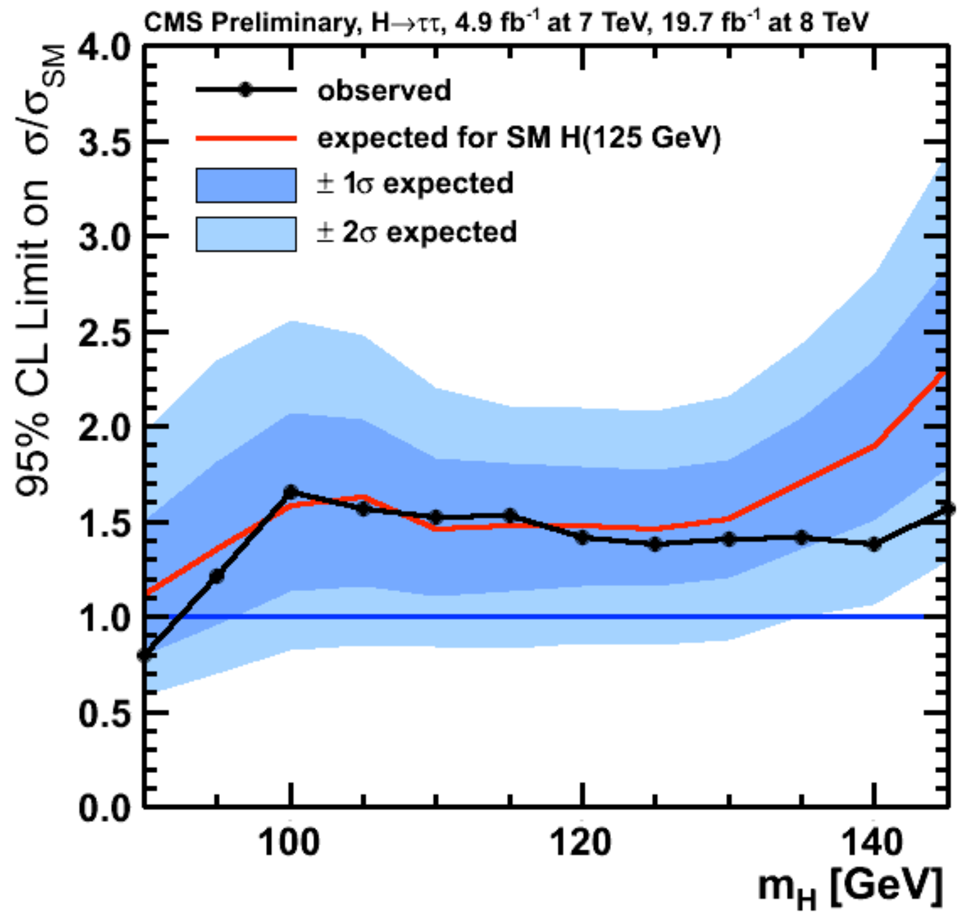


Calculate S/(S+B) in every bin of the mass distributions of every event category and channel

H→ττ: 95% CL Upper Limits

HIG-13-004





Large excess!

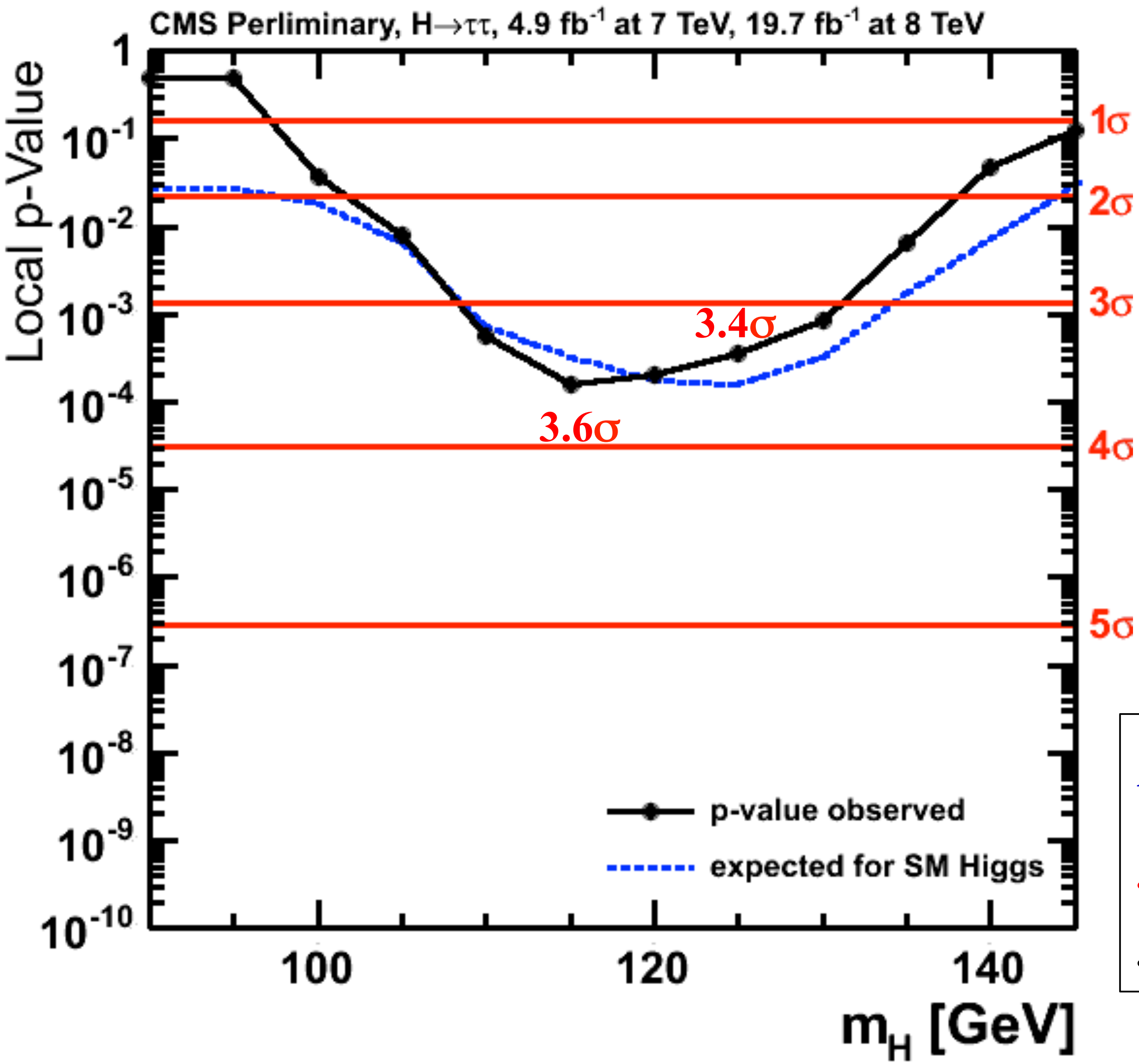
Compatible with a Standard Model Higgs boson signal @ 125 GeV

H→WW@125 is treated as background, motivated by the bosonic discovery

H→WW is always considered at 125 GeV even at other m_H

Evidence for a H→ττ signal!

HIG-13-004



>3σ of H→ττ decays for M_H between 110 and 130 GeV

At m_H= 125 GeV:

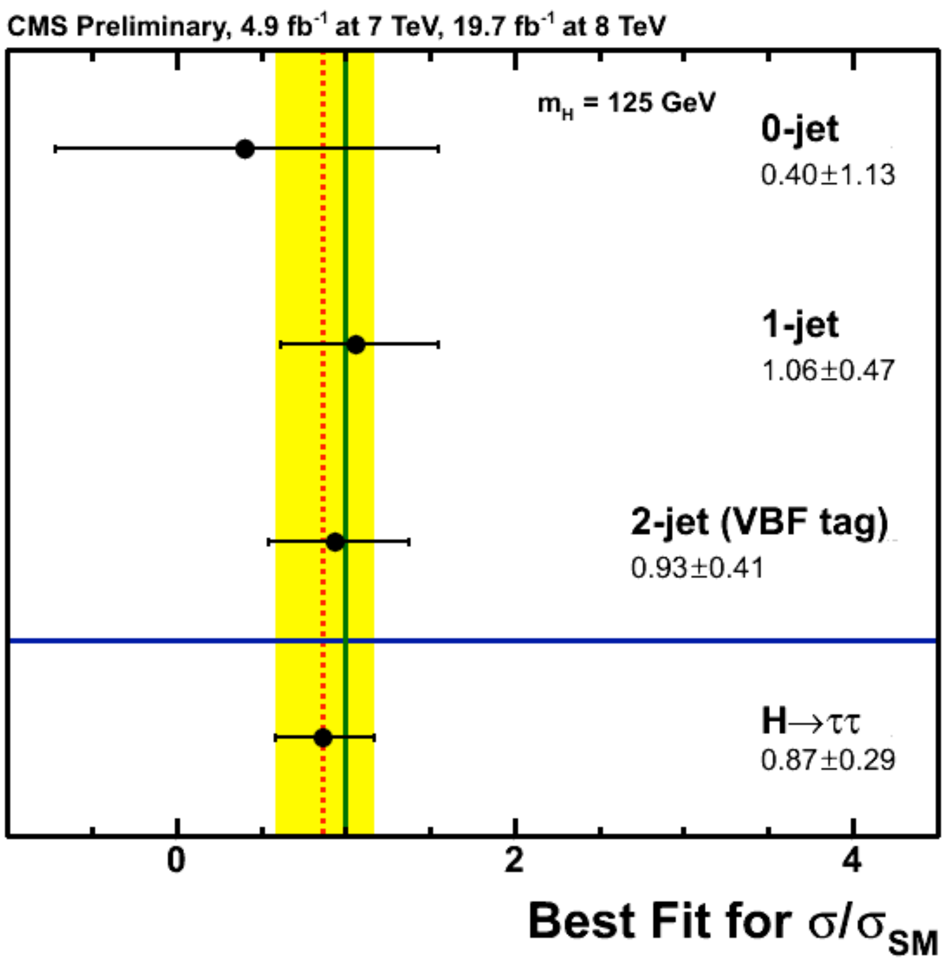
3.4σ observed excess!

3.6σ expected

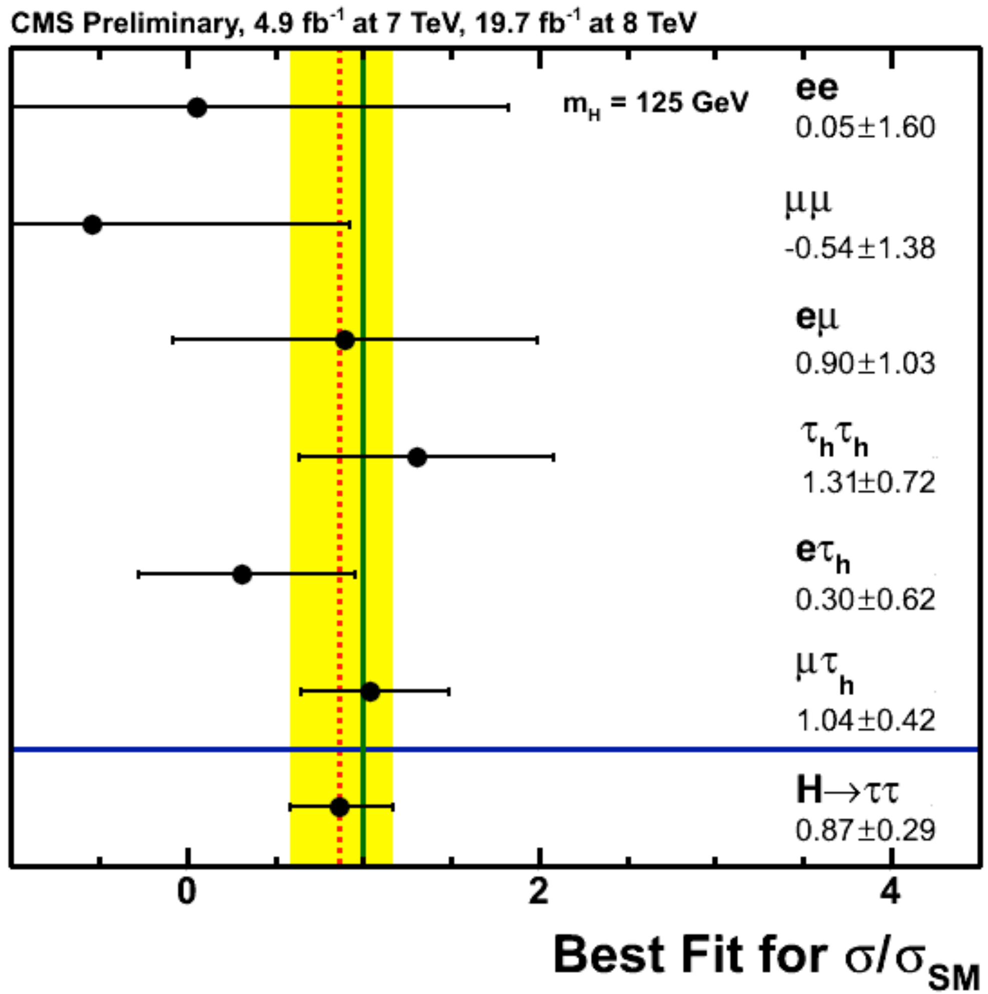
H→ττ: signal strength

HIG-13-004

Events split by category

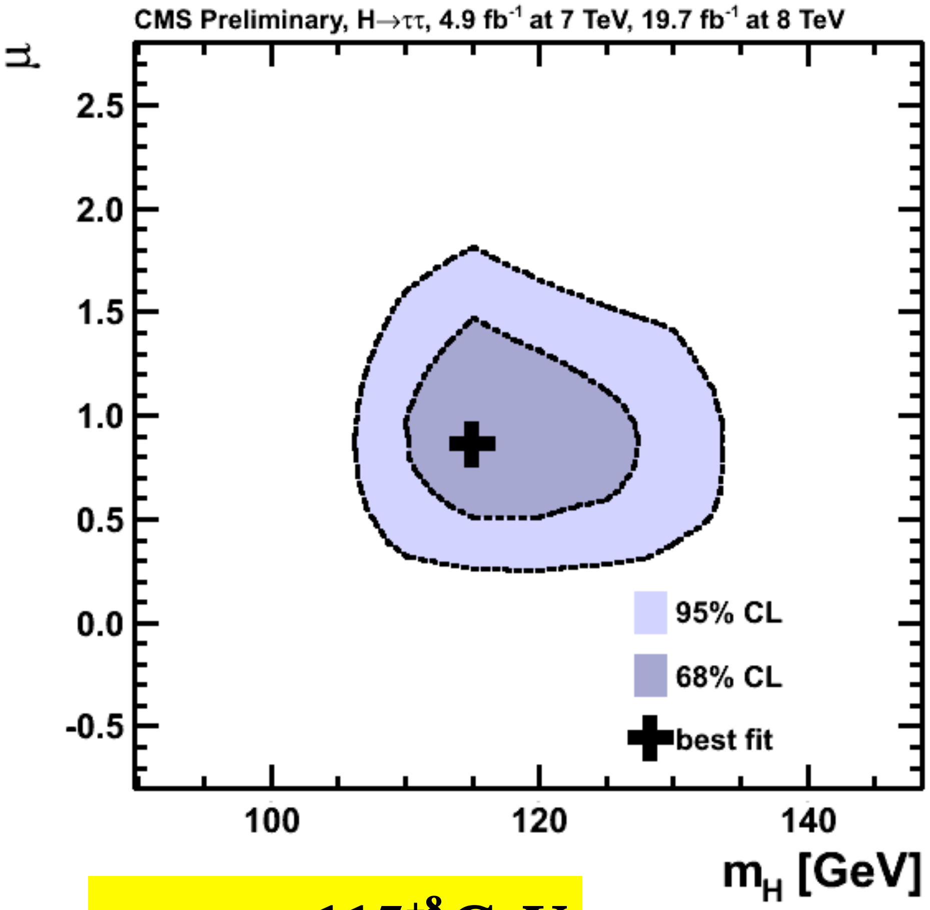


Events split by channel



$\mu = \sigma/\sigma_{SM} = 0.87 \pm 0.29$

H→ττ: mass

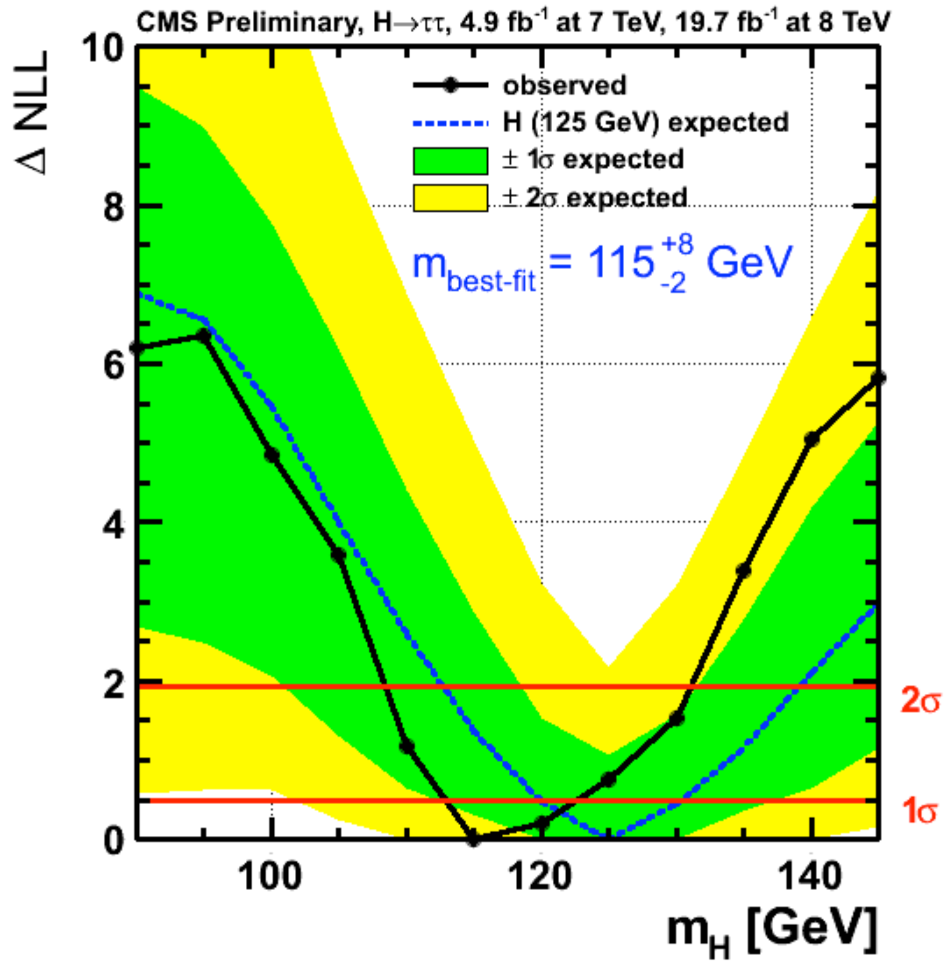


$m_{\text{best-fit}} = 115^{+8}_{-2}\,\text{GeV}$

Mass scale systematic:

Lepton energy scale & MET: < 1%

Tau energy scale < 2%



$M_{\tau\tau}$ used for statistical interpretation

→ mass measurement possible!

Measurement compatible with SM and high resolution channels

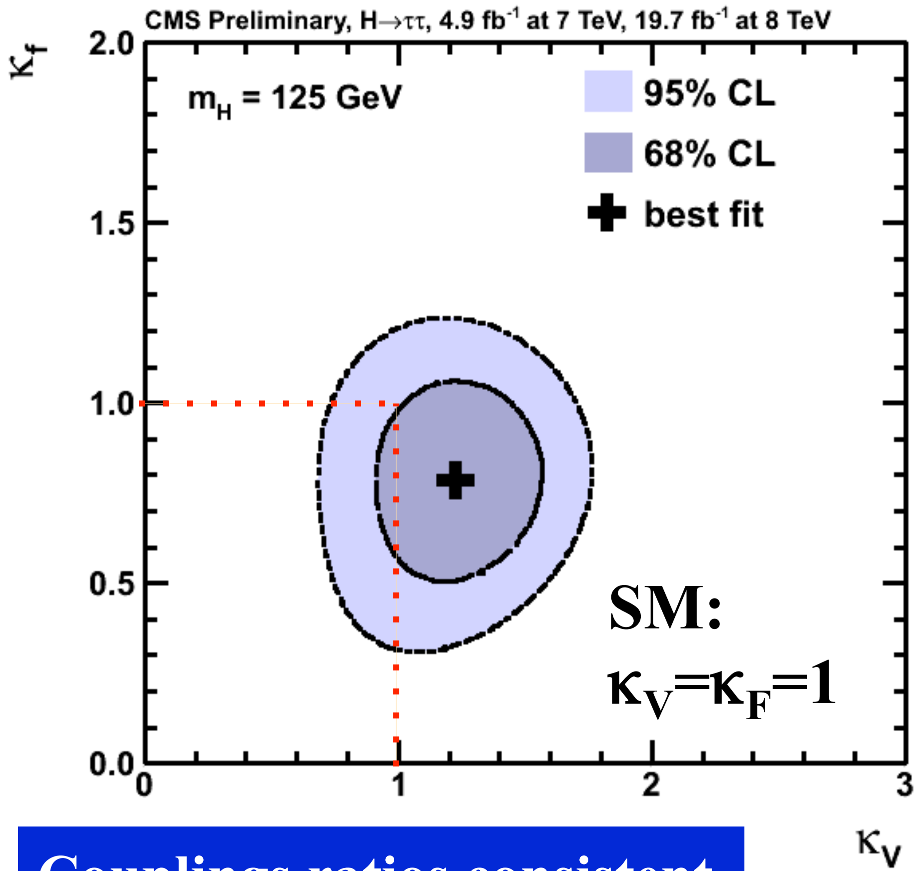
H→ττ: vector and fermion couplings

Test modification of couplings compared to SM

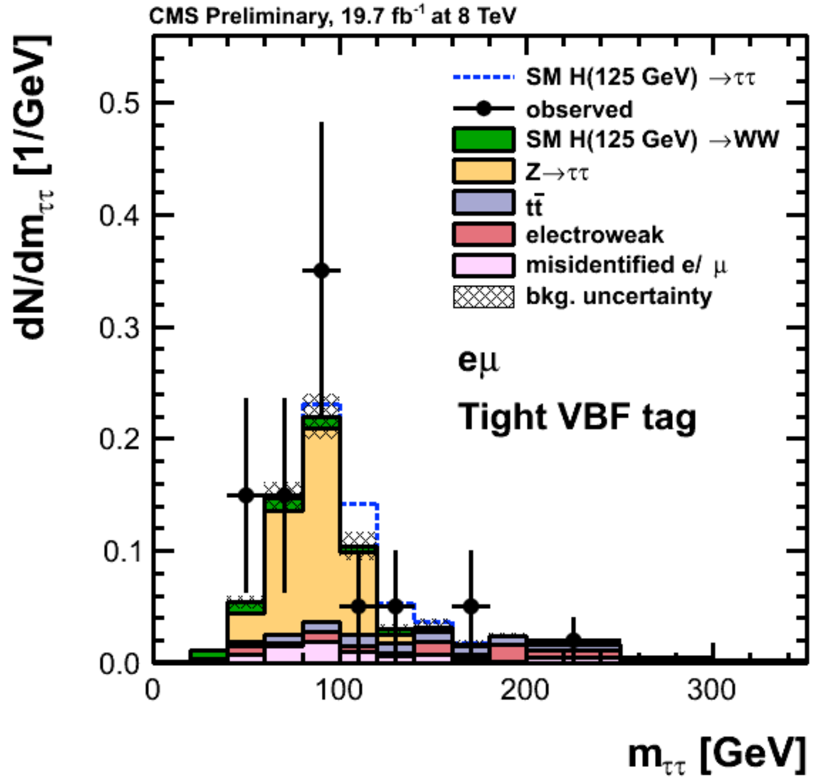
HIG-13-004

Vector and fermion couplings grouped

κ_V: $\kappa_W = \kappa_Z$ κ_F: $\kappa_t = \kappa_b = \kappa_\tau = \kappa_g$



Couplings ratios consistent with SM expectation



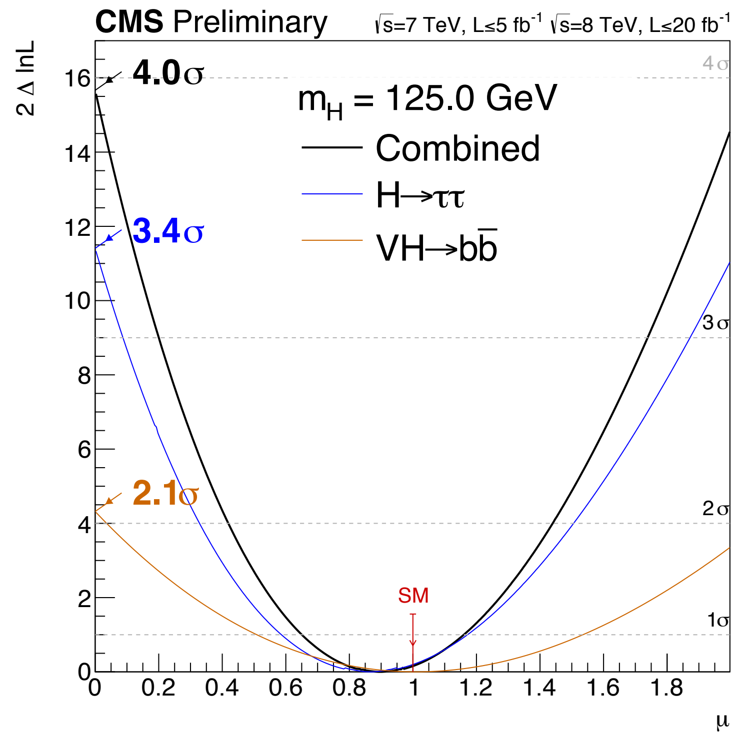
H→WW treated as a signal
κ_V constraint mainly comes from eμ events

VBF H → WW ~ κ_V^2(production) * κ_V^2(decay)

H→ττ & H→bb: Combination @ 125 GeV

Preliminary

Channel M_H= 125 GeV	Significance		μ
	Expected	Observed	
VH→bb	2.1 σ	2.1σ	1.0±0.5
H→ττ	3.6σ	3.4σ	0.87±0.29
Combination	4.2σ	4.0σ	0.90±0.26



4 σ : strong evidence of fermionic Higgs decays!

CMS $H \rightarrow \tau\tau$ + $H \rightarrow bb$ results:

4 σ evidence for fermionic Higgs decays

4.2 σ expected

$H \rightarrow \mu\mu$ & $H \rightarrow ee$ search
(test flavour non-universality)

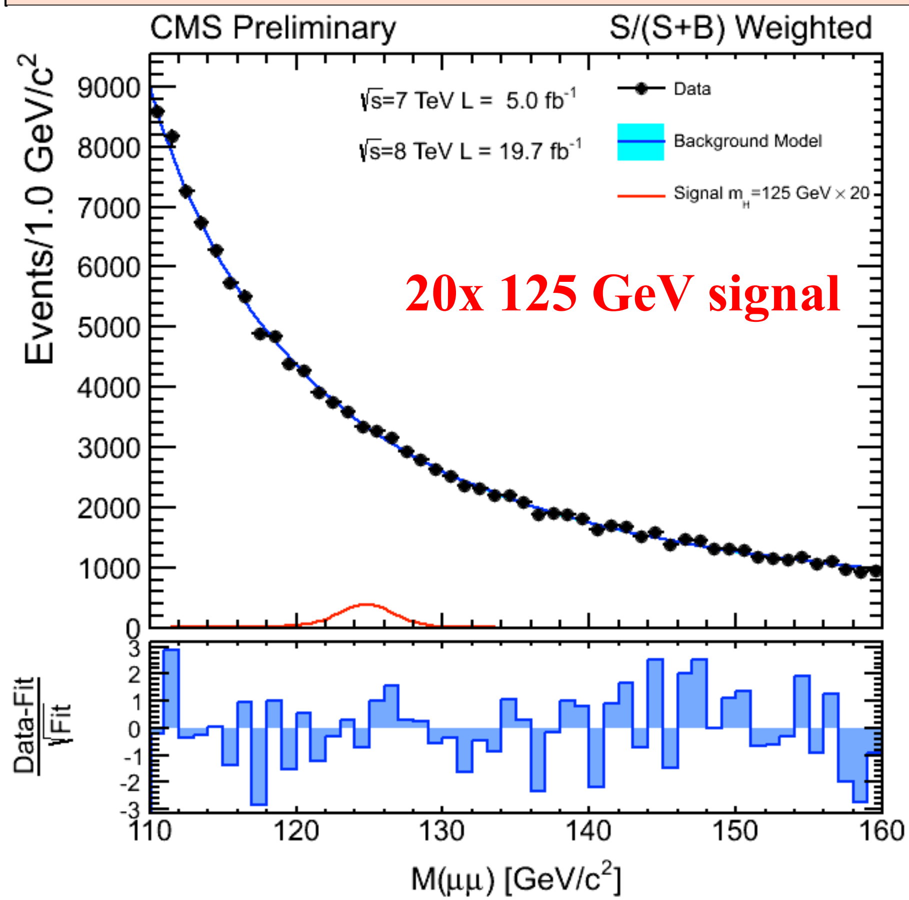
H→μμ search

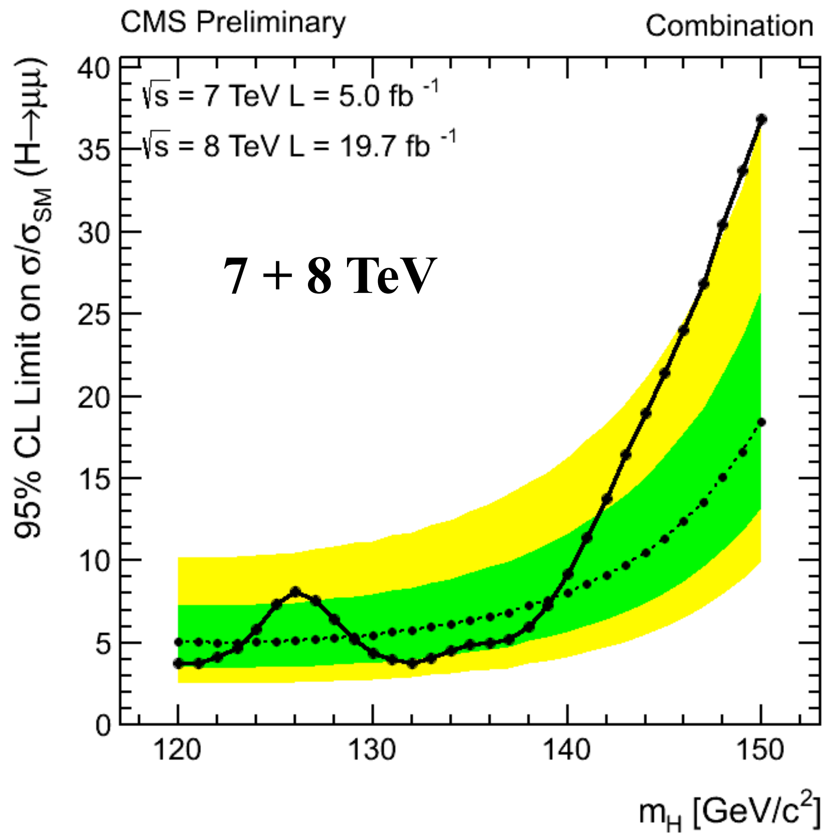
HIG-13-007

Imperial College London

Very small branching fraction: BR(H →μμ) = 2.2 x 10^{-4} at m_H = 125 GeV, but expected narrow peak on top of steep falling background from $Z/\gamma^* \to \mu\mu$

Improve sensitivity: Different categories based on η^μ, $p_t(\mu\mu)$, jet multiplicity





$\sigma(M_{\mu\mu})$: 1.6 GeV (both μ: η^μ <0.8)
2.5 GeV (both μ: 1.6<η^μ<2.1)

95% CL exclusion at m_H= 125 GeV:

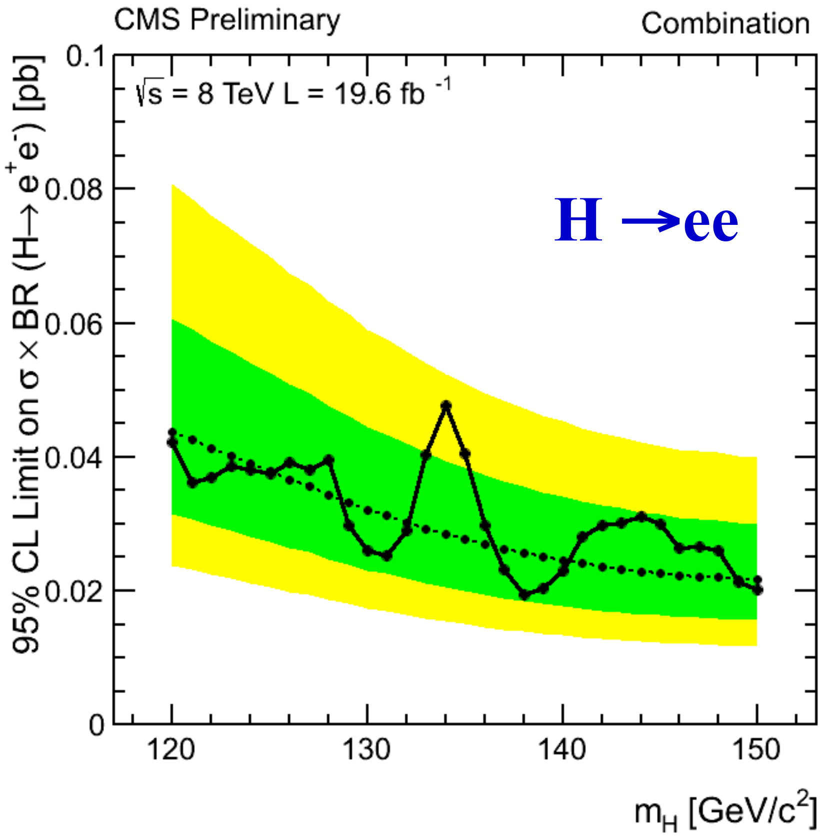
Observed limit: 7.4
Expected limit: 5.1

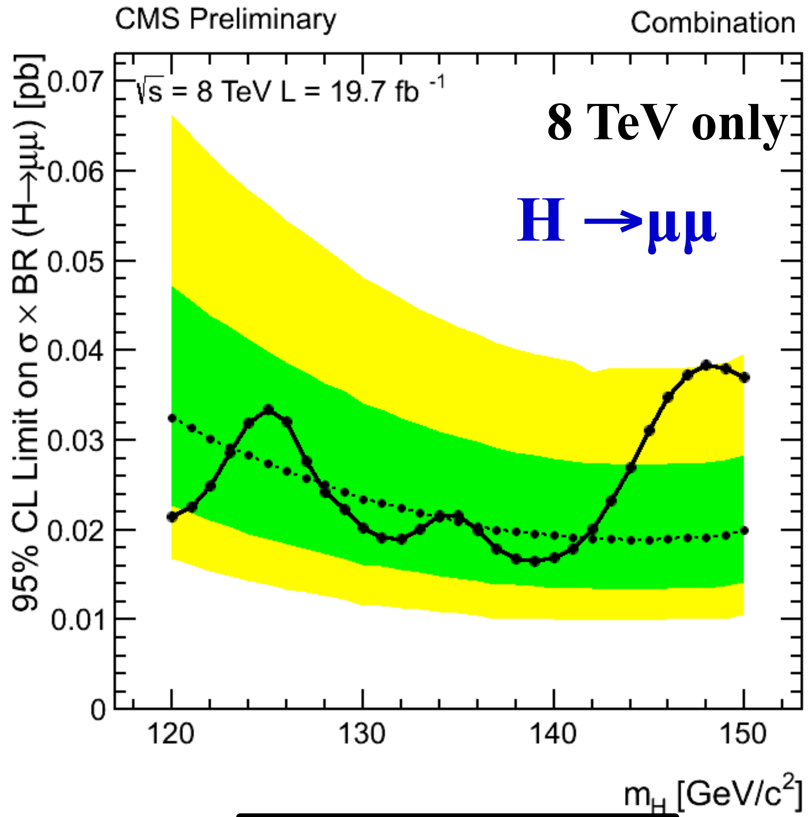
H→ee search

HIG-13-007

Very rare process: BR(H →ee) ~ 2x10^{-5} *BR(H →μμ)

Improve sensitivity: Different categories based on η^e and di-jet tag





95% CL observed upper limit σ*BR at m_H= 125 GeV:

H→ee: 0.038 pb
H→μμ: 0.034 pb

BR(H→ee) <0.0017

Evidence for flavour non-universality

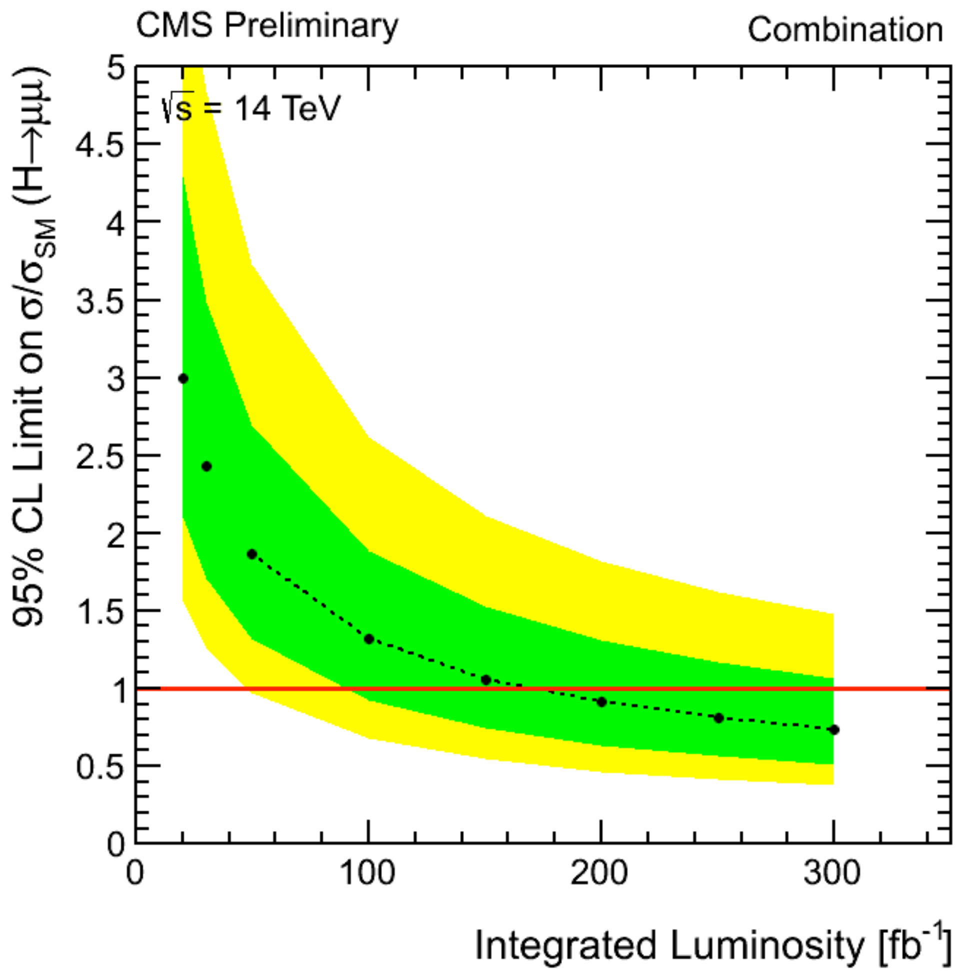
H→μμ search: projections @14 TeV

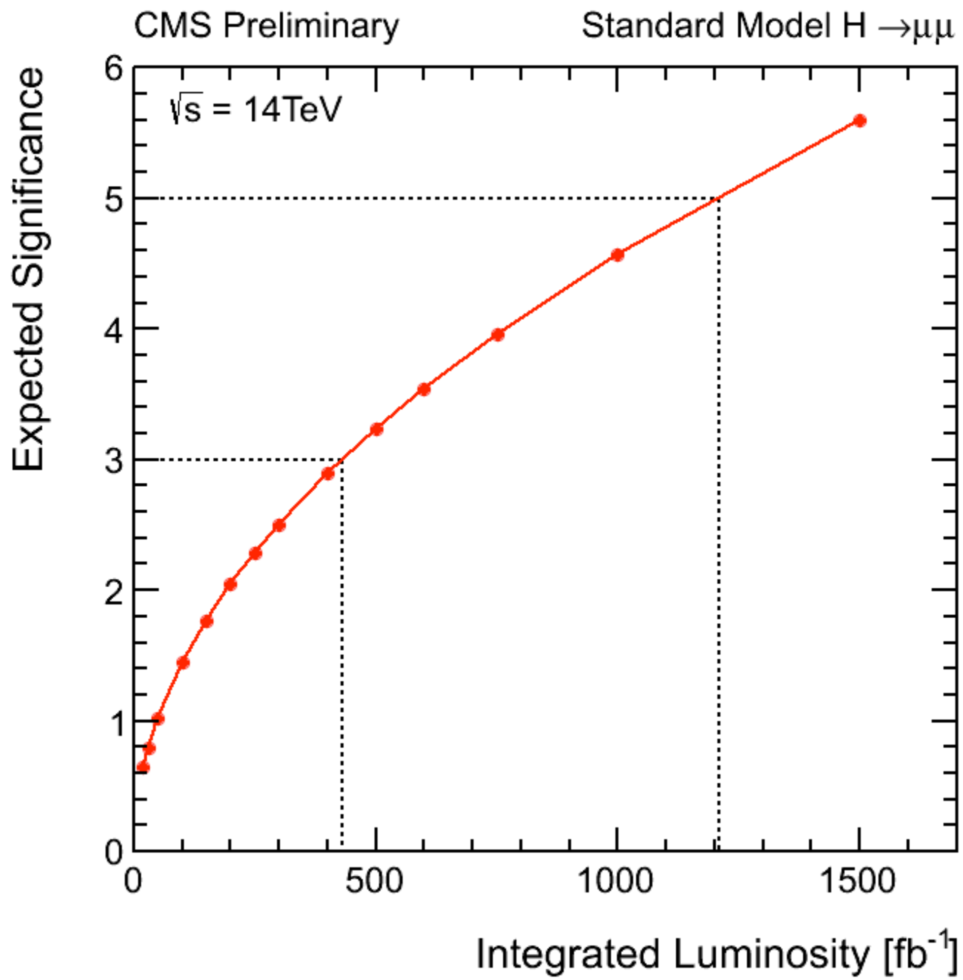
HIG-13-007

Looking ahead …

5 σ discovery with ~ 1200 fb^{-1} @ 14 TeV

Measure muon coupling with 8% precision with ~3 ab^{-1} @14 TeV





Is the Higgs fun over?

Standard Model and Supersymmetry

Imperial College London

Standard Model does great job describing physics at weak scale, but Hierarchy problem in Higgs sector

If Higgs boson is fundamental particle

i) there are no high-mass particles which couple to the Higgs field (even indirectly)

ii) Striking cancellations are needed in high-order loop corrections to m_H

SUSY at TeV scale elegant solution to hierarchy problem

- Introduces super-partners of SM particles and cancels problematic loop corrections

Minimal supersymmetric extension of SM there are 2 scalar doublets Φ_1, Φ_2

After EW symmetry breaking:

5 physical Higgs bosons
- **h, H (scalar, CP-even)**
- **A (pseudo-scalar, CP-odd)**
- **$H^{\pm}$ (charged)**

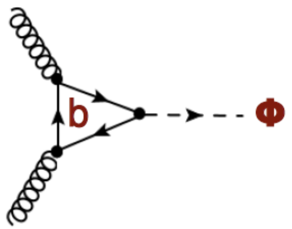
β (VEVs): $\tan\beta = v_2/v_1$ $[v_1^2+v_2^2 = v^2 = 2M_Z^2/(g_2^2+g_1^2) = (246\ \text{GeV})^2]$

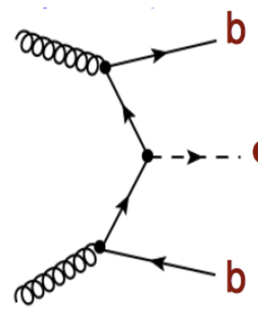
- **MSSM Higgs sector @ tree level determined by: M_A & $\tan\beta$**

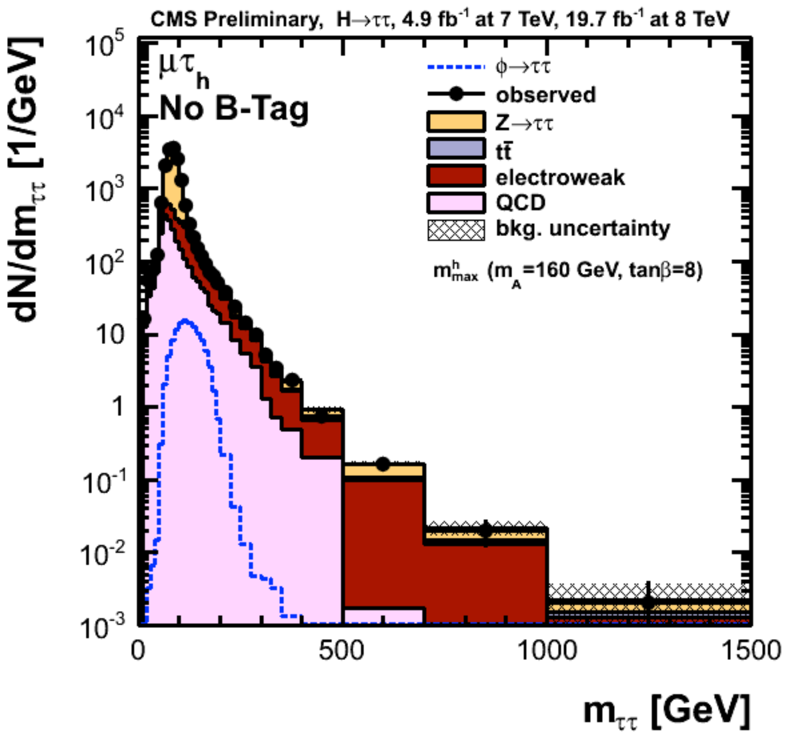
MSSM Neutral Higgs→ττ search

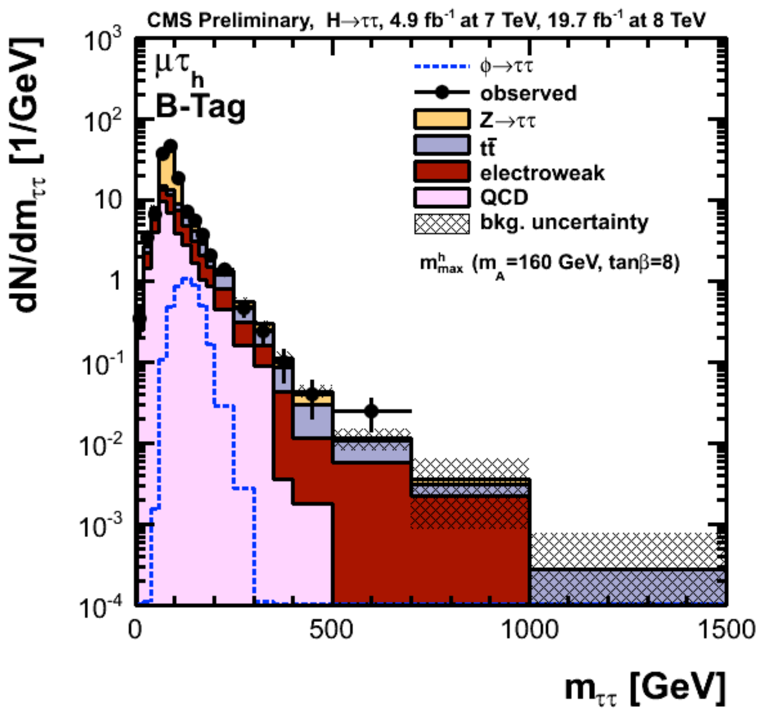
HIG-13-021

MSSM at large tanβ: enhanced Higgs couplings to b and τ
Common analysis strategy as the SM search
Increase sensitivity: Select events with and without at least one b-tagged jet







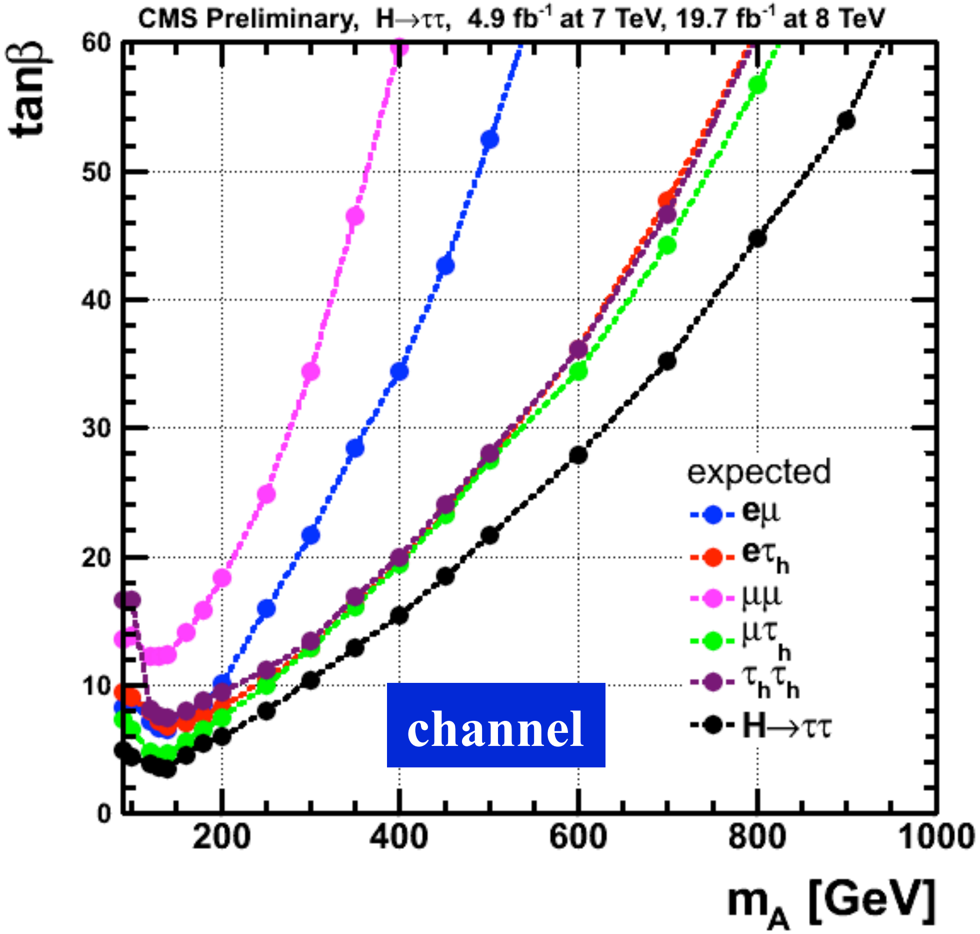


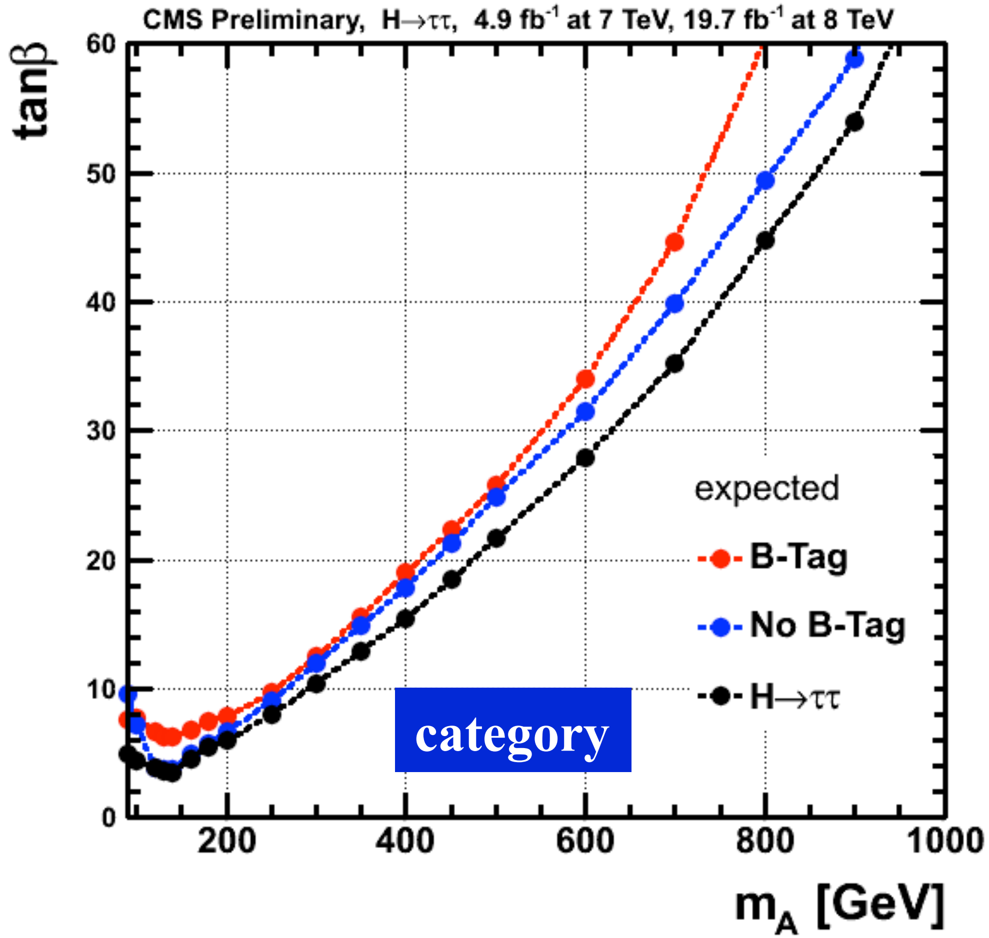
MSSM Neutral Higgs→ττ search

Di-τ final states: eμ, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$, μμ

mhmax scenario

95% CL Expected Exclusion limits in the MA-tan parameter space

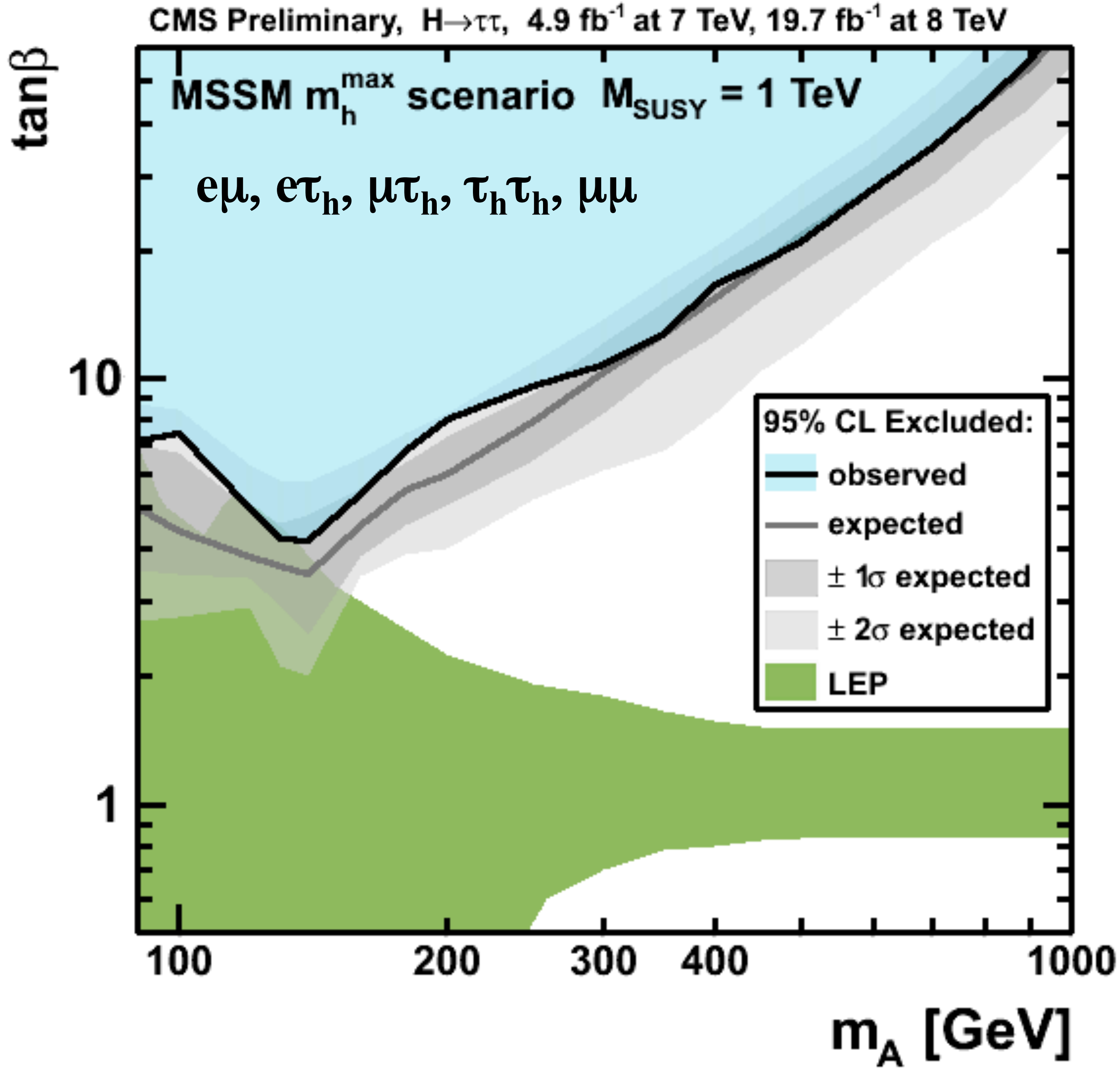




New channel $\tau_h\tau_h$ is the second-most sensitive channel

MSSM Neutral Higgs→ττ search

HIG-13-021



mhmax scenario

Search in di-ττ spectrum for 3 resonances: h/H/A scaled by expected σ

No excess
→ exclusion limit ☹

Alternative MSSM Benchmark scenarios in preparation (see backup)

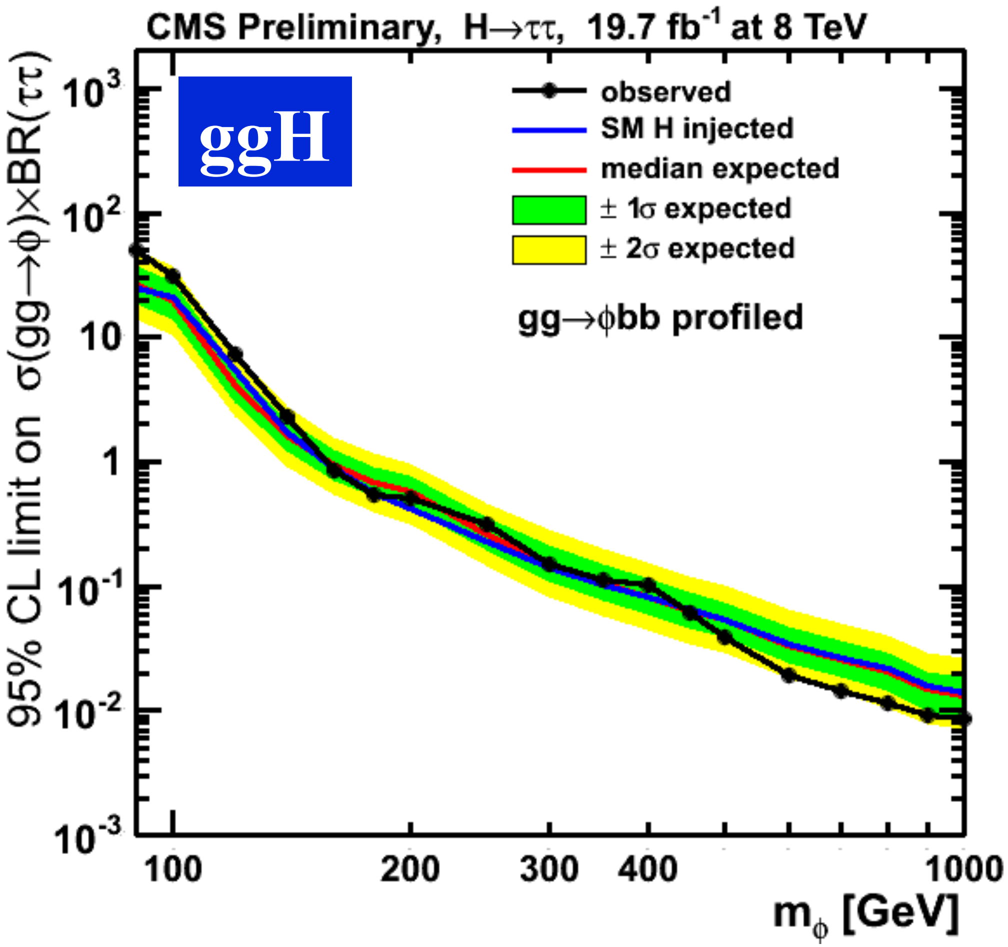
Large region of tanβ-M_A plane excluded

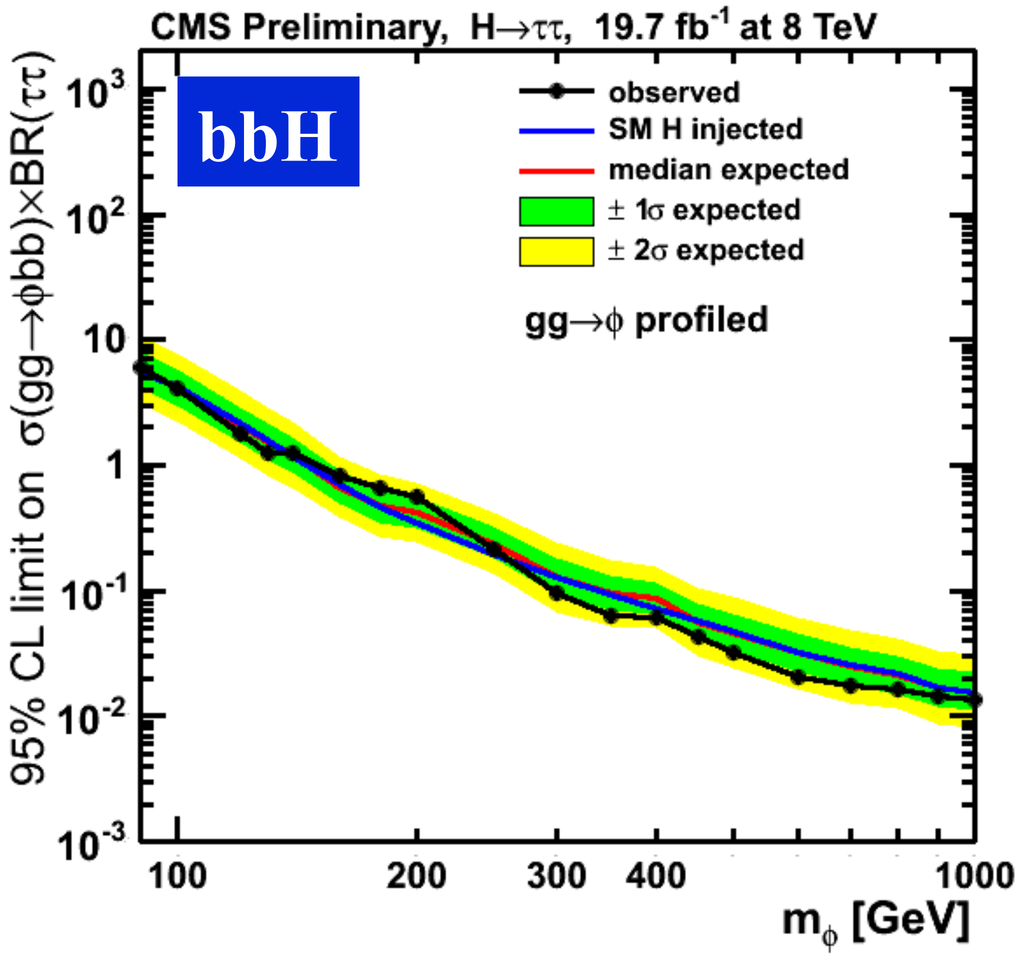
Neutral Higgs→ττ search

HIG-13-021

Single resonance search: useful to probe different theoretical models!

Upper limits on ggH and bbH cross section times BR

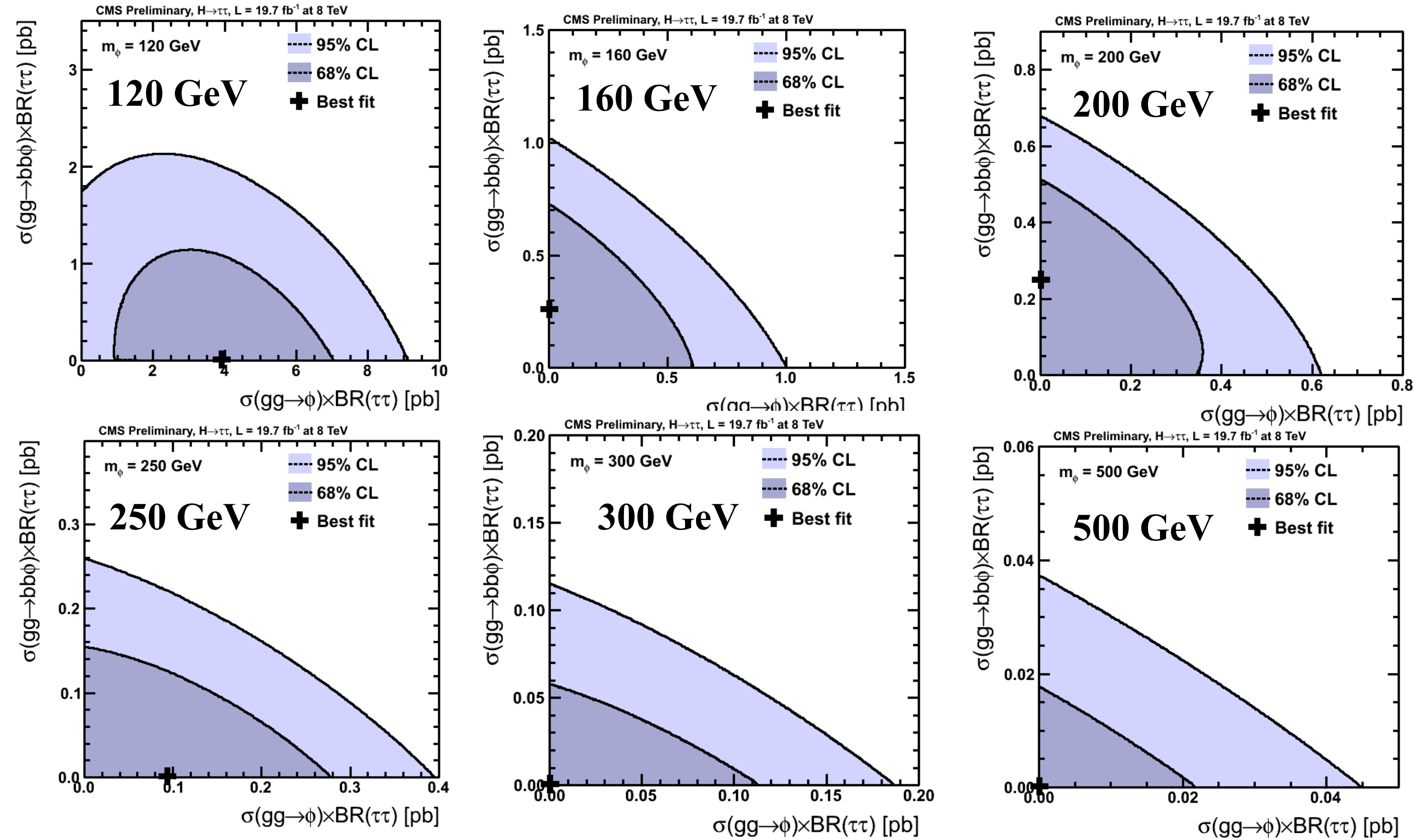




Neutral Higgs→ττ search

HIG-13-021

bbH-ggH: 2D 95% CL upper limit XSect*BR



Other BSM Fermionic Higgs results in backup …

We are trying really hard!
It's difficult to hide!

Summary

- Latest CMS results on fermionic Higgs properties have been presented
- Indirect evidence (ggH production) and a direct hint (ttH production) of the Higgs coupling to top quarks
- Clear evidence of flavour non-universality from the H→ee, H→μμ and H→ττ searches
- Direct evidence for Higgs couplings to the third-generation bottom-type fermions established
  - H→ττ: 3.4σ (observed), 3.6σ (expected)
  - H→bb: 2.1σ (observed), 2.2σ (expected)
  - H→ττ + H→bb combination: 4.0σ (observed)
    4.2σ (expected)

BACKUP

H→ττ: Moriond 2013

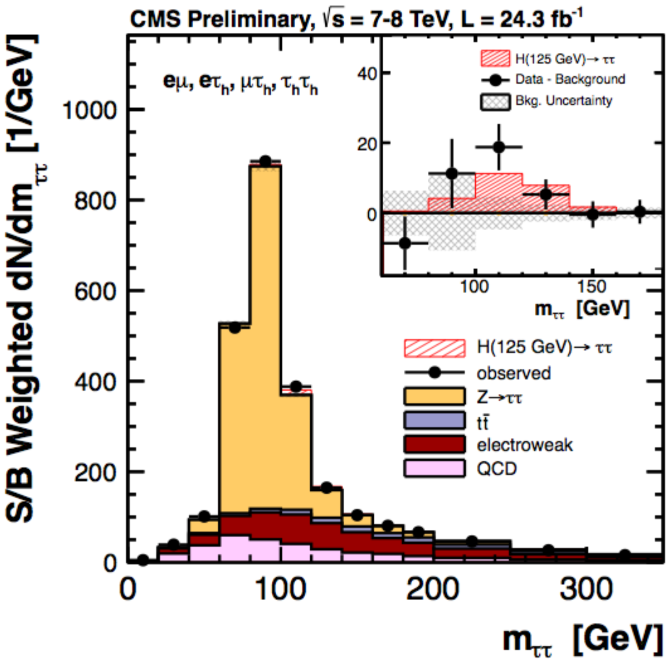
Imperial College London

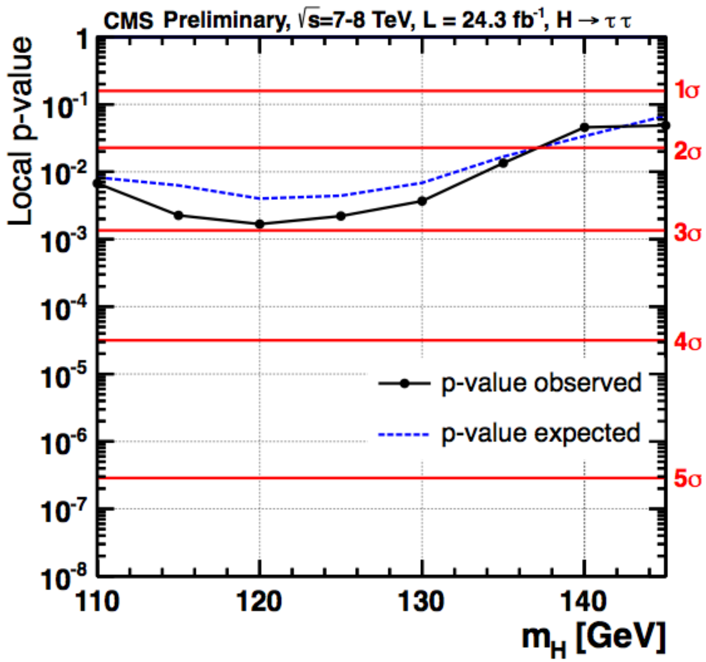
Analysis of 5 channels: $\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, $e\mu$, $\mu\mu$

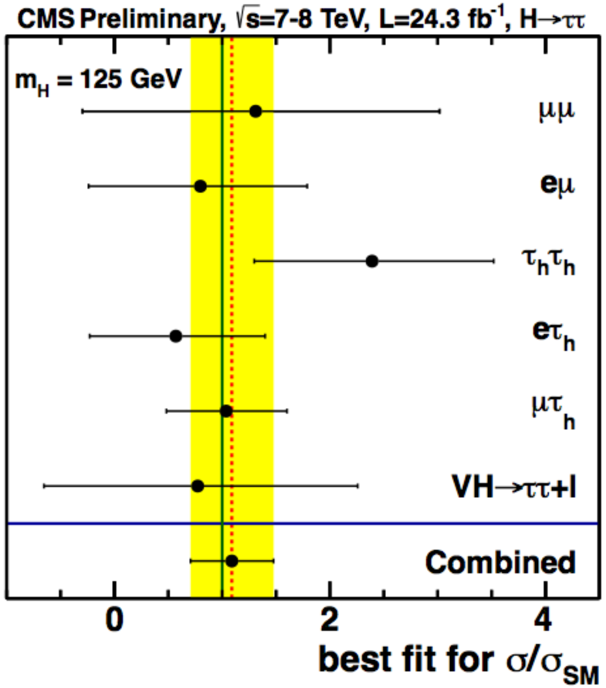
Maximum excess 2.93σ at m_H = 120 GeV

- **2.85σ at m_H = 125 GeV (expected 2.63σ)**

Signal strength: $\mu = \sigma/\sigma_{SM} = 1.1 \pm 0.4$



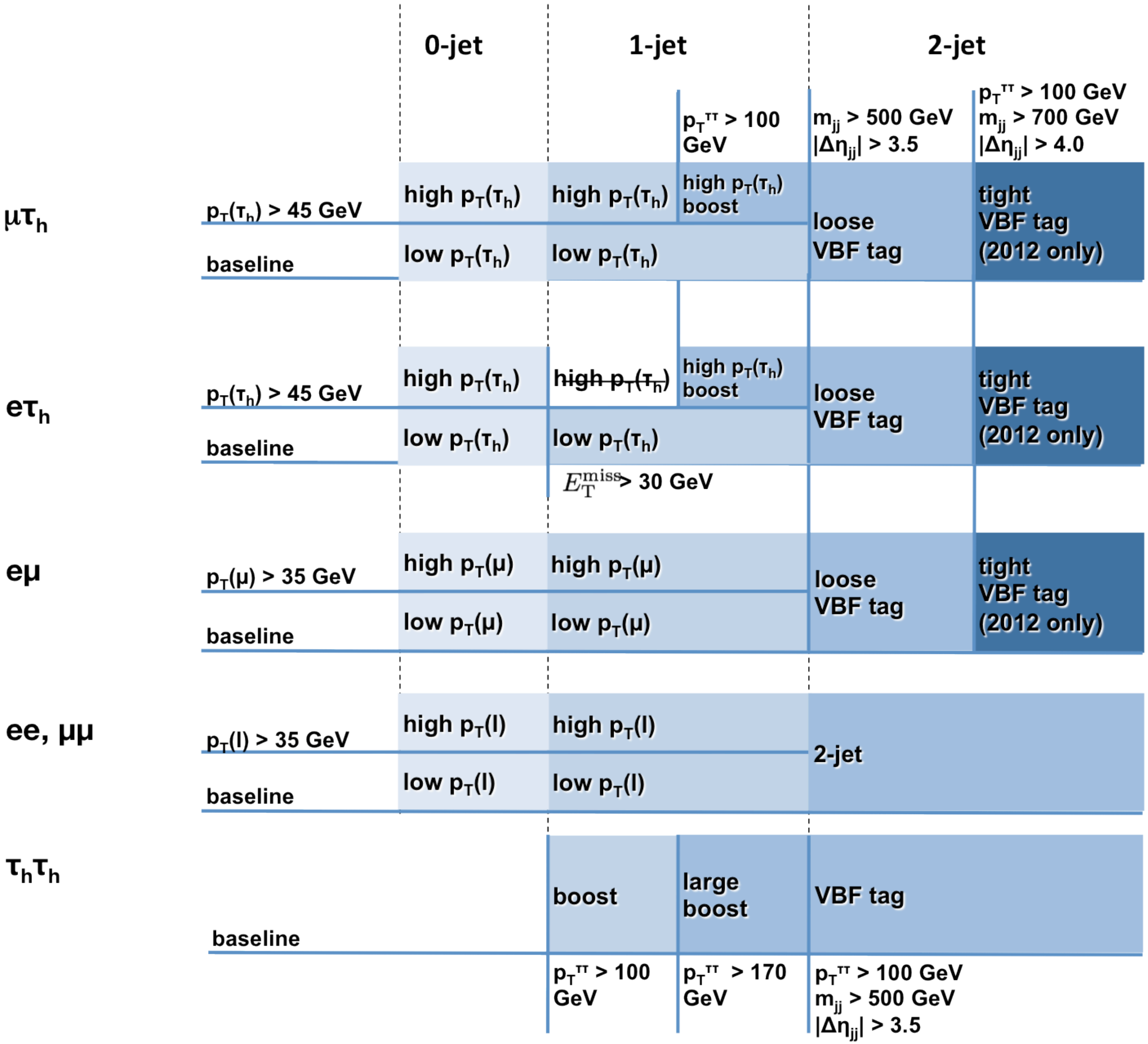




$H \rightarrow \tau\tau$: Moriond 2013 event categories

Channel	Selection	0-jet	1-jet	2-jet
				m_{jj} > 500 GeV, $\lvert\Delta\eta_{jj}\rvert$ > 3.5
$\mu\tau_h$	$p_T(\tau_h)$ > 45 GeV	high $p_T(\tau_h)$	high $p_T(\tau_h)$	VBF tag
	baseline	low $p_T(\tau_h)$	low $p_T(\tau_h)$	
$e\tau_h$	$p_T(\tau_h)$ > 45 GeV	high $p_T(\tau_h)$	high $p_T(\tau_h)$	VBF tag
	baseline	low $p_T(\tau_h)$	low $p_T(\tau_h)$	
			E_T^{miss} > 30 GeV	
$e\mu$	$p_T(\mu)$ > 35 GeV	high $p_T(\mu)$	high $p_T(\mu)$	VBF tag
	baseline	low $p_T(\mu)$	low $p_T(\mu)$	
$\mu\mu$	$p_T(l)$ > 35 GeV	high $p_T(l)$	high $p_T(l)$	2-jet
	baseline	low $p_T(l)$	low $p_T(l)$	
$\tau_h\tau_h$	baseline		large boost	VBF tag
			$p_T^{\tau\tau}$ > 140 GeV	$p_T^{\tau\tau}$ > 110 GeV, m_{jj} > 250 GeV, $\lvert\Delta\eta_{jj}\rvert$ > 2.5

H→ττ: New event categories

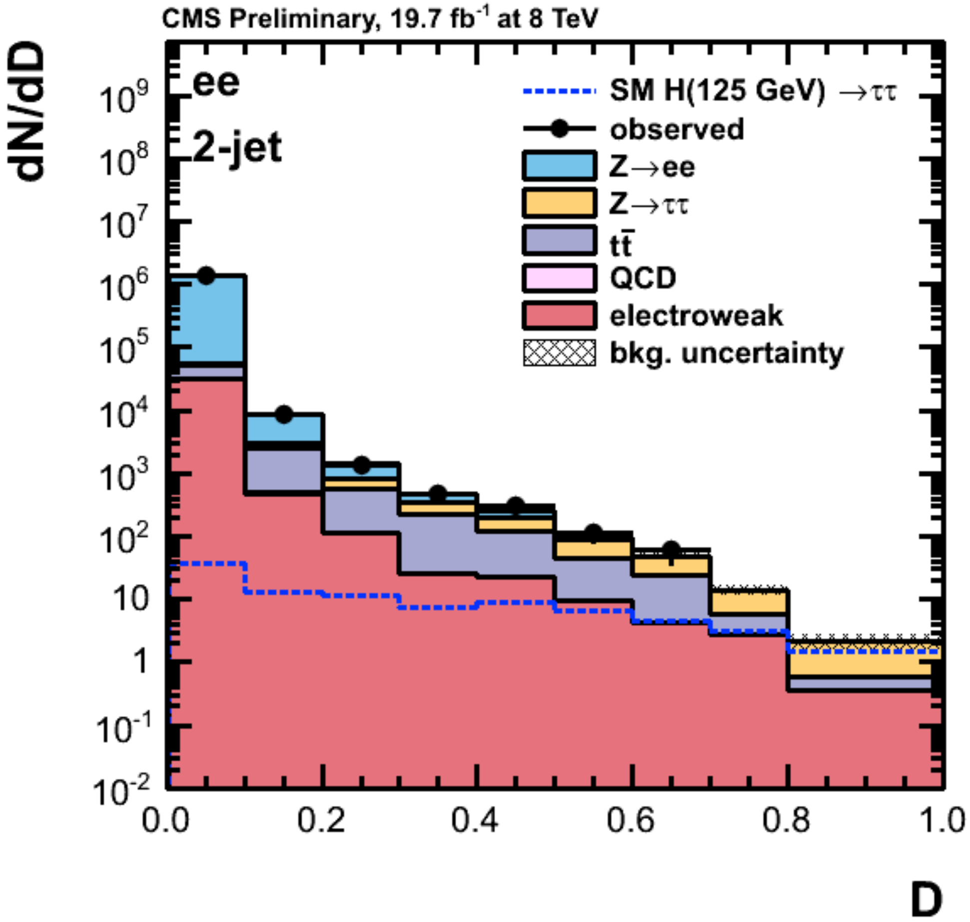


H→ττ VBF tag: ee, μμ

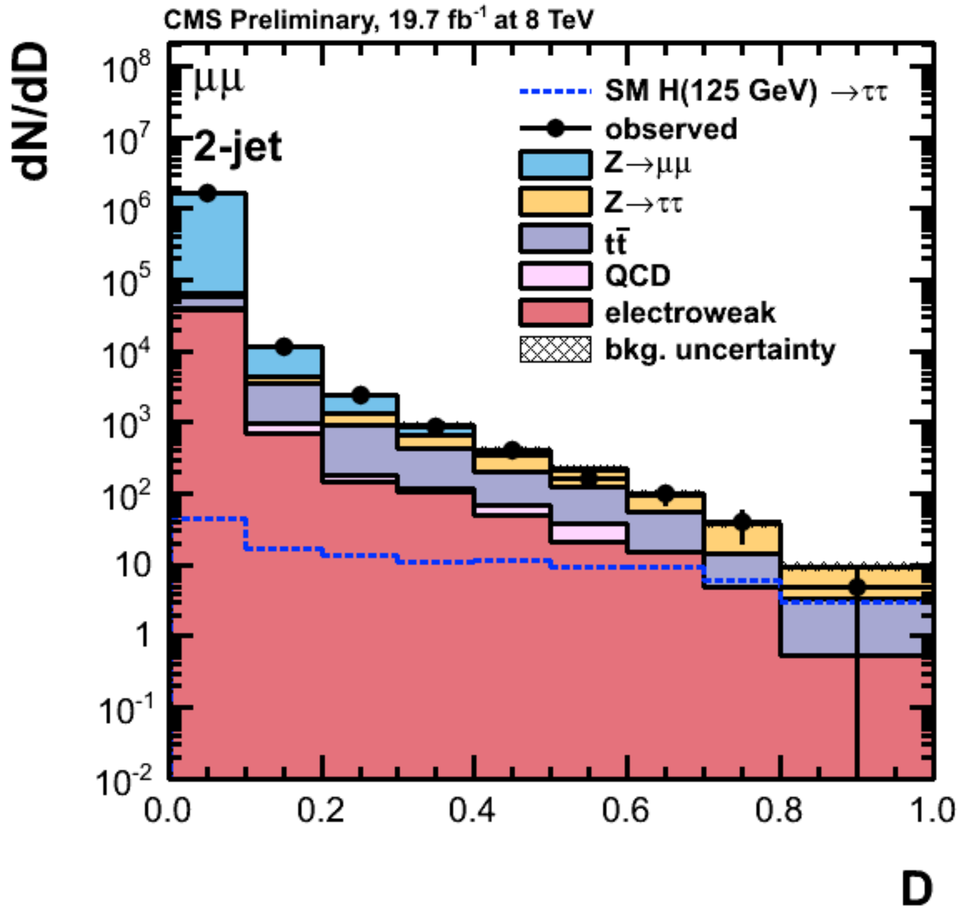
Final discriminant D used for statistical analysis derived from two BDTs

- **BDT1 trained to separate di-tau events from dominant Z→ee/μμ decays**
- **BDT2 trained to separate H→ττ from Z→ττ**
  - **Two separate training for 0/1-jet and VBF categories**
  - **Trained with all Higgs signals at different masses assuming SM cross sections**

H→ττ→ee+4ν

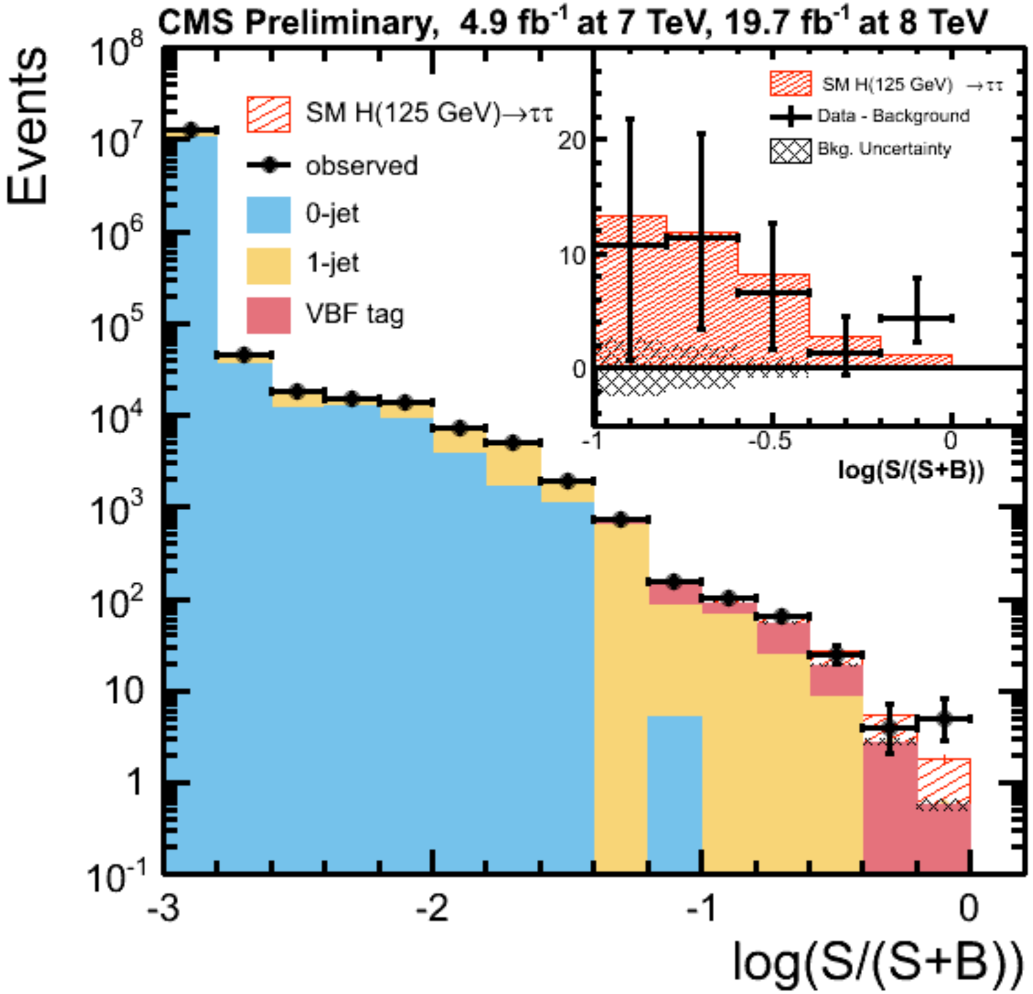


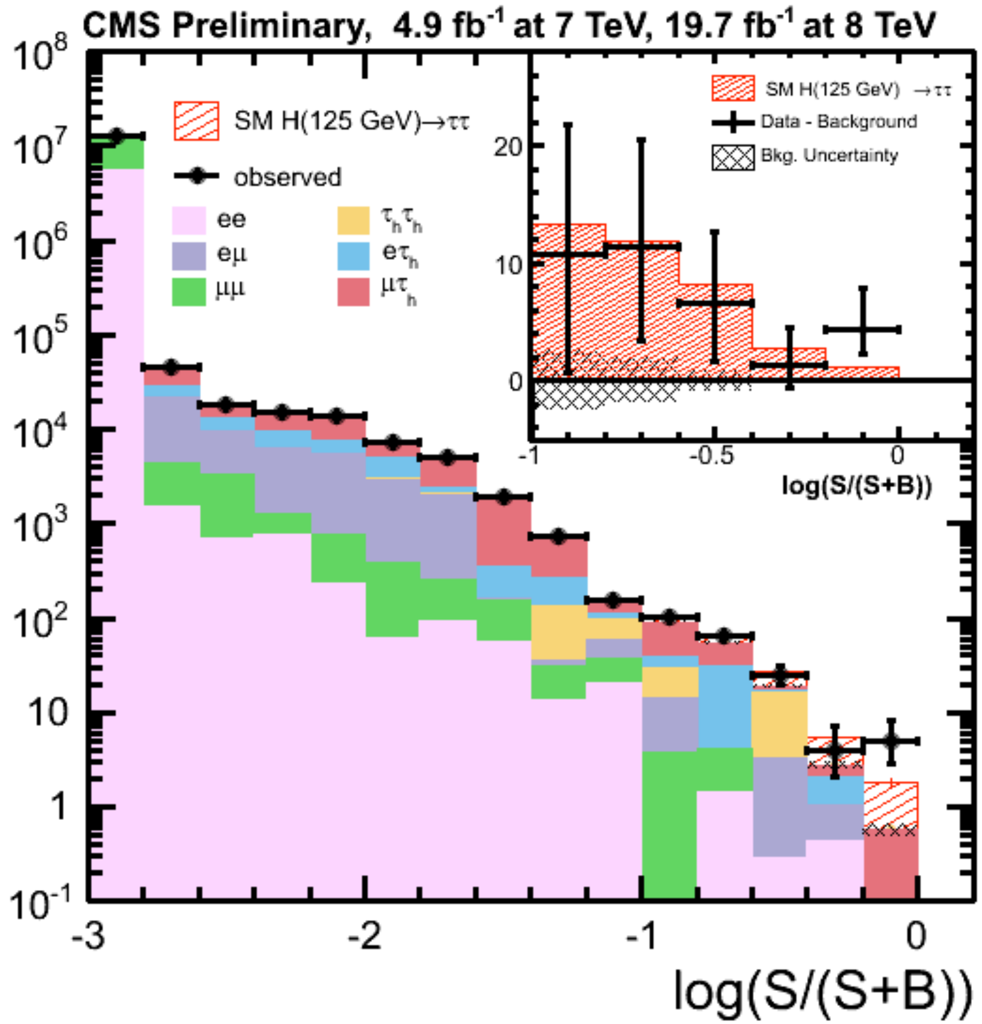
H→ττ→μμ+4ν



H→ττ: Combined distribution

Events split by category | **All di-τ final states** | **Events split by channel**

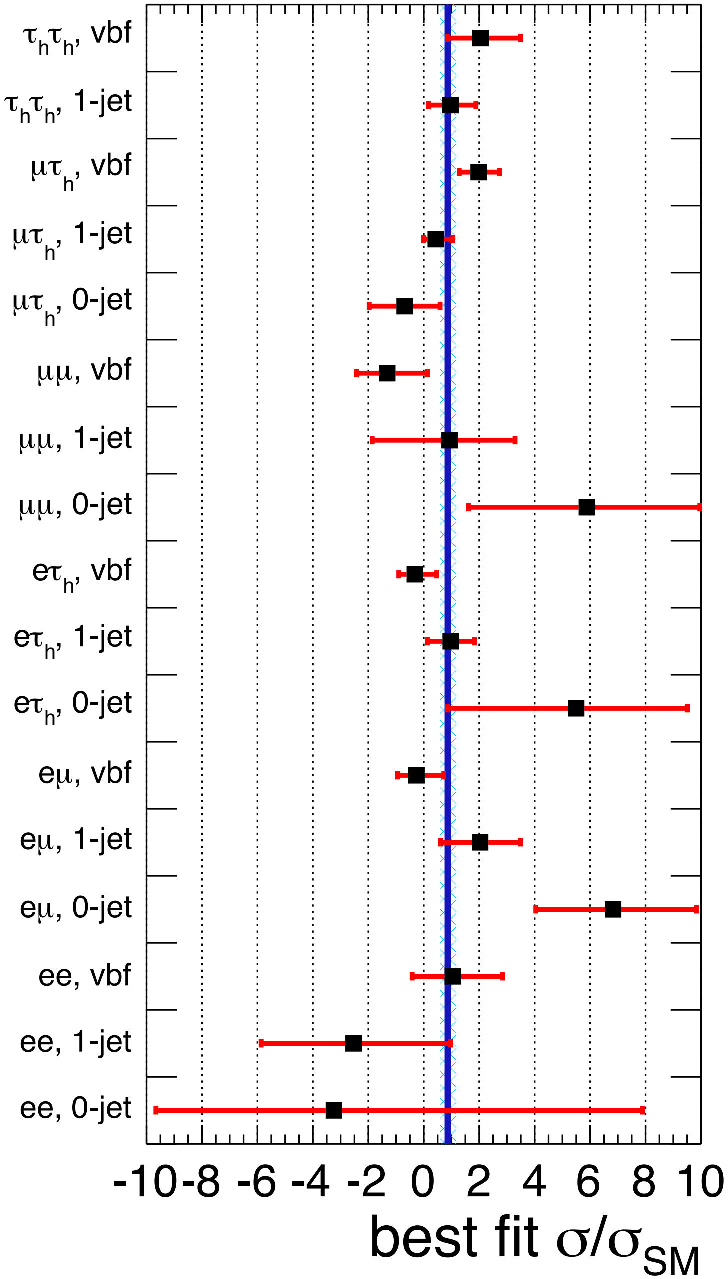




VBF most sensitive

Important to check all final-states

SM H→ττ: channel compatibility



Results in different channels and categories are compatible

ttH: di-muon SS final state

http://cms-higgs-results.web.cern.ch/cms-higgs-results/HWW/HIG-13-020/tthlep-checks-summary.pdf

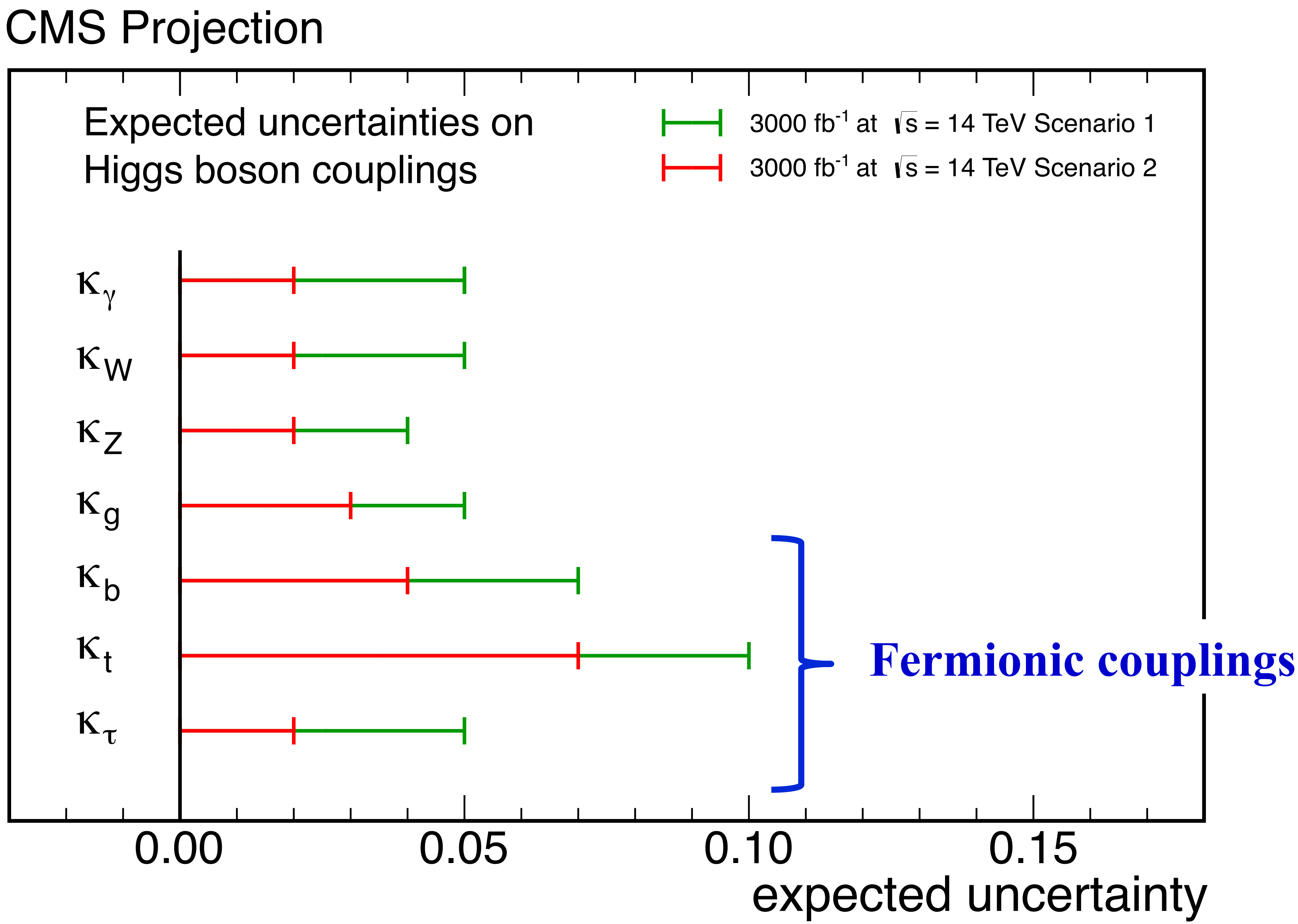
Several studies have been performed to investigate the excess in the $\mu^{\pm}\mu^{\pm}$ final state

- no anomalies seen in the properties of the selected events
- no indication of any issue in the lepton MVA ID and in the reducible background estimation
- no evidence for unaccounted backgrounds

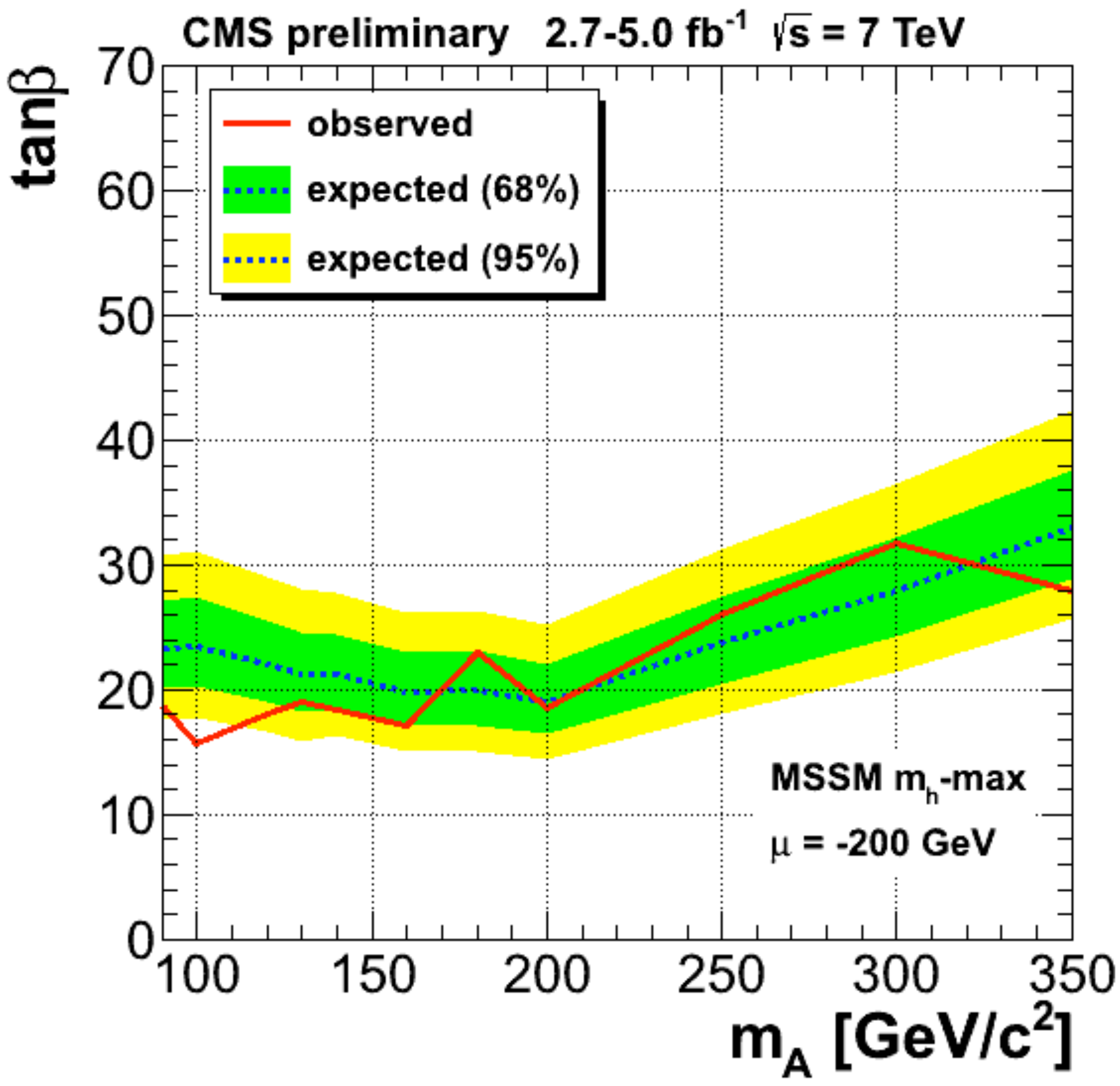
More in general, for this analysis:

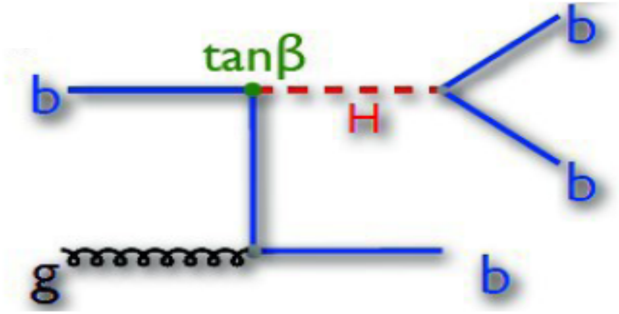
- compatible results obtained in cross-check without using multivariate methods for lepton IDs or signal extraction
- ttW and ttZ yields also fitted as cross-check, and found in good agreement with the theoretical predictions (i.e. no indication of problems there, nor in the signal efficiencies)

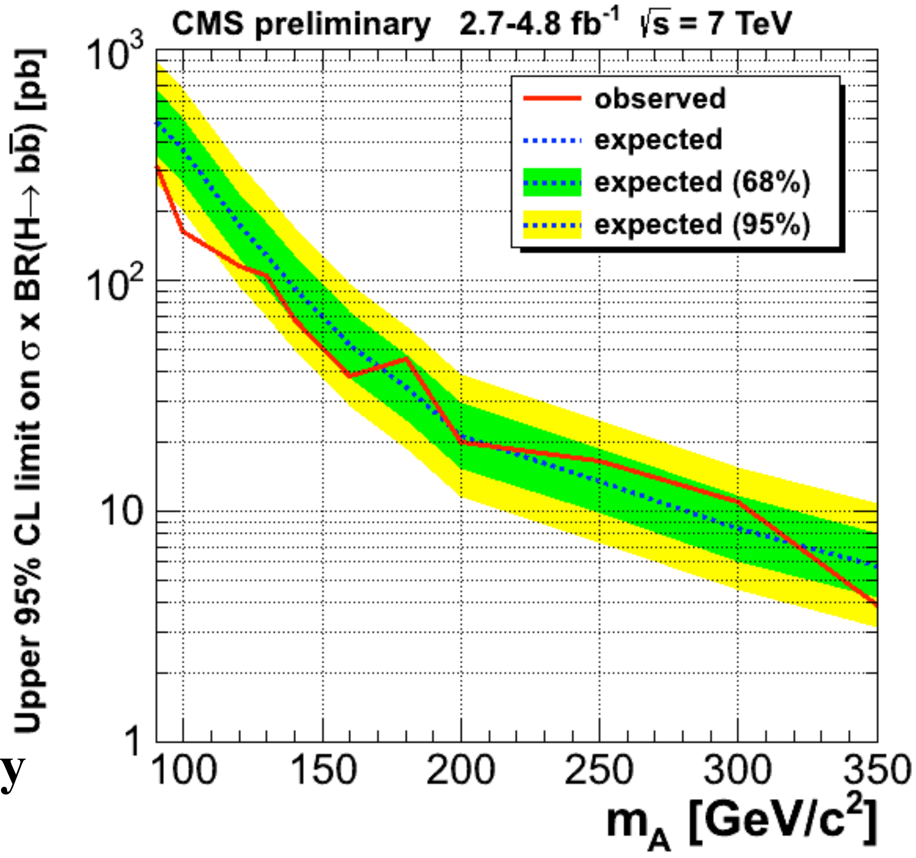
Coupling measurements: projections



MSSM Neutral Higgs→bb in association with b quarks





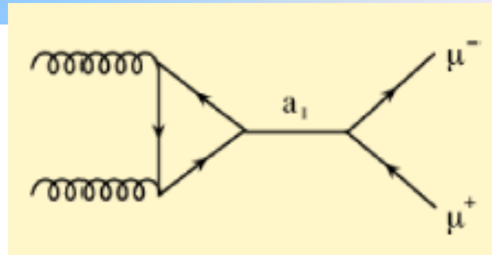


New analysis with 8 TeV data: increase sensitivity at large M_A

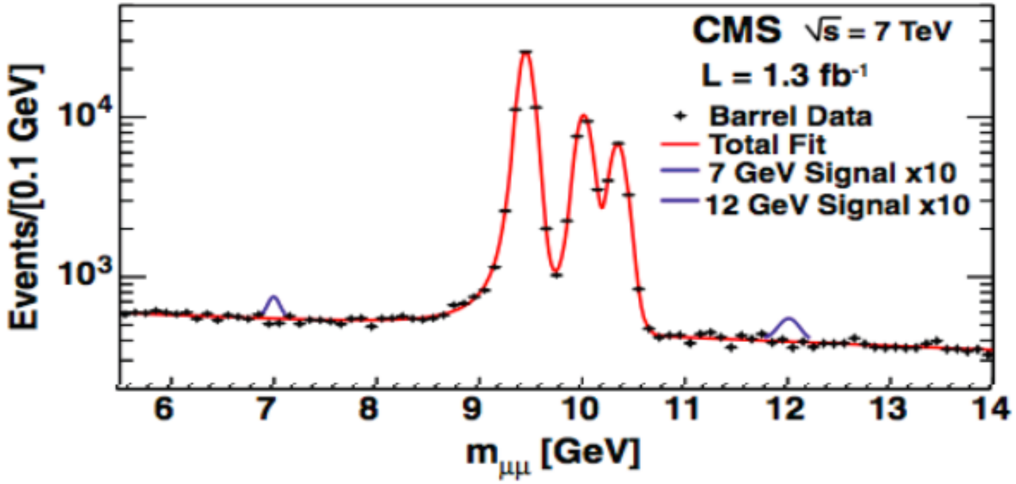
NMSSM: light pseudoscalar search

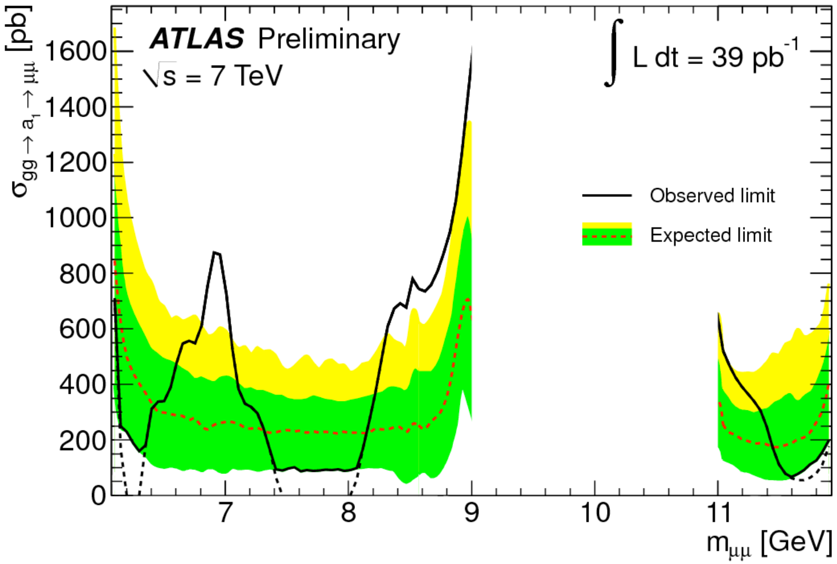
Add scalar singlet to MSSM

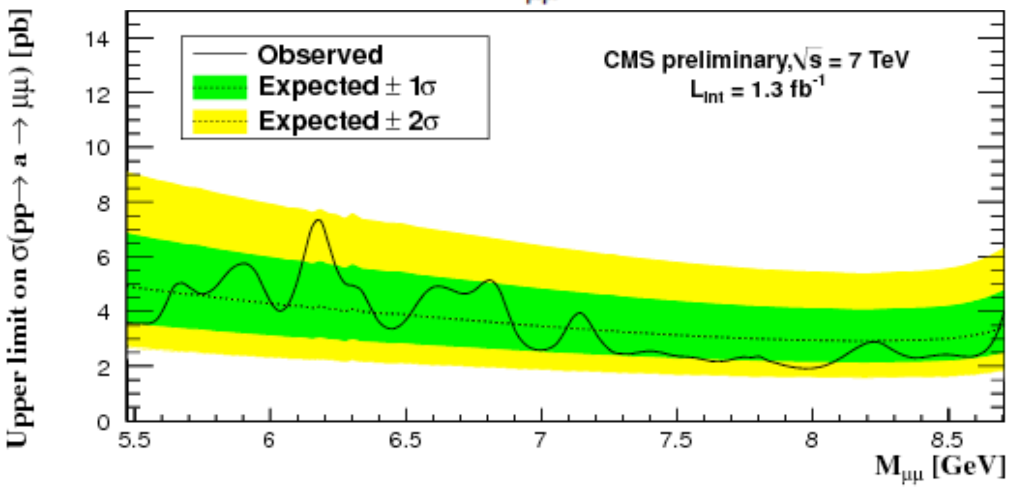
NMSSM: 3 CP-even scalars (h_1, h_2, h_3), 2 CP-odd (a_1, a_2), 2 charged ($H^{\pm}$)

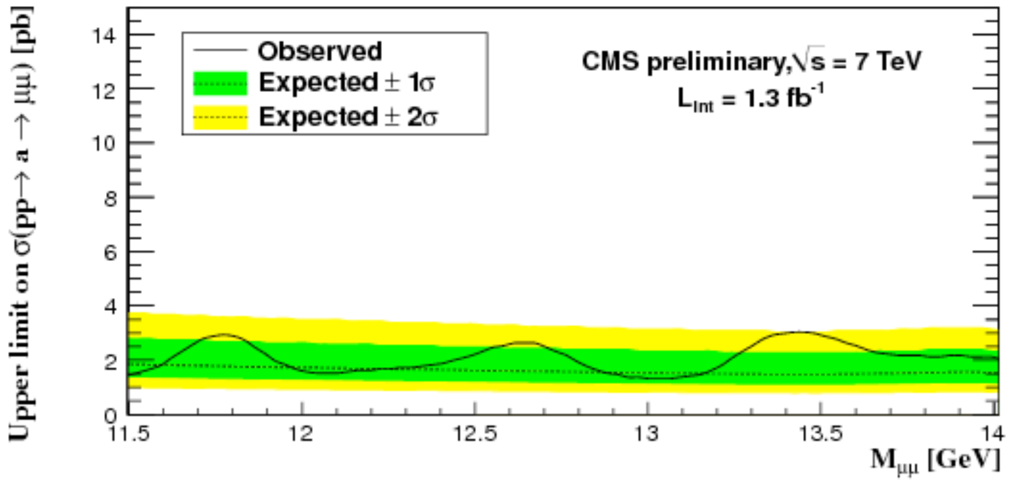


Search below & above the Υ resonance

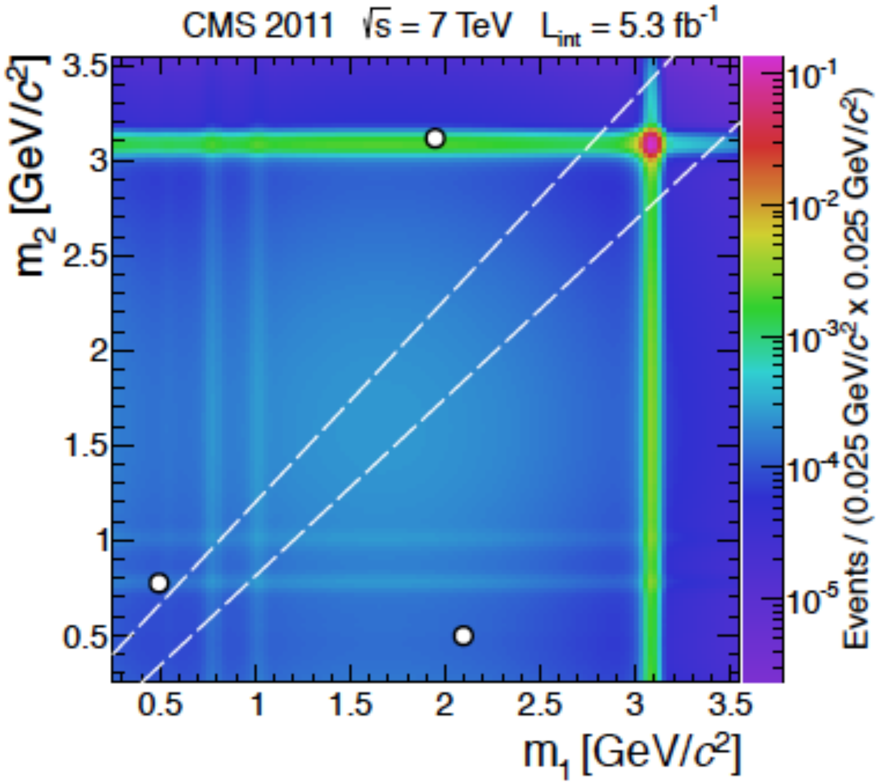


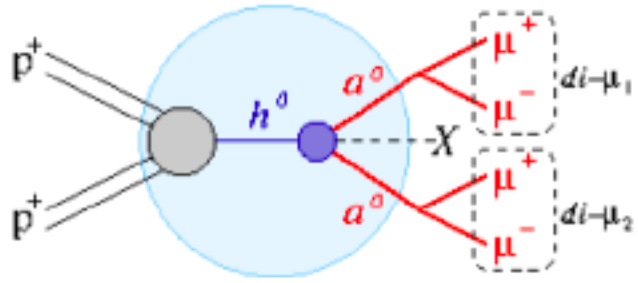


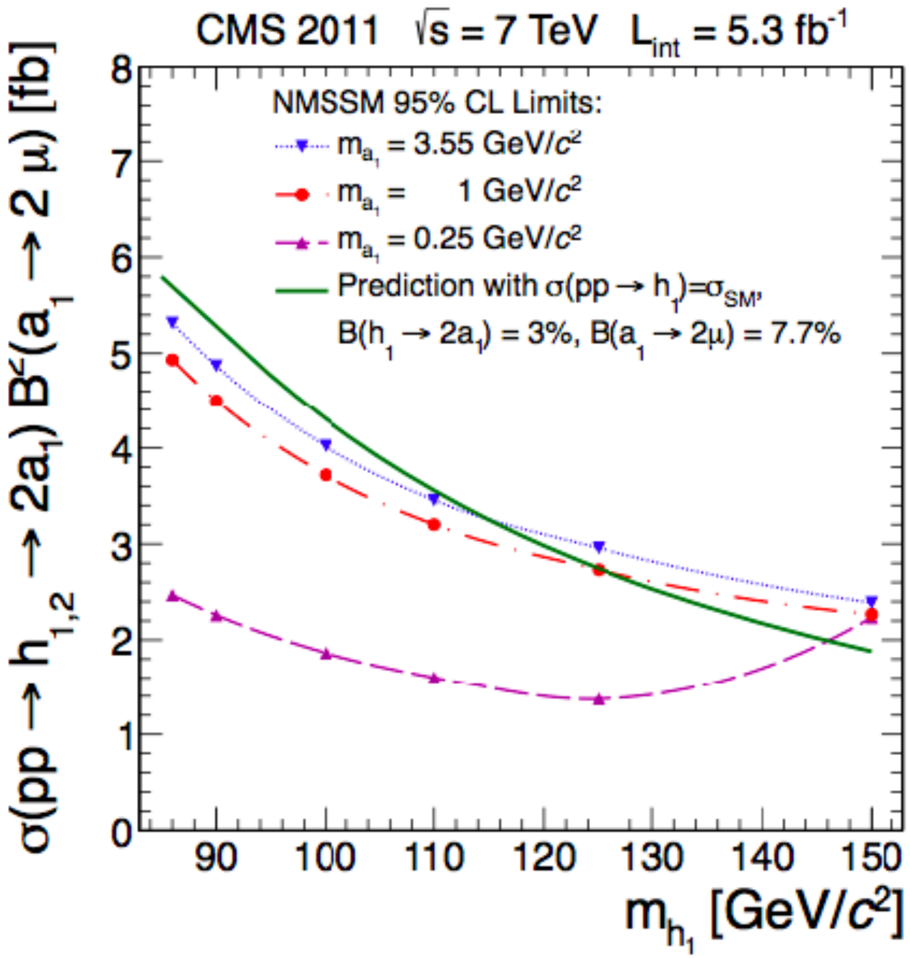




NMSSM: h→aa→μμ+μμ





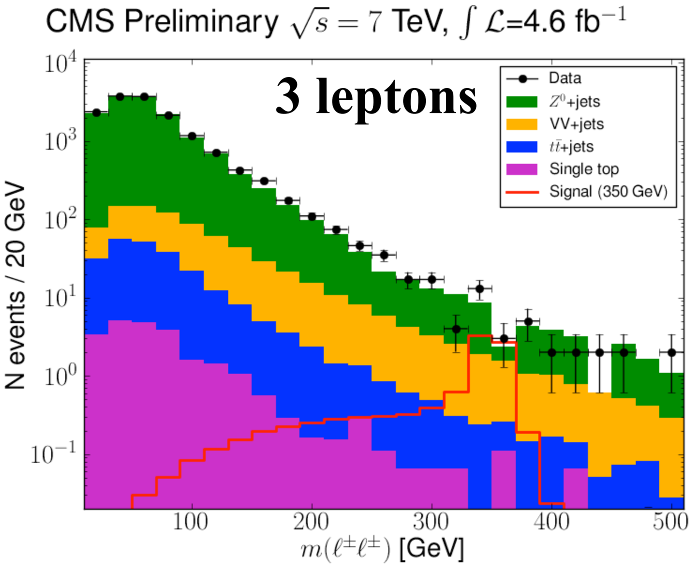


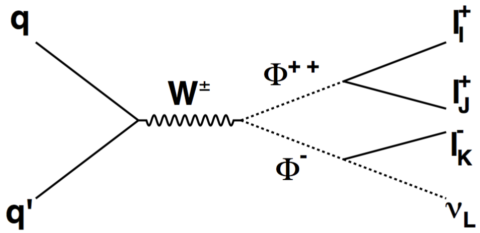
Observed 3 events in off-diagonal region, consistent with bkg expectations
Signal region: zero events (1.0±0.5 bkg)

Model-independent upper limit of 0.78±0.05 fb on cross-section x BR x acceptance

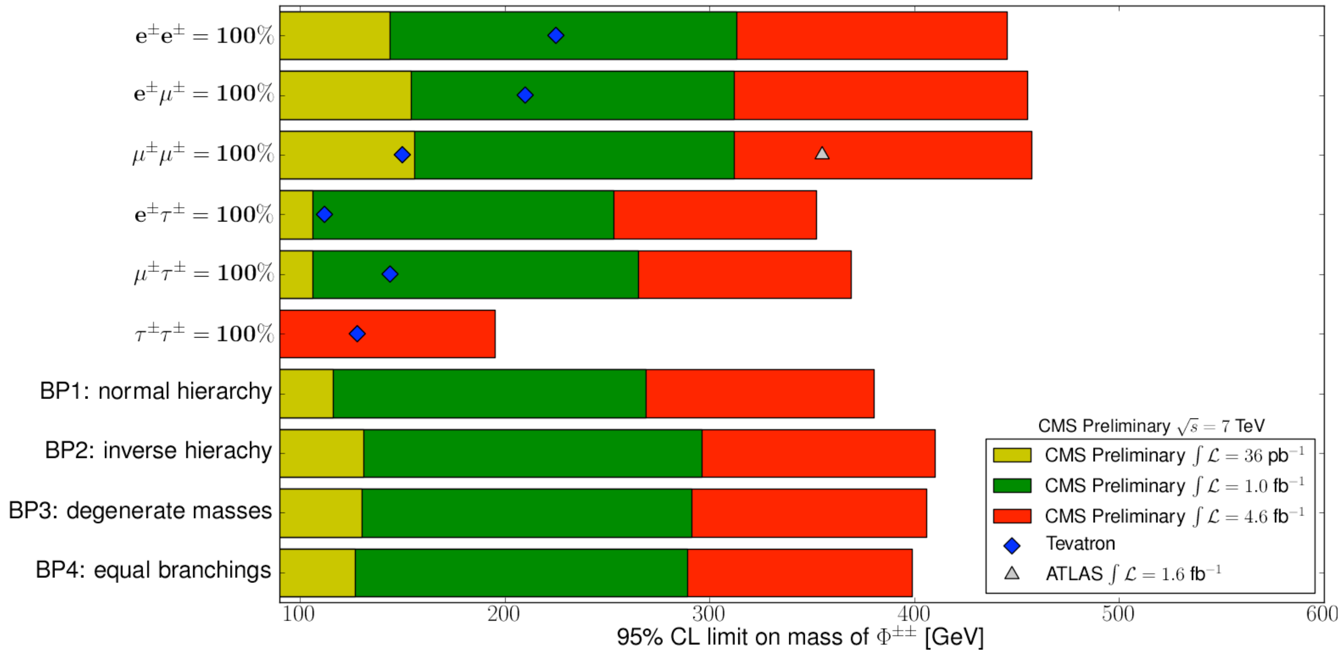
Double Charged Higgs

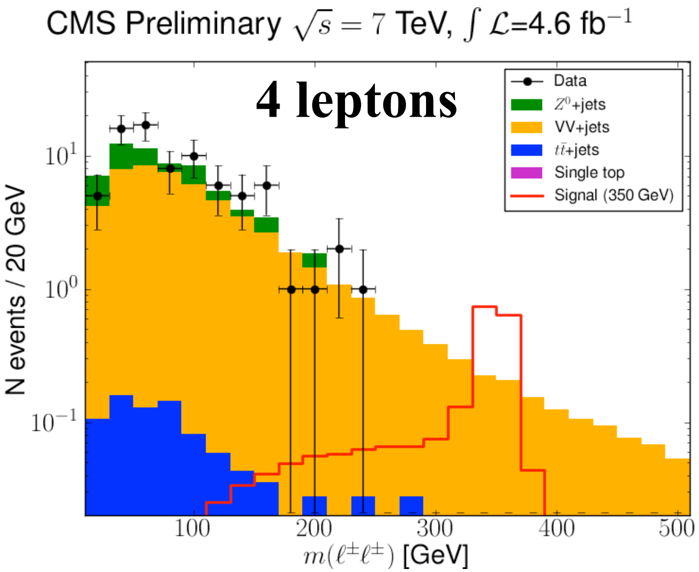
Model designed to explain neutrino masses through a scalar triplet (Φ^{++}, Φ^{+}, Φ^{o}) – Search for double and single charged Higgs

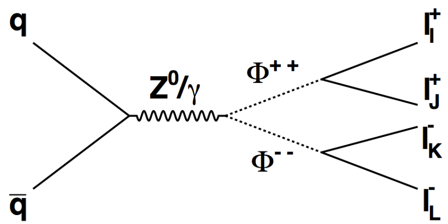




Exclusion up to ~ 450 GeV







MSSM: m_h^{max} scenario

- M_{top} = 172.5 GeV
- $m_b(m_b)_{MSbar}$ = 4.213 GeV
- $\alpha_S(M_Z)$=0.119

- M_{SUSY} = 1000 GeV soft SUSY-breaking squark mass
- X_t = 2000 GeV stop mixing parameter
- M2 = 200 GeV SU2 gaugino mass parameter
- μ = 200 GeV Higgs mixing parameter
- M3 = 800 GeV gluino mass parameter

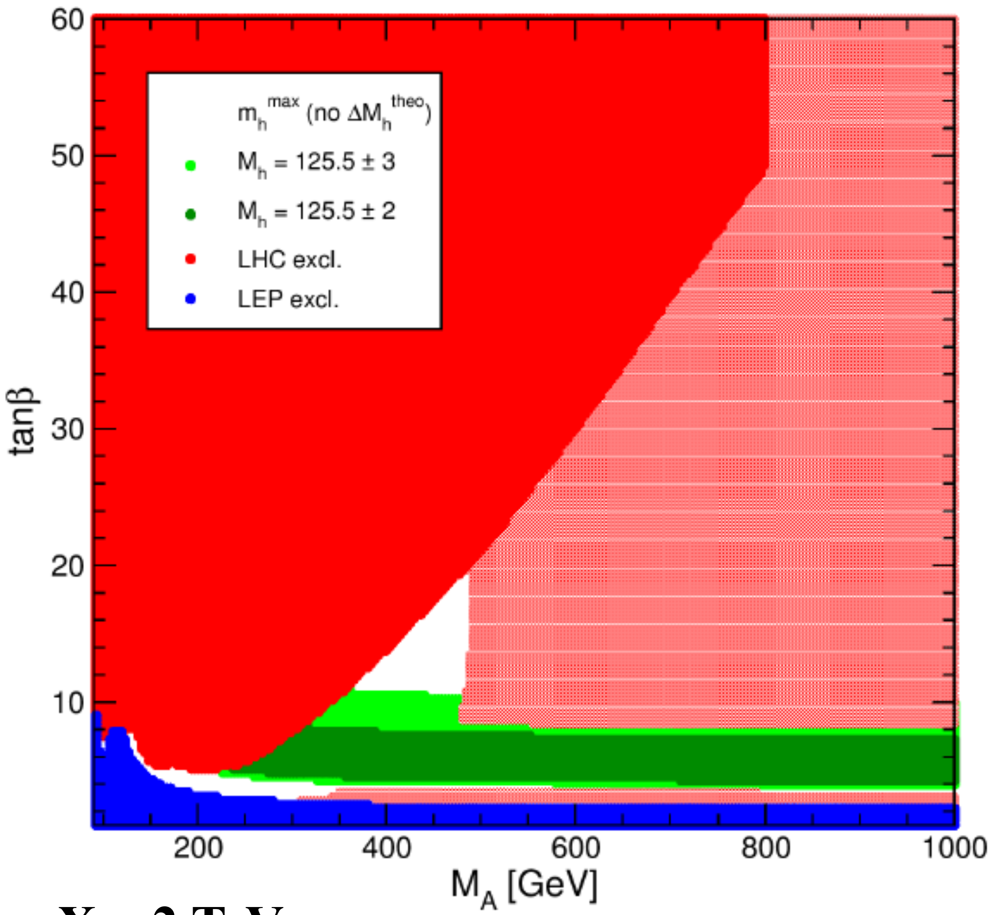
Susy loop corrections are negligible in this scenario

MSSM benchmark scenarios

Assuming the new discovered boson is the light scalar Higgs h with m_h=125.5 GeV

mhmax scenario

Allowed

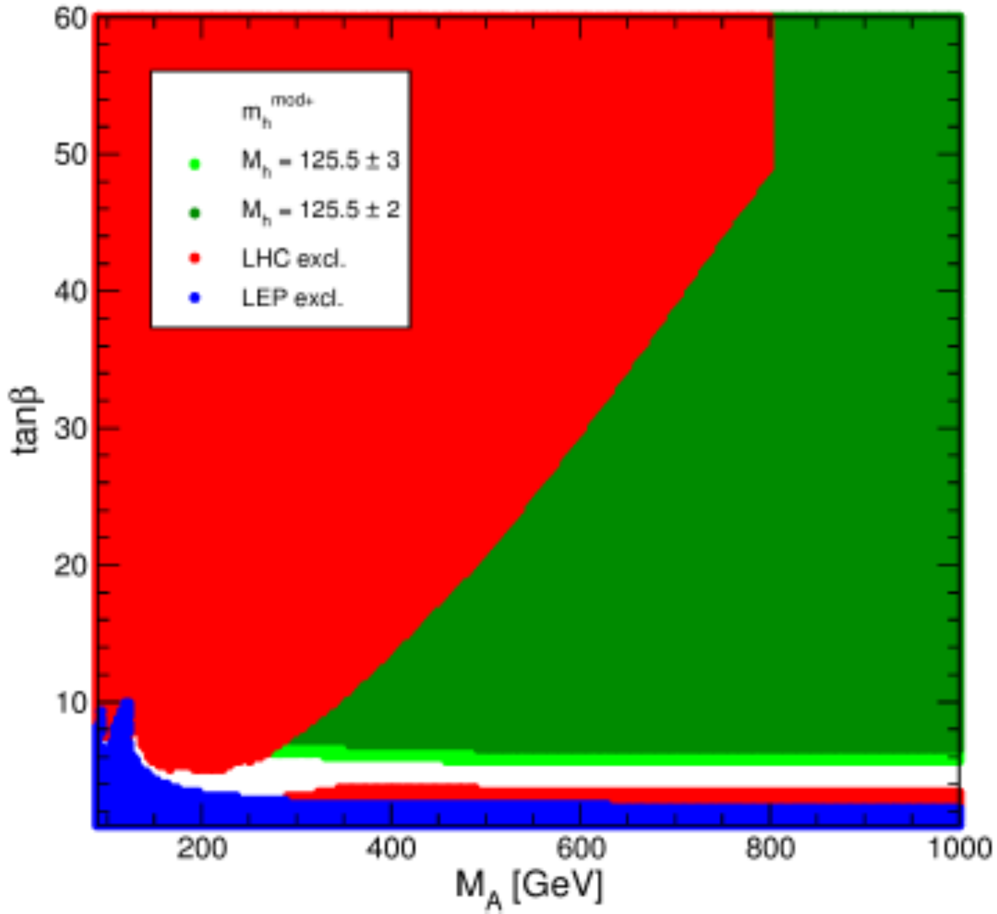


X_t= 2 TeV

X_t: stop tri-linear couplings

arXiv: 1302.7033 [hep-ph]

mhmax modified scenario



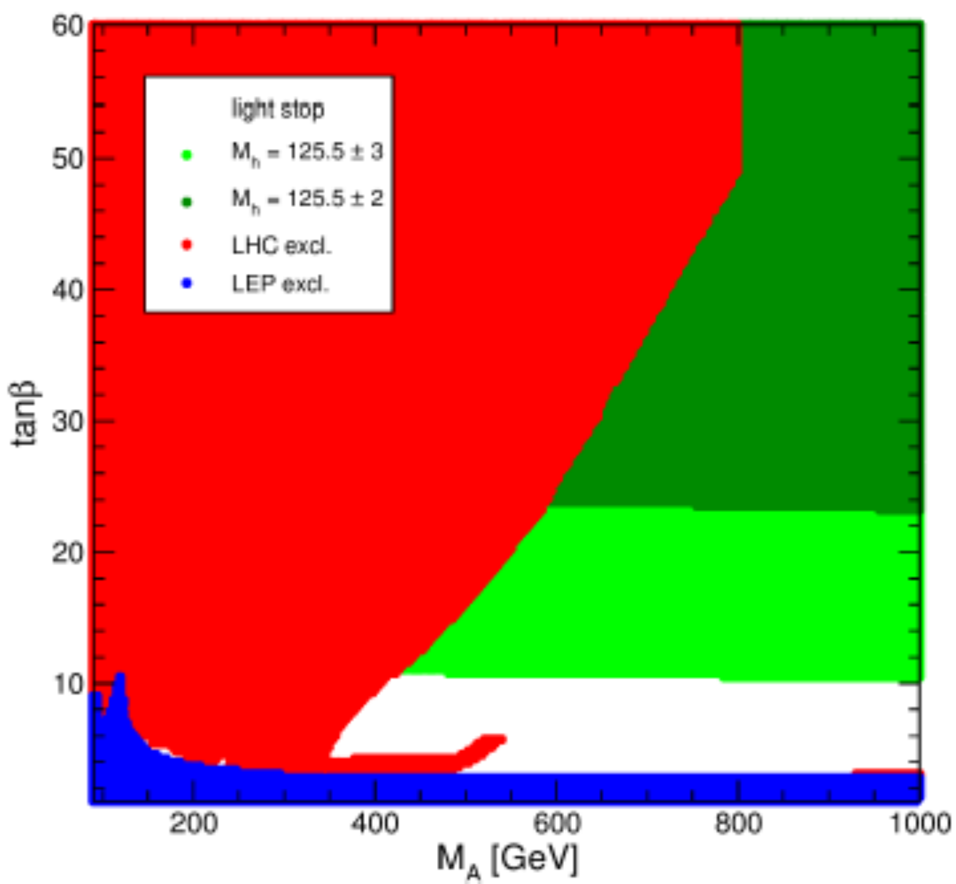
X_t= 1.5 TeV

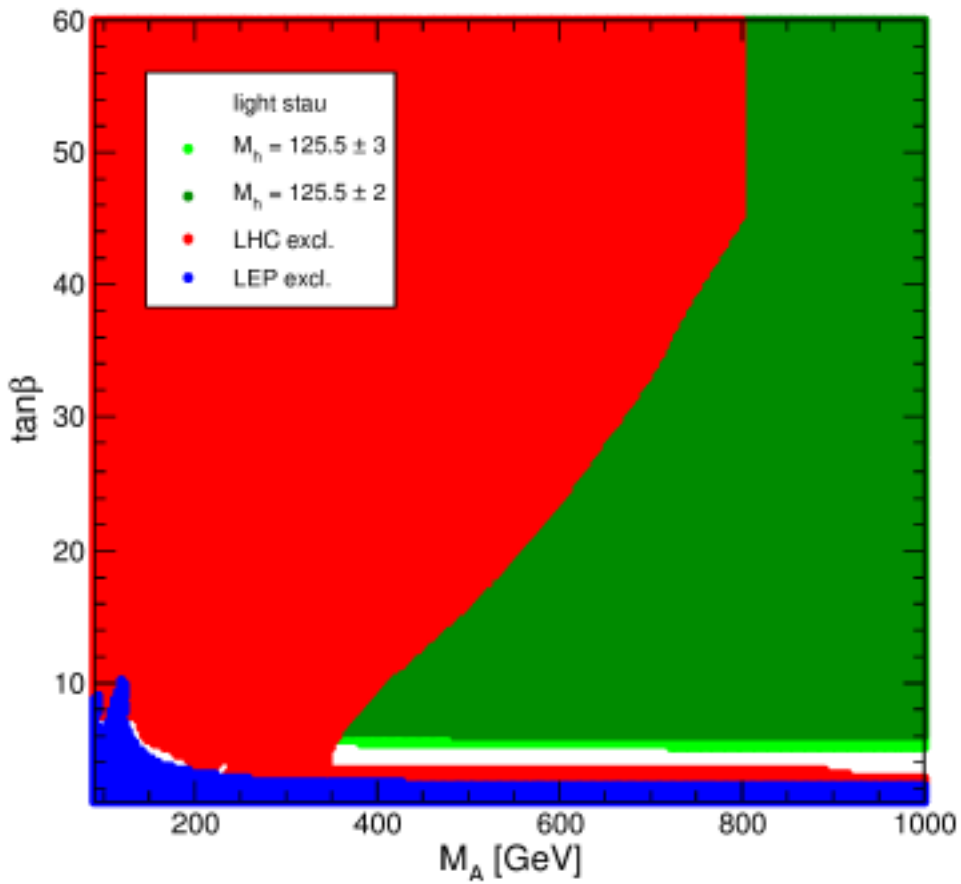
Large part of phase-space opens up

MSSM benchmark scenarios

arXiv: 1302.7033 [hep-ph]

light stop scenario | **Allowed** | light stau scenario





m_{stop}~ 325 & 670 GeV
X_t= 1 TeV, M_{SUSY}=0.5 TeV

m_{stau}~ 250 GeV
X_t= 1.6 TeV, M_{SUSY}=1 TeV