John Conway
Univ. of California, Davis

Frontiers in Particle Physics:
From Dark Matter to the LHC and Beyond
Aspen, Colorado
20 Jan 2014

Higgs Boson Decays to Fermion Pairs

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The
Higgs Boson Decays
to Fermion Pairs!

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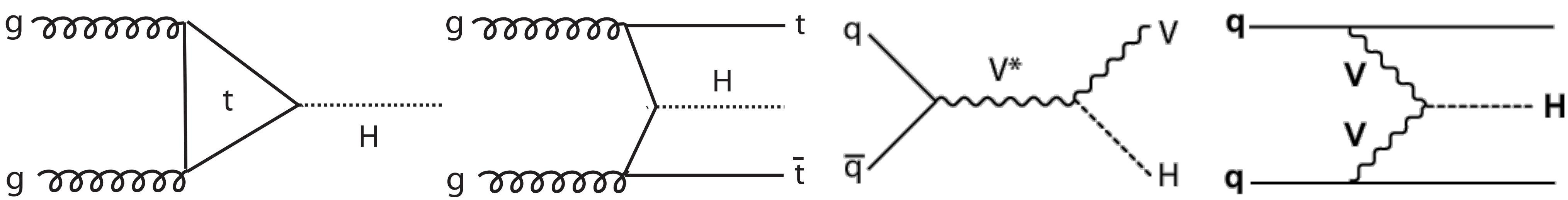
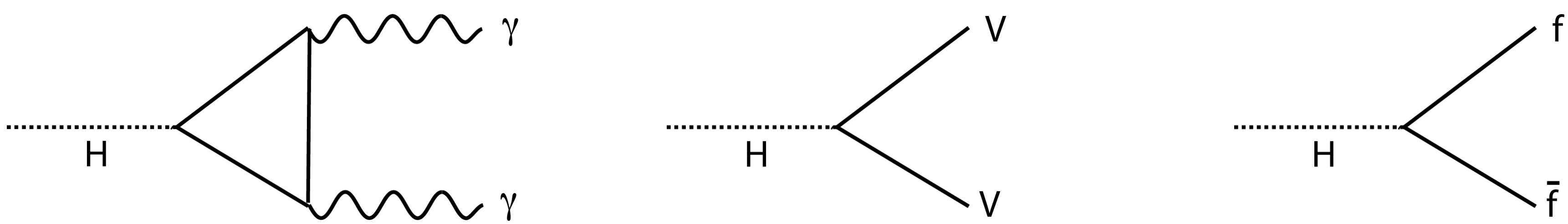
Does the Higgs(-like) state at 125 GeV couple to fermion pairs proportionally to their mass as predicted in the SM?

Production and decay can both be either due to the fermonic or gauge boson couplings:

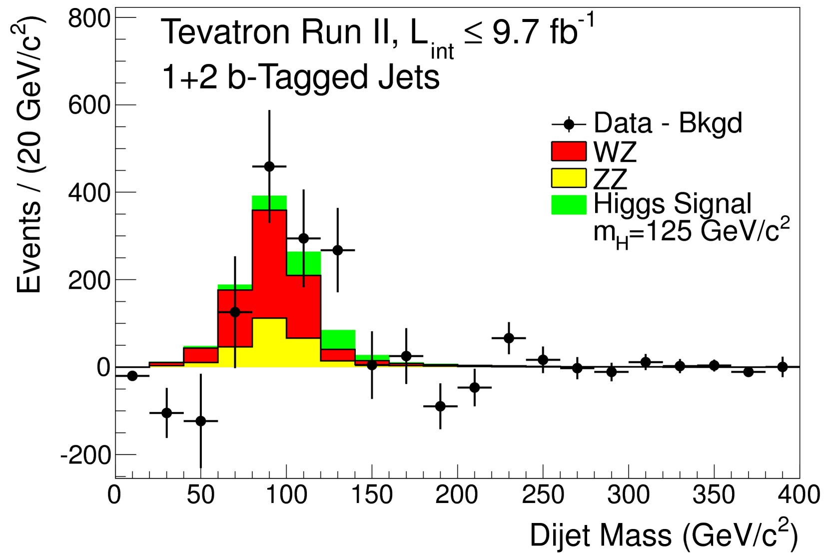




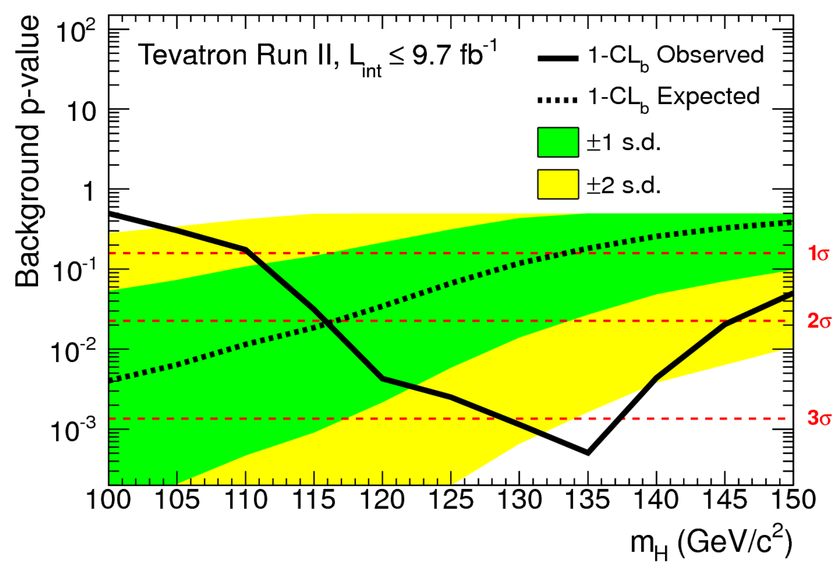
Observation of gg production relies on Htt coupling, but we would like to directly observe H → ff decays

First evidence for H→ bb came from Tevatron, 2 Jul 2012

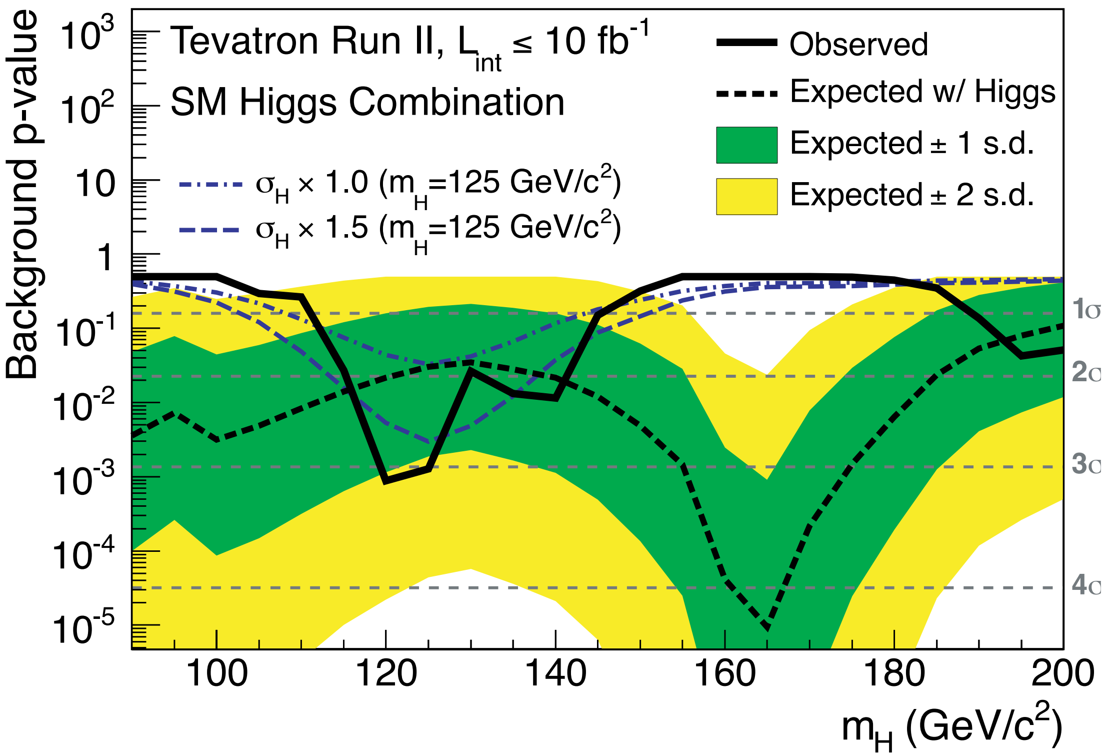
- CDF + D0, 10 fb^{-1}
- Three channels:
  - WH → ℓν bb
  - ZH → ℓℓ bb
  - ZH → νν bb

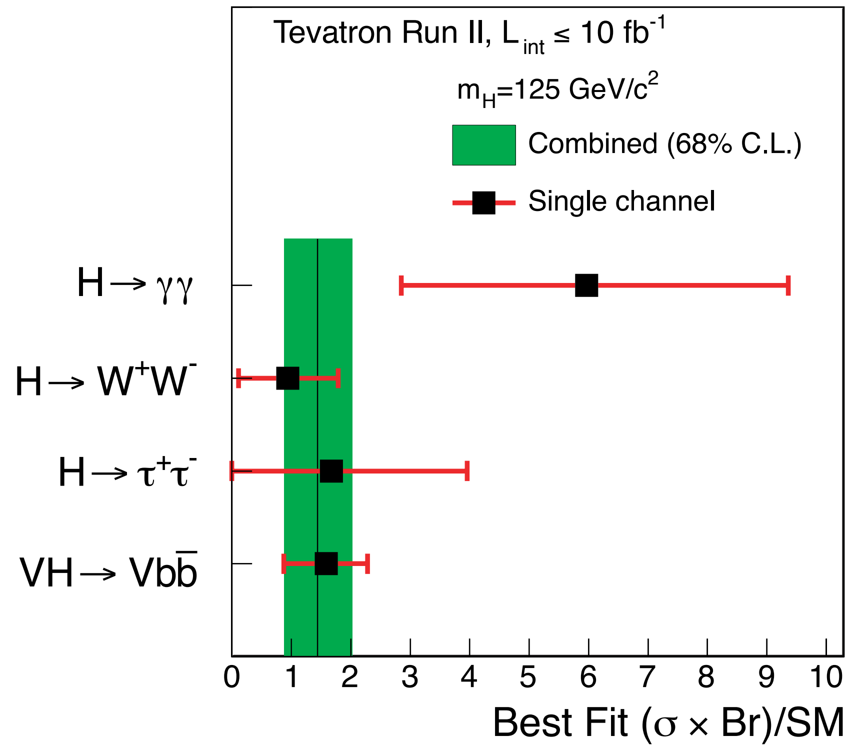


- Result: excess with more than 3σ significance at 135 GeV
- Two days later: 5σ from each LHC experiment at 125 GeV…(γγ, ZZ, WW)

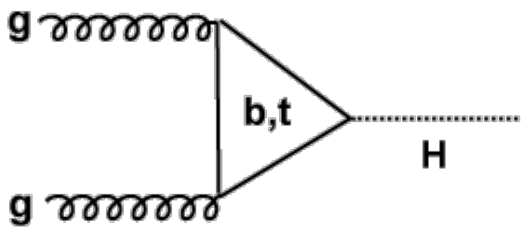


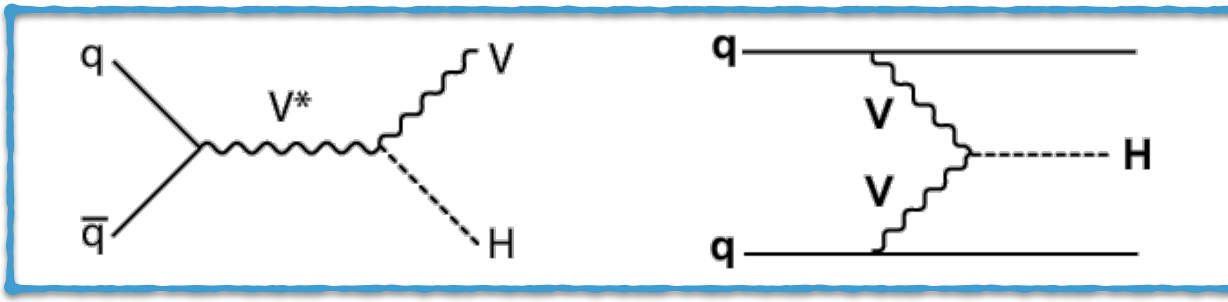
Final combined Tevatron result with all channels:





Final result, March 2013: 3σ at 125 GeV

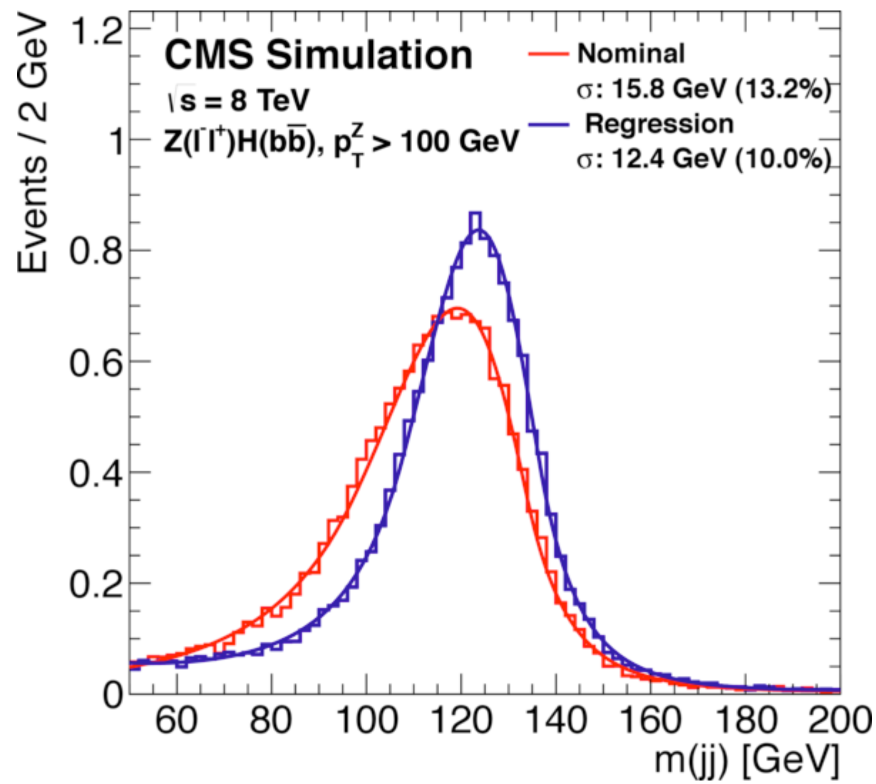


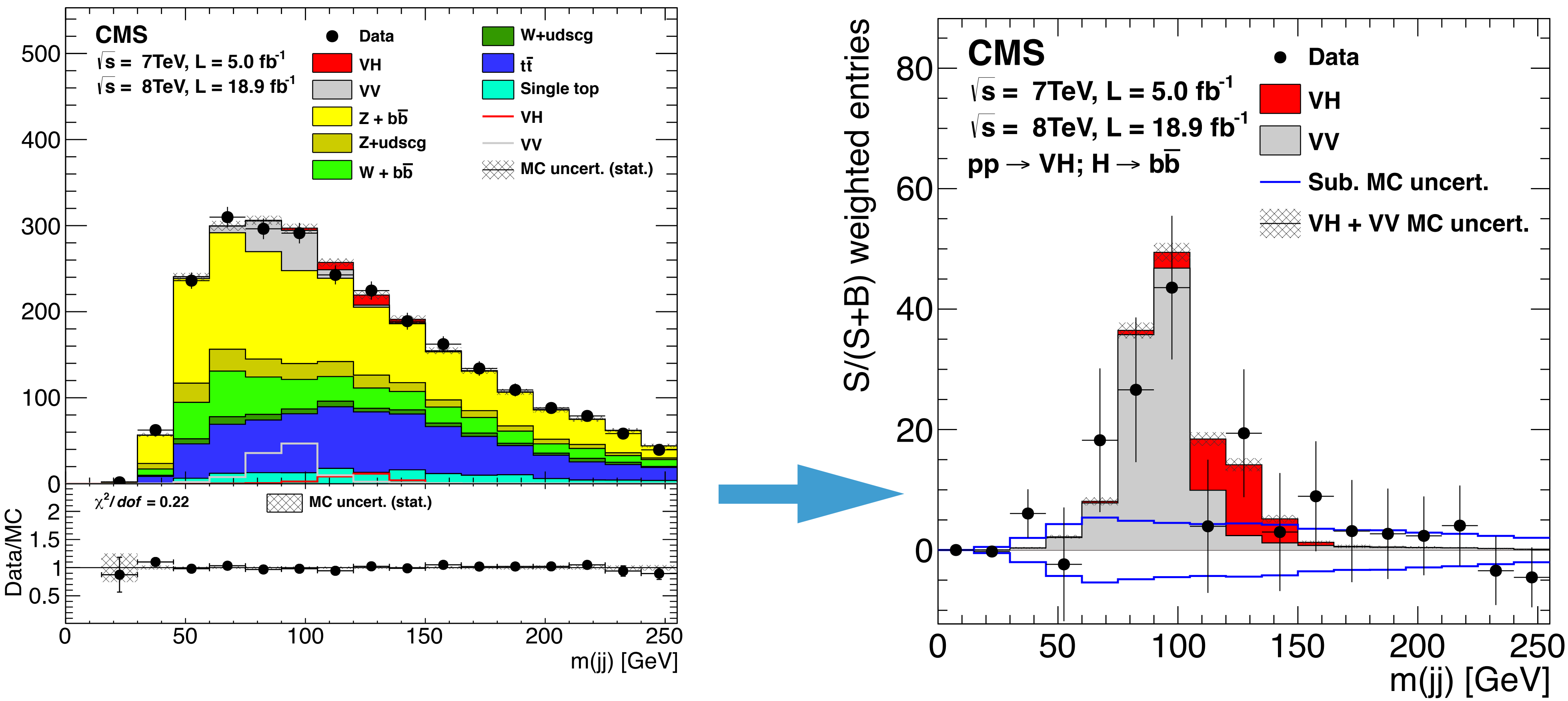


At hadron colliders, gg fusion mode very challenging; rely on associated production and VBF modes

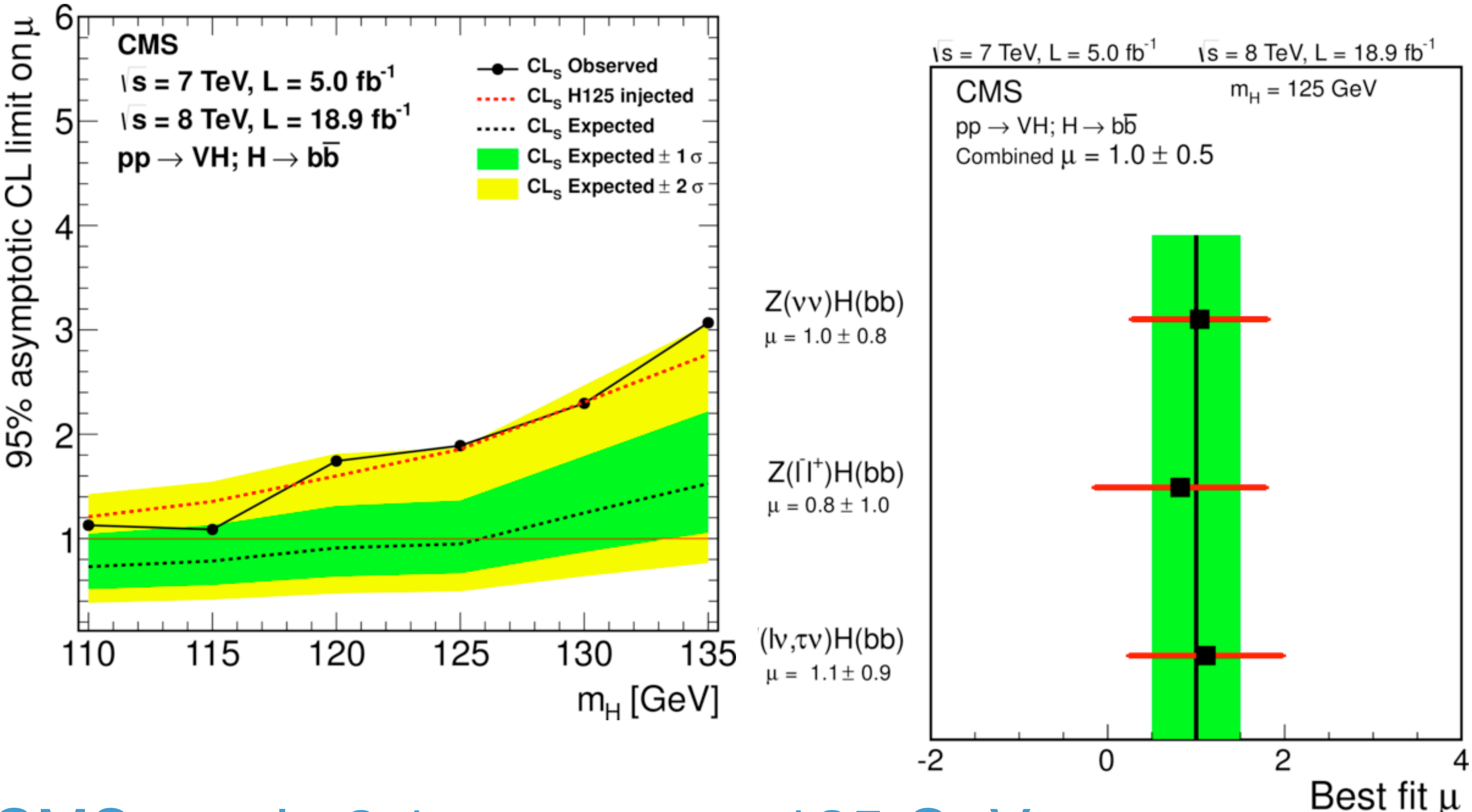
Efficient b-tagging and good dijet mass reconstruction crucial to separate signal from background

CMS uses, for example, a BDT to improve mass resolution





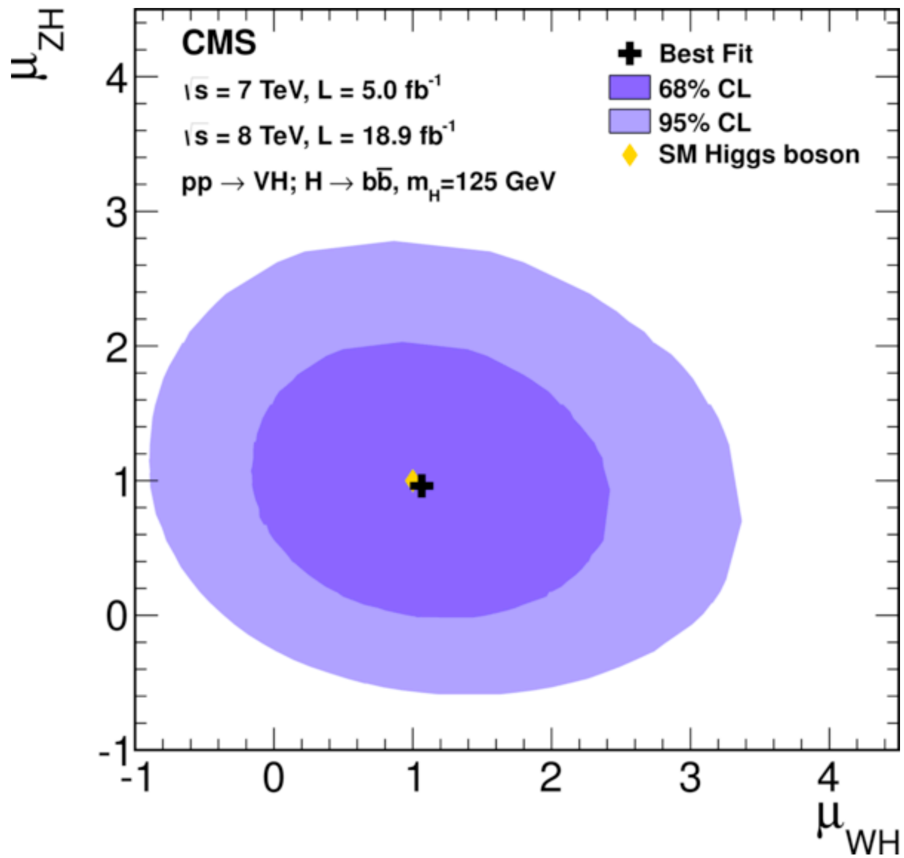
Small signal apparent after non-resonant background subtraction…apply BDT for 20% boost in sensitivity

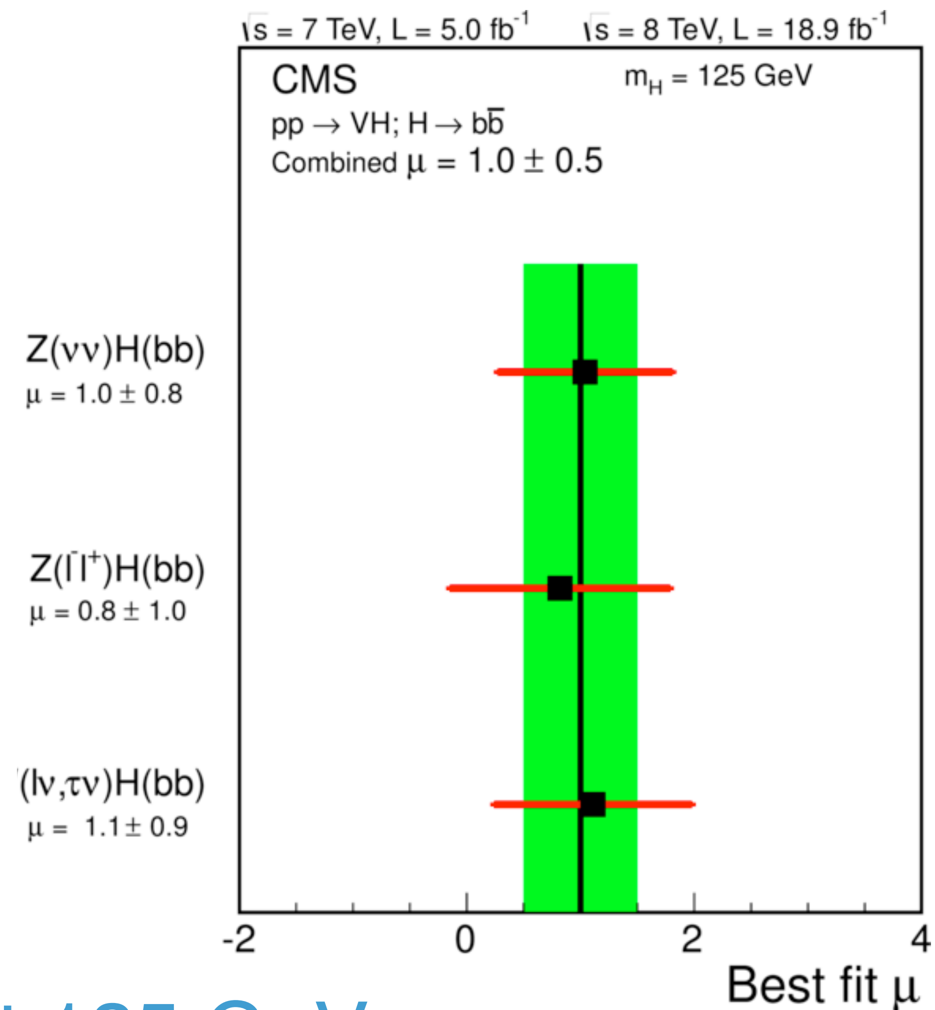


CMS result: 2.1σ excess at 125 GeV

Can split into ZH, VH, and final states

$\mu = 1.0 \pm 0.5$





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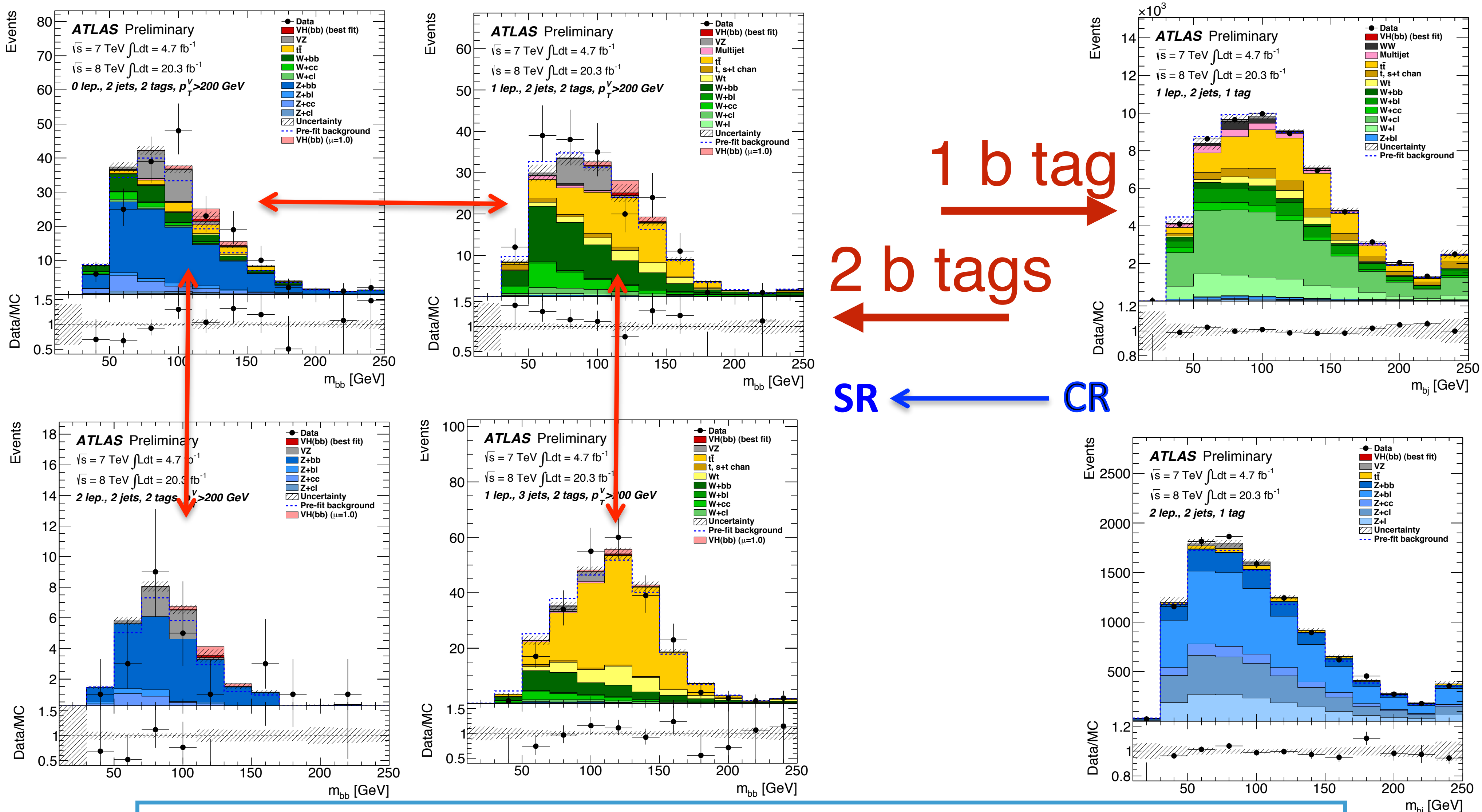

Perform simultaneous fits to m_{bb} distributions in signal and control regions to constrain nuisance parameters

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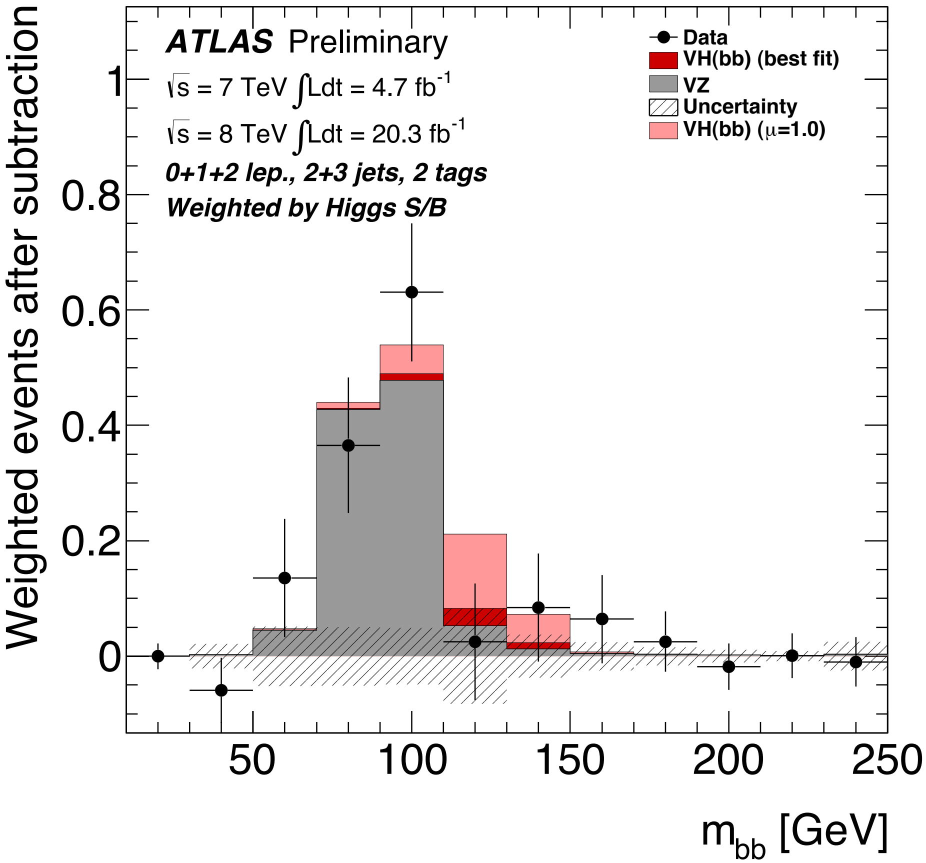
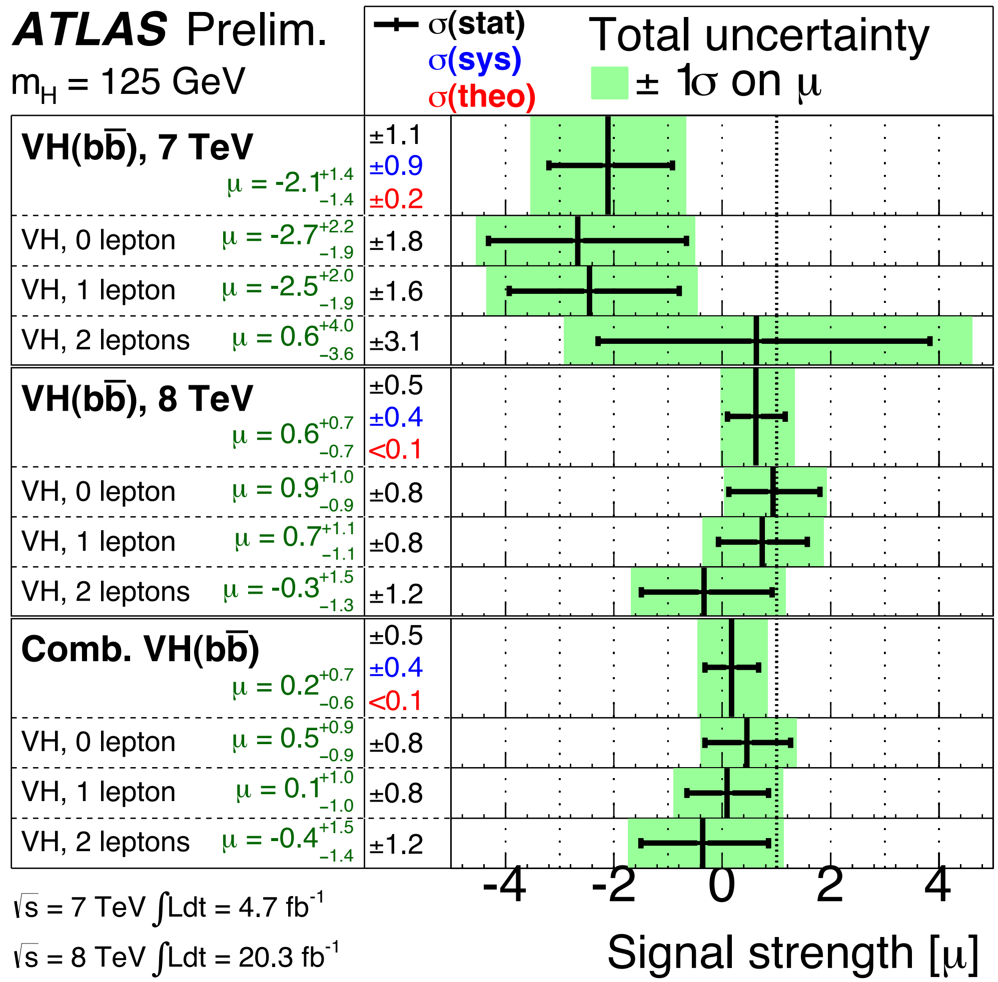
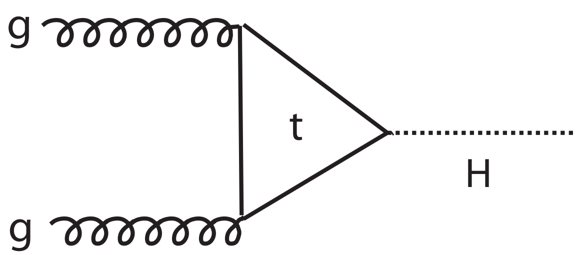
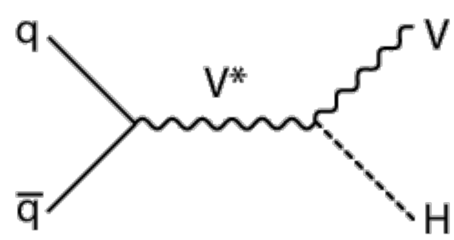
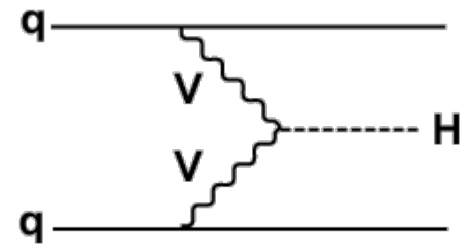


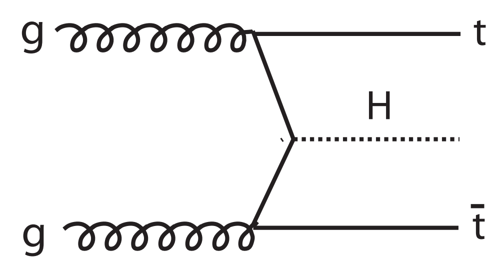


Combined result: $\mu_{bb} = 0.2^{+0.7}_{-0.6}$

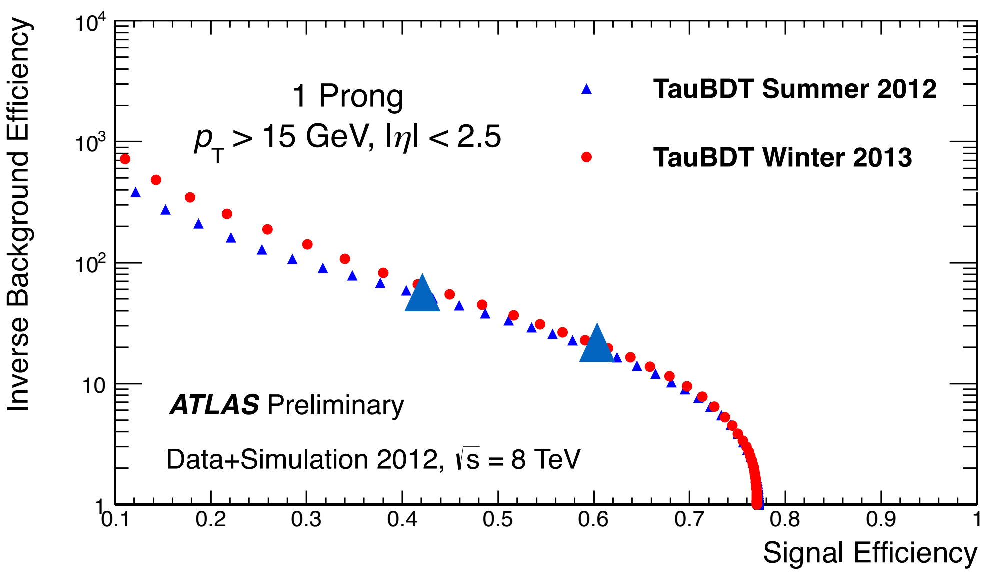


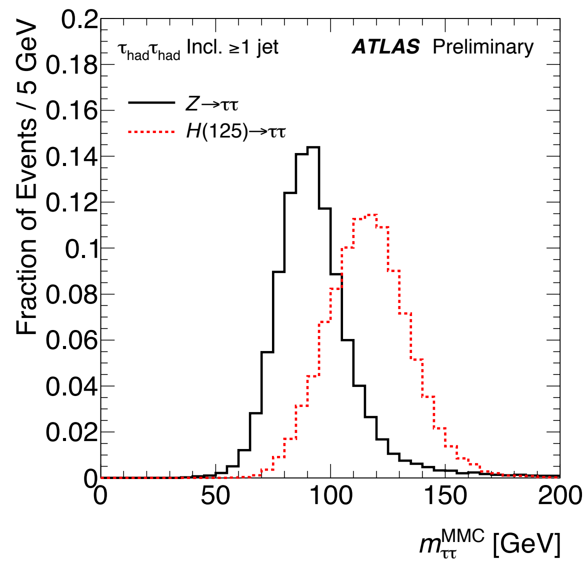






- Search for H → ττ at LHC can utilize all four modes
- Require excellent tau ID efficiency and jet rejection
- Use sophisticated tau pair mass algorithms
- *In situ* calibration using Z → ττ irreducible background

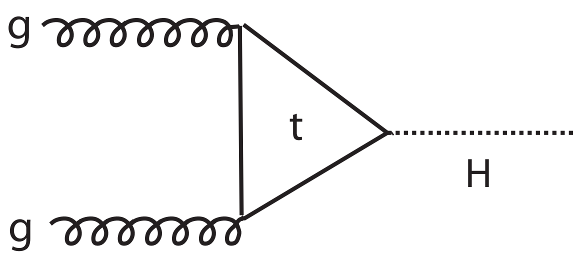


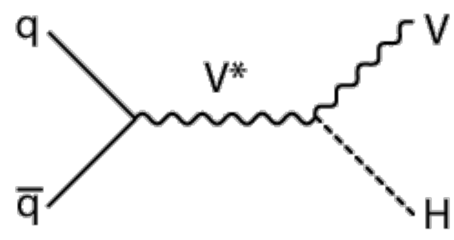


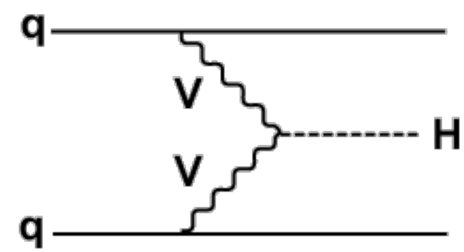
MMC

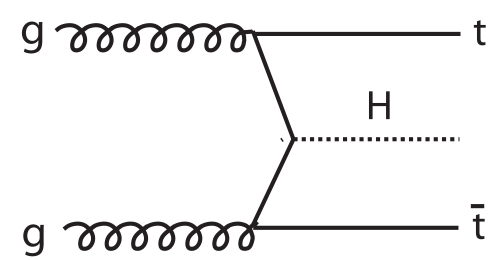
(Z → ττ) + j

ℓℓ	21.4%
ℓh	18.1%
hh	14.3%









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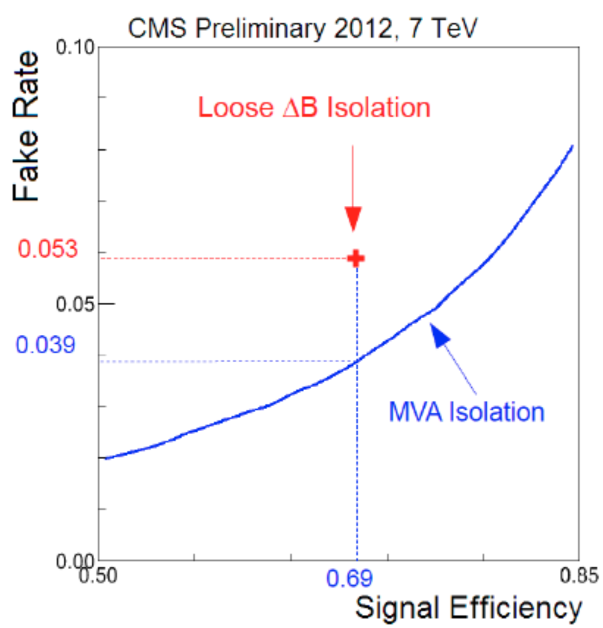
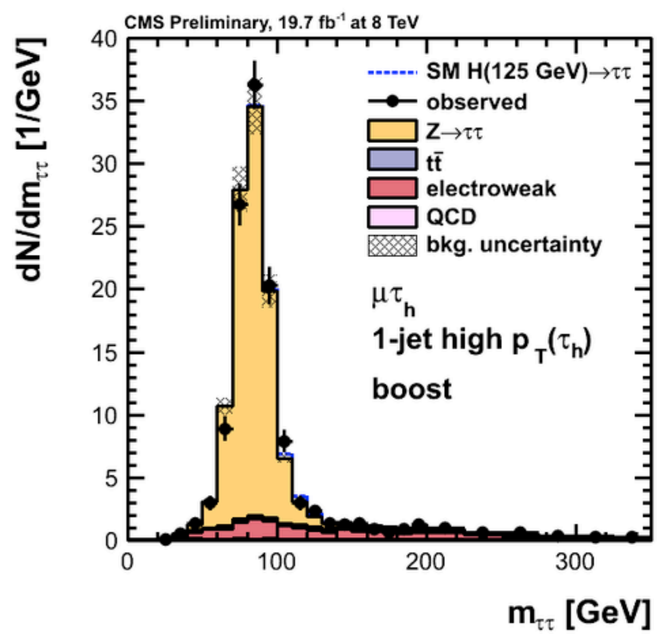




SVfit: m(ττ) full likelihood using kinematics and mass constraints on PF objects

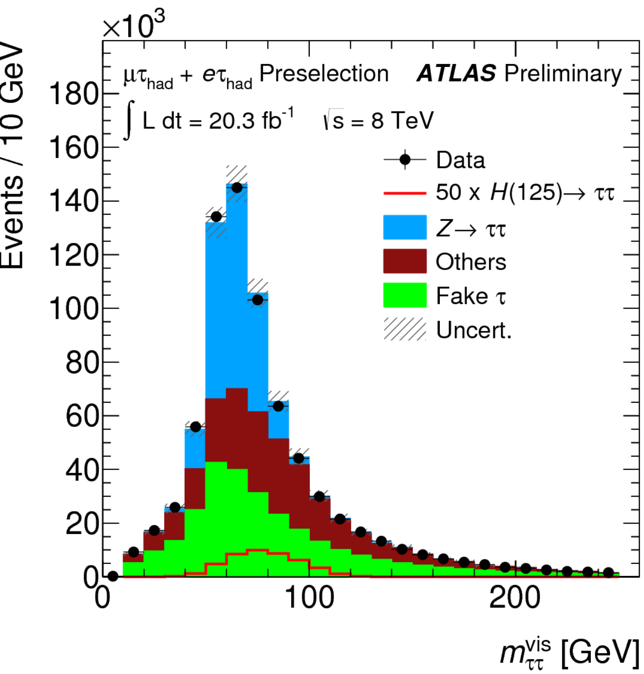
Three channels: eτ μτ ττ (τ = tau had. decay)

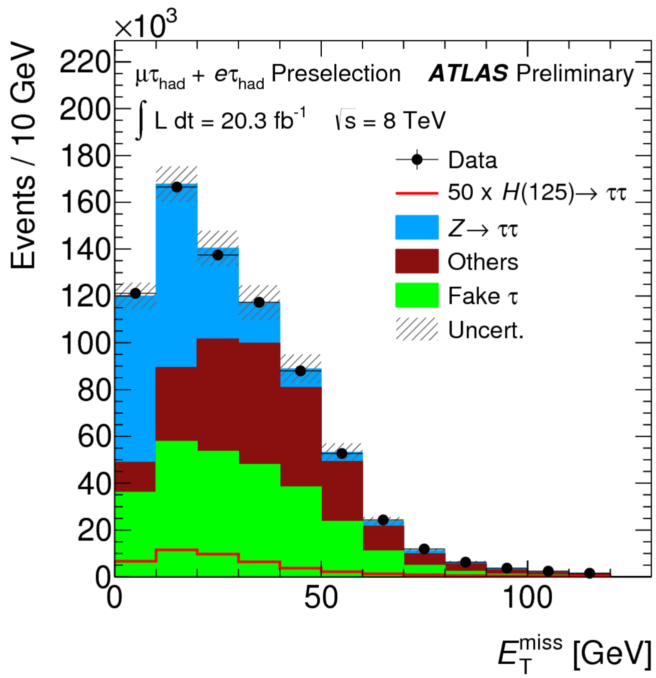
Two categories: VBF Boosted

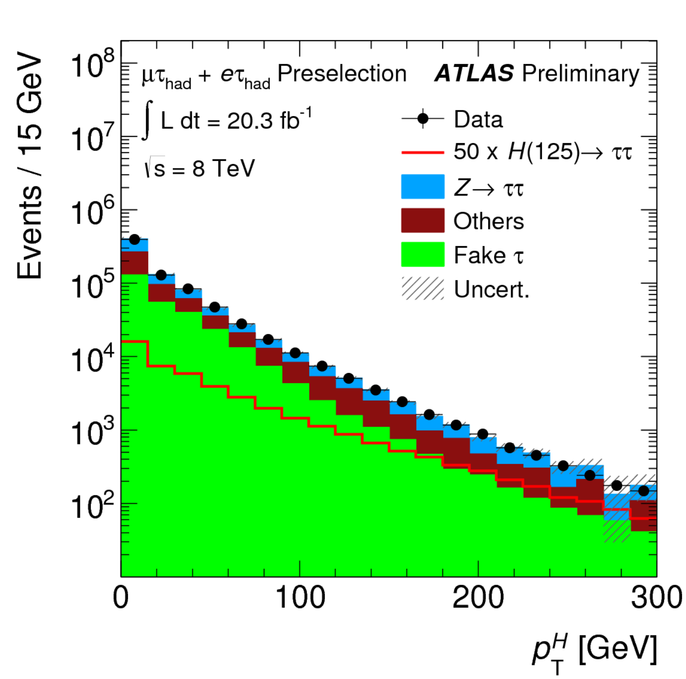
Train BDT using mass and kinematics

Strategy: fit (initially blinded) BDT output for signal

Most sensitive channels: $\ell + \tau$







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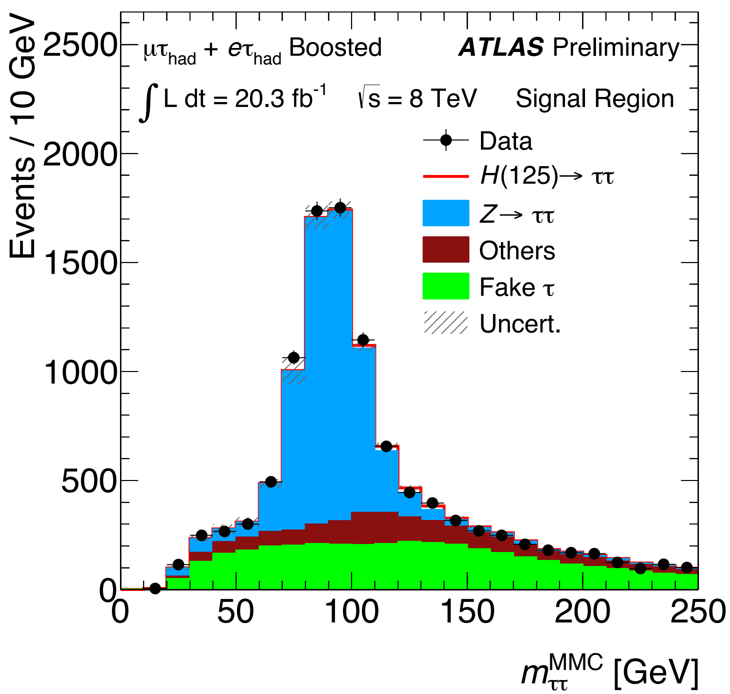
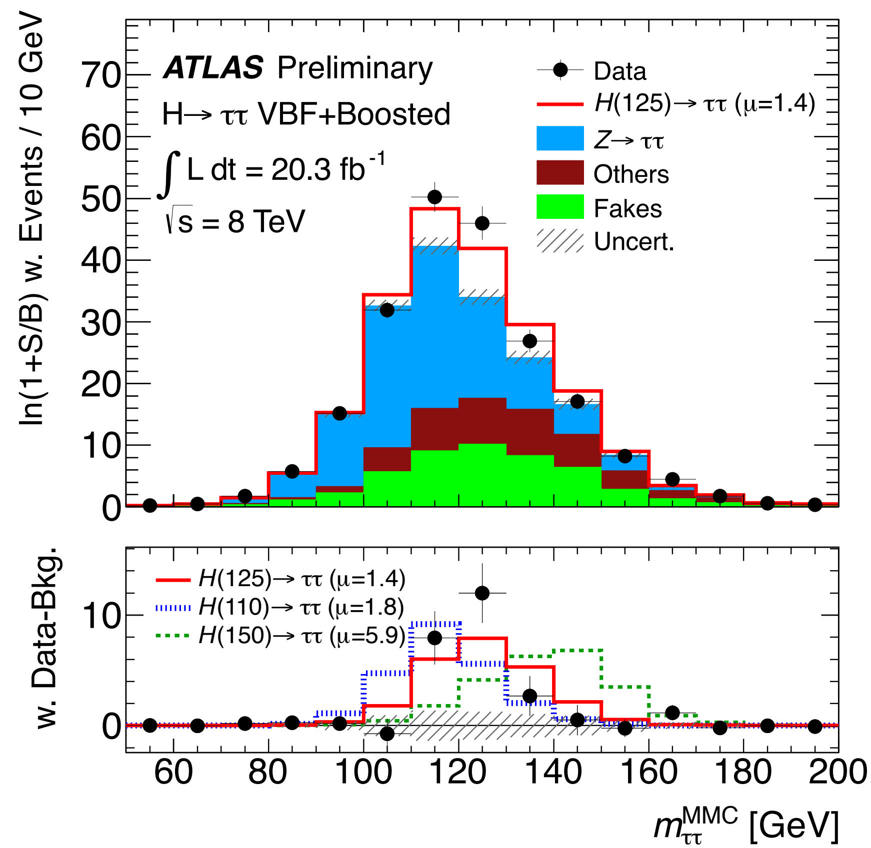


weight using BDT



- Z background: embedding
- fakes (W+jets, multijet) from data
- other: MC normalized to data CR
- blind analysis (both mass and BDT)

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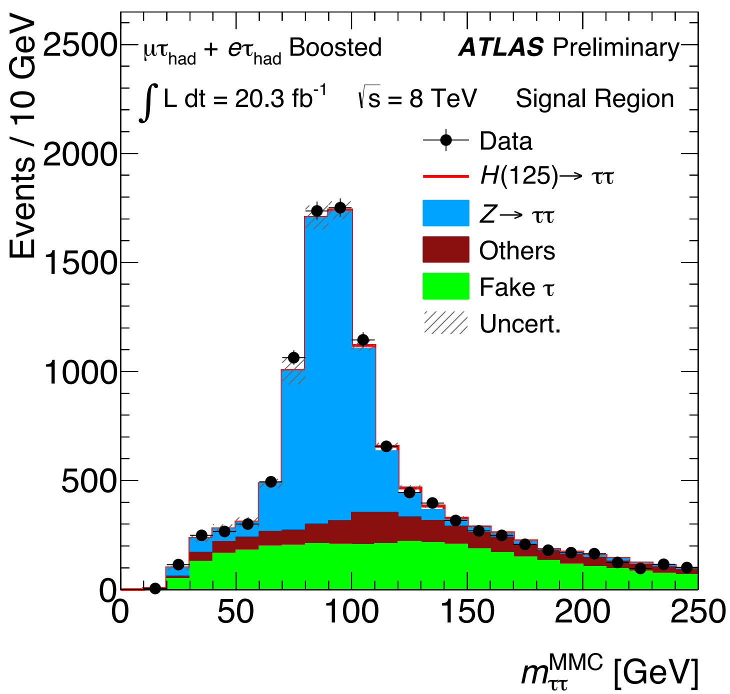

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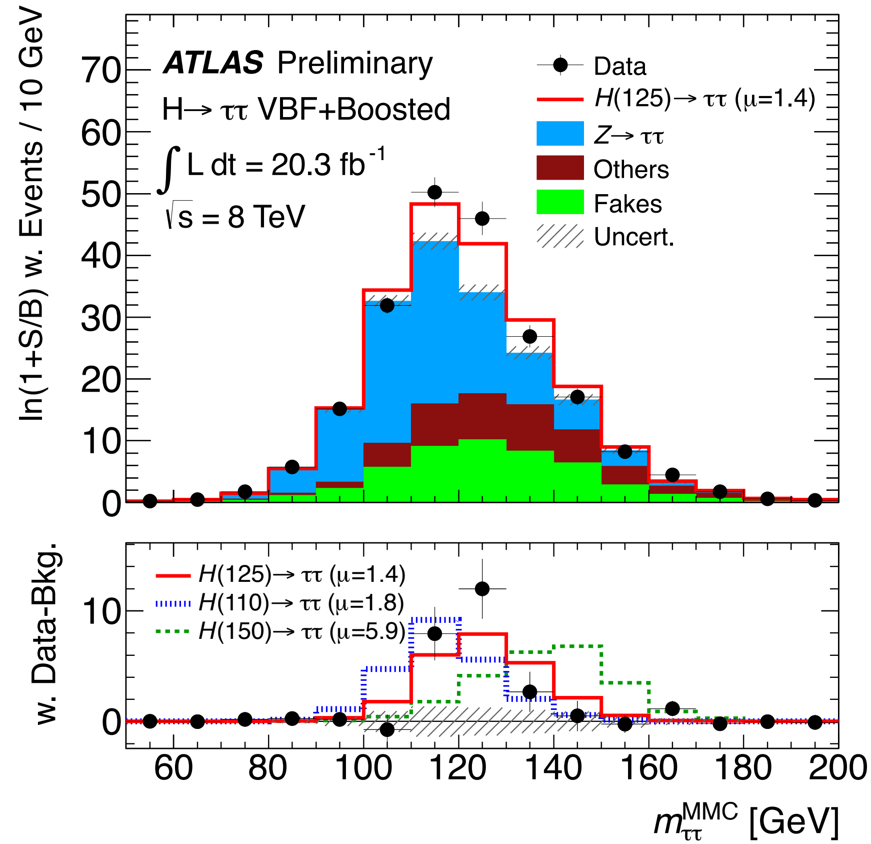

- Z background: embedding
- fakes (W+jets, multijet) from data
- other: MC normalized to data CR
- blind analysis (both mass and BDT)

Strong excess!

4.1σ obs, 3.2σ exp.

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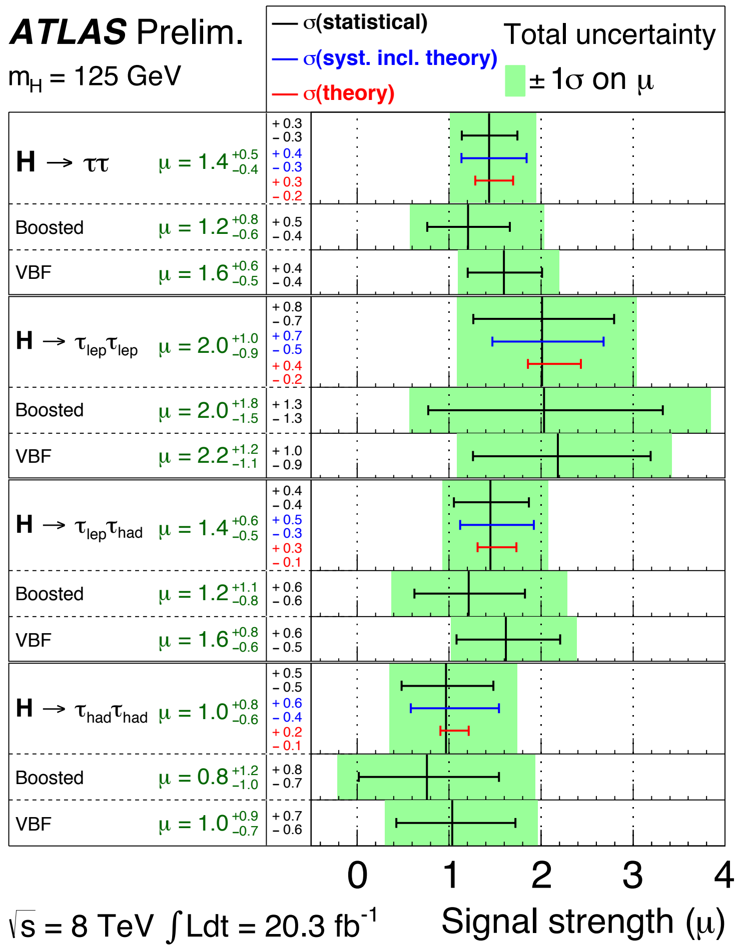
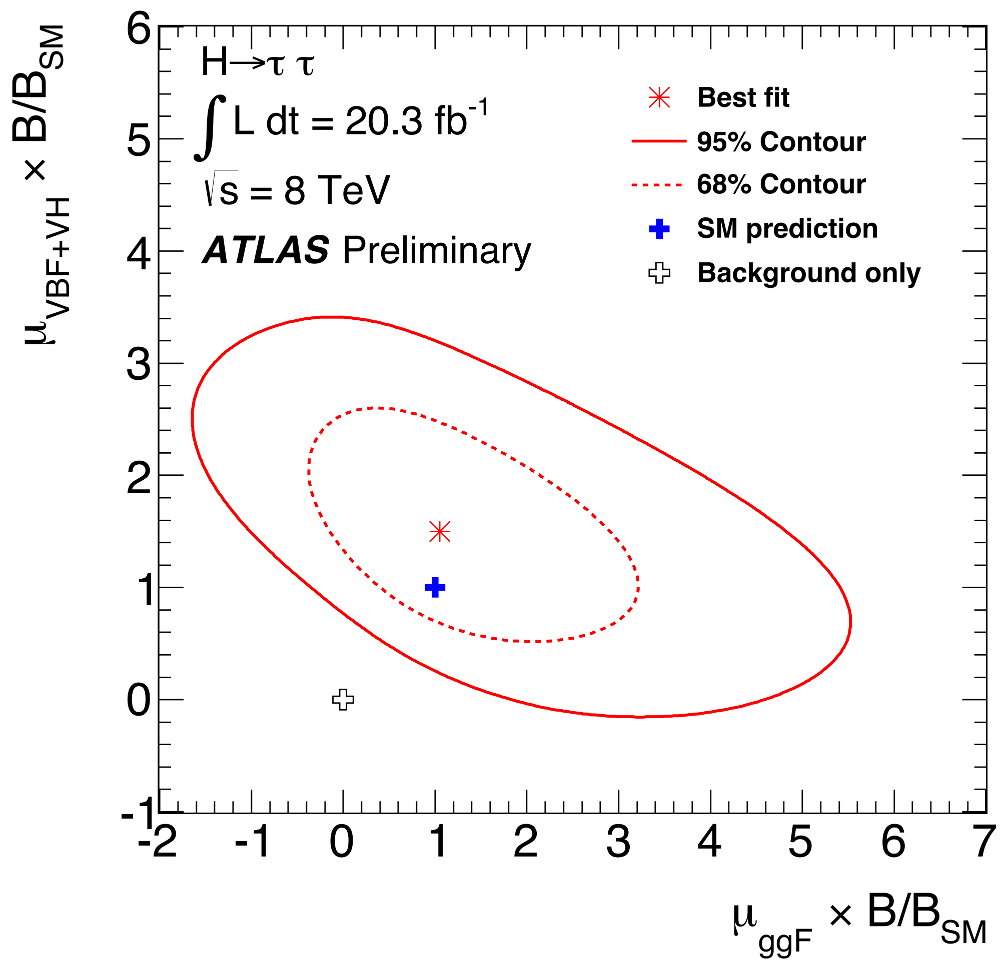




$\mu_{\tau\tau} = 1.4\,^{+0.5}_{-0.4}$

gg, VBF/VH couplings agree with SM predictions

CMS: many categories covering gg and VBF production

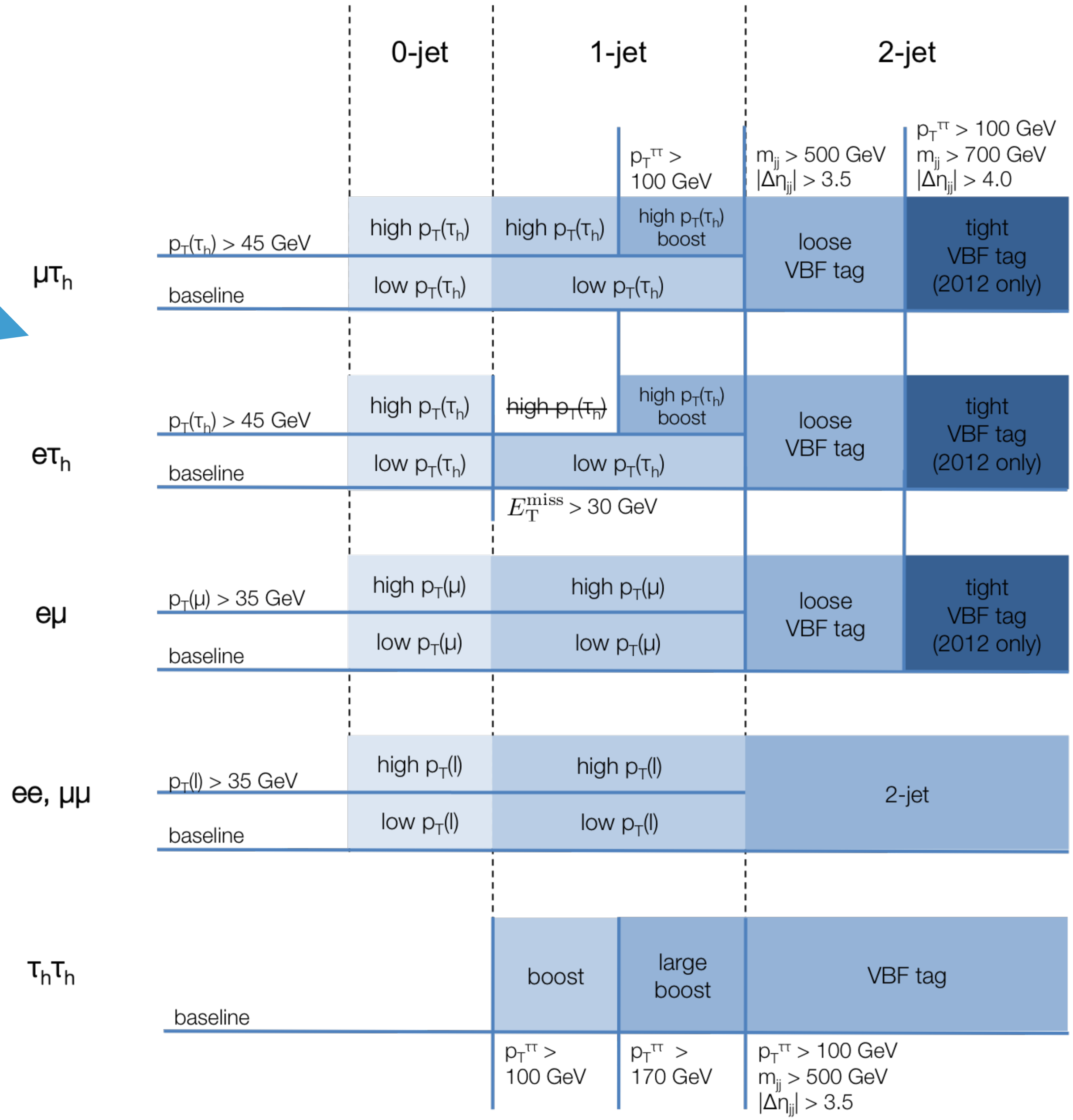
Also: VH production in the final states

$ZH \rightarrow \ell\ell\tau\tau$

$\rightarrow \ell\ell\ell\tau$

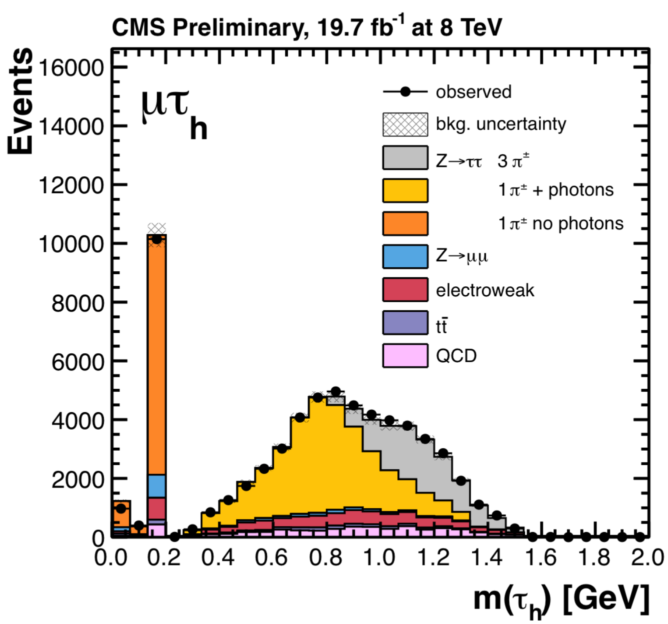
$WH \rightarrow \ell^{\pm}\ell^{\pm}\tau$

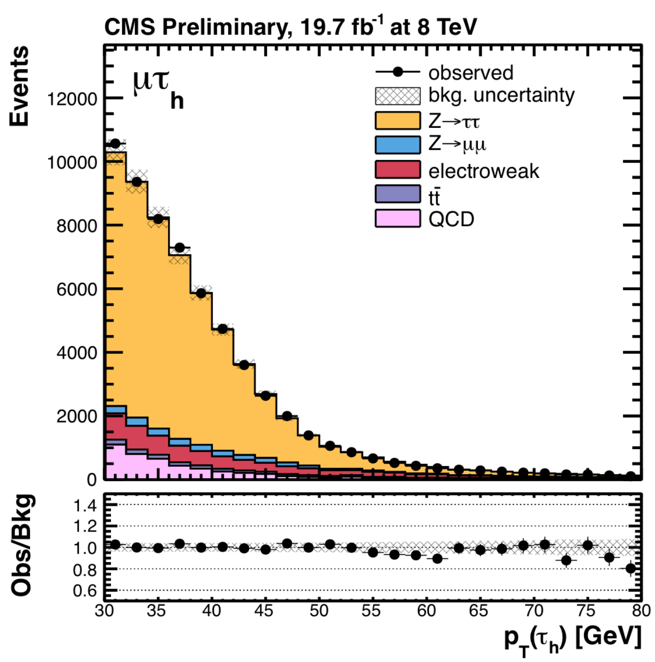
$\rightarrow \ell\tau\tau$

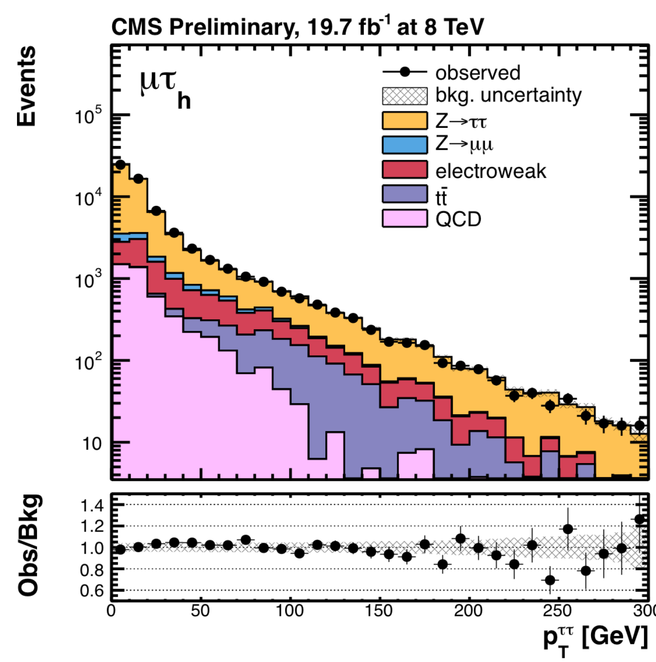


Most sensitive channel: μτ

In this and all other channels CMS studies multiple kinematic distributions to reveal systematic uncertainties and modeling issues; leave m(ττ) blind



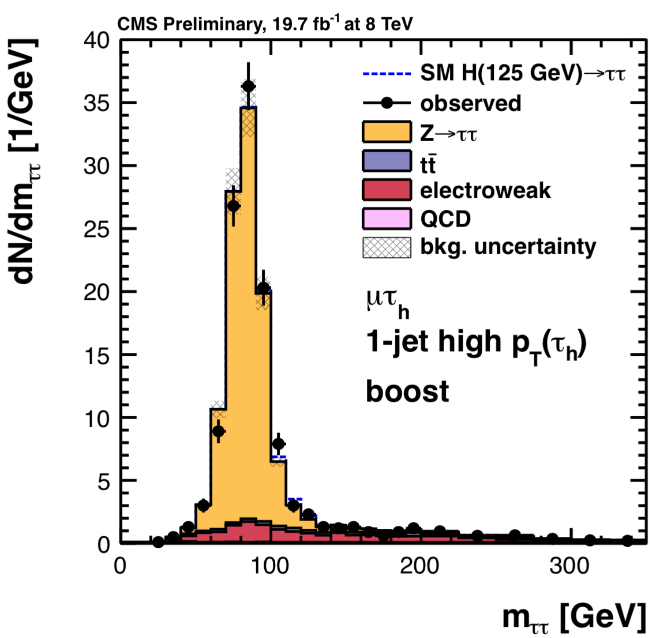




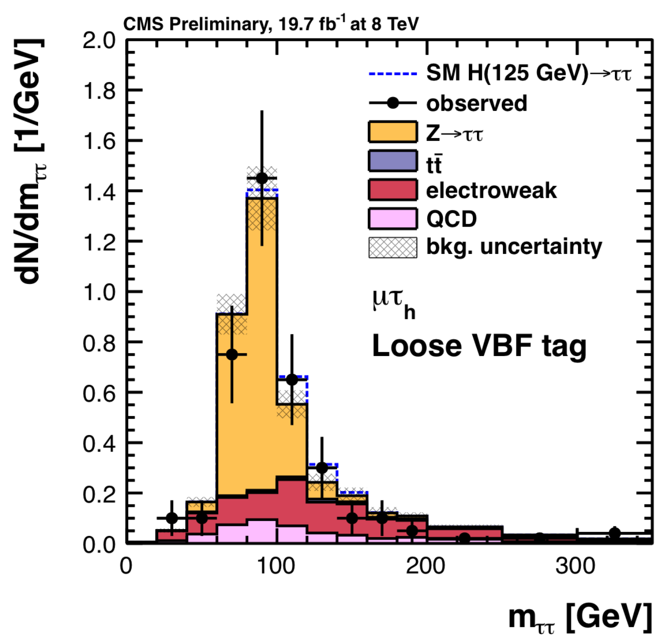
Most sensitive channel: μτ

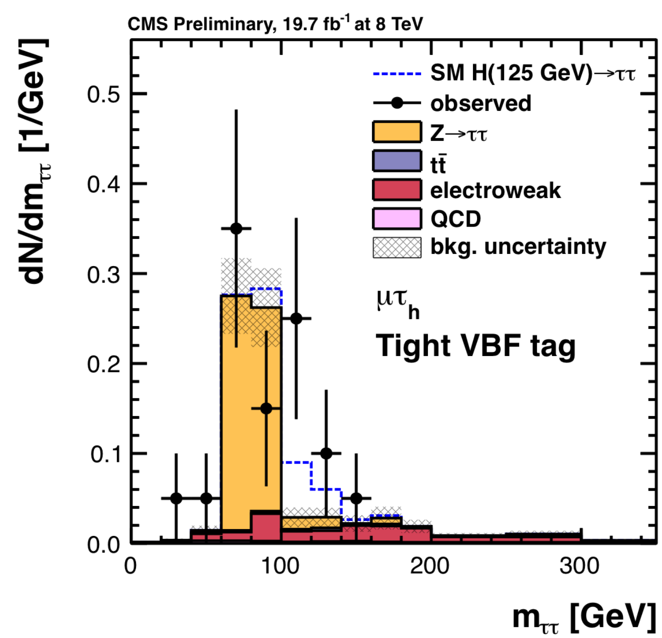
Unblinded, post-fit mass plots show excellent control of backgrounds and reveal hint of signal:

gg



VBF





VH, H→ττ

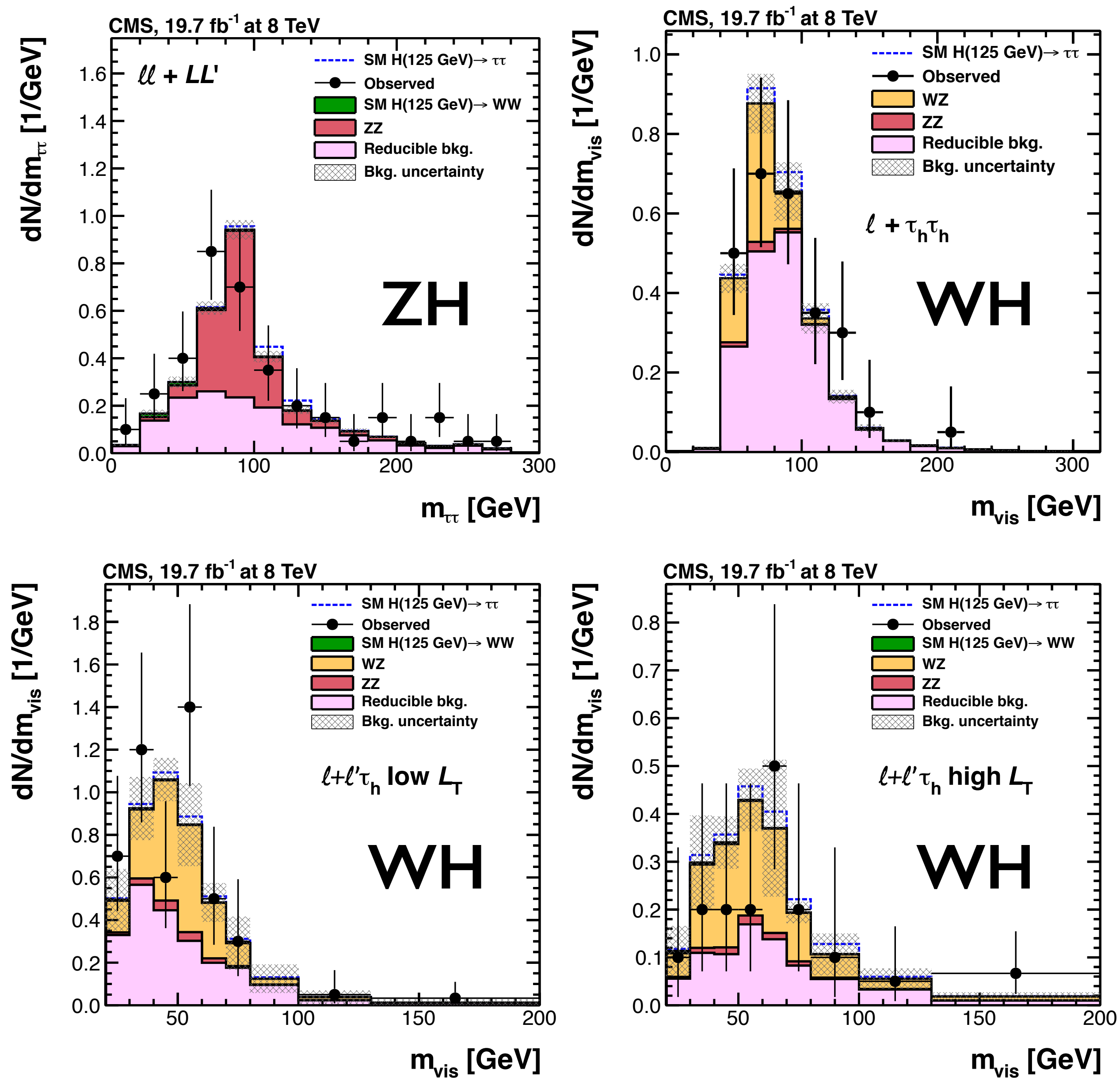
new!

ZH → ℓ ℓ τ τ

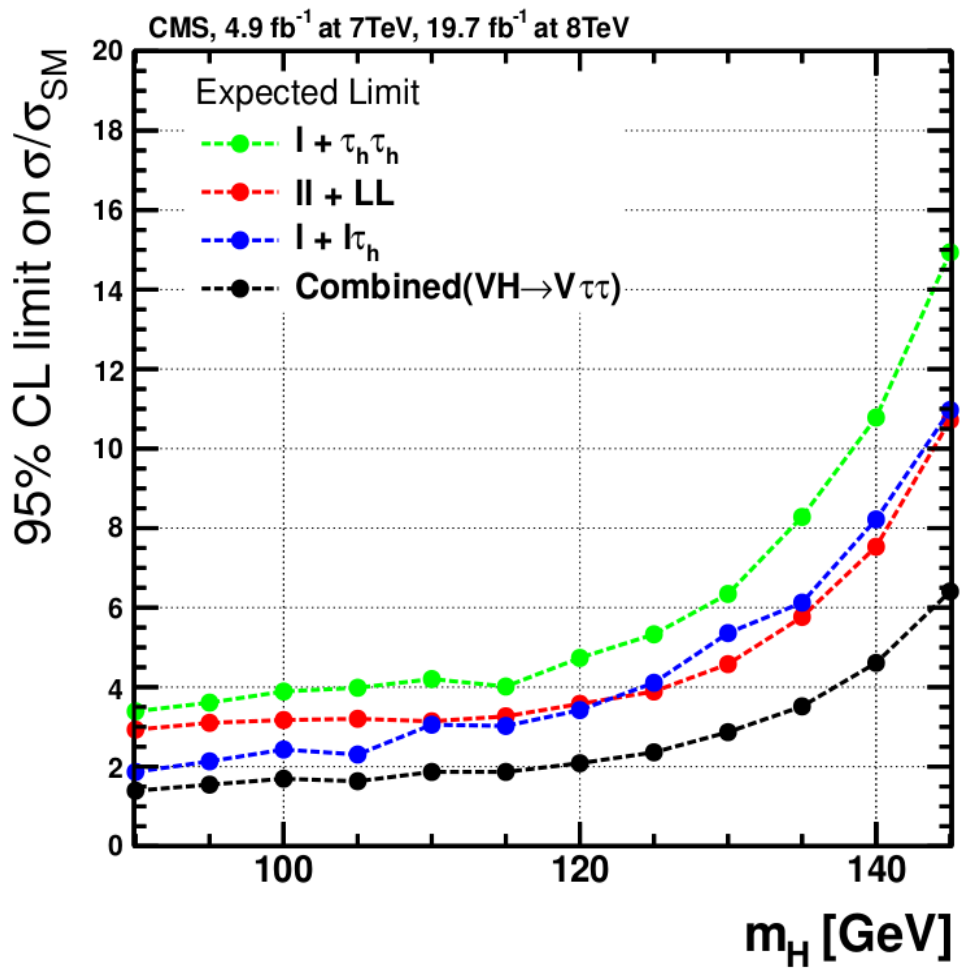
→ ℓ ℓ ℓ τ

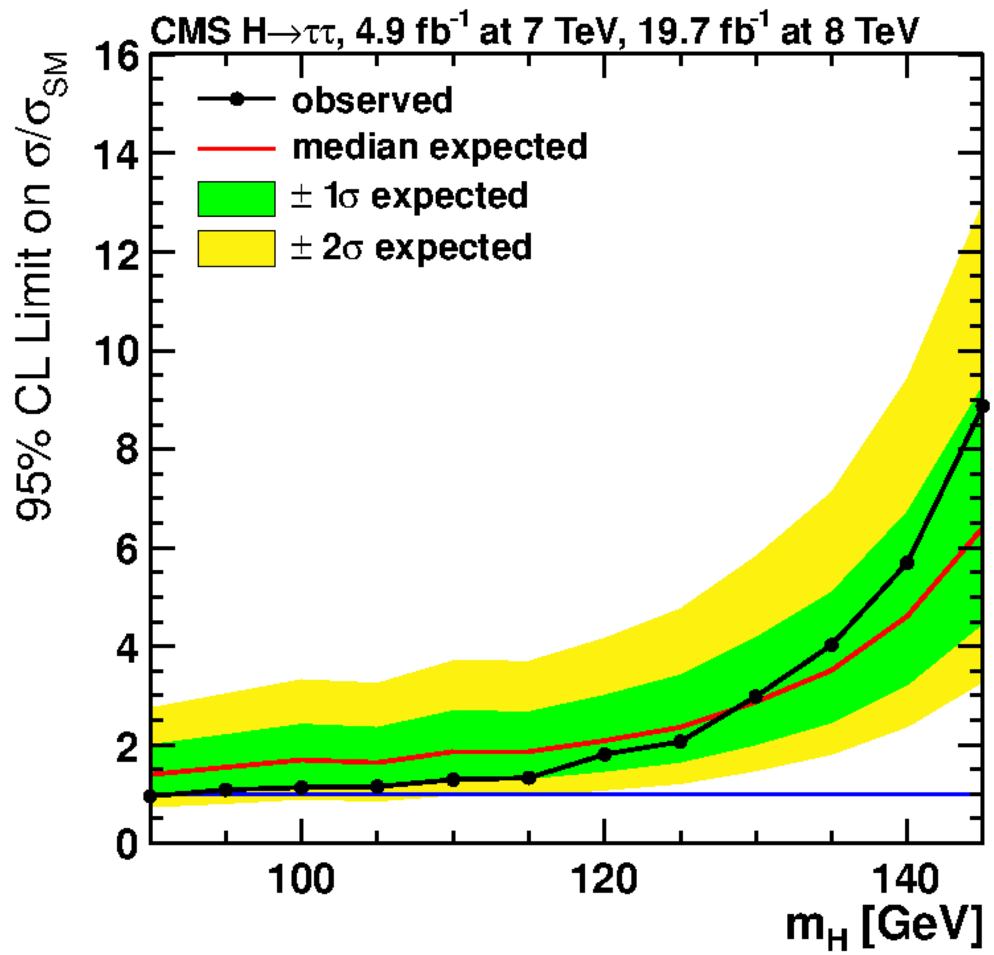
WH → ℓ± ℓ± τ

→ ℓ τ τ



→Slight downward fluctuation w.r.t. background





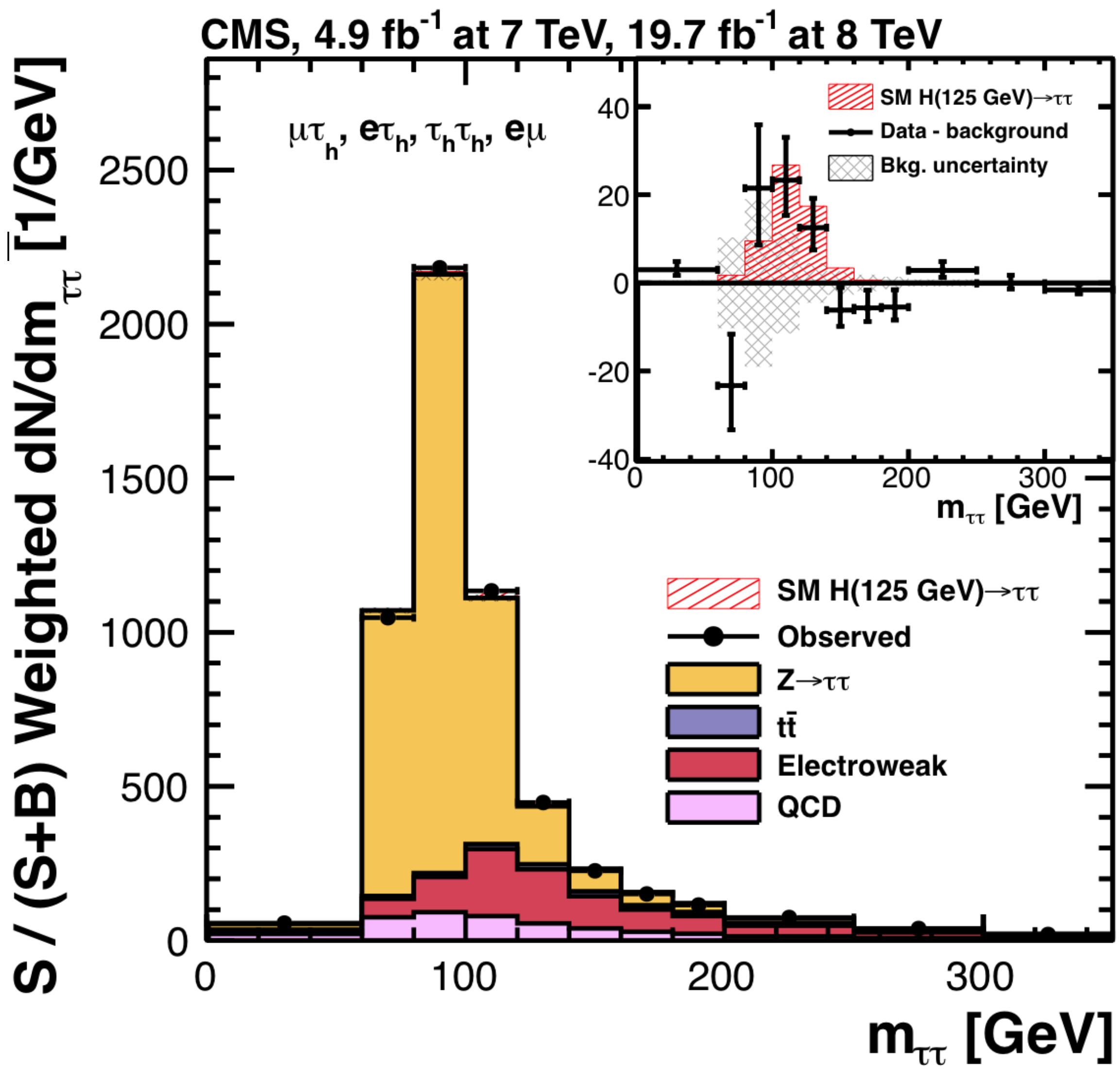
Strongest channel ZH→ℓℓLL; sensitivity at ~2x SM

Final result combining gg+VBF+VH production and all final states, weighted by bins of ln[S/(S+B)]

Clear evidence for signal!

→ 3.2σ obs (3.7σ exp)

$\mu_{\tau\tau} = 0.78 \pm 0.27$



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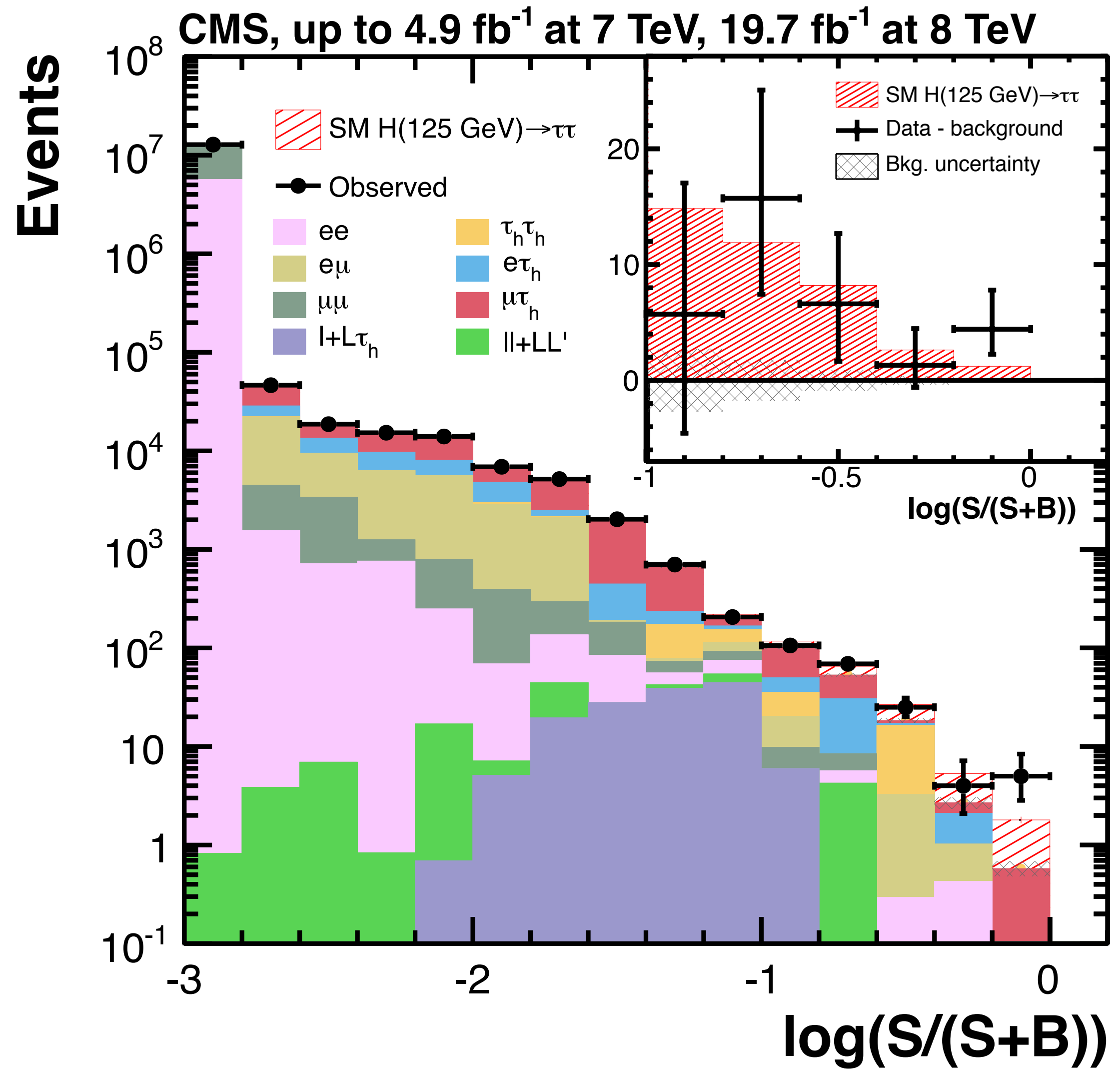
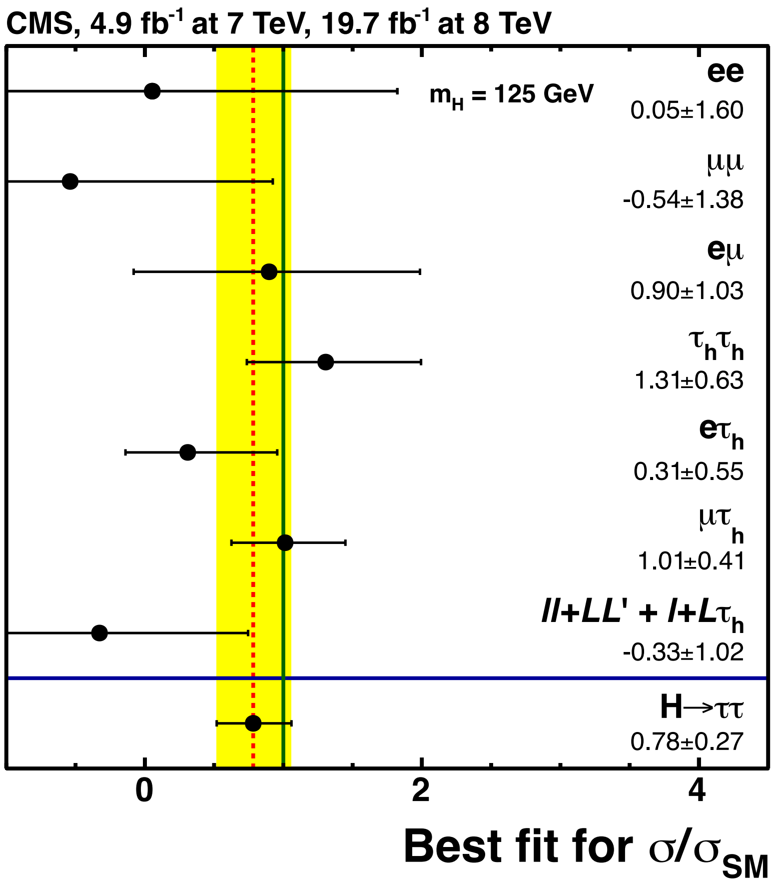
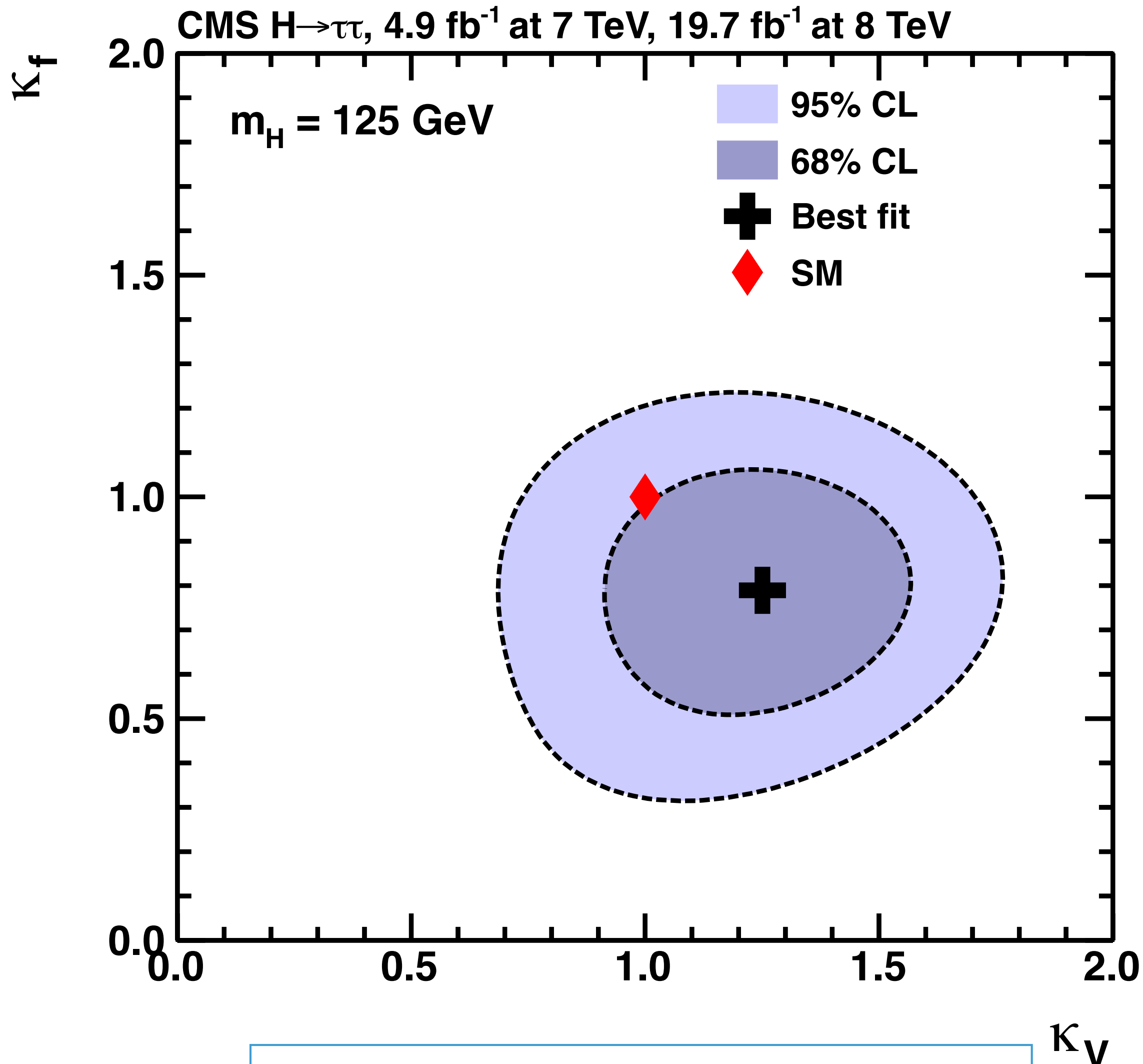
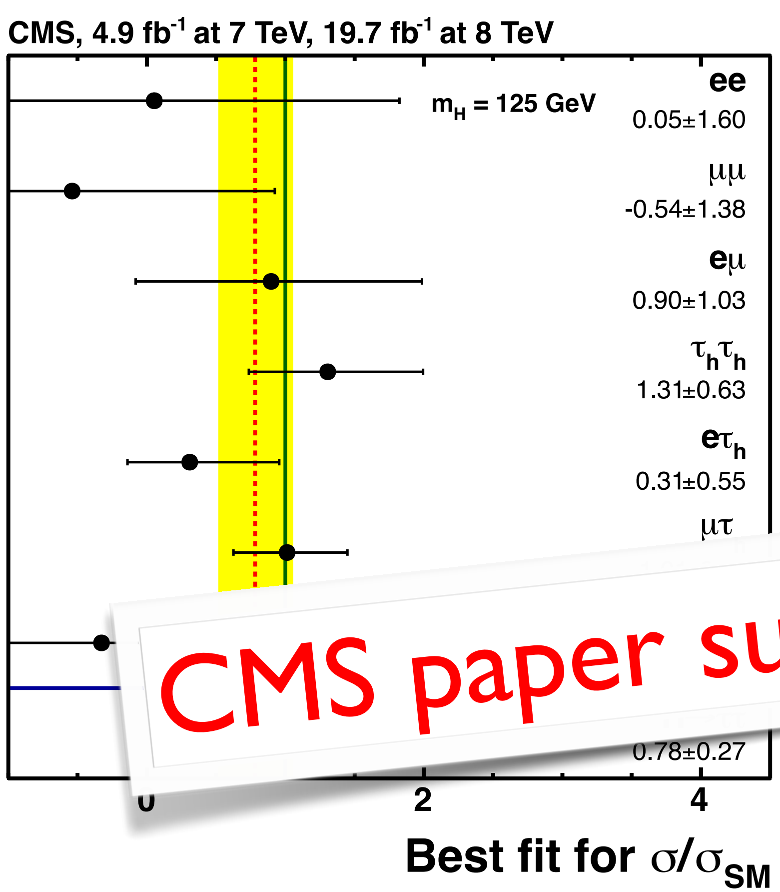


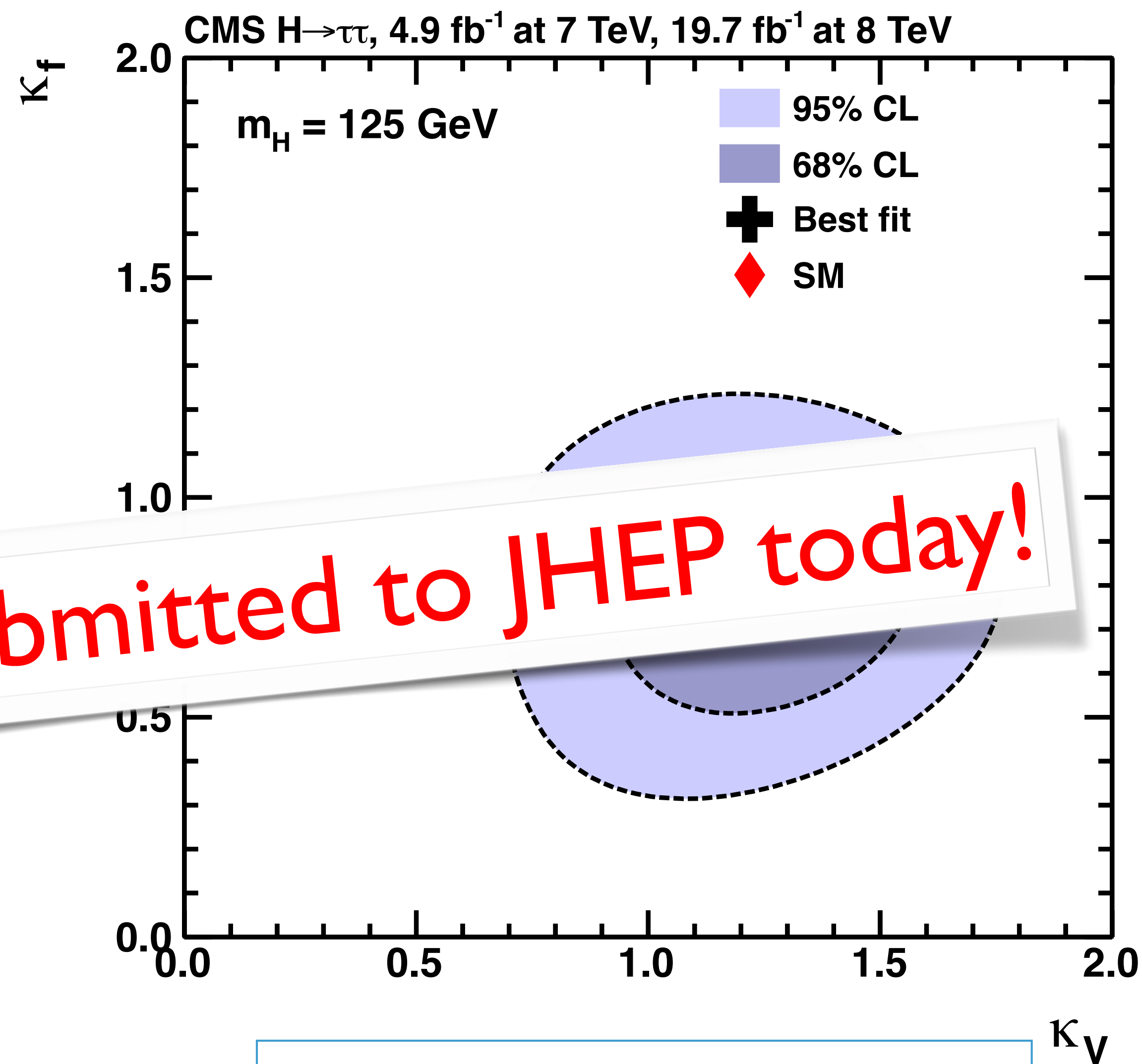




no anomalies among channels; VH pulls fit down somewhat

ff, VV couplings agree with SM predictions





CMS paper submitted to JHEP today!

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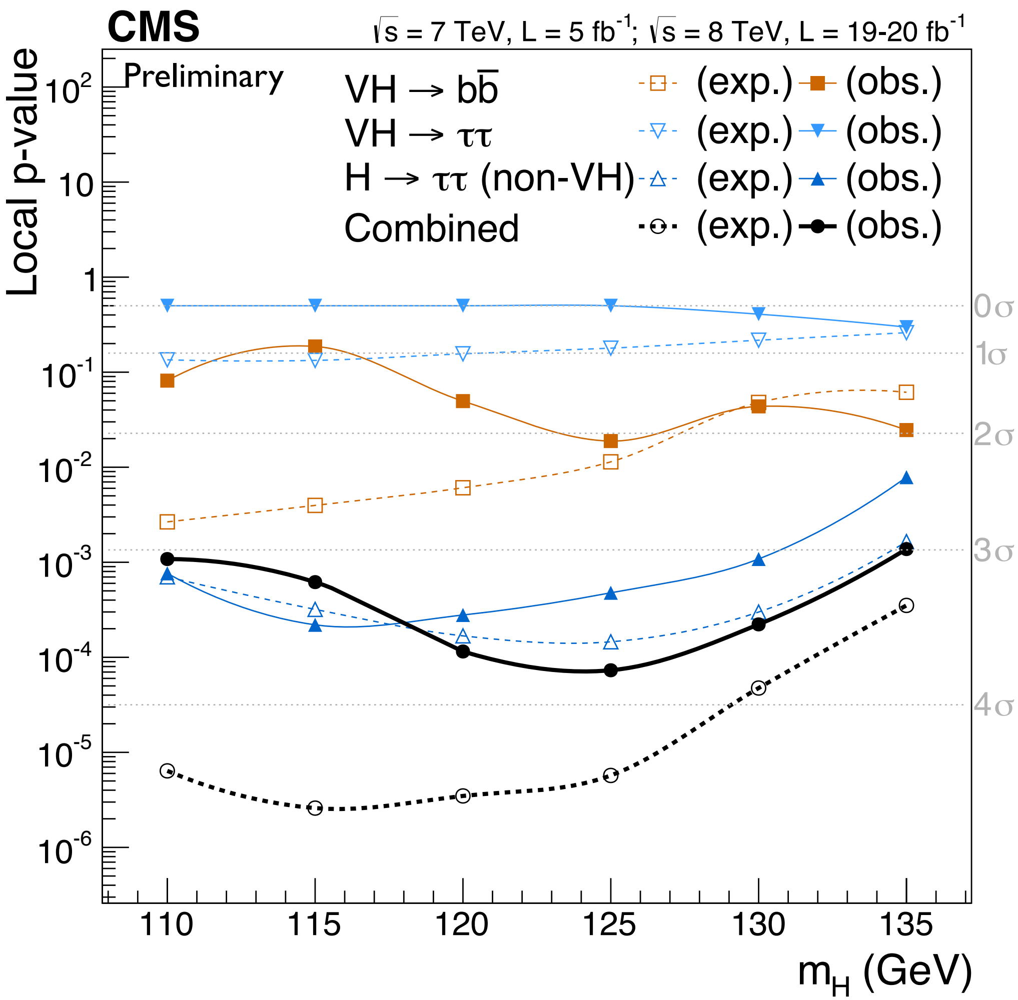
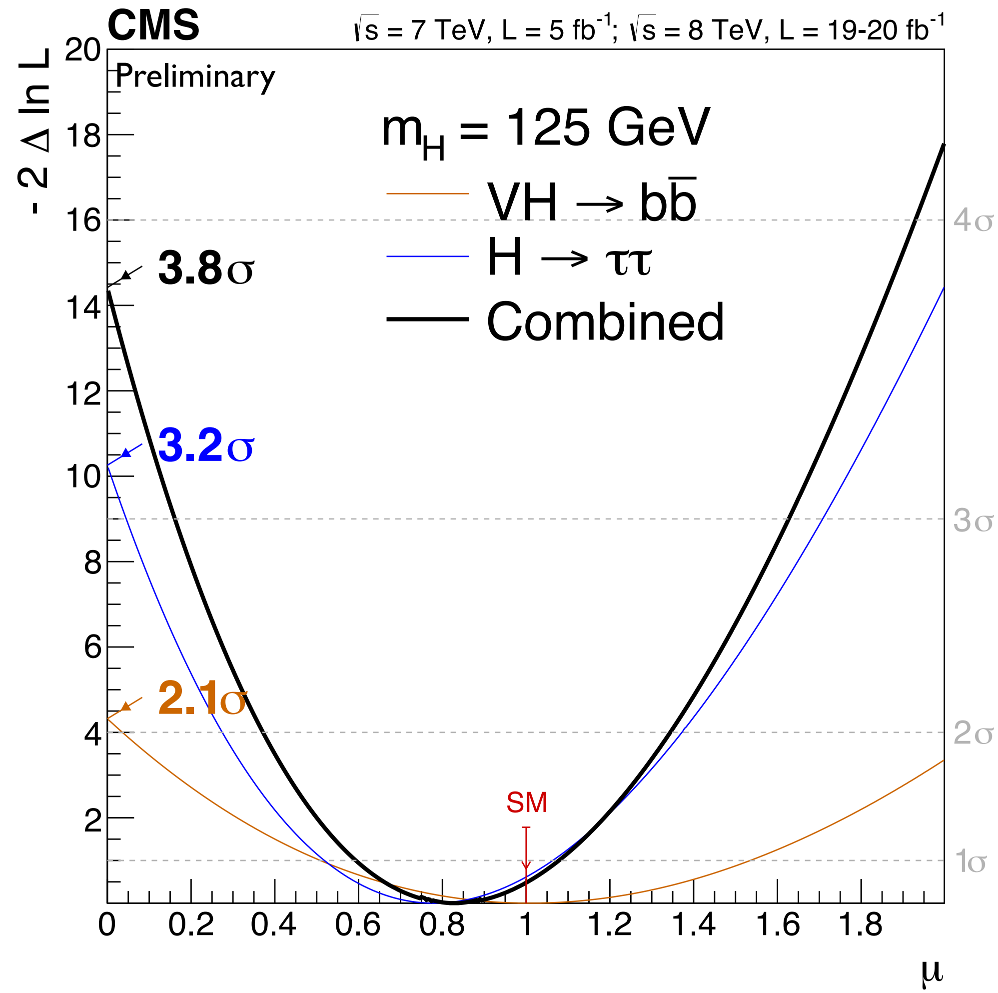
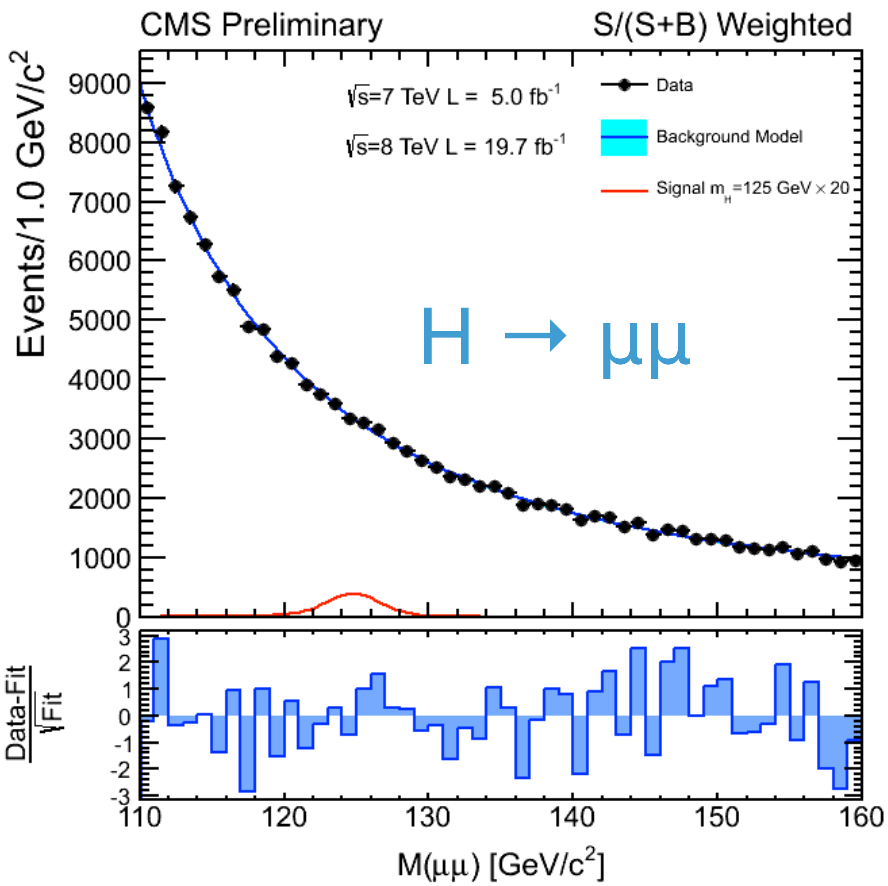
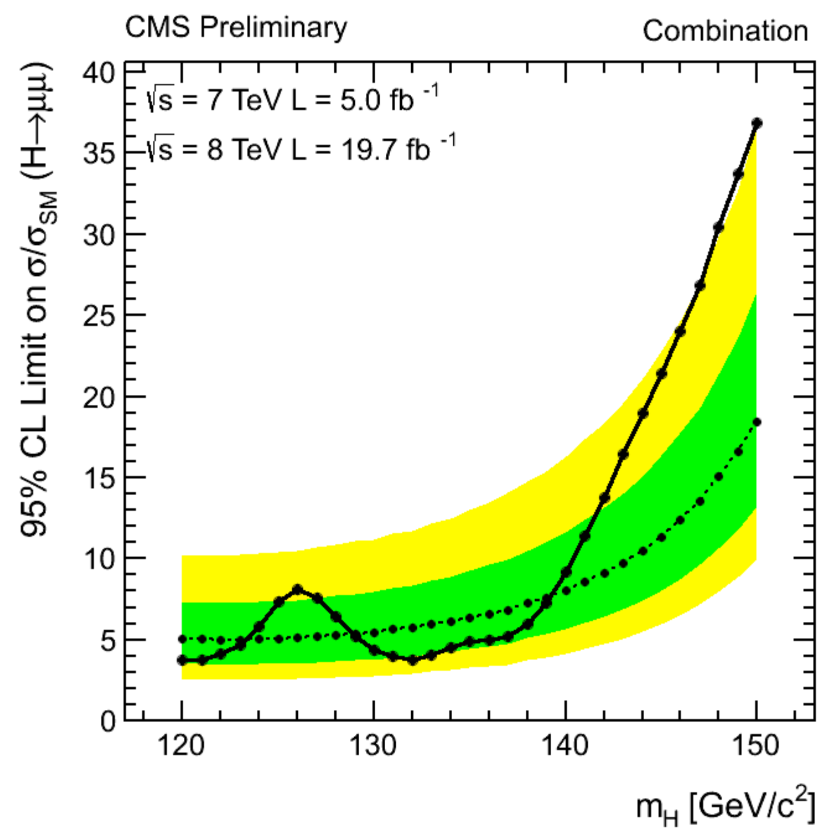




Combined results on bb + ττ: **3.8σ observed** (4.4 exp.)

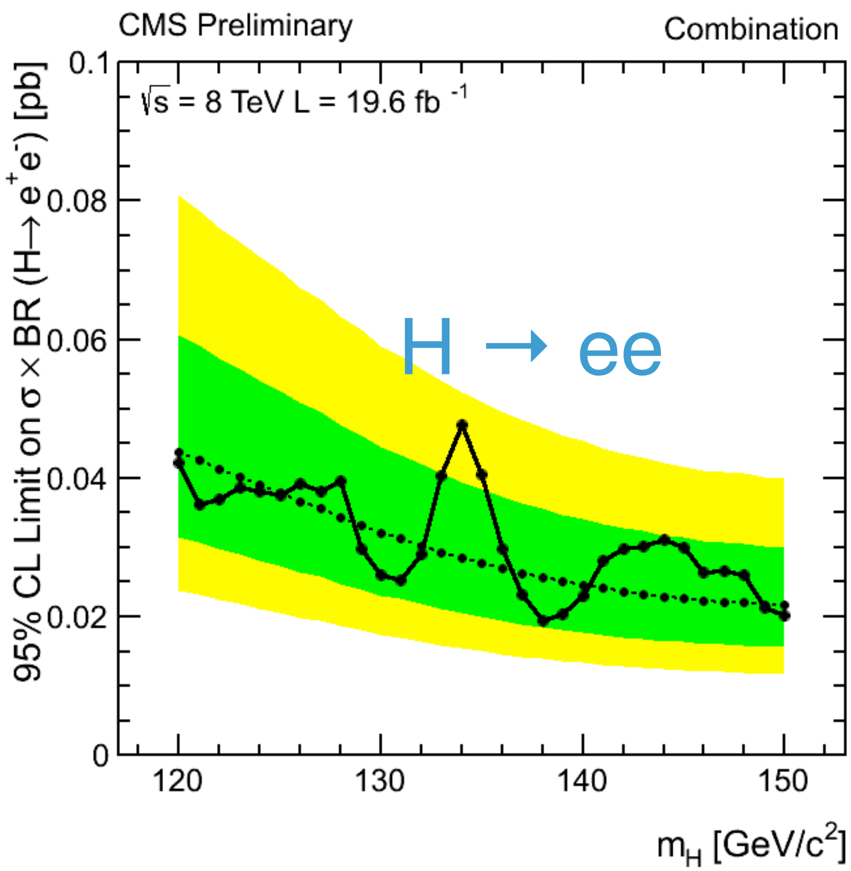


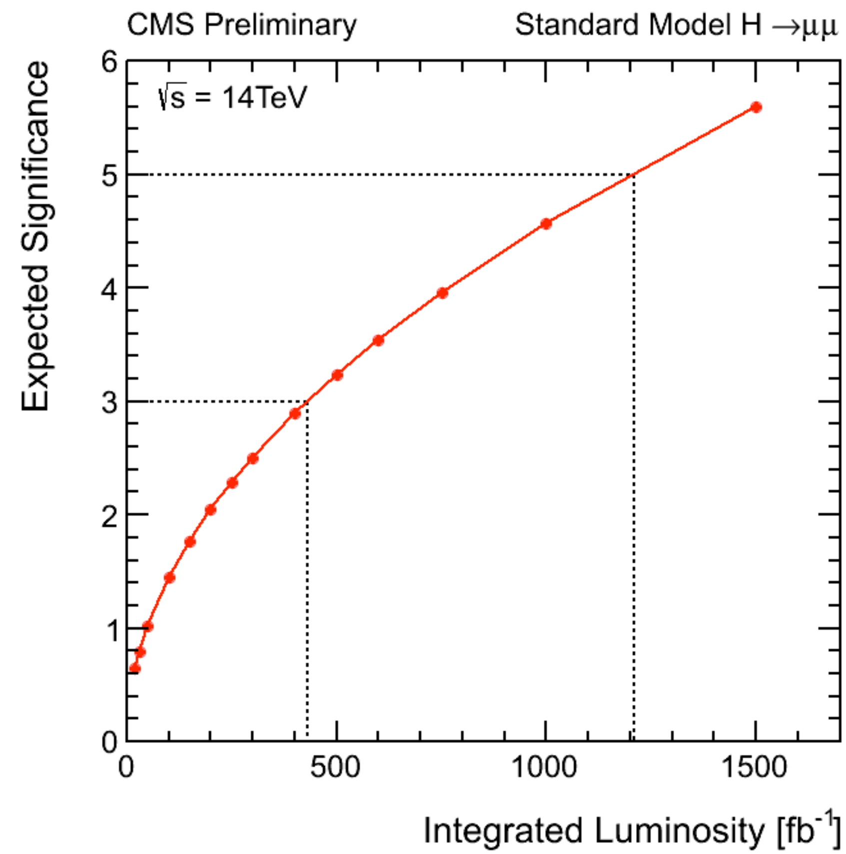


Resolution: 1.6 - 2.5 GeV

Observed limit: 7.4 x SM

Expected limit: 5.1 x SM

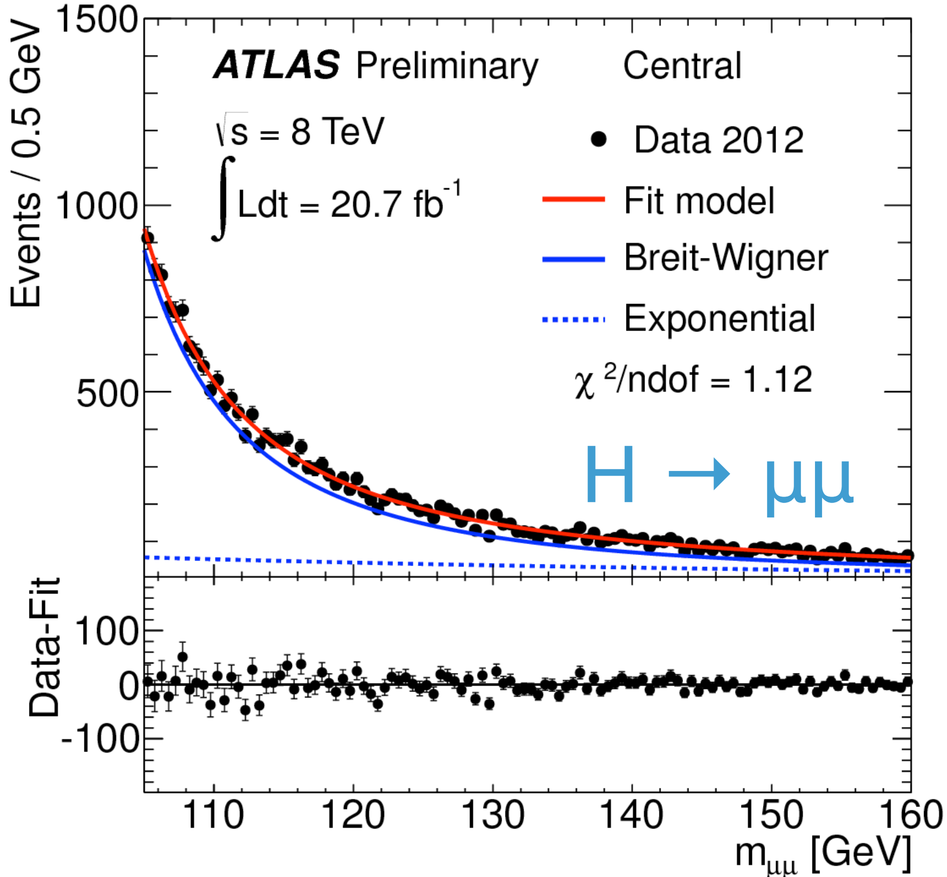




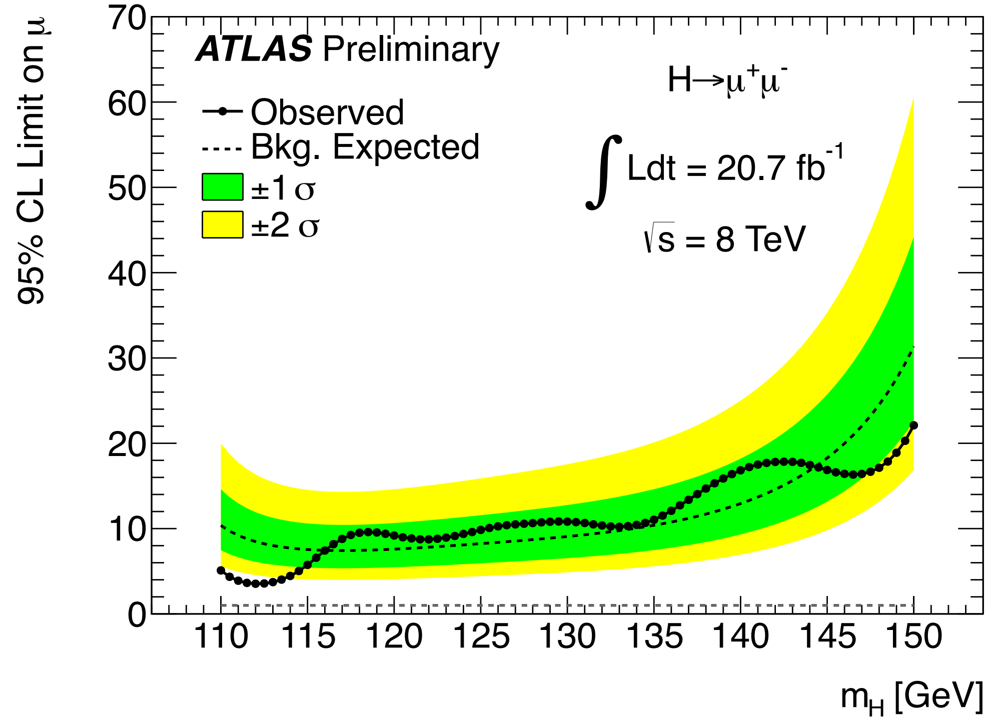
No signal in H → ee

Need 1.2 ab^{-1} for 5σ on μμ

No flavor universality in H(125) decays!



Fit to data



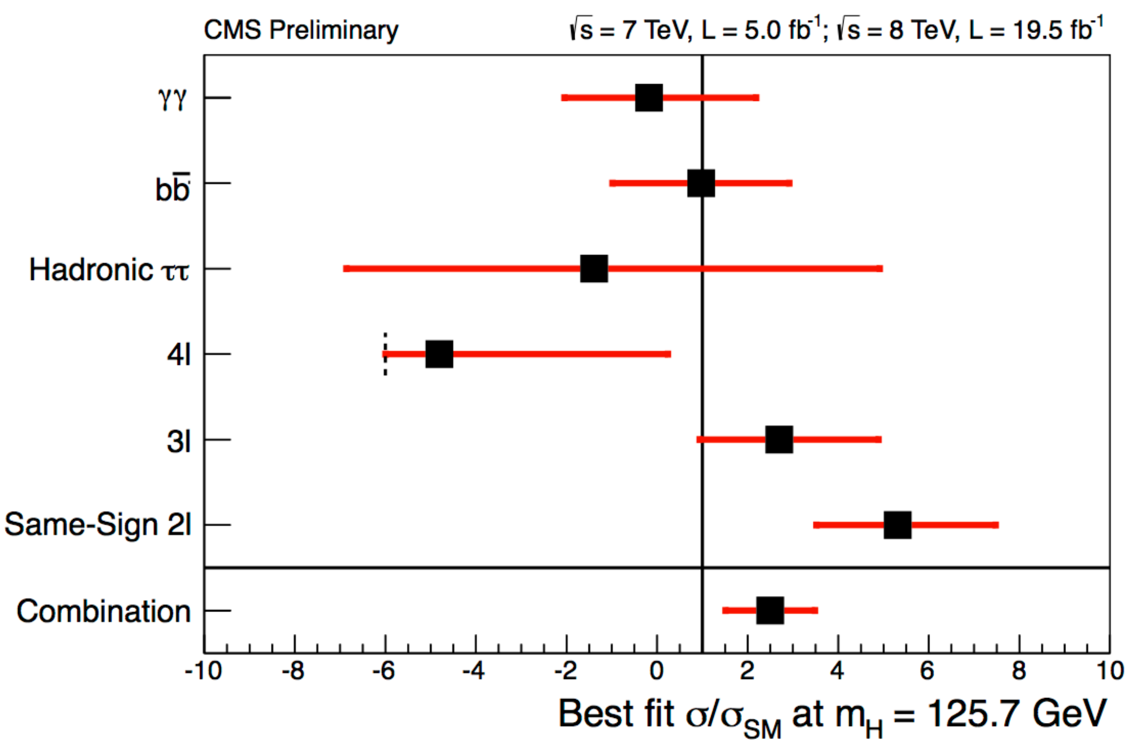
Observed limit: 9.8 x SM

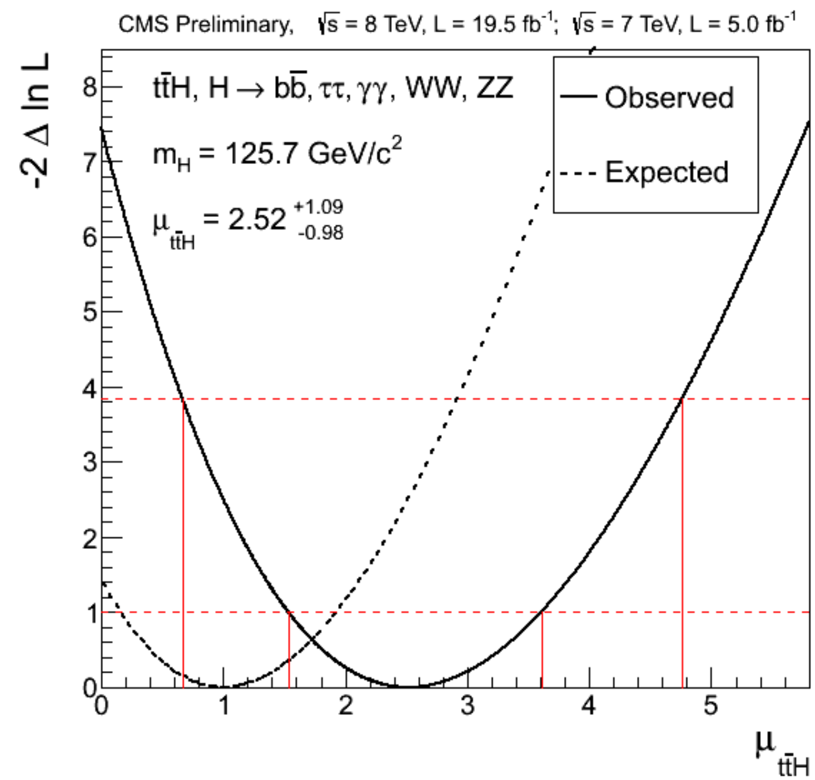
Expected limit: 8.2 x SM

What about ttH? CMS multichannel search yields

$$\mu_{ttH} = 2.5 \pm 1.0$$

⟹ One to watch for in Run 2!





LHC H→bb,ττ summary

	ATLAS sig	CMS sig	ATLAS μ	CMS μ
bb	-	2.1σ	$0.2^{+0.7}_{-0.6}$	1.0±0.5
ττ	4.2σ (3.2σ exp)	3.2σ (3.7σ exp)	$1.4^{+0.5}_{-0.4}$	0.8±0.3
bb+ττ	-	3.8σ	-	-

Summary

- Strong evidence at the 3.8σ and 4.2σ levels for $H \rightarrow bb, \tau\tau$ in CMS and ATLAS, respectively (expected 3.7σ and 3.2σ for 125 GeV SM Higgs)

- Confirms the Tevatron results, but bb at LHC still at the 2σ level in each experiment

- No evidence for $H \rightarrow \mu\mu$, ee
  - $\Rightarrow$ H decays to leptons not universal

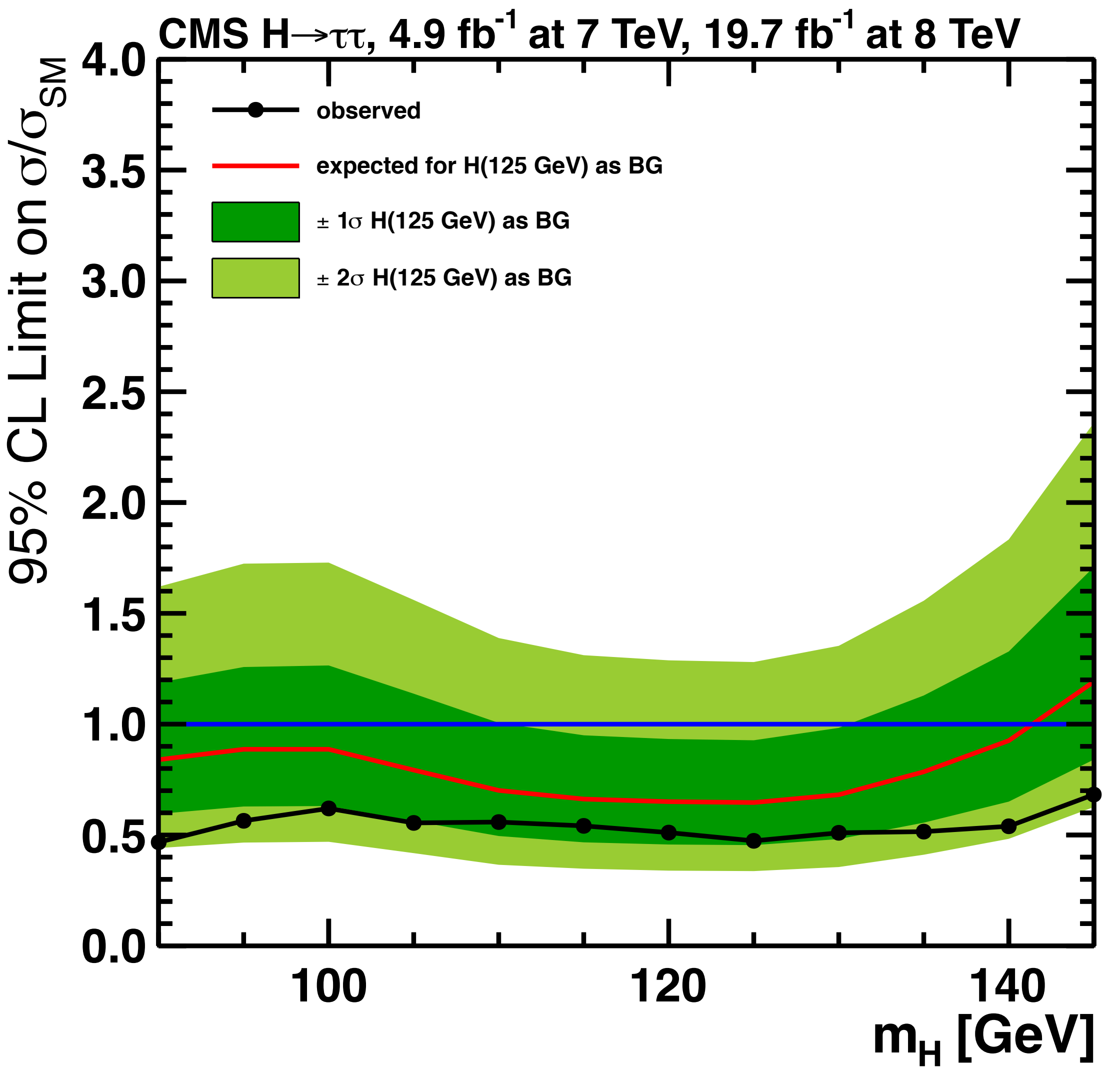
- At 14 TeV we can begin precision measurements!

Backup

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%)

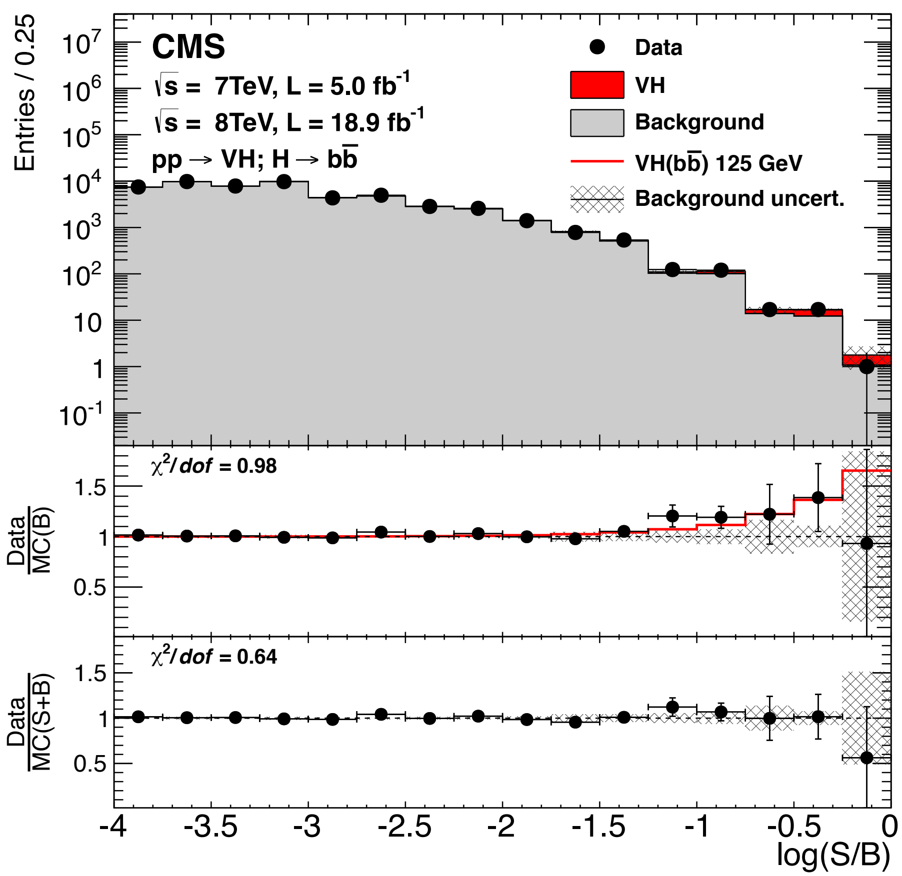
ATLAS Uncertainties on $\mu_{\tau\tau}$

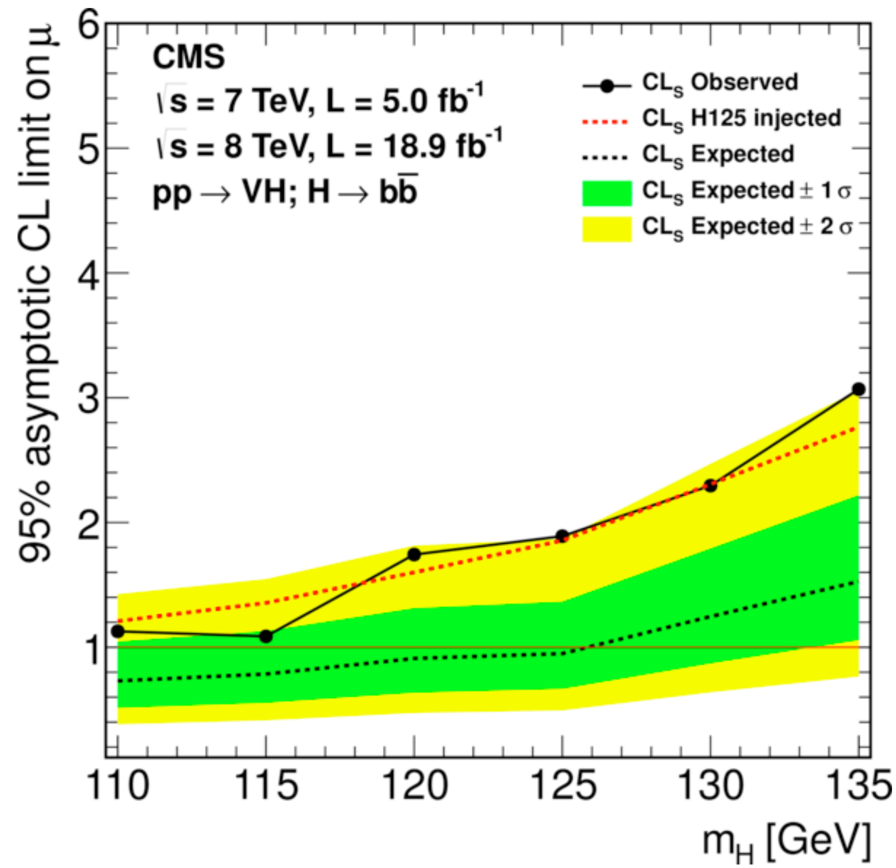
Source of Uncertainty	Uncertainty on μ
Signal region statistics (data)	0.30
$Z \to \ell\ell$ normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ boosted)	0.13
ggF $d\sigma/dp_T^H$	0.12
JES η calibration	0.12
Top normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ VBF)	0.12
Top normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ boosted)	0.12
$Z \to \ell\ell$ normalization ($\tau_{\text{lep}}\tau_{\text{had}}$ VBF)	0.12
QCD scale	0.07
di-τ_{had} trigger efficiency	0.07
Fake backgrounds ($\tau_{\text{lep}}\tau_{\text{lep}}$)	0.07
τ_{had} identification efficiency	0.06
$Z \to \tau^+\tau^-$ normalization ($\tau_{\text{lep}}\tau_{\text{had}}$)	0.06
τ_{had} energy scale	0.06



No additional Higgs states (SM-like) in nearby mass region

Limits at about 0.6 x SM





Plot in bins of ln(S/B) reveals 2.1σ excess (2.1 exp.)

$\mu_{bb} = 1.0 \pm 0.5$