CMS Di-fermion Higgs Results

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On behalf of the CMS collaboration

Higgs Hunting 2015
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Overview

Higgs boson discovered with mass close to 125 GeV

- for m_H=125 GeV many decay channels experimentally accessible
- **measurement of its properties** critical to understand **SM compatibility**

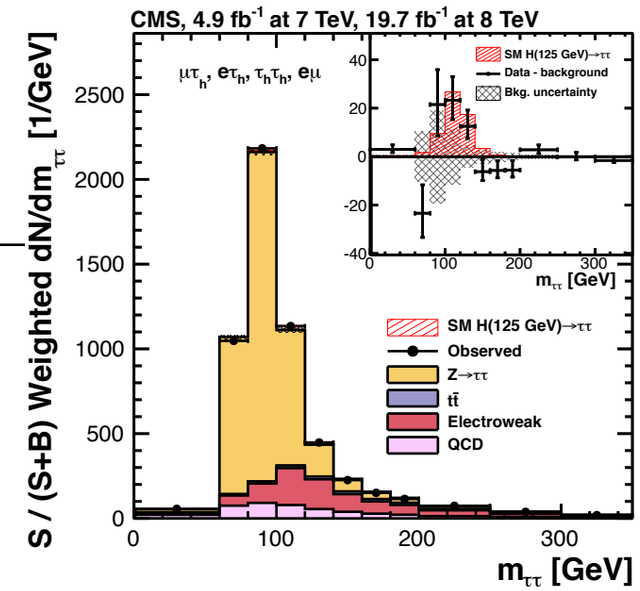
CMS run1 legacy **public results** on Higgs decaying to fermions

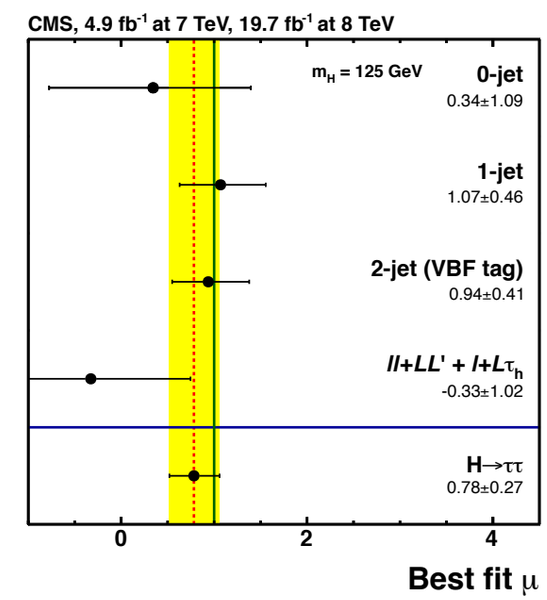
$\mu = \sigma/\sigma_{SM}$	$b\bar{b}$	$\tau\tau$	$\mu\mu/ee$
ggH	no public result	$\mu = 0.85^{+0.42}_{-0.38}$	set limit on $\sigma \cdot BR$
VBF	$\mu = 2.8^{+1.6}_{-1.4}$	$\mu = 0.95^{+0.43}_{-0.38}$	set limit on $\sigma \cdot BR$
VH	$\mu = 0.98^{+0.47}_{-0.44}$	$\mu = 0.87^{+1.0}_{-0.88}$	no public result
ttH	$\mu = 1.2^{+1.6}_{-1.5}$	$\mu = 1.33^{+6.1}_{-3.6}$	no public result

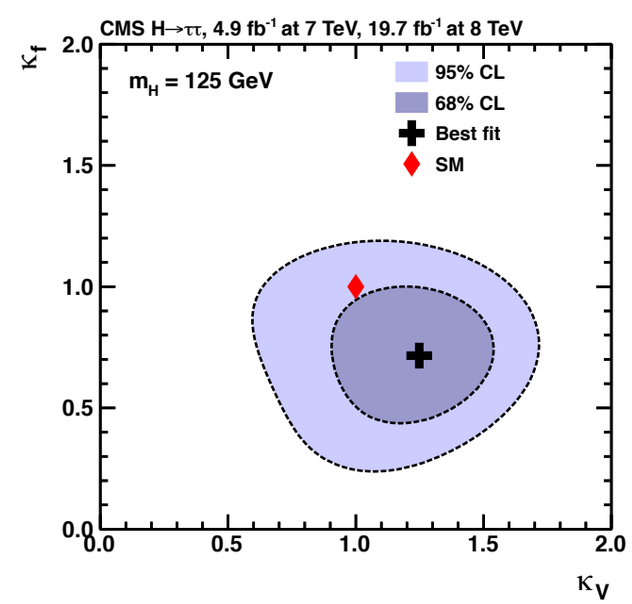
- Most sensitive channels
  - H ⟶ ττ (ggH and VBF)
  - VH, H ⟶ bb
- Combining these channels: **evidence of Higgs coupling to fermion**

H ⟶ ττ

- includes **the main 4 production modes**
- event categorised in
  - τ decay modes (e, μ, τ_h)
  - number of jets
  - boost of the Higgs candidate
- Signal extraction
  - **simultaneous fit of the Higgs mass** of all categories
- Results
  - **Evidence of H ⟶ ττ with 3.2 σ**
  - **Signal strength and couplings compatible with SM**



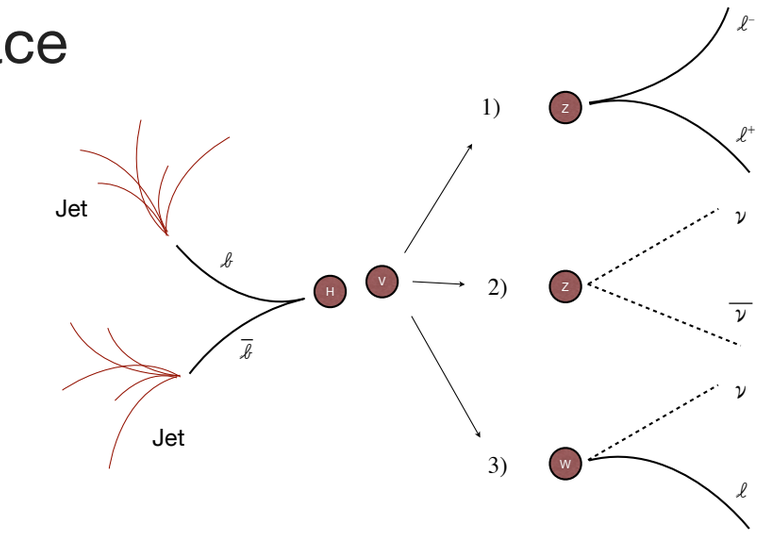




J. High Energy Phys. 05 (2014) 104 - CERN-PH-EP-2014-001

VH, H ⟶ bb

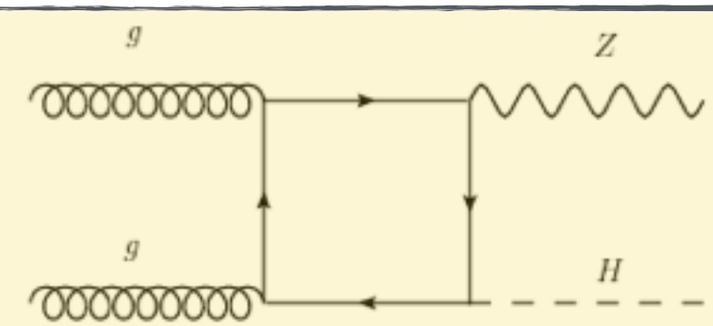
- **categorise in $p_T(V)$**: isolate signal enriched phase space
- signal extraction:
  - BDT to classify signal events using kinematic and experimental variables - specific per channel
  - **simultaneous likelihood fit of BDT output**

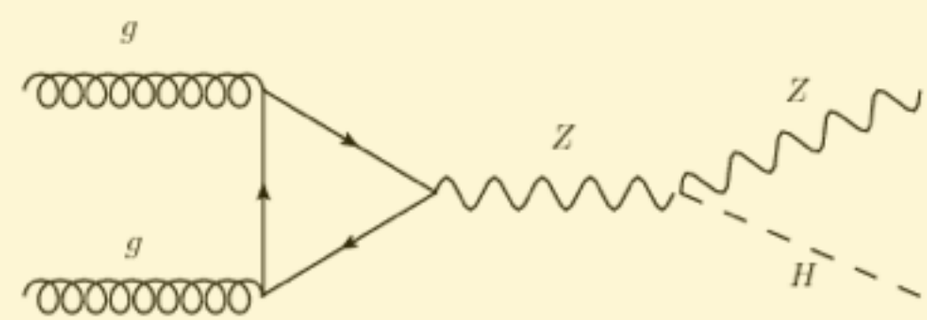


Phys. Lett. B 740 (2015) 51

Updated new results including **ggZH process in signal**

- ggZH gives **sizeable** contribution in **high p_T regions**
- updated results (CERN-PH-EP-2014-288):
  - best-fit $\mu = 0.89 \pm 0.43$
  - $\sigma/\sigma_{SM} < 1.68$ (0.85 expected)
  - significance: 2.08σ (2.52σ expected)





Phys.Rev. D, 89 (2014) 012003 - CERN-PH-EP-2013-188

Fermion combination

Evidence of the Higgs couplings to down-type fermions

Channel ($m_H = 125$ GeV)	Significance (σ)		Best-fit μ
	Expected	Observed	
$VH \to b\bar{b}$	2.3	2.1	1.0 ± 0.5
$H \to \tau\tau$	3.7	3.2	0.78 ± 0.27
Combined	4.4	3.8	0.83 ± 0.24

- combine only VH ⟶ bb and H ⟶ ττ
- **VH ⟶ bb does not include ggZH**
- significance driven by the H ⟶ ττ evidence
- combined best-fit μ = 0.83 ± 0.24 **compatible with SM**

Nature Phys. 10 (2014) 557-560 - CERN-PH-EP-2014-004

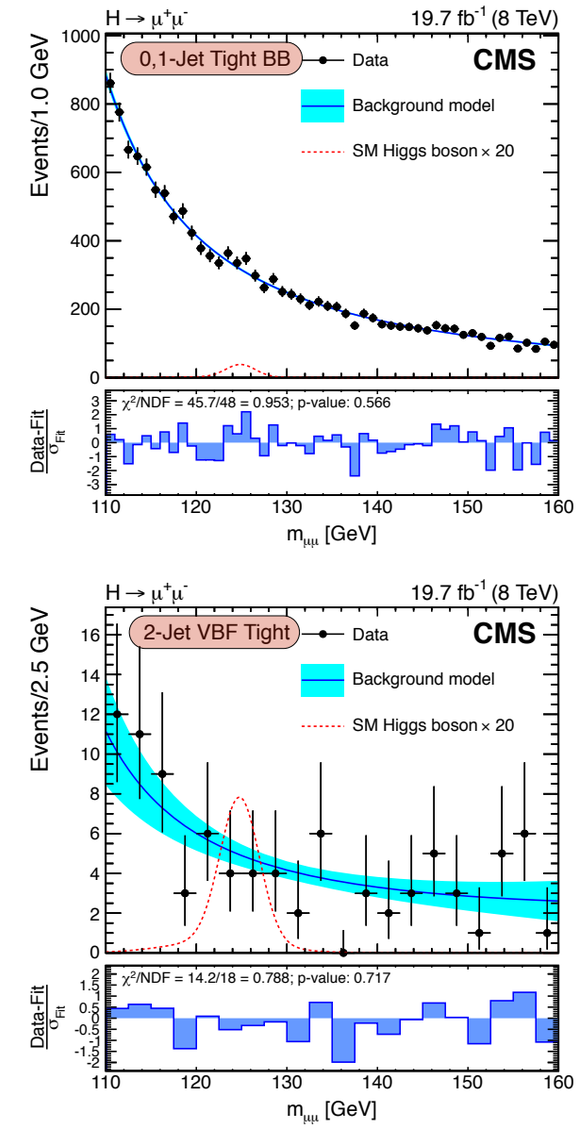
H ⟶ μμ/ee

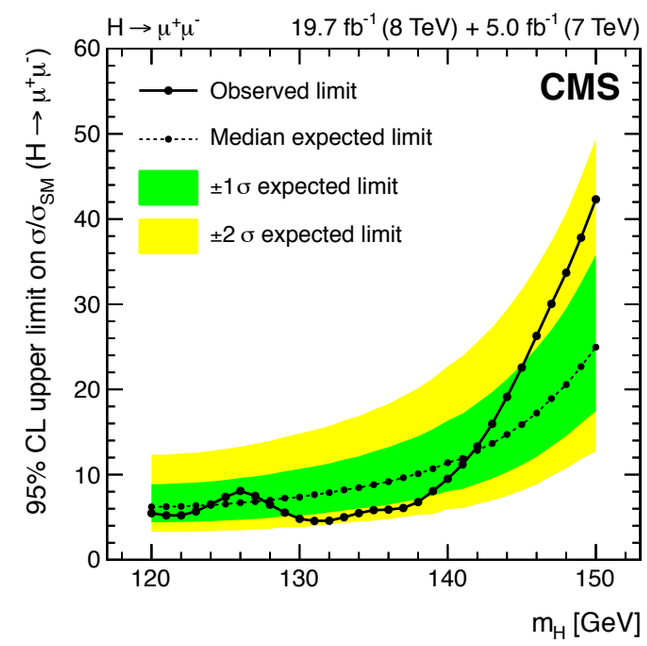
- **High mass resolution** 1.6 - 2.5 GeV FWHM @ 125 GeV
- Analysis divided in categories based on
  - Higgs mass resolution
  - Production mechanism (ggH & VBF)
- Signal extraction
  - **parametric fit of the muon/electron invariant mass**

Results @ 125 GeV - Limits @ 95% CL:

- σ x BR (H ⟶ μμ) < $3.4*10^{-2}$pb
  - σ/σ_{SM} < 7.4 (6.9 expected)
- σ x BR (H ⟶ ee) < $3.8*10^{-2}$pb
- assuming SM production
  - BR(H ⟶ μμ) < 0.0016
  - BR(H ⟶ ee) < 0.0019

2 examples out of 15 fitted

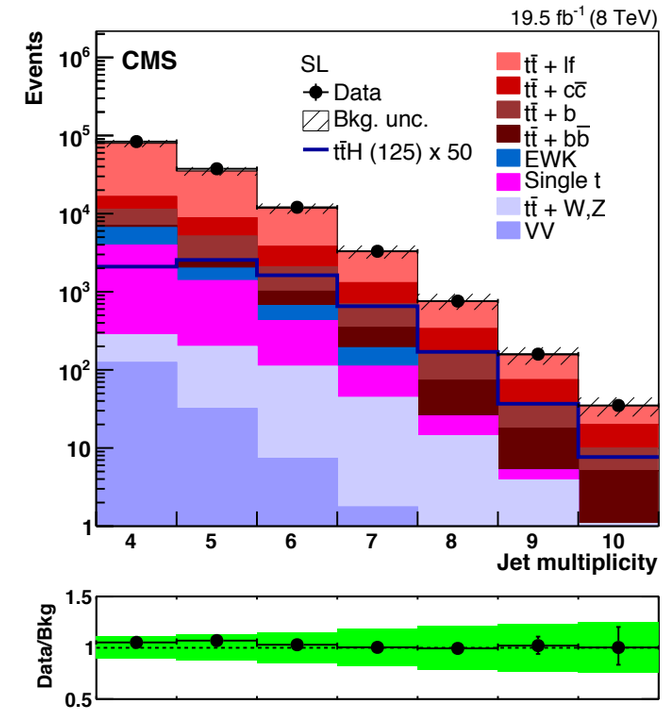


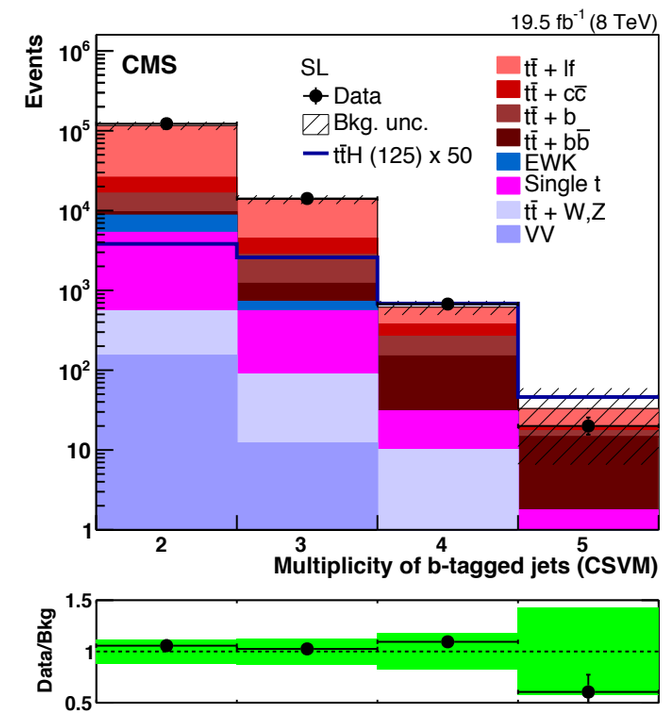


Phys. Lett. B 744 (2015) 184 - CERN-PH-EP-2014-243

ttH, H ⟶ bb - Matrix Element Method

- Selecting events with **at least one lepton and 4 jets**
- Events are categorised in number of jets number of leptons and b-tagged jets to isolate high S/B region
- main **irreducible background tt+bb**
  - large theory uncertainty
- **Matrix Element Method for signal classification**
  - **uses theory information on kinematics of signal and background (tt+bb)**
  - suits well **large combinatorics** on Higgs candidate

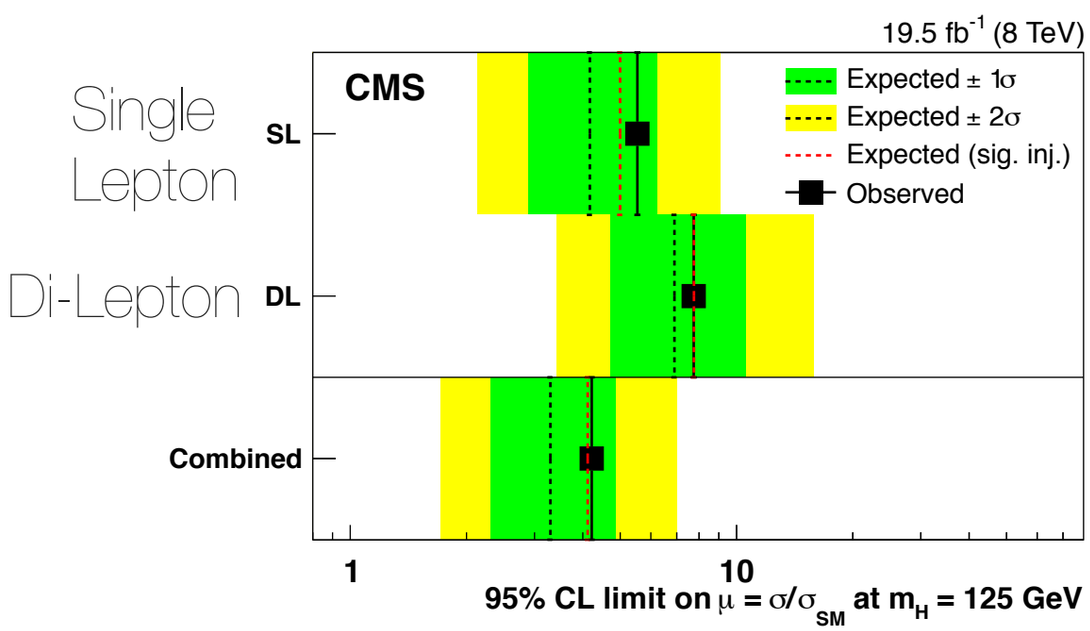


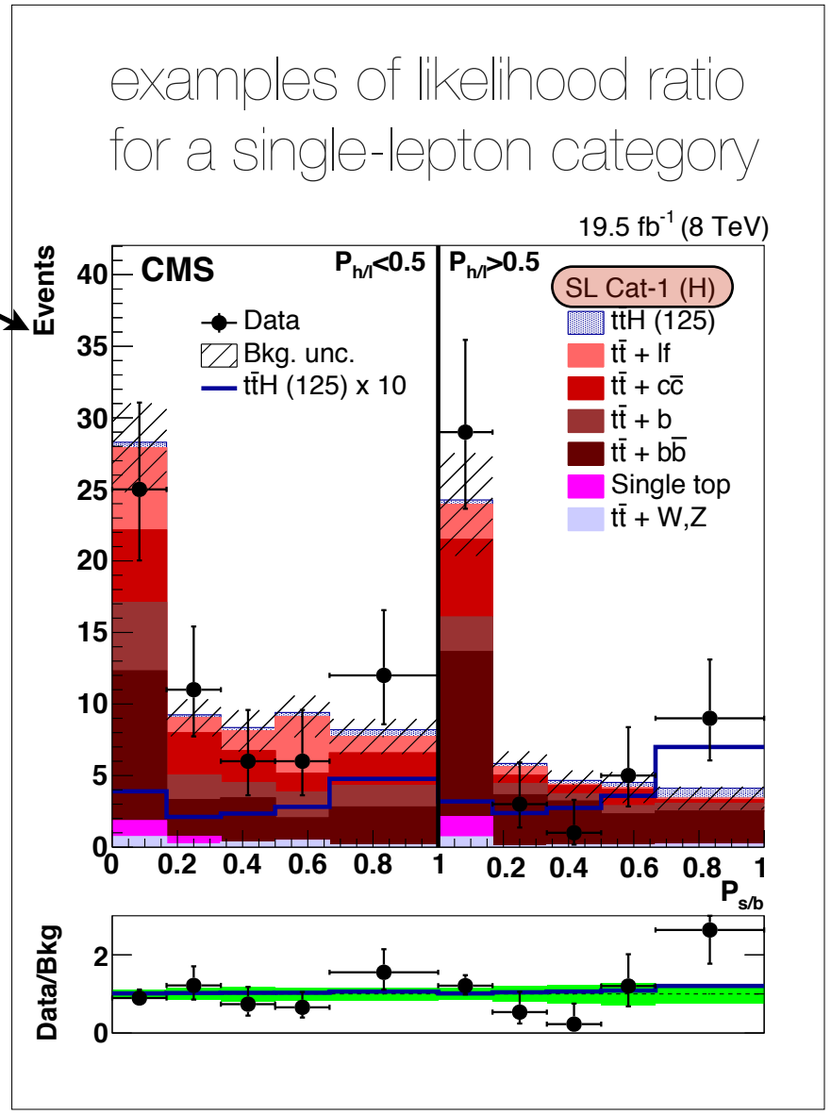


Eur. Phys. J. C 75 (2015) 251 - CERN-PH-EP-2015-016

ttH, H ⟶ bb - Matrix Element Method

- signal extraction from **fit of likelihood ratio** using templates from signal and background
- **MEM shows improvement compared to previous result using BDT instead of MEM**
- $\sigma/\sigma_{SM} < 4.2$ (expected 3.3) @95% CL
- best-fit $\mu = 1.2 \pm 1.6$

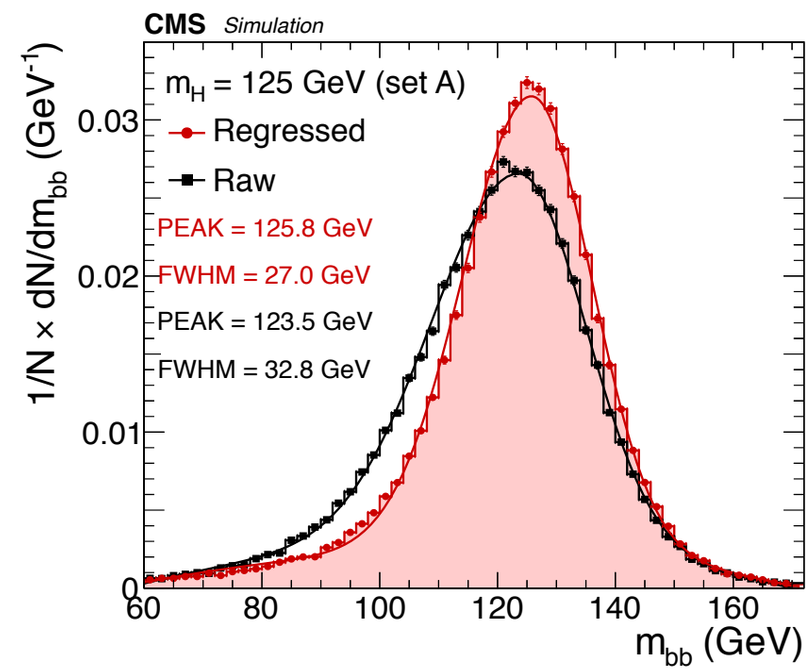


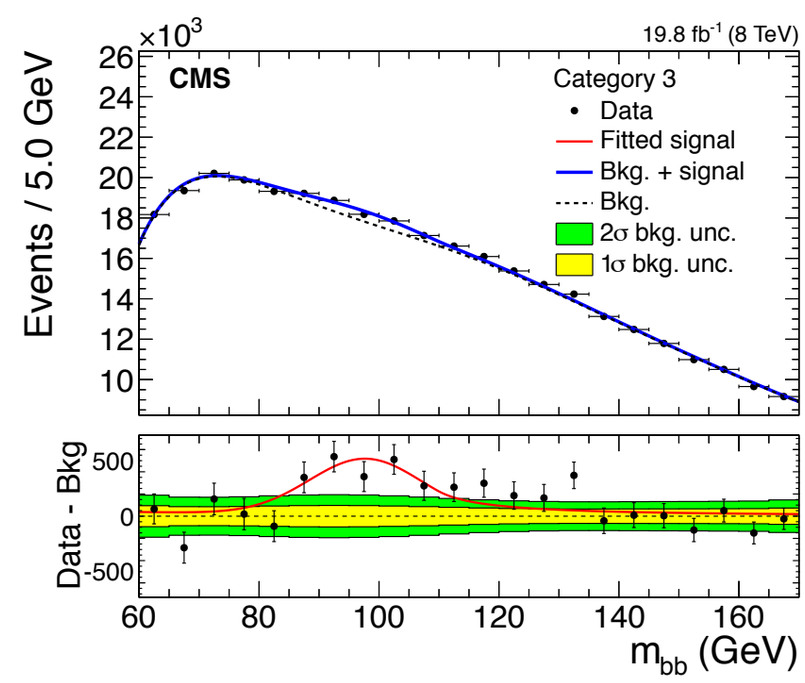


VBF/ggH, H ⟶ bb

Fully hadronic search

- **Challenging trigger** - two different strategies
  - **b-tagging** used at trigger level
  - **VBF tag**: rapidity separation and invariant mass
- **b-tagging** and **rapidity** of the jets used to **reduce combinatorics** on Higgs candidate
- analysis strategy
  - **MVA to tag the Higgs jets**
  - **b-jet energy regression** - as in VHbb
  - **quark-gluon discriminator** reduce background
- **extraction of the Z ⟶ bb peak signal**
  - **signal significance: 3.6σ (3.3σ expected)**
  - **best-fit $\mu_Z = 1.10\ ^{+0.44}_{-0.33}$**

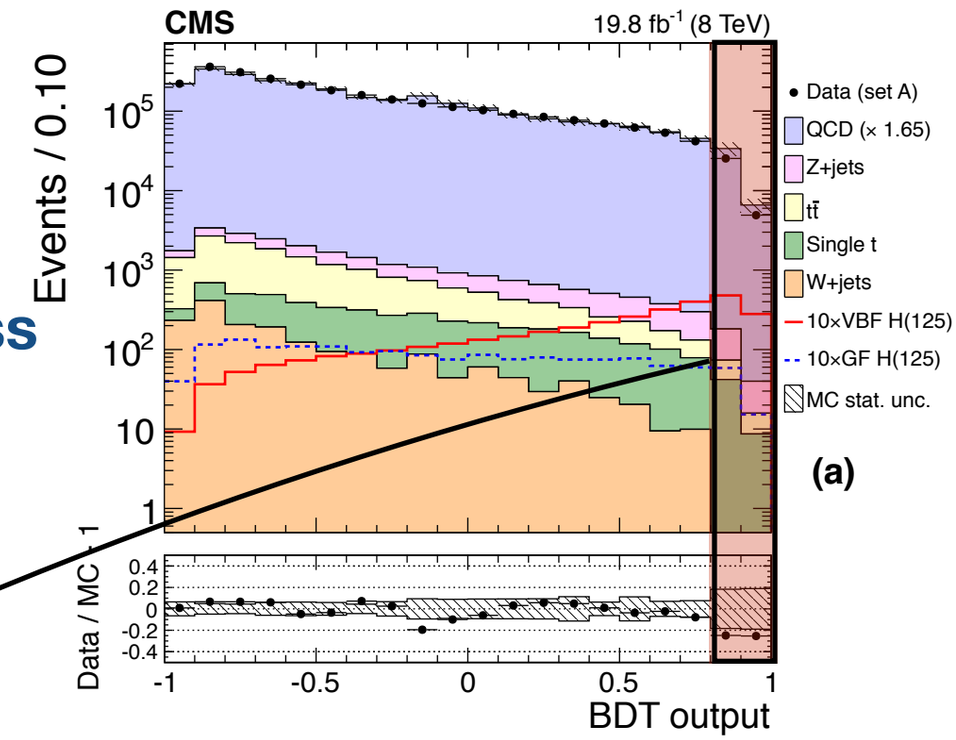


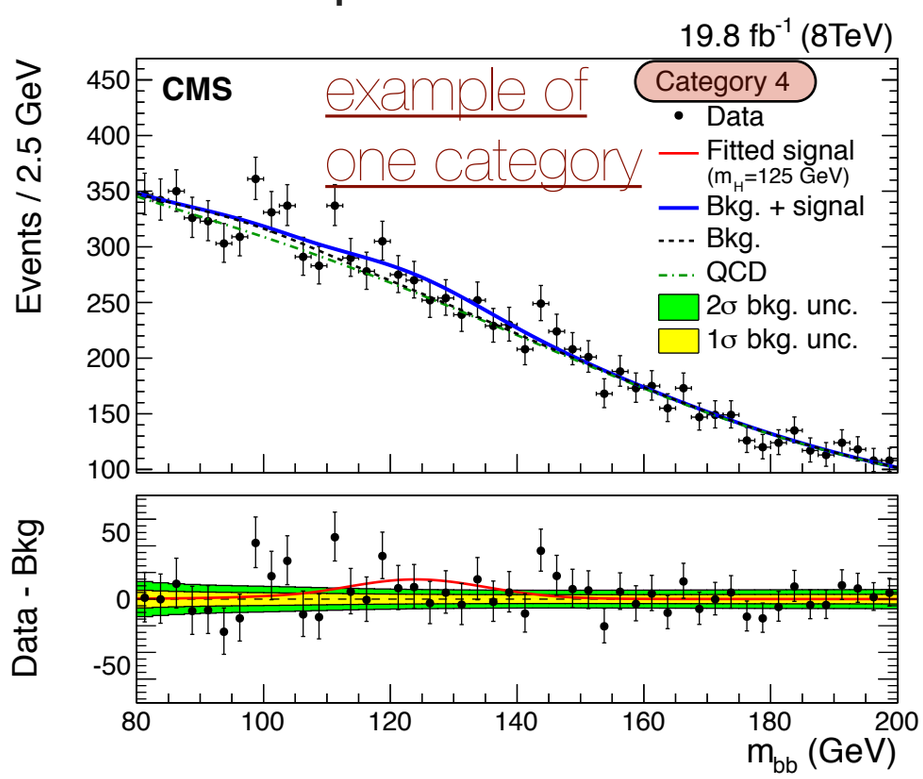


CERN-PH-EP-2015-121

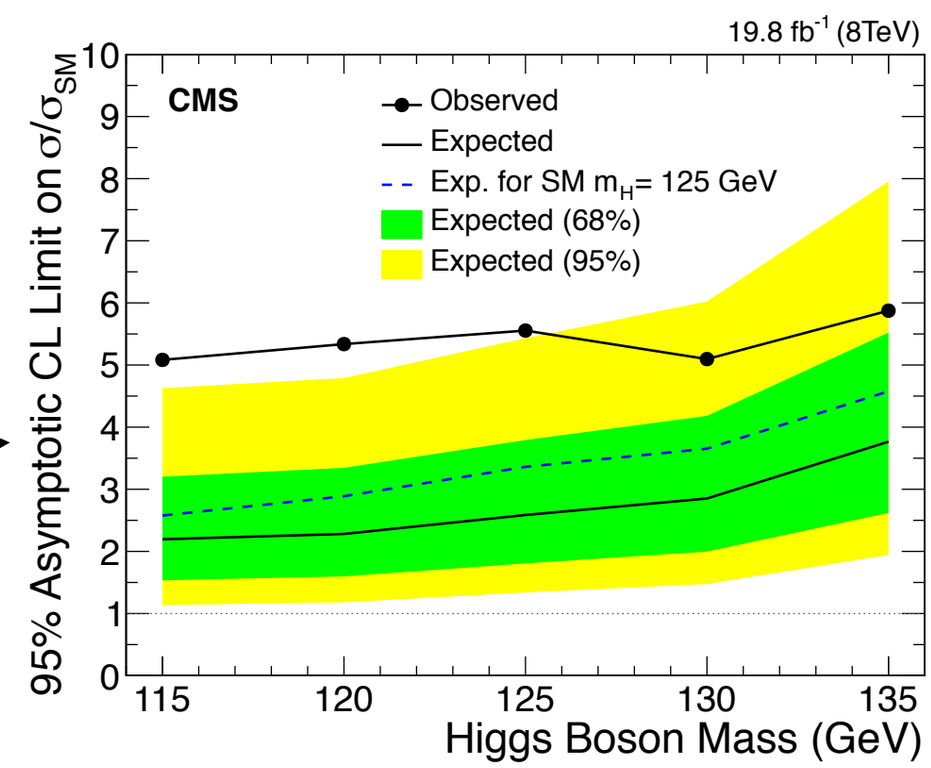
VBF/ggH, H ⟶ bb

- use of **BDT to classify signal and background**
  - only use of experimental variables (**not kinematic**)
- signal extraction: **fit of the higgs-jets invariant mass**
- results:
  - $\sigma/\sigma_{SM} < 5.5$ (2.5 expected).
  - signal significance: 2.2σ (0.8σ expected).
  - best-fit μ = 2.8 ± 1.6





Combining all categories



H ⟶ bb combination - VH/ttH/VBF

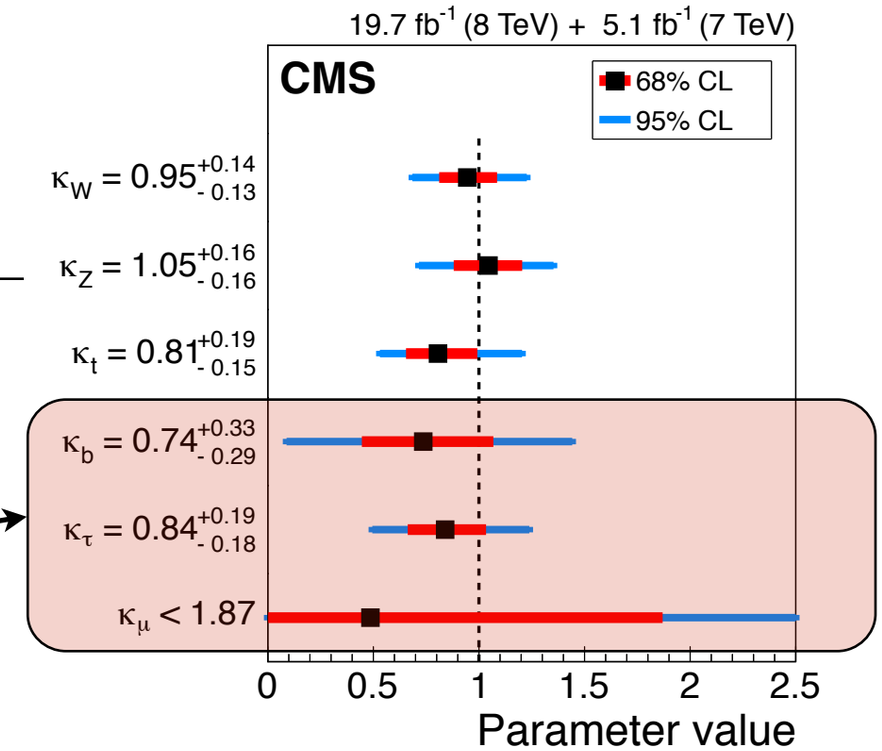
- VBF, VH, and ttH with H ⟶ bb have been combined
- **VH updated with ggZH inclusion in the signal model**
  - ggZH not negligible in high p_T region
  - signal strength reduced to 0.89 ± 0.43 compared to old result
- **ttH using the BDT analysis results**

$H \to b\bar{b}$ Channel	Best fit (68% CL) Observed	Upper limits (95% CL) Observed	Upper limits (95% CL) Expected	Signal significance Observed	Signal significance Expected
NEW VH	0.89 ± 0.43	1.68	0.85	2.08	2.52
$t\bar{t}H$	0.7 ± 1.8	4.1	3.5	0.37	0.58
VBF	$2.8^{+1.6}_{-1.4}$	5.5	2.5	2.20	0.83
Combined	$1.03^{+0.44}_{-0.42}$	1.77	0.78	2.56	2.70

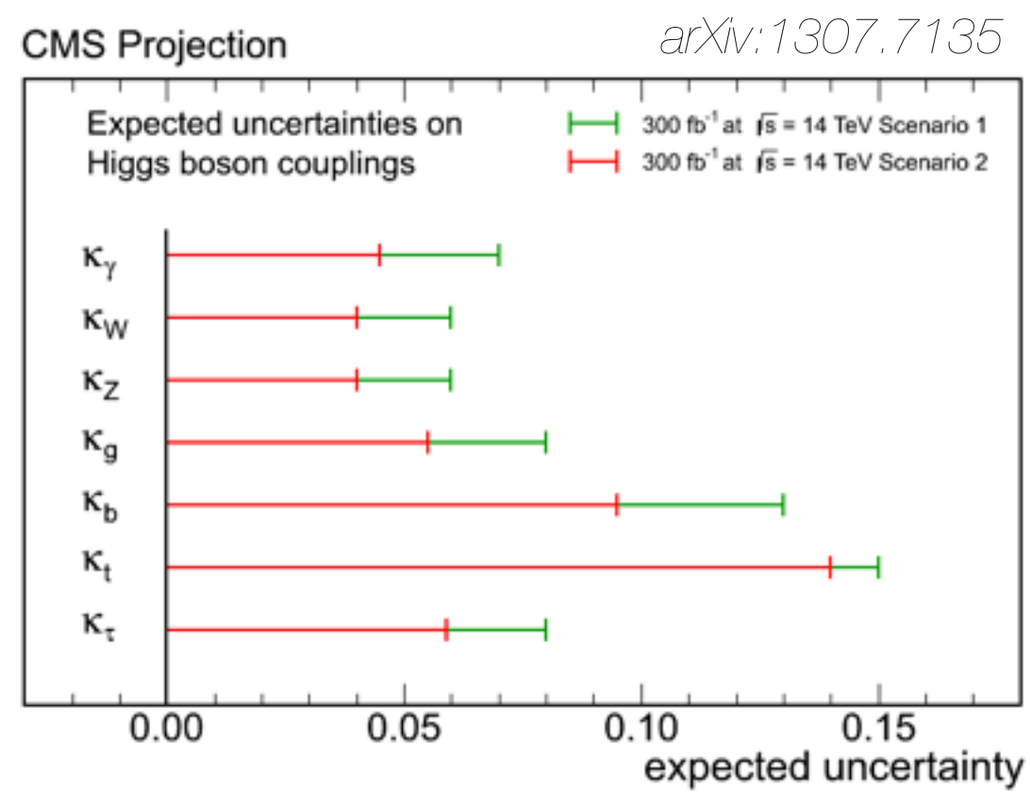
CERN-PH-EP-2015-121

Conclusion

- **legacy** from LHC run1:
  - **evidence of Higgs couplings to fermions**
  - all suggests Higgs **properties compatible with SM**
  - **introduction and validation of new techniques** (regression, MEM, etc)



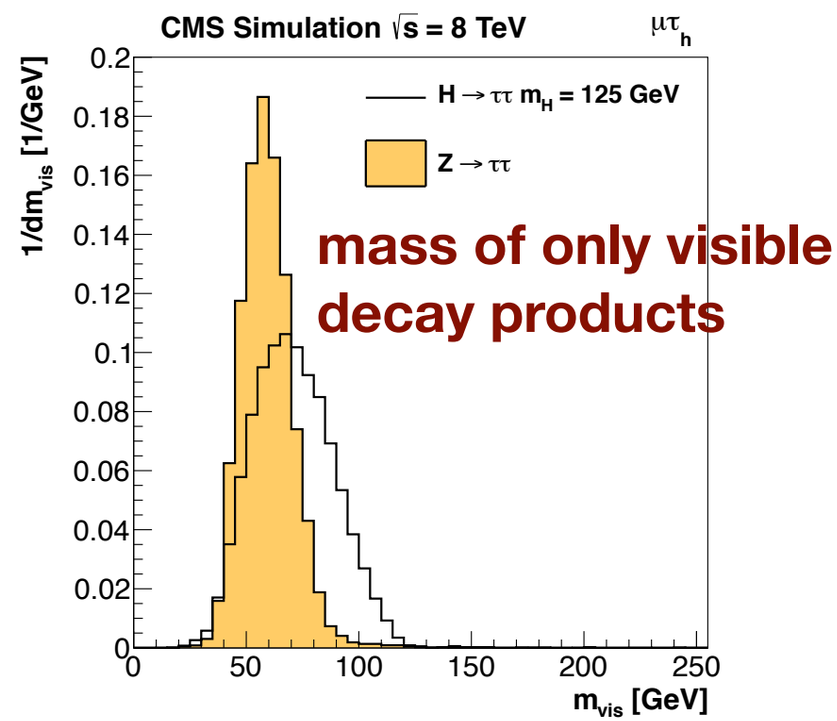
- **expectation** from phase 1 (300fb^{-1})
  - evidence of H ⟶ bb
  - reduce uncertainty on k_b to ~15%
  - reduce uncertainty on k_τ to ~8%
  - evidence of H ⟶ μμ

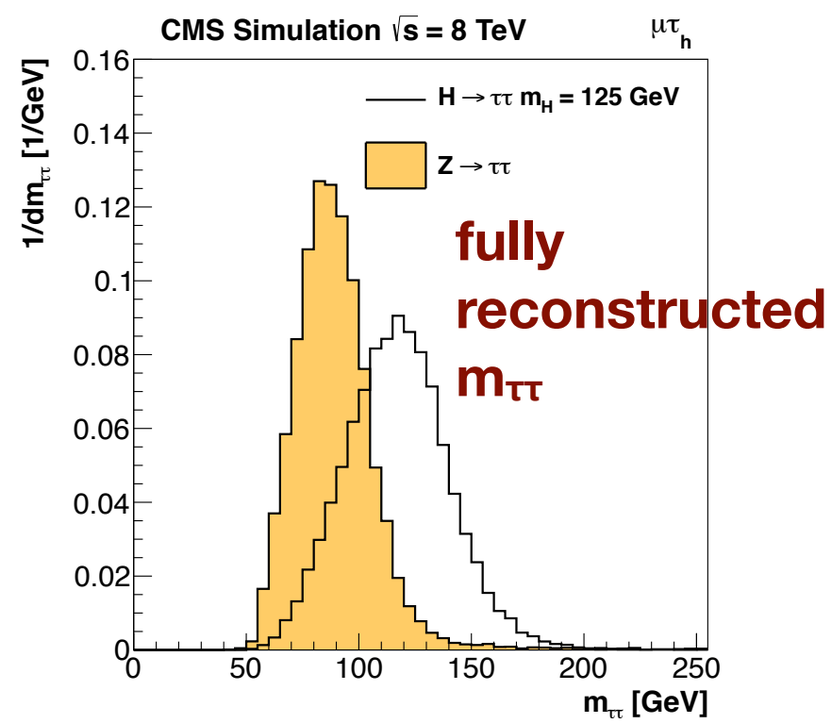


Backup

$H \longrightarrow \tau\tau$

- main production mechanisms: ggH, VBF, VH
- event categorised in
  - τ decay modes (e, μ, τ_h)
  - number of jets
  - boost on the Higgs candidate
- Higgs candidate mass reconstruction
  - neutrinos in the τ decay degrade Higgs candidate invariant mass resolution
  - numerical likelihood integration (SVFit) improves mass resolution: final mass resolution is 10-20%

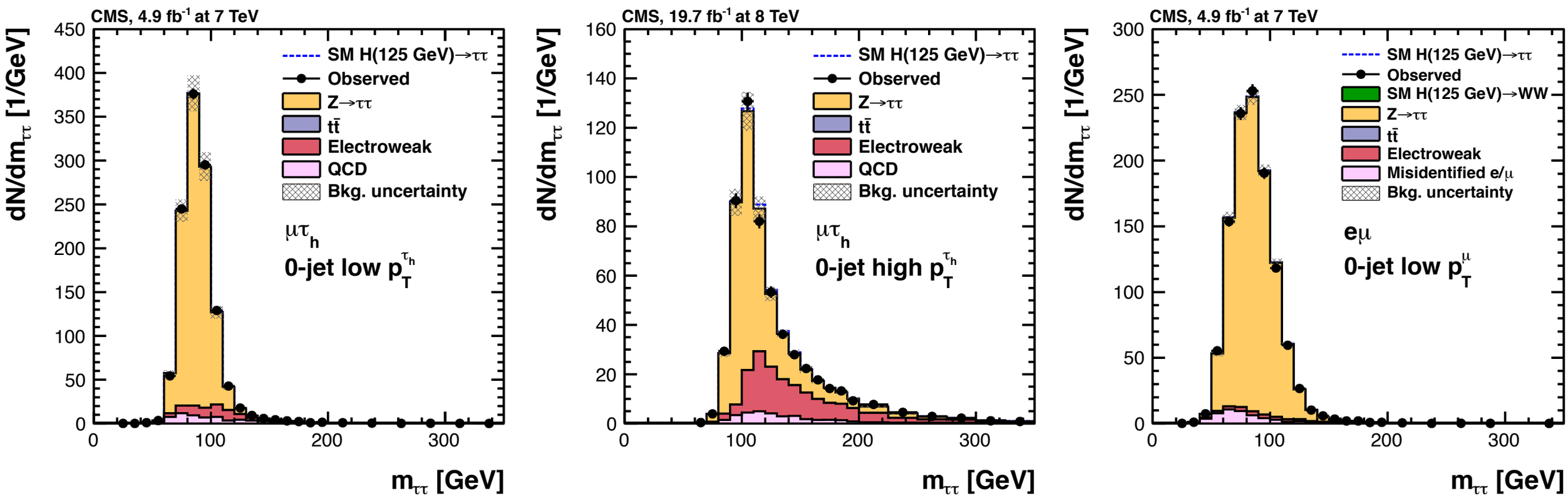




$H \longrightarrow \tau\tau$

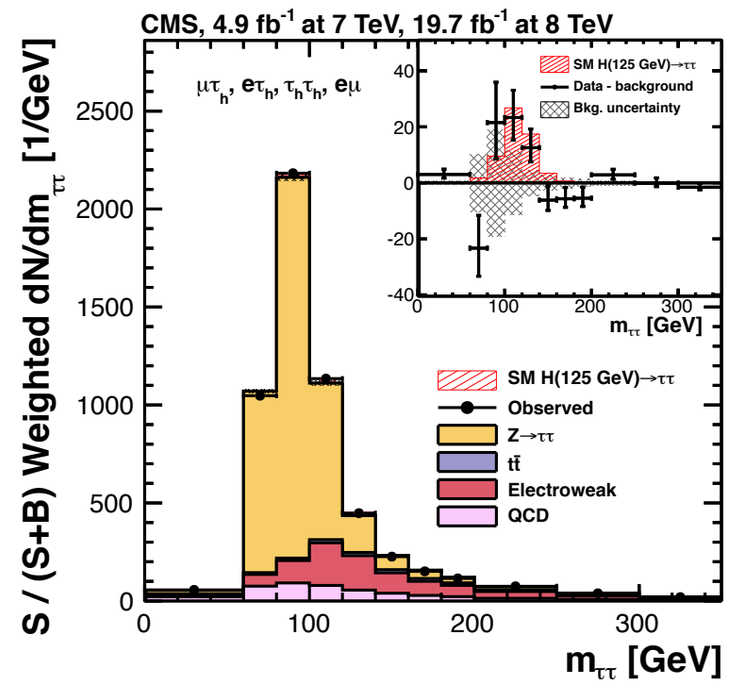
Higgs candidate mass distribution for different categories

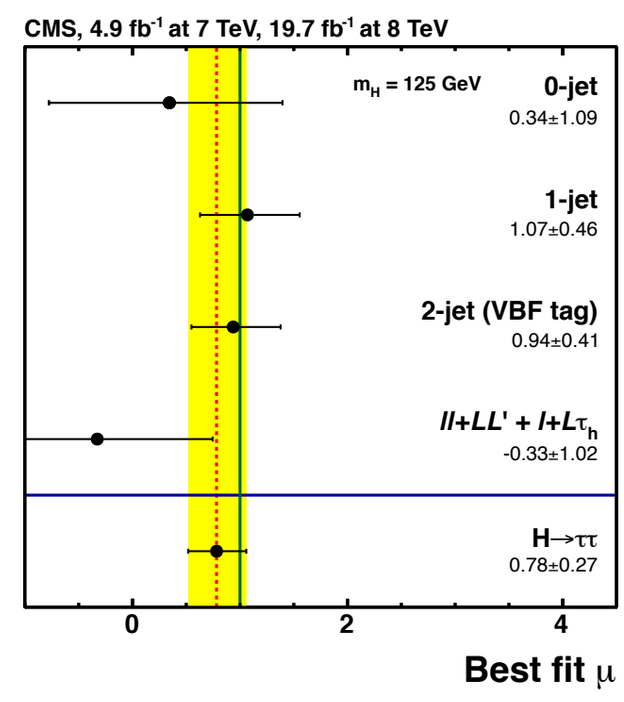
- simulation describes very well data
- different categories have different background composition



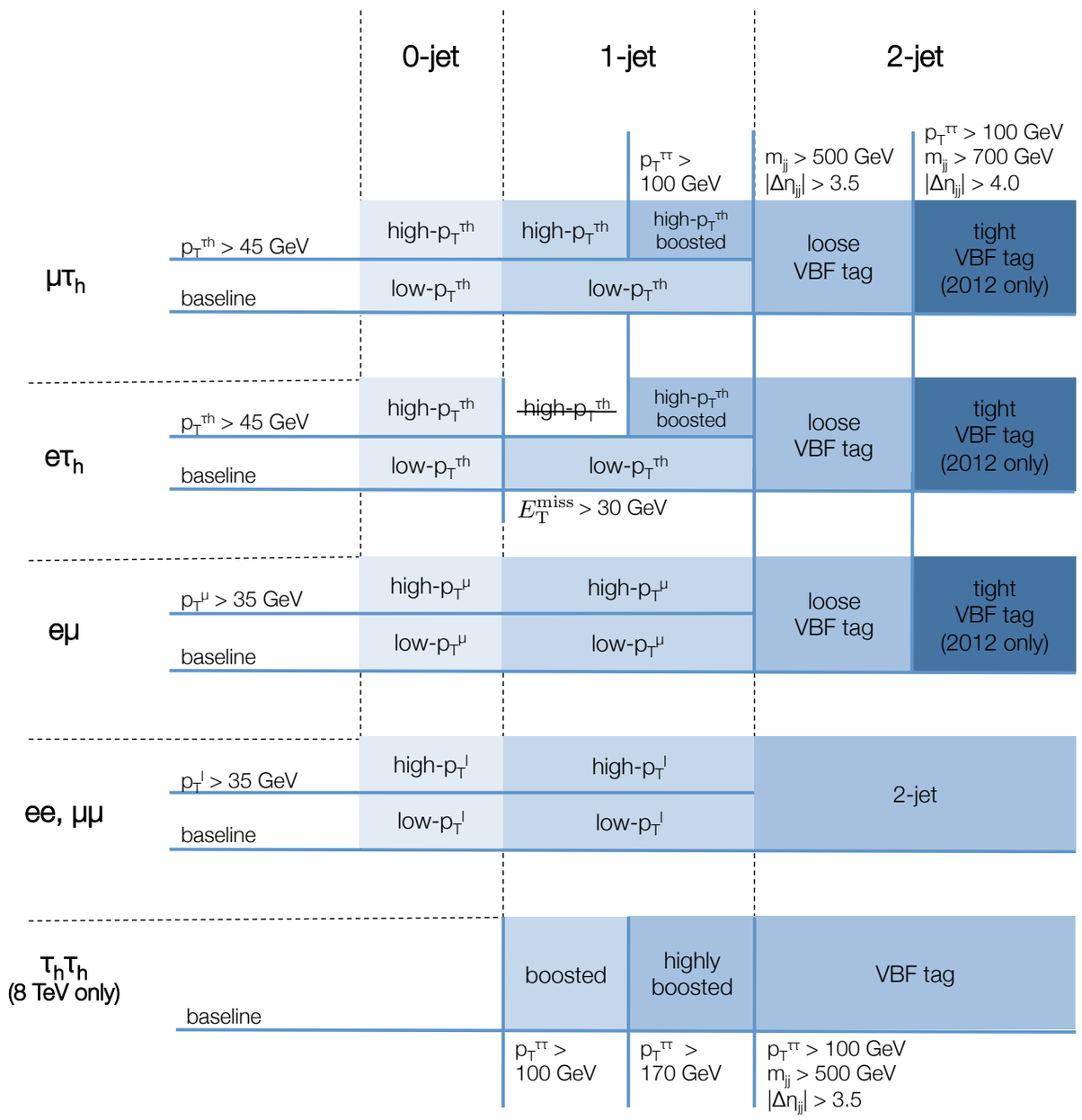
H ⟶ ττ

- Signal extraction
  - simultaneous fit of the Higgs candidate mass of all categories
  - low purity categories help to constrain main backgrounds (Z ⟶ ττ, tt+jets)
- Results
  - Evidence of H ⟶ ττ with 3.2 σ
  - Signal strength: 0.78 ± 0.27 compatible with SM

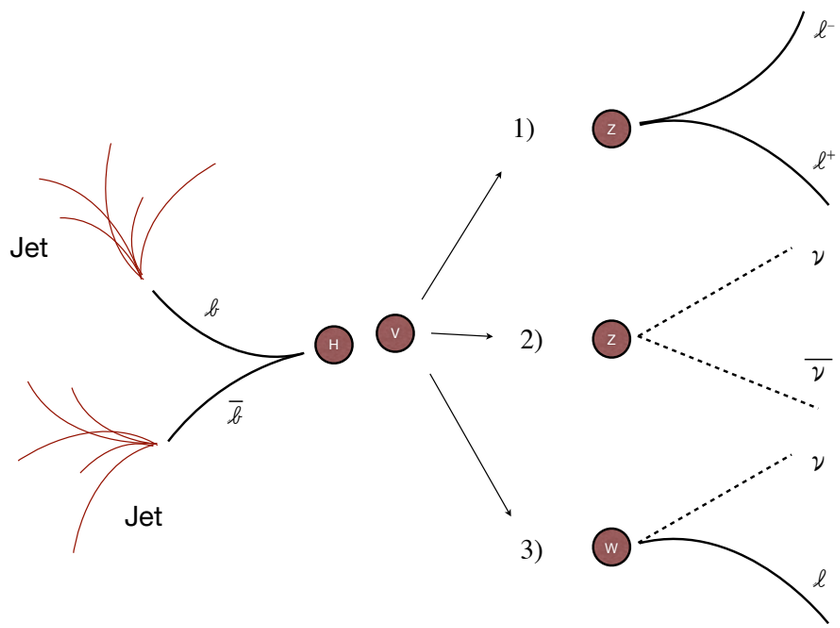


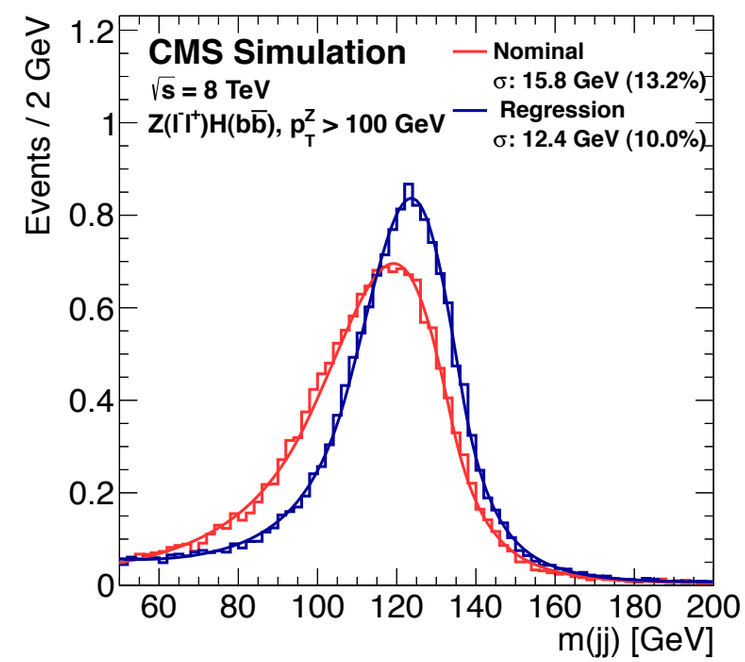


H ⟶ ττ event categorisation

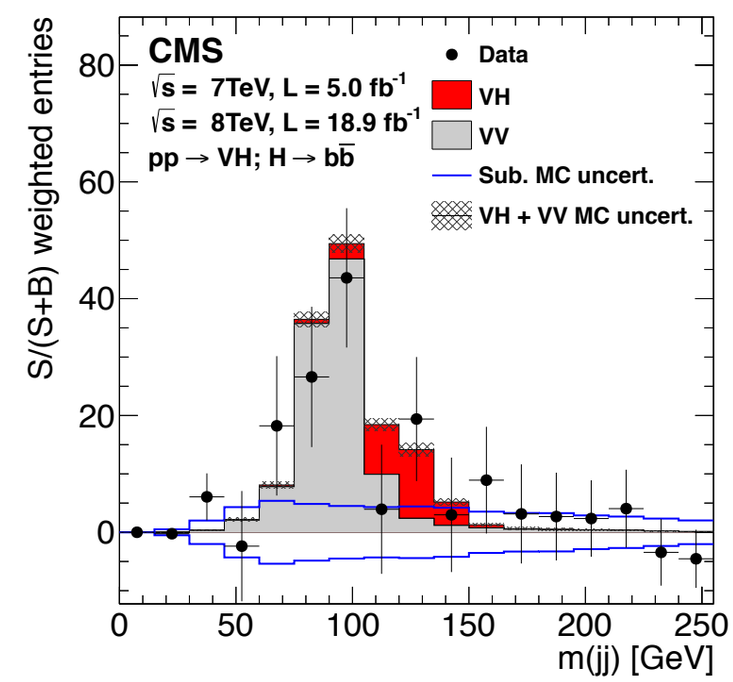


VH, H ⟶ bb



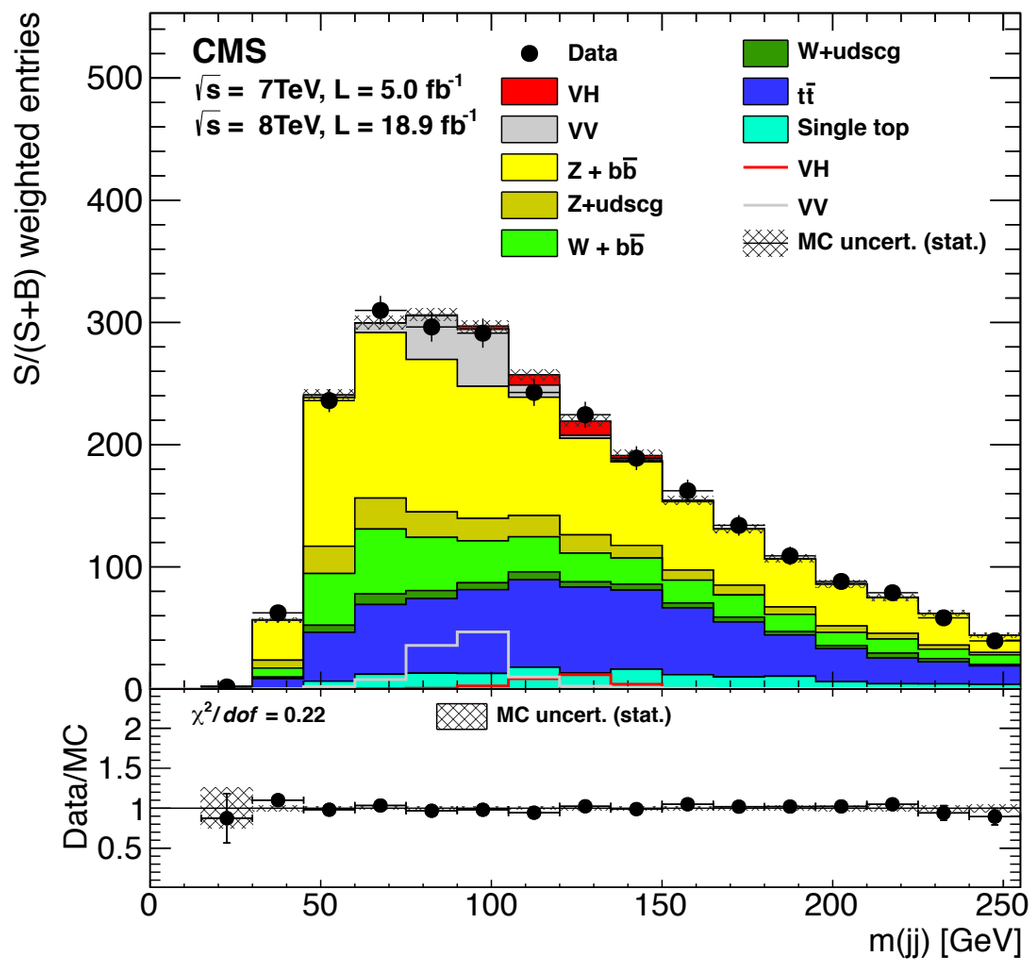


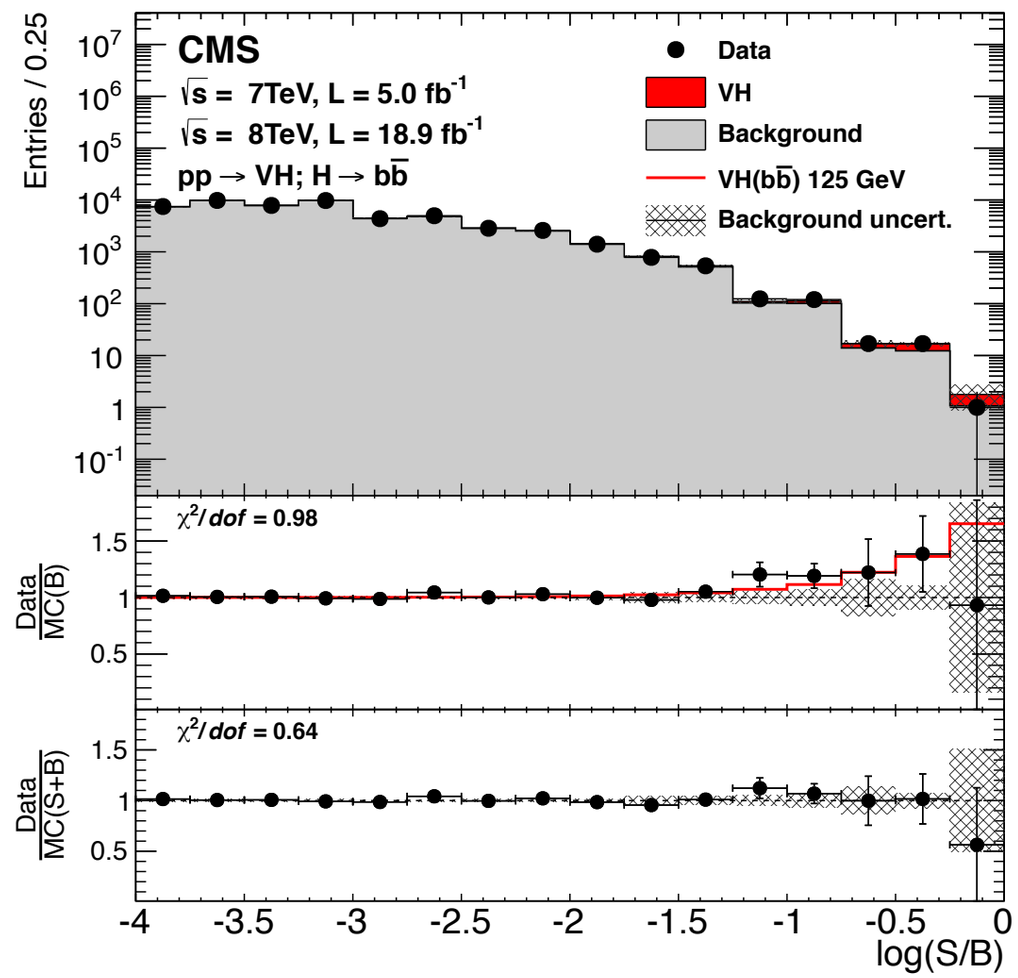
- most sensitive channel in H ⟶ bb land
- 5 channels according to vector boson decay
- high p_T of the vector boson improves S/B
- b-jet energy regression improves H mass resolution
  - final Higgs candidate mass resolution 10%



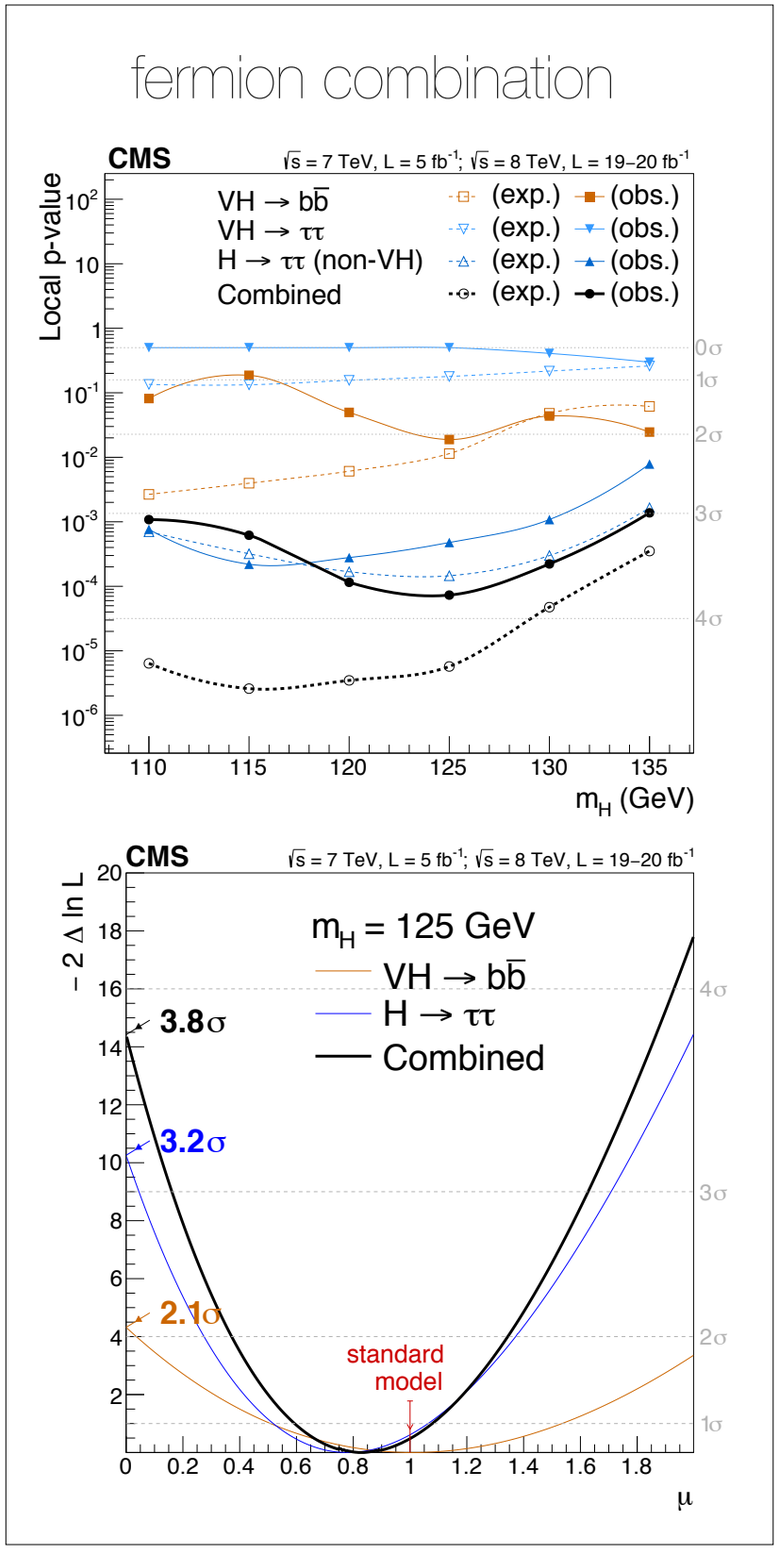
VHbb Additional plots

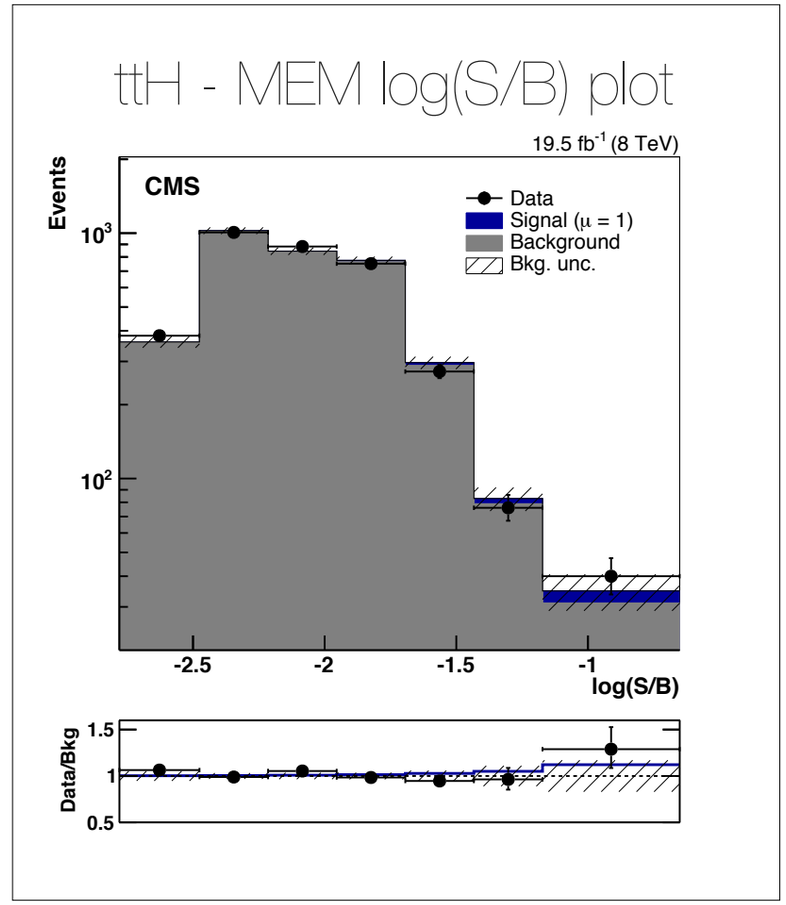
Weighed invariant mass distribution of the VHbb analysis





Additional material

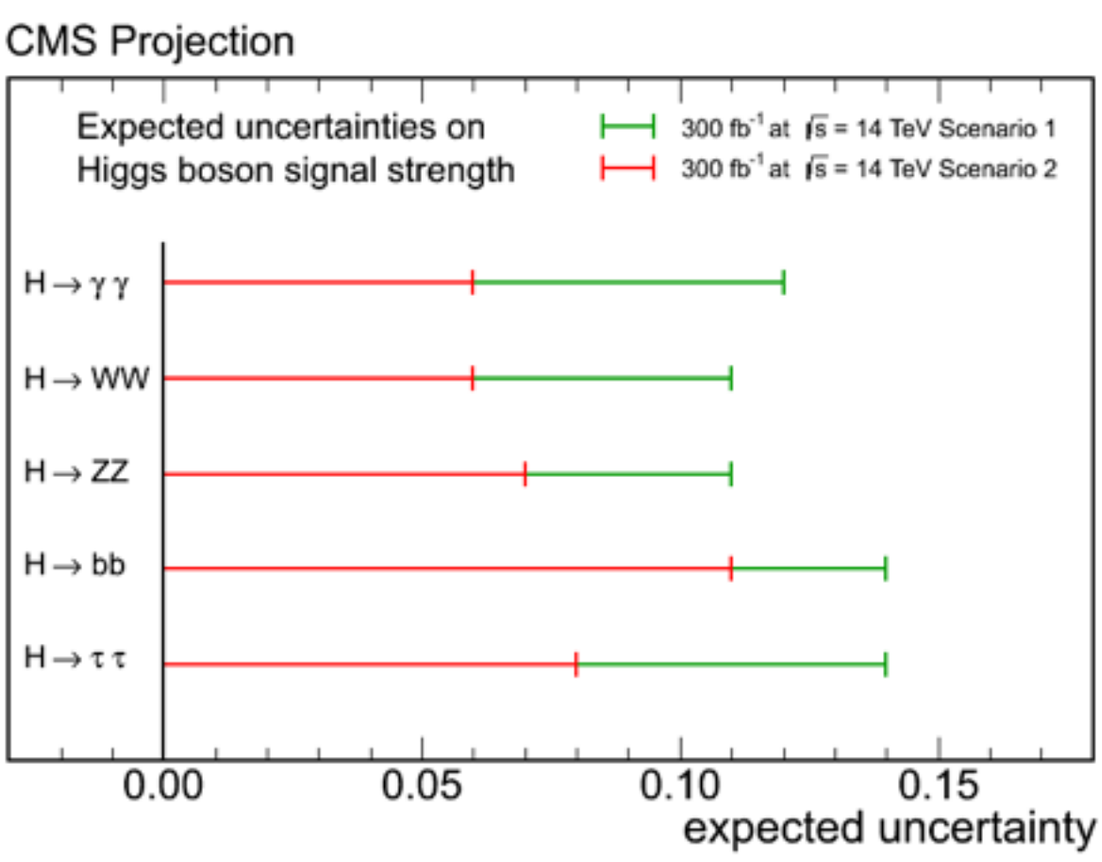


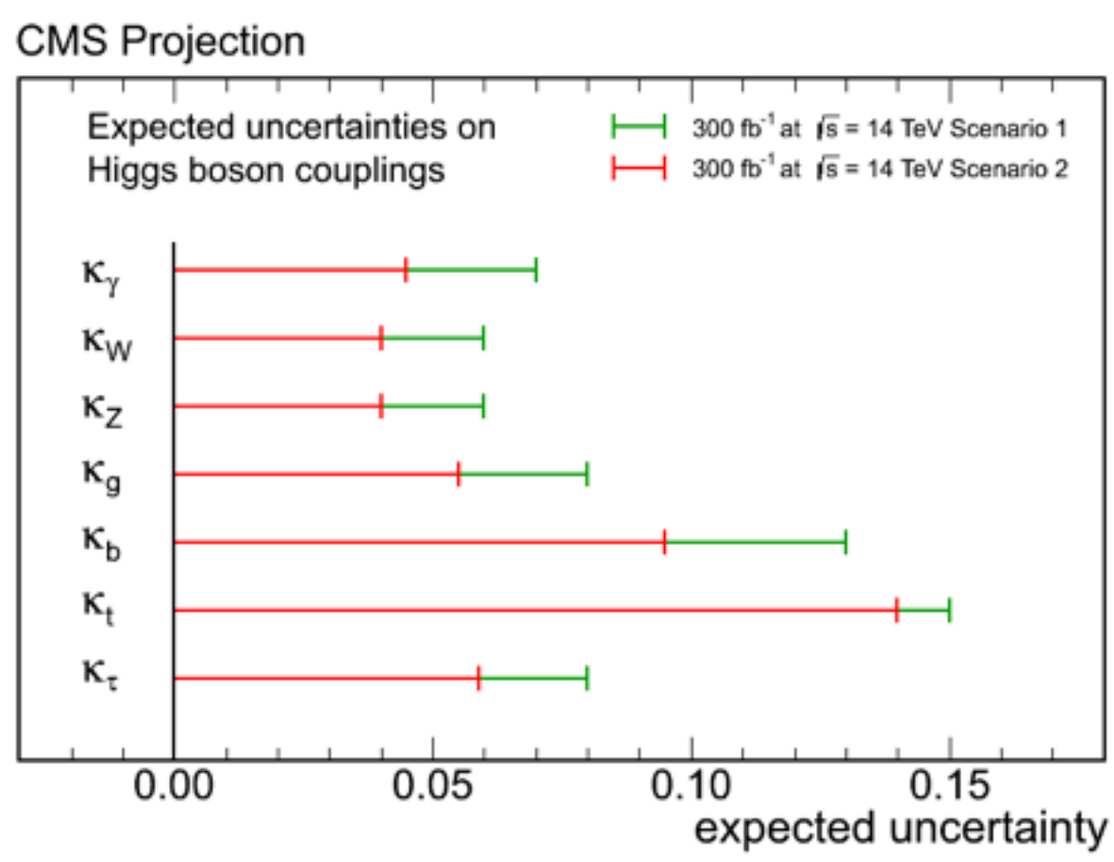


Expected results from phase1

After 300 fb^{-1} we expect to

- have evidence of $H \longrightarrow bb$ coupling
- measure the $H \longrightarrow bb$ signal strength with an uncertainty smaller than 15%
- measure the $H \longrightarrow \tau\tau$ signal straight with an uncertainty smaller than 15%
- being sensitive to the $H \longrightarrow \mu\mu$ signal

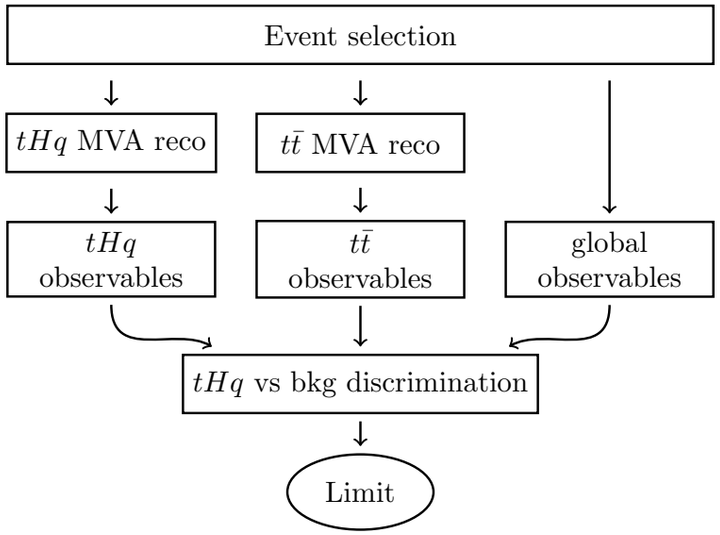


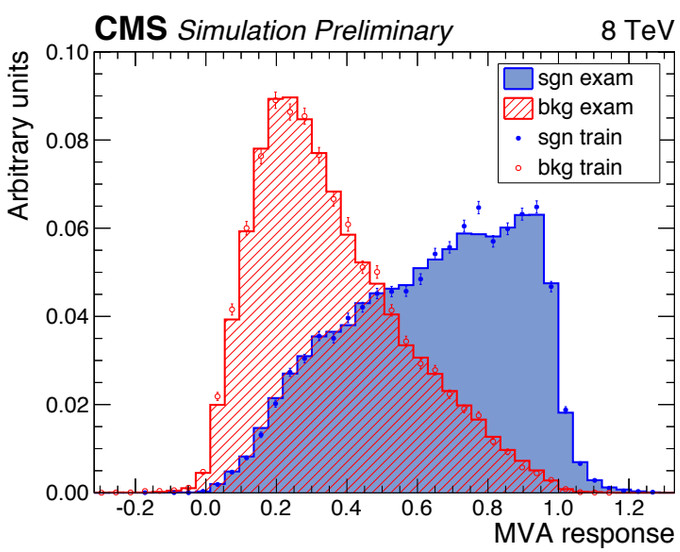


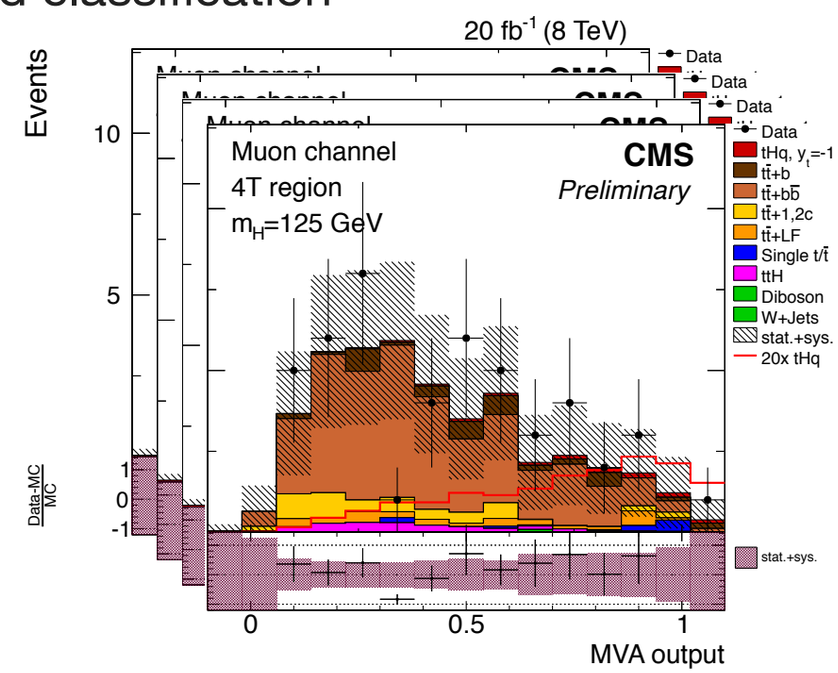
tHq, H ⟶ bb

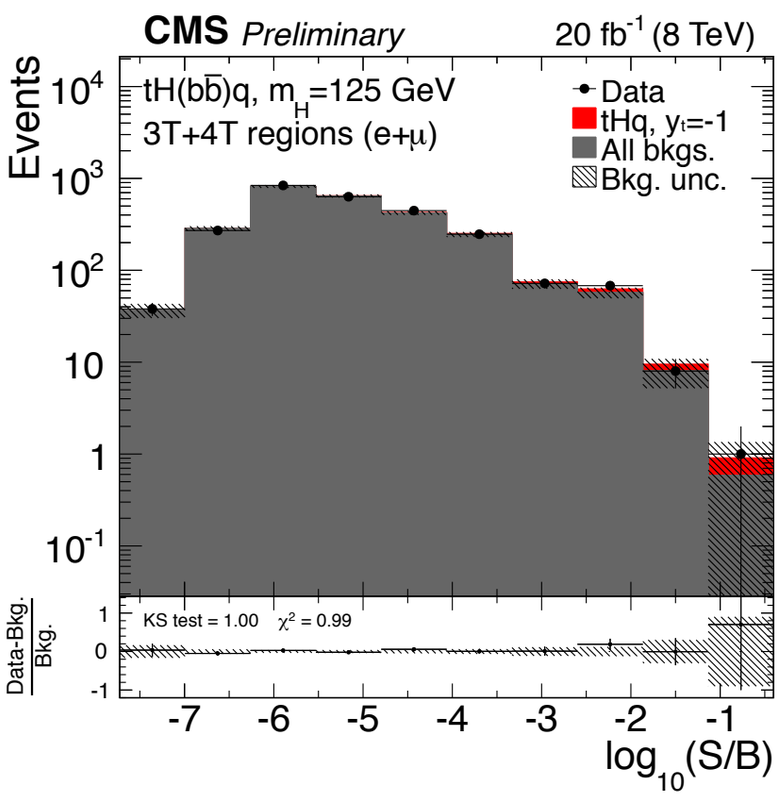
New results from CMS

- SingleTop Higgs can probe sign of Yukawa top coupling
  - ttH only sensitive to the square of y_t
- Analysis done with y_t=-1 (~10 larger σ than y_t=1)
- Analysis strategy
  - 4 categories : 4 (5) jets with 3(4) btag ⊕ electrons and muons
  - MVA for jet-quark assignement
  - MVA for signal/background classification









- 95% CL upper limit 7.57 (5.14 expected)
- significance is 1.1 σ
  - main systematics from Q^2 scale for ttbar production