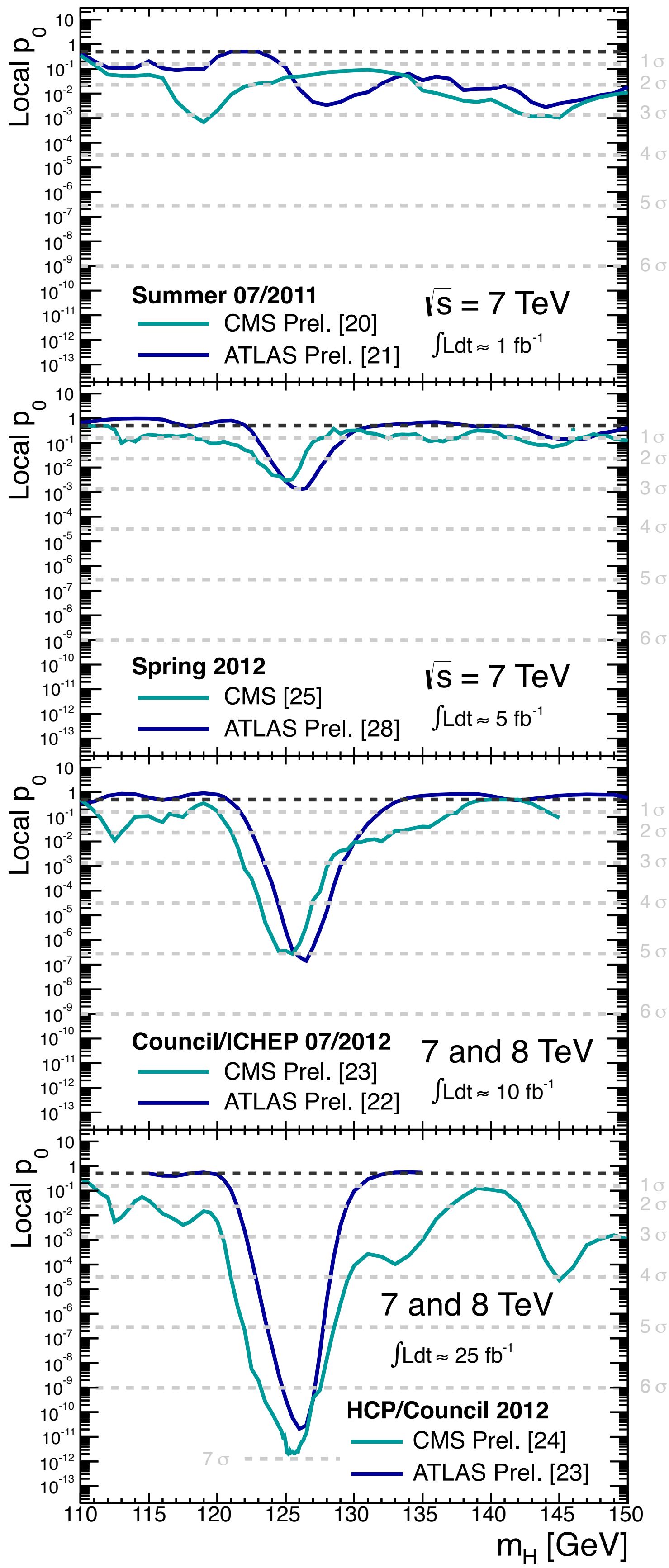
Same latest results on BEH physics from ATLAS and CMS

Yan-ping Huang (*DESY*)

LHC Physics Discussion session 2014 July28

Timely Discovery



- **Summer 2011: EPS and Lepton-Photon**

  First (and last) focus on limits (scrutiny of the p_0)

- **December 2011: CERN Council**

  First hint

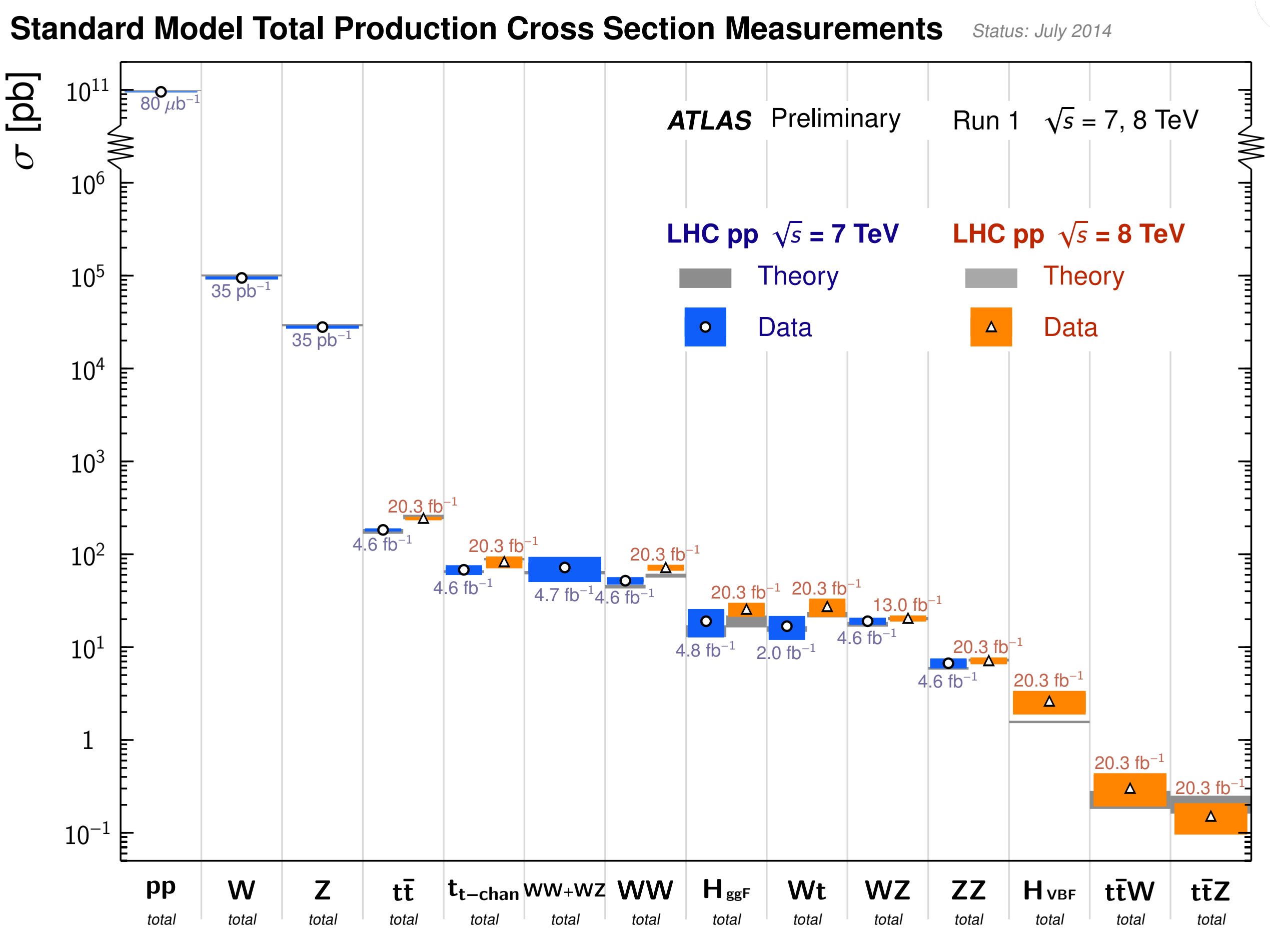
- **Summer 2012: CERN Council and ICHEP**

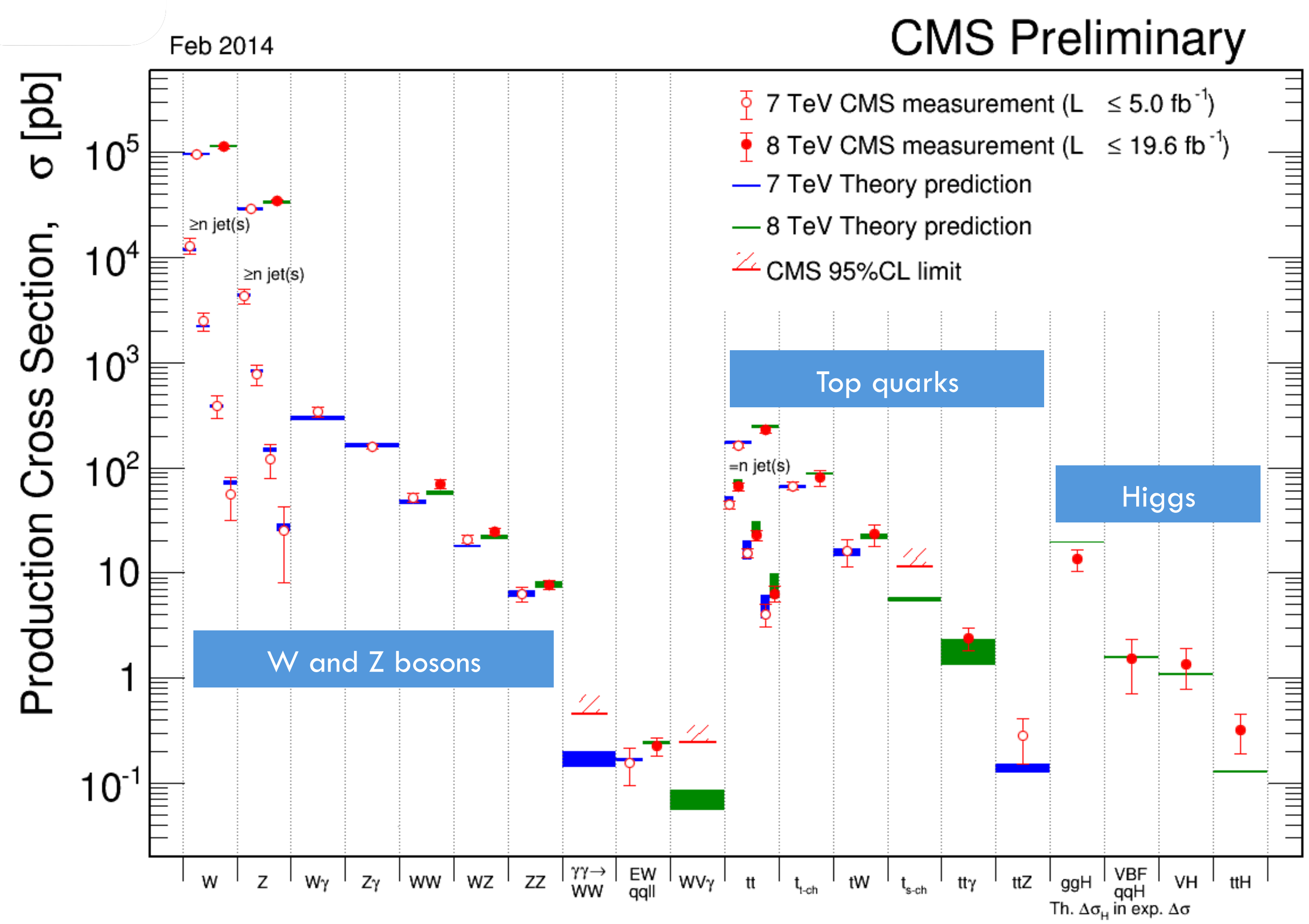
  Discovery

- **December 2012: CERN Council**

  Beginning of a new era of property measurement

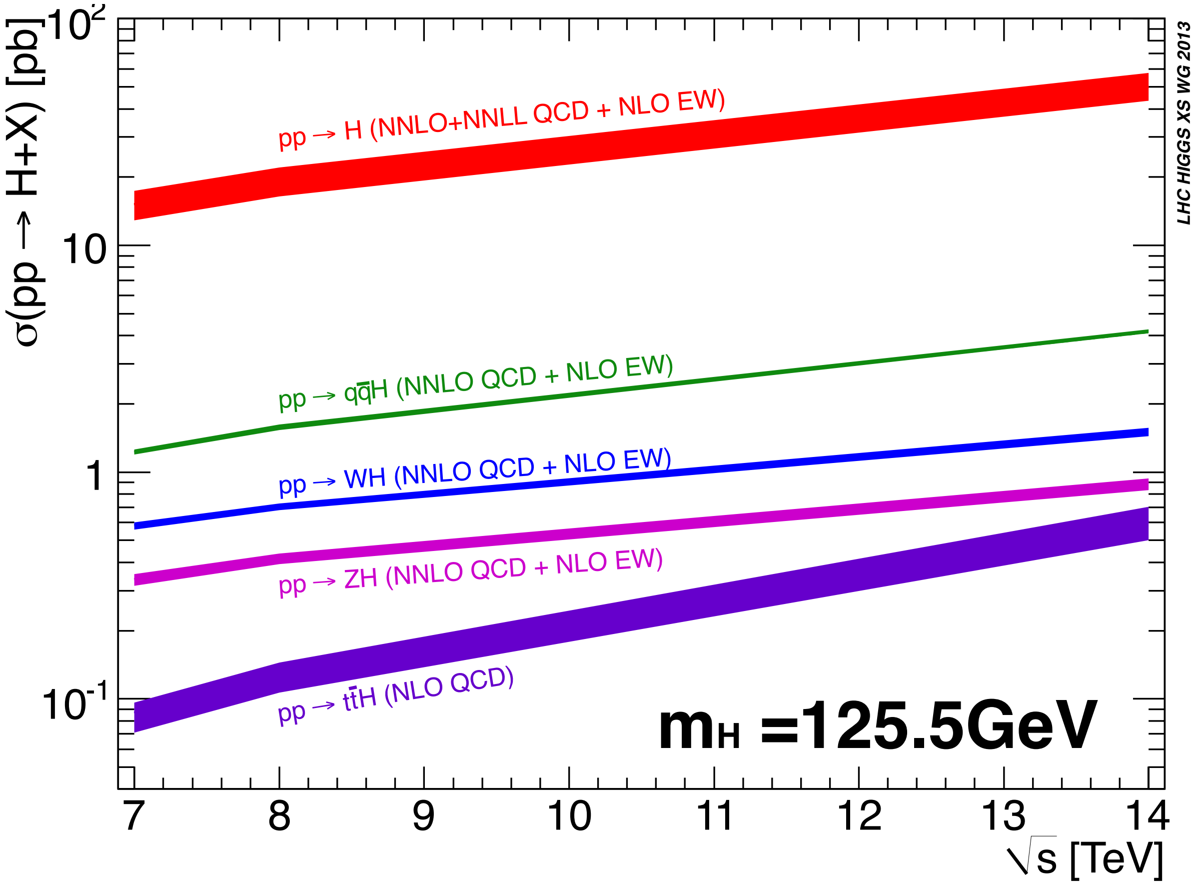
Detector makers & theory calculators

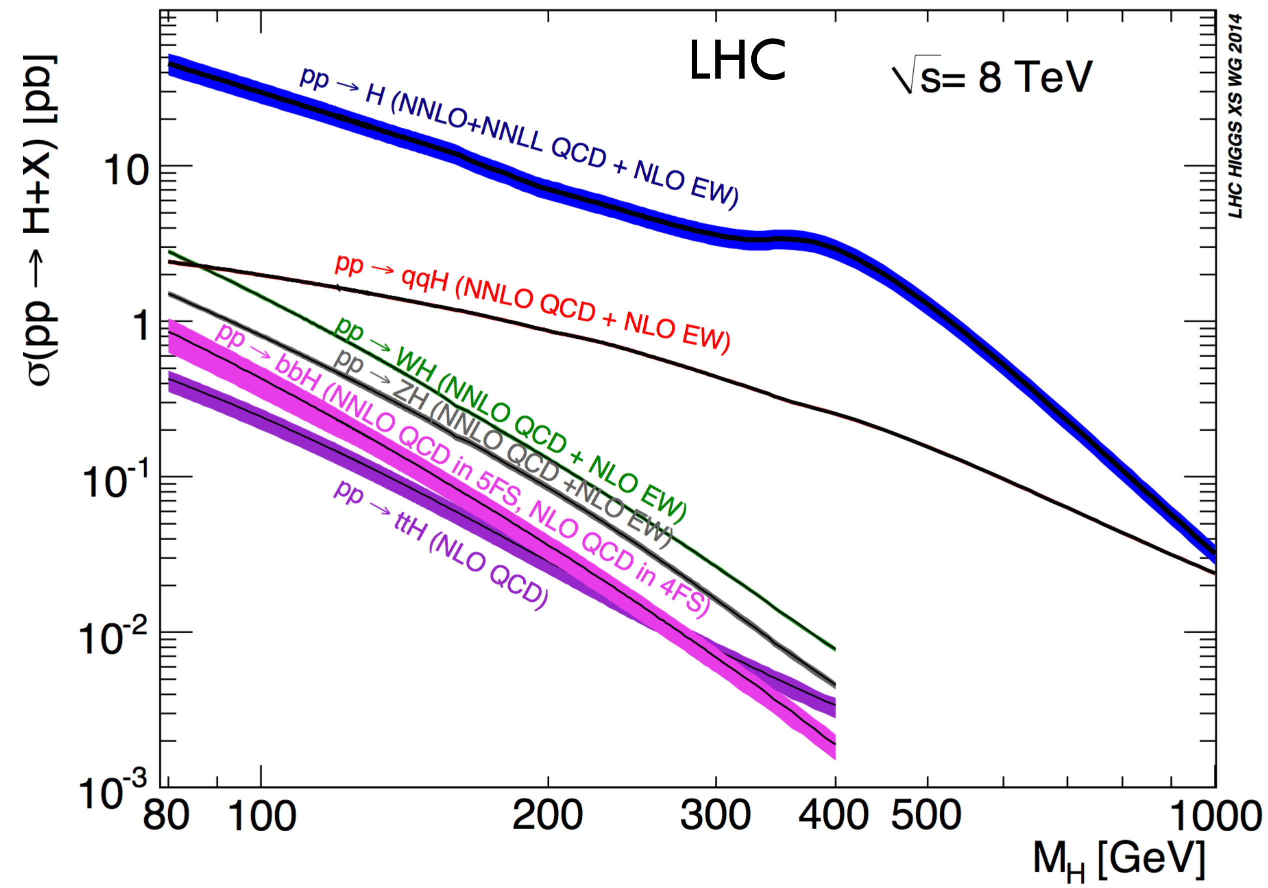


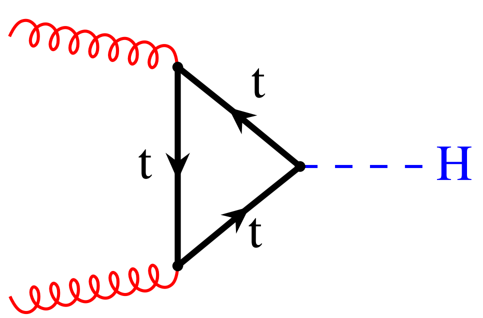


Tremendous progresses in theory calculations and simulation "next-to…" revolution. (unprecedented level of accuracy)

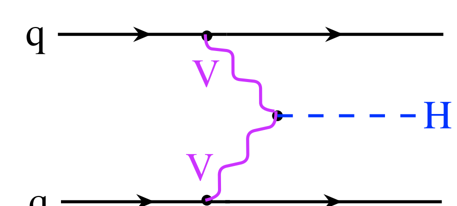
Production mode of SM Higgses



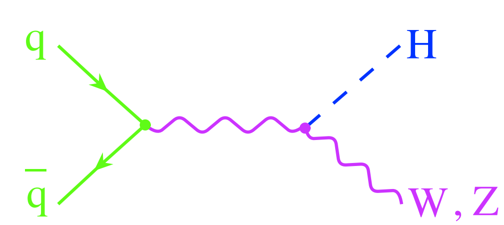




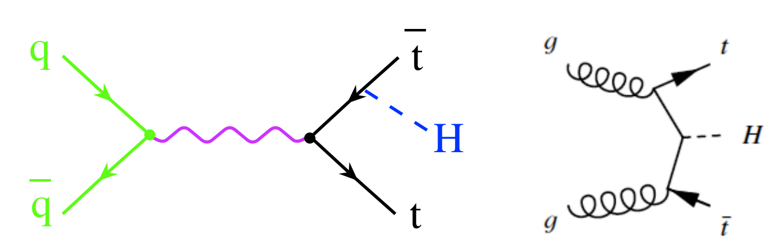
Gluon fusion



VBF



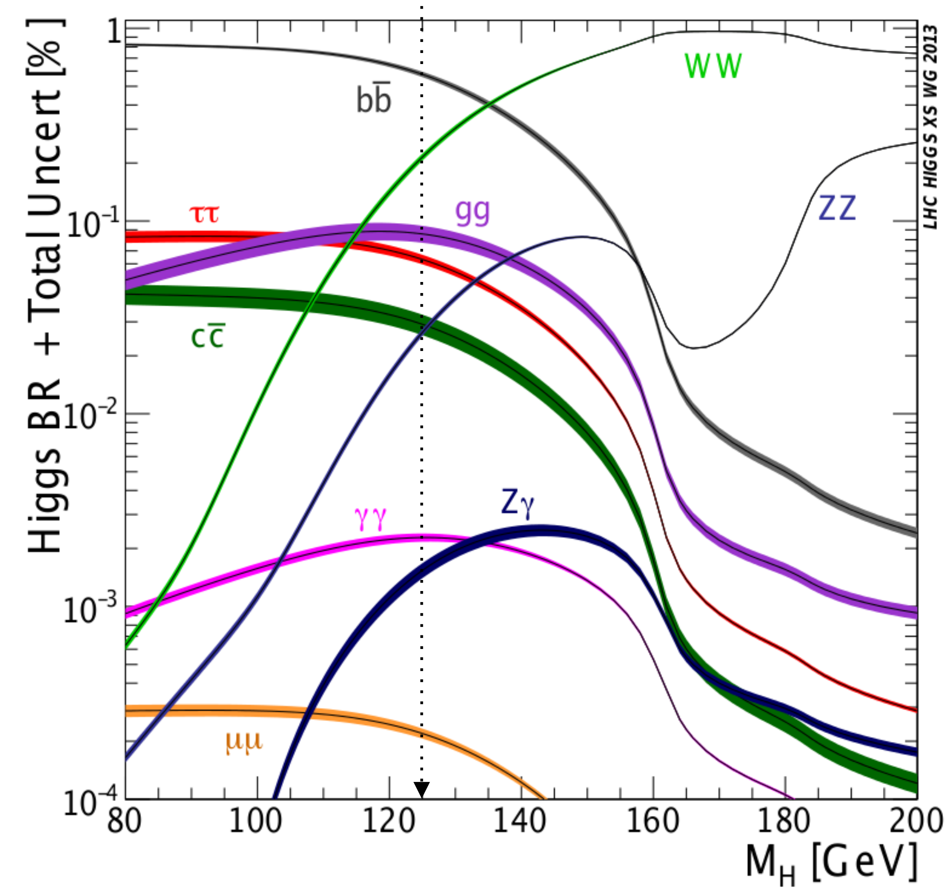
WH, ZH

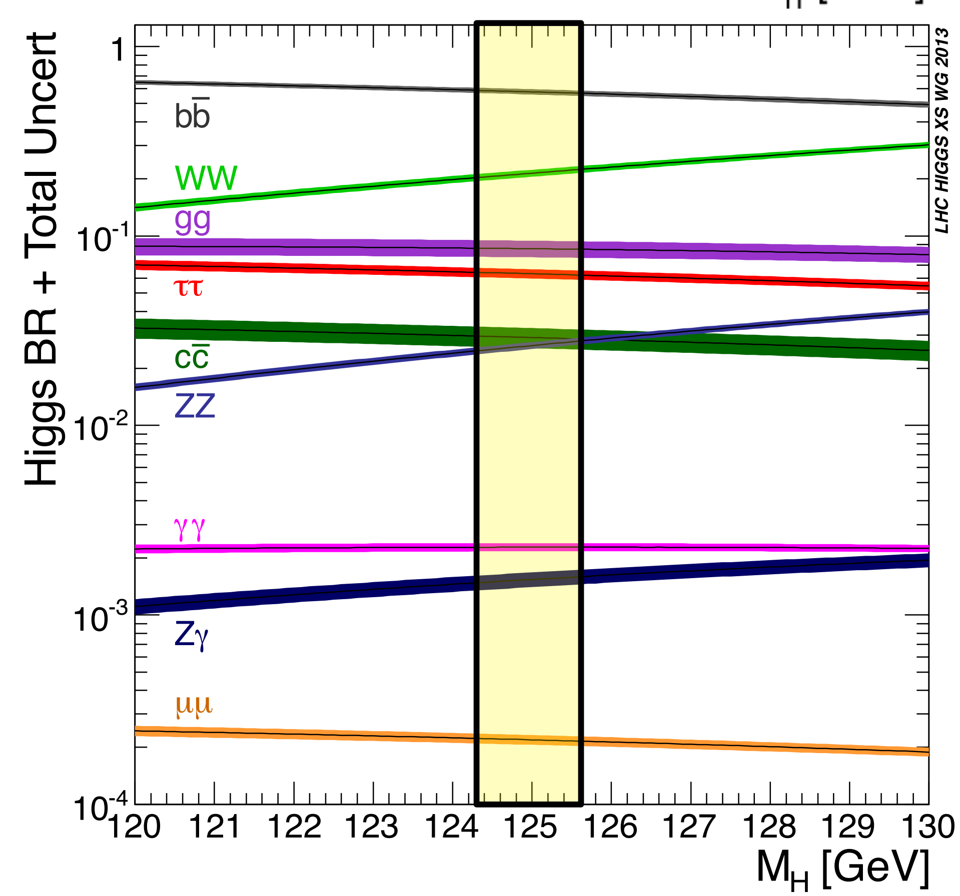


bbH, ttH

SM Higgs Decays

- Dominant: bb (57%)
- WW channel (22%)
- ττ channel (6.3%)
- ZZ channel (3%)
- cc channel (3%)
- γγ channel (0.2%)
- Zγ channel (0.2%)
- μμ channel (0.02%)





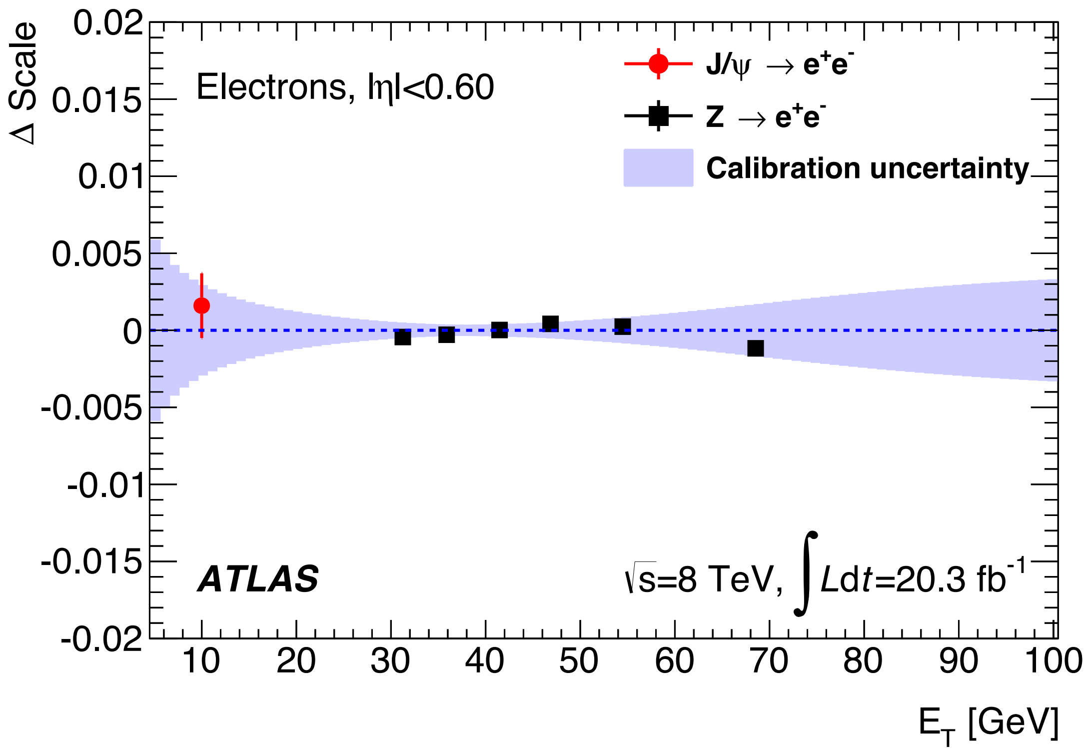
Property Measurement

- Mass and width
- Coupling properties
- Off Shell coupling and width
- Fermion decay
- Fiducial and Differential cross section measurement
- Invisible search

Improvement calibration procedure — electron

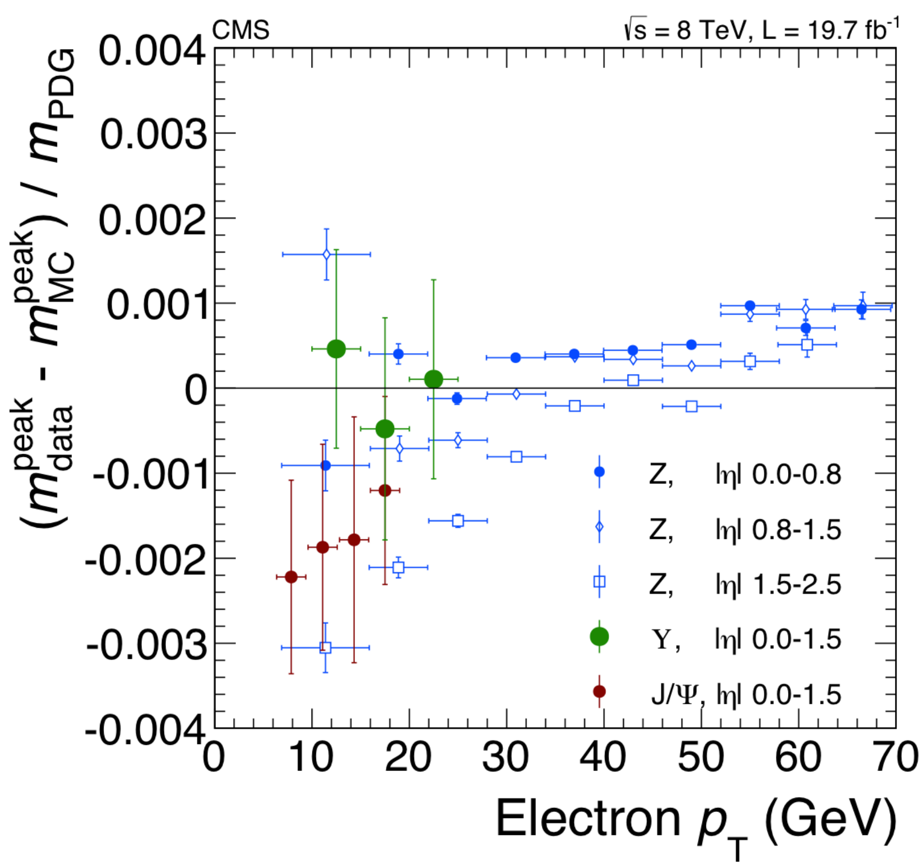
ATLAS

- Calorimeter non-uniformities and layer inter calibration correction.
- New e/gamma MVA calibration
- E-scale and resolution extracted with Z->ee
  - ES Unc. : 0.03%-0.05% for 40GeV ET electron, ER Unc.: 5-10% for 10-45GeV electron



CMS

- data/MC correction of the peak position of the Z mass (as function of time)
- pt dependent linearity correction
- MC smeared
  - ES Unc. ~0.3%, ER Unc. ~3%.



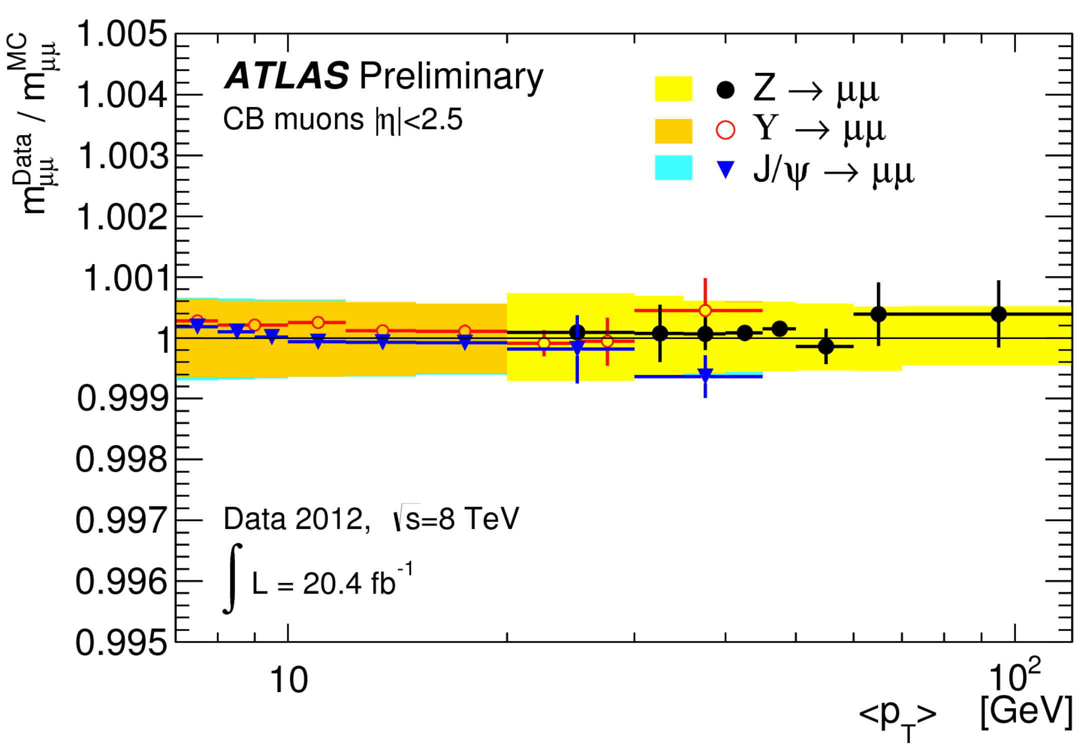
Improvement calibration procedure — muon

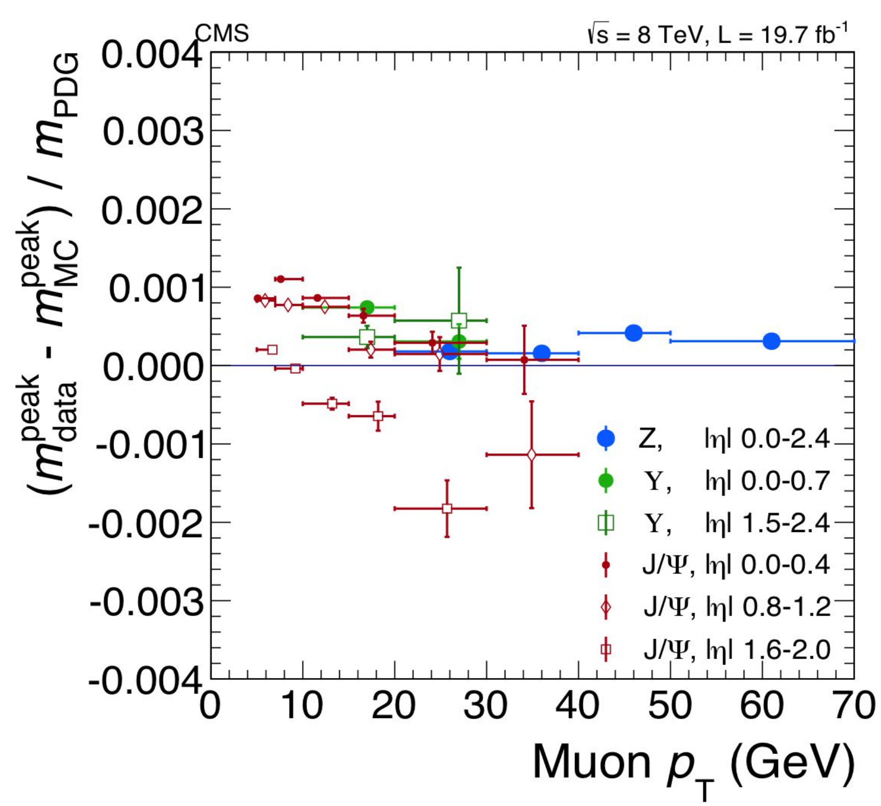
ATLAS

- Muon calibration with $J/\psi \rightarrow \mu\mu$ in additional to $Z \rightarrow \mu\mu$ and corrections determined from fits.
- Momentum scale correction are of the same order as their uncertainties: 0.04-0.2% depending on eta.

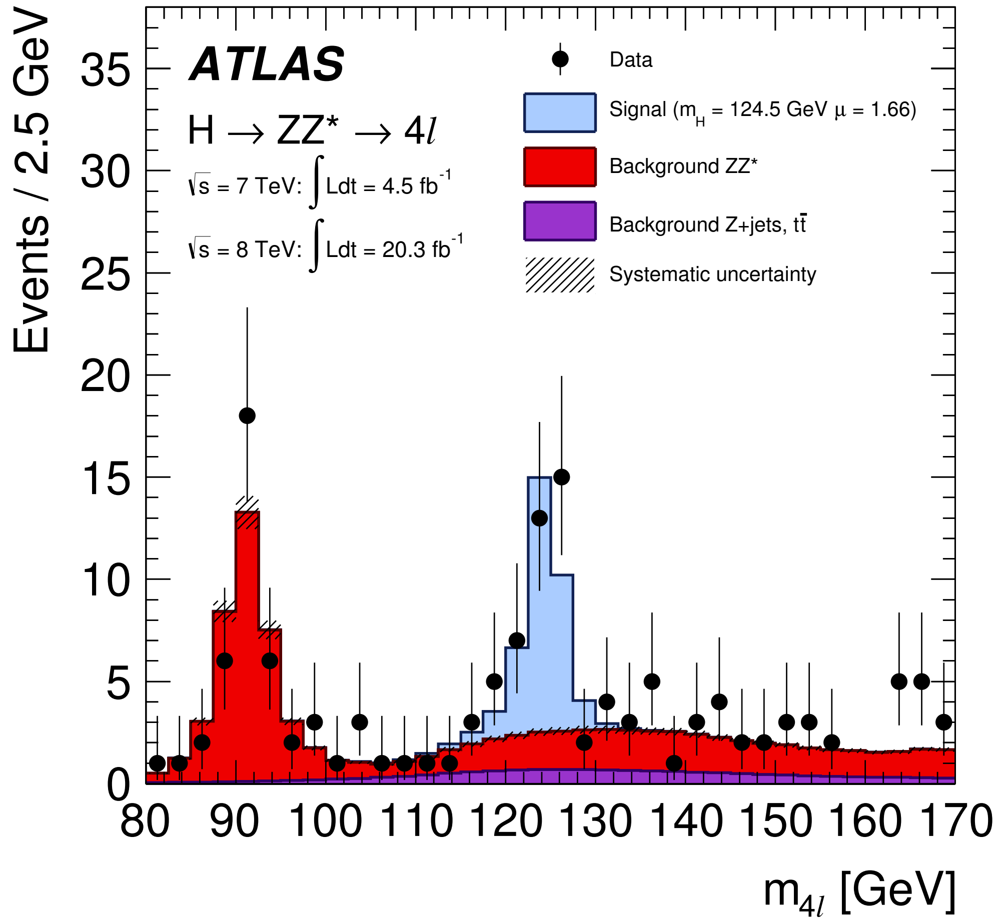
CMS

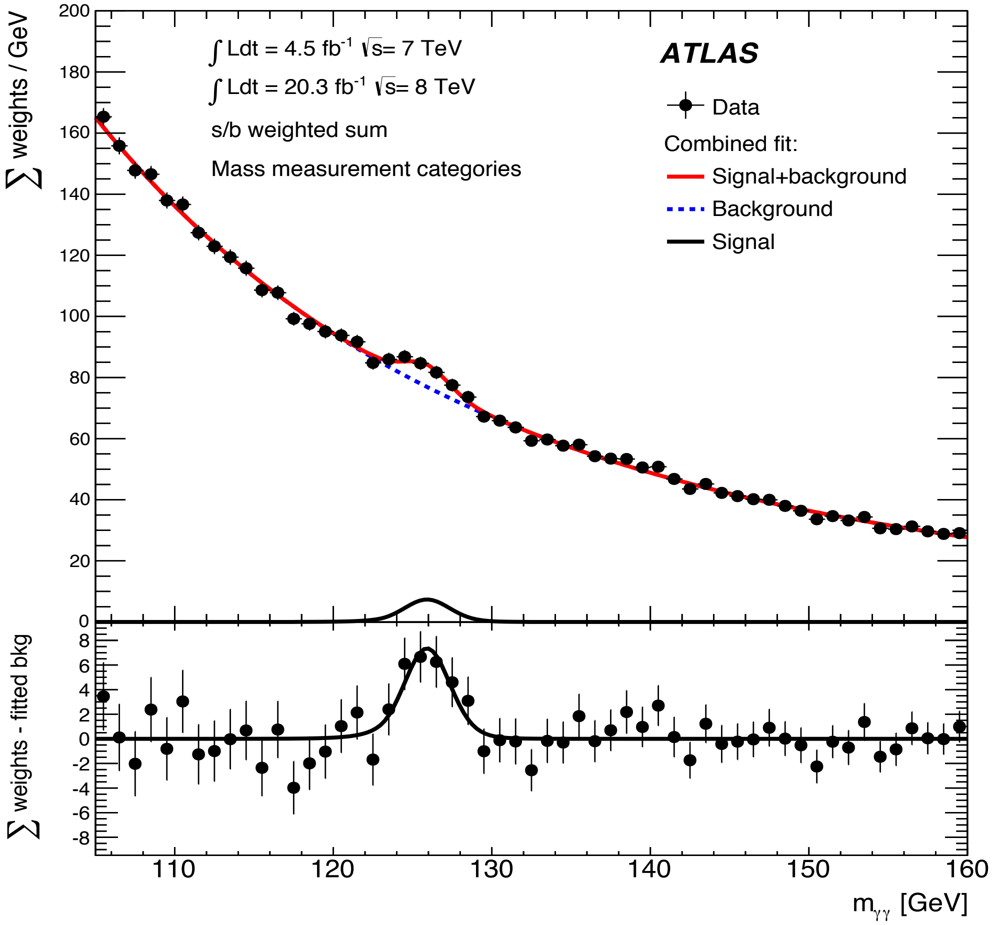
- Absolute measurement of muon momentum scale and resolution is performed by using a reference model of the Z line shape convolved with a Gaussian function.
- Data/MC mass scale agreement is within 0.1% in the entire eta range of interest





Mass measurement @ ATLAS





$124.51 \pm 0.52\ (\text{stat}) \pm 0.06\ (\text{syst})\ \text{GeV}$

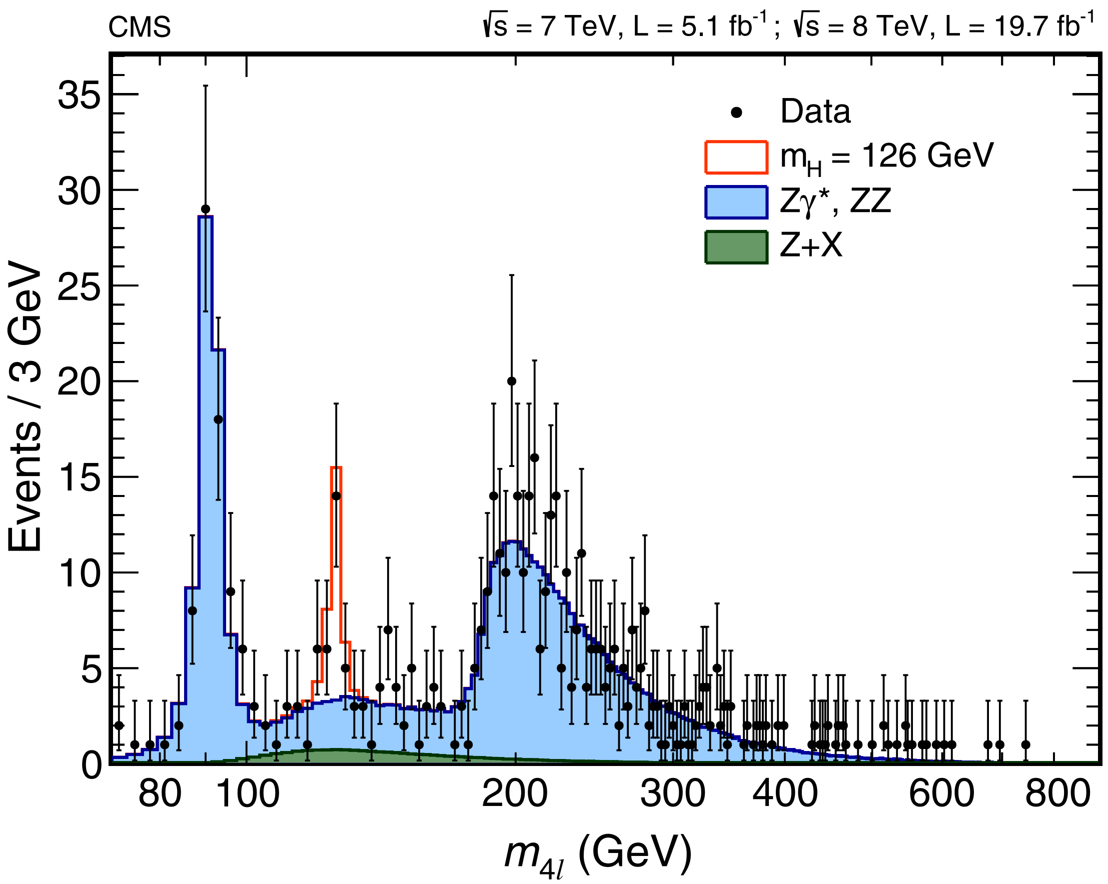
$125.98 \pm 0.42\ (\text{stat}) \pm 0.28\ (\text{syst})\ \text{GeV}$

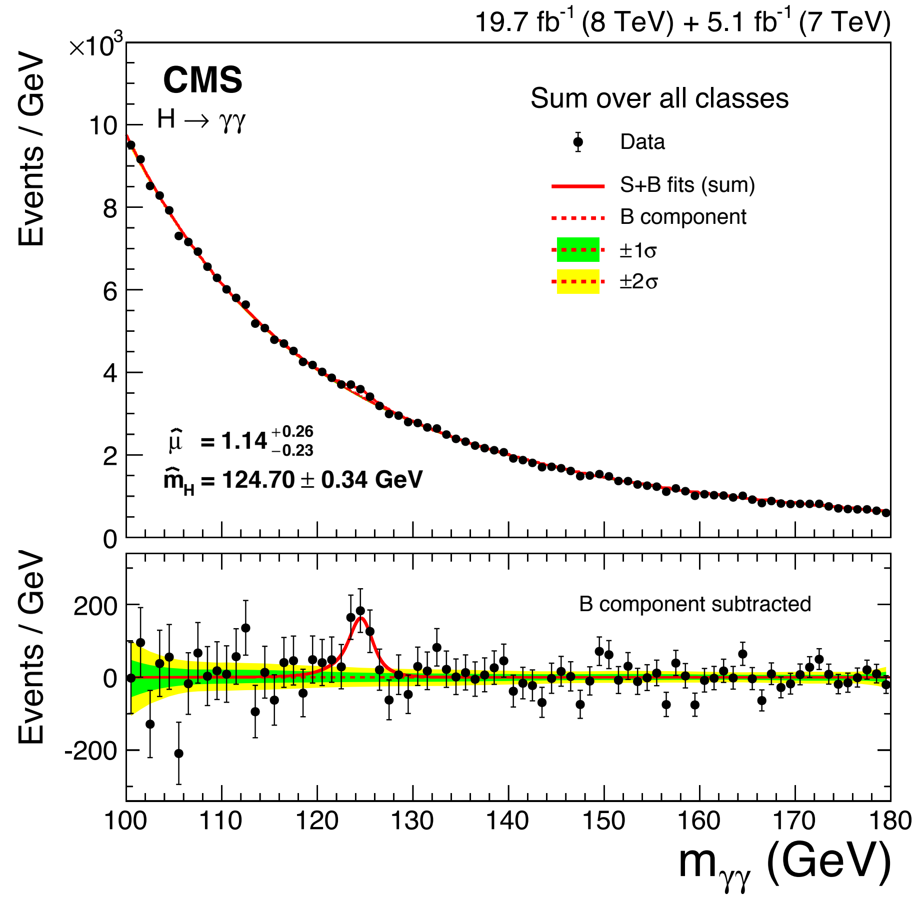
old: $124.3\ ^{+0.6}_{-0.5}\ (\text{stat})\ ^{+0.5}_{-0.3}\ (\text{syst})\ \text{GeV}$

old: $126.8 \pm 0.2\ (\text{stat}) \pm 0.7\ (\text{syst})\ \text{GeV}$

- **Analysis improvement:**
  - Categories for mass in the diphoton
  - BDT-ZZ, far FSR corrections
- **Large improvement on systematics**

Mass measurement @ CMS





mH=125.6±0.4(stat)±0.2(syst.) GeV

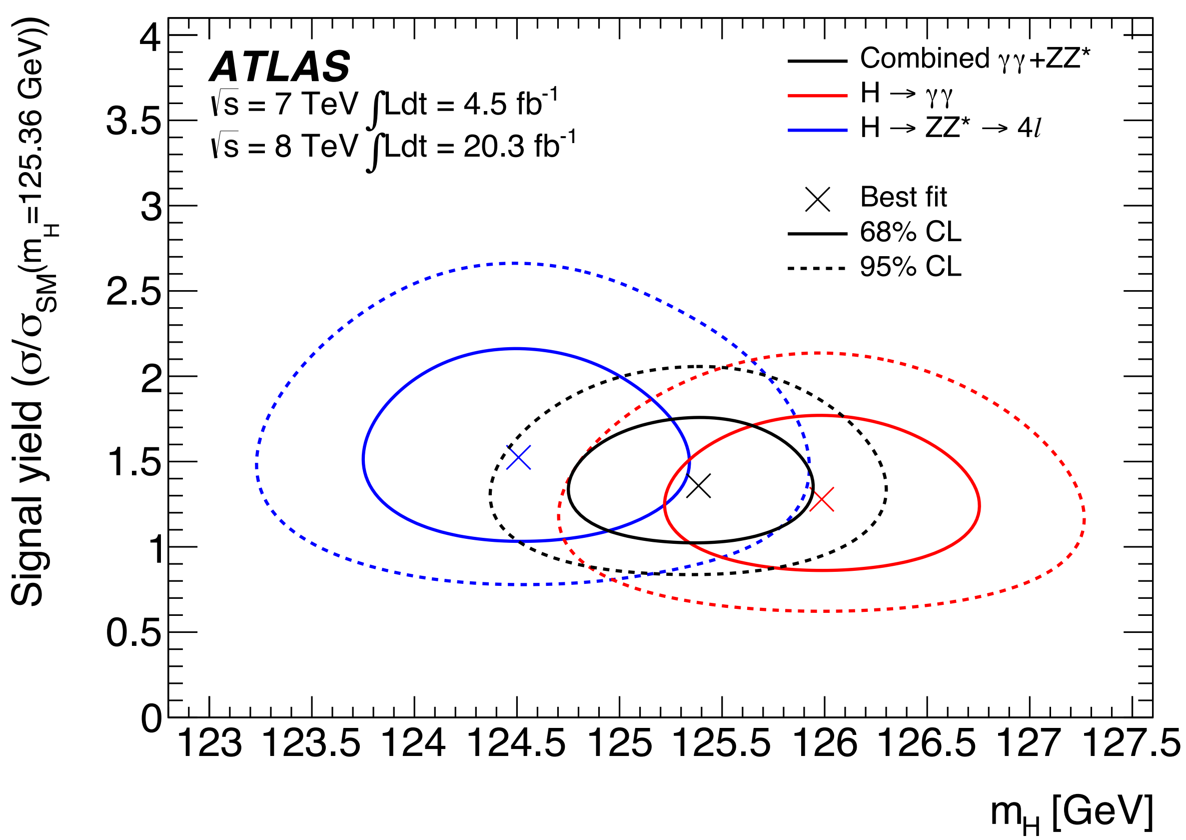
old: 125.8±0.5(stat)±0.2(syst.) GeV

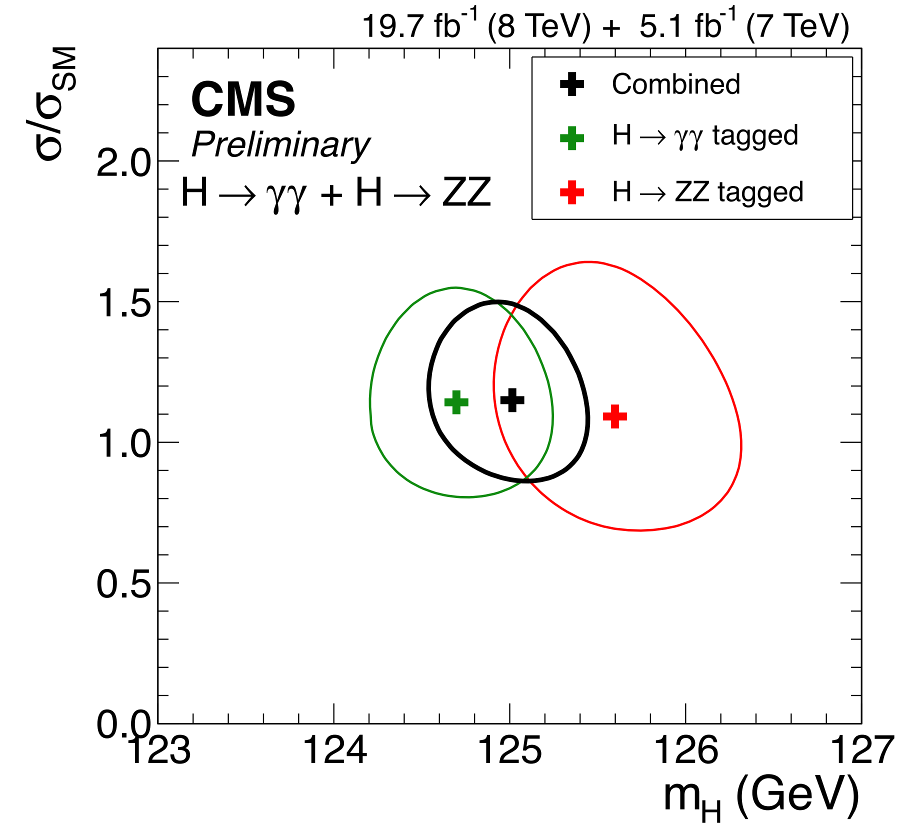
mH=124.70±0.31(stat)±0.15(syst.) GeV

old: 125.4±0.5(stat)±0.6(syst.) GeV

- In $H \to ZZ$, A matrix-element likelihood approach is used to construct kinematic discriminants.
- In $H \to \gamma\gamma$, 25 event categories tagging all production modes and new background modelling.

Combined mass measurement





	MH(GeV)		Signal strength	
	ATLAS	CMS	ATLAS	CMS
H→γγ	125.98±0.42(stat)±0.28(sys)	124.70±0.31(stat)±0.15(sys)	1.29±0.30	$1.14^{+0.26}_{-0.23}$
H→ZZ	124.51±0.52(stat)±0.06(sys)	125.6±0.4(stat)±0.2(sys)	$1.66^{+0.45}_{-0.38}$	$0.93^{+0.26}_{-0.23}{}^{+0.13}_{-0.09}$
Combined	125.36±0.37(stat)±0.18(sys)	$125.05^{+0.26}_{-0.27}$(stat)$^{+0.29}_{-0.31}$(sys)		
γγ/ZZ Compatiblity	1.97σ	1.6σ		

Framework for scalar coupling analysis

Introducing multipliers using a tree level motivated benchmark model

Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ggH}}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{\mathrm{SM}}_{\mathrm{VBF}}} = \kappa^2_{\mathrm{VBF}}(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma^{\mathrm{SM}}_{\mathrm{WH}}} = \kappa_W^2$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ZH}}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma^{\mathrm{SM}}_{t\bar{t}H}} = \kappa_t^2$$

Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma^{\mathrm{SM}}_{WW^{(*)}}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma^{\mathrm{SM}}_{ZZ^{(*)}}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma^{\mathrm{SM}}_{b\bar{b}}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{\mathrm{SM}}_{\tau^-\tau^+}} = \kappa_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma^{\mathrm{SM}}_{Z\gamma}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases}$$

Currently undetectable decay modes

$$\frac{\Gamma_{t\bar{t}}}{\Gamma^{\mathrm{SM}}_{t\bar{t}}} = \kappa_t^2$$

$$\frac{\Gamma_{gg}}{\Gamma^{\mathrm{SM}}_{gg}} : \text{see Section 3.1.2}$$

$$\frac{\Gamma_{c\bar{c}}}{\Gamma^{\mathrm{SM}}_{c\bar{c}}} = \kappa_t^2$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma^{\mathrm{SM}}_{s\bar{s}}} = \kappa_b^2$$

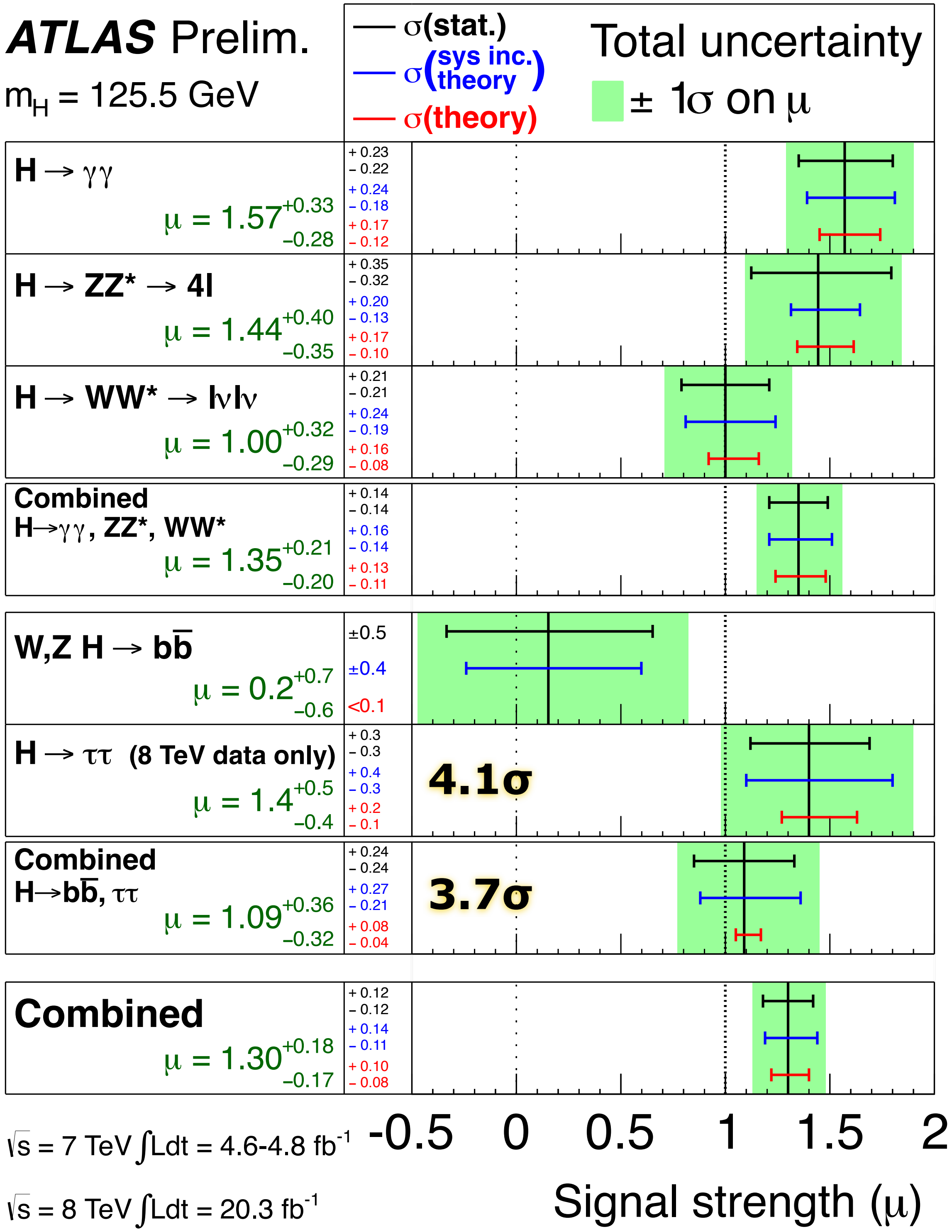
$$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma^{\mathrm{SM}}_{\mu^-\mu^+}} = \kappa_\tau^2$$

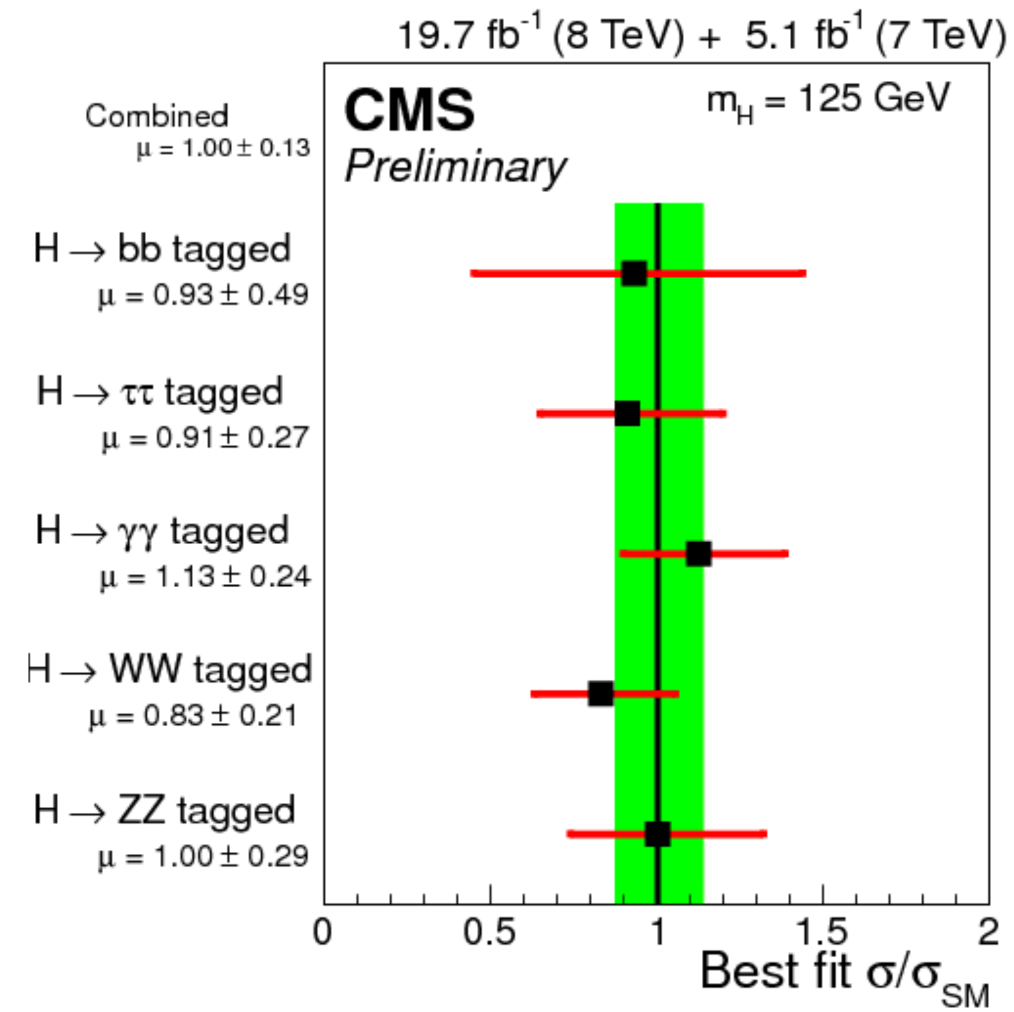
Total width

$$\frac{\Gamma_H}{\Gamma^{\mathrm{SM}}_H} = \begin{cases} \kappa_H^2(\kappa_i, m_H) \\ \kappa_H^2 \end{cases}$$

- Signal observed in the different search channels originate from a signal narrow resonance ~125GeV.
- Narrow-width approximation: $(\sigma \cdot \mathrm{BR})(ii \to \mathrm{H} \to ff) = \dfrac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$

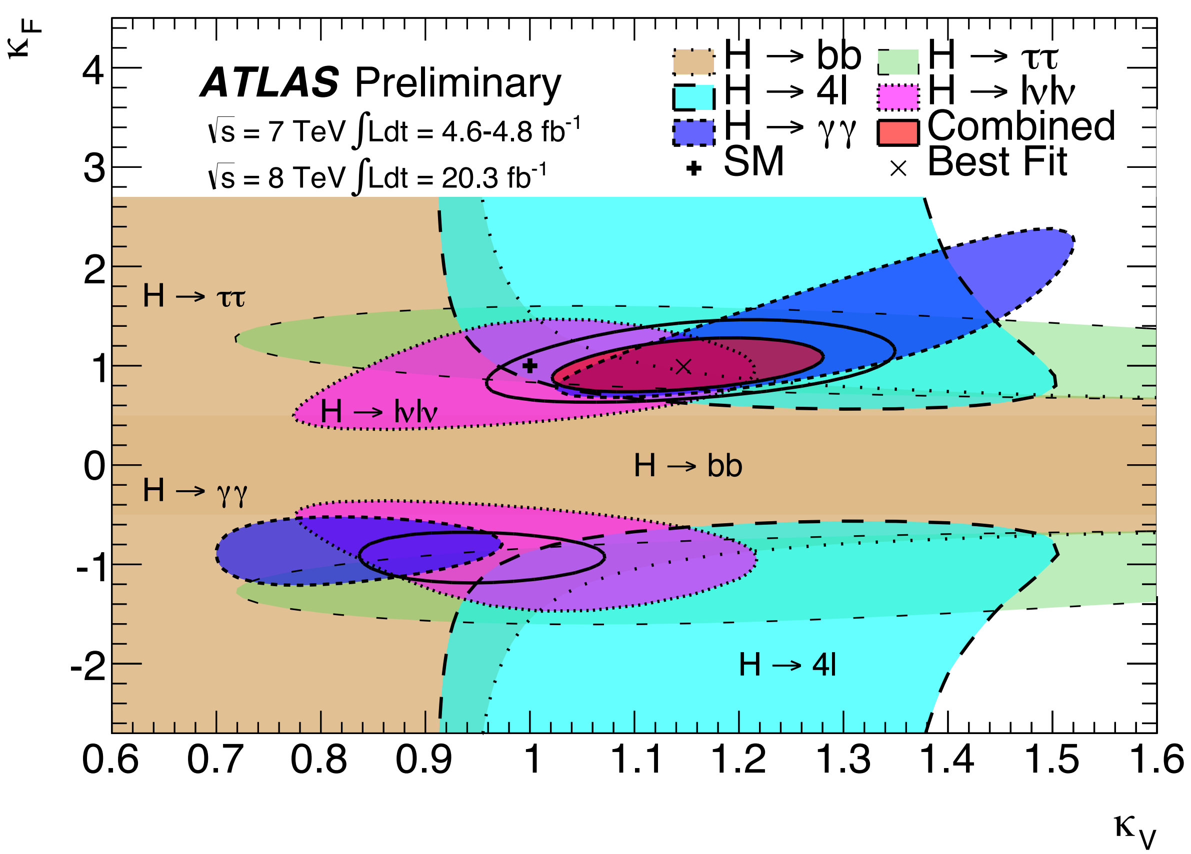
Signal strength

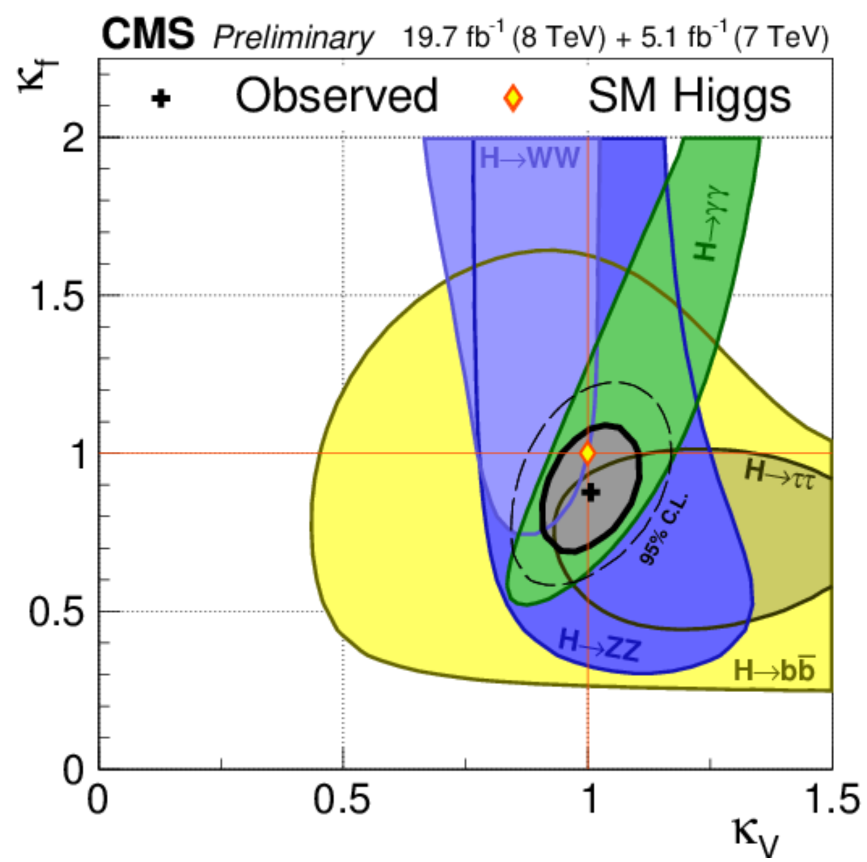




Fermion VS vector couplings

- One multiplier for the Higgs coupling to fermions: $\kappa_F = \kappa_b = \kappa_t = \kappa_\tau$
- One multiplier for the Higgs coupling to vector bosons: $\kappa_V = \kappa_W = \kappa_Z$

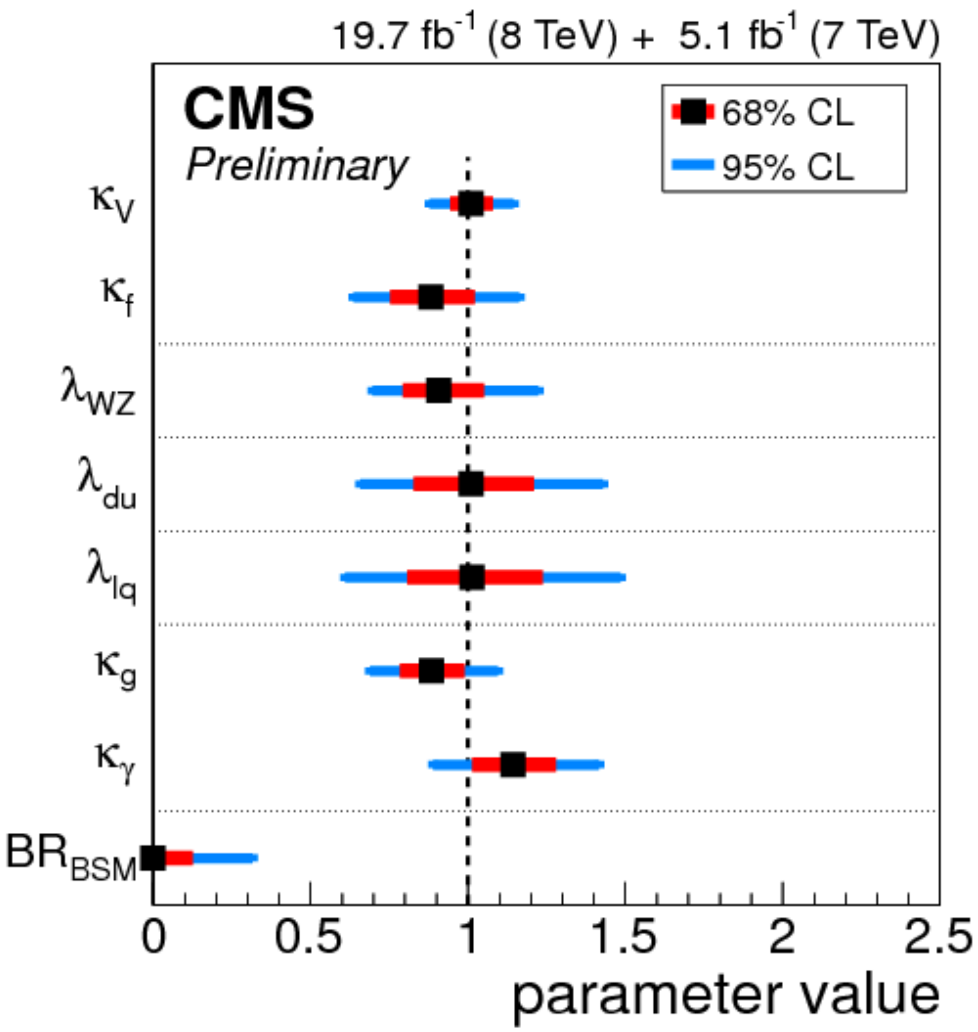


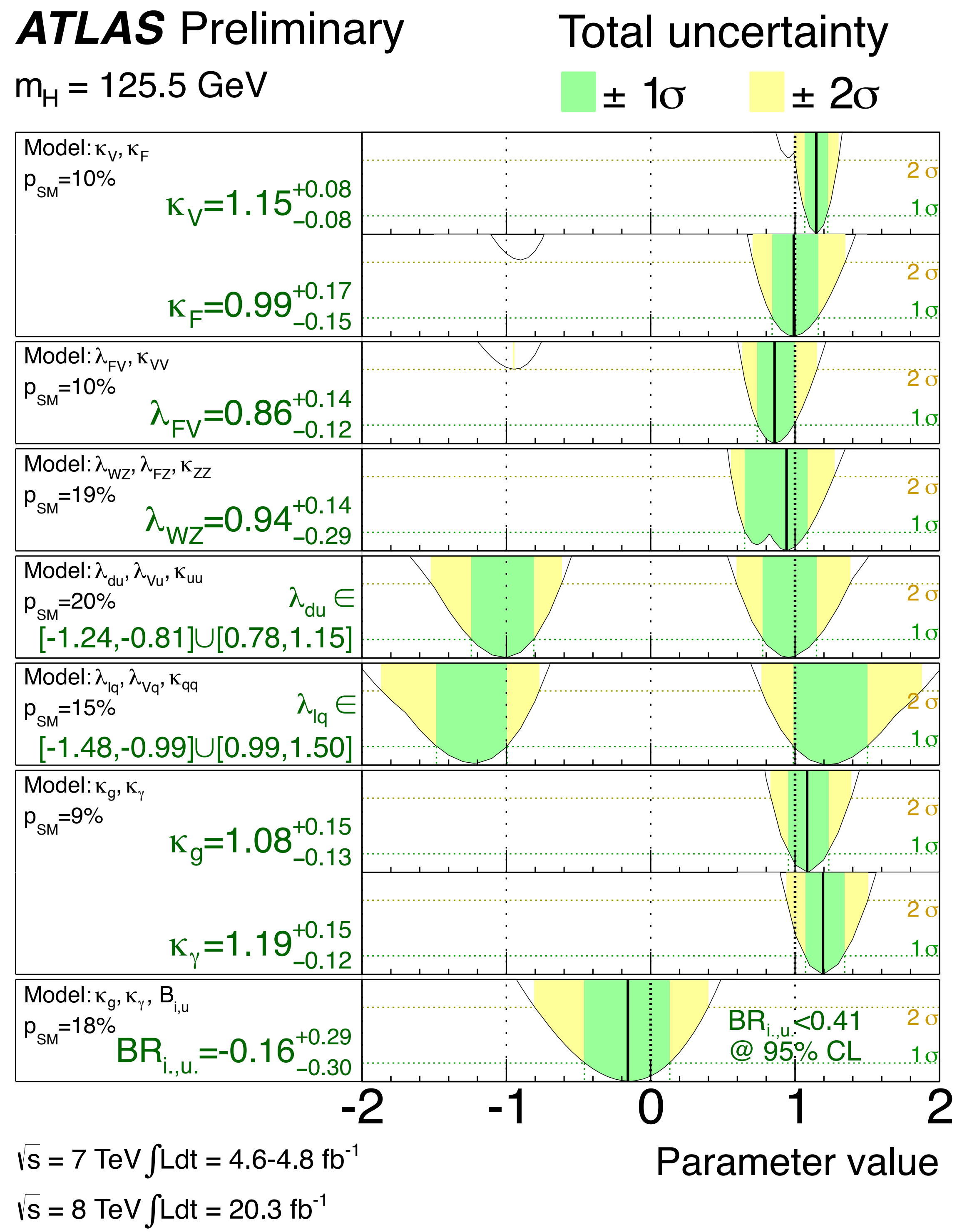


All decay channels converging around SM expectation

Summary of coupling measurement

- **Six benchmarks models probing:**
  - ✦ **Fermions and vector bosons**
  - ✦ **custodial symmetry**
  - ✦ **up/down fermion coupling ratio**
  - ✦ **Lepton/quark coupling ratio**
  - ✦ **BSM in loops: gluons and photons**
  - ✦ **Extra width**

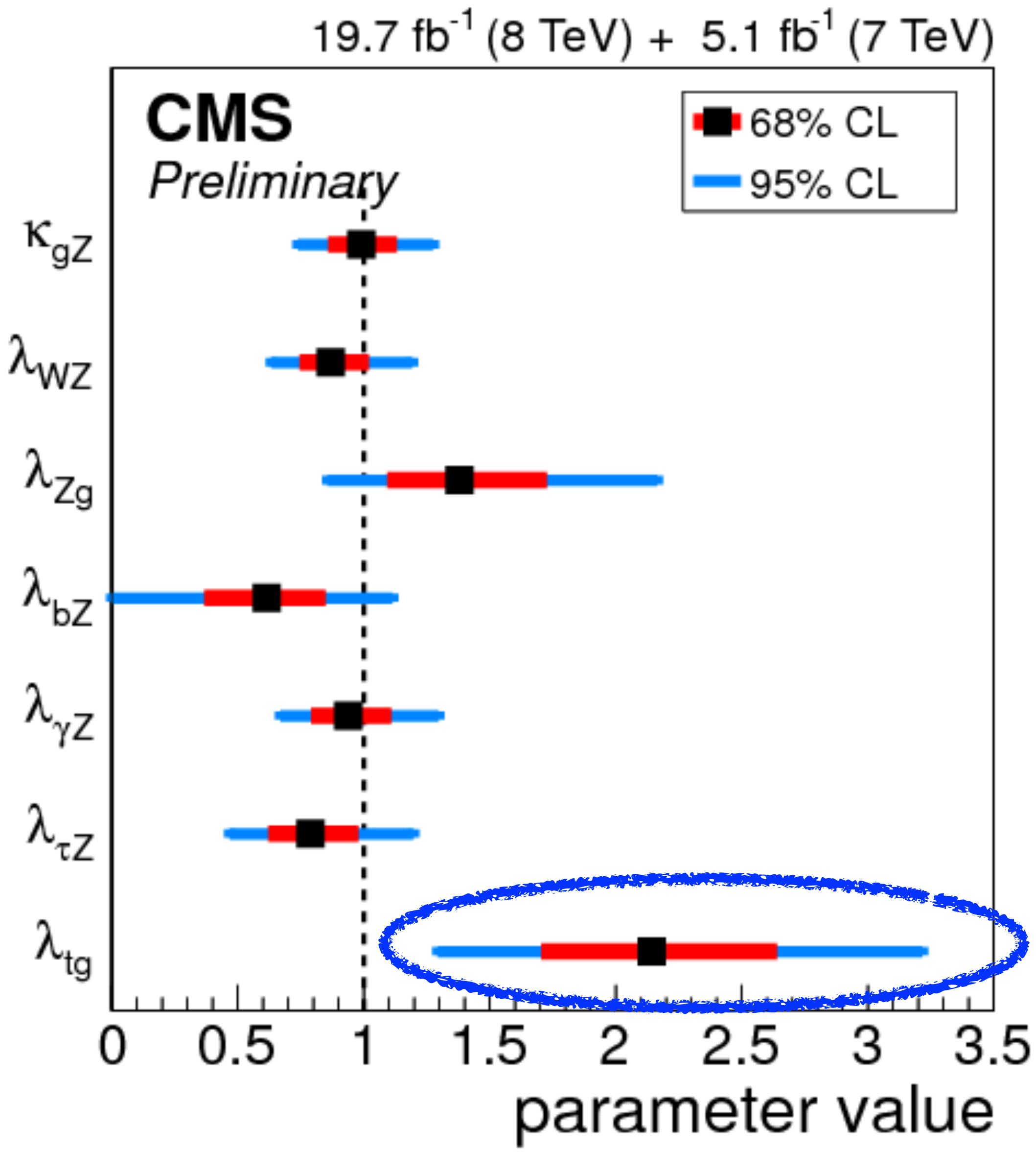


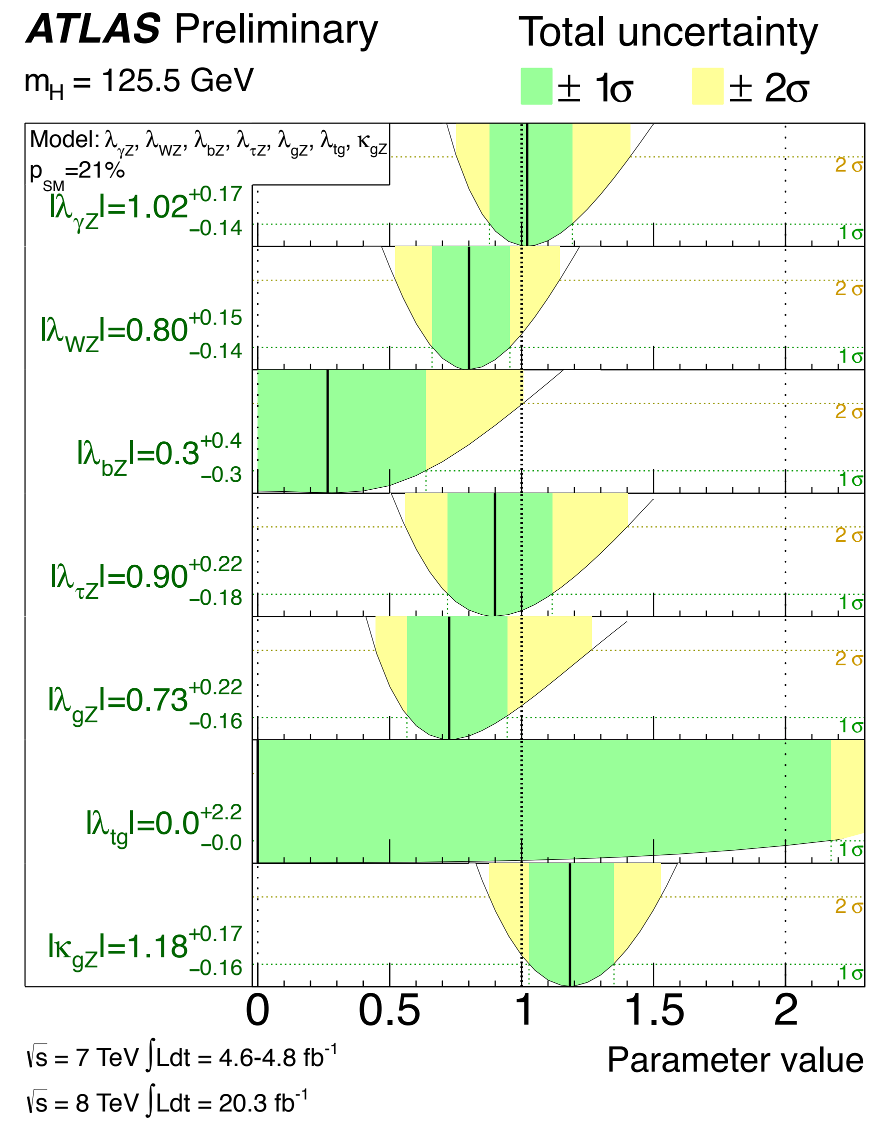


No significance deviations from SM

Summary of coupling measurement

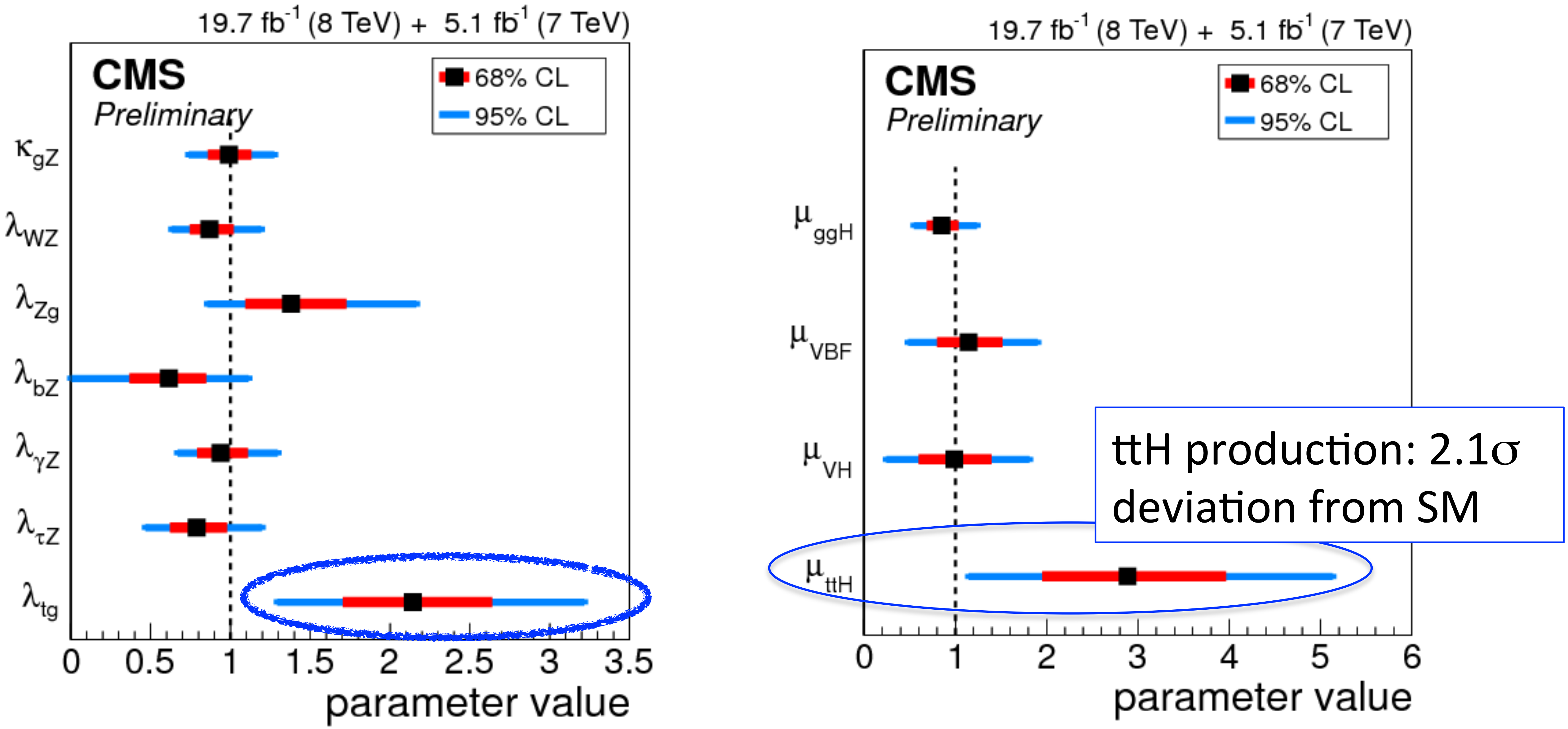
Most general benchmark without the total width assumption





Summary of coupling measurement

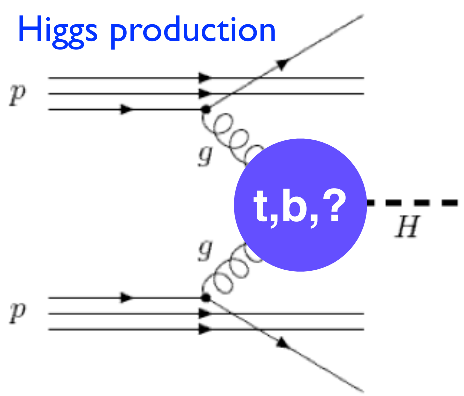
Most general benchmark without the total width assumption

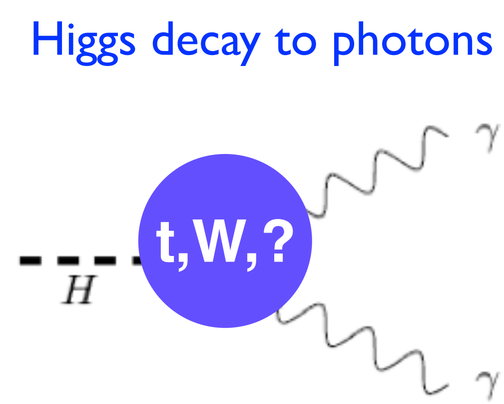


- Same ttH-related excess in λ_{tg}

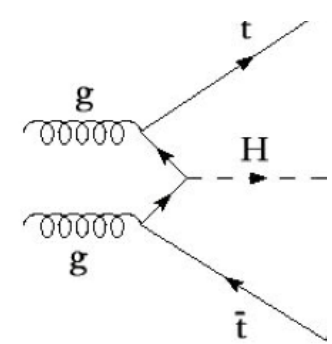
Higgs Yukawa coupling Y_t

- Indirect constraints on the Yt from measuring top-quark dominant loop-induced process like gg→H or H→γγ decays.(No beyond-standard model particles)



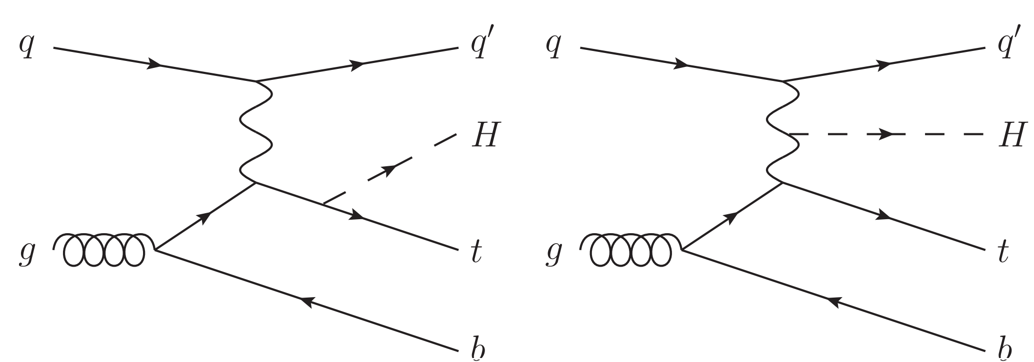


- Direct measurement of Yt in ttH production

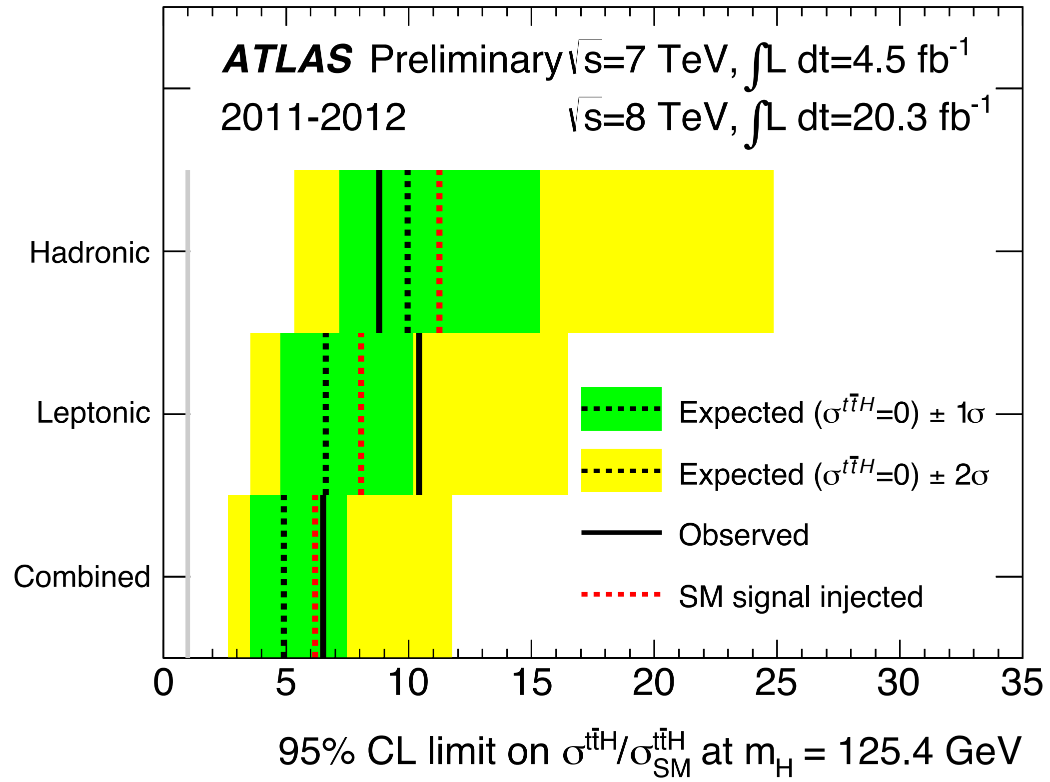


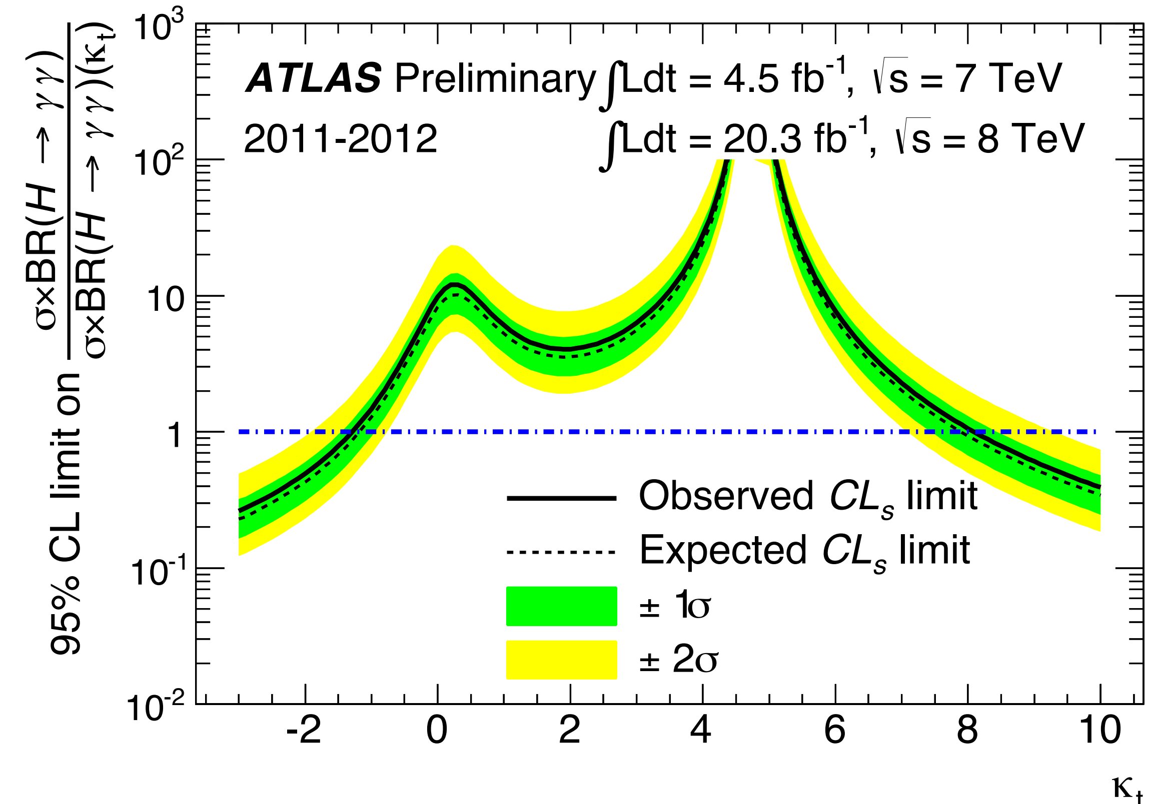
$$\sigma(t\bar{t}H) \propto g^2_{t\bar{t}H}$$

- tH produce, a small contribution due to a destructive interference, while sensitive to the sign of Yt

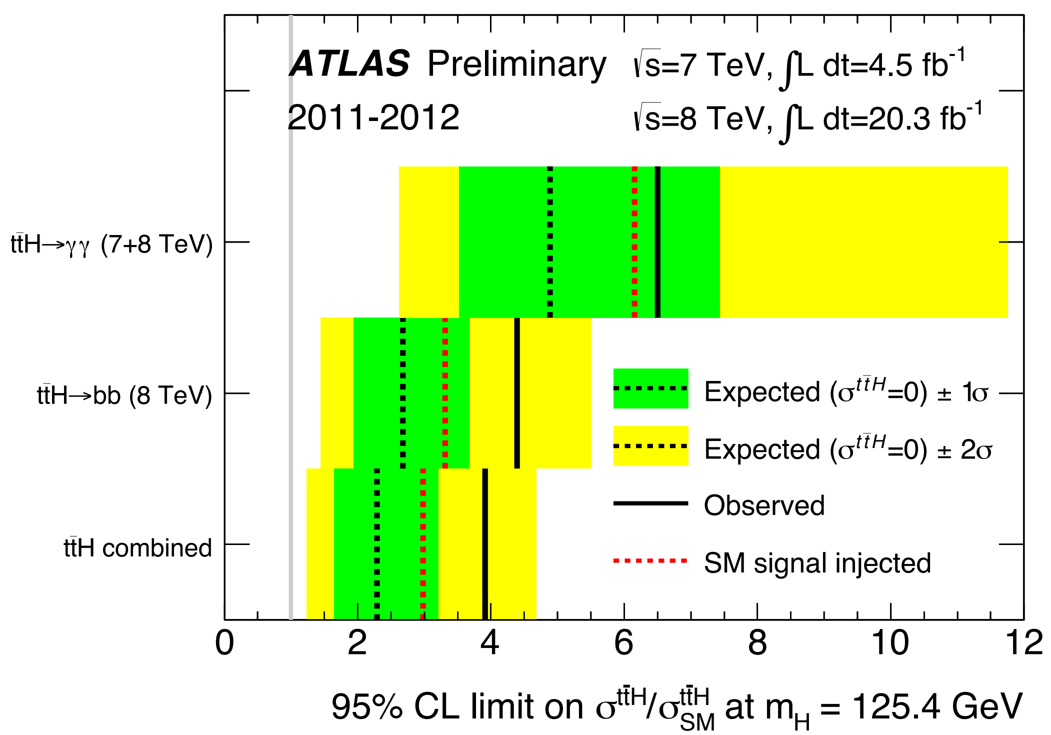


ttH: H→γγ and H→bb



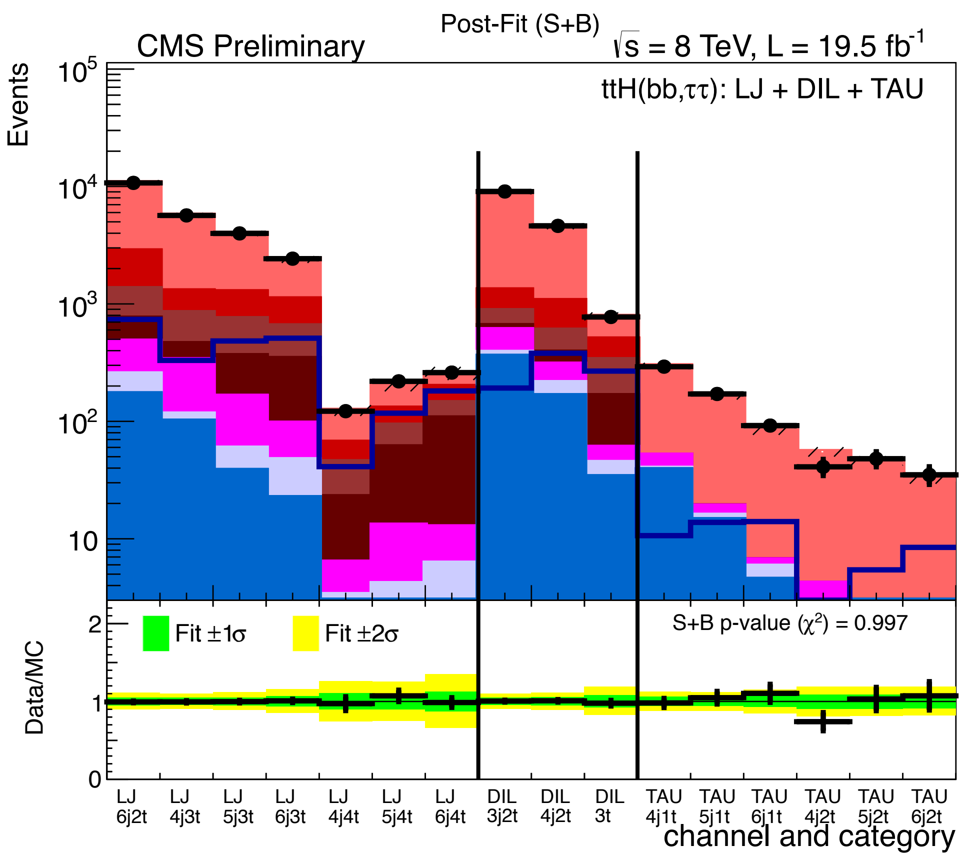


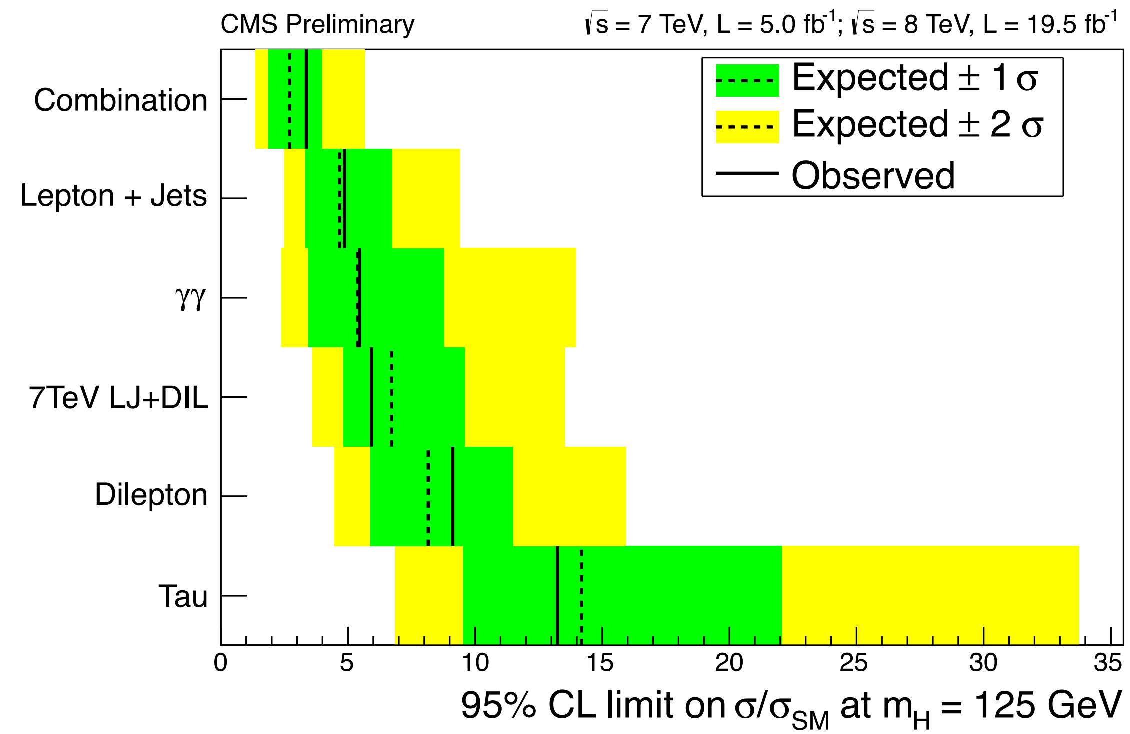
Obs.(exp.) limits on Higgs Yukawa coupling strength parameter κ_t @ 95%CL: [-1.3, 8.1] ([-1.2, 7.9])



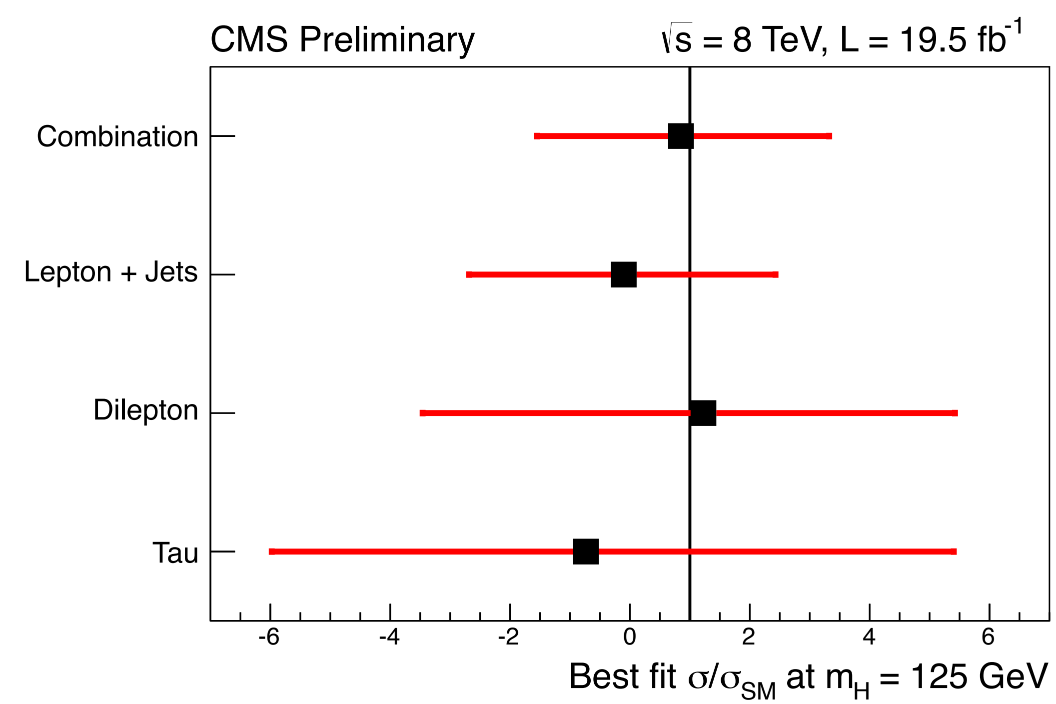
	@ 95% CL	
	observed	**expected**
ttH(bb)	4.1×SM	2.6×SM
ttH(γγ)	5.6×SM	4.9×SM
Combination	3.9×SM	2.3×SM

ttH: H→bb and H→ττ





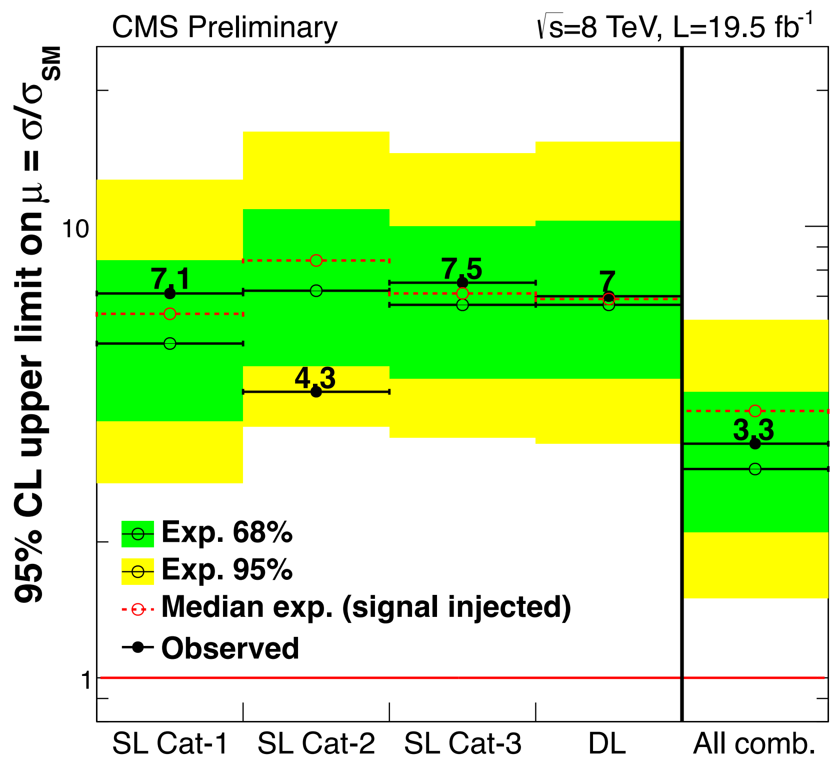
Channel	Exp (σ/σ_{SM})	Obs (σ/σ_{SM})
LJ	4.7	4.9
DIL	8.2	9.1
TAU	14.2	13.2
7 TeV LJ + DIL	6.7	5.9
$\gamma\gamma$	5.4	5.5
COMB	2.7	3.4

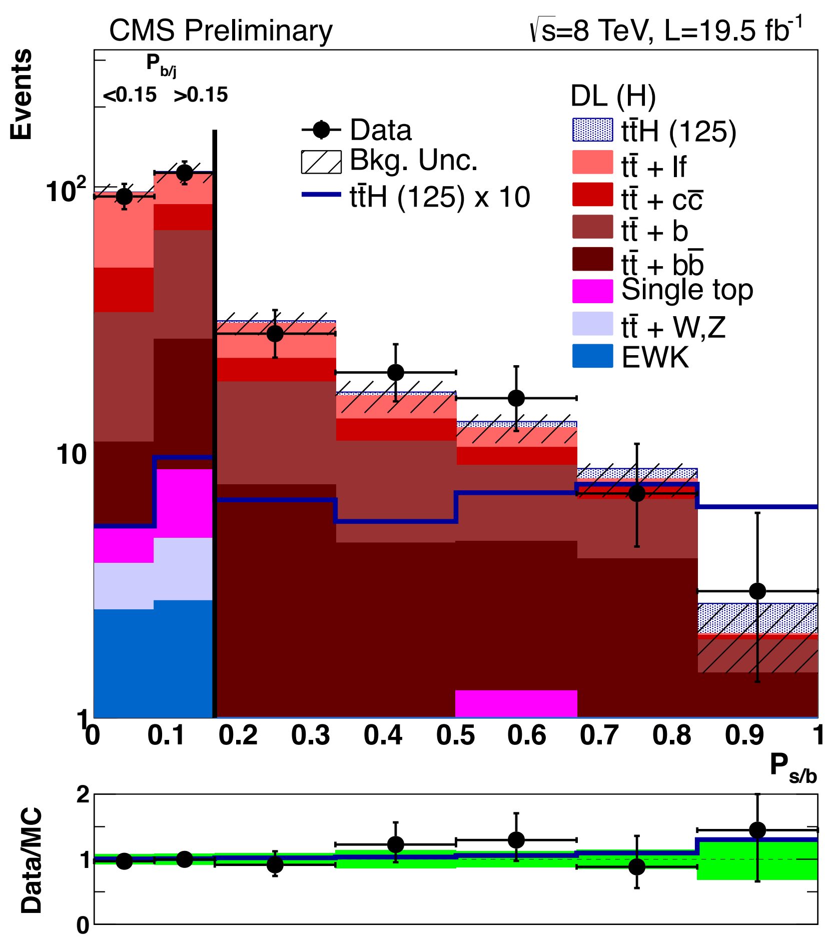


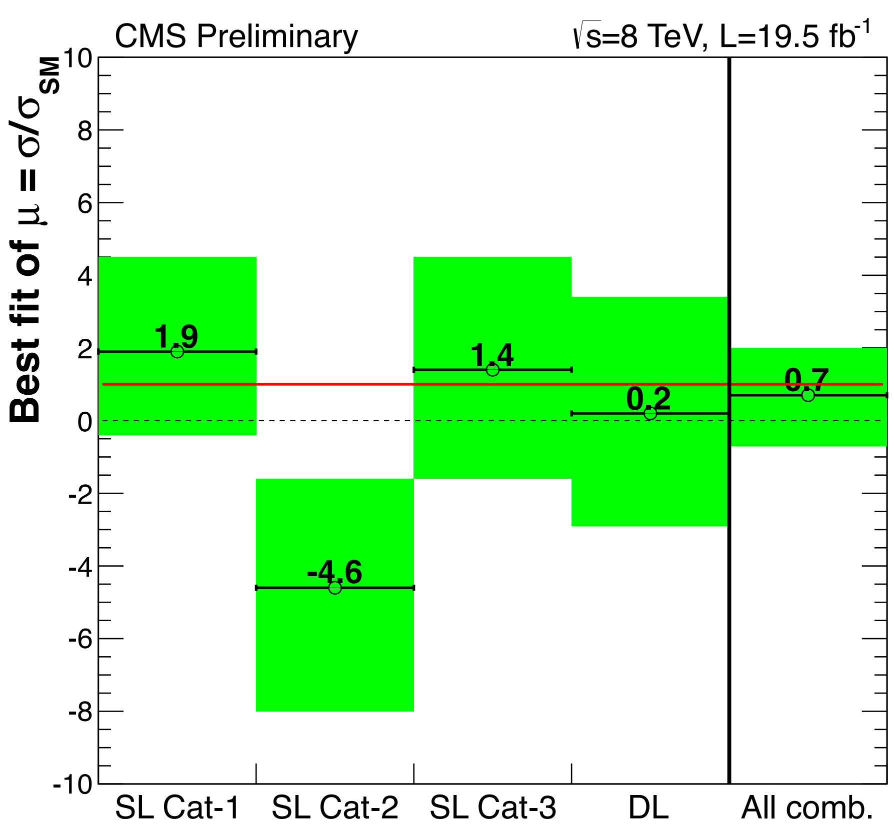
- BDT to separate signal from background
- 7 SL+jets, 3 DL+jets, 6 tau channels

ttH: H→bb

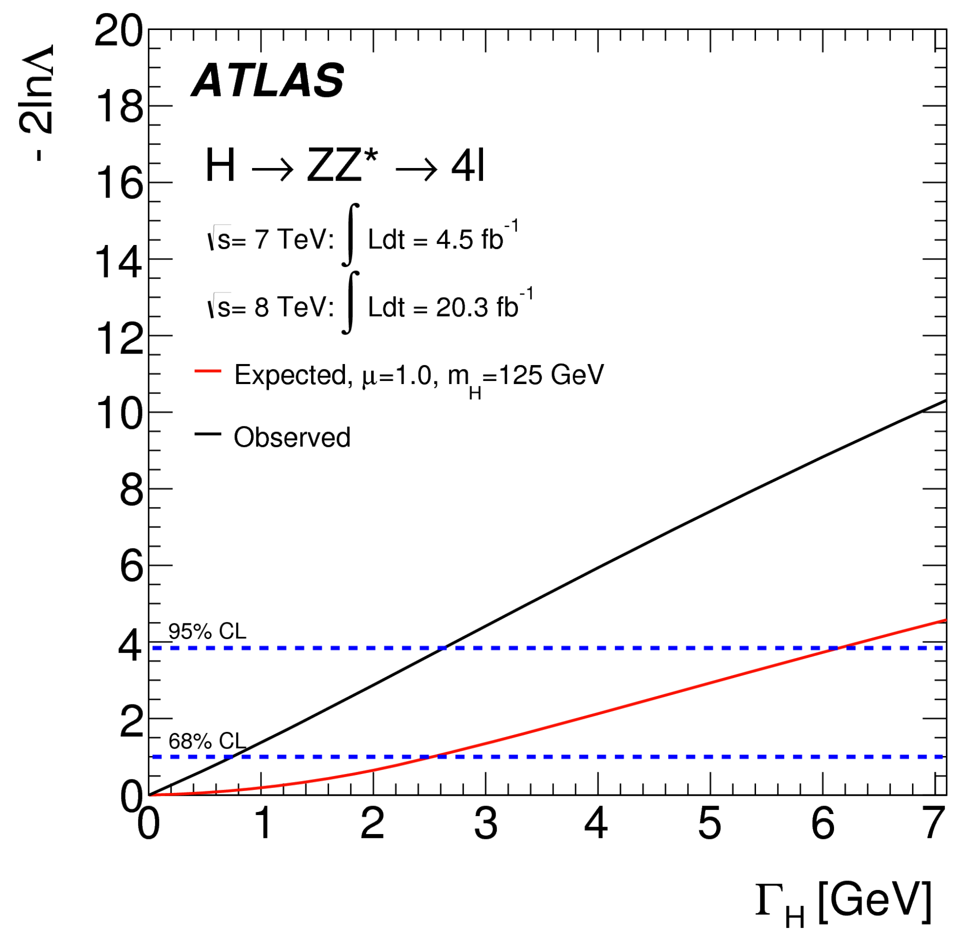
- Improved performance:
  - Under ttH(bb) or ttbb hypothesis, a discriminant of Event probability (Ps/b) based on matrix element probabilities.
  - Single lepton (SL) and di-lepton (DL) topologies.

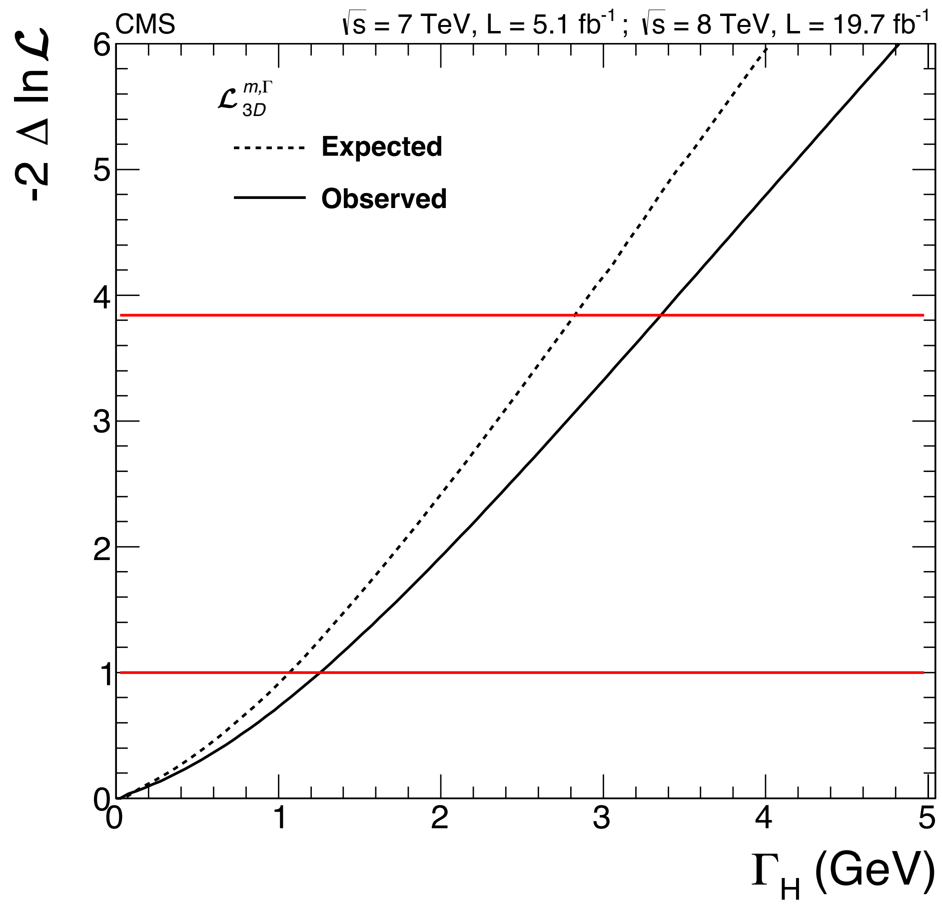






Direct Width measurement



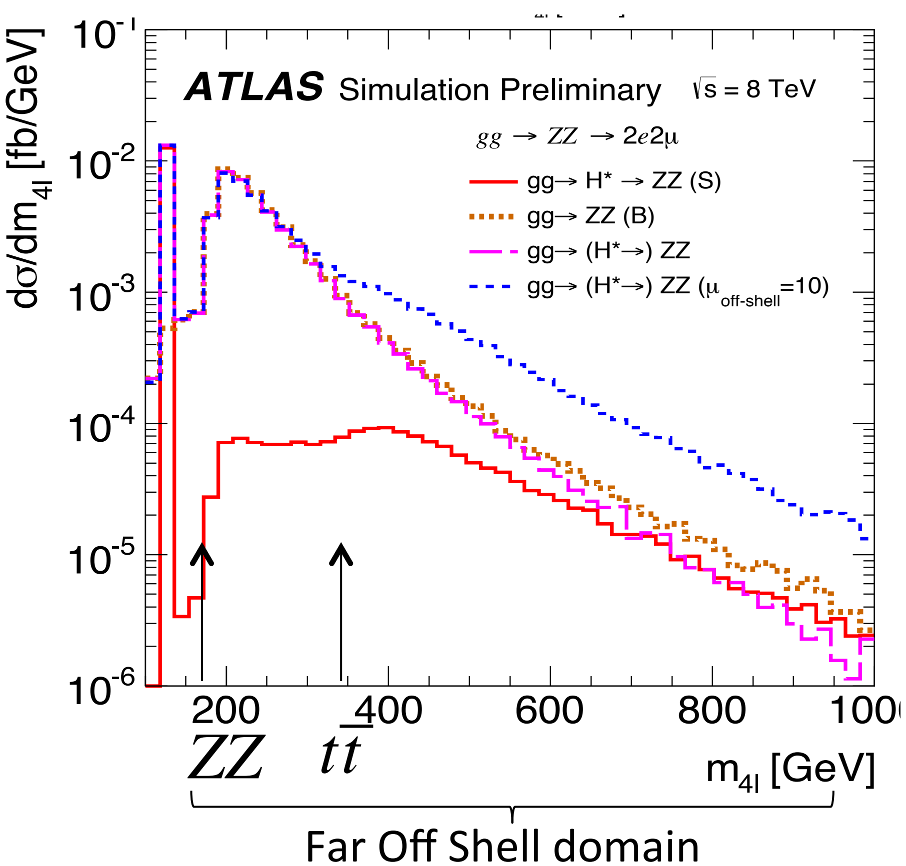


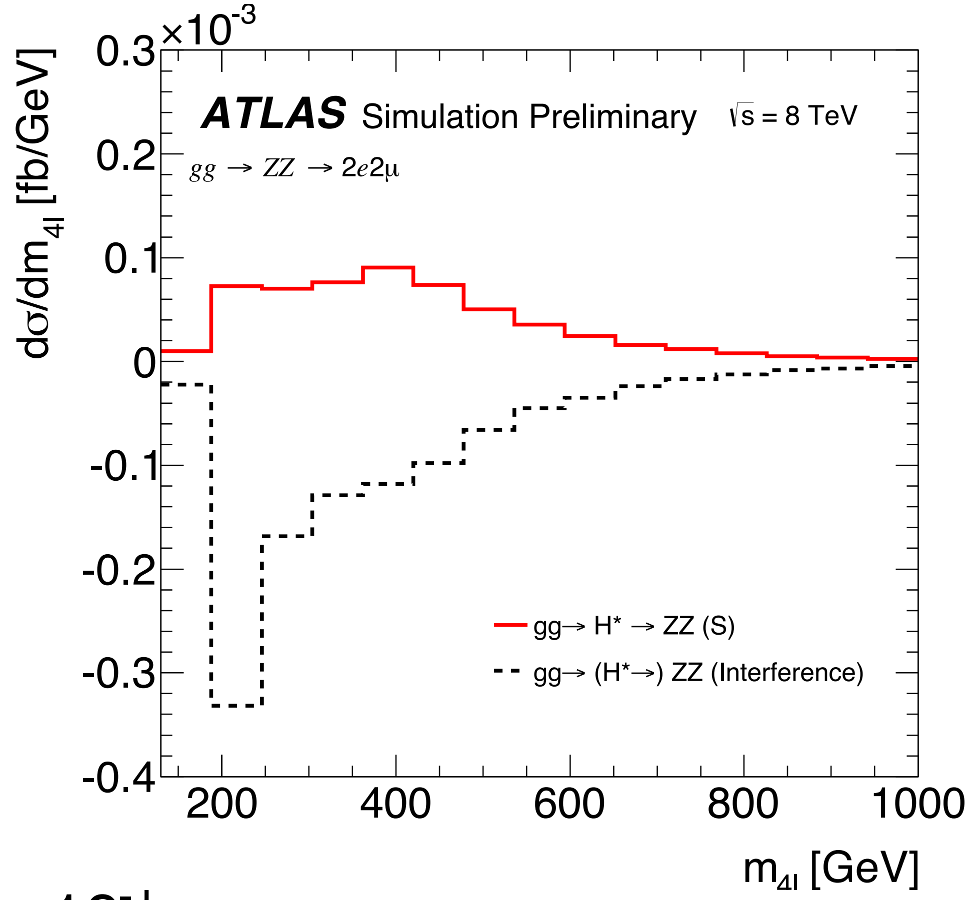
obs.(exp.)@ 95% CL	H→γγ	H→ZZ
ATLAS	5.0 (6.2) GeV	2.6 (6.2) GeV
CMS	2.4 (3.1) GeV	3.4 (2.8) GeV

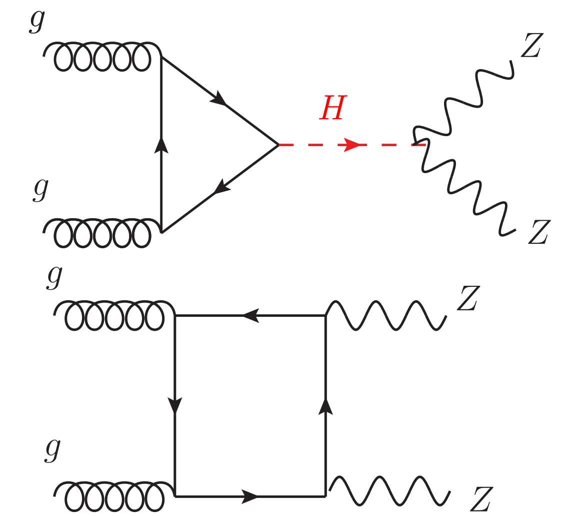
Standard Model predicts a width of Γ=4.2MeV (3 order of magnitude smaller)

Off-shell Higgs coupling properties measurement

Further constraint the Higgs width via indirect measurements based on off-shell higgs production





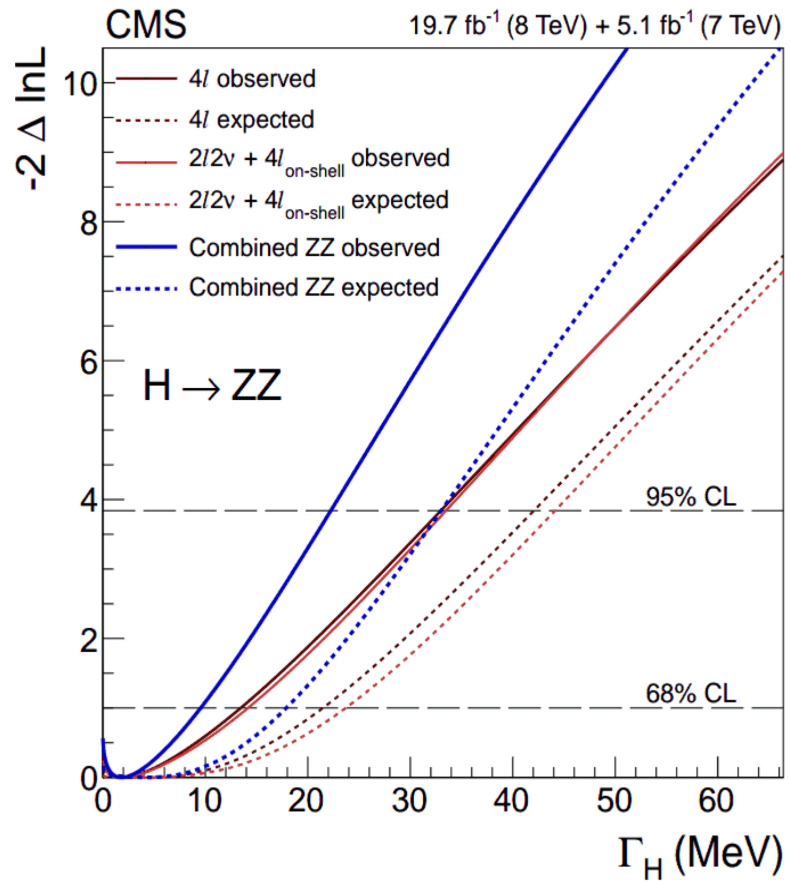


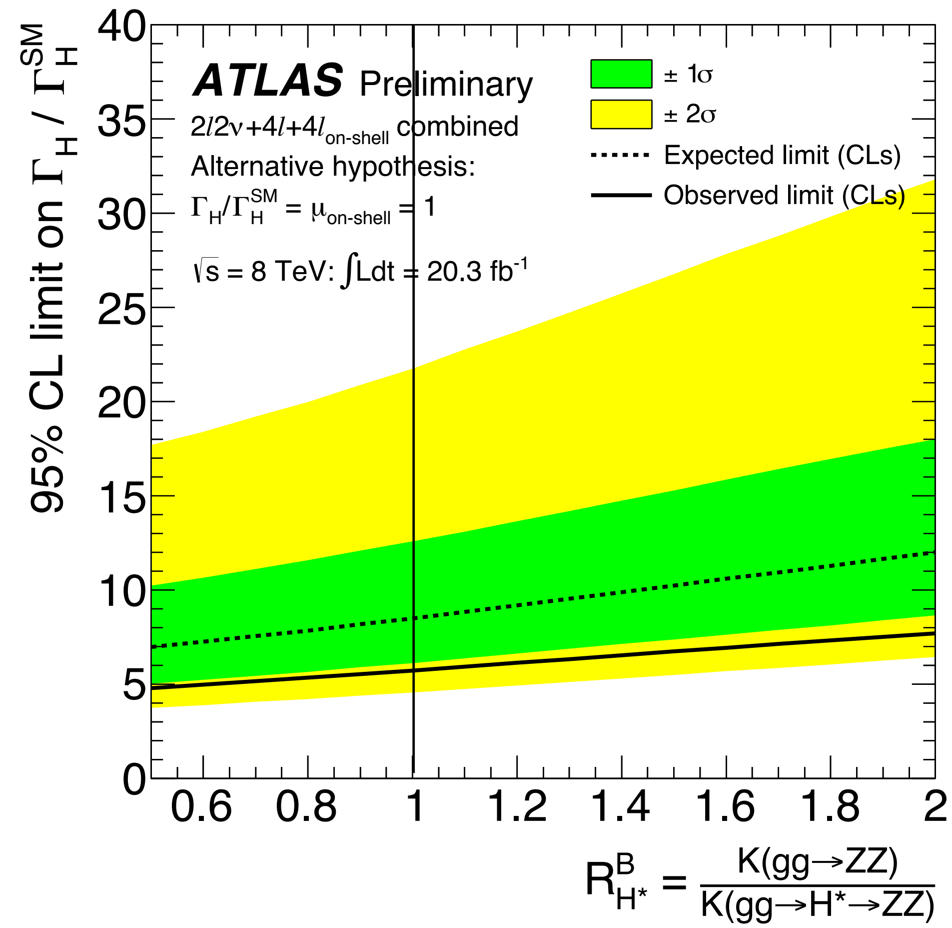
$$\mu_{OffShell} \equiv \frac{\sigma_{OffShell} Br_{VV}}{(\sigma_{OffShell} Br_{VV})_{SM}} = \kappa_t^2 \kappa_V^2$$

$$\boxed{\mu_{OnShell} \equiv \frac{\kappa_t^2 \kappa_V^2}{\Gamma_H / \Gamma_H^{SM}}}$$

- Sizeable off-shell contribution, large negative interference.
- No assumption on gg->ZZ continuum background: $R^b_{H^*} = \frac{k_{gg \to ZZ}}{k_{gg \to H^* \to ZZ}}$

Indirect width measurement

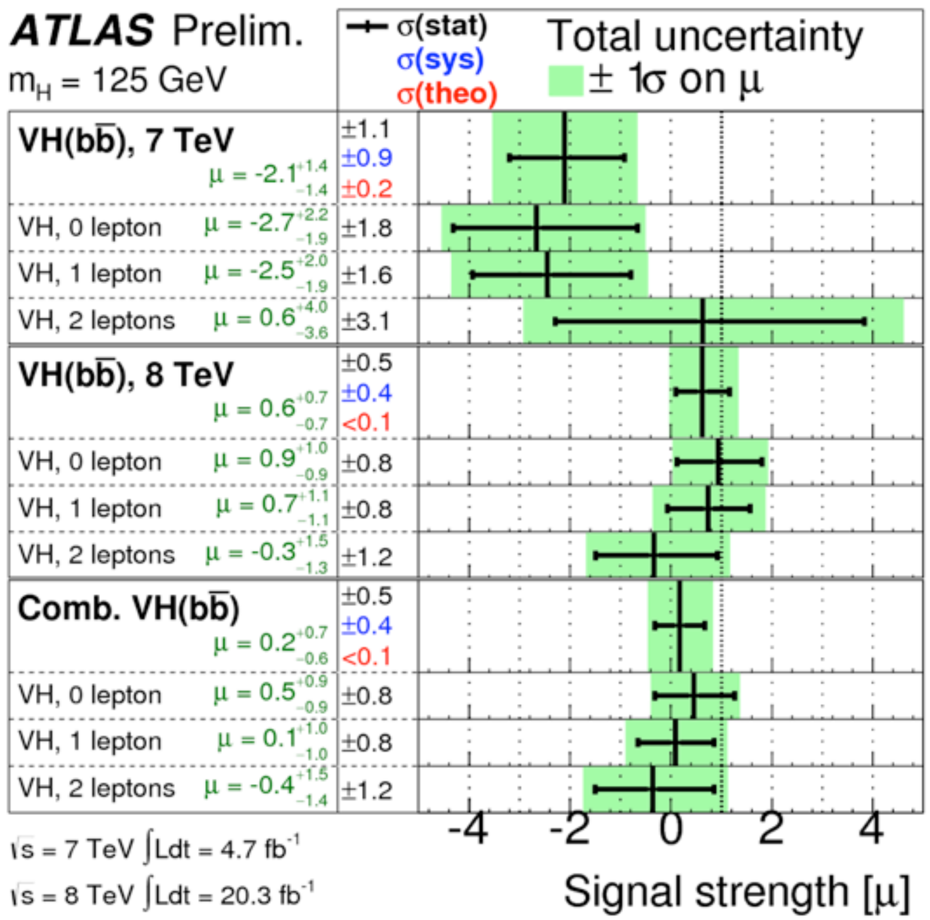


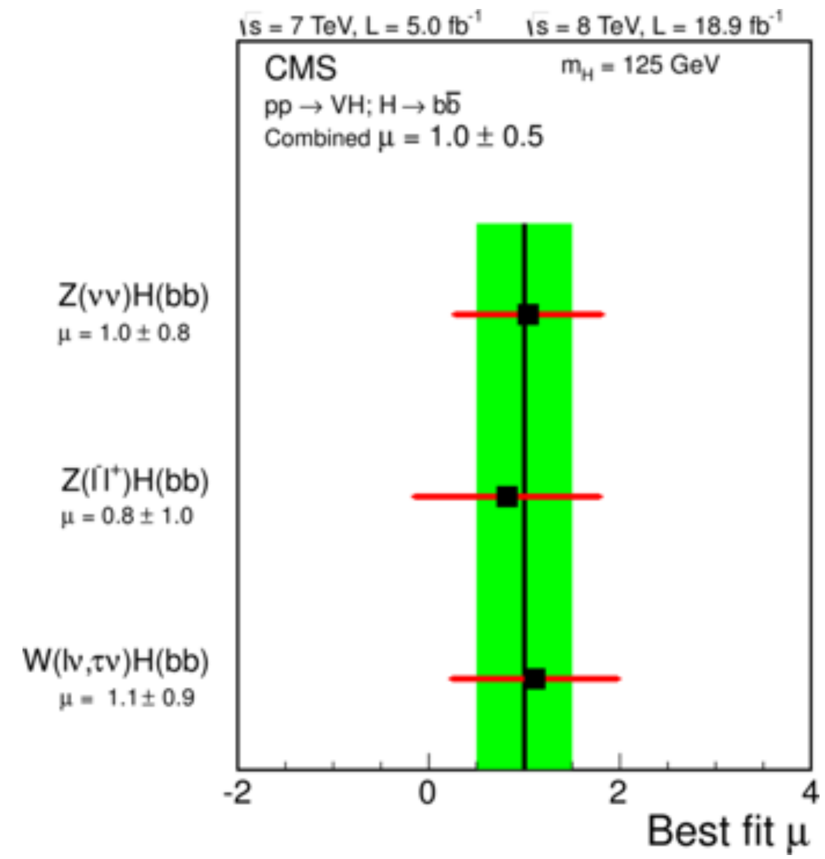


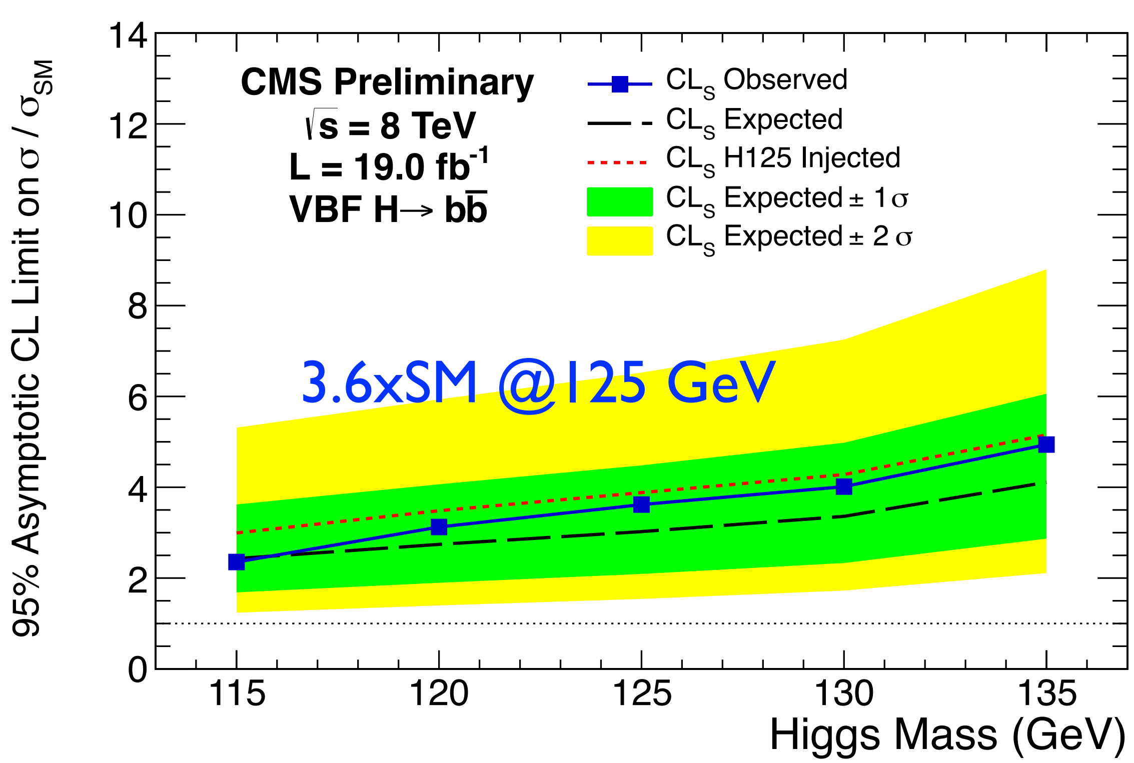
- Treatment of ggZZ background k-factors:
  - CMS uses 10% flat uncertainty
  - ATLS: a results with a scan of the k-factors.
- Treatment of the interference uncertainties:
  - CMS: 10% (correlated with ggZZ bkg)
  - ATLAS: 30% uncorrelated with the rest

Γ/Γ_{SM} =obs.(exp.)	CMS	ATLAS
4l	8.0(10.1)	7.2(10.2)
2l2ν	8.1(10.6)	11.3(9.9)
combined	5.4(8.0)	6.7(7.9)

H→bb

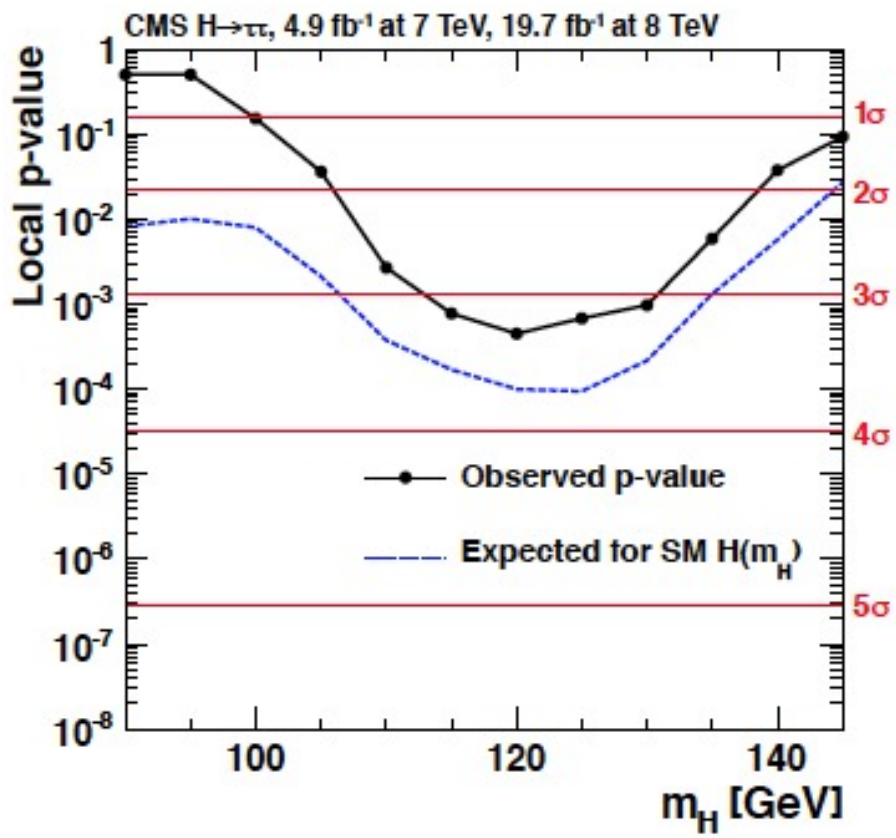




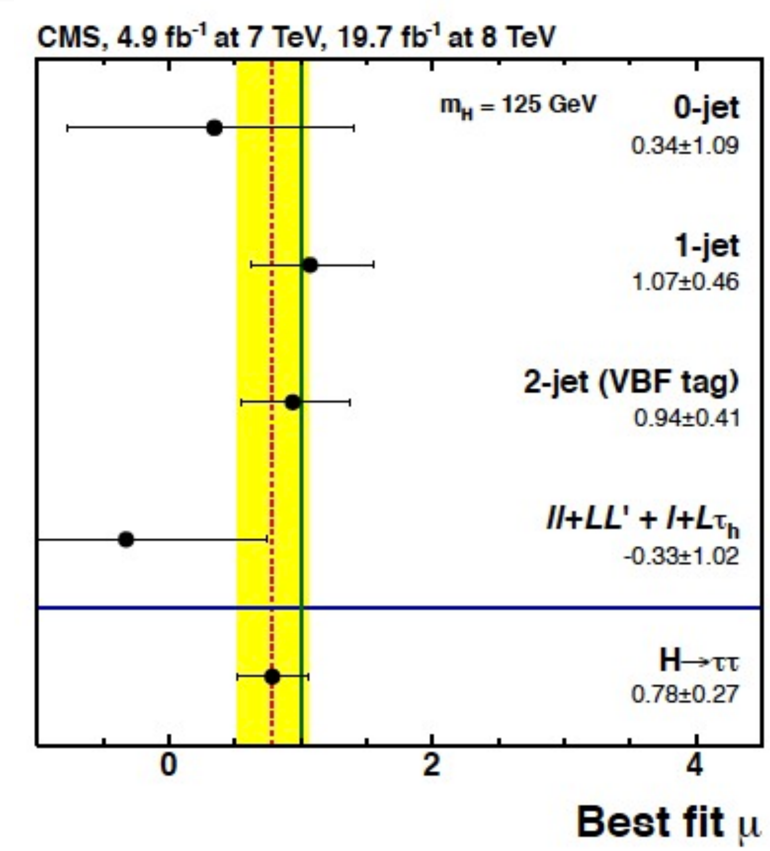


	$\mu = \sigma/\sigma_{SM}$	exp. sign.
CMS	1.0 ± 0.5	2.1 σ
CDF	2.5 ± 1.0	1.3 σ
D0	1.2 ± 1.1	1.5 σ
D0+CDF	1.95 ± 0.75	1.9 σ
ATLAS	0.2 ± 0.9	1.6 σ

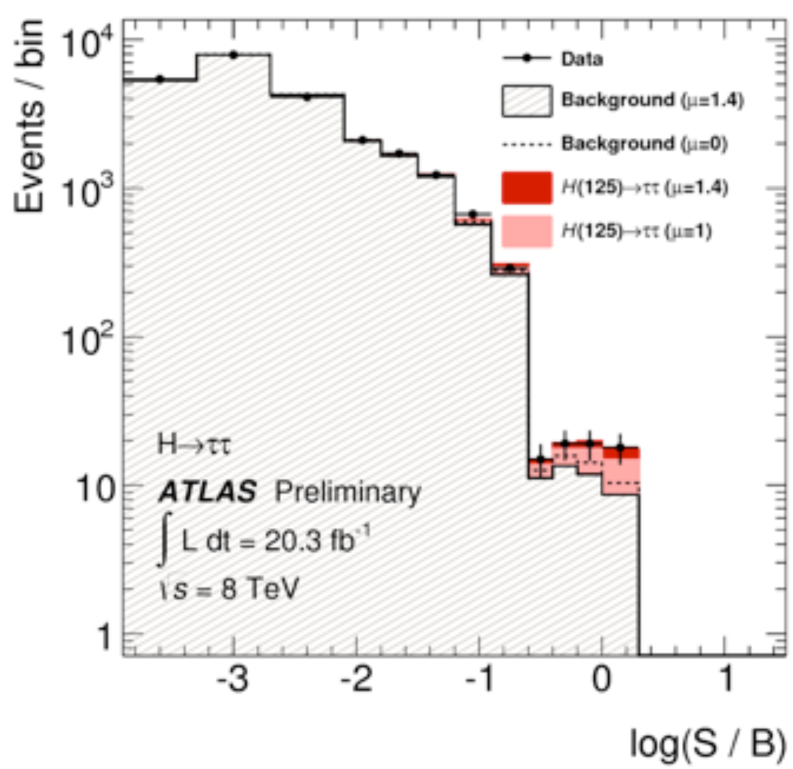
H→ττ



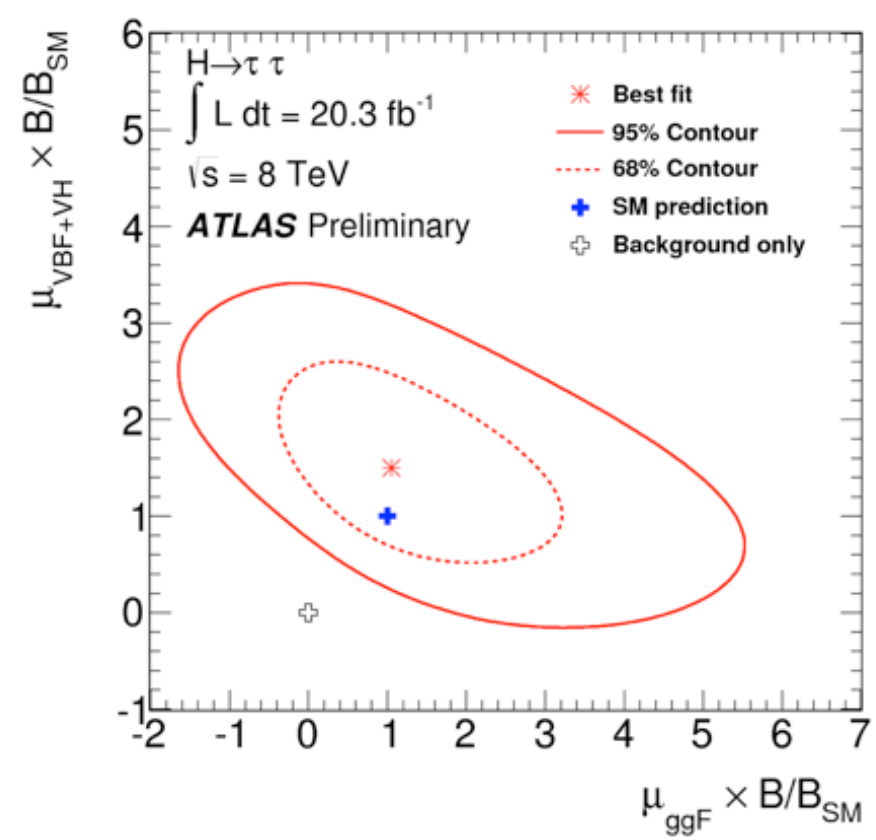
obs. (exp.) significance: 3.8(4.4)σ



μ=0.83±0.24

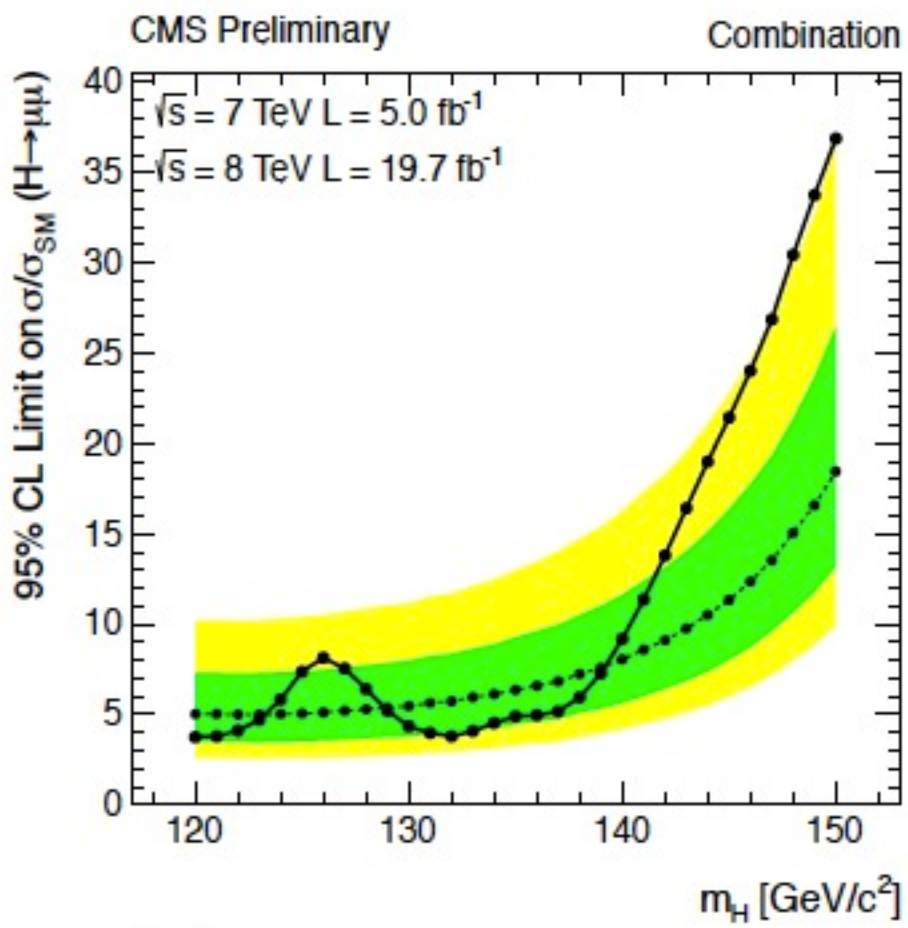


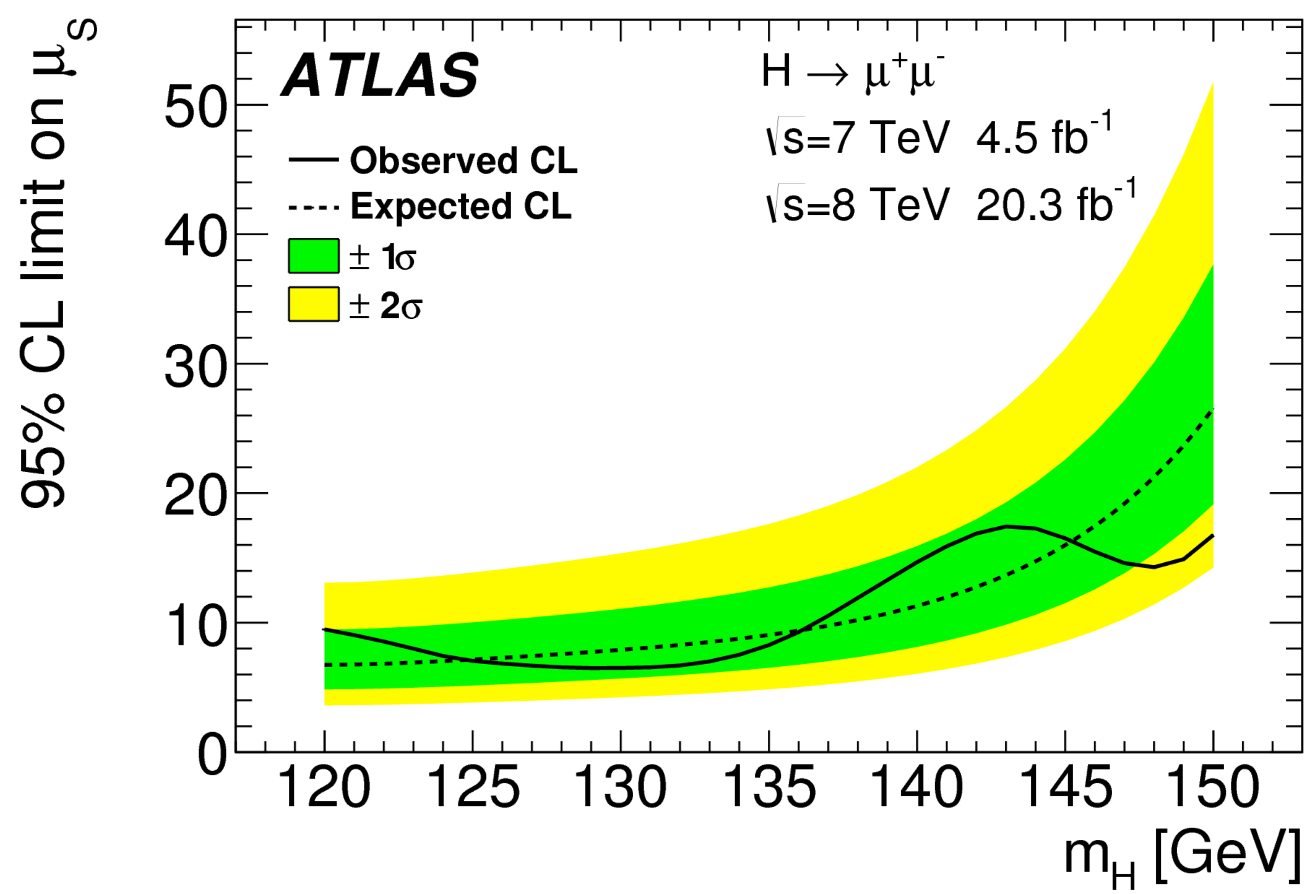
obs. (exp.) significance: 4.1(3.2)σ



$\mu=1.4^{+0.5}_{-0.4}$

H→μμ



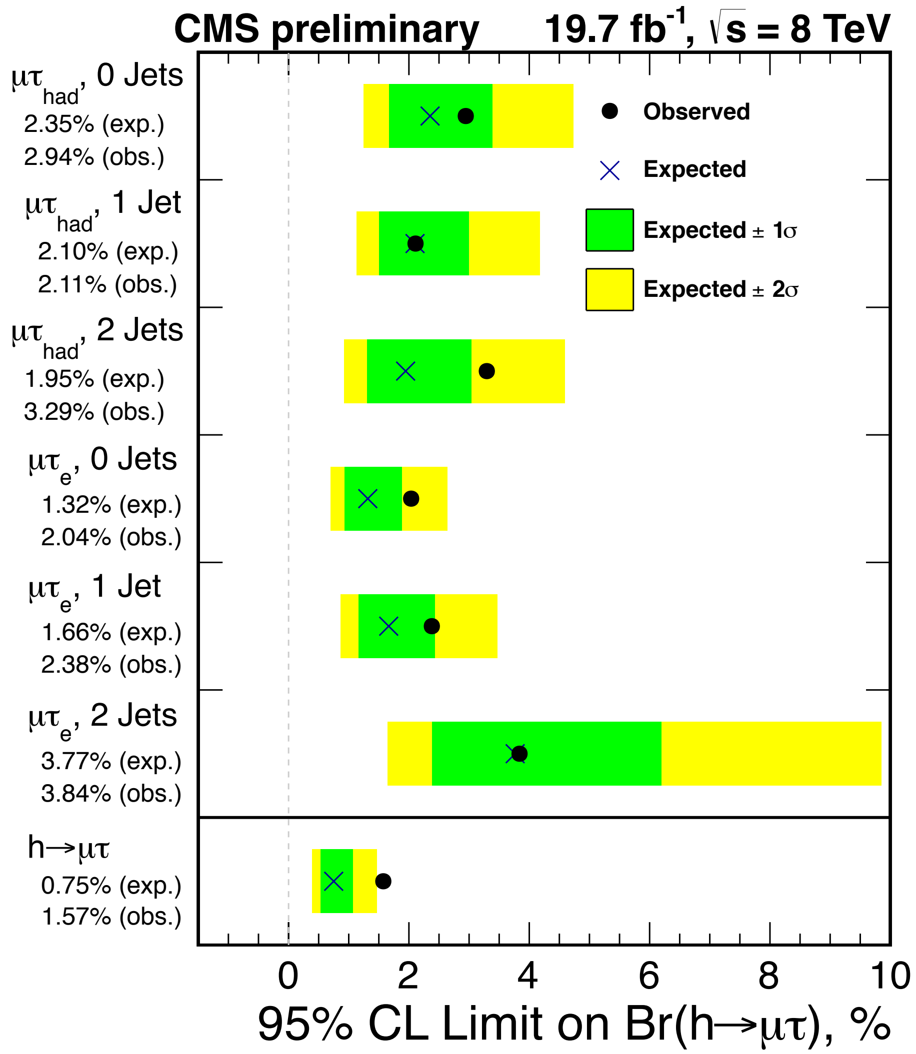


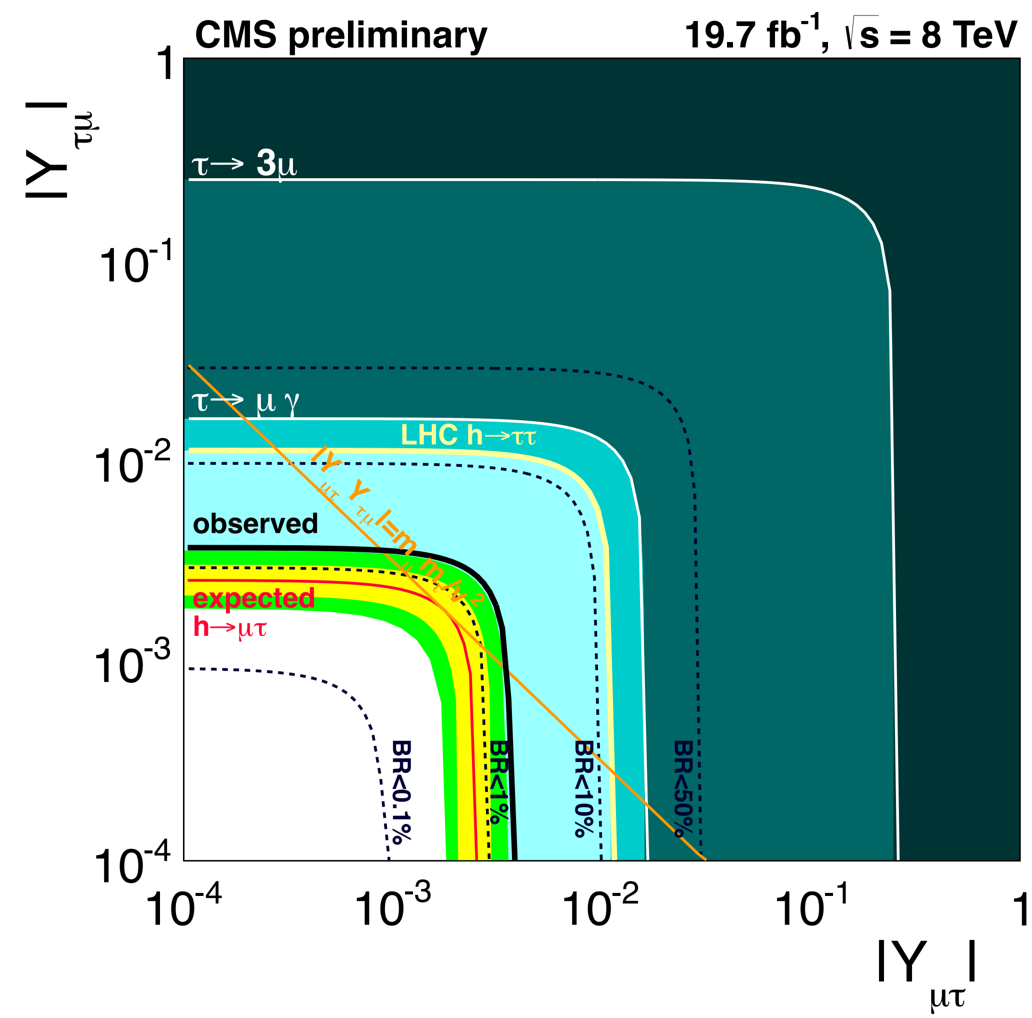
obs. (exp.) limit: 7.4(5.1)

obs. (exp.) limit: 7.0(7.2)

- Br(H→μμ)<1.5×10^{-3} @ 95% CL.
- As expected, Higgs boson decays to leptons are not universal

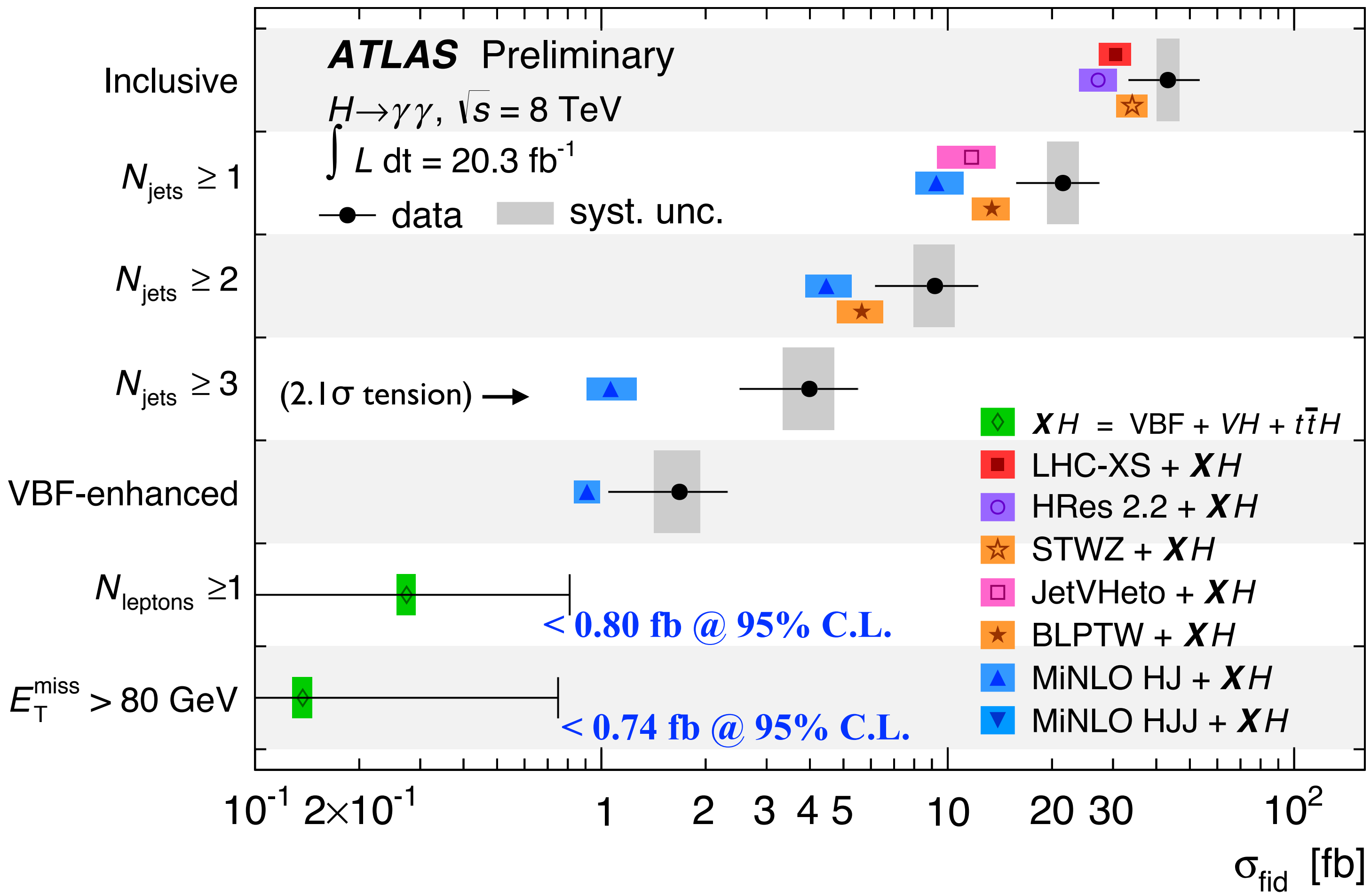
Search for H→τμ

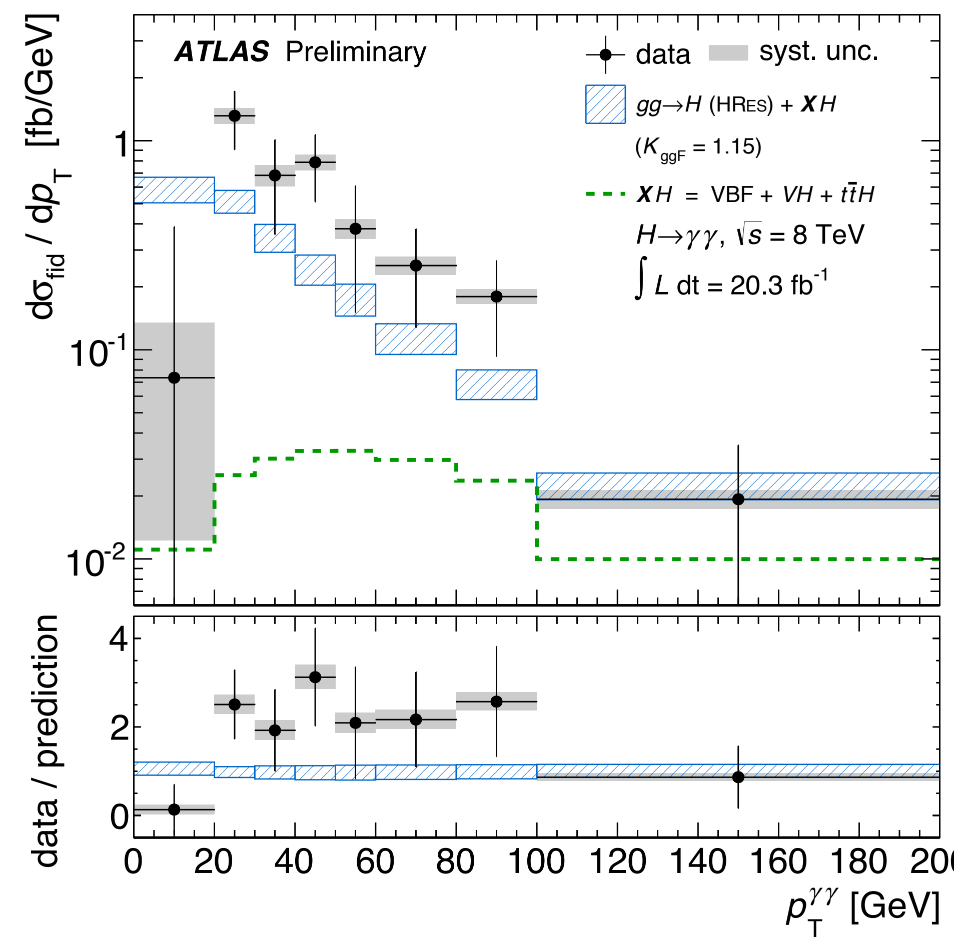




- Observed (expected) limits: 1.57%(0.75%)
- Background-only p-value of 0.007 (2.46σ)
- Best-fit: $B(H\rightarrow\mu\tau)=0.89^{+0.40}_{-0.37}\%$
- Translate branching ratio limit to limits on Yukawa couplings: $\sqrt{|Y_{\mu\tau}|^2+|Y_{\tau\mu}|^2} < 0.0036$

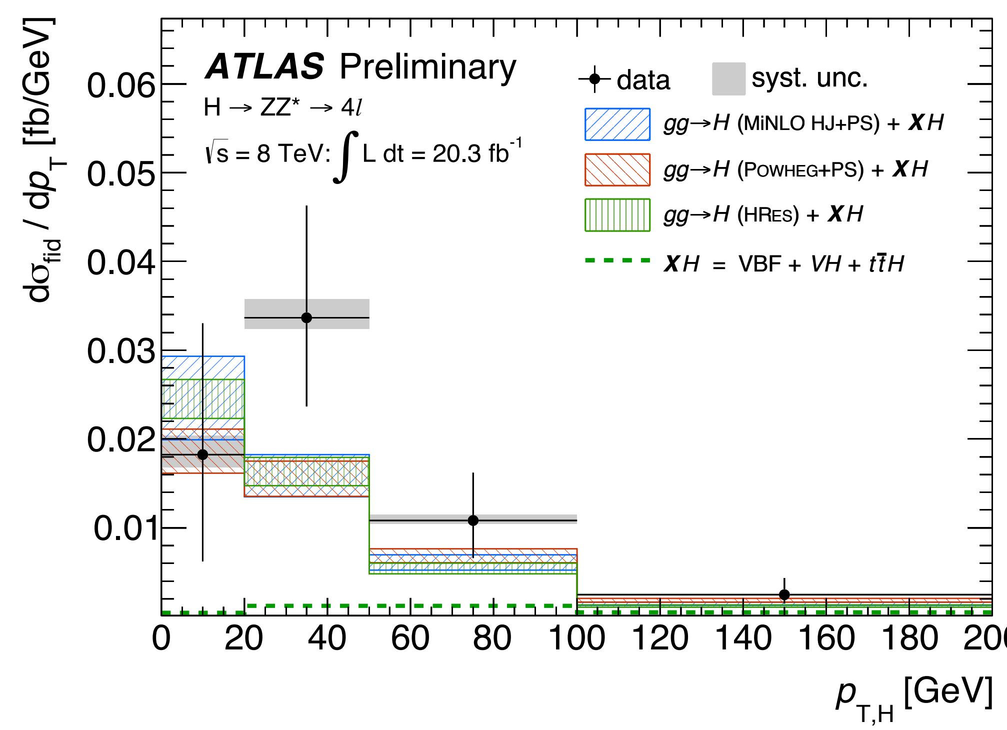
Fiducial and Differential Cross sections



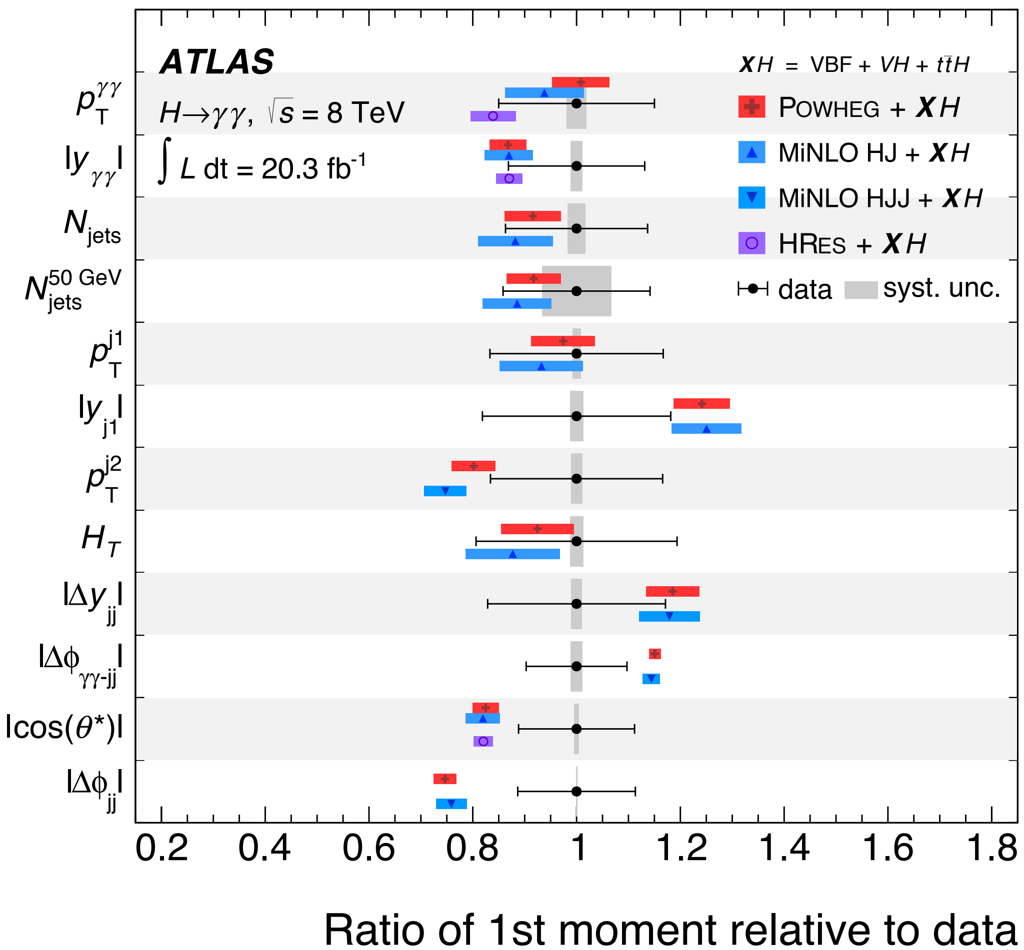


$$\sigma_{\rm fid}(pp \to H \to \gamma\gamma) = 42.7 \pm 9.3\,(\text{stat})\,^{+3.2}_{-2.9}\,(\text{syst}) \pm 1.2\,(\text{lumi})\ \text{fb}$$

$$\sigma_{\rm fid}(pp \to H \to ZZ) = 2.11^{+0.53}_{-0.47}(\text{stat}) \pm 0.08(\text{syst})\text{fb}$$



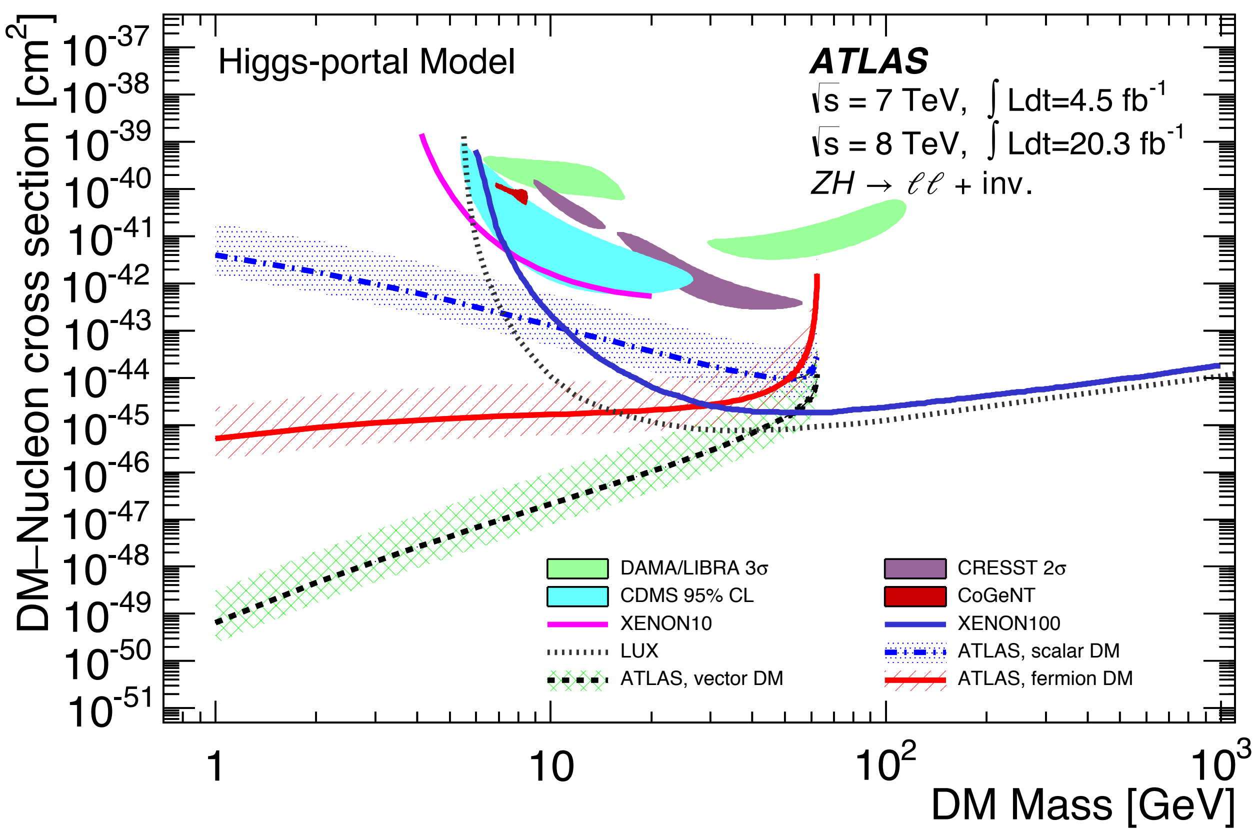
Fiducial and Differential Cross sections

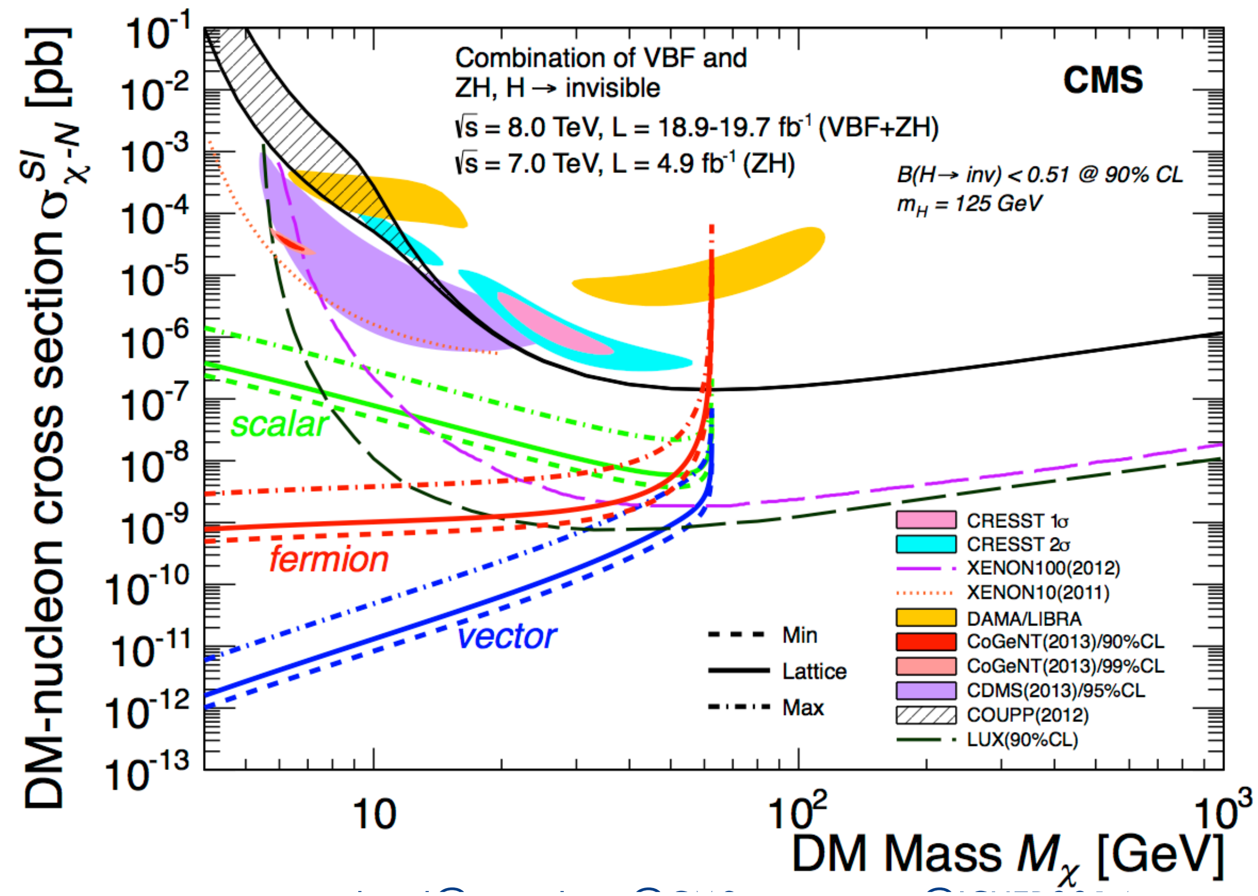


Variable	POWHEG	MINLO HJ	MINLO HJJ	HRES
$p_T^{\gamma\gamma}$	0.12	0.10	0.09	0.12
$\|y_{\gamma\gamma}\|$	0.81	0.83	0.83	0.80
$\|\cos\theta^*\|$	0.59	0.57	0.58	0.56
$N_{\rm jets}$	0.42	0.36	0.30	-
$N_{\rm jets}^{50\ \rm GeV}$	0.33	0.33	0.30	-
H_T	0.43	0.39	0.34	-
$p_T^{j_1}$	0.84	0.82	0.79	-
$\|y_{j_1}\|$	0.64	0.58	0.51	-
$p_T^{j_2}$	0.34	0.29	0.23	-
$\|\Delta\phi_{jj}\|$	0.21	0.28	0.24	-
$\|\Delta y_{jj}\|$	0.64	0.58	0.49	-
$\|\Delta\phi_{\gamma\gamma,jj}\|$	0.45	0.46	0.42	-

- Large number of observable tested
- Compatibility is quantified via 1st/2nd moment and χ2: Broadly in line with theoretical expectations.

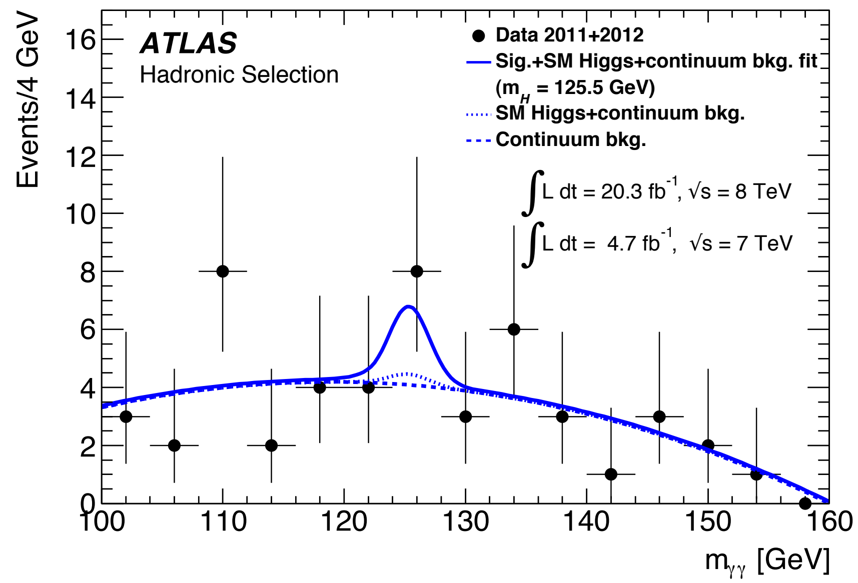
Invisible Higgs search





- No significant excess is observed over the SM expectation
- CMS Combination of VBF, Z(ll)H and Z(bb)H searches: BR(H→inv)<0.58(0.44 exp.) @95% CL.
- ATLAS Z(ll)H searches: BR(H→inv)<0.37(0.39 exp.) @95% CL
- Strongest available limits for low-mass DM candidates. No sensitivity to those model once the mass of DM candidate exceeds mH/2

Higgs as a tool for discovery



$FCNC\ t \to H(\gamma\gamma)\ q(u,c)$

In 2HDM type III (without flavor conservation)
The c(u)H coupling is present at tree level

95% CL upper limit

$$Br(t \to cH) < 0.79\ (0.51)\%$$

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$HH \to bb\gamma\gamma$

CERN-PH-EP-2014-113

$X \to HH \to bb\gamma\gamma$

Non resonant 95%CL limit:

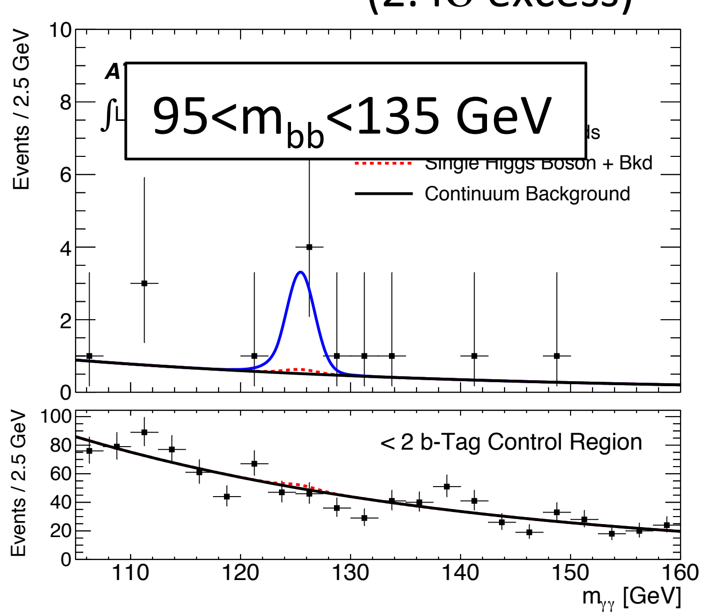
$\sigma_{HH}\ Br_{bb,\gamma\gamma} < 2.2\ (1.0)$ pb

(2.4σ excess)

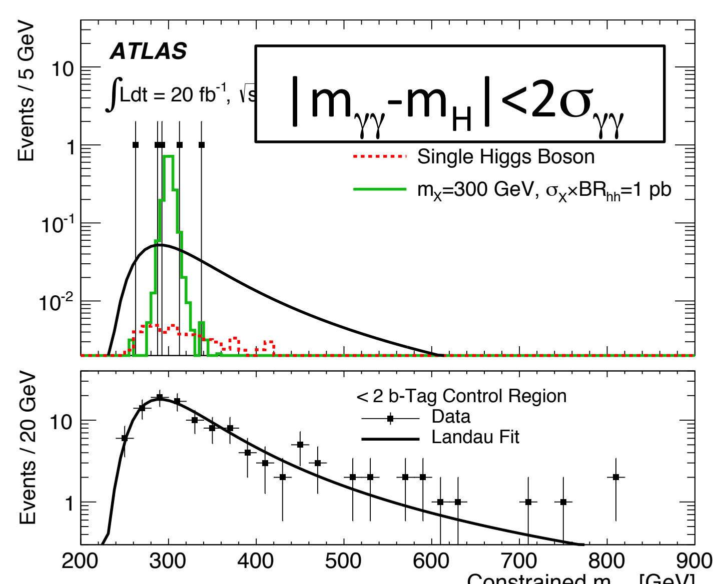
Search for a resonance
(Heavy Higgs, radion, stoponium, etc…)

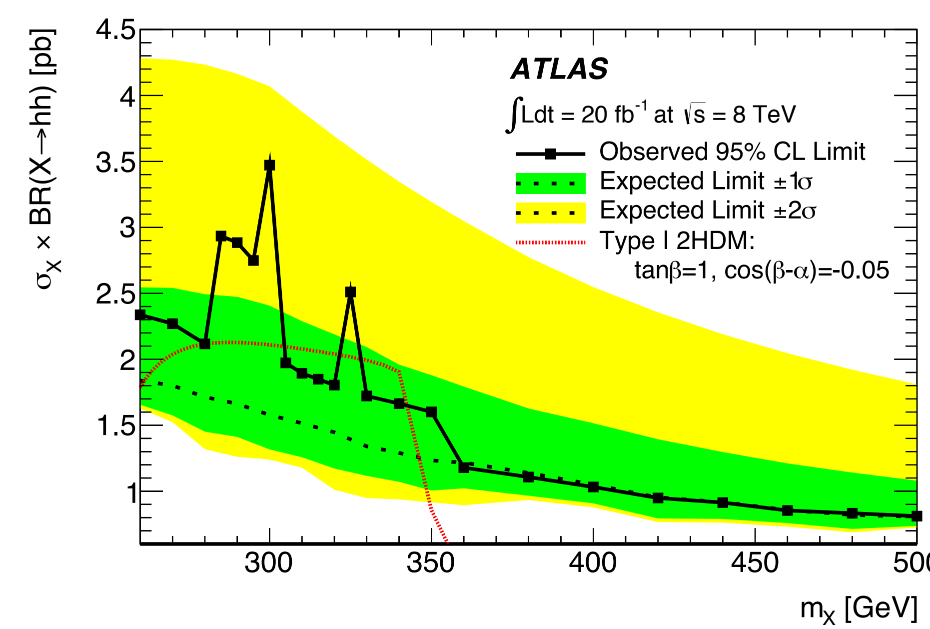
(Counting in smallest window containing 95% signal)

95<m_{bb}<135 GeV



$|m_{\gamma\gamma}-m_H|<2\sigma_{\gamma\gamma}$





Summary

- Since the discovery of Higgs boson, the property has been widely studied at ATLAS and CMS.
- So far, all the properties are consistent with SM prediction.
- Look forward to new results @ RUN2.