$H \rightarrow ff$

ATLAS and CMS Results

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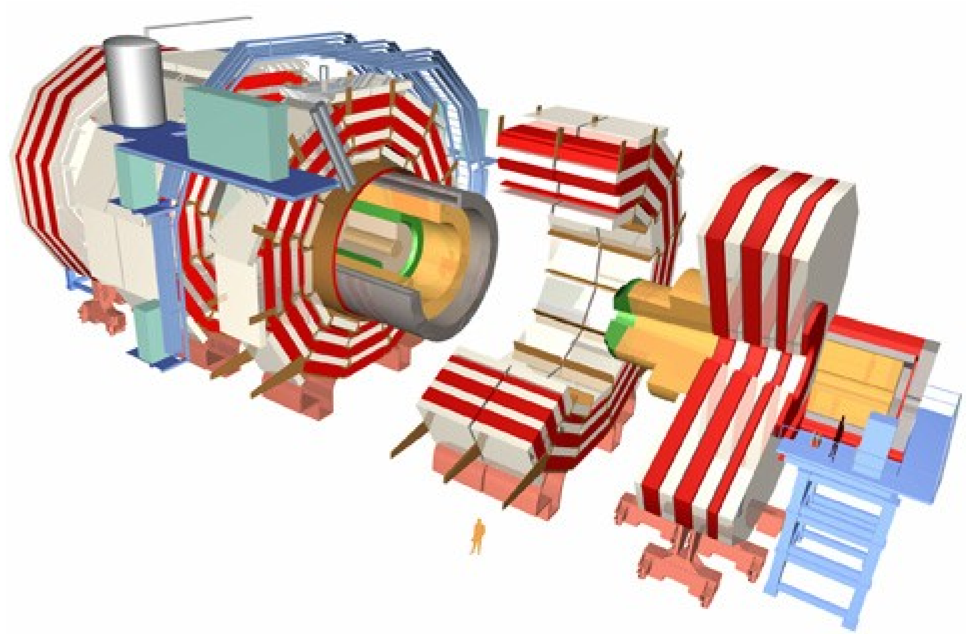
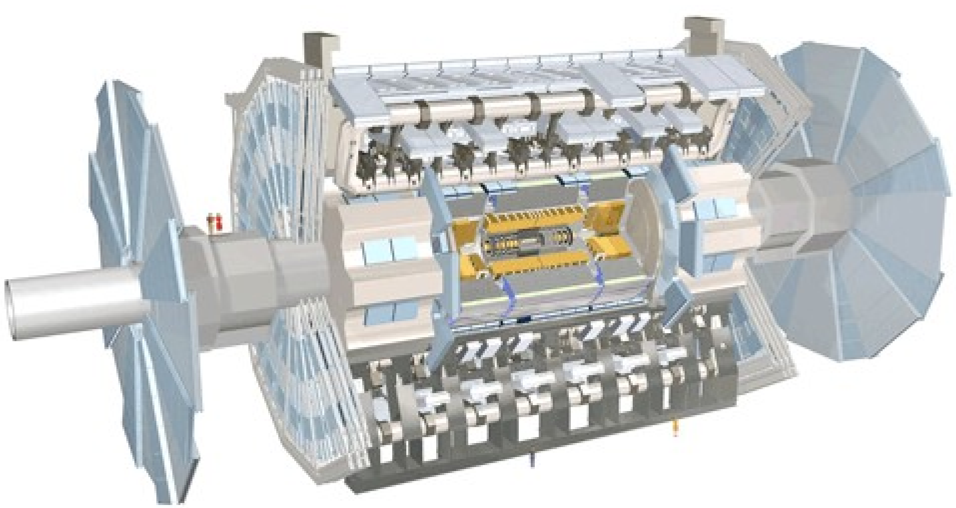
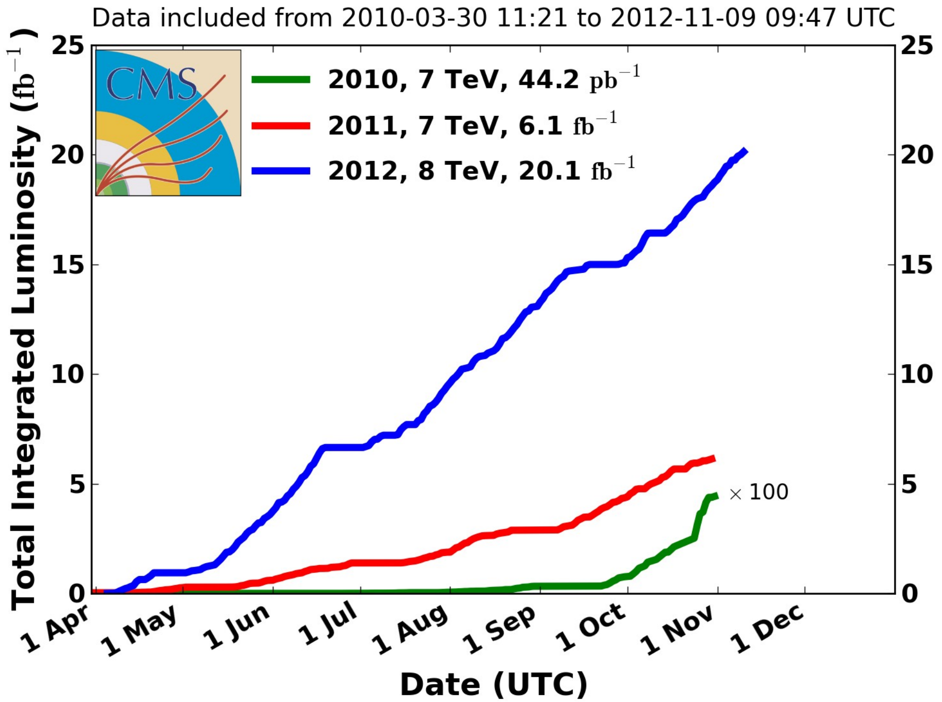
Higgs-search-in-Belgium mini workshop
22-23 November 2012
Louvain la Neuve

Outline

- Higgs candidate and Fermion couplings
- LHC Results
  - ◊ H → bb
  - ◊ H → ττ
- Summary

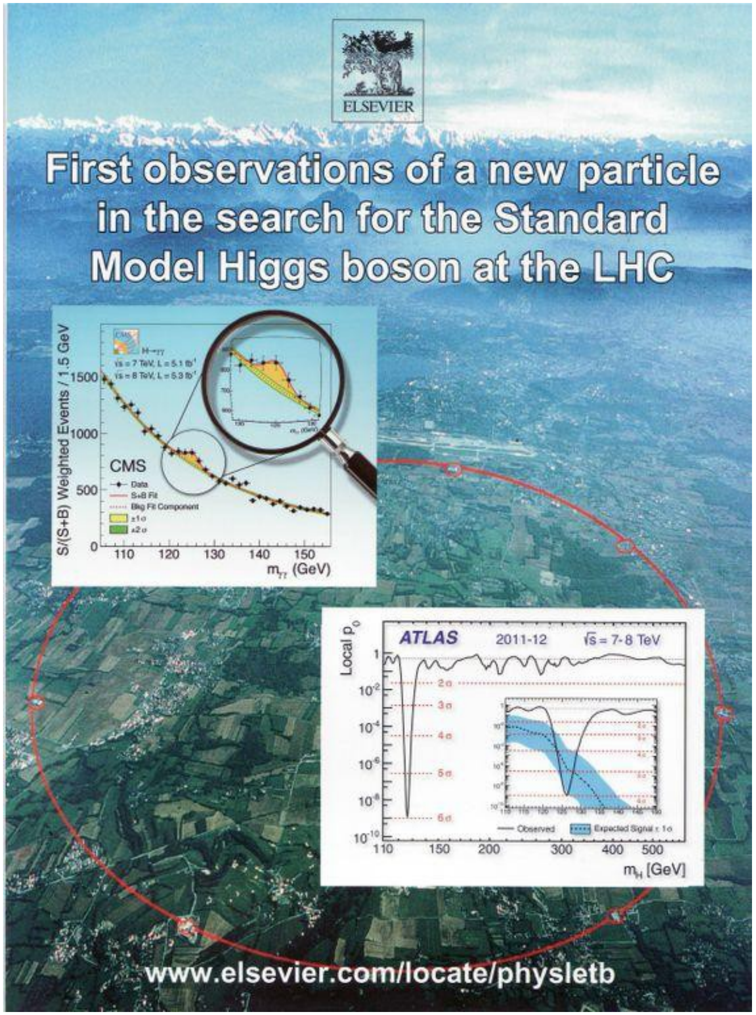






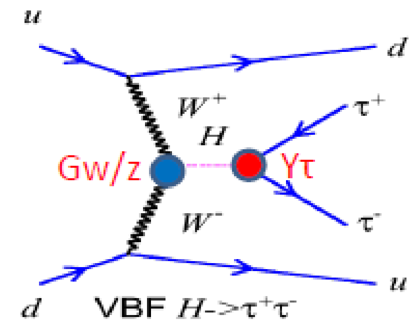
Introduction: Higgs candidate

- Higgs boson candidated discovered Summer 2012 (ICHEP) with mass ~ 125 GeV:
  - CMS and ATLAS using 10 fb^{-1} of data at 7 and 8 TeV
  - Discovery driven by high resolution channels ($H \rightarrow \gamma\gamma$, $H \rightarrow ZZ$)
  - No evidence in fermionic decay channels (**$H \rightarrow bb$, $H \rightarrow \tau\tau$**)



- Updated results from both collaborations presented last week (HCP Kyoto)
  - Searches in many modes updated including latest data: **$10fb^{-1} \rightarrow 17fb^{-1}$**
  - Including $H \rightarrow bb$, $H \rightarrow \tau\tau$ (this talk)

Introduction: fermion couplings



- Stablish nature of Higgs candidate
  - Some properties: Spin 0 or 2, CP nature, better measured using high resolution decay modes (ZZ) but...

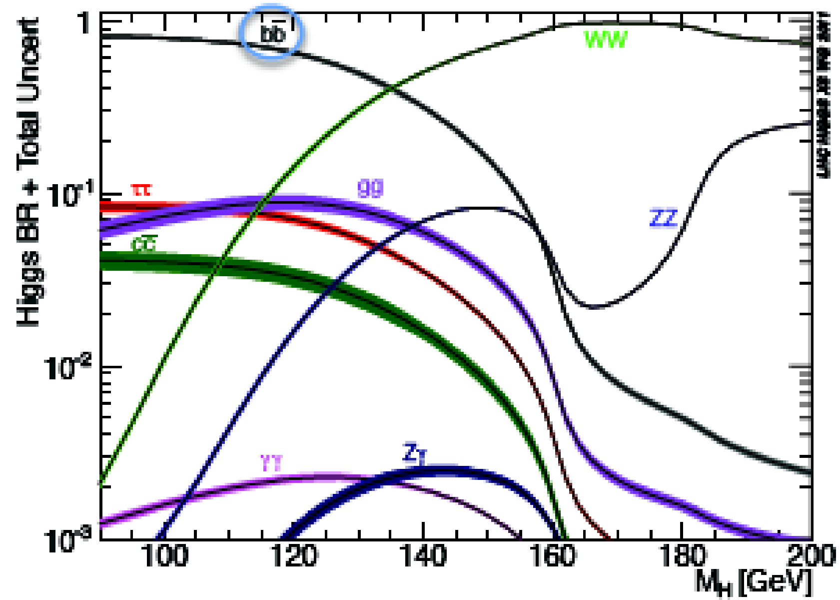
- H → ff needed to understand Higgs coupling structure
  - Direct probe Yukawa couplings and properties
  - Access multiple production modes ττ (ggH, VBF), bb (VH)

Channel	m_H range (GeV)	m_H resolution	Production mode
H → γγ	110-150	1-2%	ggH, VBF
H → ZZ	110-1000	1-2%	ggH
H → WW	110-150	20%	ggH, VBF, VH
H → bb	100-135	10%	**VH**, ttH
H → ττ	110-145	15%	**ggH**, **VBF**, VH

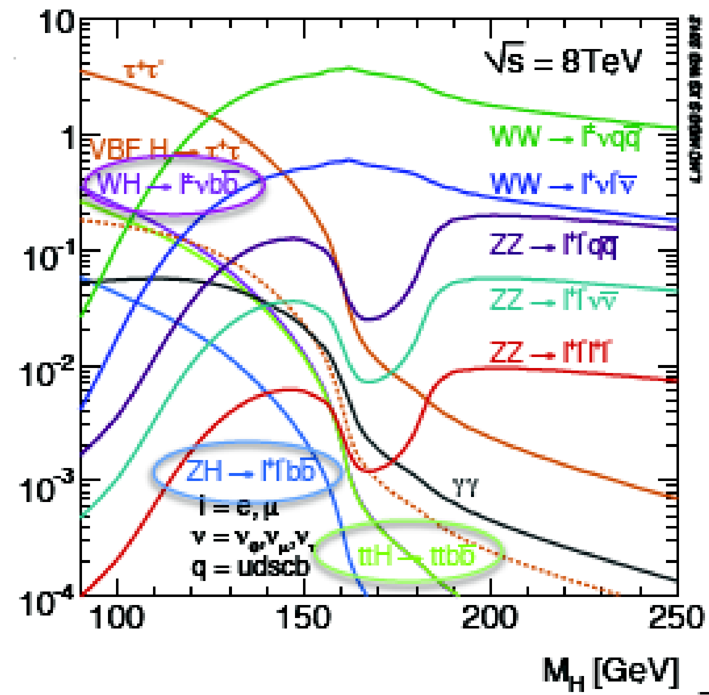
- Higgs coupling to b and tau enhanced in some models
  - Neutral MSSM Higgs Searches

H → bb

- Most prevalent SM Higgs decay
  - At m_H ~ 125 GeV: BR (H→bb) ~ 58%
  - Direct constraint on couplings to fermions
  - Input to measuring VH & tH couplings

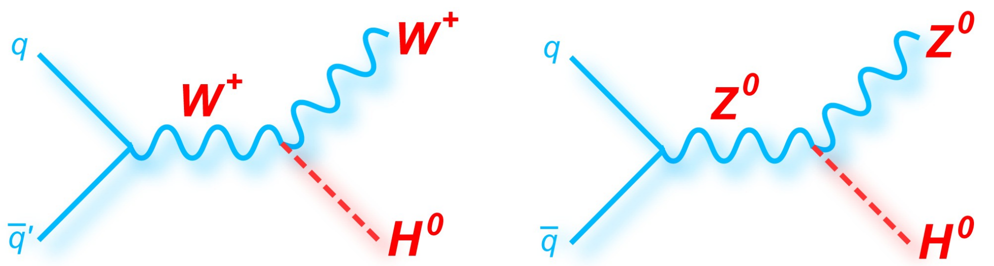


- Very challenging jet backgrounds
  - 7-8 orders of magnitude greater
- Use associated production V=W, Z, tt
  - Clean leptonic decay signatures



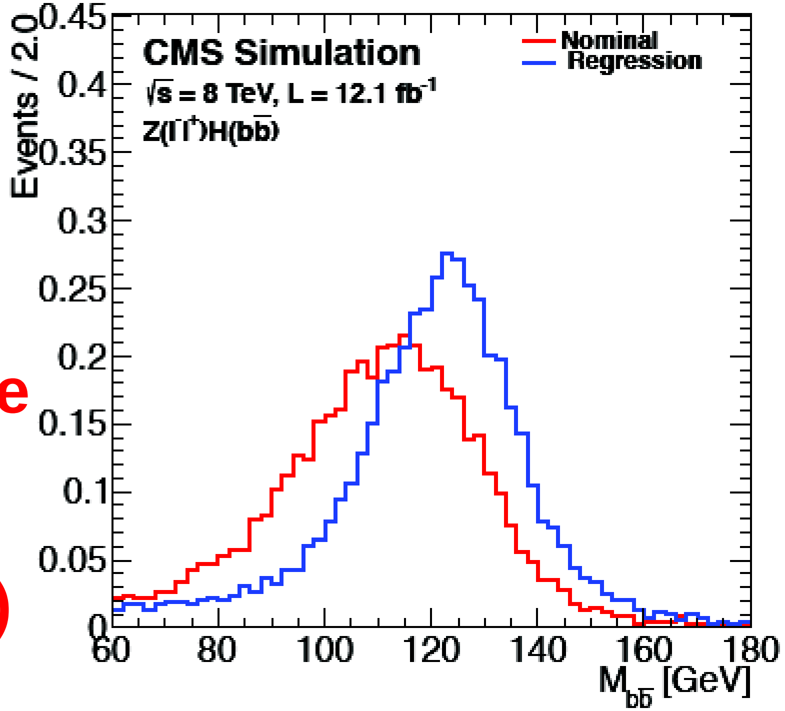
VH, H → bb

- General strategy
  - **llbb, lνbb, ννbb** channels



  - **Boosted vector boson** (V) and H, V&H back to back (CMS)
  - Different P_T(V) bins ATLAS
    - 0 lep (MET): [120-160],[160-200] > 200 GeV
      1-2 leptons: [0-50], [50-100],[100-150], [150-200] >200 GeV
  - **b-tagging** (2 tagged jets)
  - Energy resolution improved by **multivariate regression** (CMS) or treatement soft μ (ATLAS)
  - Use of **multivariate discriminators (CMS)**

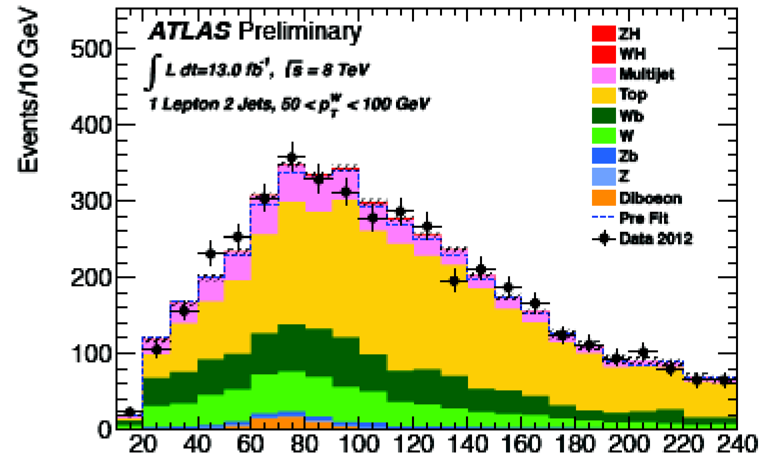
Better mass resolution (~15%)
→ 10-20% improvement in sensitivity



  - Main bkg: **V+jets, tt, single top**
    - Fits using control regions
    - Shapes from MC

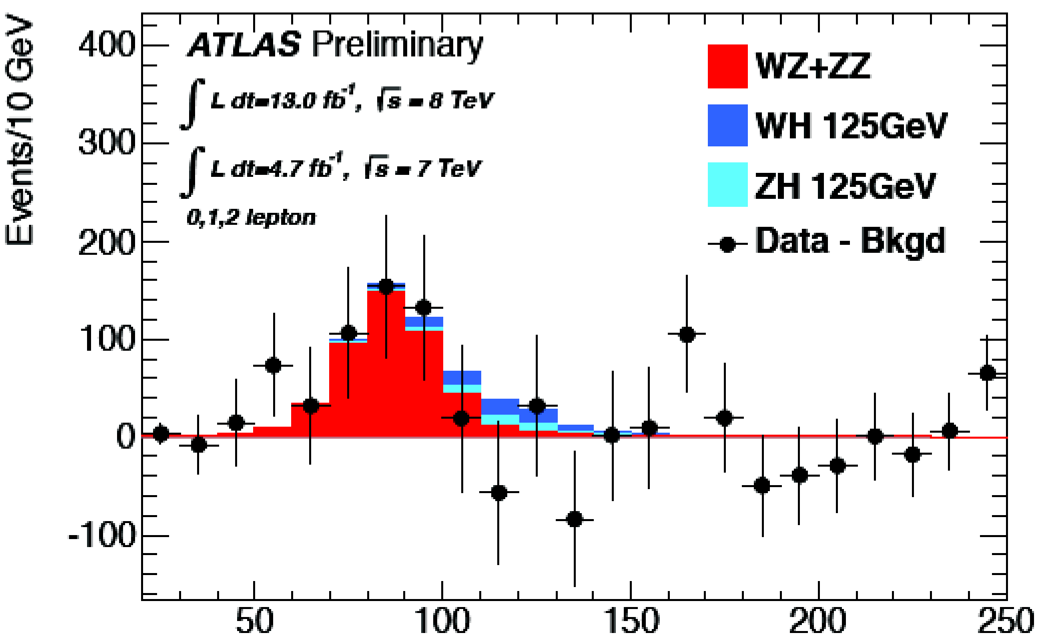
VH, H → bb:Validation of the search

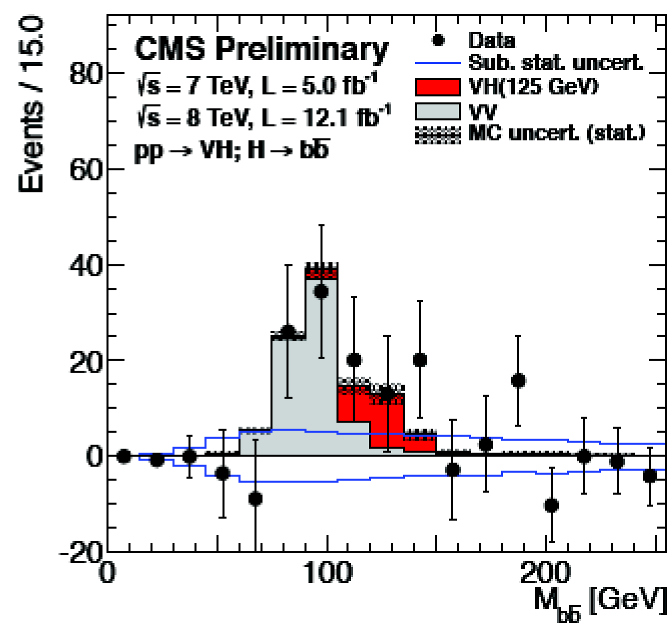
- Diboson search VZ, Z → bb
  - Similar signature, ~5 times larger
  - Same analysis strategy
  - Perform a separate fit: all background except dibosons substracted



ATLAS

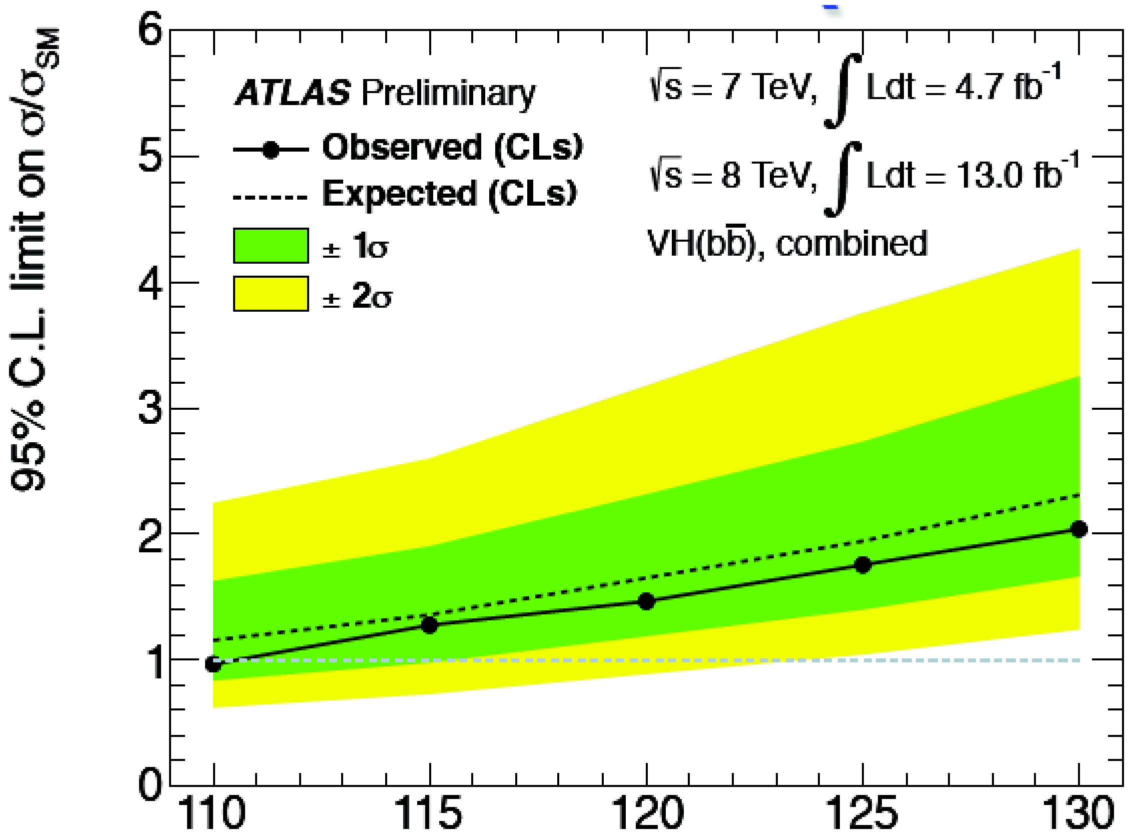
σ/σ_{SM}=1.09±0.20(stat)±0.22(sys)

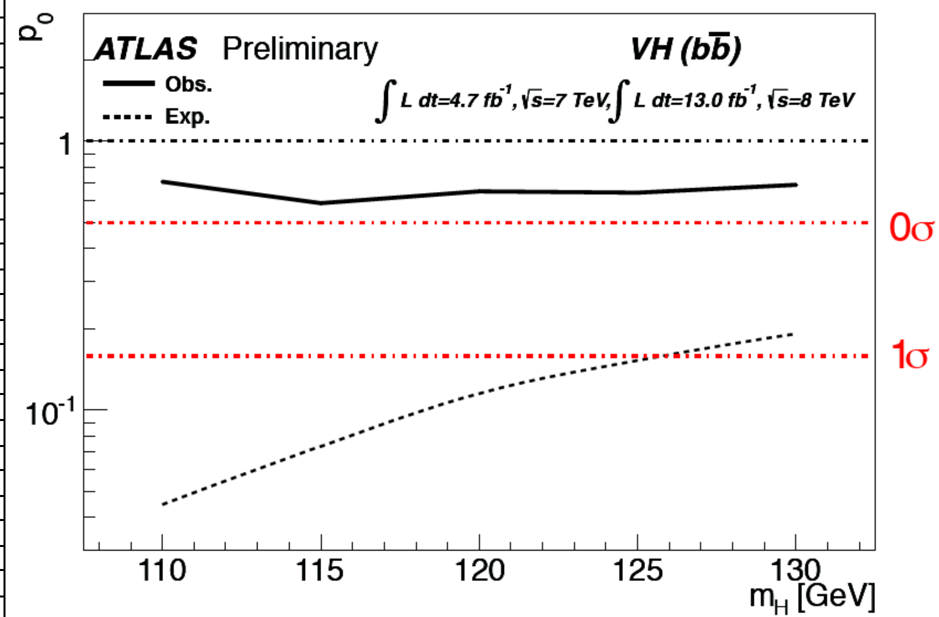




Significance of 4.0 s.d

VH, H → bb: ATLAS Results



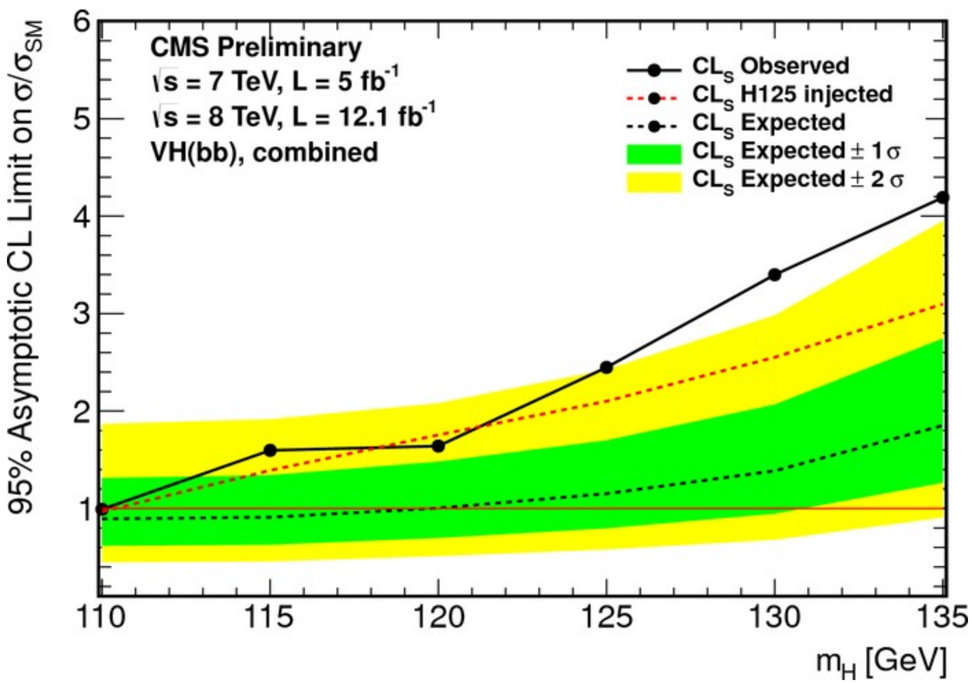


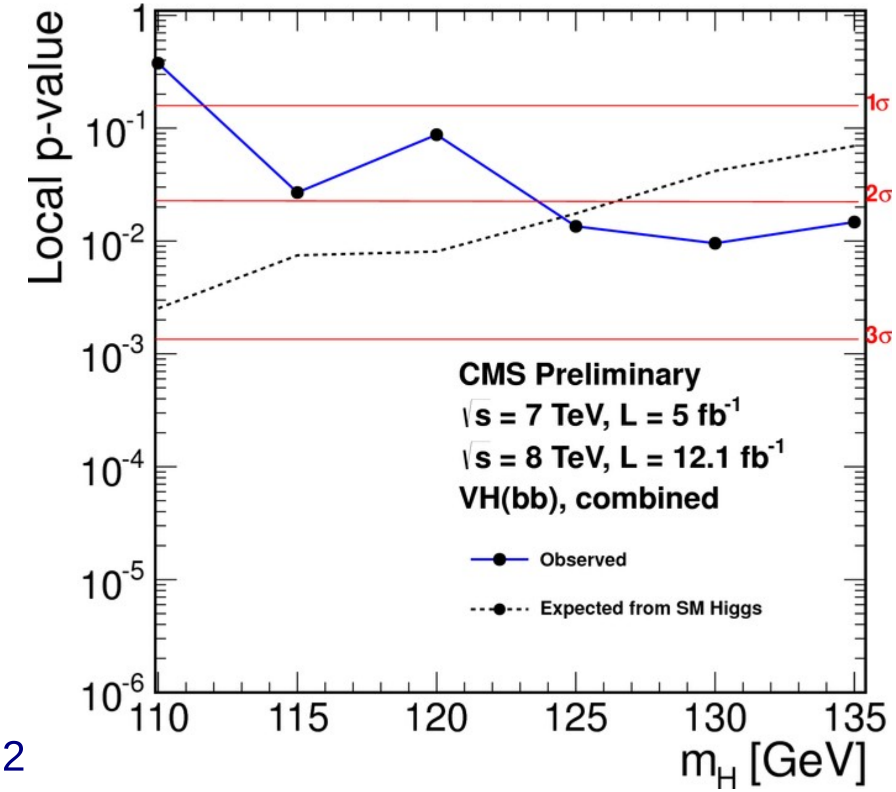
ATLAS-CONF-2012-135

m_H = 125 GeV

- 95%CL σ X BR upper limit: **1.8 (obs) 1.9 (exp)**
- σ/σ_{SM} = **-0.4 ± 0.7 (stat) ± 0.8 (sys)**
- p_0 value: **0.64 (obs) exp (0.15)**

VH, H → bb: CMS Results

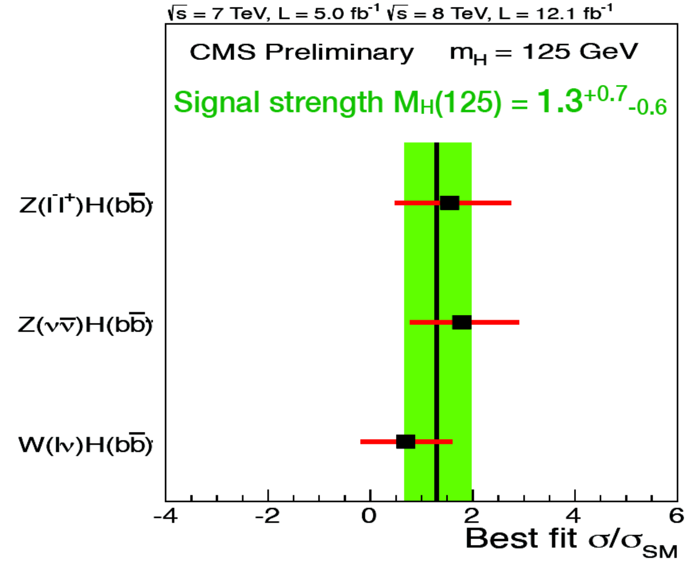




m_H = 125 GeV

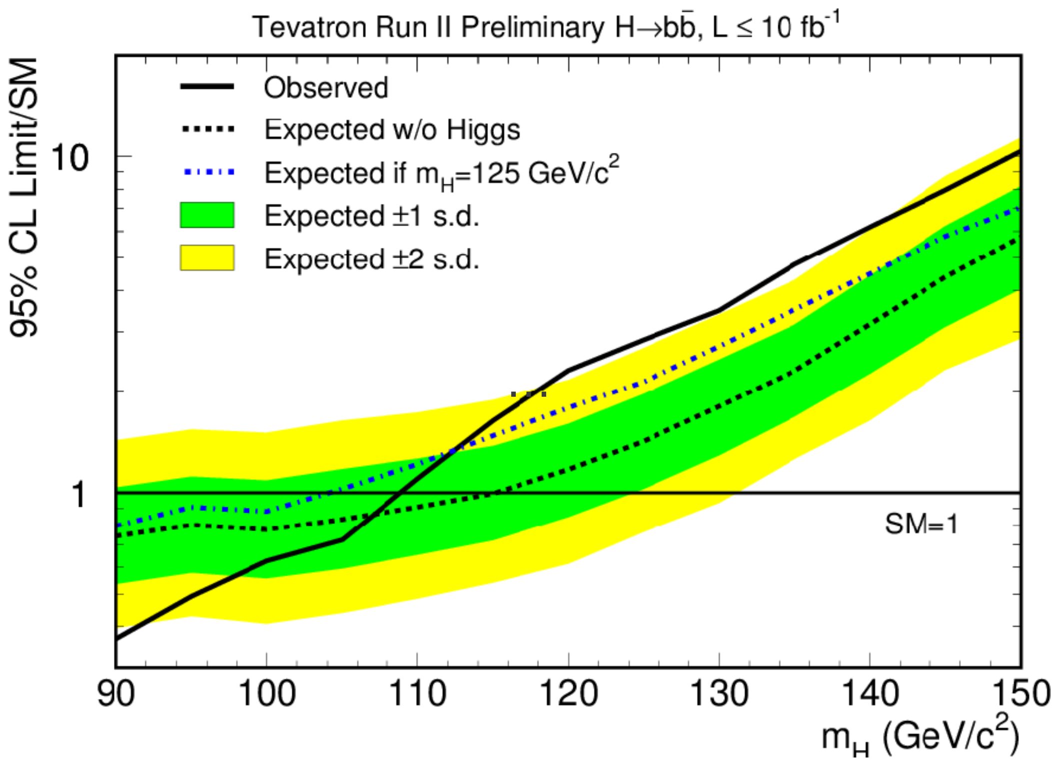
2

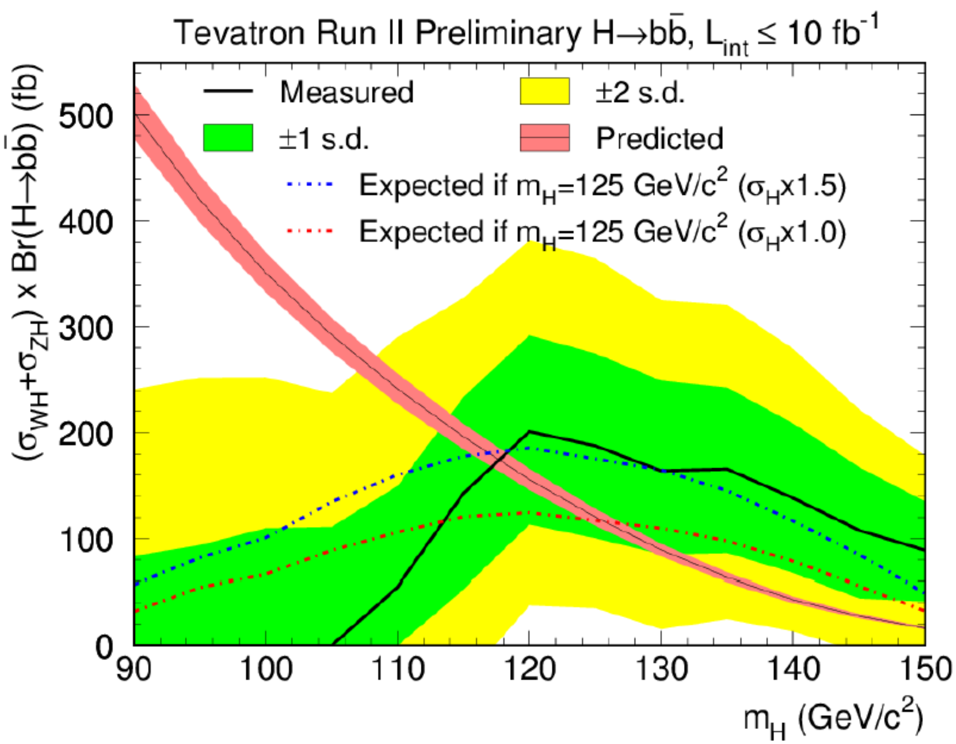
- 95%CL limit: **2.5, 1.2 (exp)**
- **2.2 s.d. excess** (expected 2.1 s.d.)
- Well consistent with SM Higgs
- σ/σ_{SM} = **$1.3^{+0.7}_{-0.6}$**



CMS PAS HIG-12-044

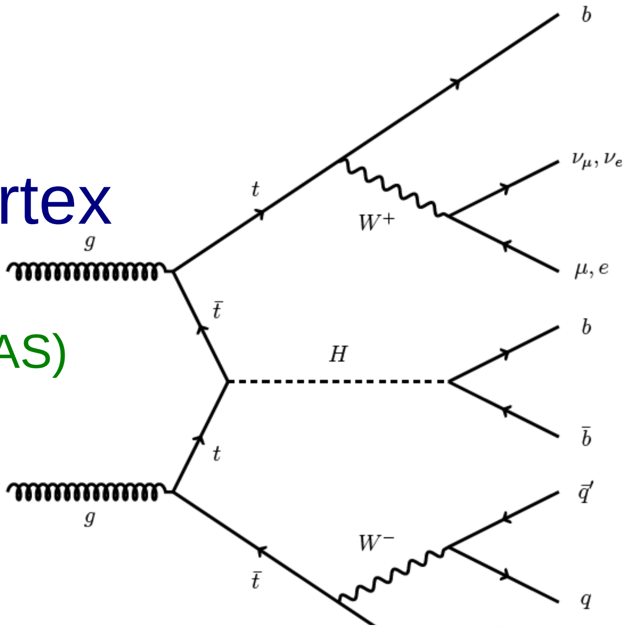
VH, H → bb: Tevatron Results





- LHC better sensitivty but Tevatron result is still competitive m_H = 125 GeV
- 95%CL σ X BR upper limit: **2.9(obs) 1.4 (exp)**
- σ/σ_{SM} = $\mathbf{1.56^{+0.72}_{-0.73}}$

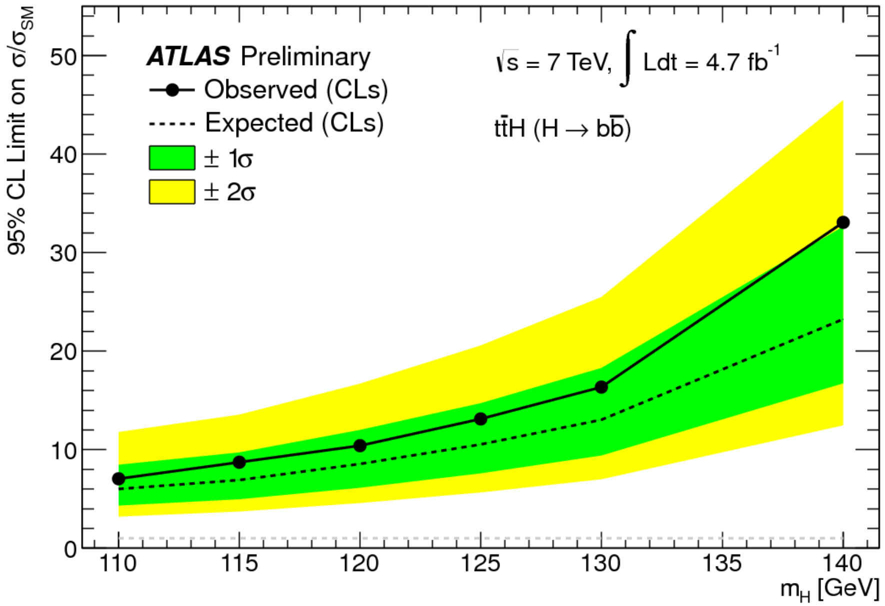
ttH, H → bb: LHC Results

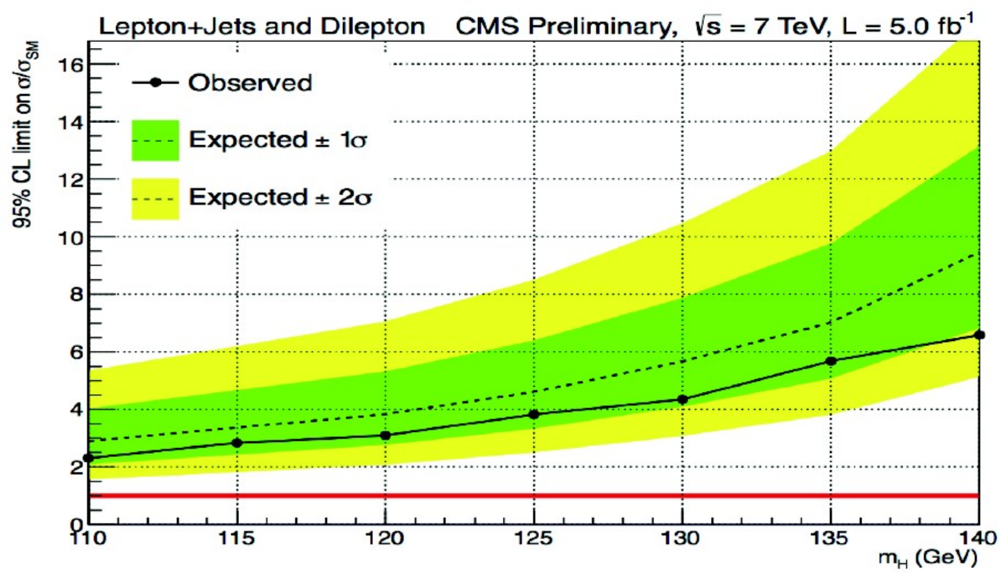


- Main opportunity to directly probe the ttH vertex
  - Main background from tt
  - Multivariate discriminant (CMS); **m_{bb}, ΣP_T^{jet}** (ATLAS)
  - Using only 7 TeV data

ATLAS-CONF-2012-135

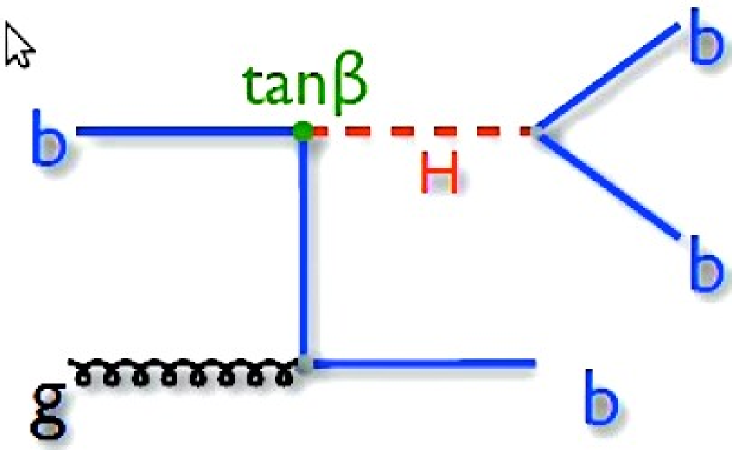
CMS PAS HIG-12-025



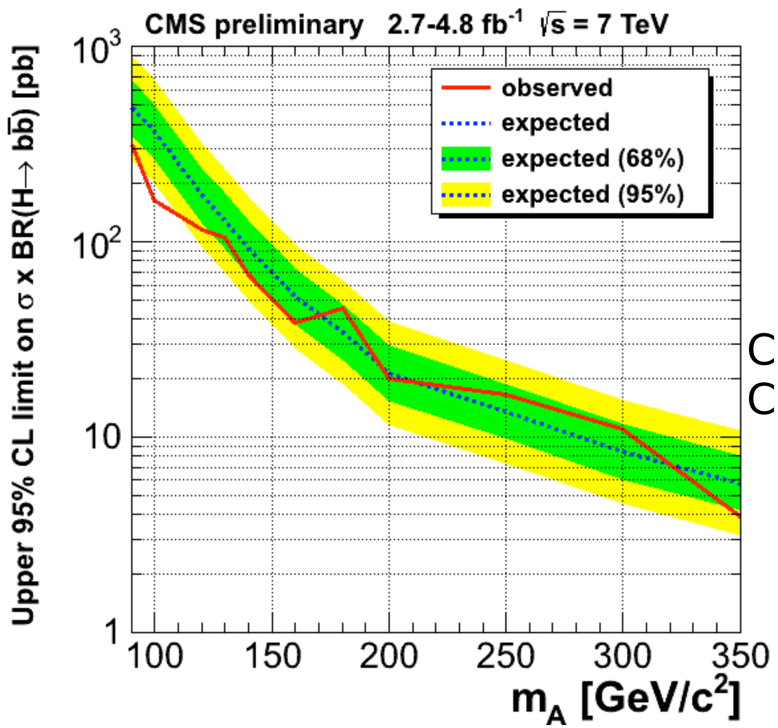


- CMS **sensitivity up to ~ 5X SM** at m_H = 125 GeV
- No evidence of excess: 95%CL limit σ/σ_{SM} **3.8 (obs) 4.6 (exp)**

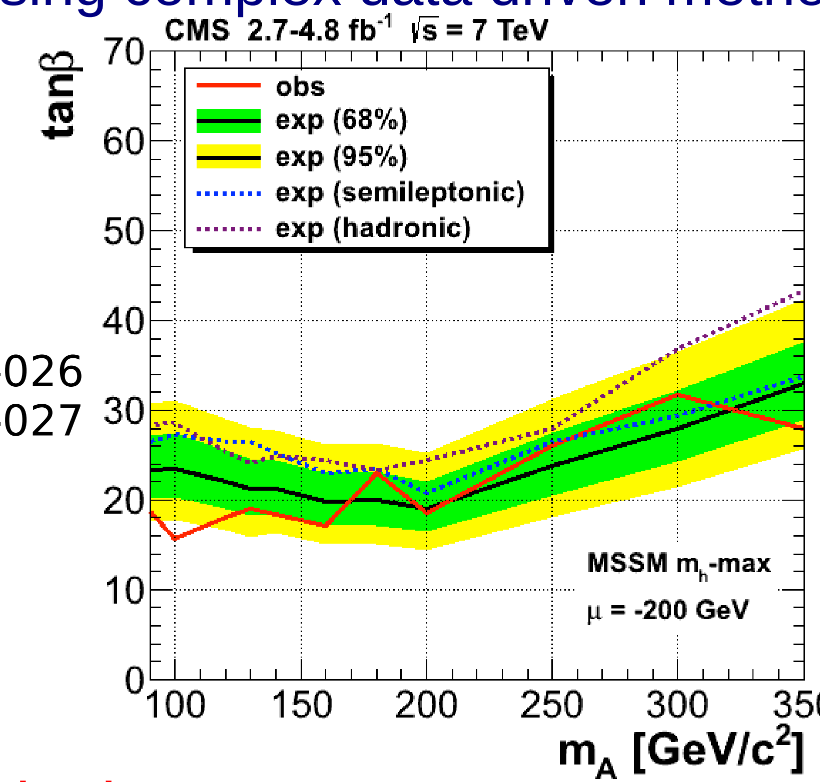
MSSM Φ→ bb: Results



- MSSM neutral Higgs boson produced in association with b-quarks
- All hadronic and semileptonic final states (**combined for the first time**)
- Using only 7 TeV data (CMS)
- Important multijet background estimated using complex data driven methods



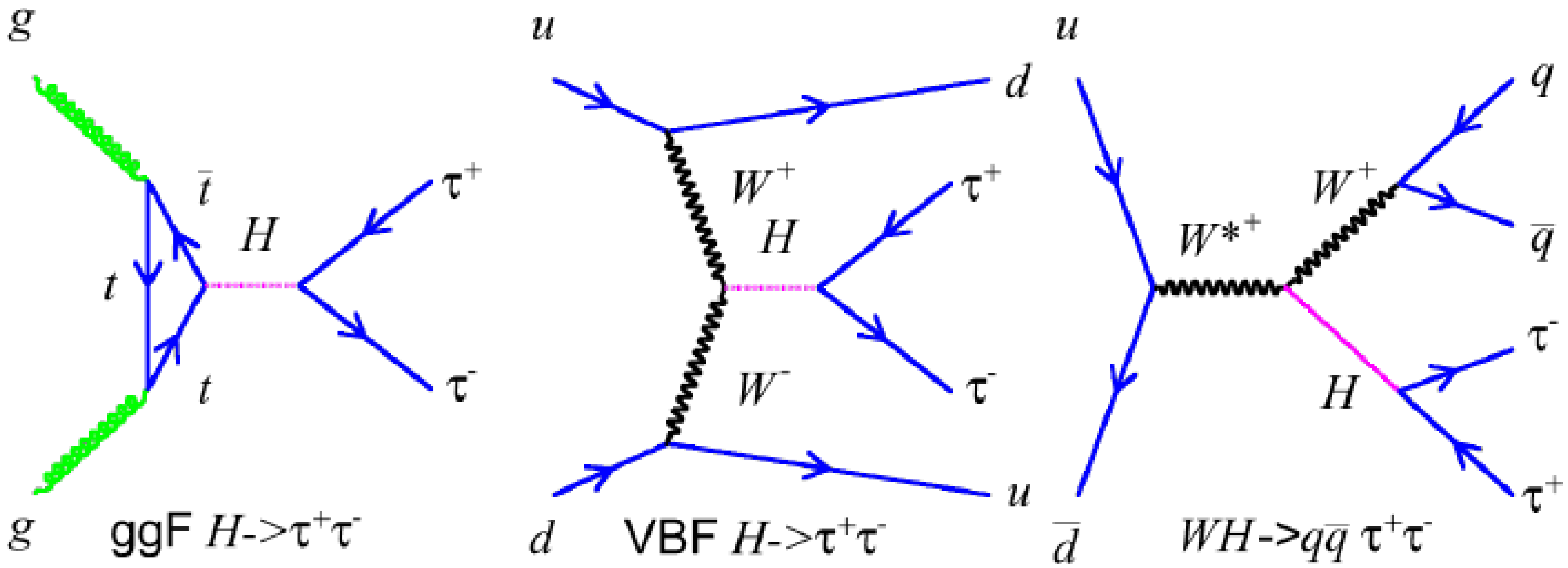
CMS PAS HIG-12-026
CMS PAS HIG-12-027



Excluded large tanβ region at the 95% CL in the MSSM parameter space (m_h^{max} scenario)

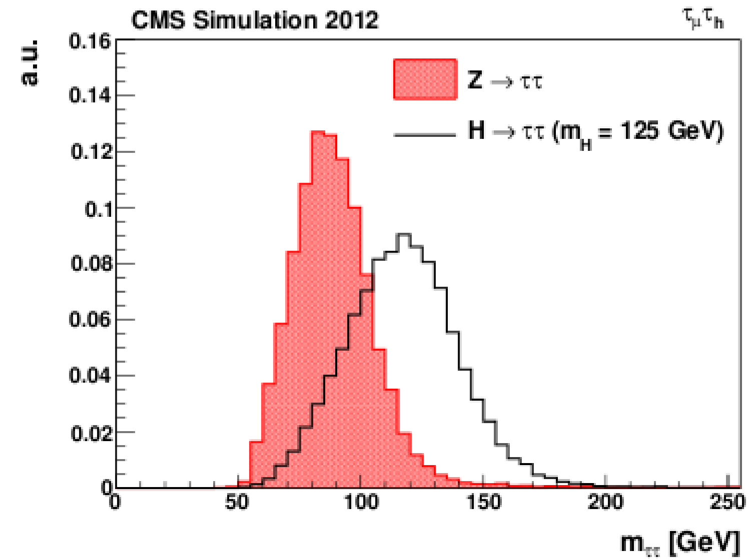
$H \rightarrow \tau\tau$

- Search for the Higgs boson in 3 production modes

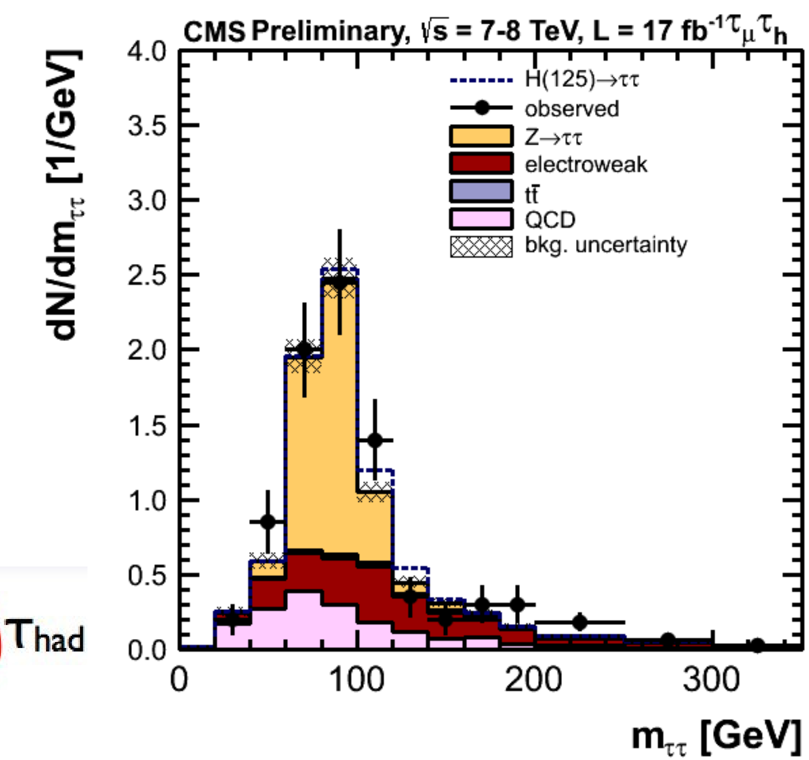


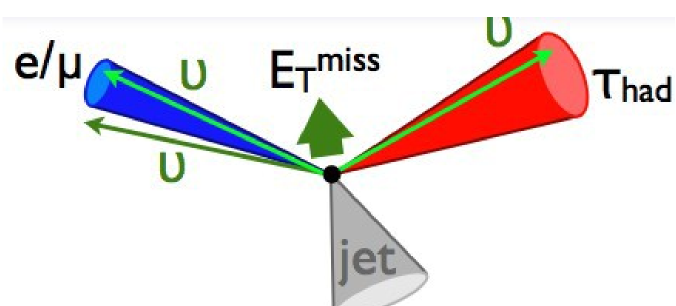
- Using ggF (1 jet) and VBF enriched regions
- Different final states based on τ decay
  - $e\tau_h$, $\mu\tau_h$ best sensitivity
  - All leptonic: eμ, μμ
  - All hadronic: $\tau_h\tau_h$

$H \to \tau\tau$



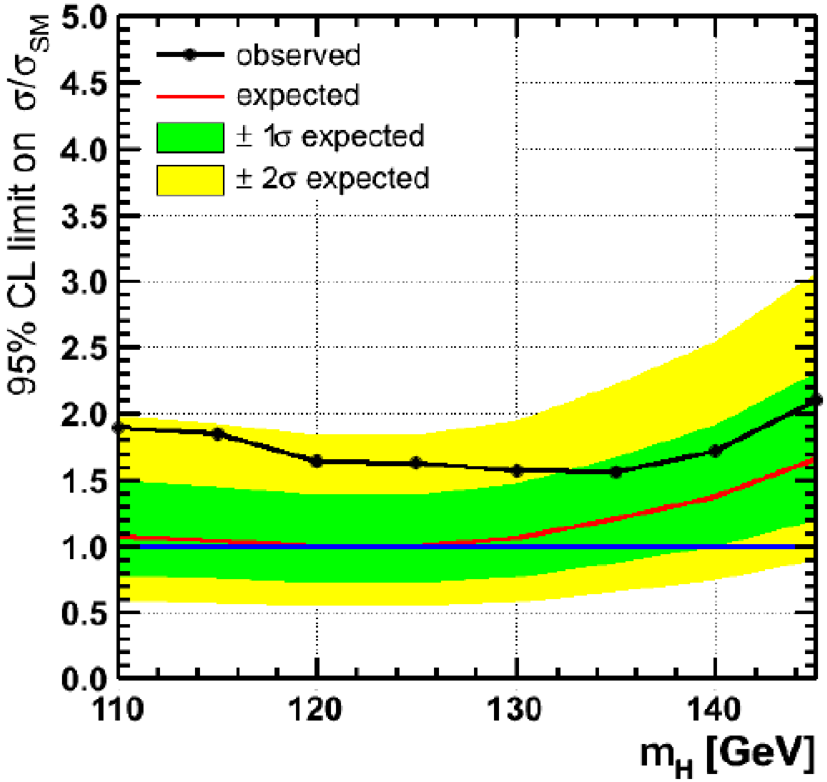
- $m_{\tau\tau}$ important discriminator
  - Maximum likelihood methods
  - Used to extract signal
- MET reconstruction
  - Used of the selection and input for $m_{\tau\tau}$
  - Resolution and PU dependence improved using MVA regression (CMS)
- Backgrounds
  - Large $Z \to \tau\tau$ using embedding technique
  - QCD, W+jets: data driven methods. Same sign events...



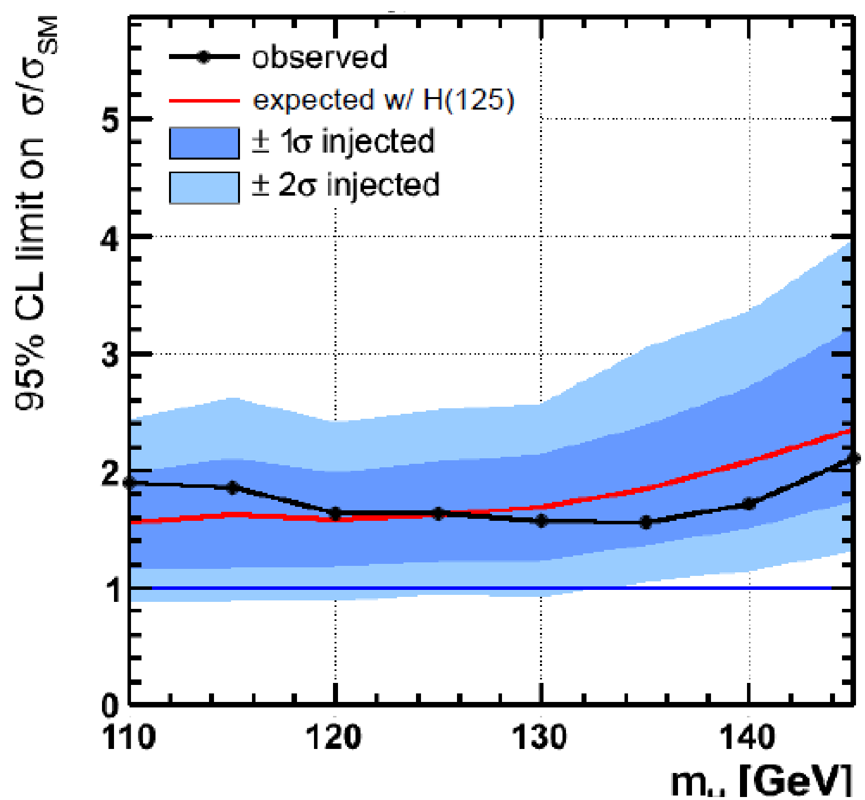


H → ττ: CMS result

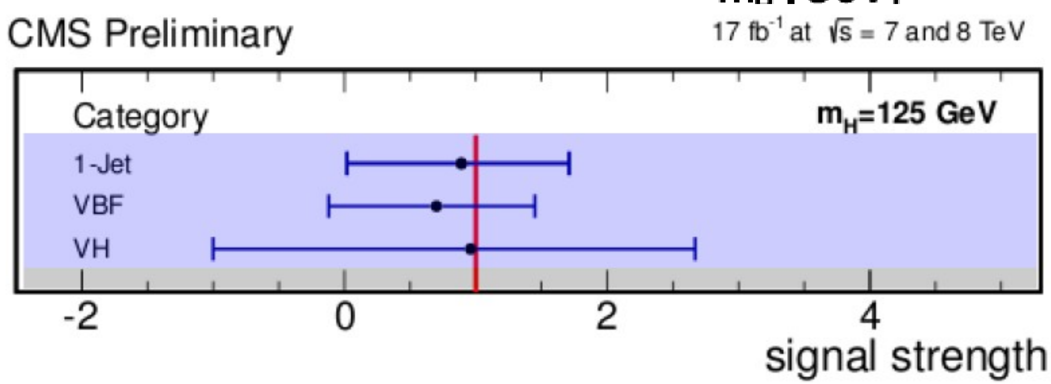
Expectation w/o Higgs:



Expectation w/ SM H(125):[1)]

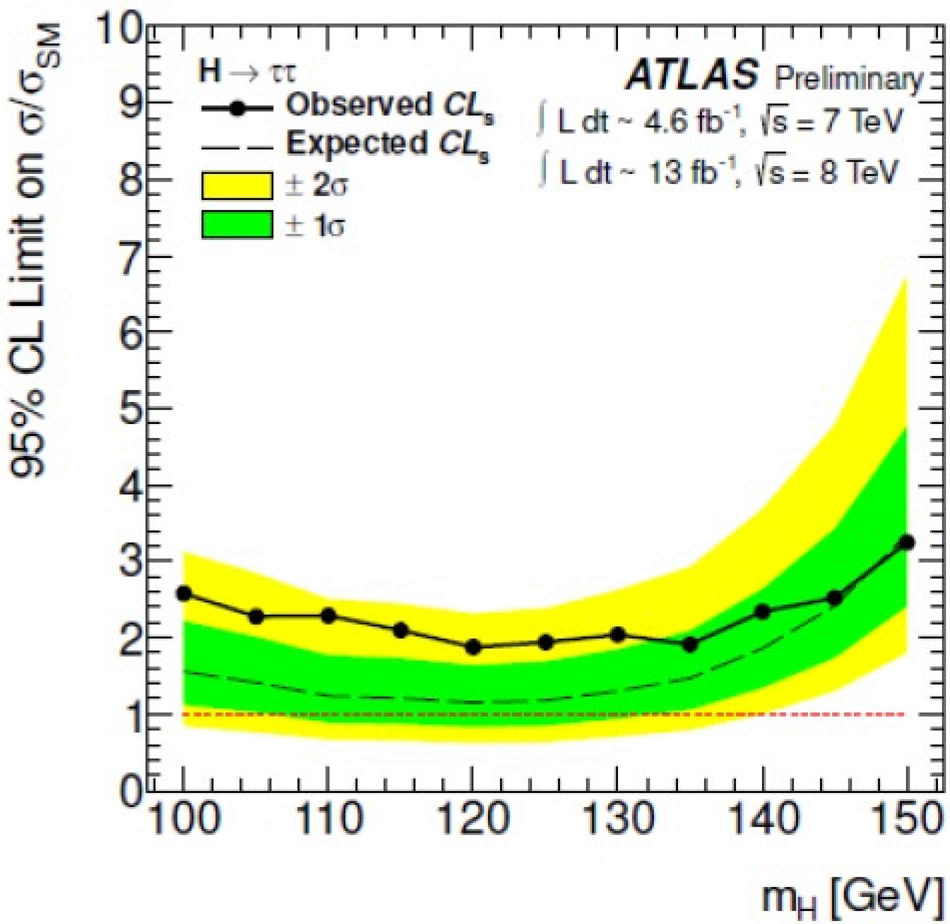


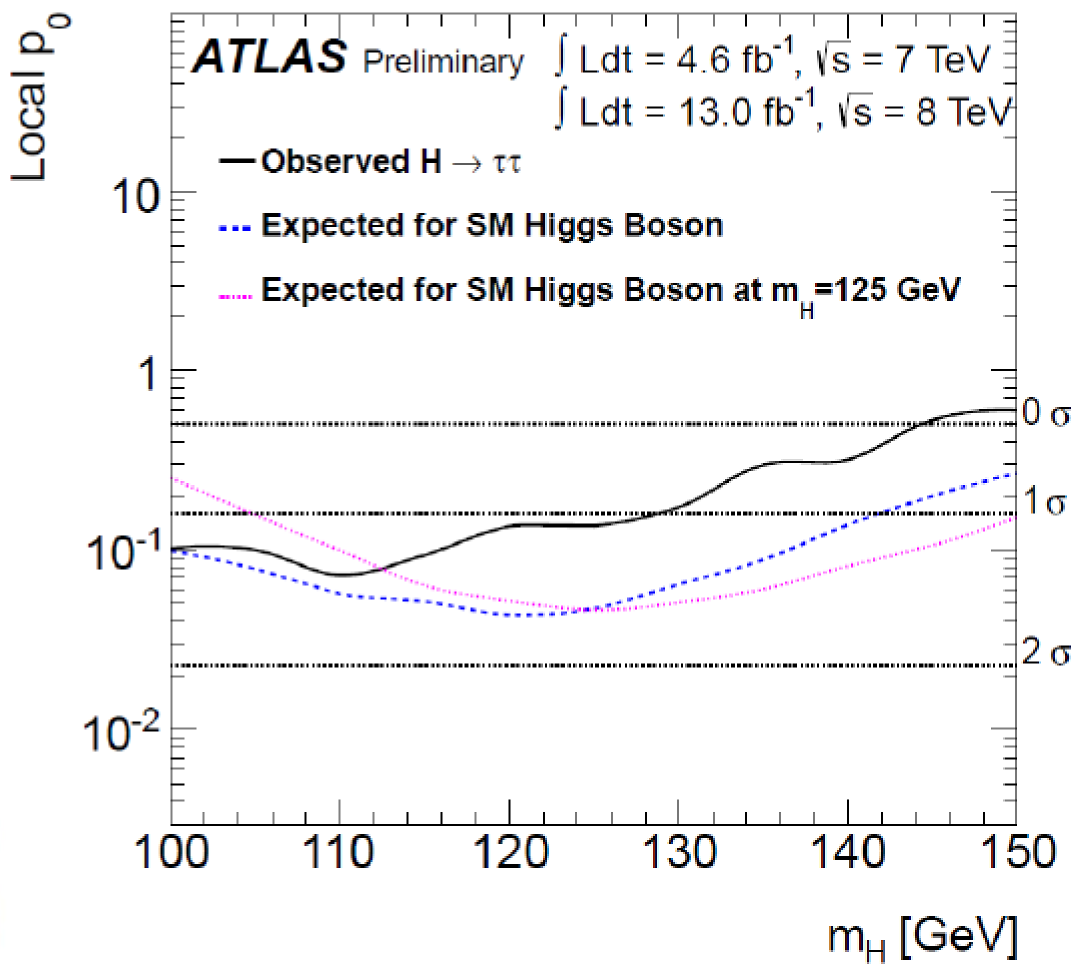
- Important improvement in sensitivity wrt ICHEP
- Upper limit: **1.66 (obs) 1.05 (exp)**
- σ/σ_{SM} = **0.72±0.52**



CMS PAS HIG-12-043

H → ττ: ATLAS result



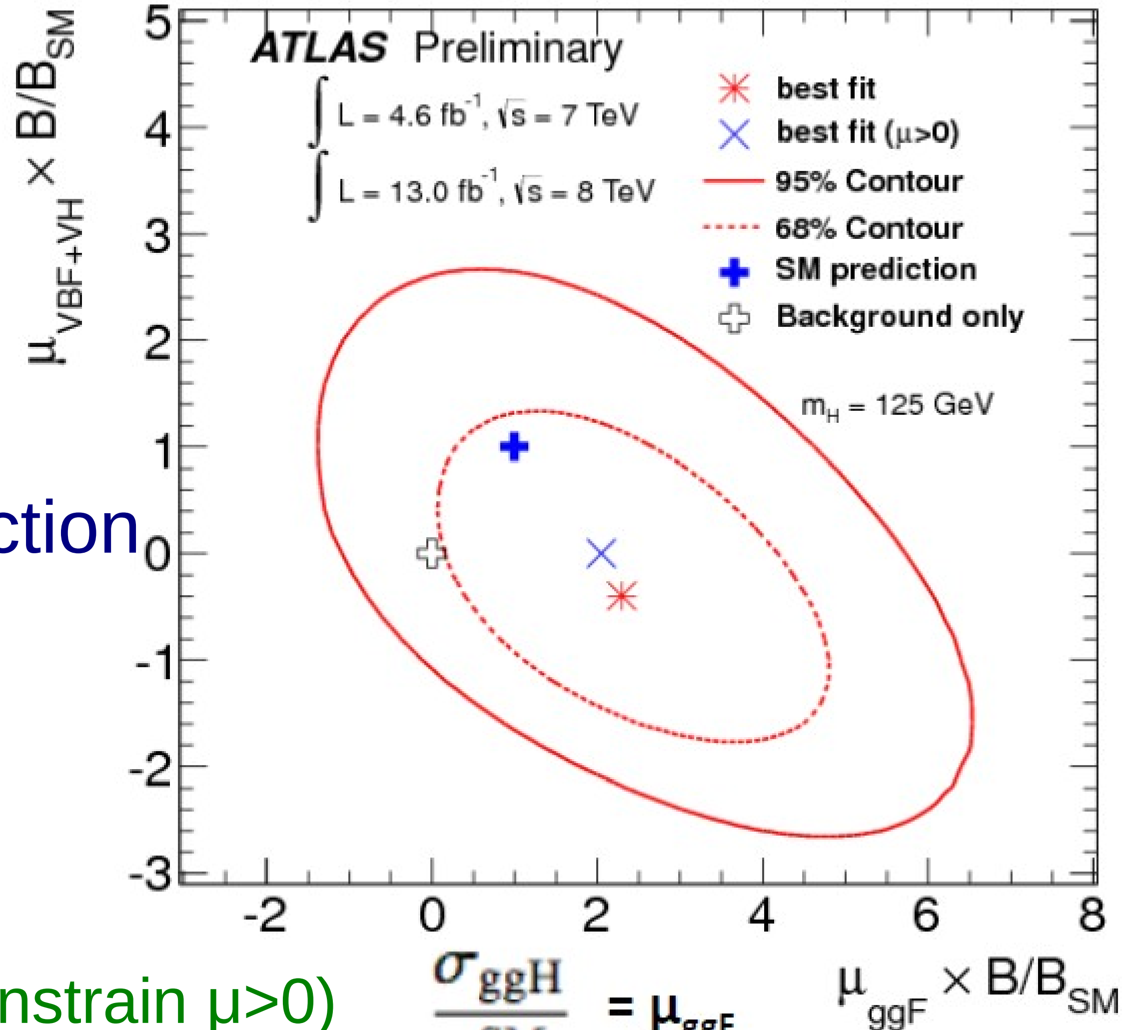


- Upper limit: **1.9 (obs) 1.2 (exp)**
- p value **1.1 s.d (1.7 expected)**
- σ/σ_{SM} = **0.7±0.7**

$H \rightarrow \tau\tau$: ATLAS result

$$\frac{\sigma_{VBF}}{\sigma^{SM}_{VBF}} = \frac{\sigma_{WH}}{\sigma^{SM}_{WH}} = \frac{\sigma_{ZH}}{\sigma^{SM}_{ZH}} = \mu_{VBF+VH}$$

- Introduce signal strength parameters for each production mode
  - Assume $\mu_{VBF}=\mu_{VH}$



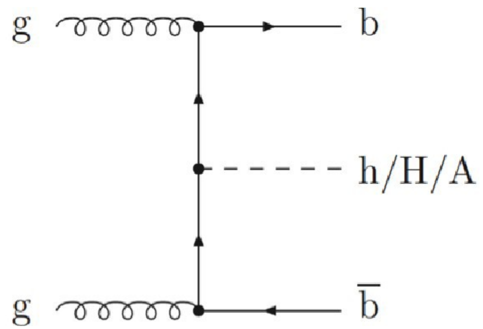
$$\frac{\sigma_{ggH}}{\sigma^{SM}_{ggH}} = \mu_{ggF}$$

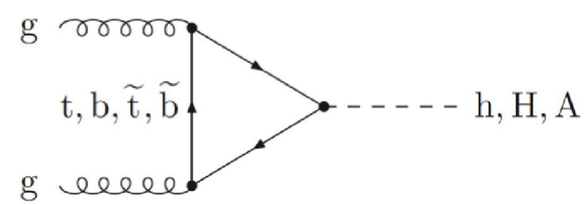
$\mu^{best}_{VBF+VH} = -0.4$, $\mu^{best}_{ggF} = 2.4$

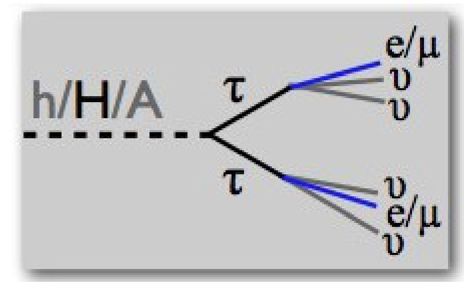
$\mu^{best}_{VBF+VH} = 0$, $\mu^{best}_{ggF} = 2.1$ (if constrain $\mu>0$)

- results are consistent with either the background only hypothesis, or the SM Higgs with a large error

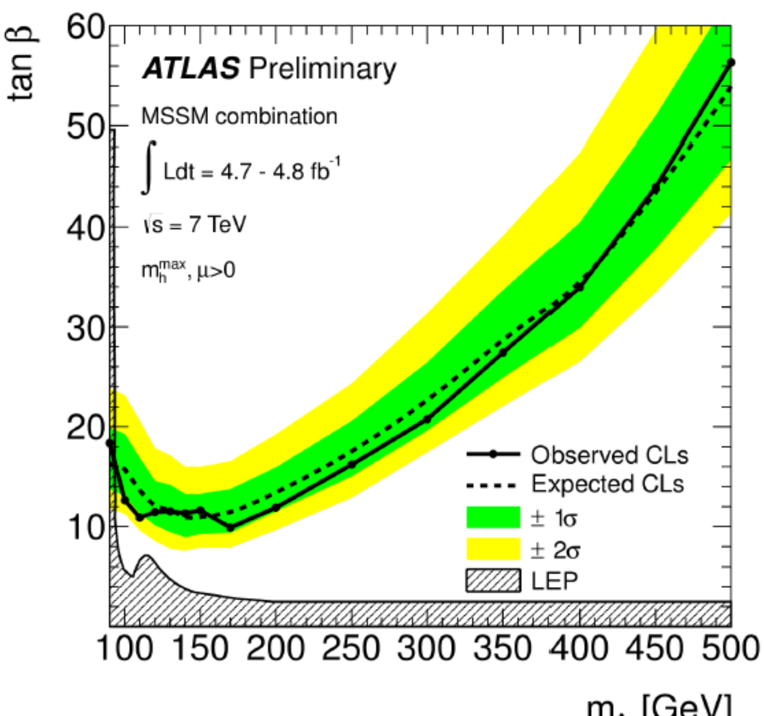
MSSM Φ→ ττ: Results

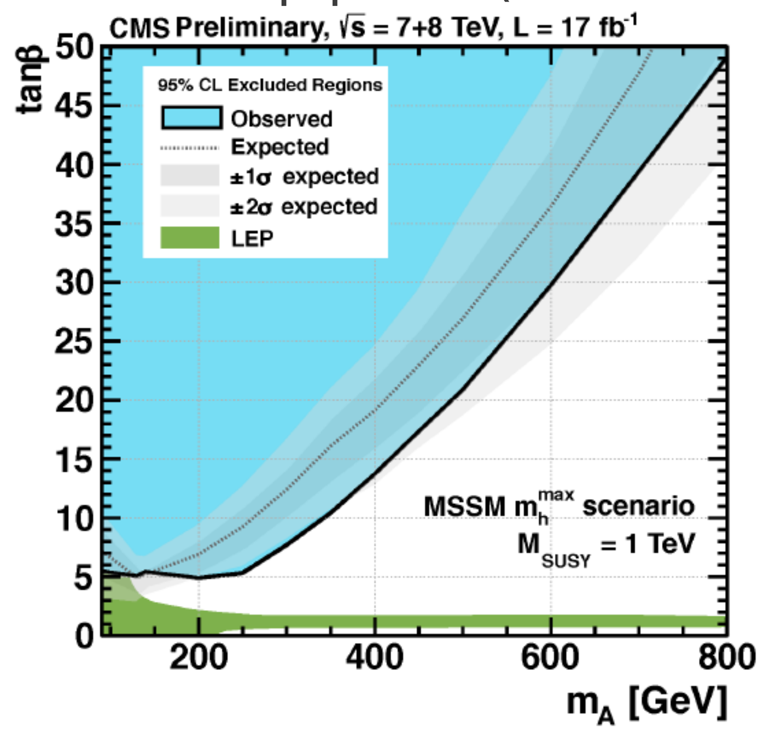


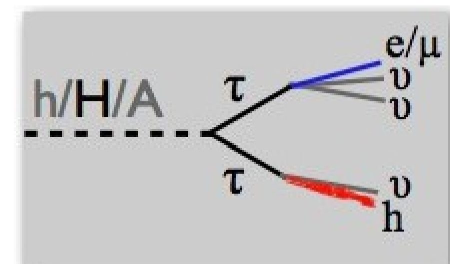


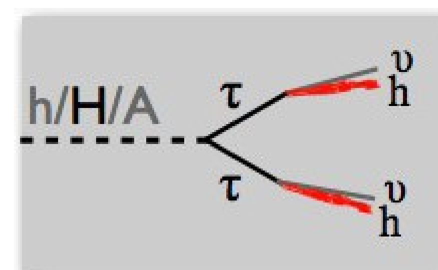


95% CLs exclusions shown in m_A-tanβ plane (m_h^{max} scenario)









- Large regions of MSSM parameter space excluded for neutral Higgs searches

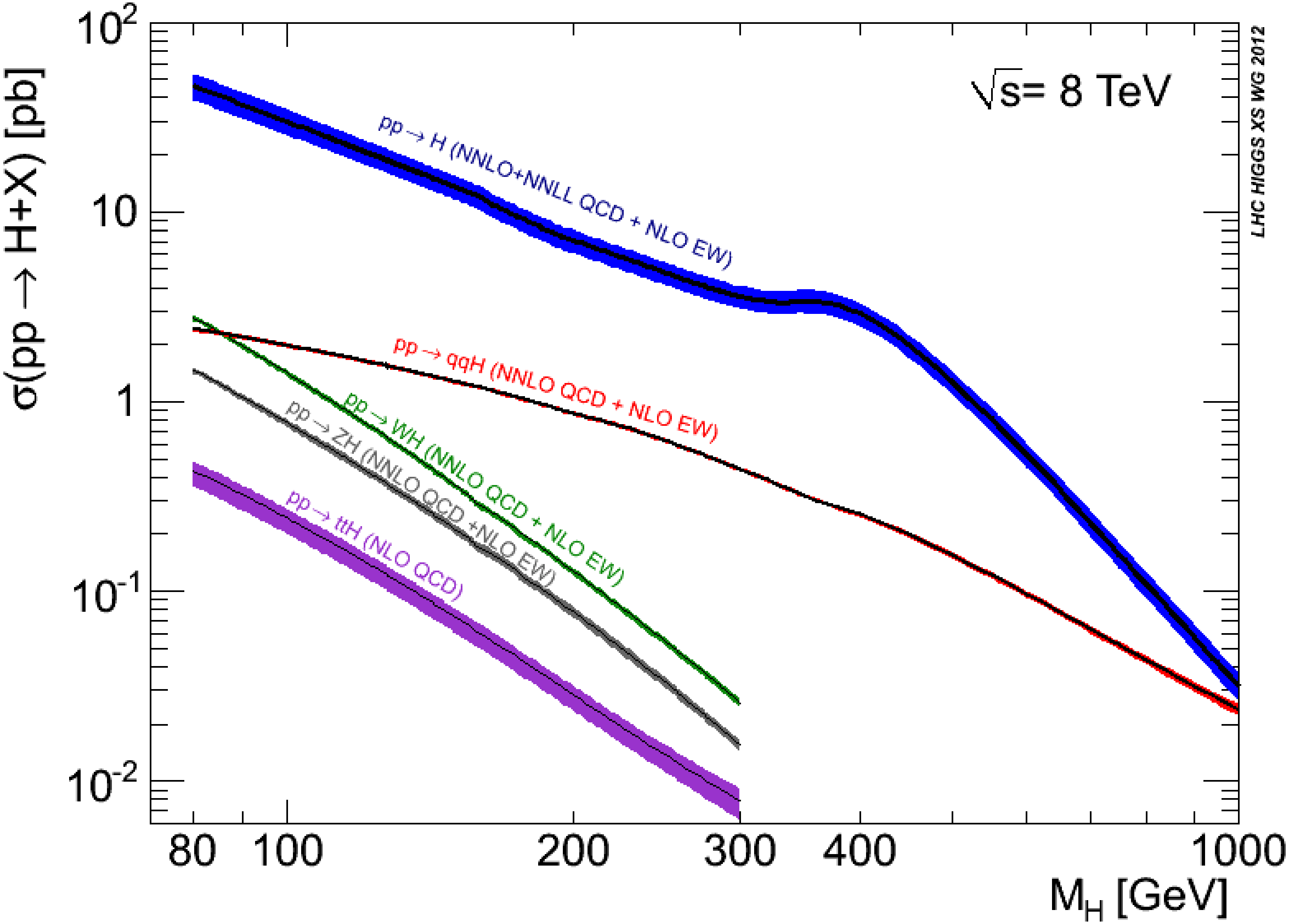
Summary

- ATLAS VH → bb
  - 95%CL limit: **1.8 (obs) 1.9 (exp)**
  - σ/σ_{SM} = -0.4± 0.7 (stat) ± 0.8 (sys)
  - p value: **0.64 (obs) exp (0.15)**
- ATLAS H → ττ
  - 95%CL limit: **1.9 (obs) 1.2 (exp)**
  - p value **1.1 s.d (1.7 expected)**
  - σ/σ_{SM} = **0.7±0.7**
- CMS VH → bb
  - 95%CL limit: **2.5, 1.2 (exp)**
  - $\sigma/\sigma_{SM} = \mathbf{1.3^{+0.7}_{-0.6}}$
  - p value: **2.2 s.d**
- CMS H → ττ
  - 95%CL limits: **1.66, 1.05 (exp)**
  - σ/σ_{SM} = **0.72±0.52**

- ATLAS: ff final states compatible bkg-only or SM Higgs
- CMS: bb and ττ final states show certain excess well compatible with SM
- Large regions of MSSM parameter space excluded for neutral Higgs searches in Φ→ ττ
- Excluded large tanβ region at the 95% CL in the MSSM parameter space in Φ→ bb

BACK UP

(taken from HCP2012 presentations)



$\sqrt{s}$= 8 TeV
pp → H (NNLO+NNLL QCD + NLO EW)
pp → qqH (NNLO QCD + NLO EW)
pp → WH (NNLO QCD + NLO EW)
pp → ZH (NNLO QCD +NLO EW)
pp → ttH (NLO QCD)
LHC HIGGS XS WG 2012
σ(pp → H+X) [pb]
10^2
10
1
10^{-1}
10^{-2}
80
100
200
300
400
1000
M_H [GeV]

VH, H → bb bkg estimation

- Most background shapes are taken from simulation and normalised using data control regions
- Multi-jet background determined entirely from data-driven techniques
- WZ(bb) & ZZ(bb) resonant bkg normalisation and shape from simulation

◊ ATLAS **QCD**

- 0 lepton
  - Use ABCD method
  - Regions defined by relative directions of MET/jets/pTmiss
  - Found to be small (~1%)
- 1 lepton
  - MET template by reverse isolation cuts
  - Normalised by fitting each WpT bin
  - Electroweak contamination removed from template
- 2 lepton
  - Template: reverse isolation/quality selection
  - Found to be small (<1%)

Main control regions

Z + jets: Pre-tag and 1 b-tag

W + jets: Pre-tag and 1 b-tag

Top:

0 & 1 lepton channel: + 1jet

2-lepton channel: veto(83< m_{ll}< 99) MET > 60)

VH, H → bb Yields

- ATLAS

Bin	0-lepton, 2 jet			0-lepton, 3 jet			1-lepton					2-lepton				
	E_T^{miss} [GeV]						p_T^W [GeV]					p_T^Z [GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
WH	0.8	0.4	0.4	0.2	0.2	0.2	10.6	12.9	7.5	3.6	3.6	0.0	0.0	0.0	0.0	0.0
Top	89	25	8	92	25	10	1440	2276	1120	147	43	230	310	84	3	0
$W + c$,light	30	10	5	9	3	2	580	585	209	36	17	0	0	0	0	0
$W + b$	35	13	13	8	3	2	770	778	288	77	64	0	0	0	0	0
$Z + c$,light	35	14	14	8	5	8	17	17	4	1	0	201	230	91	12	15
$Z + b$	144	51	43	41	22	16	50	63	13	5	1	1010	1180	469	75	51
Diboson	23	11	10	4	4	3	53	59	23	13	7	37	39	16	6	4
Multijet	3	1	1	1	1	0	890	522	68	14	3	12	3	0	0	0
Total Bkg.	361 ± 29	127 ± 11	98 ± 12	164 ± 13	63 ± 8	42 ± 5	3810 ± 150	4310 ± 86	1730 ± 90	297 ± 27	138 ± 14	1500 ± 90	1770 ± 110	665 ± 47	97 ± 12	72 ± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

MSSM Φ→ bb: Results. For each channel

In the MSSM m_h^{max} benchmark scenario, the definition of theory parameters are the following: $M_{SUSY} = 1\,\text{TeV}/c^2$; $X_t = 2M_{SUSY}$; $\mu = 200\,\text{GeV}/c^2$; $M_{\tilde{g}} = 800\,\text{GeV}/c^2$; $M_2 = 200\,\text{GeV}/c^2$; and $A_b = A_t$; $M_3 = 800\,\text{GeV}/c^2$. Here, M_{SUSY} denotes the common soft-SUSY-breaking squark mass of the third generation; $X_t = A_t - \mu/\tan\beta^2$ is the stop mixing parameter; A_t and A_b are the stop and sbottom trilinear couplings, respectively; μ is the Higgsino mass parameter; $M_{\tilde{g}}$ is the gluino mass; and M_2 is the SU(2)-gaugino mass parameter. The value of M_1 is fixed via the unification relation $M_1 = (5/3)M_2 \sin\theta_W / \cos\theta_W$.