Look Into The New Boson Properties

XV Mexican School on Particles and Fields

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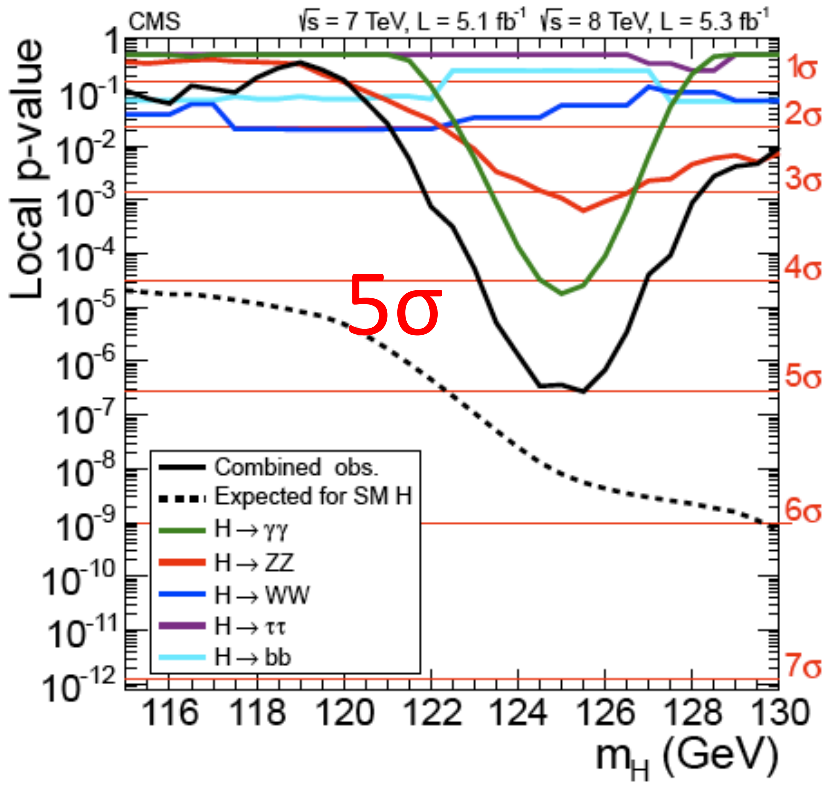
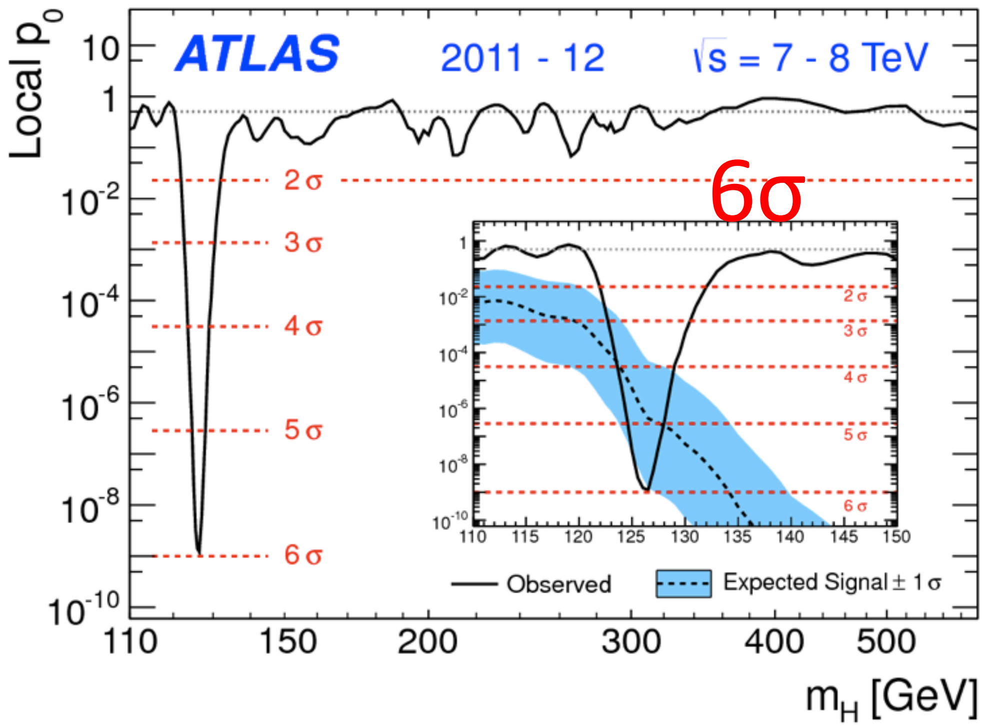
Outline

- What have we seen?
- What do we know about the new particle?
- What do not we know about the new particle?
- Why do not we see it in the bb and tt channel?
- Could it be a Fermiophobic boson?

What are we seeing?

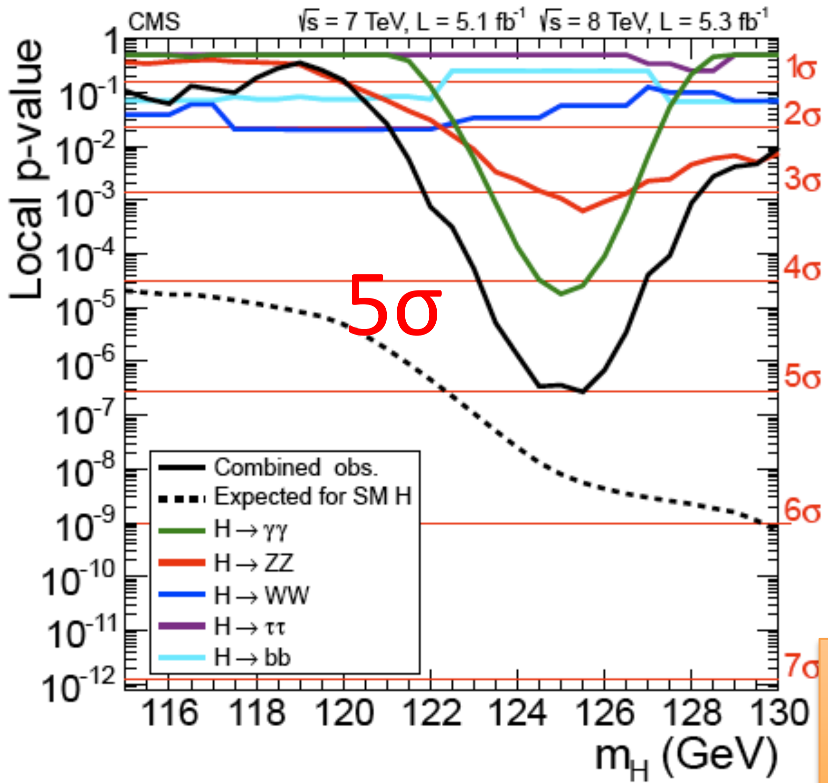


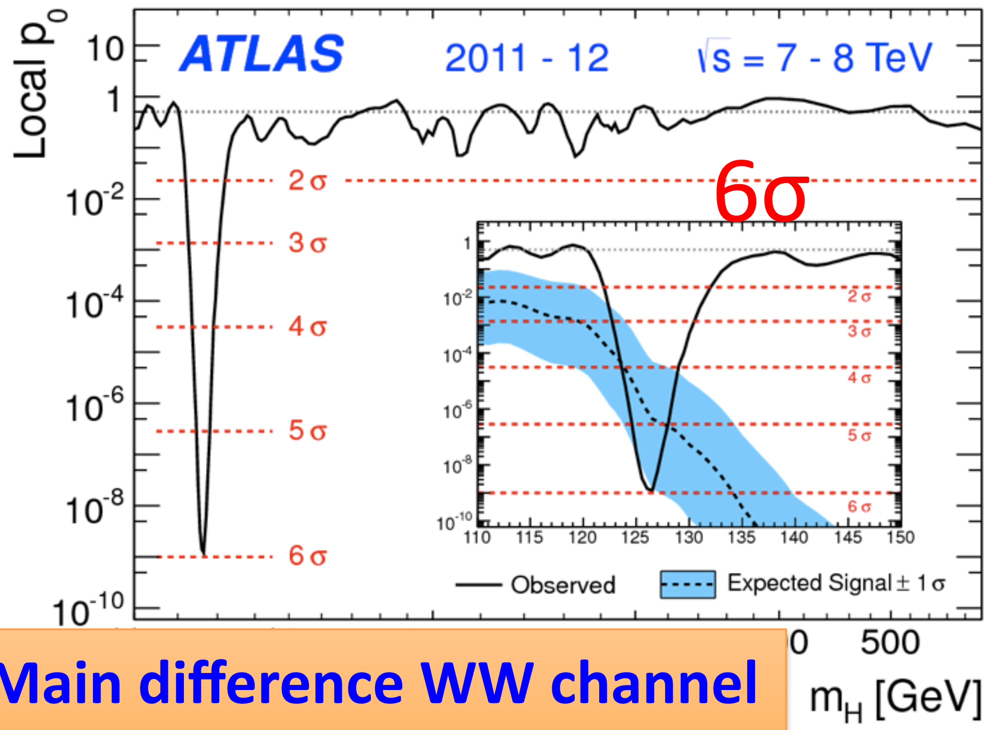


What is the difference for ATLAS and CMS?

->p_0 measures the compatibility of the data with the NO-HIGGS hypothesis.

What are we seeing?





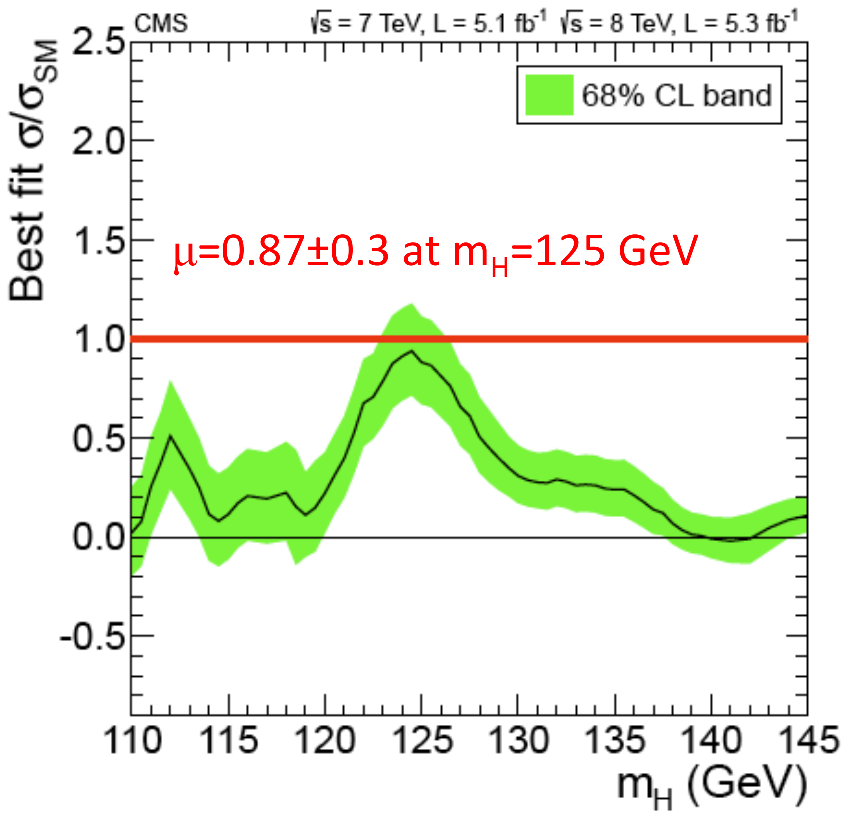
Main difference WW channel

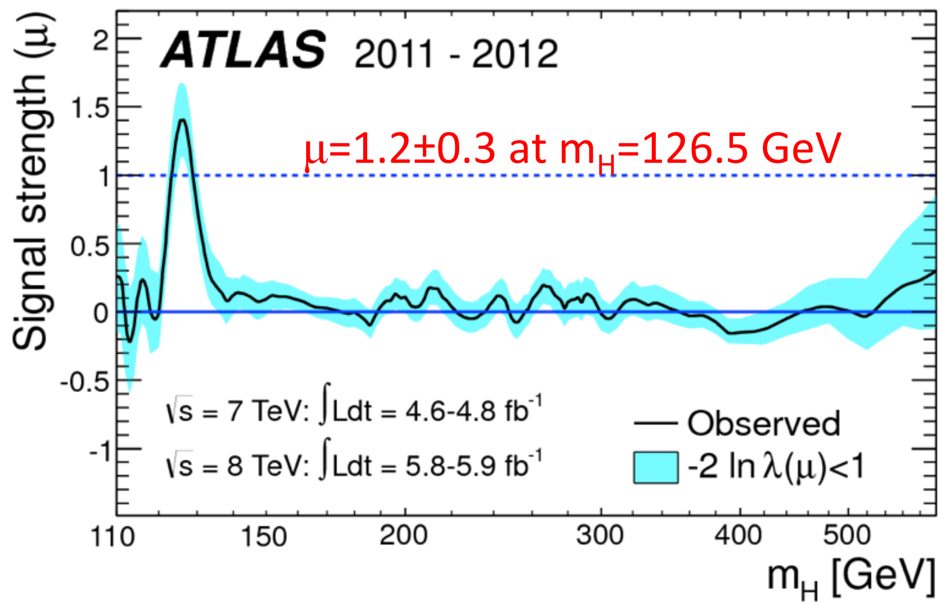
CMS 1.6 σ

ATLAS 2.8 σ

->p_0 measures the compatibility of the data with the NO-HIGGS hypothesis.

Signal strengt

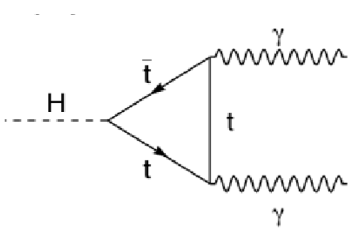


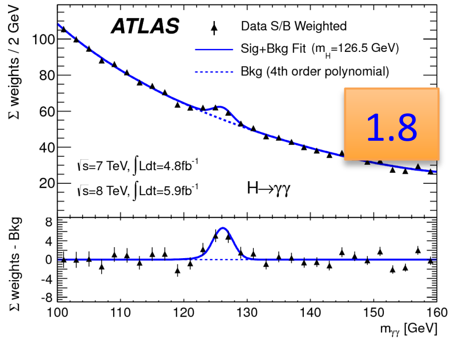


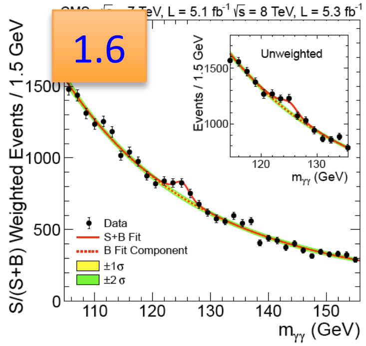
$$\mu = \frac{\sigma}{\sigma_{SM}(m_H)}$$

Signal strength (μ) =
(signal rate from fit to data) /
(expected SM signal rate at given m_H)

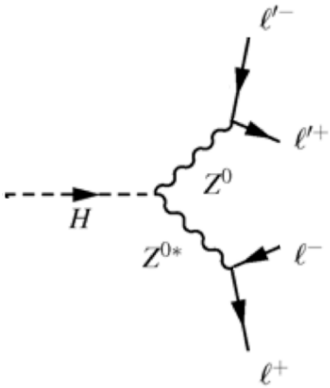
Three most sensitive channels

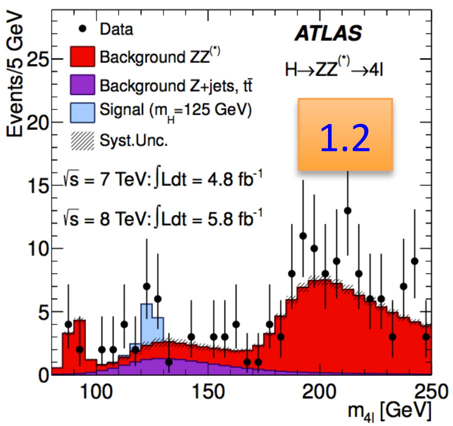


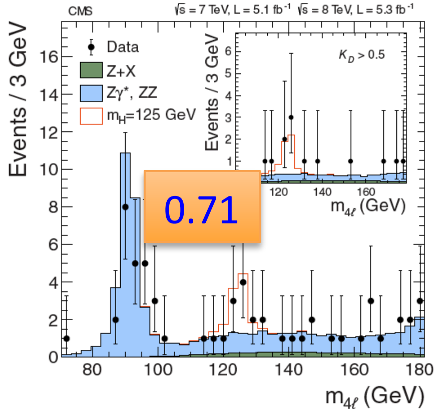




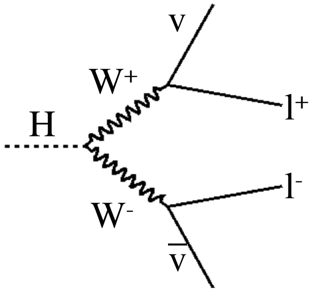
S/B = O(0.1)

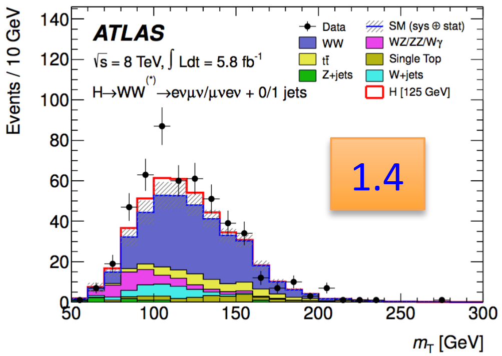


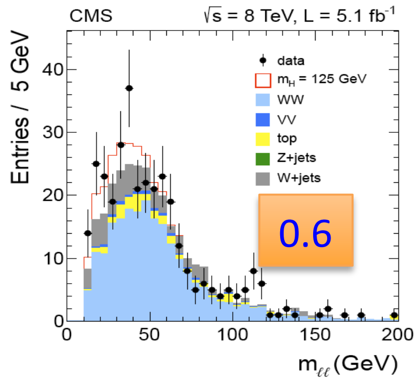




S/B = O(0.1)





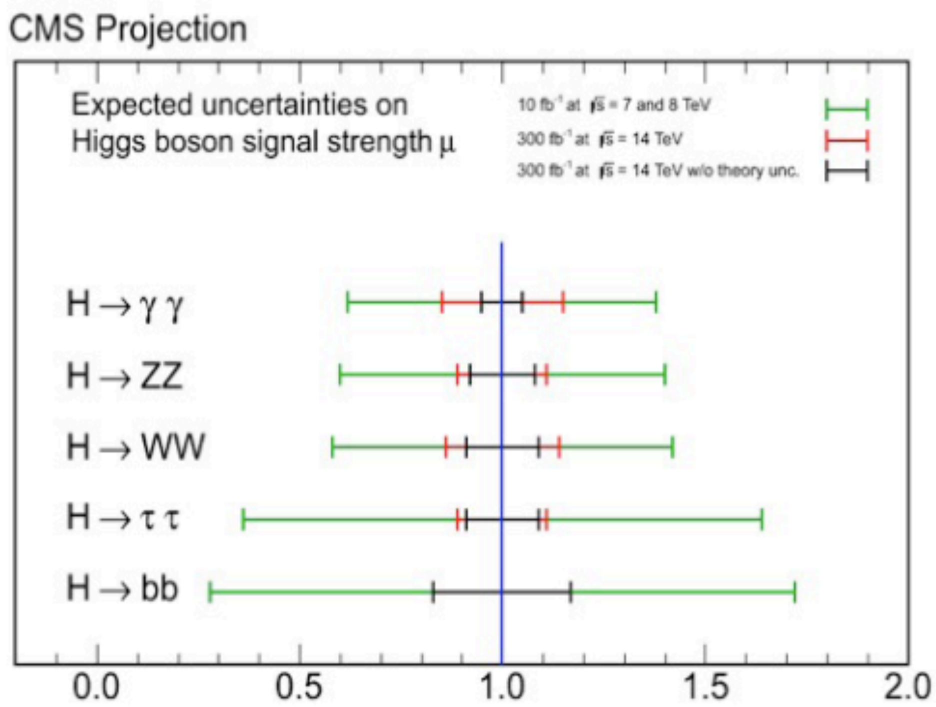


S/B = O(1)

Signal strength

Projection for signal strength

- Projecting signal strength per decay mode
- Showing 10/fb at 7/8 TeV and 300/fb at 14 TeV
  - scale signal and background cross section
  - systematic uncertainties unchanged or w/o theory uncertainties
  - analysis strategies are not optimized
- 5-15% uncertainties with 300/fb

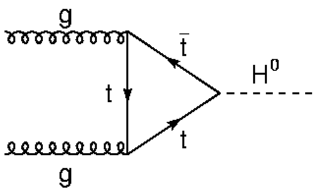


What do we know about it?

- It appeared in the SM Higgs searches
- Its mass is around 125-126 GeV
- It is a boson
  - There is no way that a fermion with an odd spin produce just two bosons
- It is not a spin one particle
  - You can imagine a Higgs producing two photons with opposite spin giving you a cero spin particle, or having both same spin and giving you a two spin particle. But there is no combination possible for one spin particle without an extra particle.

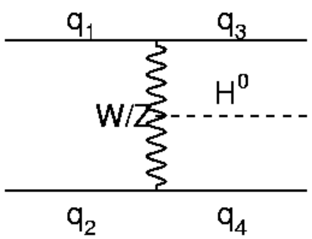
Benchmark: SM Higgs production

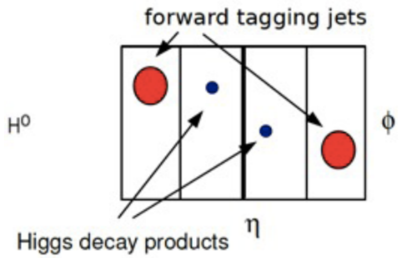
Gluon fusion
(dominant at LHC)



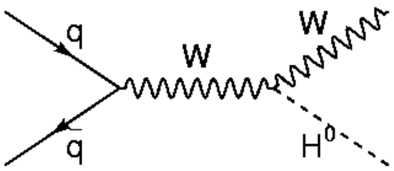
Not jets in the event or jets that do not satisfies the VBF tag

Vector boson fusion



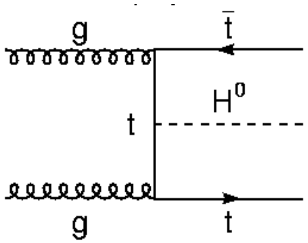


Associated production with Z/W



Higgs decay plus a W/Z decay

Associated production with top



Higgs decay plus a tt decay

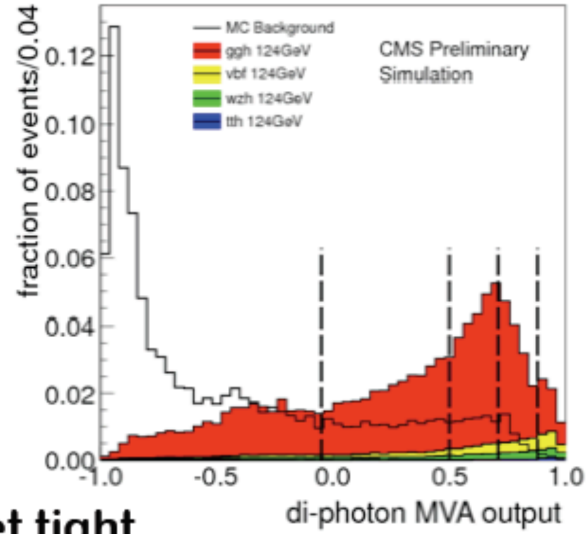
Table of SM Higgs Searches Categories

Channel	Mass range [GeV]	Lumi'11 [1/fb]	Lumi'12 [1/fb]	Topologies	gF	VBF	VH	ttH
$H \to \gamma\gamma$	110-150	5.1	5.3	incl. + VBF				
$H \to \tau\tau$	110-145	4.9	5.0	0/1 jet + VBF + WH + ZH				
$H \to bb$	110-135	5.0	5.0	WH + ZH + ttH				
$H \to ZZ \to 4l$	110-600	5.1	5.3	inclusive				
$H \to WW \to 2l2\nu$	110-600	4.9	5.3	0/1 jet + VBF + WH + ZH				
$H \to ZZ \to 2l2\nu$	200-600	5.0	5.0	0/1 jet + VBF				
$H \to ZZ \to 2l2q$	130-600	4.9	-	0/1/2 b-tags				
$H \to WW \to l\nu qq$	240-600	4.9	5.1	inclusive				

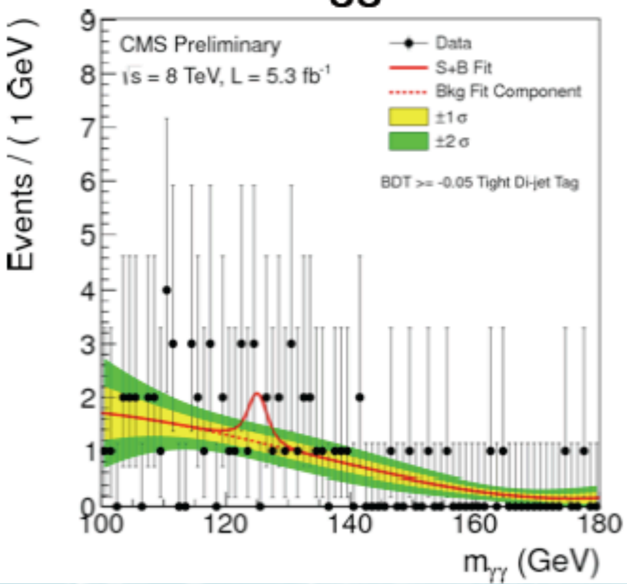
Example: H $\longrightarrow \gamma\gamma$

Expected signal and estimated background

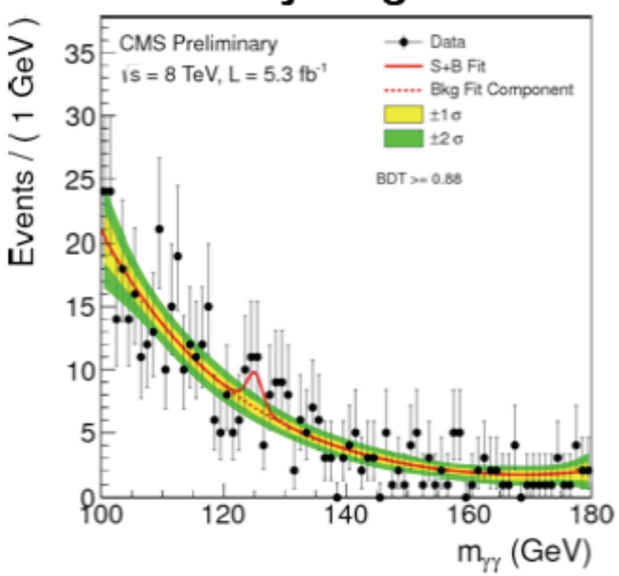
Event classes		SM Higgs boson expected signal (m_H=125 GeV)					Background $m_{\gamma\gamma}$ = 125 GeV (ev./GeV)	
		Total	ggH	VBF	VH	ttH		
7 TeV 5.1 fb^{-1}	Untagged 0	3.2	61%	17%	19%	3%	3.3	± 0.4
	Untagged 1	16.3	88%	6%	6%	1%	37.5	± 1.3
	Untagged 2	21.5	91%	4%	4%	–	74.8	± 1.9
	Untagged 3	32.8	91%	4%	4%	–	193.6	± 3.0
	Dijet tag	2.9	27%	73%	1%	–	1.7	± 0.2
8 TeV 5.3 fb^{-1}	Untagged 0	6.1	68%	12%	16%	4%	7.4	± 0.6
	Untagged 1	21.0	88%	6%	6%	1%	54.7	± 1.5
	Untagged 2	30.2	92%	4%	3%	–	115.2	± 2.3
	Untagged 3	40.0	92%	4%	4%	–	256.5	± 3.4
	Dijet tight	2.6	23%	77%	–	–	1.3	± 0.2
	Dijet loose	3.0	53%	45%	2%	–	3.7	± 0.4



Untagged 0



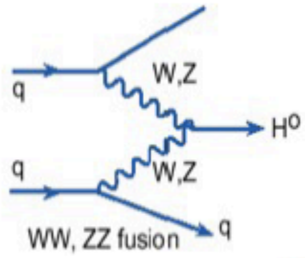
Dijet tight

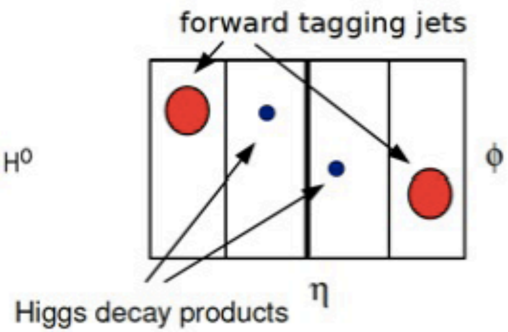


SM Higgs Searches Categories

CMS

- VBF signature
  - γγ, ττ, WW channels deploy VBF signature
  - ZZ(4l) has very low signal yield
  - bb is challenging and work in progress





- increases sensitivity and allows coupling measurement
- three analysis deploy quite different strategies

Channel	Technique	Variable	Jet kinematic	Pile-up	gluon fusion cont. at 125 GeV
$H \to \gamma\gamma$	cuts, 2 categories	m(jj), Δη(jj), Δϕ(H,jj), Zep.	pT > 20 (30) GeV, |η| < 4.7	cut jet ID	53%, 23%
$H \to \tau\tau$	MVA	m(jj), Δη(jj), Δη(H,j), Δϕ(jj), pT(ττ), pT(jj)	pT > 30 GeV, |η| < 5.0	MVA je ID	20%
$H \to WW$	cuts	m(jj), Δη(jj)	pT > 30 GeV, |η| < 4.7	MVA je ID	15%

- diversity result of independent development and optimization, but needs investigation!

ATLAS SM Higgs Searches Categories

Decay	Sub-channel	N_{obs}	$\langle N_B \rangle$	$\langle N_{ggF} \rangle$	$\langle N_{VBF} \rangle$	$\langle N_{WH} \rangle$	$\langle N_{ZH} \rangle$	$\langle N_{ttH} \rangle$
$H \to \gamma\gamma$	low-p_{Tt}	7013	6820	138	6.3	3.1	1.8	0.4
	high-p_{Tt}	320	291	14.0	2.9	1.8	1.0	0.4
	2-jet	36	24.2	1.3	3.4	0.0	0.0	0.0
$H \to ZZ^{(*)} \to 4\ell$	–	14	5.4	5.6	0.5	0.1	0.1	0.0
$H \to WW^{(*)} \to \ell\nu\ell\nu$	0-jet	667	573	75.3	0.8	0.3	0.4	0.0
	1-jet	183	141	16.7	1.7	0.3	0.2	0.0
	2-jet	3	3.7	0.3	1.3	0.0	0.0	0.0
$H \to \tau^+\tau^-$	0-jet	9277	9305	17.6	0.6	0.1	0.3	0.0
	1-jet	393	406	3.6	1.0	0.1	0.2	0.0
	2-jet	22	28.2	0.3	0.9	0.0	0.0	0.0
	VH	164	152	0.7	0.1	0.2	0.3	0.0
$H \to b\bar{b}$	ZH	322	321	0.0	0.0	0.0	4.0	0.0
	WH	1266	1311	0.0	0.0	11.1	0.0	0.0

ATLAS SM Higgs Searches Categories

Decay	Sub-channel	N_{obs}	Excess	$\langle N_{ggF} \rangle$	$\langle N_{VBF} \rangle$	$\langle N_{WH} \rangle$	$\langle N_{ZH} \rangle$	$\langle N_{ttH} \rangle$
$H \rightarrow \gamma\gamma$	low-p_{Tt}	7013	193	138	6.3	3.1	1.8	0.4
	high-p_{Tt}	320	29	14.0	2.9	1.8	1.0	0.4
	2-jet	36	11.8	1.3	3.4	0.0	0.0	0.0
$H \rightarrow ZZ^{(*)} \rightarrow 4\ell$	–	14	8.6	5.6	0.5	0.1	0.1	0.0
$H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	0-jet	667	94	75.3	0.8	0.3	0.4	0.0
	1-jet	183	42	16.7	1.7	0.3	0.2	0.0
	2-jet	3	-0.7	0.3	1.3	0.0	0.0	0.0
$H \rightarrow \tau^+\tau^-$	0-jet	9277	-28	17.6	0.6	0.1	0.3	0.0
	1-jet	393	-13	3.6	1.0	0.1	0.2	0.0
	2-jet	22	-6.2	0.3	0.9	0.0	0.0	0.0
	VH	164	12	0.7	0.1	0.2	0.3	0.0
$H \rightarrow b\bar{b}$	ZH	322	1	0.0	0.0	0.0	4.0	0.0
	WH	1266	-45	0.0	0.0	11.1	0.0	0.0

Table of SM Higgs Searches Categories

Channel	Mass range [GeV]	Lumi'11 [1/fb]	Lumi'12 [1/fb]	Topologies	gF	VBF	VH	ttH
$H \rightarrow \gamma\gamma$	110-150	5.1	5.3	incl. + VBF	☺	☺	-	-
$H \rightarrow \tau\tau$	110-145	4.9	5.0	0/1 jet + VBF + WH + ZH	☺	☺	☺	-
$H \rightarrow bb$	110-135	5.0	5.0	WH + ZH + ttH	-	-	☺	☺
$H \rightarrow ZZ \rightarrow 4l$	110-600	5.1	5.3	inclusive	☺	-	-	-
$H \rightarrow WW \rightarrow 2l2\nu$	110-600	4.9	5.3	0/1 jet + VBF + WH + ZH	☺	☺	☺	-
$H \rightarrow ZZ \rightarrow 2l2\nu$	200-600	5.0	5.0	0/1 jet + VBF	☺	☺	-	-
$H \rightarrow ZZ \rightarrow 2l2q$	130-600	4.9	-	0/1/2 b-tags	☺	-	-	-
$H \rightarrow WW \rightarrow l\nu qq$	240-600	4.9	5.1	inclusive	☺	-	-	-

Proposal – compatibility with SM Higgs

- **Start from best knowledge of SM Higgs cross section and branching fractions**

- **Derive scale factors**

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} C_g^2(C_b, C_t, m_H) \\ C_g^2 \end{cases}$$

$$\frac{\sigma_{\rm VBF}}{\sigma_{\rm VBF}^{SM}} = C_{\rm VBF}^2(C_W, C_Z, m_H)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \frac{\Gamma_{WW}}{\Gamma_{WW}^{SM}} = C_W^2$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \frac{\Gamma_{ZZ}}{\Gamma_{ZZ}^{SM}} = C_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}}^{SM}} = C_t^2$$

Detectable decay modes

$$\frac{\Gamma_{WW}}{\Gamma_{WW}^{SM}} = C_W^2$$

$$\frac{\Gamma_{ZZ}}{\Gamma_{ZZ}^{SM}} = C_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = C_b^2$$

$$\frac{\Gamma_{\tau\tau}}{\Gamma_{\tau\tau}^{SM}} = C_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} C_\gamma^2(C_b, C_t, C_W, \\ C_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} \sim C_W^2$$

Undetectable decay modes

$$\frac{\Gamma_{t\bar{t}}}{\Gamma_{t\bar{t}}^{SM}} = \frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}}^{SM}} = C_t^2$$

$$\frac{\Gamma_{gg}}{\Gamma_{gg}^{SM}} = \frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}}$$

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{SM}} = C_t^2$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma_{s\bar{s}}^{SM}} = C_b^2$$

$$\frac{\Gamma_{\mu\mu}}{\Gamma_{\mu\mu}^{SM}} = C_\tau^2$$

Total width

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \begin{cases} C_H^2(C_i, m_H) \\ C_H^2 \end{cases}$$

- **Analyze scale factors in benchmarks**

Assumptions and Limitations

- **Observations originate from a single particle**
- **Use zero-width approximation**
- **Consider only modifications to couplings strength. No modification to tensor structure, i.e. assume CP-even scalar state**
- **Additional assumptions necessary to measure Ci and not just ratios of couplings, e.g. no new Higgs decay modes**

$$C_H^2(C_i, m_H) = \sum_{\substack{k = WW, ZZ, b\bar{b}, \tau\tau, \gamma\gamma, \\ Z\gamma, gg, t\bar{t}, c\bar{c}, s\bar{s}, \mu\mu}} \frac{\Gamma_k(C_i, m_H)}{\Gamma_H^{SM}(m_H)}$$

- **Interference effects are not considered beyond SM**

Test WW/ZZ symmetry

- Compare WW and ZZ signal strength
- Fit WW (0/1 jet) and ZZ data assuming

$$\sigma \times BR_{H\to ZZ} = \boldsymbol{\mu}_{ZZ} \times [\sigma \times BR_{H\to ZZ}]_{SM\ Higgs}$$
$$\sigma \times BR_{H\to WW} = \mathbf{R}_{W/Z} \times \boldsymbol{\mu}_{ZZ} \times [\sigma \times BR_{H\to WW}]_{SM\ Higgs}$$

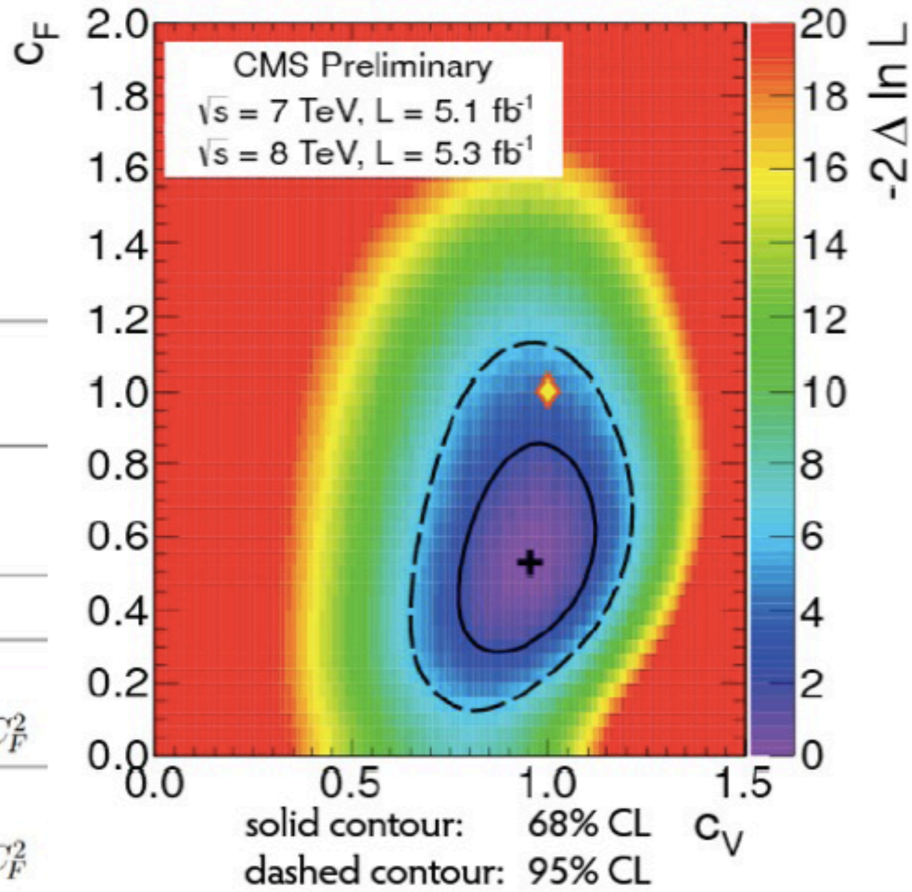
- Result compatible with SM (large uncertainties)

$$\mathbf{R}_{W/Z} = 0.9^{+1.1}_{-0.6}$$

Test compatibility

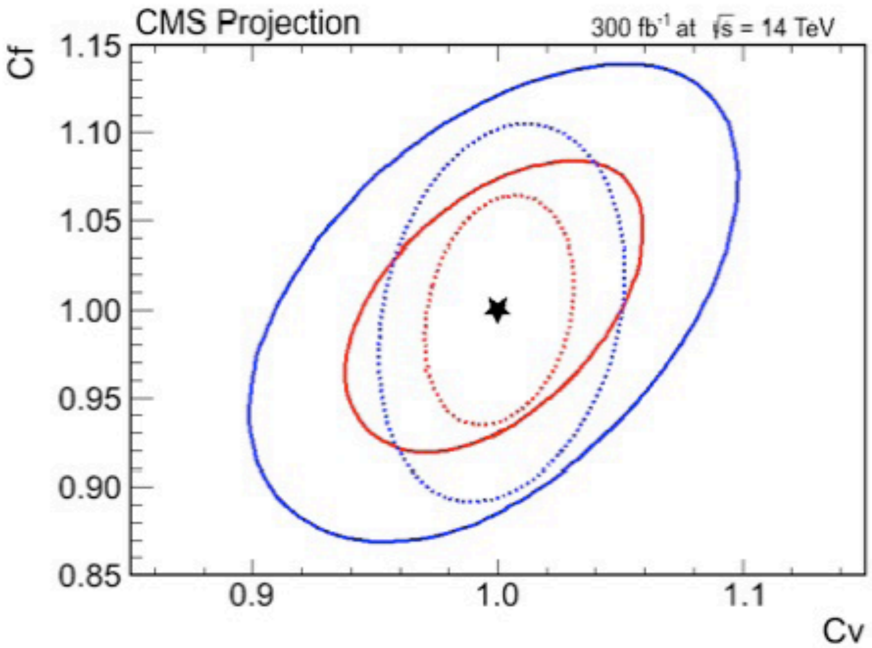
- Test compatibility by introducing two parameter (C_V, C_F)
- C_V and C_F modify expected signal yields in each mode through simple LO expressions

Production	Decay	LO SM	
VH	$H \to bb$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ttH	$H \to bb$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
VBF	$H \to \tau\tau$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to \tau\tau$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
ggH	$H \to ZZ$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to WW$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to WW$	$\sim \frac{C_V^2 \times C_V^2}{C_F^2}$	$\sim C_V^4/C_F^2$
ggH	$H \to \gamma\gamma$	$\sim \frac{C_F^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to \gamma\gamma$	$\sim \frac{C_V^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^4/C_F^2$

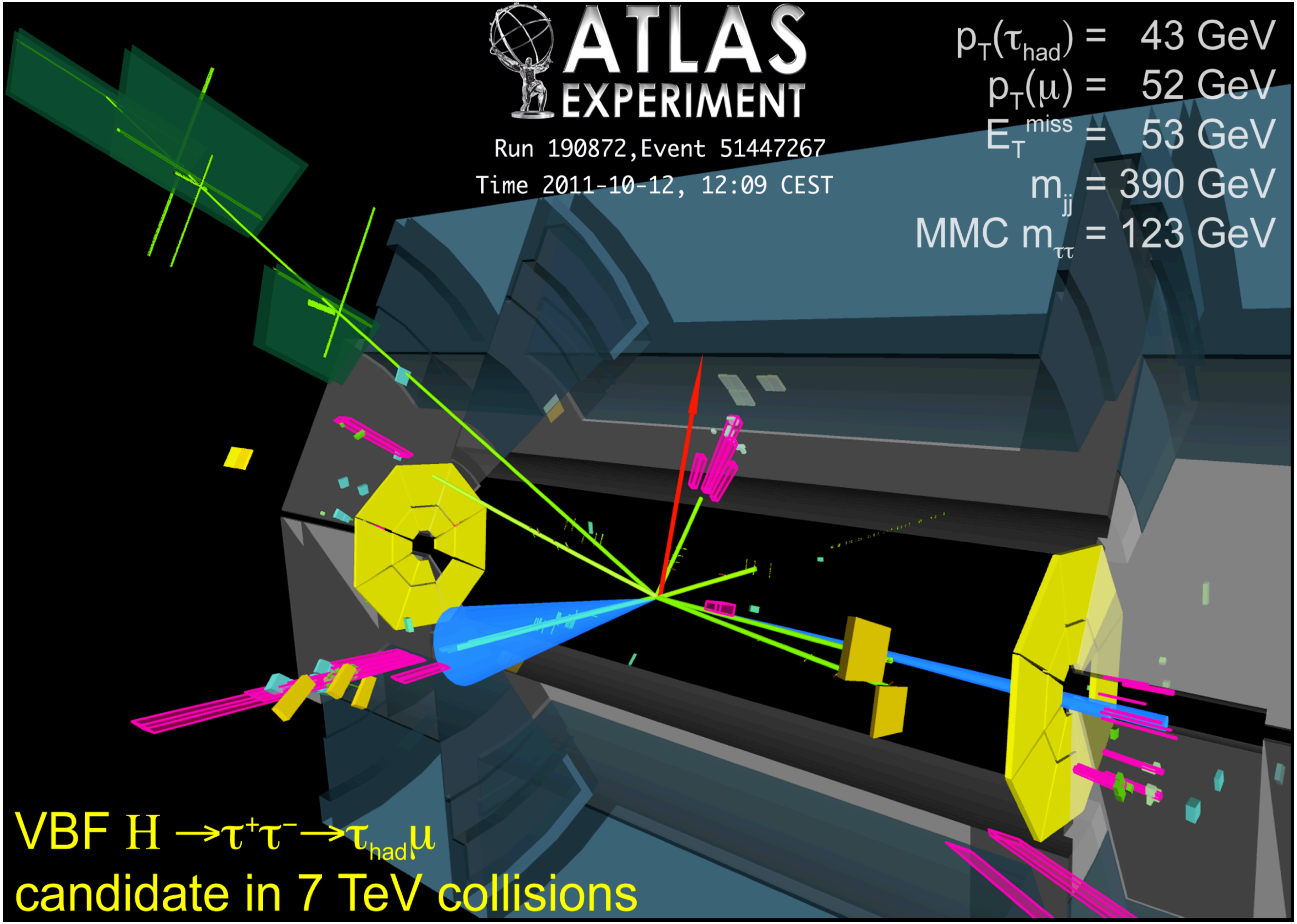


Projection

- Test compatibility by introducing two parameter (C_V, C_F)
- C_V and C_F modify expected signal yields in each mode through simple LO expressions
- Projecting to 30/fb at 8 TeV and 300/fb at 14 TeV
  - scale signal and background cross section
  - systematic uncertainties unchanged (dashed lines: no theory unc.)

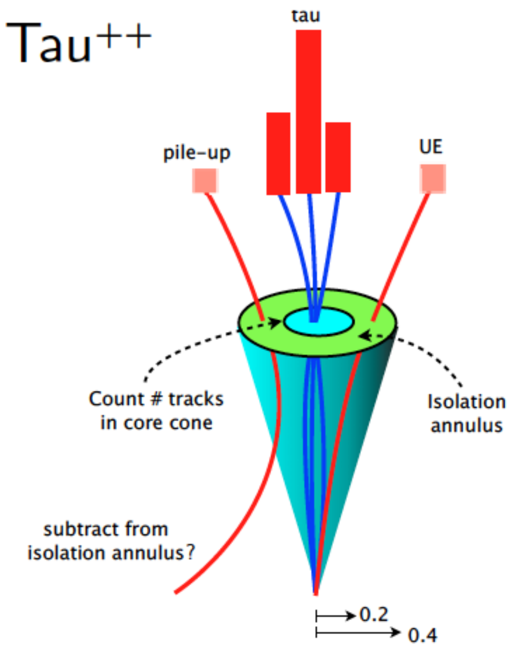


Why do not we see it in $H \rightarrow \tau^{+}\tau^{-}$?


ATLAS
EXPERIMENT
Run 190872,Event 51447267
Time 2011-10-12, 12:09 CEST
$p_T(\tau_{had})$ = 43 GeV
$p_T(\mu)$ = 52 GeV
E_T^{miss} = 53 GeV
m_{jj} = 390 GeV
MMC $m_{\tau\tau}$ = 123 GeV
VBF $H \rightarrow \tau^+\tau^- \rightarrow \tau_{had}\mu$
candidate in 7 TeV collisions

$H \rightarrow \tau^{+}\tau$

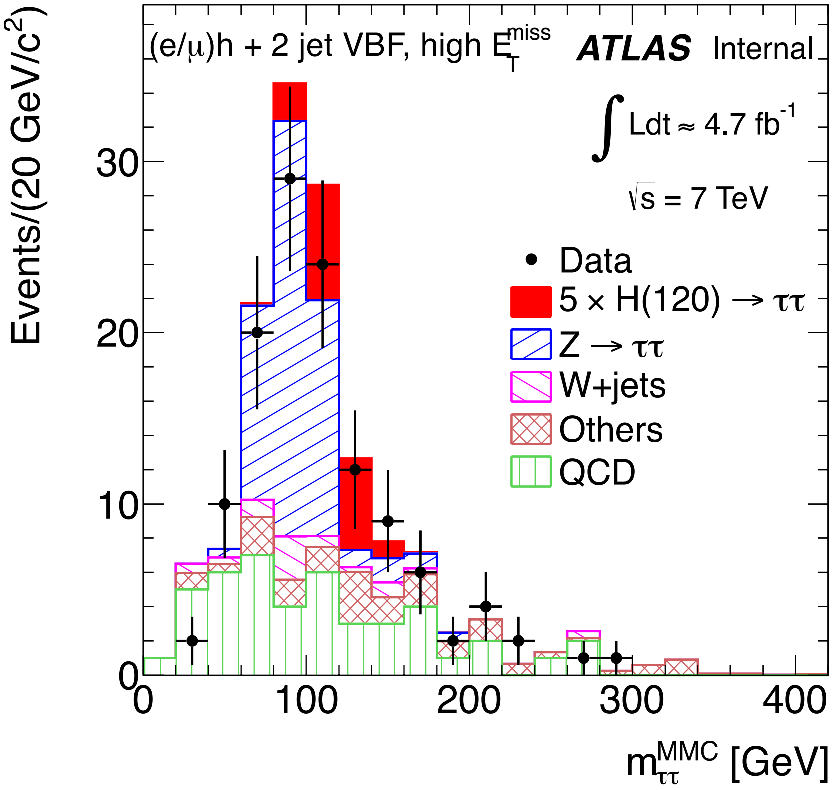
$$H \to \tau\tau \to \ell\ell + 4\nu \ (12\%)$$
$$H \to \tau\tau \to \ell\tau_h + 3\nu \ (46\%)$$
$$H \to \tau\tau \to \tau_h\tau_h + 2\nu \ (42\%)$$

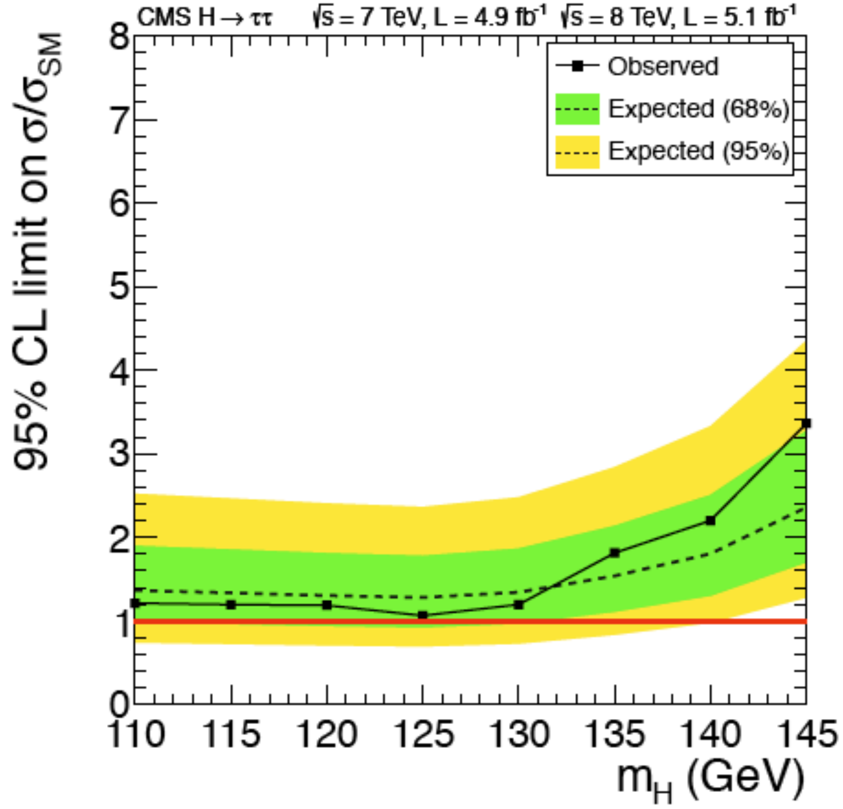


- Tau-jet reconstruction seeds with anti-k_T jets reconstructed in the calorimeters within a cone of $\Delta R = 0.4$, $p_T > 10$ GeV, $|\eta| < 2.5$
- Count the number of tracks identified within a cone of $\Delta R = 0.2$
- Pile-up robust variables describing isolation, shower shape profile, EM/hadronic energy fractions and angular separation are optimized
- Tau-jet (QCD-jet) (mis-)identification efficiency ~ 50% (<1%)

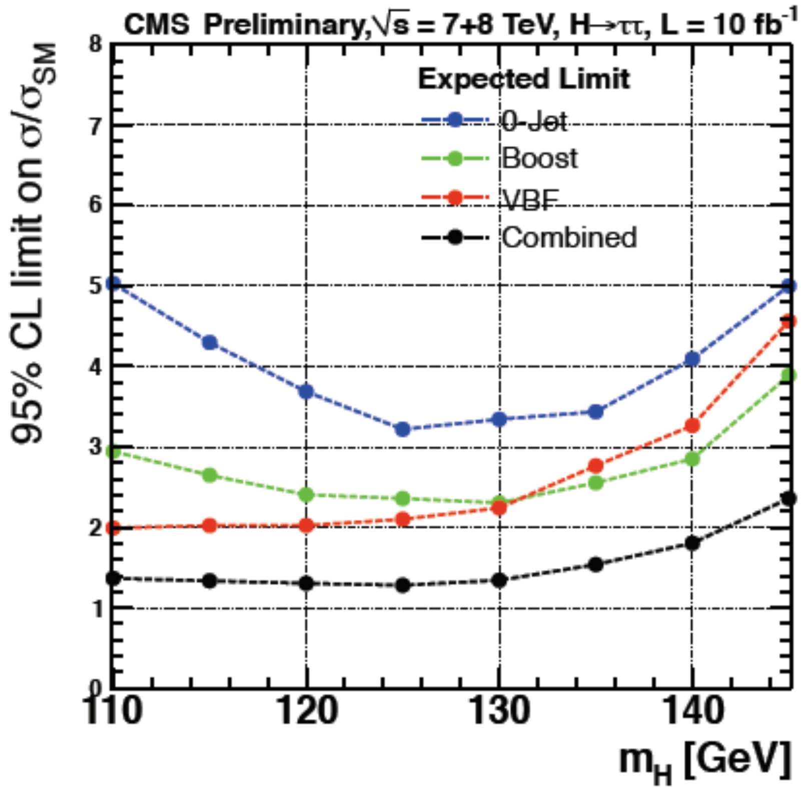
$H \rightarrow \tau^+\tau^-$

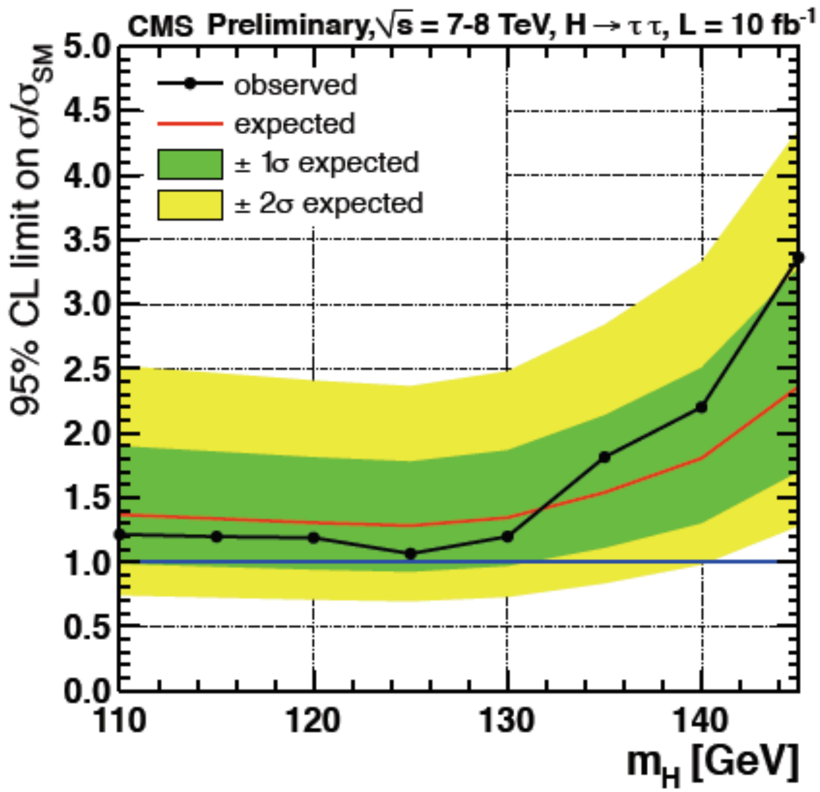
Analysis performed over 0, 1 and 2 jet categories, with highest sensitivity coming from the 2 jet VBF category





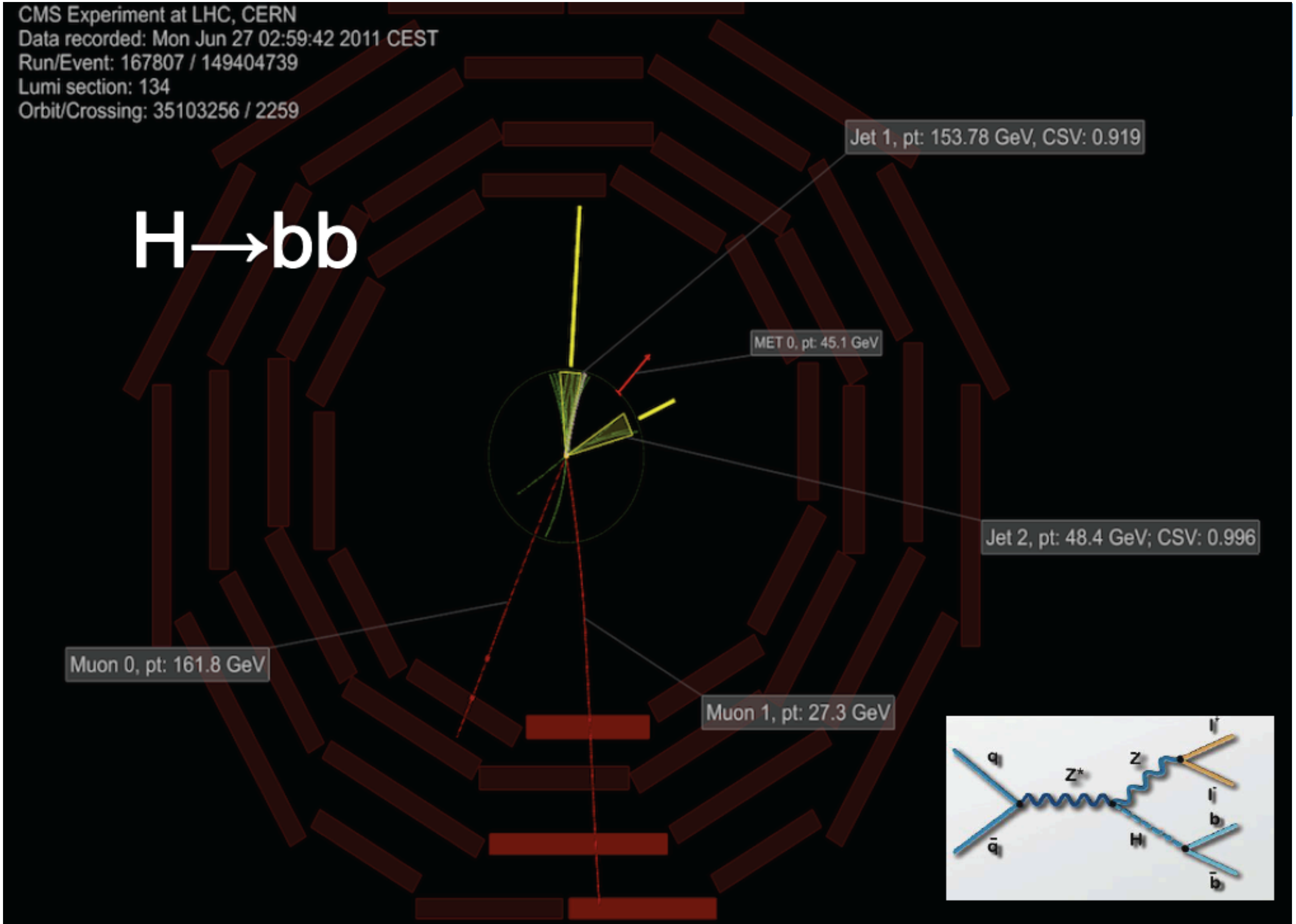
$H \to \tau^+\tau$





- No excess above SM background-only expectation
  - Observed limit: 1.06 x SM at m_H =125 GeV
  - Expected limit: 1.28

Why we do not see it in $W/Z\,,\, H \rightarrow bb$?


CMS Experiment at LHC, CERN
Data recorded: Mon Jun 27 02:59:42 2011 CEST
Run/Event: 167807 / 149404739
Lumi section: 134
Orbit/Crossing: 35103256 / 2259
H→bb
Jet 1, pt: 153.78 GeV, CSV: 0.919
MET 0, pt: 45.1 GeV
Jet 2, pt: 48.4 GeV; CSV: 0.996
Muon 0, pt: 161.8 GeV
Muon 1, pt: 27.3 GeV
q
q̄
Z*
Z
H
b
b̄

W/Z H, H → bb

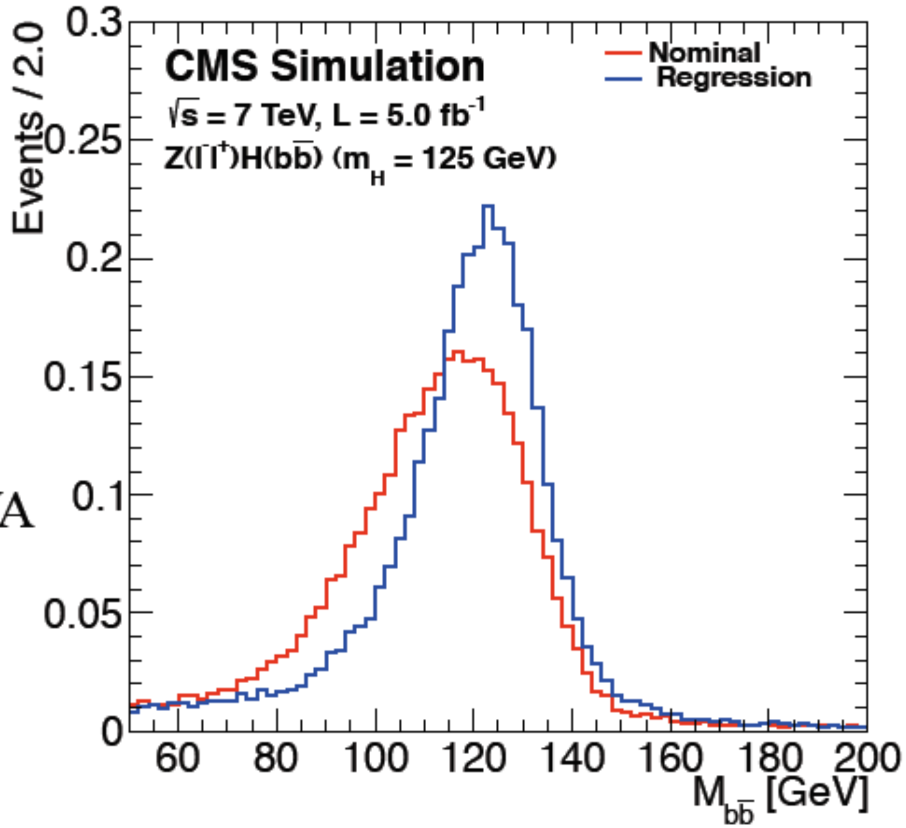
- Associated production with W or Z
- 5 channels under study
  - W(lν)H, Z(νν)H, Z(ll)H; l=e,μ

Background estimation:

- Two main backgrounds: W+jets and Top
  - estimated from MC
  - normalization from data
- QCD from data-driven method reversing lepton ID cut
- Other backgrounds from MC

n

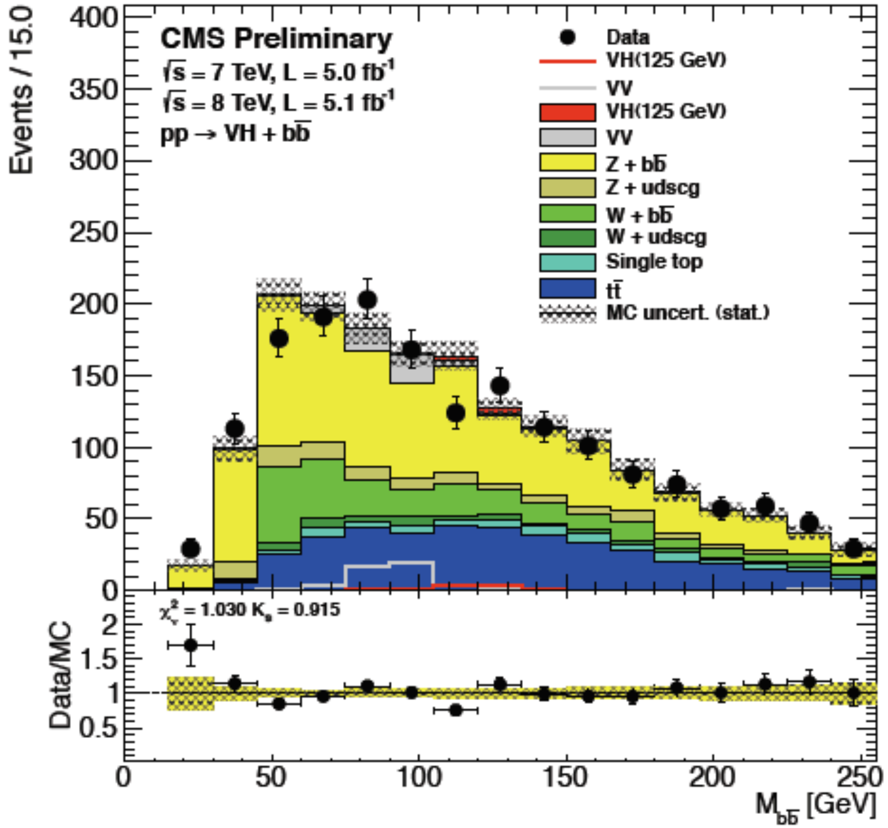
VA



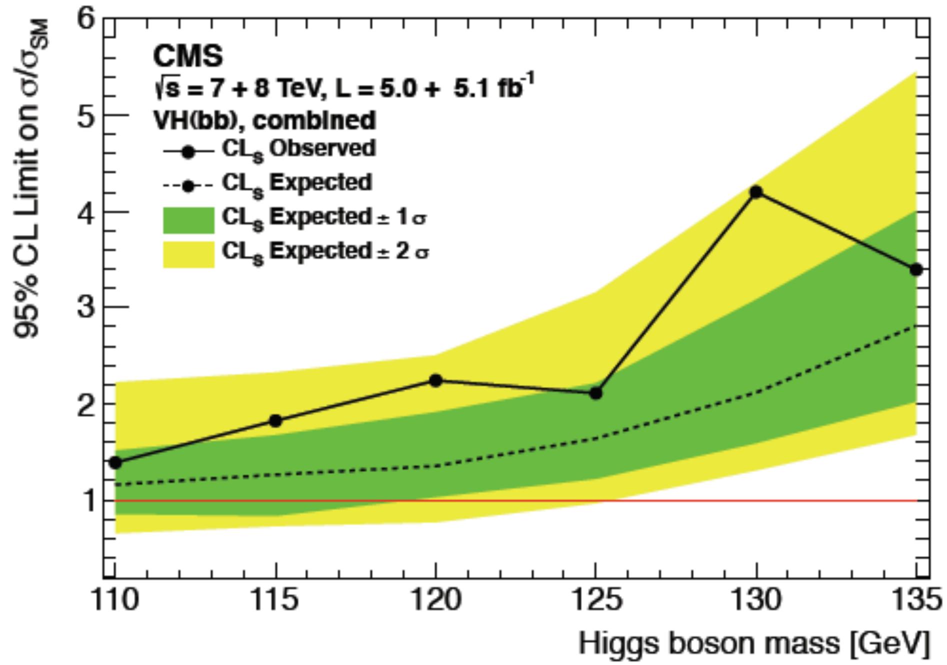
Main systematic uncertainties:

- B-tagging efficiency
- Jet energy scale and resolution

W/Z H, H → bb



7+8 TeV M_{jj} distribution

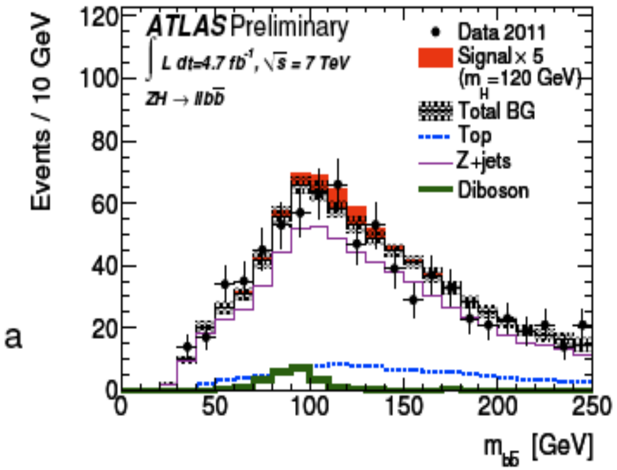


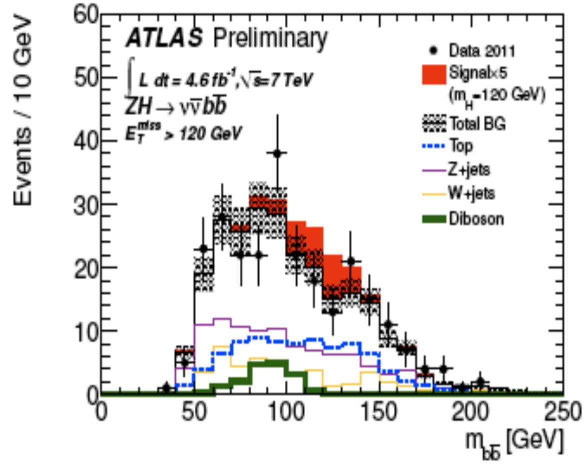
m_H(GeV)	110	115	120	125	130	135
Exp.	1.16	1.26	1.35	1.64	2.12	2.81
Obs.	1.39	1.82	2.24	2.11	4.20	3.39

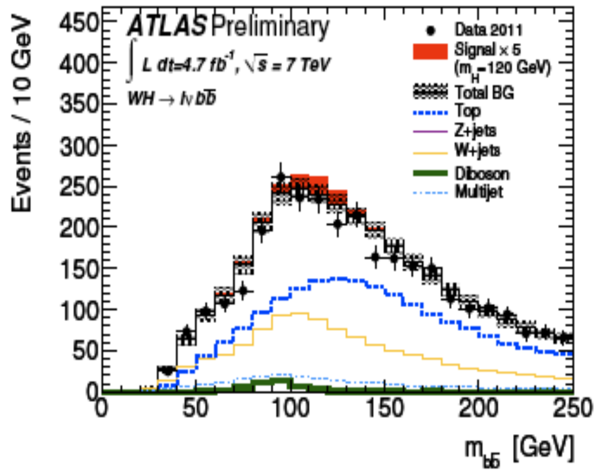
- Dijet mass distribution shows combination of all 5 channels
- Mild excess seen between 115 and 135 GeV
  - Compatible with either background or 125 GeV Higgs

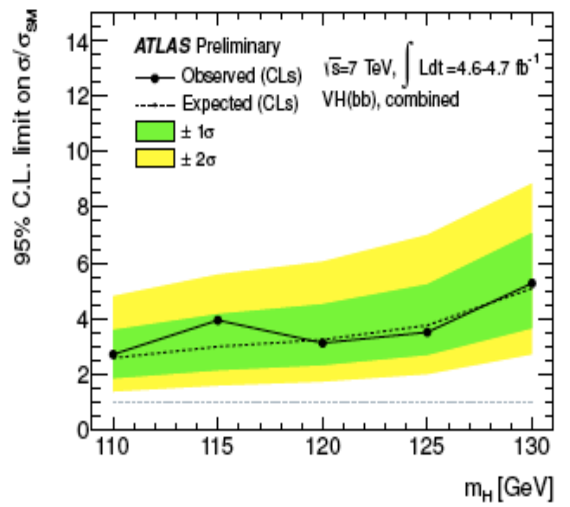
$W/H, H \rightarrow bb$

- Again three separate channels
  - $ZH \rightarrow l^+l^- b\bar{b}$
  - $ZH \rightarrow \nu\bar{\nu} b\bar{b}$
  - $WH \rightarrow l\nu b\bar{b}$
- Higgs production channel in association with a leptonically decaying vector boson used
- Provides a high p_T lepton or large E_T^{miss} to trigger on and reduces QCD backgrounds
- $m_{b\bar{b}}$ used as the discriminating variable
- No excess seen over the background expectation in any channel
- The combined upper limits are between 2.7 and 5.3 times the SM $H \rightarrow b\bar{b}$ cross section
- ATLAS-CONF-2012-015



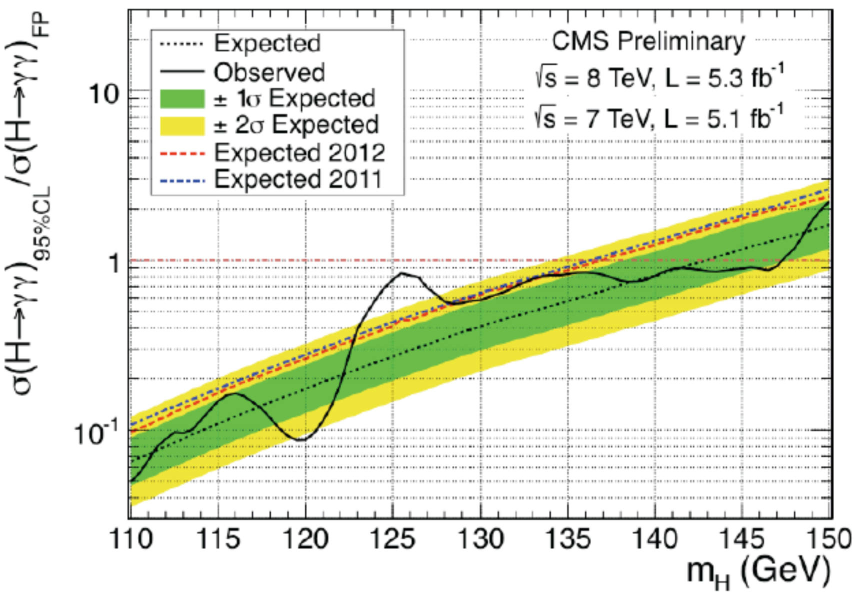


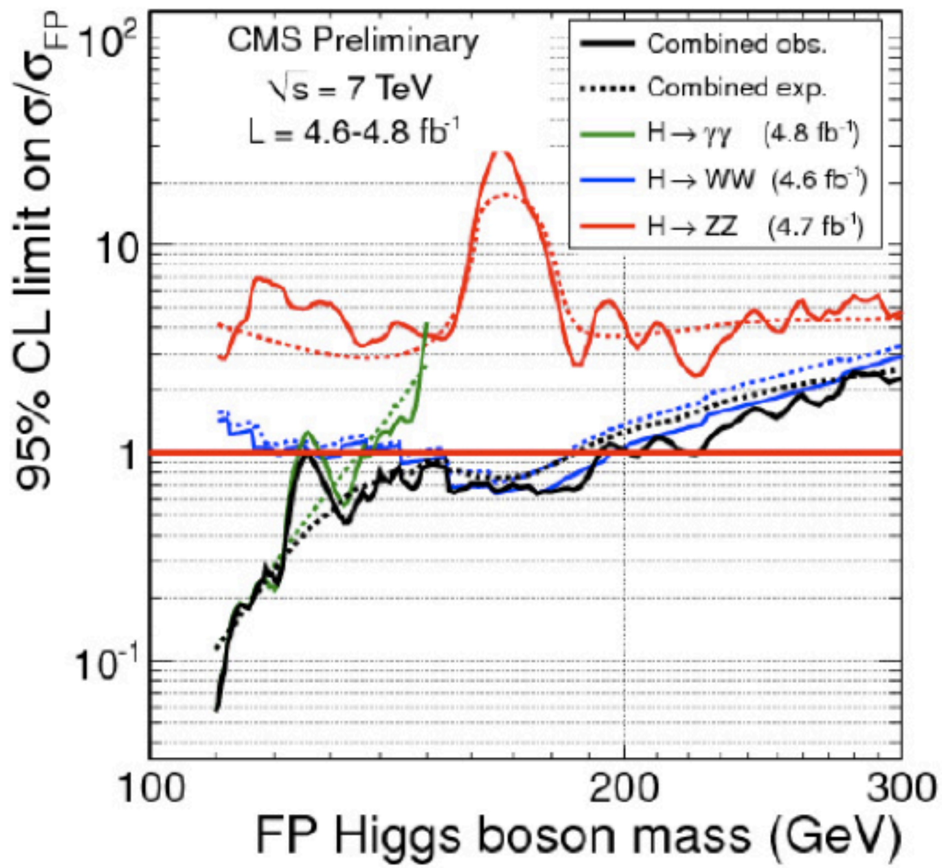




Could it be a Fermiophobic Higgs?

Is it Fermiophopic?





The observed state @ ~125 GeV is excluded at 99% CL under the fully-fermiophobic hypothesis.

Summary

CMS: Phys. Lett. B 716 (2012) 30-61

$M_H = 125.3 \pm 0.4$ (stat) ± 0.5 (syst) GeV

Local significance of the observation ($M_H = 125$ GeV): 5.0σ,

total significance ($M_H = 110 - 145$ GeV): 4.5σ

H $\rightarrow \gamma\gamma$: $\sigma/\sigma(\mathrm{SM}) = 1.56 \pm 0.43$

H $\rightarrow$ all: $\sigma/\sigma(\mathrm{SM}) = 0.80 \pm 0.22$

ATLAS: Phys. Lett. B 716 (2012) 1-29.

$M_H = 126.0 \pm 0.4$ (stat) ± 0.4 (syst) GeV

Local significance of the observation ($M_H = 122 - 131$ GeV): 5.9σ,

total significance ($M_H = 110 - 600$ GeV): 5.1σ

H $\rightarrow \gamma\gamma$: $\sigma/\sigma(\mathrm{SM}) = 1.9 \pm 0.5$

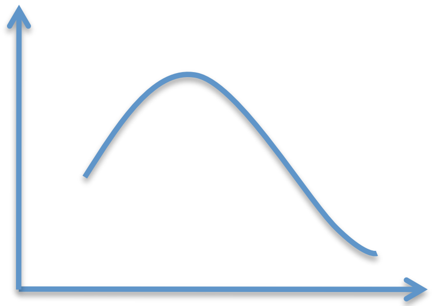
H $\rightarrow$ ZZ $\rightarrow 4\ell$: $\sigma/\sigma(\mathrm{SM}) = 1.26 \pm 0.14$

H $\rightarrow$ all: $\sigma/\sigma(\mathrm{SM}) = 1.4 \pm 0.3$

BACKUP

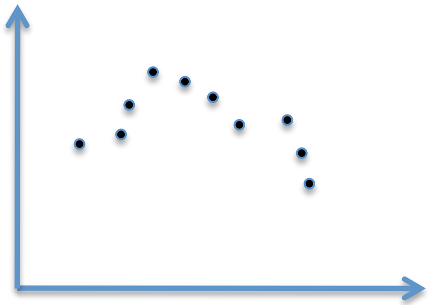
What is signal strength?

Expected Background

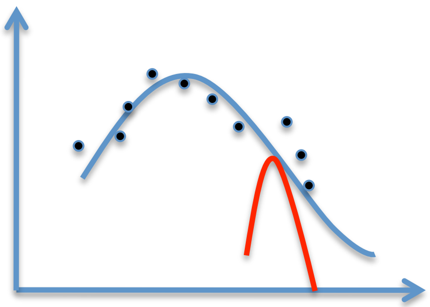


Expected shape of the signal

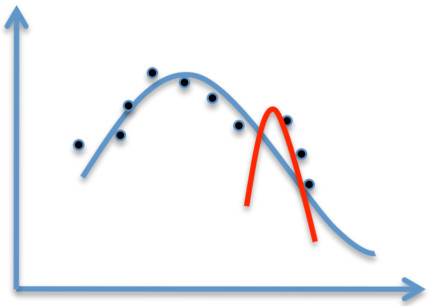
data



Assuming the value coming from the benchmark model
(Higgs searches the SM cross section)



Multiplying the benchmark model quantity by a factor X (signal strength)



$$\mu = \frac{\sigma}{\sigma_{SM}(m_H)}$$

Basic idea more complicated in practice

Main ATLAS search strategy

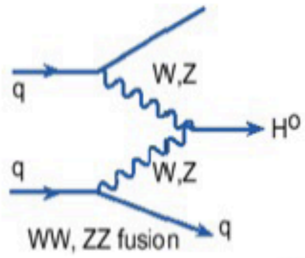
Higgs Decay	Subsequent Decay	Additional Sub-Channels	m_H Range
$H \to \gamma\gamma$	–	9 sub-channels ($p_{T_t} \otimes \eta_\gamma \otimes$ conversion)	110-150
$H \to ZZ$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110-600
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low pile-up, high pile-up}	200-280-600
	$\ell\ell q\bar{q}$	{b-tagged, untagged}	200-300-600
$H \to WW$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes$ {0-jet, 1-jet, VBF}	110-300-600
	$\ell\nu q\overline{q'}$	$\{e, \mu\} \otimes$ {0-jet, 1-jet}	300-600
$H \to \tau^+\tau^-$	$\ell\ell 4\nu$	$\{e\mu\} \otimes$ {0-jet} $\oplus$ {1-jet, VBF, VH}	110-150
	$\ell\tau_{\mathrm{had}} 3\nu$	$\{e, \mu\} \otimes$ {0-jet} $\otimes$ $\{E_T^{\mathrm{miss}} \gtrless 20$ GeV$\}$ $\oplus$ $\{e, \mu\} \otimes$ {1-jet, VBF}	110-150
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}} 2\nu$	{1-jet}	110-150
$VH \to b\bar{b}$	$Z \to \nu\bar{\nu}$	$E_T^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200$ GeV$\}$	110-130
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130

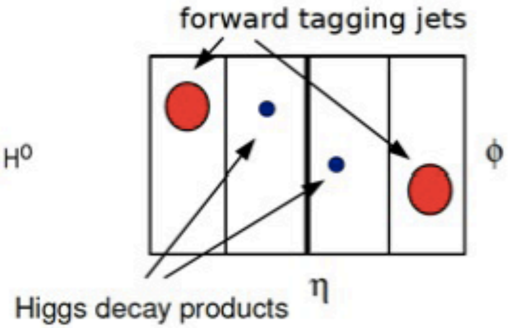
Main CMS search strategy

mode	signature	S/B	Mass Resol.	N events in $10 fb^{-1}$	Good For
$H \rightarrow bb$	two b-jets, Z or W, bb inv. mass	low O(0.1)	10%	$\sim 10^5$ ~30 (sel)	couplings to fermions
$H \rightarrow \tau\tau$	had tau, leptons, MET	low O(0.1)	15%	$\sim 10^4$ ~20 (sel)	couplings to fermions
$H \rightarrow WW$	two leptons with opposite charge MET	medium O(1)	-	$\sim 10^3$ ~60 (sel)	cross section, BR, couplings to V
$H \rightarrow \gamma\gamma$	two photons peak in inv. mass	low O(0.1)	2%	400 ~200 (sel)	H mass, couplings $C_V C_F$, discovery
$H \rightarrow ZZ$	four leptons with right charge peaks in inv. mass (Z_1 and Higgs)	high >1	1-2%	20 ~6 (sel)	H mass, discovery

VBF production

- VBF signature
  - γγ, ττ, WW channels deploy VBF signature
  - ZZ(4l) has very low signal yield
  - bb is challenging and work in progress





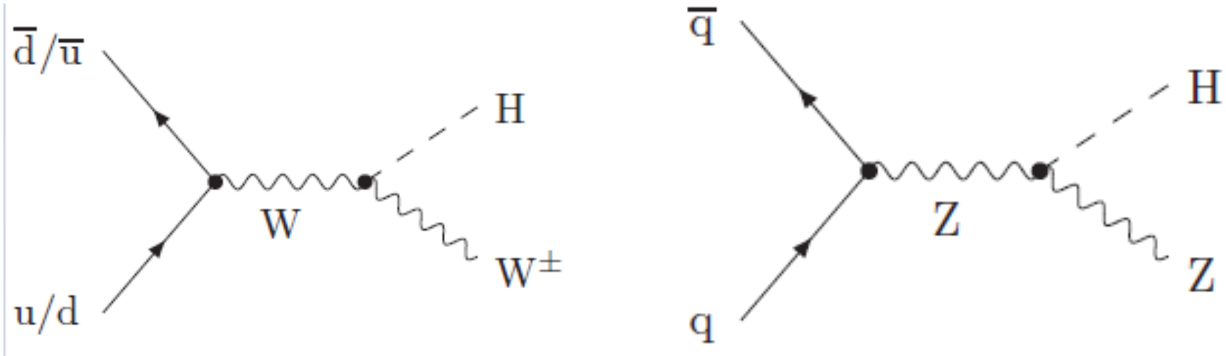
- increases sensitivity and allows coupling measurement
- three analysis deploy quite different strategies

Channel	Technique	Variable	Jet kinematic	Pile-up	gluon fusion cont. at 125 GeV
$H \to \gamma\gamma$	cuts, 2 categories	m(jj), Δη(jj), Δϕ(H,jj), Zep.	pT > 20 (30) GeV, |η| < 4.7	cut jet ID	53%, 23%
$H \to \tau\tau$	MVA	m(jj), Δη(jj), Δη(H,j), Δϕ(jj), pT(ττ), pT(jj)	pT > 30 GeV, |η| < 5.0	MVA jet ID	20%
$H \to WW$	cuts	m(jj), Δη(jj)	pT > 30 GeV, |η| < 4.7	MVA jet ID	15%

- diversity result of independent development and optimization, but needs investigation!

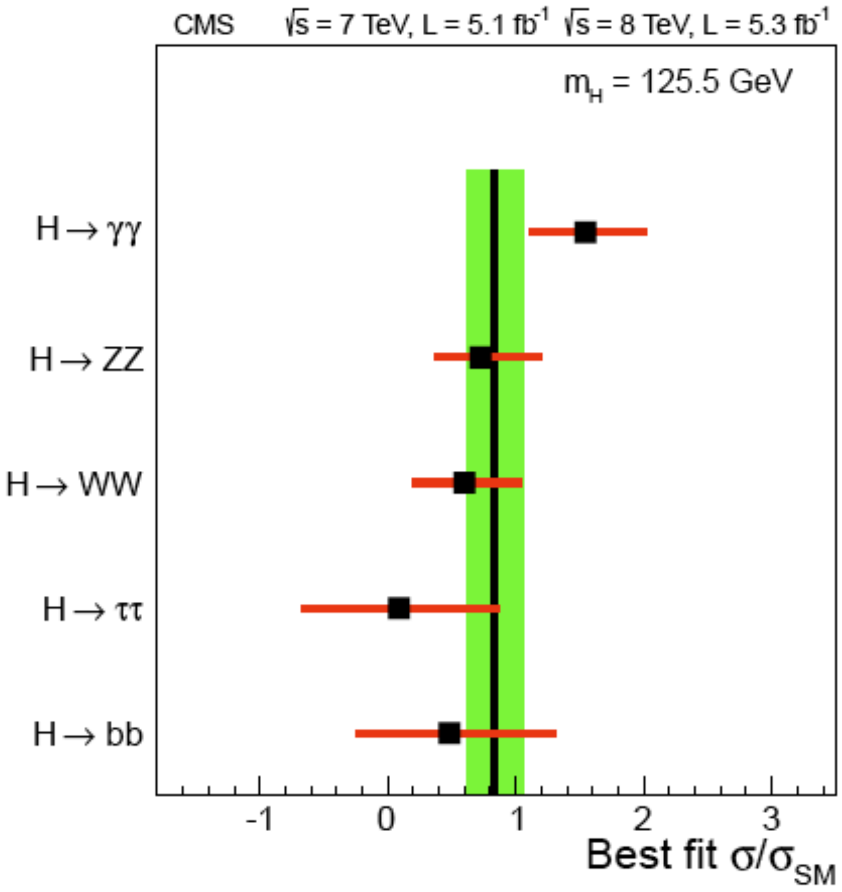
W/Z H , H→ bb

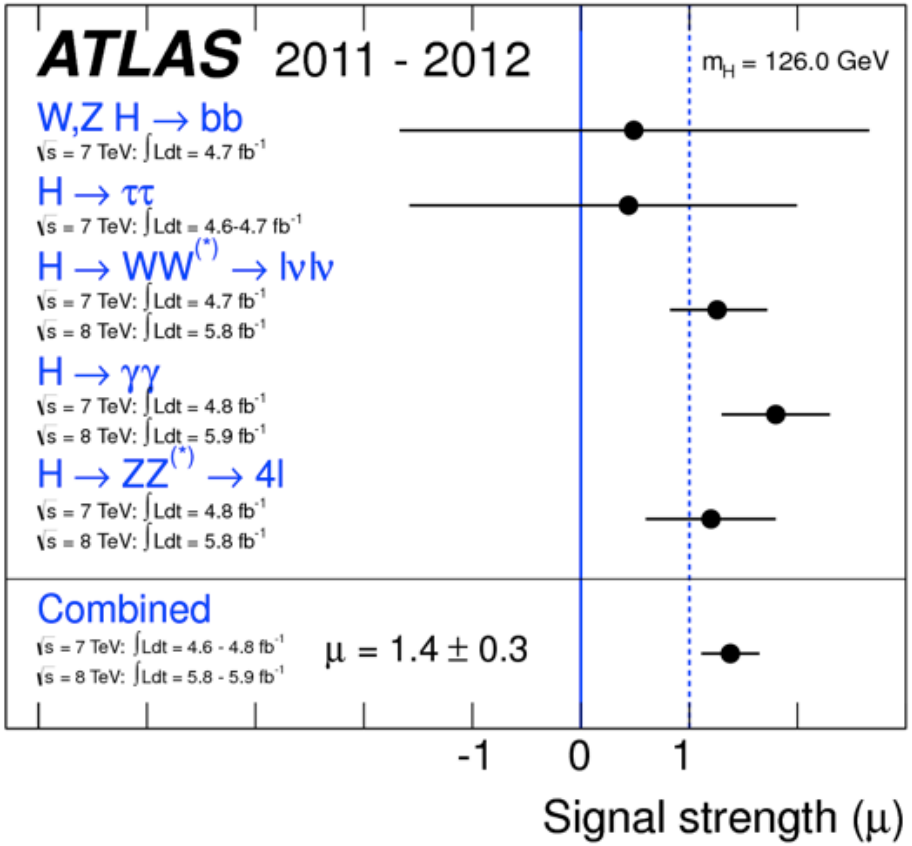
Signal:



- Would allow the direct measurement of the Higgs mass and Higgs to quark coupling
- *H→bb* dominant decay at low mass,
  but large background from W/Z+jets, and Top
- Three channels studied:
- Mass range: 110 – 130 GeV $ZH \to l^+l^-b\bar{b}, WH \to l\nu b\bar{b}, ZH \to \nu\bar{\nu}b\bar{b}$
- Expected exclusion is around 2.5 to 4.9 times the SM cross section

Signal strength got by channel

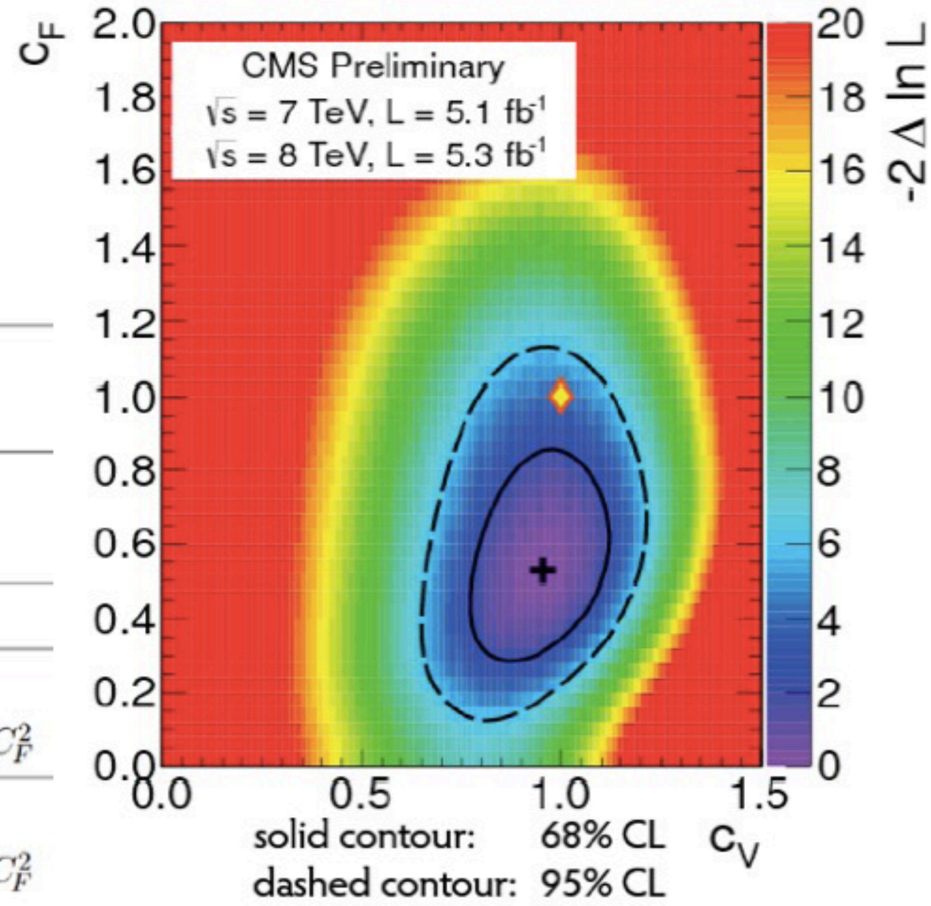




Testing couplings to fermion/boson

- Test compatibility by introducing two parameter (C_V, C_F)
- C_V and C_F modify expected signal yields in each mode through simple LO expressions

Production	Decay	LO SM	
VH	$H \to bb$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ttH	$H \to bb$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
VBF	$H \to \tau\tau$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to \tau\tau$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
ggH	$H \to ZZ$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to WW$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to WW$	$\sim \frac{C_V^2 \times C_V^2}{C_F^2}$	$\sim C_V^4/C_F^2$
ggH	$H \to \gamma\gamma$	$\sim \frac{C_F^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to \gamma\gamma$	$\sim \frac{C_V^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^4/C_F^2$



$H \rightarrow \tau^+\tau^-$

H + 0-jet		H + 1-jet	H + 2-jet VBF
(e/μ) separated no $p_T > 25$ GeV jet		(e/μ) separated ≥ 1jet, $p_T > 25$ GeV not VBF	(e⊕μ) combined 2jets, $p_T > 25$ GeV $\Delta\eta_{jj} > 3.0$ $m_{jj} > 300$ GeV
$E_T^{miss} < 20$ GeV	$E_T^{miss} > 20$ GeV	$E_T^{miss} > 20$ GeV	$E_T^{miss} > 20$ GeV

Signal region:

$$m_T = \sqrt{2 p_T^{\ell} E_T^{miss} (1 - \cos \Delta\phi)} < 30 \text{ GeV}$$

Modeling the backgrounds:

$$n_{OS}^{bkg} = n_{SS}^{all} + n_{OS-SS}^{W+jets} + n_{OS-SS}^{Z\rightarrow\tau\tau} + n_{OS-SS}^{other}$$

- n_{SS}^{all}: Multi-jet
- n_{OS-SS}^{W+jets}: Control region with $m_T > 50$ GeV
- $n_{OS-SS}^{Z\rightarrow\tau\tau}$: Embedded Sample
- n_{OS-SS}^{other}: Monte Carlo