NATIONAL & KAPODISTRIAN UNIVERSITY OF ATHENS

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On behalf of the ATLAS and CMS collaborations

Some SM Higgs results

European Union
European Social Fund

OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS
MANAGING AUTHORITY
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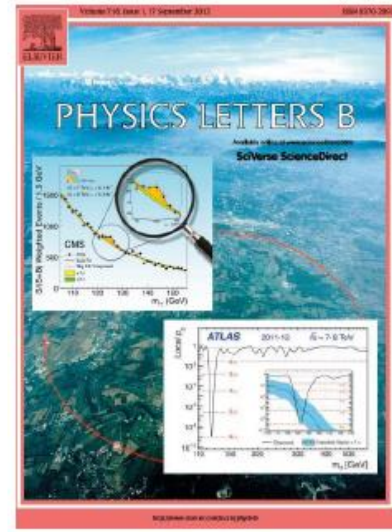
NSRF
2007-2013
programme for development
EUROPEAN SOCIAL FUND

The Higgs "history" so far..

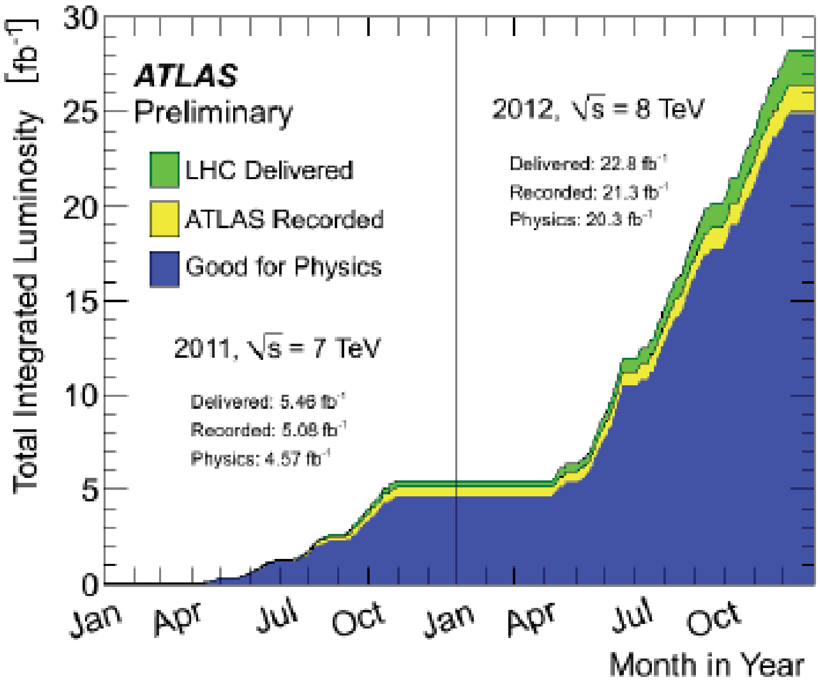
- 4th July 2012 ->ATLAS/CMS announced the discovery of a Higgs "like" particle with m~125.5 GeV (5.0 σ->5.9 σ ATLAS, 5.0 σ CMS)
- Discovery with "clean" bosonic modes (H->γγ, H->ZZ*, H->WW*)

  Easy means low BR, BUT relatively **clean signature** combined with **excellent** detector capabilities
- Sept 2012 relevant papers published in Phys.Lett. B 716
- Winter 2013 conferences: properties measured (spin, CP, rates)

  -> CERN drops "like" from Higgs "like"
- November 2013 : ATLAS/CMS observe direct evidence for fermionic decay modes
- December 2013: Nobel prize to Englert and Higgs
- Moriond 2014 : CMS sets constraint on Higgs width Γ<17MeV
- More detailed results with full data sets ->papers/talks in summer conferences
- Busy with preparations for Run II



Run I finished long ago..



- **Run I** -> Both experiments have recorded ~ **26 fb^{-1} of data**
- Both experiments run extremely well and efficiently

$\sqrt{8}$

(with excellent detector understanding)

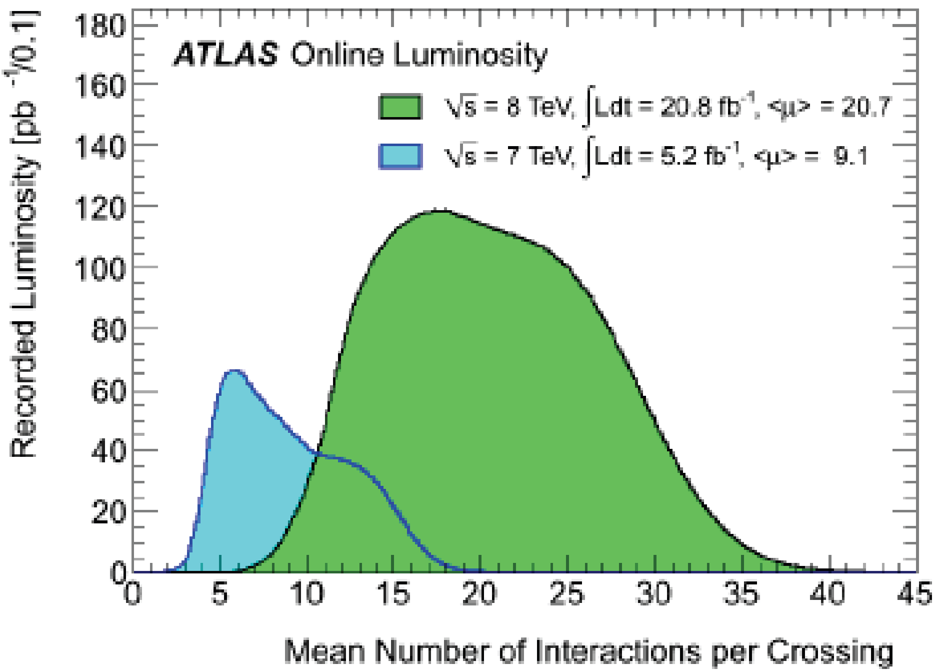
- 95% (90%) of recorded (delivered) luminosity was good for physics analysis⁻

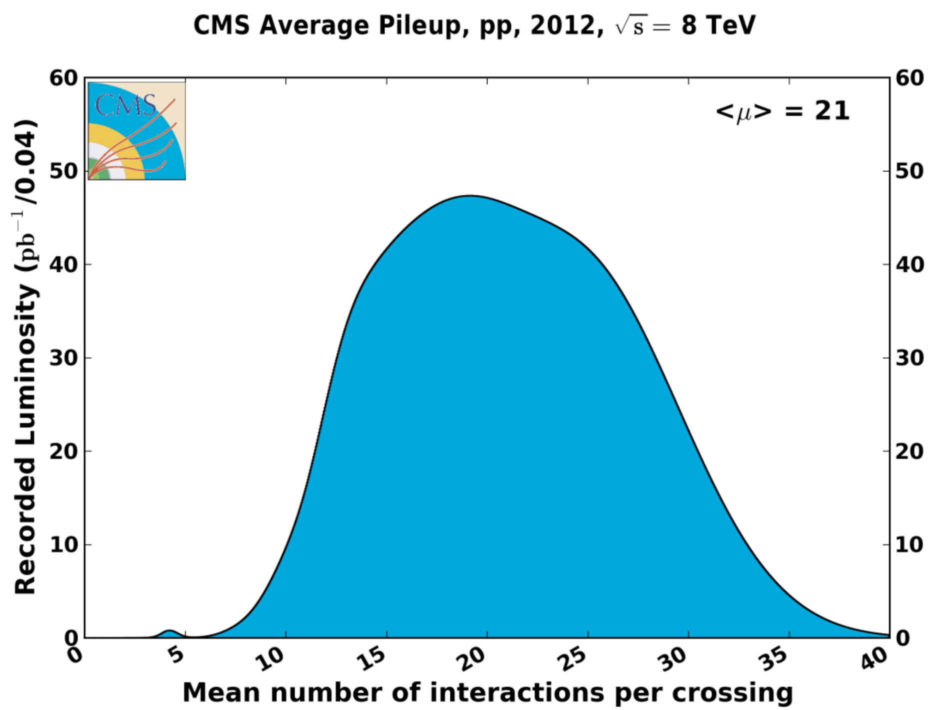
$$\sqrt{s} = 7\,\text{TeV} \sim 5\,fb^{-1} \text{ and } \sqrt{s} = 8\,\text{TeV} \sim 21\,fb^{-1}$$

Harsh data taking conditions

<21> interactions/per beam crossing

(pile-up higher than design one)





Run II to start in 7 months….

Overview

Focus: Observation, production, decay modes

Subjects which will NOT be covered

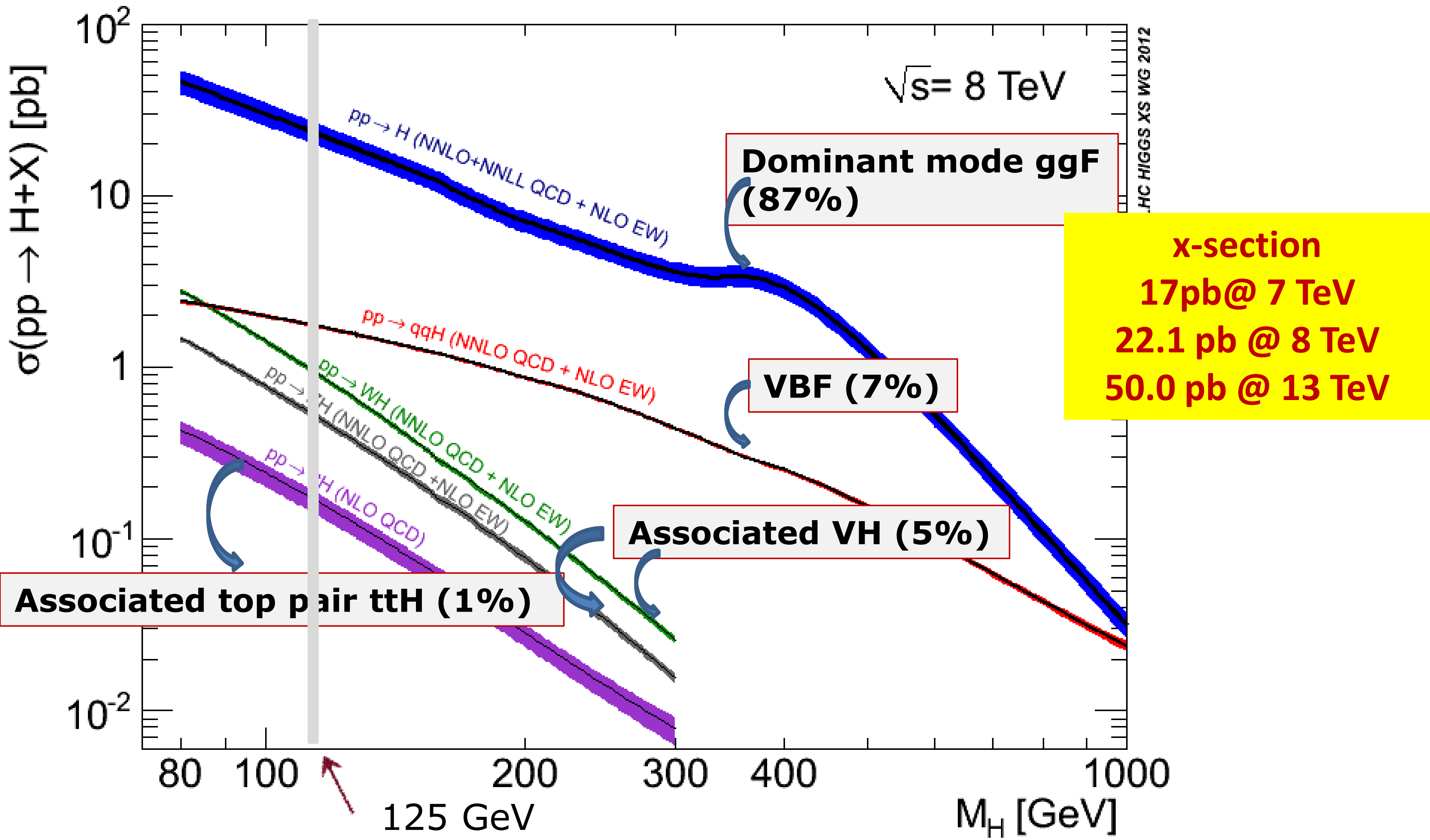
- **Mass (combinations)**
- **Properties (width/spin/CP)**
- **Higgs beyond SM (2HDM etc)**
- **Invisible decays**

Large spectrum of results 15+15 talks in Higgs parallel session of ICHEP 2014

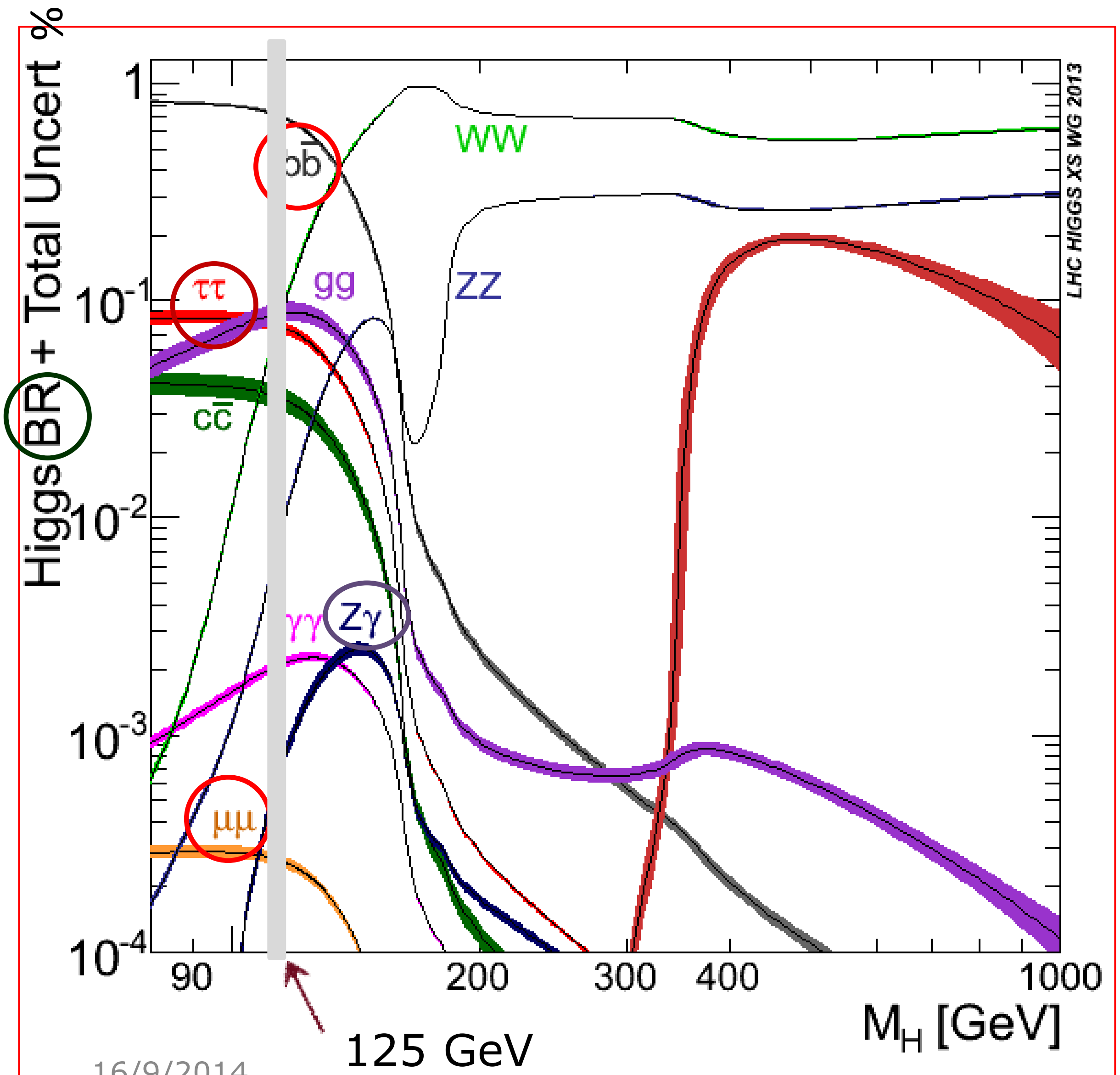
As an introduction..

Since I have the privilege to be the first speaker

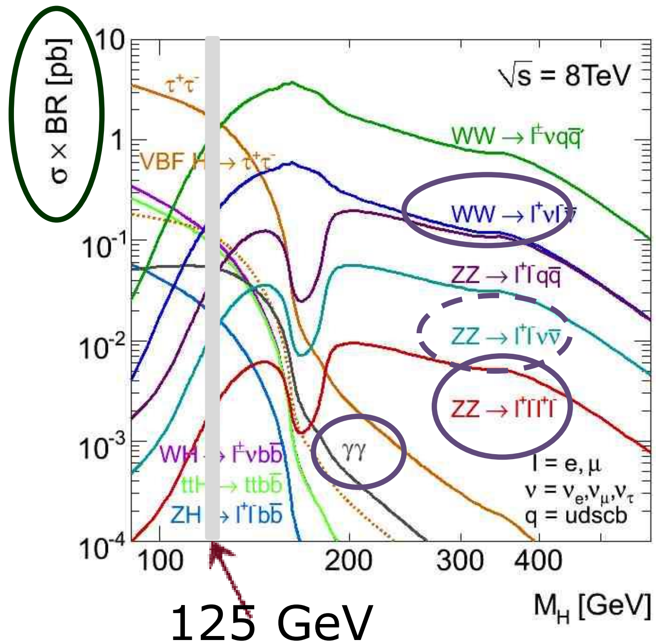
Higgs production modes (x-section)



Higgs Decay modes



Bosonic decays
ZZ*, γγ, WW*, Zγ

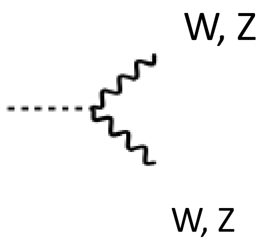


Fermionic decays
ττ, bbar, μμ

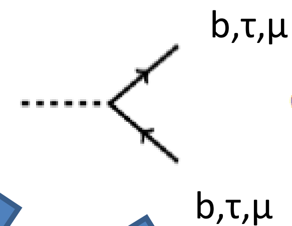
Higgs Decay modes

Bosonic couplings

Fermionic couplings



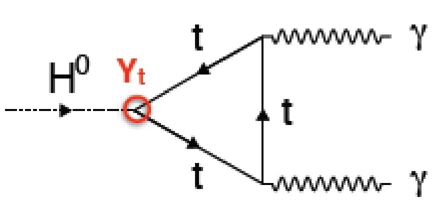
$\propto \frac{m_V^2}{v}$

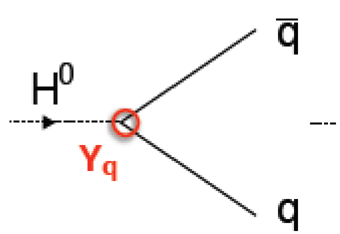


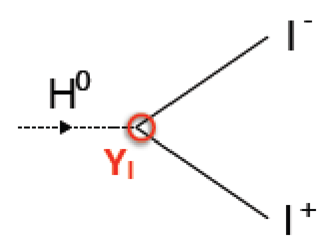
$\propto \frac{m_f}{v}$

Higgs-quark coupling:
Strong INDIRECT evidence for coupling to up-type quarks (and top) from H->γγ and ggF agreement to SM
But need **direct** measurement of Y_t, Y_b

Higgs-lepton coupling
Direct measurement of Y_μ, Y_τ







New results (since spring 2014)

- H->4l +γγ couplings (very recent)
- H->μμ
- V(H->bb)
- x-section H->γγ and H->4l
- ttH(->bb+γγ)
- o Combined mass measurement
- o Off-shell width from H->4l
- o High mass search H->γγ

- H->4l+H->γγ
- Fermionic coupling ττ+bb
- VH associated production (all)
- o Off-shell width from H->4l
- o Higgs combination
- o High mass search H->γγ
- o H->γγ*->μμγ
- o High mass search H->WW->lνjj
- o H->τμ

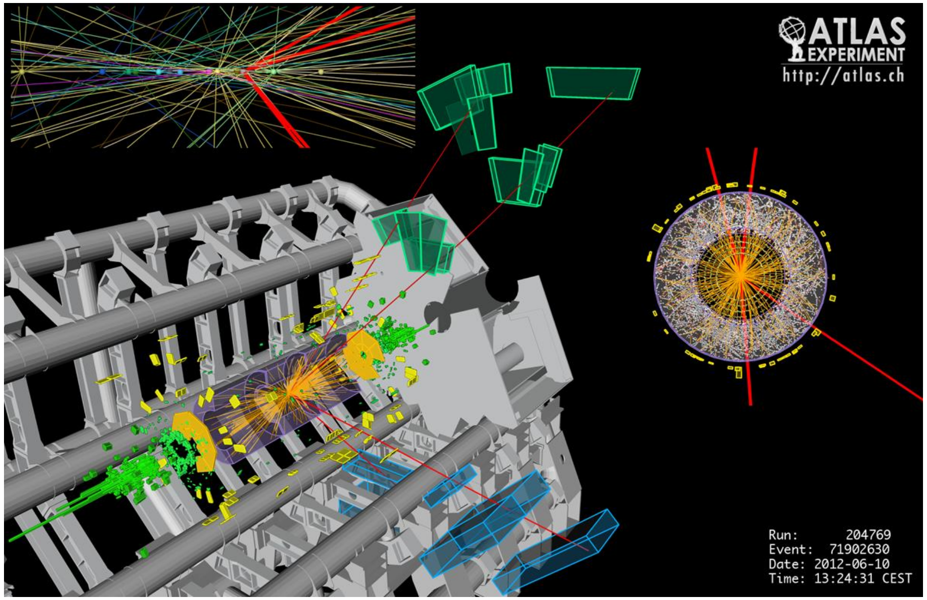
Both experiments have very recently recalibrated their electromagnetic and muon energy scales with J/ψ, Y and Z (+Z->llγ) to per mil accuracy
*-> **systematics reduced and resolutions improved***

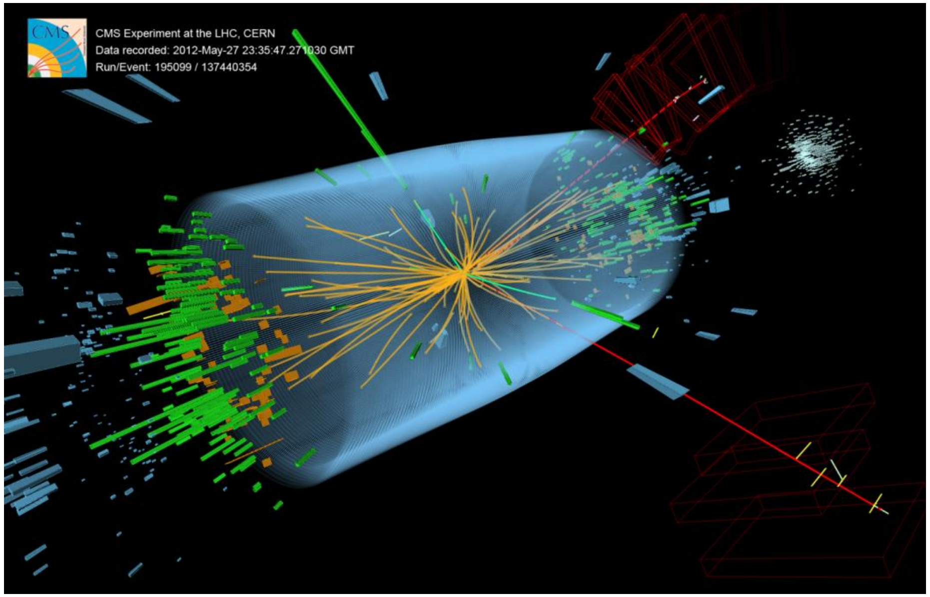
Bosonic decay modes

The tool for discovery at first
and measurement of properties (later)

H->ZZ*->4l

- “Golden” channel (7+8 TeV data)
- Four isolated leptons from primary vertex
- Small rate σ*BR ~2.5fb **BUT** fully reconstructed mass **(S/B ~1-1.9)**
- Ideal to study mass, spin, CP, couplings, width





Candidate H->4μ

Candidate H->2e+2μ

H->ZZ*->4l

Bkg-> irreducible: ZZ*, reducible: Z+jets, Zbb,ttbar

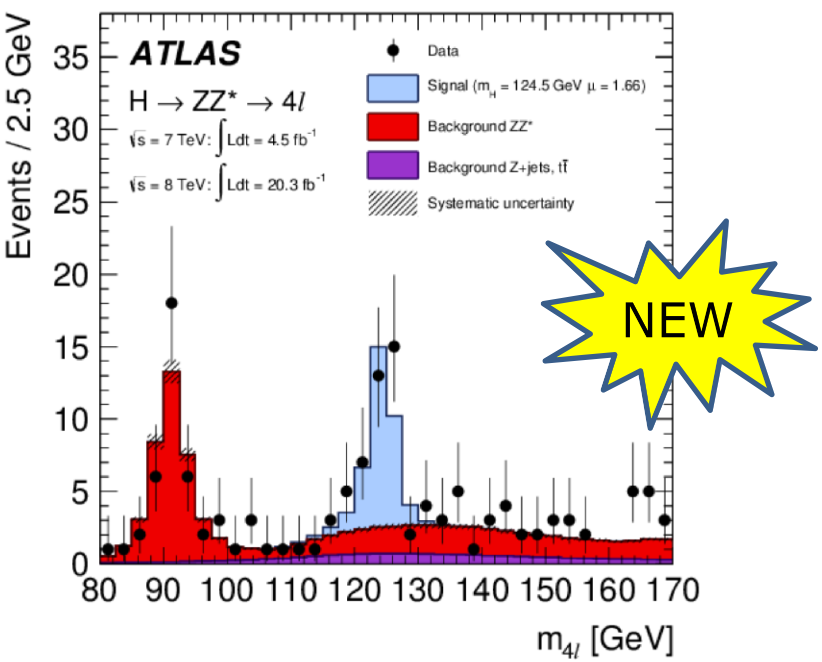
Irreducible bkg->MC based calculation
Reducible ->date driven CR's

New em MVA calibration, muon momentum scale ->improve systematics
Electron id cut based->likelihood
New BDT's to separate ZZ* bkg from signal and for production mechanism, Z mass constraint

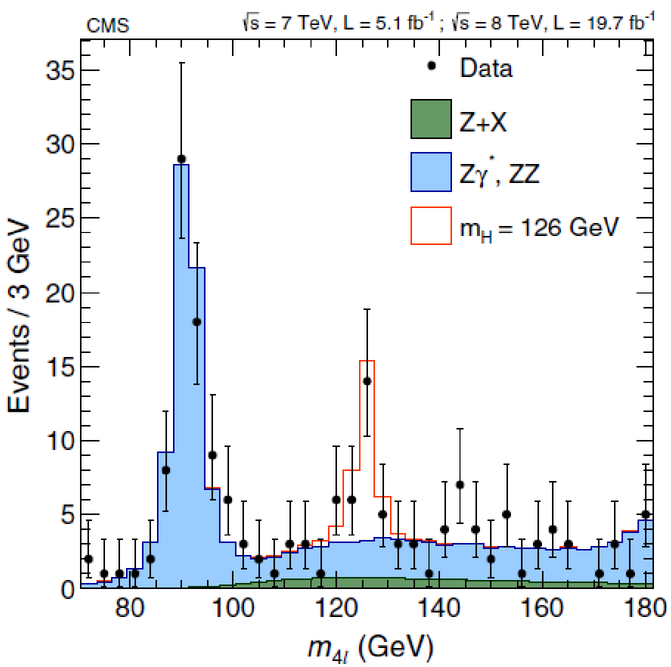
Irreducible bkg->MC based calculation
Reducible -> Two methods (OS+SS) using CR's

New alignment and calibration
new discriminant using m_{Z1},m_{Z2} and 5 angles

Twelve categories (two to distinguish production mechanisms ggF/VBF 0/1 jet,2jets)
3D likelihood used with discriminant quantities



PRD 90 (2014) 052004



PRD 89 (2014) 092007

H->ZZ*->4l (4e,4μ,2μ2e)

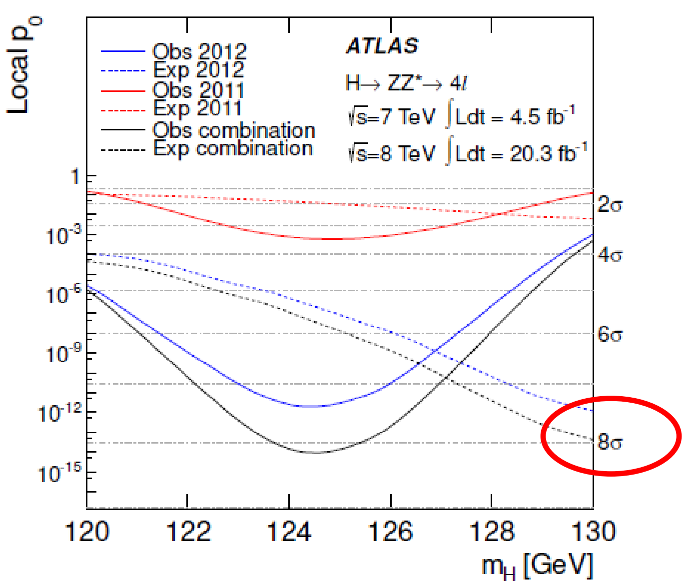
To measure mass 1D fit-> 2Dfit(m_{4l}, BDT)
Fit four categories according to lepton final state
2-10 reduction of uncertainties due to energy scale

m=124.51±0.52(stat)±0.06(sys)

NEW

8.1 σ (6.2)*@**125.36 GeV comb**

$$\mu = 1.44\ ^{+0.34}_{-0.31}\ (\text{stat})\ ^{+0.21}_{-0.11}\ (\text{syst})$$ @comb mass



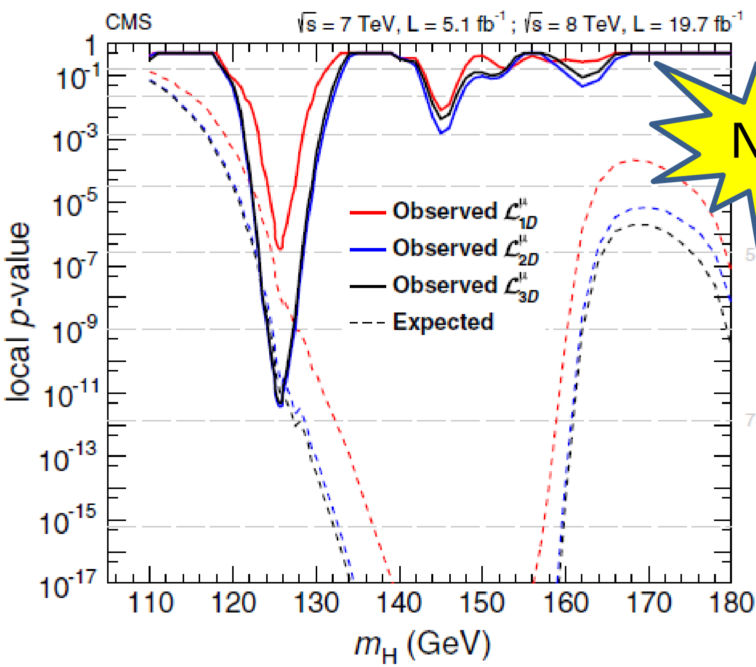
arXiv: 1408.5191 (Submitted to PRD)

Event-by-event uncertainty for mass and relative resolution used in Matrix Element

m=125.6±0.4(stat)±0.2(syst)

6.8 σ (6.7)@125.7 GeV (@min p_0)

$$\mu = 0.93^{+0.26}_{-0.23}(stat)^{+0.13}_{-0.09}(syst)$$ @125.6 GeV



NEW

CMS- HIG-13-02,PRD 89 (2014) 092007

*number in parenthesis are everywhere the SM expectations

Cross section measurement (H->ZZ->4l)

ATLAS standard analysis methods in signal bins, only $\sqrt{s} = 8$ TeV

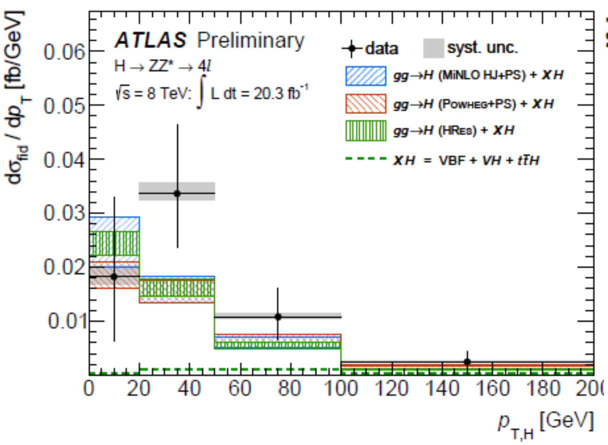
Use fiducial regions to minimize model dependence and acceptance corrections

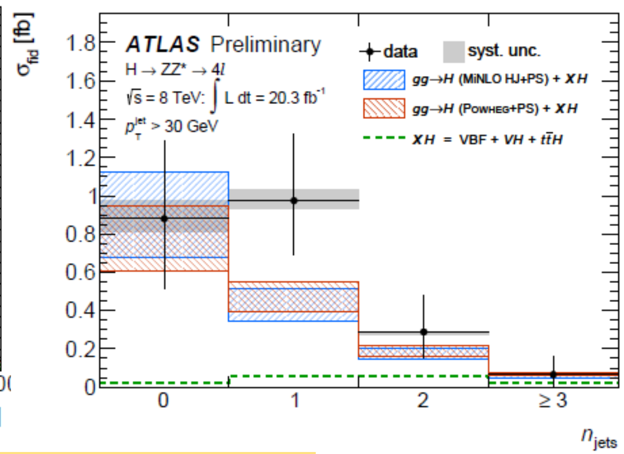
Cut and count method for differential x-section +corrections for detector effects

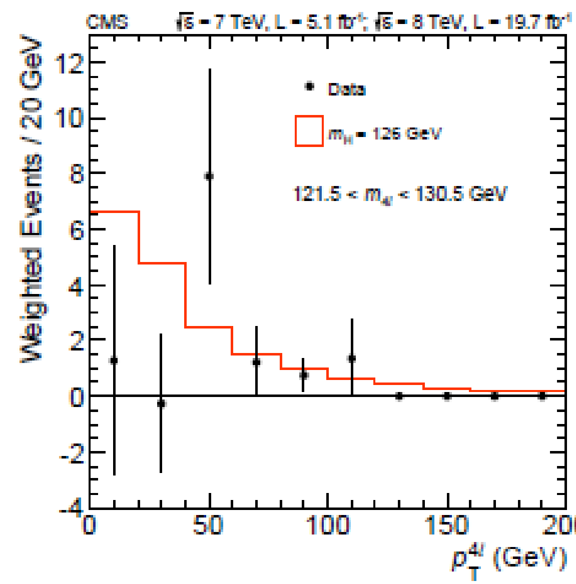
->use different variables of Higgs production and decay: p_T^H, y^H, N_{jets} etc and then compare unfolded distributions to several generators; bin-by-bin unfolding

Probe kinematics of Higgs

Probe jet activity of Higgs







No significant deviation wrt SM observed

$$\sigma^{\mathrm{fid}}_{\mathrm{tot}} = 2.11^{+0.53}_{-0.47}(\mathrm{stat})^{+0.08}_{-0.08}(\mathrm{syst})\ \mathrm{fb}.$$

SM:(1.30±0.13 fb)

arXiv: 1213.5353

Baseline theory: arXiV:1307.1347

arXiv:1408.3226

H->γγ

Signal-> two high P_T isolated photons

σ*BR~ 44 fb ->need excellent detector performance since **S/B~3%**

BR~0.2% but clean $m_{\gamma\gamma}$ peak which sits on top of γγ continuum background (irreducible)~80%

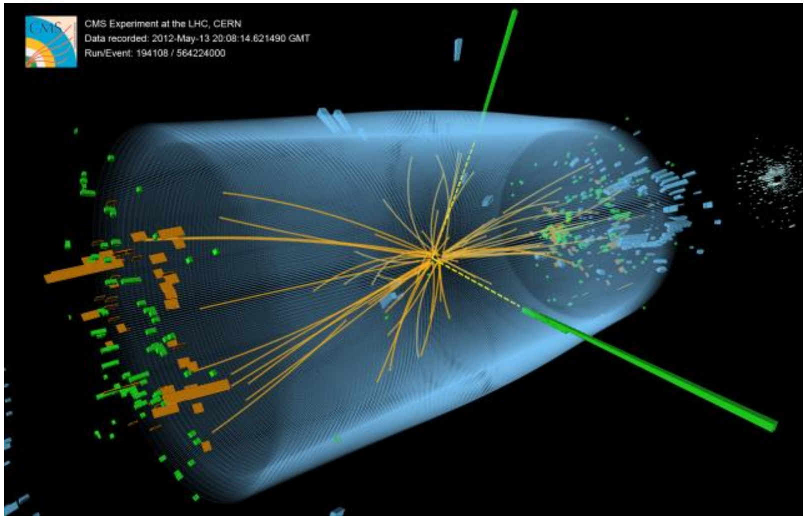
Reducible background is γ-jet, jet-jet (20%)

NEW

Both experiments have improved:

- Their analysis methods
- Their calorimeter calibration and cluster definition
- Their uncertainty calculations

Main systematics from energy scales



Candidate H->γγ

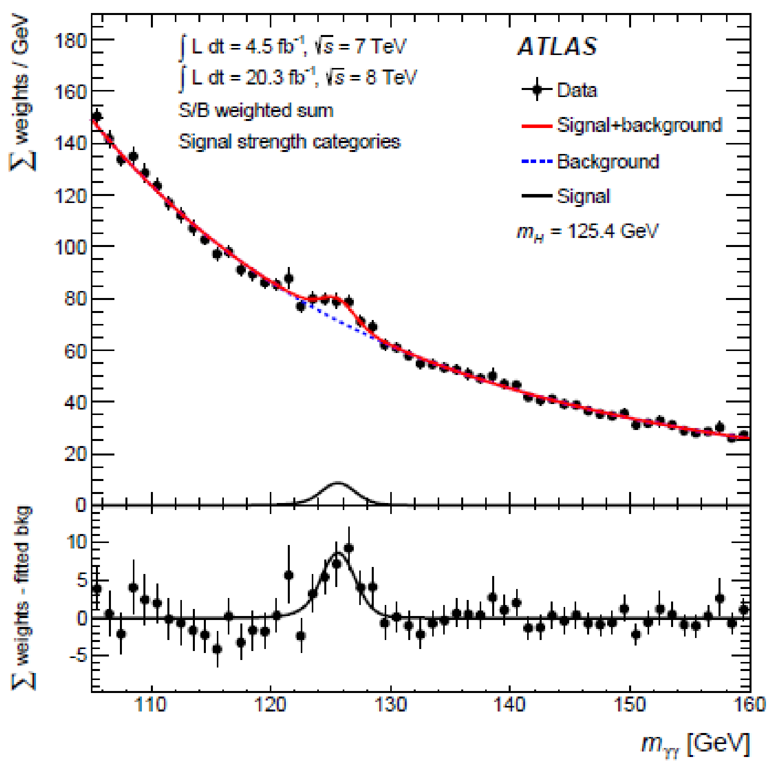
H->γγ

NEW

NEW

ATLAS cut based (ggF, VBF,VH,ttH)
12 categories according
to γ conversion, η, p_T and production mode
Signal+bkg modelling with analytical functions

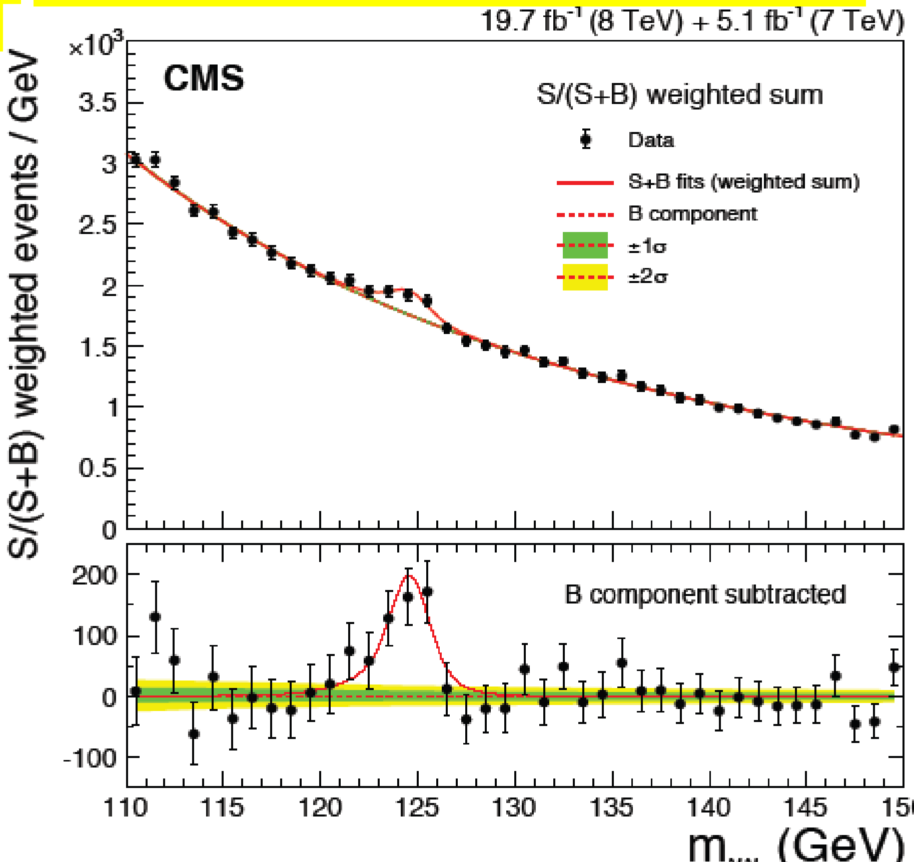
New γ, e energy and longitudinal calo calibration



arXiv:1408.7084 submitted to Phys.Rev.D

Final 25 event categories according to production, etc
Signal->simultaneous fit to categories, bkg->fit to data
Main analysis BDT for γ id, shower shape, iso, energy ρ
BDT to reconstruct diphoton vertex, MVA classification

New bkg modelling,New event selection



arXiv: 1407.0558 Submitted to EPJC

H->γγ

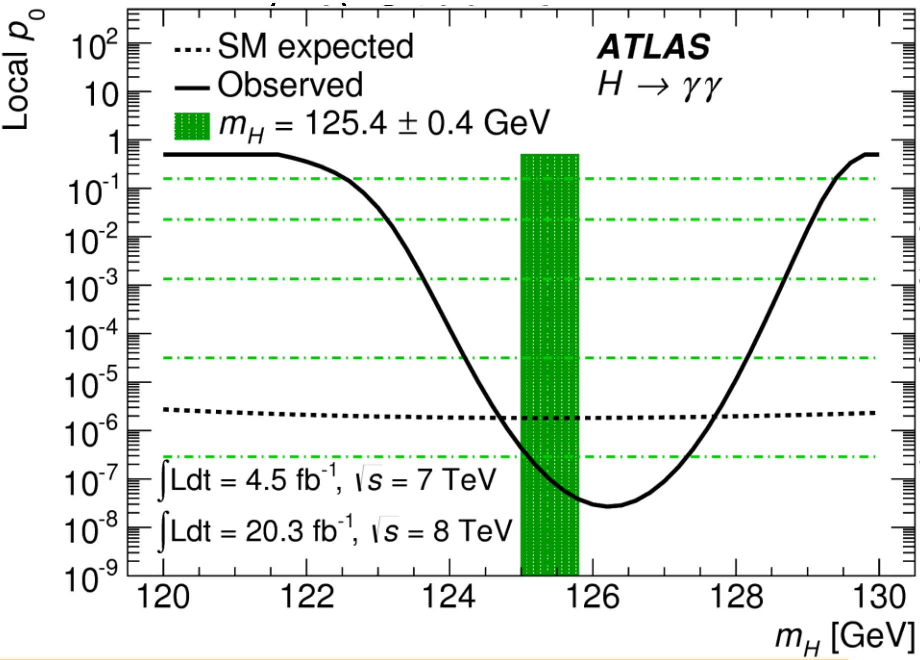
NEW

Mass resolution improved 10%
systematics reduced by a factor of two
statistics increased due to μ

m=125.98±0.42(stat)±0.28(sys) GeV

PRD 90 (2014) 052004

Main uncertainty ±0.22% due mainly to photon energy scale



μ=1.17±0.27 @combined mass

arXiv:1408.7084

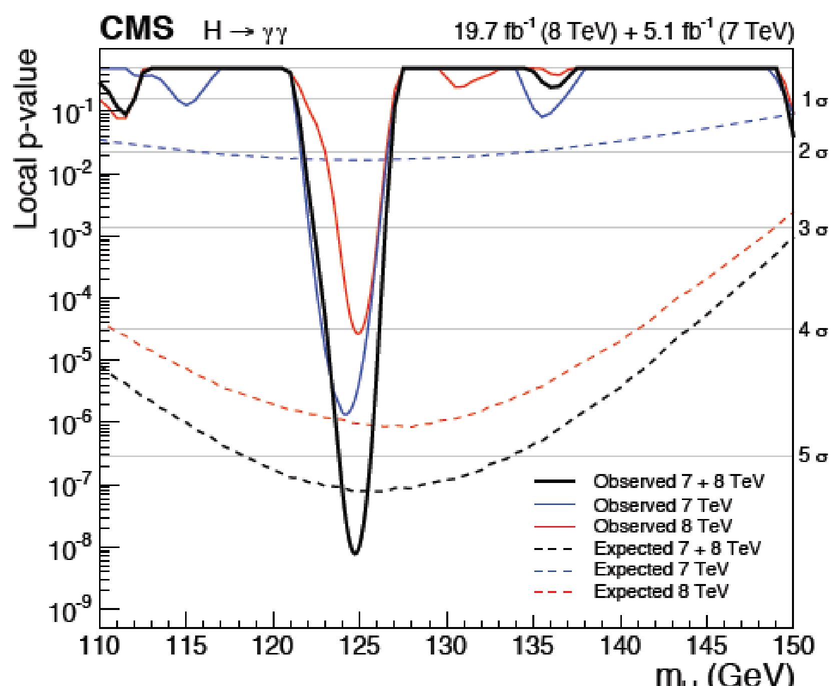
NEW

MVA using event-by-event estimator of resolution and kinematic info

m=124.70±0.31(stat)±0.15(sys) GeV

5.7 σ (5.2) @124.7 GeV
Main uncertainty e-γ difference, energy scale linearity

$$\sigma/\sigma_{SM} = 1.14^{+0.26}_{-0.23}\left[\pm0.21(\text{stat.})^{+0.13}_{-0.09}(\text{theo.})^{+0.09}_{-0.05}(\text{syst.})\right]$$



arXiv: 1407.0558 Submitted to EPJC

Cross section measurement (H->γγ)

Standard analysis methods in signal bins, only $\sqrt{s} = 8\,\text{TeV}$

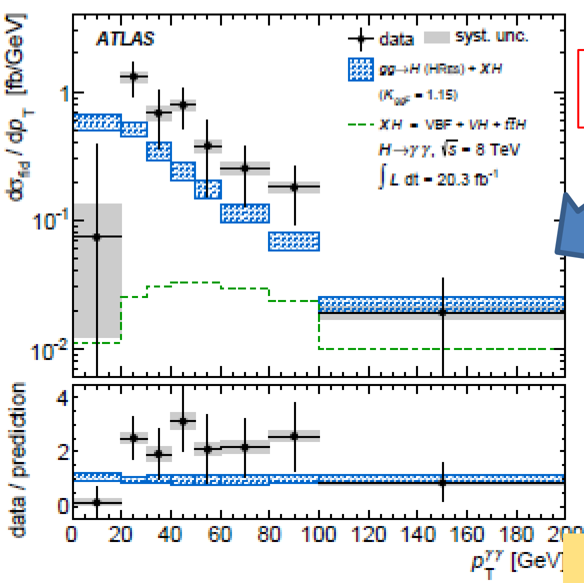
7 fiducial regions defined

Differential x-section fitting $m_{\gamma\gamma}$ in each bin (unbinned maximum likelihood)

+corrections for detector effects -> use 12 different variables p_T^H, y^H, N_{jets} etc

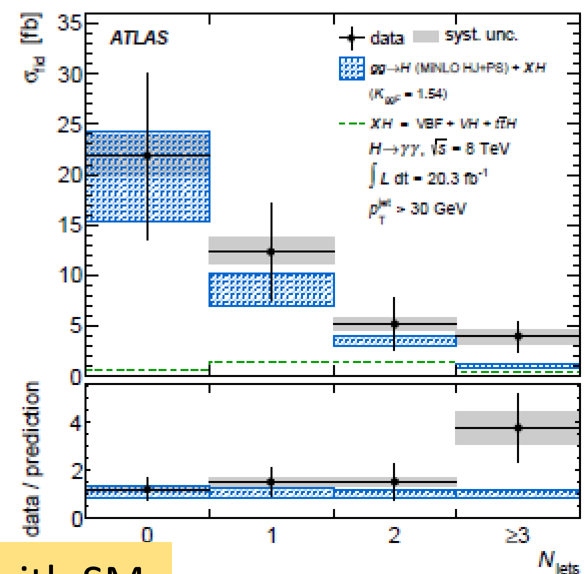
Comparison of unfolded distributions to several generators

Bin-by-bin unfolding(corrections for acceptance, efficiency and resolution)



Probe kinematics of Higgs

Probe jet activity of Higgs



Data in agreement (@1σ level) with SM

$$\sigma^{fid} = 43.2 \pm 9.4\,(\text{stat.})\,^{+3.2}_{-2.9}\,(\text{syst.}) \pm 1.2\,(\text{lumi})\ \text{fb}$$

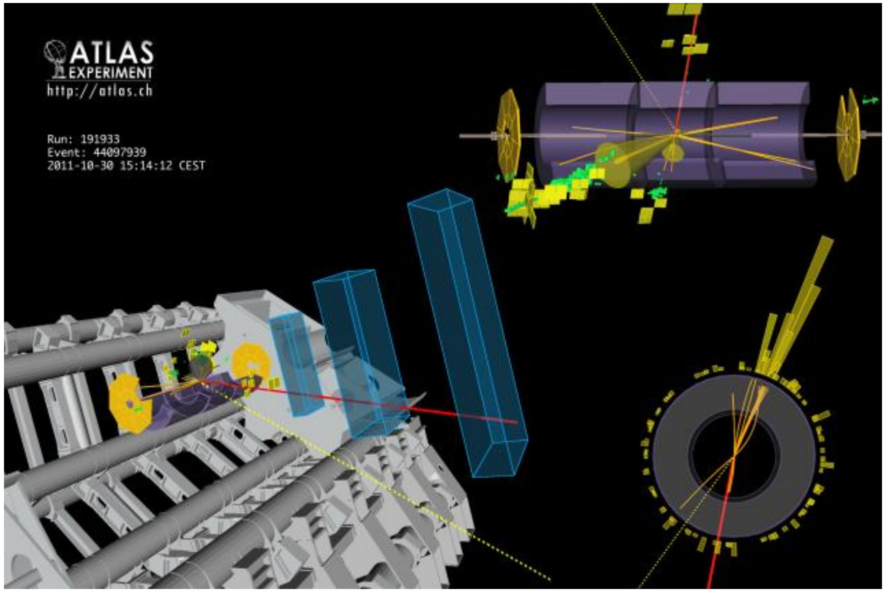
SM:(30.5±3.3 fb)

arXiV:1407.4222

Baseline theory: arXiV:1307.1347

H->WW->ll+νν

Leptonic decays of W's (2 isolated high p_T opposite sign leptons + 2ν's=E_T^{miss})
->no clear mass peak
Look for excess in m_T distribution
σ*BR~200fb, **BR~22%** (second largest after H->bbar), S/B~0.1-0.4
main (irreducible) bkg WW(*), reducible: single top, ttbar, W/Z+jets, Drell-Yan, dibosons, W+γ
Background estimate from $M_{ll} \neq Z$ Control regions and extrapolated to Signal Regions

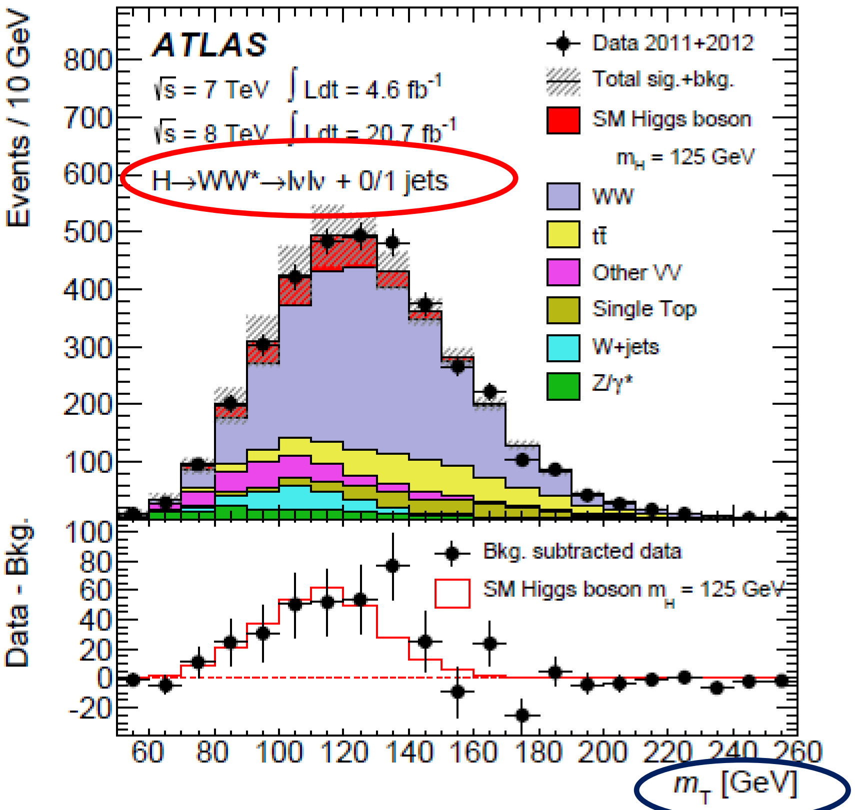


Candidate H->WW->lνlν

H->WW->lνlν

Cut based, 1D fit on discriminant variable m_T.
categories based on #of jets (0,1 jet=ggF, 2 jets=VBF) and flavor of leptons, m_{ll}
Dominant uncertainty from QCD scale

Categories: flavor, #of jets
2D analysis m_{ll} and m_T
2l2ν +0/1 jet ggF, 2l2ν +2 jets VBF/VH
WH->3l3ν+2 jets, **ZH**->3lν+2jets
Dominant uncertainty theory



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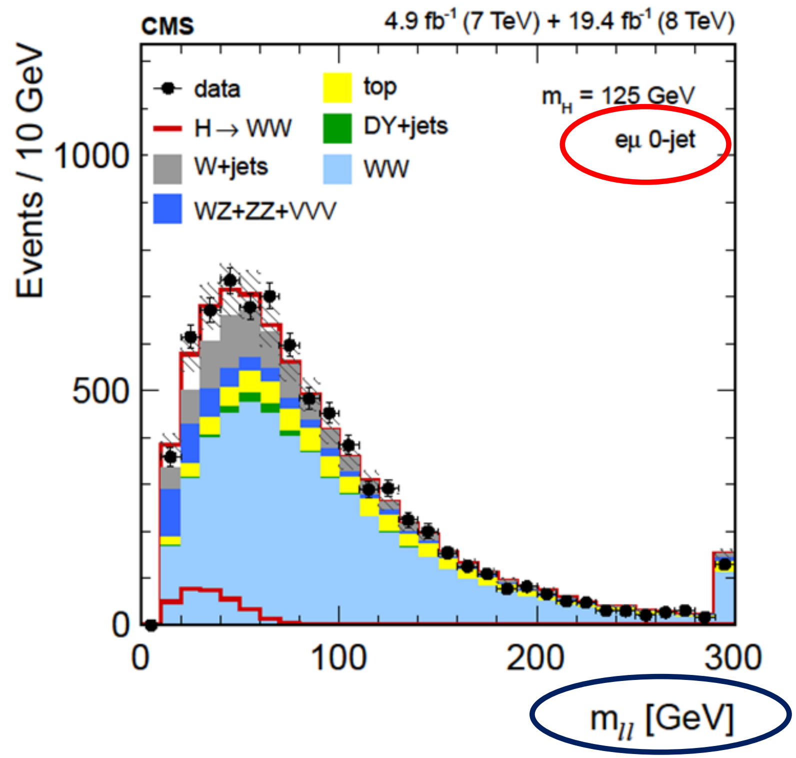


JHEP 01(2014)096

H->WW->lνlν

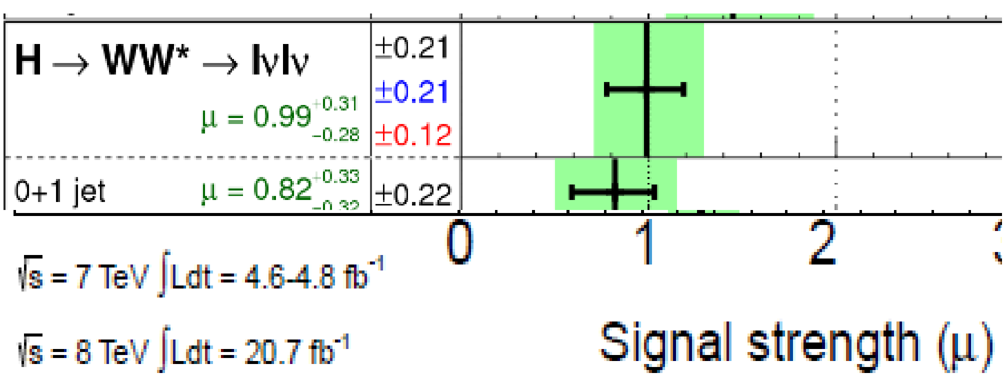
CMS includes VH, ATLAS has a separate search (ATLAS-CONF-2013-075)

4.0 σ(3.8) @125 GeV **if VH is added**

4.3 σ(5.8) @125.6 GeV

$$\mu_{\text{obs}} = 1.01 \pm 0.21\,(\text{stat.}) \pm 0.19\,(\text{theo. syst.}) \pm 0.12\,(\text{expt. syst.}) \pm 0.04\,(\text{lumi.})$$

$$0.72^{+0.20}_{-0.18} = 0.72^{+0.12}_{-0.12}\,(\text{stat.})^{+0.12}_{-0.10}\,(\text{th. syst.})^{+0.10}_{-0.10}\,(\text{exp. syst}$$



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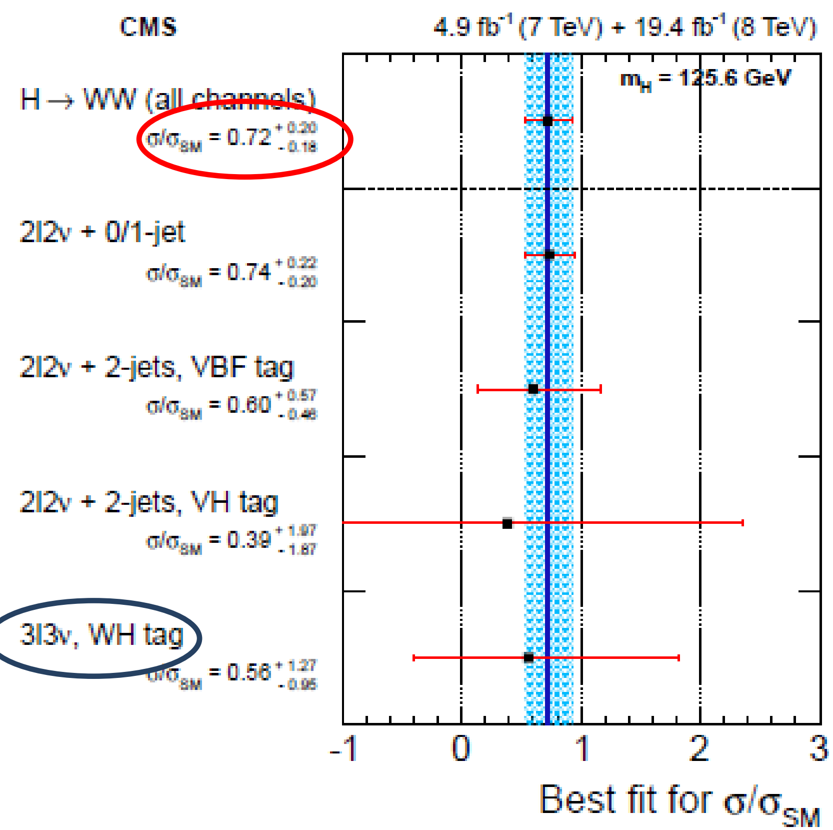


JHEP 01(2014)096

H->Zγ

Note: Rare decay BUT goes through loops ->sensitive to new physics

σ*BR~2 fb, **BR~2*10^{-3}** (similar to H->γγ), S/B~1% low BR and high bkg

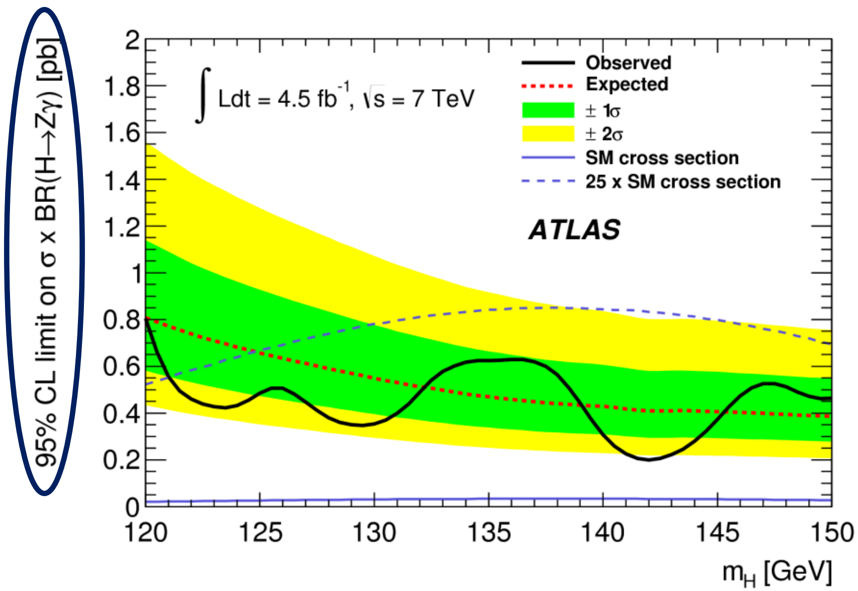
Irreducible bkg= Z+γ continuum(82%), Z+γ radiation, Z+jets (17%)

H->llγ cross-section~ H-> 4l cross-section but 5% of H->γγ

Signal two OSSF isolated leptons close to the Z mass + isolated high p_T photon

No excess in 120-150 GeV mass range, M_{ll}>80 GeV

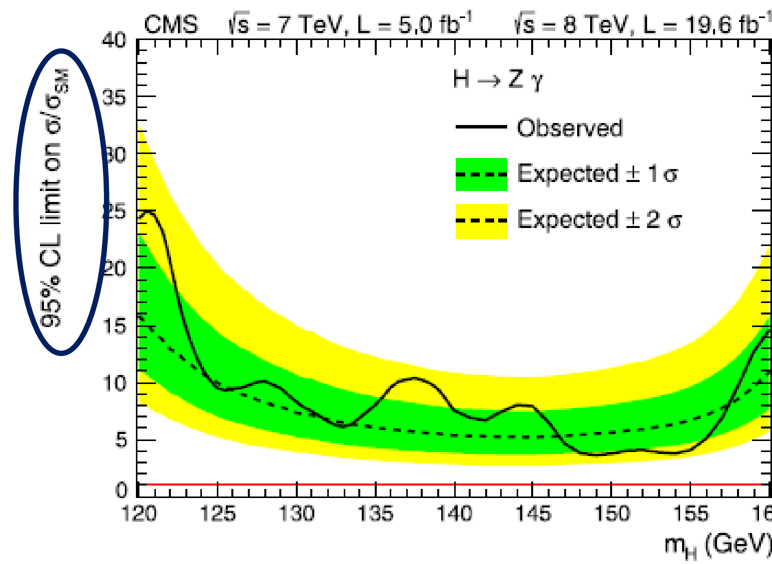
Limit/SM @95% CL->**11** (9) @125.5 GeV



Phys. Lett.732C, (2014) 8

No excess in 120-160 GeV mass range.M_{ll}>50 GeV

Limit/SM @95% CL-> **9.5** (10) @125GeV



Phys.Lett. B726 (2013) 587

Statistically limited

Fermionic decay modes

The “hard” ones:

H->ττ

H-> μμ (ee)

VH(H->bbar)

ttH(H->γγ/bbar+more)

t->qH(H->γγ)

Higgs Production/Decay modes

Some remarks on fermionic couplings:

- H->ttbar not kinematically allowed for m_H=125 GeV (probed by production ttH)
- ttH important for direct measurement of top Yukawa coupling to Higgs **(expect Y_t~1 from SM)**
- H->bbar BR~58% BUT huge QCD bkg (B/S~ 10^7)
- VH and ttH production important for H->bbar measurement
- VH(bbar) important for down type quark coupling measurement
- VBF signature (two forward jets) important for H->ττ measurement
- H->μμ and H-> ee highly suppressed
- **Combine as many decay channels as possible**

channel	σxB.R [pb]
$H\to\tau\tau$	~1.3
$VH\to b\bar{b}$	~0.1
$t\bar{t}H\to b\bar{b}$	~0.07
$H\to\mu\mu$	~0.0002

H->ττ

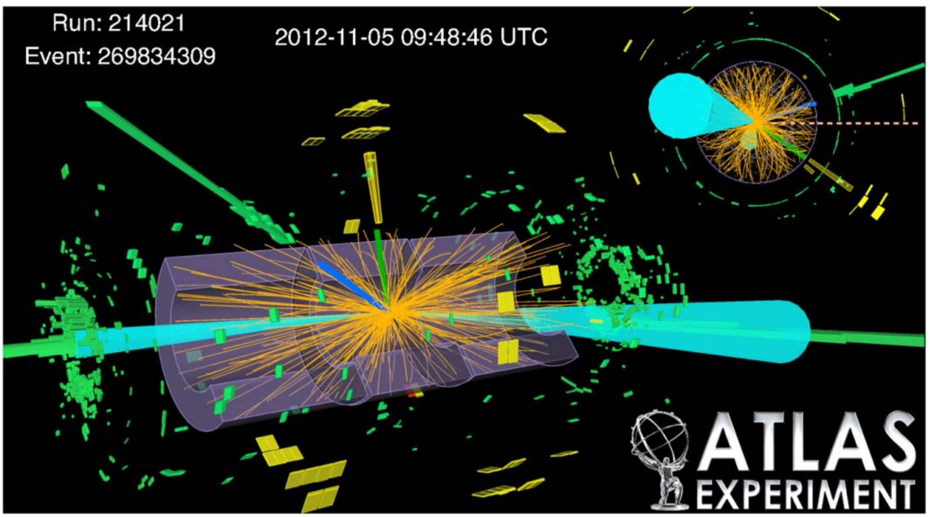
First evidence for the Higgs fermionic decay : hot news at end 2013!!

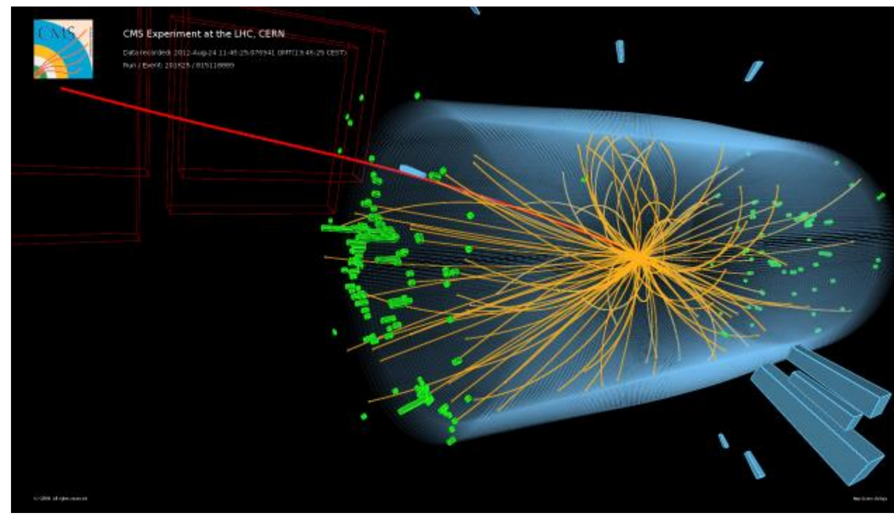
Relative large **BR=6.2%** , σ*BR~1.3 pb

IMPORTANT to confirm that couplings are proportional to $m_{fermion}$

Complimentary to H->bb for **down-type fermion couplings**

Main bkg Z->ττ (data driven from "embedded" Z->μμ), Z->ll (from MC and normalized to data)
+"fakes"+"other" ->mostly data-driven (QCD, W+jets, WW, WZ, ZZ, ttbar, single t)





Three (all) possible decay modes investigated

H->$\tau\tau_{leplep}$ (12%) small BR but very clean 2 OS leptons: μτ,μμ,ττ,τe,ee,eμ

H->$\tau\tau_{hadlep}$ (46%) clean 1 lepton+1 τ_{hadron}

H->$\tau\tau_{had,had}$(42%) high multiplicity jets, 2OS $\tau_{hadrons}$+no e/μ (hard reco)

Challenge: $m_{\tau\tau}$ ->separate Z from H

H->ττ

All possible production modes investigated ggF , VBF, VH, ttH

Event categorization by production channels and kinematics, $m_{\tau\tau}$ using missing mass calculation, ν's missing

Multivariate analysis with BDT (6-9 variables $m_{\tau\tau}$,$DR_{\tau\tau}$ etc) to separate signal from bkg

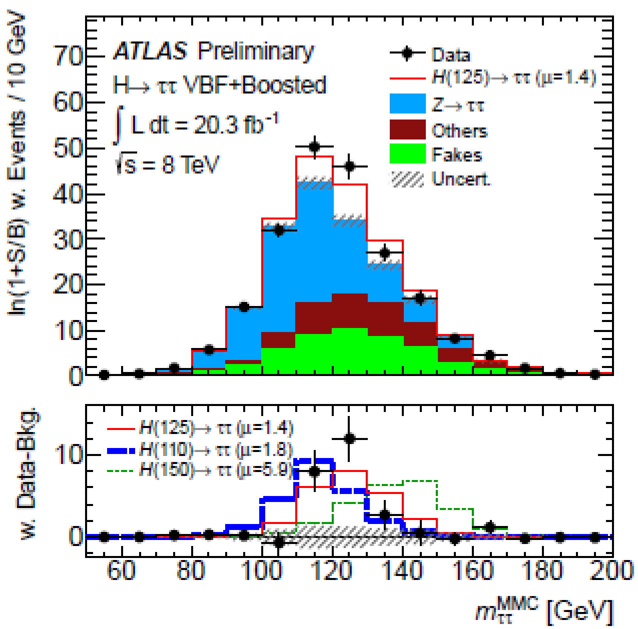
VBF+ggF "boosted" $p_T(H)$>100 GeV

Only 8 TeV, all categories

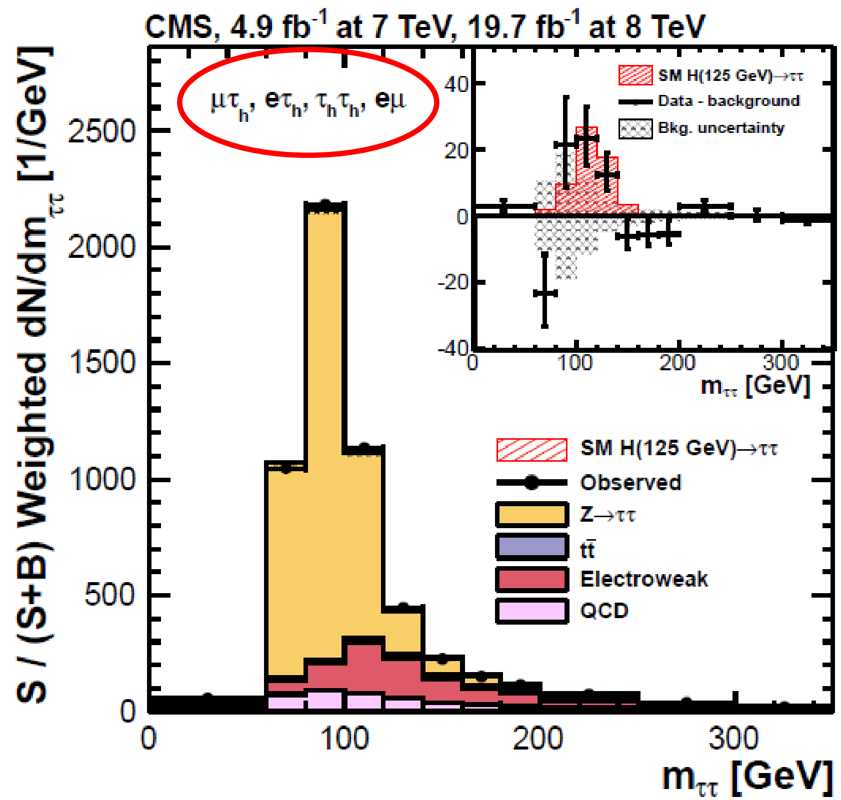
Both $\sqrt{s}$ energies, 1jet=ggF,2jet=VBF, 2jets+leptons=VH

Categories #of jets, final states, p_T, MVA for ee,μμ

weighted events by S/(S+B) in each category



ATLAS-CONF-2013-108



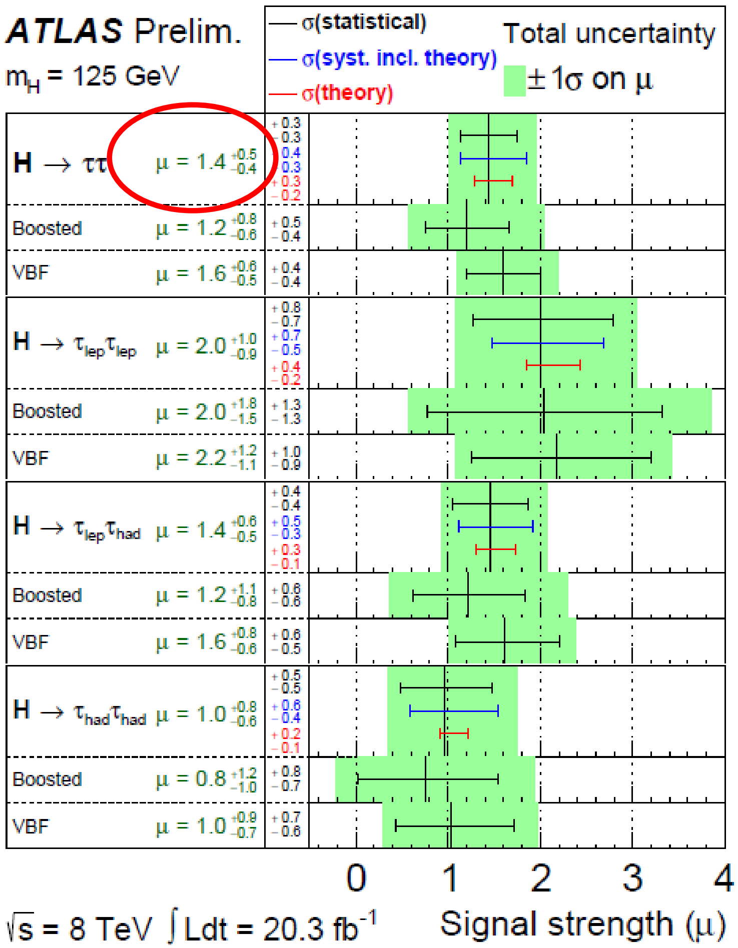
CMS-HIG-013-004, JHEP 05(2014) 104

H->ττ

Excess in all three channels

4.1(3.2)**σ**@125 GeV

$\mu = 1.43^{+0.31}_{-0.29}(\text{stat.})^{+0.41}_{-0.30}(\text{syst.})$ @125 GeV

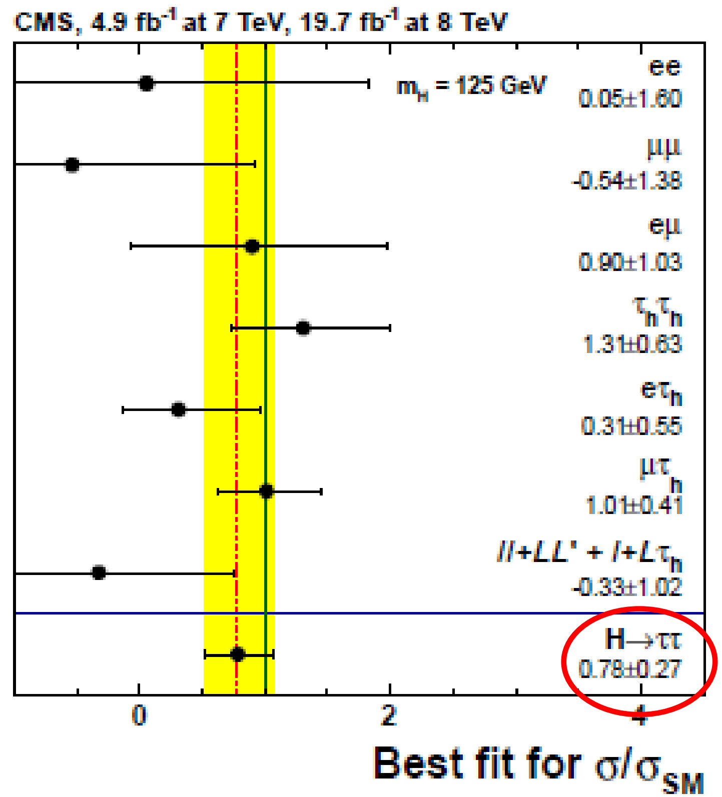


ATLAS-CONF-2013-108

VH(->WW) with extra one or two leptons or jets+jets treated as bkg

3.2 (3.7) **σ**

μ=0.78±0.27



CMS –HIG-13-004

H->μμ

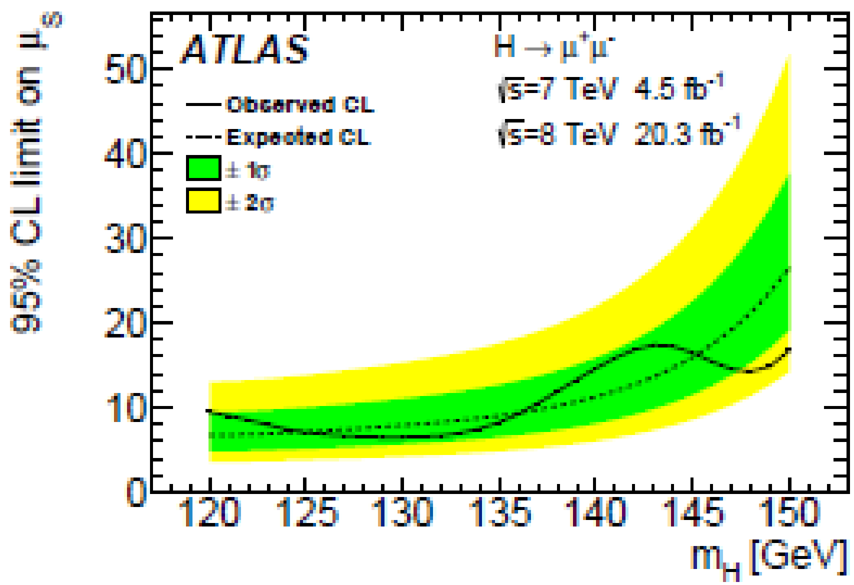
NEW

Small S/B~ 0.2% small BR~2* 10^{-4} but **very clean signature**, very good mass resolution
ONLY means to measure **2nd generation fermions**

Exactly two isolated OS muons, bkg: Huge Z/γ* ->mumu (96%), tt(3%)

Cut-based method, main systematics from theory signal+bkg analytical modelling, ggF+VBF analysis
Analysis/bkg similar to γγ, Cat:central μ's,non-central μ's,VBF
Limit/SM@95%CL ~ **7.0** (7.2) @L 125.5 GeV

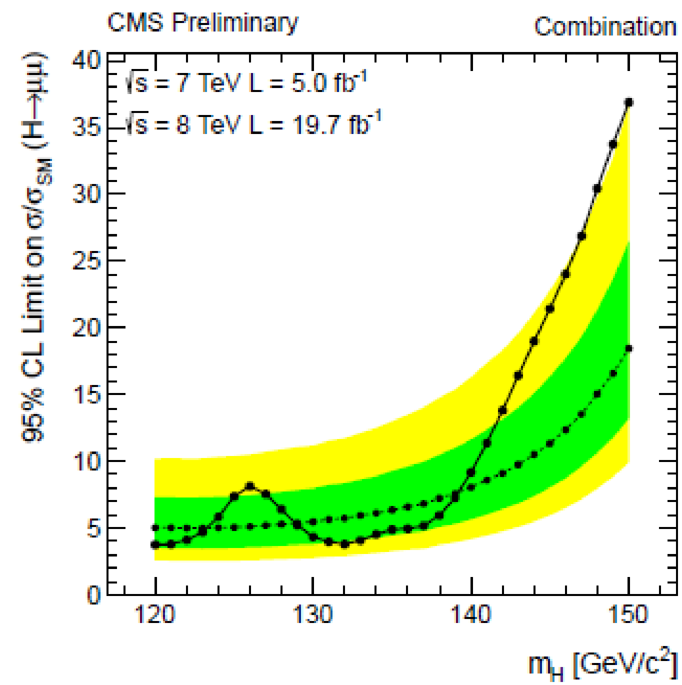
BR<1.5* 10^{-3} **MEANS no universal coupling to l's**



arXiv:1406.7663

Two independent analysis with similar results, event categories #of jets

Limit/SM ~ **7.4**(5.1)@125 GeV



CMS-HIG-13-007

NEW !!!

VH->bbar

Direct probe of **down-type quark couplings** **σ*BR~150 fb , BR (H->bbar)~58%**

bkg V+jets, ttbar, top,dibosons, multijets. **Use VZ (Z->bbar) as benchmark**

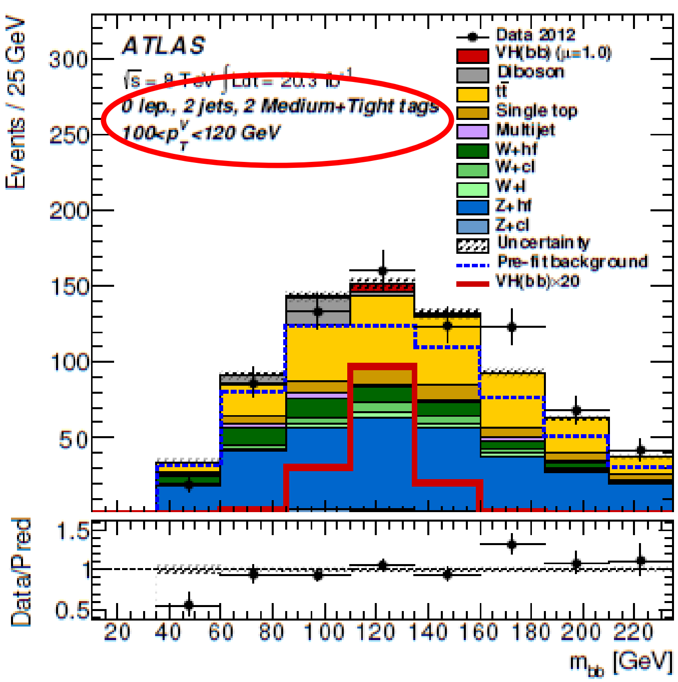
Require two b jets, look for signal excess in bbar invariant mass, **broad peak** (σ=10%),

2 b-tagged jets, Z->νν,W->lν,Z->ll,

Bins of P_T^V, #leptons, #jets, #b-jets

Control regions for bkg, data driven for QCD bkg

MVA analysis, including kinematics info
+ b-tagging info

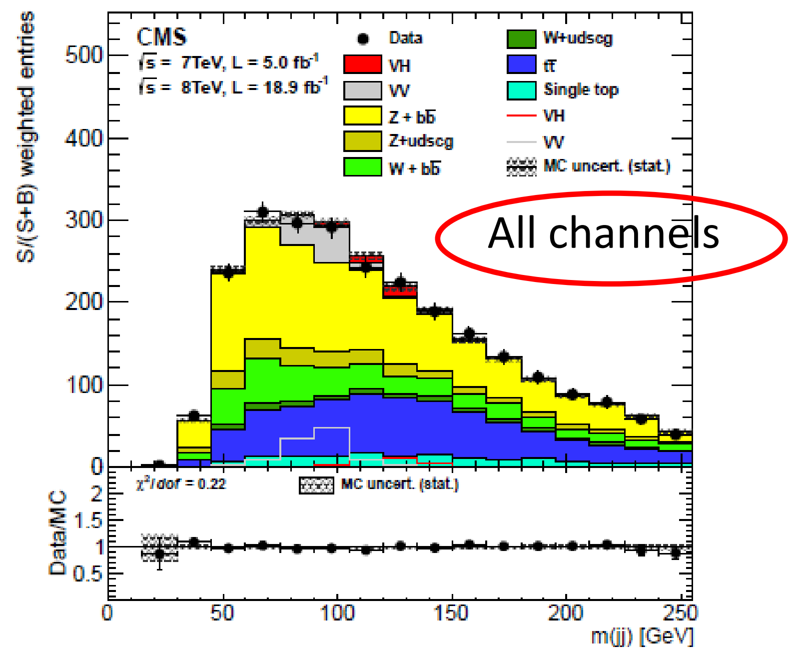


Two b-tagged jets and P_T^V bins

MVA to extract signal

Z->νν,W->lν (l=e,μ,τ),Z->ll(l=e, μ)

14 BDT's for signal/bkg separation



 Phys.RevD89,(2014)012003, HIG-13-012

NEW !!!

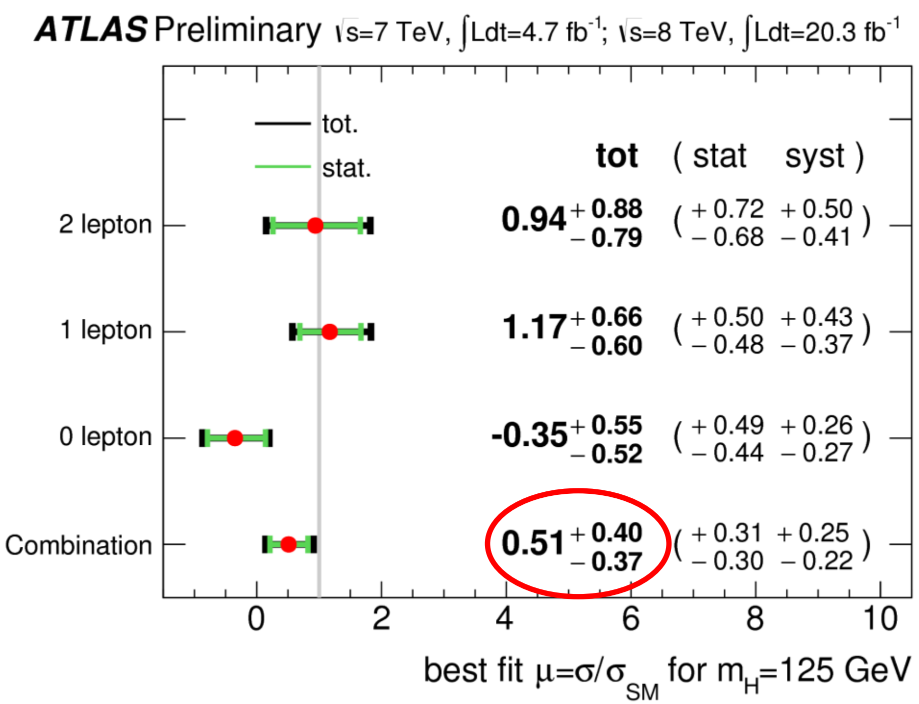
VH->bbar

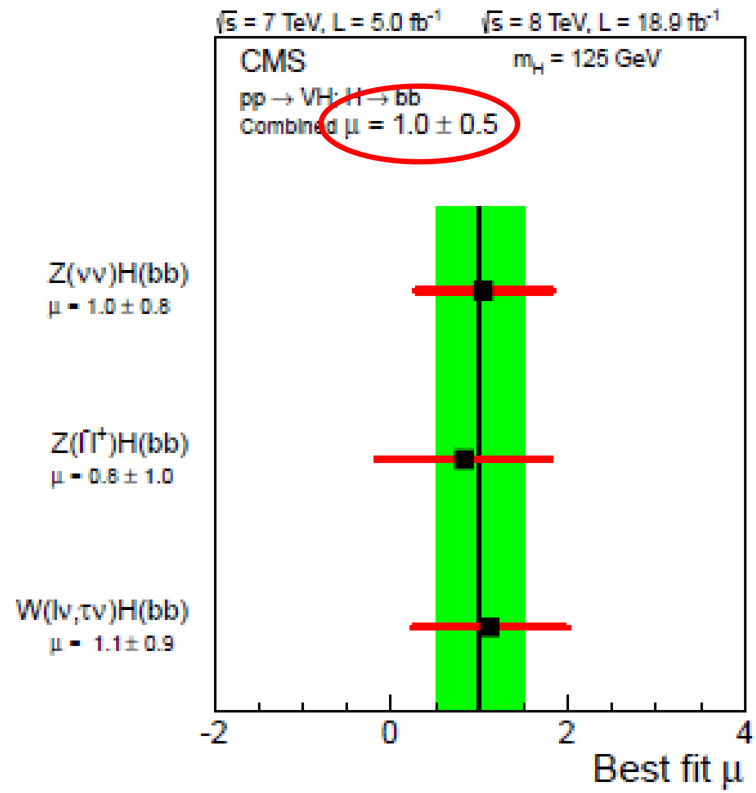
Significance above bkg 1.4 σ (2.6)

μ=0.52±0.32(stat)±0.26(syst) @125.36 GeV

Excess above bkg with 2.1 σ (2.1)

$\boldsymbol{\mu=1.0\pm0.5}$





Phys.Rev D89,(2014)012003 ,HIG-13-012

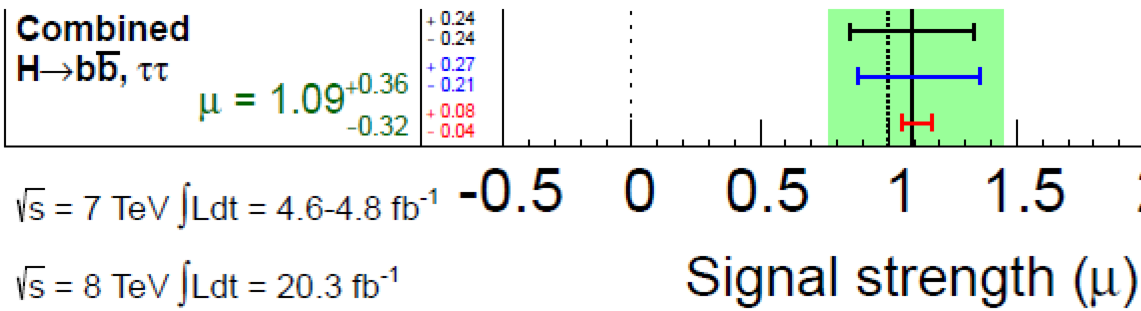
Higgs fermionic decays (H->bbar+ττ)

Evidence for direct decay into fermions is found at the **3.7 sigma level from the combination of the ττ+bb**

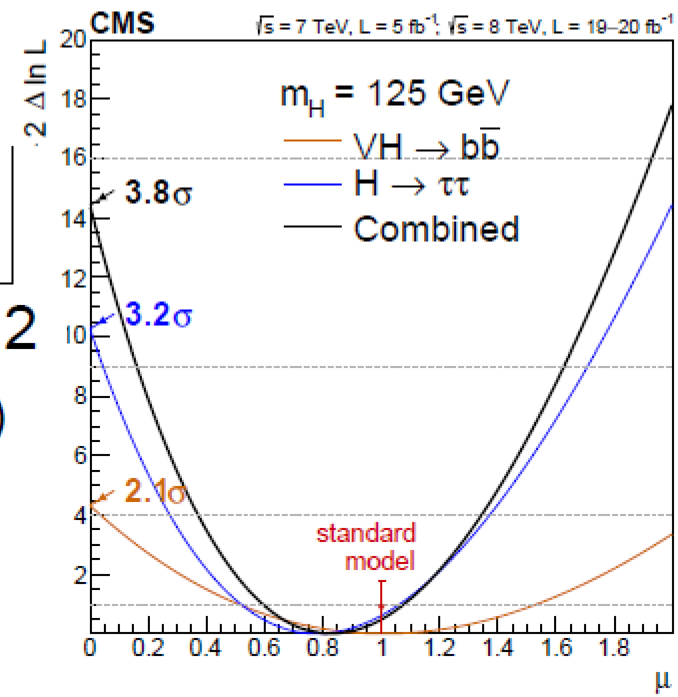
Evidence for Higgs coupling to down-type fermions quarks with significance **ττ+bb~3.8** (4.4)σ

$$\mu=1.09\pm0.24(\mathrm{stat})^{+0.27}_{-0.21}(\mathrm{sys})$$

$$\mu=0.83\pm0.24$$



ATLAS-CONF-2014-009



CMS- HIG-13-033
Nature Physics 10, (2014) 557

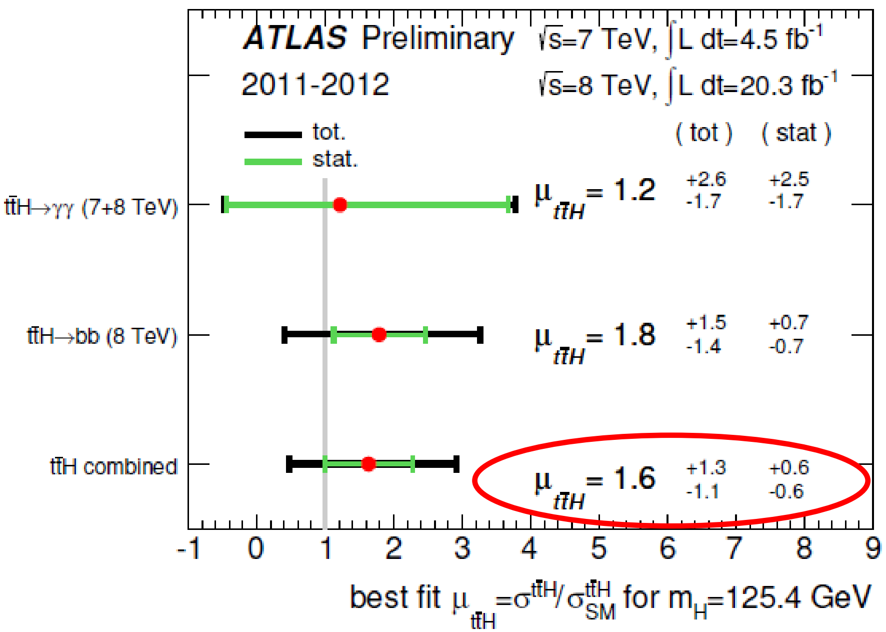
ttH (H->bbar,ττ+γγ)

NEW

Limit/SM from **bb** @95%CL->**4.1**(2.6) @125 GeV
Limit/SM from **γγ** @95%CL -> **6.7**(4.9) @125.4 GeV

ATLAS γγ+bbar

Significance/SM **1.5** (1.0) σ (with μ=1)
Limit/SM from **γγ+bb**
@95%CL -> **3.9** (2.3) @125.4 GeV



ATLAS-CONF-2014-043

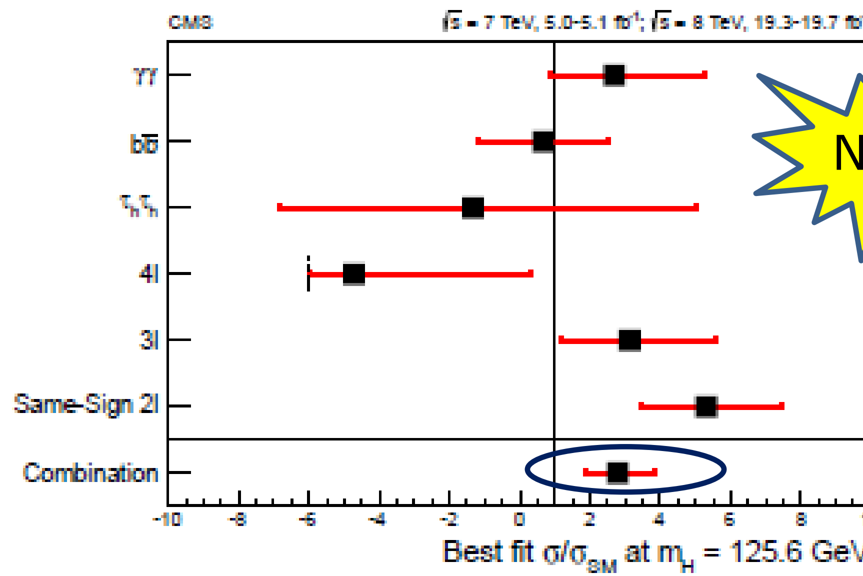
NEW

Limit/SM from **bb** @ 68%CL-> **3.3**(2.9)
Limit/SM from **γγ->5.4**(5.3) @125 GeV

CMS analysis γγ+ bbar+ WW, ZZ, $\tau_h\tau_h$
γγ+multileptons+hadrons(WW,bbar, $\tau_h\tau_h$)

Search optimized for H->WW*,ZZ*, ττ
Lepton MVA based on BDT for signal/bkg
Local significance **3.4**(2.1) @125.6 GeV
Excess 2σ over SM

$$\mu=2.8^{+1.0}_{-0.9}$$



NEW

arXiV:1408.1682

Signal strength for all channels (bosonic+fermionic)

NEW

All FIVE channels (not ttH) signal strength of:

$$\mu = 1.30 \pm 0.12(\mathrm{stat})\,^{+0.14}_{-0.11}(\mathrm{sys})$$

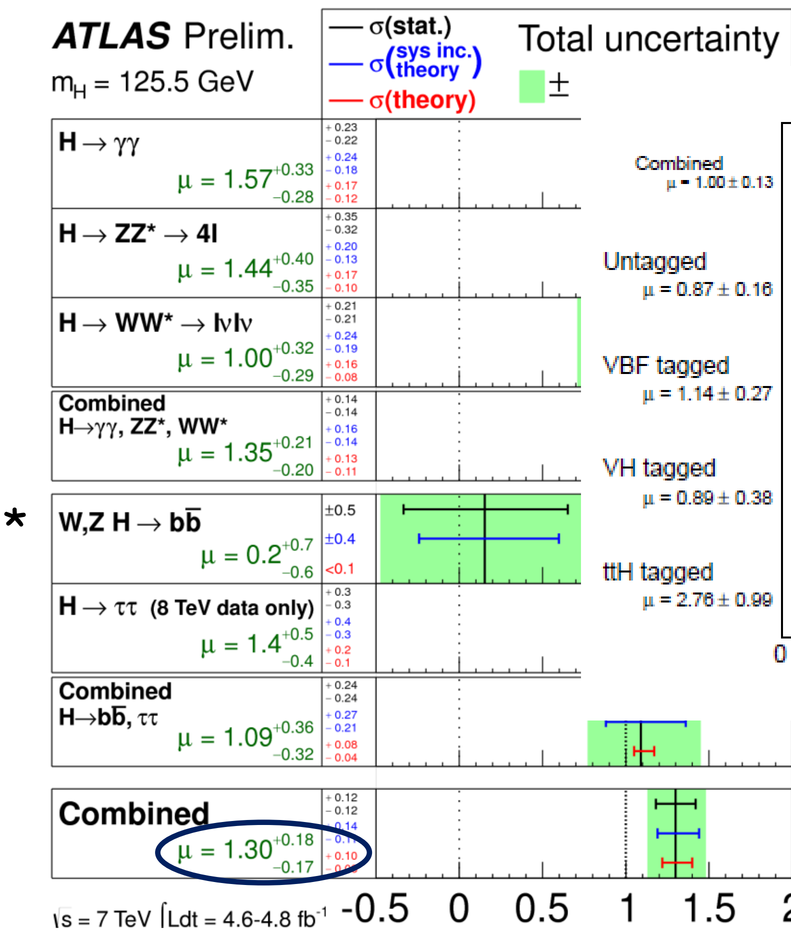
4.1 σ evidence for VBF production

New tagged by production/decay channel

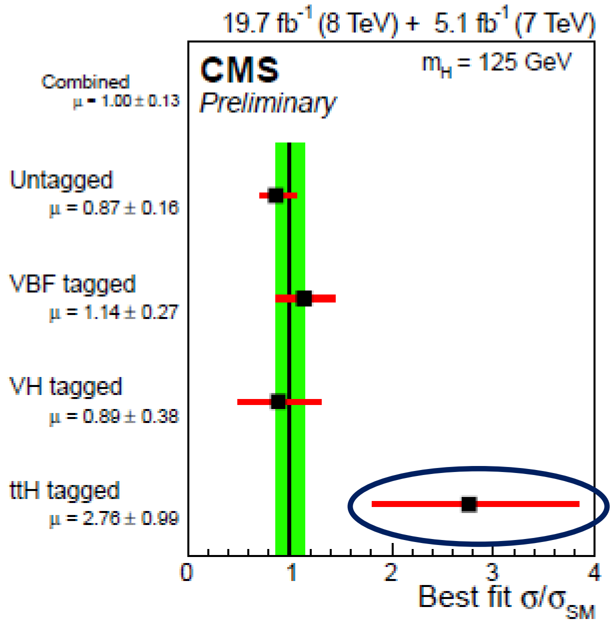
$$\sigma/\sigma_{\mathrm{SM}} = 1.00 \pm 0.13 \left[\pm 0.09(\mathrm{stat.})^{+0.08}_{-0.07}(\mathrm{theo.}) \pm 0.07(\mathrm{syst.})\right]$$

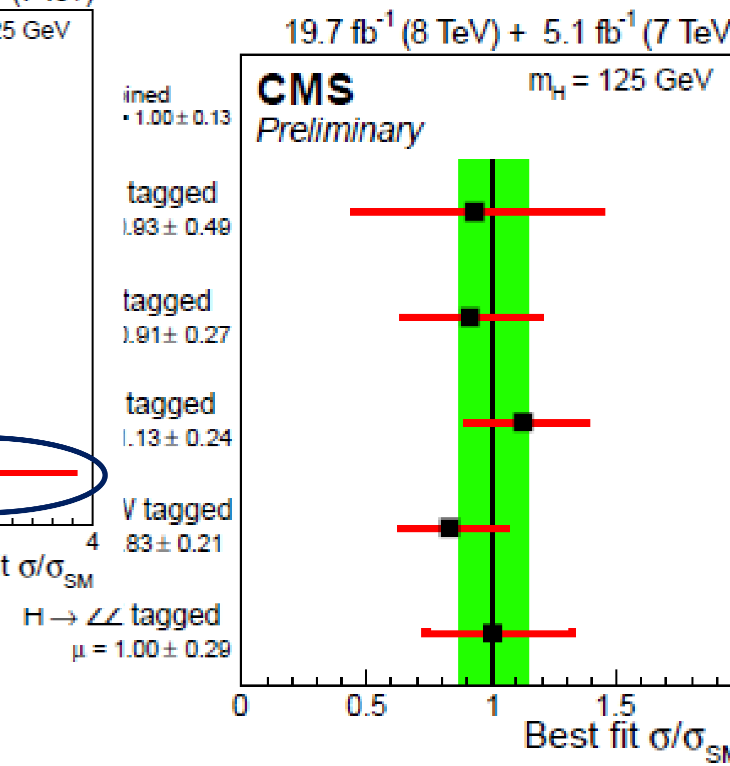
3.6 σ evidence for VBF production

ttH 2.0σ above SM



ATLAS-CONF-2014-009 and Phy.Lett B 734 (2014) 206





CMS-HIG-14-009

*not updated

Summary

Higgs decay mode	ATLAS σ/σ_{SM}* observed	ATLAS σ/σ_{SM}* expected	CMS σ/σ_{SM}* observed	CMS σ/σ_{SM}* expected
H->ZZ	8.1	5.8	6.8	6.7
H->γγ	7.4	4.3	5.7	5.2
H->WW	3.8	3.7	4.3	5.8
H-ττ	4.1	3.2	3.2	3.7
VH(H->bb)	1.4	2.6	2.1	2.1
H->ττ+bb	3.7		3.8	4.4
		Limits		
H->μμ	<7.0	<7.2	<7.4	<5.1
H->Zγ	<11	<9	<9.5	<10
ttH(H->bb)	<4.1	<2.6	<3.3	<2.9
ttH(H->γγ)	<6.5	<4.9	<5.4	<5.3

*σ/σ_{SM}->significance

Conclusions I

- **Both experiments have discovered the Higgs boson through its bosonic decays (ZZ*,γγ,WW*)**
- **They also found good evidence (>3.6σ) for its decay to fermions (ττ+bb)**
- **A plethora of new precision results exists ex. the Higgs mass is measured with per mil accuracy**
- **Nevertheless the new boson looks “very” SM-like (no significant deviation from SM found)**

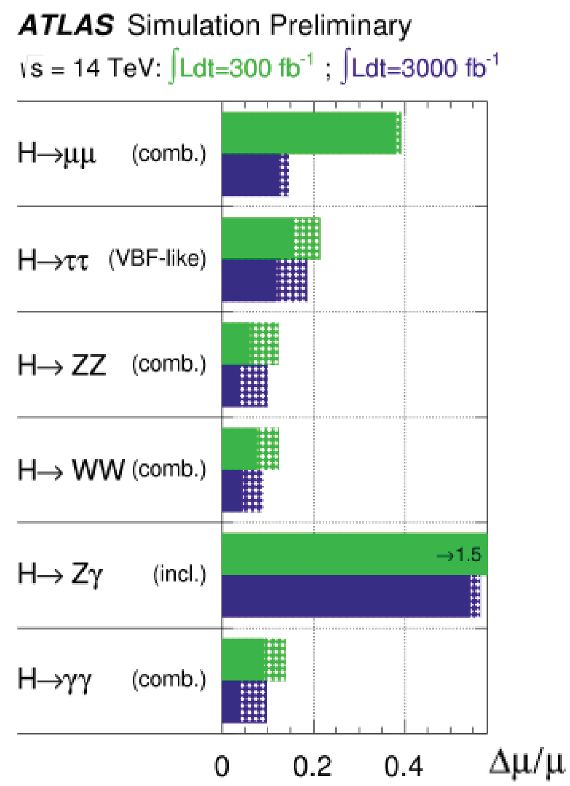
- **All data of Run I analyzed and final results by the end of the year**
- **Some results approaching the theory precision/systematics uncertainties**
- **Others need more statistics->Run II**

Conclusions II

Run II: 75-100 fb^{-1}

- **Almost all x-sections x 2-5 (ttH)**
- **Precision measurements (improve couplings)**
- **VH measurement in fermionic modes**
- **Rare decays (Zγ)**
- **Additional Higgs, BSM-> Charged, Charged ??**
- **Main uncertainty will be the gg PDF's**

THANK YOU !!



ATLAS-CONF-2013-014

VH(->bb) Δμ=25% -0.15% Run II-> III ATLAS-CONF-2014-011

European Union European Social Fund

OPERATIONAL PROGRAMME EDUCATION AND LIFELONG LEARNING investing in knowledge society

MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS MANAGING AUTHORITY

Co-financed by Greece and the European Union

NSRF 2007-2013 programme for development EUROPEAN SOCIAL FUND

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: THALES. Investing in knowledge society through the European Social Fund.

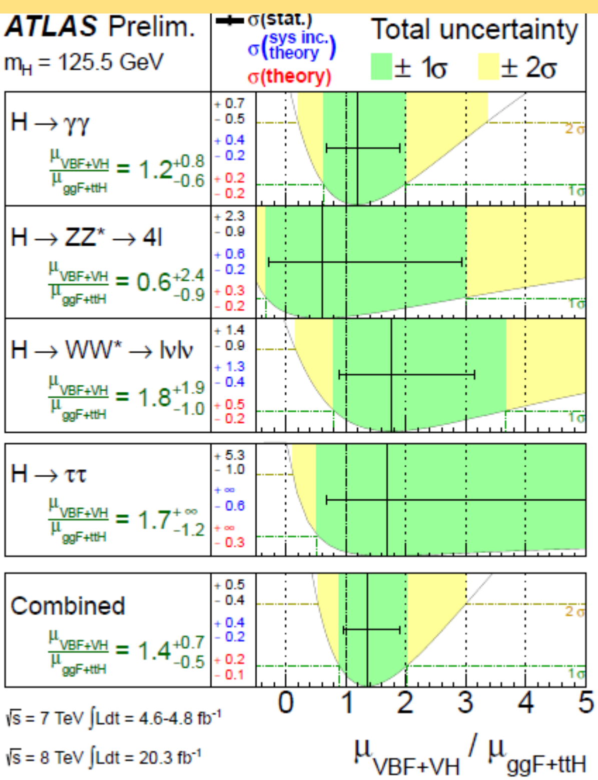
Back-up

Significance all

A combination of H->ZZ, H->γγ,H->WW,H->ττ can determine the combined ratio of signal strengths since $\mu_{VBF+VH}/\mu_{ggF+ttH}$ is independent of the BR via a profile likelihood @fixed mass 125.5 GeV

$$\mu_{VBF+VH} / \mu_{ggF+ttH} = 1.4^{+0.5}_{-0.4}(stat)^{+0.4}_{-0.3}(syst)$$

4.1 σ evidence for VBF production



- $\mu_{VBF+VH} = \mu_{VBF} = \mu_{VH}$ (coupling with vector boso
- $\mu_{ggF+ttH} = \mu_{ggF} = \mu_{ttH}$ (coupling with fermions)

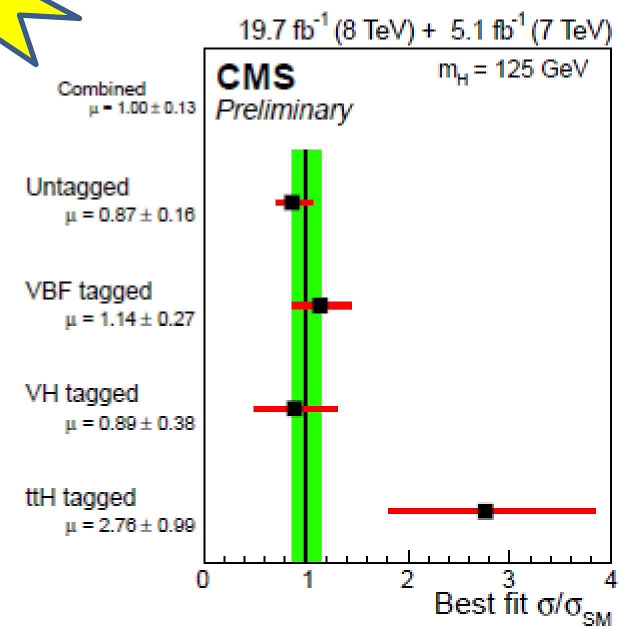
ATLAS-CONF-2014-009, Phys. Lett 734(2014),406

A combination of H->ZZ, H->γγ,H->WW, H->ττ, H->bbar +ttH production

Tagged by production channel

Combined best fit $\mu_{VBF,VH}/\mu_{ggH,t\bar{t}H}$
Observed (expected)
$1.25^{+0.63}_{-0.45}$ $(1.00^{+0.49}_{-0.35})$

NEW



3.6 σ evidence for VBF production
ttH 2.0σ above SM

CMS-HIG-14-009

Higgs width measurement(H->ZZ*)

NEW

Direct measurement "on shell" (few GeV)

Γ_H <2.5 GeV from 4l and <5.0 GeV from $\gamma\gamma$ Γ_H<3.4 GeV

Indirect measurement of Γ_H by Γ_H / Γ_H^{SM} based on ideas of:

- F.Caola and K.Melnikov, Phys.Rev. D88 (2013) 054024
- N.Kauer and G.Passarino, JHEP 08(2012)116

Use relative on-shell and off-shell production (cancellation of uncertainties), **decay rates of H->ZZ and formula below to determine Γ_H**

$$\frac{\sigma^{gg\to H\to ZZ}_{off-shell}}{\sigma^{gg\to H\to ZZ}_{on-shell}} \propto \frac{\Gamma_H}{\Gamma_H^{SM}}$$

with Γ_H^{SM}~4 MeV

To increase statistics use ZZ->4l and ZZ->2l+2v. Limitation is LO calculation for ZZ bkg First calculated by CMS @Moriond 2014 (CMS-PAS-HIG-14-002) to be 17MeV using only 8 TeV data.

Now with both c.m.s. data:

Γ_H / Γ_H^{SM}<5.7 (8.5) @ 95%CL
(with $\mu_{on-shell}$=1)

ATLAS-CONF-2014-042

Γ_H / Γ_H^{SM}<5.4 (8.0) @ 95%CL

arXiv: 1406.3455
Phys.Lett. B736 (2014)64

Mass combination H->4l+γγ

Excellent mass resolution (1-3%)

Profile likelihood $-2\ln\Lambda(m_H)$
Allowing the signal strengths for $m_{\gamma\gamma}$ and m_{4l} to vary independently

m=125.36±0.37(stat)±0.18(sys) GeV
Compatibility between two values **2σ**
probability 4.8% (was 2.5 σ)

NEW

Statistical error increased due to $m_{\gamma\gamma}$ higher one (mainly due to higher signal strength, statics ~ 1/signal strength)
Systematic reduced by x3

Previously 125.49± 0.24 (stat) $^{+0.50}_{-0.58}$ syst
0.3% precision dominated by statistics
set μ=1->mass change 80 MeV

Resolution: γγ: ~1.7 GeV, 4l: 1.6-2.2 GeV

PRD 90 (2014) 052004

Scan the profile likelihood as a function of m_H allowing the signal strengths (VBF,VH->γγ), (ggF,ttH->γγ)and H->4l to vary independently, not

$$m = 125.03^{+0.26}_{-0.27}\,stat^{+0.13}_{-0.15}\,sys$$

Compatibility between two values **1.6 σ**

As a test : the scan is repeated with single common μ or μ=1 (SM prediction)
->the mass value differs by <0.1 GeV

$$\mu = 1.00^{+0.08}_{-0.07}(stat)^{+0.08}_{-0.07}(theo) \pm 0.07(syst)$$

CMS-PAS-HIG-14-09

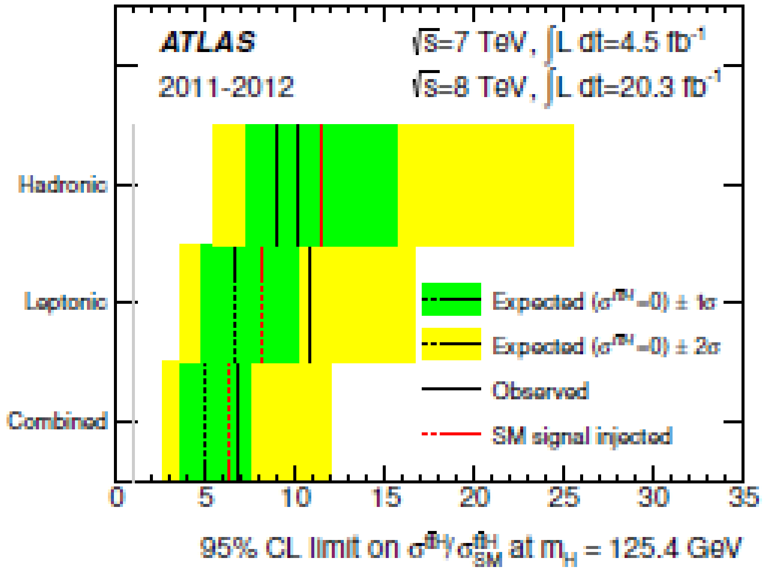
ttH (H->γγ)

NEW !!

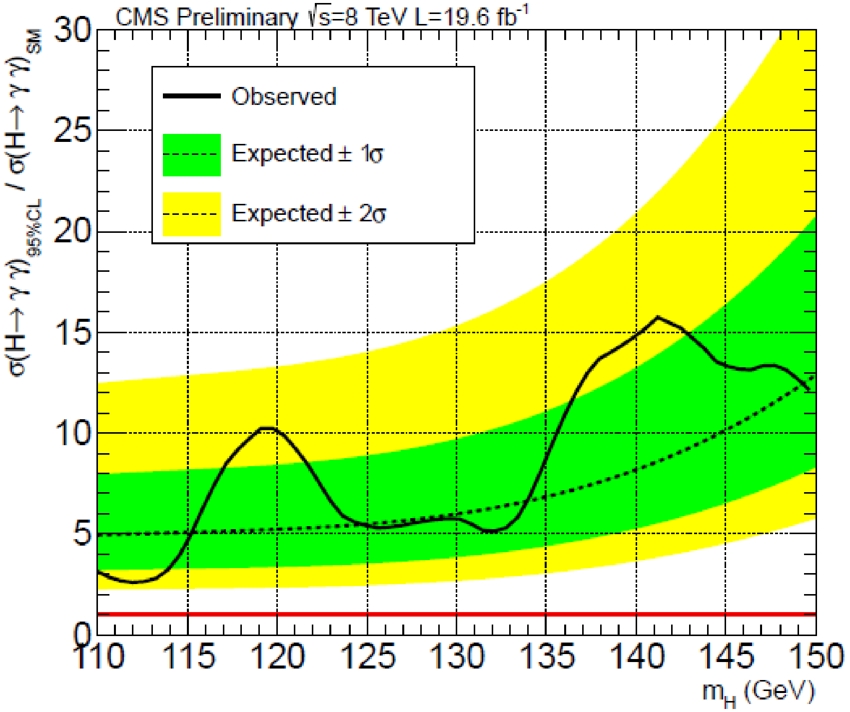
BR~2*10^{-3} but clean signature

Two isolated γ's +2b-jets
Search for resonance in $m_{\gamma\gamma}$
Leptonic+hadronic W-decays, analysis similar to γγ
CR's for bkg
Limit/SM@95%CL -> **6.7**(4.9) @125.4 GeV

Only $\sqrt{s} = 8 TeV$ analysed
ttbar hadronic+leptonic decays of W's
Fit γγ mass, sidebands->bkg
Limit/SM **5.4**(5.3) @125 GeV



arxiv:1409.3122



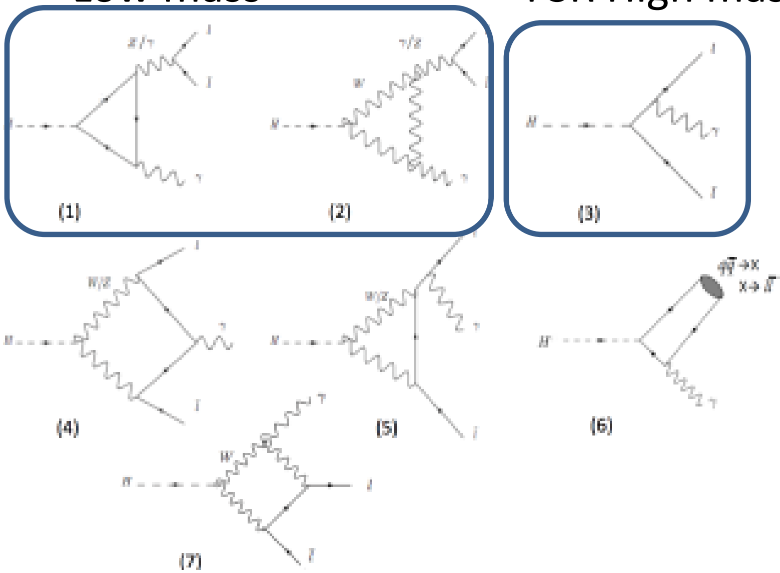
CMS-HIG-13-015

H->γγ*->μμγ

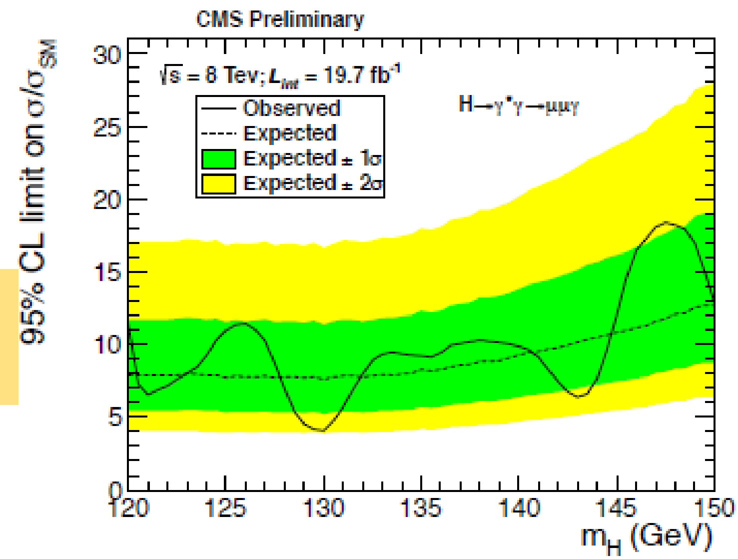
NEW

Low mass

FSR High mass



γγ* decay where one γ converts to μ pair
isolated OS μ's +high P_T photon
Dalitz γ* conversions
Results for $m_{\mu\mu}$<20GeV but window to reject J/ψ and Υ
Suppress events with γ radiation cutting on cone around photon
Irreducible bkg: initial/final state radiation of DY, DY+jets



Limit/SM @95% CL ~12 (8) @125 GeV
Similar sensitivity for Zγ->need more data

CMS-HIG-14-003

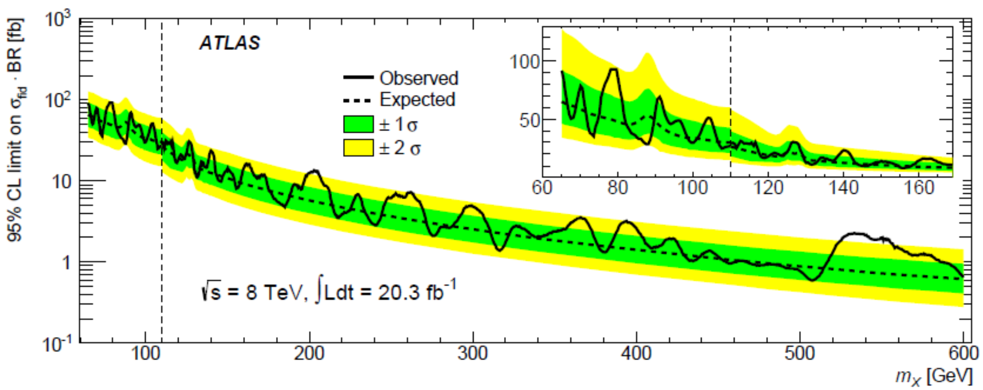
Additional H->γγ (low-high mass)

NEW

Cut based, two isolated high P_T γ's
Limit @95CL ->σ^{fid} *BR-> 90 to 1 fb
Fiducial volume where efficiency independent of topology
Higgs @125 treated as bkg

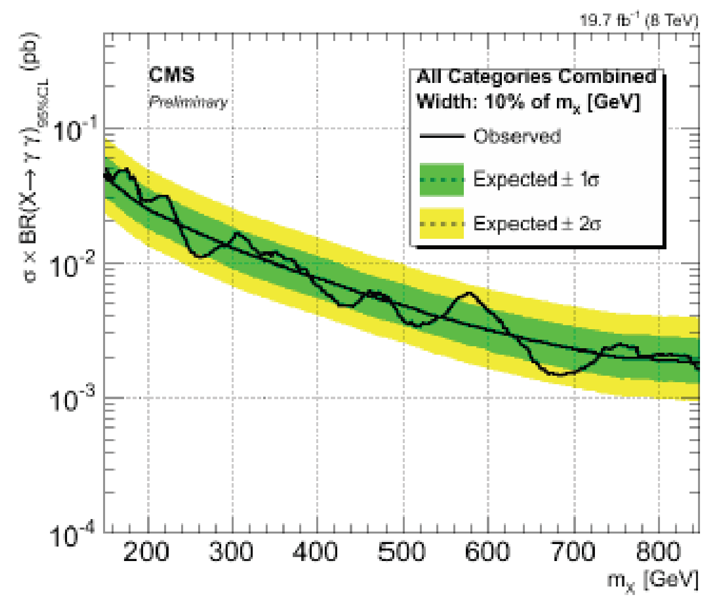
σ *BR limits for Spin 0
wide (Γ~10%*mass) width resonance

65 < $m_{\gamma\gamma}$< 600 GeV



arXiv:1407.6583

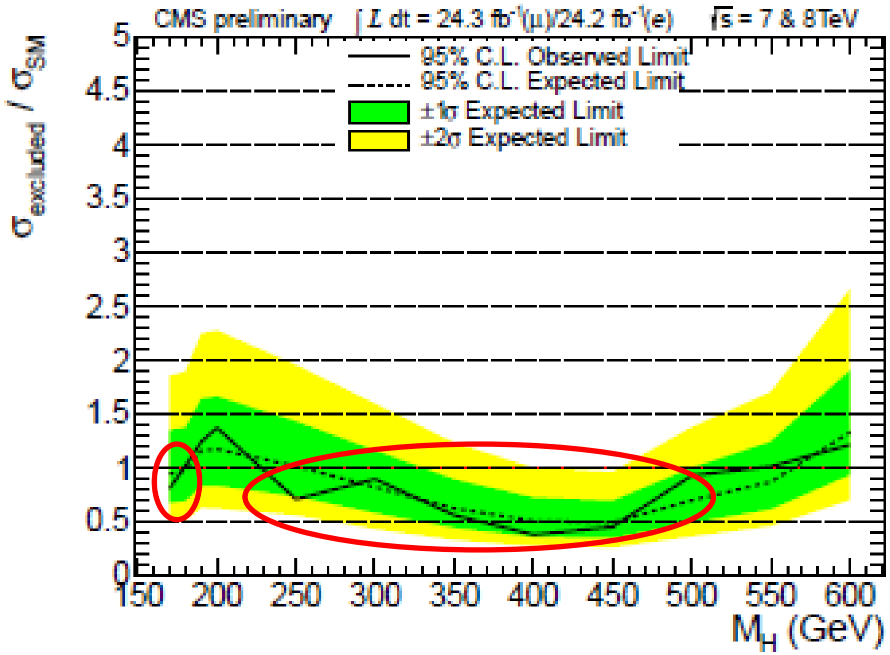
150 < $m_{\gamma\gamma}$< 850 GeV



CMS-PAS-HIG-14-006

High-mass H->WW->lvjj

Search for the electroweak heavy Higgs mixing with the light one



Excluded @95%CL for $170<m_H<180$ GeV and $230<m_H<500$ GeV

CMS-HIG-13-027

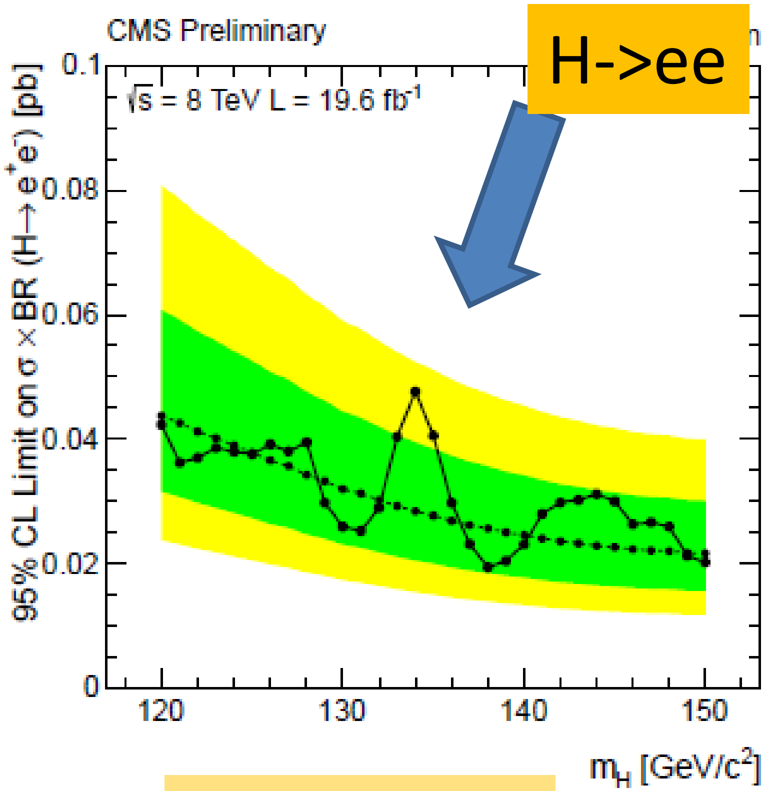
H->ee (no signal)

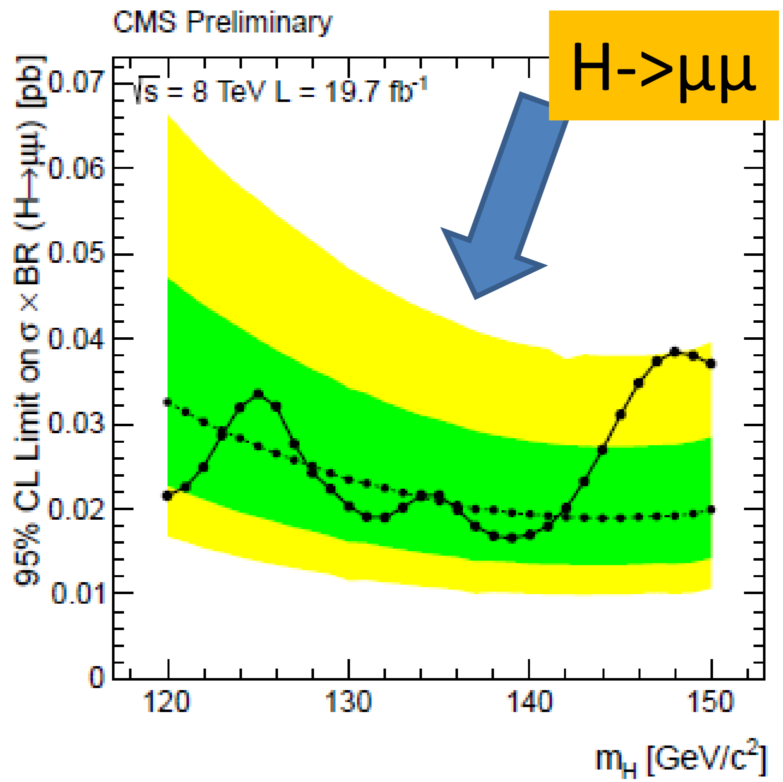
Very rare decay BR (ee)<<BR (μμ) ~2* 10^{-5}

Results only @ $\sqrt{s} = 8\,\mathrm{TeV}$

Coupling to fermions ~ m_{lepton}

Limit for H->ee σ*BR ~ 0.038 pb and H->μμ σ*BR ~0.034 (0.027 pb) @ m=125 GeV





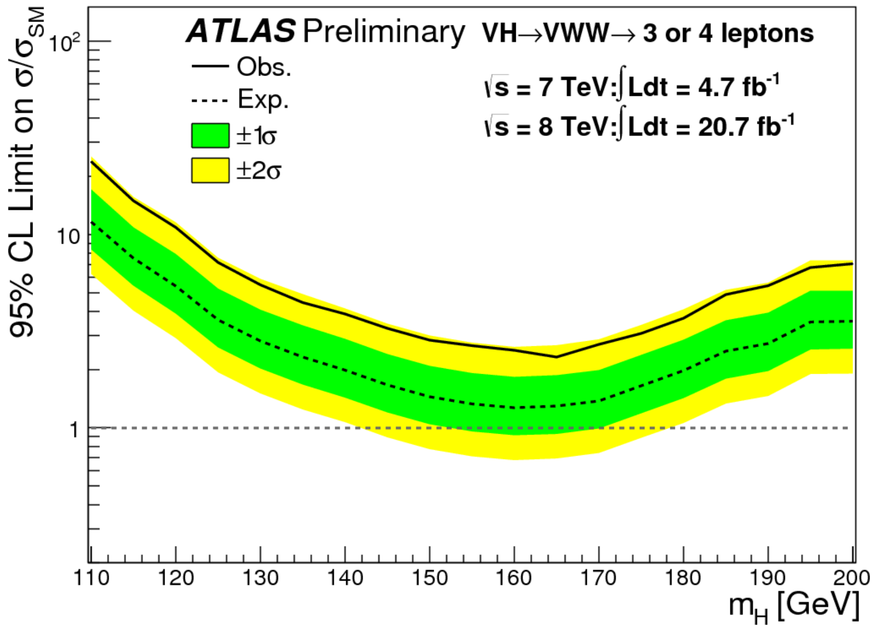
BR H->ee <0.0017

CMS-HIG-13-007 (Appendix)

VH associated production
ZWW or WWW->lllνlν or lνlνlν

Three or four leptons in final state

No excess

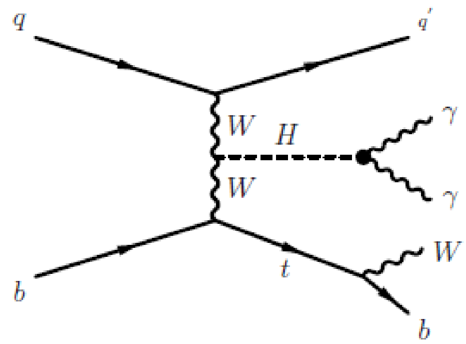


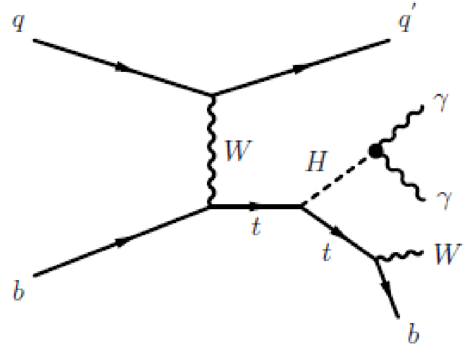
Excluded @95%CL 7.2(3.6)

ATLAS-CONF-13-075

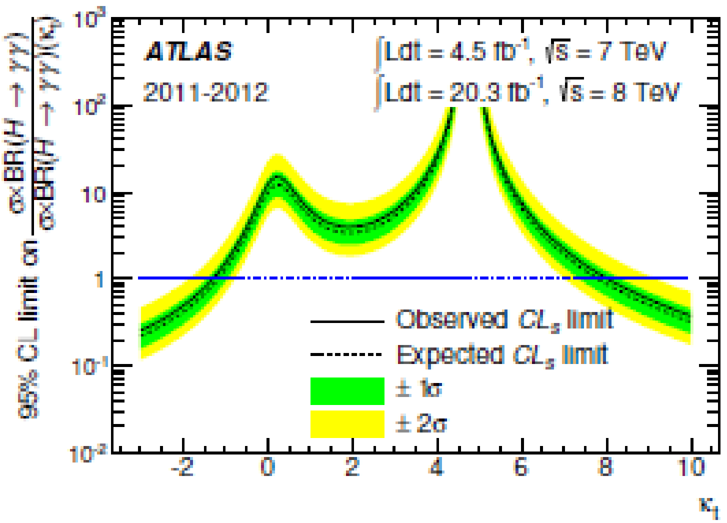
Single top tq'H (H->γγ)

Strongly suppressed wrt ttH due to the cancellation of two diagrams





Two isolated γ's +2b-jets
Search for resonance in $m_{\gamma\gamma}$
Correlated to BR(H->γγ)
Limit on Y_t coupling



Limits on $k_t = Y_t/Y_t^{SM}$ top Yukawa coupling strength
-1.3->8.0 (-1.2->7.8)

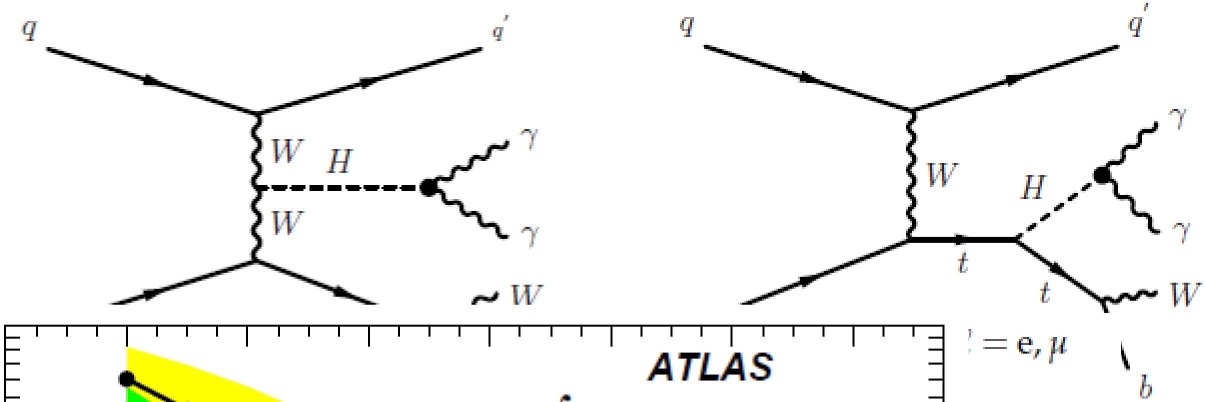
arxiV:1409.3122

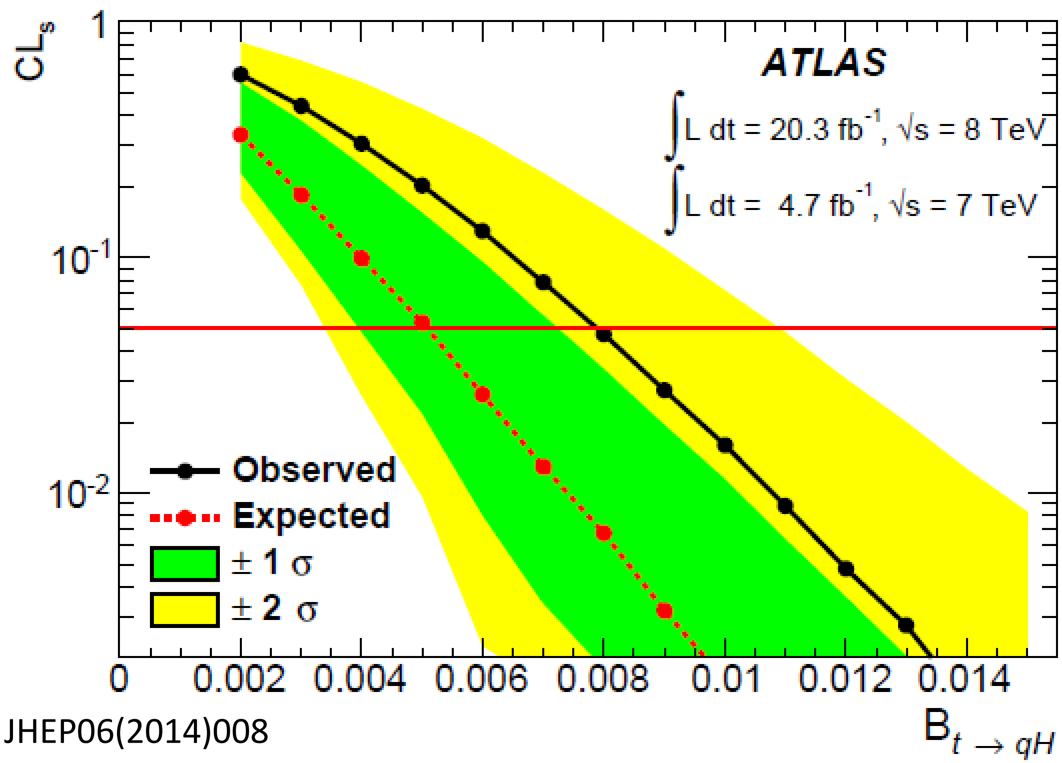
CMS-HIG-13-015

Single top t->qH(->γγ) FCNC

CMS-HIG-14-01
8 TeV data

FCNC allowed in BSM models
t->cH largest BR, leptonic+hadronic, analysis similar to γγ
Limit @95%CL of FCNC: BR (t->cH)<0.83 (0.53)%





JHEP06(2014)008

H->γγ and top->leptonic
No event pass the criteria
upper limit of 4.1 inverted Yukawa coupling

H->invisible (νν)

SM decay mode suppressed BR~1.2*10^{-3}

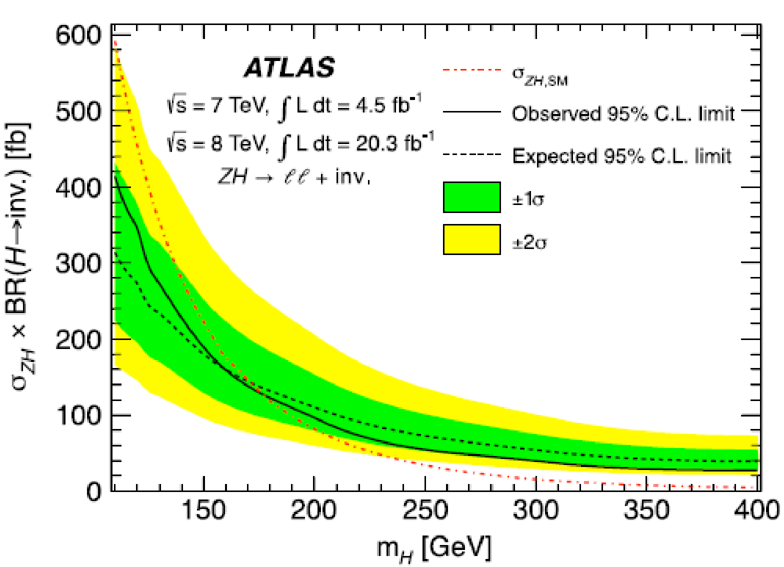
Main background dibosons: WZ->lνll (19%), ZZ->llνν (68%) irreducible

ZH decays only (Z->ll)

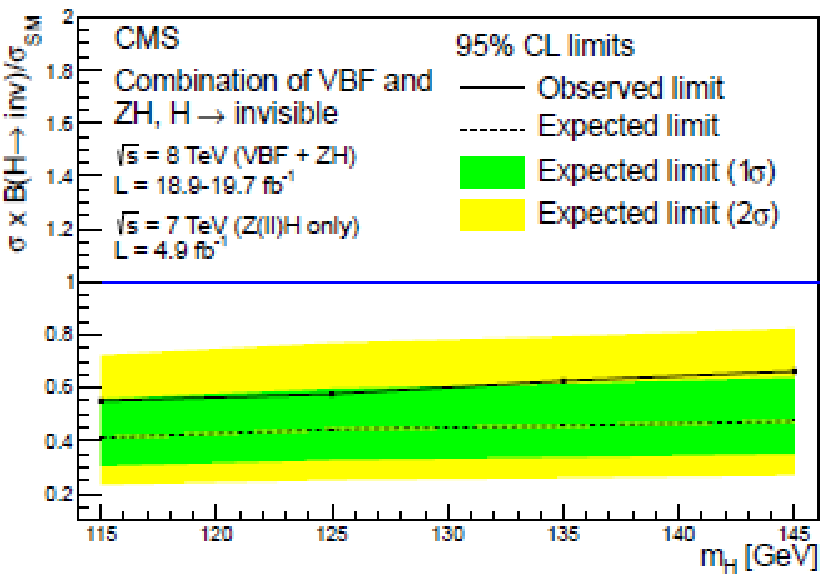
BR upper limit (H->invisible)<75%(<62%)
Gives limits to dark matter candidates
in the Higgs-portal scenario (Higgs is mediator
between DM and SM)

VBF+ZH decays (Z->ll or Z->bbar)

0.58(0.44) @95%CL



Phys.Rev.Lett.112 (2014) 201802



CMS –HIG-13-030

CMS combination of all channels PAS-HIG-2014-009

Decay tag and production tag		Expected signal composition	σ_{m_H}/m_H	Luminosity (fb^{-1}) No. of categories 7 TeV	8 TeV
$H \to \gamma\gamma$ [20], Section 2.1				*5.1*	*19.7*
$\gamma\gamma$	Untagged	76–93% ggH	0.8–2.1%	4	5
	2-jet VBF	50–80% VBF	1.0–1.3%	2	3
	Leptonic VH	≈95% VH (WH/ZH ≈ 5)	1.3%	2	2
	E_T^{miss} VH	70–80% VH (WH/ZH ≈ 1)	1.3%	1	1
	2-jet VH	≈65% VH (WH/ZH ≈ 5)	1.0–1.3%	1	1
	Leptonic $t\bar{t}H$	≈95% $t\bar{t}H$	1.1%	$1^{\dagger}$	1
	Multijet $t\bar{t}H$	>90% $t\bar{t}H$	1.1%		1
$H \to ZZ^{(*)} \to 4\ell$ [18], Section 2.2				*5.1*	*19.7*
4μ, $2e2\mu$, $4e$	2-jet	42% VBF + VH	1.3, 1.8, 2.2%‡	3	3
	Other	≈90% ggH		3	3
$H \to WW^{(*)} \to \ell\nu\ell\nu$ [17], Section 2.3				*4.9*	*19.4*
$ee + \mu\mu$, $e\mu$	0-jet	96–98% ggH	$e\mu$: 16%‡	2	2
	1-jet	82–84% ggH	$e\mu$: 17%‡	2	2
	2-jet VBF	78–86% VBF		2	2
	2-jet VH	31–40% VH		2	2
$3\ell3\nu$ WH	SF-SS, SF-OS	≈100% WH, up to 20% $\tau\tau$		2	2
$\ell\ell + \ell'\nu jj$ ZH	eee, $ee\mu$, $\mu\mu\mu$, $\mu\mu e$	≈100% ZH		4	4
$H \to \tau\tau$ [19], Section 2.4				*4.9*	*19.7*
$e\tau_h$, $\mu\tau_h$	0-jet	≈98% ggH	11–14%	4	4
	1-jet	70–80% ggH	12–16%	5	5
	2-jet VBF	75–83% VBF	13–16%	2	4
$\tau_h\tau_h$	1-jet	67–70% ggH	10–12%	-	2
	2-jet VBF	80% VBF	11%	-	1
$e\mu$	0-jet	≈98% ggH, 23–30% WW	16–20%	2	2
	1-jet	75–80% ggH, 31–38% WW	18–19%	2	2
	2-jet VBF	79–94% VBF, 37–45% WW	14–19%	1	2
ee, $\mu\mu$	0-jet	88–98% ggH		4	4
	1-jet	74–78% ggH, ≈17% WW *		4	4
	2-jet CJV	≈50% VBF, ≈45% ggH, 17–24% WW *		2	2
$\ell\ell + LL'$ ZH	$LL' = \tau_h\tau_h, \ell\tau_h, e\mu$	≈15% (70%) WW for $LL' = \ell\tau_h$ ($e\mu$)		8	8
$\ell + \tau_h\tau_h$ WH		≈96% VH, ZH/WH ≈ 0.1		2	2
$\ell + \ell'\tau_h$ WH		ZH/WH ≈ 5%, 9–11% WW		2	4
VH with $H \to bb$ [16], Section 2.5				*5.1*	*18.9*
$W(\ell\nu)bb$	$p_T(V)$ bins	≈100% VH, 96–98% WH	≈10%	4	6
$W(\tau_h\nu)bb$		93% WH		-	1
$Z(\ell\ell)bb$	$p_T(V)$ bins	≈100% ZH		4	4
$Z(\nu\nu)bb$	$p_T(V)$ bins	≈100% VH, 62–76% ZH		2	3
$t\bar{t}H$ with $H \to$ hadrons [14, 28], Section 2.6				*5.0*	*19.3*
$H \to bb$	$t\bar{t}$ lepton+jets	≈90% bb but ≈24% WW in ≥6j + 2b		7	7
	$t\bar{t}$ dilepton	45–85% bb, 8–35% WW, 4–14% $\tau\tau$		2	3
$H \to \tau_h\tau_h$	$t\bar{t}$ lepton+jets	68–80% $\tau\tau$, 13–22% WW, 5–13% bb		-	6
$t\bar{t}H$ with $H \to$ leptons [29], Section 2.6				-	*19.6*
2ℓ-SS		WW/$\tau\tau$ ≈ 3		-	6
3ℓ		WW/$\tau\tau$ ≈ 3		-	2
4ℓ		WW : $\tau\tau$: ZZ ≈ 3 : 2 : 1		-	1

† Events fulfilling the requirements of either selection are combined into one category.

ATLAS combination of all channels CONF-2014-009

Higgs boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV		
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet VBF}\}$	4.8	[3]
$H \to ZZ^*$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu, \text{2-jet VBF}, \ell\text{-tag}\}$	4.6	[3]
$H \to WW^*$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{\text{0-jet, 1-jet, 2-jet VBF}\}$	4.6	[3]
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\ \text{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	4.6	[5]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\ \text{GeV}\}$	4.7	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\ \text{GeV}\}$	4.7	
		2012 $\sqrt{s}$ =8 TeV		
$H \to \gamma\gamma$	–	14 categories: $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus$ $\{\text{loose, tight 2-jet VBF}\} \oplus \{\ell\text{-tag}, E_{\mathrm{T}}^{\mathrm{miss}}\text{-tag, 2-jet VH}\}$	20.3	[3]
$H \to ZZ^*$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu, \text{2-jet VBF}, \ell\text{-tag}\}$	20.3	[3]
$H \to WW^*$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{\text{0-jet, 1-jet, 2-jet VBF}\}$	20.3	[3]
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\ \text{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	20.3	[5]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{<90, 90\text{-}120, 120\text{-}160, 160\text{-}200, \geq 200\ \text{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	20.3	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{<90, 90\text{-}120, 120\text{-}160, 160\text{-}200, \geq 200\ \text{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	20.3	
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{ee, e\mu, \mu\mu\} \otimes \{\text{boosted, 2-jet VBF}\}$	20.3	[6]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{\text{boosted, 2-jet VBF}\}$	20.3	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{\text{boosted, 2-jet VBF}\}$	20.3	

ATLAS new 4l properties and couplings: arXiv: 1408.5191 (Submitted to PRD)

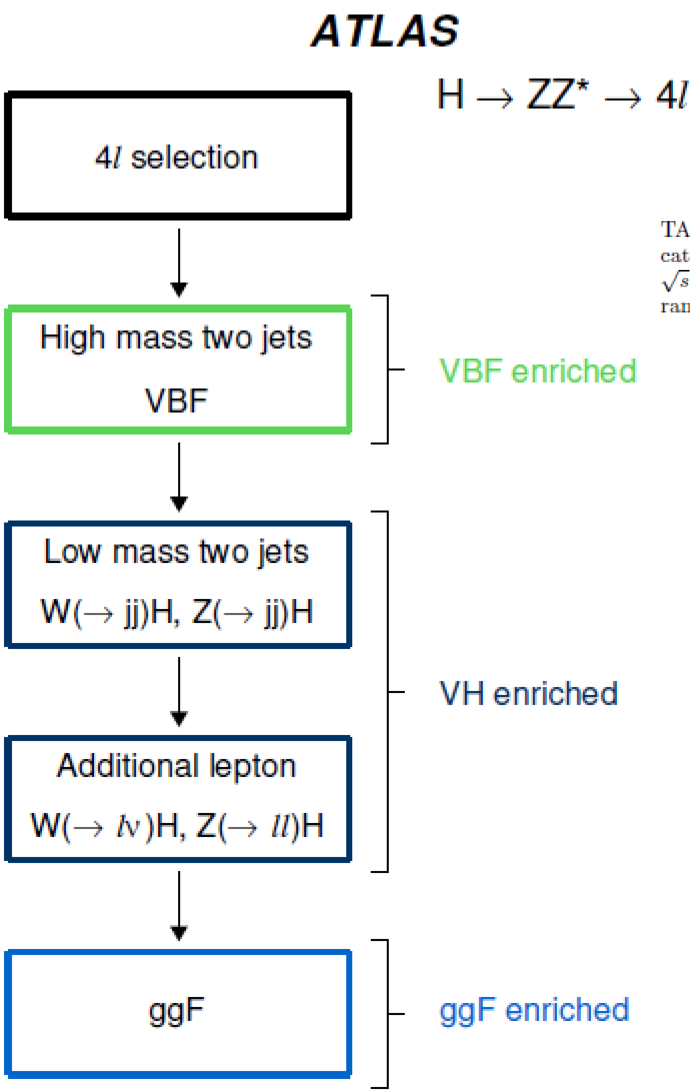
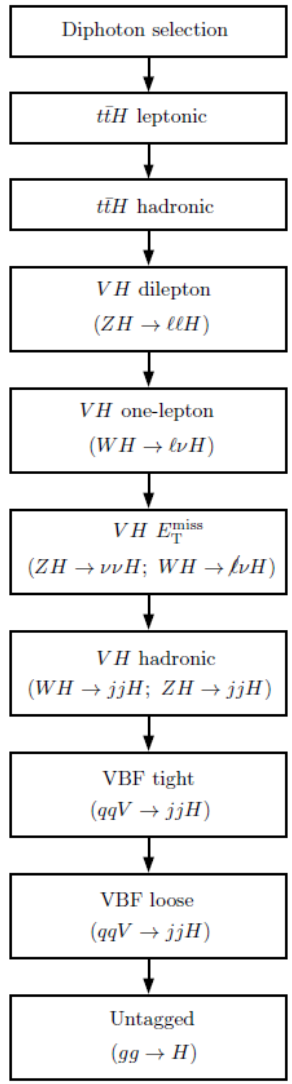


TABLE XII. Expected and observed yields in the *VBF enriched*, *VH-hadronic enriched*, *VH-leptonic enriched* and *ggF enriched* categories. The yields are given for the different production modes and the ZZ^* and reducible background for 4.6 fb^{-1} at $\sqrt{s} = 7$ TeV and 20.3 fb^{-1} at $\sqrt{s} = 8$ TeV. The estimates are given for both the $m_{4\ell}$ mass range 120–130 GeV and the mass range above 110 GeV.

Enriched category	Signal $ggF + b\bar{b}H + t\bar{t}H$	VBF	VH-hadronic	VH-leptonic	Background ZZ^*	Z + jets, $t\bar{t}$	Total expected	Observed
				$120 < m_{4\ell} < 130$ GeV				
VBF	1.18 ± 0.37	0.75 ± 0.04	0.083 ± 0.006	0.013 ± 0.001	0.17 ± 0.03	0.25 ± 0.14	2.4 ± 0.4	3
($BDT_{VBF} > 0$)	0.48 ± 0.15	0.62 ± 0.04	0.023 ± 0.002	0.004 ± 0.001	0.06 ± 0.01	0.10 ± 0.05	1.26 ± 0.15	1
VH-hadronic	0.40 ± 0.12	0.034 ± 0.004	0.20 ± 0.01	0.009 ± 0.001	0.09 ± 0.01	0.09 ± 0.04	0.80 ± 0.12	0
VH-leptonic	0.013 ± 0.002	< 0.001	< 0.001	0.069 ± 0.004	0.015 ± 0.002	0.016 ± 0.019	0.11 ± 0.02	0
ggF	12.8 ± 1.3	0.57 ± 0.02	0.24 ± 0.01	0.11 ± 0.01	7.1 ± 0.2	2.7 ± 0.4	23.5 ± 1.4	34
				$m_{4\ell} > 110$ GeV				
VBF	1.4 ± 0.4	0.82 ± 0.05	0.092 ± 0.007	0.022 ± 0.002	20 ± 4	1.6 ± 0.9	$24. \pm 4.$	32
($BDT_{VBF} > 0$)	0.54 ± 0.17	0.68 ± 0.04	0.025 ± 0.002	0.007 ± 0.001	8.2 ± 1.6	0.6 ± 0.3	10.0 ± 1.6	12
VH-hadronic	0.46 ± 0.14	0.038 ± 0.004	0.23 ± 0.01	0.015 ± 0.001	9.0 ± 1.2	0.6 ± 0.2	10.3 ± 1.2	13
VH-leptonic	0.026 ± 0.004	< 0.002	< 0.002	0.15 ± 0.01	0.63 ± 0.04	0.11 ± 0.14	0.92 ± 0.16	1
ggF	14.1 ± 1.5	0.63 ± 0.02	0.27 ± 0.01	0.17 ± 0.01	$351. \pm 20$	16.6 ± 2.2	$383. \pm 20$	420

34 ggF, 1 VBF, 0 VH

ATLAS arxiV:1408.7084
γγ categories



4l counting

ATLAS CERN-PH-EP-2014-122 (submitted to PRD)

Final state	Signal full mass range	Signal	ZZ^*	$Z+\text{jets}, t\bar{t}$	s/b	Expected	Observed
			$\sqrt{s}=7$ TeV and $\sqrt{s}=8$ TeV				
4μ	6.80 ± 0.67	6.20 ± 0.61	2.82 ± 0.14	0.79 ± 0.13	1.7	9.81 ± 0.64	14
$2e2\mu$	4.58 ± 0.45	4.04 ± 0.40	1.99 ± 0.10	0.69 ± 0.11	1.5	6.72 ± 0.42	9
$2\mu 2e$	3.56 ± 0.36	3.15 ± 0.32	1.38 ± 0.08	0.72 ± 0.12	1.5	5.24 ± 0.35	6
$4e$	3.25 ± 0.34	2.77 ± 0.29	1.22 ± 0.08	0.76 ± 0.11	1.4	4.75 ± 0.32	8
Total	18.2 ± 1.8	16.2 ± 1.6	7.41 ± 0.40	2.95 ± 0.33	1.6	26.5 ± 1.7	37

Four new events,one missing one

CMS-HIG-13-02

Channel	$4e$	$2e2\mu$	4μ	4ℓ
ZZ background	1.1 ± 0.1	3.2 ± 0.2	2.5 ± 0.2	6.8 ± 0.3
$Z+X$ background	0.8 ± 0.2	1.3 ± 0.3	0.4 ± 0.2	2.6 ± 0.4
All backgrounds	1.9 ± 0.2	4.6 ± 0.4	2.9 ± 0.2	9.4 ± 0.5
$m_H = 125$ GeV	3.0 ± 0.4	7.9 ± 1.0	6.4 ± 0.7	17.3 ± 1.3
$m_H = 126$ GeV	3.4 ± 0.5	9.0 ± 1.1	7.2 ± 0.8	19.6 ± 1.5
Observed	4	13	8	25

CMS systematics

TABLE VI. Effect of systematic uncertainties on the yields of signal ($m_H = 126$ GeV) and background processes for the 8 TeV data set and the 0/1-jet category. Uncertainties appearing on the same line are 100% correlated, with two exceptions: those related to the missing higer orders are not correlated, and those from the α_S + PDG (gg) in $t\bar{t}H$ are 100% anticorrelated. Uncertainties for the 7 TeV data set are similar.

	Signal ($m_H = 126$GeV)				Backgrounds		
Source	ggH	VBF	VH	$t\bar{t}H$	$q\bar{q} \to ZZ$	$gg \to ZZ$	$Z + X$
α_S + PDF (gg)	7.2%	⋯	⋯	7.8%	⋯	7.2%	⋯
α_S + PDF ($q\bar{q}$)	⋯	2.7%	3.5%	⋯	3.4%	⋯	⋯
Missing higher orders	7.5%	0.2%	0.4%, 1.6%	6.6%	2.9%	24%	⋯
Signal acceptance	2%				⋯	⋯	⋯
BR($H \to ZZ$)	2%				⋯	⋯	⋯
Luminosity	2.6%						⋯
Electron efficiency	10% (4e), 4.3% (2e2μ)						⋯
Muon efficiency	4.3% (4μ), 2.1% (2e2μ)						⋯
Control region	⋯	⋯	⋯	⋯	⋯	⋯	40%

ATLAS Systematic uncertainties in H->γγ

ATLAS CERN-PH-EP-2014-122 (submitted to PRD)

Table 2: Summary of the relative systematic uncertainties (in %) on the $H \to \gamma\gamma$ mass measurement for the different categories described in the text. The first seven rows give the impact of the photon energy scale systematic uncertainties, grouped into seven classes.

	Unconverted					Converted				
	Central		Rest		Trans.	Central		Rest		Trans.
Class	low p_{Tt}	high p_{Tt}	low p_{Tt}	high p_{Tt}		low p_{Tt}	high p_{Tt}	low p_{Tt}	high p_{Tt}	
$Z \to e^+e^-$ calibration	0.02	0.03	0.04	0.04	0.11	0.02	0.02	0.05	0.05	0.11
LAr cell non-linearity	0.12	0.19	0.09	0.16	0.39	0.09	0.19	0.06	0.14	0.29
Layer calibration	0.13	0.16	0.11	0.13	0.13	0.07	0.10	0.05	0.07	0.07
ID material	0.06	0.06	0.08	0.08	0.10	0.05	0.05	0.06	0.06	0.06
Other material	0.07	0.08	0.14	0.15	0.35	0.04	0.04	0.07	0.08	0.20
Conversion reconstruction	0.02	0.02	0.03	0.03	0.05	0.03	0.02	0.05	0.04	0.06
Lateral shower shape	0.04	0.04	0.07	0.07	0.06	0.09	0.09	0.18	0.19	0.16
Background modeling	0.10	0.06	0.05	0.11	0.16	0.13	0.06	0.14	0.18	0.20
Vertex measurement	0.03									
Total	0.23	0.28	0.24	0.30	0.59	0.21	0.25	0.27	0.33	0.47

CMS uncertainties in H->γγ (mass) 1407.0558

Source of uncertainty	Uncertainty in $\hat{m}_H$ (GeV)
Imperfect simulation of electron-photon differences	0.10
Linearity of the energy scale	0.10
Energy scale calibration and resolution	0.05
Other	0.04
All systematic uncertainties in the signal model	0.15
Statistical	0.31
Total	0.35

ATLAS CERN-PH-EP-2014-122 (submitted to PRD)

Systematic uncertainty on combined mass is ~180 MeV

(compared to ~540 MeV in PLB Summer 2013 publication)

Systematic	Uncertainty on m_H [MeV]
LAr syst on material before presampler (barrel)	70
LAr syst on material after presampler (barrel)	20
LAr cell non-linearity (layer 2)	60
LAr cell non-linearity (layer 1)	30
LAr layer calibration (barrel)	50
Lateral shower shape (conv)	50
Lateral shower shape (unconv)	40
Presampler energy scale (barrel)	20
ID material model ($\|\eta\| < 1.1$)	50
$H \to \gamma\gamma$ background model (unconv rest low p_{Tt})	40
$Z \to ee$ calibration	50
Primary vertex effect on mass scale	20
Muon momentum scale	10
Remaining systematic uncertainties	70
Total	180

ATLAS H->γγ categories

ATLAS CERN-PH-EP-2014-122 (submitted to PRD)

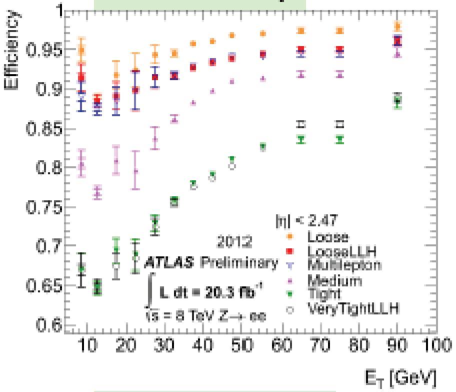
Category	n_{sig}	FWHM [GeV]	σ_{eff} [GeV]	b in $\pm\sigma_{eff90}$	s/b [%]	$s/\sqrt{b}$
			$\sqrt{s}$=8 TeV			
Inclusive	402.	3.69	1.67	10670	3.39	3.50
Unconv. central low p_{Tt}	59.3	3.13	1.35	801	6.66	1.88
Unconv. central high p_{Tt}	7.1	2.81	1.21	26.0	24.6	1.26
Unconv. rest low p_{Tt}	96.2	3.49	1.53	2624	3.30	1.69
Unconv. rest high p_{Tt}	10.4	3.11	1.36	93.9	9.95	0.96
Unconv. transition	26.0	4.24	1.86	910	2.57	0.78
Conv. central low p_{Tt}	37.2	3.47	1.52	589	5.69	1.38
Conv. central high p_{Tt}	4.5	3.07	1.35	20.9	19.4	0.88
Conv. rest low p_{Tt}	107.2	4.23	1.88	3834	2.52	1.56
Conv. rest high p_{Tt}	11.9	3.71	1.64	144.2	7.44	0.89
Conv. transition	42.1	5.31	2.41	1977	1.92	0.85
			$\sqrt{s}$=7 TeV			
Inclusive	73.9	3.38	1.54	1752	3.80	1.59
Unconv. central low p_{Tt}	10.8	2.89	1.24	128	7.55	0.85
Unconv. central high p_{Tt}	1.2	2.59	1.11	3.7	30.0	0.58
Unconv. rest low p_{Tt}	16.5	3.09	1.35	363	4.08	0.78
Unconv. rest high p_{Tt}	1.8	2.78	1.21	13.6	11.6	0.43
Unconv. transition	4.5	3.65	1.61	125	3.21	0.36
Conv. central low p_{Tt}	7.1	3.28	1.44	105	6.06	0.62
Conv. central high p_{Tt}	0.8	2.87	1.25	3.5	21.6	0.40
Conv. rest low p_{Tt}	21.0	3.93	1.75	695	2.72	0.72
Conv. rest high p_{Tt}	2.2	3.43	1.51	24.7	7.98	0.40
Conv. transition	8.1	4.81	2.23	365	2.00	0.38

ATLAS object reconstruction

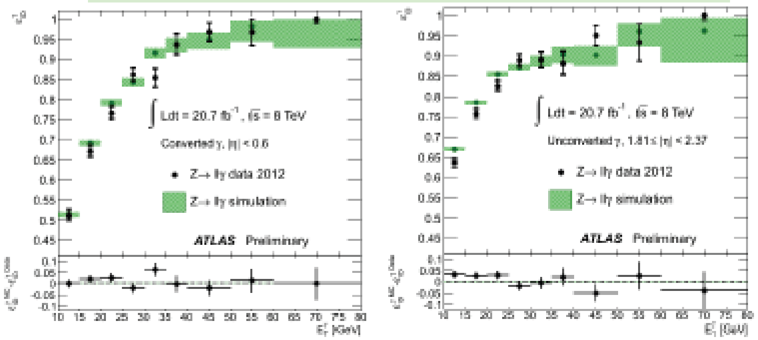
arxiv:1407.5063

μ's from J/ψ, Z, Υ(5M) e's from Z->ee (7M)

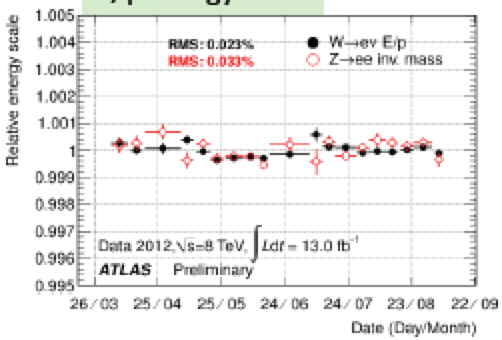
e ID efficiency



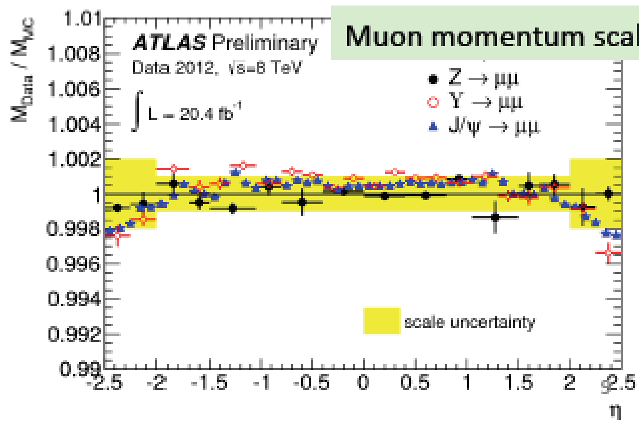
γ ID efficiency (for conv. and unconv. photons)



e/γ energy scale



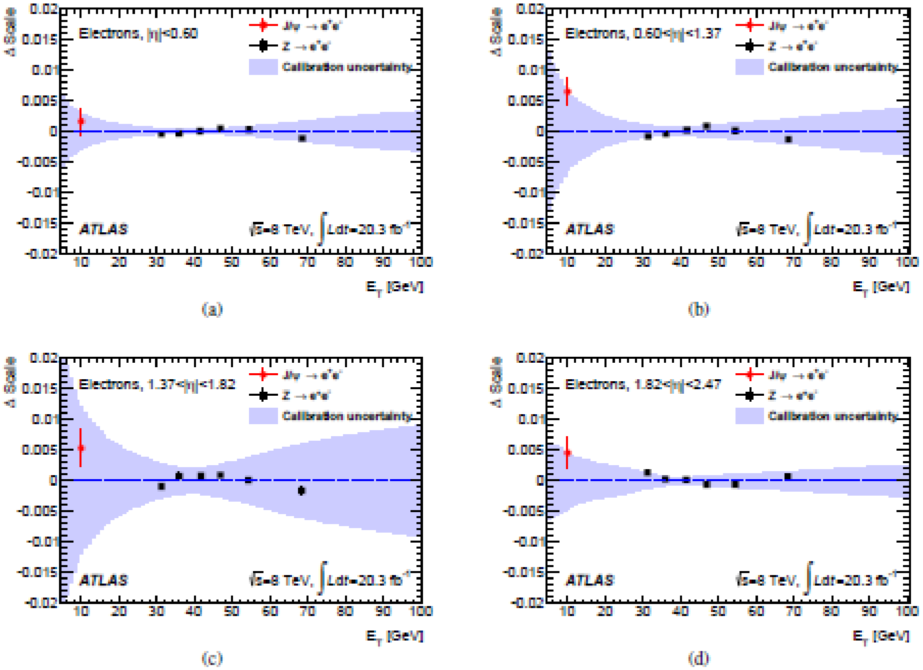
Muon momentum scale

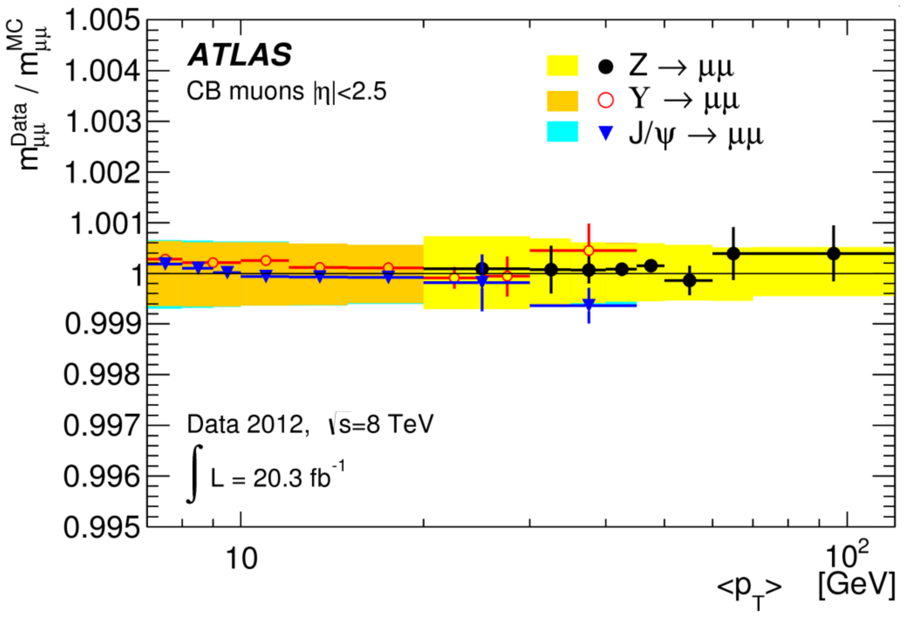


Total uncertainty on *e* energy scale: 0.03%-0.3% for E^e_T ~ 40 GeV
Total uncertainty on γ energy scale: 0.2%-0.6% for E^γ_T~ 60 GeV
Total uncertainty on μ: from 0.04% for η ~ 0 to 0.2% for |η| > 2.0

Electron energy scale 0.03% to 0.05% for 40 GeV E_T e's

accurate layer intercalibration, knowledge of material, cluster energy correction, millions of Z->ee and checked with J/ψ->ee and Z->eeγ

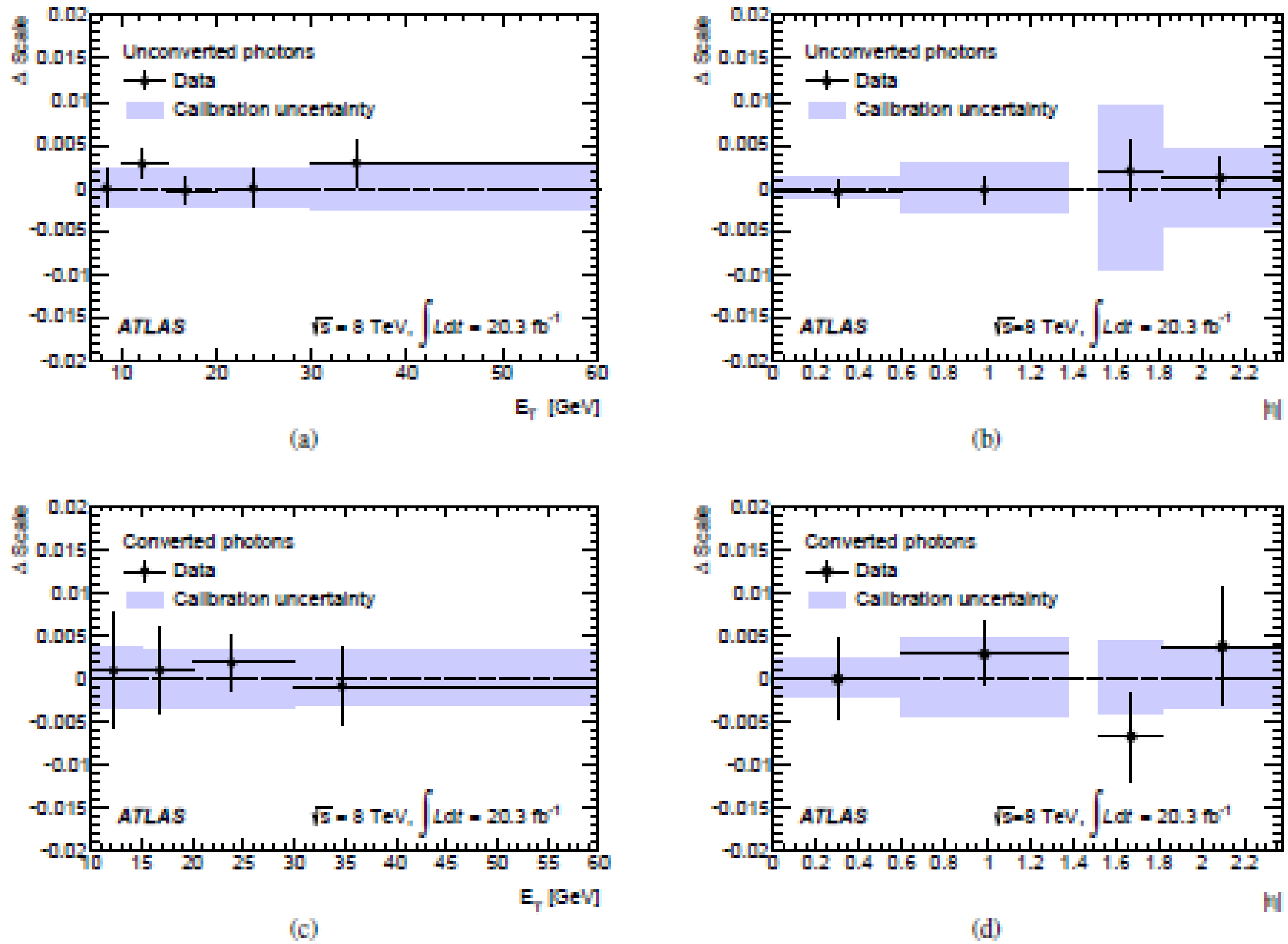




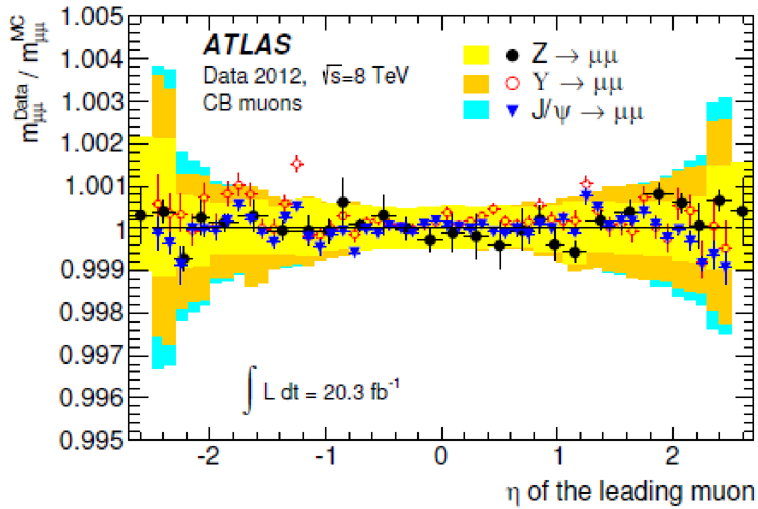
Photon energy scale intercalibration, cluster energy

0.2-0.5% (unconverted 0.2-0.9%)

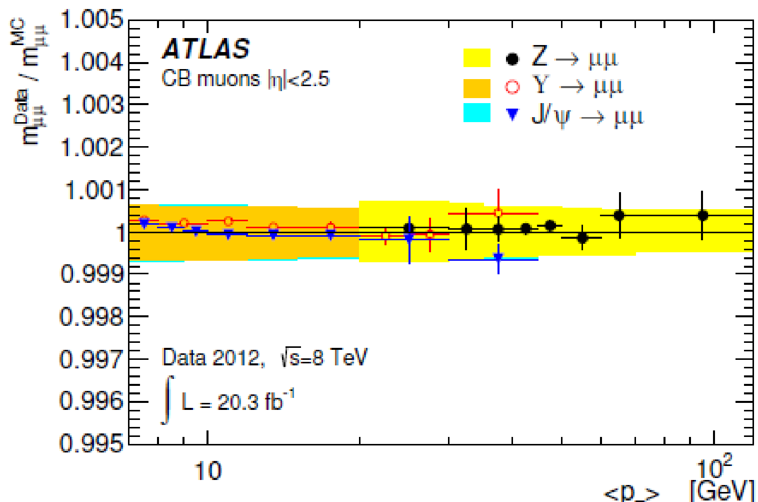
Δscale=difference of measured Z->llγ and normal energy scale



Better alignment of ID and muon spectrometer
New dimuon invariant mass calibration with 9M Z and and 6M J/ψ,checked on Υ's 0.02%(0.5%) in barrel (end-cap) impact on four muon mass 40MeV



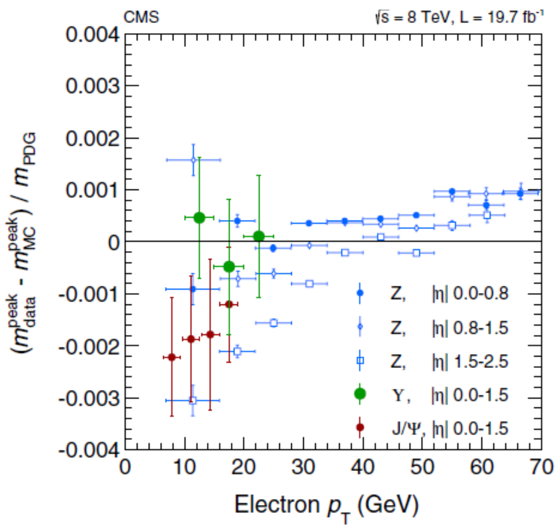
(a)



ATLAS CERN-PH-EP-2014-122 (submitted to PRD)

CMS calibration

Phys.Rev. D89 (2014) 092007



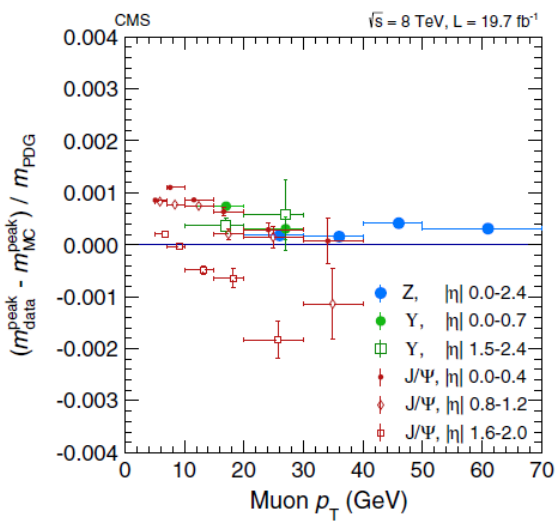


FIG. 2 (color online). Relative difference between the dilepton

TABLE I. Number of $Z \to \ell^+\ell^-$, $J/\psi \to \ell^+\ell^-$ and $\Upsilon(\mathrm{nS}) \to \ell^+\ell^-$ [sum of $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$] used to calibrate or validate lepton momentum scale and resolution and to measure lepton efficiencies ($Z \to \ell^+\ell^-$ only) in 7 and 8 TeV data. Low-mass dimuon resonances are collected with specialized triggers.

ℓ	$Z \to \ell^+\ell^-$	$J/\psi \to \ell^+\ell^-$	$\Upsilon(\mathrm{nS}) \to \ell^+\ell^-$
e	10^7	5×10^3	2.5×10^4
μ	1.4×10^7	2.7×10^7	1.5×10^7

ATLAS
MVA variables VH new analysis

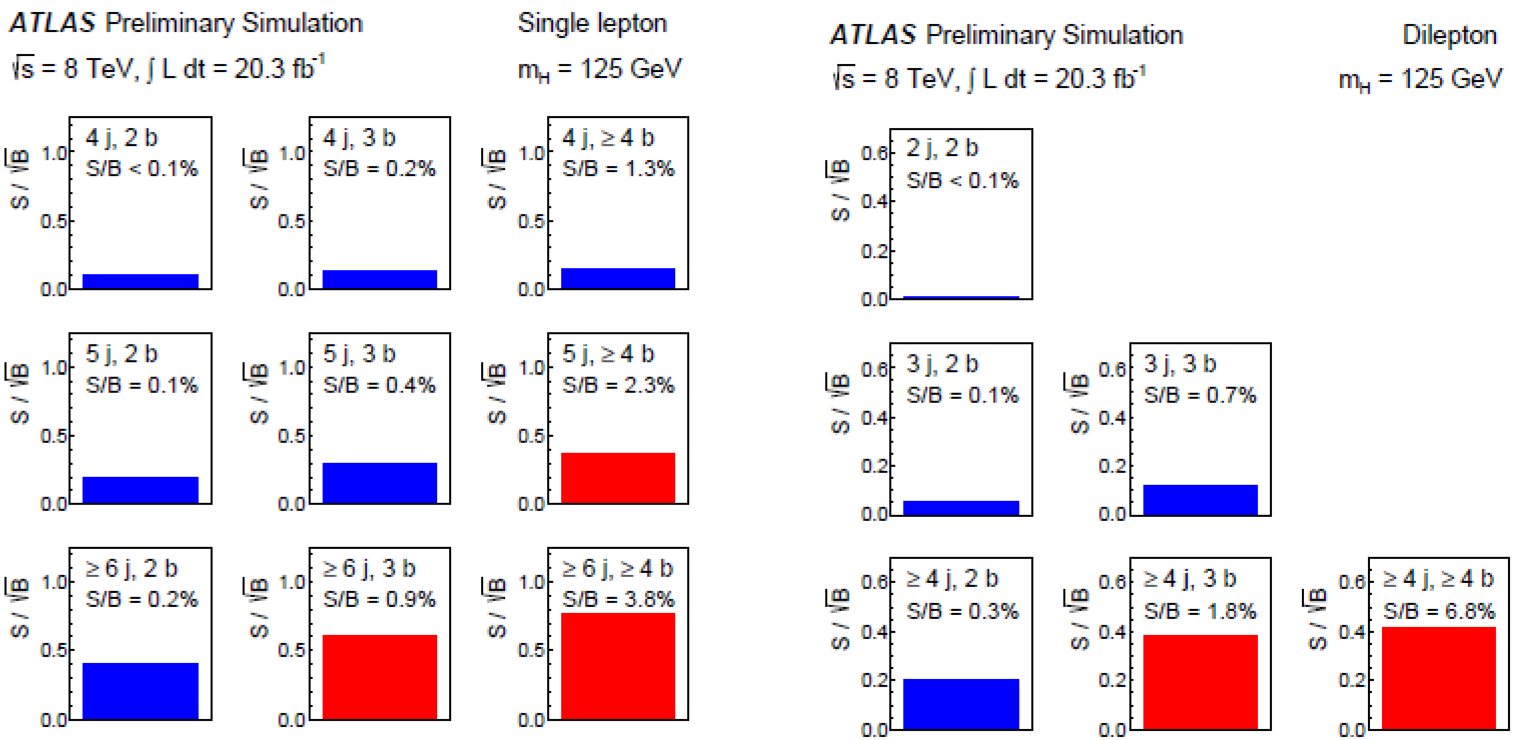
Variable	0-Lepton	1-Lepton	2-Lepton
p_{T}^{V}		$\times$	$\times$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$\times$	$\times$	$\times$
$p_{\mathrm{T}}^{b_1}$	$\times$	$\times$	$\times$
$p_{\mathrm{T}}^{b_2}$	$\times$	$\times$	$\times$
m_{bb}	$\times$	$\times$	$\times$
$\Delta R(b_1, b_2)$	$\times$	$\times$	$\times$
$\|\Delta\eta(b_1, b_2)\|$	$\times$		$\times$
$\Delta\phi(V, bb)$	$\times$	$\times$	$\times$
$\|\Delta\eta(V, bb)\|$			$\times$
H_{T}	$\times$		
$\min[\Delta\phi(\ell, b)]$		$\times$	
m_{T}^{W}		$\times$	
$m_{\ell\ell}$			$\times$
$MV1c(b_1)$	$\times$	$\times$	$\times$
$MV1c(b_2)$	$\times$	$\times$	$\times$
	Only in 3-jet events		
$p_{\mathrm{T}}^{\mathrm{jet}_3}$	$\times$	$\times$	$\times$
m_{bbj}	$\times$	$\times$	$\times$

ttH(bbar) analysis

ATLAS NOTE

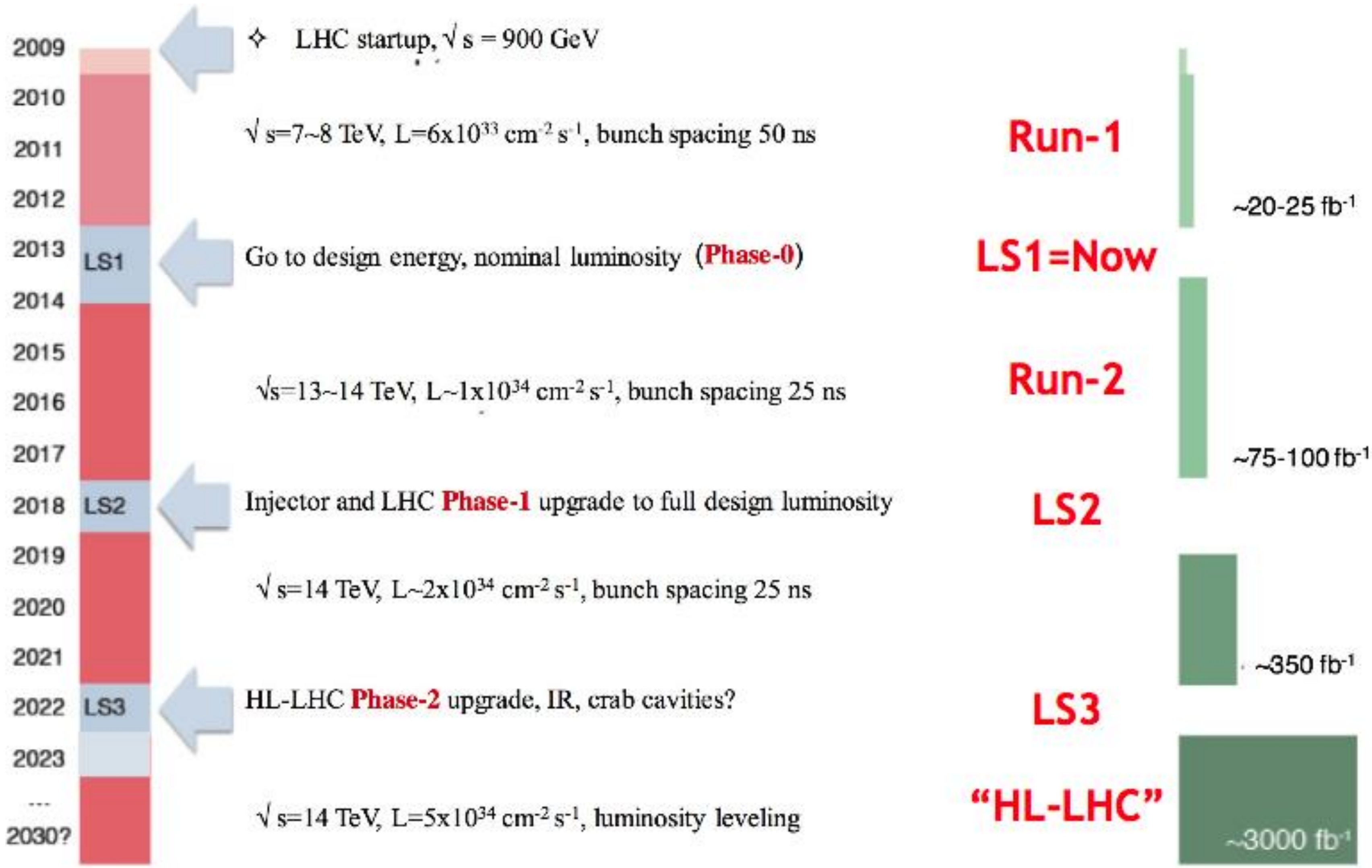
ATLAS-CONF-2014-011

March 24, 2014

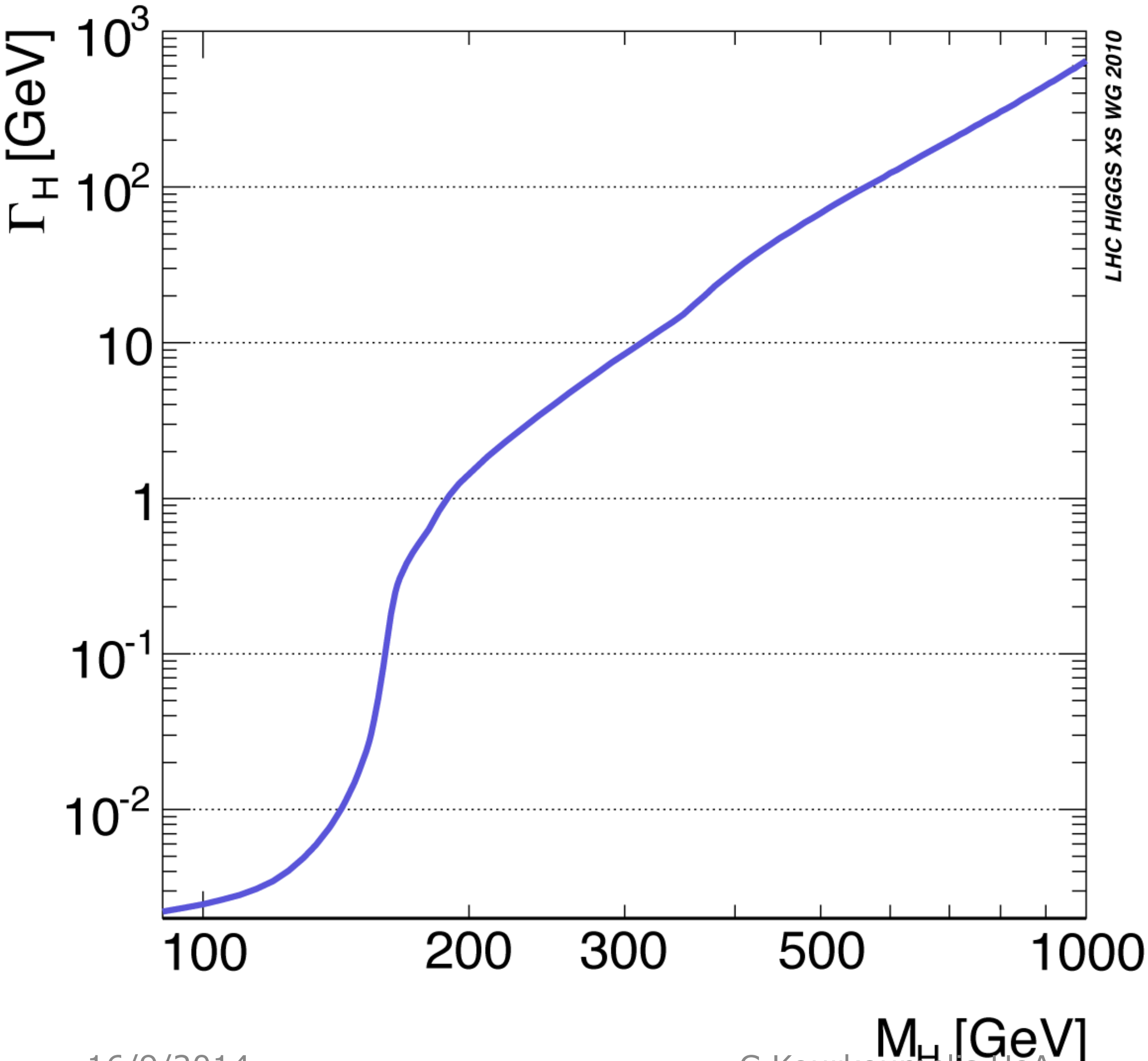


Signal-rich=red

LHC schedule



Higgs Width



Γ_H~4.2 MeV
10^{-22} sec
100fm

ATLAS arXiV:1209.0040

Table 1: Summary of the Higgs boson search channels in the ATLAS and CMS experiments by July 2012. The $\surd$ symbol indicates exclusive searches targetting the inclusive $\mathrm{gg} \to \mathrm{H}$ production, the associated production processes (with a vector boson or a top quark pair) or the vector boson fusion (VBF) production process.

Channel	m_{H}(GeV)	ggH		VBF		VH		$\mathrm{t\bar{t}H}$	
		ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
$\mathrm{H} \to \gamma\gamma$	110–150	$\surd$	$\surd$	$\surd$	$\surd$	-	-	-	-
$\mathrm{H} \to \tau^+\tau^-$	110–145	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	-	-
$\mathrm{H} \to \mathrm{b\bar{b}}$	110–130	-	-	-	-	$\surd$	$\surd$	-	$\surd$
$\mathrm{H} \to \mathrm{ZZ}^{(*)} \to \ell^+\ell^-\ell^+\ell^-$	110–600	$\surd$	$\surd$	-	-	-	-	-	-
$\mathrm{H} \to \mathrm{WW}^{(*)} \to \ell^+\nu\ell^-\overline{\nu}$	110–600	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	-	-

$$(\sigma \cdot \mathrm{BR})\,(ii \to \mathrm{H} \to ff\,) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

Zero width approximation

example

$$(\sigma \cdot \mathrm{BR})\,(\mathrm{gg} \to \mathrm{H} \to \gamma\gamma) \quad = \quad \sigma_{\mathrm{SM}}(\mathrm{gg} \to \mathrm{H}) \cdot \mathrm{BR}_{\mathrm{SM}}(\mathrm{H} \to \gamma\gamma) \cdot \frac{\kappa_{\mathrm{g}}^2 \cdot \kappa_{\gamma}^2}{\kappa_{\mathrm{H}}^2}$$

$$\kappa_F \quad = \quad \kappa_{\mathrm{t}} = \kappa_{\mathrm{b}} = \kappa_{\tau}$$

$$\kappa_V \quad = \quad \kappa_{\mathrm{W}} = \kappa_{\mathrm{Z}}$$

Statistics principles (from CMS-PAS-HIG-14-09)

To quantify the presence of an excess of events over what is expected for the background, we use the test statistic where the likelihood appearing in the numerator corresponds to the background-only hypothesis:

$$q_0 = -2 \ln \frac{\mathcal{L}(\text{data} \mid b, \hat{\theta}_0)}{\mathcal{L}(\text{data} \mid \hat{\mu} \cdot s + b, \hat{\theta})}, \text{ with } \hat{\mu} > 0, \tag{1}$$

where s stands for the signal expected under the SM Higgs hypothesis, μ is a signal strength modifier introduced to accommodate deviations from SM Higgs predictions, b stands for backgrounds, and θ are nuisance parameters describing systematic uncertainties. The value $\hat{\theta}_0$ maximizes the likelihood in the numerator under the background-only hypothesis, $\mu = 0$, while $\hat{\mu}$ and $\hat{\theta}$ define the point at which the likelihood reaches its global maximum.

The quantity p_0, henceforth referred to as the local p-value, is defined as the probability, under the background-only (b) hypothesis, to obtain a value q_0 at least as large as that observed in data, q_0^{data}:

$$p_0 = \mathrm{P}\left(q_0 \geq q_0^{\text{data}} \,\middle|\, b\right). \tag{2}$$

X-sections and BR's

For $m_H = 125$ GeV at $\sqrt{s} = 8$ TeV

	Cross-section		BR
$gg \to H$	19.27 pb	$H \to b\bar{b}$	58 %
$VBF \to H$	1.58 pb	$H \to WW^*$	22 %
WH	0.70 pb	$H \to gg$	9 %
ZH	0.42 pb	$H \to \tau\tau$	6 %
$t\bar{t}H$	0.13 pb	$H \to ZZ^*$	3 %
		$H \to \gamma\gamma$	0.2 %
		$H \to Z\gamma$	0.2 %
		$H \to \mu\mu$	10^{-4} %

ttH (H->bbar)

Important for **DIRECT MEASUREMENT of top Yukawa coupling (expect Y_t~1)**

σ_{total}~130fb @8TeV and 125 GeV

Main irreducible bkg: tt+bb, reducible: tt+light jets, also ttW/Z,W/Z+jets, dibonons, QCD

Not very well known bkg tt+jets σ~250 **pb (main challenge)**

BR (H->bbar) ~58% but σ*BR(H->bbar)~74fb

Both analyses with 8 TeV

One or both W's (from t) decaying leptonically, high multiplicity of jets and b-jets

tag tt decay by 2 leptons+jets or 1 lepton+jets+(MET)

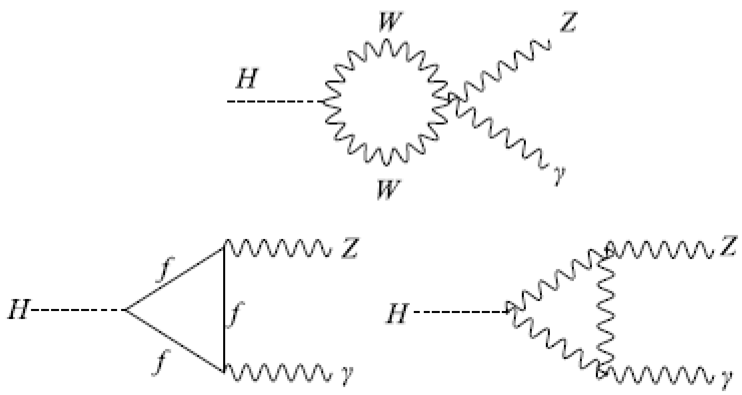
VERY promising @ RunII
x-section@13TeV~4*(x-section @8TeV)

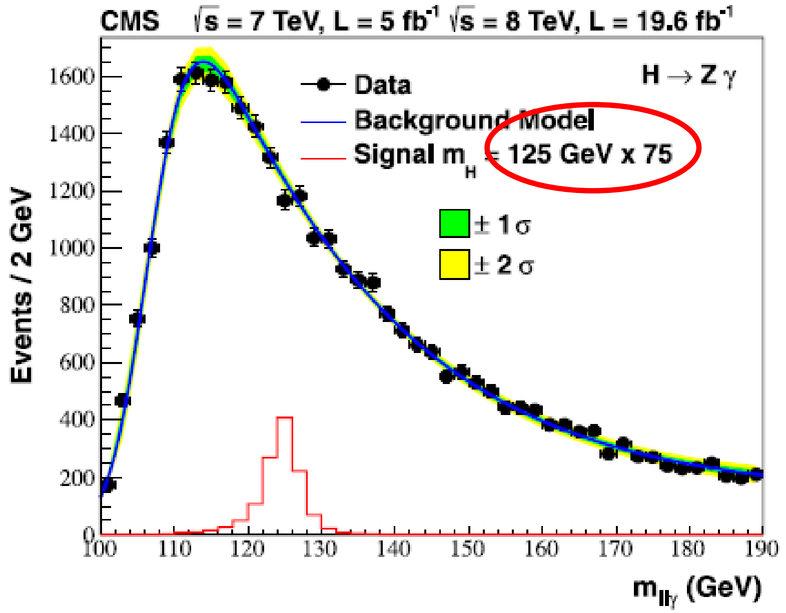
ATLAS-CONF-2014-011

CMS-HIG-14-10

H->Zγ

Note:Rare decay BUT goes through loops ->sensitive to new physics





ATLAS+CMS 7+8 TeV data

σ*BR~2 fb, **BR~2*10^{-3}** (similar to H->γγ), S/B~1% low BR and high bkg

Irreducible bkg= Z+γ continuum(82%), Z+γ radiation, Z+jets (17%)

H->llγ cross-section~ H-> 4l cross-section but 5% of H->γγ

Signal two OSSF isolated leptons close to the Z mass + isolated high p_T photon

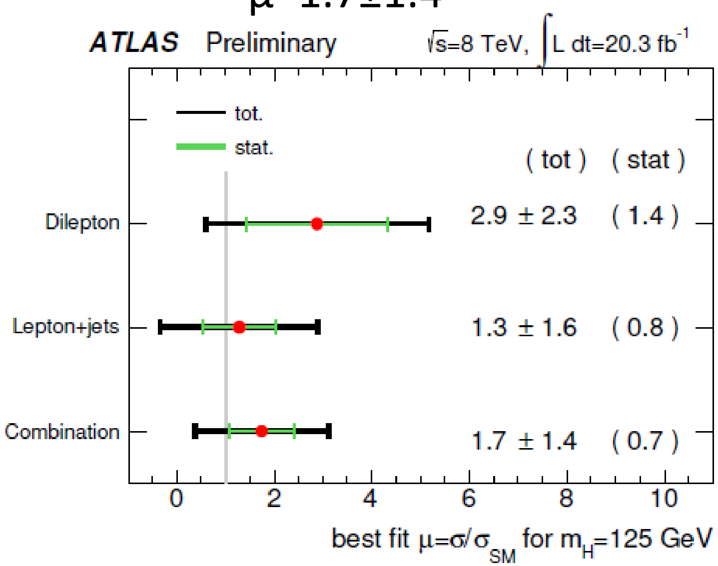
ttH

Important for **DIRECT MEASUREMENT of top Yukawa coupling (expect Y_t~1 SM)** , **σ_{total}~130fb**
Main irreducible bkg: tt+bb, reducible: tt+light jets, also ttW/Z,W/Z+jets, dibonons, QCD,
Not very well known bkg tt+bb σ~250 **pb (main challenge)**

NN for several ~10 discriminant variables trained in each signal region.
Define signal rich regions: 2lepton+≥ 4jets(≥ 3b-jets) or 1 lepton +≥5jets (≥3b-jets), CR's,SR's

Limit/SM@ 95%CL->**4.1**(2.6) @125 GeV

μ=1.7±1.4*

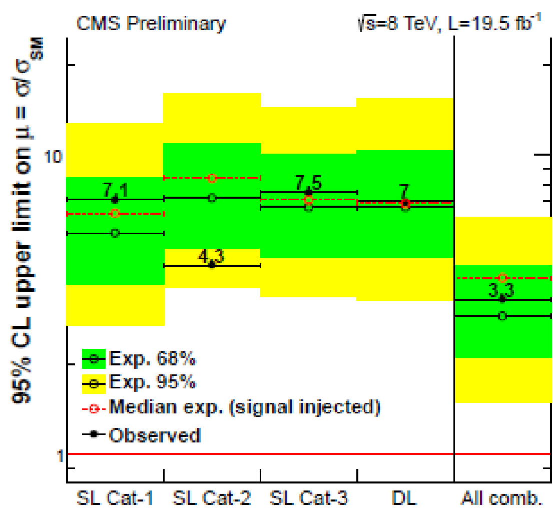


*ATLAS-CONF-2014-011 (revised in 2014-043)

Matrix element method to distinguish signal over bkg of tt+jets (tt+bb)
Four categories: Three 1lepton+ ≥5jets, one 2leptons+ ≥4jets

Limit/SM @ 68%CL-> **3.3**(2.9)

$$\mu = 0.67^{+1.35}_{-1.33}$$



CMS-HIG-14-10

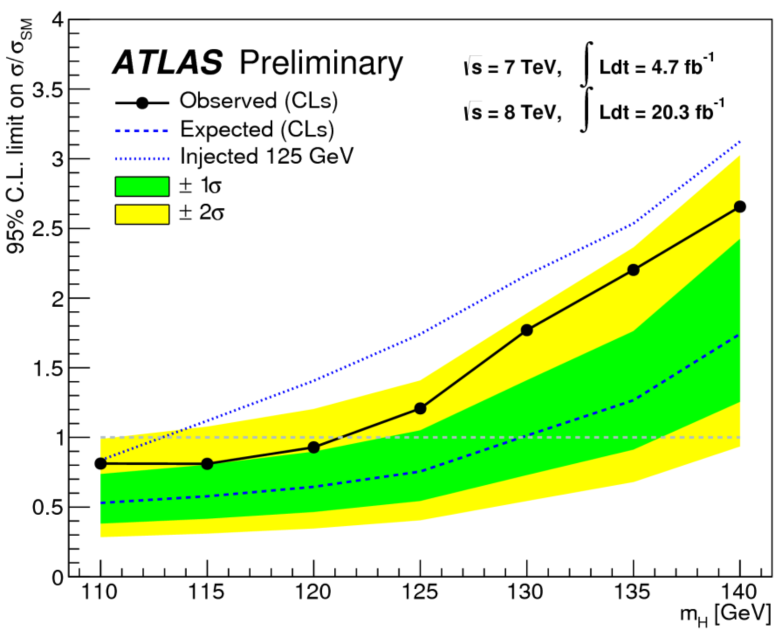
NEW !!!

VH->bbar

Direct probe of **down-type quark couplings σ*BR~150 fb , BR (H->bbar)~58%**
bkg V+jets, ttbar, top,dibosons, multijets. **Use VZ (Z->bbar) as benchmark**
Require two b jets, look for signal excess in bbar invariant mass, **broad peak** (σ=10%),

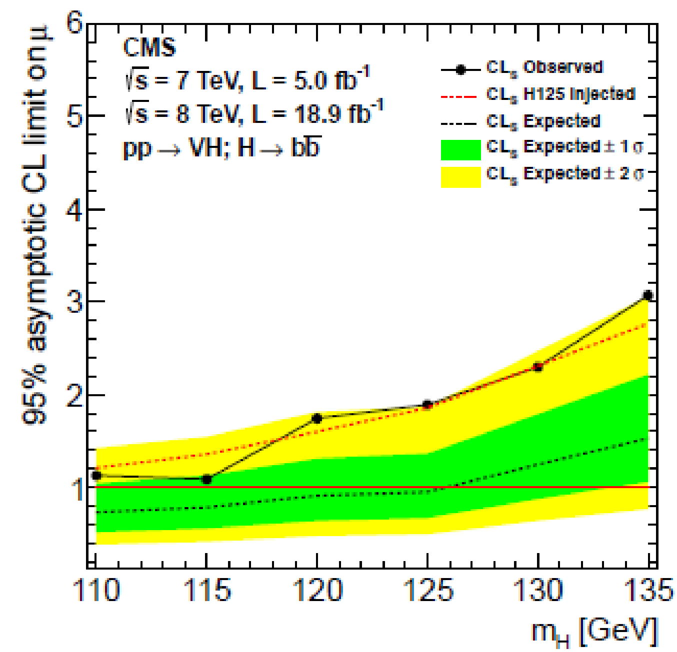
2 b-tagged jets, Z->νν,W->lν,Z->ll,
Bins of P_T^V,#leptons,#jets, #b-jets
Control regions for bkg,data driven for QCD bkg

MVA analysis, including b-tagging info



ATLAS-COM-PHYS-2014-024

Two b-tagged jets and P_T^V bins
MVA to extract signal
Z->νν,W->lν (l=e,μ,τ),Z->ll(l=e, μ)
14 BDT's for signal/bkg separation



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