Higgs boson : production and decays into bosons

28th Rencontres de Blois

29th may-3th June 2016

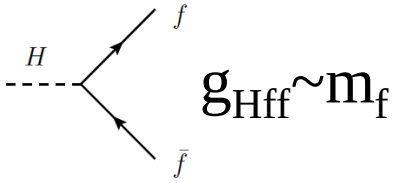
Marc Escalier, LAL, on behalf of ATLAS and CMS collaborations

Introduction

- Rich phenomenology of Higgs sector

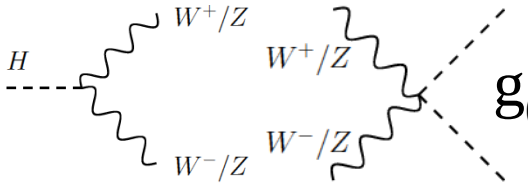
Higgs coupling=f(particles)

-Fermions :



$g_{Hff} \sim m_f$

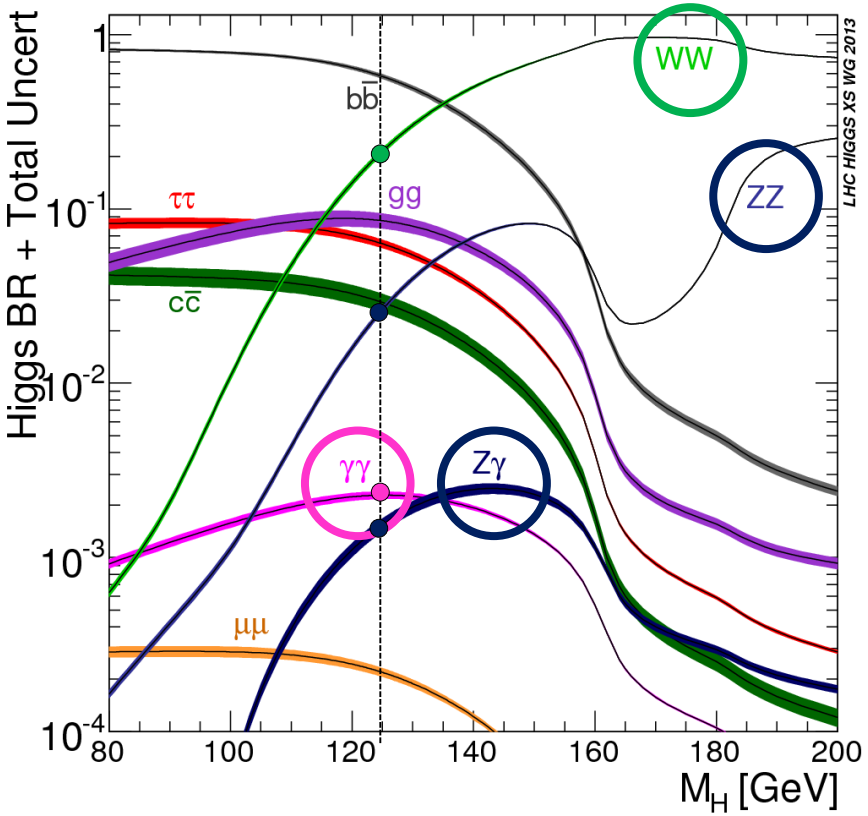
-Gauge bosons :



$g_{(H)HVV} \sim m_V^2$

-Higgs bosons :

$g_{(H)HHH} \sim m_H^2$



- Higgs→fermions : most : low resolution :

  H→bb (jets), H→ττ (jets, MET)

  H→μμ : long term (~HL-LHC)

see : Higgs boson parameters and fermionic decays Michal Bluj

- Higgs→bosons :

  ~channels with high mass resolution :

  H→γγ : S/B : few %, probe loops

  H→ZZ*→4l : low bkg ; S/B >1

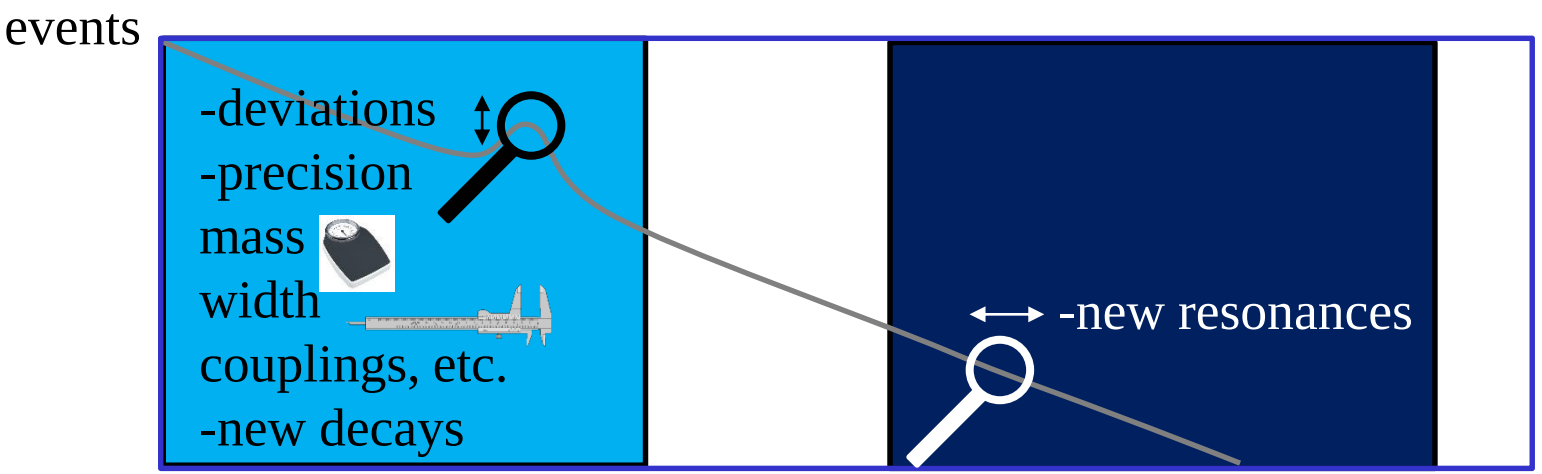
  H→WW→lνlν : worst resolution

  H→Zγ : rare, probe loops (in backup)

Significance (Z) : 3 σ : evidence

5 σ : observation

Introduction



	motivation	
	SM	BSM
Measurements on observed Higgs boson (at $m_H \approx 125$ GeV)	H→…, couplings, etc.	H→BSM, exotics
Searches involving observed Higgs boson or similar final state	pp→HH, rare decays, etc.	X→H+Y (including X→HH)

Experimental conditions : LHC : ATLAS, CMS

Run 1, 2011, $\sqrt{s}$=7 TeV, L=4.5-5.1 fb^{-1}, 2012, $\sqrt{s}$=8 TeV, L=20.3-19.7 fb^{-1}

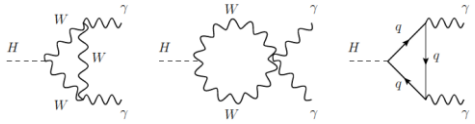
Run 2, 2015, $\sqrt{s}$=13 TeV, L=3.2-2.8 fb^{-1}

See more details : Status / highlights of LHC Run 2 Gigi Rolandi

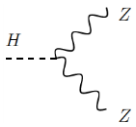
The channels, Run 1

- $H \rightarrow \gamma\gamma$

-2 high-p_T photons



- $H \rightarrow ZZ^* \rightarrow 4l$

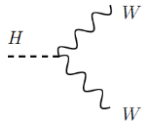


-2 high-p_T leptons pairs

-discriminant var :

separate $H \rightarrow ZZ^*$; ZZ^* bkg

- $H \rightarrow WW^* \rightarrow l\nu l\nu$



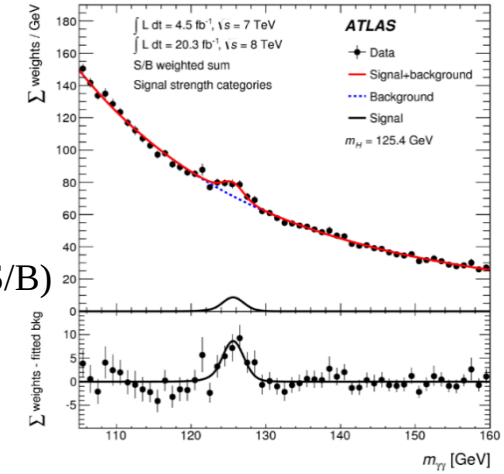
-2 high-p_T leptons, MET

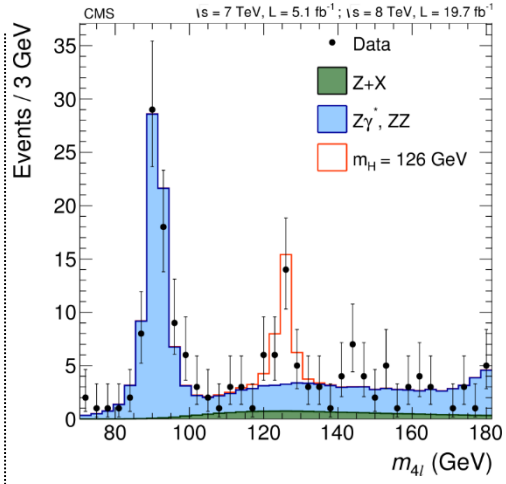
-topology leptons :

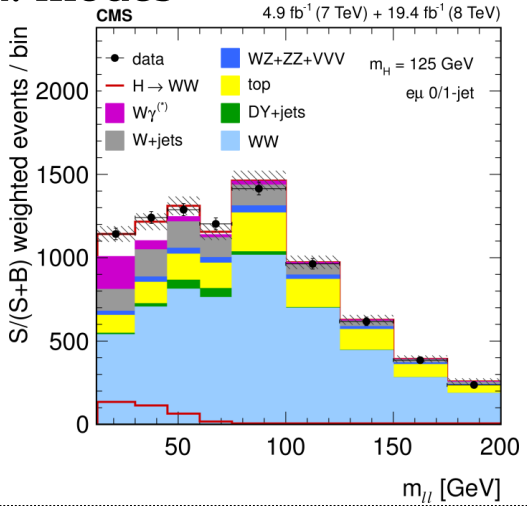
m_{ll}, spin correlation, etc.

categorization : sensitivity + prod. modes

(S/B)







ATLAS

Z_{obs}=5.2 σ (Z_{exp}=4.7 σ)
m_H=125.98 ± 0.42 (stat)
± 0.28 (syst) GeV
μ=1.17 +/- 0.27

Z_{obs}=8.1 σ (Z_{exp}=6.2 σ)
m_H=124.51 ± 0.52 (stat)
± 0.06 (syst) GeV
$\mu = 1.44^{+0.34}_{-0.31}$ (stat.) $^{+0.21}_{-0.11}$ (sys.)

Z_{obs}=6.1 σ (Z_{exp}=5.8 σ)
m_H=125.4 GeV (fixed)
$\mu = 1.09\ ^{+0.16}_{-0.15}$ (stat) $^{+0.17}_{-0.14}$ (syst)

CMS

Z_{obs}=5.7 σ (Z_{exp}=5.2 σ)
m_H=124.70 ± 0.31 (stat)
± 0.15 (syst) GeV
$\mu = 1.14\ ^{+0.26}_{-0.23}$

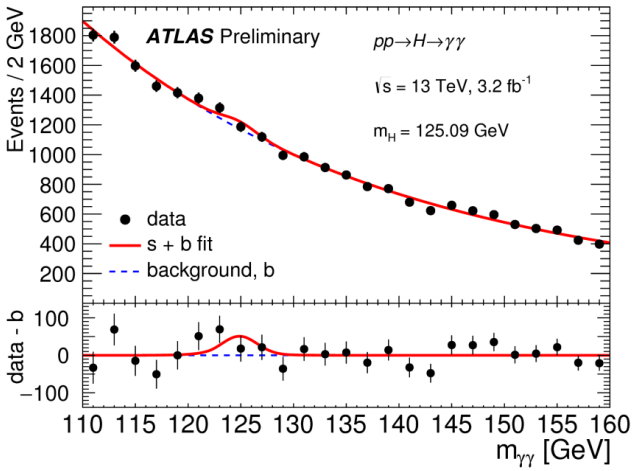
Z_{obs}=6.8 σ (Z_{exp}=6.7 σ)
m_H=125.6 ± 0.4 (stat.)
± 0.2 (syst.) GeV
$\mu = 0.93^{+0.26}_{-0.23}$ (stat.) $^{+0.13}_{-0.09}$ (sys.)

Z_{obs}=4.3 σ (Z_{exp}=5.8 σ)
$m_H = 125.5^{+3.6}_{-3.8}$ GeV
$\mu = 0.72^{+0.20}_{-0.18}$

Early Run 2 : 2015

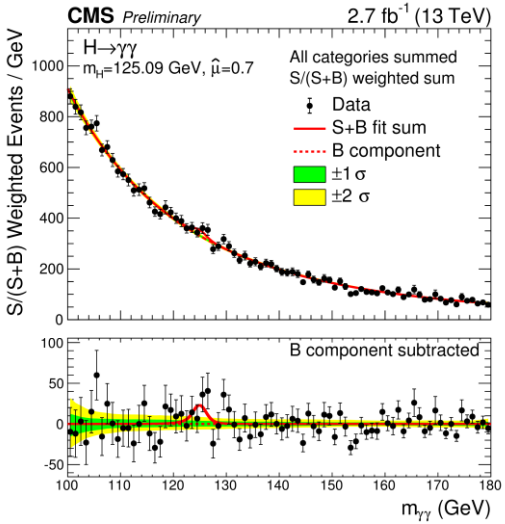
H→γγ

ATLAS m_H=125.09 GeV (fixed) CMS



inclusive

Z=1.5 σ
(exp. 1.9 σ)

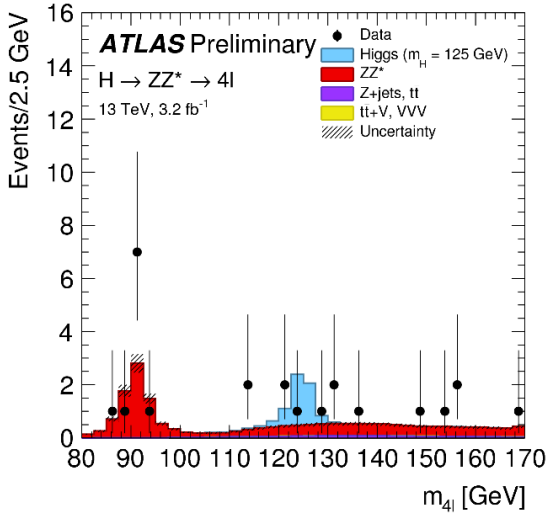


categories

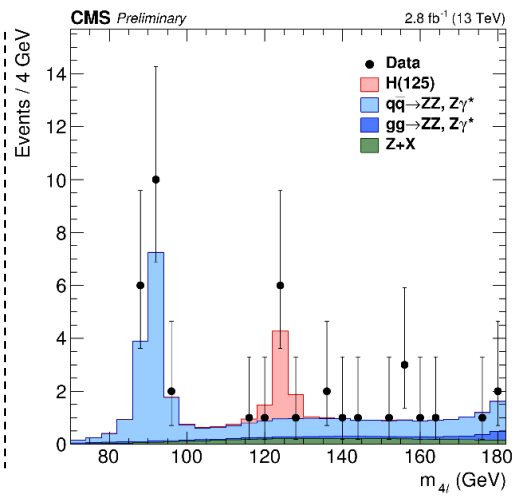
Z=1.7 σ (exp 2.7 σ)

$\mu = 0.69\ ^{+0.47}_{-0.42}$

H→ZZ→4l



inclusive



categories

Z=2.5 σ (exp : 3.4 σ)

$\mu = 0.82^{+0.57}_{-0,43}$

Not as competitive as Run 1, yet

Higgs mass and width

Good resolution of dibosons channels : H→γγ, H→ZZ→4l

- Mass m_H : first step for combination of other quantities (eg couplings)

  ATLAS-CMS : m_H=125.09 GeV ± 240 MeV (stat : ± 210 MeV ; syst : ± 110 MeV)

  uncert. : ~statistics syst : ~scales

- Width Γ_H (SM≈4 MeV)
  - Direct : $\Gamma_H \otimes \Gamma_{exp}$

    dominated by detector resolution
  - Indirect : -H→ZZ*, etc. : opening phase space above 2 x m_Z : ratio σ off-shell⇔on-shell

    $\sigma^{off-peak}_{gg\to H\to ZZ} \sim g^2_{ggH} g^2_{HZZ}$ $\sigma^{on-peak}_{gg\to H\to ZZ} \sim \frac{g^2_{ggH} g^2_{HZZ}}{\Gamma_H}$

    -H→γγ : interference gg→H→γγ ⇔gg→γγ

    prospectives studies only (ATLAS)

Limits on Γ_H

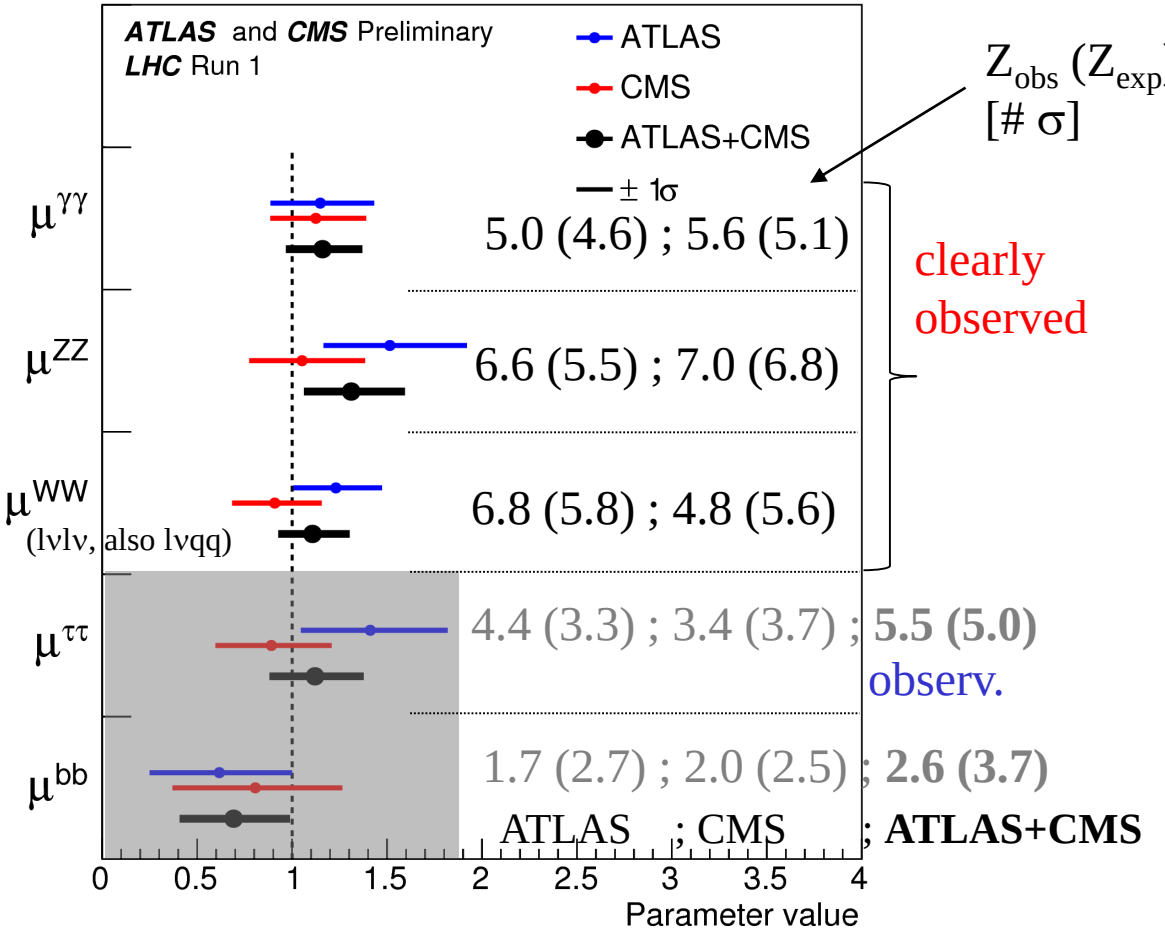
	ATLAS	CMS
• Direct		
H→γγ	<5.0 GeV at 95 % CL	<2.4 GeV at 95 % CL
H→ZZ*→4l	<2.6 GeV at 95 % CL	<3.4 GeV at 95 % CL
		comb : <1.7 GeV
• Indirect		
H→ZZ*→4l+…	<22.7 MeV at 95 % CL	<13 MeV at 95 % CL
ATL : llνν+H→WW*→eνμν		
CMS : H→WW*→lνlν		

[>3.5x10^{-9} MeV at 95 % CL (H→ZZ*→4l only) →1st cstrt on cτ$_H$]

see The profile of the H(125) from Run 1 Tatjana Lenz

Combination : decays and prod.

Decay channels



Z_{obs} (Z_{exp}) [# σ]

5.0 (4.6) ; 5.6 (5.1)

6.6 (5.5) ; 7.0 (6.8)

6.8 (5.8) ; 4.8 (5.6)

clearly observed

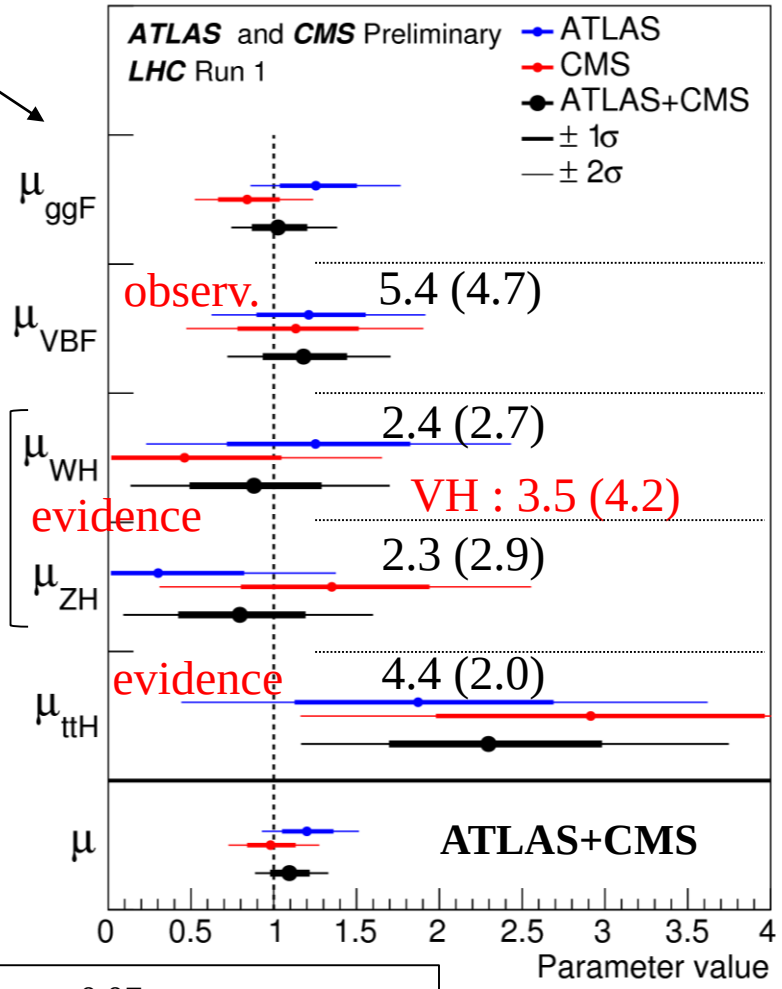
4.4 (3.3) ; 3.4 (3.7) ; **5.5 (5.0)**

observ.

1.7 (2.7) ; 2.0 (2.5) ; **2.6 (3.7)**

ATLAS ; CMS ; **ATLAS+CMS**

Prod. modes



observ. 5.4 (4.7)

2.4 (2.7)

evidence

VH : 3.5 (4.2)

2.3 (2.9)

evidence 4.4 (2.0)

$\mu = 1.09\ ^{+0.07}_{-0.07}\ (stat)\ ^{+0.04}_{-0.04}\ (exp.)\ ^{+0.03}_{-0.03}\ (th.\ bkg)\ ^{+0.07}_{-0.06}\ (th.\ sig)$

See also

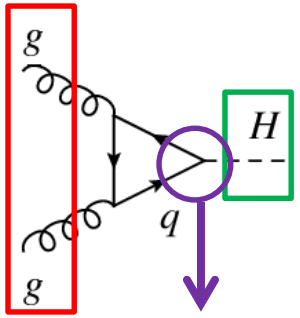
Higgs boson parameters and fermionic decays — Michal Bluj

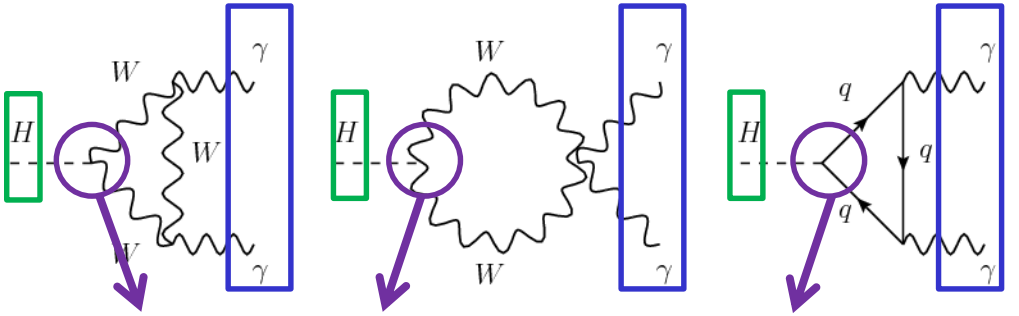
Higgs boson production (σ, dσ/dX) of the H(125) from Run1 — Mauro Donega

Combination : Higgs couplings

Initial state ii → intermediate state X (H) → final state ff (γγ)

eg : gg→H→γγ





κ : scale factor
⇔signal strength
(wrt SM)

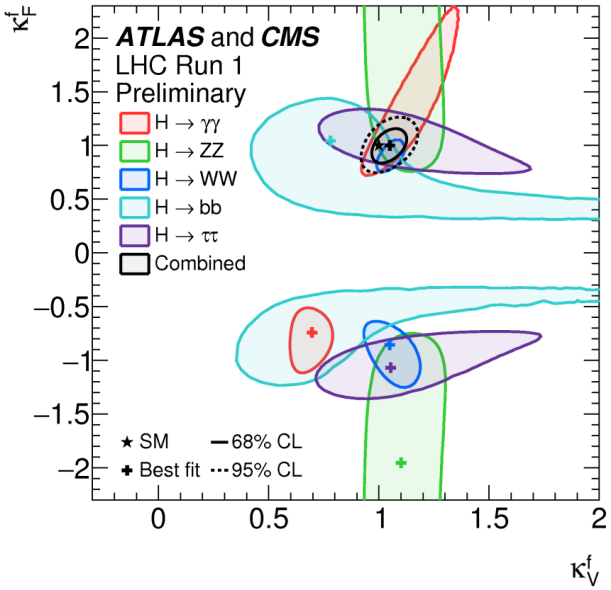
Htt →κ_t
Hbb→κ_b
ggH→$\kappa_g=f(\kappa_t, \kappa_b)$

HWW →κ_W

Hγγ→$\kappa_\gamma=f(\kappa_t, \kappa_b, \kappa_W, \kappa_\tau)$

Htt →κ_t
Hbb→κ_b
Hττ→κ_τ

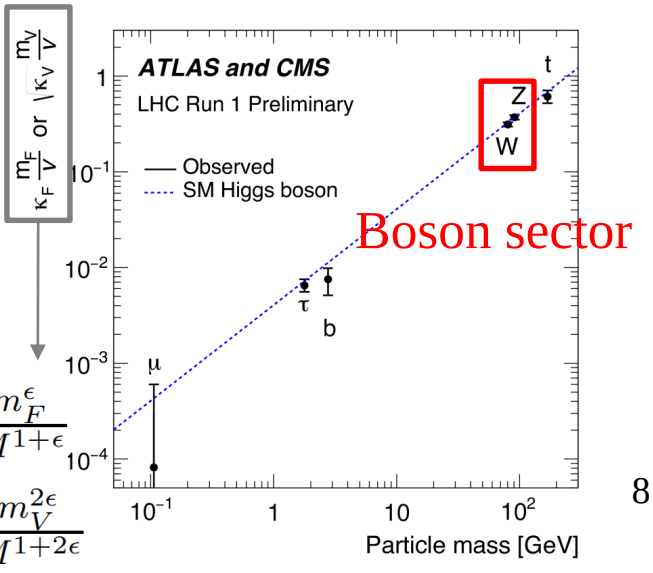
- Hff vs HVV



H→γγ : interf W, t : solve degeneracy

+ other studies

- Scaling couplings w/ mass



$$\begin{cases} \kappa_F = v\dfrac{m_F^{\epsilon}}{M^{1+\epsilon}} \\ \kappa_V = v\dfrac{m_V^{2\epsilon}}{M^{1+2\epsilon}} \end{cases}$$

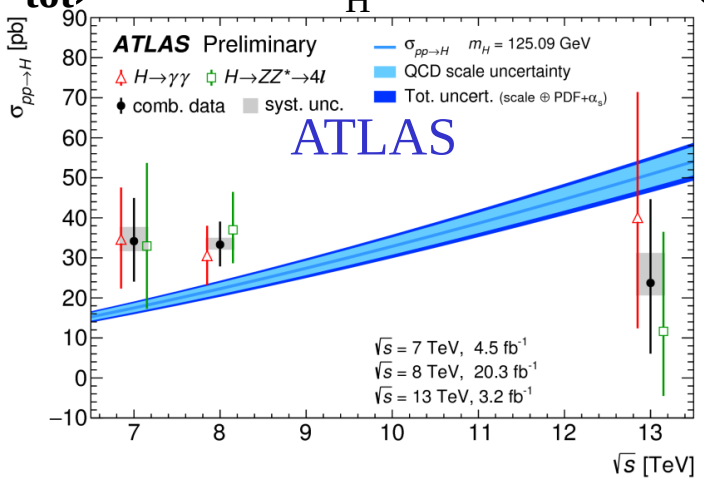
Cross-section measurements

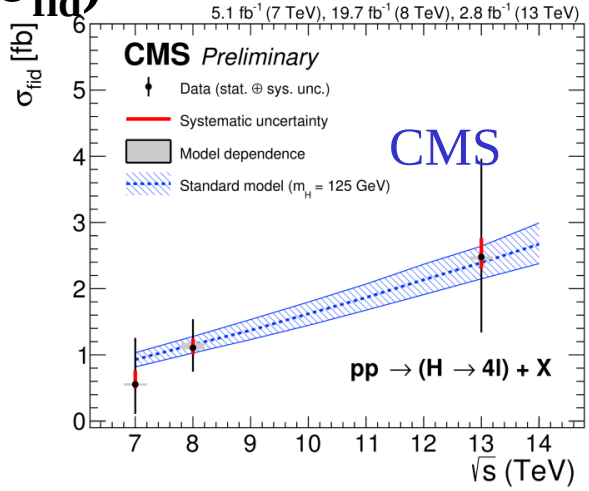
- σ_{fid}, σ_{tot} in various channels : H→γγ, H→ZZ*→4l , H→WW*

Good agreement with expectations

- Evolution with √s

(σ_{tot}) m_H=125.09 GeV (σ_{fid})

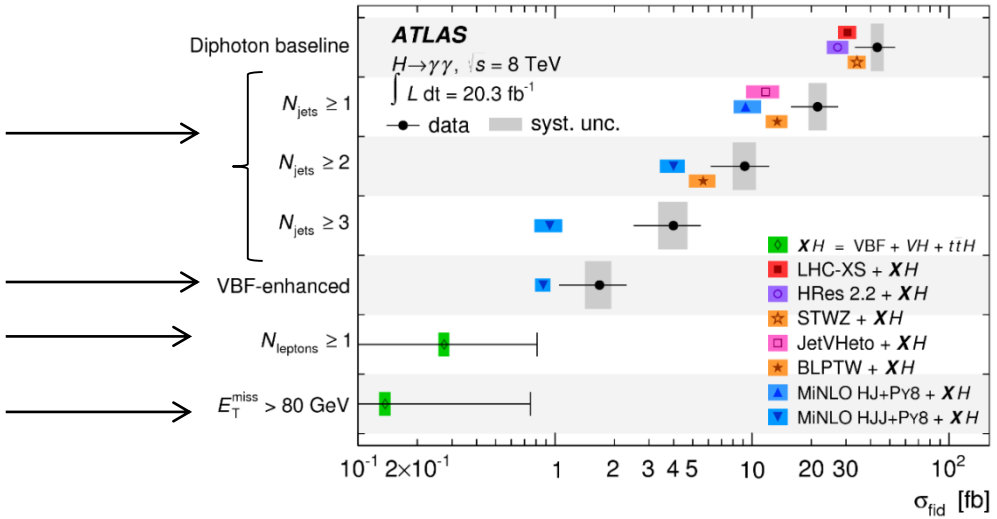




- Various phase spaces

(p_T^j>30 Gev, |y|<4.4)

VBF-region :
m_{jj}>400 GeV, $|\Delta y_{jj}|$>2.8, $|\Delta\phi_{\gamma\gamma,\,jj}|$>2.6
p_T>15 GeV, |η|<2.47
VH, H+DM, etc.



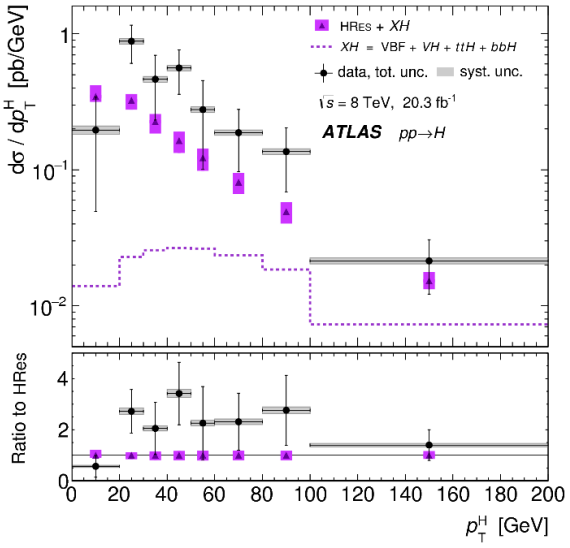
See also Higgs boson production (σ, dσ/dX) of the H(125) from Run1 Mauro Donega

dσ/dX

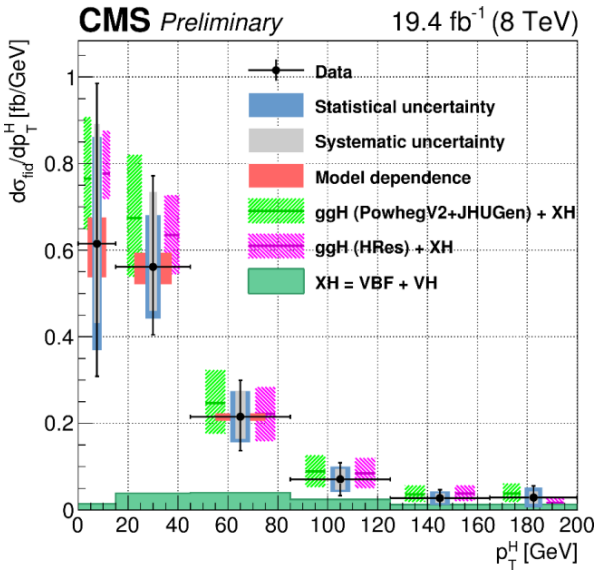
various observables : #objects, p_T, E_T, angles, etc.
various objects : photon, lepton, jet, MET, topology objects
various channels : H→γγ, H→ZZ*→4l, H→WW*→lν lν

Examples :

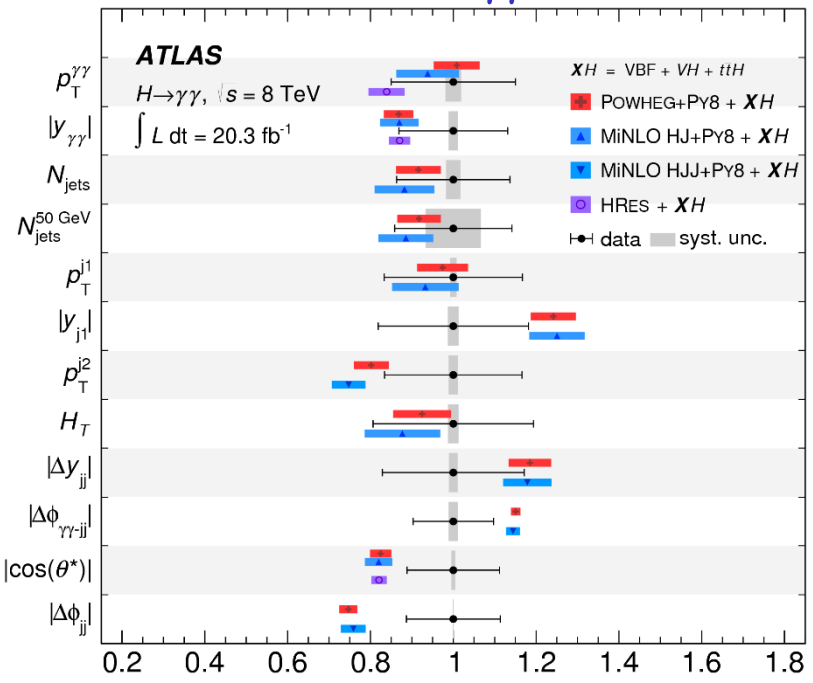
H→γγ + H→ZZ*→4l



H→WW(*)→eν μν



H→γγ



See also Higgs boson production (σ, dσ/dX) of the H(125) from Run1 Mauro Donega

Spin and J^{PC}

- Spin and parity $J^P=0^+$ tested alternative models (spin-0 and spin 2)

ATLAS

$H\rightarrow\gamma\gamma$, $ZZ\rightarrow 4l$, $WW^*\rightarrow e\nu\mu\nu$

CMS

$H\rightarrow\gamma\gamma$, $ZZ\rightarrow 4l$, $WW\rightarrow l\nu l\nu$, $Z\gamma^*\rightarrow 4l$, $\gamma^*\gamma^*\rightarrow 4l$

Variables : angular distributions (flat for spin 0), kinematics, etc.

>99 % CL exclusion tested alternative models to SM

Studies on anomalous couplings in EFT
CP violation : no deviation, but only large CP mixing excluded (above 30 %)

see also : The profile of the H(125) from Run 1 Tatjana Lenz

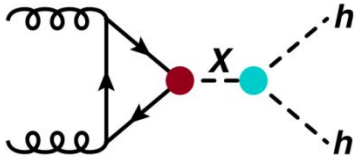
BSM

Dedicated presentations on BSM, in particular :

-generic	• Results on BSM Higgs bosons searches at ATLAS (Run 1 and Run 2)	Maddalena Giulini
-signature	• Search for diphoton resonances with the ATLAS experiment	Simone Michele Mazza
-SUSY	• Search for supersymmetry at ATLAS and CMS	Andrew James Whitbeck
	• SUSY searches at 13 TeV at ATLAS	Isabel Trigger
-exotics	• Searches for exotics at ATLAS and CMS	Claire Lee
	• Exotics searches at ATLAS	Ruggero Turra
	• Dark Matter searches at ATLAS	Giuliano Gustavino

Will restrict only to two selected topics

Resonant hh : a few examples

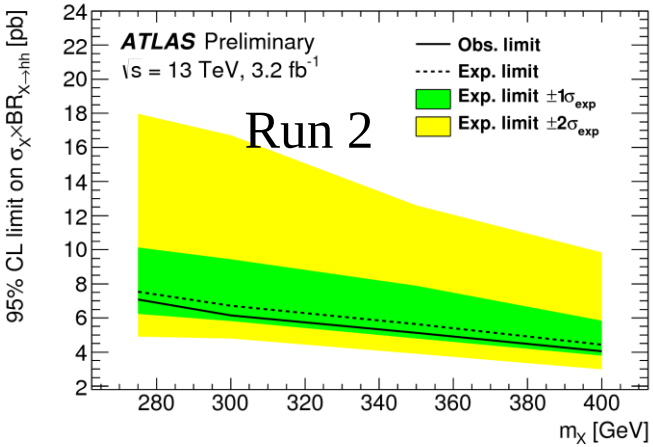


Decay of a resonance to Higgs boson pairs

ATLAS

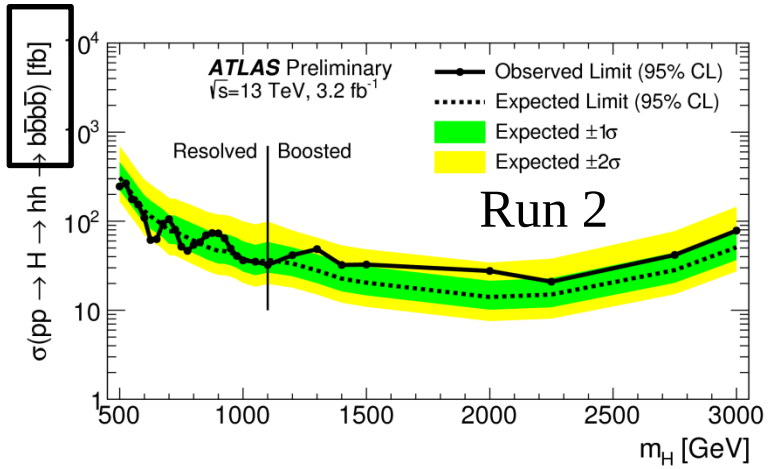
- h(γγ)h(bb)

$m_X \in$ [275-400] GeV
Limits : 7.0-4.0 pb



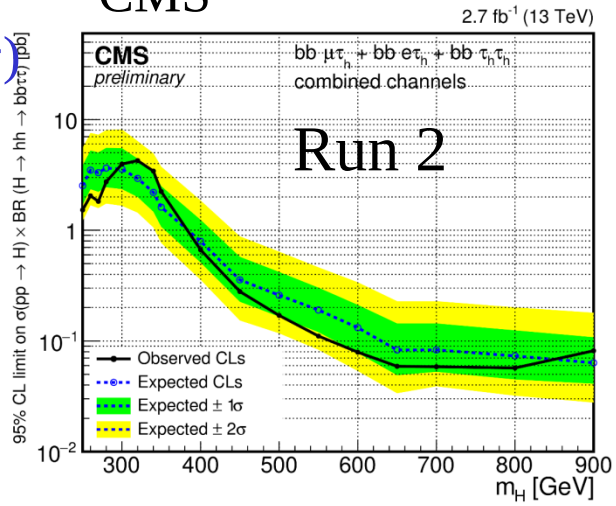
- h(bb)h(bb)

$m_H \in$ [500 ; 3000 GeV]
Limits 30-300 fb



CMS

- h(bb)h(ττ)



$m_H \in$ [250 ; 900] GeV
Limit : 1.53-0.082 pb

- ATLAS combination Run 1

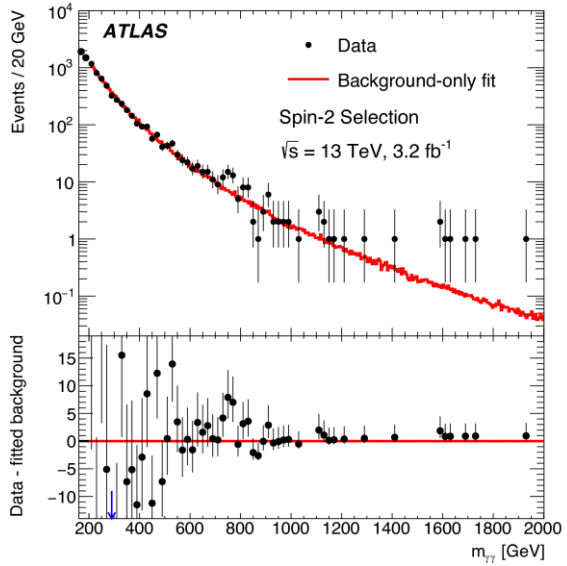
h(bb)h(ττ), h(γγ)h(WW*), h(γγ)h(bb), h(bb)h(bb)

Limits : m_H=260 GeV : 2.1 pb
m_H=1000 GeV : 0.011 pb

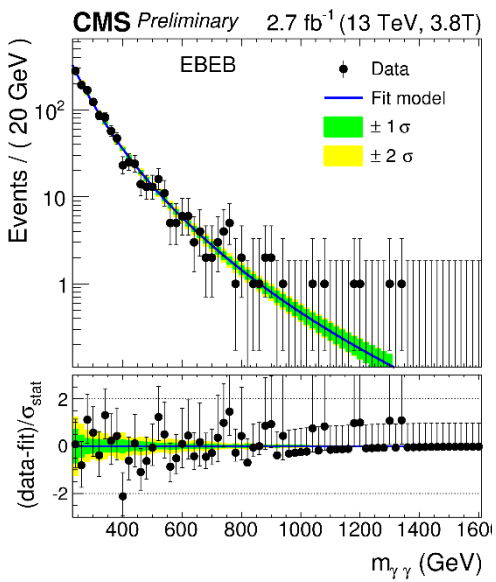
Search for high mass resonances

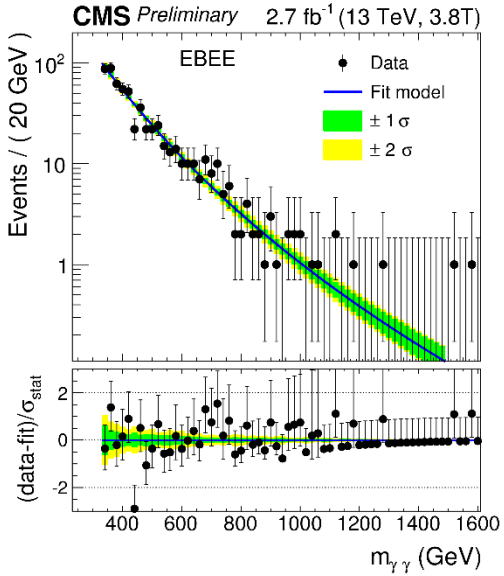
$\gamma\gamma$ final state

ATLAS
(to be submitted to JHEP)

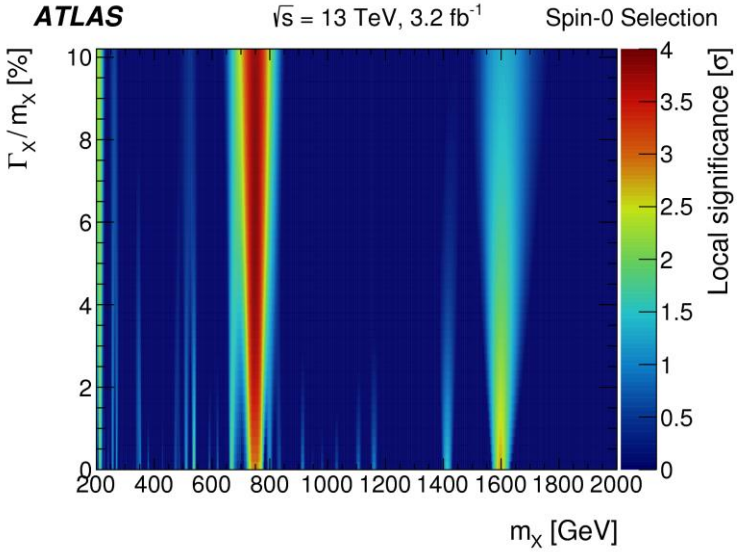


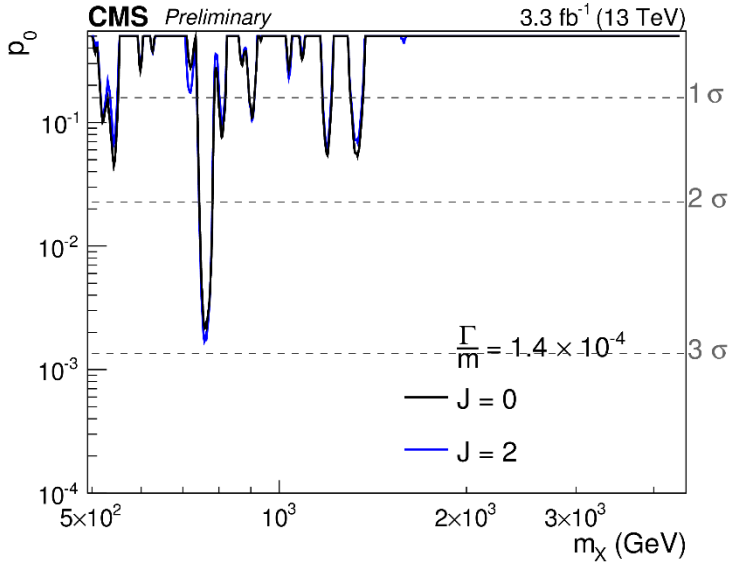
CMS





- $p_0 = f(m_X ; \Gamma_X/m_X)$





Search for high mass resonances

$\gamma\gamma$ final state

ATLAS

- significance

$m_X \approx 750$ GeV,

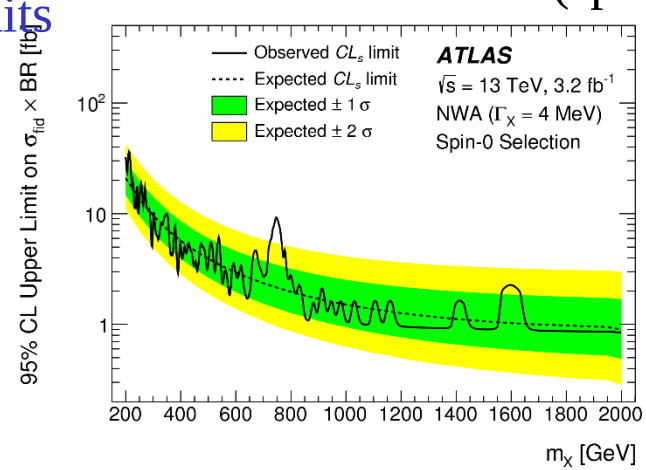
spin 0 : 3.9 σ, Γ_X=45 GeV

spin 2 : 3.8 σ, $k/\overline{M}_{Pl}$=0.23

Compatib. w/ 8 TeV data : 1.2 (spin 0)

2.7 σ (spin 2)

- Limits



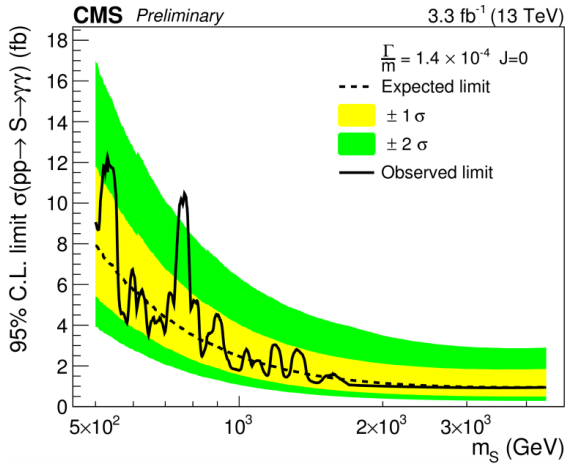
CMS

$m_X \approx 760$ GeV, $\Gamma_X/m_X = 1.4\times10^{-4}$,

scalar : 2.85 σ

RS : 2.9 σ

Comb. w/ $\sqrt{s}$=8 TeV : 3.4 σ



- Search for new resonances made systematically for all possible final states

→No excess observed so far, apart in $\gamma\gamma$ final state, at a mass ≈750 GeV

See more details :

Search for diphoton resonances with the ATLAS experiment	Simone Michele Mazza
Searches for exotics at ATLAS and CMS	Claire Lee
Exotics searches at ATLAS	Ruggero Turra

Conclusion

- Run 1 : important legacy in Higgs sector from Boson decays :
  $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^{*} \rightarrow 4l$, $H \rightarrow WW \rightarrow l\nu l\nu$, $H \rightarrow Z\gamma$

- measurement of mass, width, spin, σ, $d\sigma/dX$, production modes, couplings

- Early analyses w/ Run 2 with 2015 data, but not competitive for SM

- Decay to bosons : tool to probe New Physics

(HH resonant, high mass resonances, etc.)

- 2016 data-taking may bring answers and surprises

Backup

References : SM individual channels

- $H \rightarrow \gamma\gamma$

ATLAS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=4.5 fb^{-1}+20.3 fb^{-1}, mass : PRD 90, 052004 (2014)
couplings : PRD 90, 112015 (2014)
CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=5.1 fb^{-1}+19.7 fb^{-1}, EPJ C74, 3076 (2014)
ATLAS, Run 2, $\sqrt{s}$=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2015-060
CMS, Run 2, $\sqrt{s}$=13 TeV, L=2.7 fb^{-1}, CMS-PAS-HIG-15-005

high mass : ATLAS, Run 2, 2015, $\sqrt{s}$=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2016-018
CMS, Run 2, 2015, $\sqrt{s}$=13 TeV, L=3.3 fb^{-1}, CMS-PAS-EXO-16-018

- $H \rightarrow ZZ^{*} \rightarrow 4l$

ATLAS, Run 1, $\sqrt{s}$=7 TeV +8 TeV, L=4.5 fb^{-1}+20.3 fb^{-1}, PRD 91, 012006 (2015)
CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=5.1 fb^{-1}+19.7 fb^{-1}, PRD 89, 092007 (2014)
ATLAS, Run 2, $\sqrt{s}$=13 TeV, L=3.2 fb^{-1} ATLAS-CONF-2015-059
CMS, Run 2, $\sqrt{s}$=13 TeV, L=2.8 fb^{-1} CMS-PAS-HIG-15-004

- $H \rightarrow WW^{*} \rightarrow l\nu l\nu$

ATLAS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=4.5 fb^{-1} + 20.3 fb^{-1}, PRD 92, 012006 (2015)
CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=4.9 fb^{-1} + 19.4 fb^{-1}, JHEP 01, 096 (2014)

- $H \rightarrow Z(ll)\gamma$

ATLAS, Run 1, $\sqrt{s}$=7 TeV +8 TeV, L=4.5 fb^{-1} + 20.3 fb^{-1}, PLB 732C, 8 (2014)
CMS, Run 1, $\sqrt{s}$=7 TeV +8 TeV, L=5.0 fb^{-1} + 19.6 fb^{-1}, PLB 726, 587 (2013)

- $H \rightarrow \gamma^{*}\gamma \rightarrow ll\gamma$

CMS, Run 1, $\sqrt{s}$=8 TeV, L=19.7 fb^{-1}, PLB 753, 341 (2016)

References : some properties

- Mass m_H
  - $H \rightarrow \gamma\gamma + H \rightarrow ZZ \rightarrow 4l$

    ATLAS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=4.5 fb^{-1}+ 20.3 fb^{-1}, PRD 90, 052004 (2014)
    CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=5.1 fb^{-1} + 19.7 fb^{-1}, EPJC 75, 212 (2015)
    ATLAS-CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, PRL 114, 191803 (2015)
- Width Γ_H
  - Direct

    ATLAS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=4.5 fb^{-1}+ 20.3 fb^{-1}, PRD 90, 052004 (2014)
    CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L$\leq$5.1 fb^{-1} + $\leq$19.7 fb^{-1}, EPJC 75, 212 (2015)
  - Interference
    - $H \rightarrow ZZ \rightarrow 4l$ et al.

      ATLAS, Run 1, $\sqrt{s}$=8 TeV, L=20.3 fb^{-1}, EPJC 75, 335 (2015)
      CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L=5.1 fb^{-1} + 19.7 fb^{-1}, PRD 92, 072010 (2015)
    - $H \rightarrow \gamma\gamma$

      Shift m_H : improved estimation : ATLAS, ATL-PHYS-PUB-2016-009
      Prospectives : ATLAS, ATL-PHYS-PUB-2013-014
- Spin

  ATLAS, Run 1, $\sqrt{s}$=7 TeV + $\sqrt{s}$=8 TeV, L=4.5 fb^{-1} + 20.3 fb^{-1}, EPJC 75, 476 (2015)
  CMS, Run 1, $\sqrt{s}$=7 TeV, L=5.1 fb^{-1} + $\sqrt{s}$=8 TeV, L=19.7 fb^{-1}, PRD 92 (2015) 012004
- Couplings

  ATLAS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV , L$\leq$4.7 fb^{-1} + $\leq$20.3 fb^{-1}, EPJC 76, 6 (2016)
  CMS, Run 1, $\sqrt{s}$=7 TeV + 8 TeV, L$\leq$5.1 fb^{-1} + $\leq$19.7 fb^{-1}, EPJC 75, 212 (2015)
  ATLAS+CMS : ATLAS-CONF-2015-044
  CMS-PAS-HIG-15-002

References : σ, d σ/dX

m_H=125.4 GeV
m_H=125.09 GeV
m_H=125 GeV

		ATLAS	CMS
H→γγ	σ	√s=7 TeV, L=4.5 fb^{-1}, ATLAS-CONF-2015-060	
	σ, dσ/dX	√s=8 TeV, L=20.3 fb^{-1}, JHEP 09, 112 (2014)	√s=8 TeV, L=19.7 fb^{-1}, EPJC 76, 13 (2016) σ, dσ/dX
		√s=8 TeV, L=20.3 fb^{-1}, ATLAS-CONF-2015-060	
		√s=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2015-060	
H→ZZ*→4l	σ	√s=7 TeV, L=4.5 fb^{-1}, ATLAS-CONF-2015-059	√s=7 TeV, L=5.1 fb^{-1}, JHEP 04, 005 (2016) σ, dσ/dX
	σ, dσ/dX	√s=8 TeV, L=20.3 fb^{-1}, PLB 738 234 (2014)	√s=8 TeV, L=19.7 fb^{-1}, JHEP 04, 005 (2016)σ, dσ/dX
		√s=8 TeV, L=20.3 fb^{-1}, ATLAS-CONF-2015-059	√s=13 TeV, L=2.8 fb^{-1}, CMS-PAS-HIG-15-004 σ
		√s=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2015-059	
H→γγ	σ, dσ/dX	√s=8 TeV, L=20.3 fb^{-1}, PRL 115, 091801 (2015)	
+	σ	√s=7 TeV, L=4.5 fb^{-1}, ATLAS-CONF-2015-069	
H→ZZ*→4l		*√s=8 TeV, L=20.3 fb^{-1}, ATLAS-CONF-2015-069*	
		√s=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2015-069	
H→WW* lνlν	σ	√s=8 TeV, L=20.3 fb^{-1}, PRD 92, 012006 (2015)	
eνμν	σ, dσ/dX	√s=8 TeV, L=20.3 fb^{-1} : CERN-EP-2016-019	√s=8 TeV, L=19.4 fb^{-1}, CMS-PAS-HIG-15-010 σ dσ/dX

BSM, EFT, w/ dσ/dX, H→γγ
ATLAS, Run 1, √s=8 TeV, L=20.3 fb^{-1}, PLB 753, 69 (2016)

References non-resonant HH

- Non resonant
  - H(γγ)H(bb)
    ATLAS, Run 1, $\sqrt{s}$=8 TeV, L=20 fb^{-1}, PRL 114, 081802 (2015)
    ATLAS, Run 2, $\sqrt{s}$=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2016-004
    CMS, Run 1, $\sqrt{s}$=8 TeV, L=19.7 fb^{-1}, CERN-EP-2016-050
  - H(bb)H(ττ)
    ATLAS, Run 1, $\sqrt{s}$=8 TeV, L=20.3 fb^{-1}, PRD 92, 092004 (2015)
    CMS, Run 2, $\sqrt{s}$=13 TeV, L=2.7 fb^{-1}, CMS-PAS-HIG-16-013
  - H(γγ)H(WW)
    ATLAS, Run 1, $\sqrt{s}$=8 TeV, L=20.3 fb^{-1}, PRD 92, 092004 (2015)
  - H(bb)H(bb)
    ATLAS, Run 1, $\sqrt{s}$=13 TeV, L=19.5 fb^{-1} EPJC 75, 412 (2015)
    ATLAS, Run 2, $\sqrt{s}$=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2016-017
  - HH combination
    h(bb)h(ττ), h(γγ)h(WW^*), h(γγ)h(bb), h(bb)h(bb)
    ATLAS, Run 1, $\sqrt{s}$=8 TeV, L=20.3 fb^{-1}, PRD 92, 092004 (2015)

References resonant HH

- Resonant

  H(γγ)H(bb)

  ATLAS, Run 1, $\sqrt{s}$=8 TeV, L=20 fb^{-1}, PRL 114, 081802 (2015)

  ATLAS, Run 2, $\sqrt{s}$=13 TeV, L=20.3 fb^{-1}, ATLAS-CONF-2016-004

  CMS, Run 1, $\sqrt{s}$=8 TeV, L=19.7 fb^{-1}, CERN-EP-2016-050

- HH combination

h(bb)h(ττ), h(γγ)h(WW^*), h(γγ)h(bb), h(bb)h(bb)

ATLAS, Run 1, $\sqrt{s}$=8 TeV, L=20.3 fb^{-1}, PRD 92, 092004 (2015)

High mass resonances

$\gamma\gamma$

ATLAS, Run 2, 2015, $\sqrt{s}$=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2016-018

+ paper to be submitted to JHEP

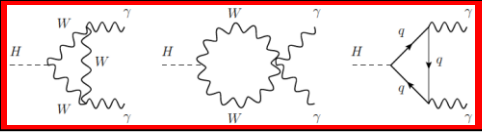
CMS, Run 2, 2015, $\sqrt{s}$=13 TeV, L=2.7 fb^{-1}, CMS-PAS-EXO-16-018

$Z\gamma$

ATLAS, Run 2, 2015, $\sqrt{s}$=13 TeV, L=3.2 fb^{-1}, ATLAS-CONF-2016-010

CMS, Run 1, 2012, $\sqrt{s}$=8 TeV, L=19.7 fb^{-1}, CMS-PAS-HIG-14-031 : mass range : 200-500

CMS, Run 1, 2012, $\sqrt{s}$=8 TeV, L=19.7 fb^{-1}, CMS-PAS-HIG-16-014 : mass range : 200-1200



H→γγ : Run 1

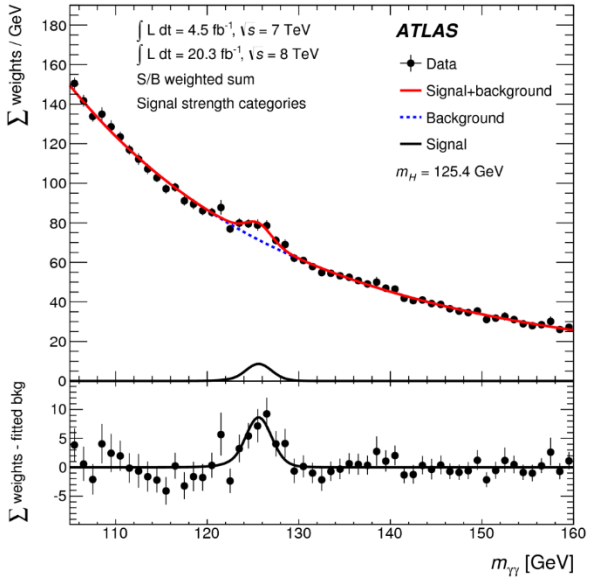
- Selection

-2 high-p_T photons

-categorization : sensitivity + prod. modes

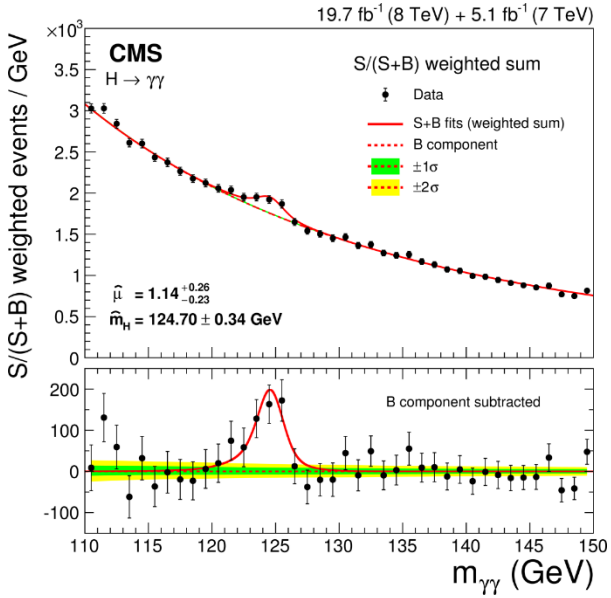
- Results

ATLAS



(S/B)

CMS



Z_{obs}=5.2 σ (Z_{exp}=4.7 σ)

m_H=125.98 ± 0.42 (stat) ± 0.28 (syst) GeV

μ=1.17 +/- 0.27

Z_{obs}=5.7 σ (Z_{exp}=5.2 σ)

m_H=124.70 ± 0.31 (stat) ± 0.15 (syst) GeV

μ=1.14 $^{+0.26}_{-0.23}$

Mass systematics dominated by energy scale

+probing production modes

$H \rightarrow ZZ^* \rightarrow 4l$: Run 1

- **Selection**

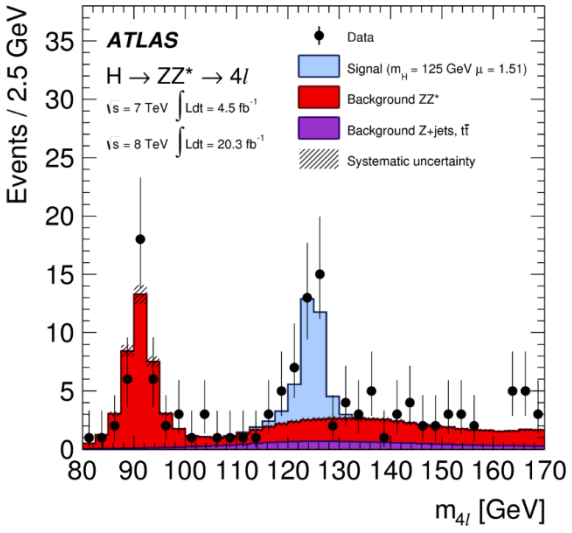
-2 high-p_T leptons pairs

-categorization : sensitivity + prod. modes

BDT : separate $H \rightarrow ZZ^*$; ZZ^* bkg $\Leftrightarrow$ Matrix Element Likelihood Discriminant

- **Results**

ATLAS

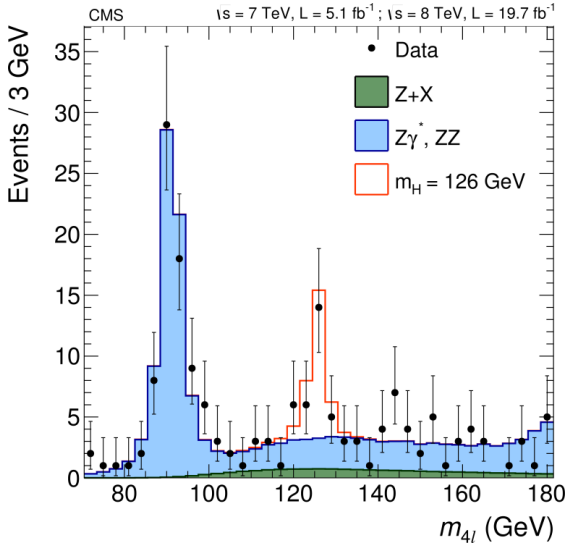


(2D fit)

$Z_{obs}=8.1\ \sigma\ (Z_{exp}=6.2\ \sigma)$

$m_H=124.51 \pm 0.52\ (stat) \pm 0.06\ (syst)$ GeV

CMS



(3D fit)

$Z_{obs}=6.8\ \sigma\ (Z_{exp}=6.7\ \sigma)$

$m_H=125.6 \pm 0.4\ (stat.) \pm 0.2\ (syst.)$ GeV

Systematics ~e/μ scales

$\mu=1.44^{+0.34}_{-0.31}\ (stat.)\ ^{+0.21}_{-0.11}\ (sys.)$

$\mu=0.93^{+0.26}_{-0.23}\ (stat.)\ ^{+0.13}_{-0.09}\ (sys.)$

$H \rightarrow WW^* \rightarrow l\nu l\nu$

- Selection

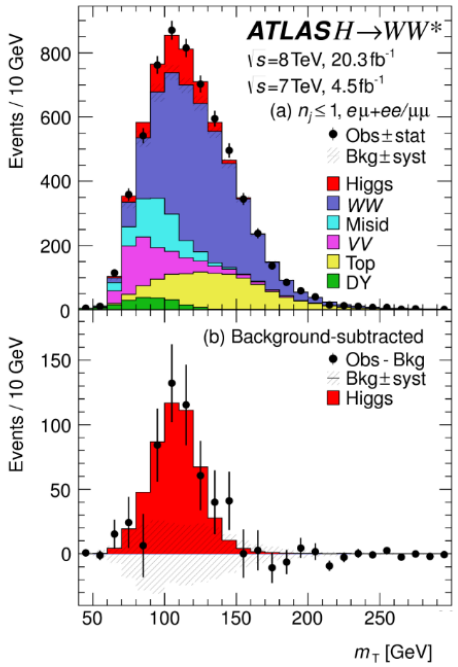
-2 high-p_T leptons, MET

-topology of leptons : m_{ll}, spin correlation, etc.

-categorization : sensitivity + prod. modes

- Results

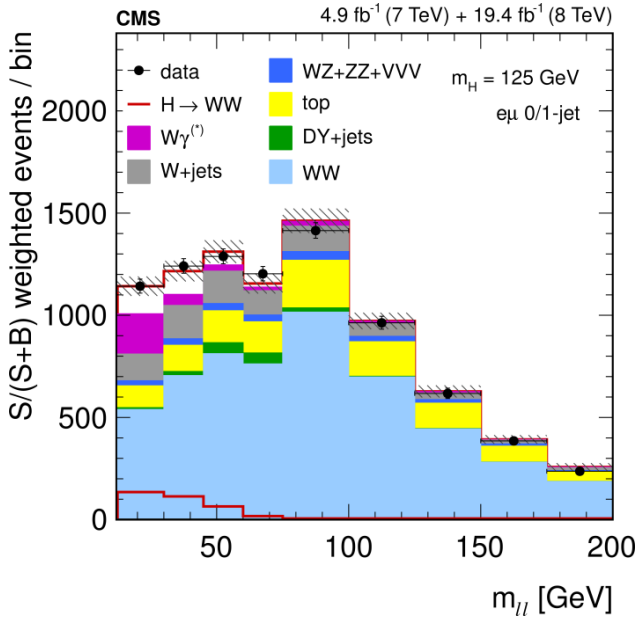
ATLAS



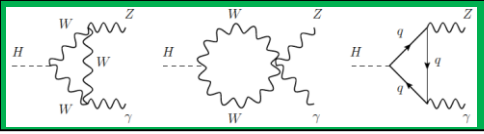
$Z_{obs}=6.1\ \sigma$ ($Z_{exp}=5.8\ \sigma$)

$\mu=1.09\ ^{+0.16}_{-0.15}\ (stat)\ ^{+0.17}_{-0.14}\ (syst)$
for $m_H=125.4$ GeV

CMS



$Z_{obs}=4.3\ \sigma$ ($Z_{exp}=5.8\ \sigma$)
$m_H=125.5^{+3.6}_{-3.8}$ GeV
$\mu=0.72^{+0.20}_{-0.18}$



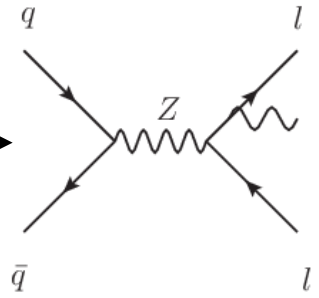
H→Z(ll)γ, Run 1

Probe loop in alternative way to H→γγ

- Selection

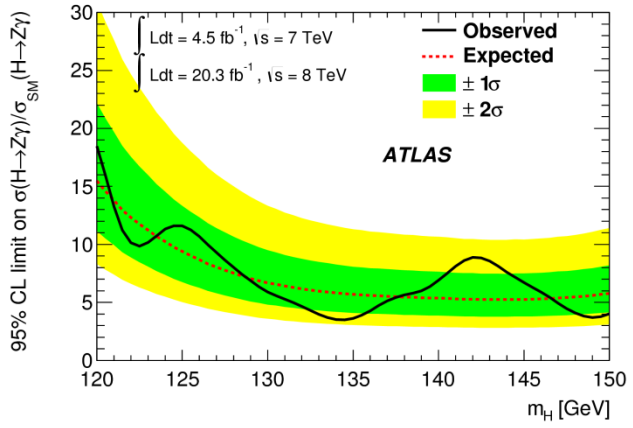
OS same flavour leptons ; γ ; Separation ΔR(l ; γ)>thr (suppr. FSR Z→llγ)

m_{ll}>thr (suppr. FSR Z→llγ, H→γγ w/ conversion) ; $m_{ll\gamma} \sim m_Z$

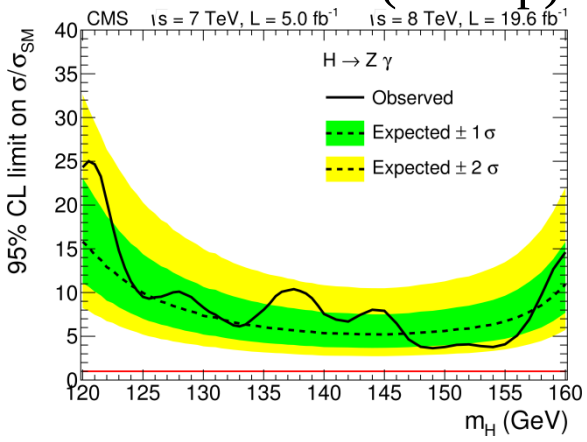


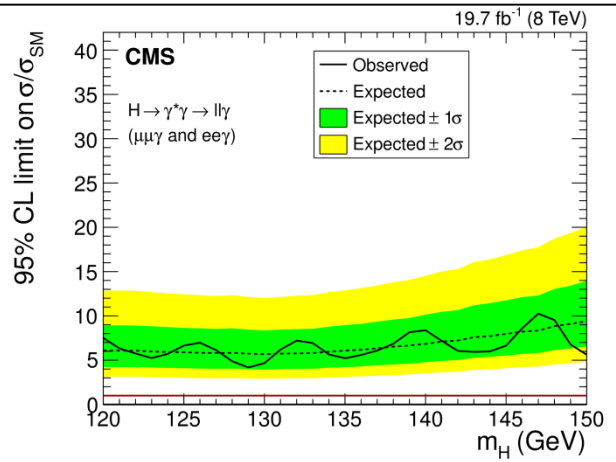
- Limits : m_H=125 GeV

ATLAS : 11xSM (≈9 exp)



CMS : ≈10xSM (≈9 exp)





H→γ*γ→llγ

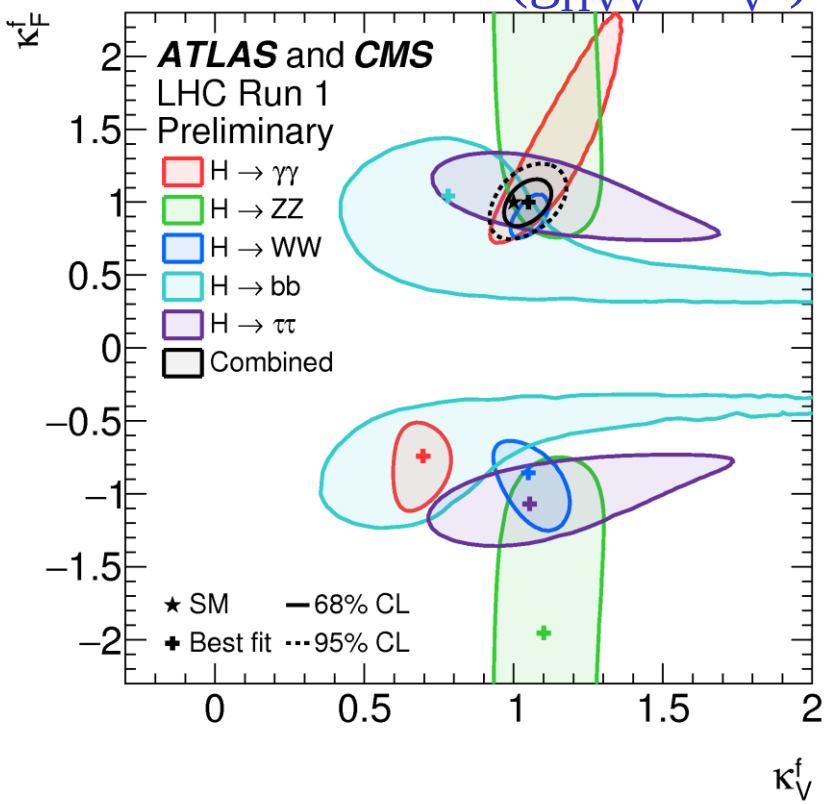
m_{ll}<thr (suppr. H→Zγ)

- Limits : m_H=125 GeV : 9.5xSM (10xSM exp)

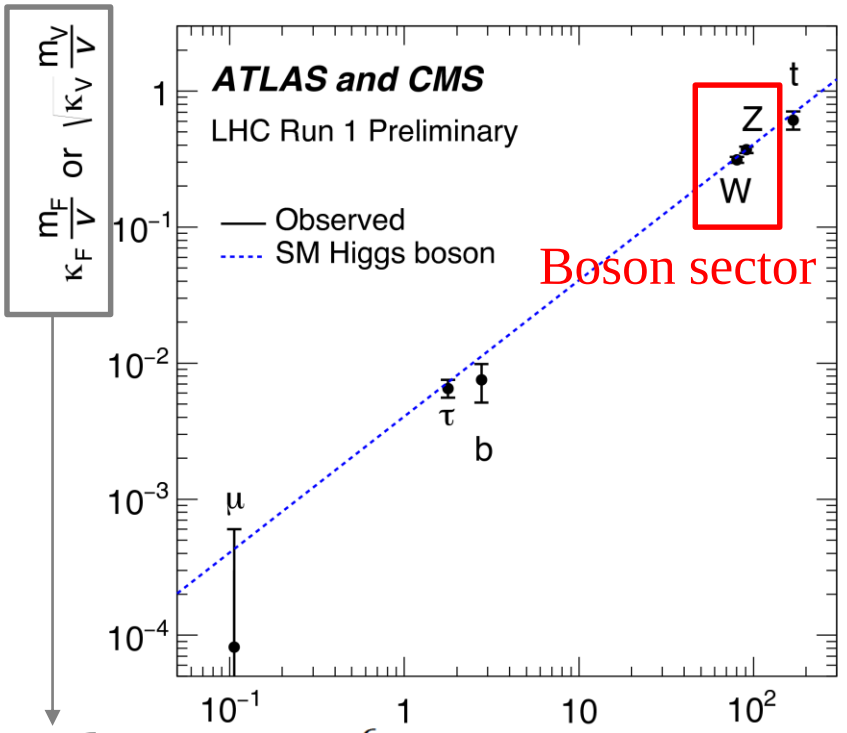
Combination : couplings + misc

+ many other benchmarks /studies : ratio of σ's, of BR's, asym fermions (u/d, l/q), Couplings Fermions vs Vector bosons, Probing loops, Scaling couplings w/ mass, etc.
Two examples

- Couplings Fermions ($g_{Hff} \sim m_f$) vs Vector bosons ($g_{HVV} \sim m_V^2$)



- Scaling couplings w/ mass

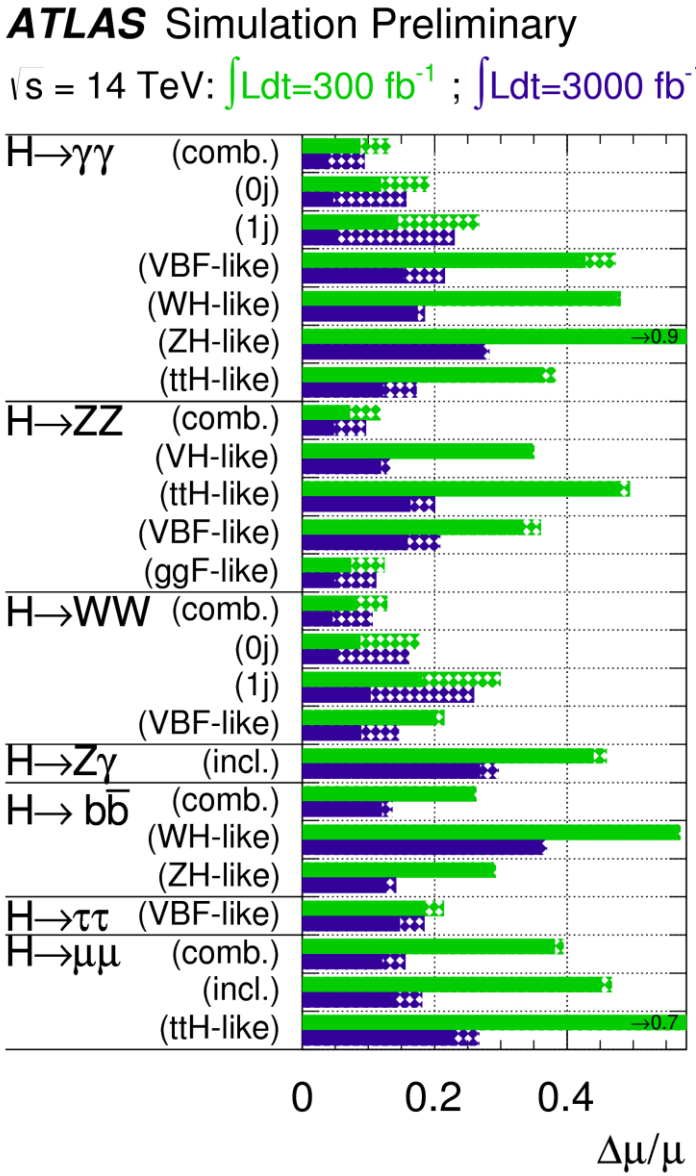


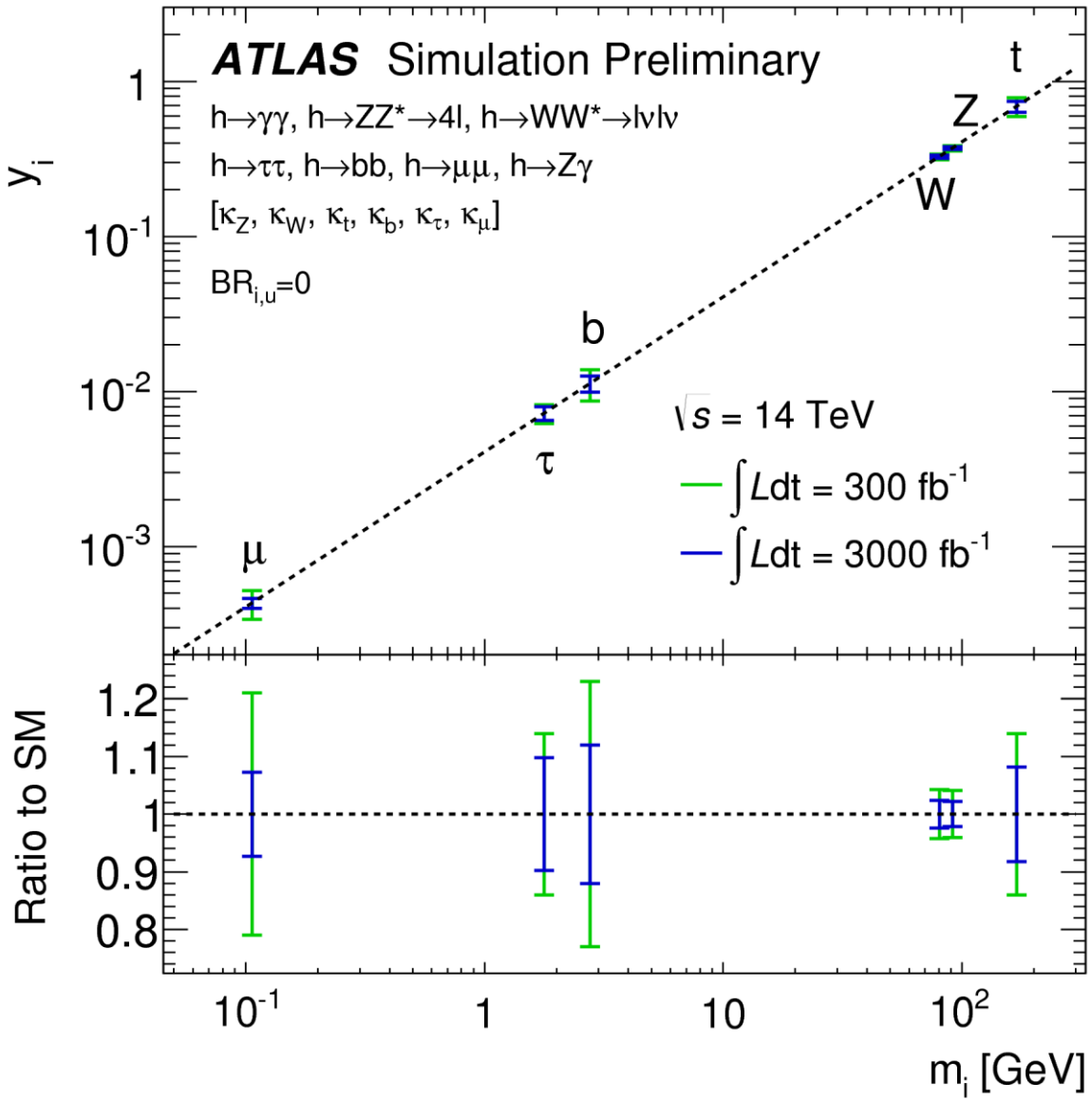
$$\begin{cases} \kappa_F = v \dfrac{m_F^{\epsilon}}{M^{1+\epsilon}} \\ \kappa_V = v \dfrac{m_V^{2\epsilon}}{M^{1+2\epsilon}} \end{cases}$$

H→γγ : interference W, t : solve degeneracy

ATL-PHYS-PUB-2014-016

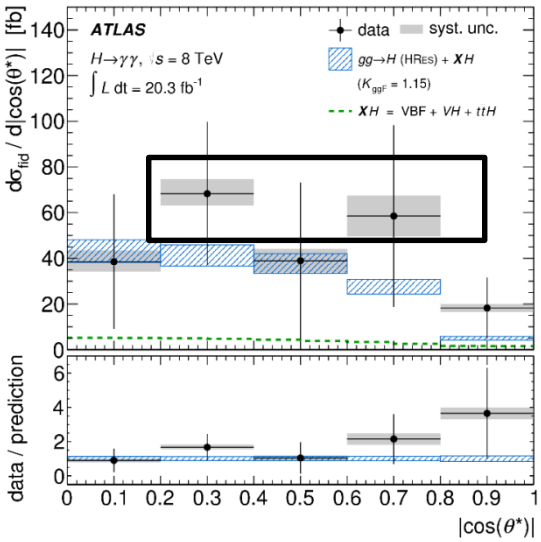
Prospective couplings

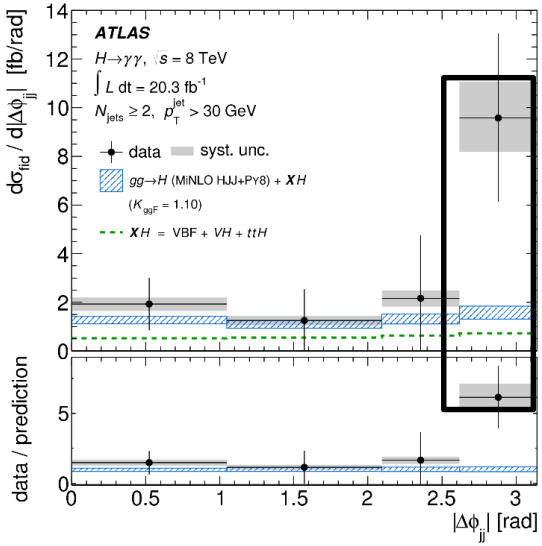




dσ/dX : overview

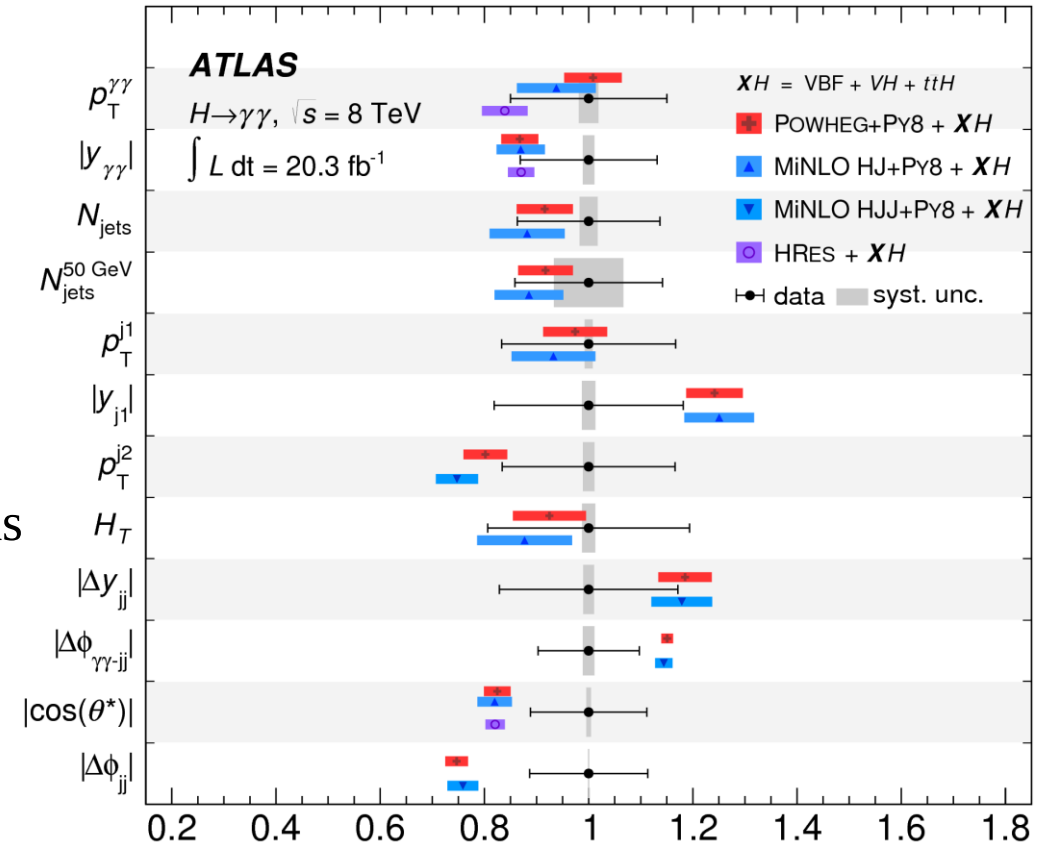
various observables : #objects, p_T, E_T, angles, etc.
various objects : photon, lepton, jet, MET, topology objects
various channels : H→γγ, H→ZZ*→4l, H→WW*→lν lν





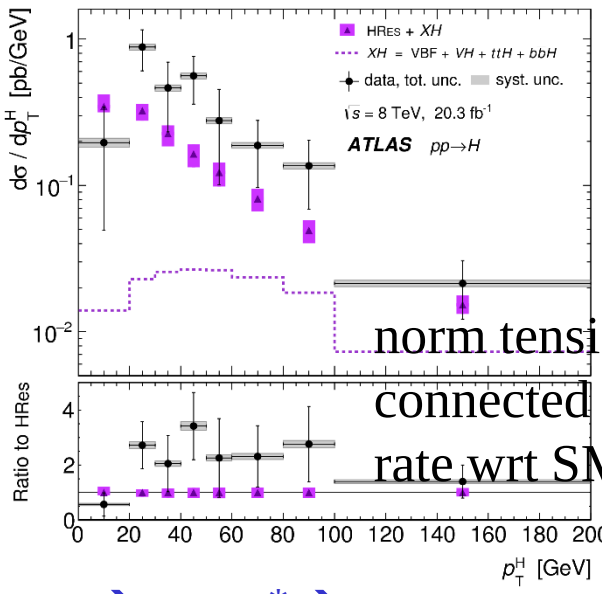
Could be interpreted by stat. fluctuations

example w/ H→γγ



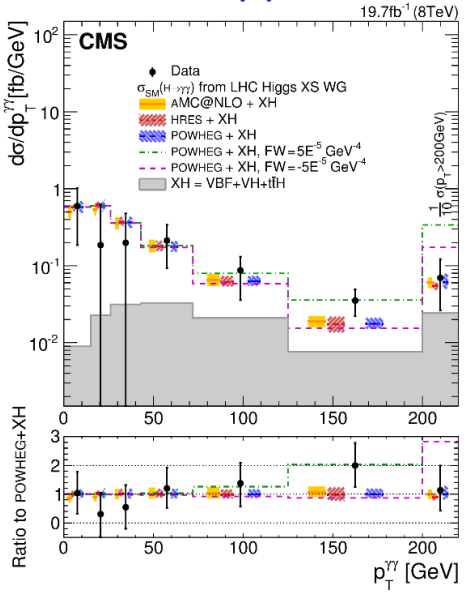
Example of p_T^H

$H\to\gamma\gamma + H\to ZZ^*\to 4l$ ATLAS

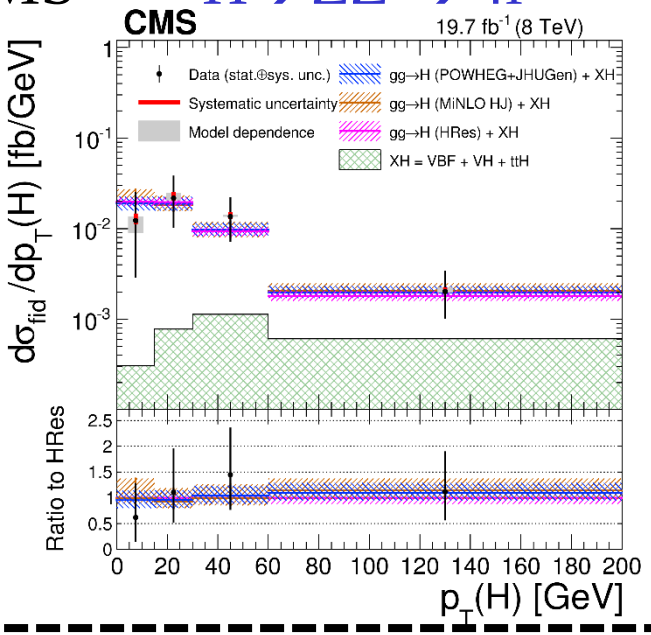


norm tension : connected to higher rate wrt SM

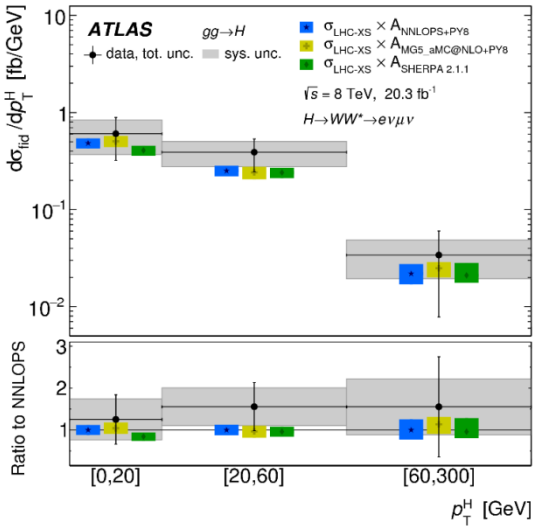
$H\to\gamma\gamma$ CMS



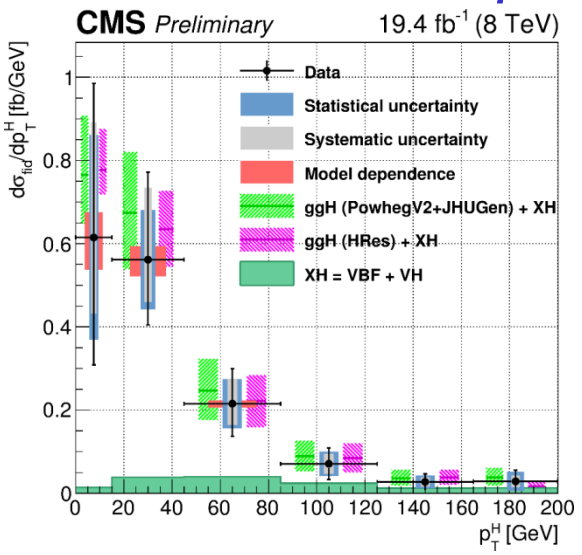
$H\to ZZ^*\to 4l$



$H\to WW^*\to e\nu\,\mu\nu$



$H\to WW^{(*)}\to e\nu\,\mu\nu$



- $p_T \ll m_H$:

non-pert. QCD

soft & collin. corr. $\alpha_S^n \ln^{2n}(m_H^2/q_T^2)$

resum. cancel divergences

- $p_T \approx m_H$ and $p_T \gg m_H$:

pert. QCD

emission soft gluons & q

N^kLO

Spin and J^{PC}

- Spin and parity $J^P=0^+$ tested alternative models (spin-0 and spin 2)

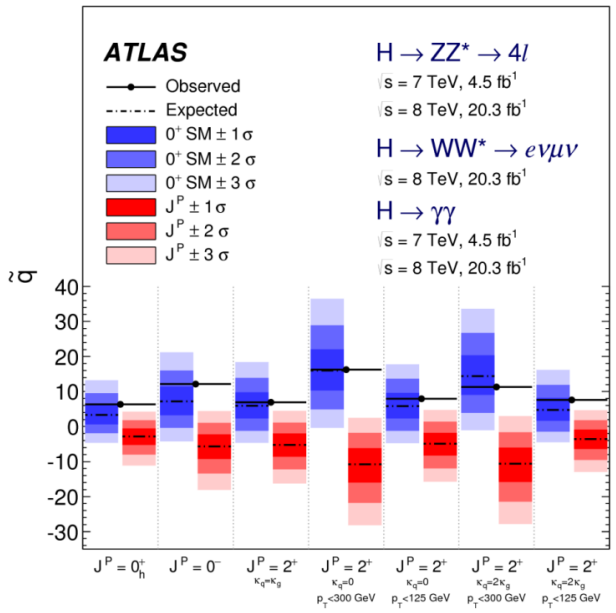
ATLAS

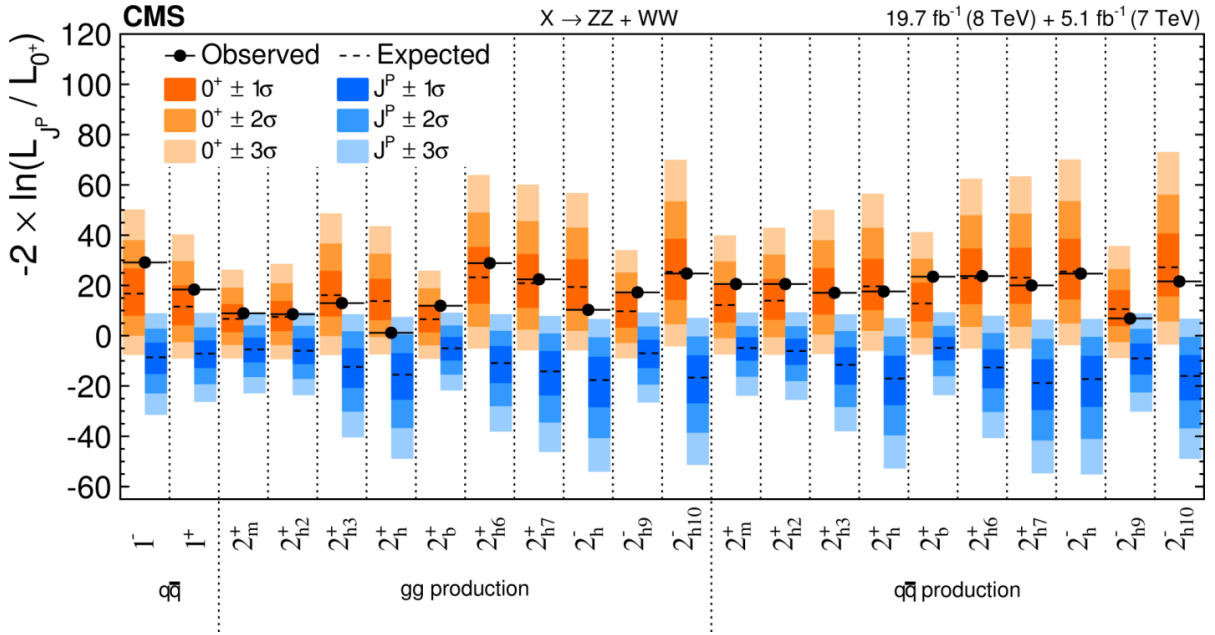
$H\rightarrow\gamma\gamma$, $ZZ\rightarrow 4l$, $WW^*\rightarrow e\nu\mu\nu$

CMS

$H\rightarrow\gamma\gamma$, $ZZ\rightarrow 4l$, $WW\rightarrow l\nu l\nu$, $Z\gamma^*\rightarrow 4l$, $\gamma^*\gamma^*\rightarrow 4l$

Variables : angular distributions (flat for spin 0), kinematics, etc.





>99 % CL exclusion alternative models

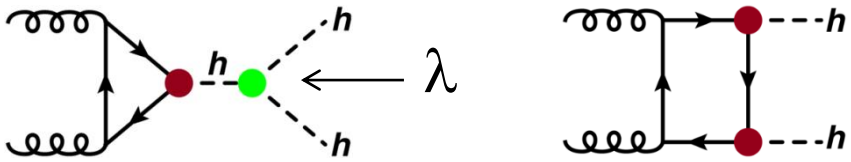
Spin tensor structure studied : consistent w/ $J^{PC}=0^{++}$

(also : studies on anomalous couplings in EFT

CP violation : no deviation, but only large CP mixing excluded (above 30 %))

see also : The profile of the H(125) from Run 1 Tatjana Lenz

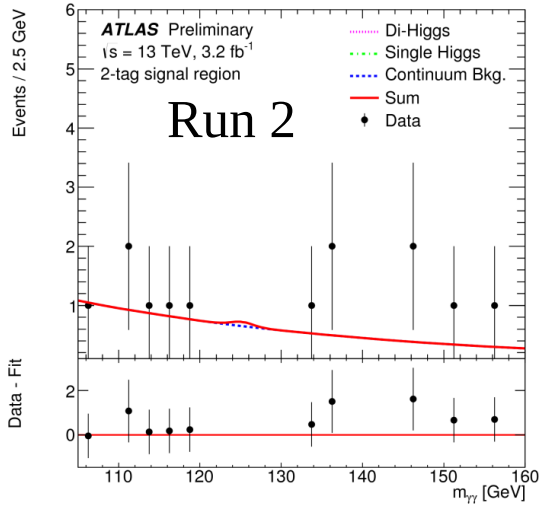
Non-resonant HH, w/ bosons decays



ATLAS

- H(γγ)H(bb)

fit $m_{\gamma\gamma}$



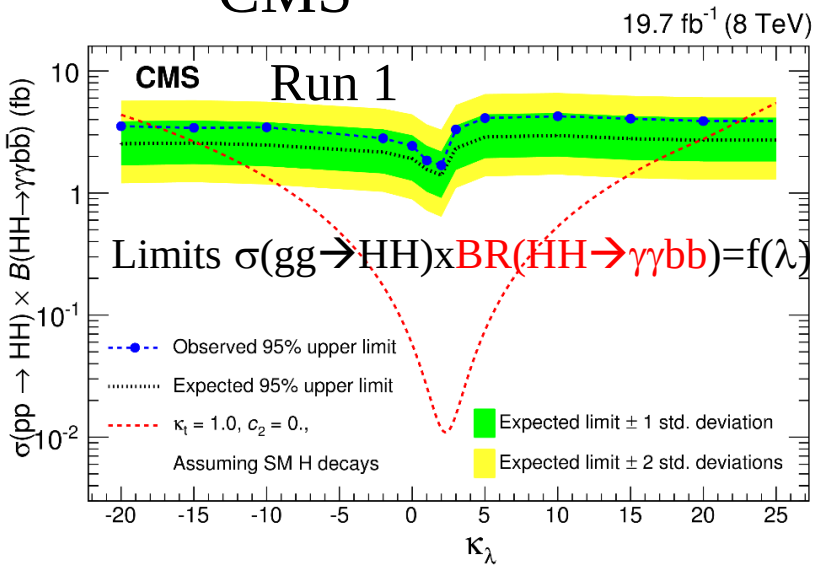
sim. fit $m_{\gamma\gamma}$, m_{bb}

Limits σ(pp→HH)

Run 1 : 2.2 pb (220xSM) ; Z=2.4 σ
(100xSM exp)

Run 2 : 3.9 pb (exp : $5.4\ ^{+2.8}_{-1.0}$ pb)

CMS



Run 1 : 0.71 pb (74xSM)
(62xSM exp)

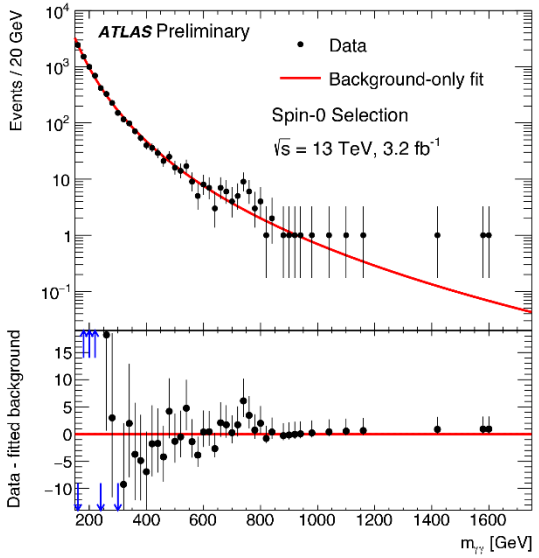
- Comb. ATLAS Run 1 : h(bb)h(ττ), h(γγ)h(WW^*), h(γγ)h(bb), h(bb)h(bb)

obs : 0.69 pb (70xSM ; 48xSM exp)

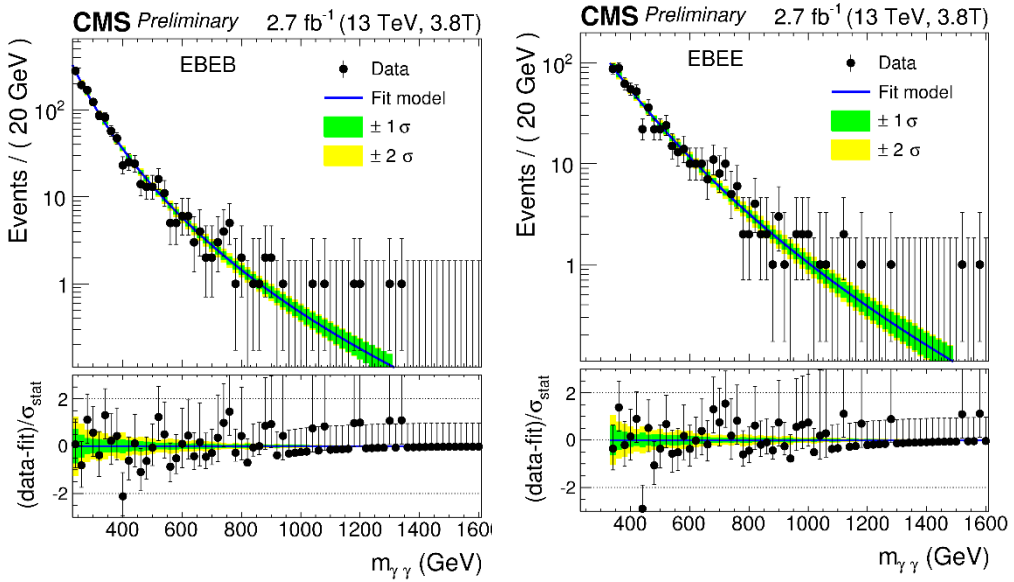
Search for high mass resonances

γγ final state

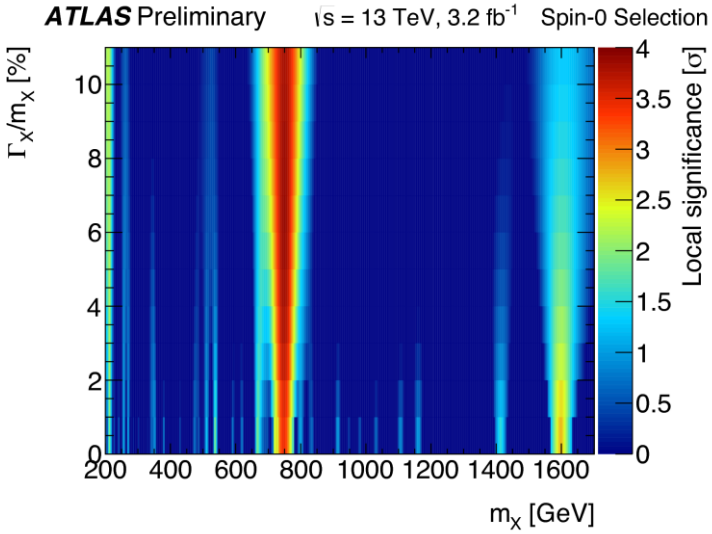
ATLAS

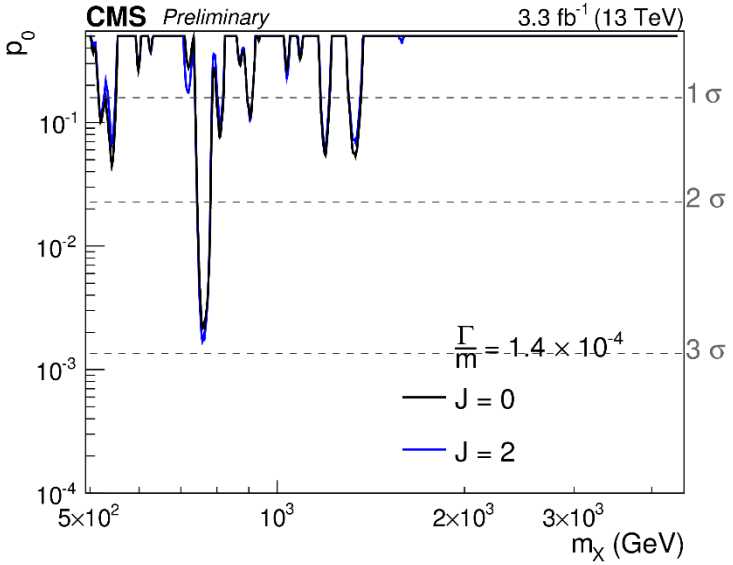


CMS



- $p_0=f(m_X ; \Gamma_X/m_X)$





Search for high mass resonances

$\gamma\gamma$ final state

- significance

ATLAS

$m_X \approx 750$ GeV,

spin 0 : 3.9 σ, Γ_X=45 GeV

spin 2 : 3.6 σ, $k/\overline{M}_{Pl}$=0.21

Compatib. w/ 8 TeV data : 1.2 (spin 0)

2.7 σ (spin 2)

CMS

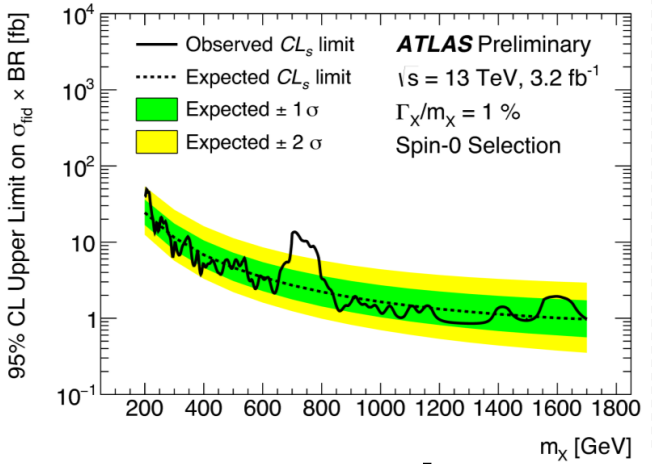
$m_X \approx 760$ GeV, $\Gamma_X/m_X = 1.4 \times 10^{-4}$,

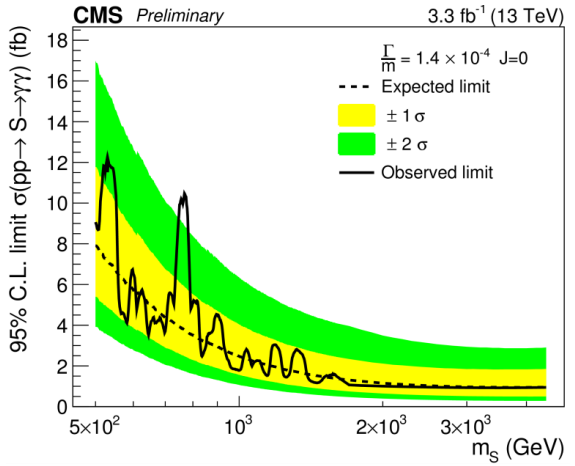
scalar : 2.85 σ

RS : 2.9 σ

Comb. w/ $\sqrt{s}$=8 TeV : 3.4 σ

- Limits





- Search for new resonances made systematically for all possible final states

→No excess observed so far, apart in $\gamma\gamma$ final state, at a mass ≈750 GeV

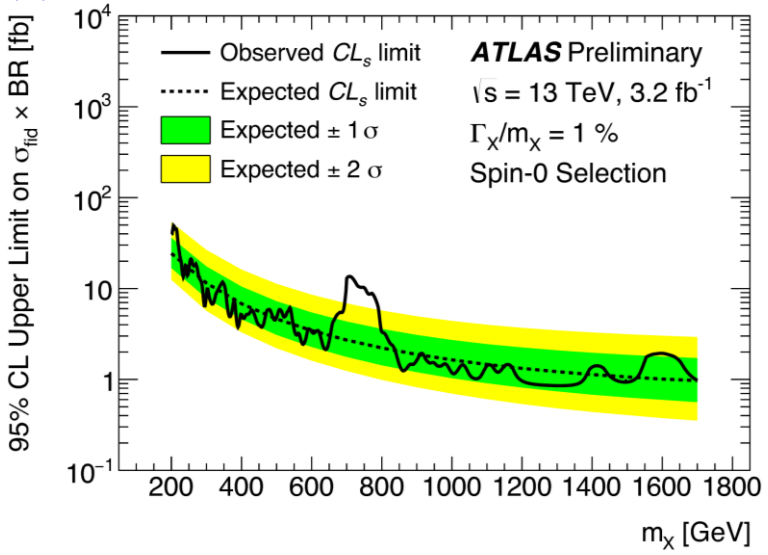
See more details :

Search for diphoton resonances with the ATLAS experiment	Simone Michele Mazza
Searches for exotics at ATLAS and CMS	Claire Lee
Exotics searches at ATLAS	Ruggero Turra

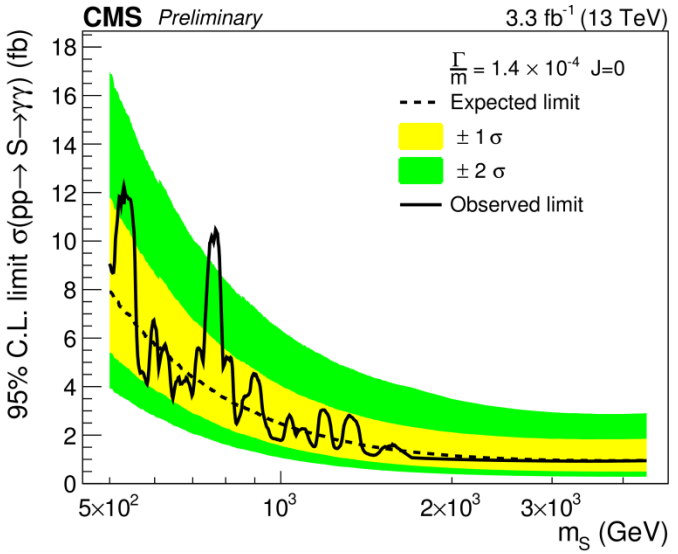
Search for high masses resonances

- $\gamma\gamma$ final state

ATLAS



CMS



$p_0=f(m_X ; \Gamma_X/m_X)$

$m_X \approx 750$ GeV,
spin 0 : 3.9 σ, Γ_X=45 GeV
spin 2 : 3.6 σ, $k/\overline{M}_{Pl}$=0.21
Compatib. w/ 8 TeV data : 1.2 (spin 0)
2.7 σ (spin 2)

$m_X \approx 760$ GeV, $\Gamma_X/m_X=1.4\text{x}10^{-4}$,
scalar : 2.85 σ
RS : 2.9 σ
Comb. w/ $\sqrt{s}$=8 TeV : 3.4 σ

See more details : Search for diphoton resonances with the ATLAS experiment Simone Michele Mazza

- Search for new resonances made systematically for all possible final states
(in particular ZZ→4l, Zγ, more generally VV, etc.)
→No excess observed so far, apart in $\gamma\gamma$ final state, at a mass ≈750 GeV

Angular distribution, for 750 GeV analysis
(too lack of stat to conclude)