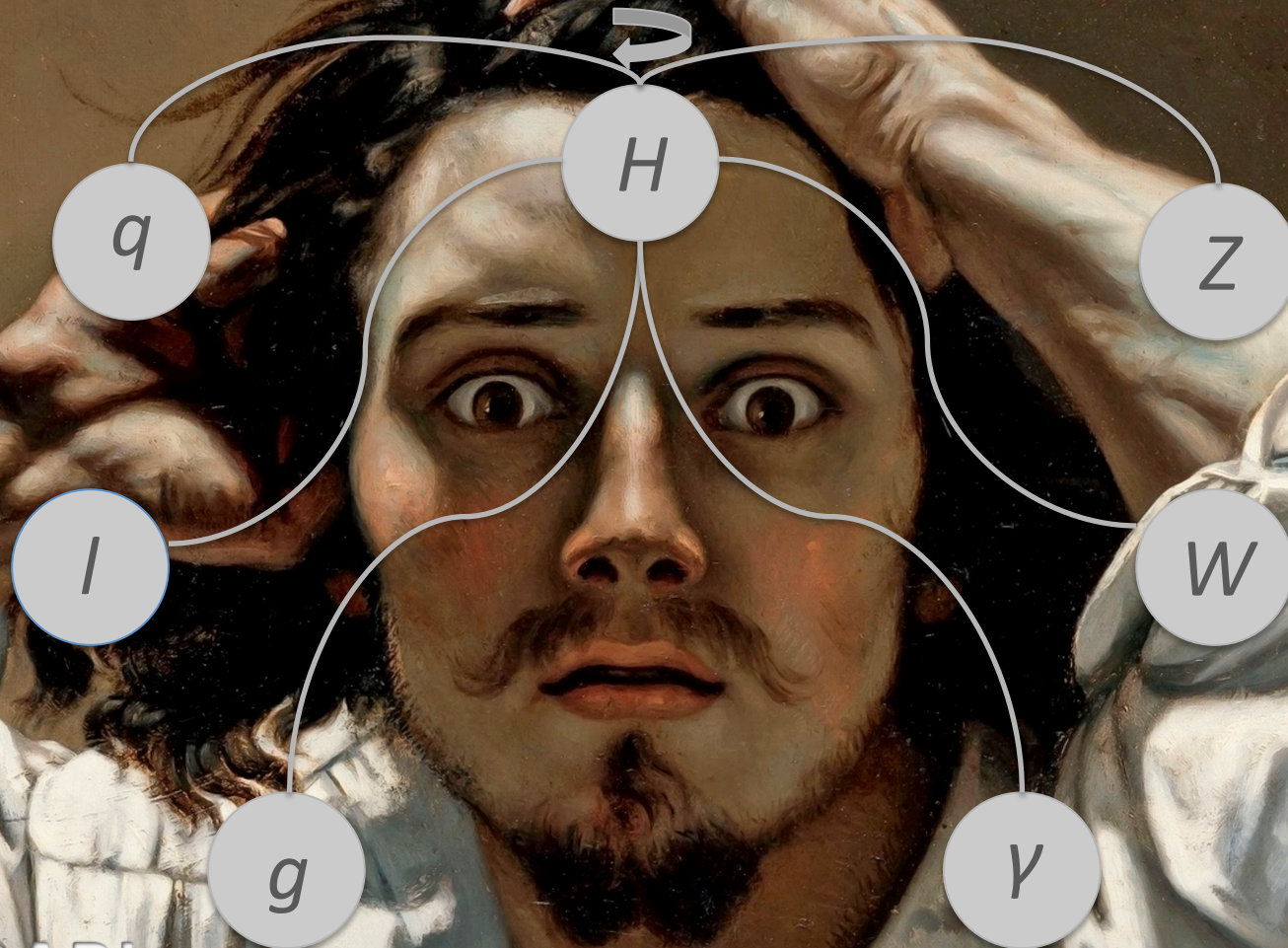


ATLAS H Couplings and Spin



N. ANDARI
(On behalf of the ATLAS Collaboration)

CERN

Higgs Hunting
21-23 July 2014



Outline

- Introduction
- Brief review of bosonic channels (for more details see Marianna's talk)
- Spin/Parity Combination Results
- Brief review of fermionic channels (for more details see Geng-Yuan's talk)
- Combination of Higgs coupling measurements
- Constraints on New Phenomena from coupling measurements
- Conclusions and Perspectives

Higgs Hunting

Discussions on Tevatron and first LHC results

July 29-31, 2010, Orsay-France



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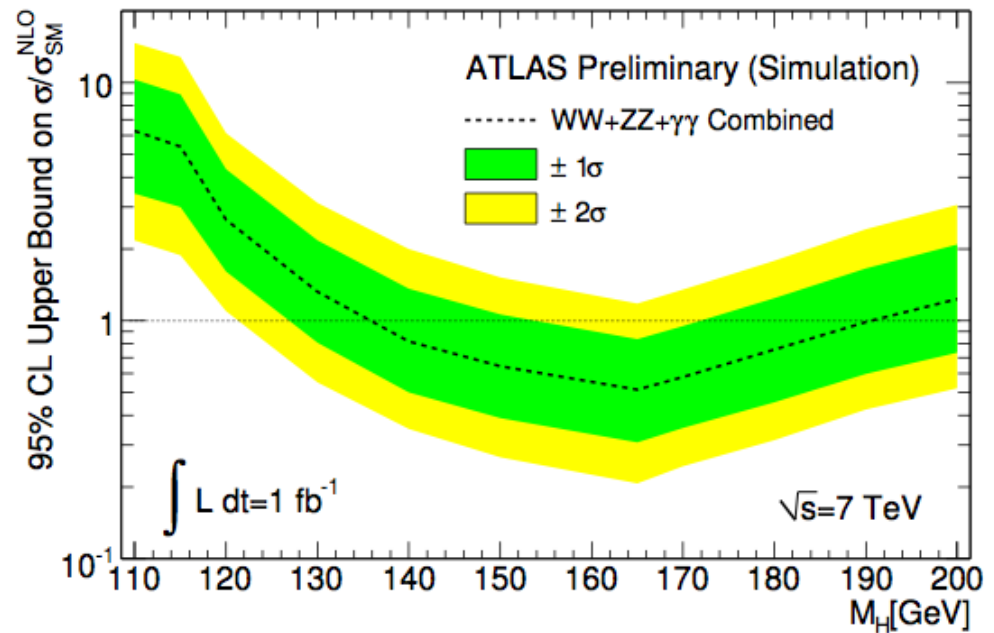
Topics:

- recent results from Tevatron
- first results from LHC
- prospects for Higgs searches at the LHC
- recent theoretical developments

<http://www.higgshunting.fr/>

2010 LHC data taking (7 TeV, $L \approx 340 \text{ nb}^{-1}$)

Performance studies and setting first exclusion limits with a projection to 1 fb^{-1}



ATL-PHYS-PUB-2010-009

Higgs Hunting

Discussions on Tevatron and first LHC results

July 29-31, 2010, Orsay-France



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Topics:

- recent results from Tevatron
- first results from LHC
- prospects for Higgs searches at the LHC
- recent theoretical developments

<http://www.higgshunting.fr/>



2010 LHC data taking (7 TeV, $L \approx 340 \text{ nb}^{-1}$)

Performance studies and setting first exclusion limits

2011 data (7 TeV, $L = 1 \text{ fb}^{-1}$)

Hunting and setting exclusion limits

$155 < M_H < 190 \text{ GeV}$ and $295 < M_H < 450 \text{ GeV}$

Higgs Hunting 2011

Discussions on Tevatron and LHC results

July 28-30, 2011, Orsay France



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Topics:

- New results from Tevatron and LHC
- Prospects for Higgs searches
- Recent theoretical developments

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Higgs Hunting 2012

Discussions on Tevatron
and LHC results

July 18 -20, 2012, Orsay-France

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Topics:

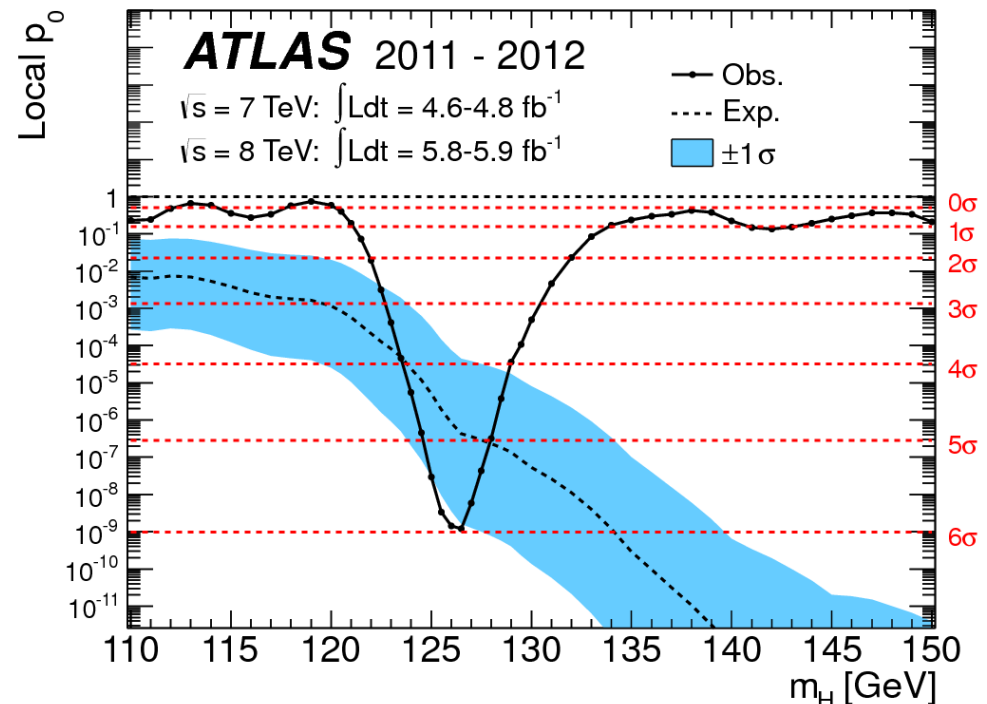
New results from Tevatron and LHC
Prospects for Higgs searches
Recent theoretical developments



«Bonne Maison à l'éventail» - Edouard Manet, 1872
musée d'Orsay, Paris

www.higgshunting.fr

Unveil the scalar boson, Discovery by the ATLAS and CMS experiments using 2011 and 2012 data (5fb^{-1} 7 TeV and 6fb^{-1} of 8 TeV)



Phys.Lett.B716(2012) 1-29

Higgs Hunting 2012

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Topics:
 New results from Tevatron and LHC
 Prospects for Higgs searches
 Recent theoretical developments

«Bonne Morsai à l'éventail» - Edouard Manet, 1872
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Unveil the scalar boson, Discovery by the ATLAS and CMS experiments using 2011 and 2012 data (5 fb⁻¹ 7 TeV and 6 fb⁻¹ of 8 TeV)

Measurement of the first properties of the scalar boson using data (5 fb⁻¹ 7 TeV and 20 fb⁻¹ of 8 TeV)

Higgs Hunting 2013

Tests and prospects for the Brout-Englert-Higgs mechanism and the electroweak symmetry breaking sector

July 25 - 27, 2013, Orsay-France

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G. Callebotte
 «Les raboteurs de parquet» - Gustave Callebotte, 1875
 musée d'Orsay, Paris

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Higgs Hunting 2014
 Results and prospects in the electroweak symmetry breaking sector

July 21-23, 2014, Orsay-France
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Le dessin: Gustave Courbet, 1827
 Collection particulière

Final LHC Run-I data analyses. Precision measurements of the properties of the scalar boson: mass, couplings, spin, differential cross section... with an improved calibration/analysis

Many Results to be updated soon. The combination result is based on results of the old analysis published in *Phys.Lett.B726(2013), pp. 88-119*, *Phys.Lett.B726(2013), pp. 120-144*, *ATLAS-CONF-2014-009* and *ATLAS-CONF-2014-010*

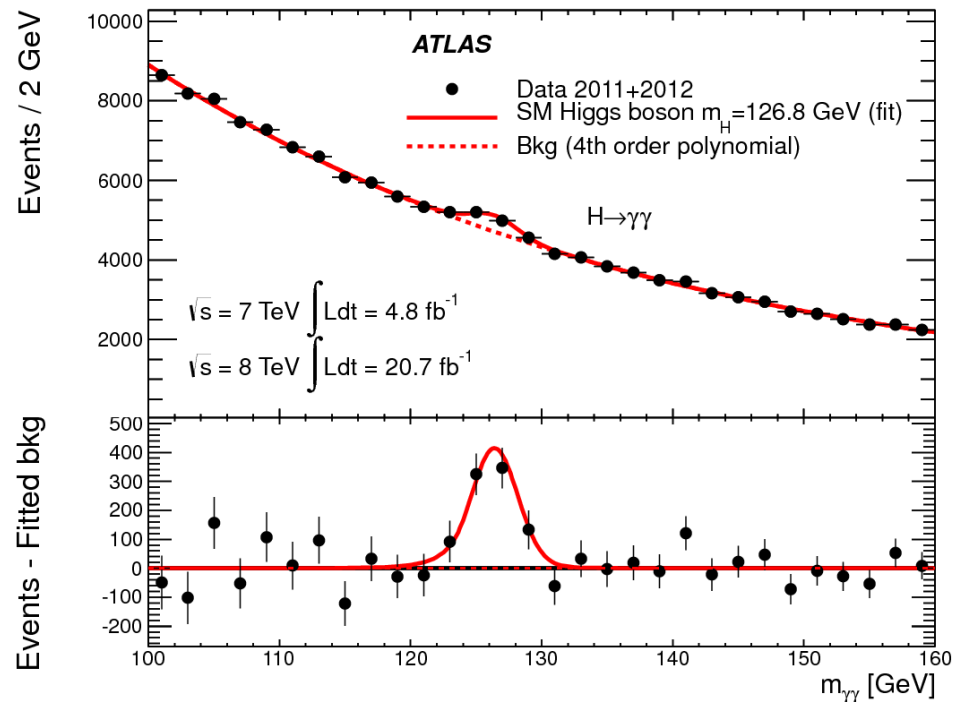


Outline

- Introduction
- Brief review of bosonic channels (for more details see Marianna's talk)
- Spin/Parity Combination Results
- Brief review of fermionic channels (for more details see Geng-Yuan's talk)
- Combination of Higgs coupling measurements
- Constraints on New Phenomena from coupling measurements
- Conclusions and Perspectives

$H \rightarrow \gamma\gamma$ analysis

Phys.Lett.B726(2013), pp. 88-119

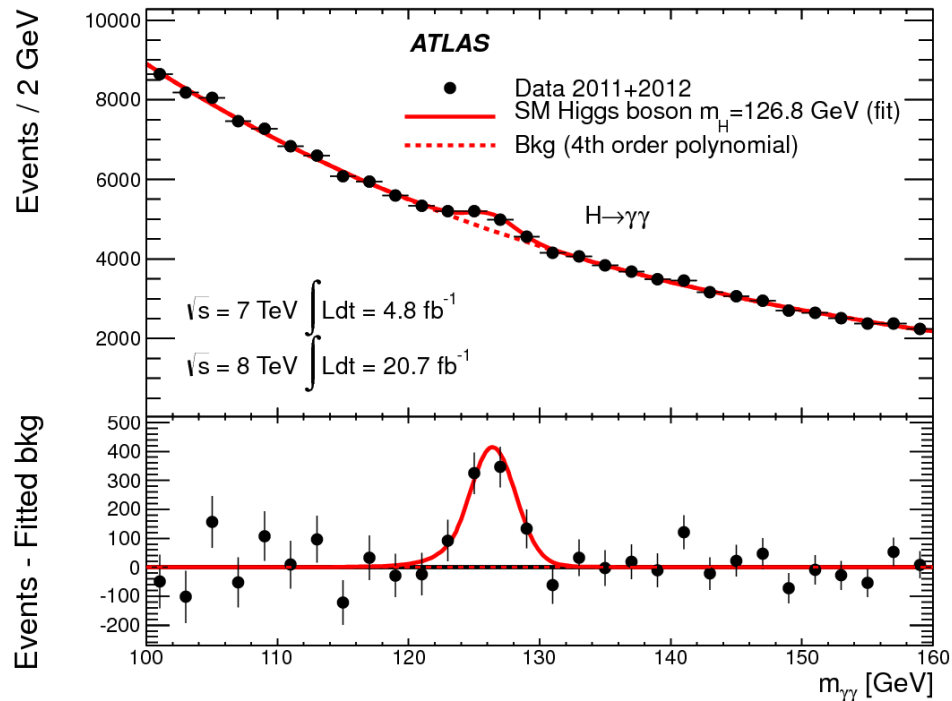


Local significance: observed 7.4σ (expected 4.1σ)

Best fit mass = 126.8 ± 0.2 (stat) ± 0.7 (syst) GeV

$H \rightarrow \gamma\gamma$ analysis

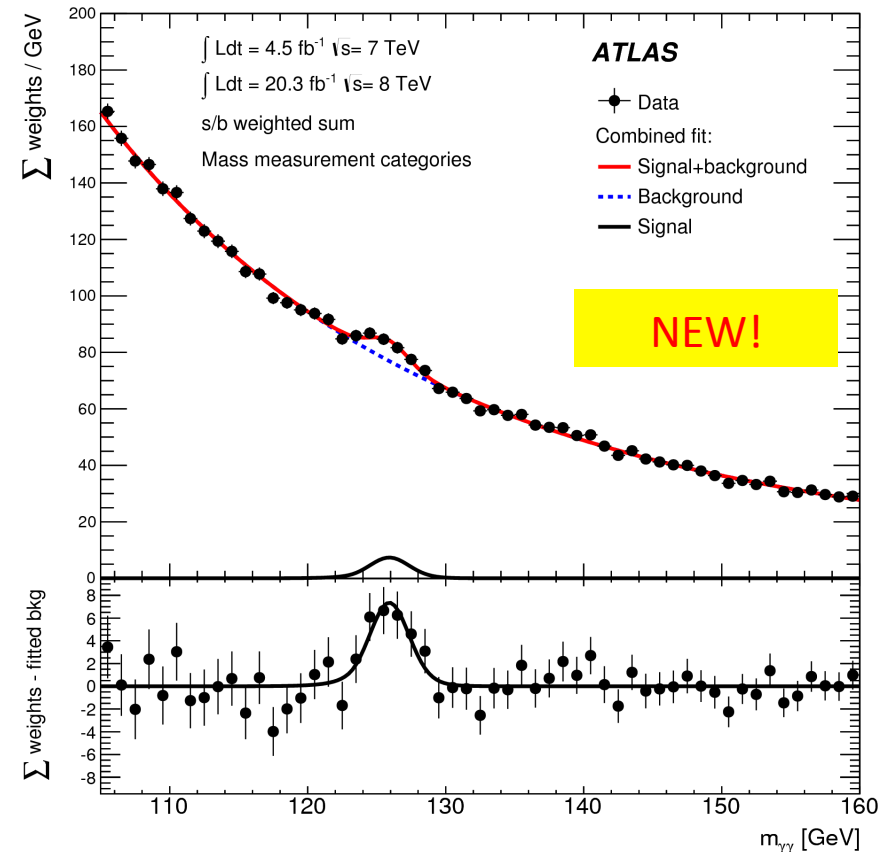
Phys.Lett.B726(2013), pp. 88-119



Local significance: observed 7.4σ (expected 4.1σ)

Best fit mass = 126.8 ± 0.2 (stat) ± 0.7 (syst) GeV

arXiv:1406.3827[hep-ex] submitted to PRD



New Mass Fit Result:
 125.98 ± 0.42 (stat) ± 0.28 (syst) GeV

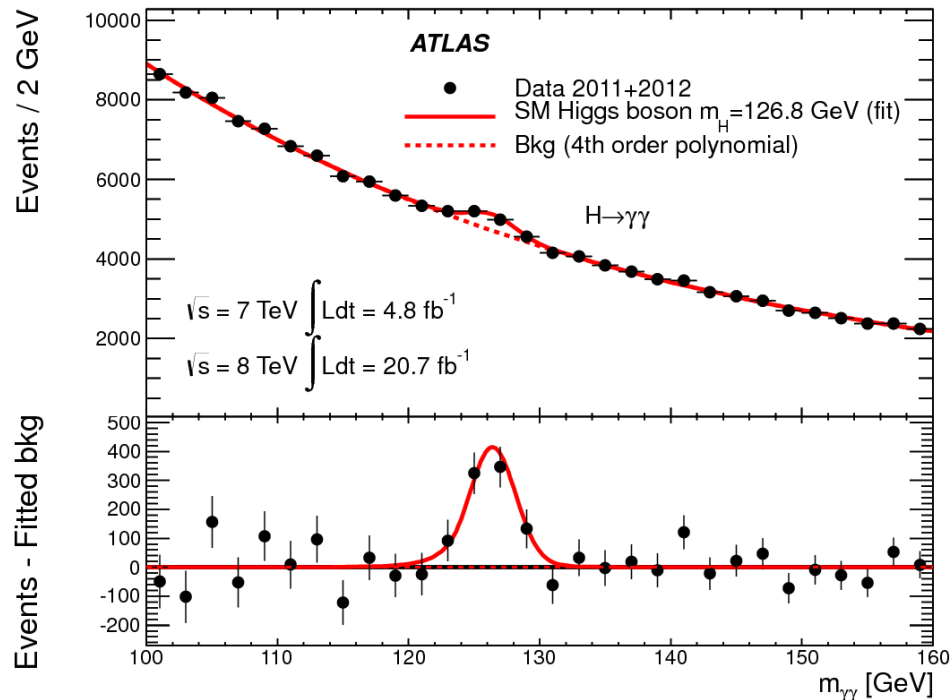
Improved calibration, detector material description and analysis

For more details on the new mass measurement see Sarah's talk

The old mass measurement is used for the combination presented in this talk

$H \rightarrow \gamma\gamma$ analysis

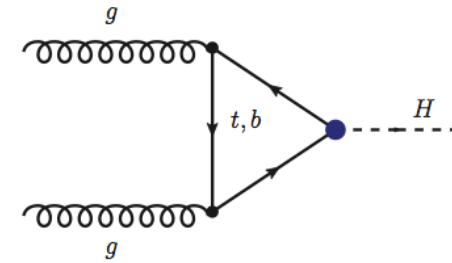
Phys.Lett.B726(2013), pp. 88-119



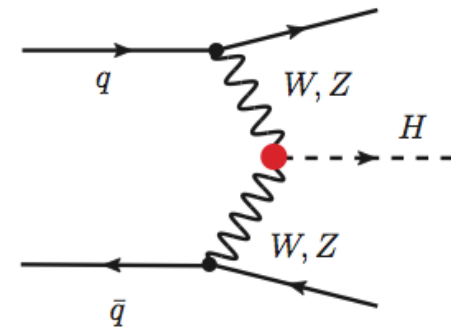
Local significance: observed 7.4σ (expected 4.1σ)
 Best fit mass = 126.8 ± 0.2 (stat) ± 0.7 (syst) GeV

Classification into 14 categories with different S/B (1-60%) and different resolutions (1.4-2.5 GeV)
 --> optimised for coupling measurements to fermions/bosons

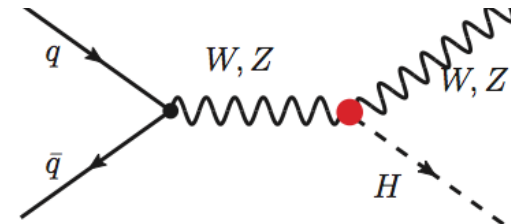
ggH



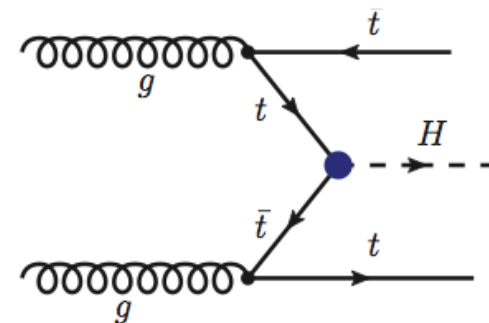
VBF



VH



ttH

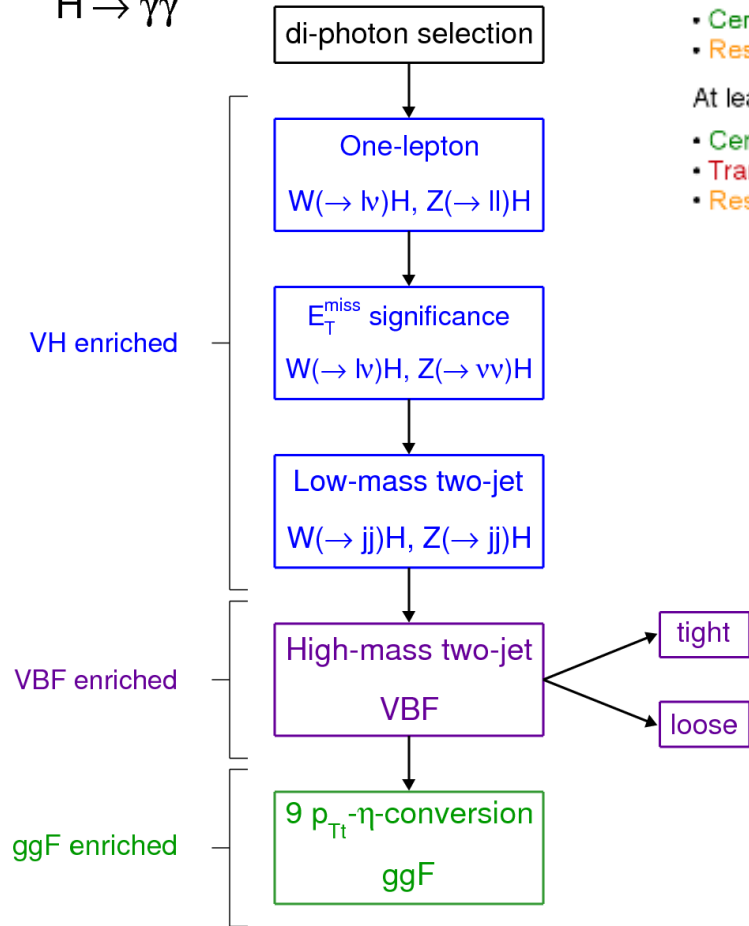


New Couplings analysis will be updated soon

$H \rightarrow \gamma\gamma$ analysis

ATLAS Preliminary

$H \rightarrow \gamma\gamma$



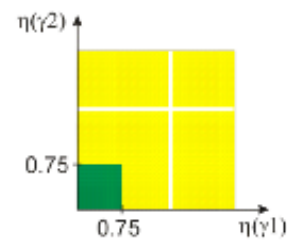
Both unconverted:

- Central
- Rest

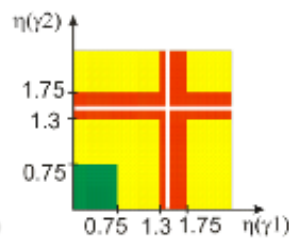
At least one converted:

- Central
- Transition
- Rest

2 unconverted:

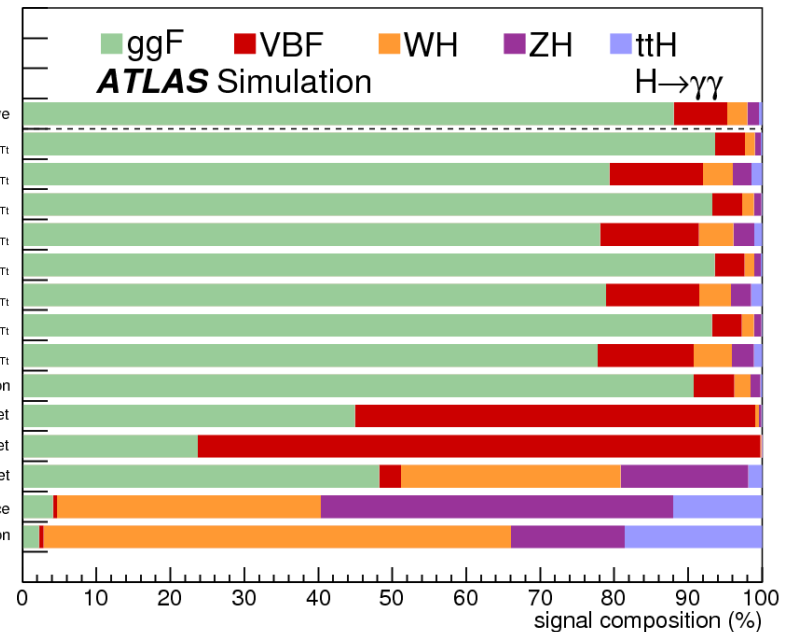
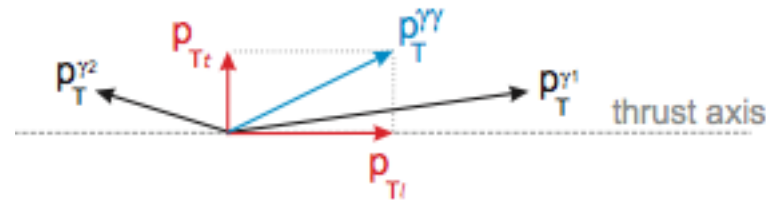


≥ 1 converted:



Resolution:

- Good
- Medium
- Poor

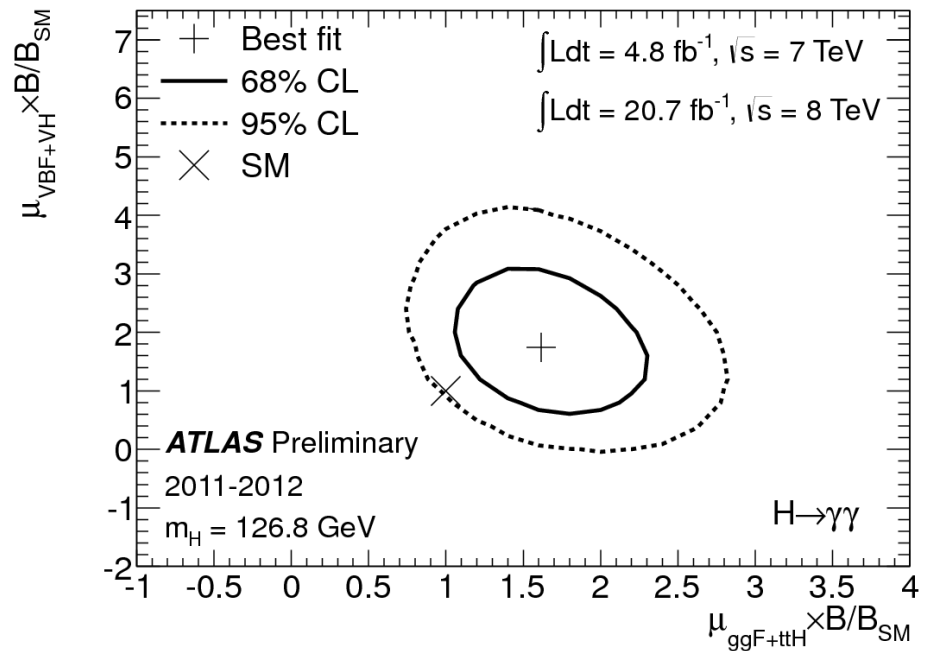
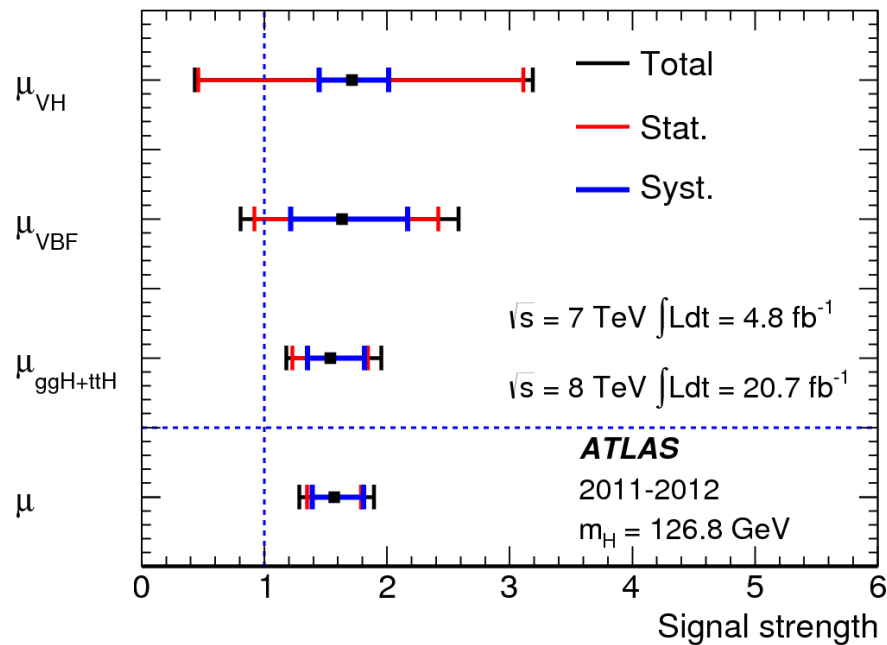


VBF-like category is built on a MVA discriminant

VBF purity $\sim 75\%$, ~ 8 signal events expected

*For 7 TeV analysis, only 10 categories are used: 9 depending on η and p_{Tt} and one VBF-like

$H \rightarrow \gamma\gamma$ couplings measurement



Best fit of signal strength @125.5 GeV:

Phys.Lett.B726(2013), pp. 88-119

$$\mu = \sigma / \sigma_{SM} = 1.55 \pm 0.23(stat) \pm 0.15(syst) \pm 0.15(th)$$

Compatibility with the SM at the level of 2σ (consistency checked in all categories)

$$\mu_{ggF+ttH} = 1.5 \pm 0.3(stat)_{-0.2}^{+0.3}(syst), \mu_{VBF} = 1.6 \pm 0.8(stat)_{-0.4}^{+0.5}(syst),$$

$$\mu_{VH} = 1.7_{-1.3}^{+1.5}(stat) \pm 0.3(syst)$$

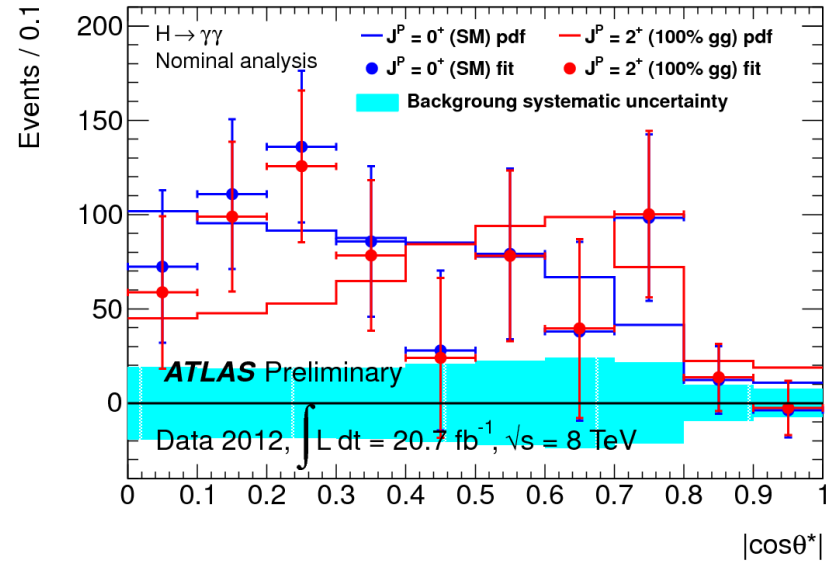
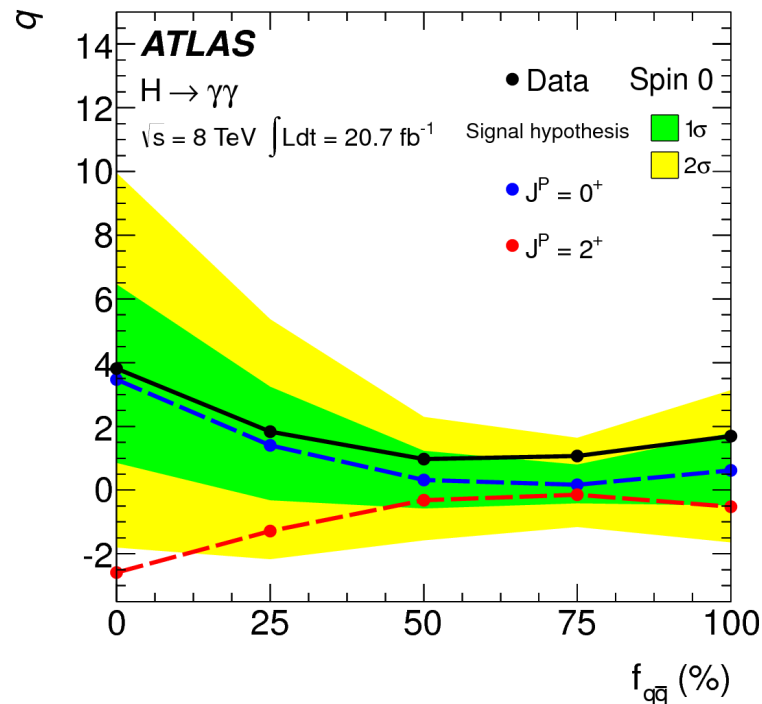
$H \rightarrow \gamma\gamma$ spin measurement

Landau-Yang theorem forbids a direct decay of an on-shell spin 1 particle to $\gamma\gamma$ -> look@spin2

Discriminant: polar angle distribution of the photons in the resonance (Collins-Soper) rest frame θ^*

2^+_m (graviton-like tensor with minimal couplings) hypothesis considered

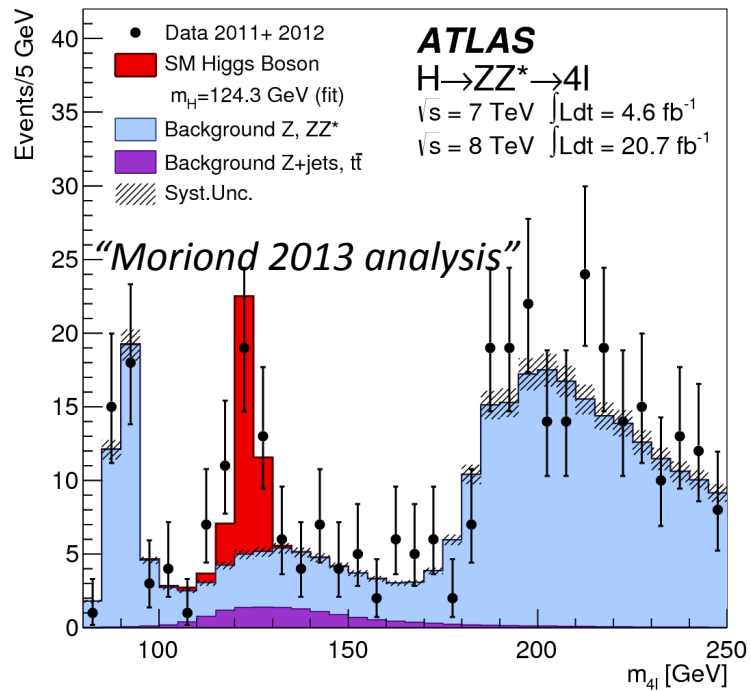
2^+ : different fractions of $q\bar{q}$ ($f_{q\bar{q}}$) are considered, from 0% to 100% in steps of 25%



The minimal spin 2^+ hypothesis is excluded at the level of **99.3% CL** (2.46σ) for 100% gg production mode

$H \rightarrow ZZ \rightarrow 4l$ analysis

Phys.Lett.B726(2013), pp. 88-119



Local significance 6.6σ (expected 4.4σ)

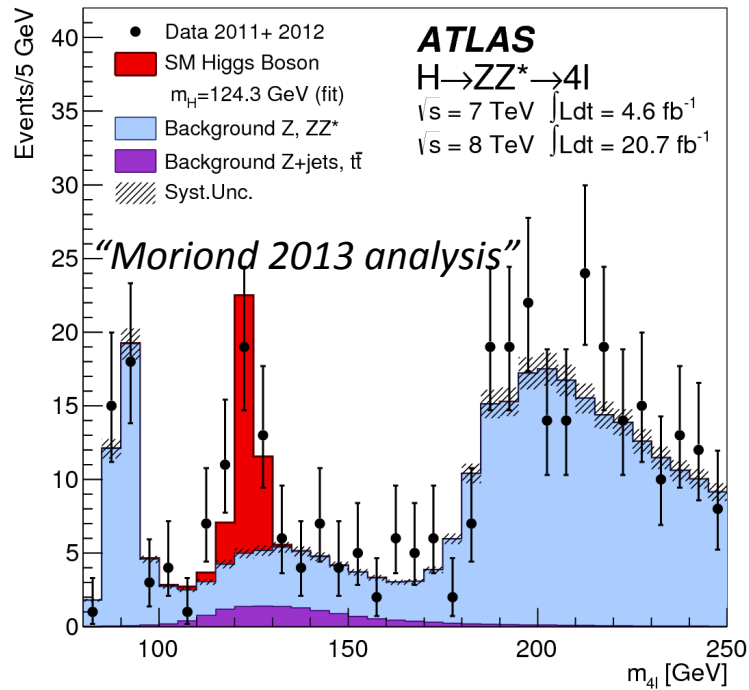
at best fit mass:

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

$H \rightarrow ZZ \rightarrow 4l$ analysis

Phys.Lett.B726(2013), pp. 88-119

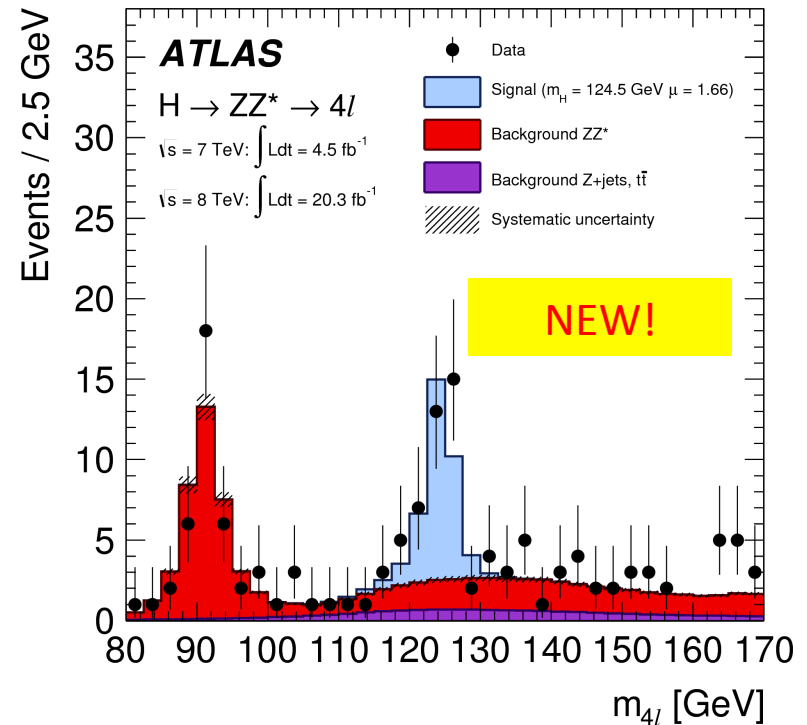
(To be submitted to PRD)



Local significance 6.6σ (expected 4.4σ)
at best fit mass:

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

No big change in the mass



Local significance 8.1σ (expected 5.8σ)
at best fit mass:

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

New in the inclusive analysis (used also for the new mass measurement) since Moriond 2013:

- new electron ID (loose likelihood for 2012 only)
- new electron and muon energy calibration
- E/p combination for the electrons
- far FSR recovery for electrons and muons
- BDT for ZZ^* background...

$H \rightarrow ZZ \rightarrow 4l$ coupling analysis

3 categories were considered in the [Moriond 2013 analysis](#):

- VBF-like (accompanied with 2 high p_T jets widely separated in rapidity),
- VH-like (accompanied with an additional lepton)
- ggF-like (all the others)

New in the specific couplings analysis:

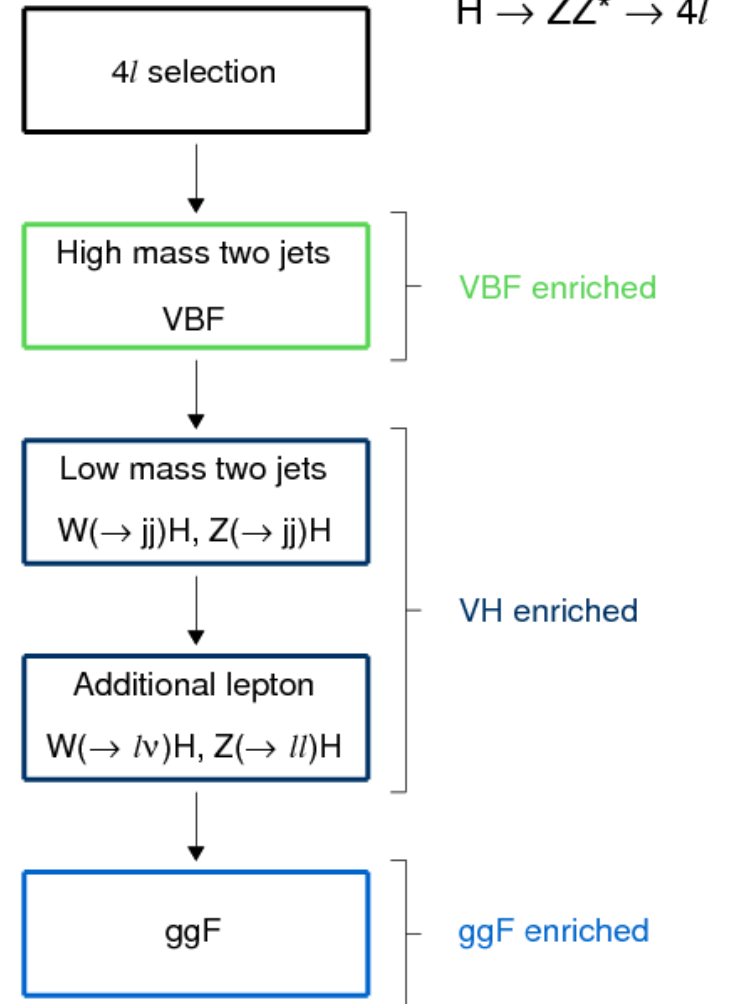
- Add a VH hadronic category
- Looser cuts on the VBF category
- BDT for both VBF and VH categories

(To be submitted to PRD)

NEW!

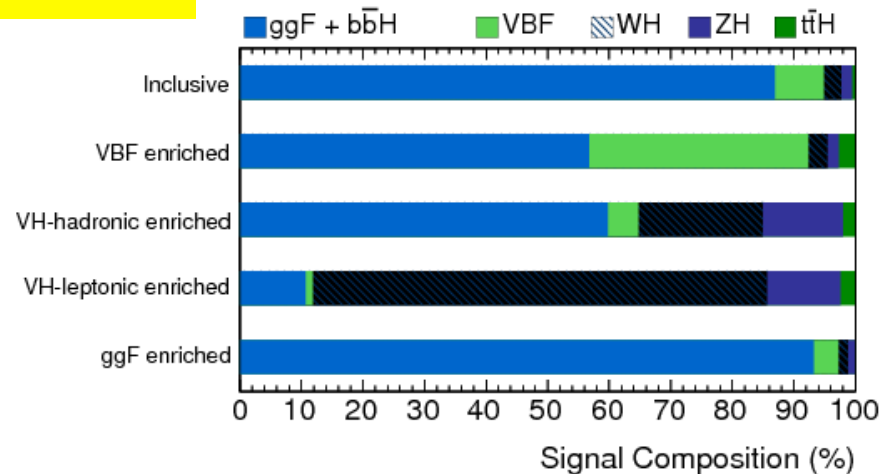
ATLAS Preliminary

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



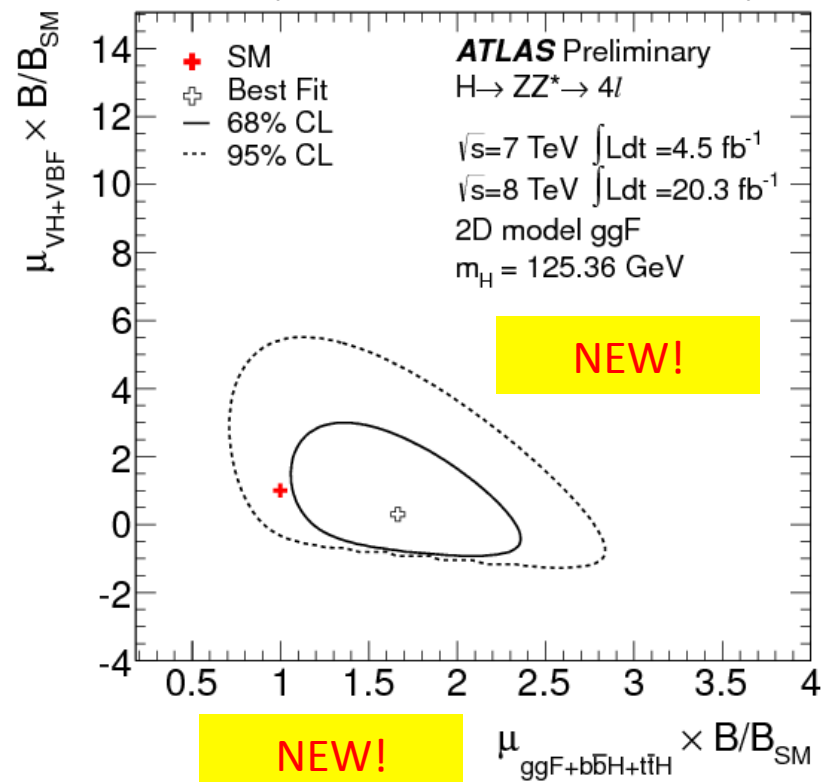
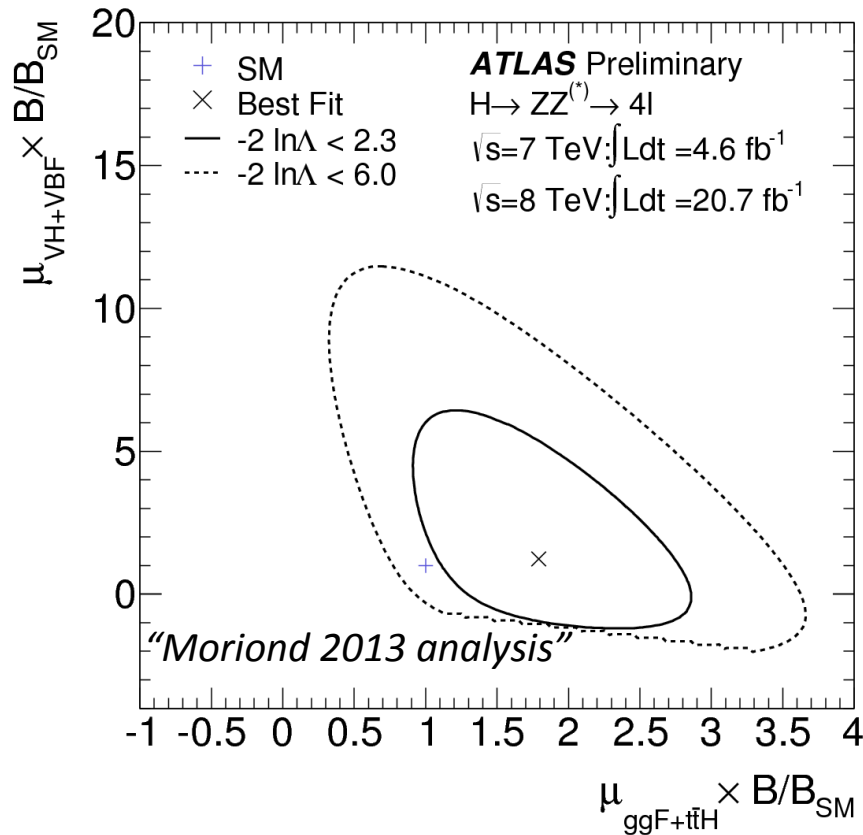
NEW!

ATLAS Simulation Preliminary $m_H = 125$ GeV $110 < m_{4l} [\text{GeV}] < 140$ $H \rightarrow ZZ^* \rightarrow 4l$



H \rightarrow ZZ \rightarrow 4l coupling measurement

(To be submitted to PRD)



@mass (4l) = 124.3 GeV @mass (4l+ $\gamma\gamma$) = 125.5 GeV

@mass (4l+ $\gamma\gamma$) = 125.36 GeV

$$\mu = 1.7^{+0.5}_{-0.4}$$

$$\mu = 1.44^{+0.40}_{-0.35}$$

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

$$\mu_{ggF+bbH+ttH} * B / B_{SM} = 1.8^{+0.8}_{-0.5}$$

$$\mu_{ggF+bbH+ttH} * B / B_{SM} = 1.66^{+0.45}_{-0.41} (stat)^{+0.25}_{-0.15} (syst)$$

$$\mu_{VBF+VH} * B / B_{SM} = 1.2^{+3.8}_{-1.4}$$

$$\mu_{VBF+VH} * B / B_{SM} = 0.26^{+1.60}_{-0.91} (stat)^{+0.36}_{-0.23} (syst)$$

No change in mu
as next combination input

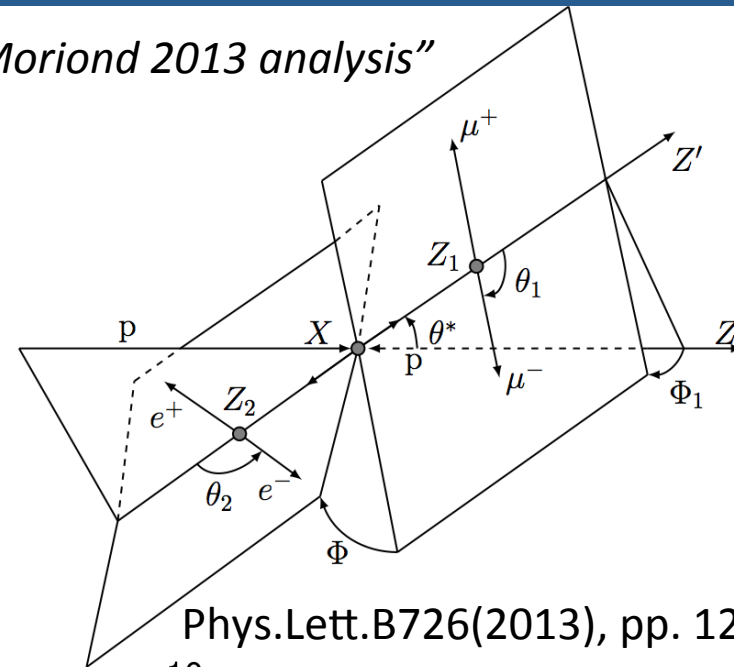
Old ZZ result is used in the current combination but no big change expected with the new result

$H \rightarrow ZZ \rightarrow 4l$ spin/CP measurement

Spin 0^- , 1^+ , 1^- and 2^+_m hypotheses are considered using kinematic properties: 5 production and decay angles, m_{12} , m_{34}
 →BDT

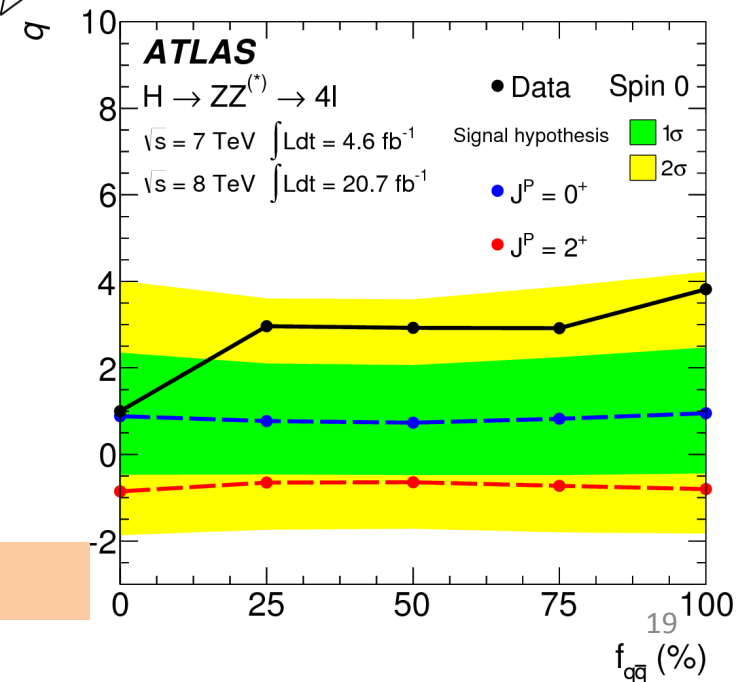
The production and decay of non-SM resonances are produced using JHU LO generator, interfaced to Pythia8 for PS and hadronisation.

“Moriond 2013 analysis”



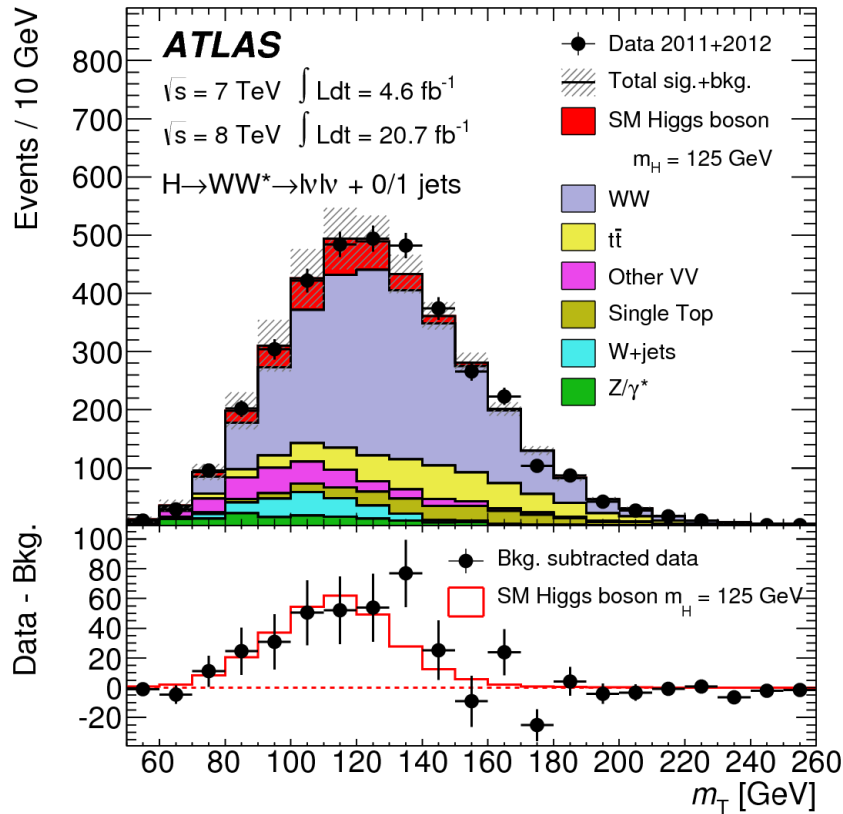
Phys.Lett.B726(2013), pp. 120-144

Spin	Observed exclusion CLs
0^-	97.8%
1^+	99.8%
1^-	94.0%
2^+_m	83.0%



The spin 0^- and 1^- are excluded > 97%CL in favour of 0^+

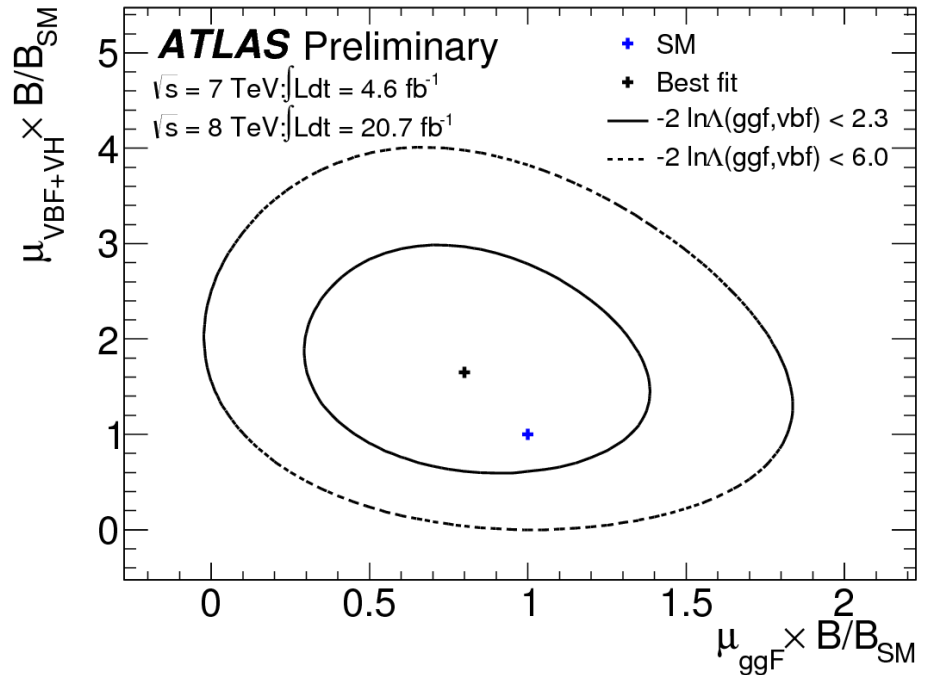
$H \rightarrow WW \rightarrow \ell\nu \ell\nu$ couplings



Observed significance@125 GeV:
3.8 σ (expected 3.7 σ)

$\mu = 1.01 \pm 0.31 (@125 \text{ GeV})$

Phys.Lett.B726(2013), pp. 88-119



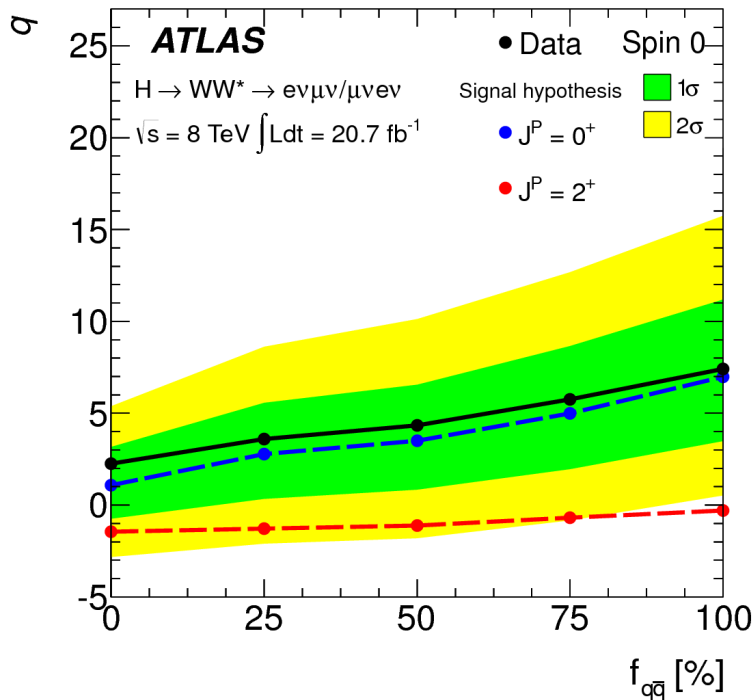
Consistency with SM $<1\sigma$ level

VBF: Observed significance@125 GeV:
2.5 σ (expected 1.8 σ)

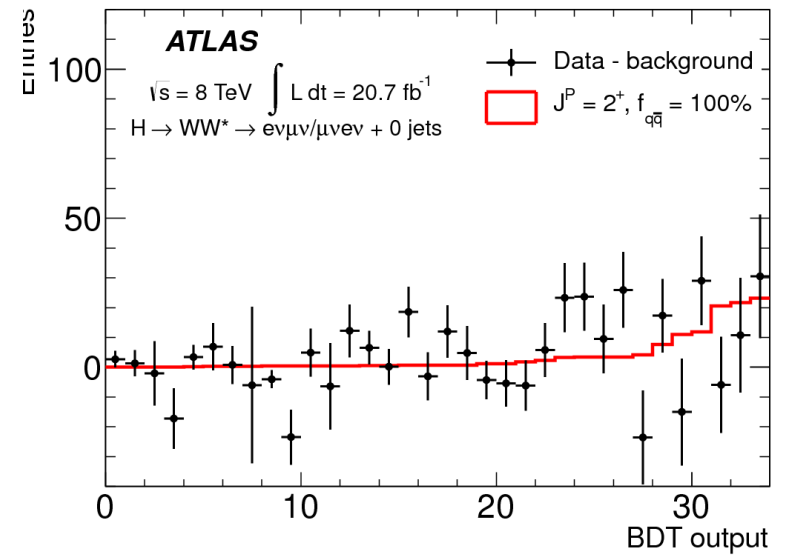
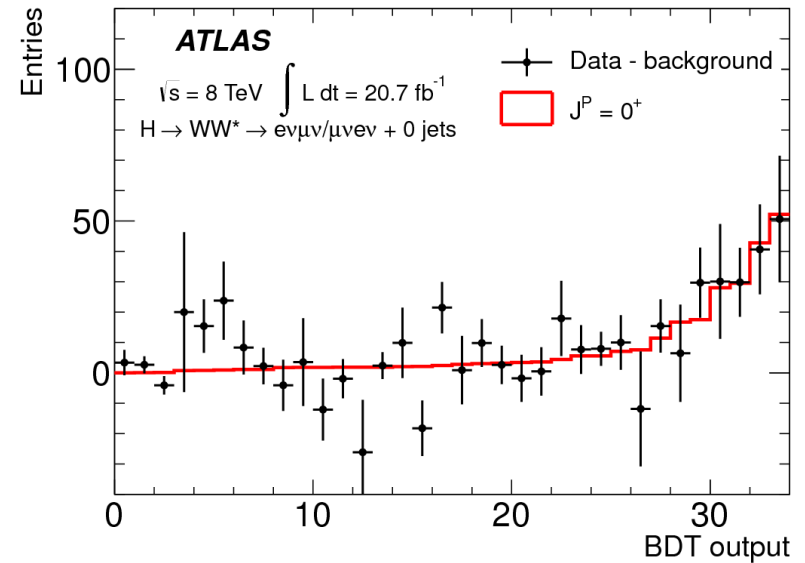
$H \rightarrow WW \rightarrow \ell\nu \ell\nu$ spin

Compare SM spin 0^+ to 2^+ (both qq and gg production considered)

Discriminant variables: m_{ll} , $\Delta\phi_{ll}$, p_T^{ll} , $E_{T,rel}^{miss}$
 --> Boost Decision Tree (BDT)



The spin 2^+ is excluded in favour of a 0^+ hypothesis at a CL varying between 99% for $f_{qq}=100\%$ and 95% for $f_{qq}=0\%$



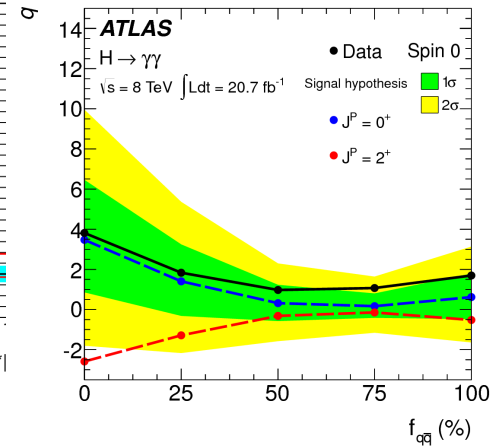
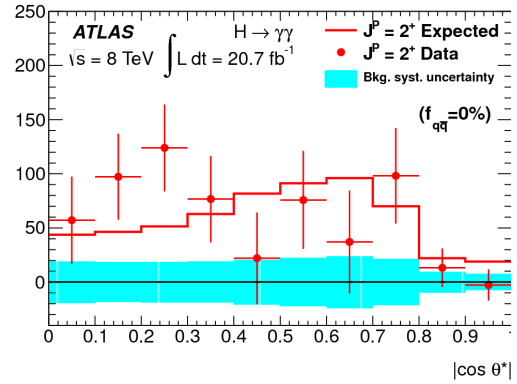
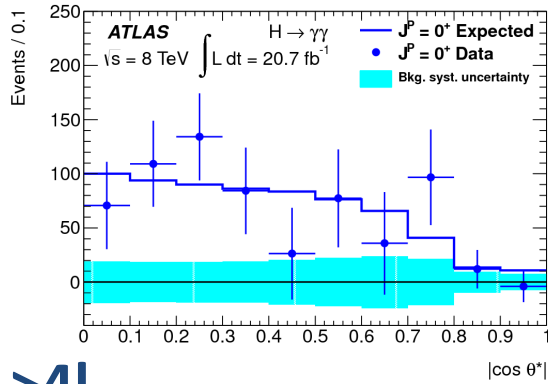
Phys.Lett.B726(2013), pp. 120-144



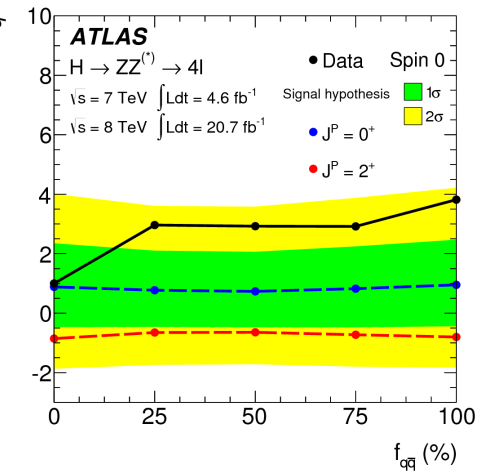
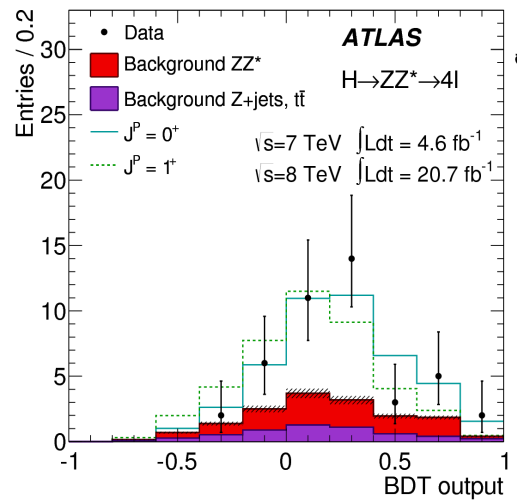
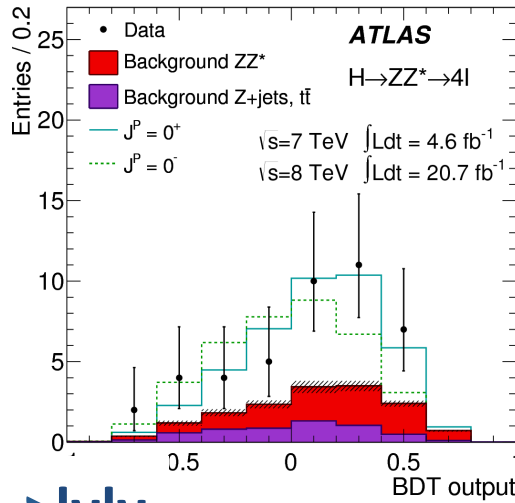
Outline

- Introduction
- Brief review of bosonic channels (for more details see Marianna's talk)
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- Brief review of fermionic channels (for more details see Geng-Yuan's talk)
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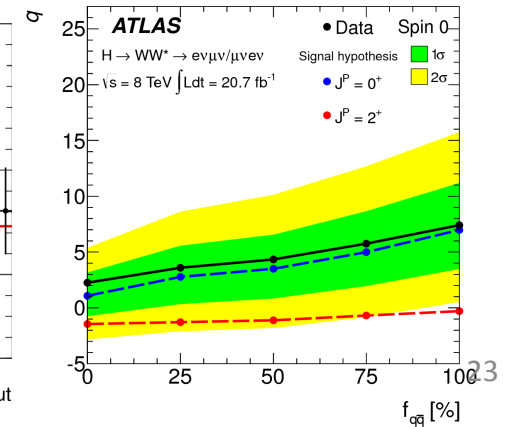
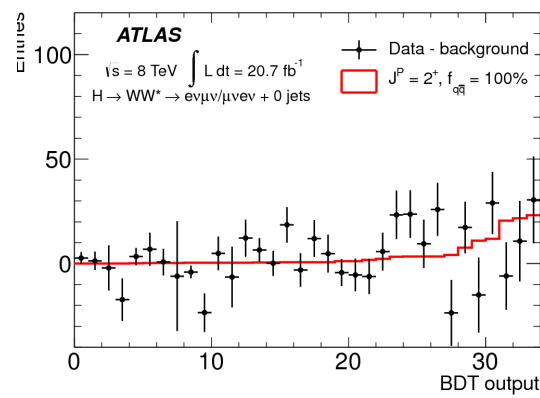
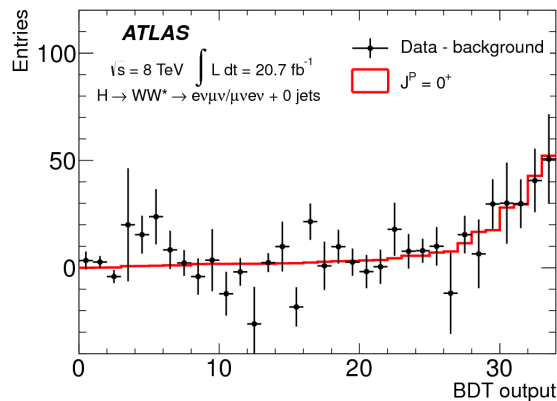
H $\rightarrow\gamma\gamma$



H $\rightarrow ZZ \rightarrow 4l$

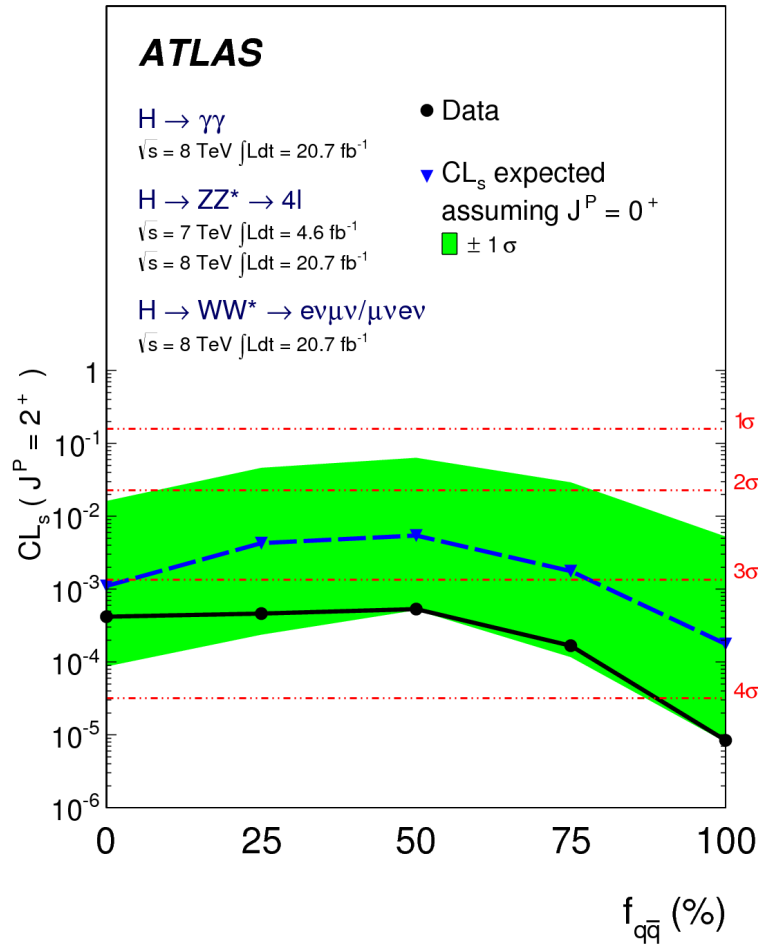


H $\rightarrow WW \rightarrow l\nu l\nu$



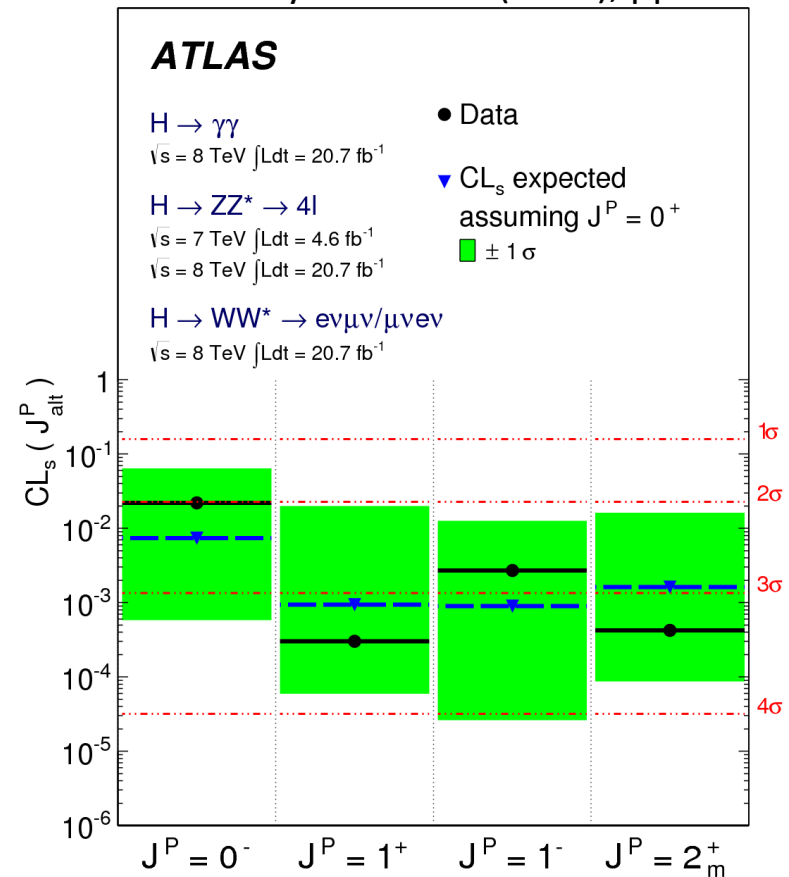
Combined Spin/CP measurement

Phys.Lett.B726(2013), pp. 120-144



Exclusion >99.9% CL for all $f_{q\bar{q}}$

Evidence for the spin-0 nature of the discovered particle



$0^+/0^-$	only ZZ	97.8% CL
$0^+/1^+$	ZZ+WW	99.97%CL
$0^+/1^-$	ZZ+WW	99.7%CL
$0^+/2^+$	$\gamma\gamma$ +ZZ+WW	>99.9%CL



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$H \rightarrow b\bar{b}$ analysis

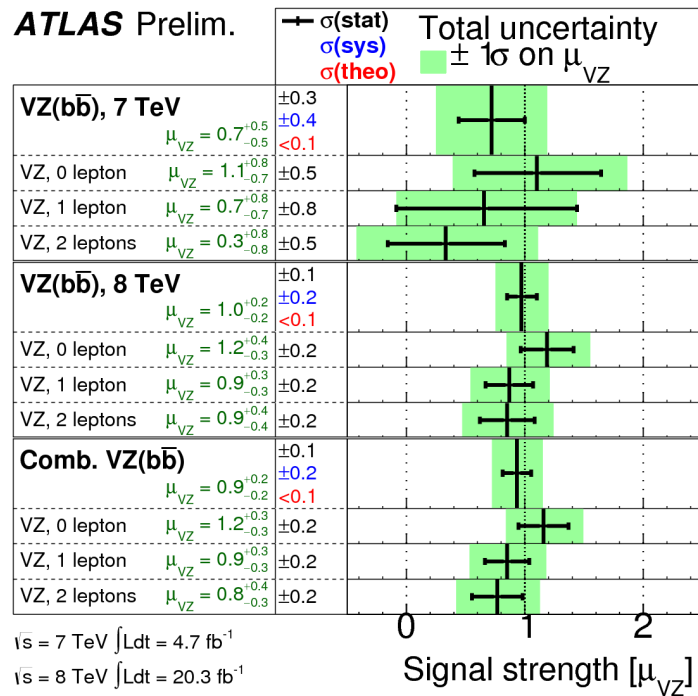
Channel with the highest branching ratio (58% for 125 GeV) but suffers from large QCD bkg

3 final states: $ZH \rightarrow ll + b\bar{b}$, $ZH \rightarrow \nu\nu + b\bar{b}$, $WH \rightarrow l\nu + b\bar{b}$ in the VH production mode

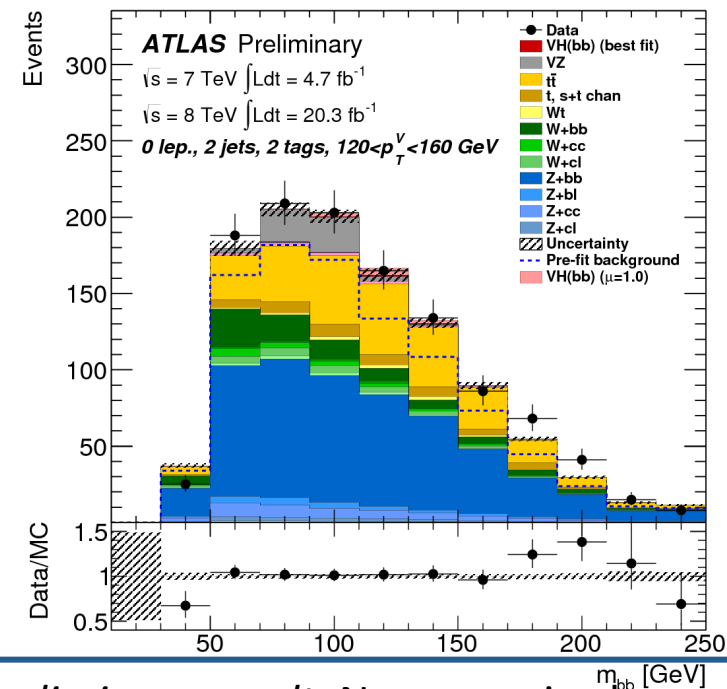
Categories: split according to the vector boson p_T , number of jets, number of b-tags

26 2-b tags signal regions, 26 1-b tag control regions and 5 top control regions

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Check with $VZ(\rightarrow b\bar{b})$: $\mu_{VZ} = 0.9 \pm 0.2$
 agrees with SM, observed significance of 4.8σ (5.1σ)

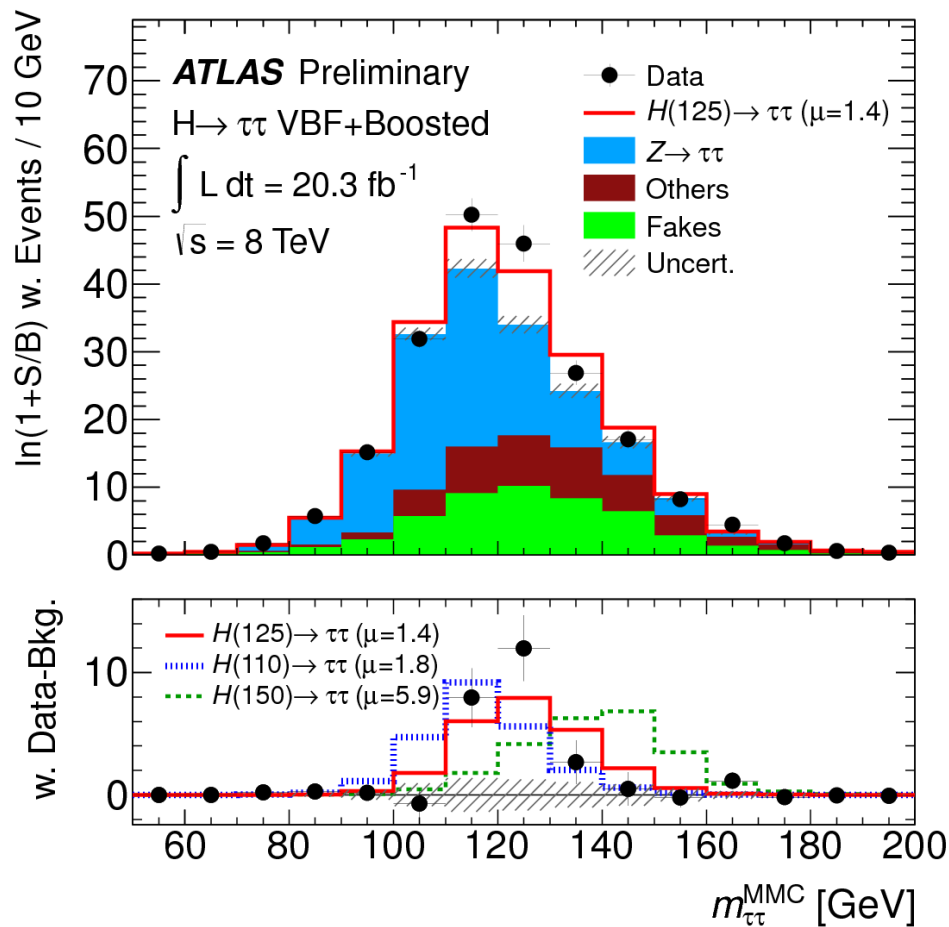


Preliminary result: No excess is observed.
 For $m_H = 125 \text{ GeV}$: $\mu = 0.2 \pm 0.5(\text{stat}) \pm 0.4(\text{sys})$
 95%CL observed upper limit: 1.4 SM (1.3)

An excess is however observed for $m_H = 125 \text{ GeV}$ at TeVatron at the level of 2.8σ and 2.1σ in CMS

H → τ τ analysis

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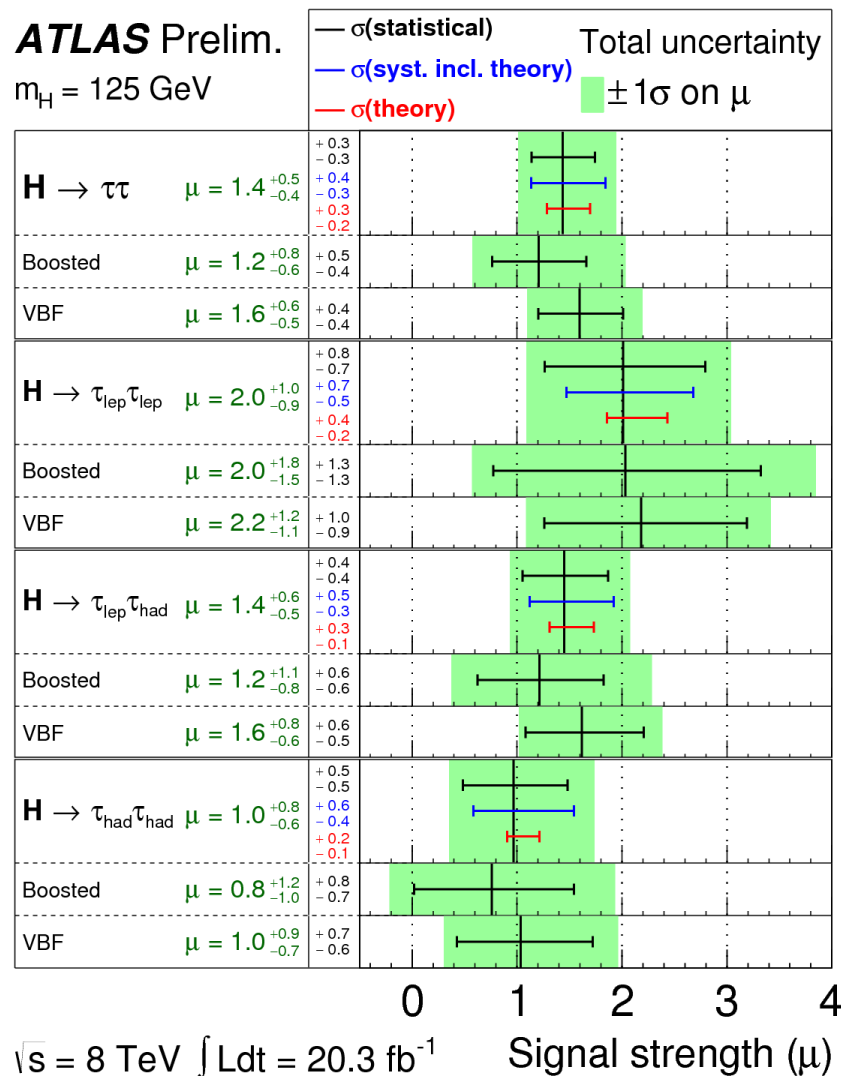


For $m_H=125 \text{ GeV}$:
 Observed local significance **4.1 σ** (expected 3.2 σ)

→ Direct Evidence of H → ττ decays

ATLAS Prelim.

$m_H = 125 \text{ GeV}$



$$\mu = 1.43^{+0.31}_{-0.29} (\text{stat})^{+0.41}_{-0.30} (\text{sys})$$

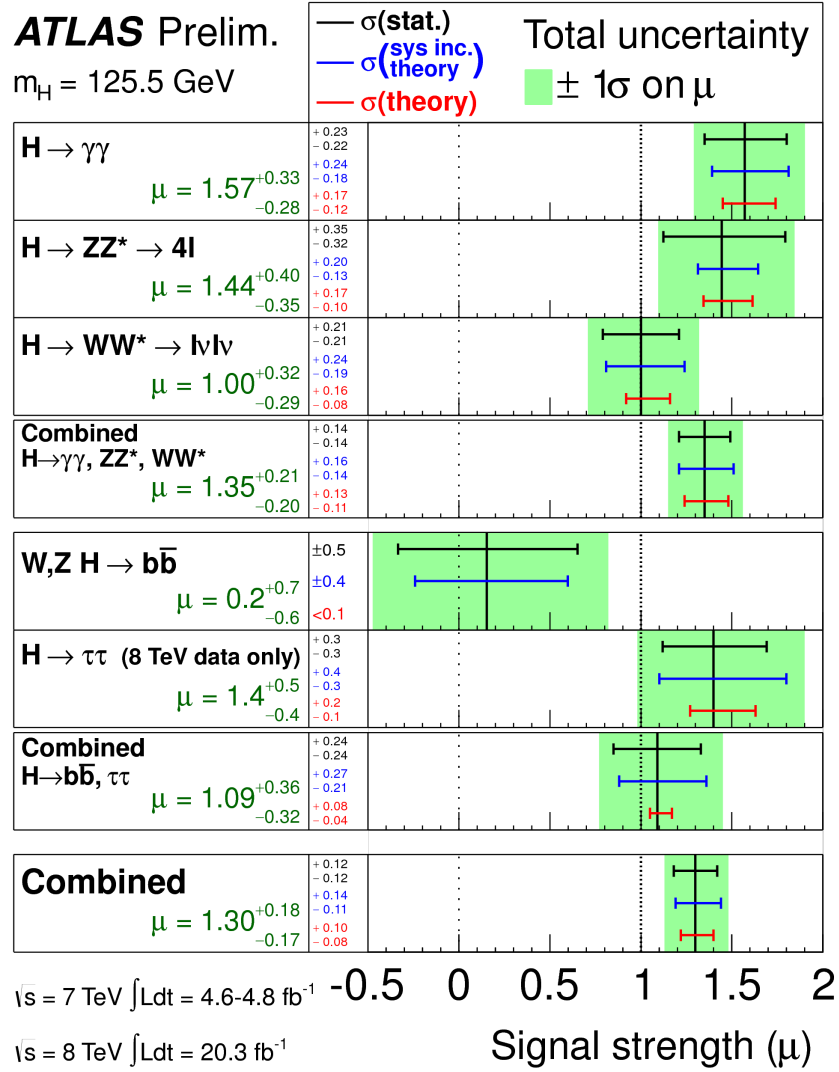
$$\mu_{\text{ggF}} = 1.1^{+1.3}_{-1.1}, \mu_{\text{VH+VBF}} = 1.6^{+0.8}_{-0.7} \quad 27$$



Outline

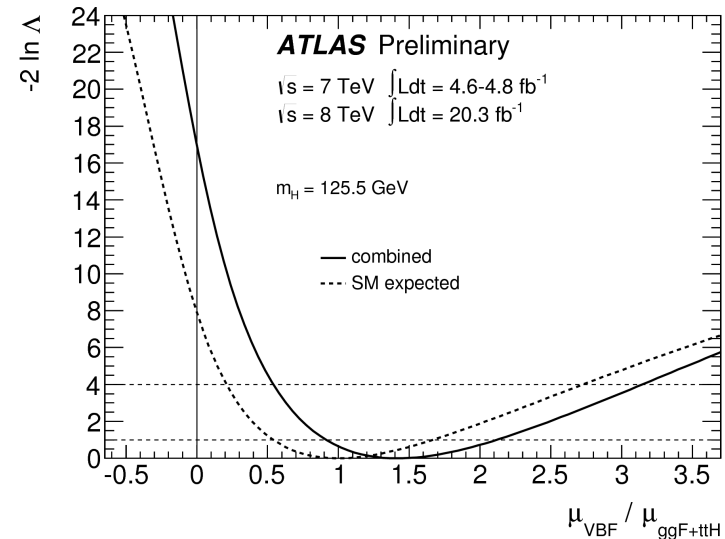
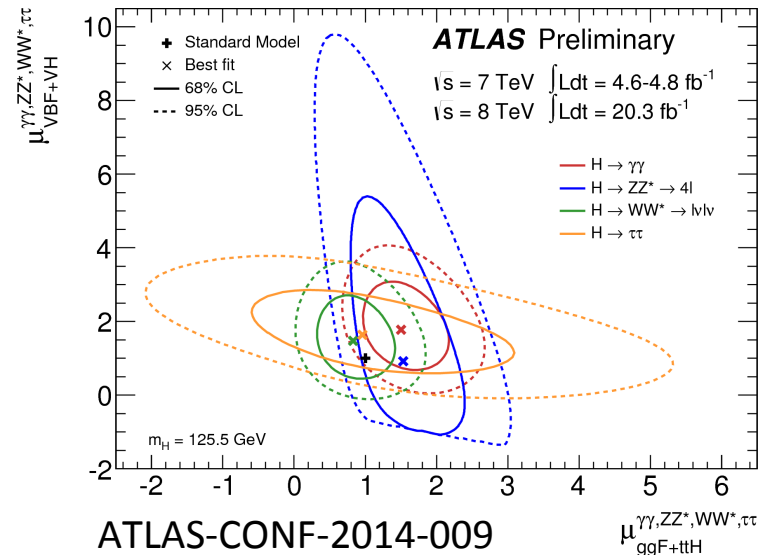
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Combined signal strength & Evidence for VBF H



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

Evidence at 3.7σ of direct fermionic decays



Evidence at 4.1σ for VBF production mode

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

Coupling framework

Introducing the κ -formalism:

$$\begin{aligned}
 L = & \kappa_3 \frac{m_H^2}{2v} H^3 + \kappa_Z \frac{m_Z^2}{v} Z_\mu Z^\mu H + \kappa_W \frac{2m_W^2}{v} W_\mu^+ W^{-\mu} H \\
 & + \kappa_g \frac{\alpha_s}{12\pi v} G_{\mu\nu}^a G^{a\mu\nu} H + \kappa_\gamma \frac{\alpha}{2\pi v} A_{\mu\nu} A^{\mu\nu} H + \kappa_{Z\gamma} \frac{\alpha}{\pi v} A_{\mu\nu} Z^{\mu\nu} H \\
 & - \left(\kappa_t \sum_{f=u,c,t} \frac{m_f}{v} f \bar{f} + \kappa_b \sum_{f=d,s,b} \frac{m_f}{v} f \bar{f} + \kappa_\tau \sum_{f=e,\mu,\tau} \frac{m_f}{v} f \bar{f} \right) H
 \end{aligned}$$



Assumptions:

- single resonance
- zero-width approximation
- modifications of the scale factors, tensor structure of the Lagrangian assume to be the same as in the SM

Production:

$$\kappa_i^2 = \frac{\sigma_i}{\sigma_i^{SM}}$$

Decay:

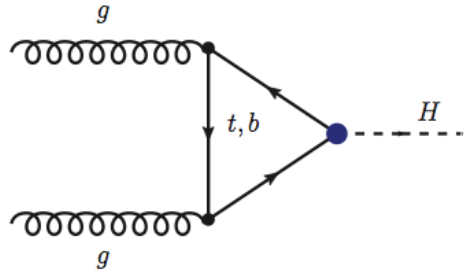
$$\kappa_j^2 = \frac{\Gamma_j}{\Gamma_j^{SM}}$$

Width:

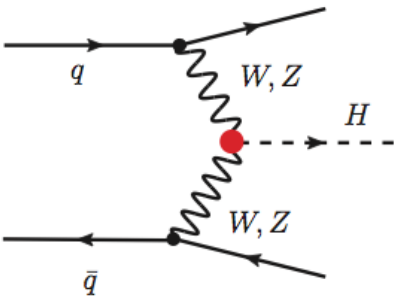
$$\kappa_H^2 = \frac{\sum \kappa_j^2 \Gamma_j^{SM}}{\Gamma_H^{SM}}$$

Coupling framework

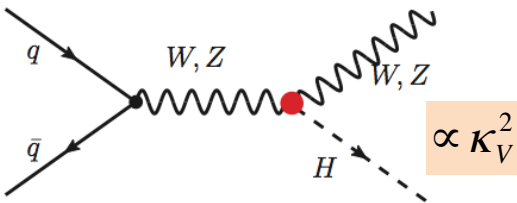
Production



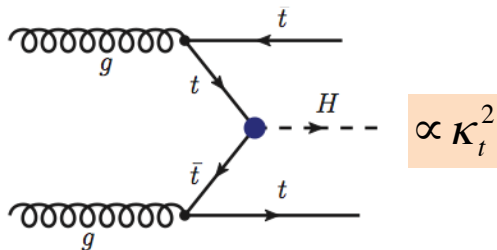
$$\propto \kappa_g^2 = 1.06\kappa_t^2 - 0.07\kappa_t\kappa_b + 0.01\kappa_b^2$$



$$\propto \kappa_V^2$$

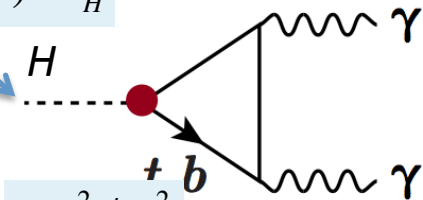
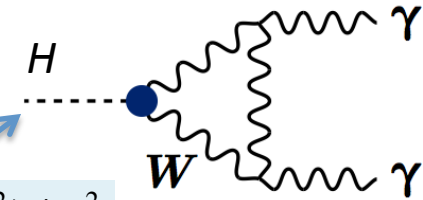


$$\propto \kappa_V^2$$

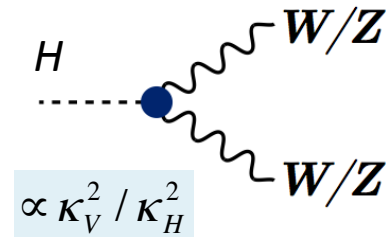


$$\propto \kappa_t^2$$

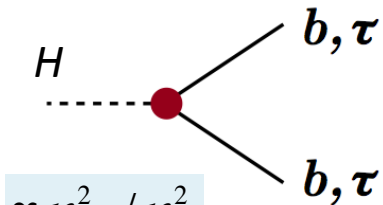
Decay



$$\propto \kappa_V^2 / \kappa_H^2$$



$$\propto \kappa_V^2 / \kappa_H^2$$



$$\propto \kappa_{b,\tau}^2 / \kappa_H^2$$

$$\propto \kappa_\gamma^2 / \kappa_H^2 = (1.59\kappa_W^2 - 0.66\kappa_W\kappa_t + 0.07\kappa_t^2) / \kappa_H^2$$

(κ_F, κ_V) formalism

$$\sigma(ggF) \times BR(H \rightarrow \gamma\gamma) \sim \frac{\kappa_F^2 \cdot \kappa_\gamma^2(\kappa_F, \kappa_F, \kappa_F, \kappa_V)}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

$$\sigma(VBF) \times BR(H \rightarrow \gamma\gamma) \sim \frac{\kappa_V^2 \cdot \kappa_\gamma^2(\kappa_F, \kappa_F, \kappa_F, \kappa_V)}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

$$\sigma(ggF) \times BR(H \rightarrow WW, ZZ) \sim \frac{\kappa_F^2 \cdot \kappa_V^2}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

$$\sigma(VBF) \times BR(H \rightarrow WW, ZZ) \sim \frac{\kappa_V^2 \cdot \kappa_V^2}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

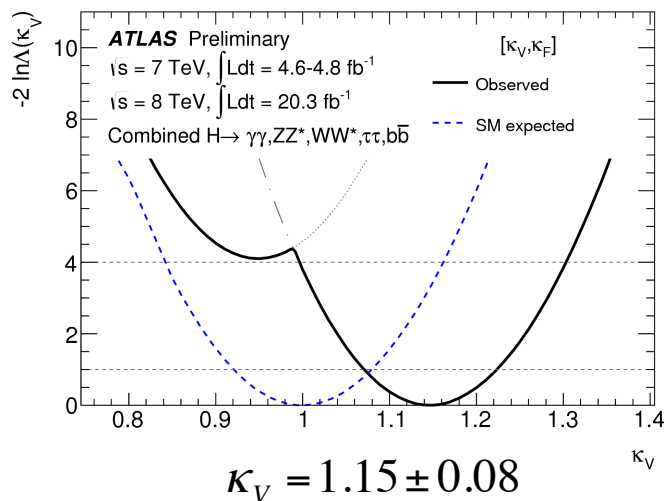
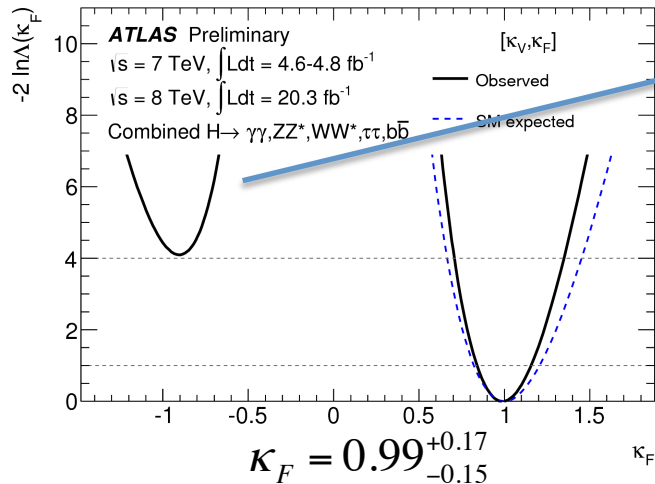
$$\sigma(VBF, VH) \times BR(H \rightarrow \tau\tau, bb) \sim \frac{\kappa_V^2 \cdot \kappa_F^2}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

Fermion vs Vector couplings

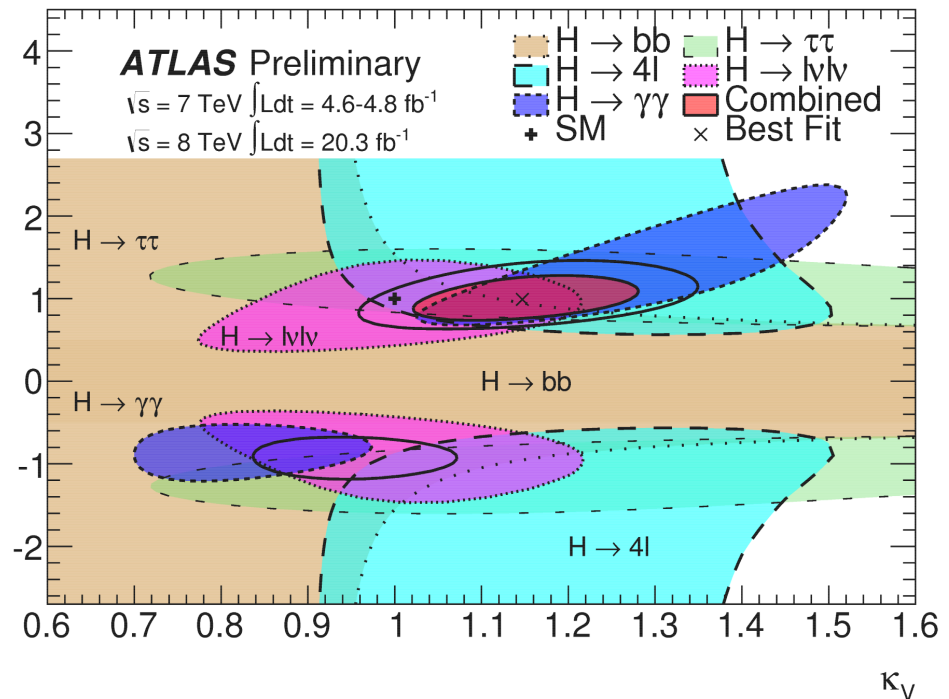
Only SM contributions to the total width, assuming no new particles in loops or decays:

$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau \quad \text{and} \quad \kappa_V = \kappa_W = \kappa_Z$$

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The $\gamma\gamma$ loop induces some sensitivity to the relative sign between κ_t and κ_W

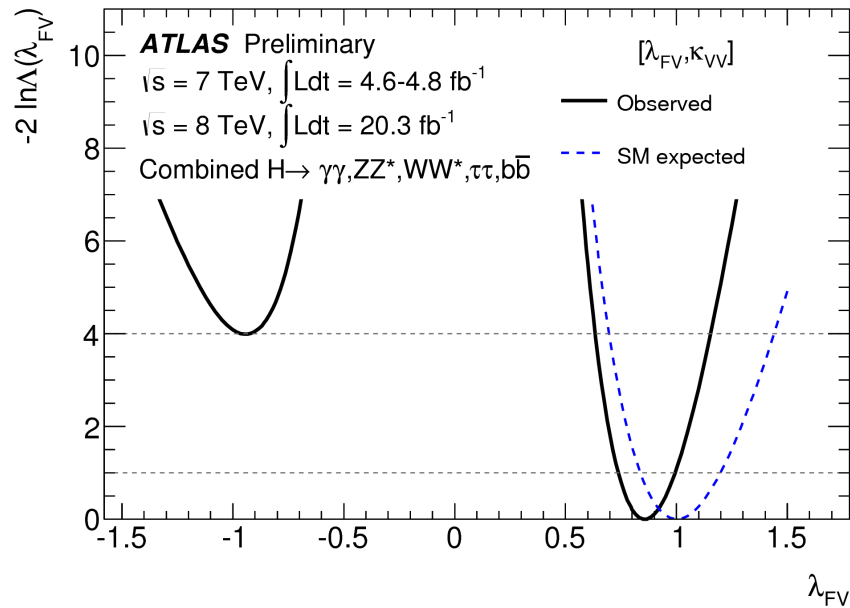


2D compatibility with the SM = 10%
Negative κ_F disfavoured

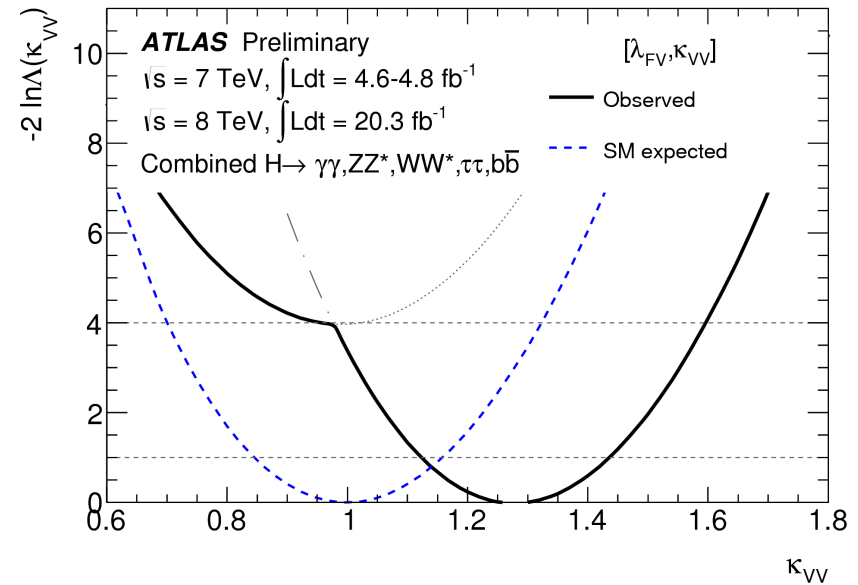
Fermion vs Vector couplings

ATLAS-CONF-2014-009

No assumption on the total width



$$\lambda_{FV} = \kappa_F / \kappa_V = 0.86^{+0.14}_{-0.12}$$



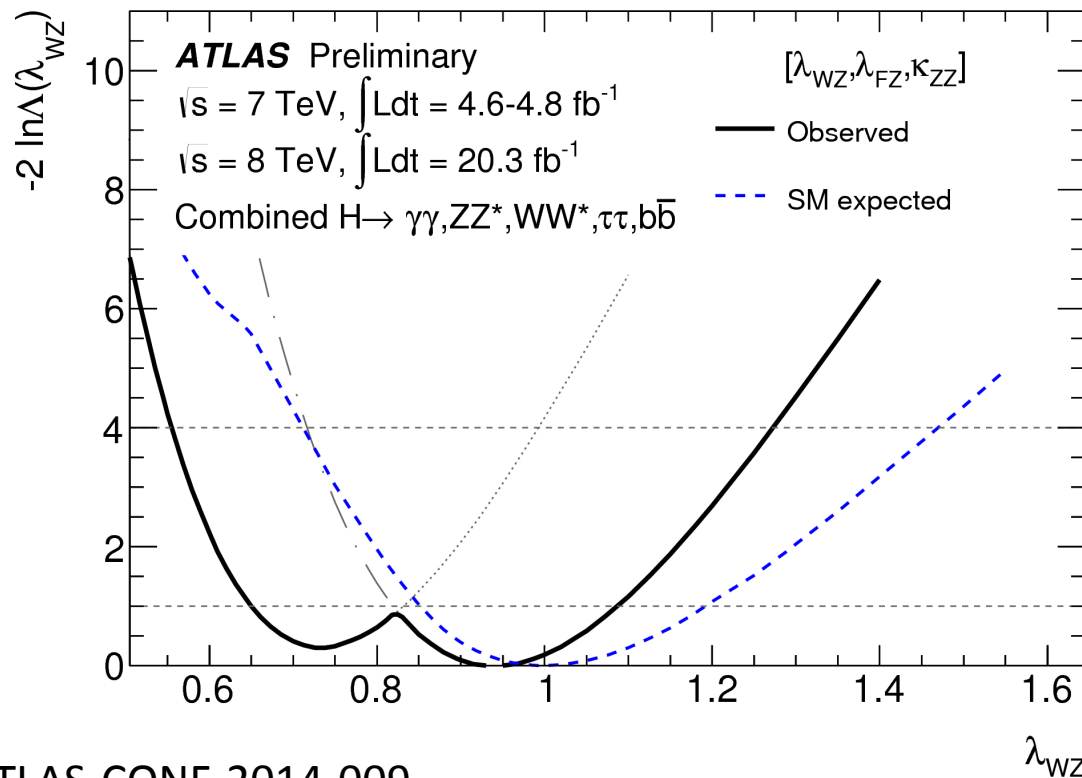
$$\kappa_{VV} = \kappa_V \kappa_V / \kappa_H = 1.28^{+0.16}_{-0.15}$$

Custodial Symmetry

Custodial symmetry imposes identical coupling scale factors for the W and Z boson

-->Probe the ratio $\lambda_{WZ} = \kappa_W / \kappa_Z$

Constraints from $H \rightarrow WW \rightarrow l\nu l\nu$ and $H \rightarrow ZZ \rightarrow 4l$ decays, WH and ZH production modes and also indirectly from VBF production process (74% W, 26%Z) and $H \rightarrow \gamma\gamma$ for κ_W



$$\lambda_{WZ} = 0.94^{+0.14}_{-0.29}$$

Relations in the fermion coupling sector

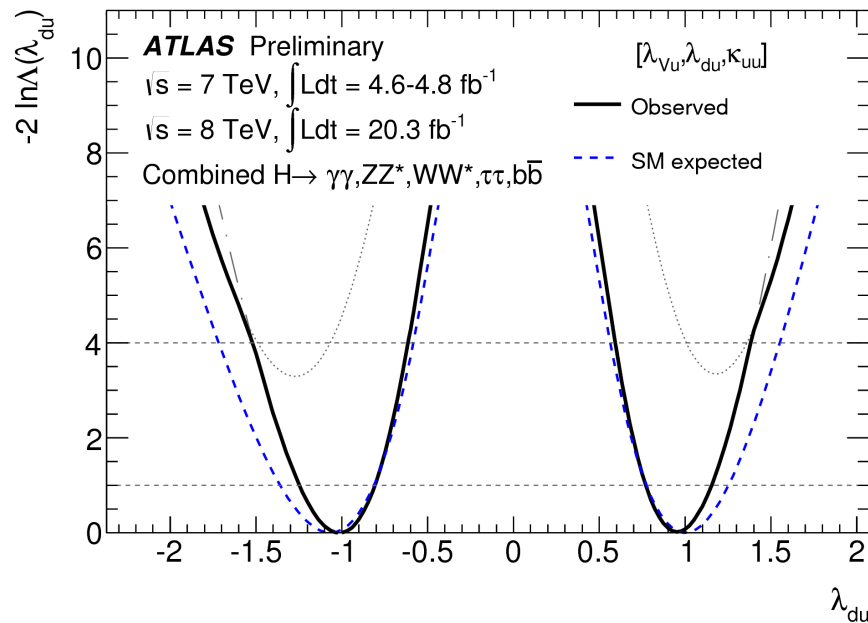
Many extensions of the SM predicts different coupling of the H to up- and down-type fermions.

$$K_u = K_t \quad K_d = K_b = K_\tau$$

$$\lambda_{du} = K_d / K_u$$

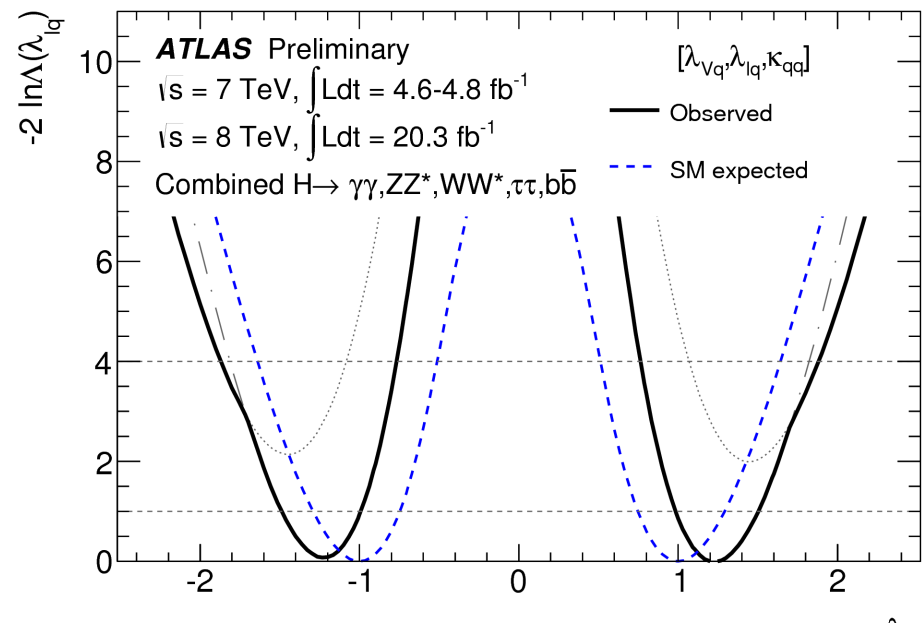
$$K_l = K_\tau \quad K_q = K_b = K_t$$

$$\lambda_{lq} = K_l / K_q$$



$$\lambda_{du} \in [-1.24, -0.81] \cup [0.78, 1.15] @ 68\% CL$$

3.6 σ evidence of the couplings to down-type fermions



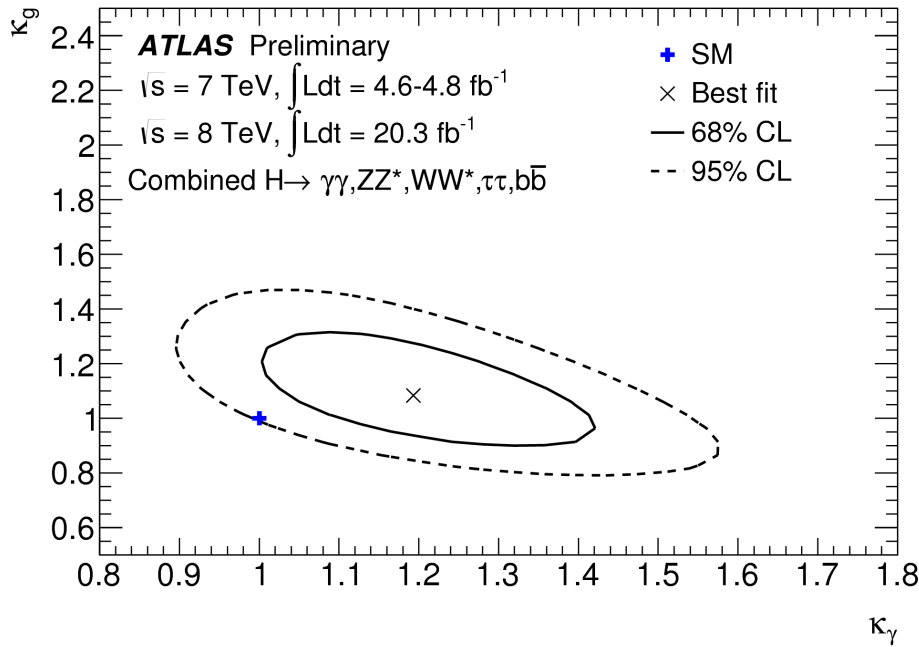
$$\lambda_{lq} \in [-1.48, -0.99] \cup [0.99, 1.50] @ 68\% CL$$

A vanishing coupling to leptons is excluded at the 4.0 σ level

Beyond the SM contributions

Contributions from new particles either in loops or in new final states are considered
 Two cases are considered: Only SM contributions to the total width or no assumption

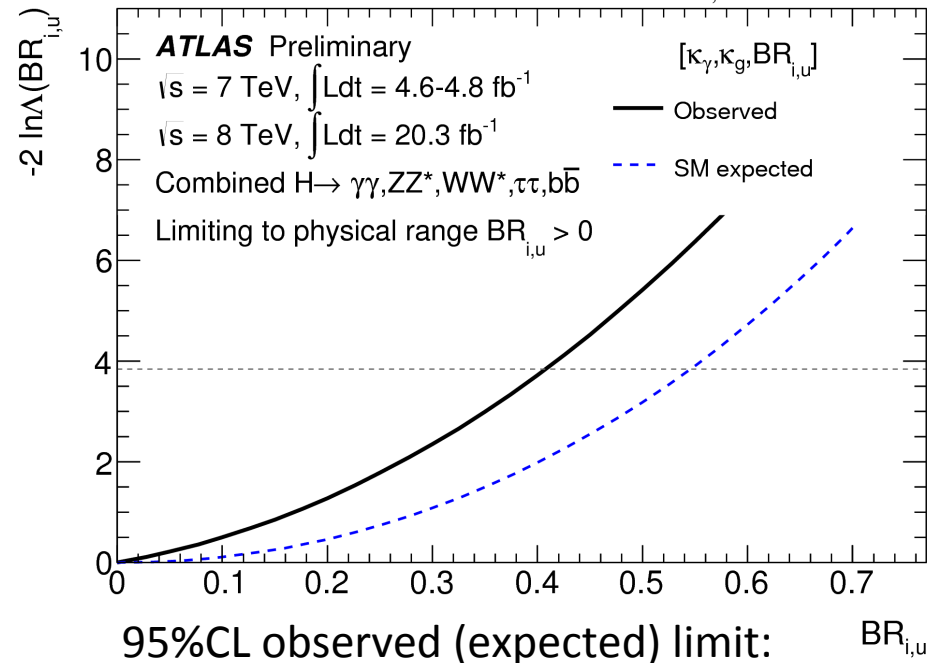
$$\kappa_H^2 = \frac{\sum \kappa_j^2 \Gamma_j^{SM}}{\Gamma_H^{SM}} \times \frac{1}{1 - BR_{i,u}}$$



$$\kappa_g = 1.08^{+0.15}_{-0.13}$$

$$\kappa_\gamma = 1.19^{+0.15}_{-0.12}$$

2D compatibility of the SM of 9%
 with the best fit point



95%CL observed (expected) limit: $BR_{i,u}$

$$BR_{i,u} < 0.41(0.55)$$

Releasing the physical boundary:

$$\kappa_g = 1.00^{+0.23}_{-0.16}$$

$$\kappa_\gamma = 1.17^{+0.16}_{-0.13}$$

$$BR_{i,u} = -0.16^{+0.29}_{-0.30}$$

Summary of combined coupling measurements

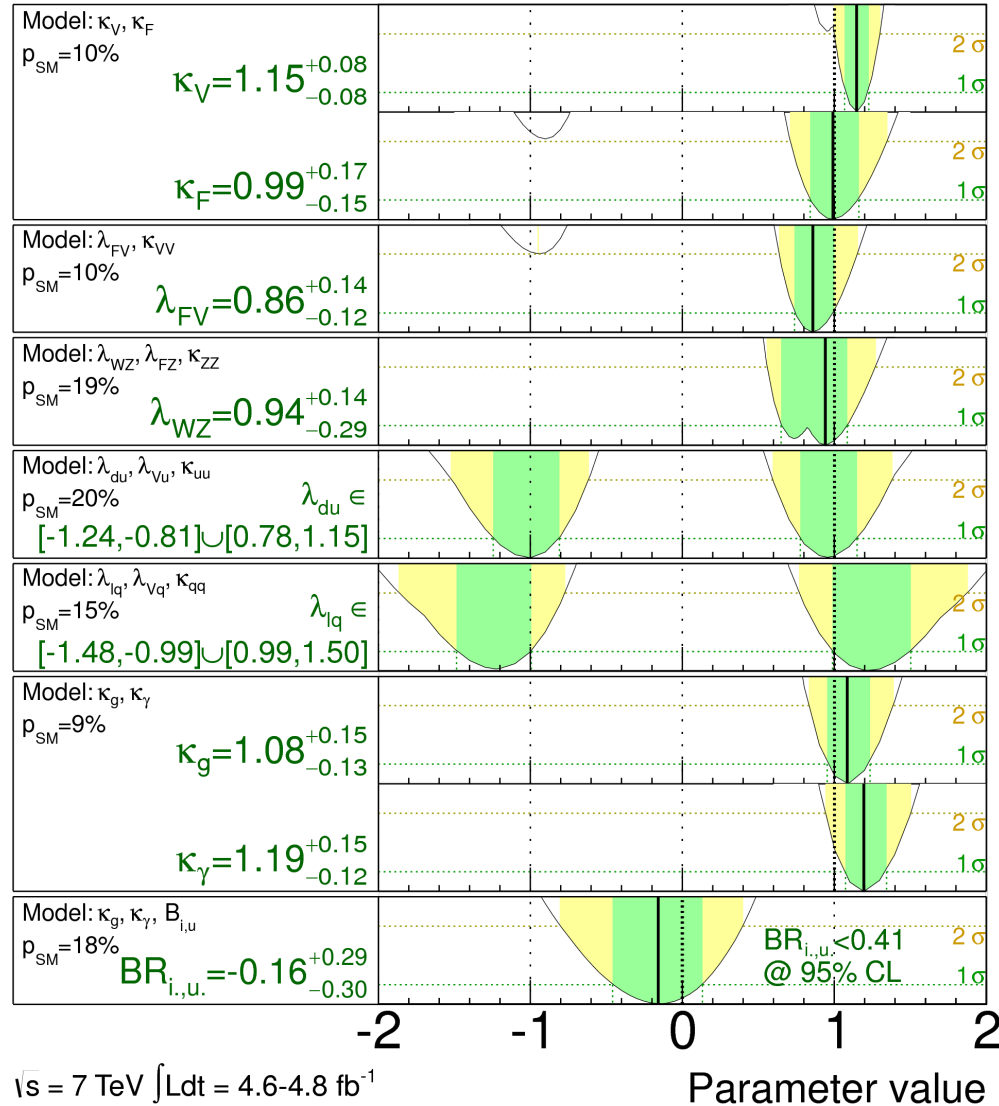
ATLAS-CONF-2014-009

ATLAS Preliminary

Total uncertainty

$m_H = 125.5$ GeV

■ $\pm 1\sigma$ ■ $\pm 2\sigma$



$\sqrt{s} = 7$ TeV $\int L dt = 4.6-4.8$ fb $^{-1}$

$\sqrt{s} = 8$ TeV $\int L dt = 20.3$ fb $^{-1}$



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Minimal Composite H Model

The H boson is composite: the H couplings to vector bosons and fermions are modified wrt SM as a function of the boson compositeness scale f

MCHM4: $\kappa = \kappa_V = \kappa_F = \sqrt{1 - \xi}$

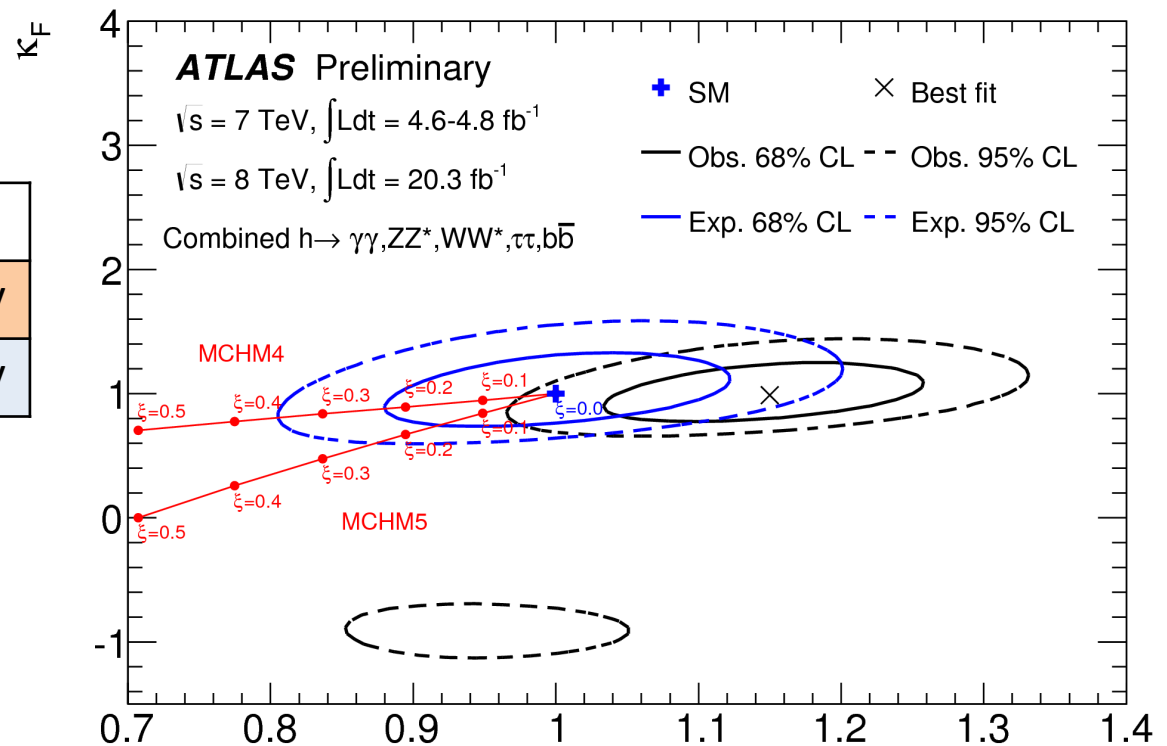
MCHM5: $\kappa_F = \frac{1 - 2\xi}{\sqrt{1 - \xi}}$ $\kappa_V = \sqrt{1 - \xi}$

$\xi = v^2/f^2$ a scaling parameter
SM recovered when $\xi \rightarrow 0$

With the physical boundary $\xi > 0$

95%CL	Expected	Observed
MCHM4	$f > 460$ GeV	$f > 710$ GeV
MCHM5	$f > 550$ GeV	$f > 640$ GeV

The observed limit is stronger than the expected one since $\mu_h > 1$



Simple MSSM interpretation

In the simplified MSSM, couplings can be expressed as a function of m_A , $\tan\beta$

$$\kappa_V = \frac{s_d(m_A, \tan\beta) + \tan\beta s_u(m_A, \tan\beta)}{\sqrt{1 + \tan^2\beta}}$$

$$\kappa_u = s_u(m_A, \tan\beta) \frac{\sqrt{1 + \tan^2\beta}}{\tan\beta}$$

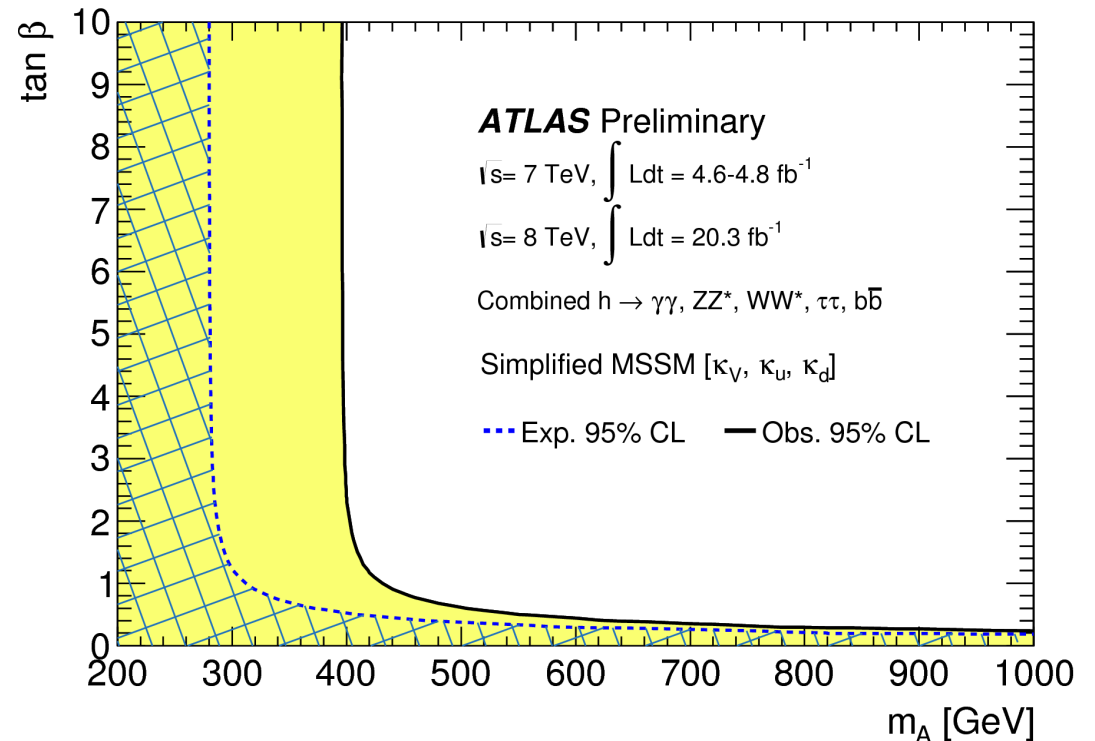
$$\kappa_d = s_d(m_A, \tan\beta) \sqrt{1 + \tan^2\beta}$$

$$s_u = \frac{1}{\sqrt{1 + \frac{(m_A^2 + m_Z^2)^2 \tan^2\beta}{(m_Z^2 + m_A^2 \tan^2\beta - m_h^2(1 + \tan^2\beta))^2}}}$$

$$s_d = \frac{(m_A^2 + m_Z^2) \tan\beta}{m_Z^2 + m_A^2 \tan^2\beta - m_h^2(1 + \tan^2\beta)} s_u$$

Considering physical boundary $m_A > 0$ and $\tan\beta > 0$:

The observed (expected) lower limit at 95%CL is $m_A > 400$ (280) GeV for $2 < \tan\beta < 10$



ATLAS-CONF-2014-010

Phys. Lett. B 64 no. 2, (1976) 159,

Phys. Lett. B69 (1977) 489, Phys. Lett. B76 (1978) 575, Nucl. Phys. B 193 (1981)150



Outline

- Introduction
- Brief review of bosonic channels (for more details see Marianna's talk)
- Spin/Parity Combination Results
- Brief review of fermionic channels (for more details see Geng-Yuan's talk)
- Combination of Higgs coupling measurements
- Constraints on New Phenomena from coupling measurements
- **Conclusions and Perspectives**

Conclusions and Perspectives

The measured properties (spin and couplings) of the H boson are **compatible with SM**

Couplings are already used to **constrain BSM** models

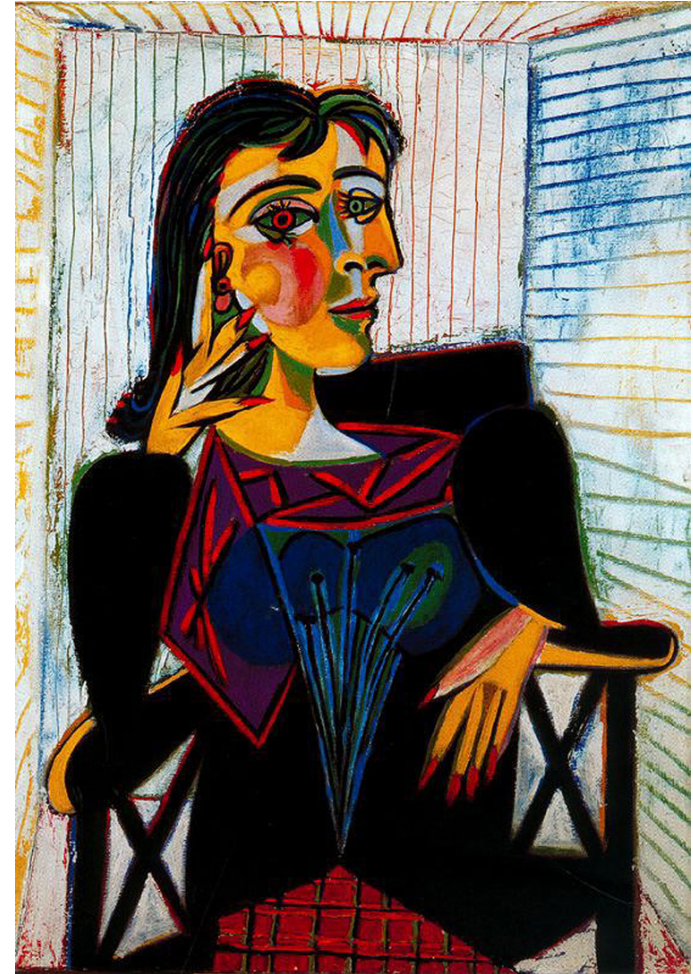
An **evidence of VBF** production and **direct fermionic** decay have been observed

More new results for the 5 main channels soon with LHC Run-I data, stay tuned 😊

In Run-II, more answers to come: what is precisely the H discovered? does it have another face of supersymmetrical type? **New Physics?**

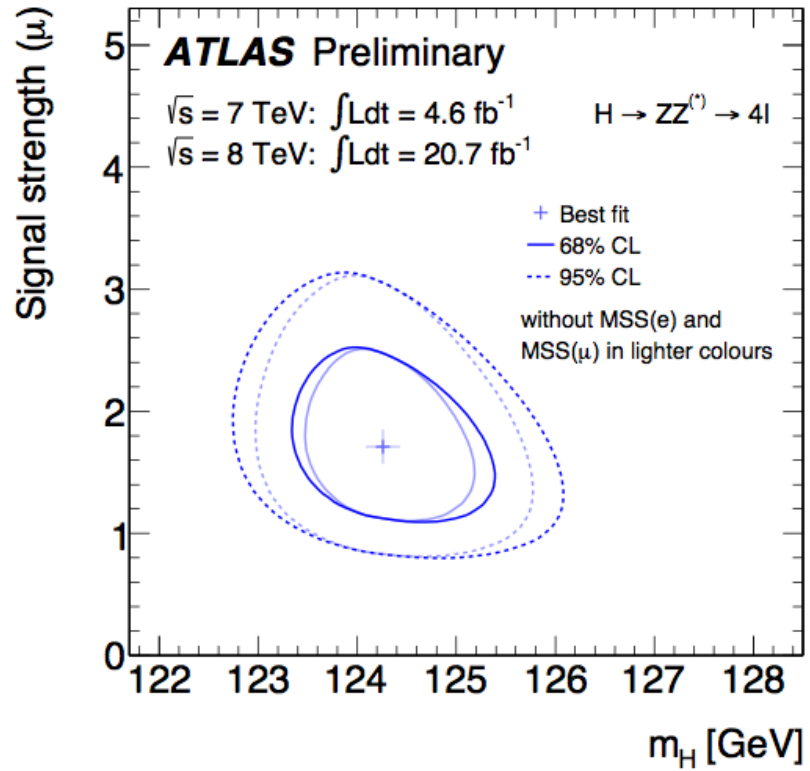
Looking forward for more precise measurements and searches for new particles...

Hopefully more answers in Higgs Hunting 2015

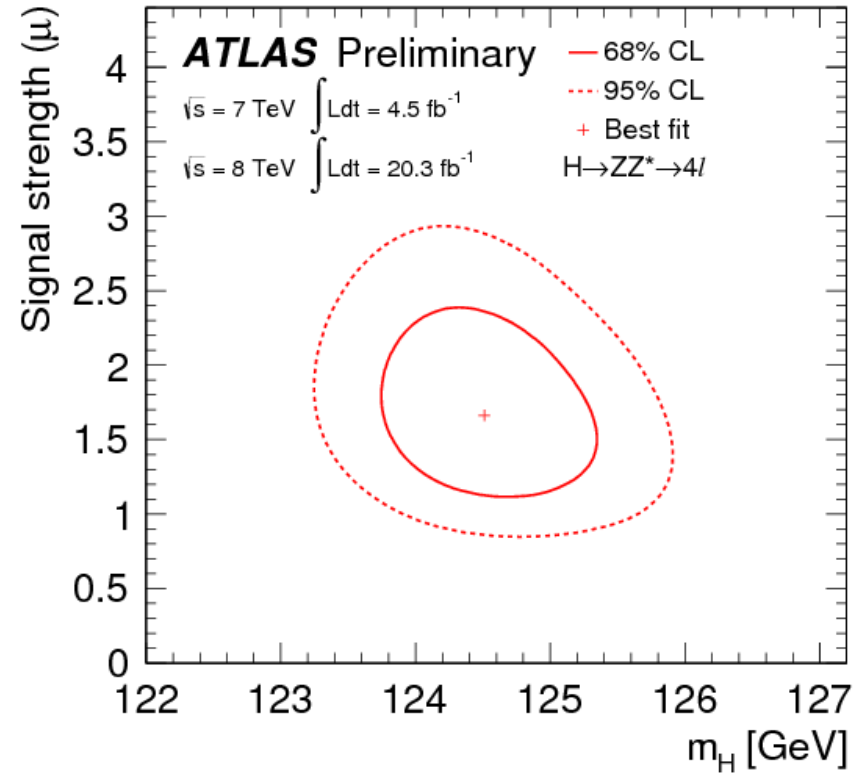


Backup Slides

"Moriond 2013 analysis"

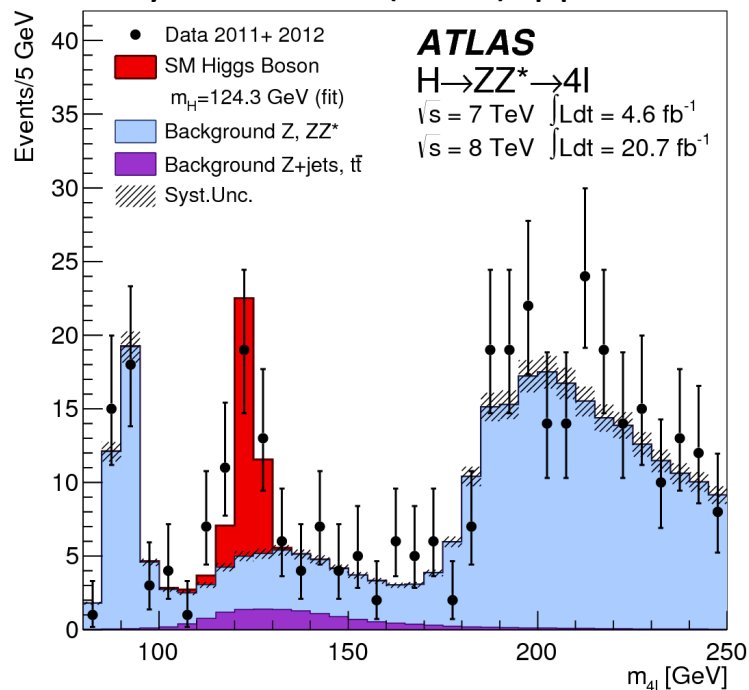


NEW!



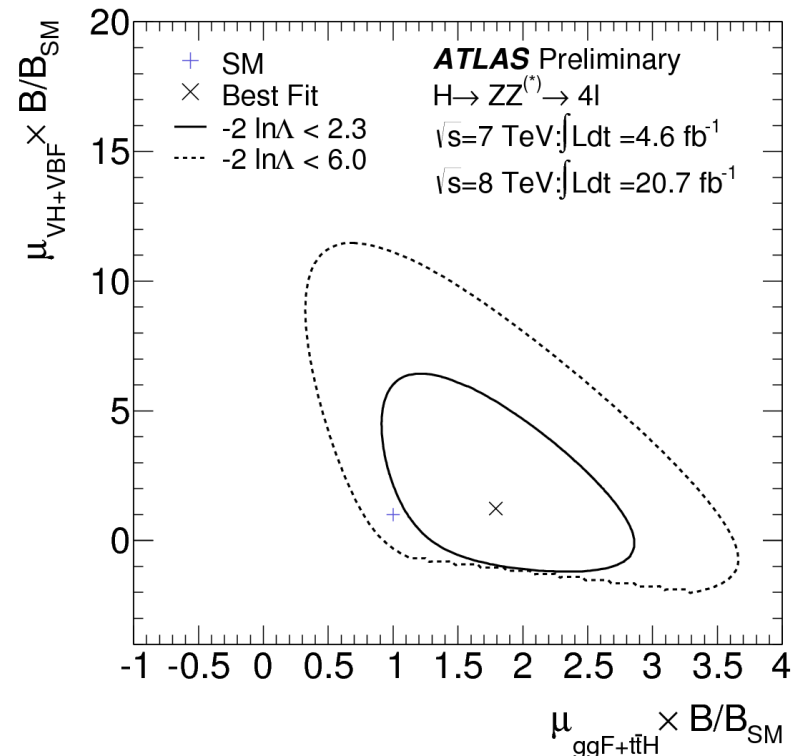
$H \rightarrow ZZ \rightarrow 4l$ coupling measurement

Phys.Lett.B726(2013), pp. 88-119



Local significance 6.6σ (expected 4.4σ) at 124.3 GeV.

3 categories are considered in the Moriond 2013 analysis:
 VBF-like (accompanied with 2 high p_T jets widely separated in rapidity),
 VH-like (accompanied with an additional lepton)
 and ggF-like (all the others)

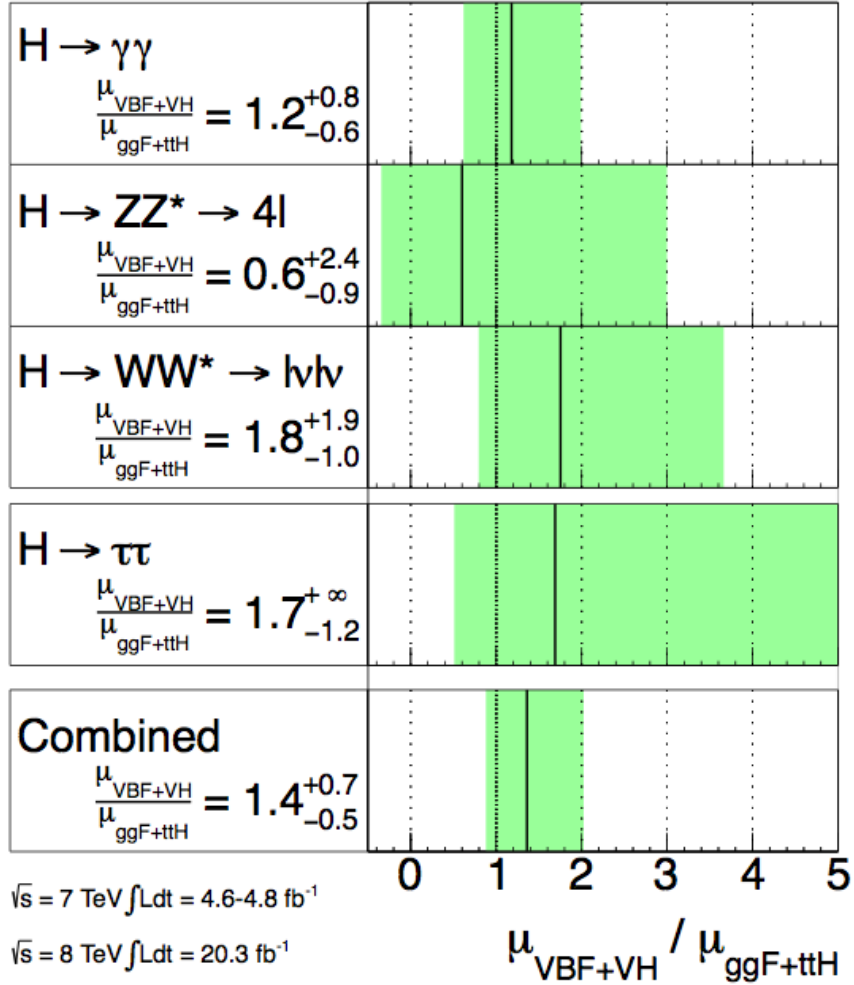


1 VBF-like event observed in $125 \pm 5 \text{ GeV}$
 (0.71 ± 0.10 expected from SM with 60%
 VBF purity and $S/B \sim 5$)

The measured values @125.5 GeV:

$$\mu = 1.43^{+0.40}_{-0.35}$$

$$\mu_{ggF+ttH} = 1.45^{+0.43}_{-0.36}, \mu_{VBF+VH} = 1.2^{+1.6}_{-0.9}$$



$$\sigma(gg \rightarrow H) * \text{BR}(H \rightarrow \gamma\gamma) \sim \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(qq' \rightarrow qq'H) * \text{BR}(H \rightarrow \gamma\gamma) \sim \frac{\kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(gg \rightarrow H) * \text{BR}(H \rightarrow ZZ^*, H \rightarrow WW^*) \sim \frac{\kappa_g^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(qq' \rightarrow qq'H) * \text{BR}(H \rightarrow ZZ^*, H \rightarrow WW^*) \sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(qq' \rightarrow qq'H, VH) * \text{BR}(H \rightarrow \tau\tau, H \rightarrow b\bar{b}) \sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(gg \rightarrow H) * \text{BR}(H \rightarrow \gamma\gamma) \sim \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - \text{BR}_{i,u.})$$

$$\sigma(qq' \rightarrow qq'H) * \text{BR}(H \rightarrow \gamma\gamma) \sim \frac{\kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - \text{BR}_{i,u.})$$

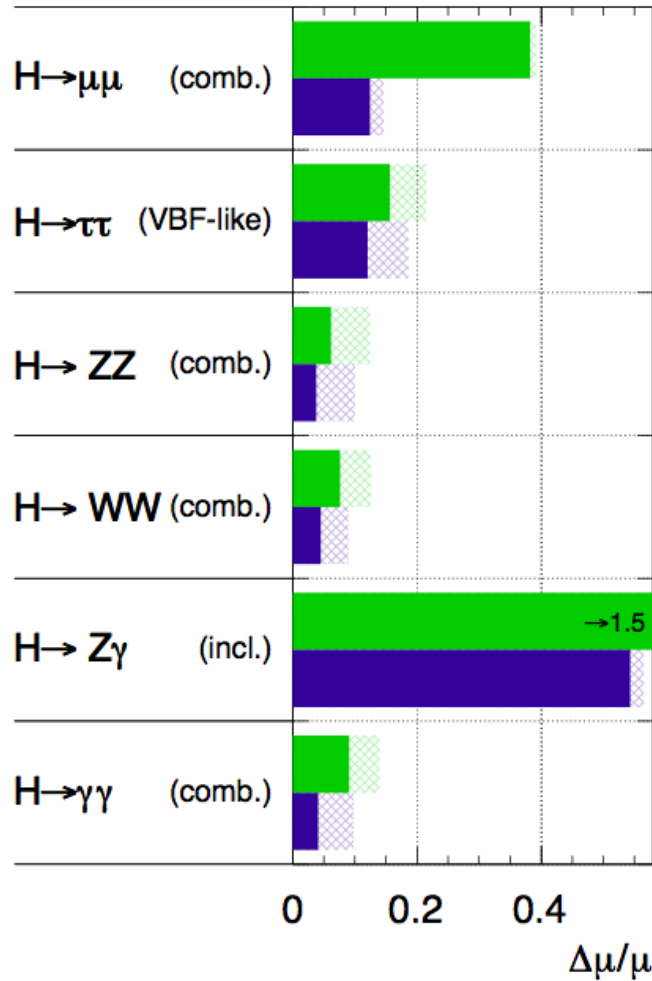
$$\sigma(gg \rightarrow H) * \text{BR}(H \rightarrow ZZ^*, H \rightarrow WW^*) \sim \frac{\kappa_g^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - \text{BR}_{i,u.}) \quad (17)$$

$$\sigma(qq' \rightarrow qq'H) * \text{BR}(H \rightarrow ZZ^*, H \rightarrow WW^*) \sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - \text{BR}_{i,u.})$$

$$\sigma(qq' \rightarrow qq'H, VH) * \text{BR}(H \rightarrow \tau\tau, H \rightarrow b\bar{b}) \sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - \text{BR}_{i,u.})$$

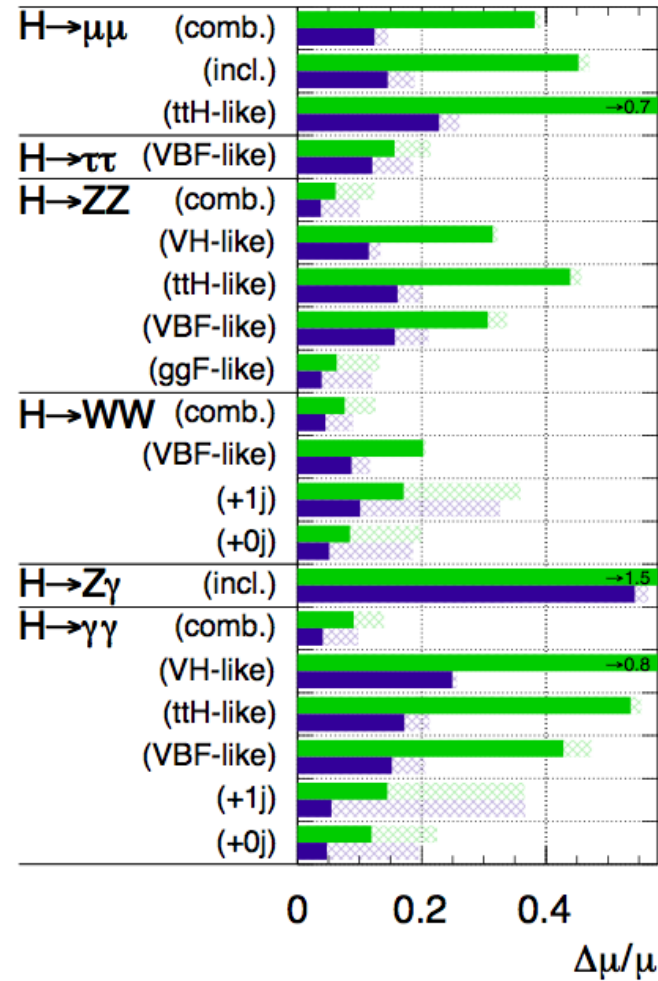
ATLAS Simulation Preliminary

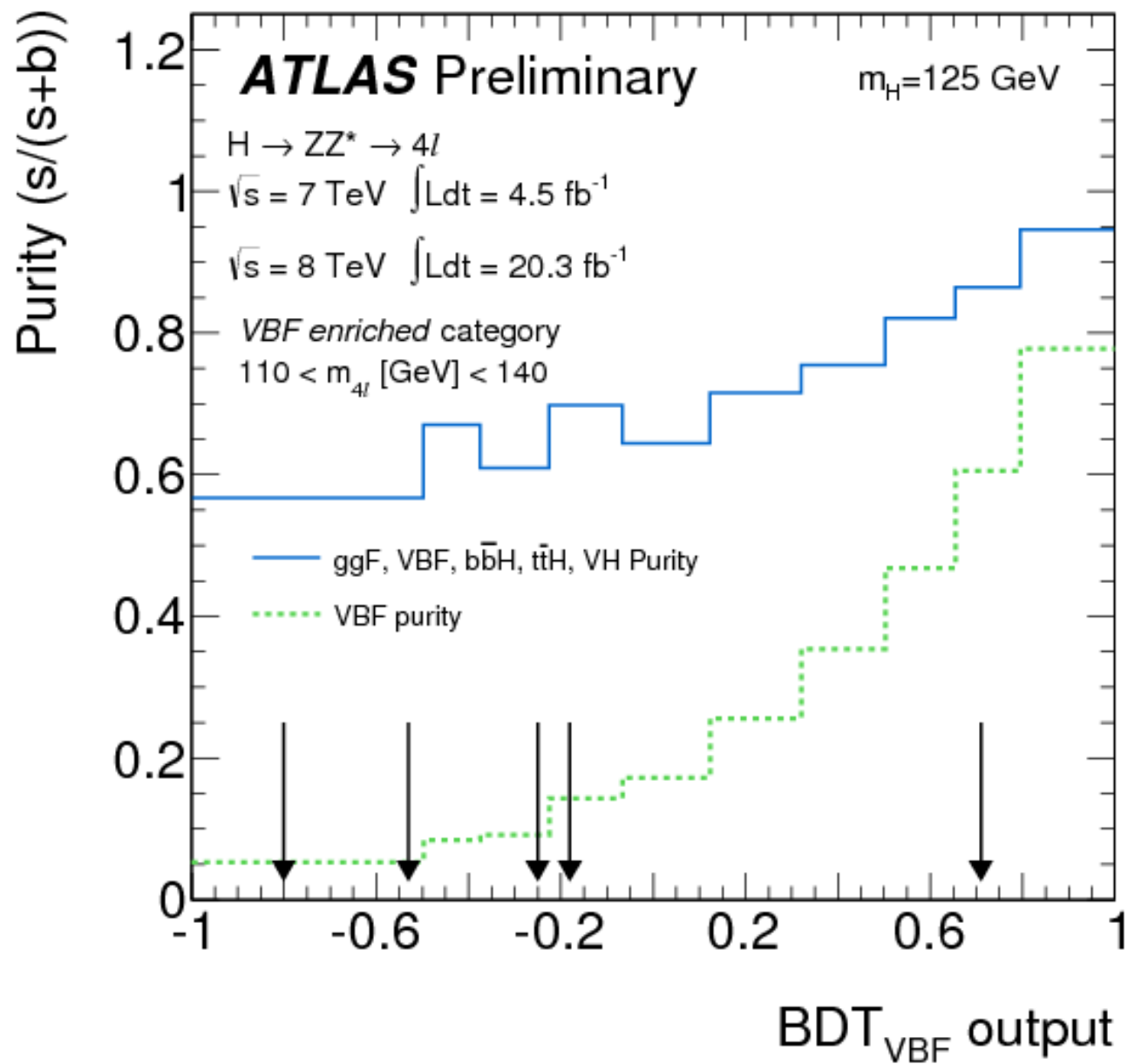
$\sqrt{s} = 14 \text{ TeV}$: $\int \mathcal{L} dt = 300 \text{ fb}^{-1}$; $\int \mathcal{L} dt = 3000 \text{ fb}^{-1}$

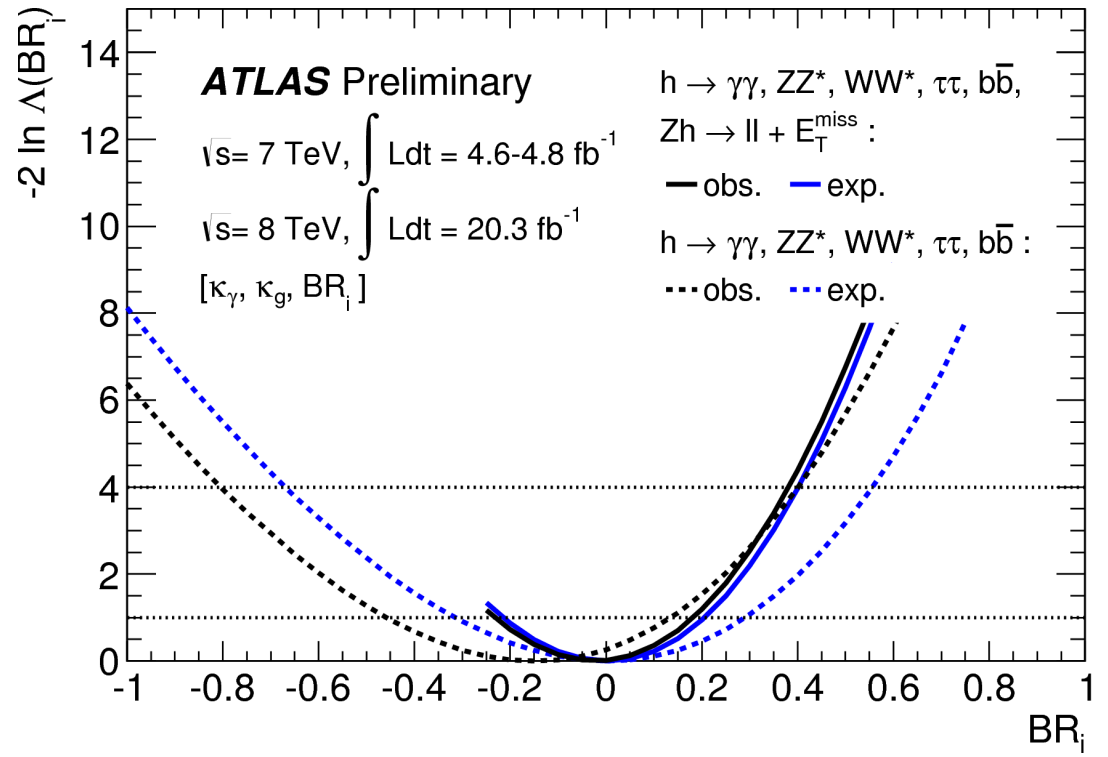
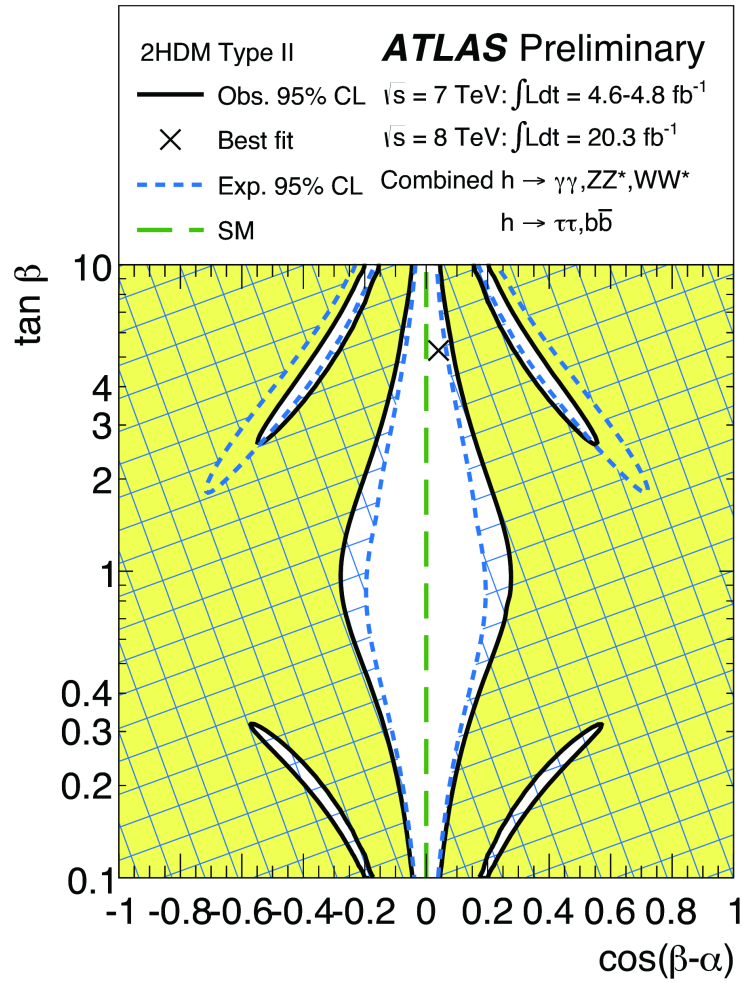


ATLAS Simulation Preliminary

$\sqrt{s} = 14 \text{ TeV}$: $\int \mathcal{L} dt = 300 \text{ fb}^{-1}$; $\int \mathcal{L} dt = 3000 \text{ fb}^{-1}$







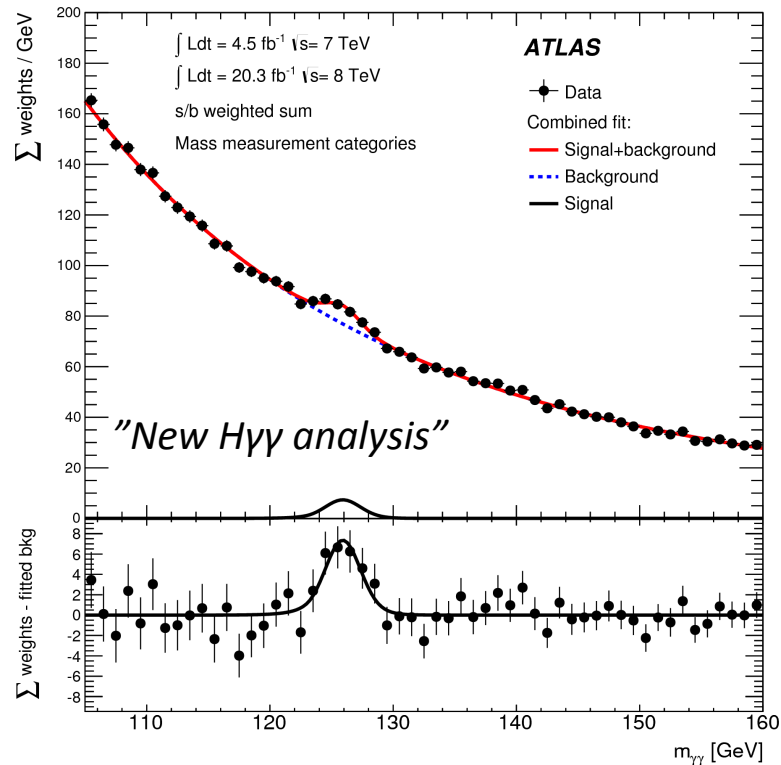
Coupling scale factor	Type I	Type II	Type III	Type IV
κ_V	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
κ_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$

$$\mathcal{M}_S^2 = (m_Z^2 + \delta_1) \begin{bmatrix} \cos^2(\beta) & -\cos(\beta)\sin(\beta) \\ -\cos(\beta)\sin(\beta) & \sin^2(\beta) \end{bmatrix} + m_A^2 \begin{bmatrix} \sin^2(\beta) & -\cos(\beta)\sin(\beta) \\ -\cos(\beta)\sin(\beta) & \cos^2(\beta) \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & \frac{\delta}{\sin^2(\beta)} \end{bmatrix} \quad (15)$$

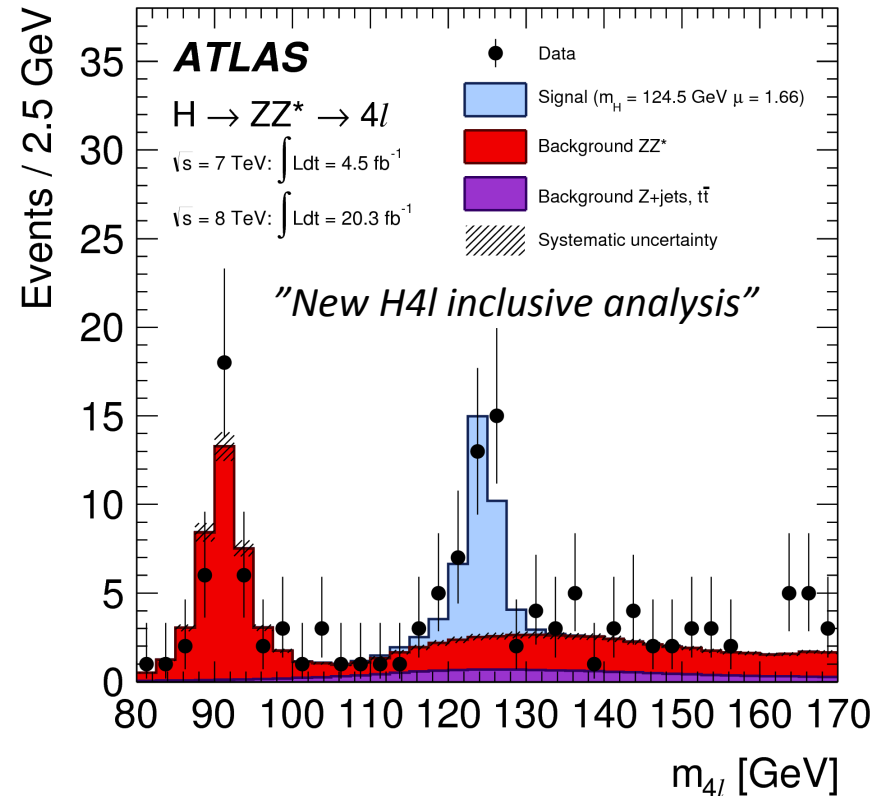
Updated New Mass Results

NEW!

Improved calibration, detector material description and analysis



Best fit mass: 125.98±0.42(stat)±0.28(syst)



Best fit mass: 124.51±0.52(stat)±0.06(syst)

Combined mass: 125.36±0.37(stat)±0.18(syst)

Reduction of the systematic uncertainty by about 60% wrt the old measurement

For more details see Sarah's talk

$H \rightarrow ZZ \rightarrow 4l$ coupling analysis

NEW!

Local significance 8.1σ (expected 5.8σ) at 124.51 GeV.

New in the inclusive analysis (used also for the new mass measurement) since Moriond 2013:

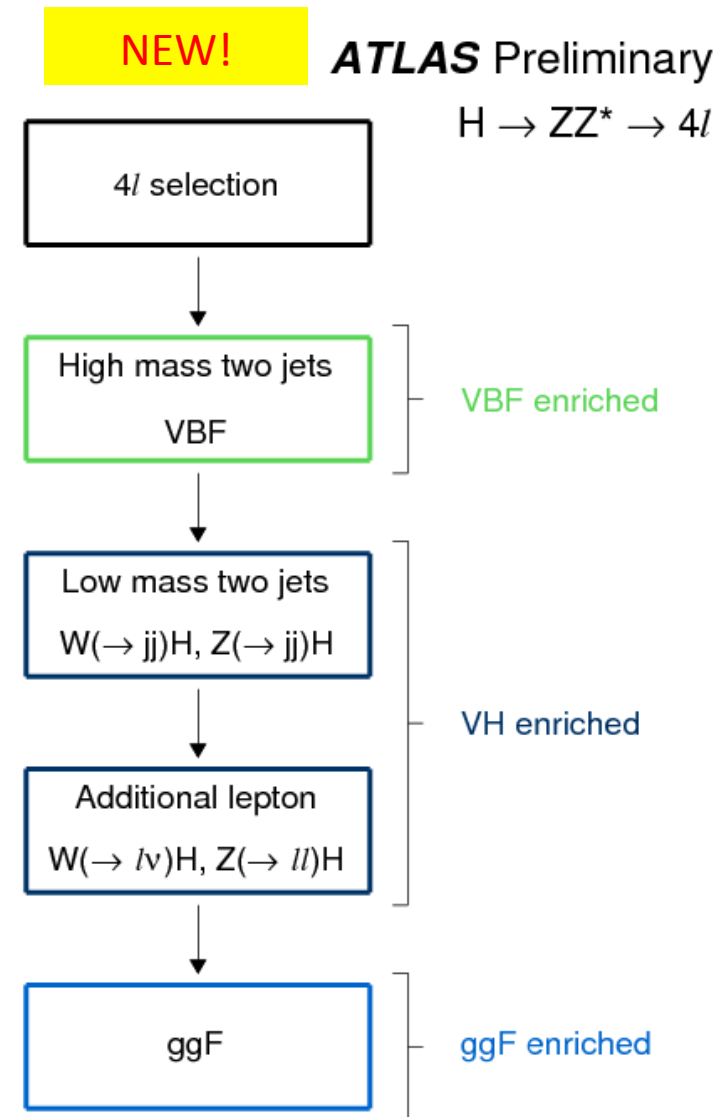
- new electron ID (loose likelihood for 2012 only)
- new electron and muon energy calibration
- E/p combination for the electrons
- far FSR recovery for electrons and muons
- BDT for ZZ^* background

3 categories were considered in the Moriond 2013 analysis:

- VBF-like** (accompanied with 2 high p_T jets widely separated in rapidity)
- VH-like** (accompanied with an additional lepton)
- ggF-like (all the others)

New in the specific couplings analysis:

- Add a **VH hadronic** category
- Looser cuts on the VBF category
- BDT for both VBF and VH categories



Updated New $4l$ Coupling Results

NEW!

H \rightarrow ZZ \rightarrow 4l: NEW Coupling results!(To be submitted to PRD)

(125.36 GeV combined mass)

NEW!

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

$$\mu_{ggF+bbH+ttH} * B / B_{SM} = 1.66^{+0.45}_{-0.41} (stat)^{+0.25}_{-0.15} (syst)$$

$$\mu_{VBF+VH} * B / B_{SM} = 0.26^{+1.60}_{-0.91} (stat)^{+0.36}_{-0.23} (syst)$$

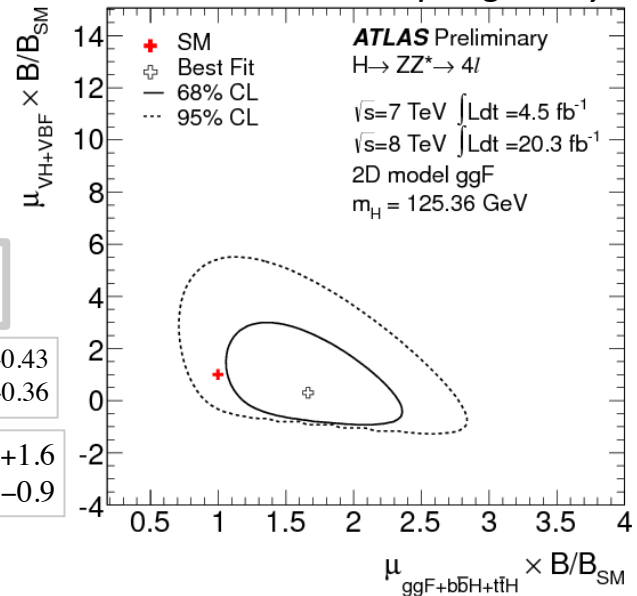
OLD!

$$\mu = 1.43^{+0.40}_{-0.35}$$

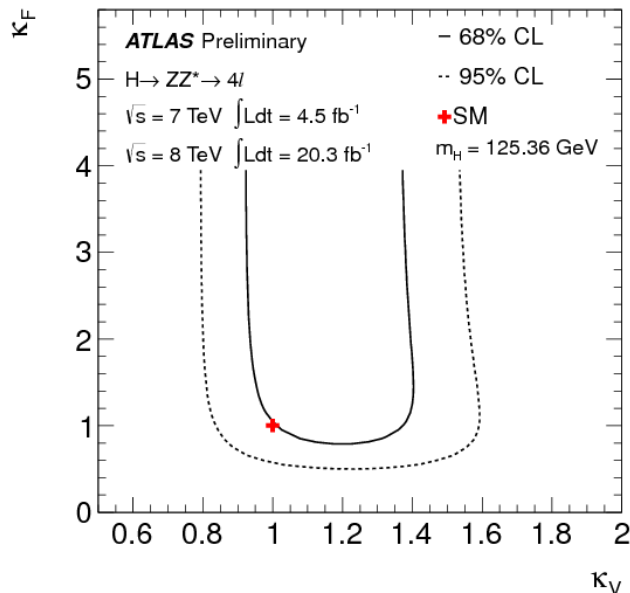
$$\mu_{ggF+ttH} = 1.45^{+0.43}_{-0.36}$$

$$\mu_{VBF+VH} = 1.2^{+1.6}_{-0.9}$$

"New H4l coupling analysis"



κ_F is unbounded since cannot exclude $\mu_{VBF+VH}=0$
2D compatibility with SM is 30%



$\lambda_{FV}=0$ is disfavoured at 4 σ level

