ХИГГС-БОЗОН В ЭКСПЕРИМЕНТАХ ATLAS и CMS НА БАК

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Семинар ОФВЭ и ОТФ

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Доклад основан на сообщениях ATLAS и CMS на Международных конференциях:

LHCP, Barcelona , 13-18.05.13
Flavor Physics &CP Violation,Rio de Janeiro,19-24.05.13
25th Rencontres de Bloi,Particles physics,Bloi,26-31.05.13
European Linear Collider Workshop, DESY,27-31.05.13

Barcelona, May 13, 2013!

Sergio Bertolucci !
CERN

There is a new boson of mass ~125 GeV, with properties consistent with the SM Higgs, within the current uncertainties. ***More data needed to ascertain the nature of this object***

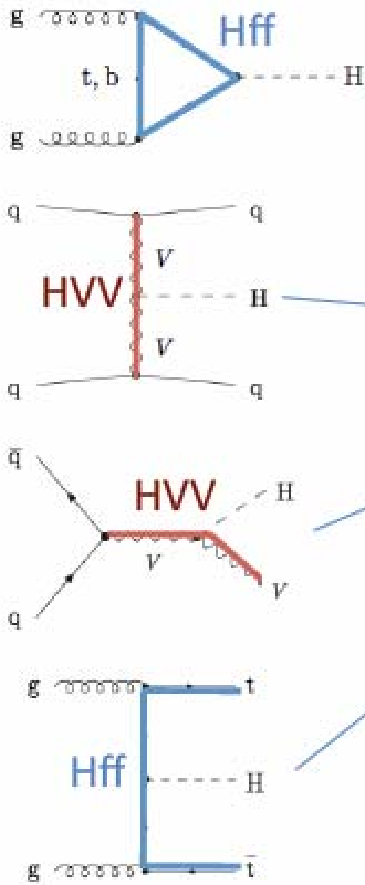
In this talk, latest results on Higgs boson properties based on full 2011+2012 datasets:

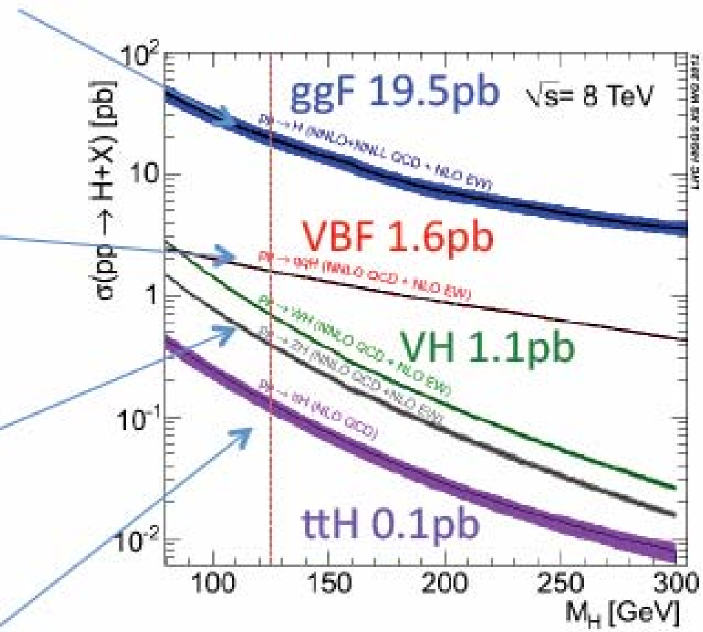
- $H \rightarrow \gamma\gamma$
- $H \rightarrow ZZ$
- $H \rightarrow WW$

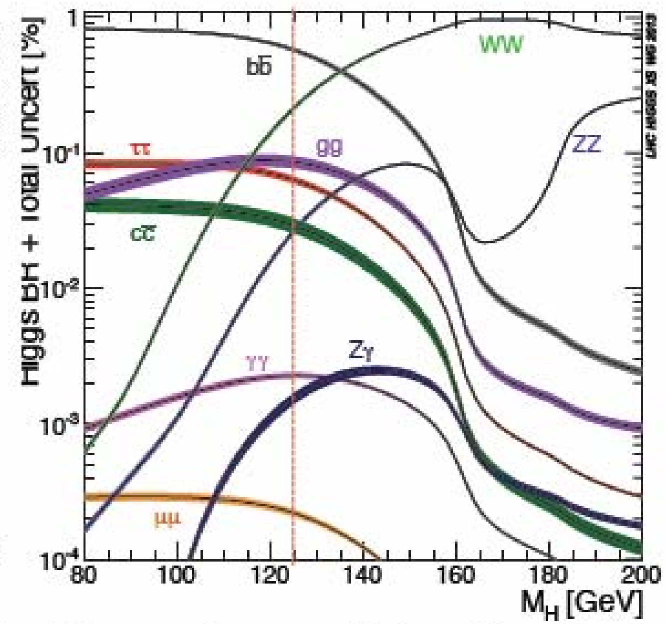
} + combination

(Fermionic final states not updated yet)

SM Higgs boson @LHC







Searches span most of the final states and are optimized for single production modes in order to fully characterize the new boson

To get a feeling of a scale of difficulties to extract the signal of rare Higgs decays…..

Total X-section of the SM Higgs production is 15(19) pb for 7(8) TeV

Integrated Lumi are 4.6 (21) 1/pb

*Br(H->4l) ~ 10**{-4}*

Expected number of events under 100% efficiency

Nevnt ~ 50

Number of selected 4 "leptons" events is ~10**6

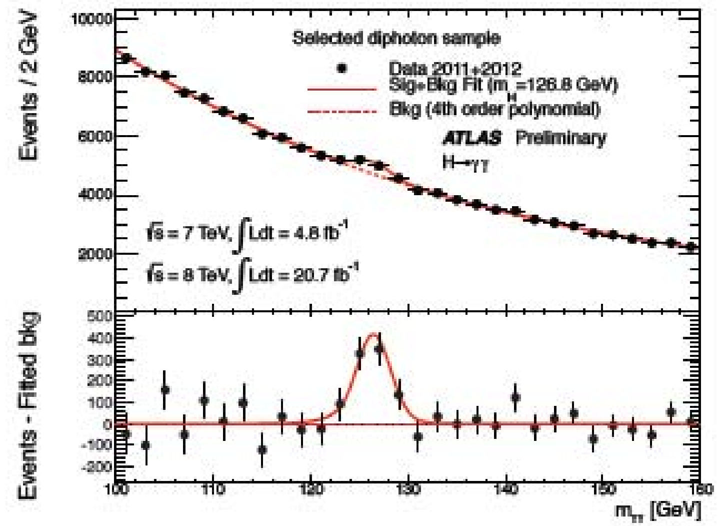
Compare: number of Z-bosons produced~10**9!!

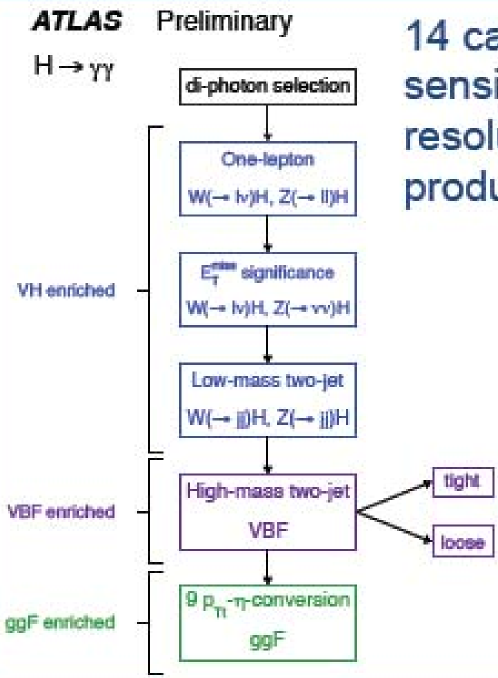
Rejecting power of the analysis procedure should be better than 10**5 . Not easy.

H→$\gamma\gamma$

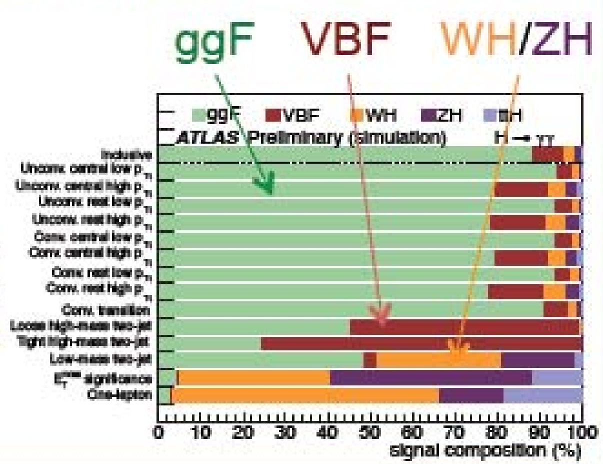
ATLAS-CONF-2013-012

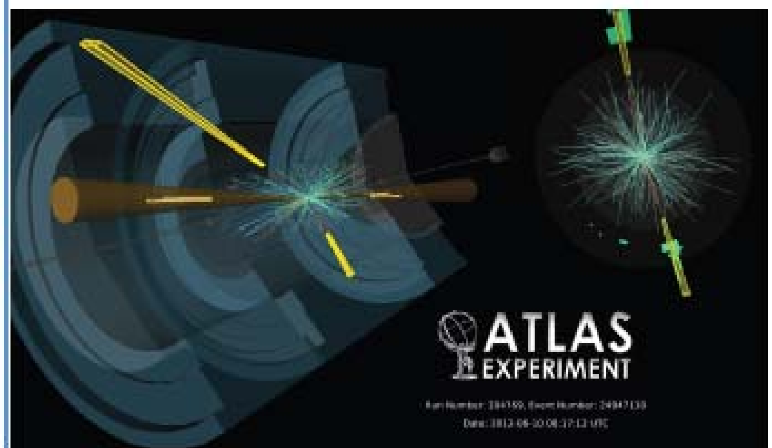
1. 2 isolated high-p_T photons (E_T>40,30 GeV)
2. Background extrapolated from side-bands in data
3. Data-driven background decomposition: $\gamma\gamma$ 75%, γj 22%, jj 3%
4. Mass resolution ~1.7GeV at m_H=126.5GeV, very stable wrt pile-up





14 categories to increase signal sensitivity (different S/B and mass resolution) and to enhance single production modes (no pure region)



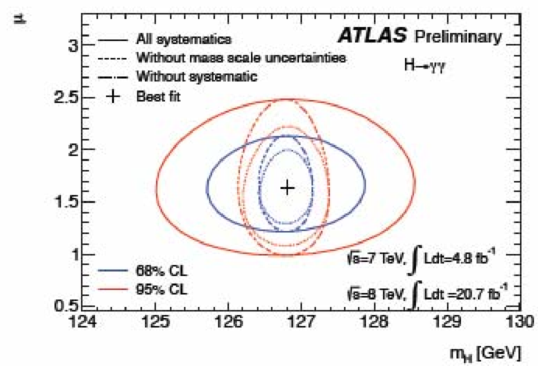


For the first time: VBF production is extracted

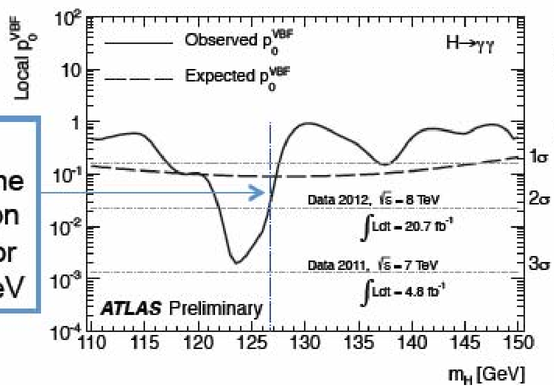
$H \to \gamma\gamma$: Mass & signal strength

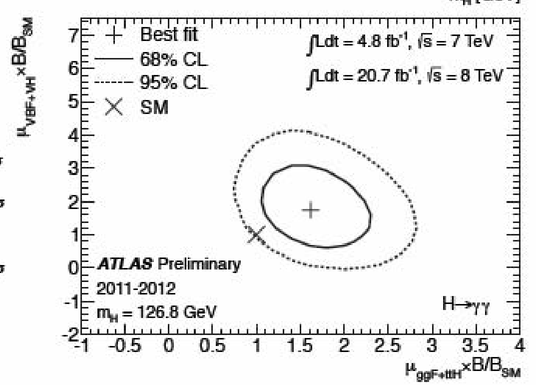
ATLAS-CONF-2013-012

1. Best-fit mass: 126.8±0.2(stat)±0.7(syst) GeV
   dominated by photon energy scale uncertainty
2. Observed(Exp.) significance at 126.5 GeV:
   7.4σ(**4.1σ**)
3. Signal strength at 126.8 GeV:
   $1.65 \pm 0.24(\text{stat})^{+0.25}_{-0.18}(\text{syst})$
   2.3σ from the SM hypothesis

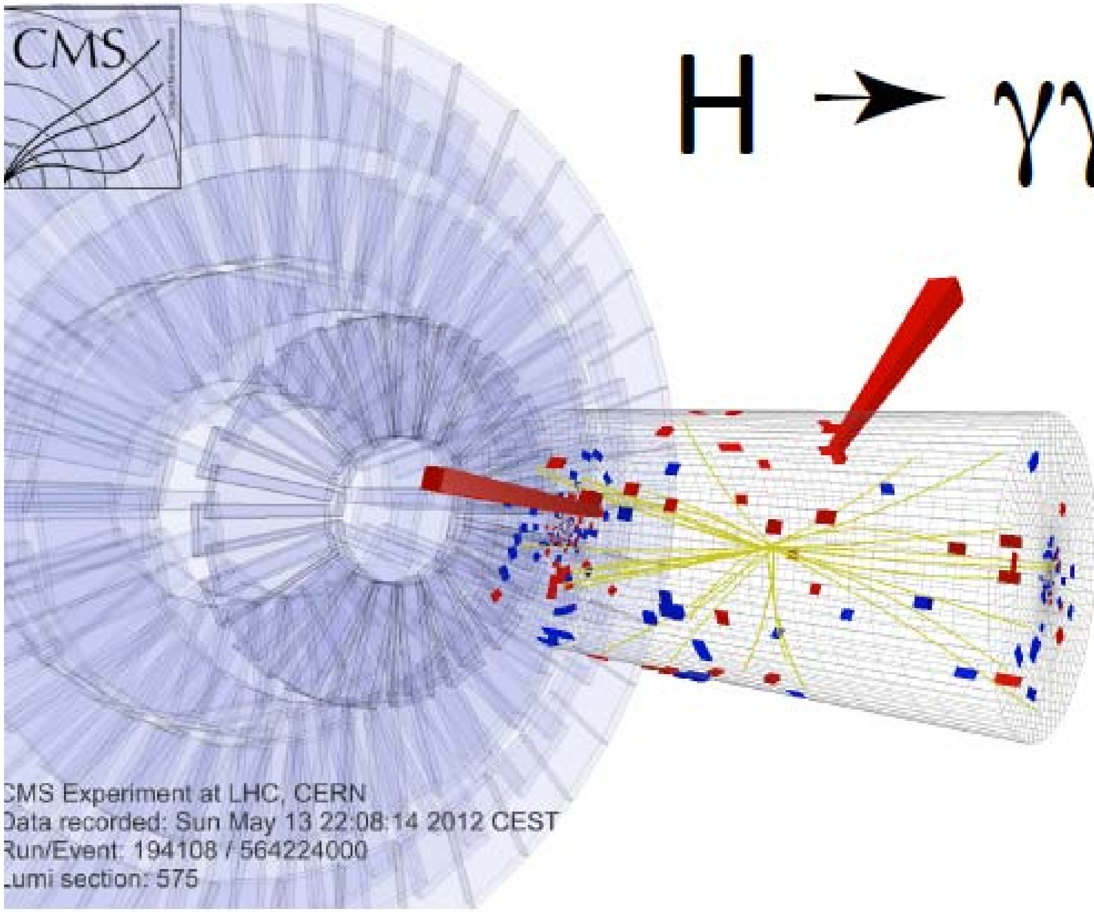


2σ **excess** observed for the VBF production mode alone for m_H = 126.8 GeV

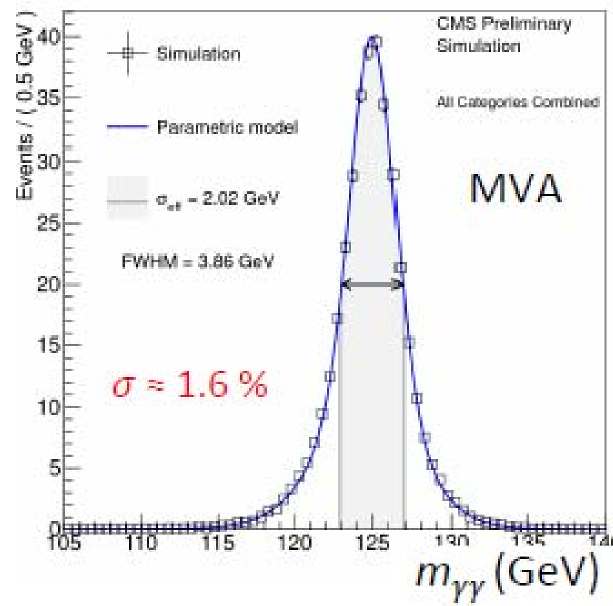




$H \rightarrow \gamma\gamma$



signal model



Two high-p_T isolated photons with a narrow mass distribution, $m_{\gamma\gamma}$, steeply falling for the background.

MVA techniques to perform γ identification, and vertex determination.

Background evaluated from a fit to the data, no reference to the simulation.

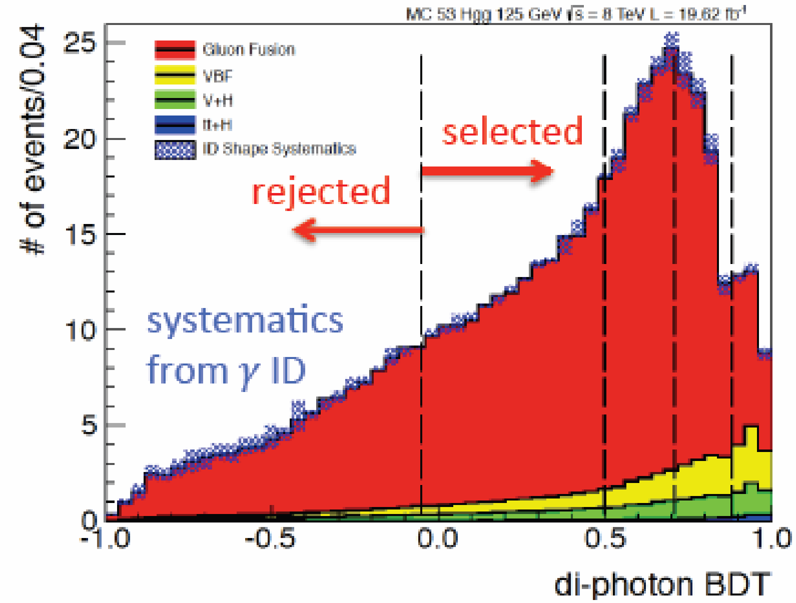
Two Inclusive analyses:

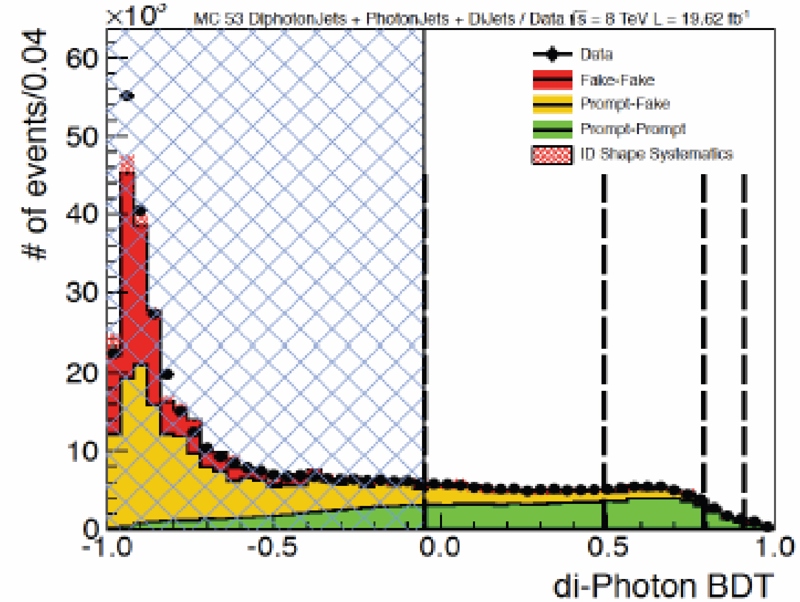
- MVA-based selection: MVA from γ shower shape and isolation (γ ID MVA), kinematics, and $m_{\gamma\gamma}$ resolution.
- Cut-based selection (cross-check): cuts on η_γ (ECAL η region), γ conversion.
- 4 categories with different S/B and $m_{\gamma\gamma}$ resolution.

Exclusive analyses:

- 3 VH channels: e, μ, MET tag
- VBF: 2 dijet categories

125 GeV H signal





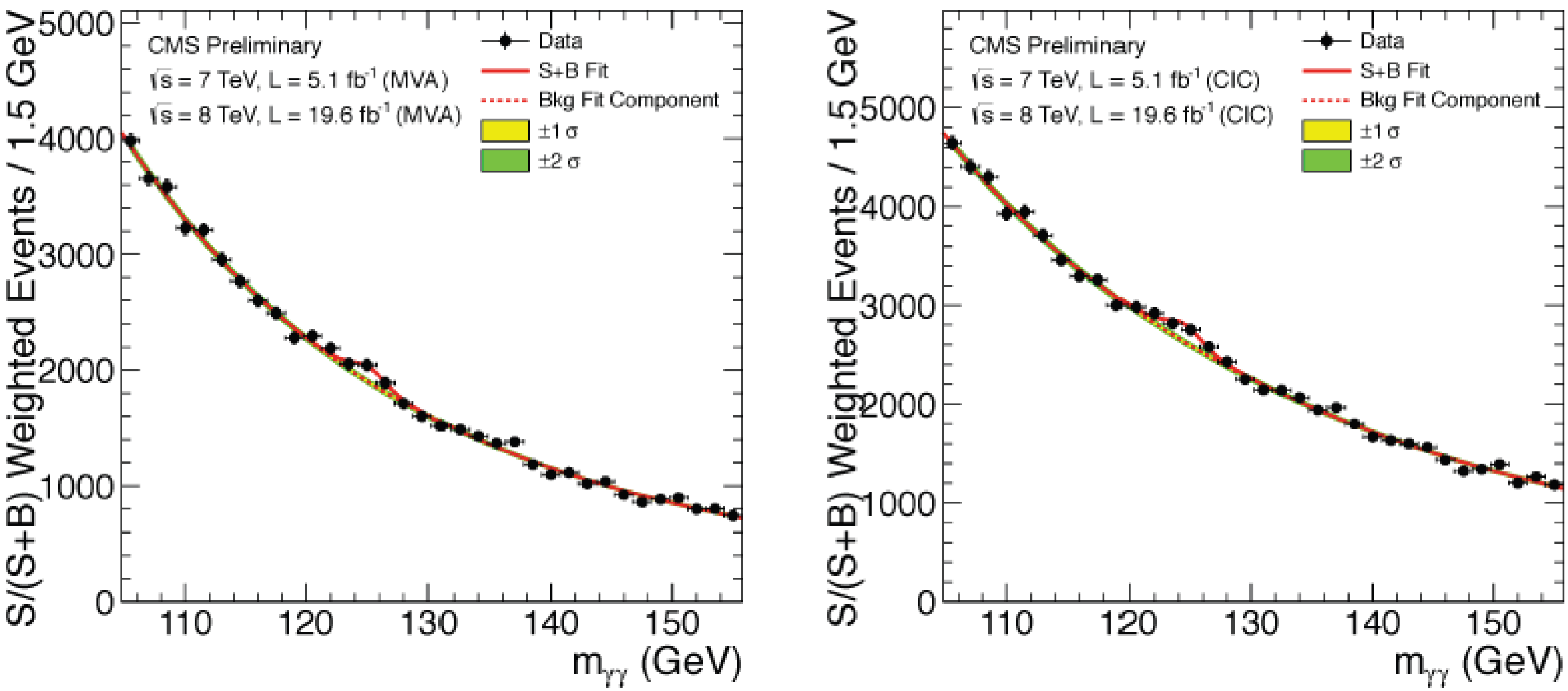
Simulated background and data

weighted mass distributions

$m_{\gamma\gamma}$ distribution with each event weighted by the S/(S+B) value of its category (for visualization only).

MVA analysis

Cut-based analysis



$m_H = 125.4 \pm 0.5\ (stat.) \pm 0.6\ (sys.)$ GeV

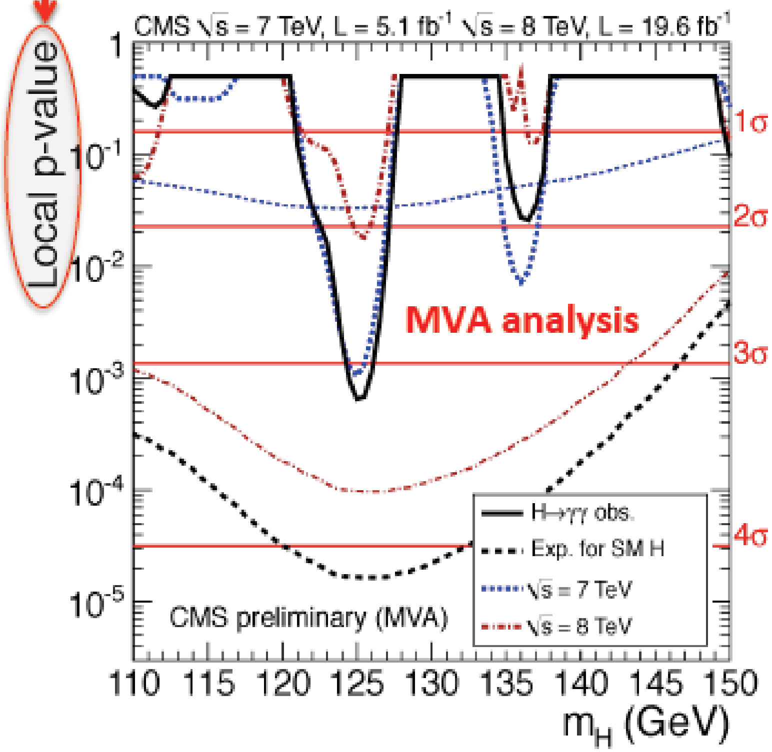
Signal strength for MVA analysis

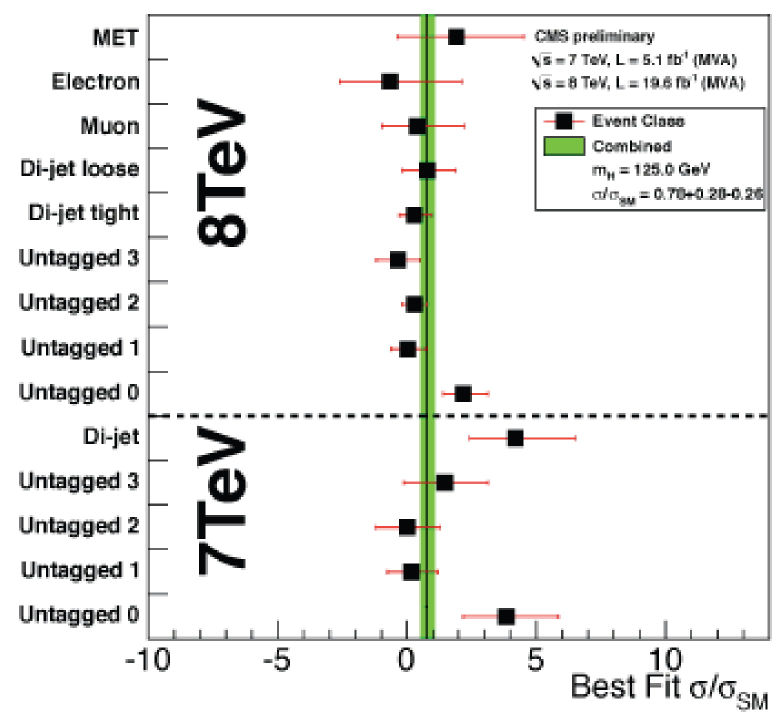
Ratio of the production cross section times the relevant branching fractions over the SM expectation: σ/σ_{SM} = 0.78 ± 0.27 (m_H = 125 GeV)

Significances (σ) for m_H = 125 GeV:

- MVA: observed 3.2, expected 4.2
- Cut-based: observed 3.9, expected 3.5

profile likelihood ratio



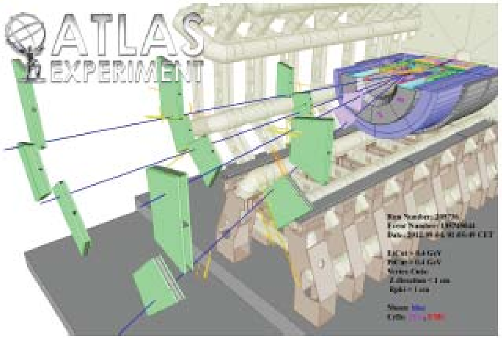


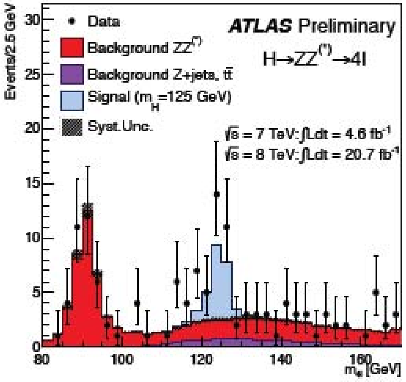
Later it will be compared with an independent study PNPI/BINP

$H \to ZZ^{(*)} \to 4l$

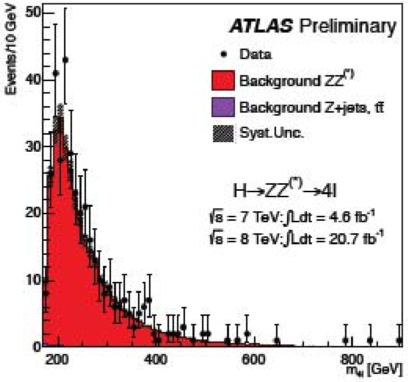
ATLAS-CONF-2013-013

1. 2 OS SF isolated lepton pairs (p_T>20,15, 10, 7(6) GeV)
2. Clean signature, high lepton ID efficiency needed (after full selection ε_{event}~40/20% 4μ/4e)
3. Mass resolution ~1.6-2.4 GeV at m_H=125GeV
4. Irreducible background $ZZ^{(*)}$ from MC, reducible Z+jets and top from control regions in data
5. Syst on lepton reco/ID eff and on energy/momentum resolution (determined using Z, Υ and J/ψ samples)
6. Categorization in VBF/VH/ggF-like events



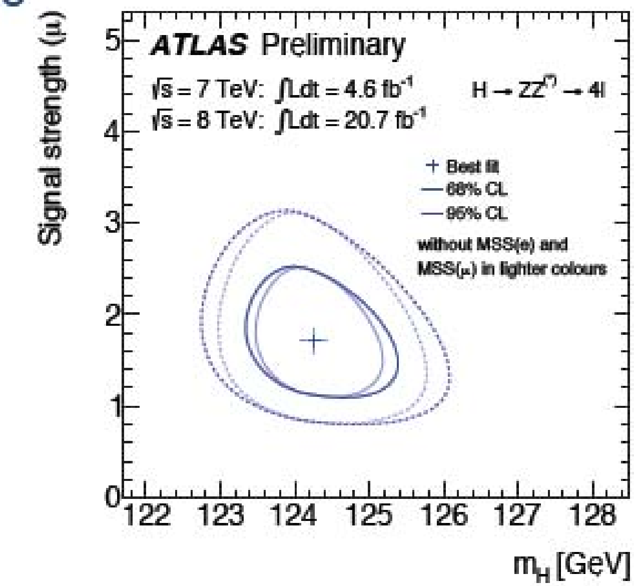


m_{4l} range [GeV]	[120-130]	>160
Observed Events	32	376
Exp. SM signal (m_H=125GeV)	15.9±2.1	
Exp. Bkg	11.1±1.3	348±26

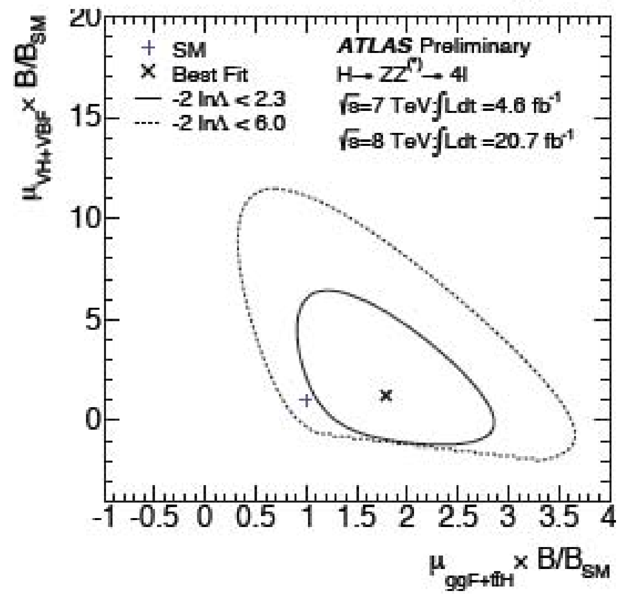


$H \to ZZ^{(*)} \to 4l$: Mass & signal strength

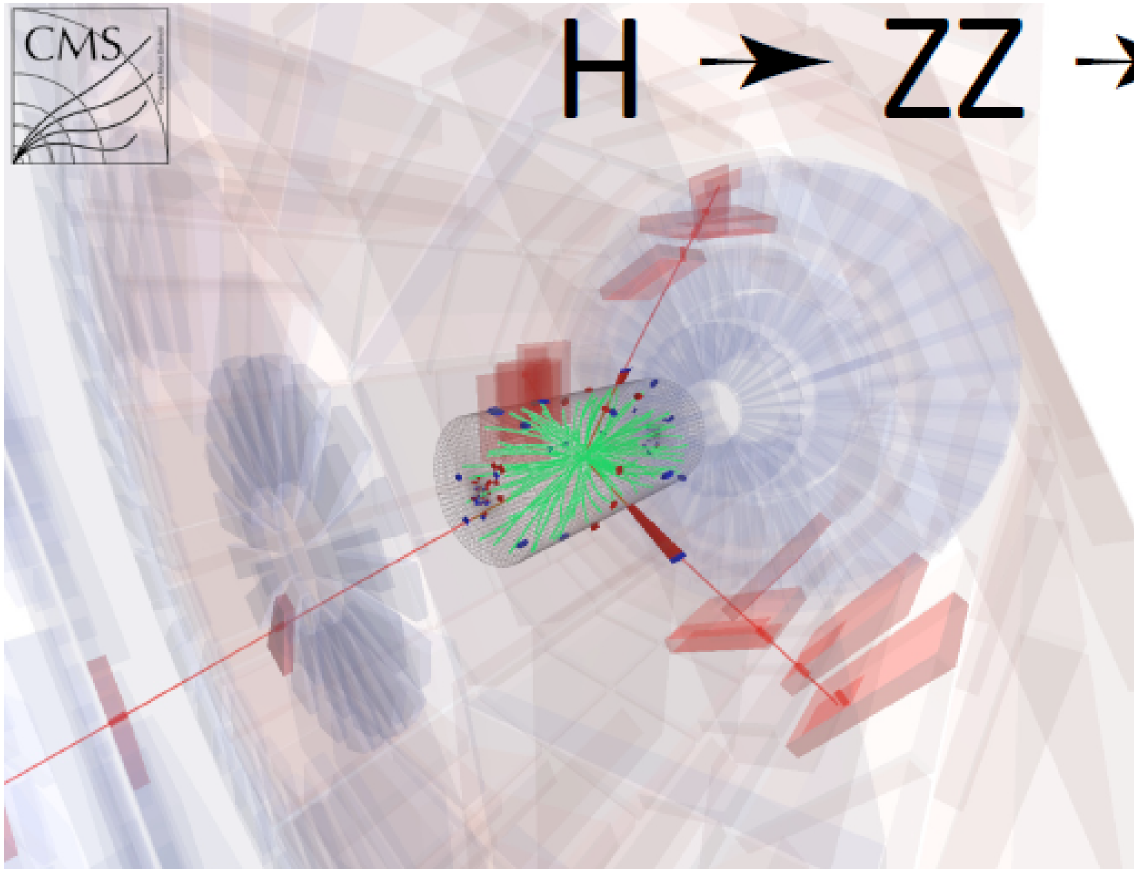
ATLAS-CONF-2013-013



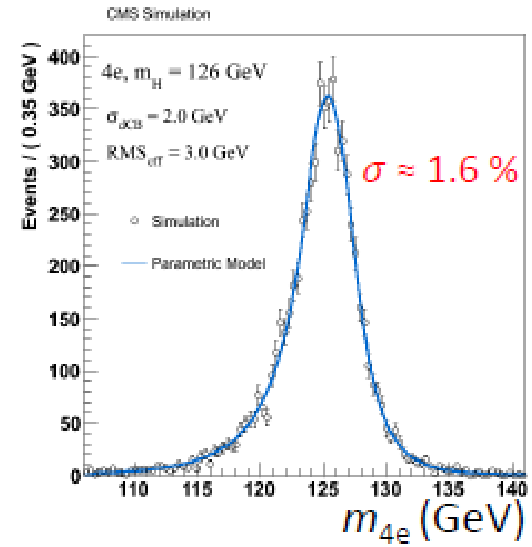
1. Best-fit mass: $124.3^{+0.6}_{-0.5}$(stat)$^{+0.5}_{-0.3}$(syst) GeV dominated by statistical error, systematic error mainly from energy/momentum scale uncertainties
2. Observed(Exp.) significance at 124.3 GeV: 6.6σ(4.4σ)
3. Signal strength at 124.3 GeV: $1.7^{+0.5}_{-0.4}$
4. $\mu_{VBF+VH}/\mu_{ggF+ttH}$ = $0.7^{+2.4}_{-1.0}$ (1 VBF candidate)

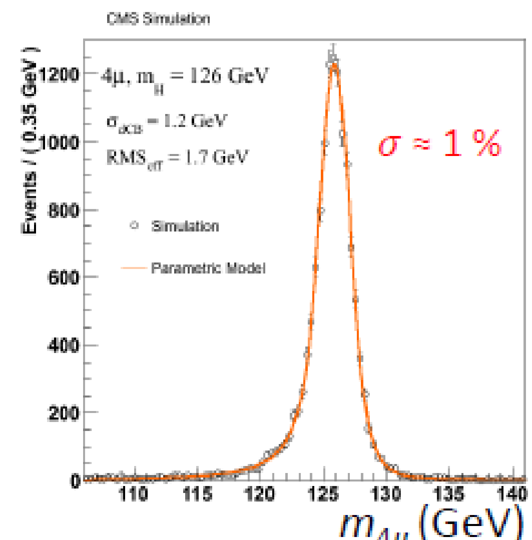


H → ZZ → 4ℓ



signal model





Four high-p_T isolated leptons from the primary vertex.

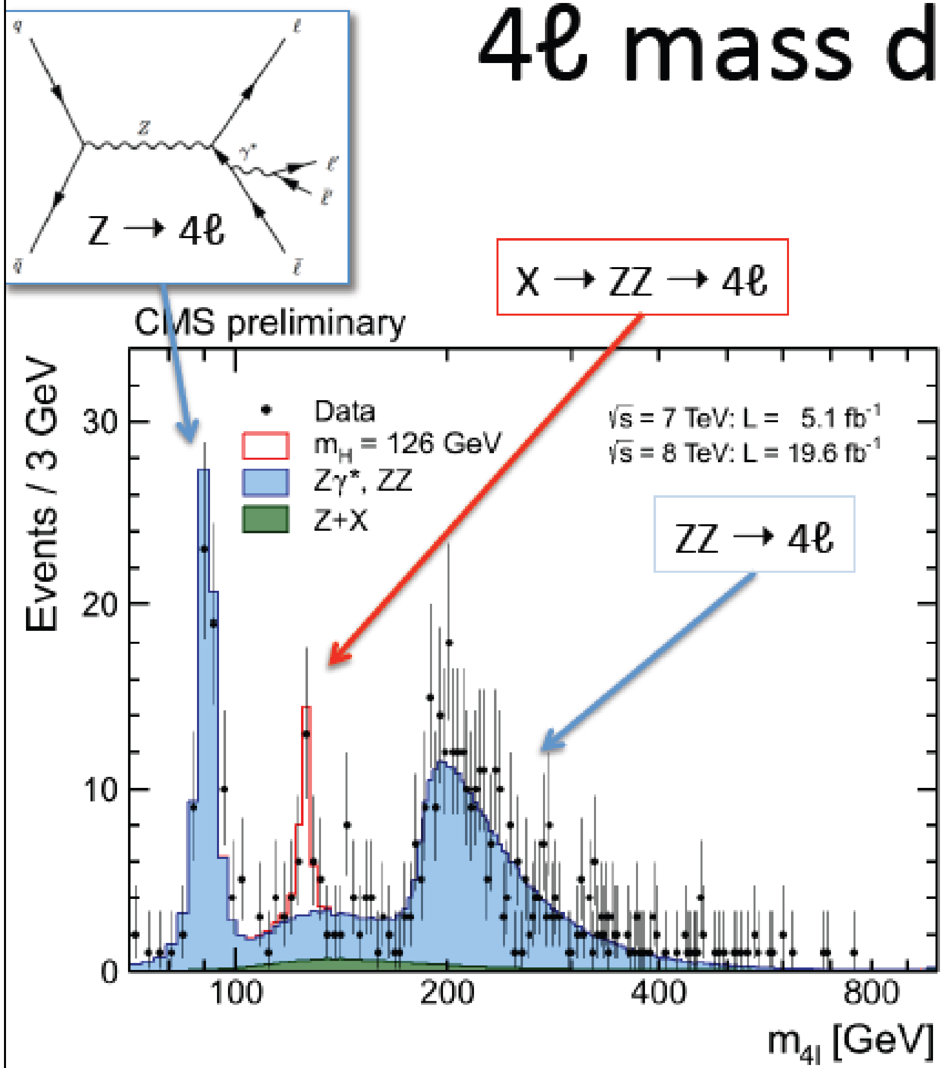
Narrow 4-lepton mass distribution, keep resolution and momentum scale under control.

Clean 4e, 4μ and 2e2μ events, but low branching ratio.

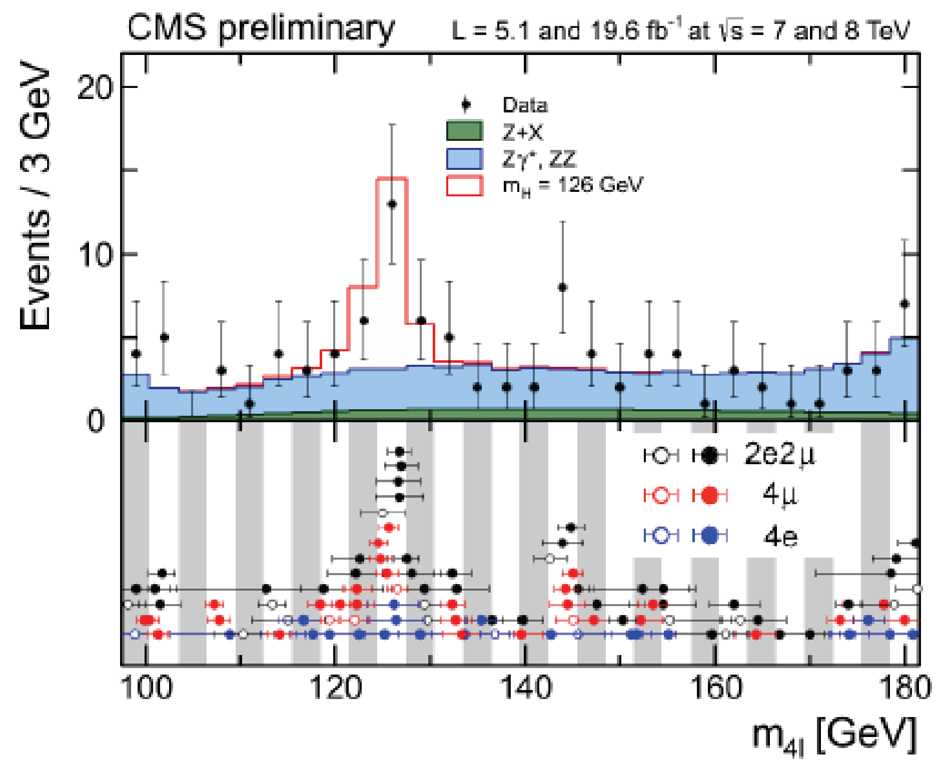
Important to keep efficiency as high as possible.

Two jet categories: untagged (0/1) and dijet tagged (≥ 2).

4ℓ mass distribution



mass of the candidates

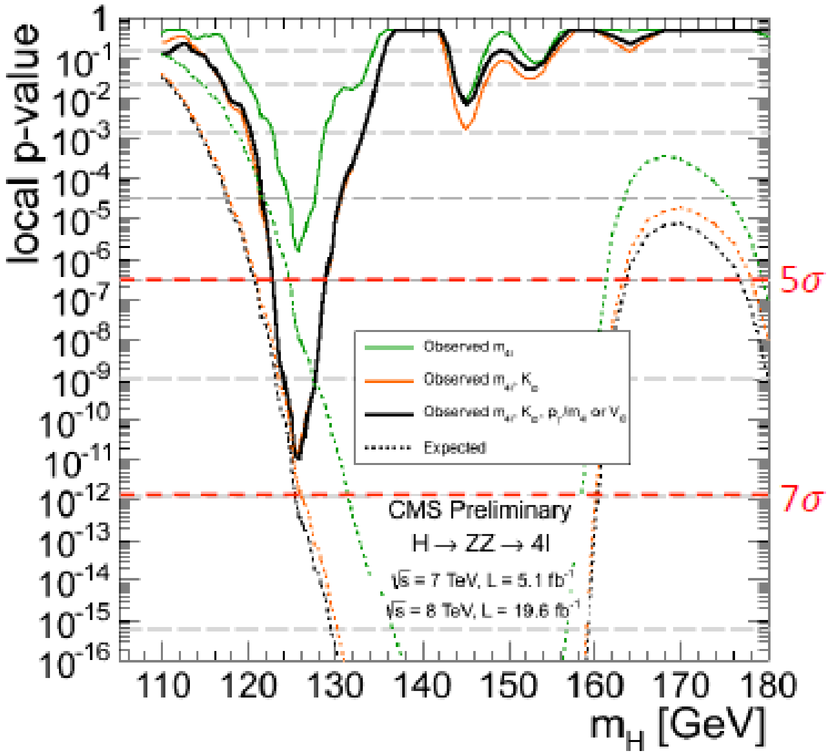


Four-lepton reconstructed mass for the sum of the 4e, 4μ, and 2e2μ channels.

Mass resolution measured from data. ZZ background well under control.

Significance of the local excess

3D fit to $m_{4\ell}$, K_D and (for jet categories) $p_T(4\ell)/m_{4\ell}$ or linear discriminant (VBF).



Significance (σ) for m_H = 125.8 GeV:

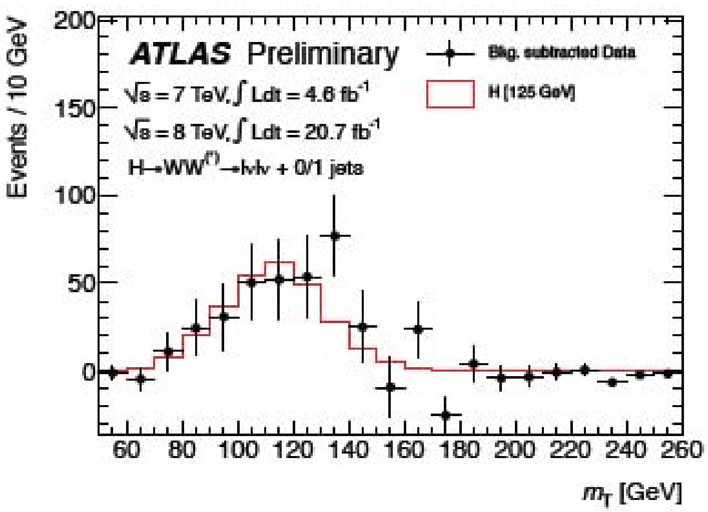
observed 6.7, expected 7.2

σ/σ_{SM} = $0.91^{+0.30}_{-0.24}$

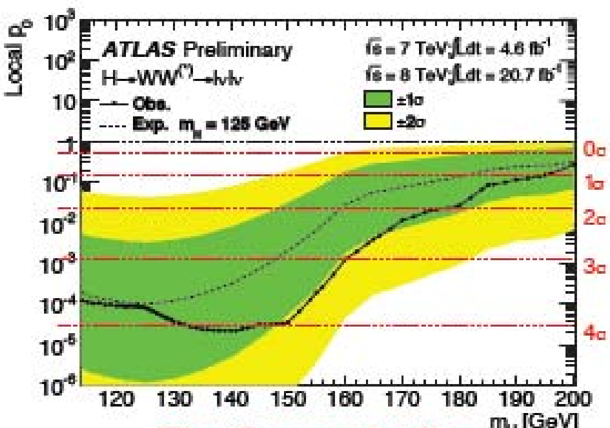
m_H = 125.8 ± 0.5 (*stat.*) ± 0.2 (*sys.*) GeV

$H \to WW^{(*)} \to l\nu l\nu$: Signal strength

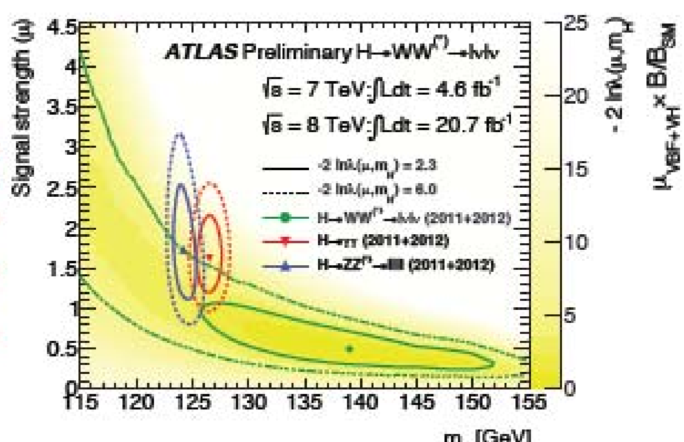
ATLAS-CONF-2013-030

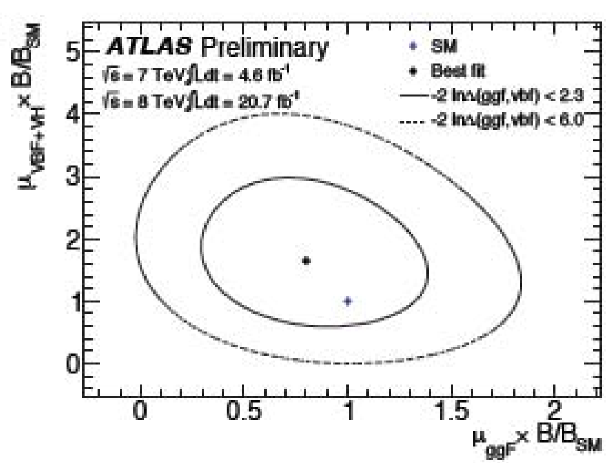


1. Observed significance at 125 GeV: 3.8σ
2. Signal strength at 125 GeV: 1.01 ± 0.31
   [±0.21(stat)±0.19(theory)±0.12(exp.syst)±0.04(lumi)]
3. Observed significance for VBF signal at 125 GeV: 2.5σ
4. $\mu_{VBF} = 1.66 \pm 0.79$ (ggF signal as background in the ≥2jet category and μ_{ggF} constrained in ≤1jet category)
5. $\mu_{ggF} = 0.82 \pm 0.36$ (VBF signal as background in the ≤1jet category and μ_{VBF} constrained in ≥2jet category)



Significance for the m_H=125GeV signal





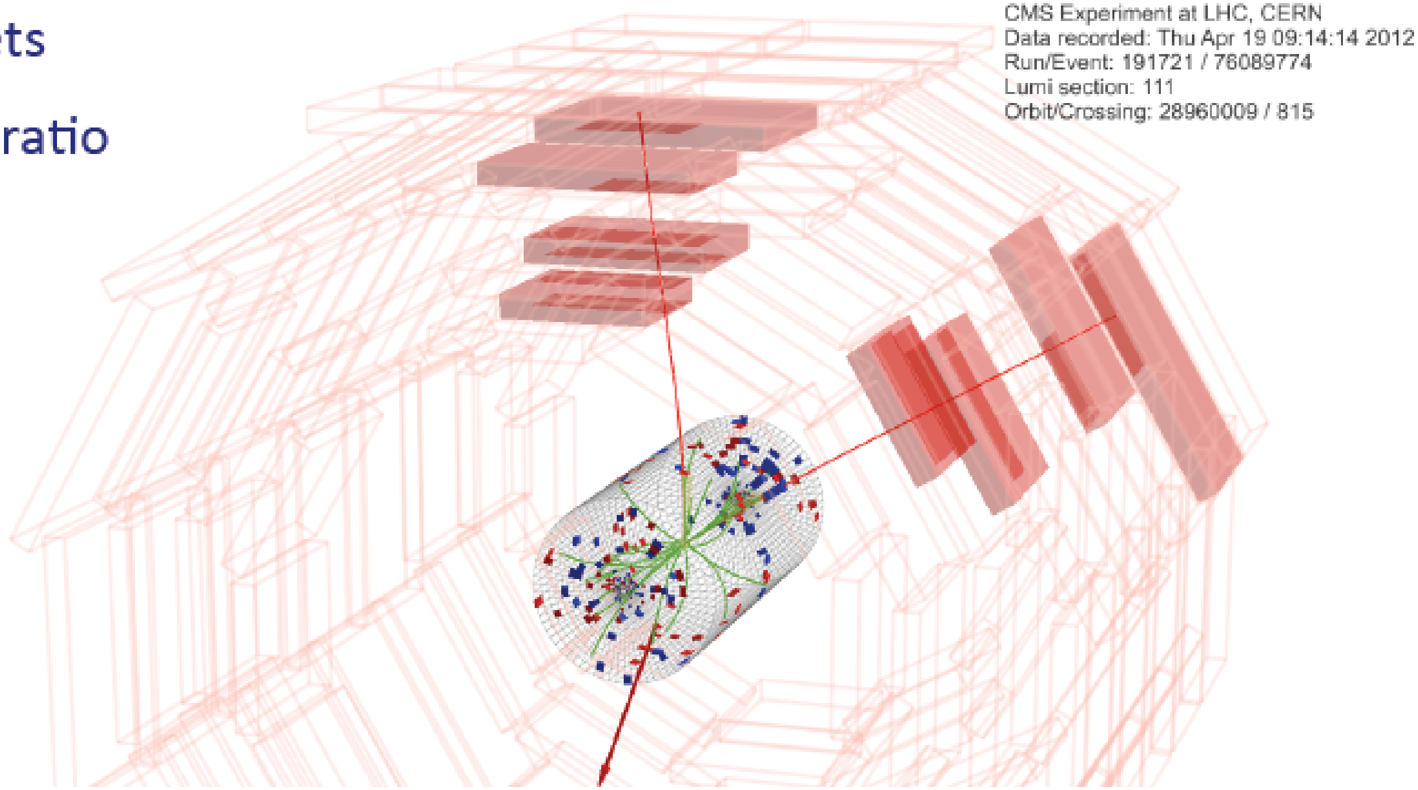
$H \rightarrow WW \rightarrow 2\ell\, 2\nu$

2 high-p_T isolated leptons, low opening angle (sensitivity to spin)

large MET (ν's), mass not reconstructed (transverse mass, M_T)

veto b-tagged jets

large branching ratio



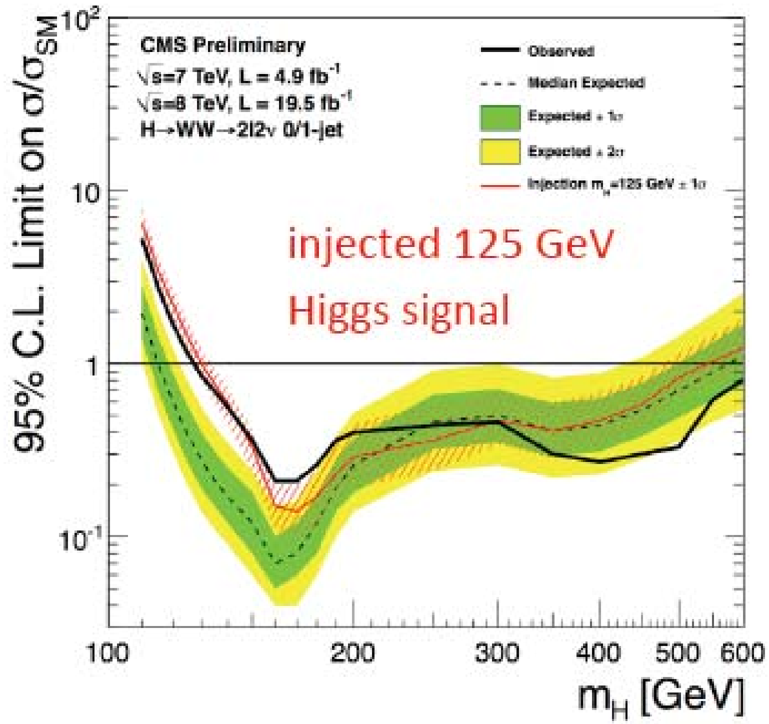
Broad excess compatible with a Higgs signal at low mass.

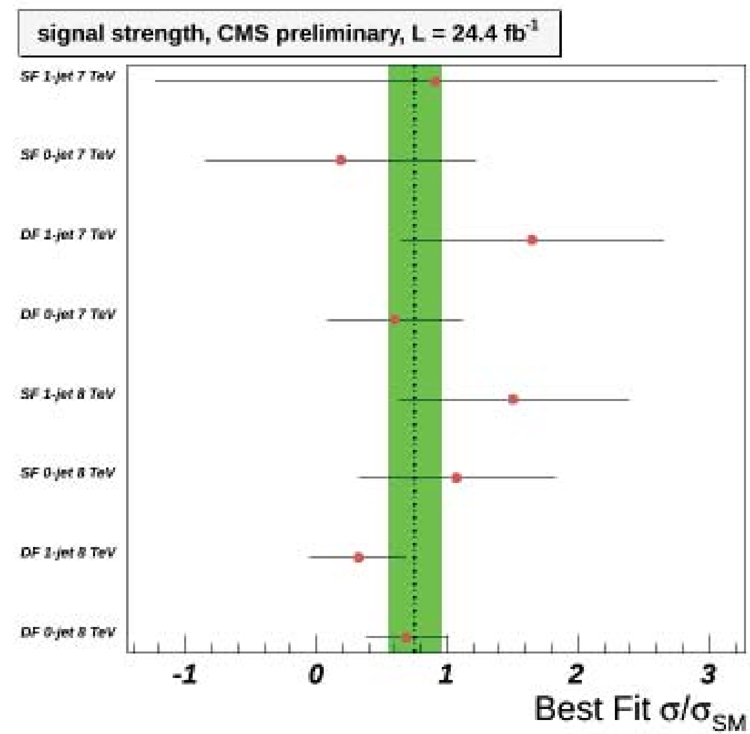
Significance (σ) for m_H = 125 GeV:

observed 4, expected 5.1

σ/σ_{SM} = 0.76 ± 0.21

Consistency among analyses.





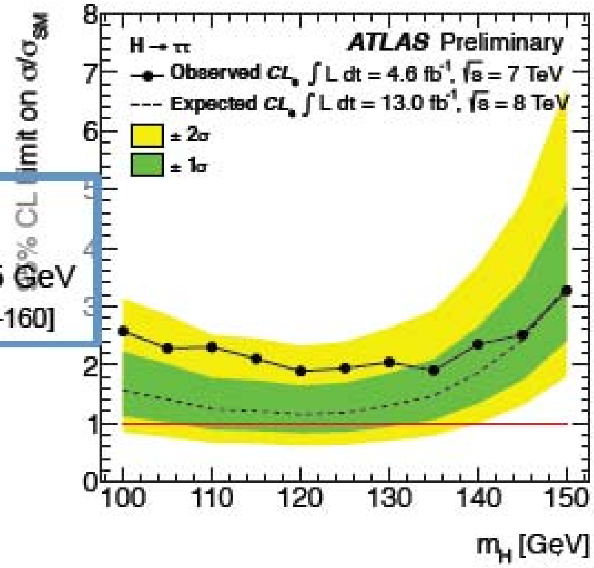
Other SM Higgs searches

13fb-1@8TeV

H→ττ

1.9(1.2)xSM @125 GeV

[ATLAS-CONF-2012-160]

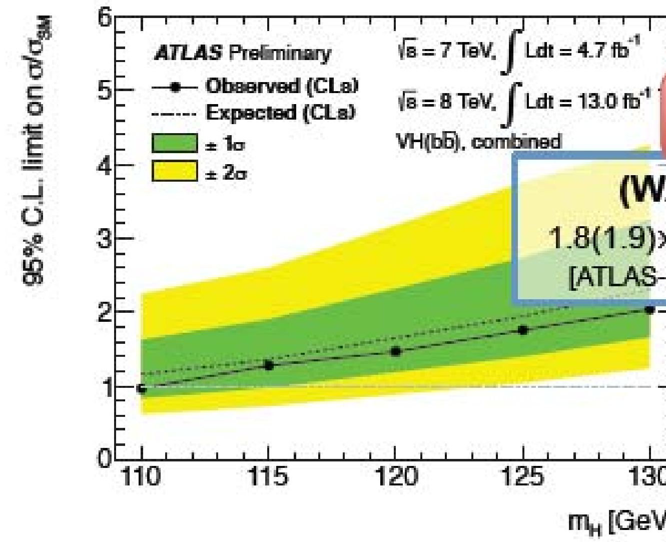


13fb-1@8TeV

(W/Z)H→bb

1.8(1.9)xSM @125 GeV

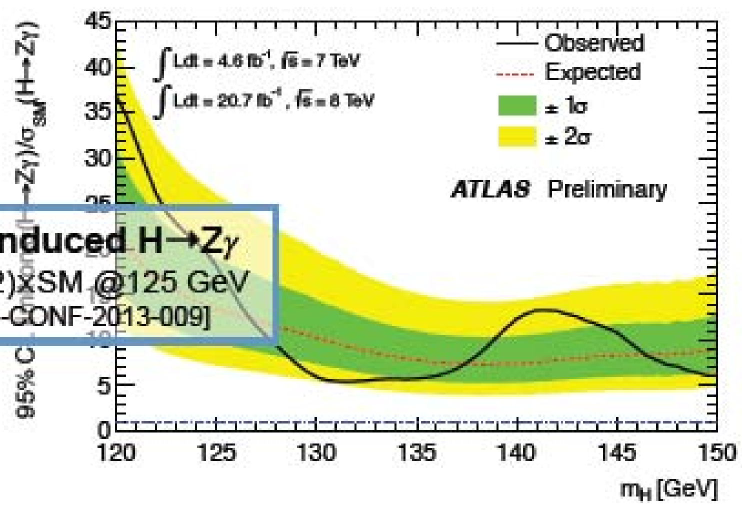
[ATLAS-CONF-2012-161]



Loop-induced H→Zγ

13.5(18.2)xSM @125 GeV

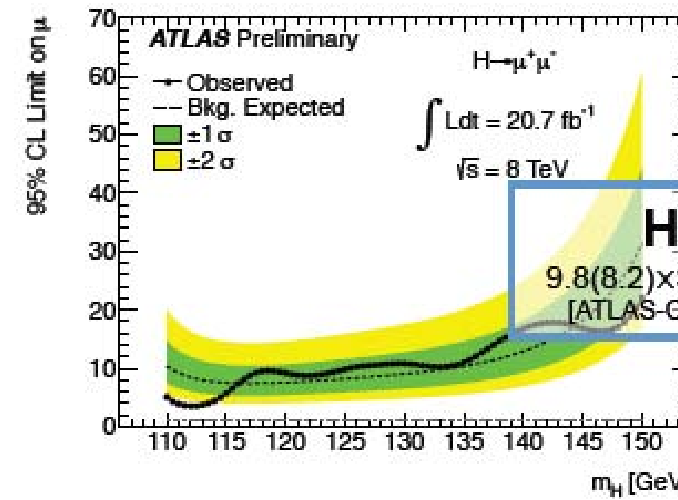
[ATLAS-CONF-2013-009]



H→μμ

9.8(8.2)xSM @125 GeV

[ATLAS-CONF-2013-010]



Mass measurement

ATLAS-CONF-2013-014, ATLAS-CONF-2013-034

High resolution channels:

1. $H \rightarrow ZZ^* \rightarrow 4l$:
   - $m_H = 124.3^{+0.6}_{-0.5}(stat)\,^{+0.5}_{-0.3}(syst)$ GeV
   - $4\mu(4e)$-event momentum resolution ±0.2%(0.4%),
2. $H \rightarrow \gamma\gamma$:
   - $m_H = 126.8 \pm 0.2(stat) \pm 0.7(syst)$ GeV
   - ±0.7GeV = energy scale uncertainty from extrapolation of photon response (0.3%), material modelling (0.3%), presampler ES (0.1%), additional syst (0.32%)

Consistency of $m_{\gamma\gamma}$ and m_{4l}:

1. correlation of e/γ energy scale
2. mass difference in m_{4e} and $m_{4\mu}$ pulls EM-scale down by 0.3% → $m_{\gamma\gamma}$ is 0.4 GeV lower

$$\Delta m = 2.3^{+0.6}_{-0.7}(stat) \pm 0.6(syst)\ GeV$$

2.4σ (p=1.5%) from $\Delta m = 0$

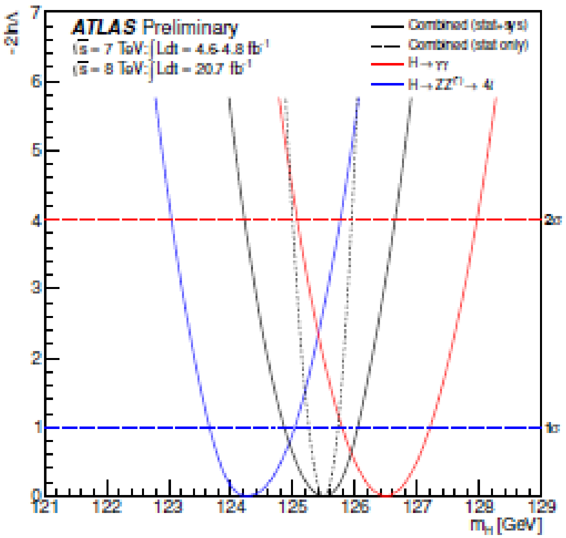
(p=8% with rectangular pdf's)

ATLAS

Measurements from separate decay channels:

$m_H^{\gamma\gamma} = 126.8 \pm 0.2(stat) \pm 0.7(syst)$ GeV

$m_H^{4\ell} = 124.3^{+0.6}_{-0.5}(stat)^{+0.5}_{-0.3}(syst)$ GeV



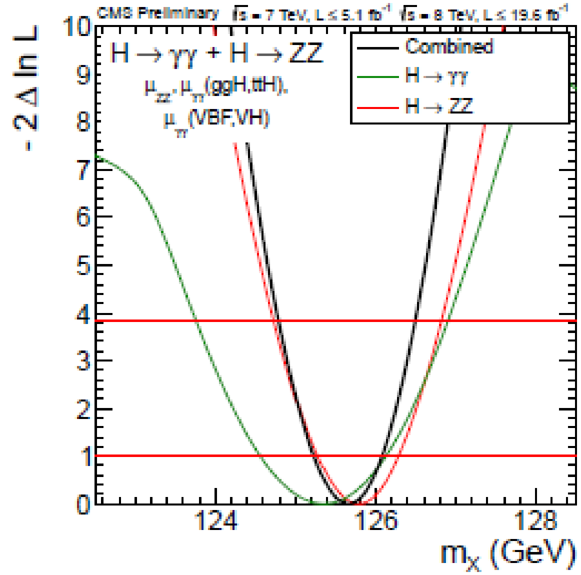
$\hat{m}_H = 125.5 \pm 0.2(stat)^{+0.5}_{-0.6}(syst)$ GeV

CMS

Measurements from separate decay channels:

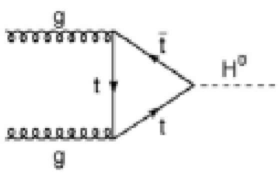
$m_H^{\gamma\gamma} = 125.4 \pm 0.5(stat) \pm 0.6(syst)$ GeV

$m_H^{4\ell} = 125.8 \pm 0.5(stat) \pm 0.2(syst)$ GeV



$\hat{m}_H = 125.7 \pm 0.3(stat) \pm 0.3(syst)$ GeV

Production modes and categories



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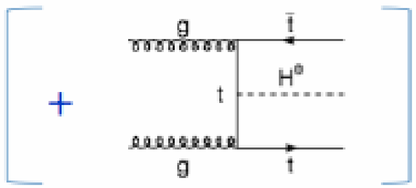

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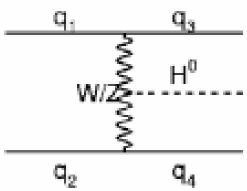
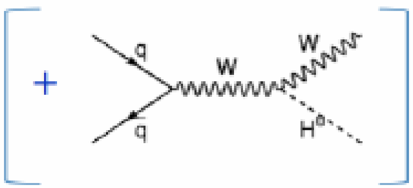
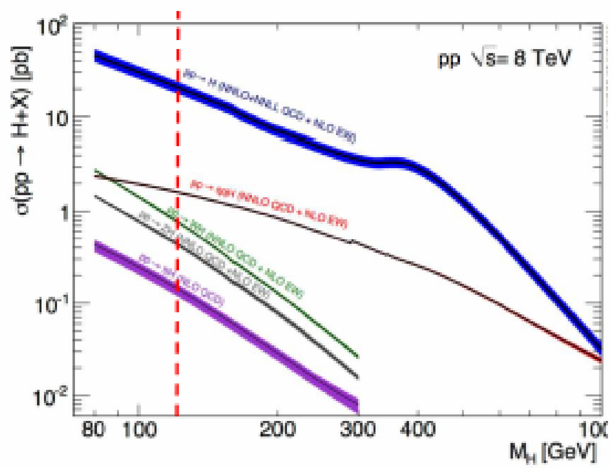


VBF



VH



More exclusive channels have a better signal-to-background ratio ⇒ introduce categories

Moreover, this provides sensitivity to production modes (therefore to fermion/vector couplings)
Possible "production tags":

- two hard jets with large $|\eta|$ and large m_{jj} ⇒ VBF mode
- two jets with small m_{jj} ⇒ VH mode with V→ jj
- identified lepton (e, μ) ⇒ VH mode with V→ $\ell(\ell)$
- missing transverse energy ⇒ ZH mode with Z→ $\nu\nu$
- "untagged" ⇒ mainly ggF
  (divide in more categories according to e.g. photons' η and conversion status)

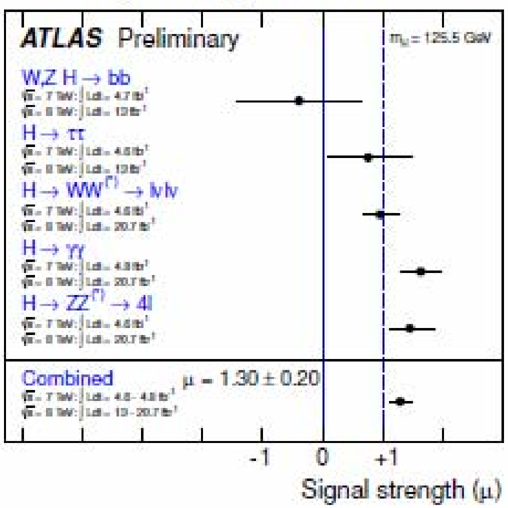
CAVEAT: "prod tags" are enriched by specific production modes, but are not pure samples

Signal strengths

By definition, $\mu = \frac{\sigma^{\mathrm{obs}}}{\sigma_{SM}}$ ($\mu \simeq 1$ means compatibility with SM Higgs boson signal)

ATLAS

by decay channel

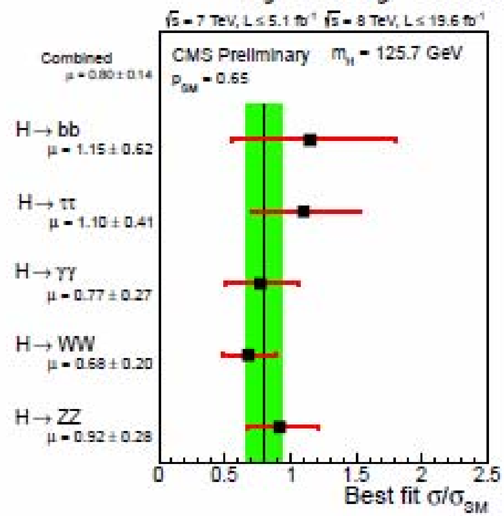


$\hat{\mu} = 1.30 \pm 0.13(stat) \pm 0.14(syst)$

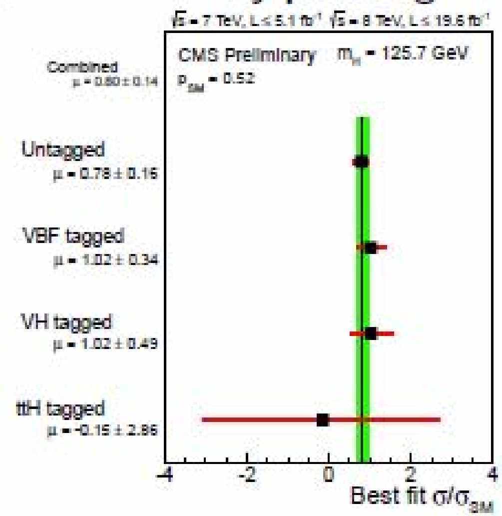
13% compatibility among channels
9% compatibility with SM

CMS

by decay channel



by prod tag

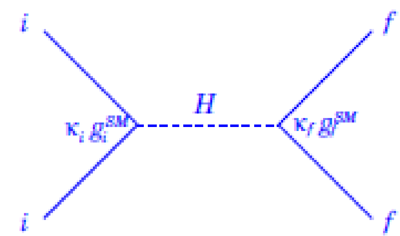


$\hat{\mu} = 0.80 \pm 0.14$

50% compatibility among decay channels
37% compatibility among production tags

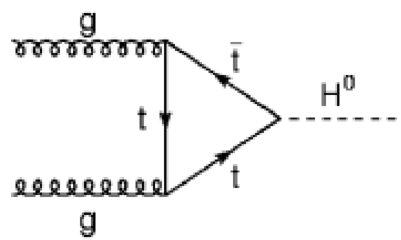
Effective couplings

Assume a tree-level model for a process $ii \to H \to ff$ with effective couplings:



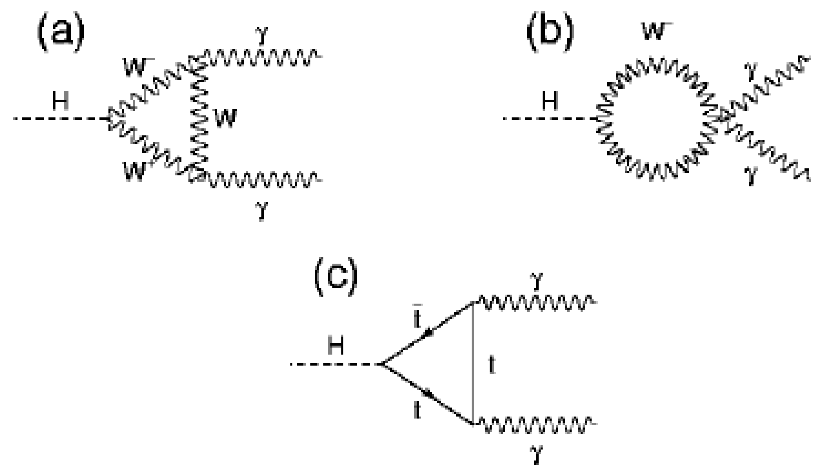
$$\sigma(ii \to H) \times BR(H \to ff) = \frac{\sigma_{ii}\Gamma_{ff}}{\Gamma_H} = \overbrace{\sigma_{SM}(ii \to H) \times BR_{SM}(H \to ff)}^{\text{SM prediction}} \times \left[\frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}\right]$$

$\kappa_{i,f}$ are scale factors wrt Standard Model couplings $g_{i,f}^{SM}$
($\kappa_{i,f} \simeq 1$ means compatibility with SM Higgs boson)



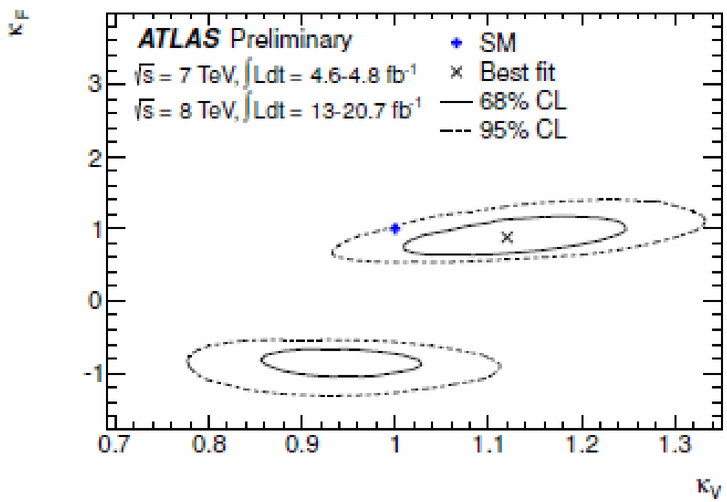
Some assumptions

- universality of κ's for fermions and for gauge bosons:
  $\kappa_t = \kappa_b = \kappa_\tau = \kappa_F$ and $\kappa_W = \kappa_Z = \kappa_V$
- gg-fusion $gg \to H$ mediated by a top loop as in SM
  $\Rightarrow \kappa_g = \kappa_F$
- $H \to \gamma\gamma$ decay mediated by W and top loops
  $\Rightarrow \kappa_\gamma^2 = (1.26 \cdot \kappa_V - 0.26 \cdot \kappa_F)^2$ (at $m_H = 125.5$)
  (sensitive to relative sign between κ_F, κ_V)
- in SM $BR(H \to f\bar{f}, gg) = 0.75$
  $\Rightarrow \kappa_H^2 = 0.75 \cdot \kappa_F^2 + 0.25 \cdot \kappa_V^2$ (at $m_H = 125.5$)



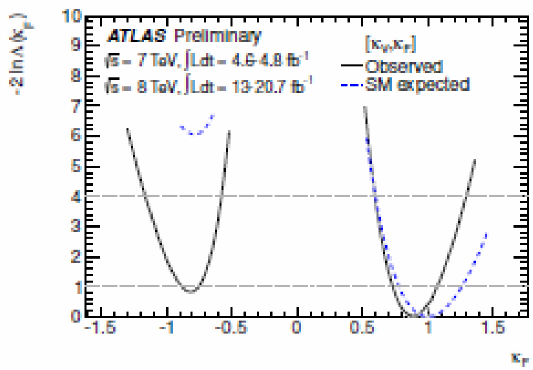
Fermion vs gauge boson couplings factors

ATLAS

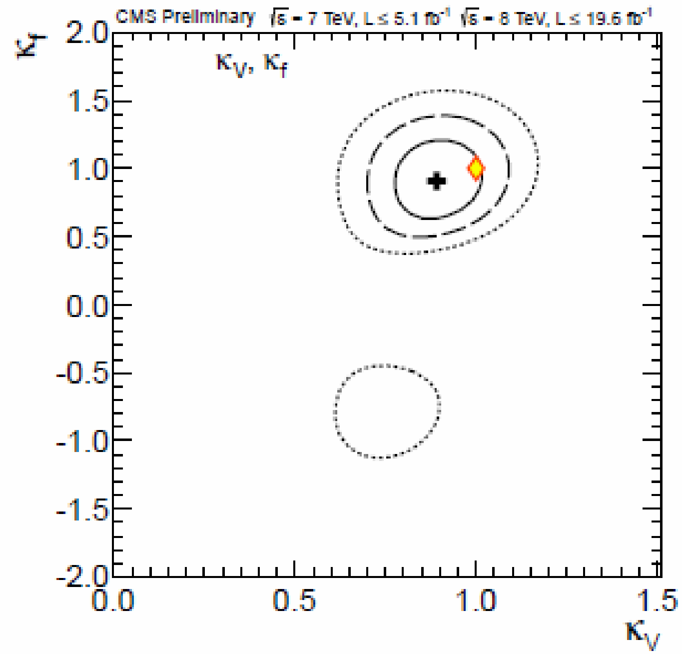


Two minima, but fit prefers same-sign κ_F, κ_V

8% compatibility with SM



CMS



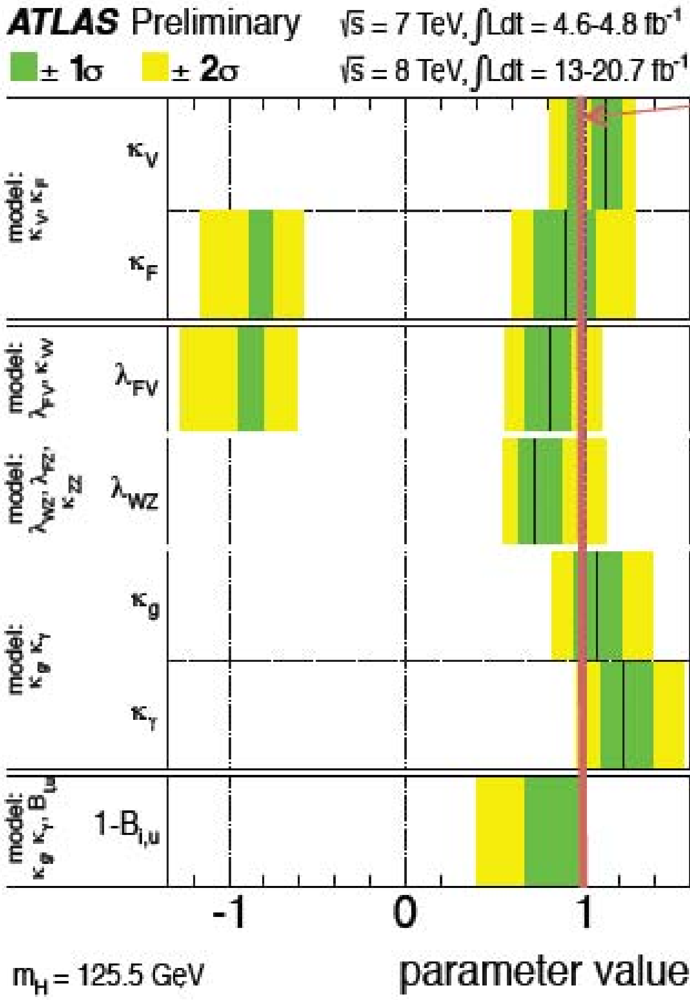
$\kappa_V > 0$ by convention ; $\pm\kappa_F$ asymmetry due to $\gamma\gamma$:
$\kappa_\gamma^2 = (1.26 \cdot \kappa_V - 0.26 \cdot \kappa_F)^2$

$\Rightarrow$ **Evidence for both fermion and vector couplings**

The difference between ATLAS and CMS is due to the large $H \to \gamma\gamma$ yield observed by ATLAS

Coupling Fits

ATLAS-CONF-2013-034



SM Expectation

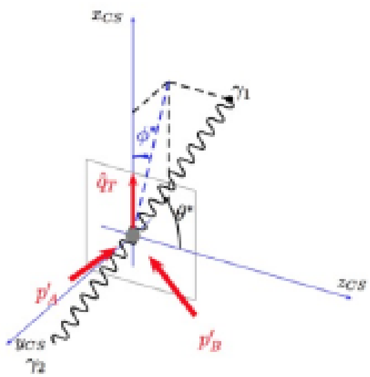
- Fermion vs Vector couplings (only SM contributions to total width)
- Fermion vs Vector couplings (no assumption on total width)
- Custodial symmetry of W and Z couplings
- BSM effects in ggF and $H\rightarrow\gamma\gamma$ loops (only SM contributions to total width, other $\boldsymbol{k}$=1)
- BSM effects in loops and decay (no assumption on total width, other $\boldsymbol{k}$=1)

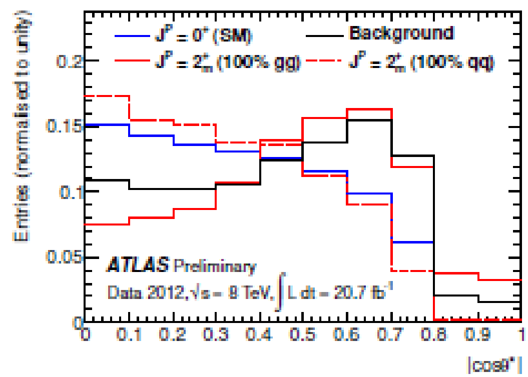
Spin measurement in the $H \to \gamma\gamma$ channel (ATLAS)

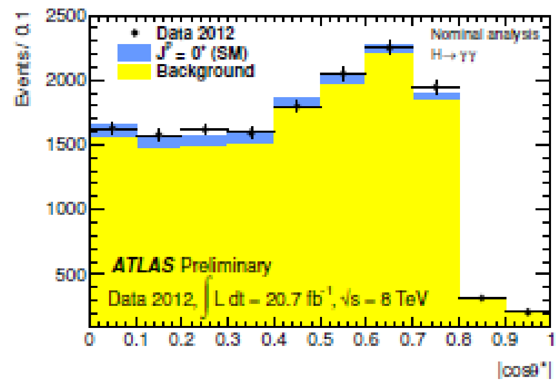
Observable: photons' production angle θ^* in $\gamma\gamma$ center-of-mass frame

$\Rightarrow$ isotropic distribution for spin-0 (uniform $\cos\theta^*$) before kinematic cuts

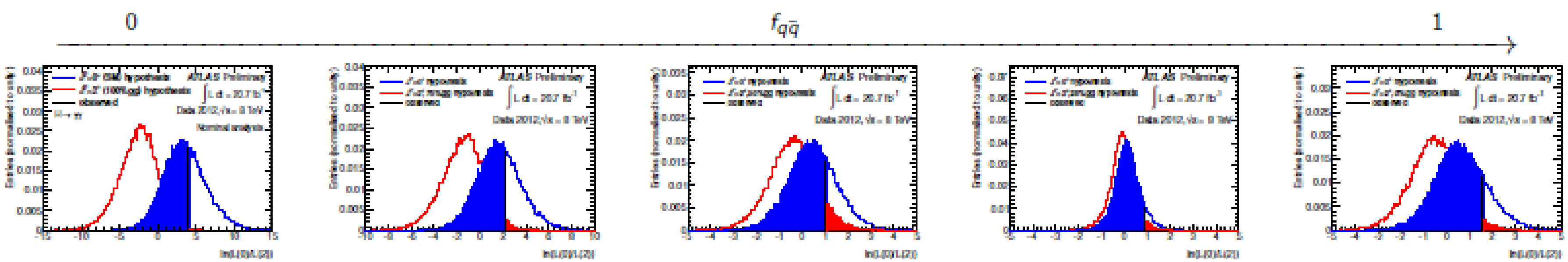
$$\Rightarrow \frac{d\sigma(gg \to (2^+_m) \to \gamma\gamma)}{d(\cos\theta^*)} \propto (1 + 6\cos^2\theta^* + \cos^4\theta^*) \quad ; \quad \frac{d\sigma(q\bar{q} \to (2^+_m) \to \gamma\gamma)}{d(\cos\theta^*)} \propto (1 - \cos^4\theta^*)$$







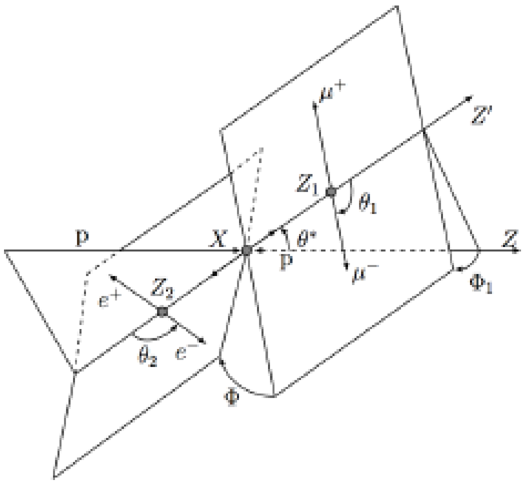
Low S/B ratio, $\approx 3\%$ $\Rightarrow$ crucial to have good understanding of the background shape and normalization (extracted from data sidebands) $\Rightarrow$ use $\cos\theta^*$ and $m_{\gamma\gamma}$ as observables



data always favour 0^+ hypothesis

Spin measurement in the $H \to ZZ^* \to 4\ell$ channel

The complete reconstruction of the final state gives access to the polarization of the resonance and of the Z bosons



Sensitive observables:

- 2 invariant masses m_{12} , m_{34} (from $Z \to \ell_1\ell_2$ and $Z^* \to \ell_3\ell_4$)
- 5 angles θ^* , Φ_1 , Φ , θ_1 , θ_2

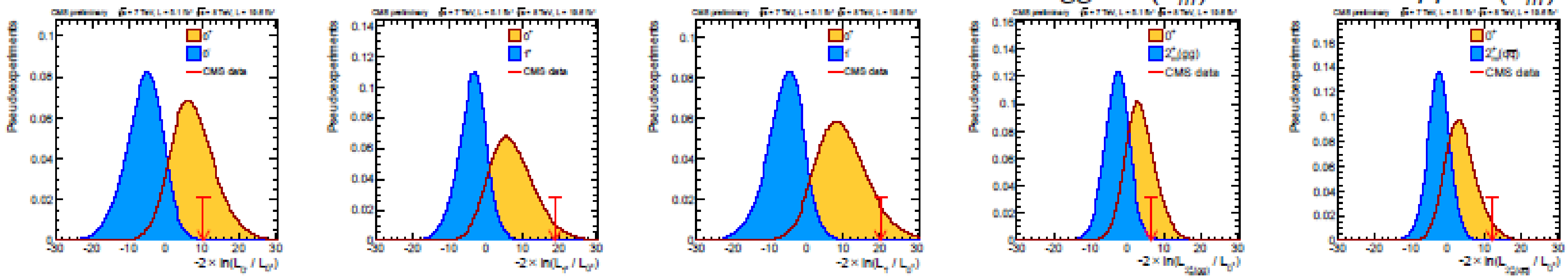
Cases $J^P = 0^{\pm}$: isotropic in $\cos\theta^*$, Φ_1 ; Φ , $\theta_{1,2}$, m_{34} sensitive to parity

Cases $J^P = 1^{\pm}, 2^{\pm}_m$: all variables are discriminant

$\Rightarrow$ multivariate analysis

from CMS: (ATLAS results in backup material)

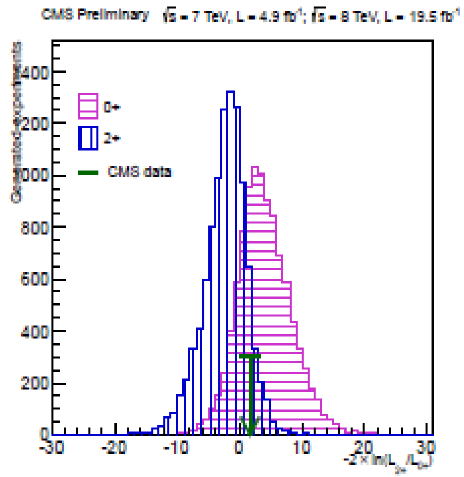
0^+ vs 0^- $\quad$ 0^+ vs 1^+ $\quad$ 0^+ vs 1^- $\quad$ 0^+ vs $gg \to (2^+_m)$ $\quad$ 0^+ vs $q\bar{q} \to (2^+_m)$



data always favour 0^+ hypothesis

More spin results in WW*, ZZ* channels

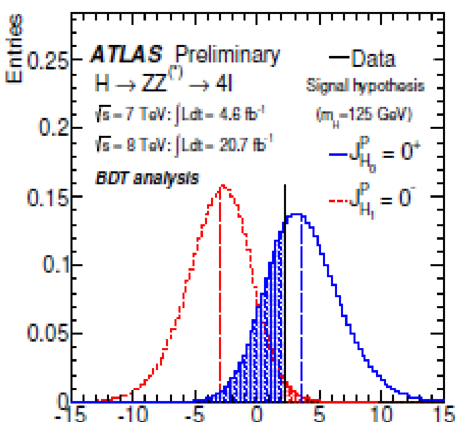
from WW* — CMS

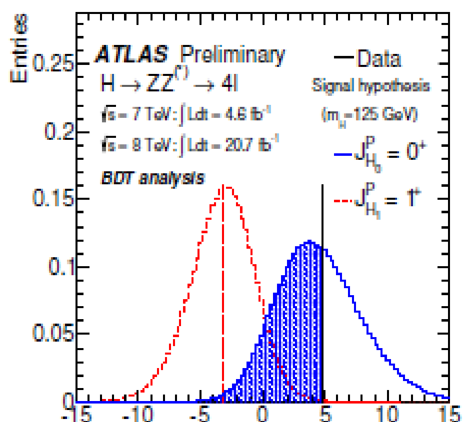


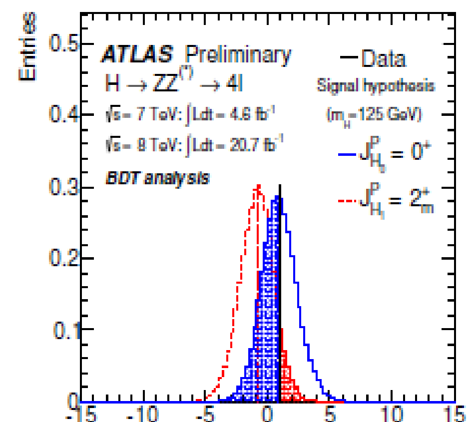
(assuming $gg \to (2^+_m)$)

from ZZ* — ATLAS

0^+ vs 0^- | 0^+ vs 1^+ | 0^+ vs 2^+_m







SUMMARY

ATLAS and CMS have analysed all LHC run-1 data for $\gamma\gamma$, $ZZ^* \to 4\ell$, $WW^* \to \ell\nu\ell\nu$ channels
($\sim 5\ \mathrm{fb}^{-1}$ @ $\sqrt{s} = 7$ TeV $\quad + \quad \sim 20\ \mathrm{fb}^{-1}$ @ $\sqrt{s} = 8$ TeV)
$\gamma\gamma$ and ZZ^* channels have now $> 5\sigma$ evidence each, at least from one experiment — WW^* channel reaches $\sim 4\sigma$
$b\bar{b}$ and $\tau^+\tau^-$ not yet well established

The "new particle" has a mass measured as: $\begin{cases} m_H^{ATLAS} = 125.5 \pm 0.2(stat)^{+0.5}_{-0.6}(syst)\ \mathrm{GeV} \\ m_H^{CMS} = 125.7 \pm 0.3(stat) \pm 0.3(syst)\ \mathrm{GeV} \end{cases}$

It is compatible with a state $J^P = 0^+$.
Alternative state 2^+ is disfavoured at $> 99.9\%$ CL. States 0^- , $1^\pm$ are disfavoured at $> 99\%$ CL

All couplings' measurements do not show any significant deviation from the Standard Model predictions
— but measurements are precise at $\gtrsim 20\%$ (at best!)

"New results indicate that particle discovered at CERN is a Higgs boson" — CERN press release

Послесловие

Disagreement in the signals strength might be connected with difficulties of efficiencies estimations (MC)

Difference in masses of ggF and VBF processes has no comments

Small statistics and large background can lead to significant difference in masses estimation as one can see in the H->4l process. As we have shown in an independent search of for leptons resonance states (PNPI/BNPI, ATLAS) there is NO mass difference in H->4l and H->GamGam processes in the ATLAS and CMS studies.

Заключение:

There is a new boson of mass ~125 GeV,
with properties consistent with the SM Higgs,
within the current uncertainties.

More data needed
to ascertain the nature of this object

Summary

1. Preliminary results based on full 2012 datasets in $H\rightarrow\gamma\gamma$, $H\rightarrow ZZ^*\rightarrow 4l$ and $H\rightarrow WW^*\rightarrow l\nu l\nu$
2. Independent observations in all three channels: a lot of Higgs candidates to be used for property measurements!
3. $m_H = 125.5\pm0.2(stat)^{+0.5}_{-0.6}(syst)$ GeV
4. $\mu = 1.30\pm0.13(stat)\pm0.14(syst)$
5. $\mu_{VBF+VH}/\mu_{ggF+ttH} = 1.2^{+0.7}_{-0.5}$
6. 3.1σ evidence of VBF production
7. Higgs couplings consistent with SM within 2σ
8. SM 0^+ hypothesis preferred against 0^-, $1^\pm$ and $2^\pm$
9. 2^+_m "graviton-like" particle excluded at $\geq$99.9% CL_S

So far no significant deviation from SM, more stringent measurements expected with the updated results in the fermionic decays