Higgs boson: latest results

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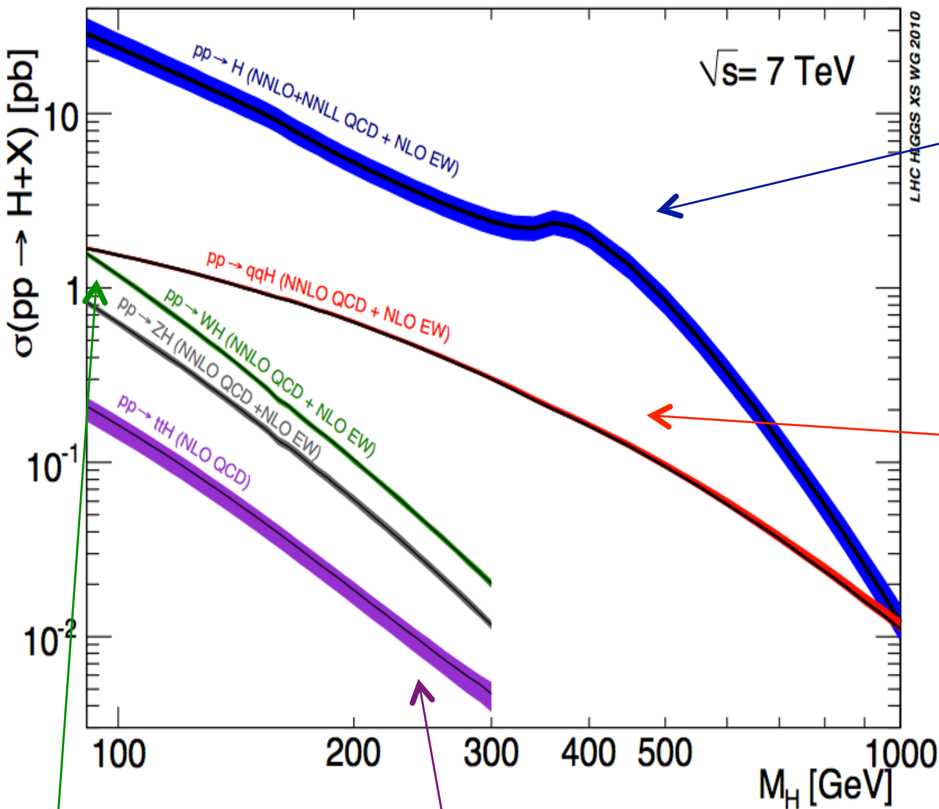
HiggsTools, Freiburg 15 April 2015

First measurements on the Higgs

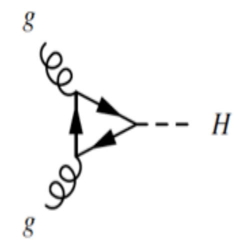
- The results from ATLAS+CMS
  - the Higgs mass
  - the Higgs width
  - spin and CP
  - the couplings
- How to proceed ?

Higgs production at LHC

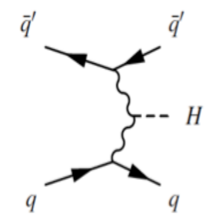
The LHC Higgs Cross Section WG
YR1, YR2, YR3



ggF: NNLO+NNLL QCD + NLO EW

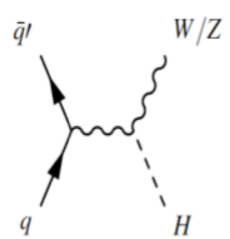


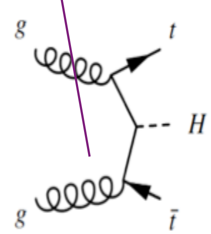
qqH: NNLO QCD + NLO EW



WH: NNLO QCD + NLO EW

ZH: NNLO QCD + NLO EW





ttH: NLO QCD

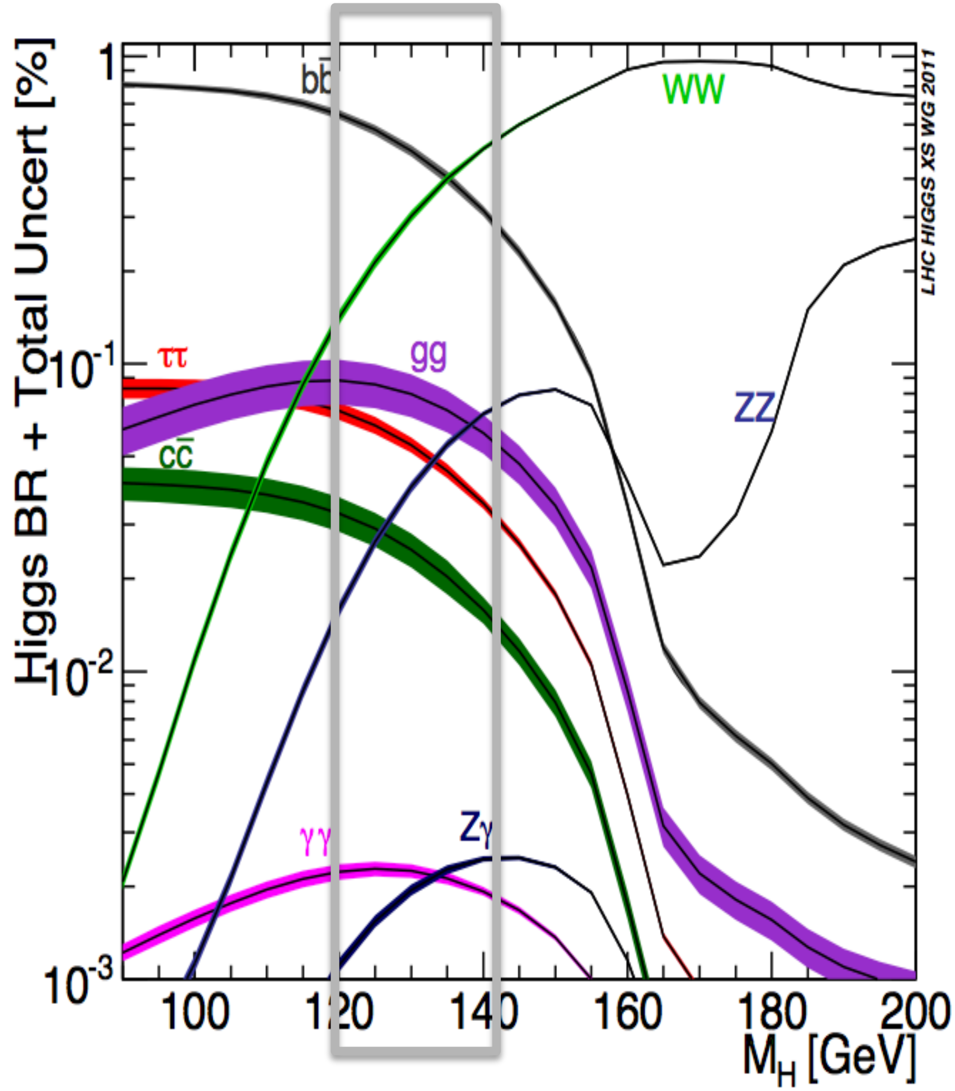
	$K_{NNLO/NLO}$ ($K_{NLO/LO}$)	Scale	PDF+a_S	Total error
ggF	+25% (+100%)	+12% -7%	±8%	+20 -15%
VBF	<1% (+5-10%)	±1%	±4%	±5%
WH/ ZH	+2-6% (+30%)	±1%	±4%	±5%
ttH	- (+5-20%)	+4% -10%	±8%	+12 -18%

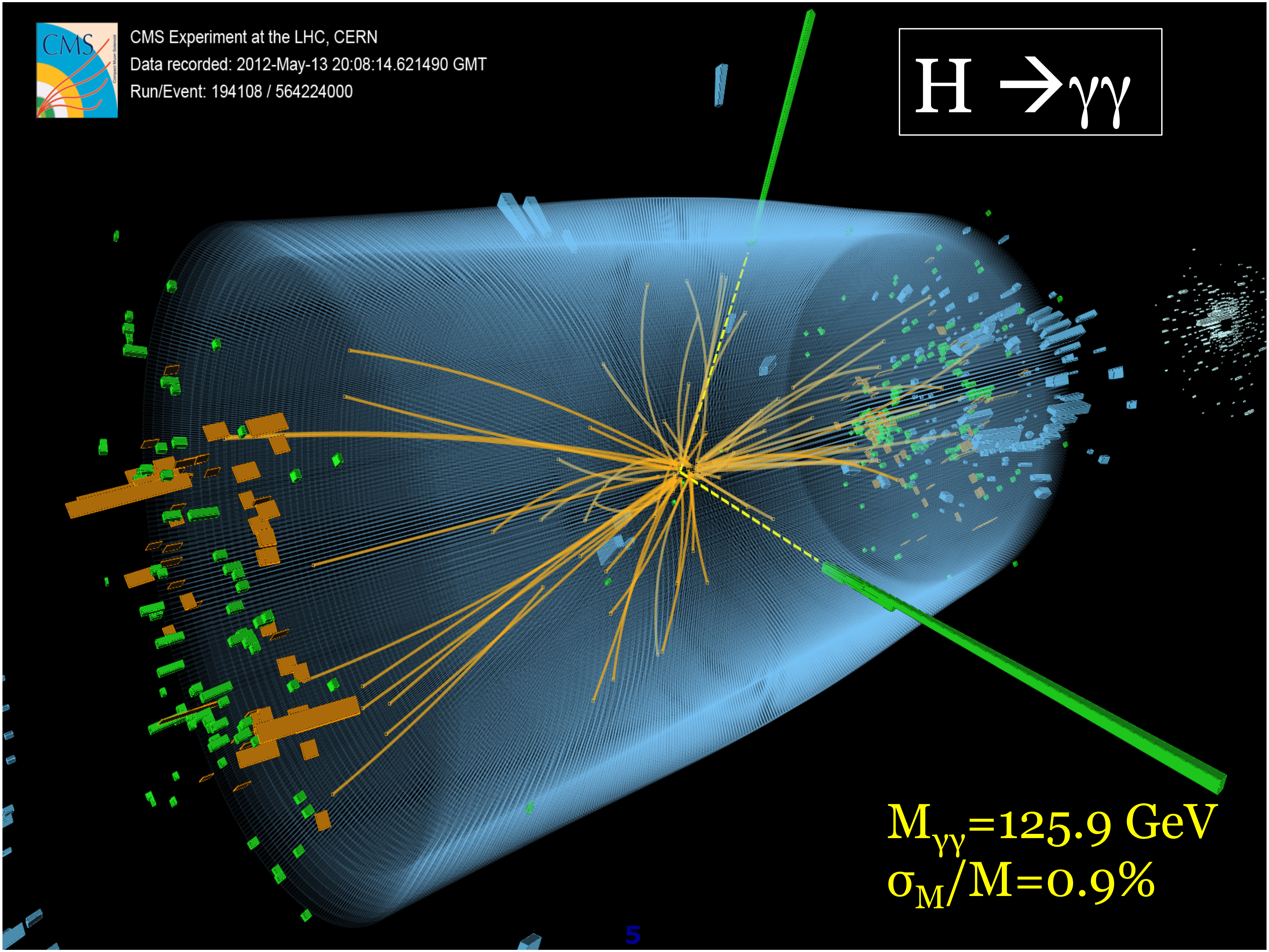
The channels at LHC

5 decay modes exploited

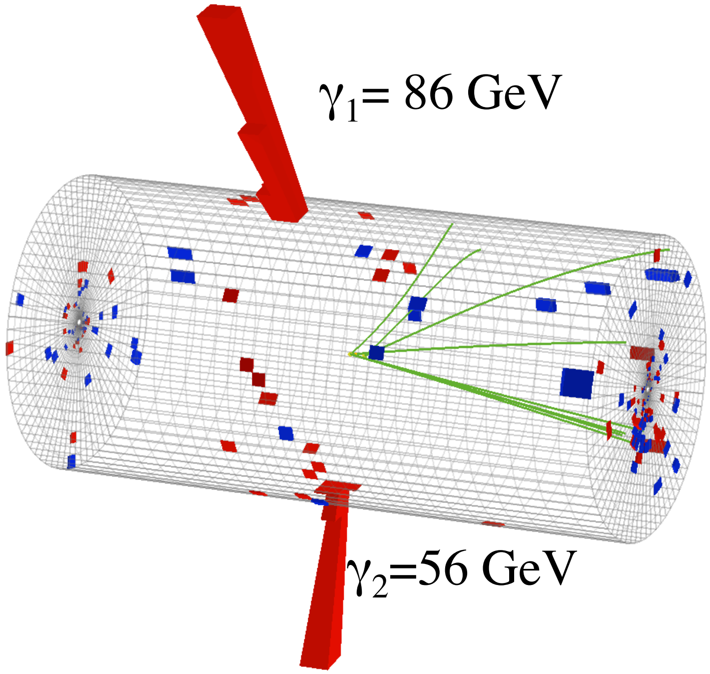
	Exp Sig (CMS) @125.7	σ_M/M
• bb	2.6σ	10%
• ττ	3.9σ	10-20%
• WW	5.4σ	16%
• ZZ	6.3σ	1-2%
• γγ	5.3σ	1-2%

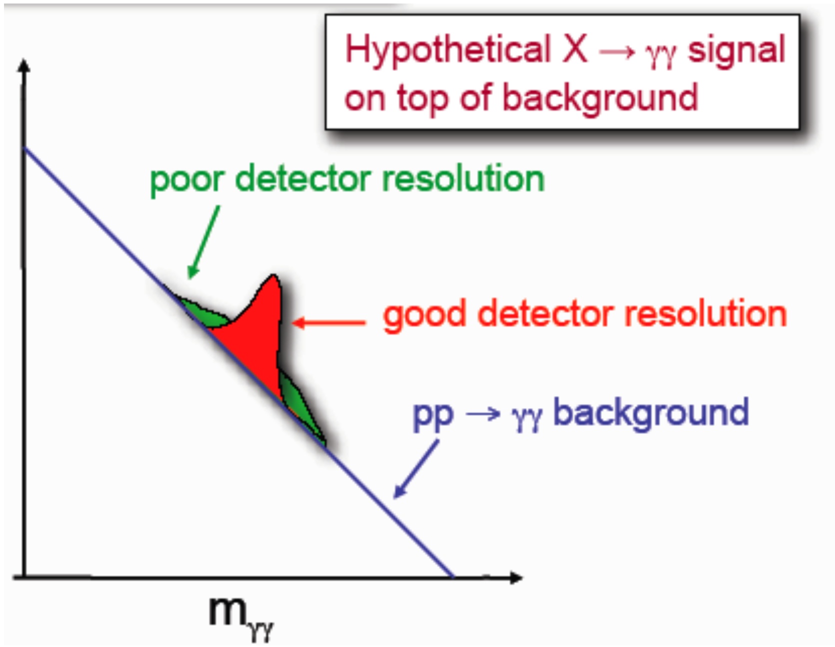
- and searches in Zγ, μμ



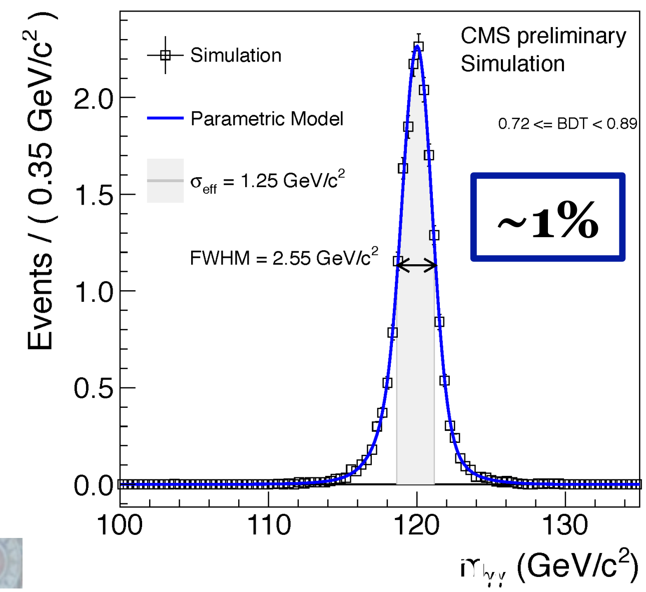

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H →γγ
$M_{\gamma\gamma}$=125.9 GeV
σ_M/M=0.9%

H → γγ





Signature: 2 energetic, isolated γ, in a narrow mass peak on top of a steeply falling spectrum

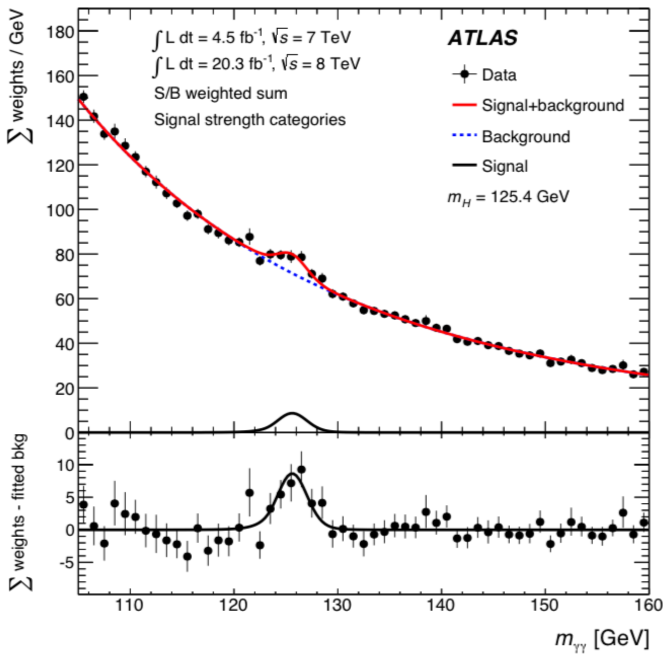


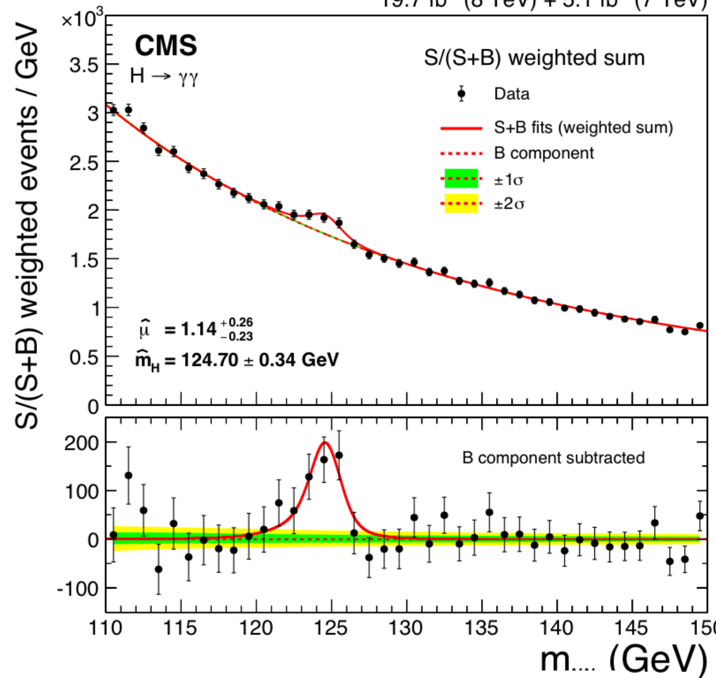
Relevant aspects:

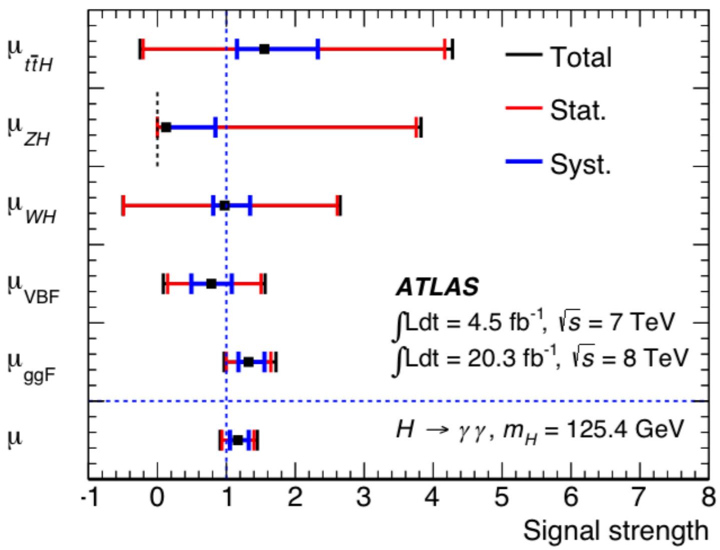
- Photon identification/ background rejection
- Di-photon mass spectrum
- Background estimation
- Primary vertex determination (pile-up!)

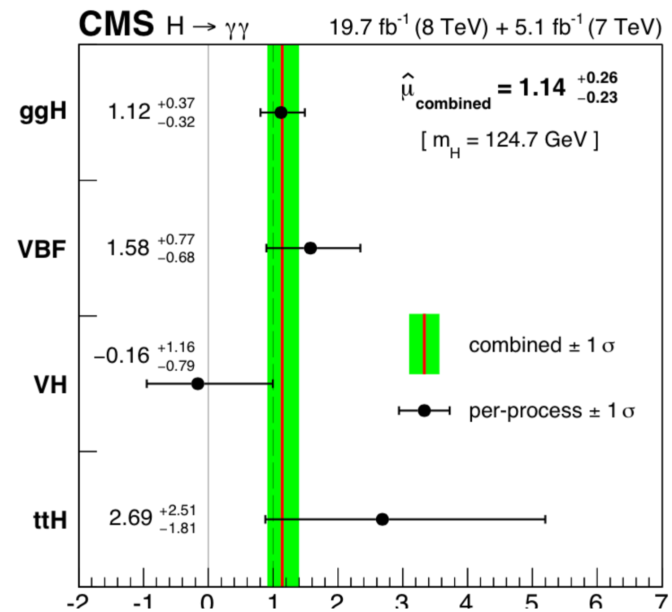
H → γγ

[Phys. Rev. D 90, 112015 (2014)]



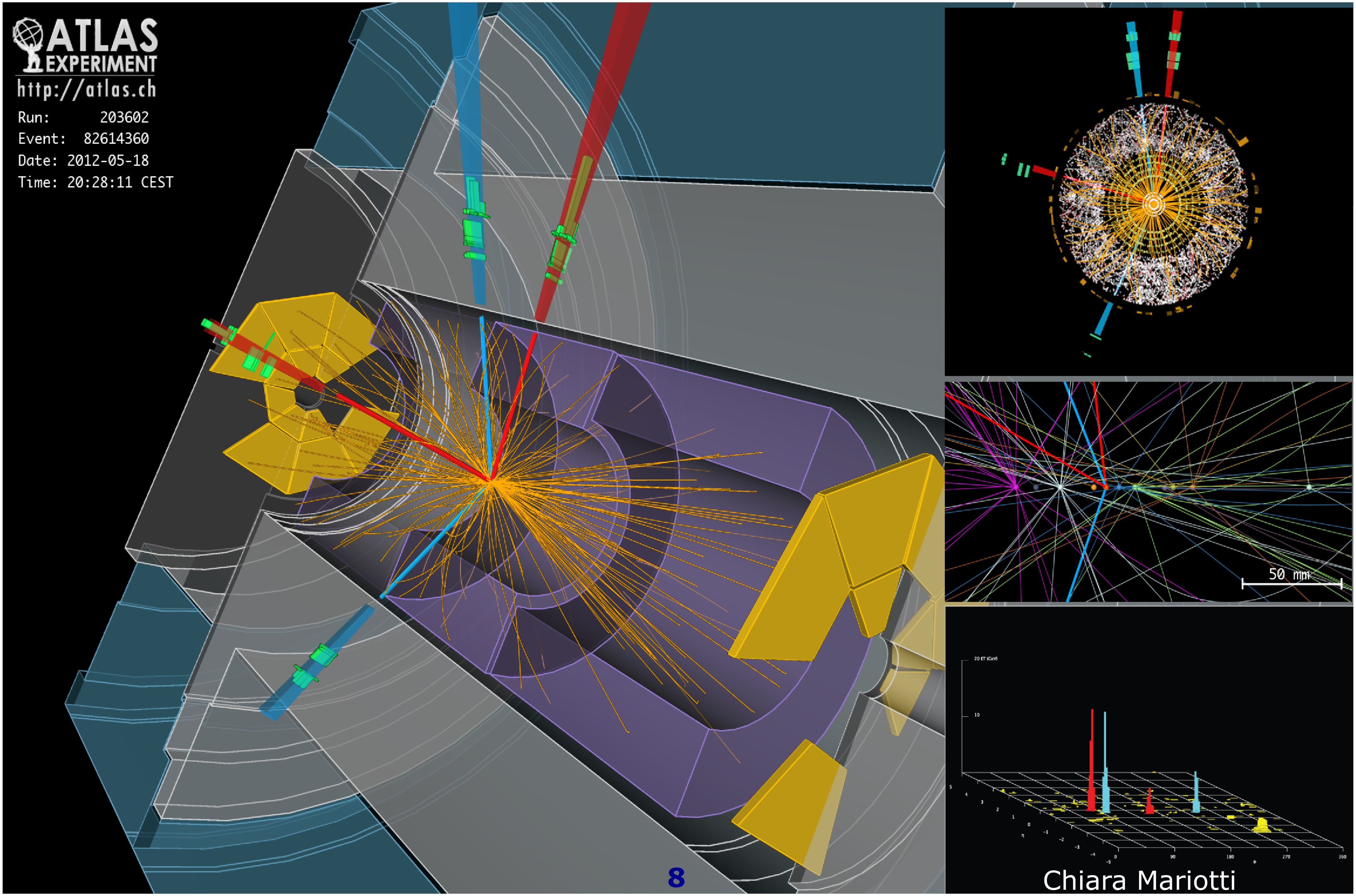






High level analysis very, very similar between Atlas and CMS:
- Categorization by S/B, resolution and p_T (ATLAS using cuts, CMS using a BDT)
- Similar di-jet categories with O(70%) purity
- Mass fit with polynomial background chosen to minimize the bias on the signal

The golden channel



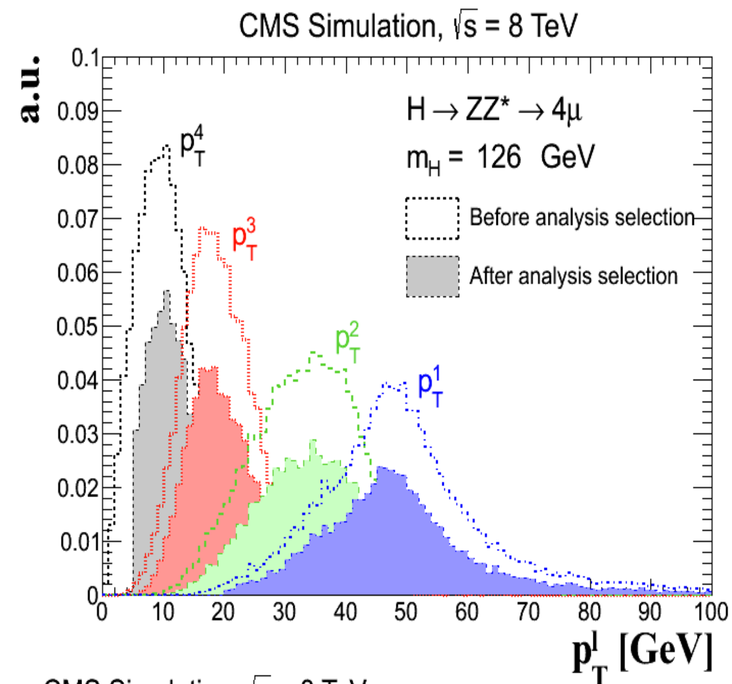
H → ZZ → 4l

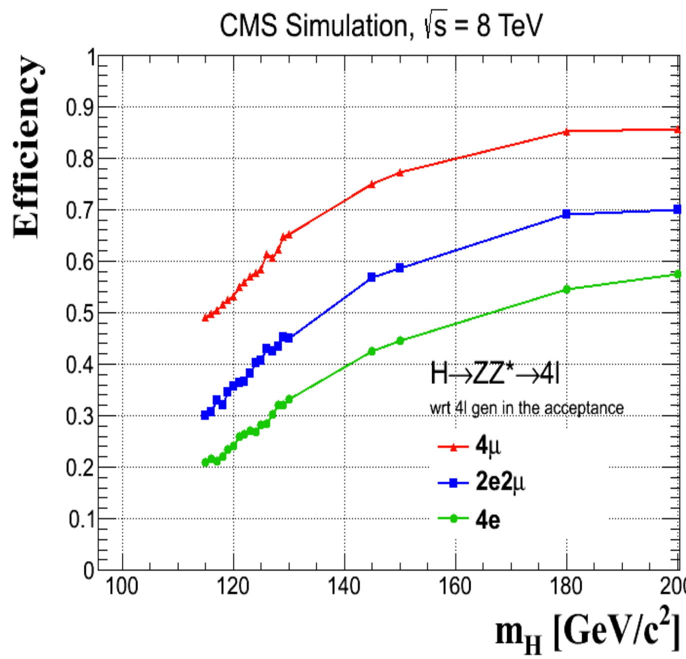
The final states considered are 4μ, 4e, 2e2μ

Very clean final state:
- 4 leptons of high p_T,
- isolated
- coming from the primary vertex

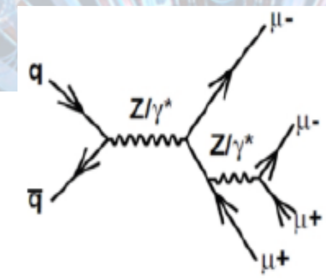
Very tiny cross section →
thus highest efficiency must be conserved

huge effort on lepton ID and efficiency
2l / 4l mass resolution

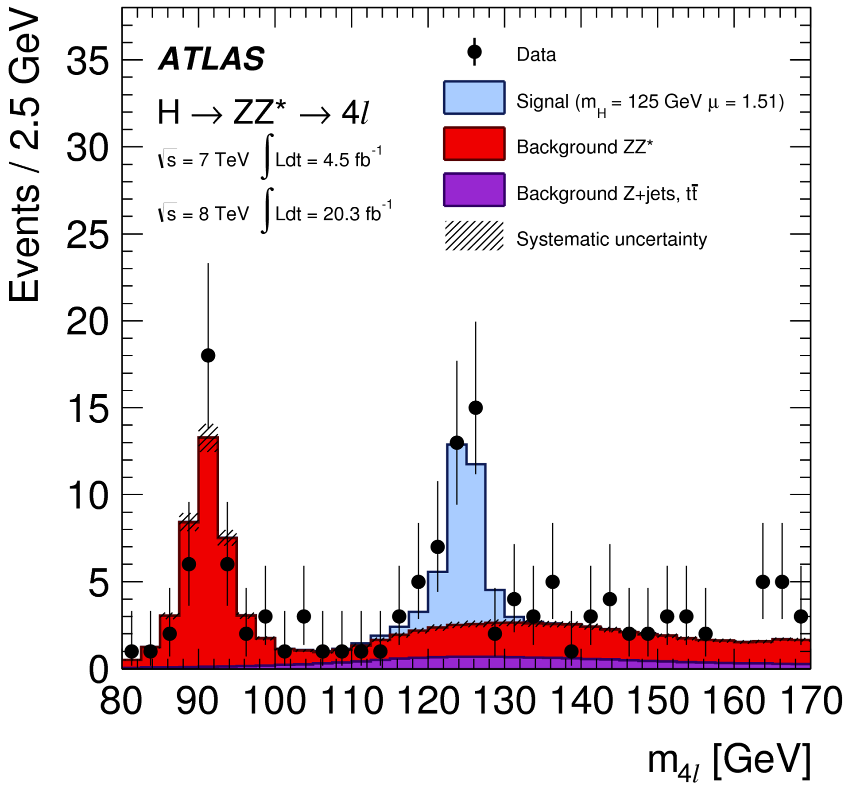




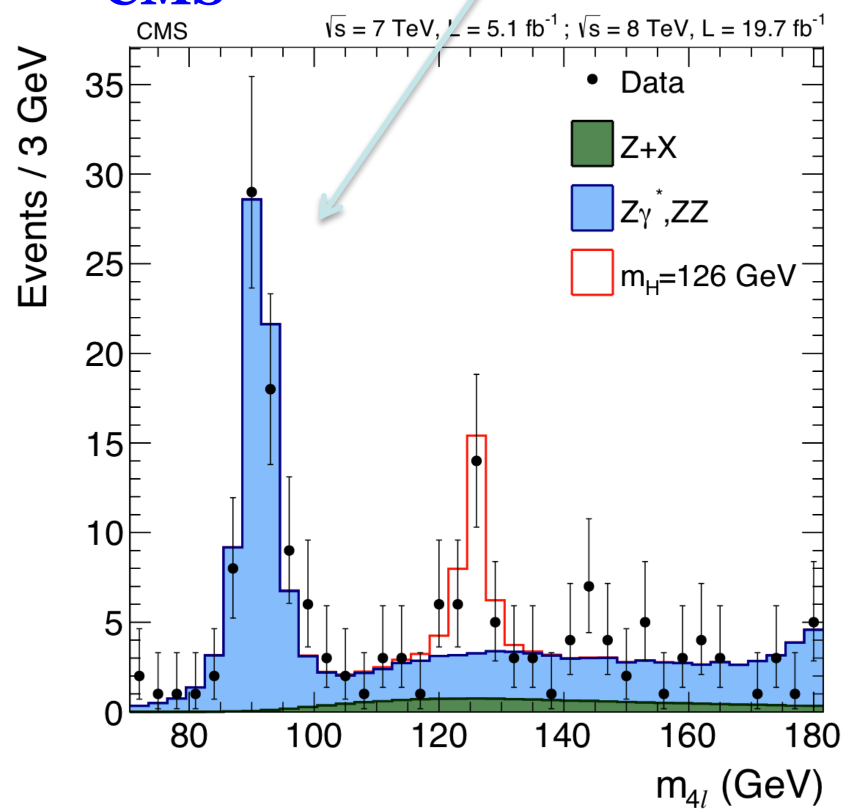
pp →4l



ATLAS



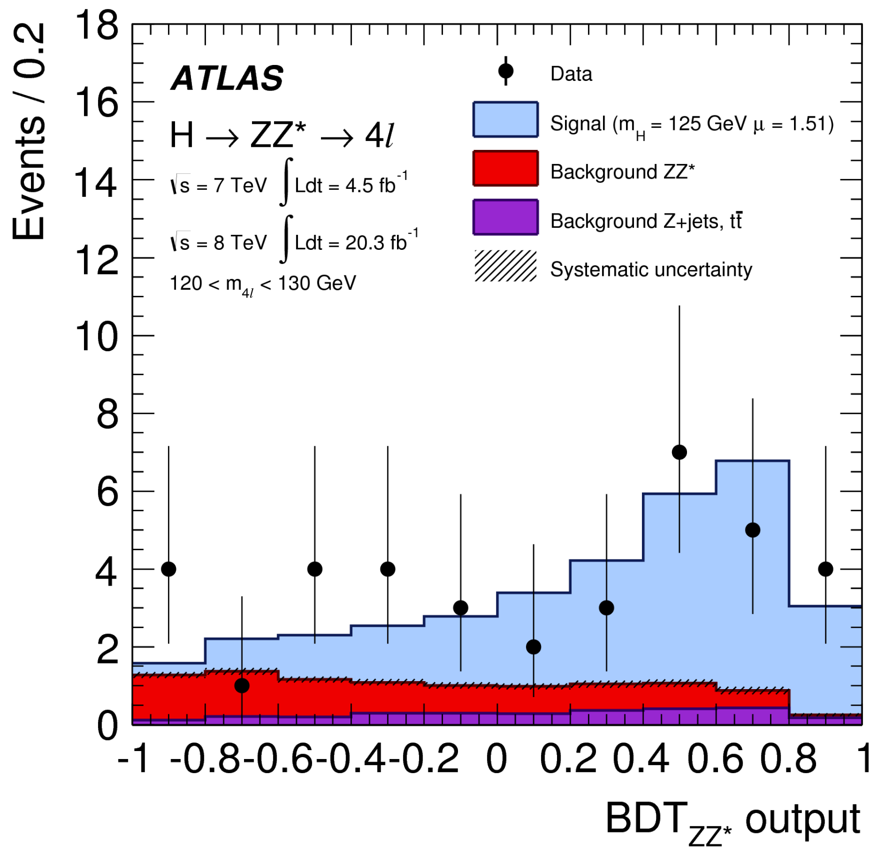
CMS

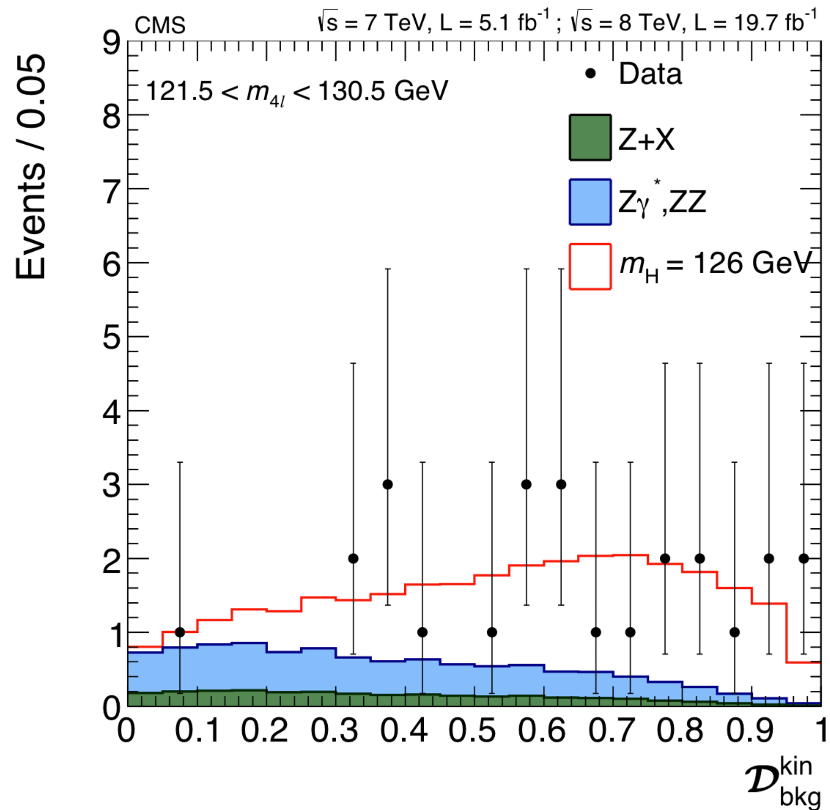


σ/σ_{SM} @ 125.36 GeV = $1.44^{+0.40}_{-0.33}$

σ/σ_{SM} @ 125.59 GeV = $0.93^{+029}_{-0.25}$

Kinematics discriminants



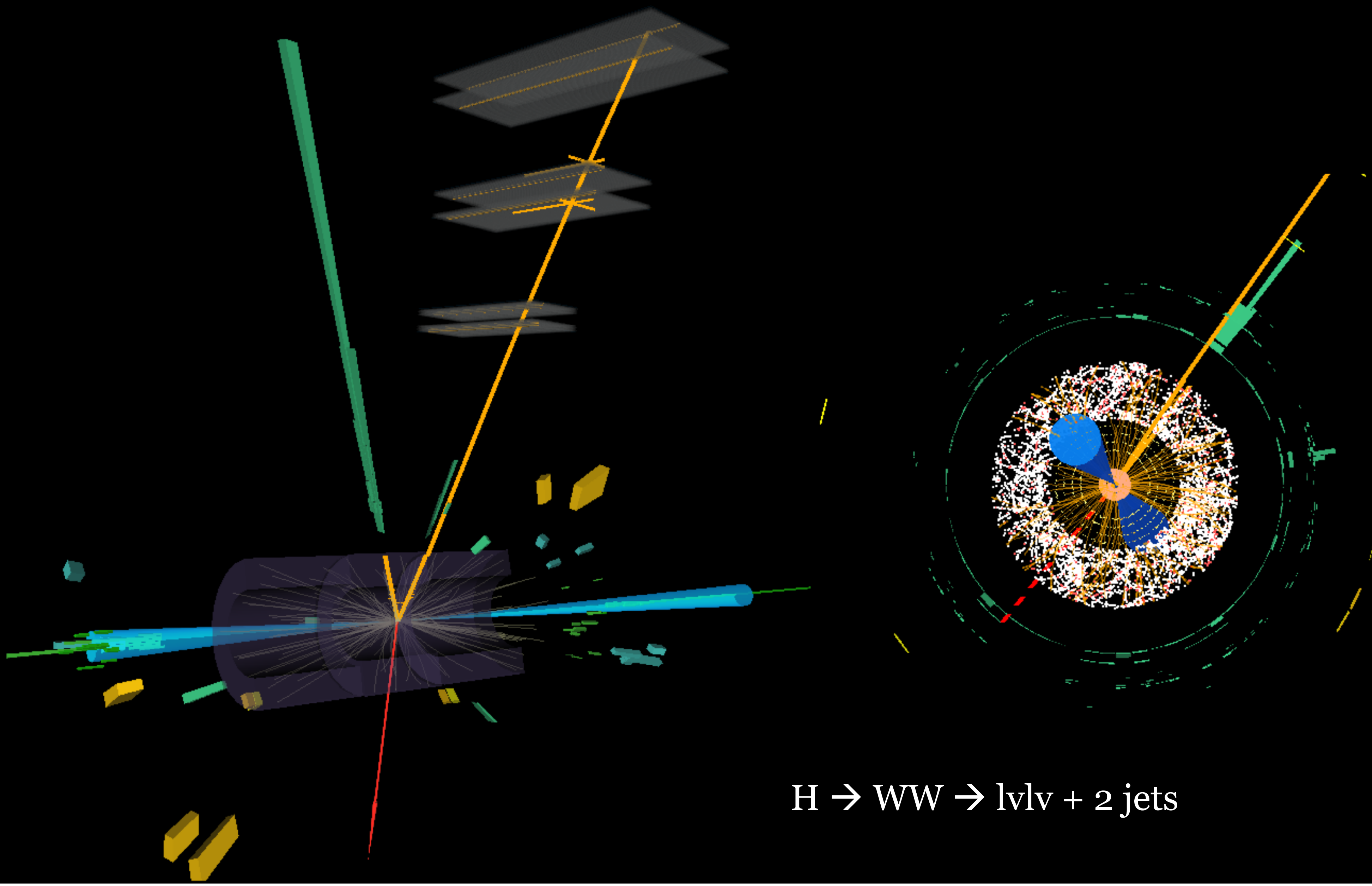


- VBF, VH and ggF enriched event categories
- kinematics distributions to separate signal from background

→ to measure cross sections, width, couplings, Spin, Parity…

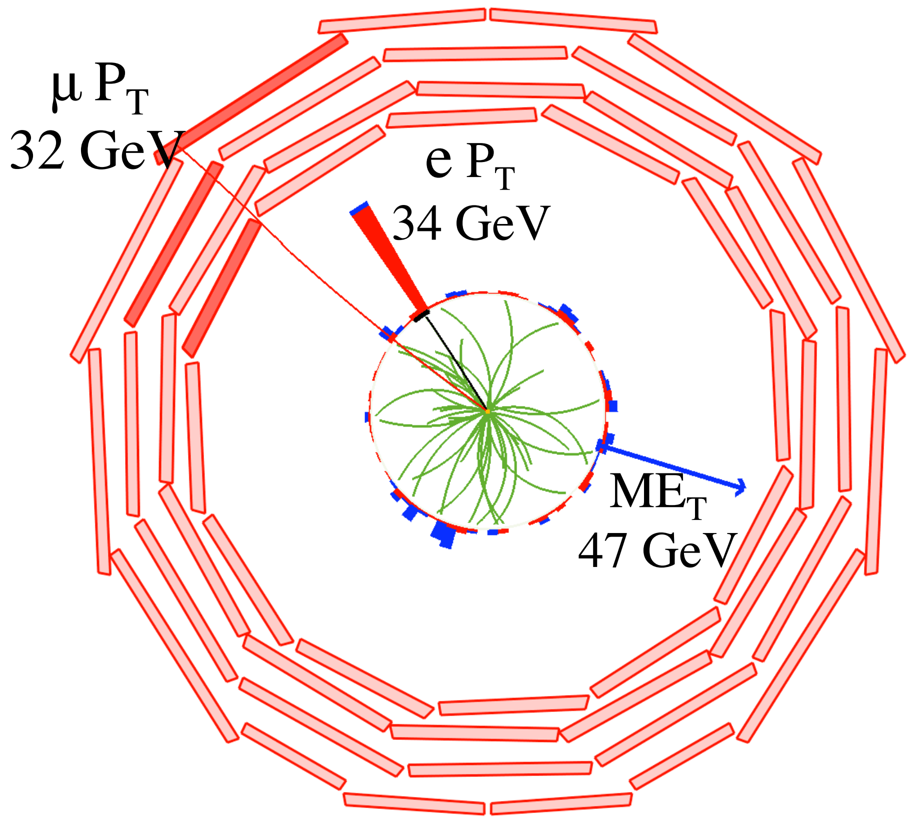
ATLAS EXPERIMENT

$H \to WW \to l\nu l\nu$



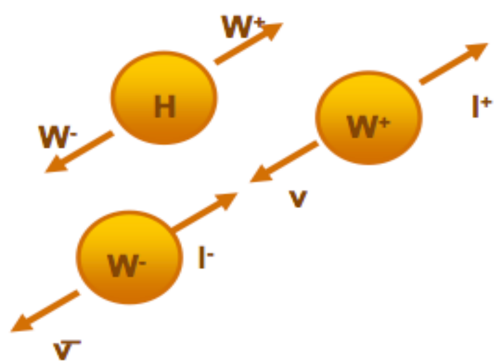
$H \to WW \to l\nu l\nu$ + 2 jets

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



- Channel with very high sensitivity
- No mass reconstruction, signal extraction from event counting
- Clean signature:
  - 2 isolated, high p_T leptons with small opening angle
  - High ME_T
  - Analysis performed on exclusive jet multiplicities (0, 1, 2-jet bins)
- Analysis optimized depending on the Higgs mass hypothesis
  - p_T^l, M_{ll}, M_T, $\Delta\phi$ as discriminating variables
  - VBF selections for the 2-jets case

Vectors from the decay of a scalar and V-A structure of W decay lead to small leptons opening angle (especially true for on-shell Ws)

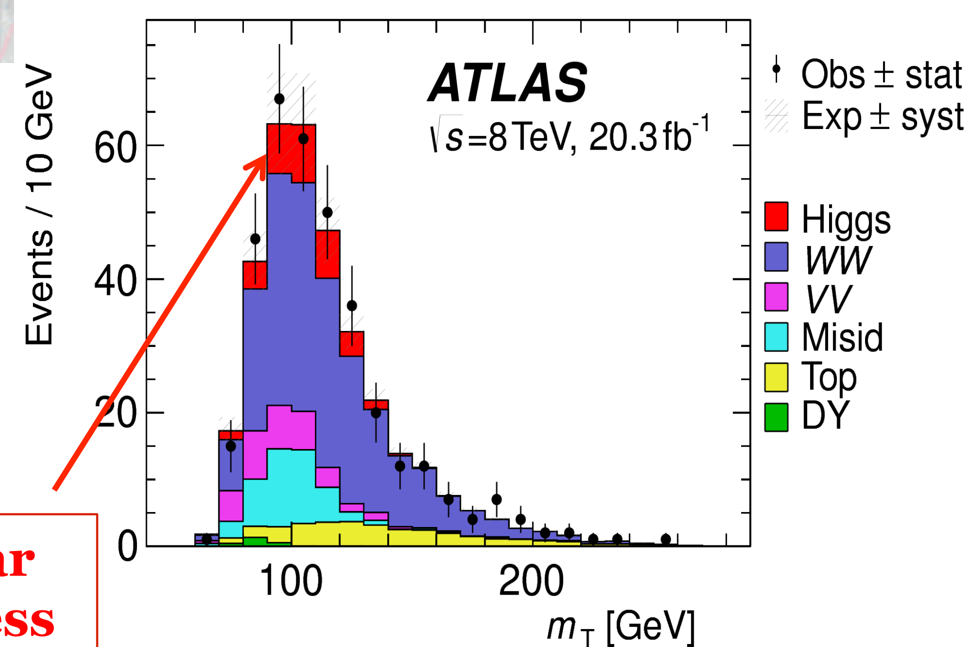


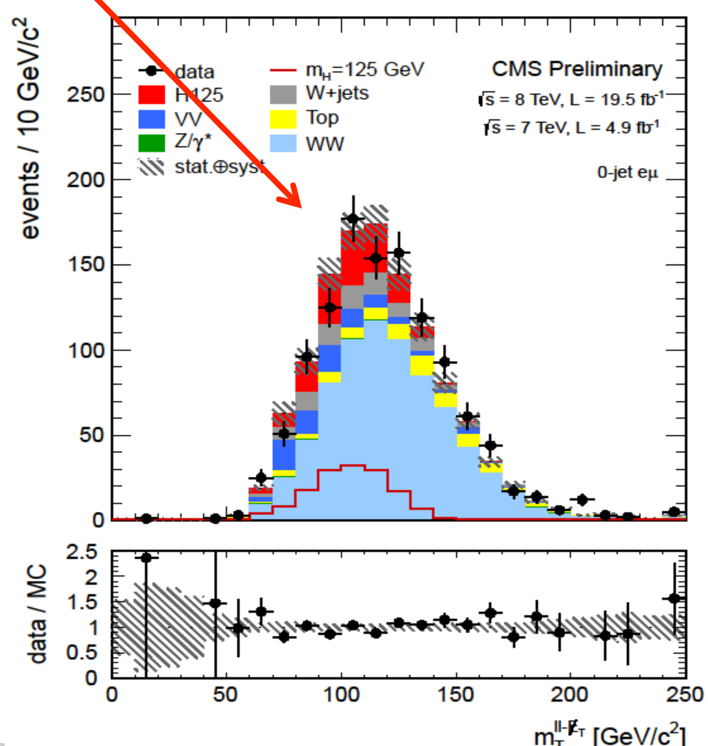
H →WW→lνlν

- **Drell –Yan:**
  Suppressed by M_{ll} and ME_T cuts (pileup affect MET)
- **W+jets (with one jet faking a lepton):**
  lepton ID is important
- **Top (tt and single top):**
  b-tag veto (or additional soft muon)
- **WW:**
  M(ll), MT and Δϕ

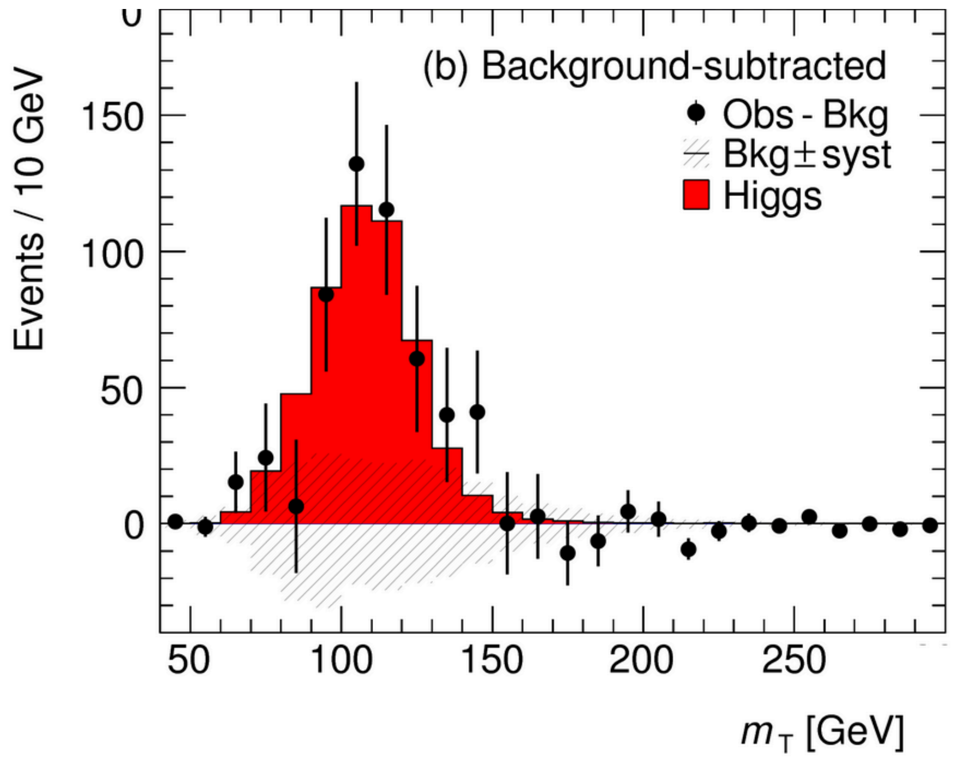
All the background are estimated from DATA in “control regions”

Clear excess





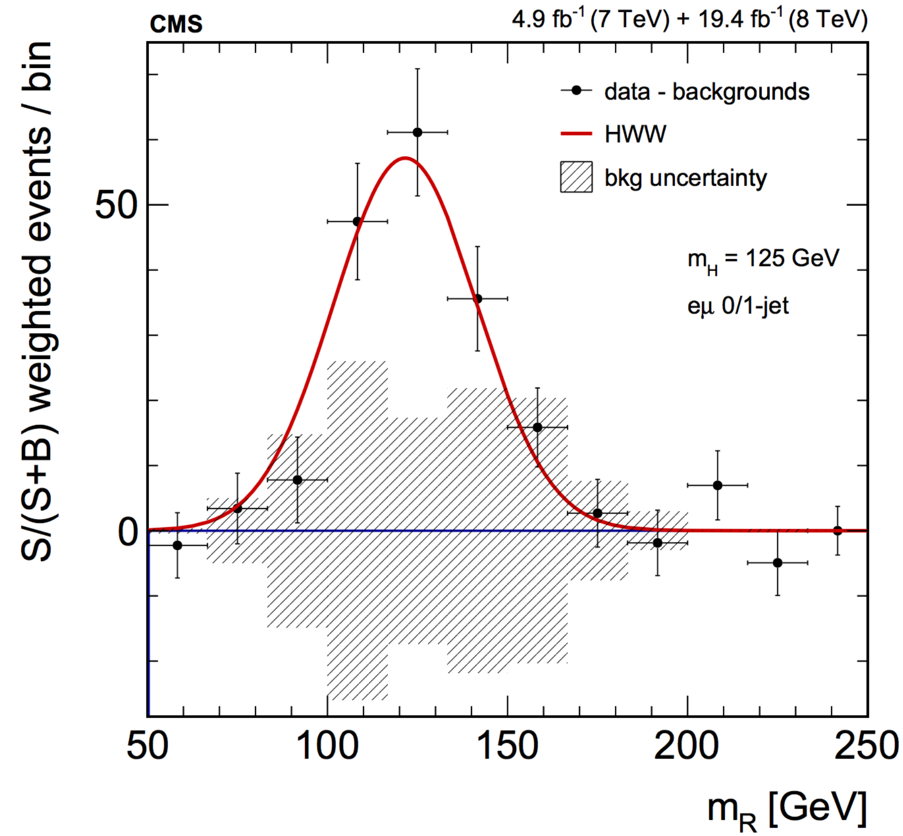
H →WW→2l2ν: Results



ATLAS: Broad excess consistent with 125 GeV

Significance(@125,36): 6.1 σ (5.8σ expected)

Fitted σ/σ_{SM} (@125.36)= 1.09 ± 0.23

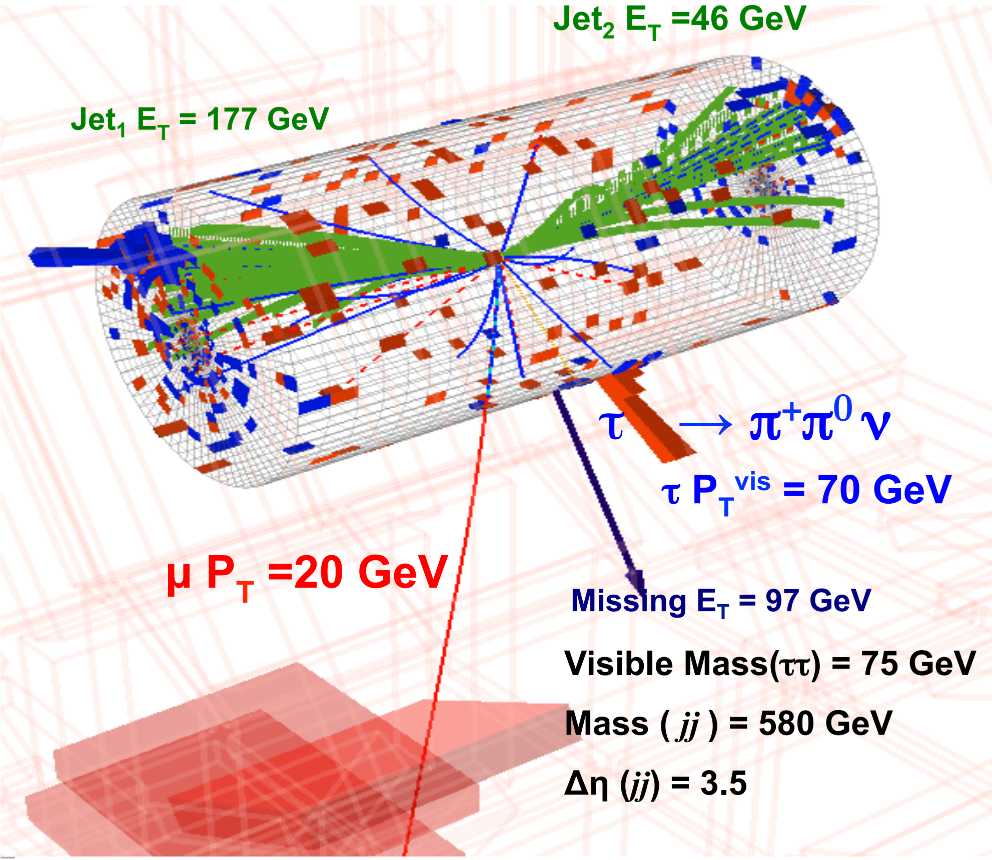


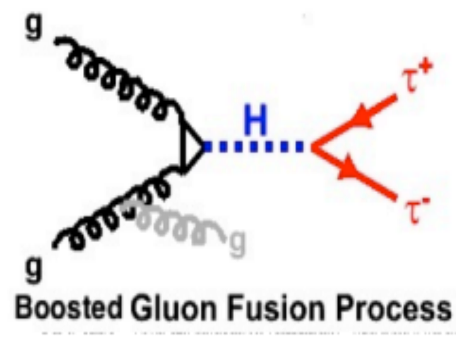
CMS: Broad excess consistent with 125 GeV

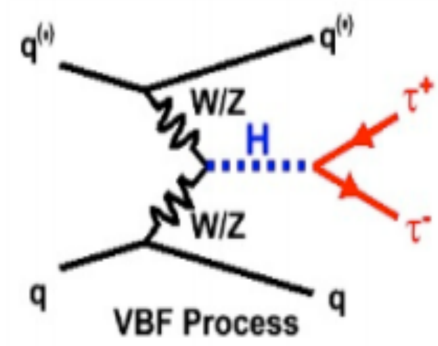
Significance: 4.0 σ (5.2 σ expected)

Fitted σ/σ_{SM} = 0.76 ± 0.21

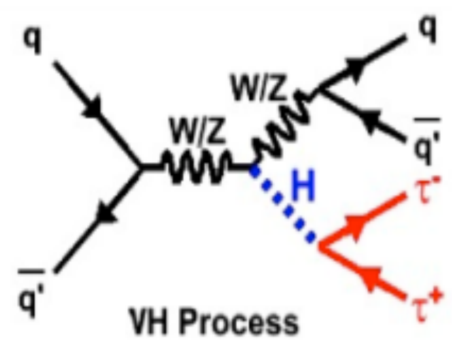
H → ττ







ggF, VBF production: $\mu\mu, e\mu, \tau_h\tau_h, e\tau, \mu\tau_h$



VH production: $l\tau_h\tau_h, ll\tau_h\tau_h, ll\tau_h$

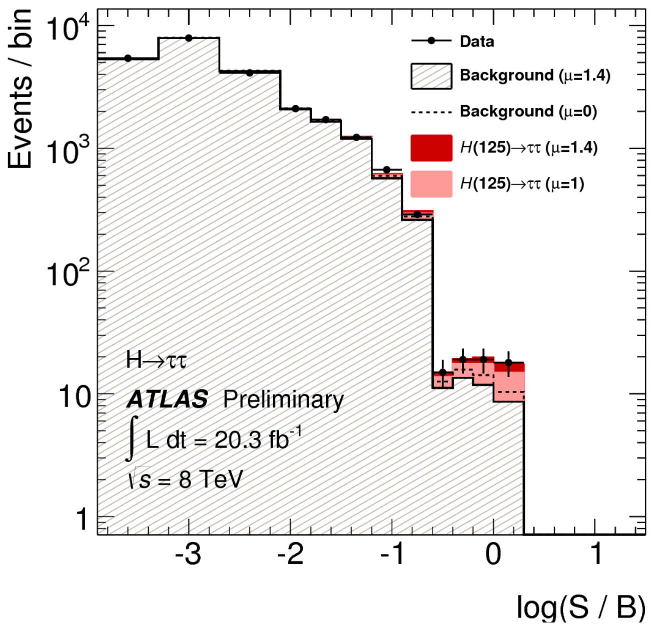
jet categories:

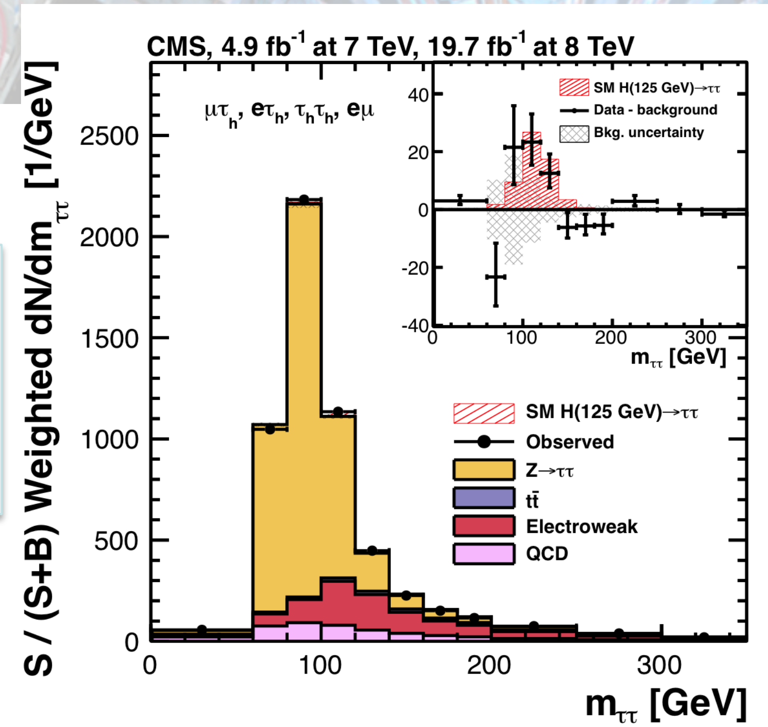
0-jet: used only to constrain the background

1-jet: low pT / high pT

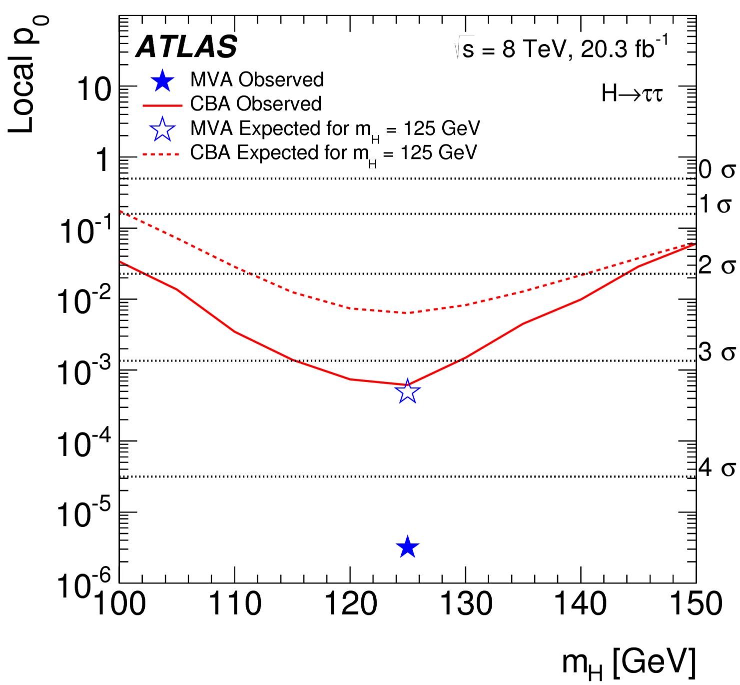
2-jets (VBF).

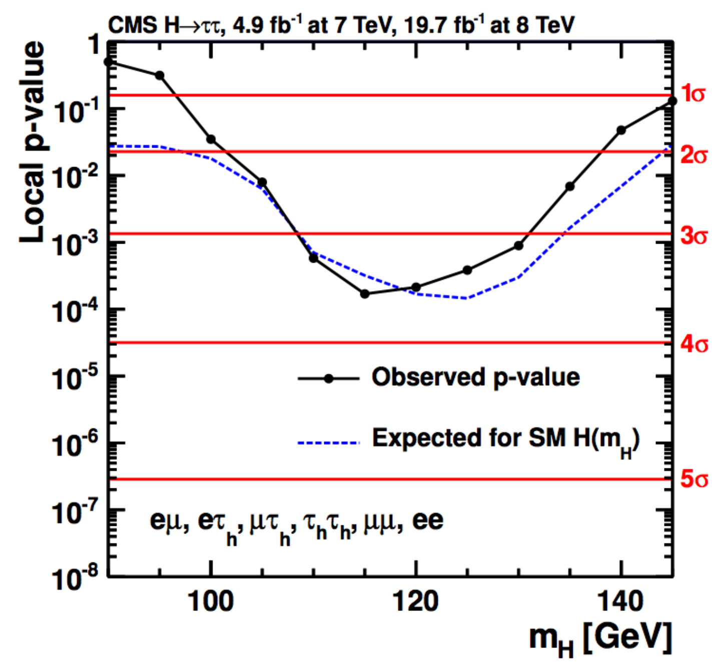
H → ττ



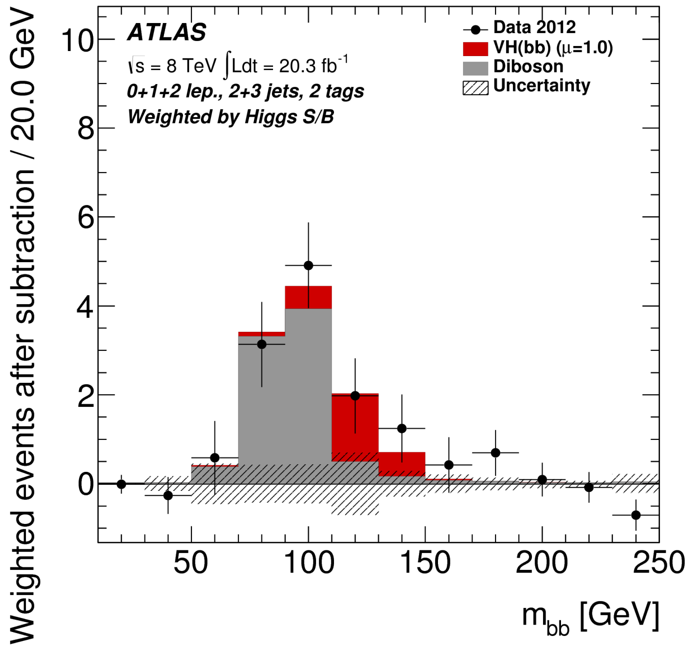


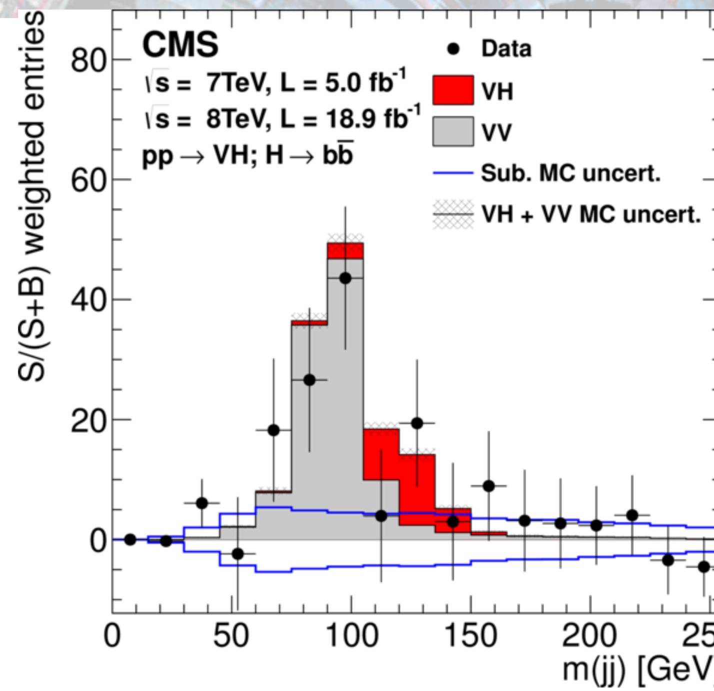
Combine the sensitive categories of all channels with a S/B weight



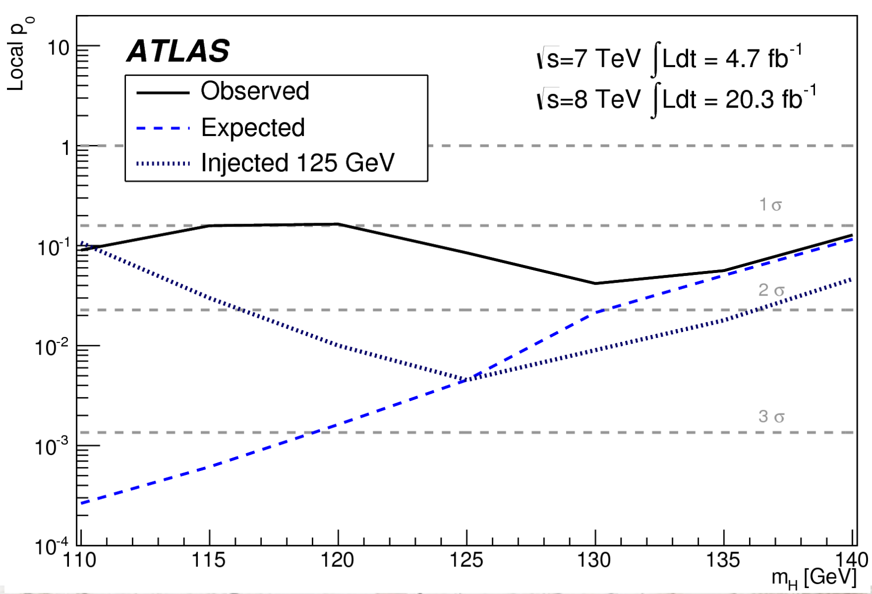


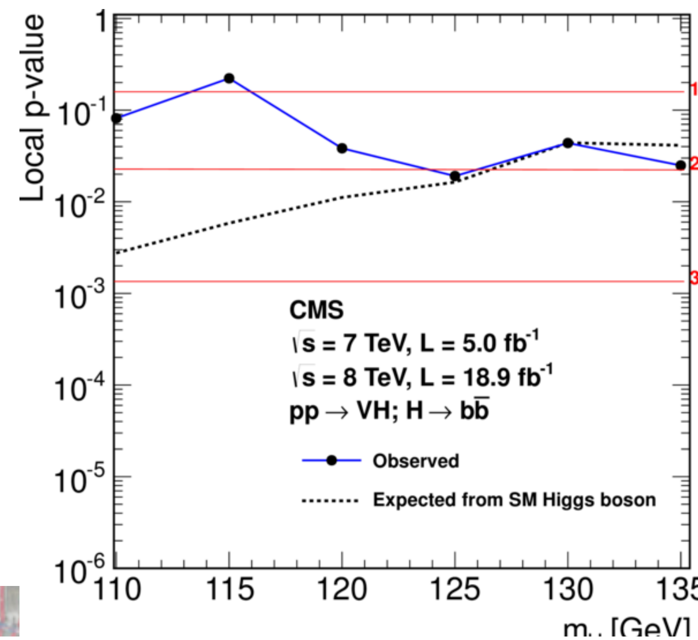
VH → bb results



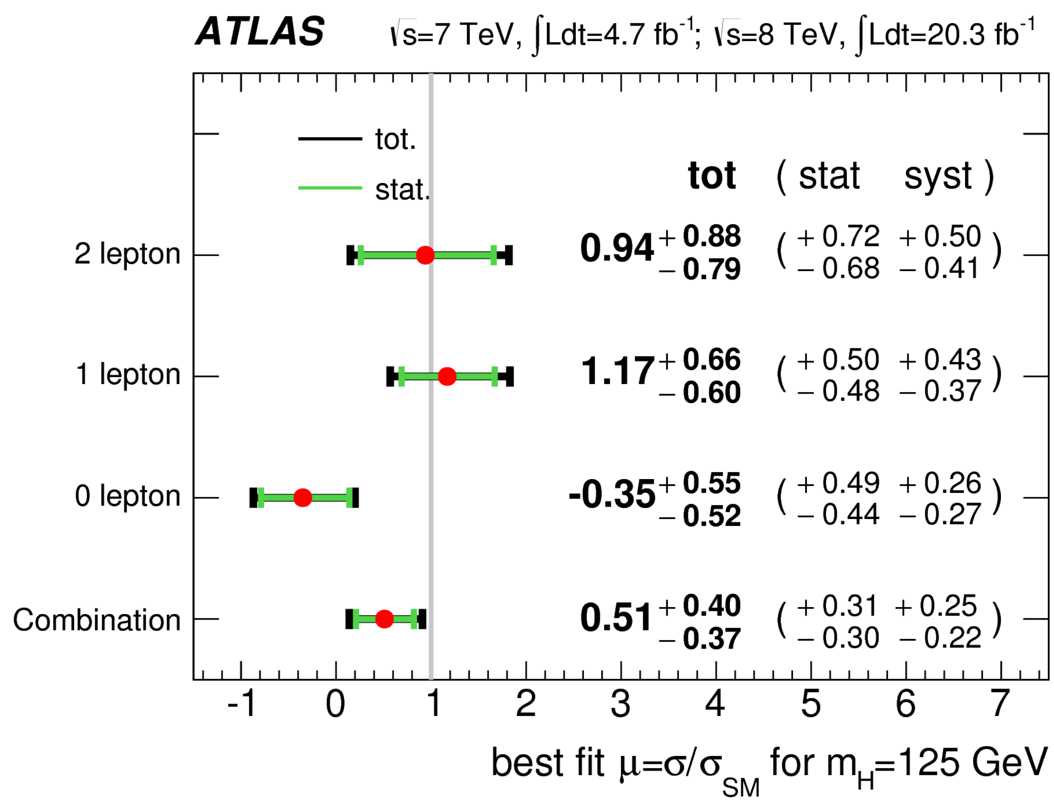


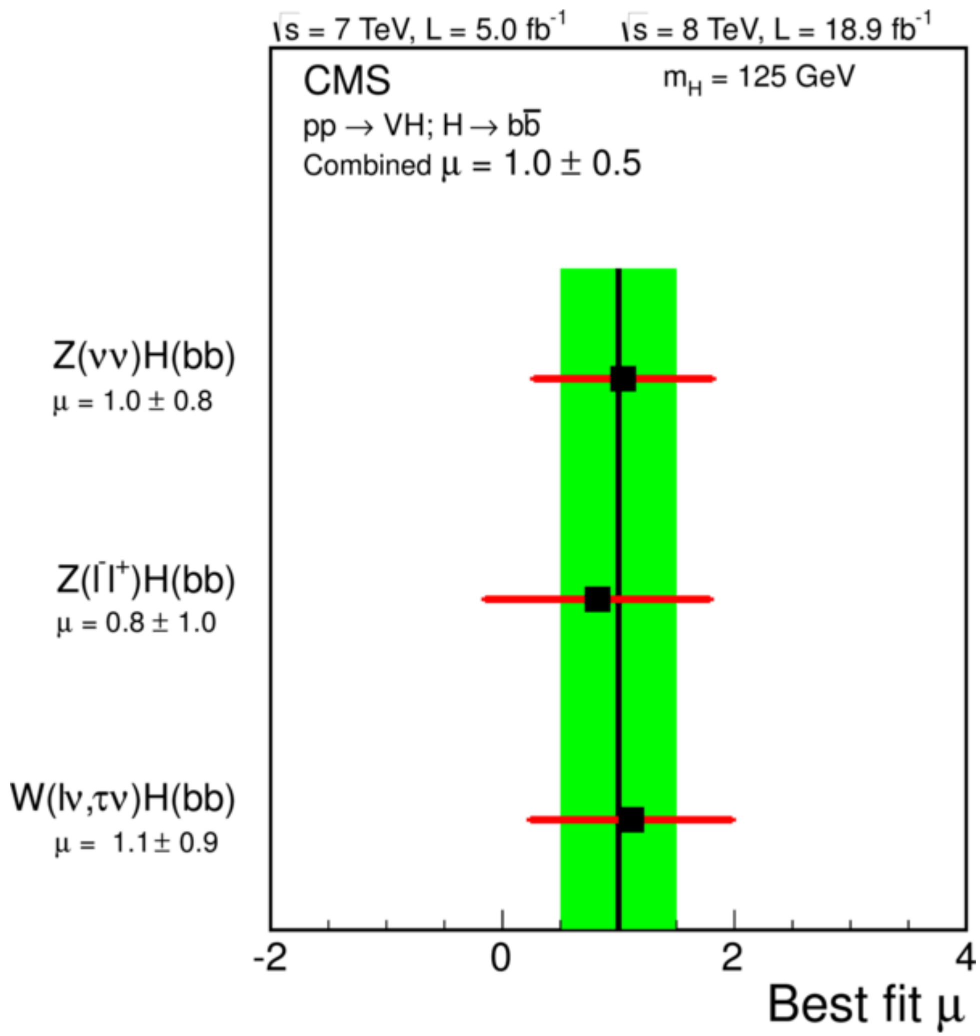
ATLAS : cut then look at *mbb* ; **CMS** : MVA (+cut based as cross check)





VH → bb results

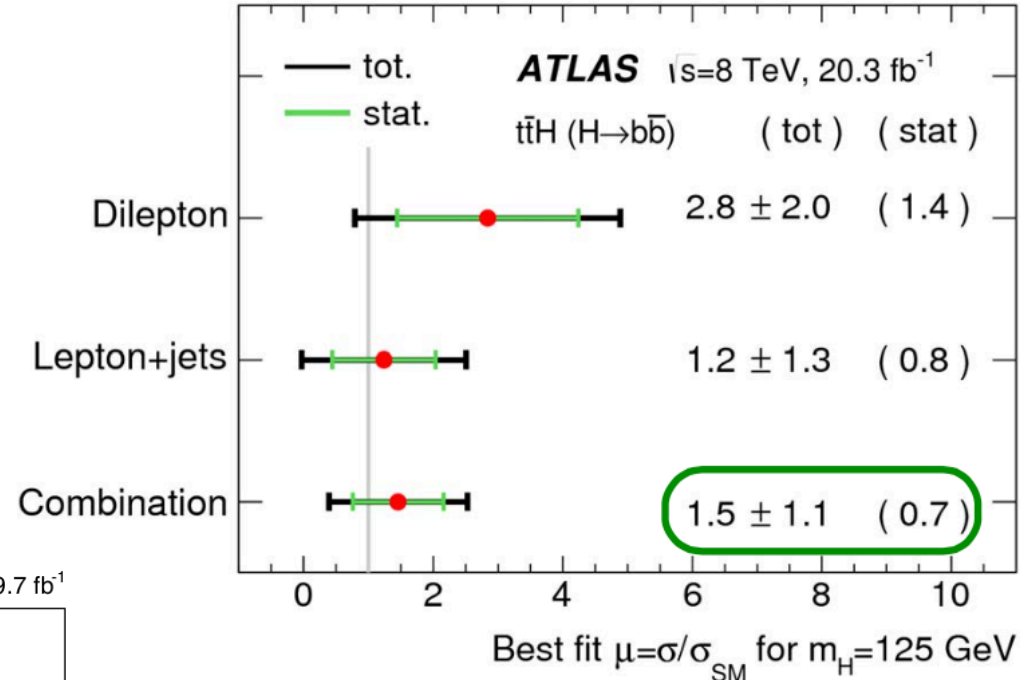




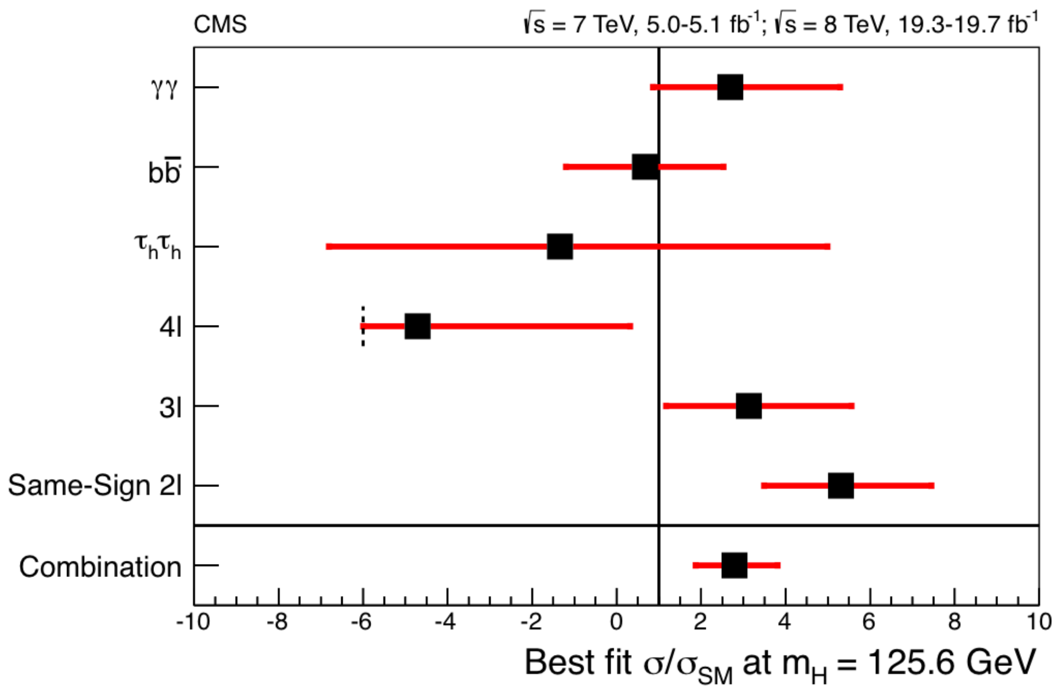
$\mu = 0.51\,^{+0.4}_{-0.37}$

$\mu = 1.0 \pm 0.5$

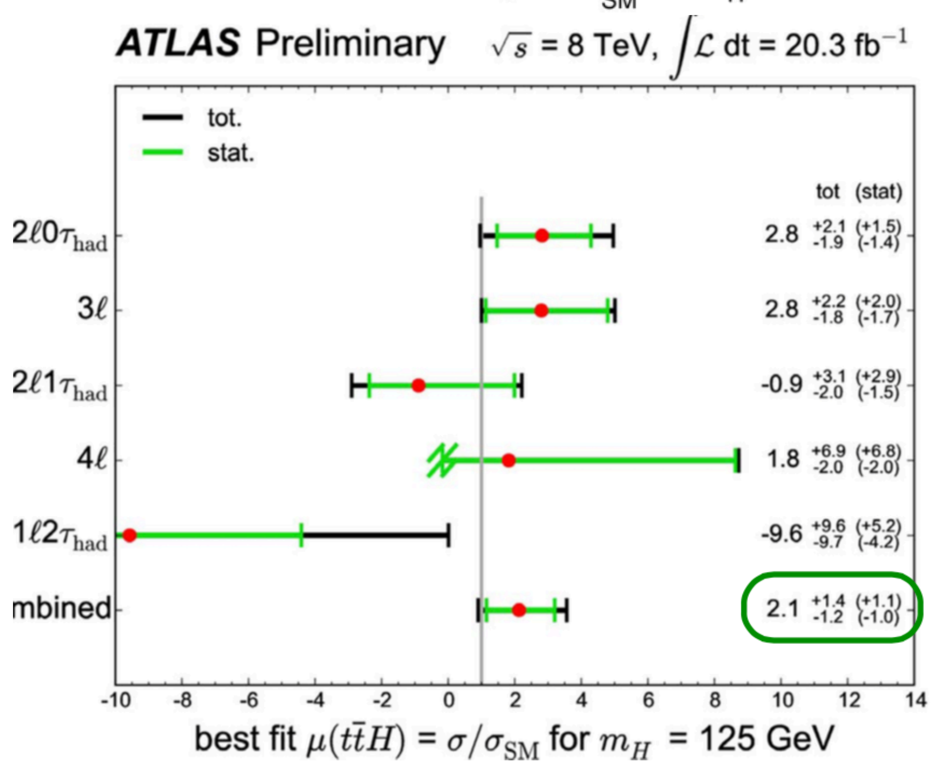
ttH, H→bb,γγ,ττ



tot.
stat.
ATLAS √s=8 TeV, 20.3 fb-1
tt̄H (H→bb̄) (tot) (stat)
Dilepton 2.8 ± 2.0 (1.4)
Lepton+jets 1.2 ± 1.3 (0.8)
Combination 1.5 ± 1.1 (0.7)
0 2 4 6 8 10
Best fit μ=σ/σSM for mH=125 GeV



CMS
√s = 7 TeV, 5.0-5.1 fb-1; √s = 8 TeV, 19.3-19.7 fb-1
γγ
bb̄
τhτh
4l
3l
Same-Sign 2l
Combination
-10 -8 -6 -4 -2 0 2 4 6 8 10
Best fit σ/σSM at mH = 125.6 GeV



ATLAS Preliminary √s = 8 TeV, ∫L dt = 20.3 fb-1
tot.
stat.
tot (stat)
2ℓ0τhad 2.8 +2.1 -1.9 (+1.5 -1.4)
3ℓ 2.8 +2.2 -1.8 (+2.0 -1.7)
2ℓ1τhad -0.9 +3.1 -2.0 (+2.9 -1.5)
4ℓ 1.8 +6.9 -2.0 (+6.8 -2.0)
1ℓ2τhad -9.6 +9.6 -9.7 (+5.2 -4.2)
mbined 2.1 +1.4 -1.2 (+1.1 -1.0)
-10 -8 -6 -4 -2 0 2 4 6 8 10 12 14
best fit μ(tt̄H) = σ/σSM for mH = 125 GeV

The mass

The mass is the most important property of the particle. Given the mass all the rest is precisely predicted by the SM.

The mass can be measured with very high precision from the $H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ decay, since photons and electrons are known with high accuracy.

Or can be inferred from the measured cross-section, assuming the SM, and thus using the theory predictions known at NNLL.

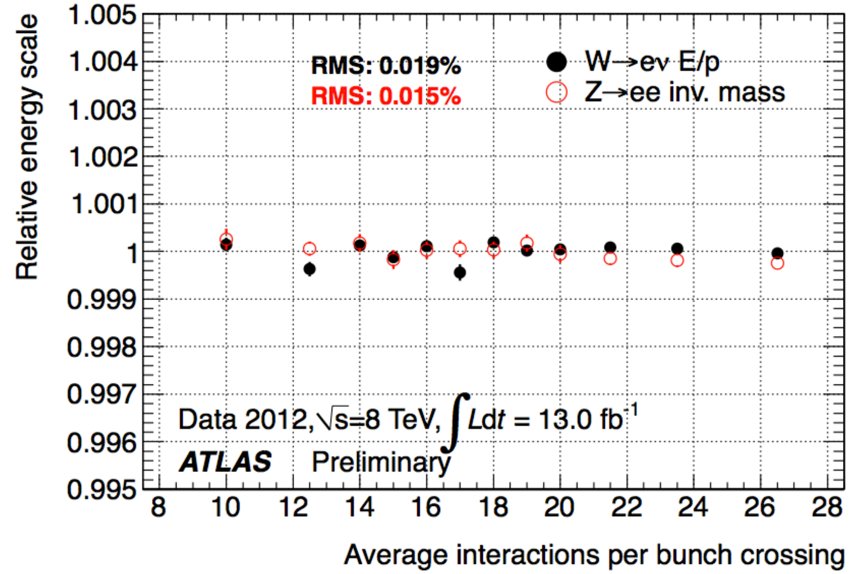
Mass from H→γγ in ATLAS

- Mass of the Higgs boson can be reconstructed:

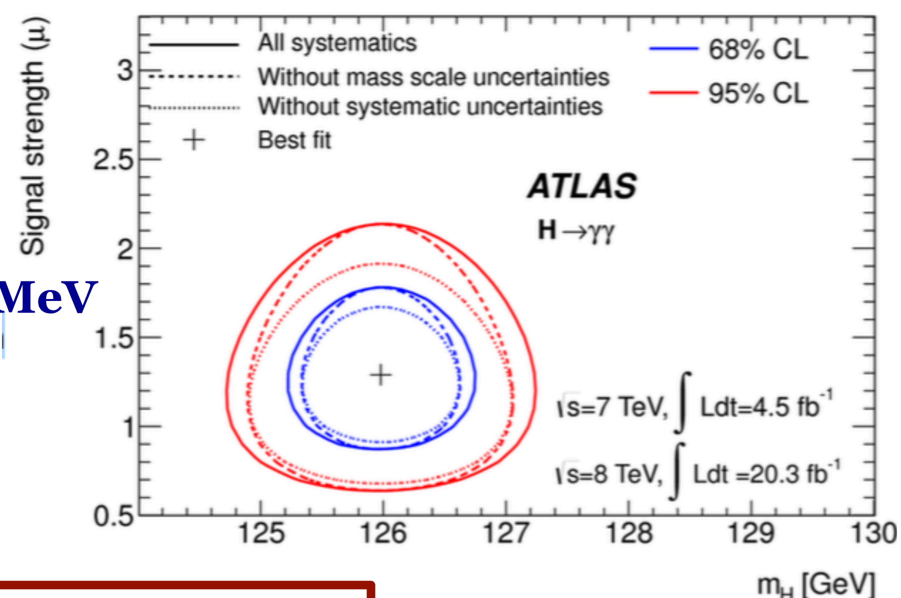
$$m^2_{\gamma\gamma} = 2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{12})$$

- **Choice of the primary vertex:**
  - **likelihood discriminant** combining:
  - calorimeter pointing, photon conversion, track recoil

- **Energy calibration:**
  - from **Z → ee** data and **extrapolation e→γ**
  - require **excellent material budget** knowledge
  - very good **stability** with **pile-up**



- **Systematic uncertainties:**
  - **Material in front of ECAL ~150 MeV**
  - **Non-linearity ~140 MeV**
  - **Longitudinal calibrations ~120 MeV**
  - **Modeling e/γ lateral shower shape ~90 MeV**
  - **Conversion classification ~50 MeV**
  - **Z->ee calibrations ~50 MeV**
  - **Background modeling ~40MeV**



m_H=125.98±0.42(stat)±0.28(sys) GeV

Mass from H→γγ in CMS

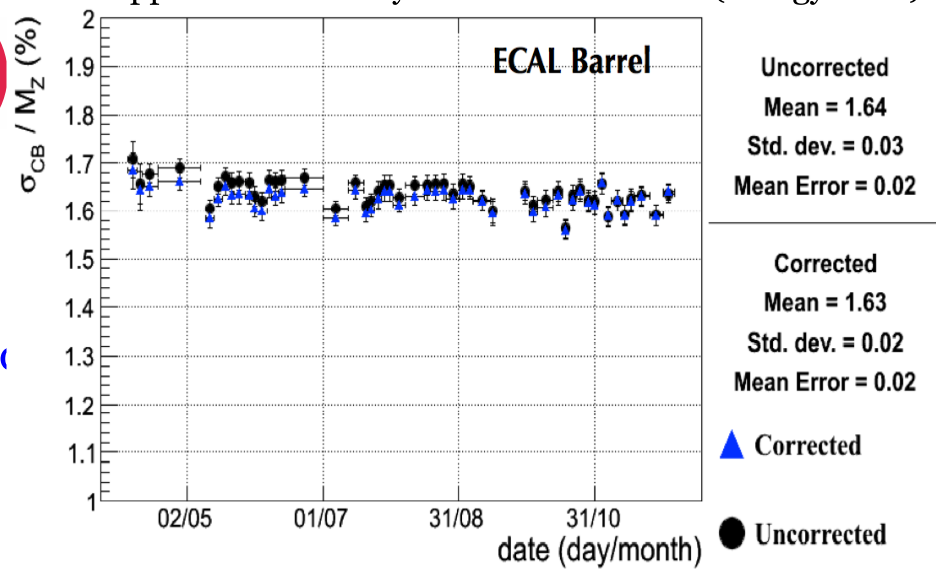
- Mass of the Higgs boson can be reconstructed :

$$m_{\gamma\gamma}^2 = 2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{12})$$

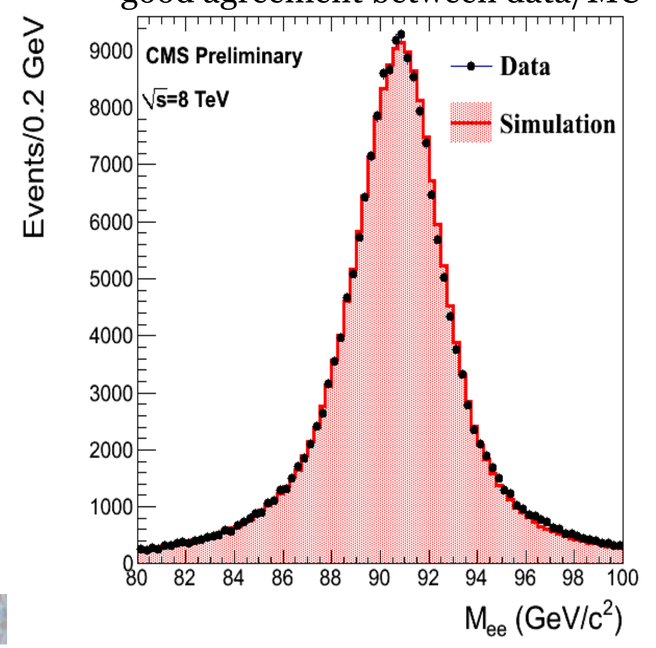
- **Choice of the primary vertex:**
  - **BDT** using $\sum p_T^2$,vertex recoil with respect to the di-photon system.
  - check with **Z→μμ** (unconv.) and **γ+jet** (converted)
- **Energy calibration:**
  - energy **regression correction** using **BDT** (energy density, shower shapes, cluster position)
  - monitor with **Z→ee**
- **Systematics uncertainties:**
  - **Electron – photon differences ~100 MeV**
  - **Linearity of the energy scale ~100 MeV**
  - **Scale/Res uncertainties propagating Z->ee calibration systematics ~50 MeV**
  - **All other uncertainties, (eff, ID etc) ~40 MeV**

m_H=124.70±0.31(stat)±0.15(sys) GeV

Z mass **resolution** as a function of time after application of analysis level corrections (energy scale)

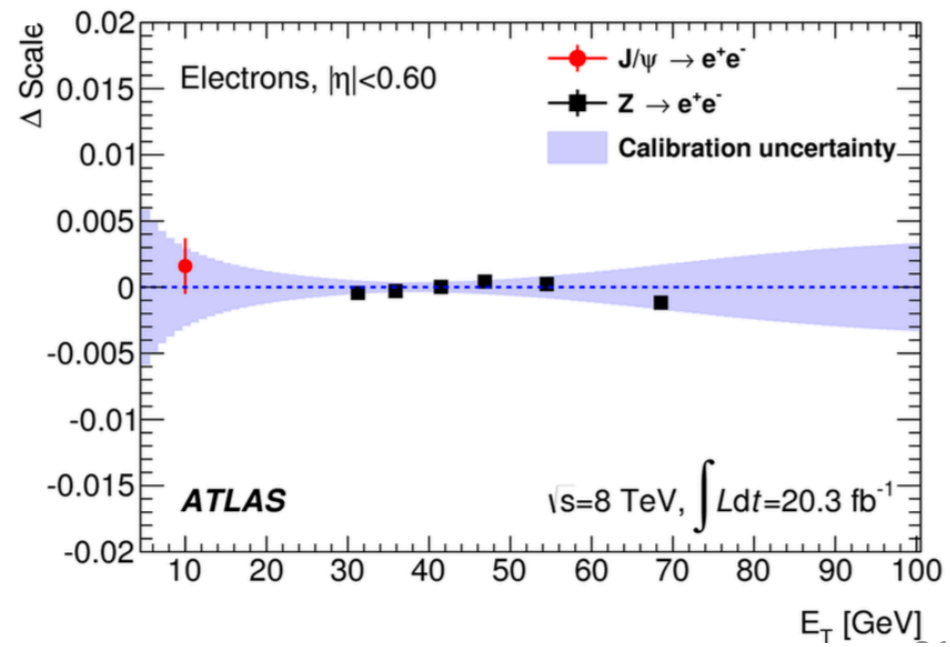


Z→ee lineshape: good agreement between data/MC



Mass from H→4l in ATLAS

- Excellent energy/momentum scale and resolution
  - **validation** with **Z**, **Y** and **J/ψ** (→2l)
  - single-resonant **Z →4l** for **validation**

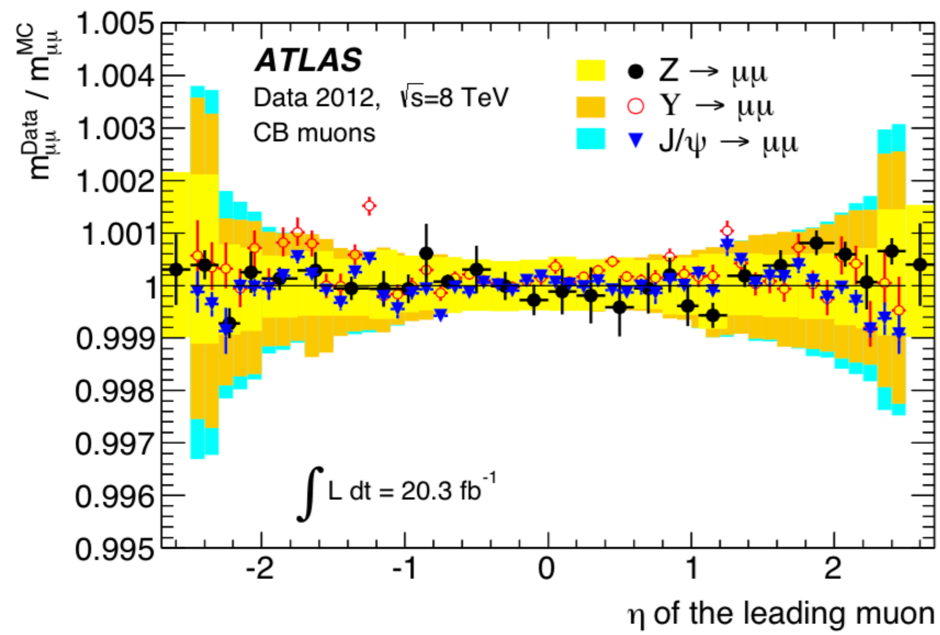


- Systematic uncertainties :

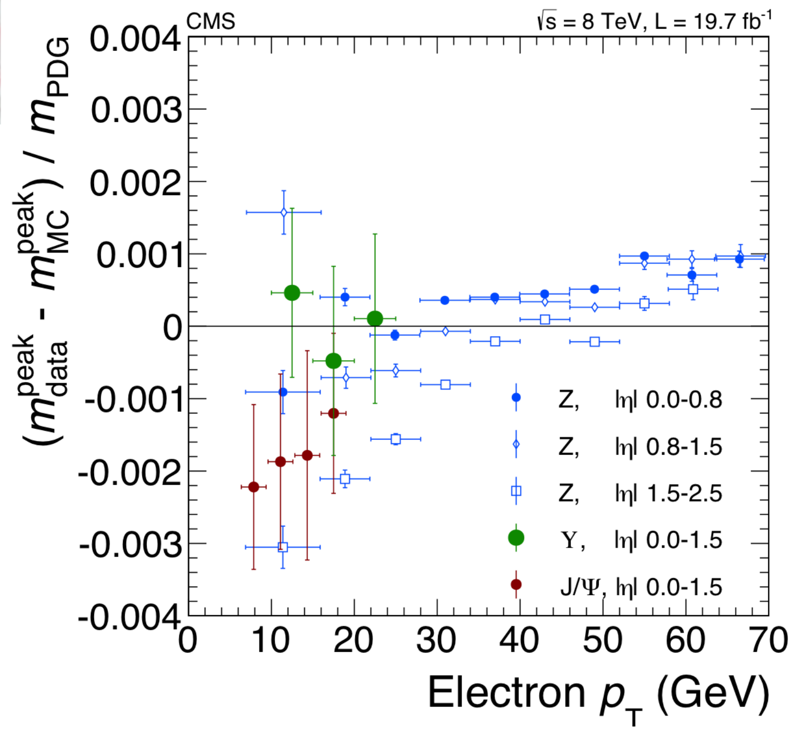
  - Lepton calibration uncertainties propagated to 4l invariant mass. 0.01/0.03% from e/μ – scale

  - Additional systematics from ID+reco efficiency for μ/e on the rate (~2%)

  - Mass measurement uncertainty 2 ~ purely statistical due to very high precision of the e/μ calibrations

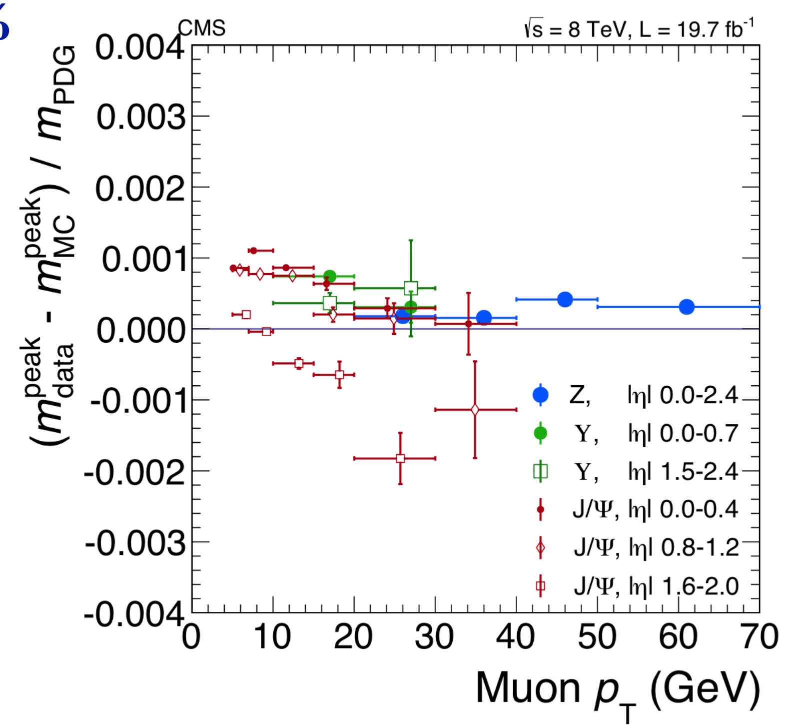


Mass from H→4l in CMS



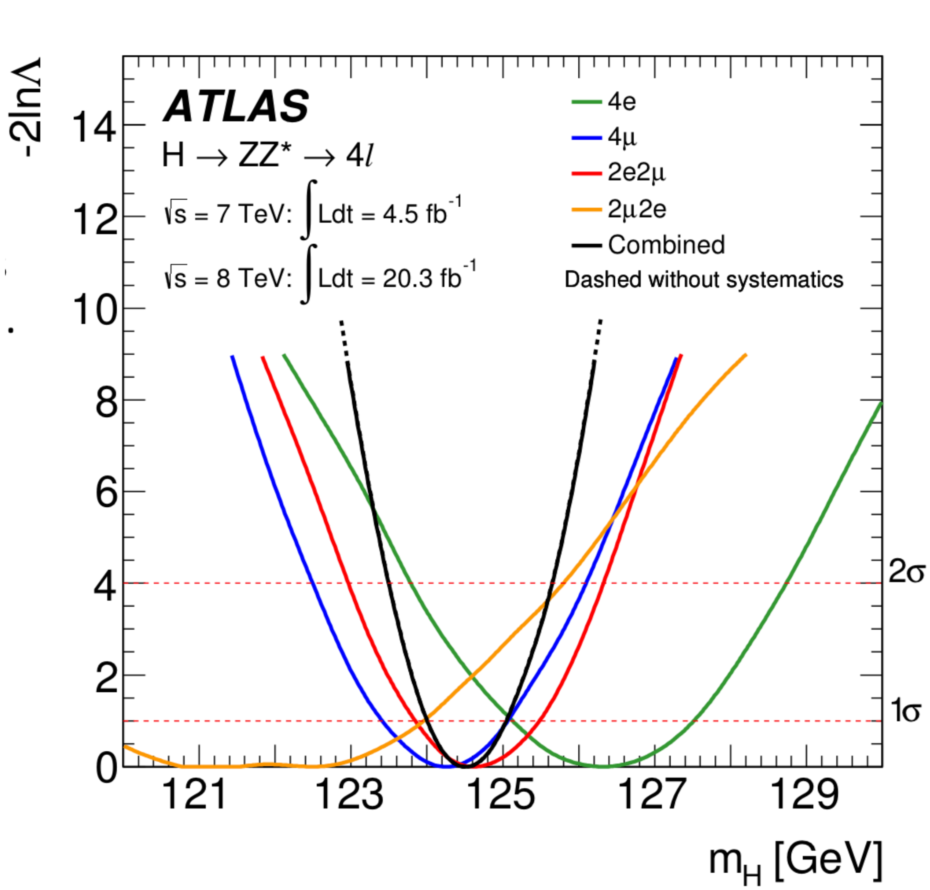
- Excellent energy/momentum scale and resolution
  - EM energy derived by **regression (BDT)**
  - **validation** with **Z, Υ** and **J/ψ** (→2l)
  - single-resonant **Z →4l** for **validation**

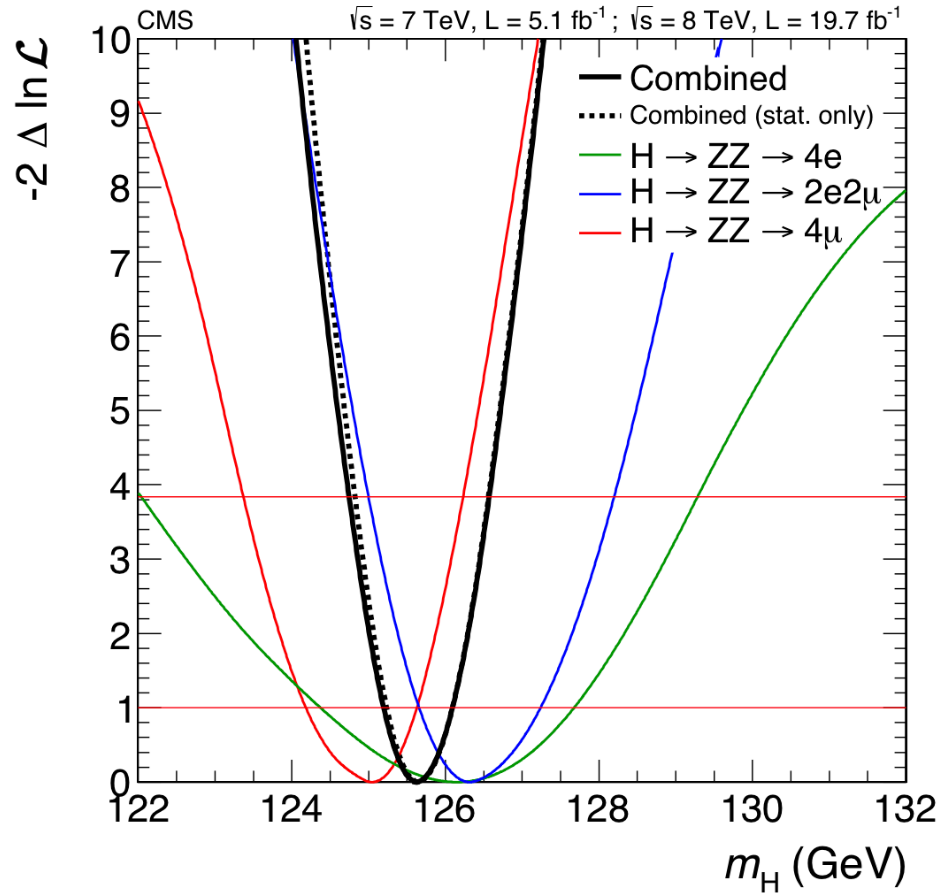
- Systematic uncertainties :
  - **Muon momentum scale uncertainty: ± 0.1%**
  - **Electron energy uncertainty: ± 0.3%**



- Mass measurement performed with a **3D** fit using
  - four-lepton invariant mass **m_{4l}**
  - associated per-event mass uncertainty **δm_{4l}**
  - kinematic discriminant **KD**

4l: Comparison between ATLAS and CMS





m_H = 124.51±0.52 (stat)±0.06 (syst) GeV

- high p_T cuts
- more stricter cuts on m_{12} and m_{34}
- Z mass constrain

m_H = 125.59±0.42 (stat)±0.17 (syst) GeV

- event by event error
- kinematic discriminant
- 3D fits

Likelihood Model

Higgs mass, determined by maximizing profile-likelihood ratio from combined dataset with respect to **all** the parameters of the model…

$$\Lambda(m_H) = \frac{L\left(m_H\,,\ \hat{\hat{\mu}}^{\gamma\gamma}_{ggF+t\bar{t}H}(m_H)\,,\ \hat{\hat{\mu}}^{\gamma\gamma}_{VBF+VH}(m_H)\,,\ \hat{\hat{\mu}}^{4\ell}(m_H)\,,\ \hat{\hat{\theta}}(m_H)\right)}{L\left(\hat{m}_H, \hat{\mu}^{\gamma\gamma}_{ggF+t\bar{t}H}, \hat{\mu}^{\gamma\gamma}_{VBF+VH}, \hat{\mu}^{4\ell}, \hat{\theta}\right)}$$

$\mu_X = \sigma_X / \sigma_{SM}$

3 signal modifiers (3μ) to vary independently the **yields** of

- ggF (+ttH) production + diphoton decay
- VBF (+VH) production + diphoton decay
- ZZ→4l

Reduces the model dependence of the measurement!

Nick Wardle

Likelihood Model

Higgs mass, determined by maximizing profile-likelihood ratio from combined dataset with respect to **all** the parameters of the model…

$$\Lambda(m_H) = \frac{L(m_H\,,\,\hat{\hat{\mu}}^{\gamma\gamma}_{ggF+t\bar{t}H}(m_H)\,,\hat{\hat{\mu}}^{\gamma\gamma}_{\mathrm{VBF}+VH}(m_H)\,,\,\hat{\hat{\mu}}^{4\ell}(m_H)\,,\,\hat{\hat{\theta}}(m_H))}{L(\hat{m}_H,\hat{\mu}^{\gamma\gamma}_{ggF+t\bar{t}H}\,,\hat{\mu}^{\gamma\gamma}_{\mathrm{VBF}+VH},\hat{\mu}^{4\ell},\hat{\theta})}$$

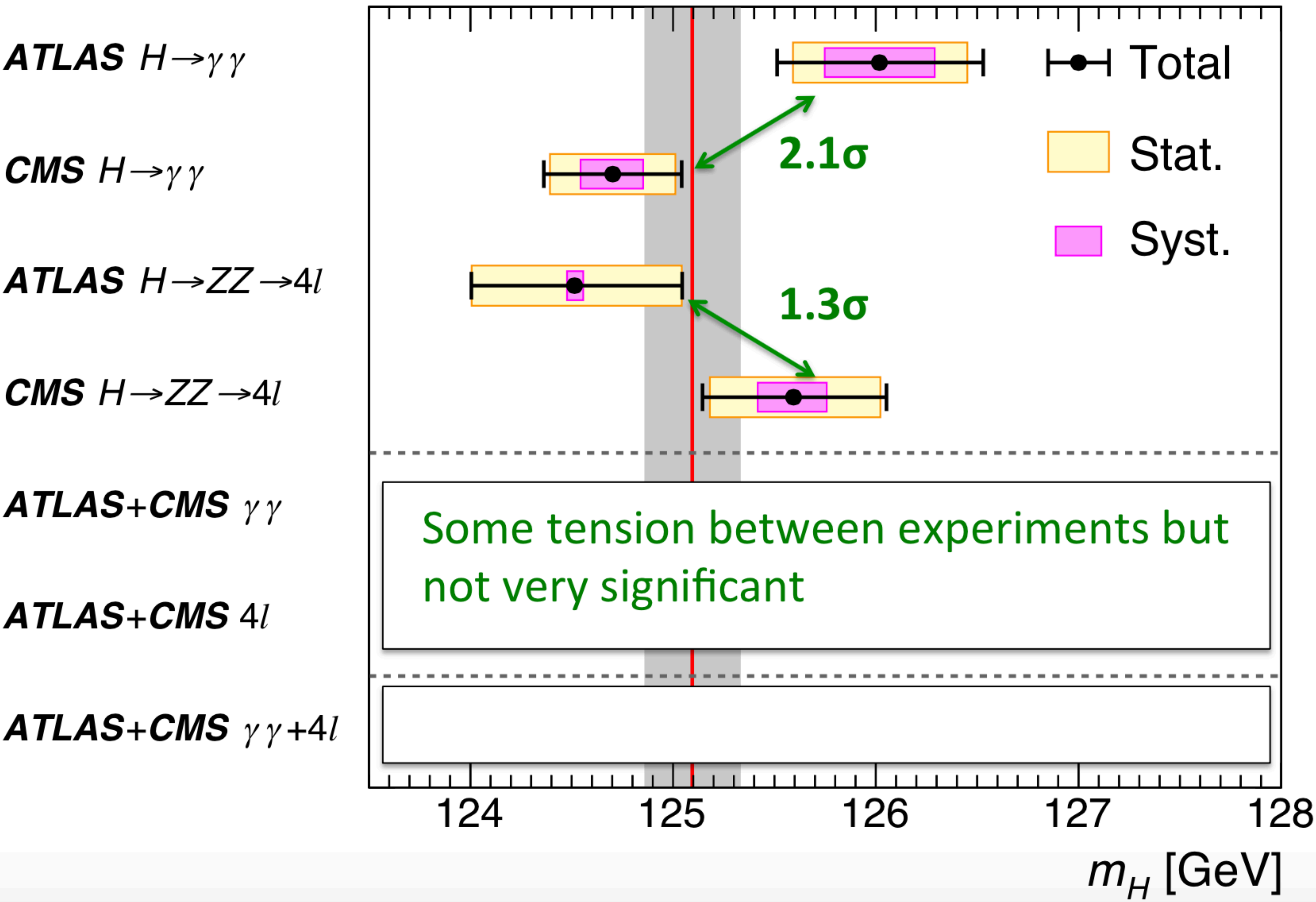
$\mu_X = \sigma_X/\sigma_{SM}$

Systematics modeled as nuisance parameters ~300 in total:

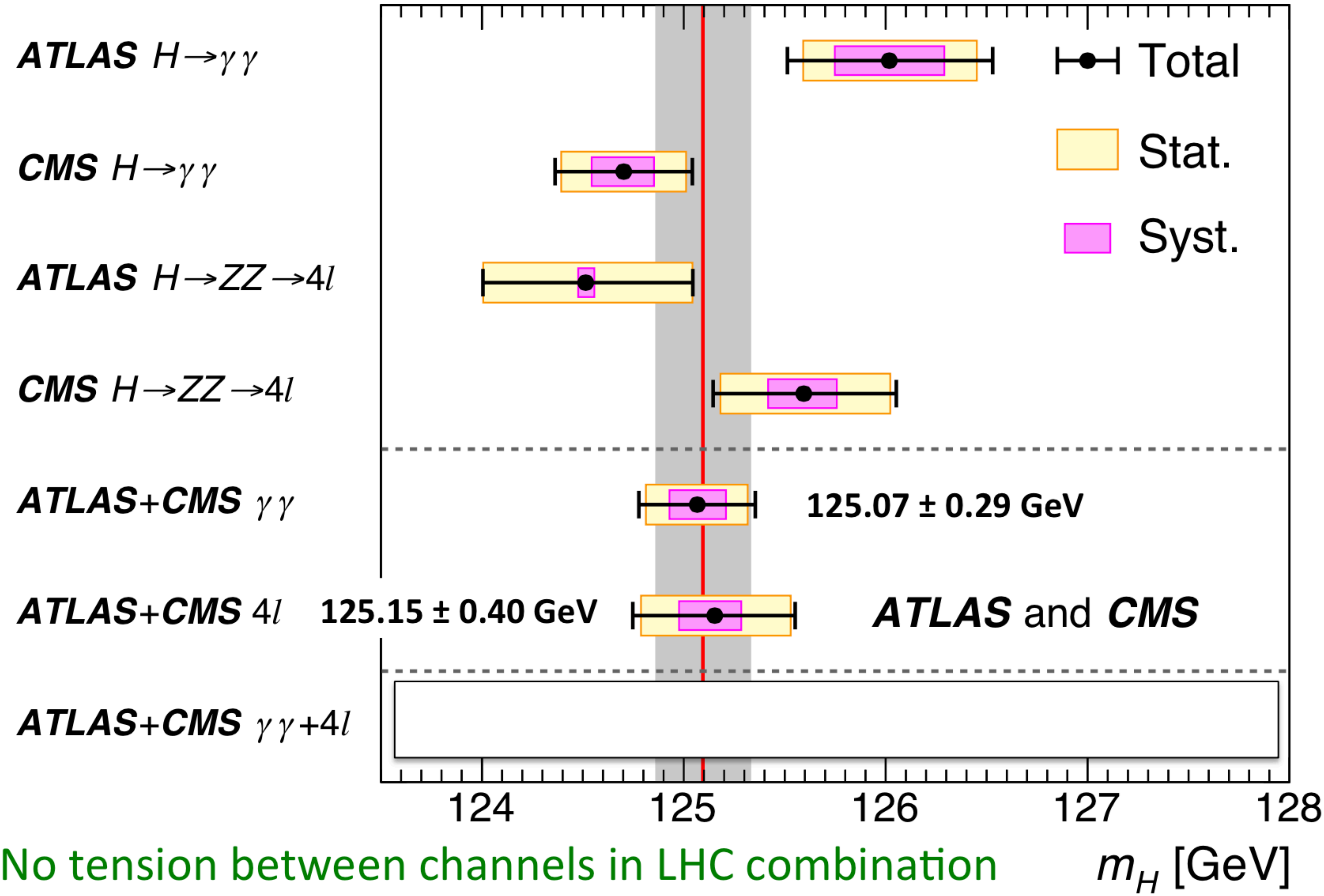
- 100 for shape parameters and normalization in H→γγ Background model (unconstrained)
- Most of the remaining ones correspond to experimental or theory (constrained)

68.3% interval (uncertainty) from $-2\log\Lambda(m_H) \leq 1$

Nick Wardle

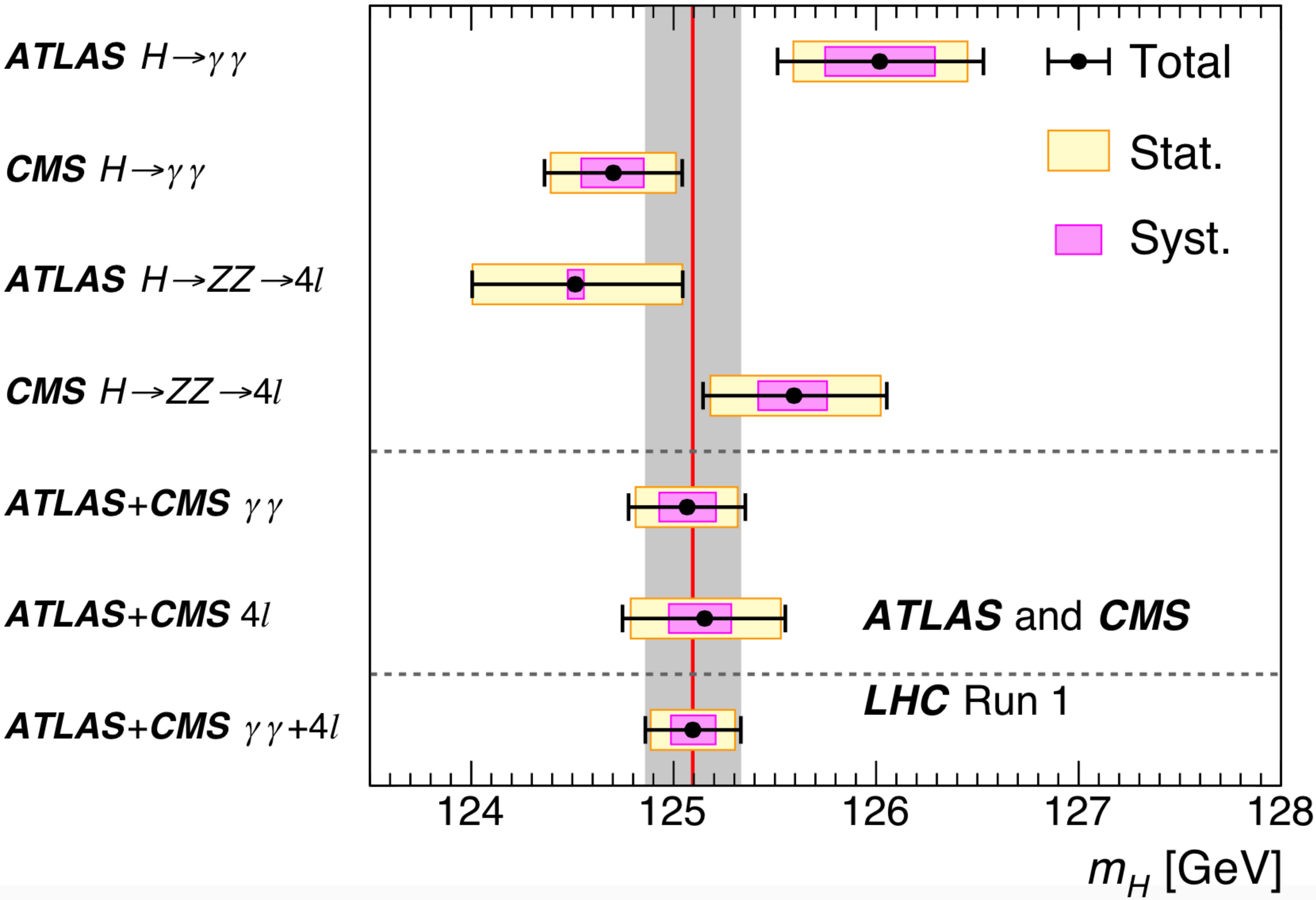


ATLAS H→γγ
CMS H→γγ
ATLAS H→ZZ→4l
CMS H→ZZ→4l
ATLAS+CMS γγ
ATLAS+CMS 4l
ATLAS+CMS γγ+4l
Total
Stat.
Syst.
2.1σ
1.3σ
Some tension between experiments but not very significant
124
125
126
127
128
m_H [GeV]

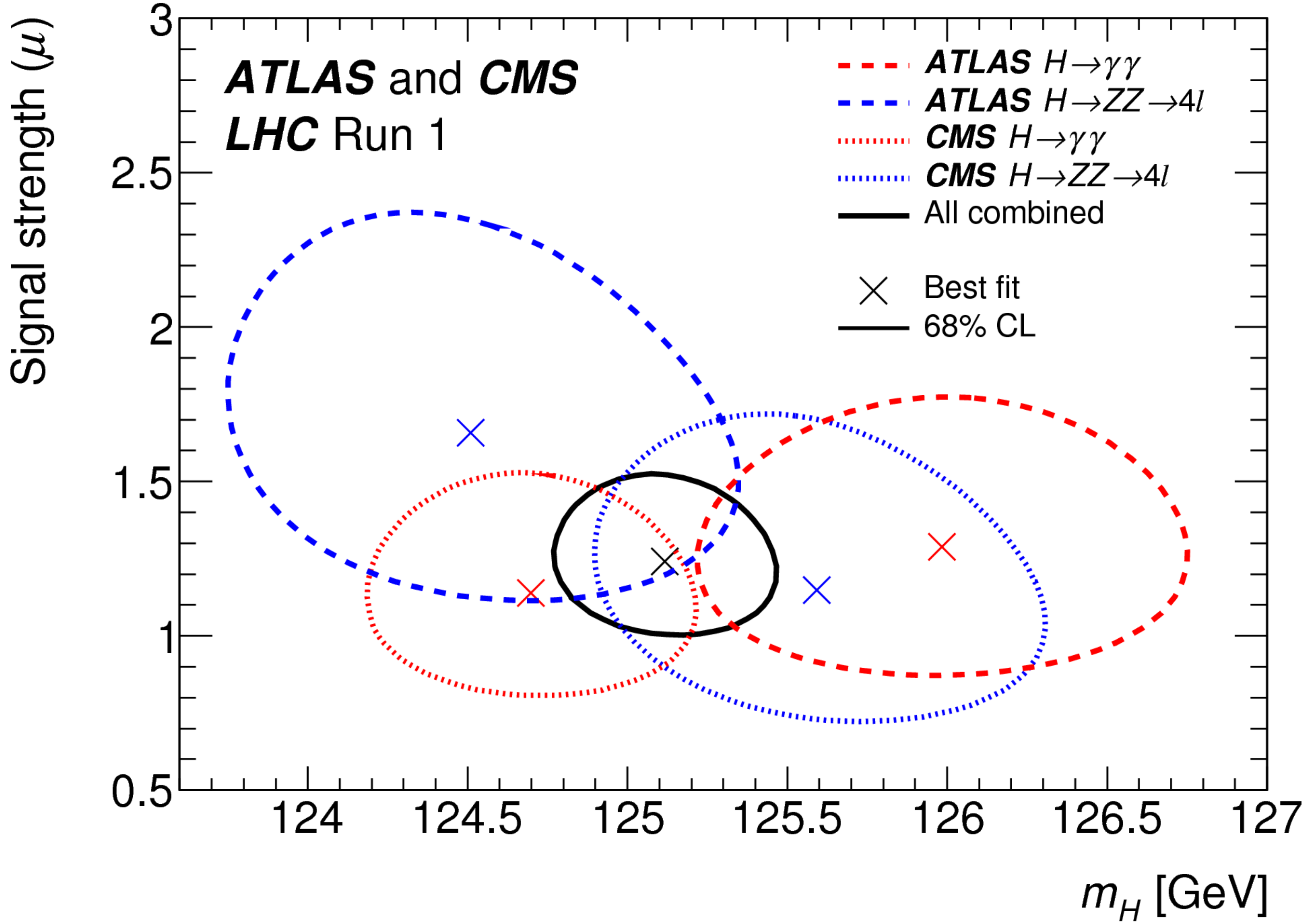


No tension between channels in LHC combination

$$m_H = 125.09 \pm 0.24\ (\pm 0.21\ \text{stat} \pm 0.11\ \text{syst})\ \text{GeV}$$



The Mass



signal **strengths**, $\mu_{\gamma\gamma}$ and μ_{4l}, allowed to vary **independently**
don't assume **SM couplings**

The result

Systematic contribution are evaluated sequentially "freezing" nuisance parameter groups to their best values and re-scanning the likelihood ratio

$$m_H = 125.09 \pm 0.21 \text{ (stat)} \pm 0.11 \text{ (scales)} \pm 0.02 \text{ (others)} \pm 0.01 \text{ (theory) GeV}$$

< 0.2 % precision

Uncertainty is mostly statistical

E/p scale uncertainties dominate the systematic

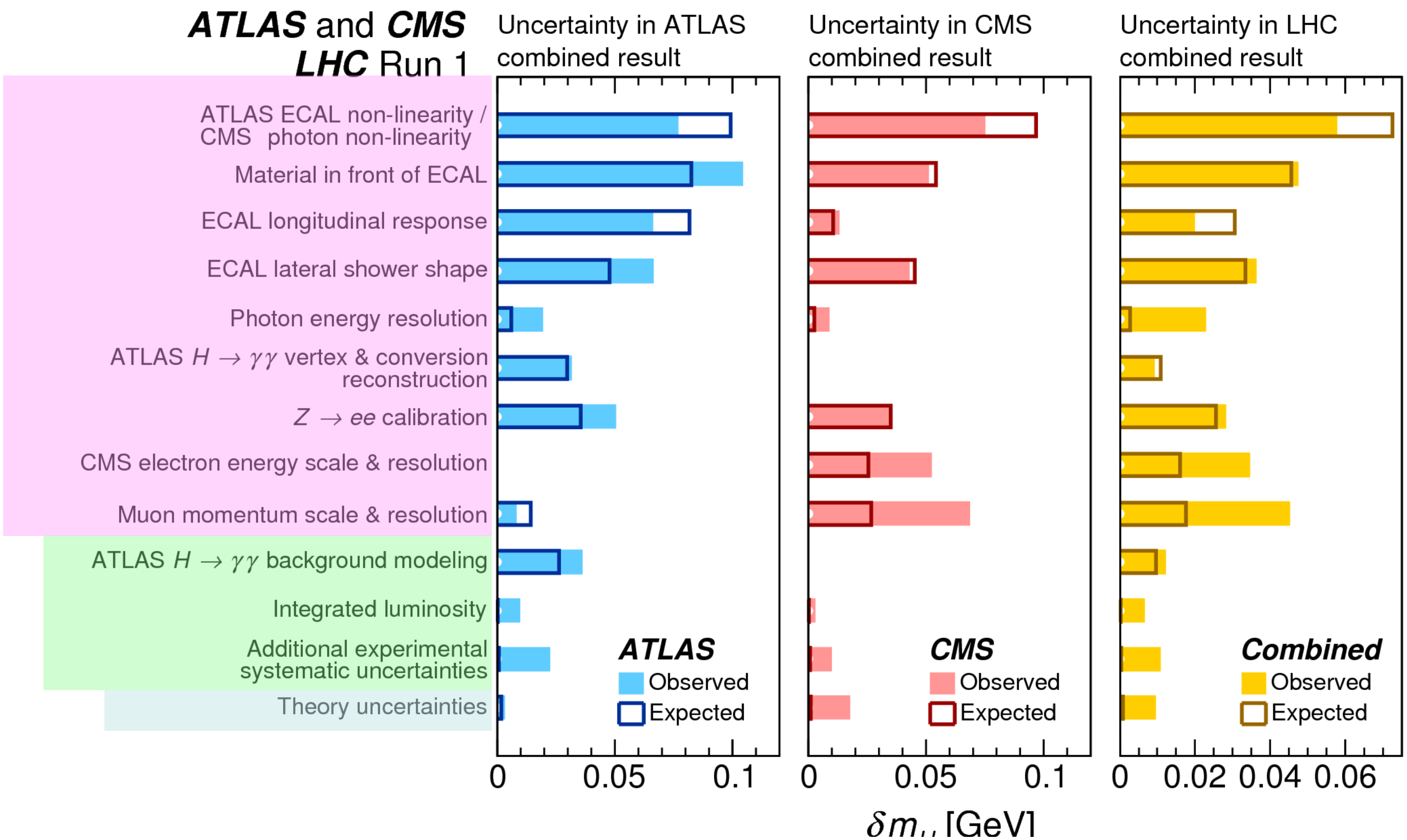
Theory uncertainties does not include interference

Systematic uncertainties

Energy/momentum scale of μ, e and γ dominate the systematic uncertainty

Backgroun, jet energy scale and luminosity (partially correlated between exp.)

Theory unceertainty (QCD scale, PDF, BR) -100% correlated between exp.



The Higgs width: Γ_H

Very narrow resonance at low mass:
~**4 MeV** at **125 GeV**

Signal model: analytic convolution of a :
Breit-Wigner distribution
(modeling a **non-zero decay width**)
Gaussian distribution (modeling the **non-zero detector resolution**)

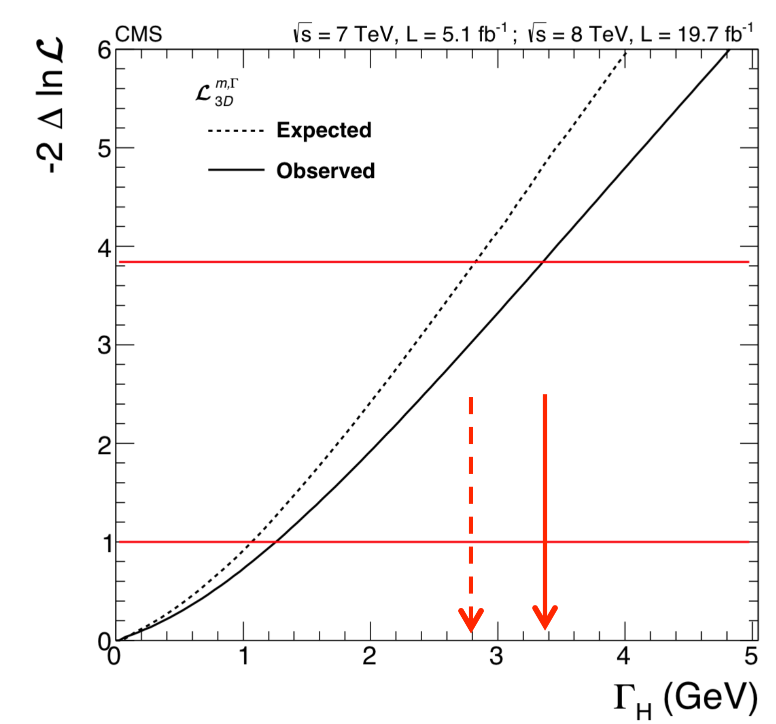
Method: profile likelihood estimator is used to calculate **upper limits** on the **width**

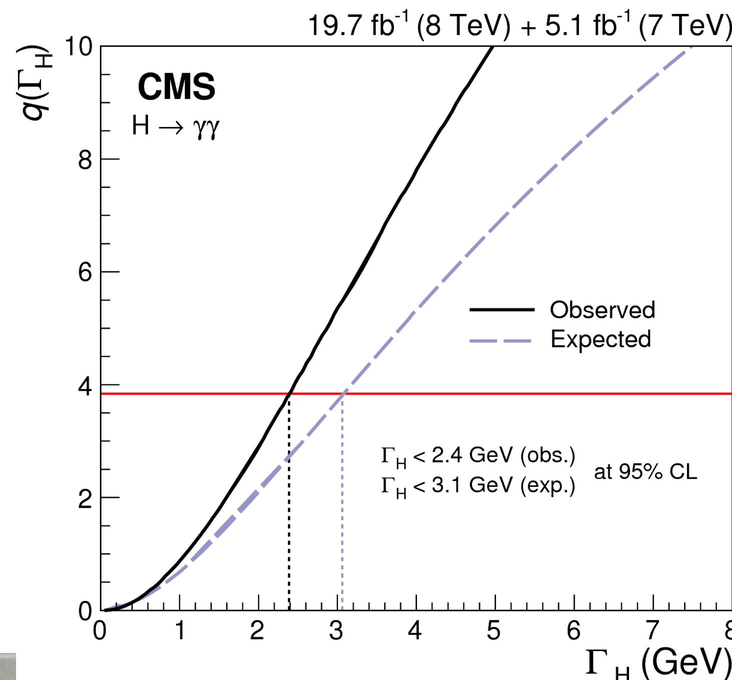
First direct **upper limit** on the Higgs boson **width**:

$H \rightarrow ZZ \rightarrow 4l$:
- **3.4 GeV** at 95% CL (- **2.8** expected)

$H \rightarrow \gamma\gamma$:
- **2.4 GeV** at 95% CL (- **3.1** expected)

$\Gamma < 600 \cdot \Gamma_{SM}$





The Higgs width: Γ_H from off-shell production

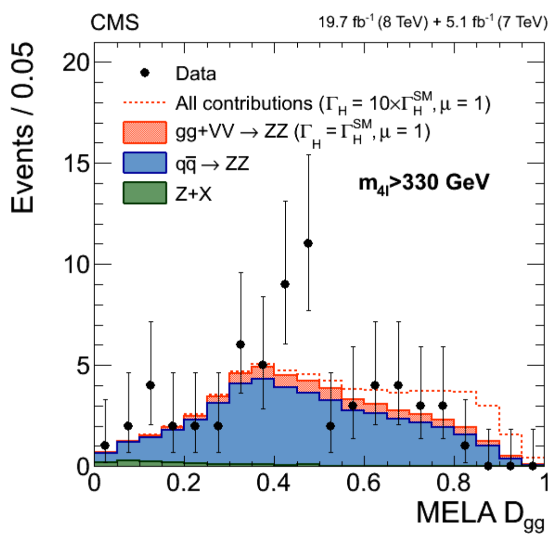
We can go from few GeV to ~tens of MeV using off-shell Higgs production

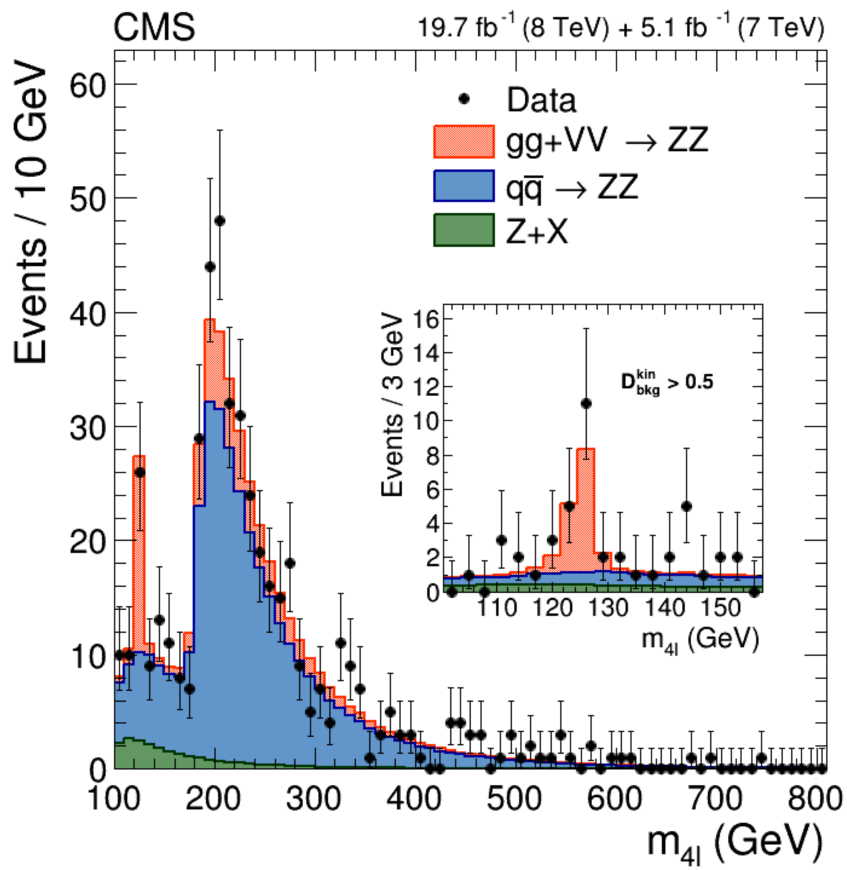
Kauer, Passarino: JHEP 1208 (2012) 116, Caola, Melnikov: Phys. Rev. D88 (2013) 054024

Off-shell Higgs boson production
is small but the BR to 2 real Z is large above $2m_Z$

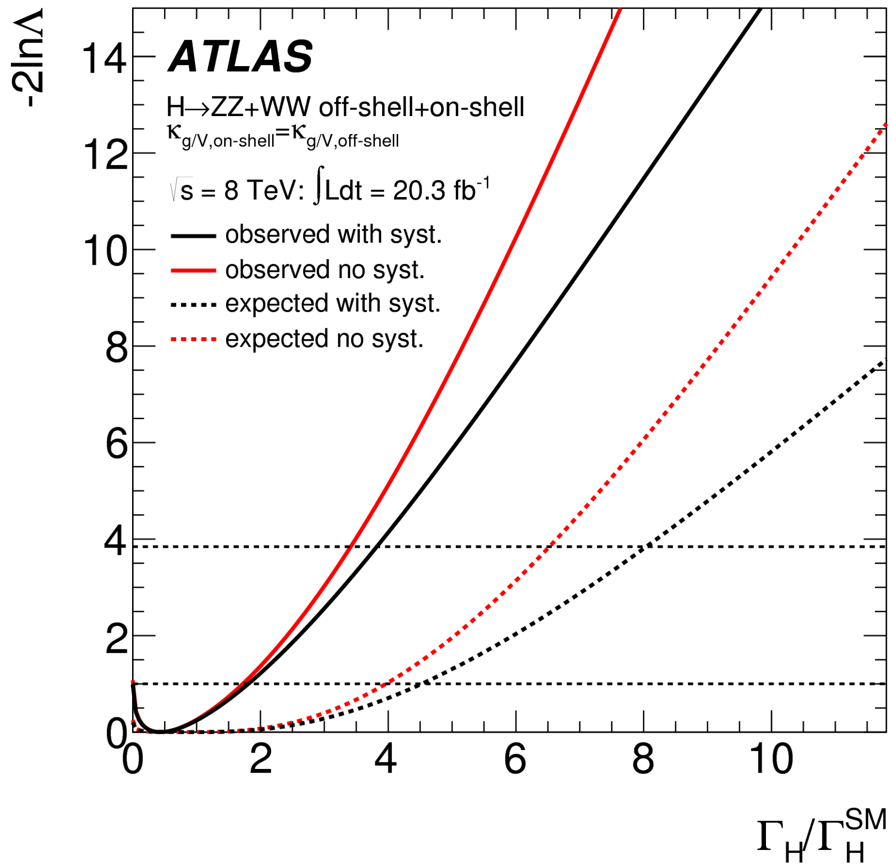
In the high M4l region, the signal
interfere with the gg background
the interference is large and destructive
(~twice the signal).

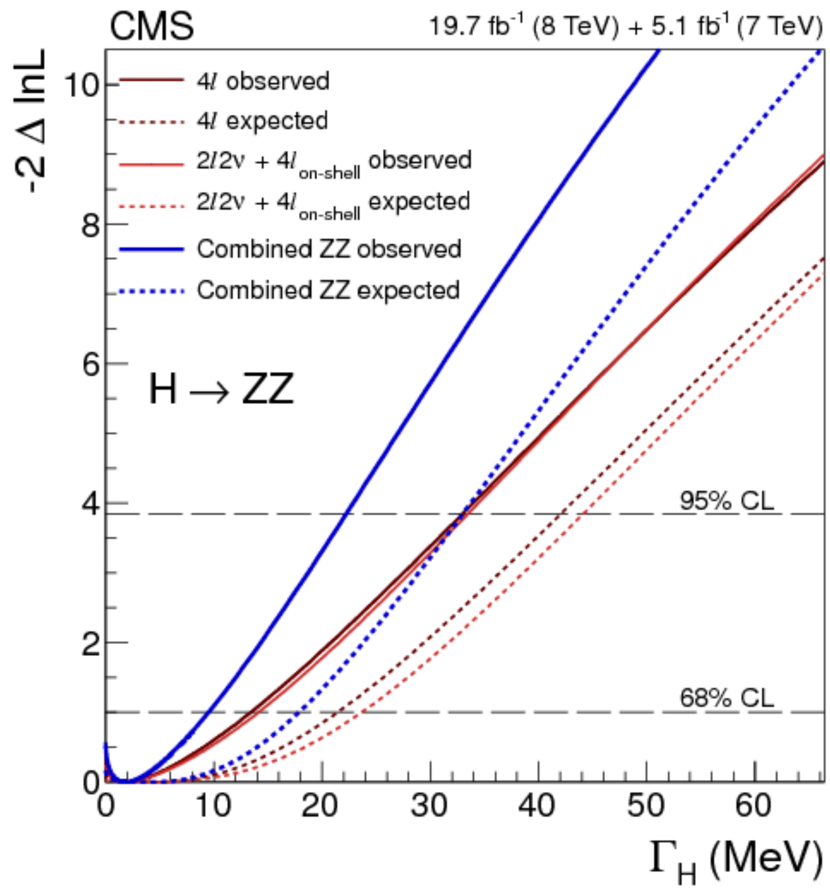
Discriminant to enhance gg/qq production





The Higgs width: Γ_H from off-shell production





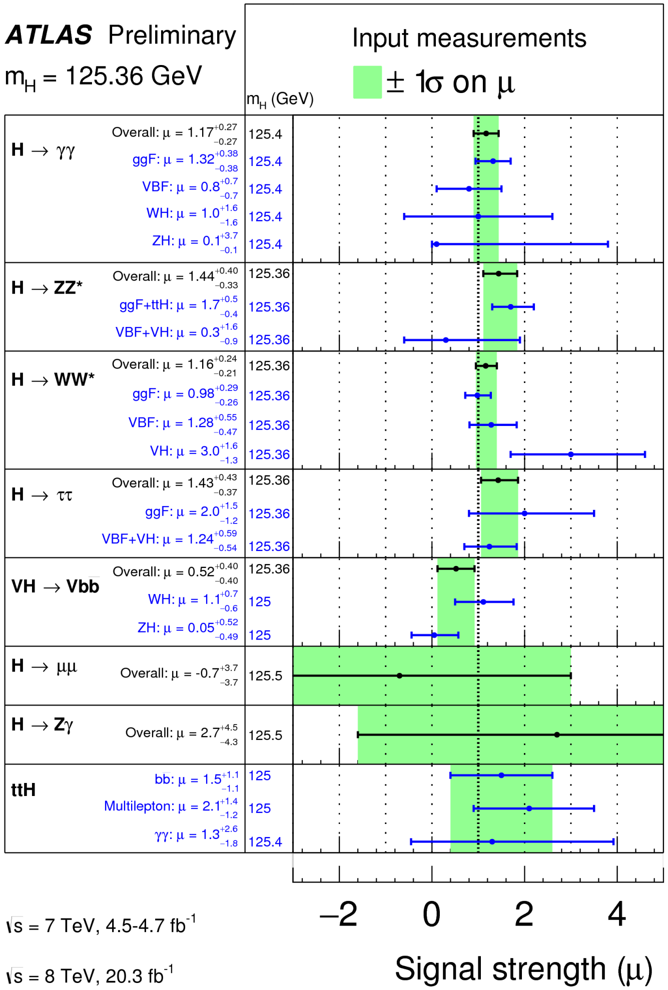
Assuming $k_{bck}=k_{sig}$

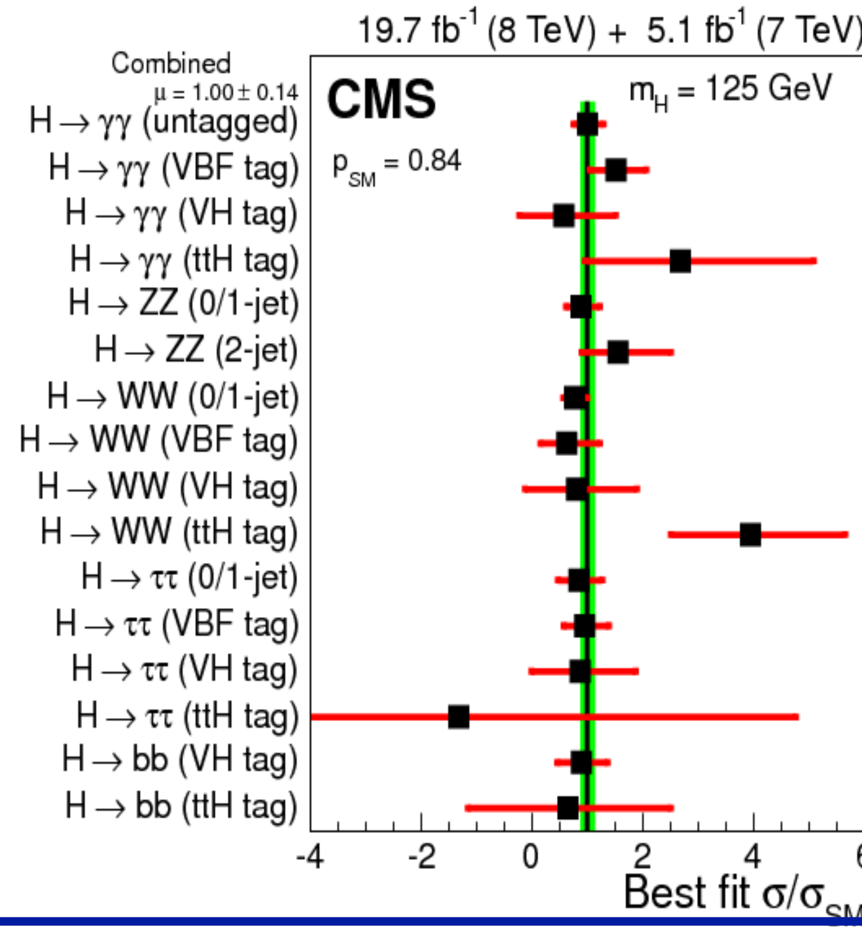
$\Gamma_H <$ 22.7 MeV (33 MeV expected)
i.e. 5.4 x SM

$\Gamma_H <$ 22 MeV (33 MeV expected)

Consistency with SM hypothesis

$$\mu = \frac{\sigma \cdot \mathrm{BR}}{(\sigma \cdot \mathrm{BR})_{\mathrm{SM}}}$$





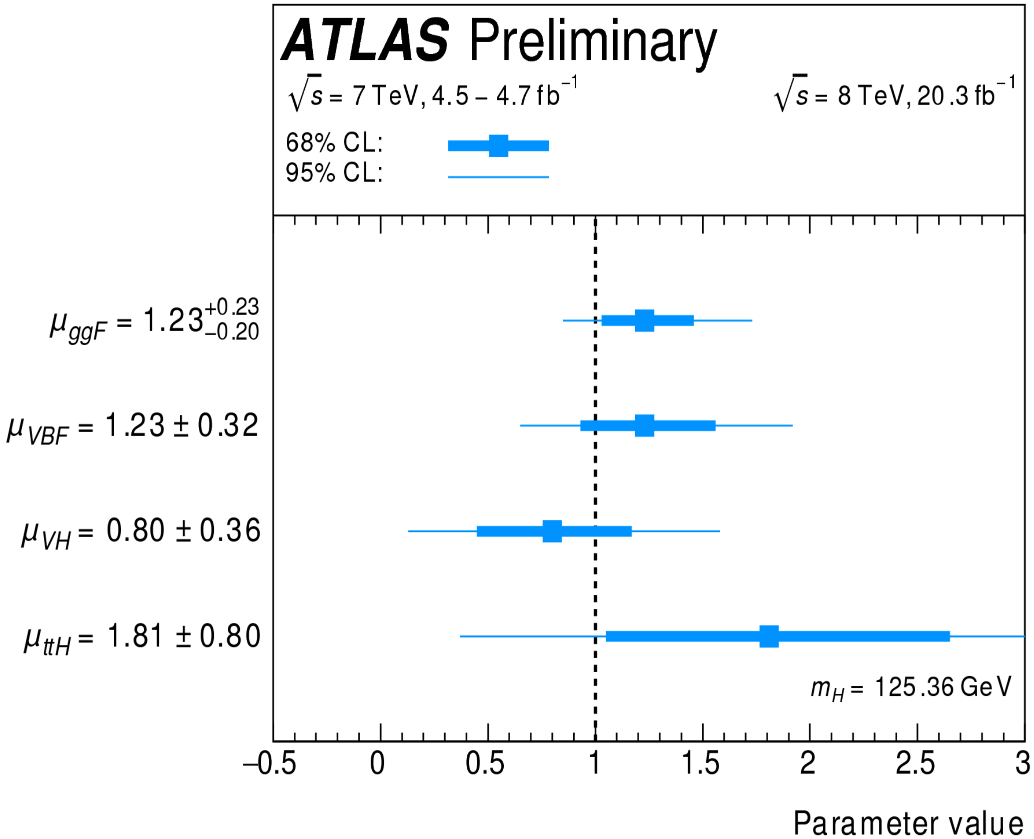
μ=1.18±0.10(stat)±0.07(sys)±0.08(th)

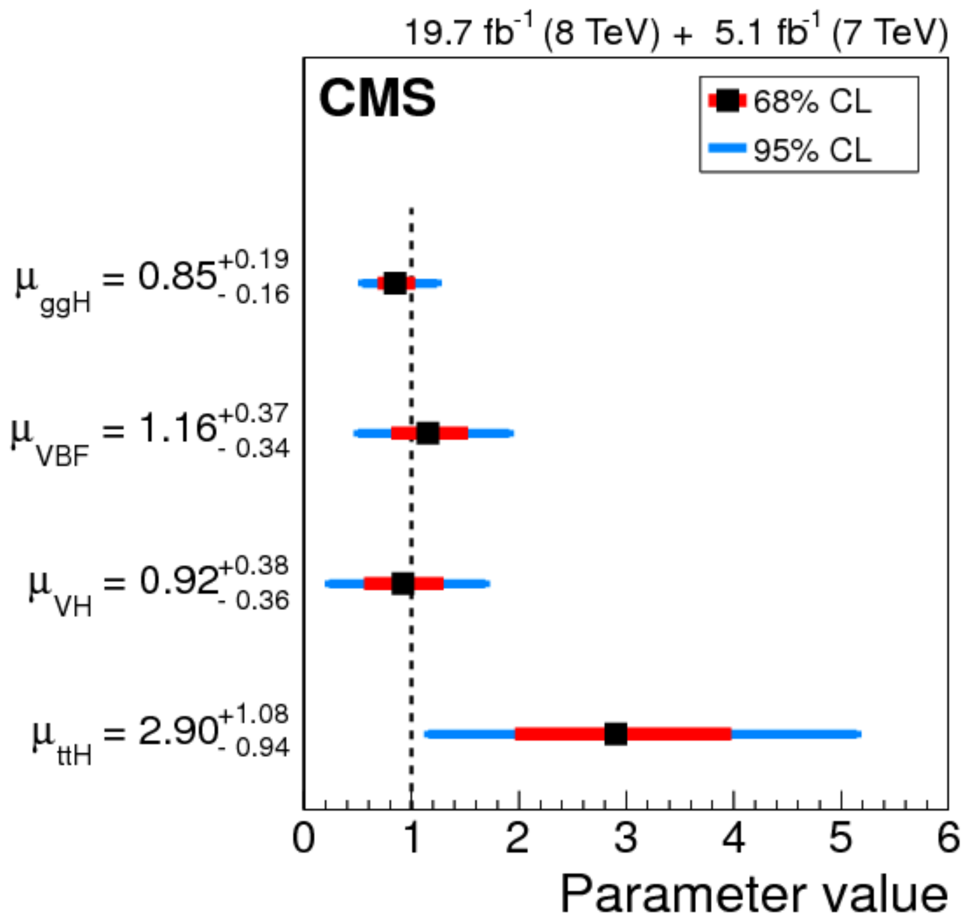
μ=1.00±0.09(stat)±0.07(sys)±0.08(th)

Consistent with the SM prediction for both ATLAS and CMS, with ~15% precision.
Theory uncertainty (QCD scale ±8%@NNLO and PDF+α_s ±8%) is comparable to experimental.

Signal Strengths by Processes

Starting to isolate all four production processes…

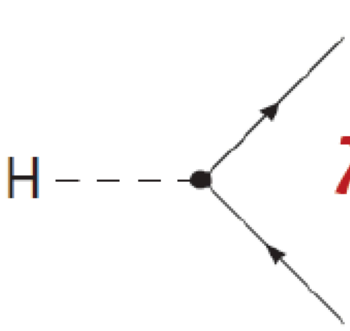




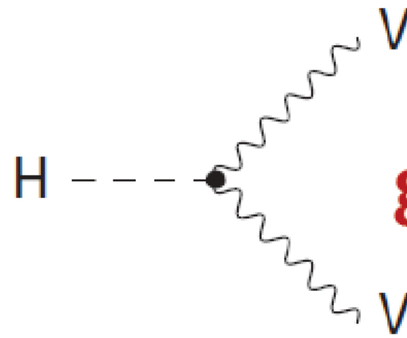
Status: ggF well established, evidence for VBF,
indication for VH, not yet sensitive to ttH

The Higgs vertexes

We want to disentangle production and decay processes to measure the "vertexes" to test the SM and search for new physics.



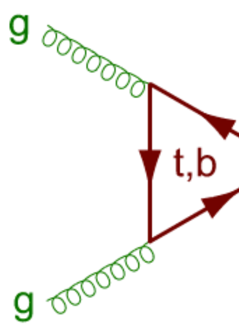
$\lambda_f = m_f / v$



$g_V = 2\, m_V^2 / v$

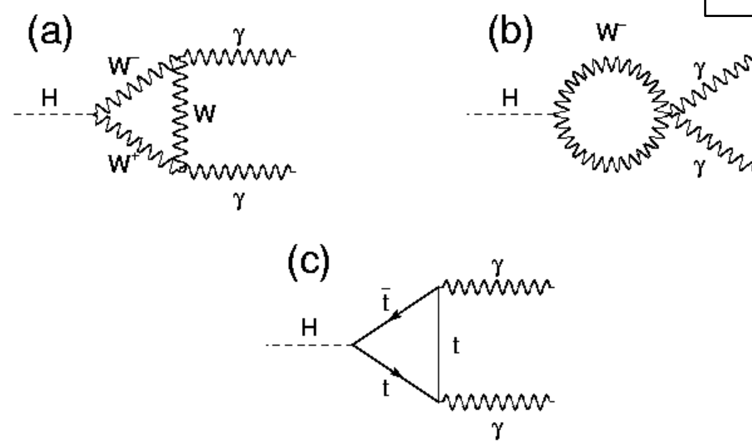
No direct decay to neutral particles – only via loops

H → gg



Top is dominating

H → γγ



destructive interference between W and top

The couplings

They can be extracted from the different final states at the LO EW and NLO QCD approximation:

$$\sigma(H) \times BR(ii \rightarrow H \rightarrow xx) = \sigma_{ii} \times \Gamma_{xx} / \Gamma_H$$

We can measure deviations from the SM couplings, by measuring ratios w.r.t. to the SM prediction.

$$g_{Hff} = \frac{\sqrt{2}m_f}{v}, \quad g_{HVV} = \frac{2m_V^2}{v} \quad \Rightarrow \quad g_{Hff} = \boxed{\kappa_f} \cdot \frac{\sqrt{2}m_f}{v}, \quad g_{HVV} = \boxed{\kappa_V} \cdot \frac{2m_V^2}{v}$$

As an example for the $gg \rightarrow H \rightarrow \gamma\gamma$ process:

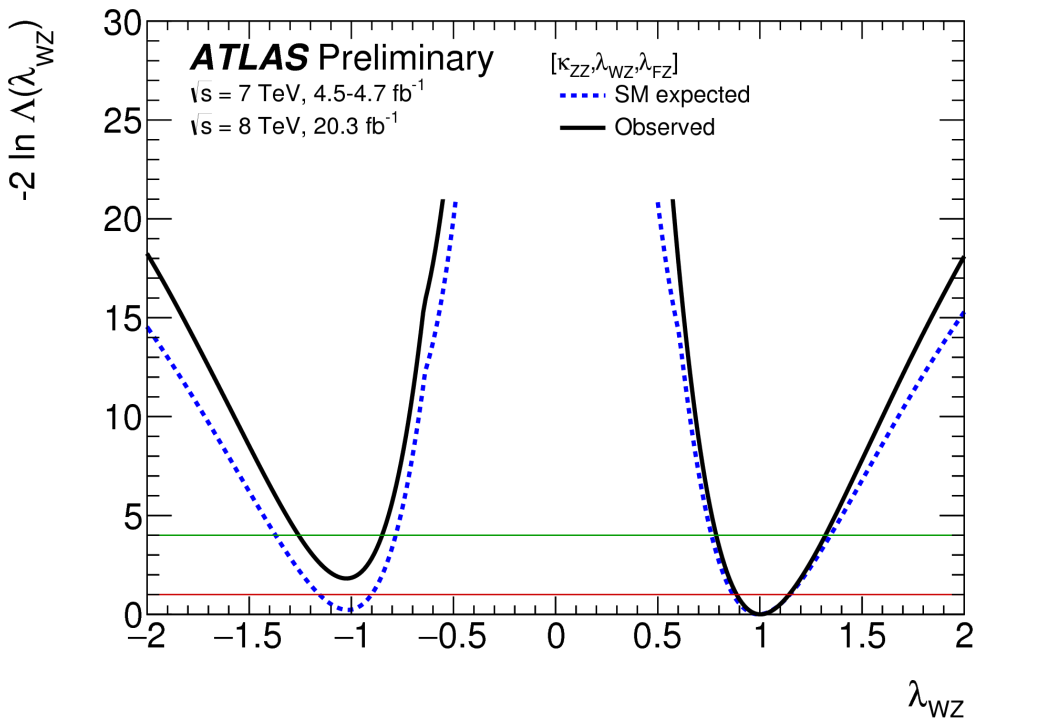
$$(\sigma \times BR)(gg \rightarrow H \rightarrow \gamma\gamma) = \sigma_{SM}(gg \rightarrow H)\, BR(H \rightarrow \gamma\gamma) \bullet \kappa_g^2 \; \kappa_\gamma^2 / \kappa_H^2$$

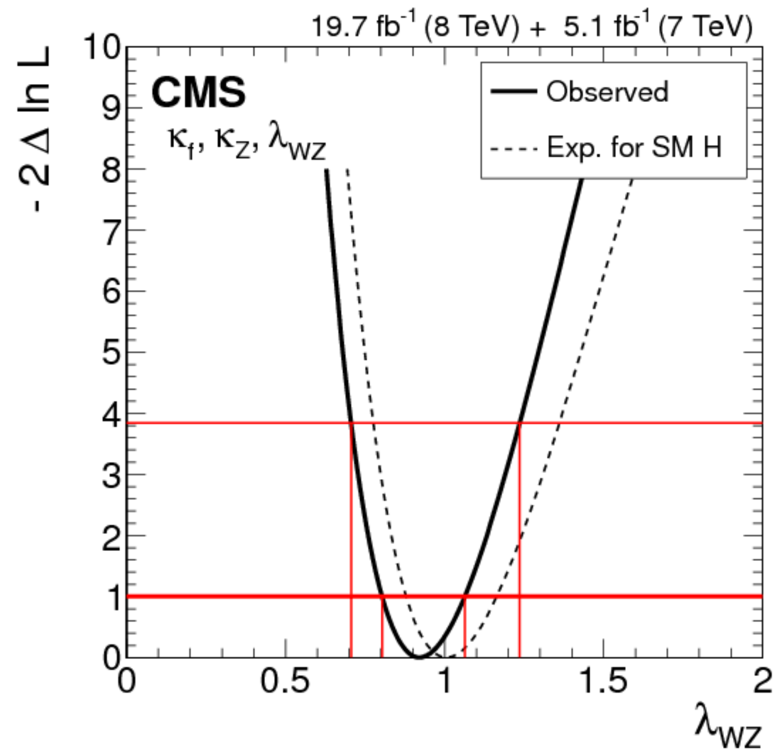
Custodial symmetry

Testing custodial symmetry (measuring HWW/HZZ couplings) will tell us if the the object produced is Higgs-like.

Because of the custodial symmetry we expect: $\kappa_W = \kappa_Z \Rightarrow \lambda_{WZ} = \kappa_W / \kappa_Z = 1$

All channels used. κ_f profiled.

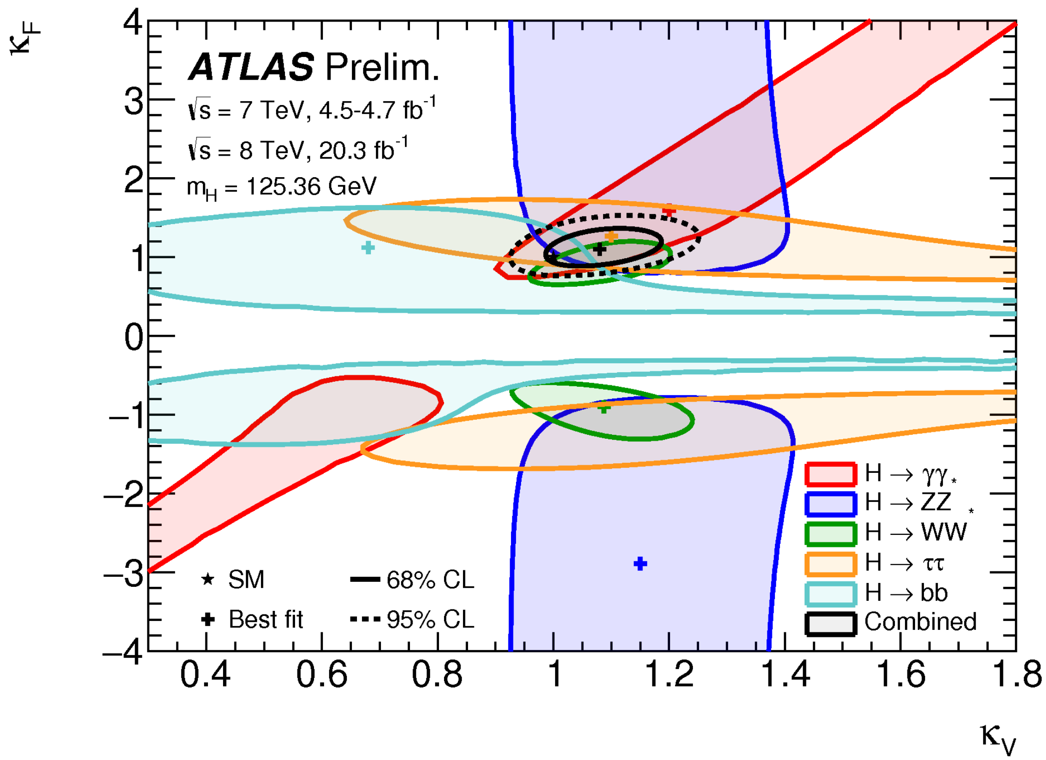


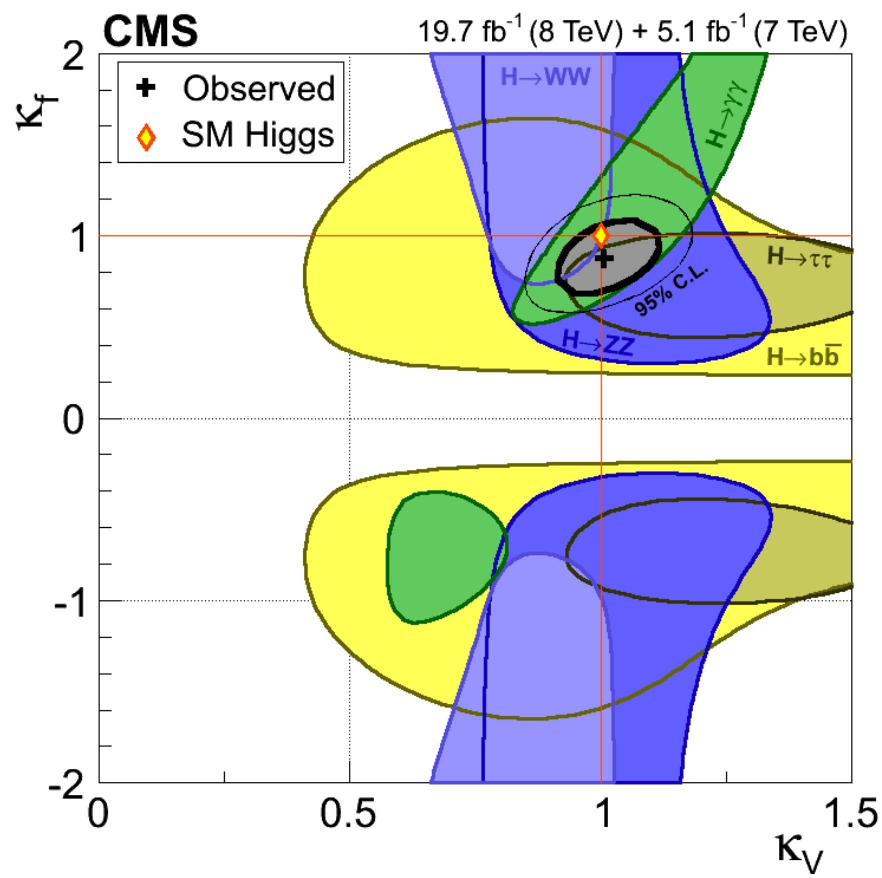


three degrees of freedom:
λ_{WZ}, κ_Z, and κ_f.
$\Gamma_{BSM} = 0$.
fitted m_H

Couplings: κ_V, κ_f

Assume all fermion couplings scale as κ_F while all vector boson couplings scale as κ_V.



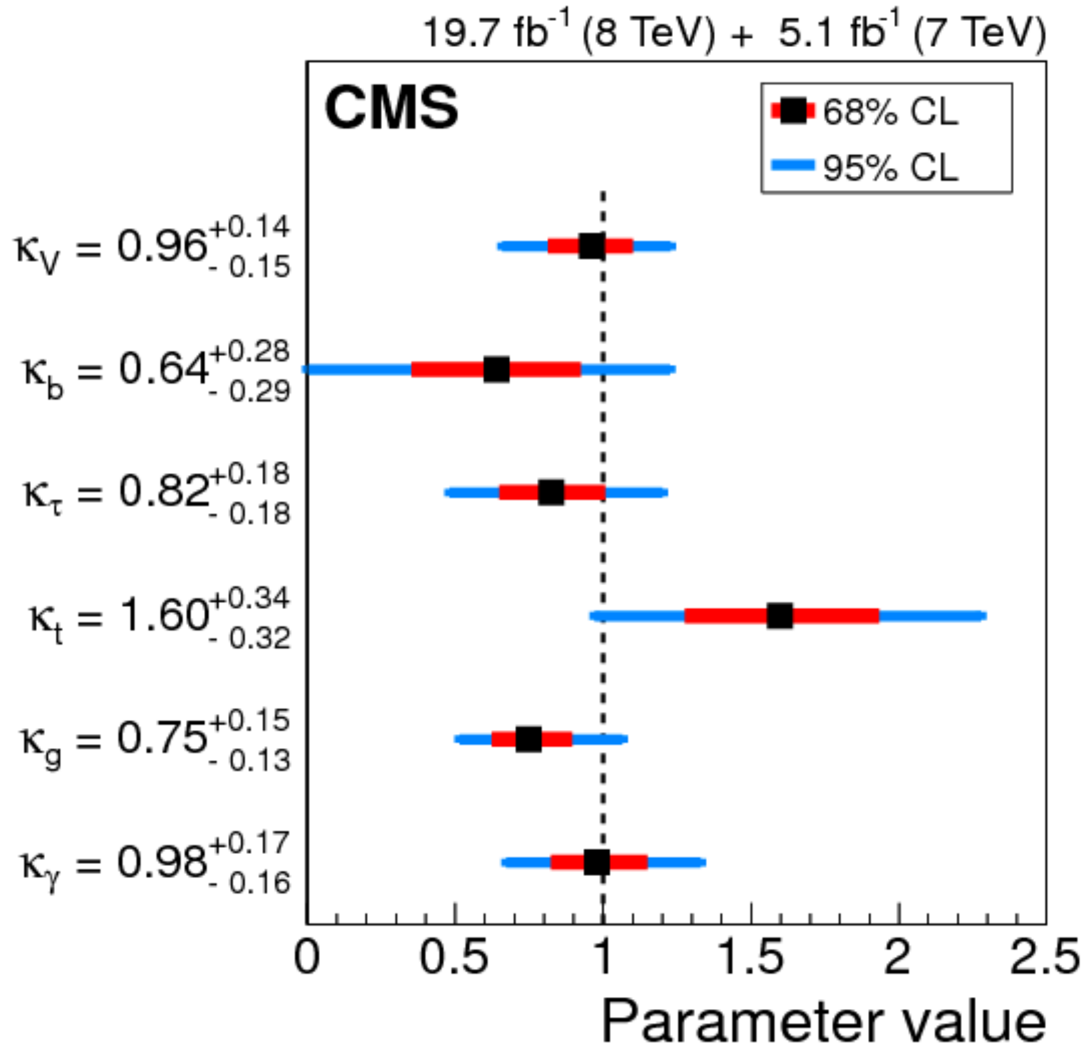


@ fitted m_H

$\Gamma(H \rightarrow \gamma\gamma) \sim |\alpha\, \kappa_V + \beta\, \kappa_f|^2$, $\alpha/\beta = -0.2$

$\Gamma_{BSM} = 0$

6 parameters model



Likelihood scans for parameters in a model with coupling scaling factors for the SM particles, one coupling at a time while profiling the remaining five together with all other nuisance parameters; from top to bottom:

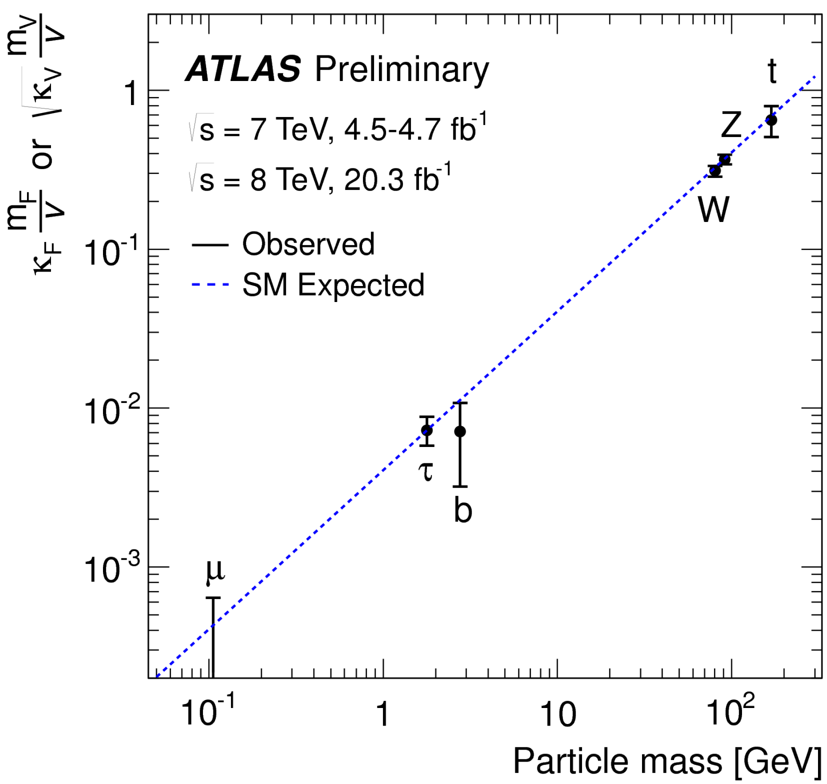
- κV (W and Z bosons),
- κb (bottom quarks),
- κτ (tau leptons),
- κt (top quarks),
- κg (gluons; effective coupling),
- κγ (photons; effective coupling).

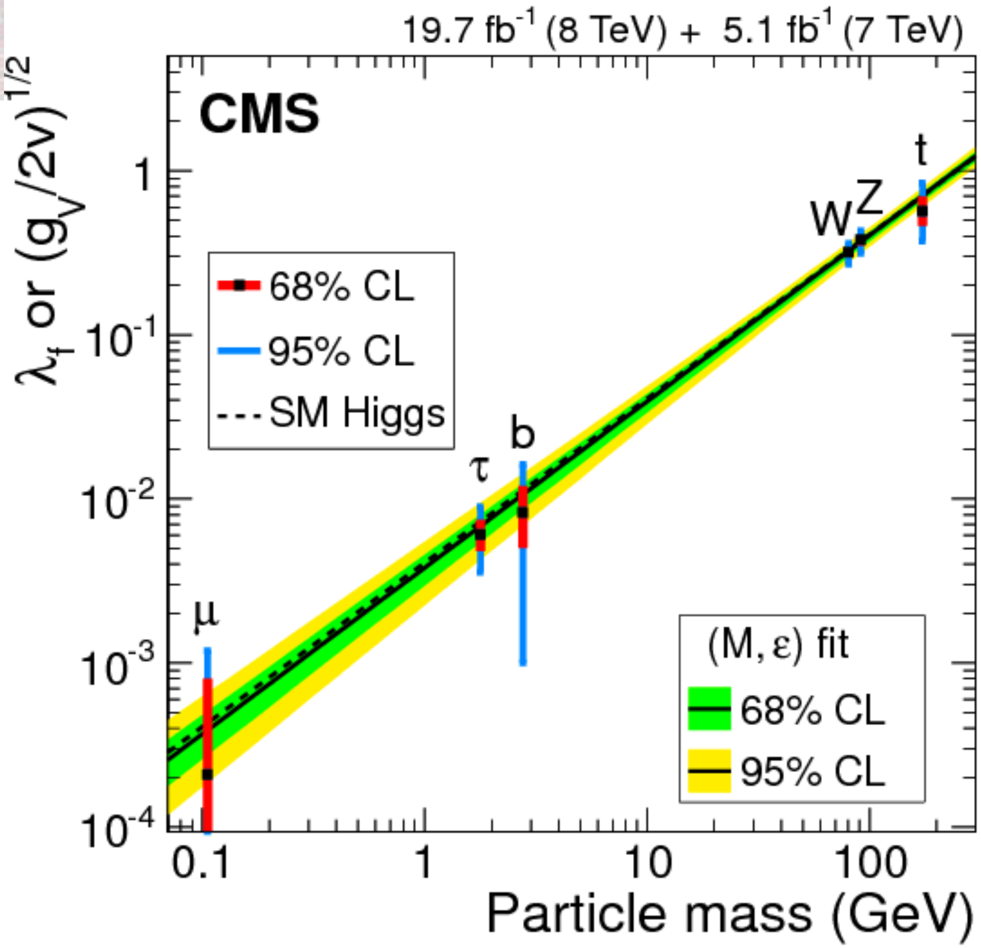
The inner bars represent the 68% CL confidence intervals while the outer bars represent the 95% CL confidence intervals.

Couplings vs mass

The Higgs couples to the mass of the particle:

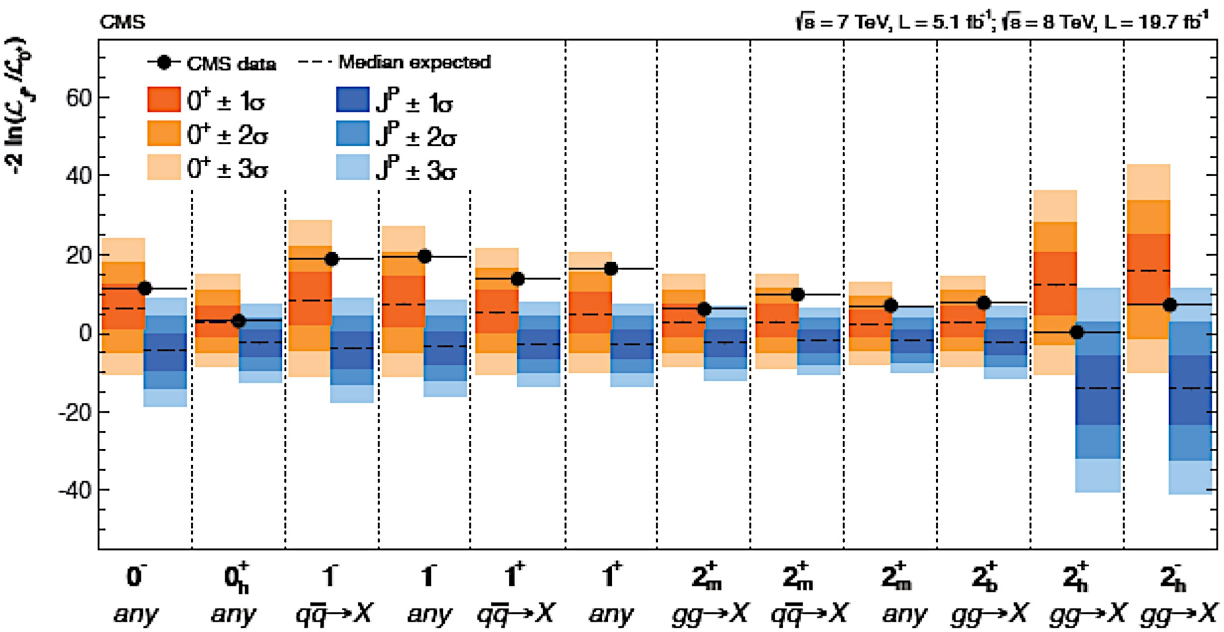
$$\lambda_f = \kappa_f m_f / v$$
$$g_V = 2\kappa_V m_V^2 / v$$





Perform a fit to the full Atlas / CMS combination, resolving gluon and photon loops in term of tree-level couplings

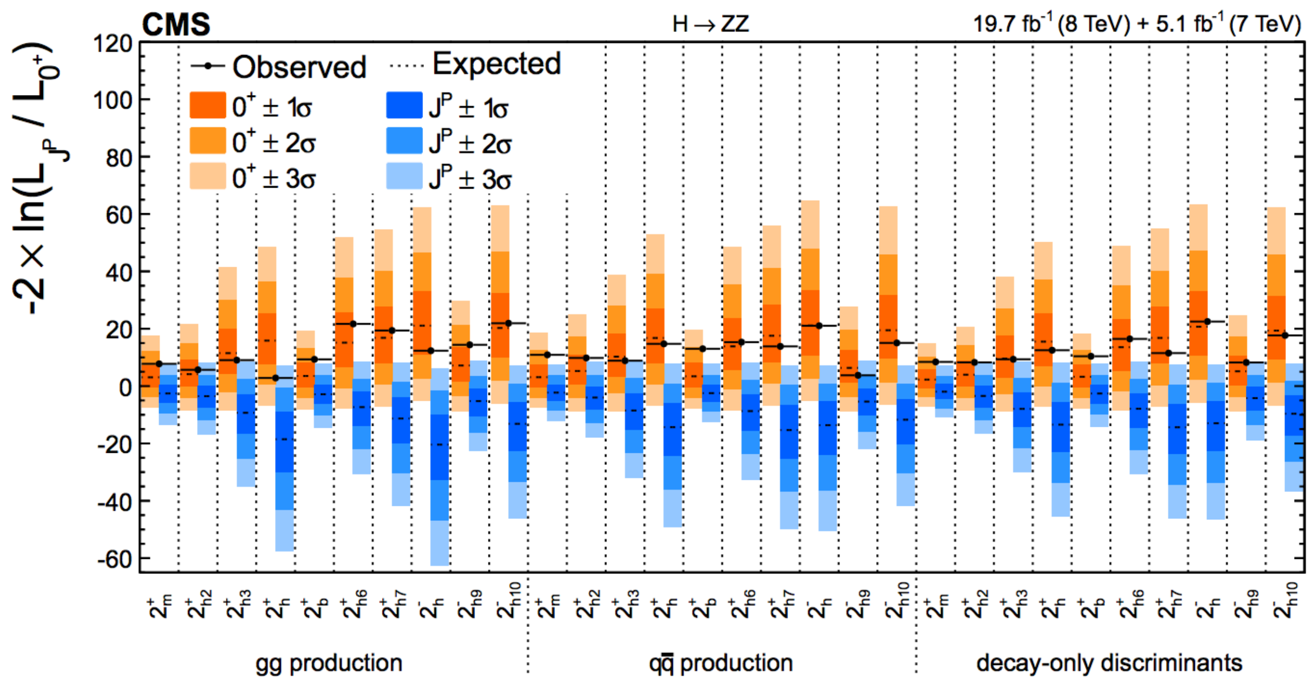
Spin and Parity from H→ZZ→4l, H→WW, H→γγ



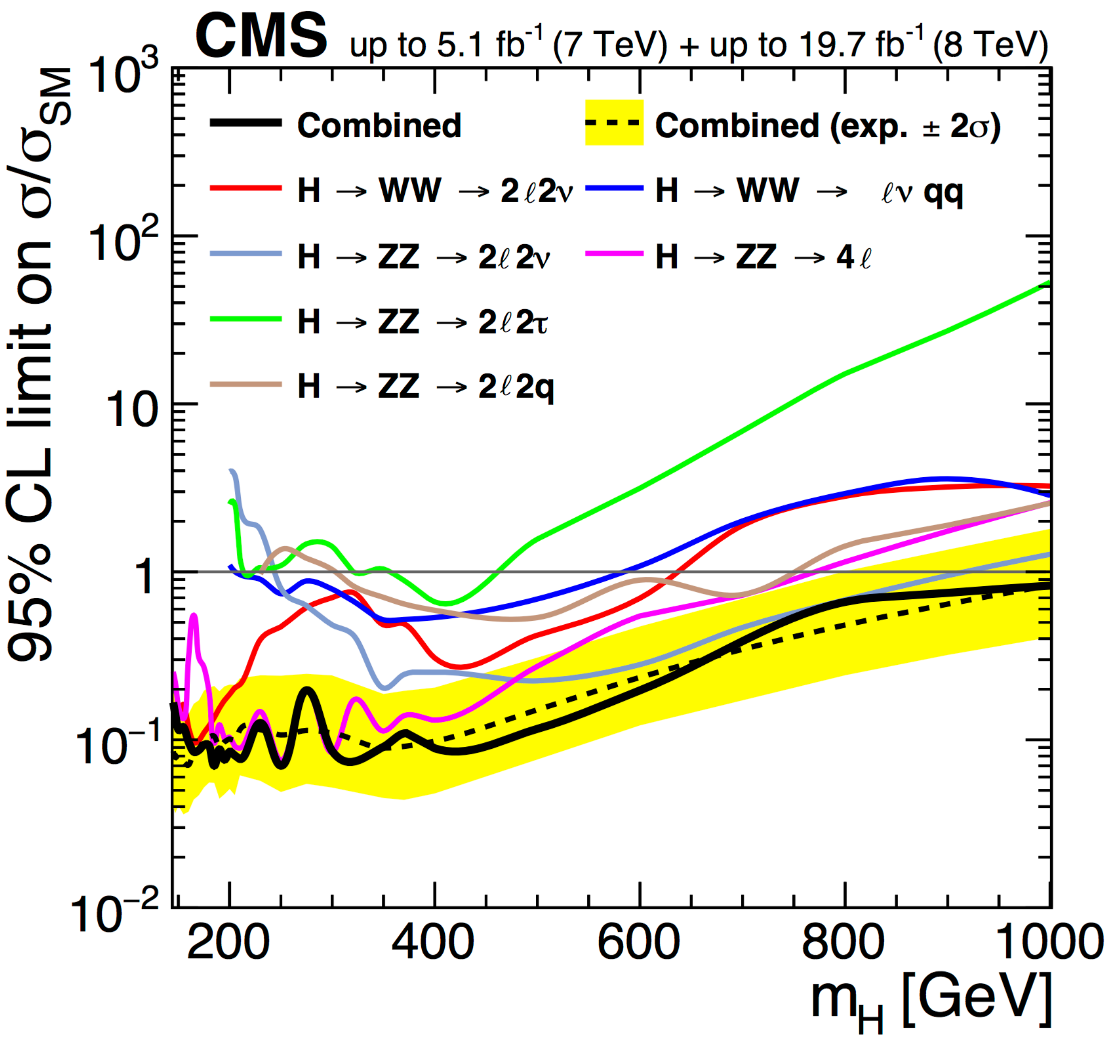
ATLAS and CMS many analyses, lots of results

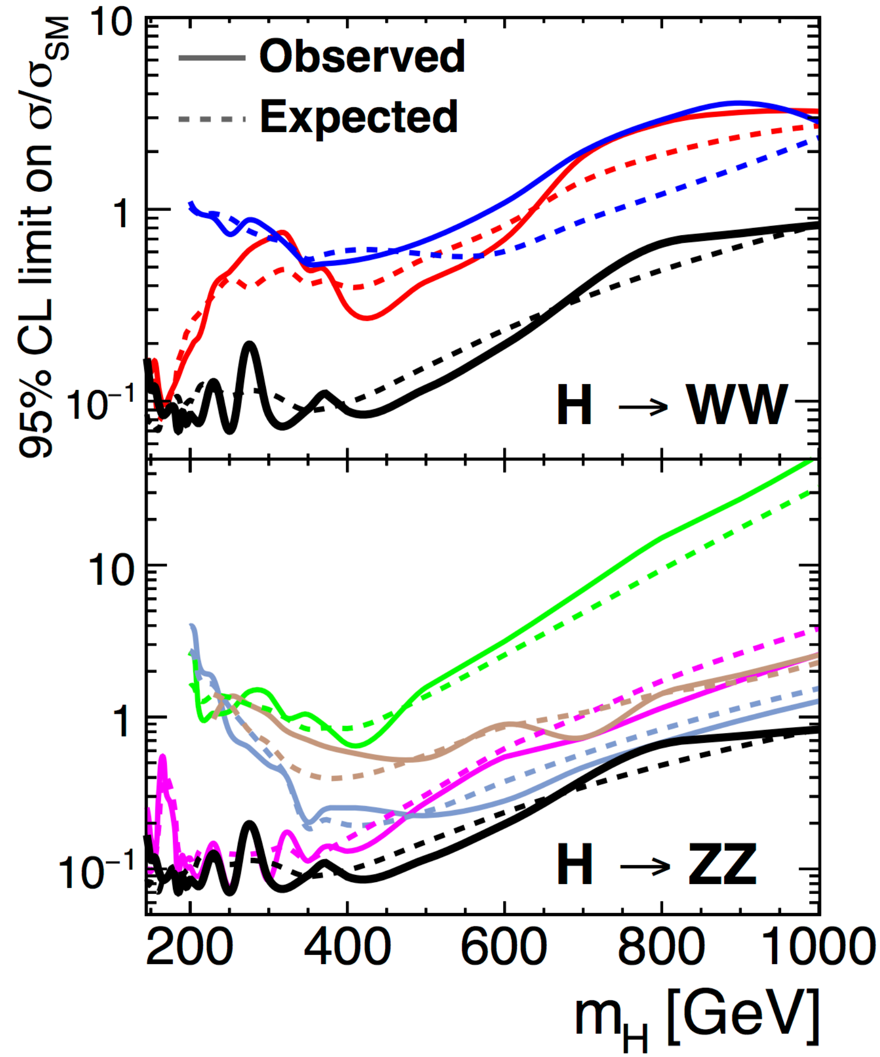
→

Spin 0
Positive parity
at > 99.9% CL



Is there another SM Higgs ?





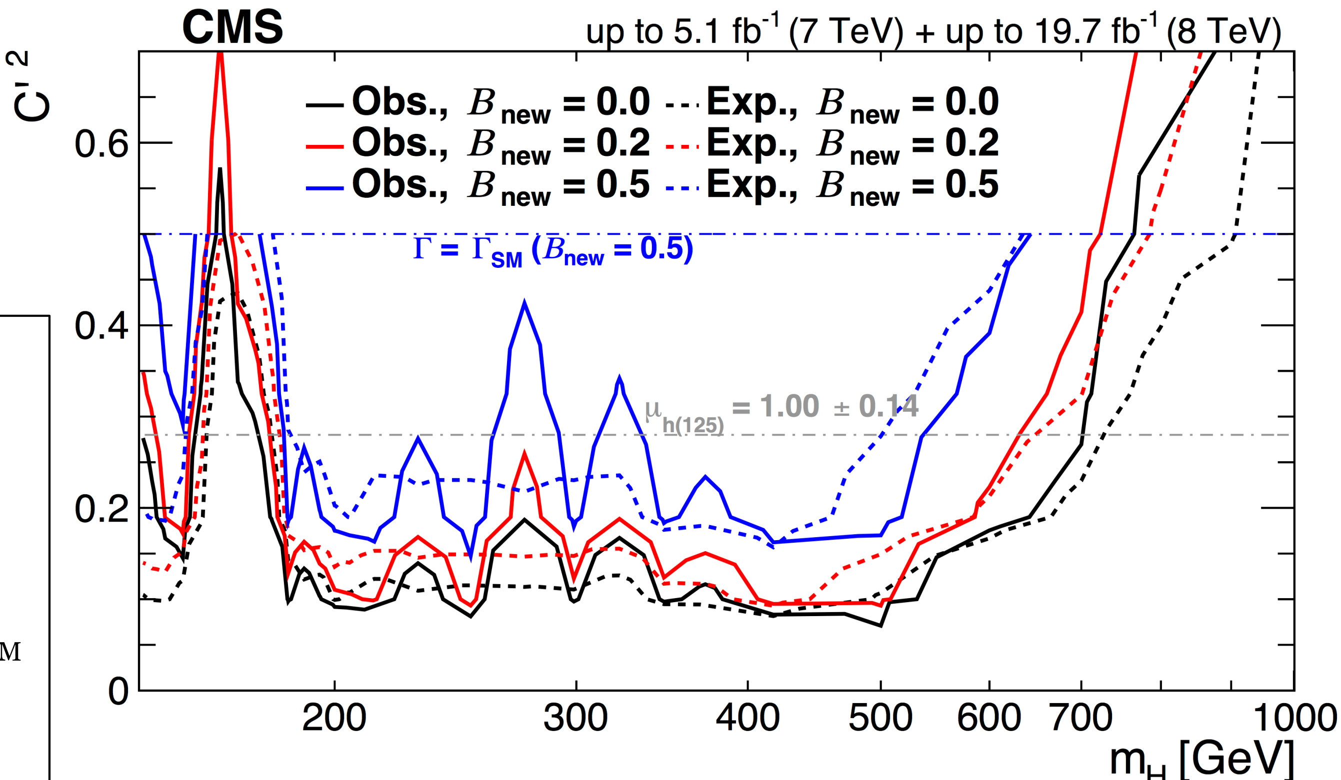
EWK singlet

$$C^2 + C'^2 = 1$$

Use the 125 GeV Higgs boson to constraint $C'^2 = 1 - C^2$

Use the full CMS combination $\mu_{h125} = 1.00 \pm 0.14$

Direct search for an additional boson

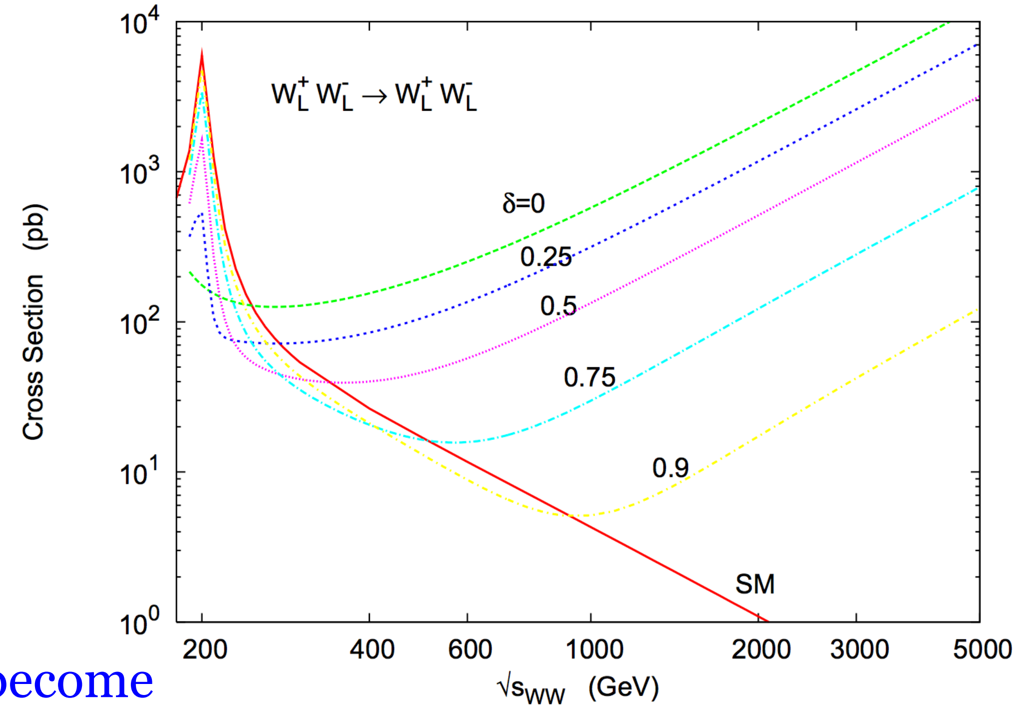


We assume that h and h' mix with each other

- Reduction of the SM coupling strength $\mu_{SM} \rightarrow C^2\, \mu_{SM}$
- The second singlet h couples with strength $C'^2(1-BR_{new})\, \mu_{SM}$
- Unitary implies: $C^2 + C'^2 = 1$

Partially Strong $W_L W_L$ Scattering

If the cancellation of the Higgs diagrams is not complete, then we expect a g_{hWW} coupling smaller than the SM.
The $W_L W_L$ will keep growing with $\sqrt{s}$, up to the the new resonance, or more generally to the new physics scale Λ.



Cheung, Chiang, Yuan

Suppose the Higgs-WW coupling is **$\sqrt{\delta}$ of the SM** value, then the amplitudes become

$$
\begin{aligned}
i\mathcal{M}^{\text{gauge}} &= -i\frac{g^2}{4m_W^2}\,u + \mathcal{O}((E/m_W)^0) \\
i\mathcal{M}^{\text{higgs}} &= i\frac{g^2}{4m_W^2}\,u\,\delta + \mathcal{O}((E/m_W)^0) \\
i\mathcal{M}^{\text{all}} &= -i\frac{g^2}{4m_W^2}u(1-\delta) + \mathcal{O}((E/m_W)^0)
\end{aligned}
$$

→ Measure with high precision hVV coupling and $V_L V_L$ scattering

How to continue

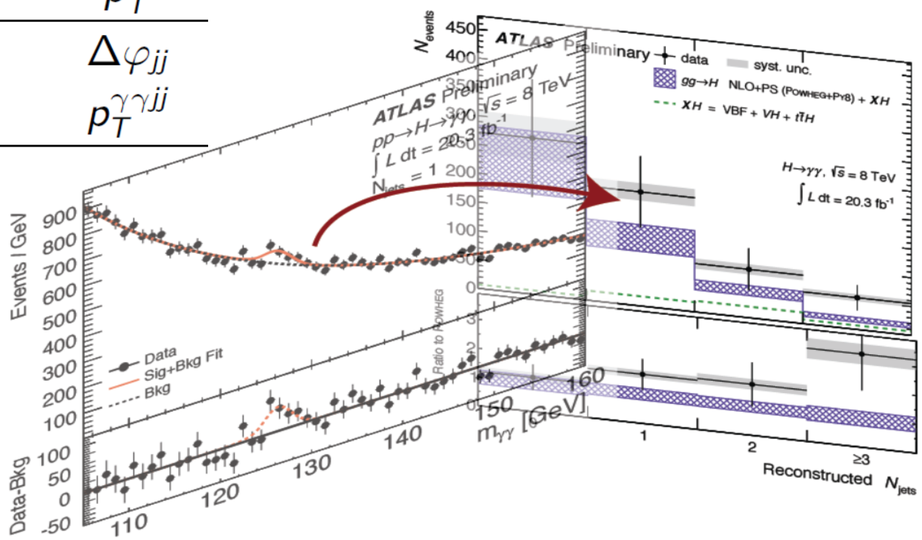
The following talks (within WP1) will go into the details of the future program:

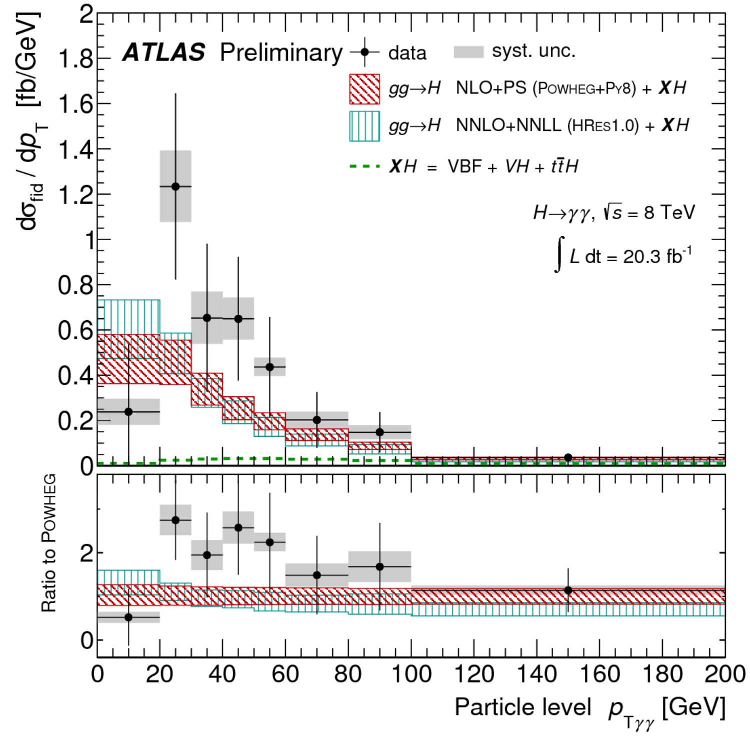
- Overview of the goals of the WP1
  Weiglein
- Measure properties and coupling with high precision:
  Grazzini, Melnikov, Duehrssen, Passarino
- Search for new "Higgses"
  Nikitenko and Ellwanger
- Measure VV scattering
  Dao

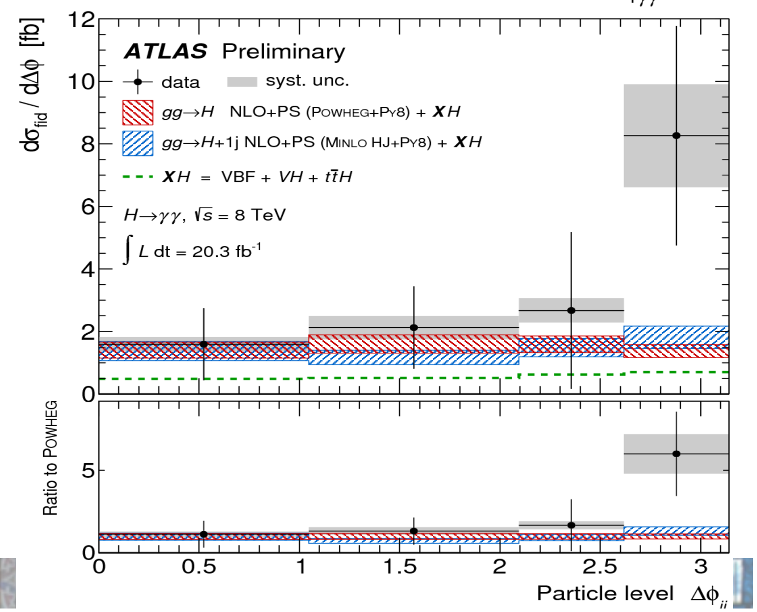
backup

ATLAS: Differential XS

	Variable
Inclusive	$p_T^{\gamma\gamma}$
	$\lvert y^{\gamma\gamma} \rvert$
	$\lvert \cos\theta^* \rvert$
	N_{jets}
	p_T^{j1}
2-jets	$\Delta\varphi_{jj}$
	$p_T^{\gamma\gamma jj}$



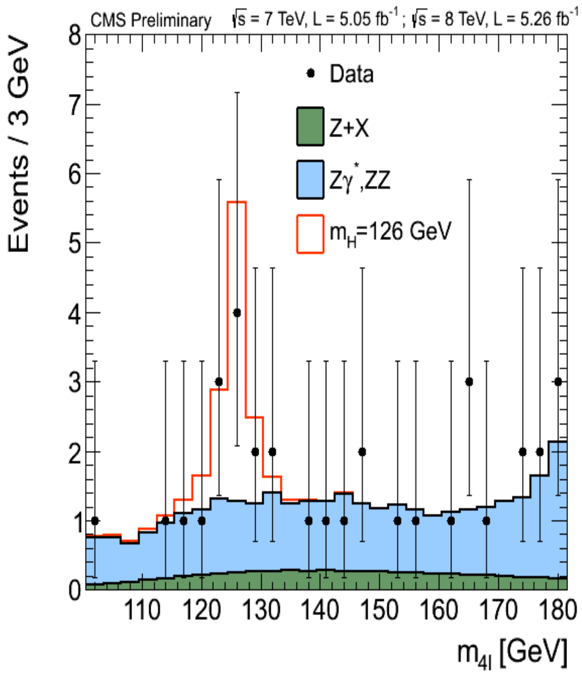




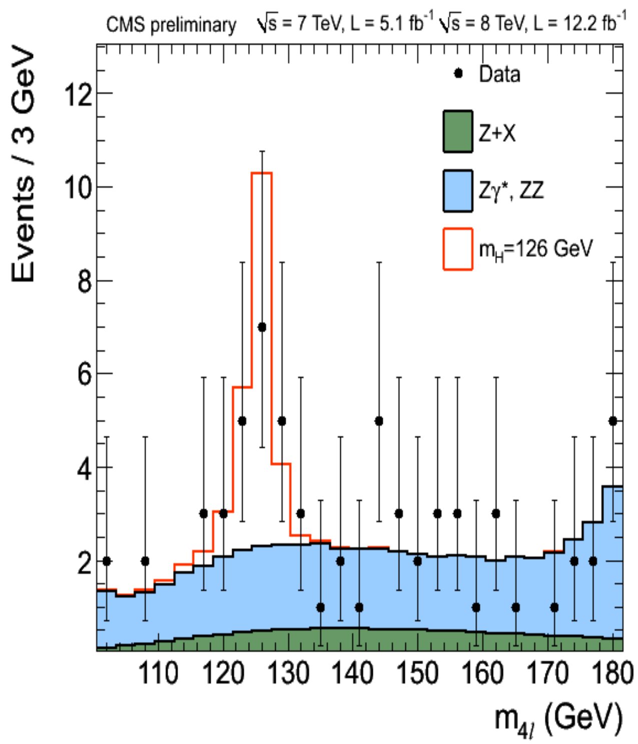
- Bin events in variables of interest
- Background estimations from the $m_{\gamma\gamma}$ side-band fit in each bin
- Unfold the reconstructed distributions to truth distributions (→ differential cross-sections)

A beautiful peak

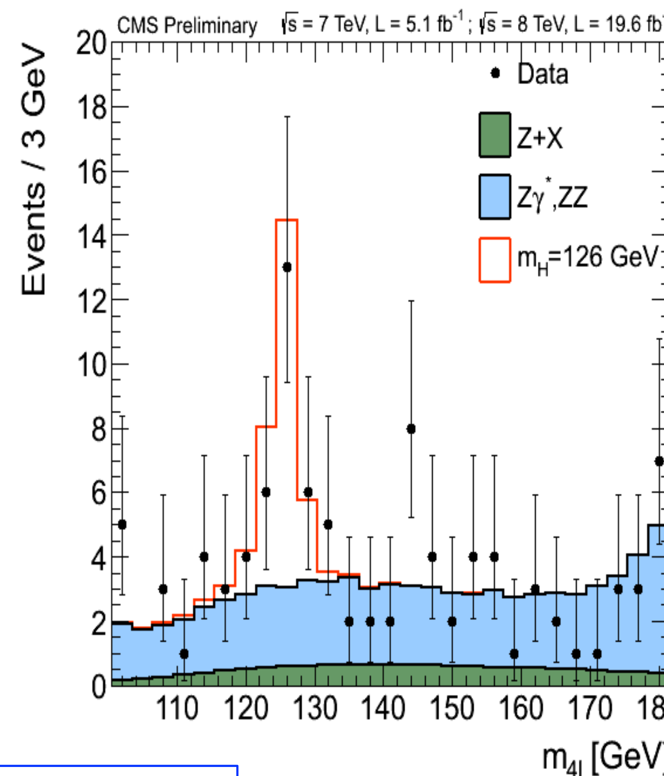
4 July



Nov 2012



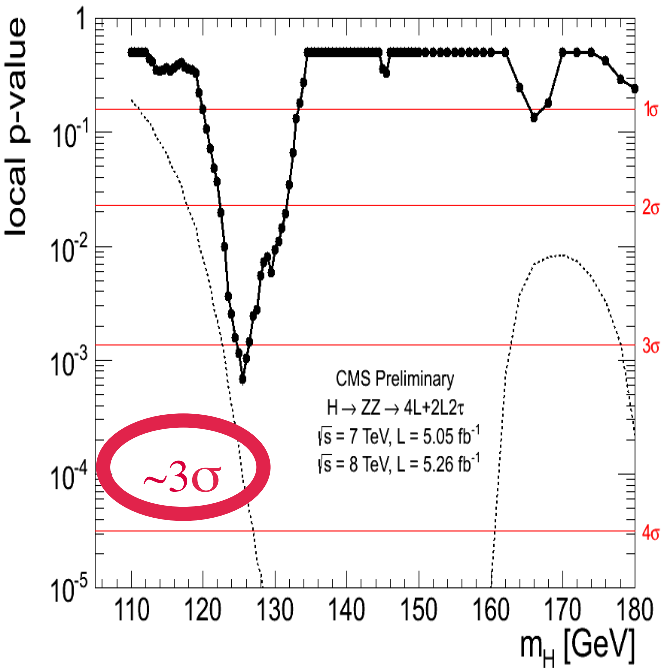
Today



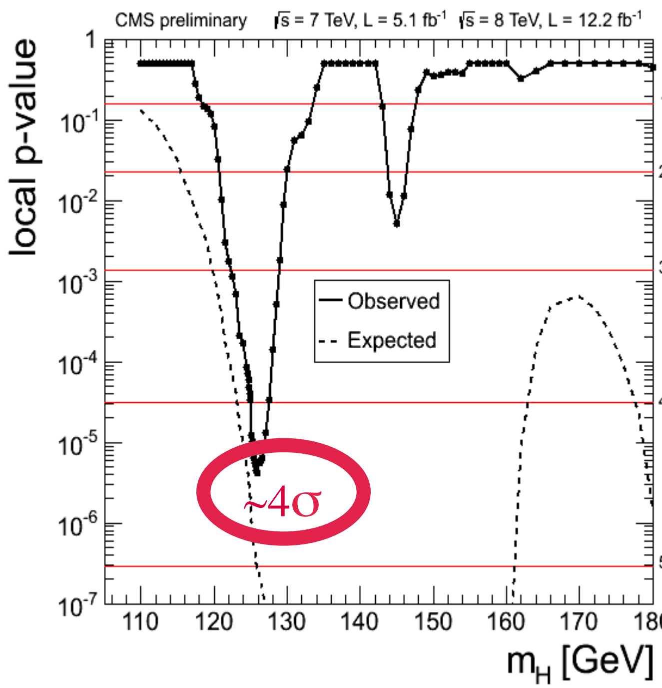
The beauty of an equation is more important than its correctness, in the sense that if an equation is beautiful, sooner or later it will be demonstrated to be correct. Paul Dirac

Compatibility with the background only hypotesis

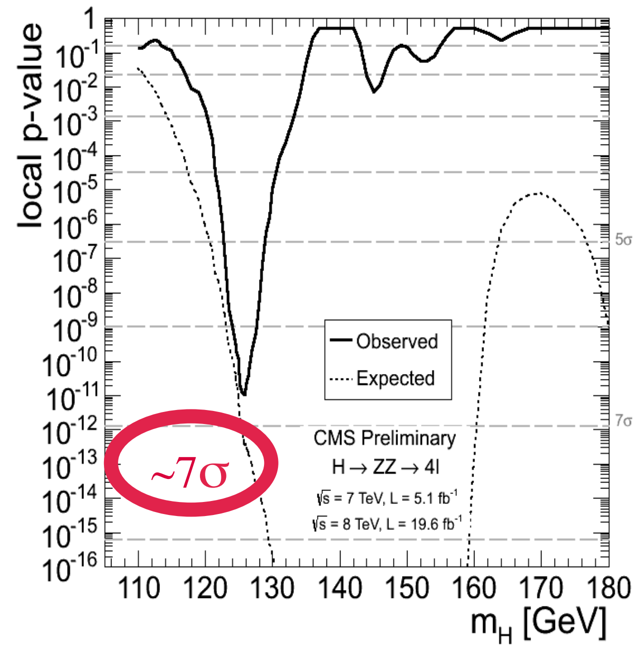
4 July



Nov 2012

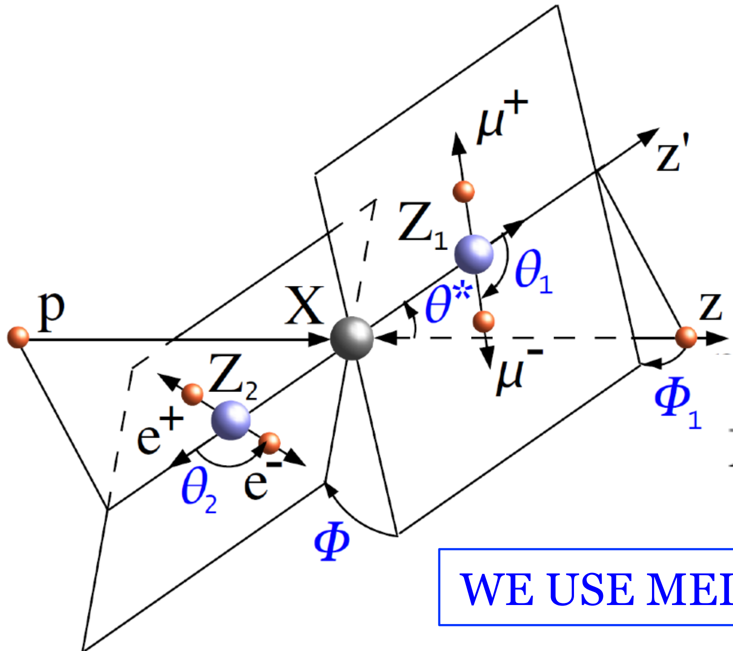


Today



The beauty of an equation is more important than its correctness, in the sense that if an equation is beautiful, sooner or later it will be demonstrated to be correct. Paul Dirac

Kinematic Discriminant

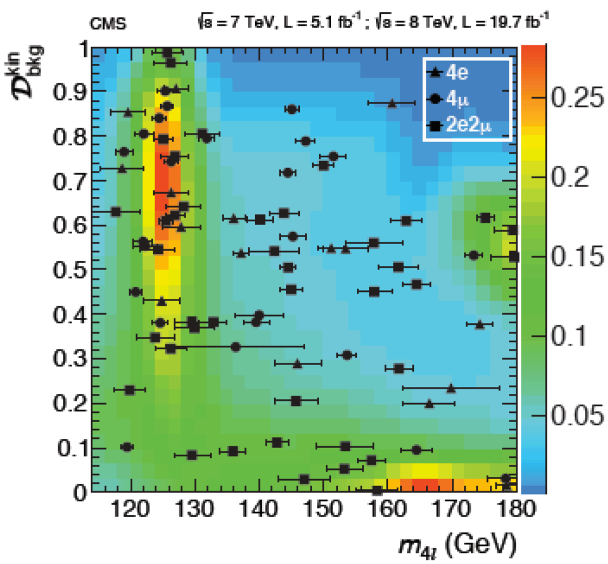


Matrix **E**lement **L**ikelihood **A**nalysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

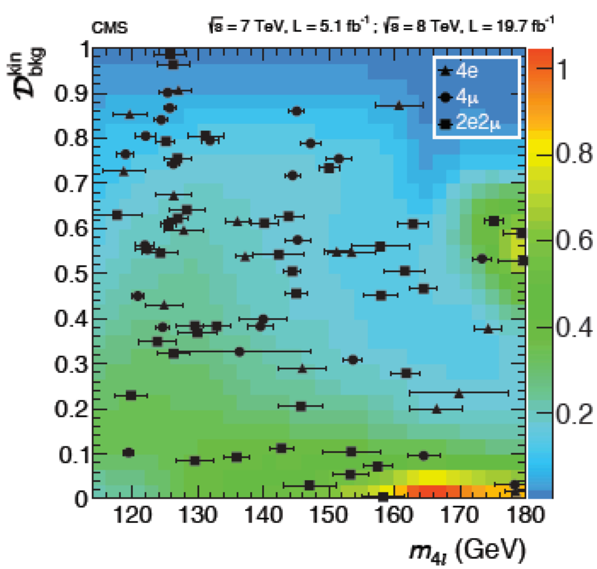
$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\rm bkg}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\rm sig}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

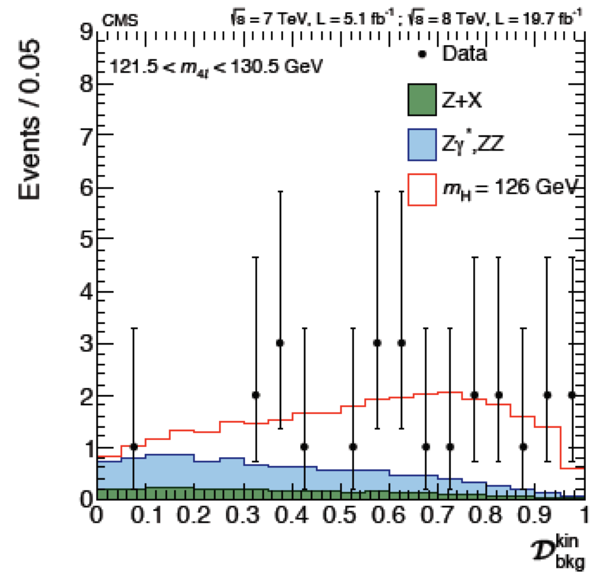
WE USE MELA IN THE FIT

SIGNAL+Background

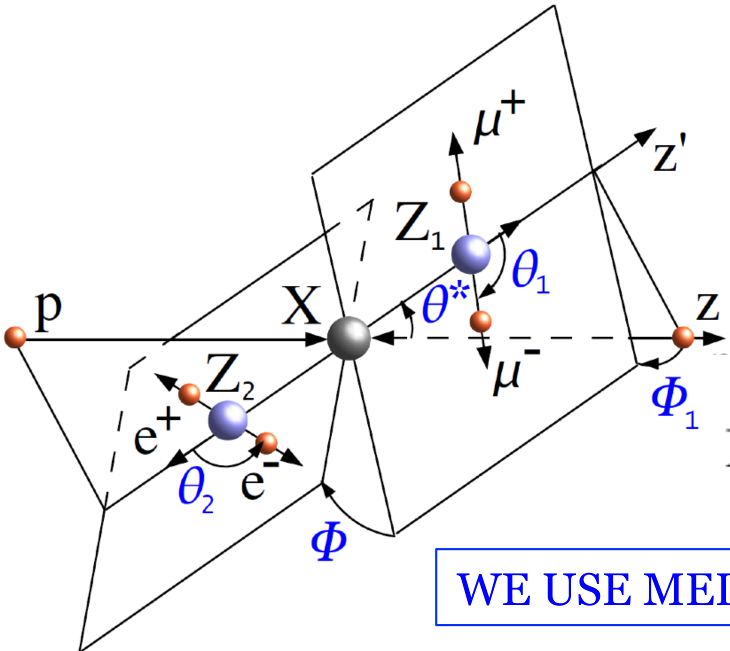


BACKGROUND





Kinematic Discriminant

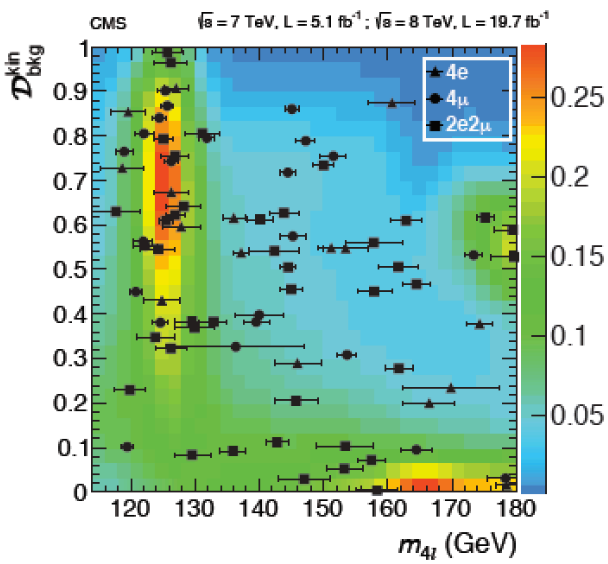


Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

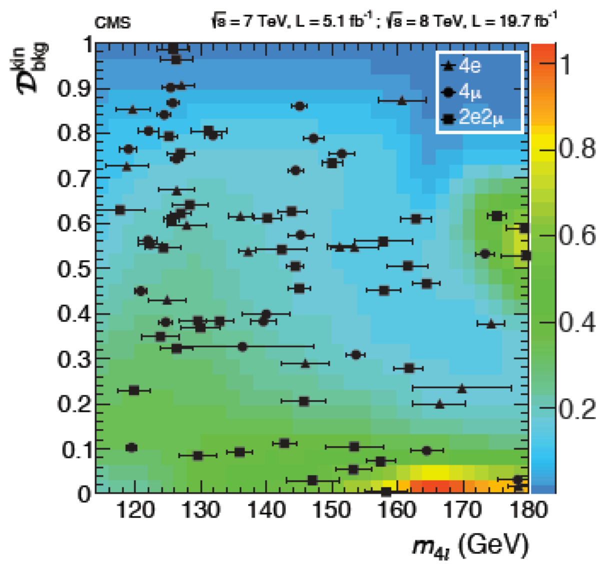
$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

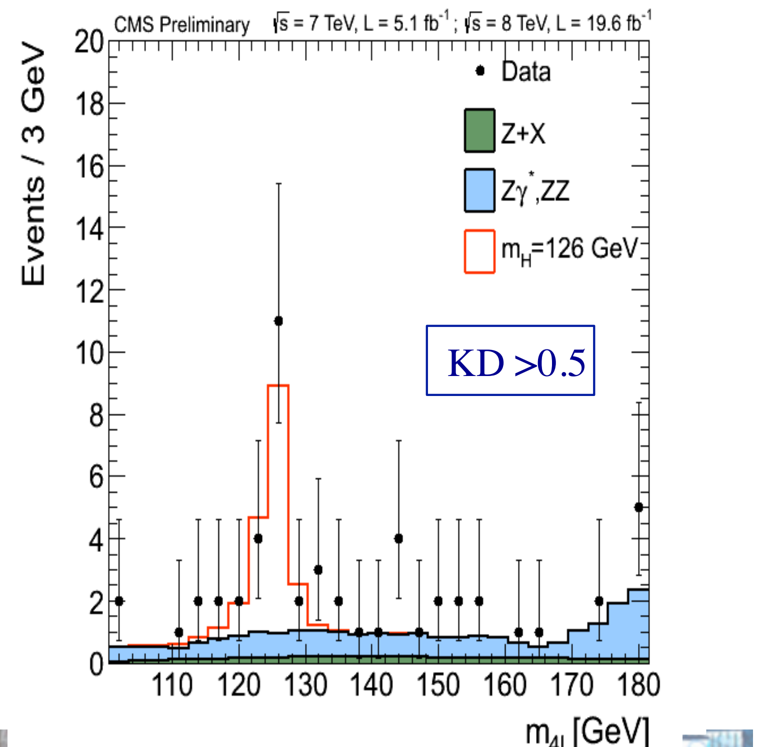
WE USE MELA IN THE FIT

SIGNAL+Background



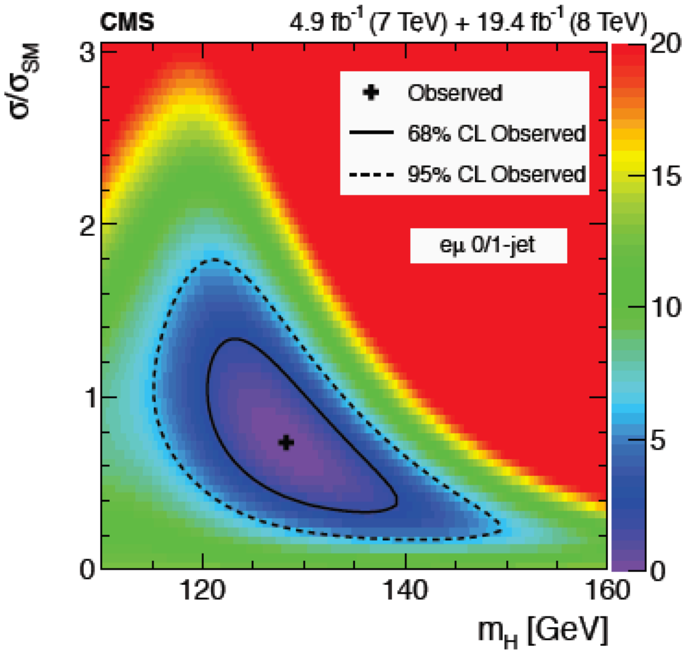
BACKGROUND

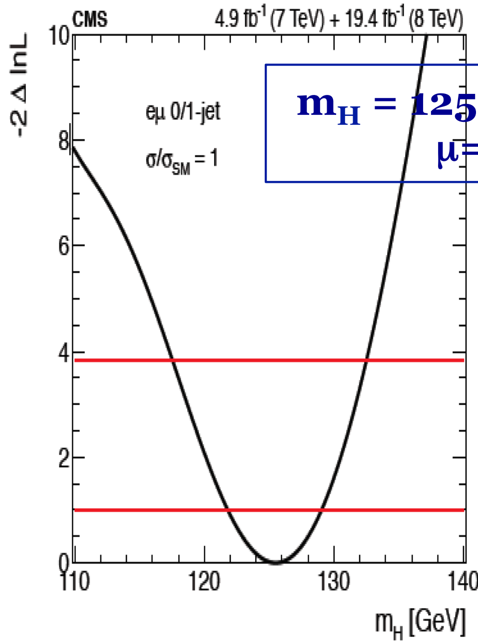




H → WW and H → tt : Results

$m_H = 128.2^{+6.6}_{-5.3}$ GeV



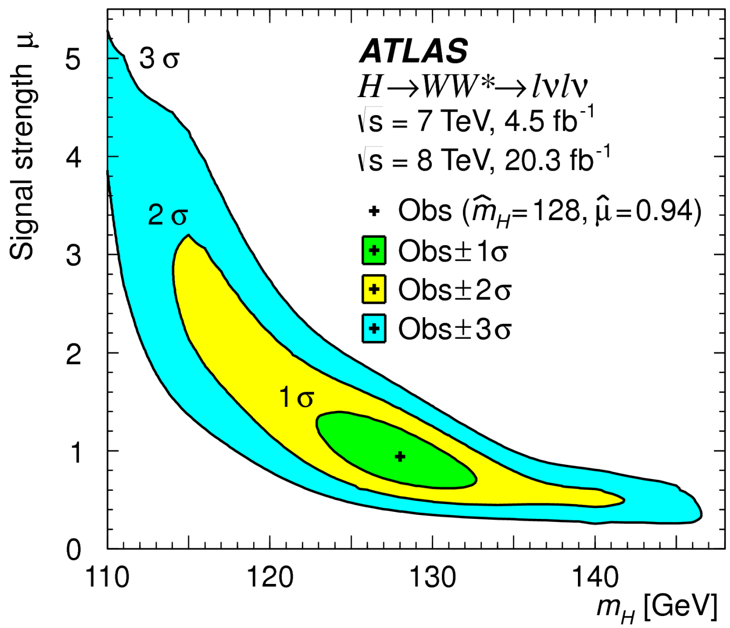


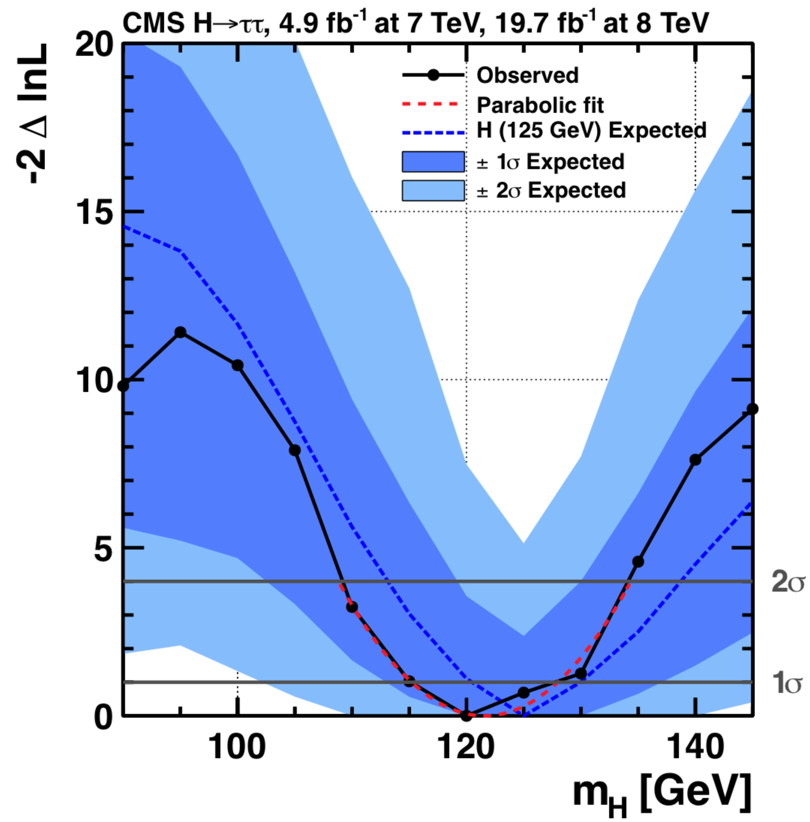
$m_H = 125.5 \pm 3.7$ GeV

$\mu = 1$

Mass: all ττ channels combined:

$m_H = 122 \pm 7$ (stat+syst) GeV





Consistency in 2D

Test production modes in the various decay modes.

Properly accounts for contamination in the tagged categories and their uncertainty.