Recent results on Higgs to *γγ* at ATLAS

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On behalf of

The ATLAS Collaboration

Les Rencontres de Physique de La Vallée d'Aoste
27/02/2013

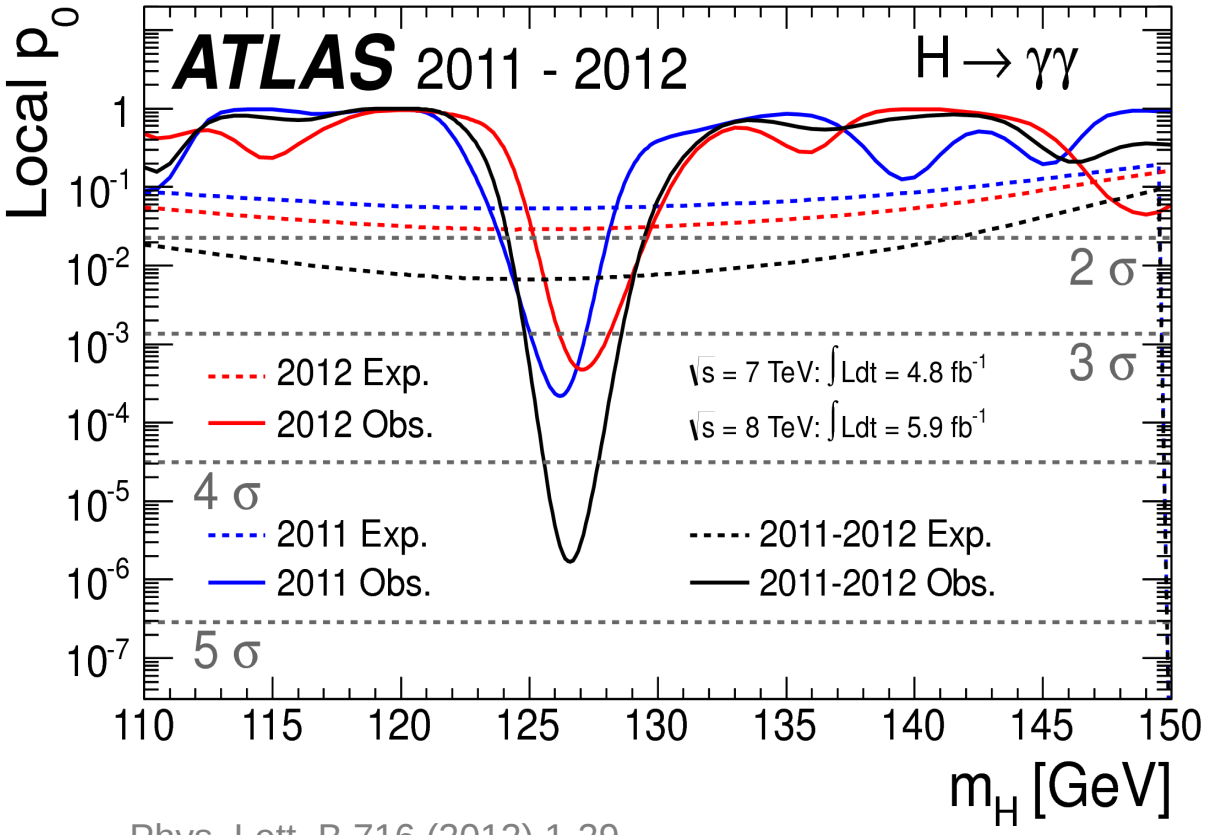
4th July 2012

- Discovery of a new boson announced by ATLAS and CMS in the search for the SM Higgs boson.
- Observation of an excess in the $\gamma\gamma$ channel.

$$\mu = \frac{N^{observed}}{N^{SM}}$$

4.5σ at m_H=126.5 GeV

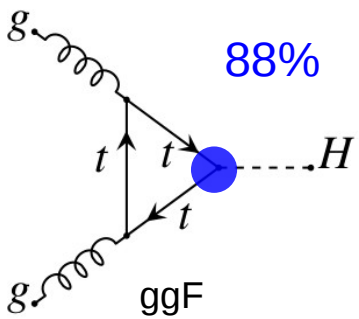
μ=1.9±0.5



Phys. Lett. B 716 (2012) 1-29

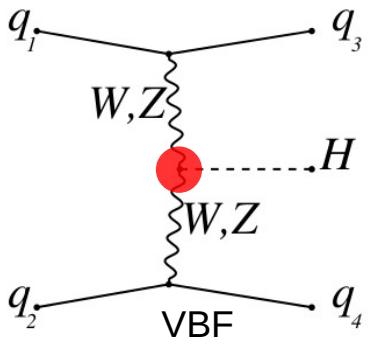
Standard Model Higgs ?

- Higgs production:
  ~10 Higgs per minute at LHC



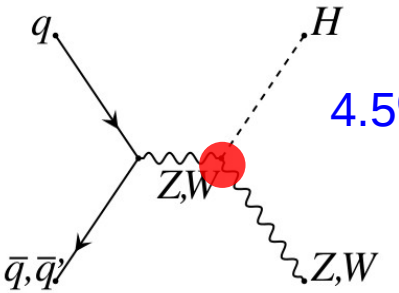
88%

ggF



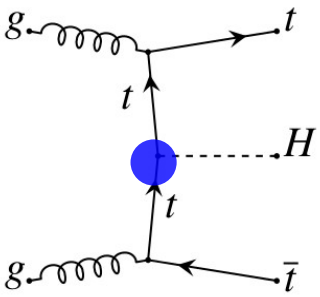
7%

VBF



4.5%

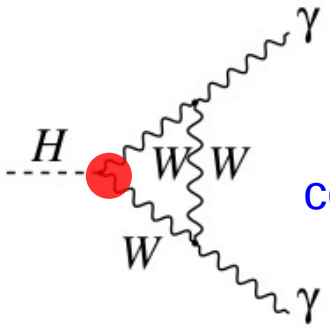
ZH, WH



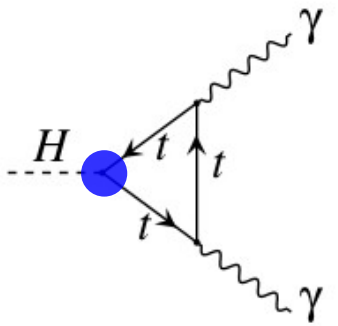
0.5%

ttH

- Higgs decay in γγ:
  $2^0/_{00}$



main contribution



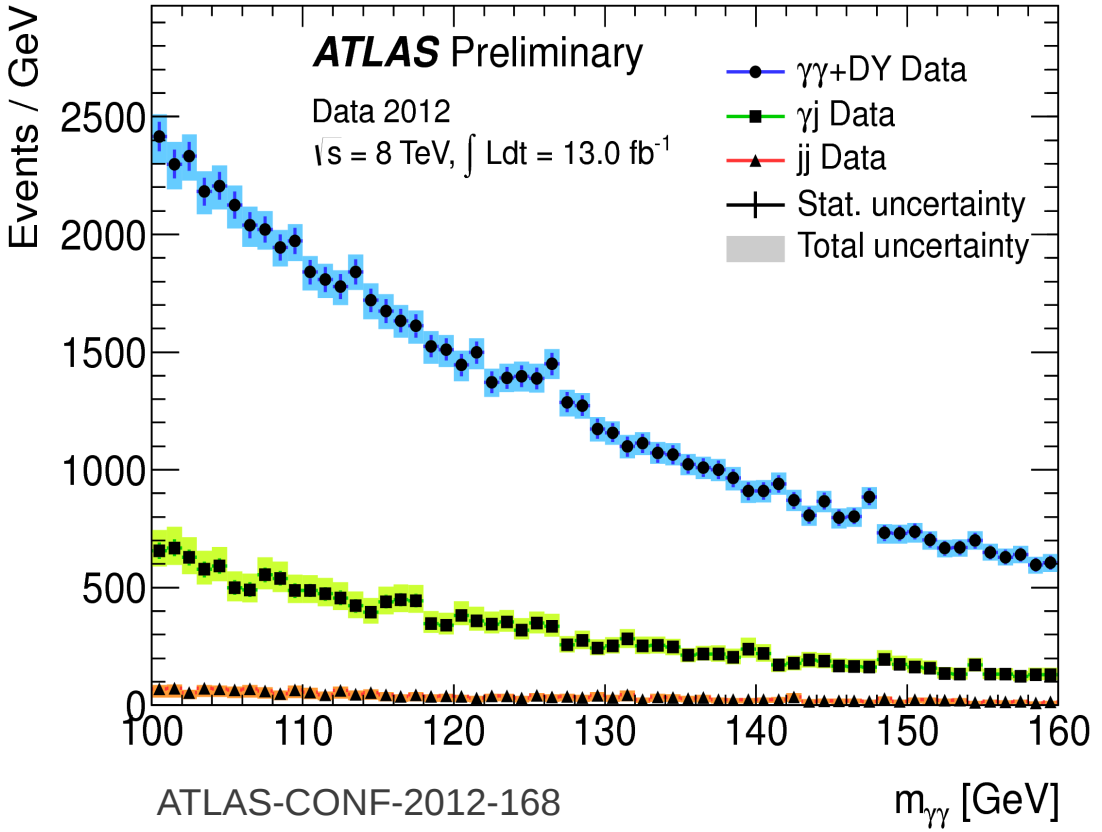
● : fermions

● : vector bosons

- Couplings, spin, mass ?

Event selection

× Two high p_T isolated photons + requirements on EM shower shape variables (photon's identification) → rejection of the reducible background *jet-jet* and *γ-jet* (cross-sections 10^7-10^4 larger than γγ).



ATLAS-CONF-2012-168

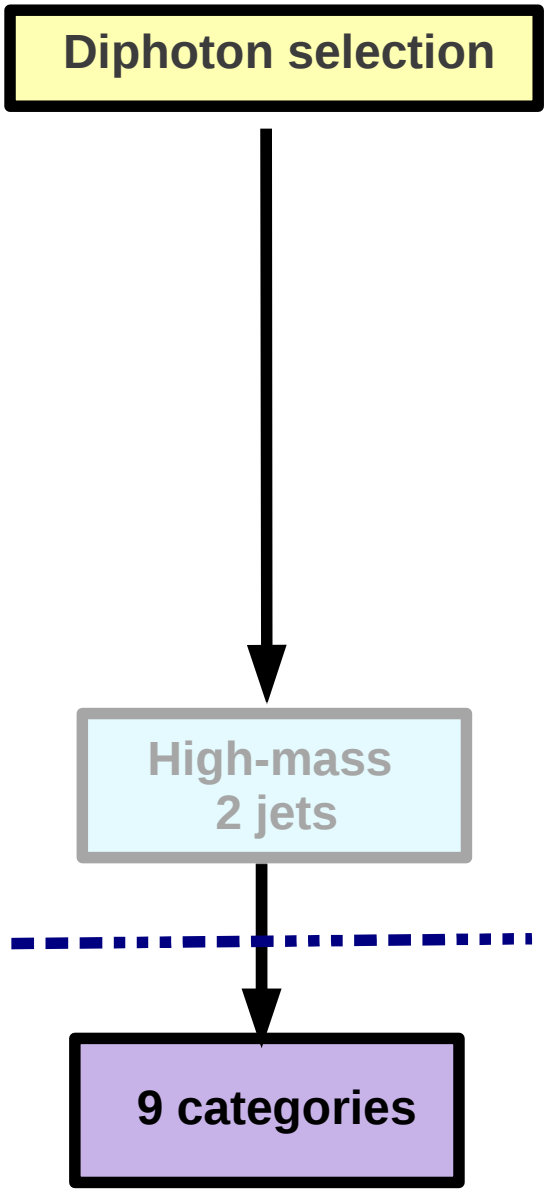
Data driven background decomposition

Rejection factor ~ 10^4
Photon ID efficiency ~ 90%
(for E_T > 40 GeV)

→ **High γγ purity 75%**

→ No excess observed in the reducible background

Event categorisation (1)



× Different S/B ratio + Different mass resolution per category → increase the overall sensitivity.

4th July 2012

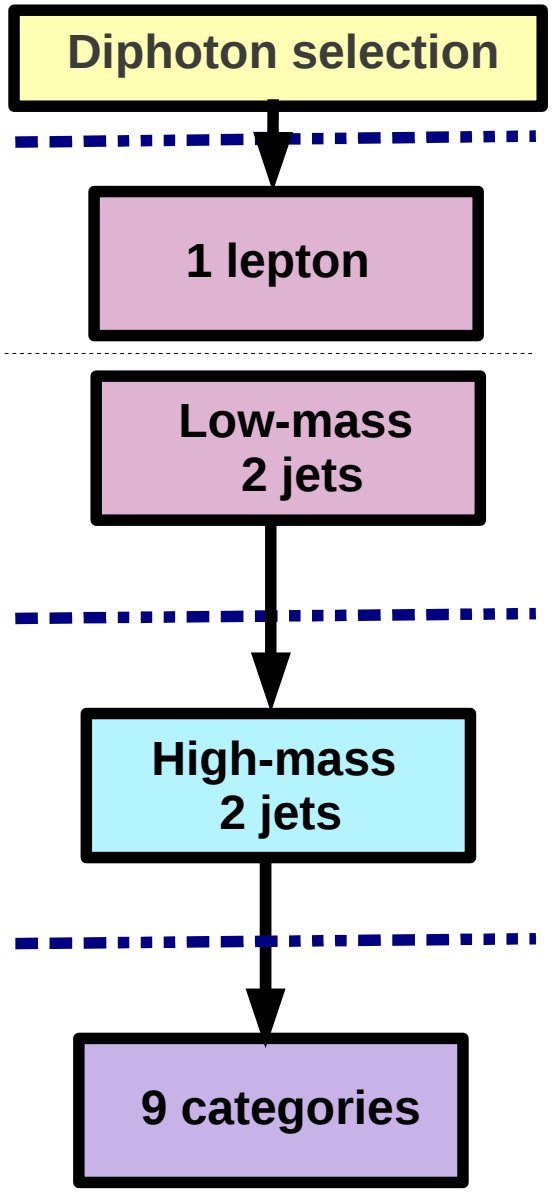
expected *p0* without categorization : ~ 1.8σ

expected *p0* with categorization : ~ 2.4σ

η, p_T, conversion categories

Event categorisation (2)

× Categories enriched in VH/VBF → decrease error on signal strength per production mode



VH categories

WH → lνγγ and Z → llγγ

Hadronic decay of *Z or W*

$60 < m_{jj} < 110$ GeV

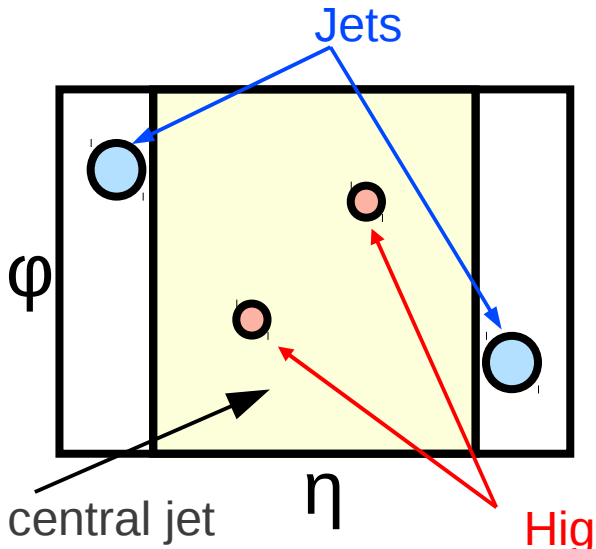
VBF categories

$m_{jj} > 400$ GeV

$|\Delta\eta_{jj}| > 2.8$

$|\Delta\varphi_{\gamma\gamma jj}| > 2.6$

η, p_T, conversion categories

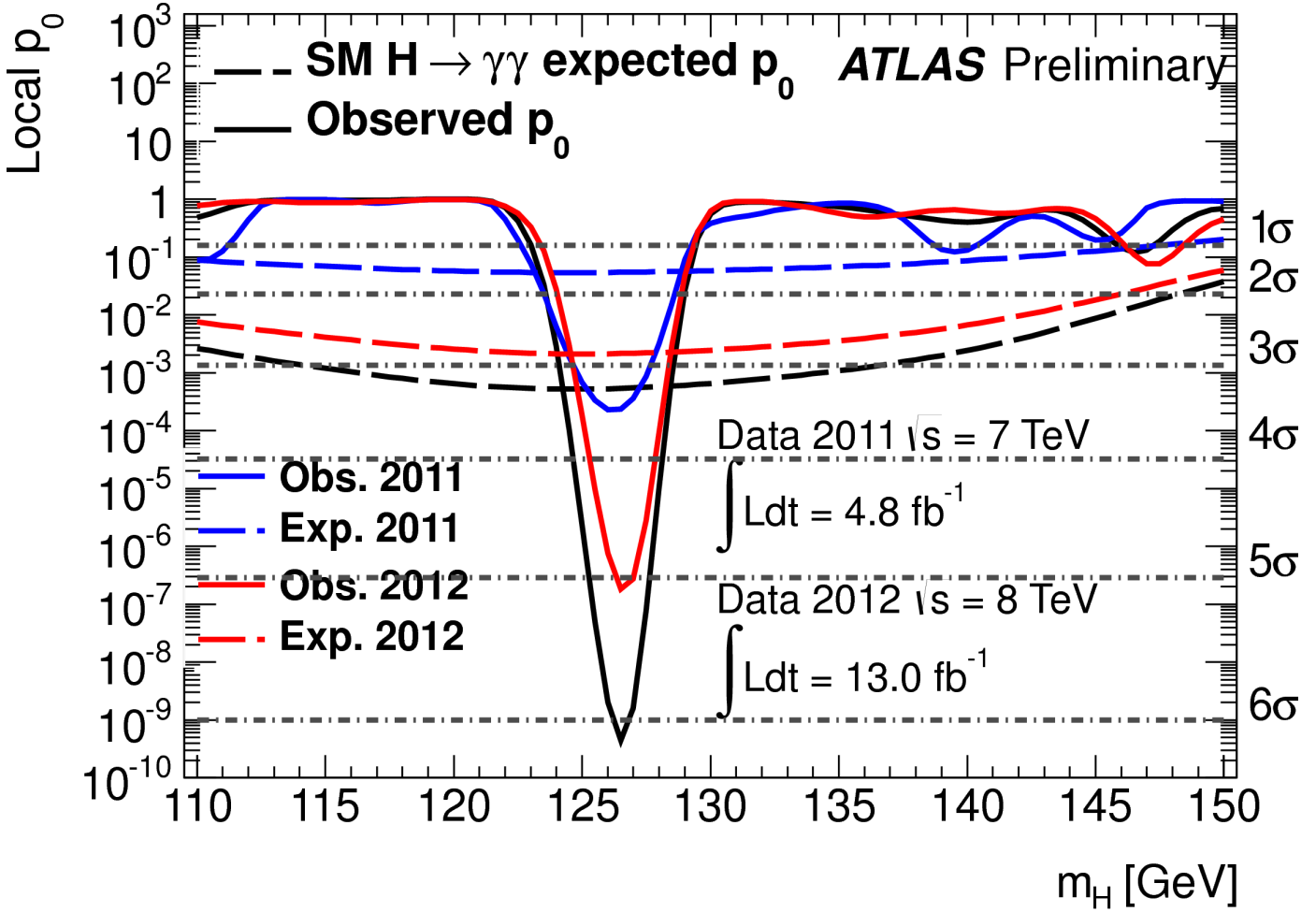


Discovery in the *yy* channel alone

- Last ATLAS update with 4.8fb^{-1} of data at 7TeV and 13fb^{-1} at 8TeV

6.1σ at m_H=126.5 GeV

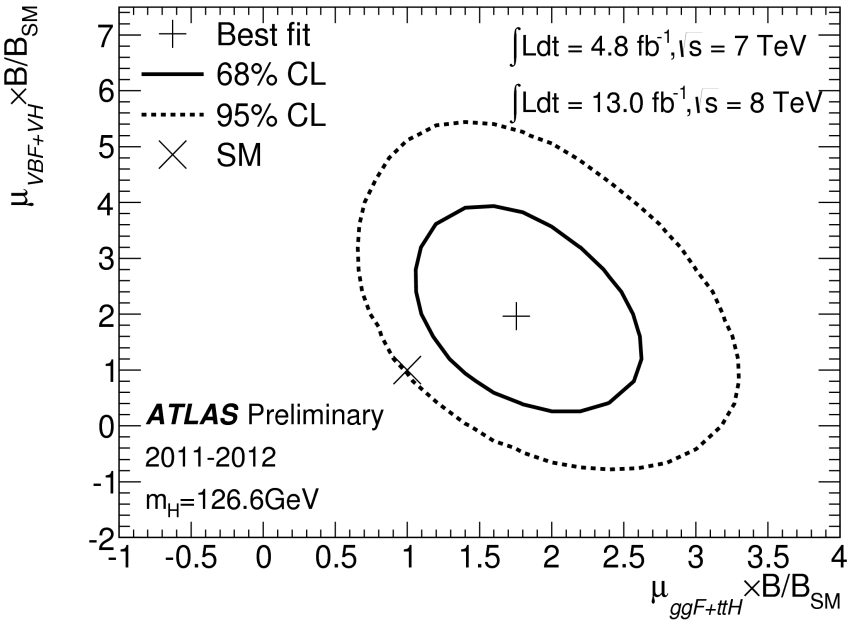
μ=1.80+0.42−0.36



Signal strength per production mode

- Signal strength

$$\mu_i = \frac{N_i^{observed}}{N_i^{SM}}$$

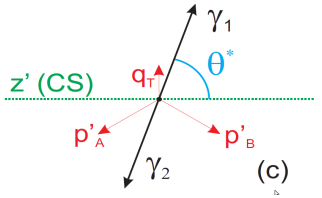


- Main experimental systematic: 5.3% photon efficiency. Theo. error includes QCD scale + PDF + Higgs BR.

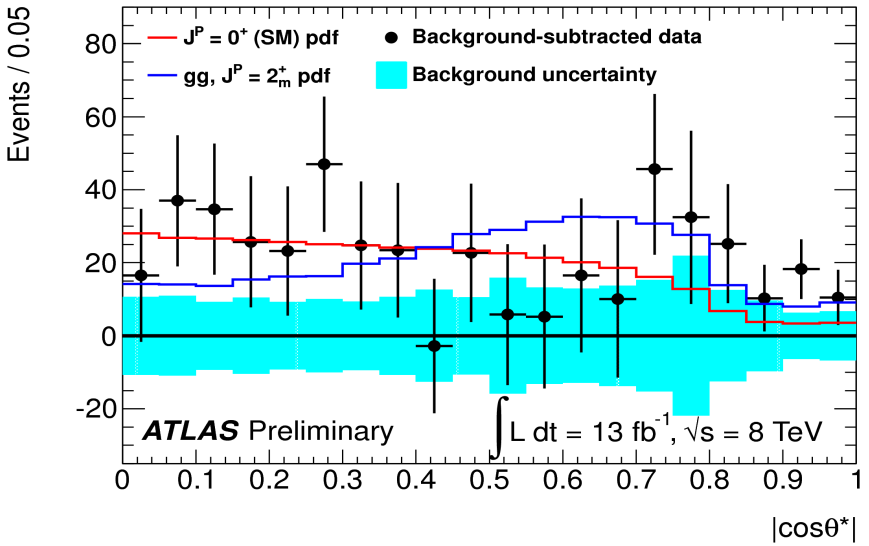
	Value	Stat. error	Syst. error	Theo. error
$\mu_{ggF+ttH} \times B/B_{SM}$	1.8	±0.4	±0.2	±0.2
$\mu_{VBF} \times B/B_{SM}$	2.0	±1.2	±0.6	±0.3
$\mu_{VH} \times B/B_{SM}$	1.9	±2.5	±0.6	±0.4

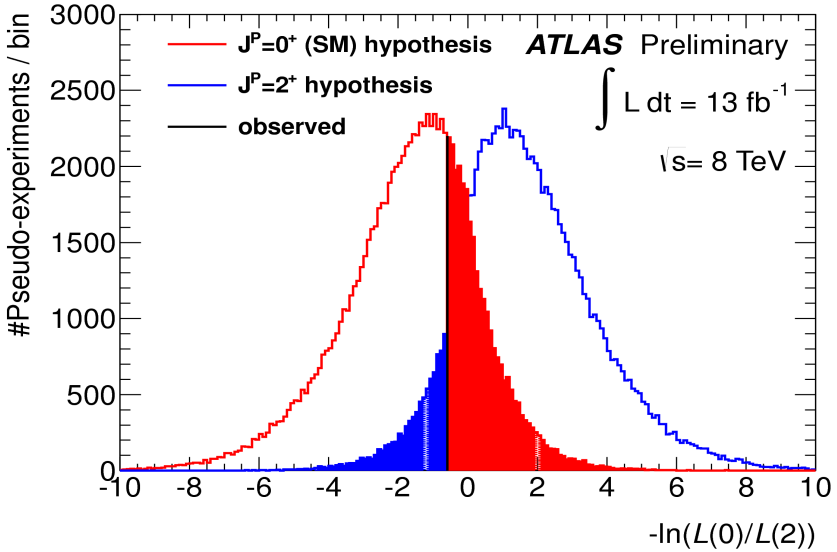
Spin

- Spin 1 is strongly disfavored due to the observation of the $\gamma\gamma$ decay (Landau-Yang theorem).
- Considered models : 0^+ SM Higgs and the graviton-like spin-2 state with minimal coupling 2^+_m
- Study based on the single discriminating variable $|\cos\theta^*|$



Expected sensitivity : 1.8σ between spin 0^+ and 2^+_m



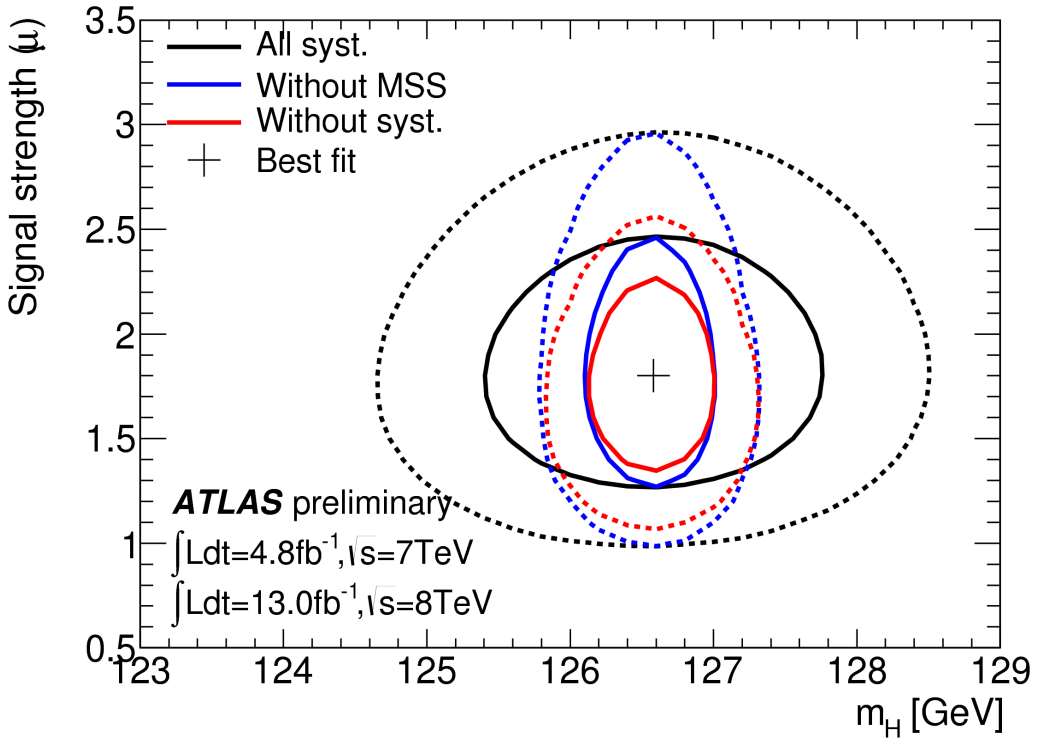


Observed p0 value for: **0^+ hypothesis 29% (0.55σ)**
2^+_m hypothesis 8.4% (1.4σ)

0^+ SM Higgs boson hypothesis favoured

Mass

× Best fit value of m_H



× 3 main uncertainties:

. Extrapolation from Z → ee energy scale
. Material modelling
. Presampler energy scale
→ 0.45% (550 MeV)

+ fraction of converted photons + signal resolution + background modelling choice +... Each < 0.2%

No correlation between mass and μ measurement

m_H=126.6 ± 0.3(stat) ± 0.7 (syst) GeV

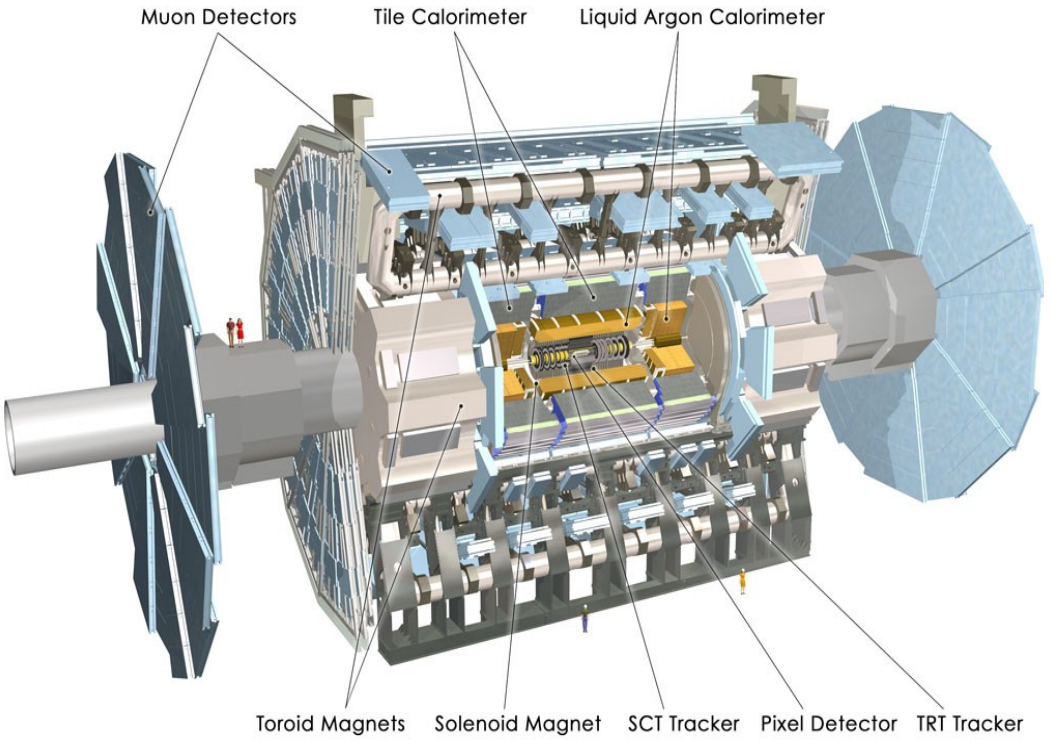
Conclusion

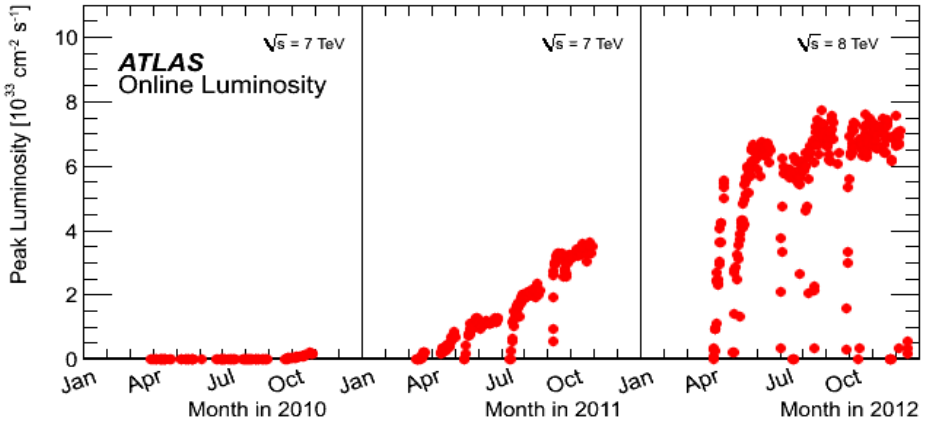
- **6.1σ** → discovery in $\gamma\gamma$ channel (expected : 3.3σ)
- μ **=1.80+0.42-0.36** at m_H**=126.6 ± 0.3(stat) ± 0.7 (syst) GeV**
  → 2.4σ from the Standard Model
- Favour **0+** state
- Next update: 21 fb^{-1} (+ analysis improvements )

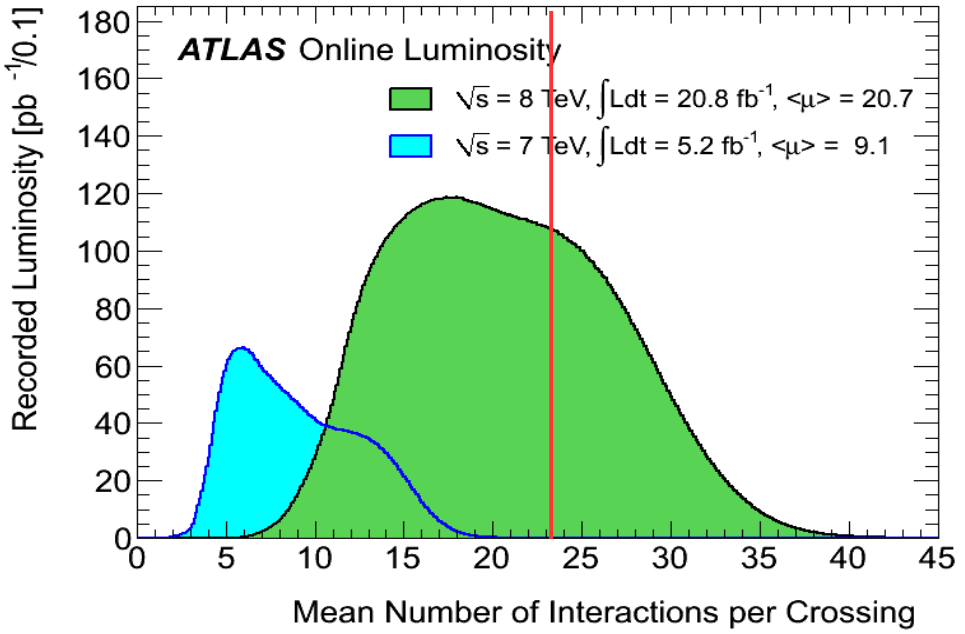
	Total	ggH	VBF	VH	ttH
Number of expected event for 21 fb^{-1}	**400**	**352**	**28**	**18**	**2**

Back-up

The ATLAS experiment







- Peak luminosity in 2012 :
  $7.7\ 10^{33}\ cm^{-2}\ s^{-1}$ at 8 TeV

Large pile-up, above experiment design value → challenge!

4^{th} July 2012

- Observation of an excess in the search for the SM Higgs boson in the $\gamma\gamma$ channel.

ATLAS

4.5σ at $m_H = 126.5$ GeV

$\mu = 1.9 \pm 0.5$

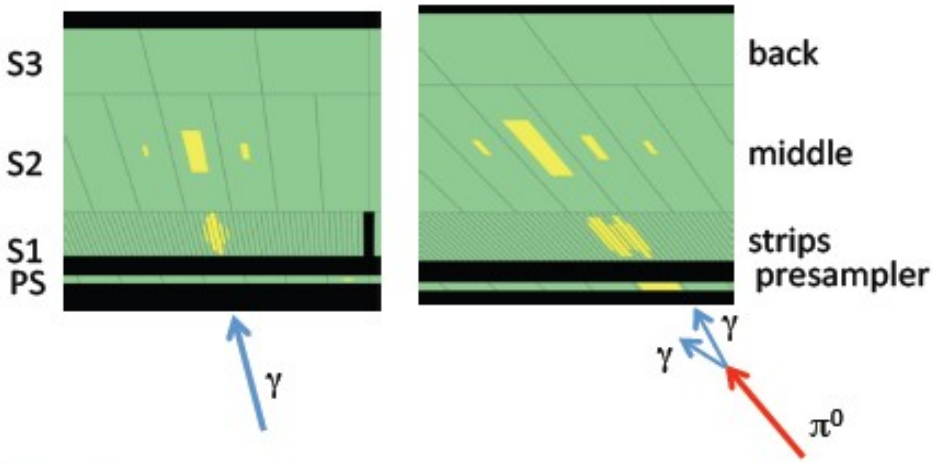
CMS

4.1σ at $m_H = 125$ GeV

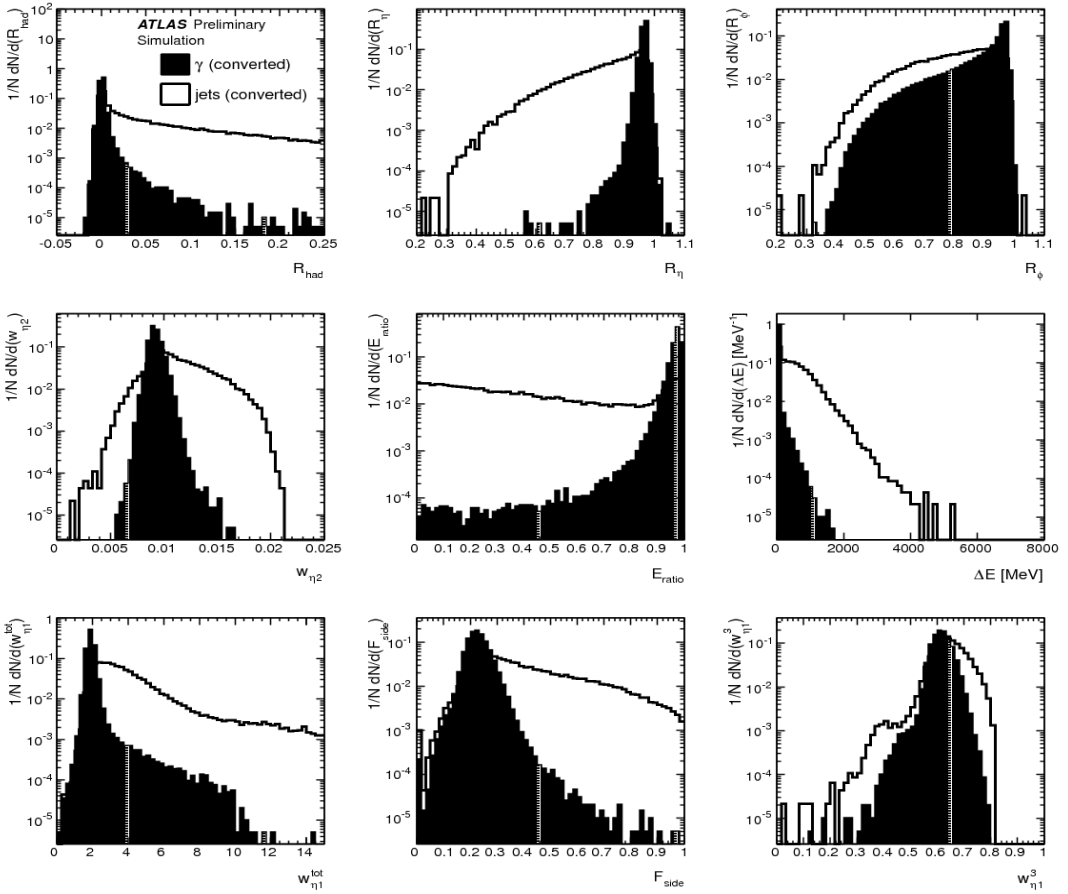
$\mu = 1.56 \pm 0.43$

Photon's identification

- 9 variables to caracterize the EM shower shape



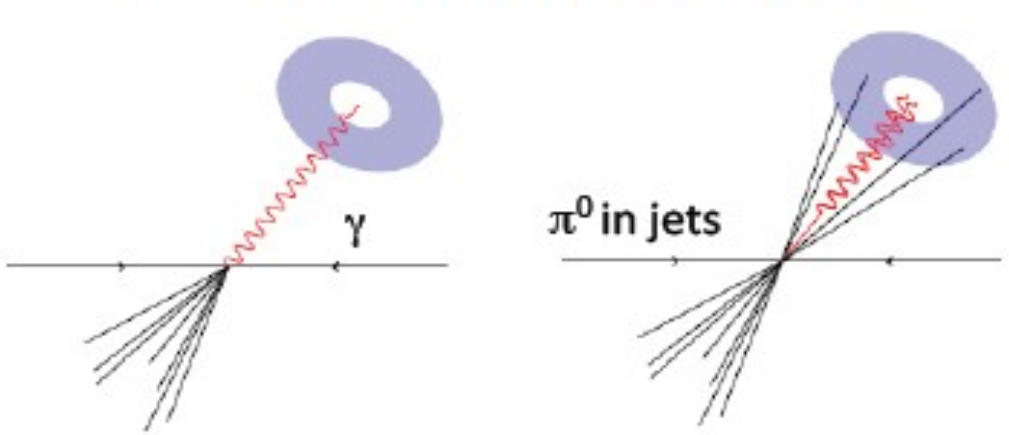
$$E_{ratio} = \frac{E_{\max 1} - E_{\max 2}}{E_{\max 1} + E_{\max 2}}$$



Photon's isolation

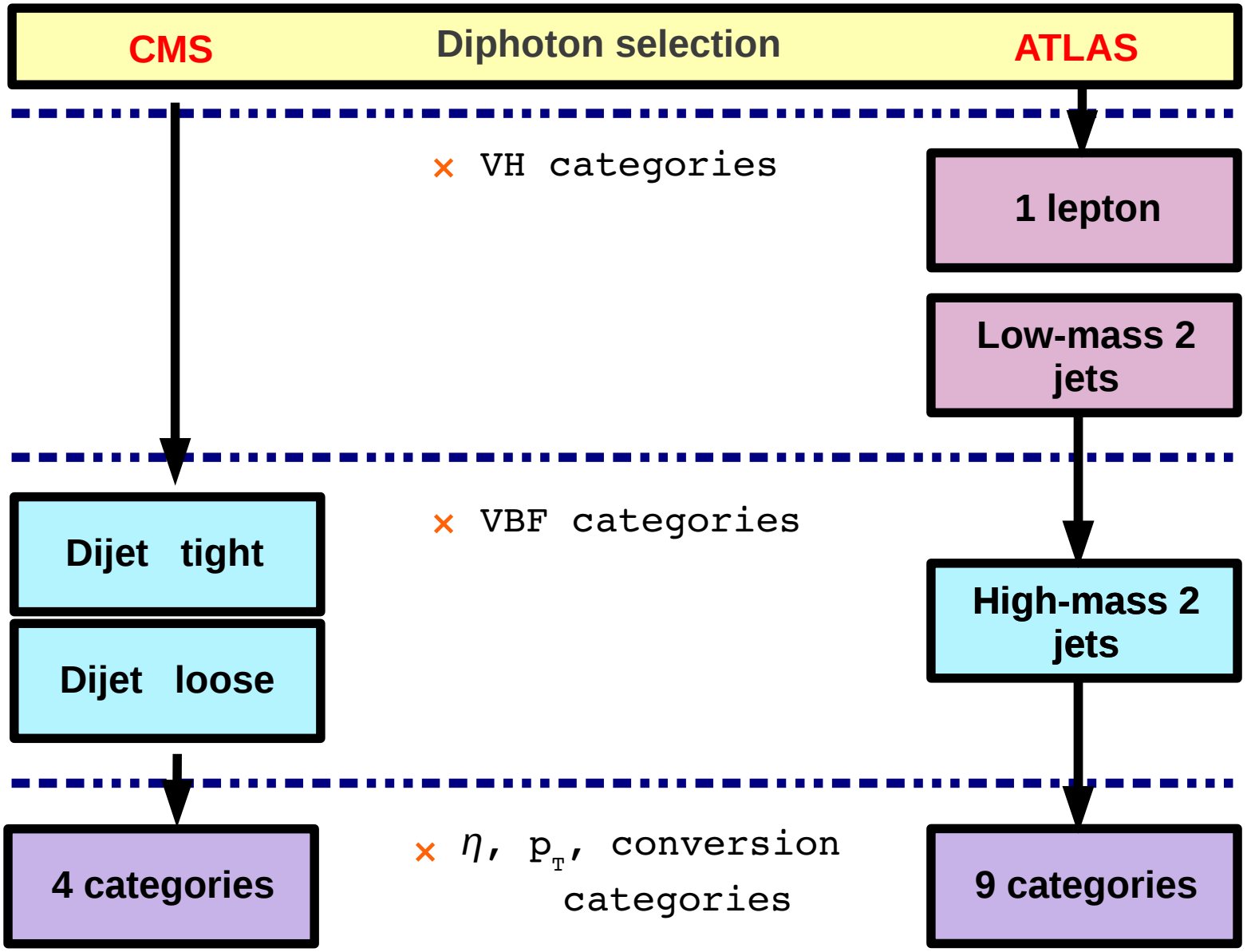
× Tracker isolation: p_T sum of all tracks with pT > 1 GeV in a cone of $\Delta R < 0.2$ around each photon. Required to be below 2.6 GeV

× Calorimeter isolation: transverse energy sum (of topological cluster) deposited in the calorimeter around the photon in a cone of $\Delta R = 0.4$. Required to be below 6 GeV



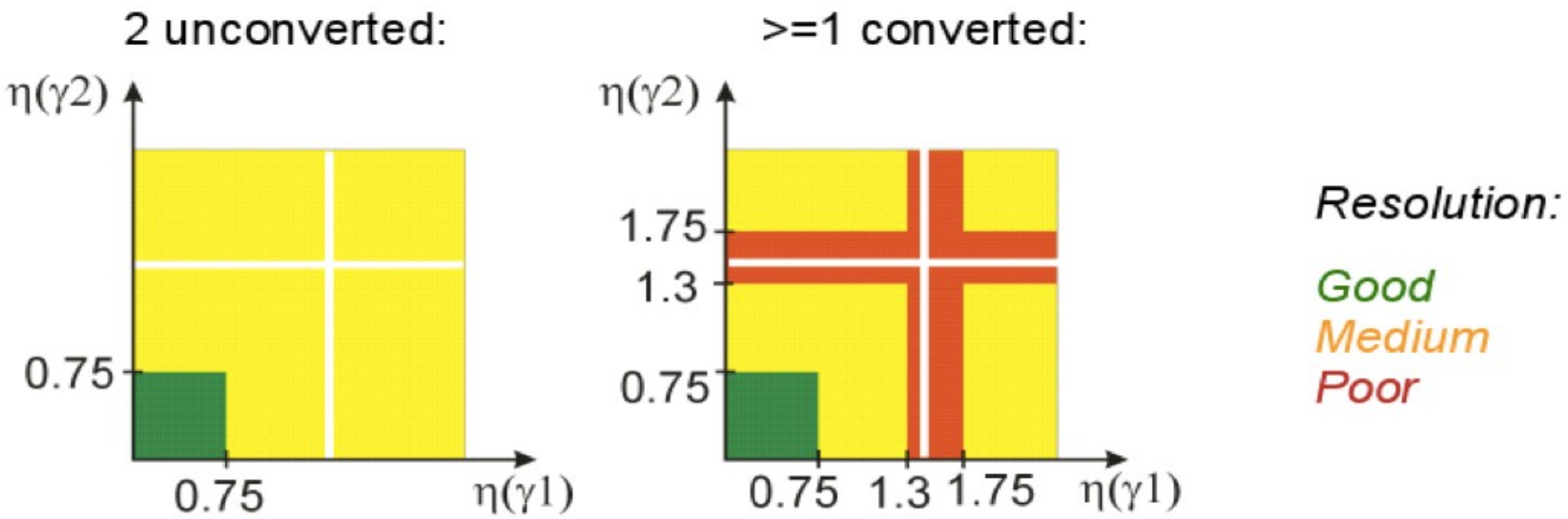
"Tight" selection + isolation requirement → rejection factor ~10000

Event categorisation CMS/ATLAS

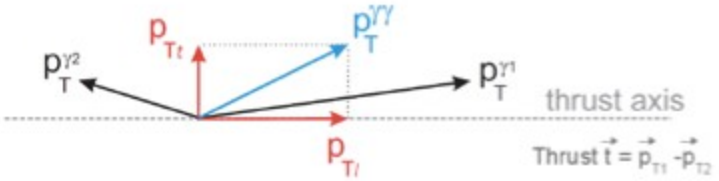


Categories

- η, p_{Tt} and conversion categories



Central and Rest divided
into $p_{Tt} < 60\,\mathrm{GeV}$
and $p_{Tt} > 60\,\mathrm{GeV}$



Purity per category

× Number of events in the data and expected number of signal events for m_H=126.5 GeV, for each category in the mass range 100-160 GeV

$\sqrt{s}$	8 TeV						
Category	N_D	N_S	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
Unconv. central, low p_{Tt}	6797	32	93	4.2	1.4	0.9	0.2
Unconv. central, high p_{Tt}	319	4.7	76	15.2	3.9	2.9	1.7
Unconv. rest, low p_{Tt}	26802	69	93	4.2	1.7	1.1	0.2
Unconv. rest, high p_{Tt}	1538	9.7	76	15.1	4.5	3.3	1.2
Conv. central, low p_{Tt}	4480	21	93	4.2	1.4	0.9	0.2
Conv. central, high p_{Tt}	199	3.1	77	14.5	4.1	2.8	1.7
Conv. rest, low p_{Tt}	24107	60	93	4.1	1.7	1.1	0.2
Conv. rest, high p_{Tt}	1324	8.3	75	15.1	4.9	3.4	1.3
Conv. transition	10891	28	90	5.6	2.3	1.5	0.3
High Mass two-jet	345	7.6	31	68.2	0.3	0.2	0.1
Low Mass two-jet	477	4.7	60	5.1	20.7	12.1	1.6
One-lepton	151	2.0	3.2	0.4	62.5	15.8	18.0
All categories (inclusive)	77430	249	88	7.4	2.8	1.6	0.5

Resolutions and S/B ratio per category

- Signal, mass resolutions and number of events in the data and expected number of signal events in a mass window around m_H=126.5 GeV containing 90% of the expected signal.

$\sqrt{s}$	8 TeV					
Category	$\sigma_{CB}(GeV)$	FWHM (GeV)	Observed	N_S	N_B	N_S/N_B
Unconv. central, low p_{Tt}	1.47	3.45	569	29	538	0.053
Unconv. central, high p_{Tt}	1.37	3.22	25	4.2	25	0.168
Unconv. rest, low p_{Tt}	1.59	3.75	2773	61	2610	0.023
Unconv. rest, high p_{Tt}	1.52	3.59	148	8.7	138	0.063
Conv. central, low p_{Tt}	1.64	3.86	446	18	417	0.044
Conv. central, high p_{Tt}	1.49	3.51	18	2.8	17	0.163
Conv. rest, low p_{Tt}	1.83	4.32	2898	54	2763	0.019
Conv. rest, high p_{Tt}	1.7	4.00	144	7.4	138	0.053
Conv. transition	2.35	5.57	1872	25	1825	0.014
High Mass two-jet	1.55	3.65	47	6.8	33	0.204
Low Mass two-jet	1.46	3.45	62	4.2	45	0.093
One-lepton	1.63	3.85	18	1.7	16	0.108
Inclusive	1.64	3.87	8802	223	8284	0.027

Systematics

× Systematic uncertainties impact on the signal yield for the analysis of the 8 TeV data.

Systematic uncertainties	Value(%)			Constraint
Luminosity	±3.6			
Trigger	±0.5			
Photon ID	±5.3			Log-normal
Isolation	±1.0			
Photon Energy Scale	±0.4			
Branching ratio	$\pm 5.9\% - \pm 2.1\%$ (m_H = 110 - 150 GeV)			Asymmetric Log-normal
Scale	ggH: $^{+7.2}_{-7.8}$	VBF: $^{+0.2}_{-0.2}$	WH: $^{+0.2}_{-0.6}$	Asymmetric
	ZH: $^{+1.6}_{-1.5}$	ttH: $^{+3.8}_{-9.3}$		Log-normal
Pdf+α_s	ggH: $^{+7.5}_{-6.9}$	VBF: $^{+2.6}_{-2.7}$		Asymmetric
	WH: ±3.5	ZH: ±3.6	ttH: ±7.8	Log-normal
Theory cross section on ggF	High Mass two-jet: 25		Low Mass two-jet: 30	Log-normal

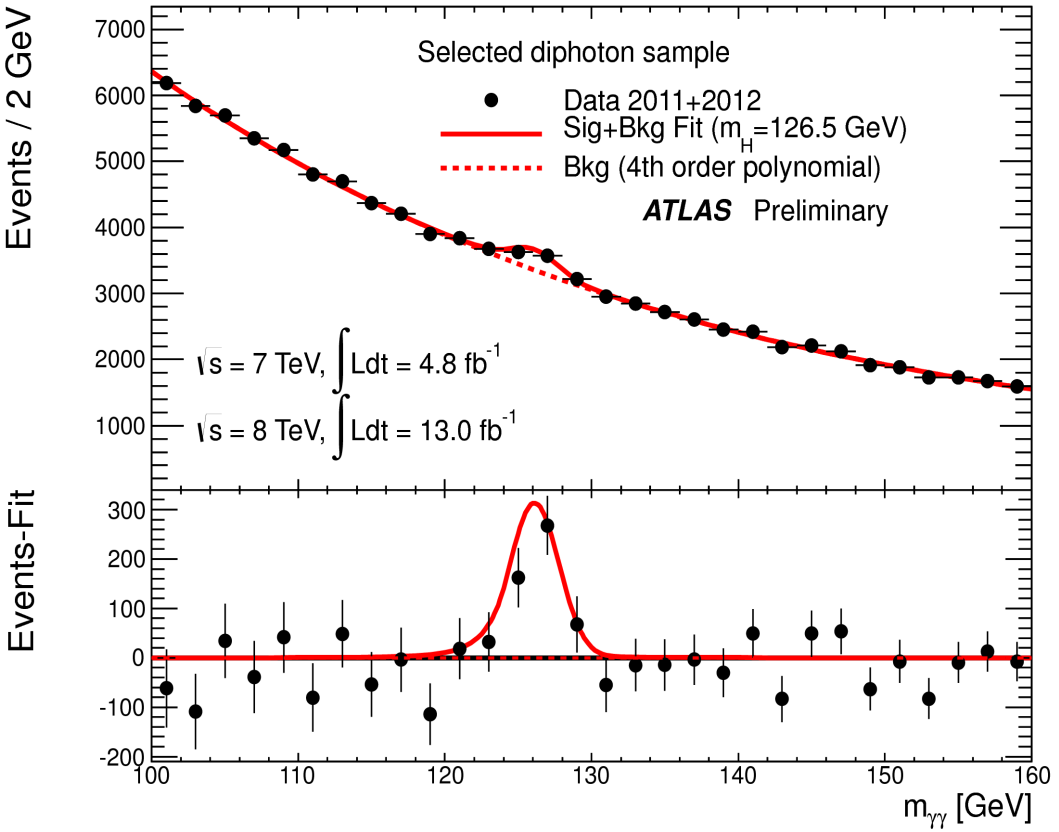
Statistical procedure

- Signal and Background modelling

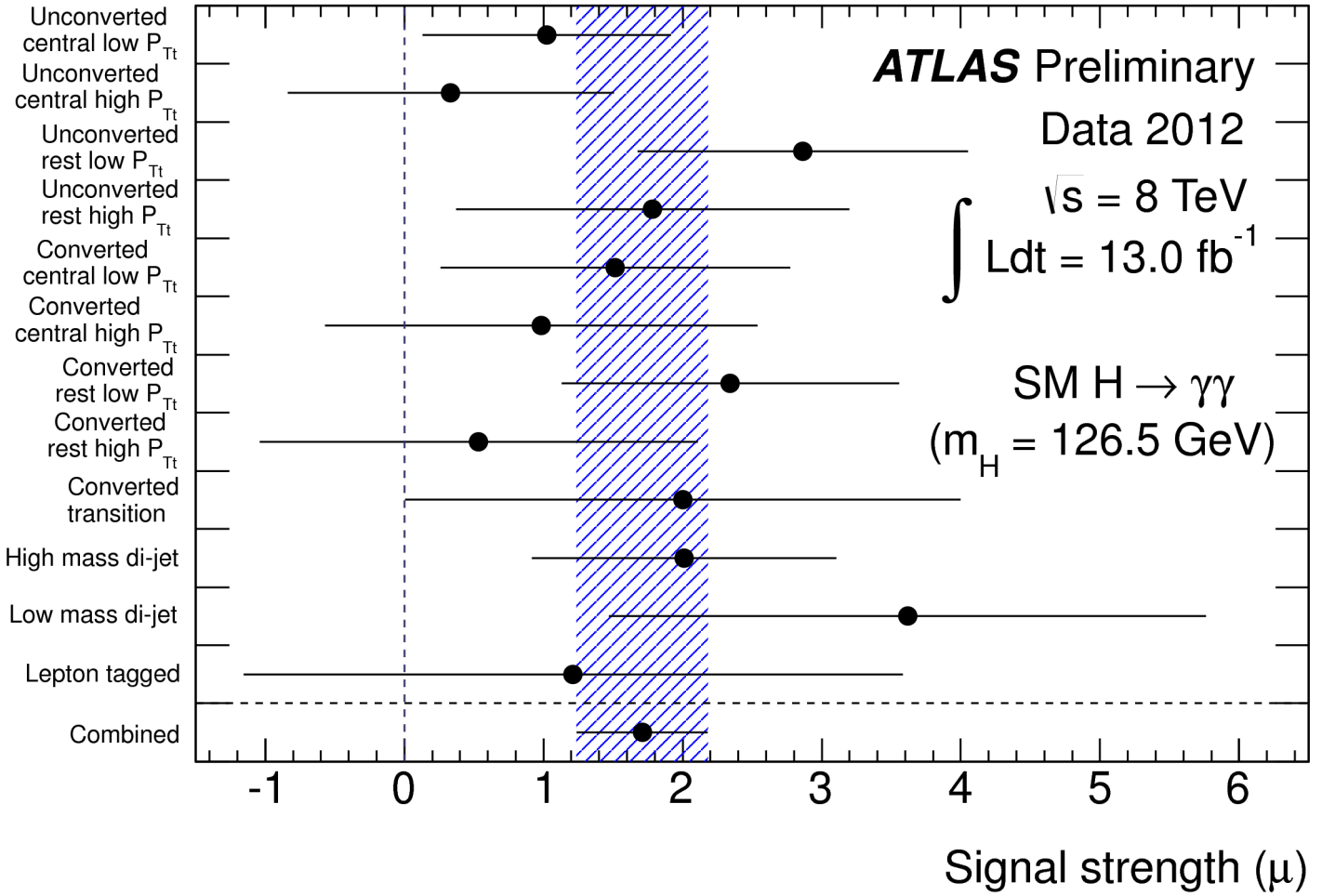
  . Signal = Crystal Ball + Gaussian (MC samples)

  . Background = Exponential or Bernstein 4 (depends on the category)

- μ = the parameter of interest.
  Profile likelihood ratio used to test different values.

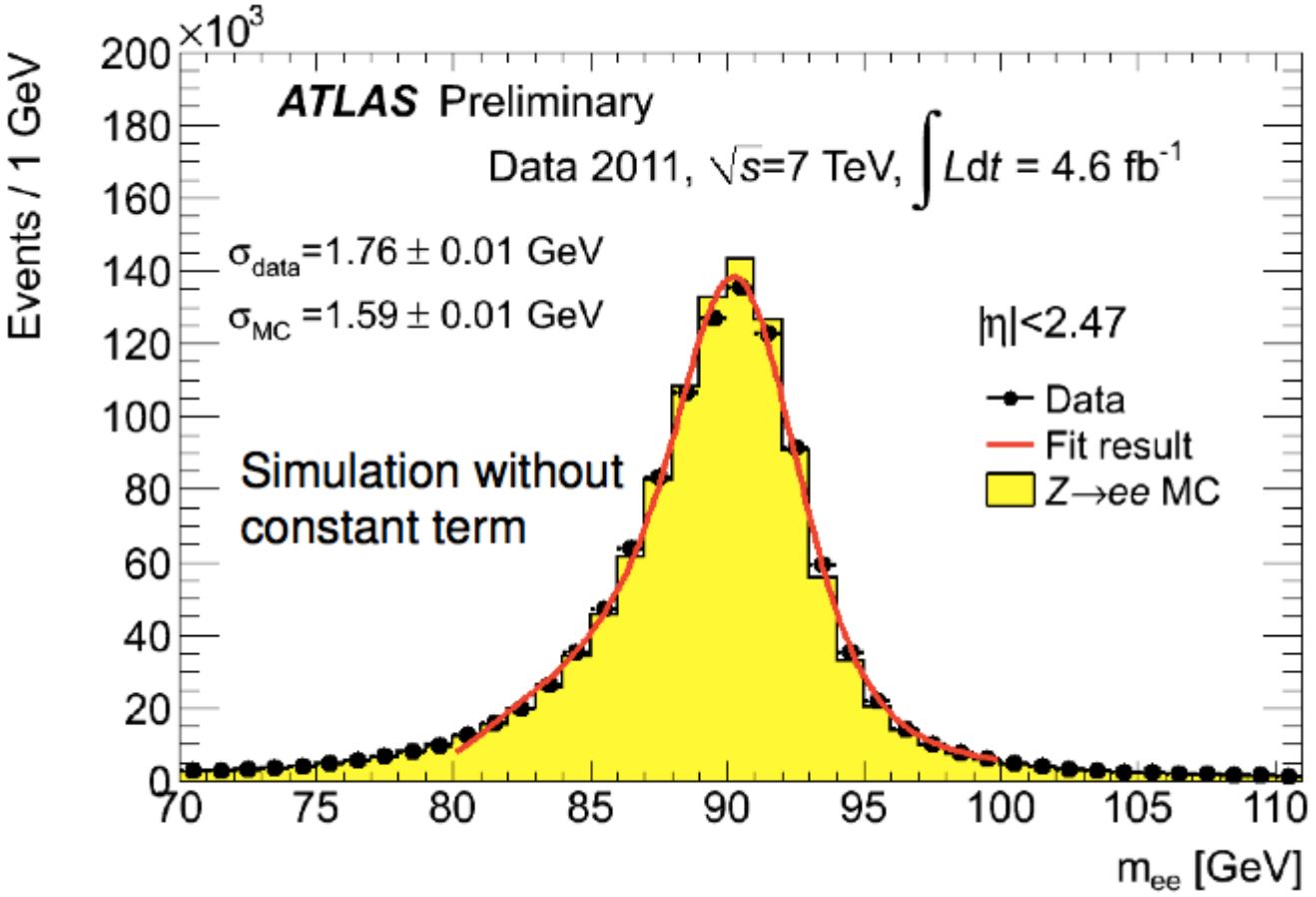


Signal strength per category



Photon energy calibration

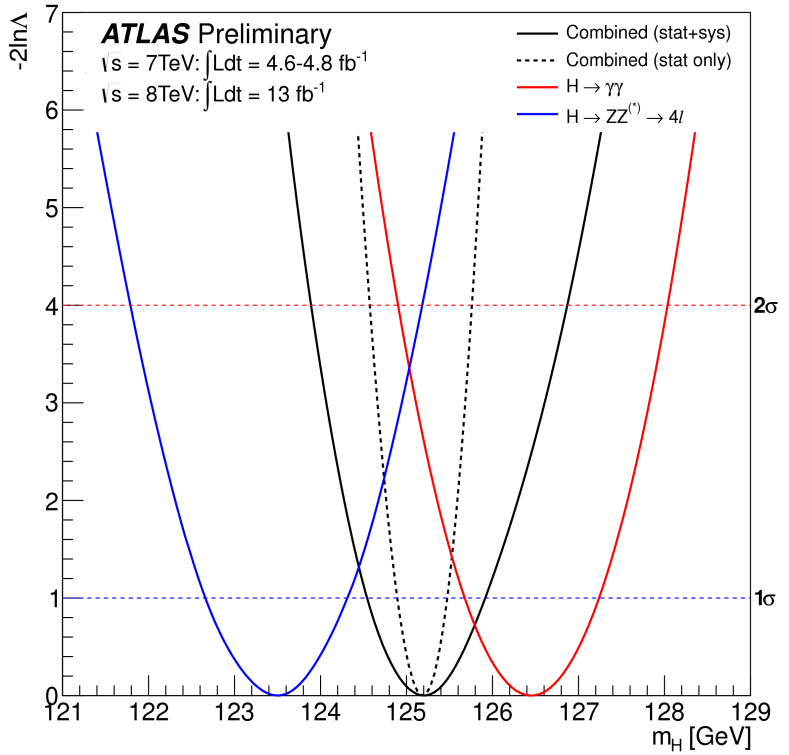
- MC based calibration + additional corrections (material mis-modelling, calorimeter non-uniformity) from $Z \rightarrow ee$ in data.
- Independent calibration for converted and unconverted photons.
- Energy scale at m_z known to 0.3%, uniformity (constant term) 1% in barrel, 1.2 to 2.1% in endcap.



Mass measurement

- Mass in $H \to \gamma\gamma$ and $H \to 4l$

  - $H \to \gamma\gamma$: m_H=126.6 ± 0.3(stat) ± 0.7(syst) GeV
  - $H \to 4l$: m_H=123.5 ± 0.8(stat) ± 0.3(syst) GeV
  - combination : m_H=125.2 ± 0.3(stat) ± 0.6(syst) GeV

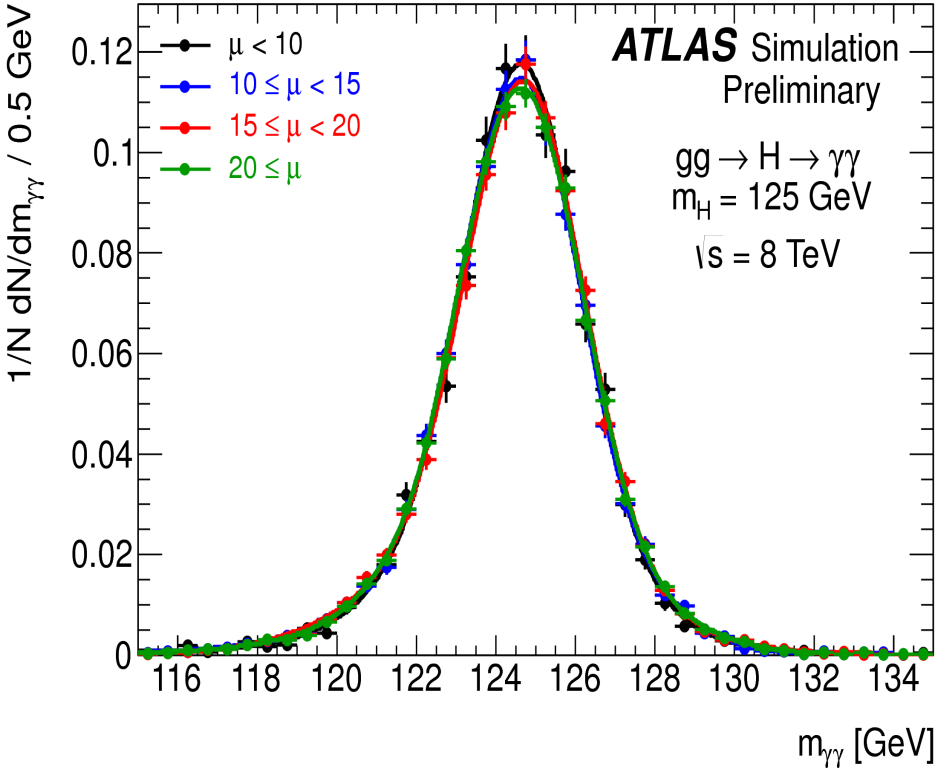


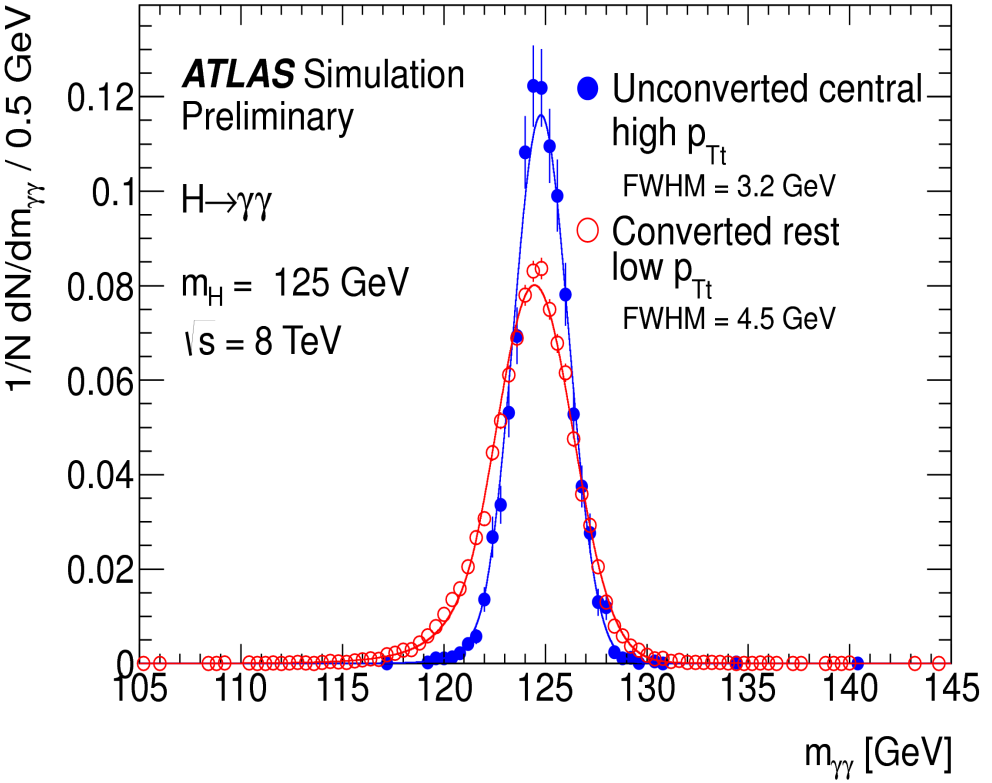
Difference:
$3.0 \pm 0.8(\text{stat})^{+0.7}_{-0.6}(\text{syst})$GeV
→ **2.7σ** (~0.8% probability)

Systematics dominated so far by photon energy scale.

Mass resolution in *yy*

- Inclusive mass resolution: 1.64 GeV
- Pile-up robust
- Main systematic: energy calorimeter scale (12%)





Contour plots

- Vary μ_i, fixe μ_f to unity

$$n^k_{\text{signal}} = \left(\sum_i \mu_i \sigma_{i,\text{SM}} \times A^k_i \times \varepsilon^k_{if} \right) \times \mu_f \times B_{f,\text{SM}} \times \mathcal{L}^k$$

  - A : detector acceptance
  - L : integrated luminosity
  - ε : reconstruction efficiency
  - $\mu_i = \sigma_i / \sigma_{i,\text{SM}}$ and $\mu_f = B_f / B_{f,\text{SM}}$

Coupling fits

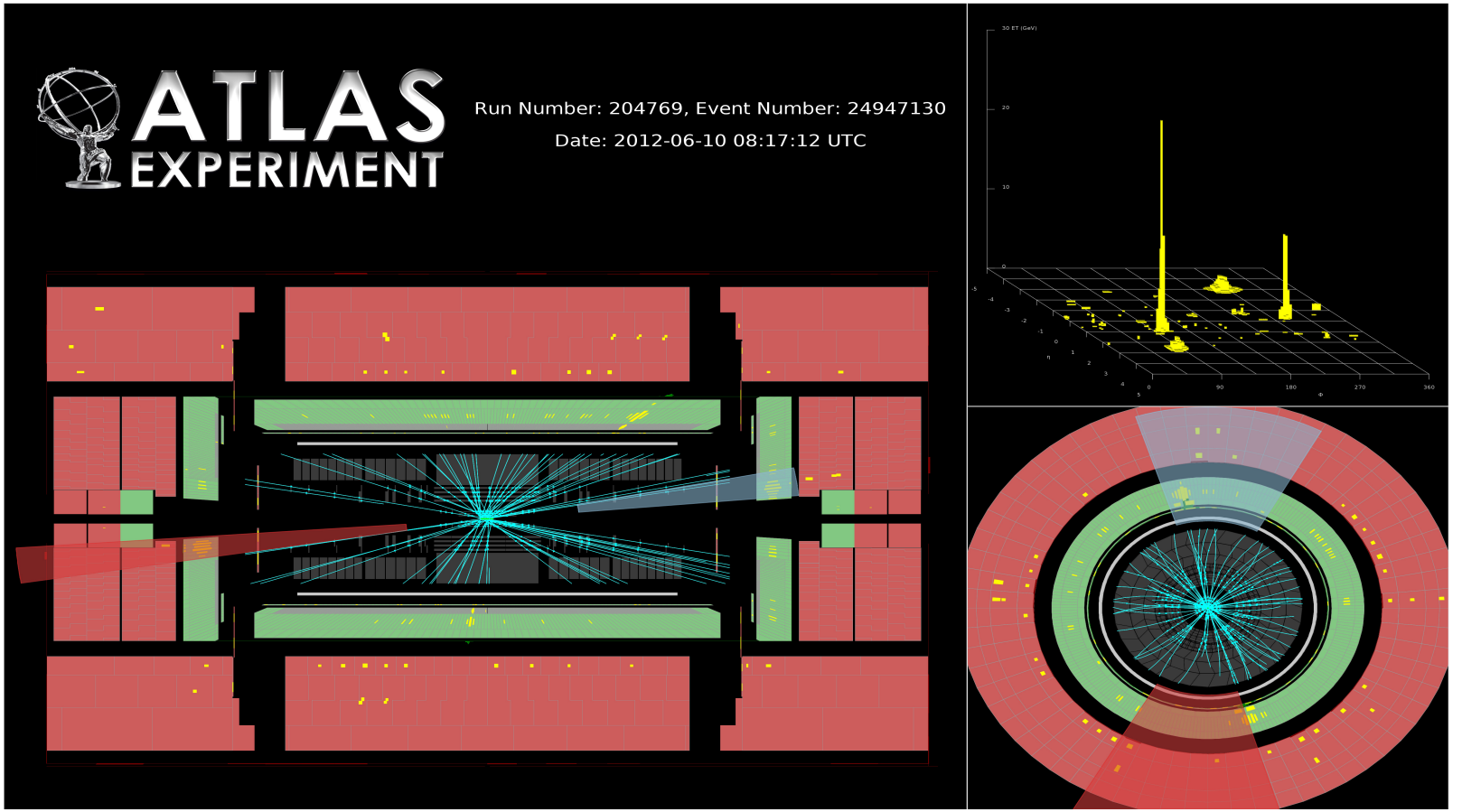
- Observed yields can be parametrized as:
  SM x coupling scale factors κ

$$\sigma \cdot BR(ii \to H \to ff) = \sigma_{SM} \cdot BR_{SM} \frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2} \quad \sim \Gamma_i \cdot \Gamma_f / \Gamma_H$$

  - κ_H : total Higgs width ~ 4 MeV, not accessible at LHC

Event display

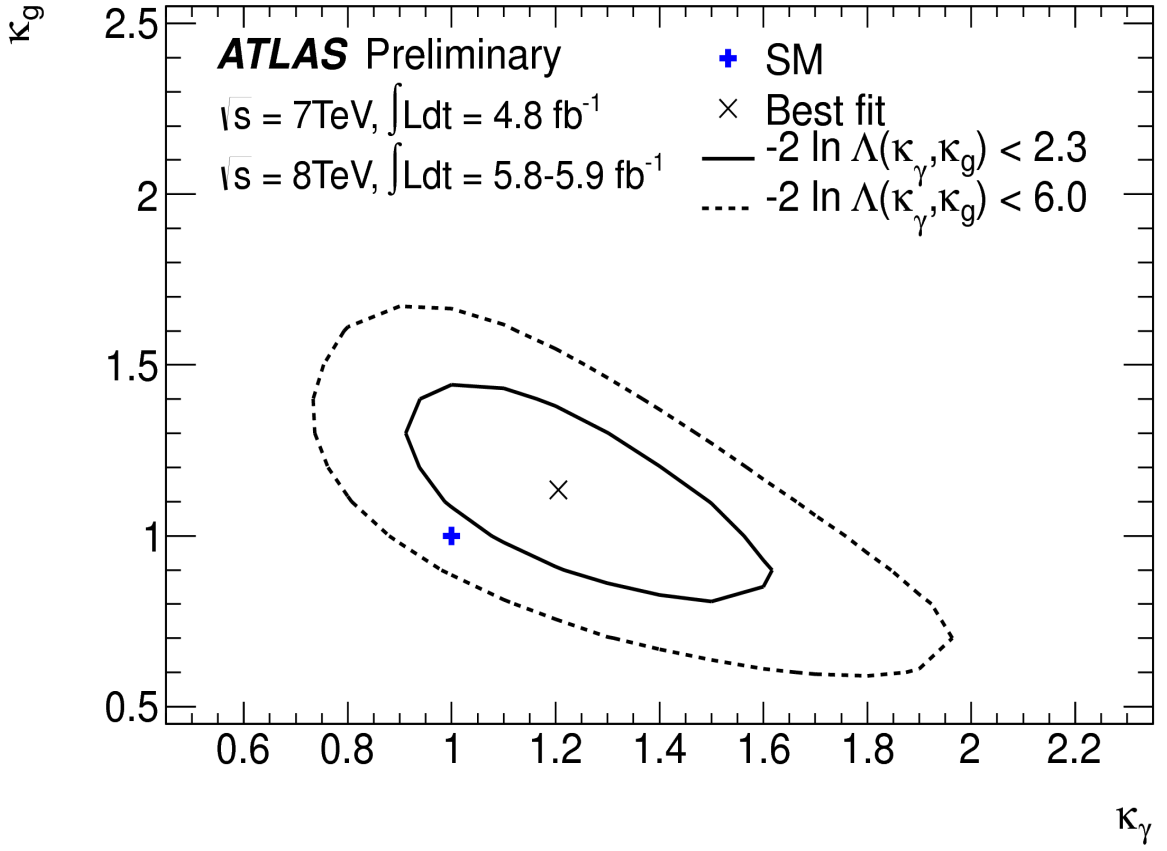
× Event display of a diphoton with two jets event candidate where both photon candidates are converted. The event number is 24947130 and it was recorded during run 204769 at sqrt(s) = 8 TeV



New contribution to *γγ* loop

× μ=1.80+0.42-0.36

→ new particle in the loop H → *γγ* or *gg* -> *H* loop (stop, stau) ?



Agreement with SM expectations better than 2 σ