Spin determination of a narrow resonance near 125 GeV with the two-photon decay channel at ATLAS

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A new particle has been observed by ATLAS and CMS!

→Need to measure the properties (spin, parity, mass, etc.)

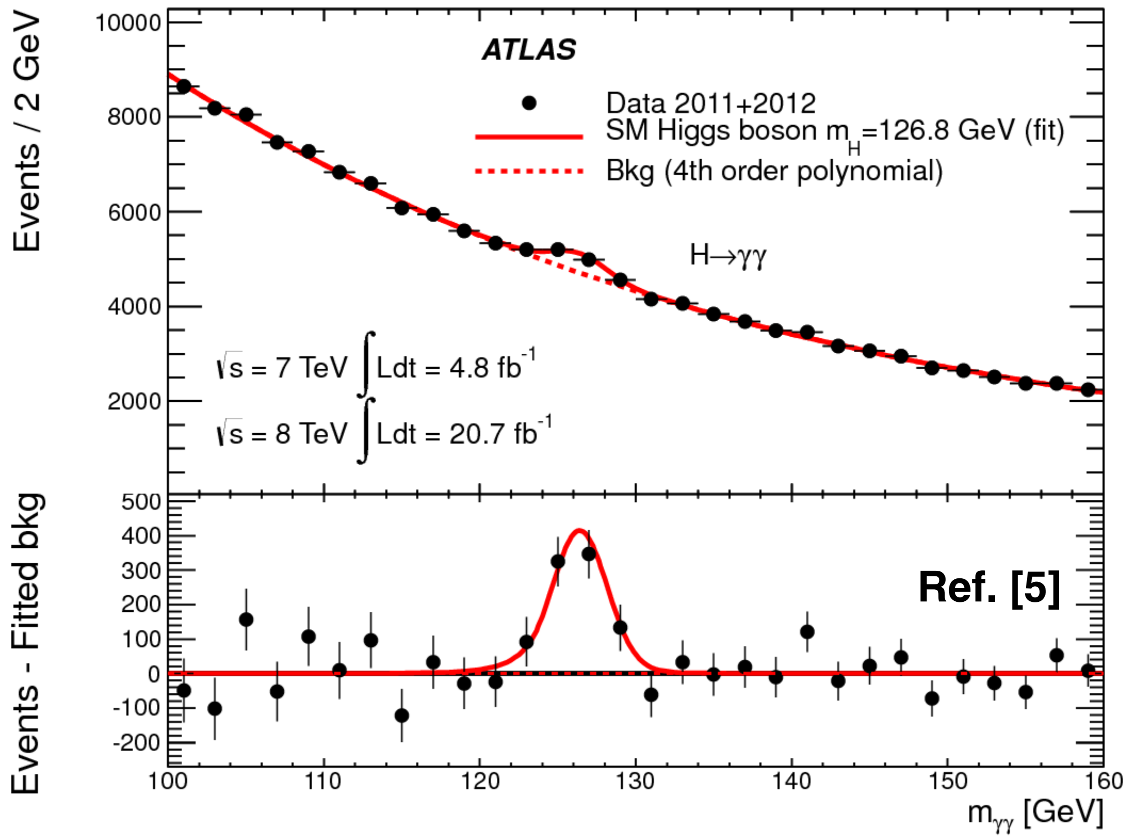
Di-photon decay indicates the new particle is a boson

- Landau-Yang theorem excludes the spin 1 hypothesis
- Other integer spins remain as possibilities

Separate the standard model (J^P=0^+) signal hypothesis from "graviton-like" models (specifically *gg*→J^P=2^+)

- Remaining model dependence lies in the coupling strengths of the spin 2 particle to the SM fields
- Focus on *gg* production. Also possible to set limits on *qq* production (appendix slides)

Study the resonance properties using di-photon events

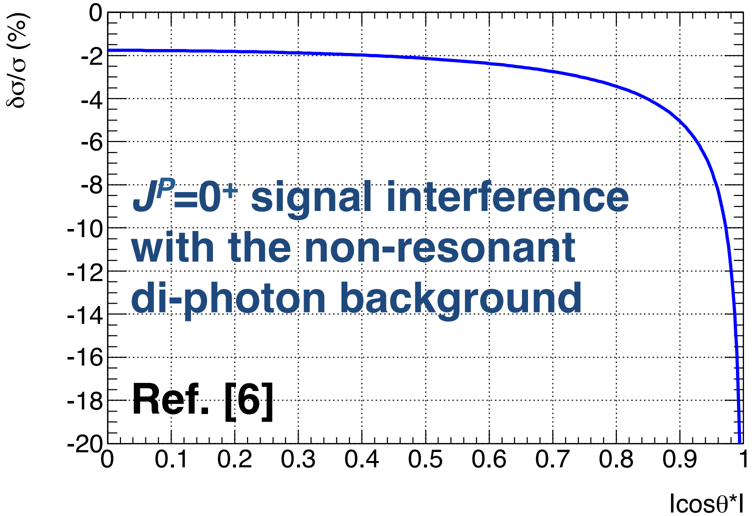


Separate signal from background with fit to the γγ mass

- Excellent mass resolution (1.77 GeV)
- Fit a narrow signal peak near 125.5 GeV on top of exponentially decreasing background

Standard Model Higgs ($J^P=0^+$)

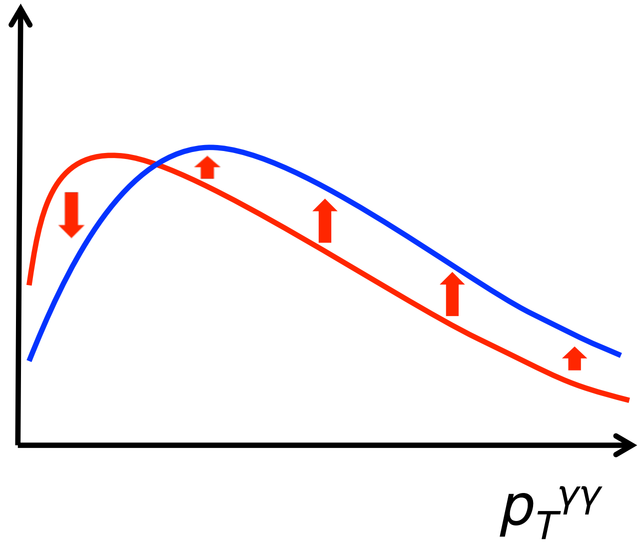
- **NLO predictions** from POWHEG + PYTHIA8 parton showering.
- Destructive interference with non-resonant di-photon background
- Tuned to reproduce the re-summed p_T calculation of the HqT program



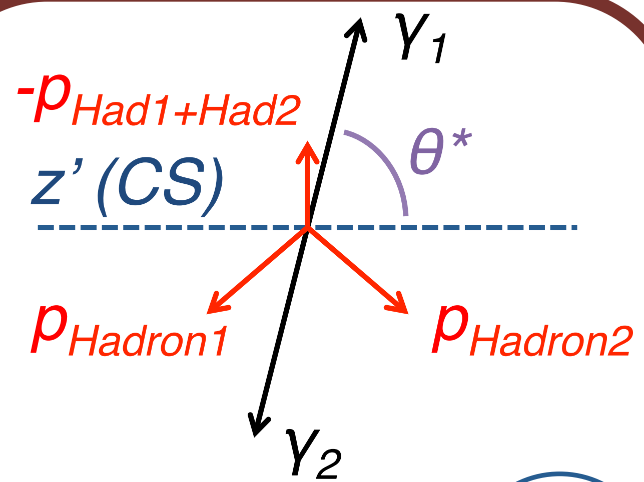
Spin 2 Model ($J^P=2^+$)

- **LO predictions** from JHU generator + PYTHIA parton showering
- Transverse momentum comes from parton showering in the initial state
- **Large impact of Higgs p_T on cos(θ*)**
- Reweight p_T to POWHEG prediction:

$$w(p_T) = \frac{1}{\sigma_{POWHEG}} \frac{d\sigma_{POWHEG}}{dp_T} \Big/ \frac{1}{\sigma_{PYTHIA}} \frac{d\sigma_{PYTHIA}}{dp_T}$$



Separate 0+ and 2+ spin hypotheses using the angular correlation of the two photons

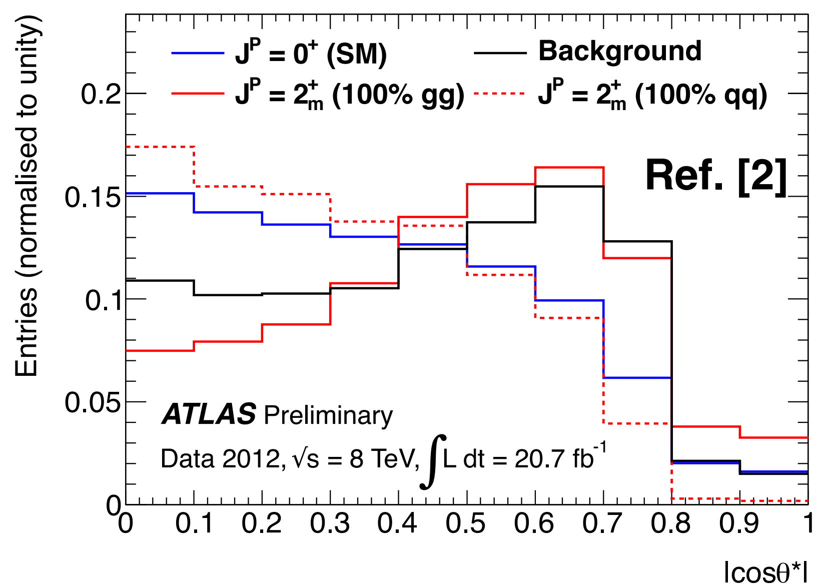


$$\left|\cos\theta^*_{CS}\right| = \frac{\left|\sinh\left(\Delta\eta^{\gamma\gamma}\right)\right|}{\sqrt{1+\left(p_T^{\gamma\gamma}/m_{\gamma\gamma}\right)^2}}\frac{2p_T^{\gamma 1}p_T^{\gamma 2}}{m_{\gamma\gamma}^2}$$

Relative p_T cuts on the photons remove most correlation with $m_{\gamma\gamma}$

Collins-Soper frame used to get reference axis z' for cos(θ^*)

- z-axis bisects angle between the momenta of colliding hadrons
- Minimizes impact of ISR
- Better 0^+ / 2^+ discrimination



Events are divided into γγ mass sidebands and signal region

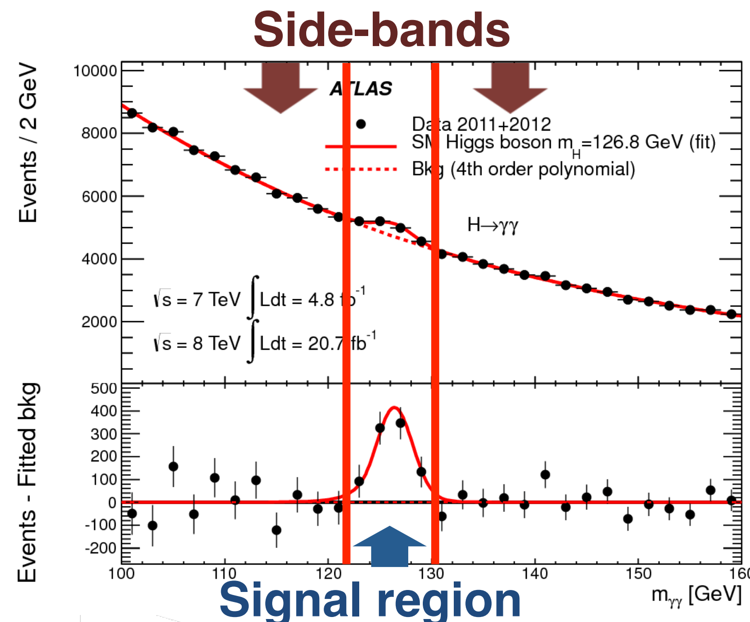
Side-bands: 1D fit in $m_{\gamma\gamma}$

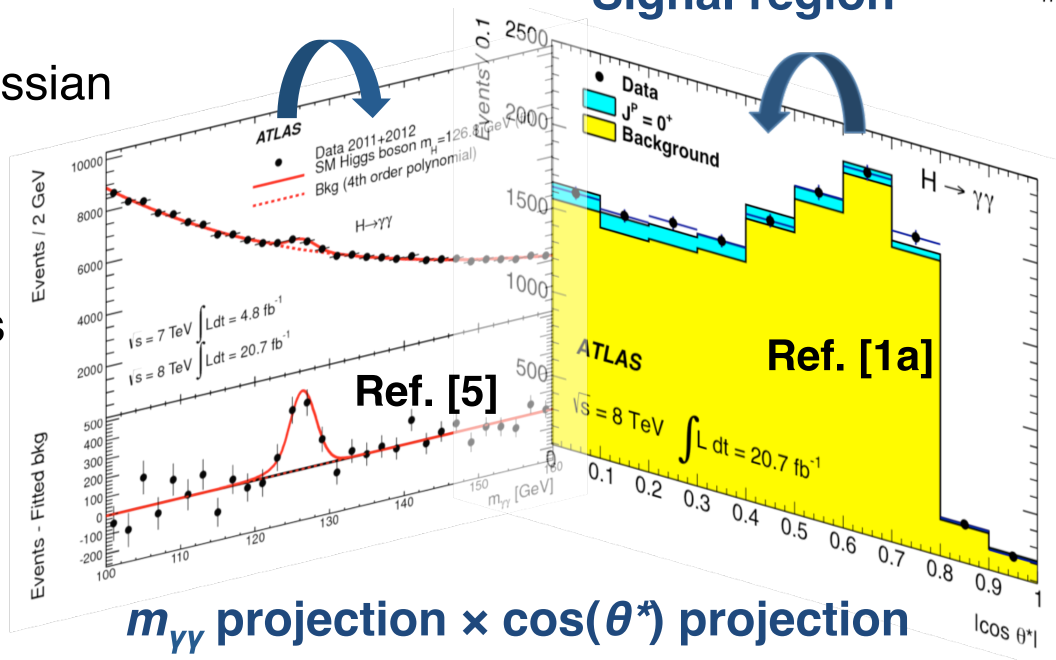
- **Background:** O(5) Bernstein polynomial
- Constrains the background shape

Signal region: 2D $m_{\gamma\gamma}$-cos(θ^*) fit

- Multiple of two 1D shapes
- **Signal:** Crystal ball + Gaussian mass peak, cos(θ*) shape from MC
- **Background:** cos(θ*) shape from $m_{\gamma\gamma}$ sidebands

Method assumes minimal correlation between mass and cos(θ*) in background





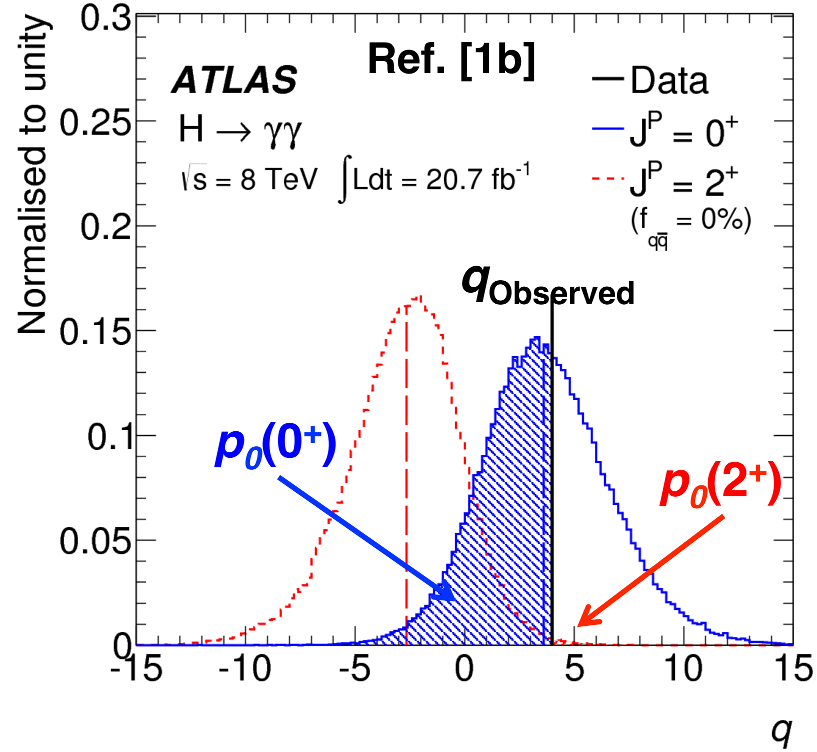
Construct a likelihood ratio test-statistic to separate hypotheses

$$q = \log \frac{L(J^P = 0^+, \hat{\hat{\mu}}_{0^+}, \hat{\hat{\theta}}_{0^+})}{L(J^P = 2^+, \hat{\hat{\mu}}_{2^+}, \hat{\hat{\theta}}_{2^+})}$$

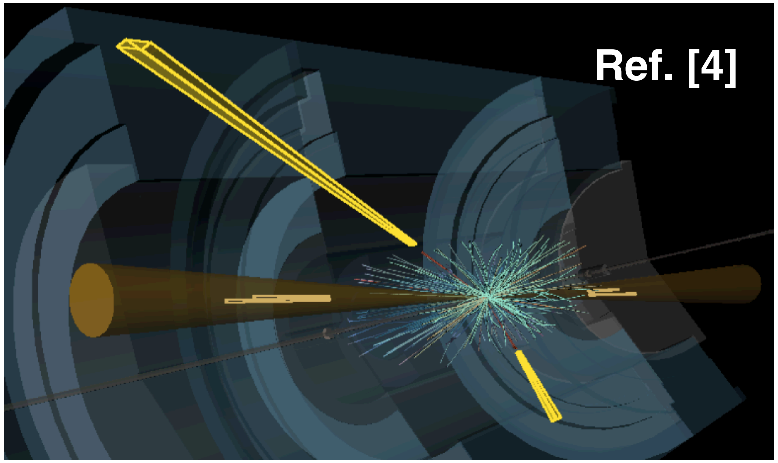
Generate pseudo-experiments to get expected distribution of the test-statistic

$$CL(J^P = 2^+) = 1 - \frac{p_0(2^+)}{1 - p_0(0^+)}$$

Exclude the J^P=2^+ hypothesis in favor of J^P=0^+ at 99.3% *CL*



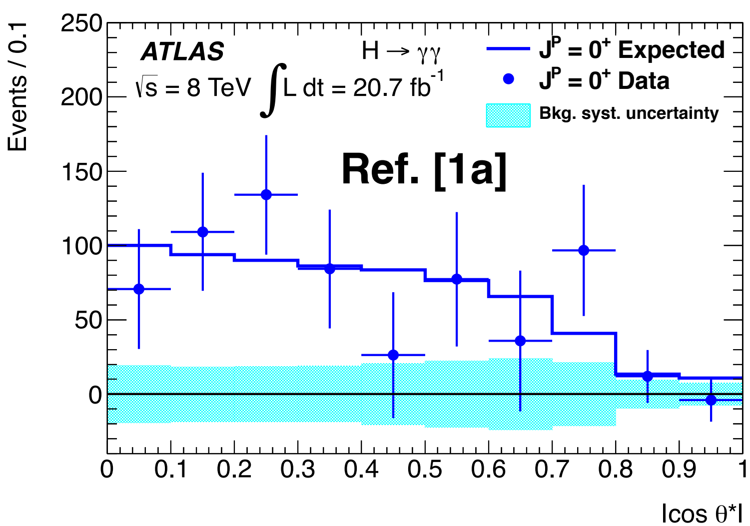
Expected distributions of the test statistics $g_{0+}(q)$ and $g_{2+}(q)$ from pseudo-experiments.



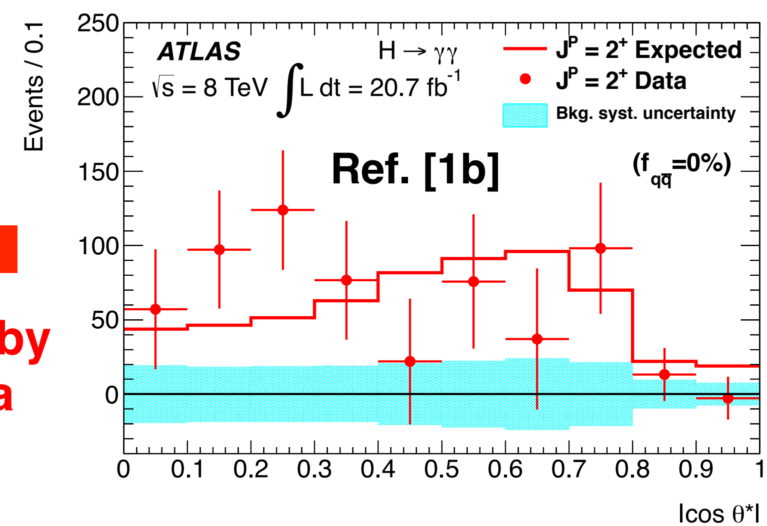
The $H \rightarrow \gamma\gamma$ channel provides a useful tool for studying the properties of a Higgs-like boson.

20.7 fb^{-1} of 8 TeV data were used to set limits on graviton-like $gg \rightarrow J^P = 2^+$ models

Exclude the $gg \rightarrow J^P = 2^+$ models in favor of 0^+ with 99.3% *CL*



Favored by the data



Fit (points) and 0^+ expectation (line)

Fit (points) and $gg \rightarrow 2^+$ expectation (line)

References

ATLAS and CMS Conference Notes and Publications

1a *Evidence for the spin-0 nature of the Higgs boson using ATLAS data*
http://arxiv.org/abs/1307.1432

1b *Evidence for the spin-0 nature of the Higgs boson using ATLAS data (auxiliary plots)*
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2013-01/

2 *Study of the spin of the Higgs-like boson in the two photon decay channel using 20.7fb^{-1} of pp collisions collected at $\sqrt{s}$=8 TeV with the ATLAS detector*
https://cds.cern.ch/record/1527124

3 *Properties of the observed Higgs-like resonance decaying into two photons (CMS)*
https://cds.cern.ch/record/1558930?ln=en

4 *Measurements of the properties of the Higgs-like boson in the two photon decay channel with the ATLAS detector using 25 fb-1 of proton-proton collision data*
http://cds.cern.ch/record/1523698

5 *Measurements of the Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC*
http://arxiv.org/abs/1307.1427

Additional References

6 L. J. Dixon and M. S. Siu, *Resonance continuum interference in the diphoton Higgs signal at the LHC*, Phys. Rev. Lett. **90** (2003) 252001, arXiv:hep-ph/ 0302233 [hep-ph]
http://arxiv.org/pdf/hep-ph/0302233.pdf

Appendix

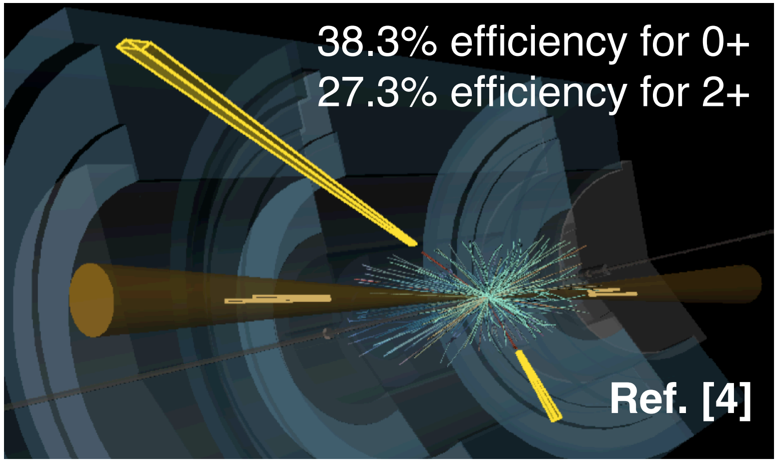
20.7 fb^{-1} of data at $\sqrt{s}$ = 8 *TeV* from the LHC in 2012

Photon reconstruction

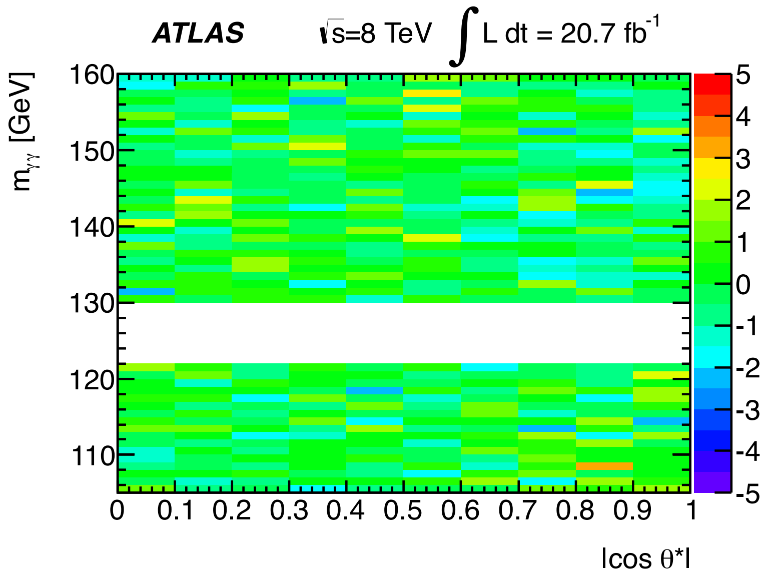
- Energy scale calibrations (and smearing for MC) from $Z \rightarrow ee$
- $p_T > 25$ *GeV*
- $|\eta|<2.37$ excluding $1.37<|\eta|<1.56$ (excluding calo. transition region)
- η corrections from electro-magnetic calorimeter pointing.
- Rectangular "tight" ID cuts on calorimeter shower shapes.
- Isolation:
  ΣE_T^{Calo} (Δr=0.4) < 6.0 *GeV*
  Σp_T^{Track} (Δr=0.2) < 2.6 *GeV*

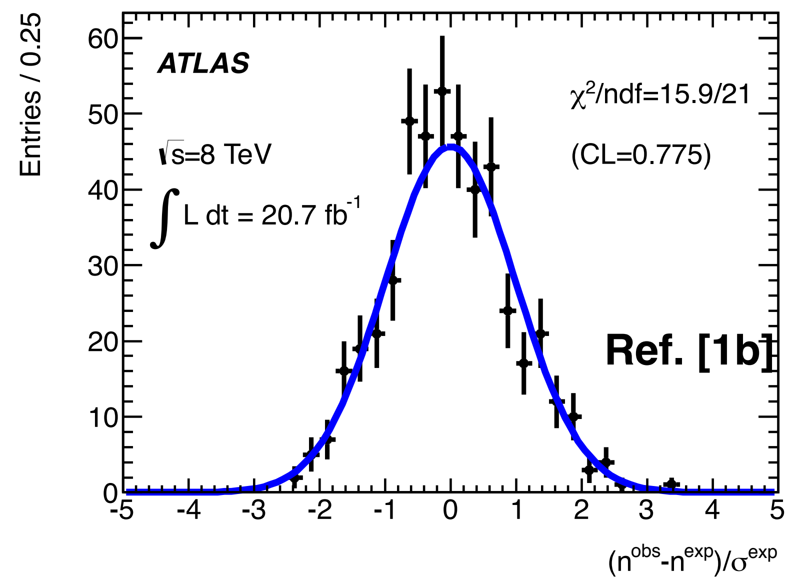
Event selection

- Trigger: EF_g35_loose_g25_loose
- Vertex reconstruction with artificial neural network, using pointing capabilities of the ATLAS EM calo.
- $p_{T,1} / m_{\gamma\gamma} > 0.35$, $p_{T,2} / m_{\gamma\gamma} > 0.25$
- $105\ GeV < m_{\gamma\gamma} < 160\ GeV$



Correlation between $m_{\gamma\gamma}$ and $\cos(\theta^*)$



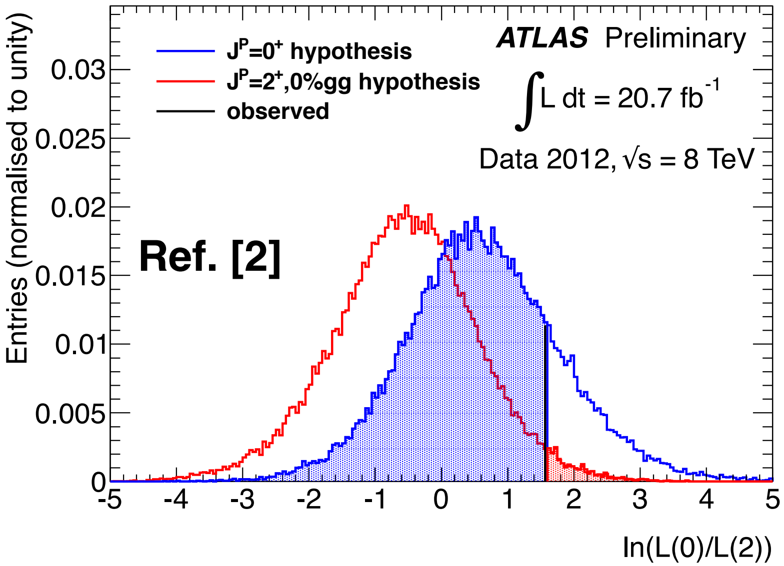


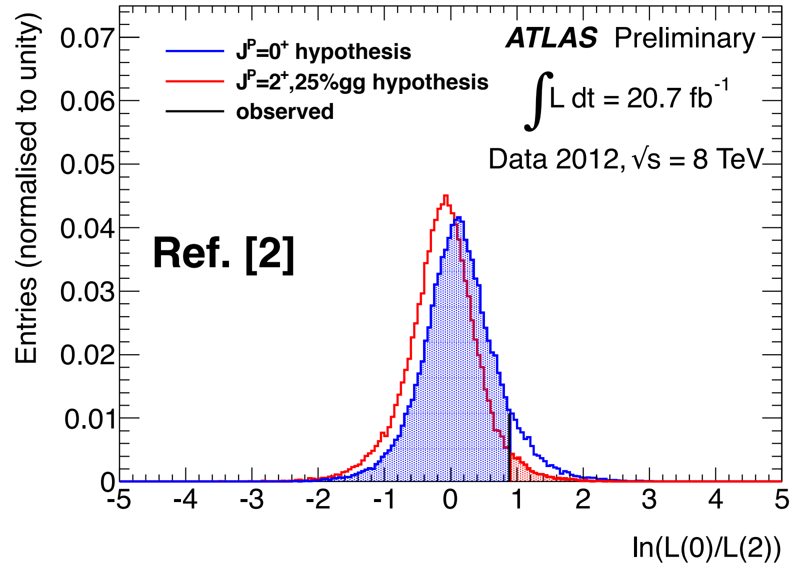
Analysis method #1 assumes no correlation between the two observables → check assumption in data sample

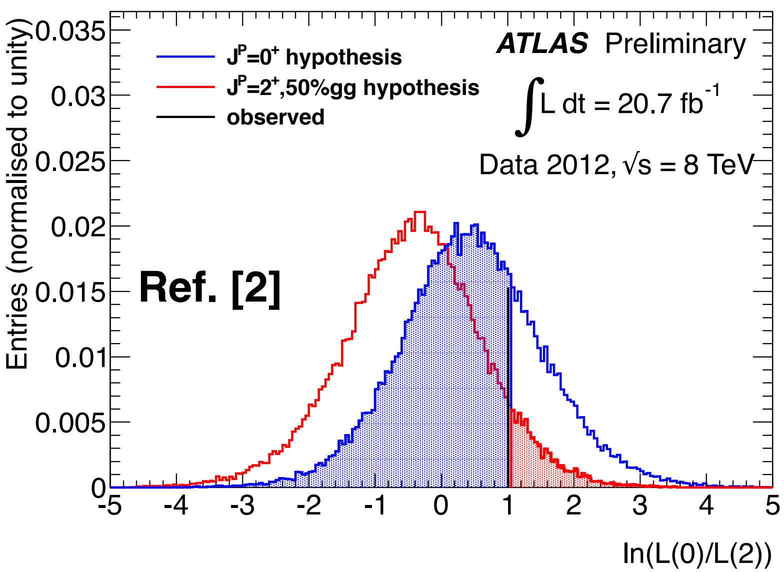
Compare the 1D×1D expectation to the observed events

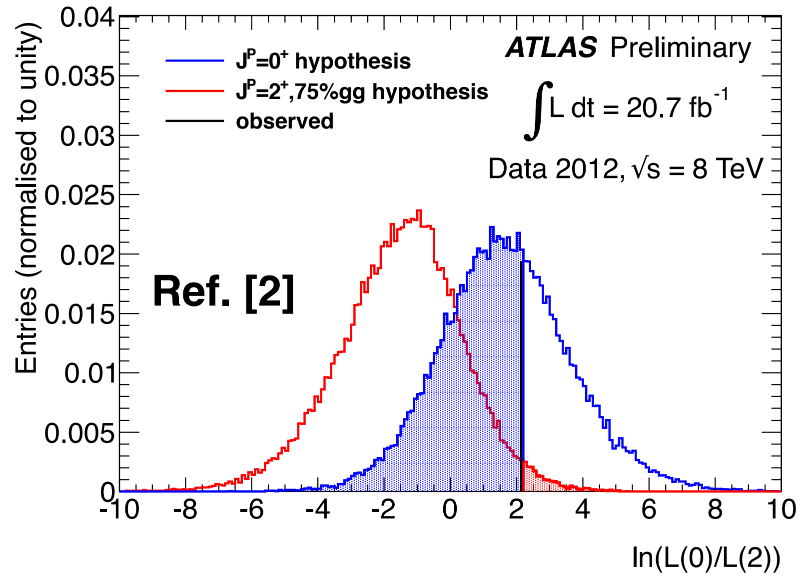
Gaussian distribution of fluctuations away from the $m_{\gamma\gamma} \times \cos(\theta^*)$ expectation → correlations between the two variables are small

Toy test statistics for mixed *gg/qq* production modes

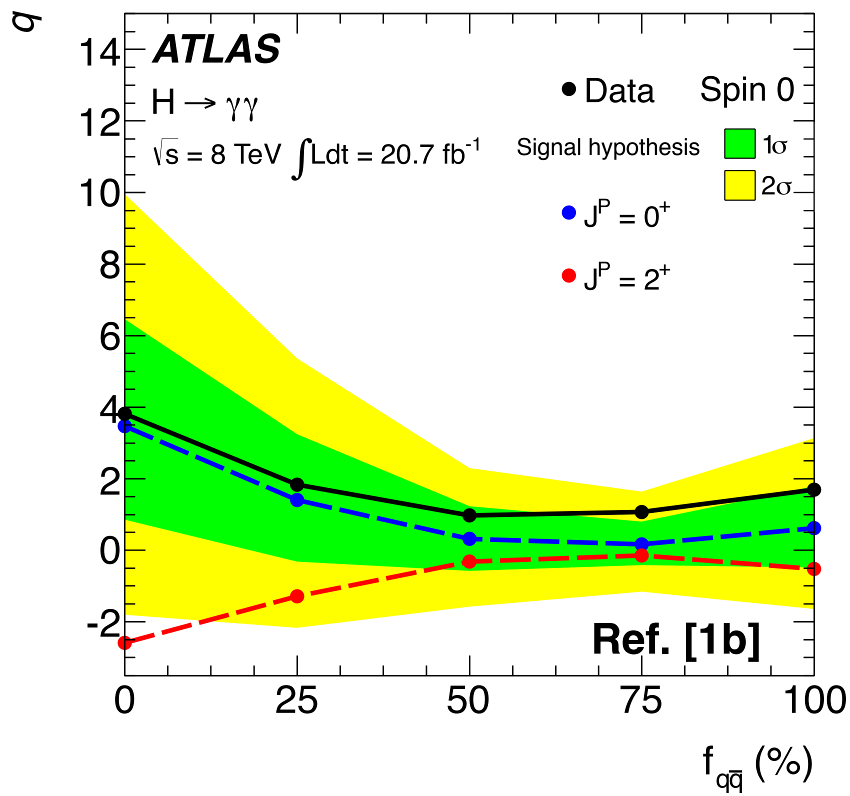








Results for various $qq \rightarrow 2^+$ production fractions



f_{qq} (%)	Spin hypothesis	Exp. p-value (%)	Obs. p-value (%)	1-$CL_S(2^+)$ (%)
0	0^+ 2^+	1.2 0.5	58.8 0.3	99.3
25	0^+ 2^+	6.3 5.3	60.2 3.1	92.2
50	0^+ 2^+	24.3 23.4	75.2 7.9	68.0
75	0^+ 2^+	29.4 28.0	88.6 3.4	70.0
100	0^+ 2^+	14.8 13.5	79.8 2.5	88.0

Signal can be produced by *qq→X* as well as *gg→X*

Look at $J^P=2^+$ signal from *qq* and *gg* in different fractions

Observations favor 0^+ hypothesis over 2^+ at every f_{qq} point