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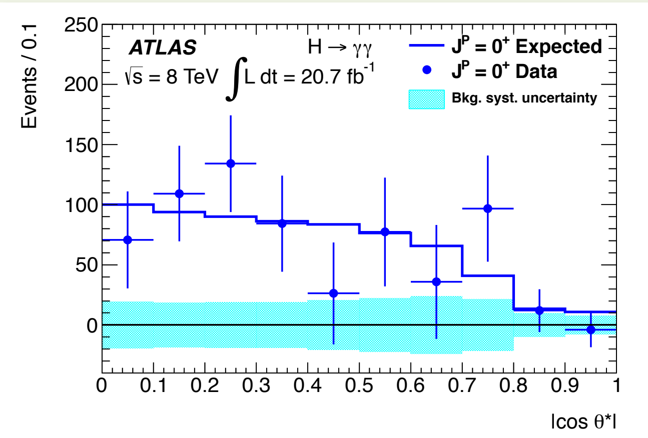
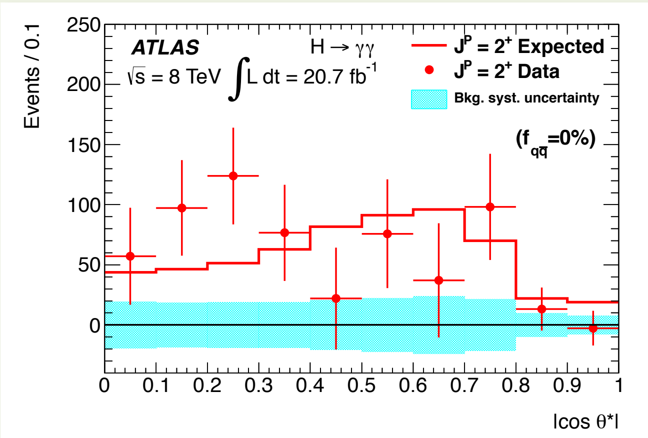
Studies of Higgs spin and parity with the ATLAS detector at the LHC

Studies of the spin and parity quantum numbers of the Higgs boson candidate are presented. They are based on pp collision data collected by the ATLAS experiment at the LHC. The Standard Model (SM) spin–parity $J^P = 0^+$ hypothesis is confronted with alternative models using the kinematic properties of the Higgs boson decays into $H \to \gamma\gamma$, $H \to WW^* \to l\nu l\nu$ and $H \to ZZ^* \to 4l$ final states, and their combinations. The datasets used correspond to an integrated luminosity of 20.7 fb^{-1} collected at $\sqrt{s}$ = 8 TeV, and for the $H \to ZZ^*$ channel an additional dataset corresponding to an integrated luminosity of 4.8 fb^{-1} at $\sqrt{s}$ = 7 TeV is used.

$H \to \gamma\gamma$ [1,3]:

- Spin extracted using $|\cos\theta^*|$, (of the photons with respect to the *z*-axis) distribution in Collins-Soper frame;
- Challenge: large background, dominated by non-resonant di-photon production;
- Two observables are used in the fit to data: $m_{\gamma\gamma}$ provides the best separation power between signal and background, and $|\cos\theta^*|$ is sensitive to the spin.

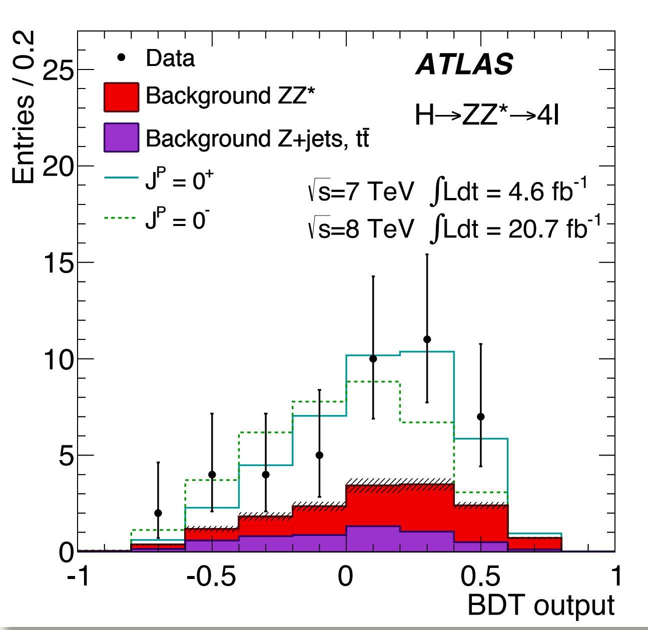


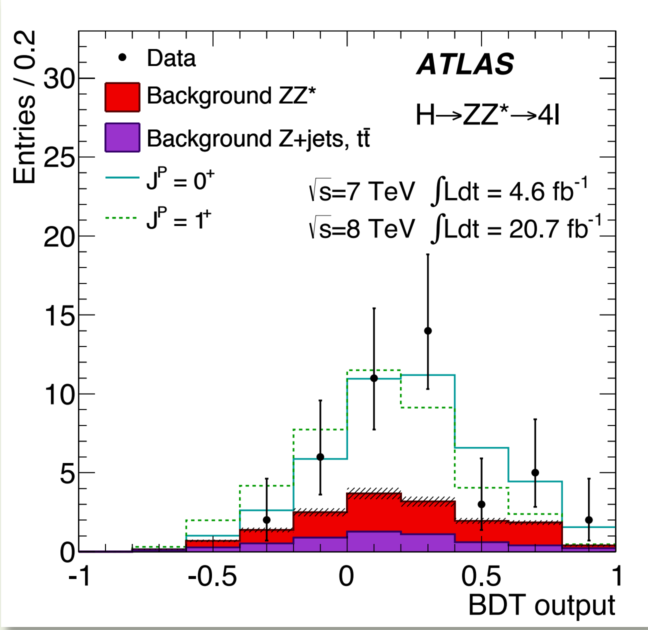


Distributions of background-subtracted data in the signal region as a function of $|\cos\theta^*|$ with the expected shape for spin-0 (left) and spin-2 (right) are reported.

$H \to ZZ^* \to 4l$ [1,4]:

- Multivariate discriminant based on a Boosted Decision Tree (BDT) is used to to distinguish between pairs of spin and parity hypothesis (five angles and two Z masses);
- Dedicated discriminants are defined for the separation between the SM $J^P = 0^+$ hypothesis and each of the considered alternative models, $J^P = 0^-, 1^+, 1^-, 2^+$.

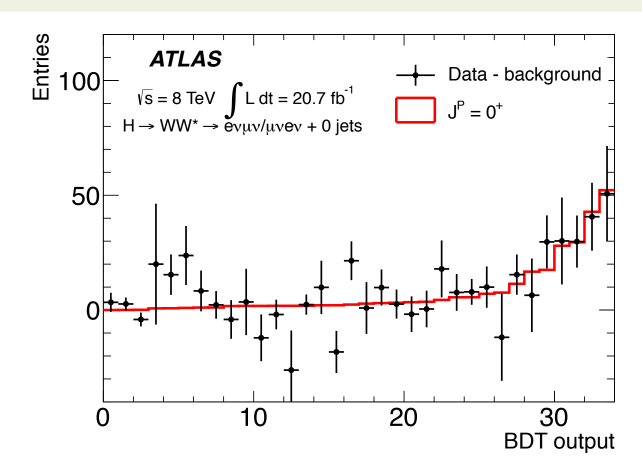


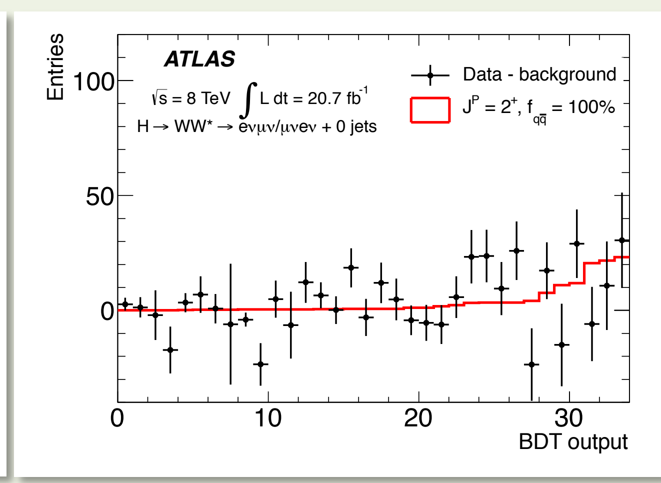


Distributions of BDT output for the ZZ* channel for SM hypothesis *vs* 0^- (left) and *vs* 1^+ (right) are reported. The contribution for each of the two hypotheses is scaled using the profiled value of the signal strength.

$H \to WW^* \to l\nu l\nu$ [1,5]:

- The analysis is restricted to events containing two leptons of different flavors
- A BDT algorithm is used to distinguish between the spin hypotheses (m_{ll}, $\Delta\varphi_{ll}$, p_T^{ll}, m_T).
- Two separate BDT classifiers: one is trained to distinguish the *SM* signal from backgrounds, while the second one separates the alternative J^P hypothesis ($J^P = 2^+$, $1^\pm$) from backgrounds.





1D projections of the outputs of the BDT for the $H \to WW^*$ channel after background subtraction for $J^P = 0^+$ (left) and $J^P = 2^+$ 100%qq (right) are reported.

Hypotheses tested against SM [2]:

The production and decay of the $J^P = 0^-$ resonance, as well as of the spin–1 and spin–2 resonances with both even and odd parities are modelled using the JHU generator @ LO

- 0^-: ZZ only. Pseudoscalar particle, no CP mixing;
- $1^\pm$: ZZ and WW without γγ. The Landau–Yang theorem forbids the direct decay of a on–shell spin-1 particle into a pair of photons;
- 2^+: graviton–inspired tensor with minimal couplings to SM particles. The studies have been performed for several production admixtures (gluon-gluon fusion and quark-antiquark annihilation), the results are quoted as a function of f_{qq}, the fraction of qq production mode.

Statistical procedure:

The test statistic q used to distinguish between the two signal J^P hypotheses is based on a ratio of likelihoods:

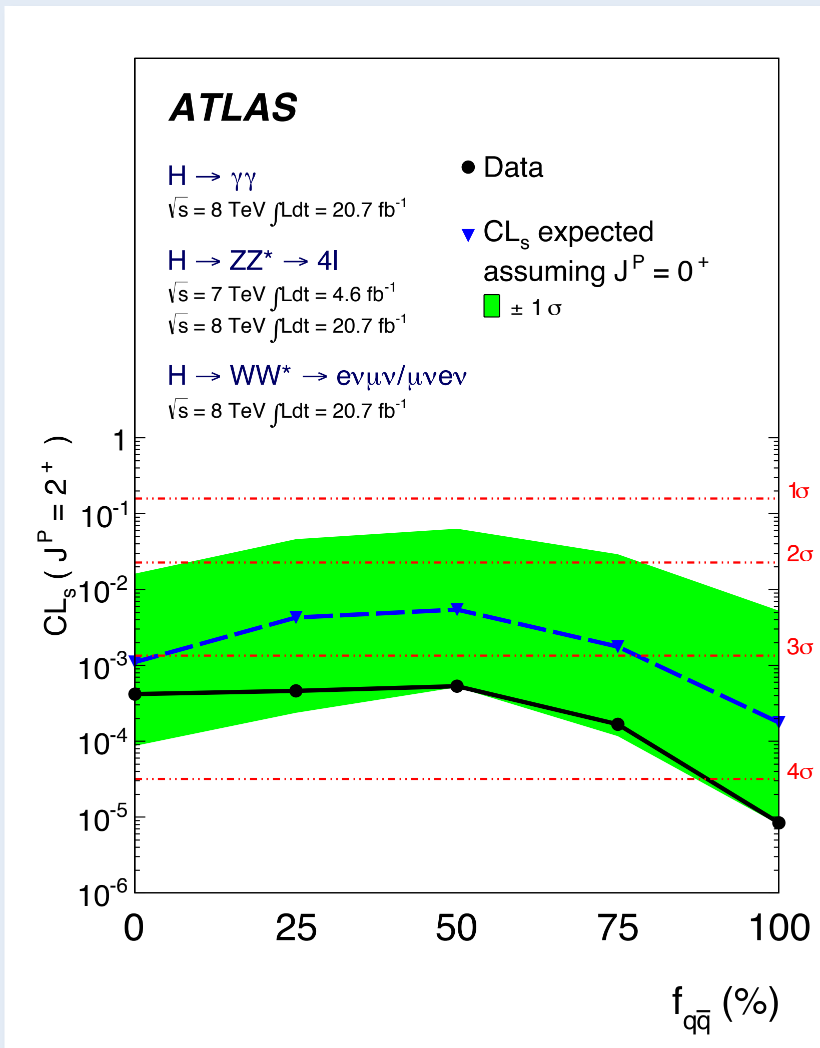
$$q = \log \frac{\mathcal{L}(J^P = 0^+, \hat{\hat{\mu}}_{0^+}, \hat{\hat{\theta}}_{0^+})}{\mathcal{L}(J^P_{alt}, \hat{\hat{\mu}}_{J^P_{alt}}, \hat{\hat{\theta}}_{J^P_{alt}})}$$

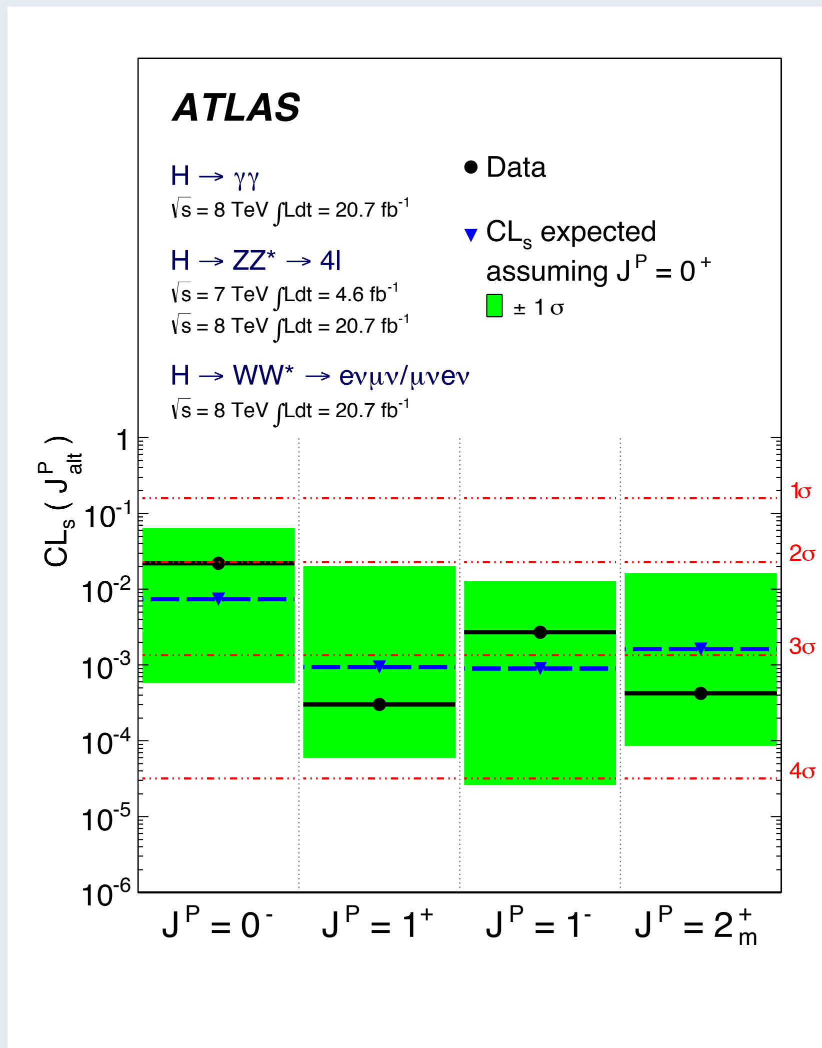
$\hat{\hat{\mu}}_{J^P}, \hat{\hat{\theta}}_{J^P}$ represent the value of the signal strength and nuisance parameters fitted to the data under the same hypothesis. The exclusion limits are evaluated in terms of the corresponding CL_s.

Spin combination [1,6]:

- *0^+ vs 0^- (ZZ only)*: 0^- excluded @97.8% CL;
- *0^+ vs 1^- (ZZ + WW)*: 1^- excluded @99.7% CL;
- *0^+ vs 1^+ (ZZ + WW)*: 1^+ excluded @99.97% CL;
- *0^+ vs 2^+ (γγ + ZZ + WW)*: 2^+ excluded > 99.9% CL for all f_{qq};

All alternative models studied are excluded without assumptions on the strength of the couplings of the Higgs boson to SM particles. These studies provide evidence for the spin-0 nature of the Higgs boson. With the current statistic +1 parity being favored by the observation w.r.t. to -1.





Expected (blue triangles/dashed line) and observed (black circles/solid line) confidence level CL_s for alternative spin–parity hypotheses assuming a $J^P = 0^+$ signal. The green bands represent the 68% expected exclusion range for a signal with assumed $J^P = 0^+$.

References:

[1] Evidence for the spin-0 nature of the Higgs boson using ATLAS data (arXiv:1307.1432 [hep-ex]);
[2] Y. Gao et al., *Spin determination of single-produced resonances at hadron colliders*, Phys. Rev. D 81 (2010) 075022.
[3] Study of the spin of the Higgs-like boson in the two photon decay channel using 20.7 fb^{-1} of pp collisions collected at $\sqrt{s}$ = 8 TeV with the ATLAS detector, ATLAS-CONF-2013-029;
[4] Measurements of the properties of the Higgs-like boson in the four lepton decay channel with the ATLAS detector using 25 fb^{-1} of proton-proton collision data, ATLAS-CONF-2013-012;
[5] Study of the spin properties of the Higgs-like boson in the $H \to WW^{(*)} \to e\nu\mu\nu$ channel with 21 fb^{-1} of $\sqrt{s}$ = 8 TeV data collected with the ATLAS detector, ATLAS-CONF-2013-031;
[6] Study of the spin of the new boson with up to 25 fb^{-1} of ATLAS data, ATLAS-CONF-2013-040.

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ATLAS EXPERIMENT