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

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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 spin-parity $J^P = 0^+$ hypothesis is confronted with alternative models using the kinematic properties of the Higgs boson decays $H \rightarrow \gamma\gamma$, $H \rightarrow WW^{*} \rightarrow l\nu l\nu$ and $H \rightarrow ZZ^* \rightarrow 4l$. The datasets used correspond to an integrated luminosity of 20.7 fb$^{-1}$ collected at $\sqrt{s} = 8$ TeV. For the $H \rightarrow ZZ^*$ channel an additional dataset corresponding to an integrated luminosity of 4.8 fb$^{-1}$ at $\sqrt{s} = 7$ TeV is added.
1. Introduction

In 2012 the ATLAS and CMS Collaborations published the discovery of a new resonance [1, 2] in the search for the Standard Model (SM) Higgs boson $H$. The present experimental challenge is to compare the properties of the new observed particle with the SM predictions for the Higgs boson. In the SM, the Higgs boson is a spin-0 and CP-even particle ($J^P = 0^+$) [4, 5]. The Landau–Yang theorem forbids the direct decay of an on-shell spin-1 particle into a pair of photons. The spin-1 hypothesis is therefore strongly disfavoured by the observation of the $H \rightarrow \gamma\gamma$ decay. In this report the $J^P = 0^+$ hypothesis of the SM is compared to several alternative hypotheses with

$J^P = 0^-, 1^+, 1^-, 2^+$. The measurements are based on the kinematic and angular variables of the three final states $H \rightarrow \gamma\gamma$ (cosine of the polar angle of the photons with respect to the z-axis of the Collins-Soper frame [6] is used), $H \rightarrow ZZ^* \rightarrow 4l$ (multivariate discriminant based on independent angular variables and masses based on the decay planes of the 4 leptons is used, for a complete description see [7]) and $H \rightarrow WW^* \rightarrow l\nu l\nu$ (multivariate discriminant based on angular distribution, $p_T$ and masses is used [8]), where $\ell$ denotes an electron or a muon. To improve the sensitivity to different spin–parity hypotheses, the final states are, in some cases, combined. To test the $J^P = 0^-$ spin–parity hypothesis, only the $H \rightarrow ZZ^* \rightarrow 4l$ decay mode is used, while for $J^P = 1^+$ and $J^P = 1^-$ hypotheses the $H \rightarrow ZZ^* \rightarrow 4l$ and $H \rightarrow WW^* \rightarrow l\nu l\nu$ channels are combined. For the $J^P = 2^+$ study, all three decay modes are combined.

2. Results

The results are reported in Figures 1, where the left side shows a summary of the expected and observed confidence levels for the different alternative hypotheses with respect to the SM hypothesis. For the case of the $2^+$ hypothesis, a model corresponding to a graviton-inspired tensor with minimal couplings to SM particles ($q\bar{q}$ fraction $f_{q\bar{q}} = 4\%$) is assumed (called $2^+_m$ in the figure). Figure 1 (right) shows the confidence level for the alternative hypothesis as a function of the $q$-$\bar{q}$ fraction. All confidence levels are evaluated according to the CLs prescription [3].

2.1 Test of SM $J^P = 0^+$ against $J^P = 0^-$

The expected and observed exclusion limits of the $J^P = 0^-$ hypothesis are summarised in Figure 1 (left). The data are in agreement with the $J^P = 0^+$ hypothesis, while the $J^P = 0^-$ hypothesis is excluded at 97.8% CL.

2.2 Test of SM $J^P = 0^+$ against $J^P = 1^+$

The expected and observed exclusion limits of the $J^P = 1^+$ hypothesis obtained from the combination of the $H \rightarrow ZZ^* \rightarrow 4l$ and $H \rightarrow WW^* \rightarrow l\nu l\nu$ channels is shown in Figure 1 (left). For both channels, the results are in agreement with the $J^P = 0^+$ hypothesis. In the $H \rightarrow ZZ^* \rightarrow 4l$ channel, the $J^P = 1^+$ hypothesis is excluded at 99.8% CL, and in the $H \rightarrow WW^* \rightarrow l\nu l\nu$ channel, it is excluded at 92% CL. The combination excludes this hypothesis at 99.97% CL.
2.3 Test of SM $J^P = 0^+$ against $J^P = 1^-$

The expected and observed exclusion limits of the $J^P = 1^-$ hypothesis obtained from the combination of the $H \rightarrow ZZ^* \rightarrow 4l$ and $H \rightarrow WW^* \rightarrow l\nu l\nu$ channels is shown in Figure 1 (left). For both channels, the results are in agreement with the $J^P = 0^+$ hypothesis in the $H \rightarrow ZZ^* \rightarrow 4l$ channel, the $J^P = 1^-$ hypothesis is excluded at 94% CL, while in the $H \rightarrow WW^* \rightarrow l\nu l\nu$ channel, the $J^P = 1^-$ hypothesis is excluded at 98% CL. The combination excludes this hypothesis at 99.7% CL.

2.4 Test of SM $J^P = 0^+$ against $J^P = 2^+$

The expected and observed exclusion limits of the $2^+$ hypothesis in the combination of the three channels are summarised in Figures 1, for all $f_{qq}$ values of the spin-2 particle considered. For all three channels, the results are in agreement with the spin-0 hypothesis. The data are in good agreement with the Standard Model $J^P = 0^+$ hypothesis over the full $f_{qq}$ range. Figure 1 (right) shows the comparison of the expected and observed CLs values for the $J^P = 2^+$ exclusion limit as a function of $f_{qq}$. The observed exclusion of the $J^P = 2^+$ hypothesis in favour of the Standard Model $J^P = 0^+$ hypothesis exceeds 99.9% CL for all values of $f_{qq}$.

![Figure 1](image-url)

**Figure 1:** Expected (blue triangles/dashed lines) and observed (black circles/solid lines) confidence level for alternative spin–parity hypotheses assuming a $0^+$ signal [4].

3. Conclusions

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. The $0^-$ hypothesis is rejected at 97.8% CL by using the $H \rightarrow ZZ^* \rightarrow 4l$ decay alone.
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References


