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Hypotheses tests for different spin-parity states in the $H \to ZZ^* \to 4\ell$ decay with the ATLAS experiment at LHC

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Summary. — The determination of the spin-parity properties of the discovered Higgs Boson is one of the main goals of the ongoing analyses at LHC. This note describes the experimental technique used by the ATLAS collaboration to test different spin-parity hypotheses, using the full dataset recorded during the Run 1, corresponding to an integrated luminosity of $\sim 25\,\text{fb}^{-1}$.

PACS 14.80.Bn – Standard-model Higgs bosons.

1. – Introduction

After the discovery of a new Higgs-like boson by ATLAS [1] and CMS [2] experiments at LHC, a major goal is to establish the nature of this particle by determining its spin-CP quantum numbers, thus providing its compatibility with the Standard Model previsions. In particular, the $H \to ZZ^* \to 4\ell$ decay, represents a channel of great importance, since the full decay kinematics is completely reconstructed with high experimental precision.

2. – Production and decay kinematics

The amplitude for a resonance decay into two vector bosons depends on form factors a_i (generally momentum-dependent complex numbers) and coupling parameters g_i of an effective Higgs Lagrangian [3]. For a spin-zero particle the amplitude has the form

$$A(X \to V_1V_2) = v^{-1}\epsilon_1^{*\mu}\epsilon_2^{*\nu}\left(a_1 g_{\mu\nu} m_X^2 + a_2\, q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta\right). \tag{1}$$

The a_i parameters are connected to experimental observables by expanding the scattering amplitude as a function of helicity amplitudes $A_{\lambda_1\lambda_2}$, which are related to the angular distributions of the final-state particles.

For the $H \to ZZ^* \to 4\ell$ decay, the observables sensitive to the spin and parity properties of the new particle are the two reconstructed masses of Z bosons, a production angle and four decay angles (fig. 1) [3]. Although the Standard Model predicts a scalar Higgs Boson ($J^P = 0^+$), alternative scenarios depending on the a_i parameters include pseudoscalar Higgs Boson ($J^P = 0^-$), CP-violating states with mixed parity, spin-2 states have been tested.

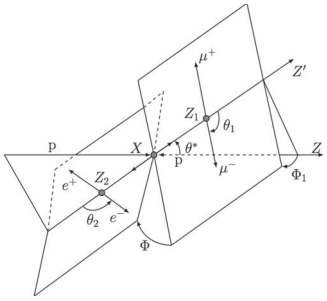

Fig. 1. – Definition of the production and decay angles in $H \to ZZ^* \to 4\ell$ decay.

TABLE I. – *Alternative hypothesis exclusion in favour of SM hypothesis (MELA approach)* [4].

J^P	CL_S confidence level
0^-	99.6%
1^+	99.4%
1^-	96.9%
2^+_m	81.8%
2^-	88.4%

3. – Results

The ultimate goal of the analysis will be the experimental determination of all the helicity-amplitude parameters to be determined through a fit to angular and mass distributions. The current collected data [4], corresponding to integrated luminosities of $4.6\,\text{fb}^{-1}$ and $20.7\,\text{fb}^{-1}$ at $\sqrt{s} = 7\,\text{TeV}$ and $\sqrt{s} = 8\,\text{TeV}$, respectively, do not allow a direct measurement of the coupling parameters. Hence, a first step is the understanding the resonance spin-parity, distinguishing between two different hypotheses through multivariate techniques (MELA and BDT [4]).

In particular MELA approach exploits the information coming from the full theoretical calculations describing the general structures of the scattering amplitudes and general angular distributions for the process $H \to ZZ^*$, obtaining a probability for each event and for each spin hypothesis. Six hypotheses for spin-parity J^P have been tested, $0^\pm$, $1^\pm$, $2^\pm$, with candidate events in the region $115\,\text{GeV} < m_{4\ell} < 130\,\text{GeV}$. The test statistic used is the log-likelihood ratio $\ln[L(H_1)/L(H_0)]$, where H_0 is the SM hypothesis and H_1 the alternative one. The results show a prevalence of the SM hypothesis compared to the alternative hypotheses (table I).

The Run 1 results are currently being revised, by including the latest calibrations of the experimental apparatus and some modifications to the ATLAS procedure for the event selection. Other improvements involve the Monte Carlo event generator used for the signal event simulation and the addition of the 0^+_h spin case.

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