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Results and perspectives on the $H \to ZZ^*$ vertex tensor structure with the ATLAS experiment at LHC

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Summary. — After the discovery of a new resonance at the LHC experiments, the determination of its properties is one of the main goals of the ongoing analyses. This note describes the experimental technique used by the ATLAS Collaboration to test different spin-parity hypotheses, using the full dataset recorded in 2011 and 2012, corresponding to an integrated luminosity of $25\,\text{fb}^{-1}$. Preliminary results on the ATLAS sensitivity to the CP-violating part of the $H \to ZZ^*$ amplitude are also presented.

PACS `14.80.Bn` – Standard-model Higgs bosons.

1. – Introduction

After the discovery of a new Higgs-like boson by ATLAS [1, 2] and CMS [3] 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. Since the full decay kinematics is experimentally accessible in $H \to ZZ^* \to 4\ell$ decays, this is an excellent channel for measuring the spin, parity, and tensor structure of couplings of the new boson.

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 [4]. For a spin-zero particle the amplitude can be presented in 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 discovered boson are the two reconstructed masses of Z bosons, a production angle θ^*, and four decay angles, Φ_1, Φ, θ_1, θ_2 (fig. 1). 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.

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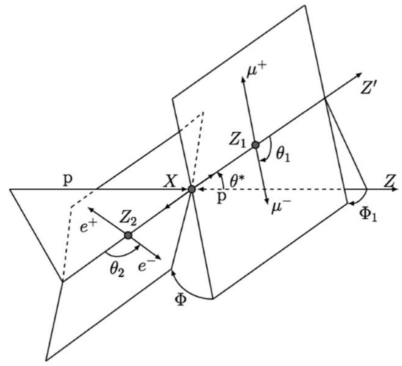

Fig. 1. – Definition of the production and decay angles in $H \to ZZ^* \to 4\ell$ decay.

3. – Results

The current collected data [5], 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 [5]).

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 hypothesis (table I). With larger integrated luminosities CP violation terms could be excluded or tested with a higher significance. With $100\,\text{fb}^{-1}$ the case of maximal interference between CP-odd and CP-even components could be excluded with 3σ or more [6].

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. This technique will be applied only after the luminosity upgrade, when a larger sample of signal events will be available.

Table I. – *Alternative hypothesis exclusion in favour of SM hypothesis (MELA approach)* [5].

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

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