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CP-mixing and New Physics in the $h \to ZZ^* \to 4\ell$ channel in ATLAS

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Summary. — The first analysis on the Higgs spin-parity favors the Standard Model hypothesis $J^P = 0^+$ against every other hypothesis tested. Hence it is interesting to study carefully the most general decay amplitude of the spin-0 hypothesis, searching for New Physics and CP-mixing effects in the Higgs sector. In this section is presented the ATLAS experiment sensitivity to non-Standard Model contributions in the hZZ vertex estimated for 300 fb^{-1} and 3000 fb^{-1} of LHC data at $\sqrt{s} = 14$ TeV and the results rescaled to the statistics collected during the RUN1 at LHC.

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With the discovery of the Higgs particle in the July 2012 it is important to verify if the new resonance with a mass of about 125.5 GeV is the same predicted by the Standard Model (SM). For this reason one of the most important properties that should be studied is the spin and parity (J^P) and the $h \to ZZ^* \to 4\ell$ channel is particularly suitable for this purpose because it is possible to reconstruct the entire final state. The spin-CP information come from the correlation between the Higgs spin and the final state's kinematics. It is possible to define the variables sensitive to the spin of the decaying particle. The observables used in this study are the masses of the on-shell and off-shell Z bosons (m_1, m_2), five angular variables defined through the directions of the four leptons and Z bosons and the mass of the four lepton system $m_{4\ell}$. This last observable is not sensitive to the spin but it is used because it is particularly useful to reject the background in the mass range of interest ($m_{4\ell}\epsilon[115, 130]$ GeV).

1. – Hypothesis tests

The first study on the Higgs spin-parity is based on the comparison of the observable distributions between two J^P hypotheses at a time with a multivariate method [1]. The $J^P = 0^+$ (SM) hypothesis is tested against $J^P = 0^-, 1^+, 1^-, 2^+_m$. The results obtained with the data collected during the RUN1 at LHC (corresponding to $\sim 25\,\text{fb}^{-1}$), combining the limits from $h \to ZZ^*$, $h \to WW^*$ and $h \to \gamma\gamma$ channels, show that the SM hypothesis is favored over all the other tested J^P hypotheses at least at the 97.8% CL.

2. – Tensorial structure study in the spin-0 Higgs hypothesis

Since the hypothesis test favored clearly the 0^+ hypothesis it is interesting to study the possibility of anomalous couplings in the decay amplitude of the spin-0 Higgs boson. The most general Lorentz invariant decay amplitude in the HZZ vertex is

$$A(h \to Z_1 Z_2) = v^{-1}\big(g_1 m_Z^2 \epsilon_1^* \epsilon_2^* + g_2 f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + g_4 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\mu\nu}\big), \tag{1}$$

where g_i are in general complex couplings (more details in [2]). The first three terms in eq. (1) are CP-even while the last one is CP-odd. The SM hypothesis expects only the first term sensitively different to zero, while in $J^P = 0^-$ only the last term is not null.

The goal of the analysis is to study and to estimate the single contributions in eq. (1) using all the information of the final state searching for:

– Higgs states which are not CP eigenstates but a mixture of CP-odd and CP-even states;

– CP violation in the decay (if $g_4\ /g_1$ is not real);

– contributions of New Physics in the loop that lead to non zero g_2/g_1.

The *8D Likelihood Fit* is a method that allows to estimate the couplings g_i. It is based on an 8-dimensional signal *pdf* found on Matrix Element calculations corrected by acceptance functions that take in account the detector effects and the cuts of the analysis. The irreducible background *pdf* is based on full simulations MonteCarlo and the reducible one is data-driven. The event selection is the same used in the mass and coupling analysis in the $h \to ZZ^* \to 4\ell$. Finally it is implemented a simoultaneous *pdf* of the four different decay channels $(4\mu, 2\mu 2e, 2e2\mu, 4e)$.

It is convenient to express the g_i parameter results in terms of the fractions of event yields corresponding to each anomalous coupling independently and the relative phases:

$$f_{g_i} = \frac{|g_i|^2\sigma_i}{|g_1|^2\sigma_1 + |g_2|^2\sigma_2 + |g_4|^2\sigma_4}, \quad \phi_{gi} = \arg\left(g_i/g_1\right). \tag{2}$$

With an integrated luminosity of $300\,\mathrm{fb}^{-1}$ and $3000\,\mathrm{fb}^{-1}$ available with LHC data at $\sqrt{s} = 14\,\mathrm{TeV}$ it will be possible to exclude $f_{g_4} > 0.20(0.06)$ and $f_{g_2} > 0.29(0.12)$ at 95% CL with an integrated luminosity of $300\,\mathrm{fb}^{-1}$ ($3000\,\mathrm{fb}^{-1}$) profiling the parameters ϕ_{gi} [3].

Rescaling this high integrated luminosity limits to the RUN1 statistics corrisponding to $25\,\mathrm{fb}^{-1}$ it is expected to exclude $f_{g_4} \gtrsim 0.75$ at 95% CL.

3. – Conclusions

The sensitivity of the ATLAS experiment to the complex structure of the non-Standard Model couplings is demonstrated. The method to estimate the decay amplitude's couplings sensitive to New Physics beyond Standard Model can give a 95% CL limit also with the RUN1 statistics and it will be very useful in the future to make precision measurements and to test carefully the validity of the Standard Model.

REFERENCES

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