Spin identification of Higgs boson in diphoton production at the Large hadron collider.

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Abstract

We discuss the identification of the spin-0 Higgs-like boson observed at the LHC in diphoton production channel against the hypothesis of a spin-2 narrow diphoton resonance with the same mass and giving the same number of signal events under the peak. We focus on the center-edge asymmetry $A_{\rm CE}$ of the cosine of the polar angle of the produced photons in the diphoton rest frame to distinguish between the tested spin hypotheses. We show that the center-edge asymmetry should provide strong discrimination between spin-0 and spin-2 hypotheses.

The inclusive two-photon production process at the LHC,

$$p + p \to \gamma\gamma + X, \tag{1}$$

represents a very important testing ground for the Standard Model (SM), in particular as a discovery channel for the Higgs boson (H) searches. Since the observation of the Higgs-like peak at $M_{\gamma\gamma} \simeq 125$ GeV by both the ATLAS and CMS experiments [1, 2], much effort has been devoted to the comparison with increased statistics of the properties of this particle with the SM predictions for the Higgs boson, in particular to test the spin-0 character, see Refs. [3, 4] where the set of data at $\sqrt{s} = 8$ TeV and luminosity 20 fb^{-1} has been employed. In this regard, the decay channel in (1) is particularly suited, because the exchange of spin-1 is excluded [5], and only spin-2 remains as a possible competitor hypothesis.

With N the number of signal peak events, the distinctive photon polar angle distributions at partonic level and leading order (LO) in QCD are of the form [$z = \cos\theta$]:

$$\frac{dN}{dz}(gg \to \gamma\gamma) \propto 1 + 6z^2 + z^4; \quad \frac{dN}{dz}(q\bar{q} \to \gamma\gamma) \propto 1 - z^4, \tag{2}$$

for a minimally coupled $J^P = 2^+$, and

$$\frac{dN}{dz} \propto \text{constant} \tag{3}$$

for the SM, spin-0,Higgs boson.

Of course, in practice the shapes in Eqs. (2) and (3) will be significantly distorted by selection experimental cuts, resolutions and contamination effects from background subtractions. Basically, the analyses of differential distributions performed in Refs. [3, 4] are based on log-likelihood statistical methods and indicate the spin-0 hypothesis as largely favoured over the spin-2 one.

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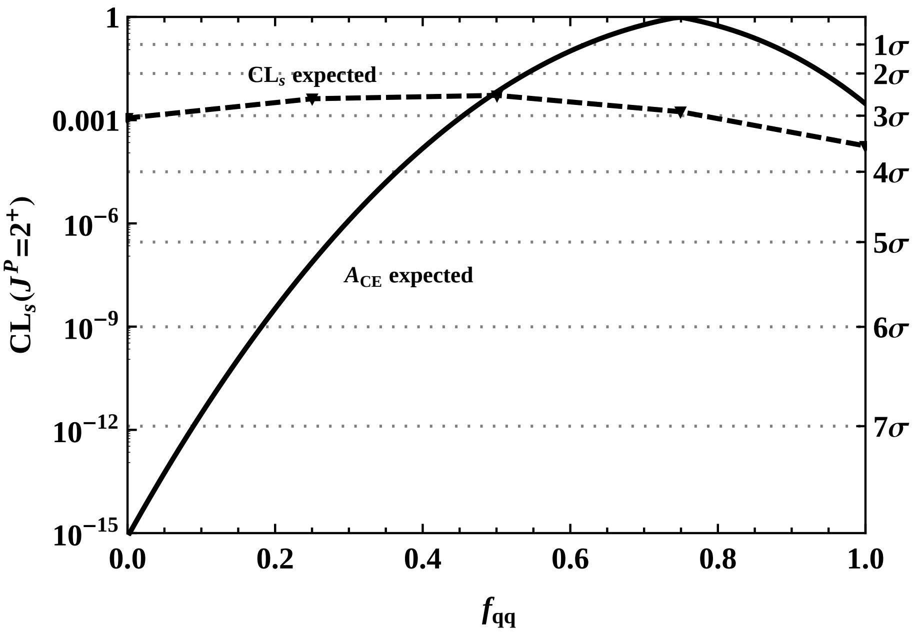

Figure 1: Comparison of the expected confidence levels, $\mathrm{CL_s}(J^P = 2^+)$, of the $J^P = 2^+$ hypothesis as functions of the fraction f_{qq} for spin-2 particle production from the angular distribution (dashed line) for the three channels $H \to \gamma\gamma$, $H \to ZZ^*$ and $H \to WW^*$ at $\sqrt{s} = 8$ TeV and luminosity 20 fb^{-1} with ATLAS [3] and expected confidence levels determined from the center-edge asymmetry measure at $z^* = 0.5$ in the $H \to \gamma\gamma$ channel (solid line).

We introduce the center-edge asymmetry to quantify the separation significance between spin-0 and spin-2 resonances following the definition given in Refs.[6, 7, 8, 9, 10, 11]:

$$A_{\mathrm{CE}} = \frac{N_C - N_E}{N_C + N_E}, \tag{4}$$

where N_C is the number of events lying within the center range $-z^* \leq z \leq z^*$ and N_E the number of events outside this range (in the edge range). Here, $0 < z^* < z_{\mathrm{cut}}$ is a kinematical parameter that can be considered as a priori free, and defines the separation between the "center" and the "edge" angular regions. For more details and references on the analysis presented here see Ref.[11].

The formulae for A_{CE} can be easily obtained from its definition (4) and the expressions for the angular distributions:

$$A_{\mathrm{CE}}^{\mathrm{spin-0}} = 2\,z^* - 1, \tag{5}$$

and for spin-2 case one reads

$$A_{\mathrm{CE}}^{\mathrm{spin-2}} = f_{qq}\,A_{\mathrm{CE},qq}^{\mathrm{spin-2}} + (1 - f_{qq})\,A_{\mathrm{CE},gg}^{\mathrm{spin-2}}, \tag{6}$$

where

$$A_{\mathrm{CE},qq}^{\mathrm{spin-2}} = \frac{1}{2}\,z^*\,(5 - z^{*4}) - 1, \tag{7}$$

$$A_{\mathrm{CE},gg}^{\mathrm{spin-2}} = \frac{5}{8}\,(z^* + 2z^{*3} + \frac{z^{*5}}{5}) - 1. \tag{8}$$

The center-edge asymmetry here depends on two parameters, namely the kinematical parameter z^* and the fraction f_{qq} of the $q\bar{q}$ production of the spin-2 particle.

To evaluate A_{CE} one needs the angular distributions of the diphoton events relevant to the particular experiment at the LHC. Such normalized $\cos\hat{\theta}$ distributions (simulations) were presented by ATLAS (Fig. 5 in Ref. [3]), after background subtractions and including cuts, hadronization and detector effects (which are different for the spin-0 and the spin-2 signal), both produced by gg and by $q\bar{q}$, together with the observed distribution from background events in the invariant-mass sidebands (105 GeV $< m_{\gamma\gamma} <$ 122 GeV and 130 GeV $< m_{\gamma\gamma} <$ 160 GeV) [3].

There is an alternative approach to quantify the separation power by using the CLs prescription [12]:

$$CLs(f_{qq}) = p(2^+)/(1 - p(0^+)),$$

where $p(2^+)$ is p-value for spin-2 and $p(0^+)$ is p-value for spin-0. It is instructive to compare the expected confidence level, obtained in the present analysis with those available from the ATLAS study of the three channels $H \to \gamma\gamma$, $H \to ZZ^*$ and $H \to WW^*$ at $\sqrt{s} = 8$ TeV and luminosity 20.7 fb^{-1} [3]. Fig. 1 shows that A_{CE} measurements are able to increase the observed confidence level in the range of parameter space $0 < f_{qq} < 0.4$. Here we extended the analysis done in [13, 14] by accounting for various admixtures of the gg and $q\bar{q}$ production modes in the application of A_{CE} to the angular study of the diphoton production process (1) at the LHC. Also, an optimization of the center-edge asymmetry on the kinematical parameter z^* can be performed in order to enhance the potential of A_{CE} as a discriminator of spin hypotheses of Higgs-like resonances.

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