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On azimuthal spin correlations in Higgs plus jet events at LHC

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We consider the recent proposal that the distribution of the difference between azimuthal angles of the two accompanying jets in gluon-fusion induced Higgs-plus-two-jet events at LHC reflects the CP of the Higgs boson produced. We point out that the hierarchy between the Higgs boson mass and the jet transverse energy makes this observable vulnerable to logarithmically enhanced higher-order perturbative corrections. We present an evolution equation that describes the scale variation of the azimuthal angular correlation for the two jets. The emission of extra partons leads to a significant suppression of the correlation. Using the HERWIG Monte Carlo event generator, we carry out a parton-shower analysis to confirm the findings.

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Introduction

Gluon fusion via the top quark loop provides the dominant mechanism for Higgs boson production at LHC. Recently, the analysis of the related ($2 \rightarrow 3$) cross section was carried out at the leading order in $\alpha_S(M_Z)$ in ref. delduca.

The proposal is to tag two extra jets, the motivation being the elucidation of the differences/similarities between this process and the weak-boson-fusion process, which also comes accompanied with two extra jets.

After imposing cuts on the jet momenta similar to the weak-boson-fusion selection criteria, the soft-gluon contribution is reduced and they obtain, as shownWe thank the authors of ref. delduca for their kind permission to reproduce the figure.n fig. delducafig, a striking correlation between the azimuthal angles ϕ of the two jets, one of which is now in the forward direction while the other one is in the backward direction. Provided that the produced Higgs boson is CP-even, the distribution of the difference $\Delta\phi$ of the two azimuthal angles is peaked at $\Delta\phi = 0, \pi$ and falls to nearly zero at $\Delta\phi = \pi/2$. If the Higgs boson is CP-odd, although the result is not explicitly shown, the distribution is peaked at $\Delta\phi = \pi/2$ and falls to nearly zero at $\Delta\phi = 0, \pi$. file=phi$_c uts_c omp.eps, width = 10cm The distribution of the azimuthal angle between the two highest$ p_T jets, taken from ref. delduca. Results shown are for the top-quark induced gluon-fusion process, with $m_t =$ 175 GeV and in the limit $m_t \rightarrow \infty$, and for the weak-boson-fusion process. delducafig

In this work, we would like to point out one potential pitfall which seems to have been neglected in their study, namely that there are two scales in this problem. The higher scale is related to the Higgs boson production. For a leading order analysis we can set it to be the Higgs boson mass for convenience. The lower scale is related to the emission leading to the tagged jets and this is characterized by the jet transverse momenta. Because of the presence of two scales, the predictions of calculations at a finite perturbative order becomes sensitive to higher order corrections.

We investigate this problem by first establishing an evolution equation that describes the scale variation of the azimuthal angular correlation coefficient. The large size of the relevant anomalous dimension implies that there is significant, up to one order of magnitude, reduction in the size of the correlation coefficient.

Although the problem is formally due to the logarithm of the ratio of the two scales which enhance the higher order contributions, we find that the ratio needs not be so large for the effect of extra emission to become important.

An alternative approach to investigating this problem is by a parton-shower level Monte Carlo simulation. We formulate this problem as a ($2 \rightarrow 1$) cross section convoluted with the leading logarithmic parton shower using HERWIG herwig, which includes the azimuthal spin correlations by default by using the algorithm of Collins and Knowles collins, knowles, peter.

The results of the two approaches are in good agreement.

We note that the weak-boson fusion mode is unaffected by extra emission, as the jet p_T scale is the only QCD scale present in this case.

We present the evolution equation analysis in sect. evolution and its comparison with the parton-shower analysis in sect. partonshower. We present the conclusions in sect. conclusions.

Evolution equation analysisevolution

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Let us consider the evolution of a jet that is due to an initial state parton. In a Monte Carlo simulation, this is described by the backward evolution.

At each stage of evolution, the probed parton has virtuality t, momentum fraction x, jet transverse momentum p_T according to some definition, and spin density ρ. We wish to measure the mean value of the component of $\rho = \rho_\|$ that is aligned with the reference direction given by p_T. The correlation arises in the first place because of the correlation, at the hard process level, between the planes of polarization of the gluons involved in the Higgs boson production. Hence the decorrelation between the plane of polarization of each gluon and the direction of the related tagged jet is equivalent to the suppression of the azimuthal angular correlation between the two tagged jets.

In the following, p_T and ρ are both two-component vectors. The spin density matrix ρ_{ij} is given in terms of the vector ρ_k by $\rho_{ij} = (1 + \rho_k \sigma^k_{ij})/2$. The third component of the vector ρ vanishes so long as the nucleon is unpolarized collins, knowles. In terms of the distribution functions $f(x, t, p_T, \rho)$, we may write the scale variation as follows: eqnarray $\partial < \rho_\| > (x, t) \partial t = \partial \partial t \int f(x, t, p_T, \rho) \rho_\| dp_T d\rho \int f(x, t, p_T, \rho) dp_T d\rho$

The change in the distribution functions when the scale is raised from t to $t + \delta t$ is given by: eqnarray $\delta f(x, t, p_T, \rho) = \delta f_{in} - \delta f_{out}, delta_f$

Combining the above with eqn. (master$_eqn), the contribution from the term \delta f_{out}$ vanishes and we obtain: eqnarray $\partial < \rho_\| > (x, t) \partial t = 1 f(x, t) \int \partial f_{in} \partial t \left(\rho_\| - < \rho_\| > (x, t)\right) dp_T d\rho$

Now let us consider the case in which the direction of p_T, or more generally the reference direction, is to a good approximation determined at one scale given, for instance, by the jet transverse momentum p_{Tj}, and we are interested in the soft emission that depolarizes the gluon between this scale and the hard process scale.

In this case, ϕ_0 can be taken as constant. Integrating over ϕ, by symmetry, the term proportional to $n(\phi)$ in eqn. (eqn2) vanishes, as does the ϕ dependent term in $F(z, \phi, \rho')$. We then have: eqnarray $\partial < \rho_\| > (x, t) \partial \ln t = - \int dz z \alpha_S 2\pi d\rho' dp'_T f(x/z, t, p'_T, \rho') f(x, t)$

The pole at $z \to 1$ of $\widehat{P}(z)$ cancels with the pole of $f_3(z)$. The expression of eqn. (eqn4) is the difference between the change in the structure function $f(x, t)$ given by the first term and the change in the spin density $< \rho_\| > f(x, t)$ given by the second term. The two terms can be treated separately by introducing the plus prescription to account for the δf_{out} term given by eqn. (f$_out). We obtain: eqnarray \partial < \rho_\| > (x, t) f(x, t) \partial \ln t = \int dz z \alpha_S 2\pi f(x/z, t) < \rho_\| > (x/z, t)\ C f_3(z)_+, eqn5$

Taking the x^j moments of the above to obtain Mellin transforms, we convert the expressions into: eqnarray $\partial \big[\widetilde{< \rho_\| > f}\big](j, t) \partial \ln t = \big[\widetilde{< \rho_\| > f}\big](j, t) \int dz z^{j-1} \alpha_S 2\pi C f_3(z)_+, eqn7$

As stated above, eqn. (eqn4) specifies the evolution of polarization in regions where extra emission does not alter the reference direction. For our purpose, the most interesting case is the soft/collinear gluon emission from the gluon line in between the hard process and the jet p_T scale.

For small enough x, such that $j \sim 1$, the behaviour of the anomalous dimensions is controlled by the $z \to 0$ region. If we choose the $g \to gg$ splitting, the fact that $P(z)$ has a pole at $z \to 0$ where as $f_3(z)_+$ does not, indicates that a large disparity arises in the two quantities. $< \rho_\| >$ is the ratio of $< \rho_\| > f$ and f, such that its running is governed by the difference of the above two anomalous dimensions. The relevant splitting function is: equation $\left[C f_3(z) - \widehat{P}(z)\right]_{g \to gg} = -2 C_A (1 - z)(1 + z^2) z.$