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On azimuthal spin correlations in Higgs plus jet events at LHC

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Abstract: 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.

Keywords: Higgs Physics, Jets, Spin and Polarization Effects, Hadronic Colliders.

Contents

1. Introduction

Gluon fusion via the top quark loop provides the dominant mechanism for Higgs boson production at LHC. Recently, the analysis of the related $(2 \to 3)$ cross section was carried out at the leading order in $\alpha_S(M_Z)$ in ref. [1].

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 shown[1] in figure 1, 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 $\Delta\phi = 0, \pi$.

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.

[1]We thank the authors of ref. [1] for their kind permission to reproduce the figure.

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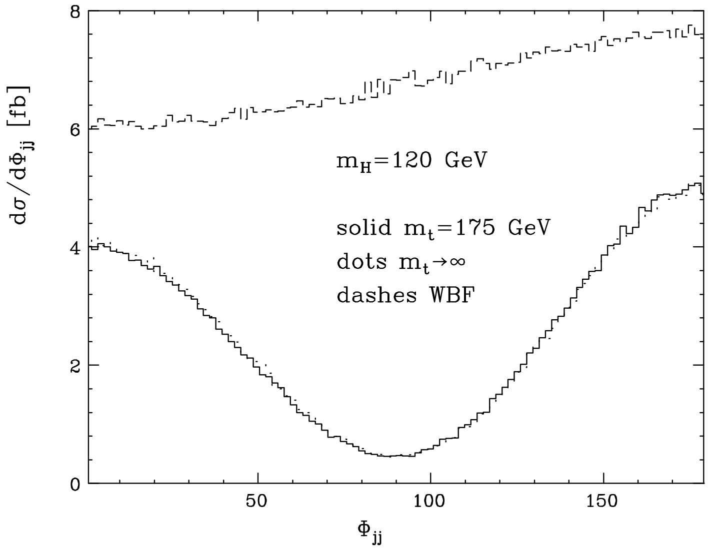

Figure 1: The distribution of the azimuthal angle between the two highest p_T jets, taken from ref. [1]. Results shown are for the top-quark induced gluon-fusion process, with $m_t = 175\,\text{GeV}$ and in the limit $m_t \to \infty$, and for the weak-boson-fusion process.

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 $(2 \to 1)$ cross section convoluted with the leading logarithmic parton shower using HERWIG [2], which includes the azimuthal spin correlations by default by using the algorithm of Collins and Knowles [3, 4, 5].

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 section 2 and its comparison with the parton-shower analysis in section 3. We present the conclusions in section 4.

2. Evolution equation analysis

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.

Process	$\widehat{P}/C$	f_2	f_3	f_4
$g \to gg$	$2\left[(1-z)/z + z/(1-z) + z(1-z)\right]$	$2(1-z)/z$	$2z/(1-z)$	$2z(1-z)$
$g \to q\bar{q}$	$z^2 + (1-z)^2$	0	0	$-2z(1-z)$
$q \to qg$	$(1+z^2)/(1-z)$	0	$2z/(1-z)$	0
$q \to gq$	$\left[1+(1-z)^2\right]/z$	$2(1-z)/z$	0	0

Table 1: The coefficients f_i, taken from ref. [4], modified to adopt the convention of ref. [7] for the normalization.

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 [3, 4]. In terms of the distribution functions $f(x, t, p_T, \rho)$, we may write the scale variation as follows:

$$\begin{aligned}\frac{\partial\langle\rho_{\|}\rangle(x,t)}{\partial t} &= \frac{\partial}{\partial t}\frac{\int f(x,t,p_T,\rho)\rho_{\|} dp_T d\rho}{\int f(x,t,p_T,\rho) dp_T d\rho} \\ &= \frac{1}{f(x,t)}\int \frac{\partial f(x,t,p_T,\rho)}{\partial t}\left\{\rho_{\|} - \langle\rho_{\|}\rangle(x,t)\right\} dp_T d\rho\,. \end{aligned} \tag{2.1}$$

The change in the distribution functions when the scale is raised from t to $t + \delta t$ is given by:

$$\delta f(x,t,p_T,\rho) = \delta f_{\rm in} - \delta f_{\rm out}, \tag{2.2}$$

$$\delta f_{\rm out} = \frac{\delta t}{t}\int dz \frac{\alpha_S}{2\pi}\frac{d\phi}{2\pi} C F(z,\phi,\rho) f(x,t,p_T,\rho)\,, \tag{2.3}$$

$$\delta f_{\rm in} = \frac{\delta t}{t}\int \frac{dz}{z}\frac{\alpha_S}{2\pi}\frac{d\phi}{2\pi} d\rho' C F(z,\phi,\rho')\delta(\rho - \rho(\rho',z,\phi)) f\left(\frac{x}{z}, t, p'_T(p_T,t,z,\phi), \rho'\right). \tag{2.4}$$

In eq. (2.4), ϕ is the emission angle. z is the remaining energy fraction during the emission, such that the emitted energy fraction is $1 - z$. ρ is determined by the following relation according to the notation of ref. [4]:

$$\rho = \frac{(f_2(z) n(\phi) + f_3(z)\rho')}{F(z,\phi,\rho')}\,, \tag{2.5}$$

where f_i are various components of the splitting function shown in table 1, and $n(\phi) = (\cos 2\phi, \sin 2\phi)$. In all of the above, C and F are the colour factor and the polarization dependent splitting function respectively, with $F(z,\phi,\rho') = \widehat{P}(z)/C + f_4(z) n(\phi)\cdot\rho'$.

Combining the above with eq. (2.1), the contribution from the term $\delta f_{\rm out}$ vanishes and we obtain:

$$\frac{\partial\langle\rho_{\|}\rangle(x,t)}{\partial t} = \frac{1}{f(x,t)}\int \frac{\partial f_{\rm in}}{\partial t}\left(\rho_{\|} - \langle\rho_{\|}\rangle(x,t)\right) dp_T d\rho \tag{2.6}$$

$$\begin{aligned} &= \frac{1/t}{f(x,t)}\int \frac{dz}{z}\frac{\alpha_S}{2\pi}\frac{d\phi}{2\pi} d\rho' dp_T d\rho C F(z,\phi,\rho')\delta\left(\rho - \frac{f_2(z)n(\phi) + f_3(z)\rho'}{F(z,\phi,\rho')}\right) \times \\ &\quad \times f\left(\frac{x}{z}, t, p'_T(p_T,t,z,\phi), \rho'\right)\left(\rho_{\|} - \langle\rho_{\|}\rangle(x,t)\right) \end{aligned} \tag{2.7}$$

$$
\begin{aligned}
&= -\frac{1}{t}\int \frac{dz}{z}\frac{\alpha_S}{2\pi}\frac{d\phi}{2\pi} d\rho' dp'_T C \frac{f(x/z,t,p'_T,\rho')}{f(x,t)} \times \\
&\quad \times \left[\langle\rho\rangle(x,t)F(z,\phi,\rho') - (f_2(z)n(\phi) + f_3(z)\rho')\right]\cdot(\cos 2\phi_0, \sin 2\phi_0)\,. \qquad (2.8)
\end{aligned}
$$

In the last line, ϕ_0 is the azimuthal angle of p_T. Between eqs. (2.7) and (2.8), we have assumed that p_T is defined in an additive manner, such that $dp_T = dp'_T$. Excepting this assumption, our discussion so far has been general.

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 eq. (2.8) vanishes, as does the ϕ dependent term in $F(z,\phi,\rho')$. We then have:

$$
\begin{aligned}
\frac{\partial\langle\rho_{||}\rangle(x,t)}{\partial \ln t} &= -\int \frac{dz}{z}\frac{\alpha_S}{2\pi} d\rho' dp'_T \frac{f(x/z,t,p'_T,\rho')}{f(x,t)}\left[\widehat{P}(z)\langle\rho_{||}\rangle(x,t) - Cf_3(z)\rho'_{||}\right] \qquad (2.9)\\
&= -\int \frac{dz}{z}\frac{\alpha_S}{2\pi}\frac{f(x/z,t)}{f(x,t)}\left[\widehat{P}(z)\langle\rho_{||}\rangle(x,t) - Cf_3(z)\langle\rho_{||}\rangle\left(\frac{x}{z},t\right)\right]. \qquad (2.10)
\end{aligned}
$$

The pole at $z \to 1$ of $\widehat{P}(z)$ cancels with the pole of $f_3(z)$. The expression of eq. (2.10) 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 $\langle\rho_{||}\rangle f(x,t)$ given by the second term. The two terms can be treated separately by introducing the plus prescription to account for the $\delta f_{\rm out}$ term given by eq. (2.3). We obtain:

$$
\begin{aligned}
\frac{\partial\langle\rho_{||}\rangle(x,t)f(x,t)}{\partial \ln t} &= \int \frac{dz}{z}\frac{\alpha_S}{2\pi} f\left(\frac{x}{z},t\right)\langle\rho_{||}\rangle\left(\frac{x}{z},t\right) Cf_3(z)_+\,, \qquad (2.11)\\
\frac{\partial f(x,t)}{\partial \ln t} &= \int \frac{dz}{z}\frac{\alpha_S}{2\pi} f\left(\frac{x}{z},t\right) P(z)\,. \qquad (2.12)
\end{aligned}
$$

Taking the x^j moments of the above to obtain Mellin transforms, we convert the expressions into:

$$
\begin{aligned}
\frac{\partial\widetilde{[\langle\rho_{||}\rangle f]}(j,t)}{\partial \ln t} &= \widetilde{[\langle\rho_{||}\rangle f]}(j,t)\int dz z^{j-1}\frac{\alpha_S}{2\pi} Cf_3(z)_+\,, \qquad (2.13)\\
\frac{\partial\widetilde{f}(j,t)}{\partial \ln t} &= \widetilde{f}(j,t)\int dz z^{j-1}\frac{\alpha_S}{2\pi} P(z)\,, \qquad (2.14)
\end{aligned}
$$

such that the anomalous dimensions are:

$$
\begin{aligned}
\gamma_{\langle\rho_{||}\rangle f} &= \int dz z^{j-1}\frac{\alpha_S}{2\pi} Cf_3(z)_+\,, \qquad (2.15)\\
\gamma_f &= \int dz z^{j-1}\frac{\alpha_S}{2\pi} P(z)\,, \qquad (2.16)
\end{aligned}
$$

respectively for the spin density and the parton distribution functions.

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As stated above, eq. (2.10) 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. $\langle \rho_{||} \rangle$ is the ratio of $\langle \rho_{||} \rangle f$ and f, such that its running is governed by the difference of the above two anomalous dimensions. The relevant splitting function is:

$$\left[C f_3(z) - \widehat{P}(z) \right]_{g \to gg} = -2C_A \frac{(1-z)(1+z^2)}{z} \, . \tag{2.17}$$

Exactly as in the case of the hadron multiplicity calculation [6, 7], the expression of eq. (2.16), when $j = 1$, is divergent as written, but a more careful analysis, taking into account the suppression of soft gluon emission due to coherence, leads to the result:

$$\Delta\gamma(j, \alpha_S) = -\sqrt{\frac{C_A \alpha_S}{2\pi}} + \frac{j-1}{4} + \cdots \, . \tag{2.18}$$

$$\frac{\widetilde{[\langle \rho_{||} \rangle f]}(1,t)}{\widetilde{f}(1,t)} \propto \exp\left[-\frac{1}{b}\sqrt{\frac{6}{\pi \alpha_S(t)}} \right] \sim \exp\left[-\sqrt{\frac{6}{\pi b} \ln\left(\frac{t}{\Lambda^2}\right)} \right] . \tag{2.19}$$

Hence the evaluation of $\langle \rho_{||} \rangle$ at the hard process scale $\sim \sqrt{\hat{s}}$, defining it to be the ratio of $\langle \rho_{||} \rangle f$ and f individually integrated over the allowed, typically small, values of x, assuming perfect polarization at the lower scale $\sim p_{Tj}$, gives:

$$\langle \rho_{||} \rangle (p_{Tj}^2) \approx \exp\left[\sqrt{\frac{6}{\pi b} \ln \frac{p_{Tj}^2}{\Lambda^2}} - \sqrt{\frac{6}{\pi b} \ln \frac{\hat{s}}{\Lambda^2}} \right] \tag{2.20}$$

Let us take the jet energy scale at around 20 GeV and the hard process scale at 100 GeV. $b = (11C_A - 2n_f)/12\pi$ at this order, and we can adopt for simplicity $\Lambda \sim 200$ MeV. We then obtain $\langle \rho_{||} \rangle = 0.42$. We are interested in the correlation between two jets, which is now given by the square of $\langle \rho_{||} \rangle$, and we obtain 0.18. Thus there is almost one order of magnitude dilution.

There would be further dilution due to the modification of the p_T direction due to extra emission, and the imperfect polarization at the jet energy scale must also be taken into account. The parton-shower analysis, which we present in the following, incorporates all of these effects.

3. Parton-shower simulation

Our parton-shower simulation is based on the Monte Carlo event generator HERWIG 6.5 [2]. For the $(2 \to 1)$ hard process,

$$gg \to \Phi \, , \tag{3.1}$$

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where Φ is either a CP-even or a CP-odd Higgs boson with $M_\Phi = 120\,\text{GeV}$ [1], we utilize the code for the MSSM H^0 and A^0 production. We set $\tan\beta = 1$, $\beta - \alpha = \pi/2$ and all supersymmetric masses equal to 10 TeV, such that the Higgs production is mostly due to the top quark loop only. The parton shower, including the azimuthal angular correlation [3, 4], follows the HERWIG default, although we found two bugs which had to be corrected before the effect of the angular correlation could be seen. One bug affects the azimuthal angle of the branching $q \to gq$, whereas the other, more serious, bug affects the Lorentz boost of the jets to the laboratory frame. The resultant code will be part of the next HERWIG sub-version.

We have performed the analysis also incorporating the heavy quark initiated hard process $Q\bar{Q} \to \Phi$, but there was no significant alteration to the results presented herein.

For jet reconstruction, we make use of the program GETJET [8]. This uses a simplified version of the UA1 jet algorithm with jet radius ΔR which we set equal to 0.4.

For the Standard Model parameters, we adopted the default values in HERWIG. For the structure function, we have used the default set in HERWIG, namely the mean of the central gluon and higher gluon leading order structure functions of MRST98 [9]. We follow the numbers in ref. [1] for the Higgs boson mass of 120 GeV and the jet selection criteria. We do not decay the Higgs boson and do not impose any cuts on its kinematics. We take the LHC centre-of-mass energy $\sqrt{s} = 14$ TeV.

The jet selection criteria, which we define to be applicable to the two jets with the highest transverse momenta p_{Tj}, are as follows:

$$\begin{aligned} p_{Tj} &> 20\,\text{GeV}\,, & |\eta_j| &< 5\,, & \Delta R_{jj} &> 0.6 \\ |\Delta\eta_{jj}| &> 4.2\,, & \eta_{j1}\cdot\eta_{j2} &< 0\,, & m_{jj} &> 600\,\text{GeV}\,. \end{aligned} \tag{3.2}$$

Thus we are picking out events with one forward jet and one backward jet, with large combined invariant mass.

The result of our parton-shower simulation on the azimuthal angular difference $\Delta\phi$, following the procedures outlined above, is shown in figure 2. The error-bars are for the statistics. We generated one million events in each case to compensate for the low acceptance. Since the total cross section is around 20 pb, this corresponds to about $50\,\text{fb}^{-1}$ integrated luminosity.

The difference in the normalization between the CP-even case and the CP-odd case is due to the different loop amplitudes depending on whether the produced Higgs boson is CP-even or CP-odd. The total cross section is similar to that shown in figure 1. The points marked 'No correlation' corresponds to the same hard process as the CP-even case but with the azimuthal correlation turned off by means of the HERWIG option `AZSPIN=.FALSE.`

The curves in figure 2 are fitted by the Fourier series analysis using the expansion $a_0 + a_1\cos(2\Delta\phi)$. Our fit gives $101.2 + 13.0\cos(2\Delta\phi)$ (fb) for the CP-even case and $82.0 - 14.9\cos(2\Delta\phi)$ (fb) for the CP-odd case. With the azimuthal correlation switched off, we obtain $100.1 - 1.45\cos(2\Delta\phi)$ (fb) so that it is possible that the case without azimuthal correlation is not completely flat. We calculated the statistical error on the Fourier coefficients to be about 1 fb for all coefficients. The coefficient in this case is found to be 1.24σ away from being flat.

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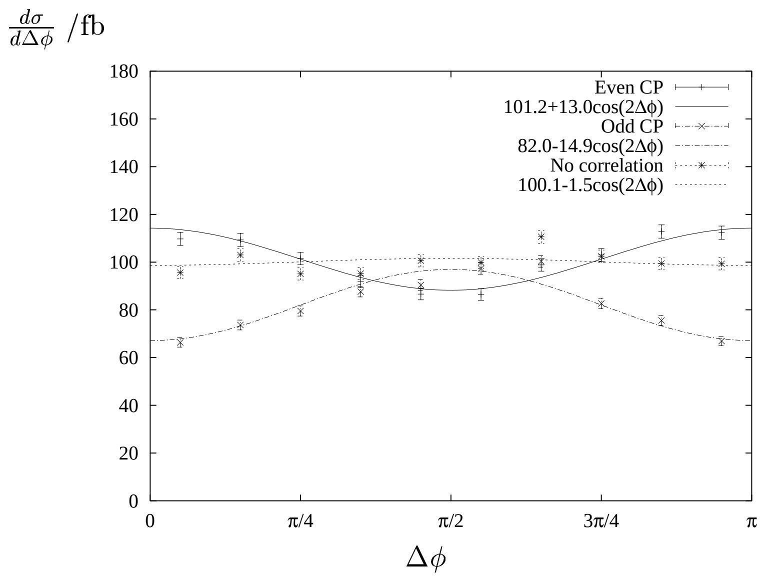

Figure 2: The distribution of the azimuthal angle between the two highest p_T jets, after imposing the cuts of eq. (3.2). Simulation at the parton-shower level. The error-bars are for the statistics.

The correlation is evidently diluted. As the distribution is almost proportional to $1 + \cos(2\Delta\phi)$ for the CP-even case in figure 1, we may say that there is dilution by nearly one order of magnitude, in agreement with the analysis in section 2.

Next, let us look at the jet p_T scale dependence of the correlation coefficient. In order to account for the possibly intrinsically non-flat distribution, we calculate the mean of the CP-even and CP-odd correlation coefficients given by:

$$\left\langle\left|\frac{a_1}{a_0}\right|\right\rangle = \frac{1}{2}\left[\left(\frac{a_1}{a_0}\right)_{\text{CP-even}} - \left(\frac{a_1}{a_0}\right)_{\text{CP-odd}}\right]. \tag{3.3}$$

For the evolution equation analysis, the correlation coefficient is calculated as the square of $\langle\rho_{||}\rangle$ given in eq. (2.20).

The result is shown in figure 3, taking the jet p_T scale to be the minimum p_{Tj} for the HERWIG simulation and p_{Tj} in the evolution equation analysis as seen in eq. (2.20). We rather arbitrarily chose $\Lambda = 180\,\text{MeV}$ in this case, equal to the value of the HERWIG variable `QCDLAM`. We set the higher scale $\sim \sqrt{\hat{s}} = 120\,\text{GeV}$ to correspond to the Higgs boson mass.

We see that the HERWIG results are in good agreement with the evolution equation analysis in section 2. The running of the correlation coefficient at low jet energy scales is slower in HERWIG. This is natural when we consider the fact that the actual p_{Tj} is always higher than the imposed p_{Tj} cut, especially so when the cut is low. We verified this by taking the $p_{Tj} > 10\,\text{GeV}$ point and further imposing the constraint that neither of the tagged jets have p_{Tj} greater than $20\,\text{GeV}$. We obtain 0.000 ± 0.024 for the coefficient in this case.

As mentioned in section 2, there is further dilution in the HERWIG analysis compared to the evolution equation analysis due to the imperfect polarization at the jet p_T scale and the modification of the p_T direction due to extra emission. The latter is expected to

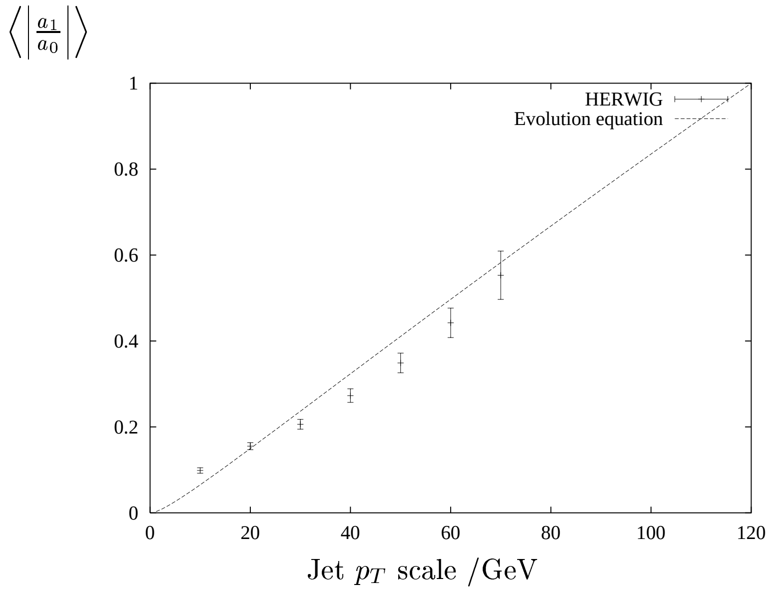

Figure 3: Jet p_T scale dependence of the correlation coefficient $|a_1/a_0|$, averaged over the CP-even and CP-odd cases. For the HERWIG numbers, the jet p_T scale is taken to be the minimum p_{Tj}, whereas for the evolution equation analysis, the jet p_T scale is as represented by p_{Tj} in eq. (2.20). The error-bars on the HERWIG numbers are for the statistics.

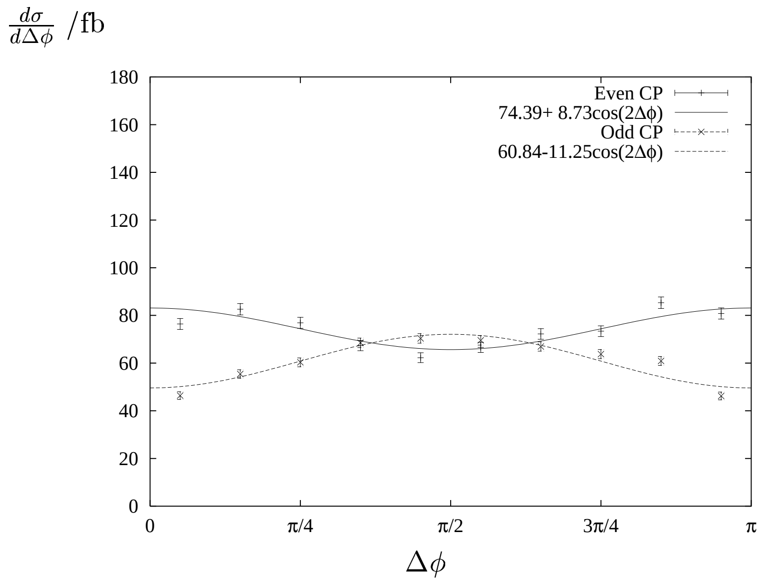

Figure 4: The distribution of the azimuthal angle between the two highest p_T jets, after imposing the cuts of eq. (3.2). Simulation at the hadron level, without soft underlying events.

be important when the jet p_T scale is low. The result in figure 3 indicates that although these effects must be present, they do not significantly alter the behaviour derived by the evolution equation analysis.

Our analysis so far has been carried out at the parton-shower level. Let us now turn our attention to the effect of hadronization. In figure 4, we show the numbers for the hadron level simulation corresponding to the cuts of eq. (3.2), i.e., with $p_{Tj} > 20\,\mathrm{GeV}$.

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We have turned off soft underlying events. We have utilized the simplified calorimeter simulation in GETJET. For the electromagnetic calorimeter, we take the resolution to be $\sigma_E/E = 10\%/\sqrt{E/\mathrm{GeV}}$, and for the hadronic calorimeter, we take the resolution to be $\sigma_E/E = 50\%/\sqrt{E/\mathrm{GeV}}$. We observe that except for the reduced acceptance rate, the result is similar to that shown in figure 2. The resulting coefficient $\langle|a_1/a_0|\rangle$ is consistent with the parton level simulation.

4. Conclusions

By means of an evolution equation analysis and the HERWIG parton shower, we have performed an all-order study of the jet azimuthal angular distribution of events containing a Higgs boson and at least two jets at LHC.

The results of the two analyses are consistent with each other and predict that due to the emission of extra partons, the azimuthal angular correlation that arises in the fixed-order analysis is diluted by almost one order of magnitude.

Although we have specialized to the case of Higgs boson production, our results are applicable to jets accompanying any hard process initiated by two gluons.

We have verified that hadronization does not significantly modify our conclusions.

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References

[1] V. Del Duca, W. Kilgore, C. Oleari, C. Schmidt and D. Zeppenfeld, *Gluon-fusion contributions to $H+2$ jet production*, *Nucl. Phys.* **B 616** (2001) 367 [hep-ph/0108030]; *$H+2$ jets via gluon fusion*, *Phys. Rev. Lett.* **87** (2001) 122001 [hep-ph/0105129]; *Higgs production plus two jets at hadron colliders*, hep-ph/0109147.

[2] G. Corcella, I.G. Knowles, G. Marchesini, S. Moretti, K. Odagiri, P. Richardson, M.H. Seymour and B.R. Webber, *HERWIG 6: an event generator for Hadron Emission Reactions With Interfering Gluons (including supersymmetric processes)*, *J. High Energy Phys.* **01** (2001) 010 [hep-ph/0011363]; *HERWIG 6.5 release note*, hep-ph/0210213.

[3] J.C. Collins, *Spin correlations in Monte Carlo event generators*, *Nucl. Phys.* **B 304** (1988) 794.

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[4] I.G. Knowles, *A linear algorithm for calculating spin correlations in hadronic collisions*, *Comput. Phys. Commun.* **58** (1990) 271.

[5] P. Richardson, *Spin correlations in Monte Carlo simulations*, *J. High Energy Phys.* **11** (2001) 029 [hep-ph/0110108].

[6] A.H. Mueller, *Multiplicity and hadron distributions in QCD jets: nonleading terms*, *Nucl. Phys.* **B 213** (1983) 85; *Multiplicity and hadron distributions in QCD jets, 2. A general procedure for all nonleading terms*, *Nucl. Phys.* **B 228** (1983) 351; *$\sqrt{\alpha(Q^2)}$ corrections to particle multiplicity ratios in gluon and quark jets*, *Nucl. Phys.* **B 241** (1984) 141.

[7] R.K. Ellis, W.J. Stirling and B.R. Webber, *QCD and collider physics*, Cambridge University Press, Cambridge 1996.

[8] F. Paige and M.H. Seymour, private communication.

[9] A.D. Martin, R.G. Roberts, W.J. Stirling and R.S. Thorne, *Parton distributions: a new global analysis*, *Eur. Phys. J.* **C 4** (1998) 463 [hep-ph/9803445].