JetViP 2.1: the hbook version

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Abstract: We present an update of the JetViP 1.1 program for performing fixed NLO calculations in jet production including direct and resolved components in a continuous range of photon virtuality $Q^2$. The new version allows to access the full event record on the parton level. The program is set up such that hbook can be used to fill histograms. The phase space generator has been optimized and the azimuthal dependence of the cross section is taken into account in LO. We comment on recent comparisons between various NLO programs for jet production at HERA. We demonstrate that the $\sum E_T$ cut for dijet cross sections is not infrared safe.

1 Introduction

Several fixed order programs are on the market now for calculating jet cross sections for non-zero photon virtuality $Q^2$ at HERA, as there are DISENT [1], DISASTER++ [2], MEPJET [3] and JetViP [4], which is based on the calculations in [5, 6]. The first two programs are based on the subtraction method, whereas the latter two employ the phase-space-slicing method. In the photoproduction limit $Q^2 \to 0$, the deep-inelastic scattering (DIS) matrix elements with a direct coupling of the photon to the partons from the proton show an additional initial state singularity on the photon leg, which has to be subtracted and absorbed in the photon structure function. Furthermore, one has to calculate a so-called resolved component, where the photon serves as a source of partons. These direct and resolved photon-proton scattering processes have been calculated by three groups in NLO QCD [7, 8, 9]. The calculation of [7] uses the subtraction method, whereas the other two groups [8, 9] use the phase-space-slicing method. One of the main features of JetViP is the possibility to include a resolved virtual photon component in NLO. In this way the photoproduction limit can be taken, which allows to cover the full range in $Q^2$ accessible at HERA.

The phase-space generator of JetViP was originally built around the $R_{sep}$-modified cone-algorithm. Though the phase-space could be optimized for this specific case, the program was obviously limited in its applicability and furthermore it was rather inconvenient to calculate spectra of variables other than the jet transverse energy and rapidity. Therefore,
in the new version partons rather than jets are accessible and an event record is provided in a user-routine, i.e., the four-vectors of all particles involved in the process are available together with the basic kinematical variables such as $Q^2, x_{Bj}, y, \ldots$ and the weight from the matrix elements convoluted with the parton distribution functions. The analysis of the events is then left entirely to the user routine.

Two further important improvements have been achieved. First, the phase space generator has been rewritten, as to generate events in $(y, Q^2)$-space, which greatly improves the statistics. Second, the azimuthal dependence of the matrix elements, which has some effect for cuts in the laboratory-frame, have been implemented in LO. As we will demonstrate, this is sufficient for small $Q^2$ and when the NLO corrections are not too large.

Recently, a comparison of the above mentioned NLO programs for DIS has become available [10]. We have recalculated the cross sections produced by JetViP presented in [10] with the new version. As will become clear, differences in the cross sections produced by the programs are due either to statistical problems or to infrared (IR) sensitive cuts on dijet variables. Similarly, a comparison of photoproduction calculations has been performed [11]. We compare photoproduction cross sections from JetViP to those from one of the programs used in [11] and briefly comment on the implications for the DIS region.

Before discussing these more physical topics, we describe the new user-routine with common-blocks and the new steering file. Further details of the JetViP program can be found [4].

## 2 Program changes

### 2.1 user routine

The events generated by JetViP have to be analyzed in a routine called user.

```fortran
subroutine user(iflag,weight,ifill)
real*8 vgweight,weight,Qs,shad,Ws,xbj,y,xa,xb,plab,pcms
integer iflag,ifill
common/parton/plab(7,7),pcms(7,7)
common/kin/Qs,shad,Ws,xbj,y,xa,xb
common/vgplot/vgweight

• iflag: the routine user is called once at the very beginning of JetViP for initialization with iflag=1 and weight=0d0. After this initialization, events are generated with iflag=2. At the very end user is called for termination with iflag=3 and weight=0d0.
```
• **weight**: weight of the event, i.e., the matrix elements convoluted with the PDF’s from the proton and/or photon, together with running $\alpha_{\text{QED}}$ and $\alpha_s$ (in pb). The entry for the histogram has to be further multiplied with the weight from VEGAS, which is vweight. The histogram entry therefore has to be vweight \times weight.

• **ifill**: for ifill=0 the phase space is scanned by VEGAS with low statistics. In this stage the histograms must not be filled. For ifill=1 the histograms can be filled.

• **plab(7,7)**: matrix containing the four-vectors, $E_T, \eta$ and $\phi$ for 7 different particles in the laboratory frame. The $z$-direction is given by the incoming proton or, for the $\gamma^*\gamma$ mode, by the real photon. 1st entry: particle. 2nd entry: variable.

\[
\begin{pmatrix}
\text{plab}(1,i) \\
\text{plab}(2,i) \\
\text{plab}(3,i) \\
\text{plab}(4,i) \\
\text{plab}(5,i) \\
\text{plab}(6,i) \\
\text{plab}(7,i)
\end{pmatrix}
= \begin{pmatrix}
\text{incoming electron} \\
\text{outgoing electron} \\
\text{incoming proton} \\
\text{incoming photon} \\
\text{outgoing parton 1} \\
\text{outgoing parton 2} \\
\text{outgoing parton 3}
\end{pmatrix}
,\begin{pmatrix}
\text{plab}(j,1) \\
\text{plab}(j,2) \\
\text{plab}(j,3) \\
\text{plab}(j,4) \\
\text{plab}(j,5) \\
\text{plab}(j,6) \\
\text{plab}(j,7)
\end{pmatrix}
= \begin{pmatrix}
E_T \\
\eta \\
\phi \\
p_x \\
p_y \\
p_z \\
E
\end{pmatrix}
\]

The outgoing partons are not ordered in $E_T$. The incoming photon vector, i.e., plab(4,i), is set equal to zero.

• **pcms(7,7)**: matrix containing the four-vectors, $E_T, \eta$ and $\phi$ for 7 different particles in the hadronic, i.e., $\gamma^*P$ cms frame. In the $\gamma^*\gamma$ mode the $\gamma^*e$ cms frame is chosen. The $z$-direction is given by the incoming proton/real photon. Same conventions as for plab(7,7). The incoming and outgoing electron vectors, i.e., pcms(1,i) and pcms(2,i), are set equal to zero.

• **Q_s,shad,Ws**: photon virtuality $Q^2 = -q^2$, total cms energy $s_H = 4E_aE_b$ and hadronic cms energy $W^2 = (P + q)^2$.

• **xbj,y,xa,xb \in \{0,1\]**: Bjorken-$x$ variable $x_b$, $y$-variable, momentum fraction of the parton in resolved photon $x_a$ and momentum fraction of the parton in proton $x_b$.

### 2.2 Steering file

An example of the steering file is given in appendix B.

**Contribution**

• **iproc**: integer $\in \{1,2\}$. Type of process. 1 = $eP$, 2 = $e^+e^-(\gamma^*\gamma$-mode)
- **isdr**: integer $\in \{1,2,3,4\}$. Selection of the D, SR, SR$^*$ or DR contribution. $1 = D$; $2 = SR$; $3 = SR^*$; $4 = DR$. Only one of the contributions D, SR, SR$^*$ or DR can be calculated at a time.

- **iborn**: integer $\in \{0,1\}$. Born process ($2 \rightarrow 2$).

- **itwo**: integer $\in \{0,1\}$. NLO twobody corrections ($2 \rightarrow 2$).

- **ithree**: integer $\in \{0,1\}$. The $2 \rightarrow 3$ contributions above the $y_s$ cut.

- **isplit**: integer $\in \{0,1\}$. Initial state singularity for the virtual photon ($2 \rightarrow 2$).

- **iqcut**: integer $\in \{0,1\}$. Insert a finite cut-off $y_s$ (cutmin) into the integration on the virtual photon side for the $2 \rightarrow 3$ NLO contributions ($= 1$) or not ($= 0$). Setting iqcut=1 is necessary for photoproduction.

In the following the main settings for LO and NLO cross sections are summarized in tabular form. These settings hold for all 4 values of isdr.

|        | LO | NLO (DIS) | NLO ($Q^2 = 0$) | $\gamma^* \rightarrow q \bar{q}$ |
|--------|----|-----------|-----------------|----------------------------------|
| iborn  | 1  | 1         | 1               | 0                                |
| itwo   | 0  | 1         | 1               | 0                                |
| ithree | 0  | 1         | 1               | 0                                |
| isplit | 0  | 0         | 1               | 1                                |
| iqcut  | 0  | 0         | 1               | 0                                |

**Initial State**

- **Ea, Eb**: real*8. Energies of the incoming lepton a and hadron/lepton b in GeV.

- **iwwa**: integer $\in \{0,1\}$. Selects formula for the photon flux in the case of photoproduction. For iwwa=0 the cross section is integrated analytically up to $Q^2_{max}$, whereas for iwwa=1 it is integrated using the value of thmax below.

- **thmax**: real*8. Maximum scattering angle of electron in photoproduction for iwwa=1.

- **P2max**: real*8 $\geq 0$. Maximum value of $P^2$ ($\gamma^*\gamma$ mode).

- **iwwb**: integer $\in \{0,1\}$. see iwwa ($\gamma^*\gamma$ mode).

- **thetbmax**: real*8. Maximum scattering angle of electron for iwwb=1 ($\gamma^*\gamma$ mode).
Subprocess

- **Nf**: real*8 \( \in \{1, 2, 3, 4, 5\} \). Number of active flavours.
- **\( \lambda \)**: real*8 \( > 0 \) in GeV. Value of \( \Lambda_{QCD} \) for \( N_f \) flavours.
- **ialphas**: integer \( \in \{1, 2\} \). One-loop (ialphas = 1) or two-loop (ialphas = 2) formula for the strong coupling constant \( \alpha_s \) without thresholds. For ialphas = 3 the value of \( \alpha_s \) is taken from the PDFLIB (automatically adjusts \( \Lambda \)).
- **ycut**: real*8 \( > 0 \). Value of \( y_s \). The independence of the NLO cross sections on \( y_s \) has been tested for \( y_s \in [10^{-2}, 10^{-5}] \). Large statistical errors occur for too small \( y_s \). Recommended value: \( y_s = 0.5 \cdot 10^{-3} \).
- **idisga**: integer \( \in \{0, 1\} \). Since all partonic cross sections in JetViP are implemented in the \( \overline{\text{MS}} \)-scheme, a photon PDF constructed in the \( \text{DIS}_\gamma \) scheme has to be transformed into the \( \overline{\text{MS}} \)-scheme. This is done for the photon on side a by settingidisga = 1 [4].
- **ipdftyp**: integer \( \in \{1, 2, 3, 4\} \). Selects the PDF for the resolved virtual photon. 1 = SaS [12], 2 = GRS [13], 3 = PDFLIB [14] (for real photons with \( Q^2 = 0 \)).
- **igroupa**: integer. For ipdftyp = 3, 4 this selects the group from the PDFLIB (see manual [14]). For ipdftyp = 1 this represents isasset \( \in \{1, 2, 3, 4\} \), which selects input scale and scheme of SaS virtual photon PDF (see [12]).
- **isetb**: integer. Selects the group from PDFLIB for the resolved component for particle b (see manual [14]).
- **isetb**: integer. Selects the set from PDFLIB (see manual [14]).
- **a, b, c**: real*8 \( > 0 \). Choosing the overall-scale \( \mu^2 \) according to \( \mu^2 = a + bQ^2 + cp_T^2 \). The \( p_T \) is the largest \( E_T^{\text{jet}} \) of an event.

Phase space integration

The phase space of JetViP is generated in the following variables.

- **Q2min, Q2max**: real*8 \( \geq 0 \). Minimum and maximum value of the photon virtuality \( Q^2 \). Setting Q2min =0.d0 will produce a photoproduction cross section.
- **ymin, ymax**: real*8 \( \in \{0, 1\} \). Minimum and maximum value of \( y \).
- **ptmin**: real*8 \( > 0 \). Minimum value of \( E_T \) on parton level. Set to \( \frac{1}{2} E_T^{\text{jet}} \cdot \min \).
Vegas and Output

- **ipoint**: integer > 0. Defines the number of events generated in the phase space defined above. Typical value: \( \text{ipoint} = 10,000,000 \). In NLO for smaller \( y_s \) larger compensations occur and therefore the statistical errors become larger.

- **itt**: integer > 0. Number of iterations for Vegas. Recommended value: \( \text{itt} = 5 \).

- **jfileout**: character*20. Name of the output-file in which the histograms are stored.

3 Comparison with other programs

3.1 Infrared safe dijet cross sections

Recently, a comparison of NLO programs for the DIS region has become available \([10]\), which shows a good agreement between the programs \textsc{DISENT} and \textsc{DISASTER}, systematic deviations of \textsc{MEPJET}, being typically of 5–8% lower than the other programs and finally the overall results of \textsc{JetViP} being comparable to \textsc{DISENT} and \textsc{DISASTER}. However, in some cases \textsc{JetViP} deviates from these programs by up to 20%. Furthermore, a significant dependence of the cross sections produced by \textsc{JetViP} on the slicing parameter \( y_s \) has been reported. In the following, these results are discussed in detail and the numbers for most scenarios described in \([10]\) are recalculated.

The details of the technical settings for the comparison can be found in \([10]\). Basically, dijet cross sections have been calculated under HERA conditions in the Breit frame, using the inclusive \( k_\perp \) algorithm \([13]\). The authors define as a central scenario the cuts

\[
30 < Q^2 < 40 \text{ GeV}^2, \quad 0.2 < y < 0.6, \quad E^1_T,2 > 5 \text{ GeV}
\]

(1)

where \( E^1_T \) and \( E^2_T \) are the highest and second highest \( E_T \) of an event. Then a number of additional cuts are proposed in six scenarios, which are meant to ensure IR safeness of the jet cross sections. In the following we will concentrate on the comparison for scenarios 1–4, since scenarios 5 and 6 are not problematic and sufficient agreement between the different NLO programs has been found. As we will show later, the scenario 1 contains IR sensitive cuts. In this section we concentrate on the IR safe scenarios, namely scenarios 2–4, which are collected for reasons of completeness in the Tab. \([1]\).

Recalculating the scenarios 2–4 with the new \textsc{JetViP} version 2.1 using higher statistics and the optimized phase space generator we find the results shown in appendix A, which mostly confirm the numbers from \([10]\). Some numbers however show better agreement. \textsc{JetViP} agrees with \textsc{DISENT} and \textsc{DISASTER} on the 1% level within the statistical errors. Only for scenario 2d \textsc{JetViP} lies 2% below the \textsc{DISENT}/\textsc{DISASTER} results. This is a statistical problem of the rather extreme scenario 2d. The cut on the higher \( E_T \) jet is at 40 GeV, however all the \( E_T \)'s down to 2.5 GeV have to be generated on the parton level, since they
can contribute to the cross section after the jet recombination. Due to the steep fall-off of the $E_T$ spectrum, too few events are generated at large $E_T$. Overall, the agreement found between the three programs DISENT, DISASTER and JetViP is very good, which is especially promising since the programs are based on different methods to treat soft and collinear singularities.

A reason for the systematic deviation of MEPJET from the other three programs, being overall about 5–8% too small, might be due to not partially fractioned matrix elements [16]. In principle the partial fractioning is not necessary if one goes to extremely small $s_{min}$ values. This, however, leads to large statistical errors and the calculation of precise results becomes impractical. Problems of this kind in connection with the phase space slicing technique are well known already from older works on jet production from $e^+e^-$ annihilation (see e.g. [17]).

A last point that has to be sorted out is the observed $y_s$ dependence of the JetViP cross sections. Except for the scenarios 1b and 1c, which are discussed below to be IR sensitive, these dependences are a statistical problem. We have observed that the adaptation procedure implemented in the Monte-Carlo integration routine VEGAS [18] becomes unreliable in the region of small slicing parameters $y_s$ and the errors are drastically underestimated. These kind of problems have been noticed recently and an alternative integration algorithm has been proposed [19]. To avoid such problems we have switched off the adaptation in VEGAS and simply generated an extremely large number of events. With this setting we have recalculated the $y_s$ dependence for three values of the slicing parameter,

| $y_s$  | scenario 2a  | scenario 3d |
|-------|--------------|--------------|
| $10^{-3}$ | 121.5±0.8 | 1.99 ±0.02 |
| $10^{-4}$ | 121.4±2.2 | 2.0 ±0.05 |
| $10^{-5}$ | 116.1±6.5 | 1.80 ±0.13 |
| DISENT | 119.5±0.3 | 1.985±0.003 |
| DISASTER | 119.8±0.4 | 1.998±0.003 |

Table 2: The dependence of JetViP cross sections on the phase space slicing parameter $y_s$ for two scenarios.
$y_s = 10^{-3}, 10^{-4}$ and $10^{-5}$ for scenarios 2a and 3d which are among the critical cases in \cite{10}. The results are shown in Tab. 2. No dependence on $y_s$ within the statistical errors is observed. Of course, the errors become larger, the smaller $y_s$ gets and it is very hard to calculate the cross section for values of $y_s \leq 10^{-5}$ since the compensation between large positive and negative contributions lead to large statistical errors, which is a well-known problem of the phase-space slicing method. However, one can obtain reliable results with JetViP for values of $y_s$ between $10^{-3}$ and $10^{-4}$ and in this region also use the adaptation technique implemented in VEGAS.

### 3.2 Infrared sensitive scenarios

The authors in \cite{10} have proposed several ways to avoid IR sensitive regions for the dijet cross sections. These are the scenarios 1a–c, collected in Tab. 3.

| No. | additional jet cut                        |
|-----|------------------------------------------|
| 1 a) | $E_{T1\text{min}} > 8 \text{ GeV}$      |
| 1 b) | $M_{jj} > 25 \text{ GeV}$              |
| 1 c) | $(E_{T1} + E_{T2}) > 17 \text{ GeV}$   |

Table 3: Proposed ways to avoid IR sensitive regions.

Unfortunately, the scenarios 1b and 1c are not IR safe. This can be understood in terms of the $E_{T1}, E_{T2}$ plane, shown in Fig. 1. The thick solid lines show the symmetric cuts $E_{T1,2} > 5 \text{ GeV}$, which are known to be IR sensitive, due to the point $E_{T1} = E_{T2} = 5 \text{ GeV}$ \cite{5, 20}. The (negative) twobody contribution, containing the analytic NLO corrections can not be compensated by (positive) threebody contributions due to the limited phase

![Figure 1: The available phase space for the two highest $E_T$ jets.](image)
Table 4: The $\sum E_T$ scenario with an additional cut $E_{T_1} = 8.5\, GeV + \Delta$

| $\Delta$ | DISASTER++ | DISENT | JETVIP | MEPJET |
|----------|------------|--------|--------|--------|
| 0.0 (LO) | 35.2       | 35.2   | 35.2   | 35.1   |
| 0.0 (NLO)| 72.3       | 72.1   | 77.2   | 67.6   |
| 0.125    | 76.4       | 79.6   |        |        |
| 0.250    | 76.6       | 79.7   |        |        |
| 0.375    | 76.1       | 79.2   |        |        |
| 0.500    | 75.6       | 78.1   |        |        |
| 0.625    | 73.7       | 77.1   |        |        |
| 0.750    | 72.3       | 75.5   |        |        |
| 2.000    | 54.2       | 55.2   |        |        |

space for the third particle. To avoid this region, one can introduce a $\Delta$-cut on the highest $E_T$ jet, $E_{T_1} = E_{T,min} + \Delta$ with $\Delta \gtrsim 1\, GeV$. Furthermore, the proposed scenario 1c is shown in Fig. 1. However, the point $E_{T_1} = E_{T_2} = 8.5\, GeV$ corresponding to a symmetric scenario is not avoided by the $\sum E_T$ cut and not enough threebody phase space is added to this point.

This IR sensitivity is the origin of the $y_s$ dependence of JetViP. Furthermore, the cross sections obtained with two different methods, namely the phase space slicing method and the subtraction method, do not agree. Apart from the $y_s$ dependence of JetViP, an explicit way to see the IR sensitivity is to introduce a $\Delta$-cut in addition to the $\sum E_T$ cut, i.e., to demand an additional cut on the higher $E_T$ jet with $E_{T_1} = E_{T,min} + \Delta\, GeV$, where $E_{T,min} = 8.5\, GeV$. We have introduced such a cut and calculated the cross sections for various $\Delta$ values for the two programs DISENT and JetViP. The results are shown in Tab. 4. Physically meaningful cross sections will drop for rising $\Delta$. However, as can be seen in Tab. 4, the NLO cross sections for the $\sum E_T$ scenario still rise up to $\Delta = 0.375$ and only reach the original value of the cross section around $\Delta = 0.625$. This behaviour is seen for both programs. We have checked several values of $\Delta$ and found $\Delta = 2\, GeV$ sufficient to avoid IR sensitivity. As can be seen from the table, at this value the programs JetViP and DISENT agree at the 2% level.

The same is true for scenario 1b, where $M_{jj} > 25\, GeV$. This cut washes out the IR sensitive region, but does not completely avoid it. This can again be seen in the $y_s$ dependence of the cross sections from JetViP. By introducing an additional $\Delta$-cut, as for the $\sum E_T$ case, one would again see a rise of the NLO cross section with increasing $\Delta$.

### 3.3 Photoproduction

Recently, a comparison of calculations in jet photoproduction has been performed [11] in which the authors find that the three calculations [7, 8, 9] agree within the statistical accuracy of the Monte Carlo integration. Only in certain restricted regions of phase
space, the calculations differ by up to 5%. Since the program JetViP allows to perform the limit \( Q^2 \to 0 \) starting from the DIS matrix elements, a comparison with one of the photoproduction calculations will serve as a further consistency check of the two methods for extracting collinear and soft phase-space regions. We have therefore calculated inclusive single-jet cross sections for photoproduction with JetViP and compared them to the calculations in [9]. The results are shown in Fig. 2 for the \( E_T \) and \( \eta \) spectra of the direct (dashed) and resolved (full) components in NLO. The agreement with the predictions from [9] (full dots) is perfect for both components with differences below 1%. All other comparisons performed so far between the two programs show a similar good agreement.

\[
\frac{d\sigma}{dE_T} [\text{pb/GeV}] = 10^6 \\
\frac{d\sigma}{dh} [\text{pb/GeV}] = 10^5
\]

Figure 2: Single-jet inclusive direct (lower curves) and resolved (upper curves) jet cross sections with JetViP compared to the calculations [9] (dots) for photoproduction.

Since the matrix elements for the resolved component are taken from [9], it is not surprising that it agrees for both programs. The direct component in JetViP is, however, completely independent from the calculations in [9]. The excellent agreement of the two programs therefore establishes the consistency between the calculations for photoproduction and for the DIS case for the phase space slicing method. Since the equivalence of the subtraction and the phase space slicing method has been shown in [11], we conclude that JetViP also agrees with the calculations based on the subtraction method in the photoproduction regime [7].

### 3.4 Dependence on azimuthal angle

We have implemented the full azimuthal dependence of the jet cross sections in the new JetViP program in LO according to the formula

\[
\frac{d\sigma}{d\phi} = A + B \cos \phi + C \cos 2\phi ,
\]
where $\phi$ denotes the azimuthal angle of the jets around the virtual photon direction in the hadronic cms frame. The lepton plane defines $\phi = 0$. The coefficients $A, B, C$ are related to the polarization density elements of the virtual photon.

The dependence in (2) can be integrated out if no cuts on the jets are imposed in the laboratory frame. This is, however, seldom the case experimentally. In the following we check how large the effect of using the integrated and unintegrated matrix elements is in LO. We calculate cross sections in LO within the central scenario defined above with no additional cuts and probe the region $Q^2 \in [0, 100]$ GeV$^2$. In Fig. 3 three rapidity regions are shown in the laboratory frame, namely

$$-1 < \eta_{\text{lab}} < 0.5, \quad 0.5 < \eta_{\text{lab}} < 1.5, \quad 1.5 < \eta_{\text{lab}} < 2.8,$$

(3)
corresponding to the backward, central and forward region of the detector. We have plotted the ratio of the integrated over the unintegrated matrix elements, denoted as $R$. As one sees, for $Q^2 < 10$ GeV$^2$ the $\phi$-dependence is below 2.5% for all regions and therefore negligible. In the central region the dependence stays below 5%, whereas in the more extreme regions the dependence can reach 10% for the largest $Q^2$-bin shown. This is in accordance with the results in [21]. We have further checked that the difference

![Figure 3: The ratio of unintegrated over integrated LO cross sections in four different rapidity regions in the lab frame.](image)
between integrated and unintegrated has a maximum at $Q^2 = 100 \text{ GeV}^2$. For larger virtualities, the difference again diminishes and falls below 5% for all rapidity regions above $Q^2 = 500 \text{ GeV}^2$. If the NLO corrections stay reasonably small, e.g., around 20%, one can estimate the error due to cuts in the laboratory-frame in NLO to be below 2%, for any value of $Q^2$.

We conclude that for the main region of applicability of JetViP, namely the region of $Q^2 < 10 \text{ GeV}^2$, where also the resolved cross sections plays a role, the $\phi$-dependence is described correctly in the present JetViP version. For all other $Q^2$, the dominant contribution has been taken into account and a correct description is given if the NLO corrections are not too large. In any case, the corrections will not be larger than 10%.

4 Summary

We have presented an updated version of the JetViP 1.1 program for jet production in $eP$- and $\gamma^*\gamma$-scattering. The most important changes are:

- a full event record is provided on the parton level
- the complete analysis of the events has to be done in the user routine
- the phase space is generated in $(y, Q^2)$-space
- the $\phi$-dependence has been implemented in LO

We have numerically shown the equivalence of two methods used to extract singular phase space regions, namely, the subtraction method and the phase-space slicing method, by comparing 4 existing NLO programs. The programs DISENT, DISASTER and JetViP agree on the 1% level within the statistical errors of integration. Any differences observed before in these programs are either of statistical nature or due to IR sensitive cutting scenarios. In particular, we have demonstrated the IR sensitivity of the $\sum E_T$ scenario. The numerical equivalence of phase space slicing and subtraction method have furthermore been underpinned by comparisons in the photoproduction regime.

The difference between using azimuthal dependent matrix elements in LO and those where this behaviour has been integrated out is negligible for all rapidity regions for $Q^2 < 10 \text{ GeV}^2$. By taking into account the azimuthal dependence of the matrix elements in LO also cross sections involving cuts in the laboratory frame are described correctly in the present JetViP version for all practical purposes.

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## Numerical results

Results of the comparison between the programs DISENT, DISASTER, MEPJET and JetViP in the DIS region for IR safe scenarios 2–4. The numbers are taken from [10], except for the NLO JetViP numbers, which have been recalculated.

| scenario | DISASTER++ | DISENT | JETVIP | MEPJET |
|----------|------------|--------|--------|--------|
| 2 a)     | 119.8 ± 0.4 | 119.5 ± 0.3 | 121.5 ± 0.8 | 113.5 ± 0.2 |
| LO:      | 41.66 ± 0.08 | 41.77 ± 0.06 | 41.75 ± 0.03 | 41.72 ± 0.03 |
| 2 b)     | 16.58 ± 0.09 | 16.53 ± 0.05 | 16.21 ± 0.07 | 15.74 ± 0.08 |
| LO:      | 6.19 ± 0.02 | 6.22 ± 0.01 | 6.214 ± 0.005 | 6.221 ± 0.003 |
| 2 c)     | 2.08 ± 0.03 | 2.052 ± 0.008 | 2.04 ± 0.1 | 1.908 ± 0.008 |
| LO:      | 1.023 ± 0.005 | 1.022 ± 0.002 | 1.025 ± 0.001 | 1.025 ± 0.0005 |
| 2 d)     | 0.140 ± 0.005 | 0.140 ± 0.001 | 0.122 ± 0.015 | 0.123 ± 0.005 |
| LO:      | 0.120 ± 0.001 | 0.1213 ± 0.0004 | 0.1207 ± 0.0002 | 0.1209 ± 0.00006 |

| scenario | DISASTER++ | DISENT | JETVIP | MEPJET |
|----------|------------|--------|--------|--------|
| 3 a)     | 341.2 ± 1.7 | 339.1 ± 1.2 | 340.1 ± 0.7 | 331.5 ± 0.4 |
| LO:      | 48.4 ± 0.1 | 48.42 ± 0.08 | 48.36 ± 0.04 | 48.40 ± 0.04 |
| 3 b)     | as 2 a) | | | |
| 3 c)     | 26.85 ± 0.06 | 26.68 ± 0.05 | 26.72 ± 0.09 | 24.68 ± 0.05 |
| LO:      | 16.94 ± 0.02 | 16.93 ± 0.02 | 16.93 ± 0.01 | 16.92 ± 0.01 |
| 3 d)     | 1.998 ± 0.003 | 1.985 ± 0.003 | 1.995 ± 0.007 | 1.8917 ± 0.0038 |
| LO:      | 1.498 ± 0.002 | 1.497 ± 0.001 | 1.496 ± 0.001 | 1.497 ± 0.001 |

| scenario | DISASTER++ | DISENT | JETVIP | MEPJET |
|----------|------------|--------|--------|--------|
| 4 a)     | 19.2 ± 0.1 | 18.96 ± 0.07 | 18.67 ± 0.04 | 17.19 ± 0.04 |
| LO:      | 11.61 ± 0.04 | 11.57 ± 0.02 | 11.59 ± 0.01 | 11.587 ± 0.006 |
| 4 b)     | as 2 a) | | | |
| 4 c)     | 6.42 ± 0.03 | 6.45 ± 0.02 | 6.40 ± 0.02 | 6.09 ± 0.03 |
| LO:      | 2.161 ± 0.006 | 2.162 ± 0.003 | 2.17 ± 0.01 | 2.160 ± 0.002 |
B Example of steering file

The following steering file is for calculating the NLO direct cross section under HERA conditions in DIS with scales $\mu^2 = Q^2$.

```plaintext
'*****************************************************************************'
' CONTRIBUTION'
'*****************************************************************************
1 iproc [1=ep; 2=ee]
2 isdr [1=D; 2=SR; 3=SR*; 4=DR]
1 iborn [2->2 Born]
1 itwo [2->2 singular contributions (for NLO)]
1 ithree [2->3 contribution]
0 isplit [gamma->qq term]
0 iqcut [yqi-min in 2->3 matrices? 1=yes; 0=no]
'*****************************************************************************'
' INITIAL STATE'
'*****************************************************************************
27.5d0 Ea [energy of lepton a]
820.d0 Eb [energy of proton/ lepton b]
'------- Lepton a --------------------------------------------------------'
0 iwwa [which Weizs.-Will.: 0=ln(Q2mx/Q2mn); 1=ln(thmax/me)]
180.d0 thmax [max angle]
'------- Lepton b (only relevant for the ee-case ) -----------------------'
4.d0 P2max [P2=virtuality of real photon]
0 iwwb [which Weizs.-Will.: 0=ln(P2mx/P2mn); 1=ln(thmax/me)]
180.d0 thetbmx [max angle for Weizs.-Will]
'*****************************************************************************'
' SUBPROCESS'
'*****************************************************************************
5.d0 Nf [Number of active flavours]
0.204d0 lambda [Lambda-QCD (has to match Nf)]
3 ialphas [QCD coupling: 1=one-loop; 2=two-loop; 3=PDFLIB]
1d-3 y-cut [phase-space-slicing parameter]
'------- PDFs for the resolved contributions -------------------------------'
0 idisga [DISg -> MSbar for photon a]
1 ipdftyp [PDF for y*(res): 1=SaS; 2=GRS; 3=DG; 4=PDFLIB]
2 igroupa (Param. for SaS or PDFLIB --> see manual)
2 iseta (")
0 idisgb [DISg -> MSbar for photon b]
4 igroupb [authors of PDF on side b: y(res) or prot]
34 isetb [Set-No]
'------- Scales ----------------------------------------------------------'
0.d0 a [Scale: mu**2=a+b*Q**2+c*pt**2]
1.d0 b
0.d0 c
```
5d0  Q2min [0.d0 selects photoproduction]
10d0  Q2max
0.1d0  ymin [min y]
0.6d0  ymax [max y]
2.25d0  ptmin [ptmin for parton in hadr cms; =Etj-min/2]

10000000  ipoin [no of events produced in phase space above]
5  itt [no of iterations]
'nlo.out'  jfileout [Filename]