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DJANGO6 version 2.4 – A Monte Carlo Generator for Deep Inelastic Lepton Proton Scattering Including QED and QCD Radiative Effects

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Abstract: We describe the event generator DJANGO6 which simulates deep inelastic lepton-proton scattering including both QED and QCD radiative effects. DJANGO6 is an interface of the Monte Carlo programs HERACLES and LEPTO. The LUND string fragmentation as implemented in the event simulation program JETSET is used to obtain the complete hadronic final state. DJANGO6, version 2.4, is an update of a former version which interfaces version 4.5.2 of HERACLES to version 6.5 of LEPTO.

Program Summary

Program name:	DJANGO6
Version number:	2.4
Date of last modification:	October 11, 1996
Program language:	FORTRAN-77
Number of program lines:	14349 lines for HERACLES 4.5.2 and 6390 lines for LEPTO 6.5 and DJANGO6.
Other programs used:	JETSET 7.4, Lund Monte Carlo for jet fragmentation, PYTHIA 5.7 and PDFLIB.
External files needed:	Files for random number seeds and for information of the integration step are needed.

1 Introduction

In the one-boson exchange approximation, the cross section for deep inelastic lepton proton scattering is described by three structure functions $F_2(x,Q^2)$, $F_L(x,Q^2)$, and $F_3(x,Q^2)$:

$$\left.\frac{d^2\sigma}{dx\,dy}\right|_{e^\pm} = \frac{2\pi\alpha^2}{xyQ^2}\left[\left(1+(1-y)^2\right)F_2(x,Q^2) - y^2 F_L(x,Q^2) \mp \left(1-(1-y)^2\right)F_3(x,Q^2)\right] \tag{1}$$

where x, y and Q^2 are the usual kinematic variables for deep inelastic scattering. At large momentum transfers Q^2, and taking into account only leading logarithmic contributions from QCD corrections, the structure functions are related to sums and differences of parton distributions $q_f(x,Q^2)$:

$$\begin{aligned} F_2(x,Q^2) &= \sum_f A_f(Q^2)\left[q_f(x,Q^2)+\bar{q}_f(x,Q^2)\right], \\ F_3(x,Q^2) &= \sum_f B_f(Q^2)\left[q_f(x,Q^2)-\bar{q}_f(x,Q^2)\right] \end{aligned} \tag{2}$$

where A_f and B_f contain electroweak couplings and propagator terms. The scale dependence of $F_{2,3}$ is determined by the DGLAP evolution equations [1]. The longitudinal structure function $F_L(x,Q^2)$ is predicted in perturbative QCD as a next-to-leading order correction of $O(\alpha_s)$ and can be calculated from the quark and gluon distribution functions. The leading logarithms taken into account by these prescriptions emerge from gluon emission by the initial and final quark and from quark-antiquark pair production by gluons. Cascades of these processes describe the leading higher-order corrections to all orders $O(\alpha_s^n)$. Many QCD Monte Carlo event generators, like LEPTO or ARIADNE, have implemented a realization of QCD cascades and thus take into account the leading higher-order QCD corrections.

For the correct description of the differential cross section $d^2\sigma/dxdy$, as well as of details of the hadronic final state, it is, however, necessary to take into account also higher-order electroweak corrections and non-logarithmic QCD corrections. First, electroweak corrections, in particular hard photon radiation, lead to large effects and may strongly distort the kinematics of events for small x and large y. Moreover, corrections from hard photon radiation strongly depend on experimental cuts. Secondly, it is well-known that n-jet cross sections in e^+e^- annihilation with $n \geq 3$ are not well described by leading logarithmic QCD cascades and matrix element calculations are needed. First data at HERA indicate that this will be the case for deep inelastic scattering, as well.

In this note we present a technical description of the event generator DJANGO6, version 2.4[1]. This program uses partly modified routines from LEPTO 6.5 [3] to simulate QCD effects and allows for generation of events according to QCD cascade models or QCD matrix elements. Matrix elements are available describing effects from perturbative QCD to first order in α_s due to virtual gluons, real gluon emission and boson-gluon fusion.

[1] A former version is described in [2].

A combination of LLA QCD cascades with first-order matrix elements is possible. QCD cascades can be generated using either the parton shower model implemented in LEPTO or the colour dipole model of ARIADNE [4]. Starting from an event defined on the parton level, i.e. having a final state which consists of quarks and gluons, one can generate the full hadronic final state with the help of JETSET [5].

The process $lp \to l'X$ including electroweak corrections of $O(\alpha)$ and the bremsstrahlung process $lp \to l'\gamma X$ is simulated with the help of HERACLES, version 4.5.2 [6, 7].

In the following section we provide a short discussion of QCD and QED radiative effects and describe the treatment of $O(\alpha\alpha_s)$ corrections as implemented in DJANGO6 as well as limitations of our approach. The subsequent section 3 is devoted to a detailed listing of technical details of the program.

2 Physics and Monte Carlo implementation

The radiative effects we are interested in can be classified in three categories: *i*) pure QCD corrections, *ii*) pure QED and weak corrections and *iii*) combined QCD–QED effects.

i) Corrections of $O(\alpha_s)$. The dominant parts of QCD corrections, i.e. the leading logarithms, are absorbed in the parton distribution functions leading to their scale dependence. Calculating the scale dependence from the DGLAP evolution equations is equivalent to resumming these leading-logarithmic corrections to all orders. Therefore, using structure functions determined via Eq. (2) from commonly used parton distribution functions, these corrections are already included in Eq. (1). Non-logarithmic $O(\alpha_s)$ corrections have to be taken into account explicitly. In the DIS scheme, these corrections show up as a non-zero longitudinal structure function F_L and a small correction to F_3. Since the contribution from F_3 is small anyway at HERA energies, it is justified to neglect the $O(\alpha_s)$ corrections to F_3 and when restricting to parametrizations of parton distributions in the DIS scheme it is sufficient to add a contribution from F_L to obtain the $O(\alpha_s)$ corrected cross section. Here again, it is sufficiently accurate to include purely electromagnetic interactions, i.e. a contribution from Z boson exchange to F_L can be ignored. F_L can be defined in such a way to absorb target mass effects and higher-twist contributions in addition to perturbative QCD (leading twist) contributions. The longitudinal structure function is taken into account in the calculation of the cross section by HERACLES.

In the $\overline{\text{MS}}$ scheme, the simple relation between the structure function F_2 and parton distribution functions as given in Eq. (2) has to be modified by explicit non-logarithmic correction terms of order $O(\alpha_s)$. Since these are not available in the present version of HERACLES, it is recommended to use the DIS version of parton distribution functions, if available, rather than the $\overline{\text{MS}}$ ones.

An important consequence of including $O(\alpha_s)$ corrections is, that they allow a more realistic and more detailed description of the hadronic final state: hard gluon emission and boson-gluon fusion give rise to events with two jets in addition to the proton remnant jet. Matrix elements for these processes to first order in α_s are available from LEPTO 6.5. The reader is refered to Ref. [3] for further details.

ii) Electroweak corrections of $O(\alpha)$ consist of one-loop virtual corrections which can be written in terms of form factors [8] modifying the coefficients A_f and B_f in Eq. (1) as well as of effects from real bremsstrahlung, i.e. radiative events $ep \to e\gamma X$. Photons are mainly radiated from the incoming or scattered lepton. In the case of neutral current scattering, the leptonic radiative cross section can be separated into three parts [9] which are dominated by singularities due to *i*) emission of photons collinear with the incoming lepton, *ii*) emission of photons collinear with the scattered lepton, and *iii*) emission of hard photons shifting the momentum transfer Q^2 to small values, i.e. a part which is dominated by the Coulomb singularity.

Version 4.5.2 of HERACLES includes $O(\alpha)$ QED corrections due to photon radiation from both the lepton and the quark as well as the complete one-loop virtual corrections. The structure of the program allows a separate treatment of the non-radiative cross section (comprising the Born term, soft bremsstrahlung and virtual corrections) and the radiative cross section. The radiative cross section for the neutral current is separated into three channels associated with the three types of singularities described above. The separation into these three radiative channels is obtained on the basis of a partial fractioning of the differential cross section into corresponding pole terms. Denoting the 4-momenta of the incoming (outgoing) lepton by l, l' and that of the photon by k, these pole terms have the form

$$\frac{A_i}{k \cdot l}, \qquad \frac{A_f}{k \cdot l'}, \qquad \frac{A_C}{(l - l' - k)^2}. \tag{3}$$

The first one, being related to the momentum of the incoming lepton, is termed 'initial state radiation' and, accordingly, the second one 'final state radiation'. The third one is dominating when the momentum transfer $(l - l' - k)^2$ becomes small and is therefore called 'Compton contribution'. Note that the interpretation of the channels in terms of initial or final state radiation is meaningful only in the leading logarithmic approximation. Beyond the leading logarithmic approximation, the separation is *not unique*. Note in particular that this separation is not a separation of the phase space for photon emission and each channel is defined in the whole phase space. This means, in particular, that the channel called 'final state radiation' may contribute to events with photons emitted in the direction of the incoming lepton (though at the level of per cent only) and, vice versa, the channel called 'initial state radiation' may contribute to events with photons parallel to the scattered lepton.

HERACLES as well as DJANGO6 are also enabled for the simulation of charged current scattering. Here, too, the radiative cross section can be separated into three contributions dominated by singularities due to the emission of photons parallel to the incoming lepton, to the incoming quark, or to the outgoing quark. This separation, however, is not gauge invariant. A gauge-invariant separation can be obtained by identifying the dependence on the electric charge of the quark entering the hard scattering process. The contribution not depending on the type of the incoming quark can be called 'leptonic', the other two are called 'quarkonic' (proportional to the square of the quark charge) and 'interference' contribution (proportional to the quark charge). The 'leptonic' contribution contains parts which are dominated by singularities due to the emission of photons parallel to the incoming lepton and to the scattered quark. In the present versions of HERACLES and DJANGO6, besides the non-radiative channel, only the 'leptonic' contribution to the radiative process is implemented. For further details of the separation of the radiative corrections into 'leptonic', 'quarkonic', and 'interference' contributions, see Ref. [10]. The corrections from 'quarkonic' and 'interference' contributions is small and may reach a few per cent only at very large Q^2. The present implementation in DJANGO6 is sufficiently accurate for a 2% measurement of the charged current process.

The inclusion of photon radiation from the scattered quark in the charged current process is required by gauge invariance. However, beyond this specific contribution, no attempt was made yet to implement the complete $O(\alpha)$ corrections due to (virtual and real) radiation of photons from the initial or scattered quark in DJANGO6 although these corrections can be taken into account in HERACLES. A consistent subtraction of quark mass singularities and matching to QCD cascades would be required in the case of initial state radiation. The observable effect of quarkonic radiation on the total deep inelastic cross section has been shown to be small at HERA energies [11].

iii) Finally, there are combined QCD–QED effects of order $O(\alpha\alpha_s)$. In the leading-logarithmic approximation, these corrections can be factorized. This is the basic property of leading higher-order corrections which allows for a step-by-step procedure where the QED and QCD effects are described in separate programs. A more complete treatment, i.e. including also non-logarithmic contributions, would require the calculation of the combined $O(\alpha\alpha_s)$ matrix elements for

$$\begin{aligned} e + q &\rightarrow e + q + \gamma + g, \\ e + g &\rightarrow e + q + \bar{q} + \gamma. \end{aligned} \tag{4}$$

Since this is not yet done, non-logarithmic corrections of order $O(\alpha\alpha_s)$ are not included in DJANGO6.

The implementation of $O(\alpha\alpha_s)$ effects is described in more detail in the following.

2.1 Radiative Scattering

The treatment of the non-radiative part of the cross section is straightforward: the Monte Carlo program HERACLES is used to generate events at the parton level which in turn are fragmented and hadronized by DJANGO6 using routines from LEPTO 6.5 and JETSET 7.4. Therefore, in the following we only consider the radiative process

$$e(l) + p(p) \rightarrow e'(l') + \gamma(k) + X(p_X). \tag{5}$$

The particle momenta are given in parentheses. We define the standard DIS variables (so-called **lepton** variables) as the ones given by the inclusive lepton measurement, i.e.

$$q_l = l - l', \quad Q_l^2 = -q_l^2, \tag{6}$$

$$x_l = \frac{Q_l^2}{2p \cdot q_l}, \quad y_l = \frac{p \cdot q_l}{p \cdot l}, \quad W^2 = (p+q_l)^2 = (p_X + k)^2.$$

The invariant mass W includes the contribution of the radiated photon. At given squared center-of-mass energy $s = (p+l)^2$ only two variables in (6) are independent by virtue of the relations

$$Q_l^2 = x_l y_l s, \quad W^2 = (1 - x_l) y_l s + m_p^2. \tag{7}$$

The kinematics can also be defined through the hadronic final state. Provided the photon in (5) can be identified, one can actually measure the **hadron** variables

$$q_h = p_X - p, \quad Q_h^2 = -q_h^2, \tag{8}$$

$$x_h = \frac{Q_h^2}{2p \cdot q_h}, \quad y_h = \frac{p \cdot q_h}{p \cdot l}, \quad W_h^2 = (p+q_h)^2 = p_X^2.$$

Note that the variable y_h is defined in terms of $p \cdot l$ rather than in terms of $p \cdot (l-k)$. The hadron variables obey relations in analogy to (7):

$$Q_h^2 = x_h y_h s, \quad W_h^2 = (1 - x_h) y_h s + m_p^2. \tag{9}$$

In HERACLES, cuts can be imposed on the lepton variables x_l, y_l, Q_l^2, or directly on the lepton scattering angle or the scattered lepton's transverse momentum. In addition, a lower cut on the mass of the hadronic final state, W_h, is possible.

2.2 Factorization

We use HERACLES to generate the variables for the semi-inclusive reaction (5). The momenta l and p are input quantities, thus k and l' are constructed by HERACLES according to the differential cross section. We classify a given event according to the channels of HERACLES as being either non-radiative, an event from leptonic 'initial state radiation', an event from leptonic 'final state radiation', or a 'Compton event' (cf. [9]). For radiative events we then define a rescaled Born-term like process so that in any case we are left with

$$E(L) + p(p) \to E'(L') + X(p_X). \tag{10}$$

In general both E and E' will be virtual particles. Since we restrict our considerations to $O(\alpha^3)$, only one of them will be virtual.

For the reduced process (10) we then apply QCD corrections and the final partons and the proton remnants fragment using the LUND string fragmentation.

2.2.1 'Initial state radiation'

In case the event is classified as resulting from leptonic 'initial state radiation' we imagine the two-step process

$$\begin{aligned} e(l) &\rightarrow \tilde{e}(\tilde{l}) + \gamma(k), \\ \tilde{e}(\tilde{l}) + p(p) &\rightarrow e'(l') + X(p_X), \end{aligned} \tag{11}$$

thus $E(L) = \tilde{e}(\tilde{l})$ and $E'(L') = e'(l')$. Here $\tilde{l} = l - k$ and we define DIS variables for the $\tilde{e}p$ subprocess

$$\begin{aligned} \tilde{s} &= (\tilde{l} + p)^2 && = s - 2k \cdot (l + p), \\ \tilde{Q}^2 &= -\tilde{q}^2 && \equiv -(\tilde{l} - l')^2, \\ \tilde{x} &= \frac{\tilde{Q}^2}{2p \cdot \tilde{q}} && = \frac{\tilde{Q}^2}{ys - 2p \cdot k}, \\ \tilde{y} &= \frac{\tilde{Q}^2}{\tilde{x}\tilde{s}}, \\ \tilde{W}^2 &= (p + \tilde{q})^2 && = (1 - \tilde{x})\tilde{y}\tilde{s} + m_p^2. \end{aligned} \tag{12}$$

Note that the tilde variables coincide with the hadron variables (8) except for s and y.

2.2.2 'Final state radiation'

A similar rescaling of variables is performed for events with leptonic 'final state radiation', now imagining the process as a hard scattering followed by a decay:

$$\begin{aligned} e(l) + p(p) &\rightarrow \tilde{e}'(\tilde{l}') + X(p_X), \\ \tilde{e}'(\tilde{l}') &\rightarrow e'(l') + \gamma(k), \end{aligned} \tag{13}$$

where $\tilde{l}' = l' + k$ and

$$\begin{aligned} \tilde{s} &= s, \\ \tilde{Q}^2 &= -\tilde{q}^2 && \equiv -(l - \tilde{l}')^2, \\ \tilde{x} &= \frac{\tilde{Q}^2}{2p \cdot \tilde{q}} && = \frac{\tilde{Q}^2}{ys - 2p \cdot k}, \\ \tilde{y} &= \frac{\tilde{Q}^2}{\tilde{x}\tilde{s}}. \end{aligned} \tag{14}$$

2.2.3 'Compton events'

Events from the Compton channel are characterized by typically small Q_h^2 and small W_h. For this reason they are not fragmented, and no hadronic final state is generated for them[2]. The number of Compton events is small, typically a fraction of a per cent if a cut on the mass of the hadronic final state of $W_h \geq W_h^{min}$ with $W_h^{min} \simeq 2$ GeV is imposed. With smaller values for W_h^{min} and at large y_l and small x_l, the Compton contribution can reach the level of tens of per cent. Experimentally, 'Compton events' are easily recognized without measuring W_h since they are characterized by a photon with high transverse momentum balancing the p_T of the scattered lepton [12].

2.3 Limitations of the approach

DJANGO6 includes the most important corrections of order α, α_s, as well as the leading combined QED–QCD effects of order $\alpha\alpha_s$. With respect to electroweak corrections, non-logarithmic corrections described by photon emission from quarks and box diagrams have not been taken into account. These contributions have been discussed in [13] and reach the level of a per cent only at very high momentum transfers Q^2. Although there is no physical interpretation of the separate channels of HERACLES beyond the leading logarithms, nevertheless, the cross section for $ep \to eX(\gamma)$ simulated by HERACLES includes both logarithmic and non-logarithmic leptonic corrections correctly to order $O(\alpha)$.

The calculation of the total cross section by HERACLES is not restricted to the use of parton model expressions for the structure functions. In particular, the contribution from the longitudinal structure function can be included correctly. In the event simulation, however, which is based on the parton model, the effect from F_L can necessarily be treated only approximately. The contribution from F_L is treated as if it gave rise to a hard scattering process involving in any case an incoming quark. The flavor of this quark is determined according to the flavor composition of F_2.

If the matrix element option is chosen, also non-logarithmic QCD corrections of order $O(\alpha_s)$ are correctly taken into account in our approach. The description of combined QED–QCD corrections of order $\alpha\alpha_s$ is based on the factorization property which works in the leading logarithmic approximation. The precision that can be reached with this approach is most probably sufficient for HERA, except for rare processes with more than 2 jets in the final state (in addition to the remnant jet) and in the very low x region where logarithms $\ln 1/x$ have to be resummed.

According to the basic parton model assumption, the algorithms used in DJANGO6 are applicable only in phase space regions where the momentum transfer Q_h^2 and the final state hadronic mass W_h are not too small. Therefore, default values of $Q^2_{min} = 4$ GeV^2 and $W_{h,min} = 5$ GeV are used in DJANGO6.

In the region of very small y_l and/or large x_l, virtual QED corrections can become large and lead to a negative non-radiative cross section. These negative cross sections are, of course, unphysical. In a more complete treatment, higher-order QED corrections (multiple photon effects) would have to be added and would eventually result in a positive cross section. In the present version of the program which does not include these higher-order

[2]See also subsection 3.2.2.

terms, the problem is avoided by simply putting the cross section to zero if it happens to be negative. This may take place in the region $y_l(1-x_l)^2 \lesssim 0.004$. For applications where this phase space region is relevant, one should use a program which includes higher-order QED corrections[3].

In HERACLES, much effort has been made to treat correctly small values for kinematic variables appearing for collinear emission of photons. The precision of the algorithm has been checked by comparing it with other programs for the calculation of radiative corrections [13]. It has been shown that results from different programs agree usually at the per mille level and the agreement is better than 1 % throughout the phase space relevant for HERA.

For events with small hadronic mass of a few GeV, round-off errors in DJANGO6 may lead to a small mismatch between energy or momentum of the initial state particles and the final state. For $W_h > 5$ GeV, only a few per mille of generated events have an energy in the final state which differs by more than 1 % from the energy of the incoming particles. For smaller values of W_h, the portion of events with energy-momentum mismatch may reach the level of a few per cent. In view of the energy resolution of the HERA experiments H1 and ZEUS, this will not be a severe problem in applications and work is in progress to improve the algorithm in this respect.

3 Technical description

The performance of DJANGO6 is determined by the structure of HERACLES. The following steps have to be performed in actual computations:

1. Integration of the different contributions to be included. Thereby partial cross sections are determined according to the actually defined phase space region. They define the relative weight of the corresponding contribution in the final step of event sampling. Furthermore, the integration procedure supplies information for the construction of the distribution function applied for event generation. This step is controlled by input via code-words `'INT-OPT-NC'` and `'INT-OPT-CC'`, see subsection 3.1.1.

2. Estimation of the local maxima of the distribution function in a predefined number of hypercubes, needed since the integration volume is subdivided to optimize the rejection procedure. This step is usually executed together with the integration step 1. For applications where only cross sections are needed and no event generation is required, this step can be suppressed, see code-word `'INT-ONLY'`, subsection 3.1.1

3. According to the partial cross sections determined in step 1, events are then generated randomly from the individual contributions. In HERACLES, only the scattered lepton and sometimes a radiative photon is added to the event record. After completion of this part of the event, routines from DJANGO6 are called to simulate

[3] See for example [14].

QCD effects and to construct the hadronic part of the event. Control input for this step is transferred via code-words `'SAM-OPT-NC'` and `'SAM-OPT-CC'`, see subsection 3.1.1.

Note that steps 1) and 2) are necessary for each individual contribution to be included in the event generation. For flexibility (in particular with respect to CPU-time requirements) and test purposes the program allows a treatment of the different steps for each contribution separately. The information obtained in steps 1) and 2) is always written to an external file which has to be assigned in the corresponding run. If step 3) is done in a separate run of the program, a corresponding file had to be prepared in a preceding run which performed at least steps 1) and 2). The random number seeds for refined integration by VEGAS or continued event sampling can also be stored on an external file. Conventions for file units are defined in subsection 3.3.1.

The user can communicate with the program by setting initial conditions (through input flags) and through a user analysis routine. The latter routine allows for *i*) additional initialization before generating events (for example booking of histograms), *ii*) analysis after having accepted an event and *iii*) a final call after completion of event generation. In the following section input flags will be documented while in section 3.2 the user analysis routine and common blocks used to store output of the program will be described.

3.1 Input to the program

The input to DJANGO6 consists of two parts: the first part deals with HERACLES options and the second one contains DJANGO6 input flags. The two parts are separated by the code word `'START'` in the sequence of input items. The format for the input in the two parts is the same as for HERACLES, i.e. an option card defining the expected information (`FORMAT (A10)`) is followed by one card containing the appropriate data (format-free – `READ(5,*)`). All data items except `'START'` (in the HERACLES part) and `'CONTINUE'` (in the DJANGO6 part) are optional and are set to default values if they are not given as input. The sequence of different options within the two parts does not matter, only the `'CONTINUE'` option triggering the actual operation of the program has to be the last one.

In the following we describe the possible input options and the corresponding data expected by the program both for the HERACLES and the DJANGO6 part. Default values are given in parentheses. For additional information concerning options of LEPTO 6.5 and JETSET 7.4 we refer to the corresponding manuals [3, 5].

3.1.1 HERACLES part

- `'TITLE'`
  data: user defined heading of the first output page.
- `'EL-BEAM'`
  data: `EELE`, `POLARI`, `LLEPT`
  quantities defining the properties of the lepton beam;

`EELE`	= energy of the lepton beam in GeV (D=27.6);
`POLARI`	= degree of beam polarization (D=0.), $-1 \leq$ `POLARI` ≤ 1;
`LLEPT`	= lepton charge (D=–1),
	= -1, electron beam,
	= $+1$, positron beam.

- `'PR-BEAM'`
  data: `EPRO`
  properties of the proton beam;

  `EPRO` = energy of the proton beam in GeV (D=820.).

- `'KINEM-CUTS'`
  data: `ICUT`, `XMIN`, `XMAX`, `YMIN`, `YMAX`, `Q2MIN`, `WMIN`
  definition of kinematical cuts to be applied;

  `ICUT` = 1 : cuts in x_l and lower cut in Q_l^2 (`Q2MIN` in GeV^2), cuts in y_l are ignored,

  = 2 : cuts in x_l, lower cut in Q_l^2 and lower cut in the hadronic mass W_h (`WMIN` in GeV), cuts in y_l are ignored,

  = 3 : cuts in x_l, y_l, Q_l^2 and W_h.

  Default values: `ICUT` = 3, `XMIN` = 10^{-3}, `XMAX` = 1.0, `YMIN` = 10^{-2}, `YMAX` = 1.0, `Q2MIN` = 4.0, and `WMIN` = 5.0. The final definition of cuts according to the most restrictive conditions is performed in the subroutine `HSPRLG`.

- `'THETA-CUT'`
  data: `THEMIN`
  lower cut on the lepton scattering angle in *rad* with respect to the incoming lepton (D=0.).

- `'PT-CUT'`
  data: `PTMIN`
  lower cut on the transverse momentum of the scattered lepton in GeV (D=0.).

- `'EGAM-MIN'`
  data: `EGMIN`
  definition of a lower cutoff energy for bremsstrahlung photons (in GeV);

  `EGMIN` = 0.0: Both radiative and non-radiative events are generated. The separation of the cross section into non-radiative and radiative parts with the help of a soft-photon cutoff is determined internally as a function of x and y. This option has to be used if integration/sampling of both radiative and non-radiative channels is requested.

`EGMIN` > 0.0: Only hard-photon bremsstrahlung (with energy above `EGMIN`) is considered for event sampling (in this case the data items `ISNC2` and `ISCC2` from input options `'SAM-OPT-NC'` and `'SAM-OPT-CC'` are ignored!).

Default: `EGMIN` $= 0$.

- `'THMIN-QRAD'`
  not available in DJANGO6.

- `'GSW-PARAM'`
  data: `LPARIN(1:11)`
  monitoring the definition of electroweak parameters and the inclusion of different virtual corrections;

`LPARIN(1)` $= 1$:	electroweak parameters set with fixed values for the boson masses M_W, M_Z,
$= 2$:	electroweak parameters calculated from fixed M_Z, G_μ.

Default: `LPARIN(1)` $= 2$. The definition of boson and fermion masses as far as they are not input from code word `'GSW-MASS'` and the calculation of coupling constants is done in the subroutine `HSSETP`.

`LPARIN(2)` $= 0$:	only Born cross section without electromagnetic or weak corrections is integrated/sampled,
$= 1$:	Born cross section including corrections as determined by the values of `LPARIN(3)` – `LPARIN(11)`.

Default: `LPARIN(2)` $= 1$.
The following options define the corresponding corrections to be included in the actual calculation (0 / ≥ 1 = no / yes):

`LPARIN(3)` (D=3) :	flag for inclusion of higher order contributions:
$= 0$:	no higher order corrections,
≥ 1 :	terms of $\mathcal{O}(\alpha^2 m_t^4)$ included,
≥ 2 :	terms of $\mathcal{O}(\alpha\alpha_s m_t^2)$ included,
≥ 3 :	running $\alpha(Q^2)$ is used for the radiative cross section;
`LPARIN(4)` (D=1) :	leptonic QED corrections;
`LPARIN(5)` (D=0) :	quarkonic QED corrections (not active in DJANGO6);
`LPARIN(6)` (D=0) :	lepton-quark interference (not active in DJANGO6);
`LPARIN(7)` (D=2) :	fermionic contributions to the photon self energy Σ^γ:
$= 0$:	not included,
$= 1$:	parametrization with the help of quark masses,

= 2 : parametrization from [15];

`LPARIN(8)` (D=0) : fermionic contribution to the $\gamma - Z$ mixing;

`LPARIN(9)` (D=0) : fermionic contribution to the self energy of the Z boson;

`LPARIN(10)` (D=0) : fermionic contribution to the self energy of the W boson;

`LPARIN(11)` (D=0) : purely weak contributions to the self energies, vertex corrections and boxes.

- `'GSW-MASS'`
  data: `MW`, `MZ`, `MH`, `MT`
  the electroweak mass parameters: W and Z boson masses, Higgs mass and the top-quark mass (in GeV). The value given for `MW` is used only if at the same time `LPARIN(1)` = 1. Otherwise, M_W is calculated in the program from the μ decay constant.

- `'STRUCTFUNC'`
  data: `ISTRFC`
  defines the parametrization of parton densities or structure functions applied in the calculation. The input is defined by

  `ISTRFC = ILQMOD*100000 + ILIB*10000 + ICODE.`

  `ILQMOD` encodes options for the treatment of structure functions in the low Q^2 region, `ILIB` defines a library of subroutines to be used for the calculation of parton distribution or structure functions and the corresponding parametrization is specified by `ICODE`. The parton distribution functions are taken via the modified LEPTO routine `LYSTFU` from PYTHIA (routine `PYSTFU`) [16]. The switches `ICODE` and `ILIB` agree with the PYTHIA parameters `MSTP(51)` and `MSTP(52)`. The meaning of `ICODE` depends on the value of `ILIB`. The allowed values are as follows:

  `ILIB` = 1 : to choose parton distribution functions from the PYTHIA routine `PYSTFU`;

  `ICODE` = 1 : Eichten et al., set 1 (1986 update) [17],
  = 2 : Eichten et al., set 2 (1986 update) [17],
  = 3 : Duke/Owens, set 1 [18],
  = 4 : Duke/Owens, set 2 [18],
  = 5 : CTEQ2M (best $\overline{\rm MS}$ fit) [19],
  = 6 : CTEQ2MS (singular at small x) [19],
  = 7 : CTEQ2MF (flat at small x) [19],
  = 8 : CTEQ2ML (large Λ) [19],
  = 9 : CTEQ2L (best leading order fit), [19],
  = 10: CTEQ2D (best DIS fit) [19],

`ILIB` = 2 : to use PDFLIB [20]. Calls are performed via `PYSTFU` and the user has to link the corresponding library;

`ICODE` = 1000∗`NGROUP` + `NSET`, the identification code for the parametrization of parton distribution functions for PDFLIB (version 4);

`ILQMOD` = 0: use unmodified parton distribution functions for all Q^2,

`ILQMOD` = 1: apply exponential low Q^2 suppression factor to parton distribution functions [21][4].

The default values are `ILQMOD` = 1 (exponential low Q^2 suppression), `ILIB` = 1 (PDF's from `PYSTFU`) and `ICODE` = 9 (CTEQ2L), i.e. `ISTRFC` = 110009. The user himself is responsible for giving consistent input. For example, the recent MRS(A) parametrizations (provided via PDFLIB, e.g.) should not be combined with `ILQMOD` = 1, since these parametrization already contain a prescription for the small-Q^2 behaviour which ensures the correct limit for the structure functions.

- `'FLONG'`
  data: `IFLOPT`, `PARL11`, `PARL19`
  for the inclusion of the longitudinal structure function F_L. The definition of `IFLOPT` coincides with the definition of `LST(11)` of LEPTO 6.5 [3]:

  `IFLOPT = LQCD + LTM*10 + LHT*100`

  and `LQCD`, `LTM` and `LHT` specifies whether QCD contributions, target mass effects and higher twist should be included. See the manual of LEPTO 6.5 [3] for details. HERACLES calls modified routines from LEPTO 6.5 to calculate F_L either event-by-event when `LQCD` = 2 or `LTM` = 2 (time-consuming) or by using a grid and linear interpolation for `LQCD` = 1 or `LTM` = 1.
  For the calculation of radiative corrections, F_L is needed for small Q^2, also in the limit $Q^2 \to 0$. The prescription for $F_L(Q^2 \to 0)$ is determined by `ILQMOD`. In the interface with DJANGO6 this means that F_L is calculated from perturbative QCD. For Q^2 values smaller than $Q_0^2 = 6$ GeV^2, F_L is assumed to be independent of Q^2 and its value is given by $F_L(Q^2 = Q_0^2)$.
  The meaning of the parameters `PARL11` and `PARL19` coincides with that of `PARL(11)` and `PARL(19)` in LEPTO 6.5:

  `PARL11` : Accuracy for the integration needed to calculate F_L;

  `PARL19` : κ^2, the scale parameter for higher-twist contributions in F_L.

  The default values are `IFLOPT` = 0, `PARL11` = 0.01, `PARL19` = 0.03.

- `'ALFAS'`
  data: `MST111`, `MST115`, `PAR111`, `PAR112`
  information defining the value of α_s needed for the inclusion of F_L. α_s enters the

[4] Other options are available if HERACLES is used as a stand-alone program.

calculation of F_L and is evaluated in the routine `ULALPS` from JETSET 7.4. The meaning of the input data corresponds to the parameters `MSTU(111)`, `MSTU(115)`, `PARU(111)`, `PARU(112)` of JETSET 7.4 and is as follows:

`MST111` :	Order of α_s evaluation in `ULALPS`: = 0: fixed α_s at the value of `PAR111`, = 1: first-order running α_s, = 2: second-order running α_s, (D=1);
`MST115` :	Treatment of the α_s singularity at $Q^2 \to 0$: = 0: allow it to diverge like $1/\ln(Q^2/\Lambda^2)$, = 1: soften the divergence to $1/\ln(1+Q^2/\Lambda^2)$, = 2: freeze Q^2 evolution below $Q_0^2 = 4$ GeV^2, (D=0);
`PAR111` :	The fixed value of α_s assumed in `ULALPS` when `MST111` = 0 (D=0.20);
`PAR112` :	Λ used in running α_s in `ULALPS` (D=0.25).

- `'NFLAVORS'`
  data: `NPYMIN`, `NPYMAX`
  minimal and maximal number of flavors to be included in the cross section. The flavors are counted from 1 to 6 in the following order: d, u, s, c, b, and t. Defaults are `NPYMIN` = 1 and `NPYMAX` = 6.

- `'INT-OPT-NC'`
  data: `INC2`, `INC31`, `INC32`, `INC33`, `INC34`
  defines the contribution(s) to neutral current interactions for which the integrated cross section is asked to be calculated in order to prepare the sampling procedure (including estimation of local maxima of the actual distribution function if `INTOPT` ≥ 0):

`INC2` :	Integration for the **non-radiative contribution** (Born term including virtual and soft corrections); integration by Gaussian quadrature, NAGLIB routine `D01FCF`,
`INC31` < 100:	number of iterations for integration of the contribution from **initial state leptonic bremsstrahlung** by `VEGAS`,
`INC31` > 100:	(INC31-100) iterations by `VEGAS1`; here the iteration procedure is restarted to estimate the integral; the grid structure is used from the previous run, but estimates of the integral and its error accumulated in the previous run(s) are discarded. The necessary information is read from an external file which had to be defined before by a run with `INCx` < 100,
`INC31` > 200:	(`INC31-200`) iterations by `VEGAS2`: the iteration procedure is restarted using both the grid information and the accumulated estimates of the integral and its error from the previous run(s);

INC32 : monitoring the integration of **final state leptonic bremsstrahlung** with the same conventions as for INC31;

INC33 : monitoring the integration of **the Compton contribution** with the same conventions as for INC31;

INC34 : monitoring the integration of **the contribution from radiation from the quark line** with conventions as for INC31 (not active in DJANGO6);

Defaults are INC2=INC31=INC32=INC33=INC34=0, no integration.

- 'INT-OPT-CC'
  data: ICC2, ICC31, ICC32, ICC33
  same as 'INT-OPT-NC' but for the charged current interaction:

  ICC2 : Integration for the non-radiative contribution (Born term with virtual and soft corrections);

  ICC31 : Integration of the contribution from 'leptonic initial state' bremsstrahlung by VEGAS;

  ICC32 : Integration of the contribution from 'quarkonic initial state' radiation (not activated);

  ICC33 : Integration of the contribution from the 'quarkonic final state' radiation (not activated).

  Defaults are ICC2=ICC31=0, no integration.

- 'INT-POINTS'
  data: NPOVEG
  upper limit for the number of integration points used by VEGAS (D=10000).

- 'INT-ONLY'
  data: INTOPT
  A negative value for INTOPT suppresses the call to subroutines needed for the preparation of the sampling steps. Only integration of the differential cross section is performed in this case (D=0).

- 'SAM-OPT-NC'
  data: ISNC2, ISNC31, ISNC32, ISNC33, ISNC34
  monitoring the inclusion of individual contributions to the neutral current cross section for event sampling. A contribution is included if the corresponding option is set to 1 or 2, resp.; ISNCx = 2 triggers continued sampling, i.e. information from a previous sampling run with ISNCx $\neq 0$ is expected:

  ISNC2 : non-radiative contribution;

  ISNC31 : initial state leptonic bremsstrahlung;

  ISNC32 : final state leptonic bremsstrahlung;

ISNC33 : Compton contribution;

ISNC34 : quarkonic radiation.

Defaults: ISNCx $= 0$.

- 'SAM-OPT-CC'
data: ISCC2, ISCC31, ISCC32, ISCC33
same as 'SAM-OPT-NC' but for the charged current. For the physical content of the charged current radiative channels, see option 'INT-OPT-CC'. Defaults: ISCCx $= 0$.

- 'WEIGHTS'
data: IWEIGS
generation of events with externally defined weight function;

  IWEIGS $= 0$: Events are generated according to the true differential cross section calculated by the program including or excluding radiative corrections as requested by the user input;

  IWEIGS $= 1$: Events are generated according to the differential cross section modified by the additional weight factor

$$\omega = x_l;$$

  IWEIGS $= 2$: Events are generated according to the differential cross section modified by the additional weight factor

$$\omega = \begin{cases} Q_l^2/Q_0^2 & \text{for } Q_l^2 \leq Q_0^2 = 100\,\mathrm{GeV}^2, \\ 1 & \text{for } Q_l^2 \geq Q_0^2. \end{cases}$$

  Other weight functions, which may depend on the lepton kinematic variables x_l and y_l, can be defined by the user in the routine HSWGTX. Default: IWEIGS $= 0$.

- 'RNDM-SEEDS'
data: ISDINP, ISDOUT
monitoring input/output of actual random seeds from/to unit LUNRND:

  ISDINP $= 0/1$: (no) input of seeds;

  ISDOUT $= 0/1$: (no) output of seeds;

  default: ISDINP = ISDOUT = 0.

- 'IOUNITS'
data: LUNOUT, LUNRND, LUNDAT
logical unit numbers for in- and output:

  LUNOUT: for standard output (D=6);

  LUNDAT: for in-/output of results from the integration step from/to an external file (D=11);

`LUNRND`: for in-/output of the random number status from/to an external file (D=10).

- `'START'`
  data: `NEVENT`
  starts the execution of the main program;

  `NEVENT` : number of requested events if any sampling option is activated (D = 1000).

3.1.2 DJANGO6 part

In the following we describe input options which determine the treatment of QCD effects in the DJANGO6, resp. LEPTO part of the program. Only a few selected flags are allowed as explicit input items. Other flags can be changed in the block data subroutine LEPTOD. Exceptions are the flags `LST(1)`, `LST(2)`, `LST(6)`, `LST(17)`, and `LST(18)` which must not be changed in order that DJANGO6 works correctly.

- `'OUT-LEP'`
  data: `LST(4)` (integer, D=1)
  regulates which information is written onto the event record:

  `LST(4)` = $I_{lepton} + 10{*}I_{shower}$;
  $I_{lepton} = 0/1$ inactive/active scattered lepton;
  $I_{shower} = 0/1$ exclude/include intermediate partons.

- `'FRAME'`
  data: `LST(5)` (integer, D=3)
  choice of frame for the event:

  `LST(5)` = 1: hadronic cms frame, z-axis along boson,
  = 2: ep cms frame, z-axis along lepton,
  = 3: ep lab system, z-axis along lepton,
  = 4: ep lab system, z-axis along exchanged boson.

- `'FRAG'`
  data: `LST(7)` (integer, D=1)

  `LST(7)` = 0: event generation at the parton level, no hadronization,
  = 1: event generation including hadronization and decays of unstable particles.

- `'CASCADES'`
  data: `LST(8)` (integer, D=12)
  describes that part of the event simulation which is determined by perturbative QCD:

LST(8) = 0: no QCD effects, i.e. no gluon radiation or boson-gluon fusion,

= 1: including QCD processes (gluon radiation and boson-gluon fusion) according to the first-order matrix elements,

= 2: QCD parton cascade evolution of initial and final quark,

= 3: QCD parton cascade evolution of initial quark only,

= 4: QCD parton cascade evolution of final quark only,

= 5: QCD switched off, but target treatment exactly as in parton cascade case,

= 9: simulating QCD cascades in the colour dipole model as implemented in ARIADNE,

= 12 – 15: as 2 – 5, but parton shower added to the event as obtained from first-order matrix elements (ME+PS).

- 'MAX-VIRT'
  data: LST(9) (integer, D=5)
  maximal virtuality in parton cascades (active only for LST(8) = 2 – 5):

LST(9) = 1: Q^2,

= 2: W^2,

= 3: $W \times Q$,

= 4: $Q^2 \times (1 - x)$,

= 5: $Q^2 \times (1 - x) \times max(1, \ln(1/x))$,

= 6: $x_0 W^2$,

= 9: $W^{4/3}$, i.e. similar as in the colour dipole model.

- 'BARYON'
  data: LST(14) (integer, D=1)
  treatment of the target remnant (for more detailed information, see [3]):

LST(14) = 0: baryon production from remnant excluded,

= 1: baryon production from remnant included,

= 2, 3: as 1 but with different energy-momentum fractions distributed over remnant parts;

= 4: using LUZDIS [5].

- 'KT-PARTON'
  data: PARL(3) (real, D=0.44)
  width of Gaussian primordial transverse momentum distribution (in GeV).

- 'DIQUARK'
  data: PARL(4) (real, D=0.75)
  probability that a ud-diquark in target remnant has spin and isospin equal to zero, i.e. I=S=0.

- 'KT-REMNANT'
  data: PARL(14) (real, D=0.35)
  width of Gaussian p_T when non-trivial target remnant is split into a particle and a jet (in GeV).

- 'AR-REMNANT'
  data: MSTA(30) (integer, D=1)
  extendedness of initial partons in ARIADNE (see [4]);

  MSTA(30) = 0: struck quark is pointlike and proton remnant extended with $\mu =$ PARA(11) (= 1 GeV by default), where μ is the inverse extension of the proton remnant,
  = 1: as for 0 but $\mu =$ PARA(11)$/(1-x)$,
  = 2: as for 1 but also struck quark is extended with $\mu = \sqrt{Q^2}$.

- 'CONTINUE'
  continue execution of the main program, start event generation.

3.2 Output and User's analysis

Any user action is expected in the user supplied subroutine HSUSER(ICALL,X,Y,Q2). The routine allows for user action in three different phases of running DJANGO6:

- before generating events (ICALL=1),
- after each generated event (ICALL=2),
- after completion of event generation (ICALL=3).

The arguments X, Y, Q2 correspond to the lepton kinematic variables of the actual event.

For each sampled event the information about the $eq \to eq(\gamma)$ subprocesses is transferred to HSUSER via the HERACLES common blocks /HEPEVT/, /HSIKP/ and /HSCHNN/ as described in [6]. The information about the hadronic final state is contained in the common block /LUJETS/ of JETSET 7.4 [5]. In case of an event with hard QED bremsstrahlung, the information about the radiated photon is found in /LUJETS/ right after the scattered lepton, i.e. in line 5. Additional information is contained in the common blocks /DJPASS/ and /LEPTOU/ (of LEPTO). Below we describe those common blocks which can be useful for the analysis of the event. For details about the content of the common block /LUJETS/ which contains the event record we refer the reader to the manual of JETSET 7.4 [5].

The event record is also stored on the common block LUJETS when the hadronization step failed (or was not attempted, as in the case of QED Compton events). In this casem the event record contains, besides the scattered electron and a potential bremsstrahlung photon, the scattered quark and the proton remnant.

3.2.1 Common block LEPTOU

```
COMMON /LEPTOU/ CUT(14),LST(40),PARL(30),X,Y,W2,Q2,U
```

Content: contains input switches (`LST(1)` – `LST(20)`) and input parameters (`PARL(1)` – `PARL(20)`) for LEPTO to specify physics, kinematic cuts and numerical procedures, as well as output flags (`LST(21)` – `LST(40)`) and output variables (`PARL(21)` – `PARL(30)`). Many of the input flags and parameters are initialized in HERACLES. Additional ones are determined either through explicit input of DJANGO6 or by default values in `BLOCK DATA LEPTOD`. Some switches of LEPTO are not optional anymore in DJANGO6, but have to be kept fixed at values given in the list below.

Parameters:

`CUT(1)` – `CUT(14)`: lower and upper limits on x_l, y_l, Q_l^2, W_h^2, ν, E', θ'; included for documentation purposes only (passed from HERACLES).

`LST(1)` : (D=2) not optional: independent variables are x and y;
`LST(2)` : (D=3) not optional: scaled variables $(\tilde{x}, \tilde{y})$ passed via `LEPTOU`;
`LST(3)` : (D=5) detailed output at all initialization calls;
`LST(4)` : (D=1) user input via code-word `'OUT-LEP'`, cf. section 3.1.2;
`LST(5)` : (D=3) user input via code-word `'FRAME'`, cf. section 3.1.2;
`LST(6)` : (D=0) not optional: no rotation of the azimuthal angle, ϕ, of the lepton scattering plane; random azimuthal orientation passed from HERACLES;
`LST(7)` : (D=1) user input via code-word `'FRAG'`, cf. section 3.1.2;
=0: parton level events generated, optionally including QCD effects according to `LST(8)`;
=1: full event generated, i.e. including hadronization and decays;
`LST(8)` : (D=12) user input via code-word `'CASCADES'`, cf. section 3.1.2;
`LST(9)` : (D=5) user input via code-word `'MAX-VIRT'`, cf. section 3.1.2;
`LST(10)` : (D=1) not used;
`LST(11)` : (D=0) user input via code-word `'FLONG'`, cf. section 3.1.1;
`LST(12)` : (D=6) `NPYMAX`, maximum flavor used in the sea structure function parametrizations, passed from HERACLES;
`LST(13)` : (D=5) heaviest flavour produced in boson-gluon fusion;
`LST(14)` : (D=4) user input via code-word `'BARYON'`, cf. section 3.1.2;
`LST(15)` : (D=9) choice of the parametrization for parton densities in the nucleon, `NPYMOD`, passed from HERACLES, cf. code-word `STRUCTFUNC`, section 3.1.1;
`LST(16)` : (D=1) choice of the structure function library, passed from HERACLES, cf. code-word `STRUCTFUNC`, section 3.1.1;
`LST(17)` : (D=1) not optional: varying energies of initial particles from event to event;
`LST(18)` : (D=0) not optional: running electromagnetic coupling α and boson masses passed from HERACLES;
`LST(19)` : (D=−10) choice of grid for first-order QCD weights;
`LST(20)` : (D=5) scheme for cut-offs against divergences in the QCD matrix elements;

LST(21) : error flag, =0 for properly generated event;
LST(22) : (D=1) information about chosen target nucleon in current event (proton);
LST(23) : specifies process simulated, passed from HERACLES;
=2: weak charged current (CC), i.e. $W^{\pm}$ exchange;
=4: neutral current (NC), i.e. γ/Z^0 exchange;
LST(24) : information about first-order QCD process in current event;
=1: q-event, i.e. no first-order QCD;
=2: qg-event, i.e. gluon radiation in first-order QCD;
=3: $q\bar{q}$-event, i.e. boson-gluon fusion in first-order QCD;
LST(25) : information about flavor of the struck quark in current event: 1=d, 2=u, 3=s, 4=c, 5=b, –1=$\bar{d}$, –2=$\bar{u}$, –3=$\bar{s}$, –4=$\bar{c}$, –5=$\bar{b}$;
LST(26) : entry line in event record of outgoing struck quark. In parton shower case, quark at boson vertex before final state shower;
LST(27) : signals split of non-trivial nucleon remnant, cf. LST(14);
=0: no split, simple diquark or LST(14) = 0;
=1: split into parton and particle, $qq+M$ or $q+B$, occurs when sea (anti)quark removed through the interaction;
=2: split into quark and diquark, $q+qq$, occurs when a gluon is removed;
LST(28) : specifies the frame in which the current event is given with code as for LST(5);
LST(29) : specifies azimuthal angle rotation with code as for LST(6);
LST(30) : chosen helicity for beam lepton in current event;
LST(31) : not optional, fixed by LST(1);
LST(32) : for internal use;
LST(33) : for internal use;
LST(34) : (D=1) used for soft color interaction in LEPTO 6.5;
LST(35) : (D=1) used for new sea quark treatment in LEPTO 6.5;
LST(36) – LST(40) : (D=0) not used.
PARL(1) : (D=1.) for internal use;
PARL(2) : (D=1.) for internal use;
PARL(3) : (D=0.44) user input via code-word 'KT-PARTON', cf. section 3.1.2;
PARL(4) : (D=0.75) user input via code-word 'DIQUARK', cf. section 3.1.2;
PARL(5) : $\sin^2\theta_W$ (weak mixing angle), passed from HERACLES (SW2);
PARL(6) : polarization of lepton beam, passed from HERACLES (POLARI);
PARL(7) : (D=0.5) used for soft color interaction in LEPTO 6.5;
PARL(8), PARL(9) : (D=0.04, 4.) cut-offs against divergences in QCD matrix elements, see the remarks in the LEPTO manual [3];
PARL(10) : not used;
PARL(11) : (D=0.01) required relative accuracy for one-dimensional integration, used for first-order QCD matrix element weights and longitudinal structure function integrals;
PARL(12) : (D=0.01) probability for intrinsic charm;
PARL(13) : (D=0.1) internal parameters used for adjustment of y_{cut} for integration of QCD matrix elements;
PARL(14) : (D=0.35) user input via code-word 'KT-REMNANT', see section 3.1.2;

PARL(15) : (D=0.01) not used;
PARL(16) : finestructure constant α, passed from HERACLES (ALPHA);
PARL(17) : weak Fermi constant G_F, passed from HERACLES (GF);
PARL(18) : Δr from radiative corrections, passed from HERACLES (DELTAR);
PARL(19) : (D=0.03) scale κ^2 in GeV^2 for higher twist correction;
PARL(20) : (D=0.1) used for the treatment of a more complicated nucleon remnant than a simple diquark;
PARL(21) : scaled $\tilde{s}$;
PARL(22) : scaled $\tilde{y}\tilde{s}$ ($= y_h s_h$);
PARL(23) : total cross section in pb, passed from HERACLES (= SIGTOT*10^3);
PARL(24) : Monte Carlo estimate of the cross section in pb associated with the generated event sample. May be reduced as compared to the value of PARL(23) when hadronization of some of the events failed;
PARL(25) : value of α_s in current event;
PARL(26) : value of Λ used in last structure function call, passed from HERACLES (filled only when LST(16) = 1);
PARL(27) : depending on the value of LST(20), present value of the cut variable for first-order QCD;
PARL(28) – PARL(30) : values of x_p, z_q, ϕ in first order massless QCD matrix elements, see LEPTO manual;

X, Y, W2, Q2, U : **rescaled** variables $\tilde{x}$, $\tilde{y}$, $\tilde{W}^2$, $\tilde{Q}^2$, $\tilde{\nu}$, see section 2.2.1. Except for $\tilde{y}$, the rescaled variables are identical to the hadron variables, Eq. (8).

3.2.2 Common block DJPASS

```
COMMON /DJPASS/ NTOT,NPASS
```

Content: contains statistics of generated events:
Parameters:
NTOT : Total number of events generated by HERACLES;
NPASS : Number of events which have been hadronized completely;
Remarks: After normal completion of the program, NTOT and NPASS should be equal. NPASS is smaller than the total number of events generated by HERACLES when the program was unable to hadronize all events. First, events from the 'Compton contribution' are not hadronized and do not increase the value of NPASS. Secondly, also events not originating from the 'Compton contribution', but nevertheless having only a small amount of hadronic mass, cannot always be hadronized. This happens more often in DJANGO6 than in LEPTO since in the former program radiative events with a hard photon can lead to a substantial reduction of W_h. Internally, a small number of attempts is allowed to hadronize such events, but after at most 5 trials the control is returned to HERACLES and a new event

with new values of x and y is generated. In test runs with $W_h^{min} = 4.0$ GeV^2, about 1 % of the events could not pass the hadronization step; for $W_h^{min} = 1.0$ GeV^2, this ratio increased to 2.7 %.
In order to increase the efficiency of the program, there is a check on the value of W_h already in HERACLES. This is done using mass cut-offs of LEPTO in the subroutine `HSWCUT`. The effective cut-off depends on the flavor of the struck quark and is controlled by the values of the parameters `PYPAR(12)` and `PARL(3)`. The number of events recognized by HERACLES to have too small a hadronic mass is used to correct the total cross section accordingly. The corrected cross section is written to `PARL(24)` in the common block `/LEPTOU/`.

3.2.3 Common block HSCHNN

```
COMMON /HSCHNN/ ICHNN
```

Content: contains information on the origin of the event from the channels of HERACLES

Parameters:

`ICHNN` : flag of channel, passed from HERACLES:
- =1: non-radiative neutral current (NC) event,
- =2: non-radiative charged current (CC) event,
- =6: leptonic initial state photon radiation (NC),
- =7: leptonic final state photon radiation (NC),
- =8: Compton event (NC),
- =12: radiative charged current event (CC).

3.3 Implementation

3.3.1 External files

The program uses two external files:

unit `LUNRND` : file to store/read random number seeds (101 double precision words on the IBM), see code word `'RNDM-SEEDS'`. The user can initialize this file with a first run of the program with `ISDINP` = 0 and `ISDOUT` = 1;

unit `LUNDAT` : information from integration procedures (and potential previous event sampling), needed for (continued) event generation, see code word `'INT-OPT-NC'`.

3.3.2 External procedures required by the program

The following external routines/packages are being used by DJANGO6:

D01FCF:	integration routine from the NAGLIB library. A substitute for this routine is contained in the file DJHERAC.FOR, see next subsection;
JETSET 7.4:	The LUND Monte Carlo for jet fragmentation [5];
PYTHIA 5.7:	The LUND Monte Carlo for hadronic processes [16];
ARIADNE 4:	The LUND Monte Carlo for colour dipole cascades [4].
PDFLIB	Library for parametrizations of parton distribution functions [20].

The user has to take care that JETSET 7.4, PYTHIA 5.7 and PDFLIB are available to the linker. In case ARIADNE is not going to be linked one needs to enable two dummy routines ARINIT and AREXEC contained in DJUSER.FOR (see next subsection).

3.3.3 Source code

The program can be obtained via e-mail from i02spi@dsyibm.desy.de.

The source code of DJANGO6 has been divided into three parts:

DJHERAC.FOR:	routines from HERACLES 4.5.2;
DJLEPTO.FOR:	routines from LEPTO 6.5.1 used by DJANGO6 (some of them modified) and new routines of DJANGO6;
DJUSER.FOR:	contains an example of the user routine HSUSER and two (commented out) dummy routines ARINIT and AREXEC used when ARIADNE is not going to be linked.

The user can consult an information file DJINFO.TEX where updates of the program will be announced and copy the tex-file DJANGO6.TEX containing this manual.

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