Computer Physics Communications 46 (1987) 241–261
North-Holland, Amsterdam

LUCIFER – A MONTE CARLO FOR HIGH-$p_\perp$ PHOTOPRODUCTION

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Received 20 March 1987

PROGRAM SUMMARY

Title of program: LUCIFER version 2.2

Catalogue number: AAXH

Program obtainable from: CPC Program Library, Queen's University of Belfast, N. Ireland (see application form in this issue)

Computers on which the program is operable: IBM, CDC, VAX, ND, Univac and others with a FORTRAN 77 compiler

Computer: IBM 3084Q; *Installation*: DESY, Hamburg, Fed. Rep. Germany

Operating system: MVS XA

Programming language used: FORTRAN 77

High speed storage required: 680 Kbytes

No. of bits in a word: 32

Peripherals used: terminal and printer for input/output

No. of lines in combined program and test deck: 3656

CPC library programs used: JETSET 6.2; *cat. no.*: AAFP; *ref. in CPC*: 39 (1986) 347, or updated version 6.3; *cat. no.*: AATJ; *ref. in CPC*: 43 (1987) 367

Keywords: photon–nucleon collisions, QED Compton, QCD Compton, photon–gluon fusion, high-$p_\perp$ particles, prompt photons, higher twist, prompt mesons, Monte Carlo simulation, hadronization, low-$p_\perp$ VDM

Nature of physical problem
Low-$p_\perp$ interactions of high energy photons with nuclear targets are described by the vector meson dominance model (VDM) in which the photon appears as a virtual vector meson (ρ^0 dominantly) which interacts strongly with the nucleon. High-$p_\perp$ interactions, on the other hand, occur through the point-like interaction of the photon with a constituent quark in the nucleon. This latter process is particularly interesting as a clean probe of quark dynamics within QED and QCD.

Method of solution
For high-$p_\perp$ interactions, perturbatively calculated matrix elements for the QED and QCD Compton processes, the photon–gluon fusion process and prompt meson production through the higher twist mechanism are used. Low-$p_\perp$ events are treated as ρ^0-nucleon interactions using a simple VDM approach. The Lund string model is used for the fragmentation of colour charged partons into final state hadrons such that complete events are simulated which facilitates easy comparison with any experimental observable.

Restrictions on the complexity of the problem
For each subprocess, only the leading order matrix elements are used, but some higher order correction effects (K-factors) can be reduced by an optimal scale choice.

Typical running time
The time needed to generate one event is 0.02 to 0.03 s depending on energy and $p_\perp$ scale.

Unusual features of the program
A random number generator and the ordinary gamma function are required.

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LONG WRITE-UP

1. Introduction

The present description of high energy photon–hadron interactions is based on two different, but complementary theoretical frameworks. On the one hand, the low-$p_\perp$ behavior that dominates the cross section is described in terms of the vector-meson dominance model (VDM) [1]. In this model, the photon appears as a vector-meson, mainly as a ρ^0, and can as such experience strong interactions with a target nucleon leading to low-$p_\perp$ events similar to those occurring in minimum bias hadron–hadron interactions. On the other hand, final states with high-$p_\perp$ particles are expected to occur through a point-like interaction of the photon with a quark constituent in the target nucleon and are therefore calculable using perturbative QED and QCD (see e.g. refs. [2–4]).Although LUCIFER attempts to cover both cases, it is essentially meant to treat only the latter in detail. This is due mainly to the much better theoretical understanding of hard interactions making a better Monte Carlo model possible and detailed studies of the interaction mechanism more meaningful. The underlying quark dynamics and charges are thus interesting topics for detailed phenomenological studies with the aid of a Monte Carlo event generator.

The programme is based on the differential cross sections on the parton level [2–6]. The outgoing partons are subsequently connected by colour force fields, and the Lund string model [7] is used to describe the hadronization process. As a result, the detailed evolution of the event can be monitored as well as the complete final particle state obtained. This allows to predict the behavior in any observable and thus makes comparisons with experimental data easier, in particular since cross section estimates of the generated processes are also provided. Included are the QCD Compton and the photon–gluon fusion processes which dominate the high-$p_\perp$ cross section, but also the pure QED Compton process as well as the higher twist processes of prompt meson and glueball production. Although these hard point-like interactions, with the exception of higher twist processes, are theoretically well understood, they have not yet been well tested with experimental data. Several photon beam experiments have taken data or are in progress and observations of high-$p_\perp$ particle production exist [8], but further and more detailed comparisons with the theoretical expectations are desirable. It is the aim of this Monte Carlo programme to be an analysis tool in these forthcoming investigations.

The higher twist processes, although being studied within QCD for a number of years [9], have never been experimentally established. Recent data indicate their existence in high-$p_\perp$ hadron–hadron scattering [10] and in low-$p_\perp$ neutrino interactions [11], but no evidence is available so far in photon experiments. A clear observation to prove their existence will need extensive analysis of both the higher twist processes themselves and the background from normal processes, e.g. with the help of the programme presented here.

In this paper we first discuss, in section 2, the included processes from the point of view of physics (with references to programme routines and variables in capital letters). We then give, in sections 3 and 4, a detailed manual for the use of the programme, LUCIFER * version 2.2. The programme is based on the Lund Monte Carlo for high-$p_\perp$ physics, PYTHIA version 3.4 [13], and also has common features with the later higher twist version, TWISTER [14]. Although the present paper is essentially self-contained, we refer the reader to these papers also for discussion not repeated here. For some results already obtained with LUCIFER we refer to [15], which contains helpful examples as well as some basic physics results of experimental relevance.

* Lucifer *n* (light-bringing, the planet Venus as) the morning star; name of Satan, the chief rebel angle, before his defeat [12].

2. Physics aspects of included processes

The hard processes considered are all of the same $2 \to 2$ scattering type with a cross section of the form

$$d\sigma_i = f_i(x, Q^2)\frac{d\hat{\sigma}_i}{d\hat{t}}dx\, d\hat{t}. \tag{1}$$

Here, x is the usual momentum fraction carried by the interacting parton, of type i, occurring in the target hadron with a probability as given by the structure functions, f_i, which can be chosen among a set of available parametrizations (see IPY(12) and PYSTFU) [16–19]. A basic cutoff (QTMIN) in $p_\perp$ of the scattered partons is used to avoid the divergences that occur for zero momentum transfer, $\hat{t} \to 0$. The hard scattering momentum transfer scale, Q^2, used in α_s and structure function parametrizations is not uniquely defined to this order and some alternative definitions are therefore available (IPY(11)). The choice $Q^2 = 2\hat{s}\hat{t}\hat{u}/(\hat{s}^2 + \hat{t}^2 + \hat{u}^2)$ is taken as default, but the optimized scale choices discussed in [20] can also be employed which may minimize the size of higher order corrections (K-factors) for a general class of processes, although they were derived for some specific processes.

The efficiency of the simulation is increased by introducing the functions $h_x(x)$ and $h_t(x, \hat{t})$ in the programme (the detailed definitions are given by comment lines in PYRAND) and rewriting the total cross section in the form

$$d\sigma = \left\{\frac{dx\, d\hat{t}}{x}h_x h_t\right\}\left\{\sum_i x f_i(x, Q^2)\frac{d\hat{\sigma}_i}{d\hat{t}}\frac{1}{h_x h_t}\right\}. \tag{2}$$

In subroutine PYRAND the random variables $(x, \hat{t})$ are first chosen exactly according to the expression in the first bracket and the remaining factor applied in a weighting procedure based on the maximum value estimated in the initialization (LUCINI) using MINUIT routines [21] (included in the program package). Hence, no weights are associated with the generated events, i.e., they all have unit weight. The h-functions were chosen according to the poles of the cross sections of the various processes such that the remaining weighting factor varies as little as possible, leading to a more efficient simulation procedure.

A particular subprocess is then chosen according to its relative contribution to eq. (2). The scattered partons as well as the target remnant parton(s) are connected by strings (PYCONF) as discussed below (see subroutine PYSPLI and [13] for details concerning non-trivial target remnants). Finally, the Lund string model [7] in its Monte Carlo implementation [22] is used to simulate the hadronization process.

The cross sections for the simulated processes are estimated through the Monte Calo sampling of the cross section formulae and stored in common PYCROS. They can, e.g., be printed at the end of a job using LUCROS. We note that their accuracy depends on the statistics essentially as $1/\sqrt{N}$ since they updated with each generated event.

2.1. The QED Compton process

The differential cross section for the pure QED process of Compton scattering

$$\gamma + q \to \gamma + q, \quad \gamma + \bar{q} \to \gamma + \bar{q} \tag{3}$$

(fig. 1a) is given by [2]

$$\frac{d\sigma}{d\hat{t}} = \frac{2\pi\alpha^2}{\hat{s}^2}e_q^4\left\{\frac{\hat{s}}{-\hat{u}} + \frac{-\hat{u}}{\hat{s}}\right\}, \tag{4}$$

where $\hat{s}$, $\hat{t}$, $\hat{u}$ are the usual Mandelstam variables in the parton level subsystem; in particular $\hat{t}$ is the squared four-momentum transfer between the incoming and the outgoing photon.

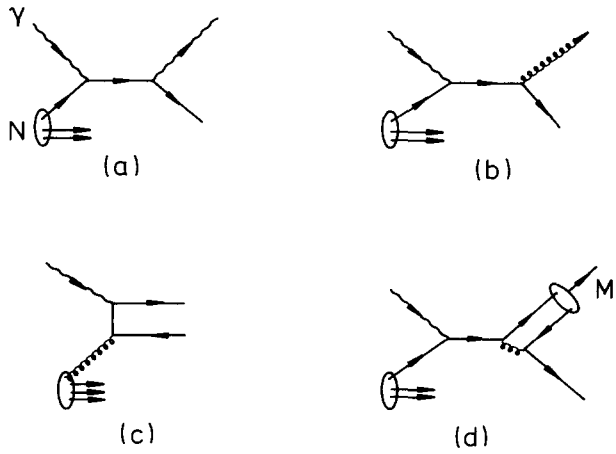

Fig. 1. Processes included in the programme: (a) QED Compton $\gamma + q \to q + \gamma$. (b) QCD Compton $\gamma + q \to q + g$, (c) photon–gluon fusion $\gamma + g \to q + \bar{q}$, (d) higher twist prompt meson production $\gamma + q \to M + q'$. (Note that these Feynman diagrams are examples only, thus q can be a quark or an antiquark and crossed diagrams are not shown.)

Despite the low rate due to the α^2 factor (as opposed to the $\alpha\alpha_s$ factor for the lowest order QCD processes), it has several interesting properties: The pure QED calculation should make the cross section calculation particularly reliable and the final state photon, being unaffected by the confinement forces, should reflect the dynamics of the parton level process without any distortions from the hadronization processes. The dependence of the quark charge to the fourth power makes it suitable to distinguish between model with fractional and integer quark charges.

The string system here is particularly simple. The scattered (anti)quark formes a colour singlet system with the target remnant, thus a single colour triplet string is stretched between them.

2.2. The QCD Compton process

In the QCD Compton process, a gluon is emitted in the final state

$$\gamma + q \to g + q, \quad \gamma + \bar{q} \to g + \bar{q} \tag{5}$$

(fig. 1b) leading to the differential cross section [2,3]

$$\frac{d\sigma}{d\hat{t}} = \frac{8}{3}\frac{\pi\alpha\alpha_s}{\hat{s}^2} e_q^2 \left\{ \frac{\hat{s}}{-\hat{u}} + \frac{-\hat{u}}{\hat{s}} \right\}, \tag{6}$$

where $\hat{t}$ is the momentum transfer squared between the incoming photon and the final gluon. Together with the photon–gluon fusion process, this process dominates the cross section for high-$p_\perp$ particle production. A single colour string-system is formed by joining the scattered (anti)quark via the gluon to the target remnant.

2.3. The photon–gluon fusion process

The cross section of the photon-gluon fusion process into a quark-antiquark pair

$$\gamma + g \to q + \bar{q} \tag{7}$$

(fig. 1c) is given by [4]

$$\frac{d\sigma}{d\hat{t}} = \frac{\pi\alpha\alpha_s}{\hat{s}^2} e_q^2 \left\{ \frac{m_q^2 - \hat{t}}{m_q^2 - \hat{u}} + \frac{m_q^2 - \hat{u}}{m_q^2 - \hat{t}} + 4\left(\frac{m_q^2}{m_q^2 - \hat{t}} + \frac{m_q^2}{m_q^2 - \hat{u}} \right) - 4\left(\frac{m_q^2}{m_q^2 - \hat{t}} + \frac{m_q^2}{m_q^2 - \hat{u}} \right)^2 \right\}, \tag{8}$$

where m_q is the mass of the produced quark. We have included the option (IPY(21)) to neglect the quark mass in the matrix element and to apply a simple threshold factor instead. This process is expected to be the dominant source for production of charm and heavier quark flavours. * With the quark mass in the matrix element there is no singularity for $p_\perp = 0$. Hence, if only fusion into heavy quark pairs (charm and heavier) is simulated one may let QTMIN $\to 0$ obtaining also an estimate of the total heavy quark production cross section. This leading order calculation may not, however, be quite reliable for too small values of QTMIN due to significant higher order corrections.

The target remnant consisting of the nucleon valence quarks in a colour octet state is in this case split in a colour triplet (quark) and a colour antitriplet (diquark) [13]. Two independent string systems are formed: one string connects the produced quark with the remnant diquark, the other the produced antiquark with the remnant quark. By a call to LUPREP in [22] each string system is checked for sufficient energy for the fragmentation routines to be applicable. Although this does usually not present a problem, heavy quark production close to threshold may fail this requirement. A heavy meson, or baryon, will be formed directly (i.e. without the normal hadronization process) in such cases, and energy and momentum slightly reshuffled in order to obtain the correct particle mass and to conserve energy and momentum.

2.4. Higher twist processes

In the so-called 'higher twist' processes a hadron is produced directly in the hard process. This is in contrast to the 'minimum twist' processes described above, where it is formed indirectly through the fragmentation process. Photoproduction of such prompt high-$p_\perp$ mesons through the higher twist processes

$$\gamma + q \to M + q', \quad \gamma + \bar{q} \to M + \bar{q}' \tag{9}$$

(fig. 1d) was first discussed in ref. [5] and later elaborated in ref. [6] to take mixing of neutral mesons into account as well as glueball production, i.e. M above can also represent a two-gluon gluonium state without orbital angular momentum. By default, the latter formalism [6] is used, but the former [5] is also implemented (IPY(23), c.f. function PYIMES).

The implementation of the cross section from [6] closely follows the one for hadron–hadron interactions in ref. [14] and we refer to section 5 therein for a rather detailed description. We emphasize that for M in eq. (9) all low-lying (S-wave) mesons composed of light quarks (u, d, s), i.e. all light vector and pseudoscalar mesons, are included as well as the expected three lightest gluonium states. When the cross sections from [5] are used, glueballs are excluded and the mixing of neutral mesons is treated in a simplified way (see DPRO in common PYPHOT).

Since the prompt meson 'decouples' from the remaining parton system these processes lead to a string configuration analogous to that occurring in the QED Compton case with a final state photon. Thus a single string is stretched between the high-$p_\perp$ (anti)quark that balances the prompt meson, and the target remnant system.

2.5. Low-$p_\perp$ VDM interactions

To facilitate the simulation of low-$p_\perp$ interactions, we use the VDM idea [1] to simulate the hadronic nature of the photon by a neutral vector meson (ρ^0 essentially) which interacts softly as modelled by the Lund low-$p_\perp$ model [23] in its Monte Carlo implementation [22]. The main idea here is that the most important properties of the event can be described by the hadronization of a single string with the valence

* Such production can be simulated separately (by using ISELEC = 3), and the flavours to be produced be specified (IPY(2), IPY(22)). For convenience, charm production only can be selected simply with ISELEC = 10.

quarks of the reacting particles 'distributed along the string' according to a definite prescription. Apart from the addition of a transverse momentum induced by the soft interaction (PYPAR(11)) we follow this model. Since this routine (LUCVDM) is a separate routine, its use does not affect the remaining part of LUCIFER. Furthermore, it does not provide any cross section estimate. The user can, however, easily associate an appropriate cross section to the generated events.

3. Description of programme components

LUCIFER version 2.2, written completely in FORTRAN77, is essentially based on the Lund Monte Carlo for high-$p_\perp$ physics, PYTHIA version 3.4 [13], and similar to TWISTER [14], a further development of [13] containing higher twist processes in hadron–hadron high-$p_\perp$ scattering. No previous knowledge of those programmers has been assumed. But, to help the users already acquainted with previous programmes or striving for a deeper understanding by studying ref. [13] or [14], we have retained most names, although many subroutines and functions have been modified internally. Also, names of variables and common blocks have been kept to a large extent. New routines and common blocks have, of course, been added to treat the new physics introduced in the programme. The naming convention is that all names of routines and common blocks names start with 'PY' or 'LUC', so name clashes with user routines can be easily avoided. 'MT' and 'HT' are used below to denote minimum and higher twist processes, respectively.

3.1. Subroutines and functions

Below follows first the most important user-called routines; to initialize, generate events and print cross sections. Other routines then follow in alphabetic order.

SUBROUTINE LUCINI(FRAME,TARGET,WIN,QTMIN)

Purpose: to initialize the generation procedure.

Arguments:

FRAME: a character variable used to specify the coordinate frame of the experiment.
- ='FIXT': fixed target, with photon beam momentum in $+z$ direction.
- ='CMS': colliding beams in CM frame, with photon beam momentum in $+z$ direction
- ='USER': full freedom to specify frame by giving photon beam momentum in P(1,1), P(1,2) and P(1,3) and target momentum in P(2,1), P(2,2) and P(2,3) in common LUJETS.

TARGET: character variables to specify targer particle; 'P' = proton, 'PBAR' = antiproton. 'N' = neutron, 'NBAR' = antineutron, 'PI + ' = positive pion, 'PI − ' = negative pion

WIN: defines the energy of the system, exact meaning depends on FRAME;
for FRAME ='FIXT', WIN = momentum of beam photon,
for FRAME ='CMS', WIN = total CM energy of system ($\sqrt{s}$),
for FRAME ='USER', WIN is a dummy variable.

QTMIN: minimum transverse momentum in the hard photon-parton scattering. It should not be lower than 1–2 GeV (depending on the energy scale) to avoid the divergences of the hard matrix elements. Because of the Fermi motion of the colliding partons, the actual distribution in transverse momentum of jets will not cut off sharply at QTMIN. If only heavy flavour production via photon–gluon fusion is simulated, the matrix element is finite for QTMIN $\to$ 0 provided that the heavy quark mass is taken into account (see IPY(21)). Nevertheless, the first order QCD calculation may not be reliable for too small values of QTMIN even in this case due significant higher order corrections.

SUBROUTINE LUCIFR

Purpose: to generate one high-$p_\perp$ event using the values specified in the LUCINI call. Also updates cross section estimates.

SUBROUTINE LUCROS

Purpose: to print out cross sections and event statistics, can be called by the user at the end of event generation.

SUBROUTINE LUCVDM(KF2,PE1,PE2)

Purpose: to generate a low-$p_\perp$ event by treating the photon as a vector meson.
Arguments:
KF2: flavour (in Lund code) of target particle.
PE1,PE2: energy of beam photon and target particle resp. (PE2 smaller than the target particle mass means that is taken to be at rest, i.e. fixed target).
Remarks: This routine is an adaptation of the Lund low-$p_\perp$ model, LULOPT in JETSET [22], where the photon is taken as a ρ^0 meson with respect to the quark content. Furthermore a transverse momentum of the soft interaction is introduced as a Gaussian $p_\perp$ distribution having a width given by PYPAR(11); technical this is achieved by a rotation of the event axis in the cms frame.

BLOCK DATA LUCDAT

Purpose: to assign physically sensible default values to all flags and parameters.

SUBROUTINE LUCGLU

Purpose: to define glueball states in Lund code as well as their decays, see section 5.1 in ref. [14].

FUNCTION PYALPH(Q2)

Purpose: to calculate the running couple constant in QCD.

SUBROUTINE PYCHID(KPART,KFL,CHI)

Purpose: to give energy fractions to the fragments when a hadron remnant is split, see ref. [13].

SUBROUTINE PYCONF

Purpose: to determine the colour field configuration, i.e. stretch the string between the colour charged partons.

FUNCTION PYDSIG(I,J,M,SHAT,THAT,UHAT)

Purpose: to calculate the parton level cross sections, $(1/\pi)\, d\sigma/dt$ for all included processes.
Arguments:
I: flavour of incoming, reacting parton of the target particle. (0 = g, 1 = u, 2 = d, 3 = s, 4 = c, 5 = b and negative numbers for the corresponding antiquarks).

J: for HT, flavour of the (produced) quark forming the prompt meson together with reacting parton I. Note that |I|, |J| cannot exceed 3 in the HT case. J = 0 for MT processes.

M: specifies the type of prompt meson produced in higher twist processes, code as for MESON in common PYPROC. M = 0 for MT processes.

SHAT, THAT, UHAT: Mandelstam variables ($\hat{s}$, $\hat{t}$, $\hat{u}$) for the subprocess.

Remark: Quark masses are neglected in case of the Compton and higher twist processes, but explicitly included for the fusion process, see IPY(21).

SUBROUTINE PYFRAM(IFRAME)

Purpose: to transform the event between different frames, if so desired.

Argument:

IFRAME: specification of the frame to which the event is to be boosted.

= 1: frame specified by user in the LUCINI call.

= 2: CM frame of the incoming particles.

= 3: CM frame of the incoming photon and the reacting parton.

SUBROUTINE PYIMES(M,QBAR2)

Purpose: to calculate the function $I_M(\overline{Q}^2)$ (eq. (14) in ref. [5]) accounting for the meson bound state in the calculation of the differential higher twist cross section.

Arguments:

M: specifies the type of the prompt meson, code as for MESON in common PYPROC.

QBAR2: relevant momentum transfer squared.

SUBROUTINE PYJETS

Purpose: to assign energy and momenta to the partons in the reaction.

SUBROUTINE PYKCUT(X,SHAT,THAT,QT,Q2,ICUT)

Purpose: to make kinematical cuts on the parton level before the event is generated.

Arguments:

X: momentum fraction of the reacting parton from the target particle.

SHAT: invariant mass square, $\hat{s}$, of photon and reacting parton.

THAT: Mandelstam momentum transfer, $\hat{t}$, at parton level.

QT: transverse momentum of scattered partons (or prompt particle) w.r.t. beam direction (primordial $p_\perp$ not included).

Q2: momentum transfer squared used in structure functions and α_s see IPY(11).

ICUT: decision flag,

= 0: passed cuts, generate complete event.

= 1: failed cuts, choose new kinematical variables.

Remarks: this routine is called before structure functions and QCD matrix elements are evaluated, so that cuts already at this stage will speed up the programme. Note, however, that in its present form it is a dummy routine which makes no cuts and should therefore be replaced by a user who wants to perform such cuts. The cross section estimates given will apply for the kinematic region allowed by the cuts, i.e. they are directly applicable for the generated events.

SUBROUTINE PYPRKT(PTX,PTY)

Purpose: to give primordial $p_\perp$ (with x, y-components PTX, PTY) to partons within the target hadron.

Procedure: If IPY(17) = 0 no primordial $p_\perp$ (PTX and PTY set to zero); if IPY(17) = 1 (defaut), primordial $p_\perp$ is chosen according to a Gaussian distribution having width PYPAR(5), cut off at a maximum $p_\perp$ of PYPAR(6).

SUBROUTINE PYPRNT

Purpose: to print the values of status flags and parameters in common PYPARA.

SUBROUTINE PYRAND

Purpose: to generate all quantities needed to specify the hard scattering on the parton level.

Procedure: The momentum fraction, X, for the parton in the target particle and the Mandelstam momentum transfer variable (THAT) are chosen according to the differential cross section formula. Also, the flavour of the reacting parton, IN, as well as the specific subprocess (ICONF) are chosen.

SUBROUTINE PYROBO(PINX,PINY,PINZ,EIN,POUTX,POUTY,POUTZ,EOUT)

Purpose: to transform momenta from the cms of the photon–parton system to the corresponding momenta in the cms of the incoming particles, and record the rotation and boosts used.

Arguments: PINX, PINY, PINZ, EIN momentum and energy in parton cms, POUTX, POUTY, POUTZ, EOUT momentum and energy in particle cms.

Procedure: The rotations and boosts which take momenta from parton cms to particle cms are stored as THE(2), PHI(2), BETA(2,1), BETA(2,2), BETA(2,3) in common PYLORE.

SUBROUTINE PYSIGM(NPAR,DERIV,DIFSIG,XF,IFLAG)

Purpose: to calculate the differential cross section for the routines that find its maximum value in the initialization.

Procedure: see section 2 (and ref. [13] for more details).

SUBROUTINE PYSPLI(KPART,KFLIN,KFLCH,KFLSP)

Purpose: to analyse the target hadron remnant, and if necessary split it into two fragments.

Method: In the simplest case, when a valence quark from a nucleon target interacted, the remnant is a diquark. When a gluon interacted, the colour octet remnant, consisting of the valence quarks, is split into a triplet and an antitriplet (e.g. a quark and a diquark for a target nucleon). When a sea quark interacted, the remnant antitriplet, consisting of a partner antiquark and the valence quarks, is split into an antitriplet and a hadron (e.g. a diquark and a meson for a target nucleon). When a sea antiquark interacted, the remnant triplet, consisting of a partner quark and the valence quarks, is split into a triplet and a hadron (e.g. a quark and a baryon for a target nucleon). For some sea (anti)quark interactions the left over partner from the quark–antiquark pair is thus assumed to go into the formed 'spectator' hadron or, if flavours match, annihilate a valence quark leaving a simpler remnant consisting of a parton without any additionally produced hadron. See ref. [13] for details.

SUBROUTINE PYSTFU(KF,X,Q2,XPQ)

Purpose: to return the values of the parton structure functions (This routine is from refs. [13,25].)

Arguments:

KF: particle flavour code (41 = proton, 42 = neutron, 17 = π^+ and negative numbers for their antiparticles).

X: momentum fraction carried by the parton.

Q2: momentum transfer Q^2 (defined by IPY(11)).

XPQ: array (−5:5) that on return contains the values of the parton structure functions. Index: 0 = g, 1 = u, 2 = d, 3 = s, 4 = c, 5 = b, −1 = $\bar{u}$, −2 = $\bar{d}$ etc.

Procedure: different parametrizations of p, n and π^+, π^- structure functions are included; the choice is determined by the value of IPY(12). Note that the output is $xq(x, Q^2)$, $xg(x, Q^2)$ for quarks, gluons. For Q^2 less than the minimum value, Q_0^2, the values of the structure functions are 'frozen' at Q_0^2.

SUBROUTINE PYTHAT(SHAT,SQTMIN,THATL,THATU,XM2)

Purpose: to calculate the lower (THATL) and upper (THATU) limits of the Mandelstam momentum transfer, $\hat{t}$, for given photon–parton invariant mass square (SHAT) and squared minimum transverse momentum $q_\perp^2$ (SQTMIN) of the scattered partons.

Remark: if only the fusion processes into heavy quark-antiquark pairs is switched on, and if the calculation is done with the massive matrix element, the limits are calculated for the lightest quark flavour that may be produced (i.e. IPY(22)).

SUBROUTINE PYTIME(TIME)

Purpose: to get the elapsed time by a call to some machine-dependent routine. The default is a call to the TIMEX routine in the CERN library.

Remark: this information is not essential, so that TIME need not be specified if a suitable routine is not available.

The following routines are adaptations of routines in the MINUIT program package [21]:
SUBROUTINE PYCMND corresponds to the MINUIT routine COMAND.
SUBROUTINE PYINTO(...) corresponds to the MINUIT routine INTOEX.
SUBROUTINE PYMIDA corresponds to the MINUIT routine MIDATA.
ENTRY PYMID2 corresponds to the MINUIT entry MIDAT2.
SUBROUTINE PYMINN corresponds to the MINUIT routine MINNEW.
SUBROUTINE PYMPRI(...) corresponds to the MINUIT routine MPRINT.
FUNCTION PYPINT(...) corresponds to the MINUIT routine PINTF.
SUBROUTINE PYRAZZ(...) corresponds to the MINUIT routine RAZZIA.
SUBROUTINE PYSIMP corresponds to the MINUIT routine SIMPLEX.

3.2. Common blocks

The common blocks, with their switches and variables, are essential for the communication with the programme. The most important ones for the user are: PYSUBS with switches to regulate which processes to simulate; PYPARA with the basic flags and parameters; PYPROC to give information on the generated event at the parton level; PYCROS containing the Monte Carlo estimates of the cross sections for all simulated processes. All variables are given sensible default values in block data PYDATA; indicated by

(D = ...) below. These values may be changed by the user to modify the behaviour of the programme, but it should be noted that some parameters are interrelated and should be changed in a consistent way.

The generated event is stored in common block LUJETS, described in ref. [22], which the user must be acquainted with.

COMMON /PYCROS/ CROSS(0:4),XHTMES(0:20)

Purpose contains cross section estimates.
Parameters:
CROSS(I): cross section in mb for all subprocesses, I = 0, and each individual subprocess, I = ICONF (ICONF as in common PYPROC).
XHTMES(M): cross section in mb for higher twist production of all mesons, M = 0, and meson M (M as MESON in common PYPROC).
Remarks: The entries of CROSS and XHTMES are set to zero by a call to LUCINI and then updated with each call to LUCIFR; no summation or averaging need to be made by the user. When PYKCUT is used for applying cuts, these will automatically be taken into account in these cross sections. For further details see ref. [13].

COMMON /PYCROZ/ NREP,NGEN(0:4),NPASS(0:4), NGENM(0:20),NPASSM(0:20)
COMMON /PYCROX/ PRECRS(0:4),PRECRM(0:20)

Purpose: used internally for cross section calculations. Should not be touched by the user.

COMMON /PYDATH/ CHR(20),KHR(60)

Purpose: used internally for the LUCVDM routine.

COMMON /PYINT1/ S,YMIN,SQTMIN,XQ(−5:5),QTX,QTY,DIR

Purpose: for internal use only, see ref. [13].

COMMON /PYINT2/ ISP(2),ICH(2),IRE(2),KFLIN(2),KFLCH(2),NPART,NPRIM,
& CHI(2),PTIN(2,2),PTSP(2,2)

Purpose: mainly for internal use, see ref. [13].
Parameters:
IRE(1), IRE(2): give the line numbers in the event record of the two high-$p_\perp$ partons; a prompt particle (photon or higher twist meson) is always given by IRE(1). Only valid if IPY(3) = 2 and no LUEDIT call has been made.

COMMON /PYINT3/ VIOL,VMAX,CONV,KI(2,2),PI(2,5)

Purpose: for internal use only, see ref. [13].

COMMON /PYLORE/ THE(2),PHI(2),BETA(2,3)

Purpose: for internal use, contains rotations and boosts between parton and particle cms frames, for details see ref. [13].

COMMON /PYMINC/ NAMKIN(4),NAM(30)

Purpose: contains character names for minimization, see ref. [13].

COMMON /PYMINU/ XKIN(4),UKIN(4),WKIN(4),AIN(4),BIN(4)
& MAXFIN,RELUP,RELERR,RELER2,FCNMAX

Purpose: starting values, boundaries and error sizes for minimization routines, see ref. [13].

COMMON /PYPARA/ IPY(30),PYPAR(20),PYVAR(10)

Purpose: contains flags and parameters which regulates the performance of the programme. Setting other than default values should be made before calling LUCINI.

Parameters:

IPY(1): (D = 2) determines the reaction to a violation of the maximum of the differential cross section calculated in the LUCINI call by the actual value calculated in PYRAND for a given set of kinematical variables.
- = 0: the generation will stop and a message printed.
- = 1: the generation will continue, but a warning will be printed.
- = 2: the generation will continue, a warning will be printed and the maximum will be increased to the higher value.

Note: in case the maximum is violated and execution continues, there might be a small error on the cross section (its size depending on the size of the violation and the ratio of events generated before and after the violation).

IPY(2): (D = 4) heaviest flavour that can be produced in the fusion process $\gamma + g \rightarrow Q + \overline{Q}$.

IPY(3): (D = 2) regulates whether the incoming particles and/or incoming reacting partons are to be included in the event record (i.e. stored in common LUJETS).
- = 0: incoming particles and partons excluded.
- = 1: beam and target particle stored in line 1 and 2, resp.
- = 2: incoming particles stored in lines 1 and 2, photon and reacting partons stored in lines 3 and 4.

IPY(4): (D = 1) determines in what coordinate frame the event will be presented.
- = 1: frame specified by the user in the last call to LUCINI.
- = 2: cms of incoming particles, photon along positive z-axis.
- = 3: cms of photon-parton, photon along positive z-axis.

IPY(5): (D = 0) a flag for LUCINI to indicate whether the maximum of the differential cross section has to be calculated or whether it is supplied by the user.
- = 0: maximum not known, should be calculated.
- = 1: maximum need not be calculated if given in PYVAR(1).

IPY(6): (D = 1) cuts on parton level system for hadronization.
- = 0: no cuts, can be used for independent fragmentation or parton level studies.
- = 1: cuts for string fragmentation.

IPY(7): (D = 1) regulates whether fragmentation is to be performed or not (saves time when only parton level is to be studied).
- = 0: skip fragmentation. Note that by a call to LUEXEC the user can let the system fragment later on.
- = 1: perform fragmentation.

IPY(8): (D = 1) choice of fragmentation scheme.
- = 1: string fragmentation.
- = 2: independent fragmentation.

IPY(9): (D = 1) regulates whether α_s depends on Q^2 or not.
- = 0: α_s fixed, value given by PYPAR(2)
- = 1: α_s running.

IPY(10): (D = 4) maximum number of 'active' flavours in the expression for running α_s. Note: the actual number depends on Q^2.

IPY(11): (D = 1) choice of Q^2-scale for the hard interaction (used in α_s, and structure functions).

= 1: $Q^2 = 2\hat{s}\hat{t}\hat{u}/(\hat{s}^2 + \hat{t}^2 + \hat{u}^2)$

= 2: $Q^2 = -\hat{t}$

= 3: $Q^2 = aq_\perp^2$, where a is the constant PYPAR(12) and $q_\perp$ the transverse momentum of the scattered parton (or prompt particle).

= 4: $Q^2 = b(1 - x_\perp)q_\perp^2$, where b is the constant PYPAR(13) and $x_\perp = 2q_\perp/\sqrt{\hat{s}}$.
Note: the last two options correspond to the optimized scale choices in ref. [20].

= 5: $Q^2 = m_\perp^2$, can be used in fusion with m the constituent mass of the lightest quark flavour produced.

IPY(12): (D = 1) choice of proton and pion structure functions.

= 0: simple scaling functions

= 1: EHLO set 1 for nucleon [16], Owens set 1 for pion [19].

= 2: EHLQ set 2 for nucleon [16], Owens set 2 for pion [19].

= 3: Duke-Owens set 1 for nucleon [17], Owens set 1 for pion [19].

= 4: Duke-Owens set 2 for nucleon [17], Owens set 2 for pion [19].

= 5: Glück-Hoffman-Reya for nucleon [18], Owens set 2 for pion [19].

IPY(13): (D = 3) maximum number of quark flavours in structure function parametrization; should be 2 in case of IPY(12) = 0, at most 4 otherwise due to dimension statements.

IPY(14): (D = 3) maximum number of quark flavours used for production of higher twist mesons.

IPY(15): presently unused.

IPY(16): internal, splitting of hadron remnant see ref. [13].

IPY(17): (D = 1) regulates the choice of the primordial $p_\perp$ distribution used in PYPRKT.

= 0: no primordial $p_\perp$.

= 1: Gaussian distribution having width given by PYPAR(5), cut off at a maximum $p_\perp$ = PYPAR(6).

IPY(18) –IPY(20): presently unused.

IPY(21): (D = 1) regulates whether the quark masses are explicitly included or not in the matrix elements for the fusion process $\gamma + g \to q + \bar{q}$.

= 0: masses neglected but threshold factor $\sqrt{1 - 4m_q^2/\hat{s}}(1 + 2m_q^2/\hat{s})$ applied.

= 1: masses included, see eq. (8).

IPY(22): (D = 1) lightest quark flavour to be produced in the fusion process; 1 = u, 2 = d, 3 = s, 4 = c etc.

IPY(23): (D = 2) choice of matrix elements for highest twist prompt meson production.

= 1: HT matrix elements of Bagger and Gunion [5].

= 2: HT matrix elements of Benayoun et al. [6].

IPY(24): (D = 1) determines the way $I_M(Q^2)$ is calculated in the Bagger and Gunion scheme for higher twist cross section for production of the higher twist meson M.

= 0: $Q^2 F_M(Q^2)$ treated as a constant, its value given by PYPAR(17).

= 1: $I_M = ac_1 f_M$ with c_1 given by PYPAR(18) through eq. (6.1) in ref. [6], f_M is the meson decay constant FMESON(M) and $a = 2\sqrt{3}$ or $2\sqrt{6}$ for pseudoscalar and vector mesons respectively.

= 2: I_M calculated with F_M given by a dipole fit (ρ-propagator), see comment lines in PYIMES for details.

IPY(25)

–IPY(28): presently unused
IPY(29): internal flag to signal failure.
IPY(30): gives the current coordinate frame of the event, code as for IPY(4).
PYPAR(1): (D = 0.0073) α_{em}, i.e. the fine structure constant.
PYPAR(2): (D = 0.2) α_s when constant (i.e. for IPY(9) = 0).
PYPAR(3): (D = 0.3) Λ_{QCD} (GeV) used in running α_s.
PYPAR(4): presently unused.
PYPAR(5): (D = 0.44) width (GeV/c) of Gaussian distribution for primordial $p_\perp$.
PYPAR(6): (D = 2.) maximum value (GeV/c) of primordial $p_\perp$ i.e. the value where the Gaussian is cut off.
PYPAR(7) –PYPAR(10): for splitting of hadron remnant, see ref. [13].
PYPAR(11): (D = 0.5) width (GeV/c) of Gaussian distribution for $p_\perp$ induced in low-$p_\perp$ interaction simulated with LUCVDM.
PYPAR(12), PYPAR(13): (D = 0.25,0.5) factors a, b used for IPY(11) = 3,4 to define Q^2 according to the optimized scale choices in ref. [20].
PYPAR(14) –PYPAR(16): (D = 3 * 1.) suppression factor for $u\bar{u}$, $d\bar{d}$, $s\bar{s}$ (resp.) quark pair production in higher twist processes (1 means no suppression).
PYPAR(17): (D = 0.25) value of $Q^2F_M(Q^2)$ used for IPY(24) = 0.
PYPAR(18): (D = 0.25) Exponent β used for IPY(24) = 1 when meson wave function is assumed to be proportional to $(x_1x_2)^\beta$.
PYPAR(19) –PYPAR(20): presently unused
PYVAR(1): (D = 0) maximum of differential cross section used for weighting. If this value is known from an earlier run, it can be supplied by the user. In that case the programme skips the (superfluous) calculation (provided that IPY(5) = 1).
PYVAR(2): value of α_s in the current event.
PYVAR(3): $-\ln(x_{min})$, where x_{min} is the minimum value of parton momentum fraction x.
PYVAR(4): presently unused.
PYVAR(5): last value of A_{QCD} in structure functions.
PYVAR(6) –PYVAR(10): presently unused.

COMMON /PYPHOT/ BH(6),ISPEED,OPTMC(9),MFL,MSS,HEL(0:1),
& JMESON(–3:3,20),DPRO(3,6),LUMES(20)

Purpose: mainly for internal use.
Parameters:
BH(J): proportional to the probability to create $q\bar{q}$-pair of flavour J in the fusion process.
ISPEED: (D = 0) switch between different sets of functions used for the importance sampling in the calculation of the cross section.
OPTMC: array of constants occurring in the functions for the importance sampling and used to optimize the speed of the Monte Carlo, see comment lines in subroutine PYRAND for details. May be changed without loss of normalization, i.e. cross section estimates. The parameters have been optimized for normal usage and should not need to be altered.
MFL: quark flavour produced in fusion iff single flavour fusion is the only occurring process, 0 otherwise (i.e. normally).

MSS: Internal variable. = 1 if only fusion into $q\bar{q}$ occurs, 0 otherwise.
HEL(I): proportional to cross section for helicity state I = 0,1 i.e. 0 and ± 1 (± 2).
JMESON(I,M): flavour of (anti)quark to go with flavour I to form a prompt HT meson M. (Codes as for IN and MESON in common PYPROC.) JMESON(I,M) = 0 signal that flavour I does not occur as valence quark in M.
DPRO(I,J): reduction factor for flavour diagonal states, i.e. the HT cross section is divided on the available states according DPRO. I = quark flavour, J = 1 to 6 for π^0, η, η', ρ^0, ω, ϕ respectively. Note that this is an approximate treatment which is only used together with the HT cross sections from ref. [5] where all meson states are not explicitly calculated as is the case in ref. [6], see IPY(23).
LUMES(M): translate HT meson code to Lund MC particle code.

COMMON /PYPROC/ IN,ICONF,JFL,MESON,MHELIC,X,SHAT,THAT,Q2

Purpose: to specify the event on the parton level.
Parameters:
IN: flavour (0 = g, 1 = u, 2 = d, 3 = s, 4 = c, 5 = b, $-1 = \bar{u}$, $-2 = \bar{d}$ etc.) of the reacting target parton.
ICONF: specifies generated process; 1 = fusion, 2 = QCD Compton, 3 = higher twist, 4 = QED Compton.
JFL: gives the flavour of the produced $q\bar{q}$ pair in the fusion process or higher twist process.
MESON: type of prompt meson produced in higher twist process: 0 = no HT meson produced, $1 = \pi^+$, $2 = \pi^-$, $3 = \pi^0$, $4 = \eta$, $5 = \eta'$, $6 = K^+$, $7 = K^-$, $8 = K^0$, $9 = 0_S$, $10 = 0_A$, $11 = \rho^+$, $12 = \rho^-$, $13 = \rho^0$, $14 = \omega$, $15 = \phi$, $16 = K^{*+}$, $17 = K^{*-}$, $18 = K^{*0}$, $19 = \bar{K}^{*0}$, $20 = 2_S$. 0_S,0_A,2_S are gluonium states, see section 5.1 in [14]. Note that $8 = K^0$ contains K^0 and $\bar{K}^0$ since they both decay into K^0_s and K^0_l and are therefore not experimentally distinguishable.
MHELIC: helicity of higher twist meson; $= -1$ for particles without spin (or if unassigned, see IHEL), = 0 or 1 for helicity 0 and ± 1 resp. For spin 2 glueball, 1 refers to ± 2.
X: momentum fraction of the reacting target parton.
SHAT: invariant mass square, $\hat{s}$, of reacting partons.
THAT: Mandelstam momentum transfer, $\hat{t}$, at parton level.
Q2: momentum transfer squared, Q^2, used in structure function and in α_s, see IPY(11).

COMMON /PYSUBS/ ISELEC,ISUBPR(4),MESHT(20),IHEL

Purpose: to allow the user to run the programme with any desired subset of high-$p_\perp$ processes.
Parameters:
ISELEC: (D = 5) switch to select between preprogramming and full user control. (For efficiency reasons the default value gives the dominating minimum twist processes only.)
$= -1$: subprocesses included according to ISUBPR set by the user.
= 0: all high-$p_\perp$ subprocesses are included.
= 1: only photon–gluon fusion included.
= 2: only QCD Compton included.
= 3: only higher twist processes included.
= 4: only QED Compton included.
= 5: only fusion and QCD Compton included.
= 10: only charm production via fusion with massive matrix element.
= 11: HT production of prompt $\pi^\pm$ only.
= 12: HT production of prompt $\rho^\pm$ only.

ISUBPR: (D = 4 * 0) array to be set when ISELEC = −1, for ISUBPR(ICONF) = 1 the corresponding process is included, for ISUBPR(ICONF) = 0 it is excluded.

MESHT(M): (D = 8 * 1,2 * 0,9 * 1,0) = 0,1 to switch off, on HT production of meson M, with code as for MESON in common PYPROC.

IHEL: (D = 1) regulates choice of helicity state for HT vector mesons.

= 0: helicity state left undefined.

= 1: choose helicity state, 0 or ±1, according to cross sections.

```
COMMON /PYTWIX/ C1Q2,C1G2,C1C0G2,FMESON(20),THETAS,FETA1,FETA8,
& THETAV,FOMEG1,FOMEG8,
& ETA1,ETA8,ETAP1,ETAP8,PHI1,PHI8,OMEGA1,OMEGA8,ALAM2,AMU2
```

Purpose: constants for higher twist cross sections. C1Q2, C1G2 are c_1^2 for mesons and glueballs respectively, C1C0G2 is $(c_1 - c_0)^2$ for glueballs, FMESON(M) is decay constant, f_M, for meson M = MESON (code as in common PYPROC). THETAS and THETAV are SU(3) mixing angles (degrees) for η–η' and ω–ϕ respectively. FETA1, FETA8, FOMEG1, FOMEG8 are decay constants for singlet and octet part of η and ω; f_{η_1}, f_{η_8}, f_{ω_1}, f_{ω_8}. The other variables are obtained from these in LUCINI.

4. Examples of how to use the programme

LUCIFER is a set of subroutines and functions which the user calls from his or her own main programme. It has to be loaded together with the fragmentation routines JETSET version 6.2 [22]. Alternatively, the updated version 6.3 [24] can be used without changes in LUCIFER *. Two external functions are required. RLU to provide a uniformly distributed random number in the interval]0, 1[; a dummy interface routine is provided in JETSET with some examples for a few different computers. The ordinary gamma function, GAMMA(X), is also called; this function is often available in FORTRAN77. An optimal routine is called by PYTIME to give the computer time used; by default the TIMEX routine in the CERN library is used but the user can simply replace it or put in a dummy statement since this information is not essential. On an IBM 3084, about 0.02 s is needed to generate one minimum twist event (with more than half the time spent in the fragmentation routines) and 0.03 s for a higher twist event.

Example 1: A simulation of the dominating fusion and QCD Compton processes in 150 GeV photon–proton collisions with a required minimum parton level $p_\perp$ of 2 GeV/c and a final print-out of the cross sections can be made as follows:

```
   CALL LUCINI('FIXT','P',150.,2.); initialize
   DO 10 I = 1,1000
   CALL LUCIFR                    ; generate one event
   IF(I.LE.5) CALL LULIST(11)     ; list first few events
   .                              ; analyse the generated event
10 CONTINUE
   .
   CALL LUCROS                    ; print cross sections + event statistics
   CALL PYPRNT                    ; print current parameter values
   .
   END
```

* Note however, that some fragmentation parameters in common LUDAT1 has been changed to be suitable for use in connection with parton cascade evolution in e^+e^- annihilation. For use with LUCIFER it is recommendable to use the old default values, i.e. PAR(12) = 0.4, PAR(23) = 1.1, PAR(25) = 1.1, PAR(31) = 1.0, PAR(33) = 1.0, PAR(35) = 0.5, PAR(32) = 0.7, PAR(34) = 0.7, PAR(36) = 0.7.

With ISELEC = 0 in common PYSUBS all processes will be generated. The produced particles with their momenta are stored in the K- and P-arrays in common LUJETS. A printout of the event record is obtained by CALL LULIST(11), giving the complete event including its history with respect to underlying partons, their primary hadronization products and the decay of unstable particles. This event record can be edited with LUEDIT in the JETSET routines.

Example 2: A study of charged particles from higher twist $\pi^\pm$ processes can be made as follows:

```
      COMMON/PYSUBS/ISELEC,ISUBPR(4),MESHT(20),IHEL
      COMMON /LUJETS/ N,K(2000,2),P(2000,5)
      .
      ISELEC = 11                    ; select HT pion production only
      CALL LUCINI('FIXT','P',150.,2.)
      DO 10 I = 1,1000
      CALL LUCIFR                    ; generate one event
      CALL LUEDIT(3)                 ; keep only charged, stable particles
      .                              ; analyse the event
10    CONTINUE
      .
      END
```

The complete programme code as well as a more non-trivial demonstration job can be obtained from the authors (T00ING@DHHDESY3 and WEIGEND@SLACVM).

Acknowledgements

We are grateful to M. Benayoun and Ph. Leruste for interesting discussions on higher twist processes.

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TEST RUN OUTPUT

Extract from test run included all possible processes in 150 GeV γ–proton scattering with a minimum parton level $p_\perp$ of 2.0 GeV/c.

```
              LUCIFER version 2.2  (Feb. 28, 1987)
              ====================================

Initialization of LUCIFER routines.
-----------------------------------

Incoming particles transformed from FIXT-frame to their CM frame:

Particle        Px          Py          Pz          E           M
    Phot       0.000       0.000       8.374       8.374       0.000
       P       0.000       0.000      -8.374       8.427       0.938

Invariant mass of incoming particles, SQRT(S) =      16.801
Required minimum pt of scattered partons, QTMIN =     2.000
Minimum value of variable Y1, YMIN =   0.5668E-01
Range of variable THAT: -0.2823E+03 < THAT <  -0.4000E+01

Choice of pre-programmed subsets of subprocesses, ISELEC =  0
Subprocesses, ISUBPR =    1   1   1   1
(1->fusion, 2->QCD Compton, 3->HT, 4->QED Compton)
Flavours included in the photon-gluon fusion process:  u d s c
Current quark mass in matrix element.
HT mesons included; MESHT =  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
HT cross-section formalism, IPY(23) =  2  IPY(24) =  1
Optimization parameters, ISPEED =     0
OPTMC  =   2.0  4.0  0.1  8.0  3.0  1.0  8.0  3.0  1.0

Terminating entry in PYSIGM after   198 calls.
Best estimate of minimum found to be  -0.1400E-04
located at X =   0.1356E+00    THAT =  -0.3375E+02
Maximum of the part of the differential cross section used for weighting,
PYVAR(1) =   0.1750E-04
```

EVENT LISTING

I	ORI	PART/JET	PX	PY	PZ	E	M
1	0	GAMM B	0.000	0.000	150.000	150.000	0.000
2	0	P + B	0.000	0.000	0.000	0.938	0.938
3	0	GAMM B	0.000	0.000	150.000	150.000	0.000
4	0	G JETB	0.187	0.292	0.555	0.655	0.000
5	0	CA JETF	0.210	1.721	34.933	35.013	1.600
6	0	U JETF	0.211	-0.488	0.979	1.160	0.325
7	0	C JETF	-0.029	-1.438	108.929	108.950	1.600
8	0	DU 0JETF	-0.398	0.196	0.148	0.801	0.650
9	5	F B- D	0.288	0.750	13.613	13.778	1.971
10	6	PI +	-0.253	-0.205	0.983	1.045	0.140
11	5	K* 0 D	0.386	0.688	21.317	21.350	0.898
12	8	N 0	0.181	0.254	1.046	1.441	0.940
.							0.767
.							2.007
17	9	RH00 D	-0.662	0.356	7.771	7.845	0.769
18	9	PI B-	0.949	0.394	5.842	5.933	0.140
19	11	K +	0.011	0.151	8.013	8.030	0.494
20	11	PI B-	0.375	0.537	13.303	13.320	0.140
.							0.140
.							0.135
45	43	GAMM	-0.003	0.007	0.042	0.042	0.000
	SUM:	1.000	-0.006	-0.010	144.988	145.923	16.490

IN, ICONF, JFL, MESON, MHELIC = 0 1 4 0 -1

LUCIFER: Summary of statistics and cross-sections

Total number of phase space points tried = 154329
Fraction of events failing fragmentation cuts = 0.0466

no	subprocess type	on/off	events #	%	cross-section in nb
0	all (ISELEC=)	0	23014	100.000	8.592E+02
1	fusion	1	14670	63.744	5.328E+02
2	QCD Compton	1	6678	29.017	2.624E+02
3	higher twist	1	1615	7.017	6.221E+01
4	QED Compton	1	51	0.222	1.846E+00

Cross-sections for higher twist meson production:

no	meson type	on/off	events #	%	cross-section in nb
0	all mesons	1	1615	100.000	6.221E+01
1	pi+	1	45	2.786	1.449E+00
2	pi-	1	36	2.229	1.345E+00
3	pi0	1	9	0.557	3.907E-01
4	eta	1	4	0.248	2.106E-01
5	eta'	1	5	0.310	1.939E-01
6	K+	1	53	3.282	1.980E+00
7	K-	1	11	0.681	4.889E-01
8	K0	1	7	0.433	1.498E-01
9	G0S	1	12	0.743	6.123E-01
10	G0A	1	31	1.920	1.379E+00
11	rho+	1	280	17.337	1.158E+01
12	rho-	1	331	20.495	1.227E+01
13	rho0	1	139	8.607	5.560E+00
14	omega	1	137	8.483	5.052E+00
15	phi	1	4	0.248	1.533E-01
16	K*+	1	312	19.319	1.196E+01
17	K*-	1	94	5.820	3.287E+00
18	K*0	1	37	2.291	1.234E+00
19	K*0bar	1	10	0.619	2.929E-01
20	G2S	1	58	3.591	2.616E+00