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TWISTER — A Monte Carlo for QCD High-$p_\perp$ Scattering

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Abstract

We present physics and programming aspects of a program to simulate complete events in high-$p_\perp$ hadron-hadron scattering. It is based on QCD for the underlying hard parton scattering process and the Lund string model for the following hadronization. All leading order $2 \rightarrow 2$ parton processes are included as well as leading order single and double prompt photon production processes and higher twist processes giving prompt mesons and glueballs at high $p_\perp$.

1 Introduction

The long standing interest for high-$p_\perp$ particle production in hadronic collisions is related to the desire to study the dynamics of the underlying parton processes. These are described by matrix elements calculated in perturbative QCD folded with structure functions giving the parton content of the colliding hadrons. Completed with phenomenological fragmentation functions to describe the confinement induced transition of the scattered partons into observable hadrons, this basic scheme has turned out very successful. Due to the complexity of the problem, e.g. involving nontrivial structure and fragmentation functions, analytic calculations are only possible in simple cases and then only through significant approximations. With the computer simulation approach the processes can be studied without numerical approximations and in all their detail both with regard to the hard parton scattering and the soft fragmentation aspects. In particular, complete final states of observable particles are simulated making also event shape and correlation studies possible.

In an earlier program [1] we only dealt with the most common scattering processes, parton-parton scattering to second order (α_s^2) in QCD, which are by now essentially understood. The present program contains improvements and extensions concerning processes with lower cross-sections, but which are now accessible for experimental study. These relates to heavy flavour production, prompt photon production and photon induced reactions. The main new class of physics processes treated is, however, the so-called higher twist mechanism where a prompt meson or glueball is produced from two partons scattered into the same direction. Thus, they form a hadron directly, without passing through the normal parton fragmentation process. Such processes have been discussed theoretically for several years [2] but never experimentally proven. Recent experimental results [3] do, however, give evidence for the existence of this type of processes, but a clear proof will involve further and more

detailed study. In particular, it is important to study the higher twist processes in comparison to the normal, and dominating, processes of parton scattering followed by hadronization. For this purpose it is advantagous to be able to simulate both types of processes within the same program.

As usual, large computer programs to solve complex problems has to be used intelligently and with care in order for the results to be reliable and the present program, TWISTER [1] version 1.0, is no exception. In the following sections we therefore give an extensive description, first of the physics aspects with short references to program and variable names (given by capital letters within parenthesis) and then a complete program manual. Those features which are common to the earlier program and already satisfactory discussed in [1] are not repeated; the user is instead recommended to study that paper also. Section 2 deals with features common to all processes and sections 3–6 with the particularities of the various included processes. Section 7 contains the description of routines and variables in common blocks. Finally, section 8 gives some explicit examples of how to use the program.

2 General features

All processes considered are of the same $2 \to 2$ scattering type and thus have the same well-known structure of the cross-section

$$d\sigma_{i,j,k} = f_i(x_1, Q^2) \cdot f_j(x_2, Q^2) \cdot \frac{d\hat{\sigma}_{ijk}}{d\hat{t}}\, dx_1 dx_2 d\hat{t} \tag{1}$$

The structure functions f_i, f_j, giving as usual the probability distributions of parton types i, j carrying momentum fractions x_1, x_2 of the colliding hadrons, can be chosen among a set of available parametrizations (see IPY(12) and PYSTFU) [5–8]. The different possible final states are enumerated by k. The divergence of the parton level scattering cross-sections appearing for zero momentum transfer, $\hat{t} \to 0$, is avoided by a basic cutoff (QTMIN) in $p_\perp$ of the scattered partons.

Since the scale, Q^2, for the hard scattering momentum transfer to be used in structure functions and α_s is not uniquely determined, some alternative definitions are available (IPY(11)). By default we use $Q^2 = \frac{2\cdot\hat{s}\cdot\hat{t}\cdot\hat{u}}{\hat{s}^2+\hat{t}^2+\hat{u}^2}$, but emphasize that the recently studied otimized scale choices [9] can also be used. Although these are derived for specific processes they may well minimize the relative size of higher order corrections (K-factors) for a more general class of processes.

To make the simulation more efficient a variable change into $y_1 = x_1 \cdot x_2$, $y_2 = x_1 - x_2$ is made and auxiliary functions $h_1(y_1)$, $h_2(y_1, y_2)$, $h_3(y_1, y_2, \hat{t})$ introduced (see comment lines in PYRAND for their detailed definition) giving the total cross-section a form

$$d\sigma = \{\frac{dy_1 dy_2 d\hat{t}}{y_1\sqrt{y_2^2 + 4y_1}} h_1 h_2 h_3\} \cdot \{\sum_{i,j,k} x_1 f_i(x_1, Q^2) \cdot x_2 f_j(x_2, Q^2) \cdot \frac{d\hat{\sigma}_{ijk}}{d\hat{t}} \cdot \frac{1}{h_1 h_2 h_3}\} \tag{2}$$

where the random variables $(y_1, y_2, \hat{t})$ can be chosen exactly according to the expression in the first bracket and the remaining factor used for a weighting procedure utilizing the maximum value estimated in the initialization procedure (TWINIT). The resulting events have therefore no weight associated with them (i.e. they have weight=1). The $h-$functions are thus chosen to obtain a remaining weighting factor with as small variations as possible leading to a more efficient procedure. They have been defined with the pole-structure of the matrix elements in mind and optimized for normal usage and should normaly not need to be altered, although this is easily done with the OPTY1 and OPTTH parameters (if the efficiency is found to be lower for some particular process in a special kinematic region).

[1] twister *n* difficult task, problem etc.; untrustworthy person, swindler [4].

The random variables are chosen according to this scheme in subroutine PYRAND and a particular subprocess chosen according to their relative contribution to eq. (2). The scattered partons as well as the beam and target partons are connected by strings (PYCONF) as discussed in [1] and the Lund string model [10] in its Monte Carlo implementation [11] is used to simulate the hadronization process. We note that for very high-$p_\perp$ jets produced at collider energies, the effects from multiple gluon emission from the partons participating in the hard interaction becomes important to properly describe the jet fragmentation properties [12]. Such effects are not explicitly taken into account here, but for smaller momentum transfers they are effectively absorbed in the parametrizations of the non-perturbative fragmentation functions.

The Monte Carlo sampling of the cross-section formulae is also used to provide estimates of the cross-sections for the processes being simulated. The results, which are stored in common PYCROS, can be printed at the end of a job using TWSTAT. Since these cross-sections are updated with each generated event their accuracy depends on the generated statistics as $\frac{a}{\sqrt{N}}$ with a of order unity.

3 Standard QCD α_s^2 processes

All QCD parton scattering processes to leading order (α_s^2) are included, i.e. the following $2 \to 2$ processes involving quarks (q) and gluons (g):

1. $q + q \to q + q, \;\; \bar{q} + \bar{q} \to \bar{q} + \bar{q}$
2. $q + \bar{q} \to q + \bar{q}$
3. $q + \bar{q} \to g + g$
4. $q + g \to q + g, \;\; \bar{q} + g \to \bar{q} + g$
5. $g + g \to q + \bar{q}$
6. $g + g \to g + g$

This part of the program is essentially unchanged and we therefore refer the reader to [1] for details. Here we only discuss the new features regarding heavy flavour production and checks of string systems.

Heavy flavour production via $q + \bar{q} \to Q + \bar{Q}$ and $g + g \to Q + \bar{Q}$ can be simulated separately (using ISELEC=−1, ISUBPR(2)=1, ISUBPR(5)=1) and with the option of selectively producing only some specific flavours (IPY(2), IPY(22)). With the matrix elements of [13] including explicit quark masses (IPY(21)) there is no singularity for $p_\perp = 0$ of the produced heavy quark. Therefore, if only fusion into heavy quark pairs (charm and heavier) is simulated one may let QTMIN→0 and also obtain an estimate of the total heavy quark production cross-section. Nevertheless, this leading order calculation may not be quite reliable for too small values of QTMIN due to significant higher order corrections.

All cross-sections (coded in PYDSIG) are rewritten so as to give the probablilities for different possible string configurations as discussed in [1]. Via a call to LUPREP in [11] the parton system is checked for having enough energy in each colour singlet system in order for the fragmentation routines to be applicable. This is normally no problem, but for heavy quark production close to threshold such a subsystem may not pass this requirement. Such a case is treated [11] by forming a heavy meson, or baryon, from that system. In order for this particle to have the correct mass and conserve energy-momentum, a slight reshuffling of energy-momentum to another colour singlet jet system in the event is necessary. An interesting implication of this string model approach is the existence of a forward (backward) component in the spectrum of those heavy mesons and baryons which contain a spectator quark, antiquark or diquark from the beam (target) remnant [14]. Thus, such a hadron can have a larger energy than its constituent heavy quark. This effect is not expected in a framework of independently fragmenting parton jets.

4 Single and double prompt photon emission

The interest of prompt photon emission is related to its well-known coupling to quarks and the fact that it is not affected by the fragmentation processes. Thus it can give undistorted information on the underlying parton subprocess where it is emitted and is therefore a particularly clean probe of the dynamics. The following prompt photon processes are included:

1. $q + \bar{q} \to \gamma + g$
2. $q + g \to \gamma + q, \;\; \bar{q} + g \to \gamma + \bar{q}$
3. $q + \bar{q} \to \gamma + \gamma$
4. $g + g \to \gamma + \gamma$

The two single photon processes are the leading order, $\alpha_s \cdot \alpha_{em}$, processes of annihilation and QCD Compton. The leading order, α_{em}^2, double photon emission is through $q\bar{q}$ annihilation. Although being of higher order, $\alpha_{em}^2 \cdot \alpha_s^2$, the process of gluon-gluon fusion via a quark loop usually gives a comparable cross-section at not too high $x_\perp$ ($= \frac{2p_\perp}{\sqrt{s}}$) due to the magnitude of the gluon structure function at small x. The matrix elements for prompt single and double photon emission are from [15].

The string systems are here simple without ambiguities. For single photon emission the recoiling parton is connected to the remaining spectator partons. For double photon emission the spectator partons are directly connected giving an underlying low-$p_\perp$ event without transversely moving partons.

5 Higher twist processes

The theory of higher twist processes, like the ones depicted in Fig. 1, where two partons are scattered into the same direction and form a prompt hadron without normal fragmentation has been dicussed for several years [2]. Until recently, however, no experimental evidence for their existence has been available. Thus it constitutes a challenge to prove or disprove the correctness of these QCD predictions. A few recent experimental results [3] have given the first evidence of their occurence, but more detailed studies are needed before conclusive statements can be made. To this end a complete simulation of these processes will be of importance.

Included in this program are all pure QCD processes to leading order, α_s^3:

1. $q + \bar{q} \to g + M$
2. $q + g \to q' + M$
3. $g + g \to g + M$

Here M is any of the normal low-lying meson (S-wave) states built of light quarks (u, d, s), i.e. the normal vector and pseudo-scalar mesons. Alternatively, M can also be a glueball or gluonium state composed of two gluons. The prompt meson/glueball is thus balanced by a hadron jet from the high-$p_\perp$ parton opposite in azimuth. The other class of included higher twist processes has a photon opposite the prompt meson/glueball. This is the QCD–QED mixed process of order $\alpha_s^2 \cdot \alpha_{em}$:

1. $q + \bar{q} \to \gamma + M$

The cross-section for the process $g + g \to \gamma + M$ is zero to this leading order and is therefore not included.

The cross-sections for all higher twist processes into the various meson/glueball states are taken from [16] and coded in the routines TWSIG1 and TWSIG2 for pure QCD and QCD–QED mixed processes respectively. Here we only give a few examples to illustrate the implementation and show how different factors are coded. Thus, for the following processes

1. $q + \bar{q}' \to \rho + g$
2. $q + \bar{q}' \to \eta + g$

the cross-sections are

$$\frac{d\sigma^\rho}{d\hat{t}}(\hat{s},\hat{t},\hat{u}) = \frac{2\pi^2\alpha_s^3}{3\hat{s}} \cdot c_1^2 \cdot f_\rho^2 \cdot \{F_1(\hat{s},\hat{t},\hat{u}) + F_3(\hat{s},\hat{t},\hat{u})\} \cdot U_\rho(q,\bar{q}') \tag{3}$$

$$\frac{d\sigma^\eta}{d\hat{t}}(\hat{s},\hat{t},\hat{u}) = \frac{\pi^2\alpha_s^3}{3\hat{s}} \cdot c_1^2 \cdot \{\lambda_1^2 \cdot F_1(\hat{s},\hat{t},\hat{u}) - \lambda_1\lambda_2 \cdot F_{12}(\hat{s},\hat{t},\hat{u}) + \lambda_2^2 \cdot F_2(\hat{s},\hat{t},\hat{u})\}\delta_{q,\bar{q}'} \tag{4}$$

respectively. The running strong coupling constant, α_s, is calculated in PYALPH using the first order formula and stored in PYVAR(2). The wave function information for the prompt meson is contained in the constant c_1^2, see [16], which is coded as C1Q2 for 'quark' mesons and C1G2 for 'gluon' mesons. The meson decay constans, f_M, are stored in FMESON(M). The λ_i's refer to the mixing expressions eq. (4.16) in [16] and have their correspondence in the ALAM1 and ALAM2 variables. Other such mixing variables, μ, λ' and μ', have similar name conventions. All parameters of this kind are stored in common PYTWIX, described in section 7.2 below. The squared invariant amplitudes F_i, see eq. (3.5) and (3.8) in [16], are coded as statement functions in TWSIG1 and TWSIG2. For vector mesons, F_1 and F_3 correspond to helicity 0 and ± 1 respectively. The U_M- and δ-functions are for requiring the proper quark flavours for a given meson and are related to the JMESON array in common PYTWIN.

The main theoretical uncertainty in these cross-sections is related to the conversion of the $q\bar{q}$ (gg) state into the proper meson (glueball) state, which is obtained from information on the overlap of the wave functions at the origin. The constant c_1, which is related (via eq. (6.1) in [16]), to the exponent, β, of a meson wave function of the form $(x_1 \cdot x_2)^\beta$, is the major unknown. For pions, the electromagnetic formfactor as well as the preliminary results of WA77 seems to favour a value $\beta \approx \frac{1}{4}$ giving $c_1 \approx 1$ (see [16] and references therein). We take this value for all mesons. The meson decay constants have only been measured for a few mesons; for the others it is taken as educated guesses based on the measured ones. For glueballs, which are not even discovered, these constants are basically unknown. We note, however, that through the non-observation of high-$p_\perp$ glueball candidates [17] upper limits can be deduced [16] for the product $c_1 \cdot f$. Since β is not expected to be the same as for mesons, we follow [16] and choose $\beta = 1$ and $f = 0.2$ GeV for the gluonium states. As seen from eqs. (3) and (4) a change of these uncertain parameters only give a change in the overall normalisation but leave the shape of differential distributions unaltered. Thus we estimate that, at present, the theoretical uncertainty on the normalisation of the higher twist cross-sections is about a factor 2 for mesons with known decay-constants, larger for other mesons and essentially unknown for the exotic glueball states.

The matrix elements for prompt vector meson and spin 2 glueball production provide the relative probabilities for the different helicity states and is used to assign a polarization state as flagged by MHELIC in common PYPROC. Note, however, that the decay routine used [11] does not make use of this information and thus decay all particles as being unpolarized. A user can thus supply his own decay routine to get the correct angular distributions if needed.

The cross-section of high-$p_\perp$ meson production via normal parton scattering and fragmentation is considerably larger than the prompt production via the higher twist mechanism [16]. However, the ratio between the higher twist and the minimum twist cross-sections typically increases with increasing $p_\perp$, in particular close to the kinematic limit. The characteristic feature of the promptly produced meson to be isolated and not accompanied by other fragmentation products can also be exploited, although a trigger condition imposes a similar structure even in the fragmentation case. We also point out that some mesons are particularly favoured in the higher twist process; in particular η' but also ρ^0, ω and ρ^+/ρ^-, $K^*/\overline{K^*}$, the latter states depending on the beam and target particle. The ϕ meson, on the other hand, has a very small higher twist cross-section. Glueballs, if they exist, are expected to have large higher twist production cross-sections.

Since the prompt meson 'decouples' from the remaining parton system the processes giving a prompt meson and an opposite parton lead to a string configuration analogous to that occuring in the prompt single photon emission in the previous section. Similarly the case of prompt meson plus a photon results in a string configuration analogous to that in double photon emission.

5.1 Gluonium states

The glueball or gluonium states considered here are only the two-gluon states without orbital excitations, i.e. S-wave, with the J^{PC} assignements 0^{++}, 0^{-+} and 2^{++}. In fact, we define [16] three states as follows: 0_S including the $0^{++}$and the helicity zero component of the 2^{++}, 0_A being the pure 0^{-+} and 2_S as the helicity ± 2 components of the 2^{++} state (there are no ± 1 helitity states for massless gluons). In order to give definite predictions of experimental relevance the gluonium states must be defined with respect to masses, widths and decay modes. We therefore choose to identify them with the $S^*(975)$, $\iota(1440)$ and $\theta(1690)$ respectively. The detailed numbers, taken from [18], are implemented in the subroutine TWDGLU (called by TWINIT) which thus define all necessary quantities for these gluonium states. We note that the phase space decay used for the 2_S state is only an approximate treatment. Since the excistence of glueball states have not been experimentally proven their production is by default excluded, but can easily be swithed on by the MESHT array in common PYSUBS.

6 Photon-induced processes

The hadronlike, $q\bar{q}$ or mesonic, structure of the photon can be expressed in terms of the photon structure function [19]

$$F_2^\gamma(x) = F_2^{VDM}(x) + F_2^{PL} = \int_0^{p^2_{\perp cut}} dp_\perp^2 \, \frac{dF_2^{VDM}}{dp_\perp^2} + \int_{p^2_{\perp cut}}^{p^2_{\perp max}} dp_\perp^2 \, \frac{dF_2^{PL}}{dp_\perp^2} \tag{5}$$

with contributions from two regions of the momentum transfer in the $\gamma \to q\bar{q}$ transition; here measured by the generated transverse momentum. For small such $p_\perp$, where bound state effects are important, the vector meson dominance model (VDM) is used to describe the meson-like (ρ^0 dominantly) appearance of the photon, whereas the 'anomalous' pointlike (PL) structure function, calculable in QCD, is applicable for larger values.

Through this hadron-like appearence the photon may also give rise to the same hard interactions as any hadron and in order to facilitate the study of such phenomena we have also defined the photon as a valid incoming particle. All interactions described above can then be simulated for the case of a

photon beam on a nucleon. The photon structure function is then, by default, taken from the VDM approach as [20,21]

$$F_2^{VDM}(x) = 0.2 \cdot \alpha \cdot (1-x) \tag{6}$$

and split into its light quark (u, d, s) components via $F_2(x) = \sum_{q,\bar{q}} e_q^2 \cdot x f_{q/\gamma}(x)$. A simple use of the normal pion structure function, defined by IPY(12), rearranged with respect to quark flavours and properly renormalised can also be used (IPY(15)). The transverse momentum of the partons within the vector meson is taken as the usual Gaussian distribution used for describing the Fermi-motion within a hadron. (Note that one may wish to lower PYPAR(6) in accordance with $p_{\perp cut} = O(1)$ GeV.)

Optionally, see IPY(15), the point-like structure function can be used in an approximate procedure where the longitudinal and transverse properties are separated. The light quark components are obtained as above from the 'standard' form, based on the leading logarithm approximation plus extra non-leading corrections [19–21]

$$F_2^{PL}(x, Q^2) = 3\frac{\alpha}{\pi} \sum e_q^4 \{x[x^2 + (1-x)^2] \cdot ln(\frac{Q^2}{m^2}\frac{1-x}{x}) + 8x^2(1-x) - x\} \tag{7}$$

were m^2 is a phenomenological cut-off parameter (PYPAR(14)). The possible numerical problems with this parametrization for $x \to 1$ are simply avoided by forcing $F_2 \geq 0$. (F_2 can be monitored by PYVAR(4).) Alternatively, the parametrizations of [22] can be used. The initial quark and antiquark from the photon are here given primordial transverse momenta according to the distribution $dp_\perp^2/p_\perp^2$ in a limited range (PYPAR(15),PYPAR(16)). It is then assumed that the subsequent hard scattering can be approximated by the normal $2 \to 2$ matrix elements in QCD without explicit initial transverse momentum and mass effects.

A few words of caution is needed for this part of the program. Although it may seem reasonable that the photon can experience hard scattering via its vector meson component it is not fully clear that the normal VDM approach is applicable for high-$p_\perp$ processes. The point-like interaction option, on the other hand, should be considered together with other point-like photon processes; like photon-gluon fusion, QED and QCD Compton scattering as well as higher twist, for which a dedicated program is available [23]. For large $p_\perp$ in particular, the above approximation is not adequate and the point-like contribution should then be treated using an exact higher order calculation. Nevertheless, we feel that assumptions like these are indeed relevant to initiate a detailed study of photon induced processes, but warn the user of possible theoretical uncertainties and conceptual problems like, e.g., double counting between different processes.

7 Description of program components

The present program, TWISTER version 1.0, is written completely in FORTRAN77. It is a further development based on the Lund Monte Carlo for high-$p_\perp$ physics, PYTHIA version 3.4 [1]. No previous knowledge of that program is necessary although it is valuable. To facilitate the comparison with that program, most routine names have been retained although many of them have been modified internally. Also names of variables and common blocks have to a large extent been kept. Several new rutines and common blocks are, of course, added to treat the new physics introduced in the program. As a naming convention we let all routine and common block names start with PY or TW so that name clashes with user routines are easily avoided. Below we use MT and HT to designate minimum and higher twist processes respectively.

For treating the hadronization of the partonic string systems defined in this program the Lund Monte Carlo for jet fragmentation, JETSET version 6.2 [11], is needed.

7.1 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 **TWINIT**(FRAME,BEAM,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 beam momentum in $+z$ direction.
='CMS' : colliding beams in CM frame, with beam momentum in $+z$ direction
='USER': full freedom to specify frame by giving 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.
BEAM, TARGET : character variables to specify beam and target particle; 'P' = proton, 'PBAR' = antiproton, 'N' = neutron, 'NBAR' = antineutron, 'PI+' = positive pion, 'PI-' = negative pion, 'PHOT' = photon (see section 6 and IPY(15)).
WIN : defines the energy of the system, exact meaning depends on FRAME;
for FRAME='FIXT', WIN = momentum of beam particle,
for FRAME='CMS' , WIN = total energy of system ($\sqrt{s}$),
for FRAME='USER', WIN is a dummy variable.
QTMIN : minimum transverse momentum in the hard parton-parton scattering. It should not be lower than 1–2 GeV (depending on the energy scale) to avoid the divergences of the QCD matrix elements. If only heavy flavour production via fusion is simulated, the matrix element is finite for QTMIN$\rightarrow$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. Because of the Fermi motion of the colliding partons, the actual distribution in transverse momentum of jets will not cut off sharply at QTMIN.

SUBROUTINE **TWISTR**

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

SUBROUTINE **TWSTAT**

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

FUNCTION **PYALPH**(Q2)

Purpose: to calculate the running coupling constant in QCD.

SUBROUTINE **PYCHID**(KPART,KFL,CHI)

Purpose: to give energy fractions to the fragments when a hadron remnant is split, see [1].

SUBROUTINE **PYCONF**

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

BLOCK DATA **PYDATA**

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

FUNCTION **PYDSIG**(I,J,KTYPE,SHAT,THAT,UHAT)
FUNCTION **TWSIG1**(I,J,M,SHAT,THAT,UHAT)
FUNCTION **TWSIG2**(I,J,M,SHAT,THAT,UHAT)

Purpose: to calculate the parton level cross section, $\frac{1}{\pi} \cdot \frac{d\sigma}{d\hat{t}}$. PYDSIG is for minimum twist processes. TWSIG1 and TWSIG2 is for higher twist processes giving meson + parton and meson + photon respectively.

Arguments:

I, J : flavours of incoming, reacting partons of the beam and target particle respectively. (0=g, 1=u, 2=d, 3=s, 4=c, 5=b and negative numbers for the corresponding anti-quarks). Note that |I|,|J| cannot exceed 3 in the HT case.

KTYPE : specification of final state, process and colour flow (for minimum twist processes only).

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

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

Remark: See [1] for details of treatment of interference terms in minimum twist.

SUBROUTINE **PYFRAM**(IFRAME)

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

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

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

= 2 : CM frame of the incoming particles.

= 3 : CM frame of the incoming reacting partons.

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.

X(I) : momentum fractions of the reacting partons from beam (I=1) and target (I=2).

SHAT : invariant mass square, $\hat{s}$, of reacting partons.

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 program. 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 some cuts.

SUBROUTINE **PYPRKT**(KF,SHAT,PTX,PTY)

Purpose: to give primordial $p_\perp$ (with x,y-components PTX, PTY) to partons within a hadron of flavour KF.

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

For the case of an incoming photon, $p_\perp$ is chosen according the same Gaussian if IPY(15)$\leq$0. Otherwise it is chosen according to the distribution $dp_\perp^2/p_\perp^2$ as discussed in section 6, see also PYPAR(15), PYPAR(16).

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 fractions, X(1) and X(2), for the partons in the beam and target particles and the Mandelstam momentum transfer variable (THAT) are chosen according to the differential cross section formula. Also, the flavour of the reacting partons, IN(1) and IN(2), as well as the specific subprocess (ICONF) are chosen. See section 2 (and [1] for more details).

Remark: A call to PYKCUT is made, whereby the user can apply cuts on kinematical variables on the parton level already, before the event is actually generated.

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

Purpose: to transform momenta from the cms of the incoming partons 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 [1] for more details).

SUBROUTINE **PYSPLI**(KPART,KFLIN,KFLCH,KFLSP)

Purpose: to analyse the hadron remnants, and if necessary split them into two fragments as discussed in [1].

SUBROUTINE **PYSTFU**(KF,X,Q2,XPQ)

Purpose: to return the values of the parton structure functions.

Arguments:

KF : particle flavour code.

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=gluon,1=u,2=d,3=s,4=c,5=b, -1=$\bar{u}$,-2=$\bar{d}$ etc.

Procedure: different parametrizations of p, π^+ and γ structure functions are included. For proton and pion, the choice is determined by the value of IPY(12); for photon by IPY(15). Note that the output is $x \cdot q(x, Q^2), x \cdot g(x, Q^2)$ 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)

Purpose: to calculate the lower (THATL) and upper (THATU) limits of the Mandelstam momentum transfer, $\hat{t}$, for given parton-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 are 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.

SUBROUTINE **PYWHAT**

Purpose: to assign ICONF the chosen subprocess (for minimum twist only).

SUBROUTINE **TWDGLU**

Purpose: to define glueball states in Lund code as well as their decays, see section 5.1 above.

SUBROUTINE **TWJMES**

Purpose: to assign the array JMESON proper values, see common PYTWIN.

SUBROUTINE **PYCMND** is the MINUIT routine COMAND.
SUBROUTINE **PYINTO**(...) is the MINUIT routine INTOEX.
SUBROUTINE **PYMIDA** is the MINUIT routine MIDATA.
ENTRY **PYMID2** is the MINUIT entry MIDAT2.
SUBROUTINE **PYMINN** is the MINUIT routine MINNEW.
SUBROUTINE **PYMPRI**(...) is the MINUIT routine MPRINT.
FUNCTION **PYPINT**(...) is the MINUIT routine PINTF.
SUBROUTINE **PYRAZZ**(...) is the MINUIT routine RAZZIA.
SUBROUTINE **PYSIMP** is the MINUIT routine SIMPLEX.

7.2 Common blocks

Most of the communication between the user and the program is via the variables and switches in the common blocks. 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; this is indicated by (D=...) below. These values may be changed by the user to modify the behaviour of the program. Note, however, that some of the parameters are interrelated.

The generated event is stored in common block LUJETS, described in [11], which the user must be aquainted with.

COMMON /**PYCROS**/ CROSS(0:13),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 TWINIT and then updated with each call to TWISTR: 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 [1].

COMMON /**PYCROZ**/ NREP,NGEN(0:13),NPASS(0:13),PRECRS(0:13),
& NGENM(0:20),NPASSM(0:20),PRECRM(0:20)

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

COMMON /**PYFUSE**/ BH(0:6,6,2),MSS,MFL,JFL,OPTY1(4),OPTTH(7)

Purpose: mainly for internal use.

BH(I,J,K) : proportional to the probability to create a flavour J in fusion of flavour I and –I in process KTYPE=K.

MSS : =1 if only fusion into $q\bar{q}$ occurs, 0 otherwise.

MFL : quark flavour produced in fusion iff single flavour fusion is the only occuring process, 0 otherwise (i.e. normally).

JFL : quark flavour produced in fusion in current event.

OPTY1 AND OPTTH : arrays of constants occuring in the functions for the importance sampling of the variables Y1 and THAT, for the details see section 2 and comment lines in subroutine PYRAND. Used to optimize the speed of the Monte Carlo. May be changed without loss of normalization, i.e. cross-section estimates. The parameters have been optimized for normal usage and should normally not need to be altered.

COMMON /**PYINT1**/ S,YMIN,SQTMIN,XQ(2,-4:4),QTX,QTY,DIR

Purpose: for internal use only, see [1].

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 [1].

COMMON /**PYINT3**/ VIOL,VMAX,CONV,KI(2,2),PI(2,5),NMAX(-4:4,-4:4)

Purpose: for internal use only, see [1].

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 [1].

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

Purpose: contains character names for minimization, see [1].

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 [1].

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

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

Parameters:

IPY(1) : (D=2) determines the reaction to a violation of the maximum of the differential cross-section calculated in the TWINIT 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 processes $q + \bar{q} \to Q + \bar{Q}$ and $g + g \to Q + \bar{Q}$.

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, incoming 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 TWINIT.
=2 : cms of incoming particles, beam along positive z-axis.
=3 : cms of reacting partons, beam parton along positive z-axis.

IPY(5) : (D=0) a flag for TWINIT 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) regulates inclusion of interference terms in QCD (MT) matrix elements and choice of fragmentation scheme.
=1 : exclude interference terms, string fragmentation.
=2 : exclude interference terms, independent fragmentation.
=3 : include interference terms, string fragmentation.
=4 : include interference terms, 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 and in quark loop for $g + g \to \gamma + \gamma$. 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 : $Q^2 = \frac{2 \cdot \hat{s} \cdot \hat{t} \cdot \hat{u}}{\hat{s}^2 + \hat{t}^2 + \hat{u}^2}$
=2 : $Q^2 = -\hat{t}$
=3 : $Q^2 = a \cdot q_\perp^2$, where a is the constant PYPAR(12) and $q_\perp$ the transverse momentum of the scattered parton (or prompt particle).
=4 : $Q^2 = b \cdot (1 - x_\perp) \cdot q_\perp^2$, where b is the constant PYPAR(13) and $x_\perp = \frac{2 \cdot q_\perp}{\sqrt{\hat{s}}}$.
Note: the last two options correspond to the optimized scale choices in [9].

IPY(12) : (D=1) choice of proton and pion structure functions.
=0 : simple scaling functions
=1 : EHLQ set 1 for nucleon [5], Owens set 1 for pion [8].

=2 : EHLQ set 2 for nucleon [5], Owens set 2 for pion [8].
=3 : Duke-Owens set 1 for nucleon [6], Owens set 1 for pion [8].
=4 : Duke-Owens set 2 for nucleon [6], Owens set 2 for pion [8].
=5 : Glück-Hoffman-Reya for nucleon [7], Owens set 2 for pion [8].

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) : (D=0) choice of photon structure function [19–21].
<0 : VDM based on pion structure function given by IPY(12)
=0 : VDM for light quarks, eq. (6) in section 6.
=1 : QCD pointlike structure function eq. (7) in section 6.
=2 : QCD pointlike structure function from [22].

IPY(16) : internal, splitting of hadron remnant see [1].

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 processes $q + \bar{q} \to Q + \bar{Q}$ and $g + g \to Q + \bar{Q}$.
=0 : masses neglected but threshold factor applied.
=1 : masses included.

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)–IPY(28) : presently unused

IPY(29) : internal flag to signal failure.

IPY(30) : gives the current coordiate 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 [1].

PYPAR(11) : (D=1.) K-factor used in subprocesses where colour annihilates, see [1].

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 [9].

PYPAR(14) : (D=0.1) cut-off mass scale, m^2 (GeV^2), used in point-like photon structure function, eq. (7) in section 6.

PYPAR(15), PYPAR(16) : (D=0.5,1.) regulates minimum and maximum transverse momentum in $\gamma \to q\bar{q}$ used in connection with point-like photon structure function. First value is minimum $p_\perp$ in GeV and second value is fraction of the maximum allowed by kinematics ($p_{\perp max} = \frac{\sqrt{\hat{s}}}{2} \geq$ QTMIN).

PYPAR(17)–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 program skips the (superfluous) calculation (provided that IPY(5)=1).

PYVAR(2) : value of α_s in the current event.

PYVAR(3) : $-ln(y_{min})$, where y_{min} is the minimum value of $y_1 = x_1 \cdot x_2$.

PYVAR(4) : last value of $F_2^\gamma(x,Q^2)/\alpha_{em}$.
PYVAR(5) : last value of Λ_{QCD} in structure functions.
PYVAR(6)-PYVAR(10) : presently unused.

COMMON /**PYPROC**/ IN(2),KTYPE,ICONF,X(2),SHAT,THAT,Q2,MESON,MHELIC

Purpose: to specify the event on the parton level.
IN(I) : flavour (0=g, 1=u, 2=d, 3=s, 4=c, 5=b, -1=$\bar{u}$, -2=$\bar{d}$ etc.) of the reacting partons; I=1 for beam and I=2 for target particle.
KTYPE : specification of final state, i.e. process and colour flow (for MT only), see [1].
ICONF : specifies process;
$1 = q + q \to q + q$
$2 = q_i + \bar{q}_i \to q_j + \bar{q}_j$
$3 = q_i + \bar{q}_i \to g + g$
$4 = q + g \to q + g$
$5 = g + g \to q_i + \bar{q}_i$
$6 = g + g \to g + g$ (colour flows A and B)
$7 = g + g \to g + g$ (colour flow C)
$8 = q_i + \bar{q}_i \to g + \gamma$
$9 = q + g \to q + \gamma$
$10 = q_i + \bar{q}_i \to \gamma + \gamma$
$11 = g + g \to \gamma + \gamma$
$12 = \textit{higher twist} \to \textit{meson/glueball} + \textit{parton}$
$13 = \textit{higher twist} \to \textit{meson/glueball} + \textit{photon}$
X(I) : momentum fractions of the reacting partons, I=1,2 for beam,target.
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 functions and in α_s, see IPY(11).
MESON : type of prompt meson produced in higher twist process: 0 = no HT meson produced, 1=π^+, 2=π^-, 3=π^0, 4=η, 5=η', 6=K^+, 7=K^-, 8=K^0, 9=0_S, 10=0_A, 11=ρ^+, 12=ρ^-, 13=ρ^0, 14=ω, 15=ϕ, 16=K^{*+}, 17=K^{*-}, 18=K^{*0}, 19=$\bar{K}^{*0}$, 20=2_S. Note that 8=K^0 contains K^0 and $\bar{K}^0$ since they both decay into K_s^0 and K_l^0 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.

COMMON /**PYSUBS**/ ISELEC,ISUBPR(13),MESHT(20),IHEL,INCLU(-4:4,-4:4,6)

Purpose: to allow the user to run the program with any desired subset of high-$p_\perp$ processes.
ISELEC : (D=1) a switch to select between preprogramming and full user control. (For efficience reasons the default value gives the dominating minimum twist processes only.)
=-2 : gives the user full freedom to include desired subprocesses by setting the corresponding entries of INCLU for MT, and ISUBPR for HT.
=-1 : subprocesses included according to ISUBPR set by the user.
=0 : all high-$p_\perp$ subprocesses are included.
=1 : only minimum twist processes into partons included
=2 : only minimum twist prompt photon processes included
=3 : only higher twist processes 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.
=13 : HT production of prompt ρ^0 only.

ISUBPR : (D=13*0) array to be set when ISELEC=−1 (and −2 for HT). For ISUBPR(ICONF)=1 the corresponding processes are 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.

INCLU : internal array specifying in detail which MT subprocesses to be included, see [1].

COMMON /**PYTWIN**/ JMESON(−3:3,−3:3,20),LUMES(20),IMT,HEL(0:1)

Purpose: internal for higher twist processes.

JMESON(I,J,M) : flavour of the high-$p_\perp$ parton opposite to the prompt meson M produced by the reacting flavours I and J. 0 refer to gluon or photon depending on process, 999 signal that I,J cannot produce M.

LUMES(I) : translates HT meson code to Lund Monte Carlo particle code.

IMT : = 0 if MT processes not included, =1 otherwise.

HEL(I) : proportional to cross-section for helicity state I=0,1 i.e. 0 and ±1 (±2).

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; $f_{\eta_1}, f_{\eta_8}, f_{\omega_1}, f_{\omega_8}$. The other variables are obtained from these in TWINIT.

8 Examples on how to use the program

The Monte Carlo is built as a slave system, i.e. the user supplies his own main proam, which calls the TWISTER routines. The program has to be loaded together with the fragmentation routines JETSET version 6.2 [11]. 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 optional 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.

The time needed to generate one minimum twist event is about 0.02 to 0.05 s, on an IBM 3081, depending on the collision energy and the minimum transverse momentum (QTMIN) required. A higher twist event requires approximately twice that time.

An ordinary 300 GeV π^+-proton collision with a required minimum parton level $p_\perp$ level of 2 GeV/c may be generated with

```
CALL TWINIT('FIXT','PI+','P',300.,2.)
CALL TWISTR
```

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 the be edited with LUEDIT in the JETSET routines.

Example 1: An analysis of all occuring processes, including a print-out of the cross-sections, can be structured in the following way for, say, the scattering of 200 GeV π^- on a fixed proton target and requiring a $p_\perp > 2$ GeV on the parton level:

```
      COMMON/PYSUBS/ISELEC,ISUBPR(13),MESHT(20),IHEL,INCLU(-4:4,-4:4,6)
      ISELEC=0              ; include all processes

      CALL TWINIT('FIXT','PI-','P',200.,2.)      ; initialize

      DO 10 I=1,1000
      CALL TWISTR           ; generate one event
      .                     ; analysis of the generated event
   10 CONTINUE
      .
      CALL TWSTAT           ; print cross-sections and event statistics
      CALL PYPRNT           ; print current parameter values
      .
      END
```

Example 2: Selective simulation of higher twist ρ^0 production only can be made as follows:

```
      COMMON/PYSUBS/ISELEC,ISUBPR(13),MESHT(20),IHEL,INCLU(-4:4,-4:4,6)
      ISELEC=13             ; select HT rho0 production only
      CALL TWINIT('FIXT','PI-','P',200.,2.)

      DO 10 I=1,1000
      CALL TWISTR           ; generate one event
      .                     ; analysis of the event
   10 CONTINUE
      .
      END
```

The complete program code as well as a more non-trivial demonstration job can be obtained from the author (T00ING @ DHHDESY3).

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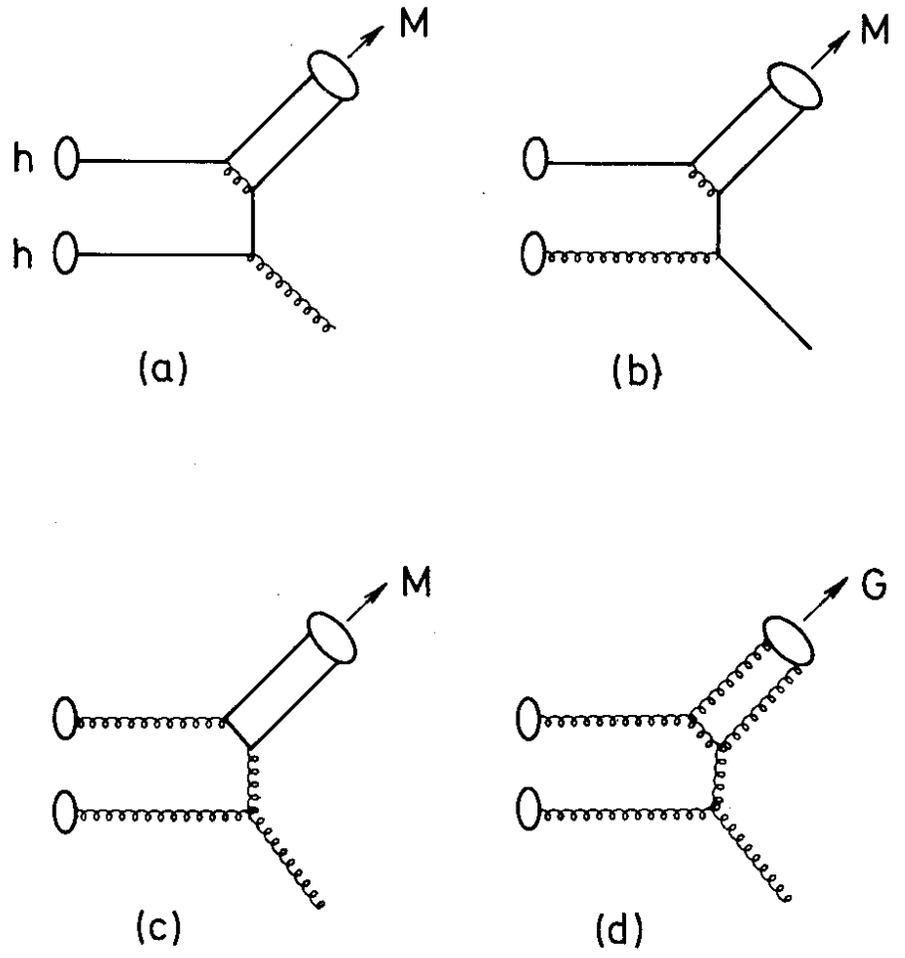

Figure 1: Examples of higher twist production of prompt meson (M) and gluonium (G) in high-$p_\perp$ hadron-hadron scattering: (a) $q+\bar{q} \to M+g$, (b) $q+g \to M+q'$, (a) $g+g \to M+g$, (a) $g+g \to G+g$.