The CCFM Monte Carlo generator CASCADE

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Abstract

CASCADE is a full hadron level Monte Carlo event generator for ep, γp and $p\bar{p}$ processes, which uses the CCFM evolution equation for the initial state cascade in a backward evolution approach supplemented with off - shell matrix elements for the hard scattering. A detailed program description is given, with emphasis on parameters the user wants to change and common block variables which completely specify the generated events.

1 Tabular Summary

|	
program name	CASCADE
version	1.00/01
date of latest version	July 2001
author	Hannes Jung (Hannes.Jung@desy.de)
program size	~ 8000 lines of code
input files needed	ccfm.dat (kms.dat, kmr.dat)
computer types	any with standard Fortran 77, tested on SGI, HP-UX, SUN, PC
operating systems	Unix, Linux
applicability	Deep Inelastic ep Scattering
	Photo-production in ep Scattering
	γp Scattering
	heavy quark production in pp and $p\bar{p}$ Scattering
hard sub-processes included	$\gamma^* g^* \to q\bar{q}$, $Q\bar{Q}$
	$\gamma g^* \to J/\psi g$
	$g^* g^* \to q\bar{q}$, $Q\bar{Q}$
QCD cascade	initial state parton shower according to CCFM
	final state parton shower with angular ordering
fragmentation model	LUND string
other programs called	PYTHIA 6.1
	BASES/SPRING 5.1
availability	http://www.quark.lu.se/~hannes/cascade/
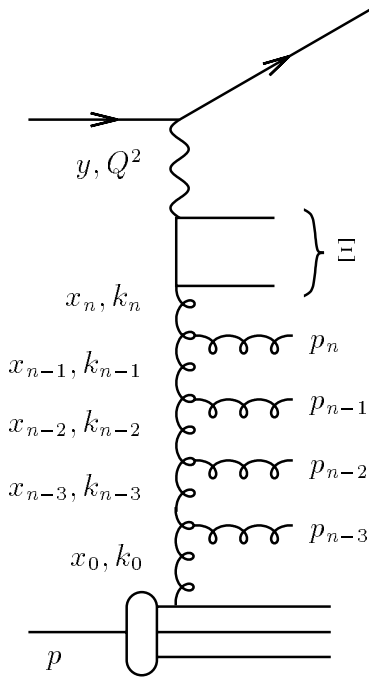
Figure 1: *Kinematic variables for multi-gluon emission. The t-channel gluon four-vectors are given by k_i and the gluons emitted in the initial state cascade have four-vectors p_i. The maximum angle for any emission is obtained from the quark box, as indicated with Ξ.*

2 The CCFM evolution equation

The formulation of the CCFM [1–4] parton evolution for the implementation into a full hadron level Monte Carlo program is described in detail in [5,6]. Here only the main results are summarized and discussed for the case of leptoproduction.

Figure 1 shows the pattern of QCD initial-state radiation in a small-x DIS event, together with labels for the kinematics. According to the CCFM evolution equation, the emission of partons during the initial cascade is only allowed in an angular-ordered region of phase space. The maximum allowed angle Ξ for any gluon emission sets the scale $\bar{q}$ for the evolution and is defined by the hard scattering quark box, which connects the exchanged gluon to the virtual photon. In terms of Sudakov variables the quark pair momentum is written as:

$$p_q + p_{\bar{q}} = Y(p_p + \Xi p_e) + Q_t \tag{1}$$

where p_p and p_e are the proton and electron momenta, respectively and Q_t is the transverse momentum of the quark pair and Y is its light-cone momentum fraction. The scale $\bar{q}$ is related to the maximum angle Ξ via $\bar{q} = x_n\sqrt{\Xi s}$, with s being the squared center of mass energy $s = (p_e + p_p)^2$.

The CCFM evolution equation can be written in a differential form [4], which is best suited for a backward evolution approach adopted in the Monte Carlo generator CASCADE [5,6]:

$$\bar{q}^2 \frac{d}{d\bar{q}^2} \frac{x\mathcal{A}(x, k_t, \bar{q})}{\Delta_s(\bar{q}, Q_0)} = \int dz \frac{d\phi}{2\pi} \frac{\tilde{P}(z, \bar{q}/z, k_t)}{\Delta_s(\bar{q}, Q_0)} x'\mathcal{A}(x', k_t', \bar{q}/z) \tag{2}$$

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where $\mathcal{A}(x, k_t, \bar{q})$ is the unintegrated gluon density, depending on x, k_t and the evolution variable $\bar{q}$. The splitting variable is $z = x/x'$ and $\vec{k}_t{}' = (1-z)/z\vec{q} + \vec{k}_t$, where the vector $\vec{q}$ is at an azimuthal angle ϕ. The Sudakov form factor Δ_s is given by:

$$\Delta_s(\bar{q}, Q_0) = \exp\left(-\int_{Q_0^2}^{\bar{q}^2} \frac{dq^2}{q^2} \int_0^{1-Q_0/q} dz \frac{\bar{\alpha}_s(q^2(1-z)^2)}{1-z}\right) \tag{3}$$

with $\bar{\alpha}_s = \frac{C_A \alpha_s}{\pi} = \frac{3\alpha_s}{\pi}$. For inclusive quantities at leading-logarithmic order the Sudakov form factor cancels against the $1/(1-z)$ collinear singularity of the splitting function.

The splitting function $\tilde{P}_g(z_i, q_i, k_{ti})$ for branching i is given by:

$$\tilde{P}_g(z_i, q_i, k_{ti}) = \frac{\bar{\alpha}_s(q_i^2(1-z_i)^2)}{1-z_i} + \frac{\bar{\alpha}_s(k_{ti}^2)}{z_i}\Delta_{ns}(z_i, q_i^2, k_{ti}^2) \tag{4}$$

where the non-Sudakov form factor Δ_{ns} is defined as:

$$\log \Delta_{ns} = -\bar{\alpha}_s(k_{ti}^2) \int_0^1 \frac{dz'}{z'} \int \frac{dq^2}{q^2} \Theta(k_{ti} - q)\Theta(q - z'q_{ti}) \tag{5}$$

The splitting function $\tilde{P}(z, q, k_t)$ in eq.(4) contains only the singular parts in z and $(1-z)$. The finite terms in the splitting function are neglected, since they are not obtained in CCFM at the leading infrared accuracy [3, p.72]. As soon as they become available they can be easily implemented into the Monte Carlo generator.

3   Backward evolution: CCFM and CASCADE

The idea of a backward evolution [7,8] is to first generate the hard scattering process with the initial parton momenta distributed according to the parton distribution functions. This involves in general only a fixed number of degrees of freedom, and the hard scattering process can be generated quite efficiently. The initial state cascade is generated by going backwards from the hard scattering process towards the beam particles.

According to the CCFM equation the probability of finding a gluon in the proton depends on three variables, the momentum fraction x, the transverse momentum squared k_t^2 of the exchanged gluons and the scale $\bar{q} = x_n\sqrt{s\Xi}$, which is related to the maximum angle allowed for any emission Ξ. To solve eq.(2) the unintegrated gluon distribution $\mathcal{A}(x, k, \bar{q})$ has to be determined beforehand.

Given this distribution, the generation of a full hadronic event is separated into three steps, as implemented in the hadron-level Monte Carlo program CASCADE:

- The hard scattering process is generated,

$$\sigma = \int dk_t^2 dx_g \mathcal{A}(x_g, k_t, \bar{q})\sigma(\gamma^* g^* \to X), \tag{6}$$

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with X being $q\bar{q}$, $Q\bar{Q}$ or $J/\psi g$ states. The hard cross section is calculated using the off-shell matrix elements given in [9, p. 178 ff] for $q\bar{q}$ and $Q\bar{Q}$ or for the case of $\gamma g^* \to J/\psi g$ in [10]. The gluon momentum is given in Sudakov representation:

$$k = x_g p_p + \bar{x}_g p_e + k_t \simeq x_g p_p + k_t \,. \tag{7}$$

where the last expression comes from the high energy approximation ($x_g \ll 1$), which then gives $-k^2 \simeq k_t^2$.

- The initial state cascade is generated according to CCFM in a backward evolution approach.

- The hadronization is performed using the Lund string fragmentation implemented in PYTHIA /JETSET[11].

The backward evolution there faces one difficulty: The gluon virtuality enters in the hard scattering process and also influences the kinematics of the produced quarks and therefore the maximum angle allowed for any further emission in the initial state cascade. This virtuality is only known after the whole cascade has been generated, since it depends on the history of the gluon evolution (as $\bar{x}_g$ in eq.(7) may not be neglected for exact kinematics). In the evolution equations itself it does not enter, since there only the longitudinal energy fractions z and the transverse momenta are involved. This problem can only approximately be overcome by using $k^2 = k_t^2/(1 - x_g)$ for the virtuality which is correct in the case of no further gluon emission in the initial state.

The Monte Carlo program CASCADE can be used to generate unweighted full hadron-level events, including initial-state parton evolution according to the CCFM equation and the off-shell matrix elements for the hard scattering process. It is applicable for $p\bar{p}$, photo-production as well as for deep inelastic scattering. The typical time needed to generate one event is ~ 0.03 sec on a Pentium II (266 MHz), which is similar to the time needed by standard Monte Carlo event generators such as LEPTO [12] or PYTHIA [11].

3.1 The unintegrated gluon density

The CCFM unintegrated gluon density $x\mathcal{A}(x, k_t, \bar{q})$ is obtained from a forward evolution procedure as implemented in SMALLX [13,14] by a fit to the measured structure function F_2 as described in [5,6]. From the initial gluon distribution a set of values x and k_t are obtained by evolving up to a given scale $\log \bar{q}$ using the forward evolution procedure. This is repeated 10^8 times thus obtaining a distribution of the unintegrated gluon density $x\mathcal{A}(x, k_t, \bar{q})$ for the slice of phase space with a given $\bar{q}$ ($\bar{q} > q_{t\,n}$). To obtain a distribution in $\log \bar{q}$, the above procedure is repeated from the beginning 50 times for the different grid points in $\log \bar{q}$ up to $\bar{q} = 1800$ GeV. Due to the complicated structure of the CCFM equation, no attempt is made to parameterize the unintegrated gluon density. Instead, the gluon density is calculated on a grid in $\log x$, $\log k_t$ and $\log \bar{q}$ with $50 \times 50 \times 50$ points and a linear interpolation is used to obtain the gluon density for values in between the grid points. The data file (`ccfm.dat`) containing the $50 \times 50 \times 50$ grid points is read in at the beginning of the program.

The parameter `IGLU` offers the possibility to compare the CCFM unintegrated gluon density $x\mathcal{A}(x, k_t, \bar{q})$ (`IGLU=1`) with other unintegrated gluon densities published: a simple numerical

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derivative of a standard integrated gluon density $\frac{dxg(x,Q^2)}{dQ^2}$ taken from [15] (IGLU=2), the one in the approach of Blümlein [16] and coded by [17,18] (IGLU=3), the unintegrated gluon density of KMS[1] [19] (IGLU=4, stored in `kms.dat`), the one of the saturation model by [20] (IGLU=5) and the one of KMR[2] [21] (IGLU=6, stored in `kmr.dat`).

Except for the default CCFM unintegrated gluon density with (IGLU=1), no initial state parton shower can be generated, because the angular variable, essential for angular ordering in the initial state cascade, is not present. However, the transverse momenta of the incoming partons are properly treated.

3.2 α_s and the choice of scales

The strong coupling α_s is calculated via the PYTHIA [11] subroutine `PYALPS`. Maximal and minimal number of flavors used in α_s are set by `MSTU(113)`,`MSTU(114)`, Λ_{QCD} =`PARU(112)` with respect to `MSTU(112)` flavors and stored in the PYTHIA common `COMMON/PYDAT1/`. In the initial state cascade according to CCFM, the transverse momenta of the t-channel gluons are allowed to perform a random walk for small z values and k_t can become very small. In the $1/z$ part of the splitting function we use $\mu = k_t$ as the scale in $\alpha_s(\mu)$ and in the $1/(1-z)$ part $\mu = (1-z)q_t$ is used. In addition we require $\mu > Q_0 = 1.4$ GeV, resulting in $\alpha_s(\mu > Q_0) < 0.6$. The parameter $Q_0 = 1.4$ GeV was determined from the requirement to describe the structure function F_2 as described in [5,6].

The scale μ which is used in α_s in the hard scattering matrix element can be changed with the parameter `IQ2`, the default choice is $\mu^2 = p_t^2$.

3.3 Quark masses

The quark mass for light quarks (u, d, s) is fixed to $m_q = 0.140$ GeV. This, together with the treatment of α_s at small scales μ, gives also a reasonable total cross-section for photo-production at HERA energies. The masses for heavy quarks are given by the JETSET / PYTHIA defaults $(m_c = 1.5$ GeV, $m_b = 4.8$ GeV) and can be changed according to the PYTHIA prescription.

3.4 Leptoproduction

CASCADE can be used to simulate leptoproduction events over the whole Q^2 range. By fixing the light quark masses to $m_q = 0.140$ GeV and α_s for small μ, the hard scattering matrix element remains finite over the full phase space. The total cross section is simulated by selecting `IPRO=10` and `NFLAV=4(5)`. With `IPRO=10` light quarks (u, d, s) are selected and with `NFLAV>3` the program automatically includes heavy flavor production via the process `IPRO=11` and `IHFLA=4` up to `IHFLA=NFLAV`.

Heavy flavor production can be generated separately via `IPRO=11`. The value of `IHFLA` determines the heavy flavor to be generated.

The matrix element for $\gamma g^* \to J/\psi g$ calculated in [10] is available for quasi-real γ's via the process `IPRO=2`.

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[1]A. Stasto kindly provided the program.

[2]M. Kimber kindly provided the program.

3.5 Photoproduction

CASCADE can be used to simulate real photoproduction events by using KE=22. The same options as for leptoproduction are available.

3.6 Hadroproduction

CASCADE can be used to simulate heavy quark production in pp or $p\bar{p}$ collisions (IPRO=14 for heavy flavor production, and IHFLA=4(5) for charm (bottom) quarks). The flavor code (KE) for beam 1 can be chosen as KE=2212 for proton or KE=-2212 for anti - proton, beam 2 is always a proton.

3.7 Initial and final state parton shower

Initial state parton showers are generated in a backward evolution approach described in detail in [5,6]. The initial state parton shower consists only of gluon branchings and is generated in an angular ordered region in the laboratory frame. In the present version, the gluons emitted during the branchings are treated on-mass shell, and no further time - like branching occurs.

All parameters (like the scale μ in α_s, the collinear cut-off Q_0) for the initial state cascade are fixed from the determination of the unintegrated gluon density. The transverse momenta of the partons which enter the hard scattering matrix element are already generated in the beginning and are not changed during the whole initial and final state parton showering (in contrast to standard DGLAP type parton shower Monte Carlo generators like PYTHIA [11] or LEPTO [12]).

The final state parton shower uses the parton shower routine PYSHOW of PYTHIA with the scale QMAX=$(m_{1\perp} + m_{2\perp})/2$, with $m_{1(2)\perp}$ being the transverse mass of the hard parton 1(2).

3.8 Remnant treatment

The proton remnant is built in subroutine CAREMN, which is a slightly modified version of the PYTHIA / LEPTO subroutine PYREMN. In the present version no intrinsic transverse momentum, in addition to the transverse momentum from the initial state cascade, is included.

4 Description of the program components

In CASCADE all variables are declared Double Precision. The Lund string model is used for hadronization as implemented in PYTHIA 6.1 [11]. The final state QCD radiation is performed via PYSHOW from PYTHIA 6.1. The treatment of the proton remnant follows very closely the ones in LEPTO[12] for the leptoproduction case and the one in PYTHIA 6.1 for the proton - proton case. However slight modifications were needed to adapt to the cascade treatment here.

The unintegrated gluon density is stored on data files (ccfm.dat,kms.dat,kmr.dat), and is read in at the beginning of the program.

The program has to be loaded together with PYTHIA 6, to ensure that the double precision code of JETSET is loaded.

4.1 Random number generator

Since the variables are declared in double precision, also a double precision random number generator has to be used to avoid any bias. The function DCASRN gives a single random number, the function DCASRNV returns an array of length LEN of random numbers. The default random number generator is RM48 (called in DCASRN and DCASRNV) from CERNLIB. The user can change this to any preferred Double Precision random number generator.

4.2 Integration and event generation

The integration of the total cross section and the generation of unweighted events is performed with the help of BASES/SPRING [22].

4.3 Subroutines and functions

The source code of CASCADE and this manual can be found under:
http://www.quark.lu.se/~hannes/cascade/

CAMAIN	main program.
CASINI	to initializes the program.
CASCADE	to perform integration of the cross section. This routine has to be called before event generation can start.
CAEND	to print the cross section and the number of events.
CAUNIGLU(KF,X,KT,P,XPQ)	to extract the unintegrated gluon density $x\mathcal{A}(x, k_t, \bar{q})$ for a proton with KF=2212, as a function of $x =$X, $k_t^2 =$KT and $\bar{q} =$P. The gluon density is returned in XPQ(0), where XPQ is an array with XPQ(-6:6).
EVENT	to perform the event generation.
ALPHAS(RQ)	to give $\alpha_s(\mu)$ with $\mu =$RQ.
PARTI	to give initial particle and parton momenta.
FXN1	to call routines for selected processes: XSEC1.
CUTG(IPRO)	to cut on p_t for $2 \to 2$ process in integration and event generation.
MEOFFSH	matrix element for $\gamma^* g^* \to q\bar{q}$ and $g^* g^* \to q\bar{q}$ including masses. q can be light or heavy quarks.
DOT(A,B)	four-vector dot product of A and B.
DOT1(I,J)	four-vector dot product of vectors I and J in PYJETS common.
PHASE	to generate momenta of final partons in a $2 \to 2$ subprocess according to phase space
P_SEMIH	to generate kinematics and the event record for ep, γp and $p\bar{p}$ processes.
CAREMN(IPU1,IPU2)	to generate the beam remnants. Copied from LEPTO 6.1 [12] and updated for the use in CASCADE.
CASPLI(KF,KPA,KFSP,KFCH)	to give the spectator KFSP and KFCH partons when a parton KPA is removed from particle KF. Copied from LEPTO 6.1 [12] and updated for the use CASCADE.
CAPS	to generate color flow for all processes and prepare for initial and final state parton showers.
CASCPS(IPU1,IPU2)	to generate initial state radiation.
GADAP	Gaussian integration routine for 1-dim and 2-dim integration. Copied from LEPTO 6.1 [12].

4.4 Parameter switches

BASES/SPRING Integration procedure.

NCAL: (D:=20000) Nr of calls per iteration for bases.

ACC1: (D:=1) relative precision (in %) for grid optimization.

ACC2: (D:=0.5) relative precision (in %) for integration.

4.4.1 Parameters for kinematics

PLEPIN: (D:=-30) momentum p [GeV/c] of incoming electron (/INPU/).

PIN: (D:=820 momentum p [GeV/c] of incoming proton (/INPU/).

QMI: (D: = 5.0) (/VALUES/) minimum Q^2 to be generated.

QMA: (D: = 10^8) (/VALUES/) maximum Q^2 to be generated.

YMI: (D: = 0.0)(/VALUES/) minimum y to be generated.

YMA: (D: = 1.0) (/VALUES/) maximum y to be generated.

THEMA,THEMI (D: THEMA = 180., THEMI = 0) maximum and minimum scattering angle θ of the electron (/CAELEC/).

NFLAV (D: = 5) number of active flavors, can be set by user (/CALUCO/).

4.4.2 Parameters for hard subprocess selection

IPRO: (D: = 10) (/CAPAR1/) selects hard subprocess to be generated.
=2: $\gamma g^* \to J/\psi g$
=10: $\gamma^* g^* \to q\bar{q}$ for light quarks.
=11: $\gamma^* g^* \to Q\bar{Q}$ for heavy quarks.

PT2CUT(IPRO): (D=0.0) minimum $\hat{p}_\perp^2$ for process IPRO (/CAPTCUT/).

4.4.3 Parameters for parton shower and fragmentation

NFRAG: (D: = 1) switch for fragmentation(/CAINPU/).
= 0 off
= 1 on

IFPS: (D: = 3) switch parton shower(/CAINPU/).
= 0 off
= 1 initial state
= 2 final state
= 3 initial and final state

ICCFM: (D: =1)
=1 CCFM evolution.

4.4.4 Parameters for structure functions α_s and scales

IRUNAEM: (D: = 0) (/CAPAR1/) select running of $\alpha_{em}(Q^2)$.
=0: no running of $\alpha_{em}(Q^2)$
=1: running of $\alpha_{em}(Q^2)$

IRUNA: (D: = 1) switch for running α_s.
=0: fixed $\alpha_s = 0.3$

	=1: running $\alpha_s(\mu^2)$
IQ2:	(D: = 3) select scale μ^2 for $\alpha_s(\mu^2)$.
	=1: $\mu^2 = 4 \cdot m_q^2$ (use only for heavy quarks!)
	=2: $\mu^2 = \hat{s}$ (use only for heavy quarks!)
	=3: $\mu^2 = 4 \cdot m^2 + p_\perp^2$
	=4: $\mu^2 = Q^2$
	=5: $\mu^2 = Q^2 + p_\perp^2$
IGLU:	(D: = 1) select unintegrated gluon density/GLUON/).
	Note for IGLU> 1, all initial state parton showers are switched off.
	=1: CCFM unintegrated gluon (ccfm.dat).
	=2: derivative of GRV [15] $\frac{dxg(x,Q^2)}{dQ^2}$.
	=3: approach of Blümlein [16].
	=4: KMS [19] (kms.dat).
	=5: saturation model [20].
	=6: KMR [21] (kmr.dat).

4.4.5   Accessing information

AVGI	integrated cross section (/CAEFFIC/).
SD	standard deviation of integrated cross section (/CAEFFIC/).
SSS	squared center of mass energy s (/CAPARTON/).
PBEAM	energy momentum vector of beam particles (/CABEAM/).
KBEAM	flavor code of beam particles (/CABEAM/).
Q2	in leptoproduction: actual Q^2 of γ (/CAPAR4/).
YY	negative light-cone momentum fraction of parton 1 (γ^*, g^*) (/CASGKI/).
YY_BAR	positive light-cone momentum fraction parton 1 (γ^*, g^*) (/CASGKI/).
XG	positive light-cone momentum fraction of parton 2 (g^*) (/CASGKI/).
XG_BAR	negative light-cone momentum fraction of parton 2 (g^*) (/CASGKI/).
KT2_1,KT2_2	transverse momenta squared $k_{t\,1(2)}^2$ [GeV^2] of partons 1(2) which enter to the matrix element.
YMAX,YMIN	actual upper and lower limits for y =YY (/CAPAR5/).
Q2MAX,Q2MIN	actual upper and lower limits for Q^2 (corresponding to KT2_1) of γ (/CAPAR5/).
XMAX,XMIN	upper and lower limits for x (/CAPAR5/).
AM(18)	vector of masses of final state particles of hard interaction (/CAPAR3/).
SHAT	invariant mass $\hat{s}$ [GeV^2] of hard subprocess (/CAPAR5/).
NIA1,NIA2	position of partons in hard interaction in PYJETS event record (/CAHARD/).
NF1,NF2	first and last position final partons/particles of hard interaction in PYJETS (/CAHARD/).
Q2Q	hard scattering scale μ^2 used in α_s and structure functions (/CAPAR4/).
ALPHS	actual α_s (/CAPAR2/).
ALPH	α_{em} (/CAPAR2/).
NIN	number of trials for event generation (/CAEFFIC/).
NOUT	number of successful generated events (/CAEFFIC/).

4.5   List of COMMON blocks

```
COMMON/CABEAM/PBEAM(2,5),KBEAM(2,5),KINT(2,5)
COMMON/CAHARD/ NIA1,NIA2,NIR2,NF1,NF2
COMMON/CAHFLAV/ IHFLA
COMMON/CAINPU/PLEPIN,PPIN,NFRAG,ILEPTO,IFPS,IHF,INTER,ISEMIH
COMMON/CALUCO/KE,KP,KEB,KPH,KGL,KPA,NFLAV
COMMON/CAEFFIC/AVGI,SD,NIN,NOUT
COMMON/CAELEC/THEMA,THEMI
COMMON/CAGLUON/IGLU
COMMON/CAPAR1/IPRO,IRUNA,IQ2,IRUNAEM
COMMON/CAPAR2/ALPHS,PI,ALPH,IWEI
COMMON/CAPAR3/AM(18),PCM(4,18)
COMMON/CAPAR4/Q2,Q2Q
COMMON/CAPAR5/SHAT,YMAX,YMIN,Q2MAX,Q2MIN,XMAX,XMIN
COMMON/CAPAR6/LST(30),IRES(2)
COMMON/CAPARTON/SSS,CM(4),DBCMS(4)
COMMON/CAPTCUT/PT2CUT(20)
COMMON/CASKIN/YY,YY_BAR,XG,XG_BAR,KT2_1,KT2_2,PT2H,SHH
COMMON/VALUES/QMI,YMI,QMA,YMA
```

5   Example Program

```
PROGRAM CASMAIN
Implicit None
Integer N1,N2
REAL PLEPIN,PPIN
INTEGER KE,KP,KEB,KPH,KGL,KPA,NFRAG,ILEPTO,IFPS,IHF
INTEGER INTER,ISEMIH
INTEGER NIA1,NIR1,NIA2,NIR2,NF1,NF2,NFT,NFLAV
COMMON/CALUCO/KE,KP,KEB,KPH,KGL,KPA,NFLAV
COMMON/CAINPU/PLEPIN,PPIN,NFRAG,ILEPTO,IFPS,IHF,INTER,ISEMIH
COMMON/CAHARD/ NIA1,NIA2,NIR2,NF1,NF2
INTEGER IHFLA
COMMON/CAHFLAV/ IHFLA

DOUBLE PRECISION THEMA,THEMI,PT2CUT
INTEGER IRUNA,IQ2,IRUNAEM
INTEGER IPRO
COMMON/CAPAR1/IPRO,IRUNA,IQ2,IRUNAEM
COMMON/CAELEC/ THEMA,THEMI
COMMON/CAPTCUT/PT2CUT(20)
REAL ULALPS,ULALEM
EXTERNAL ULALPS,ULALEM
```

```
      DOUBLE PRECISION QMI,YMI,QMA,YMA
      COMMON/VALUES/QMI,YMI,QMA,YMA

      Integer Iglu
      Common/CAGLUON/Iglu

      Integer ISEED,I


      ISEED = 124567
      n1=0
      n2=0
C initialize random number generator
      CALL RM48IN(ISEED,N1,N2)
C initialize PYTHIA 6 parameters
      CALL GPYINI
C initialize CASCADE parameters
      CALL CASINI


C Select parton shower (IPS=1 initial, =2 final, 3 initial+final PS )
      IFPS = 3
C scale for alpha_s
C IQ2 =1 mu^2 = m_q^2 (m_q = light quark or heavy quark depending on IPRO)
C IQ2 =2 mu^2  = shat
C IQ2 =3 mu^2  = m_q^2 + pt^2 (m_q = light quark or heavy quark depending on IPRO)
C IQ2 =4 mu^2  = q^2 (q^2 of virtual photon)
C IQ2 =5 mu^2  = q^2 + pt^2 (q^2 of virtual photon)
      IQ2=3
C select process (IPRO=10 for light quarks, IPRO=11 for heavy quarks)
      IPRO= 10
C total number of flavors involved
      NFLAV = 4
C select unintegrated gluon density (D=1)
      Iglu = 1
C minimum Q^2 of electron to be generated
      QMI = 0.5d0
C maximum Q^2 of electron to be generated
      QMA = 10D8
C minimum y of electron to be generated
      YMI=0.0d0
C minimum y of electron to be generated
      YMA=1.0d0
C maximum theta angle of scattered electron
      THEMA = 180.0D0
C minimum  theta angle of scattered electron
      THEMI =   0.0D0
```

```
C momentum of beam 1 (electron,proton,antiproton)
      PLEPIN =-27.5
C Lund flavor code for beam 1 (electron=11,photon=22,proton=2212,antiproton=-2212)
      KE=11
C momentum of beam 2 (proton)
      PPIN   = 820.
C perform fragmentation NFRAG=0/1
      NFRAG = 1
c for IPRO = 11  which flavor is produced
      IHFLA = 4
c
c Start integration of x-section
c
      CALL CASCADE
c
c Print out result of integration of x-section
c
      CALL CAEND(1)


c
c Start event loop
c
      Do I=1,100
c generate an event
         CALL EVENT
      Enddo
c
c Print out of generated events summary
c
      CALL CAEND(20)

      STOP
      END
```

6   Acknowledgments

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