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PEPSI – a Monte Carlo generator for polarized leptoproduction

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We describe PEPSI (Polarized Electron Proton Scattering Interactions) a Monte Carlo program for polarized deep inelastic leptoproduction mediated by electromagnetic interaction, and explain how to use it. The code is a modification of the LEPTO 4.3 Lund Monte Carlo for unpolarized scattering. The hard virtual gamma–parton scattering is generated according to the polarization-dependent QCD cross-section of the first order in α_S. PEPSI requires the standard polarization-independent JETSET routines to simulate the fragmentation into final hadrons.

PROGRAM SUMMARY

Title of program: PEPSI version 1.1

Catalogue number: ACJF

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

Licensing provisions: none

Computer: any computer with FORTRAN 77 compiler (RISC DEC station, VAX, ...); the program has been tested on RISC under UNIX.

Programming language used: FORTRAN 77

Memory required to execute with typical data: 57000 words

No. of bits in a word: 32

No. of lines in distributed program, including test data, etc.: 2950

Keywords: perturbative quantum chromodynamics (QCD), QCD improved parton model, polarized deep inelastic scattering, structure functions, cross sections

Nature of physical problem

Deep inelastic scattering of longitudinally polarized leptons off polarized nucleons or nuclei are the ideal tools to determine the spin distributions of partons inside such

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targets. Like the momentum distribution determined by unpolarized deep inelastic scattering, the partonic spin distributions contain an important dynamical information which strongly influence our understanding of the nucleon structure, and hence of non-perturbative quantum chromodynamics. The surprising result of a recent EMC experiment [1] has stimulated strong theoretical and experimental efforts to further investigate the problem of the spin structure of the nucleon. In the case of these investigations it has become clear that additional experimental information is needed to interpret the data unambiguously [2,3]. The present document contains a description of a Monte Carlo program created to simulate these experiments and polarized deep inelastic scattering in general.

Method of solution
The existing Monte Carlo program LEPTO 4.3 [4] simulation in unpolarized deep inelastic scattering (DIS) has been modified to include polarization. The relevant cross-sections for hard QCD processes mediated by the virtual photon exchange have been calculated and included in the procedure which generates the probabilities of various events and their kinematics. The subsequent fragmentation into hadrons is performed using the standard JETSET 6.3 fragmentation code [5]. For user's convenience, three unitary sets of unpolarized and polarized parton distributions are provided.

Restrictions on the complexity of the problem
At present only processes mediated by the virtual γ^* exchange are implemented. It restricts the scope of the code to the kinematic domain where effects due to weak interactions can be neglected.

A possible polarization-dependence of the fragmentation functions is not taken into account. It means that e.g. the asymmetries in the semi-inclusive spectra can be reliably simulated for spinless particles only. Also, the Q^2 dependence of the polarized parton distributions is not included and therefore care has to be taken when simulating a DIS experiment in a wide Q^2 range.

Typical running time
Generation of a complete event takes approximately 0.11 s on a RISC DEC station 3100.

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LONG WRITE-UP

1. Introduction

Deep inelastic scattering (DIS) of leptons and nucleons offers the most sensitive way to obtain the internal structure of nucleons. The scattering of unpolarized particles depends only on the momentum distribution of various partons inside the target. If the projectile and target are both longitudinally polarized one is also sensitive to the spin distribution of partons which enters via the polarized structure function $g_1(x)$. A general introduction into the subject can be found e.g. in ref. [6]. Like the momentum distribution measured in unpolarized DIS, the spin distribution [1,7] contains important dynamical information which strongly influences our understanding of the internal nucleon structure, and hence of non-perturbative quantum chromodynamics. The surprisingly low upper limit for the total spin carried by quarks obtained in the recent EMC experiment [1] has stimulated strong theoretical [2,3] and experimental [8] efforts to further investigate the problem of the spin structure of the nucleon.

The present document contains a description of a Monte Carlo program created to simulate polarized DIS experiment. The code has been written on the basis of the existing LUND Monte Carlo LEPTO version 4.3 [4] which simulates unpolarized DIS off an unpolarized target. We are presently working on the implementation of polarization into LEPTO version 5.2.

The implementation of polarization comprised the following steps:

(1) The relevant hard QCD processes, i.e. the direct virtual $\gamma^* + q \to q$ process as well as the $\gamma^* + q \to q + g$ and $\gamma^* + g \to q + \bar{q}$ were calculated up to the $\mathcal{O}(\alpha_S)$ order in QCD with effects due to the longitudinal parton polarization taken into account. The contribution from weak Z^0 exchange has not been included.

(2) The set of unpolarized quark and gluon distributions $q(x)$ and $g(x)$ was supplemented by polarized distributions $\Delta q(x)$ and $\Delta g(x)$.

Generation of a deep inelastic event requires the knowledge of the cross-section, which in turn contains input from polarized parton distributions $\Delta q(x)$ and $\Delta g(x)$, in addition to the unpolarized $q(x)$ and $g(x)$, see section 2.1. Unfortunately, contrary to the unpolarized case [9], a complete survey of available polarized parton distributions does not exists. For convenience we have supplied PEPSI with three different sets of polarized parton distributions based on refs. [10,11], but the structure of the code allows to easily implement other distributions as well.

Subsequent fragmentation of partons into hadrons is performed with the help of the standard JETSET 6.3 routines [5], which do not distinguish between various initial and final polarization states. Therefore in the present form the code can be safely used only to predict the final-state distribution of spinless particles. In this case, due to the parity-invariance, the fragmentation functions should not depend on polarization of the initial parton.

This document is organised as follows. In the next section we summarise the theoretical input necessary to taken into account polarized DIS in the LEPTO scheme. Section 3 contains a basic description of the code together with a description of the user accessible flags which can be used to generate events for a given polarization, and given parton distribution. Finally, section 4 contains simple examples which show how to implement PEPSI routines within a main program.

2. Cross-section evaluation

2.1. Hard cross-sections

In this section we present a summary of all the formulae used to generate probabilities of various types of events: $\gamma^* + q \to q$, $\gamma^* + q \to q + g$, and $\gamma^* + q \to q + \bar{q}$, see figs. 1a–1c, respectively. As explained above, our program is based on the standard LEPTO 4.3 code [4], and we follow the notation used there. The detailed description of the kinematics, as well as formulae for unpolarized scattering can be found in ref. [12]. In partic-

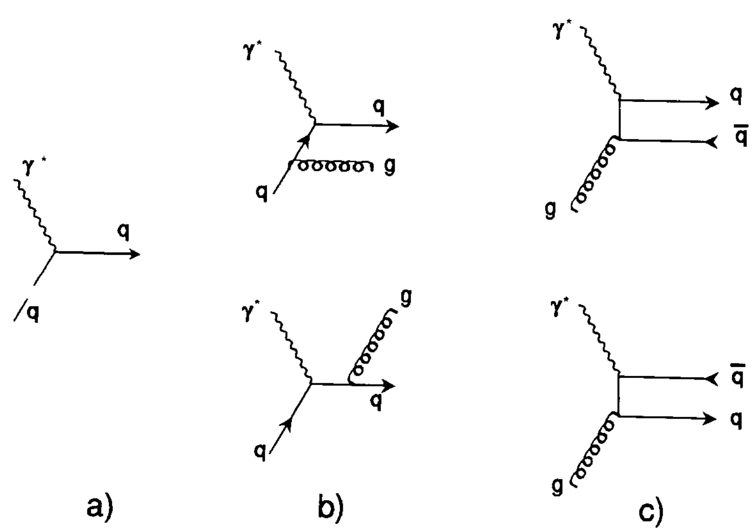

Fig. 1. Tree level diagrams which contribute to virtual photon–target scattering to $\mathcal{O}(\alpha_S)$. Direct $\gamma^* + q \to q$ scattering (a), gluon bremstrahlung (b), and gamma–gluon fusion (c).

ular, in the following we will use scaling variables x, y, z_p and x_p defined as

$$x = \frac{-q^2}{2P \cdot q}, \quad y = \frac{P \cdot q}{P \cdot l}, \quad z_p = \frac{P \cdot P_p}{P \cdot q}, \quad x_p = \frac{x}{\xi}, \tag{1}$$

respectively. P, q, and l denote the target, virtual photon, and initial lepton four-momenta, and ξ is the fraction of the target momentum carried by the initial parton.

In the QCD improved parton model the cross-section for the polarized deep inelastic scattering can be written as the convolution $\otimes$ of the parton densities with elementary cross-sections for the processes depicted in figures 1a–1c:

$$d\sigma \sim \mathscr{P} \otimes d\sigma_p + \lambda \cdot \Delta\mathscr{P} \otimes d\ \Delta\sigma_p. \tag{2}$$

$\mathscr{P}(x)$ and $\Delta\mathscr{P}(x)$ denote generic unpolarized and polarized parton, quark and gluon, distributions; $\lambda = \pm 1$ for antiparallel ($\uparrow\downarrow$) and parallel ($\uparrow\uparrow$) orientation of target and beam polarizations.

In the virtual photon–nucleon center-of-mass frame the elementary cross-sections will in general depend on the azimuthal angle ϕ between the incoming lepton and the produced parton [12]. It is therefore useful to split both $d\sigma_p$ and $d\ \Delta\sigma_p$ into

$$d\sigma_p = d\sigma_p^{(0)} + \cos\phi\ d\sigma_p^{(1)} + \cos 2\phi\ d\sigma_p^{(2)}, \tag{3}$$

and

$$d\ \Delta\sigma_p = d\ \Delta\sigma_p^{(0)} + \cos\phi\ d\ \Delta\sigma_p^{(1)}. \tag{4}$$

Formulae for the unpolarized part of the cross-section, $d\sigma_p$, were derived in ref. [12]. The polarized cross-sections, listed below, can be calculated using standard Feynman diagrams, see also ref. [13]. The contribution arising from the direct γ^*-quark scattering, fig. 1a, is given by

$$d\ \Delta\sigma_p^{(0),\text{fig.1a}} = \tfrac{1}{2}y(2-y)\ \delta(1-x_p)\ \delta(1-z_q),$$
$$d\ \Delta\sigma_p^{(1),\text{fig.1a}} = 0. \tag{5}$$

The $\gamma^* + q \to q + g$ process, fig. 1b, gives the contribution

$$d\ \Delta\sigma_p^{(0),\text{fig.1b}} = \tfrac{1}{2}y(2-y)\frac{2\alpha_S}{3\pi} \times \left[\frac{z_q^2 + x_p^2}{(1-x_p)(1-z_q)} + 2(x_p + z_q)\right], \tag{6}$$

$$d\ \Delta\sigma_p^{(1),\text{fig.1b}} = \frac{4\alpha_S}{3\pi} y \sqrt{\frac{(1-y)x_p z_q}{(1-x_p)(1-z_q)}}\ (1 - x_p - z_q).$$

Finally, the $\gamma^* + g \to q + \bar{q}$ process, fig. 1c, gives

$$d\ \Delta\sigma_p^{(0),\text{fig.1c}} = \tfrac{1}{2}y(2-y) \times \frac{\alpha_S}{4\pi}(2x_p - 1)\left(\frac{1-z_q}{z_q} + \frac{z_q}{1-z_q}\right), \tag{7}$$

$$d\ \Delta\sigma_p^{(1),\text{fig.1c}} = \frac{\alpha_S}{2\pi} y \sqrt{\frac{(1-y)x_p(1-x_p)}{(1-z_q)z_q}}\ (1 - 2z_q).$$

2.2. Polarized parton distributions

Unpolarized and polarized parton distributions $\mathscr{P}(x)$ and $\Delta\mathscr{P}(x)$ depend on the probability densities to find a parton polarized parallel ($\mathscr{P}_+$) or antiparallel ($\mathscr{P}_-$) to the polarization of the target:

$$\mathscr{P}(x) \equiv \mathscr{P}_+(x) + \mathscr{P}_-(x),$$
$$\Delta\mathscr{P}(x) \equiv \mathscr{P}_+(x) - \mathscr{P}_-(x). \tag{8}$$

A probabilistic interpretation of the individual parton densities $\mathscr{P}_+(x)$ and $\mathscr{P}_-(x)$ requires that the "unitarity condition" is fulfilled

$$|\ \Delta\mathscr{P}(x)\ | \le \mathscr{P}(x). \tag{9}$$

Equation (9) has in general to be taken into account in the process of determination the polarized parton distributions from experimental data. Care has to be taken that eq. (9) is satisfied for all relevant values of Q^2, otherwise the code will produce wrong results.

Like in LEPTO 4.3, the structure of the program allows the user to access easily that part of the code which determines the parton distributions and to modify them. For convenience, we included in PEPSI three different choices for the polarized parton distributions:

- The parton distributions introduced in ref. [10] do not assume any sea polarization and reproduce the observed asymmetry $A_1^p(x)$ with the help of a dilution factor applied to the valence quark distributions. These distributions are Q^2 independent and are based on the parametrization of the unpolarized parton distributions, which are also included.
- Among various parton distributions discussed in ref. [11] we have chosen two sets: one assuming $\Delta G(x) = 0$ and large sea polarization (set 1), and one corresponding to maximal gluon polarization (set 2) with an only weakly polarized sea. In the polarized parton distributions the value of Q^2 is fixed at 4 GeV^2. For the unpolarized parton distributions the standard Q^2 dependent parametrization of Glück, Hoffmann, and Reya is used [14]. The unitarity condition (9) is checked explicitly and, if violated, is taken care of by replacing the polarized distributions by unpolarized ones.

3. Structure of the program

PEPSI has preserved unchanged the original structure of LEPTO 4.3 as described in Ref. [4]. It is a "slave" system, i.e., it consists of callable routines only, therefore, the user must supply a main program. PEPSI requires JETSET 6.3 for the generation of the final hadronic state. In the following we assume the user is familar with the LUND program family, especially LEPTO 4.3 [4]. Here we just recall that the corresponding probabilities for the first-order QCD processes (gluon radiation from the struck quark and gamma–gluon fusion) have to be evaluated during initialization by a call to the subroutine LWEITS. Results are stored on logical I/O unit 20. The probabilities are then available as a function of x and W on a "grid" which can be chosen by the user. At the time of generation a linear interpolation is made between the points of the grid to obtain the probabilities for any value of x and W. These values are subsequently used by the event administration subroutine LEPTO to decide whether a $\gamma^* + q \to q + g$ (qg) or $\gamma^* + g \to q\bar{q}$ (qqb) event is to be generated rather then the leading $\gamma^* + q \to q$ (q) event.

Modifications have been carried out throughout the whole code, in particular:

(1) in the routine LEPTOX, which evaluates the total q event probability;
(2) inside DQCD which evaluates the first-order QCD matrix elements;
(3) inside DSIGMA which provides the differential cross-section for these processes; in these routines the polarized parts of the cross-sections, see section 2.1, have been added;
(4) in LQGEV and LQQBEV, which generate the qg and qqb events, modifications have been done in the part which determines the azimuthal angle of the final-state quark;
(5) similarly to LEPTO's function XQ (I, X, Q2), which provides the unpolarized parton distribution, a new one, XDQ (I, X, Q2) has been added to provide the polarized quark distribution for a parton of flavour I at a given value of x and Q^2;
(6) finally, a special checking procedure has been added at the initialisation stage in routine LINIT to make sure that the polarization flags of the read-in file correspond to those specified by the user in the current run.

3.1. Defining the polarization state

The polarization state is defined through the flag LST(40) which must be supplied by the user within the common block LEPTOU:

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

- If the event is of the type $\uparrow\downarrow$, where the arrows indicate the relative polarization of beam and target, one has to set LST(40) = 1 ≡ $\uparrow\downarrow$.

- The state in which both target and beam are polarized in the same direction ($\uparrow\uparrow$) is selected by setting LST(40) = $-1 \equiv \uparrow\uparrow$,
- The unpolarized case ($\lambda = 0$, default value) can be accessed by setting LST(40) = 0.

The typical experimental situation requires the measurement of differences between the antiparallel case ($\uparrow\downarrow$) and the parallel one ($\uparrow\uparrow$). For such an application at least two separate runs, one with LST(40) = +1, the other with LST(40) = −1, are required due to the "fixed" structure of event and QCD matrix elements generation. A third run, corresponding to unpolarized scattering, can be performed if the target and/or the beam depolarization effects have to be taken into account. The results from the various runs have then to be merged together according to the effective degree of polarization.

3.2. Selecting the polarized parton distributions

The user must select one of the implemented polarized quark momentum distributions by means of the flag LST(15) (default value is set to 2),

- LST(15) = 1, ref. [11], set 1 ($\Delta G(x) = 0$),
- LST(15) = 2, ref. [11], set 2,
- LST(15) = 3, ref. [10],

through the usual common block /LEPTOU/.

The functions for the polarized distributions in analogy to the unpolarized ones are called XDf (X, Q2) where f ≡ (U, UB, D, ...) denotes the flavour. The user can easily implement his or her own polarized distributions following the same scheme.

4. Sample program

At the end of this paper we give a simple example of how to use PEPSI for simulations. The program evaluates the first-order QCD weights and stores them on external file. At initialization these x and Q^2 distributions are produced with standard HBOOK routines.

5. Results of the test run

As a test we have performed the simulation of the event asymmetry $A_1^p(x)$ for lepton–proton scattering. We generated a sample of 10^6 events for each polarization and assumed the kinematics and geometrical acceptance of the detector of the proposed HERMES experiment at HERA [8]. The acceptance corrections were added at the stage of the event analyses. The Monte Carlo asymmetry A_1^{MC} is defined as

$$A_1^{MC}(x) = \frac{1}{P_B P_T D(x)} \frac{dN/dx^{\uparrow\downarrow} - dN/dx^{\uparrow\uparrow}}{dN/dx^{\uparrow\downarrow} + dN/dx^{\uparrow\uparrow}}, \tag{10}$$

where P_B and P_T are the beam and target polarizations, and $D(x)$ is the virtual photon depolarization factor [6]. In figs. 2 and 3 the Monte Carlo data for A_1^{MC} are compared with the exact theoretical result A_1^{TH},

$$A_1^{TH}(x) = \frac{2xg_1^p(x)}{F_2(x)(1+R(x))} = \frac{\sum_{i=u,d,s} e_i^2 \,\Delta q_i(x)}{\sum_{i=u,d,s} e_i^2 q_i(x)}, \tag{11}$$

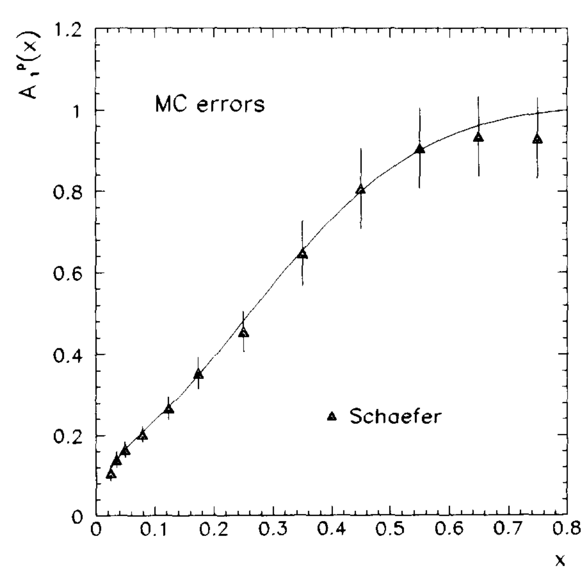

Fig. 2. Comparison of A_1^{MC} extracted from Monte Carlo data with A_1^{TH} defined by eq. (11). The polarized parton distributions of ref. [10] have been used. Error bars correspond to the estimated Monte Carlo accuracy.

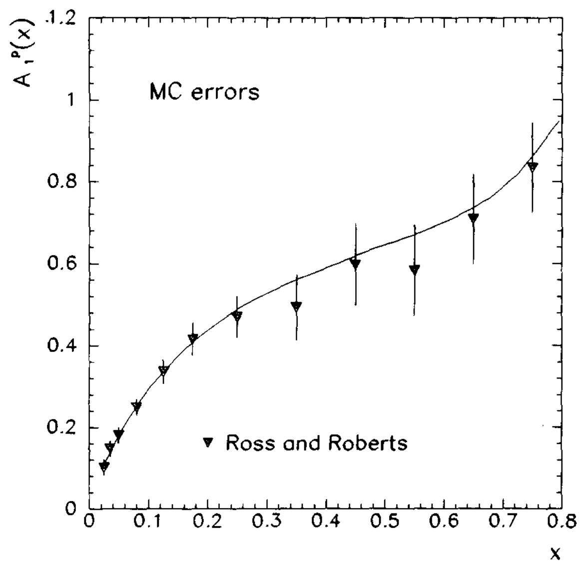

Fig. 3. Comparison of A_1^{MC} extracted from Monte Carlo data with A_1^{TH} defined by eq. (11). The polarized parton distributions of ref. [11], set 2, have been used. Error bars correspond to the estimated Monte Carlo accuracy.

where R is the ratio of longitudinal to transverse photoabsorbtion cross-section. The error bars correspond to the estimated Monte Carlo precision. Excellent agreement is found between the exact result and numerical simulation.

6. Acknowledgements

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EXAMPLE PROGRAM

```
C...Example program to generate events with PEPSI for
C...electron-proton polarized electromagnetic interaction
C...at HERMES energies (35 GeV e- on fixed p target).
C...
C...This program has to be linked to PEPSI, JETSET63 and CERN
C...libraries.
C...
      PARAMETER (NHB=40000)
      COMMON /PAWC/ HDUMMY(NHB)
      COMMON /LEPTOU/ CUT(14),LST(40),PARL(30),X,Y,W2,Q2,U
      COMMON /LUJETS/ N,K(2000,2),P(2000,5)
      EXTERNAL LEPTOD,LUDATA
C...  Kinematical cuts
*     X min cut
      CUT(1)=0.02
*     X max cut
      CUT(2)=0.80
*     Y min cut
      CUT(3)=0.
*     Y max cut
      CUT(4)=0.85
*     Q2 min cut
      CUT(5)=1.
*     Q2 max cut
      CUT(6)=20.
*     W2 min
      CUT(7)=4.
*     W2 max
      CUT(8)=500.
*     numin
      CUT(9)=0.
*     numax
      CUT(10)=30.
*     theta min
      CUT(13)=0.040
*     theta max
      CUT(14)=0.300
C...  Number of event to be listed
      ILIS=3
C...  Beam Energy (GeV)
      EBEAM=35.
C...  Target (hydrogen)
      PARL(1)=1.
C...  Select antiparallel polarization state
      LST(40)=1
C...  Select polarized distributions from Set 3
      LST(15)=3
C...  Keep exchanged virtual boson in the event record
      LST(3)=1
C...  x, y from cross section, apply cuts
      LST(2)=1

C...  Generate the file with weights on logic unit 20
C...  (once this file exists the user can skip this part;
C...  WARNING: one file per each polarization state is required)
      CALL LWEITS(7,0.,0.,EBEAM,0.,0.,0.,1)
      REWIND(20)

C...  Initialization routine. Reads QCD weights from logic unit 20
      CALL LINIT(20)
C...  Print out probabilities for q, qg, qqb events
      CALL LPRWTS(7,0.,0.,35.,0.,0.,0.,1,3)
      WRITE(6,*)'Give N. of events'
      READ(5,*) NEVENT

C...  Histogram booking
      CALL HLIMIT(NHB)
      CALL HBOOK1(10,'x Distribution: (1/NEV)*dN/dx',100,0.,1.,0.)
      CALL HBOOK1(20,'Q2 Distribution: (1/NEV)*dN/dQ2',25,0.,25.,0.)

C...  Event generation
      DO 100 I=1,NEVENT
   10 CALL LEPTO(7,0.,0.,35.,0.,0.,0.,1)
C...  Generation failed, reject event
      IF(LST(21).NE.0) GOTO 10
C...  Lund record listing
      IF(I.LE.ILIS)CALL LULIST(1)
C...  Histogram filling
      CALL HFILL(10,X,0.,1.)
      CALL HFILL(20,Q2,0.,1.)
  100 CONTINUE

C...  Normalise and print histograms
      CALL HOPERA(10,'+',10,10,100./1./MAX(1,NEVENT),0.)
      CALL HOPERA(20,'+',20,20,25./25./MAX(1,NEVENT),0.)
      CALL HISTDO

      END
```

TEST RUN OUTPUT

```
INTEGRATION OF QCD MATRIX ELEMENTS TO GIVE PROBABILITIES FOR FIRST ORDER QCD PROCESSES,

I.E. GLUON BREMSSTRAHLUNG AND VECTOR BOSON-GLUON FUSION, IN DEEP INELASTIC LEPTON-NUCLEON SCATTERING.

LEPTON TYPE :    7     LEPTON MOMENTUM (PX,PY,PZ):     0.0     0.0    35.0 GEV/C

TARGET NUCLEUS ; A =  1.0     Z =  1.0     NUCLEON MOMENTUM (PX,PY,PZ):     0.0     0.0     0.0 GEV/C

INTERACTION TYPE :    1

POLARIZATION STATE :    1

STRUCTURE FUNCTION SET :    3

MAXIMUM W =       8.1

NO. OF FLAVOURS IN TARGET NUCLEON SEA, LST(12) =    3

QCD-LAMBDA USED IN Q**2 EVOLUTION OF STRUCTURE FUNCTIONS, PARL(8) =   0.400

HEAVIEST FLAVOUR THAT CAN BE PRODUCED IN BOSON-GLUON FUSION, LST(13) =    4

PARAMETER VALUES FOR CUTS ON MATRIX ELEMENTS: PARL(11) =   1.000     PARL(12) =   0.050

PARAMETERS FOR ALPHA-STRONG (NOTE THAT ALPHA-S IS NOT INCLUDED WHEN WRITING RESULTS ON FILE):
MAXIMUM NO. OF FLAVOURS, LST(9) =    4      QCD-LAMBDA, PARL(10) =   0.300

REQUIRED PRECISION IN INTEGRATION, PARL(13) =   0.01000

GRID CHOSEN BY THE PROGRAM:
  A. W SCALE:     NO. OF POINTS, NWW =   15     W-VALUES IN ARRAY WW:
    3.0     4.5     6.0     7.0     8.0     9.0    10.0    11.0    12.0    13.0    15.0    17.5    20.0

  B. X SCALE:     NO. OF POINTS, NXX =   15     X-VALUES IN ARRAY XX:
  0.0100  0.0200  0.0300  0.0400  0.0600  0.0800  0.1000  0.1250  0.1500  0.2000  0.3000  0.4500  0.6000


PROBABILITIES FOR DIFFERENT EVENT TYPES AS A FUNCTION OF W AND X.
(ASSUMING THE SPECIFIED LEPTON ENERGY SO THAT Y IS DEFINED.)
```

W	X	"Y"	Q**2	ALPHA-S	SIGTOT	Q-EVENT	QG-EVENT	QQ-EVENT	MAX. OF MATRIX ELEMENTS FOR QG			
3.0	0.010	0.125	0.1	0.368	0.3121	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.020	0.126	0.2	0.368	0.3195	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.030	0.127	0.3	0.368	0.3216	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.040	0.129	0.3	0.368	0.3215	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.060	0.132	0.5	0.368	0.3190	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.080	0.134	0.7	0.368	0.3153	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.100	0.137	0.9	0.368	0.3112	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.125	0.141	1.2	0.368	0.3056	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.150	0.145	1.4	0.368	0.2991	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.200	0.155	2.0	0.368	0.2829	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.300	0.177	3.5	0.368	0.2372	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.450	0.225	6.6	0.325	0.1529	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.600	0.309	12.2	0.307	0.0764	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.750	0.494	24.4	0.269	0.0247	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
3.0	0.990	12.362	803.8	0.166	0.0000	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.010	0.298	0.2	0.368	0.2666	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.020	0.301	0.4	0.368	0.2743	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.030	0.304	0.6	0.368	0.2770	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.040	0.307	0.8	0.368	0.2776	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.060	0.314	1.2	0.368	0.2764	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.080	0.321	1.7	0.368	0.2740	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.100	0.328	2.2	0.368	0.2712	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(
4.5	0.125	0.337	2.8	0.368	0.2674	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00	(

4.5	0.150	0.347	3.4	0.368	0.2631	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00
4.5	0.200	0.369	4.8	0.350	0.2518	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00
4.5	0.300	0.421	8.3	0.309	0.2173	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00
4.5	0.450	0.536	15.8	0.292	0.1460	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00
4.5	0.600	0.737	29.1	0.261	0.0752	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00
4.5	0.750	1.180	58.1	0.233	0.0246	1.0000	0.0000	0.0000	0.00E+00	0.00E+00	0.00E+00
6.0	0.010	0.540	0.4	0.368	0.2198	0.9953	0.0000	0.0047	0.00E+00	0.00E+00	0.00E+00
6.0	0.020	0.546	0.7	0.368	0.2280	0.9941	0.0000	0.0059	0.00E+00	0.00E+00	0.00E+00
6.0	0.030	0.551	1.1	0.368	0.2315	0.9949	0.0002	0.0050	0.44E-01	0.12E-03	0.32E-02
6.0	0.040	0.557	1.5	0.368	0.2330	0.9929	0.0000	0.0071	0.00E+00	0.00E+00	0.00E+00
6.0	0.060	0.569	2.2	0.368	0.2335	0.9944	0.0000	0.0056	0.00E+00	0.00E+00	0.00E+00
6.0	0.080	0.581	3.1	0.368	0.2329	0.9945	0.0000	0.0055	0.00E+00	0.00E+00	0.00E+00
6.0	0.100	0.594	3.9	0.368	0.2319	0.9934	0.0000	0.0066	0.00E+00	0.00E+00	0.00E+00
6.0	0.125	0.611	5.0	0.347	0.2305	0.9961	0.0002	0.0037	0.43E-01	0.47E-03	0.10E-01
6.0	0.150	0.629	6.2	0.330	0.2288	0.9967	0.0000	0.0033	0.00E+00	0.00E+00	0.00E+00
6.0	0.200	0.668	8.8	0.305	0.2234	0.9974	0.0000	0.0026	0.00E+00	0.00E+00	0.00E+00
6.0	0.300	0.764	15.1	0.295	0.2010	0.9989	0.0000	0.0011	0.00E+00	0.00E+00	0.00E+00
6.0	0.450	0.972	28.7	0.262	0.1423	0.9994	0.0001	0.0004	0.17E-01	0.36E-03	0.13E-01
6.0	0.600	1.337	52.7	0.237	0.0753	0.9998	0.0000	0.0002	0.00E+00	0.00E+00	0.00E+00
7.0	0.010	0.740	0.5	0.368	0.1958	0.9808	0.0000	0.0192	0.00E+00	0.00E+00	0.00E+00
7.0	0.020	0.748	1.0	0.368	0.2045	0.9800	0.0019	0.0181	0.74E-01	0.18E-02	0.21E-01
7.0	0.030	0.755	1.5	0.368	0.2087	0.9784	0.0012	0.0204	0.47E-01	0.14E-02	0.16E-01
7.0	0.040	0.763	2.0	0.368	0.2109	0.9777	0.0003	0.0220	0.30E-01	0.42E-03	0.51E-02
7.0	0.060	0.779	3.1	0.368	0.2129	0.9800	0.0000	0.0200	0.00E+00	0.00E+00	0.00E+00
7.0	0.080	0.796	4.2	0.364	0.2136	0.9785	0.0036	0.0179	0.90E-01	0.76E-02	0.31E-01
7.0	0.100	0.814	5.3	0.342	0.2141	0.9819	0.0023	0.0158	0.65E-01	0.65E-02	0.28E-01
7.0	0.125	0.837	6.9	0.322	0.2146	0.9809	0.0054	0.0137	0.13E+00	0.23E-01	0.72E-01
7.0	0.150	0.862	8.5	0.307	0.2147	0.9870	0.0022	0.0107	0.81E-01	0.12E-01	0.40E-01
7.0	0.200	0.916	12.0	0.308	0.2133	0.9868	0.0067	0.0066	0.13E+00	0.27E-01	0.86E-01
7.0	0.300	1.047	20.6	0.277	0.1979	0.9946	0.0025	0.0028	0.54E-01	0.96E-02	0.39E-01
8.0	0.010	0.971	0.6	0.368	0.1847	0.9719	0.0063	0.0218	0.17E+00	0.40E-02	0.46E-01
8.0	0.020	0.981	1.3	0.368	0.1941	0.9717	0.0038	0.0245	0.89E-01	0.31E-02	0.43E-01
8.0	0.030	0.991	2.0	0.368	0.1991	0.9739	0.0012	0.0249	0.47E-01	0.14E-02	0.16E-01
9.0	0.010	1.232	0.8	0.368	0.1936	0.9730	0.0082	0.0188	0.22E+00	0.56E-02	0.97E-01

PROCESS, I.E. LST(23) = 1 HAS MAXIMUM "CROSS SECTION", SIGMAX = 0.3216

POLARIZED QUARK DIS. FROM SCHAEFER PARAM.

SUMMARY OF QCD MATRIX ELEMENT INTEGRATION

PROBABILITIES FOR DIFFERENT EVENT TYPES AS A FUNCTION OF W AND X.
(ASSUMING THE SPECIFIED LEPTON ENERGY SO THAT Y IS DEFINED.)

W	X	"Y"	Q**2	ALPHA-S	SIGTOT	Q-EVENT	QG-EVENT	QQ-EVENT
3.0	0.010	0.125	0.1	0.368	0.3121	1.0000	0.0000	0.0000
3.0	0.040	0.129	0.3	0.368	0.3215	1.0000	0.0000	0.0000
3.0	0.100	0.137	0.9	0.368	0.3112	1.0000	0.0000	0.0000
3.0	0.200	0.155	2.0	0.368	0.2829	1.0000	0.0000	0.0000
3.0	0.600	0.309	12.2	0.307	0.0764	1.0000	0.0000	0.0000
7.0	0.010	0.740	0.5	0.368	0.1958	0.9808	0.0000	0.0192
7.0	0.040	0.763	2.0	0.368	0.2109	0.9777	0.0003	0.0220
7.0	0.100	0.814	5.3	0.342	0.2141	0.9819	0.0023	0.0158
7.0	0.200	0.916	12.0	0.308	0.2133	0.9868	0.0067	0.0066
7.0	0.600	1.832	72.2	0.226	0.0770	1.0000	0.0000	0.0000
10.0	0.010	1.524	1.0	0.368	0.2303	1.0000	0.0000	0.0000

Give N. of events

THE LUND MONTE CARLO - JETSET VERSION 6.3
LAST DATE OF CHANGE: 10 FEBRUARY 1987

EVENT LISTING

I	ORI	PART/JET	PX	PY	PZ	E	M
1	0	E - B	0.000	0.000	35.000	35.000	0.001
2	0	P + B	0.000	0.000	0.000	0.938	0.938
3	0	GAMM V	-0.035	0.634	26.632	26.608	1.297
4	0	E -	0.035	-0.634	8.368	8.392	0.001
5	0	U JETF	-0.197	0.651	26.835	26.846	0.325
6	0	DU 0JETF	0.162	-0.017	-0.203	0.700	0.650
7	6	P +	0.334	0.177	0.219	1.035	0.938
8	6	RHO B- D	-0.355	-0.303	8.995	9.040	0.771
9	6	PI0 D	-0.069	0.819	17.035	17.055	0.135
10	5	PI +	0.055	-0.060	0.383	0.416	0.140
11	8	PI B-	0.209	-0.055	1.970	1.987	0.140
12	8	PI0 D	-0.565	-0.248	7.025	7.053	0.135
13	9	GAMM	0.025	0.413	7.835	7.846	0.000
14	9	GAMM	-0.094	0.407	9.200	9.209	0.000
15	12	GAMM	-0.206	-0.022	2.182	2.192	0.000
16	12	GAMM	-0.359	-0.226	4.843	4.861	0.000
	SUM:	0.000	0.000	0.000	35.000	35.938	8.159

EVENT LISTING

I	ORI	PART/JET	PX	PY	PZ	E	M
1	0	E - B	0.000	0.000	35.000	35.000	0.001
2	0	P + B	0.000	0.000	0.000	0.938	0.938
3	0	GAMM V	-1.178	0.996	11.197	11.147	1.870
4	0	E -	1.178	-0.996	23.803	23.853	0.001
5	0	D JETF	-1.135	1.204	11.272	11.397	0.325
6	0	UU 1JETF	-0.043	-0.207	-0.075	0.688	0.650
7	6	ETA' D	0.005	0.225	1.635	1.908	0.958
8	6	DELT+ D	-0.606	0.070	4.312	4.525	1.231
9	5	RHO B- D	0.168	0.017	1.563	1.751	0.771
10	6	RHO + D	-0.745	0.685	3.687	3.901	0.771
11	7	PI +	0.004	-0.022	0.042	0.148	0.140
12	7	PI B-	0.007	-0.016	0.289	0.322	0.140
13	7	ETA D	-0.006	0.263	1.304	1.439	0.549
14	8	N 0	-0.410	0.005	3.982	4.111	0.940
15	8	PI +	-0.196	0.065	0.330	0.414	0.140
16	9	PI B-	0.003	0.357	0.674	0.776	0.140
17	9	PI0 D	0.166	-0.340	0.888	0.975	0.135
18	10	PI +	-0.764	0.430	1.992	2.181	0.140
19	10	PI0 D	0.019	0.255	1.695	1.720	0.135
20	13	PI0 D	0.004	0.189	0.305	0.383	0.135
21	13	PI0 D	0.020	-0.046	0.590	0.607	0.135
22	13	PI0 D	-0.031	0.120	0.409	0.448	0.135
23	17	GAMM	0.124	-0.112	0.316	0.357	0.000
24	17	GAMM	0.042	-0.228	0.573	0.618	0.000
25	19	GAMM	0.036	0.253	1.668	1.688	0.000
26	19	GAMM	-0.017	0.001	0.027	0.032	0.000
27	20	GAMM	0.043	0.189	0.248	0.315	0.000
28	20	GAMM	-0.038	0.000	0.057	0.069	0.000
29	21	GAMM	0.070	-0.017	0.188	0.201	0.000
30	21	GAMM	-0.049	-0.029	0.402	0.406	0.000
31	22	GAMM	0.012	0.057	0.341	0.346	0.000
32	22	GAMM	-0.043	0.063	0.068	0.102	0.000
	SUM:	0.000	0.000	0.000	35.000	35.938	8.159

EVENT LISTING

I	ORI	PART/JET	PX	PY	PZ	E	M
1	0	E - B	0.000	0.000	35.000	35.000	0.001
2	0	P + B	0.000	0.000	0.000	0.938	0.938
3	0	GAMM V	-1.032	0.222	13.811	13.785	1.356
4	0	E -	1.032	-0.222	21.189	21.215	0.001
5	0	U JETF	-1.166	0.066	13.970	14.023	0.325
6	0	DU 0JETF	0.135	0.157	-0.159	0.700	0.650
7	5	OMEG D	-0.527	-0.182	5.176	5.265	0.783
8	5	RHO + D	0.132	-0.061	2.723	2.834	0.771
9	5	PI0 D	-0.157	0.182	1.024	1.060	0.135
10	5	PI0 D	-0.495	0.432	4.478	4.528	0.135
11	6	N 0	0.015	-0.149	0.410	1.036	0.940
12	7	PI +	-0.193	-0.075	2.572	2.584	0.140
13	7	PI B-	-0.329	-0.067	0.903	0.974	0.140
14	7	PI0 D	-0.005	-0.040	1.701	1.707	0.135
15	8	PI +	-0.063	-0.313	2.025	2.055	0.140
16	8	PI0 D	0.195	0.252	0.698	0.780	0.135
17	9	GAMM	-0.007	0.096	0.486	0.495	0.000
18	9	GAMM	-0.150	0.086	0.538	0.565	0.000
19	10	GAMM	-0.314	0.355	3.175	3.210	0.000
20	10	GAMM	-0.182	0.077	1.304	1.318	0.000
21	14	GAMM	-0.056	-0.020	0.374	0.379	0.000
22	14	GAMM	0.051	-0.020	1.327	1.328	0.000
23	16	GAMM	0.186	0.266	0.624	0.704	0.000
24	16	GAMM	0.008	-0.014	0.074	0.076	0.000
	SUM:	0.000	0.000	0.000	35.000	35.938	8.159

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.   HBOOK    HBOOK   CERN             VERSION    4.10        HISTOGRAM AND PLOT INDEX
.
.........................................................................................................
.
.  NO                       TITLE                          ID  B/C  ENTRIES DIM   NCHA     LOWER       UPPER
.
.........................................................................................................
.
.
.   1  x Distribution: (1/NEV)*dN/dx                       10  32    20000  1  X   100   0.000E+00   0.100E+01
.
.
.   2  Q2 Distribution: (1/NEV)*dN/dQ2                     20  32    20000  1  X    25   0.000E+00   0.250E+02
.
.
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MEMORY UTILISATION

     MAXIMUM TOTAL SIZE OF COMMON /PAWC/           40000
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x Distribution: (1/NEV)*dN/dx

HBOOK     ID =        10                                        DATE  18/02/92            NO =    1

       8.6        -
       8.4        I
       8.2        I
       8          I
       7.8        I
       7.6        I
       7.4        I
       7.2        I-
       7          II
       6.8        II
       6.6       -II
       6.4       I I
       6.2       I I
       6         I I
       5.8       I I
       5.6       I I-
       5.4       I  I-
       5.2       I   I
       5         I   I
       4.8       I   I
       4.6       I   I-
       4.4       I    I
       4.2       I    I
       4         I    I--
       3.8       I      I
       3.6       I      I-
       3.4       I       I-
       3.2       I        I-
       3         I         I-
       2.8       I          I-
       2.6       I           I -
       2.4       I           I-I
       2.2       I             I--
       2         I               I-- -
       1.8       I                 I-I
       1.6       I                   I---
       1.4       I                      I--
       1.2       I                        I---- -
       1         I                            I-I  -
        .8       I                              I--I -
        .6       I                                 I-I-- - -
        .4       I                                     I-I-I-----   -
        .2       I                                              I---I-----------------  - -   -

CHANNELS 100   0
          10   0        1         2         3         4         5         6         7         8
           1   12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

CONTENTS   1.    6875543333322222211111111111111 1
           0   00550524985218635018968455331111807785655344432222112201010100000000000000000000000000000
           0   00178659321357840345539405518834588968454760815827510191536062143241112002020001000000000

LOW-EDGE   1.            1111111111222222222233333333334444444444555555555566666666667777777777888888888
*10**  1   0   01234567890123456789012345678901234567890123456789012345678901234567890123456789012345678

* ENTRIES =       20000       * ALL CHANNELS = 0.1000E+03       * UNDERFLOW = 0.0000E+00       * OVERFLOW =
* BIN WID = 0.1000E-01        * MEAN VALUE   = 0.1528E+00       * R . M . S = 0.1229E+00
```

```
Q2 Distribution: (1/NEV)*dN/dQ2

HBOOK     ID =        20                                              DATE  18/02/92              NO =   2

       4.3      -
       4.2      I
       4.1      I
       4        I
       3.9      I
       3.8      I
       3.7      I
       3.6      I
       3.5      I
       3.4      I
       3.3      I
       3.2      I
       3.1      I
       3        I
       2.9      I
       2.8      I-
       2.7      II
       2.6      II
       2.5      II
       2.4      II
       2.3      II
       2.2      II
       2.1      II
       2        II
       1.9      II
       1.8      II
       1.7      II
       1.6      II
       1.5      II
       1.4      II
       1.3      II-
       1.2      I I
       1.1      I I
       1        I I
        .9      I I
        .8      I I
        .7      I I-
        .6      I  I
        .5      I  I
        .4      I  I-
        .3      I   I-
        .2      I    I--
        .1      I      I-----------

CHANNELS  10   0        1         2
           1   1234567890123456789012345

CONTENTS   1.   421
*10**  1   0   0272632110000000000000000
           0   0842360417444212100000000
           0   0800093146890100385500000

LOW-EDGE  10             111111111122222
           1.   123456789012345678901234

* ENTRIES =       20000      * ALL CHANNELS = 0.1000E+01      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.
* BIN WID = 0.1000E+01       * MEAN VALUE   = 0.2934E+01      * R . M . S = 0.2226E+01
```