SPHINX TT
Monte Carlo Program for Nucleon-Nucleon
Collisions with Transverse Polarization

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Abstract

We present the program summary and long write-up for SPHINX TT, a new Monte Carlo simulation for transversely polarized nucleon-nucleon scattering. The program is based on PYTHIA/JETSET.
**PROGRAM SUMMARY**

*Title of program:* Sphinx tt

*Catalogue number:

*Program available from:* Oliver Martin, [http://th.physik.uni-frankfurt.de/~martin/sphinx.html](http://th.physik.uni-frankfurt.de/~martin/sphinx.html)

*Computer:* IBM RS6000, PentiumPro 200 based PC; others with a FORTRAN 77 compiler

*Operating system:* tested under AIX and LINUX but does not depend on the particular operating system

*Programming language used:* FORTRAN 77

*High speed storage required:* 5 Mbytes

*Number of bits per byte:* 8

*Number of lines in combined test deck:* 19980

*CPC subprograms used:* Jetset 7.3

*Keywords:* transversely polarized nucleon-nucleon scattering, transversity parton distribution, high energy physics, Monte Carlo simulation

*Nature of physical problem:* This program can be used to simulate transversely polarized nucleon-nucleon collisions at high energies. Spins of colliding particles are taken into account. The program allows to calculate cross sections for various processes.

*Method of solution:* The existing Monte Carlo program Pythia 5.6 [1] has been modified to incorporate spin effects. The program incorporates nearly all features of Pythia.

*Restriction on the complexity of the problem:* The spins of the colliding hadrons must be transverse with respect to the collision axis. (A program for collisions of longitudinally polarized hadrons (Sphinx) is also available.) Furthermore, the spins of the two hadrons must be either parallel or antiparallel with respect to each other.

*Typical running time:* $\approx 0.01$ sec CPU per event on PentiumPro 200 based PC, depends strongly on kinematical cuts

*References:* For general information see the Pythia manual [4]. Specific details on Sphinx TT (and Sphinx) can be obtained from: Oliver Martin, Institut für Theoretische Physik, Goethe Universität, Robert-Mayer-Str. 8-10, 60054 Frankfurt am Main, Germany, e-mail: martin@th.physik.uni-frankfurt.de
Long Write-Up

1 Introduction

During recent years the topic of transverse spin effects has become increasingly popular. Especially the so called transversity parton distribution $\delta q(x, Q^2)$ which is comparable to $\Delta q(x, Q^2)$ in the case of a longitudinally polarized nucleon has attracted much attention (for a concise introduction see [3]). Due to experimental limitations, $\delta q(x, Q^2)$ could not be measured so far. Only high energy collisions of two transversely polarized nucleons or semi-inclusive deep inelastic electron-nucleon scattering with transverse polarization allow a determination of $\delta q(x, Q^2)$.

However, in 1992 the RHIC Spin Collaboration was constituted [4]. One of its major projects is the measurement of the transversity parton distribution by analysing collisions of transversely polarized protons at RHIC, which is now under construction at BNL. RHIC will be able to scatter protons at cm energies of up to $\sqrt{s} = 500$ GeV with high transverse or longitudinal polarization of up to 70%. A first measurement may already be possible in the year 2000 or shortly after. To plan for such experiments requires extensive Monte Carlo simulations. SPHINX TT was developed to perform such studies.

Developing a state-of-the-art Monte Carlo simulation takes several years. Therefore, we used SPHINX [5] which itself is an extension of the popular PYTHIA 5.6/JETSET 7.3 [1] as a basis for our program. SPHINX is able to simulate collisions of two longitudinally polarized nucleons in the framework of the QCD improved parton model and describes nucleons on twist-2 level [3]. On this level no new physics is involved in collisions of a transversely polarized nucleon with a longitudinally polarized nucleon [4]. For this reason we decided only to cover the scattering of two transversely polarized protons with our program, which we consequently called SPHINX TT. SPHINX is an acronym for Simulator of Polarized Hadronic Interact(X)ions.

The features of SPHINX TT are similar to those of SPHINX, namely

- Spin propagation. The spin information is propagated until the hard partonic interaction, i.e. the spin of the partons is taken into account in the initial state showering and hard partonic scattering. Final state interactions, such as final state showering and fragmentation, are treated as being spin-independent.

- Polarized hard processes are described at leading order in the electromagnetic and strong coupling constants. The processes currently implemented in the polarized mode are summarized in Table [3]. Contact interactions are not available yet in the polarized mode.
| ISUB | Process | Comment |
|------|---------|---------|
| 11   | $q_i q_j \rightarrow q_i q_j$ | (anti-)quark – (anti-)quark scattering; annihilation is not included |
| 12   | $q_i \bar{q}_i \rightarrow q_k \bar{q}_k$ | annihilation process |
| 13   | $q_i \bar{q}_i \rightarrow gg$ | annihilation into gluon pair |
| 14   | $q_i \bar{q}_i \rightarrow g\gamma$ | annihilation into gluon and prompt $\gamma$ |
| 18   | $q_i \bar{q}_i \rightarrow \gamma\gamma$ | annihilation into $\gamma$-pair |
| 28   | $q_i g \rightarrow q_i g$ | (anti-)quark – gluon scattering |
| 29   | $q_i g \rightarrow q_i \gamma$ | prompt $\gamma$-production in (anti-)quark – gluon scattering |
| 53   | $gg \rightarrow q_k \bar{q}_k$ | gluon fusion |
| 68   | $gg \rightarrow gg$ | gluon – gluon scattering |
| 191  | $q_i \bar{q}_i \rightarrow f_k \bar{f}_k$ | annihilation into lepton-pair or quark – (anti-)quark pair (Drell-Yan process); this process is new and equivalent to the $\gamma$-piece of ISUB=1 in PYTHIA |

Table 1: List of processes implemented in the polarized mode

- Polarized parton distributions. Two model parametrizations for $\delta q(x, Q^2)$ are provided, the inclusion of new ones is easy.

- Documentation. Spin information has been added to the event listing.

- SphINX TT is equivalent to PYTHIA 5.6 in its unpolarized mode.

Hereafter we do not try to explain the structure of PYTHIA 5.6 or the concepts that lead to the creation of SphINX. Readers which are unfamiliar with these programs should consult [2, 5]. In the next section we will present the most important differences between SphINX and SphINX TT. Section 2 contains a detailed description of the modified subroutines as well as three tables with all new switches and internal variables. Finally an example main program is presented.

## 2 From SphINX to SphINX TT: modifications

The most notable difference between the scattering of two *longitudinally* polarized nucleons and the scattering of two *transversely* polarized ones is that the symmetries in the cm frame are different. In the former case the system is invariant under rotations around the beam axis whereas in the latter case the transverse spin directions and the beam axis specify one or two planes in
space. As a result, the rotational invariance is broken and the partonic cross sections now also may depend on the azimuthal scattering angle.

In SPHINX TT the spins of the colliding nucleons are required to be either parallel or anti-parallel. Allowing for arbitrary transverse spins only changes the azimuthal dependence of the cross sections in a trivial way [6].

Since the partonic cross sections in PYTHIA and SPHINX are independent of the azimuth $\phi$ it simply can be chosen according to a flat distribution. In comparison, the generation of the remaining kinematical variables is a complicated process. In order to make as few modifications as possible the event machinery in SPHINX TT was not rewritten but a trick was used to include the correct generation of the azimuth.

During the initialization PYTHIA/SPHINX searches for the absolute maxima of the various selected partonic subprocesses. If “by accident” the program finds a point in the kinematical space with a larger partonic cross section, the program adjusts the maximum value. For that reason, one can simply include the normal $\phi$-dependent cross sections and all kinematical variables will be chosen correctly.

This method only works for $2 \rightarrow 2$-processes. Unfortunately, in PYTHIA / SPHINX the Drell-Yan process $q_i\bar{q}_i \rightarrow \ell \bar{\ell}$ was implemented as a $2 \rightarrow 1$-process with a successive decay of the gauge boson into a lepton pair. Furthermore, the two steps were performed by different subroutines. It was impossible to implement transverse polarization here without violating the program structure strongly and we simply included a new $2 \rightarrow 2$ subprocess for Drell-Yan events. For similar reasons the subprocesses which cover the QCD corrections to the simple Drell-Yan graph could not be made available.

The modification of the initial state showering routine was relatively simple. Only the appropriate splitting functions had to be included and the handling of the Lorentz boosts required some changes in order to treat the azimuth correctly.

3 Common Blocks and Subroutines

In this section a detailed description of the modified subroutines is given. In order for this section to be self contained we present the differences between PYTHIA and SPHINX TT rather than giving a summary of the differences between SPHINX and SPHINX TT. The general structure of the code as well as the unchanged parameters and variables are not explained. However, it is shown in detail how the local polarization switch IPOL is implemented into the different subroutines. Only the polarized case (IPOL=1) will be discussed, because in the unpolarized case (IPOL=0) each subroutine works exactly as the corresponding PYTHIA 5.6 subroutine. The subroutines of
| Parameter       | Description                                                                 | Default |
|-----------------|-----------------------------------------------------------------------------|---------|
| MSTP(171)       | beam polarization                                                           | 0       |
|                 | =0: unpolarized                                                             |         |
|                 | =1: polarization in +x direction                                             |         |
|                 | =2: polarization in −x direction                                             |         |
| MSTP(172)       | target polarization                                                          | 0       |
|                 | =0: unpolarized                                                             |         |
|                 | =1: polarization in +x direction                                             |         |
|                 | =2: polarization in −x direction                                             |         |
| MSTP(175)       | use of polarized parton distributions in polarized initial state shower (MSTP(176)=1) | 1       |
|                 | =0: unpolarized distribution; for testing only; do not use!                 |         |
|                 | =1: polarized                                                               |         |
| MSTP(177)       | set of polarized parton distributions δq(x, Q^2) used; in addition, one has to specify an unpolarized set as in standard PYTHIA | 0       |
|                 | =0: δq(x, Q^2) = 0 (no polarization)                                         |         |
|                 | =1: maximal polarization; δq(x, Q^2) = q(x, Q^2)                              |         |
|                 | =2: Model A: δq(x, 4 GeV^2) = Δq(x, 4 GeV^2) + correct DGLAP evolution set by Bartelski-Tatur [7] is used |         |
|                 | =3: same as before but Gehrmann-Stirling lo set C [8] is used                |         |
| MSTP(178)       | percentage of beam and target polarization                                   | 0       |
| MSTP(179)       | switch off polarization temporarily in PYSHIH and PYSTFU resp.               |         |
|                 | =0: no action                                                               |         |
|                 | =1: switch off polarization                                                 |         |
| MSTP(180)       | mode selection (master switch)                                              | 0       |
|                 | =0: unpolarized mode; this value overrides all other polarization switches   |         |
|                 | =1: polarized mode                                                          |         |
| NSUB(ISUB)      | mode for subprocess ISUB                                                    | 0       |
|                 | =0: unpolarized treatment                                                   |         |
|                 | =1: polarized treatment                                                     |         |
| NSEL            | menu of polarized processes                                                  | 0       |
|                 | =1: ISUB = 11,12,13,28,53,68 switched on                                    |         |
|                 | =10: ISUB = 14,18,29 switched on                                            |         |

Table 2: Parameters controlling the polarized mode
| Variable   | Description                                                                 | Com. Block |
|------------|-----------------------------------------------------------------------------|------------|
| MINT(311)  | beam polarization                                                          | PYINT1     |
|            | =0: unpolarized                                                            |            |
|            | =1: transverse polarization in +x direction                                |            |
|            | =2: transverse polarization in −x direction                                |            |
| MINT(312)  | target polarization                                                         | PYINT1     |
|            | =0: unpolarized                                                            |            |
|            | =1: transverse polarization in +x direction                                |            |
|            | =2: transverse polarization in −x direction                                |            |
| MINT(313)  | polarization of shower initiator on beam side                              | PYINT1     |
|            | =0: unpolarized                                                            |            |
|            | =1: transverse polarization in +x direction                                |            |
|            | =2: transverse polarization in −x direction                                |            |
| MINT(314)  | polarization of shower initiator on target side                            | PYINT1     |
|            | =0: unpolarized                                                            |            |
|            | =1: transverse polarization in +x direction                                |            |
|            | =2: transverse polarization in −x direction                                |            |
| MINT(315)  | polarization of hard interacting parton on beam side                       | PYINT1     |
|            | =0: unpolarized                                                            |            |
|            | =1: transverse polarization in +x direction                                |            |
|            | =2: transverse polarization in −x direction                                |            |
| MINT(316)  | polarization of hard interacting parton on target side                     | PYINT1     |
|            | =0: unpolarized                                                            |            |
|            | =1: transverse polarization in +x direction                                |            |
|            | =2: transverse polarization in −x direction                                |            |
| VINT(397)  | azimuthal angle of the hard scattering plane with respect to the x-axis    | PYINT1     |
|            | before the initial state shower and primordial transverse momentum are     |            |
|            | generated; measured in cm-frame of hard interaction                        |            |
| VINT(398)  | same as VINT(397) after generation of initial state shower and             | PYINT1     |
|            | prim. transverse momentum                                                  |            |
| VINT(399)  | scattering angle in the cm frame of the hard partonic interaction before   | PYINT1     |
|            | the initial state shower and primordial transverse momentum are generated   |            |
| VINT(400)  | same as VINT(399) after generation of initial state shower and             | PYINT1     |
|            | prim. transverse momentum                                                  |            |

Table 3: Internal variables storing polarization information
| Variable           | Description                                                                 | Com. Block |
|--------------------|-----------------------------------------------------------------------------|------------|
| ISIG(1000,6)       | hard scattering information of Nth channel                                  | PYINT3     |
| ISIG(N,1)          | particle code of Nth channel on beam side                                  |            |
| ISIG(N,2)          | particle code of Nth channel on target side                                |            |
| ISIG(N,3)          | colour flow of Nth channel                                                 |            |
| ISIG(N,4)          | polarization of Nth channel on beam side                                   |            |
| ISIG(N,5)          | polarization of Nth channel on target side                                 |            |
| ISIG(N,6)          | not used                                                                    |            |
| KD(I)              | polarization of Ith line in the event listing                              | DPYPOL     |
|                    | =0: no polarization                                                         |            |
|                    | =1: transverse polarization in +x direction                                |            |
|                    | =2: transverse polarization in −x direction                                |            |
| XSFX(2:-40:40,0:2) | x times parton distribution for given x and $Q^2$ of flavour KFL= −40:40 and transversity KFLD=0:2 on beam side (JT=1) and target side (JT=2) resp. unpolarized | PYINT3     |
| XSFX(JT,KFL,0)     | positive polarization with respect to transverse hadron polarization       |            |
| XSFX(JT,KFL,1)     | negative polarization with respect to transverse hadron polarization       |            |
| XSFX(JT,KFL,2)     | negative polarization with respect to transverse hadron polarization       |            |

Table 4: Internal variables storing polarization information
SPHINX TT which we don’t mention explicitly remain unchanged with respect to PYTHIA 5.6.

To incorporate polarization the following common blocks have either been enlarged, replacing the corresponding PYTHIA common blocks or have been added:

- COMMON/PYINT3/XSFX(2,−40:40,0:2),ISIG(1000,6),SIGH(1000)
- COMMON/PYSUBS/MSEL,NSEL,MSUB(200),NSUB(200),KFIN(2,−40:40),CKIN(200)
- COMMON/DYPOL/KD(4000)

Information about the new internal variables and enlarged arrays can be found in Table 2.

MAIN PROGRAM

Purpose: to set up the polarized event generation. The variables which have to be specified are listed in Table 2.

Remarks: An example program is given in Section 4

SUBROUTINE PYINIT

Purpose:

- to display SPHINX TT header;
- to check partially the availability of the desired polarization scenario, i.e. to check that the master switch for polarization MSTP(180) is set properly, that the selected partonic subprocesses can be treated polarized and to control and compose the polarization menu via NSEL;
- to call DPLIST instead of LULIST (see below).

New Parameters: MSTP(180), NSEL, NSUB(ISUB)

Internal Polarization Switch: IPOL=MSTP(180)

Remarks: If the chosen scenario is not allowed, the program is terminated with an appropriate error message.

SUBROUTINE PYEVNT

Purpose:

- to start polarized event generation;
- to call DPEDIT instead of LUEDIT (see below).

New Parameters: MSTP(180)

New Variables: VINT(397), VINT(398), VINT(399), VINT(400)

Internal Polarization Switch: IPOL=MSTP(180)

Remarks: VINT(397)−VINT(400) can be used to measure the rotation of
the hard scattering partonic system caused by the initial state shower and the primordial transverse momentum of the partons; if this effect is not small (check!) the transversity distribution is not used correctly in the hard scattering because the particle spins are no longer aligned along the x-axis; also, the implementation of the initial state shower is then no longer appropriate since at each partonic branching the azimuthal angles are chosen according to a flat distribution instead of the correct one. This latter shortcoming could be overcome if needed, but this would require major changes in the program.

SUBROUTINE PYINKI(CHFRAM, CHBEAM, CHTARG, WIN)
Purpose:

- to check availability of the desired hadronic polarization scenario, i.e. to control that the selected hadron can be treated polarized;

- to store the polarization of beam and target for the event listing in KD(1) and KD(2) and for internal use in MINT(311) and MINT(312).

New Parameters: KD(1), MSTP(171), MSTP(172), MSTP(180)
New Internal Variables: MINT(311), MINT(312)
Internal Polarization Switch: IPOL=MSTP(180)
Remarks: At present only nucleons and their antiparticles can be treated polarized. If a not allowed scenario has been chosen, the program is terminated with an appropriate error message.

SUBROUTINE PYRAND
Purpose:

- to adapt PYRAND to the new environment - all relevant arrays which have been enlarged or added to the common blocks in other subroutines are modified here as well;

- to extend event shape selection to incorporate transverse spin;

- to store polarization of the partons entering the hard interaction in MINT(313) - MINT(316) (see Table 3).

New Parameters: MSTP(180), NSUB(ISUB)
New internal variables: MINT(313), MINT(314), MINT(315), MINT(316)
Internal polarization switch: IPOL=MSTP(180)×NSUB(ISUB)
Remarks: Note that MINT(313)=MINT(315) and MINT(314)=MINT(316) but the values of MINT(313) and MINT(314) are changed later by the initial state shower in PYSSPA.

SUBROUTINE PYSCAT
Purpose:

- to adopt PYSCAT to the new environment (see PYRAND);
• to store transverse spin information of the partons entering the hard interaction;
• to add spin information to lines 1, 2 and 5, 6 in the event listing (see below).

New Parameters: KD(I), MSTP(180), NSUB(ISUB)
New internal variables: MINT(315), MINT(316)
Internal Polarization Switch: IPOL=MSTP(180)×NSUB(ISUB)

SUBROUTINE PYSSPA(IPU1,IPU2)
Purpose:
• to perform polarized initial state showering, transversity dependent DGLAP evolution equations are used in the backward evolution algorithm;
• to enlarge all relevant arrays in an appropriate manner to incorporate polarization;
• to check proper selection of the polarized initial state shower scenario, i.e. to control that MSTP(175) and MSTP(176) are set correctly;
• to store the polarization of the initial state shower initiators (MINT(313), MINT(314)).

New Parameters: KD(I), MSTP(171), MSTP(172), MSTP(175), MSTP(176), MSTP(180), NSUB(ISUB)
New Internal Variables: MINT(313), MINT(314), MINT(315), MINT(316)
Internal Polarization Switch: IPOL=MSTP(180)×NSUB(ISUB)
Remarks: At the present stage only QCD shower can be treated polarized, QED showering has to be done in the unpolarized manner. The combination MSTP(175)=0 and MSTP(176)=1 allows to simulate polarized showering with the use of unpolarized parton distributions. This option is just for testing and should not be selected by the user! If MSTP(175) or MSTP(176) are set improperly, the program stops with an appropriate error message. The internal variables MINT(313) and MINT(314) are changed to their final values in this subroutine.

The handling of the Lorentz boosts in PYSSPA has been modified so that the azimuthal angle is propagated through the event. Nevertheless, at each partonic branching the azimuth of the decay plane with respect to the transverse spin of the decaying parton is distributed according to a flat distribution instead of the correct one. Only if the initial state shower does not cause a substantial rotation of the hard scattering partonic system this approximation is justified. This shortcoming can be overcome if needed but would require substantial changes in the program.

SUBROUTINE PYMULT(MMUL)
Purpose: to switch off polarization in PYSLAH (set MSTP(179)=1 temporarily) when called from PYMULT. This is done because multiple interactions
cannot be treated polarized at the moment.

New Parameters: MSTP(179)

SUBROUTINE PYREMN(IPU1,IPU2)
Purpose:

- to adopt PYREMN to the new environment (see PYRAND);
- to add spin information to lines 3 and 4 in the event listing (see below).

New Parameters: KD(I)
Remarks: The generation of the primordial transverse momentum has been modified so that the azimuthal angles are now treated correctly.

SUBROUTINE PYSIGH(NCHN,SIGS,IOC)
Purpose:

- to evaluate the transversity dependent hadronic cross sections by convolution of the spin dependent parton distributions with the transversity dependent partonic cross sections;
- to supply the subroutine with the transversity dependent partonic cross sections.

New Parameters: IOC,MSTP(171),MSTP(172),MSTP(179),MSTP(180),NSUB(ISUB)
Internal Polarization Switch:
IPOL=MSTP(180)×NSUB(ISUB)×(1-MSTP(179))
New Partonic Subprocess: ISUB=191 (q_i + q̄_i → f_k f̄_k)
Remarks: PYSIGH will always run in the unpolarized mode when it is called by PYMULT which sets temporarily MSTP(179)=1 in PYSIGH. When one evaluates the spin dependent hadronic cross sections one has to be aware that the hadrons are labelled according to their absolute spin whereas the partons are specified according to their relative spin with respect to the spin of the hadron. The parton distributions are passed from PYSTFU to PYSIGH through the array XPQ(KFL,KFLD) (see below) and stored in the array XSFX(N,KFL,KFLD), where KFLD denotes the transversity. ISIG(N,I) contains the information about the Nth reaction channel of the chosen partonic subprocess. The new entries ISIG(N,4) and ISIG(N,5) specify the transverse spin of the partons at the beam and target side respectively. ISIG(N,6) is reserved but not used at the moment.

The cross sections in PYTHIA and SPHINX are independent of the azimuthal scattering angle which therefore can be easily chosen according to a flat distribution. Contrarily, in SPHINX TT the cross section depends on the azimuth Φ. Correct generation can be achieved by simply using the Φ-dependent formulae of the partonic cross sections. Furthermore, during the initial search for the maximum of the partonic cross sections the azimuth must be fixed (IOC=0). During the normal event generation IOC=1 is set by PYRAND. No
other changes are required to ensure correct generation of all kinematical variables. Contact interactions are not yet available for the polarized mode. The new partonic subprocess ISUB=191 that corresponds to ISUB=1 had to be included in PYSIGH in order to preserve the program structure. The important difference is that no $Z^0$-propagator is included in the new process and that ISUB=191 is a $2 \to 2$-process rather than a $2 \to 1$ one. One should be careful when using the subprocess ISUB=11 because here only interference graphs carry an asymmetry. These are only taken into account if one sets MSTP(34)=1.

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

**Purpose:** to evaluate the transversity dependent parton distributions for given flavour (KF), $x$ (X), and $Q^2$ (Q2) according to the selected parametrizations and models

**New Parameters:** MSTP(177), MSTP(178), MSTP(179), MSTP(180), MSUB(ISUB)

**Internal Polarization Switch:** IPOL=MSTP(180)×(1-MSTP(179))

**Remarks:** Call of PYSTFU returns $x$ times the parton distribution functions for given flavour, $x$, and $Q^2$ for both spin orientations and an averaged (unpolarized) value. The values are stored in the array XPQ(KFL,KFLD) which has been enlarged from XPQ(-25:25) to XPQ(-25:25,0:2). XPQ(KFL,0) contains the unpolarized distributions, XPQ(KFL,1) distributions for positive relative transversity and XPQ(KFL,2) distributions for negative relative transversity. The parton distributions are selected by switches described earlier in Table 2. The polarized distributions $q_{\uparrow\downarrow}(x,Q^2)$ are constructed from the unpolarized ones $q(x,Q^2)$ and the transversity distributions $\delta q(x,Q^2)$ selected by MSTP(177) according to $q_{\downarrow\uparrow} = \frac{1}{2}(q\pm\delta q)$. The interface to the CERN parton distribution library has been updated so that Pdflib 4.0 and higher versions can be used with Sphinx TT. Two subroutines have been added to calculate the polarized distributions, namely BARTAT and GEHRMA. They require the data files bartat.dat and gehrmann.dat which are supplied with the program and must be visible to the FORTRAN `open` statement. Therefore the paths of these files have to be modified appropriately in the subroutines mentioned above. When $q$ and $\delta q$ are combined to compute the distributions for fixed transversity an unitarity check is performed — if one of the resulting values is negative this value is set to zero and the value for the other spin direction is set equal to the unpolarized one. Only polarized proton parametrizations are implemented. Neutron distributions are obtained by SU(2) symmetry. Charge conjugation is used to describe the corresponding antiparticles.

**SUBROUTINE PYSTPR(X,Q2,XPPR)**

**Purpose:** to calculate the unpolarized parton distributions of the proton; to update the implementation of the CTEQ2 parton distribution functions

**Remark:** the Interface to PYCTQ2 was taken from PYTHIA 5.7
FUNCTION PYCTQ2 (Iset, Iprt, X, Q)

Purpose: to give the revised CTEQ2 parton distribution sets with extended range in parametrized form.

Remark: This function was taken from PYTHIA 5.7.

SUBROUTINE BARTAT(X,Q2,UPV,DNV,EM,DELTA)

Purpose: to return \(x\) times the polarized parton distributions evaluated at given \(x\) (\(X\)) and \(Q^2\) (\(Q^2\)) for model 1. \(UPV, DNV, EM, DELTA\) contain \(\delta u_v, \delta d_v, \delta M\) and \(\delta\) \(\delta\) repectively.

Remarks: We use \(\delta q(x, 4 \text{ GeV}^2) = \Delta q(x, 4 \text{ GeV}^2)\) for lack of any knowledge of \(\delta q(x, Q^2)\). One actually has to expect that \(\delta q\) and \(\Delta q\) differ substantially because their evolution equations are different. For \(\Delta q(x, 4 \text{ GeV}^2)\) the Bartelski-Tatur parametrization \(\cite{7}\) is used. The \(\delta q\)-values for higher \(Q^2\) were obtained by correct DGLAP evolution. BARTAT requires the data file bartat.dat.

SUBROUTINE GEHRMA(X,Q2,UPV,DNV,EM)

Purpose: to return \(x\) times the polarized parton distributions evaluated at given \(x\) (\(X\)) and \(Q^2\) (\(Q^2\)) for model 2. \(UPV, DNV, EM\) contain \(\delta u_v, \delta d_v\) and \(\delta s\) repectively. The sea is assumed to be SU(3) symmetric.

Remarks: In this model \(\delta q(x, 4 \text{ GeV}^2) = \Delta q(x, 4 \text{ GeV}^2)\) is assumed for lack of any knowledge of \(\delta q\). The Germann-Stirling Set C \(\cite{8}\) is used for \(\Delta q\). The \(\delta q\)-values for higher \(Q^2\) were obtained by correct DGLAP evolution. GEHRMA requires the data file gehrmann.dat.

SUBROUTINE DPLIST(MLIST)

Purpose: to display the polarizations of the particle in the event listing.

New Parameters: KD(I)

Remarks: DPLIST is a modification of the JETSET subroutine LULIST. It is changed to display the polarization in the final listing. The sign displayed just behind the particle code denotes polarization with respect to the \(x\)-axis. When the sign is missing the particle has been treated as being unpolarized. The information is taken from the vector KD(I) and printed using the symbols

\[= \text{‘ ‘} : \text{no polarization (KD(I)=0)}\]
\[= \text{‘\&’} : \text{transverse polarization in } +x \text{ direction (KD(I)=1)}\]
\[= \text{‘\textbackslash’} : \text{transverse polarization in } -x \text{ direction (KD(I)=2)}\]

SUBROUTINE DPEDIT(MEDIT)

Purpose: to properly compress the vector KD(I) which contains the polarization information.

New Parameters: KD(I)

Remarks: DPEDIT is a modification of the JETSET subroutine LUEDIT.
SUBROUTINE PDFSET(PARM, VALUE)
Purpose: new dummy routine for new PDLIB interface; has to be removed if PDLIB is used.

SUBROUTINE STRUCTM(XX, QQ, UPV, DNV, USEA, DSEA, STR, CHM, BOT, TOP, GLU)
Purpose: new dummy routine for new PDLIB interface; has to be removed if PDLIB is used.

4 The Main Program

4.1 The code

PROGRAM EXAMPLE
C Example of a Main Program for event generation
C in proton-proton scattering with transverse polarization
C
C One beam is polarized in +x direction, the other one in -x direction
C
C This program has to be linked with
C the programs SPHINX TT and JETSET 7.3,
C the data files BARTAT.DAT and GEHSTI.DAT, and
C the CERN Libraries
C
COMMON BLOCKS of SPHINX TT for event generation
COMMON/LUDAT1/MSTU(200), PARU(200), MSTJ(200), PARJ(200)
COMMON/LUJETS/N, K(4000,5), P(4000,5), V(4000,5)
COMMON/PYSUBS/MSEL, NSEL, MSUB(200), NSUB(200),
& KFIN(2, -40:40), CKIN(200)
COMMON/PYPARS/MSTP(200), PARP(200), MSTI(200), PARI(200)
COMMON/PYINT5/NGEN(0:200,3), XSEC(0:200,3)
COMMON/PAWC/HBOOK(10000)
DIMENSION ROBO(3)
C==============================================================================
C polarization set up
C==============================================================================
C polarized simulation
MSTP(180)=1
C beam polarized in +x direction
MSTP(171)=1
C "target" polarized in -x direction
MSTP(172)=2
C "fully" polarized parton distributions
MSTP(177)=1
C the degree of polarization of each beam is only 70%
MSTP(178)=70
C polarized initial state shower
MSTP(176)=1

C=============================================================
C event set-up
C=============================================================
C select hard subprocesses a la carte
MSEL=0
C choose "Drell-Yan" q q̅ --> gamma --> f f̅
MSUB(191)=1
C switch on polarization for 191
NSUB(191)=1
C switch off multiple interactions
MSTP(81)=0
MSTP(131)=0
C number of events to be generated
NEVENT=1000

C=============================================================
C start
C=============================================================
C initialize
CALL PYINIT(‘CMS’,’p’,’p’,200.)
C book histograms
CALL HLIMIT(10000)
CALL HBOOK1(1,’azimuthal distrib.’,20,-3.1416,3.1416,0.)
C event loop
DO 200 I=1,NEVENT

CALL PYEVNT

C list first few events
IF(I.LE.6) CALL DPLIST(1)

C detect myons and electrons
IF(ABS(K(7,2)).EQ.13.OR.ABS(K(7,2)).EQ.11) THEN
C boost to di-lepton rest-frame
DO 100 J=1,3
   ROBO(J)=(P(7,J)+P(8,J))/(P(7,4)+P(8,4))
100 CONTINUE
ROBOT=ROBO(1)**2+ROBO(2)**2+ROBO(3)**2
   IF(ROBOT.GE.0.999999) THEN
      ROBOT=1.00001*SQRT(ROBOT)
      ROBO(1)=ROBO(1)/ROBOT
      ROBO(2)=ROBO(2)/ROBOT
      ROBO(3)=ROBO(3)/ROBOT
   ENDIF
   CALL LUDBRB(1,N,0.,0.,-DBLE(ROBO(1)),
&       -DBLE(ROBO(2)),-DBLE(ROBO(3)))

C calculate azimuthal angle
   PHI=PLU(7,15)

C fill histogram
   CALL HFILL(1,PHI,0.,1.)
ENDIF

200 CONTINUE

C print cross section and statistics
CALL PYSTAT(1)
CALL HRPUT(0,'example.hbk','n')

END
4.2 The Event Listing

SPHINX TT version 1.00
** Last date of change: 10 Oct 1996 **

The Lund Monte Carlo - PYTHIA version 5.6
** Last date of change: 3 Apr 1992 **

The Lund Monte Carlo - JETSET version 7.3
** Last date of change: 10 Mar 1992 **

1************* PYINIT: initialization of PYTHIA routines ******

===============================================
I I
I PYTHIA will be initialized for a p on p collider  I
I at 200.000 GeV center-of-mass energy  I
I I
===============================================

** PYMAXI: summary of differential cross-section maximum search *

===============================================
I I
I I
I ISUB Subprocess name  I Maximum value  I
I I I
===============================================
I I
I 191 f + f~ -> f + f~  I 6.5589E-05  I
I I I
===============================================

************** PYINIT: initialization completed **************

Event listing (summary)
| particle/jet | KF orig | p_x  | p_y  | p_z   | E    | m    |
|-------------|---------|------|------|-------|------|------|
| 1 !p+!      | 2212\^ 0 | 0.000 | 0.000 | 99.996 | 100.000 | 0.938 |
| 2 !p+!      | 2212\^v | 0.000 | 0.000 | -99.995 | 100.000 | 0.938 |
| 3 \!u!      | 2\^ 1   | -0.414 | -0.069 | 25.831 | 25.835 | 0.000 |
| 4 \!u~!     | -2\^ 2  | -0.207 | -0.420 | 0.321  | 0.568  | 0.000 |
| 5 \!u!      | 2\^ 3   | -0.414 | -0.069 | 25.831 | 25.835 | 0.000 |
| 6 \!u~!     | -2\^ 4  | -0.207 | -0.420 | 0.321  | 0.568  | 0.000 |
| 7 \!u!      | 2\^ 0   | -1.025 | 0.598 | 23.197 | 23.227 | 0.006 |
| 8 \!u~!     | -2\^ 0  | 0.404  | -1.087 | 2.956  | 3.175  | 0.006 |

Warning: maximum violated by 1.017E+00 in event 10
ISUB = 191; Point of violation:
\( \tau = 4.112E-04, y^* = -1.309E+00, cthe = -0.6715451, \tau' = 0.000E+00, \)
\( \phi = 1.299 \)
\( \text{XSEC}(191,1) \) increased to 6.673E-05

Warning: maximum violated by 1.011E+00 in event 82
ISUB = 191; Point of violation:
\( \tau = 3.328E-04, y^* = -8.523E-01, cthe = 0.8431695, \tau' = 0.000E+00, \)
\( \phi = 1.961 \)
\( \text{XSEC}(191,1) \) increased to 6.745E-05

Warning: maximum violated by 1.039E+00 in event 566
ISUB = 191; Point of violation:
\( \tau = 3.455E-04, y^* = -9.051E-01, cthe = 0.8579352, \tau' = 0.000E+00, \)
\( \phi = 1.735 \)
\( \text{XSEC}(191,1) \) increased to 7.016E-05

1*** PYSTAT: Statistics on Number of Events and Cross-sections ***

| I | Subprocess | Number of points | Sigma | (mb) |
|---|------------|------------------|-------|------|
| I | All included subprocesses | 1000 | 4831 | 1.481E-05 |
| I | 191 \( f + f^- \rightarrow f + f^- \) | 1000 | 4831 | 1.481E-05 |
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