Abstract
This is the manual of the specialized event generator TopReX 3.25. The generator provides the simulation of several important processes in $pp$ and $p\bar{p}$ collisions, not implemented in PYTHIA (yet). Some of these processes include $t$-quarks whose spin polarizations are taken into account in the subsequent decay of the $t$-quarks. Several non-SM top quark decay channels are included, too. All calculated subprocesses can be accessed from PYTHIA as external processes. In addition, TopReX can be used as stand alone event generator, providing partonic final states before showering. In this mode the control of the event generation is taken by TopReX itself. A few simple examples of main routines, which show how to use TopReX in the different modes are discussed.

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Introduction

The event generator TopReX in its present version (3.25) provides the generation of important heavy particle production processes in $pp$ and $p\bar{p}$ collisions ($t$-quarks, charged Higgs, etc.), which are not implemented in the high energy physics event generator PYTHIA (yet). The subprocesses implemented in the present version of TopReX are listed in Table 1.

Table 1: TopReX processes and corresponding process numbers. The user can choose a specific process by passing, among others, the wanted process number $IPROC$ to the initialization subroutine $TOPREX(FRAME, BEAM, TARGET, IPROC, ECM)$.

| Process | $IPROC$ |
|---------|---------|
| $q(\bar{q})b \rightarrow q'(\bar{q}')t$ | 1 |
| $q(\bar{q})g \rightarrow q'(\bar{q}')t\bar{b}$ | 2 |
| $gb \rightarrow tW$ | 3 |
| $q\bar{q}' \rightarrow W^* \rightarrow tb$ | 4 |
| $q\bar{q}' \rightarrow WQQ, Q = b, c$ | 5 |
| $q\bar{q}' \rightarrow W^* \rightarrow \tau\nu$ | 6 |
| $q\bar{q}' \rightarrow W^* \rightarrow \tau\nu + jet$ | 7 |
| $gg + q\bar{q} \rightarrow t\bar{t}$ | 20 |
| $gg \rightarrow t\bar{t}$ | 21 |
| $q\bar{q} \rightarrow t\bar{t}$ | 22 |
| $gg + q\bar{q} \rightarrow (H \rightarrow) t\bar{t}$ | 50 |
| $gg \rightarrow (H \rightarrow) tt$ | 51 |
| $q\bar{q} \rightarrow (H \rightarrow) tt$ | 52 |

After the generation of a hard subprocess, TopReX returns for any generated event the following information:

- the differential cross section value,
- flavours and momenta of the initial and final state partons,
- colour flow information,
- parton shower arrangements (shower pairs/partners and scales),

which is stored in the PYTHIA common block /PYUPPR/. Subsequently, PYTHIA can be used for the fragmentation of quarks and gluons into jets, followed by the hadronization and the decay of resonances. Initial and final state radiation as well as multiple interaction models can be used as usual. In analogy to PYTHIA internal processes all TopReX subprocesses can be accessed by PYTHIA through the call of an external process (one at a time). After the simulation of a hard subprocess in TopReX through a PYTHIA call of the $PYUPEV$ subroutine, the standard PYTHIA common block /PYJETS/ is filled with all necessary information about the flavour and momenta of the initial and final state partons, the colour flow and parton shower arrangements and scales.

The polarization of final $t$-quarks is calculated and taken into account in the subsequent decay of the $t$-quarks. For processes with $\tau$-leptons in the partonic final state (originating from top decays or directly produced by $W$ or $H^\pm$ bosons) the polarization of the $\tau$-leptons is calculated, too. The decay of the polarized $\tau$-leptons is treated by the TAUOLA package. Thus TopReX provides the generation of hard subprocesses as listed in Table 1 with subsequent decays of heavy particles, given in Table 2.

$$t \rightarrow bW^+, \rightarrow bH^+, \rightarrow q\gamma, \, qq, \, qZ$$

| Process | $IPROC$ |
|---------|---------|
| $W, Z \rightarrow f\bar{f}', f = q, l, \nu$ | |
| $H^\pm \rightarrow f\bar{f}', f = q, l, \nu$ | |
| $\tau^- \rightarrow \nu_\tau l^- \nu, \nu_\tau \bar{\nu}, ...$ | |

Table 2: Decay channels of heavy particles included in TopReX.
There are two alternative ways in which TopReX can be used. Fully integrated into PYTHIA by linkage of the TopReX package as matrix element library, respecting the programming structure of PYTHIA in such a way that the impact for the user has been minimized or as stand-alone program avoiding the overhead of PYTHIA if it is not needed. While the former is more practical for the usage of already existing analysis routines and interfaced detector simulations, the latter provides a complete analysis environment with the possibility of booking and filling histograms.

Before the usage of TopReX will be discussed in more detail a closer look at the data structure and program flow gives useful insights in the functionality of the program.

1. General structure of TopReX package

The structure of TopReX and the corresponding program flow is shown in fig. [1]

If needed, the user can modify PYTHIA parameters first. This can be done in the main.f routine or in a separate user’s subroutine (e.g. subroutine TXPYIN, see appendix 2). Two examples of main.f routines and a corresponding subroutine to set PYTHIA parameters are presented in the appendices 1 and 2.

Then the subroutine TOPREX(FRAME, BEAM, TARGET, IPROC, ECM) has to be called, in which all variables are identical to those used in the call of the PYINIT subroutine except the integer variable IPROC, which specifies the number of the TopReX process. The character variable FRAME is foreseen to pass the information of the rest frame in which the generated event has to be evaluated. The colliding particles have to be specified in the character variables BEAM and TARGET and the center of mass energy of the collider has to be given in the variable ECM. These are all parameters, needed to run TopReX. Only in the case of very specific processes with Flavour Changing Neutral Current (FCNC) interactions the appropriate parameters should be specified in the subroutine FCNC_INI.

After the initialization of TopReX the subroutine PYINIT has to be called for the initialization of PYTHIA. Subsequently events can be generated. This is typically done in an event loop as shown in the example program main.f. At this place the user may call its own analysis routines (see appendix 2).

PYTHIA can access the processes of TopReX as external processes through a call to the subroutine PYUPEV. This routine, in turn, calls the appropriate TopReX routines, needed to evaluate matrix elements squared, Lorentz invariant phase spaces (LIPS), parton luminosities (quark and gluon distributions of the beam particles) as well as to provide colour flow information and to set up parton shower arrangements and scales of the hard subprocess. Finally, all information of the generated event is stored in PYTHIA common block /PYUPPR/. Returned from the PYUPEV subroutine, PYTHIA applies its standard procedure of jet fragmentation, hadronization and resonance decays. The simulated events are written to the standard common block /PYJETS/.

As default, control printout is sent to the terminal. In addition a second possibility to store the printout in a separate file (toprex.info) is provided. In this case, the user should call the subroutine TXWRIT(-6) in the main.f routine before any initialization. The parameter value ’-6’ means, that the file toprex.info will be assigned to the Logical Unit Number (LUN) 6.

As described above, all parameters can also be specified in two separate routines (main.f or TXPYIN and TopReX). In addition, the user can use a special file run.dat to read in input parameters (see appendix 3 for details).

2. TopReX linkage to PYTHIA

Along with the TopReX package comes a GNUmakefile which links the necessary libraries and the source code together and produces an executable. The program package was tested under Solaris, Digital Unix, and Linux and should also run on other platforms. The libraries PYTHIA and cernlib are assumed to be accessible under the path /cern/pro/lib. If this is not the case the user has to change
the library search path accordingly. The TAUOLA library is provided as source code and will be compiled as separate library. The TopReX source code, the slightly modified PYTHIA subroutines PYDECY, PYEVNT, PYSHOW, and PYUPIN (for PYTHIA version 6.136 and newer) are compiled together with the example main program listed below. To take into account the different cases of the different versions of PYTHIA, two targets which produce executables are provided in the GNUmakefile. For PYTHIA before version 6.157 the executable has to be produced by the command $\texttt{gmake toprex.exe}$ while $\texttt{gmake TX.exe}$ has to be used otherwise. If the user is already familiar with the event generator PYTHIA, the TopReX package may easily be integrated in existing program structures (user main program, analysis routines and detector simulation).

The user has to keep in mind to compile and link all routines of the TopReX package beside his routines. To achieve this, either the user program file names have to be added in the provided GNUmakefile, e.g. they may be appended to the $\texttt{USEROBJ}$ variable or all TopReX related file and library names have to be included in the user makefile.

3. Interface and program flow

Global TopReX parameters can be accessed and changed via the common block $\texttt{TXPAR}$:

\begin{verbatim}
COMMON/TXPAR/ Ipar(200), Rpar(200).
\end{verbatim}

Integer values like the TopReX process number to be chosen by the user are stored in the array $\texttt{Ipar}$ as indicated in Table I. Floating point values like the hadronic centre-of-mass energy available for collisions are stored in the array $\texttt{Rpar}$. A complete list of the parameters and their default values is given in appendix 4. As a minimal requirement the number of a subprocess has to be specified. Further parameters like the hadronic centre-of-mass energy, particle masses etc. are taken from PYTHIA. Two examples how to use TopReX in conjunction with PYTHIA are given in appendices 1 and 2.

In analogy to the PYTHIA common block $\texttt{/PYDAT3/}$, which offers the possibility to switch on/off specific decay channels of particles after the generation of the hard subprocess, the TopReX common block $\texttt{/TXRDEC/}$ provides this possibility for $W^\pm$, $H^\pm$, and $t$-quark decays which are part of the hard subprocess. For convenience, the numbering scheme is adopted to that of PYTHIA. Numbers of the Individual Decay Channels (IDC’s) for $W$ and $Z$-bosons are identical to those of PYTHIA (see PYTHIA Manual [1]). IDC numbers for $H^\pm$ are identical to those of the $W^\pm$ boson with one additional channel (IDC=21): $H^\pm \rightarrow \bar{b}t^* \rightarrow \bar{b}Wb$. For top quark decays the IDC’s are defined as follows:

1. (IDC = 1) SM decay, $t \rightarrow bW$
2. (IDC = 2) $t \rightarrow bW$ decay via SM and beyond SM interactions
3. (IDC = 3) $t \rightarrow bH^\pm$
4. (IDC = 4,..,11) correspond to top quark decay via Flavour Changing Neutral Current interactions

The common block $\texttt{/TXRDEC/}$ is defined as follows:

\begin{verbatim}
COMMON/TXRDEC/ MID(4,0:30), BRF(4,30), FID(4,30,5), BRS(4,5)
\end{verbatim}

with the integer parameter array $\texttt{MID}$ and the double precision parameter arrays $\texttt{BRF}$, $\texttt{FID}$ and $\texttt{BRS}$, explained below.

\textbf{Purpose}: to access particle decay data and parameters. The first index $I$ (I=1,2,3,4) of the arrays corresponds to $t$-quark, $W$, $H$, and $Z$-boson decays, respectively.

$\texttt{MID(I, IDC)}$ : on/off switch for IDC (meaning identical to PYTHIA parameter $\texttt{MDME}$)

$\texttt{MID(I, 0)}$ : total number of allowed IDC

= -1 coupling switched off
channel is switched off for decay, but it contributes to the total width
channel is switched on
channel is switched on for particle but off for anti-particle
channel is switched on for anti-particle but off for particle
are not used in current version 3.25 of TopReX.

BRF(I,IDC) : branching fraction for given IDC
FID(I,IDC,j) : contains the KF code for decay products of a given IDC,
meaning identical to PYTHIA parameter KFDP
BRS(I,IDC) : sum of branching fractions for different decay groups

4. Description of hard processes

Some comments on the hard processes of TopReX, listed in table 1, are made in the following. The kinematics of a hard process can be specified by setting the values of the PYTHIA parameters CKIN(1:4) in the main.f or TXPYIN routine. The values of the CKIN parameters are copied to the TopReX parameters Rpar(101:104) in the subroutine TOPREX. Three processes (Ipar(1) = 1, 7, 10) are singular at \( \hat{p}_\perp \to 0 \). To avoid the singularities a conventional kinematical cut on (\( \hat{p}_\perp \)) has to be used (a minimal value of 20 GeV is recommended):

\[ \text{CKIN(3) = 20.d0 (copied during initialization to the TopReX parameter Rpar(103))} \]

The \( W \)-gluon fusion processes (Ipar(1) = 1, 2), \( W^* \to \tau \nu (\text{Ipar}(1) = 6, 7) \) and \( H^{\pm*} \to \tau \nu \) (Ipar(1) = 9, 10) need some comments concerning the problem of double counting, given below. Following the work of [8] a simple method for the generation of such reactions is applied (see also [9]).

\( \diamond \) Single top Production: \( W \)-gluon fusion, Ipar(1) = 1, 2
Two different subprocesses can be used for the generation of single top production in \( W \)-gluon fusion processes: \( 2 \to 2 \) (Ipar(1) = 1) with CKIN(3) = 0.0 and \( 2 \to 3 \) (Ipar(1) = 2) with CKIN(3) = 20.0. The additional \( \bar{b} \)-quark in the first kind of events appears in the initial state and can be found in the PYJETS list. Such an event will be accepted for further analysis, if the transverse momentum of this additional \( \bar{b} \)-quark does not exceed some threshold \( p_\perp(b) \) (typically of the order \( \sim 10 \) GeV). An event of the second kind (\( qg \to q't\bar{b} \) process) will be accepted if the transverse momentum of the final \( \bar{b} \)-quark from the hard process will be greater than the \( p_\perp(b) \) value.

\( \diamond \) \( W^* \to \tau \nu (\text{Ipar}(1) = 6, 7) \) and \( H^{\pm*} \to \tau \nu \) (Ipar(1) = 9, 10) processes:
These processes are generated in the same way as for the single top production process through the \( W \)-gluon fusion mechanism. However, the user should examine the transverse momentum of the intermediate \( W^* \) or \( H^* \)-boson, here. For \( W^* \) production processes it is recommended to choose threshold values above

\[ p_\perp(W) \approx 40 \text{ GeV} \]
For the charged Higgs production the \( p_\perp(H) \) value depends on the mass of the charged Higgs and should be figured out by the user.

For processes with a charged Higgs (\( H^{\pm} \)) the default values for \( M(H^{\pm}) \) and \( \tan \beta \) are given below:

\[ M(H^{\pm}) = 300 \text{ GeV} \quad \text{Rpar(51)} \]
\[ \tan \beta = 50 \quad \text{Rpar(55)} \]
To change these values the corresponding parameters Rpar(51), Rpar(55) have to be modified in the subroutine TOPREX.

\( \diamond \) Top anti-top quark pair production: \( t\bar{t} \to bW^+\bar{b}W^- \to 6 \) fermions
The processes Ipar(1) = 20, 21, 22 provide the \( t\bar{t} \) production in the Breit-Wigner approach with off-shell \( W \) bosons [3] (see [5] for details about the top quark production). The \( t\bar{t} \) processes (Ipar(1) = 50, 51, 52, 53)
51, 52) in the on-shell approximation [6] provide the possibility to switch on an intermediate neutral Higgs boson which becomes resonant in the case of a Higgs mass above the $t\bar{t}$ production threshold. Below, the $t\bar{t}$ production via a Higgs resonance is switched off. The matrix elements calculate the coherent contribution of the resonant Higgs boson and the non resonant $t\bar{t}$ background. They are also valid in supersymmetric extensions of the standard model in case of squark masses above 400 GeV, since the contributions of such heavy squarks are negligible [7]. The scalar and pseudoscalar Yukawa couplings to top quarks are described by the parameters $R_{par}(81) = a$ and $R_{par}(82) = \tilde{a}$ respectively. The standard model couplings of the Higgs boson to the $W$ and $Z$ vector bosons are realized with a multiplicative factor, the relative coupling strength $R_{par}(80) = g_{VV}$, which depends as the reduced Yukawa couplings in a two Higgs doublet model on the ratio of the vacuum expectation values of the Higgs doublets. In the $t\bar{t}$ matrix elements used here this factor is important, to take into account the total decay width of the Higgs boson, which is also printed as control output after initialization of the processes. The user has to provide the values for the Higgs boson couplings. Several examples are listed in Table 3.

| $R_{par}(80)$ | $R_{par}(81)$ | $R_{par}(82)$ |
|--------------|---------------|---------------|
| Standard model Higgs boson: | $g_{VV} = 1$, | $a = 1$, | $\tilde{a} = 0$ |
| Pseudoscalar Higgs boson: | $g_{VV} = 0$, | $a = 0$, | $\tilde{a} = 1$ |
| CP violating Higgs boson: | $a \neq 0$, | $\tilde{a} \neq 0$ |

Table 3: Examples of the Higgs boson couplings $R_{par}(80) = g_{VV}, R_{par}(81) = a$ and $R_{par}(82) = \tilde{a}$ of the $t\bar{t}$ production processes $\text{i}_{par}(1) = 50, 51, 52$.

5. Comparison of parton distributions

To demonstrate the reliability of the processes implemented in TopReX, they are compared to the default processes of PYTHIA 6.1, for $pp$ collisions at $\sqrt{s} = 14$ TeV (LHC).

In the upper plot of figure 2 the distribution of the top quark mass is shown for the two event generators. The $2 \rightarrow 6$ $t\bar{t}$ matrix elements in the Breit-Wigner approach are in good agreement with the $2 \rightarrow 2$ $t\bar{t}$ matrix elements of PYTHIA 6.1. The lower plot shows that the $p_{\perp}$ spectrum of the top quarks are in agreement for the different event matrix elements of the compared generators.

In figure 3 the spin correlation between the top quark decay products is shown for the $t\bar{t}$ production in the di-leptonic decay channel. The angles of the two leptons are evaluated in the helicity basis convenient at the LHC [14], [15]. While the $2 \rightarrow 2$ matrix elements of PYTHIA cannot include the spin correlation, the $2 \rightarrow 6$ matrix elements of TopReX do. Conclusively, the asymmetry coefficient of the spin correlation obtained using default PYTHIA gives vanishing values. In contrast the standard model prediction, reproduced by TopReX to leading order, yields the asymmetry coefficient $A_{SM} = 0.32$ using the parton densities of CTEQ4L.

Figure 4 shows a comparison of the $t\bar{t}$ spin correlation with help of the helicity basis for the matrix elements in the Breit-Wigner (left) and on-shell (right) approach, implemented in TopReX. The contribution to this correlation of the gluon gluon fusion (top) and the quark anti-quark annihilation processes (center) is given separately. The predictions of the matrix elements in the Breit-Wigner approach and in the on-shell approach agree quite well.

6. Conclusions

The specialised event generator TopReX, which provides the simulation of several heavy quark production processes in hadronic collisions has been described. As cross check many comparisons of parton distributions between the matrix elements implemented in PYTHIA and TopReX have been applied. The agreement is very good except in cases like the spin correlation where default PYTHIA is not able to reproduce the standard model predictions.
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Appendix 1.

The example main program shows the usage of a particular (PYTHIA external) TopReX subprocess. PYTHIA parameters like particle masses, etc. and the TopReX process number (IPROC parameter) are specified in the MAIN_1 routine shown below. To access any TopReX subprocess the parameter IPROC has to be set to the desired subprocess (here IPROC = 50 specifies the $t \bar{t}$ production in the on-shell approach). The choice has to be made before the call of the TOPREX subroutine. The further initialisation of PYTHIA is done by a call to the subroutine PYINIT.

```fortran
PROGRAM MAIN_1

IMPLICIT NONE
CHARACTER*8 FRAME, BEAM, TARGET
DOUBLE PRECISION ECM ! CMS energy
INTEGER IPROC ! number of TopReX process
INTEGER I

EXTERNAL PYDATA
INTEGER MSTU, MSTJ,KCHG, MDCY,MDME, KFDP, MSEL, MSELPD, MSUB
INTEGER KFIN, MSTP, MSTI
DOUBLE PRECISION PARU, PARJ, PMAS, PARF, VCKM, BRAT, CKIN
DOUBLE PRECISION PARP, PARI

COMMON /PYDAT1/ MSTU(200),PARU(200),MSTJ(200),PARJ(200)
COMMON /PYDAT2/ KCHG(500,4),PMAS(500,4),PARF(2000),VCKM(4,4)
COMMON /PYDAT3/ MDCY(500,3),MDME(4000,2),BRAT(4000),KFDP(4000,5)
COMMON /PYSUBS/ MSEL,MSELPD,MSUB(500),KFIN(2,-40:40),CKIN(200)
COMMON /PYPARS/ MSTP(200),PARP(200),MSTI(200),PARI(200)

FRAME = 'CMS'
BEAM = 'P'
TARGET = 'P'
ECM = 14000.d0 ! LHC cms energy (in GeV)

IPROC = 50 ! tt\bar{t} production

PMAS(6,1) = 175.d0 ! top mass
PMAS(5,1) = 4.8d0 ! bottom mass
PMAS(23,1) = 91.187d0 ! Z0 mass
PMAS(24,1) = 80.41d0 ! W mass
PMAS(25,1) = 400.d0 ! Higgs mass

MSTP(51) = 7 ! PDF: CTEQ5L

CALL TOPREX(FRAME, BEAM, TARGET, IPROC, ECM)
CALL PYINIT(FRAME,BEAM,TARGET, ECM)

DO I = 1,10
   PRINT*, 'Event number I=',I
   CALL PYEVNT()
   CALL PYHEPC(1)
   IF (I.LE.2) CALL PYLIST(2)
c... at this place analysis routines and/or
c... detector simulations may be called
ENDDO
END
```
Appendix 2.

Contrary to the previously described MAIN_1 routine, this example considers the possibility to set all PYTHIA parameters in a special TXPYIN subroutine. In addition, a few parameters are read in by the TXRINT subroutine from an external input data file, named run.dat (see appendix 3 for details). An example of a special routine for user’s analysis (USRPRO) is described, too.

```fortran
PROGRAM MAIN_2
IMPLICIT NONE
DOUBLE PRECISION Ecm ! CMS energy
INTEGER IPROC ! no. of Toprex process
INTEGER Ntot, N, MODE, IER ! internal variables

*..............................................................
Ecm = 14000.d0 ! CMS energy (in GeV) for LHC option

* call TXWRT(-6) ! LUN=6, open file with output information
* call TXRINT('iproc=', iproc, ier) ! no. of TopRex process
call TXRINT('Ntot=', Ntot, ier) ! number of events to be generated
* call TXPYIN(IPROC, Ecm) ! all PYTHIA will be specified there
* for compilation user’s program WITHOUT TopRex package comment next line
if(Iproc.ge.1) call TOPREX('CMS','P','P', IPROC, Ecm) ! TopRex init.
* . . . . . . . .
* call PYINIT('CMS','P','P', Ecm)
call PYSTAT(4)
c... call analysis/detector simulation routine for initialisation
mode = -1
call USRPRO(mode, Ntot)
*... end of initialisation
DO N = 1, Ntot
  if(mod(N,1000).eq.1) write(*,*)' event no=', N
  call PYEVNT()
call PYHEPC(1)
c... call analysis/detector simulation routine for running
mode = 0
call USRPRO(mode, N)
ENDDO
*
call PYSTAT(1) ! Brief statistics output from PYTHIA
*... call analysis/detector simulation routine for closing
mode = 1
call USRPRO(mode, N)
*...
STOP
END
```

The following example routine TXPYIN is used to set PYTHIA parameters.

```fortran
SUBROUTINE TXPYIN(IPROC, Ecm)
IMPLICIT NONE

*... Standard PYTHIA ( v. >= 6.1) commons for initialization.
EXTERNAL PYDATA
INTEGER MSTU, MSTJ, KCHG, MDCY, MDME, KFDP, MSEL, MSUB, KFIN,
& MSTP, Msti, MSelpd
DOUBLE PRECISION
& PARU, PARJ, PMAS, PARF, VCKM, BRAT, CKIN, PARP, PARI
COMMON /PYDAT1/ MSTU(200), MSTJ(200), MSEL(200), MSUB(200), KFIN(200),
& MSTP, Msti, MSelpd
```

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This example routine is used for further fast simulation of CMS detector response (by call of CMSJET routine) and for writing of NTUPLE (by call of TXNT routine).

SUBROUTINE USRPRO(MODE, NV)

IMPLICIT NONE
INTEGER MODE, NV ! internal variables

if(MODE.EQ.-1) THEN
* initialisation
call CMSJET(MODE) ! reading and initialisation of CMSJET
elseif(MODE.EQ.0) THEN ! running
call CMSJET(MODE) ! running of CMSJET
elseif(MODE.EQ.1) then ! closing files, etc
call CMSJET(MODE)
ENDIF
END
Appendix 3.

Tools to read in parameters

The input data file run.dat has a simple format. The data card will be ignored, if it is:
• a totally blank card
• a card with the first non-blank '*' character (a comment card)
• a card without '=' character

The first item in the card with data is a key of a variable. The '=' character should be explicitly given behind this key. Then one or several numerical values have to be given. The rest of the card is considered as comment. Two examples of such cards are given below.

* comment
iproc = 21    ! no. of TopRex process (21 = gg -> tt⁻ production)
filout = myout.dat ! name of the output data file
*    New Physics scale (1 TeV)
Rpar(60) = 1000.0 ! in GeV

In this example the items 'iproc =', 'filout =', and 'Rpar(60) =' are the keys, while '21', 'myout.dat' and '1000.0' are the corresponding values to be read. Four different subroutines are provided to read these data:

call TXRCHR(fkey, 'filout', fname, IER) ! character value
call TXRINT(fkey, 'iproc =', iproc, IER) ! integer value
call TXRFL8(fkey, 'rpar(60) =', Rpar(60), IER) ! double precision value
call TXRFL4(fkey, 'name =', realvalue, IER) ! single precision value

where the second parameter is a key-string, the third parameter is the value of the key variable, and IER is an error flag (IER = 1 means that the subroutine is not able to find appropriate data in the file 'run.dat').

The first parameter, fkey, is the key for the file, from which the parameters are to be read (the 'run.dat' file in this example):

character *6 fkey    ! key for file with input data
data fkey/'rundat'/

The user can also read several numerical values from one card. As an example, we present the card with the key of 'H⁺⁻ boson', with two numerical values, '220.' and '25.' being the mass of the $H^±$-boson and the $\tan\beta$ parameter.

* mass and tan(beta) parameters for H⁺⁻ boson process
H⁺⁻ boson = 220. 25.

To read this card a character string (here STROUT) should be described and the TXRSTR subroutine is used to read these two values:

CHARACTER *80 STROUT ! string to be used for data input
........
call TXRSTR('h⁺⁻ boson =', STROUT, IER)
read(STROUT,*) Rpar(51), Rpar(55) ! mass and tan(beta)
........

For string-key values in the run.dat file and in the parameters of the subroutines TXR... lowercase and uppercase letters are allowed (the read in routines are not case sensitive). Blank characters are allowed, too.
Appendix 4.

The parameters of the /TXPAR/ common block are explained in the following. The default values of the parameters are given in the parentheses (D = ...)

```plaintext
COMMON/TXPAR/ Ipar(200), Rpar(200)
```

**Purpose:** to store information of several TopReX global parameters.

- **Ipar(1):** TopReX's process number
- **Ipar(2):** number of events to be generated
- **Ipar(4):** continuation flag
- **Ipar(5):** number of entries used for estimation of \( |M|^2 \) (D = 100000)
- **Ipar(6):** number of entries used for estimation of \( Q \)-quark for \( WQ \bar{Q} \) process (D = 5, \( Q = b \)-quark)
- **Ipar(8):** quark masses, (D=1 : RPP values), 2 : PYTHIA values

- **Rpar(1):** \( \sqrt{s} = E_{cm} \) in GeV.
- **Rpar(2):** \( s = E_{cm}^2 \) in GeV
- **Rpar(3):** evolution scale for PDF evaluation
- **Rpar(4):** evolution scale for evaluation of \( \alpha_s \)
- **Rpar(10):** \( \alpha_{QED} = (1/128) \) electromagnetic coupling
- **Rpar(11):** \( e = \sqrt{4\pi\alpha_{QED}} \) electric charge
- **Rpar(12):** Fermi constant \( G_F \)
- **Rpar(13:17):** \( \sin \theta_W, \cos \theta_W, \sin^2 \theta_W, \cos \theta_W, \sin 2\theta_W \)
- **Rpar(18:19):** \( g = e/\sin \theta_W, g_z = e/\sin 2\theta_W \)
- **Rpar(20):** 0.38939 transformation 1/GeV^2 to mb
- **Rpar(21:26):** \( \pi, 2\pi, (2\pi)^3, (2\pi)^4, (2\pi)^6 \)
- **Rpar(30):** SM top quark decay width (\( t \to bW \))
- **Rpar(31):** total top quark decay width (including non-SM interactions)
- **Rpar(32):** partial top quark decay width for \( t \to bH^\pm \)
- **Rpar(41:44):** \( W \)-boson parameters, \( M_W, M_W^2, \Gamma(W), M_W \cdot \Gamma(W) \)
- **Rpar(45:48):** \( Z \)-boson parameters, \( M_Z, M_Z^2, \Gamma(Z), M_Z \cdot \Gamma(Z) \)
- **Rpar(51:56):** \( H^\pm \) boson parameters, \( M_H, M_H^2, \Gamma(H), M_T, \tan \beta, \cot \beta \)
- **Rpar(60):** (D=1000.d0) New Physics scale, \( \Lambda = 1 \) TeV
- **Rpar(61:76):** anomalous FCNC top quark couplings (FCNC_INI routine)
- **Rpar(81):** \( g_{VV} \), relative coupling of Higgs boson to \( W \) and \( Z \) vector bosons (processes Ipar(1) = 50, 51, 52 only)
- **Rpar(82):** \( a \), scalar Yukawa coupling of Higgs boson to top quarks (processes Ipar(1) = 50, 51, 52 only)
- **Rpar(83):** \( a \), pseudoscalar Yukawa coupling of Higgs boson to top quarks (processes Ipar(1) = 50, 51, 52 only)
- **Rpar(101):** \( \sqrt{s_{min}} \) for hard process (D = 20 GeV), identical to CKIN(1)
- **Rpar(102):** \( \sqrt{s_{max}} \) for hard process (D = \( \sqrt{s} \)), identical to CKIN(2)
- **Rpar(103):** minimal value for \( p_{\perp} \) (D = 5 GeV), identical to CKIN(3)
- **Rpar(104):** minimal value for \( p_{\perp} \) (D = \( \sqrt{s}/2 \)), identical to CKIN(4)
Fig. 1: Program flow chart. The main program, stored in the physical file main.f, initializes TopReX and PYTHIA. The initialization of TopReX consists predominantly of the passage of electroweak parameters from PYTHIA to TopReX followed by the estimation of the maximal value of the differential cross section for the chosen hard scattering process. After the initialization the generation of scattering events takes place in the event loop of the main program through a call to the PYTHIA subroutine PYEVNT. The subroutine PYUPEV (whose PYTHIA dummy version is overwritten by TopReX) is called subsequently.
Fig. 2: The top quark mass (upper plot). The distribution of the $2 \rightarrow 6\, t\bar{t}$ matrix elements of TopReX in the Breit-Wigner approach shows agreement with the prediction of the $2 \rightarrow 2\, t\bar{t}$ matrix elements of PYTHIA 6.1. The natural width of the top quark mass is fitted with a Breit-Wigner function. The lower plot shows the $p_{\perp}$ spectrum of the top quarks. The prediction of PYTHIA 6.1 coincides with the on-shell approach of TopReX. The Breit-Wigner approach, used here with a completely different $Q^2$ scale, gives quite similar results.
Fig. 3: $t\bar{t}$ spin correlation in the helicity basis. The prediction of the $2 \rightarrow 2 t\bar{t}$ matrix elements of PYTHIA 6.1 show no correlation between the two leptons (upper plot). In contrast, the standard model predicts the correlation shown in the lower plot. This result is obtained by the $2 \rightarrow 6 t\bar{t}$ matrix elements implemented in TopReX. In the Breit-Wigner approach (shown here) the asymmetry coefficient reads $A_{SM} = 0.32$. In the on-shell approach the coefficient amounts to $A_{SM} = 0.33$. 

PYTHIA 6.1
partonic final state
87%gg + 13%qq

LHC 14TeV
CTEQ4L

PYTHIA 6.1 + M.E. Slabospitsky
partonic final state
87%gg + 13%qq

LHC 14TeV
CTEQ4L
Fig. 4: $t\bar{t}$ spin correlation of TopReX matrix elements in the helicity basis. To the left the prediction of the $2 \rightarrow 6$ $t\bar{t}$ matrix elements in the Breit-Wigner approach is shown. To the right, the same is shown for the $2 \rightarrow 6$ $t\bar{t}$ matrix elements in the on-shell approach. At the top only the contribution of the gluon gluon fusion is plotted. In the center only the contribution of the quark anti-quark annihilation is given and at the bottom both production processes are taken into account. The corresponding asymmetry coefficients are indicated in the plots. The Breit-Wigner and on-shell approaches are in very good agreement.