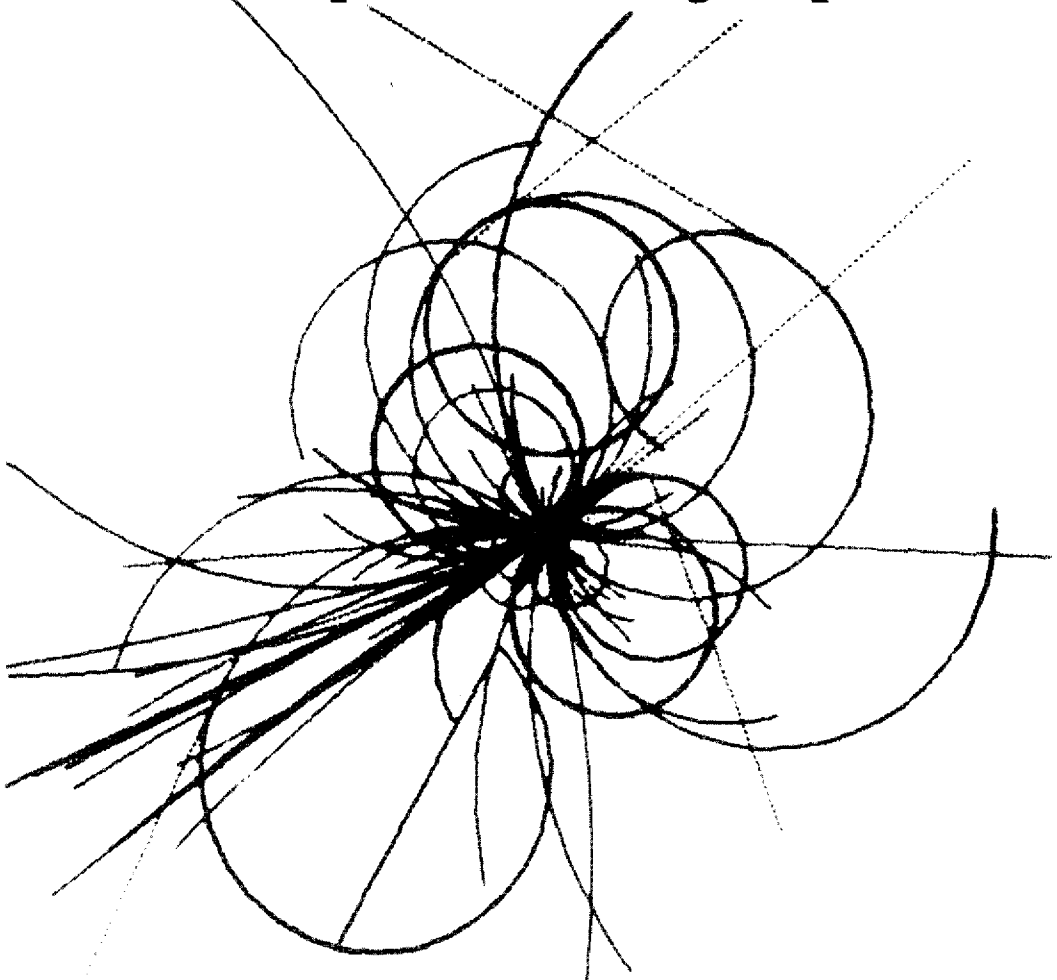
SSC-150

The Superconducting Super Collider



DTUJET-87

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SSC-150

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DTUJET-87

The first version of a new code sampling hadronic events according to the dual topological unitarization of hard and soft hadronic processes.

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Abstract

The dual topological unitarization of hard and soft hadronic cross sections is a new model of hadronic multi-particle production, which treats both soft (low $p_\perp$) and hard (minijet, large $p_\perp$) processes in a unified and consistent way. This description is important at the TeV-energies of hadron colliders, where the hard perturbative cross sections of QCD become large and comparable to the total cross sections. The code DTUJET samples Monte Carlo events in pp and $\bar{p}p$ collisions according to this new model.

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1. Program Summary

Title of program:	DTUJET
Computer:	IBM-3081, SLAC, IBM-3090, CERN
Program Language:	FORTRAN-77
Number of lines in program:	about 11,000 (19000 with parts of PYTHIA)
Other programs called: (not included in DTUJET)	FUNCTION RNDM(DYMMY) generates uniformly distributed pseudo-random numbers between 0 and 1. (Origin: CERN program library)
Other programs called: (included in modified form in DTUJET)	BAMJET [1] Sampling the hadronization of strings. DECAY [2] Sampling the decay of hadron resonances. PYTHIA [3] Sampling large $p_\perp$ constituent scattering.
Method of solution:	Monte Carlo event generator.
Typical running time:	More than 100 events at a c.m.s. energy of 40 TeV per minute running time IBM 3081 after initialization of the program (1–2 minutes)

2. Dual Unitarization of Soft and Hard Hadronic Interactions

The dual topological unitarization of hard and soft hadronic cross sections is a new model of hadronic multi-particle production. This model will be described in more detail, in a forthcoming SSC report [4].

Soft hadronic multi-particle production in the framework of the DTU model was studied in the last years by several groups [5 – 9]. These models and in particular the Monte-Carlo-formulation of this model in the form of the dual multi-string fragmentation model [8, 9] are the first starting point of the new model.

Experimental observations at collider energies made it clear that the soft and hard components of hadronic multi-particle production are closely related. We refer to the discovery of correlations between the average transverse moment of produced hadrons and the multiplicity density in the central rapidity range [10] and to the finding that the observation of "minijets" in hadronic collisions changes the properties of the underlying soft events [11]. Both of these properties could be understood within the dual multi-chain fragmentation model [9, 12] only by introducing transverse momenta at the ends of the fragmenting strings. The magnitudes of these transverse momenta could only be interpreted as due to hard constituent scattering.

The need for a uniform treatment of hard and soft hadronic multi-particle production is furthermore underlined by the fact that the perturbative QCD cross sections for hard constituent scattering rise strongly with the energy reaching values around 200 mb at the energy of the SSC. Since this is larger than the total hadronic cross section at these energies, we expect in average hadronic events in this energy range one or several hard constituent scatterings. At those energies one expects that unitarity corrections should play an important role. Those corrections then inevitably lead to several semi-hard interactions resulting in an inrease of the average number of jets.

The perturbative hard constituent scatterings are also one of the processes responsible for the rise of the hadronic cross sections. This was studied quantitatively in papers by Capella, Tran Thanh Van, and Kwiecinski [13] and Durand and Pi [14], where the consequences for the total and inelastic cross sections of the unitarization of soft and hard scattering cross sections were studied. This model in the form as formulated in [13] is the second starting point for the DTUJET-model.

For more details about the model we refer to the paper [4].

3. Description of DTUJET-87

3.1 The Structure of DTUJET-87

The main program DTUJET initializes variables and reads input cards. Each input card is identified by a code word and either changes the default values of variables and/or demands some action. Actions are test runs of certain program parts or sampling events to be either written to an output file or used to construct standard histograms.

In Fig. 1 this structure and the action demanded by most of the input cards is summarized. All variables read from the input cards have default values.

The DTUJET Source Code is stored in several FORTRAN files. The most important ones are:

—HSABR: Contains the main program and all routines to calculate the multi-Pomeron distributions, sample from these distributions, and calculate the total and inelastic cross sections.

—PARTABR: Formulates the model on the parton level, samples the strings and the partons at the ends of the strings.

—COLLABR: Formulates the model after the string fragmentation into hadrons. Calls histogramming routines.

—LUABR: Contains the routines used to sample the hard scattering of constituents. This file contains modified routines from PYTHIA [3] and JETSET [15]. The JETSET routines could be used to sample events using the Lund-hadronization scheme. This is not implemented at present.

—TCBABR: Contains the BAMJET [1] and DECAY [2] routines for string fragmentations and routines to test and call BAMJET.

Most parts of the program, for instance the

-- sampling of multi-Pomeron events,

-- hadron structure functions,

-- hard perturbative constituent scattering cross sections,

-- the method of string fragmentation into hadrons, and

-- the method of selecting the exclusive parton events (x-values and flavors),

are interchangeable. For some of these tasks DTUJET-87 already offers several options; for others this is foreseen and easy to implement.

3.2 DTUJET — Input Cards and Options

All input cards of DTUJET have the following form:

CODEWD, (WHAT(I), I = 1,6), SDUM
FORMAT (A8, 2X, 6E 10.0, A8)

In the following we describe the meaning of these variables for all input cards in alphabetical order of the code words CODEWD.

Code word: CMENERGY

This card defines the c.m. energy of the collision.
WHAT(1) = c.m. energy in GeV. Default: 540 GeV.

Code word: COMMENT

This card allows one to add comments to the input file.
WHAT(1) = Number of comment cards following this input card.
Default: 1

Code word: EVENTAPE

When this card is present, the events generated are written on an output file DTUJET EVENTS (logical unit 11). The file DTUJET EVENTS is written in the following format:

1. card: "This file contains events from DTUJET."

2. card: The TITLE of the input file is reproduced.

3. card: NHAD, FORMAT(I10): Number of secondary particles in the event.

Cards 4 to 3 + NHAD:
I, PX(I), PY(I), PZ(I), E(I), AM(I), ICH(I), IBAR(I), ANH(I), NR(I)
FORMAT (I4, 5E 16.8, 2I4, A8, I4)

PX(I), PY(I), PZ(I)	are the momentum components of the secondary particles in the c.m.s. of the collision in GeV/c.
E(I) and AM(I)	are the total energy and mass of the secondary particle.
ICH(I) and IBAR(I)	are the charge and baryon number of the particle.

ANH(I) and NR(I) are a string containing the particle name and a number label defining the kind of particle.

A list of particles known to DTUJET can be printed (see the PARTICLE input card). At present the normal output events of DTUJET contain particles which do not decay hadronically (most of them with number labels below NR = 26). It is also possible to obtain the events before the decay of the hadron resonances (vector meson nonet and baryon decuplet).

Code word: HADRONIZE

Defines the code used for hadronization.

WHAT(1) = IHADRZ Default: 1

IHADRZ=1 : BAMJET fragmentation of soft and hard (minijet) strings.

Code word: OUTLEVEL

Defines the amount of debug-printout in different parts of DTUJET. The maximum amount of output is obtained with IOUXXX = 7, the minimum amount with IOUXXX = 0. Default: IOUXXX = 1.

WHAT(1) = IOUTPO: Pomeron distribution routines.

WHAT(2) = IOUTPA: Parton x distribution sampling.

WHAT(3) = IOUXEV: Parton level events.

WHAT(4) = IOUCOL: Hadron level event sampling.

Code word: PARTEV

Defines the parton level events and/or demands a test run.

WHAT(1) = ITEST Default: 0

ITEST = 1 demands a test run printing histograms for distributions of the partons at the ends of the strings. This is done separately for soft sea strings, soft valence strings, and hard (minijet) strings.

WHAT(2) = NPEV Number of parton level events in the test run.

WHAT(3) = NVERS Used to select different versions of sampling the parton level events.

Default: 1

Implemented in DTUJET-87 is: NVERS = 1: only hard gluon-gluon scattering and (for $\bar{p}p$ collisions) hard valence quark-gluon scattering is treated correctly. All other kinds of constituent scatterings are treated like gluon-gluon scattering.

Code word: PARTICLE

This card demands the printing of a table of all particles defined in DTUJET. Printed are the particle properties and in the case of unstable particles all decay channels defined in the code. The particles defined in DTUJET are the ones defined in the BAMJET and DECAY hadronization codes.

Code word: PROJPAR

Defines the projectile particle (moving into positive z-direction)
SDUM = Projectile particle type Default: PROTON
Possible values; PROTON, APROTON

Code word: SELHARD

Defines the sampling of hard scattering of constituents and/or demands a test run.
WHAT(1) = ITEST: Test for ITEST = 1 Default: 0
WHAT(2) = IOPHRD: Selects the version of sampling the hard scattering of constituents Default: 2

IOPHRD = 2, The hard scattering is sampled using PYTHIA-48; all constituent $p_\perp$ values are $p_\perp \geq$ PTTHR.
WHAT(3) = NEVTH: Number of events in test run Default: 10
WHAT(5) = PTTHR, Threshold $p_\perp$ for the hard scattering of constituents in GeV/c Default: 2

Code word: SIGMAPOM

Defines options and/or demands a test run for the calculation of the DTU model unitarizing the soft and hard hadronic cross sections. The test run is for calculating the total and inelastic cross sections as functions of the collision energy as well as initializing and testing the sampling of multi-Pomeron events at some typical energies. Without the test run only the initialization at the energy defined in the run is done.

WHAT(1) = ITEST, test run for ITEST = 1.

WHAT(2) = ISIG, characterizes the soft and hard input cross sections for the unitarization (see SUBROUTINE SIGSHD).

Recommended and default: ISIG = 7

WHAT(3) = IPIM characterizes the method to calculate the distribution in the number of soft n_s and hard n_h Pomerons

Default and recommended: IPIM = 2

Note : IPIM = 2 uses the approximation of vanishing input triple Pomeron cross sections for calculating the $n_s - n_h$ distribution. This will eventually be replaced by the full method without this approximation.

Code word: START

Starts the sampling of hadronized events and the calculation of the standard histogram output.

Before START, there should be a PARTEV card to initialize the sampling of events at the parton level.

WHAT(1) = NCASES Default: 1000
Number of events sampled.

WHAT(3) = ISTAR For ISTAR = 1 more histogramming routines are called (in file OUTABR).

WHAT(5) = PTLAR Default: 2

If PTLAR is greater than 2.2 GeV, DTUJET samples only events with at least one jet (minijet) with $p_\perp \geq$PTLAR, rejecting all other events. For PTLAR < 0, DTUJET samples only events without hard jets (minijets).

Code word: STOP

Stops the running of the code.

Code word: STRUCFUN

Defines the structure functions used in the sampling of hard constituent scattering

WHAT(1) = ISTRUF Default: 1
ISTRUF = 1 : EHLQ, Set 1
ISTRUF = 2 : EHLQ, Set 2

ISTRUF = 3 : Duke, Owens, Set 1
ISTRUD = 4 : Duke, Owens, Set 2

Code word: TARPAR

Defines the target particle (moving into the negative z-direction)

SDUM: Target particle type Default: PROTON
Possible values: PROTON, APROTON

Code word: TECALBAM

Demands a test run of the BAMJET hadronization code. TECALBAM demands further input cards to define the test run; see comments in SUBROUTINE TECALBAM.

Code word: TITLE

This card must be followed by a card giving the title of the run, which will be reproduced in the output.

Code word: TOPDRAW

Demands the output of TOP files containing standard histograms for plotting with the TOPDRAW plotting system.
WHAT(1) = ITOPD Default: 0

For ITOPD = 1, one TOP file containing standard histograms is written (Rapidity, Pseudorapidity, Feynman-x, transverse momentum, transverse energy distribution).

For ITOPD = 2, two TOP files are written which serve to study the particle production at 40 TeV.

The TOP files are written on logical unit 7 for ITOPD = 1 and in addition on unit 9 for ITOPD = 2.

3.3 Important Subroutines and Common Blocks of DTUJET

3.3.1 Subroutine calls for generating one event

1. Initialization done in main program DTUJET
2. Initialization of the multi-Pomerons distribution by a call to the subroutine PROBLC. This is done from the main program after reading the PARTEV input card.
3. Call of COLLEV from the main program using the START input card. COLLEV initializes BAMJET and DECAY by calls to DATAR3 and CHANWT. In the standard run COLLEV also initializes the histogramming routines DIACOL and optionally DISTRI.
4. A call to XPTFL (NHARD, NSEA, NVAL) generates one parton level event with NHARD hard Pomerons and NSEA soft sea Pomerons and one soft valence Pomeron.
5. The hadronization of this event is done by a call to the routine HADRAV (NHAD, NSEA, NVAL, NHARD). The event generated has NHAD particles in its final state. The table of generated particles is available in the first NHAD entries of COMMON Block /ALLPAR/:
   CHARACTER*8 ANH

   COMMON/ALLPAR/PX(902), PY(902), PZ(902), HE(902),
   AM(902), ICH(902), IBAR(902), ANH(902), NR(902)

The variables in /ALLPAR/ are identified under the code word EVENTAPE in Section 3.2.

3.3.2 Subroutine calls for generating histograms characterizing the multi-particle events

Standard histograms are generated by calls to histogramming routines from the subroutine COLLEV. The following histogramming routines are available in DTUJET:

DIACOL, (and optimally DISTRI), which analyzes the total events.

DISCOL, analyzing that part of the event which results from the fragmentation of the soft sea strings.

DIHCOL, analyzing that part of the events which results from the fragmentation of the hard (minijet) strings.

DIVCOL, analyzing that part of the events which results from the fragmentation of the soft valence strings.

There are three kinds of calls of these histogramming routines:

-- a first call initializing the arrays,

-- a second call collecting the events after each call of the event generator (XPTFL and HADRAV),

-- a final call after the required number of events to print out tables and printer plots in the standard output (logical unit 6) and TOP files for the TOPDRAW plotting of histograms.

3.3.3 Subroutines to analyze the parton level events

A call to the subroutine PARTEV generates histograms which characterize the events on the parton level, that is, rapidity, Feynman-x, and transverse momentum distributions of partons at the end of the three kinds of strings: soft sea strings, soft valence strings, and hard (minijet) strings. These histograms are generated from subroutine PARTEV by a call to the XPTFL event generator and the DISTPA histogramming routine.

The parton level events are stored in the common blocks /ABRSOF/, /ABRVAL/, and /ABRJT/. The subroutine XPTFL generates one parton level event by successively calling the following routines:

SAMPLM (LPO,MPO)	samples an event with LPO soft and MPO hard Pomerons,
SELHARD	samples the required MPO hard constituent scatterings by calling PYTHIA routines and transmitting the required variables from PYTHIA via the common block /ABRHRD/,
PRIMPTT	(for hard scattered partons), and
SELPTH	(for the partons at the ends of the soft strings) samples primordial parton transverse momenta.

The soft sea chains are sampled directly in XPTFL. The soft valence chains are sampled by calls to the routines VALCHA and VALCHB.

3.3.4 Calculation of total and inelastic cross sections and hard and soft Pomeron distributions via the unitarization of soft and hard input cross sections

The subroutine POMDI is called from the main program when demanded by the SIGMAPOM input card.

POMDI calls the routine SIGMAS to calculate the total and inelastic cross sections according to the model as function of energy. The output is via a standard line printer plot and optimally a TOP file to generate a TOPDRAW plot.

The sampling of multi-Pomeron (hard and soft Pomeron) distributions is initialized by a call to PROBLC, which calculates the probability distribution for n_h hard and n_s soft Pomerons. A call to SAMPLM generates one event from this distribution. POMDI generates scatterplots in n_h and n_s for 1000 sampled events at some collision energies. The input hard, soft, and triple Pomeron cross sections of a given energy are defined by a call to the subroutine SIGSHD.

3.3.5 The chain fragmentation model BAMJET and the resonance decay routine DECAY

BAMJET and DECAY are well documented [1,2]. DTUJET calls BAMJET via routines, which already perform Lorentz transformations and rotations of the events generated in BAMJET. These routines are HADJET (in the COLLABR file), which calls CALBAM, which calls BAMJET. Details on HADJET and CALBAM are found in comment cards at the beginning of the codes.

3.4 Sample Input and EXEC Files

In Fig. 2 we reproduce an input file for DTUJET. This file, where we give all possible input cards even when they do not change the default settings, will lead to the calculation of 2000 events at $\sqrt{s} = 40$ TeV generating standard histograms and TOPDRAW files.

In Fig. 3 we give a sample EXEC file for running DTUJET on the IBM-3081 under the VM system. In this example some of the input FORTRAN files have to be compiled, while others are used in compiled form (TEXT files). All the output of the batch machine is being sent to the reader.

In the paper [4] many plots are shown which originate directly as DTUJET output; therefore we do not need to give examples for the output of DTUJET.

3.5 Availability of DTUJET

At SLAC-VM the FORTRAN-files of DTUJET are stored on the disk FLUK87. At CERN-VM these files are available from the PUBHC disk.

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Last but not least, I would like to thank my collaborators P. Aurenche, F. Bopp, A. Capella, K. Hahn, J. Kwiecinski, P. Maire and J. Tran Thanh Van for discussions which led to the plan for the underlying model. K. Hahn provided parts of the code used in DTUJET-87. I thank Dr. T. Sjöstrand for providing me with a copy of the PYTHIA codes and JETSET and the permission to use parts of it in DTUJET.

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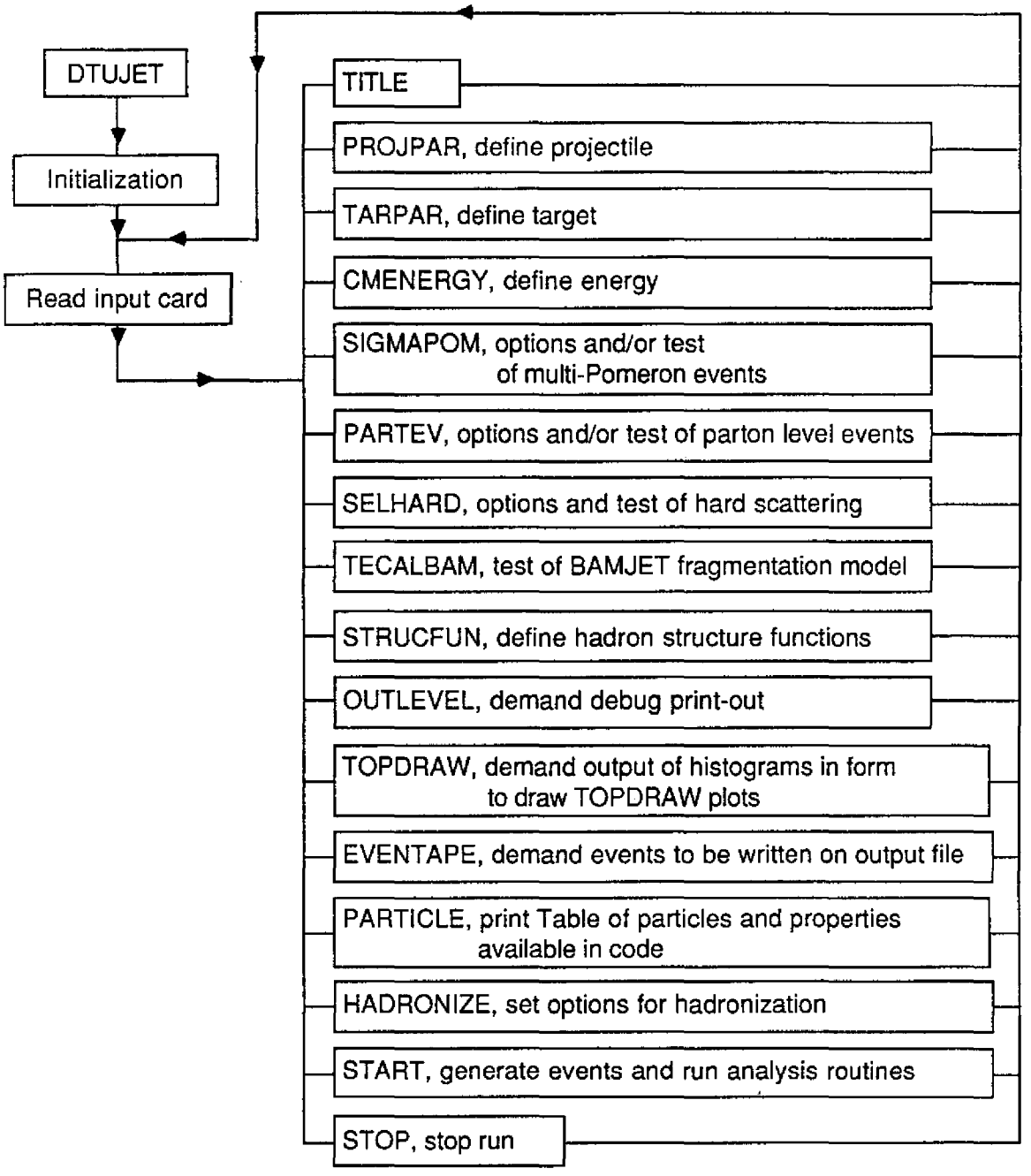
DTUJET
Initialization
Read input card
TITLE
PROJPAR, define projectile
TARPAR, define target
CMENERGY, define energy
SIGMAPOM, options and/or test of multi-Pomeron events
PARTEV, options and/or test of parton level events
SELHARD, options and test of hard scattering
TECALBAM, test of BAMJET fragmentation model
STRUCFUN, define hadron structure functions
OUTLEVEL, demand debug print-out
TOPDRAW, demand output of histograms in form to draw TOPDRAW plots
EVENTAPE, demand events to be written on output file
PARTICLE, print Table of particles and properties available in code
HADRONIZE, set options for hadronization
START, generate events and run analysis routines
STOP, stop run

Fig. 1

```
TITLE
TEST DTUJET 40 TeV standard run antiproton-proton collisions
PROJPAR                                                          APROTON
TARPAR                                                           PROTON
CMENERGY      40000.
OUTLEVEL          1.        1.        1.        0.
TOPDRAW           1.
SIGMAPOM          0.        7.        2.
PARTEV            0.        1.        1.
HADRONIZ          1.
START          2000.        0.        1.        0.       2.0
STOP
```

Fig. 2

```
/*DTUJET EXEC TO RUN DTUJET BATCH*/
   /*BATCH NOTMY191 NOPROFILE NOPROFSUBMIT TRACE */
   /*BATCH PRINT 100K  PUN 100K SEND "= = ="       */
   /*BATCH STORAGE 6M */
   /*BATCH TIME :120  */
   /*BATCH NORETURN " * *    " */
   /*BATCH LOG " hsabrJO " */
   /*BATCH JOBFILE " hsabrXXX " */
   TRACE R
   /* SEND THE FILES TO THE BATCH MACHINE */
   /*BATCH SEND " hsabr DATA c " */
   /*BATCH SEND " hsabr FORTRAN c " */
   /*BATCH SEND " partabr FORTRAN c " */
   /*BATCH SEND " collabr FORTRAN c " */
   /*********************************************************/
   /* THE I/O CONTROL      */
" CP SPOOL CONSOLE CLASS A CONT  TO HIDEO   "
" CP SPOOL PRINTER CLASS A       TO HIDEO   "
" TYPE   hsabr DATA *   "
   /* THE FILE DEFINITIONS */
" FI 5  DISK  hsabr DATA * (PERM RECFM FB  LRECL 80 )"
" FI 6  DISK  dtujet OUT A (PERM RECFM FBA LRECL 133 BLKSIZE 1330)"
" FI 7  DISK  dtujet top A (PERM RECFM FBA LRECL 133 BLKSIZE 1330)"
" FI 9  DISK  dtujetl top A (PERM RECFM FBA LRECL 133 BLKSIZE 1330)"
" FI 11  DISK  dtujet events A (PERM RECFM FBA LRECL 133 BLKSIZE 1330)"
   GIME HIDEO 191 B
"  COPYFILE luabr text B luabr text A  "
"  COPYFILE tcbabr text B tcbabr text A  "
"  COPYFILE outabr text B outabr text A  "
"FORTVS2 hsabr (
         AUTODBL(DBL4) SDUMP DISK NOOPT NOFIPS FLAG(I) GS IL(DIM))"
"FORTVS2 partabr (
         AUTODBL(DBL4) SDUMP DISK NOOPT NOFIPS FLAG(I) GS IL(DIM))"
"FORTVS2 collabr (
         AUTODBL(DBL4) SDUMP DISK NOOPT NOFIPS FLAG(I) GS IL(DIM))"
"GLOBAL TXTLIB VSF2FORT HANDYPAK NAPL FORTSLAC UGOBJLIB KERNLIB GENLIB
               VSF2MATH"
"GLOBAL LOADLIB VSF2LOAD"
"QUERY DISK"
"LOAD hsabr partabr collabr tcbabr outabr luabr(START)"
" TYPE    dtujet OUT A   "
" PRINT   dtujet OUT A  (CC "
" PRINT   dtujet top A  (CC "
" PRINT   dtujet events A  (CC "
" PRINT   dtujetl top A  (CC "
" PRINT   hsabr LISTING A  (CC "
" PRINT   partabr LISTING A  (CC "
" PRINT   collabr LISTING A  (CC "
/*" TYPE  LOAD MAP * "*/
   EXIT   RC
```

Fig. 3