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A Monte Carlo Program for Heavy Quark Jet Generation

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Abstract:

A previous paper (LU TP 78-18), dealing with the computer generation of jets from u , d and s quarks, is extended also to include c , b and t quark jets. An iterative scaling scheme is used for the generation of primary mesons. Besides strong and electromagnetic decays, heavy mesons are allowed to decay weakly. In hadronic weak decays an iterative, jetlike, scheme is used to generate the flavour of the products, while momenta are distributed according to phase space. Only three-particle semileptonic decays are simulated, here with a matrix element similar to the one in muon decay. The program components are listed in FORTRAN 77.

1. Introduction

In a previous study [1], a computer program for the generation of quark jets in the spirit of Field and Feynman [2] and Andersson, Gustafson and Peterson [3] is presented. It simulates the fragmentation of an emerging u, d or s quark into a jet of primary mesons, pseudoscalars and vectors, which then decay into stable particles.

With the increasing energy available, in particular in e^+e^- machines, not only light quark jets are produced but also jets formed by an emerging c, b or, eventually, t quark. This paper sets out to formulate one possible extension of the old model also to include these heavy quark jets. The heavy mesons then generated are too short-lived for direct experimental observation, so the introduction of a model describing their decay forms the most important part of this work.

For the new, as of yet undiscovered, pseudoscalars we have adopted the notation [4]

$$B_u^- = b\bar{u}\ ,\ B_d^0 = b\bar{d}\ ,\ B_s^0 = b\bar{s}\ ,\ B_c^- = b\bar{c}\ ,$$

$$T_u^0 = t\bar{u}\ ,\ T_d^+ = t\bar{d}\ ,\ T_s^+ = t\bar{s}\ ,\ T_c^0 = t\bar{c}\ ,\ T_b^+ = t\bar{b}\ ,$$

$$\eta_b = b\bar{b}\ ,\ \eta_t = t\bar{t}$$

and for the vector mesons

$$B_u^{*-},\ \dots\ ,\ T_u^{*0},\ \dots\ ,\ \phi_t = t\bar{t}\ .$$

Their masses have been calculated assuming

$$m_u = m_d = 300\ \text{MeV}\ ,\ m_s = 500\ \text{MeV}\ ,$$

$$m_c = 1600\ \text{MeV}\ ,\ m_b = 4800\ \text{MeV}\ ,\ m_t = 15000\ \text{MeV}$$

and adding a spin term -30 MeV for pseudoscalars and +10 MeV for vectors.

The exact size of this spin term is not particularly important. The point is that we have chosen a splitting smaller than a pion mass, so that the decays $B^* \rightarrow B\pi$ and $T^* \rightarrow T\pi$ become kinematically forbidden. This is consistent with the experimentally observed decreasing mass difference between the vector and the pseudoscalar mesons as they become heavier.

In chapter 2 we review the iterative jet fragmentation model used and present the changes and additions made in order to accommodate heavy quarks. A presentation of our scheme to handle the decays of heavy mesons is found in chapter 3. The computer program components are examined in chapter 4 and some practical information for their use is given in chapter 5. Program listings are found in Appendix 1.

2. The jet fragmentation model.

In an iterative quark jet cascade, a primary quark of flavour 'a' carrying the quantity $W_0 = E_{'a'} + p_{z'a'}$ along a given jet axis (here in the z direction) generates in its colour field a quark-antiquark pair 'b$\bar{b}$'. The quark 'a' and the antiquark '$\bar{b}$' form a primary meson 'a$\bar{b}$' with $E + p_z$ fraction $x_1 = \frac{E_1 + p_{z1}}{W_0}$ leaving $W_1 = (1 - x_1) \cdot W_0$ to a remaining quark jet with flavour 'b'. The procedure is iterated and a chain of primary mesons is produced.

The model for light quark jets described in [1] is still applicable, and is in outline as follows. Quark-antiquark pairs generated in the field may be either $u\bar{u}$, $d\bar{d}$ or $s\bar{s}$, according to given probabilities. Spin 0 or 1 is randomly assigned to each meson. The variable x is in every step randomly distributed between 0 and 1 according to

$$f_x(x)\,dx = (1 - a + 3a(1-x)^2)\,dx$$

which, with different values of a , gives the distributions of refs [2] and [3].

Every quark or antiquark is supposed to have a transverse momentum $\bar{p}_\perp$ randomly generated according to

$$f_q(\bar{p}_\perp)\,d^2p_\perp = \frac{1}{\pi\sigma^2}\,e^{-(p_\perp^2/\sigma^2)}\,d^2p_\perp$$

with the constraint that the total $\bar{p}_\perp$ of each generated pair be zero. The primary meson '$b\bar{c}$' then carries transverse momentum

$$\bar{p}_{\perp\,'b\bar{c}'} = \bar{p}_{\perp\,'b'} + \bar{p}_{\perp\,'\bar{c}'}$$

Unless otherwise prescribed, we generate $u\bar{u}:d\bar{d}:s\bar{s}$ with probabilities 2:2:1 , pseudoscalars:vectors with probability 1:1 , and use $a = 0.77$ and $\sigma = 350$ MeV [2].

In the extended model in this work the first quark may be a u , d , s , c , b or t (or a corresponding antiquark) but the pairs generated in the field will still only be $u\bar{u}$, $d\bar{d}$ or $s\bar{s}$.

For the mesons containing a heavy quark (c , b , t , $\bar{c}$, $\bar{b}$, or $\bar{t}$) the value of the parameter a in $f_x(x)$ is chosen to be zero, since experimental data [5] favour a flat distribution for D mesons, while the use of the same distribution as for light mesons, with $a = 0.77$, would not give results consistent with data.

The variables E and p_z for a primary meson with mass m (note that we work with sharp masses for all particles) and transverse mass $m_\perp = \sqrt{m^2 + p_\perp^2}$ are determined by

$$E + p_z = W$$
$$E - p_z = \frac{m_\perp^2}{W}$$

A large part of the primary mesons thus produced will be unstable and subsequently decay into stable final particles. The procedure for these decays is discussed below in chapter 3.

A cut is introduced to ensure that the first meson produced, containing the original flavour, has $p_z > 0$. In a sense this is actually a definition of having a jet with given flavour.

The generation can be terminated when the remaining $E + p_z$ in the jet is too small to produce any mesons with $p_z > 0$. Even before that, however, a number of mesons with small $E + p_z$ and thus large negative p_z may have been formed. The simplest procedure to avoid the problem of these particles is to keep only stable particles with $p_z > 0$.

In a region immediately above e.g. the B meson threshold, where a B is produced with a small $p_z > 0$ and a $\bar{B}$ with small $p_z < 0$, the recipe of just discarding all particles which go into the "wrong" hemisphere will, however, lead to serious distortions of the physical picture. In such cases it is better to have the criterion that, if a primary meson has $p_z > 0$, all its stable decay products are kept, but none of it has $p_z < 0$. Far away from such threshold effects, this new cut gives the same kind of results as the old one when producing two back-to-back jets. In other cases, e.g. the study of fragmentation functions in a single jet, the old cut may be preferable.

When producing two back-to-back jets, the sum of momenta on the two sides will balance, but the distribution of particle momenta and masses will, in general, differ for the two sides, so that they will have different invariant mass and hence different total energy. Also the total flavour will exhibit a natural variation when looking only on one side. In simulations, the problem of finding "matching" jets, so that the total energy, momentum and flavour is conserved, may of course be substantial, and is not considered here.

3. The treatment of particle decays.

The central part of the present paper is a model for weak decays of heavy mesons.

The decay of mesons containing "ordinary" u , d and s quarks is described in [1]. The branching ratios are here known and are taken from ref. [6]. The momentum distributions are given by phase space, except for ω and ϕ decaying into $\pi^+\pi^-\pi^0$. Here a matrix element of the form

$$|M|^2 \propto |\bar{p}_{\pi+} \times \bar{p}_{\pi-}|^2$$

is used, where $\bar{p}_{\pi^\pm}$ are the momenta in the CM frame.

In addition to the decays described in [1], we have also introduced the change of K^0 and $\bar{K}^0$ into K_L^0 and K_S^0 and the decay $K_S^0 \to \pi\pi$.

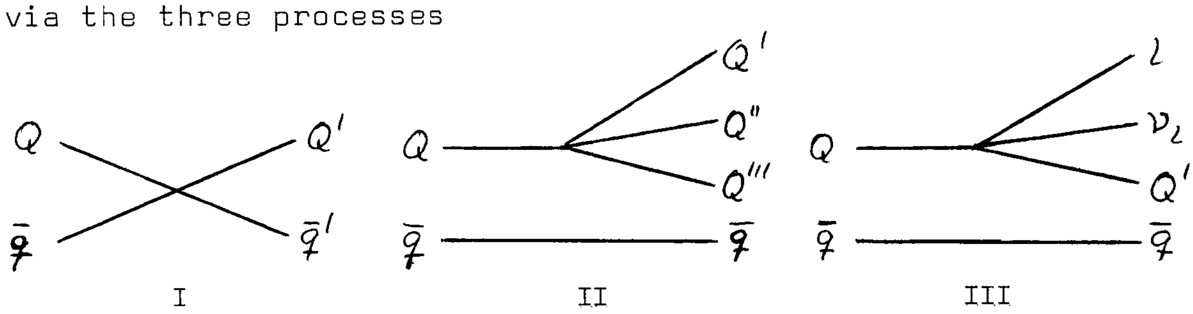
The B^* and T^* mesons are assumed to decay electromagnetically only. These decays, $B^* \to B\gamma$ and $T^* \to T\gamma$, and also $D^* \to D\pi$, $D^* \to D\gamma$ and $F^* \to F\gamma$, are treated in the same way as other two-particle decays.

3a. Weak decays of heavy mesons.

For the weak decays of heavy mesons we have developed a model with the following ingredients:

(α) Primary weak decay of a heavy quark

The weak decay of mesons containing a heavy quark Q can go via the three processes



Quark annihilation   Free quark decay   Semileptonic decay

Only the dominant decay chain $t \to b \to c \to s$ is taken into account.

For B and T mesons the relative probabilities for these processes is calculated by Ali et al. [4], and we use their results here. For D mesons, the semileptonic branching ratios are experimentally known, while process I is suppressed and here neglected. Similar calculations as in ref. [4] for the F mesons give approximately a 3:5 ratio for processes I:II, and the semileptonic decay probability is determined to give the same ratio III:II as in D meson decay.

(β) Strong final state interactions

The quarks produced in the primary decay interact in the final state via the strong force so that only hadrons come out. The momenta of the leptons in semileptonic decays are determined by the primary decay matrix element, but this is not so for the hadrons. We expect that the quarks stretch out colour force fields between them in a way similar to a quark jet in e^+e^--annihilation.

Quark-antiquark pairs can be produced in these fields and combine into hadrons. However, we know that, because of the finite transverse momenta within a jet, e^+e^--events do not look jetlike below a total energy of 6 GeV. Instead, the particle distributions are fairly well reproduced by a phase space model. For this reason we do not expect jet-like events in these weak decays, in particular in view of the fact that in most cases more than one quark-antiquark pair share the available energy. Also for t quarks, where the energy is not low, we note that due to the mass of the b quark, the maximum rest frame rapidity for a B meson in a two-body decay is as low as 1.2 units. In our model the hadrons in nonleptonic decays are therefore distributed according to phase space only.

(γ) Multiplicity

For nonleptonic decays we expect the average multiplicity to grow logarithmically with the available energy. We also expect somewhat more particles for process II than for I. Hence we will assume

$$\langle n \rangle = \frac{n_o}{2} + c_1 \ln\left(\frac{m}{c_2}\right) = \frac{n_o}{2} + c$$

where m is the mass of the decaying meson and n_o is the number of quark-antiquark pairs in the primary decay, i.e. $n_o = 1$ for I and $n_o = 2$ for II. The constants c_1 and c_2 should be determined experimentally. While waiting for more experimental data we use $c_1 = 1.8$ and $c_2 = 800$ MeV, which is consistent with observed charged multiplicities for D^0 and D^+ [7].

For convenience we use a Gaussian multiplicity distribution of the form

$$f_n(n)\,dn \propto e^{-(n-\frac{n_o}{2}-c)^2/2c}\,dn$$

(n rounded off to nearest integer, $n \geq n_o$, $n \geq 2$, $n \leq 10$). A substitution to e.g. a Poisson distribution can easily be made using local library files.

(δ) Flavour combinations

When a $q\bar{q}$ pair is produced in the colour field, we expect that the quark and the antiquark will be pulled apart by the strong force, so that they cannot combine with each other to form a meson. We also think the quarks produced in the primary weak decay are in the endpoints of the colour flux tubes, so that they are more likely to combine with the new quarks than with each other. Hence we exclude the possibility that the primary quarks and the new quarks will combine separately.

Once the multiplicity n of a decay has been determined as in the previous section, our model gives the flavour of the mesons in a way very similar to the iterative jet fragmentation scheme outlined in chapter 2. Consider a weak decay (via process II) giving four primary quarks, 'a' , '$\bar{b}$' , 'c' , and '$\bar{d}$' . A pair '$e\bar{e}$' now is created, with equal probability in either of the four colour fields, one associated with each quark. The pair is pulled apart to give a meson, either '$a\bar{e}$' , '$e\bar{b}$' , '$c\bar{e}$' , or '$e\bar{d}$' , leaving behind a new state with four quarks. This procedure is iterated $n-2$ times, the final two mesons being obtained by a random combination of the quarks then left. The case of two primary quarks (process I) is treated similarly.

Unless otherwise specified, we generate $u\bar{u}:d\bar{d}:s\bar{s}$ pairs with probabilities 2:2:1 and pseudoscalars:vector mesons with probability 1:1 , as in chapter 2.

(ε) Semileptonic decays

For semileptonic decays, the energy in the quark-antiquark system is too low to produce many new pairs. In B and T decays, usually at most one extra slow pion could be produced, which would hardly be discernible from pions produced in secondary decays. We therefore only take into account three-particle decays

$$H \to h \, l \, \nu_l \qquad\qquad l = e, \mu, \tau$$

Note however that h can be a vector meson which afterwards decays into two pseudoscalar mesons.

Here phase space only would not suffice, since the $e^{\pm}$ and $\mu^{\pm}$ will give rise to energy spectra reflecting the primary decay, little disturbed by final state interactions and secondary decays, contrary to the case for hadrons. Instead the momentum distribution is determined by a matrix element similar to the one in muon decay [8,9]. If H contains a heavy quark Q with charge + 2/3 we have

$$|M|^2 \propto (p_H \, p_{l^+})(p_{\nu_l} \, p_h)$$

whereas if Q has charge -1/3 we have

$$|M|^2 \propto (p_H \, p_{\bar{\nu}_l})(p_l \cdot p_h)$$

3b. <u>τ and "onia" decays</u>

The hadronic decays of the heavy τ lepton are treated as the hadronic decays of heavy mesons, except that ν_τ is included in n_0 and n . No particular care is thus taken with the ν_τ energy spectrum. For the leptonic decays, we use the relevant matrix element

$$|M|^2 \propto (p_\tau \cdot p_{\bar{\nu}_l})(p_l \cdot p_{\nu_\tau}) \qquad\qquad l = e, \mu$$

This program is not intended for the study of the "onium" $q\bar{q}$ states, but for completeness and since some ψ and η_c actually are produced in B meson decay, the ground states have been included using the same decay scheme as in hadronic weak decays. For the pseudoscalars, we assume annihilations into $q'\bar{q}'$ systems with probabilities $\propto e_q^2$, while for vector mesons also $\ell^+\ell^-$, $\ell = e,\mu,\tau$, decays are generated, with branching ratios from refs [6,10].

The different particle decay channels and branching ratios are summarized in Table 7. Here the notation $*q_1q_2*$ denotes a $q_1\bar{q}_2$ pair produced in the primary quark decay in either of processes I, II or III or in τ or "onium" decay.

4. The program components.

The division into different program components is unchanged. We have [1]

1) JETGEN, which generates the primary mesons of the jet,
2) DECAY, which handles the decay into stable particles,
3) EDIT, which may be used to throw away uninteresting particles or make overall rotations or Lorentz boosts,
4) LIST, which lists the particles of the jet,
5) BLOCK DATA, containing the tables and default values.

The components are written in FORTRAN 77, the only non-standard feature being the random number generator RANF.

With the extension from 19 to 87 particles, a new classification system for K(I,2) is introduced (Table 7). The stable particles in our program now are γ, $e^\pm$, $\mu^\pm$, $\pi^\pm$, $K^\pm$, K_L^0, and the neutrinos.

4a JETGEN

With the advent of c , b , and t jets, IFLBEG may be chosen between -6 and 6 , excluding 0 (Table 5). Since the new quarks can no longer bo considered massless when calculating $(E + p_z)_{initial}$, a new vector QMAS , containing suitable quark masses, is introduced. We must then demand that EBEG > QMAS(|IFLBEG|) (see also chapter 5).

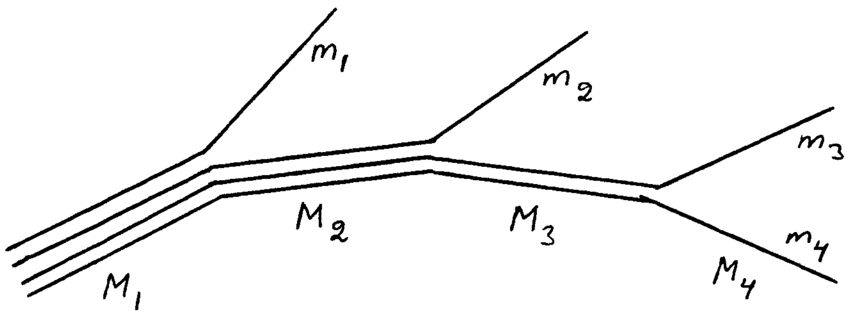
Changes not visible to the user include the new distribution in x for heavy mesons, the cut on the first meson p_z and a new internal bookkeeping for quark flavours, so that quarks consistently are denoted by positive integers and antiquarks by negative ones, as for IFLBEG .The argument for the new MESO vector is of the form 6 • (IFL(quark)-1) - IFL(antiquark) .

Also, calls to DECAY are now made on the basis of the actual values in the IDB vector in the commonblock DECPAR ; if IDB(K(I,2)) = 0 , the particle is taken to be stable.

4b DECAY

The purpose of a CALL DECAY(IPD,I) is, as before, to let the particle in row IPD decay and store the products immediately below row I, but the introduction of heavy meson decays has made a complete revision necessary.

The so-called M-generator method used for pure phase-space decay is described in ref. [11]; a short summary is given here mostly to define the terminology. An n-particle decay is suitably described as n-1 two-particle decays, schematically (for n=4)



The decay product masses $m_1, \ldots, m_n$ are stored in P(I+1,5),...,P(I+ND,5) , while the invariant many-particle masses $M_1, \ldots, M_n$ are stored in PM(1,5),...,PM(ND,5) . Furthermore, M_1 corresponds to the decaying particle itself, and $M_n = m_n$. It can now be shown that, by taking $n-2$ random numbers between 0 and 1 and ordering them so that $R_2 \geq R_3 \geq \ldots \geq R_{n-1}$, an unbiased set of M_i can be obtained:

$$M_i = \sum_{j=i}^{n} m_j + R_i \left(M_1 - \sum_{j=1}^{n} m_j \right) \qquad i = 2, \ldots, n-1$$

The weight for this set is

$$WT = \prod_{i=1}^{n-1} PAWT(M_i, M_{i+1}, m_i)$$

where $PAWT(M_i, M_{i+1}, m_i)$ is the CM momentum of m_i and M_{i+1} in the decay $M_i \rightarrow M_{i+1} + m_i$. No closed expression for the maximum value of WT is known; one upper limit is found by taking the maximum value for M_i and the minimum value for M_{i+1} in each factor above:

$$WT \leq \prod_{i=1}^{n-1} PAWT\left(M_1 - \sum_{j=1}^{i-1} m_j \, , \sum_{j=i+1}^{n} m_j \, , m_i \right)$$

This, however, is a very bad approximation to the maximum weight WTMAX we may expect in reality, and has to be improved by the use of an n-dependent correction factor WTCOR, determined by experience so that we still have WT $\leq$ WTMAX in the vast majority of cases.

Step 1: The point at which to enter the decay tables is stored in the IDB vector for each particle type. To keep down the size of these tables, an antiparticle has the same entry point as the corresponding particle, which is corrected for in step 5. The decay channel is chosen by comparing a fixed random number TBR with an accumulating sum of branching ratios, CBR(IDC) . Once the decay channel IDC is determined, the decay products are given by KDP(IDC,J) , J=1,2,3 . If KDP(IDC,J) = 0 , it means that no particle is stored there, while KDP(IDC,J) > 0 signifies a particle following the code system for K(I,2) (Table 7) and KDP(IDC,J) < 0 denotes a quark-antiquark pair stored on the form -[6 • (IFL(quark)-1) - IFL(antiquark)]. These pairs are divided into separate quarks, stored in IFLQ . The number of "ready-made" particles fetched from KDP is called NP , the number of quark-antiquark pairs NQ .

Step 2: If we only have well-defined particles, we can proceed to step 5, else the total multiplicity ND is found as described in chapter 3 (and Table 3). In particular note that ND=3 for semileptonic decays.

Step 3: The working area IFLR , containing the unpaired quarks, is in the beginning equal to IFLQ . Quark-antiquark pairs are then generated in the force fields, with probability PUDD for $u\bar{u}$, the same for $d\bar{d}$ and $1-2 \cdot$ PUDD for $s\bar{s}$. Meson flavours are formed and stored in K(I1,1) , while the new unpaired quarks are placed in IFLR . In the end, these quarks are also paired off.

Step 4: Spin is now added to the meson flavours, with probability PS1D for spin 1 and 1-PS1D for spin 0. Flavour mixing, if needed, is done as in JETGEN , after which the mesons are well defined. If PSUM , the total mass of the decay products, is too large, we must go back to step 2 and start over again.

Step 5: The aforementioned correction for the case of a decaying antiparticle (according to our arbitrary but well defined conventions) is made by replacing all particles in the final state with their antiparticles and vice versa.

Step 6: The one-particle "decays" (e.g. $K^0 \rightarrow K_S^0$) are performed. For two-particle decays, no weighting is needed.

Step 7: The maximum weight is calculated as described above.

Step 8: The M-generator method gives a set of M_i and an associated weight. The set is accepted with a probability proportional to this weight. If it is rejected, a new set of M_i is generated, and so on.

Step 9: Two-particle decays, $M_i \rightarrow M_{i+1} + m_i$, are now trivially performed in the respective CM frames. The momenta of the M_i are saved in the PM matrix.

Step 10: First the identity between M_n and m_n is again used. The i:th row $(i \geq 2)$ of the PM matrix then defines the boost that takes the particles $m_i, \ldots, m_n$ from the rest frame of M_i to that of M_{i-1}; with the first row the products are taken from the decaying particle rest frame to the lab system.

Step 11: For the semileptonic decay of heavy mesons and the leptonic decay of τ, the value of the matrix element is calculated. Here FOUR denotes the invariant four-vector product. If the event is rejected, return to step 8. The decay of ω or ϕ into $\pi^+\pi^-\pi^0$ is treated similarly, with the matrix element presented previously, times m_ω^2 or m_ϕ^2, written in Lorentz invariant form.

4c EDIT

The parts of EDIT describing rotations and Lorentz boosts are unchanged, but the first part has been changed as follows (cf. Table 4). No action at all is taken if ITHROW = 0 , while for ITHROW ≠ 0 all particles with $p <$ PMIN and all unstable particles are thrown away. Further, for ITHROW > 0 only particles with $p_z >$ PZMIN are kept, while for ITHROW < 0 we instead keep only particles coming from a primary meson with $p_z >$ PZMIN . Finally, for |ITHROW| ≥ 2 neutrinos are thrown away, and for |ITHROW| ≥ 3 also γ and K_L^0 .

4d LIST

LIST is unchanged, except that whether a particle is denoted as stable or not depends on the actual values in the IDB vector.

4e BLOCK DATA

Default values for the parameters of the commonblock DECPAR are introduced, and the particle data part is increased to include the new particle (Tables 1-7).

5. How to use the program.

The jets produced with a CALL JETGEN(N) , possibly followed by a CALL EDIT(N) , are available for analysis, stored in the N first rows of the block

```
COMMON/JET/ K(100,2) , P(100,5)
```

(Table 1). In particular, note the particle classification system used for K(I,2) (Table 7). An example of the information stored in JET after a JETGEN call is found in Appendix 2. We note that, due to the long decay chains, the numerous π^0 decays, and the production of particles with $p_z < 0$, the number N of filled rows in JET will grow rather large. The limit may be reached for high energy t quark jets; the remedy then would be to increase the size of the K and P matrices.

All parameters are provided with sensible default values. These values can be changed via the commonblocks PAR , DECPAR and EDPAR .

The parameters in the block

```
COMMON/PAR/ PUD , PS1 , SIGMA , CX2 , EBEG , WFIN , IFLBEG
```

govern the jet fragmentation process proper (Table 2). The first four are initially set to values consistent with the Field-Feynman model [2]. The flavour of the original quark is given by IFLBEG (Table 5), unless otherwise specified we have a u jet. The jet energy, by default 10000 MeV, has to be so large that we at least can give the first meson a $p_z > 0$, which in practice means

EBEG > QMAS(|IFLBEG|) + 550

where QMAS is the quark mass, Also note that EBEG does not precisely equal the total energy of the final jet.

Through the block

COMMON/DECPAR/ PUDD , PS1D , CND1 , CND2 , IDB(96)

the performance of the DECAY subroutine can be controlled (Table 3). PUDD and PS1D are initially set to the same values as PUD and PS1 , but can be varied independently. As more experimental data become available, better estimates for CND1 and CND2 may be made. Using the IDB vector, one can selectively "make" a given particle stable, e.g. IDB(51) = 0 suppresses the decay of π^0 . Particularly, to avoid the decay of K_S^0 , one may put IDB(25) = IDB(26) = 0.

The procedure of extracting a physical jet, with the use of the EDIT subroutine, can be controlled via the block

COMMON/EDPAR/ ITHROW , PZMIN , PMIN , THETA , PHI , BETA(3)
(Table 4).

Also the other commonblocks can be of use. In particular, corrections in PMAS and QMAS will certainly become necessary once the t quark is found. Further changes, e.g. the use of another scaling function in x for heavy mesons, can be made in the subroutines proper.

Although the program is intended for jet studies, DECAY can be used separately for the study of the decay of a given particle. Before making a CALL DECAY(IPD,I) , the values of I , K(I,2) , P(I,J) , J=1,2,3,4,5, and IPD have to be provided by hand. An (arbitrary) K(I,1) > 0 may also be needed to ensure correct action in subsequent EDIT calls. To simulate the complete decay chain, use a loop as in step 6 in JETGEN .

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Appendix 1

Listings of the program components

```
      SUBROUTINE JETGEN(N)
      COMMON /JET/ K(100,2), P(100,5)
      COMMON /PAR/ PUD, PS1, SIGMA, CX2, EBEG, WFIN, IFLBEG
      COMMON /DECPAR/ PUDD, PS1D, CND1, CND2, IDB(96)
      COMMON /DATA1/ MESO(36), CMIX(6,2), PMAS(96), QMAS(6)
C 1 INITIAL VALUES, PT FOR FIRST QUARK
      I=0
      IPD=0
      W=EBEG+SQRT(EBEG**2-QMAS(IABS(IFLBEG))**2)
      IFL1=IFLBEG
      PT1=SIGMA*SQRT(-ALOG(RANF(0)))
      PHI1=6.2832*RANF(0)
      PX1=PT1*COS(PHI1)
      PY1=PT1*SIN(PHI1)
C 2 FLAVOUR AND PT FOR NEXT ANTIQUARK
  100 I=I+1
      IFL2=ISIGN(1+INT(RANF(0)/PUD),-IFL1)
      PT2=SIGMA*SQRT(-ALOG(RANF(0)))
      PHI2=6.2832*RANF(0)
      PX2=PT2*COS(PHI2)
      PY2=PT2*SIN(PHI2)
C 3 MESON FORMED, SPIN ADDED AND FLAVOUR MIXED
      K(I,1)=MESO(6*(MAX(IFL1,IFL2)-1)-MIN(IFL1,IFL2))
      ISPIN=INT(PS1+RANF(0))
      K(I,2)=20+40*ISPIN+K(I,1)
      IF(K(I,1).GE.31.AND.K(I,1).LE.33) THEN
      TMIX=RANF(0)
      KM=K(I,1)-30+3*ISPIN
      K(I,2)=51+40*ISPIN+INT(TMIX+CMIX(KM,1))+INT(TMIX+CMIX(KM,2))
      ENDIF
C 4 MESON MASS FROM TABLE, PT FROM CONSTITUENTS
      P(I,5)=PMAS(K(I,2))
      P(I,1)=PX1+PX2
      P(I,2)=PY1+PY2
      PMTS=P(I,1)**2+P(I,2)**2+P(I,5)**2
C 5 SCALING IN X GIVES E AND PZ, CUT IN PZ FOR FIRST MESON
  110 X=RANF(0)
      IF(IABS(IFL1).LE.3.AND.RANF(0).LT.CX2) X=1.-X**(1./3.)
      P(I,3)=(X*W-PMTS/(X*W))/2.
      P(I,4)=(X*W+PMTS/(X*W))/2.
      IF(I.EQ.1.AND.P(I,3).LE.0.) GOTO 110
C 6 IF UNSTABLE, DECAY CHAIN INTO STABLE PARTICLES
  120 IPD=IPD+1
      IF(IDB(K(IPD,2)).GT.0) CALL DECAY(IPD,I)
      IF(IPD.LT.I.AND.I.LE.97) GOTO 120
C 7 FLAVOUR AND PT FOR QUARK FORMED IN PAIR WITH ANTIQUARK ABOVE
      IFL1=-IFL2
      PX1=-PX2
      PY1=-PY2
C 8 IF ENOUGH E+PZ LEFT, GO TO 2
      W=(1.-X)*W
      IF(W.GT.WFIN.AND.I.LE.96) GOTO 100
      N=I
      RETURN
      END
```

```
      SUBROUTINE DECAY(IPD,I)
      COMMON /JET/ K(100,2), P(100,5)
      COMMON /DECPAR/ PUDD, PS1D, CND1, CND2, IDB(96)
      COMMON /DATA1/ MESO(36), CMIX(6,2), PMAS(96), QMAS(6)
      COMMON /DATA2/ CBR(135), KDP(135,3), WTCOR(10)
      DIMENSION IFLQ(4), IFLR(4), PM(10,5), RND(10), U(3), BE(3)
      PAWT(A,B,C)=SQRT((A**2-(B+C)**2)*(A**2-(B-C)**2))/(2.*A)
      FOUR(I,J)=P(I,4)*P(J,4)-P(I,1)*P(J,1)-P(I,2)*P(J,2)-P(I,3)*P(J,3)
C 1 DECAY CHANNEL CHOICE, GIVES DECAY PRODUCTS
      TBR=RANF(0)
      IDC=IDB(K(IPD,2))-1
  100 IDC=IDC+1
      IF(TBR.GT.CBR(IDC)) GOTO 100
      NP=0
      NQ=0
      PSUMP=0.
      DO 110 I1=I+1,I+3
      K(I1,2)=KDP(IDC,I1-I)
      IF(K(I1,2).GT.0) THEN
      NP=NP+1
      K(I1,1)=-IPD
      P(I1,5)=PMAS(K(I1,2))
      PSUMP=PSUMP+P(I1,5)
      ELSEIF(K(I1,2).LT.0) THEN
      NQ=NQ+1
      IFLQ(2*NQ-1)=(5-K(I1,2))/6
      IFLQ(2*NQ)=K(I1,2)+6*(IFLQ(2*NQ-1)-1)
      ENDIF
  110 CONTINUE
C 2 DECAY MULTIPLICITY
      ND=NP+NQ
      PSUM=PSUMP
      IF(NQ.EQ.0) GOTO 170
      CND=CND1*ALOG(P(IPD,5)/CND2)
  120 GAUSS=SQRT(-2.*CND*ALOG(RANF(0)))*SIN(6.2832*RANF(0))
      ND=0.5+0.5*(NP+NQ)+CND+GAUSS
      IF(ND.LT.NP+NQ.OR.ND.LT.2.OR.ND.GT.10) GOTO 120
      IF(NP+NQ.EQ.3.AND.K(I+2,2).GE.7.AND.K(I+2,2).LE.18) ND=3
C 3 GENERATION AND PAIRING OFF OF QUARK-ANTIQUARK PAIRS
      DO 130 J=1,4
  130 IFLR(J)=IFLQ(J)
      IF(ND.EQ.NP+NQ) GOTO 150
      DO 140 I1=I+NP+1,I+ND-NQ
      IQ=1+INT(2*NQ*RANF(0))
      IFLN=ISIGN(1+INT(RANF(0)/PUDD),-IFLR(IQ))
      K(I1,1)=MESO(6*(MAX(IFLR(IQ),IFLN)-1)-MIN(IFLR(IQ),IFLN))
  140 IFLR(IQ)=-IFLN
  150 IQ=2+2*INT(NQ*RANF(0))
      K(I+ND-NQ+1,1)=MESO(6*(IFLR(1)-1)-IFLR(IQ))
      IF(NQ.EQ.2) K(I+ND,1)=MESO(6*(IFLR(3)-1)-IFLR(6-IQ))
C 4 MESONS ARE FORMED, IF TOTAL MASS TOO LARGE GO TO 2
      PSUM=PSUMP
      DO 160 I1=I+NP+1,I+ND
      ISPIN=INT(PS1D+RANF(0))
      K(I1,2)=20+40*ISPIN+K(I1,1)
      IF(K(I1,1).GE.31.AND.K(I1,1).LE.33) THEN
      TMIX=RANF(0)
      KM=K(I1,1)-30+3*ISPIN
      K(I1,2)=51+40*ISPIN+INT(TMIX+CMIX(KM,1))+INT(TMIX+CMIX(KM,2))
      ENDIF
      K(I1,1)=-IPD
      P(I1,5)=PMAS(K(I1,2))
```

```
  160 PSUM=PSUM+P(I1,5)
      IF(PSUM+5..GT.P(IPD,5)) GOTO 120
C 5 PRODUCT CHARGE CONJUGATION FOR DECAYING ANTIPARTICLE
  170 IF(2*(K(IPD,2)/2).EQ.K(IPD,2)) THEN
      DO 180 I1=I+1,I+ND
      KCOR=K(I1,2)-(-1)**(K(I1,2)-2*(K(I1,2)/2))
      IF(K(I1,2).GE.7.AND.K(I1,2).LE.50) K(I1,2)=KCOR
  180 IF(K(I1,2).GE.61.AND.K(I1,2).LE.90) K(I1,2)=KCOR
      ENDIF
C 6 ONE-PARTICLE DECAY, START ND-PARTICLE DECAY
      IF(ND.EQ.1) THEN
      DO 190 J=1,4
  190 P(I+1,J)=P(IPD,J)
      GOTO 330
      ENDIF
      DO 200 J=1,5
  200 PM(1,J)=P(IPD,J)
      PM(ND,5)=P(I+ND,5)
      IF(ND.EQ.2) GOTO 260
C 7 CALCULATION OF MAXIMUM WEIGHT
      WTMAX=1./WTCOR(ND)
      PMAX=PM(1,5)-PSUM+P(I+ND,5)
      PMIN=0.
      DO 210 IL=ND-1,1,-1
      PMAX=PMAX+P(I+IL,5)
      PMIN=PMIN+P(I+IL+1,5)
  210 WTMAX=WTMAX*PAWT(PMAX,PMIN,P(I+IL,5))
C 8 M-GENERATOR GIVES WEIGHT, IF REJECTED TRY AGAIN
  220 RND(1)=1.
      DO 240 IL1=2,ND-1
      RAN=RANF(0)
      DO 230 IL2=IL1-1,1,-1
      IF(RAN.LE.RND(IL2)) GOTO 240
  230 RND(IL2+1)=RND(IL2)
  240 RND(IL2+1)=RAN
      RND(ND)=0.
      WT=1.
      DO 250 IL=ND-1,1,-1
      PM(IL,5)=PM(IL+1,5)+P(I+IL,5)+(RND(IL)-RND(IL+1))*(P(IPD,5)-PSUM)
  250 WT=WT*PAWT(PM(IL,5),PM(IL+1,5),P(I+IL,5))
      IF(WT.LT.RANF(0)*WTMAX) GOTO 220
C 9 TWO-PARTICLE DECAY IN CM
  260 DO 280 IL=1,ND-1
      PA=PAWT(PM(IL,5),PM(IL+1,5),P(I+IL,5))
      U(3)=2.*RANF(0)-1.
      PHI=6.2832*RANF(0)
      U(1)=SQRT(1.-U(3)**2)*COS(PHI)
      U(2)=SQRT(1.-U(3)**2)*SIN(PHI)
      DO 270 J=1,3
      P(I+IL,J)=PA*U(J)
  270 PM(IL+1,J)=-PA*U(J)
      P(I+IL,4)=SQRT(PA**2+P(I+IL,5)**2)
  280 PM(IL+1,4)=SQRT(PA**2+PM(IL+1,5)**2)
C 10 DECAY PRODUCTS LORENTZ TRANSFORMED TO LAB SYSTEM
      DO 290 J=1,4
  290 P(I+ND,J)=PM(ND,J)
      DO 320 IL=ND-1,1,-1
      DO 300 J=1,3
  300 BE(J)=PM(IL,J)/PM(IL,4)
      GA=PM(IL,4)/PM(IL,5)
      DO 320 I1=I+IL,I+ND
      BEP=BE(1)*P(I1,1)+BE(2)*P(I1,2)+BE(3)*P(I1,3)
```

```
      DO 310 J=1,3
  310 P(I1,J)=P(I1,J)+GA*(GA/(1.+GA)*BEP+P(I1,4))*BE(J)
  320 P(I1,4)=GA*(P(I1,4)+BEP)
C 11 MATRIX ELEMENTS FOR SEMILEPTONIC AND OMEG AND PHI DECAYS
      IF(ND.EQ.3.AND.K(I+2,2).GE.7.AND.K(I+2,2).LE.18) THEN
      WT=FOUR(IPD,I+1)*FOUR(I+2,I+3)
      IF(WT.LT.RANF(0)*P(IPD,5)**4/WTCOR(1)) GOTO 220
      ELSEIF(ND.EQ.3.AND.(K(IPD,2).EQ.92.OR.K(IPD,2).EQ.93)) THEN
      WT=(P(I+1,5)*P(I+2,5)*P(I+3,5))**2-(P(I+1,5)*FOUR(I+2,I+3))**2
     &-(P(I+2,5)*FOUR(I+1,I+3))**2-(P(I+3,5)*FOUR(I+1,I+2))**2
     &+2.*FOUR(I+1,I+2)*FOUR(I+1,I+3)*FOUR(I+2,I+3)
      IF(WT.LT.RANF(0)*P(IPD,5)**6/WTCOR(2)) GOTO 220
      ENDIF
  330 I=I+ND
      RETURN
      END
```

```
      SUBROUTINE LIST(N)
      COMMON /JET/ K(100,2), P(100,5)
      COMMON /DECPAR/ PUDD, PS1D, CND1, CND2, IDB(96)
      COMMON /DATA3/ CHA1(36), CHA2(96), CHA3(2)
      WRITE(6,110)
      DO 100 I=1,N
      IF(K(I,1).GT.0) C1=CHA1(K(I,1))
      IF(K(I,1).LE.0) IC1=-K(I,1)
      C2=CHA2(K(I,2))
      C3=CHA3(1)
      IF(IDB(K(I,2)).EQ.0) C3=CHA3(2)
      IF(K(I,1).GT.0) WRITE(6,120) I, C1, C2, C3, (P(I,J), J=1,5)
  100 IF(K(I,1).LE.0) WRITE(6,130) I, IC1, C2, C3, (P(I,J), J=1,5)
      RETURN
  110 FORMAT(////T11,'I',T17,'ORI',T24,'PART',T32,'STAB',
     &T44,'PX',T56,'PY',T68,'PZ',T80,'E',T92,'M'/)
  120 FORMAT(10X,I2,4X,A2,1X,2(4X,A4),5(4X,F8.1))
  130 FORMAT(10X,I2,4X,1X,I2,2(4X,A4),5(4X,F8.1))
      END
```

```
      SUBROUTINE EDIT(N)
      COMMON /JET/ K(100,2), P(100,5)
      COMMON /DECPAR/ PUDD, PS1D, CND1, CND2, IDB(96)
      COMMON /EDPAR/ ITHROW, PZMIN, PMIN, THETA, PHI, BETA(3)
      REAL ROT(3,3), PR(3)
C 1 THROW AWAY NEUTRALS OR UNSTABLE OR WITH TOO LOW PZ OR P
      IF(ITHROW.EQ.0) GOTO 120
      I1=0
      DO 110 I=1,N
      IF(ITHROW.GT.0.OR.(ITHROW.LT.0.AND.K(I,1).GT.0)) PZ=P(I,3)
      IF(IABS(ITHROW).GE.1.AND.IDB(K(I,2)).GT.0) GOTO 110
      IF(IABS(ITHROW).GE.2.AND.(K(I,2).EQ.9.OR.K(I,2).EQ.10.OR.K(I,2).
     &EQ.13.OR.K(I,2).EQ.14.OR.K(I,2).EQ.17.OR.K(I,2).EQ.18)) GOTO 110
      IF(IABS(ITHROW).GE.3.AND.(K(I,2).EQ.1.OR.K(I,2).EQ.58)) GOTO 110
      IF(PZ.LT.PZMIN.OR.P(I,4)**2-P(I,5)**2.LT.PMIN**2) GOTO 110
      I1=I1+1
      K(I1,1)=IDIM(K(I,1),0)
      K(I1,2)=K(I,2)
      DO 100 J=1,5
  100 P(I1,J)=P(I,J)
  110 CONTINUE
      N=I1
C 2 ROTATE TO GIVE JET PRODUCED IN DIRECTION THETA, PHI
  120 IF(THETA.LT.1E-4) GOTO 150
      ROT(1,1)=COS(THETA)*COS(PHI)
      ROT(1,2)=-SIN(PHI)
      ROT(1,3)=SIN(THETA)*COS(PHI)
      ROT(2,1)=COS(THETA)*SIN(PHI)
      ROT(2,2)=COS(PHI)
      ROT(2,3)=SIN(THETA)*SIN(PHI)
      ROT(3,1)=-SIN(THETA)
      ROT(3,2)=0.
      ROT(3,3)=COS(THETA)
      DO 140 I=1,N
      DO 130 J=1,3
  130 PR(J)=P(I,J)
      DO 140 J=1,3
  140 P(I,J)=ROT(J,1)*PR(1)+ROT(J,2)*PR(2)+ROT(J,3)*PR(3)
C 3 OVERALL LORENTZ BOOST GIVEN BY BETA VECTOR
  150 IF(BETA(1)**2+BETA(2)**2+BETA(3)**2.LT.1E-8) RETURN
      GA=1./SQRT(1.-BETA(1)**2-BETA(2)**2-BETA(3)**2)
      DO 170 I=1,N
      BEP=BETA(1)*P(I,1)+BETA(2)*P(I,2)+BETA(3)*P(I,3)
      DO 160 J=1,3
  160 P(I,J)=P(I,J)+GA*(GA/(1.+GA)*BEP+P(I,4))*BETA(J)
  170 P(I,4)=GA*(P(I,4)+BEP)
      RETURN
      END
```

```
      BLOCK DATA
      COMMON /PAR/ PUD, PS1, SIGMA, CX2, EBEG, WFIN, IFLBEG
      COMMON /DECPAR/ PUDD, PS1D, CND1, CND2, IDB(96)
      COMMON /EDPAR/ ITHROW, PZMIN, PMIN, THETA, PHI, BETA(3)
      COMMON /DATA1/ MESO(36), CMIX(6,2), PMAS(96), QMAS(6)
      COMMON /DATA2/ CBR(135), KDP(135,3), WTCOR(10)
      COMMON /DATA3/ CHA1(36), CHA2(96), CHA3(2)
      DATA PUD/0.4/, PS1/0.5/, SIGMA/350./, CX2/0.77/,
     &EBEG/10000./, WFIN/100./, IFLBEG/1/
```

```
 DATA PUDD/0.4/, PS1D/0.5/, CND1/1.8/, CND2/800./
 DATA IDB/14*0,2*1,8*0,2*4,2*6,2*9,2*12,2*16,2*21,2*26,2*32,
&2*39,2*45,2*50,2*55,2*61,67,69,74,79,82,86,91,3*0,2*93,2*94,
&2*96,2*98,2*100,2*103,2*104,2*105,2*106,2*107,2*108,2*109,2*110,
&2*111,2*112,113,114,117,121,126,130/
 DATA ITHROW/1/, PZMIN/0./, PMIN/0./, THETA,PHI,BETA/5*0./
 DATA MESO/31,1,3,8,14,22,2,32,5,10,16,24,4,6,33,12,18,26,7,9,11,
&34,20,28,13,15,17,19,35,30,21,23,25,27,29,36/
 DATA CMIX/2*0.5,1.,2*0.5,1.,2*0.25,0.5,2*0.,1./
 DATA PMAS/6*0.,2*0.5,2*0.,2*105.7,2*0.,2*1782.,4*0.,
&2*139.6,2*493.7,2*497.7,2*1863.3,2*1868.3,2*2040.,4*5070.,2*5270.,
&2*6370.,4*15270.,2*15470.,2*16570.,2*19770.,135.,548.8,957.6,
&2850.,9400.,29970.,2*497.7,2*0.,2*765.9,2*892.2,2*896.3,2*2006.,
&2*2008.6,2*2140.,4*5110.,2*5310.,2*6410.,4*15310.,2*15510.,
&2*16610.,2*19810.,770.2,782.6,1019.6,3097.,9460.,30010./
 DATA QMAS/300.,300.,500.,1600.,4800.,15000./
 DATA CBR/.17,.34,1.,.50,1.,.13,.26,1.,.13,.26,1.,.10,.20,.70,
&1.,.17,.34,.39,.90,1.,.17,.34,.39,.90,1.,.16,.32,.37,.85,.95,
&1.,.07,.18,.29,.32,.66,.73,1.,.09,.18,.26,.55,.77,1.,.12,.24,
&.34,.71,1.,.12,.24,.34,.71,1.,.09,.18,.26,.55,.77,1.,.09,.18,
&.26,.55,.77,1.,.988,1.,.381,.681,.918,.969,1.,.426,.662,.959,
&.98,1.,.66,.83,1.,.40,.50,.60,1.,.37,.46,.55,.91,1.,.686,2*1.,
&.667,1.,.667,1.,.55,1.,.60,.80,12*1.,.899,.987,1.,.486,.837,
&.984,1.,.07,.14,.70,.85,1.,.04,.08,.12,1.,.08,.16,.24,1.,2*.0/
 DATA KDP/10,14,17,57,58,8,12,-2,8,12,-2,8,12,2*-2,10,14,18,
&-7,-16,10,14,18,-7,-16,10,14,18,-7,-16,-22,15,10,14,18,-7,2*-16,
&8,12,16,-2,-21,-26,8,12,16,-2,-21,8,12,16,-2,-21,8,12,16,-2,
&-21,-27,8,12,16,-2,2*-21,3*1,51,22,2*1,21,51,3*1,-1,-8,-15,-1,
&-8,-15,-22,-1,-8,-15,-22,-29,21,51,21,25,2*23,25,3*27,2*29,31,
&33,35,37,39,41,43,45,47,49,21,22,1,22,23,25,21,1,8,12,-1,-8,
&-15,8,12,16,55,8,12,16,56,9,13,7,11,-7,2*0,9,13,-13,9,13,-14,
&9,13,-15,0,7,11,15,2*-19,7,11,15,2*-20,7,11,15,2*-21,0,18,7,
&11,15,2*-22,0,9,13,17,2*-25,0,9,13,17,2*-26,9,13,17,2*-27,9,
&13,17,2*-28,0,9,13,17,2*-29,0,1,8,1,51,21,22,1,22,51,91,92,1,
&12*0,22,2*51,21,51,22,2*51,1,21,51,11*1,22,21,51,21,24,26,22,
&52,7,11,3*0,7,11,15,1,7,11,15,1,0,-20,2*17,3*0,2*-13,0,2*-14,
&0,2*-15,2*0,3*-19,2*0,3*-20,2*0,3*-21,4*0,3*-22,3*0,3*-25,3*0,
&3*-26,2*0,3*-27,2*0,3*-28,3*0,3*-29,4*0,7,0,2*51,21,51,2*52,
&38*0,51,4*0,51,16*0/
 DATA WTCOR/16.,150.,2.,5.,15.,60.,250.,1500.,12000.,120000./
 DATA CHA1/'UD','DU','US','SU','DS','SD','CU','UC','CD','DC','CS',
&'SC','BU','UB','BD','DB','BS','SB','BC','CB','TU','UT','TD','DT',
&'TS','ST','TC','CT','TB','BT','UU','DD','SS','CC','BB','TT'/
 DATA CHA2/'GAMM',' ',' ',' ',' ',' ','E-','E+','NUE','NUEB',
&'MU-','MU+','NUM','NUMB','TAU-','TAU+','NUT','NUTB',' ',' ',
&'PI+','PI-','K+','K-','K0','KB','D0','DB','D+','D-','F+','F-',
&'BU-','BU+','BD0','BDB','BS0','BSB','BC-','BC+','TU0','TUB','TD+',
&'TD-','TS+','TS-','TC0','TCB','TB+','TB-','PI0','ETA','ETAP',
&'ETAC','ETAB','ETAT','K0S','K0L',' ',' ','RHO+','RHO-','K*+',
&'K*-','K*0','K*B','D*0','D*B','D*+','D*-','F*+','F*-','BU*-',
&'BU*+','BD*0','BD*B','BS*0','BS*B','BC*-','BC*+','TU*0','TU*B',
&'TD*+','TD*-','TS*+','TS*-','TC*0','TC*B','TB*+','TB*-',
&'RHO0','OMEG','PHI','PSI','UPSI','PHIT'/
 DATA CHA3/'    ','STAB'/
 END
```

Appendix 2

Example of a jet generated with JETGEN and printed with LIST . In this example IFLBEG = 5 , i.e. we have a b quark jet.

I	ORI	PART	STAB	PX	PY	PZ	E	M
1	BU	BU*-		-177.7	188.1	5543.1	7543.5	5110.0
2	1	BU-		-139.6	201.3	5492.3	7478.6	5070.0
3	1	GAMM	STAB	-38.2	-13.2	50.8	64.9	.0
4	2	D*+		582.5	-733.3	2986.8	3719.2	2008.6
5	2	RHO-		-878.6	414.9	610.4	1379.6	765.9
6	2	PI+	STAB	-48.1	-135.4	67.5	211.4	139.6
7	2	RHO-		207.8	433.9	1378.8	1649.0	765.9
8	2	PI-	STAB	-3.1	221.2	448.7	519.4	139.6
9	4	D+		680.0	-680.8	2784.2	3488.3	1868.3
10	4	GAMM	STAB	-97.5	-52.5	202.6	230.9	.0
11	5	PI-	STAB	-823.7	46.9	357.9	910.0	139.6
12	5	PI0		-55.0	368.1	252.5	469.6	135.0
13	7	PI-	STAB	-27.6	469.2	1257.4	1349.6	139.6
14	7	PI0		235.4	-35.3	121.4	299.4	135.0
15	9	RHO+		348.1	-709.6	1128.6	1576.4	765.9
16	9	K*B		331.9	28.8	1655.7	1912.0	896.3
17	12	GAMM	STAB	-10.6	163.1	190.2	250.8	.0
18	12	GAMM	STAB	-44.3	205.0	62.3	218.8	.0
19	14	GAMM	STAB	73.7	-71.5	75.4	127.4	.0
20	14	GAMM	STAB	161.7	36.2	46.0	172.0	.0
21	15	PI+	STAB	537.9	-659.3	888.7	1238.3	139.6
22	15	PI0		-189.8	-50.2	239.9	338.1	135.0
23	16	K-	STAB	261.2	287.9	1307.0	1450.2	493.7
24	16	PI+	STAB	70.7	-259.2	348.7	461.8	139.6
25	22	GAMM	STAB	-205.7	-52.5	241.9	321.9	.0
26	22	GAMM	STAB	15.9	2.3	-2.1	16.2	.0
27	UD	PI+	STAB	-41.6	81.4	1091.9	1104.5	139.6
28	DU	RHO-		36.8	96.1	61.9	775.3	765.9
29	28	PI-	STAB	175.4	319.8	-142.5	415.7	139.6
30	28	PI0		-138.6	-223.7	204.4	359.5	135.0
31	30	GAMM	STAB	-72.0	-216.0	169.8	284.0	.0
32	30	GAMM	STAB	-66.7	-7.7	34.6	75.5	.0
33	UD	PI+	STAB	192.9	-549.8	738.3	950.8	139.6
34	DU	PI-	STAB	-239.8	50.5	192.9	341.7	139.6
35	UU	OMEG		-145.1	-84.5	-57780.0	57785.6	782.6
36	35	PI+	STAB	-90.4	-124.2	-11550.9	11552.8	139.6
37	35	PI-	STAB	193.0	29.9	-31880.5	31881.4	139.6
38	35	PI0		-247.7	9.7	-14348.6	14351.4	135.0
39	38	GAMM	STAB	-56.9	58.9	-5288.0	5288.6	.0
40	38	GAMM	STAB	-190.8	-49.2	-9060.6	9062.8	.0

Table 1

The meaning of the entries of the K and P matrices in the commonblock JET .

Row number I corresponds to the I:th particle produced or, after and EDIT call, the I:th particle retained. Within this row, the meaning of each elements is as follows.

Element	Description	
K(I,1)	K(I,1) > 0:	the particle is a primary meson formed by a quark and an antiquark in the string, K(I,1) gives the flavour of this pair, numbered as in Table 6
	K(I,1) = 0:	a decay product of unknown origin, the connection having been lost by an EDIT call
	K(I,1) < 0:	a product coming from the decay of the particle stored in row number -K(I,1)
K(I,2)	particle type, numbered as in Table 7	
P(I,1)	p_x , particle momentum in the x direction (in MeV/c)	
P(I,2)	p_y , particle momentum in the y direction (in MeV/c)	
P(I,3)	p_z , particle momentum in the z direction (in MeV/c)	
P(I,4)	E , particle energy (in MeV)	
P(I,5)	m , particle rest mass (in MeV/c^2), values given in Table 7.	

Table 2

Default value, allowed range and meaning for the parameters stored in the commonblock PAR and used in JETGEN .

Parameter	Default value (Allowed range)	Description
PUD	0.4 $(\frac{1}{3}-\frac{1}{2})$	probability that a pair materialized in the string will be $u\bar{u}$, the same for $d\bar{d}$, 1-2 • PUD for $s\bar{s}$
PS1	0.5 (0.-1.)	probability that a primary meson will have spin 1, 1-PS1 probability for spin 0
SIGMA	350. ($\geq$0.)	primary meson $p_\perp$ probability distribution is given by Gaussian $\frac{1}{2\pi\sigma^2} e^{-(p_\perp^2/2\sigma^2)} d^2 p_\perp$ (σ in MeV/c)
CX2	0.77 (0.-1.)	$x = \frac{(E+p_z)\text{primary meson}}{(E+p_z)\text{available}}$, 0<x<1 the probability distribution for heavy mesons is flat in x , while for light mesons it is given by $(1-CX2+3 \cdot CX2 \cdot (1-x)^2)dx$
EBEG	10000. (>QMAS(|IFLBEG|)+550.)	starting value (in MeV) for the energy available in the generation process
WFIN	100. (>0.)	value (in MeV) for the $E+p_z$ available, below which the generation of primary mesons is stopped
IFLBEG	1 (±1,±2,±3,±4,±5,±6)	flavour of the quark giving rise to the jet, numbered as in Table 5.

Table 3

Default value, allowed range and meaning for the parameters stored in the commonblock DECPAR and used in DECAY and, for IDB , in JETGEN and EDIT.

Parameter	Default value (Allowed range)	Description
PUDD	0.4 ($\frac{1}{3}$-$\frac{1}{2}$)	same meaning as PUD , but used for pairs materialized in heavy meson decay
PS1D	0.5 (0.-1.)	same meaning as PS1 , but used for mesons formed in heavy meson decay
CND1	1.8 (>0.)	for a decaying particle with mass m , CND = CND1 • $\ln(\frac{m}{CND2})$
CND2	800. (<1750.)	defines the multiplicity distribution ND = $\frac{1}{2}$(NP+NQ) + GD(CND , $\sqrt{CND}$) where NP and NQ is the number of original particles and quark-antiquark pairs, respectively, and GD(μ,σ) is the Gaussian distribution with mean μ and standard deviation σ
IDB(1) . . . IDB(96)	see Table 7	for each particle type K(I,2) , IDB(K(I,2)) gives the number of the first decay channel, according to Table 7; particles with IDB(K(I,2)) = 0 do not decay.

Table 4

Default value, allowed range and meaning for the parameters stored in the commonblock EDPAR and used in EDIT.

Parameter	Default value (Allowed range)	Description
ITHROW	1 (0,±1,±2,±3)	ITHROW = 0: keeps all the particles, no p_z or p cut ITHROW > 0: keeps only particles with $p \geq$ PMIN and $p_z \geq$ PZMIN ITHROW < 0: keeps only particles with $p \geq$ PMIN and coming from a primary meson with $p_z \geq$ PZMIN |ITHROW| = 1: keeps the stable particles (as declared in IDB) |ITHROW| = 2: keeps the stable particles except neutrinos |ITHROW| = 3: keeps the stable particles except neutrinos, γ and K_L^0
PZMIN	0.	(in MeV/c) see ITHROW
PMIN	0. ($\geq$0.)	(in MeV/c) see ITHROW
THETA (θ) PHI (φ)	0. (0.-π) 0. (0.-2π)	rotates the jet axis from the z direction (θ=0) to a given polar angle θ,φ
BETA(1) BETA(2) BETA(3) ($\bar{\beta}$)	0. 0. 0. ($\bar{\beta}^2$<1.)	gives the jet a Lorentz boost, with magnitude and direction determined by $\bar{\beta} = \frac{\bar{v}}{c}$

Table 5

Quark flavours

IFLBEG	Quark
1	u
2	d
3	s
4	c
5	b
6	t

IFLBEG	Quark
-1	$\bar{u}$
-2	$\bar{d}$
-3	$\bar{s}$
-4	$\bar{c}$
-5	$\bar{b}$
-6	$\bar{t}$

Table 6

Meson flavours, used for K(I,1) > 0

K(I,1)	Flavour
1	$u\bar{d}$
2	$d\bar{u}$
3	$u\bar{s}$
4	$s\bar{u}$
5	$d\bar{s}$
6	$s\bar{d}$
7	$c\bar{u}$
8	$u\bar{c}$
9	$c\bar{d}$
10	$d\bar{c}$
11	$c\bar{s}$
12	$s\bar{c}$

K(I,1)	Flavour
13	$b\bar{u}$
14	$u\bar{b}$
15	$b\bar{d}$
16	$d\bar{b}$
17	$b\bar{s}$
18	$s\bar{b}$
19	$b\bar{c}$
20	$c\bar{b}$
21	$t\bar{u}$
22	$u\bar{t}$
23	$t\bar{d}$
24	$d\bar{t}$

K(I,1)	Flavour
25	$t\bar{s}$
26	$s\bar{t}$
27	$t\bar{c}$
28	$c\bar{t}$
29	$t\bar{b}$
30	$b\bar{t}$
31	$u\bar{u}$
32	$d\bar{d}$
33	$s\bar{s}$
34	$c\bar{c}$
35	$b\bar{b}$
36	$t\bar{t}$

Table 7

PARTICLE DATA USED IN THE PROGRAM

K(I,2)		PART	MASS	DECAY PRODUCTS			B.R.	IDC
1	γ	GAMM	.0					
2								
3								
4								
5								
6								
7	e^-	E-	.5					
8	e^+	E+	.5					
9	ν_e	NUE	.0					
10	$\bar{\nu}_e$	NUEB	.0					
11	μ^-	MU-	105.7					
12	μ^+	MU+	105.7					
13	ν_μ	NUM	.0					
14	$\bar{\nu}_\mu$	NUMB	.0					
15	τ^-	TAU-	1782.0	NUEB	E-	NUT	17.0	1
				NUMB	MU-	NUT	17.0	2
				NUT	*DU*		66.0	3
16	τ^+	TAU+	1782.0	NUE	E+	NUTB	17.0	1
				NUM	MU+	NUTB	17.0	2
				NUTB	*UD*		66.0	3
17	ν_τ	NUT	.0					
18	$\bar{\nu}_\tau$	NUTB	.0					
19								
20								
21	π^+	PI+	139.6					
22	π^-	PI-	139.6					
23	K^+	K+	493.7					
24	K^-	K-	493.7					
25	K°	K0	497.7	K0S			50.0	4
				K0L			50.0	5
26	$\bar{K}^\circ$	KB	497.7	K0S			50.0	4
				K0L			50.0	5
27	D°	D0	1863.3	E+	NUE	*SU*	13.0	6
				MU+	NUM	*SU*	13.0	7
				UD	*SU*		74.0	8
28	$\bar{D}^\circ$	DB	1863.3	E-	NUEB	*US*	13.0	6
				MU-	NUMB	*US*	13.0	7
				DU	*US*		74.0	8
29	D^+	D+	1868.3	E+	NUE	*SD*	13.0	9
				MU+	NUM	*SD*	13.0	10
				UD	*SD*		74.0	11
30	D^-	D-	1868.3	E-	NUEB	*DS*	13.0	9
				MU-	NUMB	*DS*	13.0	10
				DU	*DS*		74.0	11
31	F^+	F+	2040.0	E+	NUE	*SS*	10.0	12
				MU+	NUM	*SS*	10.0	13
				UD	*SS*		50.0	14
				UD			30.0	15
32	F^-	F-	2040.0	E-	NUEB	*SS*	10.0	12
				MU-	NUMB	*SS*	10.0	13
				DU	*SS*		50.0	14
				DU			30.0	15
33	B_u^-	BU-	5070.0	NUEB	E-	*CU*	17.0	16
				NUMB	MU-	*CU*	17.0	17
				NUTB	TAU-	*CU*	5.0	18
				DU	*CU*		51.0	19
				SC	*CU*		10.0	20

34	B_u^+	BU+	5070.0	NUE	E+	*UC*	17.0	16
				NUM	MU+	*UC*	17.0	17
				NUT	TAU+	*UC*	5.0	18
				UD	*UC*		51.0	19
				CS	*UC*		10.0	20
35	B_d°	BD0	5070.0	NUEB	E-	*CD*	17.0	21
				NUMB	MU-	*CD*	17.0	22
				NUTB	TAU-	*CD*	5.0	23
				DU	*CD*		51.0	24
				SC	*CD*		10.0	25
36	$\bar{B}_d^\circ$	BDB	5070.0	NUE	E+	*DC*	17.0	21
				NUM	MU+	*DC*	17.0	22
				NUT	TAU+	*DC*	5.0	23
				UD	*DC*		51.0	24
				CS	*DC*		10.0	25
37	B_s°	BS0	5270.0	NUEB	E-	*CS*	16.0	26
				NUMB	MU-	*CS*	16.0	27
				NUTB	TAU-	*CS*	5.0	28
				DU	*CS*		48.0	29
				SC	*CS*		10.0	30
				CC			5.0	31
38	$\bar{B}_s^\circ$	BSB	5270.0	NUE	E+	*SC*	16.0	26
				NUM	MU+	*SC*	16.0	27
				NUT	TAU+	*SC*	5.0	28
				UD	*SC*		48.0	29
				CS	*SC*		10.0	30
				CC			5.0	31
39	B_c^-	BC-	6370.0	TAU-	NUTB		7.0	32
				NUEB	E-	*CC*	11.0	33
				NUMB	MU-	*CC*	11.0	34
				NUTB	TAU-	*CC*	3.0	35
				DU	*CC*		34.0	36
				SC	*CC*		7.0	37
				SC			27.0	38
40	B_c^+	BC+	6370.0	TAU+	NUT		7.0	32
				NUE	E+	*CC*	11.0	33
				NUM	MU+	*CC*	11.0	34
				NUT	TAU+	*CC*	3.0	35
				UD	*CC*		34.0	36
				CS	*CC*		7.0	37
				CS			27.0	38
41	T_u°	TU0	15270.0	E+	NUE	*BU*	9.0	39
				MU+	NUM	*BU*	9.0	40
				TAU+	NUT	*BU*	8.0	41
				UD	*BU*		29.0	42
				CS	*BU*		22.0	43
				BD			23.0	44
42	$\bar{T}_u^\circ$	TUB	15270.0	E-	NUEB	*UB*	9.0	39
				MU-	NUMB	*UB*	9.0	40
				TAU-	NUTB	*UB*	8.0	41
				DU	*UB*		29.0	42
				SC	*UB*		22.0	43
				DB			23.0	44
43	T_d^+	TD+	15270.0	E+	NUE	*BD*	12.0	45
				MU+	NUM	*BD*	12.0	46
				TAU+	NUT	*BD*	10.0	47
				UD	*BD*		37.0	48
				CS	*BD*		29.0	49
44	T_d^-	TD-	15270.0	E-	NUEB	*DB*	12.0	45
				MU-	NUMB	*DB*	12.0	46
				TAU-	NUTB	*DB*	10.0	47
				DU	*DB*		37.0	48
				SC	*DB*		29.0	49

45	T_s^+	TS+	15470.0	E+	NUE	*BS*	12.0	50
				MU+	NUM	*BS*	12.0	51
				TAU+	NUT	*BS*	10.0	52
				UD	*BS*		37.0	53
				CS	*BS*		29.0	54
46	T_s^-	TS-	15470.0	E-	NUEB	*SB*	12.0	50
				MU-	NUMB	*SB*	12.0	51
				TAU-	NUTB	*SB*	10.0	52
				DU	*SB*		37.0	53
				SC	*SB*		29.0	54
47	T_c°	TCO	16570.0	E+	NUE	*BC*	9.0	55
				MU+	NUM	*BC*	9.0	56
				TAU+	NUT	*BC*	8.0	57
				UD	*BC*		29.0	58
				CS	*BC*		22.0	59
				BS			23.0	60
48	$\overline{T}_c^\circ$	TCB	16570.0	E-	NUEB	*CB*	9.0	55
				MU-	NUMB	*CB*	9.0	56
				TAU-	NUTB	*CB*	8.0	57
				DU	*CB*		29.0	58
				SC	*CB*		22.0	59
				SB			23.0	60
49	T_b^+	TB+	19770.0	E+	NUE	*BB*	9.0	61
				MU+	NUM	*BB*	9.0	62
				TAU+	NUT	*BB*	8.0	63
				UD	*BB*		29.0	64
				CS	*BB*		22.0	65
				CS			23.0	66
50	T_b^-	TB-	19770.0	E-	NUEB	*BB*	9.0	61
				MU-	NUMB	*BB*	9.0	62
				TAU-	NUTB	*BB*	8.0	63
				DU	*BB*		29.0	64
				SC	*BB*		22.0	65
				SC			23.0	66
51	π°	PIO	135.0	GAMM	GAMM		98.8	67
				GAMM	E+	E-	1.2	68
52	η	ETA	548.8	GAMM	GAMM		38.1	69
				PIO	PIO	PIO	30.0	70
				PI+	PI-	PIO	23.7	71
				GAMM	PI+	PI-	5.1	72
				GAMM	GAMM	PIO	3.1	73
53	η'	ETAP	957.6	PI+	PI-	ETA	42.6	74
				PIO	PIO	ETA	23.6	75
				GAMM	RHOO		29.7	76
				GAMM	OMEG		2.1	77
				GAMM	GAMM		2.0	78
54	η_c	ETAC	2850.0	*UU*			66.0	79
				DD			17.0	80
				SS			17.0	81
55	η_b	ETAB	9400.0	*UU*			40.0	82
				DD			10.0	83
				SS			10.0	84
				CC			40.0	85
56	η_t	ETAT	29970.0	*UU*			37.0	86
				DD			9.0	87
				SS			9.0	88
				CC			36.0	89
				BB			9.0	90
57	K_S°	KOS	497.7	PI+	PI-		68.6	91
				PIO	PIO		31.4	92
58	K_L°	KOL	497.7					
59								
60								

61	ρ^+	RHO+	765.9	PI+	PI0		100.0	93
62	ρ^-	RHO-	765.9	PI-	PI0		100.0	93
63	K^{*+}	K*+	892.2	K0	PI+		66.7	94
				K+	PI0		33.3	95
64	K^{*-}	K*-	892.2	KB	PI-		66.7	94
				K-	PI0		33.3	95
65	K^{*0}	K*0	896.3	K+	PI-		66.7	96
				K0	PI0		33.3	97
66	$\bar{K}^{*0}$	K*B	896.3	K-	PI+		66.7	96
				KB	PI0		33.3	97
67	D^{*0}	D*0	2006.0	D0	PI0		55.0	98
				D0	GAMM		45.0	99
68	$\bar{D}^{*0}$	D*B	2006.0	DB	PI0		55.0	98
				DB	GAMM		45.0	99
69	D^{*+}	D*+	2008.6	D0	PI+		60.0	100
				D+	PI0		20.0	101
				D+	GAMM		20.0	102
70	D^{*-}	D*-	2008.6	DB	PI-		60.0	100
				D-	PI0		20.0	101
				D-	GAMM		20.0	102
71	F^{*+}	F*+	2140.0	F+	GAMM		100.0	103
72	F^{*-}	F*-	2140.0	F-	GAMM		100.0	103
73	B_u^{*-}	BU*-	5110.0	BU-	GAMM		100.0	104
74	B_u^{*+}	BU*+	5110.0	BU+	GAMM		100.0	104
75	B_d^{*0}	BD*0	5110.0	BD0	GAMM		100.0	105
76	$\bar{B}_d^{*0}$	BD*B	5110.0	BDB	GAMM		100.0	105
77	B_s^{*0}	BS*0	5310.0	BS0	GAMM		100.0	106
78	$\bar{B}_s^{*0}$	BS*B	5310.0	BSB	GAMM		100.0	106
79	B_c^{*-}	BC*-	6410.0	BC-	GAMM		100.0	107
80	B_c^{*+}	BC*+	6410.0	BC+	GAMM		100.0	107
81	T_u^{*0}	TU*0	15310.0	TU0	GAMM		100.0	108
82	$\bar{T}_u^{*0}$	TU*B	15310.0	TUB	GAMM		100.0	108
83	T_d^{*+}	TD*+	15310.0	TD+	GAMM		100.0	109
84	T_d^{*-}	TD*-	15310.0	TD-	GAMM		100.0	109
85	T_s^{*+}	TS*+	15510.0	TS+	GAMM		100.0	110
86	T_s^{*-}	TS*-	15510.0	TS-	GAMM		100.0	110
87	T_c^{*0}	TC*0	16610.0	TC0	GAMM		100.0	111
88	$\bar{T}_c^{*0}$	TC*B	16610.0	TCB	GAMM		100.0	111
89	T_b^{*+}	TB*+	19810.0	TB+	GAMM		100.0	112
90	T_b^{*-}	TB*-	19810.0	TB-	GAMM		100.0	112
91	ρ^0	RHO0	770.2	PI+	PI-		100.0	113
92	ω	OMEG	782.6	PI+	PI-	PI0	89.9	114
				GAMM	PI0		8.8	115
				PI+	PI-		1.3	116
93	ϕ	PHI	1019.6	K+	K-		48.6	117
				K0	KB		35.1	118
				PI+	PI-	PI0	14.7	119
				GAMM	ETA		1.6	120
94	ψ	PSI	3097.0	E-	E+		7.0	121
				MU-	MU+		7.0	122
				UU			56.0	123
				DD			15.0	124
				SS			15.0	125
95	Υ	UPSI	9460.0	E+	E-		4.0	126
				MU+	MU-		4.0	127
				TAU+	TAU-		4.0	128
				ETAB	GAMM		88.0	129
96	ϕ_t	PHIT	30010.0	E-	E+		8.0	130
				MU-	MU+		8.0	131
				TAU-	TAU+		8.0	132
				ETAT	GAMM		76.0	133