

# JAM 1.009: A microscopic simulation program for ultra-relativistic nuclear collisions

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## Abstract

JAM is a simulation program which is designed to simulate (ultra-) relativistic nuclear collisions from initial stage of nuclear collision to final state interaction in hadronic gas stage and can be used from low ( $E_{\text{lab}} = 1 - 10 \text{ AGeV}$ ) energy. In JAM, hadrons and their excited states are explicitly propagated in space-time by the cascade method. In order to describe nuclear collisions consistently from low to high energy, elementary hadron-hadron collisions are modeled by resonance production at low energies, string excitations at soft region and hard parton-parton scattering at collider energies according to the important physics at each energy range.

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## 1 Program Summary

*Title of program:* JAM 1.0

*Program obtainable from:* CPC Program Library, Queen's University of Belfast, N. Ireland and from the author at ynara@hadron03.tokai.jaeri.go.jp

*Computer for which the program is designed:* Pentium, Dec alpha, Hewlett Packard UX-A-9000 SPARC stations and other computers with a FORTRAN 77 compiler.

*Computers on which it has been tested:* DEC Workstation, SUN workstation, Pentium personal computer.

*Operating systems under which the program has been tested:* OSF1 V4.0 878 alpha, Free-BSD, Linux, Sun-OS 5.5.1.

*Programming language used:* FORTRAN 77

*Memory required to execute with typical data:* 1,450 words

*No. of bits in a word:* 64

*Number of lines in distributed program:* 64253

*Keywords:* ultrarelativistic heavy ion collisions, cascade, hadron, parton, pQCD, Boltzmann equation.

### *Nature of physical problem*

The microscopic description of ultra-relativistic nuclear collisions is necessary to understand the time evolution of hot and dense matter produced in heavy-ion collisions from non-equilibrium stage. A model which can simulate consistently from low to high incident energy nuclear collisions are required for the systematic studies of the bombarding energy dependence on some observable and the treatment of the final state interactions among produced particle.

### *Method of solution*

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The space-time evolution of hadrons including excited states is solved by the cascade method. Low energy total and elastic hadron-hadron cross sections are parameterized to experimental data if possible. Inelastic hadron-hadron collisions are modeled by the resonance picture at low energy, string picture at intermediate energy and hard parton-parton scattering at high energy.

#### *Typical running time*

The running time depends on the bombarding energy, system size and impact-parameter. For example, on the pentium II 266MHz on Free-BSD 2.2.6R:

Si(14.6AGeV/c)+Al b=1.5fm 1m 33s per 100events on DEC alpha.

#### *Unusual features of the program*

none

## LONG WRITE-UP

## 2 Introduction

In ultra-relativistic heavy ion collisions, reaction dynamics is generally complex. We have to solve basically many-body system involved several hundred particles at initial stage but due to the large number of multi-particle productions, number of particles are reached to about the several (hundred) thousands depending on both the incident energy and impact parameter. We may use Monte-Carlo simulation to solve these many-body system. In order to investigate and understand its dynamics, event generators have been made such as FRITIOF [1], LUCIAE [2], DPM [3], VENUS [4], HIJING [6], HIJET [7]. These models do not follow explicitly space-time trajectory but assume Glauber geometry for the treatment of AA collisions. Microscopic hadronic transport models such as RQMD [8, 9], QGSM [10], ARC [11], ART [12], UrQMD [14] and HSD [13] have been used to describe the nucleus-nucleus collisions from first  $NN$  collision stage to the final state interaction among produced particles. These microscopic transport models follow the space-time trajectory of the particles and can extract detailed space-time information on the reaction dynamics in nuclear collisions.

Boltzmann-Uehling-Uhlenbeck (BUU) [15] approach based on the classical kinetic one-body transport equation including the Pauli-blocking of the final state of the colliding nucleons is the first attempt to describe heavy ion collisions at the energy range  $30\text{A MeV} \sim 2\text{GeV}$ , by microscopic transport model in which two-body collision term are realized by the intra-nuclear cascade model [16, 17, 18] and nuclear meanfield is solved by the test-particle method [15]. Quantum molecular dynamics (QMD) model [20] has been developed in order to simulate the time evolution of the  $n$ -body phase space distribution function. Both relativistic version of BUU and QMD have been also appeared which are called RBUU [19] and RQMD [8] respectively. ART and HSD are an extension of BUU and RBUU model to the high energies, while RQMD and UrQMD are based on the spirit of QMD model. The most important element for high energy nuclear collisions  $E_{\text{lab}} > 10\text{AGeV}$  in above mentioned transport models are incoherent superposition of two-body collisions among particles. Some observable may strongly depend on the mean field, for example, the mean field effect on the transverse flow at AGS energies [26, 12].

In ultra-relativistic heavy ion collisions at collider energies, hard and semihard processes are expected to be important [6]. Multiple minijet production with initial and final state radiation has been included into event generator for nuclear collision in HIJING [6] and VNI [21] based on perturbative QCD (pQCD). In HIJING, the number of minijets per inelastic  $pp$  collision is calculated using an eikonal formalism and AA collision are realized by the Glauber type multiple  $NN$  collisions. VNI is a Monte Carlo implementation of the parton cascade model in which space-time evolution of on-shell as well as off-shell partons are followed by cascade method. Any multiple parton-parton collisions are, therefore, automatically included in VNI. Interaction among the produced partons would be important. Parton cascade models VNI [21] and ZPC [22] are designed to implement theses parton dynamics to study space-time evolution of partons.

JAM has been developed based on the above mentioned models for the concept that it should reduce hadronic transport model like BUU and QMD at low energies, in order to describe consistently nuclear collision from low to high energy, in addition to be able to treat the final state interaction among produced hadrons, while at collider energies, multiple minijets production is included. Although, in present version of JAM, these requirements has not been completely implemented, The main features included in JAM1.009 are as follows. (1) At low energy, inelastic hadron-hadron ( $hh$ ) collisions are modeled by the resonance productions based on the idea from RQMD and UrQMD. (2) Nuclear mean field is simulated based on the BUU theory. (3) Above resonance region, soft string excitation is implemented along the lines of the HIJING model [6]. (4) Multiple minijet production is also included in the same way as the HIJING model in which jet cross section and the number of jet is calculated using an eikonal formalism

for perturbative QCD (pQCD) and hard parton-parton scatterings with initial and final state radiation are simulated using PYTHIA [5] program.

### 3 Description of the model

In this section, we will present the main aspect of JAM [28].

#### 3.1 Main features of the model

For the description of AA collisions in cascade model, the trajectories of all hadrons as well as resonances including produced particles are followed explicitly as a function of space and time. The main components of our model are as follows. (1) Nuclear collision is assumed to be described by the sum of independent binary  $hh$  (possibility parton-parton, parton-hadron) collisions.  $hh$  collisions are realized by the closest distance approach. Two particles will collide if their distance is smaller than  $\sqrt{\sigma(s)}/\pi$ , here  $\sigma(s)$  represents the total cross section at the c.m. energy  $\sqrt{s}$ . As a default option, any mean field is not included, therefore the trajectory of hadrons are straight line in between two-body collisions or decays. As a results of  $hh$  collision, hadrons are assumed to be excited to either resonance or string at soft collisions, in the case of hard scattering, on-shell partons and remnants. (2) The initial positions of each nucleons are sampled by the parameterized distribution of nuclear density. Fermi motion of nucleons are assigned according to the local Fermi momentum. (3) all established hadronic states (see appendix 5.3) are explicitly included with explicit iso-spin states as well as their anti-particles and they can propagate in space-time. (4) the inelastic  $hh$  collisions produce resonances at low energies while at high energies ( $\sim 4\text{GeV}$  in  $BB$  collisions  $\sim 3\text{GeV}$  in  $MB$  collisions and  $\sim 2\text{GeV}$  in  $MM$  collisions) color strings are formed and they decay into hadrons according to the Lund string model with some formation time. Formation point and time are determined by assuming yo-yo formation point [35]. This gives roughly formation time of  $1\text{fm}/c$  with string tension  $\kappa = 1\text{GeV}/\text{fm}$ . (5) Hadrons which have original constituent quarks can scatter with hadrons assuming the additive quark cross section within a formation time. The importance of this quark(diquark)-hadron interaction for the description of baryon stopping at CERN/SPS energies was reported by Frankfurt group [8, 14]. (6) Pauli-blocking for the final nucleons in two-body collisions are also considered. (7) Low energy baryon-baryon, baryon-meson and meson-meson rescattering are also included assuming resonance/string excitation picture in order to treat final state interaction of hadronic gas. Extending the particle table of PYTHIA, baryon and meson resonances are explicitly propagated and they can rescatter.

#### 3.2 Modeling hh collisions

In order to consistently describe nucleus-nucleus collisions for the large energy regime from  $\sim 1\text{GeV}$  to collider energies, hadron-hadron collisions are basically modeled by the resonance production at  $\sqrt{s} < 4\text{GeV}$ , soft string excitation at  $4 < \sqrt{s} < 50\text{GeV}$ , minijet production at  $\sqrt{s} > 10\text{GeV}$ . Total hadronic cross section is divided by

$$\sigma_{tot}(s) = \sigma_{el}(s) + \sigma_{t-R}(s) + \sigma_{BW}(s) + \sigma_{t-S}(s) + \sigma_{s-S}(s) + \sigma_{ann}(s) + \sigma_{ch}(s) , \quad (1)$$

where  $\sigma_{el}(s)$  is elastic,  $\sigma_{t-R}(s)$  t-resonance production,  $\sigma_{BW}(s)$  s-channel resonance formation,  $\sigma_{s-S}(s)$  s-channel string formation,  $\sigma_{ann}(s)$  annihilation of  $\bar{B}B$ ,  $\sigma_{ch}(s)$  charge exchange cross sections respectively.  $\sigma_{t-S}(s)$  contains the soft string excitation and hard parton-parton scattering which can be written within the eikonal formalism for pQCD [6]

$$\sigma_{t-S}(s) = 2\pi \int_0^\infty db^2 \left[ 1 - e^{-\chi(b,s)} \right] , \quad (2)$$

where  $\chi(b, s)$  is defined as

$$\chi(b, s) = \left( \frac{1}{2}\sigma_{\text{soft}}(s) + \frac{1}{2}\sigma_{\text{jet}}(s) \right) T_N(b, s). \quad (3)$$

with overlap function  $T_N(b, s)$  and soft  $\sigma_{\text{soft}}(s)$  and hard  $\sigma_{\text{jet}}(s)$  cross sections. The  $\sigma_{\text{soft}}(s)$  is usually decomposed into diffractive part and low  $p_T$  non-diffractive part. The  $\sigma_{\text{jet}}(s)$  represents the cross section of hard parton scattering and can be calculated by perturbative QCD (pQCD) as

$$\sigma_{\text{jet}}(s) = \int \int \int dx_1 dx_2 d\hat{t} f_1(x_1, Q^2) f_2(x_2, Q^2) \frac{d\hat{\sigma}}{d\hat{t}}. \quad (4)$$

with parton distribution function  $f(x_i, Q^2)$  and  $Q$  is a typical momentum transfer in the partonic process. The  $d\hat{\sigma}/d\hat{t}$  expresses the differential cross section for a partonic scattering. PYTHIA is used to generate hard scattering including

initial- and final-state radiation. The space-time points of partons produced by the hard scattering are calculated applying uncertainty principle [27].

Particle productions at low energies ( $\sqrt{s} \leq 4.0$  for the BB collisions) are modeled via the excitation and decay of resonances. Inelastic cross sections are assumed to be filled up with the resonance formations  $\sigma_{t-R}(s)$  up to  $E_{cm} = 3\text{--}4\text{GeV}$ . The gap between experimental inelastic cross section and resonance formation cross sections are assigned to be string formation. The following resonance excitations are implemented in NN collisions

- (1)  $NN \rightarrow N\Delta(1232)$ , (2)  $NN \rightarrow NN^*$ , (3)  $NN \rightarrow \Delta(1232)\Delta(1232)$ ,
- (4)  $NN \rightarrow N\Delta^*$ , (5)  $NN \rightarrow N^*\Delta(1232)$ , (6)  $NN \rightarrow \Delta(1232)\Delta^*$ , (7)  $NN \rightarrow N^*N^*$ ,
- (8)  $NN \rightarrow N^*\Delta^*$ , (9)  $NN \rightarrow \Delta^*\Delta^*$ .

The strength of each branches are determine from the exclusive pion production data [29].

The cross section for the production of resonances may be written by

$$\frac{d\sigma_{12 \rightarrow 34}}{d\Omega} = \frac{(2S_3 + 1)(2S_4 + 1)}{64\pi^2 s p_{12}} \int \int p_{34} |\mathcal{M}|^2 A(m_3^2) A(m_4^2) dm_3^2 dm_4^2 \quad (5)$$

where  $S_i, i = 3, 4$  express the spin of the particles in the final state. Mass distribution function  $A(m_i^2)$  for nucleons is just a  $\delta$ -function, while that for resonances is given by the relativistic Breit-Wigner function

$$A(m^2) = \frac{1}{\mathcal{N}} \frac{m_R \Gamma(m)}{(m^2 - m_R^2)^2 + m_R^2 \Gamma(m)^2}. \quad (6)$$

where  $\mathcal{N}$  denotes the normalization constant. In this paper, we use simply take  $\mathcal{N} = \pi$  which is a value in the case of a constant width. The full width  $\Gamma(m)$  is a sum of all partial decay width  $\Gamma_R(MB)$  for resonance  $R$  into mesons  $M$  and baryons  $B$  which depends on the momentum of the decaying particle [9, 14]:

$$\Gamma_R(MB) = \Gamma_R^0(MB) \frac{m_R}{m} \left( \frac{p_{cms}(m)}{p_{cms}(m_R)} \right)^{2\ell+1} \frac{1.2}{1 + 0.2 \left( \frac{p_{cms}(m)}{p_{cms}(m_R)} \right)^{2\ell+1}} \quad (7)$$

where  $\ell$  and  $p_{cms}(m)$  are the relative angular momentum and the relative momentum in the exit channel in their rest frame. Neglecting the mass dependence of the matrix element, masses of resonances are generated according to the distribution

$$P(m_3, m_4) = 4m_3 m_4 p_{34} A(m_3^2) A(m_4^2) dm_3 dm_4 \quad (8)$$

Note that we do not give the cross sections for each resonance production but for the average cross section. We need to know the matrix element  $|\mathcal{M}|^2$  for all resonances from the formula Eq.(5). In Ref. [30], the matrix elements are fitted to reproduce the pion production cross sections up to two-pion productions as well as  $\eta$  production cross section assuming the constant value for the matrix element. In our model, we assume simply that each resonance production cross section can be selected according to the probability:

$$P(R_i, R_j) \sim (2S_i + 1)(2S_j + 1) \int \int p_{ij}(m_i, m_j) A_i(m_i) A_j(m_j) dm_i dm_j, \quad (9)$$

where  $A_i$  represents the Breit-Wigner function. This simple assumption gives reasonable results for the pp data.

### 3.3 Inverse processes

In the processes for resonance absorption, we use a generalized detailed balance formula [31, 32, 33] which takes the finite width of the resonance mass into account. The differential cross section for the reaction  $(3, 4) \rightarrow (1, 2)$  can be expressed by the cross section for  $(1, 2) \rightarrow (3, 4)$ :

$$\frac{d\sigma_{34 \rightarrow 12}}{d\Omega} = \frac{(2S_1 + 1)(2S_2 + 1)}{(2S_3 + 1)(2S_4 + 1)} \frac{p_{12}^2}{p_{34}} \frac{d\sigma_{12 \rightarrow 34}}{d\Omega} \frac{1}{\int \int p_{34} A(m_3) A(m_4) d(m_3^2) d(m_4^2)}. \quad (10)$$

### 3.4 Meson-Baryon, Meson-Meson Collisions

We now turn to the explanation of meson-baryon ( $MB$ ) and meson-meson ( $MM$ ) collisions. We also use resonance/string excitation model for  $MB$  and  $MM$  collisions.

Total cross section for  $\pi N$  incoming channel is assumed to be decomposed to

$$\sigma_{tot}(s)^{\pi N} = \sigma_{BW}(s) + \sigma_{el}(s) + \sigma_{s-S}(s) + \sigma_{t-S}(s), \quad (11)$$

where  $\sigma_{el}(s)$ ,  $\sigma_{BW}(s)$ ,  $\sigma_{s-S}(s)$ , and  $\sigma_{t-S}(s)$  denote the  $t$ -channel elastic cross section, the  $s$ -channel resonance formation cross section with the Breit-Wigner form, the  $s$ -channel and  $t$ -channel string formation cross sections, respectively. We neglect the  $t$ -channel resonance formation cross section at a energy range of  $\sqrt{s} \lesssim 2\text{GeV}$ . The  $t$ -channel elastic cross section  $\sigma_{el}(s)$  was determined so that the sum of the elastic component of the  $s$ -channel Breit-Wigner cross section  $\sigma_{BW}(s)$  and  $t$ -channel elastic cross section  $\sigma_{el}(s)$  reproduces the experimental elastic data for  $\pi N$  interaction. Above the  $\Delta(1232)$  region,  $t$ -channel elastic cross section becomes non-zero in our parameterization. String formation cross sections ( $\sigma_{s-S}(s)$  and  $\sigma_{t-S}(s)$ ) are determined to fill up the difference between experimental total cross section and  $\sigma_{BW}(s) + \sigma_{el}(s)$ . We calculate the resonance formation cross section  $\sigma_{BW}(s)$  using the Breit-Wigner formula [40, 8] (neglecting the interference between resonances),

$$\sigma(MB \rightarrow R) = \frac{\pi(\hbar c)^2}{p_{cm}^2} \sum_R |C(MB, R)|^2 \frac{(2S_R + 1)}{(2S_M + 1)(2S_B + 1)} \frac{\Gamma_R(MB)\Gamma_R(tot)}{(\sqrt{s} - m_R)^2 + \Gamma_R(tot)^2/4}. \quad (12)$$

The momentum dependent decay width Eq. (7) are also used for the calculation of decay width in Eq. (12).  $S_R$ ,  $S_B$  and  $S_M$  denote the spin of the resonance, the decaying baryon and meson respectively. The sum runs over resonances,  $R = N(1440) \sim N(1990)$  and  $\Delta(1232) \sim \Delta(1950)$ . Actual values for these parameters are taken from the Particle Data Group [37] and adjusted within an experimental error bar to get reasonable fit for  $MB$  cross sections.

Since the  $\bar{K}N$  interaction has some exoergic channels such as  $\bar{K}N \rightarrow \pi Y$ , we need to include additional terms:

$$\sigma_{tot}(s)^{\bar{K}N} = \sigma_{BW}(s) + \sigma_{el}(s) + \sigma_{ch}(s) + \sigma_{\pi Y}(s) + \sigma_{s-S}(s) + \sigma_{t-S}(s), \quad (13)$$

where  $\sigma_{ch}(s)$  and  $\sigma_{\pi Y}(s)$  denote  $t$ -channel charge exchange reaction and  $t$ -channel hyperon production cross sections which are also fixed by the requirement that the sum of  $t$ -channel contributions and Breit-Wigner contributions reproduce experimental data. Breit-Wigner formula enables us to calculate experimentally unmeasured cross sections such as  $\rho N \rightarrow \Lambda K$ . For the calculation of  $\sigma_{BW}(s)$ , we include hyperon resonances,  $R = \Lambda(1405) \sim \Lambda(2110)$  and  $\Sigma(1385) \sim \Sigma(2030)$ . The total and elastic cross sections for  $\bar{K}N$  interactions used in JAM are fit to the data [37].

The symbol  $\sigma_{\pi Y}(s)$  in Eq.(13) is the sum of  $t$ -channel pion hyperon production cross sections  $\bar{K}N \rightarrow \pi Y$ ,  $Y = \Lambda, \Sigma$ . The cross section for the inverse processes such as  $\pi Y \rightarrow \bar{K}N$  are calculated using the detailed balance formula.

$KN$  incoming channel cannot form any  $s$ -channel resonance due to their quark contents. Therefore the total cross section can be written within our model as follows,

$$\sigma_{tot}(s)^{KN} = \sigma_{t-R}(s) + \sigma_{el}(s) + \sigma_{ch}(s) + \sigma_{t-S}(s), \quad (14)$$

where  $\sigma_{t-R}(s)$  is  $t$ -channel resonance formation cross section. In the present version of JAM, only  $KN \rightarrow K\Delta$ ,  $KN \rightarrow K(892)N$  and  $KN \rightarrow K(892)\Delta$  are explicitly fitted to experimental data [29].

In meson-meson scattering, we also apply the same picture as that in meson-baryon collisions:

$$\sigma_{tot}(s) = \sigma_{BW}(s) + \sigma_{t-R}(s) + \sigma_{el}(s) + \sigma_{s-S}(s) + \sigma_{t-S}(s). \quad (15)$$

The difference between experimental inelastic cross section and resonance cross sections at energies above resonance region for the meson-baryon and meson-meson collisions are attributed to the string formation cross section where  $1/\sqrt{s}$  energy dependence of  $\sigma_{s-S}(s)$  is used [9].

For the cross sections for which no experimental data are available, we calculate the total and elastic cross sections by using the additive quark model [8, 14, 39]

$$\sigma_{tot} = \sigma_{NN} \left(\frac{n_1}{3}\right) \left(\frac{n_2}{3}\right) \left(1 - 0.4 \frac{n_{s1}}{n_1}\right) \left(1 - 0.4 \frac{n_{s2}}{n_2}\right), \quad (16)$$

$$\sigma_{el} = \sigma_{tot}^{2/3} (\sigma_{el}^{NN} / \sigma_{NN}^{2/3}), \quad (17)$$

where  $\sigma_{NN}$ ,  $\sigma_{el}^{NN}$  express nucleon-nucleon total and elastic cross sections and  $n_i, n_{si}$  are the number of quarks and  $s$ -quarks contained in the hadron respectively. This expression works well above resonance region where the cross section becomes flat.

For the  $t$ -channel resonance production cross sections  $\sigma_{t-R}(s)$ , we do not fit experimental data explicitly in this work except for  $NN$  reaction and one and two pion productions in  $KN$  reaction, because of the vast body of the possibilities for the final states. Instead, we simply determine the outgoing resonance types according to the spins  $S_3$ ,  $S_4$  in the final state and phase space for the production of resonances  $R_3$  and  $R_4$

$$P(R_3, R_4) \propto (2S_3 + 1)(2S_4 + 1)p_{34}(s)^2. \quad (18)$$

where  $p_{34}(s)$  denotes the c.m. momentum in the final state. If the incoming channel involves resonances, their ground state particles are also considered in the final state. Once the outgoing resonance types are determined, we generate masses according to the Breit-Wigner distribution.

For the angular dependence in the processes of  $t$ -channel resonance production  $\sigma_{t-R}(s)$ , we use

$$\frac{d\sigma_{t-R}(s)}{dt} \sim \exp(bt), \quad (19)$$

and the slope parameter  $b$  for the energy range of  $\sqrt{s} > 2.17\text{GeV}$  is parameterized by

$$b = 2.5 + 0.7 \log(s/2), \quad (20)$$

with invariant mass squared  $s$  given in units of  $\text{GeV}^2$ . We use the same parameterization presented in Ref. [43] for the energy below  $\sqrt{s} < 2.17\text{GeV}$  for the  $t$ -channel resonance productions. The elastic angular distribution is also taken from Ref. [43] for  $\sqrt{s} < 10\text{GeV}$  and from PYTHIA [5] for  $\sqrt{s} > 10\text{GeV}$ .

### 3.5 Soft interactions modeled by string model

At an energy range above  $\sqrt{s} > 4-5\text{GeV}$ , the (isolated) resonance picture breaks down because width of the resonance becomes wider and the discrete levels get closer. The hadronic interactions at the energy range  $4-5 < \sqrt{s} < 10-100\text{GeV}$  where it is characterized by the small transverse momentum transfer is called "soft process", and string phenomenological models are known to describe the data for such soft interaction well. The hadron-hadron collision leads to a string like excitation longitudinally. In actual description of the soft processes, we follow the prescription adopted in the HIJING model [6], as described below.

In the center of mass frame of two colliding hadrons, we introduce light-cone momenta defined by

$$p^+ = E + p_z, \quad p^- = E - p_z. \quad (21)$$

Assuming that beam hadron 1 moves in the positive  $z$ -direction and target hadron 2 moves negative  $z$ -direction, the initial momenta of the both hadrons are

$$p_1 = (p_1^+, p_1^-, 0_T), \quad p_2 = (p_2^+, p_2^-, 0_T). \quad (22)$$

After exchanging the momentum  $(q^+, q^-, \mathbf{p}_T)$ , the momenta will change to

$$p_1' = ((1 - x^+)P^+, x^-P^-, \mathbf{p}_T), \quad p_2' = (x^+P^+, (1 - x^-)P^-, -\mathbf{p}_T), \quad (23)$$

where  $P^+ = p_1^+ + p_2^+ = P^- = p_1^- + p_2^- = \sqrt{s}$  (in c.m. frame). The string masses will be

$$M_1^2 = x^-(1 - x^+)s - p_T^2, \quad M_2^2 = x^+(1 - x^-)s - p_T^2, \quad (24)$$

respectively. Minimum momentum fractions are  $x_{min}^+ = p_2^+/P^+$  and  $x_{min}^- = p_1^-/P^-$ . For light-cone momentum transfer for the non-diffractive events, we use the same distribution as that in DPM [3] and HIJING [6]:

$$P(x^\pm) = \frac{(1.0 - x^\pm)^{1.5}}{(x^{\pm 2} + c^2/s)^{1/4}}, \quad (25)$$

for baryons and

$$P(x^\pm) = \frac{1}{(x^{\pm 2} + c^2/s)^{1/4}((1 - x^\pm)^2 + c^2/s)^{1/4}}, \quad (26)$$

for mesons, where  $c = 0.1\text{GeV}$  is a cutoff. For single-diffractive events, in order to reproduce experimentally observed mass distribution  $dM^2/M^2$ , we use the distribution

$$P(x^\pm) = \frac{1}{(x^{\pm 2} + c^2/s)^{1/2}}. \quad (27)$$

The same functional form as the HIJING model [6] for the soft  $\mathbf{p}_T$  transfer at low  $p_T < p_0$  is used

$$f(\mathbf{p}_T) = \left\{ (p_T^2 + c_1^2)(p_T^2 + p_0^2)(1 + e^{(p_T - p_0)/c_2}) \right\}^{-1}, \quad (28)$$

where  $c_1 = 0.1 \text{ GeV}/c$ ,  $p_0 = 1.4 \text{ GeV}/c$  and  $c_2 = 0.4 \text{ GeV}/c$ , to reproduce the high momentum tail of the particles at energies  $E_{lab} = 10 \sim 20 \text{ GeV}$ .

The strings are assumed to hadronize via quark-antiquark or diquark-antidiquark creation using Lund fragmentation model PYTHIA6.1[5]. Hadron formation points from a string fragmentation are assumed to be given by the yo-yo formation point [35] which is defined by the first meeting point of created quarks. Yo-yo formation time is about  $1 \text{ fm}/c$  assuming the string tension  $\kappa = 1 \text{ GeV}/\text{fm}$  at AGS energies.

In the Lund string model, space-time coordinates and energy-momentum coordinates for the quarks are directly related via the string tension [41, 42]. Let us consider one-dimensional massless  $q\bar{q}$  string in the c.m.. If  $x_i^\pm = t_i \pm x_{zi}$  denote the light-cone coordinates of the  $i$ th production point, then the light cone momenta  $p_i^\pm = E_n \pm p_{zi}$  of the  $i$ th rank hadron which is produced by the energy-momentum fraction  $z_i$  from  $(i-1)$ th string  $p_i^+ = z_i p_{i-1}^+$  are fixed by

$$p_i^+ = \kappa(x_{i-1}^+ - x_i^+), \quad p_i^- = \kappa(x_i^- - x_{i-1}^-), \quad (29)$$

with initial value

$$x_0^+ = \frac{W}{\kappa}, \quad x_0^- = 0, \quad (30)$$

where  $W$  corresponds to the string initial invariant mass. Using the relation  $p_i^+ p_i^- = m_{i\perp}^2$  with  $m_{i\perp}$  being transverse mass of the  $i$ th hadron, we have the recursion formulae [41]

$$x_i^+ = (1 - z_i)x_{i-1}^+, \quad x_i^- = x_{i-1}^- + \left(\frac{m_{i\perp}}{\kappa}\right)^2 \frac{1 - z_i}{z_i} \frac{1}{x_i^+}. \quad (31)$$

Therefore, yo-yo formation points are obtained as

$$x_i^{yoyo} = (x_{i-1}^+, x_i^-), \quad (32)$$

and constituent formation points

$$x_i^{const} = (x_i^+, x_i^-). \quad (33)$$

In RQMD [9], the formation points of hadrons are calculated as the average of the two  $q\bar{q}$  production point as

$$x_i^{rqmd} = \left( \frac{x_i^+ + x_{i-1}^+}{2}, \frac{x_i^- + x_{i-1}^-}{2} \right). \quad (34)$$

Clearly, one can see that

$$x_i^{const} < x_i^{rqmd} < x_i^{yoyo}. \quad (35)$$

As a default, JAM uses yo-yo formation point. The different formation points can be used by the switch `mstc(72)`.

## 4 Program description

### 4.1 Random number generator

Default random number generator in JAM1.009 is taken from PYTHIA. Another random number generator can be used when the user rewrite the function `rn`.

### 4.2 Main subroutines

The main program has to be supplied by the user. These three subroutines are to be called by the main program.

subroutine `jaminit(nev, bmin, bmax, dt, nstep, chfram, chbeam, chtarg, cwin)`

subroutine `jamevt(iev)`

subroutine `jamfin`

subroutine `jaminit(nev, bmin, bmax, dt, nstep, chfram, chbeam, chtarg, cwin)`

Purpose: to initialize the program. This subroutine should be called only once before simulate collision event. It reads the parameters from either the initialization file named **fname(1)** specified by user or the main program.

**nev**: integer; specifying the number of total events to be generated.  
**bmin**: real\*8; Minimum impact parameter(fm).  
**bmax**: real\*8; Maximum impact parameter(fm). If **bmax** < 0, impact parameter is distributed according to the squared  $b^2$  distribution between **bmin** and **bmax**, while **bmax** > 0, impact parameter is uniformly distributed between **bmin** and **bmax**. If **mstc(18)**(number of impact parameter bin) > 1, impact parameter is distributed by the bin  $\delta b = (\text{bmax} - \text{bmin})/\text{mstc}(18)$  and total number of simulation event becomes **mstc(18) × nev**.  
**dt**: real\*8: time step size in fm/c.  
**nstep**: integer: total number of time step.  
**chfram**: character\*8 : computational frame. Available options are  
    'nn': nucleon-nucleon center of mass frame.  
    'cm': Total center of mass frame.  
    'lab': Laboratory frame.  
'collider': Collider experiment.  
    'user': User has to specified particle momemntum and coordinate. i.e. common block **jamevnt1**, **jamevnt2** and **jamjet1** should be filled up by the user as a initial condition of simulation.  
'box1.00': Box calculation to simulate infinite matter, where 1.00 corresponds to the density in  $\rho_0$  (normal nuclear matter) unit.  
**chbeam**, **chtarg**: character\*8 : Projectile and target.  
    'p': proton.  
    'pbar': antiproton.  
    'n': neutron.  
    'nbar': antineutron.  
    'pi-': negative pion.  
    'pi0': neutral pion.  
    'pi+': positive pion.  
    'k-': negative kaon.  
    'k+': positive kaon.  
    '197Au' Gold nucleus, where 197 indicates mass number of nucleus and Au specifies proton number. 'H', 'He', 'Li', 'Be', 'B', 'C', ..... can be used.  
    '100:50' total mass number 100 and 50 neutrons.  
**cwin**: character\*15 : Incident energy with a unit. In the case of **fram='user'** or **'box'**, **cwin** is used to estimate the hard cross section above the c.m. energy of 10GeV. So if the c.m. energy of expected two-body collision among hadrons are blow 10GeV, **cwin** does not matter, but should be set below 10GeV. Input examples are the follows:  
    '100mev': incident energy is 100MeV per nucleon.  
    '100mevc': incident momentum is 100MeV/c per nucleon.  
    '100gev': incident energy is 100GeV per nucleon.  
    '100gevc': incident momentum is 100GeV/c per nucleon.  
    '200gev': total energy  $\sqrt{s}$  is 200GeV per nucleon, in the case of **chframe = 'collider'**.

subroutine jamevt(iev)

**Purpose**: to simulate complete one event.

**iev**: Current event number (input).

subroutine jamfin

Purpose: to finish up simulation.

### 4.3 Common blocks for event record

```
parameter (mxv=30000)
common /jamevnt1/r(5,mxv),p(5,mxv),v(5,mxv),k(11,mxv)
common /jamevnt2/nv,nbary,nmeson
```



**nv:** Line number which is used during the simulation i.e., number of line occupied by the current event.  
**nbary:** Line number of baryons. Baryons are stored in the line  $i=1 \sim \text{nbary}$ .  
**nmeson:** The particles other than baryons are stored in the line  $i=\text{nbary}+1 \sim \text{nv}$ .

**r(1,i) :** x-position (fm).  
**r(2,i) :** y-position (fm).  
**r(3,i) :** z-position (fm).  
**r(4,i) :** time of particle (fm/c).  
**r(5,i) :** Formation time (fm/c) for the hadron which has constituent quarks. This has same value as **r(4,i)**, if the particle is newly produced particles.

**p(1,i):** x-momentum (GeV/c).  
**p(2,i):** y-momentum (GeV/c).  
**p(3,i):** z-momentum (GeV/c).  
**p(4,i):** kinetic energy  $= \sqrt{p_i^2 + m_i^2}$ .  
**p(5,i):** mass of particle (GeV/c<sup>2</sup>).

**v(1,i):** production vertex point, x-position (fm).  
**v(2,i):** production vertex point, y-position (fm).  
**v(3,i):** production vertex point, z-position (fm).  
**v(4,i):** production vertex point, time (fm/c).  
**v(5,i):** life time of the particle in fm/c if it is unstable.

**k(1,i):** status code KS, which gives the current status of the particle stored in the line.  
     < 0: particle entries which have some constituent quarks. Other virtual sea quarks are formed after a certain formation time.  
     > 11: no longer exist. i.e., absorbed particles.  
     = 1: stable particle.  
     = 2: resonance.  
     = 3: string.  
     = 4: parton.  
     = 5: nuclear cluster.  
     = -1: virtual stable particle (not resonance).  
     = -2: virtual unstable particle (resonance).  
     = -11: virtual stable particle but constituent quark can interact.  
     = -12: virtual resonance particle but constituent quark can interact.  
     = -21: virtual stable particle but constituent di-quark can interact.  
     = -22: virtual resonance but constituent di-quark can interact.  
     = -31: virtual stable particle but constituent 2quarks in a baryon can interact.  
     = -32: virtual resonance but constituent 2quarks in a baryon can interact.

**k(2,i):** KF particle code i.e. Particle Data Group numbering scheme.  
**k(3,i):**  $1000 * \text{mste}(1) + \text{mste}(2)$ . See section 4.6 for the meaning of the values **mste(1)** and **mste(2)**.  
**k(4,i):** origin of production. In the case of collision:  $1000 * \text{mste}(22) + \text{mste}(24)$ , while produced from decay: **mste(24)**=KF code of mother particle.  
**k(5,i):** collision counter (internal use to avoid second collision).  
**k(6,i):** multi-step history of collisions.  
**k(7,i):** number of collision suffered so far (initial value is set to be 1 for projectile and -1 for target respectively).  
**k(8,i):** identify the same ensemble among test particles.  
**k(9,i):** three times the baryon number.  
**k(10,i):** minimum line number of color flow connection in the case of parton. for hadrons this is zero.  
**k(11,i):** maximum line number of color flow connection in the case of parton. for hadrons this is zero.

#### 4.4 Common blocks for Particle Data

The following common blocks which contain particle data are essentially the same as PYTHIA6.1 program [5] with some modifications.

```

common/pydat2/kchg(500,7),pmas(500,4),parf(2000),vckm(4,4)
common/pydat3/mdcy(500,3),mdme(4000,3),brat(4000),kfdp(4000,5)

```

**Purpose:** to give particle/parton data. Particle data is stored by compressed code KC that can be calculated by calling function `kc=jamcomp(kf)` where `kf` corresponds to the particle flavor code. I refer users to the original PYTHIA manual [5] for detailed description.

`kchg(kc,1)`: three times particle charge.

`kchg(kc,2)`: color information.

`kchg(kc,3)`: particle/antiparticle distinction.

`kchg(kc,4)`: PDG code.

`kchg(kc,5)`: particle family ID.

`kchg(kc,6)`: three times baryon number.

`kchg(kc,7)`: strangeness.

`pmas(kc,1)`: mass in GeV.

`pmas(kc,2)`: total decay width in GeV.

`pmas(kc,3)`: deviation of BW.

`pmas(kc,4)`: the average life time in mm.

`mdcy(kc,1)`: switch to tell whether a particle may be allowed to decay or not.

= 0: the particle is not allowed to decay.

= 1: the particle is allowed to decay.

`mdcy(kc,2)`: entry point into the decay channel table for compressed code `kc`. It is 0, if no decay channels have been defined.

`mdcy(kc,3)`: total number of decay channels.

`mdme(idc,1)`: on/off switch for individual decay channel.

= 0: channel is switched off.

= 1: channel is switched on.

`mdme(idc,2)`: matrix element in decay.

= 0: momentum of particles are determined from phase space.

= 1:  $\omega$  and  $\phi$  decays into three pions.

`mdme(idc,3)`: relative angular momentum for each decay channel in two-body decay.

For the detailed meaning of `mdme(idc,1)`, `mdme(idc,2)`, `mdme(idc,3)`, See the original manual Ref. [5].

## 4.5 Further common blocks

For completeness, we list here the common blocks which contain include file `jam1.inc`.

`common/jamjet1/vq(10,mxv),kq(2,mxv)`

**Purpose:** to store parton properties or decay orientation.

For the strings,

`kq(1,i)`: flavor code of quark.

`kq(2,i)`: flavor code of diquark (anti-quark).

`vq(1,i)`:  $p_x$  (GeV/c) of parton (quark).

`vq(2,i)`:  $p_y$  (GeV/c) of parton (quark).

`vq(3,i)`:  $p_z$  (GeV/c) of parton (quark).

`vq(4,i)`: energy(GeV) of parton (quark).

`vq(5,i)`: mass (GeV/c<sup>2</sup>) of parton (quark).

`vq(6,i)`:  $p_x$  (GeV/c) of parton (diquark/anti-quark).

`vq(7,i)`:  $p_y$  (GeV/c) of parton (diquark/anti-quark).

`vq(8,i)`:  $p_z$  (GeV/c) of parton (diquark/anti-quark).

`vq(9,i)`: energy (GeV) of parton (diquark/anti-quark).

`vq(10,i)`: mass of(GeV/c<sup>2</sup>) parton (diquark/anti-quark).

For the resonances, `kq(j,i)` and `vq(j,i)` contain the following information:

`kq(1,i)`: = 999999.

`kq(2,i)`: = 0.

`vq(1,i)`:  $\beta_x$  (GeV/c) in two-body c.m..

`vq(2,i)`:  $\beta_y$  (GeV/c) in two-body c.m..

`vq(3,i)`:  $\beta_z$  (GeV/c) in two-body c.m..

vq(4,i):  $\gamma$  in two-body c.m..  
 vq(5,i):  $\phi$  in two-body c.m..  
 vq(6,i):  $\theta$  in two-body c.m..  
 vq(7,i): = 0.  
 vq(8,i): = 0.  
 vq(9,i): = 0.  
 vq(10,i): = 0.

```

common/jamsave1/rcp(5,6),pcp(5,6),vcp(5,6),kcp(11,6)
common/jamsave2/vqcp(10,6),kqcp(2,6)

```

**Purpose:** to save two-body collision information. Before performing two-body collision or decay, particle information is stored in `common jamsave1`, `jamsave2`. Meaning is the same as corresponding vectors.

```

parameter (mxcoll=50000)
common/jamcol/coll(6,mxcoll),icoll(3,mxcoll),mentry

```

**Purpose:** to store collision matrix.

**mxcoll:** Maximum collision number in each time step.  
**mentry:** number of entry of collision pair which will collide.  
**icoll(1,i):** line number of particle 1 specified by collision entry i.  
**icoll(2,i):** line number of particle 2 specified by collision entry i.  
**icoll(3,i):** cell number specified by collision entry i used in box calculation.  
**coll(1,i):** contain time of collision in computational frame (fm/c).  
**coll(2,i):** contain total cross section (mb).  
**coll(3,i):** contain elastic cross section (mb).  
**coll(4,i):** contain impact parameter squared (fm<sup>2</sup>).

```

common/jamcell/rcell(3,27)

```

**Purpose:** to store cell for box calculation.

`rcell(i,j):` cell in the case of BOX calculation.

## 4.6 The General Switches, Options and Parameters

```

common/jamdat1/mstc(200),parc(200),mstd(200),pard(200)

```

**Purpose:** to contain input parameters, default values and options in `mstc` and `parc`. The `mstd` and `pard` give event information. Default values are indicated by (D=), while variables that used internally are denoted by (I).

**mstc(1) :** (D=19780503) random seed.  
**mstc(2) :** (D=1) total number of event to be generated.  
**mstc(3) :** (D=1) total number of time step. `mstc(3) × parc(2)` is a time (fm/c) in the case of `mstc(44)=1`.  
**mstc(4) :** (D=2) computational frame.  
     = 0: laboratory system.  
     = 1: overall c.m. system.  
     = 2: nucleon-nucleon c.m. system.  
     = 3: collider.  
     = 10: box.  
     = 100: user defined initial condition.  
**mstc(5) :** number of test particles.  
**mstc(6) :** (D=0) treatment of AA collisions.  
     < -101 : Collisions are generated according to the mean free path argument. This option can only be used with baryon-nucleus collisions.  
     = -111 : mean free path method 1 with uniform matter density.  
     = -112 : mean free path method 1 with Fermi density.  
     = -121 : mean free path method 2 with uniform matter density.  
     = -122 : mean free path method 2 with Fermi density.  
     = -131 : mean free path method 3 with uniform matter density.

= -132 : mean free path method 3 with Fermi density.  
where, mean free path method 1 is defined as following [44]:  
We determine the collision point according to the probability distribution  $dP = \exp(-dr/\lambda)/\lambda dr$ ,  
with  $\lambda = 1/(P_p + P_n + P_d)$ ,  $P_p = \sigma_p \rho_p$ ,  $P_n = \sigma_n \rho_n$ ,  $P_d = \Gamma/v\gamma$ .  
In method 2 and 3, collision probabilities are calculated from  $dP = \sigma \rho(\mathbf{r}) dz$  and  $dP = \sigma \rho(\mathbf{r}) v dt$   
respectively in order to account for the defuseness of the nuclear density. Note that `mstc(6)=-112`  
would not give correct collision probability.

= -3 : Glauber type multiple collision for AA collision, sequential collisions are generated according to  
the additive quark cross section.

= -2 : Glauber type multiple collision for AA collision, but if the scattering of baryons which have only  
one-constituent quark are not considered.

= -1 : Glauber type multiple collision for AA collision, Fritiof type calculation.

= -21, -22, -23 : same as `mstc(6)=-1, -2, -3`, but after performing all predicted NN collisions and fragment  
strings, final state hadron interaction are simulated (not work now).

= 0 : Cascade mode.

= 1 : no collision and no mean field.

= 2 : BUU mode: Soft Skyrme force and no collision.

= 4 : BUU mode: Hard Skyrme force and no collision.

= 12 : BUU mode: Soft Skyrme force.

= 14 : BUU mode: Hard Skyrme force.

`mstc(7)` : (D=0) selection of a reaction type. This version only allows = 0.

`mstc(8)` : (D=0) Job mode (debug mode).  
= 0: almost no information are printed. This is useful for large JOB.  
= 1: simple information are printed.  
= 2: detailed information are printed. After every collision and decay various errors are checked (mo-  
mentum conservation ....).  
= 3: more detailed information are printed.  
= 4: more and more detailed information are printed.

`mstc(9)` : (D=27) contains number of cells for box simulation.

`mstc(10)` : (D=1) number of impact parameter bin.

`mstc(11)` : (D=1) check on possible errors.  
= 1: No.  
= 2: stop program after writing out error message.

`mstc(12)` : (D=30) number of errors that are printed.

`mstc(13)` : (D=1) printing of warning messages.  
= 0: no warning is written.  
= 1: `mstc(12)` warnings are printed.  
= 2: all warnings are printed.

`mstc(14)` : (D=30) number of warnings that are printed.

`mstc(15)` : not used.

`mstc(16)` : (D=0) display particles on any terminal during the simulation. Time step for display can be controlled  
by `parc(7)` and scale of display for `parc(6)`.  
= 0 : no display.  
= 1 : configuration space display (all hadrons).  
= 2 : configuration space display (baryons only).  
= 3 : configuration space display (mesons only).  
= 11: momentum space display (all hadrons).  
= 12: momentum space display (baryons only).  
= 13: momentum space display (mesons only).

`mstc(17)` : (D=0) switch in the case of elementary ( $pp, \pi p, \dots$ ) collisions.  
= 0 : Inelastic as well as elastic collisions are generated.  
= 1 : only inelastic collisions are generated.

`mstc(18)`-`mstc(19)` : not used.

`mstc(20)` : (D=0) flag for call of subroutine `jamsetp`. if `jamsetp` was called `mstc(20)=1`.

`mstc(21)` : (D=0)(I) number of call of subroutine `jaminit`. This is mainly used for the initialization procedures  
which is necessary only once.

`mstc(22)` : (I) starting point of KC code for  $N^*$  resonance.

**mstc(23)** : (I) end point of KC code for  $N^*$  resonance.  
**mstc(24)** : (I) starting point of KC code for  $\Delta^*$ .  
**mstc(25)** : (I) end point of KC code for  $\Delta^*$ .  
**mstc(26)** : (I) starting point of KC code for  $\Lambda^*$ .  
**mstc(27)** : (I) end point of KC code for  $\Lambda^*$ .  
**mstc(28)** : (I) starting point of KC code for  $\Sigma^*$ .  
**mstc(29)** : (I) end point of KC code for  $\Sigma^*$ .  
**mstc(30)** : (I) starting point of KC code for  $\Xi^*$ .  
**mstc(31)** : (I) end point of KC code for  $\Xi^*$ .  
**mstc(32)** : (I) starting point of KC code for mesons.  
**mstc(33)** : (I) end point of KC code for mesons.  
**mstc(34)-mstc(36)** : not used.  
**mstc(36)** : (D=1) I/O number for input configuration file: **fname(1)**.  
**mstc(37)** : (D=2) I/O number for output file : **fname(2)** that print out some information on simulation conditions.  
**mstc(38)** : (D=3) I/O number for output of error message. **fname(3)**.  
**mstc(39)** : (D=4) I/O number for multi run control file. **fname(4)**.  
**mstc(40)** : (D=8) I/O number for **fname(5)**.  
  
**mstc(41)** : (D=1) switch for resonance decay after simulation.  
    = 0           all resonances ( $\Delta, \rho, \dots$ ) will remain after the end of simulation, if their decay time is longer than simulation time.  
    = 1           all resonances ( $\Delta, \rho, \dots$ ). are forced to decay at the end of simulation, if they remain undecayed.  
**mstc(42)** : (D=1): option to turn off the weak decay of  $\pi^0, \Lambda, \dots$ .  
    = 0 :       allow weak decay after simulation.  
    = 1 :       weak decay is turned off.  
**mstc(43)** : (D=1) switch for inclusion of Fermi motion of nucleons in nucleus.  
    = 0 :       without Fermi motion of nucleons.  
    = 1 :       Fermi motion is included.  
**mstc(44)** : (D=1) switch for the end of calculation.  
    = 1 :       simulation is stopped at the time= **mstc(3)**  $\times$  **parc(2)** which is specified by the user.  
    = 2 :       simulation is continued until all collisions and decays are not expected.  
**mstc(45)** : (D=0) switch for the deuteron coalescence.  
    = 0 :       no.  
    = 1 :       deuterons are formed at the end of simulation.  
**mstc(46)** : (D=1) option for the treatment of cascading in the case of more than one parallel run.  
    = 1 :       parallel ensemble method.  
    = 2 :       full ensemble method in which all particles among test particles can collide with reduced cross section  $\sigma_{tot}/\mathbf{mstc(5)}$ .  
**mstc(51)** (D=3) : switch for two body collisions.  
    = 0 :       only baryon-baryon collisions.  
    = 1 :       only baryon-baryon and meson-baryon collisions.  
    = 2 :       hadron-hadron collisions (no parton collisions).  
    = 3 :       hadron-parton and hadron-hadron collisions.  
    = 4 :       all (not implemented in this version).  
**mstc(52)** : (D=5) switch for cascading method. Collision frame is chosen to be the two particle center of mass frame, but there are some option for the selection of ordering of collision time and point [22, 24].  
    = 2 :       collisions and decays are ordered according to the average of the two collision times.  
    = 3 :       the earlier collision time of the two collision times in the computational frame are taken to be the ordering time.  
    = 4 :       the later collision time of the two collision times in the computational frame are taken to be the ordering time.  
    = 5 :       the collision space point is the midpoint of the two particles in two-body c.m.frame.  
    = 11 :      all particles have always same time whenever collision or decay happened; all particles are propagated up to this time.  
**mstc(53)** (D=1) : switch for treatment of particles which are within a formation time.  
    = 1 :       collision can happen with  $\sigma_{hh}$  = additive quark cross section within a formation time.  
    = 2 :       any collision can not happen within a formation time.

= 3: no formation time for hadrons which has constituent quarks.  
**mstc(54)** : (D=1)  
 = 1 : avoid first collisions between nucleons among same nucleus that has not yet collided.  
 = 0 : allow all collisions.  
**mstc(55)** : (D=0) frozen resonance option.  
 = 0 : off.  
 = 1 : this keeps unstable particles stable during the simulation and only decay after the end of simulation.  
**mstc(56)** : (D=1) switch for Pauli-blocking in collisions and decays.  
 0 : no Pauli-blocking.  
 1 : blocking factor is calculated by the one-body phase space distribution function using Gaussian wave-packet as  $f_i = \sum_{i \neq j} = 8 \exp[-\frac{(\mathbf{r}_i - \mathbf{r}_j)^2}{2L} - \frac{2L(\mathbf{p}_i - \mathbf{p}_j)^2}{\hbar^2}]$ , where  $L$  is defined by the parameter **parc(15)**.  
 2 : blocking factor is calculated by Fusimi function as  $f_i = \sum_{i \neq j} | \langle \phi_i | \phi_j \rangle | = \sum_{i \neq j} \exp[-\frac{(\mathbf{r}_i - \mathbf{r}_j)^2}{4L} - \frac{(\mathbf{p}_i - \mathbf{p}_j)^2 L}{\hbar^2}]$ , where  $L$  is defined by the parameter **parc(15)**.  
**mstc(57)** : (D=0) not used.  
**mstc(61)** (D=3) : switch of baryon resonance decay angular distribution.  
 = 0 : isotropic decay.  
 = 1 : anisotropic with Gaussian  $p_t$ , width of Gaussian is **parc(43)**.  
 = 2 : anisotropic + isotropic with Gaussian  $p_t$ , width of Gaussian is **parc(43)**.  
 = 3 : anisotropic with Gaussian  $p_t$  distribution, but  $\frac{d\sigma}{dp_t}$  is reinterpreted as  $\frac{d\sigma}{p_r d\theta}$ , where  $p_r$  is relative momentum in rest frame of decaying particle. At high energies and forward angles, these become the same.  
**mstc(62)** (D=22) : option for detailed balance formula. **isw1=mod(mstc(62)/10,10)** is used for the choice of Breit-Wigner function, while **isw2=mod(mstc(62),10)** is used to specify different formula.  
**isw1=1**: non-relativistic Breit-Wigner function  $F(m)dm = \frac{\Gamma/2}{(m-m_0)^2 + \Gamma^2/4} dm$  is used.  
**isw1=2**: relativistic Breit-Wigner function  $F(m)dm = \frac{2mm_0 dm \Gamma}{(m^2 - m_0^2)^2 + (m_0 \Gamma)^2}$  is used.  
**isw1=3**: relativistic Breit-Wigner function  $F(m)dm = \frac{2m^2 dm \Gamma}{(m^2 - m_0^2)^2 + (m \Gamma)^2}$  is used.  
**isw2=0**: constant decay width is used.  
**isw2=1**: no-momentum dependence in integration [32].  
**isw2=2**: momentum dependence in integration.  
**isw2=3**: P.Danielevicz and G.F.Bertch formula [32, 33].  
**mstc(63)** : (D=3) option for the formula of  $\Delta(1232)$  decay width.  
 = 0: no decay(frozen delta).  
 = 1: formula by Frankfurt group.  
 = 2: formula by Giessen group.  
 = 3: formula in Ref. [36].  
 = 4: formula by Kitazoe *et al.* Ref [34].  
**mstc(64)** : (D=3) option for the method of sampling resonance mass distribution in non-strange baryon-baryon collisions.  
 = 0: mass is sampled according to the probability  $p(m)dm = dm/m$ .  
 = 1: mass is selected by Breit-Wigner, but individual resonance states are selected from only spin.  
 = 2: mass and individual resonance states are selected by the probability obtained from integrated Breit-Wigner.  
 = 3: same as 2 but width in Breit-Wigner function is momentum dependent.  
**mstc(65)** : (D=1) option for the resonance width for decay.  
 = 1 : momentum dependent width.  
 = 0 : constant width.  
**mstc(66)** (D=0) : option for the treatment of s-wave pion production in nucleon-nucleon collisions.  
 = 0 : s-wave one-pion production is effectively simulated by  $NN \rightarrow NN(1440)^*$ .  
 = 1 : include s-wave pion productions explicitly, as  $NN \rightarrow NN\pi$ .  
**mstc(67),mstc(68),mstc(69),mstc(70)** : (D=2,2,2,2) selection of the angular distribution for resonance production scattering in  $BB(\text{mstc(67)})$ ,  $MB(\text{mstc(68)})$ ,  $MM(\text{mstc(69)})$  and  $\bar{B}B(\text{mstc(70)})$  collisions at energy above  $\sqrt{s} = 2.17\text{GeV}$ .  
 = 2 : angular dependence is sampled by  $\exp(bt)$  distribution. See **parc(44)**-**parc(46)**.

= 4 : angular dependence is sampled by Gaussian distribution:  $\exp[-(p_T/\text{parc}(47))^2]$ .  
 = 5 : angular dependence is sampled by Gaussian plus exponential distribution:  $\exp[-p_T/\text{parc}(48)] + \text{parc}(49) \exp[-p_T/\text{parc}(47)]$ .  
**mstc(71)** (D=1) : switch for diffractive reaction in hh collisions.  
 = 0 : diffractive scattering off.  
 = 1 : on.  
**mstc(72)** (D=2) : switch for hadron formation point from string decay.  
 = 1 : constituent production formation point.  
 = 2 : yo-yo formation point.  
 = 3 : mean value of yo-yo point and constituent production point.  
 = 4 : constant formation time specified by **parc(55)**.  
**mstc(73)** : (D=2) choice of baryon production model in string decay (same as **mstj(12)** in PYTHIA).  
 = 0 : no baryon-antibaryon pair production at all.  
 = 1 : diquark-antidiquark pair production allowed; diquark treated as a unit.  
 = 2 : diquark-antidiquark pair production allowed; with possibility for diquark breaking according to 'popcorn' scheme.  
 = 3 : as =2, but with improved SU(6) treatment.  
 = 4 : as =3, but also suppressing diquark vertices with low Gamma values.  
 = 5 : revised popcorn model. Independent of **parj(3-7)**. Depending on **parj(8-10)**. Including the same kind of suppression as =4.  
**mstc(74)** (D=1) : switch for dipole-approximated QCD radiation of the string system in soft interactions.  
 = 0 : off.  
 = 1 : on.  
**mstc(75)** (D=1) : switch for the  $p_t$  kick due to soft interactions (**ihpr2(5)** in HIJING).  
 = 0 :  $p_t$  kick is sampled by Gaussian.  
 = 1 : include extra low  $p_t$  transfer to the valence quarks with parameter **parc(67-68)**.  
**mstc(76)** (D=0) : treatment string in space-time. =0: all strings decay into hadrons immediately taking the formation time into account. =1: strings from hard scattering are explicitly propagated. =2: strings from soft excitation as well as hard scattering are explicitly propagated (see **parc(72)**) (not work now).  
**mstc(81)** : (D=1) switch for hard scattering.  
 = 0 : off.  
 = 1 : hard scattering on.  
**mstc(82)** : (D=3) choice of proton structure functions.  
 = 1 : EHLQ set 1 (1986 updated version).  
 = 2 : EHLQ set 2 (1986 updated version).  
 = 3 : Duke-Owens set 1.  
 = 4 : Duke-Owens set 2.  
 = 5 : CTEQ2M (best MSbar fit)  
 = 6 : CTEQ2MS (singular at small x)  
 = 7 : CTEQ2MF (flat at small x)  
 = 8 : CTEQ2ML (large  $\Lambda$ )  
 = 9 : CTEQ2L (best leading order fit)  
 = 10 : CTEQ2D (best DIS fit)  
 = 11 : CRV LO (1992 updated version)  
 = 12 : CTEQ 3L (leading order).  
 = 13 : CTEQ 3M (MSbar).  
 = 14 : CTEQ 3D (DIS).  
 = 15 : GRV 94L (leading order).  
 = 16 : GRV 94M (MSbar).  
 = 17 : GRV 94D (DIS).  
**mstc(83)** : (D=1)  
 = 1 : probability of number of jet from HIJING formalism.  
 = 2 : probability of number of jet from PYTHIA formalism.  
**mstc(84)** : (D=0) Option for nuclear shadowing effect.  
 = 0 : off.  
 = 1 : on.

**mstc(85)** : (D=2) choice of scheme for parton collision-time estimate.  
           = 1 : exponential distribution.  
           = 2 : Gyulassy-Wang distribution.  
**mstc(101)** : (D=0) option for Coulomb potential.  
           = 0 : off.  
           = 1 : on.  
**mstc(102)** : (D=1) time step to calculate the boundary of Coulomb.

### Event study and analysis

The following switches are provided for the study of some observable and time evolution of particle in the case of **mstc()**=1. As a default (D=0), nothing is done.

**mstc(152)**: (D=0) rapidity spectra  $dN/dy$ .  
**mstc(153)**: (D=0) transverse momentum spectra  $1/p_{\perp} dN/dp$ .  
**mstc(154)**: (D=0) particle multiplicity.  
**mstc(155)**: (D=0) flow  $d \langle Px \rangle / dy$ ,  $d \langle P_t \rangle / dy$ .  
**mstc(156)**: (D=0) invariant energy distribution of two-body collisions.  
**mstc(157)**: (D=0) output sampled ground state.

Time dependent studies:

**mstc(161)**: (D=0) all analyses will not be done.  
**mstc(162)**: (D=0) count two-body collisions and decays in time.  
**mstc(163)**: (D=0) time evolution of directed transverse flow.  
**mstc(164)**: (D=0) output time evolution of phase space data.  
           = 1 : MDRAW [45] format. Before using this, directory 'DISP' is required in current directory.  
           = 2 : ANGEL [46] format.  
**mstc(165)**: (D=0) time evolution of particle.  
**mstc(166)**: (D=0) time evolution of particle density using small shell.  
**mstc(167)**: (D=0) time evolution of particle density using Gaussian smearing.  
**mstc(168)**: (D=0) time evolution of temperature written by Toshiki  
           = 1 : normal temperature fit.  
           = 2 : variable bin (under construction).  
**mstc(169)**: (D=0) =1: show how the temperature was fitted, if **mstc(168)**=1.

**parc(1)** : not used.  
**parc(2)** : (D=100.0) time step size for evolution in fm/c.  
**parc(3)** : (D=0.0) minimum impact parameter in "fm" **bmin**.  
**parc(4)** : (D=0.0) maximum impact parameter in "fm" **bmax**. If **bmax** < 0, impact parameter is distributed according to the squared  $b^2$  distribution between **bmin** and **bmax**, while **bmax** > 0, impact parameter is uniformly distributed between **bmin** and **bmax**.  
**parc(5)** : (D= -1.0fm) initial distance  $r_z$  between beam and target.  
           < 0.0:  $r_z = r_1 + r_2 + 6.0$  for  $E_{lab} < 200\text{MeV}$ ,  
                    $r_z = r_1 + r_2 + 4.0$  for  $200\text{MeV} < E_{lab} < 1\text{GeV}$ ,  
                    $r_z = r_1/\gamma_p + r_2/\gamma_t + 2.0$  for  $E_{lab} > 1\text{GeV}$ .  
           >= 0.0:  $r_z = r_1/\gamma_p + r_2/\gamma_t + \text{parc}(5)$ . where  $r_1$  and  $r_2$  represent projectile and target radius respectively, and  $\gamma_p$  and  $\gamma_t$  correspond to  $\gamma$  factor for the projectile and target.  
**parc(6)**: (D=2.0) scale of display for switch **mstc(16)**.  
**parc(7)**: (D=1.0fm/c) time slice for time dependent analysis.  
**parc(7)**: (D=1.0fm/c) time slice for display.  
**parc(8-10)**: not used.  
**parc(11)** : (D=0.54fm) diffuseness parameter in Woods-Saxon distribution for the density of nucleus.  
**parc(12)** : (D=1.124fm) parameter of Woods-Saxon tail.  
**parc(13)** : (D=0.8fm) minimum distance between identical nucleons for sampling of nucleus.  
**parc(14)** : (D=0.8fm) minimum distance between  $p$  and  $n$  for sampling of position.  
**parc(15)** : (D=2.0 fm<sup>2</sup>) width of Gaussian wave packet, here definition of  $L$  is  $\phi_i(r) = \frac{1}{(2\pi L)^{3/4}} \exp[-\frac{(r-R_i)^2}{4L} + \frac{i}{\hbar} r \cdot P_i]$ .



`parc(16)`-`parc(20)` : not used.  
`parc(21)` : ( $D=0.1681/\text{fm}^3$ ) normal nuclear matter density  $\rho_0$ .  
`parc(22)` : ( $D=-16.0\text{MeV}$ ) binding energy of nuclear matter.  
`parc(23)` : ( $D=0.001439767$ ) Coulomb constant.  
`parc(24)` : ( $D=0.93960\text{GeV}^2$ ) neutron masses.  
`parc(25)` : ( $D=0.93830\text{GeV}^2$ ) proton mass.  
`parc(26)` : ( $D=0.13500\text{GeV}^2$ )  $\pi^0$  mass.  
`parc(27)` : ( $D=0.13960\text{GeV}^2$ )  $\pi^+$  mass.  
`parc(28)` : ( $D=0.938950002\text{GeV}^2$ ) nucleon mass.  
`parc(29)` : ( $D=0.1373\text{GeV}^2$ ) average pion mass.  
`parc(30)` : not used.  
  
`parc(31)` : ( $D=5.0\text{fm}$ ) maximum spatial distance for which a two-body collision still can occur.  
`parc(32)`-`parc(38)` : low energy cut off for  $hh$  collisions.  
`parc(32)` : ( $D=55\text{mb}$ ) maximum cross section for  $pn$  collisions at low energy.  
`parc(33)` : ( $D=55\text{mb}$ ) maximum cross section for  $pp$  collisions at low energy.  
`parc(34)` : ( $D=200\text{mb}$ ) maximum cross section for  $BB$  collision at low energy (involving resonance).  
`parc(35)` : ( $D=200\text{mb}$ ) maximum cross section for  $MB$  collisions at low energy.  
`parc(36)` : ( $D=150\text{mb}$ ) maximum cross section for  $MM$  collisions at low energy.  
`parc(37)` : ( $D=350\text{mb}$ ) maximum cross section for  $\bar{B}B$  collision at low energy.  
`parc(38)` : ( $D=0.05\text{GeV}$ ) kinetic energy cutoff for two-body collisions at low energy.  
`parc(41)` : ( $D=0.001\text{GeV}$ ) minimum kinetic energy in decays.  
`parc(42)` : ( $D=0.5\text{fm}$ ) production point of daughter from mother in decay.  
`parc(43)` : ( $D=0.4\text{GeV}/c$ ) width of Gaussian  $p_t$  distribution for the decay of resonance, see `mstc(61)`.  
`parc(44)`, `parc(45)`, `parc(46)` : ( $D=2.5(\text{GeV}/c^{-2}, 0.7, 2.0)$ ) slope parameter for angular distribution in inelastic  $hh$  collisions:  $d\sigma/dt = e^{at}$  [38] for resonance production in the case of `mstc(67-70)=2`, where slope parameter is parametrized by  $a = \text{parc}(44) + \text{parc}(45) * (\log(s) - \log(\text{parc}(46)))$ .  
`parc(47)` : ( $D=0.36(\text{GeV}/c)^{-2}$ ) Gaussian width for the option of `mstc(67)=4,5`.  
`parc(48)` : ( $D=0.3$ ) exponential width for the option of `mstc(67)=5`.  
`parc(49)` : ( $D=0.2$ ) ratio for exponential for `mstc(67)=5`.  
  
`parc(51)` : ( $D=2.0\text{GeV}/c^2$ ) minimum mass of string for non-strange baryons.  
`parc(52)` : ( $D=3.5\text{GeV}/c^2$ ) mass cut off for non-strange baryon resonances.  
`parc(53)` : ( $D=2.0\text{GeV}/c^2$ ) minimum mass of non-strange mesonic string.  
`parc(54)` : ( $D=1.0\text{GeV}/\text{fm}$ ) string tension.  
`parc(55)` : ( $D=1.0\text{fm}/c$ ) formation time.  
`parc(56)` : ( $D=4.0\text{GeV}/c^2$ ) invariant mass cut-off for the dipole radiation of a string system below which soft gluon radiations are terminated.  
`parc(57)` : not used.  
`parc(61)` : ( $D=4.6\text{ GeV}$ ) Parameter of  $BB$  collision to use string model ( $\text{GeV}$ ) except non-strange baryon-baryon collision, where resonance production cross sections are explicitly parametrized.  
`parc(62)` : ( $D=2.8\text{ GeV}$ ) Parameter of  $MB$  collision to use string model.  
`parc(63)` : ( $D=1.8\text{ GeV}$ ) Parameter of  $MM$  collision to use string model.  
`parc(64)` : ( $D=1.09\text{GeV}/c^2$ ) minimum value for the non-strange baryonic resonance states.  
`parc(65)` : ( $D=0.7\text{GeV}/c^2$ ) minimum value for the invariant mass of the excited meson-like string system in a hadron-hadron interaction.  
`parc(66)` : ( $D=0.36\text{GeV}$ ) width of the Gaussian  $P_t$  distribution of produced hadron in Lund string fragmentation (`parj(21)` in PYTHIA6.1).  
`parc(67)`, `parc(68)` : ( $D=0.1\text{GeV}/c, 1.4\text{GeV}/c$ ) parameters in the distribution for the  $P_t$  kick from soft interactions (`hipr1(19)`, `hipr1(20)` in HIJING1).  
`parc(69)`, `parc(70)` : ( $D=0.05\text{GeV}/c, 1.0\text{GeV}/c$ ) parameters in the distribution for the  $P_t$  kick from resonance production interactions for the option `mstc(67)=6`.  
`parc(71)` : ( $D=10\text{GeV}$ ) lowest c.m. energy to do pQCD scattering.  
`parc(72)` : ( $D=0.1$ ) parameter for the mean reaction time for the parton-parton scattering:  $\tau = \text{parc}(71)/Q^2$ .  
`parc(73)` : ( $D=0.1$ ) parameter for the mean life time of time-like parton branching.  
`parc(74)` : ( $D=1.0$ ) parameter for the mean life time of space-like parton branching.  
`parc(151)` : ( $D=2.1\text{fm}$ ) critical separation of two-baryons above which a cluster cannot be formed.  
`parc(152)` : ( $D=0.3\text{GeV}/c^2$ ) critical separation of two-baryons in momentum space.

parc(191) : JAM version number.  
 parc(192) : JAM subversion number.  
 parc(193) : last year of modification for JAM.  
 parc(194) : last month of modification for JAM.  
 parc(195) : last day of modification for JAM.

mstd(1) : projectile ID.  
 mstd(2) : projectile mass number.  
 mstd(3) : proton number in projectile.  
 mstd(4) : target ID.  
 mstd(5) : target mass number.  
 mstd(6) : proton number in target.  
 mstd(11) : number of all initial particles.  
 mstd(12) : initial total baryon number.  
 mstd(13) : initial total charge.  
 mstd(14) : initial total strangeness.  
 mstd(15) : number of cell for box simulation, mstd(15)=mstc(9).  
 mstd(21) : current event number.  
 mstd(22) : random seed of current event.  
 mstd(23) : current time step.  
 mstd(24) : number of event for each impact parameter bin.  
 mstd(25) : count of number of warnings.  
 mstd(26) : type of latest warning given.  
 mstd(27) : count of number of errors.  
 mstd(28) : type of latest errors given.  
 mstd(29) : collision counter(internal use).  
 mstd(30) : flag for absorbed particles.  
     = 1 : there are absorbed (already dead) particles in JAM array.  
     = 0 : No.  
 mstd(41) : total number of elastic collisions in current event.  
 mstd(42) : total number of inelastic collisions in current event.  
 mstd(43) : total number of absorptions in current event.  
 mstd(44) : number of Baryon-Baryon collision in current event.  
 mstd(45) : number of Meson-Baryon collision in current event.  
 mstd(46) : number of Meson-Meson collision in current event.  
 mstd(47) : number of antibaryon-Baryon collision in current event.  
 mstd(48) : number of hadron-parton collisions in current event.  
 mstd(49) : number of parton-parton collisions in current event.  
 mstd(50) : number of decays in current event.  
 mstd(51) : number of Fermi blocks in current event.  
 mstd(52) : number of Low energy cuts in current event.  
 mstd(53) : number of decay after simulation. in current event.  
 mstd(54) : not used.  
 mstd(55) : total number of jet produced from hard scattering in current event.  
 mstd(56) : counter for formation time of newly produced hadrons.  
 mstd(57) : counter for formation time of hadrons which contains original quarks.  
 mstd(61) : average number of total collision which produce strangeness.  
 mstd(62) : same as mstd(61), but collision involved constituent. quarks.  
 mstd(63) : average number of strangeness production from string fragmentation.  
 mstd(64) : average number of strangeness production from resonance decay.  
 mstd(61-80) : not used.  
 mstd(81) : Maximum number of **nv** actually used in simulation.  
 mstd(82) : Maximum number of **mentry** actually used.  
 mstd(83) : total number of quarks in current event.  
 mstd(84) : total number of gluons in current event.

pard(1) : current global time.  
 pard(2) : current impact parameter(fm).  
 pard(3) : current minimum impact parameter.  
 pard(4) : impact parameter bin.  
 pard(5) :  $\beta$  factor for the transformation to laboratory frame.  
 pard(6) :  $\gamma$  factor for the transformation to laboratory frame.  
 pard(7) :  $R_x$ ; x-coordinate shift of projectile.  
 pard(8) :  $R_y$ ; y-coordinate shift of target.  
 pard(9) : initial total  $p_x$ .  
 pard(10): initial total  $p_y$ .  
 pard(11): initial total  $p_z$ .  
 pard(12): initial total energy.  
 pard(13): initial total energy per initial baryons.  
 pard(14) : laboratory beam energy in "GeV per nucleon".  
 pard(15) : laboratory beam momentum in "GeV/c per nucleon".  
 pard(16) : colliding energy  $\sqrt{s}$  per nucleon.  
 pard(17) : beam rapidity  $y_p$ .  
 pard(18) : c.m. momentum.  
  
 pard(21) : cell length (fm).  
 pard(22) : total energy/baryon (GeV) to set for box calculation.  
 pard(31) :  $p_x$  of projectile.  
 pard(32) :  $p_y$  of projectile.  
 pard(33) :  $p_z$  of projectile.  
 pard(34) : mass of projectile.  
 pard(35) :  $\beta$  of projectile.  
 pard(36) :  $\gamma$  of projectile.  
 pard(37) :  $r_x$  of projectile.  
 pard(38) :  $r_y$  of projectile.  
 pard(39) :  $r_z$  of projectile.  
 pard(40) : radius of projectile.  
 pard(41) :  $p_x$  of target.  
 pard(42) :  $p_y$  of target.  
 pard(43) :  $p_z$  of target.  
 pard(44) : mass of target.  
 pard(45) :  $\beta$  of target.  
 pard(46) :  $\gamma$  of target.  
 pard(47) :  $r_x$  of target.  
 pard(48) :  $r_y$  of target.  
 pard(49) :  $r_z$  of target.  
 pard(50) : radius of target.  
 pard(51) : maximum c.m. distance for  $BB$  collision.  
 pard(52) : maximum c.m. distance for  $BB$  collision.  
 pard(53) : maximum c.m. distance for  $DN$  collision.  
 pard(54) : maximum c.m. distance for  $MB$  collision.  
 pard(55) : maximum c.m. distance for  $MM$  collision.  
 pard(56) : maximum c.m. distance for  $\bar{B}B$  collision.  
 pard(71) : event average number of elastic collisions.  
 pard(72) : event average number of inelastic collisions.  
 pard(73) : event average number of absorptions.  
 pard(74) : event average number of  $BB$  collisions.  
 pard(75) : event average number of  $MB$  collisions.  
 pard(76) : event average number of  $MM$  collisions.  
 pard(77) : event average number of  $\bar{B}B$  collisions.  
 pard(78) : event average number of decays.  
 pard(79) : event average number of Fermi blocks.  
 pard(80) : event average number of Low energy cuts.

**pard(81)** : event average number of decay after simulation.  
**pard(82)** : event average multiplicity.  
**pard(83)** : event average meson multiplicity.  
**pard(84)** : not used.  
**pard(85)** : average number of hadron-parton collisions.  
**pard(86)** : average number of parton-parton collisions.  
**pard(87)** : average number of hard scattering.  
**pard(88)** : average formation time of newly produced hadrons.  
**pard(89)** : average formation time of hadron which contains ordinal constituent quark.  
**pard(101)–pard(103)** : parameters of nuclear E.O.S. in BUU mode which are defined as

$$E_{pot} = \alpha \frac{\rho_B}{\rho_0} + \beta \left( \frac{\rho_B}{\rho_0} \right)^\gamma,$$

where  $\alpha = \text{pard}(101)$ ,  $\beta = \text{pard}(102)$ , and  $\gamma = \text{pard}(103)$ . Those values depend on the choice of compressibility specified by **mstc(6)**.

**common/jamdat2/pare(200),mste(200)**

**Purpose:** to store some information to handle two-body collisions.

**mste(1)** : current collision channel.  
 = 0 : collision cannot happen.  
 = 1 : elastic collision.  
 = 2 : inelastic collisions.  
 = 3 : annihilations.  
 = 4 : string excitation.  
 = 5 : string excitation of nucleon-nucleon collisions.  
 = 6 : hard parton-parton scattering.  
 = 11 : direct s-wave pion scattering.  
 = -1 : Pauli-blocking.  
 = -2 : error after the call of **jamcross**.  
 = -9 : hard scattering false.  
 = -77 : soft interaction false.  
 = -88 : energetically not allowed collision.  
 = -99 : something was wrong.  
**mste(2)** : collision type.  
 = -1 : decay of resonance or string.  
 = -2 : decay of resonance or string after simulation.  
 = 1 : baryon-baryon collision.  
 = 2 : meson-baryon collision.  
 = 3 : meson-meson collision.  
 = 4 : antibaryon-baryon collision.  
 = 5 : parton-hadron collision.  
 = 6 : parton-parton collision.  
**mste(3)** : outgoing channel for more than two-body final state.  
 = 0 : two-body final.  
 = 1 :  $pp \rightarrow pp\pi$ .  
 = 2 :  $nn \rightarrow nn\pi$ .  
 = 3 :  $pn \rightarrow nn\pi$ .  
**mste(4)** : status of the latest soft string excitation.  
 = 1 : double diffractive.  
 = 2 : projectile single diffractive.  
 = 3 : target single diffractive.  
 = 4 : non-diffractive.  
**mste(5)** : number of jet in least hard collision.  
**mste(6)** : cell number **icoll(3,i)** in current collision.  
**mste(21)** : line number of the ingoing particle 1.

**mste(22)**: KC code of the ingoing particle 1.  
**mste(23)**: line number of the ingoing particle 2.  
**mste(24)**: KC code of the ingoing particle 2.  
**mste(40)**: =1 during the final decay after simulation, otherwise =0.

**pare(1)** : maximum time for collision search.  
**pare(2)** : c.m.energy of two-body system in the latest collision.  
**pare(3)** :  $x\sigma_{tot}(s)$  of latest collision, where  $x$  denotes random number.  
**pare(4)** : total cross section of latest collision.  
**pare(5)** : elastic cross section of latest collision.  
**pare(6)** : impact parameter squared of latest collision.  
**pare(7)** : c.m. momentum of latest collision.  
**pare(8)** : collision time for particle 1.  
**pare(9)** : collision time for particle 2.  
**pare(11)**: sum of energy of the two particles before collision in the observer frame.  
**pare(12)**:  $\beta_x$  for transformation from two-body c.m. frame to observer frame.  
**pare(13)**:  $\beta_y$  for transformation from two-body c.m. frame to observer frame.  
**pare(14)**:  $\beta_z$  for transformation from two-body c.m. frame to observer frame.  
**pare(15)**:  $\gamma$  for transformation from two-body c.m. frame to observer frame.

## 4.7 Other physics routines

The routines which is important for the main task for the simulation or is expected to be used frequently by the users are listed here.

**subroutine jamread(nevent,bmin,bmax,dt,nstep,chfram,chbeam,chtarg,cwin)** : to read input configuration file.  
**subroutine jamlist(mlist)** : to list event record or particle data.  
**subroutine jamname(kf1,kf2,kf3,chau)** : to give the particle/parton/nucleus name as character string. For nucleus,  $\text{kf1} = 1000000000 + 1000000N_n + 1000N_p + N_\Lambda$ ,  
 $\text{kf2} = 1000000000 + 1000000N_{\Sigma^-} + 1000N_{\Sigma^0} + N_{\Sigma^+}$ ,  
 $\text{kf3} = 1000000000 + 1000000N_{\Xi^-} + 1000N_{\Xi^0} + N_{\Omega^-}$ .  
 where  $N_n, N_p, N_\Lambda, N_{\Sigma^-}, N_{\Sigma^0}, N_{\Sigma^+}, N_{\Xi^-}, N_{\Xi^0}, N_{\Omega^-}$  represent the number of particle contained in nucleus respectively. Otherwise, **kf1** is usual FK flavor code and **kf2** and **kf3** are not used.  
**subroutine jamboost** : to boost the ground state nuclei/particles.  
**subroutine jamgrund** : to make the ground state of target and projectile.  
**subroutine jamjeti** : to initialize the PYTHIA and HIJING routines to simulate string fragmentation, jet production and calculation of jet-cross sections.  
**subroutine jamupdat(mupda,lfn)** : to facilitates the updating of particle and decay data by allowing it to be done in an external file.  
**subroutine jamcoll** : to administer the two-body collisions and decays.  
**subroutine jamcross** : to administer the hadron-hadron collisions.  
**subroutine jamscatt** : to perform two-body collisions.  
**subroutine jamabsrb** : to treat annihilation scattering.  
**subroutine jamchanl** : to select final scattering channel.  
**subroutine jamangel** : to calculate elastic angular distribution.  
**function jamslope** : to give slope parameter in two-body collisions.  
**subroutine jamangin** : to calculate inelastic angular distribution.  
**subroutine jamsoft** : to give masses of the excited nucleons.  
**subroutine jamhard** : to perform jets production.  
**subroutine jamdec** : to administrate the fragmentation of jet system or decay.  
**subroutine jamjdec** : to fragment jet system by Lund model.  
**subroutine jamrdec** : to calculate decay of hadrons.

## 5 Instructions on how to run the program

Program usage of JAM is very similar to other famous event generators; PYTHIA [5], FRITIOF [1], HIJING [6] and VNI [21]. for example, (1) main program by users, (2) Particle flavor code is the same as particle data group particle numbering scheme.

- Write main program in which at least call `jaminit()`, call `jamevt(iev)` and call `jamfin` must be written.
- Make executable file after rewriting Makefile for suitable machine and your main program name.

### 5.1 Output from JAM

Some output files are generated in JAM.

- General information on inputs and outputs are written in file specified by `fname(2)` (default name can be seen in `jamdata`).
- Some error or warning messages are written in file `fname(3)`.
- Current event number generated are written in file `fname(3)`, if `mstc(39) = 1`.
- If switches for event study are on, files are created, for example, with the file name `JAM162.DAT` in the case of `mstc(162) = 1`.

### 5.2 Most simple example: Main program and its output

Here is an most simple example main program. This simulates  $S(200\text{AGeV}/c)+S$  collision for impact parameter sampled by  $b < 1\text{fm}$ .

c...A main program for  $S(200\text{GeV}/c)+S$

```
include 'jam1.inc'
include 'jam2.inc'
character frame*8,proj*8,targ*8,cwin*15
```

c....Initialize JAM

```
mstc(1)=48827      ! random seed.
mevent=1          ! total simulation event
bmin=0.0d0        ! minimum impact parameter
bmax=-1.0d0       ! maximum impact parameter
dt=100.0d0        ! collision time(fm/c)
nstep=1           ! time step
cwin='200gevc'    ! incident energy
frame='nn'        ! comp. frame
proj='32S'        ! projectile
targ='32S'        ! target
mstc(156)=1       ! analysis of collision distribution on.
```

c...Initialize JAM.

```
call jaminit(mevent,bmin,bmax,dt,nstep,frame,proj,targ,cwin)
```

c...Simulation start.

```
do iev=1,mevent
```

c...Simulate one event.

```
call jamevt(iev)
```

c...List phase space data.

```
call jamlist(1)
```

end do

c...Final output.  
call jamfin

end

Some global information is written in the file "JAMRUN.DAT".

```
*****
*****
**
**
** Welcome to the JAM Monte Carlo!
**
** JJJJJJJJ AAAA MM MMM
** JJ AA AA MMM MMM
** JJ AAAAAAAA MM MMMM MM
** J JJ AA AA MM MM
** JJJJJ AA AA MM MM
**
** This is JAM version 1.009
** Last date of change: 6 Sep 1999
**
**
** JAM is a free software which can
** be distributed under the GNU Gen
** eral Public License. There is no
** warranty for the program.
**
** Copyright (c) 1998 Yasushi Nara
**
** Main author: Yasushi Nara;
** Advance Science Research Center, Japan Atomic Energy Research Institute
** Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan
** e-mail: ynara@bnl.gov
**
**
**
*****
*****
```

```
*****
*
* Reaction:
*
* mass 32( 16, 16) ==> mass 32( 16, 16)
*
* Collision of 32S on 32S
*
*
* Beam energy = 199.06 A GeV
* Beam momentum = 200.00 A GeV/c
* C.M. energy = 19.43 A GeV
*
```

```

*
*
*           Beam           Target
* Velocity/c:      0.9953164    -.9953164
* Gamma factor:    10.344       10.344
* p_x(GeV/c):      0.000       0.000
* p_z(GeV/c):      9.667       -9.667
* r_x(fm):         0.000       0.000
* r_z(fm):        -0.816       0.816
*
*
* Impact parameters are distributed according to b^2:
*           0.000 < b <  1.000 (fm)
*
*****

```

```

* Input output file name: "          non"
* Computational frame: nucl.-nucl. c.m.
* Random seed      =      48827
* # of event       =        1
* Time step size   =100.000 fm/c
* # of timestep    =        1

```

	per simulation	1 runs	1 parallel runs
-----	-----		
Total collisions	= 478.0000		
Elastic collisions	= 87.0000		
Inelastic collisions	= 391.0000		
Absorptions	= 213.0000		
baryon-baryon coll.	= 60.0000		
meson-baryon coll.	= 191.0000		
meson-meson coll.	= 222.0000		
anti-B-B coll.	= 5.0000		
hadron-parton coll.	= 0.0000		
parton-parton coll.	= 0.0000		
Resonance decays	= 405.0000		
Total particles	= 390.0000		
Mesons	= 316.0000		
Pauli blocks	= 1.0000		
Blocks due to E.con.	= 0.0000		
Low energy cuts	= 2211.		
Decay after simul.	= 7.0000		
Mean formation time	=	0.9814	114.0000
Mean const. formation time	=	1.4099	184.0000
average number of jet=	0.0000		
max. number of nv=	607		
max. number of mentry=	270		

```

=====
FINAL HADRON MULTIPLICITIES
=====

```



```

total particle  390.0000000000000
charged particle  214.0000000000000
negative particle  91.0000000000000
positive particle  91.0000000000000
  22      22  gamma          1.00
 132     111  pi0           115.
 133     211  pi+          87.0      pi-          84.0
 153     221  eta          6.00
 173     311  K0           10.0      Kbar0         7.00
 174     321  K+           5.00      K-           3.00
 252    2112  n0           35.0      nbar0         1.00
 253    2212  p+           28.0      pbar-         3.00
 327    3112  Sigma-        1.00      Sigmabar+     0.000E+00
 328    3212  Sigma0        1.00      Sigmabar0     0.000E+00
 329    3222  Sigma+        3.00      Sigmabar-     0.000E+00

* CPU time=   0 h   0 m  21 s
*****

```

### 5.3 Input from a input configuration file

As a default `fname(1)` is set to be '0'. In this case, JAM does not use any input file. If there is a statement in a main program like

```
fname(1)='jam.cfg'
```

JAM read input parameter from file name 'jam.cfg'.

- event, bmin, bmax, projectile, target, timestep, dt, win are used to specify simulation conditions.
- '#' and '!' can be used to comment. Blank line is also allowed.
- Both upper and lower case can be used.
- If you want to change default value of `mstc()`, `parc()`, put, for example, `mstc(65)= 2`.
- Input file should be ended by 'end' command.

Here is a example input file.

```

event=100          # Total number of siumulation run
MSTC(1) =8595934    # random seed.

proj =208Pb         # projectile
targ =208Pb         # target
win= 158gev         # incident energy
bmin = 0.0          # minimum impact parameter in fm.
bmax = -3.2         # maximam impact parameter in fm with $b^2$ distribution.

frame= nn           # nn c.m. frame.
dt= 100.0           # Time step size(fm/c)
timestep = 1        # total number of time step.

#####>
##### Optional input of mstc and parc #####>
#####>
fname(2)=XXX        # file name for simulation conditions.
fname(3)=YYY        # file name for Some Information

```

```

Mstc(8)=1      # job mode. =0:Job.
mstc(5)= 1     # impact parameter bin number
parc(6)= 10.0  # scale of display
mstc(16)= 0    # display on/off.

# option for analysis
mstc(155)=1    # calculate transverse flow.
mstc(156)=1    # energy distribution of collisions on.
mstc(162)=0    # Output collision histroy off.

mstc(163)=1    ! time evolution of directed transverse flow
mstc(164)=0    ! Output phase space data in time interval
mstc(165)=0    ! Output time evolution of particle yield
mstc(166)=0    ! Output time evolution of particle density
parc(7)= 2.0   ! Output time interval (fm/c)

end            ! Input end

```

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## Appendix

### A: Particle codes

Here the particle flavor codes defined in JAM are listed. Corresponding antiparticle has the negative of its flavor code. I refer the reader to Ref. [37] for the detailed meaning of the particle numbering scheme. The particle name printed in the table is obtained using subroutine `jamname`.

### B: Particle family codes

JAM has an other particle code which is rough identification of the particles comparison to the PDG code. It can be obtained from `kchg(kc,5)`.

```

c...Elementary particles.
  common/partdat3/id_quark,id_lept,id_exc,id_boson,id_diq
  $           ,id_tec,id_susy,id_special
c...Mesons.
  common/partdat2/id_pi,id_light1,id_light0
  $           ,id_str,id_charm,id_bott,id_cc,id_bb,id_mdif
c...Baryons.
  common/partdat1/id_nucl,id_nucls,id_delt,id_delts
  $           ,id_lamb,id_lambs,id_sigm,id_sigms,id_xi,id_xis,id_omega
  $           ,id_charmb,id_bottb,id_bdiff

```

Actual values are stored in block data `jamdata`.

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H. Pi, *Comp. Phys. Comm.* **71**, 173 (1992).

Table 1: Quark, lepton , gauge boson and diquark codes.

KF	Name	Printed	KF	Name	Printed
1	d	d	11	$e^-$	e-
2	u	u	12	$\nu_e$	nu_e
3	s	s	13	$\mu^-$	mu-
4	c	c	14	$\nu_\mu$	nu_mu
5	b	b	15	$\tau^-$	tau-
6	t	t	16	$\nu_\tau$	nu_tau
7	l	l	17	$\chi^-$	chi-
8	h	h	18	$\nu_\chi$	nu_chi
21	g	g			
22	$\gamma$	gamma	32	$Z'^0$	Z'0
23	$Z^0$	Z0	33	$Z''^0$	Z"0
24	$W^+$	W+	34	$W'^+$	W'+
25	$H^0$	H0	35	$H'^0$	H'0
26			36	$A^0$	A0
27			37	$H^+$	H+
91	cluster	cluster			
92	string	string			
2101	ud <sub>0</sub>	ud_0	1103	dd <sub>1</sub>	dd_1
			2103	ud <sub>1</sub>	ud_1
			2203	uu <sub>1</sub>	uu_1
3101	sd <sub>0</sub>	sd_0	3103	sd <sub>1</sub>	sd_1
3201	su <sub>0</sub>	su_0	3203	su <sub>1</sub>	su_1
			3303	ss <sub>1</sub>	ss_1

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Table 2: light and strange meson codes

KF	Name	Printed	KF	Name	Printed	KF	Name	Printed
111	$\pi^0$	pi0	10220	$\sigma$	sigma-m	130	$K_L^0$	K_L0
211	$\pi^+$	pi+	221	$\eta$	eta	310	$K_S^0$	K_S0
113	$\rho^0$	rho0	223	$\omega$	omega	311	$K^0$	K0
213	$\rho^+$	rho+	225	$f_2$	f_2	321	$K^+$	K+
10111	$a_0^0$	a_00	331	$\eta'$	eta'	313	$K^{*0}$	K*0
10211	$a_0^+$	a_0+	333	$\phi$	phi	323	$K^{*+}$	K*+
20113	$a_1^0$	a_10	335	$f_2'$	f'_2	10313	$K_1^0$	K_10
20213	$a_1^+$	a_1+	10221	$f_0$	f_0	10323	$K_1^+$	K_1+
115	$a_2^0$	a_20	10223	$h_1$	h_1	315	$K_2^{*0}$	K*_20
215	$a_2^+$	a_2+	10331	$f_0'$	f'_0	325	$K_2^{*+}$	K*_2+
10113	$b_1^0$	b_10	10333	$h_1'$	h'_1	10311	$K_0^{*0}$	K*_00
10213	$b_1^+$	b_1+	20221	$\eta(1295)$	eta(1295)	10321	$K_0^{*+}$	K*_0+
20111	$\pi(1300)^0$	pi(1300)0	20223	$f_1$	f_1	20313	$K_1^{*0}$	K*_10
20211	$\pi(1300)^+$	pi(1300)+	20333	$f_1'$	f'_1	20323	$K_1^{*+}$	K*_1+
10115	$\pi_2(1670)^0$	pi_2(1670)0	30221	$f_0(1300)$	f_0(1300)	30313	$K(1410)^0$	K*(1410)0
10215	$\pi_2(1670)^+$	pi_2(1670)+	30223	$\omega(1420)$	omega(1420)	30323	$K(1410)^+$	K*(1410)+
30113	$\rho(1465)^0$	rho(1465)0	30333	$\phi(1680)$	phi(1680)	40313	$K(1680)^0$	K*(1680)0
30213	$\rho(1465)^+$	rho(1465)+	50223	$f_1(1510)$	f_1(1510)	40323	$K(1680)^+$	K*(1680)+
40113	$\rho(1700)^0$	rho(1700)0	60223	$\omega(1600)$	omega(1600)	317	$K_3(1780)^0$	K_3(1780)0
40213	$\rho(1700)^+$	rho(1700)+				327	$K_3(1780)^+$	K_3(1780)+
						10315	$K_2(1770)^0$	K_2(1770)0
						10325	$K_2(1770)^+$	K_2(1770)+
						20315	$K_2(1820)^0$	K_2(1820)0
						20325	$K_2(1820)^+$	K_2(1820)+

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Table 3: Non-strange baryon codes

KF	Name	Printed	KF	Name	Printed
2112	n	n0	1114	$\Delta^-$	delta-
2212	p	p+	2114	$\Delta^0$	delta0
12112	$N(1440)^0$	N(1440)0	2214	$\Delta^+$	delta+
12212	$N(1440)^+$	N(1440)+	2224	$\Delta^{++}$	delta++
1214	$N(1520)^0$	N(1520)0	31114	$\Delta(1600)^-$	D(1600)-
2124	$N(1520)^+$	N(1520)+	32114	$\Delta(1600)^0$	D(1600)0
22112	$N(1535)^0$	N(1535)0	32214	$\Delta(1600)^+$	D(1600)+
22212	$N(1535)^+$	N(1535)+	32224	$\Delta(1600)^{++}$	D(1600)++
32112	$N(1650)^0$	N(1650)0	1112	$\Delta(1620)^-$	D(1620)-
32212	$N(1650)^+$	N(1650)+	1212	$\Delta(1620)^0$	D(1620)0
2116	$N(1675)^0$	N(1675)0	2122	$\Delta(1620)^+$	D(1620)+
2216	$N(1675)^+$	N(1675)+	2222	$\Delta(1620)^{++}$	D(1620)++
12116	$N(1680)^0$	N(1680)0	11114	$\Delta(1700)^-$	D(1700)-
12216	$N(1680)^+$	N(1680)+	12114	$\Delta(1700)^0$	D(1700)0
21214	$N(1700)^0$	N(1700)0	12214	$\Delta(1700)^+$	D(1700)+
22124	$N(1700)^+$	N(1700)+	12224	$\Delta(1700)^{++}$	D(1700)++
42112	$N(1710)^0$	N(1710)0	11112	$\Delta(1900)^-$	D(1900)-
42212	$N(1710)^+$	N(1710)+	11212	$\Delta(1900)^0$	D(1900)0
31214	$N(1720)^0$	N(1720)0	12122	$\Delta(1900)^+$	D(1900)+
32124	$N(1720)^+$	N(1720)+	12222	$\Delta(1900)^{++}$	D(1900)++
11218	$N(1990)^0$	N(1990)0	1116	$\Delta(1905)^-$	D(1905)-
12128	$N(1990)^+$	N(1990)+	1216	$\Delta(1905)^0$	D(1905)0
			2126	$\Delta(1905)^+$	D(1905)+
			2226	$\Delta(1905)^{++}$	D(1905)++
			21112	$\Delta(1910)^-$	D(1910)-
			21212	$\Delta(1910)^0$	D(1910)0
			22122	$\Delta(1910)^+$	D(1910)+
			22222	$\Delta(1910)^{++}$	D(1910)++
			21114	$\Delta(1920)^-$	D(1920)-
			22114	$\Delta(1920)^0$	D(1920)0
			22214	$\Delta(1920)^+$	D(1920)+
			22224	$\Delta(1920)^{++}$	D(1920)++
			11116	$\Delta(1930)^-$	D(1930)-
			11216	$\Delta(1930)^0$	D(1930)0
			12126	$\Delta(1930)^+$	D(1930)+
			12226	$\Delta(1930)^{++}$	D(1930)++
			1118	$\Delta(1950)^-$	D(1950)-
			2118	$\Delta(1950)^0$	D(1950)0
			2218	$\Delta(1950)^+$	D(1950)+
			2228	$\Delta(1950)^{++}$	D(1950)++

Table 4: Strange baryon codes

KF	Name	Printed	KF	Name	Printed
3122	$\Lambda^0$	Lambda0	3112	$\Sigma^-$	Sigma-
13122	$\Lambda(1405)^0$	L(1405)0	3212	$\Sigma^0$	Sigma0
3124	$\Lambda(1520)^0$	L(1520)0	3222	$\Sigma^+$	Sigma+
23122	$\Lambda(1600)^0$	L(1600)0	3114	$\Sigma^{*-}$	Sigma*-
33122	$\Lambda(1670)^0$	L(1670)0	3214	$\Sigma^{*0}$	Sigma*0
13124	$\Lambda(1690)^0$	L(1690)0	3224	$\Sigma^{*+}$	Sigma**
43122	$\Lambda(1800)^0$	L(1800)0	13112	$\Sigma(1660)^-$	S(1660)-
53122	$\Lambda(1810)^0$	L(1810)0	13212	$\Sigma(1660)^0$	S(1660)0
3126	$\Lambda(1820)^0$	L(1820)0	13222	$\Sigma(1660)^+$	S(1660)+
13126	$\Lambda(1830)^0$	L(1830)0	13114	$\Sigma(1670)^-$	S(1670)-
23124	$\Lambda(1890)^0$	L(1890)0	13214	$\Sigma(1670)^0$	S(1670)0
3128	$\Lambda(2100)^0$	L(2100)0	13224	$\Sigma(1670)^+$	S(1670)+
23126	$\Lambda(2110)^0$	L(2110)0	23112	$\Sigma(1750)^-$	S(1750)-
			23212	$\Sigma(1750)^0$	S(1750)0
3312	$\Xi^-$	Xi-	23222	$\Sigma(1750)^+$	S(1750)+
3322	$\Xi^0$	Xi0	3116	$\Sigma(1775)^-$	S(1775)-
3312	$\Xi^{*-}$	Xi*-	3216	$\Sigma(1775)^0$	S(1775)0
3314	$\Xi^{*0}$	Xi*0	3226	$\Sigma(1775)^+$	S(1775)+
13312	$\Xi(1690)^-$	X(1690)-	13116	$\Sigma(1915)^-$	S(1915)-
13322	$\Xi(1690)^0$	X(1690)0	13216	$\Sigma(1915)^0$	S(1915)0
13314	$\Xi(1820)^-$	X(1820)-	13226	$\Sigma(1915)^+$	S(1915)+
13324	$\Xi(1820)^0$	X(1820)0	23114	$\Sigma(1940)^-$	S(1940)-
23312	$\Xi(1950)^-$	X(1950)-	23214	$\Sigma(1940)^0$	S(1940)0
23322	$\Xi(1950)^0$	X(1950)0	23224	$\Sigma(1940)^+$	S(1940)+
3316	$\Xi(2030)^-$	X(2030)-	3118	$\Sigma(2030)^-$	S(2030)-
3326	$\Xi(2030)^0$	X(2030)0	3218	$\Sigma(2030)^0$	S(2030)0
			3228	$\Sigma(2030)^+$	S(2030)+
3334	$\Omega^-$	Omega-			

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Table 5: Heavy meson codes

KF	Name	Printed	KF	Name	Printed
411	$D^+$	D+	511	$B^0$	B0
413	$D^{*+}$	D*+	513	$B^{*0}$	B*0
415	$D_2^{*+}$	D*_2+	515	$B_2^{*0}$	B*_20
421	$D^0$	D0	521	$B^+$	B+
423	$D^{*0}$	D*0	523	$B^{*+}$	B*+
425	$D_2^{*0}$	D*_20	525	$B_2^{*+}$	B*_2+
431	$D_s^+$	D_s+	531	$B_s^0$	B_s0
433	$D_s^{*+}$	D*_s+	533	$B_s^{*0}$	B*_s0
435	$D_{2s}^{*+}$	D*_2s+	535	$B_{2s}^{*0}$	B*_2s0
441	$\eta_c$	eta_c	541	$B_c^+$	B_c+
443	$J/\psi$	J/psi	543	$B_c^{*+}$	B*_c+
445	$\chi_{2c}$	chi_2c	545	$B_{2c}^{*+}$	B*_2c+
10411	$D_0^{*+}$	D*_0+	551	$\eta_b$	eta_b
10413	$D_1^+$	D_1+	553	$\Upsilon$	Upsilon
10421	$D_0^{*0}$	D*_00	555	$\chi_{2b}$	chi_2b
10423	$D_1^0$	D_10	10511	$B_0^{*0}$	B*_00
10431	$D_{0s}^{*+}$	D*_0s+	10513	$B_1^0$	B_10
10433	$D_{1s}^+$	D_1s+	10521	$B_0^{*+}$	B*_0+
10441	$\chi_0^c$	chi_0c	10523	$B_1^+$	B_1+
10443	$h_{1c}$	h_1c	10531	$B_{0s}^{*0}$	B*_0s0
20413	$D_1^{*+}$	D*_1+	10533	$B_{1s}^0$	B_1s0
20423	$D_1^{*0}$	D*_10	10541	$B_{0c}^{*+}$	B*_0c+
20433	$D_{1s}^{*+}$	D*_1s+	10543	$B_{1c}^+$	B_1c+
20443	$\chi_{1c}$	chi_1c	10551	$\chi_0^b$	chi_0b
100443	$\psi'$	psi'	10553	$h_{1b}$	h_1b
			20513	$B_1^{*0}$	B*_10
			20523	$B_1^{*+}$	B*_1+
			20533	$B_{1s}^{*0}$	B*_1s0
			20543	$B_{1c}^{*+}$	B*_1c+
			20553	$\chi_{1b}$	chi_1b
			100553	$\Upsilon'$	Upsilon'

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Table 6: Heavy baryon codes

KF	Name	Printed	KF	Name	Printed	KF	Name	Printed
4112	$\Sigma_c^0$	Sigma_c0	5112	$\Sigma_b^-$	Sigma_b-	5432	$\Omega_{bc}^0$	Omega'_bc0
4114	$\Sigma_c^{*0}$	Sigma*_c0	5114	$\Sigma_b^{*-}$	Sigma*_b-	5434	$\Omega_{bc}^{*0}$	Omega*_bc0
4122	$\Lambda_c^+$	Lambda_c+	5122	$\Lambda_b^0$	Lambda_b0	5442	$\Omega_{bcc}^+$	Omega_bcc+
4132	$\Xi_c^0$	Xi_c0	5132	$\Xi_b^-$	Xi_b-	5444	$\Omega_{bcc}^{*+}$	Omega*_bcc+
4212	$\Sigma_c^+$	Sigma_c+	5142	$\Xi_{bc}^0$	Xi_bc0	5512	$\Xi_{bb}^-$	Xi_bb-
4214	$\Sigma_c^{*+}$	Sigma*_c+	5212	$\Sigma_b^0$	Sigma_b0	5514	$\Xi_{bb}^{*-}$	Xi*_bb-
4222	$\Sigma_c^{++}$	Sigma_c++	5214	$\Sigma_b^{*0}$	Sigma*_b0	5522	$\Xi_{bb}^0$	Xi_bb0
4224	$\Sigma_c^{*++}$	Sigma*_c++	5222	$\Sigma_b^+$	Sigma_b+	5524	$\Xi_{bb}^{*0}$	Xi*_bb0
4232	$\Xi_c^+$	Xi_c+	5224	$\Sigma_b^{*+}$	Sigma*_b+	5532	$\Omega_{bb}^-$	Omega_bb-
4312	$\Xi_c'^0$	Xi'_c0	5232	$\Xi_b^0$	Xi_b0	5534	$\Omega_{bb}^{*-}$	Omega*_bb-
4314	$\Xi_c'^0$	Xi*_c0	5242	$\Xi_{bc}^+$	Xi_bc+	5542	$\Omega_{bbc}^0$	Omega_bbc0
4322	$\Xi_c'^+$	Xi'_c+	5312	$\Xi_b'^-$	Xi'_b-	5544	$\Omega_{bbc}^{*0}$	Omega*_bbc0
4324	$\Xi_c^{*+}$	Xi*_c+	5314	$\Xi_b^{*-}$	Xi*_b-	5554	$\Omega_{bbb}^{*-}$	Omega*_bbb-
4332	$\Omega_c^0$	Omega_c0	5322	$\Xi_b'^0$	Xi'_b0			
4334	$\Omega_c^{*0}$	Omega*_c0	5324	$\Xi_b^{*0}$	Xi*_b0			
4412	$\Xi_{cc}^+$	Xi_cc+	5332	$\Omega_b^-$	Omega_b-			
4414	$\Xi_{cc}^{*+}$	Xi*_cc+	5334	$\Omega_b^{*-}$	Omega*_b-			
4422	$\Xi_{cc}^{++}$	Xi_cc++	5342	$\Omega_{bc}^0$	Omega_bc0			
4424	$\Xi_{cc}^{*++}$	Xi*_cc++	5412	$\Xi_{bc}^0$	Xi'_bc0			
4432	$\Omega_{cc}^+$	Omega_cc+	5414	$\Xi_{bc}^{*0}$	Xi*_bc0			
4434	$\Omega_{cc}^{*+}$	Omega*_cc+	5422	$\Xi_{bc}'^+$	Xi'_bc+			
4444	$\Omega_{ccc}^{*++}$	Omega*_ccc++	5424	$\Xi_{bc}^{*+}$	Xi*_bc+			