JAM 1.9: 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($E_{\rm lab} = 1 - 10$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 1.9

Program obtainable from: `www.aiu.ac.jp/~ynara/jam`
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
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.

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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 30AMeV $\sim$ 2GeV, 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 $E_{\rm lab}>$ 10AGeV 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 JAM1.9 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 or Quantum Molecular dynamics (RQMD/S). (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 ($\sim$ 4GeV in BB collisions $\sim$ 3GeV in MB collisions and $\sim$ 2GeV 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 1fm/c with string tension $\kappa = 1$GeV/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 $\sim$ 1GeV to collider energies, hadron-hadron collisions are basically modeled by the resonance production at $\sqrt{s} < 4$GeV, soft string excitation at $4 < \sqrt{s} < 50$GeV, minijet production at $\sqrt{s} > 10$GeV. Total hadronic cross section is divided by

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

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

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

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

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

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

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

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 $\sigma_{\text{t-R}}(s)$up to E_{cm} =3-4GeV. 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) $NN \to N\Delta(1232)$, (2) $NN \to NN^*$, (3) $NN \to \Delta(1232)\Delta(1232)$,

(4) $NN \to N\Delta^*$, (5) $NN \to N^*\Delta(1232)$, (6) $NN \to \Delta(1232)\Delta^*$, (7) $NN \to N^*N^*$,

(8) $NN \to N^*\Delta^*$, (9) $NN \to \Delta^*\Delta^*$.

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

$$\frac{d\sigma_{12\to34}}{d\Omega} = \frac{(2S_3+1)(2S_4+1)}{64\pi^2 s p_{12}} \int\int p_{34}|\mathcal{M}|^2 A(m_3^2)A(m_4^2)dm_3^2 dm_4^2 \tag{5}$$

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 δ-function, while that for resonances is given by the relativistic Breit-Wigner function

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

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]:

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

where ℓ 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

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

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 η 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:

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

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 $(3, 4) \to (1, 2)$ can be expressed by the cross section for $(1, 2) \to (3, 4)$;

$$\frac{d\sigma_{34\to12}}{d\Omega} = \frac{(2S_1+1)(2S_2+1)}{(2S_3+1)(2S_4+1)}\frac{p_{12}^2}{p_{34}}\frac{d\sigma_{12\to34}}{d\Omega}\frac{1}{\int\int p_{34}A(m_3)A(m_4)d(m_3^2)d(m_4^2)}. \tag{10}$$

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 πN incoming channel is assumed to be decomposed to

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

where $\sigma_{el}(s)$, $\sigma_{BW}(s)$, $\sigma_{\text{s-S}}(s)$, and $\sigma_{\text{t-S}}(s)$ 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 $\sqrt{s} \lesssim 2$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 πN interaction. Above the $\Delta(1232)$ region, t-channel elastic cross section becomes non-zero in our parameterization. String formation cross sections ($\sigma_{\text{s-S}}(s)$ and $\sigma_{\text{t-S}}(s)$) 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),

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

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 $\bar{K}N \to \pi Y$, we need to include additional terms:

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

where $\sigma_{\text{ch}}(s)$ 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 $\rho N \to \Lambda K$. 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 date [37].

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

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

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

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

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

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 $\sigma_{\text{s-S}}(s)$ 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]

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

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

where σ_{NN}, σ_{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 $\sigma_{\text{t-R}}(s)$, 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

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

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 $\sigma_{\text{t-R}}(s)$, we use

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

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

$$b = 2.5 + 0.7\log(s/2), \tag{20}$$

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

3.5 Soft interactions modeled by string model

At an energy range above $\sqrt{s} > 4-5$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} <$10-100GeV 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

$$p^+ = E + p_z, \qquad p^- = E - p_z \ . \tag{21}$$

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

$$p_1 = (p_1^+, p_1^-, 0_T), \qquad p_2 = (p_2^+, p_2^-, 0_T) \ . \tag{22}$$

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

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

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

$$M_1^2 = x^-(1 - x^+)s - p_T^2, \qquad M_2^2 = x^+(1 - x^-)s - p_T^2, \tag{24}$$

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]:

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

for baryons and

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

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

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

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

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

where $c_1 = 0.1$GeV/c, $p_0 = 1.4$GeV/c and $c_2 = 0.4$GeV/c, to reproduce the high momentum tail of the particles at energies $E_{lab} = 10 \sim 20$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 1fm/c assuming the string tension $\kappa = 1$ GeV/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 ith 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

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

with initial value

$$x_0^+ = \frac{W}{\kappa}, \qquad x_0^- = 0, \tag{30}$$

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 ith hadron, we have the recursion formulae [41]

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

Therefore, yo-yo formation points are obtained as

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

and constituent formation points

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

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

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

Clearly, one can see that

$$x_i^{const} < x_i^{rqmd} < x_i^{yoyo} \ . \tag{35}$$

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

3.6 Simulations with hadronic mean-field

3.7 Non-relativistic Skyrme potentials

The effects of the equation of state have been implemented by two different approaches: the nuclear mean-field and modified two-body scatterings. Nuclear mean field potential is implemented along the lines of the simplified version [47, 48] of the relativistic quantum molecular dynamics approach [49]. In this approach, our Hamiltonian is given by the sum of single particle energy:

$$H = \sum_{i=1}^{N} \sqrt{\boldsymbol{p}_i^2 + m_i^2 + 2 m_i V_i} \tag{36}$$

and the following equations of motion

$$\begin{aligned} \frac{d\boldsymbol{r}_i}{dt} &= \frac{\partial H}{\partial \boldsymbol{p}_i} = \frac{\boldsymbol{p}_i}{p_i^0} + \sum_{j=1}^{N} \frac{m_j}{p_j^0} \frac{\partial V_j}{\partial \boldsymbol{p}_i}, \\ \frac{d\boldsymbol{p}_i}{dt} &= -\frac{\partial H}{\partial \boldsymbol{r}_i} = -\sum_{j=1}^{N} \frac{m_j}{p_j^0} \frac{\partial V_j}{\partial \boldsymbol{r}_i}. \end{aligned} \tag{37}$$

are numerically solved. There is a option to simulate vector potential (zero-th component only):

$$H = \sum_i^N \left(\sqrt{\boldsymbol{p}_i^2 + m_i^2} + V_i \right) \tag{38}$$

The relative distances in the two-body center-of-mass frame are used in the argument of the potentials V_i (`mstc(113)`=1):

$$-q_{Tij}^2 = -(q_i - q_j)^2 + \frac{[(q_i - q_j)\cdot(p_i + p_j)]^2}{(p_i + p_j)^2}, \tag{39}$$

$$-p_{Tij}^2 = -(p_i - p_j)^2 + \frac{[(p_i - p_j)\cdot(p_i + p_j)]^2}{(p_i + p_j)^2}, \tag{40}$$

where q_i and p_i are the four-vectors for coordinate and momentum of the i-particle, respectively. Non-relativistic distance can be used when `mstc(113)`=0. There is also other option to used the rest frame of particle by `mstc(113)`=2.

For the potential V_i, the Skyrme-type density dependent and Lorentzian-type momentum dependent mean field potential [50] are implemented in the model [51, 52]. The one-particle potential is given by

$$V_i = \frac{\alpha}{2}\frac{\rho_i}{\rho_0} + \frac{\beta}{(1+\gamma)\rho_0^\gamma}\rho_i^\gamma + \sum_{k=1,2}\frac{C_{ex}^{(k)}}{2\rho_0}\sum_{j\neq i}\frac{1}{1+[p_{Tij}/\mu_k]^2}\rho_{ij} \tag{41}$$

In this work, we use the parameter set used in Ref. [52], which yields the nuclear incompressibility of $K = 272$ MeV for `mstc`(106)=14.

In QMD, interaction density in the potential is given by

$$\rho_i = \sum_{j\neq i}\rho_{ij}, \qquad \rho_{ij} = \frac{1}{(4\pi L)^{3/2}}\exp\left(\frac{q_{Tij}^2}{4L}\right), \tag{42}$$

which is used in the original RQMD and RQMD/S models. We call this implementation as RQMDs0. JQMD by Niita assumes the same form for the vector potential implementation. We call this model as RQMDv0. There may be interesting to consider other implementations. In the RQMDv1 model, we use the correct normalization of the Gaussian:

$$\rho_i = \sum_{j\neq i}\rho_{ij}, \qquad \rho_{ij} = \frac{\gamma_{ij}}{(4\pi L)^{3/2}}\exp\left(\frac{q_{Tij}^2}{4L}\right), \quad \gamma_{ij} = \frac{p_i^0 + p_j^0}{\sqrt{(p_i + p_j)^2}} \tag{43}$$

which can be simulate by the option `mstc`(114) = 1. In the case of scalar potential, we use the scalar density as

$$\rho_i = \sum_{j\neq i}\frac{m_j}{p_j^0}\rho_{ij}, \qquad \rho_{ij} = \frac{\gamma_{ij}}{(4\pi L)^{3/2}}\exp\left(\frac{q_{Tij}^2}{4L}\right), \quad \gamma_{ij} = \frac{p_i^0 + p_j^0}{\sqrt{(p_i + p_j)^2}} \tag{44}$$

which can be simulate by the option `mstc`(114) = 3. In the vector potential implementation, invariant baryon density may be used (`mstc`(114) = 2) as

$$\rho_{Bi} = \sqrt{J_i^\mu J_{i\mu}}, \quad J_i^\mu = \sum_{j\neq i}\frac{p_j^\mu}{p_j^0}\rho_{ij}, \tag{45}$$

RQMD/S simulation with scalar type potentials.

```
mstc(6)=101      ! RQMD
mstc(108)=1      ! RQMD/S mode
mstc(109)=1      ! scalar type potential
mstc(106)=14     !=14 mom-dep. soft EoS
mstc(98)=4       ! Ground state for QMD mode
dt = 0.1         ! time step size (fm/c)
timestep = 300   ! total number of time step.
```

RQMD/S simulation with vector type potentials.

```
mstc(6)=101     ! RQMD   mode
mstc(108)=1     ! RQMD/S mode
mstc(109)=0     ! vector type potentials
mstc(114)=0     ! RQMDv0 mode vector type potentials
mstc(106)=12    !=12 mom-dep. hard EoS
mstc(98)=4      ! Ground state for QMD mode
dt = 0.1        ! time step size (fm/c)
timestep = 300  ! total number of time step.
```

3.8 Relativistic mean-field: RQMD.RMF mode

Interactions from the relativistic mean-field (RMF) theory by σ-ω fields has been implemented into RQMD approach (RQMD.RMF) in JAM. RQMD.RMF is now a default mean-field mode in this version. The equations of motion for ith particle are given by

$$\dot{\boldsymbol{x}}_i = \frac{\boldsymbol{p}_i^*}{p_i^{*0}} + \sum_{j=1}^{N}\left(\frac{m_j^*}{p_j^{*0}}\frac{\partial m_j^*}{\partial \boldsymbol{p}_i} + v_j^{*\mu}\frac{\partial V_{j\mu}}{\partial \boldsymbol{p}_i}\right),$$
$$\dot{\boldsymbol{p}}_i = -\sum_{j=1}^{N}\left(\frac{m_j^*}{p_j^{*0}}\frac{\partial m_j^*}{\partial \boldsymbol{r}_i} + v_j^{*\mu}\frac{\partial V_{j\mu}}{\partial \boldsymbol{r}_i}\right). \tag{46}$$

The momentum-dependent scalar and vector potentials can be included in the following form:

$$V_{s,i}^{\rm MD} = \frac{1}{2}\frac{\bar{g}_s^2}{m_s^2}\sum_{i\neq j}^{N}\frac{m_j}{p_j^0}\frac{\rho_{ij}}{1-p_{T,ij}^2/\Lambda_s^2}, \tag{47}$$

$$V_{\mu,i}^{\rm MD} = \frac{1}{2}\frac{\bar{g}_v^2}{m_v^2}\sum_{i\neq j}^{N}\frac{p_{\mu,j}}{p_j^0}\frac{\rho_{ij}}{1-p_{T,ij}^2/\Lambda_v^2}, \tag{48}$$

where $p_{T,ij}$ is a relative momentum between ith particle and jth particle in the two-body center-of-mass frame:

$$p_{T,ij} = p_{ij} - (p_{ij}\cdot P_{ij})/\sqrt{P_{ij}^2} \tag{49}$$

where $p_{ij} = p_i - p_j$ and $P_{ij} = p_i + p_j$. Within the RQMD approach, the scalar density and baryon current are given in terms of the Gaussian wave packet:

$$\rho_{s,i} = \sum_{j\neq i}\frac{m_j}{p_j^0}\rho_{ij}, \quad J_i^\mu = \sum_{j\neq i} B_j\frac{p_j^\mu}{p_i^0}\rho_{ij}, \tag{50}$$

from which one obtains σ_i and ω_i fields at the ith particle's position:

$$m_\sigma^2\sigma_i + g_2\sigma_i^2 + g_3\sigma_i^3 = g_s\rho_{s,i}, \quad m_\omega^2\omega_i^\mu = g_v J_i^\mu. \tag{51}$$

Here B_j is baryon number of the jth particle.

The Gaussian ρ_{ij} is also computed by the canonical momentum:

$$\rho_{ij} = \frac{\gamma_{ij}}{(2\pi L)^{3/2}}\exp(q_{Tij}^2/2L). \tag{52}$$

Note that this definition of ρ_{ij} is different from the so-called interaction density which is defined by the overlap of density with other Gaussian wave-packets in the QMD approach with Skyrme force.

RQMD.RMF simulation without momentum-dependent potential:

```
mstc(6)=101     ! RQMD
mstc(106)=153   ! EoS
dt = 0.2        ! time step size (fm/c)
timestep = 200  ! total number of time step.
```

RQMD.RMF simulation with momentum-dependent potential:

```
mstc(6)=101     ! RQMD
mstc(106)=204   ! EoS
dt = 0.2        ! time step size (fm/c)
timestep = 200  ! total number of time step.
```

3.9 Simulations of EoS modified collision

The pressure of the system can be controlled by changing the scattering style in the two-body collisions [**?**]. Pressure of the system with volume V in which only two-body scatterings happen can be estimated by the Virial theorem [53]

$$P = P_f + \frac{1}{3TV}\sum_{(i,j)}(\boldsymbol{p}_i' - \boldsymbol{p}_i)\cdot(\boldsymbol{r}_i - \boldsymbol{r}_j) \tag{53}$$

during the time interval T, where $(\boldsymbol{p}_i' - \boldsymbol{p}_i)$ is a momentum transfer, and $(\boldsymbol{r}_i - \boldsymbol{r}_j)$ is a relative coordinate between two colliding particles i and j in the center-of-mass frame. P_f is the pressure from free streaming contribution. Thus the repulsive orbit $(\boldsymbol{p}_i' - \boldsymbol{p}_i)\cdot(\boldsymbol{r}_i - \boldsymbol{r}_j) > 0$ enhances the pressure, while the attractive orbit $(\boldsymbol{p}_i' - \boldsymbol{p}_i)\cdot(\boldsymbol{r}_i - \boldsymbol{r}_j) < 0$ reduces the pressure. In the standard transport approach, azimuthal angle of the two-body scattering is randomly chosen. Consequently, pressure generated by this scattering is zero in average which leads to the free hadron gas EoS. This immediately implies that one can control the pressure by appropriately choosing the scattering style. Selection of the repulsive orbit in the two-body collision [54, 55, 56] can simulate the effect of repulsive potentials. While, it is shown that selecting attractive orbit for all two-body scattering yields the compatible amount of softening of a EoS with a first-order phase transition, thus it mimics the effects of a first-order phase transition [**?**].

In the code, 'attractive orbit' mode in JAM refers to the simulation in which attractive orbits are selected for all two-body scatterings without imposing any conditions.

EoS of the system can be controlled by the formula in Ref. [**?**] by the following constraints in the two-body scattering

$$\Delta P = \frac{\rho}{3(\delta\tau_i + \delta\tau_j)}(\boldsymbol{p}_i' - \boldsymbol{p}_i)\cdot(\boldsymbol{r}_i - \boldsymbol{r}_j)\,, \tag{54}$$

where ΔP is the pressure difference from the free streaming pressure, ρ is the local particle density and $\delta\tau_i$ is the proper time interval of the i-particle between successive collisions. We have shown that a given EoS can be simulated by choosing azimuthal angle according to the constraint in Eq.(54) in the two-body scattering process [**?**]. Main advantage of this approach is to be able to simulate any given EoS with a numerically efficient way as far as there are many two-body collisions, which happens in heavy ion collision such as Au+Au collisions. We use the same EoS used in Ref. [**?**] to simulate 1OPT (JAM/1OPT) based on Eq. (54) in this paper.

If you want to simulate by selecting attractive orbits in all collisions. Set `mstc(59)` = 2.

Simulation with a first-order phase transition by using the EoS file of `eos_MF_fullB220.dat`:

```
mstc(59)=101  ! EoS modified collision term.
mstc(50)=11
fname(9)=/home/ynara/lib/eos_MF_fullB220.dat
```

Simulation with a crossover EoS by using EoS table in the UrQMD model.

```
mstc(59)=101
mstc(50)=24
fname(9)=/home/ynara/lib/
```

EoS file should be provided in the directory specified by `fname(9)`.

3.10 JAM+hydro simulation

An example inputs to simulate JAM+hydro dynamical coupling simulation:

```
proj = 209Pb
targ = 209Pb
mstc(1) = 123    ! random seed
event = 100      ! number of events
win = 20gev      ! incident energy
frame= nn        ! comp. frame  cm, nn, lab, collider
bmin =   0.0     ! minimum impact paraemter
bmax =  -4.0     ! maximum impact paraemter
dt = 0.15        ! time step size (fm/c)
timestep = 500   ! total number of time step.

mstc(140)=2   ! jam+hydro simulation on
mstc(141)=3   ! option to switch hydro: =3 dynamical
mstc(142)=3   ! hadrons except leading one
mstc(143)=0   ! particle-fluid interaction off
mstc(144)=2   !  1:Isochronous freezeout  2: isoenergy density freezeout
mstc(148)=61  ! option for sampling particle  in Cooper-Fry formula
mstc(145)=2   ! make mult. table
fname(10)=/data/schydro/ynara/lib/frmultK045.dat

parc(140)=0.5  ! energy density for particlization (GeV/fm^3)
parc(144)=0.5  ! crititал energy density for fluidzation (GeV/fm^3)
mstc(146)=3    ! option for Gaussion smearing.
parc(142)=0.5  ! Width of Gaussian smearing (fm)
parc(84)=0.5   ! Width of Gaussian smearing (fm)

mstc(50)=11   ! EoS
fname(9)=/data/schydro/ynara/lib/eos_MF_fullB235JAM.dat
end
```

4 Program description

4.1 Random number generator

Default random number generator in JAM1.9 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`.
- `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 momentum 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 ρ_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 protons.

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$\sim$ nbary.
nmeson: The particles other than baryons are stored in the line i=nbary+1$\sim$ 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^2).

`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*`mste(1)`+`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*`mste(22)`+`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: ω and ϕ 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^2) 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^2) 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)`: β_x (GeV/c) in two-body c.m..
`vq(2,i)`: β_y (GeV/c) in two-body c.m..
`vq(3,i)`: β_z (GeV/c) in two-body c.m..
`vq(4,i)`: γ in two-body c.m..
`vq(5,i)`: ϕ in two-body c.m.
`vq(6,i)`: θ in two-body c.m.
`vq(7,i)`: $x_i - x_j$ in two-body c.m.
`vq(8,i)`: $y_i - y_j$ in two-body c.m.
`vq(9,i)`: $z_i - z_j$ in two-body c.m.
`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^2).

```
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)` : (D=1) 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 $dP = \sigma\rho(\boldsymbol{r})dz$ and $dP = \sigma\rho(\boldsymbol{r})vdt$ respectively in order to account for the diffuseness 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 Skyrm force and no collision.

$= 4$: BUU mode: Hard Skyrm force and no collision.

$= 12$: BUU mode: Soft Skyrm force.

$= 14$: BUU mode: Hard Skyrm force.

$= 101$: 101=RQMD mode. See `mstc(108)` for the option for the RQMD mode (RQMD/S, RQMD.RMF), and the EoS for `mstc(106)`. The total number of time step (`mstc(3)`) and the time step size (`parc(2)`) must be set appropriately.

`mstc(7)` : (D=1)

$= 0$: No collisions.

$= 1$: Collisions.

> 1: Collision list are updated after every time step of `mstc(7)`.

`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 (momentum 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,πp...)collisions.

$= 0$: Inelastic as well as elastic collisions are generated.

$= 1$: only inelastic collisions are generated.

`mstc(18)`: (D=0) treatment of absorbed particle

$= 0$: delete absorbed particles (call jamedit)

$= 1$: do not call jamedit

`mstc(19)` : (D=0) treatment of two-body collision probability

$= 0$: geometrical,i .e. hard shpare collision profile: $P(b) = \theta(b_{\max} - b)$, where $b_{\max} = \sqrt{\sigma_{\rm tot}/\pi}$

$= 1$: Gaussian: $P(b) = G \exp\left(-G\dfrac{\pi b^2}{\sigma_{\rm tot}}\right)$ where $G =$ `parc(39)`. See GLISSANDO.

$= 2$: Probability of two body collision is given by the density overlap of two Gaussian wave packets: $P(b) = \dfrac{\sigma_{\rm tot}}{4\pi L} e^{-b^2/(4L)}$ as in the AMD model, Ono et. al, PTP87 (1992) 1185.

= 3 : Probability of two body collision $P(b) = 1 - \exp(-\sigma_{\rm eff} T_{pp})$ $T_{pp}(b) = \dfrac{1}{4\pi L} e^{-b^2/(4L)}$

`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 Δ^*.

`mstc(25)` : (I) end point of KC code for Δ^*.

`mstc(26)` : (I) starting point of KC code for Λ^*.

`mstc(27)` : (I) end point of KC code for Λ^*.

`mstc(28)` : (I) starting point of KC code for Σ^*.

`mstc(29)` : (I) end point of KC code for Σ^*.

`mstc(30)` : (I) starting point of KC code for Ξ^*.

`mstc(31)` : (I) end point of KC code for Ξ^*.

`mstc(32)` : (I) starting point of KC code for mesons.

`mstc(33)` : (I) end point of KC code for mesons.

`mstc(34)` : (D=0)

= 0

= 1 Predicted spectator nucleons are removed from a collision zone: they are forced to propagate up to the final time before simulation so that they do not really participate the reaction. This option is useful to check the shadowing effect of spectators.

`mstc(35)` : (D=0)

= 0

= 1 Suppress the collision in which collision ordering time $t_{\rm order}$ is less than the times of particles t_1 and t_2.

= 2 Suppress the collision in which collision ordering times $t_{\rm order}$ is less than the times of particles t_1 and t_2, where t_i, $(i = 1, 2)$ is the time of last collision.

`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 (Δ,ρ....) will remain after the end of simulation, if their decay time is longer than simulation time.

= 1 all resonances (Δ,ρ....). 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 π^0, Λ.....

= 0: allow weak decay after simulation.

= 1: weak decay is turned off.

`mstc(43)` : (D=2) switch for inclusion of Fermi motion of nucleons in nucleus.

= 0 : without Fermi motion of nucleons.

= 1 : Fermi motion is included by using Woods-Saxson density

= 2 : Fermi motion is included by using density of nucleons sampled.

`mstc(44)` : (D=1) switch for the end of calculation.

= 1 : simulation is stopped at the time= `mstc(3)`×`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 σ_{tot}/`mstc(5)`.

`mstc(47)(D=2)` : The definition of the local rest frame, when some quantities like pressure, density and so on. (see `mstc(50)` and `mstc(167)`)

= 1 : Eckart's definition $u^\mu = \frac{N^\mu}{\sqrt{N^\nu N_\nu}}$.

= 2 : Landau and Lifshitz's definition $u^\mu = \frac{T^{\mu\nu}u_\nu}{e}$, where $e = u_\mu T^{\mu\nu} u_\nu$ is the energy density in the local rest frame.

`mstc(48)(D=1)` : When EoS modified collision term is on; `mstc(50)` > 0,

= 1 : Pressure is defined by the average of three directions; $p = -\frac{1}{3}\Delta_{\mu\nu}T^{\mu\nu}$.

= 2 : Pressure is defined by the average of transvere direction.

`mstc(49)(D=2)` : When EoS modified collision term is on; `mstc(50)` > 0,

= 1 : Particles interact elastically after any of the standard collisions.

= 2 : Orbit of each collision is modified by changing only azimuth angle and the scattering angle is taken to be the standard collision term.

= 3 : The magnitude of particle momenta are changed by modifying their outgoing masses. (under construction)

`mstc(50)(D=0)` : When `mstc(59)` $>$ `100` or `mstc(59)` $=$ `30`: EoS modified collision term.

= 1 : EoS-Q

= 2 : EoS-Q modified

= 3 : s95p-v1

= 4 : s95p-v1.1

= 5 : super soft

= 6 : hadron resonance gas

= 11 : 1st order phase transition with hadron resonance gas + ideal QGP

`mstc(51)(D=2)` : 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 σ_{hh} = additive quark cross section within a formation time.

= 2: collision can happen with σ_{hh} = additive quark cross section within a formation time only for baryons.

= 3: any collision cannot happen within a formation time.

= 4: 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 $f_i = \sum_{i\neq j} = 8\exp[-\frac{(\boldsymbol{r}_i-\boldsymbol{r}_j)^2}{2L} - \frac{2L(\boldsymbol{p}_i-\boldsymbol{p}_j)^2}{\hbar^2}]$, where L is defined by the parameter `parc(15)`.

2 : blocking factor is calculated by Fusimi function as $f_i = \sum_{i\neq j} |<\phi_i|\phi_j>| = \sum_{i\neq j}\exp[-\frac{(\boldsymbol{r}_i-\boldsymbol{r}_j)^2}{4L} - \frac{(\boldsymbol{p}_i-\boldsymbol{p}_j)^2 L}{\hbar^2}]$, where L is defined by the parameter `parc(15)`.

`mstc(57)` : (D=0) preserve reaction plain in the two-boy collision

0 : no
1 : yes

`mstc(58)` : (D=1) Treatment of unformed hadron which has original constituent quarks.
1 : collision is reduced by the probability determined by the fraction of the number of original quarks.
2 : hadron-hadron cross section is reduced by the fraction of the number of original quarks.

`mstc(59)` : (D=0) choice of orbit in the two-boy collision.
0 : random
1 : repulsive orbit
2 : attractive orbit
3 : attractive orbit with the percentage of the choice of attractive orbit specified by `parc(83)`.
30: attractive orbit are selected according to a pressure p from a given EoS by the probability of $P =$ `parc(50)`$(p_{id} - p)/p)$, where p_{id} is a free streaming part of pressure.
101: orbit are selected according to a given EoS by H. Sorge's formula.

`mstc(60)(D=1)` : switch of resonance decay angular distribution which is created by the s-channel formation $h_1 + h_2 \to h'$.
$= 0$: isotropic decay.
$= 1$: anisotropic decay specified by `mstc(61)`.

`mstc(61)(D=2)` : 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 $NN \to NN(1440)^*$.
$= 1$: include s-wave pion productions explicitly, as $NN \to NN\pi$.
$= 2$: include s-wave pion by reducing one-delta production cross section. The ratio is controlled by `parc(80)`.

`mstc(67),mstc(68),mstc(69),mstc(70)` : (D=2,2,2,2) selection of the angular distribution for resonance produc-

tion scattering in BB(mstc(67)), MB(mstc(68)), MM(mstc(69)) and $\bar{B}B$(mstc(70)) collisions at energy above $\sqrt{s} = 2.17$GeV.

= 2 : angular dependence is sampled by exp(bt) distribution. See parc(44)-parc(46).

= 4 : angular dependence is sampled by Gaussian distribution: $\exp[-(p_T/\texttt{parc}(47))^2]$.

= 5 : angular dependence is sampled by Gaussian plus exponential distribution: $\exp[-p_T/\texttt{parc}(48))] + \texttt{parc}(49)\exp[-p_T/\texttt{parc}(47))]$.

mstc(71)(D=2) : switch for diffractive reaction in hh collisions.

= 0 : diffractive scattering off.

= 1 : on. sample according to $1/x$ distribution.

= 2 : on. diffractive scattering by the same method as Pythia6.

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(77) (D=0) : treatment of the pionic fusion process $NN \to$ deuteron $+ \pi$.

= 0 : No such process is included.

= 1 : included the cross section into one-Δ production cross section including Δ absorption process.

= 2 : included the cross section into one-Δ production cross section only for pp, pn, and nn collisions.

= 3 : included by assuming pn pair instead of creating deuteron. The momenta of the pn pair is assigned so that it will coalesce into deuteron.

= 4 : included by explicitly producing deuteron, but deuteron re-scattering has not been implemented. Namely, deuterons do not interact with other hadrons.

mstc(78) (D=0) : treatment of double pionic fusion process $NN \to$ deuteron $+ \pi\pi$. See arXiv:1212.2881[nucl-ex]. ABC effect is included in the pn collisions.

= 0 : No such process is included.

= 1 : included by assuming pn pair instead of creating deuteron. The momenta of the pn pair is assigned so that it will coalesce into deuteron.

= 4 : included by explicitly producing deuteron, but deuteron re-scattering has not been implemented. Namely, deuterons do not interact with other hadrons.

mstc(79) (D=0) : s-channel string formation

= 0 : yes.

= 1 : No.

mstc(80) : (D=0) switch for different parameterization of NN resonance production cross sections

= 0 : JAM 1999

= 1 : Kamae 2015

`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 (singuar at small x)
= 7 : CTEQ2MF (flat at small x)
= 8 : CTEQ2ML (large Λ)
= 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(86)` : (D=1) choice of scheme for EoS modified collision term when `mstc(59)` ≥ 1.
= 1 : H. Sorge. $\Delta \boldsymbol{p}_i \cdot (\boldsymbol{r}_i - \boldsymbol{r}_j) = 3\frac{(P-P_{ideal})}{\rho}(\Delta\tau_j + \Delta\tau_j)$
= 2 : Modified. $\Delta \boldsymbol{p}_i \cdot (\boldsymbol{r}_i/\Delta\tau_i - \boldsymbol{r}_j/\Delta\tau_j) = 3\frac{(P-P_{ideal})}{\rho}$
`mstc(87)(D=0)` : switch for EoS modified collisions. when `mstc(59)` ≥ 1.
= 0 : all hadron-hadron collisions.
= 1 : only baryon-baryon collisions.
= 2 : only meson-baryon collisions.
= 3 : only meson-baryon and meson-meson collisions
`mstc(88)(D=0)` : option for computing energy-momentum tensor in the EoS modified collision
= 0 : including all hadrons as well as constituent quarks
= 1 : only baryon is included in BB/MB/antiBB collisions, and only mesons in MM collisions.
`mstc(89)(D=0)` : option for computing energy-momentum tensor in the EoS modified collision
= 0 : including all hadrons as well as constituent quarks
= 1 : only formed hadrons are included. (constituent quarks are not included.)
`mstc(90)` : (D=0) EoS modified collision for s-channel reactions such as $2 \to 1 \to 2$.
= 0 : off
= 1 : on
`mstc(91)` : (D=0) Absorption for the collisions involving hadrons within a formation time.
= 0 : on
= 1 : off
`mstc(92)` : (D=0) configuration of a projecttile deformed nuclei in the case of `mstc(97)` = 1.
= 0 : random rotation
= 1 : tip: $R_z(0-\pi)R_y(0)$
= 2 : body: $R_z(0)R_y(\pi/2)$
= 3 : side: $R_z(\pi/2)R_y(\pi/2)$
`mstc(93)` : (D=0) configuration of a target deformed nuclei in the case of `mstc(97)` = 1.

= 0 : random rotation
= 1 : tip: $R_z(0-\pi)R_y(0)$
= 2 : body: $R_z(0)R_y(\pi/2)$
= 3 : side: $R_z(\pi/2)R_y(\pi/2)$

`mstc(94)` : (D=0) Output initial participant nucleons for the comuptation of e.g. eccentricities.
= 0 : No
= 1 : participant nucleons are printed out.

`mstc(95)` : (D=1) Option for nuclear distrtiubtion for QMD mode.
= 0 : Nuclear density distribution is generated according to `mstc(98)`.
= 1 : In the case of QMD simulation, the parameter `mstc(98)` = 4 is used with `parc(13)` = 0.9, `parc(14)` = 0.9, and `parc(20)` = 0.03, which replodue nuclear density distribution for Au and Pb for $L = 1$ fm^2.

`mstc(96)` : (D=0) check the binding energy of a ground state.
= 0 : off
= 1 : on

`mstc(97)` : (D=0) take account of the deformation of nucleus for Au, Cu, Pb, and U nuclei.
= 0 : off
= 1 : on

`mstc(98)` : (D=0) Nuclear distribution.
= 0 : HIJING parameterization is used for the nuclear ground state distribution.
= 1 : Woods-Saxson
= 2 : JQMD Niita parametrization to construct the QMD ground state, see PRC52(1995)2620.
= 3 : Hard sphere parametriztion from UrQMD for QMD mode. See Khaled Abdel-Waged, Phys. Rev. C 67, 064610 (2003).
= 4 : Hard sphere parametriztion for QMD with $L = 1.0$ fm^2
= 5 : Modified Woods-Saxon for QMD with $L = 0.5$ fm^2

`mstc(99)` : (D=0) option for the Yukawa potential.

`mstc(100)` : (D=0) option for the symmetry energy potential.

`mstc(101)` : (D=0) option for Coulomb potential.
= 0 : off.
= 1 : on.

`mstc(102)` : (D=1) time step to calculate the boundary of Coulomb.

`mstc(103)` : (D=0) option for RQMD/S transport.
= 0 : Calculate the displacement of $\boldsymbol{r}_i$ and $\boldsymbol{p}_i$ coming from potential derivative for the time of parc(2) at a time of potential evaluation.
= 1 : Displacement of $\boldsymbol{r}_i$ and $\boldsymbol{p}_i$ coming from potential derivative at each collision step, but after collisions, potential effects are canceled until potential is evaluated at the next time.
= 2 : Same as `mstc(103)`=1 with the time step of `parc(16)`,but collision list is kept for particles which does not feel MF. Collision list with particles feeling MF is updated with the interval of `mstc(105)`.

`mstc(104)` : (D=1) option for RQMD/S transport.
= 0 : Potential effects are counted only for formed nucleons.
= 1 : Potential effects are counted only for formed baryons.
= 2 : Potential effects are counted only for nucleons and deltas.
= 10 : Potential effects are counted for nucleons (even before formation).
= 11 : Potential effects are counted for baryons (even before formation).
= 12 : Potential effects are counted for baryons which has original constituent quarks (even before formation).
= 13: Potential effects are counted for hadrons which has original constituent quarks (even before formation). Potential is not included for formed mesons.
= 14: Same as 13, but potentials are included for all hadrons.

`mstc(105)` : (D=1) Update frequency of collision list for `mstc(103)`=2.

`mstc(106)` : (D=204) MF type in RQMD mode.
= −3 : K is specified by `parc(104)`.
= −2 : test momentum dependent part (do not use).
= −1 : Free hadron gas
= 0 : EoS-Q

= 1 : Momentum Dependent Hard MF Isee2005 $K = 448$ MeV
= 2 : Momentum Dependent Medium MF Isee2005
= 3 : Momentum Dependent Soft MF Isee2005 $K = 314$ MeV
= 4 : Momentum Independent Hard MF $K = 380$ MeV
= 5 : Momentum Independent Soft MF $K = 200$ MeV
= 11 : Momentum Dependent very hard MF AO2015 fit1 $K = 436.47$ MeV
= 12 : Momentum Dependent hard MF AO2015 fit1 $K = 371.92$ MeV
= 13 : Momentum Dependent medium MF AO2015 fit1 $K = 305.37$ MeV
= 14 : Momentum Dependent soft MF AO2015 fit1 $K = 272.60$ MeV
= 21 : Momentum Dependent very hard MF AO2015 fit2 $K = 466.82$ MeV
= 22 : Momentum Dependent hard MF AO2015 fit2 $K = 397.42$ MeV
= 23 : Momentum Dependent medium MF AO2015 fit2 $K = 328.02$ MeV
= 24 : Momentum Dependent soft MF AO2015 fit2 $K = 293.33$ MeV
= 101 : The σ-ω model $K = 553$ MeV $m^*/m = 0.546$
= 102 : Generalized σ-ω model of Ref. [57] $K = 380$ MeV $m^*/m = 0.603$
= 103 : Generalized σ-ω model of Ref. [57] $K = 300$ MeV $m^*/m = 0.639$
= 104 : Generalized σ-ω model of Ref. [57] $K = 210$ MeV $m^*/m = 0.691$
= 105 : Generalized σ-ω model of Ref. [57] $K = 170$ MeV $m^*/m = 0.722$
= 106 : Generalized σ-ω model of Ref. [57] $K = 150$ MeV $m^*/m = 0.74$
= 107 : Generalized σ-ω model of Ref. [57] $K = 80$ MeV $m^*/m = 0.83$
= 108 : More generalized σ-ω model of Ref. [57] $K = 210$ MeV $m^*/m = 0.83$
= 109 : More generalized σ-ω model of Ref. [57] $K = 380$ MeV $m^*/m = 0.83$
= 110 : More generalized σ-ω model of Ref. [57] $K = 210$ MeV $m^*/m = 0.84$
= 111 : Non-linear σ-ω model of Ref.[58] NL1 $K = 380$ MeV $m^*/m = 0.83$
= 112 : Non-linear σ-ω model of Ref.[58] NL2 $K = 210$ MeV $m^*/m = 0.83$
= 113 : Non-linear σ-ω model of Ref.[58] NL3 $K = 380$ MeV $m^*/m = 0.70$
= 114 : Non-linear σ-ω model of Ref.[58] $K = 380$ MeV $m^*/m = 0.83$ for $\rho_0 = 0.168$ 1/fm^3.
= 115 : Non-linear σ-ω model of Ref.[58] $K = 210$ MeV $m^*/m = 0.83$ for $\rho_0 = 0.168$ 1/fm^3.
= 116 : Non-linear σ-ω model of Ref.[58] $K = 380$ MeV $m^*/m = 0.70$ for $\rho_0 = 0.168$ 1/fm^3.
= 117 : Non-linear σ-ω model of Ref.[58] $K = 380$ MeV $m^*/m = 0.80$ for $\rho_0 = 0.168$ 1/fm^3.
= 119 : Non-linear σ-ω model of Ref.[58] $K = 380$ MeV $m^*/m = 0.84$ for $\rho_0 = 0.168$ 1/fm^3.
= 120 : Non-linear σ-ω model of Ref.[58] $K = 210$ MeV $m^*/m = 0.84$ for $\rho_0 = 0.168$ 1/fm^3.
= 123 : Non-linear σ-ω model of Ref.[58] $K = 300$ MeV $m^*/m = 0.722$ for $\rho_0 = 0.168$ 1/fm^3.
= 126 : Non-linear σ-ω model of Ref.[58] $K = 230$ MeV $m^*/m = 0.8$ for $\rho_0 = 0.168$ 1/fm^3.
= 152 : NS3 Non-linear σ-ω model $K = 380$ MeV $m^*/m = 0.7$.
= 153 : NS1 Non-linear σ-ω model $K = 380$ MeV $m^*/m = 0.83$.
= 154 : NS2 Non-linear σ-ω model $K = 210$ MeV $m^*/m = 0.83$.
= 203 : MD1 Non-linear σ-ω model with momentum-dependent (MD) potentials: $K = 380$ MeV $m^*/m = 0.65$, $U_{\rm opt}(\infty) = 95$.
= 204 : MD2 Non-linear σ-ω model with MD potentials: $K = 380$ MeV $m^*/m = 0.65$, $U_{\rm opt}(\infty) = 30$.
= 210 : MD4 Non-linear σ-ω model with MD potentials: $K = 210$ MeV $m^*/m = 0.83$, $U_{\rm opt}(\infty) = 67$.
= 212 : MD3 Non-linear σ-ω model with MD potentials: $K = 380$ MeV $m^*/m = 0.65$, $U_{\rm opt}(\infty) = -0.4$.

`mstc(107)` : (D=1) Treatment of potential after the collision or decay in QMD mode.
= 0 : Particles produced or already collided after the time of force evaluation does not feel potential until the next time slice.
= 1 :

`mstc(108)` : (D=5) treatment of potential type
= 0 : fully non-relativistic QMD mode.
= 1 : RQMD/S mode (obsolete) Skyrme potential is treated as scalar : $e_i = \sqrt{m_i^2 + 2m_iV_i + \boldsymbol{p}_i^2}$.
= 2 : RQMD/S mode (rewitten version):
= 3 : Skyrme potential is treated as scalar : $e_i = \sqrt{(m_i + V_i)^2 + \boldsymbol{p}_i^2}$.
= 4 : Skyrme potential is treated as four-vector (new)
= 5 : The σ-ω type model of Ref. [57, 58]. `mstc(106)` $= 101 - 200$.

`mstc(109)` : (D=2) Treatment of p_i^0
= 0 : Potential is treated as a zeroth component of vector potential: $p_i^0 = \sqrt{m_i^2 + \boldsymbol{p}_i^2} + V_i$.
= 1 : Potential is treated as a Lorentz scalar: $e_i = \sqrt{\boldsymbol{p}_i^2 + m_i^2 + 2m_iV_i}$, but p_i^0 is approximated by the

kinetic energy: $p_i^0 = \sqrt{\boldsymbol{p}_i^2 + m_i^2}$.

$= 2$: Effective mass is included: $p_i^0 = \sqrt{\boldsymbol{p}_i^2 + m_i^{*2}} = \sqrt{\boldsymbol{p}_i^2 + m_i^2 + 2m_i V_i}$ due to scalar type mean field potential.

$= 3$: Same as 2 but, effective masses $m_i^{*2} = m_i^2 + 2m_i V_i$ are computed self-consistently.

`mstc(111)` : (D=1) Inclusion of the derivatives m_j^*/p_j^{*0} and $v_j^{*\mu}$ of factors in front of the scalar and vector potentials, when scalar density is defined by $\rho_{si} = \sum_{i\neq j} m_j^*/p_j^{*0}\rho_{ij}$ and the vecotr potential is defined by using baryon current $J_i^\mu = \sum_{i\neq j} v_j^{*\mu}\rho_{ij}$.

$= 0$: No.

$= 1$: The derivatives are incluced in the EoM.

`mstc(112)` : (D=1) Treatment of momenta of particles in the evaluation of potential.

$= 0$: full momentum including effective mass is used.

$= 1$: free momentum is used in the argument of potential.

`mstc(113)` : (D=1) Treatment of the arguments of the potentials.

$= 0$: fully non-relativistic: $V(\boldsymbol{r}_i - \boldsymbol{r}_j)$, and $V(\boldsymbol{p}_i - \boldsymbol{p}_j)$.

$= 1$: relative distance in the argement of the potential is replaced by the squared four-vector distance in the two body c.m.frame.

$$-q_{Tij}^2 = -q_{ij}^2 + \frac{(q_{ij}\cdot P_{ij})^2}{P_{ij}^2}, \quad -p_{Tij}^2 = -p_{ij}^2 + \frac{(p_{ij}\cdot P_{ij})^2}{P_{ij}^2}, \tag{55}$$

where $p_{ij} = p_i - p_j$, $q_{ij} = q_i - q_j$, $P_{ij} = p_i + p_j$.

$= 2$: The rest frame of particle j is used for the relative distance in the argument of the potential:

$$-q_{Tij}^2 = -q_{ij}^2 + \frac{(q_{ij}\cdot p_j)^2}{m_j^2}.$$

`mstc(114)` : (D=2) Alternative scenario for the density entered in the argument of the potentials.

$= 0$: $\rho_i = \sum_j \rho_{ij} = \sum_j (2\pi L)^{-3/2}\exp(q_{Tij}^2)$

$= 1$: $\rho_i = \sum_j \rho_{ij} = \sum_j (2\pi L)^{-3/2}\gamma_{ij}\exp(q_{Tij}^2)$, $\gamma_{ij} = (p_i^0 + p_j^0)/\sqrt{(p_i + p_j)^2}$.

$= 2$: $J_i^\nu = \sum_j (2\pi L)^{-3/2}\frac{p_j^\nu}{p_j^0}\gamma_{ij}\exp(q_{Tij}^2)$, $\rho_i = \sqrt{J_i^\mu J_{i\mu}}$

$= 3$: $J_i^\nu = \sum_j (2\pi L)^{-3/2}\frac{p_j^\nu}{m_j}\exp(q_{Tij}^2)$, $\rho_i = \sqrt{J_i^\mu J_{i\mu}}$

$= 4$: $\rho_i = \sum_j (2\pi L)^{-3/2}\frac{m_j}{p_j^0}\gamma_{ij}\exp(q_{Tij}^2)$

`mstc(115)` : (D=2) option for vector potential.

$= 0$: only zero-th compoent of the vector potential is included with the form $B_i V_i$.

$= 1$: same as 1 but $V_i^0 = B_i V_i/\rho_{Bi} J_i^0$

$= 2$: vector potential is fully included with the form: $V_i^\mu = B_i V_i/\rho_{Bi} J_i^\mu$. where B_i is the baryon umber of the ith particle.

`mstc(116)` : (D=1) option regarding the derivative with respect to the momentum for transverse distance in the equation of motion.

$= 0$: No

$= 1$: zero-th component of the momentum is treated as dependent variable neglecting the contribution of potentials: $\frac{\partial p_i^0}{\partial \boldsymbol{p}_i} = \frac{\boldsymbol{p}_i}{p_i^0}$.

`mstc(117)` : (D=0) option for the potentials for resonances.

$= 0$: All baryons feels the same potential.

$= 1$: potentials are scaled by 2/3 for baryonic resonances and strange baryons.

`mstc(118)` : (D=0) Momentum cut-off is intrudeced in the evalution of density in the QMD mode as

$$\rho_{ij}/(1.0 + (\boldsymbol{p}_{ij}/\texttt{parc(105)})^2)$$

`mstc(119)` : (D=0) In the case that vector poential is fully incluced, we need to distinguish between kinetic and canonical momentum.

$= 0$: canonical momentum is propagated.

$= 1$: kinetic momentum is propagated. $\dot{\boldsymbol{V}}$ is computed analytically.

$= 2$: kinetic momentum is propagated. $\dot{\boldsymbol{V}}$ is computed numerically : $\boldsymbol{V}(t + \Delta t) - \boldsymbol{V}(t)$.

`mstc(120)` : (D=0) Definition of two-body distance in the momentum-dependent potential.

$= 0$: Same as `mstc(113)`.

$= 1$: Two-body c.m. for `mstc(113)` $= 2$.

`mstc(121)` : (D=0) Option for the scalar coupling for the resonances.

$= 0$: the coupling for all resonances are the same as the nucleon coupling.

$= 1$: mass dependent scaling for the scalar couping: $g_{sR}/g_{sN} = m_R/m_N$. The vector couplings are the same.

$= 2$: specified by the parameter `parc(106)` for resonances.

$= 3$: the parameter `parc(106)` is also effective for nucleons.

`mstc(122)` : (D=0) Option for the vector coupling for the resonances.

$= 0$: the coupling for all resonances are the same as the nucleon coupling.

$= 1$: specified by the parameter `parc(107)` for resonance couplings.

$= 2$: the parameter `parc(107)` is multiplied for all particles including nucleons.

`mstc(123)` : (D=0) Total energy conservation is recovered at each time step in the RQMD calculation.

$= 0$: No.

$= 1$: Yes.

`mstc(124)` : (D=0) Vector potential is updated by $\boldsymbol{V}(t + \Delta t) = \boldsymbol{V}(t) + \dot{\boldsymbol{V}}\Delta t$.

`mstc(125)` : (D=0) Option to change the strength of the potential for strange baryons.

$= 0$: No.

$= 1$: Yes.

`mstc(126)` : (D=0) Option to change the Δ decay angular distribution specified by the parameter `parc(125)`.

$= 0$: specified by `mstc(61)`.

$= 1$: p-wave distribution. See `parc(125)`.

`mstc(127)` : (D=0) Quatnum-mechanical suppression of very soft multiple collisions.

$= 0$: No.

$= 1$: Yes.

`mstc(128)` : (D=0) Treatment of two-body scattering involving pre-hadrons.

$= 0$: No.

$= 1$: scattering of pre-hadrons is diffractive scattering with a probability speficied by `parc(128)`.

`mstc(129)` : (D=0) use GPU for mean field of RQMD/S

`mstc(130)` : (D=0) In the case of `mstc(59)` $\neq 0$

$= 1$: If the collision is the first collision for one of two colliding particle, then `mstc(59)` is not done.

`mstc(131)` : (D=0) switch for nuclear cluster formation. PDG nuclear codes are given as 10-digit numbers $\pm 1SSZZZAAAI$. $A = n_p + n_n + n_\Lambda + n_\Sigma + n_\Xi + n_\Omega$ gives the total baryon number, $Z = n_p$ the total charge and S is a total number of strange quarks (not a strangeness number). The meaning of some `k(:,)`s are different:

`k(3,nv)`= number of Λ
`k(4,nv)`= number of Σ^-
`k(5,nv)`= number of Σ^0
`k(6,nv)`= number of Σ^+
`k(7,nv)`= number of Ξ^-
`k(8,nv)`= number of Ξ^0
`k(9,nv)`= number of Ω
`k(10,nv)`= number of neutron
`k(11,nv)`= number of proton

$= 0$: No.

$= 1$: Nuclear cluster formations are computed by the phase space coalecence model at the final time.

$= 2$: Nuclear cluster formations are computed by the phase space coalecence model at last collision point. Cluster formation time is assumed to be a largest time of particles.

$= 3$: Nuclear cluster formations are computed by the phase space coalecence model at last collision point. Cluster formation time is assumed to be a closest distance.

`mstc(132)` : (D=0) switch for nuclear cluster formation

$= 0$: Particles are not removed.

$= 1$: Particles are removed from the list after nuclear cluster formation.

`mstc(133)` : (D=0) switch for aviding unstable nuclear cluster formation

$= 0$: No limitation is imposed.

$= 1$: nuclear cluster which is far from β-stable nuclei is remved, which is estimated by the binding energy of the cluster greater than the value given by `parc(133)`. The binding enegy is estimated by the

Bethe and Weizsäcker mass formula.

`mstc(135)` : (D=0)
- = 0 : Full calculation.
- = 1 : linear interpolation to compute momentum dependent potential at the Cooper-Frye formula.

`mstc(136)` : (D=0) order time in the hydro evolution.

`mstc(137)` : (D=0) Evaluate local energy density of particles by using EoS like hydro.

`mstc(138)` : (D=1) Number of Gauss point to interporate energy-density at a cell.

`mstc(139)` : (D=0) Minimum number of collisions for the thermalization to be converted into fluid.

`mstc(140)` : (D=0) Integrated simulation with hydrodynamics
- = 0 : No
- = 1 : PPM to solve hydrodynamical equations.
- = 2 : HLLE to solve hydrodynamical equations.

`mstc(141)` : (D=3) Option for switching time from JAM to hydro
- = 0 : Convert all particles into fluid just after two nuclei pass each other at the passage of time `pard(140)` $\approx 2R/\gamma/\beta$.
- = 1 : Convert all particles into fluid at the time specified by `parc(141)`. Note that If `parc(141)` = 0.0, all particles are converted into fluid before collision, which is an event-by-event one-fluid simulation.
- = 2 : Convert all particles into fluid after the last collision time in the initial Gauber NN collision.
- = 3 : Hadrons from decay are put into fluids.
- = 4 : when energy density exceed a critical value, hadrons are converted into fluid.
- = 5 : (under construction) fluid generation by the energy loss

`mstc(142)` : (D=3) Option for how to switch from JAM to hydro in the case of `mstc(141)` = 3. If `mstc(142)` > 10, only particles from string fragmentaion are taken into account.
- = 1 `or 11` : mesons from decay are source of fluid.
- = 2 `or 12` : hadrons from decay are source of fluid except leading baryons.
- = 3 `or,13` : hadrons from decay are source of fluid except leading hadrons.
- = 4 `or,13` : hadron from decay are source of fluid except leading baryons.
- = 5 `or,14` : hadrons from decay are source of fluid including leading hadrons.

`mstc(143)` : (D=0) Option for fluid-particle interaction.
- = 0 : No
- = 1 : hadrons which passe thorugh inside fluid elements with energy densiry larger than the critical value is absobed by this fluid element.

`mstc(144)` : (D=2) Option for how to switch from hydro to JAM
- = 1 : isochronous hyper surface
- = 2 : isoenergy density hyper surface
- = 11 : real time particlization from isochronous hyper surface
- = 12 : real time particlization from isoenergy density hyper surface

`mstc(145)` : (D=1) Option to make multiplicity table for freeze-out before simulation.
- = 0 : Yes.
- = 1 : read multiplicity table from the file specified by `fname(10)`.
- = 2 : read multiplicity table from the EoS file specified by `fname(9)`. Thus Eos file must have the information about total particle density.

`mstc(146)` : (D=3) Option for Gaussian smearing in fluid.
- = 0 : No Gaussian smearing
- = 1 : Gaussiaa: $(2\pi\sigma^2)^{-3/2}\exp\left(-\frac{\boldsymbol{r}^2}{2\sigma^2}\right)$
- = 2 : Gaussian with a Lorentz γ only in the z-direction $\frac{\gamma_z}{(2\pi\sigma^2)^{3/2}}\exp\left(-\frac{(x-x_p)^2+(y-y_p)^2+[\gamma_z(z-z_p)]^2}{2\sigma^2}\right)$
- = 3 : Gaussian with $\frac{\gamma}{(2\pi\sigma^2)^{3/2}}\exp\left(-\frac{\boldsymbol{r}^2+(\boldsymbol{r}\cdot\boldsymbol{u})^2}{2\sigma^2}\right)$

`mstc(147)` : (D=1) Option for core-corona separation in the case of `mstc(141)` = 0 or 1.
- = 0 : No.
- = 1 : Yes.

`mstc(148)` : (D=61) Option for sampling particle at freeze-out
- = 0 : Conventional sampling; No resitriction for conserved quantum number.
- = 2 : Single Particle Rejection with Exponential Weights (SPREW) sampling
- = 10 : Mode sampling
- = 11 : Conventioal sampling, but sampling continues until total energy is filled.

= 12 : SPREW, but sampling continues until total energy is filled.

`mstc(149)` : (D=1) Option for energy-momentum conservation *after* sampling particles at freeze-out.

= 0 : No.

= 1 : Recover total momentum conservation.

= 2 : Recover total momentum conservation and total energy conservation. Note that if `mstc(148)` ≥ 10, total energy is already conserved within a few percent without this option. If this option is chosen, total energy is forced to conserved within a numerical accuracy.

`mstc(150)` : (D=0) Option for mehod of selection of freeze-out surface

= 0 : random

= 1 : select according to the probablitiy of $n_i/\sum_i n_i$, where n_i is the total number of particle at the i-th hypersurface.

`mstc(151)` : (D=1) Option for hadron cascade after burner after hydrodynamics

= 0 : No.

= 1 : Yes.

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 $d < Px > /dy$, $d < P_t > /dy$.

`mstc(156)`: (D=0) invariant energy distribution of two-body collisions.

`mstc(157)`: (D=0) output sampled ground state.

`mstc(158)`: (D=5) option for deuteron coalescence.

= 1 : phase space coalescence specified by the condition that the phase space distance in the CM frame of the two nucleons is less than the parameters $|r_1 - r_2| \leq$ `parc(151)` and $|p_1 - p_2| \leq$ `parc(152)`.

= 2 : Same as the `mstc(158)` = 1, but the spin factor of 3/4, which is saved in the vector `weid(i)` is taken into account. Thus, you have to multiply this factor for the yield of the deuteron.

= 3 : A deuteron is produced with the probability of the transition from p n pair to deuteron ground state

$$P = 8\exp(-\boldsymbol{r}_{cm}^2/A^2 - \boldsymbol{p}_{cm}^2 A^2/\hbar^2),$$

where $A =$ `parc(153)`, $\boldsymbol{r}_{cm} = \boldsymbol{r}_{n,cm} - \boldsymbol{r}_{p,cm}$, and $\boldsymbol{p}_{cm} = \boldsymbol{p}_{n,cm} - \boldsymbol{p}_{p,cm}$.

= 4 : A deuteron is produced with the probability

$$P = \frac{3}{4} \cdot 8 \exp(-\boldsymbol{r}_{cm}^2/A^2 - \boldsymbol{p}_{cm}^2 A^2/\hbar^2).$$

Isospin factor 3/4 is taken into account by `weid(i)` = 3/4.

= 5 : A deuteron is produced with the probability using Fusimi function

$$P = \frac{3}{4} \cdot 8 \exp(-\boldsymbol{r}_{cm}^2/A^2 - \boldsymbol{p}_{cm}^2 A^2/4\hbar^2).$$

Isospin factor 3/4 is taken into account by `weid(i)` = 3/4.

= 6 : A deuteron is produced with the probability using Fusimi function

$$P = \frac{1}{2} \cdot \frac{3}{4} \cdot 8 \exp(-\boldsymbol{r}_{cm}^2/A^2 - \boldsymbol{p}_{cm}^2 A^2/4\hbar^2).$$

Spin factor and Isospin factor 3/8 is taken into account by `weid(i)` = 3/8.

= 7 : A deuteron is produced with the probability using Fusimi function

$$P = \frac{3}{4} \cdot 8 \exp(-\boldsymbol{r}_{cm}^2/A^2 - \boldsymbol{p}_{cm}^2 A^2/4\hbar^2).$$

`weid(i)` = 1.

= 8 : A deuteron is produced with the probability using Fusimi function

$$P = \frac{1}{2} \cdot \frac{3}{4} \cdot \left| \sqrt{2} \cos\left(\frac{1}{2\hbar} \boldsymbol{r}_{cm} \cdot \boldsymbol{p}_{cm} \right) \right|^2 \cdot 8 \exp(-\boldsymbol{r}_{cm}^2/A^2 - \boldsymbol{p}_{cm}^2 A^2/4\hbar^2).$$

`weid(i)` $= \frac{1}{2} \cdot \frac{3}{4} \cdot |\sqrt{2} \cos\left(\frac{1}{2\hbar} \boldsymbol{r}_{cm} \cdot \boldsymbol{p}_{cm}\right)|^2$.

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.
= 3 : general output of coordinate and momentum
`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.
= 1 : Nucleons which have not collided yet are not included in the evaluation of the density.
= 2 : No restriction
`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`.
`mstc(170)` : output of relevant quantities for EoS at every collisions.
`mstc(171)` : output of time evolution of baryon rapidity and z-distributions dN_B/dy and dN_B/dz.
`mstc(172)` : output of time evolution of dN/dx and dN/dy, where x and y are the transverse coordinates perpendicular to the beam direction z.
`mstc(173)` : output of time evolution of pressure, energy and baryon density from viral theorm in RQMD mode.
`mstc(174)` : output of time evolution of $\langle N \rangle$, $\langle N^2 \rangle$, $\langle N^3 \rangle$.
`mstc(175)` : output of time evolution of v_4

`mstc(180)` : output of deviation of total energy, momentum, baryon number, charge, strangeness in hydrodynamics. File: fort.80.
`mstc(181)` : output of the time evolution of the energy and baryon density in hydrodynamics at the center: $(x, y, z) = (0, 0, 0)$. File: fort.30 (local),31 (computational frame)
`mstc(182)` : output of the time evolution of the fluid energy and particle energy. File: fort.32

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

`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= 0.0fm) initial distance r_z between beam and target.
< 0.0: $r_z = r_1 + r_2 + 6.0$ for $E_{lab} < 200$MeV,
$r_z = r_1 + r_2 + 4.0$ for 200MeV$< E_{lab} <$1GeV,
$r_z = r_1/\gamma_p + r_2/\gamma_t + 2.0$ for $E_{lab} >$1GeV.
$>= 0.0$: $r_z = r_1/\gamma_p + r_2/\gamma_t +$ `parc(5)`. where r_1 and r_2 represent projectile and target radius respectively, and γ_p and γ_t correspond to γ 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(8)`: (D=1.0fm/c) time slice for display.
`parc(9)`: (D=0.0) u-t mixing ratio for the resonance decay when resonance is produced from the t-channel reaction.
`parc(10)`: (D=0.5) u-t mixing ratio for the resonance decay when resonance is produced by the s-channel reaction.
`parc(11)` : (D=0.54 fm) diffuseness parameter in Woods-Saxon distribution for the density of nucleus.
`parc(12)` : (D=1.124 fm) parameter of Woods-Saxon tail.
`parc(13)` : (D=0.8 fm) minimum distance between identical nucleons for sampling of nucleus.
`parc(14)` : (D=0.8 fm) minimum distance between p and n for sampling of position.
`parc(15)` : (D=1.0 fm^2) 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)` : (D=0.5 fm/c) time interval to evaluate MF when `mstc(103)`=2.
`parc(17)`: (D=0.3) probability for the annihilation into 1 mesionic string in anti-baryon-baryon collision if possible.
`parc(18)`: (D=0.3) probability for the annihilation into 2 mesionic strings in anti-baryon-baryon collision if possible.
`parc(19)`: (D=0.5) probability for the annihilation into 2 mesionic strings plus stable meson in anti-baryon-baryon collision if possible.
`parc(20)` : (D=0.0 fm) paramter to reduce the radious of the nucleus: $1.19A^{1/3} - 1.61A^{-1/3} -$ `parc(20)`
`parc(21)` : (D=0.168 fm^{-3}) normal nuclear matter density ρ_0.
`parc(22)` : (D=$-$16.0MeV) binding energy of nuclear matter.
`parc(23)` : (D=0.001439767) Coulomb constant.
`parc(24)` : (D=0.93960GeV) neutron masses.
`parc(25)` : (D=0.93830GeV) proton mass.
`parc(26)` : (D=0.13500GeV) π^0 mass.
`parc(27)` : (D=0 .13960GeV) π^+ mass.
`parc(28)` : (D=0.938950002GeV) nucleon mass.
`parc(29)` : (D=0.1373GeV) average pion mass.
`parc(30)` : (D=0.0) Rapidity sepacration in calculating energy-momentum tensor when EoS modified collision is used.
`parc(31)` : (D=5.0fm) 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=55mb) maximum cross section forpn collisions at low energy.
`parc(33)` : (D=55mb) maximum cross section for pp collisions at low energy.
`parc(34)` : (D=200mb) maximum cross section for BB collision at low energy (involving resonance).
`parc(35)` : (D=200mb) maximum cross section for MB collisions at low energy.
`parc(36)` : (D=150mb) maximum cross section for MM collisions at low energy.
`parc(37)` : (D=350mb) maximum cross section for $\bar{B}B$ collision at low energy.
`parc(38)` : (D=0.05GeV) kinetic energy cutoff for two-body collisions at low energy.
`parc(39)` : (D=1.0) Parameter for `mstc(19)` = `1`.
`parc(41)` : (D=0.001GeV) minimum kinetic energy in decays.
`parc(42)` : (D=0.5fm) production point of daughter from mother in decay.
`parc(43)` : (D=0.4GeV/c) width of Gaussian p_t distribution for the decay of resonance, see `mstc(61)`.
`parc(44),parc(45),parc(46)` : (D=2.5(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 $a =$ `parc(44)` $+$ `parc(45)` $*$ (log(s) $-$ log(`parc(46)`)).
`parc(47)` : (D=0.36(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(50)` : (D=1.3) Parameter for the EoS modified scattering, when `mstc(59)` = 30. $P =$ `parc(50)`$(p_{id} - p)/p$.
`parc(51)` : (D=2.0GeV/c^2) minimum mass of string for non-strange baryons.
`parc(52)` : (D=3.5GeV/c^2) mass cut off for non-strange baryon resonances.
`parc(53)` : (D=2.0GeV/^{2}) minimum mass of non-strange mesonic string.
`parc(54)` : (D=1.0GeV/fm) string tension.
`parc(55)` : (D=1.0fm/c) formation time.
`parc(56)` : (D=4.0GeV/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(58)` : (D=1.0) enhancecd factor for baryon-baryon collisions.

parc(59) : (D=1.0) enhancecd factor for mesonk-baryon collisions.
parc(60) : (D=1.0) enhancecd factor for meson-meson collisions.
parc(61) : (D=4.6 GeV) Parameter of BB collision to use string model (GeV) except non-strange baryon-baryon collision, where resonance production cross sections are explicitly parametrized.
parc(62) : (D=3.0 GeV) Parameter of MB collision to use string model.
parc(63) : (D=1.8 GeV) Parameter of MM collision to use string model.
parc(64) : (D=1.1GeV/c^2) minimum value for the non-strange baryonic resonance states.
parc(65) : (D=0.7GeV/c^2) minimum value for the invariant mass of the excited meson-like string system in a hadron-hadron interaction.
parc(66) : (D=0.36GeV) width of the Gaussian P_t distribution of produced hadron in Lund string fragmentation (parj(21) in PYTHIA6.1).
parc(67), parc(68) : (D=0.1GeV/c, 1.4GeV/c) parameters in the distribution for the P_t kick from soft interactions (hipr1(19),hipr1(20) in HIJING1).
parc(69), parc(70) : (D=0.05GeV/c, 1.0GeV/c) parameters in the distribution for the P_t kick from resonance production interactions for the option mstc(67)=6.
parc(71) : (D=10GeV) lowest c.m. energy to do pQCD scattering.
parc(72) : (D=30GeV) If parc(73) is greater than the value of parc(71), we assume a smooth transition of the different parametrization between parc(71) and parc(72) to avoid sudden change of cross sections.
parc(73) : (D=0.1) parameter for the mean reaction time for the parton-parton scattering: $\tau = \texttt{parc(73)}/Q^2$.
parc(74) : (D=0.1) parameter for the mean life time of time-like parton branching.
parc(75) : (D=1.0) parameter for the mean life time of space-like parton branching.
parc(80) : (D=0.0) parameter for the ratio of the s-wave cross section to one-delta production cross section. See mstc(66). For example, if mstc(66)=2 and parc(80)=1.0, then all one-delta production is replaced by the s-wave one pion production. If mstc(66)=2 and parc(80)=0.5, then half of the one-delta production is replaced by the s-wave one pion production.
parc(83) : (D=0.0) percentage of the choice of attractive orbit in the case of mstc(59) = 3.
parc(84) : (D=1.0 fm) Gaussian widht in fm in calculation of energy-momentum tensor and hydrodynamics velcoity.
parc(98),parc(99): (D= -0.000498 GeV fm, 1.4 fm) parameter for Yukawa potentail: parc(98) $= V_Y^0 = -0.498$ MeV fm and parc(99) $= \gamma_Y = 1.4$ fm.

$$V_Y = V_Y^0 \frac{\exp(L/\gamma_Y^2)}{2r_{ij}} \left\{ e^{-r_{ij}/\gamma_Y} \left[1 - \mathrm{erf}\left(\frac{\sqrt{4L}}{2\gamma_Y} - \frac{r_{ij}}{\sqrt{4L}} \right) \right] - e^{r_{ij}/\gamma_Y} \left[1 - \mathrm{erf}\left(\frac{\sqrt{4L}}{2\gamma_Y} + \frac{r_{ij}}{\sqrt{4L}} \right) \right] \right\} \quad (56)$$

parc(100): (D=0.025 GeV) parameter C_s for the symmetry energy potential:

$$V_s = \frac{C_s}{2\rho_0} \sum_{i,j(\neq j)} (1 - 2|c_i - c_j|)\rho_{ij},$$

where c_i is 1 for protons and 0 for neutrons.
parc(101),parc(102),parc(103) : (D=0.0) parameters for the scalar potential, $m^* = m(1 + V(\rho_s))$, when mstc(106)=201, where

$$V(\rho_s) = \texttt{parc(101)}\rho_s + \texttt{parc(102)}\rho_s^{\texttt{parc(103)}}$$

parc(104): (D=0.210 GeV) Incompressiblity. In the case of mstc(106) $= -3$, Syrme potential parameters are computed by using incomressibility parc(104) and binding energy parc(22) at the nuclear saturation density parc(21).
parc(105): (D=1.0 GeV) momtnum cut-off parameter in the eveluation of density in QMD, when ($mstc(118) = 1$.
parc(106): (D=1.0) factor for the scalar coupling for resonances, if mstc(121) = 2
parc(107): (D=1.0) factor for the vector coupling for resonances, if mstc(122) = 1:
parc(108): (D=1.0) factor for the scalar coupling for strange baryons, if mstc(125) = 1:} factor = parc(108) $\cdot$ |number of strangeness|.
parc(109): (D=1.0) factor for the vector coupling for strange baryons, if mstc(125) = 1 factor = parc(107) $\cdot$ |number of strangeness|.
parc(125): (D=3.0) Parameter for the Δ decay angluar distribution: $dN/d(\cos\theta) \sim 1 + \texttt{parc(125)}\cos^2\theta$ when mstc(126) > 0.
parc(126): (D=1.0 fm/c) minium of collision time search This is necessary for the option mstc(127).
parc(127): (D=1.0) pre-factor for the collision time.
parc(128): (D=0.4) probability to have diffractive scattering with pre-hadrons.

`parc(131)` : (D=4.0 fm) critical separation of two-baryons above which a cluster cannot be formed for nuclear cluster formation.
`parc(132)` : (D=0.3 GeV/c) critical separation of relative momentum of two-baryons for nuclear cluster formation.
`parc(133)` : (D=$-$7.0 MeV) binding energy per mass BE/A. When the binding energy per mass computed by the Bethe Weizäcker mass formula is less than BE/A, nuclear cluster formation is accepted.
`parc(140)=0.5 GeV/fm`^{3} : Freezeout energy density in hydro siumlation.
`parc(141)=0.0` : switching time from JAM to hydro.
`parc(142)=0.5 fm`: The width of Gaussian for computation of energy-momentum tensor from JAM particle for the hydro input.
`parc(143)=1.0`: $\epsilon\sigma$ in the soruce term of hydro. $\frac{E_i}{dt} = -\frac{\epsilon}{\lambda_i} = -\epsilon\sigma\rho(\boldsymbol{r}_i(t))$
`parc(144)=0.5 GeV/fm`^{3}: Critical energy density e_f to allow fluid conversion. If `parc(144)` < 0,

$$e_f = |(\texttt{parc(144)}| + e_{\rm QGP}(T=0, \rho_B)$$

to take into account that the minumum possible energy density depends on the baryon density ρ_B.
`parc(145)=0.39693 GeVfm`$^{-3}$: Bag constant, which is used to compute pressure $P = (e-4B)/3$ when energy density exceed the EOS table. $B^{1/4} = 235$ MeV.
`parc(146)=0.0 fm`: thermalization time
`parc(147)=2.0 fm`: cut off for Gaussian smearing.
`parc(151)` : (D=2.1 fm) critical separation of two-baryons above which a cluster cannot be formed for deuteron formation.
`parc(152)` : (D=0.3 GeV/c) critical separation of two-baryons for deuteron formation.
`parc(153)` : (D=1.71 fm) deuteron coalecence parameter when `mstc(158)` ≥ 3.
`parc(164)` : (D=0.0) transverse radius for `mstc(164)`=4
`parc(165)` : (D=0.0) longituinal distance z for `mstc(164)`=4
`parc(167)` : (D=0.0) transverse radius for `mstc(167)`=1
`parc(174)` : (D=0.0) rapidity cut for `mstc(174)`=1
`parc(182)=1.0 fm`: the region of z to compute fluid fraction: $|z| <$ `parc(182)` for `mstc(182)`.

`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(8)` : current ensemble number.
`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(20)` : update collision list or not in the current time step.
`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)` : number of $RR \to NN$ collisions.
`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(65)` : number of `subroutine jamdeut` call.
`mstd(66)` : number of deuterons obtained by the coalescence in `subroutine jamdeut`.
`mstd(67-78)` : not used.
`mstd(79)` : number of initially predicted collisions.
`mstd(80)` : number of initially predicted participatns.
`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.
`mstd(91)` : flag for propagation with canonical momentum or not.
`mstd(101)` : flag for momentum dependence poteintal in RQMD/S mode which is set by the value of `mstc(106)`.
$= 0$: No.
$= 1$: Yes. momentum dependent potential is used.
`mstd(102)` : Scalar potential is computed from the non-linear σ-field in RQMD/S mode.
`mstd(140)` : time step for hydro simulation.
`mstd(143)` : cell size `maxx` for hydro simulation.
`mstd(144)` : cell size `maxy` for hydro simulation.
`mstd(145)` : cell size `maxz` for hydro simulation.

`pard(1)` : current global time.
`pard(2)` : current impact parameter(fm).
`pard(3)` : current minimum impact parameter.
`pard(4)` : impact parameter bin.
`pard(5)` : β factor for the transformation to laboratory frame.
`pard(6)` : γ 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)` : lab. rapidity y_{lab}.
`pard(18)` : beam rapidity y_p.

`pard(19)` : c.m. momentum.
`pard(20)` : used to estimate min. time for collision = `mstd(23)parc(2)`.

`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)` : β of projectile.
`pard(36)` : γ 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)` : β of target.
`pard(46)` : γ 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)` : event average $RR \to NN$ collisions.
`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(90)` : prefactor for the Gaussian for the width `parc(84)`.
`pard(101)` : scalar coupling g_s
`pard(102)` : parameter for non-linear sigma potential g_2
`pard(103)` : parameter for non-linear sigma potential g_3 $U(\sigma) = \frac{m_\sigma^2}{2}\sigma^2 + \frac{g_2}{3}\sigma^3 + \frac{g_3}{4}\sigma^4$
`pard(104)` : The width L (fm^2) of Gaussian wave packet. $\rho_i(\boldsymbol{r}) = \frac{1}{(2\pi L)^{3/2}} \exp\left(-\frac{(\boldsymbol{r}-\boldsymbol{r}_i)^2}{2L}\right)$.
`pard(105)` : Parameter μ_1 (GeV) in the momentum dependent potential

`pard(106)` : Parameter μ_2 (GeV) in the momentum dependent potential
`pard(107)` : Parameter C_1 (GeV) in the momentum dependent potential
`pard(108)` : Parameter C_2 (GeV) in the momentum dependent potential
`pard(109)` : Parameter $= 1/(4L)$
`pard(110)` : Parameter $= 1/(4\pi L)^{3/2}$
`pard(111)` : vector coupling g_v
`pard(112)` : sigma meson mass (1/fm)
`pard(113)` : omega meson mass (1/fm)
`pard(114)` : parameter for extended RQMD/NV model.
`pard(115)` : parameter for extended RQMD/NV model.
`pard(116)` : parameter for non-linear sigma potential g_4: $U(\sigma) = \frac{\frac{m_\sigma^2}{2}\sigma^2 + \frac{g_2}{3}\sigma^3 + \frac{g_3}{4}\sigma^4}{1 + \frac{g_4}{2}\sigma^2}$
`pard(140)` : Passing time of two nuclei.
`pard(141)` : Swiching time to hydro.
`pard(142)` : Potential parameter in the EoS table: $V(\rho_B) = \frac{1}{2}$`pard(142)`ρ_B^2
`pard(143)` : Δx fm in the fluid simulation
`pard(144)` : Δy fm in the fluid simulation
`pard(145)` : Δz fm in the fluid simulation

`common/jamdat2/pare(100),mste(100)`

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.
- $= 7$: antibaryon-baryon annihilation.
- $= 11$: direct s-wave pion scattering.
- $= -1$: Pauli-blocking.
- $= -2$: error after the call of `jamcross`.
- $= -9$: hard scattering false.
- $= -66$: anti-baryon-baryon annihilation 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.
- $= 1$: $pp \to pp\pi$.
- $= 2$: $nn \to nn\pi$.
- $= 3$: $pn \to nn\pi$.
- $= 11$: $pp \to d\pi^+$.
- $= 12$: $nn \to d\pi^-$.
- $= 13$: $pn \to d\pi^0$.

`mste(4)` : status of the latest soft string excitation.
= 1 : double diffractive.
= 2 : projectile single diffractive.
= 3 : target single diffractive.
= 4 : non-diffractive.
= 11 : double diffractive using PYTHIA.
= 12 : projectile single diffractive using PYTHIA.
= 13 : target single diffractive using PYTHIA.
`mste(5)` : number of jet in least hard collision.
`mste(6)` : cell number `icoll(3,i)` in current collision.
= 0 : resonance decay
= 1 : string fragmentation
`mste(7)` : flag for resonance decay or string fragmentation.
`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(25)`: line number of the outgoing particle 1, if it exists.
`mste(26)`: KC code of the outgoing particle 1, if it exists.
`mste(27)`: line number of the outgoing particle 2, if it exists.
`mste(28)`: KC code of the outgoing particle 2, if it exists.
`mste(29)`: line number of the outgoing particle 3 if it exists.
`mste(31)`: line number of the outgoing particle 4 if it exists.
`mste(40)`: =1 during the final decay after simulation, otherwise =0.
`mste(41)`: =1 fluid elements exist.
`mste(42)`: =0 local density was computed.
`mste(43)`: =0 all fluid elements are below a critical energy density for pariclization
`mste(44)`: =0 flag for subroutine call `jamepart(difm)` in which single particle potential energy is computed in QMD mode.

`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(10)` : maximum time to transport particles within a time step
`pare(11)`: sum of energy of the two particles before collision in the observer frame.
`pare(12)`: β_x for transformation from two-body c.m. frame to observer frame.
`pare(13)`: β_y for transformation from two-body c.m. frame to observer frame.
`pare(14)`: β_z for transformation from two-body c.m. frame to observer frame.
`pare(15)`: γ for transformation from two-body c.m. frame to observer frame.
`pare(16)`: ϕ for transformation from two-body c.m. frame to observer frame.
`pare(17)`: θ for transformation from two-body c.m. frame to observer frame.
`pare(18)`: Azimuthal angle of the collision in the two-body c.m.
`pare(19)`: Cosine of polar angle $\cos\theta$ of the collision in the two-body c.m.
`pare(20)`: $(\boldsymbol{p}_i' - \boldsymbol{p}_i) \cdot (\boldsymbol{r}_i - \boldsymbol{r}_j)$ in the two-body c.m. frame.
`pare(21)`: Mass modification factor S: $m_1^* = Sm_1$ for colliding particle 1.
`pare(22)`: Mass modification factor S: $m_2^* = Sm_2$ for colliding particle 2.
`pare(23)`: Mass modification factor S for colliding particle 1 or 2.
`pare(24)`: Mass modification factor S for colliding particle 1 or 2.
`pare(25)`: x-component of $\vec{r}_1 - \vec{r}_2$ in the two-boday c.m. frame.
`pare(26)`: y-component of $\vec{r}_1 - \vec{r}_2$ in the two-boday c.m. frame.

`pare(27)`: z-component of $\vec{r}_1 - \vec{r}_2$ in the two-boday c.m. frame.
`pare(28)`: $p'_x - p_x$ in the two-body c.m. frame.
`pare(29)`: $p'_y - p_y$ in the two-body c.m. frame.
`pare(30)`: $p'_z - p_z$ in the two-body c.m. frame.
`pare(31)`: energy density at collision point.
`pare(32)`: partice density at collision point.
`pare(33)`: baryon density at collision point.
`pare(34)`: pressure P_f at collision point.
`pare(35)`: transverse pressure $P_\perp = (P_x + P_y)/2$ at collision point.
`pare(36)`: longitudinal pressure P_z at collision point.
`pare(37)-pare(39)`: initial momentum of colliding particle 1 in the two-body c.m.frame.
`pare(43)-pare(45)`: coordinate of colliding particle 1 in the two body c.m. frame.
`pare(46)-pare(48)`: coordinate of colliding particle 2 in the two body c.m. frame.
`pare(49)`: collision time interval of colliding particle 1: $\delta\tau_1$
`pare(50)`: collision time interval of colliding particle 2: $\delta\tau_2$
`pare(51)`: Temperature to be used in the Cooper-Frye formula
`pare(52)`: Baryon chemical potential μ_B to be used in the Cooper-Frye formula
`pare(53)`: Strangensss chemical potential μ_S to be used in the Cooper-Frye formula
`pare(54)`: Quark fraction of colliding hadrons 1 during its formation time.
`pare(55)`: Quark fraction of colliding hadrons 2 during its formation time
`pare(56)`: γ-factor for colliding particle 1
`pare(57)`: γ-factor for colliding particle 2

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, `kf1` $= 1000000000 + 1000000N_n + 1000N_p + N_\Lambda$,
`kf2` $= 1000000000 + 1000000N_{\Sigma^-} + 1000N_{\Sigma^0} + N_{\Sigma^+}$,
`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(200AGeV/c)+S collision for impact parameter sampled by $b < 1$fm.

```
c...A main program for S(200GeV/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   390.000000000000
 charged particle   214.000000000000
 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_mdiff
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	ν_e	nu_e
3	s	s	13	μ^-	mu-
4	c	c	14	ν_μ	nu_mu
5	b	b	15	τ^-	tau-
6	t	t	16	ν_τ	nu_tau
7	l	l	17	χ^-	chi-
8	h	h	18	ν_χ	nu_chi
21	g	g			
22	γ	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			
			1103	dd_1	dd_1
2101	ud_0	ud_0	2103	ud_1	ud_1
			2203	uu_1	uu_1
3101	sd_0	sd_0	3103	sd_1	sd_1
3201	su_0	su_0	3203	su_1	su_1
			3303	ss_1	ss_1

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Table 2: light and strange meson codes

KF	Name	Printed	KF	Name	Printed	KF	Name	Printed
111	π^0	pi0	10220	σ	sigma-m	130	K_L^0	K_L0
211	π^+	pi+	221	η	eta	310	K_S^0	K_S0
113	ρ^0	rho0	223	ω	omega	311	K^0	K0
213	ρ^+	rho+	225	f_2	f_2	321	K^+	K+
10111	a_0^0	a_00	331	η'	eta'	313	K^{*0}	K*0
10211	a_0^+	a_0+	333	ϕ	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	Δ^-	delta-
2212	p	p+	2114	Δ^0	delta0
12112	$N(1440)^0$	N(1440)0	2214	Δ^+	delta+
12212	$N(1440)^+$	N(1440)+	2224	Δ^{++}	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	Λ^0	Lambda0	3112	Σ^-	Sigma-
13122	$\Lambda(1405)^0$	L(1405)0	3212	Σ^0	Sigma0
3124	$\Lambda(1520)^0$	L(1520)0	3222	Σ^+	Sigma+
23122	$\Lambda(1600)^0$	L(1600)0	3114	Σ^{*-}	Sigma*-
33122	$\Lambda(1670)^0$	L(1670)0	3214	Σ^{*0}	Sigma*0
13124	$\Lambda(1690)^0$	L(1690)0	3224	Σ^{*+}	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	Ξ^-	Xi-	23222	$\Sigma(1750)^+$	S(1750)+
3322	Ξ^0	Xi0	3116	$\Sigma(1775)^-$	S(1775)-
3314	Ξ^{*-}	Xi*-	3216	$\Sigma(1775)^0$	S(1775)0
3324	Ξ^{*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	Ω^-	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	η_c	eta_c	541	B_c^+	B_c+
443	J/ψ	J/psi	543	B_c^{*+}	B*_c+
445	χ_{2c}	chi_2c	545	B_{2c}^{*+}	B*_2c+
10411	D_0^{*+}	D*_0+	551	η_b	eta_b
10413	D_1^+	D_1+	553	Υ	Upsilon
10421	D_0^{*0}	D*_00	555	χ_{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	χ_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	χ_{1c}	chi_1c	10551	χ_0^b	chi_0b
100443	ψ'	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	χ_{1b}	chi_1b
			100553	Υ'	Upsilon'

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Table 6: Heavy baryon codes

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

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