Simplest Validation of the HIJING Monte Carlo Model

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Fulfillment of the energy-momentum conservation law, as well as the charge, baryon and lepton number conservation is checked for the HIJING Monte Carlo program in pp-interactions at $\sqrt{s} = 200$, 5500, and 14000 GeV. It is shown that the energy is conserved quite well. The transverse momentum is not conserved, the deviation from zero is at the level of 1–2 GeV/c, and it is connected with the hard jet production. The deviation is absent for soft interactions. Charge, baryon and lepton numbers are conserved.

Azimuthal symmetry of the Monte Carlo events is studied, too. It is shown that there is a small signature of a "flow". The situation with the symmetry gets worse for nucleus-nucleus interactions.

1   Introduction

A Monte Carlo event generators server (GENSER) is created in the framework of the LHC Computer Grid project (LHG). It is assumed that it will collect well-tested generators adapted for the LHC energies and experience of their application gained by the LHC collaborations. The generators will be improved in the course of the LHC implementation, test-beam experiments, receiving new experimental data, and so on. The server will give an opportunity for physicists to use the latest tested generators versions.

The improvement of the generators means their adaptation to the continuously changed computer technique, fine tuning of model parameters, and inclusion of new physical effects such as collective flow of particles, or black hole production. One of demands here is the saving of results of previous studies, or determination of their application range. The change of the generators does not mean an automatic change of the results of simulation of detector response, or change of the calibration constants of the experimental setups. The generator changes are usually connected with inclusions of new physical effects. For example, a problem of taking into account collective flows of particles and jet quenching in the existing nucleus-nucleus generators is very actual now after the RHIC experiments. Clearly, the inclusion will not change the global properties of simulated interactions dictated by soft and peripheral collisions. At the same time, it can have big influence on a small probability of the hard jet production, or on the possibility of registration of the collective flows. It is believed that the HIJING event generator can be adapted most probably to these demands.

The HIJING model [1] is the most popular one as applied for simulation of nucleus-nucleus (AA) interactions at LHC energies. It includes soft and hard interactions, nuclear modification of structure functions, jet quenching, a true geometry of nuclear collisions, and so on (description of the model see in [1, 2]. Thus, it is very important for future experiments to know its drawbacks and accuracy of the model predictions. In the paper, the so-called "theoretical" deficiency of the model will not be considered because it is rather difficult to find a common point of view in the phenomenology.

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The matter is, the authors of program-generators are solving a problem of description of existing experimental data, on the one hand, and on the other are trying to introduce new theoretical ideas. As a rule, the theoretical ideas are rather far away from everyday life, and it is not easy to transfer them to observable predictions which are the most important ones for the generators. In addition, all theoretical approaches have areas of application, and unsolved questions. The Monte Carlo event generator's authors have problems mainly with these boundary conditions (let us point out only an unsolved problem of soft and hard interaction connection). Thus, the Monte Carlo program contains a lot of phenomenological things which can not be formulated, in some cases, in a pure theoretical language.

We will concentrate on Monte Carlo program implementation of the model presented in Ref. [2], on its validation and installation.

2 Code Installation

The HIJING code located at *ftp://nta0.lbl.gov/pub/xnwang/hijing* has been successfully obtained by anonymous FTP. It contains 2 parts: *hijing1.383.f* (the latest version) and *hipyset1.35.f*. The first part collects the HIJING subroutines. The second part is Pythia and Jetset7.2 subroutines adjusted for HIJING needs. They must be compiled and linked together. **hepf77** and **g77_gcc2.32** compilers have been used.

It is assumed in the HIJING code that the random number generator is called *RAN* with dummy argument *Nseed*. As the function is not automatically linked to the compilers, an additional function was created and joined with the *main* program in order to run the HIJING model at the AFS CERN system.

```
      FUNCTION RAN(NSEED)
      RAN=RLU(NSEED)
      RETURN
      END
```

The function uses *RLU* function from *hipyset1.35.f*. The value *NSEED* was set to zero in introduced *COMMON/RANSEED/NSEED*.

A run of the executable code was unpredicted at AFS CERN system. Analysis has shown that local variables were not saved in some HIJING routines. A typical example is presented in the function *romg*:

```
      FUNCTION ROMG(X)
C ********This gives the eikonal function from a table
C calculated in the first call
      DIMENSION FR(0:1000)
      DATA I0/0/

      SAVE I0, FR                                  !Uzhi

      IF(I0.NE.0) GO TO 100
      DO 50 I=1,1001
        XR=(I-1)*0.01
        FR(I-1)=OMG0(XR)
50    CONTINUE
```

```
100    I0=1
       IF(X.GE.10.0) THEN
          ROMG=0.0
          RETURN
       ENDIF
       IX=INT(X*100)
       ROMG=(FR(IX)*((IX+1)*0.01-X)+FR(IX+1)*(X-IX*0.01))/0.01
       RETURN
       END
```

It was assumed that the array *FR* was filled, and the value of *I0* was changed to "1" at the first call of *romg* function. It was supposed that the array *FR* and the value of *I0* would not changed at all at following calls. This depends upon many circumstances: translator, operating system, computer type and so on. At least at AFS system, the array *FR* was not saved. It is sufficient to add a line marked by "*!Uzhi*" to protect a possible error.

Such type local variables have been found in the subroutines: *jetini, romg, vegas, pystfe, pystfn*. "*SAVE*" operators have been inserted in all of them The corrected code runs successfully at AFS system and produces artificial events. The event record includes multiplicity of particles, identificators of the particles, and their kinematical characteristics (E, P_x, P_y, P_z). Only stable particles were stored.

3   Code Validation

According to the existing imaginations, the events given by a Monte Carlo event generator must satisfy the following demands:

1. Kinematical properties of the events must obey the energy-momentum conservation law;

2. Conservation of charge, baryon and lepton numbers, strangeness and so on must take place;

3. The events must have an azimuthal symmetry if unpolarized particles are presented in an initial state;

4. The properties of the events and particles must be as close as possible to known experimental data;

5. There must be a possibility to generate events at arbitrary initial conditions in the range pointed by program authors, if there is such restriction.

Bellow we present the results of checking the first three demands for the HIJING program.

3.1 PP-interactions

Fig. 1 shows distributions on the sum of particle energies in the events of PP-interactions at $\sqrt{s}$ =200, 5500, and 14000 GeV in the centre-of-mass system. As seen, infact, the energy conservation takes place.
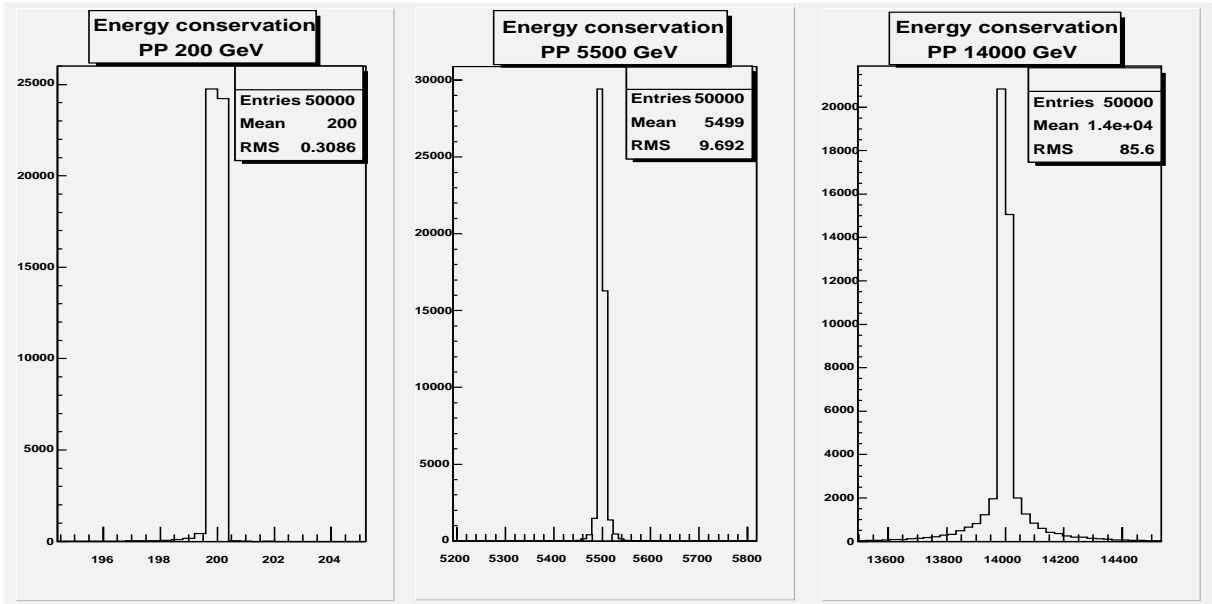
Figure 1: The energy distribution in the HIJING events

Distributions on summarized momentum components of particles in the events are presented in Fig. 2. The red histograms show the distributions for PP-interactions at $\sqrt{s} = 200$ GeV. The green ones give the distributions at $\sqrt{s} = 5500$ GeV (the energy of NN interactions in AA collisions at LHC), and the blue histograms show the characteristics at $\sqrt{s} = 14000$ GeV. At first glance, there is not a momentum conservation at all. Though the form of the distributions is not a pure gaussian one. It seems that it consists of 2 distributions: one is concentrated around zero, the other has large wings.

As it was said above, the HIJING program combined soft and hard interactions. The soft interactions are simulated according to the FRITIOF scheme [4] which saves energy and momentum. The hard interactions are treated $a'la$ Pythia algorithm. Thus, one can expect different distributions for the processes. The calculations presented in Fig. 3 confirm the expectation.

The black histograms in Fig. 3 show the distributions in the soft interactions, and the yellow ones – in hard collisions. As seen, the transverse momentum is saved in the soft interactions. The hard interactions destroy the momentum conservation. There is no longitudinal momentum conservation in both types of the interactions. So, the problem of connection of soft and hard interactions is not solved correctly in the HIJING program.

Of course, the problem of the momentum non-conservation can be solved very easily for PP-interactions in the center-of mass system, as it is usually done in the Monte Carlo generators by the replacement of a particle momentum, $\vec{p}_i$, on $\vec{p}_i - 1/N \sum_j \vec{p}_j$, where N is the multiplicity of the particles. But the problem of the connection remains.

The non-conservation of the momentum can lead to an artificial collective flow of the particles like a directed flow. In order to check the possibility, azimuthal distributions of the particles have been calculated. Fig. 4 presents small scale fluctuations of the distributions.

The distribution at $\sqrt{s} = 14000$ GeV shows quite a clear elliptic flow pattern, though the value of v_2 is very small. At lower energies the effect disappears. At the same time, the
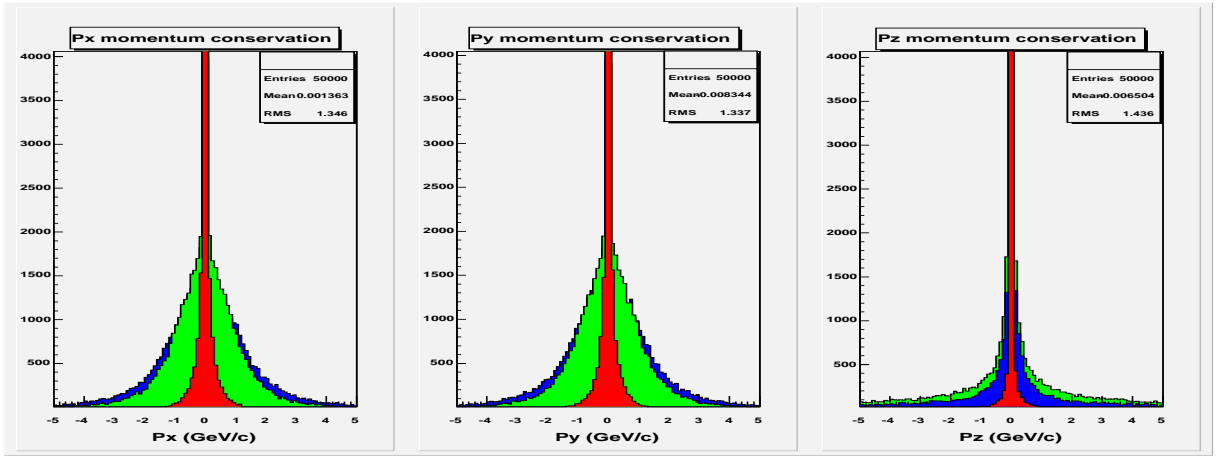
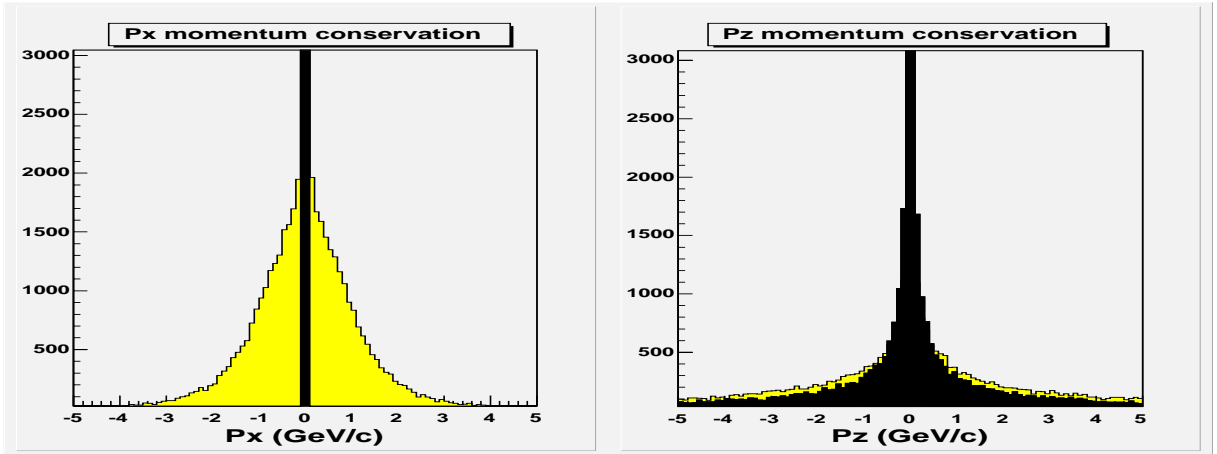Figure 2: The momentum conservation in the HIJING events

Figure 3: The summarized momentum distributions at $\sqrt{s} = 14000$ GeV. The black histograms show the distributions in the soft interactions, the yellow ones – in the hard interactions (with at least one pair of mini-jets).

fluctuations at all energies are large enough compared with pure statistical ones. They can grow up in nucleus-nucleus interactions, and imitate disoriented chiral condensate formation. The question must be studied carefully in future especially for the ALICE collaboration.
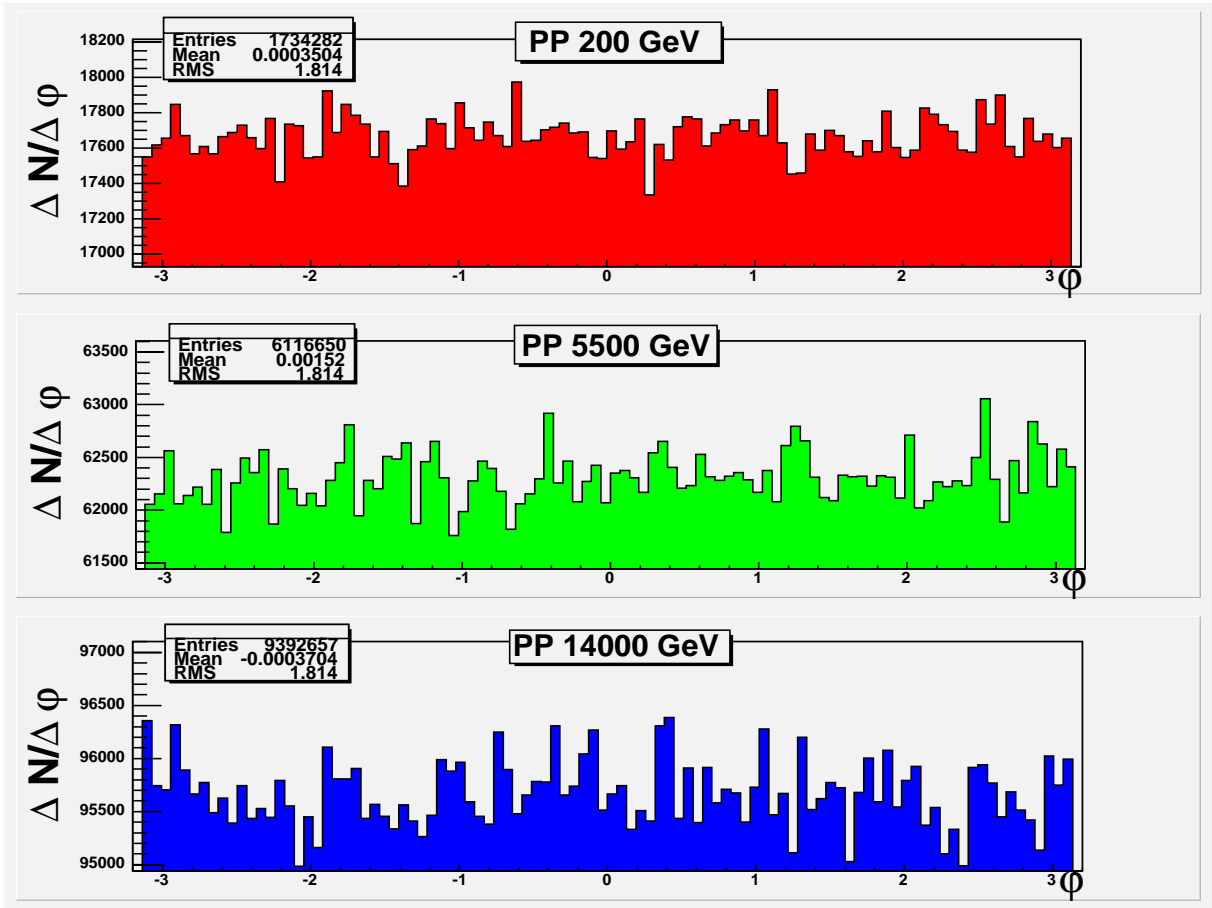
Figure 4: Azimuthal symmetry of the HIJING events

3.2 AA-interactions

The HIJING program does not consider the usual nuclear effects such as the Fermi motion of nucleons, relaxation of nuclear residuals, absorption of mesons in nuclear matter, etc. Thus one can expect that in nucleus-nucleus collisions the energy distribution in the events will have narrow peaks at $E = n * (E_{NN,cms}/2)$ where n can be 2, 3, 4, and so on. The first peak corresponds to the collision of one nucleon from "projectile" nucleus and one nucleon from "target" nucleus. The second peak is connected with the collision of one nucleon from the "projectile" nucleus and two nucleons from the "target" nucleus, and vice versa.

The analogous peaks must be in the summarized longitudinal momentum distribution at $Pz = \pm n * |P_{N,cms}|$ where n runs from 0, 1, 2, ...

The calculation results presented in Fig. 5 for minimal bias carbon-carbon interactions are in agreement with the expectations. If the energy and the longitudinal momentum are conserved as in elementary NN-collisions, the distortion of the peaks can not be seen in the chosen scale.

A worse situation as compared to that in the PP-interactions, takes place with conservation of the transverse momentum. As seen, the yield of the momentum saved component of the interactions becomes smaller. The widths of the distributions increase. The widths of

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Px and Py distributions are different, and this can reflects on azimuthal distribution of the particles.
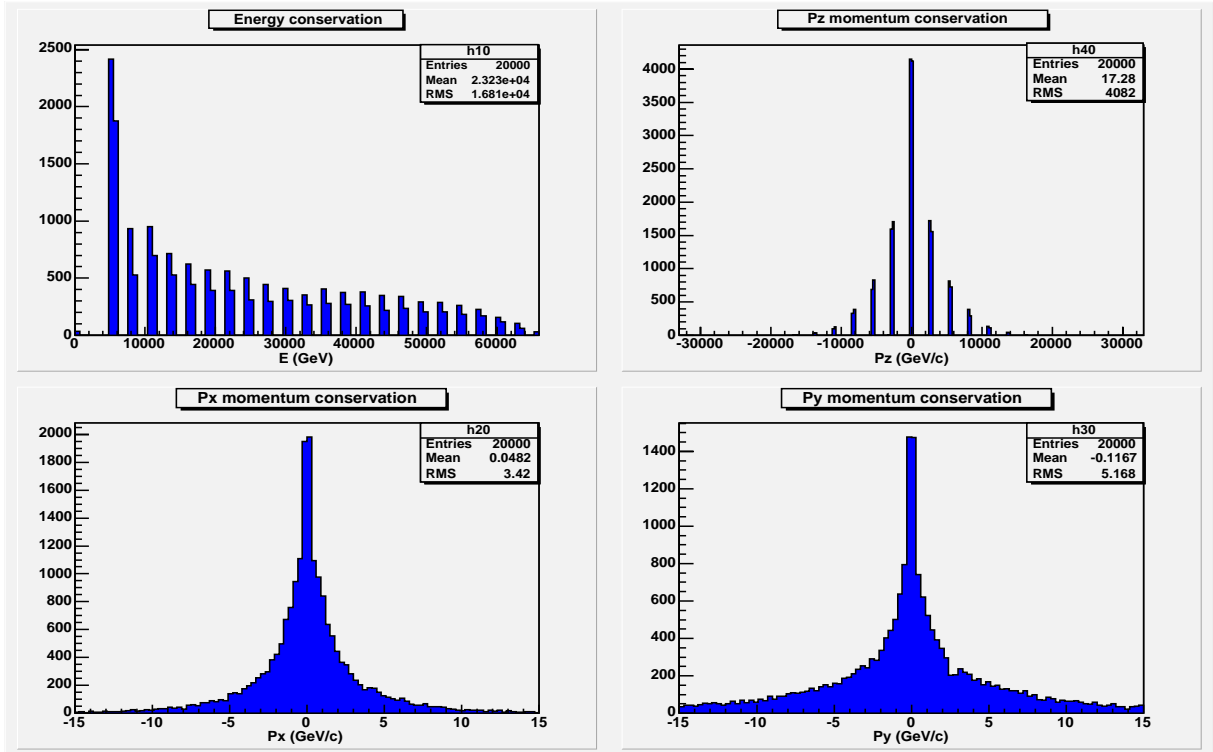

Figure 5: Properties of CC-interactions at $\sqrt{s_{NN}} = 5500$ GeV in the HIJING model.
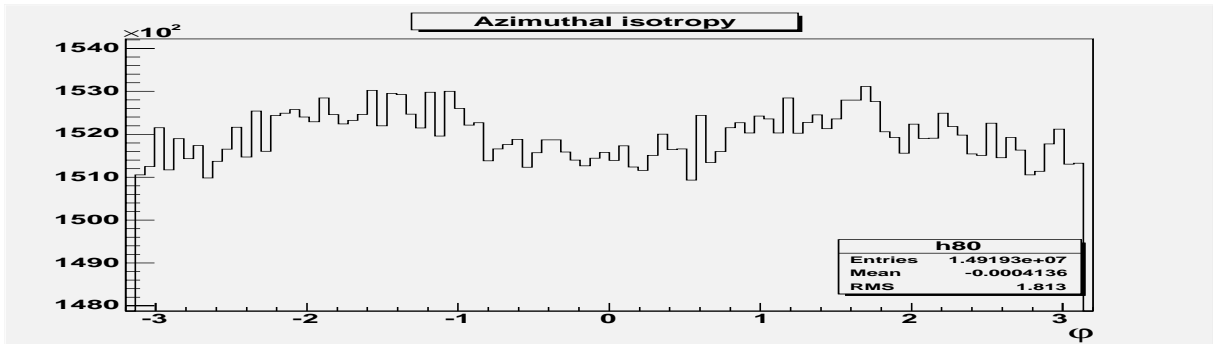

Figure 6: Azimuthal distribution of particles in CC-interactions.

Azimuthal distribution of the particles is shown in Fig. 6. As before, only small scale fluctuations are shown. As seen, a clear "flow" signal is observed! Maybe, the magnitude of the "flow" is too small, and this drawback of the program is not important for the LHC experiment. At least, the accuracy of the program must be checked up for $Pb + Pb$ interactions, where one can expect a larger 'effect".

4   Conclusion

1. Energy is quite well conserved in the HIJING events.

2. Momentum is not conserved exactly in PP-collisions. The hard interactions destroy the conservation. The violation of the momentum conservation gets larger for the AA-interactions.

3. The small "flow" pattern is presented in the azimuthal distributions of the particles.

References

[1] X-.N. Wang and M. Gyulassy, Phys. Rev. **D44** (1991) 3501.

[2] http://www-nsdth.lbl.gov/~xnwang/hijing/

[3] M. Gyulassy and X-.N. Wang, Comp. Phys. Commun. **83** (1994) 307.

[4] B. Andersson et al., Nucl. Phys. **B281** (1987) 289;
    B. Nilsson-Almquist and E. Stenlund, Comp. Phys. Commun. **43** (1987) 387.