PACIAE 2.1: An updated issue of the parton and hadron cascade model PACIAE 2.0

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Abstract

We have updated the parton and hadron cascade model PACIAE 2.0 (cf. Comput. Phys. Comm. 183 (2012) 333) to the new issue of PACIAE 2.1. The PACIAE model is based on PYTHIA. In the PYTHIA model, once the generated particle/parton transverse momentum $p_T$ is randomly sampled, the $p_x$ and $p_y$ components are originally put on the circle with radius $p_T$ randomly. Now it is put on the circumference of ellipse with half major and minor axes of $p_T(1 + \delta_p)$ and $p_T(1 - \delta_p)$, respectively, in order to better investigate the final state transverse momentum anisotropy.

Keywords: relativistic nuclear collision; PYTHIA model; PACIAE model.

PROGRAM SUMMARY

Manuscript Title: PACIAE 2.1: An updated issue of the parton and hadron cascade model PACIAE 2.0
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Program Title: PACIAE version 2.1
Journal Reference:
Catalogue identifier: none
Licensing provisions: none
Programming language: FORTRAN 77 or GFORTRAN
Computer: DELL Studio XPS and others with a FORTRAN 77 or GFORTRAN compiler

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E-mail address: sabh@ciae.ac.cn
Operating system: Linux or Windows with FORTRAN 77 or GFORTRAN compiler
RAM: ≈ 1G bytes
Number of processors used:
Supplementary material:
Keywords: relativistic nuclear collision; PYTHIA model; PACIAE model.
Classification: 11.1, 17.8
External routines/libraries:
Subprograms used:
Catalogue identifier of previous version: aeki_v1_0*
Journal reference of previous version: Comput. Phys. Comm. 183(2012)333.
Does the new version supersede the previous version?: Yes*
Nature of problem: PACIAE is based on PYTHIA. In the PYTHIA model, once the generated particle/parton transverse momentum ($p_T$) is randomly sampled, the $p_x$ and $p_y$ components are randomly placed on the circle with radius of $p_T$. This strongly cancels the final state transverse momentum asymmetry developed from the initial spatial asymmetry.
Solution method: The $p_x$ and $p_y$ component is now randomly placed on the circumference of ellipse with half major axis of $p_T(1 + \delta p)$ and the half minor axis of $p_T(1 - \delta p)$ instead of circle.
Reasons for the new version: PACIAE is based on PYTHIA, where once the generated particle/parton transverse momentum ($p_T$) is randomly sampled, the $p_x$ and $p_y$ components are randomly placed on the circle with radius of $p_T$. This is not only strongly canceling the final state transverse momentum asymmetry developed from the initial state spatial asymmetry but also inconsistent with the ATLAS observation of the final state charged particle transverse sphericity is less than unity [1].
Summary of revisions: The main revision is executed by randomly placing $p_x$ and $p_y$ components of the generated particle/parton transverse momentum $p_T$ on the circumference of ellipse with half major axis of $p_T(1 + \delta p)$ and the half minor axis of $p_T(1 - \delta p)$ instead of circle.
Restrictions: Depend on the problem studied.
Unusual features:
Additional comments: Email addresses: zhoudm@phy.ccnu.edu.cn (D.-M. Zhou), yanyl@ciae.ac.cn (Y.-L. Yan).
Running time:

- Using the attached input file of usux.dat (where the string fragmentation is selected and the elastic parton-parton interactions is considered only, the same later) to run 1000 events for the $\sqrt{s}=200$ GeV Non Single Diffractive pp collision by 21a.tar.gz spends 0.5 minute.
• Using the attached input file of usu.dat to run 10 events for the 10-40% most central Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV by 21b.tar.gz spends 5 minutes.

• Using the attached input file of usu.dat to run 10 events for the 10-40% most central Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV by 21c.tar.gz spends 17 minutes.

1.

The large azimuthal anisotropy (the large second harmonic coefficient $v_2$) of the emitted particle is an important feature of the hot and dense medium created in the ultra-relativistic nuclear collisions. This large $v_2$ has contributed to the observation of a strongly coupled quark-gluon plasma (sQGP) in the nucleus-nucleus collisions at the RHIC energies [2, 3, 4, 5].

The nuclear overlap zone created in a nucleus-nucleus collisions at a given impact parameter possesses an almond-like spatial asymmetry. Because of the strong parton rescattering, the local thermal equilibrium and asymmetric pressure gradient may build up in this initial fireball. The asymmetric pressure gradient then drives a collective anisotropic expansion. The expansion along the almond minor axis (along the large pressure gradient) is faster than the one along the major axis. This results in a strong asymmetric transverse momentum azimuthal distribution and hence a large elliptic flow coefficient $v_2$ of the final hadronic state.

As mentioned in [6], PACIAE is a parton and hadron cascade model for the ultra-relativistic nuclear collisions and is based on PYTHIA [7]. In the PACIAE model, a nucleus-nucleus collision is decomposed into a sequence of nucleon-nucleon (NN) collisions according to the collision geometry and the NN total cross section. Each NN collision is performed, in turn, by the PYTHIA model with the string fragmentation switched-off temporarily and the diquark (anti-diquark) broken into quark pairs (anti-quark pairs) randomly. The parton rescattering then proceeds. This parton evolution stage is followed by the hadronization at the moment of partonic freeze-out (exhausting the partonic collisions). The Lund string fragmentation regime and/or phenomenological coalescence model is provided for the hadronization. Then the rescattering among produced hadrons is dealt with the usual two body collision model [6].

In the PYTHIA model [7] once the transverse momentum $p_T$ of a final state hadron generated from the string fragmentation and/or the unstable
Figure 1: (Color on line) The charged particle $v_2(p_T)$ at mid-rapidity ($|\eta| < 1$) in 10-40% most central Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV. The solid symbols are the STAR data taken from [13] and open symbols are the PACIAE results calculated with $C=2$, 3, and 4.
assumed to be an ellipse with major axis of $b = 2R_A(1 + \delta_r)$ and the minor axis of $a = 2R_A(1 - \delta_r)$ for a symmetry nucleus-nucleus collision with the nuclear radius of $R_A$, we may assume

$$\delta_p = C\delta_r$$  \hspace{1cm} (1)

where $C$ is an extra model parameter. $C = 0$ corresponds to the original case of $p_x$ and $p_y$ put on the circle randomly.

In order to calculate $\delta_r$ we first calculate the reaction plane eccentricity according to the participant nucleons spatial distributions inside the nuclear overlap zone [11] in the PACIAE simulation. In the above equation, $\sigma_x^2 = \bar{x}^2 - \bar{x}^2$ (the same for $\sigma_y^2$) and $\bar{x}^2$ ($\bar{x}$) denotes an average of $x^2$ ($x$) over particles in a single event. The event average reaction plane eccentricity reads

$$\langle \epsilon_{rp} \rangle = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}.  \hspace{1cm} (3)$$

On the other hand, the geometric eccentricity [12] of the ellipse-like nuclear

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**Figure 2:** (Color on line) The charged particle $v_2(\eta)$ ($0.15 < p_T < 2.$) in 10-40% most central Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV. The solid symbols are the STAR data taken from [13] and open symbols are the PACIAE results calculated with $C=2, 3,$ and 4.
Figure 3: (Color on line) The charged particle transverse momentum distribution in 10-40% most central Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV calculated by the PACIAE model with $C=0$, 2, 3, and 4: (a) in the full $\eta$ phase space, (b) in $|\eta|<1$.

The calculated charged particle $v_2(p_T)$ at mid-rapidity ($|\eta|<1$.) in the 10-40% most central Au+Au collision at $\sqrt{s_{NN}}=200$ GeV is compared with the corresponding STAR data [13] in Fig. 1. In this figure the STAR data are denoted by solid symbols: the black circles are measured with the event plane method (EP), red squares with Lee-Yang zero point method (L-YZ), and green triangles with four particle cumulant method (4 cumulant). The PACIAE results are given by open symbols: the black circles calculated with $C=4$, red squares with $C=3$, and green triangles with $C=2$. One sees in this figure that the STAR data [13] on the charged particle $v_2(p_T)$ are able to be reproduced by the PACIAE calculations with $C=3$. The $C=0$ PACIAE results are too small compared to the STAR data.
A similar comparison for charged particle $v_2(\eta)$ ($0.15 < p_T < 2. \text{ GeV}/c$) in the 10-40% most central Au+Au collision at $\sqrt{s_{NN}}=200 \text{ GeV}$ is given in Fig. 2. Here one sees again that the STAR data on the charged particle $v_2(\eta)$ [13] are able to be reproduced by the PACIAE calculations with $C=3$. We have to mention here that in Fig. 3 of Ref. [13] the PHOBOS data [14] were introduced to compare with the STAR data and to complement the lack of the STAR data in $1.5 < |\eta| < 2.5$ region. Because the PHOBOS data were measured for the 0-40% most central Au+Au collisions at the same energy but in the full $p_T$ phase space, it is not suitable to compare the PHOBOS data with the STAR data. Therefore we do not include the PHOBOS data [14] in Fig. 2 here.

We give the calculated charged particle transverse momentum distribution in 10-40% most central Au+Au collisions at $\sqrt{s_{NN}}=200 \text{ GeV}$ in Fig. 3. Figure 3 (a) and (b) are drawn for the full and partial ($|\eta| < 1.$) pseudo-rapidity phase space, respectively. In panels (a) and (b) the solid black circles, open red circles, open green triangles, and the blue line are calculated with $C=4, 3, 2,$ and 0, respectively. We see in this figure that the charged particle transverse momentum distribution is really not sensitive to the parameter $C$ both in the full and partial $\eta$ phase space, provided the deformation parameter $\delta_p$ is less than unity (a small perturbation).

In addition, an extra switching parameter of $iparres$ is introduced in the new issue of PACIAE 2.1. We assume that the $iparres=0$ is for the elastic parton-parton rescattering only and $iparres=1$ for otherwise.

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