PACIAE Model Predictions for Pb + Pb Collisions at LHC Compared to the Au + Au Collisions at RHIC

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The parton and hadron cascade model PACIAE is used to simulate the 0-6%, 15-25, and 35-45% most central Au + Au collisions at √sNN=19.6, 62.4, 130, and 200 GeV and the 0-10% most central Pb+Pb collisions at √sNN=5500 GeV. The calculated charged multiplicity and the charged particle transverse momentum distribution, pseudorapidity distribution, and extended longitudinal scaling for Au + Au collisions well agree with the corresponding PHOBOS data. Thus the above observables calculated for Pb + Pb collisions would be a reliable prediction.

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In Ref. [1] the predictions of variety models for Pb+Pb collisions at LHC energy (√sNN=5500 GeV) have been compiled including the thermal (statistical) models [2]. The basic assumption in thermal model is that the final state hadrons in relativistic heavy-ion collisions are originated from a thermal source of a given thermal parameters of temperature and baryonic chemical potential. In [1] a parametrization of the temperature and baryonic chemical potential as a function of √sNN (in GeV) is obtained from the fits of calculated particle yields and ratios to the experimental data at mid-rapidity over a broad energy range of √sNN=2.7-200 GeV. Then they extend above parametrization to the LHC energy and provide a quantitative prediction for LHC Pb + Pb experiments.

Similarly, the transport models are also unable to be in agreement with the experimental data of nucleus-nucleus collisions in a broad energy range from AGS to SPS, RHIC, and even to LHC without adjusting any parameters. Of course, the less number of adjusting parameters the better the model is. In this letter the parton and hadron cascade model PACIAE, is used to simulate the 0-6% (15-25 and 35-45%) most central Au + Au collisions at √sNN=19.6, 62.4, 130, and 200 GeV and the 0-10% most central Pb+Pb collisions at √sNN=5500 GeV.

The charged multiplicity and the charged particle transverse momentum distribution, pseudorapidity distribution, and extended longitudinal scaling are calculated. In the calculations we fix all model parameters, except the parameter b in Lund string fragmentation function 3

\[ f(z) \propto z^{-1}(1-z)^a \exp(-b_m^2 / z). \]  

(1)

This function expresses the probability that a given z is picked, here z refers to the fraction of string energy (momentum) taken away by the produced hadron. In Eq. (1) the \( m_T = \sqrt{p_T^2 + m_h^2} \) is transverse mass of hadron, \( p_T \) and \( m_h \) are, respectively, the transverse momentum and rest mass of hadron, and the a and b are parameters. As mentioned in [2], that the parameter b is varied with string density and the higher reaction energy (temperature) is corresponding to the larger b. According to the experimental facts that the temperature of fireball, in relativistic heavy-ion collisions, as a function of √sNN increases dramatically first and then approaching saturation gradually 4, we assume b to be approximately a function of √sNN as

\[ b = b_0 \frac{\sqrt{s_{NN}}}{200}, \text{ if } \sqrt{s_{NN}} \leq 200 \text{ GeV}, \]

\[ b = b_0[1 + (1 - \frac{200}{\sqrt{s_{NN}}})], \text{ if } \sqrt{s_{NN}} > 200 \text{ GeV}, \]  

(2)

where \( b_0=6 \). As the calculated above observables in Au + Au collisions are in good agreement with PHOBOS data (see later), the calculated those observables in Pb + Pb collisions are thus a reliable prediction.

| Energy (GeV) | 19.6 | 62.4 | 130 | 200 | 5500 |
|-------------|------|------|-----|-----|------|
| Centrality | 0-6% | 0-10% |     |     |      |
| Multiplicity | Exp. | 2845±142 | 425±20 | 559±3 | 641±3 |
|              | PACIAE | 2919 | 4140 | 5001 | 14695 |
|              | b 0.58 | 2 | 4 | 6 | 12 |

1 PHOBOS data taken from [11].
2 PHOBOS data taken from [12].
3 Estimated from calculations in 0.2<η<1.4 .
4 Estimated from calculations in |η|<0.12 .

TABLE I: Charged multiplicity in Au + Au collisions at √sNN =19.6, 62.4, 130, and 200 GeV and in Pb + Pb collisions at √sNN=5500 GeV.

The parton and hadron cascade model, PACIAE 8, is based on PYTHIA (the model for hadron-hadron colli-
and hadron evolution (rescattering).

The parton initialization stage is followed by parton evolution (scattering). Here the 2-parton collision process is switched-off. Thus the consequence of a nucleus-nucleus collision is reached. The partonic initial state of a nucleus-nucleus collision is decomposed into nucleon-nucleon (NN) collisions at \( c^{2} \). Parton evolution (scattering): The String Fragmentation (independent fragmentation) [3] and is composed of four stages: the parton initialization, parton evolution (scattering), hadronization, and hadron evolution (rescattering).

1. Parton initialization:
In the PACIAE model the nucleus-nucleus collision is decomposed into nucleon-nucleon (NN) collisions according to the geometry of nucleus-nucleus collision. A NN collision is performed by the PYTHIA model [5] with the hadronization process switched-off. Thus the consequence of a nucleus-nucleus collision is a state composed of quark pairs, diquark pairs, gluons, and very few hadronic remnants. If the diquark (anti-diquark) is split forcedly into quarks (anti-quarks) randomly, the partonic initial state of a nucleus-nucleus collision is reached.

2. Parton evolution (scattering):
The parton initialization stage is followed by parton evolution (scattering). Here the 2 \( \rightarrow \) 2 LO-pQCD differential cross sections [8] are employed. The differential cross section of a sub-process \( ij \rightarrow kl \) reads

\[
\frac{d\sigma_{ij\rightarrow kl}}{dt} = K \frac{\pi \alpha_{s}^{2}}{s} \sum_{ij\rightarrow kl},
\]

where the factor \( K \) is introduced counting for the higher order pQCD and non-perturbative QCD corrections, \( \alpha_{s} \) stands for the strong (running) coupling constant, and \( s, \hat{t}, \) and \( \hat{u} \) are the Mandelstam variables. For the process \( q_{1}q_{2} \rightarrow q_{1}q_{2} \), for instance, one has

\[
\sum_{q_{1}q_{2}\rightarrow q_{1}q_{2}} = \frac{4}{9} \hat{s}^2 + \hat{t}^2.
\]

It diverges at \( \hat{t}=0 \) and has to be regularized by introducing the parton colour screen mass \( \mu \) as follows

\[
\sum_{q_{1}q_{2}\rightarrow q_{1}q_{2}} = \frac{4}{9} \hat{s}^2 + \hat{u}^2.
\]

The total cross section of the parton collision \( i+j \) is then

\[
\sigma_{ij}(\hat{s}) = \sum_{k,l} \int_{-\hat{s}}^{0} dt \frac{d\sigma_{ij\rightarrow kl}}{dt}.
\]

With above total and differential cross sections the parton evolution (parton scattering) can be simulated by the Monte Carlo method.

3. Hadronization:
The hadronization at the moment of partonic freeze-out (no more partonic collision at all) is consequent on the parton evolution stage. In the PACIAE model, the phenomenological fragmentation model (String Fragmentation, Independent Fragmentation, or Cluster Fragmentation) [8] and the coalescence model are supplied for hadronization of partons after scattering. The String Fragmentation model is adopted in this letter. We refer to [8] for the details of the hadronization stage.

4. Hadron evolution (rescattering):
After hadronization the rescattering among produced hadrons is dealt with the usual two-body collision model. The details of hadronic rescattering can see [10].

We compare the calculated charged multiplicity with the PHOBOS data (taken from [11, 12]) in 0-6% most central \( Au+Au \) collisions at \( \sqrt{s_{NN}} = 19.6, 62.4, 130, \) and 200 GeV in Table [11]. One sees here that the PHOBOS data are well reproduced within error bars by the PACIAE calculations, except the case of \( \sqrt{s_{NN}} = 19.6 \) GeV. That is consistent with the fact that the PYTHIA model is more suitable for higher reaction energy. The predicted charged multiplicity and charged particle pseudorapidity density at mid-pseudorapidity in 0-10% most central \( Pb+Pb \) collisions at \( \sqrt{s_{NN}} = 5500 \) GeV is also given in this table. That pseudorapidity density, \( \frac{dN_{ch}}{d\eta} \bigg|_{\eta=0} \sim 1200 \), is within the predicted values of other sixteen models listed.
In Fig. 1 (a) we compare the calculated charged particle transverse momentum distributions in 0-10% most central \( \text{Au} + \text{Au} \) collisions and \( \sqrt{s_{NN}} = 5500 \text{ GeV} \). The full labels are calculated results by the PACIAE model and the open labels are the corresponding PHOBOS data. PHOBOS data are taken from [11] (for \( \sqrt{s_{NN}} = 19.6, 130, \text{and} 200 \text{ GeV} \)) and [12] (for \( \sqrt{s_{NN}} = 62.4 \text{ GeV} \)).

In Fig. 1 (b) we give the charged particle pseudorapidity distributions in 0-6% most central \( \text{Au} + \text{Au} \) collisions at \( \sqrt{s_{NN}} = 62.4 \text{ GeV} \). Here the open circles, squares, and triangles are, respectively, the PHOBOS data of the 0-6, 15-25, and 35-45% most central \( \text{Au} + \text{Au} \) collisions and the full labels are the PACIAE model results. We see in panel (a) that the PHOBOS data are reasonably good reproduced. The prediction for charged particle transverse momentum distribution (triangles-down) in 0-10% most central \( \text{Pb} + \text{Pb} \) collisions at \( \sqrt{s_{NN}} = 5500 \text{ GeV} \) are given in Fig. 1 (b). For comparison, the charged particle transverse momentum distributions in 0-6 (circles) and 15-25% (squares) most central \( \text{Au} + \text{Au} \) at \( \sqrt{s_{NN}} = 200 \text{ GeV} \) are also given in panel (b). Note that the charged particle transverse momentum distributions shown in Fig. 1 (b) is integrated over full pseudorapidity.

Figure 2 shows the charged particle pseudorapidity distributions in 0-6% most central \( \text{Au} + \text{Au} \) collisions at \( \sqrt{s_{NN}} = 19.6 \) and 62.4 GeV (panel (a)) and at \( \sqrt{s_{NN}} = 130 \) and 200 GeV (panel (b)) and in 0-10% most central \( \text{Pb} + \text{Pb} \) collisions at \( \sqrt{s_{NN}} = 5500 \text{ GeV} \) (panel (c)). In this figure the open labels are the PHOBOS data and the full labels are the PACIAE model results. The squares and triangles-down in panel (a) are, respectively, for \( \sqrt{s_{NN}} = 62.4 \) and 19.6 GeV and the circles and triangles-up in panel (b) are, respectively, for \( \sqrt{s_{NN}} = 200 \) and 130 GeV. One sees again in panels (a) and (b) that the PHOBOS data are reasonably good reproduced, except the case of \( \sqrt{s_{NN}} = 19.6 \text{ GeV} \). Fig. 2 (c) gives the PACIAE model prediction for the charged particle pseudorapidity distribution in 0-10% most central \( \text{Pb} + \text{Pb} \) collisions at \( \sqrt{s_{NN}} = 5500 \text{ GeV} \). In panel (c) one sees that there is a deep valley at the mid-pseudorapidity.

In Fig. 3 we give the shifted charged particle pseudorapidity distributions in 0-6% most central \( \text{Au} + \text{Au} \) collisions at \( \sqrt{s_{NN}} = 19.6 \) (triangles-down), 62.4 (squares), 130 (triangles-up), and 200 GeV (circles) and in 0-10% most central \( \text{Pb} + \text{Pb} \) collisions at \( \sqrt{s_{NN}} = 5500 \text{ GeV} \) (diamonds). Here the shifted pseudorapidity is

\[
\eta' = \eta - \eta_{\text{beam}},
\]

where \( \eta_{\text{beam}} \) is the beam rapidity. We see in Fig. 3 that the extended longitudinal scaling [12] is well kept not only among \( \text{Au} + \text{Au} \) collisions at a variety values of \( \sqrt{s_{NN}} \) but also among \( \text{Au} + \text{Au} \) and \( \text{Pb} + \text{Pb} \) collisions.

In summary, we have used the parton and hadron cascade model PACIAE to simulate the 0-6, 15-25, and 35-45% most central \( \text{Au} + \text{Au} \) collisions at \( \sqrt{s_{NN}} = 19.6, 62.4, 130, \text{and} 200 \text{ GeV} \) and the 0-10% most central \( \text{Pb} + \text{Pb} \) collisions at \( \sqrt{s_{NN}} = 5500 \text{ GeV} \). The charged multiplicity and the charged particle transverse momentum distribution, pseudorapidity distribution, and...
extended longitudinal scaling are calculated. For $Au + Au$ collisions the calculated above observables are in good agreement with the corresponding PHOBOS data. Thus the above observables calculated for $Pb + Pb$ collisions would be a reliable prediction.

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