Study of nuclear modification factors of (anti-)hadrons and light (anti-)nuclei in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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The nuclear modification factors ($R_{AA}$) of $\pi^\pm$, $p(\bar{p})$, and $d(\bar{d})$ with $|y| < 0.5$, $p_T < 6.0$ GeV/c in peripheral (40-60%) and central (0-10%) Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV have been studied using the the parton and hadron cascade (PACIAE) model plus the dynamically constrained phase-space coalescence (DCPC) model. It is found that the distribution of $R_{AA}$ of light (anti-)nuclei $d$ is similar to that of hadrons ($\pi, p$), and the distribution of anti-particles is the same as that of particles. The suppression of high-$p_T$ particles strongly depends on event centrality and mass of the particles, i.e. the central collision is more suppressed than the peripheral collision. Besides, the yield ratios, double ratios $R_{AA}^{d}\left|_{\tilde{d}\tilde{p},\tilde{p}\pi^{-},d+p,p+\pi^{+}}\right.$, and the coalescence parameter $B_2$ for $(d, \bar{d})$ in pp, central and peripheral Pb-Pb collisions are discussed, respectively. It is observed that the yield ratios and $R_{AA}^{d}\left|_{d\tilde{p},\tilde{p}\pi^{-},d+p,p+\pi^{+}}\right.$ are also the same with the corresponding values of $d$ to $p$ and $p$ to $\pi^+$ in three different collision systems, respectively, suggesting that the suppressions of matter $(\pi^+, p, d)$ and the corresponding antimatter $(\pi^-, \bar{p}, \bar{d})$ has the same character and performance. Our results are comparable to those of experimental data.

I. INTRODUCTION

A new form of quark-gluon plasma (QGP) matter characterized by the deconfined state of quarks and gluons (partons) can be produce in heavy-ion collisions at ultra-relativistic energies, such as at the Relativistic Heavy-Ion Collider (RHIC) at BNL and Large Hadron Collider (LHC) at CERN. As a truth, QGP, which is central to the collision physics, can finally transverse to (anti-)matter (partons) can be produce in heavy-ion collisions at ultra-relativistic energies, and (anti-)nuclei ($A$) collisions to proton-proton (pp) collisions, is typically expressed as:

$$R_{AA}(p_T) = \frac{d^2N_{ch}^{AA}}{dT_{AA}\,d^2\sigma_{pp}^{ch}}/\frac{d^2N_{ch}}{dT_{AA}\,d^2\sigma_{pp}^{ch}}.$$

where $N_{ch}^{AA}$ and $\sigma_{ch}^{pp}$ denote the charged particles yield per event in A-A collision and the charged particle cross section in pp collision, respectively. The nuclear overlap function $T_{AA}$ is computed from Glauber model.

Both experimentally and theoretically, the study of the $R_{AA}$ of the $p_T$ spectrum in Pb-Pb collision compared to pp collision at the same energy can play an important role in studying the detailed mechanism by which hard partons lose energy traversing the medium. Recent measurement data of $R_{AA}$ in Pb-Pb collision from ALICE and CMS experiments have been published in succession. Compared with $R_{AA}$ of hadron (charged particles, $\pi, k, p$, etc.), $R_{AA}$ of light (anti-)nuclei is not well yet explained in high energy A-A collision experiments. Therefore we consider that the $R_{AA}$ properties of (anti-)hadrons and (anti-)nuclei in Pb-Pb collisions deserve to be further discussed in several models.

In theory, there are many successful relativistic hydrodynamics and models widely used to describe the production of hadrons and light nuclei in relativistic heavy-ion collisions. Currently, the (anti-)hadrons are usually studied with some selected transport or hydrodynamical models, such as the Ultra-Relativistic Quantum Molecular Dynamics (UrQMD) approach, the blast-wave model, and a parton and hadron cascade model.

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(PACIAE) model \cite{28}, etc. While for the light (anti-)nuclei production, the reasonable coalescence models based on the hadrons final states simulated within the above available models should be considered, such as the phase-space coalescence model \cite{27,29} and the statistical model \cite{31,32}, etc. For instance, the production of light nuclei was described theoretically in the nucleus-nucleus (A-A) collisions at relativistic collision energies by the nucleonic coalescence model + the blast-wave method \cite{33,34} or the coalescence model + a multiphase transport (AMPT) model \cite{35}.

In this paper, the production and the transverse momentum ($p_T$) of final state (anti-)hadrons ($\pi^+, \pi^-, p, \bar{p}$) are simulated by the PACIAE model \cite{28} in pp and Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV, respectively. And then the dynamically constrained phase-space coalescence (DCPC) model \cite{26} is applied to deal with the production and properties of light (anti-)nuclei ($d, \bar{d}$). Some previous satisfactory results of light (anti-)nuclei production for both pp and A-A collisions in the relativistic energy region, including transverse momentum distribution, energy dependence, scaling property, centrality dependence etc., were obtained by using this couple models \cite{25,26}. Here we will try using this mentioned method to investigate the properties of nuclear modification factors ($R_{\text{AA}}$) of (anti-)hadrons and (anti-)deuteron in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV.

The paper is organized as follows: In sect. II, we concisely introduce the PACIAE and DCPC model. In sec. III, our numerical calculation results of the $R_{\text{AA}}$ for (anti-)hadron and (anti-)deuteron are presented and compared with the available experimental data at LHC. In sec. IV, a brief conclusion is offered.

II. MODELS

The PACIAE model \cite{28} based on PYTHIA 6.4 \cite{36}, is designed and expanded to be feasible for p-p, p-A and A-A three different collision systems. In this model, the whole collision physics process can be mainly decomposed into four stages as follows:

Firstly, the partonic initial state forms. The nucleus -nucleus collision can be simplified into numerous nucleon-nucleon ($NN$) collisions according to the collision geometry and $NN$ total cross section. Each $NN$ collision is described by the PYTHIA model through the string fragmentation switches off and the (anti-)diquarks arbitrarily breaks into (anti-)quarks. And hence, one can obtain a partonic initial state of a $NN$ collision, which is consist of (anti-)quarks, and gluons. A partonic initial state of a nucleus-nucleus collision can be created when all $NN$ collisions are exhausted. This state is also considered as the quark-gluon matter (QGM) generated in heavy energy nucleus-nucleus collisions. Secondly, the parton rescattering proceeds. The partonic matter rescattering in QGM is dealt by the 2→2 LO-pQCD parton-parton cross sections \cite{42}. Here, a $K$ factor is added here to describe non-perturbative QCD and higher-order corrections. Thirdly, the hadronization happens. The partonic matter hadronization can be fulfilled through the Lund string fragmentation approach \cite{43} or the phenomenological coalescence method \cite{44}. Finally, the hadron rescattering conducts. The hadronic matter continues rescattering till the exhaustion of hadron-hadron collision pairs or the hadronic freeze-out. We can refer to \cite{28} for the detail.

Then the production of light (anti-)nuclei can be calculated with the DCPC model \cite{26} when the final state hadrons have already been provided by the PACIAE model. Due to the uncertainty principle $\Delta q \Delta p \geq \hbar^3$, one cannot simultaneously obtain the precise information both position $q \equiv (x, y, z)$ and momentum $p \equiv (p_x, p_y, p_z)$ for a particle in the six-dimension phase space, as the quantum statistical mechanics shown. Thus one can only deduce that this particle lies inside a quantum box in a six-dimension phase space or state with a phase-space volume of $\Delta q \Delta p$. Hence we can simulate the yield of a single particle using an integral:

$$Y_1 = \int_{E \leq H} \frac{d^3q d^3p}{h^3},$$

where $H$ and $E$ denote the Hamiltonian and energy of the particle, respectively. Analogously, one can compute the yield of the synthetic (anti-)nuclei containing N particles with the following integral:

$$Y_N = \int \ldots \int_{E \leq H} \frac{d^3q_1 d^3p_1 \ldots d^3q_N d^3p_N}{h^{3N}}.$$  \hspace{1cm} (3)

Note that, two constraint conditions have to be satisfied in this equation:

$$m_0 \leq m_{\text{inv}} \leq m_0 + \Delta m,$$ \hspace{1cm} (4)

$$|q_{ij}| \leq D_0, (i \neq j; i, j = 1, 2, \ldots, N)$$ \hspace{1cm} (5)

where

$$m_{\text{inv}} = \left[ \left( \sum_{i=1}^{N} E_i \right)^2 - \left( \sum_{i=1}^{N} \vec{p}_i \right)^2 \right]^{1/2},$$

and $E_i$, $\vec{p}_i$($i=1,2,\ldots,N$) represent the energy and momentum of one particle, respectively. $m_0$ and $\Delta m$ denote the rest mass of synthetic (anti-)nuclei and the allowed mass uncertainty. $D_0$ refers to diameter of (anti-)nuclei, and $|q_{ij}|$ stands for the vector distance from $i$ - $th$ and $j$ - $th$ particles. The integration in Eq. (3) should be replaced by the summation over discrete distributions, since the discreteness of position and momentum distributions of hadrons exists when simulated by this transport model.

III. RESULTS AND DISCUSSIONS

At first, we can obtain the final-state particles in pp and Pb-Pb collisions using the PACIAE model \cite{28}. In
As we all know, the transverse momentum ($p_T$) spectrum of charged particles and nuclei is a basic observable in heavy-ion collisions, which could give the original information of the hot, dense medium created in high-energy collision system. In Fig. 1 the $p_T$ spectra of $\pi$, $p$, $d$, and $\bar{d}$ (open squares) are reproduced for pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV calculated by PACIAE+DCPC model. Obviously, it can be seen from Fig. 1 that the transverse momentum ($p_T$) distributions of these hadrons ($\pi$, $p$, $d$) and (anti-)deuteron ($d$, $\bar{d}$) computed by PACIAE+DCPC model are well consistent with the ALICE data within uncertainties.

Similarly, to better compare with the experiment data, Fig. 2 shows the transverse momentum ($p_T$) spectra of $\pi$, $p$, $d$ (open symbols) in different centrality Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV calculated by PACIAE+DCPC model. Fig. 2(a) shows the $p_T$ distributions of $\pi$ (0-5%), $p$ (0-5%), $d$ (0-10%) in most central bins; Fig. 2(b) displays the $p_T$ distributions of $\pi$ (40-50%), $p$ (40-50%), $d$ (40-60%) in peripheral centrality bins. And the solid symbols are the ALICE experiment data. One can see from Fig. 2 that for $p_T < 3.0$ GeV/c, a hardening of the spectra exist going from peripheral to central events, and there is mass dependent effect, as discussed in Ref. [1, 6]. And both in most central and peripheral collisions, the $p_T$ distribution of $\pi$ meson are compatible with the experiment data, and the results of $p$ and $d$ in high $p_T$ distribution region are relatively good when compared with ALICE data. The reason caused this situation is $\pi$ meson occupies most of hadrons in heavy-ion collisions, the $p_T$ distribution of $\pi$ meson is more easier to reproduce than that of $p$ and $d$ in theoretical model.

In the following, to study jet quenching at high $p_T$ in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, the nuclear modification factor ($R_{AA}$), as Eq. (1) shows, for charged $\pi$, $p$ and $d$ are calculated by PACIAE+DCPC model in different centrality bins, as a function of $p_T$, shown in Fig. 3. The Fig. 3(a) to (c), show the distribution of ratios $R_{AA}$ for the particles $\pi^+$, $p$, $d$ and compared their corresponding antimatter $\pi^-$, $\bar{p}$, $\bar{d}$, respectively. The Fig. 3(d) to (f), show the distribution of ratios $R_{AA}$ for particles $\pi^+ + \pi^-$, $p + \bar{p}$, $d + \bar{d}$. From Fig. 3 one can seen that the distribution of the nuclear modification factor $R_{AA}$ for all the different particles and different centrality increases with the increase of $p_T$, reaches a peak, and then decreases with the increase of $p_T$, indicating that $R_{AA}$ for the meson and baryons, as well as nuclei, all have a strong suppressed effect in the region of high transverse momentum (about $p_T = 6.0$ GeV/c). And the yield in the central collision events are more suppressed than that in peripheral collision events, this is because the medium through which the particles pass, QGP, has a larger volume with a higher centrality, leading to a stronger quenching effect. Next, we can see from Fig. 3(a) to (c) that the $R_{AA}$ distribution for antihadrons and antinuclei are the same.
FIG. 2: The transverse momentum ($p_T$) distributions of $\pi^+$, $p$, and $d$ are presented in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in most central (left panel) and peripheral central (right panel) bins, respectively. (a) 0-5% centrality for $\pi^+$, $p$ and 0-10% centrality for $d$. (b) 40-50% centrality for $\pi^+$, $p$ and 40-60% for $d$. The open symbols are simulations of PACIAE+DCPC model, and the solid symbols show the ALICE data [3, 5–8]. The $\pi$ spectra are scaled by powers of 50 for visibility.

FIG. 3: The nuclear modification factor $R_{AA}$ for different particle species in most central (squares markers) and peripheral (circle markers) Pb-Pb collision events at $\sqrt{s_{NN}} = 2.76$ TeV, as a function of $p_T$. (a) For the charged pion $\pi^+$ and $\pi^-$, (d) For the $\pi^+ + \pi^-$, in centrality bins of 0-5% and 40-50% on the left panel; (b) For the $p$ and $\bar{p}$, (e) For the $p + \bar{p}$, in centrality bins of 0-5% and 40-50% on the middle panel; (c) For the $d$ and $\bar{d}$, (f) $d + \bar{d}$, in centrality bins of 0-10% and 40-60% on the right panel. Here, the open markers and solid markers are the results of PACIAE+DCPC model and the ALICE data [3, 5–8] respectively.
with that of corresponding hadrons and nuclei, showing that the suppression and quenching effect of matter and antimatter is the same in high energy Pb-Pb collisions. It is worth noting, as shown in Fig. 3 (c) and (f), that the suppression and quenching effect of matter and antimatter is the same in high energy Pb-Pb collisions.

Considering the mass ordering and “baryon-vs-meson” effects between suppression of different species mentioned in the introduction, the ratios and the double ratios ($R_{AA}^D$) of proton to pion are discussed in pp collisions and Pb-Pb collisions for centrality bins of 0-5% and 40-50% as a function of $p_T$, shown in the Fig. 4 and Fig. 5 respectively. For the double ratio $R_{AA}^D$ of proton to pion, which is to quantify the similarity of the suppression, are defined as follows:

$$R_{AA}^D = \frac{R_{AA}^{p+\bar{p}}}{R_{AA}^{\pi^+ + \pi^-}}.$$  \hspace*{1cm} (7)

where $R_{AA}^{\pi^+ + \pi^-}$ and $R_{AA}^{p+\bar{p}}$ denote the $R_{AA}$ for the charged pion and proton, respectively. Similarly, to better illustrate the suppression situation on light (anti-)nuclei, we have also analogized and extended the define and analysis means of hadron level to nucleus level. Noting that here the (anti-)proton is regarded as the primary nuclei and the component of synthetic (anti-)nuclei.

In terms of $p_T$ spectra ratios, the ratios of proton to pion and deuteron to proton, expressed in terms of $p_T$, are respectively discussed by PACIAE+DCPC model in pp collisions and Pb-Pb collisions of the most central (0-5%) and peripheral (40-50%) centrality bins at $\sqrt{s_{NN}} = 2.76$ TeV. The Fig. 4 (a) and (b), display the ratio distributions of $p/\pi^+$ and $\bar{p}/\pi^-$ and $d/p$, $d/\bar{p}$ respectively. The ratio distributions of $p + \bar{p}/\pi^+ + \pi^-$ and $d + \bar{d}/p + \bar{p}$ are shown in Fig. 4 (c) and (d). From the left panel of Fig. 4, it can be seen that for the central

FIG. 4: The ratios of proton to pion and deuteron to proton as a function of $p_T$ in pp and the most central (0-5%) and peripheral (40-50%) Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, respectively. The ratios of proton to pion are shown on the left panel, including (a) $p(\bar{p})$ to $\pi^+(\pi^-)$ and (c) $p + \bar{p}$ to $\pi^+ + \pi^-$; The ratios of deuteron to proton are shown on the right panel, including (b) $d(\bar{d})$ to $p(\bar{p})$ and (d) $d + \bar{d}$ to $p + \bar{p}$. Here, ALICE data take from [3, 6].
and peripheral Pb-Pb collisions, the ratios of proton to pion start to increase, reach a maximum values at \( p_T \sim 3.0 \text{ GeV/c} \), and then decreases as \( p_T \) increases. While for deuteron to proton, a similar logarithmic distribution trend exists during 1.0 GeV/c < \( p_T < 6.0 \) GeV/c region and the values linearly increase with increasing \( p_T \), as shown in the right panel of Fig. 4. Moreover, as the Fig. 4(a) and (b) shows, the ratios of \( \bar{p}/\pi^- \) and \( d/\bar{p} \) behave as the same values and properties with that of corresponding ratios for \( p/\pi^+ \) and \( d/p \) in three collision systems, i.e., pp collisions, central and peripheral Pb-Pb collisions, respectively. And one can see that the ratios distribution trend of \( p+\bar{p}/\pi^+\pi^- \) and \( d+d/\bar{p}+\bar{p} \) from our simulation are in agreement with ALICE data, within the error range allowed.

As for double ratios \( R_{AA}^D \), Fig. 5 shows the \( R_{AA}^D \) of proton to pion and deuteron to proton, as a function of \( p_T \), by PACIAE+DCPC predictions in the most central (0-5%) and peripheral (40-50%) Pb-Pb collisions at \( \sqrt{s_{NN}} = 2.76 \) TeV, respectively. In Fig. 5 (a) and (b), the \( R_{AA}^D \) distributions of \( R_{AA}^p/R_{AA}^{\pi^+} \), \( R_{AA}^p/R_{AA}^{\pi^-} \), and \( R_{AA}^{\bar{p}}/R_{AA}^{\bar{p}} \), \( R_{AA}^{d}/R_{AA}^{d} \) are shown, respectively. The Fig. 5 (b) and (d), exhibit the distribution of \( R_{AA}^D \) for \( R_{AA}^{p+\bar{p}}/R_{AA}^{\pi^+\pi^-} \) and \( R_{AA}^{d+d}/R_{AA}^{p+p} \). From Fig. 5 we can see that the \( R_{AA}^D \) distributions for all different particles and different centrality classes increase, rise to a peak, and then decreases with the increase of \( p_T \). And compared Fig. 5(a),(c) with Fig. 5(b),(d) , we also can obtain that the \( R_{AA}^D \) differences of deuteron to proton are larger than that of proton to pion between the most central (0-5%) and peripheral centrality (40-50%). Besides, it is clear that, as shown in Fig. 5(a) and (b), the \( R_{AA}^D \) distribution varied as \( p_T \) for \( p \) to \( \pi^+ \) and \( d \) to \( p \) are the same as that of corresponding antimatter \( \bar{p} \) to \( \pi^- \) and \( d \) to \( \bar{p} \), which indicates that matter and corresponding antimatter have the same characteristics and performance. Meanwhile, from the Fig. 5(c) it can be seen that the \( R_{AA}^D \) distribution trend of \( R_{AA}^{p+\bar{p}}/R_{AA}^{\pi^+\pi^-} \) evaluated by our simulation is closed to that of the STAR results and ALICE data from Ref. 3 within the error range allowed.

Furthermore, since different from the pion and proton...
production, (anti-)deuteron can be synthesized by (anti-)proton and (anti-)neutron within coalescence model. The coalescence parameter $B_2$ plays an important role in depicting the difficulty properties of (anti-)deuteron production in high energy collisions. And we can obtain the coalescence parameter $B_2$ ($p_T$) for pp and Pb-Pb collisions, from the transverse momentum $p_T$ spectra shown in Fig. 1 and Fig. 2, which is inspected as follows [47]:

$$B_2(p_T) = \frac{1}{2} \frac{d^2N_{AA}}{dp_T dp_T dy} \left[ \frac{d^2N}{dp_T dp_T dy} \right]^2.$$

As one can see in Fig. 6 compared with the ALICE data [3, 4, 8], the distribution of coalescence parameter $B_2$ calculated by PACIAE+DCPC model is well dependent on the transverse momentum $p_T$ in pp collisions and Pb-Pb collisions of the most central (0-5%) and peripheral (40-50%) centrality bins, expect the values of centrality bin (0-5%), since both (anti-)proton and (anti-)deuteron spectra are slightly not well estimated in this situation. Hence aiming to get a good $B_2$ coalescence parameter, an improved result for the (anti-)proton and (anti-)deuteron spectrum should be supplied and those need further careful study.

### IV. CONCLUSION

In the paper, we have used the PACIAE+DCPC model to simulate pp and Pb-Pb collision events at a center-of-mass energy $\sqrt{s_{NN}} = 2.76$ TeV with $p_T < 6.0$ GeV/c.

First we obtain the transverse momentum ($p_T$) spectra of $\pi$, $p$, $d$ and $\bar{d}$ in pp collisions and $p_T$ spectra of $\pi$, $p$, $d$ in most central and peripheral Pb-Pb collisions, which are comparable with those measured in ALICE data.

And then the nuclear modification factor ($R_{AA}$) for charged $\pi^+$, $p$, $d$ and their corresponding antiparticles $\pi^-$, $\bar{p}$, $\bar{d}$, as well as the sum $\pi^+ + \pi^-$, $p + \bar{p}$, $d + \bar{d}$ in different centrality classes, as a function of $p_T$, are evaluated by PACIAE+DCPC model. We found that the distribution of the nuclear modification factor $R_{AA}$ for all the different particles and different centrality increases with $p_T$ increasing, reaches a peak, and then decreases with the increase of $p_T$, indicating that $R_{AA}$ for the meson and baryons, as well as nuclei, all have a strong suppressed effect in the region of high transverse momentum (about $p_T = 6.0$ GeV/c). And the yield in the central collision events are more suppressed than that in peripheral collision events. Next, we also found the $R_{AA}$ distribution for antihadrons and antimatter are the same with that of corresponding hadrons and nuclei, indicating that the suppression and quenching effect of matter and antimatter is the same in high energy Pb-Pb collisions. Besides, the suppression effect of quenching in the high transverse momentum region is more significant in nuclei than in meson and baryons. In addition, it is observed that the $R_{AA}$ results of the $\pi^+ + \pi^-$, $p + \bar{p}$, and $d + \bar{d}$ from our simulation are comparable to those of the ALICE data at $p_T < 3.0$ GeV/c and as $p_T > 3.0$ GeV/c, the trend of $R_{AA}$ of the $\pi^+ + \pi^-$, $p + \bar{p}$ from our simulation being suppressed is similar to that of the ALICE data.

Next, we further study the $p_T$ spectra ratios of proton to pion and deuteron to proton, including $p/\pi^+, \bar{p}/\pi^-$, and $d/p$, $\bar{d}/\bar{p}$, as well as $p + \bar{p}/\pi^+ + \pi^-$ and $d + \bar{d}/p + \bar{p}$, respectively. We found that in central and peripheral Pb-Pb collisions, the ratios of proton to pion start to increase, reach a maximum values at $p_T \sim 3.0$ GeV/c, and then decreases as $p_T$ increases. While for deuteron to proton, a similar logarithmic distribution trend exists as $p_T > 1.0$ GeV/c region and the values linearly increase with increasing $p_T$. Moreover, the ratios of $p/\pi^-$ and $d/\bar{p}$ behaves as the same with that of corresponding ratios for $p/\pi^+$ and $d/p$ in three collision systems.

Furthermore, the double ratios $R_{AA}^{D}$ of proton to pion and deuteron to proton, were also considered. The $R_{AA}^{D}$ distributions for all different particles and different centrality classes increase, rise to a peak, and then decreases with the increase of $p_T$. And the $R_{AA}^{D}$ differences of deuteron to proton are larger than that of proton to pion between the most central (0-5%) and peripheral centrality (40-50%). Besides, it is clear that the $R_{AA}^{D}$ distribution varied as $p_T$ for $p$ to $\pi^+$ and $d$ to $p$ are the same as that of corresponding antimatter $\bar{p}$ to $\pi^-$ and $d$ to $\bar{p}$. Meanwhile, the $R_{AA}^{D}$ distribution trend of $R_{AA}^{D, p/\pi^+ + \pi^-}$ evaluated by our simulation is closed to that of the STAR results and ALICE data within uncertainties.

Last, the coalescence parameter $B_2$ ($p_T$) of $d(\bar{d})$ are also discussed. Compared with the ALICE data, our PACIAE+DCPC simulation in pp and the most central
(0-5%) and peripheral (40-50%) Pb-Pb collisions reproduces the measured dependence of the coalescence parameter $B_2$ coalescence parameter on transverse momentum $p_T$ rather well, expect the values for 0-5% centrality bin. According to the above results by PACIAE+DCPC simulation, it is noting that an improved result for the proton and deuteron transverse momentum $p_T$ spectra in high $p_T$ region should be supplied and those need further careful study in pp and Pb-Pb collisions.

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