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The production of $b\bar{b}$ dijet in heavy-ion collisions at the LHC

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We report our recent theoretical calculations for $b\bar{b}$ dijet production in high-energy nuclear collisions. The NLO+parton shower (PS) event generator SHERPA has been employed to provide the pp baseline of $b\bar{b}$ dijet production. A framework which combines the Langevin transport equation to describe the evolution of heavy quarks and the higher-twist scheme to consider the inelastic energy loss of both light and heavy partons has been implemented. Within this framework, we present the theoretical results for the transverse momentum imbalance $x_J = p_{T2}/p_{T1}$ both for inclusive dijets and $b\bar{b}$ dijets in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The energy loss of b-jets is expected to shift x_J to smaller values relative to the pp reference which is consistent with the CMS data. In addition, we show the medium modification for angular correlation of $b\bar{b}$ dijets in A+A collisions at $\sqrt{s_{NN}} = 5.02$ TeV. We observe a stronger suppression in the small $\Delta\phi = |\phi_{b1} - \phi_{b2}|$ region where the gluon splitting processes dominate relative to the large $\Delta\phi$ region. The difference leads to a modest suppression on the near-side ($\Delta\phi \sim 0$) and enhancement on the away-side ($\Delta\phi \sim \pi$).

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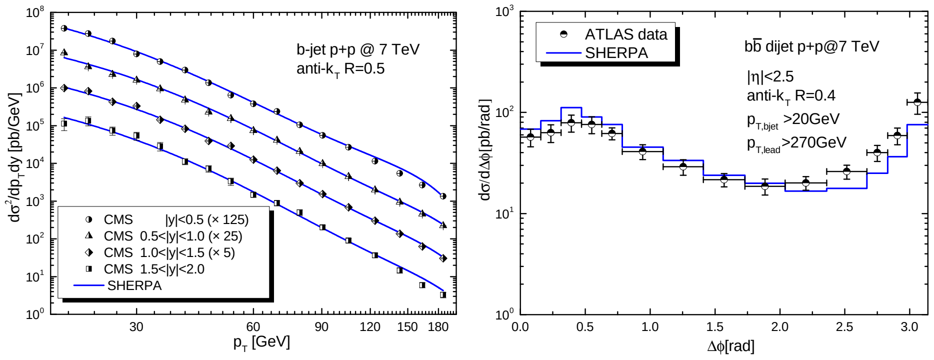
1. Introduction

The “jet quenching” effect has been proposed as a good probe to study the properties of the quark-gluon plasma (QGP) in ultrarelativistic heavy-ion collisions (HIC) [1]. Because of the large mass of the b quark, the $b\bar{b}$ dijet is a nice channel to test the flavour dependence of jet quenching. Heavy flavour production could be categorized into three mechanisms [2]: flavour creation (FCR), flavour excitation (FEX) and gluon splitting (GSP). To describe $b\bar{b}$ dijets in p+p collision succesfully, especially considering its azimuthal angular correlation, a next-to-leading order (NLO) matched parton shower (PS) event generator is required for Monte Carlo simulation [3, 4]. Furthermore, to study the observables of heavy-flavoured jets, it is still a challenge to simultaneously describe both heavy and light partons inside the jets in the same framework. In this article, we will present our latest results for the p_T imbalance and angular correlations of $b\bar{b}$ dijet [3] in p+p and Pb+Pb collisions as well as the comparison with the recent CMS data [5].

2. p+p baseline

In our work, the NLO+PS Monte Carlo event generator SHERPA [6] has been employed to provide the pp baseline for the productions of inclusive b-jets and $b\bar{b}$ dijets. The NLO parton distribution functions with 5-flavour scheme sets [7] have been chosen. FASTJET [8] with anti-k_T algorithm has been used for jet reconstruction. We find that SHERPA provides a good description of the experimental data in pp collisions measured by the CMS [9] and ATLAS [10] collaborations, as shown in Fig. 1.



(a) (b)

Figure 1: (a): Differential cross section of inclusive b-jet production as a function of jet transverse momentum at $\sqrt{s} = 7$ TeV obtained from SHERPA simulations and the comparison with CMS data. (b): Differential cross section of $b\bar{b}$ dijet production as a function of $\Delta\phi = |\phi_{b1} - \phi_{b2}|$ at $\sqrt{s} = 7$ TeV obtained from SHERPA simulations and the comparison with ATLAS data.

3. Framework of in-medium parton energy loss

To describe the propagation and energy loss of heavy quarks in the QGP, in our simulations, the modified discrete Langevin equations have been used [11],

$$\vec{x}(t+\Delta t) = \vec{x}(t) + \frac{\vec{p}(t)}{E}\Delta t \tag{1}$$

$$\vec{p}(t+\Delta t) = \vec{p}(t) - \Gamma\vec{p}\Delta t + \vec{\xi}(t) - \vec{p}_g \tag{2}$$

According to the fluctuation-dissipation theorem, the relationship between the drag coefficient Γ and diffusion coefficient κ can be expressed as $\kappa = 2ET\Gamma = \frac{2T^2}{D_s}$, where D_s denoting the spatial diffusion coefficient has been fixed at $2\pi TD_s = 4$ from the Lattice QCD calculation. The Hard-Thermal Loop result for the elastic energy loss of light partons [12] has also been considered. The last term in Eq.(2) represents the modification due to the medium-induced gluon radiation based on the higher-twist scheme [13, 14, 15, 16, 17]:

$$\frac{dN}{dxdk_\perp^2 dt} = \frac{2\alpha_s C_s P(x)\hat{q}}{\pi k_\perp^4}\sin^2\left(\frac{t-t_i}{2\tau_f}\right)\left(\frac{k_\perp^2}{k_\perp^2+x^2M^2}\right)^4 \tag{3}$$

4. Transverse momentum imbalance and angular correlation

We show the theoretical results for the medium modification of transverse momentum imbalance of $b\bar{b}$ dijets in central $(0-10\%)$ and periperal $(30-100\%)$ Pb+Pb collision at $\sqrt{s_{NN}} = 5.02$ TeV and compare them with the recent CMS data [5] in Fig. 2. Relative to the pp reference, the jet quenching effect shifts the normalized x_J distribution to smaller values which is consistent with the experimental data. Moreover, the shift is not visible in the peripheral Pb+Pb collisions because the $b\bar{b}$ dijets suffer from a much smaller energy loss.

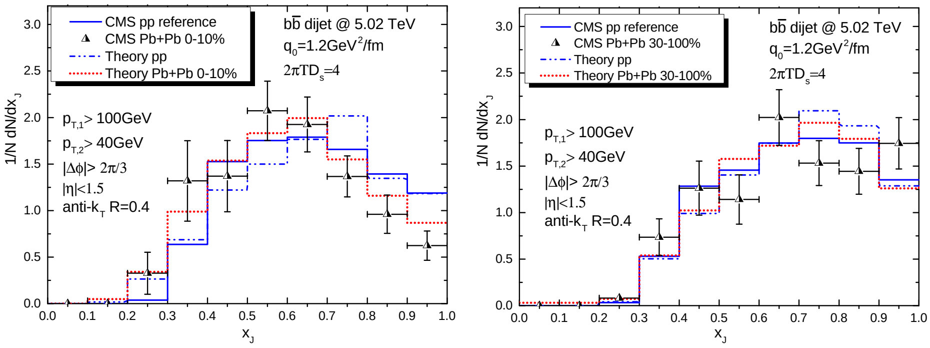


Figure 2: Normalized x_J distribution of $b\bar{b}$ dijets in (left) $0-10\%$, (right) $30-100\%$ Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ *TeV* compared with the experimental data [5] and their pp references respectively.

We also plot the averaged x_J distribution as a function of the number of participant both for inclusive dijet and $b\bar{b}$ dijet production in Pb+Pb collisions in Fig. 3. Even though the smearing treatment decreases the $\langle x_J \rangle$ with increasing centrality, the reduction of $\langle x_J \rangle$ caused by jet in-medium energy loss is clearly visible for both inclusive dijet and $b\bar{b}$ dijet production in the central Pb+Pb collisions. Furthermore, we also notice that, in peripheral Pb+Pb collisions, the reduction of $b\bar{b}$ dijets $\langle x_J \rangle$ relative to its pp reference is smaller than the one for inclusive dijets.

Since the azimuthal angle distribution in the small $\Delta\phi$ region is dominated by the gluon splitting processes while in the large $\Delta\phi$ region it is dominated by the flavour creation processes, it is

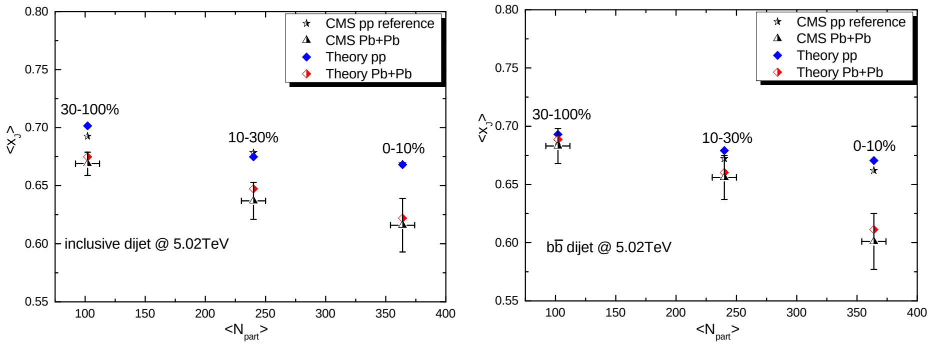
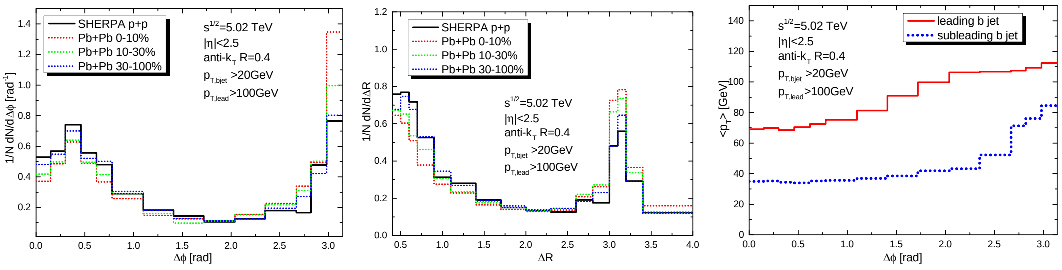


Figure 3: Simulated averaged x_J of inclusive dijets (left) and $b\bar{b}$ dijets (right) as a function of the number of participants in p+p and Pb+Pb collisions compared with the pp reference and experimental data [5] in Pb+Pb collisions respectively .



(a)

(b)

(c)

Figure 4: (a) Normalized azimuthal angle distribution of $b\bar{b}$ dijets in p+p and Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. (b) Normalized angular distance distribution of $b\bar{b}$ dijets in p+p and Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. (c) The averaged p_T distribution of leading and subleading b-jets as a function of their azimuthal angle difference.

useful to study the medium modification of the angular distribution between the two b jets. We present our predictions for the medium modification of the azimuthal angle distribution of $b\bar{b}$ dijets in Pb+Pb collisions in Fig. 4(a). Our simulations show that the jet quenching effect would suppresses the peak in small angle region but also enhances the away-side peak in this normalized $\Delta\phi$ distribution. Actually, an overall suppression of $b\bar{b}$ dijet production suffered both on the near-side and the away-side, but the stronger suppression on the near-side leads to a relative enhancement on the away-side because the distribution is normalized. We also give the calculated result of the medium modification for the angular distance distribution of $b\bar{b}$ dijets, shown in Fig. 4(b), where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. A very similar trend as that in the $\Delta\phi$ distribution is observed: suppression in the small ΔR region and enhancement in the large ΔR region. To find out why a stronger suppression suffered on the near-side, we estimate the averaged transverse momentum distribution of the leading and subleading b jet in the $b\bar{b}$ dijets as a function of their azimuthal angle difference shown in Fig. 4(c). We observe that the $\langle p_T \rangle$ in the small $\Delta\phi$ region is lower than those in large $\Delta\phi$ region both for the leading and subleading b jet. It indicates that b jets produced by gluon splitting processes are "softer" than that produced by flavour creation processes. Consequently the in-medium energy loss more easily shifts the lower p_T b-jets to a smaller value which is below the threshold given by the kinematic cut. This is the reason why a stronger suppression is observed in the small $\Delta\phi$ and ΔR region of $b\bar{b}$ dijets.

5. Summary

A Monte Carlo simulation which combines the NLO+PS event generator SHERPA for the pp baseline and the Langevin transport equation including higher-twist gluon radiation to simultaneously describe the in-medium energy loss for both light and heavy partons has been implemented. We show the first theoretical results of transverse momentum imbalance for $b\bar{b}$ dijets in Pb+Pb collisions and compare them with recent CMS data. We find an increasing p_T imbalance due to in-medium jet energy loss relative to the pp reference which is consistent with the experimental data. Furthermore, we give the first prediction for the angular correlation of $b\bar{b}$ dijets in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Since the b-jets produced in gluon splitting processes have on average a lower p_T relative to that produced in flavour creation processes, the stronger suppression suffered on the near-side ($\Delta\phi \sim 0$) relative to that on the away-side ($\Delta\phi \sim \pi$) is predicted by our simulations.

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