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 ($\Delta \phi \sim \pi$).
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 successfully, 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.

![Figure 1:](image)

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 $\Delta\phi = |\phi_1 - \phi_2|$ 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],

\[
\bar{x}(t + \Delta t) = \bar{x}(t) + \frac{\bar{p}(t)}{E} \Delta t
\]

\[
\bar{p}(t + \Delta t) = \bar{p}(t) - \Gamma \bar{p} \Delta t + \bar{\xi}(t) - \bar{\rho}_g
\]

According to the fluctuation-dissipation theorem, the relationship between the drag coefficient \(\Gamma\) and diffusion coefficient \(\kappa\) 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]:

\[
\frac{dN}{dxdk_\perp^2 dt} = \frac{2\alpha_s C_F P(x) q}{\pi k_\perp^4} \sin^2 \left( \frac{t - t_1}{2\tau_f} \right) \frac{k_\perp^2}{k_\perp^2 + x^2 M_f^2}^4
\]

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 peripheral (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](image-url)

**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
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 $\Delta R$ region and enhancement in the large $\Delta R$ 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 $\Delta R$ region of $b\bar{b}$ dijets.
The production of $b\bar{b}$ dijet in heavy-ion collisions at the LHC

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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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References