Search for a Ridge Structure Origin with Shower Broadening and Jet Quenching

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Abstract. We investigate the role of jet and shower parton broadening by the strong colour field in the $\Delta\eta$-$\Delta\phi$ correlation of high p_T particles. When anisotropic momentum broadening ($\Delta p_z > \Delta p_T$) is given to jet and shower partons in the initial stage, a ridge-like structure is found to appear in the two hadron correlation. The ratio of the peak to the pedestal yield is overestimated.

1. Introduction

RHIC experiments have offered us rich information on hot and dense matter. One of the most surprising phenomena may be the ridge structure observed in the $\Delta\eta$-$\Delta\phi$ correlation [1]. Two high p_T particles are found to have a base-like (pedestal) correlation elongated in the $\Delta\eta$ direction in addition to the normal jet peak correlation having narrow $\Delta\eta$ and $\Delta\phi$ width. We cannot explain the ridge structure in a standard hadronisation mechanism, where high p_T hadrons are formed from jet fragmentation and correlated hadrons have similar rapidities to jet. Thus the ridge structure indicates the correlation between a jet and other particles, which form high p_T hadrons. Furthermore, the correlation should be generated in the early stage, where two particles having a large rapidity gap are still spatially close.

There are several proposals on the origin of the ridge structure [2, 3, 4, 5]. Here we concentrate on the momentum broadening from glasma [4, 5]. When two colour glass condensates (CGC) collide and the system created by such a collision goes to a thermal state (QGP), we expect the existence of strong colour field before thermalisation which we call glasma. As the system expands, colour field will decay and becomes weak at the time scale of $\tau \sim 1/Q_s$, where Q_s is the saturation scale. Due to instabilities of classical colour fields [5, 6], colour fields, however, may grow exponentially and would cause momentum broadening of jet and shower partons.

In this work, we investigate the effects of the momentum broadening in the early times on the *hadronic* $\Delta\eta$-$\Delta\phi$ correlation. For this purpose, we also consider later processes in the framework of the jet-fluid string (JFS) model [8], which treats energy loss of jet partons in the QGP phase, hadronisation through formation of a string from a jet parton and a parton in a fluid element at the surface of the QGP phase and decay of it.

2. Jet-Fluid String model with Initial Momentum Broadening

For the description of high p_T hadron production, we start from the JFS model [8], which explains various high p_T QGP signals, such as jet quenching, large elliptic flow at high p_T, and disappearance of the backward azimuthal angle correlation simultaneously. Momentum broadening is assumed to act on partons just after the jet production. In total, we take the following four stages into account. (1) **Jet production**: In the initial stage, hard processes create jet partons and several shower partons are emitted from them [9]. (2) **Momentum broadening**: Momentum distribution for these partons is largely broadened in the initial strong colour fields, namely glasma. (3) **Energy loss in QGP**: When a system reaches a thermal state, jet and shower partons propagate in QGP and lose their energy [10]. We describe space-time evolution of QGP fluids using full three dimensional ideal hydrodynamics [11]. (4) **Hadronisation**: In the final state, we assume that jet and shower partons form strings with fluid partons. High p_T hadrons are formed from the decay of these strings.

Broadening in glasma has the following characteristic features. Firstly, the momentum transfer in hard processes is much larger than the saturation scale, then the transverse interaction area is smaller than the typical domain size $1/Q_s^2$. Secondly, a colour force gives momentum kicks in opposite directions to partons having opposite colour charges. Thirdly, the field strength would be stronger in the longitudinal directions than in the transverse direction up to the time scale of $\tau \sim 1/Q_s$ [7, 5]. Therefore, we expect larger broadening in the p_z direction. The same conclusion was drawn under the assumption of random transversely polarized colour-magnetic fields [4]. Thus we model the broadening in glasma, as the opposite random Gaussian kick for the two end points in the case of a simple $q\bar{q}$ initial string, and the longitudinal kick width (Δp_z) is assumed to be larger than the transverse kick width (Δp_T).

3. Results

In Fig. 1, we show the two hadron azimuthal angle correlation calculated without (left) and with (right) broadening. We have adopted the momentum broadening widths $(\Delta p_z, \Delta p_T) = (10\ \mathrm{GeV}/c, 2.5\ \mathrm{GeV}/c)$ as a typical parameter set. We find that the backward peak disappears in both cases. Without broadening, the absolute yield of the near side correlation is underestimated. This may be a natural consequence of the missing pedestal part in the $\Delta\eta$-$\Delta\phi$ correlation. With momentum broadening,

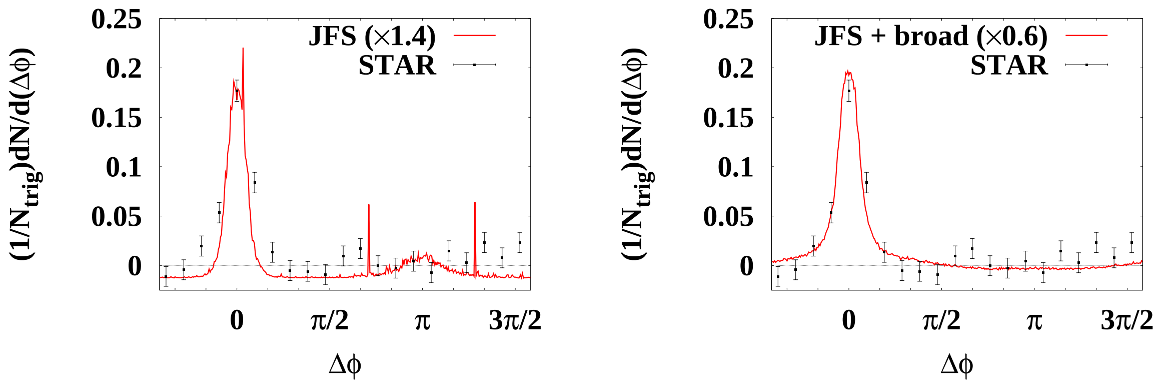

Figure 1. Azimuthal angle correlation in JFS without (left panel) and with (right panel) momentum broadening.

the near side peak has a little larger width and a larger yield compared with those without broadening. The enhanced yield mainly comes from shower partons. Shower partons generally have small p_T and most of them cannot make high p_T hadrons without momentum broadening, but they can survive in traversing QGP and make high p_T hadrons when the effect of transverse momentum broadening is enough.

In Fig. 2, we show the results of $\Delta\eta$-$\Delta\phi$ correlation without (left) and with (right) momentum broadening. JFS without momentum broadening does not show the ridge structure. While a jet-fluid string has two end points having different rapidities, the rapidity gap between the jet and fluid partons is not large and fluid partons have small p_T. As a result, all high p_T ($p_T > 2$ GeV/c) hadrons from JFS decay have similar rapidities to the jet parton. Whereas, a ridge-like structure appears when we implement momentum broadening. In this result, the peak and pedestal parts have different origins; hadrons in the peak are formed from the jet-fluid string fragmentation, but the pedestal part is constructed by the shower-fluid string fragmentation. From the calculated results with different parameter sets, we find that $\Delta p_z \gtrsim 5$ GeV/c and 2.5 GeV/$c \lesssim \Delta p_T < \Delta p_z$ is the condition for the ridge-like structure to appear, and is consistent with the estimate with instability [5]. It would be natural that large longitudinal broadening is preferred to make an elongated tail in the $\Delta\eta$ direction. It should be noted that transverse broadening is also necessary for shower partons to make high p_T hadrons, as discussed in $\Delta\phi$ correlation. But this Δp_T should not be too much to keep small $\Delta\phi$ width.

4. Summary

In this work, we have discussed the effects of momentum broadening before thermalisation as the origin of the ridge structure. This kind of broadening may be generated by the glasma. We have given the momentum broadening to the jet and shower partons in the pre-equilibrium stage, and evaluated the hadron correlation after

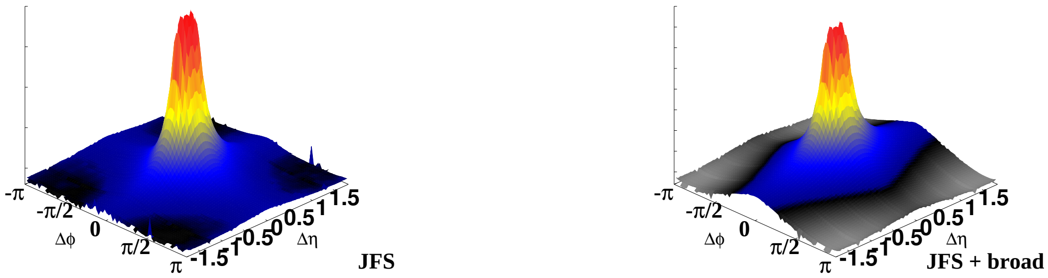

Figure 2. Calculated $\Delta\phi$-$\Delta\eta$ correlation without (left panel) and with (right panel) momentum broadening.

energy loss in QGP and hadronisation processes through string fragmentation. We have found that, if we have anisotropic momentum broadening, strings from jet and shower partons may make the ridge-like structure. Therefore, momentum broadening in glasma is a possible origin to create the ridge structure.

In this work, the momentum broadening strengths are taken as free parameters, which is independent from the position and momentum. This treatment corresponds to a constant colour electric field for one jet. In addition, the ratio of the peak to the base part in the ridge is too large. Further investigations in these directions are necessary for a deeper understanding of the ridge.

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References

[1] Adams J *et al* 2006 *J. Phys.* G **32** L37
[2] Shuryak E V 2007 *Phys. Rev.* C **76** 047901
[3] Wong C Y 2007 *Phys. Rev.* C **76** 054908
[4] Majumder A, Muller B and Bass S A 2007 *Phys. Rev. Lett.* **99** 042301
[5] Dumitru A, Nara Y, Schenke B and Strickland M 2007 arXiv:0710.1223 [hep-ph]
[6] Dumitru A, Nara Y and Strickland M 2007 *Phys. Rev.* D **75** 025016,
[7] Lappi T and McLerran L 2006 *Nucl. Phys.* A **772** 200
[8] Isse M, Hirano T, Mizukawa R, Ohnishi A, Yoshino K and Nara Y 2007 *Int. J. Mod. Phys.* E **16** 2338 [arXiv:nucl-th/0702068]
[9] Sjostrand T *et al.* 2001 *Comput. Phys. Commun.* **135** 238
[10] Gyulassy M, Levai P and Vitev I 2000 *Phys. Rev. Lett.* **85** 5535, *Nucl. Phys.* B **571** 197, Gyulassy M, Levai P and Vitev I 2001 *Nucl. Phys.* B **594** 371
[11] Hirano T and Nara Y 2003 *Phys. Rev. Lett.* **91** 082301, Hirano T and Nara Y 2004 *Phys. Rev.* C **69** 034908, Hirano T and Tsuda K 2002 *Phys. Rev.* C **66** 054905