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Leading-particle suppression and surface emission in nucleus–nucleus collisions

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Abstract. After a short summary of the predictions of the Parton Quenching Model (PQM) for the nuclear modification factor and its centrality dependence in Au–Au collisions at RHIC, we concentrate on back-to-back jet-like correlations at high transverse momentum. We illustrate how this probe is biased by the surface effect.

Keywords: heavy-ion collisions, jet quenching, model
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1. Introduction

The yield of high transverse-momentum ($p_{\rm t} \gtrsim 5$ GeV) leading particles in Au–Au collisions at the top RHIC energy, $\sqrt{s_{\rm NN}} = 200$ GeV, is about a factor of five lower than expected from the measurements in pp collisions at the same energy [1, 2]. Similarly, jet-like correlations on the azimuthally-opposite ('away') side of a high-$p_{\rm t}$ trigger particle are suppressed by a factor of four to five, while the near-side correlation strength is almost unchanged [3]. The absence of these effects in d–Au collisions at the same energy [4] supports the partonic energy loss scenario: energetic partons, produced in initial hard scattering processes, lose energy as a consequence of the final-state interaction with the dense partonic matter created in Au–Au collisions. The dominant contribution to the energy loss is believed to originate from medium-induced gluon radiation (see Ref. [5] and references therein).

The Parton Quenching Model (PQM) [6] combines the pQCD BDMPS-Z-SW framework for the probabilistic calculation of parton energy loss in extended partonic matter of given size and density [7] with a realistic description of the collision overlap geometry in a static medium. We treat partons (and parton pairs) on a parton-by-parton basis using Monte Carlo techniques. Details on the quenching procedure and its application to high-$p_{\rm t}$ data can be found in Ref. [6]. The model has one single free parameter that sets the scale of the medium transport coefficient $\hat{q}$, the average transverse momentum squared transferred to the hard parton per unit path length, and, thus, the scale of the energy loss. In this proceedings, we concentrate on the suppression phenomena, introduced above, and on the question to what extent the corresponding partonic probes penetrate the interior of the fireball.

2. Suppression of leading particles and jet-like two-particle correlations

Typically, the leading-particle suppression is quantified via the nuclear modification factor,

$$R_{\mathrm{AA}}(p_{\mathrm{t}},\eta) \equiv \frac{1}{\langle N_{\mathrm{coll}}\rangle_{\mathrm{centrality\ class}}} \times \frac{\mathrm{d}^2 N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{t}}\mathrm{d}\eta}{\mathrm{d}^2 N_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{t}}\mathrm{d}\eta}\,, \tag{1}$$

as the ratio of the yield in AA over the binary-scaled yield in pp for a given centrality class. At mid-rapidity, in Au–Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, R_{AA} is found to decrease from peripheral ($R_{\mathrm{AA}} \simeq 1$) to central events ($R_{\mathrm{AA}} \simeq 0.2$), for $p_{\mathrm{t}} \gtrsim 5$ GeV (see fig. 1).

Figure 1 shows the results of our calculation for R_{AA}. The single parameter of the model is chosen in order to match the suppression measured in 0–10% central Au–Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV [1, 2] leading to an average transport coefficient of about $\langle\hat{q}\rangle = 14\ \mathrm{GeV}^2/\mathrm{fm}$ in order to describe the data —where the average is done over all produced hard partons. For partons with initial $p_{\mathrm{t}} \simeq 10$ GeV, the mean energy loss per unit path length is as large as $\mathrm{d}E/\mathrm{d}x \simeq 2\ \mathrm{GeV}/\mathrm{fm}$. The probe interacts much stronger with the medium than expected on perturbative grounds [8]. This limits the sensitivity to $\hat{q}$ [8] and leads to *surface emission* [6, 9]: we find that surviving partons yielding hadrons with $p_{\mathrm{t}} > 5$ GeV are, on average, emitted from a depth of about 1.7 fm and suffer an energy loss of less than $0.3\ \mathrm{GeV}/\mathrm{fm}$.

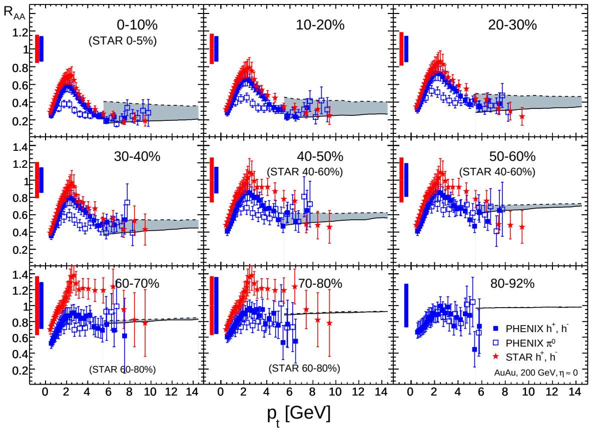

Fig. 1. $R_{\mathrm{AA}}(p_{\mathrm{t}})$ in Au–Au at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV for different centralities. Data are PHENIX charged hadrons and π^0 [2] and STAR charged hadrons [1] with combined statistical and p_{t}-dependent systematic errors (bars on the data points) and p_{t}-independent systematic errors (bars at $R_{\mathrm{AA}} = 1$). The model band is the original PQM calculation from Ref. [6].

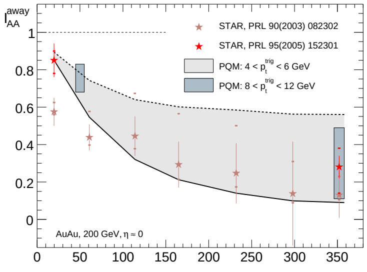

Fig. 2. $I_{\mathrm{AA}}^{\mathrm{away}}(N_{\mathrm{part}})$ in Au–Au at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. Data are for $4 < p_{\mathrm{t}}^{\mathrm{trig}} \leq 6$ GeV and $2\ \mathrm{GeV} \leq p_{\mathrm{t}}^{\mathrm{assoc}} \leq p_{\mathrm{t}}^{\mathrm{trig}}$ with statistical (bars) and systematic (ticks) errors [3]. PQM results for different p_{t} trigger ranges are shown.

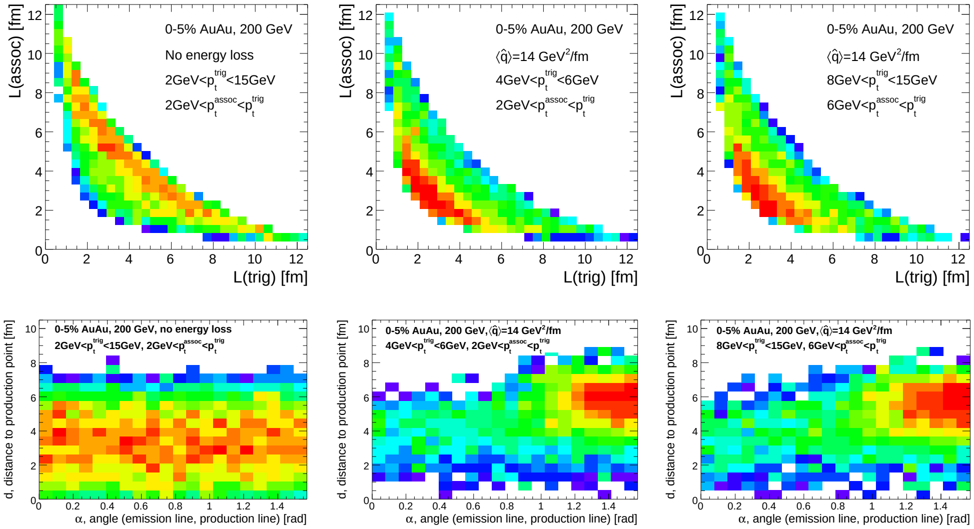

Fig. 3. (color online) Correlation of path-lengths (top) and emission phase-space — distance from the centre to production point and angle between emission direction and radial direction— (bottom) for surviving pairs of back-to-back partons for different conditions (no medium and $\langle\hat{q}\rangle = 14~\mathrm{GeV}^2/\mathrm{fm}$), yielding hadrons within the reported selection cuts in 0–5% central Au–Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV.

In light of this observation, it is interesting to consider the suppression of back-to-back jet-like two-particle correlations. The magnitude of the suppression is usually quantified by the factor $I_{\rm AA}^{\rm away} = D_{\rm AA}^{\rm away}/D_{\rm pp}^{\rm away}$, where the di-hadron correlation strength, $D_{\rm pp(AA)}^{\rm away}$, for an associated hadron, h_2, with $p_{\rm t,2}$ in the opposite azimuthal direction from a trigger hadron, h_1, with $p_{\rm t,1}$,

$$D^{\rm away}_{\rm pp(AA)} = \int_{p^{\rm trig}_{\rm t,min}}^{p^{\rm trig}_{\rm t,max}} {\rm d}p_{\rm t,1} \int_{p^{\rm assoc}_{\rm t,min}}^{p^{\rm assoc}_{\rm t,max}} {\rm d}p_{\rm t,2} \int_{\text{away side}} {\rm d}\Delta\phi \, \frac{{\rm d}^3\sigma^{h_1h_2}_{\rm pp(AA)}/{\rm d}p_{\rm t,1}{\rm d}p_{\rm t,2}{\rm d}\Delta\phi}{{\rm d}\sigma^{h_1}_{\rm pp(AA)}/{\rm d}p_{\rm t,1}}\,, \tag{2}$$

is integrated over the considered trigger- and associated- $p_{\rm t}$ intervals. Similarly to $R_{\rm AA}$, in Au–Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV, $I_{\rm AA}^{\rm away}$ is found to decrease with increasing centrality, down to about 0.2–0.3 for the most central events: see STAR data [3] for $4 < p_{\rm t}^{\rm trig} < 6$ GeV in fig. 2. In the figure we present the results of the PQM calculation for the parameter value needed to describe $R_{\rm AA}$. The result is consistent with the data, but it has a large uncertainty due to the procedure used to treat the cases in which the calculated energy loss is of the order of the parton initial energy. We show also our prediction for higher transverse momentum of the trigger particle, $8 < p_{\rm t}^{\rm trig} < 12$ GeV. It is consistent with preliminary STAR data [10] reporting $I_{\rm AA}^{\rm away} \simeq 0.25$, normalized to d–Au, for $8 < p_{\rm t}^{\rm trig} < 15$ GeV in 0–5% central collisions (data not shown in fig. 2).

In fig. 3 (top) we show the correlation of the two in-medium path lengths for parton pairs yielding hadrons within different $p_{\rm t}$ ranges (see figure). Without energy loss (left panel) the mean parton path length is about $4.5\ \mathrm{fm}$, while it reduces to about $3\ \mathrm{fm}$ for $\langle\hat{q}\rangle = 14\ \mathrm{GeV}^2/\mathrm{fm}$, both for low (central panel) and high (right panel) p_t cuts. Note that the 'banana' is symmetric: within our model, we find no strong difference in the thickness of traversed medium between the trigger and the recoil parton. This result is illustrated in the bottom panels of fig. 3, where we plot the correlation of the distance, d, from the centre of the overlap region to the pair production point with the azimuthal angle, α, between the emission direction and the radial direction. When energy loss is included, the back-to-back parton pairs that emerge are those produced *close to the medium surface* ($d \simeq 4$–$6\ \mathrm{fm}$) and with propagation direction *oriented tangentially* with respect to the medium ($\alpha \simeq \pi/2$).

For both sets of trigger cuts, the mean energy loss suffered by the surviving away-side partons is less than $0.3\ \mathrm{GeV/fm}$, which is similar to the the single inclusive case, and in agreement with the experimental observation of unmodified (relative to d–Au) hadron-triggered fragmentation functions [10]. In addition, we find no qualitative difference between the two sets of trigger cuts (central and right panels of fig. 3. This is compatible with the $I_\mathrm{AA}^\mathrm{away}$ values measured by STAR, which are similar in the two cases [3, 10].

3. Conclusions

We have discussed jet quenching effects at the top RHIC energy within the Parton Quenching Model, which combines energy loss calculations à la BDMPS and a Glauber-based implementation of the collision geometry. After tuning the single free parameter, the model describes (i) the p_t-independence of R_AA at high p_t, (ii) the centrality dependence of R_AA, and (iii) the magnitude and centrality dependence of the away-side suppression factor $I_\mathrm{AA}^\mathrm{away}$. Our analysis suggests that the production of high-p_t hadrons in central nucleus–nucleus collisions is surface-dominated, not only for single hadrons, but also for back-to-back di-jets.

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References

1. J. Adams *et al.*, STAR Coll., *Phys. Rev. Lett.* **91** (2003) 172302.
2. S.S. Adler *et al.*, PHENIX Coll., *Phys. Rev. Lett.* **91** (2003) 072301;
   S.S. Adler *et al.*, PHENIX Coll., *Phys. Rev.* **C69** (2004) 034910.
3. C. Adler *et al.*, STAR Coll., *Phys. Rev. Lett.* **90** (2003) 082302;
   C. Adler *et al.*, STAR Coll., *Phys. Rev. Lett.* **95** (2005) 152301.
4. J. Adams *et al.*, STAR Coll., *Phys. Rev. Lett.* **91** (2003) 072304;
   S.S. Adler *et al.*, PHENIX Coll., *ibidem* 072303.
5. C.A. Salgado, hep-ph/0510062; X.N. Wang, nucl-th/0511001.
6. A. Dainese, C. Loizides and G. Paić, *Eur. Phys. J.* **C38** (2005) 461.
7. C.A. Salgado and U.A. Wiedemann, *Phys. Rev.* **D68** (2003) 014008.
8. K.J. Eskola *et al.*, *Nucl Phys.* **A747** (2005) 511.
9. B. Müller, *Phys. Rev.* **C67** (2003) 061901.

10. D. Magestro (STAR Coll.), QM05 proceedings, nucl-ex/0510002.