On the Mean Parton Transverse Momentum versus Associated Hadron $p_t$ in Di-Hadron Correlations at RHIC and LHC

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Abstract

From Pythia simulations of pp collisions we determine the mean transverse momentum $\langle p_{\text{parton}}^t \rangle$ of partons producing the leading and associated particles studied in di-hadron correlations. The dependence of $\langle p_{\text{parton}}^t \rangle$ on the associated particle transverse momentum and expected differences at RHIC and LHC centre of mass energies are discussed.

1 Introduction

Azimuthal correlations of high-$p_t$ hadrons are used at RHIC to study the fragmentation properties of partons produced in $2 \rightarrow 2$ hard scatterings. The correlations are studied as a function of the transverse momentum of the trigger hadron $p_{\text{trig}}^t$ and the associated particle $p_{\text{assoc}}^t$ \cite{1,2}. The angular correlation functions show two characteristic approximately Gaussian peaks for hadrons produced from the fragmentation of the same parton that produced the trigger hadron (near-side) peak and from the fragmentation of the partons produced back-to-back approximately balancing the transverse momentum of the trigger parton (away-side peak). A strong suppression of the back-side peak in central Au+Au collisions relative to pp collisions has been observed and interpreted as evidence for in-medium partonic energy loss.

It has been demonstrated that due to the bias induced by the steeply falling production spectrum $d\sigma/dp_{\text{parton}}^t$, high-$p_t$ hadrons carry about $60-70\%$ of the original parton transverse momentum (see for example \cite{3}). Due to the steepness of the partonic fragmentation function $D(z)$ with $z = p_{\text{assoc}}^t/p_{\text{parton}}^t$, it can be expected that demanding the presence of an additional associated particle further increases the parton mean transverse momentum $\langle p_{\text{parton}}^t \rangle$ \cite{4}: for constant $p_{\text{assoc}}^t$, $z$ decreases with increasing $p_{\text{parton}}^t$. This effect should be stronger for the near-side associated hadrons, owing to the trivial fact that $p_{\text{parton}}^t$ can not be smaller than the sum $p_{\text{trig}}^t + p_{\text{assoc}}^t$. The on average higher $p_{\text{parton}}^t$ and the corresponding smaller production cross-section have to be taken...
in account when comparing near-side to away-side associated hadron $p_t$ spectra and widths of angular correlations.

In the next sections we show the results of Pythia simulations establishing the relation between $p_{t,\text{parton}}$ and the associated parton transverse momentum in the range $p_{t,\text{assoc}} > 0 - 8$ GeV for $p_{t,\text{trig}} > 8$ GeV at RHIC and LHC energies. The choice of cuts may allow to use these results for further interpretation of the di-hadron correlation data recently published by the STAR collaboration [5].

![Figure 1: Trigger normalised charged hadron fragmentation function $D(z_T)$ with $p_{t,\text{trig}} > 8$ GeV obtained from a Pythia simulation of pp collisions at $\sqrt{s} = 200$ GeV as described in the text. The simulation results are compared with the STAR d-Au data [5] (data values read from the figure).](image)

2 Method

Pythia 6.2 [6, 8] is used to simulate pp collisions at $\sqrt{s} = 200$ GeV and 5500 GeV (QCD processes, MSEL=1). The transverse momenta of all final state charged hadrons and the partons resulting from the hard $2 \rightarrow 2$ scattering process are recorded. We select the hadron with the highest $p_t$, $p_{t,\text{max}}$ within the pseudo rapidity window $|\eta| < 1$, the trigger hadron. If $p_{t,\text{max}} > p_{t,\text{trig}}$ the event is selected. Subsequently we identify the highest $p_{t,\text{assoc}}$ hadron within a distance $\Delta \phi < 0.63$ to the trigger hadron, the associated near-side hadron and within $|\Delta \phi - \pi| < 0.63$, the associated away-side hadron.

The associated parton transverse momentum is determined by identifying the parton emerging from the hard scattering closest in $\eta - \phi$ to the trigger particle. Alternatively we used the Pythia PYCELL cone jet reconstruction algorithm (with $R = 1$) to find the jet with the axis closest to the trigger hadron. Both methods give similar results. The average parton momentum $p_{t,\text{parton}}$ is determined for different ($p_{t,\text{trig}}$, $p_{t,\text{assoc}}$)-cuts.

As a benchmark for our simulations we show in Fig. 1 the $D(z_T)$ ($z_T = p_{t,\text{assoc}} / p_{t,\text{trig}}$) distributions for near-side and away-side correlated particles. The distributions agree very well with the STAR d-Au data [5].
3 Discussion of the results

Fig. 2 compares the parton spectra selected by $p_{t\text{trig}} > 8\text{ GeV, } p_{t\text{assoc}} > 0\text{ GeV}$ (solid line) to the one selected by $p_{t\text{trig}} > 8\text{ GeV, } p_{t\text{assoc}} > 2\text{ GeV. (dashed line, online:red).}$ The distribution corresponds to a statistics of $10^4$ triggers.

Fig. 3 shows $\langle p_{t\text{parton}} \rangle$ as a function of $p_{t\text{assoc}}$. $\langle p_{t\text{parton}} \rangle$ rises approximately linearly in the range $0 < p_{t\text{assoc}} < p_{t\text{trig}}$. At RHIC the difference in $\langle p_{t\text{parton}} \rangle$ for near-side and away-side associated partons reaches up to 30% at high $p_{t\text{assoc}}$. At LHC energies the difference is about a factor of 1.5 smaller and $\langle p_{t\text{parton}} \rangle$ is a factor of 1.5 higher. The difference is due to the different shape of the partonic production cross-section as a function of $p_{t\text{parton}}$: $d\sigma/dp_{t\text{parton}}$ follows a power law $1/(p_{t\text{parton}})^n$, where for parton energies considered here, $n \approx 8$ at RHIC and $\approx 4$ at LHC.

In a recent paper [5] the STAR collaboration reports on the direct observation of dijets in central Au+Au collisions at $\sqrt{s_{NN}} = 200\text{ GeV.}$ The transverse momentum distributions of near- and away-side associated hadrons is used to study the effect of the medium on dijet fragmentation. The authors emphasize that $D(z_T)$ is measurable without direct knowledge of the parton energy. Although this is true, one has to keep in mind when comparing near-side and
away-side associated hadrons, that $z_T$ covers different parton energy regions.

One directly observable effect is the kinematic suppression of the nearside peak seen in the STAR d-Au data. For increasing $p_{\text{assoc}}$, the amplitude of the near-side peak decreases relative to the away-side peak. The azimuthal correlation functions for $p_{\text{trig}} > 8 \text{ GeV}$ and $p_{\text{assoc}} > 6 \text{ GeV}$ as obtained from the Pythia simulations are shown in Fig. 4. Comparing the amplitude of the peaks at $\sqrt{s} = 200 \text{ GeV}$ to $\sqrt{s} = 5500 \text{ GeV}$ one observes that the near-side peak rises by a factor of $\approx 7$, whereas the away-side peak decreases by a factor of $\approx 1.3$.

The rise of the near-side peak is mainly due to the difference in the partonic production spectra for the two different energies. Since the difference between near-side and away-side $\langle p_{\text{parton}}^t \rangle$ is smaller at LHC the rise of the away-side peak due to the same effect is smaller. In addition, there are at least two effects that are expected to lead to the suppression of the away-side peak at LHC energies relative to RHIC.

- Broadening of the pseudorapidity correlations due to the smaller Bjorken $x_B \sim 1/\sqrt{s}$ leads to a reduction by a factor of 2.4 for $|\eta| < 1$.
- Broadening of the azimuthal correlations due to the increased contribution from higher order QCD processes. The width of the away-side peak is by a factor of two larger at LHC energies.

Figure 3: Average parton transverse momentum ($p_{\text{parton}}^t$) as a function of the associated hadron transverse momentum for $p_{\text{trig}} > 8 \text{ GeV}$ in pp collisions at $\sqrt{s} = 200 \text{ GeV}$ and $\sqrt{s} = 5500 \text{ GeV}$.
The increased nearside correlation at higher centre of mass energies can already be seen in data on charged particle correlations published by the CDF collaboration \[10\] for \(\sqrt{s} = 1800\) GeV \(^1\).

The systematics of the ratios between near-side to away-side peaks for different \(p^\text{assoc}_T\) is obtained by comparing the corresponding fragmentation functions \(D(z_T)\) (Fig. 5).

4 Conclusions

From Pythia simulations of pp collisions at RHIC and LHC energies we have determined the mean transverse momentum \(\langle p^\text{parton}_T \rangle\) of partons fragmenting into a leading trigger hadron with transverse momentum \(p^\text{trig}_T\) and/or an associated hadron with transverse momentum \(p^\text{assoc}_T\) for \(p^\text{trig}_T > 8\) GeV and \(0 < p^\text{assoc}_T < p^\text{trig}_T\). For both, near-side and away-side correlations, \(p^\text{parton}_T\) depends not only on the \(p^\text{trig}_T\) but also strongly on the associated hadron \(p^\text{assoc}_T\). Due to the additional kinematic constraint \(p^\text{parton}_T > p^\text{trig}_T + p^\text{assoc}_T\), \(\langle p^\text{parton}_T \rangle\) is higher

\(^1\)In simulation, the forward-backward peak inversion between RHIC and LHC energies has first been remarked in a HIJING study \[2\]
Figure 5: Trigger normalised charged hadron fragmentation function $D(z_T)$ with $p_T^{\text{trig}} > 8$ GeV obtained from a Pythia simulation of $pp$ collisions at $\sqrt{s} = 200$ GeV (left) and $\sqrt{s} = 5500$ GeV (right).

for near-side correlated hadrons than for away-side correlations. The difference amounts to up to 30% at RHIC and 20% at LHC.

The higher $\langle p_{\text{parton}} \rangle$ and the corresponding smaller production cross-section have to be taken in account when comparing near-side to away-side associated hadron transverse momentum spectra and widths of angular correlations. In particular, at LHC energies, where the partonic production cross-section $d\sigma/dp_{\text{parton}}$ is less steep than at RHIC energies, the near-side azimuthal correlation peak will be enhanced with respect to the one observed at RHIC.

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