Di-hadron correlations and parton intrinsic transverse momentum

George Fai[ab*], Gábor Papp[b†], and Péter Lévai[c‡]

[a]Center for Nuclear Research, Department of Physics,
Kent State University, Kent, OH 44242, USA

[b]Department of Theoretical Physics, Eötvös University,
Pázmány P. 1/A, Budapest H-1117, Hungary

[c]RMKI Research Institute for Particle and Nuclear Physics,
P.O. Box 49, Budapest H-1525, Hungary

The transverse momentum distribution of partons in the proton is studied with the help of di-hadron correlations. A simple randomization model is compared to the data.

1. INTRODUCTION

Di-hadron (and photon-hadron) correlations offer a statistical tool to study jets in the complicated final-state environment created in a relativistic collision of heavy nuclei. Other methods of examining jet properties are rendered ineffective here by total multiplicities in the thousands. Jets produced in hard partonic collisions are modified by the nuclear final state, and thus carry information on the hot and dense partonic medium they traverse[1]. The goal of jet tomography[2] is to extract the properties of the medium from an analysis of the modifications suffered by the produced jets.

However, jet structure and the associated di-hadron correlations have a rich content already in proton-proton collisions. The correlations appear, in general, as peaks in the di-hadron distribution as a function of two variables: the azimuthal difference $\Delta\Phi$ and e.g. rapidity difference Δy (equivalently, pseudorapidity or polar angle may be used). In this contribution we concentrate on the physics encoded in the widths of the near and away-side peaks of the di-hadron distribution as a function of $\Delta\Phi$ in proton-proton collisions. With midrapidity particle production in mind, the Δy dependence will be suppressed. In addition to its intrinsic interest relative to the transverse structure of the proton, this work can serve as a first step in providing the necessary background for di-hadron correlations in the collision of heavy nuclei. It is interesting to note that similar studies are carried out in proton-antiproton collisions at the Tevatron[3].

One experimental difficulty in connection with studying the transverse structure of the proton is that we seek to extract parton-level information from final-state hadrons. After

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separating initial and final-state effects, the initial-state information can be related to the intrinsic transverse momentum of partons in the proton. The history of efforts along these lines goes back to Feynman, Field and Fox on the theory side[4] and to the work of the CCOR collaboration experimentally[5], and has recently been summarized in Ref. [6].

2. CORRELATION SCENARIOS AND DEGREE OF RANDOMIZATION

The properties of the near-side peak relative to a trigger hadron in the di-hadron azimuthal distribution are determined by the fragmentation process. The deviation from a sharp back-to-back arrangement observed in the azimuth of the away-side hadrons contains information not only about fragmentation, but also about the transverse momentum of partons in the proton. We focus on this latter aspect in this contribution.

Let us take as our staring point transverse momentum conservation in a $2 \to 2$ partonic process as schematically pictured on the left-hand-side of Fig. 1. The initial partons have transverse momenta $\mathbf{k}_{T1}$ and $\mathbf{k}_{T2}$, while the secondary partons are characterized by transverse momenta $\mathbf{p}_{T1}$ and $\mathbf{p}_{T2}$, respectively, and $\mathbf{k}_{T1}+\mathbf{k}_{T2} = \mathbf{p}_{T1}+\mathbf{p}_{T2}$. This constraint results in a strongly correlated outgoing parton (and therefore jet) pair. Given the initial parton transverse momenta, and looking upon the outgoing transverse momentum $\mathbf{p}_{T1}$ as a"trigger", $\mathbf{p}_{T2}$ and all correlations are fully determined.

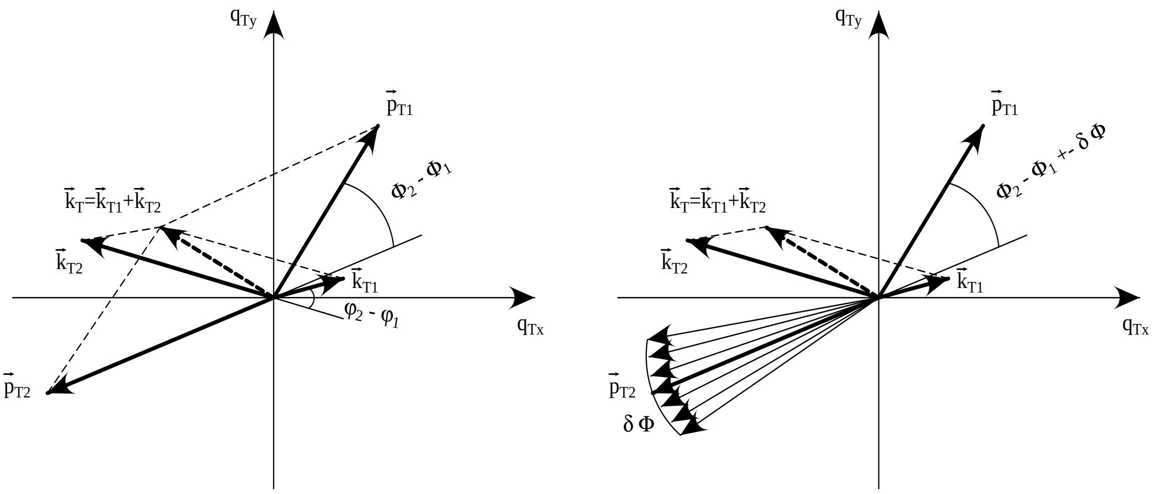

Figure 1. *Left:* strongly-correlated parton-pair production in a $2 \to 2$ reaction. *Right:* partially correlated parton-pair production where Φ_2 is randomized (see text).

If the transverse momentum distributions of the initial partons are two-dimensional Gaussians with width σ_k^2 in both protons, this strongly correlated ("sc") case yields

$$\langle (p_{T2}\sin(\Phi_2-\Phi_1))^2\rangle_{sc} = 2\cdot\sigma_k^2 \quad \text{and} \qquad \langle (p_{T2}\cos(\Phi_2-\Phi_1))^2\rangle_{sc} = p_{T1}^2 + 2\cdot\sigma_k^2 \ . \tag{1}$$

Thus, in a strongly correlated parton system the sinusoidal correlation directly displays the width of the intrinsic transverse momentum distribution without any dependence on other variables. This correlation is sought experimentally. However, there is no sterile

$2 \to 2$ process in real life, and the explicit transverse momentum conservation equation will contain the transverse momenta of all partons involved, weakening the correlations of the two final-state jet-initiating partons. We will describe this partially correlated situation by introducing a randomization of the transverse momentum $\mathbf{p}_{T2}$. Thus, for example, the azimuthal angle Φ_2 acquires a distribution around its strongly correlated value, determined by the dominant $2 \to 2$ collision as on the right-hand side of Fig. 1.

We examine two types of randomization in the transverse plane: (i) a one-dimensional Gaussian randomization in azimuth with width σ_Φ, and (ii) uniform randomization in the azimuth region $[\Phi_2 - \delta\Phi, \Phi_2 + \delta\Phi]$. We numerically evaluate the correlations (1) in the randomized (partially correlated, "pc") situation. To describe the deviation of these quantities from their strongly correlated values normalized by p_{T1}^2, we introduce dimensionless quantities α and β according to

$$\alpha \equiv 4\left[\langle (p_{T2}\sin(\Delta\Phi))^2\rangle - 2\sigma_k^2\right]/p_{T1}^2\,, \qquad \beta \equiv 4\left[\langle (p_{T2}\cos(\Delta\Phi))^2\rangle - 2\sigma_k^2\right]/p_{T1}^2\,, \tag{2}$$

where $\Delta\Phi = \Phi_2 - \Phi_1$. Fig. 2 displays our results as functions of σ_Φ (*solid lines*) and $\delta\Phi$ (*dashed lines*), respectively. The quantities α, β and γ (where γ is a suitable measure of the level of correlations) are independent of σ_k and p_{T1}. They depend only on σ_Φ and $\delta\Phi$, respectively. We see that the partially correlated system turns into a fully randomized one when $\sigma_\Phi = \pi/2$ or $\delta\Phi = \pi/2$, i.e. when the opening angle of the randomization cone becomes π. The shape of the curves slightly depends on the nature of the microscopic processes represented in our picture by the different randomization prescriptions.

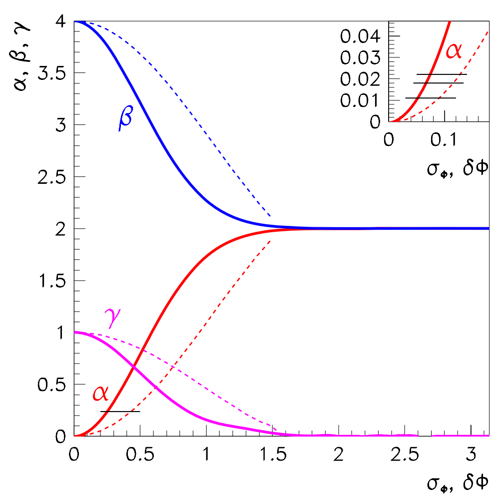

Figure 2. Parameters α, β and γ as functions of σ_Φ (*solid*) and $\delta\Phi$ (*dashed*). A horizontal line in the lower left indicates α in pp collisions at $\sqrt{s} = 200$ GeV. In the upper right a magnified view shows α at ISR energies.

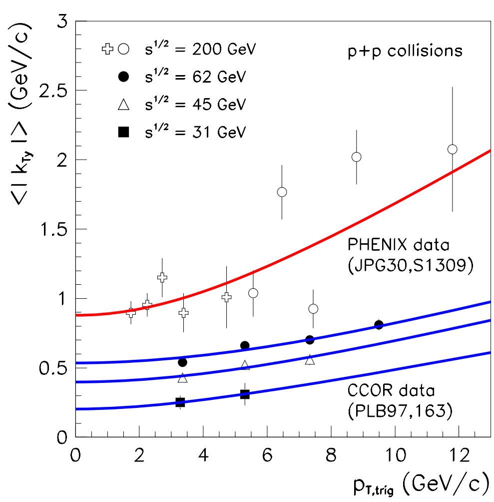

Figure 3. Data published for hadron-hadron correlations in pp collisions at ISR [5] and for parton-parton correlation at RHIC [7] together with the fit for a partially correlated parton system (see text).

3. COMPARISON TO DATA

Data on dijet correlations in pp collisions at $\sqrt{s} = 31,\ 45,\ 62$ GeV (ISR, [5]) and at $\sqrt{s} = 200$ GeV (RHIC, [7]), displayed in Fig. 3, show a dependence on the transverse momentum of the trigger hadron $p_{T,trig}$. In this contribution we disregard most of the complications associated with the hadronization of jets, and simply use the replacement $p_{T,trig} = z \cdot p_{T1}$ to take into account that the measured trigger hadron carries a fraction of the parton transverse momentum. Then, using (2) and the above replacement, the traditionally normalized width, $\langle |k_{Ty}| \rangle = \sqrt{(\langle (p_{T2} \sin(\Phi_2 - \Phi_1))^2 \rangle)/\pi}$ takes the form

$$\langle |k_{Ty}| \rangle_{pc} = \sqrt{\left[\alpha \cdot p^2_{T,trig} \,/\, (4z^2) + 2 \cdot \sigma_k^2\right] / \pi} \tag{3}$$

in the partially correlated case. Eq. (3) can be compared to data. At $\sqrt{s} = 200$ GeV, the fragmentation correction is $\langle z \rangle_{p_T > 3 \text{ GeV}} = 0.75 \pm 0.05$ [7]. For the ISR we use here an energy-independent average $\langle z \rangle \approx 0.85$ [5,7]. The energy dependence of z should be taken into account in a more detailed study. Together with the data, Fig. 3 shows our best fit with eq. (3). At $\sqrt{s} = 200$ GeV, the value of $2\,\sigma_k^2 = 2.42$ GeV^2, in good agreement with the value used earlier in a transverse-momentum augmented perturbative QCD calculation in pp collisions [8]. We obtain the width of the parton transverse momentum distribution by extrapolating the fit to $p_{T,trig} = 0$. The details of extracting the width from di-*hadron* correlations (as opposed to idealized di-parton correlations) are given elsewhere[9]. After considering the effects of fragmentation, we obtain the width of the parton transverse momentum distribution from the data (taking the limit $p_{T,trig} \to 0$) in terms of the widths of the near and away-side peaks (σ_N and σ_A, respectively) as

$$\langle |k_{Ty}| \rangle \equiv \sqrt{2\sigma_k^2/\pi} = \sqrt{\langle p^2_{T,assoc} \rangle (\sigma_A^2 - \sigma_N^2) \,/\, [\pi(1 - 2\,\sigma_N^2)]} \,/\, \langle z_{assoc} \rangle \ , \tag{4}$$

where $p_{T,assoc}$ and z_{assoc} are the transverse momentum and the momentum fraction of the associated particle. We propose an evaluation of data on near and away-side correlations in this manner. The denominator under the square root in (4) may be important numerically.

These considerations may be extended to e.g. d+Au and Au+Au collisions to determine the degree of randomization in those cases. Studying the variation with trigger momentum between p+p and d+Au collisions may provide an alternative way to distinguish initial and final state effects. Perturbative QCD calculations incorporating intrinsic transverse momentum will serve as a background to jet tomography studies.

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