CORRELATION STRUCTURES FROM SOFT AND SEMI-HARD COMPONENTS IN p–p COLLISIONS AT $\sqrt{s}$ =200 GeV*

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We present preliminary two-particle correlations for unidentified hadrons in p–p collisions at $\sqrt{s}$ =200 GeV. On two-particle transverse rapidity space $y_{\rm t} \otimes y_{\rm t}$ two distinct regions of correlated pairs are observed: a peaked structure at low $y_{\rm t}$ ($p_{\rm t} \leq 0.4$ GeV/c) and a broad structure at higher $y_{\rm t}$, where the correlation is distributed as a 2D Gaussian centered at $y_{\rm t1} = y_{\rm t2} \simeq 2.8$ ($p_{\rm t1}, p_{\rm t2} \simeq 1.2$ GeV/c). We select those regions separately, projecting correlations onto momentum-*difference* variables (η_Δ, ϕ_Δ), and observe structures interpretable in the context of string and parton fragmentations from soft and semi-hard components of p–p collisions.

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1. Introduction

In the two-component model of hadron–hadron collisions, final-state hadrons can be produced from a superposition of fragmentation processes: string fragmentation along the beam axis (soft) and fragmentation of transverse partons emitted from hard scatterings. Particle correlation measurements [1,2] have been an essential input to the evolution of particle-production descriptions [3]. We have studied two-particle correlations of uniden-

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tified hadrons from p–p collisions at $\sqrt{s}$=200 GeV with the STAR detector at RHIC to further explore those production mechanisms and to provide essential reference measurements for STAR's heavy ion program.

2. Correlation measurements

We measure two-particle correlations as difference distributions comparing *sibling* pairs from same events and mixed pairs from different but similar events: $\Delta\rho(x_1, x_2) = \rho_{\text{sibling}} - \rho_{\text{mixed}}$. Noting that a mixed reference is approximately the Cartesian product of marginal distributions $\rho(x)$ we construct a *per-hadron* correlation measure as the ratio $\Delta\rho/\sqrt{\rho_{\text{mixed}}}$ in which the denominator is the geometric mean of marginal products and measures a local single-particle density in a two-particle space. Conceptually, this quantity measures the correlation experienced by a *test* particle inserted into the system.

In this talk we present correlations on transverse rapidity ($x \to y_{\text{t}} \equiv \ln(\sqrt{1 + (p_{\text{t}}/m_\pi)^2} + (p_{\text{t}}/m_\pi)))$, motivated as a *velocity* variable (analogous to longitudinal rapidity) on which particle production from parton fragmentation along the jet thrust axis may have similar features with string fragmentation along the collision axis. We also show *autocorrelations* on difference variables, $\eta_\Delta \equiv \eta_1 - \eta_2$ and $\phi_\Delta \equiv \phi_1 - \phi_2$, on which structures associated with fragmentation processes have been previously observed.

The measurements are divided into four charge-pair combinations: like-sign (LS), unlike-sign (US), charge-independent (CI=LS+US), and charge-dependent (CD=LS−US). The event sample, about 10 million minimum-bias p–p collisions, is described elsewhere [4]. We require at least two unidentified hadron tracks in the STAR TPC originating from the primary vertex with $p_{\text{t}} \geq 0.15$ GeV/c, $-1.0 \leq \eta \leq 1.0$, and $-\pi \leq \phi \leq \pi$. We have applied dE/dx cuts to remove most of the electrons from the track sample.

3. Correlation structures on $y_{\text{t}} \otimes y_{\text{t}}$

Two-particle correlations distributed on $(y_{\text{t}1}, y_{\text{t}2})$ for all charge-pairs (CI) presented in figure 1 show two distinct structures: a narrow peak at low y_{t} (≤ 1.75) and a broad distribution centered at $y_{\text{t}1} = y_{\text{t}2} \simeq 2.8$ ($p_{\text{t}} \simeq 1.25$ GeV/c). The latter structure is well described by a $2D$ Gaussian, better characterized on the rotated space $y_{\text{t}\Sigma} \equiv y_{\text{t}1} + y_{\text{t}2}$ and $y_{\text{t}\Delta} \equiv y_{\text{t}1} - y_{\text{t}2}$ (diagonals of $y_{\text{t}1}, y_{\text{t}2}$), and centered at $y_{\text{t}\Sigma} \simeq 5.6$, $y_{\text{t}\Delta} = 0$. The two structures suggest a separation on $y_{\text{t}} \otimes y_{\text{t}}$ of correlations into soft and semi-hard components, thereby providing a cut space for projecting onto difference variables $(\eta_\Delta, \phi_\Delta)$.

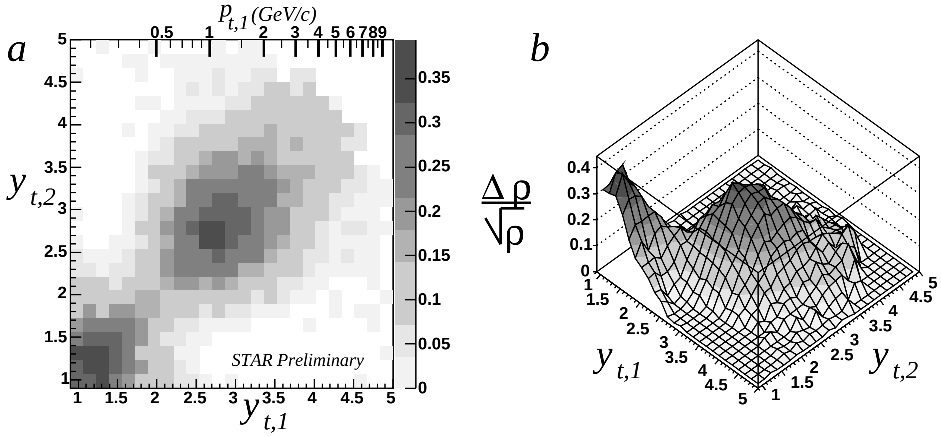

Fig. 1. Correlations, $\Delta\rho/\sqrt{\rho}$, on $y_{\rm t} \otimes y_{\rm t}$ for all charge-pairs (CI) shown as contour (a) and surface (b) plots for clarity.

From the low-$y_{\rm t}$ region of figure 1 the projected autocorrelations on $(\eta_\Delta, \phi_\Delta)$ are shown in figure 2 for LS, US, and CD charge-pairs. The plots reveal simple structures that are readily identified. The LS distribution consists mainly of a large $2D$ Gaussian peak centered at (0,0) and not present in the US distribution. This peak is attributed to Bose–Einstein (HBT) correlations which have been measured extensively in p–p collisions at similar energies [5]. The US distribution, with a very narrow peak at (0,0) from e^+e^- pairs produced by photon conversion in the detector, is dominated by a $1D$ Gaussian distribution on η_Δ. This structure is consistent with expectations from local charge conservation in longitudinally fragmenting strings, first measured more than twenty five years ago [6] and described in string fragmentation models such as the Lund model [3]. The amplitude of the Gaussian on η_Δ is suppressed at small ϕ_Δ due to the canonical constraint of momentum conservation in collisions producing fewer particles. That suppression disappears for larger-multiplicity collisions. We fit the CD distribution in figure 2 with a model function that includes a negative-amplitude Gaussian on η_Δ. We observed $\sigma_{\eta_\Delta} = 0.92 \pm 0.03 \pm 0.1(\text{sys})$, consistent with previous measurements [6]. This value is also in agreement with results [8] we obtain from the Pythia V6.131 Monte Carlo event generator [7].

To investigate the broader $2D$ Gaussian correlation on $y_{\rm t} \otimes y_{\rm t}$, we also evaluate autocorrelations on $(\eta_\Delta, \phi_\Delta)$. But in this case we find that the dominant structures are common to both LS and US charge-pair samples and therefore show CI distributions (figure 3) for selections on $(y_{\rm t1}, y_{\rm t2})$. The first plot (a) covers the entire region above $y_{\rm t1}, y_{\rm t2} \geq 2.1$ ($p_{\rm t1}, p_{\rm t2} \geq 0.6$ GeV$/c$) where we observe the correlations consist of a large peaked distri-

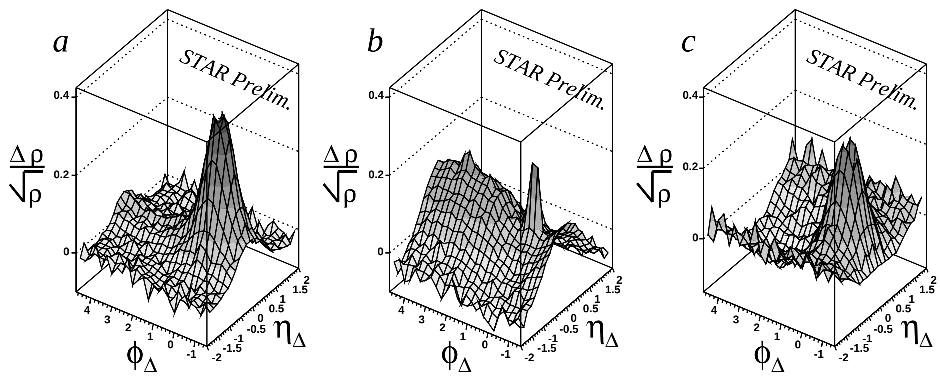

Fig. 2. Joint autocorrelations on $(\eta_\Delta, \phi_\Delta)$ for $y_{\rm t} \leq 1.75$ from LS (a), US (b), and CD (c) charge-pair combinations.

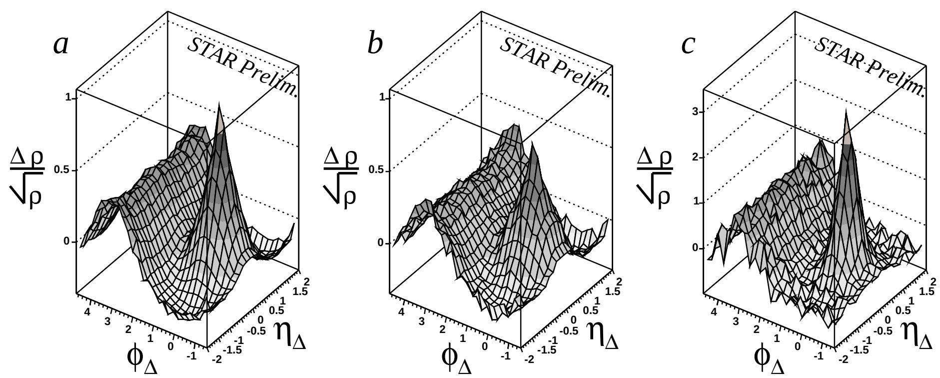

Fig. 3. Joint autocorrelations on $(\eta_\Delta, \phi_\Delta)$ for CI pair samples from $y_{\rm t} \geq 2.1$ (a), $y_{\rm t} = 2.5 \pm 0.25$ (b), and $y_{\rm t} = 3.5 \pm 0.25$ (c) selections.

bution at small opening angles and a broad η_Δ-independent structure at $\phi_\Delta = \pi$. Both of these structures are expected from semi-hard parton scattering resulting in back-to-back jet correlations [9]. The small-angle peak is due to particles from a single fragmenting parton, while $\phi_\Delta \simeq \pi$ correlations reflect momentum conservation in the original semi-hard parton scattering. Similar structures (but projected onto ϕ_Δ) previously reported by STAR [4] and associated with back-to-back jet phenomena were found with a technique in which high-$p_{\rm t}$ ($\geq$3-4 GeV/c) trigger particles are correlated with other high $p_{\rm t}$ (2 GeV/$c \leq p_{\rm t} \leq p_{\rm t,\,trigger}$) particles. The present analysis does not rely on such conditional selections to obtain jet-like correlations. The other two plots in figure 3 contain similar distributions selected from lower and higher regions of the $2D$ Gaussian on $(y_{\rm t1}, y_{\rm t2})$. We find that the three distributions differ mainly in their details and conclude that correlations over the entire region described by the $2D$ Gaussian distribution on $y_{\rm t} \otimes y_{\rm t}$ result from minimum-bias parton fragments: minijets.

The structures on $(\eta_\Delta, \phi_\Delta)$ in figure 3 are well described by a model function consisting of a $2D$ Gaussian about $(\eta_\Delta, \phi_\Delta) = (0, 0)$ and a $1D$ Gaussian on ϕ_Δ centered at $\phi_\Delta = \pi$ (plus a constant offset). Fits to these distributions for different slices of sum variable $y_{{\rm t}\Sigma}$ map the jet-like structures in terms of their widths and amplitudes and can be compared with results from both string/parton fragmentation models (such as from Pythia) and STAR heavy ion data.

4. Short- and long-range correlations on $y_{\rm t} \otimes y_{\rm t}$

In the previous section we presented autocorrelations on $(\eta_\Delta, \phi_\Delta)$ for different selections on $y_{\rm t} \otimes y_{\rm t}$. Additional details with respect to short- and long-range correlations are revealed by reversing this process, selecting specific angular separations and projecting onto $(y_{\rm t1}, y_{\rm t2})$. With respect to the transverse system, the *near-side* region $(-\pi/2 < \phi_\Delta < \pi/2)$ measures short-range correlations (SRC) in local parton fragmentation while the *away-side* region $(\phi_\Delta > \pi/2)$ reveals long-range correlations (LRC) from the original semi-hard parton scattering.

Figure 4 contains CI and CD correlations on $y_{\rm t} \otimes y_{\rm t}$ for pairs selected using the above *near-side* criterion. At low $y_{\rm t}$ both distributions are dominated by HBT (*cf.* figure 2(c)). Over the minimum-bias parton fragmentation (minijet) region at large $y_{\rm t}$ we observe a positive CI correlation and a negative CD correlation. This result is analogous to low-$y_{\rm t}$ autocorrelations in figure 2, where the positive correlation in the US distribution dominates over the LS sample (except where HBT is large) and produces a negative-

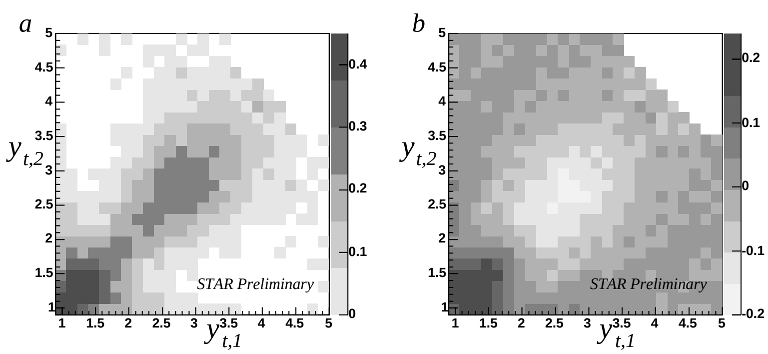

Fig. 4. Correlations on $y_{\rm t} \otimes y_{\rm t}$ selected for *near-side* pairs, $-\pi/2 \le \phi \le \pi/2$, for CI (a) and CD (b) charge-pair combinations.

amplitude Gaussian about $\eta_\Delta = 0$ in the CD result. We can take slices of the *near-side* CD distribution parallel to the $y_{t\Delta}$ (off-diagonal) axis and observe negative-amplitude Gaussians with widths approximately $\sigma_{y_{t,\Delta}} \simeq 1.0$. This result is in agreement with our width measurement, $\sigma_{\eta_\Delta} = 0.92$, along the collision axis. We therefore identify the CD *near-side* structure with local charge ordering (SRC) along the minijet thrust axis.

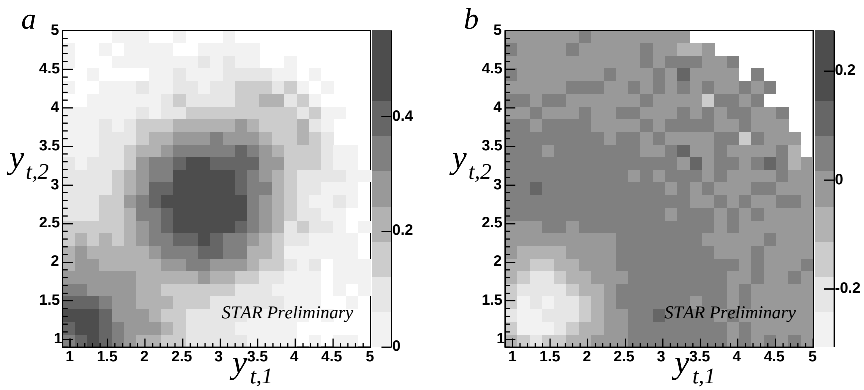

Fig. 5. Correlations on $y_1 \otimes y_t$ selected for *away-side* pairs, $\phi \geq \pi/2$, for CI (a) and CD (b) charge-pair combinations.

The CI and CD distributions selected for *away-side* pairs are shown in figure 5. The local charge conservation in the soft component is clearly visible at low-y_t in both panels. At larger y_t, we observe LRC due to momentum conservation in the CI distribution. As one might expect, the positive correlation in the *away-side* CI distribution is much broader than the corresponding *near-side* distribution of figure 4. We find negligible CD signal for the *away-side* selection over this y_t region, consistent with previous observations [10]. From this result we infer that charge conservation, local to the original semi-hard scattering, is not coupled between the oppositely moving partons and thus must be imposed between a scattered parton and the longitudinal system.

5. Summary

We have presented two-particle correlations in p–p collision at $\sqrt{s} = 200$ GeV. We observe structures clearly separated on $y_t \otimes y_t$ into soft and hard components. We are able to disentangle their sources by projections onto difference variables $(\eta_\Delta, \phi_\Delta)$. At low y_t we find evidence for longitudinal string fragmentation, with correlated US charged-pairs separated by about 1 unit in pseudorapidity due to constraints of local charge conservation. The structures at higher y_t are consistent with back-to-back jet phenomena over a large range of $p_{\rm t}$ down to $p_{\rm t} \simeq 0.5$ GeV/c. These correlations include a peaked structure at small angles where we find local charge conservation in the parton fragmentation process and an *away-side* structure about $\phi_\Delta = \pi$ indicative of momentum conservation from the original semi-hard parton scatter. In this analysis, we are able to connect the longitudinal and transverse momentum subspaces within a common conceptual framework, providing an essential reference for similar analyses of STAR heavy ion data [11].

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