# Measurement of Dijet Azimuthal Decorrelations at Central Rapidities in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$

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Correlations in the azimuthal angle between the two largest transverse momentum jets have been measured using the DØ detector in $p\bar{p}$ collisions at a center-of-mass energy $\sqrt{s} = 1.96\,\mathrm{TeV}$. The analysis is based on an inclusive dijet event sample in the central rapidity region corresponding to an integrated luminosity of $150\,\mathrm{pb}^{-1}$. Azimuthal correlations are stronger at larger transverse momenta. These are well-described in perturbative QCD at next-to-leading order in the strong coupling constant, except at large azimuthal differences where soft effects are significant.

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Multi-parton radiation is one of the more complex aspects of perturbative Quantum Chromodynamics (pQCD) and its theory and phenomenology are being actively studied for the physics programs at the Fermilab Tevatron Collider and the CERN LHC [1]. The proper description of radiative processes is crucial for a wide range of precision measurements as well as for searches for new physical phenomena where the influence of QCD radiation is unavoidable. A clean and simple way to study radiative processes is to examine their impact on angular distributions. Dijet production in hadron-hadron collisions, in the absence of radiative effects, results in two jets with equal transverse momenta with respect to the beam axis ($p_T$) and correlated azimuthal angles $\Delta\phi_{\,\mathrm{dijet}} = |\phi_{\mathrm{jet}\,1} - \phi_{\mathrm{jet}\,2}| = \pi$. Additional soft radiation causes small azimuthal decorrelations, whereas $\Delta\phi_{\,\mathrm{dijet}}$ significantly lower than $\pi$ is evidence of additional hard radiation with high $p_T$. Exclusive three-jet production populates $2\pi/3 < \Delta\phi_{\,\mathrm{dijet}} < \pi$ while smaller values of $\Delta\phi_{\,\mathrm{dijet}}$ require additional radiation such as a fourth jet in an event. Distributions in $\Delta\phi_{\,\mathrm{dijet}}$ provide an ideal testing ground for higher-order pQCD predictions without requiring the reconstruction of additional jets and offer a way to examine the transition between soft and hard QCD processes based on a single observable.

A new measurement of azimuthal decorrelations between jets produced at high $p_T$ in $p\bar{p}$ collisions is presented in this Letter. Jets are defined using an iterative seed-based cone algorithm (including mid-points) with radius $\mathcal{R}_{\mathrm{cone}} = 0.7$ [2]. The same jet algorithm is used for partons in the pQCD calculations, final-state particles in the Monte Carlo event generators, and reconstructed energy depositions in the experiment. $\Delta\phi_{\,\mathrm{dijet}}$ is reconstructed from the two jets with highest $p_T$ in an event. The observable is defined as the differential dijet cross section in $\Delta\phi_{\,\mathrm{dijet}}$, normalized by the dijet cross section integrated over $\Delta\phi_{\,\mathrm{dijet}}$ in the same phase space $(1/\sigma_{\mathrm{dijet}})\,(d\sigma_{\mathrm{dijet}}/d\Delta\phi_{\,\mathrm{dijet}})$. (Theoretical and experimental uncertainties are reduced in this construction.) Calculations of three-jet observables at next-to-leading order (NLO) in the strong coupling constant $\alpha_s$, have recently become available [3, 4]. Quantitative comparisons with data yield information on the validity of the pQCD description and increase sensitivity for gauging potential departures that could signal the presence of new physical phenomena.

Data were obtained with the DØ detector [5] in Run II of the Fermilab Tevatron Collider using $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$. The primary tool for jet detection was a compensating, finely segmented, liquid-argon and uranium calorimeter that provided nearly full solid-angle coverage. Calorimeter cells were grouped into projective towers focused on the nominal interaction point for trigger and reconstruction purposes. Events were acquired using multiple-stage inclusive-jet triggers. Four analysis regions were defined based on the jet with largest $p_T$ in

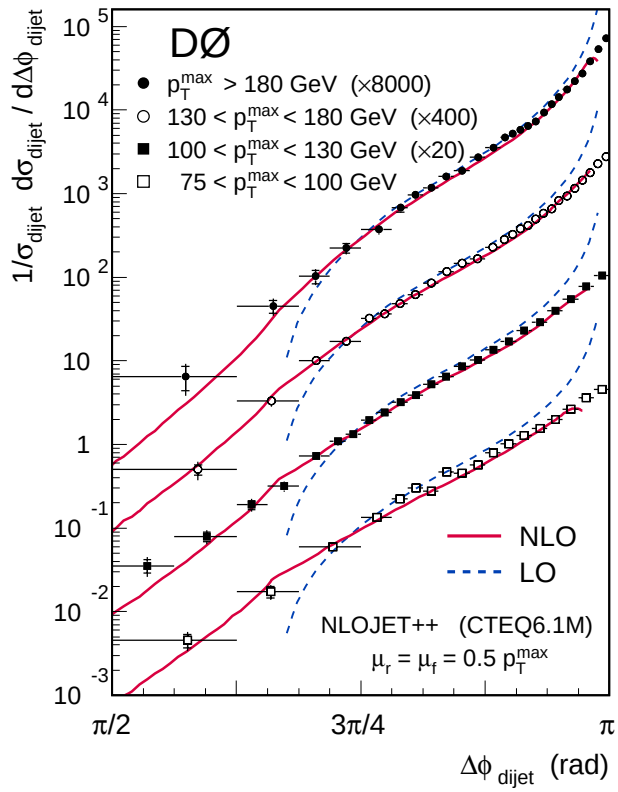


FIG. 1: The $\Delta\phi_{\,\mathrm{dijet}}$ distributions in four regions of $p_T^{\mathrm{max}}$. Data and predictions with $p_T^{\mathrm{max}} > 100\,\mathrm{GeV}$ are scaled by successive factors of 20 for purposes of presentation. The solid (dashed) lines show the NLO (LO) pQCD predictions.

an event ($p_T^{\mathrm{max}}$) with the requirement that the trigger efficiency be at least 99%. The accumulated integrated luminosities for events with $p_T^{\mathrm{max}} > 75$, 100, 130, and 180 GeV were 1.1, 21, 90, and $150\,\mathrm{pb}^{-1}$ ($\pm 6.5\%$), respectively. The second leading $p_T$ jet in each event was required to have $p_T > 40$ GeV and both jets were required to have central rapidities with $|y_{\mathrm{jet}}| < 0.5$ where $y_{\mathrm{jet}} = \frac{1}{2}\ln\left((E+p_z)/(E-p_z)\right)$ and $E$ and $p_z$ are the energy and the longitudinal momentum of the jet.

The position of the $p\bar{p}$ interaction was reconstructed using a tracking system consisting of silicon microstrip detectors and scintillating fibers located within a 2 T solenoidal magnet. The vertex $z$-position was required to be within 50 cm of the detector center which preserved the projective nature of the calorimeter towers. The systematic uncertainty associated with the vertex selection efficiency is less than 3% for $\Delta\phi_{\,\mathrm{dijet}} > 2\pi/3$ and $\approx 8\%$ for $\Delta\phi_{\,\mathrm{dijet}} \approx \pi/2$. The missing transverse energy was calculated from the vector sum of the individual transverse energies in calorimeter cells. Background from cosmic rays and incorrectly vertexed events was eliminated by requiring this missing transverse energy to be below $0.7\,p_T^{\mathrm{max}}$. Background introduced by electrons, photons, and detector noise that mimicked jets was eliminated

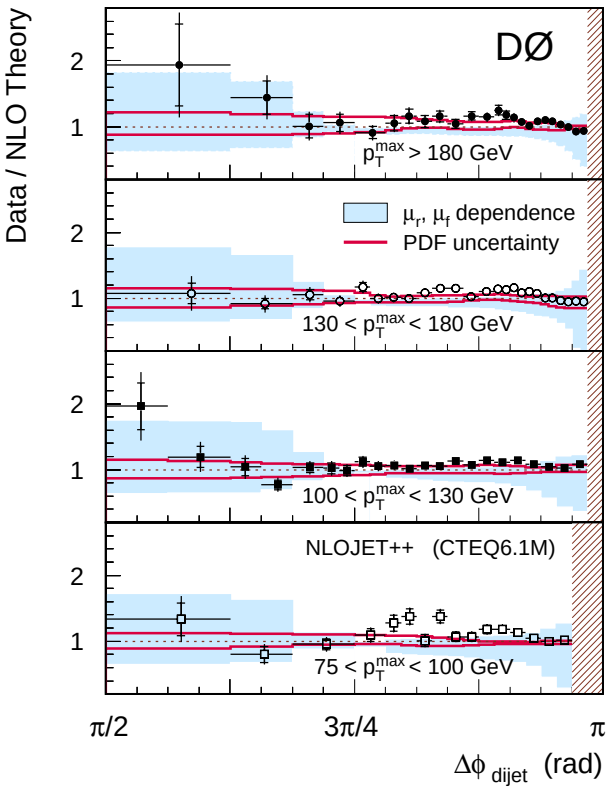


FIG. 2: Ratios of data to the NLO pQCD calculation for different regions of $p_T^{\max}$. Theoretical uncertainties due to variation of $\mu_r$ and $\mu_f$ are shown as the shaded regions; the uncertainty due to the PDFs is indicated by the solid lines. The points at large $\Delta\phi_{\,\mathrm{dijet}}$ are excluded because the calculation has non-physical behavior near the divergence at $\pi$.

based on characteristics of shower development expected for genuine jets. The overall selection efficiency is typically $\approx 83\%$ for $\Delta\phi_{\,\mathrm{dijet}} < 5\pi/6$ and drops to $\approx 78\%$ as $\Delta\phi_{\,\mathrm{dijet}} \to \pi$.

The $p_T$ of each jet was corrected for calorimeter showering effects, overlaps due to multiple interactions and event pile-up, calorimeter noise effects, and the energy response of the calorimeter. The calorimeter response was measured from the $p_T$ imbalance in photon + jet events. The relative uncertainty on the jet energy calibration is $\approx 7\%$ for jets with $20 < p_T < 250\,\mathrm{GeV}$. The sensitivity of the measurement to this calibration was reduced by normalizing the $\Delta\phi_{\,\mathrm{dijet}}$ distribution to the integrated dijet cross section. Nevertheless, this provides the largest contribution to the systematic uncertainty ($< 7\%$ for $\Delta\phi_{\,\mathrm{dijet}} > 4\pi/5$ but up to 23% for $\Delta\phi_{\,\mathrm{dijet}} < 2\pi/3$).

The correction for migrations between bins due to finite energy and position resolution was determined from events generated with the HERWIG [6] and PYTHIA [7] programs. The generated jets were smeared according to detector resolutions [8]. The angular jet resolution was determined from a full simulation of the DØ detector response. It was found to be better than 20 mrad for jets with energies above 80 GeV. The jet $p_T$ resolution was measured from the $p_T$ imbalance in dijet events. It decreases from 18% at $p_T = 40\,\mathrm{GeV}$ to 9% for $p_T = 200\,\mathrm{GeV}$. Finite jet $p_T$ resolution can lead to ambiguities in the selection of the two leading $p_T$ jets. This effect is large at small $\Delta\phi_{\,\mathrm{dijet}}$ where contributions from higher jet multiplicities dominate. The generated events were reweighted to describe the observed $\Delta\phi_{\,\mathrm{dijet}}$ distribution. This provided a good description of the observed $p_T$ spectra of the four leading $p_T$ jets. The correction for migrations is typically less than 8% for $\Delta\phi_{\,\mathrm{dijet}} > 2\pi/3$ and $\approx 40\%$ for $\Delta\phi_{\,\mathrm{dijet}} \approx \pi/2$ with a model dependence of less than 2%. Only for $p_T^{\max} < 130\,\mathrm{GeV}$ and at $\Delta\phi_{\,\mathrm{dijet}} \approx \pi/2$, is the model dependence as large as $\approx 14\%$.

The corrected data are presented in Fig. 1 as a function of $\Delta\phi_{\,\mathrm{dijet}}$ in four ranges of $p_T^{\max}$. The inner error bars represent the statistical uncertainties and the outer error bars correspond to the quadratic sum of the statistical and systematic uncertainties. The spectra are strongly peaked at $\Delta\phi_{\,\mathrm{dijet}} \approx \pi$; the peaks are narrower at larger values of $p_T^{\max}$. Overlaid on the data points in Fig. 1 are the results of pQCD calculations obtained using the parton-level event generator NLOJET++ [4] and CTEQ6.1M [9] parton distribution functions (PDFs) with $\alpha_s(M_Z) = 0.118$. The observable was calculated from the ratio of the predictions for $2 \to 3$ processes ($d\sigma_{\mathrm{dijet}}/d\Delta\phi_{\,\mathrm{dijet}}$) and $2 \to 2$ processes ($\sigma_{\mathrm{dijet}}$), both at leading order (LO) or NLO,

$$\left.\frac{1}{\sigma_{\mathrm{dijet}}}\right|_{\mathrm{(N)LO}} \left.\frac{d\sigma_{\mathrm{dijet}}}{d\Delta\phi_{\,\mathrm{dijet}}}\right|_{\mathrm{(N)LO}} .$$

The renormalization and factorization scales are chosen to be $\mu_r = \mu_f = 0.5\,p_T^{\max}$. The ratio is insensitive to hadronization corrections and the underlying event [10].

NLO pQCD provides a good description of the data. As shown in Fig. 2 data and NLO agree within 5–10%. The theoretical uncertainty due to the PDFs [9] is estimated to be below 20%. Also shown is the effect of renormalization and factorization scale variation ($0.25\,p_T^{\max} < \mu_{r,f} < p_T^{\max}$). The large scale dependence for $\Delta\phi_{\,\mathrm{dijet}} < 2\pi/3$ occurs because the NLO calculation only receives contributions from tree-level four-parton final states in this regime. Results from pQCD at large $\Delta\phi_{\,\mathrm{dijet}}$ in Figs. 1 and 2 were excluded because fixed-order perturbation theory fails to describe the data in the region $\Delta\phi_{dijet} \approx \pi$ where soft processes dominate.

Monte Carlo event generators, such as HERWIG and PYTHIA, use $2 \to 2$ LO pQCD matrix elements with phenomenological parton-shower models to simulate higher order QCD effects. Results from HERWIG (version 6.505) and PYTHIA (version 6.225), both using default parameters and the CTEQ6L [9] PDFs, are compared to the data in Fig. 3. HERWIG describes the data well over the entire $\Delta\phi_{\,\mathrm{dijet}}$ range including $\Delta\phi_{\,\mathrm{dijet}} \approx \pi$. PYTHIA with

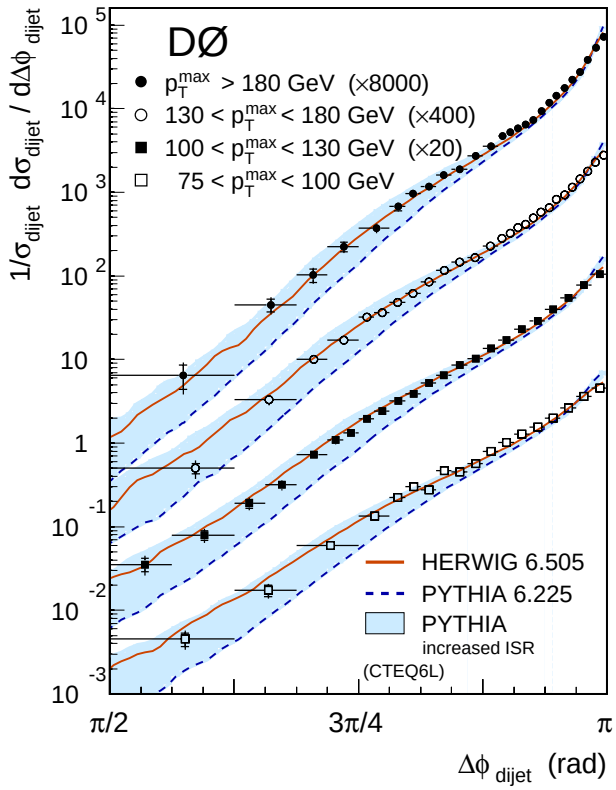


FIG. 3: The $\Delta\phi_{\rm dijet}$ distributions in different $p_T^{\rm max}$ ranges. Results from HERWIG and PYTHIA are overlaid on the data. Data and predictions with $p_T^{\rm max} > 100\,$GeV are scaled by successive factors of 20 for purposes of presentation.

default parameters describes the data poorly—the distribution is too narrowly peaked at $\Delta\phi_{\rm dijet} \approx \pi$ and lies significantly below the data over most of the $\Delta\phi_{\rm dijet}$ range. The maximum $p_T$ in the initial-state parton shower is directly related to the maximum virtuality that can be adjusted in PYTHIA. The shaded bands in Fig. 3 indicate the range of variation when the maximum allowed virtuality is smoothly increased from the current default by a factor of four [11]. These variations result in significant changes in the low $\Delta\phi_{\rm dijet}$ region clearly demonstrating the sensitivity of this measurement. Consequently, global efforts to tune Monte Carlo event generators should benefit from including our data.

To summarize, we have measured the dijet azimuthal decorrelation in different ranges of leading jet $p_T$ and observe an increased decorrelation towards smaller $p_T$. NLO pQCD describes the data except for very large $\Delta\phi_{\rm dijet}$ where the calculation is not predictive.

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[1] M. Dobbs *et al.*, in *Report of the Working Group on Quantum Chromodynamics and the Standard Model, 3rd Les Houches Workshop on Physics at TeV Colliders*, Les Houches, France, (2004), `hep-ph/0403100`.
[2] G. C. Blazey *et al.*, in *Proceedings of the Workshop: "QCD and Weak Boson Physics in Run II"*, edited by U. Baur, R. K. Ellis, and D. Zeppenfeld, Batavia, Illinois (2000) p. 47. See Section 3.5 for details.
[3] W. B. Kilgore and W. T. Giele, in *Proceedings of the 35th Rencontres De Moriond*, edited by J. Tran Thanh Van, Les Arcs, France (2000).
[4] Z. Nagy, Phys. Rev. Lett. **88**, 122003 (2002); Z. Nagy, Phys. Rev. D **68**, 094002 (2003).
[5] V. Abazov *et al.* (DØ Collaboration), in preparation for submission to Nucl. Instrum. Methods Phys. Res. A; T. LeCompte and H. T. Diehl, Ann. Rev. Nucl. Part. Sci. **50**, 71 (2000); S. Abachi *et al.* (DØ Collaboration), Nucl. Instrum. Methods Phys. Res. A **338**, 185 (1994).
[6] G. Marchesini *et al.*, Comp. Phys. Comm. **67**, 465 (1992); G. Corcella *et al.*, JHEP **0101**, 010 (2001).
[7] T. Sjöstrand *et al.*, Comp. Phys. Comm. **135**, 238 (2001).
[8] A. Kupčo, Ph.D. thesis, Charles University, Prague, Czech Republic (2003), `FERMILAB THESIS-2004-08`.
[9] J. Pumplin *et al.*, JHEP **0207**, 12 (2002); D. Stump *et al.*, JHEP **0310**, 046 (2003).
[10] M. Wobisch, to appear in *Proceedings of the 15th Topical Conference on Hadron Collider Physics, HCP2004.*
[11] The PYTHIA parameter `PARP(67)` was increased from the current default of 1.0 to 4.0 which was the default before version 6.138.