



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

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We present a preliminary measurement of azimuthal decorrelations between the two leading jets in multi-jet events acquired with the DØ detector during 2002 and 2003 studying $\bar{p}p$ collisions at a center-of-mass energy $\sqrt{s} = 1.96$ TeV. Such decorrelations provide a sensitive tool for examining the impact of QCD radiation on jet production. The analysis is based on an inclusive dijet event sample in the central region of rapidity of $|y_{\text{jet}}| < 0.5$. Jets are reconstructed using an iterative cone algorithm with radius $R_{\text{cone}} = 0.7$. The data sample corresponds to an integrated luminosity of $\mathcal{L} = 150 \text{ pb}^{-1}$. We observe smaller dijet azimuthal decorrelations at larger transverse jet momenta. Perturbative QCD at next-to-leading order in the strong coupling constant α_s provides a very good description of the data except for very small and very large azimuthal decorrelations. Monte Carlo event generators using parton showers can be tuned to produce the observed decorrelations over the whole range.

Preliminary Results for Winter 2004 Conferences

I. INTRODUCTION

According to perturbative QCD (pQCD) at lowest order in the strong coupling constant, $\mathcal{O}(\alpha_s^2)$, jets in $\bar{p}p$ collisions are produced in pairs. In this approximation, the jets have identical transverse momenta, p_T , and correlated azimuthal angles, ϕ_{jet} , with $\Delta\phi_{\text{dijet}} = |\phi_{\text{jet } 1} - \phi_{\text{jet } 2}| = \pi$. Additional jets can be produced at higher orders and the two leading jets may be decorrelated with $\Delta\phi_{\text{dijet}} < \pi$. The azimuthal decorrelation of the two leading jets is sensitive to additional radiation which manifests itself as additional p_T in an event. Soft additional radiation with $p_T \rightarrow 0$ results in $\Delta\phi_{\text{dijet}} \rightarrow \pi$, whereas values of $\Delta\phi_{\text{dijet}} \ll \pi$ are an indication of hard additional radiation. The measurement of the $\Delta\phi_{\text{dijet}}$ distribution is thus an ideal testing ground for higher order QCD effects, without the experimental problems associated with reconstructing additional jets. We measured the dijet cross section as function of $\Delta\phi_{\text{dijet}}$, normalized by the inclusive dijet cross section, integrated over the same phase space. The observable was defined as

$$\frac{1}{\sigma_{\text{dijet}}} \frac{d\sigma_{\text{dijet}}}{d\Delta\phi_{\text{dijet}}}. \quad (1)$$

The measurement was made in four ranges of the leading jet p_T , starting at $p_T > 75$ GeV. The requirement for the second leading jet was $p_T > 40$ GeV and both jets were required to be in the central rapidity region, $|y_{\text{jet}}| < 0.5$.

II. ANALYSIS

The data were acquired with the upgraded DØ detector [1] in Run II of the Fermilab Tevatron between August 2002 and September 2003 using $\bar{p}p$ collisions at a center-of-mass energy $\sqrt{s} = 1.96$ TeV. The data sample corresponds to an integrated luminosity of $\mathcal{L} = 150$ pb $^{-1}$. Events used in this analysis were triggered by one of the inclusive jet triggers, based on energy deposited in calorimeter towers [1]. Data selection was based on run quality, event properties, and jet quality criteria.

Jets were defined by the ‘‘Run II cone algorithm’’ [2] which combines particles within a cone radius $R_{\text{cone}} = 0.7$ in y and ϕ around the cone axis. Calorimeter towers were combined into jets in the ‘‘ E -scheme’’ (adding the four-vectors). The jet finding procedure was iterated until a stable solution was reached. The four-vector of every tower was used as a seed in the first stage of the iterative procedure. The algorithm was re-run using the midpoints between pairs of jets identified in the first stage as additional seeds (the second stage makes the procedure infrared safe). Jets with overlapping cones were merged if the overlap area contained more than 50% of the p_T from the lower p_T jet, otherwise the particles in the overlap region are assigned to the nearest jet.

The data were corrected for the jet energy scale, selection efficiencies, and for migrations due to the p_T and position resolution. The correction for the migrations was determined using events produced by the event generator PYTHIA [3]. These events were smeared according to the resolutions, as determined from the data (p_T resolution) and by the DØ detector simulation (ϕ_{jet}). The size of these corrections were typically below 10% and never larger than 26%. In general, the spacial direction of a jet is measured with higher precision than its energy.

The $\Delta\phi_{\text{dijet}}$ distribution was measured in different ranges of leading jet p_T . These ranges were chosen according to the regions where the jet triggers were at least 99% efficient. The $\Delta\phi_{\text{dijet}}$ distributions in each p_T range were normalized by the inclusive dijet cross section, integrated over the same phase space in p_T and y_{jet} . Many experimental uncertainties cancel in this ratio. The largest experimental uncertainty in this ratio is associated with the jet energy scale ($< 7\%$ for $\Delta\phi_{\text{dijet}} > 2.5$ and up to 23% at $\Delta\phi_{\text{dijet}} < 2$).

III. RESULTS

The preliminary results of the measurement are displayed in Fig. 1. The data are presented as a function of $\Delta\phi_{\text{dijet}}$ in four ranges of the leading jet p_T . The data points at $p_{T_{\text{jet } 1}} > 100$ GeV have been scaled by arbitrary factors in this comparison. The spectra are strongly peaked at $\Delta\phi_{\text{dijet}} = \pi$. The peaks at $\Delta\phi_{\text{dijet}} = \pi$ become narrower at larger values of $p_{T_{\text{jet } 1}}$.

The inclusive dijet cross section in fixed order pQCD receives contributions from configurations with at least two final state partons ($\mathcal{O}(\alpha_s^2)$ and higher). The differential cross section $d\sigma_{\text{dijet}}/d\Delta\phi_{\text{dijet}}$ only receives contributions from three-parton configurations ($\mathcal{O}(\alpha_s^3)$ and higher). The ratio is therefore proportional to α_s and the leading order (LO) and next-to-leading order (NLO) pQCD predictions are given by the ratio of the respective predictions for the single pieces.

$$\frac{1}{\sigma_{\text{dijet}}} \frac{d\sigma_{\text{dijet}}}{d\Delta\phi_{\text{dijet}}} \Big|_{(\text{N})\text{LO}} = \frac{1}{\sigma_{\text{dijet}}} \Big|_{(\text{N})\text{LO}} \frac{d\sigma_{\text{dijet}}}{d\Delta\phi_{\text{dijet}}} \Big|_{(\text{N})\text{LO}} = \frac{\sigma_{2 \rightarrow 3(\text{N})\text{LO}}}{\sigma_{2 \rightarrow 2(\text{N})\text{LO}}} \propto \alpha_s \quad (\text{and at NLO : } + \mathcal{O}(\alpha_s^2)) \quad (2)$$

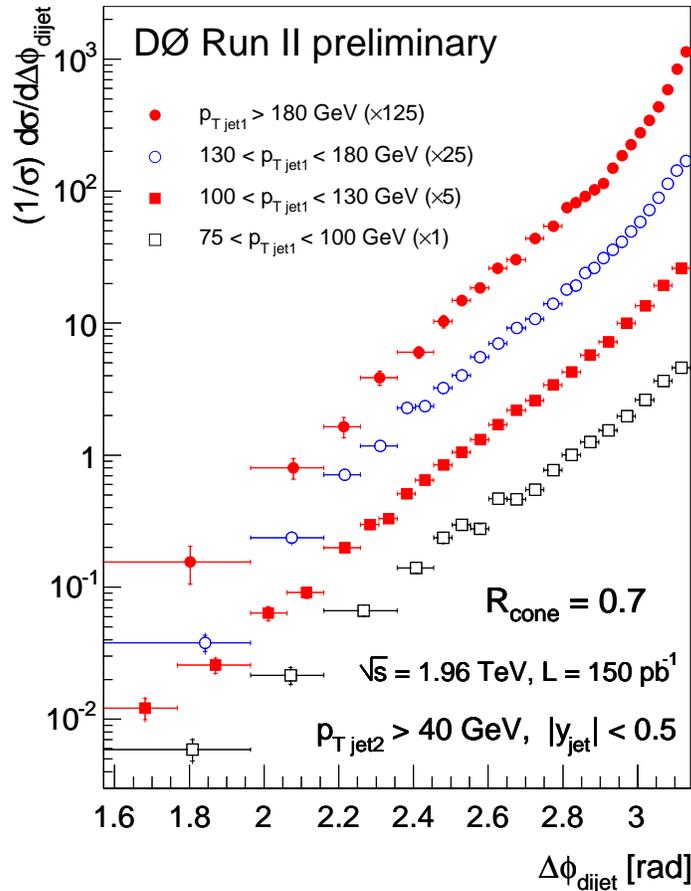


FIG. 1: The dijet azimuthal decorrelation, $(1/\sigma_{\text{dijet}}) d\sigma_{\text{dijet}}/d\Delta\phi_{\text{dijet}}$, measured in different regions of the leading jet p_T . The data for $p_{T, \text{jet } 1} > 100$ GeV have been multiplied by arbitrary factors.

The phase space for the LO prediction with three final-state partons is limited to $\Delta\phi_{\text{dijet}} > 2\pi/3$ due to the requirement that $\Delta\phi_{\text{dijet}}$ is defined between the two leading jets. For the NLO prediction with up to four final-state partons no such restriction is present. The (N)LO predictions at $\Delta\phi_{\text{dijet}} \rightarrow \pi$ is dominated by the phase space where the third jet is soft ($p_{T, \text{jet } 3} \rightarrow 0$). The (N)LO prediction therefore diverges for $\Delta\phi_{\text{dijet}} \rightarrow \pi$.

The four plots in Fig. 2 show the $\Delta\phi_{\text{dijet}}$ distribution, in different regions of $p_{T, \text{jet } 1}$, overlaid by the results of the NLOJET++ [4] NLO and LO pQCD calculations with the CTEQ6.1M PDFs [5]. The renormalization and factorization scales were set to $\mu_r = \mu_f = 0.5 p_{T, \text{jet } 1}$. The limitations of the LO calculation at low- $\Delta\phi_{\text{dijet}}$ (due to phase space) and at high- $\Delta\phi_{\text{dijet}}$ (soft limit) are obvious. Only at highest $p_{T, \text{jet } 1}$ they give a fair description of the intermediate $\Delta\phi_{\text{dijet}}$ region. The NLO predictions are in good agreement with the data in almost the whole kinematic range. These predictions only fail in the extreme regions at high- $\Delta\phi_{\text{dijet}}$ and at low- $\Delta\phi_{\text{dijet}}$ (below $\Delta\phi_{\text{dijet}} \simeq 2/3\pi$).

The limitations of fixed order pQCD are cured by calculations that resum leading logarithmic terms to all orders in α_s . Monte Carlo event generators with parton shower models, such as PYTHIA and HERWIG [6], are good approximations to such resummed calculations. Results from PYTHIA and HERWIG are compared to the data in Fig. 3. Also included in Fig. 3 is a PYTHIA calculation tuned to other $\bar{p}p$ scattering data (“tune A” from R. Field [7] based on data measured by the CDF collaboration [8]). The default versions of PYTHIA and HERWIG provide a better description of the data over the whole range of $\Delta\phi_{\text{dijet}}$ than LO pQCD. The description is substantially improved by using tuned PYTHIA parameters. However, in the intermediate $\Delta\phi_{\text{dijet}}$ region the best description of the data is still obtained by NLO pQCD. The value of the parameter PARP(67), which governs the amount of initial-state radiation, was varied to investigate the sensitivity of the PYTHIA result. Fig. 4 compares the PYTHIA predictions to the data for three settings of PARP(67). This figure clearly demonstrates the sensitivity of the measurement and its potential for future efforts to tune event generators.

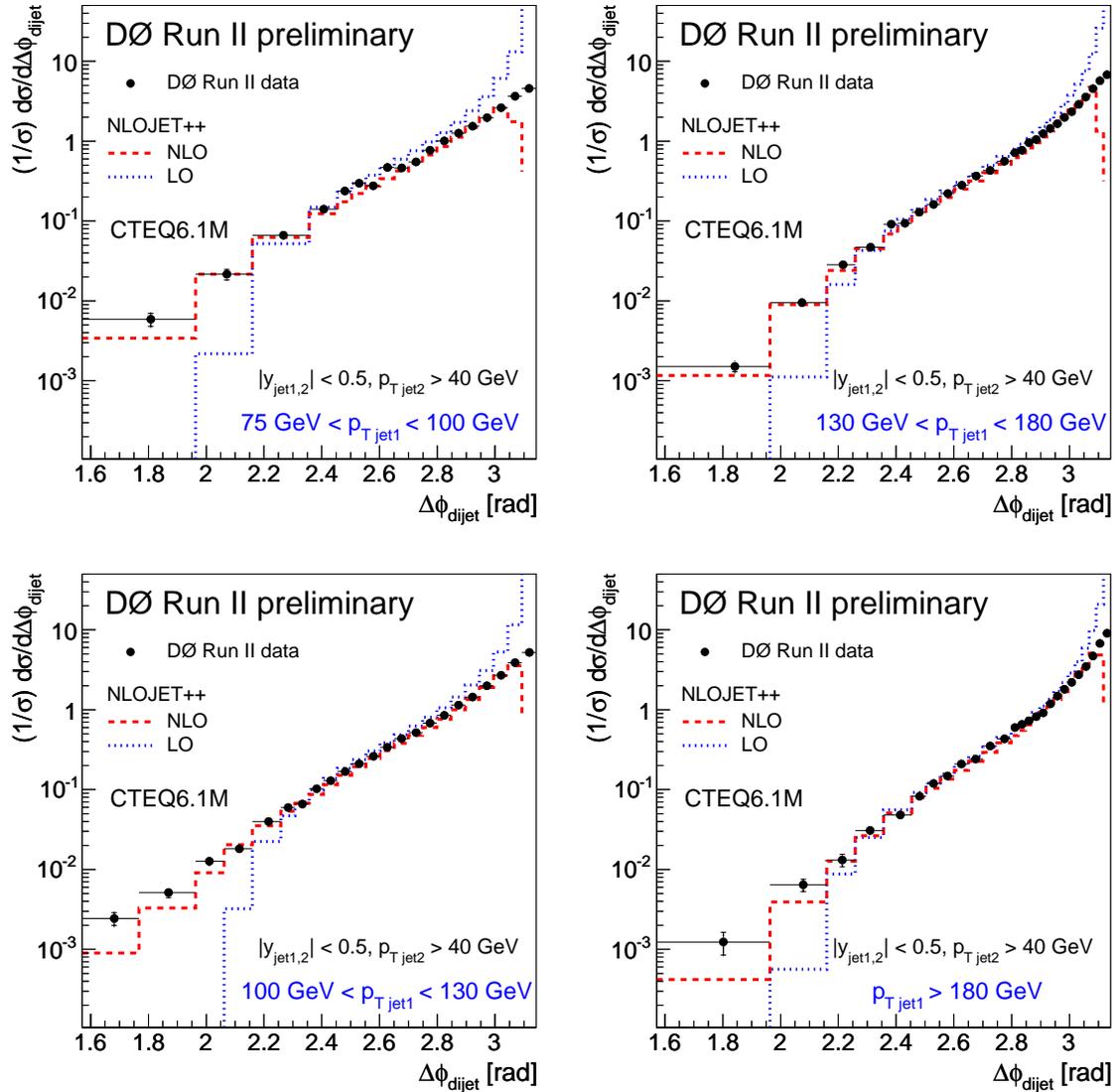


FIG. 2: The dijet azimuthal decorrelation, $(1/\sigma_{\text{dijet}}) d\sigma_{\text{dijet}}/d\Delta\phi_{\text{dijet}}$, measured in different regions of the leading jet p_T . The LO and NLO pQCD predictions are compared to the data.

IV. SUMMARY

We observe an increased dijet azimuthal decorrelation towards smaller transverse momenta. A pQCD calculation in next-to-leading order of α_s gives a good description of the data, except for very small and very large azimuthal decorrelations. Monte Carlo event generators using parton showers can be tuned to give a reasonable description of the data over the whole kinematic range.

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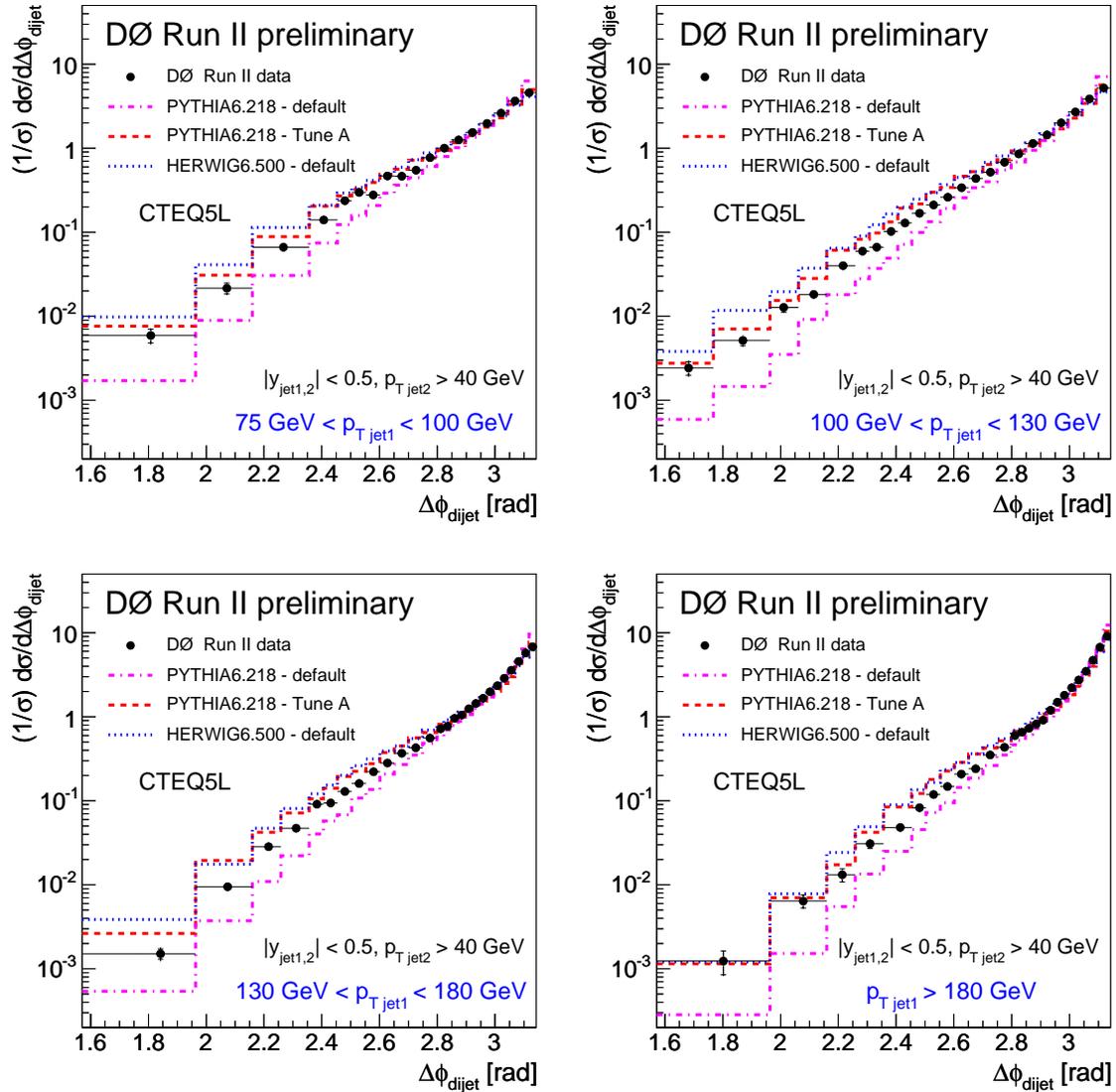


FIG. 3: The dijet azimuthal decorrelation, $(1/\sigma) d\sigma_{\text{dijet}}/d\Delta\phi_{\text{dijet}}$, measured in different regions of the leading jet p_T . The predictions from PYTHIA and HERWIG are compared to the data. The PYTHIA results are shown for the default version and for a version tuned to other data from $\bar{p}p$ collisions (see text for details).

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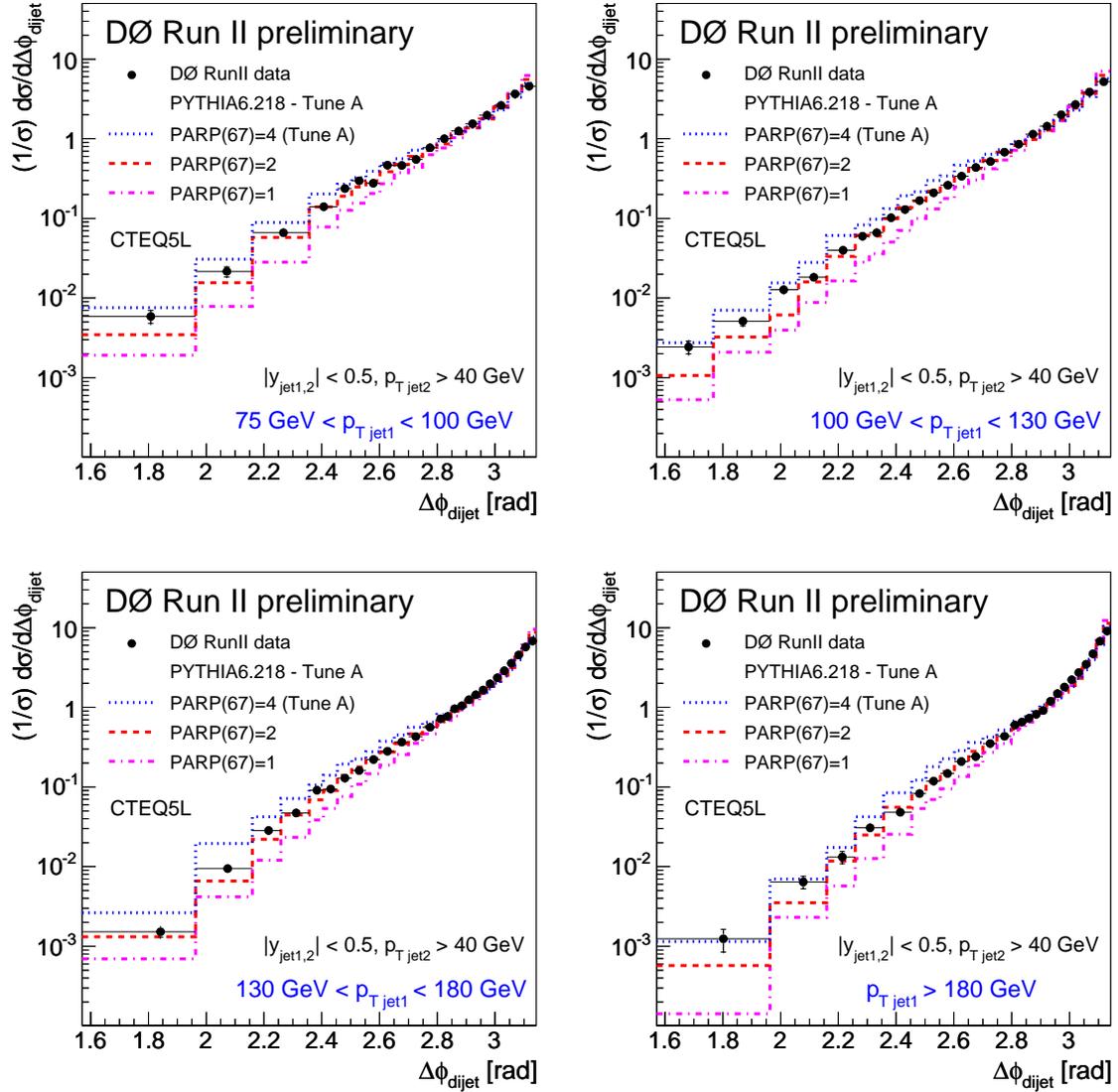


FIG. 4: The dijet azimuthal decorrelation, $(1/\sigma_{\text{dijet}}) d\sigma_{\text{dijet}}/d\Delta\phi_{\text{dijet}}$, measured in different regions of the leading jet p_T . The predictions from the tuned PYTHIA are compared to the data using different settings of the parameter PARP(67) (see the text).

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