Eur Phys J C **33**, s01, s419–s421 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2004-03-1718-2

**EPJ C direct**
**electronic only**

# Recent QCD results from DØ

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Received: 31 October 2003 / Accepted: 4 February 2004 /
Published Online: 26 February 2004 – 

**Abstract.** We present some of the most recent QCD results from DØ. The Run I measurement of the inclusive $k_T$ jet cross section is one of the first analyses on hadron-hadron colliders that uses the $k_T$-algorithm instead of the traditional cone one. We observe a good agreement with NLO QCD predictions and also with the previous Run I measurement which utilised the cone algorithm. The agreement is marginal at low $p_T$ end. The difference is attributed to the different behaviour of jet algorithms after hadronization. We also present preliminary Run II results on the inclusive jet cross section and the inclusive dijet mass spectrum. The analysis is performed on the sample of $34\,\mathrm{pb}^{-1}$. Due to a 9% increase in the center of mass energy and a higher instantaneous luminosity, in the near future, the Run II data will provide greater statistics for high $p_T$ jets than in Run I.

## 1 Introduction

Hadron-hadron interactions with jets with high transverse momentum probe the structure of matter and space at small distances. The Tevatron collider provides an excellent opportunity to study such interactions. The Tevatron provided proton and anti-proton beams with energy of 900 GeV during Run I which ended in 1995. It was upgraded in 1996-2001 and Run II started in March 2001. The main purpose of the upgrade was to increase collider luminosity. Also the Tevatron beam energy was increased by 9% to 980 GeV. Jets produced at the Tevatron reach transverse momenta up to $p_T \sim 500\,\mathrm{GeV}$ which corresponds to the distance scale of $10^{-3} - 10^{-4}$ fm. Such data are suitable for testing the QCD predictions, and they are sensitive for new physics up to this scale.

## 2 DØ detector

The DØ detector [1] is a general purpose detector intended to study high energy proton anti-proton interactions. During the five year upgrade period it underwent several improvements. Only changes that concern directly the presented analyses are described here. A completely new tracking system was installed, consisting of the Silicon Microstrip Tracker and the Central Fiber Tracker placed in the 2 T magnetic field. The position of the interaction vertex is reconstructed from the tracks of charged particles. Only information from the calorimeter together with the position of the primary vertex is used to reconstruct jets. The DØ liquid argon calorimeter, described in [2], remains the same in Run II. However, due to the much shorter time between bunch crossings (396 ns), the trigger and readout electronics had to be replaced. The calorimeter is hermetic with fine segmentation $0.1 \times 0.1$ in azimuthal angle $\phi$ and pseudorapidity $\eta$. To improve electron and photon identification, a new central and preshower detectors were installed in front of the calorimeter.

## 3 $k_T$ jet inclusive cross section

Cone algorithms are traditionally used in hadron-hadron experiments. This class of jet algorithms is known to suffer problems with infrared singularities. The cone algorithm has to be designed carefully in order to avoid such problems. On the contrary, the $k_T$-algorithms are by construction infrared safe. We present here only the results on the measurement of the jet inclusive cross Sect. [3]. There are two other DØ analyses based on the $k_T$-algorithm: measurement of subjet multiplicity of gluon and quark jets [4] and measurement of the dijet transverse thrust cross Sect. [5]. The jet cross section analysis was performed on $\mathcal{L} = 87.3\,\mathrm{pb}^{-1}$ of Run I data using the Ellis-Sopper $k_T$-algorithm [6]. Parameter $D$, which controls the size of the jet in this algorithm version, was set to $D = 1$. For this choice, the NLO QCD prediction for the cross section agrees within 1% with the prediction for the cone algorithm with cone size $R = 0.7$ which was used in the previous DØ measurement of the jet inclusive cross Sect. [7]. The inclusive cross section for jets in the central region of the calorimeter is displayed in Fig. 1. A more detailed comparison with NLO QCD and with the previous DØ result (Fig. 2) shows a good agreement between the data and theoretical prediction. The agreement is marginal at the low $p_T$ end. In order to identify the source of the difference, the properties of cone and $k_T$ jets were studied in

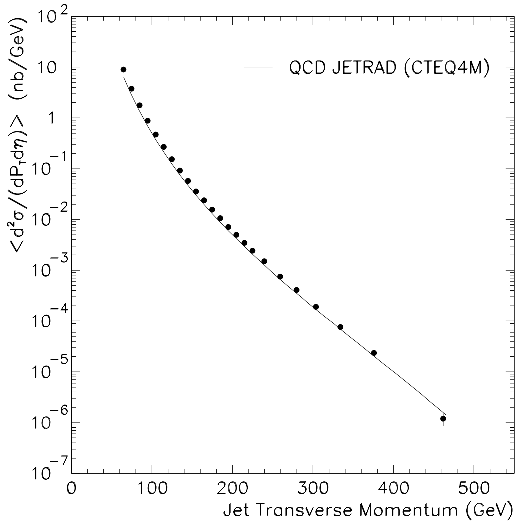


**Fig. 1.** Inclusive cross section for $k_T$ jets with $D = 1$ in the central region of pseudorapidity ($|\eta| < 0.5$). Only statistical errors are shown. The *solid line* represents NLO QCD prediction calculated with JETRAD [8] using CTEQ4M [9] parton distribution functions

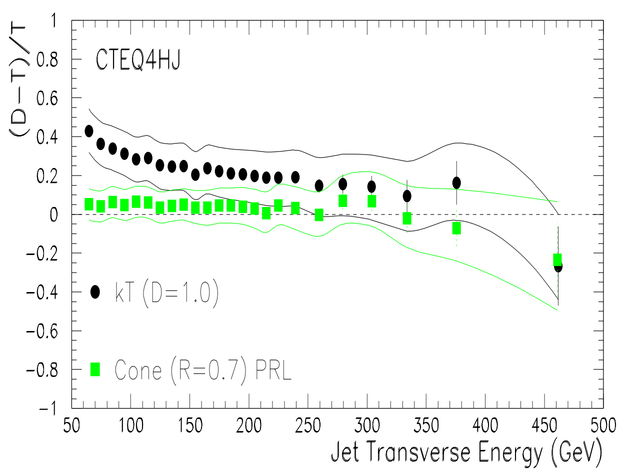


**Fig. 2.** Comparison between the measured inclusive cross section ($D$) and the NLO QCD prediction ($T$) for the $k_T$ (*circle*) and the cone (*square*) algorithms. *Solid lines* correspond to the systematic error without error on luminosity

the data and the Monte Carlo (MC) using generator Herwig 5.9 [10]. It was observed in the data that the $k_T$ jets are in average more energetic than the corresponding cone jets (4 GeV at $p_T = 60$ GeV, and 7 GeV at $p_T = 250$ GeV). The difference does not depend on instantaneous luminosity which is a nice cross check of the offset correction in the jet energy scale. Similar behaviour was also seen in Herwig; $k_T$ jets are more energetic on the hadron level than on the parton level. However, cone jets are less energetic on the hadron level than on the parton one. The magnitude of the difference in MC was only about one third of the observed difference. If those MC hadronization corrections are taken into account, the agreement between the data and theoretical prediction at the low $p_T$ end improves.

## 4 Preliminary Run II QCD results

In this section, preliminary Run II results on the measurement of the inclusive jet cross section and the inclusive dijet mass cross section are presented. The aim of the analyses is to provide a more precise measurement than in Run I, especially in the high $p_T$ region where we expect to collect much higher statistics. The presented results are obtained using $34\,\mathrm{pb}^{-1}$ of data taken between September 3, 2002 and January 12, 2003.

Following the recommendations of the Run II Jet Physics Group [11], jets are reconstructed using the Improved Legacy Cone Algorithm. As in Run I, the algorithm finds stable cones iteratively. However, in order to improve the infrared behaviour in NNLO, additional starting seeds in mid-points between the founded protojets are introduced. The Run II algorithm is also using a different recombination scheme. Instead of the traditional Snowmass scheme, the jet 4-momentum is reconstructed as a sum of 4-momenta of the associated calorimeter towers.

In order to measure the jet cross section over the large region of transverse momenta, a set of four jet triggers is used. The DØ trigger system consists of three levels. The corresponding cuts on jet transverse momenta at level three are 25, 45, 65, and 95 GeV respectively. The data from a particular trigger are used only in the region where the trigger is almost 100% effective.

Jet energies are corrected to the particle level in the same way as in Run I [12] according to the formula

$$E_{ptcl} = \frac{E_{det} - \mathcal{O}}{R_{jet} \cdot S}\,, \tag{1}$$

where $E_{det}$ is the jet energy as measured by the calorimeter, and $E_{ptcl}$ is the jet energy before it enters the detector. The offset $\mathcal{O}$ corrects for the energy not associated with the hard interaction (uranium decay in calorimeter, additional interactions in given bunch crossing or remaining energy from the previous crossings). The calorimeter response to the jet $R_{jet}$ is determined from the overall transverse imbalance in photon+jet events. So far, it is measured for energies up to 200 GeV. Finally, the showering correction $S$ takes into account losses due to energy showering in the calorimeter out of the jet cone. The presented analyses are using the preliminary Run II measurement of the jet energy scale. In the central region of the calorimeter, the scale is known within 10% precision for energies up to 200 GeV. The uncertainty then increases up to 16% at $E \sim 500$ GeV.

The measured jet cross sections are affected by the finite resolution of the detector. The data are corrected using the same unsmearing method as in Run I [7,13,14]. The necessary input for the procedure is the detector resolutions in the jet transverse momentum and in the dijet mass. The jet $p_T$ resolution is measured from the $p_T$ imbalance in the dijet back-to-back events. The dijet mass resolution is then obtained from Pythia [15] by smearing particle jet momenta.

In order to clean up the sample, the following criteria are applied. The vertex is important for the calculation of

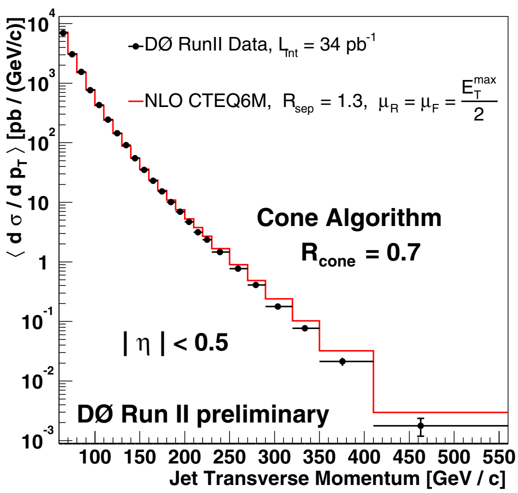


**Fig. 3.** Inclusive jet cross section for the cone jets with size of $R = 0.7$ in the central region of calorimeter ($|\eta| < 0.5$). Only the statistical errors are shown. The *solid line* corresponds to the NLO QCD prediction calculated with JETRAD using CTEQ6.0M [16] parton distribution functions

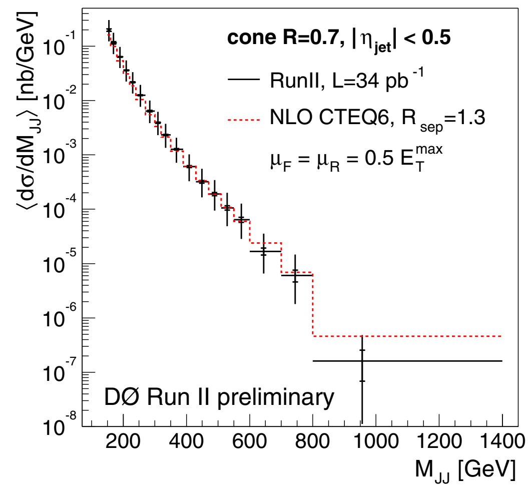


**Fig. 4.** Inclusive dijet mass cross section for cone jets of radius $R = 0.7$ for $|\eta| < 0.5$. The *error bars* represent the total error (except the fully correlated error on luminosity), small perpendicular lines correspond to statistical errors only. NLO QCD prediction calculated with JETRAD v2.0 with newly implemented E-scheme recombination is plotted as a *dashed line*

the jet transverse momentum. Only events with at least 5 tracks associated to the primary vertex were considered. The vertex is also required to be within 50 cm from the geometrical center of the detector. The efficiency of the vertex cut is estimated to be 78%. Regular QCD events are balanced in transverse momentum. Events for which the missing $E_T$ is bigger than 70% of the transverse momentum of the leading jet are rejected. The jets that enter the final plots are also required to satisfy standard jet selection criteria. The efficiencies of the cut on missing $E_T$ as well as of the jet selection criteria are almost 100%.

The fully corrected inclusive jet cross section for a cone size of $R = 0.7$ in the central region of the calorimeter is plotted in Fig. 3. The horizontal lines represent the bin averaged cross section. Only statistical errors are shown in the plot. The systematic error is completely dominated by the error on the jet energy scale. The error on cross section is about 50% for $p_T < 200$ GeV and then it rises up to about 100% at $p_T \sim 400$ GeV. The overall normalisation error is about 10%. The NLO QCD prediction (solid line) agrees, within the statistical and systematic errors, with the data.

The final result for the inclusive dijet mass cross section is displayed in Fig. 4. The dijet mass is calculated as an invariant mass of the two jets with the largest transverse momenta. The two leading jets are required to be in the central part of calorimeter ($|\eta| < 0.5$). The data are within the errors in good agreement with NLO QCD prediction.

## 5 Summary

The measurement of the inclusive $k_T$ jet cross section in Run I data at $\sqrt{s} = 1.8$ TeV is one of the first analysis on hadron-hadron colliders that uses the $k_T$ jet algorithm. The data are in good agreement with the NLO QCD predictions and with the former Run I measurement based on cone algorithm.

We presented the preliminary results on the inclusive jet cross section and the inclusive dijet mass cross section for cone jets in the central region of the calorimeter in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV on a sample of 34 pb$^{-1}$. In the near future, we expect to collect greater statistics for high $p_T$ jets than in Run I. Such data will allow us to extend the various searches for new physics that were performed on Run I data. We are also working on extending measurements in the more forward regions of the calorimeter.

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