PROCEEDINGS OF SCIENCE

Measurement of three-jet differential cross sections at Tevatron

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We present the first measurement of the inclusive three-jet differential cross section as a function of the invariant mass of the three jets with the largest transverse momenta in an event in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$. The measurement is made in different rapidity regions and for different jet transverse momentum requirements and is based on a data set corresponding to an integrated luminosity of $0.7\,\mathrm{fb}^{-1}$ collected with the D0 detector at the Fermilab Tevatron Collider. The results are used to test the three-jet matrix elements in perturbative QCD calculations at next-to-leading order in the strong coupling constant. The data allow discrimination between parametrizations of the parton distribution functions of the proton.

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1. Introduction

Measurements of the inclusive jet [1] and di-jet [2] differential cross sections are sensitive to the strong coupling constant α_s [3] up to orders of $\mathscr{O}(\alpha_s^2)$ and the parton distribution functions (PDFs) of gluons at high proton momentum fraction. This result advances the tests of the perturbative QCD (pQCD) predictions to the level of $\mathscr{O}(\alpha_s^3)$ [4, 5], while having a similar sensitivity to the proton PDFs [6, 7, 8]. A precise knowledge of the proton PDFs and α_s enhances the sensitivity of many searches for the physics beyond the standard model.

This analysis represents the first measurement of the inclusive three-jet differential cross section, $d\sigma_{3jet}/dM_{3jet}$, in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, as a function of the invariant mass M_{3jet} of the three highest transverse momentum (p_T) jets in the event [9]. The measurement is performed using a data sample of 0.7 fb^{-1} of integrated luminosity collected by the D0 detector [10] during 2004-2005 in RunII of the Fermilab Tevatron Collider. The finely segmented liquid-argon/uranium calorimeter of the D0 detector plays a key role in the reconstruction of jets.

2. Measuement

Events are triggered by the jet with the highest p_T and contain three or more jets ordered in descending p_T. Jets are reconstructed, both for the experimental data and theory calculations, using the midpoint cone jet algorithm [11] with a cone of a radius $R_{cone} = 0.7$ in rapidity $y = \frac{1}{2}\ln[(1+\beta\cos\theta)/(1-\beta\cos\theta)]$ and azimuthal angle ϕ, where $\beta = |\vec{p}|/E$ and θ is the polar scattering angle. The leading jet p_{T1} is required to be greater than 150 GeV. The measurement considers five scenarios. Two scenarios constrain $p_{T3} > 40$ GeV and $|y| < 0.8$ or 1.6, and the other three $|y| < 2.4$ and $p_{T3} > 40, 70$, or 100 GeV, with no requirement on p_{T2}. In the events chosen for all the scenarios, all pairs of jets are separated by $R_{cone} > 1.4$ to reduce the dependence on a p_T scale smaller than the requirement on the third jet p_T and the phase space where the jets are pairwise subject to overlap treatment in the cone algorithm and thus on its infrared sensitivity.

The D0 silicon micro-strip and scintillator tracker is used to precisely reconstruct the position of the $p\bar{p}$ interaction. Detector noise and physical calorimeter backgrounds due to electrons and photons are suppressed by applying cuts to discriminating variables emphasizing the characteristics of the jet shower shapes. Cosmic rays are discarded by means of a restriction applied to the missing transverse energy required to be less than a half of the highest jet p_T.

Average corrections to the jet four-momenta, amounting to between 50% and 20% for jets with $50 < p_T < 400$ GeV, are extracted from several data-driven techniques. The absolute energy calibration in the central region $|y| < 0.4$ uses samples of $Z \to ee$ events, p_T imbalance in $\gamma+$jet events, and di-jet events in the forward region. The jet four-momenta are also corrected for the calorimeter energy pile up due to the underlying event, multiple $p\bar{p}$ interactions, previous and consecutive beam crossings. Effects due to the different calorimeter response of quark and gluon initiated jets are also of the size of 2-4% and are corrected for with the help of simulated samples generated with PYTHIA [12] event generator and passed through the GEANT-based detector simulation [13].

To correct the differential cross sections $d\sigma_{3jet}/dM_{3jet}$ for other experimental effects, such as migrations between M_{3jet} bins, jet p_T resolution, muons and neutrinos inside the jets, particle-level jets are generated with SHERPA [14] using MSTW2008LO PDFs [6] and processed through

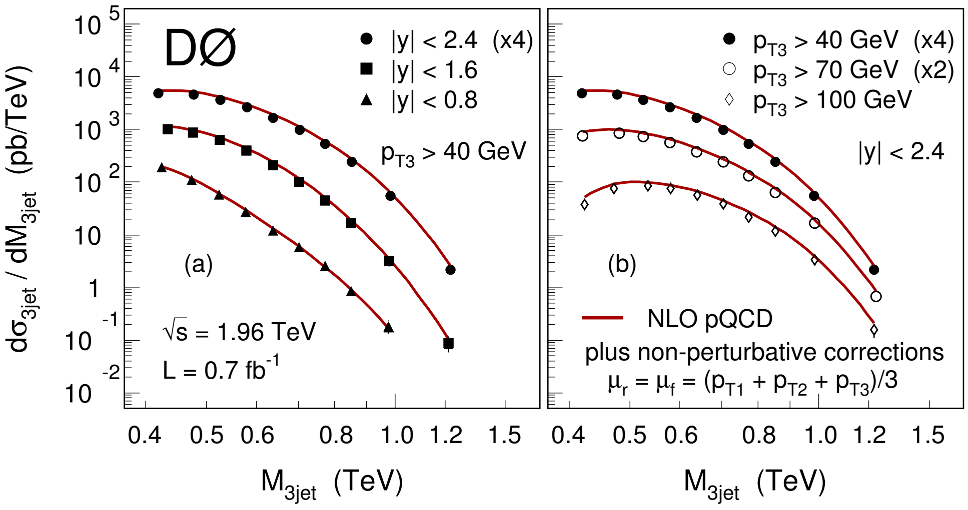

Figure 1: The differential cross sections $d\sigma_{3jet}/dM_{3jet}$ (a) in different rapidity regions and (b) for different p_{T3} requirements. The solid lines represent the NLO pQCD matrix element calculations using MSTW2008NLO PDFs and $\alpha_s(M_Z) = 0.1202$ which are corrected for the non-perturbative effects.

a fast simulation of the D0 detector. This fast simulation uses parametrizations of the detector resolution, misidentification probabilities, and reconstuction efficiencies taken either from data or from a full detector simulation using GEANT. A scaling function is constructed iteratively using the M_{3jet}, $|y_1|$, and $|y_3|$ to reweight the generator level events to maximize the agreement with the data distributions. M_{3jet} bin widths are chosen to be approximately twice the M_{3jet} resolution. After the rescaling, correction factors are extracted from the simulation to represent data cross sections at the "particle level".

In total 65 independent sources of systematic uncertainty are identified dominated by the jet energy calibration uncertainty (10-30%), luminosity uncertainty (6.1%), jet p_T resolution (1-5%), systematic shifts in $|y|$ (3%), reweighting of the generated events (2.5%), trigger efficiency uncertainties (2%), and jet θ resolution (1%).

Fig. 1 shows the results of the differential cross section measurement. The data are compared to the theory predictions obtained from NLO pQCD calculations with non-perturbative corrections applied using PYTHIA "tune DW" [15]. These corrections are due to the hadronization and underlying event, and vary between -10% and +2%.The NLO results use MSTW2008NLO PDFs [6] and $\alpha_s(M_Z) = 0.1202$. The renormalization and factorization scales are chosen as the average of the three jet p_T.

Calculations are done for additional PDFs. These include NNPDFv2.1 [8] ($\alpha_s(M_Z) = 0.119$), ABKM09NLO [16] ($\alpha_s(M_Z) = 0.1179$) , HERAPDFv1.0 [17] ($\alpha_s(M_Z) = 0.1176$), and CT10 [7] ($\alpha_s(M_Z) = 0.118$). A χ^2 discriminant is computed to quantify the level of agreement between the theory and data. It takes into account the experimental uncertainties with correlations, including those in the hadronization and underlying event corrections. The latter two are assumed to be half of the individual corrections. Fig. 2 shows the result of the calculation. The χ^2 depends on the values of α_s and renormalization and factorization scales. pQCD calculations with MSTW2008NLO and NNPDFv2.1 PDF sets show the best agreement with the results of the measurement.

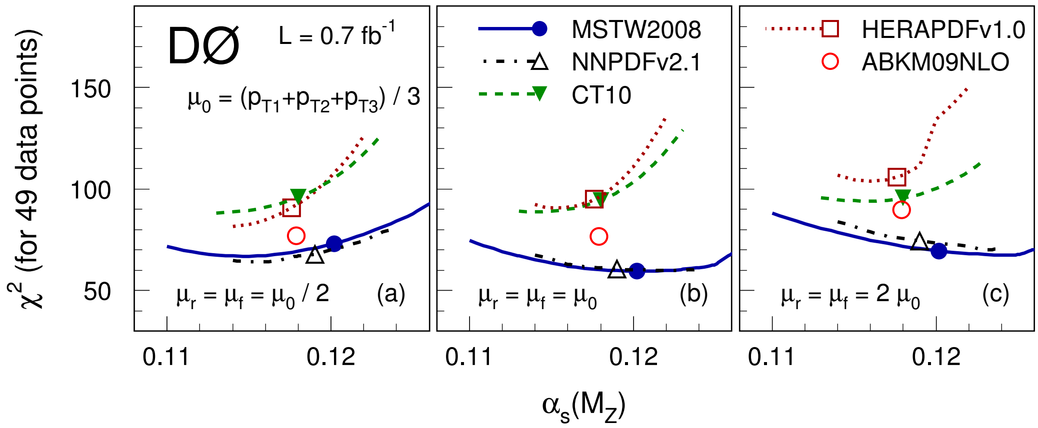

Figure 2: The χ^2 values between theory and data as a function of the value of $\alpha_s(M_Z)$ used in the matrix elements and PDFs. The results are shown for different PDF parametrizations and for different choices of the renormalization and factorization scales. The positions of the central $\alpha_s(M_Z)$ values for the different PDF sets are indicated by the markers.

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