REVIEW OF CMS LOW-x RESULTS AND PROSPECTS FOR RUN 2*

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In this paper, a brief description of three measurements sensitive to BFKL evolution effects is given: the measurement of angular correlation between forward and central jet, the measurement of Mueller–Navelet dijet angular decorrelations and the measurement of ratios of cross sections for production of jets at the CMS. The experimental results are presented as a function of the rapidity separation $\Delta\eta$ between jets, and compared to the predictions of various Monte Carlo models and theoretical calculations.

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1. Introduction

The variable x denotes the fraction of the proton longitudinal momentum carried by an interacting parton (quark or gluon). Due to large calorimetric coverage, data collected by the Compact Muon Solenoid (CMS) detector at the CERN Large Hadron Collider (LHC) provides a valuable testing ground for the QCD in the low-x region. In this paper, three measurements are presented: the measurement of angular correlation between forward and central jet, the measurement of Mueller–Navelet dijet angular decorrelations (presented also in [1]) and the measurement of ratios of cross sections for production of jets at the CMS (presented also in [2]). Measurements are sensitive to low-x effects, such as BFKL evolution. In the low-x region, the standard approach to QCD perturbative calculations used in Monte Carlo simulations, where powers of $\log(Q^2)$ are summed (DGLAP — Dokshitzer–Gribov–Lipatov–Altarelli–Parisi [3–7]) may be not sufficient. The alternative approach is the BFKL (Balitsky–Fadin–Kuraev–Lipatov [8–10]) equa-

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tion, where powers of $\log(1/x)$ are summed and terms are ordered in x, not k_{T}. The aim of the measurements was to observe BFKL effects in the experimental data.

2. Experimental setup

A complete description of the CMS detector is presented in [11]. In this section, a brief description of subdetectors important for low-x measurements is presented.

To measure momenta of charged particles at the CMS, a superconducting solenoid that provides 3.8 T magnetic field parallel to the beam axis is used. Tracks of charged particles are measured by silicon pixel detectors and strip trackers for rapidity $|y| < 2.5$. The electromagnetic calorimeter (ECAL) and hadronic calorimeter (HCAL) extend to $|y| < 3$. ECAL is a lead tungstate crystal calorimeter with cells grouped in towers of size of $\Delta y \times \Delta\phi = 0.0174 \times 0.0174$ in the central part of the detector ($|y| < 1.5$) and 0.05×0.05 in $1.5 < |y| < 3.0$ region. The HCAL is a sampling calorimeter made of alternating layers of the absorber and the scintillator. The segmentation in the central part of HCAL is 0.087×0.087 and 0.17×0.17 in $1.6 < |\eta| < 3$. The Hadronic Forward (HF) calorimeter is the calorimeter covering the most forward pseudorapidity region from $|y| = 3$ to $|y| = 5.2$. The HF detector is located 11.2 m from the nominal interaction point and consists of steel absorbers containing embedded quartz fibers. The granularity of HF is 0.175×0.175 up to $|y| < 4.7$ and 0.175×0.35 at larger pseudorapidities. The calorimetric coverage of the CMS detector extends to rapidities $y = 5.2$. For jets with transverse momenta $p_{\mathrm{T}} = 35$ GeV, such rapidity range corresponds to exchanged objects x of the order of 10^{-4}.

3. Correlations of forward and central jets

In paper [12], angular correlations of forward and central jets are presented. Forward jet is defined as a jet in $3.2 < |\eta| < 4.7$ range and central jet is defined as jet in $|\eta| < 2.8$ range. A sample of all pairs with jets passing cut $p_{\mathrm{T}} > 35$ GeV is defined as the inclusive sample. Additionally, the inside-jet tag sample is defined as a sample of events with additional emission of jet with $p_{\mathrm{T}} > 20$ GeV between forward and central jet, and the inside-jet veto sample with veto on such a jet. Analysis is based on 2010 proton–proton data taken at $\sqrt{s} = 7$ TeV and the measurement is done as a function of separation in pseudorapidity between jets $\Delta\eta$. Results for data are corrected to the stable particle level and compared to different DGLAP-based Monte Carlo predictions as PYTHIA6, PYTHIA8, Herwig++ and Herwig6.5 with different tunes. Results for inclusive sample for different $\Delta\eta$ are presented in Fig. 1. Monte Carlo predictions underestimate data for low $\Delta\phi$. The best description is provided by Herwig++. The same conclusions come from the analysis of inside-jet tag and inside-jet veto samples. Nevertheless, all results are consistent with DGLAP-based Monte Carlo generators.

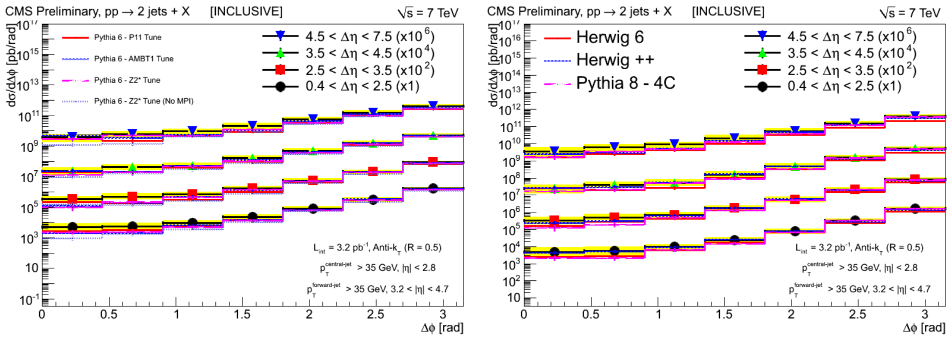

Fig. 1. Results for measurements of correlations between forward and central jets for inclusive sample compared to Monte Carlo predictions.

4. Correlations of Mueller–Navelet jets

Mueller–Navelet (MN) [13] dijets are defined as the pair of jets with the largest separation in rapidity Δy from all pairs of jets in the event. For each MN pair with jets passing the cut $p_{\mathrm{T}} > 35$ GeV, the angular distance is calculated: $\Delta\phi = \phi_1 - \phi_2$. In the analysis [14], distributions of the average cosines: $C_n = \langle \cos(n(\Delta\phi - \pi))\rangle$ for $n \in \{1, 2, 3\}$ are studied. They correspond to the coefficients of a Fourier series in $\Delta\phi$ and their ratios. Ratios of correlation factors are predicted to be more sensitive to BFKL evolution than $\Delta\phi$ distributions as some DGLAP effects cancel for ratios. The measurement is done as a function of Δy, where effects of BFKL should be more pronounced for large rapidity separation.

The analysis is based on data collected at 7 TeV in 2010. Jets are defined using the anti-kt [15] algorithm with cone radius $R = 0.5$. In addition to a standard single-jet trigger, a dedicated forward–backward trigger is used. It selects events with jets with uncorrected transverse momenta over 15 GeV and separation by at least 6.0 units of rapidity. This trigger provides a larger sample of rare events with large Δy. Two samples are merged with an algorithm described in [14]. The efficiency of the triggers for the jet sample considered is estimated to be 100%. All results are corrected for experimental effects to the stable particle level. Corrections are evaluated using PYTHIA6 [16] and Herwig++ [17] predictions passed through full detector simulation.

Jet Energy Scale is the largest input to the systematic uncertainty of the measurement. Smaller contributions to the systematic uncertainty comes from correction factors accounting for the finite resolution of the detector, and pile-up.

In Fig. 2, $\Delta\phi$ distributions for the bin with the smallest Δy ($0 < \Delta y < 3.0$) and the largest Δy ($6.0 < \Delta y < 9.4$) are presented. The systematic uncertainties are shown as a grey band. Results are compared to different Monte Carlo predictions. For the most central rapidity bin ($0 < \Delta y < 3.0$), the DGLAP-based Monte Carlo generators PYTHIA6 and Herwig++ provide a good description of the data. For large y separation, DGLAP-based generators show deviation outside experimental uncertainty for small $\Delta\phi$. The BFKL-based generator Cascade [18] shows too large decorrelation compared to the data. The best description is provided by Herwig++.

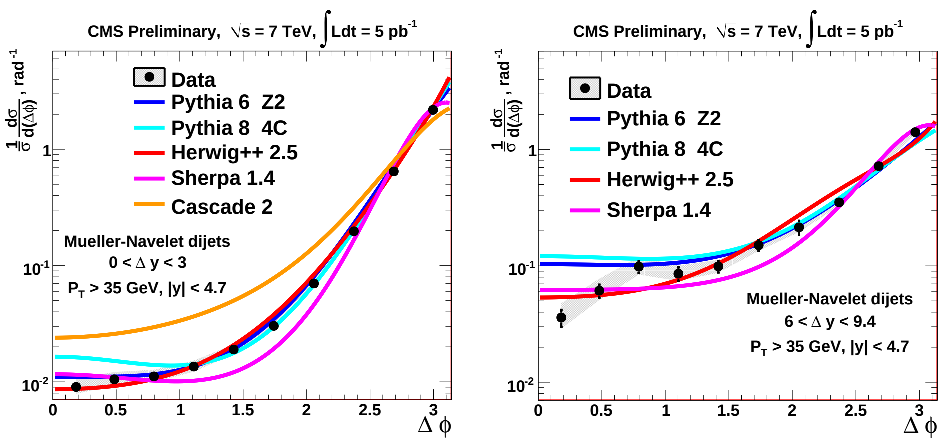

Fig. 2. Results for measurements of $\Delta\phi$ for two bins of Δy, compared to different Monte Carlo predictions.

Observables that were predicted to suppress DGLAP contribution are ratios of correlation factors. The measured C_2/C_1 ratios are presented in Fig. 3. Data is described by DGLAP-based Monte Carlos within uncertainties. There is a small difference between PYTHIA generators and Herwig++. Cascade underestimates and Sherpa [19] overestimates C_2/C_1 values. The NLL BFKL calculations [20] provide a good description of ratios, nevertheless they have large theoretical uncertainties.

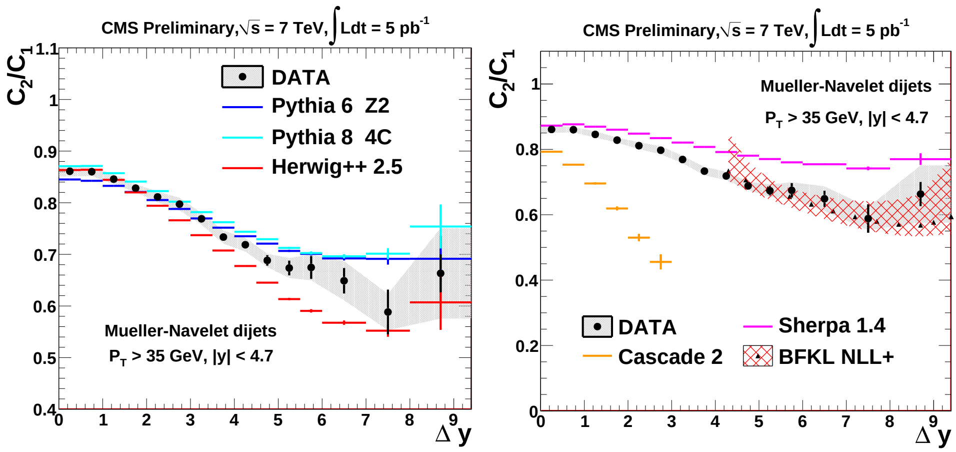

Fig. 3. Results for measurements of $C_2/C_1 = \langle\cos 2(\Delta\phi - \pi)\rangle \,/\, \langle\cos(\Delta\phi - \pi)\rangle$ for different Δy, compared to Monte Carlo predictions.

5. Ratios of dijet production cross sections

In the study [21], ratios of cross sections for dijets production are analyzed. Events with at least one pair of jets passing cuts $p_{\mathrm{T}} > 35$ GeV and $|\eta| < 4.7$ are taken to the analysis. First, the inclusive cross section σ_{incl} is defined as the one obtained by taking all pairwise combinations of jets in the event. The exclusive cross section σ_{excl} is then calculated from a subsample of events containing only one pair of jets. Additionally, Mueller–Navelet sample is defined, taking from all combinations of jet pairs the one with the largest $\Delta\eta$ separation, as in the paper with measurement of Mueller–Navelet dijets correlations. The corresponding cross section is denoted as σ_{MN}. One of the variables that could be sensitive to BFKL effects are ratios of cross sections: $R^{\mathrm{incl}} = \sigma_{\mathrm{incl}}/\sigma_{\mathrm{excl}}$ and $R^{\mathrm{MN}} = \sigma_{\mathrm{MN}}/\sigma_{\mathrm{excl}}$. Ratios are measured as a function of separation of jets in pseudorapidity $\Delta\eta$. The data were collected in 2010 and samples selected with two jet triggers were mixed to obtain high efficiency for events with large $\Delta\eta$ that are rare. Results for the data are corrected to the stable particle level.

Results of the measurement are presented in Fig. 4 and compared to the predictions of various Monte Carlo generators. PYTHIA6 tune Z2 and PYTHIA8 tune 4C agree with the measurement within systematical uncertainty presented as the grey/yellow band. Herwig++ and HEJ (+Ariadne) overestimate experimental data. Discrepancies are getting larger as the separation in pseudorapidity is being increased. Cascade predicts ratios much larger than observed in the data. Results for DGLAP-based PYTHIA are consistent with experimental data.

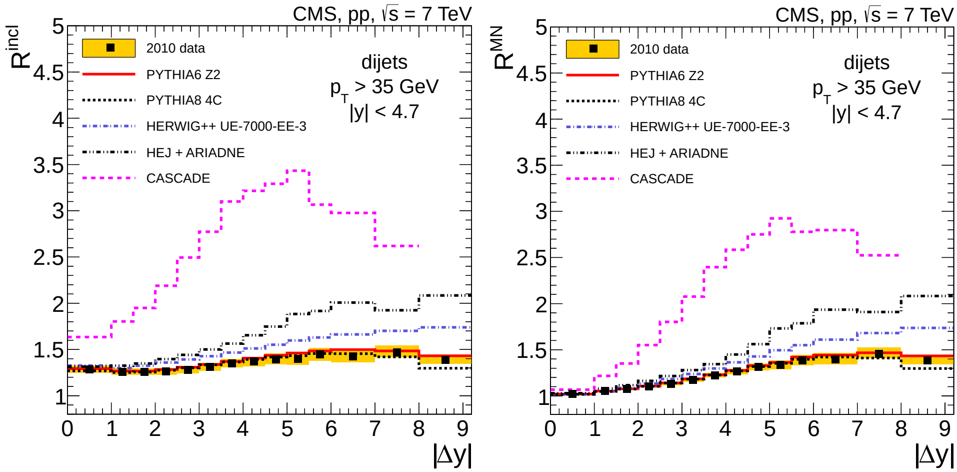

Fig. 4. Results for the measurements of $R^{\rm incl}$ and $R^{\rm MN}$ as a function of $\Delta\eta$.

6. Summary

Three measurements sensitive to BFKL data were presented. There is no clear indication of BFKL effects observed in the data. There are some discrepancies between theoretical predictions and data that will be studied in analyses of CMS Run 2 data taken in 2015.

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