Multijet Production at Low x_{Bj} and Forward Jet Production in DIS

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Multijet and forward jet production in DIS at low Bjorken- x has been studied by ZEUS. Data on jet azimuthal correlations are compared with NLO calculations. Data on rapidity correlations for three jets including at least one forward jet are compared with NLO calculations and Monte Carlo codes implementing different approaches to parton dynamics.

1 Introduction

A conventional approximation applied to calculations of hard processes in perturbative QCD is collinear factorisation and associated with it DGLAP equations. It is at present generally realized in two ways, either in Monte Carlo with LO matrix element and leading logarithm parton showers evolving according to DGLAP or in fixed order calculations and the collinear PDF as an input. Since in these approaches terms $(\log 1/x)^n$ are either omitted or summed only up to a few first orders, at small x_{Bj} they are expected to become invalid. An alternative approach, resumming $\log 1/x$ terms and realized in the BFKL equation, is expected to become relevant at small x_{Bj} . HERA has reached as low x_{Bj} as $n \cdot 10^{-5}$. A question if these x_{Bj} are low enough to reveal deficiency of collinear factorisation and applicability of BFKL and corresponding k_T factorisation is the subject of this work.

Understanding the small x_{Bj} regime is of particular relevance since at the LHC many important processes, such as the production of electroweak gauge bosons or Higgs particles, involve collisions of partons with a small fraction of the proton momentum which could be lower than x_{Bj} of HERA by more than one order of magnitude.

A key difference in the two approaches, immediately relevant for hadronic final states, is ordering of partons in transverse momentum, p_T . The DGLAP approach results in strongly ordered in p_T chains of partons, while the BFKL approach results in non-ordered in p_T chains. This difference could be best distinguished either by study of correlations in multijets states or by measuring the forward, i.e. close in rapidity to the proton, jet cross-sections, with the most resolving power in combining both. p_T non-ordering implies less correlated jets and higher forward jet cross-section. ZEUS extended in 1998-2000 years the range of accessible pseudorapidities allowing a study of forward jets up to $\eta = 4.3$. This analysis uses the data collected during this period, which correspond to an integrated luminosity of $81.8 \pm 1.5 \text{ pb}^{-1}$.

2 Calculations

Collinear factorisation is represented by the next-to-leading code NLOJET++ and leading logarithm Monte Carlo code LEPTO. The ARIADNE MC is an implementation of the Colour Dipole Model (CDM), which provides non-ordered in transverse momentum parton cascade,

i.e. BFKL-like evolution. Results with two tunings of ARIADNE are presented, the default tuning and a new tuning performed by H1 collaboration. Another representative of the k_T factorisation is the Monte Carlo code CASCADE, which is an implementation of the CCFM equations. The CCFM approach at small x_{Bj} converge to the BFKL. CASCADE is used with two sets of unintegrated parton (gluon) density function (uPDF), J2003 set-1 and set-2.

3 Results

The results in full are presented in [2] and [3]. The study was performed on the DIS small x_{Bj} sample. Jets were reconstructed with use of the inclusive k_T algorithm. The transverse energies of the jets were required to be $E_T^{\text{jet}} > 5$ GeV. In the multijets without forward jet sample one jet was required to have $E_T^{\text{jet}} > 7$ GeV.

Multijets without forward jet study was performed for $10^{-4} < x_{Bj} < 10^{-2}$. Double-differential cross-sections $d^2\sigma/dx_{Bj}d|\Delta\phi_{\text{HCM}}^{\text{jet1,2}}|$, where $|\Delta\phi_{\text{HCM}}^{\text{jet1,2}}|$ is the azimuthal separation of the two jets, for dijet sample are presented in Figure 1. Data are compared with NLOJET. The calculations $\mathcal{O}(\alpha_s^2)$ disagree with the data at low $|\Delta\phi_{\text{HCM}}^{\text{jet1,2}}|$. The calculations at $\mathcal{O}(\alpha_s^3)$ describe the data.

Figure 1: Dijet cross sections as functions of $|\Delta\phi_{\text{HCM}}^{\text{jet1,2}}|$. The NLOJET calculations at $\mathcal{O}(\alpha_s^2)$ ($\mathcal{O}(\alpha_s^3)$) are shown as dashed (solid) lines. The lower parts of the plots show the relative difference between the data and the $\mathcal{O}(\alpha_s^3)$ predictions.

Trijets with a forward jet study was performed at $0.0004 < x_{Bj} < 0.005$. A forward jet was a jet with the pseudorapidity $2 < \eta^{\text{jet}} < 4.3$ and a fraction of the proton momentum $x^{\text{jet}} = p_Z^{\text{jet}}/p > 0.036$. Two other jets could have lower pseudorapidities, $-1.5 < \eta^{\text{jet}} < 4.3$. The three selected jets were ordered in pseudorapidity such that $\eta^{\text{jet}_1} < \eta^{\text{jet}_2} < \eta^{\text{jet}}$. Cross sections were plotted as functions of two pseudorapidity separation $\Delta\eta_1 = \eta^{\text{jet}_2} - \eta^{\text{jet}_1}$ and $\Delta\eta_2 = \eta^{\text{jet}} - \eta^{\text{jet}_2}$. Additionally, the cross section as a function of $\Delta\eta_2$ was plotted for two intervals of $\Delta\eta_1$, $\Delta\eta_1 < 1$ and $\Delta\eta_1 > 1$.

Figure 2: The forward jet+dijet cross sections. Data are compared with the NLO QCD calculations (solid line). The hatched area shows the theoretical uncertainties. The shaded area shows the cumulative uncertainty of the CAL and FPC energy scales.

significantly below the data. ARIADNE with default tuning overestimates the cross sections, which implies that energetic multiple jets are too often produced. The new tuning of the ARIADNE parameters brings this model into very good agreement with data for all distributions.

A comparison of the CASCADE MC to the data is presented in Figure 4. Neither of two uPDF sets provides a satisfactory agreement with the data.

Figure 2 shows the comparison of the data with the calculations of NLOJET++. The calculations agree with data at large $\Delta\eta_2$, while do not describe the data at small $\Delta\eta_2$, especially when $\Delta\eta_1$ is small. The large $\Delta\eta_2$ kinematics at low x_{Bj} favours dijets originating from the photon-gluon fusion, with an additional gluon responsible for the forward jet. This case is well treated by NLOJET++. The small $\Delta\eta_1$ and $\Delta\eta_2$ region corresponds to the event configuration in which all the three jets tend to go forward, away from the hard interaction. This configuration favours multigluon emission, which lacks in NLOJET++.

Figure 3 presents the comparison of the data with LEPTO and ARIADNE. The LEPTO predictions are generally sig-

Figure 3: The forward jet+di-jet cross sections. Data are compared with LEPTO, default ARIADNE and newly tuned ARIADNE.

Figure 4: The forward jet+di-jet cross sections. Data (dots) are compared with the CASCADE set-1 (solid histogram) and CASCADE set-2

4 Conclusions

Multijet and forward jet production in DIS at low Bjorken- x has been studied by ZEUS. Two jet azimuthal correlations reveal deficiency of NLO calculations at $\mathcal{O}(\alpha_S^2)$. Higher order, $\mathcal{O}(\alpha_S^3)$, suffices to describe the data. More sensitive probe is correlations in pseudorapidity of three jets with at least one forward jet, which $\mathcal{O}(\alpha_S^3)$ fails to reproduce. The LEPTO MC, representing the DGLAP approach, also fails, the cross-sections are generally much below the data. The CASCADE MC, representing the CCFM approach, is unable to satisfactorily describe the data with neither set of unintegrated gluon density, J2003 set-1 or J2003 set-2. Only CDM based MC ARIADNE with new tuning provides good description of the data.

References

- [1] Slides:
<http://indico.cern.ch/contributionDisplay.py?contribId=204&sessionId=13&confId=24657>
- [2] ZEUS Collaboration; S. Chekanov et al., Eur. Phys. J. C52 515 (2007)
- [3] ZEUS Collaboration; S. Chekanov et al., Nucl. Phys. B 786 152 (2007)