Forward Jets and Multiple Interactions

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Abstract
HERA provides a unique possibility to investigate the dependence of multiple interactions on transverse interaction sizes through variation of the photon virtuality Q^2. In order to observe effects of multiple interactions at Q^2 substantially different from zero we have to look into regions of phase space where resolved processes dominate over direct ones. The forward jet production at small values of Bjorken x is one example. PYTHIA and RAPGAP have been employed to estimate contribution of the multiple interactions to forward jet production cross section.

Comparisons of HERA photoproduction data with QCD NLO calculations for high transverse momentum jets revealed that the observed jets are not well described by the calculations. The energy flow adjacent to jets - the underlying event or jet pedestal - was found to be far above QCD expectations [1]. Similar excess of underlying energy was observed in $p\bar{p}$ data, see [2] and [3] for recent studies. It appears that both HERA and TEVATRON data can be described by adding beam remnant interactions, from soft to hard, as first proposed in ref. [4]. The remnant beam-beam interactions can result in multiple hard parton interactions (MI) thus creating additional pairs of jets. Therfore the presence of four high transverse momentum objects in the hadronic final state (e.g. four jets or prompt photon and three jets) allows searches for signatures of multi-parton interactions in a region of phase space where their effects may be maximized. The evidence of MI coming from 4-jet studies is more explicit and is not complicated by initial/final state radiation and soft beam-remnant components of the underlying event. Both ZEUS [5] and CDF [6] observed explicite double parton interactions in rough agreement with PYTHIA [4, 7] simulations.

The very interesting aspect of measurements at HERA is that variation of the photon virtuality Q^2 provides information about transverse interaction sizes. Observation of the dependence of MI on Q^2 could be important from the phenomenological point of view. In order to see MI at photon virtuality substantially different from zero we have to look into regions of phase space for deep inelastic scattering where the resolved virtual photon processes dominate over direct ones. The forward jet production at small values of Bjorken x is one example. Here one could expect that additional interactions between the remnants of the proton and resolved virtual photon would produce extra hadron multiplicity in an underlying event. Although the transverse momentum of these hadrons would be limited, they could still give a substantial effect on the rate of forward jets which have a steeply falling $p_\perp$ spectrum.

The forward jet cross-section is especially interesting since it has been notoriously difficult to reproduce by standard DGLAP-based parton shower event generators. It has been shown that the description of the forward jet cross section can be improved by adding resolved virtual photon component in eg. the RAPGAP Monte Carlo [8], but the jet rates produced in the simulations are still a bit too low in the small-x region. In order to check if MI can give measurable contribution to this process we have performed a study in which we estimate MI effect using both PYTHIA 6.2 and RAPGAP 3.1. We use PYTHIA since the MI model there has been shown to be able to give a good description of underlying events and jet pedestal effects in hadron-hadron collisions and in photoproduction, and it is fairly easy to apply the same model to the resolved part of the $\gamma^\star - p$ collisions. However, PYTHIA does not describe correctly the transverse energy flow in in DIS at HERA above $Q^2 \approx 5\ \mathrm{GeV}^2$. We can still use PYTHIA to estimate the relative effect of MI and we have generated forward jet cross section with H1 cuts [9]:

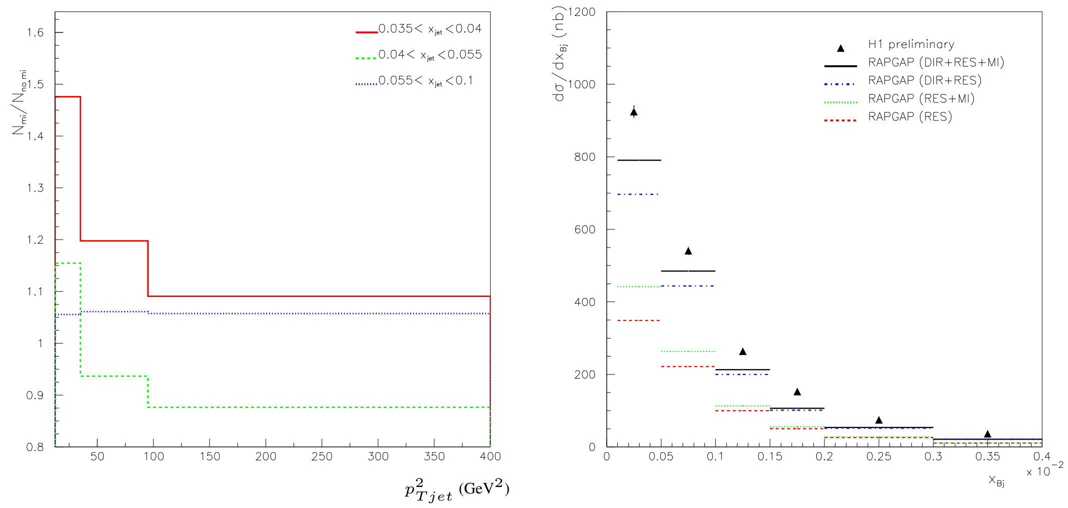

Fig. 1: **Left:** Ratio of forward jets with and without multiple interactions as a function of jet transverse momentum squared for three regions of proton momentum fraction carried by jet **Right:** The H1 forward jet cross section data compared with RAPGAP 3.1 simulation. Multiple interactions are included as x, Q^2, x_{jet} and p^2_{Tjet} dependent weights to resolved component, calculated using PYTHIA 6.2

($p_{Tjet} > 3.5$ GeV,$x_{jet} > 0.035$, $20° > \Theta_{jet} > 7°$ and $0.5 < p^2_{Tjet}/Q^2 < 5$) using PYTHIA 6.2 with default settings in γp mode (MI in mode 2) with $\gamma^\star$ momentum corresponding to several values of x and Q^2 within DIS kinematical phase space $0.0001 < x < 0.004$ and $5 < Q^2 < 85$ GeV^2.

In Fig. 1 (left) we show example of the ratio of number of the forward jets with and without MI, here for $x = 0.0004$ and $Q^2 = 8$ GeV^2, as a function of p^2_{Tjet}. It can be seen that effect of MI is quite substantial in the lowest p^2_{Tjet} bin. Treating the above mentioned ratios as weights depending on x, Q^2, x_{jet} and p^2_{Tjet}, we have generated inclusive forward jet cross section using RAPGAP 3.1 within above mentioned H1 cuts. The Fig. 1 (right) shows the result of this calculation. The inclusive forward jet cross section is enhanced by MI for about 15% in the lowest x bin, in fact improving description of the data. The effect of MI diminishes quickly with increasing x as result of decreasing contribution of the resolved photon component.

This very preliminary study suggests that Q^2 dependence of multiple interactions can be studied at HERA. This will require large statistics and an improved understanding of the underlying QCD evolution in forward jet production.

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