Subjet Distributions in NC DIS

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$e (E_e = 27.5 \text{ GeV}) \quad p (E_p = 920 \text{ GeV}) \quad \sqrt{s = 318 \text{ GeV}}$

HERA
The investigation of the internal structure of jets gives insight into the transition between a parton produced in a hard process and the experimentally observable jet of hadrons.

At sufficiently high $E_T^{jet}$, the internal structure of jets is expected to be calculable in pQCD, since the fragmentation effects are small.

Parton radiation is described in pQCD by means of the splitting functions $P_{ab}(x, \mu)$, which give the probability of a parton $b$ arising from a parton $a$ with a fraction $x$ of its momentum.

$O(\alpha_s^2)$ calculations can be obtained in the laboratory frame with up to have 3 partons in one jet, which corresponds to the NLO contribution to substructure.
The internal structure of jets can be studied by means of **subjets**.

Subjets are obtained within a jet by **reapplying the** $k_T$ **cluster algorithm** on all the particles belonging to the jet, until for every pair of clusters the distance between them is greater than $d_{cut}$, with

$$d_{cut} = y_{cut} (E_T^{jet})^2$$

$y_{cut} = \text{resolution parameter}$

The remaining clusters are called **subjets**.

The **subjet multiplicity** depends on the value of $y_{cut}$.
In this analysis, jets were reconstructed in NC DIS events with $Q^2 > 125 \text{ GeV}^2$

The jets must satisfy:

- $E_T^{jet} > 14 \text{ GeV}$ and $-1 < \eta^{jet} < 2.5$

We studied in detail the pattern of QCD radiation from a primary parton by measuring normalised cross sections as a function of the subjet observables in two different jet samples.

- The first sample corresponds to jets with exactly two subjets at a value of $y_{cut} = 0.05$. (82 $\text{pb}^{-1}$ of ZEUS data)
- The second sample corresponds to jets with exactly three subjets at a value of $y_{cut} = 0.03$. (334 $\text{pb}^{-1}$ of ZEUS data)
• Measurements of normalised cross sections as functions of observables sensitive to the pattern of parton radiation:

\[ \frac{E_{T}^{s\text{bj}}}{E_{T}^{\text{jet}}}, \eta^{s\text{bj}} - \eta^{\text{jet}}, |\phi^{s\text{bj}} - \phi^{\text{jet}}| \text{ and } \alpha^{s\text{bj}} \]

and their variation with the scale by studying the dependence with:

\[ E_{T}^{\text{jet}}, Q^{2} \text{ and } x_{\text{BJ}} \]

• The value of \( y_{\text{cut}} = 0.05 \) and \( y_{\text{cut}} = 0.03 \) chosen are a compromise between statistics, resolution and hadronisation corrections.
NLO CALCULATIONS

- Next to leading order calculations were performed using DISENT
- Some of the contributing diagrams are

The following uncertainties were considered:
- Uncertainty in the modelling of the parton shower
- Contribution of higher-order terms
- Choice of $\mu_F$
- Uncertainty in PDFs
- Uncertainty in $\alpha_s$
DATA vs NLO: RESULTS

Two-subjet jets

- Normalised cross sections for:
  - $E_T^{s_bj}/E_T^{jet}$
  - $\eta^{s_bj} - \eta^{jet}$
  - $|\phi^{s_bj} - \phi^{jet}|$
  - $\alpha^{s_bj}$

- NLO calculations give an adequate prediction of the data
- We also study the **coherence effects** between initial and final states parton radiation.

- Soft emissions (low-$E_T$ subjets) will tend to be in the direction of the **proton beam**.
- Highest $E_T$ subjet expected to be in the **rear part** of the jet.

Jet axis is reconstructed as the transverse-energy-weighted of the subjet axes. Highest $E_T$ subjet tends to be closer to jet axis.

- Expectation of the **colour-coherence effects** **supported**.
DATA vs NLO: RESULTS

- Normalised cross sections for:
  - $E_T^{sbj} / E_T^{jet}$
  - $\eta^{sbj} - \eta^{jet}$
  - $|\phi^{sbj} - \phi^{jet}|$
  - $\alpha^{sbj}$

  versus the gluon- and quark- induced processes separately.

- The $O(\alpha_S^2)$ prediction: 82% of q-induced and 18% of g-induced

- The data are better described by the prediction of the q-induced processes.
DATA vs NLO: RESULTS

Two-subjet jets

Dependence with $E^\text{jet}_T$

- Data have similar shape for all $E_T$ regions, which agrees with the expected scaling behaviour of the splitting functions.

- These features are reasonably reproduced by the NLO calculations.
DATA vs NLO: RESULTS

Two-subjet jets

Dependence with $E_T^{\text{jet}}$

- Data have similar shape for all $E_T$ regions, which agrees with the expected scaling behaviour of the splitting functions.

- These features are reasonably reproduced by the NLO calculations.

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**DATA vs NLO: RESULTS**

Two-subjet jets

**Dependence with $Q^2$**

- fraction of gluon-induced events varies from 32% in the first bin to 14% in the other regions.

- At low $Q^2$ scaling violations are more prominent.

- These features are reasonably reproduced by the NLO calculations.

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**DATA vs NLO: RESULTS**

Two-subjet jets

**Dependence with $x_{BJ}$**

- Data have similar shape for all $x_{BJ}$ regions, which agrees with the expected scaling behaviour of the splitting functions.

- At low $x_{BJ}$ scaling violations are more prominent.

- Similar features as in $Q^2$
Subjet distributions in NC DIS

Three-subjet jet structure

- We now extend our studies of jet substructure by measuring subjet cross sections with respect to the variables:

  $\alpha^{sbj}$: The angle, as viewed from the jet centre in the $\eta - \phi$ plane, between the lowest $E_T$ subjet and the proton beam direction.
DATA vs LO: RESULTS

- Normalised cross sections for:
  \( E_T^{\text{subj}} / E_T^{\text{jet}} \), \( \eta^{\text{subj}} - \eta^{\text{jet}} \), \( |\phi^{\text{subj}} - \phi^{\text{jet}}| \)

Three-subjet jets at \( y_{cut} = 0.03 \)

The \( O(\alpha_s^2) \) calculations describe the data adequately.
Subjet distributions in NC DIS

DATA VS LO: RESULTS

- Normalised cross sections for:
  \( \alpha^{s\text{bj}} \), \( \eta^{s\text{bj}} - \eta^{\text{jet}} \), \( \eta^{s\text{bj}} - \eta^{\text{jet}} \)

Three-subjet jets at \( y_{\text{cut}} = 0.03 \)

The \( O(\alpha_s^2) \) calculations describe the data adequately
CONCLUSIONS

- The data show:
  - Subjets tend to have similar transverse energies.
  - The lowest $E_T$ subjet tends to be in the forward direction.
  This supports the presence of colour coherence effects between initial and final states.

- In the two-subjet sample:
  - A weak dependence on $E_T^{\text{jet}}$ is observed, in agreement with the expected scaling behaviour of the splitting functions.
  - At low $Q^2$ and low $x$ some differences are observed, which can be attributed to scaling violations.

- This features about the pattern of QCD radiation, as well as the evolution of the cross sections with the scale are reasonably well described by the NLO calculations.

- As well, the data are better described by the calculations for jets arising from a quark-gluon pair.