Forward Jet Production in DIS

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OUTLINE:

- QCD Dynamics at Low x
- MC Modes and QCD Calculations
- ZEUS Detector and FPC Component
- Inclusive Forward Jet Measurement with ZEUS data 98-2000
- Conclusions
QCD Dynamics at Low $x$

**DGLAP** (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) is expected to break down at low $x$ and $Q^2$ region

**BFKL** (Balitsky-Fadin-Kuraev-Lipatov) can be applicable at low $x$

**CCFM** (Ciafaloni-Catani-Fiorani-Marchesini) describes an evolution in both $Q^2$ and $x$ and approaches BFKL at low $x$ and DGLAP at high $Q^2$; angular ordering
MC Models and QCD Calculations

• **DISENT**: Fixed order QCD partonic cross section, on mass shell ME + DGLAP

• **LEPTO**: LO ME+PS , (DGLAP)
  - Strong ordering in $k_T$

• **ARIADNE**: LO, an implementation of Color Dipole Model (CDM)
  - Independently radiating dipoles formed by quarks and emitted gluons
  - Random walk in $k_T$ like in BFKL

• **CASCADE**: LO off mass shell ME + parton shower based on $k_T$ factorized CCFM evolution model
  - Angular ordering in parton emission
  - Unintegrated gluon densities fits *J2003 set 1* (with new treatment of soft region) and *J2003 set 2* (fit form includes non singular terms)
Inclusive Event Selection

**Jet carries a large fraction of longitudinal momentum of proton in order to maximise phase space for BFKL evolution.**

**DGLAP type of evolution is suppressed, leaving no room for strong ordering in transverse momenta.**

**CCFM incorporates both types of evolution.**

**Forward jet selection:**
- inclusive $k_T$ -algorithm; mode 3212 in Breit frame; CAL and FPC cells; position of CAL cells corrected with imbalance
- Forward jet cut
  - $E_{jet} > 33$ GeV ($x_{jet} > 33/920$)
- BFKL-cut
  - $0.5 < E_{T, jet}/Q^2 < 2$
  - $E_{T, jet} > 5$ GeV
  - safe for the jet algorithm used
- $2 < \eta_{jet} < 4.3$, forward region

**DIS event selection:**
- $0.04 < y < 0.7$
- $20 < Q^2 < 100$ GeV$^2$
- $0.0004 < x < 0.005$
Di-Jets Plus Forward Jet Selection

- In addition to the forward jet, at least two more jets are found. Out of these, the two with the highest transverse momenta are chosen.

- For the ‘2+forward jet’ sample the $E_{T,\text{jet}}$ is required: $E_{T,\text{jet}} > 5$ GeV for all 3 jets; in this case evolution with strong $k_t$-ordering is not favoured.

- The other cuts on the forward jet are kept the same as specified before, except that no $0.5 < \frac{E_{T,\text{jet}}^2}{Q^2} < 2$ cut applied.

- The two additional jets are required to lie in pseudorapidity:
  \[ \eta_{\text{jet}1} < \eta_{\text{jet}1} < \eta_{fwd-jet} \]
  \[ -1.5 < \eta_{\text{jet}1}, \eta_{\text{jet}2} < 4.3 \]

The cross sections are measured for all ‘2+forward jet’ events and versus $\Delta \eta_2$ in two intervals of $\Delta \eta_1$:

- $\Delta \eta_1 < 1$, favours small invariant masses of the di-jet system and thereby small values of $x_g$ - phase space for evolution in $x$ (BFKL)
- $\Delta \eta_1 > 1$
Forward Jet Measurement with Forward Plug Calorimeter (FPC)

- Forward Plug Calorimeter in the 20 x 20 cm² beam hole of FCAL for 98-2000
- Lead-scintillator sandwich with 60 EMC and 16 HAC cells
- Extend calorimeter acceptance by about 1 unit in pseudorapidity to $\eta \leq 5$
Forward Jets with $\eta^{\text{JET}} > 2.5$

- Only EMC cells are drawn
- Reconstructed jet position is shifted into direction of jet energy deposit in FCAL
- Cell size in FCAL and FPC is different
- Large difference in $P_T$ for cells in 1st and 2nd rings seems to make a shift into a lower reconstructed $\eta^{\text{JET}}$ values
- An access of reconstructed jets around the range $2.8 < \eta^{\text{rec}} < 3.4$ was cleared with a “Fiducial” cut
Differential Cross Sections

- Systematic errors generally small except the bins where corrections with ARIADNE and LEPTO differ

- Systematic checks including CAL energy variations +/- 3% and FPC energy scale variations +/- 10% in simulations drawn separately

- CDM (ARIADNE) gives a good description of data except of very forward $\eta$

- CASCADE set1 closer to data as set2. However both CASCADE sets do not reproduce shapes of cross sections
Comparison with DISENT

- Average hadronisation correction obtained with LEPTO and ARIADNE MC
- Proton pdf CTEQ5
- NLO predictions lower than data by a factor of ~ 2
- Theory has too large uncertainty
CDM (ARIADNE) higher by a factor of ~2 then measured differential di-jets plus forward cross-sections.

CASCADE set2 closer to data as set1 (!)
Conclusions

- Parton dynamics at low-x has been studied in forward jet production in DIS by ZEUS

- CDM (ARIADNE) gives a good description of data in all measured inclusive forward jet cross sections except of very forward $\eta$ range

- LO CCFM-based CASCADE does not describe shapes of inclusive forward jet cross sections

- NLO calculations below data

- CASCADE set2 model favors measured di-jets plus forward jet cross sections; CDM and CASCADE set1 do not
Forward Jets with $\eta^{\text{JET}} > 2.5$

Clear access of reconstructed jets around the range:

$$2.8 < \eta_{\text{rec}} < 3.4$$
"Fiducial" cut out of problematic jets in the range:

\[2.8 < \eta_{\text{rec}} < 3.4, \quad \phi \in (0., 0.4), (1., 2.2), (2.7, 3.6), (4.2, 5.3), (5.7, 6.3) \text{ rad}\]