Studies of the hadronic final state with the H1 detector

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Recent Results from H1

- Photoproduction of Dijets with High Transverse Momenta at HERA.
- Multi-jet production in high Q2 neutral current deeply inelastic scattering at HERA and determination of $\alpha_s$.
- H1 Search for a Narrow Baryonic Resonance Decaying to $K^0_s p(\bar{p})$.
- Measurements of Forward Jet Production at low $x$ in DIS.
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HERA + H I
electrons
27.6 GeV
electrons 27.6 GeV
Protons 920 GeV
electrons 27.6 GeV
Protons 920 GeV
electrons

27.6 GeV

Protons

920 GeV

PETRA
Solenoid 1.16 T
Liquid Argon Calorimeter
Instrumented Iron Detector
Forward Muon Spectrometer
27.6 GeV
920 GeV
Forward Tracker
Silicon Tracker
Central Tracker
Central MWPCs
ToF Scintillators
Backward MWPC
Spaghetti Calorimeters
Forward Jet Production at HERA
Inelasticity

\[ y = \frac{p.q}{p.k} \]

\[ s = Q^2 \]

\[ x = \frac{Q^2}{2p.q} \]

Kinematics overstrained
calculable from electron or proton side

Kinematics

Four-momentum transfer squared

\[ Q^2 = -q^2 = (k-k^\prime)^2 \]

Bjorken \( x (x_{bj}) \)

\[ x = \frac{Q^2}{2p.q} \]

Inelasticity \( y \)

\[ y = \frac{p.q}{p.k^\prime} \]
Parton Evolution

\[ x_i = \text{longitudinal momentum fraction} \]
\[ k_t = \text{transverse momentum} \]
Monte Carlo and NLO predictions

DGLAP Type
DISENT, RAPGAP

'BFKL'-Type
ARIADNE

CCFM
CASCADE

Colour Dipole Model
Emission from independent
dipoles produces
no $k_t$-ordering

'${k}_t$-factorisation'
Enhancing non-DGLAP Parton Emissions

Suppress DGLAP $P_{t,\text{jet}}^2 \sim Q^2$

Opens up phase space to BFKL type emissions

$x_{\text{jet}} >> x_{\text{bj}}$

Forward Jet takes large fraction of proton momentum

kinematic acceptance $x_{\text{bj}} \sim 10^{-4}$, $\theta_{\text{jet(lab)}} > 7^\circ$, $\eta_{\text{jet}} < 3.0$
### Event selection

<table>
<thead>
<tr>
<th>Condition</th>
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<tbody>
<tr>
<td>( E_{e'} &gt; 10 \text{ GeV} )</td>
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<tr>
<td>( 156^\circ &lt; \theta_{e'} &lt; 175^\circ )</td>
</tr>
<tr>
<td>( 0.1 &lt; y &lt; 0.7 )</td>
</tr>
<tr>
<td>( 0.0001 &lt; x_{bj} &lt; 0.004 )</td>
</tr>
<tr>
<td>( 5 \text{ GeV}^2 &lt; Q^2 &lt; 85 \text{ GeV}^2 )</td>
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<th>Condition</th>
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<tr>
<td>( p_{t,\text{jet}} &gt; 3.5 \text{ GeV} )</td>
</tr>
<tr>
<td>( 7.0^\circ &lt; \theta_{\text{jet(lab)}} &lt; 20^\circ )</td>
</tr>
<tr>
<td>( x_{\text{jet}} &gt; 0.035 )</td>
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Inclusive \( k_t \) jet algorithm in Breit frame
Inclusive Forward Jet Production

H1 forward jet data

- H1 prelim.
- E scale uncert.
- NLO di-jet 1+HAD
- PDF uncert.
- LO di-jet
- H1 forward jet data

NLO = DISENT
PDF = CTEQ6M

\[ \mu_r^2 = E_T^2 \text{ of Jet} \]

\[ \mu_f^2 = \langle E_T^2 \rangle = 45 \text{ GeV}^2 \]

NLO significantly below data

Is scale uncertainty large enough?
Large difference from LO to NLO predictions!
Inclusive Forward Jet Production

Significant improvement in RapGap (DGLAP) description if resolved photon interactions included

CDM similar model to RG-DIR+RES

Both still too low at low $x_{bj}$

CASCade shape wrong!
Predictions sensitive to proton PDF used.
Triple Differential Cross Sections

Good description at high $Q^2$, high $P_{t,jet}^2$ and high $x_{bj}$

Additional emissions needed at low $Q^2$, $P_{t,jet}^2$, $x_{bj}$

$$r = \frac{p_{t,jet}^2}{Q^2}$$
Triple Differential Cross Sections

- **RG DIR Fails**
- **RG DIR+RES Better**
- **CDM good**
  - problems at high $p_{t,jet}^2$
- **CAScade wrong**
  - shape, sensitivity to PDF
Forward Jet + Dijet

Two central jets ($p_t > 6$GeV) + Forward Jet

$\Delta \eta_1 < 1,$
$\eta_g$ small, $\Delta \eta_2$ large,
room for BFKL ladder

$\Delta \eta > 1,$
$\Delta \eta_2$ small, shorter
ladder, less BFKL like
3 jet predictions from NLOJET++

scale uncertainties large

no model able to work in all phase space
Photoproduction of Dijets with high Transverse Momenta at HERA
\[ x_p = \frac{1}{2E_p} \sum_{i=1}^{2} p_{t,i} e^{+\eta_i} \]
\[ x_\gamma = \frac{1}{2yE_e} \sum_{i=1}^{2} p_{t,i} e^{-\eta_i} \]

**Photoproduction**

\[ Q^2 < 1 \text{ GeV}^2 \]

Experimentally

no electron seen

\( x_\gamma < 0.8 \rightarrow \) resolved

\( x_\gamma > 0.8 \rightarrow \) direct
QCD Models

PYTHIA 6.1
Born level QCD matrix elements of hard processes
  + minimum $p_t$ cutoff
  + LO proton (CTEQ5L) PDF
  + photon (GRV-LO) PDF
  + leading log parton shower models
  + multiple interactions + string hadronisation

only contain 2→2 photoproduction processes
have to apply scale factor 1.2 (1.55 for HERWIG)

Only PYTHIA shown, HERWIG very simmilar
NLO Calculations

pQCD NLO jet cross sections on parton level obtained from programs by Frixione + Ridolfi

proton PDF = CTEQ6M
photon PDF = GRV-HO

Factorisation and renormalisation scale ($\mu_f \mu_r$) set to sum of pt of outgoing partons /2

Hadronisation correction ($\delta_{\text{had}}$) from Monte Carlo
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<tr>
<td>$</td>
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<tr>
<td>$p_{t,\text{miss}} &lt; 20$ GeV</td>
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<tr>
<td>non-ep topological background finder</td>
</tr>
<tr>
<td>no identified scattered electron</td>
</tr>
<tr>
<td>jet mass $&gt; 2$ GeV</td>
</tr>
<tr>
<td>Not (Jet in $\varphi$ crack and jet size $&lt; 0.05$)</td>
</tr>
<tr>
<td>$p_{t,\text{jet}} &gt; 25$ GeV</td>
</tr>
<tr>
<td>$p_{t,\text{jet}2} &gt; 15$ GeV</td>
</tr>
<tr>
<td>$-0.5 &lt; \eta_{\text{jet}} &lt; 2.75$</td>
</tr>
<tr>
<td>$0.1 &lt; \gamma_{\text{JB}} &lt; 0.9$</td>
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</tbody>
</table>
\[ \cos^* = \frac{1}{\Delta \eta_1 \Delta \eta_2} \]

- For \( x_\gamma < 0.8 \):
  - \( \frac{d\sigma}{d\cos^\ast} \) varies with a different dependence on \( \cos^\ast \).
  - The dependence is \( \propto (1-\cos^\ast)^{-2} \) compared to the \( x_\gamma > 0.8 \) region.

- For \( x_\gamma > 0.8 \):
  - The dependence is \( \propto (1-\cos^\ast)^{-1} \).

- The data points are shown with error bars, and the theoretical predictions are represented by different colored lines:
  - Black: H1 preliminary
  - Dotted: NLO
  - Yellow: NLO \times (1 + \delta_{\text{scale}})
  - Green: Pythia \times 1.2

**Legend:**
- Yellow: Scale
- Green: Scale + PDF

**Summary:**
- The plot illustrates the distribution of differential cross sections for different kinematic regions, demonstrating the impact of the scale and PDF uncertainties on the predictions.
$x_{\gamma}$

$d\sigma/dx_{\gamma} [pb]$

$x_p < 0.1$

H1 prel.

- NLO

NLO $\times (1+\delta_{\text{nlo}})$

Pythia $\times 1.2$

$x_p > 0.1$

photon - gluon

photon - quark

nlo dominated by the scale uncertainty
high $x_p$ sensitive to proton PDF

high $x_p$ - high jet $\eta$

scale uncertainty smallest
Multi-jet production in high $Q^2$ neutral current deeply inelastic scattering at HERA and determination of $\alpha_s$

H1prelim-05-033
Multi-jet production in high $Q^2$ neutral current deeply inelastic scattering at HERA and determination of $\alpha_s$

H1prelim-05-033
Multi-jet production in high $Q^2$ neutral current deeply inelastic scattering at HERA and determination of $\alpha_s$

H1prelim-05-033

$\alpha_s(M_Z) = 0.1175 \pm 0.0017$ (stat.) $\pm 0.0050$ (syst.)

$\{+0.0054\}\{-0.0068\}$ (th.)
H1 Search for a Narrow Baryonic Resonance Decaying to $K_0^s\, p(p)$

H1prelim-05-031
H1 Search for a Narrow Baryonic Resonance Decaying to $K^0_s \, p(p)$

Upper limit on cross section at 1520MeV is roughly 100pb, does not exclude ZEUS observation

H1 preliminary data
bgr fit

Low momentum dE/dx selection

95 % C.L.
20<Q^2<100 GeV^2
Summary

• Studies of Forward Jets show need for additional terms beyond present collinear DGLAP

• New results on the photoproduction of high Et dijets, sensitive to the proton PDF, have been made.
Parton Dynamics in DIS

DGLAP direct photon

DGLAP resolved photon

CCFM or BFKL

Strong ordering in $k_t$ of parton emissions

angular ordering of parton emissions