HADRONIC FINAL STATES AT H

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for the H1 and ZEUS Collaborations

- **Charged multiplicities**
- **Inclusive jets**
- **Multijets**
- **Forward jets**
- **Strange particles**
- **Bose-Einstein co**

HERA: 920 GeV p on 27.5 GeV $e^{\pm}$. Q^2 = virtuality of e

Aims:
DIS Breit Frame at lowest order looks like 1/2 an e^+e^- scattering event.
Study fragmentation in terms of charged particle multiplicity $<n_{\rm ch}>$.
Current (jet) region mostly within ZEUS CTD.

Main selections:
– $E_{e'} > 12$ GeV for scattered $e^{\pm}$
– cuts to reject remaining photoproduction
– reject diffractive events
– p_T of tracks > 150 MeV
– $\eta_{\rm lab} < 1.75$ for good tracks

Compare with ARIADNE 4.08 (Colour dipole model) and with LEPTO 6.5, both using Lund strings.

- **The HERA measurements agree with others over wid scale, provided E_{current} or W is used.**
- **ARIADNE gives a better description than LEPTO**

Aims:
Improved jet measurements in Breit Frame,
$\longrightarrow$ **better comparison with models,**
$\longrightarrow$ α_S **determination.**

Main selections:
– $Q^2 > 125$ **GeV^2**
– **cuts to reject remaining photoproduction**
– **Good jet acceptance:** $-0.7 < \cos\gamma < 0.5$
where $\gamma =$ **angle of LO emerging**

Reconstruct jets from calorimeter signals, with longitudin
cluster algorithm.
Select $-2 < \eta^B < 1.8$ **and** $E_T^B > 8$ **GeV for jet in Brei**

Compare with DISENT (LO + NLO) ($\alpha_S = 0.1175$**)**
Theory uncertainty: vary PDFs and vary renorm. scale by

Good agreement with earlier results and with NLO QCD

Evaluate α_S from $d\sigma/dE^{jet}_{T,B}$ for $E^{jet}_{T,B} > 8$ GeV:

$$\alpha_S(M_Z) = 0.1201 \pm 0.0006(\text{stat.})\ {}^{+0.0033}_{-0.0038}(\text{exp.})\ {}^{+0.004}_{-0.003}$$

from $d\sigma/dQ^2$ for $Q^2 > 500$ GeV^2:

$$\alpha_S(M_Z) = 0.1196 \pm 0.0011(\text{stat.})\ {}^{+0.0019}_{-0.0025}(\text{exp.})\ {}^{+0.002}_{-0.001}$$

Aims:
2- and 3-jet measurements in Breit Frame,
$\rightarrow$ compare with NLO calculation, α_S determination.

Main selections:
– $150 < Q^2 < 15000$ GeV^2
– $0.2 < y < 0.6$
– reject photoproduction

Reconstruct jets from tracks and calorimeter signals, w
invariant k_T cluster algorithm.
Require $-1 < \eta^B < 2.5$ and $E_T^B > 5$ GeV for jet in Br

Correct measured and parton Xsecs to hadron level
RAPGAP.
Compare with NLO++.
(DISENT and DISASTER do 2-jet but not 3-jet states in
Theory uncertainty: vary PDFs, vary renorm. scale by fac

Good agreement between 2-, 3-jet cross sections and NLO
Ratio $R_{3/2}$ agrees well except at highest Q^2 point.

(nb. e/w contribution not included in highest point.)

RESULTS (continued):

Use $R_{3/2}$ to evaluate α_S and $\alpha_S(M_Z)$ as functions of
Agreement with world average, running is apparent.
Fitted value from this analysis:

$$\alpha_S(M_Z) = 0.1175 \pm 0.0017(\mathrm{stat}) \pm 0.0050(\mathrm{sys})^{+0.0054}_{-0.0068}$$

Similar analysis from ZEUS using NLOJET (checked agai

Fitted value of α_s:

$$\alpha_S(M_Z) = 0.1179 \pm 0.0013(\mathrm{stat})^{+0.0028}_{-0.0046}(\mathrm{exp.})^{+0.0064}_{-0.0046}(\mathrm{th}$$

Aims:
Try to reveal BFKL dynamics by studying forward jets with

$$x_{\text{jet}} = \frac{E_{\text{jet}}}{E_p} \gg x_{Bj} \quad \text{and} \quad p_T^2 \approx Q^2$$

In addition, properties of a central dijet system can correlate with a transition between resolved-photon-like and BFKL processes.

BFKL

H1 cuts: (all quantities in lab.):
– $E_{e'} > 10$ **GeV,** $156° < \theta_e < 175°$; $5 < Q^2 < 85$ **Ge**
– $0.1 < y < 0.7$
– $0.0001 < x_{Bj} < 0.004$

ZEUS:
– $E_{e'} > 10$ **GeV,+min. ang. cut;** $20 < Q^2 < 100$ **GeV**^{2}
– $0.04 < y < 0.7$
– $0.0004 < x_{Bj} < 0.005$

Use k_T-defined jets with:

H1: $p_{T,\mathrm{jet}} > 3.5$ **GeV;** $x_{\mathrm{jet}} > 0.035$; $7° < \theta_{\mathrm{jet}} < 20°$.

ZEUS: $p_{T,\mathrm{jet}} > 5$ **GeV;** $x_{\mathrm{jet}} > 0.036$ **or** $E_{\mathrm{jet}} > 33$ **GeV**
$0.5 < Q^2/E^2_{T,\mathrm{jet}} < 2.0$; $2.0 < \eta_{\mathrm{jet}} < 3.5$.

Compare to models:
– **DGLAP: LEPTO, NLOJET++, DISENT**
– **Colour dipole model in ARIADNE**
– **CCFM model in CASCADE**

ARIADNE ≈OK.

LEPTO fails.

CASCADE 1, 2 poor

H1: DISENT fails.

ZEUS: DISENT is OK! – within large theory uncertainties

H1 Xsecs for different separations $\Delta\eta$ between forward jet and jets of dijet pair.

All models poor in lowest $\Delta\eta 2$ bin.
DGLAP OK in highest $\Delta\eta 2$ bin.

ARIADNE, CASCADE 2, NLOJET++ $\approx$OK,

Aims:

- **Xsecs for K^0 and Λ production;**
- **$\Lambda/\bar{\Lambda}$ asymmetry;**
- **Λ/K^0 production ratio;**
- **Λ polarisation $=$ $P_{\perp}^{\Lambda}$, $P_{||}^{\Lambda}$;**

  $$\frac{dN}{d\Omega} = \frac{1}{4\pi}(1 \pm \alpha P \cos\theta)$$ **in Λ rest frame.** $\alpha = 0.$

Longitudinal $P_{||}^{\Lambda}$ has θ between proton and Λ;
Transverse $P_{\perp}^{\Lambda}$ has θ between proton and plane of electr

Laboratory frame: detect as $K^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi$

– $Q^2 > 25$ **GeV^2**
– $0.02 < y < 0.95$
– $0.6 < p_T < 2.5$ **GeV for each species**
– $|\eta| < 1.2$ **for each species**

Compare with ARIADNE 4.08 predictions

$\longleftarrow$ **Typical set of results.**

ARIADNE mostly OK.

Polarisation consistent with zero apart perhaps from $P_{||}^{\bar{\Lambda}}$

Breit Frame analysis to come.

Aim:
Measure Bose-Einstein Correlations in DIS for K^0 and

Summary of formalism:
Define 2-particle correlation function as

$$R(Q^2) = \frac{P(Q_{12})^{\mathrm{Data}}}{P_{\mathrm{mix}}(Q_{12})^{\mathrm{Data}}} \Bigg/ \frac{P(Q_{12})^{\mathrm{MC,noBEC}}}{P_{\mathrm{mix}}(Q_{12})^{\mathrm{MC,noBEC}}}$$

Density P in terms of Q_{12} = 4-momentum difference, c
- **particle pairs in Data events;**
- **particle pairs in different events (mix);**
- **Ditto for MC samples with no B.E.C.**

Fit results using Goldhaber expression :

$$R(Q^2) = \alpha \left(1 + \lambda e^{-Q_{12}^2 r^2}\right)(1 + \delta Q_{12})$$

α = normalisation factor; r = radius of source;
λ = strength term;
(second term describes long-range effects here found to

Select:
ZEUS tracks,
– $p_T > 0.15$ **GeV**
– $|\eta| < 1.75.$
Particle ID uses
dE/dx **measurement.**

Results: $\longrightarrow$
c.f. ZEUS $\pi^{\pm}$**:-**
($r = 0.666 \pm 0.009^{+0.022}_{-0.036}$
$\lambda = 0.475 \pm 0.007^{+0.011}_{-0.003}$ **)**

λ **smaller for** $K^{\pm}$ **than** K^0**.**
Maybe due to resonances?

- ARIADNE and NLO QCD in general are successful in
aspects of hadronic states in DIS.

- One high H1 bin at very low x (that ZEUS don't reach
$\longrightarrow$ signs of BFKL??

- Charged multiplicities form a consistent picture.

- Strange particles present no surprises.

- B.E.C. measured with kaons now.

- More opportunities to measure α_s.

- HERA is still a very lively area to study QCD!