The Fragmentation of Quarks in DIS and Strangeness in Photoproduction in ep Collisions at HERA

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ABSTRACT

Deep Inelastic scattering (DIS) data, taken in 1993 by the H1 experiment at HERA. The fragmentation function of the quark is examined in the Breit frame of reference and compared with e^+e^- data. The measured area, peak and width of the fragmentation function shows that the kinematic evolution variable equivalent to the e^+e^- squared centre of mass energy is the invariant square of the four-momentum transfer.
The comparison of the differential K_s^0 cross-section with the measured inclusive charged particle cross-section shows the contribution of strangeness in photoproduction events. Comparisons of the measured cross-sections with QCD based Monte Carlo models including leading order matrix elements and fragmentation effects are presented.

1. ep Collider Kinematics

The HERA collider at DESY, which delivered the first ep interactions in 1992, has opened new kinematical domains in deep inelastic lepton-nucleon scattering in both the small x (Bjorken scaling variable) and large Q^2 (negative 4-momentum transfer squared) regions. In DIS, the scattered electron can be clearly identified in the central barrel region defining the high Q^2 ($Q^2 > 100$ GeV^2) or in the backward region defining the low Q^2 ($12 < Q^2 < 80$ GeV^2) sample. Photoproduction events are characterised by an electron which is scattered through small angles down the beam pipe into an electron tagger and thus are at very low Q^2 ($Q^2 < 10^{-2}$ GeV^2).

The large phase space for QCD radiation at HERA energies makes the hadronic final state an ideal testing ground for QCD.

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2. The Breit Frame

In e^+e^- interactions, the momentum distribution of the hadrons from quark fragmentation scales with E^*, the overall centre of mass (CMS) energy. The momentum of a given charged hadron scaled to the maximum energy that it could have in any arbitrary hemisphere, $x_p = 2p^{\pm}_{hadron}/E^*$, is thus a natural variable in terms of which e^+e^- experiments [1,2] have described hadronic spectra. In e^-p interactions there is no exact equivalent of the e^+e^- centre of mass system.

The Breit frame is defined such that the virtual photon is entirely space-like, having a momentum of p_z = -Q. If the momentum of the incoming proton is P, then within the QPM, the incident parton approaches with momentum $xP = +Q/2$, absorbs the photon, and leaves with momentum $-Q/2$, in what is then called the 'current' hemisphere. The spectator quarks, which have the same momentum before and after the interaction, $(1-x)P$, continue along the positive z-direction in what is known as the 'target' hemisphere. Therefore, in the current hemisphere of the Breit frame, $x_p = 2p^{\pm}_{hadron}/Q$ is the equivalent of the e^+e^- definition of a fragmentation variable.

The Breit frame is defined solely by the kinematics of the virtual current and is concerned with quark-current rather than proton-current interactions. The spectator system has a reduced significance and, rather than the γp CMS, the current hemisphere has been claimed a better approximation to one half of an e^+e^- annihilation event, where off mass-shell quark flavours are pair created democratically, with equal and opposite momentum.

3. Fragmentation Functions

Following the removal of photoproduction background to the event sample and applying sensible track selection criteria, the properties of charged tracks, in the current hemisphere of the Breit frame, are investigated [3].

The distribution $D^{\pm}(x_p) = (1/N_{evnts}) \cdot dn^{\pm}_{trks}/dx_p$ is a charged track density normalised to the number of events and is termed the fragmentation function. It is a soft function with a small probability of yielding partons/hadrons with an x_p close to its maximum value 1. As x_p decreases the function rises rapidly and turns-over near zero. The area under this function constitutes the average charged particle multiplicity.

The turn-over region can be expanded into a *hump-backed* plateau when the fragmentation function is expressed in terms of the variable $\xi = ln(1/x_p)$. The expectation of the Modified Leading Logarithm Approximation (MLLA)[a] to perturbative

[a]The MLLA gives the soft gluon momentum distribution at a fixed CMS energy and predicts the evolution of this spectrum, its peak, width and multiplicity as the energy scale is evolved.

QCD predicts that for partons, $D(\xi)$, is distributed in a roughly Gaussian manner. Assuming Local Parton-Hadron Duality (LPHD), this distribution would also follow for the hadrons [4].

The charged particle fragmentation functions in terms of the variable ξ, for the current hemisphere of the Breit frame, are displayed in fig. 1(a,b) for two Q^2 intervals.[b] The results show the Gaussian shape as predicted from the discussion above and also as in e^+e^- data. It should be noted that with the present statistics, the individual fragmentation functions for positive and negative hadrons are indistinguishable, and are treated inclusively in this study.

The low and high Q^2 data of fig. 1 have each been further subdivided to give a total of ten intervals of Q in order to study the evolution of the area, peak and width of the fragmentation function in more detail. The variation of the integrated area (the mean charged multiplicity, $< n_{ch} >$) is shown in fig. 2. A phenomenological fit [5] to many e^+e^- data points[c] as a function of E^* is also shown for comparison .

If Q is taken to be equivalent to E^* the variation of the fragmentation peak and width is examined for each of the Q^2 intervals. These results are presented in fig. 3(a,b) together with a similar analysis by the ZEUS collaboration [6].

The predicted MLLA behaviour for the peak and width is given by simple formulae in terms of two free parameters, Λ_{eff}, which sets the scale of the mass of the final state fragmented hadrons, and $O(1)$, which contains higher order terms;

$$\xi_{peak} = 0.5Y + c_2\sqrt{Y} + O(1) \tag{1}$$

$$\xi_{width} = \sqrt{Y^{\frac{3}{2}}/2c_1} \tag{2}$$

where c_1, c_2 are constants dependent only on the number of colours and flavours in QCD, and Y is a dimensionless variable defined as $Y = ln(Q/2\Lambda_{eff})$.

From a simultaneous fit (solid line) to the peak and width we obtain $\Lambda_{eff} = 0.24 \pm 0.04$ GeV and $O(1) = -0.38 \pm 0.11$. The results obtained from e^+e^- experiments to the peak give $\Lambda_{eff} = 0.21 \pm 0.02$ GeV and $O(1) = -0.32 \pm 0.06$. Attention should be drawn to the dashed lines which are the predictions from a Monte Carlo with matrix elements matched to parton showers (MEPS). Both use the Lund string model for final hadronisation. However, one is with an angular-ordered approximation to coherent gluons (dashed) in the parton shower, while the other abandons any attempt to model coherence (dashed-dotted). The two predictions are almost indistinguishable and we conclude that although we are in agreement with all data that claim gluon coherence, the necessity for coherence, other than that already parameterised by the

[b] Note that whereas a given e^+e^- experiment has one fixed value of E^*, an ep experiment results in a wide range of Q enabling the evolution of the fragmentation function to be tested in a single experiment.

[c] Note that the published results refer to e^+e^- *events*. Average track multiplicities have been reduced by a factor two to correspond to results for each quark.

string model, has not been demonstrated.

4. Strangeness in Photoproduction Events

We now proceed from the fragmentation of all charged species in DIS to the fragmentation of K_s^0 in photoproduction[d] events where the cross-section is much higher.

Cross-section measurements are limited to the kinematic region $0.3 < y < 0.7$ and $Q^2 < 10^{-2}$ GeV^2 where y is the fraction of the incoming electron energy carried by the photon. In the 1993 data sample the average centre-of-mass energy for photoproduction events is $< W_{\gamma P} > \approx 190$ GeV which is an order of magnitude larger than that available to previous fixed-target experiments [7].

Strangeness can be produced via direct or resolved processes. However, the majority of strangeness production arises from the fragmentation process. Restricting the analysis to the central region ($|\eta| < 1.5$, where η is the laboratory pseudo-rapidity of the K_s^0) of the H1 detector where the tracker acceptance is high, approximately 1100 K_s^0 candidates are found with a reconstructed mass, $m(\pi^+\pi^-) \approx 497.4 \pm 0.3$ MeV, as shown in fig. 4. The invariant cross-section for K_s^0 (open triangles) is shown in fig. 5 as a function of the laboratory p_t compared to the total inclusive cross-section for charged particle production (open circles).

A preliminary comparison of the measured K_s^0 cross-section to that predicted by the PYTHIA 5.7 Monte Carlo has been investigated [8]. Although other experiments [9] suggest a strangeness suppression factor of 0.2 rather than 0.3 as determined by e^+e^- experiments [10], the statistical and systematic uncertainties do not allow H1 to make a definite statement in that regard.

5. Conclusions

Studies in the Breit frame show that properties of the fragmentation function evolve with Q in the same way as the e^+e^- event does with E^*. Furthermore, H1 is consistent with the expectations of gluon coherence in the fragmentation of quarks, as much as any other experiment, but the necessity for gluon coherence has not been demonstrated. The inclusive cross-section of K_s^0 in photoproduction have been measured and compared to PYTHIA predictions. The statistical and systematic uncertainties do not allow an unambiguous estimate of the strangeness suppression factor.

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[d]Photoproduction is the collision of quasi-real photons with protons.

conference in most pleasant surroundings.

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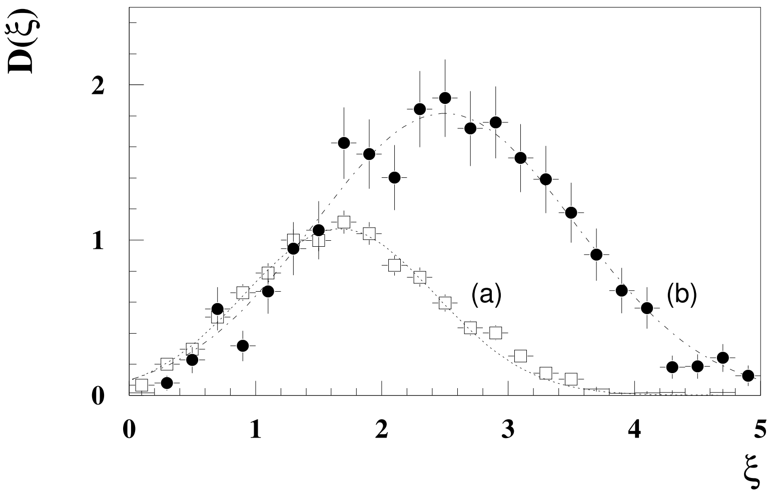

Figure 1: *The fragmentation functions for the current hemisphere of the Breit frame, $D(\xi)$, for (a) the low Q^2 ($12 < Q^2 < 80$ GeV^2) and (b) the high Q^2 sample ($Q^2 > 100$ GeV^2), with statistical errors only and with simple Gaussian fits superimposed.*

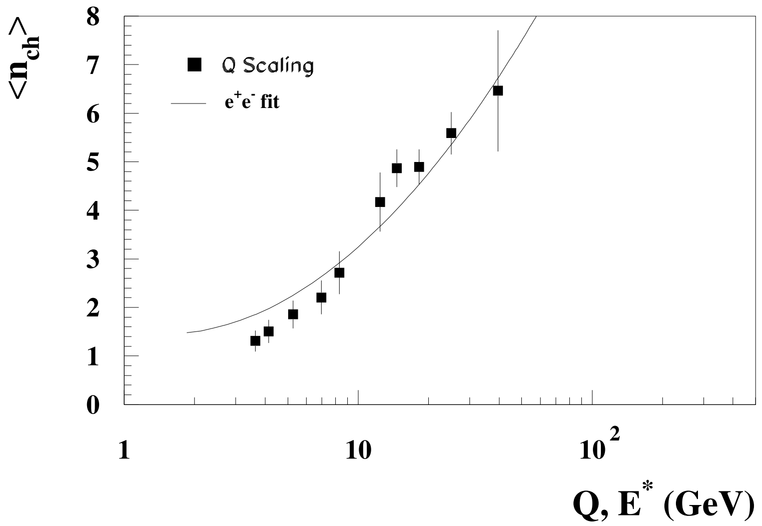

Figure 2: *Average charged particle multiplicity in the current region of the Breit frame for data which scales with the event Q (solid squares). For comparison, the parameterisation (line) of one half of average corrected track multiplicities in e^+e^- events as a function of the e^+e^- centre of mass energy.*

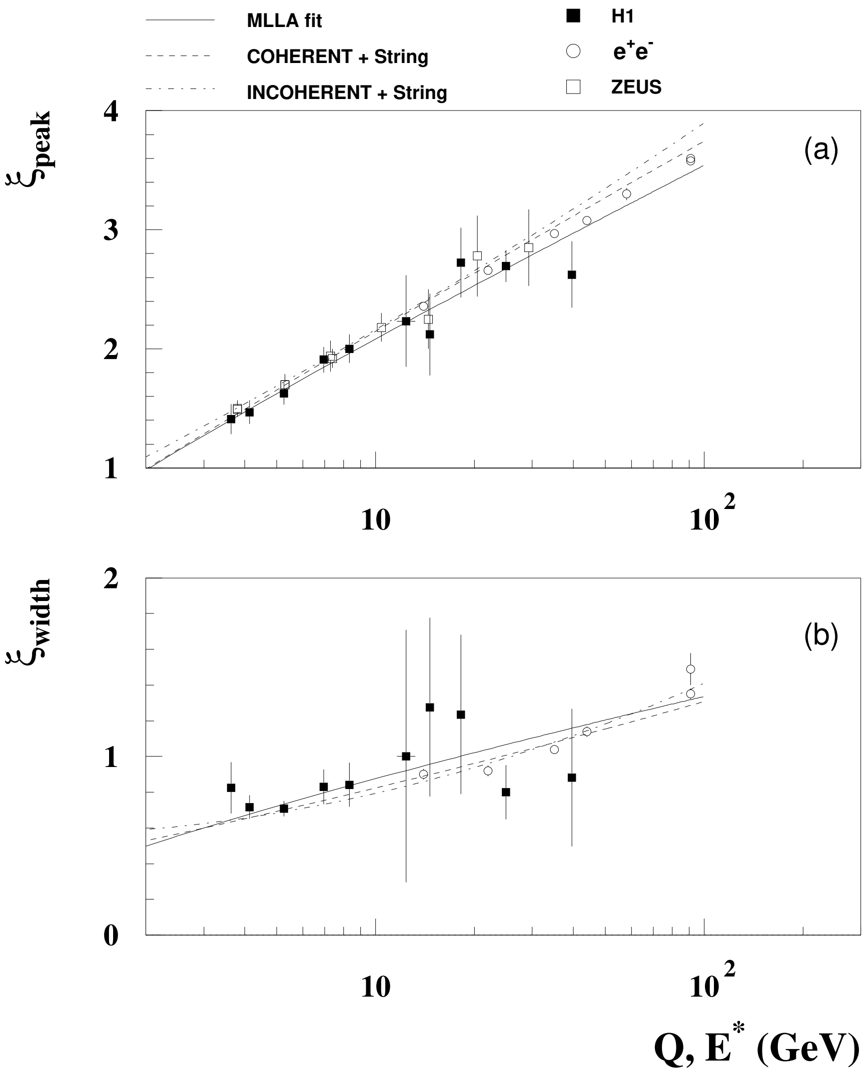

Figure 3: *Evolution of a) the peak position and b) the width (σ) of a fitted Gaussian fragmentation function compared with similar fits to e^+e^- data and with the results of a ZEUS analysis (open squares), with points at the same Q being at different x. The solid line is a two-parameter simultaneous MLLA-expectation fit to the H1 data. See text for a discussion of the various model predictions.*

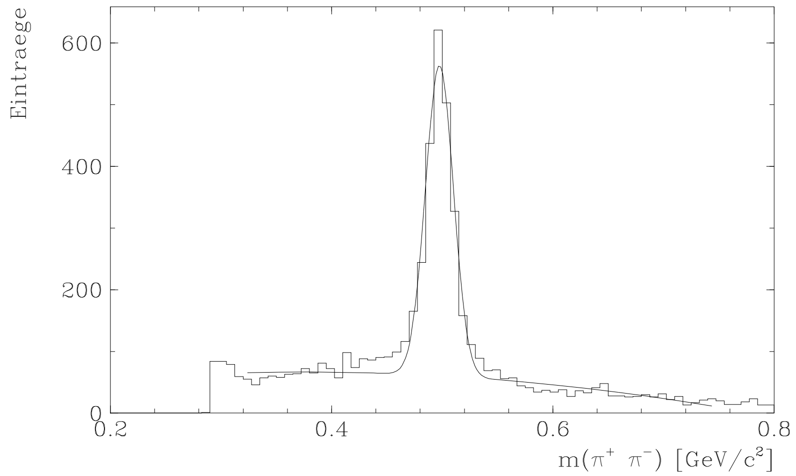

Figure 4: *Invariant mass distribution for reconstructed K_s^0 in the interval $|\eta| < 1.5$, where η is the pseudo-rapidity of the K_s^0 in the laboratory reference frame.*

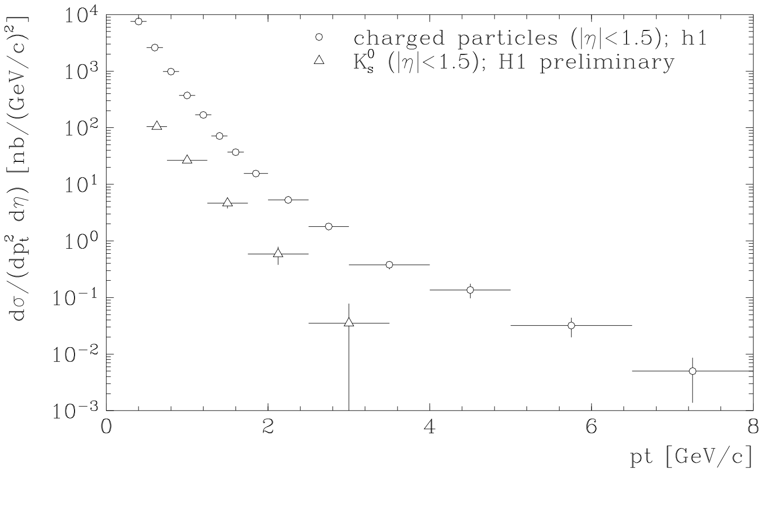

Figure 5: *Inclusive ep cross-section for charged particles (open circles) and the cross-section for K_s^0 (open triangles) in photoproduction at HERA in the kinematic region* $0.3 < y < 0.7$ *and* $Q^2 < 10^{-2}$.