RECENT RESULTS ON BOSE-EINSTEIN CORRELATIONS, FRAGMENTATION FUNCTIONS AND EVENT SHAPES IN *ep* DIS

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Bose-Einstein correlations are studied with respect to two-particle correlation functions at small distances and possible differences between diffractive and non-diffractive events. The second part deals with the dependence of charged particle fragmentation functions on the four-momentum transfer squared. The observed scaling violations are compared with predictions of pQCD. In the last section the energy dependence of the mean values of event shape variables is investigated. Applying power corrections to account for hadronisation effects, fits to second order pQCD calculations are carried out.

1 Bose-Einstein Correlations

1.1 Introduction

Bose-**E**instein **C**orrelations (BEC) are a consequence of the particle exchange symmetry properties of the wave functions for identical bosons and show up as a tendency of like-sign π-pairs to be closer together in momentum space than unlike-sign π-pairs. They have been studied for various reactions [1] including **D**eep-**I**nelastic *ep* **S**cattering (DIS) at HERA.[2]

In the H1 analysis they are characterized in form of the two-particle correlation function

$$R := \frac{\rho_2(i,j)}{\rho_1(i)\rho_1(j)}\,,$$

where $\rho_1(i)$ and $\rho_2(i,j)$ are the single- resp. two-particle density functions evaluated at phase space points i, j. The phase space distance T is defined as $T^2 := -(p_1 - p_2)^2$ with p_1 and p_2 being the four-momenta of the two particles. Depending on assumptions on the boson-emitting source different behaviours of $R(T)$ for small T are predicted: A Gaussian shape,[1] an exponential rise [3] or a power law behaviour conjectured by recent studies on fluctuation phenomena.[4]

1.2 Experimental Procedure

The employed 1994 H1 data [2] cover a kinematic region of $Q^2 = 6 - 100\,GeV^2$ in momentum transfer squared and $10^{-4} - 10^{-2}$ in the scaling variable x_{Bj}. The selected DIS sample consists of around 48000 non-diffractive and 2500

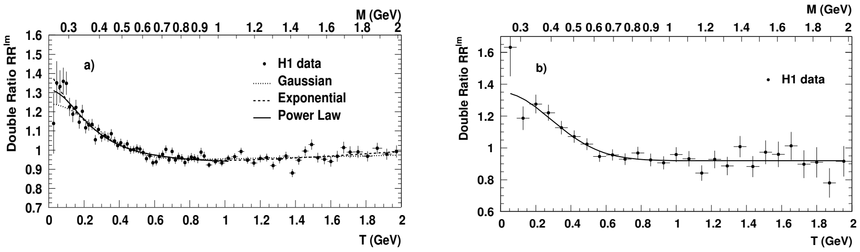

Figure 1: The double ratio $RR^{lm}(T)$ for the non-diffractive (**a**) and diffractive H1 data (**b**). In **a**) also fits to a Gaussian (dotted), exponential (dashed) and power law (full line) parametrization are shown. The full line in **b** corresponds to a Gaussian fit.

diffractive events. The latter are characterized by a large gap of hadronic activity between the proton direction and the scattered quark.

In order to measure $R(T) = \rho_2^l(T)/\rho_2^{ref}(T)$ a reference density function ρ_2^{ref} is needed, which should exhibit the same correlations as ρ_2^l except for BEC. Two possible choices for ρ_2^{ref} are applied: The so-called event **m**ixing method evaluates the correlations between particles from different events, ρ_2^m, and is topologically biased, whereas the use of **u**nlike-sign π-pairs, ρ_2^u, suffers from resonance decays. To correct for these shortcomings Monte Carlo simulations without BEC for the correlated and reference densities are applied by use of the double ratio

$$RR(T) = \frac{R^{data}(T)}{R^{MC}(T)} .$$

Since both choices yield compatible results only the mixing method is shown in figure 1. A steeper than Gaussian rise for $T \to 0$ is preferred and no significant differences between diffractive and non-diffractive data are observed.

2 Fragmentation Functions and Event Shapes in the Breit frame

To confront QCD with experiment momentum spectra and event shapes have been studied in ep DIS. Due to the proton remnant fragmentation that can not be handled within the framework of **p**erturbative **Q**uantum **C**hromo**D**ynamics (pQCD), it is not suitable to work in the laboratory system and the Breit frame is used instead. The struck quark and the proton remnant fragment in different hemispheres and a close correspondence can be established between the current hemisphere H_C of the Breit frame and one half of an e^+e^- event.[5] The relevant hemisphere energies E are respectively $Q_{DIS}/2$ and $\sqrt{s_{e^+e^-}}/2$, where $s_{e^+e^-}$ denotes the center of mass energy squared.

Compared to e^+e^- experiments[6,7] it is a great advantage of ep scattering that the energy dependence can be investigated over a large range within the same experiment.

To link predictions of pQCD with experimental observations the non-perturbative transition from partons to hadrons still has to be made. Two approaches are applied for that purpose. Assuming quark fragmentation universality, fragmentation functions measured in e^+e^- experiments[8] at a scale Q_0^2 are taken as additional input in the case of momentum spectra. For the event shapes, which will be discussed in the last section, a power correction ansatz as proposed by Webber[9] is used.

3 Fragmentation Functions

3.1 *Definition*

The fragmentation function

$$D_{h/i}(x_p, Q^2) = \frac{1}{\sigma_{tot}} \frac{d\sigma}{dx_p}$$

gives the probability to find a hadron h in the fragmentation products of parton i with rel. momentum $x_p := p_h/(Q/2)$ at a scale Q^2. Similar as for structure functions $D_{h/i}$ is a priori unknown but process independent and can be evolved to other scales Q'^2 in the QCD improved parton model. All well measured charged hadrons in H_C contribute to $D_{h/i}$, quark flavors are not differentiated.

3.2 *Measurements*

H1[10] as well as ZEUS[11] have analysed their data in a Q^2 range of roughly 10 – 1000 GeV^2. The measured data clearly exhibit scaling violations.

In addition the experiments employ the concept of local parton hadron duality and demonstrate that within a modified leading logarithmic approximation[12] the Q dependence of the peak position and width of the fragmentation function, written in terms of $\log(1/x_p)$, can be well described. ZEUS applies $\mathcal{O}(\alpha_s^2)$ pQCD calculations[13] together with e^+e^- fragmentation functions[8] and finds a good agreement with their data as shown in figure 2. In future this may lead to an extraction of α_s from scaling violations of fragmentation functions.[14]

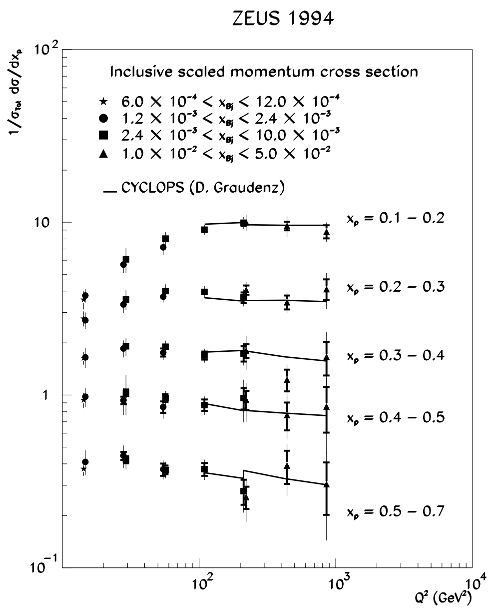

Figure 2: The inclusive charged particle distribution in H_C, $1/\sigma_{tot}\, d\sigma/dx_p$. The filled symbols are ZEUS data with statistical (thick bars) and total errors (thin bars). The lines show the $\mathcal{O}(\alpha_s^2)$ pQCD predictions.

4 Event Shapes

4.1 Definition

The infrared safe event shape variables considered by H1[15] are two variants of thrust, T_C and T_Z, the jet broadening B_C and the jet mass ρ_C:

$$T_C = \max_{\mathbf{n_T}} \frac{\sum_h |\mathbf{p_h} \cdot \mathbf{n_T}|}{\sum_h |\mathbf{p_h}|}, \qquad T_Z = \frac{\sum_h |\mathbf{p_h} \cdot \mathbf{n}|}{\sum_h |\mathbf{p_h}|} = \frac{\sum_h |p_{z\,h}|}{\sum_h |\mathbf{p_h}|},$$

$$B_C = \frac{\sum_h |\mathbf{p_h} \times \mathbf{n}|}{2\sum_h |\mathbf{p_h}|} = \frac{\sum_h |p_{\perp h}|}{2\sum_h |\mathbf{p_h}|}, \qquad \rho_C = \frac{\left(\sum_h \mathbf{p_h}\right)^2}{Q^2}.$$

In these definitions the summation index h extends always over all objects in H_C, which may be either partons in the pQCD calculations or calorimetric clusters in the detector. $\mathbf{n_T}$ denotes the thrust axis of the maximizing procedure in the definition of T_C, whereas the boson axis is given by $\mathbf{n} = (0, 0, -1)$.

4.2 QCD Calculations and Power Corrections

According to [16] the Q or energy dependence of any event shape mean $\langle F\rangle$ can be written as sum of a perturbative part $\langle F\rangle^{pert}$ and a power suppressed contribution $\langle F\rangle^{pow}$. Currently, there are two programs at hand, MEPJET [17] and DISENT,[18] to compute the perturbative part to $\mathcal{O}(\alpha_s^2)$. Since MEPJET, however, is not able to do so for the full phase space in F, DISENT is used for the analysis.

The power suppressed contribution is written as [16]

$$\langle F\rangle^{pow} = a_F \frac{16}{3\,\pi} \frac{\mu_I}{Q} \ln^p \frac{Q}{\mu_I} \left[\overline{\alpha_0}(\mu_I) - \alpha_s(Q) - \frac{\beta_0}{2\,\pi} \left(\ln \frac{Q}{\mu_I} + \frac{K}{\beta_0} + 1 \right) \alpha_s^2(Q) \right]$$

with $\beta_0 = 11 - 2/3N_f$, $K = 67/6 - \pi^2/2 - 5/9N_f$ and $N_f = 5$ flavours. a_F and p are shape dependent coefficients deduced in.[16] The infrared matching scale $\mu_I = 2\,GeV$ divides the Q range into two parts, an upper one, where pQCD is applicable and α_s represents the strong coupling strength, and a lower one with an effective mean coupling $\overline{\alpha_0}$. The coupling parameters are simultaneously determined by a fit to the data.

4.3 Fit Results

Figure 3 shows the H1 data for the means of all investigated event shapes together with the corresponding pQCD calculations and the fit results for their Q dependence. The data are nicely described and exhibit a clear $1/Q$ behaviour. $1/Q^2$ terms are not needed.

Note that for $1 - T_Z$ an additional factor of $1/2$ is introduced to account for the different thrust ranges, which are $0 \leq 1 - T_C \leq 0.5$ and $0 \leq 1 - T_Z \leq 1$ respectively.

The fit results for the parameters $\overline{\alpha_0}$ and $\alpha_s(M_Z^2)$ in the $\overline{\text{MS}}$ scheme are compiled in table 1. Except for B_C the general outcome is in good agreement with the assumed $1/Q$ power correction behaviour and compatible values for $\overline{\alpha_0}$ and $\alpha_s(M_Z^2)$ are determined. The errors are dominated by theoretical uncertainties with the largest contribution stemming from the variation of the renormalization scale, which serves as a measure for the influence of higher order corrections.

Concerning B_C it must be emphasized that with $p = 1$ [16] a good fit was not possible even with the scale μ_I in $\ln^p(Q/\mu_I)$ replaced by an additional free parameter Q_0. As for the other event shapes $p = 0$ was used and the additional logarithmic factor for B_C was discarded. A more complete discussion may be found in.[15]

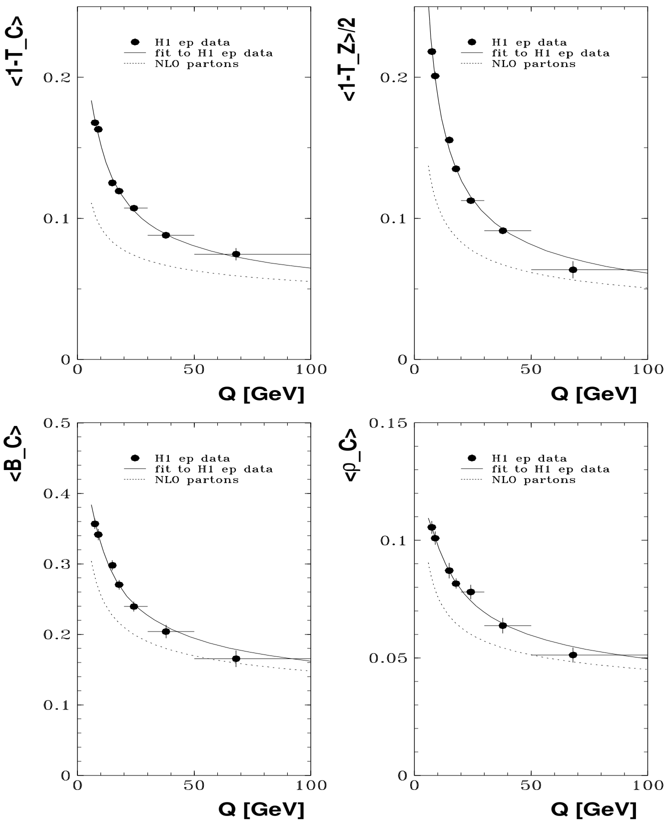

Figure 3: Event shape means $\langle 1 - T_C \rangle$, $\langle 1 - T_Z \rangle / 2$, $\langle B_C \rangle$ and $\langle \rho_C \rangle$ as a function of Q. H1 data (full symbols, errors include statistics and systematics) are compared with QCD fits (full lines) and NLO pQCD calculations of DISENT (dotted lines).

Table 1: Results on $\overline{\alpha_0}$ and $\alpha_s(M_Z^2)$ from fits to the Q dependence of the event shape means (first error experimental, second error theoretical uncertainties).

Observable	$\overline{\alpha_0}\,(\mu_I = 2\,GeV)$	$\alpha_s(M_Z^2)$	χ^2/ndf
$\langle 1 - T_C \rangle$	$0.497 \pm 0.005\ ^{+0.070}_{-0.036}$	$0.123 \pm 0.002\ ^{+0.007}_{-0.005}$	5.0/5
$\langle 1 - T_Z \rangle / 2$	$0.507 \pm 0.008\ ^{+0.109}_{-0.051}$	$0.115 \pm 0.002\ ^{+0.007}_{-0.005}$	8.5/5
$\langle B_C \rangle$	$0.408 \pm 0.006\ ^{+0.036}_{-0.022}$	$0.119 \pm 0.003\ ^{+0.007}_{-0.004}$	5.3/5
$\langle \rho_C \rangle$	$0.519 \pm 0.009\ ^{+0.025}_{-0.020}$	$0.130 \pm 0.003\ ^{+0.007}_{-0.005}$	3.1/5

Acknowledgements

I want to thank the H1 and ZEUS collaborations, especially the people providing me with the necessary information, and the organizers at the Universidad Autónoma de Madrid for their hospitality.

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