Jets and High-$E_\perp$ Phenomena

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Abstract: The working group on jets and high-$E_\perp$ phenomena studied subjects ranging from next-to-leading order (NLO) corrections in deeply inelastic scattering (DIS) and photoproduction with the corresponding determinations of physical quantities, to the physics of instanton-induced processes, where a novel non-perturbative manifestation of QCD could be observed. Other centres of interest were the physics of the forward direction, the tuning of event generators and the development of a new generator which includes a consistent treatment of the small- and large-x QCD evolution. The recommendations of the working group concerning detector upgrades and machine luminosity are summarized.

Introduction

The physics of hadronic final states is currently one of the main interests at HERA. To mention only a few points, the study of jets has led to a determination of the strong coupling constant and of the gluon density, and the investigation of the hadronic activity in the forward direction has improved our understanding of parton radiation in the initial state. Concurrently with these phenomenology issues, there was the development of tools such as next-to-leading order Monte Carlo programs for jet production and event generators modelling the hadronic final state. The goal of the working group was to study the future prospects of the physics of jets and high-$E_\perp$ phenomena in the light of the two different improvements of an increased machine luminosity (of the order of $\int \mathcal{L}dt = 250 - 1000\,\mathrm{pb}^{-1}$) and improved detectors in the forward direction. Because of the wide range of subjects, the working group was organized in four subgroups:

- **Deeply Inelastic Scattering.** The subjects considered in this subgroup were the study of QCD-instanton-induced processes, the calculation of jet cross-sections in NLO and the extraction of the strong coupling constant and the gluon density via hadronic final states. A particular emphasis has been the study of the statistical and systematic errors for large luminosity. One project studied the semi-DIS region, defined by events with $p_\perp \gg Q \gg \Lambda_{\mathrm{QCD}}$, and the prospects of the determination of the virtual photon structure function.

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- **QCD Evolution and the Forward Region.** This subgroup studied the prospects of measuring in deeply inelastic scattering the QCD evolution in the initial state. Several small groups searched for relevant observables in order to (a) distinguish the QCD evolution schemes of DGLAP and BFKL, (b) detect instanton formation, and (c) establish 'hot spots' in the proton. Also studied were detector upgrades in the outgoing proton direction which concern the results of this working group and the working group on *Diffractive Hard Scattering*. All results from the two working groups which are related to a detector upgrade in the forward direction are summarized in a separate report [9].

- **Photoproduction.** Two projects considered the calculation of the NLO corrections to jet cross-sections, where in one of the projects the matching of theoretical and experimental jet cross-sections has been studied in detail. The measurement of the gluon density of the photon by means of the rapidity distribution of charged particles has been studied. Two projects considered the effects of colour coherence and of rapidity gaps between jets, respectively, and one project studied prompt photon, Drell–Yan and Bethe–Heitler processes.

- **Event Generators and Tuning.** In this subgroup, a standardized framework (HZTOOL) for the comparison of experimental data and generator predictions has been developed and used to tune existing generators. Another project considered the implementation of the linked dipole chain model in a Monte Carlo program interfaced to ARIADNE.

The outline of this working group summary is as follows. The next section introduces the notation. In the following four sections the activities of the subgroups are summarized. A concluding section then gives the final recommendations of the working group concerning detector upgrades and machine luminosity.

Notation

The momenta of the incident and outgoing electron[1] and of the incident proton are denoted by l, l' and P, respectively. In deeply inelastic scattering, the electron phase space is parametrized by the Bjorken variable[2] $x_B = Q^2/2Pq$ and by $y = Pq/Pl$, where $q = l - l'$ is the (space-like) momentum of the exchanged virtual photon, and $Q^2 = -q^2$ is the square of the photon virtuality. In this way Q represents the energy scale of the scattering and x_B may be interpreted, in the case of lowest-order QCD sub-processes, as the momentum fraction of the proton carried by the scattered parton. For some processes such as heavy-flavour production or the photoproduction of large transverse energy jets the energy scale is not determined by the photon virtuality. In these cases the photon virtuality may be denoted by P (not to be confused with the proton momentum), where for photoproduction, $P^2 \approx 0$.

Because of the hadronic component of a real photon, the parton densities $f_{i/\gamma}(x_\gamma, \mu^2)$ of the photon have to be introduced for photoproduction. Here x_γ denotes the momentum fraction of the photon carried by the parton i. More commonly used is the experimentally observed quantity $x_\gamma^{\mathrm{OBS}} \equiv (E_{\perp 1}e^{-\eta_1} + E_{\perp 2}e^{-\eta_2})/2yE_l$ derived from the two jets with the highest $E_\perp$.

[1] We use the term "electron" as synonymous to "positron". Charged-current processes and Z° exchange have not been studied in the working group.

[2] The variable x_B is sometimes also denoted by x.

The convention of placing the proton along the positive z-axis in the laboratory frame, and the virtual photon along the positive z-axis in the hadronic centre of mass and Breit frames is used throughout. For jet rates in DIS the "(n+1)" counting convention is used, where the "+1" refers to the proton remnant jet.

References to contributions printed in these proceedings are made by quoting the *author names*, printed in italics.

Deeply Inelastic Scattering

The subgroup on deeply inelastic scattering had three main focuses: QCD instantons, the calculation of next-to-leading-order jet cross-sections, and the determination of the strong coupling constant $\alpha_s(\mu_r^2)$ and the gluon density $g(x, \mu_f^2)$ from hadronic final states. Deeply inelastic scattering is defined by a photon virtuality much larger than the fundamental QCD scale parameter, $Q \gg \Lambda_{\mathrm{QCD}}$. The presence of this large scale allows the calculation of infrared-safe quantities in perturbative QCD. A possible approach to the inclusion of hadronization effects in an analysis is to take them into account by data unfolding or by the inclusion of correction factors based on a comparison of the hadron level and the parton level by means of event generators.

QCD Instantons. QCD instantons give rise to helicity-violating non-perturbative processes, whose experimental discovery would clearly be of basic significance. *M. Gibbs, T. Greenshaw, D. Milstead, A. Ringwald and F. Schrempp* considered the discovery potential for these processes at HERA by studying the characteristics of the hadronic final state. Because the processes are flavour-democratic, strange particles would be produced in abundance. In addition, a suitably defined event-shape variable might help to discriminate the QCD-instanton-induced processes from standard QCD background. Despite large uncertainties in the first (preliminary) estimates of the cross-section, HERA offers a distinct discovery window for these spectacular processes, notably with a substantial luminosity upgrade.

NLO Corrections. The calculation of jet cross-sections in NLO was considered in two projects. *E. Mirkes and D. Zeppenfeld* have calculated the (2+1) jet cross-section by means of the phase space slicing method, employing helicity amplitudes and the technique of universal crossing functions. *S. Catani and M. Seymour* used the subtraction method, where the subtraction term in the collinear and soft regions is obtained by means of the recently developed dipole formalism. Because the Monte Carlo program based on the latter calculation has been finished only recently, a numerical comparison of the two different approaches has not yet been done.

The Strong Coupling Constant. The future prospects of the determination of α_s via the (2+1) jet rate has been considered by *Th. Hadig, Ch. Niedzballa, K. Rabbertz and K. Rosenbauer.* They studied the dependence of statistical and systematic errors in dependence of the available luminosity. It turns out that the energy scale error of the detector is the dominant experimental systematic error. Assuming this error to be 2%, a total error of ± 0.007 can be achieved for $\alpha_s(M_Z^2)$ with $\int \mathcal{L} dt = 250\,\mathrm{pb}^{-1}$, which is to be compared with the present error of the world average of $\alpha_s(M_Z^2)$ of ± 0.006. A further increase of the luminosity might lead to a reduction of the energy scale error and thus to a further improvement of the error. The effect of additional acceptance cuts to reduce the systematic error has also been studied. In particular, a cut in the jet transverse momentum seems to be promising. The systematic error induced by the dependence of parton densities on Λ_{QCD} has been estimated by *J. Chýla and*

J. Rameš by considering the relative importance of α_s in the matrix element and in the evolution of the parton densities. At moderately large Q^2, where the present α_s measurements have been done, the former is dominant. It would be desirable to find a way to consistently include this dependence at smaller Q^2, where the data sample is much larger. An α_s measurement by means of scaling violations of fragmentation functions has been studied by *D. Graudenz*. Here a large systematic error is induced by the choice of parton densities. This error can be reduced by going to large values of Q^2. Because of the rapid fall-off of the cross-sections, a large luminosity is required. It turns out that the measurement would not be competitive concerning the size of the error (the effect being only logarithmic in the factorization scale), but might be an interesting complementary measurement at HERA.

The Gluon Density. The photon–gluon fusion process, giving rise to (2+1) jets in the final state, can be exploited for a measurement of the gluon density. *G. Lobo* has studied the prospects for a combined global fit of F_2 and jet rates. By including the jet rate data, the error at large $x \gtrsim 0.03$ can be reduced considerably. The global approach also allows a combined fit of the quark and gluon densities. The direct measurement of $g(x)$ by means of the Mellin transform method has been studied by *D. Graudenz, M. Hampel and A. Vogt.* Here the quark densities are assumed to be input distributions; the momentum sum rule is taken care of by means of the normalization of $g(x)$. An increased luminosity of the order of $250\,\mathrm{pb}^{-1}$ may allow the reduction of the error band by a factor of two, compared to the present integrated luminosity of $3\,\mathrm{pb}^{-1}$.

The Semi-DIS Region. *J. Chýla and J. Cvach* have studied the prospects of a measurement of the virtual photon structure function by looking at DIS events with some additional hard scale $p_\perp \gg Q \gg \Lambda_{\mathrm{QCD}}$, and conclude that an integrated luminosity of $50\,\mathrm{pb}^{-1}$ is sufficient for a measurement that allows for a discrimination between various models, assuming the virtual photon structure functions suppression is x-independent. To measure the x-dependence of the virtual photon structure functions, an integrated luminosity at least 10 times higher would be necessary.

Except for the analysis in the semi-DIS region, all projects in this subgroup related to the extraction of physical quantities as well as the QCD instanton study strongly favour a substantial luminosity increase, whereas a detector upgrade in the forward direction is not required. The α_s analysis shows that above an integrated luminosity of about $250\,\mathrm{pb}^{-1}$ the systematic errors will eventually dominate over the statistical ones. A similar situation can be expected in the case of the direct determination of the gluon density via jets. It should be kept in mind, however, that the energy scale error, and thus the systematic error of the extracted physical quantities, also depends on the available integrated luminosity, since high-$p_\perp$ jets are required to calibrate the detector [1].

QCD Evolution and the Forward Region

The leading question of the 'forward physics' group was: how can we understand the QCD evolution of the initial state? Compared to the interpretation of inclusive measurements of the proton structure function F_2, exclusive measurements in the forward direction (outgoing proton) are sensitive to the explicit details of the evolution between the proton and the photon–quark vertex.

Today's conventional description of the evolution of a single parton are the DGLAP evolution equations. These equations resum terms of the form $(\alpha_s \ln Q^2)^n$. At small fractional parton momenta x, contributions of the form $(\alpha_s \ln(1/x))^n$, not described by the DGLAP equations, become important. It is, however, still debated at which values of x this will be the case. HERA offers the opportunity to settle this question empirically, for instance by testing predictions of the BFKL type against those of DGLAP evolution. Apart from these perturbatively calculated effects, also non-perturbative effects, such as instanton formation, are expected to contribute to the parton evolution. Beyond single parton evolution, multi-parton evolution effects are expected which could exhibit inhomogeneous regions in the proton, e.g. regions of high parton density ('hot spots'). Their detection would imply a significant step forward in our understanding of the proton.

It is essential to find observables which reflect the evolution of the partons from the proton to the γq vertex:

a) Indirect access is given by a measurement of kinematical variables of the final-state proton which can, in the case of a hard scattering process, be described by models where the proton initially lost partons during the scattering and finally received partons for the colour neutralization process (*I. Gialas, J. Hartmann; A. Edin, G. Ingelman and J. Rathsman*).

b) Direct measurements of the parton evolution require observables which involve high transverse momenta in order to suppress the influence of non-perturbative effects (*A. Edin, G. Ingelman and J. Rathsman*). Single charged particle spectra can distinguish at high transverse momenta different scenarios of QCD evolution (*M. Kuhlen*). In a similar way, jet cross-sections can be used to study parton evolution in the forward direction (*T. Haas and M. Riveline; J. Bartels, A. De Roeck and M. Wüsthoff*). In a related project (*E. Mirkes, D. Zeppenfeld*) it has been found that the measured forward jet cross section at small x_B [2] is not described by a fixed-order NLO calculation. However, it can be explained by a LO calculation amended with a BFKL ladder in the initial state [3]. A different class of observables are shape variables which can, in principle, resolve short range effects at sufficiently large transverse momenta (*H. Heßling*).

Detector upgrades in the direction of the outgoing proton will give essential improvements in all the direct measurements of parton evolution (*M. Kuhlen; A. Bamberger, S. Eisenhardt, H. Heßling, H. Raach and S. Wölfle*). The extension of the ZEUS detector by a PLUG calorimeter which enlarges the rapidity coverage by 1.6 units, was studied in detail (*A. Bamberger et al.*).

A high luminosity upgrade of the HERA machine, as proposed by the working group *HERA Optics and Layout of Interaction Region*, will signal the end of the physics described in this section. Before such upgrade, data corresponding to a luminosity of order $100\,\mathrm{pb}^{-1}$ should be collected in order to ensure that the HERA project may contribute significantly to the understanding of QCD evolution.

Photoproduction

A further, important field of testing perturbative QCD is the study of photoproduction processes with large transverse energy in the hadronic final state. Here one of the goals is to obtain new information on the partonic structure of the photon and the proton. Whereas F_2^γ measurements in e^+e^- collider experiments constrain the quark distribution in the photon, the gluon distribution is largely unknown. In the region where x_γ is close to zero or unity, even the quark distribution is not well constrained at present. In this workshop, three different final states were considered to study the structure of the photon and proton: jets, inclusive hadronic particle distributions, direct photons and lepton pairs.

Jets. *J. Butterworth, L. Feld, M. Klasen and G. Kramer* have made a detailed comparison in order to match the definition of jets in experimental and theoretical studies. It is shown that one can match jets of NLO calculations to various experimental jet definitions by tuning a parameter R_{sep}. The matching is better when the $E_\perp$ of jets becomes larger. Smearing effects from hadronization are smaller at high $E_\perp$ as well. By selecting high-$E_\perp$ jets in a good detector acceptance region ($E_\perp^{jet} \geq 30\,\mathrm{GeV}$ and $\eta^{jet} < 2$), one can test the photon and proton structure in the high-x region provided a large integrated luminosity ($\geq 250\,\mathrm{pb}^{-1}$) is available. *P. Aurenche, L. Bourhis, M. Fontannaz and J.Ph. Guillet* have developed a Monte Carlo program describing the 2- and 3-jet photoproduction in NLO. These jet cross-sections can be extracted from the generated events using a cone algorithm together with desired experimental cuts.

Inclusive Particle Production. *J. Binnewies, M. Erdmann, B. Kniehl and G. Kramer* have demonstrated that inclusive differential rapidity cross-sections of charged particles with large transverse momenta are sensitive to the gluon distribution of the photon, at low x_γ. Assuming that the gluon fragmentation function will be better known from LEP data on the longitudinal polarized cross-sections, the extraction of the NLO gluon distribution in the photon can be done with a precision of the order 10% using an integrated luminosity of $100\,\mathrm{pb}^{-1}$.

Prompt Photon and Lepton Pair Production. With a high integrated luminosity, it is possible to study the quark distribution of the photon using processes which are suppressed by the fine structure constant α relative to the dominant di-jet production, but with the advantage of a very clean environment. Processes with non-hadronic particles directly coming from the hard scattering process is an example of this. *P. Bussey* estimated the event rates with a high-$p_\perp$ photon (prompt photon). One can obtain sufficient data to determine the quark distributions in the photon at the 5–10% level with an integrated luminosity of $1000\,\mathrm{pb}^{-1}$. *B. Levtchenko and A. Shumilin* studied Drell–Yan process. It is important to separate Drell–Yan lepton pairs from the pairs that come from the Bethe–Heitler process, which has a much larger cross-section. Kinematical cuts for this separation are proposed.

There are two studies on event topology of high-$p_\perp$ photoproduction, on the colour coherence effect and on colour-singlet exchange.

Colour Coherence. *L. Sinclair and E. Strickland* studied the effect of colour coherence in multi-jet events. In order to obtain a large sample of multi-jet events it is necessary to have high luminosity. However, it turned out that a large acceptance in the forward region is also important. The luminosity upgrade at the expense of reducing the forward region acceptance is not worthwhile for this study. By extending the detector coverage up to 4 in pseudorapidity, the effect could be more pronounced. *A. Lebedev and J. Vazdik* studied the process-dependence of colour coherence. Particle flows in the inter-jet region are sensitive to the effect.

Colour-Singlet Exchange. *J. Butterworth, M. Hayes, M. Seymour and L. Sinclair* studied events with a rapidity gap between jets. The colour-singlet exchange appears here at a scale where perturbative QCD calculations give reliable predictions. Such data therefore give access to the origin of the so-called hard Pomeron. It is shown that with a larger detector coverage in the forward region one can obtain an unambiguous signature for the colour-singlet exchange. The luminosity requirement is of the order of $100\,\mathrm{pb}^{-1}$.

Event Generators and Tuning

The importance of theoretically well-founded event generators which give a good description of data cannot be emphasised enough. The situation at HERA in this respect has not been very satisfactory, especially when comparing to the extraordinary success of event generators at LEP [4]. This can be exemplified in DIS where all available generators have had great problems with describing fairly simple distributions, such as the $E_\perp$-flow [5].

This is not surprising considering the extra complications introduced at HERA which are not present in e^+e^- annihilation. In photoproduction there is the problem that the photon sometimes behaves as a point-like object and sometimes as a resolvable hadron. In the latter case, multiple interactions may occur, giving rise to an underlying event. Also, in photoproduction as well as in DIS, there is the problem of initial-state QCD evolution and how to handle it, especially in the small-x region, and in relation with the fragmentation of the proton remnant.

During the course of this workshop, the situation has much improved. Both for DIS and photoproduction, the available generators have been developed and the agreement with data is now at a level where a tuning of the parameters is meaningful. Two closely related projects have been working with the tuning of event generators. One of them *(J. Bromley, N. Brook, A. Buniatian, T. Carli, G. Grindhammer, M. Hayes, M. Kuhlen, L. Lönnblad and R. Mohr)* developed a library of FORTRAN routines called HZTool for easy comparison of event generators with published data. The other *(N. Brook, T. Carli, R. Mohr, M. Sutton and R.G. Waugh)* used this library to perform a first tuning of the DIS generators Ariadne [6], HERWIG [7] and Lepto [8]. A few of the measured distribution were selected, from which a global χ^2 was constructed to measure the quality of the fits. For all three programs the χ^2 was much improved by the tuning. The final numbers presented were $\chi^2 = 0.81$, 1.85 and 1.36 per degree of freedom for Ariadne, HERWIG and Lepto, respectively.

One new generator has been developed by *G. Gustafson, H. Kharraziha and L. Lönnblad.* It implements the Linked Dipole Chain model, which is a reformulation on the CCFM evolution equations based on the colour dipole picture. Here a careful division between initial and final state emissions results in a model well suited for an event generator implementation. This is the first complete generator where QCD coherence is correctly taken into account in the small-x region and where DGLAP and BFKL dynamics both are reproduced in the relevant limits. The preliminary comparison with data presented here looks promising.

Summary of Recommendations

The recommendations of the working group concerning a detector upgrade in the forward direction and an upgrade of the luminosity, as summarized in Table 1, are not unambiguous, because the two options are conflicting. The physics involving processes with large transverse momenta of final state jets would benefit substantially from a luminosity upgrade. This would allow the study of processes at large Q^2, thus increasing, for instance, the lever arm for a measurement of the *running* coupling constant $\alpha_s(Q^2)$. A larger data sample would also permit the application of strict acceptance cuts to bias the sample towards a phase region where perturbative QCD is applicable unambiguously, i.e. without taking into account large hadronization or resummation effects. It would moreover allow a reduction of the energy scale error, which has a direct impact on the extraction of physical quantities.

On the other hand, HERA offers a unique opportunity to study the QCD evolution and the physics of the forward direction in a comparably clean environment. The results of the working group show that most studies in this phase space region would already benefit from an increase of the detector acceptance by one unit of rapidity, with a total integrated luminosity requirement of the order of $100\,\mathrm{pb}^{-1}$. However, the proposed high luminosity upgrade of the HERA machine would to a large extent make such studies impossible. In a separate report by members from both the *Jets and High-$E_\perp$ Phenomena* and *Diffractive Hard Scattering* working groups, the cases for a forward detector upgrade are summarized [9], strongly recommending that a luminosity upgrade should at least be postponed to allow for more studies of forward physics.

In conclusion: the physics of jets and high-$E_\perp$ phenomena will continue to be a very interesting topic at HERA. Both options for the future of HERA, a substantial luminosity increase and a forward detector upgrade, which have been studied in the working group, would mean new physics opportunities. It is worth while to consider running HERA for two or three years with a total integrated luminosity of $100\,\mathrm{pb}^{-1}$, to allow for the instrumentation of and measurement in the forward direction, and then moving to the luminosity upgrade, which is definitely required for precise QCD studies at large transverse momenta.

References

[1] J. Gayler, private communication.

[2] H1 Collaboration, A. Aid et al., *Phys. Lett.* **B356** (1995) 118.

[3] J. Bartels, V. Del Duca, A. De Roeck, D. Graudenz, M. Wüsthoff, DESY 96-036 (1996), [hep-ph/9604272].

[4] I.G. Knowles et al., *QCD Event Generators*, in Proc. LEP2 workshop, CERN report 96-01, Eds. G. Altarelli, T. Sjöstrand and F. Zwirner.

[5] H1 Collaboration, I. Abt et al., *Phys. Lett.* **B356** (1995) 118.

[6] L. Lönnblad, *Comput. Phys. Commun.* **71** (1992) 15.

[7] G. Marchesini et al., *Comput. Phys. Commun.* **67** (1992) 465.

[8] G. Ingelman, in Proc. HERA workshop, Eds. W. Buchmüller and G. Ingelman, Hamburg (1991) vol. 3, 1366.

[9] H. Abramowicz, L. Lönnblad et al., *The Physics Case for a Forward Detector Upgrade*, these proceedings.

Process	Jets and High-$E_\perp$ Measurements[1,2]	Competition[3]	$\int \mathcal{L}dt$ $[\mathrm{pb}^{-1}]$[4]	Luminosity Upgrade[5]	Detector Upgrade[6]
DIS	Instanton ($K, \mu, E_\perp$)		1000	yes	
	α_s (particles, jets)	e^+e^-	250	–	
	gluon in proton (jets)	$\overline{p}p$	250	–	
	QCD evolution (jets)		30	no	ZEUS plug
	(particles)		100	no	very forward H1 tracker
	(shape variables)		>10	no	ZEUS plug
	proton fragm. (LPS)		>10	–	
$\gamma p \leftrightarrow$ *DIS*	quark in γ^* (2 jets)	quark at LEPII	50/500	no	H1 VLQ
	gluon in γ^* (2 jets)	none			
γp	gluon in γ ($d\sigma^{\mathrm{particle}}/d\eta$)	(charm at LEPII)	100	–	
	quark in γ (prompt γ)	quark at LEPII	1000	yes	
	(Drell–Yan)		1000	yes	
	(high-$E_\perp$ jets)		250	–	
	hard Pomeron ($\Delta\eta^{\mathrm{jets}}_{\mathrm{gap}}$)	($\overline{p}p$)	100	no	ZEUS plug
	colour coherence (jets)	e^+e^-, $\overline{p}p$	250	no	ZEUS plug

Table 1: Future HERA measurements recommended by the *Jets and High-$E_\perp$ Phenomena* working group; the columns show
1) process type: deeply inelastic scattering (DIS), photoproduction (γp),
2) physics topic (experimental method); LPS stands for the leading proton spectrometer,
3) (possible) competition from other laboratories,
4) required luminosity in pb^{-1},
5) statement on the luminosity upgrade *including acceptance losses in the current detectors*,
6) a detector upgrade which would significantly improve the results. (VLQ = very low Q^2 tagger)