Hadron Distributions in Deep Inelastic Electron-Nucleus Scattering at Collider Energies

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Abstract: Electron nucleus scattering at very high energies reached in collider machines allows to search for new nuclear effects in the deep inelastic scattering process. Here some physics topics which could be investigated with future eA collider machines running at high luminosities are discussed.

Introduction

Electron-nucleus scattering experiments offer some strong advantages over other high energy physics experiments when studying nuclear effects in the hadronic final state produced. The electron is a pointlike particle and its coupling through the electro-weak forces is well described in the Standard Model. No deconvolution of projectile and target fragments is necessary. Thus, by comparing the results of scattering on nuclei with different size the influence of nuclear matter on the DIS process can be studied most directly.

In order to do high precision electron-nucleus (eA) scattering experiments, not only high luminosities are needed, but also an excellent control of all systematic errors which do not cancel when taking the ratio of distributions from scattering on different nuclei. Therefore effects of multiple scattering and external bremsstrahlung in a target, difference in the acceptance and detector efficiciency between data sets with different targets have to minimised.

At low energies this can be most easily achieved by using an intensive electron beam and an internal gas jet target, as planned by the HERMES Collaboration. In this experiment the upper limit of the energy transfer ν [1] is about $\nu = 25\,\mathrm{GeV}$ since the electron ring at HERA

variable	description
$Q^2 = -(k-k')^2$	square of the four momentum transfer
ν= (P q)/(P k)	energy of the boson exchanged
$x_{Bj} = Q^2/(2Pq) = Q^2/(2M_{nucleon}\,\nu)$	Bjorken scaling variable
$W = Q^2/x_{Bj} * (1 - x_{Bj})$	inv. mass of the hadronic final state
M_X	inv. mass of the had. final state in LRG events

Table 1: Kinematic variables in DIS used in this text; the four momenta are defined in Fig.1

[1] the kinematic variables are defined in Tab.1 and Fig.1

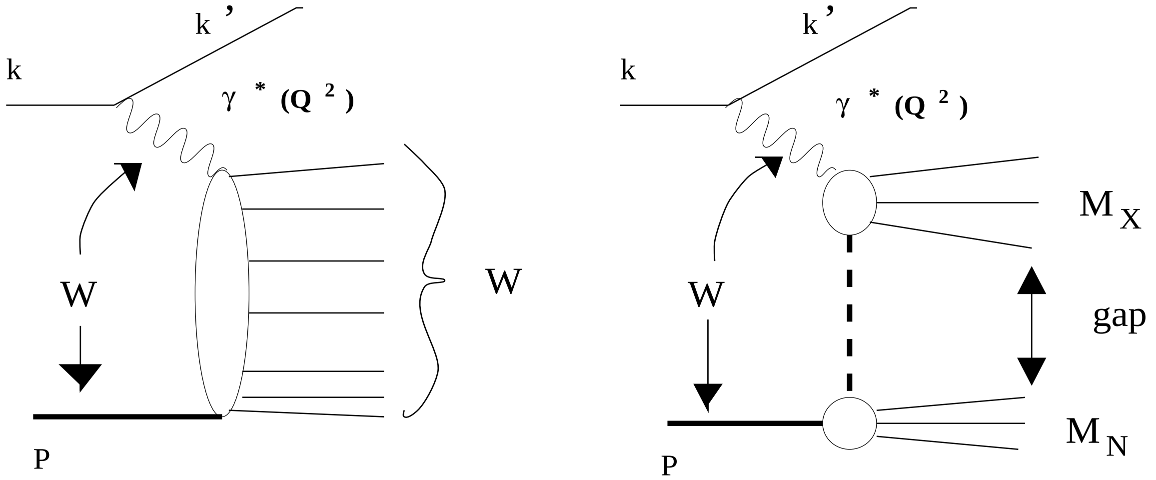

Figure 1: Schematic diagram of the particle production in DIS events without (a) and with a large rapidity gap (b) (called in text NRG and LRG events respectively). With k, k' and P the four momenta of the incoming and scattered electron and the proton beam are denoted respectively; $q = (k - k')$ is the four momentum of the virtual photon exchanged. W is the invariant mass of the $\gamma^* p$ system, M_X denotes the invariant mass of the hadronic final state observed in LRG events and M_N represents the scattered proton or a low mass nuclear state.

operates at 27.5 GeV; a cut on y ($y < 0.9$) to reduce the systematic uncertainty from coherent radiactive correction on nuclei, is here already considered.

In order to access the higher energy range one has to work with an eA collider where one also meets conditions which allow to minimise the systematic errors for measurement of ratios of cross sections as much as by using an internal gas jet targets. At the present time two options for the realisation of such an experiment are discussed: The first option is to inject light and heavy nuclei into the proton ring of HERA and to use the existing detector of the ep collision experiments for the measurements. The second option is to build two storage rings for electrons and heavy ions at the GSI, where a lower center of mass energy of the collisions is envisaged. In this article the first experiment will be labelled by 'HERA-N' and the second by 'GSI-N'.

The kinematic range covered in Q^2, x_{Bj} and ν for both options in the current phase of planning is shown in Fig.2, where cuts on the scattered electron energy and angle are imposed which are necessary to ensure a reliable identification of the neutral current DIS events and a precise determination of the event kinematic. Also the kinematic region which will be investigated by the HERMES experiment is indicated by the hatched area. One can see that the three experiments together cover a vast range in ν, Q^2 and x_{Bj}, where the GSI-N experiment fills in the gap between the HERMES and HERA-N experiment. By small variations of the beam energies of the collider experiments a partial overlap of the kinematic ranges can be achieved.

Physics Aims

The physics questions which are primarily addressed in the eA collider experiments will be somewhat different from those in past analyses of hadron distributions in eA scattering, where intranuclear hadron- and quark-reinteraction effects were studied from which one can infer information about the space-time structure of the hadronisation process. The arguments going

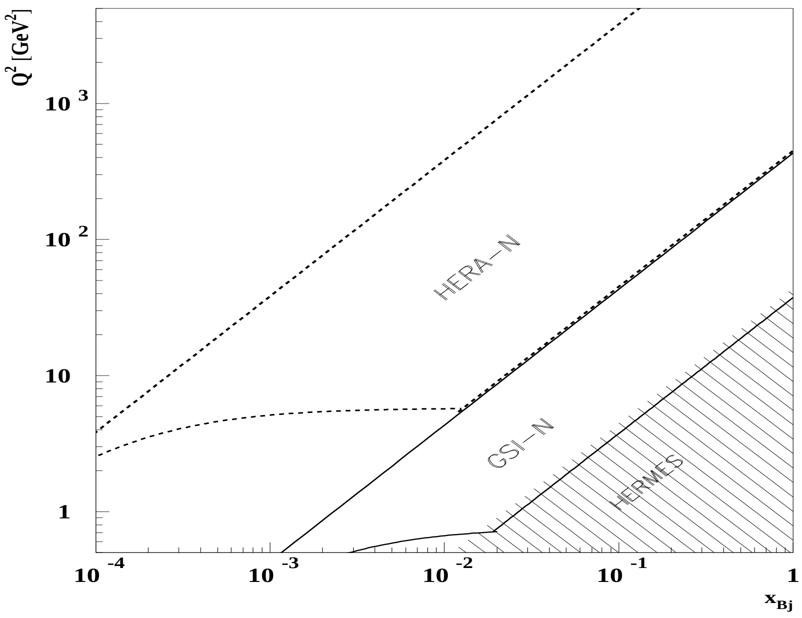

Figure 2: The comparison of the kinematic range covered by electron-nucleus collider experiments under study (HERA-N and GSI-N experiment). A cut on the scattered electron angle ($\vartheta'_e < 175°(170°)$ for HERA-N and GSI-N resp.) is considered to ensure a reliable identification of a DIS neutral current event and the precise determination of its kinematics. The region covered in the fixed target experiment HERMES is also shown.

along with these ideas are briefly sketched elsewhere in these proceedings [1] Measurements with electron [2], muon [3, 4, 5] and neutrino [6] beams had been performed in the range of ν from $10-200$ GeV. While at very low ν ($\nu \lesssim 25$ GeV) sizeable nuclear effects have been observed, at higher ν ($\nu \gtrsim 70$ GeV) the effects were found to be very small. But the errors on the ratio of distributions were of the order of several percent and the distributions had to be integrated over large intervals in z_h as well as in Q^2 and x_{Bj} (for a more detailed review see [7, 6]).

Much more precise data are required not only in the low ν range which will be covered by HERMES but also in the higher energy range to complete the investigation of the space-time structure. This could be done best in the eA collision experiment GSI-N, where one aims for luminosities as high as $10^{32} cm^{-2} s^{-1}$.

At sufficiently high values of ν, where hadronic intranuclear rescattering effects should vanish, one can search for effects of a possible interaction of the struck quark with the nuclear matter. The energy loss or broadening of transverse momentum of a quark during its passage through nuclear matter has been estimated in many publications e.g. [8]. This question is closely related to the phenomena observed in heavy ion collisions. Experimental information on this topic is very important for a better understanding of the hadron production in such complex reactions and for the identification of the quark gluon plasma, which one wants to create in high energy heavy ion collisons. Also the investigation of more subtle relationships between the hadron distributions in eA scattering and the EMC effect, which has been initiated in [3], should be pursued. In earlier studies of this problem only weak conclusions could be drawn since the statistics were not sufficient to study the effects as a function of x_{Bj}.

With the HERA-N collider eA scattering can be investigated at even higher values of ν, where the above questions can be futher studied. The major part of the events populate the very low-x_{Bj} region ($x_{Bj} \lesssim 10^{-3}$). It is evident that the experimental analysis will be focussed on the parton dynamics at very low x_{Bj} and high parton densities. Here, however, another topic will be briefly discussed for which the measurement of the hadronic final state is essential and where again the nucleus is used as a kind of 'tool' for the investigation.

Recently a class of DIS events has been observed at HERA which is characterised by a large rapidity gap between the observed hadronic final state and the proton beam direction [9, 10], which will be called here 'large rapidity gap (LRG)' events. The fraction of these LRG events in the total DIS event sample has been found to be independent of Q^2, which shows that the production mechanism for LRG events is a leading twist effect. The qualitative difference in the event topology for non-rapidity-gap (NRG) and LRG events is sketched in Fig.1.

One possible interpretation of these events is that there is a colourless particle, with which the photon interacts, while the proton remains unaffected like in a diffractive ep interaction. This particle could be identified with the pomeron, since diffractive scattering processes amongst hadrons have been successfully described by the pomeron exchange picture. One could further assume that the pomeron is a short lived quantum state with some partonic substructure, which is probed by the virtual photon such that the photon couples to a pointlike constituent in the pomeron [11].

On the other hand the leading twist behaviour of the cross section for the LRG events can also be explained in the model of Buchmüller [12], which is not based on the pomeron exchange model. In that model the LRG events are interpreted as being produced by the boson-gluon-fusion (BGF) process (i.e. a leading twist, non-diffractive DIS process), where the $q\bar{q}$ cluster evolves with a certain probability into a colour singlet parton cluster, which fragments independently from the rest of the nucleon into hadrons.

Since the latter model involves soft colour interaction it is to be expected that the amount of nuclear matter surrounding the vertex of the primary BGF process strongly influences the probability of the production of a LRG event and thus the fraction of LRG events observed. The relevant scale for this nuclear effect would be the size of the nucleus, i.e. the atomic number A. All other kinematic dependencies should be same as those found in ep scattering. In the Pomeron based models, nuclear effects may be induced by multi-pomeron exchange or by additional higher twist contributions due to coherent scattering on more than one nucleon in the nucleus. In this case a different x_{Bj} and Q^2 dependence of the LRG event in scattering on different nuclei is expected.

Besides the measurement of the LRG event rate, the hadron distributions themselves should be studied. Experimentally it was found that the transverse momentum spectra in LRG events in ep scattering resemble those of DIS at the an invariant mass of the hadronic final state W of $W = M_X$ [13]. This observation supports the hypothesis that the scale of the the phase space available for the particle production is given by M_X rather than by W. In that case it should be possible to investigate the space-time structure of the hadronisation in diffractive dissociation processes in a similar way to that done for DIS events without a large rapidity gap at lower energies [7]. The important question to be answered in this context would be, whether the hadrons are formed at a larger distance from the the primary hard scattering vertex or whether this process is universal as far as the space-time structure and the nature of the preconfined states are concerned. This aspect of the diffractive multiparticle production has been only poorly if at all studied in the past.

Conclusions

Electron-nucleus collider machines offer the unique possibility to measure with high precision hadron distributions in electron-nucleus scattering at energies, at which the effects of intranuclear hadron rescattering are expected to be neglibly small. In that kinematic regime one can search for the effect of quark interaction in dense nuclear matter. This information would be most valuable for the undestanding of the hadron production in high energy heavy ion collisions. Also the relationship between the hadron production in eA scattering and the EMC effect can be investigated in order scrutinize the origin of the EMC effect. Moreover it will be possible to study the mechanism of diffractive scattering at high scattering in detail using the nucleus as a kind of test medium. The information from these analysis is expected to contribute to discriminate between the various models for this kind of process.

References

[1] N.A. Pavel, 'Study of the Hadronisation Process at HERMES', this Proceedings.

[2] L.S. Osborne et al., Phys. Lett. B166 (1978) 1624.

[3] N.A. Pavel, Ph.D. thesis, Univ. of Wuppertal WUB 89-24 (1989); EMC coll., J. Ashman et al., Z. Phys. C52 (1991) 1.

[4] EMC Collab., J. Ashman et al., Z. Phys. C52 (1991) 361.

[5] A.F. Salvarani, PhD thesis, (1991) Univ. of California, San Diego.

[6] BEBC WA21/WA59 Collab., W. Burkot et al., Z. Phys. C70 (1996) 47.

[7] N.A. Pavel, Nucl. Phys. A532 (1991) 465.

[8] S.J. Brodsky, P. Hoyer, Phys. Lett. B298 (1993) 165;
R. Baier, Y.L. Dokshitzer, S. Peigne, D. Schiff, Phys. Lett. B345 (1995) 277;
X. Wang, M. Gyulassy, M. Plümer, Phys. Rev. D51 (1995) 3436;
M. Luo, J.W. Qiu, G. Sterman, Phys. Rev D50 (1994) 1951.

[9] ZEUS Collab., M. Derrick et al., Phys. Lett. B315 (1993) 481.

[10] H1 Collab., I. Abt et al., Phys. Lett. B348 (1995) 682.

[11] G. Ingelmann, P. Schlein, Phys. Lett. B152 (1985) 256.

[12] W. Buchmüller, Phys. Lett. B335 (1994) 479;
W. Buchmüller, DESY 95-065 (1995); W. Buchmüller, A. Hebecker DESY 95-077 (1995).

[13] N.A. Pavel, Habilitationsschrift (University Hamburg Oct.'94), DESY 95-147 (1995).