What can we gain by detecting nuclear fragments in electron-nucleus collisions at HERA?

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Abstract: Detecting nuclear debris in deep inelastic electron-nucleus scattering is a challenge at HERA collider, where the energies of ions could reach 400 GeV/nucleon. If realized, it may provide a very useful tool to tag the number of nucleons which interacted with the virtual photon. In this note we point out that such a tag could be of primordial importance in searches for nonlinear QCD effects and in measuring the structure of the Pomeron in coherent electron-nucleus collisions.

1 Introduction

The nuclear option for HERA, if realized in the future, could provide new and unique possibility of studying electron-nucleus interactions in the new, so far unexplored, energy domain of $\sqrt{s} \simeq 3\ TeV$. To reach such an energy in interactions with electrons of 30 GeV the nuclei have to be accelerated to a very large energy, exceeding the binding energy of nucleons in the nucleus by 5 orders of magnitude. The nuclear debris will thus emerge at very small angles, which will be typically of the fraction of miliradians. The detection of these debris is a difficult task, especially for charged fragments with Z/A equal to that of the beam nucleus. In this paper we leave out the discussion how this can be done but rather try to point out why designing such a detection system could be of importance.

One of the challenges of the nuclear option at HERA is to discover nonlinear QCD effects which are responsible for taming the growth of the partonic distributions at low x [1]. These effects are expected to be amplified in the electron-nucleus collisions by the factor $A^{1/3}$ with respect to electron-nucleon collisions, provided that x is sufficiently small and the collisions are central. In the central collisions the virtual photon can interact with partons originating from several nucleons ejecting these nucleons from the nucleus. The number of these "wounded" nucleons may thus be a measure of an effective density of the partonic system which interacted with the virtual photon. By analyzing events in which large number of wounded nucleons is detected we expect to increase the discovery potential of the nonlinear QCD effects.

The unexpectedly large cross section for deep inelastic diffractive scattering measured at HERA allows for a precise measurement of the Pomeron structure at modest luminosities. One of the question of primordial importance, which could be addressed within the nuclear program of HERA is: how universal is the concept of the Pomeron? In particular: is the structure of the Pomeron which originates from the nucleon the same as of the Pomeron which originates from the nucleus? Within the present HERA optics it will be difficult, if not impossible, to detect coherently recoiled nucleus in diffractive deep inelastic electron-nucleus scattering. It may turn out however, that incoherent processes give rise to large multiplicities of neutrons which are evaporated from the nucleus. If a large fraction of evaporation neutrons is detected we could use their signal as an anti-tag to select coherent processes with respect to incoherent ones.

In this note we present Monte Carlo studies which illustrate the ideas sketched above. In section 2 we describe a model of nuclear evaporation which we use in our studies. Section 3 is devoted to the discussion of merits of wounded nucleons tagging while in section 4 we show that with help of the Forward Neutron Counter [2], [3], we may be able to filter out coherent from incoherent diffractive processes.

2 A model of nucleus evaporation and its implementation in the VENUS Monte Carlo

We use, in our analysis, the Venus Monte Carlo [4] to simulate the eA interactions. We incorporated into this Monte Carlo the PDF library [5] and chose the GRV 94 HO structure function set for our studies [6]. In order to investigate the nucleus fragmentation processes we have developed a toy model of nuclear evaporation. This model is based on parametrisations of the proton-nucleus [7] and muon-nucleus [8] scattering data and includes the production of the following fragments: $p, n, t, \alpha, Li, Be, B, C$. The fragment multiplicities are fixed using the data of [9]. Their spectra are described by:

$$E\frac{d\sigma_f}{dp} \propto exp(-\frac{T_f - 125MeV}{T_{0f}})$$

were T_{0f} is the fragment dependent characteristic temperature, given in Table 1, and T_f is the fragment kinetic energy. The neutron spectra are described by a combination of three exponentials as suggested in [8]. The evaporation spectra are, in this simpleminded model, uncorrelated with the type and kinematics of the primary interaction.

Table 1: Characteristic temperatures of evaporations.

fragment	p	n	d, t, α, Li, Be, B, C
$T_{0f}(MeV)$	45	0.7, 5, 45	35

In Figure 1 we show the pseudorapidity distribution of all particles emerging from interactions of 30 GeV electrons with lead nuclei of 410 GeV/nucleon. We requested that: $Q^2 > 1GeV^2$, $0.05 < y_{Bj} < 0.5$, $0.05 < x_{Bj} < 0.01$ and the angle between the momenta of the incident and scattered electron greater than 3. We observe an abundant production of evaporation fragments in the nucleus hemisphere. These fragments are emitted at small angles. The wounded nucleons (represented on this plot as a difference of the spectra of nucleons and

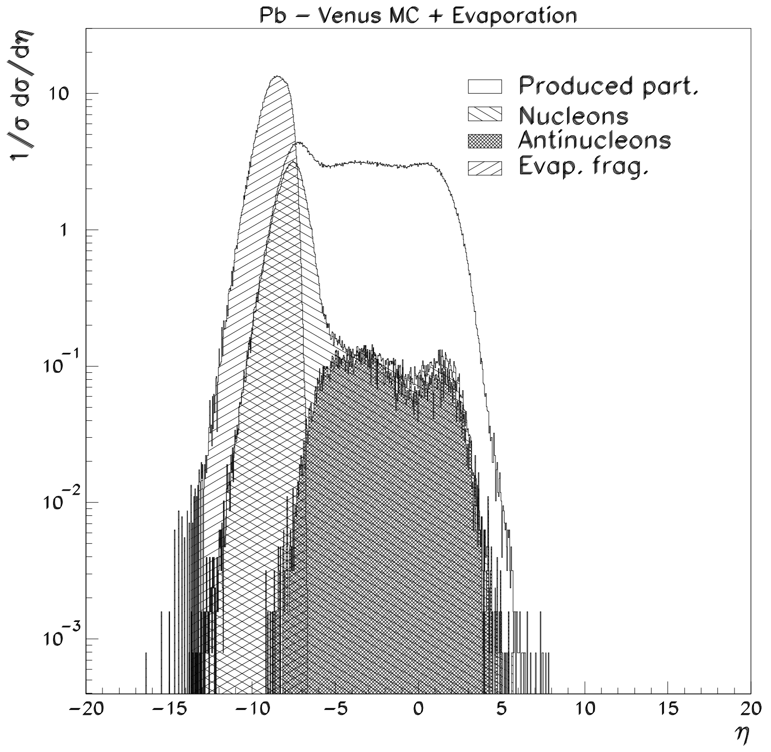

Figure 1: *Pseudorapidity distribution of all particles in ePb interactions in the HERA reference frame.*

antinucleons) are emitted at larger angles (larger η). In Figure 2 we show the correlation between the particle (fragment) energy and its pseudorapidity. This plot shows a clear separation of various nuclear fragments in the (E,η) plane. It is worth pointong out that the fragments can be identified unambigously, owing to an apparent quantization of their energies in units of 410 GeV.

3 Wounded nucleon tagging of multiparton processes

The experiments at HERA [10], [11] discovered strong rise of partonic density in the low x domain. The challenge for HERA is to find a mechanism responsible for dumping the growth of partonic distributions such that the unitarity constraint is preserved. As it has been shown in [12], the HERA electron-proton scattering data will likely be insufficient to establish a presence of such mechanism because the effective partonic densities are still relatively low down to the x values of 10^{-4}.

In electron-nucleus scattering the effective partonic densities are, for the central collisions and $x \leq 1/(2R_A m_p)$, amplified by a factor $A^{1/3}$. Therefore, already in the x-domain accessible at HERA we reach the limit of saturation of partonic densities and may observe a break-down of the applicability of linear QCD evolution equations [13], [14] to the dense partonic system.

It is clear, from the above arguments that, the heaviest nuclei are the best for searches of non-linear QCD phenomena (provided that the luminosity achievable at HERA is inverse-

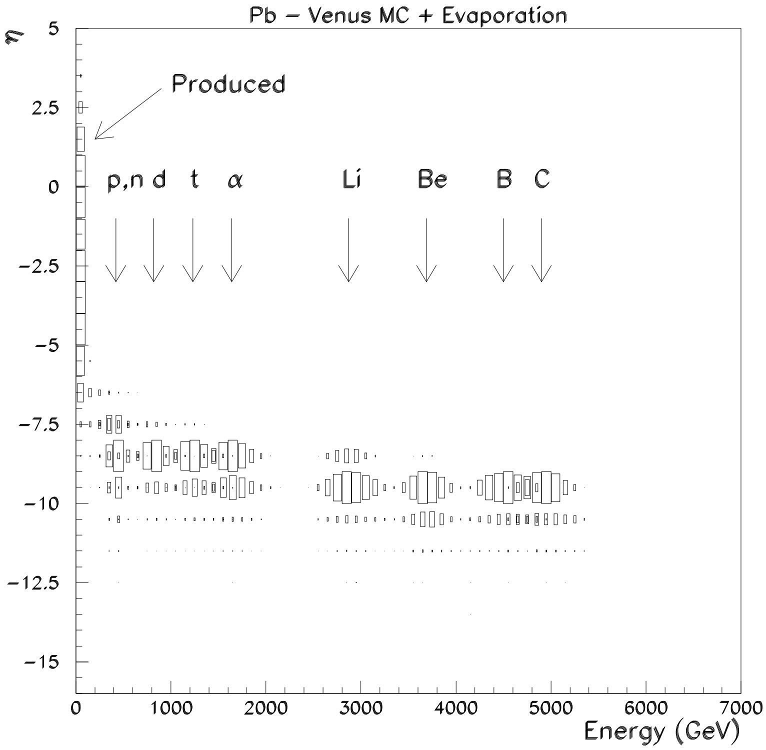

Figure 2: *Correlation between particle energy and rapidity.*

proportional to the atomic number and that the measurement errors of partonic densities are independent of the accelerated ion type). It may however turn out that the two above conditions can not be fulfilled and high statistical and systematic precision can be achieved only for the isoscalar nuclei. Can we produce a high partonic density fluctuations in interactions of the electrons with the heaviest of isoscalar nuclei - Calcium. In Fig. 3a we show the correlation between the "thickness of the nucleus" ($A^{1/3}$) and the number of wounded nucleons which have been ejected from the nucleus, as predicted by the VENUS model. The apparent high degree of correlation, if confirmed experimentally, would allow to use the collision dependent number of wounded nucleons as a measure of an effective density of partons in the nucleus. The multiplicity spectrum of wounded nucleons is shown in Fig. 3b for ePb and eCa scattering. It is apparent that the large multiplicity tail for eCa scattering is extended towards multiplicities which are significantly larger than the average multiplicity of wounded nucleons for ePb scattering. There are two reasons for fluctuations of wounded nucleon multiplicities. The first is related to the dispersion of the impact parameter of the virtual photon (central collisions lead to larger multiplicities). The second is related to the fluctuations in the final state rescattering processes. We propose a way to disantangle these two sources of fluctuations by looking at the multiplicities of hadrons produced in the central region. We are aware that the efficiency of relating a large multiplicity fluctuation to the a large partonic density fluctuation will remain most likely to some extent uncertain. Nevertheless, we expect to increase significantly the sensitivity to high partonic density effects already for light nuclei by using the wounded nucleon tag. We consider this approach as a back-up solution if it turns out that only light nuclei can be accelerated at HERA.

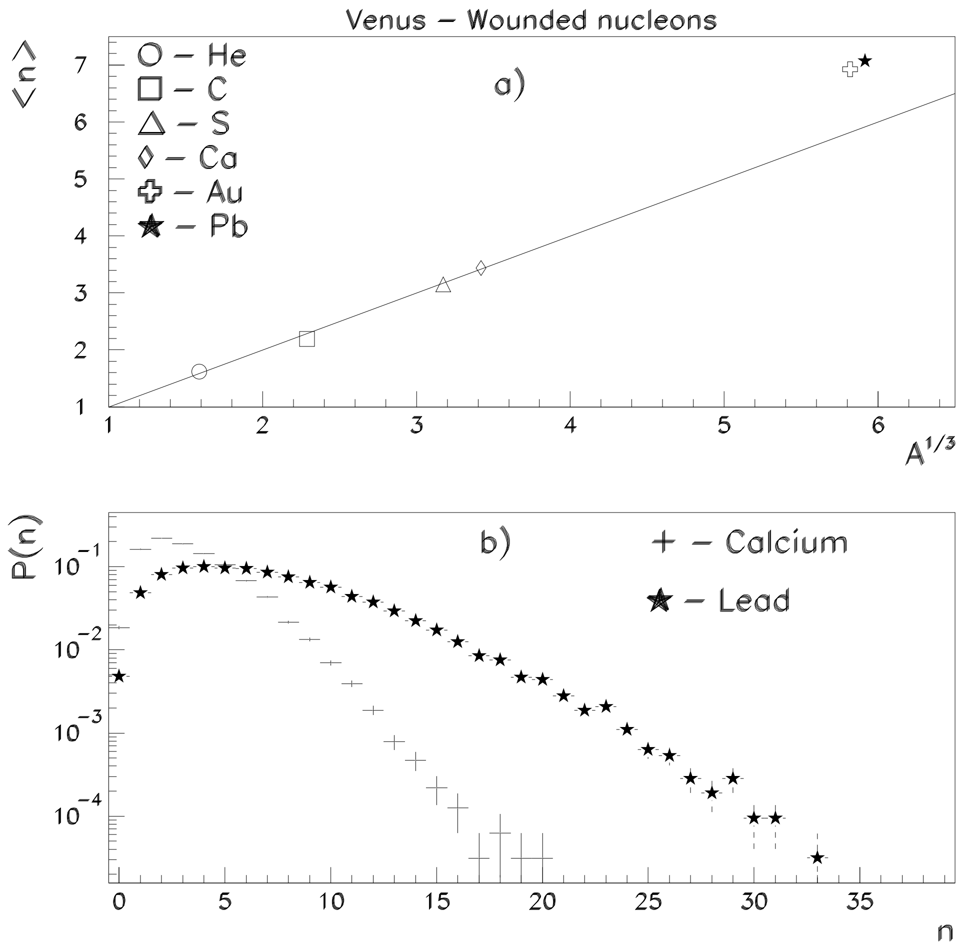

Figure 3: *a) Average multiplicity of wounded nucleons vs.* $A^{1/3}$. *Solid line corresponds to* $< n >= A^{1/3}$. *b) Wounded nucleon multiplicity distribution for Lead and Calcium.*

4 Evaporation of neutrons from wounded nucleus and selection of coherent diffractive processes

Testing universality of the Pomeron structure by using "Pomeron sources" of different partonic compositions is one of the challenges of the nuclear program for HERA. We propose a test in which the Pomeron structure function F^{3D} [15] measured in the electron-nucleus scattering is compared with the one measured in electron-proton scattering. The electron-nucleus diffractive scattering can be coherent ($eA \rightarrow eA+X_{diff}$) or incoherent ($eA \rightarrow e(A-N)+N+X_{diff}$, where N is the number of ejected nucleons from the initial nucleus) providing two distinct "classes of Pomeron sources" for universality test. Is it feasible to tag coherent diffraction events in electron-nucleus scattering at HERA? The most natural way would be to tag coherently recoiled nucleus. Unfortunately, in particular for heavy nuclei, if one uses the low β beam optics, an identification of low transverse momentum recoil is difficult to realize. The idea we present here is to tag instead the incoherent processes by detecting neutrons evaporated from the nucleus. In Fig. 4a we present the integrated number of neutrons emitted in the ePb incoherent scattering within a circle of the radius R at the distance of 100 m from the ePb interaction point, as predicted by the evaporation model described in section 2. The distance of 100 m corresponds to the position at which both H1 and ZEUS experiments installed their Forward Neutron Counters (FNC). Owing to the Lorenz boost almost all neutrons can be detected within the acceptance region of the FNC of 10 cm. As it is shown in Fig.4b the probability of zero neutron multiplicity events in incoherent deep inelastic eCa events is below 2 % while for the ePb scattering this probability in negligible. If these probabilities turn out not to be significantly larger for a subsample of incoherent deep inelastic events with rapidity gap, we may be able to select incoherent with respect to coherent events using the neutron tag.

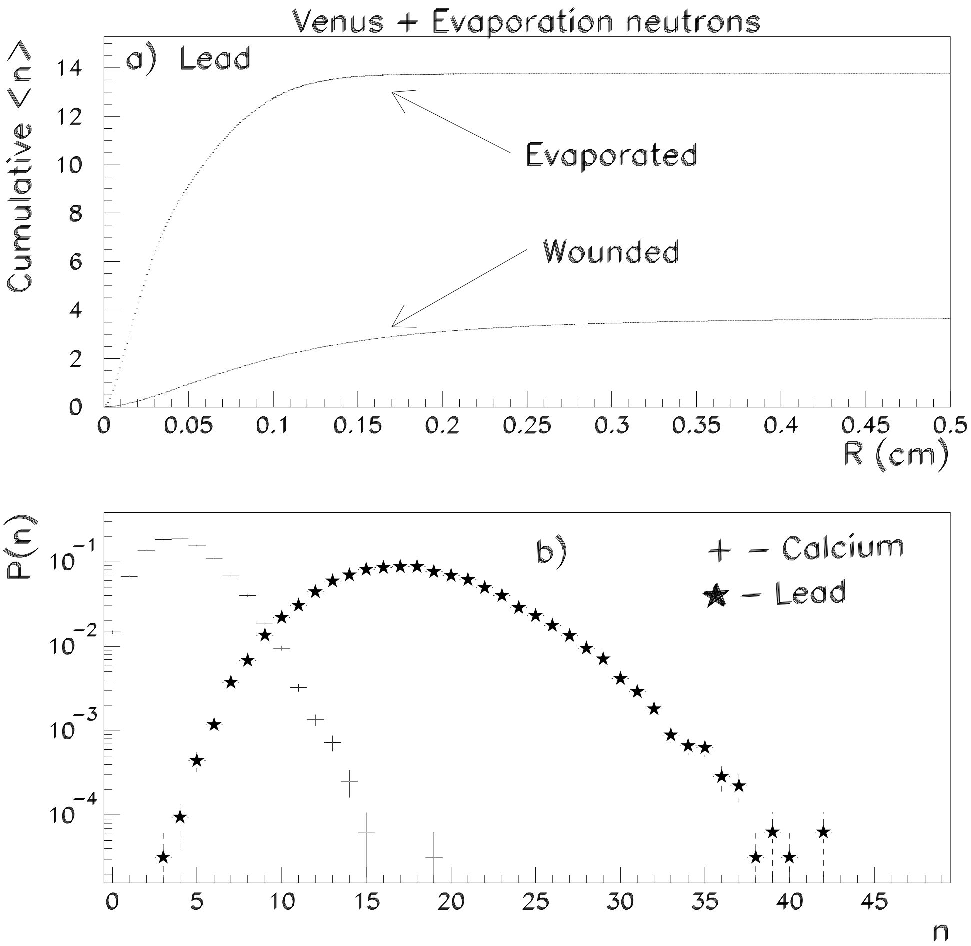

Figure 4: *a) The integrated multiplicity of wounded and evaporated neutrons within a circle of R (m) at the distance of 100 m from the ePb interaction point. b) The multiplicity distribution of evaporated and wounded neutrons for ePb and eCa scattering.*

5 Conclusions

The two examples of processes shown above illustrate what we may gain by detecting nuclear debris, in particular wounded and evaporated nucleons, in eA interactions. While detection of evaporated neutrons can be realized using the existing H1 and ZEUS setup, the detection system of charged fragments require designing a new detection scheme and, most likely, a new beam optics for the interaction point. We hope that the qualitative preliminary studies presented in this contribution will trigger further studies on both the physics and detector issues related to detection of nuclear fragments in deep inelastic electron nucleus collisions at HERA.

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References

[1] L.N. Gribov, E.M. Levin and M.G. Ryskin, Phys. Rep. 100 (1983) A.H. Mueller, J.Qiu, Nucl.Phys. B 286 (1986) 427.

[2] M. Derrick et al., DESY 96-093 (May 1996).

[3] I.Abt et al., DESY Desy internal report H1-96-01 (1996).

[4] K.Werner, Phys. Rep. 232 (1993) 88.

[5] H. Plothow-Besch, PDFLIB - User's Manual, CERN Program Library W5051, 1995.

[6] M. Glück, E. Reya and A. Vogt, DO-TH 94/24.

[7] Yu.D. Bayukov et al., Leningrad Radium Institute ITEP-85-5 preprint.
Yu.D. Bayukov et al., Leningrad Radium Institute ITEP-83-172 preprint.

[8] E665 Collab., M.R. Adams et al.,Phys.Rev.Lett 74 (1995) 5198.

[9] KLMM Collab., M.L. Cherry et al., Phys. Rev. C 52 (1995) 2652.

[10] I. Abt et al., Nucl.Phys. B 407 (1993) 515.

[11] M.Derrick et al., Phys. Lett. B 316 (1993) 412.

[12] K. Golec-Biernat, M.W. Krasny and S.Riess, Phys.Lett. B 337 (1994) 367.

[13] G. Altarelli, G. Parisi, Nucl.Phys. B 126 (1977) 297.

[14] E.A. Kuraev, L.N. Lipatov, V.S. Fadin, Phys.Lett. 60B (1975) 50.

[15] T. Ahmed et al., Phys.Lett. B 348 (1995) 681.