PROCEEDINGS OF SCIENCE

Nuclear Physics in eA collisions

Néstor Armesto*
Departamento de Física de Partículas and IGFAE, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Galicia-Spain
E-mail: nestor.armesto@usc.es

I discuss some aspects of heavy-ion collisions and, in general, of nuclear physics, about which the study of lepton-nucleus collisions as proposed in the EIC and the LHeC/FCC-eh, can provide crucial information. First, I analyse aspects related with the nuclear wave function: nuclear parton densities, small-x dynamics and transverse structure. Second, I focus on items related with the initial stages of heavy-ion collisions, mainly on azimuthal correlations and the ridge. Finally, I mention the analysis of the medium created in high-energy heavy-ion collisions through hard probes, specifically on the nuclear modifications of QCD radiation and hadronisation.

XXV International Workshop on Deep-Inelastic Scattering and Related Subjects
3-7 April 2017
University of Birmingham, UK

*Speaker.

PoS(DIS2017)107

1. Introduction

The central goal of the study of nuclear collisions at high energies is the understanding of the phenomenon of confinement and chiral symmetry breaking in Quantum Chromodynamics (QCD) through the creation and characterisation of a new phase of strongly interacting matter, for whose description the right degrees of freedom would be quarks and gluons and not hadrons or nuclei. While considerable success has been achieved at the Relativistic Heavy Ion collider at BNL and the Large Hadron Collider (LHC) at CERN, uncertainties remain [1]. They can be roughly classified in: (a) those that limit the precision in the characterisation of the properties of such created medium, like our knowledge of nuclear parton densities, hadron and nuclear transverse structure or the nuclear modification of QCD radiation and hadronisation; and (b) those that compromise our understanding of the onset of a collective behaviour that, until recently, was considered a consequence of the creation of the deconfined medium - the Quark-Gluon Plasma, like correlations in the initial state and the dynamics and mechanism of particle production at high energies.

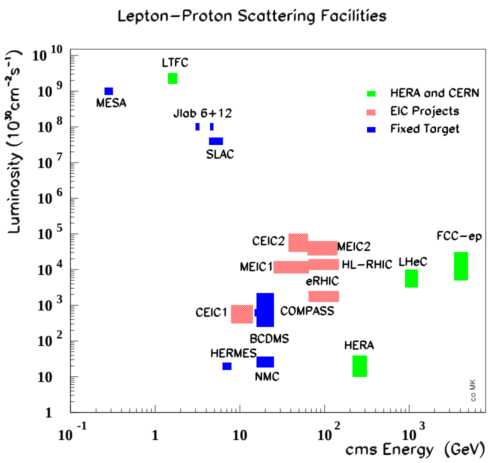

Figure 1: Lanscape of lepton-hadron/nucleus facilities. Courtesy of M. and U. Klein.

The aim of this contribution is discussing what we can learn in lepton-nucleon/nucleus colliders that will provide key information about high-energy nuclear collisions. Note that projected high-energy lepton-nucleus colliders like the Large Hadron-electron Collider (LHeC) or the Future Circular Collider in electron-hadron mode of operation (FCC-eh) at CERN [2], or the Electron Ion Collider (EIC) in the US [3], will reach large center-of-mass energies and luminosities, see Fig. 1, so they will explore uncharted region of the x-Q^2 kinematic plane, see Fig. 2, with large statistics. They will allow a precise characterisation of the structure and dynamics of hadrons and nuclei in a region of large enough Q^2 where perturbative methods should be applicable. Let me emphasise that many of the new phenomena expected in high-energy nuclear collisions e.g. non-linear dynamics at small x, modifications of QCD radiation,..., are density effects so they are enhanced by the increase not only in collision energy but also in the size of the colliding objects. Thus they need not be qualitatively different for pp, pA and AA collisions (for example, multiple parton interactions). This fact makes both ep and eA essential to achieve a quantitative understanding of them.

Specifically, I will consider the knowledge about the nuclear wave function that can be gained in eA colliders in Section 2. In Section 3 I will address the problem of correlations and its relation with the ridge phenomenon observed in pp, pA and AA collisions at the LHC, of key importance for our understanding of the initial stages of heavy-ion collisions. Finally, I will briefly discuss how eA collisions can provide information for the understanding of medium modifications of QCD radiation and hadronisation, used to characterise the deconfined medium. Due to limitations of space, I have not attempted to be comprehensive and just a few references will be provided.

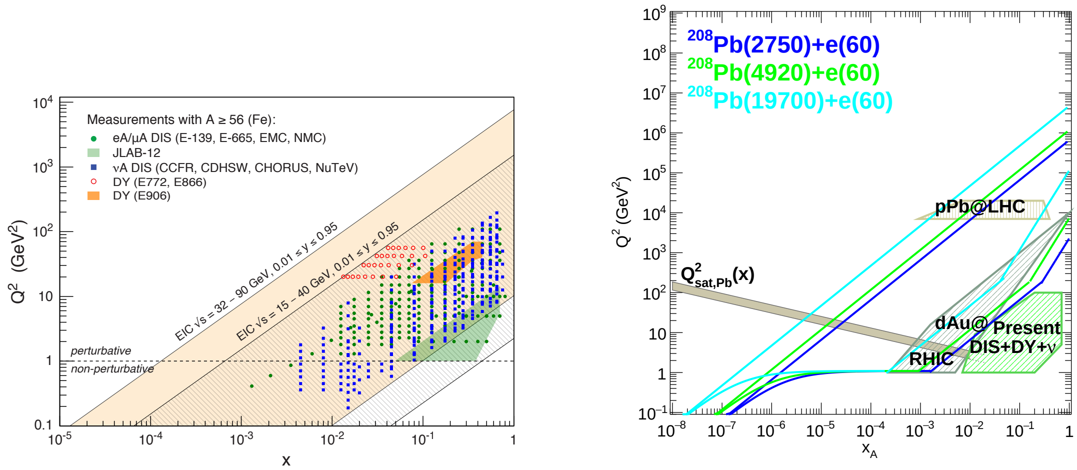

Figure 2: Kinematic planes of the EIC (left plot, from [4]) and the LHeC and the FCC-eh (right plot, with different options shown). Presently existing experimental data used to constrain nuclear PDFs are also displayed [5], as well as an estimation of the saturation scale for a Pb nucleus.

2. The nuclear wave function

Within the standard framework of collinear factorisation, all nuclear parton density functions (nPDFs) are basicly unknown at small x and, for moderate to large x, large uncertainties exist in its flavour decomposition and the gluon. This is due to the fact that available experimental data are restricted to small regions of phase space, see Fig. 2, and strongly influences the interpretation of the results for the quantitative characterisation of the medium created in high-energy heavy-ion collisions, see e.g. Figs. 84 and 88 in [6] for the case of J/ψ production in PbPb collisions at the LHC. Measurements of the reduced cross section at both the EIC and LHeC offer large possibilities for improving this situation, see [7] and [8] respectively. For the LHeC, the increase in the explored kinematic regions by 4 orders of magnitude both in x and in Q^2 reflects in a substantial improvement of our knowledge on the nPDF, though the u/d decomposition becomes limited by the approximate isospin symmetry of the Pb nuclei. The experimental separation of heavy flavours would additionally constraint the glue at small and large x beyond fully inclusive measurements.

Concerning the small-x dynamics, much work has been done lately to improve the accuracy of calculations in the Color Glass Condensate (CGC) for many observables. Still, they are restricted to the scattering of a dilute projectile on a dense target, a situation for which eA collisions offers an ideal testing ground. Concerning the possibilities to clearly unravel the existence of physics beyond standard collinear factorisation and a non-linear regime of QCD, calculations show that these effects would show in a tension in the simultaneous description of F_2 and F_L (i.e. sea and gluon PDFs) at small x, both in ep [2] and eA [9].

Diffraction may be a very sensitive observable [2, 3, 10], although there are some experimental challenges to clearly define diffractive events and to separate coherent from incoherent diffraction. Incoherent diffraction has been recently discussed as a very suitable observable to discriminate the transverse structure of hadrons and the existence of hot spots in the nucleon [11, 12].

Finally, I note that in many models, see e.g. [9], saturation effects seem less noticeable than naively expected when going from p to A. The origin of this can be traced to their use of an already saturated proton as input for the extension to nuclei, and to the sharper nuclear profile where the transition between the dilute and dense nuclear regions is relatively smaller than in a proton.

3. The initial stages

Concerning the initial stages of hadronic collisions, the greatest puzzle at present is the fact that azimuthal asymmetries, taken as a signature of collective behaviour, seem to be present at the LHC in all systems from moderately large multiplicity pp collisions to PbPb [1]. Viscous relativistic hydrodynamics seems to be provide a good description [13]. So the statement of the success of hydrodynamics as a signal of an equilibrated medium is moving to the statement of what this is telling us about the non-equilibrium evolution of a partonic system in QCD: the ubiquitous emergence problem [14]. ep/eA collisions offer an ideal testing ground for the non-hydrodynamical explanations, mainly in the CGC framework, that address the existence of azimuthal correlations to those existent in the hadron/nucleus wave function that are not destroyed by the scattering process [15]. They will also provide information on the approach of the colliding system to a situation where a hydrodynamic description is feasible, and the initial conditions for such hydrodynamic expansion in AA where it is used as a tool to extract transport coefficients of deconfined matter.

4. The analysis of the medium

The analysis of the deconfined medium produced in AA collisions through the modification of the yields of some perturbatively computable observable (called hard probe) with respect to the expectation from pp collisions requires both a detailed knowledge of the benchmark and, for a quantitative characterisation of the medium, of the dynamics underlying the modifications. eA collisions, again, may offer information on both aspects. Concerning the benchmark, the possibilities to constrain nPDFs has been discussed in Section 2. Note that the determination of the nPDFs comes intrinsically linked with a high-precision test of the validity of collinear factorisation in collisions involving nuclei.

Related with those hard probes that imply a modification of the yield of particles with high momentum, and of the structure and yield of jets (named jet quenching), two aspects must be discussed. On the one hand, the modification of the process of QCD branching when it happens inside the nuclear medium, see [16]. In this respect, the EIC and the LHeC/FCC-eh, with their large center-of-mass energies and luminosities, will provide large yields of high transverse momentum jets [2, 3]. While the transverse momenta and yields that can be reached may look modest when compared to those at the LHC, the absence of pileup and the much cleaner environment should make jet reconstruction possible down to much smaller transverse momenta, and the achieved precision enough to detect small nuclear modifications.

On the other hand, the modification of hadronisation [17] inside the nuclear medium can be studied by a combination of measurements at the EIC and the LHeC [2, 3], for different ranges of parton/particle momenta in the nuclear rest frame. The possibility of comparing ep and eA and of varying the nuclear size by using different nuclear species, should provide important information on the nature of the hadronisation process and improve our understanding of the results obtained in hard probes in heavy-ion collisions at particle level.

Acknowledgements: I thank the conveners of WG7, Max Klein and Rik Yoshida, for their invitation to provide this talk. The research was supported by the EU FP7 IRSES network "High-Energy QCD for Heavy Ions" under REA grant agreement #318921, the European Research Council grant HotLHC ERC-2011-StG-279579, Ministerio de Ciencia e Innovación of Spain under project FPA2014-58293-C2-1-P and Unidad de Excelencia María de Maetzu under project MDM-2016-0692, Xunta de Galicia (Consellería de Educación) within the Strategic Unit AGRUP2015/11, and FEDER.

References

[1] H. Caines, these proceedings.

[2] J. L. Abelleira Fernandez *et al.* [LHeC Study Group], J. Phys. G **39** (2012) 075001; `http://lhec.web.cern.ch/`; D. Pellegrini, these proceedings.

[3] A. Accardi *et al.*, Eur. Phys. J. A **52** (2016) no.9, 268; `https://www.bnl.gov/rhic/eic.asp`; `https://eic.jlab.org/wiki/index.php/Main_Page`; R. Ent, these proceedings.

[4] E. C. Aschenauer, S. Fazio, M. A. C. Lamont, H. Paukkunen and P. Zurita, arXiv:1708.05654 [nucl-ex].

[5] K. J. Eskola, P. Paakkinen, H. Paukkunen and C. A. Salgado, Eur. Phys. J. C **77** (2017) no.3, 163.

[6] A. Andronic *et al.*, Eur. Phys. J. C **76** (2016) no.3, 107.

[7] S. Fazio, these proceedings.

[8] H. Paukkunen, these proceedings.

[9] C. Marquet, M. R. Moldes and P. Zurita, Phys. Lett. B **772** (2017) 607.

[10] P. R. Newman, these proceedings.

[11] H. Mäntysaari and B. Schenke, Phys. Rev. D **94** (2016) no.3, 034042.

[12] J. Cepila, J. G. Contreras and J. D. Tapia Takaki, Phys. Lett. B **766** (2017) 186.

[13] R. D. Weller and P. Romatschke, arXiv:1701.07145 [nucl-th].

[14] P. Romatschke, Eur. Phys. J. C **77** (2017) no.1, 21.

[15] S. Schlichting and P. Tribedy, Adv. High Energy Phys. **2016** (2016) 8460349; A. Kovner and M. Lublinsky, Int. J. Mod. Phys. E **22** (2013) 1330001.

[16] J. P. Blaizot and Y. Mehtar-Tani, Int. J. Mod. Phys. E **24** (2015) no.11, 1530012; Y. Mehtar-Tani, J. G. Milhano and K. Tywoniuk, Int. J. Mod. Phys. A **28** (2013) 1340013.

[17] A. Accardi, F. Arleo, W. K. Brooks, D. D'Enterria and V. Muccifora, Riv. Nuovo Cim. **32** (2010) 439. doi:10.1393/ncr/i2009-10048-0