Heavy-Ion Physics with high-energy e-A scattering

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(on behalf of the LHeC working group)

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Outline

- Motivation
- The accelerator
- Kinematics & comparison with LHC
- nPDFs
- Small-x & saturation
- Jets
- Hadronization
- Vector Meson
- Summary & outlook
we do not have a QUANTITATIVE understanding of the nuclear behaviour
we do not have a QUANTITATIVE understanding of the nuclear behaviour required for A-A and QGP studies
we do not have a QUANTITATIVE understanding of the nuclear behaviour

**Small x:**
- Nuclear structure functions
- Factorization in eA?
- Initial conditions for plasma formation

**Modification of QCD radiation and hadronization in the nuclear medium**

Friday, July 4, 2014
\[ \sqrt{s} \approx 0.8 \text{ TeV/nucleon} \]

<table>
<thead>
<tr>
<th>electron beam</th>
<th>LR</th>
<th>ERL</th>
<th>LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>e+ energy at IP [GeV]</td>
<td>60</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>luminosity [(10^{32} \text{ cm}^{-2}\text{s}^{-1})]</td>
<td>10</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>polarization [%]</td>
<td>90</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>bunch population [(10^9)]</td>
<td>2.0</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>e- bunch length [mm]</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>bunch interval [ns]</td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>transv. emit. (\gamma_{x,y}) [mm]</td>
<td>0.05</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>rms IP beam size (\sigma_{x,y}) [(\mu\text{m})]</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>e- IP beta funct. (\beta^*_{x,y}) [m]</td>
<td>0.12</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>full crossing angle [mrad]</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>geometric reduction (H_{hg})</td>
<td>0.91</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>repetition rate [Hz]</td>
<td>N/A</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>beam pulse length [ms]</td>
<td>N/A</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>ER efficiency</td>
<td>94%</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>average current [mA]</td>
<td>6.6</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>tot. wall plug power [MW]</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**Luminosity per nucleon**

\[
L_{eN} = \begin{cases} 
9 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1} & \text{(Nominal Pb)} \\
1.6 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} & \text{(Ultimate Pb)} 
\end{cases}
\]

\[ eD: L_{eN} = A L_{eA} > 3 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1} \]
Kinematics

nuclear DIS - $F_{2,a}(x,Q^2)$

Proposed facilities:
- LHeC

Fixed-target data:
- NMC
- E772
- E139
- E665
- EMC

$e$-$Pb$ (LHeC)
(70 GeV - 2.75 TeV)

$Q^2 (Pb, b=0 \, fm)$

perturbative

non-perturbative
The LHeC will explore a region overlapping with the LHC:

- in a cleaner experimental setup
- on firmer theoretical grounds
we do NOT understand the gluon behaviour at small x

large uncertainties for A-A benchmarking
radiation as $x$ decreases

$\rightarrow$ large number of gluons

breaks down at high densities

$\rightarrow$ non-linear effects

$$\frac{x G_A(x, Q_s^2)}{\pi R_A^2 Q_s^2} \sim 1 \implies Q_s^2 \propto A^{1/3} x^{-0.3}$$
can LHeC improve this?

neutral-current DIS pseudo-data generated assuming:

\[ E_{\text{lepton}} = 60 \text{ GeV} \]
\[ E_{\text{lepton}} = 20 \text{ GeV}, \quad E_{\text{proton}} = 7000 \text{ GeV}, \quad E_{\text{Pb}} = 2750 \text{ GeV} \]
\[ E_{\text{lepton}} = 26.9 \text{ GeV} \]

for \[ 10^{-5} < x < 1 \quad \& \quad 2 < Q^2 < 10^5 \text{ GeV}^2 \]

\[ \text{EPS09 & CTEQ6.6 as baseline } \Rightarrow \text{new fit} \]
great improvement on sea distributions & gluons
**JETS**

constrain the gluons at large $x$

data to be analyzed

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Eskola, Paukkunen, Salgado, arXiv:1308.6733

clear effect

Preliminary CMS data "by eye"
Jets: large $E_T$ even in eA.
Useful for studies of parton dynamics in nuclei and for photon structure.
Background subtraction, detailed reconstruction pending.
RADIATION AND HADRONIZATION

Relevant for particle production and QGP analysis in HIC

\[
R_A^h(z, \nu) = \frac{1}{N_A^e} \frac{dN_A^h(z, \nu)}{d\nu \, dz} \left/ \frac{1}{N_D^e} \frac{dN_D^h(z, \nu)}{d\nu \, dz}\right.
\]

Low energy: hadronization inside

High energy: partonic evolution altered

N. Armesto, Heavy Ion Physics in e-A and p/A-A
ELASTIC VM PRODUCTION IN $eA$

For the **coherent case**, predictions available

**Challenging experimental problem** (neutron tagging in ZDC?)

$\gamma^* A \rightarrow J/\Psi A$

$W (GeV)$

$1/A^2 d\sigma/dt \ (\mu b/GeV^2)$

**Saturation effects**

$0 \ 200 \ 400 \ 600 \ 800 \ 1000$

$0 \ 0.5 \ 1 \ 1.5 \ 2 \ 2.5$

$W (GeV)$

Armesto, Heavy Ion Physics in e-A and p/A-A

Friday, July 4, 2014
t-differential measurements give a gluon transverse mapping of the hadron/nucleus

\[ \gamma^* A \rightarrow J/\Psi A \]
\[ Q^2 = 0 \]

\[ d\sigma/dt \, (\text{nb}/\text{GeV}^2) \]

Lead
- b-Sat
- b-NonSat

\[ W = 400 \, \text{GeV} \]

with breakup

Armesto, Heavy Ion Physics in e-A and p/A-A

Friday, July 4, 2014
t-differential measurements give a gluon transverse mapping of the hadron/nucleus

Large extent in t with good precision

Sizable saturation effects expected

Armesto, Heavy Ion Physics in e-A and p/A-A

Friday, July 4, 2014
The LHeC@CERN

- High-precision tests of collinear factorization(s)
- Access to small $x$ in $p$ and $A$
- Sensitivity to physics beyond standard pQCD.
- Stringent tests of QCD radiation
- Many uncovered topics
- ... with implications on our understanding of QGP.
**Summary**

**The LHeC@CERN**

- High-precision tests of collinear factorization(s)
- Access to small $x$ in $p$ and $A$
- Sensitivity to physics beyond standard pQCD.
- Stringent tests of QCD radiation
- Many uncovered topics
- ... with implications on our understanding of QGP.

It will give an answer to the question of saturation/non-linear dynamics (ep AND eA essential)
With CERN and NuPECC mandate to further motivate the physics case and produce a TDR around 2015, lots of work to do:

- refine DGLAP fits with flavour decomposition, optimized $F_L$ scenarios and LHC data
- Monte Carlo generators
- Studies on diffraction: separation of coherent from incoherent, ndPDFs, dijets, ...
- Large $x$, EW bosons
- Nuclear GPDs: nuclear DVCS, etc
- eD
- Jet reconstruction, angular decorrelation, ...
- ...

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http://cern.ch/lhec