Parton propagation and fragmentation
– summary & outlook –

Alberto Accardi
Hampton U. & Jlab

Nuclear QCD @ EIC
Argonne, 7-9 April, 2010
The 'ppf' working group

Wiki:


Weekly phone meetings

Please join us!

Review papers

Accardi, Arleo, Brooks, d'Enterria, Muccifora,

Majumder, van Leuween,  arXiv:1002.2206
Physics motivations

- Nuclei as space-time analyzers
- Non perturbative aspects of hadronization
  - Color confinement dynamics: how do partons dress up?
  - What do gluons look like? [Majumder]
  - Test of fragmentation mechanisms [Bentz]
- Parton propagation in perturbative QCD
  - testing pQCD
  - DGLAP parton showers, jets
- Connection to other fields
  - Properties of QGP, $\nu$-oscillations
  - TMDs in nucleons [Avakian]
  - gluon GPDs [Majumder]
- Experimental data!! [Di Nezza, Mineeva]
Physics motivations

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THE QUESTION:

Electron scattering gives the charge density or quark density inside a nucleon.

What does the gluon density look like?

How confined are low-\(x\) gluons (fluctuations)?

Are there other long range correlations in nuclei?

How does this change with resolution?

Need a colored probe!
Fragmentation in the NJL model

[Bentz]

\[ D^\pi_q(z) = \sum_{k=1}^{N} P(k) \left( \sum_{m=1}^{k} W_0 \cdots W_{m-1} \right) \]

- How to test in nDIS?
- Medium modifications of the NJL vertex?
- Formation length?
Modification of Cahn effect

\[ \langle \cos \phi \rangle_{eN} \propto \frac{|k_T| x f_{qN}^\perp(x, k_T)}{f_N^q(x, k_T)} \]

\[ f_N^q(x, k_T) = \frac{1}{\pi \mu_2^2} f_N^q(x) e^{-k_T^2/\mu_2^2} \]

\[ \frac{\langle \cos \phi \rangle_{eA}}{\langle \cos \phi \rangle_{eN}} = \frac{\mu_2^2}{\mu_2^2 + \Delta_{2F}} \sim qhat \]

Gao, Liang & Wang
arXiv:1001.3146

- Nuclear modification of Cahn may provide info on \( k_T \) broadening and proton TMDs
Can this observable distinguish energy loss vs. absorption, i.e., short vs. long formation times?

$
\langle \cos \phi \rangle_{eN} \propto \frac{\sqrt{k_T} q(x, k_T)}{f_N^q(x, k_T)}
$

$f_N^q(x, k_T) = \frac{1}{\pi \mu^2} f_N^q(x) e^{-\frac{k_T^2}{\mu^2}}$

$\langle \cos \phi \rangle_{eA} = \frac{\mu^2}{\mu^2 + \Delta_{2F}}$

\[ \mu^2 \left( f_N^q \right) / \mu^2 \left( f_N^q \right) = 0.94 \]

\[ \mu^2 \left( f_N^q \right) / \mu^2 \left( f_N^q \right) = 0.5 \]

Gao, Liang & Wang
arXiv:1001.3146

- Nuclear modification of Cahn may provide info on $k_T$ broadening and proton TMDs

H. Avakian, Argonne, April 8
Relaxing the assumptions on the gluon correlation consider photon Brem.

This is basically a gluon GPD

It does not yet involve color correlations over several nucleons

only momentum correlations
Observables – priority list

For longer list: https://eic.jlab.org/wiki/index.php/EA_propagation:_observables

Light quarks

- $\pi^0, \eta$ (energy loss vs prehadron absorption)
- Attenuation at smallish $\nu$
  - Benchmark on HERMES / JLAB data
  - check, improve EMC data
- $p_T$-broadening:
  - vs. $Q^2$ – to understand HERMES data growing values
  - vs. $z$ - for precision tests of theory models
  - as a measure of the saturation scale $Q_s$
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- $EIC' = \frac{E_{IC}}{E_{HERMES}} = 0$
  - Energy loss model
  - Absorption model

(Simulations by R. Dupré)
(Curves by A. Accardi)
**Observables – priority list**

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- **Light quarks**
  - $\pi^0, \eta$ (energy loss vs prehadron absorption)
  - Attenuation at smallish $\nu$

\[ \langle \nu \rangle = 14 \text{ GeV} \]
\[ \langle z \eta \rangle = 0.4 \]

**HERMES $\pi^0$**

**EIC $\pi^0$**

**EIC $\eta$**

\[ \Delta \left\langle p_T^2 \right\rangle = \left\langle p_T^2 \right\rangle_A - \left\langle p_T^2 \right\rangle_D \]

medium-modified DGLAP  
(Domdey et al.)

pQCD scaling of pions

(Simulations by R.Dupré)  
\[ Q^2 \text{[ GeV}^2] \]
Observables – priority list

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- Light quarks
- Heavy Quarks
  - heavy vs. light mesons in general
  - B vs D mesons (heavy flavor puzzle)
  - Attenuation, $p_T$-broadening
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![graph](attachment:image.png)

11+30 GeV/A Fe

$L = 0.4 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$

1 month 100% running

[Dupré]
Observables – priority list

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Light quarks
Heavy Quarks
Jets (1+1)

- rates vs. cone radius – gluon radiation will broaden jets
- ... vs. $p_T^{\text{min}}, E^{\text{min}}$ : more handles on energy loss [Vitev]
- jet $p_T$-broadening – direct parton $p_T$-broadening
Observables – to be investigated

For longer list: https://eic.jlab.org/wiki/index.php/EA_propagation:_observables

 لعبة

 photons

 induced \(\gamma\) absent in pure absorption mechanisms !!
calculable angular pattern relative to hadron
different from fragmentation \(\gamma\)
access to nuclear gluon GPDs

Intensity scale

\[ \omega = 1 \text{ GeV} \]

\[ \omega = 3 \text{ GeV} \]

\[ \omega = 10 \text{ GeV} \]

Majumder, Vitev(?)

Timescales ??

IV, PLB (2005)

N.B. The calculation is for coherent FS gluon emission. Expect similar pattern for \(\gamma\)
Observables – to be investigated

For longer list: https://eic.jlab.org/wiki/index.php/EA_propagation:_observables

- **Photons**
  - induced $\gamma$ absent in pure absorption mechanisms !!
  - calculable angular pattern relative to hadron
  - different from fragmentation $\gamma$
  - access to nuclear gluon GPDs

- **Neutrons in target fragmentation**
  - impact parameter measurement
  - correlation to leading hadrons

- **Nuclear modifications of spin asymmetries**
  - medium properties / time scales
  - properties of nucleon TMDs

Majumder, Vitev(?)

Timescales ??

Strikman, Ciofi(?), J.C.Peng(?)

Timescales ??

Avakian & TMD friends (?)

Timescales ??
**Observables – to be investigated**

For longer list: https://eic.jlab.org/wiki/index.php/EA_propagation:_observables

- **2+1 jets: access to nuclear gluons**
  - Ploszkon (?)
  - BNL summer students (?)

\[
\frac{d^2\sigma_{2+1}}{dx_p dQ^2} = A_q(x_p, Q^2) q(x_p, Q^2) + A_g(x_p, Q^2) g(x_p, Q^2),
\]

known from inclusive DIS

calculable in pQCD
Observables – to be investigated

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2+1 jets: access to nuclear gluons

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\[ \text{[G. Soyez, unpublished (ask M. Lamont)]} \]

A final note concerns the medium effects in e+A collisions. Since the outgoing jets have to travel in the medium, the coefficients \( A_q \) and \( A_g \) will be affected by in-medium propagation. We shall assume here that the measurements of 1+1-jet cross-sections allow to control how jets propagate in the medium and hence to know the corrections to \( A_q \) and \( A_g \). This is not completely trivial as 1+1-jet events will be highly dominated by quark-initiated jets, while in the 2+1-jet case, we can have both quarks and gluons. As a consequence, the medium effects on \( A_q \) and \( A_g \) will probably introduce an additional systematic error coming from the uncertainty on the gluon-jet propagation.\(^3\)
Agenda

- **Estimate statistical errors**
- **Angles, momentum plots**
  - help for detector design

- **Simulations with physics effects:**
  - En.loss vs. absorption – potential for separation
  - pure en.loss regime at large nu:
    - signatures,
    - tests of en. loss
    - differences between models
  - ...

**Now:** no detectors, just cut out the beam fold in branching ratios only, if needed

**Future:** geometric acceptance, fast MC real particle reconstruction
Monte Carlo priorities

- Finish PyQM implementation  
  - Dupré  
  - enables to study Lund fragmentation vs. FF

- Cold nuclear geometry in Q-Pythia  
  - Volunteers needed!!
  - jets
  - modified DGLAP

- Q-Pythia development  
  - HT energy loss  
    - Majumder – at least 6 months
  - integration with PyQM  
    * Lund fragmentation vs. FF
    * SW vs GLV

Daniel + Loizides
Monte Carlo questions

- Is $p_T$-broadening correctly implemented in our MCs ??
  - PyQM: known issues, need help for solutions [Dupré]
  - Q-Pythia ??
  - GiBUU: no direct $p_T$-broadening, “nuclear filtering” effect [Gallmeister]

- Do we need en.loss & absorption in the same MC?
  - as separate options, sharing the rest of the simulation
  - merging them together ?? If so, how ??
  - Embed GiBUU absorption routines in Q-Pythia ?
  - Embed (some) energy loss option in GiBUU ?
Towards the white papers

“ppf” WG note
- general intro, EIC characteristics / peculiarities [done]
- list of hadrons, production rates, channels [done*]
- quick list of open questions, interesting observables [from this w.shop]

June 7-9: Jlab users group meeting
- Use “ppf” note as draft
- add list of observables under study, or planned

Summer: Jlab white paper
- add results for observables, plots, simulations, new ideas
  [results can be preliminary]
- serious effort, will need real commitment from everybody
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All speakers, WG members & friends!

Send me in writing your ideas:
- a brief summary of your talk (speakers)
- your ideas for observables
- anything to be included in these documents

DEADLINE: MAY 20th
Towards the white papers

“ppf” WG note

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End of Sep: INT program on nuclear matter – November: EIC workshop @ INT
- present nice nearly-final results

Winter: INT white paper on “The science cas for an EIC”
- Detailed presentation of propagation and hadronization program @ EIC
INT program “gluons and quarks at high-E”

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<thead>
<tr>
<th>week</th>
<th>dates</th>
<th>topics</th>
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<tr>
<td>1</td>
<td>13–17 Sept</td>
<td>Workshop on &quot;Perturbative and Non-Perturbative Aspects of QCD at Collider Energies&quot;</td>
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<td>2</td>
<td>20–24 Sept</td>
<td>open conceptual issues: factorization and universality, spin and flavor structure, distributions and correlations</td>
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<td>3–5</td>
<td>27 Sept –15 Oct</td>
<td>small x, saturation, diffraction, nuclear effects; connections to p+A and A+A physics; fragmentation/hadronization in vacuum and in medium</td>
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<td>6–7</td>
<td>18–29 Oct</td>
<td>parton densities (unpolarized and polarized), fragmentation functions, electroweak physics</td>
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<td>8–9</td>
<td>1–12 Nov</td>
<td>longitudinal and transverse nucleon structure; spin and orbital effects (GPDs, TMDs, and all that)</td>
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<tr>
<td>10</td>
<td>15–19 Nov</td>
<td>Workshop on &quot;The Science Case for an EIC&quot;</td>
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http://www.int.washington.edu/PROGRAMS/10-3/
**The EIC parton energy loss and hadronization program**

- Precision tests of pQCD energy loss, DGLAP showers
- Jet event shape modifications, time evolution
- Space-time picture of parton fragmentation (perturbative regime)
- Hadronization from current to target region

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<tr>
<th>EIC</th>
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Not energy nor luminosity hungry (except B mesons, rare had's, 5D ?) but **needs good PID, vertex detector**

accardi@jlab.org  Argonne Lab, 7-9 April 2010