Initial stage and jet quenching in High-Energy Nuclear Collisions

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Outlinne

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   - A-Z NNLO nPDFs
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4. Jet quenching
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   - The puzzle
   - Harmonics
   - Outlook

October 2012-July 2013: Masters course, Universidade de Santiago de Compostela (Spain).

December 2013-September 2017: PhD student at the Universidade de Santiago de Compostela.

- Supervisors: Carlos A. Salgado and Carlos Pajares
- Collaborators: Nestor Armesto, Pia Zurita, Matthew Luzum...
- August 17th 2014-September 17th 2014: CERN, Theory Division.
- October 5th 2016-December 5th 2016: McGill University, Montréal.
  Supervisors: Charles Gale and Jeon Sangyong.
Heavy-ion collision

Initial stage: nPDFs and CGC evolution.

Jet quenching: single-inclusive production..., heavy-flavour, EM probes...
Factorisation

\[
\frac{d\sigma^{AA\rightarrow h+X}}{dp_T\, dy} = \int \frac{dx_2}{x_2} \frac{dz}{z} \sum_{i,j} x_1 f_{i/A}(x_1, Q^2)x_2 f_{j/A}(x_2, Q^2)
\times \frac{d\hat{\sigma}^{ij\rightarrow k}}{d\hat{t}} D_{k\rightarrow h}(z, \mu_F^2)
\]

- nPDFs, linearly evolved using DGLAP evolution equations.
- Partonic cross-section: pQCD.
- Medium modifications of FFs: energy loss, hadronisation, recombination for quarkonia...
Current status

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<th>nCTEQ</th>
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<td>medium modified FFs</td>
<td>flavour separation considered, not enough sensitivity</td>
<td>deuteron data included</td>
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**EPPS: NLO (with di-jet data)**

**A-Z: NNLO GM-VFNS**

EPPS16: W’s, Z’s and di-jet. 1811 data points.

Thanks to Pia Zurita.
Current status

- High $x$: no constrain ($g$)
- Low $x$: no constrain, ($g$, sea, valence).
  Extrapolations.
- No sensitivity to flavor separation ($R_u = R_d$).
- No LHC data included YET.

EPPS16

Neutrinos, W’s, Z’s and di-jets included.

EPPS16: arXiv:1612.05741 [heph.ph]
A-Z NNLO nPDFs

- NNLO precision mandatory for future facilities: EIC and LHeC.
- First NNLO nPDF set in GM-VFNS.
- Evolution at NNLO in Mellin space.
- Neutral and neutrino DIS data already included (around 2000 data points).
- LHC, Drell-Yan in progress.
- Nuclear efects in deuteron.
- Flavour separation?

In preparation with Pia Zurita.
Future improvements

- nPDFs **uncertainties significant.**

A better knowledge of the nPDFs will be **essential** to future facilities as the **EIC**.

- More data required: LHC run 2, EIC and LHeC DIS.
- Inclusion of photon distributions.
- QCD-QED evolution.
- More sophisticated treatment of heavy quarks.
- Proton PDFs and nPDFs in a single fit
Neural network determination of nuclear PDFs in Lead

- nPDFs contain a **few lead data**.

- *Transform* neutral DIS data for different nuclei into lead data. Fit the new data with the **NNPDF** methodology.

\[
\frac{F_{2}^{Pb}(x, Q^2)}{F_{2}^{d}(x, Q^2)_{exp+th}} = \frac{F_{2}^{A1}(x, Q^2)}{F_{2}^{A2}(x, Q^2)_{exp}} \cdot C_{th}(x, Q^2, A_1, A_2)
\]

\[
C_{th}(x, Q^2, A_1, A_2) \equiv \frac{F_{2}^{A2}(x, Q^2)}{F_{2}^{A1}(x, Q^2)_{th}} \cdot \frac{F_{2}^{Pb}(x, Q^2)}{F_{2}^{d}(x, Q^2)_{th}}
\]

th: EPS09 or DSSZ.
Pb NNPDFs

- Using neutral DIS data: sensitivity only to the gluon and to the singlet.
- Structure functions computed in the FONLL GM-VFNS.
- NNLO evolution given by APFEL.

Future improvements: include Drell-Yan data.

Carlota Andres, Nathan P. Hartland and Juan Rojo, in preparation
Heavily Ion Collisions

- **QGP** created in HIC.
- Probe the properties of the QGP using bulk observables or hard probes, such as: quarkonia, high $p_t$ hadrons, jets...

\[ \text{Dijet in: } p-p... \]

High energy jets lose energy to the medium and A-A...

- **Jet quenching** as a tool to extract medium properties.
Motivation

\[ R_{AA} = \frac{dN_{AA}/d^2p_T\,dy}{\langle N_{\text{coll}}\rangle dN_{pp}/dp_T^2\,dy} \]

- Smooth hydro + ASW Quenching Weights

\[ \hat{q}(\xi) = K\hat{q}_{QGP}(\xi) \simeq K \cdot 2\epsilon^{3/4}(\xi) \]

**K-factor vs. centrality**

Smooth hydro

EKRT+minijet

**K** depends mainly on the energy and it is almost independent of the centrality of the collision
Difficult to reconcile the energy and centrality dependence!! A new puzzle??

Next steps: Check this result with an ebye hydro. Use this hydro to compute high-$p_T$ harmonics.
$\nu_2$ and $\nu_3$ at high $p_T$

- Using the fitted value of $K$ for $R_{AA}$

Preliminary. ONLY 10 events!!

Carlota Andrés, Néstor Armesto, Harri Niemi, Risto Paatelainen, Carlos A. Salgado and Pia Zurita.
Compute high $p_T$ harmonics with EKRT hydro (work in progress).

Compute other observables: di-jets, heavy-quark suppression... (work in progress).

Implement the antenna radiation in the QW.

Collisional energy loss?

In the QW perturbative tails are neglected. These tails are included in AMY formalism.

Compute the $R_{AA}$ using AMY rate equation.

Work in progress in collaboration with Charles Gale and Sangyong Jeon.