Discovering partonic rescattering in light nucleus collisions

Aleksi Kurkela

A. Huss, AK, Aleksas Mazeliauskas,
R. Paatelainen, W. van der Schee, U. Wiedemann,

[2007.13754, 2007.13758]

Universitetet
i Stavanger

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- Two mutually exclusive descriptions of hadronic collisions:
  - min-bias pp: no parton rescattering ⇒ ideal gas
    PYTHIA, Herwig, ...
  - central AA: Many rescattering ⇒ perfect fluid
    (viscous) hydrodynamics

- Observation of collectivity in small systems challenges both paradigms

- **Big question: How does one interpolate between these two extremes?**

- **Complication:** Only some of the signs of collectivity are seen in small systems
  - Collective flow, v_n's
  - Strangeness enhancement
  - …but no parton energy loss?

- **Assuming** that collectivity arises from parton rescattering, *some* amount of parton energy loss must be present also in small systems

- Is energy loss avoiding detection because
  - it is a small?
  - it is not there $\Rightarrow$ different mechanism of collectivity

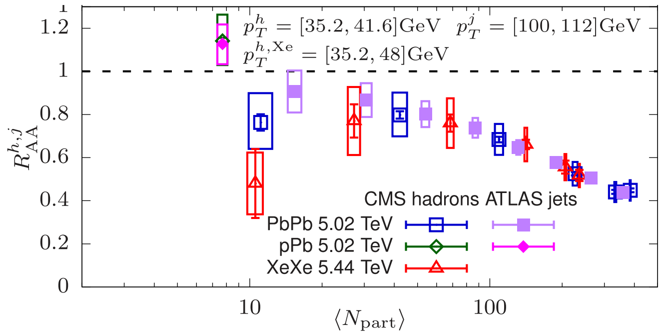
Hadron (jet) nuclear modification factor

- Compares yield in AA to an equivalent number of *pp* collisions $\langle N_{\mathrm{coll}} \rangle = \sigma_{pp}^{\mathrm{inel}} \langle T_{AA} \rangle$

$$R_{AA}^{h,j}(p_T, y) = \frac{1}{\langle T_{AA} \rangle} \frac{(1/N_{\mathrm{ev}}) dN_{AA}^{h,j}/dp_T dy}{d\sigma_{pp}^{h,j}/dp_T dy}$$

- System-size dependence studied in terms of centrality dependence of R_{AA}
- Nuclear overlap function $\langle T_{AA} \rangle$ from *model calculations*

$\Rightarrow$ high-p_T observable depends on soft physics assumptions



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Is there energy loss at $\langle N_{\mathrm{part}} \rangle \approx 10$?
Are the different collision systems in agreement?

- Systematic uncertainty (boxes) dominated by $\langle T_{AA} \rangle$

$\Rightarrow$ Need hard observable independent of soft modelling

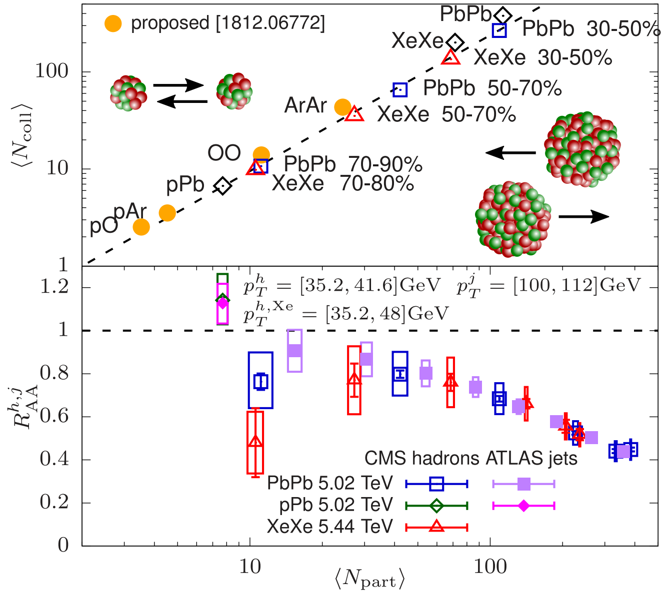
Inclusive nuclear modification factor

Replace $\langle T_{AA} \rangle$ with **experimentally measurable** beam luminosity

$$R^{h,j}_{AA,\mathrm{minbias}}(p_T, y) = \frac{1}{A^2} \frac{d\sigma^{h,j}_{AA}/dp_T dy}{d\sigma^{h,j}_{pp}/dp_T dy}$$

- No dependence on soft modelling
- Only applicable to min bias measurements
- but system size can be controlled by changing A

For small systems, need to collide light nuclei



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Proposed OO collisions probe the physically interesting region.

1812.06772

The null hypothesis

- In order to detect a small signal of parton rescattering the **null hypothesis** (= no energy loss) must be known accurately.
- In absence of parton rescattering the $R_{AA,\text{minbias}}$ can be computed in a systematically improvable way in QCD factorization: $p_T \gg \Lambda_{QCD}$

$$\sigma(p + p \to j + X) = \text{PDFs} \otimes \sigma_{a+b\to c+d}$$

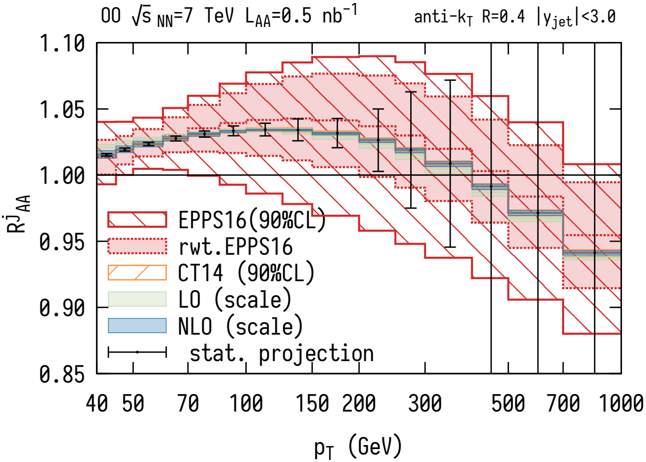
$$\sigma({}^{16}_{8}O + {}^{16}_{8}O \to j + X) = \text{nPDFs} \otimes \sigma_{a+b\to c+d}$$

The null hypothesis

The state-of-art-calculation of the null hypothesis:

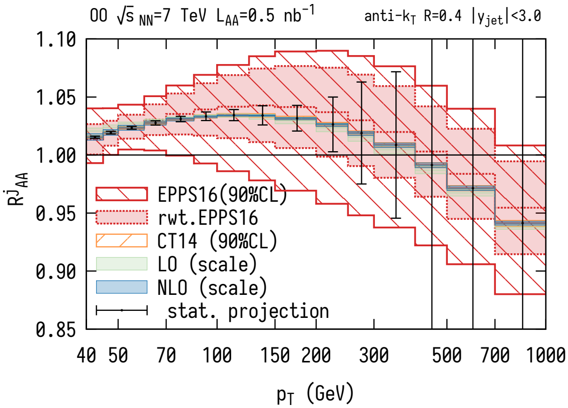
- **NLO** inclusive $R_{AA,minbias}$ **without parton rescattering**

EPPS16 nPDFs



Deviation form null hypothesis ⇒ discovery of energy loss

The null hypothesis



- Under perturbative control
- nPDFs dominate uncertainty

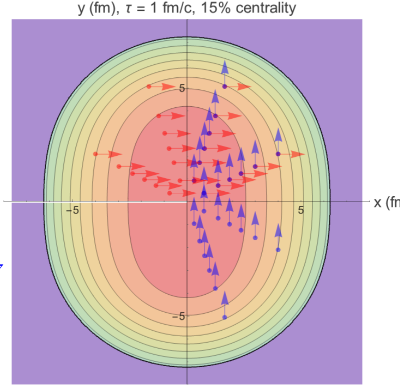
- nPDF errors systematically improvable with new data
  - reweighting with additional di-jet data further reduces uncertainty CMS 1805.04736, Eskola et al. 1903.09832
- Illustration of the statistical uncertainties with 0.5nb^{-1}
  few hours with 'moderately optimistic' scenario 1812.06772

Model predictions for light-ion collisions

- Model calculations give an estimate on the signal size and inform about feasibility of detection
- None of the available Monte-Carlo tools for heavy-ion collisions are tuned for small systems JetScape, JEWEL, etc
- Simple modular energy-loss model
  - **Standard methods developed for heavy-ion collisions extrapolated to OO** Baier et al. hep-ph/0106347
  - Restricted to hadron R_{AA}^{h} for simplicity
  - Model agnostic approach, vary model assumptions for a **conservative estimate of model uncertainty**

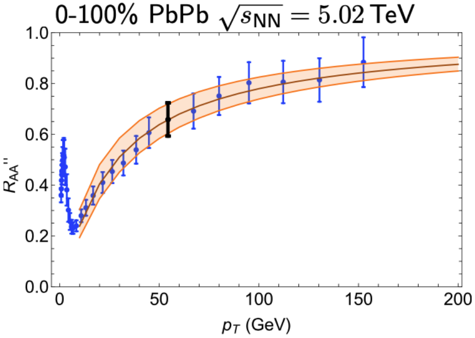
Model predictions for light-ion collisions

- Background $T(\tau, r)$-profile:
  - From Hydro-like to free streaming
  - with and w/o freeze-out
  - confromal EoS vs. lattice EoS
  - dynamical geometry vs. Bjorken $\tau^{-1/3}$
  - isotropic geometry vs. azimuthal anisotropy ϵ_2.



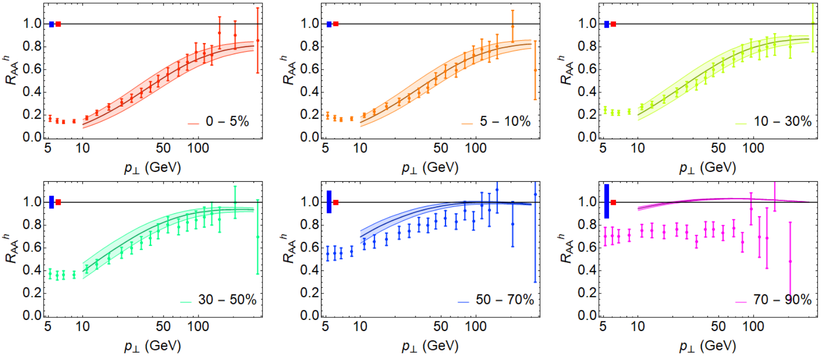
- Energy-loss models:
  - BDMPS-Z Arnold 0808.2767
    vs. AdS/CFT inspired
    vs. $dE/dL \sim L^{0.4}T^{1.2}$
    vs. $dE/dL \sim LT^3$
  - Varying starting time of energy loss $\tau_0 = 0.05 - 0.5\text{fm/c}$
  - With or without nPDFs and FFs

Model predictions for light-ion collisions



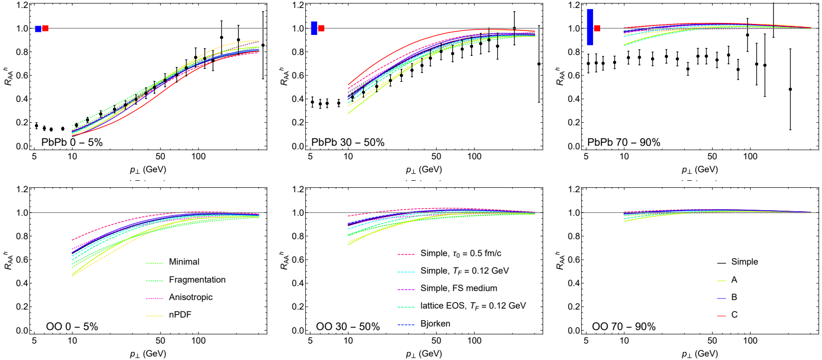
- For each of the models: **fit** model parameter $\hat{q}$ at single point $R^h_{PbPb}(p_T = 54.4\text{GeV})$ CMS 1611.01664
- System-size, and p_T-dependence are then predictions

Model predictions in light-ion collisions



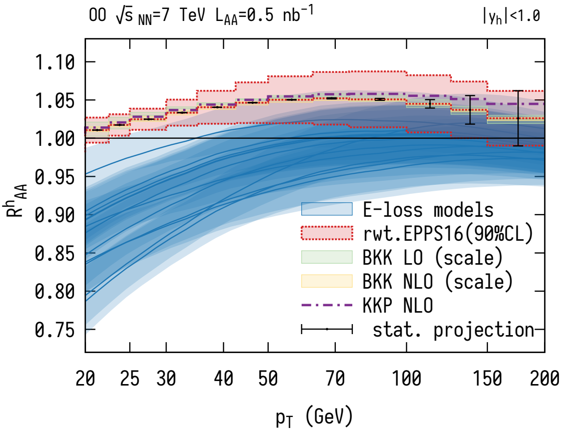
- Validation of the simple model by comparing to centrality and p_T-dependence in PbPb (and similarly for XeXe)
  - Good agreement for central to mid-central data

Model predictions for light-ion collisions



- Dramatic variation of model assumptions quantifies modelling uncertainty

Null-hypothesis vs. model prediction



- Improved accuracy of the baseline allows to separate most of the models from null hypothesis for

$$20\text{GeV} < p_T < 50\text{GeV}$$

Conclusions

- Interpretation of collectivity in small systems as a sign of parton rescattering demands that some amount of parton energy loss is present
- Irreducible model uncertainties in centrality selected R_{AA} make it difficult to separate the signal from background
- Improved accuracy of min-bias R_{AA} allows to use an OO run to either
    - discover partonic rescattering in small system
    - exclude a wide range of energy loss models, challenging the picture of collectivity in small systems as a result of parton rescattering.