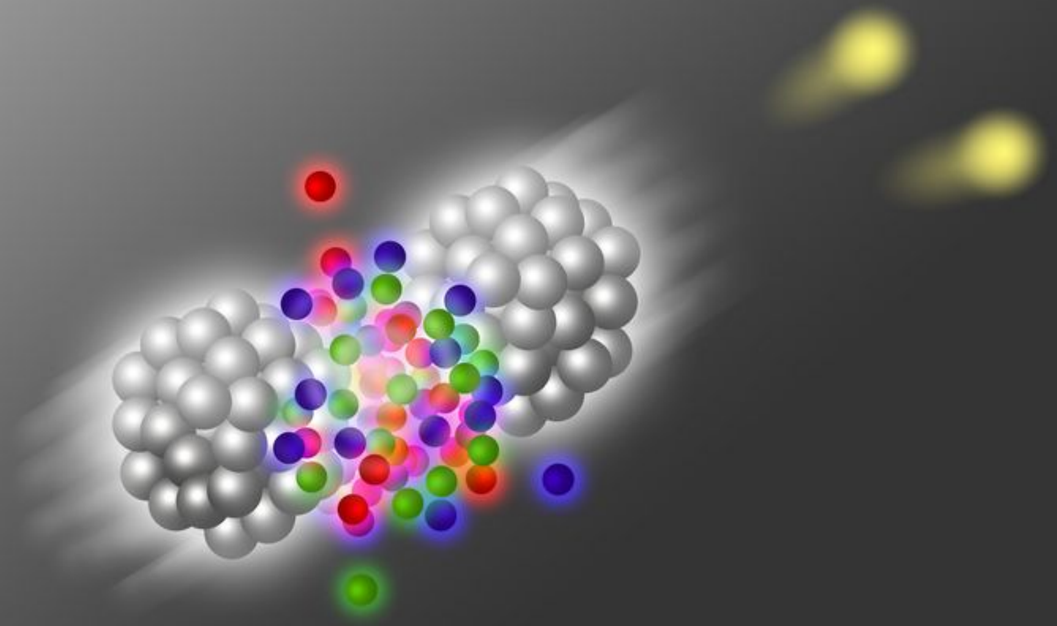
Early Colour-Coherence Effects in Jet Quenching



L. Apolinário,

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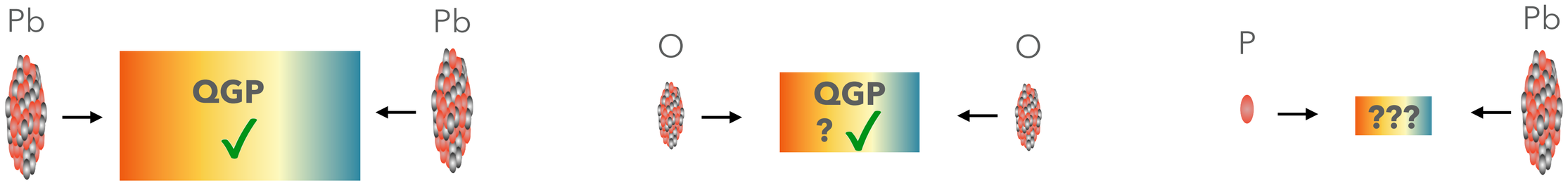
C. Le Roux, K. Zapp

Light ion collisions at the LHC - 2025

Dec 2nd, 2025

Motivation

- QGP formation across system size:



  - Is there any early jet modification in small systems?

First observable **in-medium modification**?

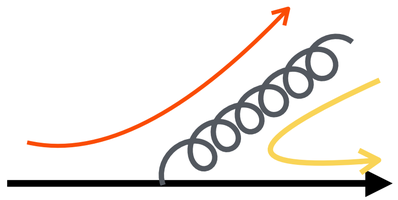
How about loss of colour coherence induced by a single early colour exchange?

(No other medium-induced effects required)

One Early Re-Scattering

- A hard parton may undergo one soft re-scattering in a small system.

If no re-scattering with the medium:



Vacuum-like fragmentation

Coherence effects originate angular ordering pattern

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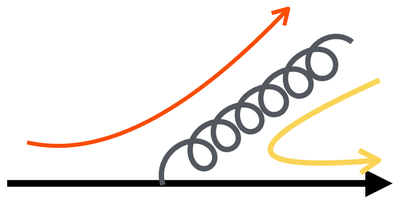

Vacuum-like fragmentation

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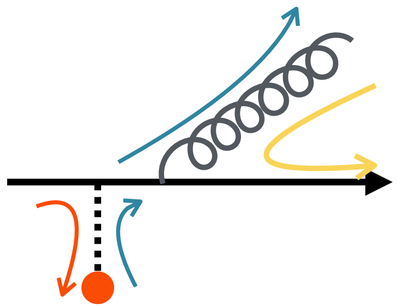
If re-scattering with thin/dilute medium:



$q_\perp \to 0$

No momentum transfer → Kinematics essentially unchanged

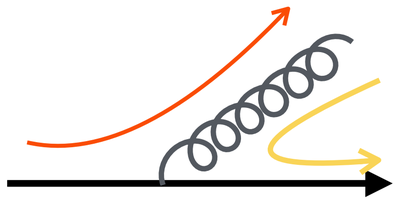
Color exchange ⇒ Loss of coherence

⇒ **Phase space for radiation is modified!**

Our approach

- **No medium re-scattering** (vacuum) but changed the angular ordering on the **first emission only**:

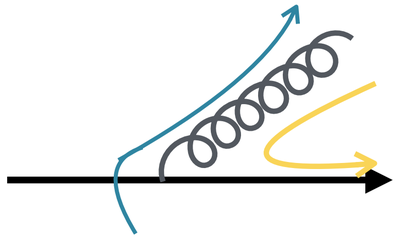
Mimics no early colour exchange:



Model: **JEWEL Vacuum**

Angular ordering = ON

Mimics single early colour exchange:



Model: **JEWEL Vacuum**

Angular ordering = OFF

Jet Reconstruction

- τ-reclustering **maps** formation time of the first **parton shower emission** to the first **unclustering step** on a jet tree:
  - Anti-k_T R=1.0 jets & no Soft-Drop

    Retain wide-angle radiation to capture decoherence signal

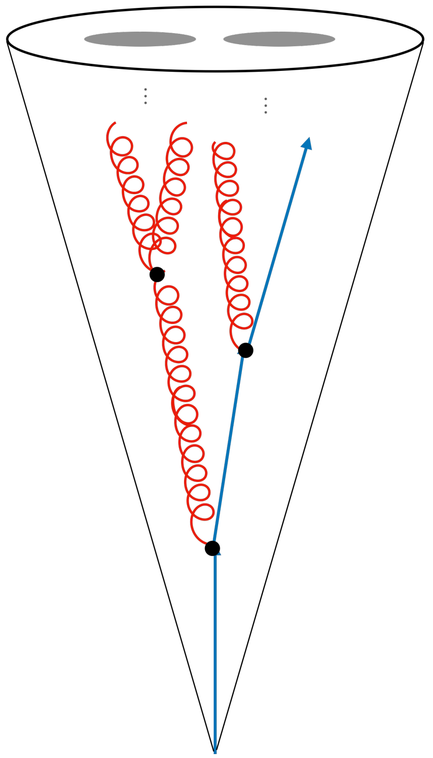
$$z = \frac{E_{\text{soft}}}{E_{\text{hard}}}$$

$$\theta_{12} = \frac{M}{E\sqrt{z(1-z)}}$$

$$\tau = \frac{1}{2Ez(1-z)(1-\cos\theta_{12})}$$

Angular ordering = ON

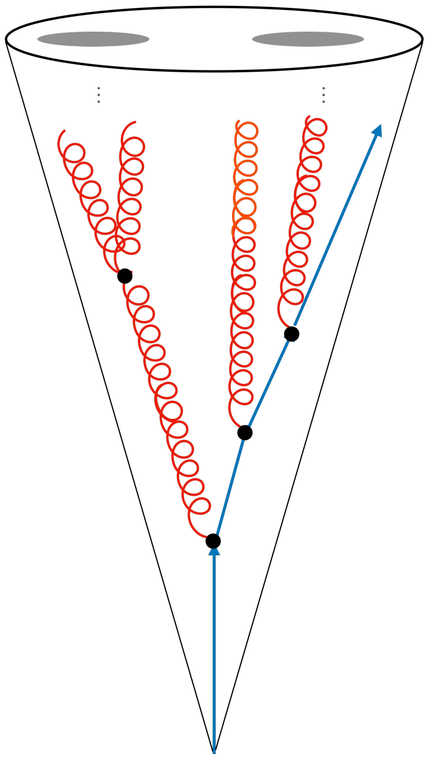
Soft: z Hard: $1-z$



Jet Energy (E) and Mass (M)

Angular ordering = OFF

Soft: z Hard: $1-z$



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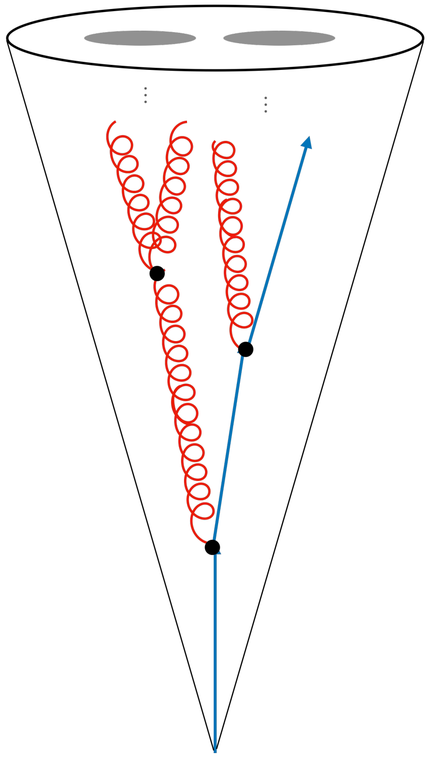
Angular ordering = ON

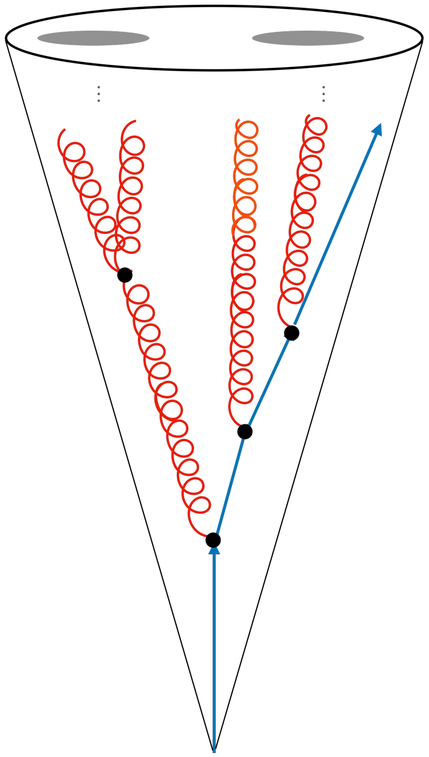
Longer τ



Small θ_{12}

Angular ordering = OFF

Shorter τ

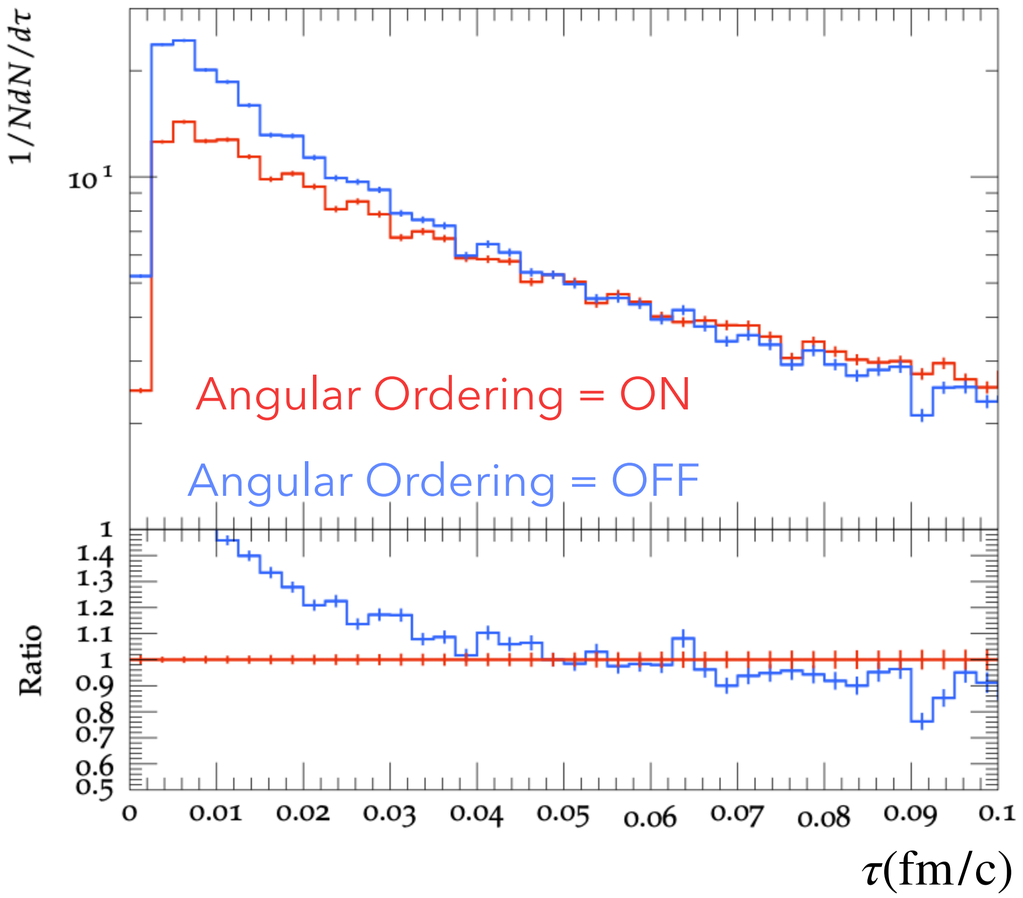


Larger θ_{12}

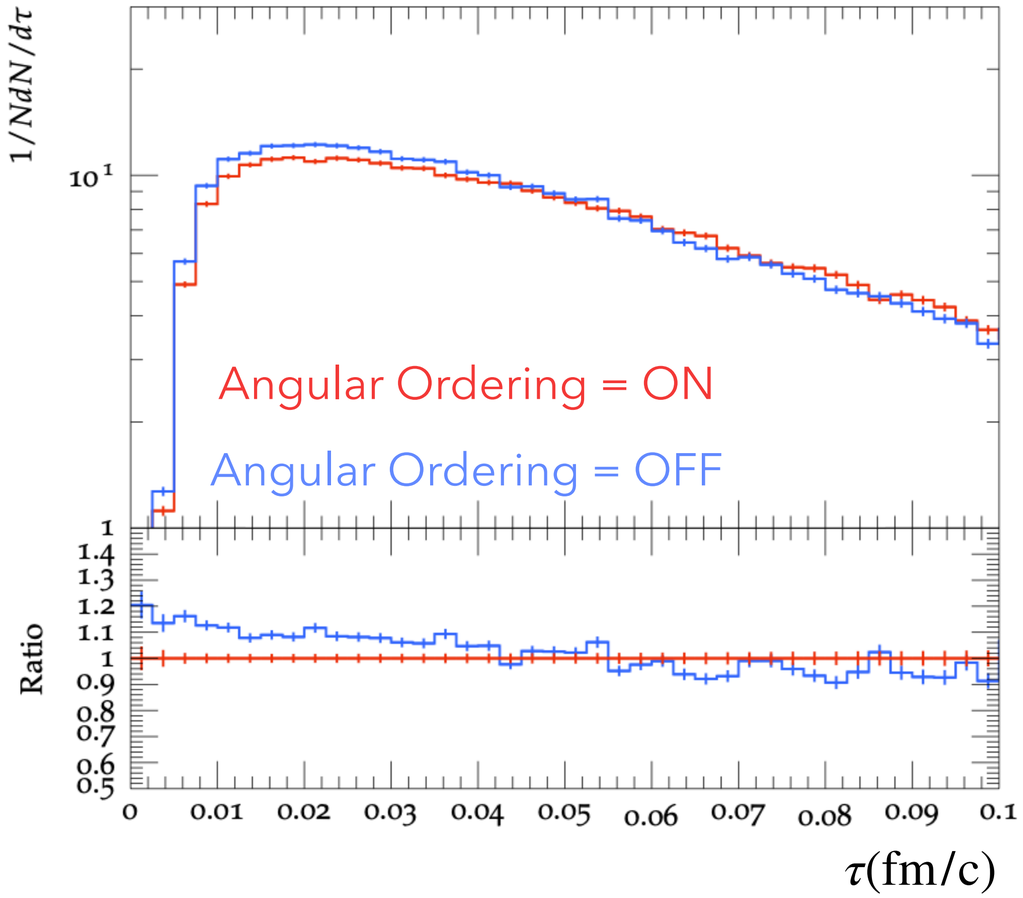
Formation time

LA, C. Le Roux, K. Zapp, arXiv: 2510.11914

Parton Level (MC-truth)



Hadron Level (Reconstructed)



Shift remains visible at hadron level! Is the jet spectra modified?

Jet Broadening

- Without interference effects, jet transverse momentum spectrum is still depleted
  - **Large-angle emissions** are out-of-cone (jet broadening)

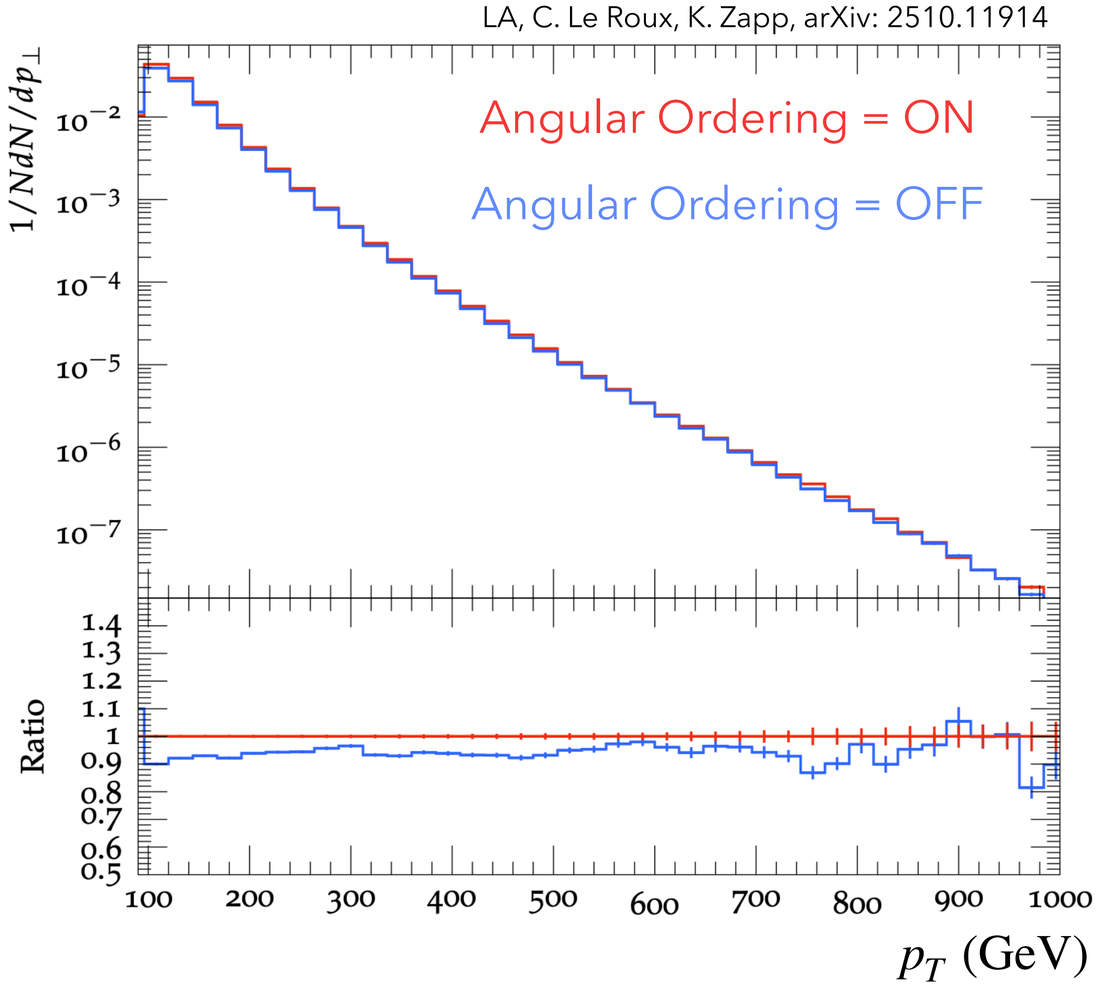
~10% apparent energy loss effect

from decoherence only

(no other medium effects)

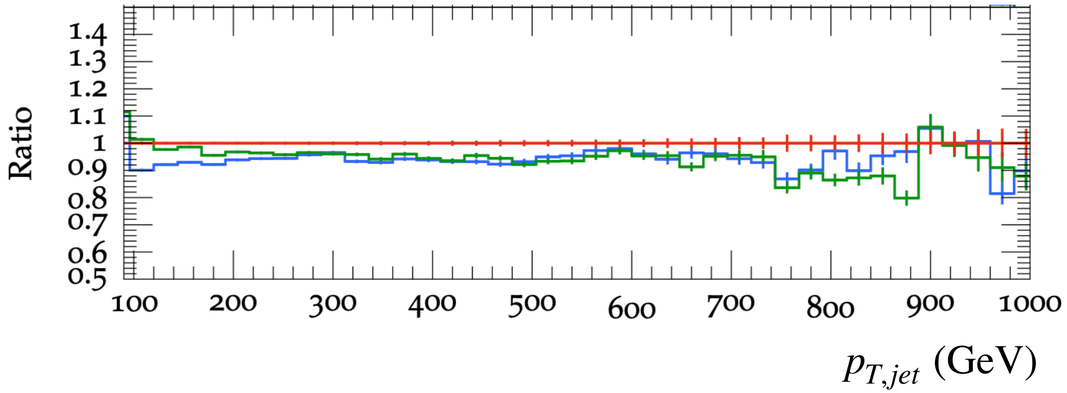
How to distinguish energy loss from decoherence effects?

LA, C. Le Roux, K. Zapp, arXiv: 2510.11914



Distinguishing in-medium effects

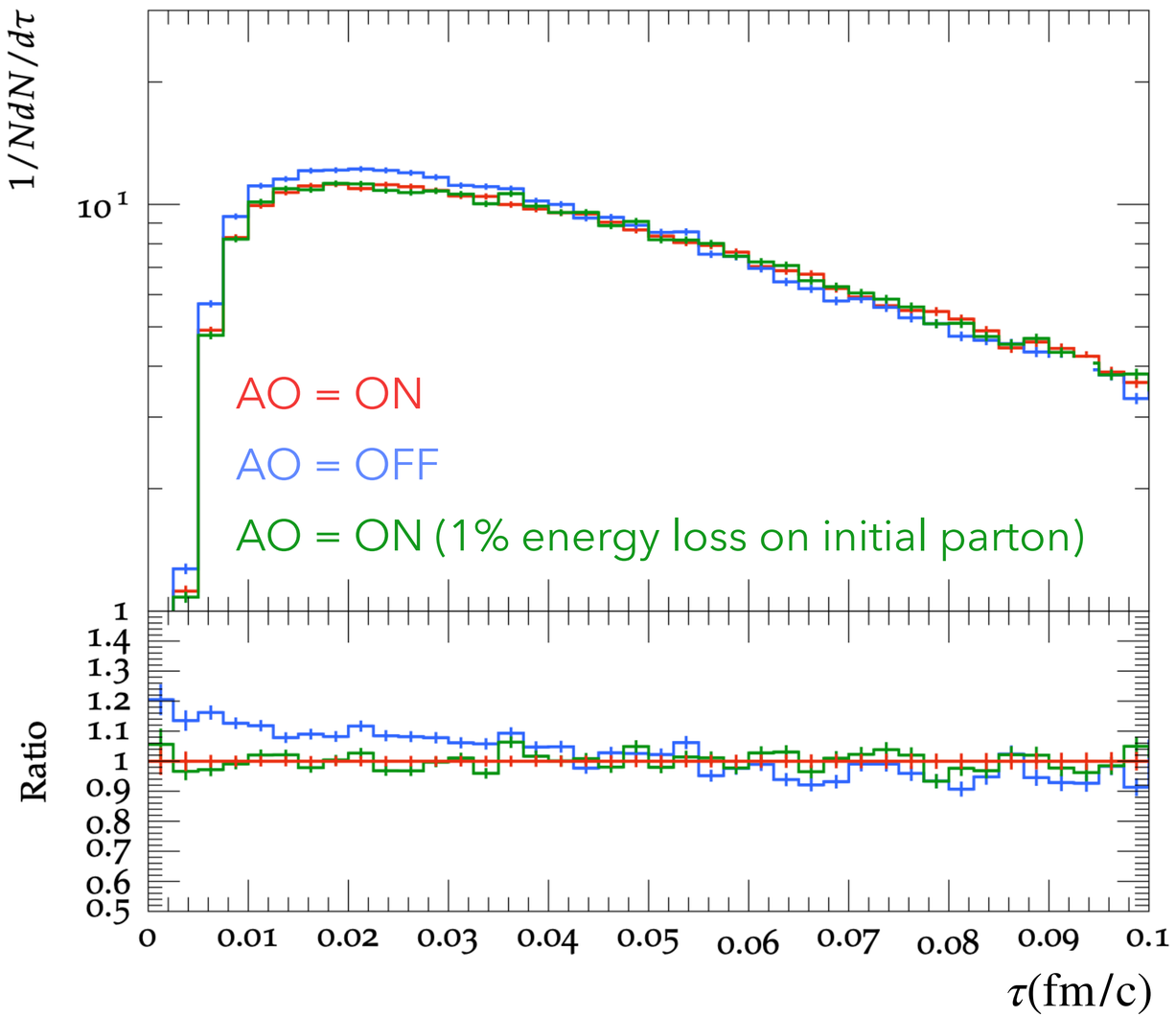
- Both jet broadening (decoherence) and actual energy loss can suppress jet spectra:



- But for **small energy loss** effects, τ **distribution** remains **unchanged**.

τ distribution can hint to decoherence effects in small systems!

LA, C. Le Roux, K. Zapp, arXiv: 2510.11914

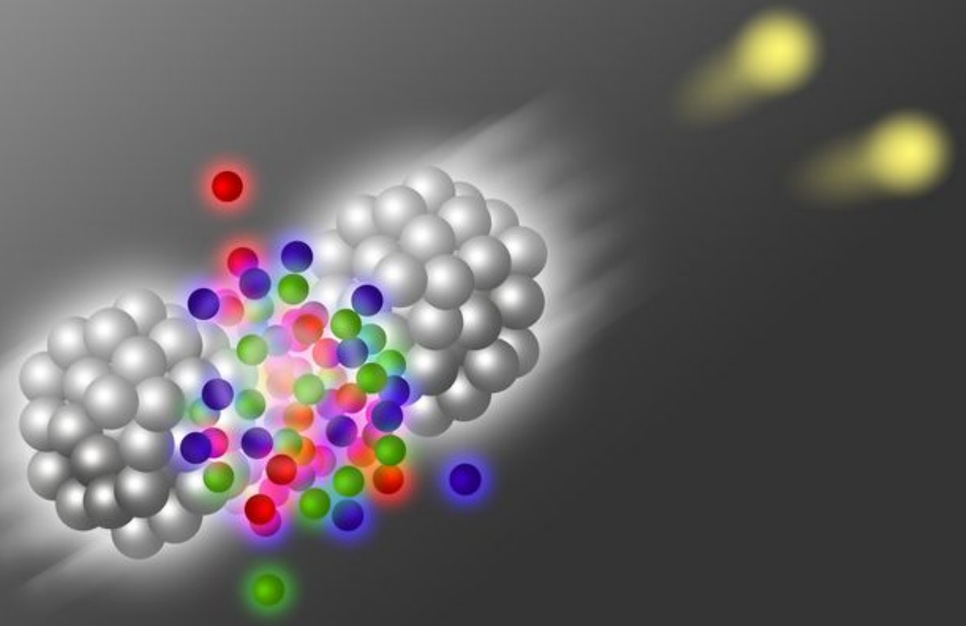


Outlook

- **First sign of QGP** in small systems **may be loss of coherence.**

- **Jet substructure** (e.g: τ_{form}) observables, via τ-algorithm, show sensitivity to the very first re-scattering.
  - Distinguishes small energy loss from decoherence effects
  - Large-R jets or subjet-angle observables could provide **experimental proxies**.

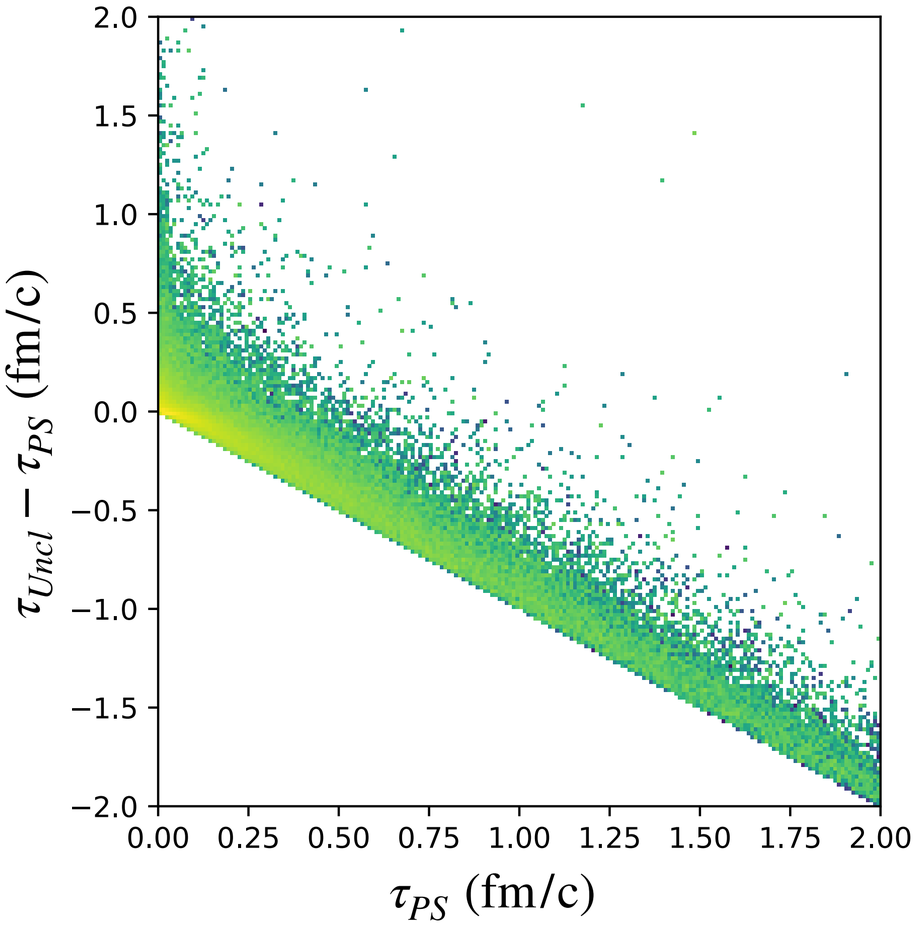
- LHC **light-ion** runs provide a unique chance to see **earliest signs of QGP droplets**.



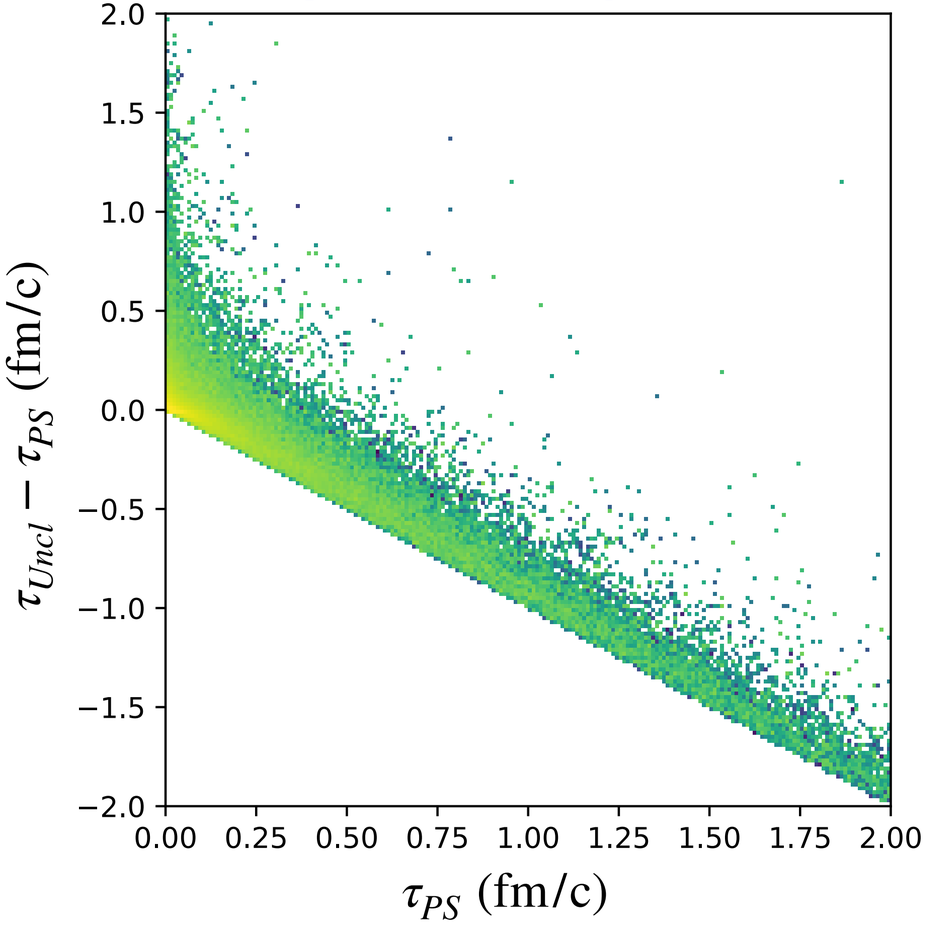
Backup Slides

Resolution effects

Angular Ordering = ON



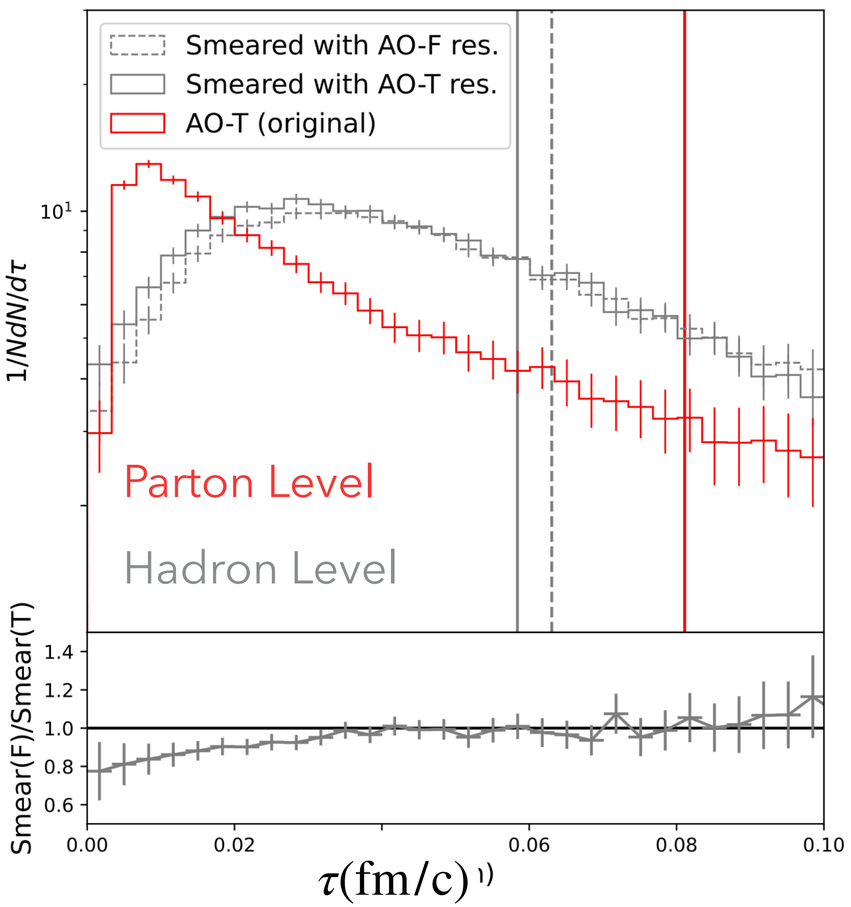
Angular Ordering = OFF



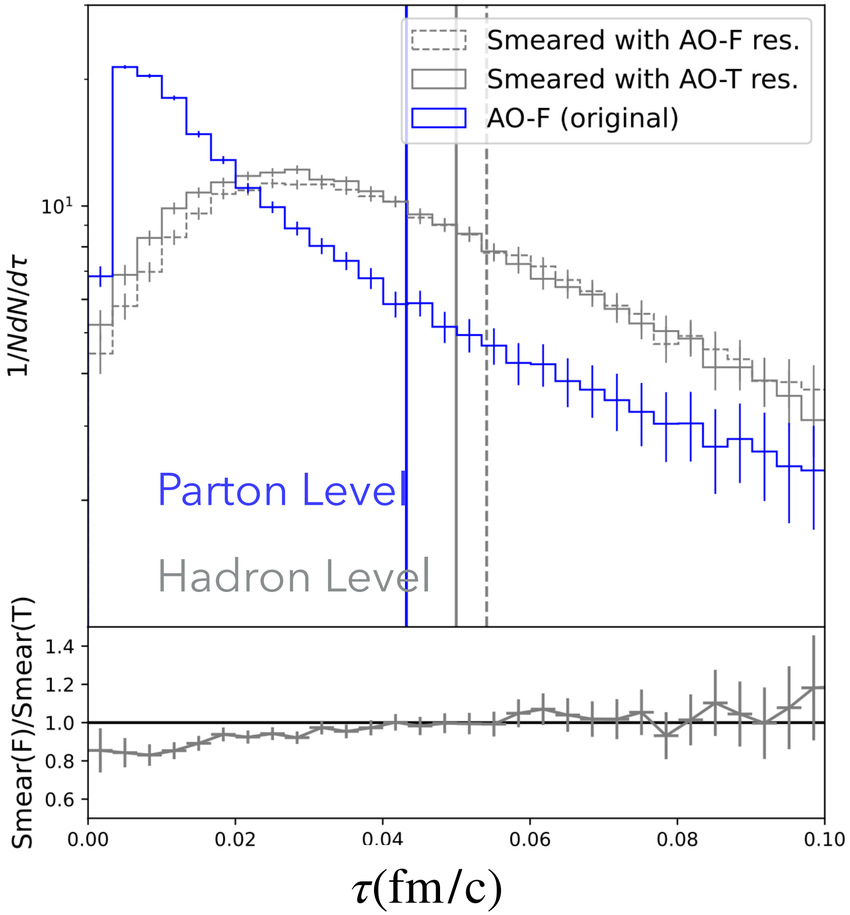
Resolution extracted in bins of τ_{PS} and used as a proxy for resolution effects

Resolution effects

Angular Ordering = ON



Angular Ordering = OFF



Resolution alone cannot reproduce results… **Remaining effect is loss of coherence!**