Longitudinal Fluctuations in Heavy-Ion Collisions

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Initial State of Heavy-Ion Collisions

- Various theoretical models assume boost invariance
- Density fluctuations influence the early time entropy production well before the onset of the collective flow, and manifest as long-range correlations in $\eta$
- Main consequence: asymmetric density of the fireball at different $\eta$ windows
  - Asymmetry in A-A collisions?

Soft probes ($p_T < 3-4$ GeV):

- Anisotropic flow
- Longitudinal fluctuations

$$A_{\text{part}} = \frac{N_F - N_B}{N_F + N_B}$$

Target

Projectile

15 target
10 projectile

$A_{\text{part}} = \frac{1}{5}$
The $\eta$ of the final particle distribution is sensitive to EbyE longitudinal fluctuations.

- Decompose longitudinal fluctuations with orthogonal polynomials, e.g., Legendre polynomials (A. Bzdak & P. Bozek, Phys. Rev. C 93, 024903 (2016)).

- AMPT model includes collective effects, while HIJING does not.
  - Longitudinal fluctuations do not depend on whether the QGP is present, hence asymmetry may be related to the initial state.

- ATLAS found that $\langle a_1^2 \rangle \sim 1/N_{ch}$ and is numerically similar for p+p, p+Pb and Pb+Pb collisions with $|\eta| < 2.4$. 
Single-particle longitudinal decomposition

- For a rapidity range $[-Y, Y]$, $a_n$ can be directly extracted $EbyE$
  \[ a_n = \int_{-Y}^{Y} \sqrt{\frac{1}{Y}} \left( n + \frac{1}{2} \right) (R(\eta) - 1) \ P_n \left( \frac{\eta}{Y} \right) \ d\eta \]

- Statistical noise subtraction carried out with a realistic background generated from the observed $\eta$ distribution
  \[ \langle a_n^2 \rangle = \langle (a_n^{obs})^2 \rangle - \langle (a_n^{ran})^2 \rangle \]

- Model (HIJING) where the nuclear participants generate asymmetries is disfavored

- Universal scaling fitting to $c/N_{ch}^{\alpha}$

<table>
<thead>
<tr>
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<th>$\alpha$</th>
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<tbody>
<tr>
<td>Pb-Pb Data</td>
<td>0.531±0.003</td>
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<tr>
<td>Pb-Pb HIJING</td>
<td>0.456±0.075</td>
</tr>
<tr>
<td>Xe-Xe Data</td>
<td>0.532±0.020</td>
</tr>
<tr>
<td>Xe-Xe HIJING</td>
<td>0.471±0.016</td>
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</tbody>
</table>

First look in longitudinal coefficients in ALICE

ALICE Preliminary
Charged tracks: $|\eta| < 0.8$
$0.2 < p_T < 2.0 \ (GeV/c)$

- Pb–Pb Data $\sqrt{s_{NN}} = 5.02 \ TeV$
- Pb–Pb HIJING $\sqrt{s_{NN}} = 5.02 \ TeV$
- Xe–Xe Data $\sqrt{s_{NN}} = 5.44 \ TeV$
- Xe–Xe HIJING $\sqrt{s_{NN}} = 5.44 \ TeV$

ALI-PREL-514423
First look in longitudinal coefficients in ALICE

Scale to $\alpha = 0.5$, the observed data suggests that $N_{\text{ch}}^{\text{rec}}$ grows more slowly compared to the total clusters from the projectile and target.

ALICE Preliminary
Charged tracks; $|\eta| < 0.8$

0.2 < $p_T < 2.0$ (GeV/c)

Charge conservation effects and impact of resonances from like-sign charged tracks

Summary:

➢ First measurement of longitudinal coefficient $a_1$ in ALICE
➢ $a_1$ represents the forward-backward asymmetry among the participants
➢ Results are qualitatively comparable to ATLAS
➢ Universal multiplicity scaling following $\sqrt{\langle a_1^2 \rangle} \sim 1/N_{\text{ch}}^{\text{rec}}$, $\alpha \sim 0.5$
➢ Stronger asymmetry from charged hadrons, compared to positive or negative
➢ Higher-order coefficients ($a_2, a_3$) may be of interest to measure, physics behind is yet to be understood