

Conformal pre-hydrodynamical effects in large and small systems

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In collaboration with T. Nunes da Silva, D. Chinellato, A. V. Giannini, J. Takahashi, G. S. Denicol, M. Luzum, M. Hippert and J. Noronha

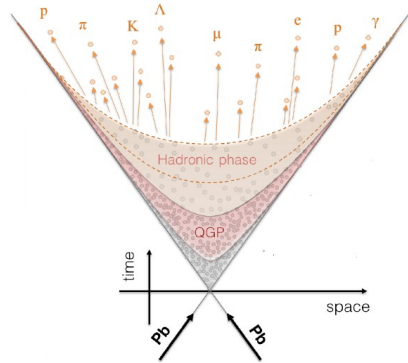
[The ExTrEMe Collaboration]



Multistage simulations of heavy-ion collisions

The QCD matter formed in heavy-ion collisions is modeled to evolve in discrete stages:

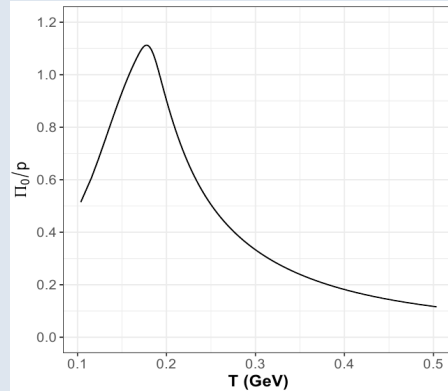
H. Petersen, et al, Phys. Rev. C 78, 044901 (2008).



Observed particles
 Interacting hadron gas
 Hydrodynamic evolution
Pre-hydrodynamic stage
 Initial hard scattering

- Most pre-hydrodynamic models in use are **conformal**.

- But QCD EoS is **nonconformal**;
- **Discontinuous** transition to hydrodynamic stage.
 T. Nunes da Silva, et al., Phys. Rev. C 103, 054906 (2021).
- Artificial bulk pressure at start of hydrodynamics.

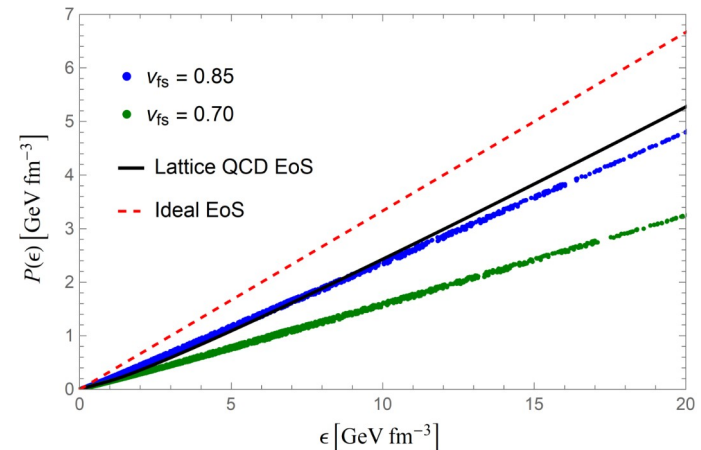


We seek to quantify the error introduced by the use of conformal pre-hydrodynamic models.

A simple **nonconformal** model for the pre-hydrodynamic stage is **freestreaming with arbitrary velocity**, $v_{fs} < c$.

G. Nijis, et al, Phys. Rev. C 103, 054909 (2021).

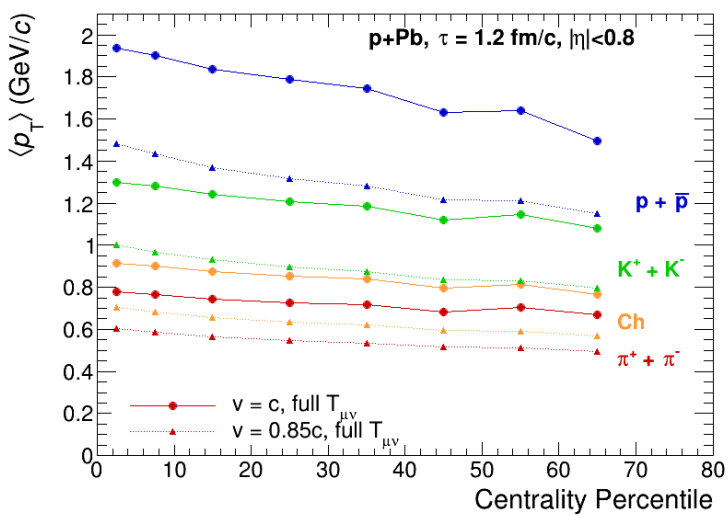
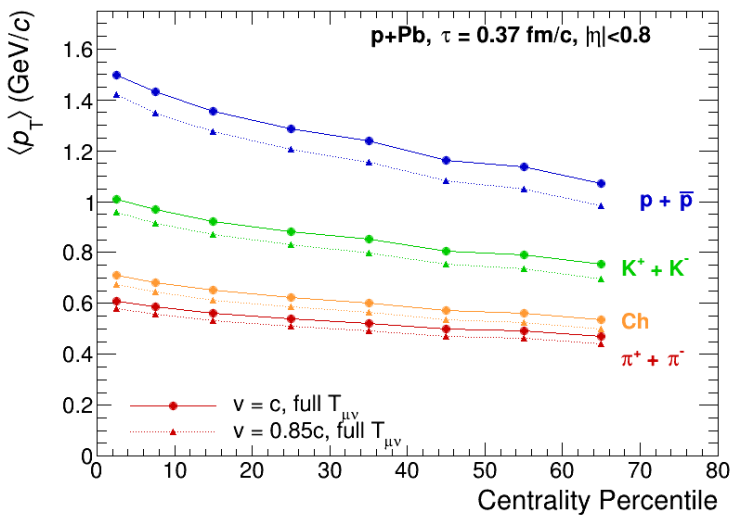
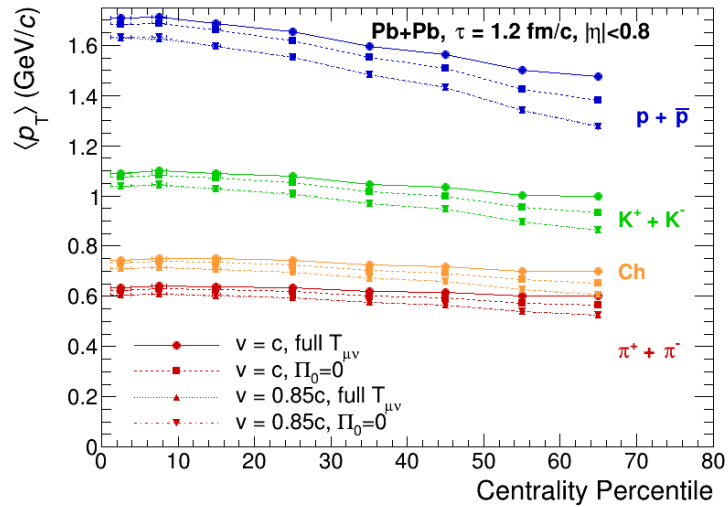
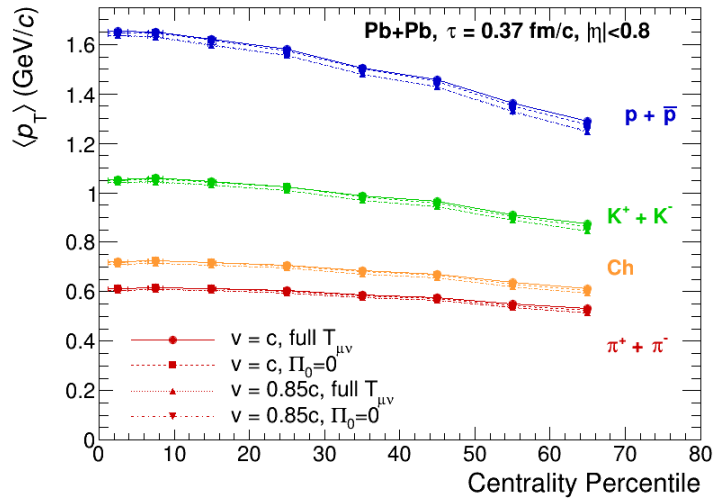
- 1) Leads to **non-ideal total pressure**,



- 2) In particular, for $v_{fs} < 0.85c$ it approximates the QCD EoS for a considerable range of energy densities.
- 3) We incorporate this model into the Duke simulation chain
 J. Scott Moreland, et al, Phys. Rev. C 101, 024911 (2020).

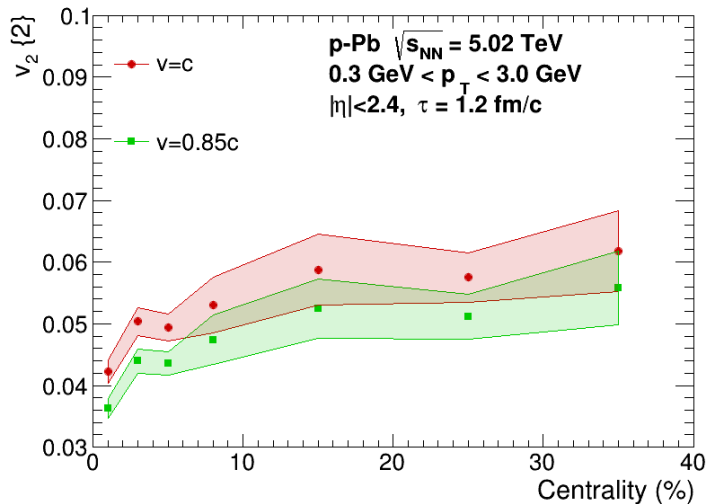
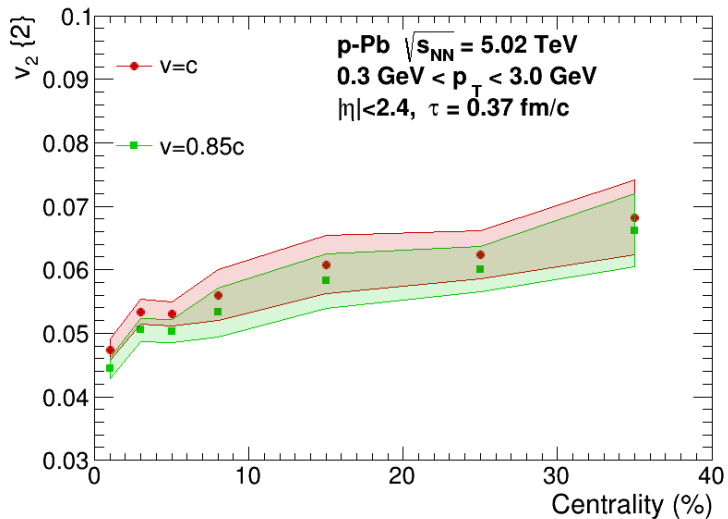
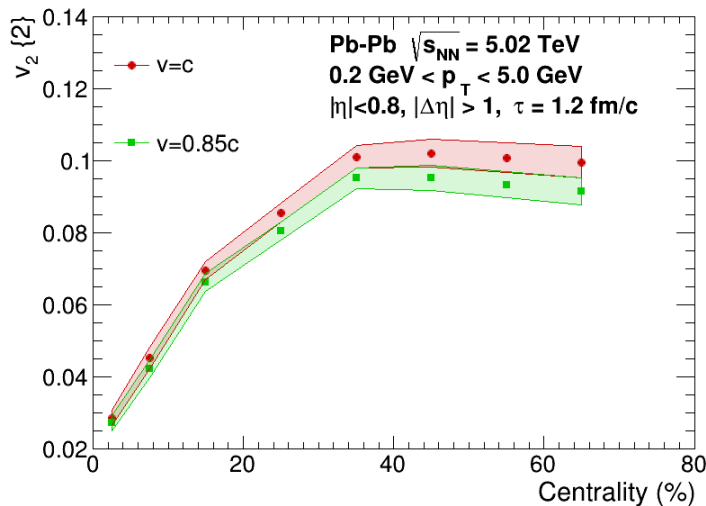
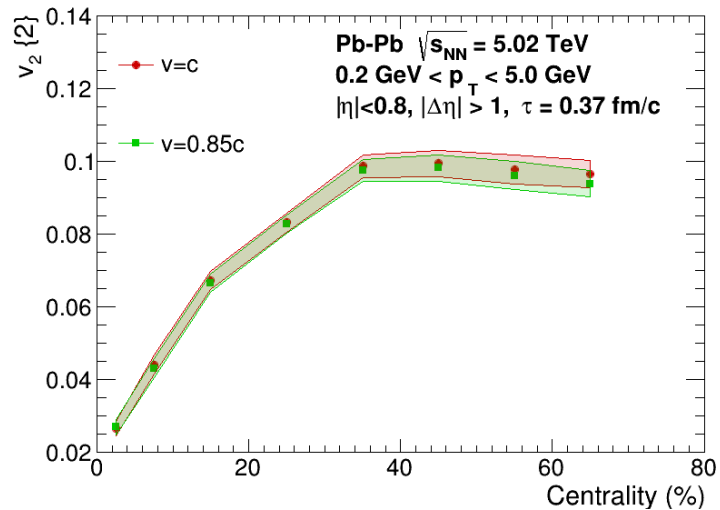
Explore effects in observables of **p+Pb** and **Pb+Pb** collisions at **5.02 TeV**.

Effect on mean transverse momentum, $\langle p_T \rangle$



- $\langle p_T \rangle$ is **largest** in conformal limit;
- Effect increases with **duration**, τ , of freestreaming stage;
- Effect is most important for **p+Pb**;
- Increase in momentum largely **due to artificial bulk viscous pressure** at hydrodynamization time.

Effect on elliptic flow coefficient, v_2



- v_2 is **largest** in conformal limit;
- Effect increases with **duration**, τ , of freestreaming stage;
- Effect is most important for **p+Pb**;
- Similar effects are found for v_3 and v_4 .

Conclusions

- While QCD is **nonconformal**, most pre-hydrodynamic models used in simulations of heavy-ion collisions are **conformal**.
 - We want to quantify the errors that this simplifying assumption introduces.
 - To that end, freestreaming with arbitrary velocity constitutes a simple nonconformal model for the pre-hydrodynamic stage.
- We find **important effects on mean transverse momentum and anisotropic flow coefficients**:
 - Both are **overestimated by conformal pre-hydrodynamic models**.
 - Artifacts are largely due to the artificially large bulk pressure at hydrodynamization time produced by conformal models, which leads to enhanced p_T spectra.
 - These effects are **most important in small systems**, such as **p+Pb**
 - Moreover, it increases with the duration of the pre-hydrodynamic stage.