Experimental signatures of pre-hydrodynamic evolution

Or, the importance of conformal symmetry breaking

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Based on:
EXTEME Collaboration; Phys.Rev.C 103 (2021) 054906; article in preparation

University of São Paulo

From initial gluons to hydrodynamics
October 25, 2022

Outline

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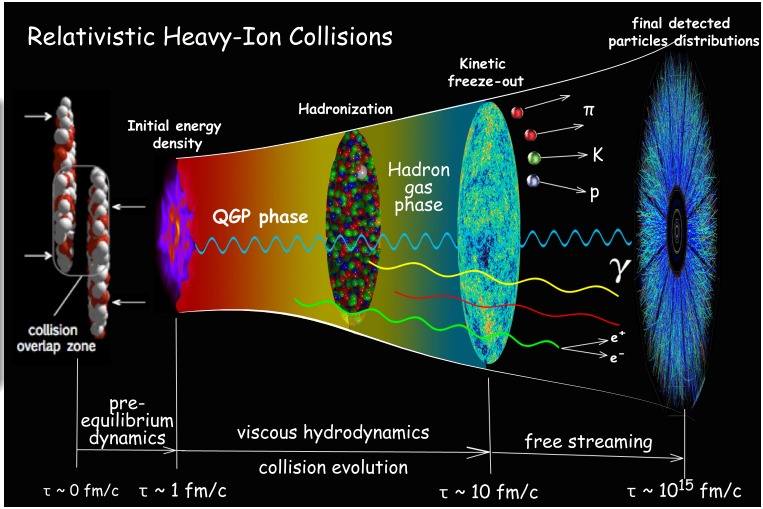
Time line of heavy-ion collision

- Incoming nuclei
- Initial scattering
- Pre-equilibrium ("hydrodynamization")
- Relativistic Fluid
  - Quark-Gluon Plasma
  - Hadrons
- Hadronic scattering



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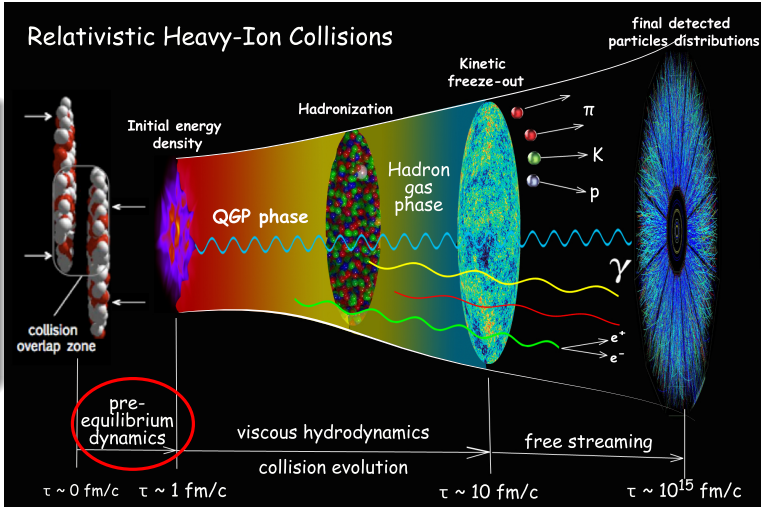
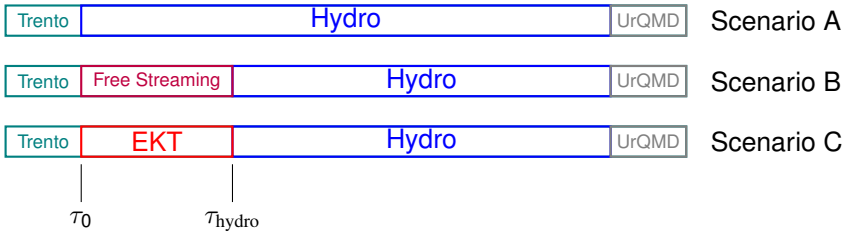


PRE-HYDRODYNAMIC SIGNATURES

- Effects of initial scattering / hydro evolution on observables is well studied
- What about pre-equilibrium?
- What can we learn about first $\sim$1 fm/c from data?
- First test: vary pre-equilibrium dynamics and see whether/how observables change.

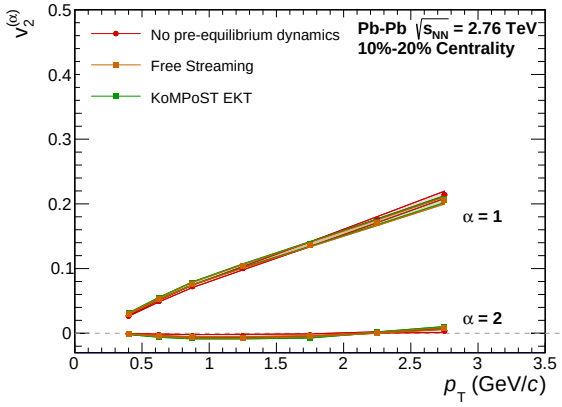
Outline

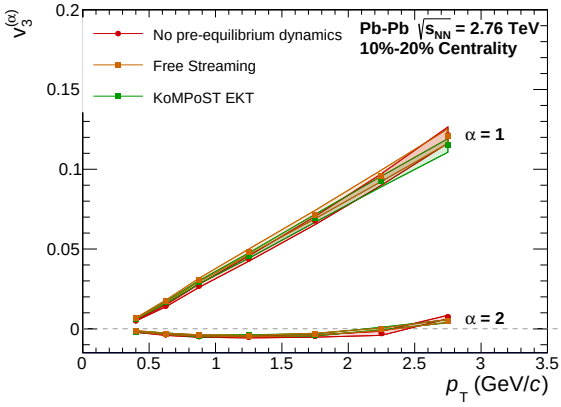
Scenarios



- Start with energy density from Trento
- Model evolution between $\tau_0 = 0.2$ fm and $\tau_{\text{hydro}} = 1.2$ fm with 3 types of dynamics
  - Viscous hydrodynamics
  - Free streaming (via KøMPøST)
  - QCD Effective Kinetic Theory (via KøMPøST)
- Evolve from τ_{hydro} with hydrodynamics + hadron cascade

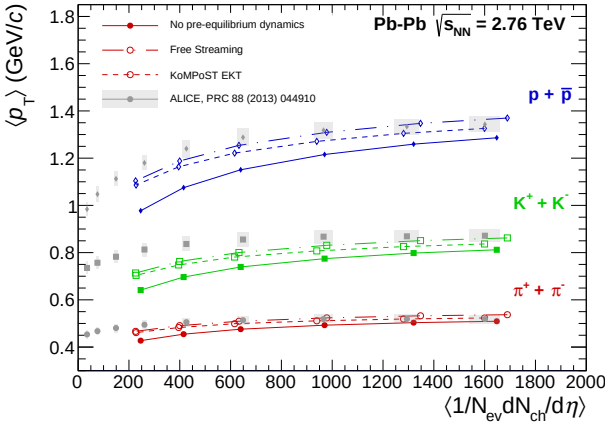
Results





- Most observables insensitive to details of pre-hydro evolution
- E.g., principle components of v_n in p_T.

Results

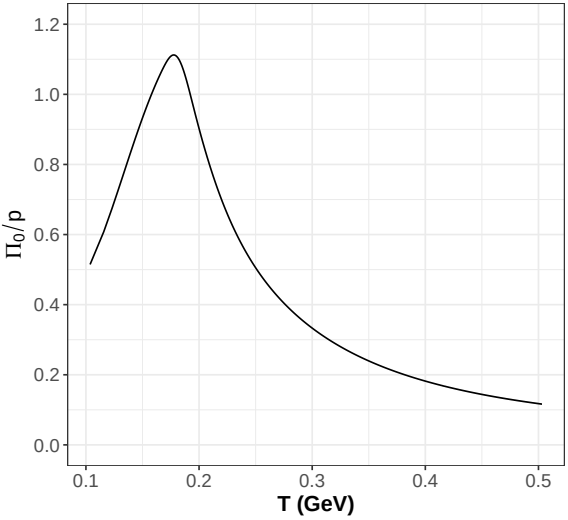


- Main effect: $\langle p_T \rangle$.
- EKT and free streaming larger than to hydro, with EKT$\sim$ FS
- Why? What do EKT and free streaming have in common?

Outline

Conformal symmetry

- Many calculations and models of initial stages assume conformal symmetry
  - Free-streaming
  - EKT (KøMPøST)
  - CGC / Classical Yang-Mills
- Good approximation at asymptotically high energy
- Conformal $\implies T^{\mu}_{\mu} = 0 \implies P = \frac{e}{3}$ (independent of proximity to equilibrium)
- Actual QCD: equilibrium $p(e) < \frac{e}{3}$. Expanding system: expect $P = \Pi + p(e)$ with $\Pi < 0$.
- Conformal hydro initial conditions: anomalously large pressure. Π_0 fixed by symmetry rather than local conditions/dynamical history: $\Pi_0 = \frac{e}{3} - p(e)$
- Is this important?



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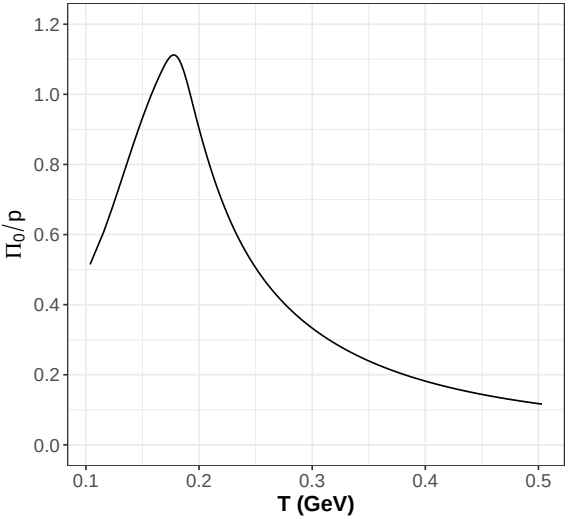
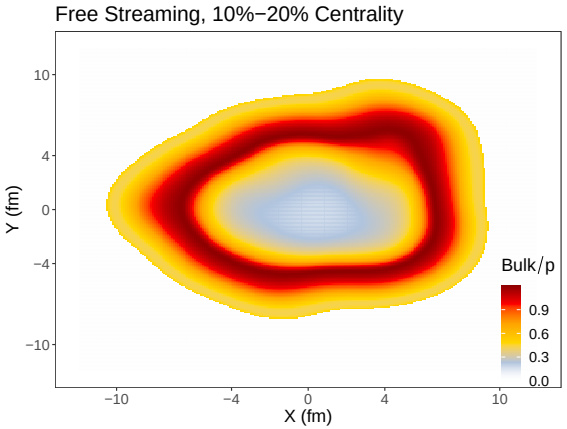
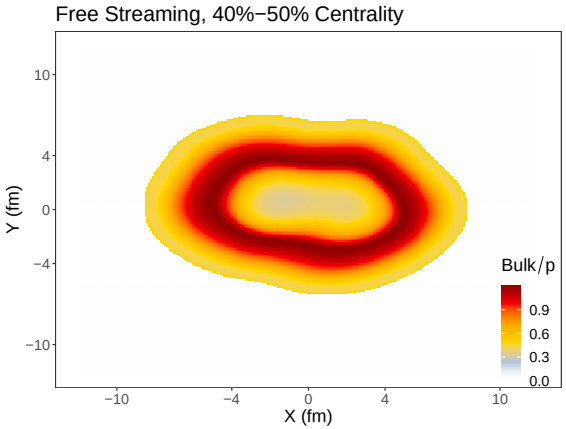


Size of conformal artifact





- Large Π in significant part of system
- Independent of dynamics

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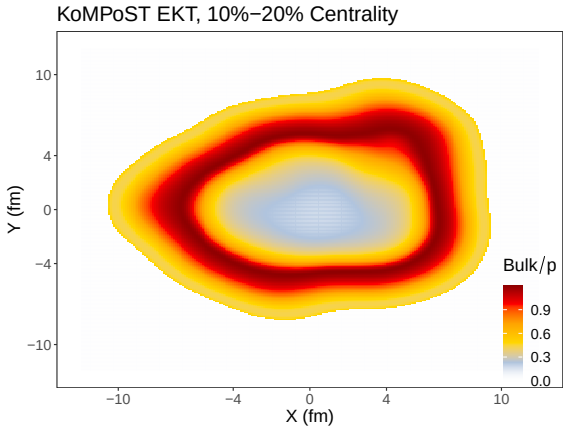

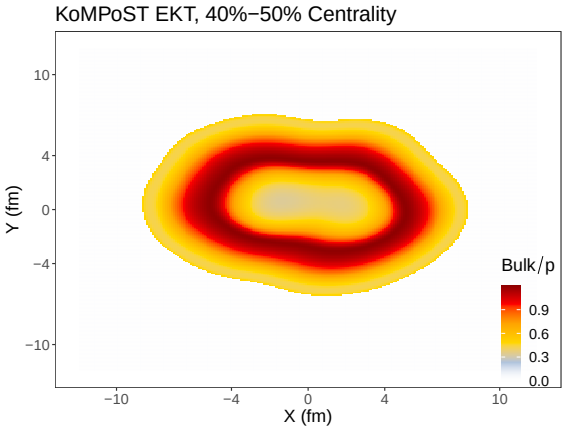

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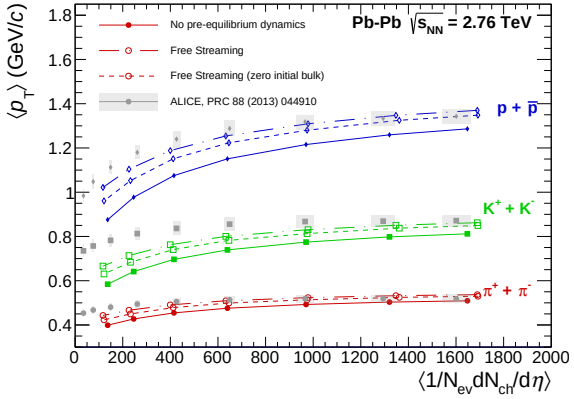
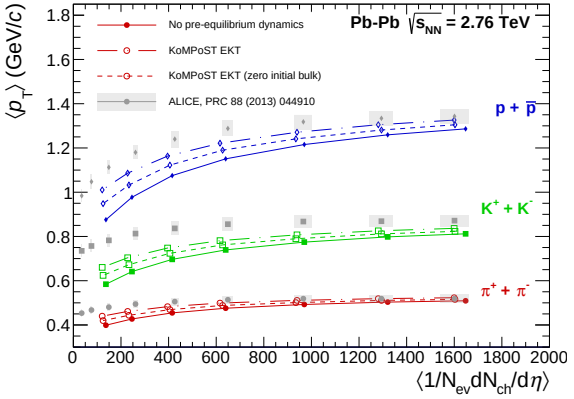
Effect of conformal artifact



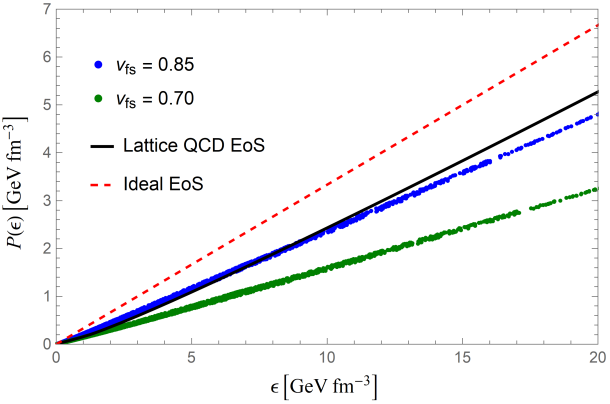


- Crude estimate of effect: set $\Pi = 0$ at start of hydro
- Non-negligible fraction of effect comes from unphysical artifact
- Masks potential signatures of hydrodynamization dynamics
- Biases results of precision analysis (e.g., Bayesian estimation QGP properties)

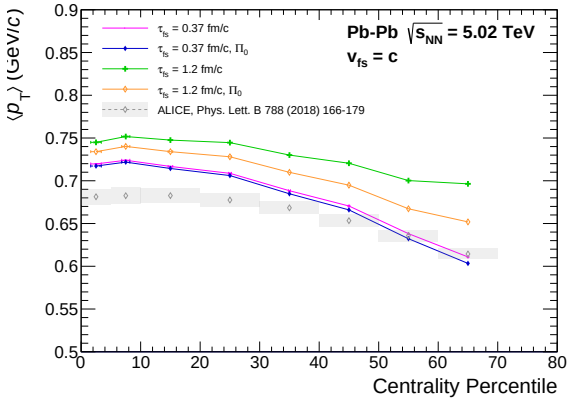
Outline

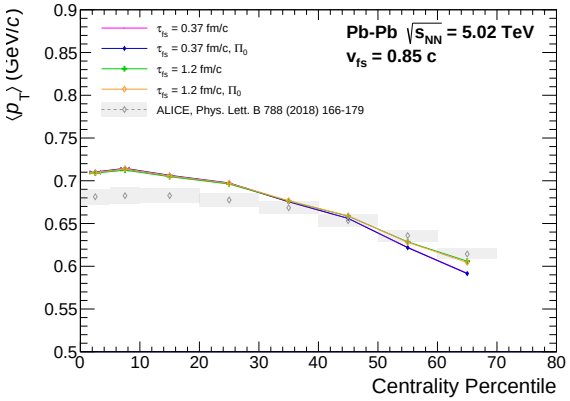
Free streaming with variable velocity

- To study in more detail, use idea from G. Nijs *et al.* (PRL. 126 (2021) 20, 202301; PRC 103 (2021) 5, 054909)
- At $\tau = 0$, energy density from Trento
- Assume non-interacting particles with initial (isotropic) transverse velocity v, streaming for time τ_{fs}.
- For $v < c$, pressure is closer to expected QCD value



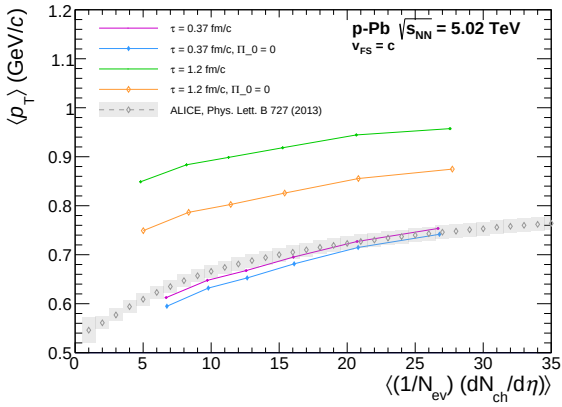
Effect of streaming time and system size

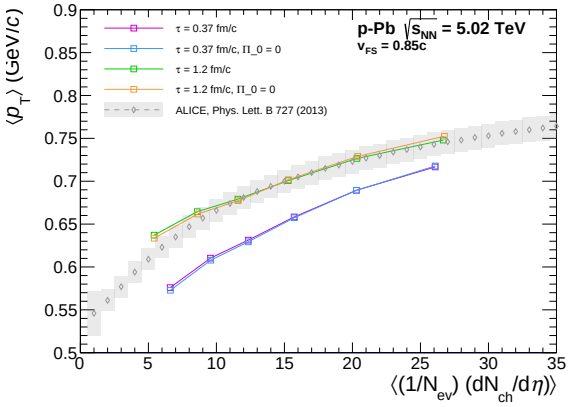




- Smaller effect with smaller τ_{fs} (larger average energy density)
- Almost no artifact (and little τ_{fs} dependence) with $v_{\mathrm{fs}} = 0.85c$.

Effect of streaming time and system size





- Larger effect in small systems
- Artifact very small, but significant τ_{fs} dependence with $v_{\mathrm{fs}} = 0.85c$.

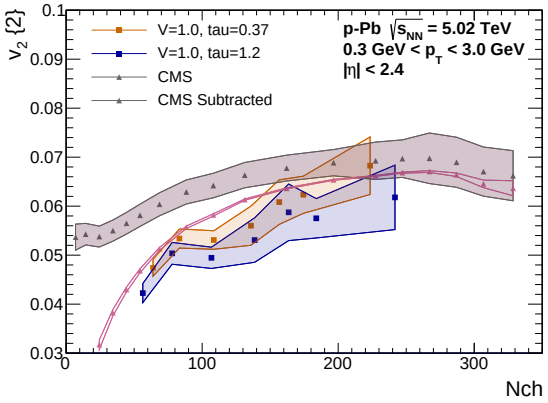
Outline

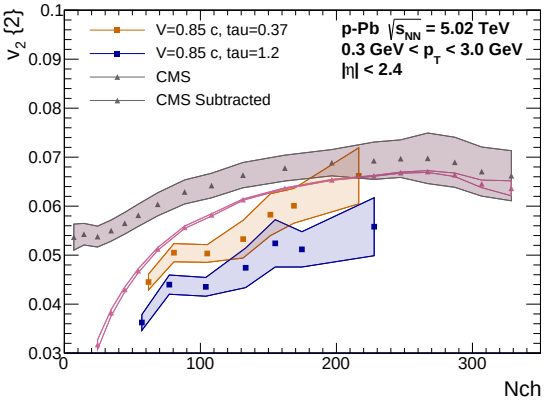
Conclusions

- Signatures of pre-hydrodynamic stage can be dominated by artifacts from assumption of conformal symmetry
- Worse for smaller systems and for later hydro start times
- To probe details of pre-hydro dynamics (and to avoid bias in parameter extraction), will require models with broken conformal symmetry, realistic equation of state.

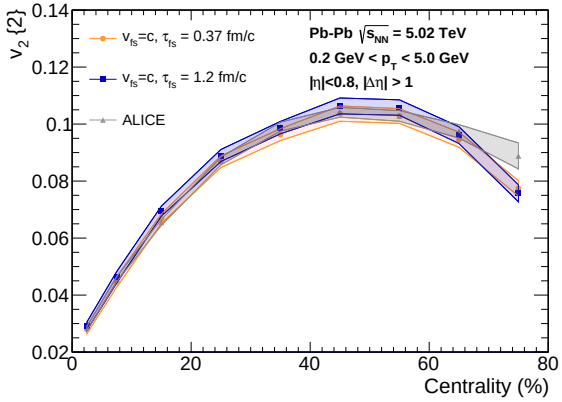
Extra Slides

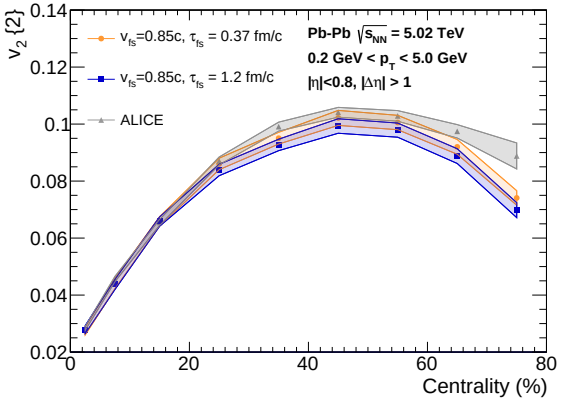
Integrated v_2 pPb





Integrated v_2 PbPb





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