Reinterpretation of higher harmonics from mini-jet propagation

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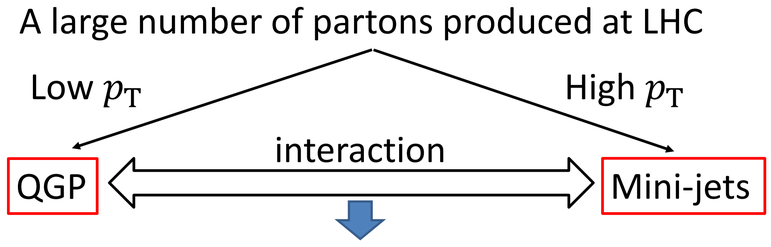
1. Introduction

A large number of partons produced at LHC

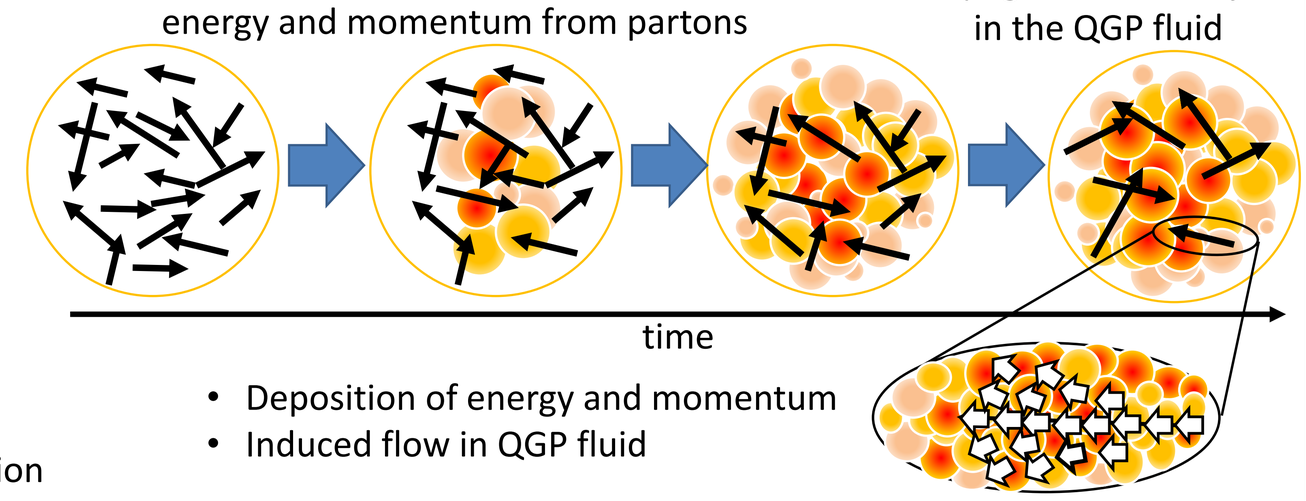


Change of collective dynamics?

Purpose of study

- Hydrodynamic responses to propagation of mini-jets in the QGP
- Construction of a model describing dynamics from low to high p_{T}
- Reinterpretation of higher harmonics with effects of mini-jets propagation

Creation of the QGP fluid



- Deposition of energy and momentum
- Induced flow in QGP fluid

2. QGP fluid + jet model

Hydrodynamic evolution

time

$\tau = 0^+$ Partons generated by PYTHIA ・・・(1)

$\tau_{00} = 0.1$ fm

(2) Deposition of energy and momentum from generated partons (constant loss $= 5$ GeV/fm) → Creation of initial state for hydrodynamic fields

$\tau_0 = 0.6$ fm Hydrodynamic initial state with random flow velocity ・・・(3)

(2) $T > T_{\mathrm{f}} = 160$ MeV Energy loss (jet-like) ・・・(4) → Expansion of the QGP + Deposition of energy and momentum from mini-jets

$T < T_{\mathrm{f}} = 160$ MeV No energy loss

Freeze-out

(1) Initial distribution of partons in phase space

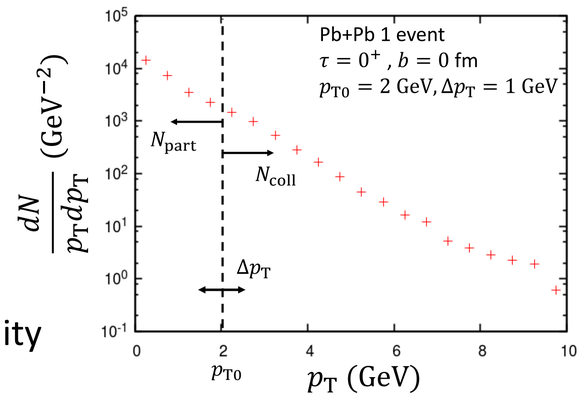
- Momentum space

  p+p collision from PYTHIA × N_{coll} from MC-Glauber

- Configuration space

  Transverse positions from MC-Glauber

  Space time rapidity =momentum rapidity from PYTHIA



(2) Hydrodynamic equations with source terms

Deposition of energy and momentum from partons to the QGP fluid

$$\partial_\mu T^{\mu\nu} = \sum_i J_i{}^\nu \ , \qquad J^\mu(x) = -\frac{dp_{\mathrm{jet}}{}^\mu}{dt}\delta^{(3)}\left(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{jet}}(t)\right)$$

$T^{\mu\nu}$: Energy-momentum tensor of the QGP fluid

J^μ : Source term from partons to the QGP fluid

$\tau_{00} < \tau < \tau_0$: Creation of the QGP fluid

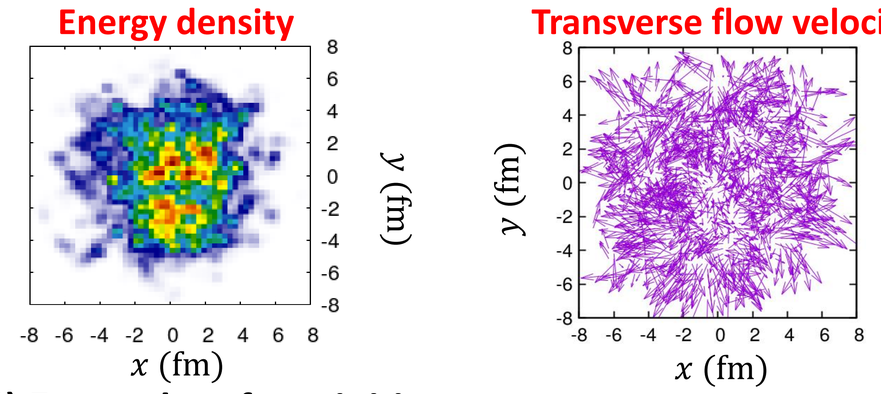
$\tau_0 < \tau$: Energy-momentum deposition from mini-jets to the QGP fluid

Y. Tachibana and T. Hirano, Phys. Rev. C **90**, no. 2, 021902 (2014)

- Instantaneous local thermalization of energy and momentum deposited from partons
- Ideal hydrodynamic approximation
- Lattice EoS (S. Borsanyi *et al.*, Phys. Lett. B730, 155 (2014))

(3) Hydrodynamic initial state ($\tau_0 = 0.6$ fm)

Energy density **Transverse flow velocity**



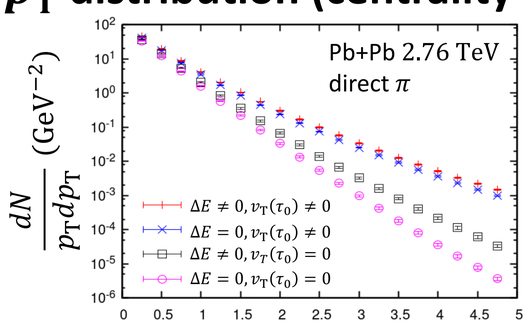
Pb+Pb 1 event
$b = 0$ fm
$\eta_{\mathrm{s}} = 0$

(4) Energy loss for mini-jets

$$\frac{dp_{\mathrm{jet}}{}^0}{dt} = -\left(\frac{T\left(t, \boldsymbol{x}_{\mathrm{jet}}(t)\right)}{T_0}\right)^3 \left.\frac{dE}{dt}\right|_0 , T_0 = 500 \text{ MeV}, \left.\frac{dE}{dt}\right|_0 = 5 \text{ GeV/fm}$$

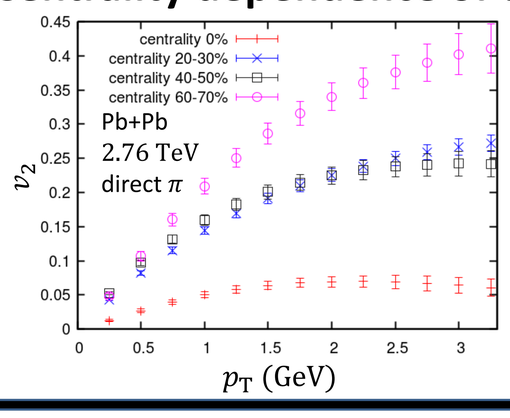
3. Results

p_{T} distribution (centrality 40 -50 %)



- Enhancement of pion yields at $p_{\mathrm{T}} =$ 3-5 GeV due to mini-jets' energy loss and initial flow velocity fluctuations
- Power law behavior even with fluid components due to initial flow velocity fluctuations

Centrality dependence of v_2 (default model)

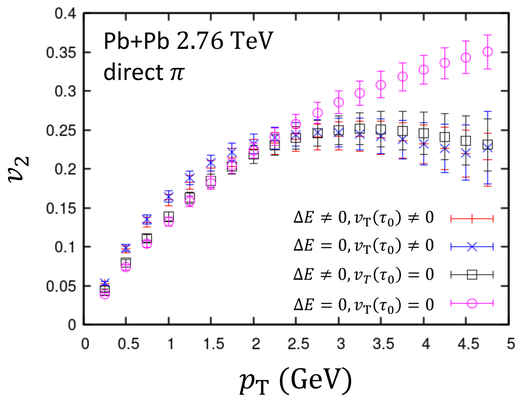


- Increase of v_2 with centrality percentage

→ Consistent with hydrodynamic results with conventional initialization

- Non-zero v_2 even at "0 %" centrality ($b = 0$ fm)

p_{T} dependence of v_2 (centrality 40 -50 %)



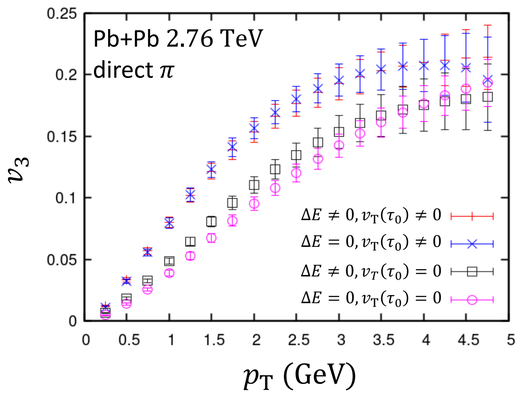
$p_{\mathrm{T}} =$ 0-2 GeV

- A little enhancement due to initial flow fluctuations

$p_{\mathrm{T}} =$ 3-5 GeV

- No monotonic increase due to mini-jets' energy loss and initial flow velocity fluctuations

p_{T} dependence of v_3 (centrality 40 -50 %)



- Large enhancement due to initial flow velocity fluctuations
- Small effect of mini-jets' energy loss on v_3

→ Need correction to shear viscosity in dissipative hydrodynamic model?

4. Summary

- Description of hydrodynamic initialization and mini-jets' energy loss in QGP in a unified framework (i.e., hydrodynamics with source terms)
- Initial flow velocity fluctuations naturally generated
- Calculation of higher harmonics v_n → Large effects of initial flow velocity fluctuations on v_n

  Effects of mini-jets energy loss visible in vanishing initial flow velocity fluctuations

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