Factorization breaking in transverse momentum from hydrodynamic fluctuations

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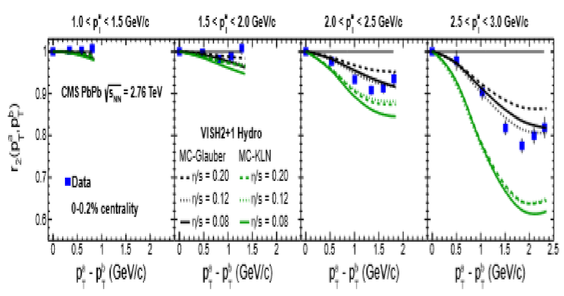
Abstract

The factorization breaking in transverse momentum direction has been measured by CMS collaboration. We analyze results of the factorization ratio using an integrated dynamical model with hydrodynamic fluctuations.

1. Introduction

Factorization ratio $r_2(p_T^a, p_T^b)$



CMS collaboration, Phys. Rev. C92, 034911 (2015)

Factorization ratio $r_2(p_T^a, p_T^b)$
⇒ Event plane decorrelation in different p_T regions

Factorization breaking known to be sensitive to
- Initial state model
- Granularity of initial transverse profile

Do hydrodynamic fluctuations affect transverse dynamics ?

Purpose of this study

We investigate the effects of hydrodynamic fluctuations on factorization ratios in p_T using an integrated dynamical model towards understanding of transport properties of the quark gluon plasma.

2. Integrated dynamical model

T.Hirano *et al.*,Prog. Part. Nucl. Phys.70, 108 (2013)

5. Analysis

Two particle azimuth distribution

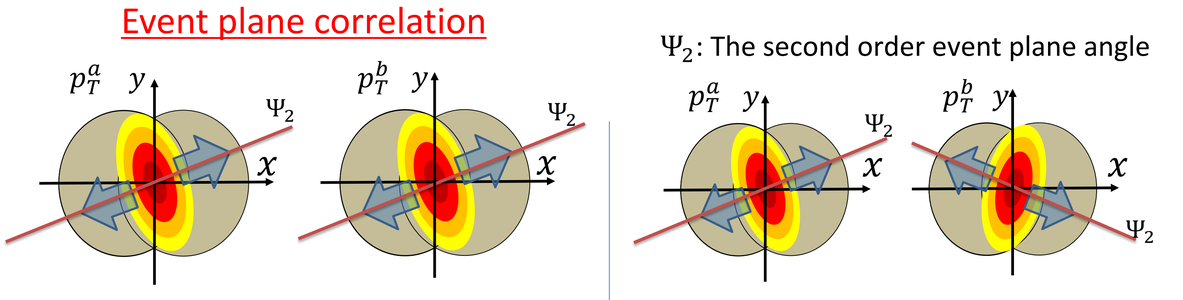
$$\frac{dN_{\text{pair}}}{d\Delta\phi} \propto 1 + 2\sum V_{n\Delta}\cos(n\Delta\phi)$$

$V_{n\Delta} = <\cos(n\Delta\phi)>$

ϕ: Azimuthal angle measured from the reaction plane
$\Delta\phi$: Difference of azimuthal angle between two particles

Event plane correlation

Ψ_2: The second order event plane angle



$\Psi_2(p_T^a) = \Psi_2(p_T^b)$
$\Rightarrow V_{2\Delta}(p_T^a, p_T^b) \cong v_2(p_T^a)v_2(p_T^b)$

$\Psi_2(p_T^a) \neq \Psi_2(p_T^b)$
$\Rightarrow V_{2\Delta}(p_T^a, p_T^b)$
$\cong v_2(p_T^a)v_2(p_T^b)\cos[n(\Psi_2(p_T^a) - \Psi_2(p_T^b))]$

Factorization ratio

$$r_2(p_T^a, p_T^b) = \frac{V_{2\Delta}(p_T^a, p_T^b)}{\sqrt{V_{2\Delta}(p_T^a, p_T^a)\, V_{2\Delta}(p_T^b, p_T^b)}} \cong \cos[n(\Psi_2(p_T^a) - \Psi_2(p_T^b))]$$

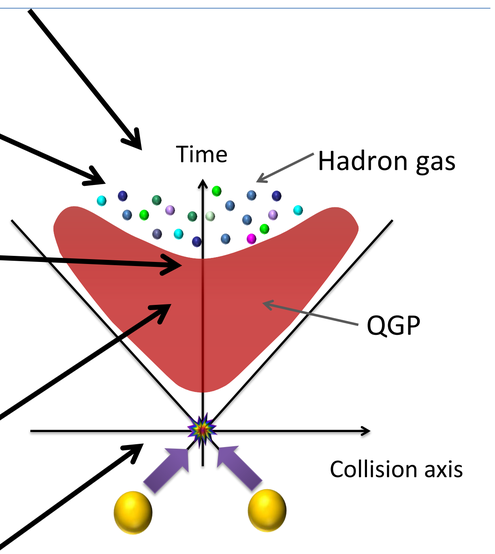
4. Hadron cascade simulations (JAM)

3. Fluids to particles at $T_{\text{sw}} = 155$ MeV (Cooper-Frye formula)

2. Full (3+1)-dim.
Relativistic fluctuating hydro simulations
Shear viscosity: $\eta/s = 1/4\pi$
Cutoff parameter: $\lambda = 1.5$ fm, 1.0 fm

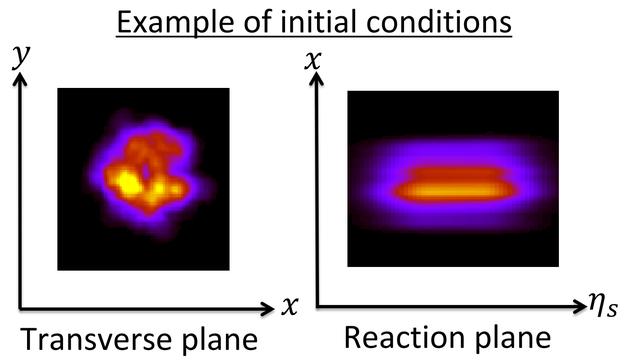
K. Murase, Ph.D thesis, The University of Tokyo (2015)

1. Generating initial conditions
^{208}Pb+^{208}Pb, $\sqrt{s_{NN}} = 2.76$ TeV
Transverse:
Monte Carlo Glauber model
Longitudinal:
Modified BGK model
4000 hydro events
× 100 oversampling of cascades (minimum bias)



Space-time evolution of heavy ion collisions

Example of initial conditions



3. Relativistic fluctuating hydrodynamics

K. Murase, Ph.D thesis, The University of Tokyo (2015)

Second order constitutive equation

Hydrodynamic fluctuations

$$\tau_\pi \Delta^{\mu\nu}{}_{\alpha\beta} u^\lambda \partial_\lambda \pi^{\alpha\beta} + \left(1 + \frac{4}{3}\tau_\pi \partial_\lambda u^\lambda\right)\pi^{\mu\nu} = 2\eta\Delta^{\mu\nu}{}_{\alpha\beta}\partial^\alpha u^\beta + \delta\pi^{\mu\nu}$$

τ_π: Relaxation time $\pi^{\mu\nu}$: shear stress tensor $g^{\mu\nu} \equiv \text{diag}(+,-,-,-)$ $\Delta^{\mu\nu} \equiv g^{\mu\nu} - u^\mu u^\nu$
η: Shear viscosity u^μ: Landau frame $\Delta^{\mu\nu}{}_{\alpha\beta} \equiv \frac{1}{2}(\Delta^\mu{}_\alpha \Delta^\nu{}_\beta + \Delta^\mu{}_\beta \Delta^\nu{}_\alpha) - \frac{1}{3}\Delta^{\mu\nu}\Delta_{\alpha\beta}$

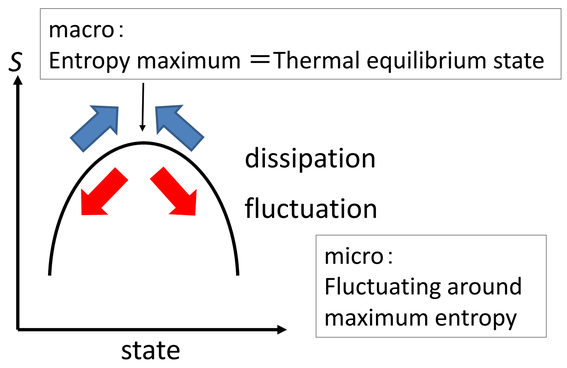
Fluctuation dissipation relation

Stability condition of thermal equilibrium

$$\langle \delta\pi^{ij}\delta\pi^{ij}\rangle \sim 4T\eta\delta^4(x - x')$$

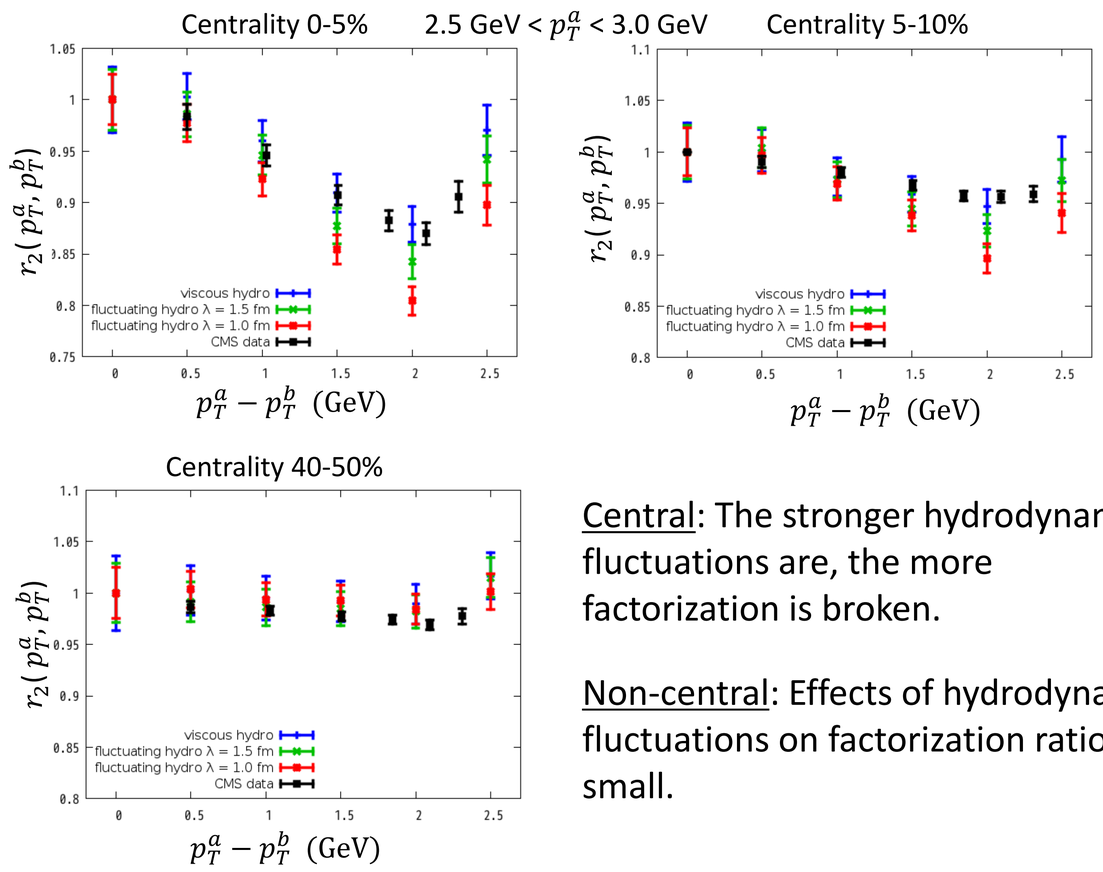
$$\delta^4(x - x') \to \frac{1}{\Delta t}\frac{1}{(4\pi\lambda^2)^{\frac{3}{2}}} e^{-\frac{(x-x')^2}{4\lambda^2}}$$

λ: Cutoff parameter



4. Results

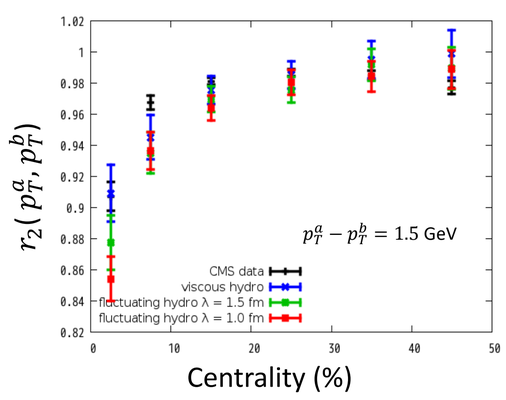
Factorization ratio in p_T in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV



Central: The stronger hydrodynamic fluctuations are, the more factorization is broken.

Non-central: Effects of hydrodynamic fluctuations on factorization ratio are small.

Centrality dependence of factorization ratio



Central collisions: Factorization is broken due to initial fluctuation of transverse profile and hydrodynamic fluctuations turn out to break factorization furthermore.

Non-central collisions: Event plane angle tends to be correlated due to collision geometry.

5. Summary

- We analyzed the factorization ratios in transverse momentum using the integrated dynamic model with hydrodynamic fluctuations.
- Factorization ratios in central collisions depend on the strength of hydrodynamic fluctuations.
- Factorization is not broken significantly in non-central collisions even when hydrodynamic fluctuations are introduced.