Personal notes: differential radial flow coefficient $v_0(p_T)$

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1 Introduction

A new momentum differential observable for radial flow has recently been proposed. It measures isotropic expansion of medium in heavy-ion collisions. It opens a new avenue to study small vs. large system and radial flow can be now investigated with similar rigor as anisotropic flow. Besides it, we can use this observable to study heavy – strange – light quark carrying hadrons, exploiting their production and freeze-out time scales. All these things pointed out that the momentum differential observable is an excellent observable to be included in Bayesian analysis to extract transport properties and speed of sound/EOS.

Differential measurements of radial flow offers a new tool to probe the fluid-like expansion in detail, establishing its collective origin and complementing decades of studies of anisotropic flow.

The transverse-momentum differential radial flow fluctuations observable $v_0(p_T)$, also called the radial flow coefficient, is a p_T-differential measure of radial flow fluctuations. It is defined as a normalized covariance between the event-wise particle yield in a given p_T bin ($\delta n(p_T)$) and the event-wise fluctuation of the mean transverse momentum ($\delta[p_T]$). The general expression is given by:

$$v_0(p_T) = \frac{\langle \delta n(p_T) \delta[p_T] \rangle}{\langle n(p_T) \rangle \sigma[p_T]}, \tag{1}$$

where $n(p_T)$ is the normalized event-by-event particle yield in a given p_T bin, $[p_T]$ is the mean transverse momentum in the event, $\delta x = x - \langle x \rangle$ denotes fluctuations from the ensemble average, and $\sigma[p_T]$ is the standard deviation of $[p_T]$ across events. These definition in Eq. 1 is analogous to a Pearson correlation coefficient.

$v_0(p_T)$ exhibits hydrodynamic features – momentum and mass dependence. It has the following properties:

- $v_0(p_T)$ increases with p_T;
- Changes sign around mean p_T;

- Zero without fluctuations;
- Mass ordering at low p_T: consistent with hydrodynamic expectation;
- Intermediate transverse momentum: baryon meson grouping – consistent with coalescence/recombination picture;
- NCQ scaling observed similar to those seen for anisotropic flow.

These features are qualitatively similar features seen for anisotropic flow and isotropic flow.

In heavy-ion collisions, the ordering of baryon-to-meson production is generally observed to be a higher baryon-to-meson ratio than expected from standard models, especially at intermediate transverse momenta, a phenomenon known as the "baryon anomaly". This ordering is attributed to different hadronization mechanisms: at lower momentum, hadron production is dominated by the recombination/coalescence of quarks and antiquarks, which favors the creation of baryons, while at higher momentum, parton fragmentation becomes more significant.

Another important investigation is to understand which physical properties this obserbale is sensitive. From previous works we can notice that $v_0(p_T)$ is sensitive to:

- Changes in bulk viscosity $(\zeta/s) \rightarrow$ additional constraints to the bulk viscosity;
- Largely insensitive to changes in shear viscosity (η/s);
- Changes in speed of sound (c_s^2) in the medium;
- Changes in initial conditions.

Double-scaling the differential radial flow, we have a centrality-independent shape.