Soft-Hard Event Engineering (SHEE)

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Motivation

While the measured data on the nuclear modification factor for charged particles at RHIC and LHC energies can be well described by various models based on pQCD and AdS/CFT, the simultaneous description of the high-p_T v_2 remains a challenge.
To solve this high-p_T v_2-puzzle, it has recently been shown [1,2] that a pQCD-energy loss based on a non-fluctuating background must include the medium transverse flow fields and a jet-medium coupling including the effects of the jet energy, the temperature of the medium, and non-equilibrium effects close to the phase transition.
However, wide distributions of the low-p_T v_n's (see Fig. 1) have proven that medium background models must not only render the mean value of low-p_T v_n's but also the correct amount of fluctuations within a centrality class.

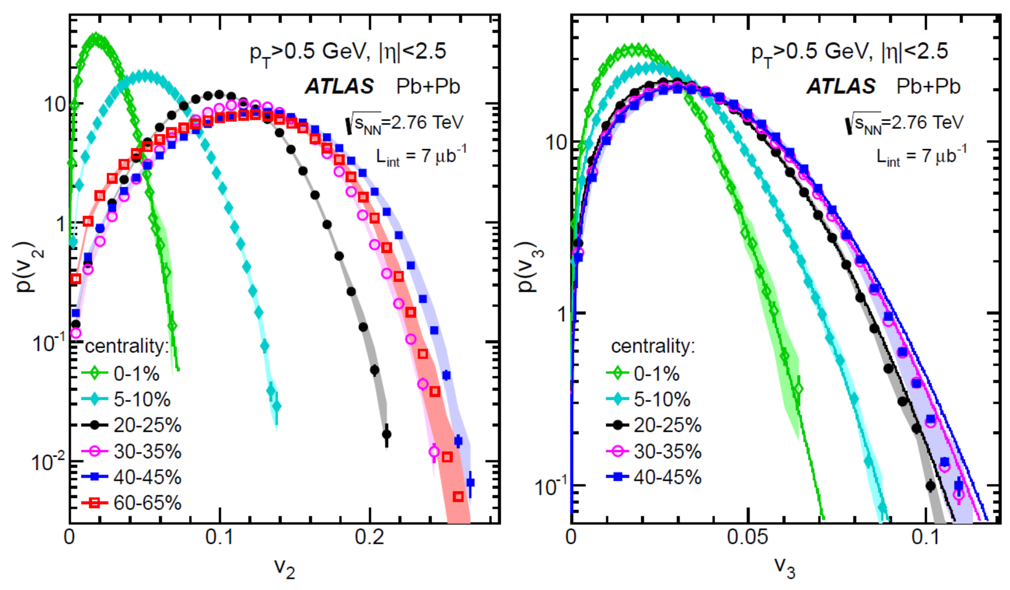

Fig. 1: Probability distribution for event-by-event v_n's measured in different centrality classes [3].

Idea

From experiment, it is clear that high-p_T v_2 can only be measured from events that produce enough high-p_T v_2 particles. Events with a smaller eccentricity are less likely to produce high-p_T particles since hard scattering processes are more likely to be absorbed by the medium.

We study if the eccentricity selection of the background medium within a given centrality class influences the high-p_T v_2. For this, we couple the BBMG pQCD jet-energy loss model [1,4] with the event-by-event v-USPhydro model [5].

Soft-p_T part

For the soft-p_T part, we use v-USPhydro [5], an event-by-event, relativistic viscous hydrodynamical model based on Glauber initial conditions. 15,000 initial conditions were generated and 1,000 events run through v-USPhydro in the centrality classes of 0-5% and 20-30% for η/s=0.08. A distribution of δe_2 and δv_2 is shown in Fig. 2.

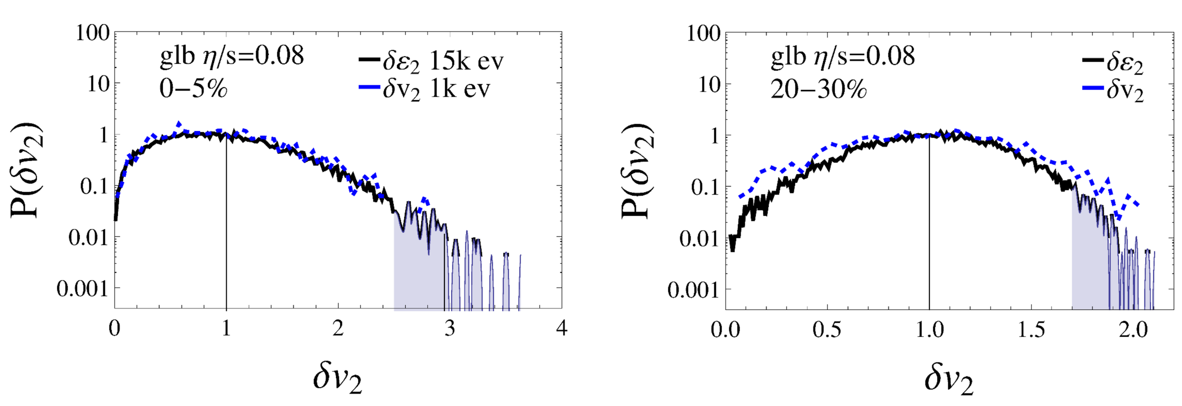

Fig. 2: Probability distribution of δe_2 and δv_2 for Glauber initial conditions at $\sqrt{s_{NN}}$ =2.76 TeV obtained from v-USPhydro.

Eccentricity selection

We selected 150 events per centrality class (out of the 15,000 initial conditions) with

- an event-by-event random e_2,
- the top 1% e_2 shown by the shaded area in Fig. 2, and
- a smoothed background medium profile.

Hard-p_T part

For the hard-p_T part, we use BBMG energy-loss model [1,4] where the pQCD-like energy loss is given by

$$\frac{dE}{dx} = \frac{dE}{d\tau} = -\kappa(E^2, T)\, E^0\, \tau^1\, T^3\, \zeta_0\, v_f. \quad (1)$$

Here, E is the energy of the jet, T the temperature of the medium, and τ the path length.
The model includes jet-energy loss fluctuations via ζ_0, fragmentation to pions, the effect of transverse flow via $v_f \mathrel{\widehat{=}} \gamma_f\,[1 - v_f \cos(\phi_{\rm jet} - \phi_{\rm flow})]$, and the temperature-dependent jet-medium coupling of Ref. [2] fixed to meet a reference point of the nuclear modification factor.
The $R_{AA}(p_T, \phi_{\rm jet})$ is calculated event-by-event, leading to the respective v_n's via a Fourier expansion:

$$v_n(p_T) = \frac{\int_0^{2\pi} d\phi \cos\left[n\left(\phi - \psi_n(p_T)\right)\right] R_{AA}(p_T, \phi)}{\int_0^{2\pi} d\phi\, R_{AA}(p_T, \phi)}, \quad (2)$$

where $\psi_n(p_T)$ is the event-plane angle. For a direct comparison with experiment [6], we calculate

$$v_n^{\rm high}(p_T) = \frac{\langle v_n^{\rm low} v_n^{\rm high}(p_T) \cos\left[\psi_n^{\rm low} - \psi_n^{\rm high}(p_T)\right]\rangle_{\rm events}}{\sqrt{\langle v_n^{2,\rm low}\rangle_{\rm events}}}, \quad (3)$$

using the low-p_T information from the events calculated by v-USPhydro.

The nuclear modification factor

Fig. 3 depicts the nuclear modification factor for central and mid-central events at $\sqrt{s_{NN}}$ =2.76 TeV LHC energy for the three e_2-eccentricity selections of the centrality classes 0-5% and 20-30%.

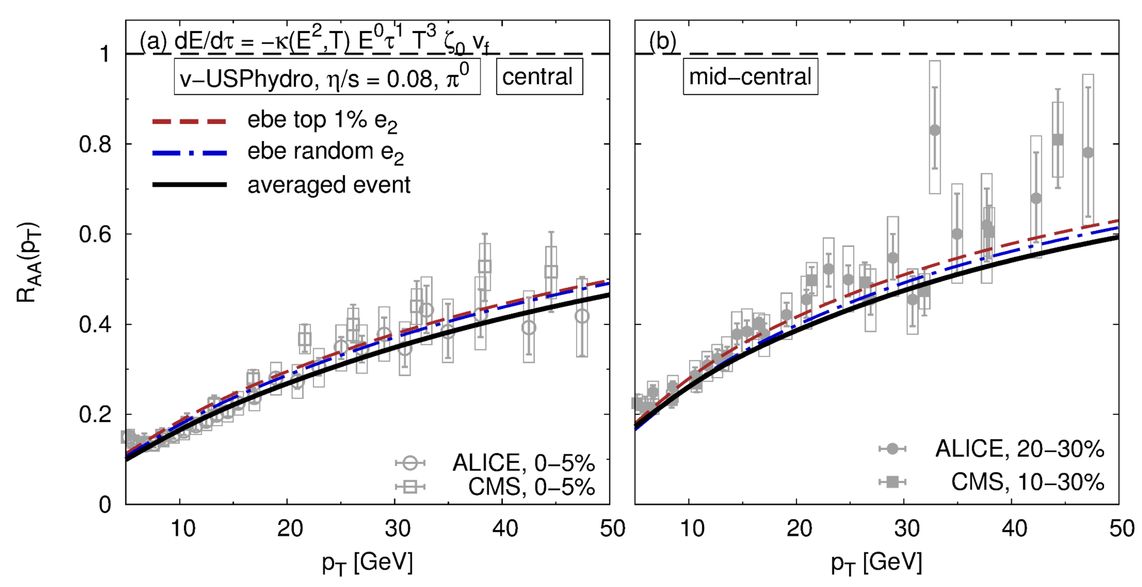

Fig. 3: The nuclear modification factor for central and mid-central events at $\sqrt{s_{NN}}$ =2.76 TeV LHC energy for the three e_2-eccentricity selections of the centrality classes 0-5% and 20-30%.

Fig. 3 shows that all e_2-eccentricity selections allow for a description of the measured data. The Figure demonstrates that the nuclear modification factor is independent of the e_2-eccentricity distribution of the medium, once a single reference point is met.

The high-p_T v_2

Fig. 4 depicts the high-p_T v_n calculated via Eq. (3) for the three different e_2-eccentricity selections of the centrality class 20-30% at $\sqrt{s_{NN}}$ =2.76 TeV LHC energy.

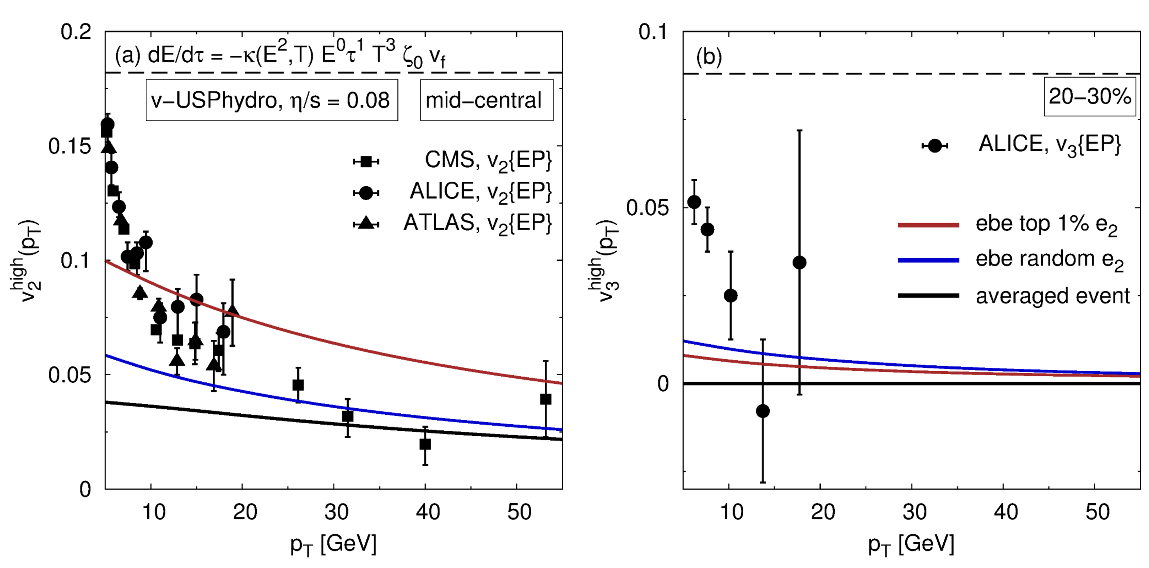

Fig. 4: The high-p_T v_n's calculated via Eq. (3) for the three different e_2-eccentricity selections of the background medium.

Fig. 4a shows that the high-p_T v_2 for events with random e_2-eccentricity and the result from an averaged, smoothed background converge for very large p_T.
The high-p_T v_2 for the top 1% e_2 events of the centrality class 20-30%, however, are enhanced over the other two scenarios.
The Figure demonstrates that the high-p_T v_2 is directly proportional to the low-p_T v_2 and that the width of the low-p_T v_2 distribution influences the value of the high-p_T v_2. Besides that, the Figure shows that event-by-event fluctuations enhance the high-p_T v_2.
Fig. 4b confirms that the high-p_T v_3 depends entirely on fluctuations with a magnitude that is 10 times lower than the high-p_T v_2. Please note that the anti-correlation of e_2 and e_3-eccentricities is proven with Fig. 4b as the high-p_T v_3 for the random e_2-events is larger than for the top 1% e_2 events.

Impact of the method used to determine v_n

There are various ways of extracting the high-p_T v_n's. Besides Eq. (3), the arithmetic mean of the v_n's calculated in Eq. (2) or their root mean square are commonly used.
Fig. 5 depicts a comparison of these three methods to determine the high-p_T v_2 and v_3.
The Figure shows that the results for the arithmetic mean and the root mean square are usually very close to each other, while the difference to the v_n's calculated via Eq. (3) increases for the top 1% e_2-eccentricity selections of the background medium considered.

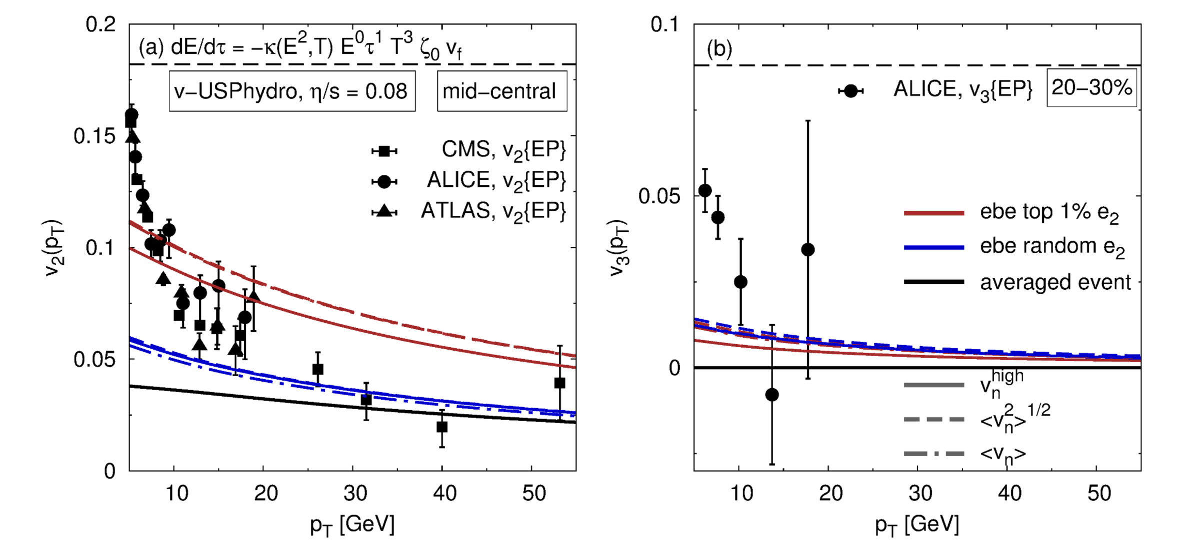

Fig. 5: The high-p_T v_n's calculated via the arithmetic mean, the root mean square, and Eq. (3) for the three different e_2-eccentricity selections of the background medium.

Conclusions and Outlook

We coupled the BBMG pQCD jet-energy loss model [1,4] with the event-by-event, viscous hydrodynamical model v-USPhydro [5] and determined the high-p_T v_2 and v_3 for three different e_2-eccentricity selections of the background medium. We show that

- the R_{AA} is independent of the e_2-eccentricity distribution of the background medium,
- the high-p_T v_2 is directly proportional to the low-p_T v_2,
- the width of the low-p_T v_2 distribution influences the value of the high-p_T v_2.

Our study confirms that

- event-by-event fluctuations enhance the high-p_T v_2,
- e_2 and e_3-eccentricities are anti-correlated.

In the future, we plan to apply the formalism to heavy quarks and pA collisions.

References

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