Non-interdependent Collective Motions in Heavy-ion Collisions

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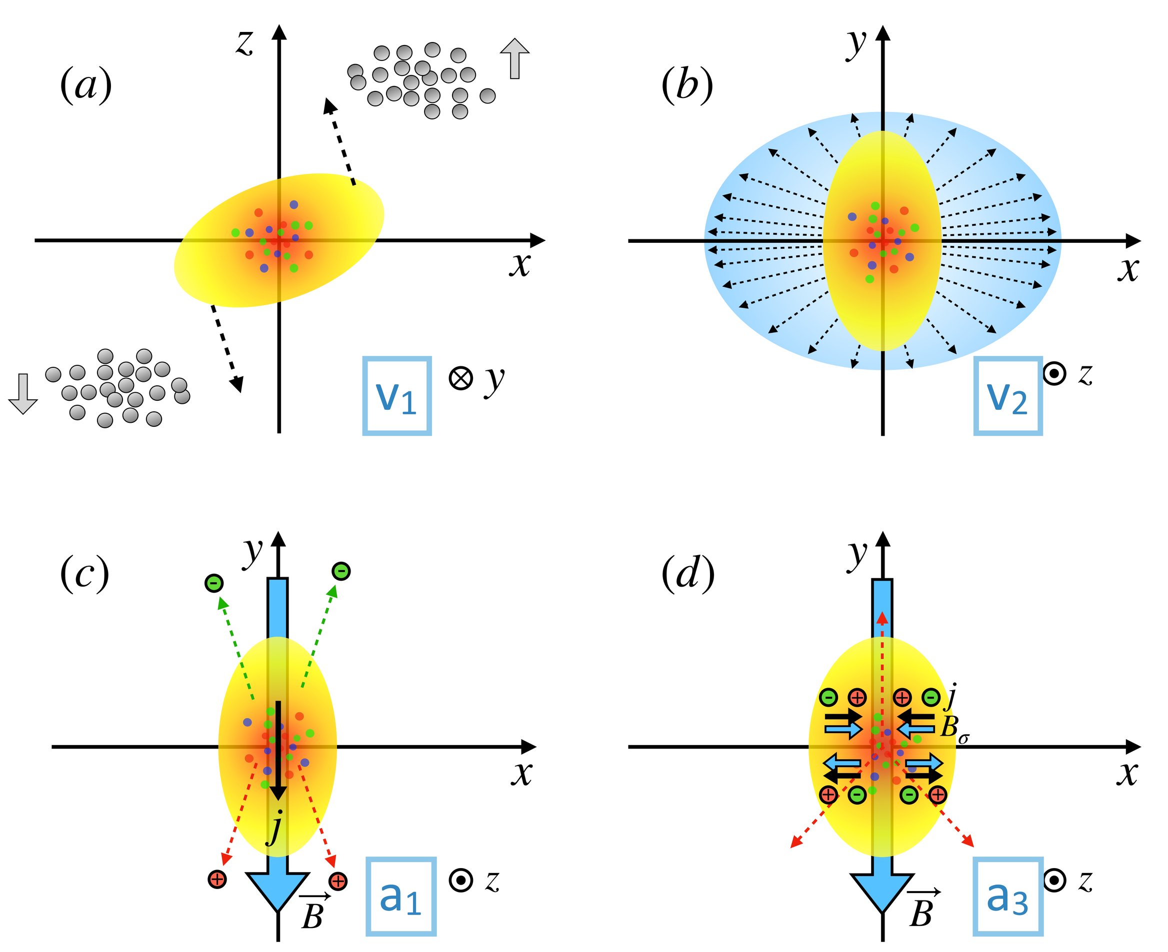
Collective Motions

Various Fourier harmonics in heavy-ion collisions correspond to distinct collectivity modes:

a) v_1 directed flow;
b) v_2 elliptic flow;
c) a_1 chiral magnetic effect (CME);
d) a_3 sheer-induces CME[1] (si-CME).

If collective motions are non-interdependent, the observed Fourier coefficients are inter-linked.



Propose the New Form

$$\frac{2\pi}{N^{\pm}}\frac{dN^{\pm}}{d\varphi} = 1+\sum_{n=1}^{\infty} 2a_n^{\pm}\sin n\Delta\varphi+\sum_{n=1}^{\infty} 2v_n^{\pm}\cos n\Delta\varphi$$

$$\frac{2\pi}{N^{\pm}}\frac{dN^{\pm}}{d\varphi} = \prod_{n=1}^{\infty}(1+2\tilde{a}_n^{\pm}\sin n\Delta\varphi)\prod_{n=1}^{\infty}(1+2\tilde{v}_n^{\pm}\cos n\Delta\varphi)$$

$$4\tilde{a}_1\tilde{v}_2\sin\Delta\varphi\cos 2\Delta\varphi = -2\tilde{a}_1\tilde{v}_2\sin\Delta\varphi + 2\tilde{a}_1\tilde{v}_2\sin 3\Delta\varphi.$$

Noumenon

$$\tilde{a}_1 = \frac{a_1 - a_3 v_2}{1 - v_2 - v_2^2}$$
$$\tilde{a}_3 = \frac{a_3 - a_1 v_2 - a_3 v_2}{1 - v_2 - v_2^2}$$

$$\tilde{v}_1 = \frac{v_1 - v_3 v_2}{1 + v_2 - v_2^2}$$
$$\tilde{v}_3 = \frac{v_3 - v_1 v_2 + v_3 v_2}{1 + v_2 - v_2^2}$$

Phenomena

$$a_1 = \tilde{a}_1 - \tilde{a}_1\tilde{v}_2 + \tilde{a}_3\tilde{v}_2$$
$$a_3 = \tilde{a}_3 + \tilde{a}_1\tilde{v}_2$$
$$v_2 = \tilde{v}_2 + \tilde{a}_1\tilde{a}_3$$

$$v_1 = \tilde{v}_1 + \tilde{v}_1\tilde{v}_2 + \tilde{v}_3\tilde{v}_2$$
$$v_2 = \tilde{v}_2 + \tilde{v}_1\tilde{v}_3$$
$$v_3 = \tilde{v}_3 + \tilde{v}_1\tilde{v}_2$$

We introduce new sets of non-interdependent Fourier coefficients $\tilde{a}_n$ and $\tilde{v}_n$ to better represent the physics, and takes factorized form in azimuthal distribution.

The mapping between old and new sets reveals inter-dependency between conventional coefficients.

Assuming the prominent elliptic flow magnitude is almost unchanged, $v_2 \approx \tilde{v}_2$, we study the relation among (a_1, v_2, a_3) and (v_1, v_2, v_3) with model simulations.

Conclusion

We stipulate a likely scenario where collective motions in heavy-ion collisions may be non-interdependent, and that the particle azimuthal distribution can take a factorized form, which complements the widely used long linear Fourier series.

We predict the extra cross terms between the CME-induced $\tilde{a}_1$ and elliptic flow v_2. EBE-AVFD verifies the observed a_3 receives a sizable contribution from a_1 and v_2. A finite a_3, if confirmed, constitutes a strong evidence of the CME, whether it originates from si-CME or CME coupled with v_2. In addition, the observation of a v_3^{odd} component with AMPT establishes another signature of the factorized Fourier expansions.

Model Evidence: AVFD

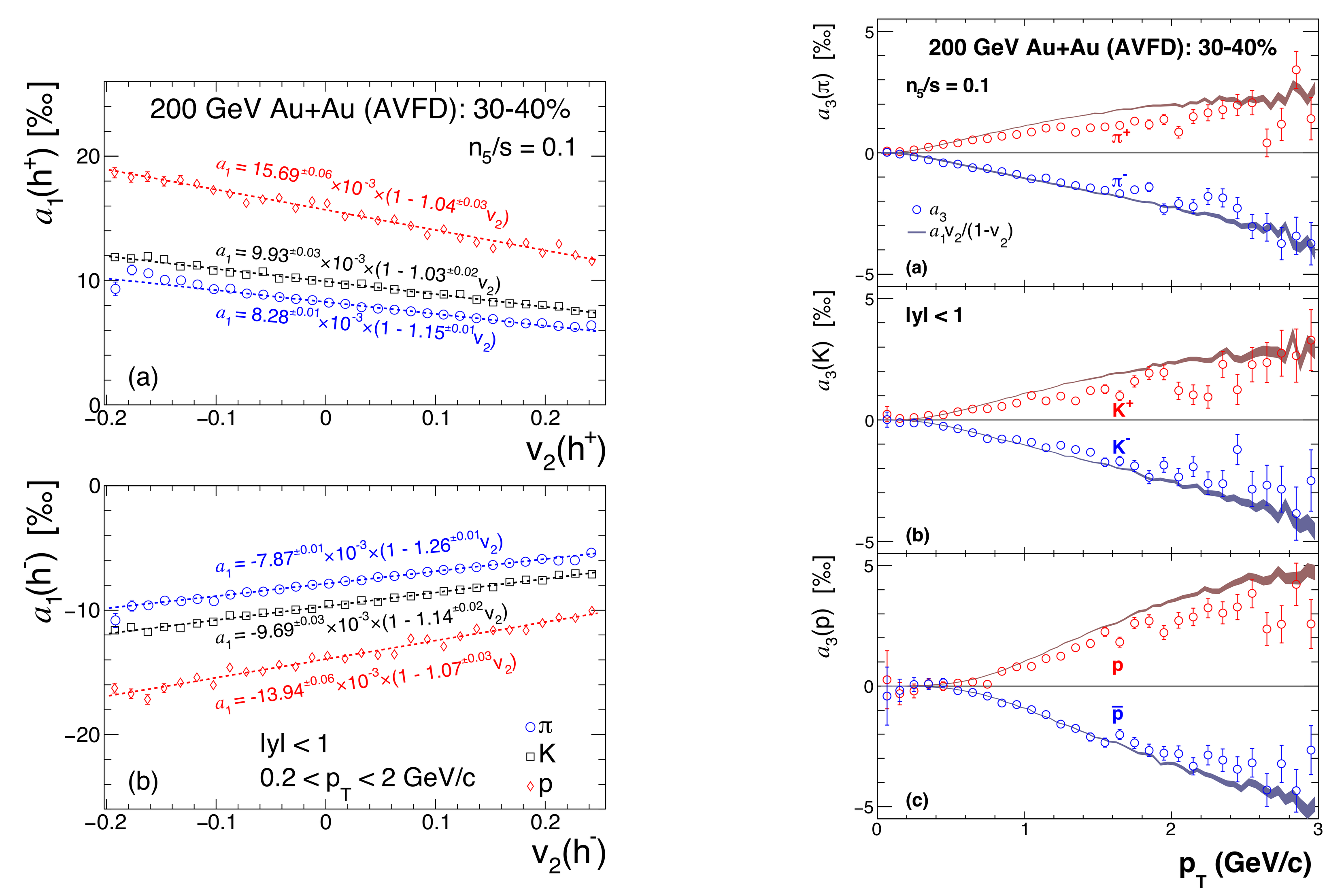
Event-by-Event Anomalous-Viscous Fluid Dynamics (AVFD)[2] model simulates the dynamical CME transport for *u*, *d* and *s* quarks in addition to the hydrodynamic expansion, and further handles local charge conservation and resonance decays.

$\tilde{a}_3 = 0\,;\, v_2 \approx \tilde{v}_2$

$a_1 = \tilde{a}_1(1 - v_2)$

$a_3 = \tilde{a}_1 v_2$

- Correlations between a_1 and v_2 may contain trigonometric identity in addition to the math relation we look for.
- The observed a_3 as a function of p_T can be described by $a_1v_2/(1-v_2)$ (shaded bands) as predicted.



Model Evidence: AMPT

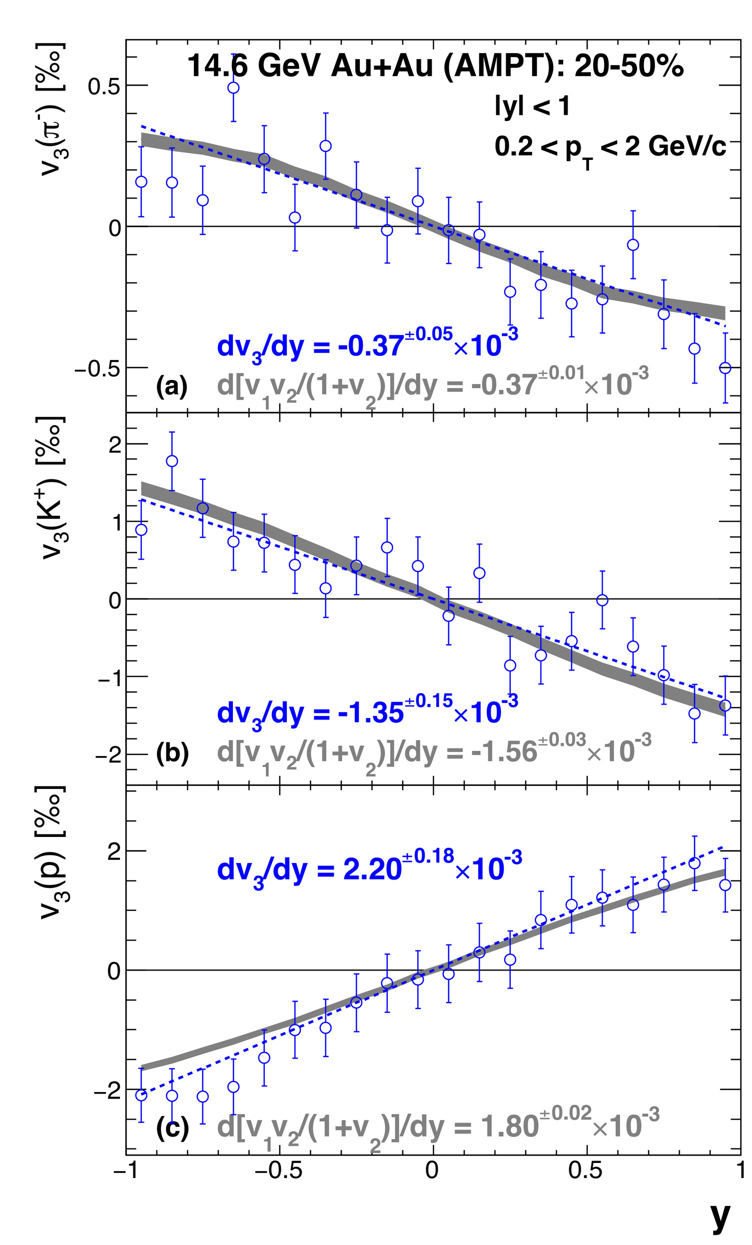
A multi-phase transport (AMPT)[3] model with string melting version properly reproduces particle spectra and flow dynamics at both RHIC and LHC energies.

$\tilde{v}_3 = 0\,;\, v_2 \approx \tilde{v}_2$

$v_1 = \tilde{v}_1(1 + v_2)$

$v_3 = \tilde{v}_1 v_2$

- Third-order geometry is averaged to zero from e-by-e fluctuation.
- The observed v_3 is rapidity-odd, can be well described by $v_1v_2/(1+v_2)$ (shaded bands) as predicted.
- The trend and magnitude of v_3^{odd} meets our expectations for all the particle species. The simulations support and verify another imprint of factorized actions.
- Further analyses can be applied to RHIC/LHC data.



Reference:

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QR code for paper