Rebuttal to: “Comment on Scaling properties of background- and chiral-magnetically-driven charge separation in heavy ion collisions at $\sqrt{s_{NN}} = 200$ GeV”

Roy A. Lacey$^1$ and Nisem Magdy$^2$

$^1$Depts. of Chemistry & Physics, Stony Brook University, Stony Brook, New York 11794, USA
$^2$Department of Chemistry, Stony Brook University, Stony Brook, New York 11794, USA

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Recently, F. Wang commented [1] on our work – “Scaling properties of background- and chiral-magnetically-driven charge separation in heavy ion collisions at $\sqrt{s_{NN}} = 200$ GeV” [2] – and made several claims to support his conclusion that the results in Ref. [2] are fallacious. His conclusion and claims are not only incorrect; they show a fundamental disconnect with the rudiments of the $R_{\Psi_2}(\Delta S)$ correlator. This rebuttal addresses the root misconception responsible for Wang’s false claims.

In the recent publication of the STAR Collaboration’s isobar data [3], the ratios between Ru+Ru and Zr+Zr collisions of the observables $\Delta \gamma/v_2$ (the azimuthal correlator $\Delta \gamma$ divided by the elliptic flow coefficient $v_2$) and $1/\sigma_{R_{\Psi_2}}$ (the inverse width of the $R_{\Psi_2}(\Delta S)$ distribution $\Psi_2$) were reported. Both correlators indicated ratios ($R_{\text{Ru/Ru}}/Zr$) less than unity but more significant deviations from unity for $\Delta \gamma/v_2$. Because these ratios are different from the predefined values $R_{\text{Ru/Zr}} > 1$ expected for the chiral magnetic effect (CME) [3], it was hypothesized that the signal difference (between the isobars) obtained in the STAR blind analysis is incompatible with the presence of a CME signal. This conclusion is, of course, predicated on the notion that the background difference between Ru+Ru and Zr+Zr is negligible and the correlators are sensitive to the small-signal difference expected [3]. A non-negligible background difference influencing $R_{\text{Ru/Zr}}$ was reported in Ref. [3] and several post-blind analyzes’ attempted to evaluate its consequence on the ratios for $\sigma_{R_{\Psi_2}}$ [2] and $\Delta \gamma/v_2$ [4, 7]. This rebuttal addresses the essential question raised by F. Wang in his comment [1] to the post-blind results we reported in Ref. [2].

A central underpinning to Wang’s critique [1] of our work in Ref. [2] is the misconception that $\sigma_{R_{\Psi_2}}^2 \approx N_{\text{ch}} \Delta \gamma \propto v_2$ [1, 4], where $N_{\text{ch}}$ is the charged particle multiplicity. In the following, we debunk this misconception by showing that the $R_{\Psi_2}(\Delta S)$ correlator for background-driven charge separation is only sensitive to the charge-dependent non-flow background [5, 10, 11], and $\sigma_{R_{\Psi_2}}^2 \propto 1/N_{\text{ch}}$.

The $R_{\Psi_2}(\Delta S)$ correlator measures charge separation relative to the $\Psi_2$ plane via the ratios:

$$R_{\Psi_2}(\Delta S) = C_{\Psi_2}(\Delta S)/C_{\Psi_2}^\perp(\Delta S),$$

where $C_{\Psi_2}(\Delta S)$ and $C_{\Psi_2}^\perp(\Delta S)$ are correlation functions that quantify charge separation $\Delta S$, approximately parallel and perpendicular (respectively) to the $\vec{B}$-field. The charge shuffling procedure employed in constructing these correlation functions ensures identical properties for their numerator and denominator, except for the charge-dependent correlations, which are of interest [3, 10].

The inverse variance $\sigma_{R_{\Psi_2}}^{-2}$ of the $R_{\Psi_2}(\Delta S)$ distributions quantifies the charge separation [3, 10] as:

$$\sigma_{R_{\Psi_2}}^{-2} = [\sigma_{\Delta S\text{Real}}^2 - \sigma_{\Delta S\text{Shuffled}}^2]/\sigma_{\Delta S\text{Real}}^2 = [\sigma_{\Delta S}^2 - \sigma_{\Delta S\text{Shuffled}}^2]/\sigma_{\Delta S\text{Real}}^2 \propto 1/N_{\text{ch}}$$

indicating that $\sigma_{R_{\Psi_2}}^{-2}$ is the difference between the inverse variances for the distributions of Real and Shuffled events. This is illustrated in Fig. 1 for events simulated with the anomalous viscous fluid dynamics (AVFD) model [13] for background-driven charge separation; these results incorporate the requisite corrections for number fluctuations and event plane resolution [5, 10]. Fig. 1(a) shows that $v_2$ is proportional to the shuffled term in Eq. 4 indicating the difference be-

FIG. 1. Comparison of the $N_{\text{ch}}$-dependence of $v_2$ and the inverse variances for Real and Shuffled events (cf. Eq. 4) obtained for background-driven charge separation simulated with the AVFD model (a). The open and closed symbols in panel (b) compare $\sigma_{R_{\Psi_2}}^{-2}$ vs. $1/N_{\text{ch}}$ for fits to the $R_{\Psi_2}(\Delta S)$ distributions (Eq. 1) and the inverse variances extracted via Eq. 4.
tween the Real and Shuffled terms [Eq. 4] reflects only the influence of the charge-dependent non-flow correlations. The well-known $1/N_{ch}$ dependence of such correlations is made more transparent in Fig. 1(b), which shows that $\sigma_{R_{\Psi}}^2 \propto 1/N_{ch}$; this dependence is similar for both isobars but with different $N_{ch}$ values. Wang et al. [1, 3, 14, 15] have been repeatedly made aware of these facts to no avail.

In Ref. [2], the $\sigma_{R_{\Psi}}^2$ values extracted for background and signal + background at a given centrality, were checked to establish their sensitivity to variations in the magnitude of the anisotropic flow coefficient $v_2$, using event-shape selection via fractional cuts on the distribution of the magnitude of the $q_2$ flow vector [16]. The checks indicated that, while $v_2$ shows a sizable increase with $q_2$, the corresponding $\sigma_{R_{\Psi}}^2$ values are insensitive to $q_2$ regardless of background or signal + background. Similar patterns were observed for the Isobar data reported in Ref. [3].

In contrast to Wang’s stated confusion about the $q_2$ dependence of $\sigma_{R_{\Psi}}^2$ [1, 3], it is straightforward to see that the observed insensitivity stems from a cancellation which results from the difference between the Real and Shuffled terms in Eq. 4 (cf. Fig. 1). Note, however, that $q_2$ selection methods which result in a small $N_{ch}$ bias, especially for large $q_2$ [3], could lead to small modifications to the insensitivity trend. It is straightforward to implement a methodological change that prevents a possible $N_{ch}$ bias. Wang et al. [1, 3] has persistently ignored these facts.

In summary, we have shown that $\sigma_{R_{\Psi}}^2 \propto 1/N_{ch}$ which debunks the the root claim by Wang et al. that $\sigma_{R_{\Psi}}^2 \approx N_{ch}\Delta \gamma \propto v_2$ [1, 3, 14, 15]. This falsification renders all direct and collateral inferences in Wang’s comment [1] false.

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* Roy.Lacey@stonybrook.edu
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