# New Method for measuring longitudinal flustuations and directed flow in ultrarelativistic heavy ion reactions

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PHYSICAL REVIEW C **86**, 024912 (2012)

L. P. Csernai,[1] G. Eyyubova,[2,3] and V. K. Magas[4]

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# Fluctuating initial states

[1] Gardim FG, Grassi F, Hama Y, Luzum M, Ollitraut
PHYSICAL REVIEW C **83**, 064901 (2011); ($v_1$ also)
[2] Qin GY, Petersen H, Bass SA, Mueller B
PHYSICAL REVIEW C **82**, 064903 (2010)

QIN, PETERSEN, BASS, AND MÜLLER

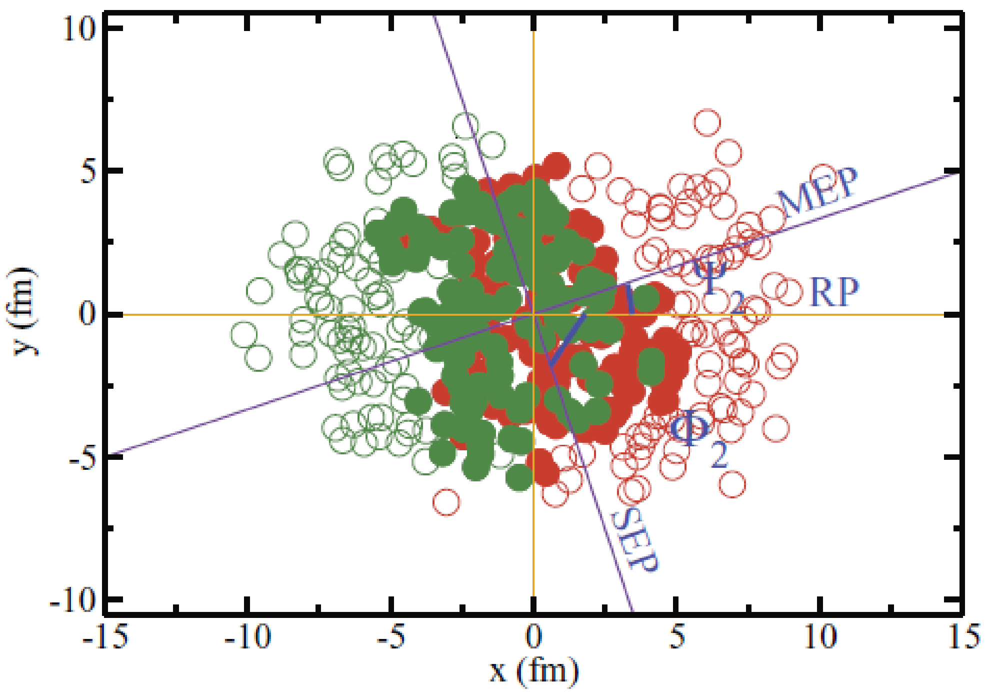


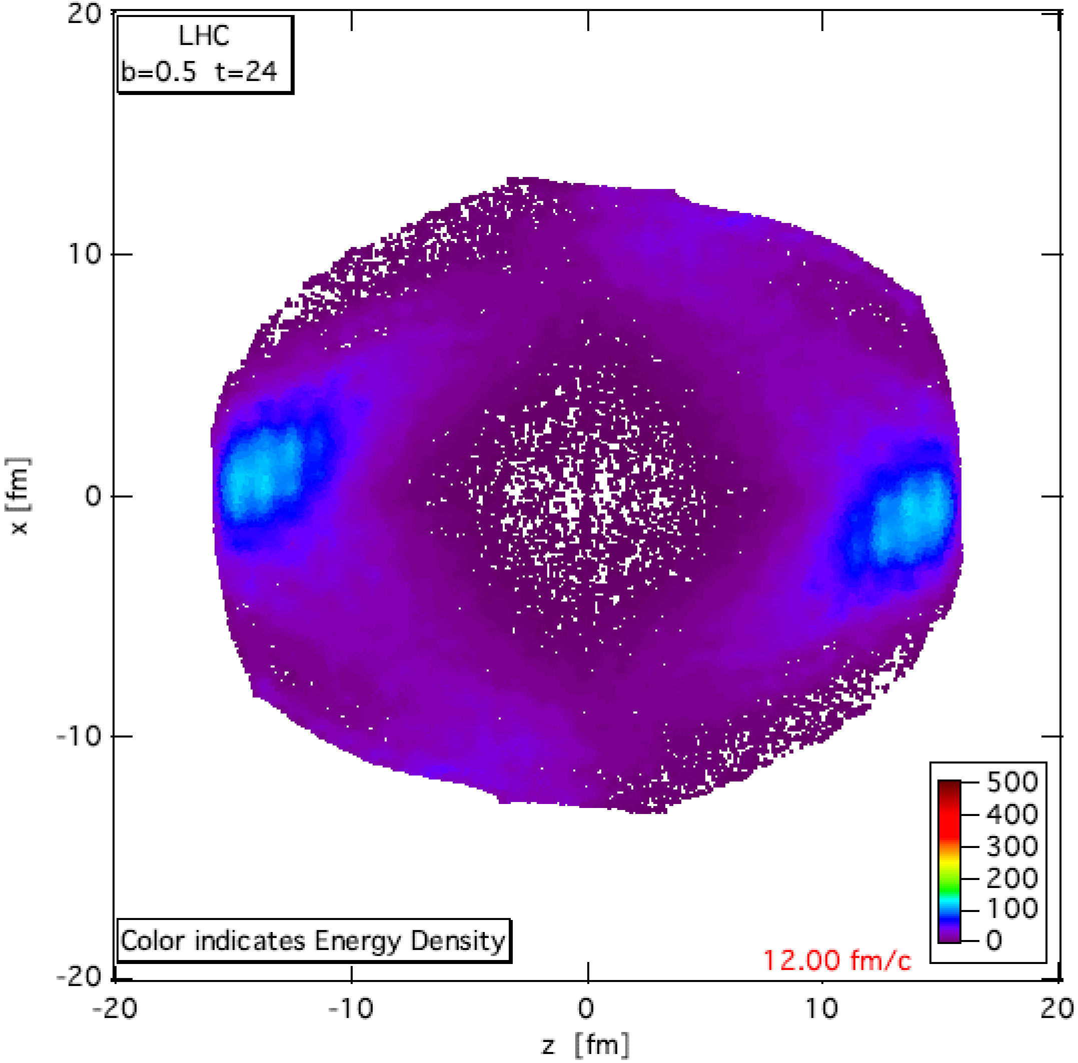

FIG. 3. (Color online) The transverse plane for one typical collision event, where the circles represent nucleons from two nuclei, with shaded ones for participating nucleons. Also shown are the locations of different planes: the reaction plane (RP), the spatial event plane (SEP), and the momentum event plane (MEP) for $n = 2$.

Cumulative event planes show weak correlation with the global collective reaction plane (RP).

If the MEP is set to zero (by definition) then CM rapidity fluctuations do not appear, and $v_1$ by definition is zero.

In [2] v1(pt) is analyzed (for RHIC) and the effect is dominated by fluctuations. (Similar to later LHC measurements.)

# Anti-flow (v1)

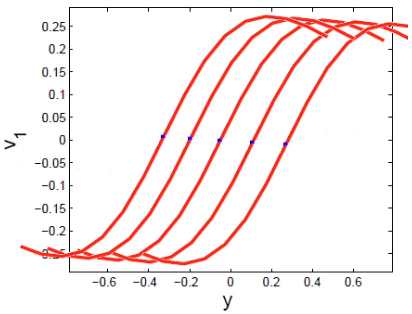



The energy density [GeV/fm3] distribution in the reaction plane, [x,z] for a Pb+Pb reaction at 1.38 + 1.38 A.TeV collision energy and impact parameter b = 0.5b_max at time 12 fm/c after the formation of the hydro initial state. The expected physical FO point is earlier but this post FO configuration illustrates the flow pattern.

[LP. Csernai, VK. Magas, H. Stocker, D. Strottman, arXiv: 1101.3451 (nucl-th)]

# Anti-flow (v1)

With & without longitudinal fluctuations



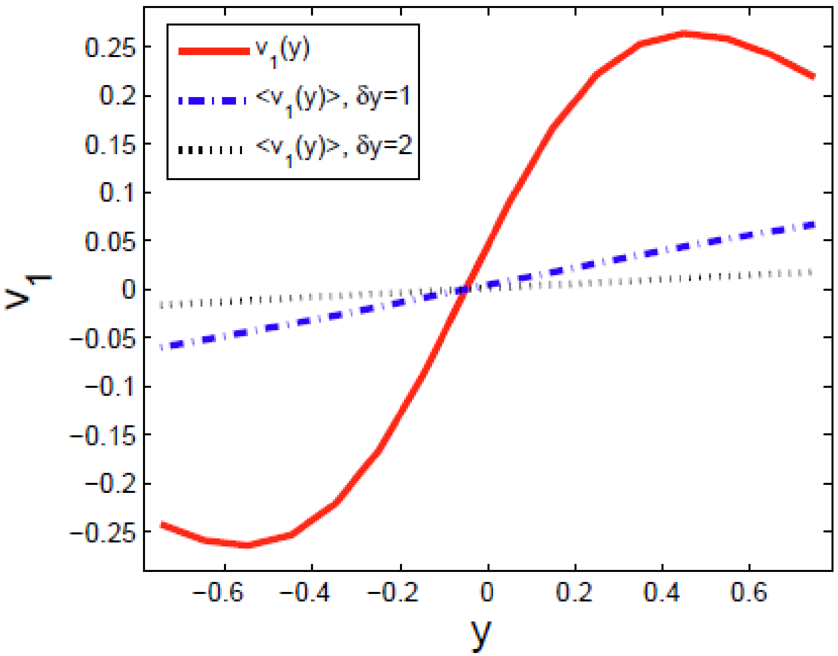

Initial fluctuations in the positions of nucleons in the transverse plane

→different number of participants from projectil and target

→Reduce $v_1$ at central rapidities, as v1 has a sharp change at y=0, and the initial fluctuations have not.

→$v_1$ is reduced but still measurable

*[ Yun Cheng, et al., Phys. Rev. C* ***84*** *(2011)* 034911. ]



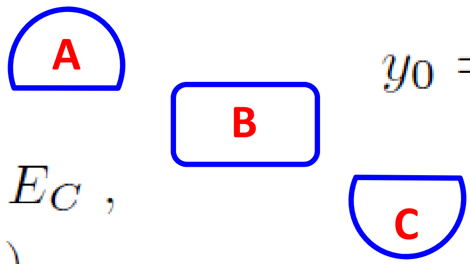
# Method to compensate for C.M. rapidity fluctuations

1. Determining experimentally EbE the C.M. rapidity
2. Shifting each event to its own C.M. and evaluate flow-harmonics there

L.P. Csernai[1,2], G. Eyyubova[3] and V.K. Magas[4] arXiv:1204.5885v1 [hep-ph]

## Determining the C.M. rapidity

The rapidity acceptance of a central TPC is usually constrained (e.g for ALICE $|\eta| < \eta_{lim} = 0.8$, and so: $|\eta_{C.M.}| << \eta_{lim}$ , so it is not adequate for determining the C.M. rapidity of participants.




$$y_0 = 7.986$$

**Participant rapidity from spectators**

$$E_B = A_B \, m_{B\perp} \cosh(y^B) = E_{tot} - E_A - E_C \ ,$$
$$M_B = A_B \, m_{B\perp} \sinh(y^B) = -(M_A + M_C)$$

$$E_{tot} = 2 A_{Pb} \, m_N \cosh(y_0)$$

$$E_A = A_P \, m_N \cosh(y_0),$$
$$E_C = A_T \, m_N \cosh(-y_0),$$

give the spectator numbers, $A_P$ and $A_T$,

$$M_A = A_P \, m_N \sinh(y_0),$$
$$M_C = A_T \, m_N \sinh(-y_0),$$

$$y_E^{CM} \approx y^B = \mathrm{artanh}\left(\frac{M_A + M_C}{E_{tot} - E_A - E_C}\right)$$

arXiv:1204.5885v1 [hep-ph] 26 Apr 2012

by L.P. Csernai, G. Eyyubova & V.K. Magas

### B. Participant rapidity from spectators

Let us consider that we have three subsystems: (A) projectile spectators, (B) participants, and (C) target spectators. We can measure the energies of A and C, $E_A$ and $E_C$, in the respective Zero Degree Calorimeters (ZDC): $ZDC_a$ and $ZDC_c$. Then the energy and momentum conservation gives

$$E_B = A_B\, m_{B\perp}\, \cosh(y^B) = E_{tot} - E_A - E_C \ ,$$
$$M_B = A_B\, m_{B\perp}\, \sinh(y^B) = -(M_A + M_C) \qquad (5)$$

For example, at the present LHC Pb+Pb reaction with energy per Nucleon $\epsilon_N = 1.38$ TeV/nucleon, the beam rapidity is $y_0 = 7.986$ and

$$E_{tot} = 2A_{Pb}\, m_N\, \cosh(y_0)\,,$$

where $m_N = 938.8$ MeV/c$^2$.

Furtermore the equations

$$E_A = A_P\, m_N\ \cosh(y_0),$$
$$E_C = A_T\, m_N\ \cosh(-y_0),$$

give the spectator numbers, $A_P$ and $A_T$, and

$$M_A = A_P\, m_N\ \sinh(y_0),$$
$$M_C = A_T\, m_N\ \sinh(-y_0),$$

as well as the mass number of subsystem $B$:

$$A_B = 2A_{Pb} - A_P - A_T\ .$$

Thus for an event, dividing the second of eq. (5) by the first we can determine the rapidity of subsystem $B$, which should be close to the rapidity of the participant system.

$$y_E^{CM} \approx y^B = \mathrm{artanh}\left(\frac{M_A + M_C}{E_{tot}-E_A-E_C}\right)\ . \qquad (6)$$

Our system $B$ includes high energy "pre-equilibrium" particles, which are not detected by the ZDCs, and do not form a locally equilibrated system. To separate these two components from one-another would need more information, and a quantitative definition.

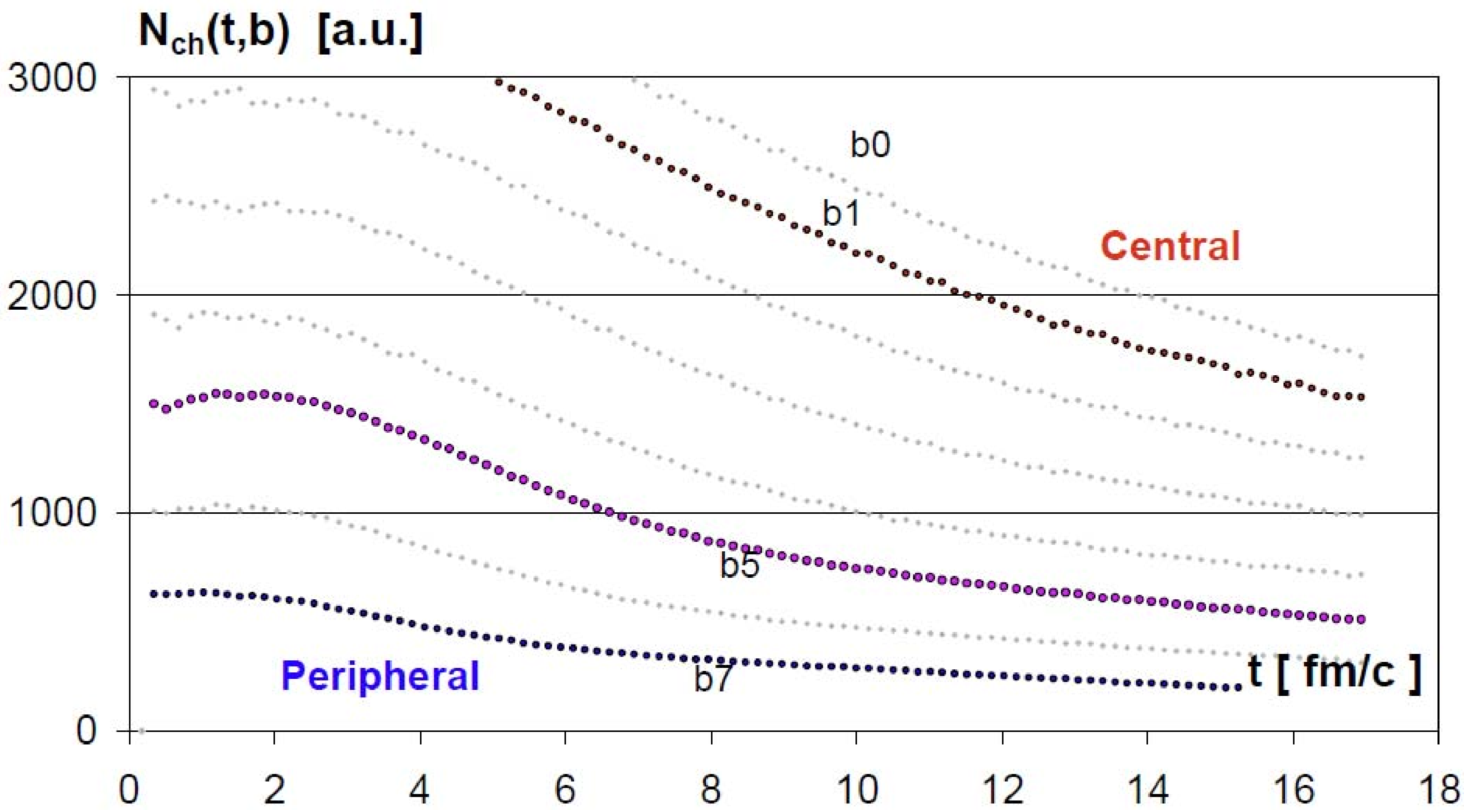



FIG. 1. Simulation of the Pb+Pb collision at LHC with $\epsilon_N = 1.38$ TeV/nucleon [5]. The calculated charged particle multiplicity, $N_{ch}$, as a function of FO time (assuming a $t_{FO} = const.$ FO hyper-surface), for different impact parameters, $b = 0.0, 0.1, 0.2, ...0.7 b_{max}$. The indicated (b0, b1, ... b7) FO times for different impact parameters reproduce the measured charged particle multiplicities, $N_{ch}$, in the corresponding centrality bins. The visible fluctuations arise from the feature of the PIC method [5], that the volume increases by one cell when a marker particle crosses the boundary. Thus at the initial state with relatively few cells and large relative surface, this leads to fluctuations.

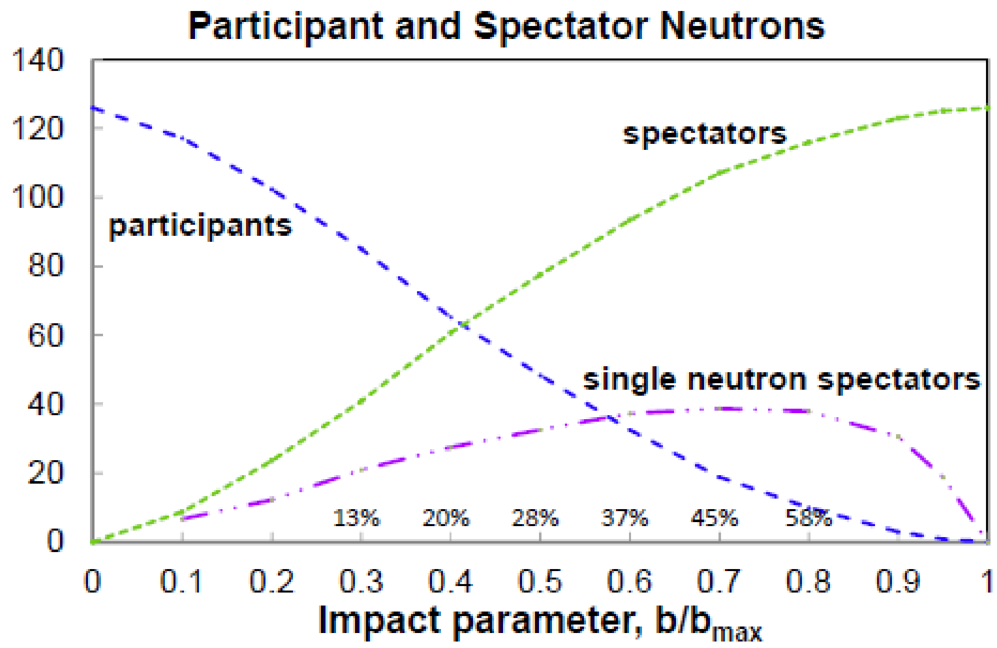



FIG. 2. (color online) The number of participant neutrons from the projectile or from the target (dashed blue line) and the corresponding number of spectator neutrons (dotted green line) in one of the spectators (forward or backward) obtained in the initial state calculation [11] for Pb+Pb collision.. The neutron distribution is assumed to be homogeneous in the system, $N/A = 126/208$. At large impact parameters part of spectator neutrons remain in nuclear fragments, which are charged and so do not reach the neutron ZDCs. Based on the FD estimates we relate impact parameter with the centrality percentage, and based on nuclear multi-fragmentation studies [13], see Table I, we estimate the number of single nucleons, which reach the neutron ZDCs (magenta dashed double dotted line).

| $b/b_{max}$ | centrality [%] | $\langle N_n(b)\rangle$ | $P_n(b)$ |
|---|---|---|---|
| | 0-10 | 6.7 | 8.8 |
| (0.2) | 6 | 12.3 | 23.5 |
| 0.3 | 13±5 | 21.0 | 40.9 |
| 0.4 | 20±5 | 27.5 | 60.8 |
| 0.5 | 28±5 | 32.6 | 77.6 |
| 0.6 | 37±5 | 37.3 | 93.4 |
| 0.7 | 45±5 | 38.8 | 107.1 |
| (0.8) | 58±5 | 38.0 | 116.0 |
| (0.9) | 72±5 | 30.6 | 123.0 |
| (0.95) | (84±5) | 18.8 | 124.6 |
| (1.0) | (90±5) | 0.0 | 126.0 |

TABLE I. The number of single spectator neutrons as function of centrality bins and the corresponding impact parameters as estimated based on nuclear multi-fragmentation model [13]. The initial geometrical spectator numbers corresponding to a given impact parameter are also given.

$$E_A(b) = (A/N)E_A^{sn}P_n(b)/N_n(b)$$
$$E_C(b) = (A/N)E_C^{sn}P_n(b)/N_n(b)\,. \tag{7}$$

This yields the corresponding spectator momenta, $M_A, M_C$, and we can get the event by event C.M. rapidity as in eq. (6)

$$y_E^{CM}(b) \approx y^B = \mathrm{artanh}\left(\frac{M_A + M_C}{E_{tot} - E_A - E_C}\right) - y^{CM}(b)\ , \tag{8}$$

where the last term is added to correct for eventual detector asymmetry, which is measurable, for all events of the sample for a given multiplicity percentage bin. Now, $E_A, E_C, A_P, A_T$ are estimated and in the estimate we used the average $N_n(b)$, based on the estimated or eventually measured ZDC energies.

## II. ADJUSTMENT OF THE CENTER OF MASS

Substantial initial state rapidity fluctuations will average out all flow structures around the CM when the measurements are assuming that the CM is identical with the pre-collision CM of the given experiment (i.e. fixed to the Laboratory frame in a colliding beam experiment with a symmetric, A+A, collision). Odd components of global collective flow patterns, ($v_1$, $v_3$, ...) are Mirror Asymmetric (MA) around the real participant CM, so these are severely effected by the EbE CM fluctuations.[5, 6]

Based on the above results, we suggest to use the CM rapidity, EbE, determined from the ZDC data. Let us assume that the CM rapidity is measured for each Event, ($E$):

$$y_E^{CM}(b) = \frac{1}{2} \ln \frac{E + P_z}{E - P_z}.$$

shift each event to its own CM by the measured $y_E^{CM}$ so that each particle rapidity $y_i$ will be moved to

$$y_i' = y_i - y_E^{CM}(b) \tag{9}$$

This transformation will not effect the azimuth angle of the emitted particles, $\vec{p}_{\perp,i}$, nor $m_{\perp,i}$, however, the longitudinal momentum and the energy will change to,

$$p_{z,i}' = m_{\perp,i} \sinh(y_i - y_E^{CM})$$
$$E_i' = m_{\perp,i} \cosh(y_i - y_E^{CM}).$$

flow harmonics can be determined EbE averaging over **all measured particles in the Event**

$$v_n(y', p_\perp)_E = \langle \cos[n(\phi_i - \Psi_{EP})] \rangle_E \ , \qquad (10)$$

and then one can make an average over **all events in a centrality bin:**

$$v_n(y', p_\perp) = \langle v_n(y', p_\perp)_E \rangle \ . \qquad (11)$$

We can quantify the identification of the collective symmetric versus the random fluctuating contribution to the flow the following way. We can evaluate the *odd* and *even* components of the flow [3]:

$$\begin{aligned} v_n^{odd}(y', p_\perp) &= [v_n(y', p_\perp) + v_n(-y', p_\perp)] \\ v_n^{even}(y', p_\perp) &= [v_n(y', p_\perp) - v_n(-y', p_\perp)] \,. \end{aligned}$$