Three Particle Correlations as a Probe of Eccentricity Fluctuations

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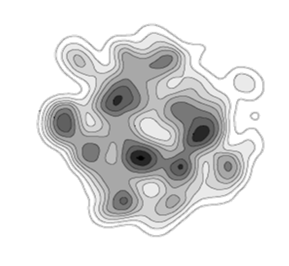
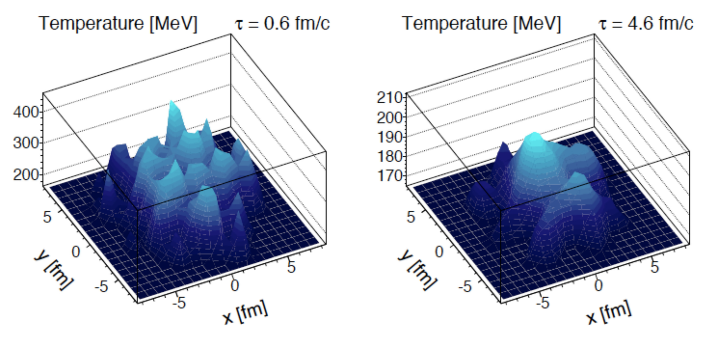
Initial Density Fluctuations

Hama, Grasi, Kodama, et. al.



NexSPheRio using Nexus initial conditions

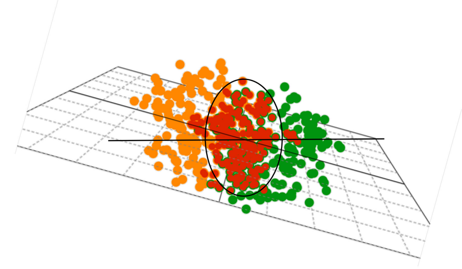


From: A.Mocsy, P. Sorensen: arXiv:1008.3381 [hep-ph] using entropy distributions found in: K. Werner, et al. arXiv: 1004.0805 [nucl-th]

The participant zone in heavy ion collisions is not smooth and symmetric. Lumpy initial conditions are intrinsic to Glauber models , transport codes such as RQMD and perhaps Nature. These initial conditions can be incorporated into Hydro models; and they give observable consequences via multi-particle correlations wrt the reaction plane.

Previously, Sorensen suggested that fluctuations of $\sqrt{\langle v_3^2 \rangle}$ may be related to the Ridge and Shoulder formation. Interesting structures have been seen in various models; for example Alver and Roland used RQMD to explicitly demonstrate that lumpiness in the initial conditions can lead to a finite $\sqrt{\langle v_3^2 \rangle}$ in azimuthal particle production.

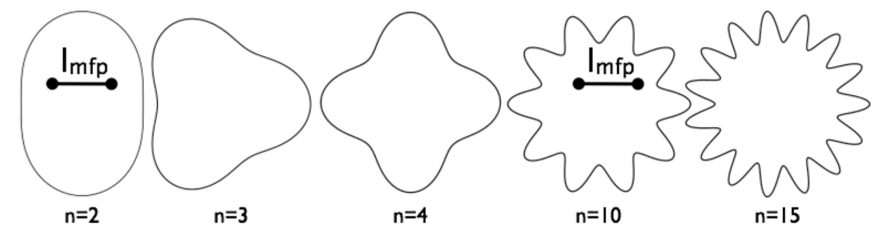
Participant Eccentricity and Higher Harmonics



Glauber like fluctuations in the initial state mean that the participant plane is not the same as the reaction plane, $\psi_{PP} \neq \psi_{RP}$, and in addition the eccentricity of the collision overlap zone is not equal to the participant eccentricity

$$\varepsilon^2_{part,n} = \varepsilon_x^2 + \varepsilon_y^2 = \frac{\langle r^n \cos(n\varphi_{part})\rangle^2 + \langle r^n \sin(n\varphi_{part})\rangle^2}{\langle r^n \rangle^2}$$

Participant eccentricity considers the length of the eccentricity vector and is positive definite, even for n=1,3,5,7…



From: A.Mocsy, P. Sorensen: arXiv:1101.1926v1 [hep-ph]

Why are higher harmonics interesting?

Higher Harmonics probe smaller length scales if hydrodynamics is an accurate description of the participant zone in HI collisions.

Ideal Hydro including Glauber Style Initial Conditions

Teaney and Yan arXiv:submit/0123932 [nucl-th] 9 Oct 2010

$$\left\langle\!\left\langle \frac{dN_{\text{pairs},\alpha\beta}}{d\phi_\alpha d\phi_\beta} \right\rangle\!\right\rangle \simeq \frac{N_\alpha N_\beta}{(2\pi)^2}\Big[1+\sum_n 2\left(\frac{v_{n\alpha}v_{n\beta}}{\epsilon_n^2}\right)\langle\!\langle \epsilon_n^2\rangle\!\rangle \cos(n\phi_\alpha - n\phi_\beta)$$
$$+ 2\frac{v_{2\alpha}}{\epsilon_2}\langle\!\langle \epsilon_2\rangle\!\rangle \cos(2\phi_\alpha - 2\Psi_{PP})$$
$$+ 2\frac{v_{2\alpha}v_{2\beta}}{\epsilon_2^2}\langle\!\langle \epsilon_2^2\rangle\!\rangle \cos(2\phi_\alpha + 2\phi_\beta - 4\Psi_{PP})$$
$$+ 2\frac{v_{1\alpha}v_{1\beta}}{\epsilon_1^2}\langle\!\langle \epsilon_1^2 \cos(2\psi_{1,3} - 2\Psi_{PP})\rangle\!\rangle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{PP})$$
$$+ 2\frac{v_{1\alpha}v_{3\beta}}{\epsilon_1\epsilon_3}\langle\!\langle \epsilon_1\epsilon_3 \cos(\psi_{1,3} - 3\psi_{3,3} + 2\Psi_{PP})\rangle\!\rangle \cos(\phi_\alpha - 3\phi_\beta + 2\Psi_{PP})$$
$$+ \alpha \leftrightarrow \beta\Big].$$

Dipole term

Triangle term

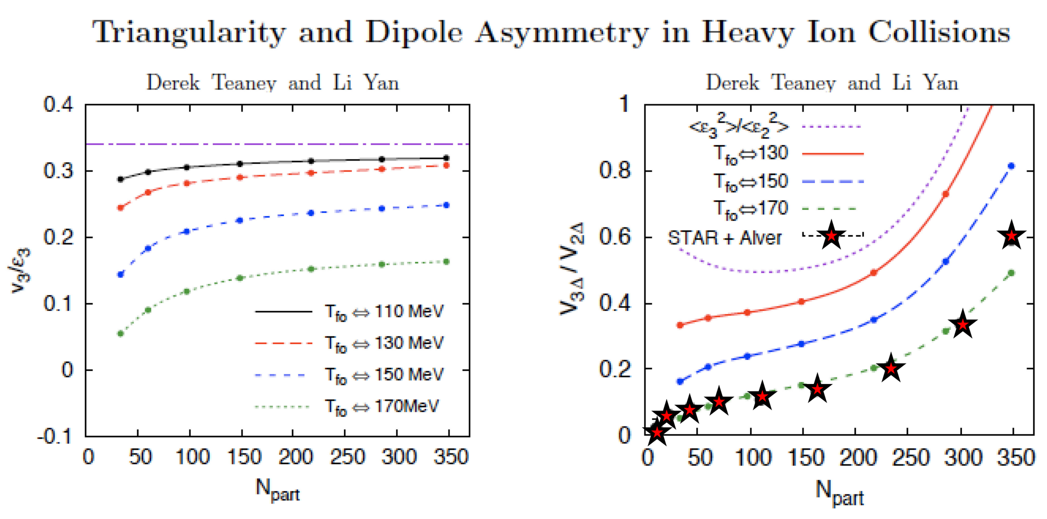
Teaney and Yan use a cumulant expansion to include Glauber style initial conditions in an ideal hydrodynamics model. They employ an expansion in terms of cumulants which is mathematically convenient and experimentally easy to measure.

General form of the two particle correlation wrt to the angle of the participant plane, ψ_{pp}, averaged over Glauber configurations. α labels a p_t interval and β labels "all" particles.

First term is not sensitive to ψ_{pp}, while the 2nd and 3rd terms are elliptic flow. The new terms have coefficients 1,1,-2 and 1,2,-3. The 1,1,-2 terms is dipole flow out of plane which represents v1 preferentially out of plane due to Glauber fluctuations. STAR has measured this. The 1,2,-3 term represents the correlations between dipole and triangular flow terms. The measurement of this term is shown, below.

Until Recently v_3^2 has Been Overlooked

Triangularity and Dipole Asymmetry in Heavy Ion Collisions

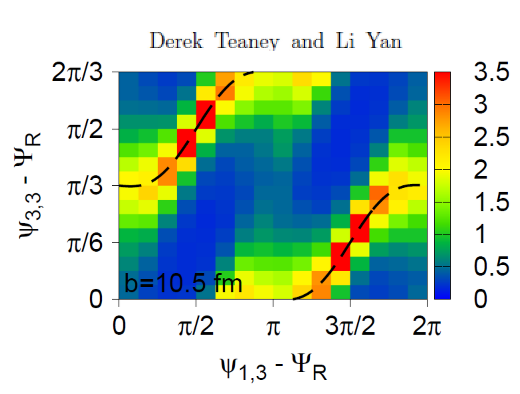


See poster by Li Yi B33 and talk by P. Sorensen ID 644

Teaney and Yan simulate spectra using ideal hydro plus the distribution function for a classical massless gas. Once the freezeout temperature is chosen then v_1/ε_1, v_2/ε_2, v_3/ε_3 can be calculated, as shown above.

The figure on the right shows the predicted ratio of v_3/v_2 compared to the Alver-Roland fit to STAR 2 particle correlation function data. B. Alver and G. Roland, Phys. Rev. C 81, 054905 (2010) , arXiv:1003.0194 [nucl-th]
B. I. Abelev et al. [STAR Collaboration], arXiv:0806.0513 [nucl-ex]

Another Consequence of Initial Geometry Fluctuations



The 3rd and 1st plane are correlated with the 2nd

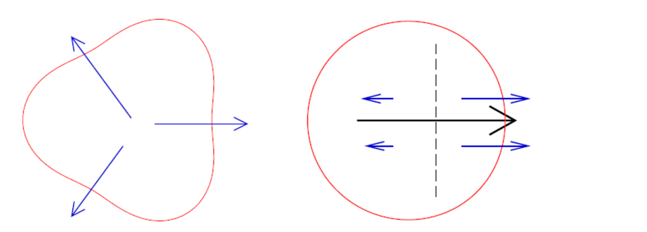


FIG. 1: A schematic of an event with (a) net triangularity and (b) net dipole asymmetry. The triangularity produces a net $v_3(p_T)$ and the dipole asymmetry produces a net $v_1(p_T)$. The cross in (b) indicates the center of entropy (analogous to the center of mass) and the large arrow indicates the orientation of the dipole.

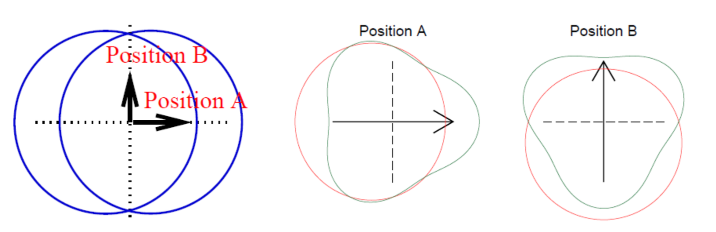
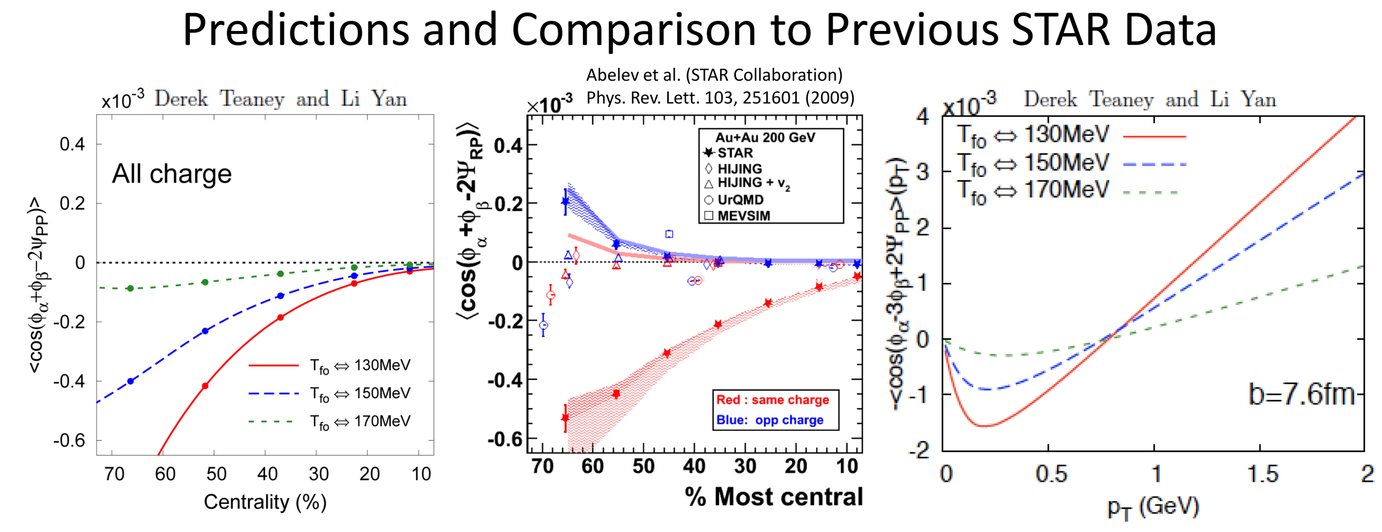


FIG. 5: The figure qualitatively describes the fluctuations associated with the Glauber model as illustrated in Fig. 4. When the dipole asymmetry is in plane (Position A), then the tip of triangularity is aligned with dipole asymmetry. When the dipole asymmetry is out of plane (Position B), the tip of the triangle is anti-aligned with the dipole asymmetry.

Predictions and Comparison to Previous STAR Data



The figure on the left is the prediction for the dipole term. Previously published STAR data are shown in the middle figure. The data are grouped into same charge and opposite charge particle groups. For comparison to the all charged particle predictions, on the left, the same and opposite charge data should be averaged together.

The figure on the right shows the predicted triangle term ($v_1 v_3$ cross correlation term). It is initially negative and then goes positive at about 750 MeV/c due to the v_1 term. The v_3 contribution is positive.

$$\langle\!\langle \cos(\phi_\alpha - 3\phi_\beta + 2\Psi_{PP})\rangle\!\rangle = \frac{v_1(p_T)}{\epsilon_1}\frac{v_3}{\epsilon_3}\langle\!\langle \epsilon_1\epsilon_3 \cos(\psi_{1,3} - 3\psi_{3,3} + 2\Psi_{PP})\rangle\!\rangle$$

Data Analysis

In this work, we have calculated the triangle term due to the v_1v_3 cross correlation. We used 200 GeV Au+Au collision data taken during Run IV at RHIC. A total of 11.5 Million minimum Bias events were analyzed and subjected to the standard STAR 'flow' cuts.

Data Set:	Au+Au at 200 GeV
Trigger:	Minimum Bias
Centrality Bins:	0-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80%
DCAcut:	3 cm
Pt Range:	150 MeV/c to 2 GeV/c
Eta Range:	-1 to 1
nHits:	15 to 100 (45 max possible for η = 0 tracks)
nHits/nHitsPoss	> 0.52 (ratio of the number of pad row hits in the fit, to the maximum possible for that track)
Vertex Z range:	-30 cm to 30 cm

Low p_t acceptance and efficiency weights have not yet been included in the analysis framework. This means that the current results do not completely represent 'all charged particles' as predicted by the theoretical calculations.

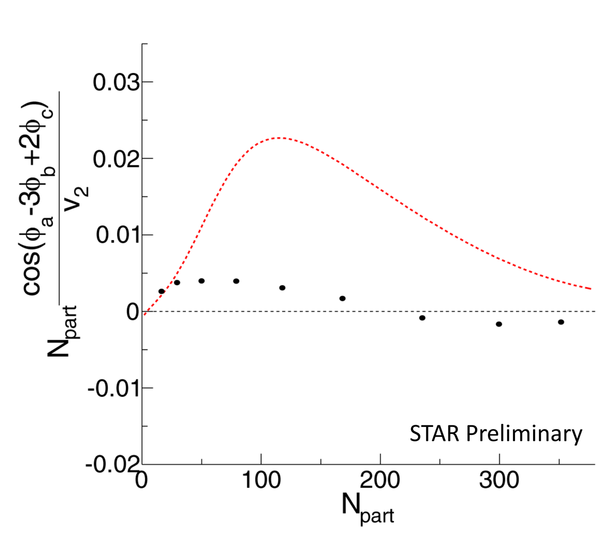
Calculating the Correlator

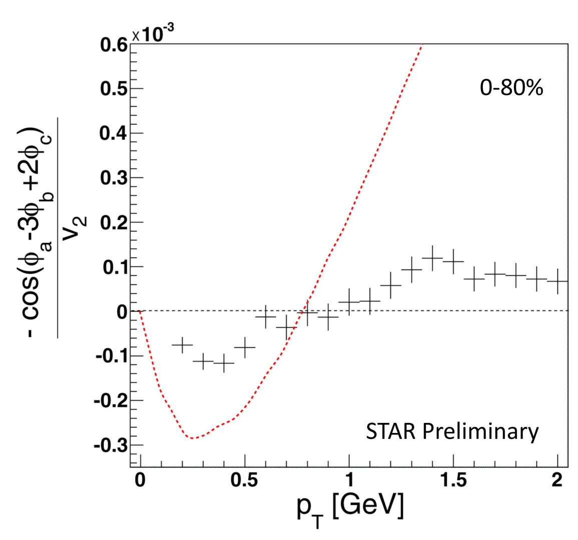
There are six non-identical particle permutations to iterate over if (and only if) $w_1 \neq w_2 \neq w_3$
(1,2,3) (1,3,2) (2,1,3) (2,3,1) (3,1,2) (3,2,1)
so a typical analysis loop might look like this:

```
for ( Int_t i = 0 ; i < Number_of_pions ; i++ )
  {
   for ( Int_t j = i+1 ; j < Number_of_pions ; j++ )
     {
      for ( Int_t k = j+1 ; k < Number_of_pions ; k++ )
        {
         Sum123 += Cos ( w1 *PionAngle[i] + w2 *PionAngle[j] + w3 *PionAngle[k] ) ;  counter123++ ;
         Sum123 += Cos ( w1 *PionAngle[i] + w3 *PionAngle[j] + w2 *PionAngle[k] ) ;  counter123++ ;
         Sum123 += Cos ( w2 *PionAngle[i] + w1 *PionAngle[j] + w3 *PionAngle[k] ) ;  counter123++ ;
         Sum123 += Cos ( w2 *PionAngle[i] + w3 *PionAngle[j] + w1 *PionAngle[k] ) ;  counter123++ ;
         Sum123 += Cos ( w3 *PionAngle[i] + w1 *PionAngle[j] + w2 *PionAngle[k] ) ;  counter123++ ;
         Sum123 += Cos ( w3 *PionAngle[i] + w2 *PionAngle[j] + w1 *PionAngle[k] ) ;  counter123++ ;
        }
     }
  }
```

Double Check: These six terms will be summed over the N(N-1)(N-2)/3! unique 3 particle permutations in the loops … or in other words 6*N(N-1)(N-2)/3! = N(N-1)(N-2) which is the number of combinations you expect for all 3 particle combinations with autocorrelations removed.

Results





- Correlation observed between $\psi_{1,3}$, $\psi_{3,3}$, and $\psi_{2,2}$
- Data are smaller than ideal hydro predictions (Data in black; Teaney & Yan 170 MeV curves are shown in red)
- p_T dependence consistent with expectations for shape of $v_1v_3(p_T)$ correlation
- Correlation becomes negative for central events, not yet understood
- Non-flow effects not included

Conclusions

Hydrodynamics, together with geometric fluctuations of the Glauber model make specific predictions for dipole and triangle terms in the observed azimuthal distribution of particles

Preliminary results on the v_1v_3 correlator are presented for 11.5 M 200 GeV Au+Au collisions

Data were compared to an ideal hydro calculation by Teaney and Yan. The results agree in sign and shape but are generally smaller in magnitude than their predictions.

This may be due to fact that the ideal hydro model uses a simple EOS, does not include viscosity, or resonance decays. Shear viscosity, for example, is expected to dampen the higher harmonic modes and thus reduce the correlation strength. Experimentally we need to investigate and correct for acceptance and efficiency at low p_t.

The primary conclusion is that the v_1v_3 correlations are present in the data and are suggestive of finite values for v_1 and v_3 due to initial geometry fluctuations. This is strong evidence for the hydrodynamic and geometric interpretation of two particle correlations at RHIC.

Improved theoretical calculations are possible and desirable.