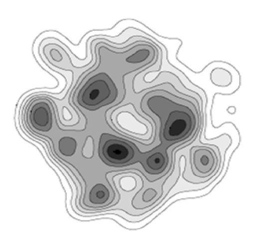
Three Particle Correlations as a Probe of Eccentricity Fluctuations

Jim Thomas[1] and Paul Sorensen[2] for the STAR Collaboration

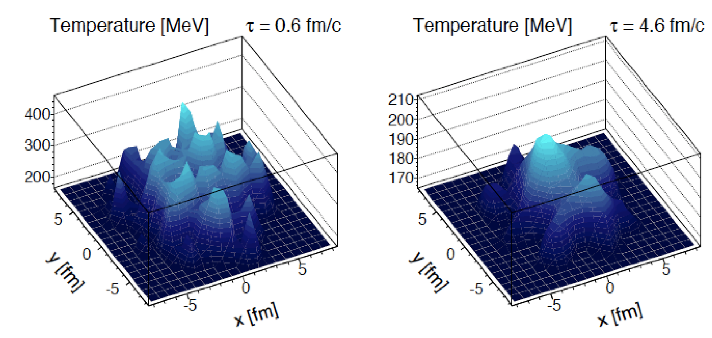
[1]Lawrence Berkeley National Laboratory, [2]Brookhaven National Laboratory

Initial Density Fluctuations

Hama, Grasi, Kodama, et. al.



NexSPheRio

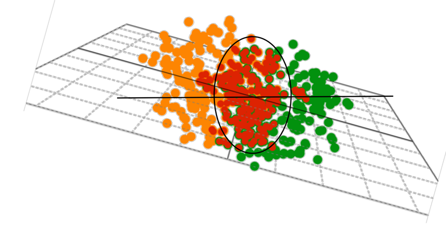


From: Mocsy, P. Sorensen: arXiv:1008.3381 [hep-ph] using entropy distributions found in: K. Werner, et al. arXiv: 1004.0805 [nucl-th]

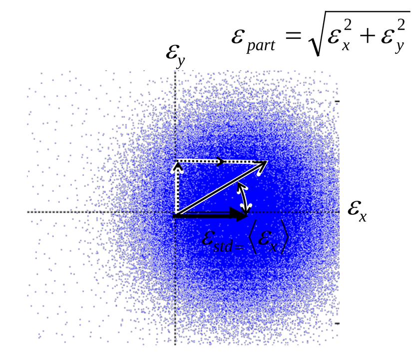
The nuclear overlap zone defined in heavy ion collisions is not smooth and symmetric. Lumpy initial conditions are intrinsic to transport codes such as RQMD and Glauber models. These initial conditions can be incorporated into Hydrodynamical models; and they give observable consequences via 2 particle correlations wrt ψ_{pp}

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 with NexSpheRio (Hydro Model) while 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



$$\varepsilon_{part} = \sqrt{\varepsilon_x^2 + \varepsilon_y^2}$$



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

The eccentricity calculation is a random walk with varying step sizes.

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

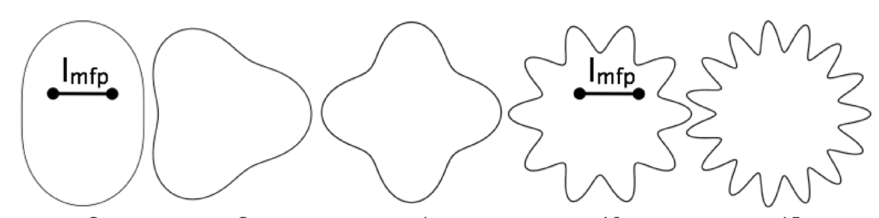
Each additional participant adds a step

The distribution of eccentricity will end up as a 2-D gaussian.

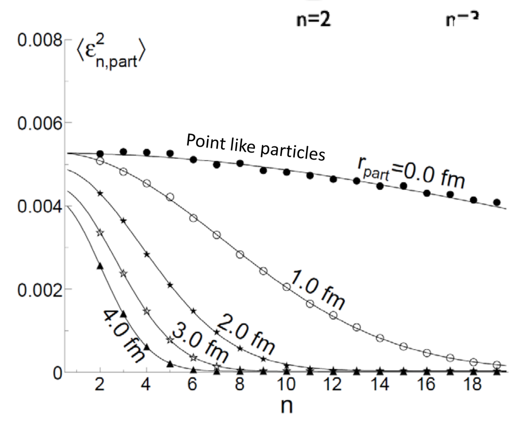
- The shift in x is the standard eccentricity
- The number of steps determines the width
- For odd n, the shift is zero

But participant eccentricity considers the length of the eccentricity vector which is positive definite, even for n=1,3,5,7…

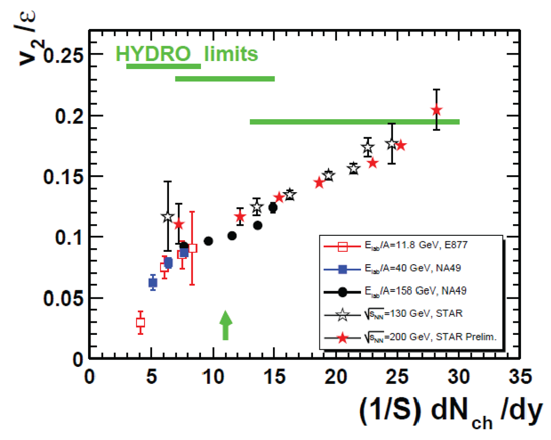
Why are higher harmonics interesting?



Higher Harmonics probe smaller length scales



ε_{part} accounts for geometry fluctuations. The "size" of the participant dampens the higher harmonic terms. $\langle \varepsilon^2_{n,part} \rangle > 0$ for even and odd harmonics.



v_2/ε_2 illustrates the conversion of ε_2 into v_2, shown here .vs. transverse mult. density

S. Voloshin, et al., http://arxiv.org/pdf/0809.2949

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

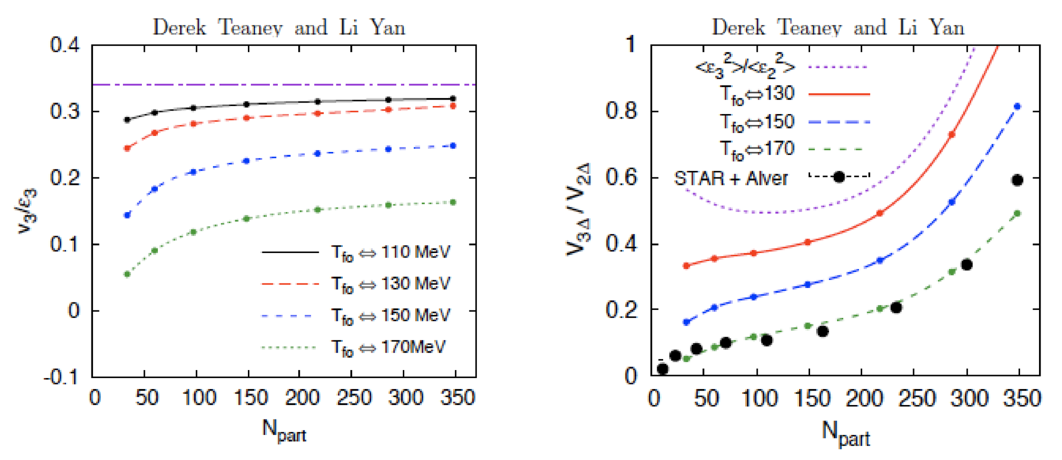
Teaney and Yan use a cumulant expansion to include Glauber style initial conditions in an ideal hydrodynamics model. They employ an expansion in terms of cumulants which is mathematically convenient and experimentally easy to measure.

General form of the two particle correlation wrt to the 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

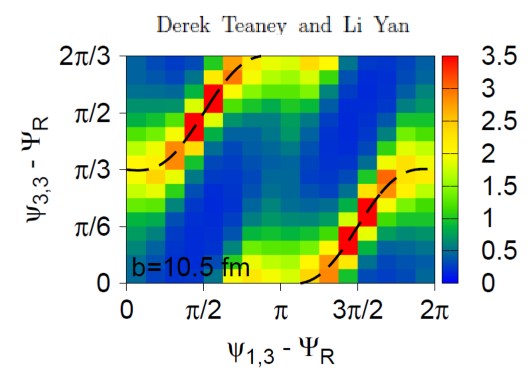
Triangularity and Dipole Asymmetry in Heavy Ion Collisions



Teaney and Yan simulate spectra using ideal hydro plus the distribution function for a classical massless gas. Once the freezeout temperature has been selected 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 STAR 2 particle correlation function which was fit by Alver and Roland.

Another Consequence of Higher Harmonics



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

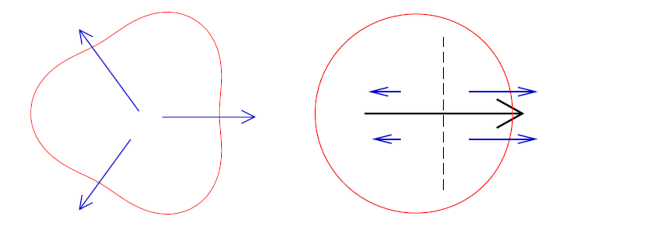


FIG. 1: A schematic of an event with (a) net triangularity and (b) net dipole asymmetry. The triangularity produces a net $v_3(p_T)$ and the dipole asymmetry produces a net $v_1(p_T)$. The cross in (b) indicates the center of entropy (analogous to the center of mass) and the large arrow indicates the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

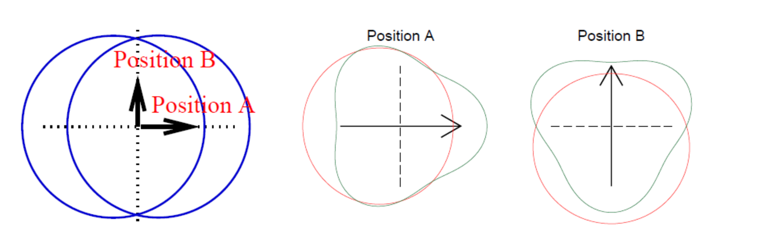
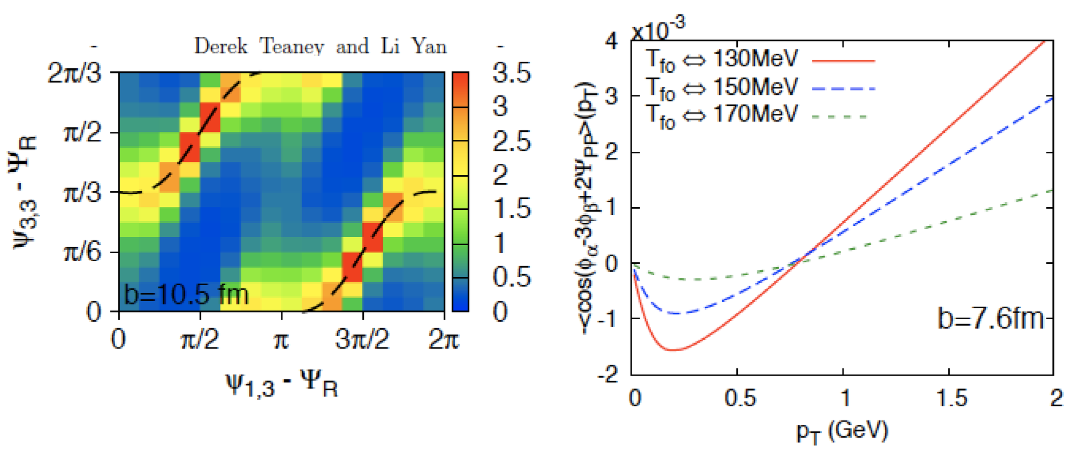


FIG. 5: The figure qualitatively describes the fluctuations associated with the Glauber model as illustrated in Fig. 4. When the dipole asymmetry is in plane (Position A), then the tip of triangularity is aligned with dipole asymmetry. When the dipole asymmetry is out of plane (Position B), the tip of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

Predictions for the v_1 v_3 correlation term



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

We've calculated this for 200 GeV Run IV Au+Au data

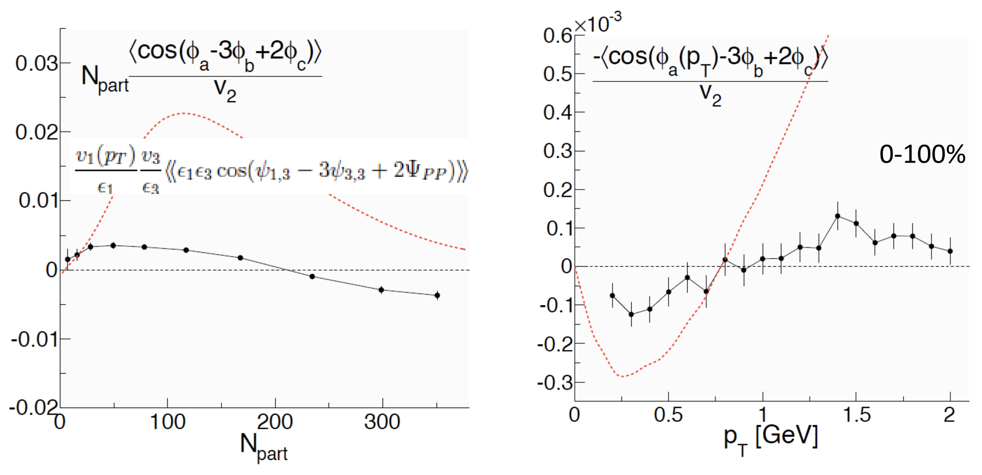
Calculating the Correlator

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
- p_T dependence consistent with expectations for $v_1(p_T)$
- Correlation becomes negative for central events?

Conclusions

Hydrodynamics, together with geometric fluctuations of the Glauber model make specific predictions for a 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.

This may be due to fact that the ideal hydro model uses a simple EOS, does not include viscosity, nor resonance decays. Shear viscosity, for example, is expected to dampen the higher harmonic modes and thus reduce the correlation strength.

The primary conclusion is that the correlator is non-zero and is suggestive of a finite value for v_3

Strong evidence for the hydrodynamic and geometric interpretation of two particle correlations at RHIC. Better theory is possible and desirable.