Flow correlations in rapidity

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with: W. Broniowski
arXiv: 1711.03325
- Glauber Monte Carlo model $\rightarrow$ different distributions for forward and backward going participants
- different event-planes at forward and backward rapidities
Matter distribution in space-time rapidity

Asymmetric emission functions

(Białas, Czyż, 2005)

also other models of initial state: fluctuating strings, hybrid models ... → additional fluctuations

signatures of tilt:
charged particles $\nu_1$, tilted source HBT, D meson directed flow

$\rho(\eta, x, y) \propto f_+(\eta)N_+(x, y) + f_-(\eta)N_-(x, y)$
Twisted event-plane angles - torque effect

- due to fluctuations
- left-right orientation and angle magnitude are random
- only “smooth” long range twist
- random decorrelations on small scale, difficult to observe

Bozek, Broniowski, Moreira, 1011.3354
Twist angle distribution - Glauber model

\[ \psi_2(\eta) - \psi_2(-\eta), \quad \Delta \eta = 1.5 \]

- very forward (backward), maximal decorrelation
- in between, intermediate
- linear around \( \eta = 0 \)

- \( n = 2 \), largest decorrelation for central collisions
- \( n = 3 \), similar decorrelation for all centralities
One-shot 3+1D hydro evolution (2010)

initial density with a twist

\[ s(x, y, \eta) \propto \rho_+ (R_x, R_y) f_+ (\eta) + \rho_- (R^T x, R^T y) f_- (\eta) \]

forward (backward) participants rotated in the transverse plane

- the twist survives the hydrodynamic evolution
$$\cos(2\Delta \psi) = \frac{\langle \langle \cos[2(\phi_i(F) - \phi_j(B))] \rangle \rangle}{\sqrt{\langle \langle v_2^2(F) \rangle \rangle} \sqrt{\langle \langle v_2^2(B) \rangle \rangle}}$$
3-bin measure of event-plane decorrelation (CMS)

\[ r_2(\eta) = \frac{\langle q(-\eta)q^*(\eta_{\text{ref}}) \rangle}{\langle q(\eta)q^*(\eta_{\text{ref}}) \rangle} \]

only pairs with large rapidity gap \( \Delta\eta = \pm\eta - \eta_{\text{ref}} \)

- nonflow under control
- torque effect seen in the CMS data
- semiquantitative agreement
- small factorization breaking observed
Flow asymmetry + Twist angle

\[ r_2(\eta) = 1 - 2F_n \eta = 1 - 2F_n^{asy} \eta - 2F_n^{twi} \eta \]

the two can be separated using

3-bin and 4-bin correlators \textit{ATLAS} 1709.02301

flow angle decorrelation

\[ R_n(\eta) = \frac{\langle q_n(-\eta_{ref})q_n^{*}(\eta)q_n(-\eta)q_n^{*}(\eta_{ref}) \rangle}{\langle q_n(-\eta_{ref})q_n^{*}(-\eta)q_n(\eta)q_n^{*}(\eta_{ref}) \rangle} \approx 1 - 2F_n^{twi} \eta \]

flow angle+flow magnitude decorrelation

\[ r_{n,2}(\eta) = \frac{\langle q(-\eta)^2q^{*}(\eta_{ref})^2 \rangle}{\langle q(\eta)^2q^{*}(\eta_{ref})^2 \rangle} \approx 1 - 2F_n^{asy} \eta - 2F_n^{twi} \eta \]

\( (r_{n,1}(\eta) \) first measured by CMS 1503.01692)
Observation of separate flow magnitude decorrelation and twist angle decorrelation

\[ r_2 \simeq 1 - 2F_2^{asy} \eta - 2F_2^{twi} \eta \]

\[ R_2 \simeq 1 - 2F_2^{twi} \eta \]
twist angle and flow magnitude decorrelation

3+1D hydro model

**surprising result:** “inverted hierarchy”

magnitude decorr. < “magnitude decorrelation + twist” < twist
central versus peripheral

0 − 5%

30 − 40%

the “inverted hierarchy” effect is stronger in central collisions
large elliptic flow in semi-central collisions → less fluctuations
elliptic versus triangular

the “inverted hierarchy” effect is stronger for \( v_3 \)

triangular flow - fluctuation dominated
**Correlation between flow magnitude and twist angle**

- **Strong** correlation between flow magnitude and twist angle
- Events with large flow have smaller twist angle
- Twist angle measure: $< \cos(\Delta \Psi_2) > \propto (v_2)^0$
  “magnitude decorr. + twist” $< q_2(\eta)q_2^*(\eta_{ref}) > \propto (v_2)^2$
- Different weighting by $(v_2)$ powers explains “inverted hierarchy”
central versus peripheral

0 – 5%

30 – 40%

stronger correlation in central collisions
elliptic versus triangular

\[ v_2 \]

\[ v_3 \]

stronger correlation for \( v_3 \)
Correlators weighted by powers of $v_n$

- hierarchy of correlators consistent with expectations

$$\frac{\langle q_n(-\eta)q_n^*(\eta_{ref})\rangle}{\langle q_n(\eta)q_n^*(\eta_{ref})\rangle} < \frac{\langle q_n(-\eta)q_n^*(\eta_{ref})v_n^2\rangle}{\langle q_n(\eta)q_n^*(\eta_{ref})v_n^2\rangle} < \frac{\langle q_n(-\eta)q_n^*(\eta_{ref})v_n^4\rangle}{\langle q_n(\eta)q_n^*(\eta_{ref})v_n^4\rangle}$$

- the correlation between flow magnitude and twist can be measured experimentally
similar for triangular flow
Factorization of factorization breaking

flow magnitude factorization breaking (square)

\[ r_n^2(\eta) = \frac{\langle v_n^2(-\eta) v_n^2(\eta_{\text{ref}}) \rangle}{\langle v_n^2(\eta) v_n^2(\eta_{\text{ref}}) \rangle} \]

twist angle factorization breaking (weighted with \( v_n^4 \))

\[ R_{n|n;2}(\eta) = \frac{\langle q_n(-\eta_{\text{ref}}) q_n^*(\eta) q_n(-\eta) q_n^*(\eta_{\text{ref}}) \rangle}{\langle q_n(-\eta_{\text{ref}}) q_n^*(-\eta) q_n(\eta) q_n^*(\eta_{\text{ref}}) \rangle} \]

angle+magnitude factorization breaking

\[ r_{n|n;2}(\eta) = \frac{\langle q_n(-\eta)^2 q_n^*(\eta_{\text{ref}})^2 \rangle}{\langle q_n(\eta)^2 q_n^*(\eta_{\text{ref}})^2 \rangle} \]

(angle+magnitude f. b.) \( \simeq \) (twist angle f. b.)(flow magnitude f. b.) measured by ATLAS
Longitudinal flow decorrelation $\text{angle} + \text{magnitude}$

Additional event-by-event correlations
- Large flow magnitude $\leftrightarrow$ Small twist angle
- Small flow magnitude $\leftrightarrow$ Large twist angle
  (cannot be easily separated)

New measures weighted by powers of flow magnitude
- to estimate angle-magnitude correlations
Flow correlations in rapidity

\[ r_n(\eta) \approx 1 - 2F_n^\eta \eta \]

- fair description of mid-central collisions
- overestimates decorrelation in central collisions
- \( F_4 \approx 4F_2 \)