Flow correlations in rapidity

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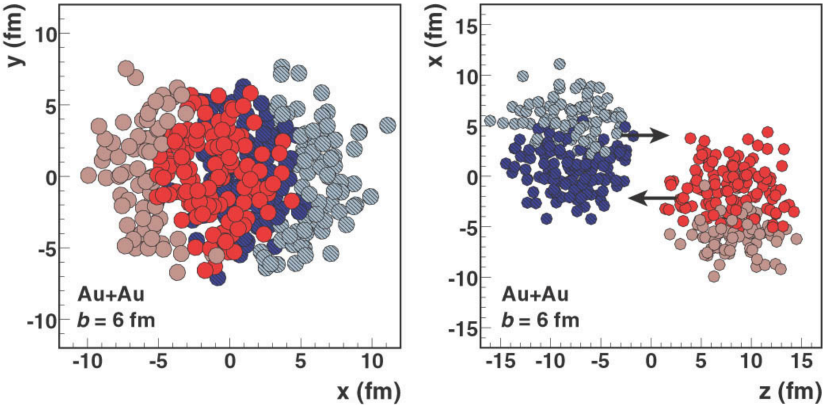
with: W. Broniowski

arXiv: 1711.03325

Forward-Backward Asymmetry



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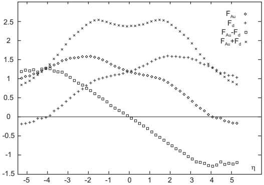
- Glauber Monte Carlo model ⟶ different distributions for forward and backward going participants
- different event-planes at forward and backward rapidities

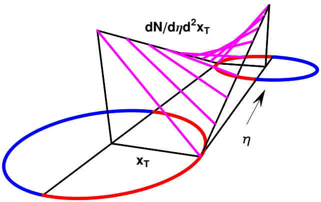
Matter distribution in space-time rapidity



Asymmetric emission functions

(Białas, Czyż, 2005

$\rho(\eta, x, y) \propto f_+(\eta) N_+(x, y) + f_-(\eta) N_-(x, y)$

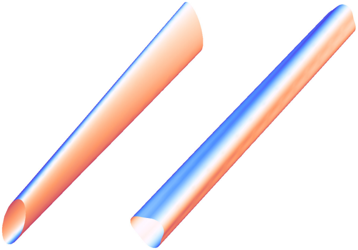


bremsstrahlung Adil Gyulassy, 2005

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

signatures of tilt:
charged particles v_1, tilted source HBT, D meson directed flow

Twisted event-plane angles - torque effect

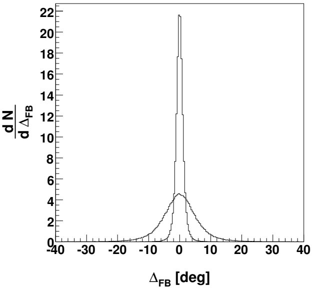


- due to fluctuations
- left-right orientation and angle magnitude are random
- only “smooth” long range twist
- random decorrelations on small scale, difficult to observe

Bozek, Broniowski, Moreira, 1011.3354

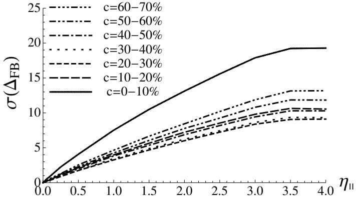
Twist angle distribution - Glauber model

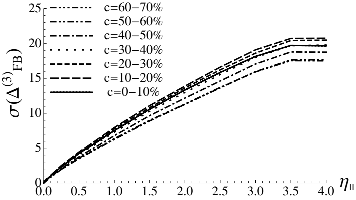
$\Psi_2(\eta) - \Psi_2(-\eta), \qquad \Delta\eta = 1,5$



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

width of the twist angle distribution





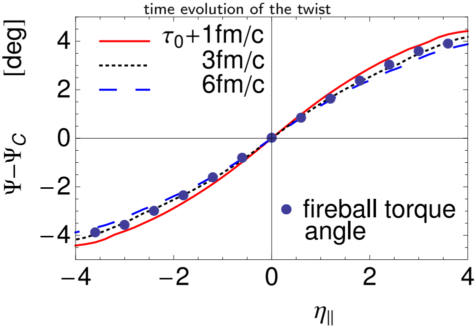
- $n = 2$, largest decorrelation for central collisions
- $n = 3$, similar decorrelation for all centralities

One-shot 3+1D hydro evolution (2010)

initial density with a twist

$$s(x, y, \eta) \propto \rho_+(Rx, Ry) f_+(\eta) + \rho_-(R^T x, R^T y) f_-(\eta)$$

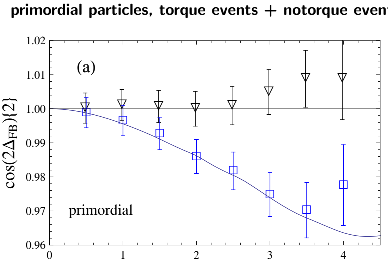
forward (backward) participants rotated in the transverse plane

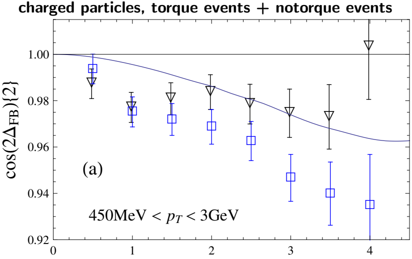


- the twist survives the hydrodynamic evolution

2-bin observable

$$cos(2\Delta\Psi) = \frac{<< cos[2(\phi_i(F) - \phi_j(B))] >>}{\sqrt{< v_2^2(F) >}\sqrt{< v_2^2(B) >}}$$



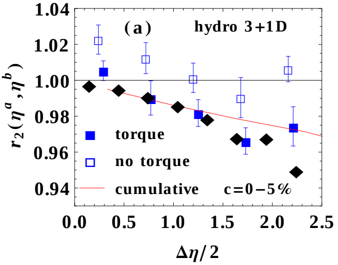


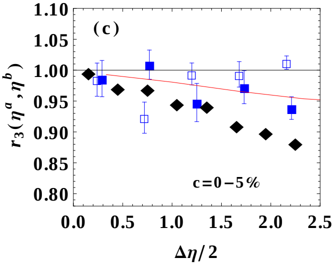
equivalent to factorization breaking

3-bin measure of event-plane decorrelation (CMS)

$$r_2(\eta) = \frac{< q(-\eta) q^\star(\eta_{ref} >}{< q(\eta) q^\star(\eta_{ref}) >}$$

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





- nonflow under control

- torque effect seen in the CMS data

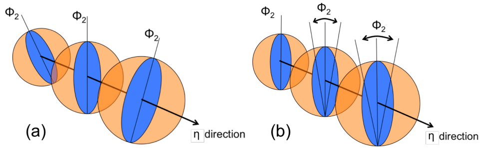
- semiquantitative agreement

- small factorization breaking observed

F-slope $\quad r_n(\eta) \simeq 1 - 2F_n^\eta \eta$

Flow asymmetry + Twist angle

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



Jia, Huo 1402.6680

the two can be separated using

3-bin and 4-bin correlators **ATLAS** 1709.02301

$$R_n(\eta) = \frac{< q_n(-\eta_{ref})q_n^\star(\eta)q_n(-\eta)q_n^\star(\eta_{ref}) >}{< q_n(-\eta_{ref})q_n^\star(-\eta)q_n(\eta)q_n^\star(\eta_{ref}) >} \simeq 1 - 2F_{n,2}^{twi}\eta$$

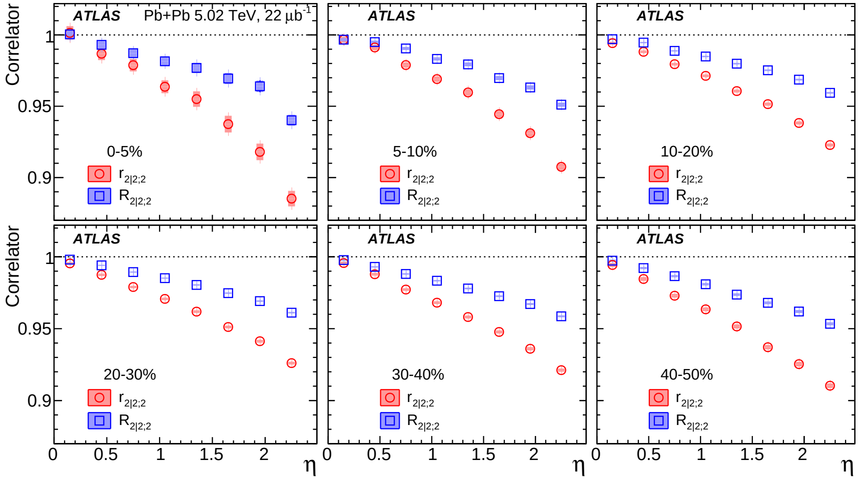
flow angle decorrelation

$$r_{n,2}(\eta) = \frac{< q(-\eta)^2 q^\star(\eta_{ref})^2 >}{< q(\eta)^2 q^\star(\eta_{ref})^2 >} \simeq 1 - 2F_{n,2}^{asy}\eta - 2F_{n,2}^{twi}\eta$$

flow angle+flow magnitude decorrelation

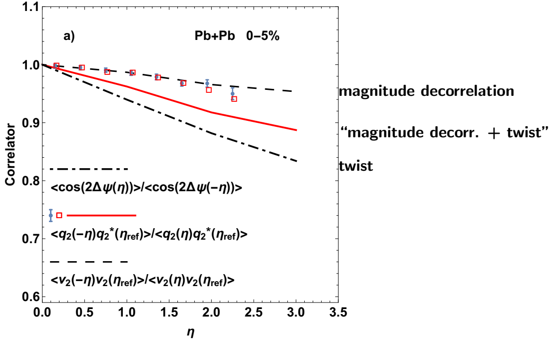
($r_{n,1}(\eta)$ first measured by CMS 1503.01692)

Observation of separate flow magnitude decorrelation and twist angle



$$r_2 \simeq 1 - 2F_2^{asy}\eta - 2F_2^{twi}\eta \qquad R_2 \simeq 1 - 2F_2^{twi}\eta$$

twist angle and flow magnitude decorrelation
3+1D hydro model

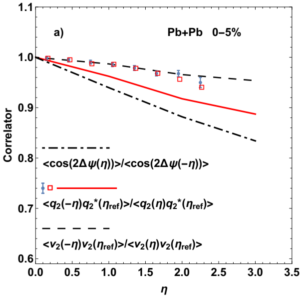


surprising result: "inverted hierarchy"

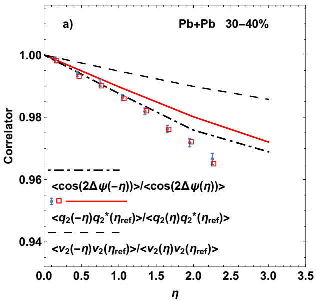
magnitude decorr. < "magnitude decorrelation + twist" < twist

central versus peripheral

$0 - 5\%$



$30 - 40\%$

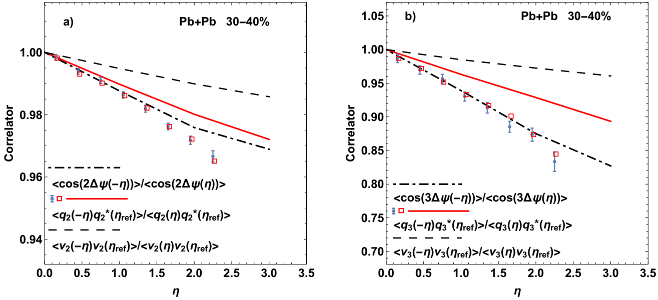


the “inverted hierarchy” effect is stronger in central collisions

large elliptic flow in semi-central collisions $\rightarrow$ less fluctuations

elliptic versus triangular

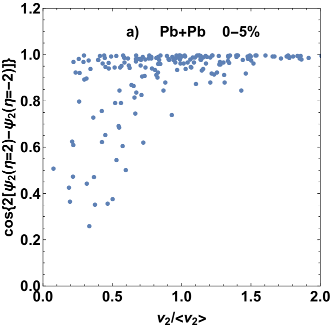
v_2 v_3



the "inverted hierarchy" effect is stronger for v_3

triangular flow - fluctuation dominated

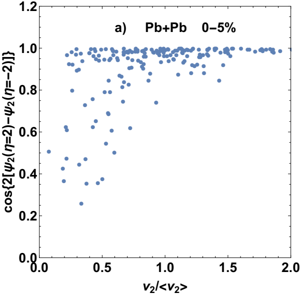
Correlation between flow magnitude and twist angle



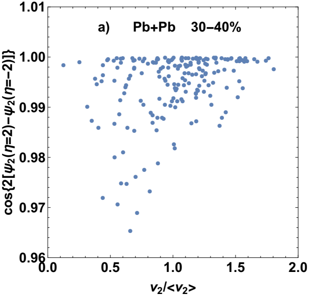
- **strong** correlation between flow magnitude and twist angle
- events with large flow have smaller twist angle
- twist angle measure $< cos(\Delta\Psi_2) > \propto (v_2)^0$
  "magnitude decorr.+twist" $< q_2(\eta) q_2^\star(\eta_{ref}) > \propto (v_2)^2$
- different weighting by (v_2) powers explains "inverted hierarchy"

central versus peripheral

$0-5\%$

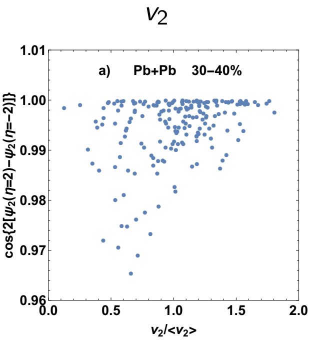


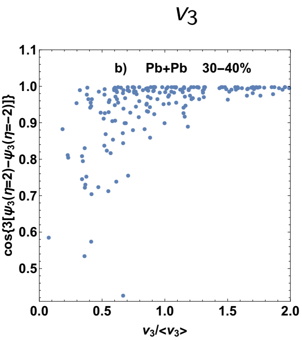
$30-40\%$



stronger correlation in central collisions

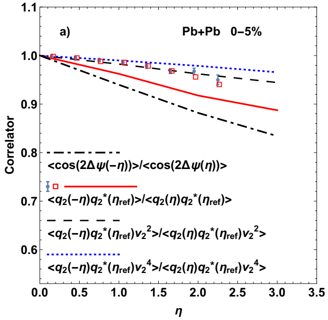
elliptic versus triangular





stronger correlation for v_3

Correlators weighted by powers of v_n

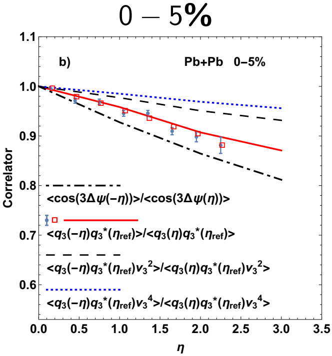


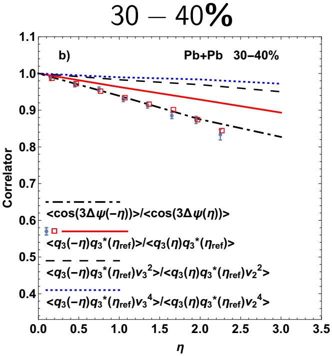
- hierarchy of correlators consistent with expectations

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

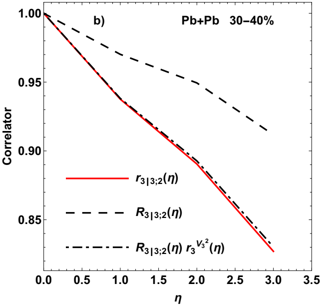
- the correlation between flow magnitude and twist can be measured experimentally

similar for triangular flow





Factorization of factorization breaking



- flow magnitude factorization breaking (square)

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

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

$$R_{n|n;2}(\eta) = \frac{< q_n(-\eta_{ref}) q_n^\star(\eta) q_n(-\eta) q_n^\star(\eta_{ref}) >}{< q_n(-\eta_{ref}) q_n^\star(-\eta) q_n(\eta) q_n^\star(\eta_{ref}) >}$$

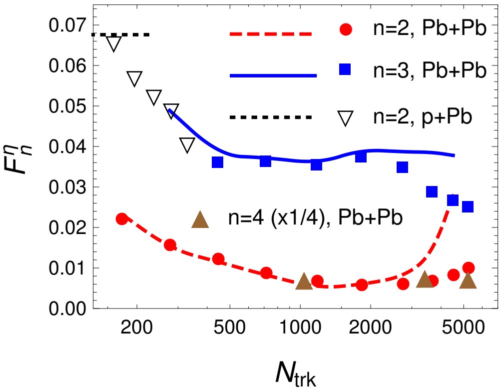
- angle+magnitude factorization breaking

$$r_{n|n;2}(\eta) = \frac{\langle q_n(-\eta)^2 q_n^\star(\eta_{ref})^2\rangle}{\langle q_n(\eta)^2 q_n^\star(\eta_{ref})^2\rangle}$$

(angle+magnitude f. b.) $\simeq$ (twist angle f. b.)(flow magnitude f. b.)
measured by ATLAS

- Longitudinal flow decorrelation **angle+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

F slope $\quad (r_n(\eta) \simeq 1 - 2F_n^\eta \eta)$



- fair description of mid-central collisions
- overestimates decorrelation in central collisions
- $F_4 \simeq 4F_2$