

Mapping initial state correlations in rapidity using collective flow

Piotr Bożek

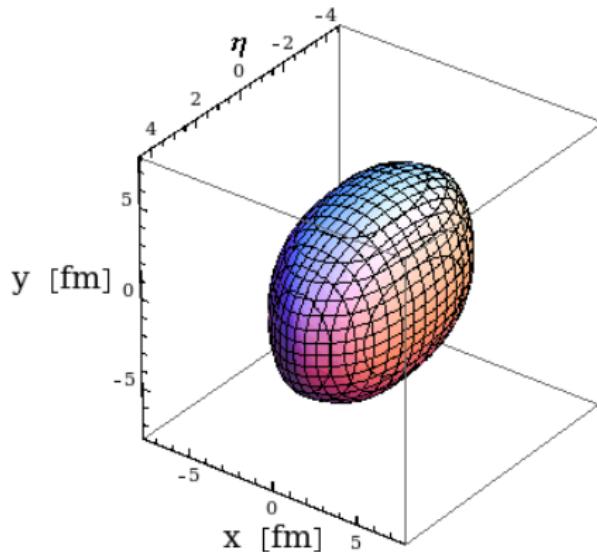
AGH University of Science and Technology, Kraków

with: W. Broniowski, A. Olszewski

arXiv: 1011.3354, 1503.07425, 1509.04362

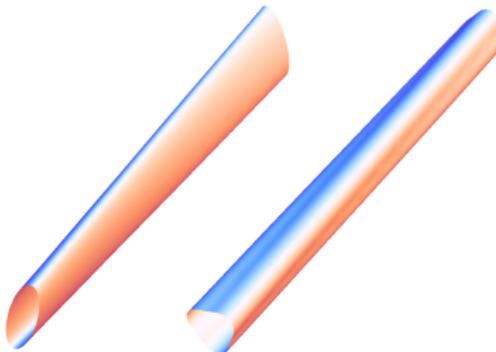


Fireball at different rapidities



is the shape similar at different rapidities
- same event-planes
often assumed (even for event-by-event simulations)

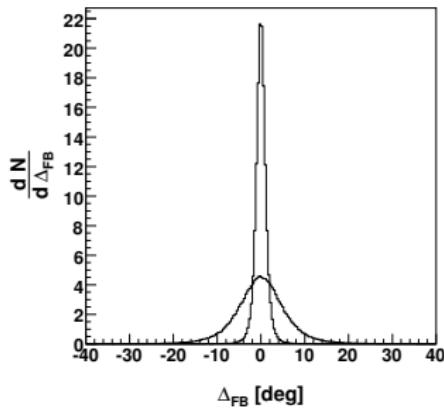
Twisted event-plane angles - torque effect



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

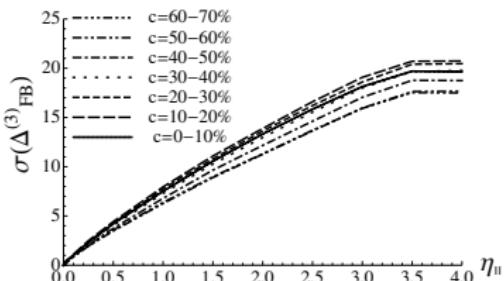
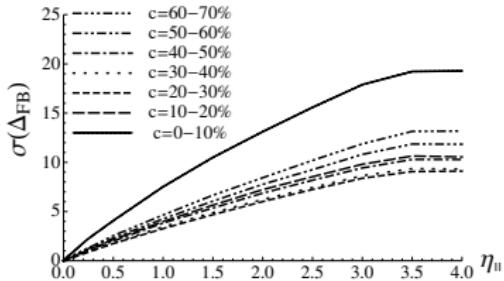
Twist angle distribution - Glauber model

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



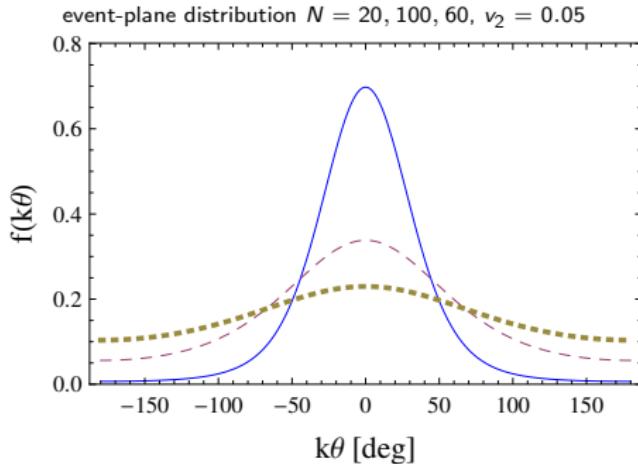
- very forward (backward), maximal decorrelation
- in between, intermediate
- linear around $\eta = 0$

width of the twist angle distribution



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

Event-plane resolution at finite multiplicity



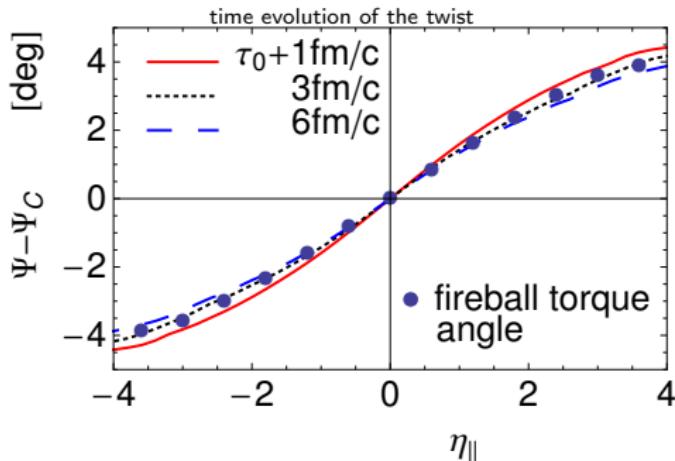
- event-plane resolution much worse than signal
- $\Delta\Psi$ cannot be measured directly
- observables must be quadratic in $\Delta\Psi$

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

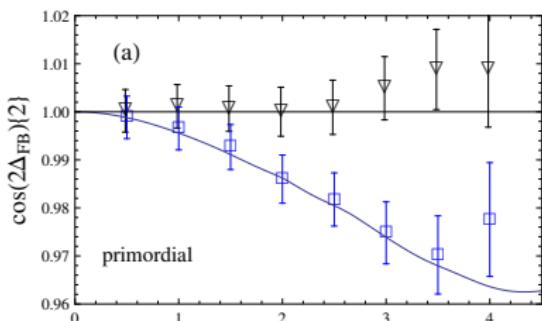


- the twist survives the hydrodynamic evolution

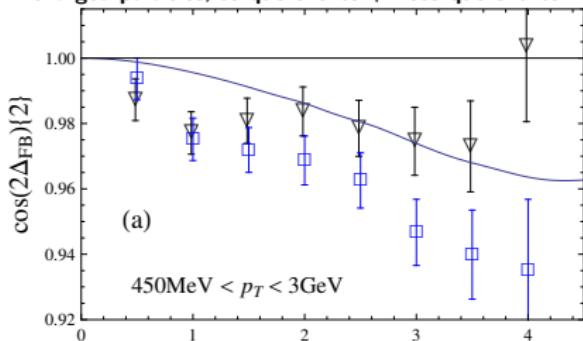
2-bin observable

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

primordial particles, torque events + notorque events



charged particles, torque events + notorque events



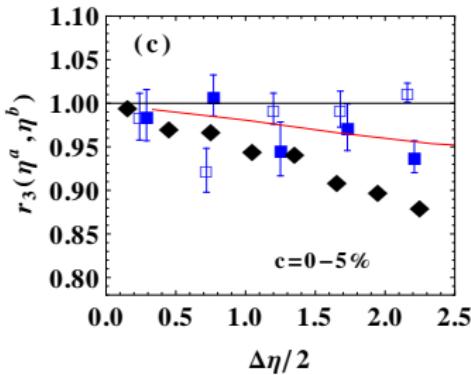
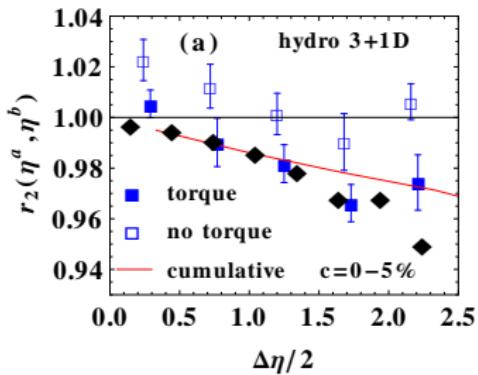
substantial nonflow contribution

2-bin observables in η dominated by nonflow!

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

$$r_2(\eta_a, \eta_b) = \frac{<< \cos[n(\phi_i(-\eta_a) - \phi_j(\eta_b))] >>}{<< \cos[n(\phi_i(\eta_a) - \phi_j(\eta_b))] >>} \simeq \frac{\cos[n(\Psi(-\eta_a) - \Psi(\eta_b))]}{\cos[n(\Psi(\eta_a) - \Psi(\eta_b))]}$$

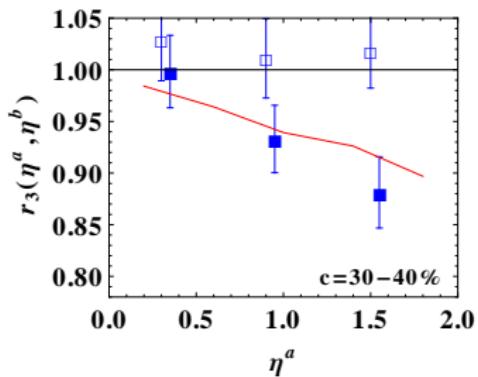
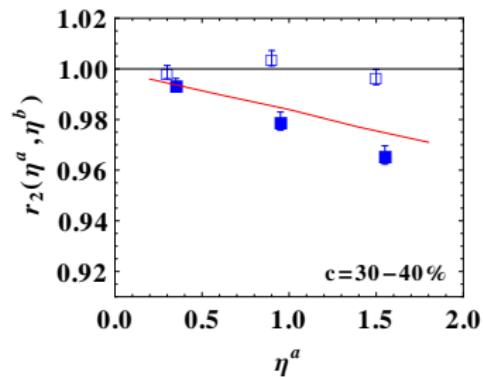
only pairs with large rapidity gap $\eta_a - \eta_b$



- nonflow under control
- torque effect seen in the CMS data
- semiquantitative agreement, but need more fluctuations
- other calculation (hybrid hydro, AMPT) reproduce the data) see talk by L.-G. Pang on Thursday

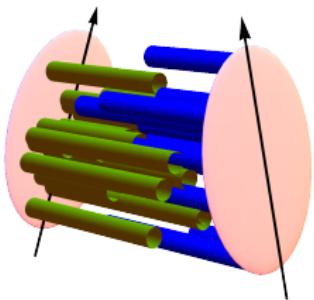
$r_n(\eta_a, \eta_b)$ Au-Au at 200GeV

predictions ($3 < \eta_b < 4.5$)



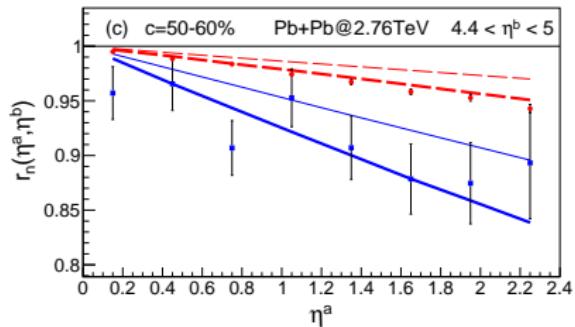
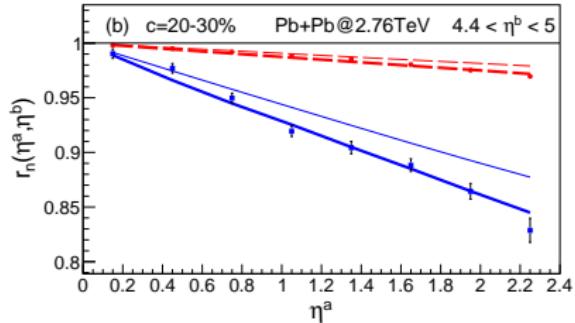
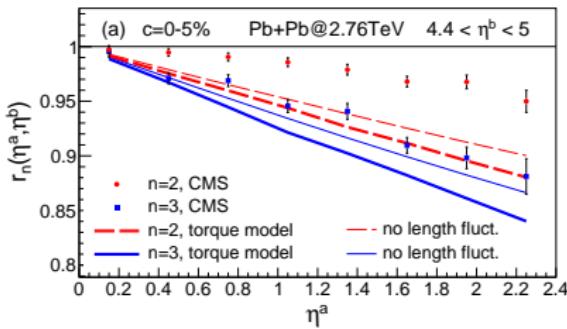
- larger twist angle at RHIC energies

Fluctuations in energy deposition from each source



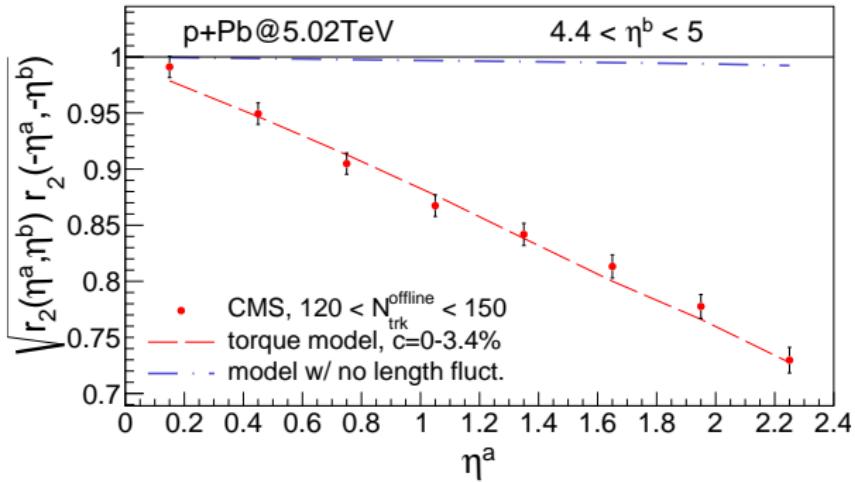
- the position (in rapidity) of string ends is random
- long range fluctuations
- each source fluctuates differently → event-plan decorrelation in p-Pb
- short range fluctuations possible, but irrelevant for the CMS r_2
- average deposition same as in old model (linear in η)

Fluctuating strings $r_n(\eta_a, \eta_b)$ (initial state only)



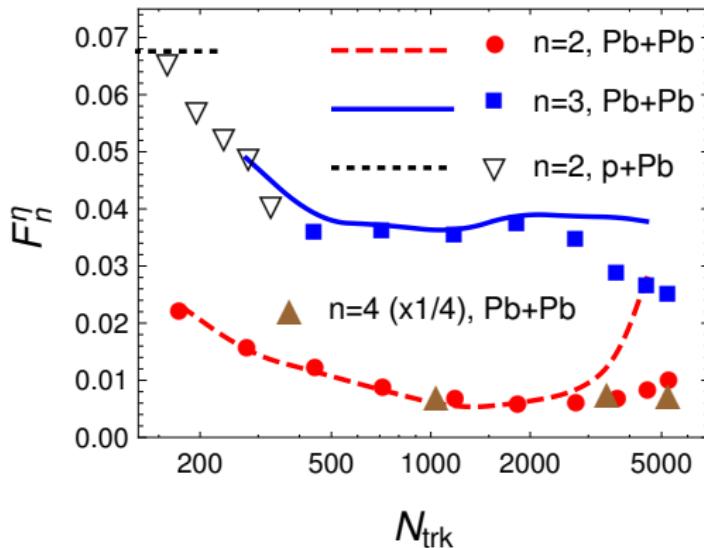
fluctuations improve description of r_2
in Pb-Pb
except for r_2 in central collisions

Fluctuating strings p-Pb



- fluctuations essential to describe event-plane decorrelation in p-Pb

F slope



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

Higher cumulants for correlations in rapidity

- ▶ we want to measure event by event fluctuations of particle density $\rho(y, \phi, p_\perp)$
- ▶ fluctuations from left and right going participants (Bzdak, Teaney, 2012)

$$\rho(y) = \rho_0(1 + a_1 y + \dots) = \rho_0(1 + d(N_+ - N_-)y + \dots)$$

- ▶ two particle correlations measure $\langle a_1 a_1 \rangle$, **with strong nonflow !**
- ▶ **Solution !**

Measure higher cumulants of a_n coefficients (Bzdak, Bozek, 1509.02967)

$$\langle a_1 a_1 a_1 a_1 \rangle - 3 \langle a_1 a_1 \rangle \langle a_1 a_1 \rangle$$

$$\langle a_1 a_1 a_1 a_1 a_1 a_1 \rangle - 15 \langle a_1 a_1 a_1 a_1 \rangle \langle a_1 a_1 \rangle + 30 \langle a_1 a_1 \rangle^3$$

and many other cumulants for different a_n combinations

- ▶ higher cumulants of a_n coefficients **are different than** v_2 cumulants
- ▶ for density fluctuations from forward-backward asymmetry

$$\rho(y) = \rho_0(1 + a_1 y + \dots) = \rho_0(1 + d(N_+ - N_-)y + \dots)$$

we measure cumulants of the participant asymmetry

$$\langle a_1 a_1 a_1 a_1 \rangle_c = d^4 \langle (N_+ - N_-)^4 \rangle_c$$

but cumulants of $N_+ - N_-$ are close to zero (Glauber model)

- ▶ So what can be measured with cumulants?
long range sources of 4, 6, ... particles
- ▶ cumulants can be defined also for
rapidity correlations of $v_n v_p \dots v_m$

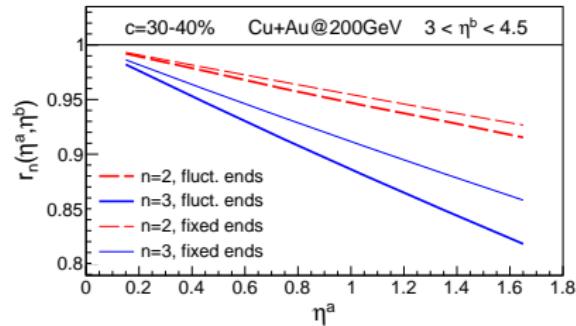
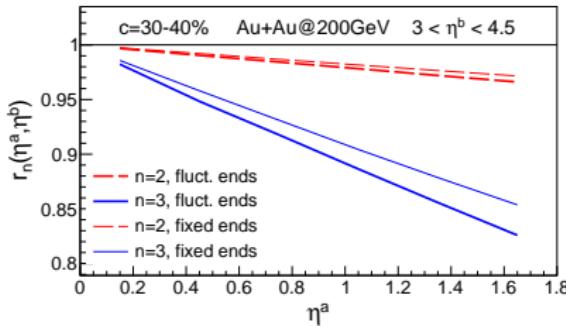
$$\langle a_{i_1}[m_1] \dots a_{i_n}[m_n] \rangle_c = \left\langle \sum_{a_1, \dots, a_n} \frac{T_{i_1}\left(\frac{\eta_{a_1}}{Y}\right) e^{im_1 \phi_{a_1}}}{Y \langle N(\eta_{a_1}) \rangle} \dots \frac{T_{i_n}\left(\frac{\eta_{a_n}}{Y}\right) e^{im_n \phi_{a_n}}}{Y \langle N(\eta_{a_n}) \rangle} \right\rangle_c$$

(for details see Bozek, Broniowski, Olszewski 1509.04362)

- ▶ Collective flow enables a mapping of the initial longitudinal profile and its fluctuations to some observables
- ▶ Torque effect observed by CMS
- ▶ $r_2(\eta_a, \eta_b)$ in p-Pb requires additional long range fluctuations in the energy deposition
- ▶ The observed relation $F_4 \simeq 4F_2$ consistent with flow with dominant v_2
- ▶ Nonflow is a serious issue
Measure higher cumulants of multiplicity or flow correlations in rapidity !

Studies of rapidity correlations give insight into (largely unexplored) mechanism of energy deposition in the longitudinal direction

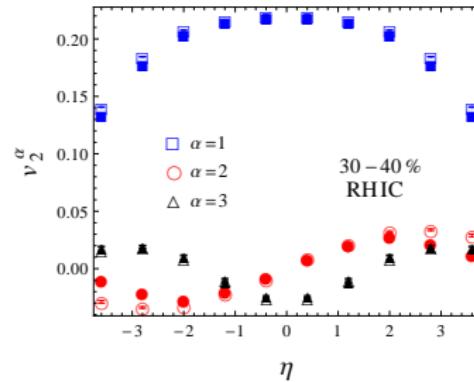
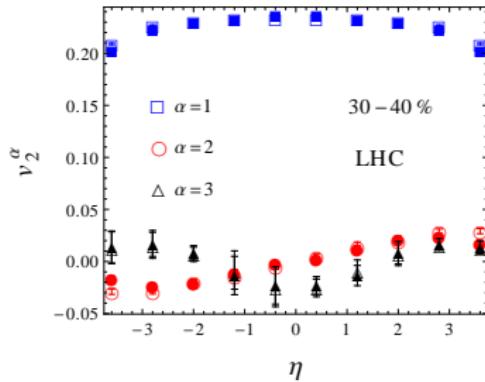
Fluctuating strings $r_n(\eta_a, \eta_b)$ RHIC energies



longitudinal fluctuations can be seen at RHIC

PCA - nonflow strikes again

Principal Component Analysis (PRL 114 (2015) 152301)



torque (full symbols), notorque (open symbols)

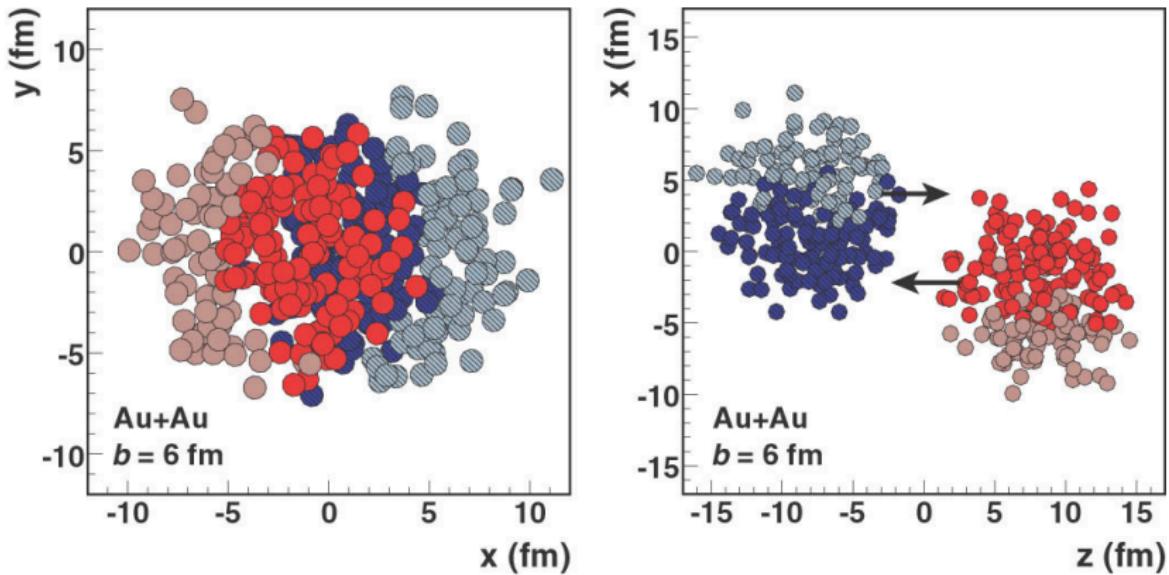
or was it the other way round?

PCA in η dominated by nonflow!
PCA works for oversampled events

factorization breaking ratio $r_n(\eta_a, \eta_b)$

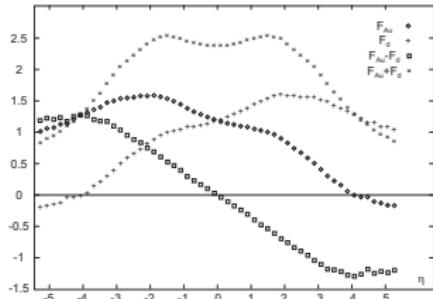
- ▶ $r_n(\eta_a, \eta_b) \simeq 1 - 2n^2 \langle (\Psi_n(0) - \Psi_n(\eta_b)) \frac{d\Psi_n(0)}{d\eta} \rangle \eta_a$
- ▶ linear in η_a $r_n(\eta_a, \eta_b) \simeq 1 - 2f_n \eta_a \simeq \exp(-2F_n \eta_a)$
- ▶ if $\Psi_4 \simeq \Psi_2$
 $F_4 \simeq 4F_2$
- ▶ F_n is an estimate of the decorrelation angle variance
$$F_n \simeq 2n^2 A \frac{\langle (\Psi_n(0) - \Psi_n(\eta_b))^2 \rangle}{\eta_{range}}$$

Forward and backward going participants



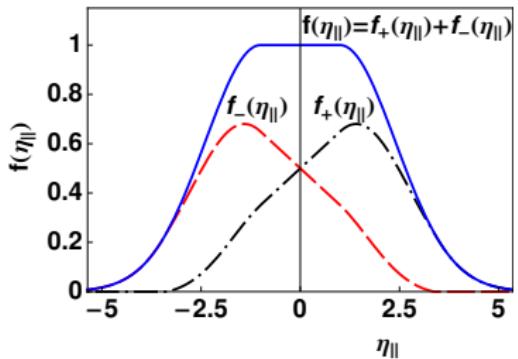
Ann.Rev.Nucl.Part.Sci. 57 (2007) 205

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

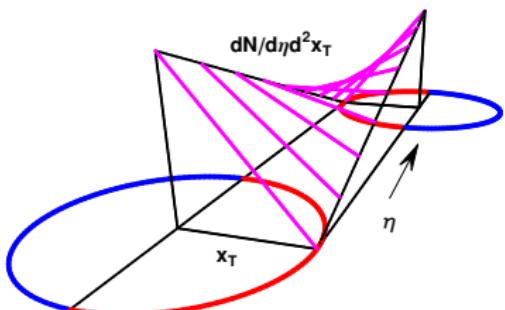


Asymmetric emission

(Bia{\l}as, Czy{\z}, Acta Phys. Polon. B36, 905 (2005))



$$\begin{aligned}\rho(\eta, x, y) &\propto f_+(\eta)N_+(x, y) \\ &+ f_-(\eta)N_-(x, y)\end{aligned}$$



bremsstrahlung Adil Gyulassy, Phys. Rev.

C72, 034907 (2005)