Correlations of the event-plane angles in pseudorapidity

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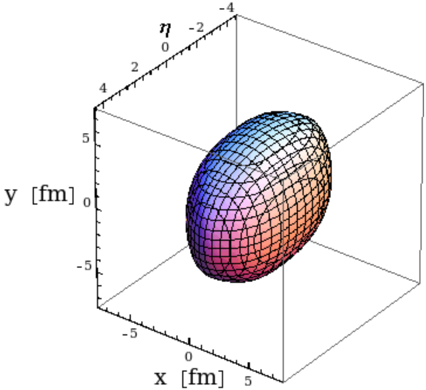
arXiv: 1011.3354, 1503.07425, 1506.04362

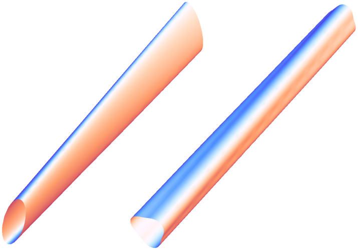
Fireball at different rapidities



is the shape similar at different rapidities
- same event-planes

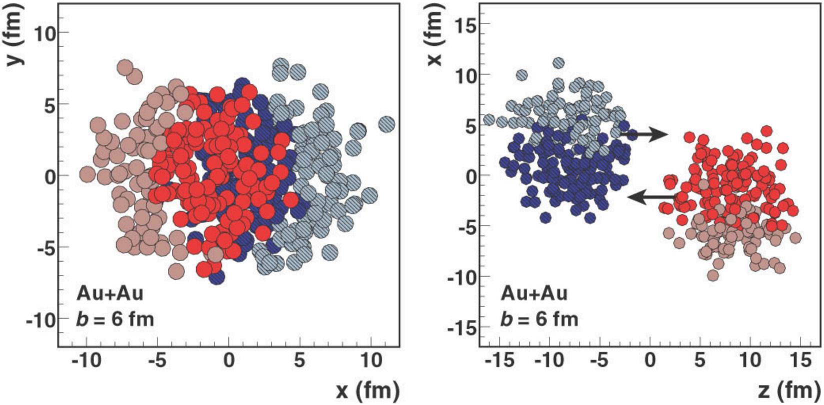
often assumed (even for event-by-event simulations)

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

Forward and backward going participants



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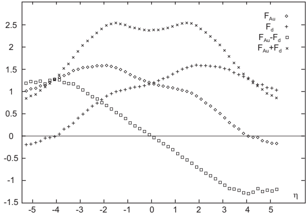
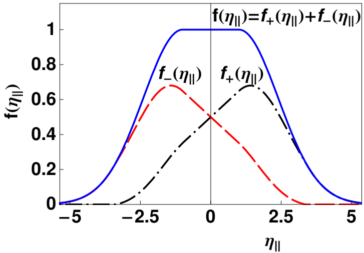
- Glauber Monte Carlo model $\longrightarrow$ different distributions for forward and backward going participants
- different event-planes at forward and backward rapidities

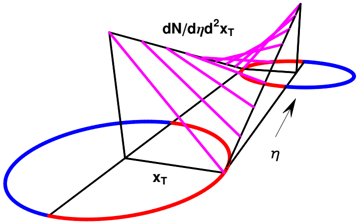


Asymmetric emission

(Białas, Czyż, Acta Phys.Polon.B36, 905 (2005)

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

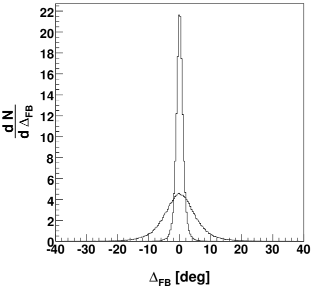




bremsstrahlung Adil Gyulassy, Phys. Rev. C72, 034907 (2005)

Twist angle distribution - Glauber model

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

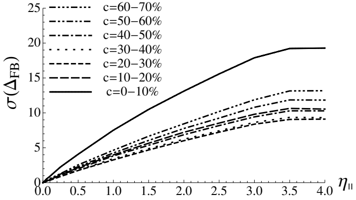


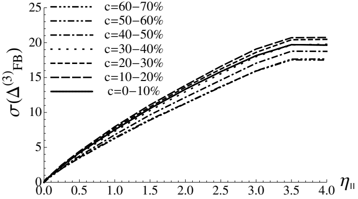
- very forward (backward), maximal decorrelation

- in between, intermediate

- linear around $\eta = 0$

width of the twist angle distribution

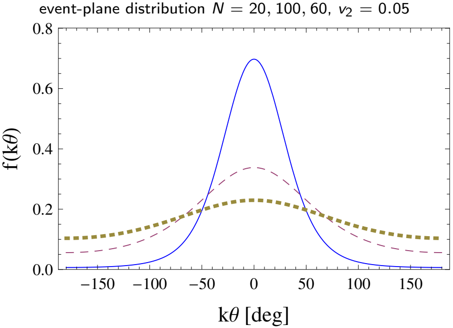




- $n = 2$, largest decorrelation for central collisions

- $n = 3$, similar decorrelation for all centralities

Event-plane resolution at finite multiplicity



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

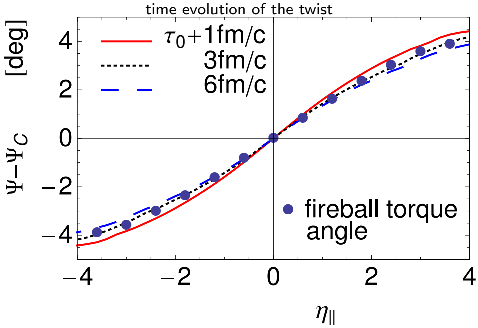
- observables must be quadratic in $\Delta\Psi$

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

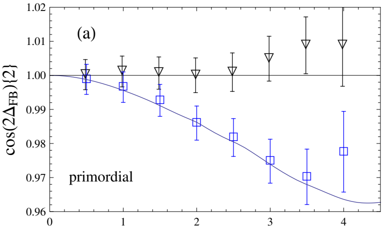


- the twist survives the hydrodynamic evolution

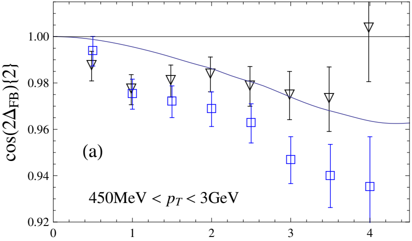
2-bin observable

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

primordial particles, torque events + notorque events



charged particles, torque events + notorque events

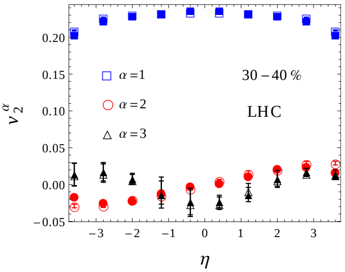


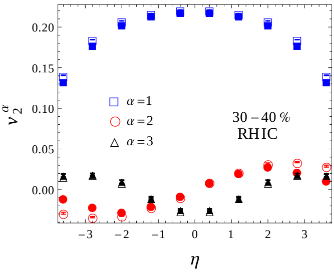
substantial nonflow contribution

2-bin observables in η dominated by nonflow!

PCA - nonflow strikes again

Principal Component Analysis - ask Jean-Yves (PRL 114 (2015) 152301)





torque (full symbols), notorque (open symbols)

or was it the other way round?

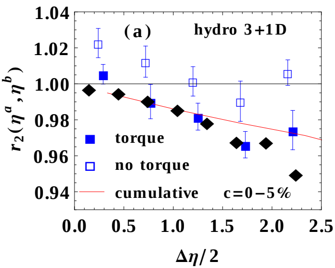
PCA in η dominated by nonflow!

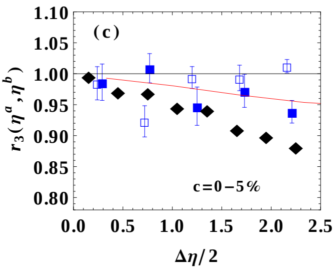
PCA works for oversampled events

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 $\eta_a - \eta_b$

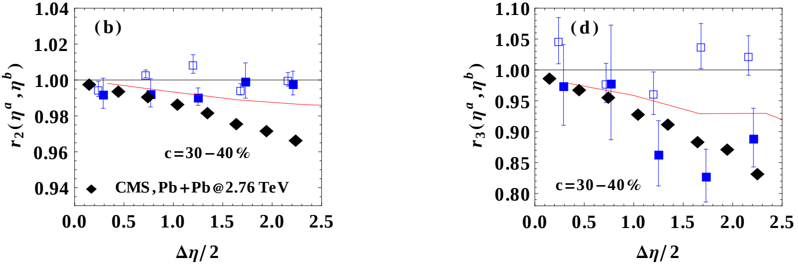




- nonflow under control
- torque effect seen in the CMS data
- semiquantitative agreement

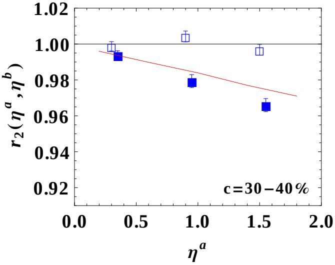
- does not work for p-Pb !

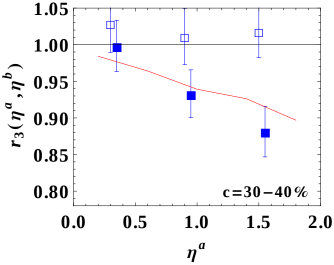
30-40%


(b)
1.04
1.02
1.00
0.98
0.96
0.94
c=30−40%
CMS, Pb+Pb@2.76 TeV
0.0 0.5 1.0 1.5 2.0 2.5
Δη/2
r2(ηa, ηb)
(d)
1.10
1.05
1.00
0.95
0.90
0.85
0.80
c=30−40%
0.0 0.5 1.0 1.5 2.0 2.5
Δη/2
r3(ηa, ηb)

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

predictions $(3 < \eta_b < 4.5)$



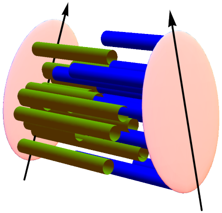


- larger twist angle at RHIC energies

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

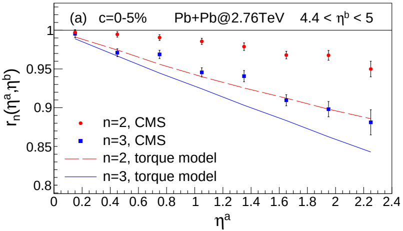
- $r_n(\eta_a, \eta_b) \simeq 1 - 2n^2 \langle (\Psi_n(0) - \Psi_n(\eta_b)) \frac{d\Psi_n(0)}{d\eta} \rangle \eta_a$
- linear in η_a $\quad r_n(\eta_a, \eta_b) \simeq 1 - 2f_n\eta_a \simeq exp(-2F_n\eta_a)$
- if $\Psi_4 \simeq \Psi_2$
  $F_4 \simeq 4F_2$
- F_n is an estimate of the decorrelation angle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

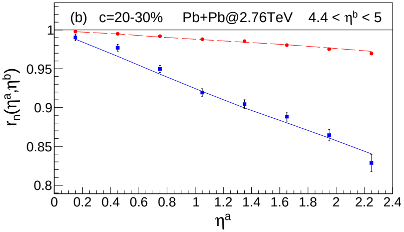
Fluctuations in energy deposition from each source

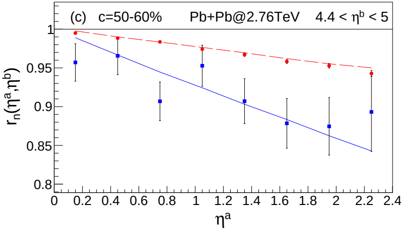


- the position (in rapidity) of string ends is random
- long range fluctuations
- each source fluctuates differently $\longrightarrow$ event-plan decorrelation in p-Pb
- short range fluctuations possible, but irrelevant for the CMS r_2
- average deposition same as in old model (linear in η)

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



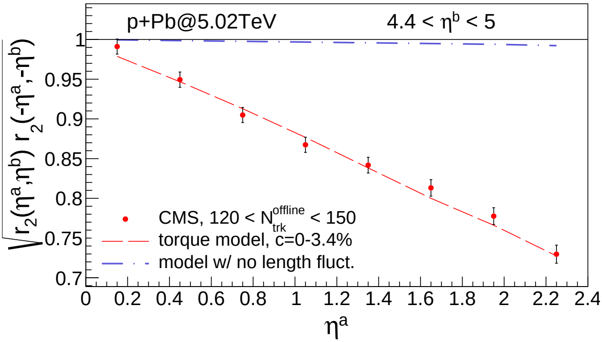




fluctuations improve description of r_2 in Pb-Pb

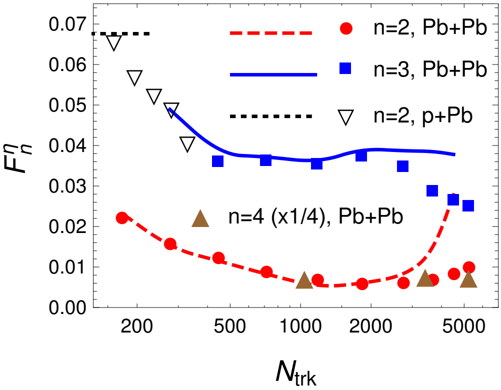
except for r_2 in central collisions

Fluctuating strings p-Pb



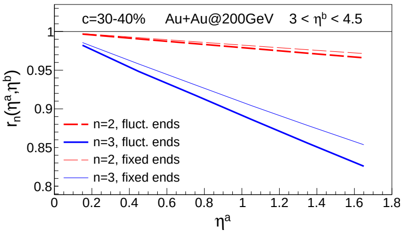
- fluctuations essential to describe event-plane decorrelation in p-Pb

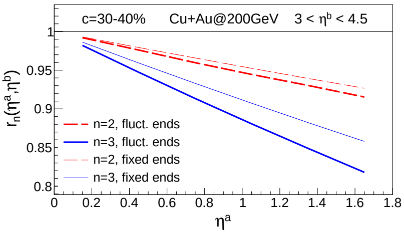
F slope



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

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





longitudinal fluctuations can be seen at RHIC

- Entropy deposition in the longitudinal direction is poorly known, both average and its fluctuations
- Collective flow enables a mapping of the initial longitudinal profile and its fluctuations to some observables
- Nonflow is a serious issue $\longrightarrow$ observables with a large rapidity gap
- Torque effect observed by CMS
- $r_n(\eta_a, \eta_b)$ in Pb-Pb fairly well described, asymmetric emission from forward (backward) going participants
- $r_2(\eta_a, \eta_b)$ 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

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