Forward-backward flow correlations in relativistic heavy-ion collisions[1]

Wojciech Broniowski
Jan Kochanowski University, Kielce
Institute of Nuclear Physics PAN, Cracow

ISMD 2011

Miyajima, 25-30 September 2011

[1] Based on P. Bozek, WB, J. Moreira, PRC 83, 034911 (2011)

Outline

Basic idea

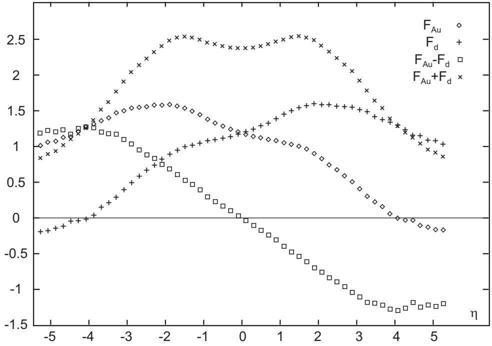
- determination of the initial state is crucial [review by S. Bass]
- event-by-event fluctuations

These elements jointly lead to interesting new effects, in particular to forward-backward flow correlations

Collision geometry

[Bialas and Czyz, Acta Phys. Polon. B36, 905 (2005)]

d-Au collisions at RHIC

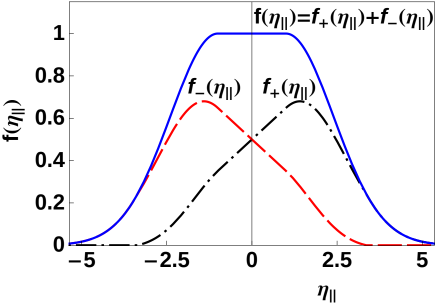


Wounded nucleons emit predominantly in their forward hemisphere

[similar ideas: Brodsky, Gunion, Kuhn (1977); Adil, Gyulassy (2005); Adil, Gyulassy, Hirano (2006)]

Extension to AA collisions

[Gazdzicki, Gorenstein (2006); Bzdak (2009); Bzdak, Wozniak (2010); Bozek, Wyskiel, PRC 81 (2010) 054902]



mixed model: three sources

N_{bin}, N_w^+, N_W^-

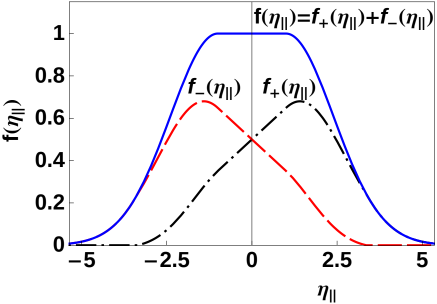
$$N_{\text{prod}} \sim \frac{1-\alpha}{2} N_w + \alpha N_{\text{bin}}$$

$\alpha \sim 14\%$ at RHIC

explains the F-B multiplicity fluctuations (Bzdak+Wozniak)

Extension to AA collisions

[Gazdzicki, Gorenstein (2006); Bzdak (2009); Bzdak, Wozniak (2010); Bozek, Wyskiel, PRC 81 (2010) 054902]



mixed model: three sources

N_{bin}, N_w^+, N_W^-

$$N_{\rm prod} \sim \frac{1-\alpha}{2} N_w + \alpha N_{\rm bin}$$

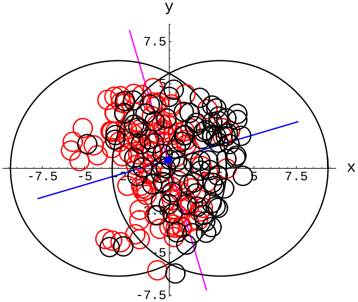
$\alpha \sim 14\%$ at RHIC

explains the F-B multiplicity fluctuations (Bzdak+Wozniak)

Key formula: space-time rapidity ($\eta_{||}$) and transverse (x, y) distribution:

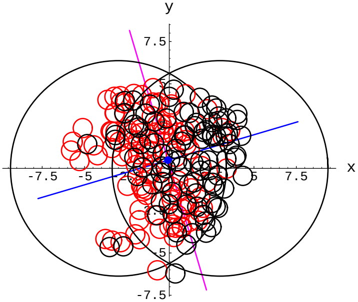
$$F(\eta_{||}, x, y) = (1-\alpha)[\rho_+(x,y) f_+(\eta_{||}) + \rho_-(x,y) f_-(\eta_{||})] + \alpha \rho_{\rm bin}(x,y) f(\eta_{||})$$

Fluctuations in the Glauber approach



- shape and size fluctuations originate from the statistical nature of the distribution of sources in the transverse plane
- increased eccentricity → hydro → increased v_2
- e-by-e fluctuations of v_2
- triangular flow, higher Fourier components, the ridge

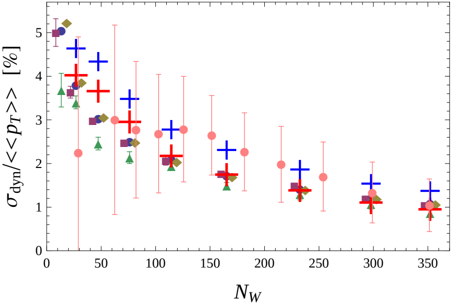
Fluctuations in the Glauber approach



clusters with $N_W^A \neq N_W^B$!

- shape and size fluctuations originate from the statistical nature of the distribution of sources in the transverse plane
- increased eccentricity $\rightarrow$ hydro $\rightarrow$ increased v_2
- e-by-e fluctuations of v_2
- triangular flow, higher Fourier components, the ridge

Digression: p_T fluctuations



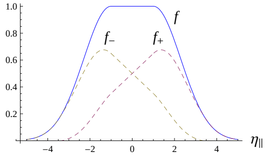
radial size fluctuations → hydro → radial flow fluctuations → explanation of p_T fluctuations at RHIC

GLISSANDO + 3+1 perfect hydro + THERMINATOR

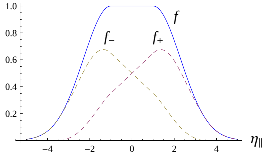
mixed model, wounded-nucleon model, STAR and PHENIX data

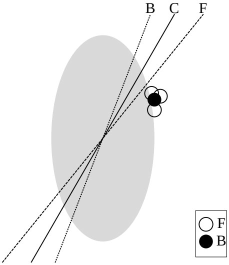
[WB, Chojnacki, Obara, PRC 80 (2009) 051902(R)]

The torque

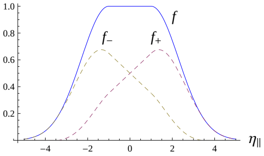


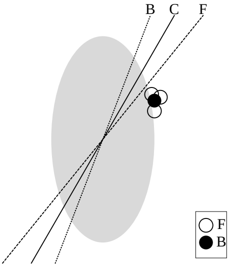
The torque

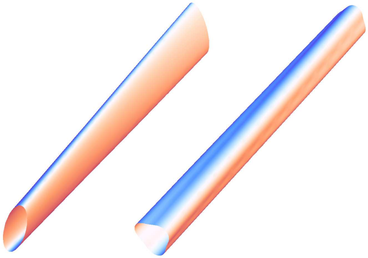




The torque





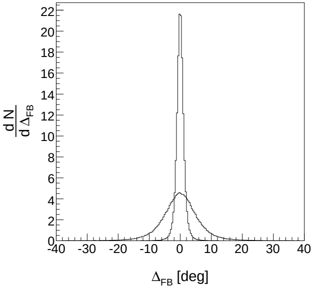


e-by-e fluctuation of the relative angle of the F and B principal axes

Distribution of the torque angle

GLISSANDO simulations in the mixed model

Δ_{FB} - torque angle between the forward and backward rapidity regions

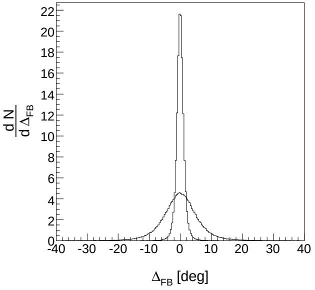


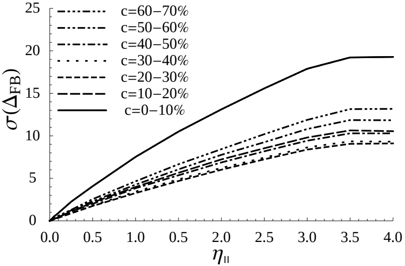
narrow: $\eta_{||} = 0.5$, broad: $\eta_{||} = 2.5$
$(c = 20 - 30\%)$

Distribution of the torque angle

GLISSANDO simulations in the mixed model

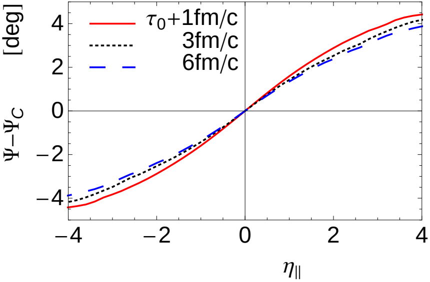
Δ_{FB} - torque angle between the forward and backward rapidity regions





narrow: $\eta_{||} = 0.5$, broad: $\eta_{||} = 2.5$
$(c = 20 - 30\%)$

Hydrodynamic evolution



- hydro (here perfect 3+1 with realistic EoS) evolution → the torque survives
- statistical hadronization leads to additional fluctuations - can we sort out the effect?

Measures of the torque based on cumulants

$$\left\langle e^{i2(\phi_F-\phi_B)}\right\rangle = \frac{1}{N_{\rm events}} \sum_{\rm events} \frac{1}{n_F n_B} \sum_{i=1}^{n_F} \sum_{j=1}^{n_B} e^{i2(\phi_i-\phi_j)}$$

When no correlations, then

$$f(\phi) = v_0 + 2\sum_{k=1} v_k \cos[k(\phi - \Psi^{(k)})]$$

and

$$\left\langle e^{i2(\phi_F-\phi_B)}\right\rangle = \langle v_{2,F} v_{2,B} \cos(2\Delta_{FB})\rangle_{\rm events}$$

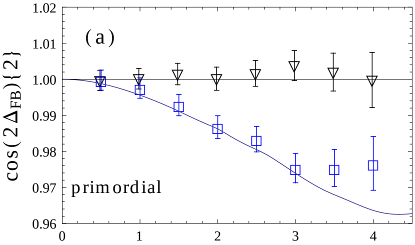
Since we are interested in measuring the average $\cos[2(\Psi_F - \Psi_B)]$, we need to divide by $v_{2,F}v_{k,B}$. This can be achieved by considering the ratio

$$\cos(2\Delta_{FB})\{2\} \equiv \frac{\left\langle e^{i2(\phi_F-\phi_B)}\right\rangle}{\sqrt{\left\langle e^{i2(\phi_{F,1}-\phi_{F,2})}\right\rangle \left\langle e^{i2(\phi_{B,1}-\phi_{B,2})}\right\rangle}} = \langle\cos(2\Delta_{FB})\rangle_{\rm events} + \text{nonflow}$$

(similar for higher Fourier components, also more-particle cumulants may be used)

Simulations with THERMINATOR

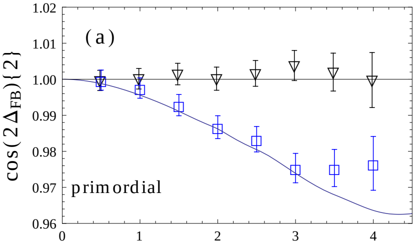
triangles - no torque, squares - with torque (100 000 events)

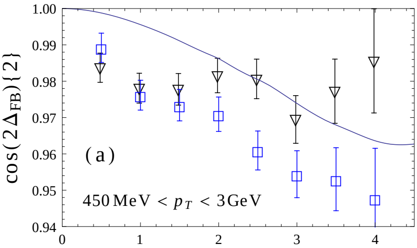


only the primordial particles created at freeze-out included
(test)

Simulations with THERMINATOR

triangles - no torque, squares - with torque (100 000 events)





only the primordial particles created at freeze-out included (test)

all final particles (with resonance decays)
effect is observable !

Summary

- Rapidity dependent reaction plane from simple assumptions: asymmetric emission profiles in rapidity + fluctuations → torque
- $\sim 20^o$ torque angle between F and B regions in most central and $\sim 10^o$ in mid-peripheral Au+Au collisions at the highest RHIC energy
- Similar for higher-order Fourier components
- Torqued fireball → torqued collective flow → torqued principal axes of the p_T distributions at different rapidities
- Signal detectable through the use of cumulants involving F and B particles
- With the fantastically high statistics available in experiments the effect can be examined in experiments, but large rapidity coverage needed
- The effect influences the elliptic and directed flow studies, which use the reaction planes determined in different pseudorapidity intervals
- Because of the increase in the statistical noise, one should look for the torque effects in mid-central/mid-peripheral collisions ($v_2\sqrt{n}$ should be maximal)

- The effects momentum, angular-momentum, and charge conservation should be examined
- The torque fluctuations in other multi-source models should be investigated
- The experimental detection of the torque would provide independent information on the initial state, in particular would confirm the assumptions on the initial emission profile from the sources

- The effects momentum, angular-momentum, and charge conservation should be examined
- The torque fluctuations in other multi-source models should be investigated
- The experimental detection of the torque would provide independent information on the initial state, in particular would confirm the assumptions on the initial emission profile from the sources

Please, analyze the data!