Longitudinal correlations in the initial stages of ultra-relativistic nuclear collisions

Wojciech Broniowski

Jan Kochanowski U., Kielce
Institute of Nuclear Physics PAN, Cracow

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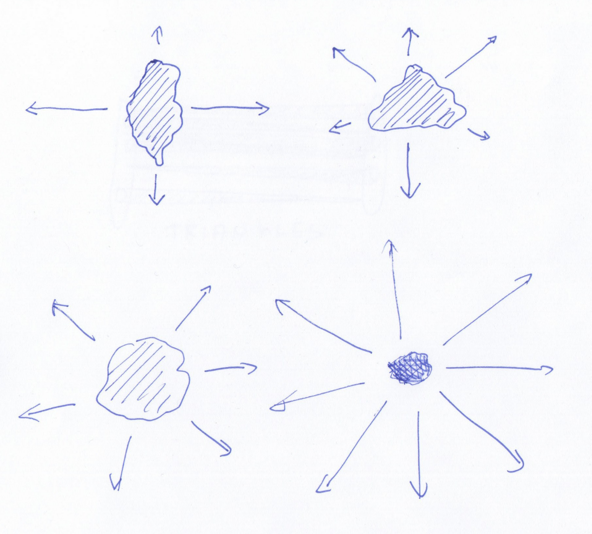
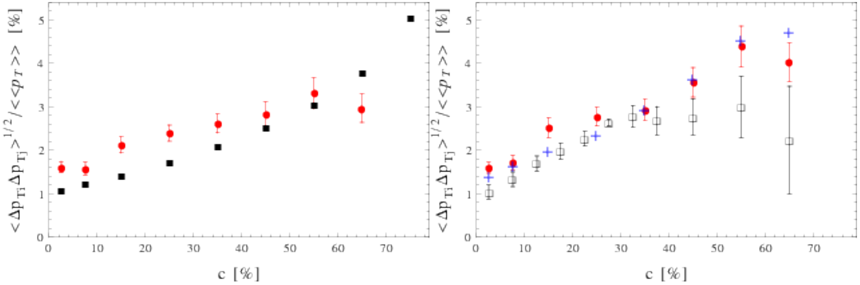
Research with **Piotr Bożek**

Introduction

Collectivity: shape–flow transmutation



Transverse momentum fluctuations in Au+Au@200GeV

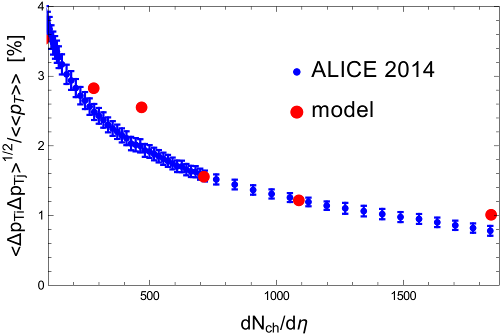


STAR PHENIX

red points – model

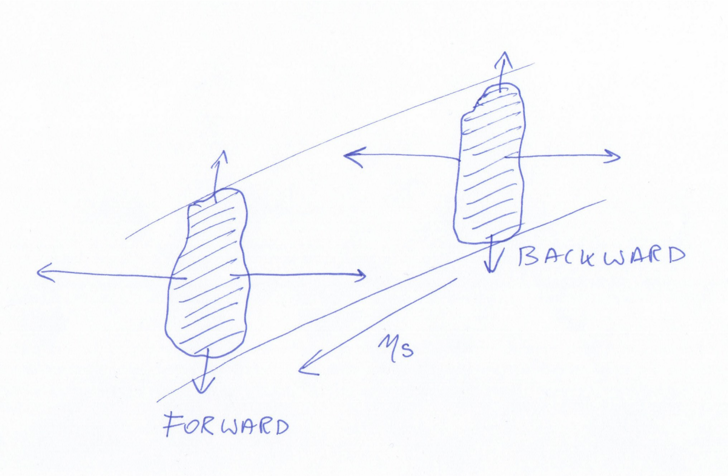
[more details in WB+Chojnacki+Obara 2009 & PB+WB 2012]

Transverse momentum fluctuations in Pb+Pb@2.76TeV



Modeling in rapidity

Factorization of the transverse and longitudinal distributions



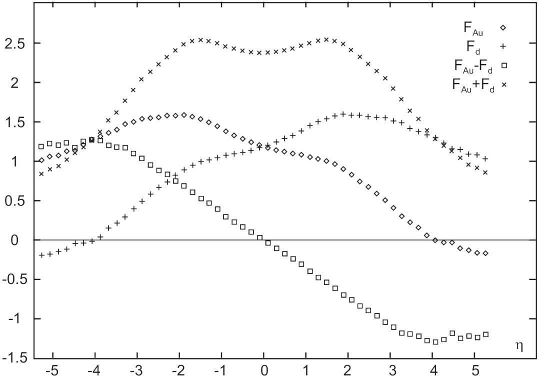
approximate (up to fluctuations) alignment of F and B event planes

collimation of flow at distant longitudinal separations → ridges!

Surfers - the near-side ridge

Modeling in rapidity

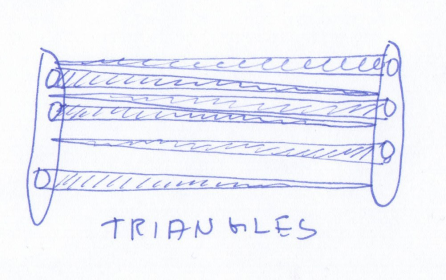
Extracted from the d-Au collisions at RHIC:



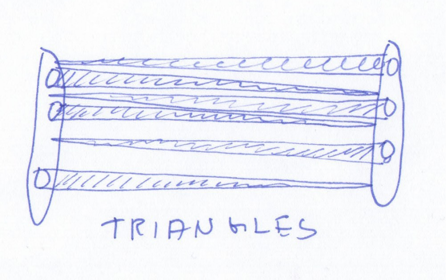
[Białas, Czyż 2004]

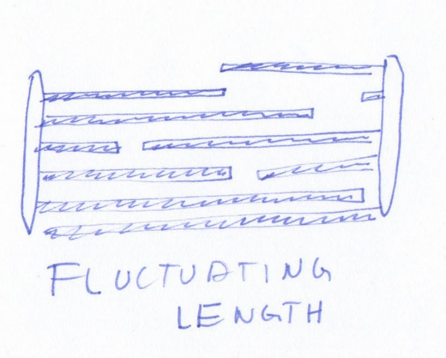
Source fragments mostly in its own froward hemisphere

Modeling in rapidity



Modeling in rapidity

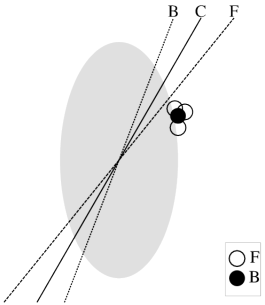


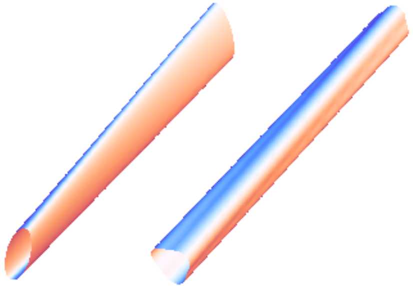


[see also Bierlich, Gustafson, Lönnblad 2016, Monnai, Schenke 2015, Schenke, Schlichting 2016 . . . Brodsky, Gunion, Kuhn, 1977]

Torque

Torque effect (event-by-event)





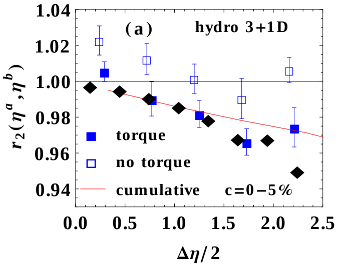
- due to fluctuations and asymmetry of emission profile

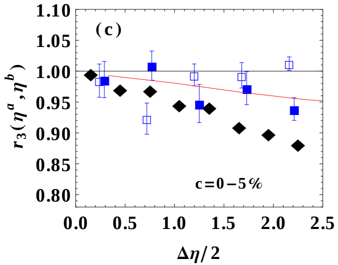
[prediction in PB+WB+Moreira 2010 & PB+WB+Olszewski 2015]

Three-bin measure (CMS, Pb+Pb@2.76TeV)

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

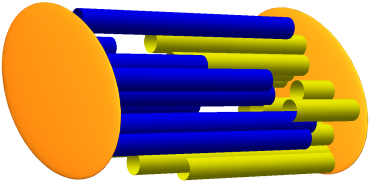
($4 < \eta^b < 5$: pairs with large rapidity gap $\eta_a - \eta_b$, $\Delta\eta = 2\eta^a$)



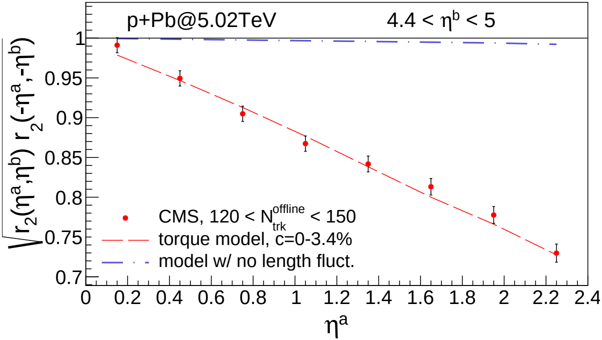


- nonflow under control
- torque effect seen in the CMS data
- hydro, AMPT reproduce the data

Fluctuating strings

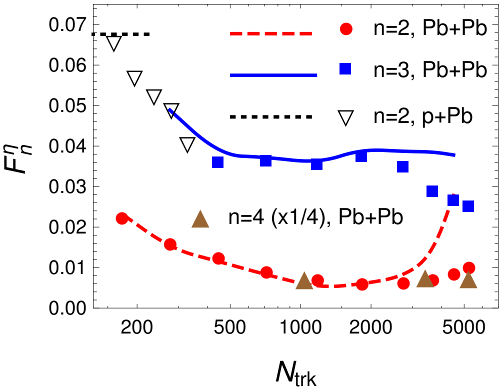


Torque in p-Pb



- fluctuations essential to describe torque in p-Pb

Slope



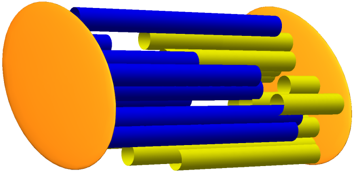
- fair description of mid-central collisions
- too much decorrelation in central collisions
- $F_4 \simeq 4F_2$

$$C(\eta_1, \eta_2)$$

$C(\eta_1, \eta_2)$ with fluctuating strings

Hydro: provides mapping $\eta_s = \frac{1}{2}\log\frac{t+z}{t-z} \to \eta$

For long-range separations not much mixing between the bins $\to$
$C^s(\eta_{s,1}, \eta_{s,2}) \simeq C^n(\eta_1, \eta_2)$



[more details in WB+PB, arXiv:1512.01945]

$C(\eta_1, \eta_2)$ with fluctuating end-points of strings

Average number of particles: $\langle N(\eta)\rangle = \langle N_A\rangle\langle f_A(\eta)\rangle + \langle N_B\rangle\langle f_B(\eta)\rangle$ with symmetric and antisymmetric parts $\langle f_{A,B}(\eta)\rangle = f_s(\eta) \pm f_a(\eta)$

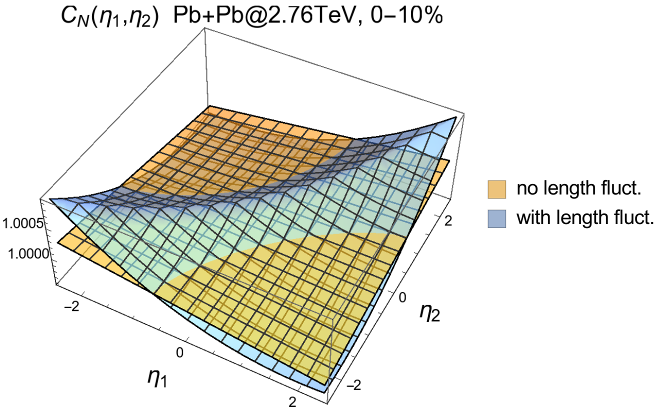
With $N_+ = N_A + N_B, \;\; N_- = N_A - N_B$, we have (for the symmetric case) a simple analytic formula

$$\begin{aligned} C(\eta_1, \eta_2) &= 1 + \frac{1}{N_+^2}\Big\{\langle N_+\rangle \mathrm{cov}_{A,B}(\eta_1, \eta_2) \\ &+ \mathrm{var}(N_+) + \mathrm{var}(N_-)\frac{f_a(\eta_1) f_a(\eta_2)}{f_s(\eta_1) f_s(\eta_2)}\Big\} \sim \frac{1}{N_+} \end{aligned}$$

Correlations in elem. production + fluctuation of the number of sources [Bzdak & Teaney 2013]

Results for C_N

$$\bar{C}_N(\eta_1,\eta_2) = \frac{C_N(\eta_1,\eta_2)}{\int_{-Y}^{Y}\frac{d\eta_1}{2Y}\int_{-Y}^{Y}\frac{d\eta_2}{2Y}C_N(\eta_1,\eta_2)} \quad \text{(normalization to 1)}$$



Generation of the saddle in the ridge (seen in experiment)

Fluctuating string length yields a large contribution

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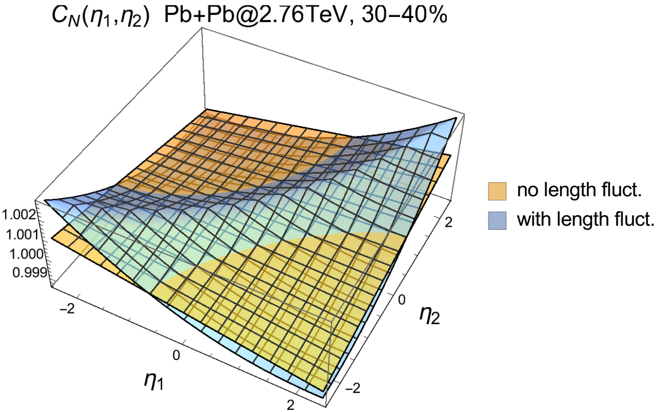

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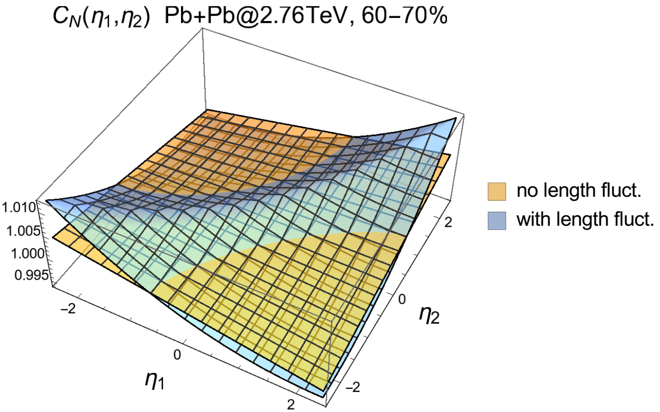

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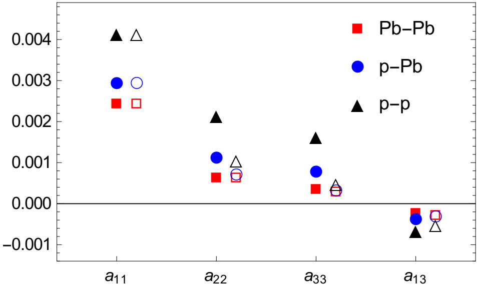
a_{nm} coefficients

$$a_{nm} = \int_{-Y}^{Y} \frac{d\eta_1}{Y} \int_{-Y}^{Y} \frac{d\eta_2}{Y} C(\eta_1, \eta_2) T_n\left(\frac{\eta_1}{Y}\right) T_m\left(\frac{\eta_1}{Y}\right), \quad T_n(x) = \sqrt{2 + 1/2} P_n(x)$$

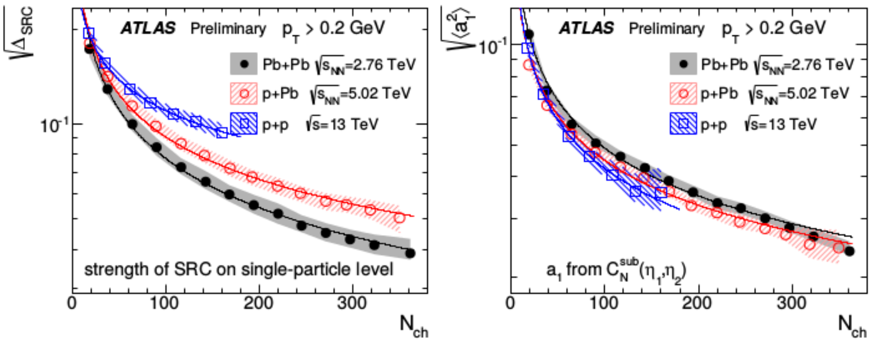
[Bzdak+Teaney 2013, Jia 2015]

Pb-Pb@2.76TeV, $c = 35 - 40\%$ $(N_{\rm ch} = 110)$



(filled – from Fig. 7 of ATLAS-CONF-2015-020, open – model)

Scaling with the number of sources



$N_{\rm ch}/N_+$ fitted by adjusting $a_{11}^{\rm exp} = c^{\rm exp}/N_{\rm ch} = a_{11}^{\rm mod} = c^{\rm mod}/N_+$

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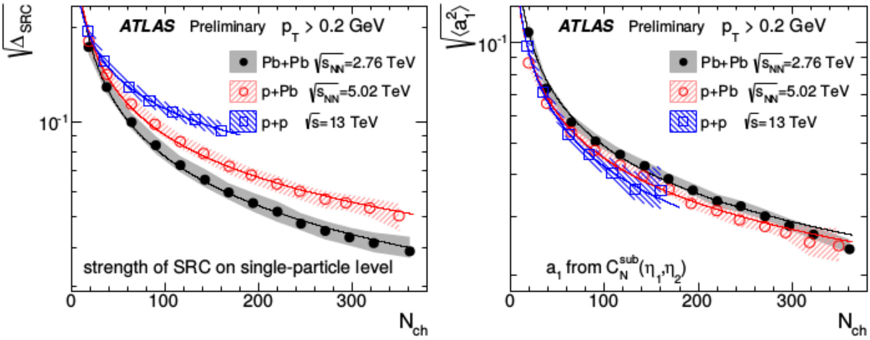

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Matching $\rightarrow$ $N_{\rm ch} = 4.7N_+$, acceptance $\Delta\eta = 4.8 \longrightarrow dN_{\rm ch}/d\eta \simeq 1 \times N_+$

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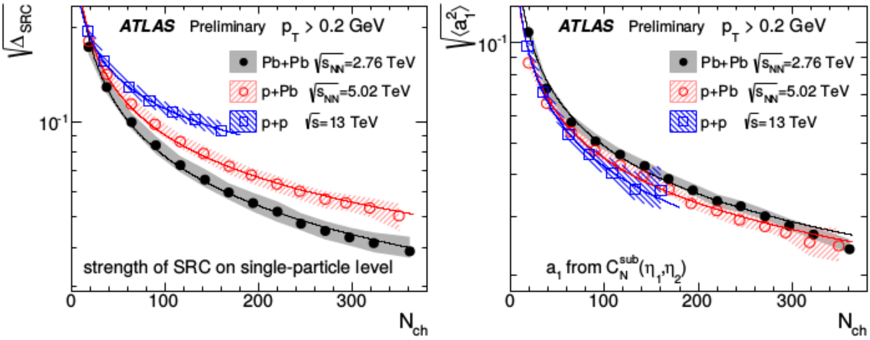

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From multiplicity data $dN_{ch}/d\eta \simeq (3-4) \times N_W$ and $dN_{ch}/d\eta \simeq 1.3 \times Q_W$

$\to$ wounded constituents)

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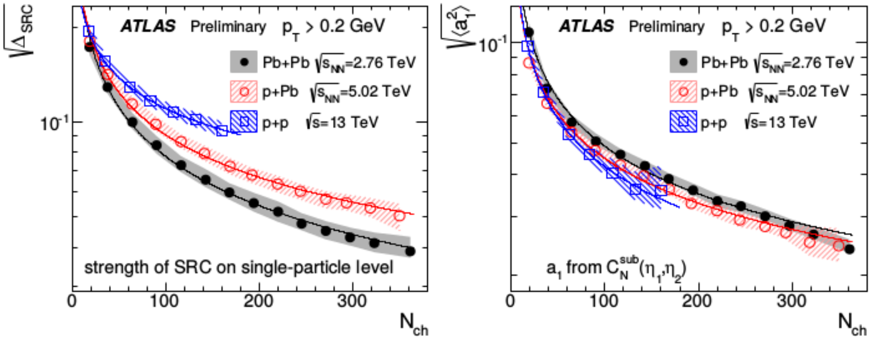

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$\to$ wounded constituents)

$N_{\rm ch} = 5.1 N_A$ for p-Pb@5.02TeV

$N_{\rm ch} = 8.1 N_+$ for p-p@13TeV – requires sources at partonic level

Conclusions

Conclusions

Flow:

- 1) p_T fluctuations
- 2)Torque (event-plane decorrelation)
- Torque in p-Pb from CMS $\rightarrow$ fluctuating longitudinally-extended sources
- 3) $C(\eta_1, \eta_2)$ from ATLAS
- $1/N_{ch}$ scaling of a_{11} $\rightarrow$ linear relation $N_{\rm ch} = \kappa N_{\rm sources}$, with the value of κ suggesting wounded constituents as degrees of freedom

Non-flow

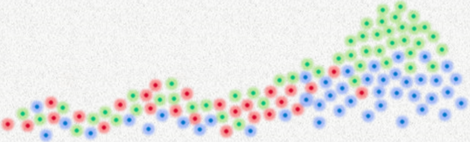
Photo: Voica Radescu 2016

12-th Polish Workshop on Relativistic Heavy-Ion Collisions

from instabilities to fluctuations

Institute of Physics, Jan Kochanowski University

4 - 6 November, 2016, Kielce



Key speakers

Marek Gaździcki
Tadeusz Kosztołowicz
Jan Rafelski
Ewa Rondio
Edward Shuryak
Wojciech Wiślicki
Mark Gorenstein
Marek Pajek
Anton Rebhan
Bjoern Schenke
Michael Strickland
Włodzimierz Zawadzki

Organizers

Wojciech Broniowski, Wojciech Florkowski, Francesco Giacosa, Ewa Maksymiuk, Maciej Rybczyński, Milena Sołtysiak, Grzegorz Stefanek, Agnieszka Wojtaszek-Szwarc