Rapidity Fluctuations in the Initial State of Ultra-Relativistic Heavy-Ion Collisions

Wojciech Broniowski[1,2]

[1]Jan Kochanowski U., Kielce
[2]Institute of Nuclear Physics PAN, Cracow

Initial stages in High-Energy Nuclear Collisions
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Research with **Piotr Bożek**

Introduction

Motivation/new data

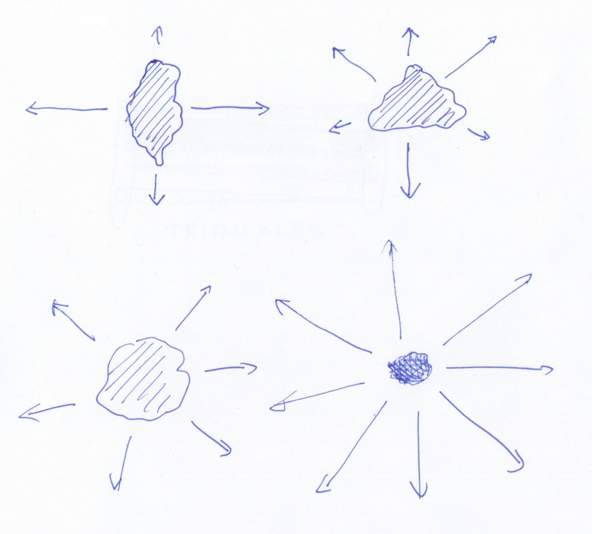
- Rapidity correlations are an old story ...
- New data from the LHC, new methodology (ATLAS notes 2015)
- Longitudinally-extended source model

Goal: understand anatomy of the rapidity correlations

Physics issues: production mechanism in the early stage, degrees of freedom,...

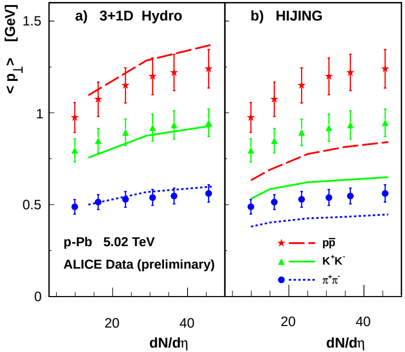
Based on [WB+Piotr Bożek, arXiv:1512.01945]

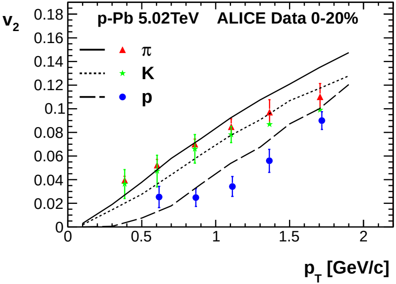
Transverse dynamics: shape–flow transmutation



Mass ordering in p-Pb (small system) from flow

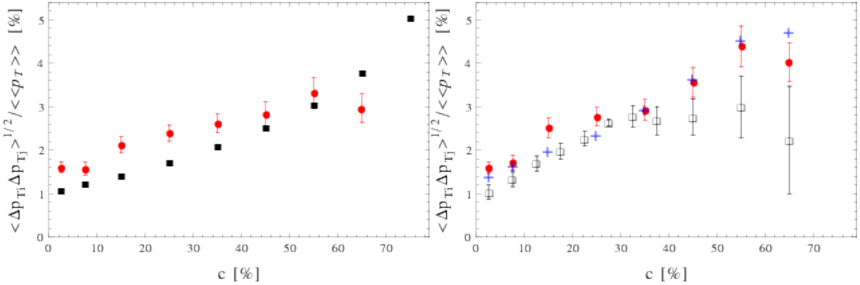
same velocity (from flow) $\to$ more momentum to heavier particles





[more details in PB+WB+Torrieri, PRL 111 (2013) 172303]

Transverse momentum fluctuations in Au+Au@200GeV



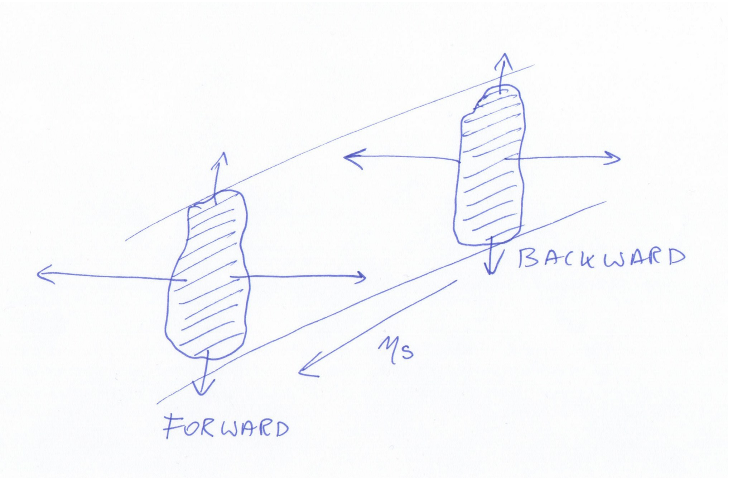
STAR

PHENIX

red points – model

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

Factorization of the transverse and longitudinal distributions



alignment of F and B event planes

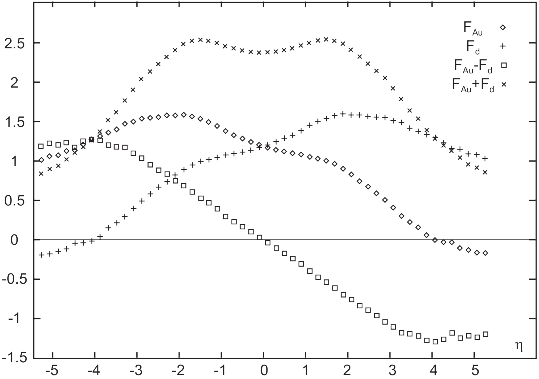
collimation of flow at distant longitudinal separations $\to$ ridges!

Surfers - the near-side ridge

Modeling in rapidity

Modeling in rapidity

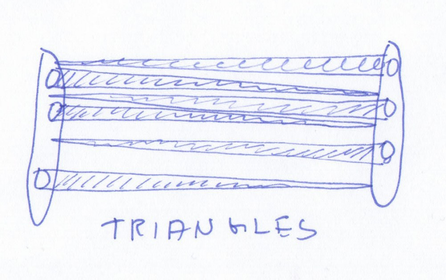
Extracted from the d-Au collisions at RHIC:



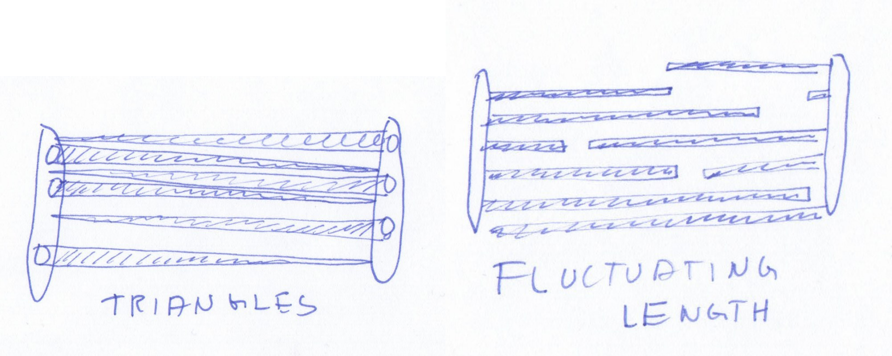
[Białas, Czyż 2004]

Source fragments mostly in its own froward hemisphere

Modeling in rapidity



Modeling in rapidity



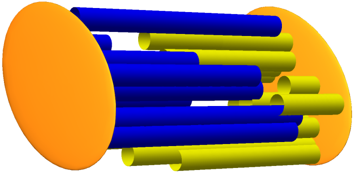
[see the next talk by **Piotr Bożek** on the torque effect (factorization breaking)]

New data, new challenge!

$C(\eta_1, \eta_2)$ 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 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

$$\langle f_{A,B}(\eta)\rangle = f_s(\eta) \pm f_a(\eta)$$

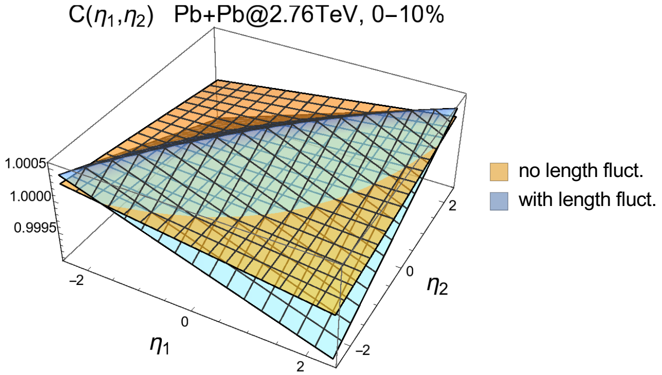
With $N_+ = N_A + N_B, \;\; N_- = N_A - N_B$, we have (for the symmetric case) a simple analytic formula

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

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

Results for C

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



Generation of the ridge (structure from $\mathrm{cov}_{A,B}$)

Fluctuating length affects both short- and long-range components

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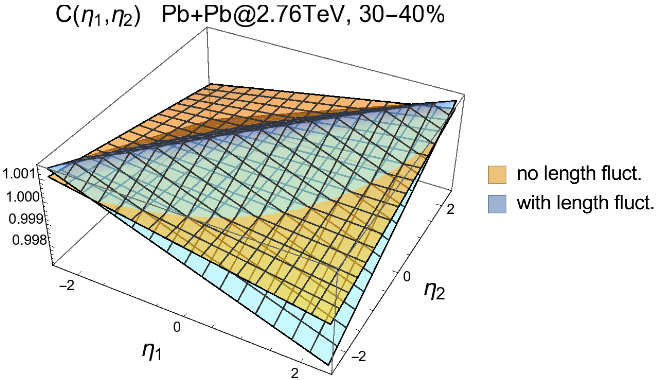

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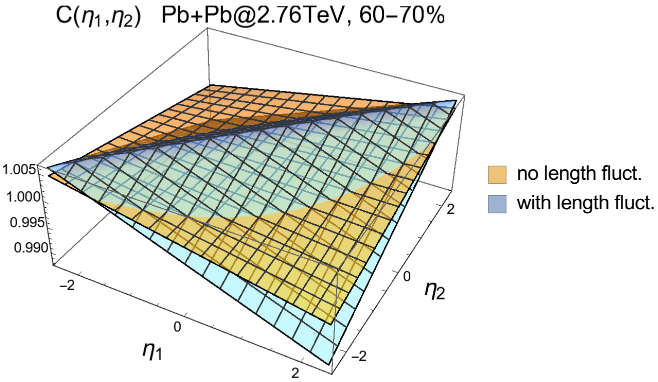
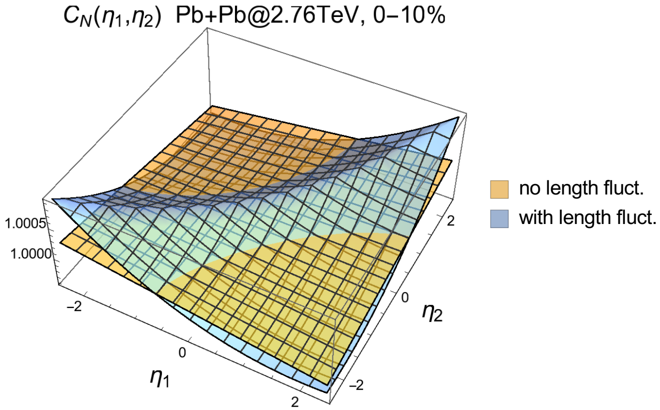


Generation of the ridge (structure from $\mathrm{cov}_{A,B}$)

Fluctuating length affects both short- and long-range components

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) is trivial

Fluctuating string length yields a large contribution

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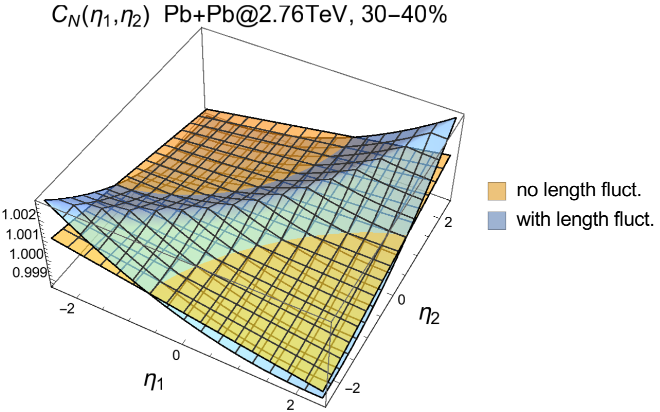

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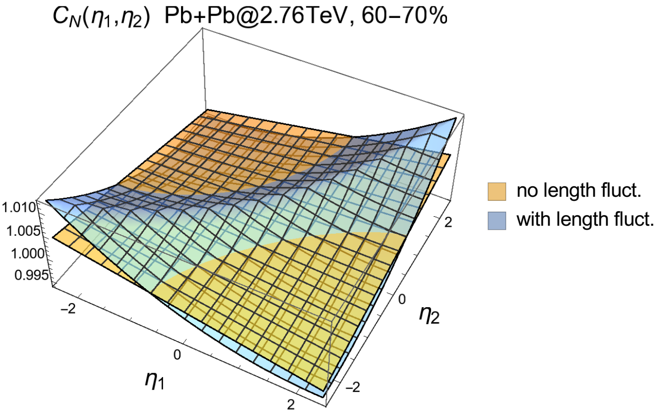

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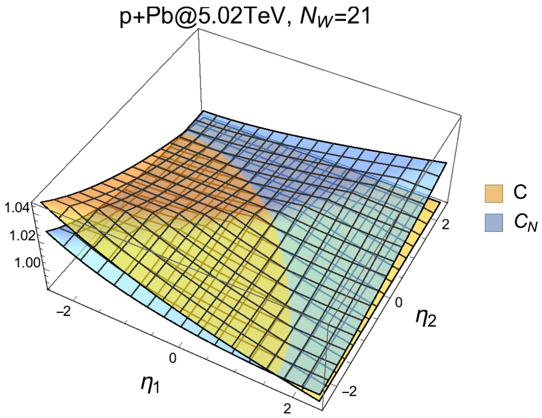
C and C_N for p-Pb collisions



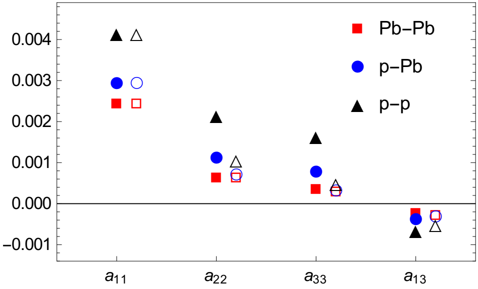
What are the sources?

a_{nm} coefficients

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

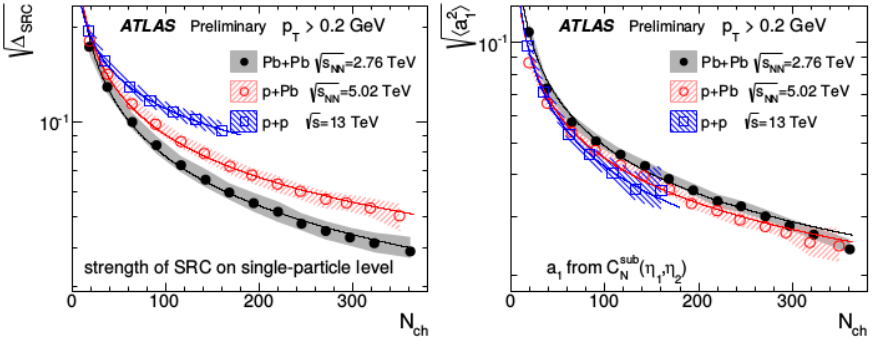
[Bzdak+Teaney 2013, Jia 2015]

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



(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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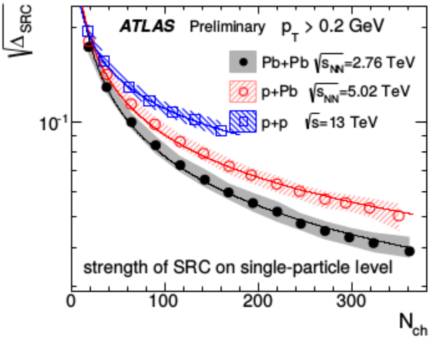

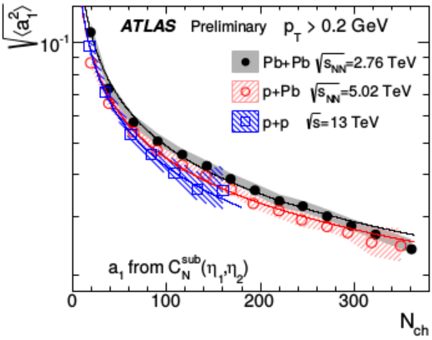

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Matching $\to N_{\rm ch} = 4.7 N_+$, acceptance $\Delta\eta = 4.8 \longrightarrow dN_{\rm ch}/d\eta \simeq 1 \times N_+$

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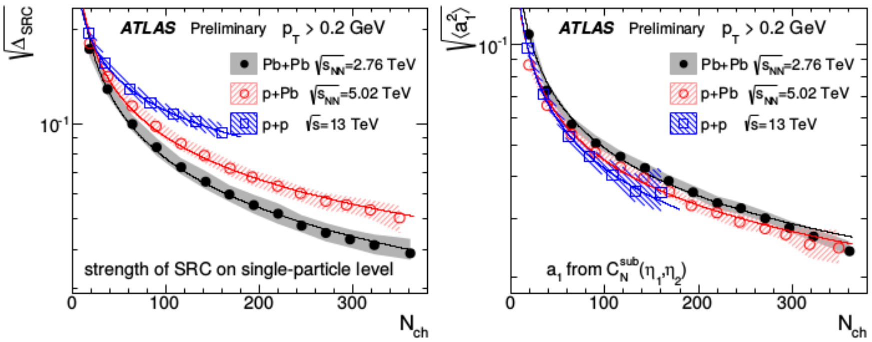

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From multiplicity data $dN_{\rm ch}/d\eta \simeq (3-4) \times N_W$ and $dN_{\rm ch}/d\eta \simeq 1.3 \times Q_W$

$\to$ wounded quarks/partons)

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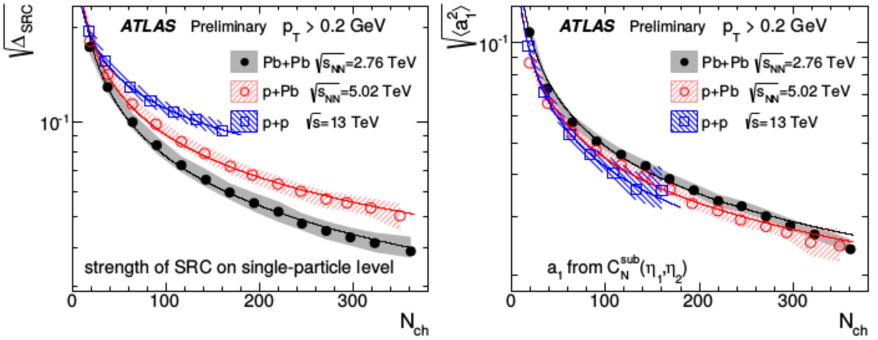

N_{ch}/N_+ fitted by adjusting $a_{11}^{exp} = c^{exp}/N_{ch} = a_{11}^{mod} = c^{mod}/N_+$

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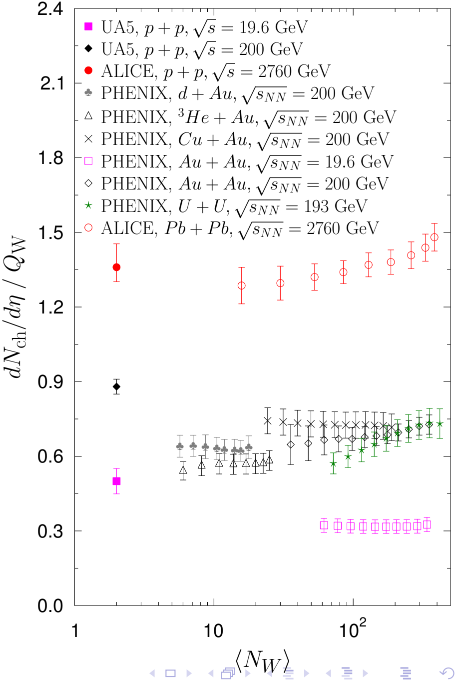
→ wounded quarks/partons)

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

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

Wounded quarks



[PB+WB+Rybczyński, arXiv:1604.07697]

Conclusions

Conclusions

- New correlation data challenge models
- $\rightarrow$ fluctuating longitudinally-extended sources
- Derived analytic expressions for rapidity correlations in a simple model, grasping features of more involved approaches
- $1/N_{ch}$ 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
- More detailed modeling: hydro push, chopping-off the short-range component, diffusion between bins, charge conservation, ... (decrease)
- Resonance decays – relevant effect [PB+WB+Olszewski 2015] $\rightarrow$ (increase)
- To eliminate short-range component use the multiparticle cumulant method [Bzdak+Bożek 2015]