

p_\perp fluctuations and correlations

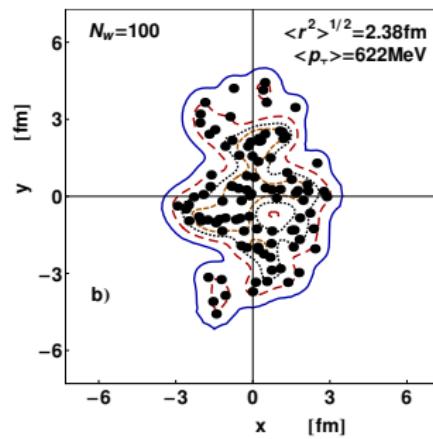
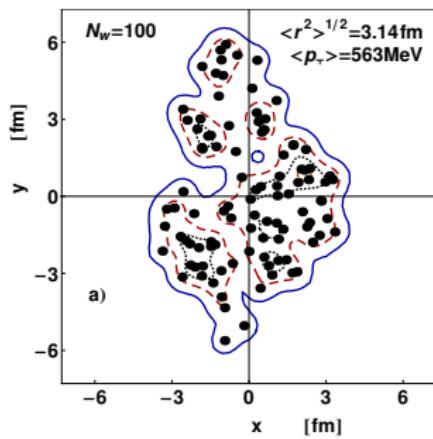
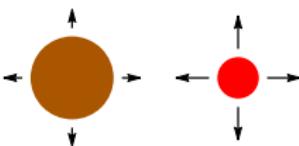
Piotr Bożek

AGH University of Science and Technology, Kraków

with: W. Broniowski, arXiv: 1701.09105
and S. Chatterjee, arXiv: 1704.02777



Size fluctuations $\leftrightarrow p_\perp$ fluctuations

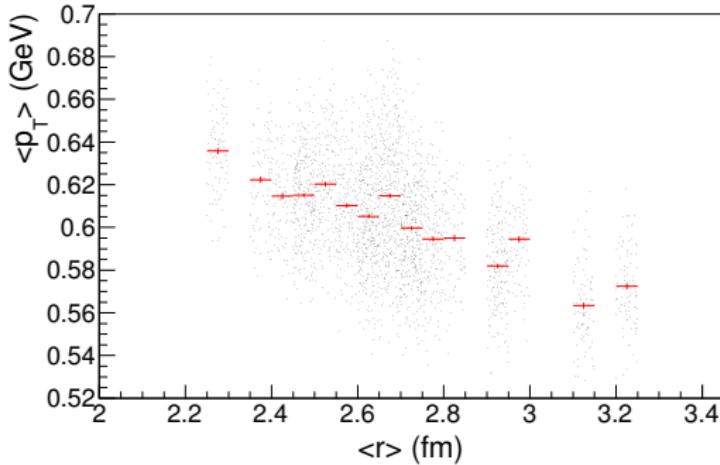


proposed by Broniowski et al. Phys.Rev. C80 (2009) 051902 :

two-shots calculation

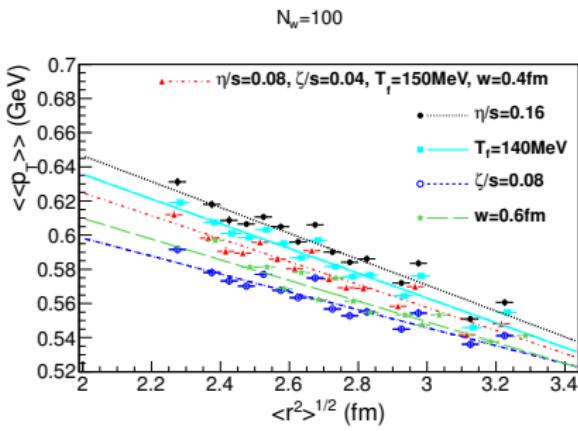
Physical and statistical fluctuations

$N_w=100$



$$C_{p_\perp} = \frac{\frac{1}{N(N-1)} \sum_{i \neq j} \langle (p_i - \langle \langle p \rangle \rangle)(p_j - \langle \langle p \rangle \rangle) \rangle}{\langle \langle p_\perp \rangle \rangle^2}$$

Initial state, viscosity or ...

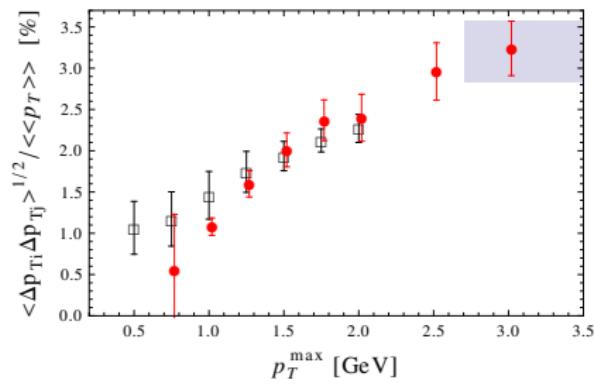
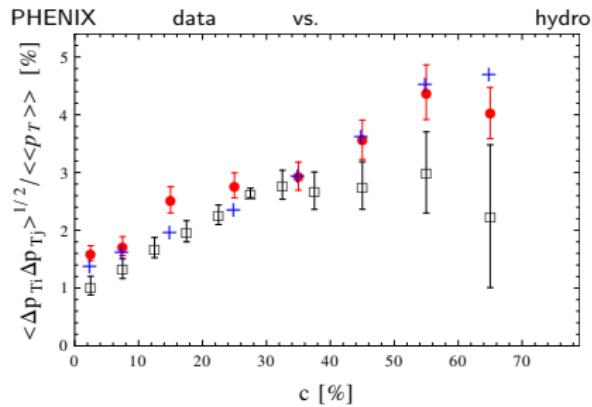


- ▶ size fl. $\leftrightarrow p_\perp$ fluctuations
- ▶ hydro. response not modified by
 - ▶ viscosity
 - ▶ T_F
 - ▶ smearing
 - ▶ core-corona
 - ▶ P_{tot} conservation
 - ▶ centrality def.

sensitive only to initial state fluctuations

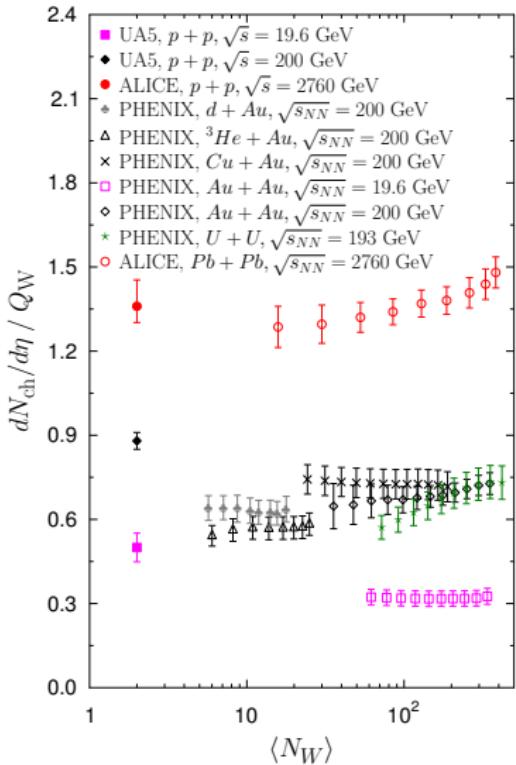
$$\frac{\Delta p}{p} \simeq 0.4 \frac{\Delta r}{r}$$

RHIC energies



Explains data (STAR and PHENIX) at RHIC energies
too much fluctuations?

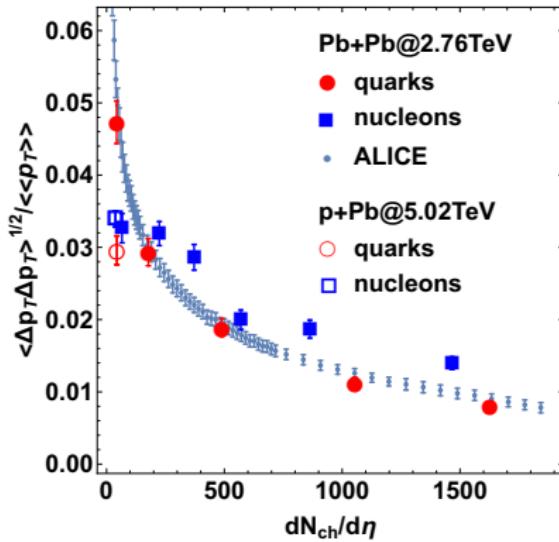
Wounded quark model in AA



- very good (full) scaling at LHC
- approximate scaling at RHIC
- LHC - 3 partons , RHIC - 2 partons ?

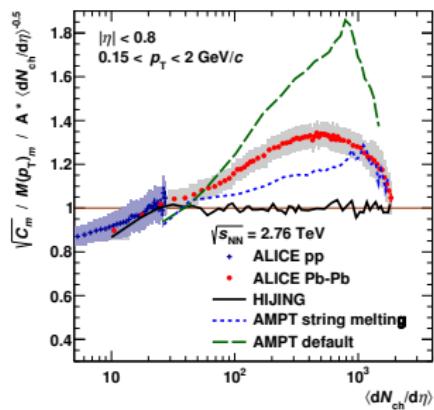
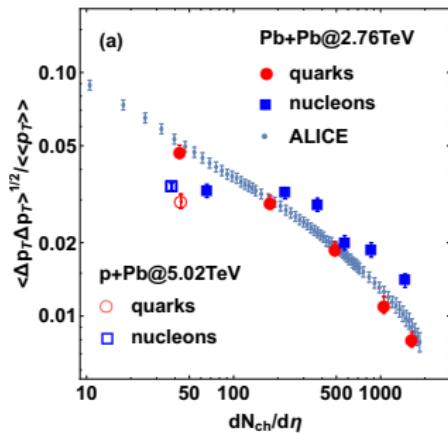
PB, W. Broniowski, M. Rybczyński,
PRC 2016

p_{\perp} fluctuation quark Glauber model initial conditions



Quark Glauber model gives better description of initial volume fluctuations

Same in log scale

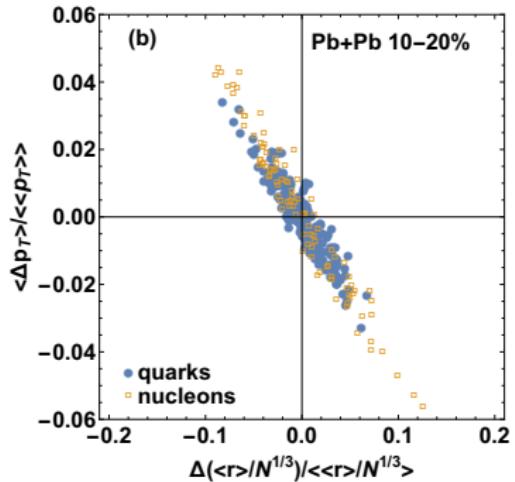
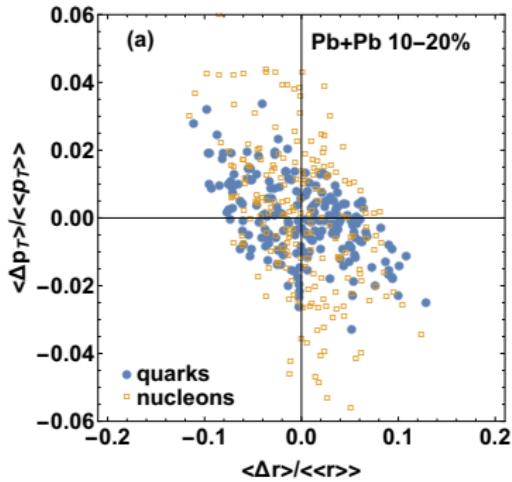


ALICE 1407.5530

more than simple $N^{-1/2}$ scaling

both experiment and theory → not minijets

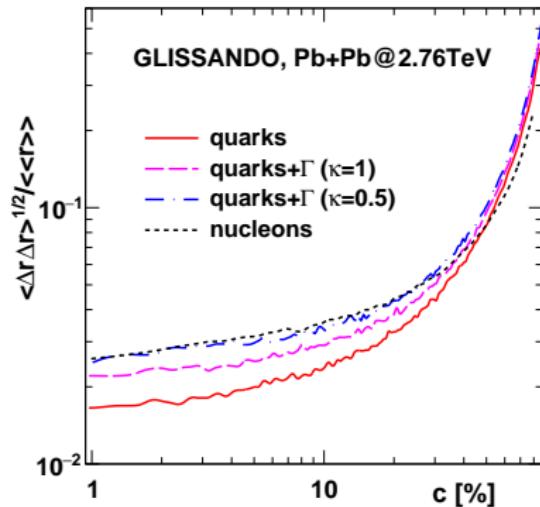
Size - p_{\perp} correlation



$\frac{N_q^\alpha}{\langle r \rangle}$ - predictor of the final p_{\perp} ($\alpha \simeq 0.3 - 0.4$)

consistent with predictor of Mazellauskas-Teaney, PRC 2016

Caution - additional fluctuation may change the results



additional fluctuations of width Γ ?

new constraint on the initial state

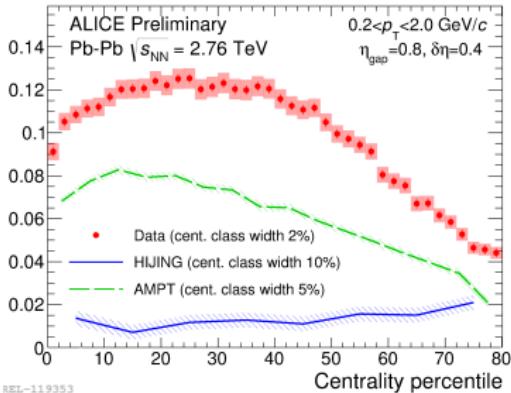
$p_\perp - p_\perp$ correlation in rapidity - ALICE preliminary

$$b_{\text{corr}} = \frac{\langle FB \rangle - \langle F \rangle \langle B \rangle}{\langle F^2 \rangle - \langle F \rangle^2}$$

$$B \equiv \overline{p_T}_B = \frac{\sum_{i=1}^{n_B} p_T^{(i)}}{n_B}$$

The plot shows the rapidity distribution η from -0.8 to 0.8. The 'Backward' region is shaded green and covers $\eta < -0.4$. The 'Forward' region is shaded orange and covers $\eta > 0.4$.

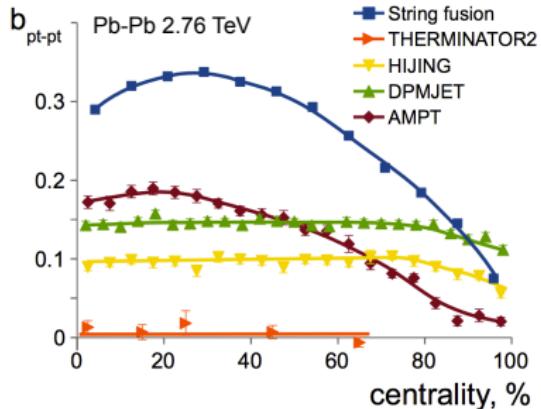
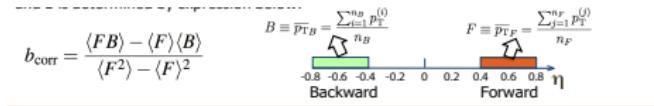
$$F \equiv \overline{p_T}_F = \frac{\sum_{j=1}^{n_F} p_T^{(j)}}{n_F}$$



QM poster I. Altsybeev for ALICE

event generators have problems to reproduce data

$p_{\perp} - p_{\perp}$ correlation in rapidity - ALICE preliminary

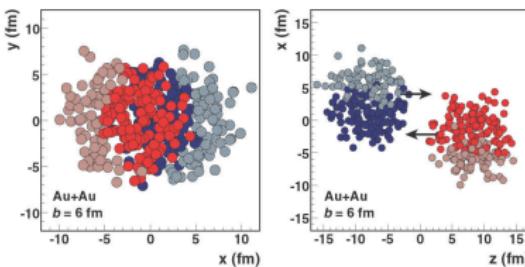


QM poster I. Altsybeev for ALICE

b mixes statistical and physical p_T fluctuations

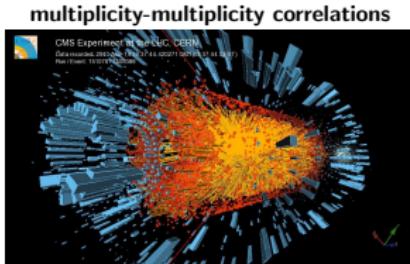
in some models both scale in the same way $1/N$

Hydrodynamics - forward and backward assymetry in initial state



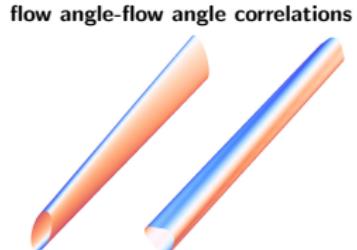
Ann.Rev.Nucl.Part.Sci. 57 (2007) 205

- Glauber Monte Carlo model → different forward and backward distributions
- different fireball shape at forward and backward rapidities



dozens of years, hundreds of papers

many effects sum up ...

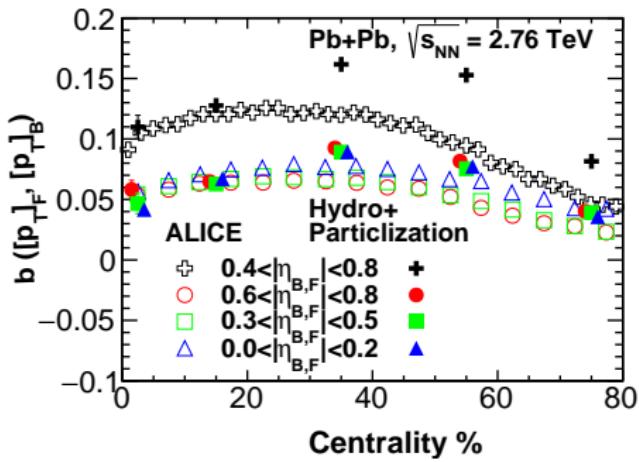


PB, W. Broniowski, J.Moreira : 1011.3354

experiment and theory picks up momentum

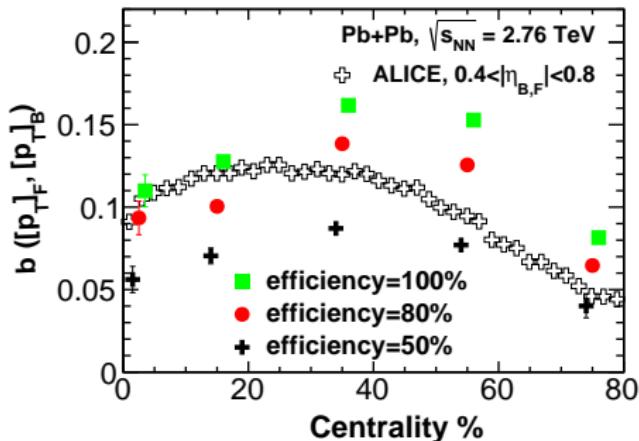


$p_\perp - p_\perp$ correlation in rapidity - hydro



reasonable description of the data does the model correctly describe rapidity correlations?

$p_T - p_T$ correlation coefficient - statistical fluct.



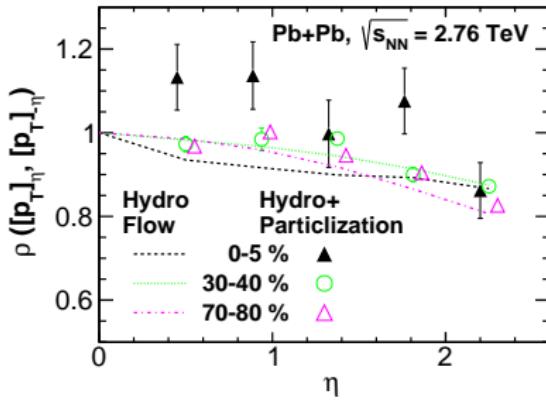
$$b = \frac{Cov([p]_F, [p]_B)}{\sqrt{Var([p]_F)Var([p]_B)}} \simeq \frac{Cov([p]_F, [p]_B)}{\sqrt{\left(C_{p_T}^F + \frac{1}{N_F} \int dp (p- < [p] >)^2 < f(p) > \right) (\dots)}}$$

sensitive to acceptance, particle multiplicity

dominated by statistical fluctuations!

$[p_\perp] - [p_\perp]$ correlation coefficient

$$\frac{\text{Cov}(\int dpf(p)_F, \int dpf(p)_B)}{\sqrt{\text{Var}(\int dpf(p)_F) \text{Var}(\int dpf(p)_B)}} = \frac{\text{Cov}([p]_F, [p]_B)}{\sqrt{C_{p_\perp}^F C_{p_\perp}^B}} = \frac{\dots}{\sqrt{\frac{1}{n_F(n_F-1)} \sum_{i \neq j} p_i^F p_j^F}}.$$

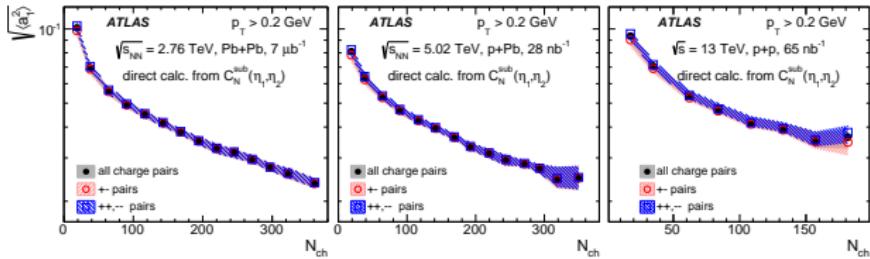


$$\rho([p_T], [p_T]) \simeq 1$$

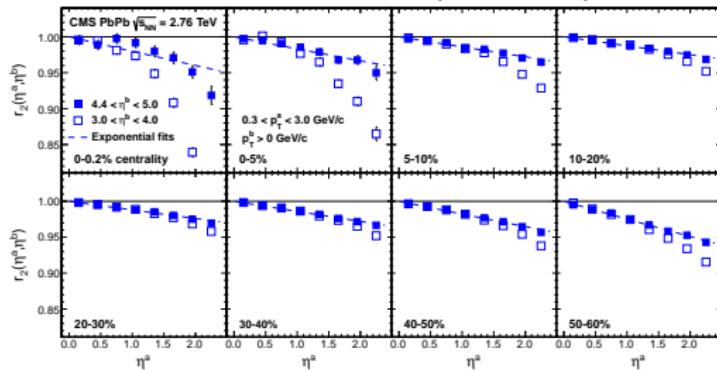
in the current model - strong correlations

Small decorrelation expected!

FB multiplicity fluctuations $\rho_2(\eta_1, \eta_2) \simeq <\rho(\eta_1)><\rho(\eta_2)>(1 + a_1 a_1 \frac{\eta_1}{Y} \frac{\eta_2}{Y})$

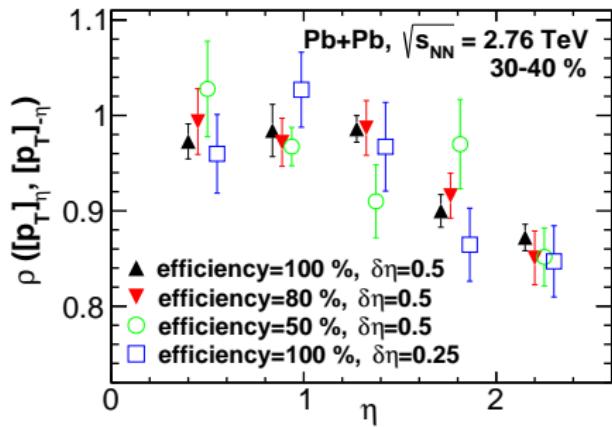


Azimuthal flow decorrelations (3-bin measure)



small decorrelation of flow and multiplicity in pseudorapidity

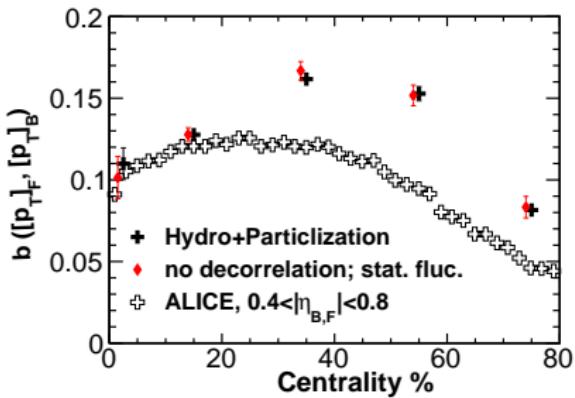
$[p_T] - [p_T]$ correlation coefficient



insensitive to acceptance, efficiency, multiplicity

robust measure of flow-flow correlations

Statistical fluctuations



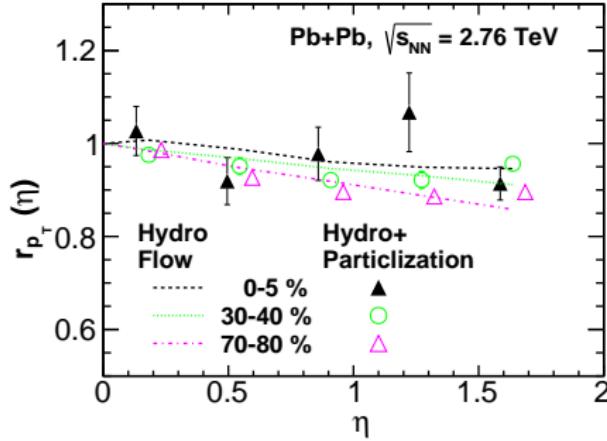
in our calculation $b([p_T]_F, [p_T]_B)$ dominated by stat. fluct.

$\rho = 1$ or $\rho < 1$ makes almost no difference

(even if fireball is FB symmetric in each event $b \simeq 0.1 - 0.15$)

3-bin measure of $[p_T]$ decorrelation

$$r_{p_T}(\Delta\eta) = \frac{\text{Cov}([p_T], [p_T])(\eta_{\text{ref}} + \eta)}{\text{Cov}([p_T], [p_T])(\eta_{\text{ref}} - \eta)}$$



Measure of $[p_T]$ decorrelation in pseudorapidity
expect small decorrelation

less sensitive to non flow, no need to define $[p_T]$ variance

Correlations and fluctuations - flow dominated dynamics

moments and correlations of flow observables

- ▶ azimuthal flow coefficients
 v_n^2, \dots , flow decorrelations in p_T or pseudorapidity
- ▶ $[p]_T$ fluctuations and decorrelations
 - $[p]_T$ fluctuations $C_{p_T} = \frac{1}{N(N-1)} \sum_{i \neq j} (p_i - \langle [p] \rangle)(p_j - \langle [p] \rangle)$
 - correlations with $[p_T]$, e.g. (1601.04513)

$$\rho([p_T], v_2^2) = \frac{\text{Cov}([p_T], v_2^2)}{\sqrt{\frac{1}{N(N-1)} \sum_{i \neq j} (p_i - \langle [p] \rangle)(p_j - \langle [p] \rangle) \text{Var}(v_2^2)}}$$

- ▶ multiplicity (density) fluctuations
 - moments of the density (Bialas, Zalewski 1101.5706)
 $\langle s \rangle \propto \langle N \rangle$, $\langle s^2 \rangle \propto \langle N^2 \rangle - \langle N \rangle$, ...
 - correlations with density, e.g.

$$\rho(s, v_2^2) = \frac{\text{Cov}(N, v_2^2)}{\sqrt{(\langle N^2 \rangle - \langle N \rangle - \langle N \rangle^2) \text{Var}(v_2^2)}}$$

Summary

- ▶ size fluctuations $\leftrightarrow p_\perp$ fluctuations
- ▶ Glauber+hydro qualitatively consistent
- ▶ suggest scenarios with less fluctuations (quark Glauber model)
- ▶ p_\perp correlations in η interesting
- ▶ small $[p_\perp] - [p_\perp]$ decorrelation? - should be measured