

Torque effect and long-range rapidity fluctuations

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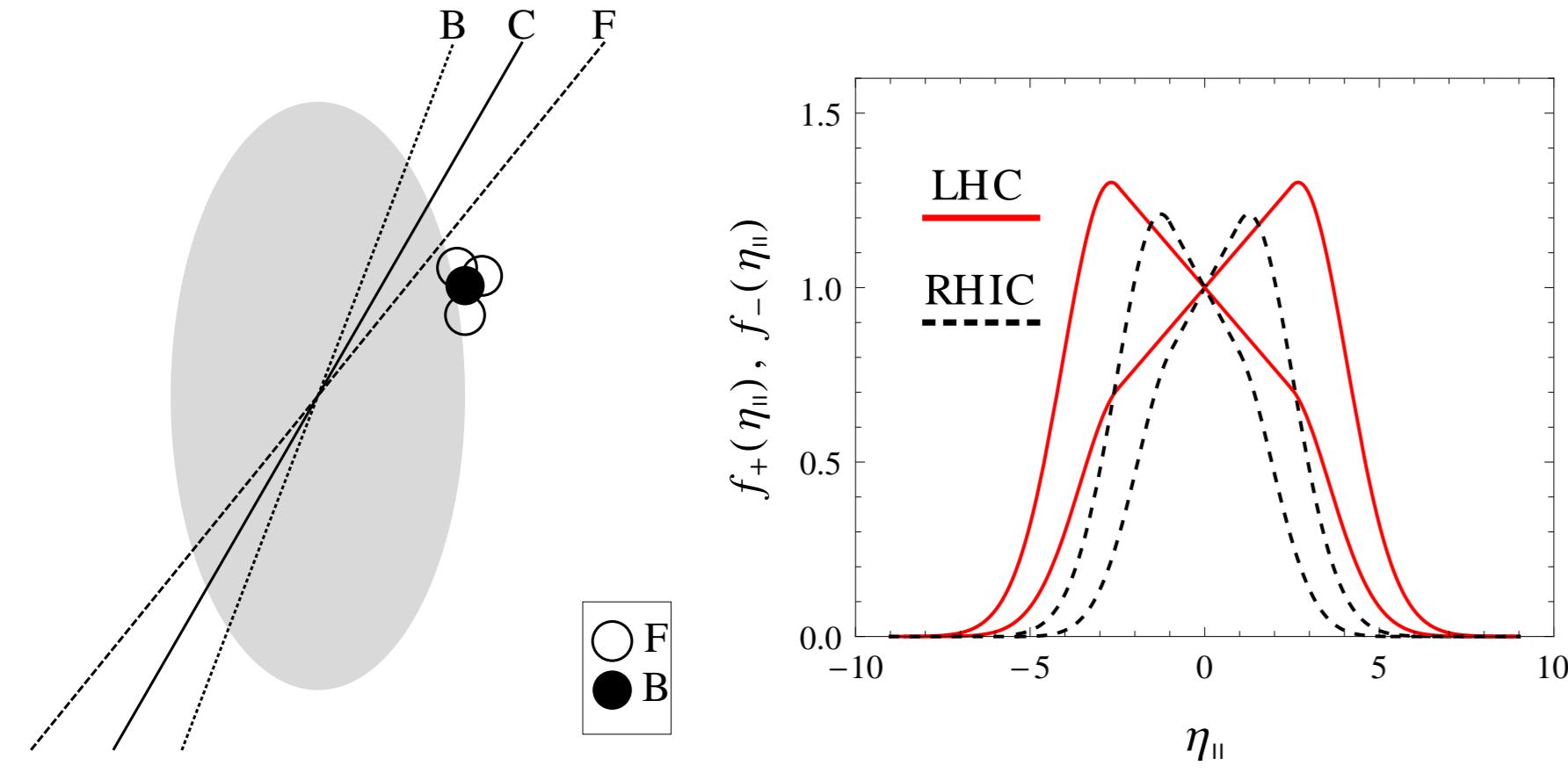
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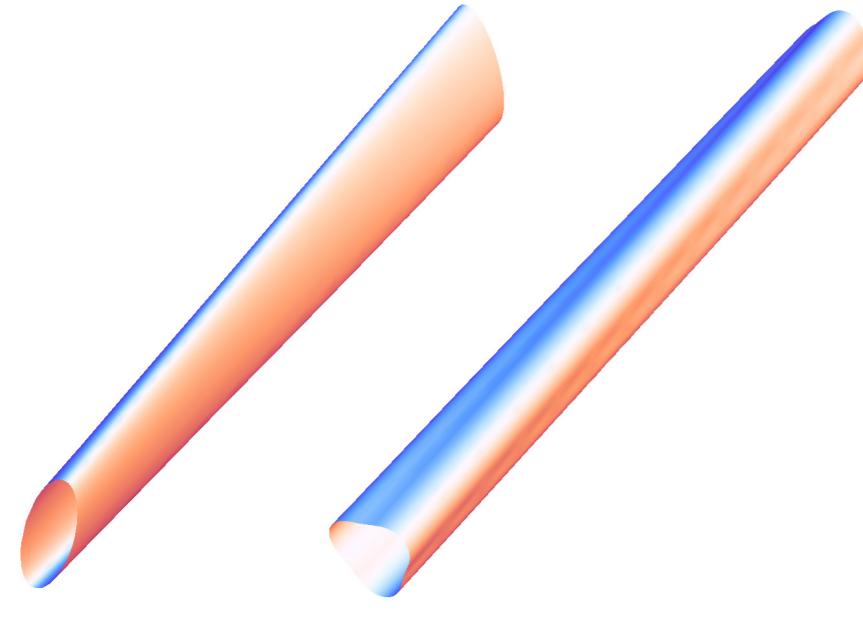
Abstract

- Torque effect → decorrelation of event planes in rapidity) [1, 2]
- CMS [3] results for p+Pb → specific fluctuations of the initially deposited entropy [4]
- Hydro modeling [5] of two-particle pseudorapidity correlations as recently measured by ATLAS [6, 7]

Torque



Fluctuations in the number of forward- and backward-going wounded nucleons + asymmetry of the emission profile in rapidity → torque (decorrelation of the event-plane angles)

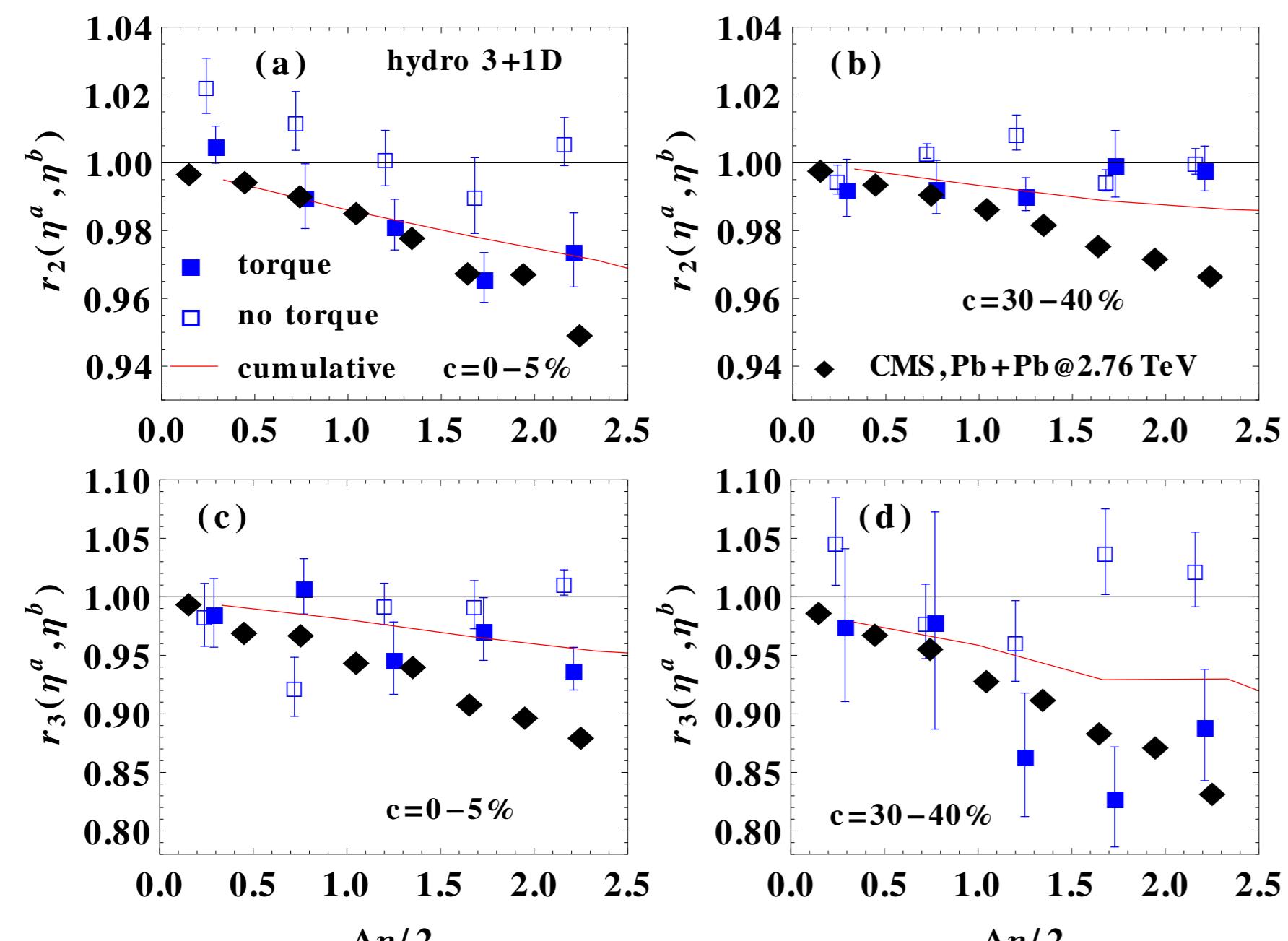


Torque at CMS

CMS introduced the measure

$$r_n(\eta^a, \eta^b) = \frac{V_n \Delta(-\eta^a, \eta^b)}{V_n \Delta(\eta^a, \eta^b)}, \quad V_n \Delta(\eta_a, \eta_b) = \langle \langle \cos[n(\phi_a - \phi_b)] \rangle \rangle$$

where the average is over events and over all pairs with particles i in a bin around η_i

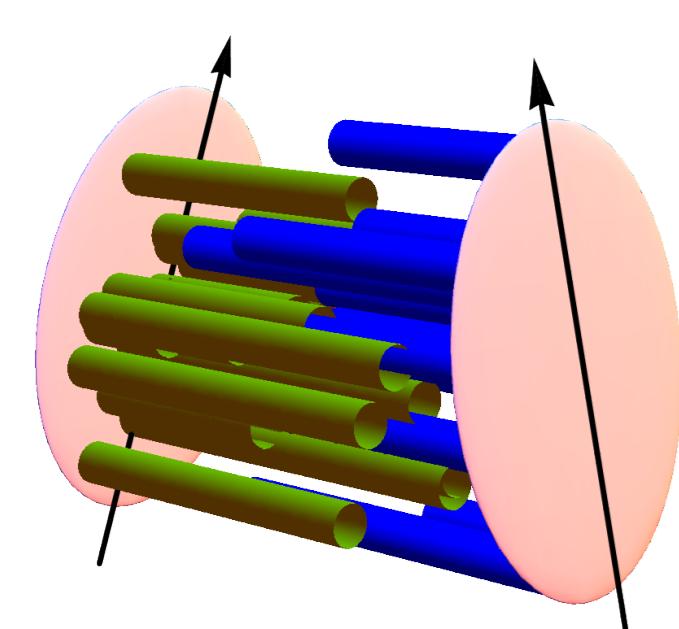


About half of the experimental effect explained by the model

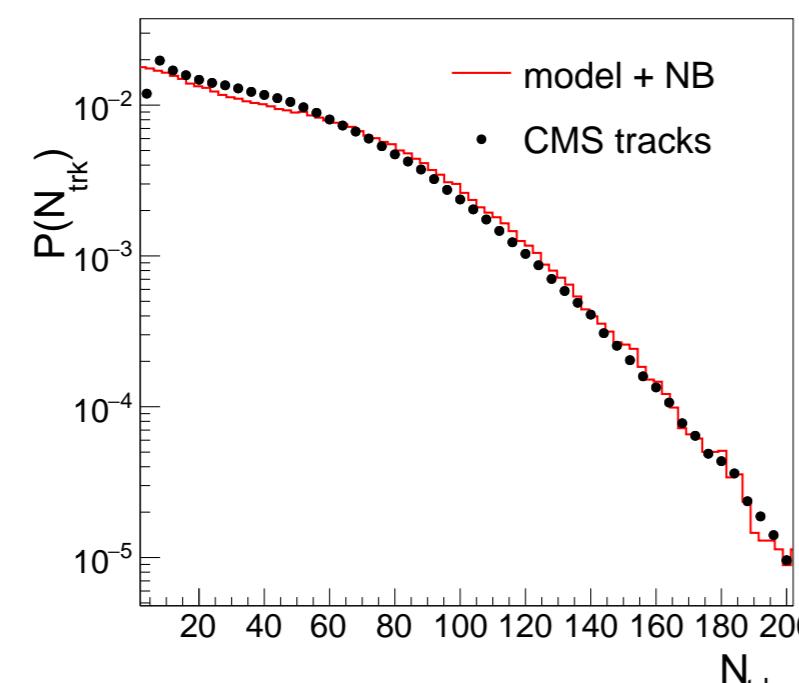
Fluctuating length

→ More fluctuation needed for decorrelation

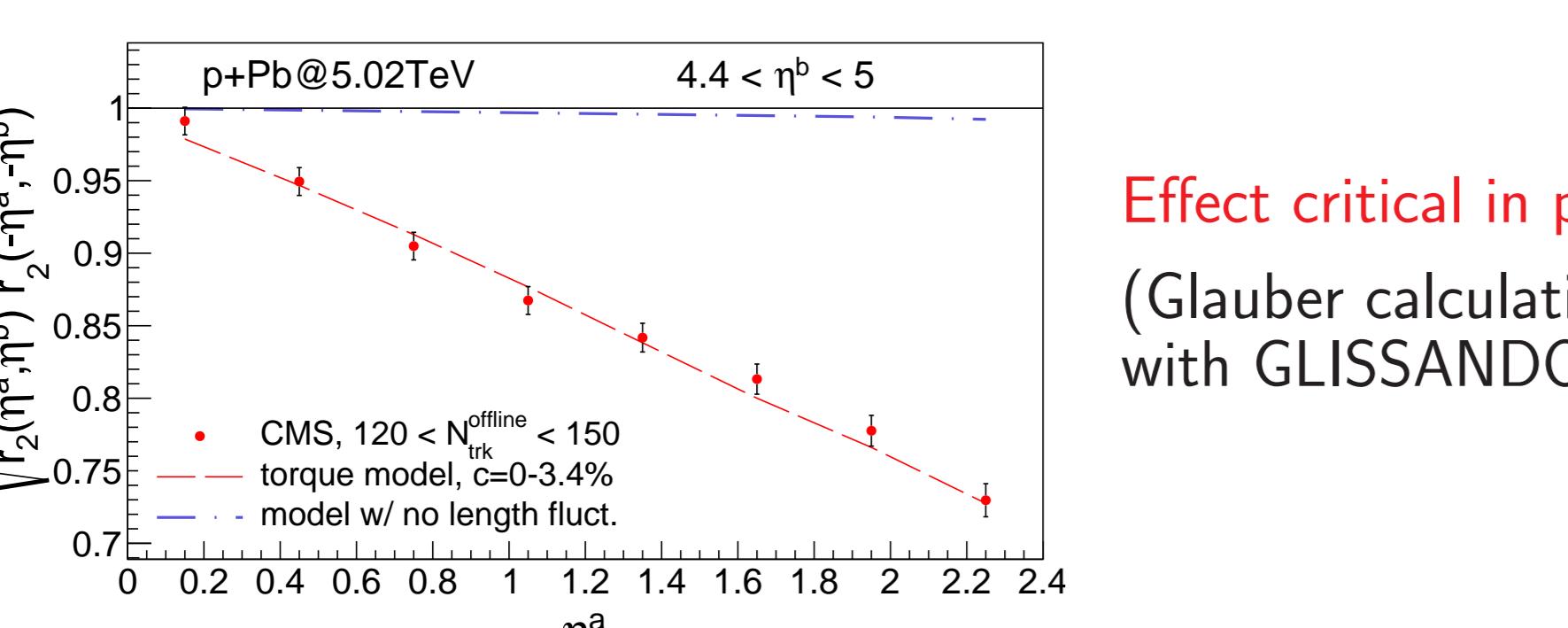
Fluctuating rapidity of tubes [3]



Multiplicity fluctuations in p+Pb are reproduced

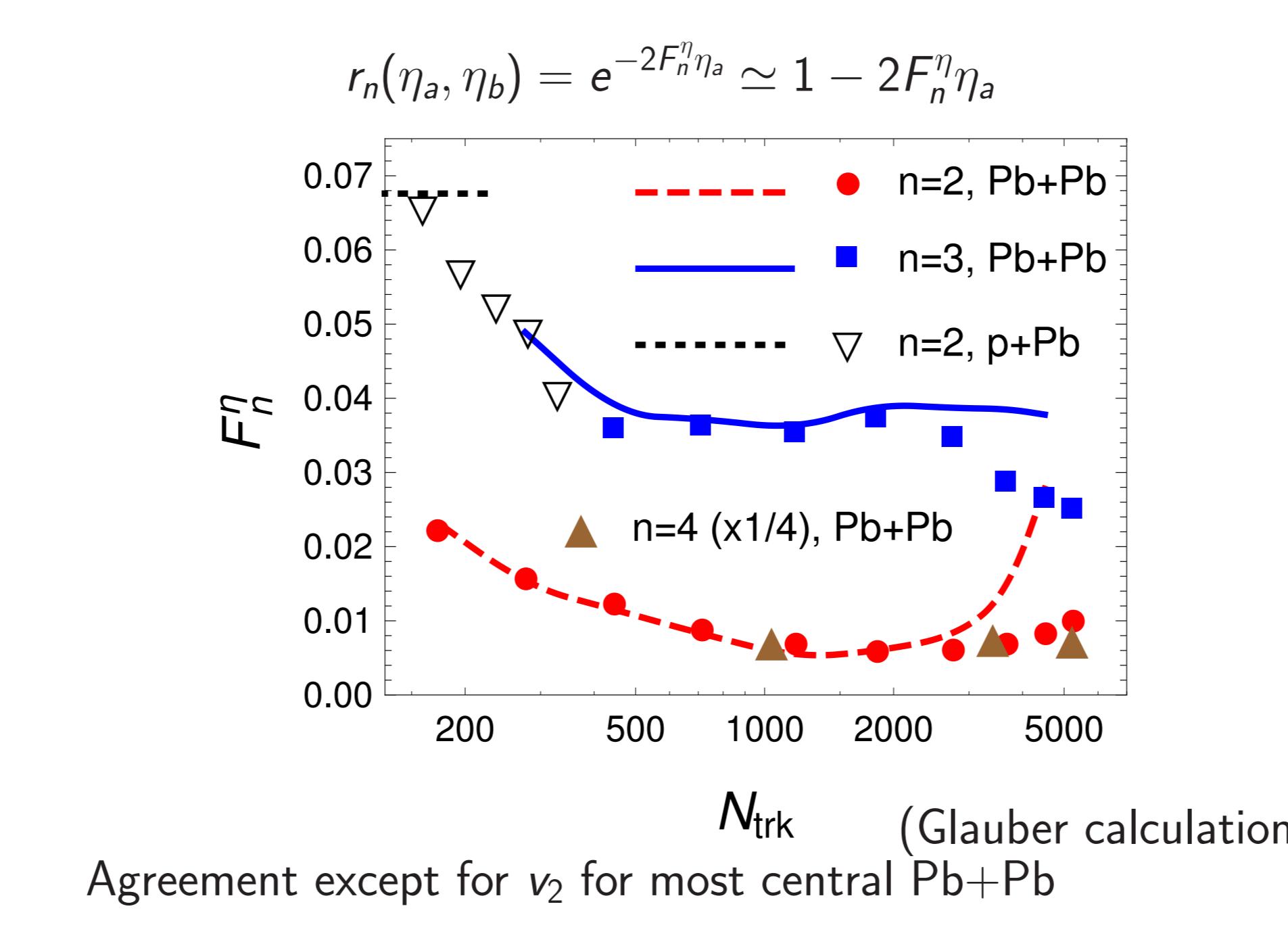


Comparison to CMS, p+Pb



Effect critical in p+Pb
(Glauber calculation with GLISSANDO)

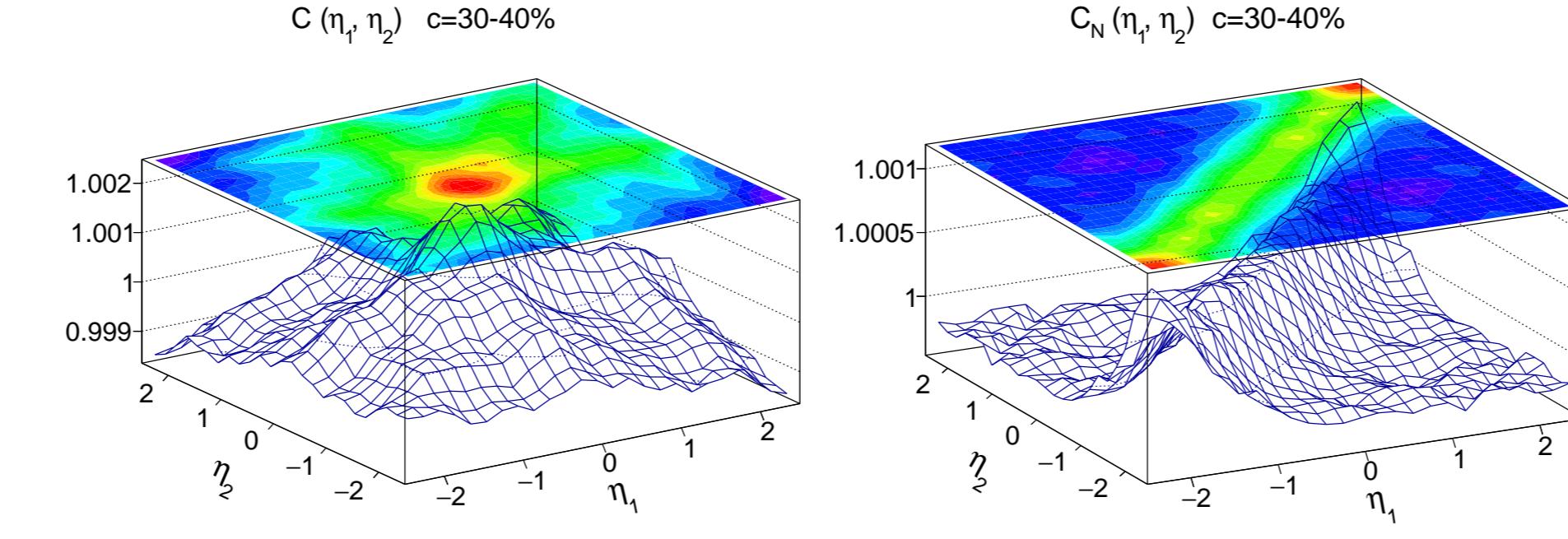
Slope coefficient



Pseudorapidity correlations

$$C(\eta_1, \eta_2) = \frac{S(\eta_1, \eta_2)}{B(\eta_1, \eta_2)}, \quad C_N(\eta_1, \eta_2) = \frac{C(\eta_1, \eta_2)}{C_p(\eta_1)C_p(\eta_2)}$$

with $C_p(\eta_1) = \frac{1}{2Y} \int_{-Y}^Y C(\eta_1, \eta_2) d\eta_2$



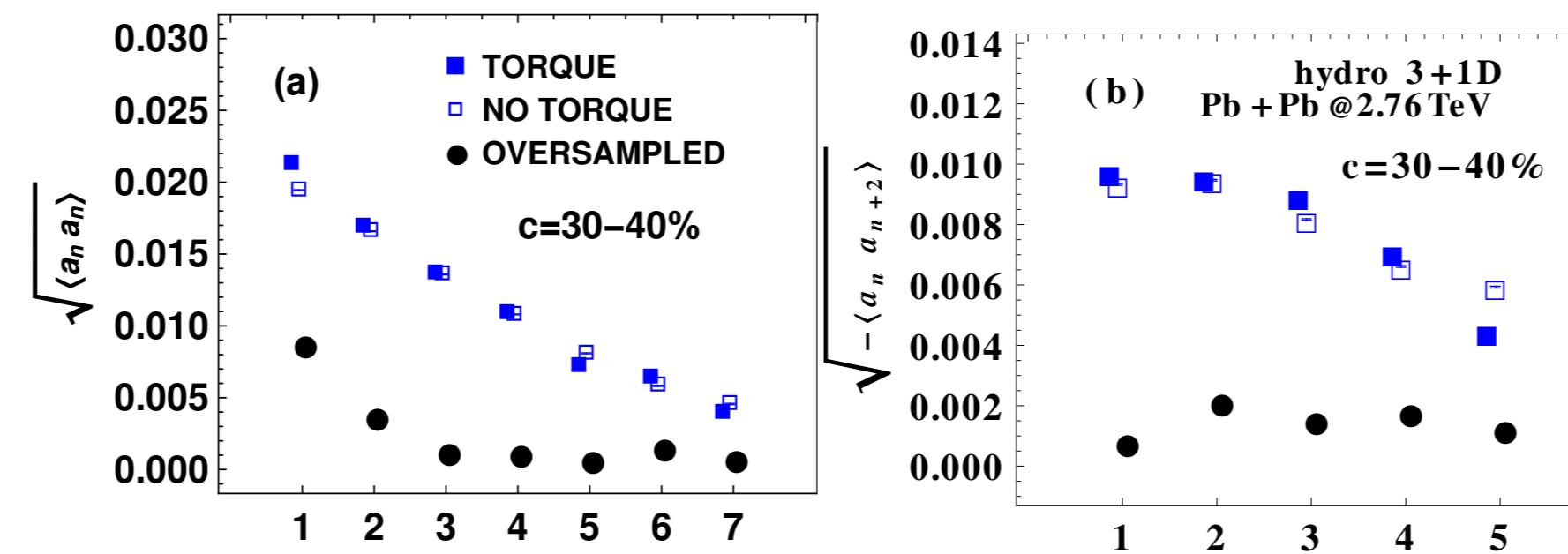
Note that passing from C to C_N is not innocuous; it generates the saddle form (this effect appears on purely mathematical grounds also in toy functions)

Expansion in the Legendre polynomials

As proposed in [8], one defines

$$\langle a_n a_m \rangle = \int_{-Y}^Y \frac{d\eta_1}{Y} \int_{-Y}^Y \frac{d\eta_2}{Y} C(\eta_1, \eta_2) T_n\left(\frac{\eta_1}{Y}\right) T_m\left(\frac{\eta_2}{Y}\right),$$

where $T_n\left(\frac{\eta}{Y}\right) = \sqrt{\frac{2n+1}{2}} P_n(x)$, and $P_n(x)$ are the Legendre polynomials [7]



Our model used in above plots does not yet include the fluctuating length of the sources. It gives about 60-70% of the experimental numbers. The result comes predominantly from "non-low" resonance decays

Additional correlations in the initial state move up the model predictions [9]

A simple way to compute $\langle a_n a_m \rangle$

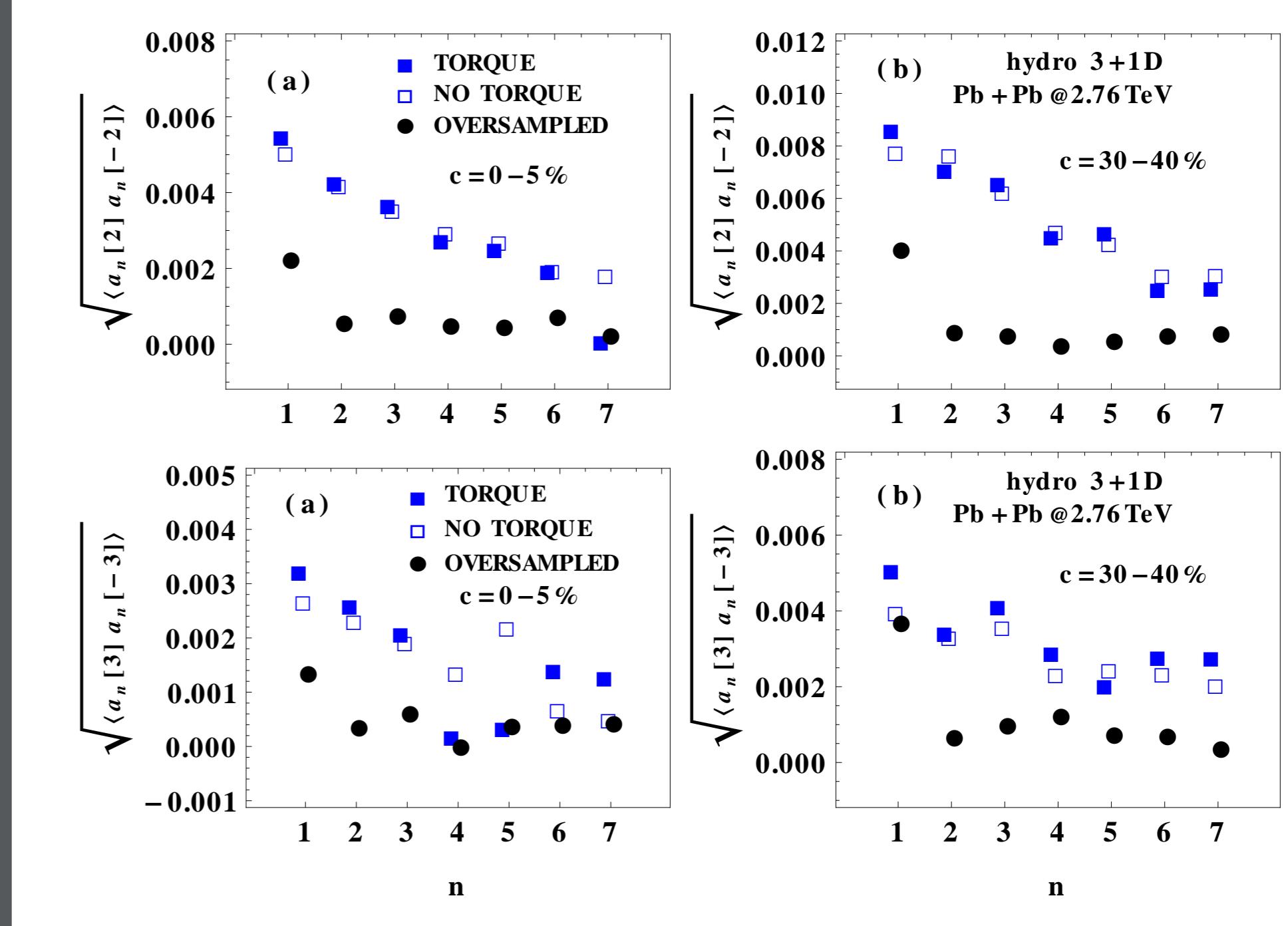
$$\begin{aligned} \langle a_n a_m \rangle &= \left\langle \sum_{a \neq b} \frac{T_n\left(\frac{\eta_a}{Y}\right)}{Y \langle N(\eta_a) \rangle} \frac{T_m\left(\frac{\eta_b}{Y}\right)}{Y \langle N(\eta_b) \rangle} \right\rangle = \\ &\left\langle \sum_a \frac{T_n\left(\frac{\eta_a}{Y}\right)}{Y \langle N(\eta_a) \rangle} \sum_b \frac{T_m\left(\frac{\eta_b}{Y}\right)}{Y \langle N(\eta_b) \rangle} \right\rangle - \left\langle \sum_a \frac{T_n\left(\frac{\eta_a}{Y}\right)}{Y \langle N(\eta_a) \rangle} \frac{T_m\left(\frac{\eta_a}{Y}\right)}{Y \langle N(\eta_a) \rangle} \right\rangle \end{aligned}$$

- independent of binning and requiring a single loop over particles

Higher harmonics

Correlation coefficients for the k -th order harmonic flow:

$$\langle a_n[k] a_m[-k] \rangle = \left\langle \sum_{a \neq b} \frac{T_n\left(\frac{\eta_a}{Y}\right) e^{ik\phi_a} T_m\left(\frac{\eta_b}{Y}\right) e^{-ik\phi_b}}{Y \langle N(\eta_a) \rangle Y \langle N(\eta_b) \rangle} \right\rangle$$



Higher cumulants

To make the results insensitive to non-flow effects (which, as we have shown, are large), it would be very interesting to analyze the data with higher-order cumulants [10], e.g.

$$\begin{aligned} \langle a_k^4 \rangle_c &= \left\langle \sum_{a,b,c,d} \frac{T_k\left(\frac{\eta_a}{Y}\right)}{Y \langle N(\eta_a) \rangle} \frac{T_k\left(\frac{\eta_b}{Y}\right)}{Y \langle N(\eta_b) \rangle} \frac{T_k\left(\frac{\eta_c}{Y}\right)}{Y \langle N(\eta_c) \rangle} \frac{T_k\left(\frac{\eta_d}{Y}\right)}{Y \langle N(\eta_d) \rangle} \right\rangle \\ &- 3 \left\langle \sum_{a,b} \frac{T_k\left(\frac{\eta_a}{Y}\right)}{Y \langle N(\eta_a) \rangle} \frac{T_k\left(\frac{\eta_b}{Y}\right)}{Y \langle N(\eta_b) \rangle} \right\rangle, \end{aligned} \quad (1)$$

Conclusions

- The predicted torque effect [1] (decorrelation of event-plane orientations along pseudorapidity) has been observed experimentally
- To explain it in p+Pb collisions, one needs extra longitudinal fluctuations in the early stage; these are naturally provided with the fluctuations of lengths of sources along pseudorapidity [4]
- The two-particle correlation function in rapidity, $C_N(\eta_1, \eta_2)$, carries along sensitivity to non-flow effects (resonance decays shown here, jets, charge conservation, ...) Analyses based on higher-order cumulants would reduce/eliminate these effects

References

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Acknowledgements

Supported by the Polish Ministry of Science and Higher Education, by the National Science Center (grants DEC-2012/05/B/ST2/02528 and DEC-2012/06/A/ST2/00390), and by PL-Grid Infrastructure