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Multivariate cumulants in flow analyses: The Next Generation

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When two heavy ions collide at ultrarelativistic energies a very rich and non-trivial sequence of stages emerges in the evolution of the produced fireball. An important ongoing program in the field is the development of new observables and analysis techniques for anisotropic flow measurements, which would be sensitive only to one particular stage at a time in the heavy-ion evolution (e.g. only to the initial stages, to the deconfined Quark-Gluon plasma stage, etc.). In addition, the new observables which can disentangle the effects of different system properties (e.g. shear and bulk viscosities) are called for. In this contribution, we introduce new experimental methods and observables for anisotropic flow analyses in high-energy physics, which address these open questions.

We start by presenting the theory behind the recently developed observables dubbed higher order Symmetric Cumulants, whose development introduced a new paradigm in the field on how multivariate cumulants need to be used in flow analyses [1]. Since these are the first multivariate cumulants of flow amplitudes, by definition their measurements extract information that is not accessible to the previous lower order measurements. When it comes to fluctuations, these observables have revealed the new possible patterns of event-by-event flow fluctuations, which cannot be described with previous results. The current state-of-the-art in the field is that there are no observables which can separate effects of shear and bulk viscosities — since higher order Symmetric Cumulants exhibit in mid-central heavy-ion collisions different sensitivity to the isotropic fluctuations (predominantly sensitive to bulk viscosity) and shape fluctuations (predominantly sensitive to shear viscosity), they are the pioneering work in that direction.

Next, we present the new estimator for the improved measurements of symmetry plane correlations [2]. We demonstrate that the previous measurements, obtained with the standard Event Plane and Scalar Product methods are plagued by large systematic biases, and present how our new estimator removes them. We discuss the particular use case of constraining the true event-by-event symmetry plane correlations, which are inaccessible to the other methods.

Finally, we generalize in [3] the new paradigm for flow analysis with cumulants introduced in [1] for other observables of interest. We attempt for the first time to reconcile the strict mathematical formalism of multivariate cumulants, with the traditional usage of cumulants in the last two decades in this field. We demonstrate that, somewhat surprisingly, such reconciliation is not feasible in most of the cases. For instance, we prove that a widely used observable in this context, $v_n\{4\}$, fails to satisfy the mathematical properties of cumulants. As a consequence, this study yields to the next generation of multivariate cumulants to be used in flow analyses, which satisfy all mathematical properties of cumulants [3].

[1] C. Mordasini, AB, D. Karakoc, and S. F. Taghavi, *"Higher order Symmetric Cumulants,"* Phys. Rev. C **102**, 024907 (2020), arXiv:1901.06968 [nucl-ex].

[2] AB, M. Lesch, S. F. Taghavi, *"New estimator for symmetry plane correlations in anisotropic flow analyses,"* Phys. Rev. C **102**, 024910 (2020), arXiv:2004.01066 [nucl-ex].

[3] AB, M. Lesch, C. Mordasini, S. F. Taghavi, *"Multivariate cumulants in flow analyses: The Next Generation,"* work in progress (to be posted on arXiv and submitted for publication before the conference).

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