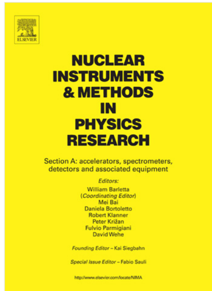
Accepted Manuscript



A general procedure for detector-response correction of higher order cumulants

Toshihiro Nonaka, Masakiyo Kitazawa, ShinIchi Esumi

PII: S0168-9002(18)30957-4
DOI: https://doi.org/10.1016/j.nima.2018.08.013
Reference: NIMA 61054

To appear in: *Nuclear Inst. and Methods in Physics Research, A*

Received date : 25 May 2018; Revised date : 8 July 2018; Accepted date : 6 August 2018

Please cite this article as:, A general procedure for detector-response correction of higher order cumulants, *Nuclear Inst. and Methods in Physics Research, A* (2018), https://doi.org/10.1016/j.nima.2018.08.013

J-PARC-TH-0118

A general procedure for detector-response correction of higher order cumulants

Toshihiro Nonaka,[1,2,*] Masakiyo Kitazawa,[3,4,†] and ShinIchi Esumi[2,‡]

[1] *Key Laboratory of Quark & Lepton Physics (MOE) and Institute of Particle Physics, Central China Normal University, Wuhan 430079, China*
[2] *Tomonaga Center for the History of the Universe, University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
[3] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[4] *J-PARC Branch, KEK Theory Center, Institute of Particle and Nuclear Studies, KEK, 203-1, Shirakata, Tokai, Ibaraki, 319-1106, Japan*

(Dated: July 8, 2018)

We propose a general procedure for the detector-response correction (including efficiency correction) of higher order cumulants observed by the event-by-event analysis in heavy-ion collisions. This method makes use of the moments of the response matrix characterizing the property of a detector, and is applicable to a wide variety of response matrices such as those having non-binomial responses and including the effects of ghost tracks. A procedure to carry out the detector-response correction of realistic detectors is discussed. In test analyses, we show that this method can successfully reconstruct the cumulants of true distribution for various response matrices including the one having multiplicity-dependent efficiency.

I. INTRODUCTION

Fluctuations are important observables in relativistic heavy-ion collisions for the search for the QCD critical point and the phase transition to the deconfined medium [1, 2]. In particular, non-Gaussianity of fluctuations characterized by the higher order cumulants is believed to be sensitive to these phenomena [3–5]. Active measurements of fluctuation observables have been performed by the event-by-event analyses at RHIC [6–9], the LHC [10, 11], and the NA61 [12] and HADES [13] Collaborations. Future experimental facilities, J-PARC [14], FAIR [15], and NICA [16], will also contribute this subject.

In relativistic heavy-ion collisions, the cumulants of a particle-number distribution are obtained from an event-by-event histogram of the particle number observed experimentally. However, because of the imperfect capability of detectors the experimentally-observed event-by-event histogram is modified from the true distribution, and accordingly their cumulants are also altered by these artificial effects. In the experimental analysis, this effect has to be corrected. In this paper we call this procedure as the detector-response correction.

Compared to standard observables given by expectation values, the detector-response correction of the cumulants higher than the first order is more involved, because the change of a distribution function modifies its cumulants in a non-trivial way [1]. So far, the detector-response correction has been discussed by focusing on the efficiency correction, i.e. the correction for the effects of the loss of particles at the measurement. It has been established that the correction can be carried out if one assumes that the probability that the detector observes a particle (efficiency) is uncorrelated for individual particles. In this case, the detector's response is described by the binomial distribution [1, 17], that we call the binomial model [17–24]. Recently, using the method proposed in Ref. [24], the analysis of the net-proton number cumulants is realized up to sixth order [25].

The assumption for the binomial model, however, is more or less violated at typical detectors in heavy-ion collisions. First, the multiplicity dependence of the efficiency of realistic detectors [9, 13, 26] suggests the existence of the correlations between efficiencies of different particles [27]. Even worse, typical detectors sometimes measure ghost tracks, i.e. non-existing particles. The estimate on systematic uncertainty arising from these effects is important for reliable experimental analyses of higher order cumulants.

One of the general procedures for the detector-response correction is the unfolding method [28–30]. This method analyzes the true *distribution function* from experimental results and knowledge on the detector. Strictly speaking, however, the reconstruction of the true distribution function is an ill-posed problem. The estimate on the systematic uncertainty of the final results is a nontrivial task in this method, and a large numerical cost is required for the iterative analysis to obtain the distribution. Furthermore, the analysis of the distribution itself seems redundant because the cumulants are relevant quantities for many purposes. It is desirable to have a method which enables the analysis of the cumulants directly without using the distribution.

In the present study, we propose a new method to perform the detector-response correction of cumulants directly. In this method, we relate the moments of true and observed distributions without using the distribution explicitly. This method can solve the detector-response correction exactly for a wide variety of detector's responses; for example, those parametrized by the hypergeometric distribution and the binomial model with fluctuating probability. By introducing an approximation with a truncation this method can also deal with the correction of realistic detectors whose response is estimated only by Monte Carlo simulations. We demonstrate by explicit numerical analyses that the correction by this method can be carried out successfully for non-binomial response matrices and the response matrix representing multiplicity-dependent efficiency.

This paper is organized as follows. In Sec. II, we discuss a general procedure for the detector-response correc-

* tnonaka@rcf.rhic.bnl.gov
† kitazawa@phys.sci.osaka-u.ac.jp
‡ esumi.shinichi.gn@u.tsukuba.ac.jp