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CORRECTING FOR DETECTOR EFFECTS IN HIGH-MULTIPLICITY EVENTS WITH THE HBOM METHOD*

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Measurements of particle multiplicities in high-energy collisions may be affected by various detector effects which distort the values of measured observables. We present tests of a procedure of correcting for these effects called the HBOM method which is an alternative to unfolding procedures based on inverting the response matrix of the detector. Studies of the method are performed using a sample of high-multiplicity Pb+Pb collisions generated at $\sqrt{s_{NN}} = 2.76$ TeV with the HIJING generator. The HBOM method is tested on factorial moments of the charged particle distribution distorted by a track reconstruction efficiency similar to those observed in high-energy experiments. Closure tests show that the method is able to correct factorial moments very well in the whole considered pseudorapidity range.

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1. Introduction

Measurements of the multiplicities of particles produced in high-energy collisions are susceptible to detector effects such as:

— inefficiency in the detection of particles,

— incorrectly reconstructed tracks (called fakes),

— contributions from secondary particles produced in decays of primary particles or due to their interaction with the detector material.

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The first effect results in an underestimation of particle multiplicities, while the other effects lead to higher values of multiplicities than the true ones.

In particular, high-multiplicity events as produced *e.g.* in heavy-ion collisions are affected by these. In order to obtain correct multiplicities, the raw measured values have to be corrected for these effects.

2. Unfolding

In general, the measurement with a detector can be expressed in a discrete form as

$$\boldsymbol{y} = \boldsymbol{A}\boldsymbol{x}\,, \tag{1}$$

where $\boldsymbol{y}$ is a histogram representing the distribution of an observable measured by the detector, $\boldsymbol{x}$ is a histogram representing the true distribution of this observable and $\boldsymbol{A}$ is the response matrix of the detector.

A commonly used set of correction procedures are unfolding methods based on the inversion of the response matrix, see *e.g.* [1] and references therein. To correct an observable for detector effects, its measured distribution has to be simply multiplied by the inverted response matrix $\boldsymbol{A}^{-1}$,

$$\boldsymbol{x} = \boldsymbol{A}^{-1}\boldsymbol{y}\,. \tag{2}$$

The response matrix and its inverse are obtained using a simulation of the studied physics process where both the true and measured distributions of an observable are known. However, these methods are not suitable in cases when the measured distribution is narrower in the simulation than in experimental data, because then it is not possible to correct the observable in the full measured range.

3. Hit Backspace Once More method

An approach alternative to unfolding procedures, called the Hit Backspace Once More (HBOM) method, was first proposed in Ref. [2]. The method relies only on a correct estimation of the track reconstruction efficiency and contributions from fake tracks and secondary particles. The main idea of the HBOM method is to repeatedly imitate detector effects, either estimated from Monte Carlo simulation or extracted from data, on the analyzed sample and extrapolate this behavior back to a point, where the data sample can be considered as unaffected by detector effects. The HBOM method was used in measurements of angular correlations in *pp* collisions by the ATLAS experiment [3], as well as in measurements of jet suppression in Pb+Pb collisions by the ALICE experiment [4].

In order to correct measured observables for detector effects, the following procedure is applied:

— The 0^{th} iteration of the method is defined by measuring the observable using all reconstructed tracks which satisfy quality criteria specific to the analysis;

— Tracks are randomly removed from the sample with the same probability as they are lost due to inefficiencies in track reconstruction;

— The measurement of the observable is repeated on the reduced sample of tracks which completes a full iteration of the method;

— Several further iterations of random track removing and measuring the observable are performed;

— The distribution of the observable as a function of the iteration number is fitted with a polynomial or exponential function;

— An extrapolation of the fitted function to the iteration -1 gives an estimate of the true value of the observable.

The imitated application of detector effects on the sample of reconstructed tracks is achieved by comparing the reconstruction efficiency for a given track ε_i to a random number r_i generated uniformly between 0 and 1

$$\varepsilon_i > r_i\,. \tag{3}$$

Tracks which do not pass this condition are removed from the sample. In general, the n^{th} iteration can be obtained from the previous iteration by applying the same condition or directly from the 0^{th} iteration using a modified version of the rejection condition

$$\varepsilon_i^n > r_i\,. \tag{4}$$

This modification allows also to generalize the HBOM method to non-integer iterations. The contributions from fakes and secondary particles can be accounted for by increasing the efficiency value correspondingly.

4. Performance studies

To study the performance of the HBOM method, we use data from Pb+Pb collisions generated at a center-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 2.76$ TeV with the HIJING generator [5]. From a sample of 400 k collisions we select, according to the number of participating nucleons, the 10% most central ones in which very large particle multiplicities are produced. The resulting distribution of the charged particle multiplicity is presented in figure 1 for particles with a transverse momentum $p_{\mathrm{T}} > 500$ MeV emitted in the pseudorapidity region $|\eta| < 2.5$. These requirements correspond to selection criteria used in analyses of Pb+Pb collisions in the ATLAS experiment. It can be noticed that, indeed, very high particle multiplicities of up to 4500 charged particles per event are reached.

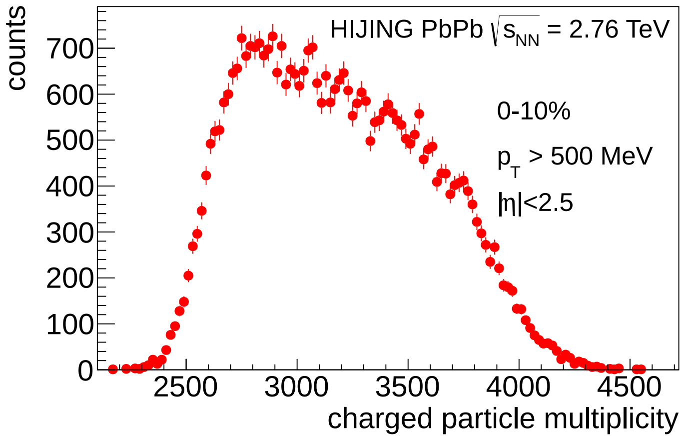

Fig. 1. Distribution of the charged particle multiplicity in the 10% most central collisions generated.

Example observables to be corrected for detector inefficiencies are factorial moments of the particle multiplicity distribution in B pseudorapidity bins defined as

$$F_{i_1,\dots,i_B} \equiv \left\langle \prod_{j=1}^{B} \frac{n_j!}{(n_j - i_j)!} \right\rangle , \tag{5}$$

where n_j denotes the multiplicity of charged particles emitted into a given pseudorapidity interval. The sum of indices $i_1, \dots, i_B$ defines the rank of a factorial moment. For three pseudorapidity bins, the above equation can be expressed as

$$F_{i_\mathrm{L},i_\mathrm{C},i_\mathrm{R}} \equiv \left\langle \frac{n_\mathrm{L}!}{(n_\mathrm{L} - i_\mathrm{L})!} \frac{n_\mathrm{C}!}{(n_\mathrm{C} - i_\mathrm{C})!} \frac{n_\mathrm{R}!}{(n_\mathrm{R} - i_\mathrm{R})!} \right\rangle , \tag{6}$$

where L, C and R denote the left, central and right pseudorapidity interval, respectively.

In our studies, we focus on the factorial moments F_{100} and F_{120} which are measured in bins having a width of 0.2 pseudorapidity units each. The left and right bin are placed symmetrically around $\eta = 0$ with the distance between their centers varying from 0.4 to 4.8 pseudorapidity units.

We assume a track reconstruction efficiency described by a function of track transverse momentum p_{T} and pseudorapidity η

$$\varepsilon\left(p_{\mathrm{T}},\eta\right)=\frac{2}{\pi}\tan^{-1}\left(\frac{p_{\mathrm{T}}-80\text{ MeV}}{150\text{ MeV}}\right)\exp\left(-\frac{\eta^2}{36}\right) \tag{7}$$

which simulates a real track reconstruction efficiency as observed in high-energy physics experiments, *e.g.* the ATLAS experiment. Figure 2 presents the assumed track reconstruction efficiency which is low in the low-p_{T} region and reaches a plateau for high-p_{T} tracks. It is also higher in the central pseudorapidity region than in the outward regions.

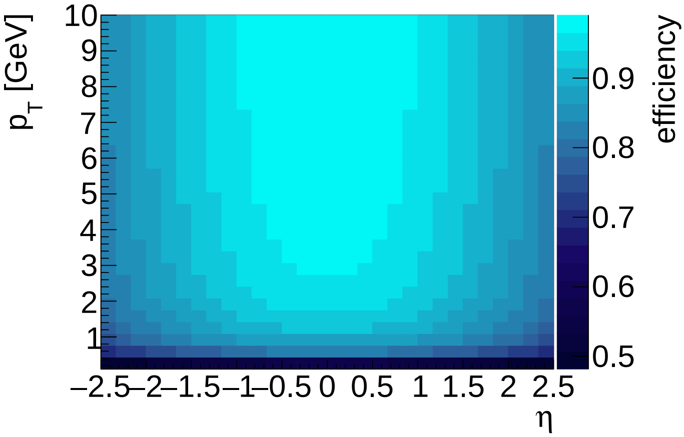

Fig. 2. Track reconstruction efficiency used in performance studies of the HBOM method as a function of track p_{T} and η.

The performance of the HBOM method is studied in closure tests which compare measured and corrected values of factorial moments from the detector level to generated ones. The detector level values are obtained after removing generated particles according to the track reconstruction efficiency and are corrected using the HBOM method with two types of fitting functions: 3^{rd} order polynomials and exponential functions $\exp\left(ax^2+bx+c\right)+d$.

Figure 3 presents extrapolation fits of 3^{rd} order polynomials used to correct factorial moments in the central pseudorapidity region $|\eta|<0.3$. It can be noticed that the generated values of factorial moments are reproduced very well in these intervals. On the other hand, the closure tests performed as a function of the distance in pseudorapidity $\Delta\eta$ between the centers of the left and right interval (presented in figure 4) show that the corrected factorial moments of rank two and three are shifted with respect to truth values. This non-closure becomes larger with $\Delta\eta$.

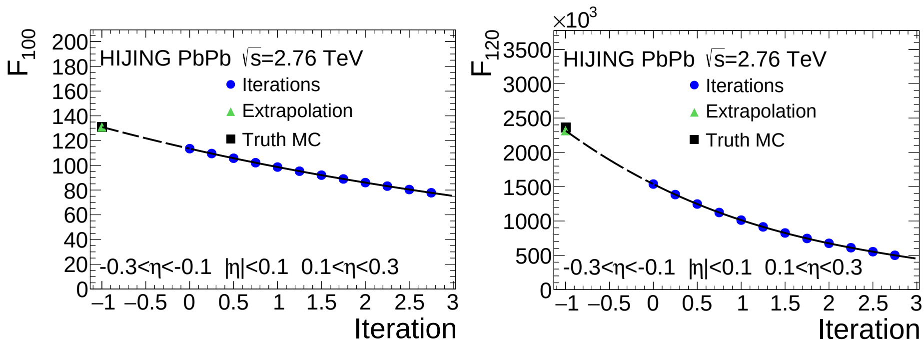

Fig. 3. Extrapolation fits of 3[rd] order polynomials used to unfold the true value of selected factorial moments of the charged particle distribution with $p_{\mathrm{T}} > 500$ MeV in the pseudorapidity intervals $-0.3 < \eta < -0.1$, $|\eta| < 0.1$, $0.1 < \eta < 0.3$.

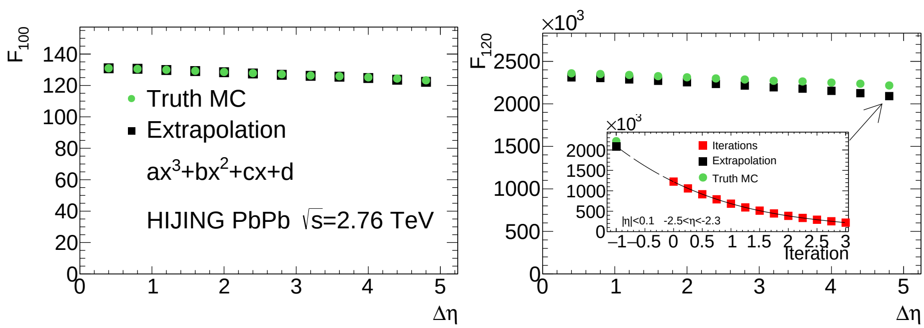

Fig. 4. Closure tests of selected factorial moments as a function of the distance in pseudorapidity $\Delta\eta$ between centers of the left and right interval. Extrapolation fits of 3[rd] order polynomials are used to correct values measured at the detector level. The corrected values (full dots) are compared to generated ones (open circles).

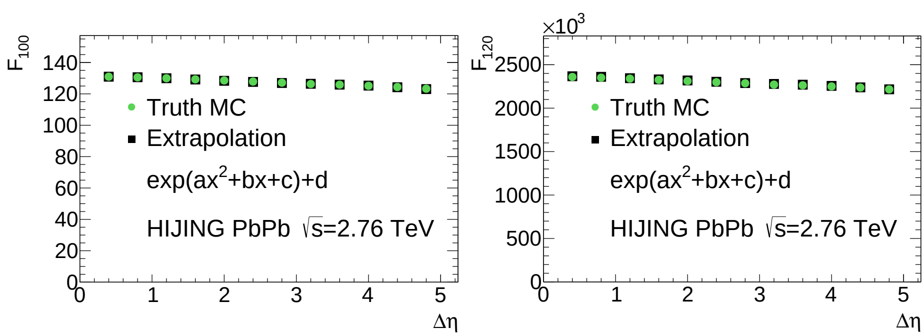

Fig. 5. Closure tests of selected factorial moments as a function of the distance in pseudorapidity $\Delta\eta$ between centers of the left and right interval. Extrapolation fits of exponential functions $\exp\left(ax^2 + bx + c\right) + d$ are used to correct values measured at the detector level. The corrected values (full dots) are compared to generated ones (open circles).

In figure 5, closure tests are presented for factorial moments corrected using fits of exponential functions $\exp\left(ax^2+bx+c\right)+d$. The performance of the HBOM method is much better with this kind of function, as the true values of all studied factorial moments are reproduced very well in the whole pseudorapidity range.

5. Summary

We have presented an application of the procedure of correcting measurements of particle multiplicities based on the HBOM method. The procedure is an alternative to unfolding techniques based on inverting the response matrix of the detector. Studies of the method are performed using a sample of high-multiplicity Pb+Pb collisions generated at $\sqrt{s_{NN}} = 2.76$ TeV with the HIJING generator. Performance tests of the HBOM method are conducted using factorial moments of the charged particle distribution with $p_{\mathrm{T}} > 500$ MeV in the pseudorapidity range $|\eta| < 2.5$. The values of these observables are distorted at detector level by a track reconstruction efficiency similar to those observed in high-energy experiments. Closure tests, which compare detector level values corrected with the HBOM method to generated ones, are performed. The conclusion is that the method is able to correct factorial moments very well in the whole considered pseudorapidity range, if exponential functions $\exp\left(ax^2+bx+c\right)+d$ are used in extrapolation fits.

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