Detecting multiparton interactions in minimum-bias events at ALICE

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Abstract
The observed long tail of high-multiplicity events has questioned the current modelizations for the charged-particle multiplicity distribution. It has been interpreted as an indirect observation of multiparton interactions becoming increasingly important at higher collision energies. The ALICE detector will measure the frequency of very high-multiplicity events. The performance for measuring the charged-particle multiplicity distribution in ALICE is presented.

1 Introduction

Being at LHC the heavy-ion dedicated experiment, ALICE – A Large Ion Collider Experiment [1] – has some unique capabilities, complementary to those of the dedicated p-p experiments. Its 18 detector systems have been designed to provide high-momentum resolution as well as excellent Particle Identification (PID) over a broad momentum range (in particular with very low p_T-cutoff) and up to the highest multiplicities predicted for LHC.

Besides running with Pb ions, the physics programme includes collisions with lighter ions, lower energy running and dedicated proton-nucleus runs. ALICE will also take data with proton beams at varying energies, up to the top LHC energy, to collect reference data for the heavy-ion programme and to address several QCD topics for which ALICE is complementary to the other LHC detectors.

The charged-particle multiplicity distribution is among the measurements which are expected to shed light on the dynamics of multiparton interactions. We recall here the results of a study for evaluating the performances of measuring the charged-particle multiplicity distribution with the ALICE detector.

The frequency of non-jet events with very high multiplicity observed by CDF [2] has questioned the models for multiparticle production. Multiparton scattering increases the number of soft particles both in minimum-bias events and in the underlying event associated with high-p_t jets. It is expected that multiparton interactions are responsible for the high-multiplicity tails that break Koba-Nielsen-Olesen (KNO) [3] scaling and become significantly more important at LHC energies. The ALICE detector can make use of its very low-p_T cutoff ($p_T \approx 100$ MeV) and of its high-multiplicity trigger to investigate the production of large numbers of soft particles in minimum-bias events.

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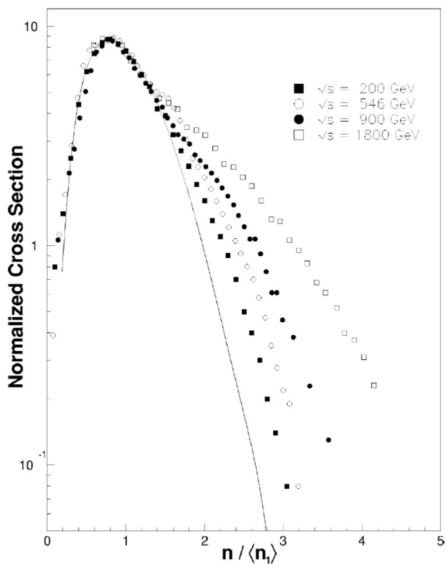

Fig. 1: Comparison of multiplicity distributions at different colliding energies normalized at their maximum value, taken from [4]. The explanation is in the text.

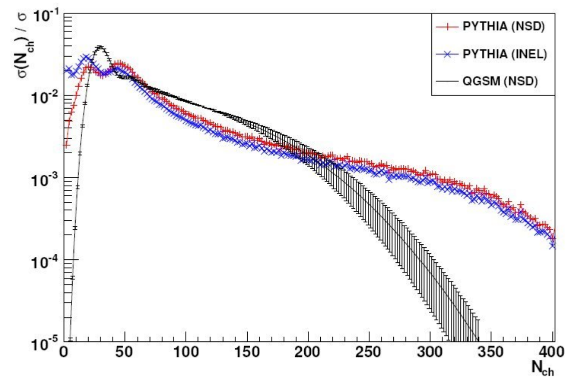

Fig. 2: Predictions for the normalized multiplicity distribution in full phase space for p-p collisions at $\sqrt{s}$ = 14 TeV. The distribution given by the PYTHIA event generator (red and blue for non-single diffractive and inelastic events respectively) is compared to a calculation based on the QGSM framework.

2 Multiplicity distribution and multiparton interactions at ALICE

For p-p and p-$\bar{\text{p}}$ collisions at low center-of-mass energies, KNO scaling describes well the multiplicity distribution. As was first observed by UA5 (SPS) and E735 (Tevatron) experiments, thus for energies $\sqrt{s} > 200$ GeV, increasing the energy of the collision system leads to increasingly significant deviations from KNO scaling. This is shown in Figure 1, where it is assumed that the part of the distribution obeying KNO scaling is due to single-parton interactions, while the deviations are due to multiparton contributions. In this plot the number of particles n on the x-axis has been scaled by the average number of particles $\langle n_1 \rangle$, calculated from the solid curve, obtained by fitting the multiplicity at low energy using a polynomial fit in the quantity $x = n/\langle n_1 \rangle$.

Among the different explanations of this fact, it has been proposed in the framework of the Dual Parton Model (DPM) [5] and the Quark Gluon String Model (QGSM) [6] of soft hadronic interactions, that the parts of the distributions that do not scale are due to multiparton interactions [7].

2.1 Multiplicity analysis

The ALICE detector will perform measurements of the multiplicity distribution in pseudorapidity intervals up to $|\eta| < 1.4$. We expect that comparison of model predictions with these measurements will provide valuable information for understanding multiple particle production and for tuning the multiparton models included in different event generators. Figure 2 compares the normalized multiplicity distribution for a PYTHIA [8] simulation [1] to a QGSM model prediction

[1] The version used is 6.2.14 with the so-called "ATLAS tune" [9].

showing the large inconsistency between the two predictions.

The initial estimate of the multiplicity distribution at ALICE will be determined by both, counting the SPD tracklets (combination of two clusters in the two innermost pixel layers) in the region $|\eta| < 1.4$, and counting the tracks reconstructed in the ALICE central barrel, in the region $|\eta| < 0.9$. In both cases a set of cuts is applied for rejecting secondaries.

From full detector simulation one can determine the probability R_{mt} that a collision with a true multiplicity t is measured as an event with the multiplicity m and, by varying t, one can fill the response matrix R, pictorially shown in Figure 3. In the ideal case of perfect knowledge of the response matrix R, and assuming it to be non-singular, the true multiplicity spectrum T can be obtained from the measured spectrum M by:

$$T = R^{-1}M. \tag{1}$$

In practice, the assumptions above do not hold and Eq. 1 generates severe artificial oscillations in the true spectrum; thus unfolding procedures need to be applied. Two unfolding procedures have been studied and evaluated for measurements of the multiplicity distribution in ALICE [10]. Bayesian unfolding [11] is an iterative procedure based on the following equation:

$$\tilde{R}_{tm} = \frac{R_{mt}P_t}{\sum_{t'} R_{mt'}P_{t'}}. \tag{2}$$

It relates the conditional probability $\tilde{R}_{tm}$ of a true multiplicity t given a measured value m to the elements of the response matrix R_{mt} and to the a priori probability P_t for the true value t; at each iteration the a priori probability is obtained from the following equation:

$$U_t = \frac{1}{\epsilon(t)} \sum_m M_m \tilde{R}_{tm}. \tag{3}$$

As initial a priori distribution the measured one can be used.

The second method, χ^2 minimization, e.g. used in [12], consists of finding the unfolded spectrum that minimizes a χ^2 function measuring the distance between measured and guessed spectra. It can be expressed by:

$$\chi^2(U) = \sum_m \left(\frac{M_m - \sum_t R_{mt}U_t}{e_m} \right)^2 + \beta P(U) \tag{4}$$

where e is the error on the measured spectrum M and $\beta P(U)$ is a regularization term to prevent high-frequency fluctuations.

2.2 Performance of the unfolding methods

The performance of the unfolding methods has been evaluated over a rich set of input distributions to check the behavior of unfolding for different shapes of the input spectra.

The performance is assessed by calculating the deviation between input and unfolded distributions in different regions of the distribution. The free parameters (e.g. the number of iterations and the weight of the smoothing in the case of the Bayesian method) have been choosen such that the result is not sensitive to them. Furthermore the residuals are evaluated, i.e. the difference between the measured distribution and the unfolded distribution convoluted with the response matrix. Calculating the residuals is an important cross-check which can be performed also on real data.

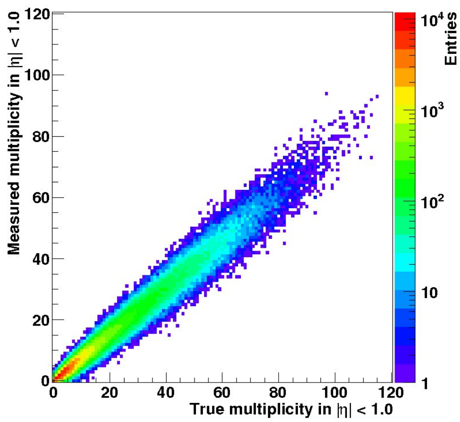

Fig. 3: Detector response matrix visualized by the number of tracklets found in the SPD vs. the number of generated primary particles in $|\eta| < 1$.

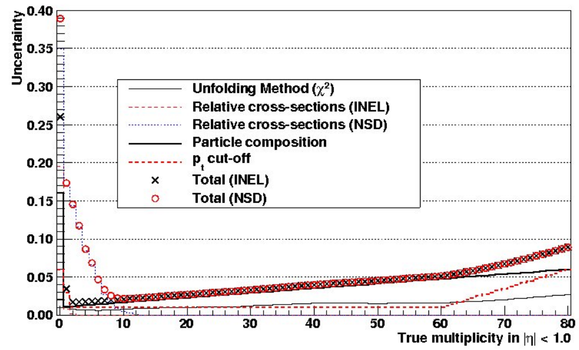

Fig. 4: Summary of the various systematic uncertainties as a function of multiplicity.

The comparison of unfolding results obtained with Bayesian unfolding and χ^2 minimization methods has shown that they agree within statistical errors; a similar comparison should also be performed for real data as a crosscheck that the unfolding works successfully on the measured data.

2.3 Systematic uncertainties

Unfolding using the response matrix is not sensitive to the shape of the multiplicity distribution, while it might be sensitive to the internal characteristics of the events and thus to assumptions made in the MC generator. Also effects like misalignment have an impact on the reconstruction and thus on the response matrix. Furthermore, the unfolding method itself causes a non-negligible systematic uncertainty. An estimate of these uncertainties is summarized in Figure 4, where they are shown as a function of the multiplicity; the values reported here refer to worst-case scenarios and are thus expected to reduce improving the knowledge of the detector (in particular through alignment and calibration) and of the characteristics of the event (like p_t spectrum and particle abundances). These uncertainties refer to a specific MC sample and distribution; they will need to be re-evaluated for the real spectrum.

3 Summary and conclusions

The ALICE detector will be able to measure the multiplicity distribution with high sensitivity in the central barrel rapidity range. Precise measurements for the different collision systems and colliding energies included in the ALICE physics programme are expected to contribute clarifying the role of multiparton interactions in shaping the multiplicity distribution. We expect also that the multiplicity distribution provided by ALICE will provide a reference against which models for multiple particle production and their parameters can be validated. We have presented a procedure for the measurement of the charged-particle multiplicity distribution with the ALICE detector and the evaluation of its performance.

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