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p–Pb collisions: Particle production and centrality determination in ALICE

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Abstract

Proton–nucleus collisions are an important part of the LHC heavy-ion program for their crucial role in disentangling cold nuclear matter effects from final state effects. Many initial state effects are expected to depend on the number of binary nucleon–nucleon collisions. The centrality determination is needed to provide a geometrical scale to study the underlying collision dynamics. Differently from nucleus–nucleus collisions, where the centrality can be determined by measuring charged particle multiplicity produced at midrapidity, in proton–nucleus collisions the presence of large fluctuations together with the reduced range of particle multiplicity generate a bias which depends on the kinematical range used for the event characterization.

Keywords: Heavy-ions; Cold nuclear matter; Binary scaling; Centrality; Nuclear modification factor

1. Introduction

Proton–lead collisions have been included in the LHC heavy-ion program for their reference role in the understanding and interpretation of the nucleus–nucleus data since they allow to disentangle final state effects, signature of the formation of a hot QCD matter, from initial state effects, already present in cold nuclear matter. However, the importance of p–Pb collisions at LHC has soon been recognized not only as a baseline for heavy-ion results. In fact, several measurements clearly indicate that p–Pb collisions cannot be explained by a simple incoherent superposition of proton–nucleon collisions, but rather indicate the presence of effects already observed in A–A collisions where they have been attributed to collective behaviors. Centrality

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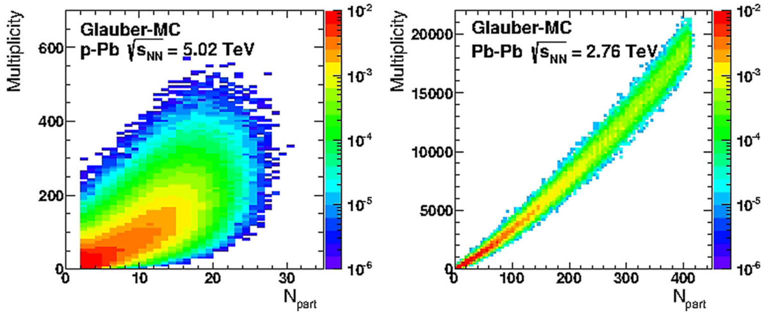

Fig. 1. Correlation between number of participating nucleons and particle multiplicity in p–Pb (left) and in Pb–Pb (right) from HIJING.

dependent studies require the classification of events in percentiles of the hadronic cross-section. In p–A collisions, typically the centrality has been determined from the number of low momentum particles emitted by the fragmenting nucleus or from the charged particle multiplicity. However, in contrast to Pb–Pb collisions, for p–Pb the multiplicity fluctuations for a fixed N_{coll} (or $N_{part} = N_{coll} + 1$) value are comparable to the full multiplicity dynamic range, as can be inferred from Fig. 1. In order to study nuclear modification factors, R_{pA}, the average number of binary proton–nucleon (p–N) collisions, N_{coll} is needed to scale the pp reference. For the minimum bias R_{pA}, the average N_{coll} can be calculated from the ratio of p–N and p–A inelastic cross-section: $\langle N_{coll}\rangle^{MB} = A \cdot \sigma_{pN}/\sigma_{pA} = 6.9$ [1].

2. Centrality estimators

In ALICE, the centrality can be estimated by measuring either the charged particle multiplicity or the zero degree energy. At midrapidity the multiplicity is measured by the innermost silicon pixel layers of the Inner Tracking System (ITS), specifically the number of clusters measured in the second layer ($|\eta_{LAB}| < 1.4$) is used and the corresponding estimator is labeled as CL1. At more forward rapidities, two hodoscopes of scintillators placed on both sides relative to the interaction point (IP) have been employed: V0A placed on the Pb-remnant side ($2.0 < \eta_{LAB} < 5.1$) and V0C on the proton remnant side ($-3.7 < \eta_{LAB} < -1.7$). At very forward rapidities, the Zero Degree Calorimeters (ZDC), placed at ± 112.6 m on both sides from the IP, detect the energy carried by knocked out nucleons or emitted in de-excitation processes by the interacting nucleus, usually called “slow” nucleons [2]. Each ZDC set is composed by a neutron (ZN) and a proton (ZP) calorimeter. To estimate the centrality we exploited ZN on the Pb-remnant side, ZNA ($\eta_{LAB} > 8.7$).

To determine the relation between the measured observable and the collision geometry (N_{part}, N_{coll}, T_{pA}), usually a Glauber model is used in combination with a model for particle production. This kind of approach has already been used by ALICE for the centrality determination in Pb–Pb [3]. Charged particle production is modeled using a Negative Binomial Distribution (NBD), assuming N_{part} as the number of particle sources (ancestors). The multiplicity simulated with the Glauber model is then used to connect a measured experimental quantity to the collision geometry. For the zero degree energy, a model to account for the slow nucleon (SNM) emission has to be coupled with Glauber. The SNM is a very simple phenomenological model based on experimental results at lower energies, where it has been reported that the features of the emitted

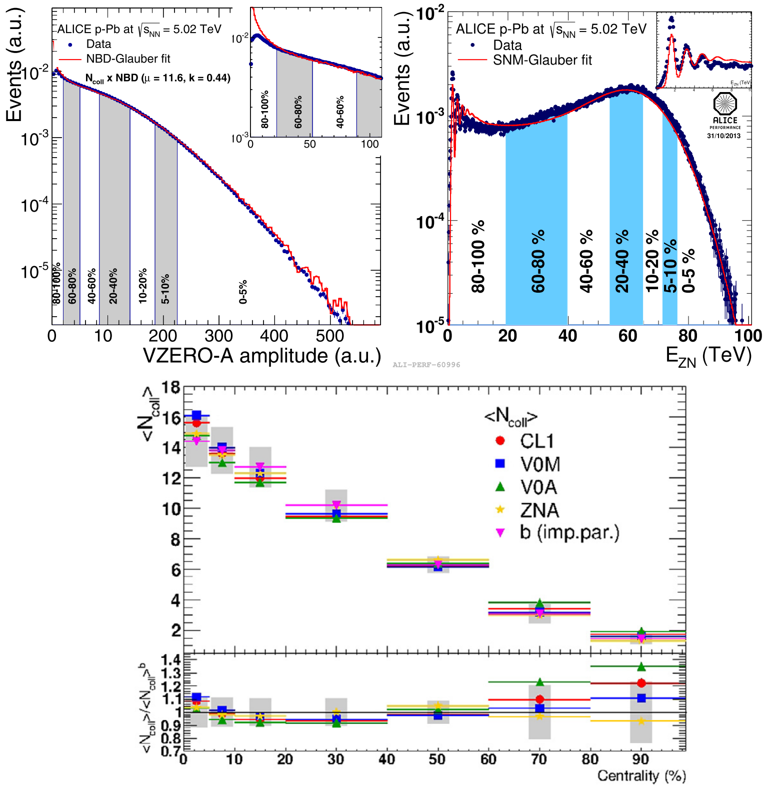

Fig. 2. Top left: amplitude of V0A signal fitted with NBD-Glauber function. The inset shows a zoom on the low multiplicity range. Top right: ZNA spectrum with SNM-Glauber fit superimposed. The low energy part of the spectrum is shown in the inset. Bottom: $\langle N_{coll} \rangle$ obtained from Glauber fit approach applied to different estimators.

nucleons weakly depend on the incident proton beam energy in a rather wide range, going from 1 GeV to 1 TeV [2].

In Fig. 2 V0A multiplicity and ZNA energy are shown with superimposed results from the Glauber fit. For V0A, the fit is performed excluding the 90–100% bin to avoid the region with lower trigger efficiencies. The values of NBD parameters are similar to those obtained fitting the corresponding multiplicity in pp collision. The SNM implementation allows to reproduce the essential features of the ZN spectrum, however the uncertainties on the SNM result in large errors on the extracted N_{coll} values. The average values of N_{coll} estimated through the Glauber approach using different estimators are shown in Fig. 2. Values from the different estimators agree within the systematic uncertainty (estimated by varying the Glauber parameters and with a MC closure test using HIJING [5]).

3. Multiplicity bias

These large fluctuations on particle multiplicity make dynamical biases important and are the origin of a bias in the centrality determination. This is illustrated in the left panel of Fig. 3, where the ratio between the average multiplicity per ancestor from Glauber and the average NBD multiplicity is shown as a function of centrality. While in Pb–Pb we see deviations from unity

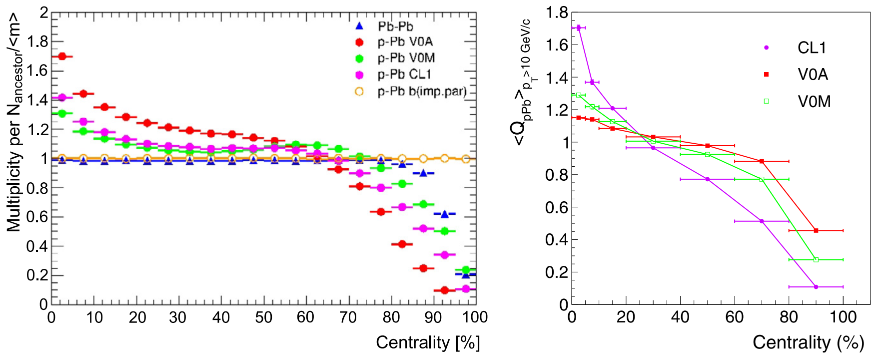

Fig. 3. Left: multiplicity fluctuation bias calculated from NBD-Glauber MC as the ratio between mean multiplicity per ancestor and mean NBD multiplicity. Right: Q_{pPb} at high p_T versus centrality (see text for details).

(indication of bias) only for very peripheral events, in p–Pb collisions we observe large deviations over the whole centrality range. The most central (peripheral) collisions have on average much higher (lower) multiplicity per ancestor. Furthermore, in case of peripheral events the mean impact parameter between two nucleons b_{NN} rises significantly, reducing thus the probability of pN interactions [4].

A more detailed dynamical interpretation needs Monte Carlo generators that correctly simulate multi-particle production in NN collisions. In Monte Carlo generators, a large part of the multiplicity fluctuations is due to fluctuations in the number of sources, i.e. hard scatterings via multi-parton interactions (MPI). For example, the HIJING generator accounts for fluctuations of MPI per NN interaction via an NN overlap function $T_N(b_{NN})$. The average number of hard scatterings is related to this NN overlap function: $\langle n_{hard}\rangle(b_{NN}) = \sigma_{hard} T_{NN}(b_{NN})$. Therefore the bias on the multiplicity corresponds to a bias on the number of particle sources (ancestors in NBD-Glauber approach, hard scattering in more sophisticated models). In addition, for very peripheral collisions there is another source of bias due to correlations that arise between the centrality estimator and the presence of high p_T particles in the events. We call this the *jet-veto effect*. This bias will be most important for CL1 estimator that has a full overlap with the tracking region. In summary, for centrality classes based on particle multiplicity measurement we expect to observe a bias that causes deviation of the nuclear modification factor R_{pPb} from binary scaling at high p_T.

4. Biased nuclear modification factors

All these sources of bias imply that the average N_{coll} from NBD-Glauber cannot be used to scale pp data. For this reason we define a "biased" nuclear modification factor Q_{pPb}:

$$Q_{pPb} = \frac{dN_{pPb}/dp_T}{N_{coll}^{Glauber} dN_{pp}/dp_T}$$

that will differ from unity at high p_T since the bias on hard scatterings is not included in the Glauber approach. In Fig. 4, this ratio is shown as a function of centrality for CL1 and for V0A estimators. The ratio differs from unity at high p_T over the whole centrality range. There is also a clear indication of the jet-veto effect in the most peripheral CL1 class where Q_{pPb} has a negative slope with increasing p_T. The spread between different centrality classes is reduced

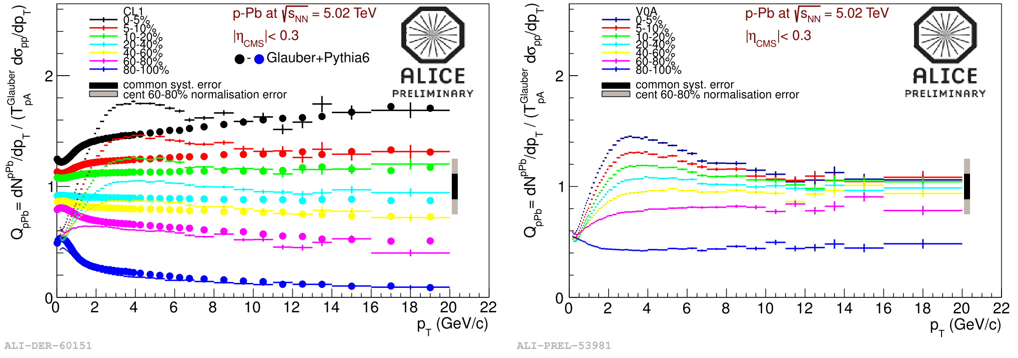

Fig. 4. Left: Q_{pPb} ratio for CL1 estimator (points) compared with results from a toy MC (lines). Right: Q_{pPb} ratio for V0A estimator.

increasing the rapidity gap between the region where the tracking is performed (midrapidity) and the centrality estimator. The average Q_{pPb} for $p_T > 10$ GeV/c is shown in the right panel of Fig. 3 for the three different centrality estimators based on multiplicity measurement as a function of centrality. It shows the same S-shape dependence observed in the multiplicity bias (Fig. 3, left plot). The mean Q_{pPb} diminishes with increasing rapidity gap between the centrality estimator and the region where the p_T measurement is performed.

We evaluated the Q_{pPb} ratios using a toy MC coupling Pythia6 [6] to a Glauber calculation, superimposing N_{coll} collisions with a probability given by the Glauber distribution. The obtained results (lines in the left panel of Fig. 4) describe surprisingly well the bias at high p_T for all centrality classes. Moreover a good agreement is also found at lower p_T values for the most peripheral bin where also the jet-veto effect is reproduced. The good agreement with the model suggests that the proper scaling for high p_T particle production could be an incoherent superposition of pp collisions.

5. Conclusions

Centrality estimators based on particle multiplicity measurements induce a bias on the hardness of p–N collision that can be quantified by the number of binary hard scatterings. The bias effects can be reduced by increasing the rapidity gap between the tracking region and the multiplicity estimator. The smallest bias is expected to hold for the estimator based on zero-degree energy since the slow nucleon emission is independent from hard processes.

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