

Particle production in p–Pb collisions with ALICE at the LHC

ALBERICA TOIA, on behalf of the ALICE COLLABORATION

Goethe University, Frankfurt, Germany and GSI, Darmstadt, Germany

Abstract

Measurements of the transverse momentum spectra of light flavor particles at intermediate and high p_T are an important tool for QCD studies. In pp collisions they provide a baseline for perturbative QCD, while in Pb–Pb they are used to investigate the suppression caused by the surrounding medium. In p–Pb collisions, such measurements provide a reference to disentangle final from initial state effects and thus play an important role in the search for signatures of the formation of a deconfined hot medium. While the comparison of the p–Pb and Pb–Pb data indicates that initial state effects do not play a role in the suppression of hadron production observed at high p_T in heavy ion collisions, several measurements of particle production in the low and intermediate p_T region indicate the presence of collective effects.

1 Introduction

The p–Pb physics program has developed from crucial control-experiment to study cold nuclear effects and to establish a baseline for Pb–Pb to an area where to find groundbreaking discoveries but also new challenges.

Nuclear modification factors measured by ALICE in minimum bias (MB) p–Pb collisions for charged particles [1], heavy flavor and jets show no deviations from unity at high- p_T , demonstrating that the observed strong suppression in Pb–Pb collisions is due to final state effects. However several measurements [2–5] of particle production in the low and intermediate p_T region can not be explained by an incoherent superposition of pp collisions,

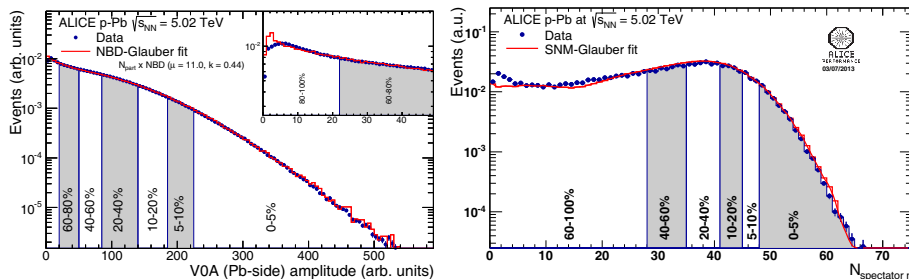


Figure 1: Distribution of the sum of amplitudes in the V0 hodoscopes (left) and of the neutron energy spectrum measured in the ZN calorimeter (right) in the Pb-remnant side (A). (Pb-going). Centrality classes are indicated by vertical lines. The distributions are fitted with a Glauber model coupled to a NBD (left) or with the SNM-model (right) and are shown as a line.

but rather call for coherent and collective effects. As their strength increases with multiplicity, a more detailed characterisation of the collision geometry is needed. Moreover, a knowledge of the geometry dependence is necessary to interpret the suppression pattern of charmonia (J/ψ $\psi(2S)$) and in Pb–Pb collisions relative to the effects observed in the nuclear medium produced in p–Pb collisions.

ALICE has carried out detailed studies of the centrality determination in p–Pb collisions, and the possible biases induced by the event selection on the scaling of hard processes in a selected event sample. The centrality determination consists in relating a Glauber model, which calculates the geometric properties of the event (N_{coll}), to a measured observable related to the event activity in a specific rapidity region [6], via the conditional probability to observe a certain activity for a given N_{coll} . More specifically, particle production measured by detectors at mid-rapidity can be modeled with a negative binomial distribution (NBD). The zero-degree energy is related to the number of the slow nucleons emitted in the nucleus fragmentation process, which we model with a Slow Nucleon Model (SNM) [7]. Fits of both models to our data are shown in Fig. 1.

However, the connection of the measurement to the collision geometry has to be validated, eg by correlating observables from kinematic regions causally disconnected after the collision, or by comparing a Glauber MC with data for a known process, as eg the deuteron dissociation probability at RHIC [8].

In addition the consistency of the approach must be demonstrated. As in general the selection in a system with large relative fluctuations can in-

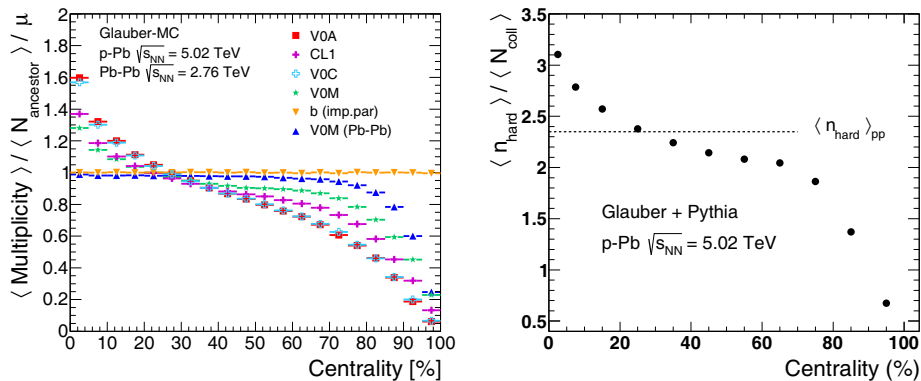


Figure 2: Left: Multiplicity fluctuation bias quantified as the mean multiplicity per $\langle N_{\text{part}} \rangle / \mu$ from the NBD-Glauber MC in p-Pb and Pb-Pb calculations. Right: Number of hard scatterings (MSTI(31) in PYTHIA6) per N_{coll} as a function of the centrality calculated with a toy MC that couples a pp PYTHIA6 calculation to a p-Pb Glauber MC.

duce a bias, one needs to identify the physics origin of the bias in order to correct centrality dependent measurements. In p-Pb collisions, the relative large size of the multiplicity fluctuations has the consequence that a centrality selection based on multiplicity may select a biased sample of nucleon-nucleon collisions. In essence, by selecting high (low) multiplicity one chooses not only large (small) average N_{part} but also positive (negative) multiplicity fluctuations per nucleon-nucleon collision. This is shown on the left in Fig. 2. These fluctuations are partly related to qualitatively different types of collisions, described in all recent Monte Carlo generators by impact parameter dependence of the number of particle sources via multiparton interaction. Hence, the biases on the multiplicity discussed above correspond to a bias on the number of hard scatterings (n_{hard}). As a consequence, for peripheral (central) collisions we expect a lower (higher) than average number of hard scatterings per binary collision, corresponding to a nuclear modification factor less than one (greater than one), see Fig. 2, right. However also other types of biases have an influence on the nuclear modification factor: the jet-veto effect, due to the trivial correlation between the centrality estimator and the presence of a high- p_T particles originating from jets in the event; the geometric bias, resulting from the mean impact parameter between nucleons rising for the most peripheral events [9].

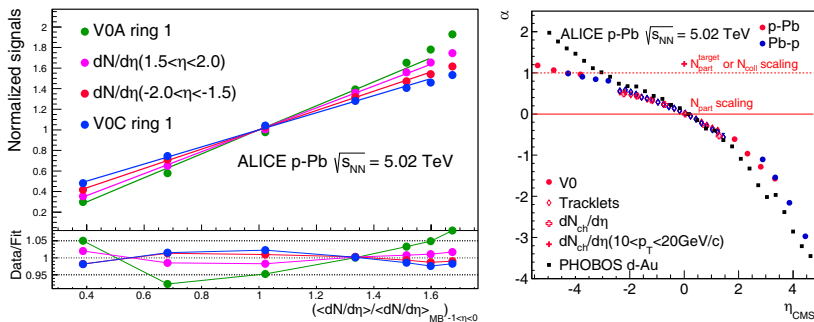


Figure 3: Left: Normalized signal from various observables versus the normalized charged-particle density, fit with a linear function of N_{part} . Right: Results from the fits as a function of the pseudorapidity covered by the various observables. The red horizontal lines indicate the ideal N_{part} and N_{coll} geometrical scalings. The most central point is excluded from the fit, to avoid pile-up effects. PHOBOS points taken from [10].

2 The ALICE approach

The ALICE approach aims to a centrality selection with minimal bias and, therefore, uses the signal in the Zero Degree Calorimeter (ZNA). In this case we cannot establish a direct connection using a well established model to the collision geometry but we can study the correlation of two or more observables that are causally disconnected after the collision, e.g because they are well separated in rapidity.

In centrality classes selected by ZNA, we study the dependence of various observables in different η and p_T regions on the charged particle density at mid-rapidity. Fig.3 indicate a monotonic change of the scaling with rapidity. The correlation between the ZDC energy and any variable in the central part shows unambiguously the connection of these observables to geometry.

Exploiting the findings from the correlation analysis described, we make use of observables that are expected to scale as a linear function of N_{coll} or N_{part} , to calculate N_{coll} :

- N_{coll}^{mult} : the multiplicity at mid-rapidity proportional to the N_{part} ;
- $N_{coll}^{Pb-side}$: the target-going multiplicity proportional to N_{part}^{target} ;
- $N_{coll}^{high-p_T}$: the yield of high- p_T particles at mid-rapidity is proportional to N_{coll} .

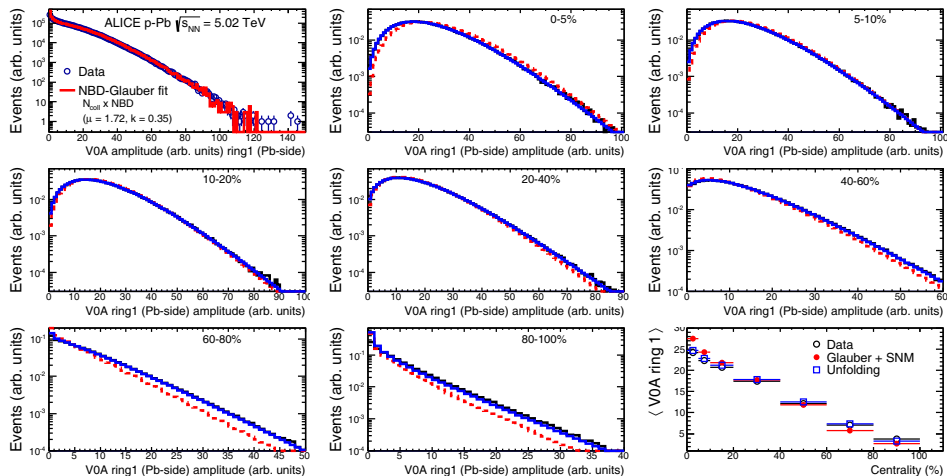


Figure 4: V0A ring1 signal distributions. The top left panel shows the distribution for MB events together with a NBD-Glauber fit. The remaining panels show the distributions and mean values for centrality classes selected with ZNA. These are compared to those obtained by the convolution of the $\mathcal{P}(N_{\text{coll}}|\text{cent}_{\text{ZNA}})$ distributions from the SNM with the NBD from the NBD-Glauber fit to V0A ring1. Data are also compared to the distributions obtained with an unfolding procedure, where the N_{coll} distributions have been fitted to the data using the parameters from the NBD-Glauber fit. The bottom right panel compares the mean values of these distributions as a function of the centrality.

These scalings are used as an ansatz, in the ALICE so-called *hybrid method* to calculate N_{coll} , rescaling the MB value $N_{\text{coll}}^{\text{MB}}$ by the ratio of the normalized signals to the MB one. We therefore obtain 3 sets of values of N_{coll} . The relative difference does not exceed 10%.

We have performed a consistency check, correlating ZNA and V0A centrality measurements, to establish their relation to the centrality. This is shown in Fig. 4. The N_{coll} distributions for centrality classes selected with ZNA, obtained from the SNM-Glauber fit, are convolved with the NBD from the fit to the V0A distribution. These are compared to the data and a good agreement is found. Moreover, a good agreement is also achieved with an unfolding procedure, where the N_{coll} distributions have been fitted to the data using the parameters from the NBD-Glauber fit. For each V0A distribution selected by ZNA, we find the N_{coll} distribution that, convolved with the NBD_{MB} , fits the data, i.e. the parameters of the fit are the relative contributions of each N_{coll} bin. The existence of N_{coll} distributions that folded with NBD agree with measured signal distributions is a necessary condition for ZNA to behave as an unbiased centrality selection. This

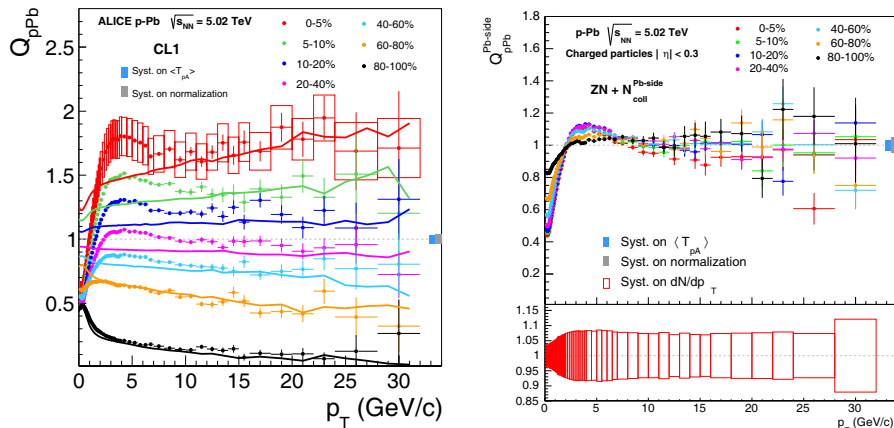


Figure 5: Q_{pPb} calculated with CL1 estimator (left), the lines are the G-PYTHIA calculations; with the hybrid method (right), spectra are measured in ZNA-classes and N_{coll} are obtained with the assumption that forward multiplicity is proportional to N_{part}^{target} .

procedure, which actually does not work for a biased centrality selection (eg CL1) shows that the energy measured by ZN is connected to the collision geometry.

3 Physics results

3.1 Nuclear modification factors

The nuclear modification factors Q_{pPb} calculated with multiplicity based estimator (shown in Fig.5 for CL1, where centrality is based on the tracklets measured in $|\eta| < 1.4$) widely spreads between centrality classes. They also exhibit a negative slope in p_T , mostly in peripheral events, due to the jet veto bias, as jet contribution to particle production increases with p_T . The Q_{pPb} compared to G-PYTHIA, a toy MC which couples Pythia to a p-Pb Glauber MC, show a good agreement, everywhere in 80-100%, and in general at high- p_T , demonstrating that the proper scaling for high- p_T particle production is an incoherent superposition of pp collisions, provided that the bias introduced by the centrality selection is properly taken into account, as eg in G-PYTHIA.

With the hybrid method, using either the assumption on mid-rapidity multiplicity proportional to N_{part} , or forward multiplicity proportional to N_{part}^{target} , the Q_{pPb} shown in Fig. 5, are consistent with each other, and also

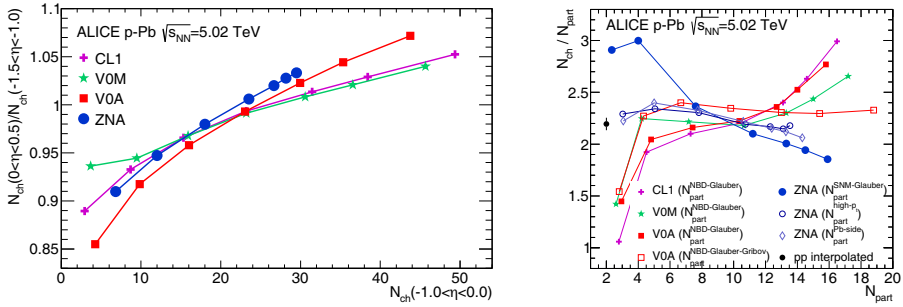


Figure 6: Left: Asymmetry of particle yield, as a function of the pseudorapidity density at mid-rapidity for various centrality classes and estimators. Right: Pseudorapidity density of charged particles at mid-rapidity per participant as a function of N_{part} for various centrality estimators.

consistent with unity for all centrality classes, as observed for MB collisions, indicating the absence of initial state effects. The observed Cronin enhancement is stronger in central collisions and nearly absent in peripheral collisions. The enhancement is also weaker at LHC energies compared to RHIC energies.

3.2 Charged particle density

Charged particle density is also studied as a function of η , for different centrality classes, with different estimators. In peripheral collisions the shape of the distribution is almost fully symmetric and resembles what is seen in proton-proton collisions, while in central collisions it becomes progressively more asymmetric, with an increasing excess of particles produced in the direction of the Pb beam. We have quantified the evolution plotting the asymmetry between the proton and lead peak regions, as a function of the yield around the midrapidity (see Fig. 6, left): the increase of the asymmetry is different for the different estimators. Fig. 6 right shows N_{ch} at mid-rapidity divided by N_{part} as a function of N_{part} for various centrality estimators. For Multiplicity-based estimators (CL1, V0M, V0A) the charged particle density at mid rapidity increases more than linearly, as a consequence of the strong multiplicity bias. This trend is absent when N_{part} is calculated with the Glauber-Gribov model, which shows a relatively constant behavior, with the exception of the most peripheral point. For ZNA, there is a clear sign of saturation above $N_{part} = 10$, due to the saturation of forward neutron emission. None of these curves points towards the pp

data point. In contrast, the results obtained with the hybrid method, using either $N_{\text{part}}^{\text{target}}$ -scaling at forward rapidity or N_{coll} -scaling for high- p_{T} particles give very similar trends, and show a nearly perfect scaling with N_{part} , which naturally reaches the pp point. This indicates the sensitivity of the N_{part} -scaling behavior to the Glauber modeling, and the importance of the fluctuations of the nucleon-nucleon collisions themselves.

4 Conclusions

Multiplicity Estimators induce a bias on the hardness of the pN collisions. When using them to calculate centrality-dependent Q_{pPb} , one must include the full dynamical bias. However, using the centrality from the ZNA estimator and our assumptions on particle scaling, an approximate independence of the multiplicity measured at mid-rapidity on the number of participating nucleons is observed. Furthermore, at high p_{T} the p-Pb spectra are found to be consistent with the pp spectra scaled by the number of binary nucleon-nucleon collisions for all centrality classes. Our findings put strong constraints on the description of particle production in high-energy nuclear collisions.

References

- [1] B. Abelev et al. (ALICE Coll.), arXiv:1405.2737, 2014.
- [2] B. Abelev et al. (ALICE Coll.), Phys.Lett. B719, 29-41, 2013.
- [3] B. Abelev et al. (ALICE Coll.), Phys.Lett. B727, 371-380, 2013.
- [4] B. Abelev et al. (ALICE Coll.), Phys.Lett. B728, 25-38, 2014.
- [5] B. Abelev et al. (ALICE Coll.), Phys.Lett. B726, 164-177, 2013.
- [6] B. Abelev et al. (ALICE Coll.), Phys.Rev. C88 (2013) 044909.
- [7] J. Adam et al. (ALICE Coll.), Phys.Rev. C91 (2015) 064905
- [8] A. Adare et al. (PHENIX Coll.), Phys.Rev. C90 (2014) 3, 034902
- [9] J. Jia, Phys.Lett. B681, 320-325, 2009.
- [10] B.B. Back et al. (PHOBOS Coll.), Phys.Rev. C72, 031901, 2005.