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Charged particle production in Pb–Pb collisions at the LHC with the ALICE detector

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Abstract

The ALICE collaboration measured charged particle production in $\sqrt{s_{NN}} = 2.76$ TeV Pb–Pb collisions at the LHC. We report on results on charged particle multiplicity and transverse momentum spectra. All the results are presented as a function of the centrality of the collision, estimated with a Glauber Monte Carlo fit to multiplicity distributions reconstructed in various detectors. The applicability of the Glauber model at LHC energies, the precision of the centrality determination and the related systematic uncertainties are discussed in detail.

Particles are tracked in the pseudorapidity window $|\eta| \lesssim 0.9$ with the silicon Inner Tracking System (ITS) and the Time Projection Chamber (TPC), over the range $0.15 < p_T \lesssim 50$ GeV/c. The low-p_T cut-off is further reduced in the multiplicity measurement using "tracklets", reconstructed in the 2 innermost layers of the ITS.

The charged particle multiplicity is measured in $|\eta| < 0.5$ to be $dN_{ch}/d\eta = 1601 \pm 60$ in 5% most central Pb–Pb collisions, indicating an energy density a factor ~ 3 higher than at RHIC. Its evolution with centrality shows a pattern strikingly similar to the one measured at RHIC. Intermediate ($5 \lesssim p_T \lesssim 15$ GeV/c) transverse momentum particles are found to be most strongly suppressed with respect to pp collisions, consistent with a large energy loss of hard-scattered partons in the hot and dense medium. The results are presented in terms of the nuclear modification factor R_{AA} and compared to theoretical expectations.

Keywords: heavy-ion, charged particles, LHC, Nuclear modification factor

1. Introduction

The ALICE experiment took data at the LHC in pp collisions at $\sqrt{s} = 0.9$, 2.76 and 7 TeV and in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Measurements of charged particles are very important early studies which allow for a first characterization of the system produced in such collisions and provide basic constraints to theoretical models. In this paper we present results obtained in Pb–Pb collisions for charged primary particles, defined as all charged particles produced in the collision, including their decay products, but excluding products of weak decays of strange particles.

The ALICE detector is mainly composed of a central barrel and of a forward muon spectrometer [1]. The main tracking elements in the central barrel are a large volume Time Projection Chamber (TPC) and a six-layered silicon detector, the Inner Tracking System (ITS). They are embedded in a 0.5 T solenoidal field and cover the pseudorapidity window $|\eta| \lesssim 0.9$. The material budget for a track going through the TPC is about 10% of a radiation length. The small material budget and moderate field lead to a low p_T cut-off of about 150 MeV/c for full tracks reconstructed

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with the combined information of the ITS and TPC [2]. The p_T resolution in the present analysis is about 10% up to p_T = 50 GeV/c. The resolution on the transverse impact parameter relative to the primary vertex is about 200 μm at p_T = 300 MeV/c and 35 μm at p_T = 5 GeV/c. This allows for a good separation of primary and secondary particles, an important requirement for charged particle measurements at low p_T. The multiplicity measurements employed track segments made of 2 hits in the 2 SPD layers pointing to a common vertex ("tracklets") as the default estimator [3, 4]. As compared to full-fledged tracks, the tracklets have the advantage of a lower p_T cutoff (∼ 50 MeV/c) and of an extended η coverage ($|\eta| \lesssim 2$). For triggering purposes, two forward scintillator hodoscopes, the VZERO detectors, covering the pseudorapidity windows $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$ were used. The present analyses use data collected with a minimum bias trigger requiring a combination of hits in the two innermost layers of the ITS (made of silicon pixel detectors, SPD) and in the VZERO.

2. Centrality determination

The determination of the "centrality" of a collision, that is a measurement of the transverse overlap of the two nuclei, is one of the first important steps towards a full characterization of heavy-ion collisions. The data are divided in several centrality bins corresponding to well-defined percentiles of the total hadronic cross-section. The bins are defined using cuts on the multiplicity distributions measured in one of the sub-detectors. Our main estimate is based on the VZERO detector information [5]. Other estimators are used as cross-checks: clusters reconstructed in the SPD, tracks reconstructed in the TPC and energy deposited in the Zero Degree Calorimenters (ZDC, see below). In order to translate a cut in any of the above estimators into a given centrality percentile, the knowledge of the total hadronic cross-section is needed. This can be extracted from the data in two ways: *i)* fitting the experimental distribution with a Glauber model [6, 7], *ii)* correcting the experimental distribution for the trigger efficiency and subtracting any background from non-hadronic interactions. The two approaches yield consistent results, with the former used as the default. The Glauber fit was done using a Monte Carlo calculation, which assumed Woods-Saxon nuclear density profiles (with parameters constrained by low energy electron-nucleus scattering measurements) and a nucleon-nucleon inelastic cross-section of $\sigma_{\rm NN}^{\rm inel} = 64 \pm 5$ mb, as interpolated from cosmic rays and pp data at different energies. This value is also consistent with the measured $\sigma_{pp}^{\rm inel}$ [8]. From the Glauber model calculation, one can extract the number of participants $N_{\rm part}$ and the number of binary collisions $N_{\rm coll}$. It is then assumed that the number of particle production centers ("ancestors") is related to the number of participants and binary collisions as $N_{\rm ancestors} = f \cdot N_{\rm part} + (1-f) \cdot N_{\rm coll}$. Each ancestor then produces particles according to a Negative Binomial Distribution (NBD). The NBD parameters and the f parameter are the free parametres in the fit.

The ZDCs are a set of forward hadronic calorimeters, placed on either side of the detector, approximately 114 m away from the interaction point, at zero degree with respect to the beam axis. For the most central events, the energy deposit in the ZDCs is proportional to the number of spectator nucleons. They therefore measure a quantity qualitatively different from the other estimators, providing another implicit confirmation of the applicability of the Glauber model at the LHC.

Comparing the different estimators event-by-event, it is possible to estimate the precision of the centrality measurement. For the VZERO estimator, the centrality resolution is ∼ 0.5% for central events and ∼ 2% for peripheral events. The residual contamination and purity of the events used in the analysis was also studied. This is particularly important for peripheral events. A pure hadronic sample is found after the basic offline selection down to about 90% centrality [5]. The minimum bias trigger efficiency ranges between 97 and 99%, according to the actual trigger settings. More details on the centrality studies can be found in [5].

3. Multiplicity measurements

The charged particle multiplicity was measured in the central rapidity region ($|\eta| < 0.5$) using "tracklets" as the default estimator and crosschecked with tracks. The $dN_{\rm ch}/d\eta$ as a function of $N_{\rm part}$ is compared in Fig. 1 with previous RHIC results at $\sqrt{s_{\rm NN}}$ = 200 GeV/c (left) and with theoretical models (right, see [3] and references therein). The dependence on centrality is very similar at the two energies, with an overall scaling factor of ∼ 2.14. Models incorporating a moderation of the multiplicity with centrality (i.e. shadowing or saturation) are favored by the data. The measurement has recently been extended to cover a much wider pseudorapidity range ($|\eta| \lesssim 5$) [9], putting

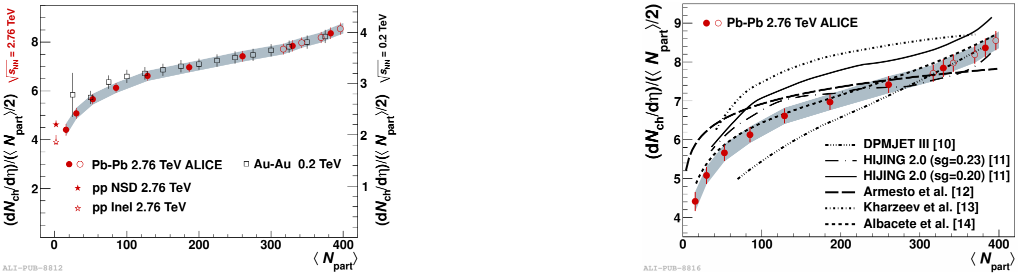

Figure 1: Charged particle pseudorapidity density per participant pair $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta/(N_{\mathrm{part}}/2)$ measured by ALICE, as a function of the number of participants N_{part}, compared to previous RHIC results (scaled by a factor 2.14, left) and theoretical models (right).

further constraints on theoretical models. The future measurement in p–A collisions, foreseen at the beginning of 2013 with the first p–A run at the LHC, will also be of great importance for constraining the initial conditions for nuclear collisions at LHC energies.

4. High p_{T} particle suppression

The study of single inclusive charged particle spectra allows to investigate the possible suppression of high p_{T} hadrons, due to parton energy loss in the medium. The production (and suppression) of high p_{T} particles was studied in terms of the nuclear modification factor R_{AA}, defined as the ratio of the yield in Pb–Pb collisions to the pp yield scaled by the number of binary collisions. This ratio can also be written as:

$$R_{\mathrm{AA}} = \frac{d^2N/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta}{\langle T_{\mathrm{AA}}\rangle \mathrm{d}^2\sigma_{pp}^{\mathrm{inel}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta},$$

where T_{AA} is the nuclear overlap function computed from the Glauber model and $\sigma_{pp}^{\mathrm{inel}}$ the pp inelastic cross section. The pp reference is a crucial ingredient for the calculation of the R_{AA}. It is based in the present analysis on a direct measurement in pp collisions at $\sqrt{s} = 2.76$ TeV. This allows for a reduction of the systematic uncertainty and increased p_{T} range with respect to the first published results [10]. The pp measurement extends up to $p_{\mathrm{T}} = 35$ GeV/c. In order to reduce the effect of the statistical fluctuations and to extend the p_{T} coverage, it was fitted to a modified Hagedorn function and extrapolated to higher p_{T} [11, 12].

The R_{AA} as a function of p_{T} for central collisions is shown in Fig. 2 (left)[1]. A strong suppression is observed, with the R_{AA} showing a pronounced minimum at $p_{\mathrm{T}} \simeq 6$ GeV/c. At lower p_{T}, the R_{AA} rises and develops a peak at $p_{\mathrm{T}} \simeq 2$ GeV/c. This can be understood in terms of hydrodynamic flow [14]. In the range $2 \lesssim p_{\mathrm{T}} \lesssim 6$ GeV/c the R_{AA} decreases, reaching the mimimum mentioned above. This intermediate p_{T} region is likely driven by an interplay of soft and hard processes. Above $p_{\mathrm{T}} \simeq 6$ GeV the R_{AA} shows a rise, which becomes progressively less steep, possibly reaching a saturation. The R_{AA} is also compared in Fig. 2 (left) to a similar measurement by the CMS experiment [15]. The results from the two experiments are consistent with each other [11]. The right panel of Fig. 2 shows the centrality dependence of the R_{AA} in different p_{T} regions, as a function of N_{part}. The data are also compared to previous measurements by the PHENIX experiment in Au–Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV [13] for the region around the minimum ($4 < p_{\mathrm{T}} < 7$ GeV/c). The suppression increases with N_{part} (and hence with centrality) at all p_{T}. The strongest centrality dependence is observed for the region around the minimum [11]. As compared to the lower energy result we observe that the suppression is stronger at the LHC at all centralities (expressed in terms of N_{part}). If central RHIC results are compared to LHC results at a similar $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \simeq 700$, however, it is found that the suppression is comparable at the 2 energies.

The comparison with the theoretical calculations depicted in Fig. 2 (left) [16, 17, 18, 19, 20] shows that many models can reproduce the trend and level of suppression above $p_{\mathrm{T}} \simeq 6$ GeV/c. Due to the uncertainties in several

[1] In this paper the final results, which became available after the conference presentation [11], are presented.

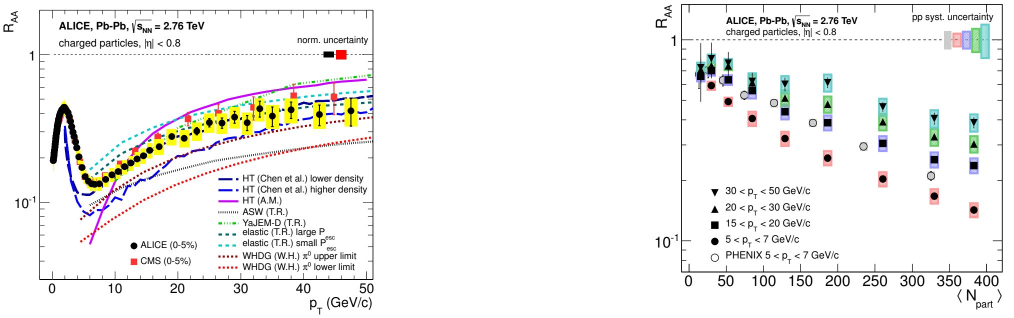

Figure 2: Nuclear modification factor R_{AA} for the 5% most central collisions, compared to theoretical calculations and to CMS data (left); Centrality dependence of R_{AA} in four p_T windows, compared to PHENIX results in Au–Au collisions at $\sqrt{s_{NN}}$ = 200 GeV (right).

of the input parameters to the model, different approaches are reproducing in a satisfactory way the R_{AA} results. The uncertainty on the initial conditions will be better constrained with the upcoming p–A run at the LHC, with a measurement of the nuclear modification factor R_{pA} and a measurement of the charged particle multiplicity over a large pseudorapidity range. Additional constraints [16] on the models come from the recently-released ALICE results on identified light flavour hadrons up to p_T = 20 GeV/c [21].

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