CHARGED PARTICLE MULTIPLICITY, CENTRALITY AND THE GLAUBER MODEL IN Pb–Pb COLLISIONS AT $\sqrt{s_{NN}} = 2.76$ TeV WITH ALICE*

Plamen Petrov

for the ALICE Collaboration

University of Birmingham, Birmingham B15 2TT, UK

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Charged particle multiplicity and transverse energy at midrapidity are key observables to characterize the properties of matter created in heavy-ion collisions. Their dependence on the heavy-ion collision centre-of-mass energy and the collision geometry are important for understanding the dominant particle production mechanisms and the relative contributions from hard scattering and soft processes. The Glauber model connects the geometry and multiplicity of heavy-ion collisions using the nucleon–nucleon cross section. This work will discuss the centrality definition and how it is obtained by ALICE via the Glauber model. The measurement of the inelastic proton–proton cross section and the fraction of the Pb–Pb inelastic cross section seen by the ALICE detector, will be outlined. Finally, the charged particle multiplicity $dN_{\mathrm{ch}}/d\eta$ and transverse energy $dE_{\mathrm{T}}/d\eta$ as a function of the centrality and energy of the colliding system will be presented.

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1. Introduction

The main focus of the ALICE experiment is to study the properties of strongly interacting matter at extreme energy density. Quantum chromodynamics (QCD), the theory of the strong interaction, predicts that at high enough temperature a phase transition occurs between hadronic and a deconfined state of matter, the quark-gluon plasma. With the first ultra-relativistic collisions of ^{208}Pb ions in November 2010 the Large Hadron Collider (LHC) at CERN started its heavy-ion programme and delivered Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The charged particle multiplicity and the transverse energy produced at midrapidity are fundamental observables to

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characterize the global properties of the systems created in these collisions, such as the initial quark and gluon density and the initial energy density. Due to the relatively large size of the heavy nuclei the collisions are differentiated by their centrality, a property related to the collision impact parameter. The dependence of the charged particle multiplicity and transverse energy on the collision geometry is sensitive to the soft and hard nature of the particle production. We present the first results of $dN_{\mathrm{ch}}/d\eta$ and $dE_{\mathrm{T}}/d\eta$ measured at $\sqrt{s_{NN}} = 2.76$ TeV by the ALICE experiment [1,2].

2. Measurement of the centrality

The main detectors used for triggering were the VZERO and the Silicon Pixel Detector (SPD). The VZERO counters are two arrays of 32 scintillator tiles covering the forward pseudorapidity region of $2.8<\eta<5.1$ (VZERO-A) and $-3.7 < \eta < -1.7$ (VZERO-C). The SPD, the innermost part of the Inner Tracking System (ITS), consists of two cylindrical layers of hybrid silicon pixel assemblies covering $|\eta| < 1.4$. The signals from these detectors are combined in a programmable logic unit which supplies the trigger signal. The trigger was configured for high efficiency for hadronic events and was successively tightened during the data taking period. The trigger efficiency, estimated from simulations, ranges from 97% to 99% depending on what combination of the following conditions was used: *(i)* two pixel chips hit in the outer layer of the SPD, *(ii)* a signal in VZERO-A, *(iii)* a signal in VZERO-C. The most peripheral collisions are strongly contaminated by electromagnetic background which is why a Glauber Model is used to isolate the hadronic fraction of the total cross section. In order to study centrality dependence, the data was organized into nine centrality classes corresponding to the most central 80% of the hadronic cross section.

2.1. Glauber model

The initial geometry of heavy-ion collisions, which includes the impact parameter and the shape of the collision region, cannot be determined directly. However, the simple geometrical picture provided by the Glauber Model [3] relates the number of observed particles to the number of nucleons participating in the collision, N_{part}, and hence to the centrality of the collision. The model assumes that the nucleons follow straight line trajectories and have a cross section independent of the number of undergone collisions. Two nucleons are assumed to collide if the transverse distance between them is less than the distance corresponding to the inelastic nucleon–nucleon cross section. The nucleon–nucleon cross section was estimated, by interpolating data at different centre-of-mass energies, to be 64 ± 5 mb at $\sqrt{s} = 2.76$ TeV. Thanks to Van der Meer scans during the proton–proton running, this value is now confirmed by ATLAS, CMS and ALICE, with ALICE measuring $62.1 \pm 1.6 \pm 4.3$ mb [4,5]. The nuclear density for ^{208}Pb is given by a Woods–Saxon distribution for a spherical nucleus with a radius of 6.62 fm and a skin depth of 0.546 fm. Assuming that the impact parameter is monotonically related to the particle multiplicity we can define the centrality experimentally using the minimum bias distributions of various detector responses.

2.2. Multiplicity distributions and centrality resolution

The distribution of the VZERO amplitude is fitted with a model inspired by the Glauber description of nuclear collisions (Fig. 1). The number of particle-producing sources, $N_{\text{ancestors}}$ is given by $N_{\text{ancestors}} = f \times N_{\text{part}} + (1 - f) \times N_{\text{coll}}$, where N_{part} is the number of participating nucleons, N_{coll} is the number of binary nucleon–nucleon collisions and f quantifies their relative contributions. The number of particles produced per ancestor is assumed to follow a negative binomial distribution (NBD). In order to avoid the region of the most peripheral collisions, characterized by high trigger inefficiency and strong contamination by electromagnetic processes, the fit is restricted to amplitudes above a value corresponding to 88% of the hadronic cross section. It is important to stress that the Glauber model is used only to find an anchor point to determine the fraction of the cross section that we see, and hence to select the 0–80% most central events. The performance of the centrality determination is evaluated by comparing the estimates using the VZERO amplitudes, the SPD outer layer hits, the TPC tracks multiplicity and the information from the two neutron zero degree calorimeters (ZDC) positioned at ± 114 m from the interaction point. The centrality resolution ranges from 0.5% in the most central to 2% in peripheral collisions [6].

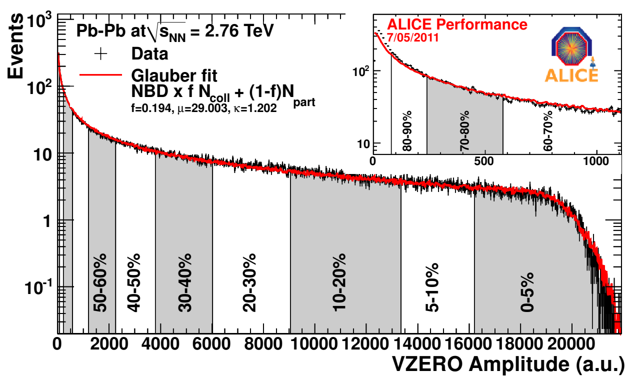

Fig. 1. The fit of the Glauber model to the distribution of the summed amplitudes in the VZERO scintillator tiles. The vertical lines separate the centrality classes used in the analysis.

3. Measurement of $dN_{\rm ch}/d\eta$ and $dE_{\rm T}/d\eta$

The measurement of the charged particle pseudorapidity density $dN_{\rm ch}/d\eta$ is based on the reconstruction of tracklets, where a tracklet is defined as a pair of SPD hits consistent with being caused by a particle coming from the primary vertex. The correction factor for acceptance and efficiency, α, of a primary track to form a tracklet as well as the fraction of background tracklets, β, from uncorrelated hits are estimated from MC simulated data. The corrected charged particle pseudorapidity density is obtained from the raw tracklet multiplicity according to $dN_{\rm ch}/d\eta = \alpha \times (1-\beta) \times dN_{\rm tracklets}/d\eta$.

The transverse energy is estimated by measuring the charged hadrons energy with the central barrel tracking detectors and correcting for the fraction of neutral particles not seen by tracking detectors (*e.g.* π^0, n, Λ, $K^0_{\rm s}$, η, ω). The correction factors are estimated from MC simulations. The yields of the strange hadrons are typically underestimated by MC generators and therefore their contributions are derived from the proton–proton data at $\sqrt{s} = 0.9$ TeV.

4. Results: centrality and energy dependence

Figure 2 shows the charged particle pseudorapidity density per pair of participants $(dN/d\eta)/(\langle N_{\rm part}\rangle/2)$ as a function of $N_{\rm part}$. The measurement shows a steady increase by a factor of 2 going from peripheral to central collisions and the most peripheral point matches well the corresponding proton–proton measurement. The centrality dependence is very similar to the RHIC results at $\sqrt{s_{NN}} = 0.2$ TeV [7]. Taking into account measurements at lower energy, both $dN_{\rm ch}/d\eta$ and $dE_{\rm T}/d\eta$ show a power law dependence on the centre-of-mass energy. The growth of the multiplicity density with

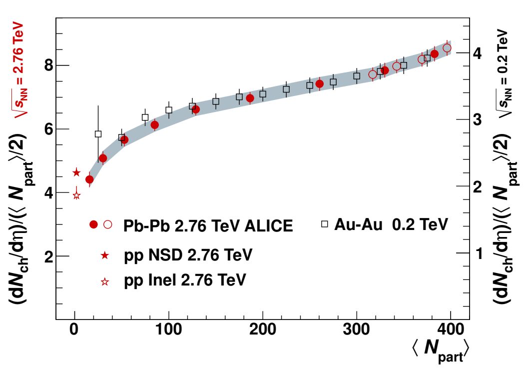

Fig. 2. The charged particle pseudorapidity density per participant pair $(dN/d\eta)/(\langle N_{\rm part}\rangle/2)$ as a function of $N_{\rm part}$ measured for Pb–Pb at 2.76 TeV [2] and Au–Au collisions at 0.2 TeV [7].

the centre-of-mass energy is stronger than the logarithmic scaling suggested by lower energy data and also different from the proton–proton. Comparing to Au–Au at $\sqrt{s_{NN}} = 0.2$ TeV we observe an increase of a factor 2.1 for $dN_{\rm ch}/d\eta$ and 2.5 for $dE_{\rm T}/d\eta$ (Figs. 3 and 4). We can apply the Bjorken formula to estimate the energy density of the collisions

$$\epsilon = \frac{1}{\pi R^2 \tau} \frac{dE_{\rm T}}{dy} \,, \tag{1}$$

where τ is the formation time and πR^2 is the effective area of the collision. The Bjorken energy density for the most central 0–5% nucleus–nucleus collisions is estimated to be $\epsilon\tau \approx 15$ GeV$/(\mathrm{fm}^2 c)$ at the LHC, which is a factor 2.7 larger than at RHIC [7].

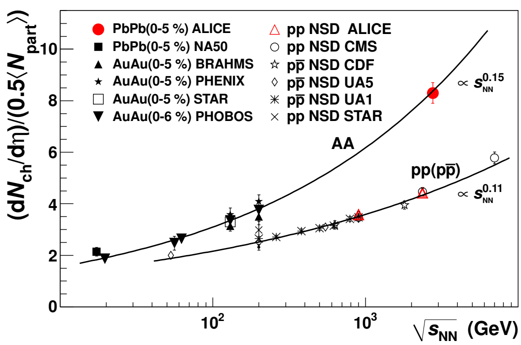

Fig. 3. Charged particle pseudorapidity density per participant pair $(dN/d\eta)/(\langle N_{\rm part}\rangle/2)$ for central nucleus–nucleus and nonsingle diffractive proton–proton collisions [1].

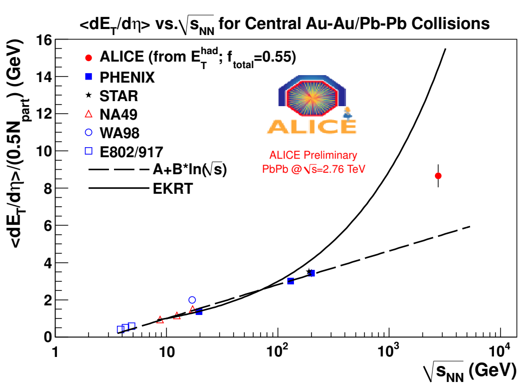

Fig. 4. Transverse energy pseudorapidity density per participant pair $(dE_{\rm T}/d\eta)/(\langle N_{\rm part}\rangle/2)$ for the most central nucleus–nucleus collisions [6].

In Fig. 5 the $dN/d\eta$ data have been compared to model calculations. The various models which describe the particle production in nuclear–nuclear collisions can be divided into two categories — two component models (DPMJET [8] and HIJING 2.0 [9]) combining pQCD processes with soft interactions and the so-called saturation models [10,11,12] with various parametrisations for the energy and centrality dependence of the quark and gluon density saturation scale. In general, the data seems to favour models that include a mechanism for moderation of the multiplicity evolution with energy and centrality. The two component HIJING 2.0, tuned after the most central $dN/d\eta$ value was published [1], describes reasonably well the data. The model limits the rise of particle production with centrality by including a strongly impact parameter dependent gluon shadowing $g_{\rm s}$. The centrality dependence of the multiplicity is well reproduced by saturation models [11,12], published after $dN/d\eta$ for the most central Pb–Pb collisions was known [1], but only the latter predicts correctly the magnitude of $(dN/d\eta)/(\langle N_{\rm part}\rangle/2)$.

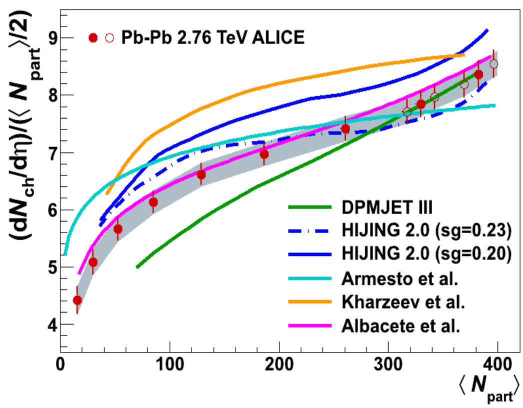

Fig. 5. Comparison of $(dN/d\eta)/(\langle N_{\rm part}\rangle/2)$ to model calculations for Pb–Pb at 2.76 TeV. The HIJING 2.0 curve is shown for two values of the gluon shadowing parameter $g_{\rm s}$.

5. Conclusions

The measurement of the centrality and energy dependence of the charged particle multiplicity and transverse energy at midrapidity in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV have been presented. The centrality dependence is found to be remarkably similar for the data at $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 0.2$ TeV showing a steady increase from peripheral to central collisions. The Bjorken energy density for central nucleus–nucleus collisions is estimated to be $\epsilon\tau \approx 15$ GeV/(fm^2c) at $\sqrt{s_{NN}} = 2.76$ TeV, about a factor of 2.7 larger than at RHIC.

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