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First Results with the ALICE Experiment at LHC

C. Zampolli(*) for the ALICE Collaboration
INFN, Sezione di Bologna - Bologna, Italy

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Summary. — In this paper, the first results from the ALICE experiment at LHC will be presented. The focus will be on Pb-Pb collisions at $\sqrt{s} = 2.76\,\text{TeV}$. An overview of the pp results at 0.9 and 7 TeV will be also given.

PACS `25.75.-q` – Relativistic heavy-ion collisions.
PACS `25.75.Dw` – Particle and resonance production.
PACS `13.75.Cs` – Nucleon-nucleon interactions.
PACS `12.38.Mh` – Quark-gluon plasma.

1. – Introduction

ALICE (A Large Ion Collider Experiment) [1] is the experiment at the Large Hadron Collider (LHC) devoted to the study of ultra-relativistic heavy-ion collisions. The extreme energy density ($> 10\,\text{GeV/fm}^3$) and temperature ($\geq 3\,\text{GeV}$) conditions reached in Pb-Pb collisions at LHC energies are expected to lead to a phase transition from ordinary colourless hadronic matter to a deconfined plasma of quarks and gluons (the so-called Quark-Gluon Plasma, QGP [2]). In order to investigate the formation and the properties of the QGP, the very rich physics program of ALICE will span from the global characteristics of the event (such as multiplicities, η distributions...), to the attributes of the system produced in the collisions (*e.g.*, hadrochemistry, temperature, energy density, HBT, elliptic flow, jet...). ALICE has also a genuine interest in the pp program of the LHC. Besides being the natural reference for the Pb-Pb data, pp collisions will also offer the possibility to provide results in the low-p_{T} region where ALICE, thanks especially to its powerful tracking and particle identification capabilities, can be complementary to the other LHC experiments dedicated to pp physics, ATLAS and CMS. Finally, pp data will serve as a fundamental base to Monte Carlo generators' tuning.

In this paper, the results obtained from the first Pb-Pb LHC run at the end of 2010 and from the pp collisions at $\sqrt{s} = 0.9$ and 7 TeV in 2009, 2010 and 2011 will be discussed.

(*) E-mail: `Chiara.Zampolli@bo.infn.it; Chiara.Zampolli@cern.ch`

2. – The ALICE setup and data taking

The results discussed herein mainly involve the ALICE central barrel detectors (covering the pseudorapidity range $|\eta| < 0.9$), briefly presented in the following.

In a magnetic field of 0.5 T, going outwards from the center of the experiment, in $|\eta| < 0.9$, the Inner Tracking System (ITS) and the Time Projection Chamber (TPC) are the main tracking devices. The ITS is primarily dedicated to the reconstruction of the primary and secondary vertices (with a transverse impact parameter resolution better than $75\,\mu$m for $p_{\mathrm{T}} > 1\,\mathrm{GeV}/c$). The two innermost layers of the ITS, the Silicon Pixel Detector (SPD), are also used to provide the minimum-bias trigger to the experiment. Together with the ITS, the ALICE TPC achieves a momentum resolution of 20% at $p_{\mathrm{T}} \sim 100\,\mathrm{GeV}/c$.

Both the ITS and the TPC will perform particle identification mainly at low p_{T}(1) (from $\sim 100\,\mathrm{MeV}/c$ up to $\sim 500\,\mathrm{MeV}/c$ and $\sim 1\,\mathrm{GeV}/c$ respectively) for charged hadrons via dE/dx measurements. Externally to the TPC, the Transition Radiation Detector (TRD) focuses on electron identification via hadron rejection from $1\,\mathrm{GeV}/c$, on top of contributing to the ALICE tracking and momentum reconstruction. After the TRD, a Time Of Flight detector (TOF) serves as particle identification device for ALICE, identifying charged hadrons in the low and intermediate momentum range, with a p/K separation of 2σ up to $5\,\mathrm{GeV}/c$. For a more exhaustive description of the ALICE setup, see ref. [1].

The ALICE heavy-ion data taking at 2.76 TeV resulted in $\sim 3 \times 10^6$ minimum-bias Pb-Pb events collected during a one month run at the end of 2010. The pp data taking at $\sqrt{s} = 0.9\,\mathrm{TeV}$ in 2009 and 2010 consisted of $\sim 8.5 \times 10^6$ events, while in 2010 until April 2011 $\sim 800 \times 10^6$ pp minimum bias events were collected at $\sqrt{s} = 7\,\mathrm{TeV}$.

2˙1. *Centrality determination in Pb-Pb collisions.* – One of the most important parameters of a heavy-ion collision, which makes it differ from pp, is centrality. It is related to the impact parameter b of the collision, defined as the distance between the centres of the colliding nuclei perpendicular to the beam axis: while small values of b correspond to central events, large b denote peripheral events. The value of b is bonded to the number of participating nucleons N_{part}, of binary collisions N_{coll}, and of spectators N_{spec} ($= 2A - N_{part}$). Various observables can be used in order to determine the centrality starting from the measurements of N_{part} and N_{coll} for the Pb-Pb collisions in ALICE, such as the energy deposited in the ZDC calorimeters(2) (proportional to the number of non-interacting nucleons close to beam rapidity) and the sum of the VZERO detector(3) amplitudes (proportional to the event multiplicity). Little dependence on the centrality estimator has been observed. In order to determine the centrality of the collision, the distribution is fitted according to the Glauber model [3] to describe the collision geometry. A two-component approach is used. First, it is assumed that the number of sources

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(1) The TPC particle identification capabilities can be extended to the relativistic rise of the $\mathrm{d}E/\mathrm{d}x$ distribution using statistical unfolding.

(2) The ALICE Zero Degree Calorimeter (ZDC) (two sets of neutron and proton calorimeters at ~ 116 cm from the interaction point on both sides with respect to it) is the detector responsible for the measurement of the number of nucleons participating in the collision.

(3) The ALICE VZERO detector (covering the pseudorapidity regions $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$), is made up of two arrays of scintillator tiles on both sides of the interaction point, and is aimed at providing the minimum-bias trigger, and centrality and luminosity information.

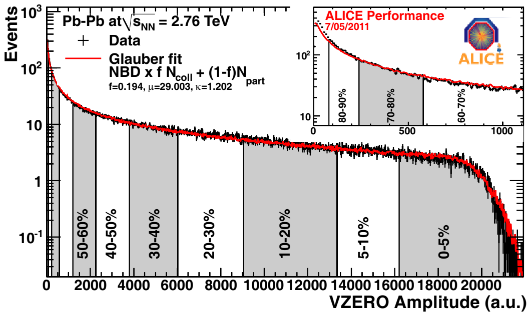

Fig. 1. – Distribution of the summed VZERO amplitudes (inset: zoom on the low amplitude region). The vertical lines are used to show the different centrality classes defined according to the Glauber fit (also shown) to the distribution.

emitting particles can be parametrized as $f \times N_{part} + (1-f) \times N_{coll}$, where f if the relative contribution of N_{part} and N_{coll}. Secondly, each source is supposed to emit particles following a negative binomial distributions defined by two quantities, μ and κ. Values of f, μ and κ are obtained fitting the summed VZERO scintillators' tiles, as shown in fig. 1 (after offline beam-background removal). Finally, the centrality classes are defined by integrating the measured distribution above an efficiency cut corresponding to $\sim 88\%$ of the total hadronic cross-section. For more details see ref. [4].

3. – Results

3˙1. *Pb-Pb*

3˙1.1. Particle production. The first characterization of the system created in heavy-ion collisions comes from the measurement of the charged particle multiplicity density. This observable sheds light on the particle production mechanism, allowing to derive information such as the initial energy density. In the 0–5% most central collisions, at midrapidity ($|\eta| < 0.5$) ALICE has found a density of charged particles $\mathrm{d}N_{ch}/\mathrm{d}\eta = 1584 \pm 4(\mathrm{stat}) \pm 76(\mathrm{syst})$, which, normalizing per participant pair $0.5\langle N_{part}\rangle$, leads to $\mathrm{d}N_{ch}/\mathrm{d}\eta/(0.5\langle N_{part}\rangle) = 8.3 \pm 0.4(\mathrm{syst})$, with a negligible statistical error. Figure 2, left panel, shows $\mathrm{d}N_{ch}/\mathrm{d}\eta/(0.5\langle N_{part}\rangle)$ as a function of $\sqrt{s_{NN}}$ as measured by ALICE in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$, and by other experiments in Au-Au and Pb-Pb at different energies. Nonsingle diffractive pp and p$\bar{\mathrm{p}}$ results are also drawn. A steeper energy dependence for heavy-ion than pp (p$\bar{\mathrm{p}}$) collisions can be seen, also from the curves $\propto s_{NN}^{0.15}$ and $\propto s_{NN}^{0.11}$ drawn for heavy-ion and pp (p$\bar{\mathrm{p}}$) data, respectively. Compared to the RHIC data at 200 GeV, the pseudorapidity density in Pb-Pb at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$ is higher by a factor 2.2. Moreover, the average multiplicity per participant pair found by ALICE in the most central Pb-Pb events is 1.9 times higher than that for pp and p$\bar{\mathrm{p}}$ at similar energies. The centrality dependence of the charged particle multiplicity density at midrapidity scaled by the number of participant pairs is presented in the right panel of fig. 2. As one can observe, $\mathrm{d}N_{ch}/\mathrm{d}\eta/(0.5\langle N_{part}\rangle)$ increases as a function of $\langle N_{part}\rangle$ going from 4.4 ± 0.4 to 8.4 ± 0.3 from peripheral to central events. The panel includes also the curves corresponding to different model predictions. For more details, see ref. [4].

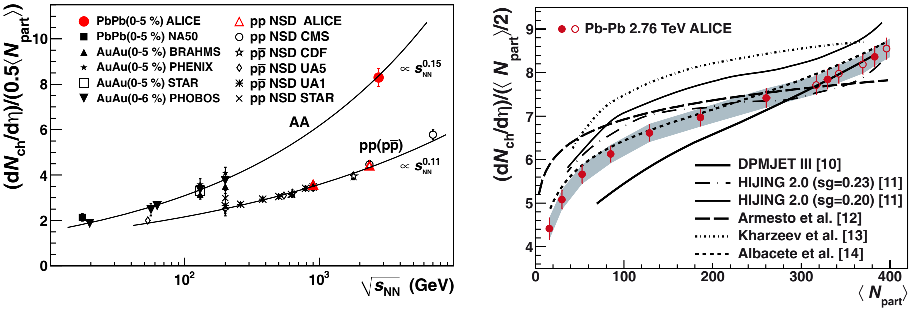

Fig. 2. – Left: $\mathrm{d}N_{ch}/\mathrm{d}\eta/(0.5\langle N_{part}\rangle)$ as a function of $\sqrt{s_{NN}}$ measured in Pb-Pb collisions by the ALICE experiment at 2.76 TeV. Results from other experiments in Pb-Pb and Au-Au collisions and pp and p$\bar{\mathrm{p}}$ are also shown. Right: $\mathrm{d}N_{ch}/\mathrm{d}\eta/(0.5\langle N_{part}\rangle)$ as measured by ALICE as a function of centrality, compared to the theoretical predictions.

3·1.2. Charged particle spectra. The left panel of fig. 3 shows the p_{T} spectra of unidentified charged particles measured by ALICE in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$, in $|\eta| < 0.8$ and for $p_{\mathrm{T}} < 20\,\mathrm{GeV}/c$. Two different centrality ranges are presented: the most central events (belonging to the centrality class 0–5%), and the most peripheral ones (in the centrality class 70–80%). For comparison, the reference yields, obtained from pp collisions at 900 GeV and 7 TeV, scaled by the number of binary collisions, are shown. The pp reference yields have been derived assuming that the increase of the yield with $\sqrt{s}$ follows a power law. As one can see, while peripheral events well match the shape of the corresponding reference pp spectrum falling according to a power law for $p_{\mathrm{T}} > 3\,\mathrm{GeV}/c$, central events are far from their reference with an exponential behavior below $5\,\mathrm{GeV}/c$. The comparison between heavy-ion and pp particle production can be

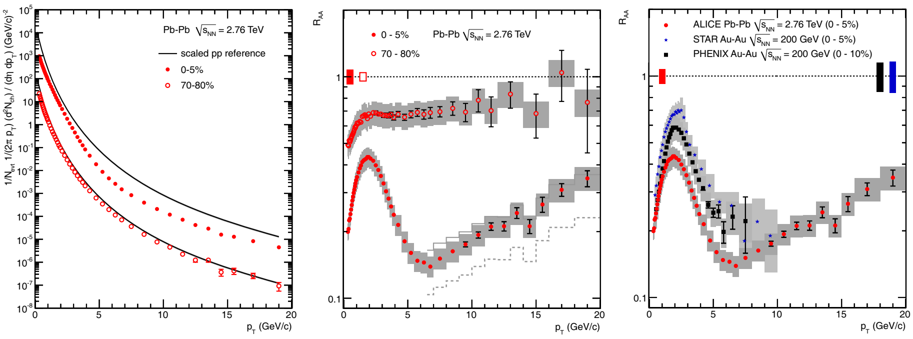

Fig. 3. – Left: p_{T} distribution of primary charged particles in $|\eta| < 0.8$ for central (0–5%) and peripheral (70–80%) Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$. The scaled pp reference spectra are also shown. Middle: R_{AA} in central (0–5%) and peripheral (70–80%) events. For central collisions, the results obtained with alternative pp references are drawn. Right: Comparison of the ALICE R_{AA} with those from RHIC in Au-Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$.

expressed in terms of the nuclear modification factor R_{AA}:

$$R_{AA}(p_\mathrm{T}) = \frac{(1/N_{evt}^{AA})\,\mathrm{d}^2 N_{ch}^{AA}/\mathrm{d}\eta \mathrm{d}p_\mathrm{T}}{\langle N_{coll}\rangle (1/N_{evt}^{pp})\,\mathrm{d}^2 N_{ch}^{pp}/\mathrm{d}\eta \mathrm{d}p_\mathrm{T}}$$

which quantifies the effect of the hot and dense medium created in heavy-ion collisions. Any observed deviation from unity of the R_{AA} may arise from such effect. The middle panel of fig. 3 shows the R_{AA} obtained from the particle yields previously discussed for both central and peripheral events. While the latter shows no dependence on p_T starting from $2\,\mathrm{GeV}/c$, central events appear to be strongly influenced by parton energy loss at $p_\mathrm{T} \sim 6 \div 7\,\mathrm{GeV}/c$, where $R_{AA} \sim 0.14$. For $p_\mathrm{T} > 7\,\mathrm{GeV}/c$, a significant increase in the R_{AA} is found. In the figure, the R_{AA} for central events obtained from pp references built with different approaches are also shown. Figure 3, right panel shows the comparison of the R_{AA} for central collisions measured by ALICE with the results obtained at RHIC in Au-Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$. In the low p_T range ($p_\mathrm{T} \sim 1\,\mathrm{GeV}/c$) the different experiments show similar results. Then, up to $2\,\mathrm{GeV}/c$, where the maximum value is located for all the three cases, and just beyond, the shapes are comparable. However, going to higher p_T, at $6 \div 7\,\mathrm{GeV}/c$, ALICE shows an R_{AA} which is smaller than the one found at RHIC, suggesting a hotter and denser medium. For more details on the ALICE R_{AA} analysis see ref. [5].

3˙2. *pp results.* – On top of the very wide and diverse heavy-ion program, the ALICE physics involves many pp analyses. Starting from the measurement of the charged particle pseudorapidity density [6], the ALICE results include identified particle spectra [7], two-pion Bose-Einstein correlations [8], heavy flavour analyses both for open charm and quarkonia [9], and many others. These analyses are not only the baseline for the Pb-Pb studies, but represent an important contribution to a better understanding of proton-proton collisions in a low-p_T region which is complementary to CMS and ATLAS results.

4. – Conclusions

The first results of the ALICE experiment for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$ have been presented. ALICE has measured the highest charged particle density observed so far. The p_T spectra analysis of Pb-Pb data has allowed to derive the R_{AA} using as reference an extrapolation from real ALICE pp data at $\sqrt{s} = 0.9$ and $7\,\mathrm{TeV}$. The stronger suppression of charged particle production in ALICE with respect to previous experiments suggests that a hotter and denser medium was formed. The pp data, on which ALICE has exercised its tracking and particle identification techniques, have been the crucial starting point for the heavy-ion physics.

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