RECENT RESULTS FROM ALICE*

Barbara Guerzoni

for the ALICE Collaboration

INFN and University of Bologna, Bologna, Italy

(Received July 11, 2013)

The ALICE experiment at the LHC has as its main purpose the study of the properties of the Quark-Gluon Plasma (QGP) produced in ultra-relativistic heavy ion collisions. To reach this goal ALICE has excellent vertexing, tracking and particle identification capabilities on a wide rapidity and transverse momentum range that make it perfect not only for the study of Pb–Pb collisions but also of *pp* and *p*–Pb interactions. In this paper, some of the latest ALICE results in Pb–Pb collisions will be shown together with the first results in *p*–Pb interactions.

DOI:10.5506/APhysPolBSupp.6.803

PACS numbers: 25.75.Ag, 25.75.Cj, 25.75.Dw, 25.75.Ld

1. Introduction

From the LHC startup, ALICE [1] collected not only Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV to study the QGP, but also *pp* interactions at $\sqrt{s} = 0.9$, 2.76 and 7.0 TeV. These data are fundamental to test QCD inspired models, tune MC models, provide reference for Pb–Pb data and get results that complement the other LHC experiments. In addition, *p*–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV have been recorded since they provide the possibility to discriminate between initial (cold nuclear matter) and final (QGP) effects, study the properties of QCD at low parton fractional momentum x and high gluon density and provide reference for Pb–Pb data. Some of the most recent results on *p*–Pb and Pb–Pb collisions will be presented.

2. First results in *p*–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

In Fig. 1 (left), the pseudorapidity density of primary charged particles[1] in non-single diffractive (NSD) *p*–Pb collisions is shown [2]. The data are

* Presented at the Workshop "Excited QCD 2013", Bjelašnica Mountain, Sarajevo, Bosnia–Herzegovina, February 3–9, 2013.

[1] Primary particles are defined as prompt particles produced in the collision, including decay products, except those from weak decays of strange particles.

compared to predictions of different particle production models [3–7]. Most of the models that include shadowing or saturation predict the measured multiplicity within 20%.

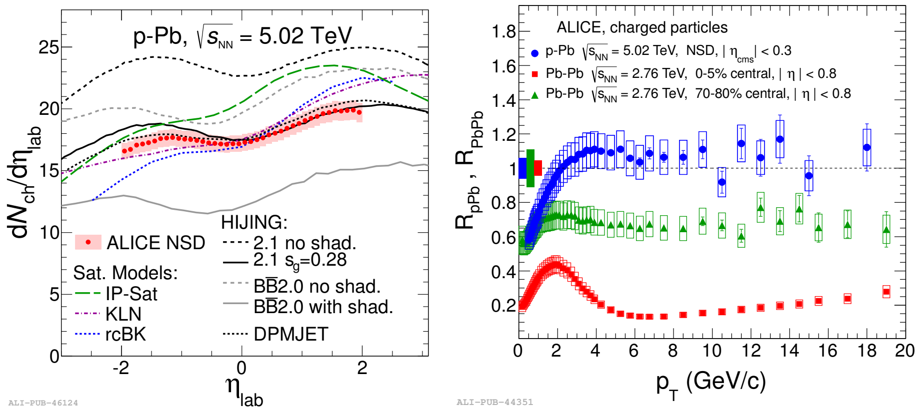


Fig. 1. Left: Charged particle pseudorapidity density in NSD p–Pb collisions compared to theoretical predictions [3–7]. Right: Nuclear modification factor of charged particles as a function of p_{T} in p–Pb collisions compared to the same measurements in central and peripheral Pb–Pb collisions [8].

In Pb–Pb collisions, ALICE has measured a high suppression of charged hadron production at high transverse momentum (p_{T}) if compared to what is expected from a pure superimposition of nucleon–nucleon collisions (nuclear modification factor $R_{\mathrm{PbPb}} < 1$)[2]. It was also noticed that the suppression increases with the centrality of the collisions, this increase being greater than that measured at RHIC at lower collision energies. In Fig. 1 (right), R_{PbPb} for central and peripheral Pb–Pb collisions is compared with the nuclear modification factor measured in p–Pb collisions ($R_{p\mathrm{Pb}}$) [8]. For $p_{\mathrm{T}} > 2$ GeV/c, $R_{p\mathrm{Pb}}$ is consistent with unity suggesting that the strong suppression of hadrons produced at high p_{T} in central Pb–Pb collisions is not due to an initial-state effect but is a fingerprint of jet quenching in hot QCD matter. $R_{p\mathrm{Pb}}$ is consistent with unity also at intermediate p_{T} indicating a smaller magnitude of the Cronin effect at the LHC compared with what measured in d–Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC.

In p–Pb collisions, ALICE has also measured the two-particle correlations that is measuring the distributions of relative angles $\Delta\eta$ and $\Delta\phi$ between pairs of particles[3]. In Fig. 2, the $\Delta\eta$ and $\Delta\phi$ distribution of the associated yield per trigger particle for central (0–20%) collisions minus the corresponding quantity in peripheral (60–100%) collisions is reported [9]. Two

---

[2] $R_{\mathrm{PbPb}} = 1$ for processes which exhibit binary collision scaling.

[3] $\Delta\eta$, $\Delta\phi$ difference in pseudorapidity and azimuthal angle between the two particles.

long-range ridge-like structures, one in the near side and one in the away side are visible. It was noticed that yields and widths of both away and near sides ridges are always in agreement even considering different classes of events, suggesting a common underlying physical origin. Predictions for two-particle correlations arising from collective flow in p–Pb collisions in the framework of a hydrodynamic model [10] can qualitatively describe the data but further analyses are needed to understand completely the origin of these two ridges.

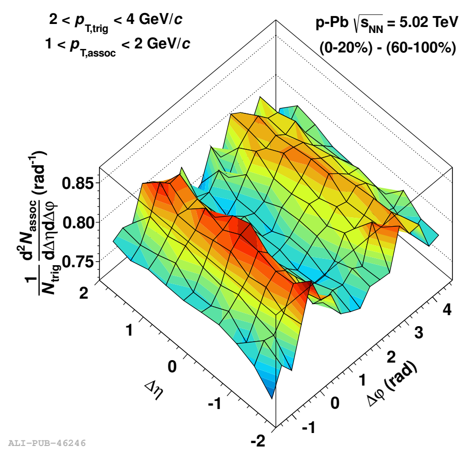


Fig. 2. Long-range ridge-like structures, one in the near side and one in the away side measured by ALICE in p–Pb collisions.

3. Some of the most recent results in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

In ultrarelativistic heavy ion collisions, after the first hard scatterings between partons that lead to the production of heavy quarks, jets and direct photons, there is the formation of a thermalized deconfined matter, the QGP that expands and cools down. When the temperature gets lower than the critical one, the hadronization phase takes place with the formation of the first bound states. When the temperature reaches the chemical freeze-out value $T_{\rm ch}$, the inelastic collisions stop and the relative abundance of particles is fixed. When the temperature reaches the kinetic freeze-out value $T_{\rm kin}$, also the elastic collisions stop and the $p_{\rm T}$ spectra of particles is fixed. Results from lower energies have shown that $p_{\rm T}$ spectra can be described by hydrodynamic models providing information about the collective transverse expansion (radial flow) $\beta_{\rm T}$ of the bulk and $T_{\rm kin}$. Hadron spectra and yields give hence the possibility to study collective and thermal properties of the QGP important since the signals produced in the QGP phase have to be folded with space-time evolution of the whole system.

In Fig. 3 (left), the $p_{\rm T}$ spectra of primary pions, kaons and protons measured by ALICE [11] in central Pb–Pb collisions are shown and compared with the RHIC results [12]. At the LHC energies, the spectra are harder due to the presence of a stronger radial flow that, in hydro models, is a consequence of an increased particle density. To quantify $\beta_{\rm T}$ and $T_{\rm kin}$, a Blast–Wave fit [13] has been performed; the results are $\beta_{\rm T} = 0.65 \pm 0.02$, 10% higher than the RHIC consistent with the observed increasing of $\langle p_{\rm T} \rangle$ with the collision energy for π, K, p, ϕ, K^* and $T_{\rm kin} = 95 \pm 10$ MeV comparable with the RHIC. The ALICE spectra are also compared to hydrodynamic models: VISH2+1 [14], a viscous hydro model with no description of the hadronic phase; HKM [15], a hydro model combined with UrQMD description of the hadronic phase that builds additional radial flow (due to elastic interactions) and affects the particle ratios (due to inelastic interactions) and Kraków [16] that introduces non-equilibrium corrections due to viscosity at the transition from the hydrodynamic description to particles which change the effective $T_{\rm ch}$.

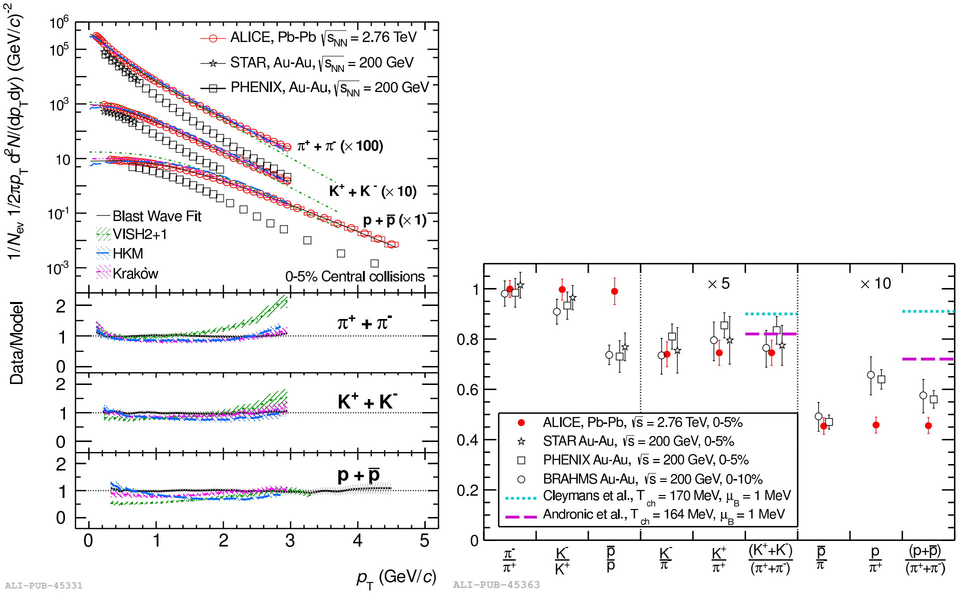
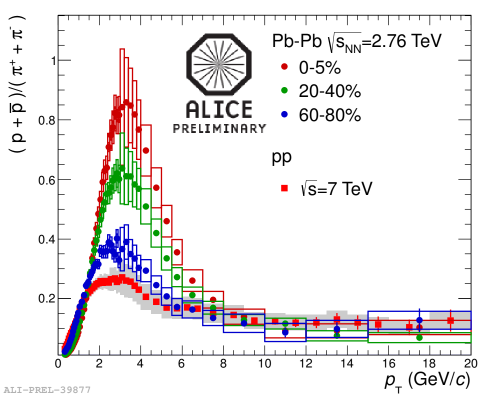


Fig. 3. Left: $p_{\rm T}$ spectra of primary pions, kaons and protons compared to the RHIC data and hydrodynamic models. Right: Particle ratios compared to the RHIC results and thermal model predictions.

The last two models give a better description of the data: it seems that at the LHC energies the hadronic final state interactions (in particular, antibaryon–baryon annihilation) cannot be neglected.

In Fig. 3 (right), particle ratios (computed from p_{T} integrated particle yields) measured by ALICE [11] in central Pb–Pb collisions are compared with the RHIC results and predictions from thermal models [17]. While K/π is in line with predictions, p/π is lower than expected by a factor 1.5. The same problem can be found for Λ/π ratio. At lower energies, particle abundances were described by thermal models assuming thermal and chemical equilibrium, that is negligible interactions modifying particle ratios in the hadronic phase. Deviations from thermal predictions can be explained by final state interactions in hadronic phase (HKM model), non-equilibrium SHM [18] or by the existence of flavor and mass dependent prehadronic bound states in the QGP phase [19].

From baryon/meson ratio, it is possible to get information on bulk particle production mechanism. In Fig. 4 (left), p/π ratio as a function of p_{T} in three centrality classes of Pb–Pb collisions and in pp interactions is shown. At intermediate momentum, $2 < p_{\mathrm{T}} < 7$ GeV/c, the enhancement respect to pp data that increases with the centrality of the collisions can be qualitatively consistent with hadron formation from medium constituents. At high momentum, $p_{\mathrm{T}} > 10$ GeV/c, the ratio is similar in Pb–Pb and pp collisions. A possible interpretation is that the parton fragmentation (jet chemistry) is not modified by the medium but further investigation is needed to provide a final explanation of the baryon/meson ratio.



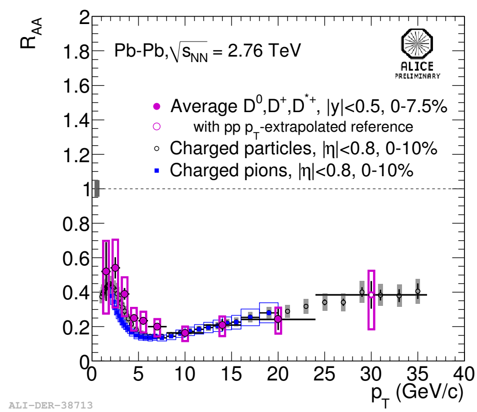


Fig. 4. Left: Proton/pion ratio as a function of p_{T} for three centrality classes of Pb–Pb collisions. Results in pp interactions at $\sqrt{s} = 7$ TeV are also shown. Right: R_{AA} in central Pb–Pb collisions for charged pions, charged particles and D mesons.

Quarkonium states and hadrons with open heavy flavors provide information on properties of strongly-interacting system formed in the early stages of heavy ion collisions since the heavy quarks are produced in the primary partonic scatterings, there is no extraproduction at the hadronization and we expect medium-induced gluon radiation depending on parton mass $E_g > E_{u,d} > E_c > E_b \rightarrow R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$. In addition, studying the J/Ψ production give the possibility to test models that have to take into account direct J/Ψ production, dissociation due to Cold Nuclear Matter effects (CNM) and J/Ψ dissociation and regeneration from deconfined charm quarks in the medium and to get an estimate of the initial temperature of the system. In Fig. 4 (right), R_{AA} for D mesons, charged particles and charged pions computed in central Pb–Pb collisions is shown. It can be noticed that $R_{AA}(D)$ is similar to R_{AA}(light) even if there could be hints of the hierarchy R_{AA}(charm) $>$ R_{AA}(light) but more statistics is needed. ALICE has also seen indications for R_{AA}(charm) $<$ R_{AA}(beauty) [20].

REFERENCES

[1] ALICE Collaboration, *JINST* **3**, S08002 (2008).

[2] ALICE Collaboration, *Phys. Rev. Lett.* **110**, 032301 (2013).

[3] A. Dumitru, D.E. Kharzeev, E.M. Levin, Y. Nara, *Phys. Rev.* **C85**, 044920 (2012).

[4] G. Barnafoldi *et al.*, *Phys. Rev.* **C85**, 024903 (2012).

[5] P. Tribedy, R. Venugopalan, *Phys. Lett.* **B710**, 125 (2012).

[6] R. Xu, W.-T. Deng, X.-N. Wang, `arXiv:1204.1998 [nucl-th]`.

[7] J.L. Albacete, A. Dumitru, H. Fujii, Y. Nara, *Nucl. Phys.* **A897**, 1 (2013).

[8] ALICE Collaboration, *Phys. Rev. Lett.* **110**, 082302 (2013).

[9] ALICE Collaboration, *Phys. Lett.* **B719**, 29 (2013).

[10] P. Bozek, *Phys. Rev.* **C85**, 014911 (2012).

[11] ALICE Collaboration, *Phys. Rev. Lett.* **109**, 252301 (2012).

[12] STAR Collaboration, *Phys. Rev.* **C79**, 034909 (2009); PHENIX Collaboration, *Phys. Rev.* **C69**, 034909 (2004).

[13] E. Schnedermann *et al.*, *Phys. Rev.* **C48**, 2462 (1993).

[14] C. Shen *et al.*, *Phys. Rev.* **C84**, 044903 (2011).

[15] A. Karpenko *et al.*, *Phys. Rev.* **C87**, 024914 (2013).

[16] P. Bozek, *Phys. Rev.* **C85**, 034901 (2012).

[17] J. Cleymans *et al.*, *Phys. Rev.* **C74**, 034903 (2006); A. Andronic, P. Braun-Munzinger, J. Stachel, *Phys. Lett.* **B673**, 142 (2009).

[18] M. Petran, J. Rafelski, *Phys. Rev.* **C82**, 011901 (2010).

[19] C. Ratti *et al.*, *Phys. Rev.* **D85**, 014004 (2012); R. Bellwied, `arXiv:1205.3625 [hep-ph]`.

[20] B. Abelev *et al.*, *J. High Energy Phys.* **09**, 112 (2012).