Particle production in pp and Pb–Pb collisions with the ALICE experiment at the LHC

F. Bellini* for the ALICE Collaboration
Department of Physics, University of Bologna and I.N.F.N
Via Irnerio 46, 40126 Bologna - Italy

The performance and capabilities of the ALICE experiment allow to study the hadron production over a wide range of momenta both in pp and Pb–Pb collisions at the LHC. ALICE, with respect to the other LHC experiments, contributes especially with the measurement of identified particles, resonances and multi-strange baryons down to very low $p_{\rm t}$. A review of the most recent results obtained in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV is reported. Transverse momentum spectra allow to characterize the dynamical evolution of the system produced in nuclear collisions, while production yields and ratios are discussed from a thermodynamical point of view. Results are finally compared to measurements at lower energies and predictions for the LHC.

1 Introduction

The ALICE experiment [1] has been taking data in pp collisions at $\sqrt{s} = 0.9$, 2.76 and 7 TeV and Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV. The ALICE detector has been designed and optimized to allow particle identification (PID) with different techniques, especially in the central barrel. A six-layer silicon Inner Tracking System (ITS) provides precise tracking and vertex determination and allow PID down to 100 MeV/c via a dE/dx measurement in the 4 external layers, with a resolution of 10-15% on the dE/dx. A large-volume Time Projection Chamber (TPC) provides the global tracking and PID through the measurement of the specific energy loss in gas, with a resolution of 5%. The Time-Of-Flight system is a large Multigap Resistive Plate Chamber (MRPC) array. Its PID is based on the measured particle time-of-flight for matched tracks extrapolated from the TPC. Thanks to a resolution on the particle time-of-flight of $\sigma_{TOF} = 86$ ps, there is a 2σ separation for π/K up to $\rm p_t = 3.0$ GeV/c and a 2σ separation for K/p up to $\rm p_t = 5.0$ GeV/c. At higher particle energies the relativistic rise of the Bethe-Bloch distribution of the dE/dx in the TPC can be used for PID. Finally, topological reconstruction of V-shaped decays is exploited for the reconstruction of strange and multi-strange baryons in their “cascade” decays.
This contribution focuses in particular on Pb–Pb collisions results, referring to the available literature for the results in pp [2, 3].

2 Identified particle $p_{\rm t}$ spectra

The study of primary hadron transverse momentum ($p_{\rm t}$) spectra and particle ratios gives insights on the medium properties at the freeze-out. Primary π/K/p $p_{\rm t}$ spectra have been measured by ALICE for different collision centrality in the following ranges: 0.1–3.0 GeV/c for pions, 0.2–3.0

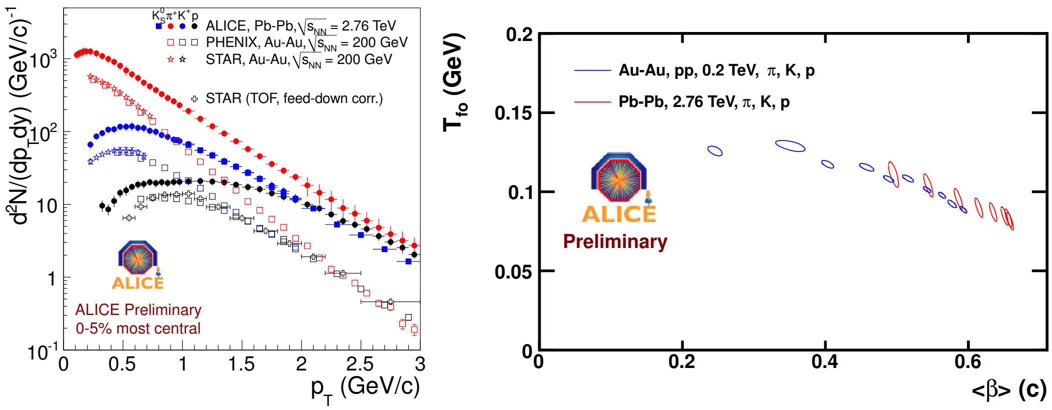

Figure 1: Positive π/K/p p_t spectra in the 0–5% most central Pb–Pb events, measured by ALICE at $\sqrt{s_{\rm NN}} = 2.76$ TeV (left) and the freeze-out temperature (T_{fo}) and radial flow parameter ($\langle\beta\rangle$) resulting from a blast-wave fit to the primary hadron spectra for different centrality bins. The comparison with RHIC measurements is shown.

GeV/c for kaons, 0.3–3.0 GeV/c for protons. Fig. 1 (left) shows the comparison to similar measurements performed at RHIC in Au–Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV [4, 5]. At the LHC the spectral shapes look much flatter at low p_t and spectra are harder, indicating a stronger radial flow at the LHC. A blast-wave fit [6] has been performed simultaneously on the π, K and p spectra for each centrality in order to extract the kinetic freeze-out temperature and radial flow ($\langle\beta\rangle$ parameter), as shown in Fig. 1 (right). While the former seems slightly lower than at RHIC, ALICE measures $\langle\beta\rangle = 0.66c$, which corresponds to a value about 10% higher than the one measured by STAR [4] for the most central collisions.

3 Multi-strange baryon production and strangeness enhancement

As observed at the SPS and then at RHIC, the enhancement of multi-strange hadron production supported the hypothesis that the state of matter produced in ultra-relativistic nucleus-nucleus collisions was different from a hadron gas created at the same energy in nucleon-nucleon collisions. It suggested instead the presence of a medium with large correlation volume and fast equilibration phase [7]. The measurement of multi-strange baryon p_t spectra has been performed at mid-rapidity in four centrality classes via the topological reconstruction of the following weak decays: $\Xi^- \to \pi^- + \Lambda$, $\Omega^- \to K^- + \Lambda$, where $\Lambda \to \pi^- + p$, and similarly for the anti-particle decay, where the corresponding branching ratios for Ξ and Ω are 63.9% and 43.3% respectively. The spectra integrated over all centralities are reported in Fig. 2 (left). It has been verified that the anti-particle to particle ratio is close to unity, as expected at the LHC where the baryochemical potential (μ_B) is close to zero. The yields which were extracted with a Blast-wave fit, are further used to estimate particle ratios, which have been compared with thermal model predictions [8]. The measured values for kaon and multi-strange baryons over pion are compatible with a model prediction that assumes a chemical freeze-out temperature of the medium T = 160-170 MeV. The p/π ratio is in better agreement with T = 148 MeV, which however fails for multi-strange.

The comparison between the yields of multi-strange hadrons in pp and Pb–Pb collisions has been carried out through the definition of the enhancement factors which are reported in Fig. 2 (right) for different hyperon species as a function of $\langle N_{part}\rangle$. Several experiments at different energies, WA97/NA57 at the SPS ($\sqrt{s_{\rm NN}} = 17.2$ GeV) [9, 10], STAR at RHIC ($\sqrt{s_{\rm NN}} = 200$ GeV) [11] and finally ALICE ($\sqrt{s_{\rm NN}} = 2.76$ TeV) are compared. Details can be found in the original references. The enhancement increases with centrality, and follows the hierarchy of the

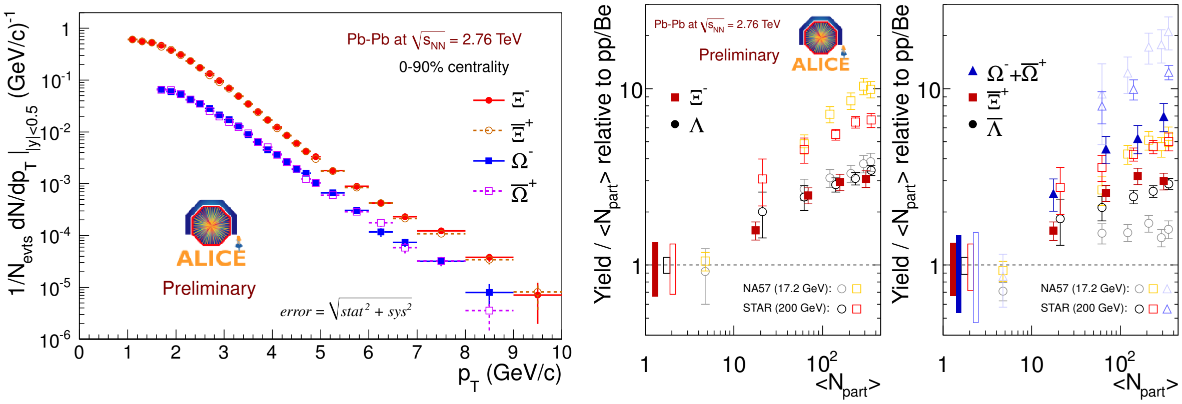

Figure 2: Transverse momentum spectra for Ξ^-, $\bar{\Xi}^+$, Ω^- and $\bar{\Omega}^+$ in the 0-90% centrality range, on the left. On the right: enhancement for hyperon yields measured at mid-rapidity and for different centralities by ALICE (filled points), compared with SPS and RHIC data (open points). The vertical bars indicate the quadratic sum of statistical and systematic error. ALICE's measurement of the Λ enhancement is not reported, as still in progress.

strangeness content in terms of valence quarks of the hyperons. Moving from SPS to LHC the relative enhancements seem to decrease with increasing collision energy, although it must be stressed that the absolute production of hyperons in heavy-ion collisions increases with energy from the SPS to the LHC, as expected.

4 Λ and K^0_S production

It was firstly observed at RHIC [12] that in Au–Au collisions the baryon (anti-baryon) production at intermediate p_t becomes comparable to that of mesons and that the maximum value of the Λ/K^0_S ratio in central collisions exceeds unity. In nucleus-nucleus (A-A) collisions the interplay between soft and hard processes involved in particle production is a candidate to explain this "baryon-to-meson anomaly". In ALICE, the K^0_S and Λ particles are reconstructed via their V0 decay topology in a wide momentum range, the spectra of Λ being feed-down corrected for the contribution of Λ coming from the weak decays of Ξ^- and Ξ^0. ALICE measured the Λ/K^0_S ratio as function of p_t in five centrality bins, as reported in Fig. 3 (left). Baryon/meson ratio decreases from central to peripheral events, where it reaches the value measured in pp collisions. For most central Pb–Pb collisions it well goes above unity, reaching it maximum for $p_t \simeq 3$ GeV/c. A direct comparison with RHIC result indicates a dependence of the Λ/K^0_S both from the centrality and the collision energy. At higher p_t, up to 20 GeV/c, a suppression of a factor 4 in the Λ and K^0_S production in Pb–Pb collisions with respect to pp is observed. The suppression, measured in terms of the nuclear modification factor, R_{AA}, is seen to increase with the centrality of the collision. As shown in Fig. 3 (right), relative to collision centrality 0–5 %, the Λ exhibits an enhancement at intermediate p_t then a suppression for $p_t \geq 3$ GeV/c, while the K^0_S exhibits suppression in the full range. The mesons appear to be more suppressed than the baryons, up to $p_t = 8$ GeV/c. Above this value, the suppression is similar to that of the charged particles. This suppression effect has been interpreted as resulting from the energy loss by the partons that once produced with high energy in hard-scattering processes, traverse the hot and dense medium created with the collision. A common behaviour shared by the strange baryons, mesons and the other charged particles, suggests that the parton energy loss may not be strongly dependent by the (light) flavour of the parton involved. The significantly higher R_{AA} of Λ at intermediate p_t could be related to the presence of other hadronization mechanisms, as suggested by the Λ/K^0_S ratio.

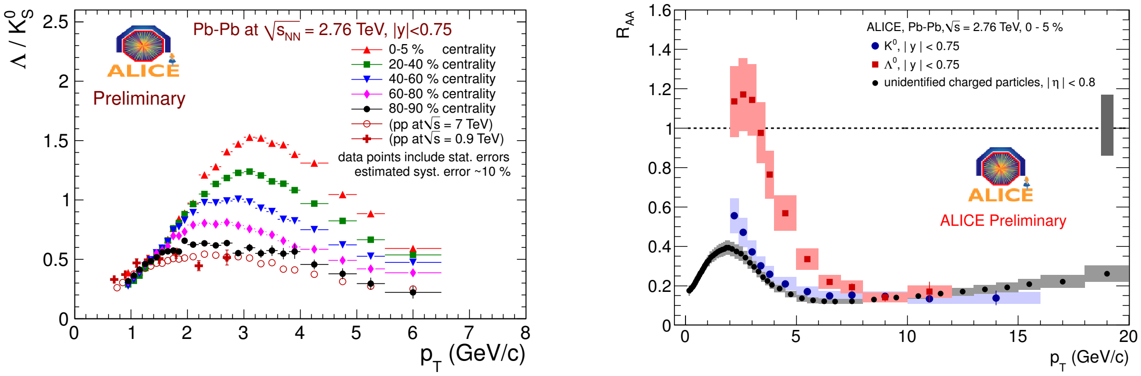

Figure 3: Strange baryon over meson ratio as function of p_t and centrality in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and compared with minimum bias pp collisions at $\sqrt{s_{NN}} = 0.9$ and 7 TeV, on the left. On the right: nuclear modification factor for Λ, K^0_S and charged particles in 0–5 % central Pb–Pb collisions. Vertical error bars represent statistical error, while rectangles represent systematic errors. The grey bar indicates the uncertainty in the calculation of the mean number of binary collisions.

5 Summary

We have presented the measurements of several observables that contribute to the investigation of the properties of the strongly interacting matter created in heavy-ion collisions at $\sqrt{s_{NN}} = 2.76$ TeV at the LHC. Identified π, K, p and multi-strange baryon p_t spectra have been measured for different centralities and compared to results at lower energies. The radial flow measured at the LHC is stronger that the one measured at RHIC. ALICE's measurement has been compared to the previous experiments to describe the excitation functions of the strange hyperons enhancement: the relative values seem to decrease with increasing energy, confirming the trend observed at the SPS and between the SPS and RHIC. Moreover we have reported the observation of the "baryon-to-meson anomaly" in most central Pb–Pb collisions. Finally the nuclear modification factor of Λ and K^0_S exhibits for $p_T \geq 8$ GeV/c a similar behaviour to that of the charged particles, suggesting no strong light flavour dependence of the parton energy loss in the medium produced in Pb–Pb collisions at the LHC.

References

1. K. Aamodt *et al.* [ALICE Collaboration], JINST **3**, S08002 (2008).
2. M. Chojnacki (Quark Matter 2011 proceedings), arXiv:1109.6744 [hep-ex].
3. B. Abelev *et al.* [ALICE Collaboration], arXiv:1204.0282v1 [nucl-ex].
4. B. I. Abelev *et al.* [STAR Collaboration], Phys. Rev. C **79**, 034909 (2009).
5. S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. C **69**, 034909 (2004).
6. E. Schnedermann, J. Sollfrank and U. W. Heinz, Phys. Rev. C **48**, 2462 (1993).
7. J. Rafelski and B. Muller, Phys. Rev. Lett. **48**, 1066 (1982).
8. A. Andronic *et al.* Phys. Lett. B **673**, 142 (2009).
9. E. Andersen *et al.* [WA97 Collaboration], Phys. Lett. B **449**, 401 (1999).
10. F.. Antinori *et al.* [WA97/NA57 Collaboration], Nucl. Phys. A **698**, 118c (2002).
11. B. I. Abelev *et al.* [STAR Collaboration], Phys. Rev. C **77**, 044908 (2008).
12. J. Adams *et al.* [STAR and STAR-RICH Collaborations], arXiv:0601042 [nucl-ex].