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

Francesca Bellini* **for the ALICE Collaboration**
Università di Bologna and I.N.F.N.
E-mail: `bellini@bo.infn.it`

The ALICE experiment can benefit from its excellent particle identification capabilities to study hadron production in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, over a wide range of momenta. This allows one to probe different stages of the medium evolution. Transverse momentum spectra of identified particle and resonances characterize the bulk freeze-out properties and the dynamical evolution of the system. Results from hydrodynamics-motivated blast-wave model fits to the data are shown, while production yields and ratios are discussed from a thermodynamical point of view. Since the colliding nuclei have no net strangeness content, the study of strange and multi-strange particle production is an important probe of the early partonic stages of the collision. The enhancement of strangeness production in relativistic heavy-ion collisions relative to proton-induced reactions was one of the predicted signatures of the formation of the deconfined medium known as Quark-Gluon Plasma. ALICE results are presented. Moreover, high-p_{T} particle production can be used to investigate the energy loss of the fast partons produced in early hard scatterings, while traversing the medium. To this purpose, measurements of the nuclear modification factor (R_{AA}) of identified particles have been performed and are discussed. Pb–Pb results are finally compared to measurements at lower energies and predictions for the LHC.

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*Speaker.

1. Introduction

The ALICE experiment [1] at the LHC has been collecting data in order to characterise the hot and dense medium which is formed in Pb–Pb collision at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. The collective expansion of the medium has been studied within a hydrodynamic picture, by measuring the radial and elliptic flow. ALICE results on elliptic flow have been presented at this conference and can be found in [2]. The radial flow has been estimated by measuring the primary hadron transverse momentum ($p_{\rm T}$) spectra, that also provide information about the system temperature at the kinetic freeze-out (T_{kin}), i.e. at the stage in which the elastic interactions among the hadrons in the expanding system cease. The measured particle ratios have been compared to the prediction of the thermal model [3], which has been proven to successfully describe the data in a broad range of lower collision energies. This model assumes that particles are created in thermal equilibrium and are governed by a scale parameter, defined as the chemical freeze-out temperature (T_{ch}). In addition to T_{ch}, the volume (V) and the baryo-chemical potential ($\mu_{\rm B}$) have been extracted by performing a thermal model fit [3] of the measured integrated yields at mid-rapidity in most central collisions. This picture has been enriched with the information provided by the analysis of the strange and multi-strange hadron production. The measurement of strangeness production in heavy-ion collisions has itself been of great interest after the prediction [4] that the presence of a hot and dense medium allows the thermal production of strange quarks, leading to a strangeness enhancement in the final state. The enhancement is defined as the ratio between the yields in Pb–Pb collisions and the yields in pp collisions, where the former is appropriately scaled by the number of participant nucleons to account for the increased interaction volume.

Finally, the comparison of identified particle $p_{\rm T}$ distributions in Pb–Pb collisions with respect to pp collisions is performed by measuring the nuclear modification factor ($R_{\rm AA}$). Particle yields in nucleus-nucleus collisions are much lower than the expected initial state production that can be predicted by pQCD calculations in pp collisions scaled to Pb–Pb collisions. This suppression has been considered as a hint for the presence of strong final state interactions with the surrounding medium. In particular, results on the $R_{\rm AA}$ for the hadrons containing light quarks are presented, as they also establish a benchmark for the study of in-medium energy loss of heavy quarks [5].

2. Hadron production measurements with ALICE

The measurement of hadron production in Pb–Pb collisions has made large use of the unique particle identification (PID) performance of ALICE. The central barrel detectors have been exploited for the measurements in the central rapidity region, $|y|\leq 0.5$. A six-layer silicon Inner Tracking System (ITS) and a large-volume Time Projection Chamber (TPC) provide vertex determination and tracking. The ITS allows PID down to 100 MeV/c thanks to the dE/dx measurement in its 4 external layers, with a resolution of 10-15%. The TPC provides PID information through the measurement of the specific energy loss with a resolution of 5%. The relativistic rise of the Bethe-Bloch distribution of the dE/dx in the TPC can also be used for PID of particles with momentum larger than 5-10 GeV/c. The TOF is a large Multigap Resistive Plate Chamber (MRPC) array with a resolution on particle time-of-flight $\sigma_{TOF} = 86$ ps. The time-of-flight information for matched tracks extrapolated from the TPC extends the PID reach at intermediate $p_{\rm T}$, with a 2σ

separation for π/K up to p_{T} = 3.0 GeV/c and a 2σ separation for K/p up to p_{T} = 5.0 GeV/c. Finally, topological reconstruction of V-shaped decays is exploited for the reconstruction of strange and multi-strange baryons in their “cascade" decays.

3. Identified hadron p_{T} spectra and ratios

Primary identified π/K/p p_{T} spectra have been measured for different collision centrality intervals. Primary particles are defined as the prompt particles produced in the collision. This includes the decay products, except those resulting from the weak decay of the strange hadrons. ALICE results are reported in Fig. 1 (red circles) for the most central collisions (0-5%). The comparison to a similar measurement performed at RHIC in Au–Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV [9, 10] (black markers in Fig. 1) shows that the average p_{T} is higher at LHC than at RHIC and that the spectral shapes look flatter at low p_{T}. In a hydrodynamic picture, harder spectra indicate that the medium expansion at LHC is driven by a significantly stronger radial flow. The hydrodynamic interpretation of the transverse momentum spectra is supported by the comparison with different viscous hydrodynamic–based models, VISH2+1 [6], HKM [7] and Krakow[8]. In HKM, a hadronic cascade model (UrQMD [11]) description follows the hydrodynamic phase and adds a contribution to the radial flow mostly due to elastic interactions. In the Krakow model, the transition to the

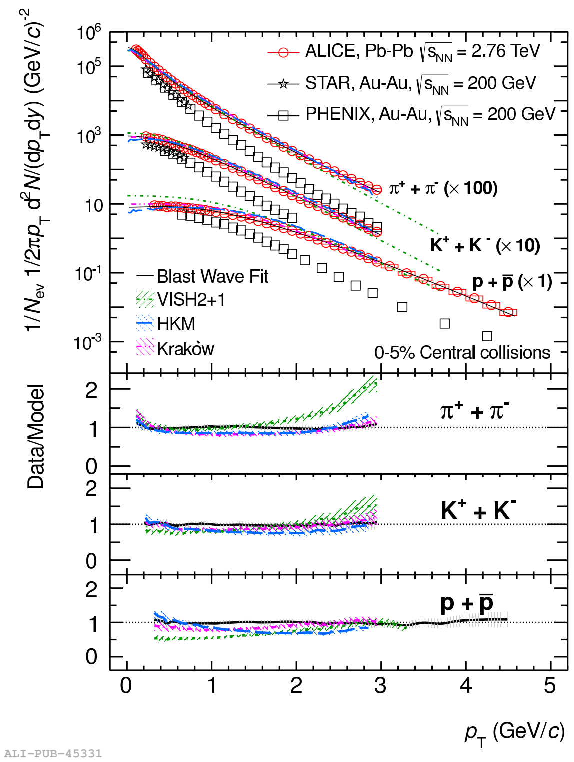

Figure 1: π/K/p p_{T} spectra in the 0–5% most central Pb–Pb collisions, measured by ALICE at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV and compared with RHIC results [9, 10] and hydrodynamic-based model prediction [6, 7, 8].

hadronic phase is described by non-equilibrium corrections due to viscosity which change the effective T_{ch}. HKM and Krakow better describe the data, suggesting the importance of taking into account the contribution from the hadronic phase on the measured flow. More details can be found in [12] and references therein. The transverse radial flow parameter $\langle\beta_T\rangle$ is measured by a simultaneous blast-wave fit [13] on the π, K and p spectra. For the most central collisions ALICE measures $\langle\beta_T\rangle = 0.66\,c$, which corresponds to a value about 10% higher than the one measured by STAR [9].

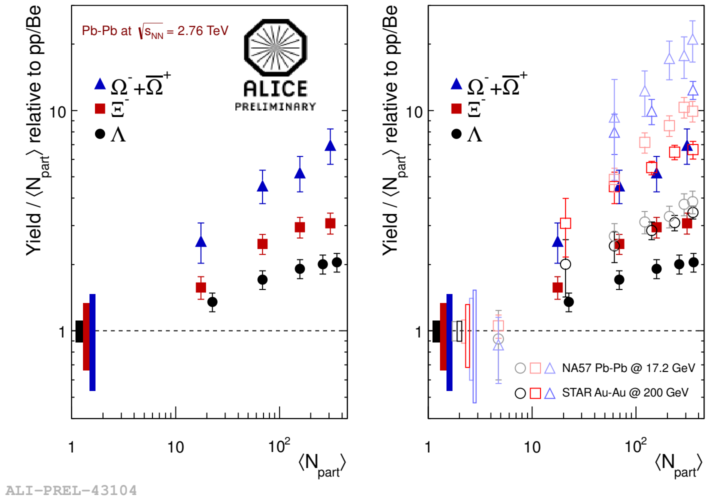

Figure 2: Hyperon yields in Pb–Pb collisions scaled by the number of participant nucleons, relative to the yields in pp (p–Be) collisions, measured at mid-rapidity and for different centrality intervals. ALICE results (filled points), are compared with SPS and RHIC data (open points). The vertical bars indicate the quadratic sum of statistical and systematic uncertainty.

Strange particle and multi-strange baryon production at mid-rapidity has been measured [14] via the topological reconstruction of the decays $K^0_S \to \pi^+\pi^-$, $\Lambda \to \pi^- p$, $\Xi^- \to \pi^-\Lambda$, $\Omega^- \to K^-\Lambda$, and similarly for the anti-particle decays. The Λ spectra have been feed-down corrected for the contribution of Λ coming from the weak decays of Ξ^- and Ξ^0. The spectra show that anti-baryon to baryon ratio is compatible with unity, confirming that the baryochemical potential is close to zero, as expected at the LHC. The yields of baryons with increasing strangeness content ($|S| = 1, 2, 3$) in pp and Pb–Pb collisions have been compared by defining the enhancement factors which are reported in Fig. 2 as a function of $\langle N_{part}\rangle$. As the strangeness content in terms of valence quarks of the hyperons increases the enhancement also increases. A similar trend is seen as function of centrality. Moreover, the comparison with similar measurements at SPS (WA97/NA57 [16, 17], $\sqrt{s_{NN}}$ = 17.2 GeV) and RHIC (STAR [18], $\sqrt{s_{NN}}$ = 200 GeV) shows that the relative enhancements decrease with increasing collision energy. The results on identified particle spectra have been combined in the measurement of particle ratios in order to study the hadrochemistry of the medium. A thermal fit [3] of the hadron integrated yields for the 0-20% central collisions provides a temperature of $T_{ch} = 152 \pm 3$ MeV. Thermal model predictions of particle ratios with this value of T_{ch} are close to the measured p/π and Λ/π ratios, but do not agree with the measured Ξ/π and

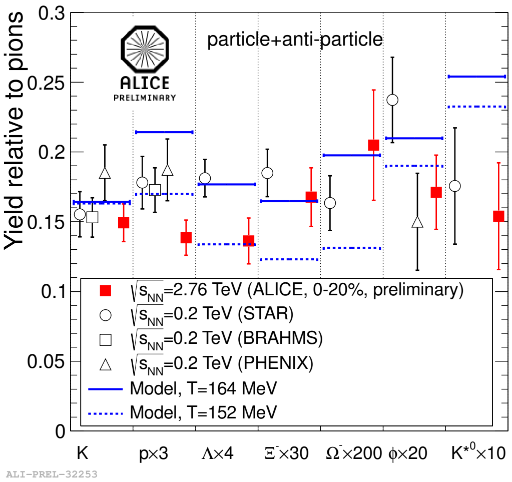

Figure 3: Integrated yields at mid-rapidity relative to pions in central (0-20%) Pb–Pb collisions compared to RHIC measurements and thermal model predictions.

Ω/π, as shown in Fig. 3. A model where the T$_{ch}$ is extracted from a fit to the RHIC data, T$_{ch}$ = 164 MeV, instead seems to agree with the ratios involving multi-strange baryons, missing p/π and Λ/π. The deviation from the thermal model is still under discussion, after the suggestion that particle interactions during the hadronic phase, and in particular antibaryon-baryon annihilation, may affect the measured yields and ratios.

4. Light hadron suppression in Pb–Pb collisions

The R_{AA} in central (0–5 %) Pb–Pb collisions is reported in Fig. 4 for different identified particle species. Going to more peripheral collisions, the suppression decreases [20]. The p_{T} range can be divided in three regions. At low momentum ($p_{\mathrm{T}} \leq 2$ GeV/c) the behaviour of the different particle species is dictated by hydrodynamic flow and the hadron mass dependence. In the intermediate p_{T} region, up to p_{T} = 8 GeV/c, the strange mesons appear to be more suppressed than the baryons. In particular, the Λ production is enhanced up to $p_{\mathrm{T}} \leq 3$ GeV/c and suppressed afterwards, while the $\mathrm{K}^0_{\mathrm{S}}$ exhibits a suppression in the full range. This result is consistent with the "baryon-to-meson anomaly" observed in the baryon/meson ratio already at RHIC [19] and reported by ALICE in [21]. The $\Lambda/\mathrm{K}^0_{\mathrm{S}}$ ratio is larger than unity in most central collisions, reaching it maximum for $p_{\mathrm{T}} \simeq 3$ GeV/c, and decreases down to the pp values as the centrality of the collision decreases. This effect is thought to be due to the interplay between soft and hard processes involved in particle production and in particular to the possible role of quark coalescence at intermediate p_{T}, which favors the formation of baryons over mesons [22]. For $8 \leq p_{\mathrm{T}} \leq 20$ GeV/c, the Λ and $\mathrm{K}^0_{\mathrm{S}}$ suppression is similar to that of charged particles and identified pions. Such common behaviour shared by strange baryons, mesons and other charged particles, suggests that any (light) flavour-dependent effects on the in-medium parton energy loss must be small. This constitutes an important reference for the study of heavy-flavour particles R_{AA} and an input to theoretical models.

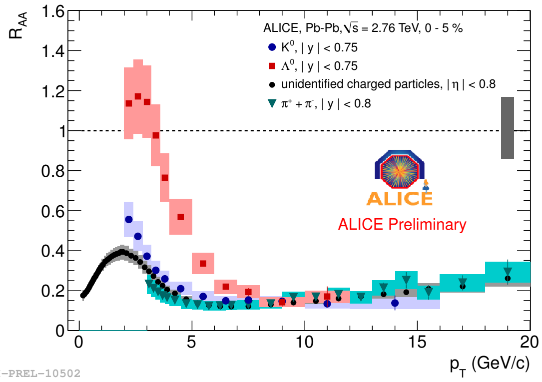

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Figure 4: Nuclear modification factor for unidentified charged particles and identified charged π, Λ, K^0_S in 0–5 % central Pb–Pb collisions.

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