Nuclear modification of strange and light-flavour hadrons measured with ALICE at the LHC

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The ALICE experiment at CERN was designed to study the properties of the strongly-interacting hot and dense matter created in heavy-ion collisions at the LHC energies. Hard partons propagating through such a medium lose energy via multiple scattering and gluon radiation: this reflects in a modification of the transverse momentum (p_T) spectra of the final-state hadrons since their yields at high p_T are suppressed compared to the reference values from a simple superposition of incoherent proton-proton collisions.

Results on the suppression patterns for identified hadrons with and without strangeness content can be connected with the predicted energy loss dependence on the parton mass, while the comparison of baryon and meson suppressions at high p_T can probe different energy losses for quarks and gluons. In addition, results from Pb–Pb collisions compared with the corresponding measurements carried out in p-Pb allow to investigate possible contributions due to initial-state nuclear matter effects.

38th International Conference on High Energy Physics
3-10 August 2016
Chicago, USA

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1. Introduction

Hard partons propagating through the hot and dense strongly-interacting matter created in ultra-relativistic heavy-ion collisions (Quark Gluon Plasma, QGP [1]) are predicted to lose energy via multiple scattering and gluon radiation. As a result, the yield of final-state hadrons at high transverse momentum will be suppressed compared to the reference value from a simple superposition of incoherent proton-proton collisions [2, 3]. This modification of the p_T spectra, quantified by the nuclear modification factor (R_{AA}) and measured for light-flavour hadrons with different quark content, allows to study the parton energy-loss mechanisms and medium properties. Similar measurements performed in p–A collisions (R_{pA}) may help in determining whether initial or final state nuclear effects play a role in the suppression of hadron production observed in A–A.

The design of the ALICE experiment was optimized to study the properties and the evolution of the hot and dense matter created in heavy-ion collisions at the LHC. Its apparatus consists of a central barrel with a large solenoid providing a 0.5 T magnetic field for tracking and particle identification, plus a dimuon spectrometer equipped with its own dipole magnet with a 0.7 Tm field integral, and other forward detectors for triggering and centrality selection. It has specific unique capabilities for measuring the production of strange and light-flavour hadrons over a wide range of transverse momentum, from pp and p–Pb interactions up to the highest-multiplicity environment of the central Pb–Pb collisions. Tracking and vertexing are performed using the Inner Tracking System (ITS), consisting of six layers of silicon detectors, and the Time Projection Chamber (TPC). The two innermost layers of the ITS and the VZERO detector (scintillation hodoscopes placed on either side of the interaction region) are used for triggering. The VZERO also provides the centrality (multiplicity) class definition in Pb–Pb (p–Pb) collisions, while ITS and TPC provide particle identification in the low and intermediate p_T region, respectively. Particle identification in the intermediate p_T region is provided by a Time-Of-Flight (TOF) detector. A complete description of the ALICE sub-detectors can be found in [4, 5]. In the next section the main ALICE results on the nuclear modification factors R_{AA} for identified strange and light-flavour hadrons are presented, together with the corresponding measurements for p–Pb collisions.
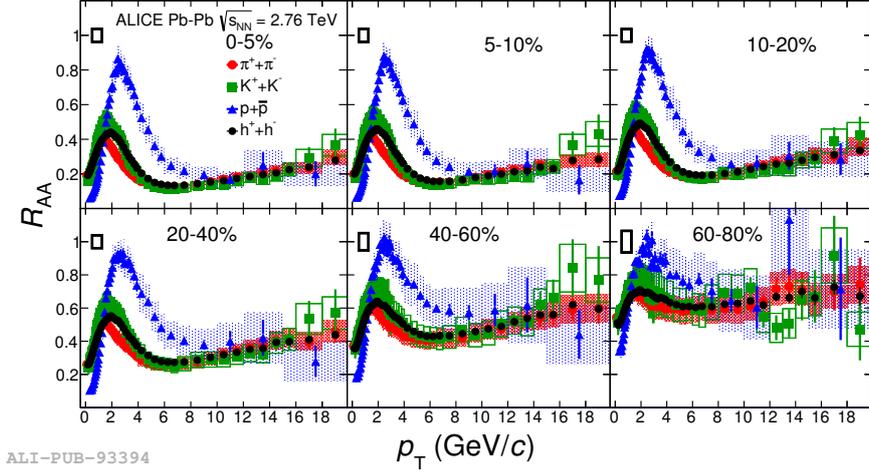
2. Results and discussion

In order to study the modification of the transverse momentum spectra and to disentagle suppression due to QGP in hot nuclear matter from initial-state nuclear matter effects (e.g. Cronin enhancement [6]), the nuclear modification factor is introduced for both Pb–Pb and p–Pb collision systems according to the following definition:

$$R_{AA} = \frac{\mathrm{d}^2 N_{AA}/\mathrm{d}y\mathrm{d}p_T}{\langle T_{AA}\rangle \mathrm{d}^2 \sigma_{pp}^{INEL}/\mathrm{d}y\mathrm{d}p_T} \qquad R_{pPb} = \frac{\mathrm{d}^2 N_{pPb}/\mathrm{d}y\mathrm{d}p_T}{\langle T_{pPb}\rangle \mathrm{d}^2 \sigma_{pp}^{INEL}/\mathrm{d}y\mathrm{d}p_T} \qquad (2.1)$$
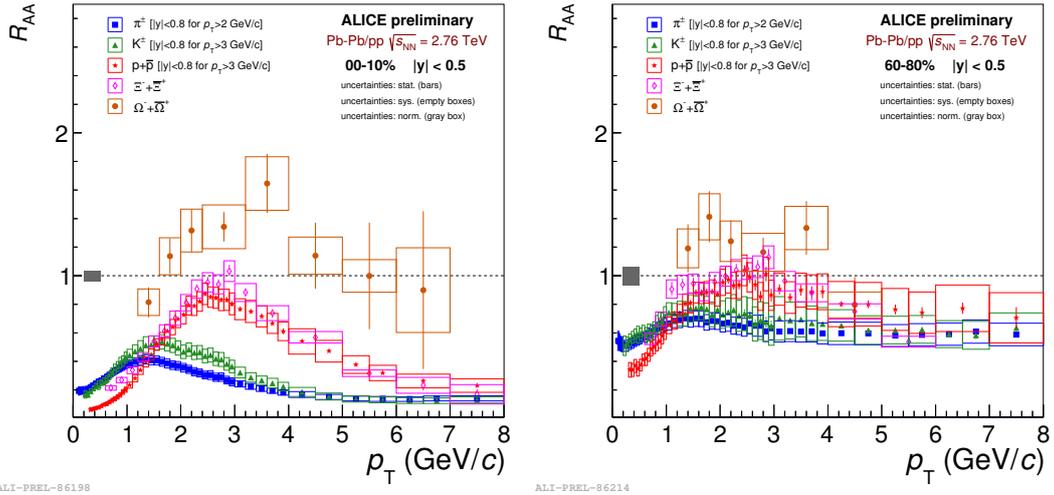
where N_{AA} (N_{pPb}) and σ_{pp}^{INEL} represent the particle yields in Pb–Pb (p–Pb) and the inelastic cross section in pp collisions, respectively. Both in Pb–Pb and p–Pb the nuclear overlap function (corresponding to $\langle T_{AA}\rangle$ and $\langle T_{pPb}\rangle$, respectively) is determined from the Glauber model [7] and proportional to the average number of binary nucleon-nucleon collisions $\langle N_{coll}\rangle$. By construction, R_{AA} and R_{pPb} are expected to be equal to unity in absence of nuclear effects.

Fig. 1 shows the R_{AA} for π, K and p as a function of p_T, compared with that for unidentified charged particles in six centrality classes of Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [7]. Results indicate that all particle species are equally suppressed for p_T above 10 GeV/c, hence particle ratios are similar to those from jet fragmentation in the vacuum. At lower (intermediate) p_T protons are less suppressed for all centralities. The mass dependence of the nuclear modification of the spectra is qualitatively consistent with the expectations from the presence of radial flow.

Figure 1: Nuclear modification factor R_{AA} for π, K, p and charged particles, for different centralities in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.
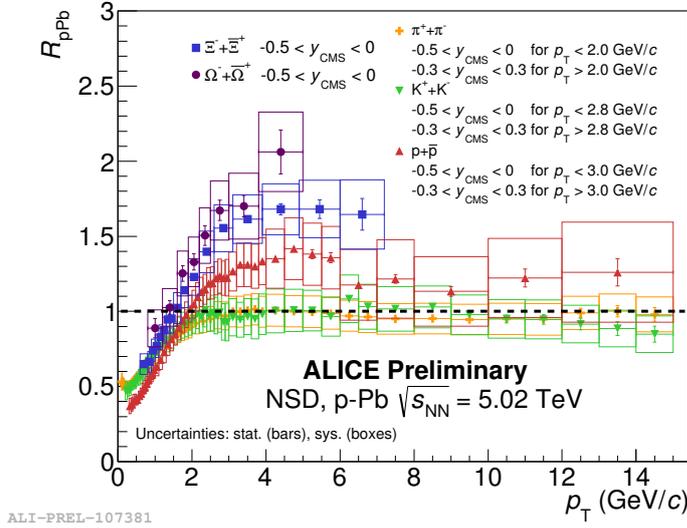
The comparison of non-strange and strange baryon and meson suppression patterns at high p_T may help to disentagle the different energy loss of quarks and gluons, which arises from their different colour-coupling factors. In Fig. 2 the R_{AA} for π, K and p are compared with those for multi-strange baryons, both in central (0-10%) and peripheral (60-80%) Pb–Pb collisions.

Figure 2: R_{AA} for Ξ and Ω compared to those for charged identified particles, for 0-10% (left) and 60-80% (right) centrality Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

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For central collisions, similarities of the curves for two groups of particles (baryons and mesons) and mass ordering at intermediate p_T can be identified. In particular, the behaviour of the nuclear modification for the Ξ as a function of p_T is similar to that for protons. The large suppression at high p_T, already mentioned for π, K and p, is found also for Ξ up to 8 GeV/c and with the same value common to the lighter particles. The larger R_{AA} values for the Ω can be related to the suppressed strangeness production in pp collisions. As expected, for peripheral events R_{AA} values become closer to unity and reduced differences among the different species are observed.

As already mentioned, similar measurements of nuclear modification factors in p–Pb collisions, where the formation of a QGP state is not expected, can be used to investigate possible contributions due to (ground state) nuclear matter effects. Fig. 3 shows the R_{pPb} for charged π, K and p up to 15 GeV/c and for Ξ and Ω up to 7 and 5 GeV/c, respectively, in non-single diffractive (NSD) p–Pb collisions.

Figure 3: R_{pPb} for π, K, p and multi-strange baryons in NSD p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

The nuclear modification factors for pions and kaons are flat over the full measured p_T range above 3 GeV/c and do not differ from that of unidentified charged particles within the systematic uncertainties. At intermediate p_T (in the Cronin region), a mass ordering is observed, with higher mass particles exibiting a larger R_{pPb}. In Pb–Pb, this effect is interpreted as due to radial flow. Only p, Ξ and Ω exibit a Cronin peak, which indicates that the enhancement seen for charged particles is mostly driven by protons. For larger transverse momenta ($p_T > 8$ GeV/c) all particles exibit an R_{pPb} consistent with unity, indicating that the suppression in Pb–Pb is a hot matter effect.

3. Conclusions

The ALICE Collaboration has measured the nuclear modification factors in both Pb–Pb and p–Pb collisions at the LHC. The R_{AA} of charged particles shows suppression for all centralities, with the strongest effect for the most central collisions, decreasing towards higher p_T with the expected reduction of the relative parton energy loss. No particle species dependence is observed

at high p_T. At lower p_T, protons are less suppressed and the mass ordering reflects radial flow. Similar behaviour to protons is found for the Ξ, while for the Ω a larger R_{AA} may indicate a greater effect of strangeness suppression in pp collisions. The nuclear modification in p–Pb collisions shows a moderate Cronin enhancement for protons and multi-strange baryons at intermediate p_T. At high p_T the R_{pPb} is consistent with binary collision scaling, indicating that the strong suppression observed in Pb-Pb is due to final state effects.

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