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Experiment summary

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Abstract

The measurement of the production of particles coming from hard scattering processes covers a fundamental role in the characterization of the system formed in heavy-ion collisions, allowing to probe the microscopic processes underlying the interaction of high energy partons with the medium. An impressive amount of measurements related to jet, quarkonia, open heavy flavor, and electroweak signal production in nucleus-nucleus as well as p(d)-nucleus collisions was delivered by experiments at RHIC and LHC in past years. In these proceedings, the main experimental results presented during the Hard Probes conference are summarized.

Keywords: QGP, hard probes, heavy quark, quarkonia, electroweak, ALICE, ATLAS, CMS, LHCb, PHENIX, STAR

During the last two decades, high-energy nuclear physics has seen a tremendous progress. Several evidences were collected supporting the presence of a phase transition to a medium of deconfined quarks and gluons (Quark-Gluon Plasma, QGP) in relativistic heavy-ion collisions. With "hard-probes", i.e. with particles produced in hard-scattering processes with large momentum transfer, we can (with a maybe improper expression) resolve the medium constituents and connect global medium properties, determining the evolution of the medium as an extended system, to the parameters (e.g. transport coefficients) characterizing "local" partonic interactions. Thus, hard-probes represent a unique opportunity to achieve a microscopic description of the medium. In these proceedings, the experimental results presented during the 7$^{\text{th}}$ edition of the Hard Probes conference are reviewed. This summary is not exhaustive: in particular, for a review of results related to dilepton production and direct photons at low p_{T}, see [1, 2].

1. Electromagnetic probes for validating Glauber-model scaling

The measurement of the nuclear modification factors (R_{AA}) of W and Z bosons and of isolated photons at high transverse momenta represents a fundamental and unique opportunity to measure initial state effects directly in nucleus-nucleus collisions and to support the assumption that, in the absence of nuclear effects, the production of signals produced in hard scatterings of partons from the colliding nuclei scales with the number of binary nucleon-nucleon collisions estimated with the Glauber model. The ATLAS experiment measured the production of isolated photons as a function of transverse momentum in the range $22 < p_{\mathrm{T}} < 280$ GeV$/c$ in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV in four centrality intervals, from 0 to 80%, and in two pseudorapidity intervals ($|\eta| < 1.37$ and $1.37 < \eta < 2.37$) [3]. The p_{T}-differential spectra, divided by the average nuclear thickness function, are described within uncertainties by NLO pQCD calculations implemented in the program JETPHOX 1.3 [4], with and without incorporating EPS09 nuclear modification of nucleon PDF [5]. The pseudorapidity distribution of positively and negatively charged electrons and muons from W decay and the centrality dependence of their production are well reproduced by expectations based on a realistic cocktail of POWHEG [6] simulations of W production in proton-proton, proton-neutron, and neutron-neutron collisions, as observed by ATLAS [7]. While the usage of proper proton and neutron PDFs is fundamental to account for the different valence quark composition

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of proton and neutrons and describe the data, there is no evidence, considering the uncertainty of both data points and theoretical predictions, for a better description of the data if EPS09 parametrization of nuclear PDF is used. Agreement with binary scaling was also found for Z-boson production, measured by CMS in the dimuon ($|y| < 2.0$) and dielectron ($|y| < 1.44$) channels in $0 < p_T < 100$ GeV/c, as a function of transverse momentum in minimum-bias Pb–Pb collisions and, p_T-integrated, as a function of rapidity and centrality [8]. In general, although the task of validating binary scaling seems at certain extent completed, more precision is needed on all measurements of high-energy electroweak signals to further constrain modes including initial-state effects.

2. Results related to the investigation of partonic in-medium energy loss

High-energy partons lose energy interacting with the medium constituents via both radiative (gluon emission) and collisional processes. The characterization of the partonic energy loss, from which information can be obtained on the transport coefficients of the medium, is a major goal to achieve a microscopic description of the medium. The study of the modification of production rates and internal structure of jets over a wide kinematic range is a key step to quantify the amount and the spatial distribution of the energy lost. A different (smaller) energy loss is predicted for quarks than gluons and for heavy-quarks than light quarks. Stringent constraints to models can be set by comparing the modification to the production rates of heavy-flavour and light-flavour particles.

2.1. Jet suppression and jet structure

The nuclear modification factor of inclusive jets measured by ATLAS [9] indicates a suppression by a factor about two of jet ($R = 0.4$) production from p_T = 50 GeV/c up to 400 GeV/c in the 0-10% most central Pb–Pb collisions, with none or little dependence on p_T. The suppression, which does not show a significant difference in the rapidity ranges $0.3 < |y| < 0.8$ and $1.2 < |y| < 2.1$, reduces with centrality and R_{AA} is about 0.8 in the 60-80% centrality range. In the 0-10% most central collisions, ALICE observed a suppression by a factor about 3 down to p_T = 40 GeV/c for jets with $|y| < 0.5$ reconstructed with $R = 0.2$ and requiring a charged particle with $p_T > 5$ GeV/c among the jet constituents [10, 11]. The two measurements imply a strong interaction of partons with the medium up to very high momentum and indicate that at least part of the energy lost is dissipated outside the jet cone. Within uncertainties the measurements are reproduced by models.

The nuclear modification factor of charged particles in the 0-5% most central Pb–Pb collisions was measured by ATLAS up to p_T = 200 GeV/c ($R_{AA} \sim 0.65$) with sufficient precision to appreciate an inflection point around p_T = 50 GeV/c ($R_{AA} \sim 0.5$) after which R_{AA} rises with p_T is milder [13]. Compatible values were observed by ALICE, ATLAS, and CMS in the overlapping range of their measurements, all showing a minimum of $R_{AA} \sim 0.15$ at $p_T \sim 6$ GeV/c [12, 13, 14]. Charged particles with high momentum are in most cases leading hadrons of jets. Therefore, the measured *RAA* indicates a suppression of the higher p_T part of jet constituents that composes the jet “core”, with particle momenta closer to the jet axis and carrying a large fraction of jet energy. ALICE has found that the relative abundances of pions and protons for $p_T > 10$ GeV/c, and pions and kaons for $p_T > 4$ GeV/c are the same within uncertainties in pp collisions and in central Pb–Pb collisions [15]. This implies that the hadrochemical composition of the jet “core” is unaltered despite the strong suppression of jet production. ALICE measured the Λ/K^0_s ratio in jets and found it compatible within (large) uncertainties with the values measured in pp and p–Pb collisions and significantly smaller than the inclusive value measured in central Pb–Pb collisions [16], suggesting that radial flow and hadron formation via coalescence do not affect the kinematic properties and particle composition of jet constituents. However, more precise measurements exploring a wider kinematic range in terms of jet momenta are needed for concluding.

The measurement of the jet momentum fraction (z) carried by charged particles [18, 17] and the analysis of jet shape modification [20, 19] performed by ATLAS and CMS in recent years suggest a small modification of jet anatomy, consisting of an enhancement of the multiplicity of low-p_T constituents with small z and at large angles with respect to the jet cone. The jet core, composed of particles at high z, contributing up to 85% of jet energy, and contained inside a cone of $R = 0.1$ with respect to the jet axis, does not show significant modifications in central Pb–Pb collisions with respect to pp collisions. Further insight into the spatial distribution and kinematic properties of the radiated energy is provided by dijet analyses. Since the energy loss increases with the distance covered by the parton in the medium, particles and jets with high-p_T typically probe partons produced in the external layers of the fireball and going outward. Therefore, the