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A unified description of the reaction dynamics from pp to pA to AA collisions

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Abstract

There is little doubt that in heavy ion collisions at the LHC and RHIC, we observe a hydrodynamically expanding system, providing strong evidence for the formation of a Quark Gluon Plasma (QGP) in the early stage of such collisions. These observations are mainly based on results on azimuthal anisotropies, but also on particle spectra of identified particles, perfectly compatible with a hydrodynamic evolution. Surprisingly, in p–Pb collisions one observes a very similar behavior, and to some extent even in p–p. We take these experimental observations as a strong support for a unified approach to describe proton–proton (p–p), proton–nucleus (p–A), and nucleus–nucleus (A–A) collisions, with a plasma formation even in tiny systems as in p–p scatterings.

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1. Experimental evidence for a unified picture

Collective hydrodynamic flow seems to be well established in heavy ion (HI) collisions at energies between 200 and 2760 A GeV, whereas p–p and p–A collisions are often considered to

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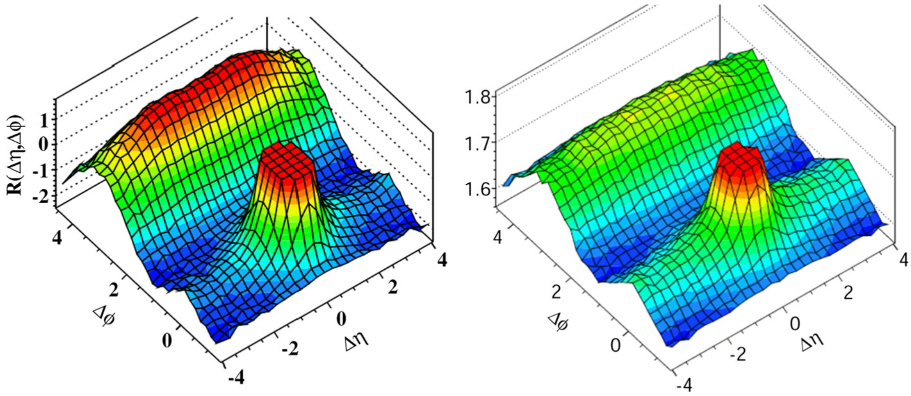

Fig. 1. (Color online.) Two particle correlation functions as a function of the pseudorapidity difference $\Delta\eta$ and the azimuthal angle difference $\Delta\phi$, from the CMS experiment. Left: p–p, right: p–Pb. In both cases, the jet peak at $\Delta\eta = 0$ and $\Delta\phi = 0$ has been truncated, for better visibility. In both cases a "ridge structure" shows up, at $\Delta\phi = 0$ and very broad in $\Delta\eta$.

be simple reference systems, showing "normal" behavior, such that deviations of HI results with respect to p–p or p–A reveal "new physics". Surprisingly, the first results from p–Pb at 5 TeV on the transverse momentum dependence of azimuthal anisotropies and particle yields are very similar to the observations in HI scattering [1,2].

Information about flow can be obtained via studying two particle correlations as a function of the pseudorapidity difference $\Delta\eta$ and the azimuthal angle difference $\Delta\phi$. So-called ridge structures (at $\Delta\phi = 0$, very broad in $\Delta\eta$) have been observed first in heavy ion collisions, later also in pp [3] and very recently in p–Pb collisions [4–6], as shown in Fig. 1. In case of heavy ions, these structures appear naturally in models employing a hydrodynamic expansion, in an event-by-event treatment – provided the azimuthal asymmetries are (essentially) longitudinally invariant, as in the string model approach.

To clearly pin down the origin of such structures in small systems, one needs to consider identified particles. In the fluid dynamical scenario, where particles are produced in the local rest frame of fluid cells characterized by transverse velocities, large mass particles (compared to low mass ones) are pushed to higher transverse momenta. When plotting ratios "heavy over light" versus p_t, one observes a peak at intermediate p_t, more and more pronounced with increasing flow. In Fig. 2, we show lambda over kaon ratios from ALICE for Pb–Pb (right plot, [7]) and p–Pb (left plot, [2]). In both cases, for more central collisions the peak is more pronounced, which may be interpreted as stronger radial flow compared to more peripheral collisions. Unexpectedly, the p–Pb results are qualitatively very similar to the Pb–Pb ones.

Finally, one can combine the power of dihadron correlations and particle identification: The mass effect discussed above for particle spectra, is also very clearly visible in correlations, leading to the so-called mass-splitting in the elliptical flow coefficient v_2 as a function of p_t, as shown in Fig. 3, where we plot v_2 for different hadrons for Pb–Pb (right plot, [8]) and p–Pb (left plot, [9]). In both cases, one can clearly see the separation of particles of different masses. Again, the p–Pb results are very similar to the Pb–Pb ones.

There are many more examples, where p–Pb (and even p–p) shows a very similar behavior compared to Pb–Pb, which strongly supports the idea of a unified picture in all these different reactions, from p–p to Pb–Pb.