Abstract

Ultra-relativistic heavy-ion collisions are essential in probing strongly interacting matter at high temperatures and low baryon density. One of the important discoveries made at the Relativistic Heavy Ion Collider (RHIC), and more recently at the Large Hadron Collider (LHC), is the large elliptic flow $v_2$. Collective flow, as manifested by the anisotropic emission of particles in the plane transverse to the beam direction, known as the reaction plane, is characterized by a series of Fourier coefficients. The observed second order harmonic $v_2$ near the mid-rapidity region ($|y| < 0.5$), for not too large impact parameters between the colliding nuclei and low transverse momenta of the detected hadrons, agree remarkably well with predictions made by relativistic viscous fluid dynamics. Most prominently, these predictions verify the experimentally extracted dependence of $v_2(p_T)$ on transverse momentum $p_T$ and hadron rest-mass. It is then of common belief that in these collision energies a Quark-Gluon Plasma (QGP) is formed, which thermalizes on a very rapid time scale and subsequently evolves as an almost ideal fluid with exceptionally low viscosity.

While earlier studies had focused on elliptic flow, most of the recent activity is concerned with the effect of fluctuations in the initial geometry. The conventional assumption of a smooth initial almond-shape profile has hindered full exploitation of the odd harmonics. Such fluctuations result in initial density profiles, which have no particular symmetry and new types of flow, such as the triangular flow $v_3$, are not required by definition to be zero. Flow harmonics (both of even and odd order) stem from a so-called eccentricity-driven hydrodynamic expansion of the matter in the collision zone, i.e. a finite eccentricity $\varepsilon_n$ drives uneven pressure gradients, hence the resulting anisotropic expansion leads to the anisotropic emission of particles about the reaction plane. The $v_n$ coefficients are sensitive to both the initial eccentricity and the ratio of the QGP shear viscosity $\eta$ to its entropy density $s$. It is expected that $v_n$ for identified particles will provide further constraints on the underlying models that treat initial conditions and the evolution of the hot plasma.

During the actual study, Fourier coefficients of order 2-4 have been measured as a function of transverse momentum $p_T$ in the (0-60)% most central PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for the case of $\Lambda + \bar{\Lambda}$ hyperons and compared to various species. The Scalar Product technique has been employed, which consistently produces the root-mean-square $\sqrt{\langle v_n^2 \rangle}$ of the correlation between the identified hadrons under study and the reference-flow particles. Residual short-range correlations have been diminished by imposing a pseudorapidity gap between particles of interest and reference-flow particles, with the former having been reconstructed in the central barrel of the ALICE detector (TPC) and with unidentified particles having been recorded in the forward region (VZERO).

All three anisotropy coefficients, i.e. $v_2$, $v_3$ and $v_4$, have been observed to increase with $p_T$ up to about 3.5 GeV/c, then to saturate and decrease, a pattern persistent all over centralities. Elliptic and triangular flow are the dominant harmonics, and it seems to be driven mainly by the associated ellipticity $\varepsilon_2$ and triangularity $\varepsilon_3$. In the most central collisions, where the $\varepsilon_n$ moments are expected to be comparable due to event-by-event fluctuations in the initial geometry, the hadronic azimuthal anisotropy is found of similar magnitude across the different $n^{th}$-order harmonics. Interestingly, the less dominant quadrangular flow $v_4$ seems to receive contributions both from its corresponding $\varepsilon_4$ and the lower-order anisotropy $\varepsilon_2$.

The characteristic features of collective dynamics, i.e. the linear-$p_T$ dependence and the mass ordering at low $p_T \lesssim 2$ GeV/c, are clearly observed across harmonics of all the identified cases considered during the actual study. At variance with their low-$p_T$ behavior, these final-state coefficients exhibit a centrality-dependent crossing point at intermediate $p_T$. The enhanced flow of baryons over mesons at the intermediate $2.5 \lesssim p_T \lesssim 8$ GeV/c window has been investigated in the realm of the coalescence mechanism. The constituent quark scaling of anisotropic flow $v_n(p_T) \approx n v_2(p_T/n)$ found to barely hold at LHC energies. Last, a non-particular particle species dependence is evident for $v_2$ at $p_T \gtrsim 10$ GeV/c, consistent with expectations from a path-length driven emission of particles. Fluctuations might become unimportant for $v_3$ and $v_4$ in such a parton fragmentation dominated regime, whereas more data are undoubtedly needed before drawing a conclusive answer.