PROCEEDINGS OF SCIENCE

Flow analysis methods in ALICE
Event plane from Lee-Yang zeroes

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The measurement of anisotropic flow in heavy ion collisions gives insight into the equation of state of the matter formed in the collision. Several methods are available for measuring anisotropic flow. However, methods based on two-particle correlations do not reproduce the flow signal if nonflow is present. Methods based on multi-particle correlations do. A new reaction plane estimate is presented based on the Lee-Yang zeroes method, that enables an unbiased analysis of e.g. jets or charm versus the reaction plane.

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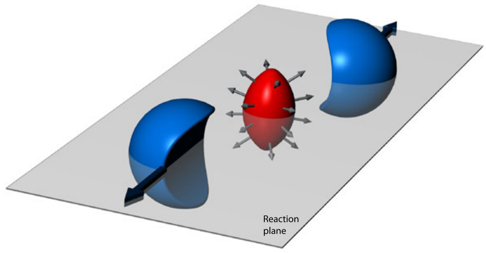

Figure 1: Illustration of a non-central heavy ion collision.

1. Introduction

In non-central heavy ion collisions the azimuthal symmetry is broken. The spacial anisotropy of the interaction volume is converted into a momentum anisotropy. As a consequence, collective motion in the reaction volume is azimuthally dependent. The azimuthal dependence of particle production is described in terms of a Fourier expansion,

$$\frac{dN}{d\phi} = \frac{N}{2\pi}(1 + 2v_1\cos(\phi) + 2v_2\cos(2\phi) + \cdots) \ . \tag{1.1}$$

The first two harmonics, v_1 and v_2, are called directed and elliptic flow, respectively. Elliptic flow is the most dominant contribution to the azimuthal dependence. Initial measurements of v_2 at RHIC have shown that the system created in the collision can be described, to first order, as a thermalized fluid that expands hydrodynamically [1, 2, 3, 4]

At the LHC, due to high initial energy densities, most elliptic flow will be generated before hadronization takes place, making v_2 a probe of the equation of state of the Quark Gluon Plasma. A detailed measurement of v_2 is made possible at the LHC because of the expected increase in multiplicity and the increase in the magnitude of elliptic flow itself.

Elliptic flow is defined as,

$$v_2 \equiv \langle cos(2(\phi - \Psi_R))\rangle_{particles,events} \ . \tag{1.2}$$

It is the average cosine of the particles angle with respect to the reaction plane Ψ_R. The reaction plane is defined by the impact parameter direction and the beam direction. It is illustrated in figure 1.

In practice calculating v_2 is not that easy. The reaction plane in each event is not known and there are nonflow contributions present. Nonflow represents all correlations other than flow correlations, e.g. momentum conservation, resonance decays and jets.

Several methods for detailed measurements of anisotropic flow are available; the so-called event plane, cumulants and Lee-Yang zeroes methods. The event-plane method [5] gives an estimate of the reaction plane based on two particle correlations. It calculates elliptic flow with respect to that estimate. Since nonflow arises mostly from two particle correlations, the method is very sensitive to nonflow. In addition, corrections for detector inefficiencies are needed. The cumulant method [6] calculates flow based on multi-particle correlations. It removes lower order nonflow

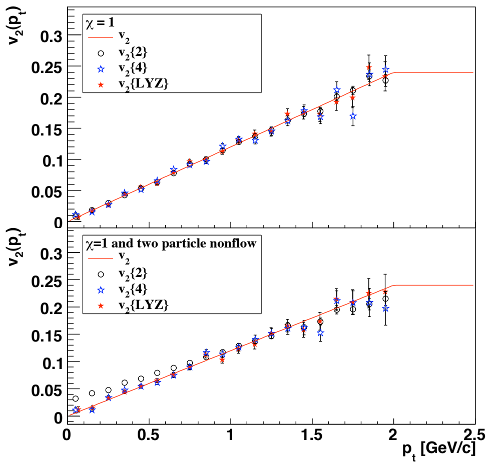

Figure 2: Differential elliptic flow $v_2(p_t)$ reconstructed using different methods. The solid line is the input, $v_2\{2\}$ the second order cumulant, $v_2\{4\}$ the fourth order cumulant and $v_2\{LYZ\}$ the Lee-Yang zeroes result. The upper panel shows the results when only flow is present, the lower panel when nonflow is also present.

correlations and takes care of detector acceptance effects. However, it does not give a reaction-plane estimate. The Lee-Yang Zeroes method [7] calculates flow based on the correlation of all the particles in the event. Therefore all nonflow correlations are removed. The method also corrects for detector inefficiencies. These methods all have different sensitivities to nonflow and flow fluctuations. Combined they give a better understanding of the true flow signal.

While methods based on multi-particle correlations are less influenced by nonflow, they do not provide an event plane, i.e. an estimate of the reaction plane. The event plane is needed for correlation studies of a particle species with respect to the reaction plane. With the adjustments to the Lee-Yang zeroes method presented in section 3 it can provide an event plane. This enables unbiased correlation studies.

2. Comparison of flow analysis methods

For illustrating the effect of nonflow and showing that methods using many-particle correlations are less affected by it, a sample of Monte-Carlo data (28k GeVsim [8] events) was analysed using the different methods. The events have a total multiplicity of 500 in the pseudorapidity region $-0.9 < \eta < 0.9$. They contain only flow correlations. Therefore, one expects that all methods will yield the same flow signal. This is indeed the case as shown in the top panel of Figure 2. The value of v_2 obtained with the second and fourth order cumulant and with the the Lee-Yang zeroes agree with the input flow signal (solid line). When (artificial) nonflow correlations are added, by doubling all the tracks in the event, methods based on two-particle correlations, e.g. the event-plane method and the second order cumulant, do not reproduce the flow signal correctly (see the bottom panel of Figure 2). Higher order cumulants and Lee-Yang zeroes do agree with the input.

3. Event Plane Analysis using the Lee-Yang Zeroes method

From the previous section the advantages of using multi-particle correlations for calculating flow are clear. The disadvantage is that these methods do not provide an estimate of the reaction plane. Until recently only the event-plane method was used in ALICE for the estimation of the second order reaction plane. However, the standard Lee-Yang zeroes method can be cast in a similar form as the event-plane method, with the addition that each event gets a weight W_R. This is the key ingredient of the new method.

In the event-plane method v_2, or more generally v_n, is calculated from

$$v_n\{EP\} = \frac{1}{R}\langle\cos(n(\phi - \Psi_R))\rangle \ , \tag{3.1}$$

where R is the resolution correction factor. For the Lee-Yang zeroes event-plane it becomes

$$v_n\{LYZ\} = \langle W_R \cos(n(\phi - \Psi_R))\rangle \ . \tag{3.2}$$

The event weight W_R takes care of the corrections for nonflow correlations and detector inefficiencies. Its value depends on the size of the flowvector Q, defined as

$$Q_x = Q\cos(n\Psi_R) = \sum w_j \cos(n\phi_j) \ , \ Q_y = Q\sin(n\Psi_R) = \sum w_j \sin(n\phi_j) \ . \tag{3.3}$$

Figure 3 shows W_R as a function of $|Q|$ (see virtical scale on the right) for an integrated elliptic flow V_2 of 0.0625 (integrated over p_t and η, and denoted with a capital V). The stars are the GeVSim data, the solid line the theoretical result. It also shows the probability distribution of Q (see virtical scale on the left). The upper panel shows results for $\chi = 1.5$ and the lower panel for $\chi = 1$. The resolution χ is proportional to $\sqrt{M}v_2$. Note that for the lower value of χ the distribution of Q is broader.

The sign of W_R is not uniquely defined. The simplest convention is $W_R > 0$. However, in that case for some events the estimate of the reaction plane angle from the Lee-Yang zeroes method differs by π from the angle obtained with the event-plane method, which is shown in Figure 4. Shifting the angle by π amounts to changing the sign of W_R which gives the weight as in Figure 3, where W_R can take on negative values as well. For more details see [9].

4. Summary

Due to the high multiplicity in ALICE, using multi-particle correlation methods is possible. Since the different methods for flow measurement are affected differently by nonflow, but also by fluctuations of the flow signal, all available methods will be used in parallel for a systematic study of the anisotropic flow in ALICE.

The reaction plane estimate from the Lee-Yang zeroes method makes studying correlations with the reaction plane, that are not influenced by nonflow or detector effects, possible, thanks to the event weight.

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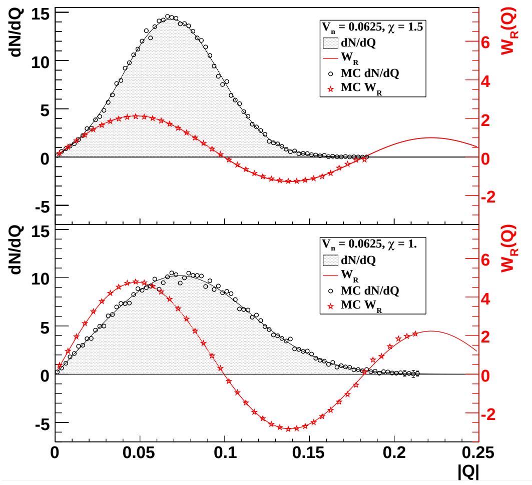

Figure 3: The solid curve and the open stars are the event weights W_R from theory and simulation respectively. The shaded area and the open circles are the probability distributions of Q from theory and simulation. The top plot for $\chi = 1.5$ and the bottom plot for $\chi = 1$.

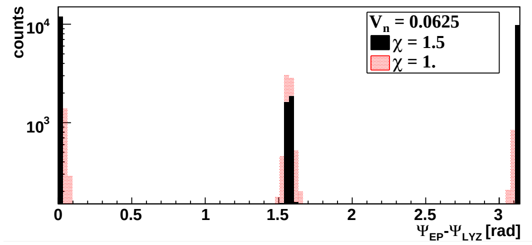

Figure 4: Distribution of the relative angle between the event-plane Ψ_R from the Lee-Yang zeroes method and from the event-plane method in the case when $W_R > 0$.

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