Nuclear Collective Flow from the Method of Lee-Yang Zeroes

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This report presents the first analysis of collective flow with the new method of Lee-Yang zeroes [1]. So far in the SIS energy range all directed and elliptic flow analyses were performed using standard procedures. In these methods, based either on the reaction plane reconstruction or on two-particle correlations one assumes that correlations between particles are only due to flow. This shortcoming motivated the development of alternative procedures where other correlations due to quantum statistics, resonance decays, final state interactions,... are not neglected. The method based on a cumulant expansion of multiparticle (typically, four-particle) correlations [2] eliminates most of non-flow effects. It is intensively exploited at SPS and RHIC energies [3, 4] and the results differ significantly from those obtained with conventional methods, showing the importance of non-flow effects. More recently, the theory of Lee-Yang zeroes [1] has been proposed to extract for the first time the genuine flow directly from the correlation between a large number of particles. This latter is expected to provide the cleanest separation between collective flow and non-flow effects.

Here both the cumulant method (applied for the first time at SIS energies) and Lee-Yang zeroes are used to extract flow in semi-central ($<\mathrm{b_{geo}}> = 3.8$ fm) Ru + Ru reactions at 1.69 AGeV measured with the FOPI detector at GSI. The theory of Lee-Yang zeroes, applied for the first time to experimental data, is explained in the following. The procedure is based on the projection of the event flow vector on a fixed, arbitrary direction under an angle nθ relative to the x-axis. This projection is $\mathrm{Q}^\theta = \sum_{\mathrm{j}=1}^{\mathrm{M}} \omega_\mathrm{j} \cos(\mathrm{n}(\varphi_\mathrm{j} - \theta))$ (ω_j is a weight to optimize the statistical errors, n is the Fourier harmonic, φ_j is the azimuthal angle). The probability distribution of Q^θ is fully characterized by the moment generating function $\mathrm{G}^\theta(\mathrm{z}) = < \mathrm{e}^{\mathrm{z}\mathrm{Q}^\theta} >$, with z = ir. Figure 1 displays the amplitude of $\mathrm{G}^\theta(\mathrm{ir})$ *versus* r for $\theta = 0$ and n = 1 (results are comparable for other θ values). One clearly observes two minima which correspond to the zeroes of $\mathrm{G}^\theta(\mathrm{ir})$. This is a clear indication of collective flow effects in this system [1]. Furthermore, the position of the first minimum, r_0^θ, directly yields an estimate for the integrated directed flow, v_1^θ (r_0^θ scales as $1/\mathrm{v}_1^\theta$) used afterwards to analyze differential flow. In practice one performs the analysis for several equally spaced values of θ and the results are averaged over θ.

The proton differential directed flow calculated with the Lee-Yang theory (circles) is shown in Fig. 2. The values are compared to the ones obtained from the standard flow analysis (squares). Also shown are the two (stars) and fourth (crosses) particle cumulant values. The (small) differences between the standard method and the second order cumulant could be partially explained by momentum conservation effects not taken into account with two-particle cumulant. The Lee-Yang zeroes and the fourth order cumulant give same values for v_1. This is an indication that, like at SPS and RHIC energies [3, 4] for elliptic flow, the four-particle correlation analyses can reliably separate flow and non-flow effects. Similar conclusions are also valid for the proton elliptic flow. One can also mention that statistical errors, which are the main limitation of the method, are not a problem here: the resolution parameter χ, measuring the relative strength of flow compared to finite multiplicity fluctuations, is well above one ($\chi = 1.7$). The method of Lee-Yang zeroes will be applied to pion flow studies. It should provide more reliable results than standard methods by eliminating correlations, like the decay of Δ resonances which is a typical non-flow effect.

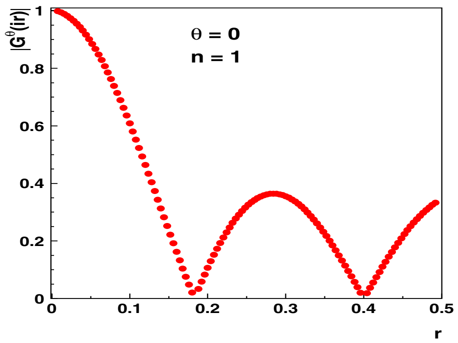

Figure 1: $|\mathrm{G}^\theta(\mathrm{ir})|$ *versus* r for semi-central Ru (1.69 AGeV) + Ru reactions.

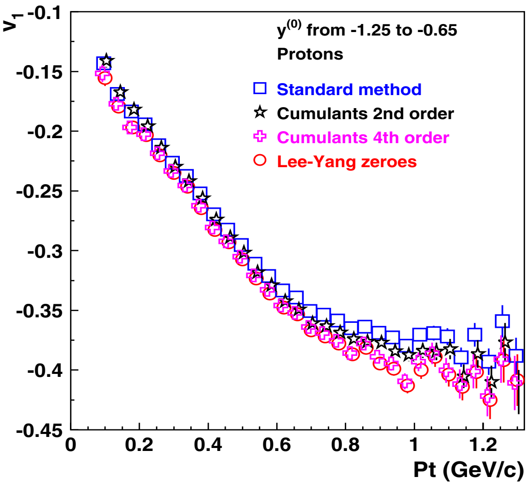

Figure 2: Proton differential directed flow in semi-central Ru (1.69 AGeV) + Ru reactions in a rapidity window of backward hemisphere.

References

[1] R.S. Bhalerao et al., Nucl. Phys. A 727 (2003) 373 and Phys. Lett. B 580 (2004) 157; N. Borghini et al., nucl-th/0402053 (2004)

[2] N. Borghini et al., Phys. Rev. C 64 (2001) 054901

[3] C. Alt et al., Phys. Rev. C 68 (2003) 034903

[4] C. Adler et al., Phys. Rev. C 66 (2002) 034904