Chasing a quantum anisotropy with GPUs

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One of the most exciting observations in high-energy heavy-ion collisions is an "elliptical" (left-right vs top-down) momentum anisotropy $v_2 = \langle \cos(2\phi) \rangle$ in the plane transverse to the colliding beams. The standard interpretation is that v_2 comes from a femtometer-scale asymmetric droplet of hot and dense plasma, with a roughly elliptical initial density profile, which droplet then expands hydrodynamically [see, e.g., Gale et al, arXiv:1301.5893 for a review]. On the other hand, it is a general feature of quantum mechanics that coordinate and momentum space are intimately related via the uncertainty relation. Thus, a nonzero eccentricity in coordinate space automatically implies a nonzero v_2. This intrinsic "quantum" anisotropy vanishes for very large systems, and it also vanishes in the classical limit because the spacing between energy levels becomes negligible compared to kT. So the intrinsic v_2 is completely missed by the canonical formulation of statistical physics in terms of phase space integrals.

In an earlier work [arxiv:1404.4119v1] we showed that the quantum anisotropy is sizeable in Au+Au collisions at the Relativistic Heavy Ion Collider (RHIC) - in particular, we estimated for the pion v_2 tens of percents at p_T ~ 1-2 GeV transverse momentum. However, that calculation assumed nonrelativistic $K = p^2/2M$ kinetic energy (questionable for p_T/Mpi ~ 10). Very recently [arxiv:1404.4119v2] we have also computed the anisotropy, numerically, for massless particles (i.e., $K = |p|$), and found a rather different pion $v_2(p_T)$ shape with percent-level magnitude only. This leaves the question wide open regarding how large the quantum v_2 is, quantitatively, for correct relativistic $K = \sqrt{p^2 + m^2}$.

The calculation of the intrinsic anisotropy takes two steps: first the Hamiltonian of the system is diagonalized in a large computational basis (N x N matrix with N ~ 10^5), and then the squares of the eigenfunctions are summed using thermal weights to construct v_2. With relativistic kinetic energy, the computation of the matrix elements is the most time-consuming task. We implement this part of the calculation on GPUs, and present preliminary pion $v_2(p_T)$ results with unapproximated kinetic energy.