Is there flow without flow at RHIC?

a.k.a.

Is there elliptic flow without radial flow at RHIC?

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Is there elliptic anisotropy without radial flow at RHIC?

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Anisotropic particle distribution

Non-central collision:

Anisotropy in configuration space
\[
\downarrow
\]
Anisotropy in particle distributions
i.e. in momentum space

Characterized by Fourier coefficients:

\[
E \frac{dN}{d^3p} = \frac{dN}{2\pi p_t dp_t dy} \times [1 + 2v_1(p_t) \cos(\phi) + 2v_2(p_t) \cos(2\phi) + \cdots]
\]

or as averaged over \( p_t \):

\[
\frac{dN}{dyd\phi} = \frac{dN}{2\pi dy} \times [1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi) + \cdots]
\]
Bjorken brick

- boost invariant
- rectangular in transverse plane
- opaque
- emission
  - on surface
  - at final breakup
- parameters: $R_y/R_x$, $\tau/R_x$, $v_x$, $v_y$, $T$

Modified Cooper-Frye:

$$E \frac{dN}{d^3p} = \int d\sigma p^\mu f(p \cdot u, T) \theta(d\sigma p^\mu)$$
$v_2$ of pions without flow

No satisfactory fit with any realistic parameters
$v_2$ of pions with flow

![Graph showing $v_2(\mathbf{p}_t)$ vs. $p_t$ (GeV/c)]

- Blue line: $R_y/R_x \neq 1$, $v_y/v_x \neq 1$
- Green line: $R_y/R_x = 1$, $v_y/v_x \neq 1$
- Red line: $R_y/R_x \neq 1$, $v_y/v_x = 1$

Data: $v_2(\mathbf{p}_t)$ of charged particles, not pions
Hydrodynamical model

- Boost-invariant 2+1 dim. model
- Initial spatial distributions based on wounded nucleon model
- Tuned to reproduce charged particle multiplicity in central collisions measured by Phobos collaboration
  \[- \frac{dN}{d\eta} \bigg|_{\eta<1} = 545 \]
  \[- \frac{\bar{p}}{p} = 0.65 \]
- Decoupling temperature unknown
  \[- \text{use } T_f \approx 140 \text{ MeV and } T_f \approx 120 \text{ MeV} \]
- Equations of state with
  \[- T_c = 165 \text{ MeV} \]
  \[- T_c = \infty \]
- Initial parameters at b=0 collision
  \[- \epsilon_0 = 23.0 \text{ or } 22.3 \text{ GeV/fm}^3 \]
  \[- n_{8,0} = 0.12 \text{ or } 0.25 \text{ fm}^{-3} \]
  \[- \tau_0 = 0.6 \text{ fm} \]
  \[- T_0 = 330 \text{ or } 270 \text{ MeV} \]
- See Peter Kolb’s poster
$v_2$ @ RHIC, $\sqrt{s} = 130$ AGeV

charged hadrons, $|\eta| < 1.3$, minimum bias

Data: STAR collaboration, nucl-ex/0009011
$v_2 \oplus$ RHIC, $\sqrt{s} = 130$ AGeV

pions and protons, $y = 0$, minimum bias
Summary

- Finite $v_2$ is *not* a signal of flow
- The shape of $v_2(p_t)$ is!
- The data strongly favours existence of collective motion
- Hydrodynamical model gives excellent fit to data
- Collision system behaves like a system which thermalizes rapidly