Elliptic Flow

$$E\frac{d^3N}{d^3p} = \frac{d^3N}{p_T dy dp_T d\phi} = \frac{1}{2\pi}\frac{d^2N}{p_T dy dp_T}\left[1+\sum_{n=1}^{\infty} 2v_n \cos\left(n(\phi - \psi)\right)\right]$$

ψ = event plane angle

v_2 = elliptic flow parameter

- Hard scattering of initial-state partons may cause the hydrodynamic description of the system to break down at high p_T .
- Hydrodynamic models describe elliptic flow up to $p_T = 2GeV$.
- Perturbative QCD predicts high energy partons will lose energy as they traverse the dense nuclear medium.
- v_2 may be calculated from the particle distribution with respect to the reaction plane or from two-particle correlation analysis. If azimuthal correlations are caused entirely by correlations with the reaction plane the two methods are identical.
- Correlations localized in both η and ϕ are characteristic of jets.

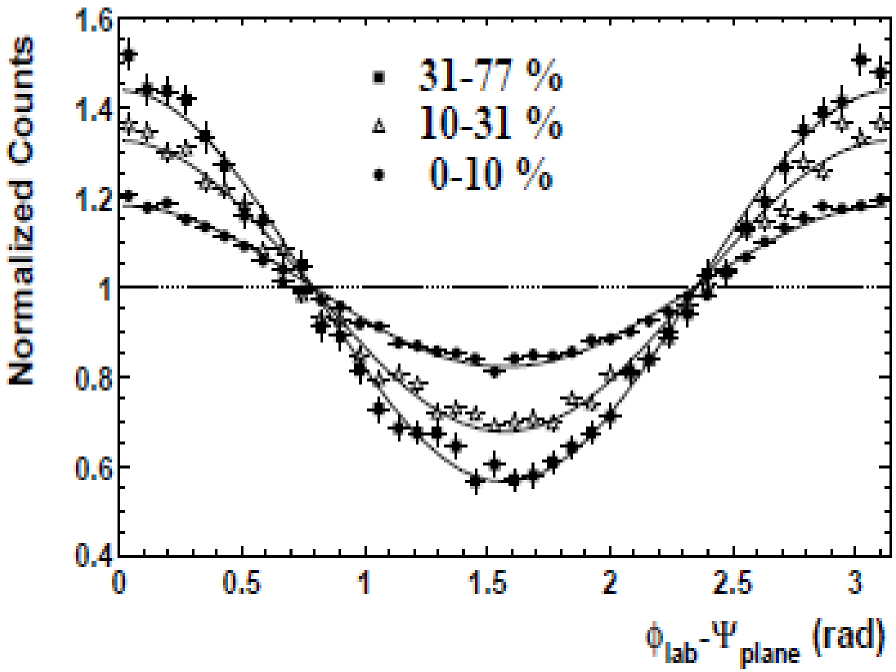

FIG. 1: Azimuthal distributions with respect to the reaction plane of charged particles within $2 < p_T < 6$ GeV/c, for three collision centralities. The percentages are given with respect to the geometrical cross section σ_{geo}. Solid lines show fits by $1 + 2v_2 \cos 2(\phi_{lab} - \Psi_{plane})$.

- $2GeV < p_T < 6GeV$
- Corrected for reaction plane resolution.
- Elliptic flow behavior for all centralities.
- Fitting with $1 + 2v_2 \cos(2(\phi - \psi))$ gives

$v_2 = 0.218 \pm 0.003$ (31-77%)

$v_2 = 0.162 \pm 0.002$ (10-31%)

$v_2 = 0.090 \pm 0.001$ (0-10%)

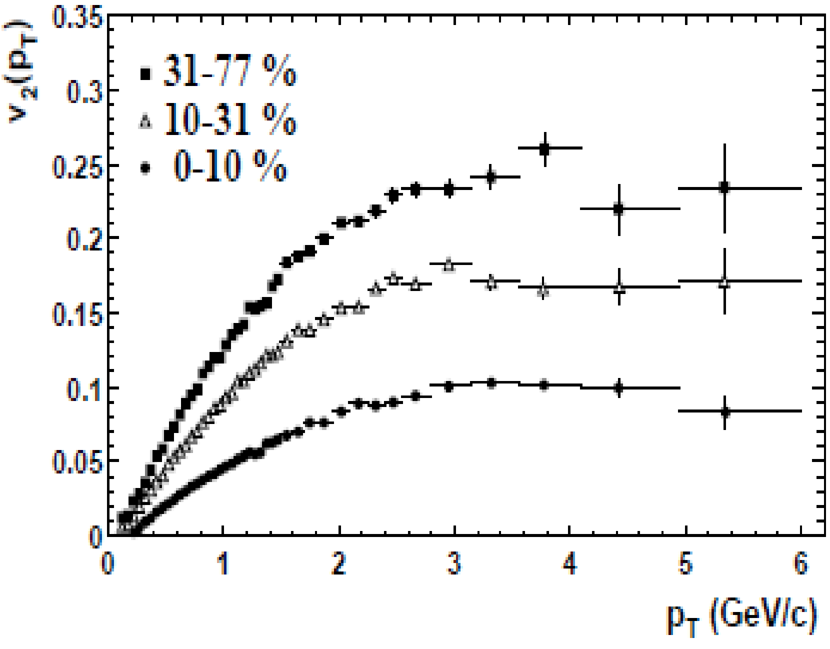

FIG. 2: $v_2(p_T)$ for different collision centralities. The errors are statistical only. The systematic uncertainties, which are highly correlated point-to-point, are $^{+5}_{-20}\%$.

- Obtained from average values of $\cos(2(\phi - \psi))$.
- Corrected for reaction plane resolution.
- Larger v_2 for peripheral collisions.
- Non-dissipative hydrodynamics predicts continuous rise of v_2 with p_T .

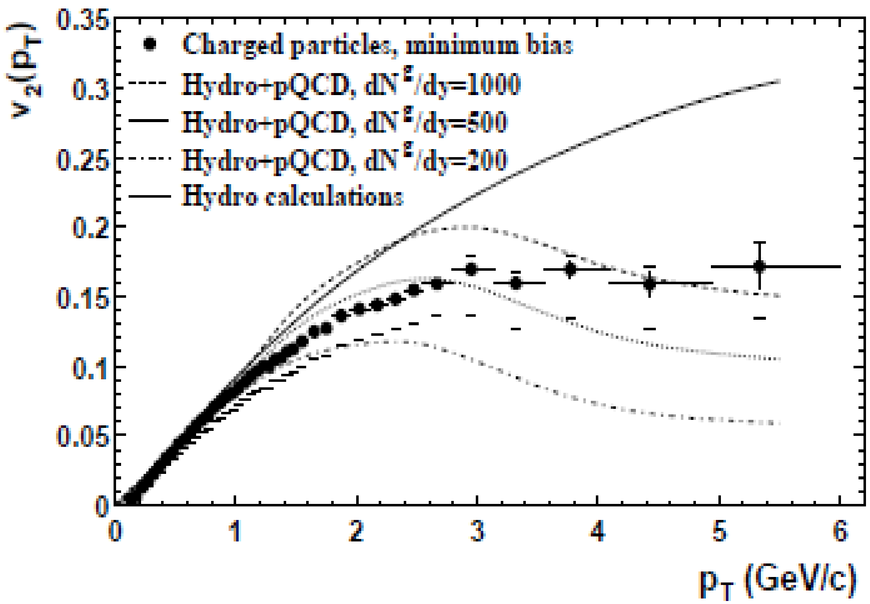

FIG. 3: $v_2(p_T)$ for minimum-bias events (circles). The error bars represent the statistical errors and the caps show the systematic uncertainty. The data are compared with hydro+pQCD calculations [9] assuming the initial gluon density $dN^g/dy = 1000$ (dashed line), 500 (dotted line), and 200 (dashed-dotted line). Also shown are pure hydrodynamical calculations [16] (solid line).

- Min-bias differential elliptic flow compared to calculations using hydrodynamics and perturbative QCD.
- Calculations predict a decrease of v_2 with increasing p_T at high p_T .

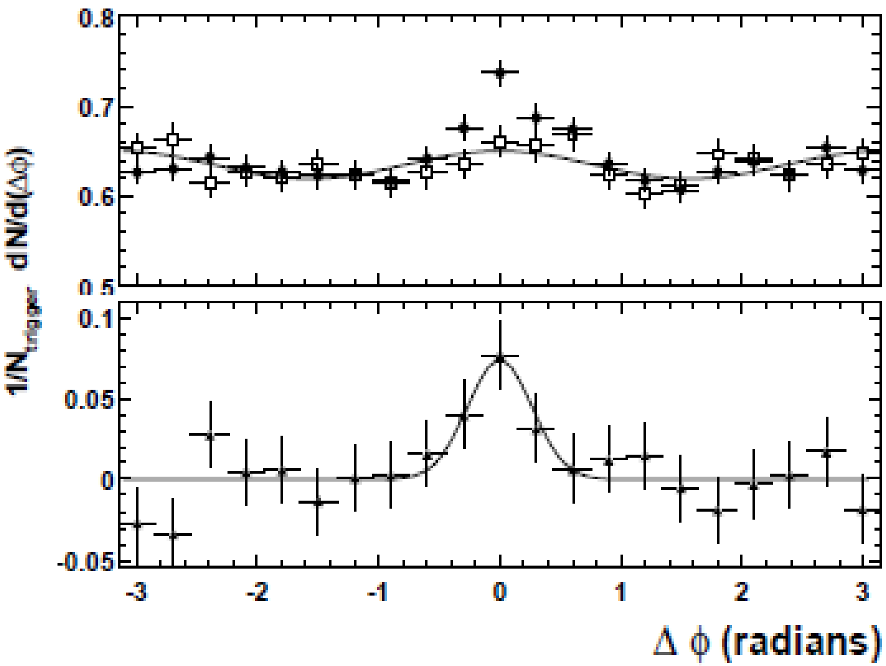

FIG. 4: High p_T azimuthal correlation functions for central events. Upper panel: Correlation function for $|\Delta\eta| < 0.5$ (solid circles) and scaled correlation function for $0.5 < |\Delta\eta| < 1.4$ (open squares). Lower panel: Difference of the two correlation functions. Also shown are the fits to the data (described in the text).

- Two-particle azimuthal correlation functions for $|\Delta\eta| < 0.5$ and $|\Delta\eta| > 0.5$.
- Large $|\Delta\eta|$ correlation function scaled to match small $|\Delta\eta|$ correlation function for $0.75 < |\Delta\phi| < 2.25$.
- Bump at $\Delta\phi = 0$ may be evidence of hard scattering and fragmentation.
- Large $|\Delta\eta|$ correlation function fitting with
  $$\frac{dN}{d(\Delta\phi)} \propto 1 + 2v_2^2\cos(2\Delta\phi)$$
  gives $v_2 = 0.11 \pm 0.02$.

- Azimuthal correlation functions for $|\Delta\eta| > 0.5$ give $v_2 = 0.203 \pm 0.012$ (31-77%)

  $v_2 = 0.160 \pm 0.007$ (10-31%)

  $v_2 = 0.091 \pm 0.003$ (0-10%)

- The difference between small and large $|\Delta\eta|$ is fit by a Gaussian giving $\sigma = 0.27 \pm 0.09(stat.) \pm 0.04(sys.)$ consistent with pp jets at similar energy.
- HIJING event generator predicts $\sigma = 0.20 \pm 0.01$.

Summary

- The saturation of v_2 and dependence on centrality is inconsistent with non-dissipative hydrodynamics but may be consistent with parton energy loss predicted by perturbative QCD.
- Two-particle azimuthal correlation functions for $|\Delta\eta| < 0.5$ and $|\Delta\eta| > 0.5$ suggest a short-range correlated component at high p_T in addition to elliptic flow.