Charge-Asymmetry Dependence of Proton Elliptic Flow in 200 GeV Au+Au Collisions

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STAR

Abstract

The Chiral Magnetic Wave (CMW) is predicted to manifest a finite electric quadrupole moment in the quark-gluon plasma produced in high-energy heavy-ion collisions [1]. This quadrupole moment generates a difference in the azimuthal anisotropy (v_2) of positively and negatively charged particles such that $v_2(+) < v_2(-)$. This effect is proportional to the apparent charge asymmetry (A_{ch}) of particles in the same rapidity window. The A_{ch} dependence of v_2 has already been observed in the cases of charged pions and kaons [2, 3]. We present preliminary STAR measurements of v_2 for protons and anti-protons as a function of A_{ch} from $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions for different centralities. The results are then compared with the previously reported results for pions and kaons.

Heavy Ion Collisions & Elliptic Flow

When heavy ions collide, they almost never hit head-on. The nucleons that do not participate in the collision (spectators) produce a very strong magnetic field as they fly past.

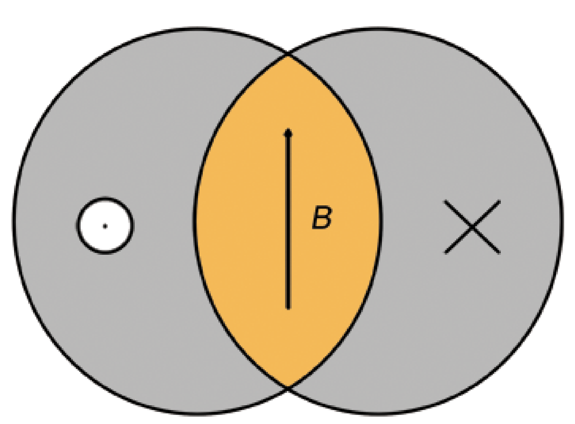


Fig 1: A heavy ion collision.

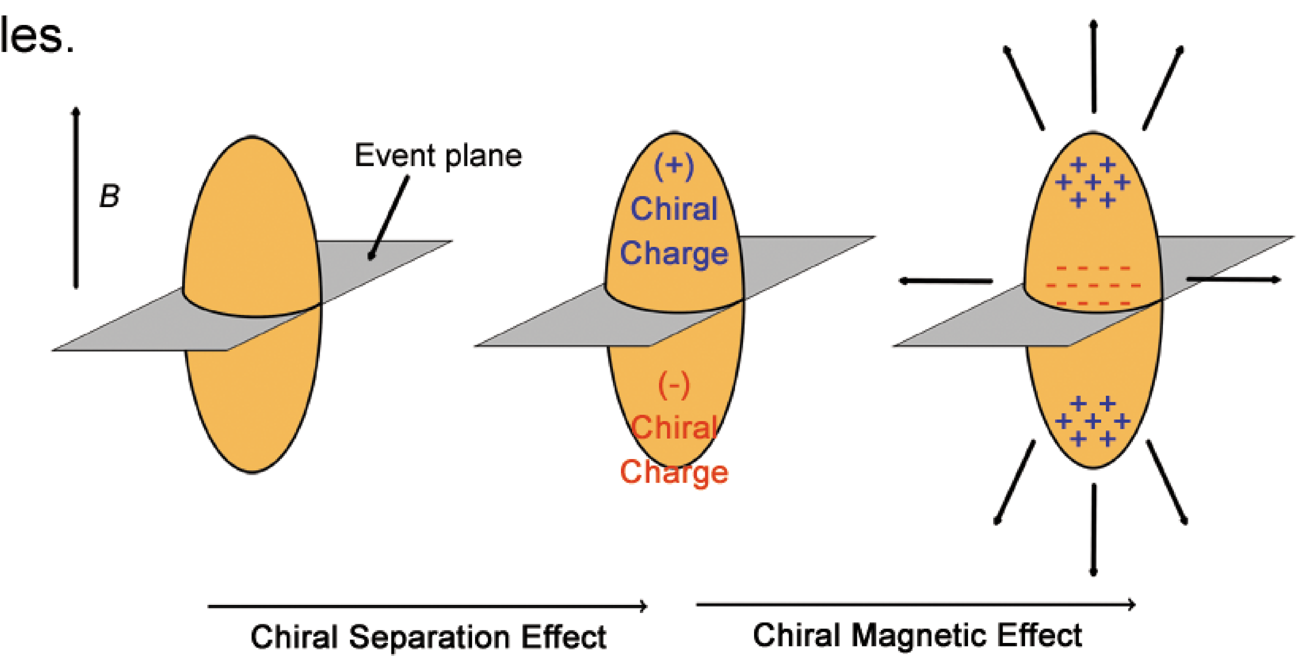
The plasma does not expand symmetrically. In this analysis we use elliptic flow (v_2) to measure particle azimuthal anisotropy. (Particle azimuthal anisotropy can be expanded in a Fourier series where the second harmonic, v_2, is dominant.)

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

$$v_2 = \langle \cos\left[2\left(\phi - \Psi_{RP}\right)\right]\rangle$$

Chiral Magnetic Wave

The Chiral Magnetic Wave (CMW) is a type of collective excitation in QGP caused by the compounding effects of the Chiral Separation Effect (CSE) and the Chiral Magnetic Effect (CME) [1]. At finite baryon density the CSE implies the separation of chiral charge along the magnetic field produced at the moment of the collision. The CME current then flows in opposite directions at the poles. This produces a static electric quadrupole moment with positively charged particles at the poles and negatively charged particles at the equator (given an initial positive net charge of the system). The greater the initial A_{ch}, the greater the expected difference in v_2 between positively and negatively charged particles.



$$\vec{j}_A = \frac{N_c e}{2\pi^2}\mu_V \vec{B} \qquad \vec{j}_V = \frac{N_c e}{2\pi^2}\mu_A \vec{B}$$

Fig 2: An overview of the Chiral Magnetic Wave. The final figure shows the expected difference in v_2 between positively and negatively charged particles.

STAR Detector

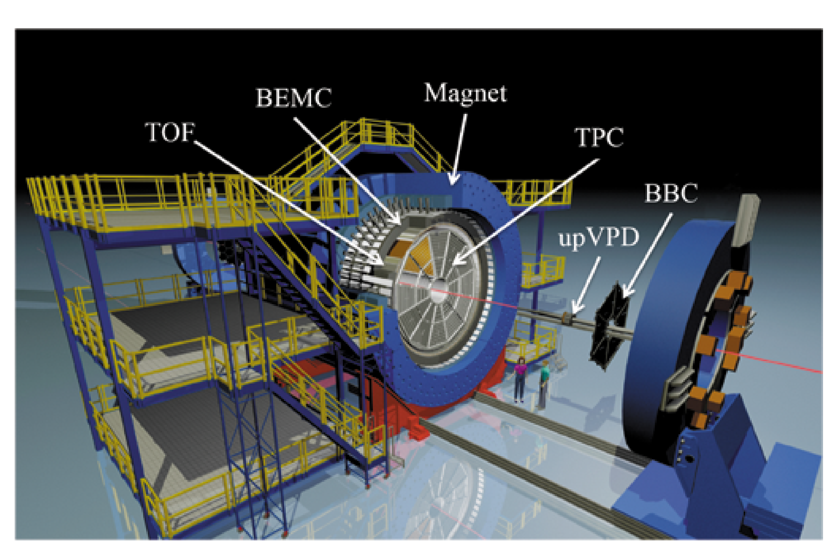


Fig 3: A computer-generated model of STAR.

All the data for this analysis come from minimum bias events taken by the STAR experiment at RHIC. The data from the Time Projection Chamber (TPC) and Time of Flight detector (TOF) provide particle identification information and kinematic parameters of tracks.

Results

We first calculate the A_{ch} dependence of Δv_2 using two methods:

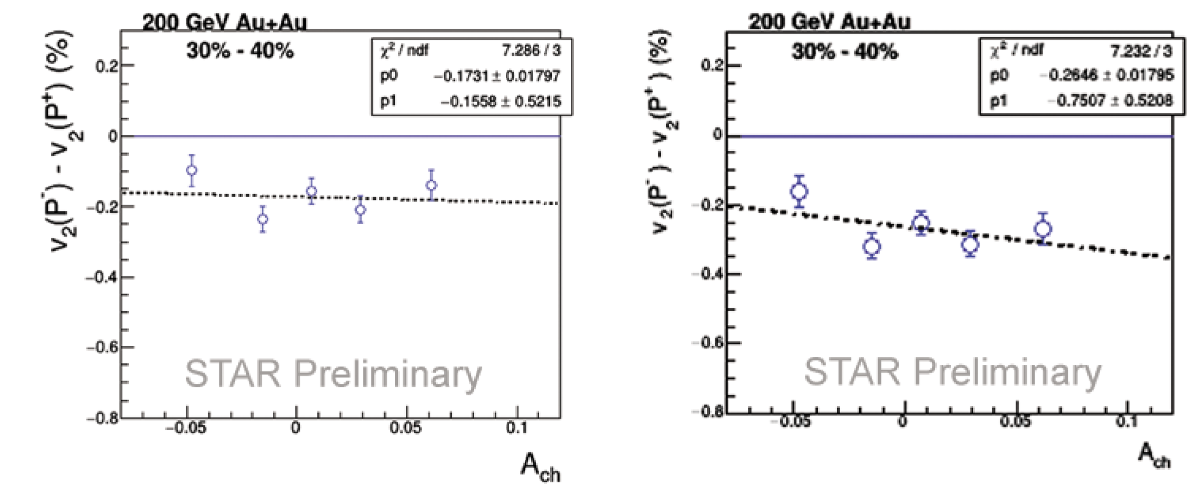


Fig 4: Δv_2 is determined by fitting a plot of Δv_2 vs p_T with a constant fit.
Fig 5: Δv_2 is determined by finding the difference between p_T-integrated v_2.

$$\Delta v_2(A_{ch}) = v_2(p^-) - v_2(p^+) = c + rA_{ch}$$

The slope (r) of these plots is the CMW observable for protons. We plot it as a function of centrality and compare with previously reported results for pions and kaons:

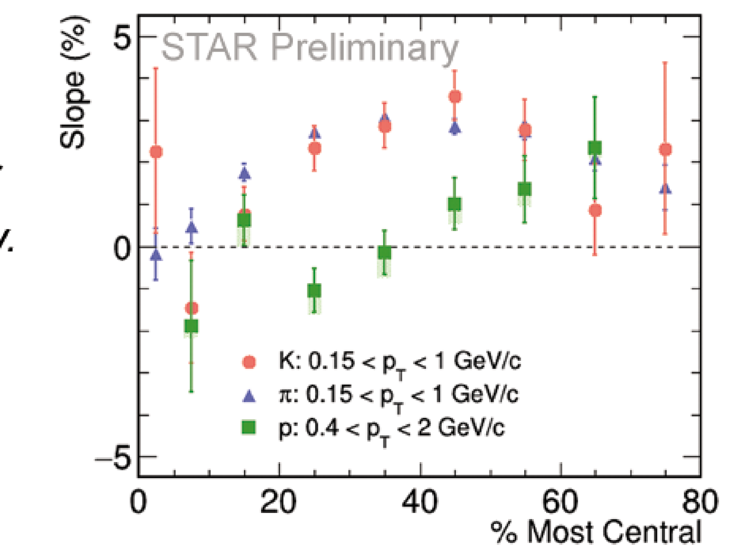


Fig 6: A plot of the slope parameter for protons as a function of centrality. The error bars are statistical only, while the green shaded boxes indicate the systematic errors.

Conclusion

We measured the charge-asymmetry dependence of proton v_2 in 200 Gev Au+Au collisions. The CMW observable of protons has a smaller magnitude and is generally more negative than that of pions and kaons. This discrepancy motivates future studies of proton v_2. Similar studies can be performed at different beam energies to confirm the trend.

References

[1] Y. Burnier, D. Kharzeev, J. Liao and H. Yee, Phys. Rev. Lett. 107 (2011) 052303.

[2] L. Adamczyk, et al, Phys. Rev. Lett. 114 (2015) 252302.

[3] Q.-Y Shou, Nucl. Phys. A 931 (2014) 758.